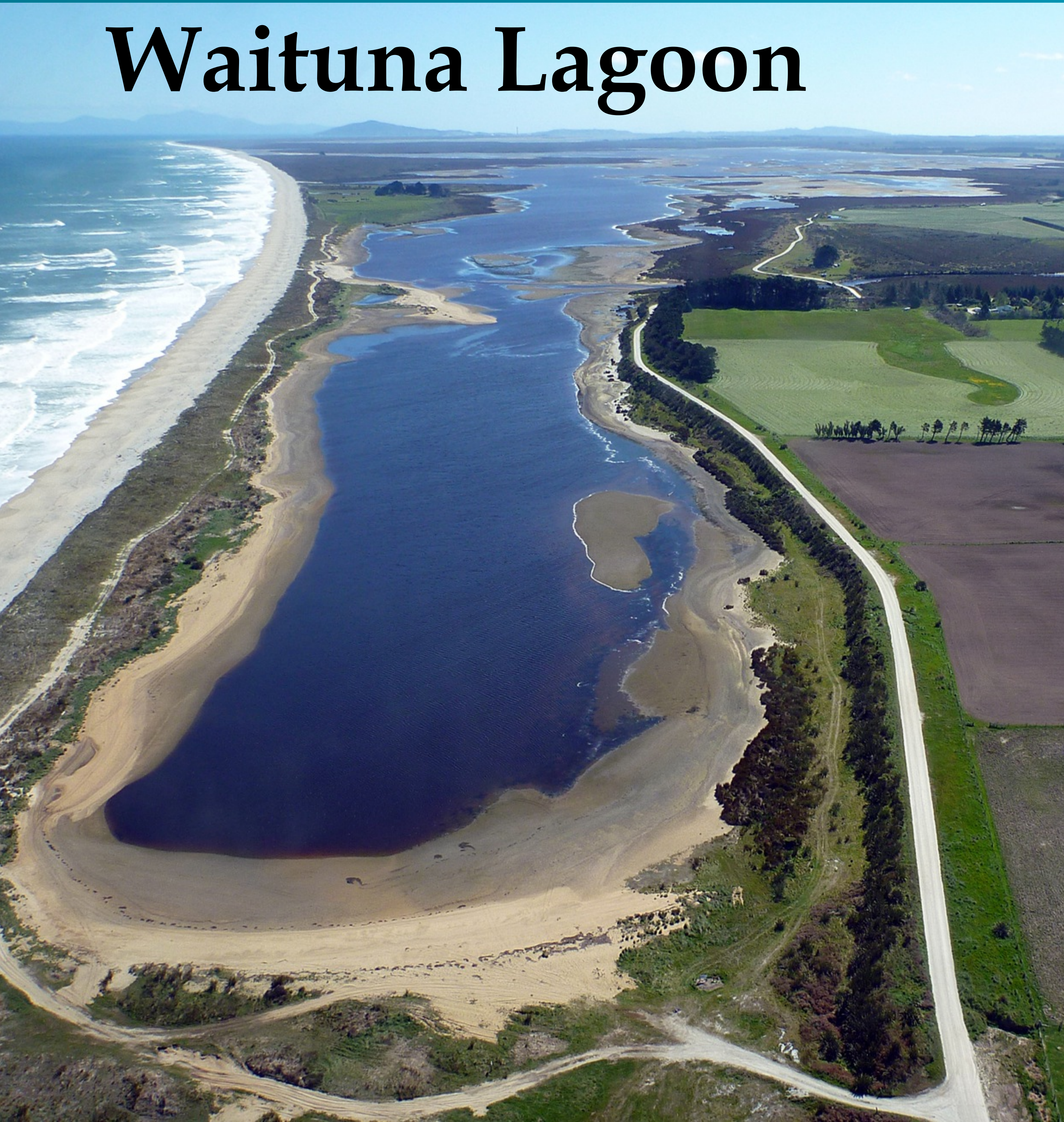
Waituna Lagoon
No other place like it

Prepared by –

the Lagoon Technical Group
for Environment Southland

December 2013

Ecological Guidelines for Waituna Lagoon



This report has been prepared by the Waituna Lagoon Technical Group (or LTG), a group established by Environment Southland as a part of its wider response to environmental issues in the Waituna catchment. The LTG comprises of: Emily Funnell (Department of Conservation), Keith Hamill (River Lake Ltd.), David Hamilton (University of Waikato), Andy Hicks (Environment Southland), Jane Kitson (Kitson Consulting), Greg Larkin (Private Contractor), Barry Robertson (LTG Chair, Wriggle Coastal Management), Hugh Robertson (Department of Conservation), Marc Schallenberg (University of Otago), Mike Scarsbrook (DairyNZ), Dean Whanga (Te Ao Mārama Inc.), Karen Wilson (Environment Southland). Editing and formatting by Greg Ryder (Ryder Consulting Ltd.)

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Cover photo: East end of Waituna Lagoon, looking west.

Contents

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Executive Summary

Waituna Lagoon is in an unstable ecological state and requires active management to improve its ecological condition and reduce the risk of further degradation. The recommendations made in this document seek to provide management guidelines based on our current understanding of how the lagoon functions and responds to environmental variables.

We recommend setting an ecological health objective for the lagoon based on a stable and self-sustaining native macrophyte (aquatic plant) population. We recommend a target of >30-60% cover of *Ruppia* and other native macrophytes (based on average annual % cover at permanently wetted sites). To achieve this objective, we recommend setting specific nitrogen and phosphorus loading rates to the lagoon and establishing a lagoon opening regime that is consistent with the objective.

Waituna Lagoon currently exhibits symptoms of eutrophication that are consistent with a high risk of this highly valued system shifting to an algal-dominated state. These symptoms of eutrophication are commonly experienced in systems where intensive forms of agriculture dominate in the catchment, which is the case for Waituna.

The recommended catchment nutrient loading rates required to achieve the proposed macrophyte target are < 125 tonnes/year for nitrogen (a lagoon aerial loading of < 90 kg N/ha/yr) and < 7.7 tonnes/year for phosphorus (a lagoon aerial loading of < 5.7 kg P/ha/yr). These were determined from three independent methods which produced similar results for nitrogen but were more variable for phosphorus. The recommended load reduction for phosphorus has therefore been selected to be proportional to the reduction in nitrogen. We estimate these loading rates are approximately 50% of the current estimated nitrogen and phosphorus inputs to the lagoon. The recommended catchment loads are not intended as broad brush reductions across the whole catchment, or for all farm land in the catchment, but rather as reductions in the amount of nutrients reaching the lagoon.

The evidence also suggests a change in the management of the lagoon opening regime would help to protect lagoon ecology. We recommend periodic openings to flush out accumulated sediment and nutrients, but recommend avoiding the extended openings during summer which threaten the keystone aquatic vegetation community (i.e., *Ruppia*). Thus, we suggest that opening management should aim for regular winter openings. This is because winter openings have a high chance of closing before summer and should also be associated with the most efficient flushing effect. By comparison, spring openings have had a high likelihood of staying open through the summer period, with a consequently large disturbance to the aquatic vegetation cover.

The recommendations in this document are based on the available science in relation to maintaining a healthy *Ruppia*-dominated ecosystem. Other values within the lagoon and in the wider catchment have not been explicitly addressed. However, based on scientific evidence, if the catchment inputs remain as high as they are now, and lagoon openings are ecologically ill-timed, then the risk of Waituna Lagoon shifting to an algal dominated system will remain high. If protecting the lagoon ecosystem is a high priority then changes to the lagoon opening regime should be adopted immediately. Likewise, catchment options for achieving the recommended load reduction targets need to be investigated and implemented with the highest priority.

These guidelines are recommendations for protecting lagoon ecological health based on our interpretation of scientific information. They are not statutory-based management decisions.

Background

This report updates the Lagoon Technical Group's interim recommendations and guidelines made in May 2011 (Robertson *et al*. 2011). The purpose of the updated guidelines is to:

- update and assess evidence that the health of the lagoon is in decline;
- describe the ecosystem targets for protecting Waituna Lagoon in a healthy and functioning state;
- update recommended targets for external nutrient loads to Waituna Lagoon;
- update recommendations regarding the opening and closing regime and trigger levels for opening;
- identify the requirements for monitoring and further research to fill key knowledge gaps.

This is a summary document and further details can be found in supporting documents referred to throughout the text. The recommendations presented in this report are based on our current understanding of the data and information before us, and are intended to be updated again as further monitoring and research comes to hand.

Waituna Lagoon lies at the bottom of a small, intensively farmed catchment in Southland. The lagoon is one of the best remaining examples of a natural coastal lagoon in New Zealand and is unique in Southland and New Zealand. Long known for its diverse ecological characteristics and cultural values, it is part of the Awarua Wetlands. The significance of the lagoon and its margins was recognised internationally in 1976 when it became a Ramsar site and and nationally by gaining Scientific Reserve status in 1983. The cultural significance to the local Ngāi Tahu people was recognised under a Statutory Acknowledgement with the Ngāi Tahu Claims Settlement Act 1998. The lagoon and associated peatlands are identified by the Department of Conservation (DOC) as a priority ecosystem for the conservation of our natural heritage. Waituna Lagoon is also one of three wetland systems in DOC's Arawai Kākāriki wetland restoration programme, which aims to enhance New Zealand's foremost freshwater sites (Robertson & Suggate 2011). The local community through the Waituna Landcare Group have been active for a number of years in protecting the unique values of the area.

Northern shore of Waituna Lagoon with Bluff Hill in the distance (photo: B. Robertson).

The lagoon covers an area of 1,350 hectares and is Southland's biggest coastal lake.
It is shallow (water depth is usually less than 2 m) and usually closed from the sea by a gravel bar. Historically, a mouth has broken through the bar when high water level in the lagoon coincides with favourable sea conditions. With the advent of farming land surrounding the lagoon, a mechanical opening of the lagoon to the

Ramsar - The Ramsar Convention is an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the "wise use", or sustainable use, of all of the wetlands in their territories.

Tranquil Waituna Lagoon
(photo: B. Robertson).

sea typically using excavators, has been undertaken regularly to assist with land drainage.

The intermittent opening and closing of the lagoon to the sea is a feature that strongly influences the lagoon's ecology and water quality. The changes in salinity and water level associated with freshwater and seawater influxes create an environment that favours some species over others, but not always at the same time. In this dynamic environment, species alter their distributions and abundances in response to changing water level, salinity, other environmental factors, and interactions with other species present.

What's the problem?

Over the last decade or so, species that characterise a healthy lagoon environment have reduced in prominence and been replaced by species that are more commonly associated with enriched and degraded systems (e.g., slime algae).

As with many other regions in New Zealand and overseas, the development of land to increase agricultural productivity in the Waituna catchment has resulted in an increase in the export of nutrients and fine sediment to the lagoon. This change in land use intensity has coincided with changes that have destabilised the lagoon.

Concerns about the ecological state of Waituna Lagoon raised by a number of parties prompted Environment Southland and partners in 2011 to initiate an emergency response to find a way to halt what appeared to be a high risk of irreversible change in the ecological health of Waituna lagoon. A Lagoon Technical Group (LTG) was established, comprising of experts in coastal lagoon/lake ecology and water quality, and in May 2011 this group issued a document containing interim recommendations including guidelines to reduce the risk of creating a permanent degraded ecological state. We referred to this phenomenon as 'flipping' but now consider it more appropriate to use the term 'regime shift'. Our reasoning for using this term instead of flipping is outlined in this document, but in short we are now of the view that a change to a more permanent degraded ecological lagoon state is an oversimplification of the situation.

We have carefully reviewed a large amount of local, national and international data and have concluded that Waituna Lagoon remains in an unstable ecological state. It requires active management to improve its ecological condition and reduce the risk of further degradation. The recommendations we have made in this document seek to provide management guidelines and are based on our current understanding of how the lagoon functions and responds to environmental variables.

Features and Values

Waituna Lagoon has very high habitat diversity and supports large areas of relatively unmodified wetland and riparian vegetation. The lagoon is highly valued for its aesthetic appeal, rich native biodiversity, duck shooting, fishing, boating, bird watching, walking, scope for scientific study and its significance to the Ngāi Tahu whanui.

Waituna Lagoon is a highly valued, brackish coastal lagoon fed by three streams (Waituna, Moffat and Carran creeks). While it used to have occasional temporary openings to the sea, it is now opened more frequently by mechanical means to assist in the drainage of surrounding land. This is managed under a consent that expires in 2014. In terms of estuary classification, Waituna is classified as an "intermittently closed and open coastal lake or lagoon" (or ICOLL for short). When closed, Waituna Lagoon has no tidal connection and behaves like a freshwater lake with a water residence time in the order of months. In this state, its water level is determined by catchment runoff, evaporation and seepage. When open, the water level drops and the lagoon becomes tidal, experiencing marine intrusions and mixing with sea water.

Ecology

Historically, the lagoon was surrounded by an extensive peatland (blanket bog wetland) which gave the lagoon's water its characteristic brown colour. Waituna Lagoon has a diversity of vegetation types, and of zoned sequences, on its different types of shore, creating a dynamic environment for plants (Johnson & Partridge 1998). The dominant *Leptocarpus similis* rushland has increased its extent around the shore in response to a generally lower lagoon level.

Waituna is renowned for its bird life. Over 80 different birds have been recorded in the area and many visitors come to Southland to bird watch at the lagoon. Some of the birds migrate from their breeding grounds in Siberia to seek food in our summer months. Rare species that can be found at the lagoon include the Southern New Zealand dotterel, the Australasian bittern (matuku), the marsh crake, Eastern bar-tailed godwit (kuaka) and the fernbird (mātātā). Plentiful ducks and other water fowl attract hunters to the lagoon.

Royal Spoonbills foraging in Waituna Lagoon (photo: B. Robertson).

Eighteen species of fish have been recorded from within the Waituna catchment. These include native and introduced freshwater species. Common bully, longfin and shortfin

Ruppia is a critical species in Waituna Lagoon because it:

- absorbs nutrients and stabilises sediment by reducing turbulence
- maintains clear water by reducing sediment re-suspension
- oxygenates the sediments, preventing phosphorus from being recycled
- limits shoreline erosion
- provides habitat and food for aquatic species (fish, macroinvertebrates, birds)

eels, and giant and banded kokopu have all been found in the catchment. The Waituna system is recognised as a stronghold for giant kokopu. The brown trout fishery in the lagoon is very important in Southland, and fish are typically larger than average due to the presence of sea-run individuals.

A bed of flowering *Ruppia* (photo: A. Hicks).

Ruppia is an aquatic plant (or macrophyte) that grows on the bed of the lagoon. It favours clear freshwater or brackish water. Macrophytes provide cover for fish and a place for aquatic invertebrates to live. They also produce oxygen and act as food for some fish and wildlife.

Ruppia has been identified as playing a key role in regulating water quality as well as providing habitat for animals. Two species are present in Waituna Lagoon; *Ruppia polycarpa* and *Ruppia megacarpa*. *R. polycarpa* is a small delicate annual which occurs most commonly in shallower water. An important feature of this species is it is resistant to drying and desiccation as it produces seeds or rhizomes and turions to regenerate when conditions are favourable. *R. megacarpa* is a surface-flowering, large, robust perennial with long, much branched stems. Seeds germinate and form seedlings in spring, while flowering and fruiting occur in summer and autumn.

Other macrophytes are present in Waituna Lagoon and may also play important roles in maintaining a healthy ecosystem. One species, *Myriophyllum triphyllum* (commonly called water milfoil), can be abundant on occasions, but does not survive when the lagoon is open.

Myriophyllum triphyllum emerging through the surface of Waituna Lagoon (photo: A Hicks).

Community

Traditionally, Waituna Lagoon has been valued for its recreational opportunities, largely centred around fishing (eel, flounder and trout), duck hunting and bird watching. Recounts by local individuals, some of whose families have known the area well over the last 100 years, tell stories about fishing and hunting - activities involving spending time in the area, walking, boating, hanging out at huts and bonding with family and friends.

Father and son angling, Waituna opening day, 2009 (photo: Z. Moss).

Attempts to control the water levels have not always gone to plan, but the openings were a sight to behold when seen at the right time, as well as a scene for community gatherings (Larkin 2012).

Interviews with farmers note the huge effort that has gone into draining and developing land in the Waituna catchment, particularly in the 1950s and 60s, although land drainage practices started well before then. The development of early small farms involved hard physical work and difficult lives, where it could be hard to eke out a living. However, these early pioneering farms developed into many successful and profitable farms, thanks in part to the dairying boom of recent years.

Ngāi Tahu

The cultural, spiritual, historic and traditional association of Ngāi Tahu whanui with Waituna was recognised by the Crown in a Statutory Acknowledgement within the Ngāi Tahu Claims Settlement Act 1998. Waituna and its wetland was a major food basket with seasonal and permanent settlements located within and nearby because of the wide variety of reliable mahinga kai and other cultural materials. Wahi ingoa (place names) in the area attest to the importance of the area for mahinga kai. The actual lagoon was known as Waiparera (waters of the Grey Duck), and two of its tributaries were named after eels, Waituna and Waihao[1]. Ara Tawhito (traditional trails) navigated to and around Waituna. These trails linked settlements to each other and to the resources of Waituna. Wahi tapu (sacred places) and wahi taonga (treasured resources) are located in the area. This rich history of use shows Waituna was extremely valued by Ngāi Tahu, and remains so to this day.

Mauri is a central component of the Maori perspective on the environment. Mauri represents the essence that binds the physical and spiritual elements of all things together, generating and upholding all life. All elements of the natural environment possess a life force, and all forms of life are related. Mauri is a critical element of the spiritual relationship of Ngāi Tahu with Waituna. The overuse, depletion and destruction of natural resources leads to deterioration of Mauri.

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[1] Waihao refers to a variety of short fin eel that are viewed as a delicacy.

Heading up the east side of Waituna Lagoon (photo: S. Chesterfield).

Waituna sunrise, 2008 (photo: Z. Moss).

A duck hunter checks out prospects (photo: Z. Moss).

Evidence of a Problem

Over the past two years, we have been acquiring and analysing data and information about the lagoon from various sources. In this section, we summarise the concerns associated with Waituna Lagoon's ecology and background information in support of these concerns. The information presented in this section is an overview of many extensive and intensive studies and literature reviews. Some of our findings are explained in more detail in subsequent sections and appendices, and a number of reports we cite can be accessed from Environment Southland's Waituna webpage. In simple terms, there are numerous lines of evidence in the last 10-15 years which suggest that the lagoon has become increasingly vulnerable to a regime shift. These are summarised in the table on the adjacent page and explained with supporting data in Appendix One.

ICOLLs are complex systems. Their biological, chemical and physical states are constantly changing in response to internal and external variables such as climate, inflows from groundwater, streams and the sea, the water quality of these inflows, and competition between species. Consequently, understanding whether an observed adverse change in the lagoon's ecology is a long term (permanent) shift, or rather a temporary shift that falls within the normal limits of change, is not a straightforward exercise, particularly when there is a lack of quantifiable long-term monitoring data to use as a reference. In the interim guidelines document, we highlighted a rapid decline in lagoon condition to the point where it had deteriorated from a high value *Ruppia* dominated state to a more degraded condition with nuisance epiphyte and algal blooms and sediment anoxia causing stress to the keystone *Ruppia* species. We were of the view that unless urgent intervention occurred, the lagoon could potentially undergo a rapid regime change to an even more degraded state dominated by phytoplankton (e.g., characterised by algal blooms), which would endanger the *Ruppia* community and change the fundamental values and character of the lagoon. Such rapid shifts have occurred in other lagoons (e.g., Lake Ellesmere/Te Waihora) leading to the loss of valued fisheries and birdlife, as well as cultural and recreational attributes.

Since the publication of a report highlighting the importance of *Ruppia* for lagoon health (Schallenberg & Tyrrell 2006), the results of annual monitoring from 2009 - 2013 indicate a decline in lagoon condition and *Ruppia* biomass and cover, and an increase in nuisance slime algae blooms and associated sediment anoxia, which causes stress to the *Ruppia* beds.

The concerns outlined in the adjacent table indicate that recent changes to Waituna Lagoon and its catchment have occurred. Consequently, management interventions should be undertaken to prevent an irreversible regime shift in the lagoon. Despite some inadequacies associated with biological indicator data, multiple lines of evidence show that the lagoon is currently in a vulnerable state and is not on a sustainable trajectory.

Slime algae bloom and dying *Ruppia* sp. in Waituna Lagoon (photo: A. Hicks).

Concern	Explanation	Supporting evidence from Waituna
Low coverage of aquatic plants (macrophytes including *Ruppia*)	Overseas studies have shown that submerged aquatic plant cover needs to be consistently >30–60% to ensure a clear water state (e.g., Jeppesen *et al.*, 1994; Kosten *et al.*, 2009; Tatrai *et al.*, 2009; Blindow *et al.*, 2002).	Late summer coverage of aquatic plants from 2009 – 2013 has repeatedly been below 35% (see Fig. A1-3 of Appendix One).
Highly fluctuating cover and biomass of aquatic plants from year-to-year	Studies of complex ecosystems suggest that sudden regime shifts are preceded by periods during which key indicators vary wildly in time (Carpenter & Brock 2006; Scheffer *et al.* 2009).	Variability of late summer aquatic plant cover and biomass have varied between 3 and 33% (cover) and 10 and 660 biomass units (biomass) from 2009 – 2013. (see Figs. A1-3 & A1-4 of Appendix One).
Periodic blooms of nuisance slime algae	Blooms of slime algae are often the first major stressor on the aquatic plant communities of ICOLLs and lagoons (Viaroli et al. 2009).	Although different methods have been used to measure slime algae cover and biomass, it is apparent that the abundance of slime algae in the lagoon has increased on occasions since 2009. High slime algae biomass has been observed smothering *Ruppia* and other plants in Waituna Lagoon (see photo opposite and in Appendix One).
Catchment land use intensity indicative of high nutrient and sediment loads	▸ Since 1993, the percentage of Waituna Lagoon's catchment that is used for dairy farming has increased substantially such that, by 2011, dairying accounted for 44% of the lagoon's catchment area (Fig. A1-5 of Appendix One). ▸ Elliott & Sorrell (2002) reported that downstream nutrient losses from dairy farming are among the highest for any land use (see Fig. A1-6 of Appendix One). ▸ As of 2008, 70% of the catchment was under some form of pasture agriculture and conversion of natural wetland and scrub to pasture by installing tile drains is continuing (see Figs. A1-7 & A1-8 of Appendix One). A study of 37 shallow New Zealand lakes by Schallenberg & Sorrell (2009) showed that 87% of the lakes with 70-79% pasture by area in their catchments had experienced sudden macrophyte collapse (see Fig. A1-9 of Appendix One).	
Tributary stream nutrient levels reflect land use intensity	Comparison of the current water quality data from the Waituna catchment with New Zealand reference conditions indicate the creeks are significantly impacted by agricultural land use (Muirhead 2013).	
Evidence of recent internal phosphorus loading	Internal nutrient loading from lagoon bed sediments to the water column indicates de-oxygenation of sediments and the release of sediment-bound phosphate. This is likely to occur when the lagoon is closed, vertical mixing of the water column is weak, there are high levels of organic detritus in/on the sediment and sediment oxygen demand is high.	Phosphorus levels in the water column of the lagoon increased during lagoon closures in 2007 and 2008, suggesting that the lagoon could have experienced substantial internal phosphorus loads during these periods (see Fig. A1-11 of Appendix One)
Macrophyte decline following spring/summer opening	*Ruppia* can reproduce both vegetatively and by seed. Spring is when *Ruppia* seed germination mainly occurs and high salinity during this time inhibits *Ruppia* germination. Therefore, to allow *Ruppia* to complete its life cycle and to germinate from seed in Waituna Lagoon, it is beneficial for the lagoon to remain closed during the spring germination period. In addition, *Ruppia* flowering and seed production is negatively affected by the lagoon being open to the sea during summer because the amount of *Ruppia* habitat is severely constrained by low water levels. Thus, for optimal *Ruppia* germination and reproduction, the lagoon should be closed during spring and summer. The current consented opening regime does not protect *Ruppia* and allows for spring/summer openings which negatively affect *Ruppia.* Summer *Ruppia* cover and biomass monitoring commenced in Waituna Lagoon in 2009 and since then, annual monitoring occurred three times when the lagoon was closed (2009, 2010, 2012) and twice when it was open (2011, 2013).	Negative effects of spring/summer lagoon openings on *Ruppia* biomass in the lagoon (see Fig. A1-12 of Appendix One). In 2011, the LTG recommended a short, late winter opening. As forecasted, the lagoon closed three weeks after the opening was carried out, allowing ideal conditions for *Ruppia* germination, flowering and seeding. Despite this intervention, *Ruppia megacarpa* did not recover from the summer opening of 2010-2011. Although winter openings are typically shorter than spring and summer, the July 2013 opening at Walker's Bay has stayed open into December 2013.
Nutrient levels in lagoon pose a significant risk to sustaining aquatic plants	In a survey of New Zealand brackish lakes and lagoons sampled in late summer, the cover of aquatic plants was inhibited with increasing water column total nitrogen concentration while the chlorophyll a concentration in the water column increased with total nitrogen in the water column (see Fig. A1-13 of Appendix One). The data suggest a threshold nitrogen concentration of 1000 µg/L, which delimits systems dominated by aquatic plants from those dominated by phytoplankton.	The late summer total nitrogen concentration of Waituna Lagoon has been increasing over the past decade and now approaches the inferred threshold of 1000 µg/L, suggesting that the lagoon is vulnerable to macrophyte collapse.

Indicator Targets for Lagoon Health

It is well documented that once shallow lakes are degraded to the extent where aquatic plants are lost, new ecological feedbacks develop, which cause the degraded systems to be resilient against restoration efforts (Scheffer 2004). Therefore, the restoration of aquatic plant communities from a degraded state is difficult and expensive, and restoration targets become more challenging than those necessary to prevent a system from experiencing a regime shift and losing its aquatic plants in the first place. For these reasons, we believe that urgent management action should be undertaken to prevent a regime shift in Waituna Lagoon. We have developed a suite of indicators for the lagoon, some with numerical targets, that can be used to assess ecosystem health.

Using our knowledge of published literature, our experience from other ICOLLs, shallow lakes and coastal embayments, and our developing knowledge of the Waituna Lagoon system, we recommend a suite of healthy lagoon indicator targets that represent an ecological condition of 'moderate'*. Currently, Waituna lagoon is showing signs of being 'highly disturbed', e.g., unstable aquatic plant community and periods of algal domination. These indicators are classified as either primary or secondary. The primary indicators are measures and thresholds of key indicators which provide desired values and secondary indicators are those which assist with the use and interpretation of the primary indicators. These are presented in the following tables.

Primary indicator targets	Explanation	Supporting information
Mean aquatic plant cover in March/ April should be between >30–60% at permanently inundated sites	We do not know what a realistic minimum cover target for Waituna is. This is due to variability in sediment and exposure characteristics within the lagoon, and also disturbance caused by the recommended winter lagoon openings that may limit the expansion and stability of aquatic vegetation. Given this uncertainty, we suggest the minimum target will be somewhere between >30–60% based on international research, and acknowledge that a recent review suggested 50% coverage as a conservative level to ensure a clear water state. In recent years, cover in Waituna Lagoon has fallen well short of 50% (see Appendix A; Fig. A1-3).	Jeppesen *et al.* (1994) Blindow *et al.* (2002) Kosten *et al.* (2009) Tatrai *et al.* (2009)
Mean aquatic plant biomass index between 1000 and 1500 at permanently inundated sites	Aquatic plant cover addresses only one aspect of the health of the plant community. Health and resilience are also related to biomass. For the purpose of monitoring, biomass can be estimated by an index of plant cover *x* height. For Waituna Lagoon data, see Fig. A1-4 of Appendix One.	We are developing this index specifically for Waituna Lagoon and our target range is a preliminary one. Lower and upper limits will be needed.
Mean slime algae cover < 10% at permanently wetted sites	A key response to eutrophication is the proliferation of benthic slime algae. Excessive growths of filamentous algae on lake substrate are indicative of nutrient enrichment. Cover of benthic and epiphytic filamentous algae should be less than 10%. The latest cover estimate is 28% (Sutherland *et al.* 2013).	Joint Nature Conservation Council (Defra 2005) Sutherland *et al.* (2013)
Mean chlorophyll *a* in water column during closed periods < 5 μg/L (mesotrophic-eutrophic boundary), on occasions when samples are not affected by wind-induced resuspension	A key response to eutrophication is phytoplankton proliferation. Therefore, mean chlorophyll *a* should not exceed the mesotrophic range (defined as moderately productive) as calculated by the TLI equation in Burns *et al.* (2000). Typical levels for Waituna Lagoon are less than 5 μg/L although occasional spikes above 30 have been recorded.	Burns *et al.* (2000)
Cyanobacteria counts < 500 cells/ mL and cyanobacteria biovolume < 0.5 mm^3/L (for bloom forming cyanobacteria such as *Nodularia* and *Anabaena*) (does not include picocyanobacteria)	Cyanobacterial blooms are a key indicator of severely eutrophic conditions. Cyanobacteria may produce toxins, affecting recreation and wildlife. *Nodularia spumigena* and *Anabaena* sp. are species which could bloom in Waituna Lagoon. Large numbers of problematic cyanobacteria have not been recorded in Waituna Lagoon since monitoring began in April 2011.	Ministry for the Environment and Ministry of Health (2009)

The maintenance of a healthy rooted aquatic plant community (particularly species like *Ruppia* spp.) is a key indicator of lagoon ecosystem health. In shallow lakes (< 3 metres deep), the total lagoon coverage of submerged macrophytes and species richness are key indicators of macrophyte community health (Søndergaard *et al.* 2010), hence our emphasis on establishing targets for these values.

There is a close coupling of interactions between lagoon bed sediments, the water column and the biological components, thus the health and cover of *Ruppia* in Waituna Lagoon is influenced by both symptoms of eutrophication (e.g., increased slime algae/epiphytes, increase in phytoplankton, reduced water clarity, sediment trophic state (nutrients - N+P and anoxia) and the hydrological (water depth) and salinity regime - determined by whether the lagoon is open or closed to the sea. Opening and closing the lagoon also influences the symptoms of eutrophication by flushing and diluting nutrient concentrations and phytoplankton with cleaner sea water. There is an important trade-off between flushing and maintaining a hydrological and salinity regime that supports macrophyte growth (Robertson & Funnell 2012).

In addition to indicators of lagoon health, we have also recommended nutrient load reductions and hydrological management to allow the lagoon to remain in a healthy, long-term sustainable condition. These are summarised in the next two sections with more detail on the reasoning behind targeting nutrient loads and lagoon hydrology (specifically barrier bar opening and closing) provided in Appendices Two and Three.

Secondary indicator targets	Explanation	Supporting information
Mean water column nutrient levels during closed periods < mesotrophic - eutrophic boundary, when samples not affected by wind-induced resuspension **TN < 337 µg/L** **TP < 20 µg/L**	These indicators allow the monitoring of lagoon water nutrient levels. They can be affected by uptake by aquatic plants and benthic slime algae. Therefore, their values must be interpreted with caution. Typical levels for Waituna Lagoon are over 1,000 µg/L for TN and over 30 µg/L for TP.	Burns *et al.* (2000)
Low incidence of sediment anoxia.	Sediment anoxia can be a driver of phosphorus release, algal blooms and aquatic plant collapse.	Grizzle & Penniman (1991) Tett *et al.* (2004)
Hydrological regime **Lagoon closed during *Ruppia* growing season (spring and summer).**	A closed lagoon has implications for water depth, the area of lagoon inundation and degree of salinity. Salinity and water level affect *Ruppia* growth. Salinity indicates the amount of mixing of freshwater and sea water at the time of sampling. Closed lagoon situations are associated with higher water levels and lower salinities which are favourable for aquatic plant community.	Gerbeaux (1989) Robertson & Funnell (2012)
Light attenuation (photosynthetically active radiation) **Low in spring** **(ideally looking for > 10% at Z_{max})**	This indicates to what extent light can penetrate into the lagoon waters, which indicates how much of the bed is available to germinating seeds and propagules of aquatic plants as well as to benthic slime algae.	Congdon & McComb (1979) Gerbeaux (1989)

*Scanes (2012) summarised estuary status as a function of catchment disturbance as follows:

Reference condition: clear waters with minimal algal blooms, strong seagrass growth and good fish assemblages;
Moderately Disturbed: some eutrophic symptoms but still supporting healthy seagrass and fish communities;
Highly Disturbed: algal dominated, turbid systems, seagrass absent or reduced with associated changes in fish assemblages.

Targets for Lagoon Input Loads

The 2011 interim load estimates and reduction targets were acknowledged at the time as best estimates and needed to be revised once further monitoring and investigations had been completed. We have now revisited those nutrient and sediment load estimates and targets, and have concluded that in order to maintain a healthy macrophyte community and avoid a regime shift in Waituna Lagoon, the current nutrient loads to Waituna Lagoon need to be substantially reduced. These targets relate to the total input load to the lagoon from the catchment, but are not intended as individual farm targets.

We continue to recommend that Waituna Lagoon is managed for both nitrogen and phosphorus because nutrient limitation can vary with salinity, season, and/or plant species composition (Boesch 2002, Wriggle 2012). Previously, our interim guidelines for Waituna Lagoon recommended reductions in nutrient and sediment inputs in order to achieve a lagoon target of 'moderate' ecological condition and ensure the maintenance of a macrophyte-dominated regime. Our revised recommended nutrient load limits to Waituna Lagoon are presented in the highlight box on the following page. As explained in Appendix One, we first had to estimate the current loads to the lagoon and that in itself was not an easy task. Indeed, catchment nutrient load estimates remain an area of uncertainty requiring additional research (see Gaps and Uncertainties). Nutrient loads to the lagoon have now been estimated using using two different methodologies. One method (Diffuse Sources & NIWA) used rating curves, while the other (University of Waikato) used linear interpolations of monthly nutrient load measurements. Both methods also accounted differently for groundwater nutrient inputs.

Three independent approaches were used to set nutrient load targets appropriate for the long-term sustainability of the aquatic plant community in Waituna Lagoon, recognising that *Ruppia* is a key component of this community:

1. The University of Waikato developed a numerical model of the ecological functioning of Waituna Lagoon (Hamilton *et al.* 2012). This model was used to test different nutrient loading scenarios to simulate their effects on the *Ruppia* community, slime algae and phytoplankton. Key scenarios related to nutrient loads included the status quo, a 25%, 50% and 90% reductions in nitrogen and phosphorus loads in combination with various opening and closing scenarios.
2. An extensive review of the scientific literature was carried out to determine whether experiences from ICOLLs, lagoons and coastal embayments from New Zealand and other temperate regions around the world could shed light on whether a threshold nutrient loading rate exists above which *Ruppia* no longer dominates and regime shifts to slime algae and eventually phytoplankton occur (Schallenberg & Schallenberg 2012).
3. An Australian expert on ICOLLs, Dr Peter Scanes, was commissioned to write a report on nutrient load targets for Waituna Lagoon based on different ecological outcomes (Scanes 2012). These included a highly degraded ecological state, a moderately degraded state and a minimally degraded state.

Recommended nutrient load limits to Waituna Lagoon

Nitrogen	**< 125 tonnes/year (a lagoon aerial loading of < 90 kg N/ha/yr)**
Phosphorus	**< 7.7 tonnes/year (a lagoon aerial loading of < 5.7 kg P/ha/yr)**

The nitrogen load targets for Waituna Lagoon that were determined from these three independent methods were very consistent (Fig. 1). Thus, we have confidence in the loading targets derived from all three methods. The average of the N target estimates was used to derive the recommended N load target. There was more variability in the current and recommended phosphorus loads, and so we have less confidence in prescribing a phosphorus load target. The evidence indicates a significant P reduction is required, and because reducing N:P ratios may favour cyanobacteria blooms, we have recommended that a 50% reduction in P load is also required to balance the required reduction in N. As such, we estimate nitrogen and phosphorus targets to be approximately 50% of the current estimated nutrient inputs to the lagoon.

We recommend that greater emphasis is placed on the loading of nutrients and sediment to the Waituna Lagoon than on the instantaneous concentration of nutrients in the lagoon. This is because nutrient loading to coastal lagoons is the main driver of eutrophication while nutrient concentrations are a "response variable" in that they reflect the net effects of both nutrient loading to the lagoon and nutrient assimilation in the lagoon (e.g., slime algae uptake).

Waituna Lagoon is estimated to be infilling with sediment at a rate approximately 10-fold greater than pre-European times (Cadmus 2004). Infilling with fine sediments adversely affects both the ecology and human uses of the lagoon. While we consider it may be necessary to reduce the fine sediment load to the lagoon, we do not have sufficient information to recommend a quantitative cap. As such, we recommend that additional studies be undertaken to further refine a load target, particularly in light of the fact that modelling has confirmed that suspended sediments are important in controlling light availability for macrophytes in the lagoon.

Plume of sediment-laden water entering the surface drainage system of the Waituna catchment (photo: A. Hicks).

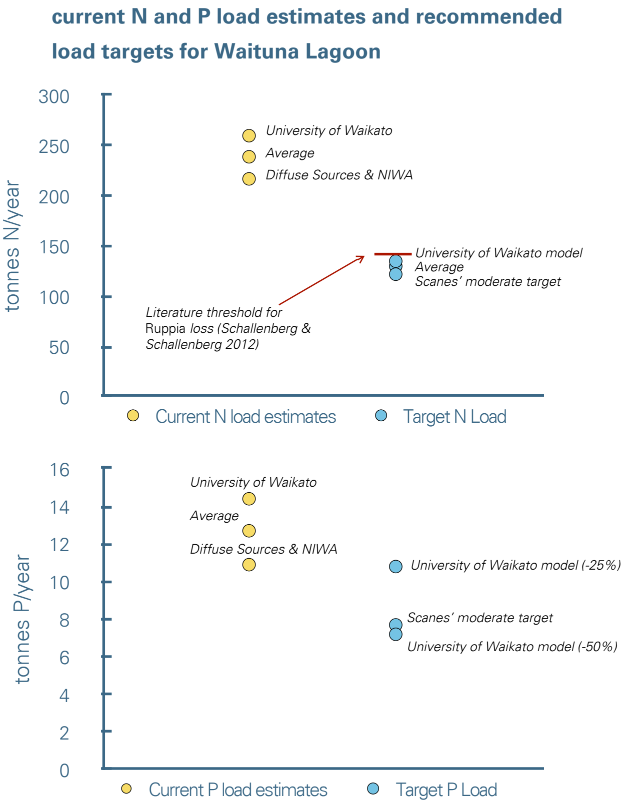


Fig. 1. Current nitrogen (top) and phosphorus (bottom) load estimates and recommended nutrient load targets for Waituna Lagoon.

Recommended Opening Regime

In the medium term, mechanical opening of the lagoon is required to reduce the nutrient and sediment load within the lagoon and assist catchment drainage. Without openings, nutrient load reduction targets would need to be much lower to safeguard the lagoon ecosystem. But ill-timed openings threaten the viability of the macrophyte community. In the longer term, achieving sustainable nitrogen and phosphorus loads will reduce the need for opening to regulate water quality.

The ecological effects from opening Waituna Lagoon are complex and any opening regime should account for the various ecological costs and benefits it produces. Currently, the primary purpose for a consented lagoon opening is to maintain catchment drainage, but opening the lagoon to the sea is also necessary at present to flush nutrient laden water and sediment out in order to prevent sustained algal growth. However when the lagoon is open for too long it has a negative effect on *Ruppia* and other macrophytes. These effects include reducing the cover of macrophytes necessary for maintaining good lagoon health, and instead enhancing nuisance slime algae and causing marine sand intrusion. The reduction in macrophyte abundance is due to a 30% loss in available habitat associated with lower water levels, competition with slime algae which seem to thrive at higher salinities, and suppressed growth and reproduction of *Ruppia* related to open conditions.

Cut in the Waituna Lagoon barrier (photo: Katrina Robertson).

The recommended guidelines for lagoon openings are presented in the highlight box on the adjacent page and include five main components. The rationale behind each component is expanded upon in Appendix Two, but is summarised below. A key objective of the opening regime is to maintain at least a ‘moderate’ state for Waituna Lagoon (see section on Indicator Targets for Lagoon Health). For this to be achieved it is desirable to have a predominantly fresh-water lagoon with a short marine phase (e.g., two months).

The lagoon should preferably be opened in winter (May to July). This will allow more catchment-derived nutrients and sediments to be flushed from the lagoon and will give a high probability that the mouth will close before spring and summer. There will also be a reduced risk of nuisance slime algae proliferation during a winter opening due to shorter daylight hours and cooler water temperatures. It is strongly advised that in order to protect ecological values the lagoon is not opened between August and March. It is during spring and summer that macrophytes like *Ruppia* are germinating and growing, so are more sensitive to desiccation and high salinity.

Lagoon opening at Walker’s Bay July 2013 (photo: K. Erikson).

To promote favourable conditions for the Waituna Lagoon macrophyte community, the following opening regime is recommended:

1. **(a) Minimise the risk of the lagoon being open during spring and summer (August to March).**
   (b) Open the lagoon between May and June if water levels are above 2.0 metres.
   (c) Open the lagoon in July when water levels are above 1.8 metres.
2. **When high lagoon levels cause drainage problems during spring and summer, seek advice on the likely duration of high water levels to help avoid unnecessary spring/summer openings.**
3. **Time opening so that lagoon is draining during a windy period when resuspension and flushing effect will be highest.**
4. **Investigate the feasibility of manually closing the lagoon. Any assisted closure would need to work in with favourable tides and weather to enhance the likelihood of success.**
5. **Use Walker's Bay as the standard opening location, but experimental openings at Hansen's Bay should be explored further to determine whether alternative opening locations could reduce the threat to the aquatic vegetation community while extending flushing benefits to other parts of the lagoon.**

Upper and lower water levels for the lagoon opening have been identified that reflect the ability to provide good flushing, increase the chances of the lagoon being opened in winter, while decreasing the chances of needing to open it later in spring/summer.

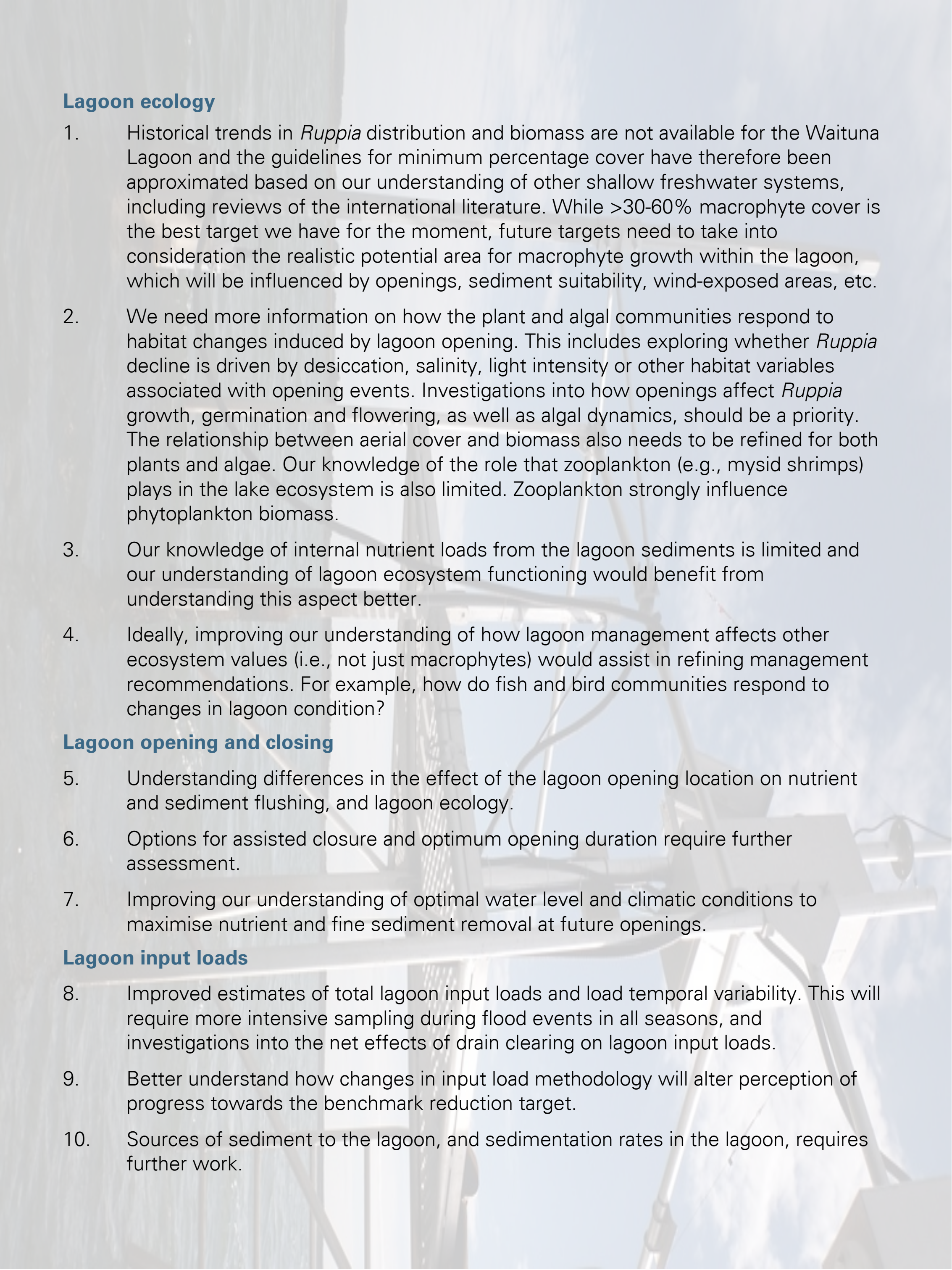
The impact of a change in opening management has been investigated using a hydrological model to predict lagoon water level based on surface water inflows, direct rainfall inputs and seepage through the barrier. Observations in the patterns of previous lagoon openings support avoiding spring openings because these have a high chance of extending into the summer months, which are critical months for growth and reproduction of the lagoon's macrophyte community.

An examination of water quality data for Waituna Lagoon shows that there are relationships between wind strength, temperature (strongly affected by time of year) and the concentrations of nutrients and suspended sediment in the water column. The quantity of nutrients flushed out to sea during an opening event can be increased by breaching the bar during colder conditions (May to July) when the lagoon is more turbid and the amount of nutrients suspended in the water column is greater. Flushing at this time of the year has the additional benefit of having less impact on the lagoon's macrophyte community.

The majority of lagoon openings have occurred at Walker's Bay and so we have the greatest understanding of the effects of lagoon openings using this location. We have limited understanding of the effects of openings at Hansen's Bay, or at more eastern sites, and these sites represent a greater risk of causing unforeseen adverse effects. However, it is possible that openings at other locations could prove more favourable to the lagoon's macrophyte community (e.g., less chance of an extended opening duration and increased chance of flushing accumulated load from eastern end). Consequently, we do not want to rule out other opening locations, but at this point in time there is insufficient data to choose any site other than the current, well understood, opening location at Walker's Bay.

Gaps and Uncertainty

There are a number of information gaps or areas of uncertainty that, if addressed, would improve the ecological management of Waituna Lagoon and reduce the risk of ecosystem regime shifts. These are:



Lagoon ecology

1. Historical trends in *Ruppia* distribution and biomass are not available for the Waituna Lagoon and the guidelines for minimum percentage cover have therefore been approximated based on our understanding of other shallow freshwater systems, including reviews of the international literature. While >30-60% macrophyte cover is the best target we have for the moment, future targets need to take into consideration the realistic potential area for macrophyte growth within the lagoon, which will be influenced by openings, sediment suitability, wind-exposed areas, etc.
2. We need more information on how the plant and algal communities respond to habitat changes induced by lagoon opening. This includes exploring whether *Ruppia* decline is driven by desiccation, salinity, light intensity or other habitat variables associated with opening events. Investigations into how openings affect *Ruppia* growth, germination and flowering, as well as algal dynamics, should be a priority. The relationship between aerial cover and biomass also needs to be refined for both plants and algae. Our knowledge of the role that zooplankton (e.g., mysid shrimps) plays in the lake ecosystem is also limited. Zooplankton strongly influence phytoplankton biomass.
3. Our knowledge of internal nutrient loads from the lagoon sediments is limited and our understanding of lagoon ecosystem functioning would benefit from understanding this aspect better.
4. Ideally, improving our understanding of how lagoon management affects other ecosystem values (i.e., not just macrophytes) would assist in refining management recommendations. For example, how do fish and bird communities respond to changes in lagoon condition?

Lagoon opening and closing

5. Understanding differences in the effect of the lagoon opening location on nutrient and sediment flushing, and lagoon ecology.
6. Options for assisted closure and optimum opening duration require further assessment.
7. Improving our understanding of optimal water level and climatic conditions to maximise nutrient and fine sediment removal at future openings.

Lagoon input loads

8. Improved estimates of total lagoon input loads and load temporal variability. This will require more intensive sampling during flood events in all seasons, and investigations into the net effects of drain clearing on lagoon input loads.
9. Better understand how changes in input load methodology will alter perception of progress towards the benchmark reduction target.
10. Sources of sediment to the lagoon, and sedimentation rates in the lagoon, requires further work.

Summary of Recommendations

We have described ecological condition in terms of macrophytes, slime algae, phytoplankton, sediment anoxia, water clarity and nutrients. We have recommended the objective of maintaining a healthy macrophyte community because this is a key indicator of a healthy lagoon. We therefore recommend a target of:

>30-60% cover of *Ruppia* and other indigenous macrophytes.

To protect the ecological health, nutrient loads to Waituna Lagoon should be:

Nitrogen	**< 125 tonnes/year (a lagoon aerial loading of < 90 kg N/ha/yr)**
Phosphorus	**< 7.7 tonnes/year (a lagoon aerial loading of < 5.7 kg P/ha/yr)**

To promote favourable conditions for the Waituna Lagoon macrophyte community, the following opening regime is recommended:

1. **(a) Minimise the risk of the lagoon being open during spring and summer (August to March).**
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5. **Use Walker's Bay as the standard opening location, but experimental openings at Hansen's Bay should be explored further to determine whether alternative opening locations could reduce the threat to the aquatic vegetation community while extending flushing benefits to other parts of the lagoon.**

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Glossary of Terms

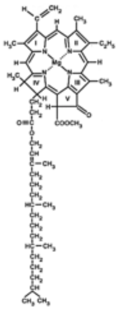
Anoxia: A condition in which free oxygen (O_2) is absent.

Benthic: Relating to the lake or lagoon bed.

Biomass: A way of describing the abundance of living things. Biomass is usually a measure of the mass or weight of an organism, per unit volume (e.g., per litre) or area (e.g., per square metre).

Chlorophyll *a*: Expressing the abundance or biomass of plants. This is determined by measuring the amount of the main plant pigment, chlorophyll a, in a sample.

Cyanobacteria: Also known as blue-green algae. Similar to algae although cyanobacteria have two important characteristics which distinguish them from algae: 1) some cyanobacteria 'fix' gaseous nitrogen compounds from the water to compensate for periods of low nitrate or ammonia nitrogen compounds using nitrogen gas, 2) some cyanobacteria produce cyanotoxins, which are deleterious to humans and wildlife.



Chlorophyll *a*

Denitrification: The second step in the nitrification-dentrification process, a natural, microbial process whereby oxidised forms of nitrogen, such as nitrate and nitrite, are converted to inert nitrogen gas. See Nitrification.

Epiphytic: Epiphytes are plants and algae that grow on the surface of other plants. Algae growing on seaweeds are examples of epiphytes. *Bachelotia* is an epiphytic algae that can reach nuisance levels in Waituna Lagoon.

Eutrophic: Describes a state of high nutrient enrichment in aquatic systems. In a eutrophic condition, algal blooms are likely to occur.

Eutrophication: The process of change in aquatic systems from a low-nutrient condition to a nutrient-enriched condition. Eutrophication describes the process of becoming nutrient-enriched and becoming more prone to algal blooms and other undesirable conditions.

Filamentous algae: Algae that grow in the form of filaments or "chains". These are often nuisance algae in aquatic systems.

ICOLL: Intermittently Closed and Open Lake/Lagoon. These coastal systems have barrier bars which sometimes separate them from the ocean. However, ICOLLs are sometimes connected to the sea via breakages in the barrier bar.

Macroalgae: (referred to as slime algae in the guidelines): macroalgae are algae that are visible to the naked eye. They may be floating, rooted in the sediment or attached to rocks, invertebrates or even other plants. They are distinguished from phytoplankton and macrophytes (see below).

Macrophyte: An aquatic plant (e.g., *Ruppia*), usually a vascular plant, but sometimes includes large algae rooted to the sediment.

Mesotrophic: Describes a state of moderate nutrient enrichment in aquatic systems. In a mesotrophic condition, algal blooms may occasionally occur.

Nitrification: This is the first step in the nitrification-denitrification process, which removes reactive nitrogen from aquatic systems. Nitrification is a natural, microbial process that converts ammonium to nitrate. See Denitrification.

Oligotrophic: Describes a state of low nutrient enrichment in aquatic systems. In an oligotrophic condition, algal blooms are unlikely.

Phytoplankton: Microscopic algae and cyanobacteria that live suspended in the water column.

Picocyanobacteria: A very tiny plant-like micro-organism that is part of the phytoplankton. This cyanobacterium doesn't usually produce toxins and isn't usually able to use nitrogen from nitrogen gas.

PPT: The salinity of water is commonly reported as "parts per thousand" in reference to the concentration of grams of salt per kilogram of water (g/kg). For example, the average concentration of salt in seawater is about 35 g/kg. This quantity is usually expressed as the measure of parts salt per thousand parts seawater (ppt). For example, 35 grams of salt dissolved in 1 kilogram of seawater is equal to 35 parts of salt dissolved in 1000 parts of seawater, or 35 ppt. Freshwater salinity is typically <0.5 ppt while estuarine salinity can vary between >0.5 ppt and <30 ppt.

Ruppia: The dominant aquatic plant (macrophyte) in Waituna Lagoon comprising two species: *Ruppia megacarpa* and *Ruppia polycarpa*. A type of macrophyte that can tolerate shifts in salinity. Typically forms extensive beds in healthy ICOLLs of New Zealand and temperate Australia.

Slime algae: Describes nuisance macroalgae. Can be floating in the water column, growing on top of macrophytes, or growing on rocks and sediments.

TLI: Trophic Level Index. A numerical system used to describe the degree of nutrient enrichment in lakes.

Z_{max}: A term to describe the maximum depth of a lake.

Appendices

Appendix One

Information Contributing to Our Concerns about the Health of Waituna Lagoon

Some data from Waituna Lagoon were not included in the section on 'Evidence of a Problem' because they did not show clear trends. These data include the components of the trophic level index, or TLI (total nitrogen, total phosphorus and chlorophyll *a* concentrations), and data on catchment nutrient loads to the lagoon, which show no trends or only weak trends over the past decade. We believe that such ambiguous data are not indicative of the problems facing the lagoon. For example, water column nutrient data can be misleading because the concentration of nutrients in the water column reflects both the input of the nutrients as well as the uptake of the nutrients by plant life in the lagoon. Therefore, a high spring or summer biomass of benthic slime algae in the lagoon would likely reduce water column nutrient concentrations, leading to the false conclusion that the ecological condition of the lagoon is good or improving. Blooms of slime algae are often the first major stressor on the aquatic plant communities of ICOLLs and lagoons (Viaroli *et al.* 2009) and unless their abundance is monitored carefully, then inferences on the condition of the lagoon based on water column nutrients and chlorophyll *a* data can be falsely construed.


Slime algae bloom in Waituna Lagoon (photo: B. Robertson).

Similarly, estimates of nutrient and sediment loading from the catchment can be misleading if based on occasional (e.g., monthly) sampling of inflow nutrient concentrations. The nutrient loads from catchment land use activities occur mainly during floods. For example, a single flood event can deliver more than the mean annual nutrient load from the catchment to a river or lake (Chris Jenkins, Environment Southland, unpubl. data). Therefore, because floods can be easily missed when sampling on a monthly basis, monthly sampling of streams provides only a crude estimate of the nutrient load. In addition, climatic variability related to wet and dry years (e.g., droughts such as the one in summer 2012-13) can have a marked effect on the nutrient flux from a catchment. For example, nutrient loads calculated for the same stream in a dry and a


Slime algae bloom smothering live *Ruppia* sp. in Waituna Lagoon (photo: B. Robertson).

wet year can be different by 200% or 300%. Consequently, the possibility of observing real trends in nutrient loading over time in the tributaries of Waituna Lagoon is compromised by inadequacies of the data related to sampling frequency and to climatic variability.

Despite such data challenges, we consider that the evidence tabulated in the section on 'Evidence of a Problem' indicates there is an urgent need to address conditions which appear to be leading towards a possible collapse of aquatic plants in Waituna Lagoon. While eutrophication is usually the main driver of aquatic plant collapse in lakes, other factors can also contribute to this sudden collapse. For example, a storm can trigger such regime shifts, as occurred in the ICOLL, Lake Ellesmere/Te Waihora (Fig. A1-1). In this ICOLL, eutrophication was the underlying driver, but a large storm in 1968 shifted the system into a phytoplankton dominated state, exhibiting greatly reduced water clarity and increased phytoplankton biomass (Fig. A2; Schallenberg *et al.* 2010). In addition, blooms of the toxic cyanobacterium, *Nodularia spumigena* have been detected in Lake Ellesmere from at least as far back as 1980 (Carmichael *et al.* 1988). Such regime shifts to slime algae-, or plankton-dominated states are often difficult to reverse (Scheffer 2004; Schallenberg & Sorrell 2010) as illustrated by Lake Ellesmere, which has remained in a plankton-dominated state since 1968. Efforts are now being made to restore *Ruppia* and other aquatic plants to Lake Ellesmere, but it will be years before it is known whether restoration will be successful. Unlike in shallow freshwater lakes, an increase in slime algae biomass/cover is often a precursor to aquatic plant collapse in ICOLLs. In such systems, slime algae have a great potential to rapidly proliferate and grow on top of aquatic plants, causing their collapse by changing the light and physico-chemical environment on the bed of the ICOLL. While we don't know if slime algae proliferation was a precursor to the loss of aquatic plants in Lake Ellesmere, slime algae have removed *Ruppia* and other aquatic plant populations in Australian ICOLLs and lagoons which have been subject to eutrophication and altered hydrological regimes.

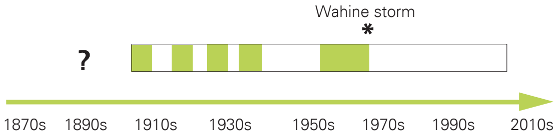


Fig. A1-1. Inferred vegetated (green) and de-vegetated (white) periods in Lake Ellesmere/Te Waihora (Canterbury).

Based on the above evidence, we believe that Waituna Lagoon is now in a state in which it is vulnerable to the collapse of aquatic plants and the subsequent loss of many of its key values. It is well documented in shallow lakes that, once degraded to the extent where aquatic plants are lost, new ecological feedbacks develop, which cause the degraded systems to be resilient to restoration efforts (Scheffer 2004). Therefore, the restoration of aquatic plant communities from a degraded state is difficult and expensive and must achieve more challenging nutrient load reduction targets than those necessary to prevent a system from experiencing a regime shift and losing its aquatic plants.

Decline in macrophyte cover

There is good evidence to demonstrate that in recent years macrophyte cover has consistently been low. Repeat annual survey since 2009 indicate that average cover is less that 35% in late summer and as low as 3% (Fig. A1-3) while macrophyte biomass (assessed as % aerial cover x plant height) has fluctuated widely ranging from 10 to 660 biomass units over the same period (Fig. A1-4). Conversely, high slime algae biomass has been observed frequently over this period (see photos on page 28).

Fig. A1-2. State of water clarity in Lake Ellesmere/Te Waihora in 2006. The lake has been de-vegetated since 1968 (photo: M. Schallenberg).

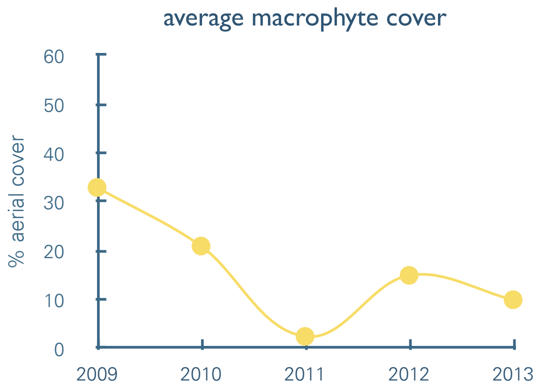


Fig. A1-3. Waituna Lagoon average cover of macrophyte species from 2009 - 2013 at permanently submerged sites. Macrophyte species include *R. megacarpa*, *R. polycarpa*, *Myriophyllum triphyllum*, and a charophyte. Data from DOC.

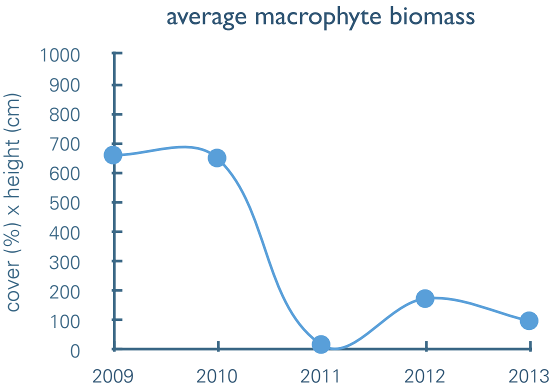


Fig. A1-4. Waituna Lagoon average biomass of macrophyte species from 2009 - 2013. Data from DOC.

Land use intensity increasing nutrient & sediment loads

Land development and land use intensification for farming has been steadily increasing in recent decades and we believe this is linked to higher inputs of nutrients and sediments to the lagoon relative to historic levels. Since 1993, the proportion of Waituna Lagoon's catchment that is used for intensive dairy farming has increased substantially such that, by 2011, dairying accounted for 44% of the catchment area of the lagoon (Fig. A1-5). Elliott & Sorrell (2002) reported that downstream nutrient losses from dairy farming are among the highest for any land use (Fig. A1-6).

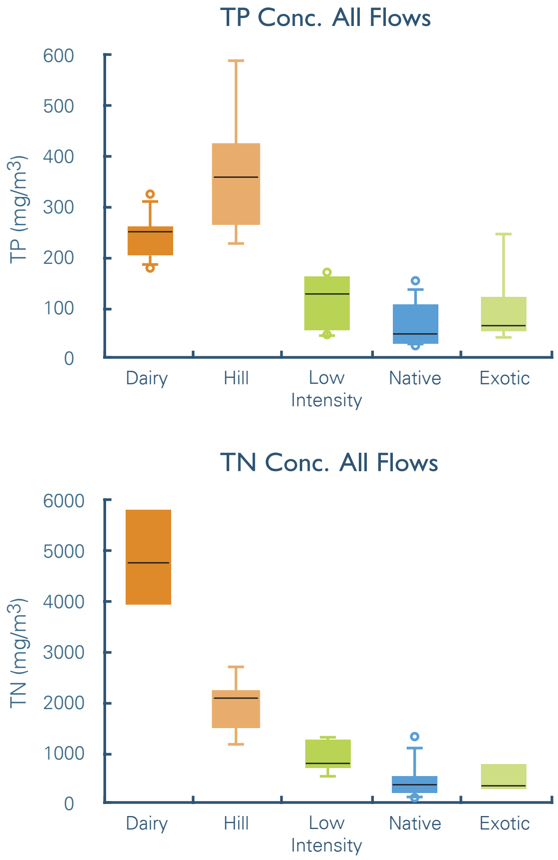


Fig. A1-6. Concentrations of total phosphorus (top) and total nitrogen (bottom) in streams draining catchments with different land uses. Values are temporally integrated, but not flow-weighted. The central solid line is the median value, the ends of the box are at the 25th and 75th percentiles, whiskers are at the 10th and 90th percentiles (where appropriate), and circles are outliers. Redrawn from Elliott & Sorrell (2002).

A significant proportion of the Waituna catchment (70%) is under some form of pasture agriculture and the conversion of natural wetland and scrub to pasture by installing tile drains is continuing (Figs. A1-7 and A1-8). Schallenberg & Sorrell (2009) showed that 87% of shallow New Zealand lakes with 70-79% pasture quotas in their catchments had experienced sudden macrophyte collapse (Fig. A1-9).

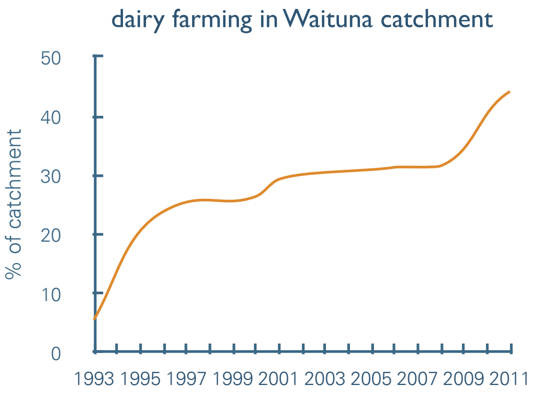


Fig. A1-5. Percentage of Waituna Lagoon catchment in dairy farming from 1993 to 2011. Data from Environment Southland.

Fig. A1-7. Wetland clearance and drain laying near the shore of Waituna Lagoon, December 2009 (photo: M. Schallenberg).

Fig. A1-8. Wetland clearance and drain laying in the lower Waituna catchment, December 2009 (photo: M. Schallenberg).

An analysis of Environment Southland water quality monitoring data for Waituna Creek shows that, in general, estimated daily loads of total nitrogen and nitrate (Fig. A1-10a), and total phosphorus (Fig. A1-10b) have increased in recent years and so are of concern and worthy of further investigation.

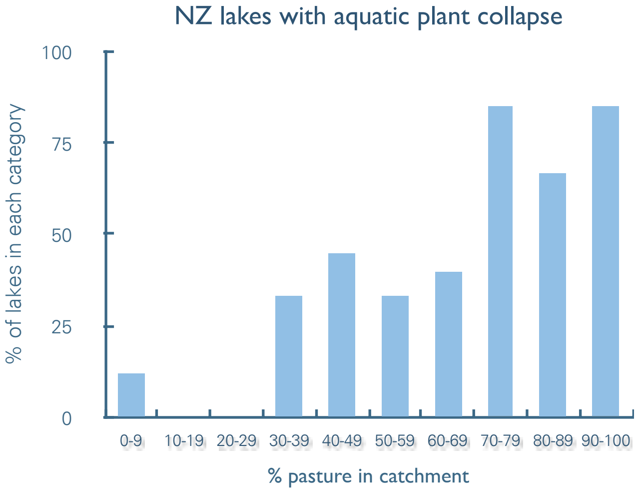


Fig. A1-9. Percentage of shallow New Zealand lakes (out of a total of 37) that have undergone sudden collapses of aquatic plants in relation to the percentage of pasture in their catchments. Figure redrawn from Schallenberg & Sorrell (2009).

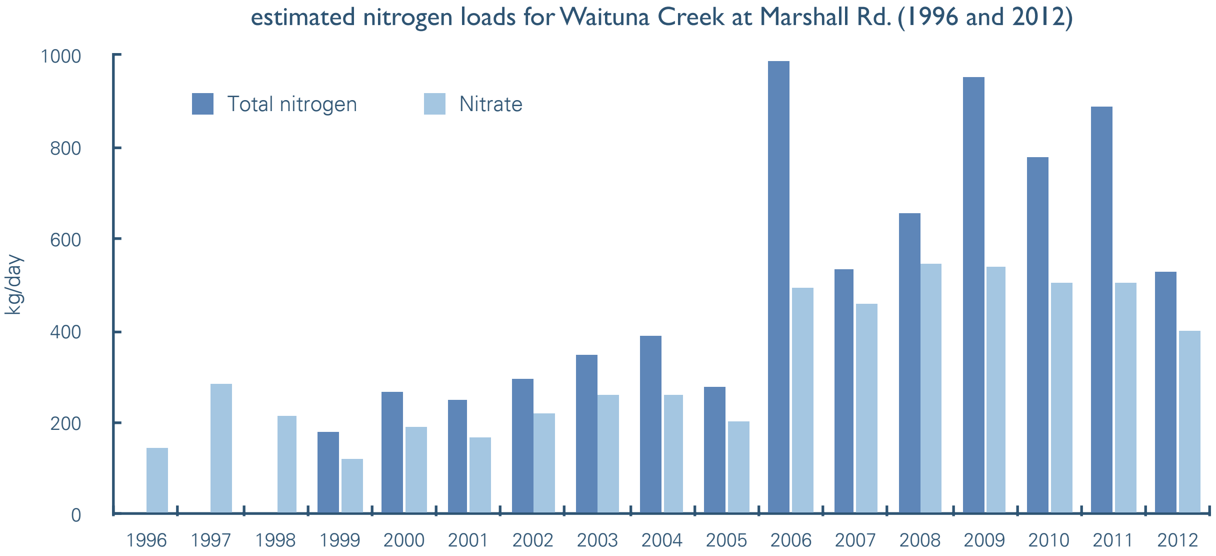


Fig. A1-10a. Estimated daily nitrate and total nitrogen loads (expressed as kg/day) for Waituna Creek at Marshall Road (1996 and 2012). Based on collected samples from Environment Southland's water quality and flow monitoring programme. Note that data for total nitrogen starts from 1999.

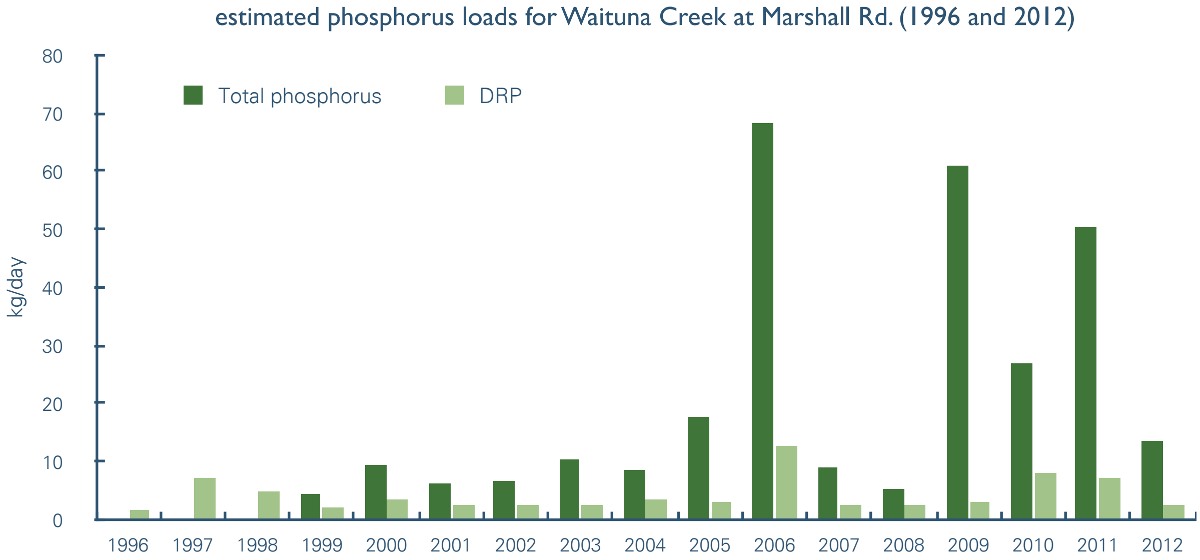


Fig. A1-10b. Estimated daily dissolved reactive phosphorus (DRP) and total phosphorus loads (expressed as kg/day) for Waituna Creek at Marshall Road (1996 and 2012). Based on collected samples from Environment Southland's water quality and flow monitoring programme. Note that data for total phosphorus starts from 1999.

Fig. A1-11 shows that the phosphorus levels in the water column of the lagoon increased during lagoon closures in 2007 and 2008, suggesting that the lagoon could have experienced substantial internal phosphorus loads during these periods.

Fig. A1-12 shows the negative effects of spring/summer lagoon openings on *Ruppia* biomass in the lagoon. In 2012, we recommended a short, late winter opening. As forecast, the lagoon closed three weeks after the opening was carried out, allowing ideal conditions for *Ruppia* germination, flowering and seeding. Despite this intervention, *Ruppia megacarpa* still has not recovered from the summer opening of 2011.

In a survey of New Zealand brackish lakes and lagoons sampled in late summer, the cover of aquatic plants was inhibited with increasing water column total nitrogen concentration while the chlorophyll a concentration in the water column increased with total nitrogen in the water

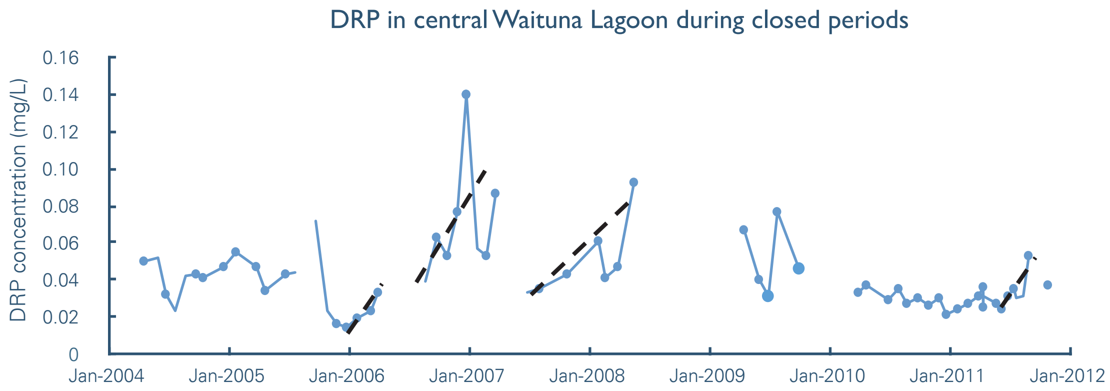


Fig. A1-11. Dissolved reactive phosphorus (DRP) concentrations in central Waituna Lagoon during closed periods. Dashed lines show where increasing DRP concentrations could suggest internal phosphorus loading to the lagoon. Data from Environment Southland.

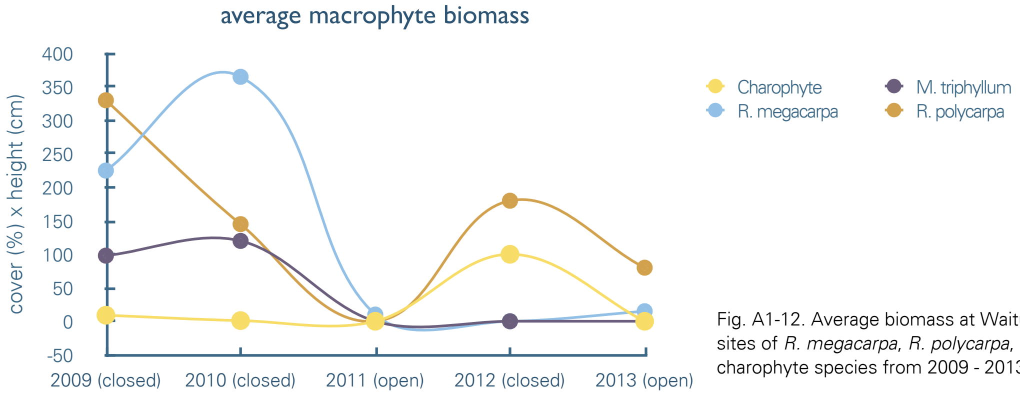


Fig. A1-12. Average biomass at Waituna Lagoon monitoring sites of *R. megacarpa*, *R. polycarpa*, *M. triphyllum* and charophyte species from 2009 - 2013. Data from DOC.

column (Fig. A1-13). The late summer total nitrogen concentration of Waituna Lagoon has been increasing over the past decade and now approaches the inferred threshold of 1000 μg nitrogen/L (Fig. A1-14), suggesting that the lagoon is vulnerable to macrophyte collapse. The data suggest a threshold nitrogen concentration of 1000 μg/L, which delimits the systems dominated by aquatic plants from those dominated by phytoplankton.

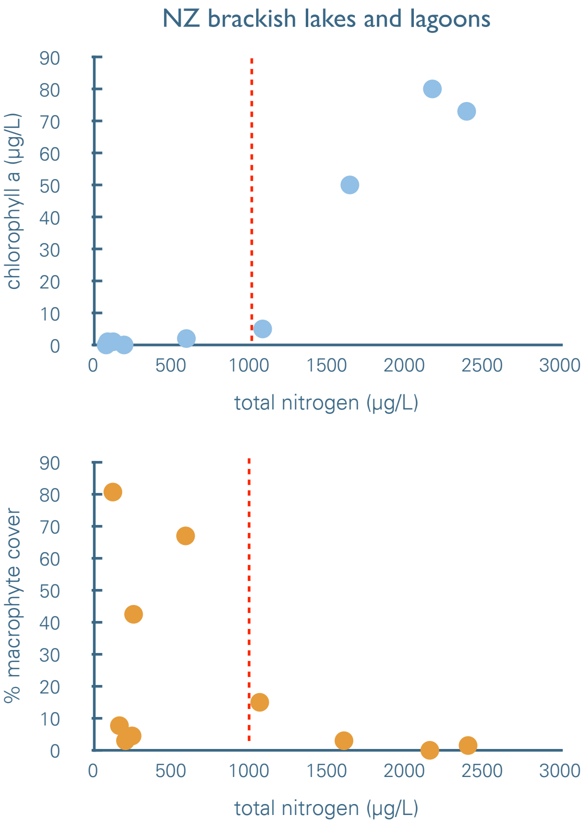


Figure A1-13. Relationships between indicators of eutrophication (chlorophyll *a* - top chart and % macrophyte cover - bottom chart) and total nitrogen concentration in 11 brackish New Zealand lakes and lagoons. Systems were sampled once in late summer. Dashed red line is inferred threshold for regime shifts in these systems. Data from Schallenberg (in press).

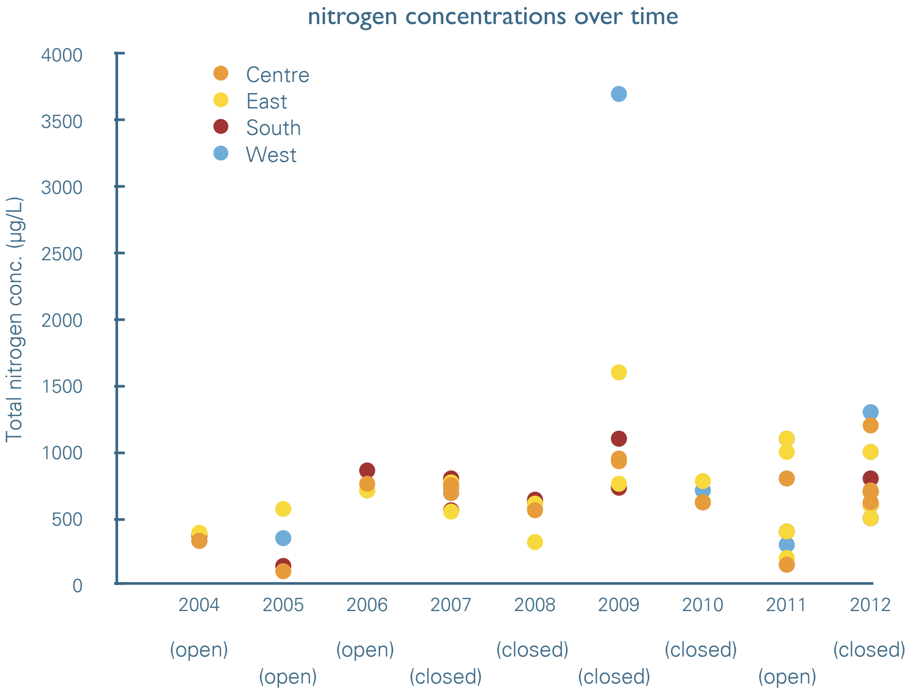


Fig A1-14. Late summer total nitrogen concentrations in Waituna Lagoon. Inferred threshold for regime shift is 1000 µg Nitrogen/L, as indicated in Fig. A1-13.

Water quality trends in streams entering Waituna Lagoon

This section describes water quality trends in streams entering Waituna Lagoon to support statements regarding concerns we have about the degradation of Waituna Lagoon due to inputs of nutrients and sediment. These water quality analyses are based on Environment Southland monitoring data. Unfortunately, commencement of routine water quality monitoring of input streams has been relatively recent. Note also that the length of data record varies between monitoring sites, so we urge caution when comparing differences in trends between sites. The record lengths used were:

- Waituna Creek at Marshall Road: July 1995 - January 2013
- Waituna Creek 1m upstream Waituna Road: August 2001 - January 2013
- Carran Creek at Waituna Lagoon Road: August 2001 - January 2013
- Craw's Creek (Carran Creek tribe.) at Waituna Lagoon Rd: August 2001 - January 2013
- Moffat Creek at Moffat Road: August 2001 - January 2013

Water quality trends were assessed using the seasonal Kendall test and the software "TimeTrend". The analysis was done on 12 seasons per year starting in January. A trend test was only considered to be statistically significant if the *p*-value was less than 0.05 (after Burns *et al.* 2000), and only considered to be meaningful if it had an annual trend of more than 1% of the median value. The lower the *p*-value, the more likely it is that the lagoon has changed with time, and the smaller the rate of change the less substantial is the trend.

The analysis was done on the full data set and flow adjusted data. The results of the trend analysis are shown in Table A1-1 for the non-adjusted data only. The following statistically significant water quality trends were found:

- Waituna Creek at Marshall Road: nitrate (NNN) deteriorating (concentration increasing); total phosphorus (TP), dissolved reactive phosphorus (DRP), total ammonia (NH_3-N) and clarity all improving (see Fig. A1-15, Fig. A1-17 and Fig. A1-20)
- Waituna Creek at Waituna Road: nitrate deteriorating (concentration increasing), DRP improving (concentration decreasing) (see Fig. 16).
- Moffat Creek: TP improving (concentration decreasing).

- Carran Creek: DRP deteriorating (concentration increasing), total ammonia improving (concentration decreasing).
- Craw's Creek: nitrate improving (concentration decreasing), total ammonia improving (concentration decreasing), clarity improving, TP and DRP significantly deteriorating (see Figures 4 and 5).

Craw's Creek showed quite different patterns than other sites. There appears to have been a pulse of TP and DRP in the tributary from early 2009 to 2013 (see Fig. A1-18). At the same time total ammonia declined, with average total ammonia over the period about half that of any other site (see Fig. A1-19). In the context of nutrient loads to Waituna Lagoon, the reduction in total ammonia and nitrate concentrations in Craw's Creek is negligible (i.e., both concentrations and flows are small), but the pattern of DRP and total ammonia is constant with the draining of peat land and development into pasture. Recent research from AgResearch has found that peat soils under agriculture are very 'leaky' for DRP (Mike Scarsbrook pers. comm. 2013).

The declining trend in DRP observed in Waituna Creek at Marshall Road may also be due to an extended period of elevated DRP from about 1997 to 2006. It is possible that this resulted from land development in the lower catchment, but further analysis comparing with changes in land use would be needed to confirm this.

Nitrate is trending upward in Waituna Creek, but the strength of the trend was weak (less than 2% per annum). We expect this trend to be stronger given the changes in land use intensification over the same period. More work is required to understand the relationships between water quality trends and catchment land use.

Table A1-1. Results of seasonal Kendal test. Period analysed for Marshall Road was July 1995 to Jan 2013 (except for TN and TP which had a period 1998 to 2013); at all other sites the period analysed was August 2001-January 2013. Values in bold indicate statistical significance. %PAC = percent annual change.

Non-adjusted data		**TN**			**NNN**			**TP**	
	p-value	median	%PAC	*p*-value	median	%PAC	*p*-value	median	%PAC
Waituna St. @ Marshall Rd.	0.2	2.15	0.8	**0.02**	**1.34**	**1.2**	**0.011**	**0.057**	**-2.3**
Waituna St. @ Waituna Rd.	0.056	2.55	1.6	**0.05**	**1.93**	**1.7**	0.33	0.037	-1.6
Carran Ck.	0.6	1.2	-0.3	0.15	0.32	1.3	0.5	0.11	0.2
Craw's Creek	0.45	0.68	0.6	**<0.0001**	**0.02**	**-10**	**<0.0001**	**0.0585**	**11.6**
Moffat Ck.	0.9	1.3	0	0.8	0.21	-0.4	**0.0003**	**0.13**	**-2.8**
Non-adjusted data		**DRP**			**Clarity**			**NH_3-N**	
	p-value	median	%PAC	*p*-value	median	%PAC	*p*-value	median	%PAC
Waituna St. @ Marshall Rd.	**<0.0001**	**0.02**	**-4**	**<0.0001**	**0.64**	**3.8**	**0.0011**	**0.062**	**-2.1**
Waituna St. @ Waituna Rd.	**<0.0001**	**0.009**	**-4.4**	0.7	1.14	0.3	0.6	0.0575	-1.2
Carran Ck.	**0.011**	**0.04**	**2.5**	0.22	0.385	1.9	**<0.0001**	**0.078**	**-5.8**
Craw's Creek	**<0.0001**	**0.029**	**21**	**0.044**	**0.39**	**2.2**	**0.0002**	**0.0195**	**-5.6**
Moffat Ck.	0.4	0.059	-1.2	0.19	0.5	1.5	**0.0059**	**0.038**	**-5**

Ballantine and Hughes (2012) found that, following drain clearing operations, there was a reduction in water clarity and an increase in turbidity, suspended solids and total phosphorus for several months (see Figs. A1-21 and A1-22). In order to distinguish whether the trends in the Waituna Creek were determined by changes associated with drain clearing operations, or changes associated with land use or climatic factors, the trend analysis was repeated after filtering data to distinguish between years when drain clearing occurred and years when it did not occur.

The result of this analysis is shown in Table A1-2. The improving trend in TP and clarity was apparent in years when drain clearing occurred as well as years when it did not occur, suggesting that it is being driven by factors independent of drain clearing operations (e.g., land management practices and or climatic factors).

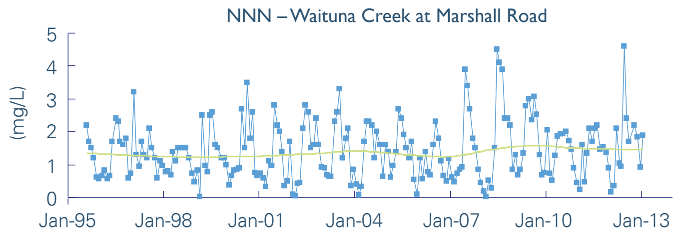


Fig A1-15. A weak upward trend in Nitrate-nitrite-nitrogen in Waituna Creek at Marshall Road. A Lowess smoothed line is fitted through the points.

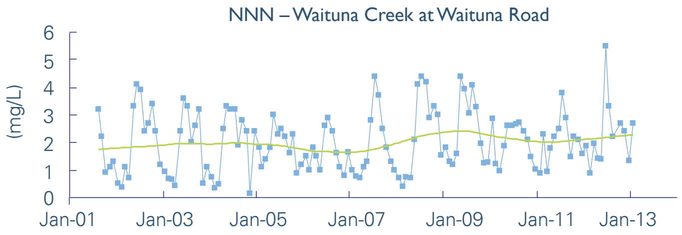


Fig A1-16. A weak upward trend in Nitrate-nitrite-nitrogen in Waituna Creek at Waituna Road. A Lowess smoothed line is fitted through the points.

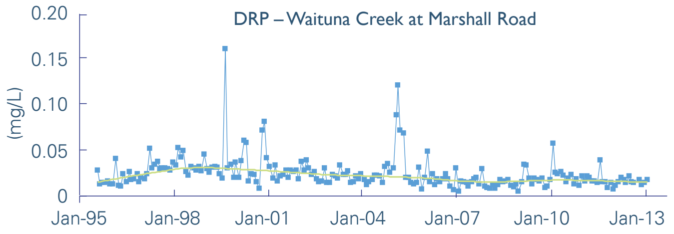


Fig A1-17. A decline in DRP in Waituna Creek at Marshall Road possibly caused by elevated concentrations during the period 1997 to 2006.

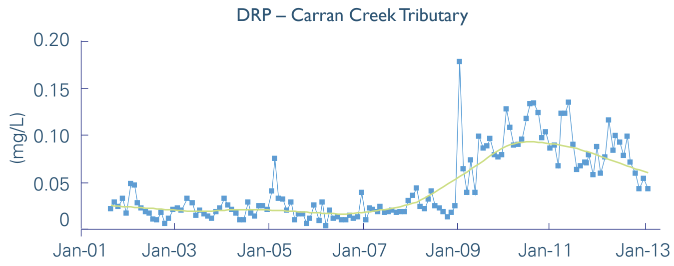


Fig A1-18. Pulse in DRP in Craw’s Creek (Carran Creek tributary) since 2009.

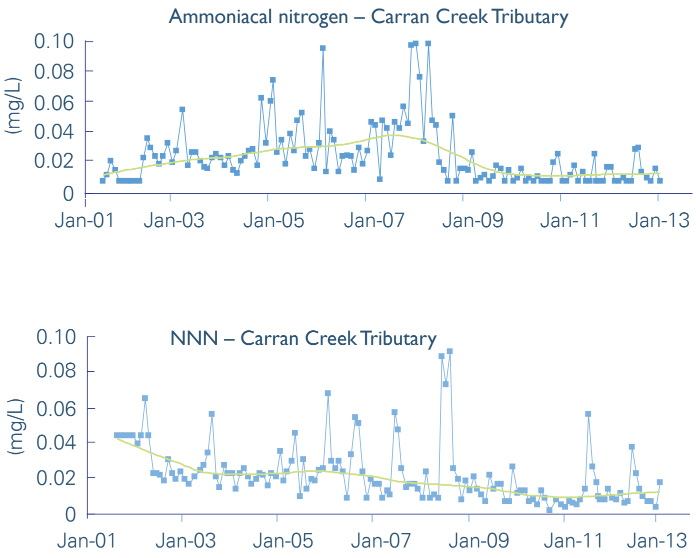


Fig A1-19. Decline in total ammonia (top chart) and nitrate (bottom chart) in Craw's Creek (Carran Creek tributary) since 2009. A Lowess smoothed line is fitted through the points.

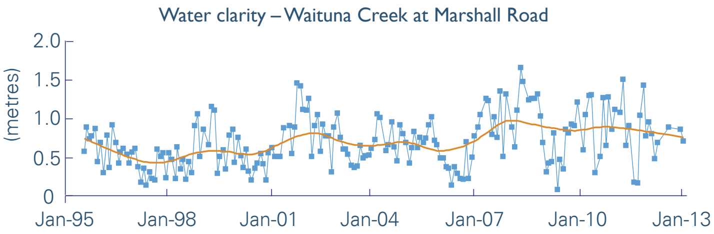


Fig A1-20. Improving water clarity in Waituna Creek at Marshall Road punctuated by periods of low clarity during months following drain clearing operations (e.g., 1997, 2000, 2003, 2006, 2009 and 2012).

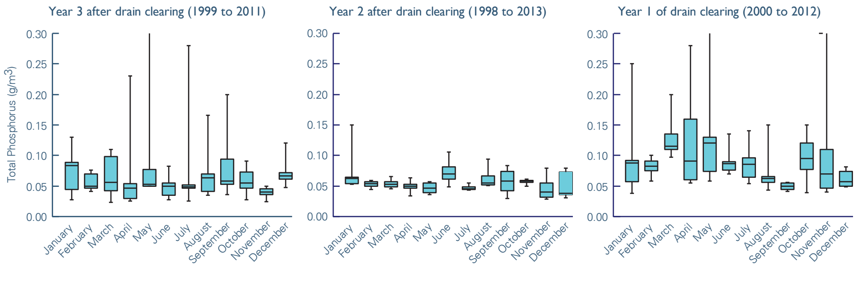


Fig A1-21. Monthly TP in Waituna Creek at Marshall Road during years when drainage operations occurred and two subsequent years.

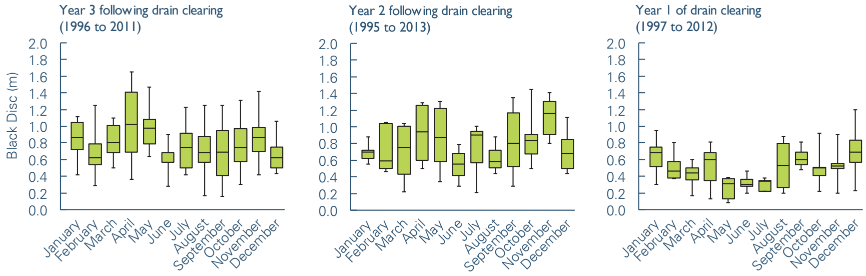


Fig A1-22. Monthly clarity in Waituna Creek at Marshall Road during years when drainage operations occurred and two subsequent years.

Table A1-2. Results of seasonal Kendal test after filtering data for years in which drain clearing occurred and did not occur. Period analysed for Marshall Road was July 1995 to Jan 2013 (except for TN and TP which had a period 1998 to 2013). Values in bold indicate statistical significance.

Years drain clearing occurred	**Clarity**			**TP**			**TN**		
	p-value	median	%PAC	*p*-value	median	%PAC	*p*-value	median	%PAC
raw data	**0.0005**	**0.48**	**4.7**	0.2	0.081	-3.2	0.5	2.3	0.2
flow adjusted	**0.0003**	**0.453**	**3.4**	**0.03**	**0.083**	**-3.4**	0.5	2.33	0.7
raw data	**0.024**	**0.8**	**4.4**	0.5	0.0505	-3.3	0.07	2.55	2.6
flow adjusted	0.072	0.78	2.4	0.6	0.0467	-5	0.07	2.45	2.8
Years drain clearing did not occur	*p*-value	median	%PAC	*p*-value	median	%PAC	*p*-value	median	%PAC
raw data	**<0.0001**	**0.76**	**3.7**	**0.001**	**0.053**	**-3.2**	0.19	2.1	0.9
flow adjusted	**<0.0001**	**0.77**	**3.7**	**0.002**	**0.0503**	**-3.4**	**0.005**	**2.14**	**-1.1**
raw data	0.5	1.31	0.5	**0.027**	**0.03**	**-3.3**	0.24	2.55	1.3
flow adjusted	0.5	1.34	0.4	**0.05**	**0.024**	**-5**	0.9	2.54	0

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Appendix Two

Information in Support of Waituna Lagoon Opening Recommendations

Understanding the dynamics of Waituna Lagoon opening and closing events is critical to managing the health of the lagoon.

Opening period

To achieve the 'moderate' ecological target we have recommended for Waituna Lagoon, it is desirable to have a fresh-water lagoon with a short marine phase (e.g., two months). The primary aim of a short marine phase is to limit the levels of salinity over spring and summer. The preferred germination and growth range for *Ruppia* observed in New Zealand is between 4 and 8 ppt (Gerbeaux 1989). It has been noted that adult plant survival declines above 45 ppt (Sim *et al.* 2006; Nicol 2005). Salinity concentrations in Waituna Lagoon do not exceed 45 ppt, however concentrations of 8 ppt are regularly recorded. The critical period for *Ruppia* germination is likely to be September to November (Gerbeaux 1989; Nicol 2005). Salinity was recorded at greater than 8 ppt over this entire period in both the 2009–2010 and 2010–2011 seasons, which may explain the recorded down trend in *Ruppia* abundance, both in terms of site occupancy and foliage cover.

We consider that the timing of the opening period is important. Interactions between when the lagoon is opened and how long it stays opened for mean that this aspect of the guidelines required careful consideration. Although having the lagoon open in August and September may not overly disturb the aquatic vegetation community, the data indicate there is less chance of the lagoon closing in time if it is opened in those two months. Fig A2-1 below shows that, on average, August openings have a duration of 95 days, and September openings have an average duration of 131 days, both of which would result in an opening that extended into the critical growth and reproduction period of the aquatic plants in Waituna Lagoon. Fig. A2-2 shows the average number of days the lagoon was open divided by the number of times the lagoon closed during the four seasons. Fig. A2-2 highlights how unlikely a summer closure is, and if the lagoon is open during the summer months it has a very low probability of closing. This analysis supports the need to avoid spring openings because these have a high chance of extending into the summer months, which in turn have a low probability of closure. Note, however, that winter openings can extend into summer as has occurred in 2013.

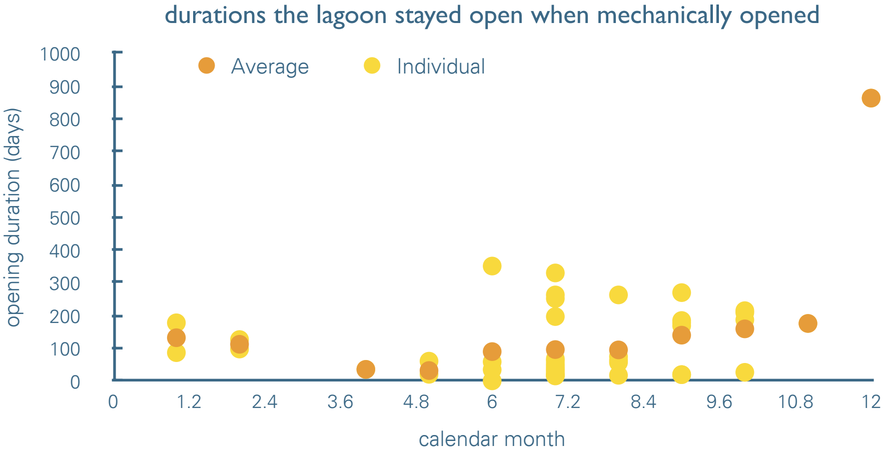


Figure A2-1. Durations the lagoon stayed open when mechanically opened in each month (individual opening events and averages for all openings occurring in each month).

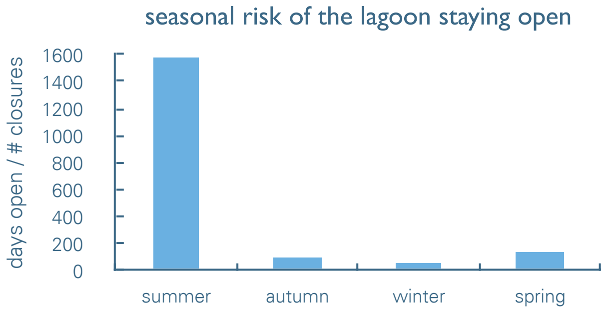


Figure A2-2. Seasonal risk of the lagoon staying open, as estimated from the number of days the lagoon was open in each season, divided by the number of times the lagoon closed in each season.

To explore the impact of a change in opening management, the lagoon water level was predicted using an Environment Southland in-house hydrological model developed by Chris Jenkins (the Jenkins model). The model accounts for surface water inflows, direct rainfall inputs and barrier loss, but does not account for evaporation losses or groundwater inputs. Surface water inflows from Waituna Creek, Carran Creek and Moffat Creek were extrapolated using the data series from the Waihopai River @ Kennington. The flow record for Waituna Creek only started in 2001 and is not continuous, flow measured from the Waihopai River @ Kennington was used because this enabled lagoon levels to be predicted dating back to the 1978. We are confident with the use of the Waihopai flow record as it has a strong correlation with flows in the Waituna tributaries (see Table A2-1). The model performs quite well as shown in Fig. A2-3, which compares the modelled water levels against observed water levels.

Table A2-1. Correlations (relationship strength) between flows in Waihopai River and flows in Waituna Creek tributaries.

Site	Correlation
Moffat Creek @ Moffat Road	0.97
Waituna Creek @ Marshall Road	0.99
Craw's Creek @ Waituna Lagoon Road	0.75
Carran Creek @ Waituna Lagoon Road	0.93

Fig. A2-5 shows the predicted number of times the lagoon would have stayed open for different durations, over the period 1978 to 2013, if our opening recommendations had been followed. For over half of the times that the lagoon water level breached 2.0 metres a.s.l., the lagoon would have only stayed above that level for three weeks or less. Table A2-2 summarises the exceedances of the predicted breaches.

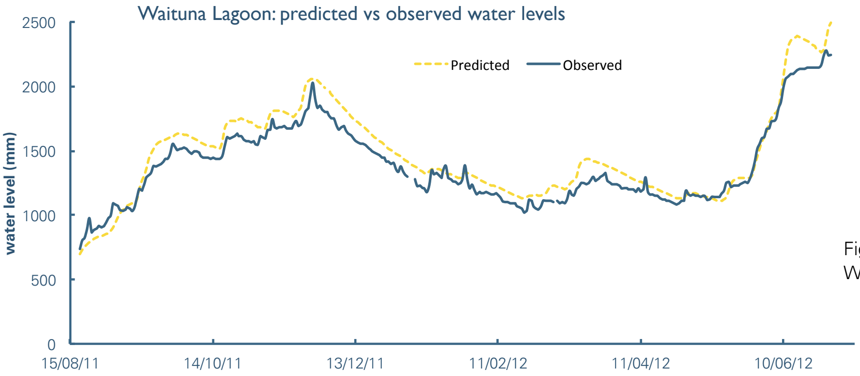


Figure A2-3. Jenkins model performance against Waituna Lagoon observed water levels.

Fig A2-4 of the next page shows predicted water levels from the Jenkins model if the lagoon had only been opened in winter in accordance with our recommendations, and stayed open for 3 months on each occasion.

If the lagoon had not been mechanically opened between 1978 and 2013, the lagoon would have breached 2.0 metres on 92 occasions and been above that height for over 3000 days. It would have been above 2.6 metres 22 times and for about 305 days. By comparison, if the lagoon had been opened according to the LTG

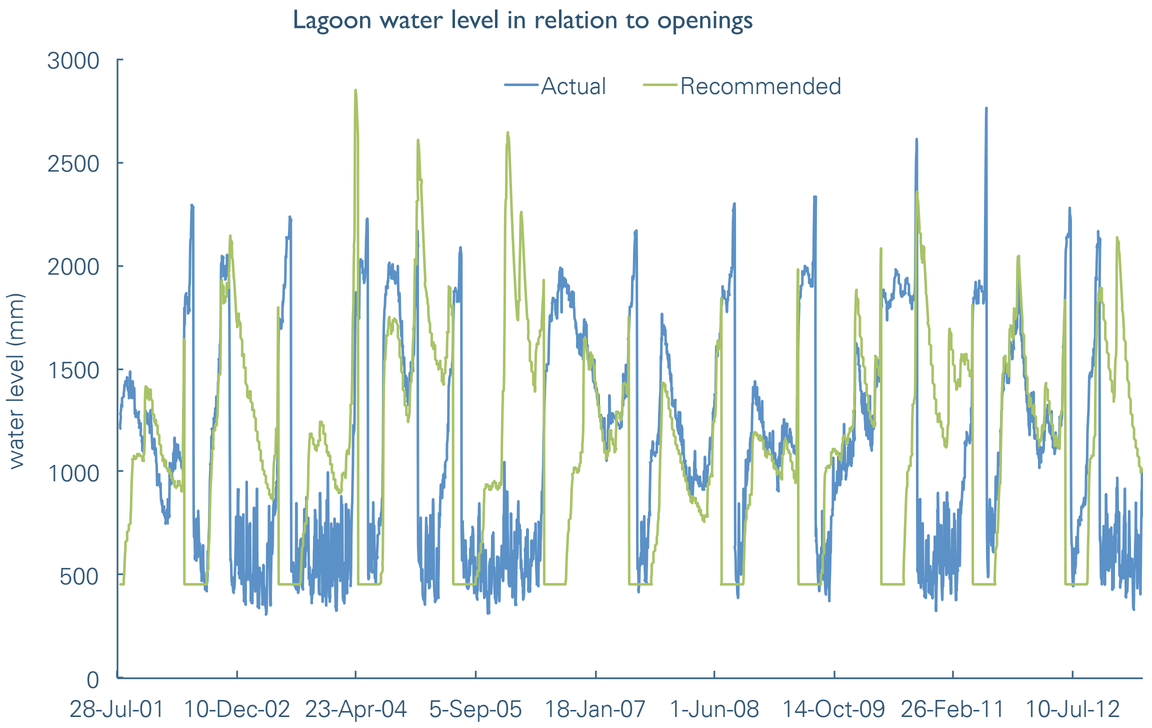


Figure A2-4. Jenkins model predictions of water level based on our opening regime recommendations.

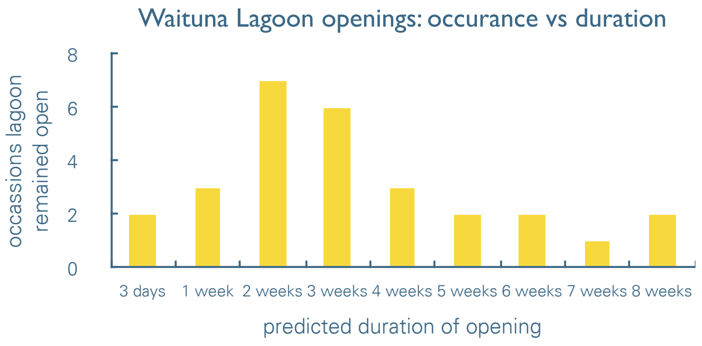


Figure A2-5. Predicted occasions and duration of each occasion that Waituna Lagoon would have stayed open above 2.0 metres a.s.l. if the lagoon was only opened during winter between 1978 - 2013.

Table A2-2. Comparisons of the frequency (number of occasions) and duration (number of days above specified height) for natural lagoon openings versus openings based on the recommended guidelines for the period 1978 to 2013.

Scenario	**Frequency (# occasions) & Duration (# days)**		
	above 2.0m	**above 2.3**	**above 2.6**
Natural (predicted level if no opening occurred)	92 (3104.4)	58 (1267.5)	22 (305.4)
Opened May-June @ 2.0m for 3 months, opened July @ 1.8m Not opened spring / summer, 1 day open duration	38 (784.8)	15 (196.16)	4 (48.8)
Opened May-June @ 2.0m for 3 months, opened July @ 1.8m Not opened spring / summer, 1 month open duration	31 (686.7)	15 (214.0)	4 (47.5)
Opened May-June @ 2.0m, opened July @ 1.8m Not opened spring / summer, 2 month open duration	31 (654.3)	13 (168.15)	4 (44.9)
Opened May-June @ 2.0m, opened July @ 1.8m Not opened spring / summer, 3 month open duration	28 (565.1)	13 (158.8)	4 (38.6)
Opened May-July @ 2.0m, not opened spring / summer 3 month open duration	29 (602.7)	13 (158.8)	4 (38.6)

recommendations, the lagoon would have breached only 28 times and stayed above this height for 565 days. It would have been above 2.6 metres 4 times, and stayed above 2.6 metres for 38 days.

Seek advice

We have recommended advice be sought when high lagoon levels are at risk of causing drainage problems with surrounding land in spring and summer. Environment Southland is able to advise on the likely duration of high water levels using the Jenkins model which is linked to rain forecasts and can be used to predict likely lagoon water levels over time. For example, this tool would have indicated that water levels were likely to quickly return below the 2.0 metres level in October 2012, as shown in Fig. A2-6.

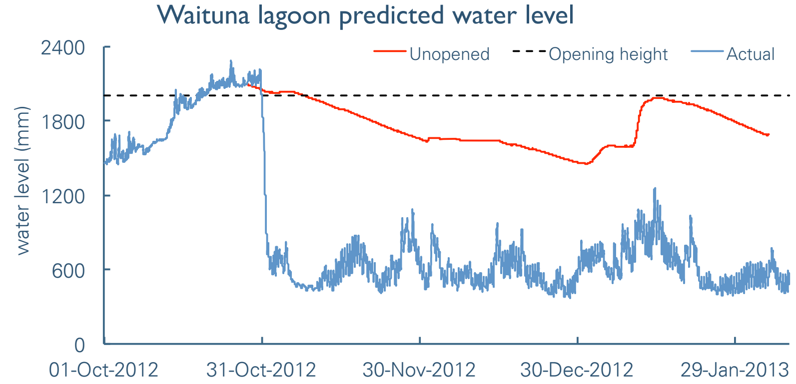


Figure A2-6. Predicted water level for Waituna Lagoon if it had not been opened on 30/11/2012.

The model can be used to determine whether water in the lagoon is likely to stay above a certain height for an extended period, or whether it is likely to fall. This tool could be used to assist in deciding whether the lagoon should be opened during spring or summer.

Coincide openings with wind events

Where possible, we recommend that openings be timed to coincide with a windy period when sediment resuspension and flushing effect will be highest. Figs. A2-7 shows the mean concentrations of total phosphorus, total nitrogen and suspended sediment when the lagoon has been closed (and salinity is less than 10 ppt). Clear water conditions occurred when the turbidity was less than 5 NTU, and low clarity conditions occurred when the turbidity was equal to or greater than 5 NTU. Cool conditions occur from May to August, when the water temperatures are typically less than 10°C. Warm conditions occur from September to April.

The data shows that turbid lagoon conditions are associated with the highest total phosphorus levels, and cold conditions are associated with the highest total nitrogen levels. Almost twice as much total phosphorus was suspended in the water column when conditions were turbid, and almost twice as much total nitrogen during the colder conditions. The highest suspended solids concentrations were associated with warmer and more turbid conditions.

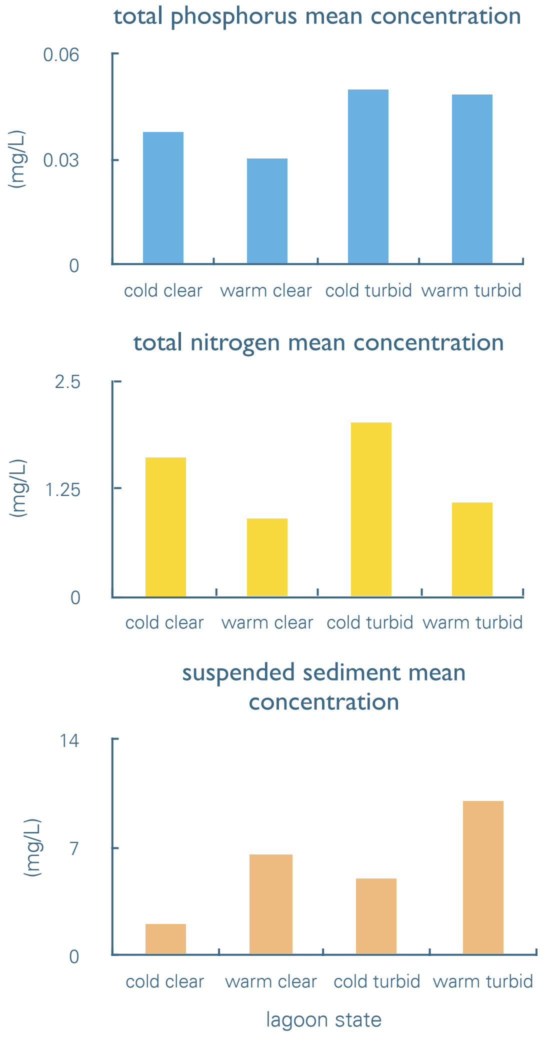


Figure A2-7. Mean concentrations of nutrients and suspended solids when Waituna Lagoon has been closed. cold = May-August, warm = September-April, clear = <5NTU, turbid = >5NTU.

Consequently, we consider that to increase the amount of nutrient flushed out of the lagoon during opening events, the lagoon barrier should be breached during colder periods of the year (May to August) and when the lagoon is turbid due to wind action. Using the mean nutrient concentration values for the lagoon, and multiplying these by a typical flushing volume of 25 million cubic metres, the flushing benefit of a strategically timed opening would be about ¾ of a tonne of phosphorus and 25 tonnes of nitrogen (Fig. A2-8). In our view, these values are likely to be conservative because sampling periods have been limited mainly to fairly calm conditions (mean turbidity level of 8.3 NTUs). The turbidity sensor at the DOC/Environment Southland lagoon monitoring platform commonly records sustained values of over 50 NTUs when conditions have been too dangerous for boating and collecting grab water samples. If a barrier opening was timed to coincide with these extremely rough periods, the load flushing benefits would be even greater.

We note that the length of time when the benefits of lagoon flushing are maximised due to increased dissolved and suspended nutrient concentrations overlaps with our recommendation made in relation to managing the lagoon's aquatic vegetation community. In other words, to maximise the benefits of nutrient and sediment flushing and provide protection to the aquatic vegetation community, the lagoon should only be opened during the winter months.

Investigate the feasibility of manually closing the lagoon

Any assisted closure would need to work in with favourable tides and weather conditions to enhance the likelihood of success. Given the continued potential issue of opening the lagoon to meet the needs of draining surrounding farm land versus that necessary to manage the lagoon to sustain its ecological health, we recommend the feasibility of lagoon closures be investigated further.

Larkin (2013) investigated the role of tide, lagoon inflow, wave and wind conditions on lagoon closures and prolonged openings. His analysis indicates that lagoon closure probability is linked to the neap tide cycle, as well as low inflows and calm conditions. Any forced closures should work in with these factors to decrease the chance of failure.

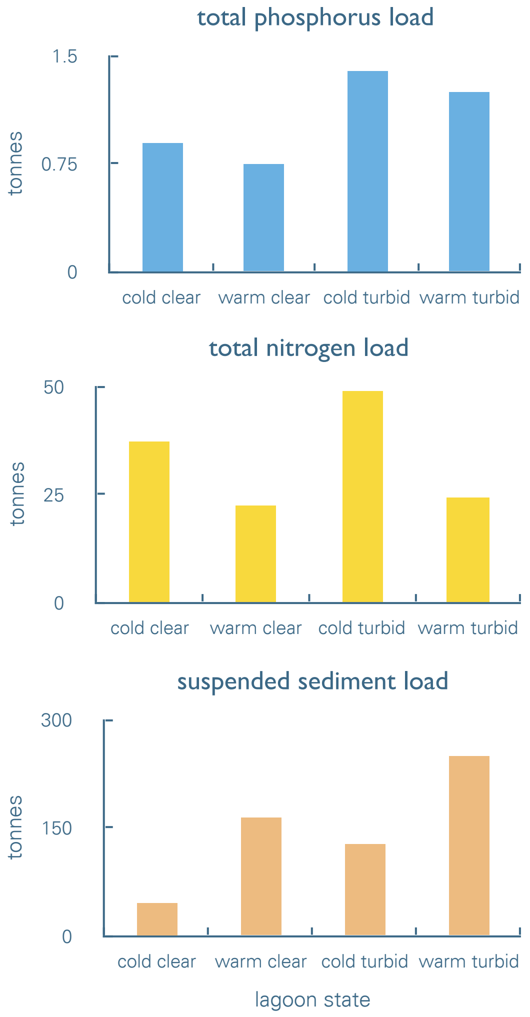


Figure A2-8. Estimated lagoon flushing loads of nutrients and suspended solids based on mean concentrations shown in Fig. A2-7.

Opening location

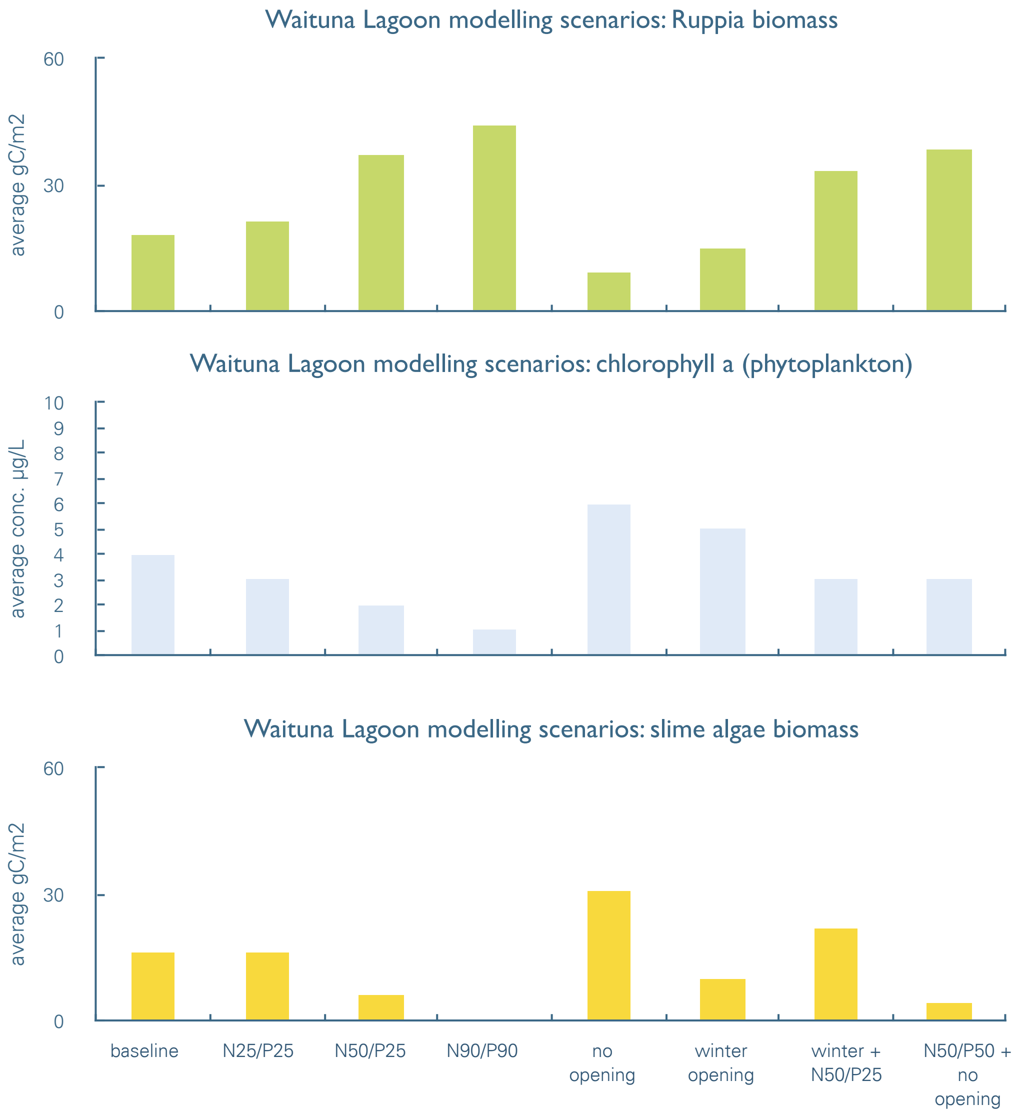
Our recommendation is to use Walker's Bay as the standard opening location, but we do not wish to permanently rule out alternative locations such as Hansen's Bay subject to further investigation. Our reluctance to recommend Hansen's Bay at this point in time is based on the limited data available for openings at that site, and hence there is a higher risk of unknown outcomes when opening the lagoon there or at more eastern sites. Larkin (2013) provides more detail on the pros and cons of lagoon openings at various sites.

We recommend further experimental openings of at least Hansen's Bay because there is a chance openings at other locations could prove more favourable to the aquatic vegetation community. Potential benefits include; 1) less chance of an extended opening duration, and 2) increased chance of flushing accumulated nutrient and sediment loads from the eastern end of the lagoon (which is where the dominant westerly weather systems tends to force sediment to accumulate).

Why the need for a managed lagoon opening regime if we are also recommending nutrient load reductions?

Modelling scenarios undertaken by the University of Waikato indicated that high *Ruppia* and low slime algae could only be achieved with a combination of nutrient load reduction and continued use of mechanical openings (Hamilton *et al*. 2012).

The 'no opening' scenario produced very low *Ruppia* biomass, and high slime algae and chlorophyll *a*, indicating that without openings elevated nutrient levels in the lagoon would be too high to support an abundant *Ruppia* community. Keeping the lagoon closed but decreasing nitrogen and phosphorus inputs by 50% resulted in an increase in *Ruppia* levels, but algal levels were still high. Slime algae were only reduced to minimal levels when the loads of both nitrogen and phosphorus were reduced by 90%. The less drastic scenario of a 50% reduction in nitrogen, and 25% reduction in phosphorus, alongside regular winter openings, decreased slime algae and chlorophyll a levels while maintaining high *Ruppia* biomass.


Waituna Lagoon modelling scenarios: Ruppia biomass

Waituna Lagoon modelling scenarios: chlorophyll a (phytoplankton)

Waituna Lagoon modelling scenarios: slime algae biomass

Fig. A2-9. University of Waikato modelling scenarios (Hamilton *et al*. 2012) including combinations of nutrient load reductions and lagoon opening closing options. Outputs are average changes in *Ruppia* and slime algae biomass (amount of carbon per unit area of lagoon bed) and phytoplankton biomass assessed as water column concentration of chlorophyll *a*.

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Opening Waituna Lagoon at Hansen's Bay, July 2011 (photo: A. Henderson).

Appendix Three

Lake Processes: Factors that Influence Lagoon Condition

To manage the water quality and health of Waituna Lagoon, it is necessary to understand some of the processes and interactions between different components of the plant and algae community, nutrients, and the periodic opening of the lagoon to the sea. Some of the key reasoning behind developing guidelines for nutrient inputs and lagoon openings is presented here.

General lake response to eutrophication

Ruppia are considered keystone species in the lagoon. Maintaining a healthy *Ruppia* community is important for regulating water quality and phytoplankton growth, as habitat for invertebrates and fish, and as a food source for invertebrates and water fowl (Robertson *et al.* 2011 and references within).

Eutrophication (excessive loads of N and P) can stimulate a series of responses in a lake's biology. Increases in nutrients stimulate epiphytic algae and slime algae that shade and stress macrophyte populations (such as *Ruppia*). These plant and algal species compete for nutrients with phytoplankton, but as nutrient loads increase further the phytoplankton become dominant, shading out the slime algae and macrophytes. The macrophyte communities can tolerate and buffer increasing nutrient loads for some time, with abundance often see-sawing up and down, but they become vulnerable to a rapid decline, which can often be triggered by an event like a storm, hence the terms 'regime shift' and 'flipping'. The ability to buffer nutrient loads is in part due to macrophytes using and storing nutrients as they grow and in part because macrophytes reduce the resuspension of bed sediments. However when submerged macrophyte cover is reduced, the bed sediments become unstable and prone to resuspension, reducing light availability and restricting the regeneration of *Ruppia*. Nutrients stored in plant material and in the sediments can also be released to the water column.

Once a high biomass of slime algae or phytoplankton develops in a lake it can further reinforce eutrophication by sedimentation, decomposition and causing sediments to become anoxic. When coastal lagoon sediments become anoxic they release dissolved phosphorus and ammonium which can further stimulate algae growth. The roots of macrophytes can help oxygenate the sediments so a reduction in macrophyte cover also makes sediments more vulnerable to anoxia.

Another way of describing these processes is that plants and algae help create conditions that suit themselves. Macrophytes promote conditions allowing clear water (e.g., stabilise the lake bed and oxygenate bed sediments), while phytoplankton promote turbid water. An increase in nutrients reduces the resilience of macrophyte communities to disturbance (e.g., due to a storm event or lagoon opening). Often, this is observed as an increased variability in the cover of different species between years. This seems to be the case with Waituna Lagoon with the cover of *Ruppia* and other macrophytes highly variable between years.

One process that can help bring the system back to a clear water state is to open the lagoon to the sea to flush out nutrients, phytoplankton, slime algae and sediment from the lagoon. Lagoon openings need to be carefully timed to avoid destabilising the macrophyte community. Of course, reducing nutrient inputs into the lagoon is also necessary to sustain the ecological health of the lagoon over the long-term. Further rationale behind the revised lagoon opening regime and nutrient load reductions are discussed in other appendices.

Desiccation

Ruppia is adapted to withstand naturally fluctuating water levels, but since it is an aquatic plant species and

Stressors to *Ruppia* growth and reproduction

There are a number of factors driving the cover and biomass of *Ruppia* in Waituna Lagoon. These include:

- desiccation of plants in shallow areas when the lagoon is opened;
- high salinity when lagoon is open restricting germination;
- wind and wave disturbance;
- turbid water reducing light availability to plants in deeper water (when lagoon is closed);
- nutrients promoting growth of competing epiphytes, slime algae and phytoplankton;
- smothering by sediment deposition;
- grazing losses.

dependent on the presence of water, its upper depth limit is determined by exposure to air which results in desiccation (Robertson and Funnell 2012). *Ruppia* distribution in Waituna Lagoon is limited to areas where the depth is not so shallow that it is desiccated and not so great that it is strongly limited by light.

When the lagoon is opened (depths <0.5 metres RL), 30% of the area on which *Ruppia* can grow is exposed and the submerged areas are also prone to sediment resuspension.

R. polycarpa is better adapted to withstanding seasonal desiccation than *R. megacarpa* and is often found in high elevation sites and ephemeral habitats where it germinates from seed after inundation (e.g., Nicol 2005). The cover of *R. polycarpa* is drastically reduced in years when the lagoon is open during spring and summer and these sites are not inundated.

Light

Light penetration is a key factor promoting macrophyte growth and health. *R. megacarpa* is potentially more at risk from insufficient light because it typically grows in deeper water (1 - 3 metres depth) compared to *R. polycarpa* which has a typical depth range of 0.1 - 0.4 metres (Robertson *et al.* 2011, Brock 1983).

Water monitoring data show that water clarity is often greater when the lagoon has been closed for long periods compared to when the lagoon is open, probably due to wave action resuspending bed sediments. However, when the lagoon water levels are high, reduced light penetration can restrict the growth of recently-germinated *Ruppia* in deeper water. Robertson and Funnell (2012) suggested that *Ruppia* may be able to withstand up to 30 – 40% of the growing season in a moderately stressed light environment (>1.0 metres deep).

Light availability to *Ruppia* is also reduced by epiphytic algae (e.g., *Bachelotia*) growing on the plants.

Salinity

Studies from Australia and New Zealand indicate that species of *Ruppia* have a wide salinity tolerance (Brock 1982, Gerbeaux 1989), but that key periods of their reproduction are sensitive to periods of high salinity (Sim *et al.* 2006). Optimal salinities for *Ruppia* establishment and growth in New Zealand are between 4 and 8 ppt (Gerbeaux 1989). It is particularly important to maintain low salinity (<8 ppt) during spring (September to November) which is the critical period for *Ruppia* germination (Gerbeaux 1989; Nicol 2005). Robertson and Funnell (2012) noted that the decline in *Ruppia* cover from 2009 to April 2011 was associated with high salinity (>20 ppt) during the preceding spring of each year.

Observations of *Ruppia* establishment before and after opening events add evidence to *Ruppia* sensitivity to high salinity. Schallenberg (pers. comm. 2012) found small healthy-looking shoots of *R. polycarpa* and larger (perennial) shoots of *R. megacarpa* in the lagoon in October 2012 when the lagoon was closed. Observations in November 2012, just after the lagoon was opened, found both *Ruppia* species had grown significantly, but by December (lagoon open for 1 month), *R. polycarpa* had disappeared from the sites and *R. megacarpa* had diminished substantially in length at the one site where it was still found.

The results of modelling *Ruppia* in Waituna Lagoon showed a better match with observed data when a mild salinity limitation was imposed on *Ruppia*. This was consistent with literature that indicates that although *R. polycarpa* may require fresh/brackish water during germination, generally, *Ruppia* spp. are adapted to live in environments with fluctuating salinity (Hamilton *et al.* 2012).

Negative effects of opening the lagoon could be minimised by reducing the length of time the lagoon is open during spring when *Ruppia* germination is most sensitive to high salinity. This could be achieved by finding a method to assist lagoon closure once it is opened or by avoiding opening the lagoon between 1 August and 31 March. Both options present challenges; assisting early lagoon closure would be technically challenging, while restricting openings during spring and summer would cause drainage problems.

Nutrients

Nutrient limitation in Waituna Lagoon is being studied by Dr Marc Schallenberg (University of Otago) in a project for DOC. Nutrient deletion experiments were done with samples collected between October to December 2012 to assess if either N or P was limiting growth of phytoplankton or *Bachelotia*. In October, phytoplankton was strongly N and P co-limited at all sites. In November, phytoplankton was P limited at all sites, but responded positively to N omission at two of the sites, suggesting that the experimental N and ammonium concentrations may have been inhibiting phytoplankton growth. There was evidence of *Bachelotia* being N limited (Central site in October, Moffat Creek and Carran Creek in November), but some of the experiments suggested complex interactions with nutrients after lagoon opening raises the salinity.

Fine sediment and increased sedimentation rate

Ruppia seedlings require firmer substrates for successful anchoring, so increases in fine sediment across the lagoon pose a risk to germination and establishment (Robertson *et al.* 2011). Fine sediment can also increase sediment anoxia and reduce light penetration when resuspended. Sediment deposition rates have increased with land development since the 1950s/60s with one sedimentation rate estimate reported as 2.8 mm/year from 1960 to present (Robertson & Stevens 2007).

Sediment anoxia

Increasing organic enrichment leads to higher sediment oxygen demand and results in reduced conditions and production of sulphides which are known to be highly toxic to rooted macrophytes such as *Ruppia* (Koch & Mendelssohn 1989 ; Goodman *et al.* 1995, Holmer & Bondgaard 2001, Geurts *et al.* 2009). However, the potential for reduced conditions can be decreased if plant root density remains high because a dense mat of plants can build up a high O_2 bulk during the day and thereby prevent anoxic conditions overnight (Tessenow & Baynes 1978).

The depth of the redox potential discontinuity (RPD) layer is often used as an indicator of the extent of sulphide production. The RPD depth is a recognisable division zone between oxidised (sub-oxic) and reduced chemical conditions in the sediment (Santschi *et al.*, 1990). The oxidised part appears as rust-brown, and the reduced layer below this is generally grey-green or black. There is some evidence to suggest that the RPD should be deeper than 2 cm to allow the existence of a normal macrobenthic community (Grizzle & Penniman 1991, Tett *et al.* 2004). In this case it is recommended that if the plant root zone is blackened with sulphides over greater than 20% of the sediment sampling sites then further investigations be undertaken to determine existing sulphide concentrations and any phyto-toxicity impacts. Research has shown that there seems to be compounding effects of shading (caused by algal blooms) and pore water sulphide, leading to seagrass death at sulphide concentrations around 300μM (NYS Seagrass Taskforce 2009).

Grazing by water birds

Robertson *et al.* (2011) noted that "*Waituna Lagoon is an important bird habitat. Grazing pressure from waterfowl can lead to a reduction in plant height and the ability of aquatic plants to harvest sunlight. Annual consumption of* Ruppia *species by game birds has been estimated to be from 30% to 50% of peak standing crop in various lakes (Gerbeaux 1989, Dept. Environment 2003). Although many bird surveys have been undertaken on the lagoon over the years, information on the impact on the macrophyte beds is lacking.*"

Climate change

Future climate change may have a number of effects on *Ruppia* and the general health of Waituna Lagoon. Increased frequency of strong winds from the west to south-west would increase the risk of uprooting macrophytes and sediment resuspension. Lake Ellesmere 'flipped' in 1968 due to uprooting of macrophytes during the Wahine storm. Increased rainfall intensity could increase the load of nutrients and sediment to the lagoon; and sea level rise will likely increase salinity and water levels in the lagoon which could affect the opening regime (Robertson & Stevens 2007). In the event of sea level rise the long term future of the lagoon will depend on allowing water levels when it is closed to move higher, so as to continue to provide habitat and continue to allow potential for flushing nutrients when it is opened.

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Appendix Four

Trophic State Guidelines for Shallow Lakes (Overseas Studies)

Shallow lakes are defined as generally:

- having an average depth of less than three metres and therefore interactions between the sediment, water phase and biological components are closely coupled
- being able to support large aquatic plant life
- not being stratified - their shallow depth means the lake’s water is stirred up regularly due to wind and wave action.

Macrophyte cover monitoring

Regular monitoring of macrophyte cover is the preferred method for assessing the trophic status of a shallow lake, rather than physical, chemical and chlorophyll a variables alone (Sondergaard *et al.* 2010).

Macrophyte cover compared with that required to ensure a clear state

Various overseas studies have shown that submerged macrophyte cover needs to be >30-60% to ensure a clear water state. For example, it has been suggested that coverage should be >30% to ensure maintenance of a clear water state in shallow lakes (Jeppesen *et al.*, 1994; Kosten *et al.*, 2009), but coverage of 50% (Tatrai *et al.*, 2009) or 60% (Blindow *et al.*, 2002) has also been reported. In a recent review, 50% coverage has been used as a conservative level to ensure a clear water state (Joint Nature Conservation Council - Defra 2005).

Eutrophic shallow lakes are characterised by a reduction in species diversity and development of bare areas, and an eventual decline in macrophyte growth to low levels or complete absence (De Nie 1987) and an accompanying increase in phytoplankton (chlorophyll a concentrations consistently > 0.015 mg/L) and phosphorus (TP >0.04 - 0.05 mg/L) (Sayer *et al.* 2010). At TP concentrations above approximately 0.15 mg/L the likelihood of low macrophyte growth is very high. For example, in a 13-year study of 10 Dutch lakes, Coops *et al.* (2007) found that submerged vegetation cover >20% never occurred when TP was >0.15 mg P/L, while coverage was always higher than 20% with TP <0.08 mg P/L. Bachmann *et al.* (2002) studied macrophyte abundance and water quality in 319 mostly shallow, fully mixed, Florida lakes and showed that if TP >0.16 mg/L, TN >3.75 mg/L and chlorophyll a >0.18 mg/L, then submersed macrophytes would be predictably absent and the lakes algal dominated. Below these levels, macrophyte abundance could be high or low. Sondergaard *et al.* (2010), in a study of 300 mostly shallow Danish lakes, showed that plant cover varied according to TP range as follows; TP 0.03 - 0.07 mg/L macrophyte coverage ranged from nearly 0 to 100%; TP 0.10 - 0.20 mg/L only 29% of the lakes had coverage >10%. The surveys of Danish shallow lakes indicates that the shift from macrophytes to phytoplankton takes place at P concentrations in the range 0.05 - 0.125 mg/L. TP guidelines for shallow lakes (moderate alkalinity) were set at 20 µgP/L for mesotrophic conditions, and for shallow brackish coastal lagoons, 35 µgP/L (Joint Nature Conservation Council - Defra 2005).

Benthic Macroalgae/Epiphytes

Excessive growths of filamentous algae on lake substrate or macrophytes are indicative of nutrient enrichment. Cover of benthic and epiphytic filamentous algae should be less than 10% (Joint Nature Conservation Council - Defra 2005).

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Appendix Five

Data Supporting Lagoon Input Load Estimates and Targets

In Appendix One, we outlined evidence indicating that Waituna Lagoon is suffering from nutrient enrichment which is adversely affecting the lagoon's macrophyte community, a component of the lagoon's ecology. Nutrients enter the lagoon primarily from surface and groundwater inputs from the Waituna catchment. We have recommended revised targets for nutrient loads to the lagoon and information in support of our recommendation is presented below.

Current load estimates

Estimating nutrient loads to Waituna Lagoon is a difficult task as it requires a number of assumptions relating to the adequacy of data collection. Diffuse Sources & NIWA (2012) note that there are many examples of researchers trying to determine whether there is an optimal load estimation method for inputs to the lagoon, however, it is clear from these studies that there is no clear "best" load estimation method.

Two methods were used to estimate the current nutrient and sediment export loads from the catchment to Waituna Lagoon. Both probably underestimate the true loads to the lagoon.

Diffuse Sources & NIWA (2012) estimated the nutrient loads in the three main tributaries to Waituna Lagoon using a rating curve method by developing a relationship between measured contaminant concentrations in the tributaries and stream discharge (at the time of sampling). This relationship was then applied to the entire discharge record. The nutrient and sediment load estimates of Diffuse Sources & NIWA were only for the three tributaries of Waituna Lagoon and did not did not take into account any load from groundwater inputs direct to the lagoon.

Waikato University (Hamilton *et al.* 2012) derived daily nitrate, ammonium and phosphate concentrations for all major inflows to Waituna Lagoon by linear interpolation between monthly samples collected as a part of Environment Southland's surface water monitoring programme. Groundwater inputs directly into the lagoon were estimated based on an annual catchment water balance and groundwater seepage estimates provided by

Table A5-1. Summary of current annual nitrogen and phosphorus load estimates for inflows to Waituna Lagoon.

Source	Nitrogen annual load estimate (tonnes/yr)	Phosphorus annual load estimate (tonnes/yr)	Strength of approach	Assumptions
University of Waikato (2001-2011)	260	14.4	Used water balance to derive groundwater contribution to lagoon.	Used monthly nutrient and hydrology data to derive loads which were linearly interpolated from month to month.
Diffuse Sources & NIWA (1995-2011)	217	10.9	Used rating curves to estimate nutrient fluxes.	Assumed groundwater input incorporated into stream flow information.
Average	239	12.7		

Environment Southland. The interpolation method potentially underestimates the effect of storm events that may not be captured by routine monitoring (Hamilton *et al.* 2012).

The current nitrogen load estimates from the two approaches are summarised in Table A5-1. They are in fairly good agreement and so we decided to average the nitrogen load estimates for the purposes of these guidelines.

The current phosphorus load estimates differed somewhat, but as both methods have various strengths and weaknesses, with no method deemed superior to the other, we decided to average the two estimates to derive a "working" current phosphorus load estimate for Waituna Lagoon for the purposes of these guidelines (see Table A5-1).

Revised nutrient and sediment load targets

As noted previously, in setting nutrient targets for the lagoon, we considered three separate approaches from the University of Waikato (Hamilton *et al.* 2012), a literature review of New Zealand studies and studies from other temperate regions (Schallenberg & Schallenberg 2012) and a commissioned report from an Australian ICOLL expert (Scanes 2012).

The University of Waikato modelling of water quality, slime algae and seagrass in Waituna Lagoon (Hamilton *et al.* 2012) found stable *Ruppia* biomass and low slime algae and chlorophyll a levels when the total nitrogen and phosphorus loads were 130 tonnes/year and 10.8 tonnes/year respectively, equating to 50% and 25% reductions of estimated current nitrogen and phosphorus loads to the lagoon. *Ruppia* cover was predicted to be marginally better under a 25% phosphorus reduction scenario than a 50% reduction scenario. However we did not favour a more aggressive removal of nitrogen from the lagoon relative to phosphorus because this could lead to nitrogen limitation, which is a condition that could favour nitrogen-fixing cyanobacteria (some planktonic species that 'fix' nitrogen can also form nuisance blooms and produce toxins, for example *Nodularia spumigena* in lakes Ellesmere and Forsyth, Canterbury). For this reason, and because the degree of internal phosphorus loading in the lagoon is poorly understood and may be increasing, we are in favour of reductions of nitrogen and phosphorus that do not result in reductions in the ratio of total nitrogen to total phosphorus. Furthermore, recent experiments on nutrient limitation in Waituna Lagoon indicate that phytoplankton and slime algae are limited by both nitrogen and phosphorus at times (Table A5-2).

The potential vulnerability of the lagoon to cyanobacterial blooms, and the indication that the availability of both nitrogen and phosphorus fuels phytoplankton and slime algae proliferation, suggests that an equal proportional reduction of both nitrogen and phosphorus is the most prudent approach to protecting the ecological health and environmental values of the lagoon.

The Scanes (2012) study used data from 57 ICOLLs in various ecological conditions to estimate nutrient loads to Waituna Lagoon which would deliver three different ecological endpoints:

Table A5-2. Nutrients that stimulated phytoplankton and slime algae growth rates in Waituna Lagoon during experiments in October to December 2012. Three sites were tested: a site near the Carran Creek inflow, a site near the centre of the main basin of the lagoon, and a site near the Moffat Creek and Waituna Creek inflows. Data from M. Schallenberg, University of Otago, unpubl. data.

Date	Carran		Central		Moffat	
	Phytoplankton	Slime algae	Phytoplankton	Slime algae	Phytoplankton	Slime algae
Oct-12	N+P	–	N+P	N	N+P	–
Nov-12	P*	N+P	P	O	N+P	N
Dec-12	–	O	–	O	–	O

N+P: nitrogen and phosphorus stimulated growth
P: only phosphorus stimulated growth
–: no data
*: apparent nitrogen toxicity (growth was greater when nitrogen was deleted.
N: only nitrogen stimulated growth
O: no response to added nutrients

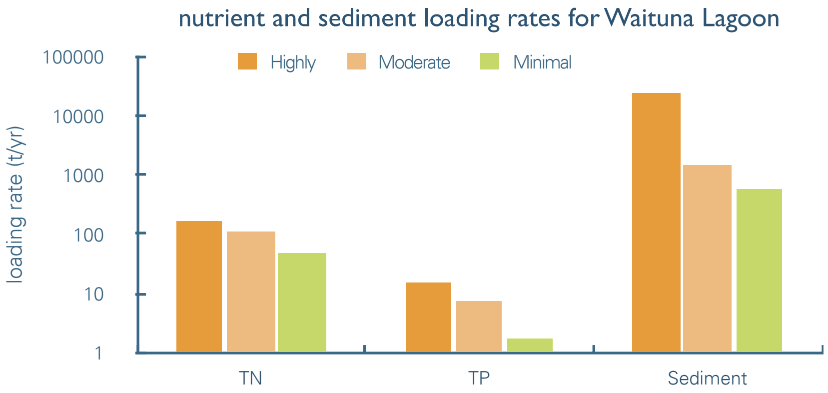

Fig. A5-1. Nutrient and sediment loading rates for Waituna Lagoon to produce three different ecological disturbance endpoints. Data from Scanes (2012). The moderate disturbance endpoint was selected for target setting in Table A5-1.

- Highly disturbed with algal dominated turbid systems, *Ruppia* absent or reduced;
- Moderately disturbed with some eutrophic symptoms but still supporting healthy *Ruppia* and fish communities; and
- Minimally disturbed with clear waters, minimal algal blooms, strong *Ruppia* growth and good fish assemblages (Fig. A51).

We chose the moderate disturbance endpoint for setting Waituna Lagoon's nutrient target loads (Table A5-1).

Schallenberg and Schallenberg (2012) reviewed nutrient loading thresholds for NZ, Australian and overseas ICOLLs. They found that variable factors such as water residence time, opening regime, fetch, sediment characteristics, amongst others, affected the thresholds in specific systems. Nevertheless the range of nitrogen loading thresholds in these different systems which precipitated a collapse of macrophyte beds was constrained between 20 and 100 kg/ha/yr, equivalent to 27 to 135 tonnes/yr entering Waituna Lagoon. According to this information, the nitrogen loading rates of both Waituna Lagoon and Lake Ellesmere/Te Waihora exceed the maximum thresholds, suggesting the Waituna Lagoon is at risk of losing its macrophyte community unless nitrogen loads are reduced (Fig. A5-2).

Sediment load targets

Waituna Lagoon is estimated to be infilling at a rate approximately 10-fold greater than pre-European times (Cadmus and Schallenberg 2007). This is a lower multiplier than the infilling rates calculated for Lake Waihola, South Otago, which is infilling at a rate approximately 30-fold greater than in pre-European times. This type of accelerated infilling is due to land disturbance, land use practices, and hydrological

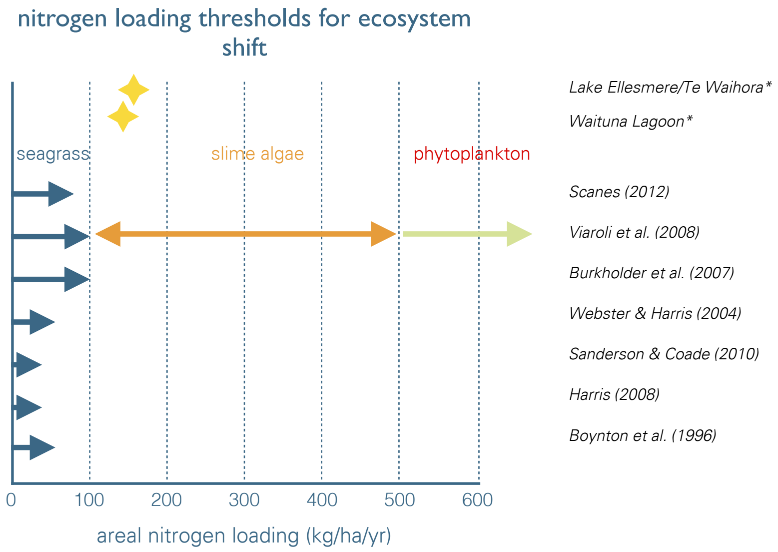

Fig. A5-2. Nitrogen loading thresholds for shifts between macrophyte dominance, dominance by slime algae and dominance by phytoplankton reported for temperate ICOLLs and coastal embayments. The threshold of 100 kg/ha/y corresponds to a load of 135 t/y for Waituna Lagoon. Data are from Schallenberg & Schallenberg (2012).

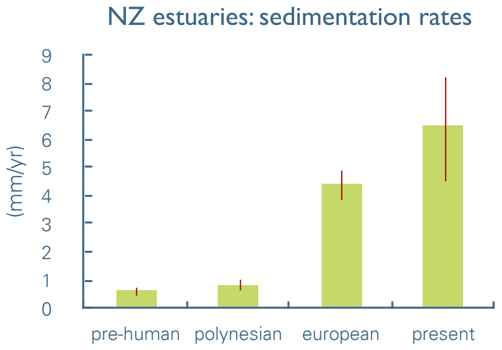

Fig. A5-3. Reported sedimentation rates calculated for 17 New Zealand coastal lakes, lagoons and estuaries. Data are from Cosgrove (2011). The Polynesian period is averaged from c. 1300AD until 1860AD. The European period is averaged from the 1860AD until the present.

modifications which generally deliver far more sediment to coastal areas than was delivered prior to European settlement of New Zealand. Figure A5-3 shows the effects of these activities as illustrated by measured increases in sedimentation rates from 17 New Zealand coastal lakes, lagoons and estuaries.

The current sediment load to Waituna Lagoon is estimated by Diffuse Sources & NIWA (2012) to be 1158 tonnes/yr. This amount is a typical load for a mixed agricultural land use, low gradient Southland catchment (i.e., a sediment yield of 55 kg/ha/yr which is similar to that found for the Bog Burn catchment). However this sediment yield is fairly low due to the low gradient of the catchment and is below that recommended by Scanes (2012) of 1678 tonnes/yr (Fig. A5-1) to reflect a moderate level of disturbance while maintaining some ecosystem values. Nevertheless, infilling with predominantly fine sediments adversely affects both the ecology and human uses and is a further stressor (along with nutrients and their effects on the ecology), to the Waituna Lagoon ecosystem. While we considered recommending a maximum fine sediment annual load for Waituna Lagoon, we have decided there was insufficient information to settle on a specific amount and recommend that additional studies be undertaken to further refine a load target. This is also a considerable degree of uncertainty associated with the effect of drain clearance years on sediment loads to the lagoon and sediment export during flood events has not been well characterised.

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