coastalmanagement

Waituna Lagoon 2007

Ecological Vulnerability Assessment and Monitoring Recommendations

Prepared for **Environment Southland**

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Cover Photo: Waituna Lagoon

Waituna Lagoon 2007

Ecological Vulnerability Assessment and Monitoring Recommendations

Prepared for
Environment Southland

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EXECUTIVE SUMMARY

SCOPE

To assess the major issues faced by New Zealand (NZ) estuaries, Environment Southland (ES) established a long-term monitoring programme in the 1990's using the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002). Recently, ES have added Waituna Lagoon (1,350ha), a "coastal lake" type estuary, and its associated wetland (~2,200ha), centred in Toetoes Bay in Eastern Southland, to its long-term monitoring programme.

As Waituna Lagoon has been identified as having a high risk of nutrient, sedimentation, pathogen and, to a lesser extent, habitat loss problems (Johnson & Partridge 1998, Thompson & Ryder 2003, Cadmus & Schallenberg 2007, Schallenberg & Tyrrell 2007), ES contracted Wriggle Coastal Management to undertake two studies:

1. A series of broad scale mapping and sedimentation studies (see Stevens & Robertson 2007).
2. An Ecological Vulnerability Assessment to determine monitoring and management priorities (this report).

The second study, the Ecological Vulnerability Assessment, is an adaptation of a UNESCO methodology (UNESCO 2000), and has five key components that need to be completed:

1. Human Uses and Values.
2. Ecological Richness or Values.
3. Presence of Stressors (likely causes of estuary issues).
4. Existing Condition and Susceptibility to Stressors.
5. An Estuary Vulnerability Matrix.

The aim of the assessment is to represent how an estuary ecosystem is likely to react to the effects of stressors - the causes of estuary issues (often human activities) so that an overall "vulnerability" rating can be determined, and priority monitoring indicators can be identified. Components 1-4 are tables that provide background information used to assign ratings (e.g. "high", "medium", or "low"). These components are then brought together in Component 5, a pre-developed Estuary Vulnerability Matrix, which summarises the ratings and is used to identify monitoring and management priorities.

A monitoring programme is then designed for the priority monitoring indicators using the tools provided in the EMP (Robertson et al. 2002), plus recent extensions developed by Wriggle (e.g. Robertson & Stevens 2007a).

This report describes the Ecological Vulnerability Assessment undertaken for Waituna Lagoon to determine monitoring needs and priorities for ES. It provides an overview of coastal lake characteristics, the completed Ecological Vulnerability Assessment, and monitoring and management recommendations.

COASTAL LAGOON CHARACTERISTICS

Because coastal lakes are shallow and their mouth is often blocked, they are naturally susceptible to water quality problems. In terms of their ecology, they tend (in their natural state) to have high habitat diversity and ecological richness, which is driven to a large extent by the following features:

- **Extensive Saltmarsh Habitat:** Because coastal lakes have a large area of shallow, wet marginal land with relatively low water level fluctuations, they tend to have a large proportion of their total area in saltmarsh vegetation.
- **Extensive Submersed Aquatic Macrophyte Beds:** Because catchment-specific sediment yields are relatively small (providing good water clarity) and the lakes are shallow (<3m deep), they grow extensive beds of submersed aquatic macrophytes. Such beds are important for regulating water quality and as habitat for invertebrates, fish and waterfowl.

EXECUTIVE SUMMARY (CONTINUED)

COASTAL LAGOON CHARACTERISTICS (CONTINUED)

Most NZ coastal lakes have been heavily modified through catchment landuse intensification, drainage of wetlands, flood control and frequent artificial mouth openings. The key issues resulting from such actions are excessive sedimentation, excessive nutrients, disease risk, toxic contaminants, and habitat loss; with responses including increased muddiness, algal blooms, presence of disease-causing organisms, and loss of saltmarsh and macrophyte beds.

KEY FINDINGS

The Estuary Vulnerability Assessment, and previous studies, have identified Waituna Lagoon as a largely unmodified example of a temperate shallow coastal lagoon with its remaining coastal wetland system mostly intact.

HUMAN AND ECOLOGICAL VALUE

High Ecological Values

Waituna Lagoon has a moderate level of human use but has very high ratings for its habitat and ecological richness (birdlife, fish, plantlife). In particular, it has a unique submerged aquatic plant community (*Ruppia*-dominated), internationally renowned birdlife, and large areas of relatively unmodified wetland and terrestrial vegetation that should be maintained and encouraged or a major adverse shift in their condition may occur.

PRESENCE OF STRESSORS

Intensive dairying

High nutrients & pathogens

Low-Moderate sediment

Sea level rise threatens *Ruppia*

The major threats or stressors to these existing values were identified as follows:

- Excessive catchment inputs of sediment, nutrients and pathogens.
- Sea level rise.
- Salinity shifts from variable lagoon opening regimes.
- Less importantly; drainage of margin areas, invasive weeds, and fire.

Based on available landuse information, catchment loadings of nutrients, sediment and pathogens are elevated to levels that would cause problems. In particular, nutrient loads (total nitrogen (TN) and total phosphorus (TP)) and pathogen indicators (*Escherichia coli* (*E. coli*)) from dairy farms in the catchment are estimated to be extremely high (e.g. 30kgN/ha/year from the 21,000ha catchment with 20,400 cows on 5,600ha (3.6 cows/ha), significantly higher than rates reported elsewhere in NZ). Mean TN, TP and *E. coli* concentrations in Waituna Creek exceed the mean values for NZ low elevation rivers. Suspended sediment yield from the catchment is estimated to be in the low-moderate range relative to the rest of NZ.

Because the lagoon is shallow and is opened artificially to the sea, any increase in sea level rise above that of the sedimentation rate is another major risk. In the past century sea level rose at 2.1mm/year (close to the current sedimentation rate of 2.8mm/year), but is set to increase up to 7mm/year or more. This means likely increases in water depth, salinity and open lagoon time. All of which are a threat to *Ruppia* habitat and the rest of the ecosystem, particularly saltmarsh.

EXISTING LAGOON AND WETLAND CONDITION

Eutrophic:
Algal Blooms
High Nutrient Inputs

The assessment of the existing condition of the lagoon showed a number of problems:

- It is eutrophic (high nutrient levels and both phytoplankton and macrophyte blooms), and likely to be phosphorus limited.
- It has large areas of muddy sediments, particularly around rushland margins, stream plumes and sheltered embayments.
- Water clarity is low at times (although data is poor).
- Disease risk indicator (e.g. *E. coli*) concentrations are expected to be elevated near stream outlets.
- It has localised areas of anoxic sediments.
- The area of rushland is changing (expanding at present).

KEY FINDINGS (CONTINUED)

SUSCEPTIBILITY

High Susceptibility

Because Waituna Lagoon is shallow, poorly flushed, has a long residence time, and is artificially opened and closed, it is very susceptible to having water quality problems that would adversely affect habitats if the relevant stressors (e.g. terrestrial runoff, climate change, invasive weeds) were present. Available information indicates that these stressors are present and have already adversely affected existing condition.

RISKS

Loss of *Ruppia*

Loss of *Ruppia* Beds: *Ruppia* is a keystone species in the lagoon whose growth will be discouraged if water clarity is reduced through such actions as excessive inputs of fine sediments, by frequent changes in water or salinity levels through lagoon openings, or if excessive nutrient inputs result in phytoplankton or macroalgal blooms. It is also possible that the shift may be irreversible and result in a dramatic and adverse change to aquatic life in the lagoon and margins. Because the lagoon is already experiencing excessive algal blooms and lowered clarity, immediate action is required to reduce the magnitude of the stressors causing the problem (i.e. limits on nutrients and sediment entering the lagoon, and developing lagoon opening guidelines designed to maintain the *Ruppia* beds).

Fish decline

Decline in Fish, Birdlife: Because of the importance of *Ruppia* as a habitat for invertebrates and fish, as a food source for invertebrates and waterfowl, and its role in regulating water quality, its loss from the lagoon is likely to lead to adverse impacts on other parts of the ecosystem such as fish and birdlife. Also the shift towards a turbid, eutrophic, phytoplankton dominated system will mean that the current high aesthetic appeal of the lagoon will be lowered.

Rushland at risk

Degradation of Wetland and Terrestrial Margin: Wetland and terrestrial margin vegetation is important because it acts to improve water quality, maintain local biodiversity, provide fish and wildlife habitat, protect shorelines from erosion, provide flood storage and mitigation, and is a natural filter and trap for sediment and nutrients. Two issues were identified in relation to these communities:

- Encroachment of farmland into the terrestrial margin and rushland through vegetation clearance and drainage to the north and east of the lagoon.
- The establishment of various introduced weeds and grasses within the wetland area.

MONITORING

Monitoring recommendations have been made to establish a baseline of current habitat and conditions, to measure future changes that may result in impacts on existing values, and to extend the current lagoon monitoring to provide additional information to aid management and monitoring decisions. The proposed monitoring targets the four key issues identified as significant issues in Waituna Lagoon (sedimentation, eutrophication (excessive nutrients), disease risk, and habitat loss). It includes existing monitoring undertaken by ES, and it is envisaged that the key management agencies (ES, DOC) will undertake different parts of the programme as appropriate.

EXECUTIVE SUMMARY (CONTINUED)

RECOMMENDED MONITORING

Sedimentation	Elevated sedimentation rates are likely to lead to major and detrimental ecological changes (e.g. loss of *Ruppia* beds), and indicate where changes in land use management may be needed. Increased sediment inputs may reduce light penetration by decreasing clarity, a key factor affecting *Ruppia* growth and health. A shift towards smaller grain sizes (particularly silts and muds) in areas that are currently dominated by sands or gravels is likely to be indicative of excessive sedimentation of fine sediments from catchment developments, and may detrimentally alter biotic assemblages. To determine the extent and rate of sedimentation the following is recommended: • Broad scale mapping of sediment type at five yearly intervals (repeat 2007 survey in 2012). • Fine scale monitoring of surface sediment grain size along selected transects at five yearly intervals (beginning 2008). • Assessment of sedimentation rate (using buried sedimentation plates) at two high deposition areas (including rushland). Ideally measured at annual intervals. • Measure water clarity (Secchi disc - SD) at monthly intervals at representative sites.
Eutrophication	Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota. 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. The following is recommended: • Broad scale mapping of lagoon macroalgal percent cover annually in January-March (when the lagoon mouth is open). • Monthly monitoring during the main growing period (September-April) for the following parameters: lagoon light penetration or SD, chlorophyll-*a*, phytoplankton, total nitrogen, nitrate, ammonia, total phosphorus, dissolved reactive phosphorus, salinity, dissolved oxygen, temperature, and water level. In addition, establish a baseline of sediment organic carbon (determined from ash free dry weight) at representative sites.
Disease Risk	Potential disease causing bacteria and pathogens are commonly associated with inputs of faecal matter from warm blooded animals. Because of the high numbers of dairy cows in the catchment, inputs are expected to be elevated in incoming streams. The following is recommended: • Monthly monitoring during the main periods of contact recreation for *E. coli*.
Macrophytes	The presence of extensive macrophyte (e.g. *Ruppia*) beds in shallow open/closed coastal lake estuaries, like Waituna Lagoon, are likely to be indicative of a healthy and biodiverse ecosystem (i.e. not too muddy or nutrient enriched). The following is recommended: • Repeat broad scale mapping of percent cover of *Ruppia* at annual intervals.
Wetland and Terrestrial Margin	A terrestrial margin dominated by native vegetation almost certainly acts as an important buffer between developed areas and the wetland and lagoon. This buffer protects against introduced weeds and grasses, and naturally filters sediments and nutrients. Additionally, there have been significant areas of saltmarsh drained for pastoral use in the past and this has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary. Saltmarsh is also highly susceptible to sea level rise. The following is recommended: • Broad scale mapping of wetland and terrestrial margin vegetation at five yearly intervals (repeat 2007 survey in 2012).
Catchment Monitoring	As the characteristics of the surrounding catchment, and the landuse undertaken within it, are major determinants of downstream conditions, the following catchment monitoring is recommended: • Identify areas where a combination of different factors (e.g. land cover, slope, area, soil type, geology, rainfall, etc) highlight a high potential for immediate or potential inputs of sediment. Use existing catchment data to identify "hotspots" such as erosion prone areas, easily mobilised sediment reserves etc. and target these for specific management. • Monitor suspended sediment, total nitrogen, total phosphorus and *E. coli* concentrations in the streams draining the major developed catchment (i.e. Waituna Creek and possibly Currans Creek) on three occasions during low flows, three during medium flows and hourly throughout three high flow events to better characterise likely loadings.

EXECUTIVE SUMMARY (CONTINUED)

RECOMMENDED MANAGEMENT

Monitoring is a key step to effective management. In order to help assess the monitoring results, make the best use of existing data, and provide options for protecting and improving the ecological quality of the lagoon, consideration of the following management work is recommended:

Develop Condition Ratings for Reporting Monitoring Results

- Condition ratings are criteria for monitoring indicators that rate lagoon condition (e.g. very good/good/fair/poor), guide the type and frequency of monitoring, and indicate the type of management responses that may be needed. Because of the unique conditions present, ratings need to be developed specifically for Waituna Lagoon. Examples of the types of condition ratings proposed for development for Waituna Lagoon are included in Technical Annex 2.

It is recommended that condition rating categories be developed for the following key indicators:

• Area of soft mud	• *Ruppia* percent cover
• Grain size	• Rushland percent cover
• Sedimentation rate	• Terrestrial margin percent cover
• Water clarity	• Macroalgal cover

Catchment Management

- Catchment runoff was identified as one of the major stressors in Waituna Lagoon. To prevent avoidable inputs, best management practices should be identified and implemented to reduce runoff of sediment, nutrients and pathogens from catchment "hotspots".
- Supporting this, studies to determine appropriate loads of sediment, phosphorus, nitrogen and faecal bacterial indicators entering the lagoon in streams should be undertaken (i.e. develop a lagoon phosphorus budget, a trophic response model, and a light model for *Ruppia* growth). Ideally this would enable Total Daily Maximum Loads (TDMLs) to be set for sediment, phosphorus, nitrogen and faecal bacterial indicators in streams entering the lagoon.

Ruppia Management

- The submersed macrophyte *Ruppia* is considered a keystone species within the lagoon and an indicator of a healthy and biodiverse ecosystem. To maintain favourable depth and salinity regimes for *Ruppia* growth, limits should be established for managing the lagoon level and lagoon openings to ensure available habitat is maximised.
- *Ruppia* may also be susceptible to overgrazing by waterfowl. Options should be considered for how to monitor and prevent overgrazing if it is a problem.

Lagoon Management

- Current lagoon management focuses more on flood mitigation than lagoon ecology. It is recommended that a lagoon management plan be developed that addresses lagoon opening/closing guidelines and incorporates the maintenance of *Ruppia* beds, potential macroalgal blooms, as well as maximising area for sedimentation of fine materials.

Wetland and Terrestrial Margin Management

- Maintenance of the wetland and terrestrial margin is an important way to filter runoff and limit the establishment of weeds and the effects of climate change. If not already developed, a wetland and terrestrial margin management plan to maintain and enhance the protective strip around the lagoon is recommended.

1. INTRODUCTION

BACKGROUND

To assess the major issues faced by New Zealand (NZ) estuaries, Environment Southland (ES) established a long-term monitoring programme in the 1990's using the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002). Recently, ES have added Waituna Lagoon, a "coastal lake" type estuary to its long-term monitoring programme.

Waituna is a large, brackish intermittently open/closed lagoon separated from the sea by a spit or barrier beach. It is fed by three streams (Currans Creek, Waituna Creek and Moffats Creek) (Figure 1), and drains to the sea through a managed opening at the western end of the lagoon. Historically, the lagoon was surrounded by a huge peat bog wetland (area ~20,000ha stretching from Fortrose Estuary to New River Estuary) whose drainage gave the lagoon water its characteristic clear brown humic stain, low nutrient status, and low pH. Now the catchment is dominated by farmland (intensive sheep, beef and dairying, Figure 2).

Coastal lakes are common in the South Island and Kirk & Lauder (2000) list their distinctive characteristics as:

- Associated with mixed sand and gravel coasts, with high wave energy, strong longshore sediment transport, small tides and undergoing long-term erosion.
- Openings to the sea are rare and short-lived unless created by human action.
- Natural water levels are generally higher and have a smaller range than those now occurring through ongoing human intervention. Lower average water levels relate to agricultural uses of low-lying land marginal to lagoons.
- Ocean salt content of the water body is low. It is derived from salt spray, from overwash of the enclosing barrier beach, or from inlet throughflow by the tide in the later stages of artificial openings.
- Wind waves and currents are an important, if not dominant, agent of mixing within the lagoon.

In terms of the ecology, coastal lakes (in their natural state) tend to have high habitat diversity and ecological richness, which is driven to a large extent by the following features:

- **Extensive Saltmarsh Habitat:** Because coastal lakes have a large area of shallow, wet marginal land with relatively low water level fluctuations, they tend to have a large proportion of their total area in saltmarsh vegetation.

- **Extensive Aquatic Macrophyte Beds:** Because catchment-specific sediment yields are relatively small (providing good water clarity) and the lakes are shallow (less than 3m deep), they grow extensive beds of aquatic macrophytes (e.g. horse's mane weed, *Ruppia* spp.). *Ruppia* has been suggested as a keystone species in Waituna Lagoon (Schallenberg & Tyrrell 2007) because of its importance as a habitat for invertebrates and fish, as a food source for invertebrates and waterfowl, and its role in regulating water quality.

The major issues associated with coastal lakes/lagoon type estuaries in New Zealand are summarised in Table 1.

1. INTRODUCTION (CONTINUED)

Table 1. Summary of the major issues affecting NZ coastal lakes/lagoons.

Key Coastal Lake Issues	
Excessive Sedimentation	Because coastal lakes are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived. Because coastal lakes are shallow, the muds are easily resuspended. This causes low turbidity which limits (or in some cases curtails) macrophyte growth, which in turn encourages phytoplankton growth and further lowers water clarity. Symptoms of eutrophication can result if nutrient levels are excessive and flushing is restricted (i.e. the mouth is not opened regularly).
Excessive Nutrients	Increased nutrient richness of coastal lake ecosystems stimulates the production and abundance of aquatic macrophytes (e.g. *Ruppia*) and saltmarsh vegetation. If excessive, it stimulates fast-growing algae such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce and *Enteromorpha*). Under phytoplankton bloom conditions, water column clarity can be reduced to low levels, limiting light available for macrophyte growth and drastically reducing habitat diversity and ecological richness (e.g. Lake Ellesmere). Also of concern are the mass blooms of macroalgae which can become widespread on intertidal flats and shallow subtidal areas of coastal lakes and cause major ecological impacts on water and sediment quality and 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 coastal lake environment, can survive for some time. Every time we come into contact with the lake water that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick.
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), toxic heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and some can bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Coastal lakes have many different types of habitats including shellfish beds, aquatic macrophyte beds, salt marshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and hard shores. The major stressors causing habitat degradation or loss in coastal lakes are: artificial mouth openings (increasing salinity and lowering lake levels), drainage and reclamation of salt marsh, sea level rise, population pressures on margins, pest and weed invasion, altered river input flows (damming, diversion and irrigation), over-fishing, polluted runoff and wastewater discharges.

CONSERVATION STATUS

As Waituna Lagoon itself remains a largely unmodified example of a temperate shallow coastal lagoon with its remaining coastal wetland system largely intact, it has been given special conservation status. In 1976, it was designated as being of international significance under the RAMSAR Convention. The wetlands and lagoon were recognised under RAMSAR on the grounds that “they support an appreciable assemblage of endemic and threatened species and communities, have special value for maintaining the genetic and ecological diversity of the region and provide habitat for plants and animals at critical stages of their biological cycles”. In 1983, it was also established as a scientific reserve and is administered by DOC. The lagoon is also culturally significant to the local Ngai Tahu people (recognised under a Statutory Acknowledgement with the Ngai Tahu Claims Settlement Act 1998).

1. INTRODUCTION (CONTINUED)

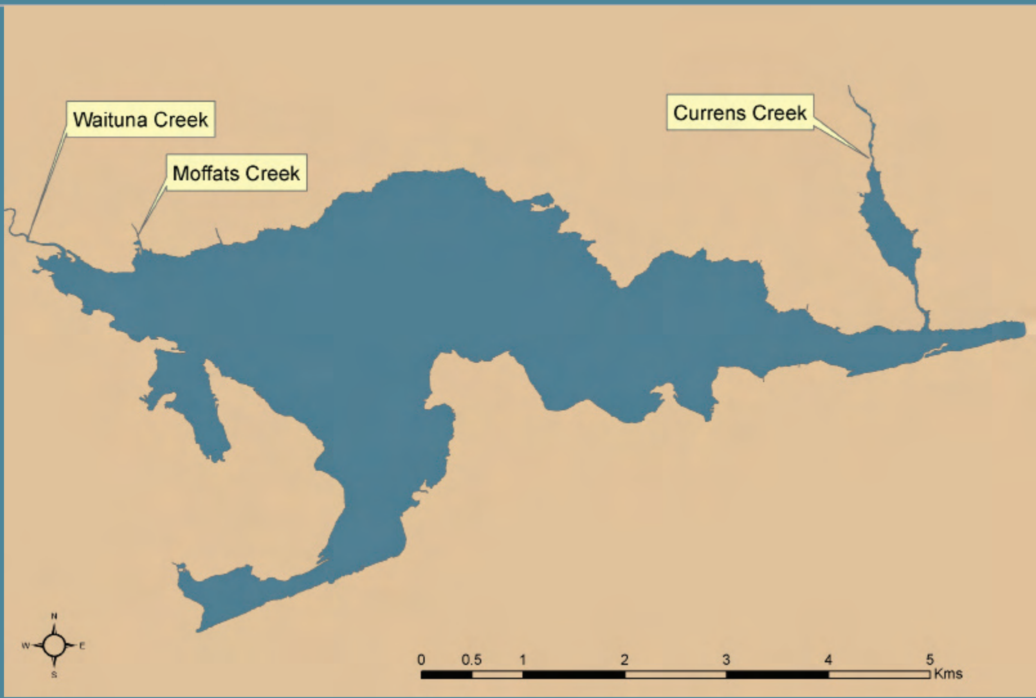


Figure 1. Map showing major creeks entering Waituna Lagoon.

HUMAN USES

In terms of human uses the lagoon is popular both locally and regionally, and also draws many tourists. It is valued for its aesthetic appeal, its rich biodiversity, game-bird shooting, fishing (for brown trout primarily), boating, walking, and scientific appeal.

MODIFICATIONS

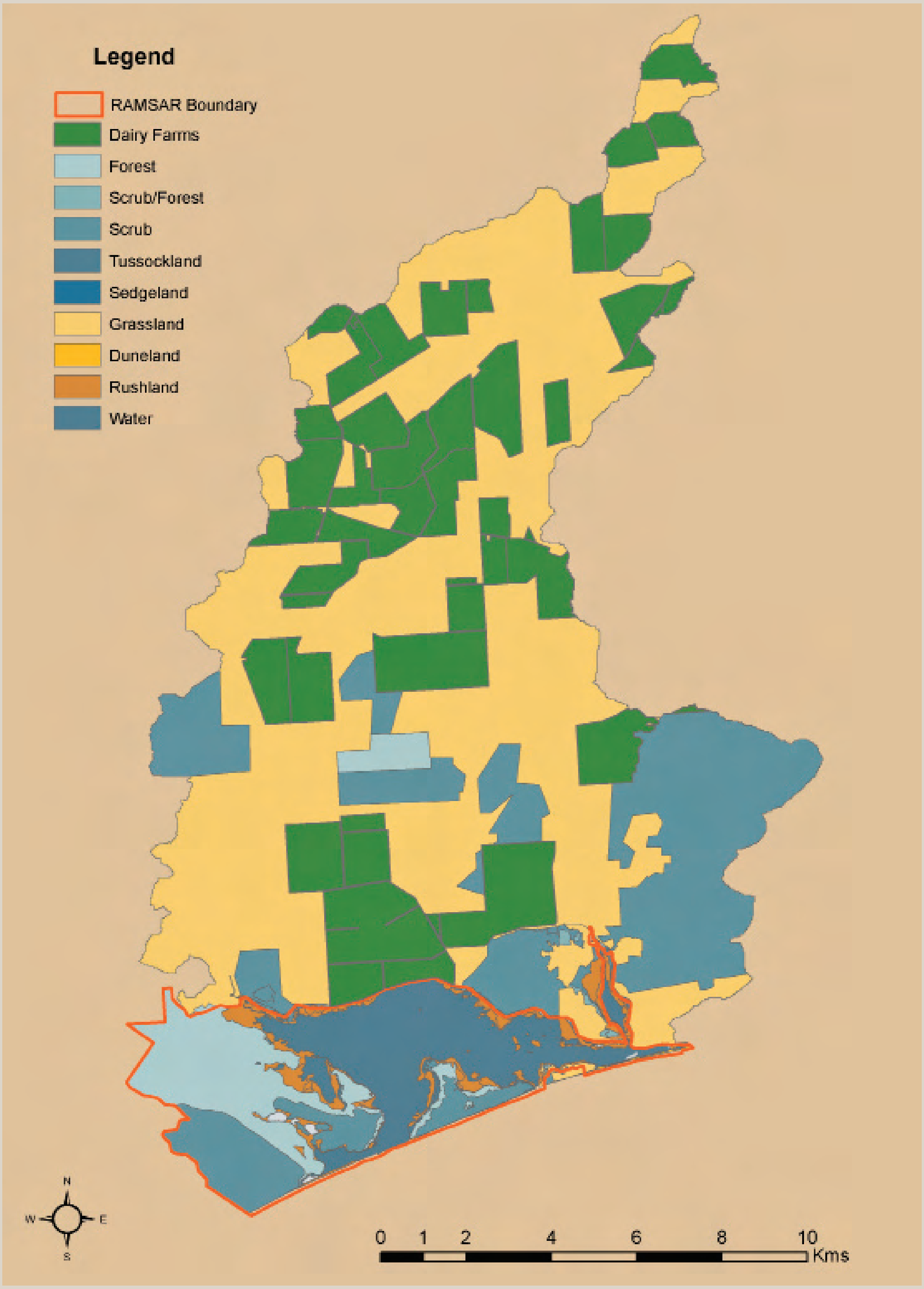
Dairy farming - the dominant landuse in the catchment.

During the last 150 years, there have been a number of significant modifications to Waituna Lagoon and the associated wetland as follows:

- **Drainage:** Much of the peat bog catchment has been drained and the land used for agriculture. More recently, there has been a large shift towards intensive dairy farming in the catchment. The combination has almost certainly increased sediment, nutrient and pathogen loads to the lagoon, and enhanced weed growth in wetland areas.
- **Artificial Lagoon Openings:** Historically, the lagoon breached to the sea once water level became too high (approximately 4m above sea level). In 1908, the first artificial breach was made in order to improve fishing. Thereafter, many artificial breaches have been undertaken and since 1972 they have been undertaken almost annually (Thompson & Ryder 2003). The main reason for breaching was to ensure free drainage of surrounding farmland. This has resulted in much longer periods of low water level in the lagoon, higher mean salinities, less habitat for aquatic biota and reduced water volume for assimilation of catchment runoff.
- **Expansion of Rushland:** The area covered by rushland vegetation (jointed wire rush, *Leptocarpus similis*) has expanded, probably in response to the artificial lagoon openings but possibly enhanced by increased sediment and nutrient loads.

Recently Waituna Lagoon has been identified as having a high risk of nutrient, sedimentation, pathogen and, to a lesser extent, habitat loss problems (Johnson & Partridge 1998, Thompson & Ryder 2003, Cadmus & Schallenberg 2007, Schallenberg & Tyrrell 2007). The key issues identified in these studies are summarised in Box 1.

Figure 2. Map of Waituna Lagoon and catchment showing the RAMSAR site boundary.



BOX 1. SUMMARY OF ECOLOGICAL ISSUES IN WAITUNA LAGOON

The results of studies on the ecology of the lagoon (Johnson & Partridge 1998, Thompson & Ryder 2003, Cadmus & Schallenberg 2007, Schallenberg & Tyrrell 2007) point to the following issues:

EXCESSIVE NUTRIENTS, SEDIMENTS, HABITAT CHANGE

- "Nutrient levels in inflows are very high and have the potential to result in eutrophication," (Thompson & Ryder 2003).
- "There is evidence within the lagoon of high sedimentation rates and infilling in some areas," (Thompson & Ryder 2003).
- "The expansion of *Leptocarpus* may be due to infilling of the lagoon by fine sediment," (Thompson & Ryder 2003).
- "The lagoon margin vegetation has changed in response to a generally lower lagoon level, combined with apparent increases in sedimentation. *Leptocarpus* rushland has responded to these changes by increasing its extent," (Johnson & Partridge 1998).
- "Steps should be taken to monitor, and to minimise sediment and nutrient inputs to the lagoon. Intensification of agriculture, especially of dairying with its associated application of nitrogenous fertilizers and disposal of dairy shed effluent, are incompatible with the health of a basically low-nutrient status coastal lagoon," (Johnson & Partridge, 1998).
- Cadmus & Schallenberg (2007) indicate a very low sedimentation rate of 0.05-0.06mm/yr from 7000 years BP to 1960, which increased to 2.8mm/yr in the period 1960 till present. In this latter period, the grain size of the particles also became coarser, which was attributed to the loss of the sediment filtering action of wetlands following drainage. "Prior to drainage, the Waituna Wetlands would have absorbed water and slowed its travel down the catchment, reducing the grain size of sediment transported by the creeks and the amount of sediment washed into the lagoon. Our findings indicate that, as wetlands were drained, this hydrological buffering capacity was reduced, causing the creeks running into the Waituna Lagoon to rise and fall more quickly with precipitation events and, therefore, to transport more and coarser sediment into the lagoon. These changes would have resulted in runoff reaching the lagoon at a faster rate, causing lagoon levels to rise quicker, prompting more frequent artificial openings of the lagoon".

MACROPHYTE IMPORTANCE

These studies also point to the importance of the aquatic plant, *Ruppia*, as a keystone species in the lagoon because of its importance as a habitat for invertebrates and fish, as a food source for invertebrates and waterfowl, and its role in regulating water quality. They also identified a number of key factors affecting the presence and management of *Ruppia* in Waituna Lagoon.

- The lagoon is unique in New Zealand because of its intact *Ruppia*-dominated macrophyte communities.
- Waituna Lagoon is particularly susceptible to the environmental stressors that could cause *Ruppia* collapse including; extreme wind events (physical uprooting), excess nutrient loading (phytoplankton blooms), decreased light penetration (from excess sediment or phytoplankton), increased water levels (limiting light to plants on bed), sediment oxygen depletion, overgrazing by waterfowl, and salinity changes (long periods of excessive salinity).
- If any of these stressors caused "whole lagoon" macrophyte collapse, it is likely that the lagoon would enter an undesirable phytoplankton-dominated regime and that *Ruppia* would be unlikely to re-establish once lost.
- *Ruppia* distribution in Waituna Lagoon is limited to areas where the depth is not so great that light can't penetrate, or so shallow that it is desiccated or stressed by wave action.
- When water depth is too high, large areas of available habitat are lost due to light limitation. There is a recommendation that periods of high water level should be kept to less than 60 days.
- Excessive phytoplankton growth and suspended sediment concentrations reduce light penetration and habitat for *Ruppia* growth.
- The best means of controlling phytoplankton biomass is to reduce phosphorus inputs to the lagoon as this is likely to be the limiting nutrient (excess nitrogen is available in the lagoon).
- The best means of controlling excessive suspended sediment concentrations is to reduce suspended sediment concentrations entering the lagoon.
- Long periods with the lagoon open to the sea results in higher mean salinities in the lagoon which may adversely affect *Ruppia* if salinities exceed the optimum 4-8ppt level.
- Periods of closure provide the low salinity conditions important for seed germination and seedling establishment.
- Studies at Lake Ellesmere and in Australia and Europe (Gerbeaux & Ward, 1991), indicate that *Ruppia* requires good illumination and sheltered conditions for growth. Their studies also suggest that, although plants can be absent from some sites in some years, they can appear again under the right environmental conditions (i.e. low water salinities to stimulate germination and high water clarity that enables light to reach the bottom).

1. INTRODUCTION (CONTINUED)

SCOPE

In response to the ecological and human values associated with the lagoon, and concerns about nutrient, sedimentation, pathogen, and localised habitat loss, ES as part of their long term monitoring programme, contracted Wriggle Coastal Management (Wriggle) to undertake two studies:

1. A series of broad scale mapping and sedimentation studies (see Stevens & Robertson 2007).
2. An Ecological Vulnerability Assessment to determine monitoring and management priorities (this report).

The first of the reports (Stevens and Robertson 2007) describes field surveys and monitoring undertaken as part of the overall assessment of Waituna Lagoon.

The second report (the current one) describes the Ecological Vulnerability Assessment undertaken. It builds on the information collected in the first report, summarises existing knowledge on the major issues affecting the lagoon, and makes a series of monitoring and management recommendations to address identified issues within Waituna Lagoon.

The project scope was limited to the use of expert judgement to quickly and cost effectively review existing knowledge and identify what issues are most likely to affect Waituna Lagoon, and from this make recommendations on monitoring and managing identified issues. The report structure is as follows:

- Section 1. Introduction.
- Section 2. Ecological Vulnerability Assessment Methods.
- Section 3. Ecological Vulnerability Assessment Tables.
- Section 4. Summary and Conclusions.
- Section 5. Recommendations.
- Section 6. Acknowledgements.
- Section 7. References.
- An Executive Summary is provided at the beginning of the report.

Although outside the scope of the project, the report also includes Technical Annexes:

- Technical Annex 1 - a transparent summary of the workings and rationale behind the ratings as a forum to encourage expert revision and refinement of data where appropriate, and to allow new information to be incorporated in the assessment as it becomes available.

- Technical Annex 2 - examples of Condition Ratings to indicate the type of assessment criteria recommended for development for Waituna Lagoon to assist in the reporting and interpretation of monitoring data, to provide a warning of rapid or unexpected change, and to guide monitoring and management effort.

2. METHODS

OVERVIEW

The Ecological Vulnerability Assessment is a tool adapted from a UNESCO methodology (UNESCO 2000) that is designed to be used by experts to represent how an estuary ecosystem is likely to react to the effects of potential "stressors" (the causes of estuary issues - often human activities).

The approach uses various assessment techniques to produce an overall "vulnerability" rating of the extent to which potential stressors may affect the uses and values of an area. This is then combined with how susceptible the uses and values are to the identified stressors to identify the priority issues that need addressing.

The approach used is to summarise background information in four key tables:

1. **Human Uses and Values** (see Section 3.1).
2. **Ecological Values or Richness** (see Section 3.2).
3. **Presence of Stressors (Likely Causes of Estuary Issues)** (see Section 3.3).
4. **Existing Condition and Susceptibility to Stressors** (see Section 3.4).

This information is then summarised within a pre-developed Estuary Vulnerability Matrix (Table 2, Section 3.5) that ascribes "vulnerability" ratings (e.g. "very high" "high", "medium", or "low") based on an expert appraisal of the combined inputs. The "vulnerability" ratings are then used to design a monitoring programme for the priority monitoring indicators using the tools provided in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), plus recent extensions developed by Wriggle (Robertson & Stevens 2007a). The monitoring tools include the elements summarised in Table 3.

Table 2. Example of an Estuary Vulnerability Matrix.

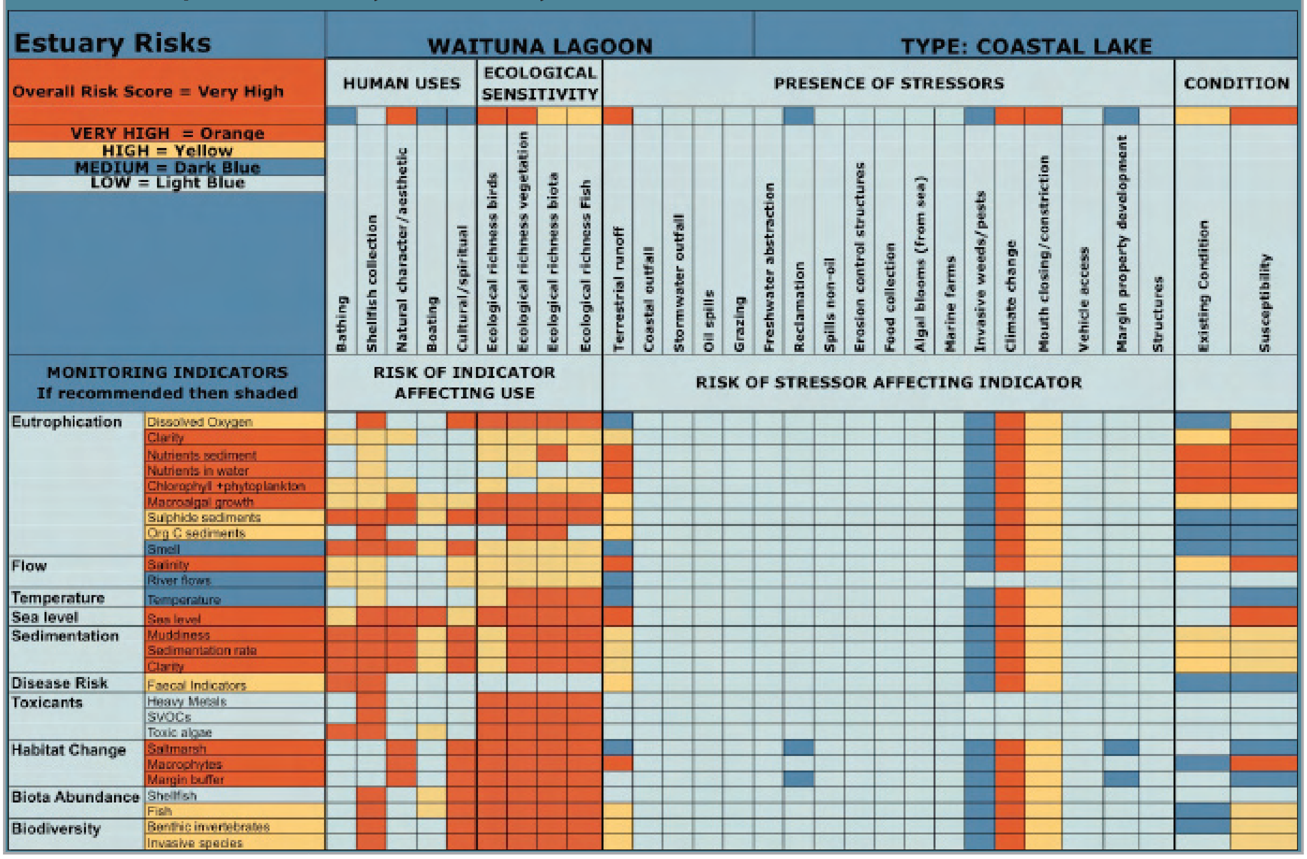


Table 3. Summary of EMP tools and recent extensions used by ES.

National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002)	• Broad scale habitat mapping using GIS. Broad scale habitat mapping records the location and type of vegetation (e.g. saltmarsh, seagrass, macroalgae) and substrate (e.g. mud, sand, gravel, etc); and is used to provide information primarily on the issues of habitat and margin loss, sedimentation (through the mapping of substrate type), and eutrophication (by mapping macroalgae percent cover). • Fine scale (i.e. detailed) monitoring of dominant intertidal habitat. Fine scale monitoring focuses primarily on the physical, chemical, and biological characteristics of estuary sediments as these tend to be the most sensitive to degradation (Church 1975). Fine scale monitoring includes various indicators of estuary condition to provide information on sedimentation, eutrophication, and toxins (i.e. sediment particle size, organic matter, nutrients, heavy metals, and macrofauna).
Recent Extensions (Robertson & Stevens 2006, Robertson & Stevens 2007a,b)	• Establishment of sedimentation rate measures (using plates buried in sediment). • Estimation of historical sedimentation rates (using radio-isotope ageing of cores). • Assessment of the % cover of macroalgae and macrophytes (separate GIS layers). • Broad scale mapping of the 200m terrestrial margin surrounding the estuary. • Development of regional condition ratings for key indicators. • Provision of georeferenced digital photos (as a GIS layer). • Development of an Upper Estuary Monitoring and Assessment Protocol.

A key feature of the methodology is that it can be used with varying levels of detail. Because many potential stressors may be either absent or unlikely to have a significant impact, expert judgement is commonly used to quickly and cost effectively review existing knowledge and identify what issues are most likely to affect a particular estuary. This then provides a basis for deciding what level of effort should be put into addressing different issues. For example, existing knowledge or a synoptic survey may be sufficient to identify an issue as being both significant and present in a susceptible estuary. If more detailed studies are likely to reach the same conclusion, it may be most appropriate to focus resources on management rather than further study. Conversely, more detailed study may be needed to determine whether management is possible or likely to be effective before it is initiated.

Because these types of decisions require a "judgement call" by experts, a transparent summary of the workings and rationale behind the ratings is provided as a forum for experts to encourage revision and refinement of data where appropriate, and to allow new information to be incorporated in the assessment as it becomes available. The calculations and data used to determine the ratings presented in the summary tables are included in a Technical Annex to the report. While outside the scope of the current report, these working notes are provided as supplementary background information.

The following sections describe the key components of the vulnerability assessment, and the sources of information used to assess and rate each component. The underlying premise is that existing information is used wherever possible to complete the assessment, with expert opinion used to evaluate the adequacy of the available knowledge, and to determine where additional work may be needed.

The completed assessment is presented in Section 3.

2. METHODS (CONTINUED)

2.1 ECOLOGICAL VULNERABILITY ASSESSMENT - BACKGROUND TABLES

The Ecological Vulnerability Assessment consists of a series of four background tables (1. Human Uses and Values, 2. Ecological Richness (Value), 3. Presence of Stressors, 4. Existing Condition and Susceptibility) summarising existing knowledge, and to which broad "vulnerability ratings" (e.g. Low, Moderate, High) are given to each component based on predefined criteria, or expert judgement.

The key decision-making part of the Vulnerability Assessment falls under Table 4. This is where the vulnerability ratings within each table are combined, and the existing condition and susceptibility of the values to the stressors present are rated. A pre-developed Estuary Vulnerability Matrix is then used to summarise the ratings and highlight the major issues and their monitoring indicators to identify monitoring and management priorities (Section 3.5).

The level of detail used and the extent of reporting included in this type of assessment is essentially limitless. The current project is restricted to an expert summary with brief notes on the decision-making included within the summary tables. More detailed notes included in Technical Annex 1 provide workings used in the decision summaries. As reporting on this aspect was outside the scope of the contracted work, the technical workings have not been prepared for general readership.

The assessment criteria used for the tables are described below:

1. Human Uses

Information on the human uses and values of the lake and its margins were based on local knowledge and available information. The human use rating is based primarily on the estimated number of persons involved:

- Low: < 10 per year.
- Medium: 10 to 50 per year (< 30 per day in summer).
- High: > 30 per day (maybe just in summer) but < 200 per day.
- Very High: > 200 per day.

2. Ecosystem Richness (Values)

Ecosystem richness defines an ecosystem's natural riches (generally interpreted as habitat diversity and biodiversity). It can be supposed that the more rich and diversified an ecosystem is, the greater the losses will be in the event of a disruption. The ecological richness component is divided into four subcategories; birds, vegetation, fish and other biota.

3. Presence of Stressors

Stressors are activities (often in the catchment) that affect the ecological condition of coastal habitat (e.g. terrestrial runoff, grazing, stormwater discharges, reclamation). Because their harmful effects cause a variety of environmental deteriorations they are identified, and their risk characterised according to their estimated effect on relevant condition indicators (e.g. loss of saltmarsh, macroalgal growth, etc.). The assignment of risk is based on a combination of existing data (e.g. landuse, sediment and nutrient areal loadings, rock type, erosion susceptibility, river input quality), observation and expert opinion.

2. METHODS (CONTINUED)

2.1 ECOLOGICAL VULNERABILITY ASSESSMENT - BACKGROUND TABLES (CONT.)

4. Ecosystem Existing Condition and Susceptibility

The **"existing condition"** is a measure or estimate of the existing condition of the estuary as assessed by relevant condition indicators (e.g. signs of eutrophication, sedimentation, habitat loss). The existing condition of the Waituna area was primarily assessed based on expert opinion, supported by available information and monitoring data (see Box 2). In addition, salinity, temperature, depth, and water clarity were assessed from a number of sites throughout the lake during field visits in February 2007. In addition, sediment samples were collected from the lake bed, and qualitative assessments were made of sediment type and the presence of sulphides (Stevens and Robertson 2007).

"Susceptibility" is assessed to provide an estimate of the susceptibility of the ecosystem to degradation. For example, an estuary where the mouth closes regularly and is poorly flushed, is physically susceptible to water and sediment quality degradation. Various tools were used to help determine the susceptibility of Waituna Lagoon, in particular flushing potential estimates and eutrophication susceptibility protocols (e.g. Bricker et al. 2001). Where uncertainty existed over the presence or potential impact of stressors, a conservative (protective) estimate was used.

5. Vulnerability Matrix and Monitoring Recommendations

The combined information collected and assessed in components 1, 2, 3, and 4 is used to determine an overall "vulnerability" rating and identify the priority monitoring indicators. This information is then used to design a monitoring programme using the tools provided in the National Estuary Monitoring Protocol (Robertson et al. 2002) plus recent extensions developed by Wriggle (e.g. Robertson & Stevens 2007a, b). The risk assessment is designed as a framework to enable input by other parties and recalculation of risks, if required.

BOX 2. SUMMARY OF EXISTING ES MONITORING IN WAITUNA LAGOON

ES currently undertake a range of monitoring in Waituna Lagoon and inflowing streams. Summary results of which have been used in the present report:

Waituna Lagoon: Monthly sampling at four sites.
Monitoring parameters include: Dissolved oxygen (DO), Temperature, pH, Chlorophyll-*a* , Conductivity, Dissolved reactive phosphorus (DRP), Ammoniacal nitrogen, Total nitrogen (TN), Total phosphorus (TP), Turbidity, *Escherichia coli* (*E. coli*), Salinity. Lagoon level is also monitored.

Stream inputs: Monthly sampling at the following streams:
Currens Creek (at Waituna Lagoon Road and tributary at Waituna Lagoon Road), Moffat Creek (at Moffat Road), and Waituna Creek (at Marshall Road and at Mokotua)

Monitoring parameters include: Nitrate nitrite nitrogen; TN, TP, DRP, Ammoniacal nitrogen; faecal coliforms, *E. coli*, DO, Temperature; Turbidity; Black disk clarity, Conductivity, and Biochemical Oxygen Demand* (BOD). In addition, macroinvertebrates and periphyton are monitored annually at Waituna Creek (at Marshall Road and at Gorge Road).
* measured only at Waituna Creek.

3. VULNERABILITY ASSESSMENT TABLES

3.1 HUMAN USES AND VALUES

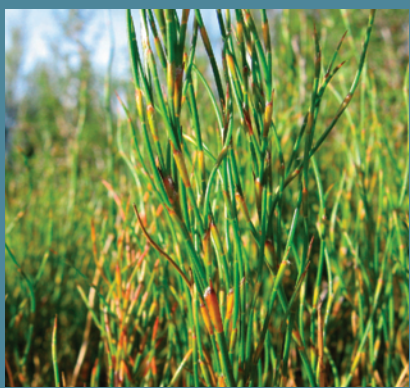
Low	Moderate	High

Human Uses and Values	Bathing	Low-moderate - some areas favoured.
	Shellfish collection	Low. No resource present.
	Duckshooting/Fishing	High.
	Natural character	High. Focal point for area and margins still relatively natural.
	Aesthetics	High.
	Boating (sailing, rowing, motor boats)	Moderate.
	Cultural/spiritual	High.
	Birdlife	High. High numbers of threatened bittern. Fernbird breeds in area.
	Aquatic Plants	High. Unique assemblage of *Ruppia*.
	Biota	Moderate.
	Fish	Moderate.
	Shellfish	Low.
	Wharves, Shipping, Marinas	Low.
	Point Source Waste Disposal	Low; Stormwater.
Overall Rating MODERATE	The lagoon is popular locally and regionally, and also draws many tourists. It is valued for its aesthetic appeal, its rich biodiversity, gamebird shooting, fishing (primarily brown trout), boating, walking, and scientific appeal.	

3.2 ECOSYSTEM RICHNESS (VALUES)

Low	Moderate	High

Ecosystem Richness (Values)	**Birdlife**	High. High numbers of threatened bittern. Fernbird breeds in area.
	Vegetation	High. Unique assemblage of *Ruppia*. Extensive rushland and terrestrial wetland.
	Fish	Moderate.
	Other Biota	Moderate.
Overall Rating HIGH	The lagoon has a unique submerged aquatic plant community (*Ruppia*-dominated), internationally important birdlife, and large areas of relatively unmodified wetland and terrestrial vegetation.	



3. VULNERABILITY ASSESSMENT TABLES (CONT.)

3.3 PRESENCE OF STRESSORS

Low	Moderate	High

	Terrestrial Sediment	Low - Moderate sediment loss range compared to rest of NZ. Background approx 50t/km^2/yr (native forest) then deforestation, currently around 160-200t/km^2/yr based on likely landuse yield estimates.
	Terrestrial Nutrients	Moderate-High. Current N yield estimated at 11.4kgN/ha/yr based on likely landuse yield estimates. Compared to rest of NZ is in moderate N loss range. But dairy N yield in very high range. Current P yield estimated at 0.82kgN/ha/yr based on likely landuse yield estimates. Compared to rest of NZ is in moderate P loss range. But dairy P yield in very high range.
	Terrestrial Pathogens	Moderate-High. The estimated input of 2 x10^{15} faecal coliforms per year from the catchment is elevated, primarily the result of intensive animal operations operating in the catchment.
	Terrestrial Contaminants	Low. No measures as yet but likely sources are absent from catchment.
	Point Source Sediment	Low.
	Point Source Nutrients	Low.
	Point Source Pathogens	Low.
	Point Source Contaminants	Low.
	Margin Encroachment	Low. Some areas of wetland threatened.
	Reclamation, Drainage, Floodbanks, Floodgates	Low.
	Grazing in margins	Low.
	Man-made structures	Low.
	Spills	Low risk of spills.
	Seafood Collection	No edible shellfish.
	Algal Blooms (sea)	Low.
	Aquaculture	Low.
	Invasive weeds/pests	Low. Some weeds growing in wetland areas.
	Sea Level Rise	Moderate. Lagoon is likely to be eroded on seaward side as sea level rises with climate change - causing loss of lagoon area. Also gradual margin erosion of saltmarsh vegetation reducing its overall area.
	Fire	Moderate.
	Water Abstraction	Low.
	Vehicle access	Low.
Overall Rating MODERATE	Prior to European influence (150 years ago), Waituna Lagoon received very low sediment, nutrient and pathogen loadings from catchment runoff. However, with extensive drainage, and the catchment landuse now dominated by intensive animal farming (including dairying), loadings have increased to moderate levels. 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. This means water depth and salinity are likely to increase as the lagoon spends more time in an open condition.	

3. VULNERABILITY ASSESSMENT TABLES (CONT.)

3.4 EXISTING CONDITION AND SUSCEPTIBILITY

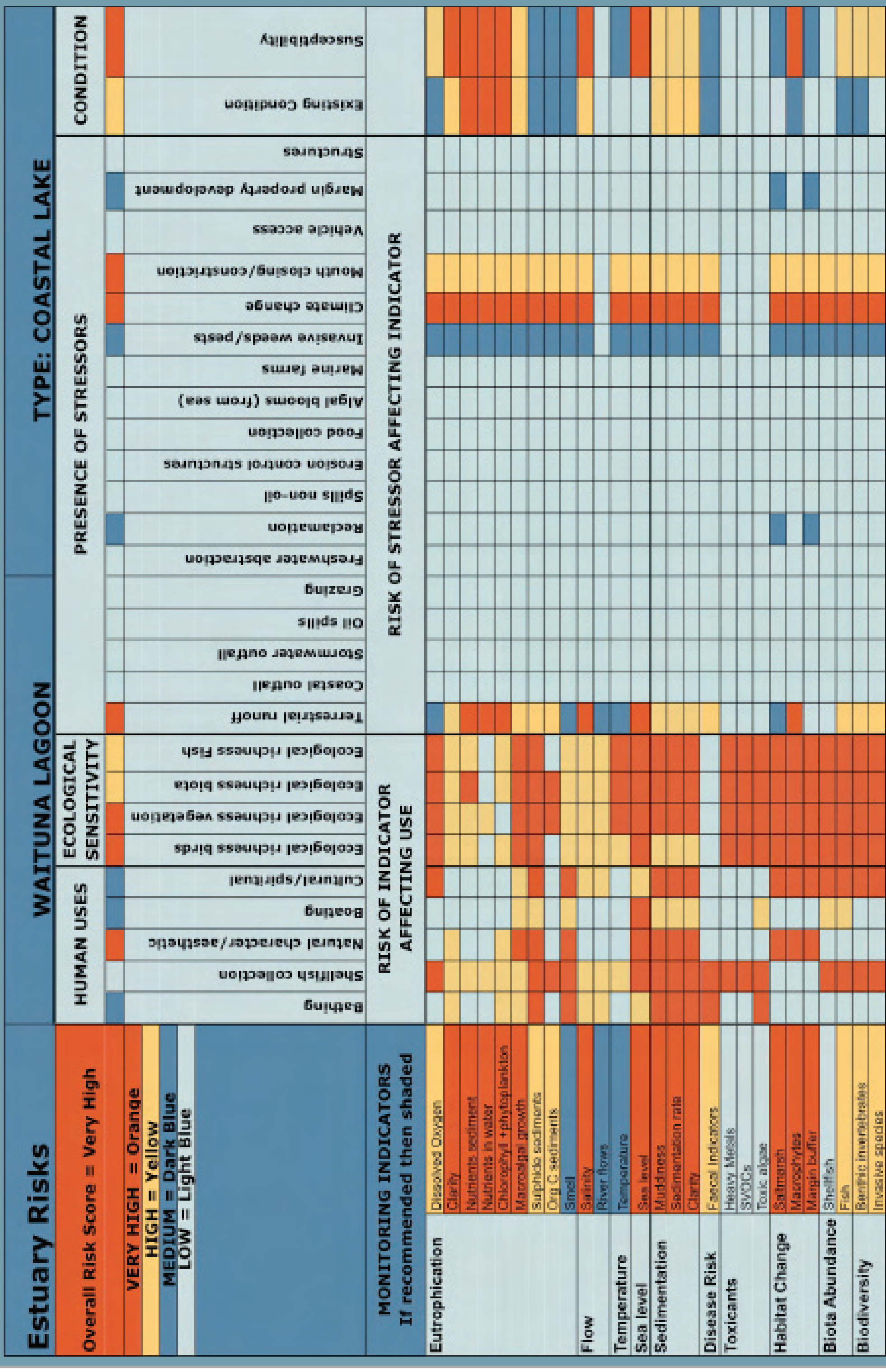
Good	Moderate	Poor
Low	Moderate	High

Issue	Indicators	Waituna Lagoon
Eutrophication	Dissolved Oxygen	Moderate. Water column Good, generally above 8mg/l in water. Anoxic sediments, especially in sediment plumes around stream inputs and shallow areas under macrophyte blooms.
	Nutrients	Poor. Elevated in water column (see Annex1 for additional technical detail).
	Phytoplankton blooms	Poor. Chlorophyll-*a* elevated to eutrophic status when closed.
	Macroalgal blooms	Moderate. Present.
	Sulphide	Moderate. Localised areas.
	Smell	Moderate. Localised noxious smell in margins where macrophyte blooms rotting.
Susceptibility High	Because Waituna Lagoon is poorly flushed and has a long residence time, it is susceptible to nutrient build-up within the lagoon and excessive growths of phytoplankton and macroalgae. With increased drainage in the catchment and removal of much of the natural wetland filtering effect, the susceptibility has increased.	
Sedimentation	Area of Muddiness	Moderate. Localised areas around streams, rushland beds and sheltered embayments.
	Sedimentation rate	Moderate. Averages in mm/yr; post 1960 2.5-3mm/yr in localised areas. Likely to be lower elsewhere. These are low-moderate compared with high NZ levels of 10-20mm/yr.
	Clarity	Moderate. Secchi disc 1-3m.
Susceptibility High	Because Waituna Lagoon is poorly flushed and has a long residence time when closed, it is susceptible to excessive rates of sedimentation. This means that if fine sediment (i.e. mud) inputs are high then we would expect the lagoon bed to be getting muddier. Because the lagoon floods over beds of rushland for long periods, it is likely that sedimentation is favoured in such sheltered locations. With increased drainage in the catchment and removal of much of the natural wetland filtering effect, the susceptibility has increased.	
Disease Risk	Faecal Indicators	Moderate. Very few measurements in lagoon. Loading from runoff in catchment likely to be high from intensive beef, sheep and dairying.
Susceptibility High	Because Waituna Lagoon is poorly flushed and has a long residence time, it is susceptible to a build-up in faecal indicator bacteria and consequently a greater disease risk than estuaries that are well flushed. With increased drainage in the catchment and removal of much of the natural wetland filtering effect, the susceptibility has increased.	
Toxicants	Heavy Metals	Good. No measurements but also no obvious sources in catchment.
	SVOCs	Good. No measurements but also no obvious sources in catchment.
	Toxic algae	Good.
Susceptibility High	Because Waituna Lagoon is poorly flushed and has a long residence time, it is susceptible to a build-up in contaminant levels and consequently a greater toxicity risk than estuaries that are well flushed. With increased drainage in the catchment and removal of much of the natural wetland filtering effect, the susceptibility has increased.	
Habitat Loss & Biodiversity Change	Saltmarsh/Wetland	Good - Moderate.
	Aquatic Macrophytes	Moderate; *Ruppia* growing well under optimal conditions in 2007, but under stress other times.
	Margin buffer	Good. Most of 200m margin with wetland is unmodifed.
	Shellfish (edible)	Good.
	Fish	Good - Moderate.
	Benthic Invertebrates	Good.
	Invasive Species	Good.
	Temperature	Good.
	Sea Level Rise	Poor. Past century 2.1mm/yr, set to increase up to 7mm/yr or more. Means a likely increase in water depth, salinity and open lagoon time, all of which are a threat to *Ruppia* habitat and growth.
Susceptibility High	The lagoon has unique and important wetland, aquatic plant and animal communities that are highly susceptible to change. Because the lagoon is shallow and the wetland margin is large, the susceptibility to habitat and biodiversity change through sea level rise is high.	

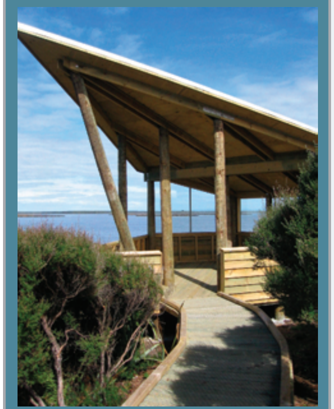
3. VULNERABILITY ASSESSMENT TABLES (CONT.)

3.5 WAITUNA LAGOON ESTUARY VULNERABILITY MATRIX

The completed Waituna Lagoon Estuary Vulnerability Matrix presented here shows that the overall combination of the existing condition, susceptibility, and the risk of the stressors causing issues (and affecting indicators), was in the very high category.



4. SUMMARY AND CONCLUSIONS



Existing studies on Waituna Lagoon indicate that it is a largely unmodified example of a temperate shallow coastal lagoon with its remaining coastal wetland system mostly intact. It currently experiences three main issues:

- Excessive sediments and increased (localised) muddiness.
- Excessive nutrients and algal blooms (both phytoplankton and macroalgal).
- Expansion of rushland areas, probably as a result of increased sediment and nutrient inputs.

The existing studies also provide important information on the two key components of the Waituna complex, the submersed aquatic macrophytes, and the wetland terrestrial margin vegetation:

- The main aquatic plant, *Ruppia*, was still thriving in the lagoon when conditions were optimal (extended period of lagoon closure, good clarity), thus ensuring its importance as habitat for invertebrates and fish, as a food source for invertebrates and waterfowl, and in regulating water quality.
- The wetland and terrestrial margin vegetation in the internationally significant Waituna complex was found to be relatively unmodified, diverse and expansive. Major assemblages included lagoon edge saltmarsh, turf and cushion bogs characterised by herbs and shrubs, tussock lands, and manuka and inaka scrublands.

In order to further assess the extent of these issues and define future monitoring and management priorities, an Ecological Vulnerability Assessment was undertaken. The key findings (and overall ratings) are summarised as follows:

USES AND VALUES

Moderate

- The lagoon is popular locally and regionally, and also draws many tourists. It is valued for its aesthetic appeal, its rich biodiversity, gamebird shooting, fishing (primarily brown trout), boating, walking, and scientific appeal.

ECOSYSTEM RICHNESS

High

- The lagoon has a unique submerged aquatic plant community (*Ruppia*-dominated), internationally important birdlife, and large areas of relatively unmodified wetland and terrestrial vegetation.

PRESENCE OF STRESSORS

Moderate

- **Catchment runoff:** Prior to European influence (150 years ago), the lagoon received very low sediment, nutrient and pathogen loadings from catchment runoff. However, with extensive drainage, and the catchment landuse now dominated by intensive animal farming (including dairying), loadings have increased to moderate levels.
- **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. This means water depth and salinity are likely to increase as the lagoon spends more time in an open condition.
- **Introduced weeds/drainage/reclamation:** Currently localised issues although introduced weeds have the potential to significantly change the predominantly native characteristics of the wetland vegetation.

EXISTING CONDITION

Nutrients	Eutrophic
Sediment	Moderate
Pathogens	Moderate
Wetland	Good
Ruppia	Good
Biota	Good
Margin	Good

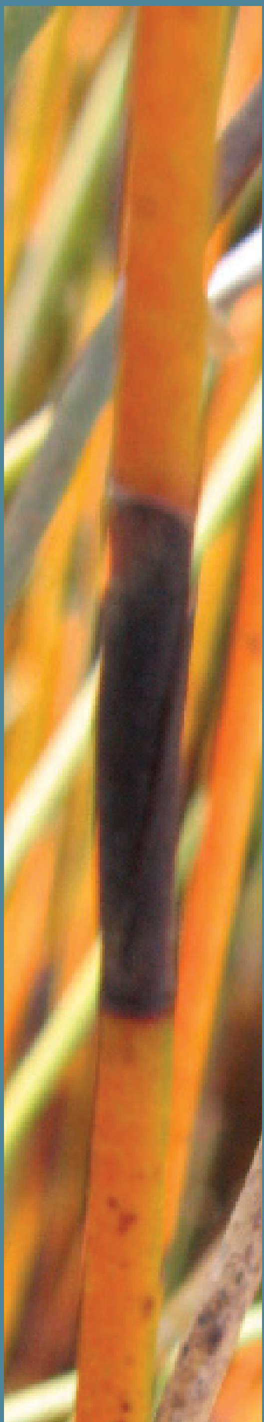
- The lagoon has very elevated phosphorus and nitrogen concentrations and excessive levels of phytoplankton and macroalgal blooms. Such conditions place the lagoon in a "eutrophic" category in terms of trophic status.
- The lagoon has low-moderate sedimentation rates compared with other NZ estuaries and this manifests as increasing muddiness in certain preferred locations around the lagoon.
- Rushland beds are expanding in response to increased sedimentation and high lagoon levels.
- The lagoon has moderate levels of faecal indicator bacteria but available monitoring data is limited.
- The terrestrial margin and wetland vegetation, and aquatic plant life, is in good condition. However, little information is available for other biota in the lagoon.

PHYSICAL SUSCEPTIBILITY

High

- The lagoon is shallow, and poorly-flushed due to the fact that its outlet to the sea is closed for long periods.
- It has extensive and relatively unmodified areas of wetland vegetation and a unique aquatic plant community.
- The lagoon has a relatively complex shape, with some sheltered arms where muddy sediments tend to settle and accumulate.
- Such physical features makes the lagoon highly sensitive to inputs of sediment, nutrients, pathogens, and toxins. If excessive levels of such stressors enter the lagoon then it will experience problems.

4. SUMMARY AND CONCLUSIONS (CONTINUED)



The Ecological Vulnerability Assessment showed that the lagoon has a moderate level of human use but has very high ratings for its ecological values. In particular, it has a unique submerged aquatic plant community (*Ruppia*-dominated), internationally important birdlife, and large areas of relatively unmodified wetland and terrestrial vegetation that should be maintained and encouraged.

However, because Waituna Lagoon is shallow, poorly flushed, has a long residence time, and is artificially opened and closed, it is susceptible to a number of problems that could affect the ecology if the relevant stressors were present. Information on the presence of lagoon stressors in the catchment and the existing condition of the lagoon, indicates they are both present, and causing problems.

Available landuse information indicates that catchment loadings of nutrients, sediment and pathogens are elevated to levels that would cause problems in highly susceptible downstream waterbodies. Monitoring data shows that the existing condition of the lagoon is detrimentally affected by these excessive loadings as follows:

- It is eutrophic (having high levels of nutrients and both phytoplankton and macrophyte blooms).
- Muddy sediments are relatively common throughout the lagoon.
- Water clarity is lowered.
- The area of rushland is changing (expanding at present).

We know from studies and experience elsewhere that *Ruppia* growth may be discouraged if water clarity is reduced through such actions as excessive inputs of fine sediment, by frequent changes in water or salinity levels through lagoon openings, or if excessive nutrient inputs result in phytoplankton or macroalgal blooms. It is also possible that the shift may be irreversible and result in a dramatic and adverse change to aquatic life in the lagoon and margins.

We also know that the wetland and terrestrial margin vegetation is important because it acts to improve water quality, maintain local biodiversity, provide fish and wildlife habitat, protect shorelines from erosion, provide flood storage and mitigation and is a natural filter and trap for sediment and nutrients. Two issues were identified in relation to these communities:

- Encroachment of farmland into the terrestrial margin and rushland through vegetation clearance and drainage to the north and east of the lagoon.
- The establishment of various introduced weeds and grasses within the wetland area.

The key risks to the lagoon and surrounding vegetation have been identified as:

- Excessive catchment inputs of sediment, nutrients and pathogens.
- Sea level rise.
- Salinity shifts from variable lagoon opening regimes.
- Drainage of margin areas.
- Invasive weeds.
- Fire.

A proposed monitoring programme to address the issues identified above is presented in the following section. Note, some of the recommendations are already part of existing monitoring undertaken by ES, while it is envisaged that the key management agencies (ES, DOC) will coordinate effort and undertake different parts of the programme as appropriate.

5. RECOMMENDATIONS

5.1 RECOMMENDED MONITORING

Sedimentation	Elevated sedimentation rates are likely to lead to major and detrimental ecological changes (e.g. loss of *Ruppia* beds), and indicate where changes in land use management may be needed. Increased sediment inputs may reduce light penetration by decreasing clarity, a key factor affecting *Ruppia* growth and health. A shift towards smaller grain sizes (particularly silts and muds) in areas that are currently dominated by sands or gravels is likely to be indicative of excessive sedimentation of fine sediments from catchment developments, and may detrimentally alter biotic assemblages. To determine the extent and rate of sedimentation the following is recommended: • Broad scale mapping of sediment type at five yearly intervals (repeat 2007 survey in 2012). • Fine scale monitoring of surface sediment grain size along selected transects at five yearly intervals (beginning 2008). • Assessment of sedimentation rate (using buried sedimentation plates) at two high deposition areas (including rushland). Ideally measured at annual intervals. • Measure water clarity (Secchi disc - SD) at monthly intervals at representative sites.
Eutrophication	Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota. 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. The following is recommended: • Broad scale mapping of lagoon macroalgal percent cover annually in January-March (when the lagoon mouth is open). • Monthly monitoring during the main growing period (September-April) for the following parameters: lagoon light penetration or SD, chlorophyll-*a*, phytoplankton, total nitrogen, nitrate, ammonia, total phosphorus, dissolved reactive phosphorus, salinity, dissolved oxygen, temperature, and water level. In addition, establish a baseline of sediment organic carbon (determined from ash free dry weight) at representative sites.
Disease Risk	Potential disease causing bacteria and pathogens are commonly associated with inputs of faecal matter from warm blooded animals. Because of the high numbers of dairy cows in the catchment, inputs are expected to be elevated in incoming streams. The following is recommended: • Monthly monitoring during the main periods of contact recreation for *E. coli*.
Macrophytes	The presence of extensive macrophyte (e.g. *Ruppia*) beds in shallow open/closed coastal lake estuaries, like Waituna Lagoon, are likely to be indicative of a healthy and biodiverse ecosystem (i.e. not too muddy or nutrient enriched). The following is recommended: • Repeat broad scale mapping of percent cover of *Ruppia* at annual intervals.
Wetland and Terrestrial Margin	A terrestrial margin dominated by native vegetation almost certainly acts as an important buffer between developed areas and the wetland and lagoon. This buffer protects against introduced weeds and grasses, and naturally filters sediments and nutrients. Additionally, there have been significant areas of saltmarsh drained for pastoral use in the past and this has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary. Saltmarsh is also highly susceptible to sea level rise. The following is recommended: • Broad scale mapping of wetland and terrestrial margin vegetation at five yearly intervals (repeat 2007 survey in 2012).
Catchment Monitoring	As the characteristics of the surrounding catchment, and the landuse undertaken within it, are major determinants of downstream conditions, the following catchment monitoring is recommended: • Identify areas where a combination of different factors (e.g. land cover, slope, area, soil type, geology, rainfall, etc) highlight a high potential for immediate or potential inputs of sediment. Use existing catchment data to identify "hotspots" such as erosion prone areas, easily mobilised sediment reserves etc. and target these for specific management. • Monitor suspended sediment, total nitrogen, total phosphorus and *E. coli* concentrations in the streams draining the major developed catchment (i.e. Waituna Creek and possibly Currans Creek) on three occasions during low flows, three during medium flows and hourly throughout three high flow events to better characterise likely loadings.

5. RECOMMENDATIONS (CONTINUED)

5.2 RECOMMENDED MANAGEMENT

Monitoring is a key step to effective management. In order to help assess the monitoring results, make the best use of existing data, and provide options for protecting and improving the ecological quality of the lagoon, consideration of the following management work is recommended:

Develop Condition Ratings for Reporting Monitoring Results

- Condition ratings are criteria for monitoring indicators that rate lagoon condition (e.g. very good/good/fair/poor), guide the type and frequency of monitoring, and indicate the type of management responses that may be needed. Because of the unique conditions present, ratings need to be developed specifically for Waituna Lagoon. Examples of the types of condition ratings proposed for development for Waituna Lagoon are included in Technical Annex 2.

It is recommended that condition rating categories be developed for the following key indicators:

• Area of soft mud	• *Ruppia* percent cover
• Grain size	• Rushland percent cover
• Sedimentation rate	• Terrestrial margin percent cover
• Water clarity	• Macroalgal cover

Catchment Management

- Catchment runoff was identified as one of the major stressors in Waituna Lagoon. To prevent avoidable inputs, best management practices should be identified and implemented to reduce runoff of sediment, nutrients and pathogens from catchment "hotspots".
- Supporting this, studies to determine appropriate loads of sediment, phosphorus, nitrogen and faecal bacterial indicators entering the lagoon in streams should be undertaken (i.e. develop a lagoon phosphorus budget, a trophic response model, and a light model for *Ruppia* growth). Ideally this would enable Total Daily Maximum Loads (TDMLs) to be set for sediment, phosphorus, nitrogen and faecal bacterial indicators in streams entering the lagoon.

Ruppia Management

- The submersed macrophyte *Ruppia* is considered a keystone species within the lagoon and an indicator of a healthy and biodiverse ecosystem. To maintain favourable depth and salinity regimes for *Ruppia* growth, limits should be established for managing the lagoon level and lagoon openings to ensure available habitat is maximised.
- *Ruppia* may also be susceptible to overgrazing by waterfowl. Options should be considered for how to monitor and prevent overgrazing if it is a problem.

Lagoon Management

- Current lagoon management focuses more on flood mitigation than lagoon ecology. It is recommended that a lagoon management plan be developed that addresses lagoon opening/closing guidelines and incorporates the maintenance of *Ruppia* beds, potential macroalgal blooms, as well as maximising area for sedimentation of fine materials.

Wetland and Terrestrial Margin Management

- Maintenance of the wetland and terrestrial margin is an important way to filter runoff and limit the establishment of weeds. If not already developed, a wetland and terrestrial margin management plan to maintain and enhance the protective strip around the lagoon is recommended.

6. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from various people, local farmers who provided access to the estuary, Chris Owen who provided valuable local information and a skippered boat, Gay Munro who provided Waituna Landcare Group data, staff of the Department of Conservation (particularly Emily Atkinson, Ken Murray, and Eric Edwards), Marc Schallenberg (University of Otago), and Environment Southland (particularly Chris Arbuckle, Jane Kitson, Greg Larkin, and Kirsten Meijer, Les McGraw, Ingrid Darragh, Chris Jenkins, and Karl Erikson).

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Technical Annex 1

Summary of technical notes supporting expert decisions used in the main report.

ANNEX 1. TECHNICAL NOTES - WAITUNA LAGOON CHARACTERISTICS

Type	Coastal Lake.
Frequency of Mouth Closure	Generally closes annually. Opened artificially around 2.2m above msl.
Mean Depth (m)	Approximately 1m when lagoon at 1.13m above msl. Max depth is 3m.
Depth of Central Basin (m)	1-1.5m.
Wetland/Salt Marsh Area (ha)	472ha.
Salinity Regime	Varies from 32ppt to <2ppt. When open, 30ppt throughout the lagoon.
Catchment Rock Type	Hard quartz gravels.
Dominant Landuse (since 1960)	Dairying currently, previously intensive sheep/beef.
Estuary Area (ha)	1,350ha.
Limiting Nutrient	Most likely to be phosphorus.
Sheltered Fringe Areas	Several sheltered embayments/arms.
Macrophyte Abundance	*Ruppia* dominant species. Both *R. megacarpa* and *R. polycarpa* are present. March 2007 *Ruppia* Rating = GOOD based on first broad scale survey (see Stevens and Robertson 2007).
Macrophyte Threats	Reducing light penetration from excessive fine sediment or phytoplankton blooms. Excessively long periods of high salinity. Large and frequent variations in lagoon level.
Macroalgal Abundance	*Enteromorpha* blooms common. LOW when lagoon level high,. MODERATE when open and lagoon level low.
Macroalgal Frequency	Regular.
Phyto. Blooms Spatial Cover	Extensive when closed.
Phytoplankton (Surface Conc.)	Chlorophyll-*a* elevated occasionally up to 15ug/l. Mean 7ug/l when closed.
Phytoplankton Blooms Frequency	Regular.
DO Depletion Surf Conc.	No problem.
DO Depletion Frequency	Never.
Macrophyte Loss Trend	Low.
Macrophyte Magnitude Loss	Low.
HAB Frequency	Harmful Algal Blooms (HABs) never reported.
Anoxic Sediments Frequency	Anoxic sediments near stream mouths and in shallow waters around lagoon margins where decaying macroalgae and other plant remains accumulate and rot.
Residence Time and Flushing	Poorly flushed and long residence time when closed. At present lagoon is opened at approximately annual intervals.
Slope of Catchment	Flat.
Wind Exposure	Exposed particularly to the south.
Mean Tidal Range (m)	Varies according to whether open or closed. Tidal range at Bluff is mean 1.5m neap tides and mean 2.2m spring tides.
Mean Freshwater Inflow (m^3/d)	Not available.
Sediments in Estuary	Mix of gravels, sands, muddy sands and a small amount of muds.

Mean Inflow Water Quality (Waituna Creek at Marshalls Road; ES data 1995-2007) - high values in orange.

Flow	Faecal Coliform	*E. coli*	Total N	Nitrate Nitrite Nitrogen	Nitrate N	Total Ammoniacal N	Total Phosphorous	DRP	Dissolved Oxygen	Water Temp	pH	Turbidity	Black Disc	Suspended Solids	Conductivity
m3/s	CFU/ 100ml	CFU/ 100ml	g/m3	mg/l	mg/l	mg/l	g/m3	mg/l	g/m3	degC	units	NTU	m	mg/l	uS/cm
1.50	1815	1220	2.12	1.32	1.32	0.117	0.081	0.027	8.95	11.0	6.55	11.6	0.62	14	212.1

ANNEX 1. TECHNICAL NOTES - WAITUNA LAGOON CHARACTERISTICS (CONT.)

Catchment Landuse and Area (ha)

	Dairying	Native Forest	Exotic Forest	Scrub	Sheep/ Beef	Wetland	TOTAL
Area (ha)	5,660	250	600	3,000	8,098	2,000	21,228

Dairying Statistics

Total Area Dairying (ha)	No. Cows	No. Farms	Cows/ha
5,660 (75% in Waituna Creek catchment)	20, 400	46	3.64

TSS Loading (tonnes/year)

Estimates based on likely specific yields for different landuse types.

Sources: Wilcock et al. 1999, Elliot and Sorrell 2002.

Estimated Total Suspended Solids) (TSS) Loads (tonnes TSS/year): Waituna Catchment		
Total Catchment	2,100 to 42,500	10-200 tonnesTSS/km^2/yr x 212.28 km^2 = 2,100-42,500 tonnesTSS/yr
(NIWA SS Yield estimator gives 100-2000kgTSS/ha/yr for this area which is in the low-moderate category)		

N Loading (tonnes/year)

Estimates based on likely specific yields for different landuse types.

Sources:
Wilcock et al. 1999
Monaghan et al. 2004
Elliot and Sorrell 2002

Estimated Total Nitrogen Loads (tonnes N/yr): Waituna Catchment		
Native Forest/ Wetland	0.75	3 kgN/ha/yr x 2250ha = 6 tonnesN/yr
Scrub	9	3 kgN/ha/yr x 3000ha = 9 tonnesN/yr
Exotic Forest	1.8	3 kgN/ha/yr x 600 ha = 1.8 tonnesN/yr
Dairy (leachate/runoff) excludes effluent spray	130+	23 kgN/ha/yr x 5,660ha = 130 tonnesN/yr (cf. Bog Burn, 18-23 kgN/ha/yr). NOTE: at 3 cows/ha it is more likely to be up around 30 kgN/ha/yr (based on Environment Waikato criteria)
Dairy Oxidation Ponds	28	5.4 kgN/cow/yr x 20,400 cows = 110 tonnes/yr if untreated. Assume 75% removal in dual ponds = 28 tonnesN/yr
Sheep/Beef	72	9 kgN/ha/yr x 8098ha = 72 tonnesN/yr
Human wastewater	1	4.2 kg/person/yr x 300 persons = 12 tonne/yr untreated. Assume 20% removal = 1 tN/yr
TOTAL	242+	

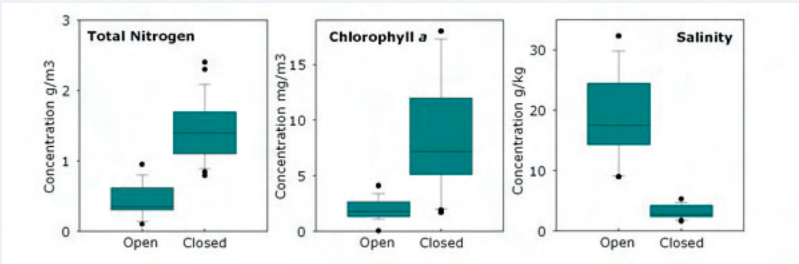
P Loading (tonnes/year)

Estimates based on likely specific yields for different landuse types.

Sources; Wilcock et al. 1999, Monaghan et al. 2004, Elliot and Sorrell 2002.

Estimated Total Phosphorus Loads (tonnes P/yr): Waituna Catchment		
Native Forest/Wetland	0.9	0.39 kgP/ha/yr x 2250ha = 0.9 tonnesP/yr
Scrub	1.2	0.39 kgP/ha/yr x 3000ha = 1.2 tonnesP/yr
Exotic Forest	0.2	0.35 kgP/ha/yr x 600 ha = 0.2 tonnesP/yr
Dairy (leachate/runoff) excludes effluent spray	7.4	1.3 kgP/ha/yr x 5,660ha = 7.4 tonnesP/yr (cf. Bog Burn, 1.3 kgP/ha/yr)
Dairy Oxidation Ponds	3	0.66 kgP/cow/yr x 20,400 cows = 13.4 tonnes/yr if untreated. Assume 75% removal in dual ponds = 3 tonnesP/yr
Sheep/beef	3.7	0.46 kgP/ha/yr x 8100ha = 3.7 tonnesP/yr
Human wastewater	1	1.5 kgP/person/yr x 300 persons = 12 tonne/yr untreated. Assume 20% removal = 1 tP/yr
TOTAL	17.4	

<table>
<tr><th colspan="2">ANNEX 1. TECHNICAL NOTES - EUTROPHICATION</th></tr>
<tr><td>Key Question</td><td>Is there a risk of phytoplankton or macroalgal blooms in the lagoon?</td></tr>
<tr><td>Limiting Nutrient</td><td>Phosphorus (based on Environment Southland N and P data as reviewed by Schallenberg and Tyrrell 2007).</td></tr>
<tr><td>Key Indicators</td><td>Chlorophyll-a, TP, DRP concentrations in lagoon.</td></tr>
<tr><td>Waituna Creek [TN], [TP]</td><td>Waituna Creek TN mean 2.12mg/l, TP mean 0.081mg/l.
High compared with NZ Low elevation rivers mean TN: 1.71mg/l, TP: 0.07mg/l (Larned et al. 2004).</td></tr>
<tr><td>Lagoon [TP] [TN]; mean (range) ug/l</td><td>TP; 2001/05: 40ug/l (10-190ug/l).
DRP; 2001/05: 14ug/l (5-41ug/).
TN; 2001/05: 620ug/l (100-1900ug/) - Source ES data.</td></tr>
<tr><td>Lagoon [Chlorophyll-a] ug/l</td><td>2001/05: 3.7 (0.4-17) - Source ES data.
When closed mean is 7ug/l.
When open 2ug/l (see ES plots below).


</td></tr>
<tr><td>Annual areal P loading (g/m^2/yr)</td><td>17 Tonnes P/yr input into 1,350ha. 17,000,000 gP into 1350 x 10,000 m^2 = 1.26 gP/m^2/yr
High compared with most lakes e.g. eutrophic Lake Hayes has an areal loading of 0.87gP/m^2/yr.</td></tr>
<tr><td>Recent Lagoon Water Quality
Open/Closed 2006-7
Mean Water Quality Data (Source ES)

Chl-a Data Problem</td><td>Environment Southland's latest lagoon monitoring data show a telling picture of elevated nutrients and chlorophyll-a concentrations both during closed and open periods. It is noted that the chlorophyll results were provided by the analytical laboratory (ESR) 3 orders of magnitude less than we have presented them below. Such extremely low levels are very highly unlikely for this lagoon at such elevated nutrient levels and because such low values have never been reported before. ES subsequently confirmed a mistake was made in reporting the units.
The measured chlorophyll a range was therefore 2-7ug/l when open and 1-35ug/l when closed. However, I am suspicious of these very high levels as well. Two sampling occasions had concentrations over 30ug/l which is difficult to believe, but is possible. Given these concerns, I would strongly recommend checking the accuracy and reliability of all future chlorophyll-a data.

<table>
<tr><th>Open/Closed (Waituna West)</th><th>Salinity
ppt</th><th>Chl-a
ug/l</th><th>TN
mg/l</th><th>TP
mg/l</th><th>E. coli MPN
CFU/100ml</th></tr>
<tr><td>Open Dec 2006 to June 2006</td><td>28.9</td><td>5.2</td><td>0.45</td><td>0.05</td><td>78</td></tr>
<tr><td>Closed June 2006 to July 2007</td><td>2.6</td><td>12.4</td><td>1.07</td><td>0.04</td><td>18</td></tr>
</table></td></tr>
</table>

ANNEX 1. TECHNICAL NOTES - EUTROPHICATION (CONT.)

Algal Blooms Risk Ratings (Surface Water Concentrations)

Chlorophyll-*a* concentrations

- ANZECC (2000) Guideline Trigger Values: Tasmanian Lakes 3ug/l; SE Aust Lakes 5ug/l; SE Aust estuaries 4ug/l.
- Swedish EPA 2002; (estuary season with highest average concentrations); Very low <1.5ug/l, Low 1.5-2.2ug/l, Moderate 2.2-3.2ug/l, High 3.2-5.0ug/l, Very High >5.0ug/l.
- US State of Nations Estuaries. Low <5ug/l, Moderate 5-20ug/l, High >20ug/l (using data for the season with the highest average concentration).

It is recommended that the Swedish rating categories are used given the low flushing potential of the lagoon (i.e. problem conditions would be less likely in well flushed estuaries).

Total Phosphorus Concentration

- Swedish EPA 2002; (Summer); Very low <15ug/l, Low 15-18.6ug/l, Moderate 18.6-24ug/l, High 24-31ug/l, Very High >31ug/l.

Total Nitrogen Concentration

- Swedish EPA 2002; (Summer); Very low <252 ug/l, Low 252-308 ug/l, Moderate 308-364 ug/l, High 364-448 ug/l, Very High >448 ug/l.

Trophic Level Ratings for NZ Lakes (source Burns et al. 2000)

	Microtrophic	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Chlorophyll-*a* (ug/l)	< 0.82	0.82 – 2.0	2.0 – 5.0	5.0 – 12	>12
Secchi depth (m)	> 15	15 – 7.0	7.0 – 2.8	2.8 – 1.1	>1.1
TP (ug/l)	< 4.1	4.1 – 9.0	9.0 - 20	20 – 43	>43
TN (ug/l)	< 73	73 – 157	157 – 337	337 – 725	>725

Waituna Lagoon TP Rating

Very High

2001-2005 Summer mean = 34ug/l which places it in the Very High rating based on Swedish guidelines or eutrophic status based on NZ lake ratings.

2006-2007 Summer mean (open or closed) >40ug/l = Very High

Waituna Lagoon TN Rating

Very High

2001-2005 Summer mean = 800-1200ug/l which places it in the Very High rating based on Swedish guidelines or eutrophic status based on NZ lake ratings.

2006-2007 Summer mean (open or closed) 400-1200ug/l = Very High

Waituna Lagoon Chlorophyll Rating

Very High or Eutrophic

2001-2005 When lagoon closed, mean = 7ug/l which places it in the Very High rating based on Swedish guidelines or eutrophic status based on NZ lake ratings.

2006-2007 Summer mean (open or closed) 5.2-12.4ug/l = Very High

ANNEX 1. TECHNICAL NOTES - EUTROPHICATION (CONT.)

Conclusions Phytoplankton Blooms	• When the lagoon was closed (2001-2007), it fitted the category of a eutrophic lake or estuary. As such it had very high concentrations of both key nutrients (nitrogen and phosphorus) and chlorophyll-*a*, and lowered water clarity, compared with available guidelines. • When the lagoon was open in 2001-2005, nutrient concentrations were less and it fitted the category of a mesotrophic waterbody. • When the lagoon was open in 2006, nutrient concentrations were elevated and it fitted the category of a eutrophic waterbody. • Given that the lagoon can be closed for long periods (in 2006-7 it was for 13 months), it is clear that the lake is generally eutrophic for this period but it can also be eutrophic in open periods. • To return the lagoon to a lower trophic status when closed, the areal P loading would need to be reduced considerably. Given that the current TP concentration (40ug/l) places the lagoon in the upper end of the eutrophic category, by reducing P inputs by 50% would likely reduce the trophic status to just inside the mesotrophic status (unless there are significant internal loads of P). • This information now begs the obvious question; if the lagoon is already eutrophic for long periods, why hasn't water clarity reduced to a level that limits light available to *Ruppia* and curtails its growth? • The answer is relatively simple. Although the water clarity is lowered (Secchi disc 1-3m), the water depth of the lagoon is mostly in the 0.5-2m depth range, so *Ruppia* continues to receive adequate light. However, if excess fine mud particles were present in the water column at the same time, then clarity would be reduced further and *Ruppia* would likely be adversely affected.
Conclusions Macroalgal Blooms	• When the lagoon is open and closed, macroalgal blooms are common but at times mostly isolated to areas of shallow water (or intertidal areas when the lagoon is open). • The cause of these macroalgal blooms is likely to be excessive nutrient concentrations and poor flushing at times. Concentrations of both N and P almost always exceed levels that limit sea lettuce growth (Pederson & Borum 1997) (approximately 300ug/l DIN). The reason for the absence of large areas of nuisance macroalgal cover, despite the abundance of nutrients, may be attributed to other limiting factors such as salinity stress, grazing, and exposure to strong winds.
Monitoring and Management Eutrophication	• Monitoring Recommendations * Lagoon Macroalgal percent cover annually. * Lagoon light penetration or Secchi depth, chlorophyll-*a*, TN, TP, Nitrate, Ammonia, DRP, salinity, DO, temperature, water level, open/closed. * Catchment TP and TN input loads (low and high flows). • Management Recommendations * Total Daily Maximum Loads on TN and TP inputs.

ANNEX 1. TECHNICAL NOTES - SEDIMENTATION

Key Question	Is there a risk of excessive sedimentation in the lagoon?
Key Indicators	Secchi disc, sedimentation rate, areal extent of soft muddy sediments.
Lagoon Sedimentation Rate	2.5-3mm/yr in moderate to high sedimentation areas. Cadmus & Schallenberg (in press) have recently undertaken a comprehensive historical analysis of sediment cores which tends to support this conclusion. Their results indicate a very low sedimentation rate of 0.05-0.06mm/yr from 7000 years BP to 1960, which increased to 2.8mm/yr in the period 1960 till present.
Discussion and Conclusions Sedimentation	• The measured sedimentation rate of 2-3mm/yr is low-moderate compared with most other NZ estuaries with developed catchments. • Firstly, consider if this rate is occurring all over the lagoon or is it confined to certain preferred areas. • If it was present all over the lagoon then we would expect a Suspended Solid Input Load of around 30,000-40,000tonnes/yr (40,000,000kg spread over 13,500,000m^2 = 3kg/m^2. Assuming lagoon sediment is 1200kg/m^3, then the depth of 3kg spread over 1m is equal to 3/1200 x 1000 = 2.5mm/yr). • Now to convert this to a SS specific yield from the 21,228 ha catchment; * 40,000 tonnes per 21,228ha = 1.9 tonnesSS/ha/yr = 190 tonnes/km^2/yr • This SS Input Load of 190 tonnes/km^2/yr is in the LOW-MODERATE range and is similar to that predicted based on the rating given in the NIWA SS Yield estimator. **SS Input Load = Low -Moderate** • This SS Input Load is therefore likely to be an average over the lagoon of 2-3mm/yr but the mapping sediment study shows that this is not evenly spread around the lagoon. Higher rates are likely to occur in the rushland beds, river outlets and sheltered embayments. • Currently, the clarity data for the lagoon is very limited but available information indicates it is in the 0.5-2m range.
Monitoring and Management Sedimentation	• Monitoring Recommendations * Lagoon Sedimentation rate (sediment plates). * Wetland margin Sedimentation rate (sediment plates in rushland beds). * Lagoon Clarity. * Catchment Sediment input loads (low and high flows). • Management Recommendations * Total Daily Maximum Loads on suspended sediment inputs.

ANNEX 1. TECHNICAL NOTES - DISEASE RISK

Key Question	Is there a disease risk in the lagoon?
Key Indicators	*E. coli*, faecal coliforms, numbers of warm blooded animals in catchment.
Catchment Loads	See table below

Waituna Catchment: Faecal Coliform Loads

Native Forest	Very low	
Scrub	Very low	
Exotic Forest	Very low	
Dairy Runoff	5 x10^{14} FCs/yr	1 x 10^{11} FCs/ha/yr for flatland Waikato dairy farms (Wilcock 2006). For Waituna catchment, this equates to 5,660 ha X 10^{11} = 5.6 x10^{14} FCs/yr.
Dairy (in stream, crossings etc	4 x10^{14} FC/yr	7.4 x10^{10} FCs/ha/yr (Wilcock 2006). Waituna = 5,660 ha x 7.4 x10^{10} = 4.2 x10^{14} FC/yr
Dairy Oxida-tion ponds	1 x10^{14} FC/yr	2 x10^{10} FCs/ha/yr (Wilcock 2006). Waituna = 5,660 ha x 2 x10^{10} = 1 x10^{14} FC/yr
Total Dairy	1 x10^{15} FC/yr	
Sheep and Beef	1 x10^{15} FC/yr	If intensive, FC runoff expected to be similar to dairy (Wilcock 2006). Area similar to dairy so assume similar.
TOTAL	2 x10^{15} FC/yr	

Discussion and Conclusions Disease Risk	• The estimated input of 2 x10^{15} faecal coliforms per year from the catchment is elevated, primarily the result of intensive animal operations operating in the catchment.
Monitoring and Management Disease Risk	• Monitoring Recommendations * Lagoon *E. coli*. * Stream *E. coli*. * Catchment *E. coli* input loads (low and high flows). • Management Recommendations * Total Daily Maximum Loads on *E. coli* inputs (with limits set to enable bathing in the lagoon).

ANNEX 1. TECHNICAL NOTES - HABITAT/BIODIVERSITY CHANGE

Key Question	Is there a risk of detrimental change to wetland and terrestrial margin vegetation in the lagoon?
Key Indicators	Percentage change of rushland, percentage change of terrestrial margin vegetation.
Existing Condition	Wetland (rushland); primarily unmodified except for following; • Expansion of rushland areas in response to increased sedimentation, nutrients and longer periods of lagoon opening. • The establishment of various introduced weeds and grasses within the wetland area. Terrestrial margin mix of modified and unmodified. Main issue; • Encroachment of farmland into the terrestrial margin and rushland through vegetation clearance and drainage to the north and east of the lagoon.
Discussion and Conclusions Habitat/ Biodiversity	The wetland and terrestrial margin vegetation in the Waituna complex is relatively unmodified, diverse and expansive. Major assemblages included lagoon edge saltmarsh, turf and cushion bogs characterised by herbs and shrubs, tussock lands, and manuka and inaka scrublands. The wetland is internationally significant. This vegetation is important because it acts to improve water quality, maintain local biodiversity, provide fish and wildlife habitat, shoreline erosion protection and flood storage and mitigation and a natural filter and trap for sediment and nutrients. The key risks are: • Sea level rise • Salinity shifts • Drainage • Excessive sedimentation • Invasive weeds • Fire

Monitoring and Management Habitat/Biodiversity	• Wetland and Terrestrial Margin Monitoring Recommendations
	  * Repeat broad scale mapping of wetland and terrestrial margin vegetation at five yearly intervals.
	  * Sedimentation plates in rushland.
	
	• Wetland and Terrestrial Margin Management Recommendations
	  * Develop a wetland and terrestrial margin management plan (if not already developed).

ANNEX 1. TECHNICAL REFERENCES

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Technical Annex 2

Example of Condition Ratings recommended for development for Waituna Lagoon.

ANNEX 2. EXAMPLE CONDITION RATINGS FOR WAITUNA LAGOON

OVERVIEW

RATING
Very Good
Good
Fair
Poor
Early Warning Trigger

At present, there are no formal criteria for rating the overall condition of estuaries in NZ, and development of scientifically robust and nationally applicable condition ratings requires a significant investment in research and is unlikely to produce immediate answers.

Therefore, to help ES interpret their monitoring data, a series of interim broad and fine scale estuary condition ratings have been proposed for Southland's estuaries (Robertson & Stevens 2006, 2007). The interim condition ratings (presented below) are based on a review of monitoring data, use of existing guideline criteria (e.g. ANZECC (2000) sediment guidelines), and expert opinion. They indicate whether monitoring results reflect poor, fair, good, or very good conditions, and also include an "early warning trigger" so that ES is alerted where rapid or unexpected change occurs. For each of the condition ratings, a recommended monitoring frequency is proposed and a recommended management response is suggested. In most cases the management recommendation is simply that ES develop a plan to further evaluate an issue and consider what response actions may be appropriate.

The interim condition ratings presented below are examples of what would ideally be developed for Waituna Lagoon. **They have been included at this stage as examples of how different criteria can be used, but need to be reviewed for their appropriateness**, and ratings developed for other indicators e.g. macroinvertebrate (infauna and epifauna) density and abundance, etc. The condition ratings are based on Robertson & Stevens (2006, 2007) and are presented below along with a brief rationale for their use.

Metals

Heavy metals provide a low cost preliminary assessment of toxic contamination in sediments and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for the presence of other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

METALS CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<0.2 x ISQG-Low	Monitor at 5 year intervals after baseline established
Good	<ISQG-Low	Monitor at 5 year intervals after baseline established
Fair	<ISQG-High but >ISQG-Low	Monitor at 2 year intervals and manage source
Poor	>ISQG-High	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 Nitrogen

In shallow estuaries like those in Southland, 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
Low-Mod Enrichment	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Enriched	2000-4000mg/kg	Monitor at 2 year intervals and manage source
Very Enriched	>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

ANNEX 2. EXAMPLE CONDITION RATINGS FOR WAITUNA LAGOON (CONT.)

Soft Mud

The presence of large and increasing areas of muddy sediments are likely to lead to major and detrimental ecological changes (e.g. loss of *Ruppia* beds), and indicate where changes in land use management may be needed.

SOFT MUD CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Area of soft mud cover (ha) not increasing	Monitor at 5 year intervals after baseline established
Good	Soft mud cover (ha) increase <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Soft mud cover (ha) increase 5-15% from baseline	Monitor at 5 year intervals and manage source
Poor	Soft mud cover (ha) increase >15% from baseline	Monitor at 5 year intervals and manage source
Early Warning Trigger	Trend of increase in area of soft mud cover (ha)	Initiate Evaluation and Response Plan

Grain Size

A shift towards smaller grain sizes (particularly silts and muds) in selected areas that are currently dominated by sands or gravels is likely to be indicative of excessive sedimentation of fine sediments from catchment developments.

GRAIN SIZE CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Grain size becoming coarser	Monitor at 5 year intervals after baseline established
Good	Grain size remaining same as in 2007 survey	Monitor at 5 year intervals after baseline established
Fair	Grain size reducing >10% from baseline	Monitor 5 yearly. Initiate Evaluation & Response Plan
Poor	Grain size reducing >25% from baseline	Monitor 5 yearly. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend of % cover increasing	Initiate Evaluation and Response Plan

Sedimentation Rate

Elevated sedimentation rates are likely to lead to major and detrimental ecological changes (e.g. loss of *Ruppia* beds), and indicate where changes in land use management may be needed. It is recommended that the "high rating" be set at the post 1960 sedimentation rate (2-3mm/yr).

SEDIMENTATION RATE CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	<0.5mm/yr (typical pre-European rate)	Monitor at 5 year intervals after baseline established
Low	0.5-1mm/yr	Monitor at 5 year intervals after baseline established
Moderate	1-2mm/yr	Monitor at 5 year intervals after baseline established
High	2-3mm/yr	Monitor yearly. Initiate Evaluation & Response Plan
Very High	>3mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

Water Clarity

Light penetration is a key factor promoting *Ruppia* growth and health, and prolonged periods of low clarity are likely to lead to major and detrimental ecological change (e.g. loss of *Ruppia* beds)

WATER CLARITY CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Secchi depth always greater than 2m	Monitor monthly Sept-Mch.
Good	Secchi depth 1.5-2m	Monitor monthly Sept-Mch.
Fair	Secchi depth 1-1.5m	Monitor monthly. Initiate Evaluation & Response Plan
Poor	Secchi depth always less than 1m	Monitor monthly. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend of decline in Secchi depth	Initiate Evaluation and Response Plan

ANNEX 2. EXAMPLE CONDITION RATINGS FOR WAITUNA LAGOON (CONT.)

Rushland

The loss of the dominant wetland vegetation in Waituna Lagoon (i.e. rushland), will result in lower biodiversity, a reduced natural filtering and trapping of sediment and nutrients. Maintaining these features is important in a sensitive lagoon like Waituna.

RUSHLAND CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Rushland (ha) same or increased from baseline	Monitor at 5 year intervals after baseline established
Good	Rushland (ha) diminished by <5%, or increased	Monitor at 5 year intervals after baseline established
Fair	Rushland (ha) has diminished by 5-10%	Monitor 5 yearly. Initiate Evaluation & Response Plan
Poor	Rushland (ha) has diminished by >10%	Monitor 2 yearly. Initiate Evaluation & Response Plan
Early Warning Trigger	Change in area of rushland cover (ha).	Initiate Evaluation and Response Plan

Ruppia

The presence of extensive macrophyte (e.g. *Ruppia*) beds in shallow open/closed coastal lake estuaries, like Waituna Lagoon, is likely to be indicative of a healthy and biodiverse ecosystem (i.e. not too muddy or nutrient enriched).

***RUPPIA* CONDITION RATING**

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	*Ruppia* cover exceeds that of 2007	Monitor annually after baseline established
Good	*Ruppia* cover similar to 2007	Monitor annually after baseline established
Moderate	*Ruppia* cover 10-30% less than 2007	Monitor annually. Initiate Evaluation & Response Plan
Fair	*Ruppia* cover 30-70% less than 2007	Monitor annually. Initiate Evaluation & Response Plan
Poor	*Ruppia* absent from lagoon	Monitor annually. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend of % cover increasing or decreasing	Initiate Evaluation and Response Plan

Macroalgae Percent Cover

Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota.

MACROALGAE CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	%cover <1%. No nuisance conditions	Monitor at 5 year intervals after baseline established
Good	%cover 1-10%. No nuisance conditions	Monitor at 5 year intervals after baseline established
Fair	%cover 10-50%. Isolated nuisance conditions	Monitor annually. Initiate Evaluation & Response Plan
Poor	%cover >50%. Widespread nuisance conditions	Monitor annually. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend of % cover increasing	Initiate Evaluation and Response Plan

Terrestrial Margin

A terrestrial margin dominated by native vegetation almost certainly acts as an important buffer between developed areas and the wetland and lagoon. This buffer protects against introduced weeds and grasses, and naturally filters sediments and nutrients.

TERRESTRIAL MARGIN CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Terrestrial margin is 100% native	Monitor at 5 year intervals after baseline established
Good	Native margin (ha) diminished by <5%, or increased	Monitor at 5 year intervals after baseline established
Fair	Native margin (ha) has diminished by 5-10%	Monitor at 5 year intervals after baseline established
Poor	Native margin (ha) has diminished by >10%	Monitor at 5 year intervals after baseline established
Early Warning Trigger	Decrease in area of native cover in margin (ha).	Initiate Evaluation and Response Plan