This document contains a summary of scientific and technical reports on the Waituna Lagoon and contributes to the Waituna Technical Strategy.

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Waituna Science Bibliography

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1. Lagoon Science

Duggan, I. C., and White, M. A., 2010. Consequences of human-mediated marine intrusions on the zooplankton community. *New Zealand Journal of Marine and Freshwater Research, 44:1,* March 2010. 17-28pp.

Barrier bars separating lagoons from oceans are frequently breached as a management tool to prevent flooding of terrestrial ecosystems. The effects of such human-mediated openings on zooplankton have been investigated only in one tropical system. We investigated the temperate Waituna Lagoon, New Zealand, over a 2-year period when the barrier bar was 'artificially' breached on three occasions. Increases in salinity associated with opening of the barrier bars greatly influenced zooplankton community composition, and recovery of communities was dependent on the rate at which salinity returned to pre-disturbance conditions. As such, resilience of zooplankton in coastal lagoons is a function of the lagoon conditions returning to those experienced prior to barrier breach, rather than being a result of the zooplankton community simply recovering from a single defined disturbance event. In contrast to the tropical lagoon studies, temperature in Waituna Lagoon was inferred to explain a significant proportion of the variability in zooplankton community composition, independent of salinity. Appropriate timing for the opening of barrier bars by management authorities in temperate lagoons, which would allow the greatest opportunity for freshwater zooplankton communities to recover rapidly, will rely on determining the best time for rapid barrier bar reformation and high freshwater inflow rates (i.e. the recovery of zooplankton relies on return to initial conditions). However, such an approach is in direct conflict with the opening of barrier bars for management

Hamill, K., 2010. *Southland Water 2010: Our Ecosystems Technical Report for Lakes and Lagoon.* Prepared for Environment Southland by Opus International Consultants Limited. 38p.

Environment Southland, in collaboration with Te Ao Marama Inc is preparing reports on the state of the Southland freshwater environment. This technical report describes the state and trends in lake and lagoon water quality in Southland and will contribute to the lakes and lagoons section of Southland Water 2010: Our Ecosystems.

State of lake water quality
The key points about the state of water quality in Southlands lakes are:

- Regular water quality monitoring occurs in three lakes: Lake Te Anau, Lake Manapouri, and Waituna Lagoon;
- Lake Te Anau and Manapouri have very clean water and are classified as 'microtrophic' to 'oligotrophic'. Their water quality is in the top 10% of lakes monitored in New Zealand.
- Waituna Lagoon has high nutrient levels and is classified as 'eutrophic'. The estimated median Secchi depth in the lagoon breaches the Water Plan standard. However, median chlorophyll *a* concentrations meet the standard. Chlorophyll *a* concentrations are relatively low compared to the nutrient concentrations, suggesting that some other factor(s) is limiting the amount of algae growth in the lagoon.
- The CCME Water Quality Index classified the east, south and centre sites in Waituna Lagoon as "Fair" (i.e. conditions sometimes depart from desirable levels), but the west site as classified as "Marginal" due to a single failure of pH against the Water Plan standard.
- Historic spot sampling of other small coastal lakes (Forest Lake, Lake George, Lake Vincent and the Reservoir) indicate that these small coastal lakes are in a eutropic to supertrophic condition, with high concentrations of nutrients.
- Water quality monitoring results from Lake Te Anau and Lake Manapouri have a large number of samples recorded as 'below detection'. The large number of these non-detect samples present a problem for accurately assessing the state of the lake and seriously limits the ability of the monitoring to detect water quality trends. Recommendations are made to improve the monitoring methods.
- The deep water sites monitored on Lake Te Anau and Lake Manapouri are stratified for about 33% and 44% of the time respectively. The lowest dissolved oxygen recorded in the bottom waters when these lakes are stratified are 8.4 g/m3 and 6.5 g/m3 for Lake Te Anau and Lake Manapouri respectively.
- Ecological condition has been assessed in six southland lakes using LakeSPI. All were natural state lakes in Fiordland and all had 'high' LakeSPI scores (i.e. 50%-75%). This puts them in the top one third of NZ lakes.
- All major water quality variables in the Waituna Lagoon (e.g. total nitrogen, total phosphorus, chlorophyll *a*, electrical conductivity, turbidity) responded to whether it was open or closed. The strongest impact of opening or closing the lagoon was on salinity, electrical conductivity, total nitrogen, and the trophic level index.
- Open Waituna Lagoon to the sea results in an improvement in water quality however, care is needed to ensure that any change in the opening regime to improve water quality does not result adversely affect germination of *Ruppia* sp. the lagoon.

Trends in lake water quality
Lake water quality data was analysed for trends using a seasonal Kendall test. Water quality data from Waituna Lagoon was adjusted to account for when the lagoon was open or closed. The trend analysis found:

Lake Manapouri:

- A strong decreasing (deteriorating) trend in Secchi depth since about 2005. This is possibly part of a cyclic pattern but should be carefully monitored in case it is due to external pressures.
- A change in detection limits have caused artificial trends in TP and probably turbidity.
- There is a limited ability to detect trends due to a large number of values below detection limit, consequently trends could be occurring without being detected.

Lake Te Anau:

- A downward (improving) trend in TN at both Blue Gum Point and in South Fiord.
- A change in detection limits have caused artificial downward trend in TLI (South Fiord) and probably turbidity.

- There is a limited ability to detect trends due to a large number of values below detection limit, consequently trends could be occurring without being detected.

Waituna Lagoon:

- An increasing (deteriorating) trend in TP at Waituna Lagoon sites Centre (before and after turbidity adjustment) and West (after turbidity adjustment). This is concerning because Waituna Lagoon is probably P limited and it should be carefully monitored.
- A downward (improving) trend in chlorophyll *a* at Waituna Lagoon sites south and West was apparent after adjusting data for open and closed regime. Blooms of macroalgae (attached to sediments and plants) have been recorded in recent years (i.e. 2009 and 2010) and this may have suppressed the growth of planktonic algae (and chlorophyll *a* concentrations) by competing for nutrients.
- More periods of lagoon closure since ~2006 have caused an apparent increase (deterioration) in TN.
- Concentrations of nitrate during winter have increased at some sites, independent of the 'open and closed' regime. Summer nitrate concentrations are still often low, probably due to plant and algae utilisation.
- Maintaining at least monthly sampling of Waituna Lagoon is important to ensure any trend analysis has sufficient power after making other adjustments (e.g. for EC, turbidity or 'open and closed' regime).

Could Waituna Lagoon 'Flip'?

Waituna Lagoon is dominated by the native aquatic plants (macrophytes) *Ruppia* sp and *Myriophyllum triphyllum*. *Ruppia* sp. in particular is a keystone species in Waituna Lagoon because of its importance as a habitat for invertebrates and fish, as a food source for invertebrates and waterfowl, and because of its role in regulating water quality by stabilising the sediments, and reducing turbulence.

In some lakes this state of having clear water in a macrophyte dominated lake suddenly changes in a phenomenon known as lake flipping. When a lake flips, it undergoes a regime shift from a macrophyte-dominated clear water state to a de-vegetated, turbid water state. At least 37 lakes in New Zealand that have undergone a lake flip between clear water and turbid states and/or vice versa (Schallenberg and Sorrell 2009). A collapse of the macrophyte community is followed by deterioration in water quality (Hamill 2006).

In the turbid state, light penetration is limited, preventing macrophytes from establishing again, allowing continued re-suspension of sediment by wave energy, which exacerbates the poor light penetration. Sediment resuspension from the bottom also increase the loading of phosphorus and nitrogen in the water column, potentially favouring phytoplankton growth over macrophytes.

Waituna Lagoon has estimated water clarity (Secchi depth) of about 1.2m, which is not sufficient for light to reach the bottom of the deepest parts of the lagoon. A decline in water clarity could impact on the cover of *Ruppia* sp. in deeper parts of the lagoon with the potential for this to cause the lagoon to flip to a turbid state. If this were to occur it could mean the loss of aquatic plants (*Ruppia sp.*) and relatively clear water, as the water becomes increasingly turbid with suspended sediment and phytoplankton.

The likelihood of Waituna Lagoon exhibiting a regime shift was assessed using the relationship between land use variables and % regime-shifting lakes developed by Schallenberg and Sorrell (2009). This predicted that the likelihood of Waituna Lagoon flipping would double to almost 80% if the % pasture in the catchment increased from its current 65% cover to 71% cover.

The likelihood of Waituna Lagoon flipping may significantly increase if the trend of increasing phosphorus concentrations continues. It could also increase if:

- There was an increase in the percentage of pasture in the catchment, an increase in the intensity of land use or a loss of native plant cover resulting in increased loads of nutrient or sediments;
- The extent of native macrophyte cover was reduced by changes in the salinity or light regime;
- The lagoon was invaded by exotic macrophytes;
- The lagoon or upstream catchment was invaded by coarse fish species (e.g. catfish, goldfish, rudd, tench, or koi carp).

Hamilton, D. P, Jones, H. F. E., Özkundacki, D., McBride, C., Allan, M. G., Faber, J and Pilditch, C. A., 2012. ***Waituna Lagoon Modelling: Developing quantitative assessments to assist with lagoon management.*** **Prepared for Environment Southland by University of Waikato, September 2012. ERI report number 004. 92p.**

A decision support tool has been developed to assist with managing *Ruppia* beds and maintaining the biological diversity of Waituna Lagoon. The results from this tool are presented as outputs from model simulations of physical, chemical and biological variables within the lagoon. Input data for the model simulations were adjusted to simulate sensitivity of the model to (i) input data quality and quantity, (ii) complexity and formulations used in the model itself, (iii) parameters used to adjust physical and biogeochemical environmental responses in the model, and (iv) potential management options. Parts i-iii were necessary to assure a level of confidence in the model so that part iv, the management options, could be used to provide a basis for what might be required to sustain persistent, productive *Ruppia* beds in the lagoon.

Waituna Lagoon, and the wider Awarua complex, was designated a Ramsar site in 1976, signifying a wetland of international importance. The lagoon has high biological diversity and a number of rare and endangered species. New Zealand's obligations to the Ramsar Convention (1971) require that Waituna Lagoon be managed by statutory authorities to preserve habitats that are important to sustain its endemic species. A species that has been identified as critical for sustaining biodiversity in Waituna Lagoon is the macrophyte *Ruppia*, considered a "keystone" species. Two species of *Ruppia* occur in Waituna Lagoon; *Ruppia polycarpa* and *Ruppia megacarpa*, and they are often found within the same ecosystem but are reproductively isolated.

The present report was initiated because of concern that *Ruppia* beds may be threatened by increasing nutrient loads from the catchment, and recent observations of *Ruppia* population decline. Conversions of relatively low-intensity sheep and beef farms to dairy farms over the past 10-15 years, as well as establishment of pasture in areas of peat which would otherwise be inundated during high lagoon water levels will increase nutrient concentrations in tributary and groundwater inputs to the lagoon. A possible sequence of events that would lead to loss of *Ruppia* might be nutrient-stimulated increases in epiphytic algae and macroalgae that would shade and stress *Ruppia* populations and, with further increases in nutrient supply, a subsequent increase in phytoplankton biomass as macroalgae were in turn shaded out by increasing phytoplankton biomass. This sequence (sometimes referred to as a "regime-shift") may be reinforced by loss of stability of the shallower bed sediments as submerged macrophytes disappear, compounding reductions in water column light availability and restricting any regeneration of *Ruppia*.

The modelling approach adopted in this study used a deterministic numerical model (DYRESM-CAEDYM) which required specification of sufficient variables so as to adequately capture the dynamics of the ecosystem. DYRESM-CAEDYM is a coupled hydrodynamic-ecological model that is one-dimensional in spatial representation, i.e., it represents the lagoon as a series of horizontally homogeneous layers that are stacked on top of each other. The state variables selected for the ecological component of the model, CAEDYM, included three groups of phytoplankton (broadly representing cyanophytes, cryptophytes and diatoms), a single group of filamentous macroalgae and a single group that represented the two *Ruppia* species. The inclusion in CAEDYM of the state variables macroalgae and *Ruppia* required development of specific algorithms to represent processes such as shading (e.g., macroalgae that tend to cover and shade *Ruppia*), effects of salinity, and dynamic feedback between *Ruppia* biomass and resuspension of sediment, organic matter and phytoplankton.

An analysis was undertaken to quantify model sensitivity with a view to defining how the simulation was affected by a range of potential errors associated with input data (e.g., meteorology, inflows), selective removal of key state variables and processes (e.g., *Ruppia*, sediment resuspension) and parameters that adjusted the kinetics of biogeochemical processes. The results were not unexpected; *Ruppia* was a key state variable, in agreement with its keystone species status. Macroalgae were also important in terms of their system-wide effects, and sediment resuspension strongly affected all of the primary producers both directly (e.g., via direct transfers of biomass from the bottom sediments to the water column) and indirectly (e.g., via attenuation of light by resuspended sediments). Growth and loss rates for *Ruppia* and macroalgae were identified as sensitive parameters in terms of their effects not only on the biomass of the relevant state variable but also as a result of flow-on effects to many other components of the Waituna Lagoon ecosystem.

The "base" simulation for Waituna Lagoon consisted of obtaining a best fit of simulated state variables to measured (or derived) state variables which included *Ruppia* biomass derived from areal coverage surveys, nutrients (total phosphorus, total nitrogen, nitrate, ammonium and dissolved reactive phosphorus), suspended sediment, chlorophyll *a* (as a proxy for total phytoplankton biomass) and macroalgae biomass (based on visual estimates). The model parameters were adjusted for a calibration period of Oct 2001-Oct 2007 and remained

fixed for a validation period of Oct 2007-Oct 2011. A range of statistical measures was used to assess the model fit for the calibration and validation periods, and these measures indicated that the model fit to the observed data was amongst the best of any applications documented in the literature, despite some limitations imposed by detection limits for nutrients and chlorophyll *a*, and with a caveat that some measures of primary producers were based only on visual assessments of percentage cover (*Ruppia* and macroalgae).
A series of model simulations were run to examine how the model responded to an imposed set of environmental conditions and management regimes different from those of the calibration and validation period. These scenarios were based on scientific inputs provided through the Waituna Lagoon Technical Group, Environment Southland and iwi, and categorised broadly into changes in (i) hydrology and climate, (ii) catchment-derived nutrient and sediments, (iii) both hydrology and nutrients. The scenarios were used to assess whether various management scenarios could meet goals to prevent a "regime shift" and sustain a "healthy" *Ruppia* population in the lagoon. A "healthy" *Ruppia* population was defined as being both abundant and stable, with average *Ruppia* biomass similar to that observed in 2007, a year described by Stevens and Robertson (2007) as having high *Ruppia* coverage, and with minimum biomass not less than that observed in 2009, the beginning of a period of *Ruppia* decline in the lagoon (Robertson and Stevens, 2009; Robertson and Funnell, 2012). A "regime-shift" was defined as an ecological change in which macroalgae and/or phytoplankton dominate primary producer biomass and *Ruppia* biomass declines to very low levels.

The hydrological scenarios involved changes to the lagoon opening regime and demonstrated that the timing and duration of opening of the lagoon had a significant impact on lagoon water quality and ecology. Scenarios that did not include actively managed openings, or raised the opening trigger level so that openings were very infrequent over the simulation period, resulted in a collapse in *Ruppia* biomass as macroalgae and subsequently, phytoplankton biomass increased, meeting the criteria of a "regime shift". The absence of regular tidal flushing of nutrients transported to the lagoon via surface and groundwater inflows, promoted growth of phytoplankton and macroalgae. Hydrological scenarios involving openings ranging from 3-6 months, resulted in biomass of *Ruppia*, macroalgae and phytoplankton similar to the "base" case. These scenarios indicate that it is not possible to maintain a "healthy" *Ruppia* population in the lagoon with changes to the opening regime alone, i.e., nutrient load reductions are required simultaneously. Regardless, opening the lagoon for long periods would represent a shift away from the more natural state of the lagoon as a coastal lake, and towards a periodically estuarine ecosystem.

Current catchment nutrient loads are highly influenced by anthropogenic, or "non-natural", inputs. The nutrient and sediment reduction scenarios that were relatively low in magnitude (i.e., 10-25% reduction of current loads, when current loads may represent c. 100-fold increase in nitrogen and 10-fold increase in phosphorus relative to "natural" loads), resulted in only a small change in modelled variables. Nutrient reduction scenarios that included a reduction in nitrogen loading of 50% or more resulted in increased *Ruppia* biomass, decreased macroalgae biomass and chlorophyll *a* concentrations. There was an approximately proportional reduction in modelled chlorophyll *a* with reductions in nutrient concentrations. A scenario involving a 50% reduction in nitrogen and 25% reduction in phosphorus loading resulted in an abundant and stable *Ruppia* biomass on an inter-annual basis, we well as reduced macroalgae and chlorophyll *a* concentrations.

If the lagoon is not opened at all (i.e. natural opening regime) then very substantial nutrient load reductions (70-90% reduction in nitrogen and phosphorus) are required to obtain a "healthy" *Ruppia* population, and to reduce macroalgae and phytoplankton biomass to low levels. However, 3-month winter openings combined with a 50% reduction in nitrogen loading and 25% reduction in phosphorus loading resulted in a "healthy" *Ruppia* population and reduced macroalgae and phytoplankton biomass, consistent with research on nutrient loading thresholds for sustaining macrophytes in lagoon ecosystems by Scanes (2012), Schallenberg and Schallenberg (2012) and Wriggle (2012).

Simulation of lagoon hydrodynamics with the three-dimensional model (ELCOM) indicated that when the lagoon is open salinity distributions may be horizontally and vertically variable, particularly in the eastern arm of the lagoon. This is an area that has not historically been the focus of water quality monitoring, despite the proximity to *Ruppia* beds in this part of the lagoon. The three-dimensional model simulations also showed substantial short-term variations of the water level (by up to 0.5 m) at the eastern end of the lagoon in association with the strength of the prevailing westerly winds. Anecdotal observations of scouring of accumulated fine sediments during lagoon opening were reinforced in simulations which gave outputs of very high water velocities for grid cells near the lagoon opening during the initial opening phase. A remote sensing scoping exercise was also undertaken in this study which explored the possibility of using Landsat images to measure chlorophyll *a* in the lagoon. However, remote sensing may have limited potential as a water quality monitoring tool for Waituna Lagoon, due to the shallowness and bottom reflectance present.

The model applications to Waituna Lagoon have highlighted complex interactions and processes that have a significant effect on the lagoon ecology. Results from this study are consistent with previous research that suggests that increasing eutrophication in this type of system tends to result in, firstly, dominance of macroalgae over *Ruppia* beds, with subsequent dominance of phytoplankton over macroalgae. Results indicate that it is not possible to maintain an abundant and stable *Ruppia* population in the lagoon with changes to the opening regime alone. If the lagoon is not opened at all, substantial (70-90%) nutrient load reductions are required; alternatively winter openings in combination with nutrient load reductions of 50% nitrogen and 25% phosphorus are likely to maintain a healthy lagoon ecosystem, consistent with other research on nutrient loading thresholds for macrophyte health in coastal ecosystems.

Johnson, P. N., and Partridge, T. R., 1998. *Vegetation and water level regime at Waituna Lagoon, Southland.* Department of Conservation, Science for Conservation: 98. ISSN 1173-2946, ISBN 0-478-21760-9. 34p.

Waituna Wetlands Scientific Reserve is a Wetland of International Importance. Waituna Lagoon, c. 10 x 3 km, is a relatively shallow coastal lagoon, with a bed of quartz gravels and fresh to slightly brackish water, which is normally closed to the sea. Like several other coastal lagoons of its type, it is now subject to a lower-than-natural water fluctuation regime, regular openings being made, especially to maintain drainage of adjacent farmland.

Shore transects, surveyed in relation to water levels, show a generalised sequence of vegetation types from aquatic beds of *Ruppia* and milfoil, to turf of semi-aquatic prostrate herbs, to *Leptocarpus* rushland, to manuka scrub, plus localised sward communities, and gravel beach colonists.

Anecdotal evidence, air photographs, and comparisons of relative plant elevation limits all indicate that *Leptocarpus* rushland has increased in extent, in response to the lowered water regime and to increased sedimentation. A corresponding downslope migration in the woody vegetation zone (including the weedy gorse) has apparently not yet occurred.

Although native plants still dominate the shore vegetation, there remains an ongoing need to maintain control of gorse infestations and vigilance against aquatic weed invasion and the threat of fire. It is not clear whether the present shore vegetation is yet in equilibrium with the current water regime, nor how it might further respond to ongoing inputs of sediment and nutrients from intensified agriculture in the catchments. Further basic hydrological data are required in order to better understand how the lagoon system operates. Whether lagoon levels should be managed to more closely match the natural regime is a question which requires further discussion and inputs from other parties and disciplines. A critical consideration for the management of Waituna, and other coastal lagoons, relates to how such systems will respond to continuing rising sea level.

Kirk, R. M., and Lauder, G. A., 2000. *Significant Coastal Lagoon Systems in the South Island, New Zealand: Coastal processes and lagoon mouth closure.* Department of Conservation, Science for Conservation 146. ISSN 1173.2946, ISBN 0.478.21947.4. 29p.

Two distinctly different kinds of coastal lagoons are identified on the east and south coasts of the South Island, New Zealand. So-called 'river mouth lagoons' (the mouths of the Rakaia and Waiau Rivers) are one type, referred to here as 'hapua'. Published research on the physical evolution and processes of hapua is summarised. The second type is the 'coastal lake', for which the term 'Waituna type' lagoon is used. Waituna Lagoon, Southland, is a quintessential example, others are: Waihora/Lake Ellesmere, Wairau Lagoon, Washdyke Lagoon, and Wainono Lagoon. These lagoons develop landward of barrier beaches formed from sands and gravels mainly derived from greywacke terrains subjected to Quaternary glaciation. Lagoons occur in interfan depressions or at the extremities of major outwash fan complexes, on microtidal coasts with very high wave energies and strong longshore transport of sediments. The coasts are either in erosion, or adjacent to 'hinge-points' around which entire coastlines are rotating to face dominant swell directions. Long-term erosion has greatly reduced present areas of Waituna-type lagoons over the last few thousand years. Entire lagoon systems and interconnections between coastal water bodies have been lost. Waituna-type lagoons are normally closed to the sea. Accumulated head, and scour by the water in the lagoons opens them. Wave processes, particularly longshore transport in storms, close them. Artificial opening of Waihora/Lake Ellesmere and Waituna has increased the frequency and duration of openings and lowered water levels. This has greatly reduced areas, water volumes, and wind-driven processes (waves, seiches, and currents) in the lagoons. US research on mid-latitude coastal lagoons shows that relative sedimentation rate is critical. Where rates are faster than sea level rise, lagoons will infill and be short-lived. Where sedimentation rates and sea level rise are roughly equal, a lagoon will maintain a constant water volume while sediments accumulate. Where sea level rise is faster than sedimentation, relative deepening will occur and the water volume will increase. Obtaining adequate data on sedimentation rates in Waituna-type lagoons is a high priority for their management.

Larkin, G., 2013. *Waituna Lagoon Mechanical Opening Site Assessment.* Prepared for Environment Southland, February 2013. 34p.

The Waituna Lagoon is manually opened to the Southern Ocean at Toetoes Bay, primarily for the purposes of improving the effectiveness of farm drainage.

The ecological effects of mechanical openings of the Waituna Lagoon is very complex, involving many variables, most of which are not yet quantified. The openings reflect a type of ecological 'trade off' between flushing nutrient laden water and sediment out of the lagoon in order to prevent (blah blah) ecological effects, versus the adverse ecological impacts which occur when the lagoon is opened such as of loss of vegetative habitat through drying, desiccation and sand intrusion.

Following an opening, the lagoon closes naturally due to sediment build-up. This can occur over a period of anywhere between a few weeks to over a year depending on a number of factors including wind direction and speed, tides, etc. Current understanding of the near shore environment is limited due to its inherently chaotic nature. This makes it very difficult, if not impossible, to predict when mouth closures will occur with any level of certainty. The monitoring record of opening/closing cycles is also very limited with knowledge based largely on anecdotal evidence and historical openings at only one of the four opening locations.

The objective of this report is to describe the benefits and risks of mechanical opening at four locations in Waituna Lagoon. Both positive and negative ecological effects are considered with a primary focus on *maximising the removal of nutrient laden water and sediment, whist minimising stress to macrophyte beds*. This report is intended to provide supporting information for the Lagoon Technical Group and should not be used in isolation when considering lagoon opening management or likely negative ecological effects from mechanical openings.

The advantages and disadvantages of each location considered are summarised below.

Walkers Bay

- Good flushing potential due to lagoon bed channels, but offset by longer opening period and sand intrusion which is filling the bay;
- Overall cost is same as Charlie's Bay, but both sites double the cost of the Eastern End; and,
- Little physical scouring of macrophytes in Bay as cover general low but offset by un-favourable growing habitats and higher salinities in main body of lagoon which hinder recovery.

Charlie's Bay

- Currently moderate flushing potential but offset by requiring several more openings to 'train' lagoon channels to maximise the flushing ability;
- Cost of opening same as Walkers but double that of Eastern End sites;
- Physical scouring effect outside Bay will be limited, but offset by compete removal of macrophytes inside the Bay;
- Saline waters takes 2-3 weeks to reach far western end of Lagoon but offset by very high salinities in the Central and Eastern macrophyte area; and,
- Return to low salinity conditions same as Walkers Bay even though further from Freshwater inputs.

The 'Fence' and Far Eastern End

- Local evidence suggests flushing potential to be large but offset by site not been utilized since mid-1970's;
- Historically had quick mouth closures but this would require several 'trials' to verify;
- Digger cost cheaper than Charlie's and Walkers Bay but is offset by both sites would require multiple openings to remove localised sediment build-up;
- The Far Eastern End site is likely to be only site of the four to trial assisted 'pitch' mouth closure;
- Macrophyte scouring is likely to be very significant from these two sites
- Salinities in the main lagoon lower 10-20 ppt (parts per trillion) due to distance, tidal head difference and tide times required but offset by very high salinities 30-35 ppt in the Central and East of the lagoon; and,
- Return to low salinity conditions (<8 ppt) in the shallower edge habitats where macrophytes exist possible < 6 weeks but offset by reduced fetch and wind mixing which leads to salinity stratification in the deeper main channel.

The selection of a single favoured location is difficult because each location has site specific advantages and disadvantages compared to each of the other locations. In addition, the assessment in this report is based on information from, at most, a few opening events at each site with the exception of the Walkers Bay site. It is important to consider the accumulative effects of continual usage of a specific opening location and its wider effect to the remaining lagoon ecology. For example, the continual reliance on Walkers Bay opening site over the last 20 years has created a well-defined series of lagoon channels. This has then favoured good flushing events but also longer opening durations, marine sand intrusion and no chance of recovery of macrophytes in the central part of Walkers Bay.

Further geomorphological and surveying work may assist in addressing some of the existing knowledge gaps however to accurately determine the optimal time and location for mechanical opening, three locations (Charlie's Bay, the Fence and the Far Eastern site) will require 'trial' openings.

It is recommended that future management of the Waituna Lagoon openings consider introducing a rolling opening location schedule across all of the four locations. The schedule should consider a range of factors including the condition and combination of the:

- Season (winter versus early summer);
- Life-stage of the macrophytes;
- Lagoon turbidity;
- Tide cycle (neap tide versus spring tide); and,
- Wind direction and speed.

Opus International and SKM, 2011. *Waituna Lagoon Management Study Stage One – Urgent Measures Report.* Prepared for Environment Southland, July 2011. 21p.

Coastal lagoons in good ecological health are becoming rarer around the World, and are of high conservation and ecological importance, as evidenced by the international Ramsar designation for Waituna Wetland. Seagrass (Ruppia) is regarded as a 'keystone' species to indicate the ecological health of the lagoon. Over recent years the extent of healthy seagrass beds has reduced considerably at the same time as the clarity and quality of the lagoon water has decreased. This is thought to be associated with a rapid rise in nutrient load in the lagoon as a result of run-off from the increasing agricultural intensification of the catchment.

There is concern that the lagoon could 'flip' to a phytoplankton/algal dominated state which would have a significant negative impact on the quality of the lagoon. Previous experience is that once a lagoon has flipped, it very rarely reverts to its original condition (see Hamill 2010), instead assuming an altered steady state. For example Lake Ellesmere in Canterbury is a coastal lagoon of a similar type, this flipped in 1968, and still remains in a super-eutrophic state of very low ecological value, even though it continues to be mechanically opened to the sea when water levels triggers are met (Schallenberg et al 2010), and despite intensive monitoring and management.

The most sustainable solution for Waituna Lagoon would be to manage land-use in the catchment to reduce the nutrient and sediment load entering the lagoon. This is recognised by many parties, but is likely to take some time (upward of two years) before it can achieve a tangible improvement.

Consequently, at the same time as pursuing this more long-term solution, there needs to be immediate action taken to stop the lagoon from 'flipping' within the next two years.

This report assesses what urgent actions can be taken and recommends that a breach be formed in the beach at Charlies Bay at an appropriate time around the end of July 2011.

Roberston, B[1], Stevens, L[1], Schallenberg, M[2]., Robertson, H[3]., Hamill, K[4]., Hicks, A[3]., Hayward, S[5]., Kitson, J[6]., Larkin, G[6]., Meijer, K[6]., Jenkins, C[6]., Whaanga, D[7]., 2011. *Interim Recommendations to Reduce the Risk of Waituna Lagoon Flipping to an Algal-Dominated State.* Prepared by the Lagoon Technical Group, 26th May 2011; Wriggle Coastal Management[1], University of Otago[2], Department of Conservation[3], Opus International Consultants[4], DairyNZ[5], Environment Southland[6], Te Ao Marama Incocporated[7]. 16p.

Waituna Lagoon is currently considered to have a high likelihood of "flipping" from its high value clear-water, seagrass (*Ruppia*) dominated state, to a highly undesirable turbid, algal dominated (phytoplankton/epiphytic) state due to excessive inputs of nitrogen, phosphorus, and sediment from intensification of landuse in the catchment. In response, Environment Southland (ES) has convened a Lagoon Technical Group (LTG) to provide short-term immediate guidance to minimise the risk of the lagoon flipping and identification of a recommended pathway for the long-term management of lagoon condition.

The following recommendations are preliminary and based on the best knowledge on the Waituna Lagoon system, however there are information gaps and as such these recommendations will be reviewed six-monthly and updated. These preliminary recommendations are viewed as necessary due to the urgency and risk of the lagoon flipping and to inform the research needs and mitigation work within the Waituna Lagoon catchment.

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

The key recommendations from this document are:

1. Short term immediate guidance to minimise the risk of lagoon flipping:
    - water quality targets for lagoon health;
    - recommendations for lagoon sediment and nutrient load reductions;
    - lagoon opening/closing decision criteria;
    - monitoring recommendations;
    - recommendations for further research;
    - role of the Lagoon Technical Group (LTG).

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

Robertson, B., and Stevens, L., 2012. ***Guidance Document: Nutrient Load Criteria to Limit Eutrophication in Three Typical New Zealand Estuary Types – ICOLL's, Tidal Lagoon and Tidal River Estuaries.*** **Prepared for Environment Southland by Wriggle Coastal Management, August 2012. 8p.**

Catchment runoff and point source discharges can carry excessive nutrients to the coast. Excessive nutrients (nitrogen and phosphorus) lead to eutrophic coastal habitats, particularly estuaries and inshore coastal areas, which reduces human use and ecological values. Eutrophication is defined as "enrichment of water by nutrients, especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned" (Websters On-Line Dictionary).

Eutrophication causes changes in plant and animal communities, favouring rapidly reproducing opportunistic algal and animal species. Opportunistic algal species in particular can adversely affect ecosystems. For example, mass occurrences of phytoplankton and/or macroalgae and epiphytes often lead to the loss of long-lived seagrass species through direct displacement, or creation of sub-optimal growing conditions. When the nutrients fuelling excessive algal growth have been depleted, the algal blooms decay, leading to oxygen depletion, possible kills of fish and benthic invertebrates, and the formation of toxic hydrogen sulphide (H2S).

As well as causing impacts on the ecosystem, eutrophication can also affect human activities. For example, algal blooms and decaying algae can clog fishing nets, create unsightly foam masses on beaches, and cause unpleasant smells that interfere with tourism and recreation. Although some algae produce toxins that can harm humans through consumption of contaminated shellfish, the link to nutrient enrichment is uncertain.

In many countries around the world, nutrient guidelines for coastal waters have been set or are close to being set. A summary of the various approaches is provided in Appendix 1. In Australia and New Zealand (NZ), the ANZECC (2000) guidelines, developed primarily for freshwaters, provide some precautionary and limited guidance for estuaries and marine waters. However, they are widely acknowledged as being inappropriate for NZ estuaries and coastal waters, particularly the common shallow well-flushed tidal lagoon and tidal river estuaries.

In NZ, significant eutrophication problems generally only occur in shallow estuaries and bays with restricted circulation. This is attributed to the fact that in well-flushed estuaries (e.g. tidal river and lagoon estuaries), the majority of the nutrient loads are flushed out to sea. In shallow intermittently open closed lakes or coastal lagoons (ICOLL's) where residence time often greater than 100 days - e.g. Waituna Lagoon, Southland, nutrient loads are retained to an increasing extent as water residence time increases.

As such, sensitivity to nutrient loads, and consequent eutrophication, is greatest in shallow ICOLL's. Sensitivity to eutrophication is in the moderate category for shallow tidal lagoon estuaries (water residence times <3 days and always open to sea - e.g. New River Estuary, Southland), and least sensitive in shallow tidal river estuaries with limited stratification (residence time < 0.1 day - e.g. Rowallan Burn, Southland). The following sections provide information to help identify appropriate nutrient load criteria for each of these three estuary types.

1. ICOLL's - Most Sensitive to Nutrient Loads

Maintenance of a healthy rooted aquatic plant community (particularly seagrasses like *Ruppia* sp.) is considered the most appropriate guideline for ensuring no eutrophication of ICOLL's (Lagoon Technical Report 2011). To achieve this, co-management of both N and P is likely to be required given that nutrient limitation can vary with salinity, season, and/or plant species composition (Boesch 2002). Management options that aim to reduce only one nutrient should be considered with caution and need to extend beyond the sole consideration of limiting planktonic biomass.

Scanes (2012) examined 57 ICOLLs in New South Wales, Australia and assessed their condition as described by chlorophyll a, TN and TP, as well as the nutrient and sediment loads derived from their catchments. From this dataset, nutrient load criteria were derived to provide for "moderate environmental quality" (including maintenance of seagrass communities) as follows; 25 mg.m-2.d-1 for N, and 1.6 mg.m-2.d-1 for P.

A recent review of nutrient loading thresholds for NZ, Australian and overseas ICOLL's by Schallenberg and Schallenberg (2012), found that although variable factors such as water residence time, opening regime, fetch, and sediment characteristics will also affect the thresholds in specific systems, there was convergence with regard to nitrogen loading rates that negatively affect seagrass communities. Their review indicated N areal loading rates of <30 mg.m-2.d-1 were needed to safeguard seagrass communities in ICOLL's.

2. Tidal Lagoon Estuaries - Moderately Sensitive to Nutrient Loads
Maintenance of an estuary with a low abundance of nuisance macroalgae is considered the most appropriate guideline for ensuring no eutrophication of shallow tidal lagoon estuaries. These are estuaries with large basins that are mostly drained at low tide and where phytoplankton growth is limited by the high flushing rate. By meeting this criteria, a healthy seagrass community is expected to be maintained. While, a number of variables (e.g. tidal range, wind fetch, and sediment loads) can influence macroalgal growth in shallow estuaries, in general the major driver is considered to be nutrient loads. Management of nitrogen is recommended as tidal lagoon estuaries are generally nitrogen-limited with respect to the potential for the development of eutrophic conditions (USEPA 2010).

A review of available monitoring data for representative NZ shallow tidal lagoon estuaries with short residence times and variable areas of saltmarsh (Appendix 1, Figure 1), indicated that nuisance macroalgal blooms occur when N areal loads exceed ~50 mg.m-2.d-1 (Figure 1). This is consistent with guidelines and results for overseas estuaries as follows:

- 50 mg.m-2.d-1 guideline set by Heggie (2006) as a conservative estimate to avoid eutrophication and triggering of significant ecological changes for tidal lagoon estuaries of temperate Australia.
- Eelgrass loss began to occur at N loads above 18.2 mg.m-2.d-1 and eelgrass disappeared at 36.5 mg.m-2.d-1 (Latimer and Rego 2010), in New England estuarine systems.

3. Tidal River Estuaries - Moderately Sensitive to Nutrient Loads
Like tidal lagoon estuaries, maintenance of a low abundance of nuisance macroalgae is considered the most appropriate guideline for ensuring no eutrophication of shallow tidal river estuaries. These are estuaries with relatively narrow channels/basins, and where phytoplankton growth is very limited by the high flushing rate. Seagrass growth is often limited in such estuaries by low salinities and muddy conditions.

These estuaries are much less sensitive to nutrient inputs and available monitoring data indicates that nuisance macroalgal blooms do not occur until N areal loads exceed much higher loads (preliminary data indicates a load of approximately 750 mg.m-2.d-1 for such estuaries - Appendix 1, Figure 2). While such a limit appears appropriate to protect against nuisance blooms within tidal river estuaries, the supply of high concentrations of nutrients can still result in localised blooms of nuisance algae like *Bachelotia* in the nearshore coastal zone.

Preliminary guidance for determining appropriate nutrient loading criteria to limit eutrophication symptoms in three typical NZ estuary types is proposed as follows:

Estuary Type	N Areal Load	P Areal Load
Shallow NZ ICOLL's	<30 mg.m-2.d-1	<1.5 mg.m-2.d-1
Shallow Tidal Lagoon Estuaries	<50 mg.m-2.d-1	Not applicable
Shallow Tidal River Estuaries	<750 mg.m-2.d-1	Not applicable

Nitrogen has been identified as the element most limiting to algal production in most coastal marine ecosystems in the temperate zone and is therefore the preferred target for eutrophication management (Howarth and Marino 2006). In ICOLL's, which vary between marine and near-freshwater salinities, a co-limiting situation between N and P is expected and management of both N and P is likely to be required.

It is anticipated that the above criteria will facilitate decision-making in relation to setting appropriate nutrient loading criteria for Waituna Lagoon, Southland, and in particular help support the catchment nutrient load recommendations to be used in the Waituna Lagoon model scenarios. It is emphasised that the 2010 estimated N and P areal loads to Waituna Lagoon were approximately 50 mgN.m-2.d-1 and 2 mgP.m-2.d-1 and therefore well above the preliminary criteria recommended for shallow NZ ICOLL's.

Robertson, B., 2012. *Proposed Eutrophication Criteria for New Zealand Tidal Lagoon Estuaries.* Prepared for Environment Southland by Wriggle Coastal Management, July 2012. 7p.

Introduction
Catchment runoff and point source discharges can carry excessive nutrients to the coast. Excessive nutrients (nitrogen and phosphorus) lead to eutrophic coastal habitats, particularly estuaries and inshore coastal areas, which reduces human use and ecological values. Eutrophication is defined as "enrichment of water by nutrients especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned."

Eutrophication causes changes in plant and animal communities, favouring rapidly reproducing opportunistic algal and animal species. Opportunistic algal species can adversely affect ecosystems. For example, mass occurrence of phytoplankton and/or macroalgae and epiphytes often leads to loss of long-lived seagrass species. Once the nutrients have been depleted, the algal blooms decay, leading to oxygen depletion, possible kills of fish and benthic invertebrates, and the formation of toxic hydrogen sulphide (H2S).

As well as causing impacts on the ecosystem, eutrophication can affect human activities. For example, algal blooms and decaying algae can clog fishing nets, create unsightly foam masses on beaches and unpleasant smells that interfere with tourism and recreation. Although some algae produce toxins that can harm humans through consumption of contaminated shellfish, the link to nutrient enrichment is uncertain.

Eutrophication problems in coastal New Zealand are relatively widespread but mainly limited to estuaries and bays with restricted circulation.

In many countries around the world, nutrient guidelines for coastal waters have been set or are close to being set. In Europe in the North Atlantic area, guidelines were put in place in the 1990's to achieve reductions in inputs of nitrogen and phosphorus to areas affected or likely to be affected by eutrophication, in the order of 50% compared to input levels in 1985 (OSPAR 2008). In 2005, six of nine reporting countries met the 50% reduction target for phosphorus and three for nitrogen. In the US, the EPA is currently setting numeric criteria for estuaries and coastal waters (deadline August 2012). Currently, NZ has not set numeric nutrient guidelines for its estuaries and coastal waters.

Nitrogen has been identified as the element most limiting to algal production in most coastal marine ecosystems in the temperate zone and therefore the preferred target for eutrophication management (Howarth and Marino 2006). In ICOLL's, which vary between marine and close to freshwater salinities, a co-limiting situation between N and P is expected.

Predictive methods for assessing the vulnerability of coastal ecosystems to eutrophication in other countries has primarily revolved around three main approaches: the setting of guidelines or thresholds based on available data and expert judgement, the establishment of empirical relationships and the development of numerical modelling tools. Guidelines or thresholds and empirical relationships (e.g. nutrient loads that cause eutrophication) are the most preferred methods for assessing eutrophication susceptibility and existing condition. Numerical modelling tools are available but are considered too complex and waterbody-specific for application in a broad-brush coastal risk assessment process.

Conclusion
Preliminary data from representative shallow tidal lagoon and tidal river estuaries in New Zealand suggest that the susceptibility to eutrophication symptoms, as indicated by macroalgal cover (the primary eutrophic symptom for such waterbodies), increases as the flushing potential declines and reaches nuisance conditions at the following approximate N areal loadings:

- Tidal lagoon estuaries 50 mgN.m-2.d-1
- Tidal river estuaries 750 mgN.m-2.d-1

Such findings, strongly suggest that for estuaries with even lower flushing potentials and water residence times to tidal lagoon estuaries (e.g. ICOLL's like Waituna Lagoon), one can expect nuisance algal growth at much lower nitrogen areal loadings.

Robertson, H, A, and Funnell, E, P., 2012. Aquatic plant dynamics of Waituna Lagoon, New Zealand: trade-offs in managing opening events of a Ramsar site. *Wetlands Ecology and Management*, 1:13.

Coastal lagoons are at risk internationally due to impacts associated with human-induced land use change. The resilience of aquatic macrophytes in these systems is threatened by altered hydrological regimes, elevated nutrient loading, and increased dominance of nuisance species. We describe the aquatic plant dynamics of the Waituna Lagoon Ramsar Site, a 1,350 ha lagoon frequently opened to the sea for flood mitigation which is characterised by fluctuating water levels and salinity. The shallow lagoon supports a macrophyte community dominated by *Ruppia megacarpa* and *R. polycarpa*. Repeated survey of 48 sites across the lagoon during late summer in 2009, 2010 and 2011 were applied to describe aquatic plant composition and abundance. This period coincided with three opening events (winter 2008; winter 2009; spring 2010) when the lagoon switched from a predominantly fresh-brackish system to being influenced by tidal exchange and lower water levels. The lagoon experienced a period of 43 days open to the sea in 2008–2009, 67 days in 2009–2010 and 181 days in 2010–2011, during which macrophytes were subject to saline conditions in excess of 10 ppt. We observed a decline in the occurrence of *Ruppia* from 2009 (69 % sites) to 2011 (23 % sites). The shift in productivity was associated with the duration of the open phase and the period plants were subject to saline conditions >20 ppt and low water levels. The resilience of the system is also at risk from increased algal-dominance due to the intensification of agricultural land use occurring in the Waituna Lagoon catchment. While lagoon opening events cause extreme changes in water depth and salinity that can limit macrophyte growth, they also provide a mechanism to reduce the effects of eutrophication. Understanding these trade-offs is pivotal in management decisions regarding the likely impact of opening events on the ecological character of coastal lagoons.

Scanes, P., 2012. ***Nutrient Loads to Protect Environmental Values in Waituna Lagoon, Southland, New Zealand.*** **Prepared for Environment Southland, May 2012. 10p.**

Conclusion and Recommendations

The ecological condition of Waituna lagoon is clearly deteriorating (Stevens and Roberston 2007, Robertson et al. 2011). Eutrophication and loss of benthic macrophytes is occurring in Waituna, most probably as a result of excessive nutrient loading from the catchment exacerbated by salinity stress, desiccation and loss of habitat from the opening of the lagoon to the sea to alleviate farm inundation. There is a concern that if this trajectory is allowed to continue, then a state change from clear, healthy seagrass dominated community to a turbid pelagic dominated community is a real possibility. If this occurs it will have an extensive impact on the environmental and cultural values of the lagoon. As indicated previously, a common feature of changes of state from benthic dominance to pelagic dominance is a hysteresis response. Given this, it is clearly preferable and considerably cheaper to take action now to prevent the change of state from occurring, than to try and restore the lake in the future.

Comparisons were made between the loads expected for moderately and highly disturbed estuaries in NSW and the estimates for Waituna for 2010. The 2010 estimates for Waituna were used because they are the most recent and the data show a trend for loads to be increasing each year in Waituna.

The TN loads for Waituna estimated for 2010 (Table 2) are well in excess of the mean (and median) values for estuaries with highly disturbed catchments (TN, 19 (Waituna) c.f 12.76 (mean NSW)) and the consequences are evident in the current loss of environmental values being experienced in Waituna. TP loads for Waituna were however slightly lower than highly disturbed NSW estuaries (0.74 (Waituna) c.f 1.05 (mean NSW)). This is most probably a consequence of slightly differing landuses resulting in different proportions of nutrients being generated. It also suggests that Waituna is particularly sensitive to increased P loads, showing symptoms of degradation and lower loads than similar systems from NSW. The analysis of catchment loads from similar NSW lagoons would suggest that the loads required to maintain a moderate environmental quality (some eutrophic symptoms but still supporting healthy seagrass and fish communities) would be total nitrogen and total phosphorus loads of 9 and 0.57 t/km2/yr (respectively). This represents a 52% reduction in TN load and a 23% reduction in TP load over 2010 conditions in Waituna Lagoon (Table 3).

In light of the somewhat lower TP load in Waituna, it may be tempting for decision makers to consider reductions in just one nutrient (either N or P), but a recent review by Glibert et al. (2011) has shown that strategies which manage a single nutrient, rather than both N and P, have the potential to significantly skew and alter ecological assemblages resulting in a wide range of unintended consequences including facilitation of invasive organisms.

Table 3 Comparison of TN and TP loads (t/km2/yr) from NSW and Waituna Lagoon.

	Waituna 2010	NSW Mean (moderate disturbance)	% Reduction Required	NSW Mean (low disturbance)	% Reduction Required
Total Nitrogen	19	9	52%	3.9	79%
Total Phosphorus	0.74	0.57	23%	0.21	72%

Table 4 Recommended interim TN and TP load targets (t/km2/yr) to maintain Waituna Lagoon in a moderate ecological condition (some eutrophic symptoms but still supporting healthy seagrass and fish communities)

	Interim Target Loads for Waituna Lagoon	% Reduction Required from Current Waituna Loads
Total Nitrogen	9	52%
Total Phosphorus	0.57	23%

Overall Conclusion

In order to prevent a drastic and potentially irreversible change to the ecological character of Waituna Lagoon, it is recommended that, as an interim step, the mean nutrient loads of both N and P associated with NSW estuaries that have moderately disturbed catchments be adopted as interim load targets (Table 4) while a more detailed assessment is made of the ecological condition of Waituna Lagoon and it's response to stressors such as catchment derived nutrients, entrance manipulation and salinity stress.

Schallenberg, M., and Tyrrell, C., 2006. *Report on Risk Assessment for Aquatic Flora of Waituna Lagoon.* , L., 2012. *Eutrophication of Coastal Lagoons: A Literature Review.* Prepared for Environment Southland by Hydrosphere Research Ltd, July 2012. 43p.

1. This study was undertaken to assess threats to aquatic macrophyte (see glossary) communities in Waituna Lagoon, Southland.
2. The study drew on:
   i) Samples collected and measurements made during a field trip to Waituna Lagoon,
   ii) datasets of water level, opening regime, and water quality of the lagoon,
   iii) published and unpublished reports, and
   iv) published scientific peer-reviewed literature.
3. The aquatic plant, horse's mane weed (*Ruppia megacarpa*) is a keystone species in Waituna Lagoon because of its importance as a habitat for invertebrates (see glossary) and fish, as a food source for invertebrates and waterfowl, and its role in regulating water quality. The macrophyte community of Waituna Lagoon appears to be unique in New Zealand and is similar to that which existed in Waihora/Ellesmere prior to the Wahine storm of 1968.
4. The distribution of the macrophyte community in Waituna Lagoon is delineated by a lower depth threshold caused by light limitation and an upper growth limit caused by wave wash and desiccation. Extended periods of high water are detrimental to the macrophyte community because the variable threshold of light limitation approaches the upper growth limit.
5. Maintenance of a high light environment is essential to macrophyte survival. Therefore, high water levels should persist for less than 2 months to ensure macrophyte growth is not light limited for prolonged periods of time. Phytoplankton (see glossary) biomass and suspended sediment concentrations also reduce light penetration and reduce the habitat for macrophyte growth. Phytoplankton appear to be phosphorus limited at times. Therefore, the reduction of phosphorus availability in the lagoon currently represents the best means for controlling phytoplankton growth and biomass accumulation. Excess nitrogen is available in the lagoon, indicating the increases in phosphorous loading may result in increased phytoplankton biomass and reduced light penetration.
6. Since 1975, the opening regime has tended towards maintaining the lagoon in an open state for longer periods of time, probably resulting in higher mean salinities in the lagoon. As the optimum growth rates of *Ruppia* are between 4 and 8 ppt salinity, the opening regime may be increasingly subjecting *Ruppia* to suboptimal growth rates. Studies on *Ruppia* from Lake Ellesmere/Waihora and overseas, show that *Ruppia* seed germination and seedling establishment require periods of low salinity, and that seedling growth is reduced under low light levels associated with high turbidity. Light studies are required to see whether closing Waituna Lagoon in spring (October/November) allows sufficient light penetration to create the condition of low salinity followed by high light, which is desirable for effective seedling recruitment
7. Various threats to the maintenance of *Ruppia* beds in the lagoon may result in catastrophic macrophyte loss, with subsequent establishment of undesirable plankton (see glossary) dominance. Although our available data is inadequate to quantify risk probabilities, our current light model shows that in the event of the lagoon 'flipping' to a phytoplankton-dominated state, the present light climate and opening regime would not allow for the regrowth of *Ruppia* beds in Waituna lagoon.
8. Climate change presents new potential threats to the macrophyte community, and the ecology of the lagoon. Increasing westerly and south-westerly winds are likely to uproot macrophyte communities and increase sediment resuspension in the lagoon. Increasing precipitation is likely to result in greater nutrient and suspended sediment inflows to the lagoon. Sea level rise will likely increase the salinity in the lagoon but could benefit the aquatic macrophyte community by potentially reducing water level variation in the lagoon. On the scale of decades, changes to coastal geomorphology (such as the gravel bar barrier) will impact on the lagoon and its long-term sustainability will depend on the balance between sea level rise and increasing sediment inputs from both terrestrial and marine sources.
9. Published research on similar temperate lagoon systems with similar threats in Australia and the USA is relevant to the Waituna Lagoon ecosystem. Furthermore, the history of Waihora/Ellesmere (Canterbury) illustrates the serious consequences of ignoring the ecological processes at work in the lagoon, and of failing to sustainably manage these important and as yet poorly understood ecosystems.
10. Recommendations for the sustainable management of the aquatic plant communities of the lagoon ecosystem are listed on page 44 of this report.

Schallenberg, M., Larned, S. T., Hayward, S., and Arbuckle, C., 2010. Contrasting effects of managed opening regimes on water quality in two intermittently closed and open coastal lakes. ***Estuarine, Coastal and Shelf Science*** **(2010)1-11.**

Intermittently closed and open lakes and lagoons (ICOLLs) are shallow barrier lakes which are intermittently connected to the sea and experience saline intrusions. Many ICOLLs are mechanically opened to prevent flooding of surrounding agricultural and urban land and to flush water of poor quality. In this study, the effects of modified opening regimes (frequency and duration of barrier openings and closures) on water quality and phytoplankton in two New Zealand ICOLLs were investigated over a number of opening/closure cycles. Water quality in Lake Ellesmere (Te Waihora) responded weakly to both opening and closing events, indicating that sea–ICOLL exchange did not markedly improve water quality. Conversely, water quality in Waituna Lagoon responded rapidly to barrier openings; water level decreased to near sea level within days of opening and subsequent seawater exchange resulted in rapid decreases in nitrate and chlorophyll a concentrations. The closure of Waituna Lagoon resulted in rapid rise in water level and a pulse of nitrate and phosphorus in the water column and phytoplankton chlorophyll a concentrations increased with increasing closed-period duration. Based on data on the underwater light climate and nutrient dynamics, phytoplankton in Lake Ellesmere was probably lightlimited, whereas phytoplankton in Waituna Lagoon was rarely light-limited, and appeared to be predominately P-limited. The marked differences in responses of Lake Ellesmere and Waituna Lagoon to barrier openings and closures reflected differences in ICOLL water levels and morphological characteristics, which dictated the degree of tidal flushing when the barriers were open. The inter-ICOLL differences observed in this study indicate that unless the effects of ICOLL openings/closures on phytoplankton and nutrient dynamics are understood, changes to ICOLL opening regimes may have unintended consequences for the water quality and ecology of these systems.

Schallenberg, M., and Schallenberg, L., 2012. *Eutrophication of Coastal Lagoons: A Literature Review.* Prepared for Environment Southland by Hydrosphere Research Ltd, July 2012. 43p.

Summary

- This literature review was undertaken to help inform the management of Waituna Lagoon and, specifically, to obtain guidance from previously published work on nutrient and sediment loading rates that are compatible with Ruppia or other seagrass communities.

- In this report we summarise published studies, the available 'grey' literature and some unpublished data that are relevant to the seagrass, macroalgae and phytoplankton dynamics in Waituna Lagoon.

- Our survey of the published literature revealed that the majority of information relevant to the aims of this report comes from studies of the multitude of ICOLLs and lagoons in southern Australia.

- In particular, the ICOLLs, Lake Illawara, Wilsons Inlet and Smiths Lake in Australia and East Kleinemonde Estuary in South Africa show strong similarities to Waituna Lagoon and a deeper study of their dynamics could improve understanding of the functioning of Waituna Lagoon.

- A number of models have been developed for ICOLLs and lagoons. Some are specific to a particular ICOLL (e.g. the model of Everett et al. (2007) of Smiths Lake) whereas others are more easily scalable to Waituna Lagoon (e.g. the model of the model of Sanderson & Coade, (2010)). The model of Webster & Harris (2004) also appears applicable to Waituna Lagoon and has been developed to simulate regime shifts and changes in denitrification efficiency, which indicates that it may be appropriate for scenario forecasting for Waituna Lagoon.

- A number of studies have demonstrated useful relationships across a wide range of ICOLLs and lagoons. These often showed consistent nutrient thresholds for seagrass collapse which generally lie between 20 and 100 kg N/ha/y, with the threshold for many ICOLLs in the lower end of this range. The nutrient thresholds for seagrasses are compared and summarised in this report and thresholds for macroalgae and dentirification are also presented. In addition, estimates of N loading for Waituna Lagoon and Lake Ellesmere/Te Waihora are compared to the empirical thresholds, indicating that N loading in these ICOLLs exceeds the published thresholds for seagrass health.

- This literature review has identified detailed studies on individual ICOLLs, ICOLL models of different types, and empirical relationships among ICOLLs, lagoons and embayments which help place Waituna Lagoon in to a broader context and could potentially provide guidance as to the management and restoration of Waituna Lagoon.

Stevens, L., and Robertson, B., 2007. *Waituna Lagoon 2007: Broad Scale Habitat Mapping and Historical Sediment Coring.* Prepared for Environment Southland by Wriggle Coastal Management, October 2007. 33p.

Overivew
In the 1990's, Environment Southland (ES) established a long-term monitoring programme to assess some of the major issues faced by New Zealand estuaries using the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002). The programme, being undertaken in a staged manner in Southland's key estuaries, includes Waituna Lagoon (1,350ha), and its associated wetland (~2,200ha), centred in Toetoes Bay in Eastern Southland.

Waituna Lagoon has been identified as having a high risk of nutrient, sedimentation, pathogen and, to a lesser extent, habitat loss problems (Johnson & Partridge 1998, Thompson & Ryder 2003, Cadmus & Schallenberg 2007, Schallenberg & Tyrrell 2007). ES contracted Wriggle Coastal Management (Wriggle) to undertake an Ecological Vulnerability Assessment (see Stevens and Robertson 2007) to determine monitoring and management priorities, and a series of monitoring studies in February/March 2007 to provide a baseline against which change can be measured. The present report summarises the results of the 2007 monitoring for Waituna Lagoon, which included the following work:

- Broad scale mapping of sediment types.
- Broad scale mapping of lagoon depth.
- Broad scale mapping of wetland vegetation.
- Broad scale mapping of macroalgal beds (i.e. sea lettuce (*Ulva*), *Gracilaria, Enteromorpha*).
- Broad scale mapping of the 200m terrestrial margin vegetation surrounding the estuary.
- Broad scale mapping of terrestrial vegetation within the RAMSAR site.
- Assessment of the recent historical sedimentation rate (using radio-isotopes).
- Establishment of sediment rate monitoring plates.

In addition, the present report includes the results of work Wriggle undertook for the Department of Conservation Southland Conservancy (DOC) at the same time:

- Broad scale mapping of the dominant lagoon macrophyte - *Ruppia* - see Robertson & Stevens (2007a).

The methods used are based on the broad scale habitat mapping tools described in the EMP (Robertson et al. 2002), and a number of extensions to the EMP and its monitoring outputs developed by Wriggle (see Robertson & Stevens 2006, 2007b).

The extensions include:

- Monitoring sedimentation rate.
- Mapping the percent cover of nuisance macroalgae.
- Mapping the percent cover of aquatic macrophytes.
- Mapping the 200m terrestrial margin vegetation/landuse.
- Development of condition ratings for reporting.

The results of the monitoring undertaken in Waituna Lagoon are summarised below:

Sedimentation Type: A variety of sediment types occur in the lagoon. Unvegetated sediment (total area 1,365ha) was dominated by firm sand (38%) located mainly in the central basin towards the lagoon mouth, mixed soft mud sand and gravel (28%) predominantly in the eastern arm, and gravels (20%) mostly around the lagoon margin. The extent of soft mud/sand in the lagoon where there was no gravel was relatively low (12%), but overall soft mud was present across 42% of the lagoon. This excludes mud deposited in the rushland when the lagoon level is high. Very soft muds (2%) were mainly associated with small, narrow sediment plumes near the stream mouths, and in the western embayment. There were localised areas of anoxic sediments associated with macroalgal mats and inflowing streams.

Sedimentation Rate: The historical sediment core collected near the mouth of Waituna Creek had three visually distinct layers. The top 6cm was well oxygenated firm sand/mud overlying a crumbly brown organic layer that extended to 18cm. Below this depth the core was predominantly peat, with sand mixed in with the peat below 22cm to the bottom of the core (33cm). Radio-isotope dating using Caesium (137Cs) activity indicated a gross sedimentation rate over the past 47 years (1960-2007) of 2.5-3.0mm/year, greatly exceeding pre-European rates.

Lagoon Depth: The majority of the lagoon was less than 1.5m deep when the lagoon was at 1.13m above mean sea level (msl) in early March 2007. The deepest areas (~3m) were in the narrow eastern arm adjacent to Currens

Creek. Narrow channels were present at the stream entrances, and also in the southwest near where the lagoon is opened to the sea.

Macroalgae: Macroalgal growth was relatively low throughout the lagoon in March 2007 with areas of high percent cover only occurring in localised shallow areas near the sea and in the central basin. Most of the growth occurred in the shallow waters around the margins. Macroalgal growth is expected to be greatest when the lagoon is low, open to the sea and exposed to tidal water level changes.

Macrophytes: Macrophyte presence was dominated by two species of Horse's mane weed (*Ruppia*). Shallower areas, particularly the north-eastern shoreline, were dominated by relatively small *R.polycarpa*, while deeper parts of the lagoon to the south and east were dominated by much larger *R. megacarpa* plants. Areas with very high cover (80-100%) were spread throughout the lagoon, but appeared limited to areas relatively sheltered from wind and wave disturbance (e.g. the head of Waituna Creek, the western embayment and arm, and the deep and narrow eastern arm near Currans Creek). Most *Ruppia* was in the eastern half of the lagoon in gravels and sands with relatively little mud. Low and very low percentage cover areas (<1%) tended to be restricted to shallow exposed areas with either muddy or sandy sediments.

Wetland Vegetation: Wetland vegetation covered 472ha of which 97% was rushland, and was dominated by thick stands of *Leptocarpus similis* (jointed wire rush) fringing the lagoon and providing a relatively wide and uniform band of buffering vegetation. The wetland also included varieties of herbs, sedges, tussocks and many introduced grasses and weeds. In general, the wetland was in good condition as reflected by its largely undeveloped state, however, historical drainage has significantly modified the wetland area.

200m Terrestrial Margin Vegetation: The 200m terrestrial margin vegetation (1,029ha), consisted of a relatively even split of grassland (23%), manuka scrub (30%), and manuka forest (29%). Thick native scrub and forest on elevated land dominated to the south and west of the lagoon. To the north and east the terrestrial margin was dominated by grassland (dairy and beef farms) which had been channelled and drained, and extended close to the edge of the wetland with only a narrow strip of scrub (e.g. manuka, gorse, bracken) or tussockland (flax, toetoe, red tussock) separating the wetland from the surrounding farms.

RAMSAR Vegetation: Terrestrial and wetland vegetation within the 2,161ha RAMSAR site was dominated by native scrub and forest (78%), and wetland rushland (18%). This represents around 80% of all the remaining forest and rushland within the wider Waituna catchment and, as such, the protected areas of the lagoon are an important repository of local biodiversity. Most of the remaining native scrub and tussockland buffering the northern margins of the lagoon fell outside RAMSAR protection, as did the rushland being reclaimed on the western side of the Currens Creek embayment.

Key Aspects
This first report summarises the major habitat types and condition of Waituna Lagoon. It indicates that Waituna is a largely unmodified example of a temperate shallow coastal lagoon (whose water level is artificially controlled) with its remaining coastal wetland system largely intact. Key aspects are:

- Sedimentation rates were elevated and mud was relatively common throughout the lagoon.
- Nuisance macroalgal growth was present around margins in localised areas.
- There were localised areas of anoxic sediments often associated with macroalgal mats and inflowing streams.
- The main submersed aquatic plant, *Ruppia*, was still thriving in the lagoon when conditions were optimal (extended period of lagoon closure, good clarity).
- The wetland and terrestrial margin vegetation in the internationally significant Waituna complex was found to be relatively unmodified, diverse and expansive.
- Localised areas of rushland were being lost through drainage and reclamation.
- Introduced weeds and grasses were relatively common in the wetland.

The information on habitat types, condition and issues collected in this study is used in the second study (the Ecological Vulnerability Assessment - Stevens and Robertson 2007), to identify long term monitoring and management priorities.

Stevens, L., and Robertson, B., 2007. *Waituna Lagoon 2007: Ecological Vulnerability Assessment and Monitoring Recommendations.* Prepared for Environment Southland by Wriggle Coastal Management, October 2007. 24p.

Scope

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

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

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

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

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

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

A monitoring programme is then designed for the priority monitoring indicators using the tools provided in the EMP (Robertson et al. 2002), plus recent extensions developed by Wriggle (e.g. Robertson & Stevens 2007a).
This report describes the Ecological Vulnerability Assessment undertaken for Waituna Lagoon to determine monitoring needs and priorities for ES. It provides an overview of coastal lake characteristics, the completed Ecological Vulnerability Assessment, and monitoring and management recommendations.

Coastal Lagoon Characteristics

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

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

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

Key Findings

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

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

Presences of Stressors – Intensive dairying; high nutrients and pathogens; low-moderate sediment; sea level rise threatens *Ruppia*.
The major threats or stressors to these existing values were identified as follows:

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

Based on available landuse information, catchment loadings of nutrients, sediment and pathogens are elevated to levels that would cause problems. In particular, nutrient loads (total nitrogen (TN) and total phosphorus (TP)) and pathogen indicators (*Escherichia coli* (*E. coli*)) from dairy farms in the catchment are estimated to be extremely high (e.g. 30kgN/ha/year from the 21,000ha catchment with 20,400 cows on 5,600ha (3.6 cows/ha), significantly higher than rates reported elsewhere in NZ). Mean TN, TP and *E. coli* concentrations in Waituna Creek exceed the mean values for NZ low elevation rivers. Suspended sediment yield from the catchment is estimated to be in the low-moderate range relative to the rest of NZ.
Because the lagoon is shallow and is opened artificially to the sea, any increase in sea level rise above that of the sedimentation rate is another major risk. In the past century sea level rose at 2.1mm/year (close to the current sedimentation rate of 2.8mm/year), but is set to increase up to 7mm/year or more. This means likely increases in water depth, salinity and open lagoon time. All of which are a threat to *Ruppia* habitat and the rest of the ecosystem, particularly saltmarsh.

Existing Lagoon and Wetland Condition – Eutropic: algal blooms, high nutrient inputs.
The assessment of the existing condition of the lagoon showed a number of problems:

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

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

Risks – Loss of *Ruppia*; fish decline; rushland as risk.
Loss of *Ruppia* Beds: *Ruppia* is a keystone species in the lagoon whose growth will be discouraged if water clarity is reduced through such actions as excessive inputs of fine sediments, by frequent changes in water or salinity levels through lagoon openings, or if excessive nutrient inputs result in phytoplankton or macroalgal blooms. It is also possible that the shift may be irreversible and result in a dramatic and adverse change to aquatic life in the lagoon and margins. Because the lagoon is already experiencing excessive algal blooms and lowered clarity, immediate action is required to reduce the magnitude of the stressors causing the problem (i.e. limits on nutrients and sediment entering the lagoon, and developing lagoon opening guidelines designed to maintain the *Ruppia* beds).
Decline in Fish, Birdlife: Because of the importance of *Ruppia* as a habitat for invertebrates and fish, as a food source for invertebrates and waterfowl, and its role in regulating water quality, its loss from the lagoon is likely to lead to adverse impacts on other parts of the ecosystem such as fish and birdlife. Also the shift towards a turbid, eutrophic, phytoplankton dominated system will mean that the current high aesthetic appeal of the lagoon will be lowered.
Degradation of Wetland and Terrestrial Margin: Wetland and terrestrial margin vegetation is important because it acts to improve water quality, maintain local biodiversity, provide fish and wildlife habitat, protect shorelines from erosion, provide flood storage and mitigation, and is a natural filter and trap for sediment and nutrients. Two issues were identified in relation to these communities:

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

Monitoring

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

Sedimentation

Elevated sedimentation rates are likely to lead to major and detrimental ecological changes (e.g. loss of *Ruppia* beds), and indicate where changes in land use management may be needed. Increased sediment inputs may reduce light penetration by decreasing clarity, a key factor affecting *Ruppia* growth and health. A shift towards smaller grain sizes (particularly silts and muds) in areas that are currently dominated by sands or gravels is likely to be indicative of excessive sedimentation of fine sediments from catchment developments, and may detrimentally alter biotic assemblages. To determine the extent and rate of sedimentation the following is recommended:

- Broad scale mapping of sediment type at five yearly intervals (repeat 2007 survey in 2012).
- Fine scale monitoring of surface sediment grain size along selected transects at five yearly intervals (beginning 2008).
- Assessment of sedimentation rate (using buried sedimentation plates) at two high deposition areas (including rushland). Ideally measured at annual intervals.
- Measure water clarity (Secchi disc - SD) at monthly intervals at representative sites.

Eutrophication

Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota. The sediment compartment is often the largest nutrient pool in the system, and nitrogen exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae. The following is recommended:

- Broad scale mapping of lagoon macroalgal percent cover annually in January-March (when the lagoon mouth is open).
- Monthly monitoring during the main growing period (September-April) for the following parameters: lagoon light penetration or SD, chlorophyll-*a*, phytoplankton, total nitrogen, nitrate, ammonia, total phosphorus, dissolved reactive phosphorus, salinity, dissolved oxygen, temperature, and water level. In addition, establish a baseline of sediment organic carbon (determined from ash free dry weight) at representative sites.

Disease Risk

Potential disease causing bacteria and pathogens are commonly associated with inputs of faecal matter from warm blooded animals. Because of the high numbers of dairy cows in the catchment, inputs are expected to be elevated in incoming streams. The following is recommended:

- Monthly monitoring during the main periods of contact recreation for *E. coli*.

Macrophytes

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

- Repeat broad scale mapping of percent cover of *Ruppia* at annual intervals.

Wetland and Terrestrial Margin

A terrestrial margin dominated by native vegetation almost certainly acts as an important buffer between developed areas and the wetland and lagoon. This buffer protects against introduced weeds and grasses, and naturally filters sediments and nutrients. Additionally, there have been significant areas of saltmarsh drained for pastoral use in the past and this has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary. Saltmarsh is also highly susceptible to sea level rise. The following is recommended:

- Broad scale mapping of wetland and terrestrial margin vegetation at five yearly intervals (repeat 2007 survey in 2012).

Catchment Monitoring

As the characteristics of the surrounding catchment, and the landuse undertaken within it, are major determinants of downstream conditions, the following catchment monitoring is recommended:

- Identify areas where a combination of different factors (e.g. land cover, slope, area, soil type, geology, rainfall, etc) highlight a high potential for immediate or potential inputs of sediment. Use existing catchment data to identify "hotspots" such as erosion prone areas, easily mobilised sediment reserves etc. and target these for specific management.
- Monitor suspended sediment, total nitrogen, total phosphorus and *E. coli* concentrations in the streams draining the major developed catchment (i.e. Waituna Creek and possibly Currans Creek) on three occasions during low flows, three during medium flows and hourly throughout three high flow events to better characterise likely loadings.

Recommended Management

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

<u>Develop Condition Ratings for Reporting Monitoring Results</u>

- Condition ratings are criteria for monitoring indicators that rate lagoon condition (e.g. very good/good/fair/poor), guide the type and frequency of monitoring, and indicate the type of management responses that may be needed.

Because of the unique conditions present, ratings need to be developed specifically for Waituna Lagoon. Examples of the types of condition ratings proposed for development for Waituna Lagoon are included in Technical Annex 2.

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

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

<u>Catchment Management</u>

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

<u>*Ruppia* Management</u>

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

<u>Lagoon Management</u>

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

<u>Wetland and Terrestrial Margin Management</u>

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

Stevens, L., and Robertson, B., 2010. *Waituna Lagoon 2010: Macrophyte (Ruppia) Monitoring.* Prepared for Department of Conservation by Wriggle Coastal Management, May 2010. 10p.

Discussion and Conclusions:

The results of the 2010 monitoring indicate the continuing presence of the ecologically important macrophyte species *Ruppia* within Waituna Lagoon. However, *Ruppia* had decreased in presence from 35 of 48 sites sampled in 2009, to 25 sites in 2010. Nuisance macroalgal species, particularly the slimy filamentous brown macroalgae *Bachelotia antillarum*, and accompanying black, anoxic, sulphide-rich surface sediments remained widespread in the lagoon, and sediment anoxia had increased since 2009.

While the lagoon waters appeared in a better condition in 2010 than compared to 12 months earlier (higher clarity, less suspended filamentous algae), the 2010 results indicate a continuing shift towards more eutrophic conditions. Specifically, a decline in the condition of the *Ruppia* beds, decreased sediment oxygen, rotting organic matter on the sediment surface, and the continued presence of nuisance macroalgae, as summarised in Table 3. High nutrient loads are considered the primary driver of the decline observed. The opening/closing regime of the lagoon is also a key driver of lagoon condition as it will flush sediment and nutrients from the lagoon, change light levels (via changes in water depth) and salinity, and expose parts of the lagoon bed.

Based on the sequence of change described in Figure 1, the results suggest the lagoon is moving further towards the point to which a switch to an algal dominated system is predicted. Consequently, the viability of Ruppia under the current conditions in Waituna Lagoon continues to be at risk.

Table 3. Summary of conditions in Waituna Lagoon, March 2007 and February 2009 and 2010.

Indicators	March 2007	February 2009	February 2010
Macrophytes	*Ruppia polycarpa* dominant in shal-lower waters and *Ruppia megacarpa* in the deeper waters. *Myriophyllum* presence very low.	*Ruppia polycarpa* dominant grow-ing and fruiting at moderate levels within the lagoon. *R. megacarpa* less apparent. Increased presence of *Myriophyllum*.	*Ruppia polycarpa* remained domi-nant but reduced sharply within the lagoon. Increased presence of *R. megacarpa*. Little change to *Myriophyllum*.
Macroalgae and Epiphytic Growth	Green filamentous *Enteromorpha* sp. present around edge in localised areas. Brown filamentous slime algae *Bachelotia antillarum* present but in low abundance.	Bloom growths of the nuisance macroalgae *Bachelotia antillarum* were found throughout much of the lagoon. It was most dense in suspension near the lagoon bed, but was also present as epiphytic growth over *Ruppia* and other mac-rophyte species. *Enteromorpha* was common around lagoon margins.	Bloom growths of the nuisance macroalgae *Bachelotia antillarum* throughout much of the lagoon. Most dense in suspension near the lagoon bed. Reduced epiphytic growth over *Ruppia* and other macrophyte species. *Enteromorpha* common around lagoon margins.
Sediment Quality	Clean, well-oxygenated sediments throughout most of lagoon. Sand and gravels dominant. Black, anoxic, sulphide rich layer only at surface in a few localised areas.	Eutrophic sediments; poorly oxy-genated, often muddy on surface but still dominated by sands and gravels. Black, anoxic, sulphide rich layer often at surface or close to surface.	Eutrophic sediments; poorly oxy-genated, often muddy on surface but still dominated by sands and gravels. Black, anoxic, sulphide rich layer often at surface (or close) and worse conditions than 2009.
Water Quality	Moderately high water clarity. Sec-chi Disc 1.5-2m. But at other times it has been reported as low.	Brackish (salinity 0.4-3.2 ppt). Temperature 12-16 deg. C. Low water clarity. Secchi Disc 0.5m (range 0.2-0.72m). Likely low con-centrations of dissolved nutrients available for plant growth based on previous months WQ data. High concentrations of total N (likely organic). DIN < 0.014 mg/l, TN 0.73 mg/l. DRP <0.004 mg/l, TP 0.03 mg/l.	Brackish (salinity 3.5-4.2 ppt). Temperature 13-14 deg. C. Moder-ate water clarity. Secchi Disc 1.2m (range 0.4-1.5m). Likely low con-centrations of dissolved nutrients available for plant growth based on previous months WQ data. High concentrations of total N (likely organic). DIN 0.02 mg/l, TN 1.1 mg/l. DRP <0.004 mg/l, TP 0.03 mg/l.

Lagoon Open/ Closed	Lagoon closed since 2 June 2006 (272 days) following a long period (10 mths) of opening/high salinities.	Lagoon closed since 7 October 2008 (144 days).	Lagoon closed since 1 October 2009 (137 days).
Trophic Stage	MARCH 2007 Stage 2. Towards the PRISTINE side of Stage 2.	FEBRUARY 2009 Stage 2. Towards the increasing eutrophication side of Stage 2.	FEBRUARY 2010 Stage 2. Towards the increasing eutrophication side of Stage 2.

Thompson, R. M. C., & Ryder, G. R. (2003). Waituna Lagoon: summary of existing knowledge and identification of knowledge gaps. Department of Conservation. 37p.

Waituna Lagoon represents an exceptional example of a largely unmodified coastal lake-type lagoon within a largely intact coastal wetland system. This report reviews existing information on the Lagoon with a view to making recommendations for future research and management. The Lagoon contains important habitat for resident and migratory birds including nationally critical and endangered species. The aquatic community includes a Ruppia-dominated macrophyte community not well represented elsewhere and a number of native fish species, in addition to a valued recreational trout fishery. Shoreline vegetation patterns are largely unmodified and include notable cushion-bog and sand-ridge plant associations. In surrounding areas the presence of several alpine and sub-alpine species at sea level is of botanical interest. Lagoon levels have traditionally been managed by opening the Lagoon to the sea to improve local drainage and increase access for sea-run trout. In recent history the Lagoon has been open for a greater proportion of the year. The effects of these prolonged openings on the Lagoon flora and fauna are unknown but potentially significant, and require urgent study. Recent hydrological research suggests that lagoon opening may have a minimal effect on farm drainage and that a reappraisal of this activity is required. Other threats to the ecology of the Lagoon include poor water quality in the inflows due to intensification of land use in the catchment. Nutrient levels are very high and have the potential to result in eutrophication. There is evidence from within the Lagoon of high sedimentation rates and infilling of some areas. A coordinated programme involving regional authorities, DOC and local community groups is required to improve catchment land management and develop clear management goals for Waituna Lagoon.

Keywords: Waituna, lagoon, threats, hydrology, catchment, botany, birds, fish, water quality, management, South Island, New Zealand

Introduction

Estuary and lagoon ecosystems are amongst those most strongly impacted by human activities. These environments are subject to the combined influences of changes throughout their catchments. In addition, lagoons and estuaries are often physically altered by management to prevent flooding, improve passage for vessels or reclaim land for agriculture or housing.

Waituna Lagoon, near Invercargill (Fig. 1) represents a largely unmodified example of a temperate, shallow coastal lagoon, within a largely intact coastal wetland system (the Awarua Wetlands). In recognition of their importance, the Lagoon and a section of the Wetlands were ‘ reserved for wetlands management purposes’ in 1971, and in 1976 the Waituna Wetlands Scientific Reserve was one of two New Zealand wetlands to be designated of international significance under the Ramsar convention. In 1983 the area was established as a scientific reserve, and is administered by DOC. In addition to its national and international significance as a wetland of note, the Waituna Wetland is also culturally significant to the local Ngai Tahu people. The special relationship between the area and Ngai Tahu is recognised under a Statutory Acknowledgement within the Ngai Tahu Claims Settlement Act of 1998. The Lagoon is also valued by recreational fishers, particularly for the large sea-run brown trout (Salmo trutta) often caught there.

The Wetlands and Lagoon at Waituna were recognised by Ramsar on the grounds that they ‘ support an appreciable assemblage of endemic and threatened species and communities, have special value for maintaining the genetic and ecological diversity of the region and provide a habitat for plants and animals at critical stages of their biological cycles’ . The Ramsar criteria in particular, value wetlands of international importance to waterfowl, those that represent a near-natural wetland type in a particular biogeographic region, and those that support rare or endangered species. The Waituna Lagoon and wetland complex are both nationally and internationally significant on those grounds (Cromarty & Scott 1996).

Despite the largely unmodified nature of the immediate surroundings of the Lagoon, the continuing protection of the lagoon/wetland complex and the biota within it requires an appreciation of the changes that are ongoing within the catchment. Intensification of agriculture and degradation of water quality have the potential to affect the physical structure of the Lagoon, the nature of its nutrient cycles and the plants and animals that live within it.

This report aims to fulfill the following objectives:

- To briefly review existing information on the Lagoon
- To identify potential risks to the Lagoon and define management priorities

 To identify knowledge gaps that need to be addressed to aid management

2. Catchment Science

Ballantine, D., and Hughes, A., 2012. *The effects of drain clearing on water quality of receiving environments.* Prepared for Environment Southland by NIWA, May 2012, funded by Envirolink Medium Advice Grant. 29p.

Environment Southland maintains over 1,200 kilometres of waterways. This maintenance includes clearing sediment and weeds that accumulate over time in the waterways and decrease outfall and hydrological efficiency. During drain clearing, water quality decreases markedly, with large fluxes of suspended sediment and nutrients. This study was undertaken to help Environment Southland understand the potential water quality impacts of drain clearing, and the effects of the associated release of nutrients and sediments to downstream ecologically sensitive environments. A review of relevant literature and analysis of data from the drain clearing events in Southland was carried out and the findings evaluated.

Analysis of data showed that, through the drain clearing procedure, total suspended solids concentrations and concentrations of some water quality variables increased sharply. Total phosphorus concentrations increased through the drain clearing events. The highest total suspended solids and total phosphorous concentrations since measurements began in Southland (1995) were during the drain clearing period. There was little difference in nitrate and total nitrogen concentrations between the drain clearing period and the long term record. After drain clearing, even small increases in flow gave sharp increases in turbidity and concentrations of water quality variables.

As well as having water quality effects, drain clearing significantly affects the morphology of the drain channel, bank vegetation and structure, in-stream ecology (significant disturbance to fish populations) and in-stream physical conditions (e.g. water temperature).

Where drains have been cleared, turbidity will be elevated in the short term immediately following clearance. The reduced visual clarity may have impacts on any remaining aquatic animals and associated reduction in light penetration may cause light 'starvation' of (remaining) aquatic plants. We would expect that elevated flows shortly after the drain clearing events will give rise to higher sediment and sediment-associated loads of pollutants and light attenuation being transported from the drains to downstream environments.

Depending on environmental conditions in receiving waters, there may be the potential for phosphorus release from sediments which may trigger ecological changes. Visual clarity and light attenuation will be reduced in the short terms, until suspended sediment settles and consolidates, and accumulation of sediment in downstream environments may smother aquatic ecosystems. As channel beds re-stabilise, we would expect that turbidity levels and water quality variable concentrations would 'relax' to pre-clearing levels.

In the longer terms, we advocate the implementation of beneficial management practices (BMPs) to reduced sediment and nutrient loads from agricultural land, so that clearing of drainage channels is needed less often. In the meantime however, we suggest promoting improved drain clearing procedures so that environmental impacts are minimised.

Burbery, L., 2012. *Analysis of Groundwater Level Data: Waituna Lagoon.* Prepared for Environment Southland by Lincoln Ventures Limited, Report No 1008-2-R1. Funded by Envirolink Advice Grant ESRC152. 17p.

Groundwater level monitoring data from four (approximately 6 m deep) wells in the Waituna Lagoon catchment were analysed using the Groundwater Data Analysis tool recently developed by Lincoln Ventures Ltd. Due to the relatively complex boundary conditions of the Waituna catchment that is drained by various creeks and artificial drainage channels, well records were analysed on an individual basis. As a consequence, results reflect the local scale hydrodynamic characteristics of the shallow sand and gravel aquifer system, rather than a complete fully integrated catchment model.

Records from well F47/0252 however are believed to probably represent the main characteristics of the aquifer system drained by Waituna Creek and much of the catchment. Observed Waituna Creek flows were reasonably well reproduced by the mathematical Eigenmodel predictions based on analysis of F47/0252 data, and suggest fast groundwater throughflow.

The over-riding characteristic of the shallow Quaternary sand and gravel aquifer system at Waituna is one of a very rapidly draining groundwater system. Drainage is no doubt assisted by the numerous drainage channels and creeks that dissect the catchment, thus there appears to be a strong hydraulic connection between surface water and groundwater in the catchment.

The hydrographs of well F47/0252 (located near Waihopai) and F47/0260 (located near the coastal bar in the Carran Creek sub-catchment) exhibit similar characteristics. Groundwater levels in these localities respond rapidly to rainfall recharge events. An aquifer storage residence time in the realm of 1 – 2 weeks is predicted for the local system characterised by well F47/0252 and is probably a generalised characteristic of the shallow aquifer system, certainly inland of Invercargill Highway. The storage residence time for the groundwater system as characterised by F47/0260 is estimated to be somewhere in the region of 12 – 50 days.

Wells F47/0256 and F47/0253 are located towards the northern edge of Waituna Lagoon, conceivably close to the aquifer discharge boundary. Their monitored groundwater levels exhibit slightly different dynamics from the other two monitoring wells.

Well F47/0256 is sensitive to water levels in Waituna Lagoon, albeit qualitative assessment of the available water level data tends to suggest possibly low groundwater conductance, given it appears it took almost 4 months for lagoon and groundwater levels to re-equilibriate following the last Lagoon drainage event on 15 July 2011. The periodic artificial drainage (opening up to the sea) of Waituna Lagoon provides a significant hydraulic stress to the shallow aquifer that might be analysed with F47/0256 monitoring data and from which it might be possible to infer some detail of potential hydrodynamic characteristics of the shallow groundwater system in the future.

Similar to F47/0256, land surface recharge of the shallow local aquifer system monitored by F47/0253 appears to be attenuated, most probably by the poorly draining, heavier (peatier?) soils about the region. With the monitoring data currently available, it is estimated that the shallow groundwater system as monitored by F47/0253 (located between Moffat Creek and the Lagoon) exhibits a hydraulic storage residence time in the region of 16 to 35 days.

Diffuse Sources and NIWA, 2012. *Waituna Catchment Loads*. Report prepared for Environment Southland, April 2012. 65p.

Catchment runoff containing sediments and nutrients threaten the ecological integrity of Waituna lagoon. There are fears that land intensification will exacerbate the observed decline in the lagoon. Environment Southland (ES) commissioned Diffuse Sources and NIWA to develop a robust methodology for calculating nutrient loads for the streams discharging to the Waituna Lagoon, which can be used to estimate loads across different time scales (e.g, season, years) and compare these through time.

Three regression approaches for estimating contaminant loads are recommended for both future and historical estimates of contaminant loads. These regressions are based on the fact that concentrations vary significantly with flow rate, and so regressions employ rating curve for load calculations.

We recommend that the SedRate software (NIWA, Christchurch) be used for these load calculations because it is fairly easy to use, it allows for LOWESS curves in the future if necessary, is defensible, and provides uncertainty estimates. Loads can estimated for different time periods (years and seasons) by applying the relevant period of flow record to the rating curve.

We concluded that it is not necessary at this stage to take account of long-term trends in concentration for TN or TP when establishing measured loads over the period of the historical monitoring record. We also concluded that it was not necessary to include seasonal effects (most of which is caused by flow) or hysteresis (although the latter needs to be checked by further sampling of storms). A caveat to this conclusion is the possible influence of climate change on flows, which may have a small effect on load trend analysis.

We concur with the bimonthly sampling strategy. We recommend that additional storm sampling be conducted, because the dataset has only limited storm monitoring. There is a need to confirm that the concentration predictions made by the recommended regression approach reasonably describe other storm events. We have not been prescriptive about number of samples and storm size, because this should be determined by achieving adequate coverage of the flow duration curve.

We have, however, made recommendations on flow 'triggers' within the various subcatchments and methods for determining appropriate sampling frequency. We suggest that flow monitoring at Waituna @ Marshalls coupled with sufficient gauging at other sites (covering the flow range, and is ongoing to check for consistent runoff behaviour) is adequate given the response of the catchments. However, continuous flow recording should be installed if significant land use changes occur or are predicted to (e.g., significant change in proportion of farm types, farm drainage systems, drain management) of if the gauging programme shows changing flow characteristics or unstable relationships.

The present sampling method does not represent particulate P and N. This may turn out to be insignificant for loads given relatively small concentration range and relatively low responsiveness to flow. However, this should be checked with a field study (including measuring TDP and DON) and calculation of the true particulate loads for P and N.

There are inconsistencies in sediment load and proposed impacts in the estuary. This should be reassessed. Sediment loads are very low, but probably consistent with runoff from catchments of this type. The present parameter list could be expanded to include colour (to help understand these peat catchment responses to rainfall – the present 'measure of colour" – black disk - also responds to suspended particulate matter). TDP and DON should also be measured.

The analysis in this report shows how monitoring to date can be used to derive load estimates and their uncertainty, and describes how other factors, such as seasonality and time trends can be incorporated in the future if necessary. It also points to some future refinements involving accurate flow estimation, additional sampling to confirm the behaviour at high flows and ensure coverage of flow duration curves, additional chemical analysis for dissolved and particulate forms, and sampling methods.

Elliott, S., 2012. *Comparison of catchment modelling approaches for the Waituna Lagoon catchment*. Prepared for Environment Southland by NIWA, 27th February 2012. 12p.

The capabilities of SWAT and CLUES in relation to the needs identified earlier are summarised in Table 2. In summary both models have strengths and weaknesses. While SWAT entails a number of physical processes, it misses on some important processes in the study catchment and it would be difficult to represent some key mitigation measures. Also, while SWAT provides daily predictions, based on past experience there is a significant risk that those predictions will not be accurate. On the other hand, CLUES often required adjustments to achieve good predictions, and there is heavy reliance on external calculations/assessments to estimate the effect of mitigation measures. Given these strengths and weaknesses, **we consider that CLUES (or a model similar to CLUES) should be used in addition to the SWAT modelling that is already underway.**

Neither of these models captures the effect of regional groundwater. However, the reasonable balance between measured and predicted flows in Table 1, the expectation of fairly short groundwater residence times, and the lack of detailed knowledge of the aquifer properties suggests that it is not necessary to use a model with regional groundwater modelling capabilities.

In addition, we anticipate that the Waituna work will require further attention to spatial detail (where within a subcatchment do the nutrients come from) and also more emphasis on capturing variations in management (which properties use which type of fodder cropping, which ones have underdrains). This is more detail that can currently be accommodated by CLUES. Therefore, we recommend the use of a modelling approach that is more resolved – both spatially and in terms of land management – than the current version of CLUES. This will have the same general structure as CLUES, but will extend its capabilities. In the Clean Water Productive Land research programme, we are currently investigating and preparing to trial such more detailed approaches. The Waituna application would serve as a suitable site for application and refinement of these methods. We do not anticipate that it would be practicable to incorporate these improvements into the main CLUES user interface in the short term, but instead recommend that calculations be conducted outside the CLUES, making use of GIS for display of results. This more customised approach will also enable new results from field investigations (for example, loss rates from organic soils) to be incorporated into the model rapidly.

Greer, M. J. C[1,2]., Closs, G. P[1]., Crow, S. K[2]., and Hicks, A. S[3]., 2012. ***Complete Versus Partial Macrophyte Removal: The Impacts of Two Drain Management Strategies on Freshwater Fish in Lowland New Zealand Streams.*** **University of Otago[1], NIWA[2] and Environment Southland[3]. In prep for the Ecology of Freshwater Fish Journal.**

Complete macrophyte removal to maintain drainage performance in lowland streams can have a negative effect on resident fish communities, but few studies have quantified this impact. Moreover, limited research has been carried out exploring alternative approaches for macrophyte removal that minimise the impact on the resident fish community.

The aims of this study were:

- to determine how the current practice of removing almost 100 % of available macrophyte cover affects native fish populations in lowland New Zealand streams, and
- to see if this impact can be reduced by limiting macrophyte removal to alternating 50 meter sections of the waterway.

Native fish populations were surveyed before and after experimental macrophyte removal for the following three treatments: 1-complete macrophyte removal. 2-macrophyte removal from alternating 50 m reaches, 3-control with no macrophyte removal. Radiotelemetry was used to monitor the behavioural response of individual giant kokopu (*Galaxias argenteus*) to the different treatments.

The results of this study suggests that current drain management practices reduce CPUE of fish by 60%. Although limiting macrophyte removal to alternating 50 m sections did not minimise the community impacts of drain clearing, large giant kokopu did benefit from this strategy. All tagged giant kokopu remained in streams reaches partially cleared of macrophytes while in completely cleared reaches all individuals were displaced. These results demonstrate the threat current drain management practices pose to New Zealand native fish and highlight the value of trialling alternative methods of macrophyte removal.

Hicks, A. S., 2012. *Update on Waituna drain clearing project*. Environment Southland Technical Comment, 27th April 2012, file reference 701/13/07. 5p.

Introduction

Environment Southland undertakes routine channel maintenance in the Waituna Creek catchment to provide land drainage and flood protection. This maintenance often involves the use of diggers to mechanically remove accumulated weed and sediment from the stream network, commonly referred to as drain clearing. The channel disturbance associated with drain clearing may potentially result in a temporary increase load of nutrient and sediment being carried downstream in these systems. Because Waituna Creek is the major tributary to the Waituna Lagoon, there was concern about how drain clearing activities in this catchment would affect water quality in the lagoon. Environment Southland has undertaken an extensive water quality monitoring investigation on the Council's drainage works that were performed between February to March this year.

Summary

It is too early to quantify what effect the sediment and nutrient load increases associated with drain clearing may have on the Waituna Lagoon. To date, only minor effects have been observed within the lagoon and there are no detectable changes in water quality in the four lagoon monitoring sites. However, it may be that the effects have not yet fully propagated down catchment to the lagoon so monitoring data will continued to be analysed.

All data collected for the drain clearing study will be forwarded to Drs Deborah Ballantine and Andrew Hughes (NIWA) to be analysed using an Envirolink medium advice grant to explore the effects of drain clearing on the water quality of receiving environments. This report is due for completion by the 30th of June 2012.

Jackson, R., Phillips, C., and Ekanayake, E., 2001. ***Hydrology of the Waituna Lagoon.*** **Prepared for Department of Conservation by Landcare Research, report number LC0001/139, July 2001. 18p.**

In 1998, the Department of Conservation Southland Conservancy identified the need for a scientific basis for guidelines for the artificial manipulation of the water level of Waituna Lagoon, east of Invercargill. An understanding of the soil characteristics including their drainage behaviour coupled with measurements of soil-water-level changes at two sites on the margins of Waituna Lagoon has enabled us to distinguish between influences of high water levels in the lagoon and rainfall influences on land wetness.

Soil wetness of farmland showed gradients with topography and distance from a stream (or lagoon margin). This indicates that changes in external water level in the lagoon (unless it is high enough to cause inundation at the lagoon margins) will only have effects within 20 m of the stream or drains that are directly coupled to the lagoon.

One of the threats to the long-term survival of the lagoon and its surrounding ecosystems is land development and intensification within the contributing catchment. Intensification from dairying, drainage of peat for further pasture development, drainage and V-blading or humping and hollowing for tree crop establishment will all continue to put increased pressures on the lagoon and its ecosystem. We recommend that a Catchment group or lagoon care group be established to act as spokesperson or advocate for the lagoon.

McDowell, R. W., Smith, C., and Stevens, D, R., 2011. *Quantifying the loss of nutrients and sediment in surface runoff from a spring-grazed forage crop and pasture in the upper Waituna lagoon catchment.* Prepared for DairyNZ by AgResearch, November 2011.

(From EMC item and is not report executive summary due to confidentiality)
DairyNZ commissioned AgResearch to investigate nutrient and sediment loss in surface runoff from a spring-grazed forage crop and pasture in the upper Waituna catchment. Monitoring has been carried out on one property during spring 2011 and DairyNZ have made the results available to Environment Southland staff on a confidential basis until the report has been finalised.

From the 3rd August 2011, 70 cows were strip-grazed across eight monitoring plots located in a forage crop paddock until all the feed had been consumed by the 26th August. The cows grazed the paddock from the bottom of the gully and no un-grazed riparian areas were left in high risk areas. On the 12th August, four of the plots were fenced off to simulate back fencing. Grazing of eight monitoring plots on the neighbouring pasture paddock occurred as animals were taken off to calve a few at a time. No fertiliser was applied to either the pasture or forage crop paddocks during the monitoring period.

Rainfall and soil moisture were monitored on site and surface runoff from the monitoring plots was collected using a v-shaped outlet in the plot frame at the down slope point. Surface runoff water quality samples were collected after each runoff event. In total, there were seven runoff events totalling 111mm from the cropped plots and ten runoff events totalling 28 mm from the pasture plots. On the 24th August, soil samples were taken in the grazed and un-grazed areas of each paddock in order to assess water infiltration rates and to take soil quality samples.

During the monitoring period, rainfall was approximately 20 percent higher than normal so the data collected is considered to be representative of a wet year.

In summary, the results showed:

- the flow-weighted mean concentrations of total nitrogen, phosphorus and suspended sediment were enriched in runoff of the forage crop relative to pasture;
- fencing of four of the forage crop monitoring plots (to simulate back-fencing) decreased suspended sediment loss by 17 percent;
- much of the particulate nutrient lost in runoff was hypothesised as originating from excretal returns due to lower concentrations in events that occurred more than seven days after the crop was grazed; and,
- the losses from the trial were similar to those reported for winter-grazed forage crops in Southland and Otago and may partly explain the catchment's high spring phosphorous and suspended sediment load.

Based on the findings of this and other studies, a range of mitigation strategies are available to decrease losses from grazed forage crops including the use of nitrification inhibitors, restricted grazing, positioning the forage crop away from waterways, grazing direction and the widespread use of riparian areas however these strategies vary with respect to their cost-effectiveness and ease of implementation.

As a result of the findings the project team propose to model alternative options for spring feed management, including the removal of spring grazed forage crops from the system, to determine the impact on performance and profitability. In addition, later calving and alternative pasture management will be investigated in a farm systems study as part of the Pastoral 21 project work at Telford which commences in June 2012.

McDowell, R. W., Gongol, C., and Woodward, B., 2012. ***Potential for controlled drainage to decrease nitrogen and phosphorus losses to Waituna Lagoon.*** **Prepared for Environment Southland by AgResearch, June 2012. 13p.**

A brief review of traditional controlled drainage systems highlighted their potential to decrease the load of nitrogen and phosphorus via a combination of decreased flow rates and increase sedimentation and denitrification rates. Although controlled drainage aims to raise the water table in warmer months, and as such may improve the yield of deep rooted crops, the technology tends to increase the amount and frequency of surface runoff. An increased water table also increases the potential for pugging and, via interaction with P-rick topsoil, the dissolution and enrichment of dissolved P concentrations which may boost periphyton growth. As an alternative option, Peak Runoff Control (PRC) structures were investigated. 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. A design process is outlined that requires the analysis of hydrologic and LIDAR data to isolate areas suitable for PRC structures. However, it is also recommended that additional work be conducted to determine soil and sediment specific potential for erosion, deposition and resuspension that will help optimise the nitrogen, phosphorous and sediment mitigation potential for the structuress within the Waituna Lagoon.

Meijer, K. 2011. *Surface Water Quality – Waituna Catchment.* Environment Southland Technical Comment, 27th June 2011. File reference 701/13/07. 9p.

Summary

Water quality sites in the Waituna catchment regularly exceeded guidelines for water clarity, dissolved reactive phosphorus, faecal coliforms, nitrate nitrite nitrogen and unionised ammonia over 2005-2010. Nitrate and total nitrogen showed an increasing trend over the last 10 years in the Waituna Creek, with mixed trends recorded at other sites.

Current loads of nitrogen, phosphorus and sediment from the catchment to the Waituna lagoon are high and above interim targets set for lagoon health. Modelled total nitrogen loss rates ranged from 12.8 to 20.6 kgTN/ha/y in 2010, with phosphorus loss rates ranging from 0.7 to 1.3 kg TP/ha/y. Sediment losses in 2010 ranged from approximately 71 to 122 kgTSS/ha/y. Nitrogen losses were the greatest in the Waituna Creek catchment, while phosphorus and sediment losses were greatest in the Moffat Creek catchment.

Catchment research gaps

- A lack of high resolution water quality data over all seasons to more accurately determine areas of the catchment with higher or lower nutrient and sediment loss rates.
- A lack of water quality monitoring data during flood events in all seasons, especially total phosphorus during rising limbs in spring and summer.
- No known relationship between TSS and sedimentation rates in the lagoon.
- A lack of detailed landuse information for the catchment (including current areas in forest, dairy, sheep etc) makes calculating accurate catchment loss rates not possible at present.
- It is not known if the current SOE water quality sites accurately represent the entire catchment in terms of nutrient and sediment losses.
- We do not currently understand the sources of nutrients and sediments in the catchment.
- No knowledge of direct lagoon infiltration loads.
- Limited understanding of internal lagoon nutrient loads.

Recommendations

- Twice monthly (including flood event) longitudinal water quality monitoring and regular flow gauging's in the Waituna catchment.
- More water quality monitoring of the rising limb of floods, especially in spring and summer.
- Derive a relationship between TSS and sedimentation rates in the lagoon and/or a TSS load target.
- Get current landuse data for the Waituna catchment for use in accurate catchment loss modelling.
- Analyse available water quality data, including recently added sites on the Waituna and Moffat Creeks to determine if existing SOE water quality sites represent nutrient and sediment losses of the entire catchment.
- Investigate sources of nitrogen, phosphorus and sediment in the catchment.
- Determine loads contributed by direct infiltration to the lagoon.
- Determine internal lagoon nutrient load contribution.

Olsen, D., 2012. *Waituna Lagoon: Visual Assessment of Drain Clearing Activities.* Prepared for Environment Southland by Ryder Consulting, March 2012. 20p.

A visual assessment of drain clearing activities was conducted in the catchment of Waituna Creek. Visual inspections of drains previously cleaned were conducted in Mahers Tributary, Taylors Tributary, Henderson Tributary and the Waituna Creek in the vicinity of Mahers and Taylors Tributaries (*Figure 1*). In addition, active drain cleaning was observed in Taylors Tributary and Henderson Tributary. Best management practices for drain cleaning developed by the Waikato Regional Council (formerly Environment Waikato) (Environment Waikato 2007) were used in these assessments.

The purpose of this report was to:
1. Document the drain cleaning practices observed on 23 February 2012.
2. Comment on whether the drain cleaning practices observed comply with the BMPs developed by Waikato Regional Council and suggest ways of reducing potential environmental effects.
3. Comment on the likely consequences of drain cleaning for fish habitat and other potential environmental effects.

These assessments are focussed solely on the environmental effects of these activities and engineering/farm management considerations are not assessed.

Conclusion
Generally, the works observed during the visit on 23 February 2012 were conducted in a manner consistent with the Waikato Regional Council guidelines (Environment Waikato 2007). Cleaning was being conducted from one bank, the channels were not being over-dug, the excavators being used were wide tracked and a weed rake or stream-cleaning bucket was being used. No stranded fish were observed during this visit, although the sites being cleaned during the visit were small, grass-choked channels that offered habitat of limited suitability for most fish. The use of weed rakes is likely to reduce the likelihood of fish stranding, as the open structure of the rake is likely to provide greater opportunity for fish to escape back into the water than if a solid bucket is used.

It was evident during the visit that banks were disturbed in some areas. While such disturbance may be unavoidable in some circumstances, there was no evidence of rehabilitation of these areas having been undertaken. This is recommended to reduce the likelihood of erosion and sedimentation.

Substantial water discolouration was evident during cleaning. Given current concerns regarding the water quality in Waituna Lagoon, and the prospect of the lagoon 'flipping' from a clear water state to a turbid state and the possibility of drain cleaning activities liberating nutrients (particularly phosphorus, Young *et al.* 2004), it is recommended that steps be taken to reduce suspended sediment concentration during drain cleaning, where possible.

Risk, J. 2011. *Waituna catchment science gaps – land.* Environment Southland Technical Comment, 14th June 2011. File reference 701/13/07. 4p.

With the current level of concern about water quality and health of the Waituna Lagoon the following technical comment provides a starting point into the science gaps that require further investigation to improve the accuracy and knowledge of nutrient losses to the lagoon from land based activities within the catchment.

Recommendations

- Research priorities should be undertaken on those soil orders and based around land management practices where there are current knowledge gaps. For example P loss from winter grazing on Podzol and Organic soils.
- Take guidance from research providers on specific science gaps relating to sediment, P and N loss where current research needs to be targeted with particular attention to the Waituna catchment and those soil types that there is a lesser understanding off.
- Take guidance on research gaps that will provide the most value within available budgets.
- Investigation into target levels (1995) for lagoon health on a per hectare basis.
- Guidance on likely margin of error that can be expected from modelling software.
- Quantify N & P losses from sources outside of the farm system.

Rissmann, C[1]., Wilson, K L[1]., and Hughes, B. N[2]., 2012. *Waituna Catchment Groundwater Resource Technical Report.* [1]Environment Southland[1] and Liquid Earth Limited[2], 22nd May 2012. Environment Southland publication number 2012-04, Invercargill. 92p.

As part of a wider response to concerns over the ecological health of the Waituna Lagoon, an intensive groundwater resource characterisation study was undertaken by Environment Southland in the Waituna catchment during 2011/12. The characterisation study builds on an earlier technical comment (Wilson, 2011b) that highlighted a critical lack of data surrounding the groundwater resource of the Waituna catchment. From this report, it emerged that the only evolved data set surrounded geological data associated with the lignite exploration programs of the 1970s and 1980s. A recommended approach to addressing key data gaps in an effort to characterise the role of the groundwater resource over the water quality of the Waituna Lagoon was developed with input from groundwater experts at the Environment Southland hosted Waituna 'Think Tank' Science Workshop in July 2011.

The fundamental groundwater question explored during the Waituna Science Workshop was:

What role, if any, does groundwater play in nutrient loadings to the Waituna Lagoon?

In order to answer the above question, two dominant groundwater discharge mechanisms needed to be explored, namely: groundwater discharge via the surface water network and groundwater discharge as direct seepage into the lagoon. In order to assess the role of each discharge mechanism on lagoon health, Environment Southland embarked on a physical and chemical characterisation study of the Waituna groundwater resource, including:

- an assessment of the spatial and temporal variability in the groundwater hydrological and geochemical response;
- the relationship between land use, hydrogeology and groundwater quality in the catchment, and;
- the relationship between the Waituna Lagoon and groundwater resources.

In order to characterise groundwater resources within the Waituna catchment, a network of bores were selected 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 (baseflow) conditions during the summer of 2011/12, and;
- two groundwater seepage trials undertaken at the eastern and western portions of the Waituna Lagoon.

Groundwater quality investigations included the setup of a monthly Waituna groundwater quality run and two "one-off" characterisation surveys. Characterisation surveys sought to provide a spatial snapshot of the shallow (unconfined) groundwater quality throughout the catchment. A significant southerly storm (rainfall) event in mid-July 2011 triggered the artificial opening of the Waituna Lagoon. During this period high-resolution groundwater sampling was undertaken on a selection of wells around the lagoon margin in an attempt to capture temporal behaviour in groundwater level and groundwater quality associated with the artificial opening of the lagoon.

In addition to groundwater sampling, snowmelt, tile and open drain, soil water and surface water samples (Waituna, Moffat and Carran Creeks) were collected throughout the catchment. Soil water, tile drain waters and bulk soil samples were collected from grazed pastures and winter grazed forage crops in the north and south of the catchment. Bulk soil samples and soil water (using a teflon suction cup) were also collected from the Waituna

Lagoon Reserve and wetland soils adjacent to the Waituna Lagoon. A drive point piezometer (miniature portable well) was deployed to sample groundwaters in mixed peat-quartz gravel aquifers adjacent to the Waituna Lagoon.

The results of the characterisation program are best summarised through the segregation of the Waituna catchment into three zones according to areas of distinct hydrogeological (physical and chemical) properties, specifically:

1. ***Northern Waituna Zone***
The northern section of the Waituna Creek catchment (north of Mokotua) has relatively good groundwater quality compared to regional norms due to a combination of factors including the presence of thick, stone less, mineral brown soils. The soils buffer groundwater in this area from the effects of intensive land use due to cation exchange and chemical sorption processes which are aided by a long mean residence times (months) within the unsaturated zone (soil and unsaturated sediments above the water table). Excluding tile drainage, which is elevated in nutrients, shallow aquifers across this zone show little impact from intensive land use;

2. ***Mokotua Infiltration Zone***
A zone of rapid infiltration in the Waituna Creek catchment between Mokotua and Caesar Road, associated with the reworking of soil and aquifer materials during a former sea level highstand during the last interglacial period (~70,000–100,000 years ago). Across this area, groundwater quality is poor due to the rapid infiltration of soil water with little or no attenuation of soil zone contaminants from intensive land use. The movement of water through the unconfined aquifer within the Mokotua Infiltration Zone (MIZ) is rapid (1-2 week mean residence time) and appears to contribute to the deterioration in the water quality of Waituna Creek south of Mokotua.

3. ***Southern Waituna Zone***
The southern, predominately wetland portion of the catchment, extends south of Caesar Road to the Waituna Lagoon and includes both the Moffat and Carran Creek catchments. This area is dominated by reducing groundwater conditions due the abundance of organic carbon associated with wetland peat deposits and to a lesser extent lignite measures. Recharge to shallow groundwater systems in this zone occurs relatively rapidly via the soil profile.

   Although naturally reducing conditions prevent assimilation and contamination in nitrate (NO_3-N)[1], median phosphorus (P) concentrations in reduced southern groundwaters are up to 50 times higher than oxic redox state groundwaters occurring in the north. The elevated P within these groundwaters likely reflects both the leakiness of P from organic soils, the naturally higher solubility and mobility of P under reducing conditions and a potentially significant P input from the underlying lignite measure aquifers. Although there is some evidence for anthropogenic P contamination of southern groundwaters due to diffuse soil leaching and localised septic inputs, further work is required to ascertain the magnitude of anthropogenic sources in this sector of the catchment.

4. ***Direct groundwater seepage into Waituna Lagoon***
Direct groundwater seepage into the Waituna Lagoon was estimated at between 340 to 460 litres per second (l/s). While seepage measurements indicate a relatively significant volume of groundwater seepage inflow into Waituna Lagoon, the relative contribution of discharge from the unconfined aquifer versus diffuse leakage from the underlying lignite measure aquifers is unknown. From median nutrient values[2], it is estimated that groundwater contributes approximately 26 tonnes of total nitrogen (TN) to the Waituna Lagoon per year, of which approximately 40 percent is derived from base flow to Waituna Creek in the MIZ. The total phosphorus input from groundwater is estimated at approximately 1,250 kg per year of which approximately 60 percent is sourced from direct groundwater seepage into the lagoon.

Collectively, the findings of this report indicate that groundwater plays a minor, albeit important role, in the transport of nutrient loads into the Waituna Lagoon. When compared to estimated surface water nutrient loadings (Diffuse Sources and NIWA, 2012) groundwater inputs may contribute approximately 13 percent of the cumulative TN and TP loadings.

The work completed to date has identified a number of areas requiring further investigation. These include:

[1] The median NO_3-N concentration of <0.03 mg/L for southern groundwaters falls far below the natural background for Southland of ~1 mg/L.
[2] It is acknowledged that the relative contribution from the confined aquifer system to direct seepage is currently unknown. However, median P concentrations for both the unconfined and confined aquifer systems are similar.

- 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 P in southern groundwaters including the possibility that winter grazing on organic soils and septic tank outfalls play an important role in the elevated P concentrations in southern groundwaters and ultimately the Waituna Lagoon;
- whether discharge of low TN groundwaters 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 P and ultimately how P 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.

Bearing in mind the above uncertainties, the general findings of this report allows some assessment of how to most effectively target catchment management in order to limit or reduce nutrient loads to the Waituna Lagoon. Catchment management should recognise different parts of the catchment behave differently and therefore we recommend management responses are targeted to higher risk areas, specifically:

- current land use activities across the MIZ may constitute a relatively high risk to water quality in Waituna Creek and appropriate intervention within this zone may yield a disproportional improvement in the surface water quality of Waituna Creek and ultimately the Waituna Lagoon;
- Phosphorus is both prone to leaching and of higher mobility within the southern Waituna zone due to a combination of the presence of organic soils and the low oxygen (reducing) conditions. Accordingly, the implementation of P loss management strategies across this portion of the catchment may be of value, and;
- groundwater base flow to Waituna Creek in the northern zone of the catchment likely maintains relatively good water quality in Waituna Creek, due to the thick mineral brown soils, except for during heavy rainfall events when surface runoff and artificial drainage is significant. The most effective land management response will therefore relate to potential contamination from overland flow and artificial drainage.

Robson, M., Monaghan, R., and McDowell, R., 2011. *Potential Nitrogen and Phosphorous Losses from Example Farms in the Waituna Catchment: Sources and Mitigation.* Prepared for Environment Southland by AgResearch, June 2011. 19p.

There is current concern about the condition of Waituna Lagoon. The condition of the lagoon is linked to land use in the catchment through losses of nitrogen, phosphorus and sediment. This report models, using the OVERSEER nutrient budgeting model, the losses of nitrogen and phosphorus from an example dairy and sheep & beef farm in the catchment under different management practices and on different soil types, and considers the effectiveness of some relevant mitigation measures, based on expert knowledge and modelling. Although no sediment modelling has been undertaken, some reported sediment losses are given for different land uses and management practices. The report is provided under the context that it represents an initial scoping study aimed at highlighting gaps in the knowledge and future areas of work relevant to the Waituna lagoon catchment. As such, this report should not be viewed as comprehensive assessment of measures that will restore water quality in the catchment.

Stock type has a significant impact on nitrogen and phosphorus losses from farms, with typical dairy systems modelled to lose more than typical sheep & beef enterprises on the same soils. Soil type also has an important effect on contaminant losses. This effect is more evident for phosphorus losses which decrease in the order Peat>Podzol>Gley>Brown. For nitrogen, the soil type effect is evident but less pronounced than for phosphorus, and has the pattern of Brown>Podzol>Peat>Gley.

For both the dairy and the sheep & beef systems, the important sources of nitrogen loss to water are urine patches and winter grazing losses (a large component of which are urine patch losses). For both the dairy and the sheep & beef systems, the important sources of phosphorus loss are: winter grazing of forage crops; stock access to watercourses; soil phosphorus (as indicated by Olsen P); and losses from applying farm dairy effluent (via surface or sub-surface flow).

Reported sediment losses on Pallic soils suggest that sediment losses are generally higher under cattle than sheep grazing, winter grazed forage crops yield greater sediment losses than pasture, and that restricted grazing of winter grazed fodder crops reduces sediment losses under both sheep and cattle compared with unrestricted grazing.

Tier one (cost effective) and tier two (those likely to be either less cost effective, or well proven) mitigation measures relevant to the Waituna catchment have been identified. Suggested tier one measures for the Waituna catchment include: nutrient management plans to apply no more nitrogen and phosphorus than is needed; for Olsen P not to exceed agronomic optimum levels; the exclusion of stock from watercourses and wetlands; preventing runoff from tracks and lanes from entering waterways; management of effluent to prevent nitrogen and phosphorus losses; and management of winter forage crops which could include restricted or strategic grazing or wintering outside of the catchment.

However, an important caveat to the assessments provided in this report is to acknowledge the lack of information available on phosphorus losses from Peat, Podzol and Gley soils. The assessments provided here are our "best guess" based on the principles of phosphorus sorption and movement through these soil types. Further research is urgently needed to validate these assessments.

Wilson, K. L., 2011(a). *Groundwater in the Waituna Catchment.* Environment Southland Technical Comment, 23rd March 2011. 23p.

The Waituna catchment is located in an area of relatively high geological complexity. The geology is made up of two terranes which have been folded and faulted to form shallow sedimentary basins infilled with marine and alluvial sediments. The contact between the basement geology and overlying sediments appears to exert significant influence over existing surface water hydrology and hydrogeology as catchment drainage does not always follow surface topography. The complexities of the area unfortunately add to the uncertainties in interpreting data however the following conclusions can be made based on the data presented in this report:

- The underlying geology is relatively complex as evident by the presence of basement rocks at the surface (e.g. Gorge Road platform), fault systems (e.g. the Morton Mains fault), regional folding (e.g. Southland Syncline) and shoreline aggradation. The underlying geology appears to have a significant effect on catchment drainage where surface water drainage, the geology and possible paleochannels in the Gore Lignite measures and gravels are orientated in a shallow gradient in a predominately southwest direction. This does not exactly mirror surface topography or the Waituna catchment orientation which is predominately aligned north-south. This suggests groundwater and surface water catchments are probably not aligned and that water resources within the Waituna catchment are likely to be strongly influenced by the underlying geology. This could have significant implications with regards to delineating the capture area of the Waituna Lagoon (i.e. the surface water catchment may not be sufficient to encapsulate the entire hydrological or nutrient input area for the lagoon).

- The thickness of the Quaternary gravel deposits which host the unconfined aquifer are variable, generally ranging from thin in the upper part of the Waituna catchment (less than 5 metres thick), thickening in the middle reaches (to about 10 to 20 metres thick) and thinning again in the lower reaches (to no more than 10 metres thick). The gravel thickness also thickens in the area of the Moffat Creek catchment (interpolated to be 10 to 20 metres thick) which may reflect a paleochannel or geological structure infilled with gravels that is aligned in a southwest direction which follows the dip of the underlying Tertiary sediments. The thicker gravels in the area of Moffat Creek could host an aquifer system with sufficient yields to substantially contribute to stream flows and the alignment means there is potential for groundwater to discharge directly into the Waituna Lagoon. Therefore, it is concluded that this catchment may not be suited to a Living Streams approach to the monitoring and management of nitrogen as any nutrients which leach into the underlying groundwater system may not discharge into surface water within the property boundary area and may discharge directly into the Waituna Lagoon and would therefore not be captured through a surface water monitoring program.

- The soils in the catchment are also influenced by geological and geomorphological processes. The Q5 (70,000 to 130,000 year old) shoreline marks the boundary of an old marine terrace across which the predominately brown soils to the north are well to imperfectly drained, compared to the podzol, gley and organic soils to the south which are poorly to imperfectly drained. The soils in the southern half portion of the catchment can become waterlogged due to the low topographical gradient, low permeability lenses and layers within the soil matrix which impedes surface drainage or a near surface groundwater table. The different soil characteristics between what is essentially the northern half and southern half of the catchment can result in different environmental impacts for the same landuse activity.

- The possible mechanisms for groundwater discharge from the Waituna catchment are discharge of groundwater directly to the sea, baseflow discharge into Carran's, Moffat and Waituna Creek's, direct lateral groundwater inflow into the Waituna Lagoon and vertical groundwater inflow from the underlying confined aquifer systems. The potential magnitude of groundwater discharge offshore, directly into the lagoon and through vertical flow is unknown. Based on the similar hydrology of the Moffat Creek and Waituna Creek catchments with the Waihopai River, it is interpolated that approximately 20 to 50 percent of stream flow in Moffat Creek and Waituna Creek is sourced from groundwater discharge. Therefore, groundwater is likely to comprise a significant component of surface water flow.

- Groundwater quality is influenced by a range of factors including geology, the nature and source of aquifer recharge and the overall rate of groundwater circulation within an aquifer system. Groundwater hosted in the Gore Lignite Measure sediments typically exhibits oxygen-reduced water that is in high iron, manganese and sulphur (often to the point where hydrogen sulphide can be smelled in the water). Nitrate is not normally present in the water due to its anoxic state however ammoniacal nitrogen can be present and is believed to be sourced from the organic lignite deposits (i.e. naturally occurring). Groundwater hosted in the Quaternary gravel deposits typically display nitrate concentrations above natural levels reflecting the vulnerability of the shallow unconfined aquifer to the impacts of overlying landuse. However, in the Waituna catchment, water quality results from the unconfined aquifer are highly variable reflecting the influence of the underlying Tertiary sediments. Where the gravels are thickest, nitrate concentrations in the range of 5 to 18 mg/L have been measured.

The following recommendations are intended to address the most significant information gaps surrounding groundwater resources in the Waituna catchment as identified in this report. In particular, these information gaps relate to the possible sources of groundwater discharge within the Waituna catchment.

It is recommended that:

- Flowing artesian bores are known to exist in the Carran's and Moffat Creek catchments so artesian springs are possible where the aquatard(s) have sufficiently thinned or are absent. It is therefore recommended that enquiries are made of local landowners to ascertain if any springs are present and that these be inspected by a groundwater specialist in order to establish the source aquifer.

- In order to determine the potential rate and nutrient input of lateral groundwater flow directly into the Waituna Lagoon, it is recommended that temporary piezometers are placed around the landward face of the Lagoon so that the hydraulic gradient and water quality can be monitored for different water levels within the lagoon. The piezometers should be situated in a number of sites on an east-west transect in order to monitor the effect of the sediment changes observed in this report.

- It is recommended consideration is given to installing an automated groundwater level monitoring site in the unconfined aquifer in the Waituna catchment in order to establish a "real-time" hydrograph to improve estimations of baseflow for Waituna Creek and Moffat Creek. This data will also help improve characterisation and understanding of groundwater recharge and lag-times within the system.

- If additional bores in the unconfined aquifer are able to be identified through discussions with landowners, it is recommended these are sampled to improve the spatial resolution and characterisation of water quality within the aquifer most likely to influence surface waters. Ideally, a baseline monitoring site would also be established within the catchment, if a suitable site can be found, in order to improve understanding of temporal groundwater processes.

Wilson, K., L. 2011(b). ***Update on groundwater activities and proposed projects in the Waituna Catchment.*** **Environment Southland Technical Comment, 21st June 2011. File reference 218/04/12. 11p.**

In May 2011 a technical report characterising groundwater knowledge of the Waituna catchment was produced by Environment Southland. The following is intended to provide an update on groundwater activities in the Waituna catchment since that report was produced and to review critical future information requirements. This document is intended to inform the workings of the Waituna Catchment Technical Group and is not intended for public distribution.

Key Groundwater Questions

The following has been developed by the groundwater team as a result of a brainstorming exercise on the 16th June. The following items are listed in no particular order.

Top three priorities:

1. Understanding the lagoon – groundwater interface and its effect on phosphorus
2. Understanding groundwater – stream interaction and associated nitrate loading
3. Characterising groundwater resources within the catchment

The following questions were identified as key information gaps:

- What are the sources of nitrate and phosphorus in groundwater?
- What role does redox play in influencing groundwater quality? – how does surface water affect groundwater redox and what/where does geology exert influence over redox?
- What are the lag-times within the system?
- What are the aquifer properties (e.g. transmissivity, permeability etc)?
- Is groundwater quality influenced by seasonal signatures or the opening/closing regime of the lagoon, or both?
- What is the interplay between the saline groundwater interface with respect to chemical and hydrological processes?
- Are the total phosphorus values in AW4 (reported by MWH) real?
- What is the groundwater water balance, particularly interflow between aquifers and the associated impacts on water quality?
- What are the groundwater N and P loadings into streams?
- Where are the groundwater flow paths/aquifer boundaries (preliminary studies suggest do not align with surface water catchments)?
- What are the spatial and temporal patterns/variability with respect to groundwater quality?
- What influence does the difference in major soil types have on groundwater quality?

3. In-Progress Reports

Lagoon Science

Title	Author	Funder	Contact Person	Date Due
Coastal lakes reference condition	Hugh & Marc	Department of Conservation	Hugh Roberston	?
Cultural Health Index/SOT for the Lagoon	Jane/Dean	TAMI	Jane Kitson	?
Nutrient limitation of *ruppia* and macroalgae	Marc Schallenberg (University of Otago)	?	Marc Schallenberg	?
SWAT catchment model & report for the Lagoon model	David Hamilton (University of Waikato)	Environment Southland	Karen Wilson	20th Dec 2012

Catchment Science

Title	Author	Funder	Contact Person	Date Due
Attenuating nutrient and sediment loads to Waituna Lagoon: Assessment of options using filter strips, wetlands and sediment traps	Keith Hamill (Opus)	DairyNZ	Mike Scarsbrook	Mar 2013
Sediment Fingerprinting	Richard McDowell (AgResearch)	Environment Southland	Karen Wilson	Jun 2013
Nutrient losses under organic soils/wintering	Richard McDowell (AgResearch)	DairyNZ	Mike Scarsbrook	?
Surface water quality study (longitudinal study)	Roger Hodson (Environment Southland)	Environment Southland	Karen Wilson	Apr 2013
Soil amendments to improve P-retention of organic soils	Richard McDowell (AgResearch)	Balance AgriNutrients	Richard McDowell	?
Organic soil development project	? PhD student	AgResearch?	Richard McDowell	?
Waituna catchment nutrient and sediment stocktake	Richard Muirhead (AgResearch)	Environment Southland	Karen Wilson	Apr 2013