Waituna Lagoon
No other place like it

Interim recommendations to reduce the risk of Waituna Lagoon flipping to an algal-dominated state

Prepared by the Lagoon Technical Group (LTG)

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Credits

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Executive Summary

Waituna Lagoon is currently considered to have a high likelihood of "flipping" from its high value clear-water, seagrass (*Ruppia*) dominated state, to a highly undesirable turbid, algal dominated (phytoplankton/epiphytic) state due to excessive inputs of nitrogen, phosphorus, and sediment from intensification of landuse in the catchment.

In response, Environment Southland (ES) has convened a Lagoon Technical Group (LTG) to provide short-term immediate guidance to minimise the risk of the lagoon flipping and identification of a recommended pathway for the long-term management of lagoon condition. The following recommendations are preliminary and based on the best knowledge on the Waituna Lagoon system, however there are information gaps and as such these recommendations will be reviewed six-monthly and updated. These preliminary recommendations are viewed as necessary due to the urgency and risk of the lagoon flipping and to inform the research needs and mitigation work within the Waituna Lagoon catchment.

A Catchment Technical Group (CTG) is being developed to determine the implications of the Interim Lagoon Recommendations for the catchment.

The key recommendations from this document are:

1. Short term immediate guidance to minimise the risk of lagoon flipping:

   - water quality targets for lagoon health;
   - recommendations for lagoon sediment and nutrient load reductions;
   - lagoon opening/closing decision criteria;
   - monitoring recommendations;
   - recommendations for further research;
   - role of the Lagoon Technical Group (LTG).

2. A pathway for the medium to long-term management of Waituna, which links to the development of a whole catchment plan for lagoon recovery undertaken by the Catchment Technical Group (CTG).

What is the Problem?

Waituna Lagoon is a highly valued, large brackish coastal lagoon that is fed by three streams. It drains to the sea through a managed opening. In terms of estuary classification it is classified as an intermittently closed and open coastal lake or lagoon (ICOLL). Historically the lagoon was surrounded by peat bog wetland which gave the lagoon's water its characteristic brown colour, and low pH. It is a system that has very high ecological habitat diversity and supports an intact seagrass community (*Ruppia* dominated), internationally important birdlife, and large areas of relatively unmodified wetland and terrestrial vegetation. In addition it has been highly valued for its aesthetic appeal, its rich native biodiversity, duck shooting, fishing (for brown trout primarily), boating, walking, and scientific appeal. In 1976, it was listed as a wetland of international importance (Ramsar site), in 1983 was designated a DOC scientific reserve, and the cultural significance to the local Ngai Tahu people was recognised under a Statutory Acknowledgement with the Ngai Tahu Claims Settlement Act 1998.

However, through land development of the catchment over the past century (e.g. clearance of wetlands, drainage enhancement and fertiliser inputs) and an opening regime managed for farm drainage, the lagoon is now experiencing a number of ecological problems. This includes a decline in abundance of *Ruppia* (seagrass) that is central to the lake's ecological functioning, increased abundance of nuisance filamentous algae, and reduced oxygenation of bed sediments. These issues are exacerbated by the lagoon's susceptibility to water quality problems because the lagoon's opening to the sea is intermittent, resulting in periods when flushing of the lagoon is restricted. Therefore, sediment and nutrient inputs tend to affect the lagoon and are key drivers in the changes described above. With recent further conversion of the catchment to more intensive dairy farming, the risks of eutrophication and excessive fine sediment deposition in the lagoon are of concern.

In the last 10 years, monitoring results have highlighted a rapid decline in lagoon condition to the point where it has deteriorated from a high value seagrass (*Ruppia*) dominated state, to a more degraded condition with nuisance epiphyte and algal blooms and sediment anoxia causing stress to the keystone *Ruppia* species. Current expert opinion is that unless urgent intervention occurs, the lagoon could undergo a rapid "flip" to an even more degraded phytoplankton dominated state (e.g. algal bloom), which would endanger the *Ruppia* community and change the fundamental values and character of the lagoon. Such rapid shifts have occurred in other lagoons leading to the loss of valued fisheries and birdlife, as well as cultural and recreational attributes of lagoons.

Lagoon Technical Group (LTG)

To initiate steps to minimise the risk of flipping, Environment Southland (ES) convened a Lagoon Technical Group (LTG) of individuals with particular experience in monitoring the condition of the lagoon, and with scientific knowledge of coastal lagoon ecosystems to:

1. analyse data and other evidence to determine the risk of flipping;

Lagoon Technical Group:
Dr Barry Robertson – Wriggle Coastal Management
Leigh Stevens – Wriggle Coastal Management
Dr Marc Schallenberg - University of Otago
Dr Hugh Robertson - Department of Conservation
Keith Hamill – Opus Consulting
Dr Jane Kitson – Environment Southland
Greg Larkin – Environment Southland
Kirsten Meijer – Environment Southland
Chris Jenkins – Environment Southland
Dean Whaanga - Te Ao Marama Inc
Shirley Hayward – DairyNZ
Andy Hicks – Department of Conservation

2. recommend lagoon management options including:

   - decision criteria for lagoon openings;
   - water quality targets for lagoon health;
   - recommendations for lagoon sediment and nutrient load reductions;

3. recommend monitoring requirements to:

   - assist with decision-making on lagoon openings
   - measure lagoon response to management intervention

4. recommend further research to understand Waituna lagoon processes

The LTG met for the first time on 24 February 2011 to prepare summary information for the Waituna Lagoon stakeholder workshop on 28 February 2011. At that meeting the LTG were tasked with summarising evidence of a problem within Waituna Lagoon, and compile interim recommendations to reduce the risk of Waituna Lagoon flipping (this document).

Purpose of the report

This report documents the progress by the LTG on addressing the above tasks. The LTG has used information available at the time to develop the set of recommendations in this report, but also recognises the need for further studies to fill in gaps in knowledge and refine recommendations. These recommendations will be updated in 6 months to reflect any changes in information.

Environment Southland is developing a Catchment Technical Group (CTG) to determine the implications of the Interim Lagoon Recommendations for the catchment.

Evidence of a problem

Indications that the lagoon is under stress and could "flip" are:

- stream nutrient inputs (N and P) have increased over the past 5-10 years (Appendix 1);

- lagoon nutrient and chlorophyll-*a* concentrations are currently at eutrophic levels in the surface waters (Hamill 2011) (Appendix 2) and are even higher in the bottom waters (Feb 2011 ES monitoring data, see Appendix 4). The lagoon becomes more eutrophic the longer the lagoon is closed to the sea as N and P accumulate from stream inputs and release from anoxic bed sediments, respectively (Appendix 2);

- deteriorating trends are apparent in lagoon total phosphorus (TP) concentrations and winter nitrate concentrations over the past 5 years (Hamill 2011);

- symptoms of eutrophication are apparent including:
  - sediment anoxia that has become widespread throughout the lagoon since 2007 (Stevens & Robertson 2010) e.g. general depth of sediment oxygen penetration (redox potential discontinuity (RPD) has decreased; in 2007: >5 cm, 2009: 0-3 cm, 2010: 0-1 cm);

- the native, brown alga *Bachelotia antillarum* (growing attached to wood, stones, or epiphytic on macrophytes, particularly *Ruppia*) was present at very low abundance in 1995, 2006, and 2007 (Johnson & Partridge 1998, Stevens & Robertson 2007). By 2009 *Bachelotia* had increased to widespread growths throughout the lagoon (94% of monitored sites), which persisted in 2010 (85% of monitored sites) under conditions when the lagoon had been closed for periods of 141 and 137 days respectively (Robertson & Stevens 2009, Stevens & Robertson 2010). Such periods of closure are typical for the lagoon;
- the widespread growth of *Bachelotia* has continued in 2011 while the lagoon has remained open for 160+ days;
- a marked decline in *Ruppia* cover since 2009 can be attributed to loss of habitat through artificial opening of the lagoon, sediment anoxia and epiphyte shading (Robertson & Stevens 2009, Stevens & Robertson 2010) e.g. *Ruppia* recorded at 85% of monitored sites in 2007, 73% in 2009 and 52% in 2010[1]. The 2011 survey recorded only sparse *Ruppia* in the lagoon (H. Robertson pers comm);
- likely release of sediment P to the water column (i.e. internal P loading) based on the presence of widespread shallow sediment anoxia and steadily increasing TP concentrations in the lagoon during closed periods.

In addition to eutrophication, excessive infilling of the lagoon bed by sediments has been widely reported by local fishermen and Environment Southland monitoring data, as occurring in the lagoon since at least 1960 (Stevens and Robertson 2007). This exacerbates the potential for lagoon flipping through wind-induced turbidity, smothering of *Ruppia*, and the increase of sediment-bound P in the lake bed.

Broad goals for lagoon health

The response to catchment and lagoon management interventions would be measured as a shift towards:

- reduced nutrient and sediment concentrations in the inflows and lagoon;
- decreased biomass of phytoplankton and macroalgae;
- increased distribution, abundance and health of *Ruppia* in the lagoon;
- improved sediment oxygenation and reduced sedimentation in the lagoon;
- maintenance or improvement of ecological, recreational and cultural values (e.g. fish, birds, wetland fringing vegetation).

Interim water quality targets for lagoon health

Because the underlying cause of eutrophication is excessive inputs of nitrogen and phosphorus, it is recommended that these be reduced to a level that will enable the lagoon condition to be sustained in a "healthy" state and away from the brink of "flipping". In addition, because eutrophication is exacerbated by excessive inputs of fine sediments, it is recommended that sediment loads be reduced.

To achieve this, it is recommended as an interim approach that the annual average total nitrogen (TN), total phosphorous (TP) and chlorophyll-*a* concentrations in Waituna Lagoon do not

[1] note a different method to record Ruppia abundance was used in 2007. The preliminary method (2007) was more descriptive than quantitative (H. Robertson per s comm)

exceed the mesotrophic/eutrophic boundary classification for NZ lakes given by Burns et al. (2000) as follows:

TP = 0.02mg/L, TN = 0.300 mg/L, Chlorophyll *a* = 0.005 mg/L.
(Appendix 5: shows the range of values for these variables over 2005-2010)

In addition, reducing suspended solids inputs to the lagoon is recommended to reduce sediment deposition and turbidity in the lagoon. Increased turbidity is a factor linked to the flipping of shallow lakes due to the light stress it induces on macrophytes (Scheffer 2004), including *Ruppia*. Based on loadings to healthy estuaries (Swales et al. 2005), and historical loadings to Waituna Lagoon (Cadmus 2004), an **interim sedimentation rate guideline of 0.5 mm/yr i**s recommended within the lagoon to protect against excessive turbidity and sediment deposition.

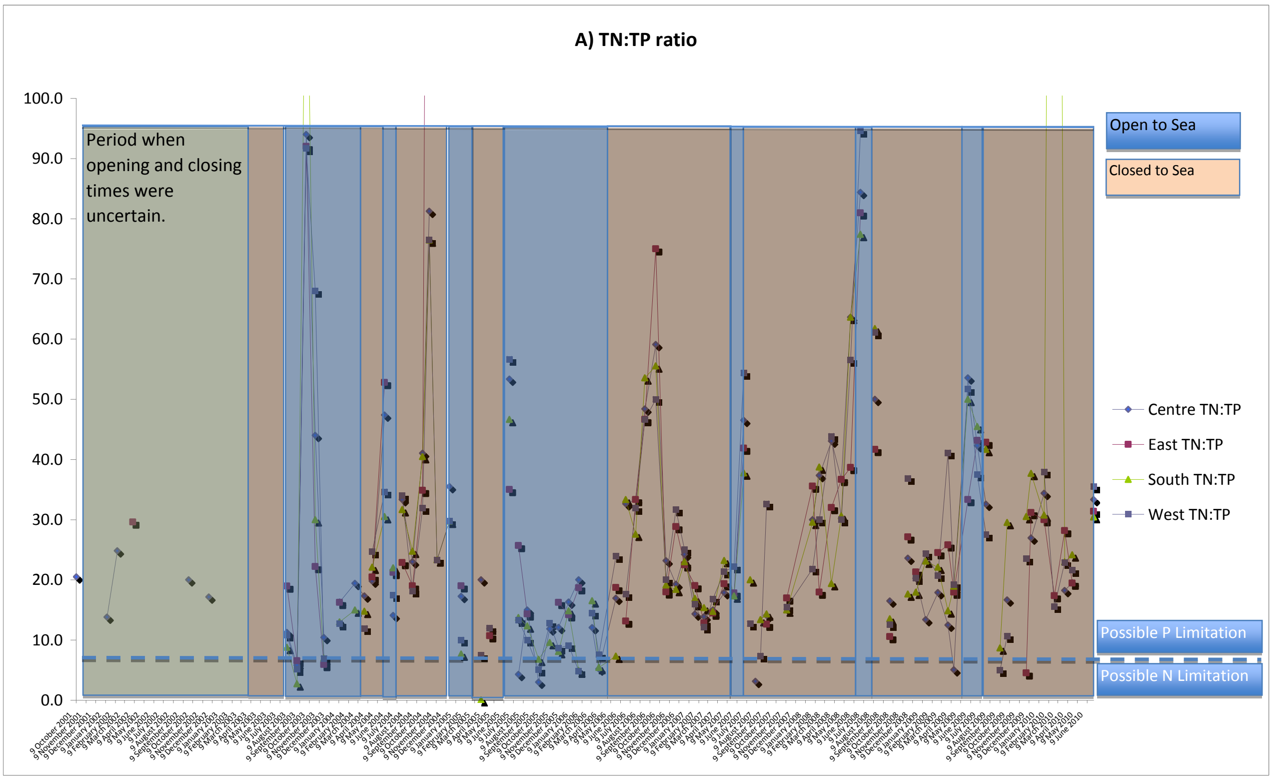
Beyond setting nutrient targets, it is important to identify the nutrient(s) most likely to limit the growth of nuisance algal species. Aquatic plant and algae growth is commonly constrained by the availability of nitrogen or phosphorus or both. If direct experimental data on plant responses to nutrient additions are lacking (as in the case of Waituna Lagoon), the growth-limiting nutrient is often inferred through the ratios of nitrogen to phosphorus (N:P ratio) in the plants, or nitrogen to phosphorus available in the water. However, such an approach is relatively simplistic and for a number of reasons can lead to erroneous conclusions. These reasons include the following:

- available evidence indicates that nutrient uptake, and therefore optimum N:P ratio, differs between the various types of plants i.e. N:P-ratios (by weight) of 7.2:1, 22:1 and 9:1 for microalgae, macroalgae and rooted macrophytes, respectively (Redfield et al. 1963; Duarte 1992)

- the N:P ratio generally assumes a constant supply of nutrients, whereas in reality they are often supplied in pulses (e.g. during floods), with N:P ratios constantly altered depending on both pulse and uptake rates;

- the N:P ratio can vary between surface and bottom waters and on sediment surface which means phytoplankton in surface waters can be exposed to different limitations than epiphytes, macroalgae and rooted plants in bottom water and sediments.

Taking these facts into consideration, and the fact that the lagoon surface water data from 2001-2010 suggests that both N and P could be limiting at different times (Figure 1 provides both TN:TP and DIN:DRP ratios), with possible nitrogen limitation more likely during summer, it is recommended that both nitrogen and phosphorus be targeted for management of Waituna Lagoon.



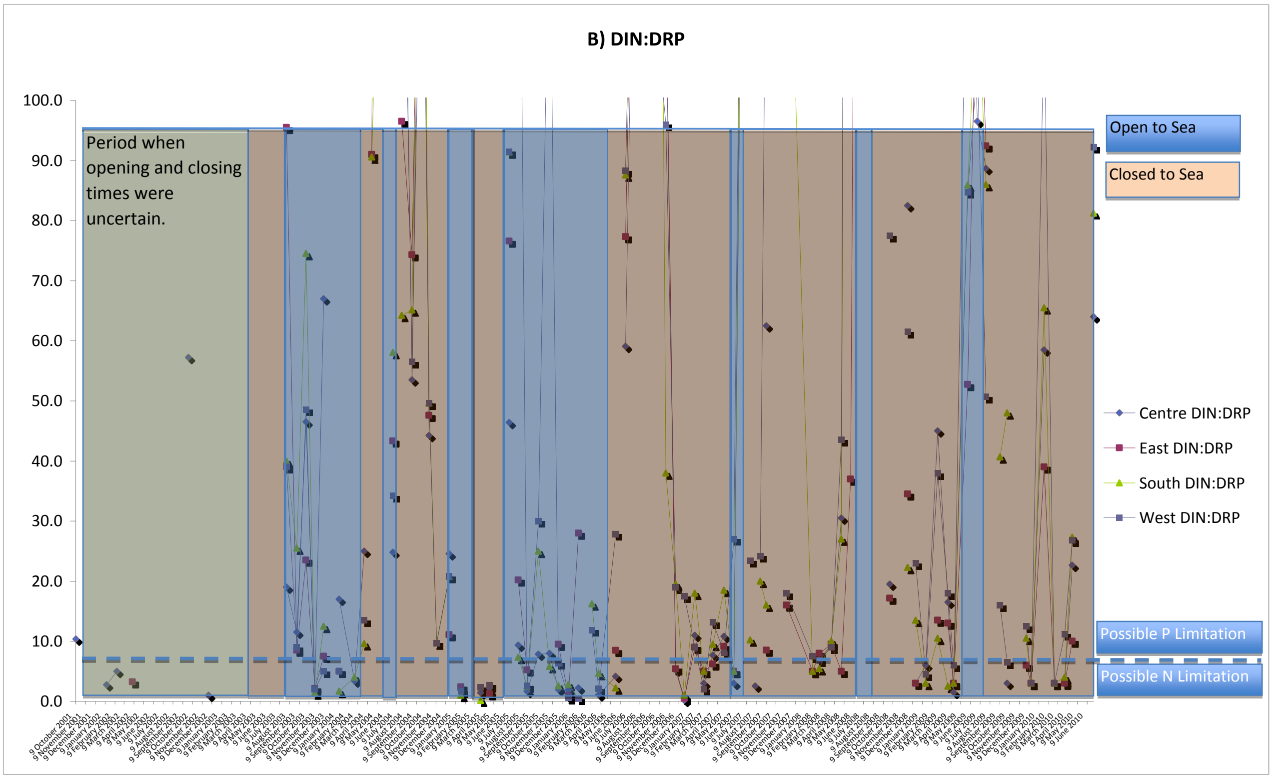


Figure 1: A) Ratio of total nitrogen to total phosphorus (TN:TP) and, B) dissolved inorganic nitrogen to dissolved reactive phosphorus (DIN:DRP) at the four lagoon sites monitored by ES(2001-2010)

Interim recommendations for input load limits

In order to ensure the long-term viability of the lagoon, it is necessary to reduce current nutrient and sediment inputs from the catchment. At present, although the available information for determining appropriate catchment load targets is limited, an initial assessment of potential load targets provides an early indication of the order of magnitude of changes that may be required. However, because new information may support the fine-tuning of these targets in the future, the guidelines must have some in-built flexibility (i.e. we suggest a prudent, adaptive management approach). In addition, to enable revision of the guidelines it is recommended that relevant detailed scientific investigations (experiments and possibly modeling) be undertaken (See section on Monitoring Recommendations).

In the absence of historical input monitoring data prior to 2000, catchment yield estimates have been used to define preliminary nutrient and sediment load reductions needed to protect lagoon values (Table 1 and Appendix 3). Because the lagoon was in relatively good condition prior to 1995, with low abundance of measured nuisance epiphyte growth (*Bachelotia*) and widespread *Ruppia* growth (Johnson & Partridge 1998), the pre-1995 land use was used to estimate targets for catchment nutrient and sediment load reductions. Table 1 also shows the estimated 2009 loadings based on estimated land use at that time.

Because the catchment yield information uses yield data from other NZ catchments as presented in "*Land use and land management risks to water quality in Southland*" (Monaghan et al. 2010) this approach must be viewed as 'ballpark' as it does not account for catchment specific variations such as farm practices, soil types, catchment topography and attenuation processes. As a consequence, it is recommended that a more robust, catchment specific approach using a specific model incorporating catchment inputs and recent land use data be undertaken to more accurately identify these target loads.

Table 1: Estimated input loads of total nitrogen and total phosphorus (tonnes/year) to Waituna Lagoon based on catchment specific yields for land use in 1995 and 2009 (excludes groundwater). Refer Appendix 3 for further details

1995 Loadings	TN (t/yr)	TP (t/yr)
Point Source (septic tank leachate)	2	0.7
Non Point	177	9
TOTAL	179	9.7
Areal Loading to Lagoon (t/km²/yr)	13	0.7

2009 Loadings	TN (t/yr)	TP (t/yr)
Point Source (dairy pond/irrigation/septic)	27	7
Non Point	396	14
TOTAL	423	21
Areal Loading to Lagoon (t/km²/yr)	31	1.5

Based on this approach the TN and TP inputs from the Waituna Lagoon catchment are likely to need to be reduced significantly. These interim results suggest N and P load reductions of approximately 50% are required to return to 1995 levels. This would mean a reduction in lagoon areal nitrogen and phosphorus load (i.e. annual load per unit area of waterway surface) from the current estimated levels of 31 $tN/km^2/yr$ and 1.5 $tP/km^2/yr$ to 15 tN/km^2 of lagoon/yr and 0.7 $tP/km^2/yr$.

However, based on the relationship between area nutrient load rates and lagoon response for 10 New South Wales Intermittently Closed and open Lake or Lagoons (ICOLLs) that are similar to Waituna (in size, opening regime and residence time), it is likely that such a reduction in nitrogen would not be sufficient to return the lagoon to a healthy state but would be for phosphorus (pers. comm. Peter Scanes, Head Coastal Catchments Science, NSW Dept Environment and Climate Change). The data for NSW lagoons categorises ICOLLs into three trophic states; pristine or reference, moderate disturbance and high disturbance and mean nutrient loadings for each are as follows:

Table 2: Trophic states and mean nutrient loadings for 10 New South Wales coastal lagoons that have similar characteristics to Waituna Lagoon (Scanes unpublished data)

Trophic state	TN tonnes/km^2/yr	TP tonnes/km^2/yr
reference (pristine)	2.8	0.2
moderate (some eutrophic symptoms but still support healthy seagrass and fish communities)	6.4	0.7
high (algal dominated, turbid systems, seagrass absent or reduced)	14	2

These findings suggest that the Waituna catchment nutrient loads would need to be reduced to at least 6.4 tN/km^2/yr and 0.7 tP/km^2/yr to meet a condition in which the lagoon still shows some eutrophic conditions but still supports healthy seagrass and fish communities in the long term. This equates to a 75% catchment load reduction for nitrogen and a 50% reduction for phosphorus.

In addition, until the store of old catchment nutrients in the lagoon bed sediments are depleted, release of nutrients from the sediment is likely to delay the return of the lagoon to a healthier state. Experience with similar lagoons in NSW indicates that this may take anything from 2-10 years.

However more study is required to determine the similarities of lagoon responses between Waituna Lagoon and NSW ICOLLS.

In relation to sediment inputs to the lagoon, an alternative approach for deriving SS guidelines has been used. Sediment rate monitoring within Waituna Lagoon shows elevated rates (2.5-3.0 mm/yr) of fine sediment deposition in localised areas since c.1960 to the present day (Cadmus 2004, Stevens and Robertson 2007). Prior to this it is predicted that SS loadings to Waituna Lagoon were much lower (Cadmus 2004). Therefore to reduce the buildup in sediment at localized areas, current loadings will need to be reduced. However, because of uncertainty about current input loads, especially in relation to drainage works and maintenance within the catchment, further work is proposed to determine the extent of catchment load reduction.

Interim guidelines to support lagoon opening decision

Because input reductions may take time to reduce N and P concentrations in Waituna Lagoon to target values, a short term measure is proposed to minimise the risk of the lagoon flipping. The proposed measure is to open the lagoon to dilute nutrients and sediment, and increase flushing to the sea when critical ecological trigger levels are exceeded and when hydrological and sea conditions allow. This process involves setting an initial warning trigger that initiates an increased frequency of lagoon monitoring, and a critical trigger level at which a recommendation on whether the lagoon should be opened is made by the LTG. The draft guidelines have been derived from both Waituna Lagoon monitoring data, and indicators of lagoon health from other shallow lakes. The trigger levels are presented in Table 3, with a rationale for each provided in Table 4.

Table 3: Key indicators and draft warning and critical triggers to guide decisions on whether to open the lagoon to minimise the risk of lagoon flipping

Primary Indicators	Warning trigger	Critical trigger
Chlorophyll *a*	0.008 mg/L	0.012 mg/L

Secondary Indicators	Warning trigger	Critical trigger
Total Phosphorus	0.030 mg/L	0.045 mg/L
Total Nitrogen	0.500 mg/L	0.700 mg/L

Tertiary Indicators	Warning trigger	Critical trigger
Nuisance epiphytes or benthic algae	>30% cover at >50% of sites	>50% cover at >80% of sites
Ruppia and other macrophytes	>20% decrease in site occupancy from baseline abundance[2]	>50% decrease in site occupancy from baseline abundance
RPD (Redox Potential Discontinuity) – bottom sediments	1-3cm at >50% of sites	<1cm at >80% of sites
Turbidity (still under development)	Non-wind-induced, organic and inflow-induced turbidity > 20% above background for non-bloom phytoplankton periods	Non-wind-induced, organic and inflow-induced turbidity > 30% above background for non-bloom phytoplankton periods
Temperature (still under development)	–	–
Bottom water dissolved oxygen	5 mg/L	2 mg/L
Aquatic and surrounding wetland life	Significant adverse effects to biota e.g. fish kills, impacts on critical *Ruppia* life stages, wetland vegetation die back	

Table 4: Rationale for the proposed indicators and draft triggers to guide LTG recommendations on whether to open the lagoon to minimise the risk of lagoon flipping

Primary Indicators	Rationale	Currently monitored by
Chlorophyll *a*	Monitors the biomass of planktonic algae. Blooms of these algae can trigger the loss of macrophytes, eventually triggering lake flipping (Scheffer 2004). The critical trigger of 12 mg/m^3 equates to Trophic Level Index (TLI) = 5 (low supertrophic) and warning trigger of 8 mg/m^3 equates to TLI = 4.5 (mid eutrophic).	ES
Secondary Indicators	**Rationale**	**Currently monitored by**
Total Phosphorus	This is a key plant nutrient as excessive levels stimulate planktonic and epiphytic (slime) algae over *Ruppia* (Schallenberg 2004). The critical trigger of 0.045 g/m^3 equates to TLI = 5 and Warning trigger of 0.030 g/m^3 equates to TLI = 4.5.	ES

[2] Baseline abundance needs to be defined.

Total Nitrogen	This is a key plant nutrient as excessive levels stimulate planktonic and epiphytic (slime) algae over *Ruppia* (Schallenberg 2004). Schallenberg et al. 2010, noted nitrate spikes can occur soon after lagoon closing, probably sourced from newly inundated sediments (old dewatered and decomposed biomass). This spike immediately after closing should not trigger lagoon opening. The warning trigger of 0.5 g/m^3 is greater than the target of 0.3 g/m^3 for the pragmatic reason that current TN concentrations are almost always above the target when the lagoon is closed.	ES
Tertiary Indicators	**Rationale**	**Currently monitored by**
Epiphytes or benthic algae	The proliferation of these algae may trigger the loss of macrophytes, eventually triggering lake flipping (Scheffer 2004).	DOC Arawai Kakariki programme and ES
Ruppia and other vascular macrophytes	These macrophytes have been designated as a keystone community, enhancing lake health and providing many valued ecosystems services (Schallenberg & Tyrrell 2006). The decline in *Ruppia* growth, or die back during a growing season, may facilitate a shift to other primary producers (e.g. phytoplankton; Scheffer 2004).	DOC Arawai Kakariki programme and ES
Turbidity	Low water clarity as measured by turbidity can trigger the loss of macrophytes through reduced light availability. Measure using in-situ turbidity loggers that will allow for separation (eventually) of wind induced, organic and inflow-induced turbidity.	Not monitored by in-situ loggers
Bottom water dissolved oxygen and sediment oxygenation (RPD)	Sediment anoxia can trigger the loss of macrophytes from stress to roots or by the release of internal nutrients bound in sediments. The result is increased bioavailable forms of nitrogen (nitrate and ammonium) and phosphorus (phosphate).	Not monitored
Water temperature	Higher water temperatures can trigger phytoplankton and macroalgal growth, which can flip the lagoon. However, specific temperature triggers for Waituna Lagoon are still under development.	Partially monitored by ES
Aquatic and surrounding wetland life	To protect against significant adverse effects to biota from either nutrient and/or sediment inputs to the lagoon, or any subsequent management actions taken to minimise the potential for lagoon flipping. For example, the negative effect of salinity on *Ruppia* germination.	Some aspects monitored by DOC Arawai Kakariki programme

Timing of lagoon openings needs to consider allowing the lagoon to fill up and ensuring lagoon closure prior to the main *Ruppia* growing and germination period (spring – summer). The timing of open and closed periods has to be carefully considered as prolonged opening events are likely to affect *Ruppia* germination.

A reviewable term of 1-2 years has been set because of the potential for long-term adverse impacts to the lagoon's ecology and the wetlands from more frequent openings. For example salinity stress to *Ruppia* germination, drying out of *Ruppia* beds and fringing wetland plants, invasion of terrestrial weeds into wetland areas, loss of fish habitat, increased inputs of marine sand (refer to Hadwen & Arthington 2006, Robertson et al. 2009, Duggan & White 2010 for further detail).

It is acknowledged that the proposed ecological guidelines may impact upon other lagoon uses and values in some instances, including recreation (incl. fishing and hunting), and for drainge.

Other important considerations are as follows:

1. ***location of lagoon opening*** – openings may potentially occur at different, or multiple, sites to maximise flushing, e.g. historical breakout points near Walker Bay and at the eastern end of the lagoon. However, the feasibility and ecological impacts of alternative opening sites need detailed assessment prior to any use for lagoon management.

2. ***water level prior to opening*** - past experience has shown that the greatest flushing of sediment and nutrients to sea occurs when the lagoon is opened when it has a high water level, lagoon waters are well mixed, and the breakout occurs on an ebbing tide during calm seas.

3. ***artificial lagoon closing*** - further work is required to determine if it is feasible to artificially close the lagoon, and if so, the conditions that would trigger such a response, e.g. to introduce a freshwater phase to promote the germination and growth of *Ruppia*, increase water levels to inundate fringing wetland habitat/vegetation, or improve fish habitat.

4. ***prolonged lagoon opening*** – currently *Ruppia* is under stress from nuisance epiphyte growth which is likely exacerbated by the prolonged opening of the lagoon and the accompanying elevated salinities which promote ideal conditions for *Bachelotia* growth – a marine brown algae. This means *Ruppia* is more susceptible to other stressors e.g. light limitation, sediment anoxia, wind disturbance. By closing the lagoon, it is intended that more favourable habitat for *Ruppia* would result i.e. greater water depths, lower salinities, increased habitat area, less wind disturbance, less smothering by epiphytes. In the longer term it is envisaged that *Bachelotia* tolerance to low salinities would be investigated and that artificially regulating salinity could possibly be used as a tool to control excessive growth.

Due to the complex nature of Waituna Lagoon and the technical considerations in interpreting the monitoring data, lagoon conditions, and ecological requirements, it is recommended to build an interim decision support framework in consultation with the LTG and stakeholders. This framework would explicitly outline the analytical requirements needed to inform management of lagoon opening events.

Monitoring Recommendations

Co-ordinated monitoring of the lagoon needs to be initiated to measure catchment inputs and lagoon condition. This monitoring falls into several categories in terms of urgency, and therefore some aspects require immediate action. To identify these, a detailed monitoring schedule is recommended based on the following guidance.

1. Catchment Inputs

Objective: Catchment inputs of nutrients and sediment to the lagoon under a range of flow conditions need to be measured in order to ensure guideline input loads for N, P and SS Loads are being adhered to.

Parameters: Flow, total nitrogen, oxidized nitrate/nitrite nitrogen, ammonia nitrogen, total phosphorus, dissolved reactive phosphorus, total suspended solids, volatile suspended solids, turbidity, clarity, temperature, salinity/conductivity, dissolved oxygen.

Frequency:

- ***Water quality*** - weekly samples for representative base flows. Hourly samples for representative floods. Flow; monitor continuously at representative catchment (Waituna Creek) and periodically at other flow inputs to enable assessment of relative contributions.

Locations:

- ***Water quality*** - all stream inputs (Waituna, Moffat, Carrans Creeks).

Commencement: Urgent

From these data, calculate daily nutrient and sediment input loads to the lagoon from each stream using flow/WQ variable relationships.

2. Waituna Lagoon

Objective: To determine if the lagoon meets: 1) set water quality and sediment criteria, and 2) guideline triggers which indicate whether the lagoon should be opened or closed (in the short term) to reduce the risk of lagoon flipping. Primary trigger values have been set for TN, TP, and chlorophyll-*a*. In addition, a number of other secondary indicators including; bottom water DO, presence of nuisance epiphytes and benthic macroalgae, *Ruppia* abundance, sediment RPD, water clarity and impacts to other aquatic biota and surrounding wetland life. Sediment monitoring is included to provide preliminary information that will later be used to design a more comprehensive programme to determine the exchange of N and P between the surface waters and the sediment and to estimate the magnitude of the sediment nutrient pool.

Parameters:

- ***Water quality*** - (in surface water and in water immediately (0-5 cm) above the lagoon sediments): total nitrogen, oxidized nitrate/nitrite nitrogen, ammonia nitrogen, total phosphorus, dissolved reactive phosphorus, total suspended solids, volatile suspended solids, turbidity, total organic carbon, dissolved oxygen, Secchi depth, salinity, temperature, depth at sample site, lagoon water level, chlorophyll *a*, phytoplankton abundance and species composition. In addition, measure surface water lagoon metabolism (48 hr in situ DO sensor deployment).
- ***Sediment quality*** - Porewaters; oxidised nitrate/nitrite nitrogen, ammonia nitrogen, dissolved reactive phosphorus. Whole Sediment: total nitrogen, total phosphorus, total organic carbon, grain size (mud sand gravel), sediment RPD, depth of soft mud, depth at sample site, lagoon water level, and sedimentation rate.
- ***Vegetation mapping*** Epiphyte and macroalgal abundance and diversity, particularly the presence of bloom-forming epiphytic and macroalgae (note: a semi-quantitative visual rating scale to describe the abundance of the dominant epiphyte *Bachelotia* has yet to be developed). Seagrass abundance and diversity. Fringing wetland vegetation condition.
- ***Lagoon water level*** – data logger.

Frequency:

- ***Water quality*** – monthly (more frequently if data loggers or automatic samplers are used), planktonic lagoon metabolism quarterly.
- ***Sediment quality*** - monthly; Sediment rate – annually. Criteria to be set to increase monitoring frequency as lagoon approaches trigger values when it is closed e.g. weekly once 80% of threshold value reached.
- ***Vegetation mapping*** – Epiphytes and macroalgae - 3 monthly. Seagrass – annually. Surrounding fringing wetland vegetation – 3 yearly.

Locations:

- ***Water quality*** - Four existing lagoon sites (west, centre, east, south).
- ***Sediment quality*** - Four existing lagoon sites (west, centre, east, south).
- ***Vegetation mapping*** - Epiphytes and macroalgae - Four existing lagoon sites (west, centre, east, south). In addition, sediment RPD, sediment depth, and epiphyte and macroalgal abundance and diversity in representative areas of the lagoon where epiphytes and macroalgae are most commonly found (e.g. the central channel in the east of the lagoon, Walkers Bay, Shands Bay and the southwestern (seaward) edge of the lagoon). Seagrass – at the existing 48 DOC transect sites. Fringing wetland vegetation – transects used in previous surveys (e.g. Johnson & Partridge 1998).

Commencement: Urgent

From these data, determine if lagoon water and sediment targets are met. Assess if lagoon ecological trigger values are met to indicate increased monitoring or opening required. Assess the store of internal nutrients and influence of internal loading. Monitor response of sea-grass and other vegetation to changing conditions.

Peer Review

Scientific peer review of these recommendations was undertaken by Professor David Hamilton (University of Waikato), a specialist in lake management.

The LTG undertook an additional final review just prior to the release of these recommendations.

Role of LTG

It is anticipated that the LTG will continue to provide information and advice so that any decisions regarding the future management and monitoring of Waituna Lagoon are carefully considered. It may also be necessary to seek external support for technical issues that require particular expertise, e.g. lagoon response modelling.

Recommendations for further studies

The LTG has identified a number of priority actions and information gaps, some of which need to be urgently addressed if the risk of the lagoon flipping is to be minimised (Immediate Recommendations) and others where the urgency is somewhat less (Medium Term Recommendations).

Immediate Recommendations

- Identify and evaluate contaminant sources (N, P and sediment) for different landuses in the Waituna catchment and for the catchment as a whole (e.g. use of catchment modeling tools).

- Identify management options and interventions to reduce catchment loads, with ground-truthing to validate model predictions.

- Develop a monitoring schedule to collect data on catchment input loads and lagoon condition.

- Explore options for closing the lagoon as soon as possible after flushing to provide more favourable habitat for *Ruppia* and conditions predicted as less suitable for *Bachelotia* growth.

- Determine whether *Bachelotia* growth is suppressed at low salinities and whether salinity can be used to mitigate against excessive growth.

- Carry out an assessment of lagoon response to contaminants (including internal loading) under different opening and closing regimes, and more comprehensive assessment of contaminant load guidelines to maintain lagoon in healthy state (e.g. lagoon response modeling).

- Assess methods of measuring and monitoring epiphyte production and biomass.

- Assess salinity effects on *Ruppia* for different lifecycle stages.

- Carry out an assessment and comparison of information in relation to Australian ICOLL where *Ruppia* is present.

Medium Term Recommendations

- Plan the transition from short term to long term monitoring and management. This will include the development of an ecological management strategy to determine appropriate options for long term lagoon monitoring and management. The strategy will be informed by the following investigations:

  - once the internal load has been quantified, an evaluation of the available methods for internal (bottom sediment) nutrient removal and their suitability for application in Waituna Lagoon;
  - determine impacts on the wider ecosystem of various opening and closing regimes;
  - define nutrient limitation dynamics of phytoplankton, epiphytes and *Ruppia* to validate the lagoon response model;
  - define environmental limits on *Ruppia* reproduction (e.g. pollination, fruiting, and germination and vegetative reproduction);
  - explore physiological indicators of *Ruppia* stress (e.g. as indicated by alcohol dehydrogenase);
  - define light requirements of *Ruppia*, other macrophytes, epiphytes and phytoplankton.

Catchment Technical Group

Environment Southland is developing a Catchment Technical Group (CTG) to determine the implications of the Interim Lagoon Recommendations for the catchment.

Summary

The key points that arise from this LTG output are:

1. short term immediate guidance to minimise the risk of lagoon flipping:

   - water quality targets for lagoon health;
   - recommendations for lagoon sediment and nutrient load reductions;
   - lagoon opening/closing decision criteria;
   - monitoring recommendations;
   - recommendations for further research.

2. A medium to long-term pathway which primarily consists of the development of a whole ecosystem plan for long-term lagoon recovery, including monitoring and management and a LTG to inform key decisions.

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Appendix 1: Data showing recent changes in nutrient inputs to the lagoon

Table 1 shows the combined catchment inputs from three streams (Waituna, Carran and Moffat Creeks) to Waituna Lagoon based on ES monitoring data. While there is variance between years, the overall trend of increasing nutrient inputs from 2001-2005 to 2006-2010 is clear (Table 1). However, because very few measurements have been collected at elevated flows (floods when inputs are known to be greatest), the data presented in Table 1 almost certainly underestimate actual loading.

Table 2 shows the results of a statistical analysis of trends in loads using a Mann-Kendall test. The trends in total nitrogen, nitrate and total ammonia were all highly significant. The trends in total phosphorus and dissolved reactive phosphorus were not statistically significant, but still of concern, due to the very high values recorded in 2009 and 2010.

Table 1: Combined catchment nutrient inputs as tonnes/yr (mean of the monitored daily inputs - approx.12/yr) from three streams (Waituna, Carran and Moffat Creeks) to Waituna Lagoon based on ES monitoring data (2001–2010)

Year	TN Load (t/yr)	Nitrate-N Load (t/yr)	Ammonia-N Load (t/yr)	TP Load (t/yr)	DRP Load (t/yr)
2002	151	100	5.3	6.3	1.9
2003	194	137	10.0	8.3	2.6
2004	238	142	8	6.1	2.4
2005	167	105	6.3	2.9	1.1
2006	339	172	14.8	22.8	4.7
2007	171	128	8.4	5.7	1.6
2008	209	160	3.3	3.0	1.4
2009	296	151	12.6	22.6	2.1
2010	390	220	13.7	21.5	0.0
Mean 2002-2010	240	146	9.2	11.00	3.0
Mean 2002-2005	188	121	7.4	5.9	2.0
Mean 2006-2010	281	166	10.5	15.1	3.8

Table 2: Trends in nutrient loads to Waituna Lagoon (using Mann-Kendall test of annual loads 2002-2010)

Variable	% annual change	p-value	Statistically significant?
Total nitrogen	+11%	0.02	Yes
Nitrate	+8%	0.02	Yes
Total ammonia	+9%	0.2	No
Total phosphorus	+12%	0.46	No
Dissolve reactive phosphorus	-8%	0.38	No

Appendix 2: Representative data indicating lagoon trophic status:

Hamill (2011) summarises monitoring data to show Waituna Lagoon is in a eutrophic state. Examples are presented below in Figures 1 and 2 of total nitrogen and total phosphorus concentrations at the four lagoon sites plotted against guidelines on eutrophic condition (Burns et al. 2000). The plots show eutrophic nutrient concentrations in the lagoon most of the time, and consistently since 2006, with conditions worsening the longer the lagoon is closed to the sea.

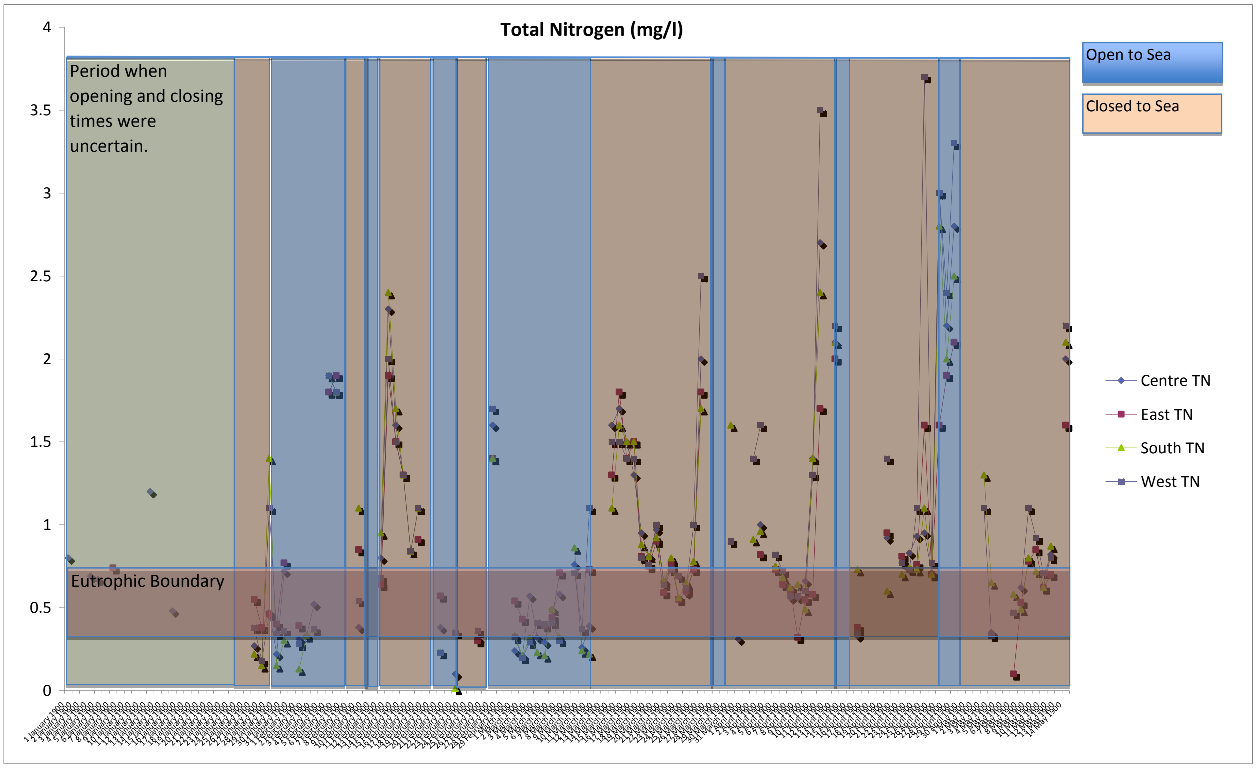

Figure 1: Total nitrogen concentrations at the four lagoon sites (2001-2010). Eutrophic criteria (Burns et al. 2000) shaded in red

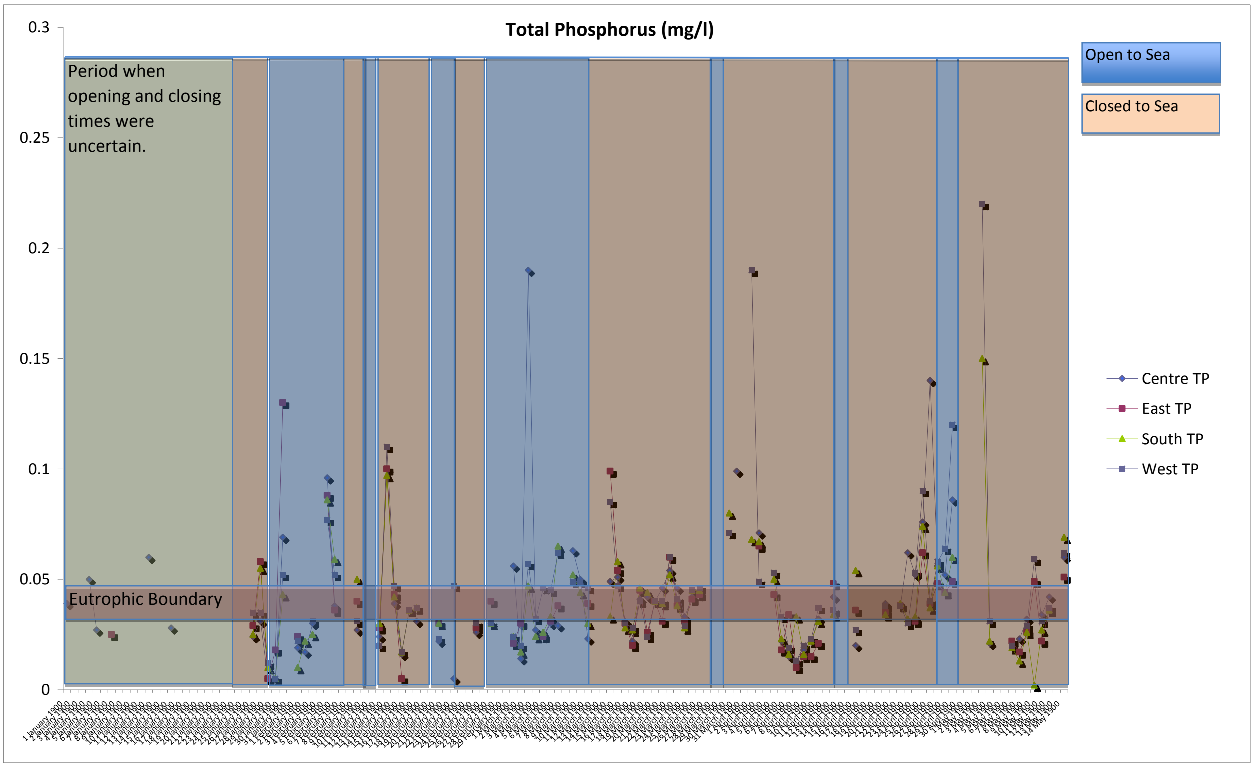

Figure 2. Total phosphorus concentrations at the four lagoon sites (2001-2010). Eutrophic criteria (Burns et al. 2000) shaded in red.

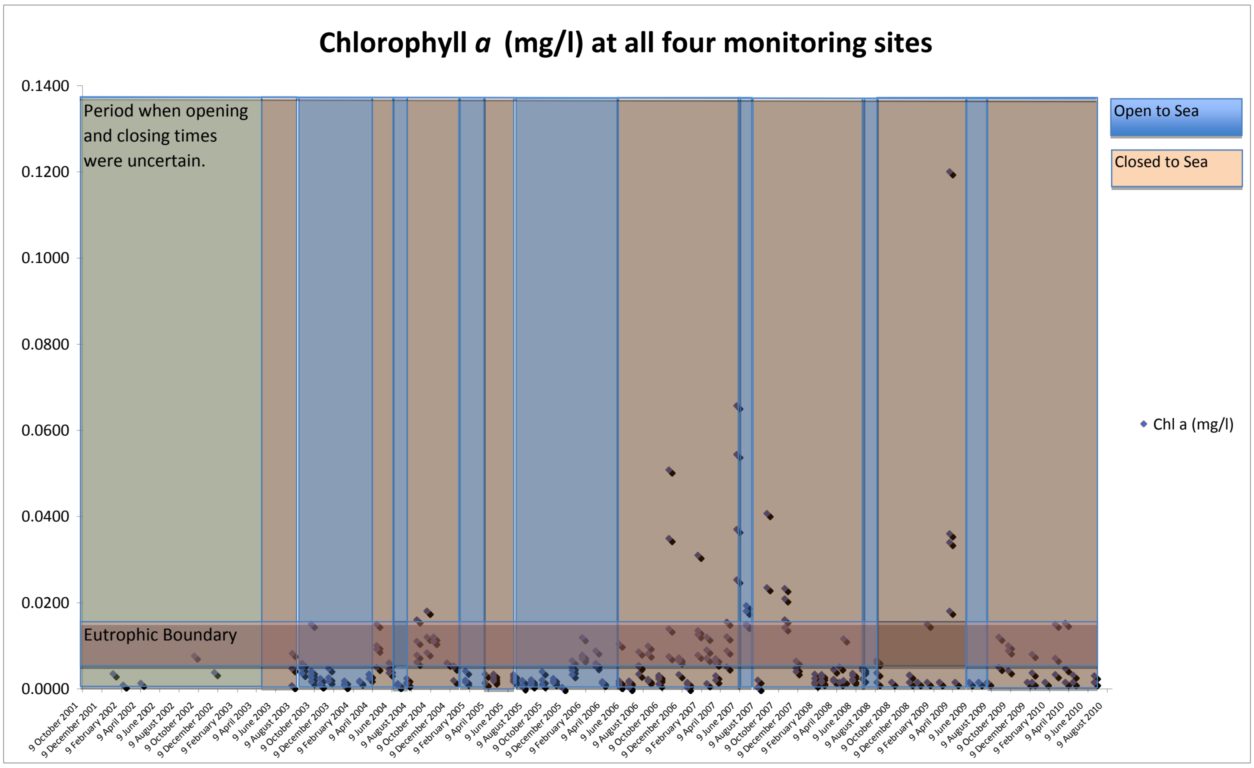

Figure 3: Chlorophyll *a* concentrations at the four lagoon sites (2001-2010). Eutrophic criteria (Burns et al. 2000) shaded in red

Appendix 3: Land use and yield information used to estimate input loads of nutrients and sediment in 1995 and 2009.

Table 3: Land use, N and P yields, septic tank and dairy farm effluent characteristics used to estimate input loads of nutrients and sediment to Waituna Lagoon in 1995 and 2009. Source of yield estimates (Monaghan et al. 2010). Note these estimates are derived from a very simplified approach and do not account for variations in farm practices, soil types, catchment topography and attenuation processes. Source of estimates for septic tanks and dairy ponds from Elliot and Sorrel (2002).

NON POINT LOADINGS	TN (kg/ha/yr)	TP (kg/ha/yr)	2009 Area (ha)	1995 Area (ha)
Dairying Intensive	26	0.80	14204	500
Sheep/beef	10	0.46	1300	15,000
Unimproved Pasture	6	0.17	100	100
Forest (exotic)	3	0.35	640	640
Forest (Indigenous)	3	0.39	3816	3,816
Urban Land use	5	0.50	10	10

	Average Flow	TN (mg/L)	TP (mg/L)	Population equiv.
Septic Tanks	$0.4 m^3/d$/person	28	10	500
Dairy Farm 2 pond system wastewater *	0.04 m^3/d/cow	170	45	20,000

* Final Loadings taking irrigation etc into account (assume 50% of original load)

Appendix 4: Environment Southland Waituna bottom waters Feb. 2011 Monitoring Data (mg/L)

Site	Walker Bay	1km W Carran Creek	Moffat Creek mouth	1.5km E Moffat Creek	Waituna Creek Mouth
Date	2/22/2011	2/22/2011	2/16/2011	2/16/2011	2/16/2011
TN	<0.3	0.3	0.6	<0.3	2.3
NNN	0.002	0.006	<0.002	<0.002	1.5
NH4	<0.010	<0.010	<0.010	<0.010	<0.010
TP	0.079	0.013	0.06	0.015[1]	0.076
DRP	<0.004	<0.004	0.013	0.016[1]	0.019

[1] It has been noted that the results for DRP were greater than that for TP, but within the analytical variation of these methods.

Appendix 5: Range of median water quality within Waituna Lagoon from all four monitoring sites when the lagoon is closed (2005-2010; from Hamill 2011)

TN	TP	Chl *a*
0.78-1.00	0.036-0.042	0.002-0.0037