Waituna Partners' Group

Waituna Stock-take Exercise: Science Component

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Prepared for Waituna Partners' Group

by

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Document version: 2014

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1. INTRODUCTION

1.1 Background

Waituna Lagoon is part of the internationally recognised Awarua Wetland and is one of the best remaining examples of a natural coastal lagoon in New Zealand. Waituna Lagoon is a highly valued, brackish coastal lagoon fed by three streams (Waituna Creek, Moffat Creek and Carran Creek) as well as direct inputs of groundwater. 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 was due to expire in 2014. The lagoon was last opened on the 10 September 2015 (Figure 1).

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.

The Waituna Lagoon sits at the bottom of a small, intensively farmed catchment. Because of many years of land development in the catchment, including drainage of wetland areas and clearance of indigenous vegetation, the lagoon is now experiencing a number of problems. In an agricultural catchment like Waituna, the primary concerns are excessive nutrients and sediment leading to eutrophication.

Monitoring has shown that water quality in the lagoon and waterways has decreased in recent years, with elevated levels of nitrogen and phosphorus being recorded. A lagoon macrophyte called *Ruppia* is a critical species that the lagoon ecosystem depends on and is being stressed. There is concern that the lagoon ecosystem could change from having clear water and an aquatic environment dominated by *Ruppia* to turbid, murky water dominated by algal slime and suspended phytoplankton. The rate of deterioration in the lagoon appears to have increased markedly since about 2009. However, the lagoon system is highly complex and the causes of the water quality decline, and the relationships between land use activities, lagoon openings and lagoon ecosystem health, are still not fully understood.

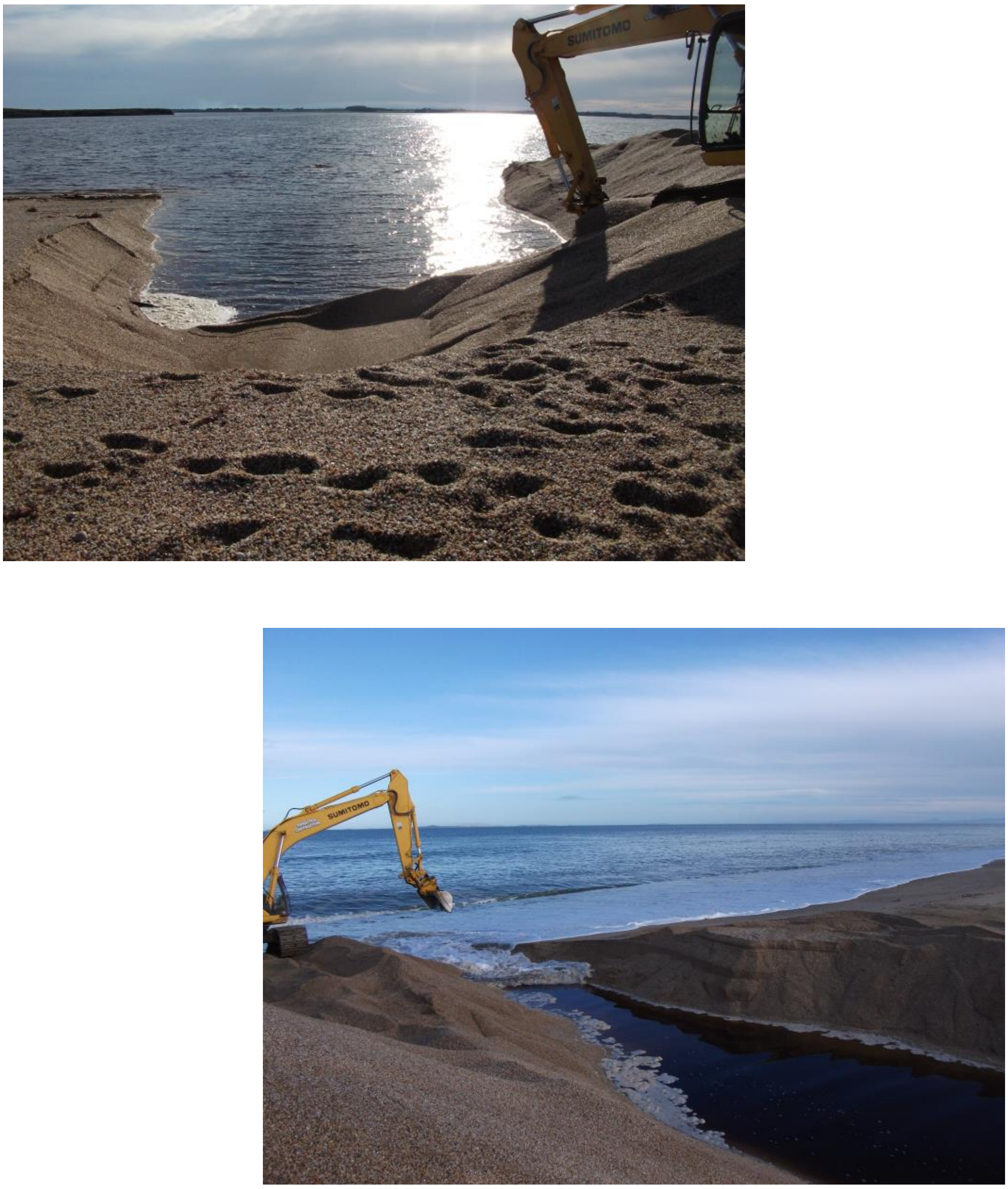

Figure 1 *A digger opens a cut in the Waituna Lagoon sand bar, 2013 (photos: K. Robertson).*

1.2 Waituna Project

The Waituna Project was established to improve the health and wellbeing of Waituna Lagoon, its catchment and community, for the use and enjoyment of present and future generations, while recognising and providing for the traditional relationship of Ngai Tahu with their ancestral lake/rohe. The Project will enable a collaborative approach to setting (and ultimately achieving) a common vision and goals for Waituna.

The Project includes three key groups: a Partners' Group, made up of the statutory agencies, namely the Department of Conservation, Environment Southland, Te Runanga o Ngai Tahu and the Southland District Council, a Stakeholder Group and a Working Group.

A key role of the Partners' Group is to draw together the various work streams being undertaken in the catchment and lagoon and work collaboratively, alongside the community and other stakeholders, to improve the environmental health of the catchment and lagoon. A first step in this role is undertake a 'Stock-take' exercise to draw out and analyse work currently being done in Waituna by each of the Partner organisations.

1.3 Objectives of the Stock-take Exercise

The objective of the Stock-take Exercise is to gather information about, and analyse work currently being done in the catchment and lagoon by each of the Partner organisations. Included in this Stock-take is a science component which includes:

- Science investigations that have been done to date;
- Findings from these investigations;
- Implications from the findings about what needs to happen in the catchment or lagoon. What should landowners and land managers in Waituna be doing?
- Recommendations for future management of the lagoon and catchment. Do information gaps still exist or have new ones been identified since the 2003 science review of the catchment? Where/on what does future science need to be focused (suggestion for priorities)?

2. BACKGROUND ON SCIENCE INVESTIGATIONS AND FINDINGS

In 2003, Thompson and Ryder (2003), on behalf of the Department of Conservation, undertook a literature review of ecological and water quality information relevant to the Waituna Lagoon and its catchment. The review concluded that there was evidence of land use effects in the catchment. The review provided a number of recommendations regarding gaps in existing knowledge and research needs relating to this conclusion.

A further review of the ecology and water of Waituna Lagoon by Schallenberg and Tyrrell (2006) reinforced concerns identified by Thompson and Ryder (2003). Schallenberg and Tyrrell (2006) analysed water quality data collected from four sites in the lagoon over the 2001 to 2005 monitoring period. Their analysis identified major patterns in the lagoon's water quality, and how they relate to lagoon hydrology (i.e. water level, days elapsed since opening or closing) and phytoplankton biomass/ecology[1].

Since then, in particular as part of Environment Southland's emergency led response to the Waituna issue that commenced in 2011, there have been many extensive and intensive studies and literature reviews undertaken in relation to the lagoon and its catchment.

A Waituna Technical Strategy was prepared in November 2012 that summarised work streams that were being undertaken up to that time. That document also contained a 'Waituna Science Bibliography' (Environment Southland 2013) that summarised scientific and technical reports on the lagoon and its catchment.

The studies and investigations can be loosely grouped into three categories:

- Lagoon/Coastal Science;
- Catchment Science;
- Engineering Interventions.

[1] Phytoplankton are microscopic free-floating plants (e.g., algae). They are useful indicators of nutrient enrichment, which can result in 'blooms' (excessive proliferations) and may favour species that are toxic to livestock and humans (e.g. some species of cyanobacteria). There have been anecdotal reports in the past of blooms of cyanobacteria around the margins of the lagoon (Thompson and Ryder 2003a).

3. LAGOON/COASTAL SCIENCE

A number of investigations have been undertaken to examine aspects of the Waituna Lagoon's ecology and how it is affected by water quality and lagoon openings to the sea.

3.1 Monitoring

Monitoring of lagoon water quality by Environment Southland has been ongoing for many years now, but has been targeted in more recent years in response to interim guideline recommendations for Waituna Lagoon prepared by the Lagoon Technical Group (Robertson *et al*. 2011). In parallel with investigations to better understand relationships between catchment biophysical processes and the lagoon ecosystem, monitoring of surface and ground waters has been ongoing since Environment Southland first initiated its emergency response. This monitoring built on some existing monitoring of the lagoon and its surface water inflows, undertaken as a part of Environment Southland's State of the Environment (SOE) monitoring programme.

The monitoring programme has been designed to understand the processes driving lagoon ecosystem health. The programme will also help determine whether lagoon water quality targets are being met by catchment land use and lagoon opening practices, and whether further initiatives in these areas are required.

Environment Southland, in conjunction with the Department of Conservation, commissioned and installed in the lagoon a water quality and meteorological monitoring platform in June 2012. Telemetered equipment provides real-time information on key water quality parameters (chlorophyll, conductivity, dissolved oxygen, temperature, turbidity) as well as water level, rainfall. The equipment has been problematical at times due to conditions in the lagoon.

Prior to the installation of this equipment water quality of the lagoon was assessed by collecting grab samples at periodic intervals. This approach, while labour intensive, has provided valuable information on lagoon water quality over many years and indeed has been central to identifying problems with the lagoon. This form of monitoring continues as part of the State of the Environment (SOE) monitoring responsibilities performed by Environment Southland. Four lagoon sites are regularly monitored as a part of the SOE programme.

Up until 2013, ecological monitoring of Waituna Lagoon has been undertaken in the form of quantitative assessments of suspended algae (plankton), macroalgae and macrophyte (e.g., *Ruppia*) biomass at periodic (three monthly) intervals. These assessments are critical to understanding the ongoing ecological health of the lagoon.

The Department of Conservation initiated macrophyte surveys in Waituna Lagoon in 2007. The surveys have been repeated at least annually since 2009. The most recent survey undertaken in February 2013 (Sutherland *et al*. 2013) was used to document the status of the lagoon vegetation using previous methodologies and to provide an inter-annual comparison of its condition. Water quality and sediment parameters were also assessed (dissolved oxygen, salinity, Secchi depth, temperature, turbidity, sediment type and depth to blackened sulphide layer).

The survey found that loss of macrophytes at sites within the lagoon was mainly related to a reduction in the number of sites submerged at the time of the survey and was most noticeable for the 1-25% cover class (i.e., % of the bed covered by macrophytes) compared to closed years. These sites were typically located along the margins of the shoreline and are most vulnerable to stressors such as desiccation, wave action and grazing by bird life, meaning these sites will frequently undergo loss and regeneration cycles (Sutherland *et al*. 2013). The report expected a recovery of the macrophyte beds during the 2013-14 growth season following the 2012-13 prolonged lagoon opening (approximately eight months between October 2012 and June 2013), assuming that an opening of a similar duration does not occur.

Sutherland and Taumoepeau (2012) and Sutherland *et al*. (2013) recommended the inclusion of sentinel sites for more frequent monitoring to better understand the temporal variation in the *Ruppia* beds. The purpose of this is to better understand the growth of *Ruppia* in the Waituna Lagoon during the defined growing season and which short and long-term stressors (such as water level, salinity, high wind events, grazing, etc.) have the most negative impact on the *Ruppia* beds. Sutherland *et al*. (2013) considered this information would be important in order to best manage the beds, in relation to lagoon openings as well as catchment nutrient management.

Sutherland *et al*. (2013) also recommend the continual monitoring of periphyton (benthic algae) along the northern shoreline sites, in particular near the river inflows as a means of early detection of response to nutrient loading to assist with management of the lagoon.

In 2013, Environment Southland suspended its macrophyte and algal monitoring work in the lagoon due to high cost and health and safety concerns associated with the length of time required to undertake each survey under sometimes difficult survey conditions.

3.2 Lagoon ecosystem modelling

An important component of the lagoon investigations has been the development of a hydrodynamic-ecological model (DYRESM-CAEDYM) of the lagoon to provide quantitative assessments to assist with lagoon management (Hamilton *et al.* 2012). The model was used to predict how the lagoon will respond to different environmental conditions (e.g., changes in hydrology including opening and closing regimes, climate, salinity, nutrient and sediment inputs) and determine how effective various management regimes (e.g., nutrient reductions, opening and closing regimes) will be in sustaining the natural values of the lagoon.

Modelling demonstrated that lagoon water quality and macrophyte ecology was sensitive to changes to the timing and duration of lagoon opening, with regular actively managed openings of the lagoon needed to maintain the aquatic plant community (macrophytes including *Ruppia*). Modelling also showed that changes to the lagoon opening regime alone were not sufficient to maintain lagoon health, and reductions to the lagoon nutrient load were also necessary to increase macrophyte biomass, and reduce growth of nuisance algae. A combination of a 3-month winter opening regime, a 50% reduction in nitrogen load and a 25% reduction in phosphorus load were predicted to result in a healthy macrophyte community.

Has the modelling exercise been successful? The modelling exercise has been closely scrutinised by lake experts including one overseas peer review. The model has had its limitations in particular its ability to accurately predict the spatial and temporal dynamics of *Ruppia* biomass. The model suffers from a lack of long term *Ruppia* monitoring data, which has meant there is relatively little historic data on this key lagoon ecosystem indicator against which to verify and assess the influence of past environmental variables on lagoon health. It should not be solely used to underpin ecological targets and management recommendations for the ecology of Waituna Lagoon, however its use in combination with other available information (e.g., see section 3.3 below) is valuable.

The model gives an indication of trends rather than describing the state of a particular variable at a particular point in time. Importantly, however, the modelling strongly indicates that if the lagoon is not opened at all, substantial (70-90%) nutrient load reductions would be required to maintain a healthy lagoon ecosystem.

3.3 ICOLL literature reviews

Independent literature reviews commissioned by Environment Southland confirmed that the model recommendations for nutrient loading thresholds in Waituna Lagoon were consistent with thresholds for sustaining macrophytes in other lagoon ecosystems (Robertson and Stevens 2012, Scanes 2012, Schallenberg and Schallenberg 2012).

These reviews of intermittently closed and open lakes and lagoons (ICOLLs) were undertaken to provide information to contribute to the effective management of the lagoon, including the development of management guidelines. One area of review focused on the international literature on the ecology of ICOLLs, and on the environmental factors and thresholds that have caused many ICOLLs around the world to lose their aquatic plant communities and become degraded water bodies (Schallenberg and Schallenberg 2012). The other reviews focused on data from New Zealand representative shallow tidal lagoon and tidal river estuaries, with emphasis on possible eutrophication criteria appropriate for Waituna Lagoon (Robertson and Stevens 2012, Scanes 2012).

Collectively, the literature reviews and lagoon modelling confirmed the need to reduce nutrient loads to the lagoon, in conjunction with a lagoon opening and closing regime that targeted winter openings so as to reduce the risk of prolonged opening periods and effects of salinity changes on the *Ruppia* germination and growing season (warmer months of the year). In this respect, the reviews provided a level of confidence regarding the predictions associated with nutrient load and lagoon opening scenarios considered by the lagoon model described in section 3.2.

3.4 Lagoon opening investigations

As modelling confirmed, the lagoon opening regime is an important component of maintaining lagoon health. Investigations have been undertaken to examine various opening options and to determine if the lagoon can be mechanically close once opened (Larkin 2013a and b). Historically, the lagoon has been manually opened regularly to the Southern Ocean, initially for fishing, then in later years to improve drainage of surrounding farmland.

Larkin (2013a) investigated the benefits and risks of mechanical opening of the lagoon at four different locations (Walker's Bay, Hansen's Bay, the 'fence' and far eastern end), with the primary focus on maximizing the removal of nutrient laden water and sediment, whilst minimizing stress to macrophyte beds. Each location was found to have site specific advantages and disadvantages, and for some sites the assessment was based on only a few opening events (with the exception of Walker's Bay), which made selection of a single favoured location difficult. It was recommended that future management consider introducing a rolling opening schedule across all four locations, following the consideration of factors such as season, macrophyte life-stage, lagoon turbidity, tide cycle and wind direction and speed.

Following opening, the lagoon eventually closes naturally due to sediment build-up, however this can take anywhere from between a few weeks to over a year (Larkin 2013a). In order to attempt to better understand the processes involved with lagoon closure, Larkin (2013b) examined available meteorological and hydrological data in the two days prior to Waituna Lagoon closure to determine if this data could be used to predict closure and what conditions (if any) disrupt the closing process. Wind and tidal phase were found to be the two most influential conditions, and for closure there needed to be a sequential alignment of wind direction, wind speed, swell, tide and catchment hydrology.

Tidal phase was found to be the only reliable predictor of closure, with a 'closing window' existing on the approach of neap tides each month. The most probable 'closing months' were found to be May to August, with winter representing the 'best' chance of closure. It was recommended that all openings be avoided over the late-spring and summer months as they provided the 'worst' chance of closure after opening.

Low-salinity water is considered critical to the growth and reproduction of the aquatic plant community in Waituna Lagoon, particularly *Ruppia*. When the water level in the lagoon rises above two metres it can be mechanically opened to the sea by the Lake Waituna Control Association to help dry out the surrounding farmland. Once the lagoon is open, the saltwater rapidly moves into the lagoon.

To understand the opening dynamics better, Environment Southland collected salinity information from around the lagoon in late 2012 to see how much, and how quickly, saltwater spreads. After the lagoon had been opened for three weeks in November 2012, saltwater had spread throughout the lagoon but there were still areas of low salinity. However, six weeks after opening, the entire lagoon had become very salty, with most sites being more than 30 parts per thousand. The lagoon stayed open and salty for the remainder of the summer and autumn, which suppressed the recovery of the aquatic plant community.

3.5 Recommended ecological guidelines

Based largely on the information described above, the Waituna Lagoon Technical Group (2013) recommended a lagoon health target of 'moderate' ecological condition, with greater than 30-60% cover of *Ruppia* and other indigenous macrophytes. To achieve this objective, it has been recommended that specific nitrogen and phosphorus loading rates to the lagoon are set, and a favourable lagoon opening regime established.

To achieve lagoon ecological objectives for favourable macrophyte growth, current nutrient loads need to be reduced by approximately 50% (Waituna Lagoon Technical Group 2013). Lagoon nutrient load targets were determined from three independent methods (Hamilton *et al.* 2012, Scanes 2012 and Schallenberg and Schallenberg 2012). The methods gave similar targets, which have been averaged as < 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). A reduction in the fine sediment loading to the lagoon may also be required; however at this stage there is not sufficient information to recommend a quantitative cap.

A change to lagoon opening management has also been recommended with regular openings in winter to flush out accumulated sediment and nutrients (Waituna Lagoon Technical Group 2013). The recommendation for winter openings is based on maximizing the flushing effect and also, because winter openings have a high change of closing before summer, avoiding extended summer openings.

4. CATCHMENT SCIENCE

4.1 Monitoring of catchment water

4.1.1 Surface water

Surface water is thought to be the primary component of the conveyance system that delivers nutrients and sediments from the catchment to the lagoon. Hence, understanding flow and water quality dynamics are important requirements for understanding how the catchment affects lagoon health.

The Waituna Surface Water Quality Study ran from December 2011 until early 2013, with a total of 18 sites monitored monthly for water quality in the catchment including five SOE sites. Flow on one day of sampling at each site was also measured. Results from this study were reported quarterly in Environment Southland's Waituna newsletter providing land owners and stakeholders with regular information on the state of surface water quality. The information has also been used to estimate the export of nutrients and sediment from the various sub-catchments and also to understand the role of base-flow and flood flows in contaminant transport (e.g., Diffuse Sources and NIWA 2012). A report on this monitoring will be available in 2014.

Monitoring over the period 2005-2010 found that the water quality monitoring sites in the Waituna catchment regularly exceeded guidelines for water clarity, dissolved reactive phosphorus (a bioavailable form of phosphorus), faecal coliforms, nitrate nitrite nitrogen and unionised ammonia (both bioavailable forms of nitrate). Nitrate and total nitrogen showed an increasing trend over the last 10 years in the Waituna Creek, with mixed trends recorded at other sites (for which the monitoring period wasn't as long).

Surface water flows are monitored continuously by Environment Southland at the lower end of Waituna Creek, Moffat Creek and Carran Creek. Waituna Creek is the largest stream (average discharge approximately 1,800 L/sec) draining a catchment of 10,604 ha (approximately 63% of the total Waituna catchment). Carran Creek is considerably smaller (average discharge 790 L/sec, catchment area 2,871 ha), while Moffat Creek is smaller still (average discharge 190 L/sec, catchment area 1,733 ha). A number of much smaller streams enter the lagoon, particularly along the western and northern shores.

4.1.2 Groundwater

In order to characterise groundwater resources within the Waituna catchment, a network of bores were selected by Environment Southland for groundwater level and water quality sampling. A lack of bores in the unconfined aquifer adjacent to the fringes of the lagoon was identified early, resulting in Environment Southland installing five piezometers in mid-2011 around the landward side of the lagoon. Existing domestic and farming bores were added to the monitoring network through engagement with the Waituna catchment community, with preference given to those bores occurring within the shallow unconfined aquifer system. The network of bores chosen sought to maximise spatial coverage across the catchment including the margins of the Waituna Lagoon.

In addition to the monthly groundwater quality and level baseline monitoring programme, additional groundwater investigations were undertaken to improve characterisation of the overall aquifer water balance including:

- installation of real-time groundwater level, electrical conductivity and water temperature data loggers at five sites throughout the catchment;
- a catchment wide groundwater level (piezometric) survey undertaken utilising more than 70 bores and 30 surface water sites;
- a concurrent gauging and water quality survey of Waituna Creek completed under low flow (base-flow) conditions during the summer of 2011/12, and;
- two groundwater seepage trials undertaken at the eastern and western portions of the Waituna Lagoon.

Environment Southland also took a limited number of water quality samples of soil water beneath wintering paddocks to better understand potential nutrient losses and denitrification processes in the catchment. These samples will be used to help chemically characterise different nitrogen sources to groundwater so that we can understand the relative contributions from different land use activities.

4.1.3 Sub-surface drainage

Developed land in the Waituna catchment includes extensive artificial drainage (mole, tile and surface drains). Originally, groundwater and extensive wetland areas (like the Awarua Plains) stored and slowly released excess rainfall to surface waterways and in a sense acted like a natural water quality filter. However, with the onset of artificial drainage, water now flows much more rapidly to streams thereby reducing summer stream flows and reducing the opportunity for natural biochemical processes to improve water quality.

What is the role of this sub-surface drainage in conveying nutrients and sediment to streams and, ultimately, to Waituna Lagoon? Further, can these contaminant loads be attenuated prior to reaching surface waters? Data to address the first question is generally lacking. NIWA (Tanner *et al*. 2013) was contracted by Environment Southland and DairyNZ to undertake an analysis exercise to: identify the most appropriate locations and types of constructed wetlands that could be implemented in the Waituna catchment to intercept nutrients and sediments; provide cost estimates using a common measurement unit, and recommendations on wetland locations, size, and type to optimise environmental improvement for the funding available.

Potential locations for wetlands were assessed at a range of scales within the catchment, ranging from small on-farm wetlands targeting tile-drain flows to larger wetlands on tributaries and stream channels. The study found that, because of diminishing returns per unit area as wetland size increases, smaller wetlands removing a small fraction of the load will generally show the lowest cost per kilogram of contaminant removed. This means that prioritisation of sites needs to be done in relation to an agreed wetland contaminant removal target. So, while treatment of tile drain/sub-surface discharges are possible, the cost effectiveness of such an approach needs to be closely assessed against the wider benefits gained and the effectiveness of other similar approaches (such as catchment-scale wetlands, see section 4.5 below).

4.2 The role of groundwater

Groundwater is thought to play a minor, although important, role in the transport of nutrients to Waituna Lagoon (Rissmann 2011, Wilson 2011, Rissmann *et al.* 2012). Rissmann *et al.* (2012) divided the Waituna catchment into separate groundwater quality zones according to distinct physical and chemical properties (see Figure 2):

1. Northern Waituna Zone (NWZ) – (north of Mokotua) relatively good groundwater quality compared to regional norms, and shallow aquifers show little impact from intensive land use (except tile drainage, which is elevated in nutrients);
2. Mokotua Infiltration Zone (MIZ) – (between Mokotua and Caesar Road) poor groundwater quality due to rapid infiltration of the soil water with little or no attenuation of soil zone contaminants from intensive land use. Rapid water movement appears to contribute to the deterioration of water quality of Waituna Creek south of

Mokotua;

3. Southern Waituna Zone (SWZ) – (south of Caesar Road to Waituna Lagoon, including both Moffat and Carran Creek catchments) elevated phosphorus levels, with some evidence this may be due to soil leaching and localized septic inputs, however further work is required to determine the significance of these contributions. Wetland conditions limit nitrate contamination of groundwater;

4. Direct groundwater seepage into Waituna Lagoon – direct groundwater inflow is a relatively significant component of the overall lagoon water balance. Further analysis of seepage water quality is required.

These findings highlight the importance of nutrient management in areas of the catchment with high sensitivity to nitrate accumulation (Rissmann 2011). For example, management of land use within the Mokotua Infiltration Zone may lead to a disproportionate improvement in the surface water quality of Waituna Creek and ultimately the lagoon. Also, phosphorus is prone to leaching and is of higher mobility within the Southern Waituna Zone, so management practises that reduce phosphorus loss in this zone are likely to be of value.

Rissmann *et al.* (2012) concluded that the most effective land management response for Waituna Creek will be to reduce potential contamination from overland flow and artificial drainage, as groundwater base-flow to the creek likely maintains relatively good water quality. Aquifers in the lower half of the Waituna catchment have a natural ability to attenuate nitrate build-up in groundwater (Rissmann 2011). This denitrification potential is associated with the presence of peat wetlands and may buffer the Waituna Lagoon from receiving high nitrate loads in groundwater discharging from up catchment. The drainage of wetlands in this area of the catchment however reduces the extent of this buffering effect. Installation of sub-surface drains that allow water drainage to bypass groundwater also increase the risk of nitrates entering the lagoon directly (Rissmann *et al.* 2012).

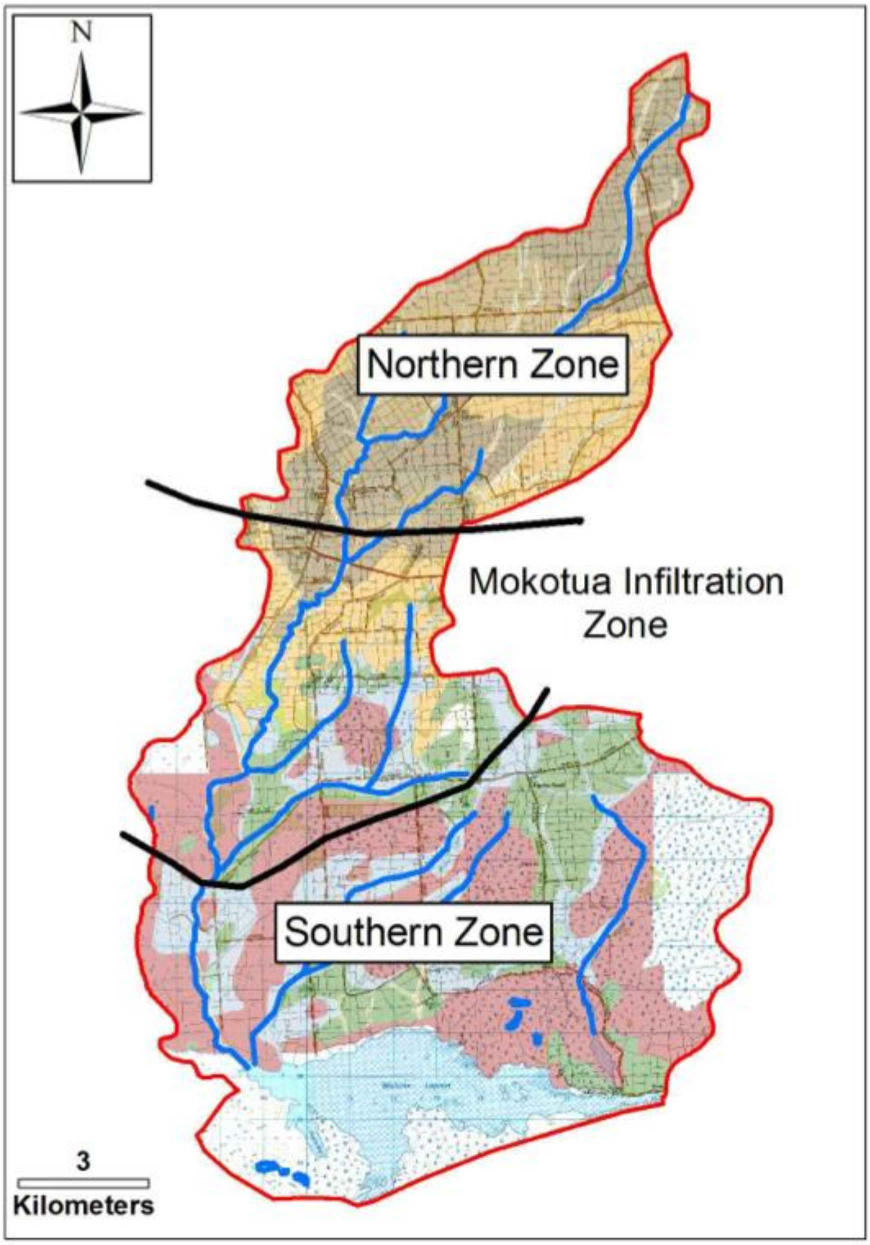

Figure 2 *Groundwater quality zones of the Waituna catchment as defined by natural variation in hydrogeological properties, soli and aquifer types and hydrochemical variation. Changes in colour, from north to south, of solid contours reflects the change from thick mineral brown soils in the north to wetland soil types in the south (from Rissmann* et al. *2012).*

Rissmann *et al.* (2012), however, noted a number of uncertainties with the investigation, which provided a basis for identifying areas requiring further investigation:

- the overall magnitude of key components of the catchment water balance including groundwater recharge, base flow and direct seepage to Waituna Lagoon;
- the physical extent of the MIZ (e.g. whether it extends into the upper portion of the

Moffat Creek catchment) and its significance with respect to surface water quality and NO_3-N loads to Waituna Creek;

- the source of elevated phosphate in southern groundwater including the possibility that winter grazing on organic soils and septic tank outfalls play an important role in the elevated phosphate concentrations in southern groundwater and ultimately the Waituna Lagoon;
- whether discharge of low total nitrogen groundwater from the southern and northern zones of the catchment plays an important role in diluting NO_3-N rich inputs to the Waituna Lagoon from the surface water network;
- the role of seasonality (recharge events) in soil zone contaminant loss to groundwater across the MIZ and other sectors of the catchment;
- the origins of direct groundwater seepage into the lagoon (i.e. from the unconfined or confined aquifer system). This has significance as to the source of phosphate and ultimately how phosphate may best be managed; and,
- additional monitoring on the effect artificial opening of the lagoon has over groundwater inflows (and associated nutrient loading) as direct seepage and stream base flow.

4.3 Relationships between land use and loss of nutrients and sediment to water

4.3.1 General

In order to achieve reduced nutrient and sediment loads, better understanding was required of the loss of nutrients and sediment from the catchment and their export to the lagoon. Nutrients can be bound to sediment acting as a vehicle to transport nutrient. However, large quantities of fine sediment also act to smother the bed of the lagoon and in doing so alter the habitat and create conditions not favourable to a healthy lagoon system.

Estimates of contaminant losses from the catchment were prepared for the Catchment Technical Group by Ross Monaghan (AgResearch) in 2012 based on an understanding of farming activities and other land uses within the Waituna catchment, and knowledge of general nutrient losses from these land types – they did not use data specific to Waituna catchment farms. These estimates also did not account for any assimilation or attenuation of contaminants within the catchment's drainage network. That is, they assumed any loss of nutrients and sediment from land was potentially available to be exported to the lagoon.

An additional piece of work was commissioned by Diffuse Sources and NIWA (2012) to determine the most appropriate method of calculating nutrient and sediment exports from the Waituna catchment. This was based on Environment Southland flow and water quality monitoring data of the three main surface tributaries of the lagoon and the contribution of groundwater direct to the lagoon. This work provided estimates of annual export of nitrogen, phosphorus and sediment over a 10 year period (1995 - 2011) and was more site-specific than the estimates prepared by Monaghan in that they were based on actual nutrient and sediment concentrations in streams and stream flows in the catchment. The work identified a number of issues associated with the current monitoring programme, including the need to monitor and better understand high flow events (see section 4.1.1) which have potential to carry large amounts of nutrients and sediment over a short period of time.

The primary source of nutrient and sediment entering the lagoon is from the catchment, and consequently a high priority has been afforded to better understanding the amounts of losses from the catchment and where they are coming from. A range of investigations were therefore initiated under the broad heading of estimating catchment contaminant losses.

Science investigations associated with the Waituna catchment have continued to progress since the Technical Strategy was prepared in 2012. In November 2013, DairyNZ organised a catchment science workshop attended by 14 scientists from around the country. The purpose of the workshop was to explore and review within-catchment attenuation options to reduce nutrient and sediment loads to Waituna Lagoon. The primary focus was identifying practical, cost-effective and high impact solutions which could be applied off-farm.

The workshop reviewed the current state of catchment science, short-listed options with the most potential for further application and test-bedding, and identified crucial knowledge gaps which still need to be addressed before application. While the workshop outcomes reinforced that there is no silver bullet, and a combination of options need to be considered, the workshop led to a better understanding of possible ideas which could be pursued further in the Waituna catchment. These included the use of constructed wetlands, treatment beds at the end of tile drains and different ways of engineering channel embankments. DairyNZ together with ES and the Department of Conservation (DOC)-Fonterra Living Water partnership are now further working through these ideas including the establishment of pilot trials.

4.3.2 Land use contributions

(i) Muirhead (2013)

Muirhead (2013) prepared a summary of existing knowledge of nutrient and sediment losses in the Waituna catchment, and completed an analysis of the potential variability associated with modelled estimates of nitrogen and phosphorus losses from farms in the catchment. His investigation found that there are spatial hot spots of contaminant losses in the catchment, and current levels of sediment and nutrient loads are much higher than would have been expected from the catchment prior to farming development.

The Waituna Creek drains the largest area of the catchment and therefore, dominates the total load of nutrients and sediment discharged to the lagoon. However, specific yields (i.e., kg/ha/year) identify Waituna Creek as the greatest nitrogen source, but Moffat and Carran creeks as greater sources of phosphorus. These specific yields are a reflection of spatial distribution of soil types in the catchment: Brown soils in the northern part of the catchment that drain into Waituna Creek and in the southern catchment, Organic and Podzol soils that drain into Moffat and Carran Creeks. Direct groundwater seepage to the lagoon is estimated as 10% of nitrogen and 18% of phosphorus loads, while inputs from water birds have been estimated at 1 and 4% of the catchment loads for nitrogen and phosphorus, respectively (Burger 2013).

Muirhead (2013) noted that modelling of contaminant losses from the catchment is critical for estimating the effect of applying mitigation options to reduce future loadings to the lagoon. Three different modelling tools have been used in the Waituna catchment. Overseer® is a farm-scale model that is useful for predicting losses of nutrients from a farm and for including the effect of some mitigations applied to farms. Overseer® does not account for attenuation of nutrients as the water flows from the root zone (nitrogen) or first order streams (phosphorus) to the lagoon and therefore, catchment scale losses cannot be determined by simply summing the losses predicted by Overseer®. However, the losses predicted by Overseer® do reflect specific yields measured in the three creeks.

Catchment-scale models CLUES (catchment land use and environmental sustainability) and SWAT (soil and water assessment tool) are designed to account for stream attenuation and have been run for the catchment. The SWAT has been set up to provide estimates of the stream inputs into the lagoon on a daily basis which is required for the lagoon models. However, it is difficult to incorporate mitigation options into the SWAT. The CLUES model operates on an annual time step, and is much more suitable for determining the effect that mitigations applied on farms will have on annual loads of nutrients discharged to the lagoon.

Overseer® modelling of various farm systems in the catchment indicates that nitrogen and phosphorus losses from dairy farms are typically higher than losses from dry-stock farms. There is potential to reduce nitrogen losses from the dairy farm systems, but this will require the implementation of difficult and complex mitigation options (Muirhead 2013). Maximising the effectiveness of wetlands by putting them in the right place will be central to decreasing nitrogen loads to the lagoon (Tanner *et al*. 2013). The high phosphorus losses from dairy farm systems on Brown soils can be reduced by strategies such as good FDE management and by fencing off of all waterways. These mitigations would be effective in the Organic soils, but still leave a large potential for phosphorus loss (Muirhead 2013). Other mitigations are available, but cannot, at present, be modelled by Overseer®. Careful thought will need to be given to how these mitigations could be included in quantitative catchment targets. However, it is possible that phosphorus losses may not be mitigated to desired targets leaving land use change (or retirement) as the only option.

(ii) More recent surveys of land use contribution

One of the most significant knowledge gaps for the Waituna catchment is the absence of reliable and farm-specific Overseer nutrient budget data. In 2013, Environment Southland, in conjunction with industry representatives (in particular DairyNZ), mapped catchment land use to determine what land use types are found where within the wider Waituna catchment. The mapping is a work in progress and information is continually being updated to improve the level of land use resolution on a spatial scale. Categories such as dairy, dairy support, dairy and sheep, dairy support and sheep, drystock, forestry and wetland (to name some) have been used and these have been broken down into the three main sub-catchments. This information is being entered into a database that has other information on catchment character (e.g., soil types) and, ultimately, will be developed into a revised, more accurate, model to estimate nutrient and sediment losses from the entire catchment.

Farm system modelling is being conducted by DairyNZ with 10 farmers in the catchment to determine (a) what additional mitigation strategies can be applied on-farm to reduce nutrient losses while still maintaining farm profitability, (b) which combinations of mitigation strategies are the most cost effective, (c) what is the maximum reduction in farm nutrient losses achievable at the catchment-scale while still maintaining economic viability, and (d) what is the impact of a range of nutrient load reduction scenarios on farm viability.

(iii) Sediment fingerprinting study

A sediment fingerprinting study was commissioned by Environment Southland to identify sources of sediment (e.g., topsoil, subsoil, bank sediment, bed sediment) to the three main tributaries of the lagoon (McDowall in prep.). The study found that the majority of suspended sediment throughout Waituna Creek was coming from bed sediment, but topsoil also provided an important contribution in the upper Waituna Creek. Subsoil formed an insignificant component at all sites.

The study indirectly raises an important issue associated with the origin of stream bank sediment that requires further investigation. In Waituna Creek, silt and sediment build up on the bank profile resulting in a near a vertical slope with all of the accumulated sediment. So if the bank source sediment is taken as this accumulated silt, rather than the underlying and original bank slope, it raises the question as to whether this 'bank' sediment is material that was either (1) true bank material, or (2) accumulated silt that has built up the bank and which may have come from a variety of sources. In other words, is the 'bank' sediment just a temporary storage site for sediment that has eroded from the wider catchment, including farm land, and is in the process of being exported to the lagoon?

(iv) Forage crops and other considerations

Studies have also been undertaken to investigate nutrient and sediment losses from spring-grazed forage crops, and from Organic soils in a Waituna catchment dairy farm. In addition to forage crops grazed in winter, forage crops are grazed in spring to transition cows back onto pasture when coming back onto the milking platform from elsewhere. A one year study in the northern part of the Waituna catchment showed that these spring grazed forage crops lose a similar load of nutrients and sediment as winter grazed forage crops (McDowell *et al.* 2011).

Dennis *et al.* (2012), cited by Muirhead (2013) showed that delaying the return of the cows to the milking platform or removing spring forage crops and good pasture management was financially no different than utilising a spring forage crop, but would result in less contaminant loss in surface runoff.

With all of these investigations described above, there are still some potentially important science knowledge gaps in relation to: 1) farm dairy effluent irrigation on the Organic and

Podzol soils in the Waituna catchment; 2) losses of nutrients from winter grazing practices for all animal types; and 3) stream bank erosion.

AgResearch has completed a two-year study for DairyNZ to: 1) quantify losses of nitrogen and phosphorus in surface runoff and sub-surface drainage from soils rich in organic matter on a milking platform within the Waituna catchment; and 2) use this data to calibrate and define gaps in Overseer® nutrient load outputs. The results suggest that there is a high risk of phosphorus leaching from fodder crops on organic soils. Further work will focus on quantifying the total phosphorus load associated with peat soils in the catchment relative to all sources.

4.3.3 Catchment modelling

A catchment water quality model is being funded by DairyNZ to evaluate the total nutrient loading to the lagoon from all sources, and to provide a framework for evaluating the collective impacts of different mitigation strategies for lagoon management. The water quality model contains actual or estimated farm-specific nutrient loss information and is underpinned by a hydrological model to estimate water and load transport through the drainage network.

4.4 Drainage maintenance and management

4.4.1 On farm

Controlled drainage involves the use of weirs to regulate water level in a manner beneficial to agriculture or for water quality purposes (can reduce nitrogen, phosphorus and sediment loads by 30-50%). Traditional controlled drainage approaches (raise water level) are not recommended for Waituna because of potential negative effects like pugging and overland flow on saturated soils. However, an alternative technique, 'Peak Runoff Control' (PRC), shows promise. This involves slowing down flows during wetter periods by installing holed weirs, rather than raising the water level *per se*. An Envirolink funded report has been completed by AgResearch (McDowall *et al*. 2012).

Unlike traditional controlled drainage systems, PRC structures aim to attenuate (not stop) runoff for a period of 1-5 days allowing for sedimentation. A series of pipes built into the PRC dam at different heights can be engineered to allow for different flow rates and residence times. Below the bottom pipe, a small wetland area will provide, with careful management, conditions conducive to denitrification. McDowall et al. (2012) outlined a design process that requires the analysis of hydrologic and LIDAR data to isolate areas suitable for PRC structures. They also recommended that additional work be conducted to determine soil and sediment specific potential for erosion, deposition and re-suspension that will help optimise the nitrogen, phosphorous and sediment mitigation potential for the structures within the Waituna Lagoon.

4.4.2 Scheduled drain maintenance

Although the short-term impacts of drain clearing are acknowledged to be negative (an increase in nutrient and sediment loads), the total nutrient and sediment loads to the lagoon may actually be decreased (i.e., the diggers may remove substantial amounts of nutrient and sediment from the waterways). Environment Southland's 2012 three-yearly maintenance of the Waituna Creek Drainage District removed roughly 25,000 tonnes (10,000m^3) of weed and 25,000 tonnes (10,000m^3) of sediment, over a 50km length of the 80km system (the entire 80km is not cleared each time, it is done on an as required basis). This service is provided to maintain drainage outfall, with costs met by a rate across the Waituna Creek Drainage District. Individual landowners undertake their own drain clearing activities at various times of the year on the other main tributaries to the lagoon (Moffat Creek and Carran Creek), and other waterways around the catchment.

Additional monitoring has taken place in association with recent drain cleaning operations managed by Environment Southland (Ballantine and Hughes 2012, Hicks 2012, Olsen 2012). In their assessment of drain cleaning in February and March 2012, Ballantine and Hughes (2012) found that the concentrations of suspended solids and total phosphorus, for a given flow in Waituna Creek, were higher during the monitored drain clearing period than for the long-term record. Furthermore, the highest suspended solids and total phosphorus concentrations ever measured at the Waituna Creek Marshall Road site occurred during this drain clearing period. However, it should be noted that this study only monitored one drain clearing period, and assessed drain cleaning that was on a wide-scale when more cleaning was done than what typically occurs. Also, once the Environment Southland diggers start moving through the system clearing drainage outfall, individual landowners often then start clearing out any blocked sub-surface drains which adds to the sediment load.

Community concern regarding the continuing loss of soil from stream bank erosion of Waituna Creek resulted in Environment Southland applying to the Ministry for the Environment's Fresh Start for Freshwater Clean-up Fund to help address this issue. A trial of erosion control works in the form of bank reconstruction along an approximately 1 km long reach of Waituna Creek within Stevenson Farm was undertaken in early 2013. The purpose of these works is to maintain the stability of Waituna Creek, and to minimize the loss of land through erosion and therefore minimise the amount of sediment impacting on the creek and lagoon ecosystems. The works included the rebattering of the channel banks to create a 2:1 slope and installation of rock edge protection on eroding bends. Bank reconstruction in this trial required the removal of approximately 7,300-9,180 cubic metres of material from the banks using an excavator, and armouring the installation with approximately 960 tonnes of rock.

Environment Southland is now seeking a new resource consent to undertake further bank reconstruction in Waituna Creek within an 'envelope' of works, which would involve using one of a number of options in a particular reach of the creek, depending on the erosion-control requirements in that reach. A report commissioned by the Department of Conservation (Hudson 2013) recommended both active and passive (i.e., riparian margin tree growth and vegetation succession) rehabilitation, and these ideas will be incorporated into the bank reconstruction trials, the costs of which are being met by local landowners, Environment Southland and the Ministry for the Environment. Active rehabilitation is recommended for eroding bends, reaches with unstable trapezoidal channels, and channels that are less than the required hydraulic capacity. It includes compound (multi-stage) channel, bank reshaping, structural engineering approach with riprap and 1:2 batters (trapezoidal), drainage maintenance, and interception wetlands. Passive rehabilitation is recommended where existing channel profiles are effectively multi-stage compound channels with benches that promote sediment deposition.

4.5 Treatment systems

Methods such as filter strips, wetlands and sediment traps have been reviewed as options for the Waituna catchment (Hamill *et al*. 2012). Tanner *et al.* (2013) undertook a recent assessment of potential constructed wetland sites within the Waituna catchment. They found that the Waituna Creek catchment has the highest yield of suspended solids and nitrogen, and offers the greatest range of potentially viable opportunities for wetland construction, ranging from large main-channel wetlands in the centre of the catchment approaching 50 ha down to small wetlands in the contributing catchment of 600m^2. Opportunities were less common at the bottom of the catchment where the low gradient would necessitate large-scale excavation for wetland construction and there was high potential to impact on water tables and drainage efficiency in adjacent areas.

NIWA and DairyNZ, together with support from Environment Southland, are completing a follow-up study to further identify alternative low-cost constructed wetland design options in the upper Waituna catchment and determine their feasibility in terms of engineering/construction costs and nutrient and sediment removal efficacy. This information, together with the results of the Phase 1 wetland study (Tanner *et al*. 2013), will be used to provide an expert consensus on the suitability of wide-scale application of constructed wetlands to reduce catchment nutrient loads in the Waituna catchment, including key design criteria that need to be considered when identifying suitable locations and their likely efficacy rate. Ultimately, this work will lead to a subsequent constructed wetland pilot study.

A tile drain passive filter pilot study is being co-funded by DairyNZ, the DOC-Fonterra Living Water partnership and NIWA. The research is being undertaken by NIWA, and supported by Environment Southland. This study will design, apply and assess the performance of two passive treatment filter systems to reduce nitrogen and phosphorus loads associated with agricultural tile drain discharges in the Waituna catchment. Specifically, available data on drainage flows and water quality, and targets for the Waituna catchment will be used to develop regional loading criteria and system designs for denitrifying wood-chip filters (nitrate-N removal) and phosphorus sorption (dissolved phosphorus removal) filter systems. These will then guide site selection, construction and monitoring of pilot-scale wood-chip and phosphorus-sorption filter systems. Monitoring of treatment inflow and outflow water quantity and quality will initially be carried out for a one year period to evaluate and demonstrate their performance for attenuation of nutrients exported in farm drainage in the Waituna catchment.

4.6 Other

A socio-economic analysis of the catchment has been funded by DairyNZ to develop a baseline understanding of the social-economic values of the catchment and to provide an assessment of the impacts of different farm and economic scenarios on the community.

5. ENGINEERING INTERVENTIONS

Intervention options are activities or engineering initiatives that may provide a physical means of reducing nutrient and/or sediment levels in Waituna Lagoon or in tributaries that feed into it. Some of the intervention options that have undergone pre-feasibility assessments include: dredging; controlling the water level using permeable barriers, siphons, pipes or pumps; and phosphorus inactivation.

A qualitative pre-feasibility assessment investigated using dredging to reduce the internal load of nitrogen, phosphorus and suspended sediment loads to Waituna Lagoon (Opus 2012a). Dredging physically removes sediment from a water body along with nitrogen and phosphorus bound to the sediment. This would have potential benefits of improving water clarity by reducing the amount of material available for re-suspension and reducing the internal nutrient load (particularly of phosphorus). The assessment concluded that dredging of fine sediment could probably occur in about 150ha of Waituna Lagoon. This is estimated to remove about 270,000 m^3 of muds and 10.9 tonnes of phosphorus. A rough order cost estimate is $3.5 million to $12.5 million, with substantial additional costs for sludge disposal and consenting. There remains considerable uncertainty about the feasibility of disposing and treating 270,000 m^3 of wet mud dredged from the lagoon. If dredging is pursued as an intervention option for Waituna Lagoon it will be very important to choose the right dredging method and confirm the feasibility of sludge disposal.

The pre-feasibility assessment into controlling the water level in Waituna Lagoon using permeable barriers, siphons, pipes or pumps found that the use of large culverts or pumps are feasible for controlling maximum water levels in Waituna Lagoon, and would avoid the extended periods of low water levels that occur with the current opening regime (Opus 2012b). However, adopting this approach would stop the benefit of flushing large amounts of nutrients and sediment from the lagoon. The amount of nitrogen, phosphorus and sediment exported during a flush is considerable and stopping this export could have significant adverse effects on the lagoon ecology unless inputs are reduced by a similar amount. Efforts should be made to increase the effectiveness of this flushing rather than reduce it. In terms of removing nitrogen, phosphorus and sediment this option has a large 'dis-benefit' and was considered not worth pursuing. However, temporary or permanent culverts could be considered alongside continuation of beach opening, as a way to manage the timing of openings.

Phosphorus inactivation is a water quality management technique that uses a product to reduce the amount of phosphate in the water column in order to reduce the growth of nuisance phytoplankton species. The growth of phytoplankton requires three key elements: light, nitrogen and phosphorus. Removal of any one of these key elements will stop phytoplankton growth, but it is easier to remove or inactivate the biologically available phosphorus than it is to remove nitrogen.

In New Zealand, alum has been used at a low dose rate in Lake Okaro and is currently being used as an inoculum to remove phosphate from three inflows to the Te Arawa/ Rotorua lakes. In Lake Rotorua this has resulted in a marked improvement in water clarity and quality. Alum has been used in overseas lakes for at least 50 years. Phoslock was used in Lake Okareka in New Zealand and has been used in a number of lakes and reservoirs in the United Kingdom and European countries with success. The study found that there is high certainty of phosphorus-inactivation using these agents in the freshwater parts of Waituna Lagoon and stream inflows. These effects are well documented in the literature and have recently been tested in New Zealand laboratory studies.

Disadvantages identified in the study include:

i) Aluminium salts may not be effective phosphorus-inactivation products in brackish water and need testing in the lagoon waters;

ii) Shallow water will allow wave-induced re-suspension of sediment that will bury any capping agent applied to the lagoon. This has the potential to reduce the efficacy of the phosphorus-binding from the overlying water and localise the zone of influence for phosphorus-binding in the sediment;

iii) Without catchment interventions to reduce or stop soil erosion, fine sediment from land use will replace the phosphorus removed by the phosphorus-inactivation agents, requiring on-going or repeat treatments to manage the phosphorus load in the lagoon.

6. RECOMMENDATIONS FOR FUTURE MANAGEMENT OF THE LAGOON AND CATCHMENT

6.1 The lagoon

The primary focus of the Waituna Project has been to address concerns surrounding the ecological health of Waituna Lagoon. Primarily through the work of the Lagoon Technical Group and associated work streams including surveys undertaken by Environment Southland and the Department of Conservation, our understanding of the science behind how the lagoon ecology functions and responds to internal and external variables has improved significantly since the reviews of Thompson and Ryder (2003) and Schallenberg and Tyrrell (2006).

There is an improved understanding of how opening and closing of the lagoon with the sea affects water quality and ecosystem health within the lagoon. When it comes to ecosystem health, however, lagoon openings are a double-edged sword. On the one hand, openings have benefits in the form of flushing nutrient-laden water and sediments out to sea, and this helps prevent nuisance algae growths from developing. On the other hand, leaving the lagoon open for too long, or opening it at inappropriate times of the year, have negative effects on the macrophyte beds within the lagoon, in particular the *Ruppia* plant communities, which produce oxygen and, either directly or indirectly provide cover and food for fish and wildlife. Hence, the 2013 Ecological Guidelines for Waituna Lagoon target macrophyte biomass and cover as a key (primary) indicator target of lagoon health.

Notwithstanding the importance of *Ruppia*, our knowledge of its growth and how it is affected by environmental variables is far from perfect and management of Waituna Lagoon would benefit from better understanding of the following matters:

1. The realistic potential area for macrophyte growth within the lagoon, which will be influenced by openings, sediment suitability, wind-exposed areas, etc. 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 the Lagoon Technical Group has identified for the moment, future targets will need to account for new information on macrophyte growth potential in Waituna Lagoon;
2. 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. Knowledge of the role that zooplankton (e.g., mysid shrimps) plays in the lake ecosystem is also limited. Zooplankton strongly influence phytoplankton biomass;

3. Knowledge of internal nutrient loads from the lagoon sediments is limited and understanding of lagoon ecosystem functioning would benefit from understanding this aspect better;
4. Ideally, a better 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?

The opening regime recommended by the Lagoon Technical Group employs a strategy that attempts to maximise ecological benefits for *Ruppia* while minimising the potential risks associated with a prolonged opening, and without compromising drainage of productive land adjacent to the lagoon. The strategy relies on a combination of knowledge gained through scientific investigations, monitoring and modelling, and reliance on nature to do its bit when it comes to climate and sea conditions at particular times of the year. There remain gaps and uncertainties that, if addressed, would result in greater refinement of the opening regime guidelines and greater confidence in their outcomes. The key gaps that have been identified are:

1. Understanding differences in the effect of the lagoon opening location on nutrient and sediment flushing, and lagoon ecology;
2. Further assessment of options for assisted closure and optimum opening duration;
3. Improving the understanding of optimal water level and climatic conditions to maximise nutrient and fine sediment removal at future openings.

6.2 The catchment

The decline in the ecological health of Waituna Lagoon has been inextricably linked with an increase in land use intensification in the Waituna catchment over a long period of time. In particular, the export of nutrients and sediment from the catchment to the lagoon has been identified as the primary link between catchment land use activities and lagoon degradation.

While this linkage has been clearly identified as a problem, understanding all the processes that are involved requires further consideration and refinement in order to make informed and targeted decisions on managing and mitigating these losses.

Importantly, the level of spatial detail required for targeting on-farm mitigation and potentially off-farm (or sub-catchment) nutrient and sediment attenuation measures requires further refinement of land use activities and nutrient pathways to the lagoon. For example, Rissmann *et al.* (2012) made a number of recommendations relating to Waituna groundwater and nutrients including:

- ongoing monitoring of the groundwater resource to improve characterisation of the spatial and temporal variability of key water balance and water quality inputs;
- further work to understand the links between the confined and unconfined aquifer systems in terms of the contribution of each to nutrient loads occurring as direct seepage and base flow;
- an assessment of the role of land-based application of phosphate over the elevated phosphate concentrations in southern groundwater and ultimately phosphate loads to the Waituna Lagoon;
- refinement of the nature and extent of the high permeability MIZ (Mokotua Infiltration Zone) along with the recharge frequency, contaminant range and magnitude of groundwater nutrient inputs from the MIZ to Waituna Creek;
- further seepage monitoring under winter time conditions to assess the role of relative groundwater head over direct groundwater seepage rates and nutrient fluxes to the lagoon.

In much the same way that a modelling approach was used to incorporate physical, chemical and biological information on the lagoon in order to understand how it functions, and to predict how it might behave given future scenarios associated with nutrient and sediment inputs and opening/closing regimes, a catchment model is also required that incorporates information on individual farm nutrient and sediment losses and is capable of assessing the effects of land use change on water quality at the catchment scale.

Muirhead (2013) suggested an approach that essentially addresses the recommendations for a catchment model and entails:

- results from the nutrient loss study undertaken by AgResearch (Muirhead 2013) are used to calibrate Overseer® model outputs from Waituna farm systems;
- Overseer® data, and that contained in the AgResearch report, are used with spatial

data to generate maps of potential nutrient losses from farms in the catchment for a range of mitigation scenarios including easy and more appropriate options with the current land use and with land use change;

- this data is then used in spatially resolved modelling of the catchment (e.g., using the CLUES model) to account for in-stream attenuation of nutrients and sediment and their delivery to the lagoon.

Specific catchment information gaps identified for filling by the Lagoon Technical Group (2013) include:

1. 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;
2. Better understanding of how changes in input load methodology will alter perception of progress towards the benchmark reduction target;
3. Sources of sediment to the lagoon, and sedimentation rates in the lagoon, are uncertain and require further assessment.

It is worth noting here that Environment Southland has been working with DairyNZ on the issue of developing a catchment modelling approach. This work would seem to be of a high priority.

7. IMPLICATIONS FOR LAND OWNERS AND LAND MANAGERS

The main implication for land owners and land managers within the Waituna catchment is the recommendation within the 2013 Ecological Guidelines for Waituna Lagoon (Waituna Lagoon Technical Group 2013) for a 50% reduction in nutrient inputs to the lagoon in order to protect its ecological health. The guidelines are recommendations only and not statutory-based management decisions, however immediate progress in reducing nutrient inputs is recommended if protecting the lagoon ecosystem is a deemed a high priority.

The lagoon nutrient load targets are not intended to apply across all land within the catchment, but rather as reductions in the amount of nutrients reaching the lagoon. How this is to be best achieved will vary within the catchment depending on local land characteristics and use. This point reinforces the need for good quality information on land use effects and ways to either mitigate nutrient and sediment losses from farm land or to attenuate (i.e., trap and/or remove) these contaminants once they have left the farm.

Muirhead (2013) noted that "There is potential to reduce nitrogen losses from the dairy farm systems, but this will require the implementation of difficult and complex mitigation options. Maximising the effectiveness of wetlands by putting them in the right place will be central to decreasing nitrogen loads to the lagoon. The high phosphorus losses from dairy farm systems on Brown soils can be reduced by strategies such as good farm dairy effluent management and by fencing off of all streams. These mitigations would be effective in the Organic soils, but still leave a large potential for phosphorus loss. Other mitigations are available, but cannot (at present) be modelled by Overseer®. Careful thought will need to be given to how these mitigations could be included in quantitative catchment targets. However, it is possible that phosphorus losses may not be mitigated to desired targets leaving land use change (or retirement) as the only option."

A number of mitigation options have already been examined, to varying degrees of scrutiny, including both on-farm and catchment-wide measures, but the majority require more attention to detail and need to be assessed in relation to an updated, catchment-wide assessment of contaminant losses, at farm-scale resolution. This work is currently underway and is being managed through the joint initiatives of Environment Southland and DairyNZ.

Any measures to reduce nutrient and sediment exports to the lagoon will need to be integrated with the wider catchment (and the lagoon) in mind, but implemented on a two-tier spatial scale; (1) at an individual farm scale for on-farm mitigation measures and (2) at a sub-catchment scale for attenuating contaminants that have left the farm. Without that level of detail, it would seem unlikely that land owners and managers would be able to make decisions about implementing mitigation measures with confidence.

With these thoughts in mind, land owners and managers need to ensure that relationships between land use practices and contaminant losses to the lagoon are clearly understood. Known activities that may exacerbate these losses at the catchment scale probably warrant immediate scrutiny, and include further drainage of wetlands and intensive farming practices on Organic soils.

The above commentary should not imply management of lagoon openings carries any less of a priority. Further, the recommendations associated with nutrient load reductions and a controlled opening regime need to be continually assessed against updated water quality and ecology monitoring data for the lagoon.

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