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Science Summary and Overseer® Analysis of the Waituna Catchment

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Report prepared for Environment Southland

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Table of Contents

1. Executive Summary

The Waituna Lagoon in Southland is recognised as a highly valued and unique wetland-lagoon complex that is under threat of eutrophication. To address this threat Environment Southland (ES) established the Catchment Technical Group (CTG) and asked it to outline where the nutrient and sediment loads from the catchment are coming from and the potential for these loads to be reduced. This report to the CTG is intended to summarise our current knowledge of losses in the catchment and our best estimates of the mitigation potential to reduce the load of nutrients discharged to the lagoon.

The Waituna is a wet catchment with extensive artificial drainage to maintain high agricultural production. Historically the terms 'development' and 'drainage' have gone hand and hand in the Waituna. The extensive artificial drainage networks result in the land in the catchment being highly 'connected' to the lagoon. The flip side of this high connectivity is that the implementation of mitigations on the land should have rapid benefit to the lagoon.

Estimates of the natural baselines of sediment and nutrient loads to the lagoon indicate that current levels are much higher than would be expected from the catchment prior to development for farming.

The combined effect of water flow and contaminant loss pathways in the Waituna catchment results in spatial hot spots of contaminant losses. The sediment concentrations and loads are low (relative to other catchments in NZ), but the lagoon is heavily impacted by sediment. The Waituna Creek drains the largest area of the catchment and therefore, dominates the total load of nutrients and sediment discharged to the lagoon. However, specific yields (kg ha^{-1} $year^{-1}$) identify Waituna Creek as the greatest nitrogen source, but Moffat and Carran Creeks as greater sources of phosphorus. These specific yields are a reflection of spatial distribution of soil types in the catchment: Brown soils in the northern part of the catchment that drain into Waituna Creek and in the southern catchment, Organic and Podzol soils that drain into Moffat and Carran Creeks. Direct groundwater seepage to the lagoon is estimated as 10% of N and 18% of P loads, while inputs from water birds have been estimated at 1 and 4% of the catchment loads for N and P, respectively.

Modelling of contaminant losses from the catchment is critical for estimating the effect of applying mitigation options to reduce future loadings to the lagoon. Three different modelling tools have been used in the Waituna catchment. Overseer® is a farm-scale model that is useful for predicting losses of nutrients from a farm and for including the effect of some mitigations applied to farms. Overseer® does not account for attenuation of nutrients as the water flows from the root zone (N) or first order stream (P) to the lagoon and therefore, catchment scale losses cannot be determined by simply summing the losses predicted by Overseer®. However, the losses predicted by Overseer® do reflect specific yields measured in the 3 creeks. Catchment-scale models CLUES (catchment land use and environmental sustainability) and SWAT (soil and water assessment tool) are designed to account for stream attenuation and have been run in the catchment. The SWAT has been set up to provide estimates of the stream inputs into the lagoon on a daily basis which is required for the lagoon models. However, it is difficult to incorporate mitigation options into the SWAT. The CLUES model operates on an annual time step and is much more suitable for determining the effect that mitigations applied on farms will have on annual loads of nutrients discharged to the lagoon.

The creeks and drains in the catchment fill up with sediment reducing the effectiveness of the drainage system. This sediment has to be regularly removed by mechanical diggers which have an impact on water quality and stream habitat. It is unclear where most of this sediment comes from. A sediment finger-printing project is underway to identify sediment sources within streams. There is some evidence of bank erosion in the creeks and there are projects underway to re-batter the banks to reduce erosion.

As well as the sediment finger-printing project there are additional projects underway looking at nutrient losses from the Organic soils in the catchment as there is no measured data from these soil types and hence no data to calibrate models. However, due to low anion storage capacity, P losses are expected to be high. There are also projects looking at suitable sites for locating constructed wetlands in the catchment and on good management practices (GMPs) with reports due in July 2013.

With all of this data there are still some potentially important science knowledge gaps in relation to: 1) farm dairy effluent irrigation (FDE) on the Organic and Podzol soils in the catchment; 2) losses of nutrients from winter grazing practices for all animal types; and 3) stream bank erosion.

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

Recommendations

1. The results of the sediment finger-printing project are used to decide on a strategy for reducing the sediment inputs to the drains and creeks to reduce the amount of drain clearing needed.
2. The results from the nutrient loss study are used to calibrate Overseer® outputs.
3. Future Overseer® data, and that contained in this report, are used with the spatial data to generate maps of potential nutrient losses from farms in the catchment for a range of mitigation scenarios including easy and more appropriate options with the current land use and with land use change.
4. NIWA to utilise this data in a spatially resolved CLUES modelling of the catchment to account for in-stream attenuation and delivery to the lagoon as recommended in Elliott (2012).
5. The results of steps 2 to 4 are used to inform a discussion with the Waituna community on the key challenges faced by the community if they are to achieve the targets set by the Lagoon Technical Group. These challenges are likely to include:
    a. Achieving the desired lagoon values at the recommended catchment nutrient targets.
    b. The economic cost of implementing mitigations and/or land use change in the catchment.
    c. The implications of time lags required to implement changes.

2. Introduction

The Waituna Lagoon in Southland is recognised as a highly valued and unique wetland-lagoon complex. However, the lagoon is under threat of eutrophication due to increasing nutrient concentrations in the lagoon. To address this threat, Environment Southland (ES) has established a response plan that includes a Lagoon Technical Group (LTG) and a Catchment Technical Group (CTG). The LTG has been charged with developing an understanding of the factors that control the water quality in the lagoon and to come up with guidelines to ensure that the lagoon remains in the preferred macrophyte dominated condition. These guidelines for managing the lagoon will include catchment load limits of nutrients and sediments that the lagoon can absorb from the catchment (Robertson et al., 2011). The CTG has been charged with developing an understanding of where the nutrient and sediment loads from the catchment are coming from and the potential for these loads to be reduced. These two work-streams need to come together to inform the long-term management of the lagoon .

The CTG worked with ES, the catchment community and scientists and identified a number of information gaps specific to the Waituna catchment. Since 2011 there have been a number of studies and projects conducted to fill these gaps with more than 12 written reports. The aim of the first part of this report is to summarise all of these reports into a single document to determine the overall understanding of the catchment so far. This summary will also provide a list of other projects still operating in the catchment, including a brief summary of those projects and the information they will provide, and identify any potential knowledge gaps that may remain.

A question that is frequently asked is how much impact is due to agricultural land use relative to the “natural” losses that would have occurred prior to human development of the catchment. McDowell et al. (2012b) has recently completed a report for MfE on establishing reference or baseline conditions of nutrients in streams throughout New Zealand. This information, along with baseline data being measured in the catchment, will be used to estimate the natural median nutrient concentrations in streams of the Waituna catchment relative to the current median concentrations that are impacted by agricultural development.

The final section of this report is a series of Overseer® modelling runs based on data representative of farms in the Waituna catchment. The key step to managing the nutrient loads in the catchment in the long term will be determined by the limits set by the LTG. However, ES did not want to wait for these limits to be derived before starting to look at current loads and the mitigation potential. However, the results of the modelling analysis are not intended to be used as a definitive analysis of all farming operations, but rather to provide an indication of the magnitude of N and P losses and potential to mitigate to targeted nutrient losses for a few common farm systems and soil types in the catchment.

3. Summary of Current Knowledge

3.1 Completed reports

Catchment hydrology

The Waituna catchment can be best described as cool-temperate climate with an annual rainfall of 1070 mm year^{-1} (Rissmann et al., 2012). The average monthly rainfall is evenly spread throughout the year, so the surplus rainfall (i.e. available drainage water) is driven by evaporation rates resulting in most drainage occurring from April to August each year. The lower parts of the Waituna catchment have always been referred to as swampy (Anon, 2012), requiring land to be drained for agriculture. Drainage improves plant growth and the load bearing capacity of the soil. Under heavy rainfall it can be impossible to prevent soils from becoming wet, but drainage is used to minimise the period of time that soils remain saturated. Historical knowledge from the Waituna catchment indicates that land ‘development’ and ‘drainage’ were activities that went hand in hand (Anon, 2012).

There is some variability in flow pathways by which this surplus rainfall makes its way into the Waituna Lagoon (Rissmann et al., 2012). In the north of the catchment (above Mokotua/Kapuka), which is dominated by the brown soils, groundwater appears to have a “long residence time and shows little evidence of impact from intensive land use” (Rissmann et al., 2012). However, this part of the catchment does contain areas with artificial drainage (Mole and Pipe drains) enriched in nutrients (Hamill et al., 2012). The artificial drainage system will rapidly direct the water to the Waituna Creek and then to the lagoon itself. The central part of the catchment has been referred to as the Mokotua Infiltration Zone (MIZ; Rissmann et al., 2012). In this area there is rapid infiltration into the groundwater with minimal attenuation of contaminants. As a result of this rapid infiltration the water yield (L s^{-1} km^{-2}) in the Waituna Creek increases and groundwater has a mean residence time of 1-2 weeks (Rissmann et al., 2012). The influx of contaminated groundwater into the Waituna Creek in the MIZ has been posited as responsible for the deterioration of water quality detected during surface water quality monitoring (Rissmann et al., 2012). The southern, predominantly wetland proportion of the catchment, is characterized by rapid recharge of the shallow ground water from the soil profile (Rissmann et al., 2012). The Organic soils (including the sub-category of Peat soils) in the southern zone have high lateral water flow into the open drains that have been dug along the edge of each paddock. There is also evidence of direct ground water seepage into the lagoon (Rissmann et al., 2012). From the combination of artificial drainage networks throughout the catchment and the rapid ground water recharge rates in the middle and lower parts of the catchment land in the Waituna catchment is be termed “highly connected” to the creeks and hence to the lagoon. This means that the management of all of the land in the catchment will have a strong effect on the lagoon. The flip side of this connectivity is that mitigation strategies may quickly decrease loads to the lagoon.

Contaminant movement

When water moves from the land into runoff or groundwater and into streams it always takes contaminants with it. However, contaminants vary in their rates of movement via different water flow paths. When different forms of nitrogen are deposited on the soil, if not utilised by growing plants or immobilised in the soil, they are transformed by microbes into nitrate (NO_3-N). Nitrate ions are very soluble and do not sorb onto soil. Therefore, in the soil, nitrate remains in the soil water and is leached from the soil profile in drainage water to emerge via groundwater or runoff (i.e. as lateral shallow drainage) as streamflow. In contrast to nitrogen, phosphorus can sorb onto sites within the soil occupied by Al, Fe or Ca (depending on soil pH). Hence, P loss in soils with good sorptive capacity (otherwise termed P retention) contains a larger particulate associated component. The transport of P occurs via surface runoff (*viz*. overland flow), shallow lateral drainage or in soils of poor sorptive capacity in groundwater. Sediment (*viz*. soil particles) is readily trapped by the soil matrix which works like a sieve to trap particles. Therefore, sediment (and particulate associated phosphorus) is transported mainly by surface runoff. Anaerobic conditions, as commonly found in the Organic soils, increase the loss of phosphorus to runoff and groundwater (via dissolution of Fe oxide-phosphorus bonds and the inhibition of sorption sites with organic ligands), but decrease nitrogen losses (via denitification and emission of entrained nitrogen as di-nitrogen gas). Poor drainage also increases phosphorus and sediment losses due to the increased amount and frequency of surface runoff. In contrast, nitrogen losses are enhanced from free draining soils due to the higher volumes of drainage water percolating through the soil profile.

The overall pattern of contaminant movement can appear to be modified in Organic soils compared to the other soil types. In Organic soils, such as in the southern zone of the Waituna catchment, the ground waters are reducing due to the abundance of organic carbon (Rissmann et al., 2012). In these soils the nitrate is leached from the top soil as usual, but when the nitrate gets to the ground water the nitrate is reduced to nitrogen gas and is then lost to the atmosphere. The organic material in these shallow ground waters form a coating on the soil particles reducing their negative surface charge and also the anaerobic conditions increase the solubility of phosphorus ions. The effect of this is to decrease the nitrogen and increase the phosphorus concentrations in the ground water of Organic soils (Rissmann et al., 2012).

The combined effect of water flow and contaminant loss pathways in the Waituna catchment results in spatial hot spots of contaminant losses. The northern zone of the catchment with the freer draining Brown soil types will be the dominant area for nitrogen losses from the catchment (Robson et al., 2011). In contrast the poorer draining Organic and Podzol soils with low P retention in the southern zone will be the dominant area for phosphorus losses in the catchment (Robson et al., 2011).

Measured losses

Environment Southland has monitored both the flow of water and the quality of the water in the 3 main tributaries that discharge into the Waituna Lagoon. The data has been analysed by Diffuse Sources and NIWA to estimate the annual loads of sediment and nutrients discharged to the lagoon.

The sediment concentrations and loads from the catchment are very low relative to other NZ catchments (Diffuse Sources & NIWA, 2012). These low sediment yields are likely to be an effect of the extremely flat topography of the Waituna catchment leading to naturally low erosion rates. These low sediment yields are at odds with the historical sedimentation rates measured in the lagoon (Stevens & Robertson, 2007). This miss match between measured sediment inputs from the creeks and the sediment cores measured in the lagoon could indicate additional sediment sources from the ocean and bar, underestimating the loads from the creeks or a miss-match in the method of measuring sedimentation (i.e. mass or volume assessments vary greatly if influenced by organic materials or detritus). A key, potentially underestimated, source from the catchment is pulses of sediment from drain cleaning activities. This issue of the effect of drain cleaning is discussed further on in this section of the report.

Nitrate is the dominant form of nitrogen measured in the Waituna Creek. In contrast, nitrate concentrations are comparable to organic and particulate nitrogen concentrations in the Carran and Moffatt creaks (Diffuse Sources & NIWA, 2012). Ammoniacal-nitrogen concentrations are generally low and are considered a minor component of the total nitrogen load. However, very high concentrations of ammoniacal-nitrogen have been detected in some samples which could be attributed to poor farm dairy effluent management (Diffuse Sources & NIWA, 2012). Nitrate concentrations show an increase with flow at low flows and then a "levelling off", which is consistent with nitrate flushed from groundwater (Diffuse Sources & NIWA, 2012; Rissmann et al., 2012).

Total phosphorus (TP) concentrations are higher in the Moffat and Carran Creeks relative to the Waituna Creek (Diffuse Sources & NIWA, 2012). Dissolved reactive phosphorus (DRP) is a large proportion of TP present in Moffat Creek, less so in Carran Creek and only a minor portion of TP in the Waituna Creek. This pattern reflects the spatial distribution of soil types in the catchment mentioned above, i.e. the poorer draining and/or poor P retention soils in the lower catchment will have higher losses of phosphorus (Robson et al., 2011).

The Waituna Creek drains the largest catchment area and therefore, dominates the load of contaminants discharged to the lagoon (Table 1). However, losses differ when catchment area is taken into account. The specific yields for the Waituna Creek are higher for sediment and all nitrogen species and lower for the phosphorus species relative to the Carran and Moffat Creeks. This is again expected from the spatial distribution of different soil types and catchment hydrology. There are also direct groundwater inputs into the lagoon that are not included in Table 1. The direct groundwater inputs are estimated to range from 28 to 48 tonnes of nitrogen and 1.4 to 2.4 tonnes of phosphorus per year (Rissmann et al., 2012). These direct groundwater inputs represent approximately 10 to 18% of the total contaminant loads discharged to the Waituna Lagoon.

There are numerous water birds in the Waituna and they defecate directly into the lagoon. An assessment of the annual load of nutrients discharge directly into the lagoon has been assessed as 1 and 4% of the N and P inputs, respectively (Burger, 2013). This indicates that water birds are a minor source of nutrients to the Waituna Lagoon.

Table 1. Summary of the estimated total loads and the specific yields from the three creeks that discharge into the Waituna Lagoon. The total load data is from Diffuse Sources & NIWA (2012) and catchment area data supplied by ES.

Characteristic		**Waituna Creek**	**Carran Creek**	**Moffat Creek**	**Total Catchment**
Catchment area (ha)		9348	2616	1432	13,396
Sediment (TSS)	Total load (T y^{-1})	894.9	166.4	97.4	1158.7
	Yield (kg ha^{-1} y^{-1})	95.7	63.6	68.0	86.5
Nitrate (NO_3-N)	Total load (T y^{-1})	112.0	9.3	7.8	129.1
	Yield (kg ha^{-1} y^{-1})	12.0	3.6	5.4	9.6
Ammonia (NH_4-N)	Total load (T y^{-1})	11.3	1.2	0.7	13.2
	Yield (kg ha^{-1} y^{-1})	1.2	0.5	0.5	1.0
Total Nitrogen (TN)	Total load (T y^{-1})	165.8	21.3	17.3	204.4
	Yield (kg ha^{-1} y^{-1})	17.7	8.1	12.1	15.3
Dissolved reactive phosphorus (DRP)	Total load (T y^{-1})	1.5	0.6	0.9	3.0
	Yield (kg ha^{-1} y^{-1})	0.2	0.2	0.6	0.2
Total phosphorus (TP)	Total load (T y^{-1})	6.0	2.0	1.7	9.7
	Yield (kg ha^{-1} y^{-1})	0.6	0.8	1.2	0.7

Modelling approaches

Measuring water quality is the best way to understand the current situation in catchments and trends due to land management over time. Historical data can be used to calibrate models to provide future predictions of water quality as a result of land management decisions. A range of models are available and each have advantages and disadvantages for specific tasks: thus far, three have been used in the Waituna catchment.

The Overseer® nutrient budgeting model is a farm-scale model used to predict nutrient losses from an individual farm (e.g. Robson et al., 2011; and this report) and the effect of some mitigation options. One approach to estimate the cumulative effect at a catchment scale is to sum the load of nutrients lost from individual farms. However, this approach negates the effect of in-stream processes that may increase or decrease losses (Elliott, 2012). Hence, another model CLUES (catchment land use and environmental sustainability) will also be used to scale-up farm losses to the catchment scale.

When the Overseer® data is summed, the proportion of nutrients estimated to be lost to each of the three creeks in the Waituna catchment was very similar to that estimated as the annual load via sampling and flow measurement (Figure 1). This suggests that Overseer® outputs reflect the relative differences in soil types in the respective catchments and that due to high connectivity (via drainage) in stream processes may play a minor role in influencing loads (Figure 1). High connectivity also means that the effectiveness of mitigation options at the farm scale, regardless of the initial magnitude of loss, will likely result in a similar effectiveness at a catchment scale (if implemented across all land).

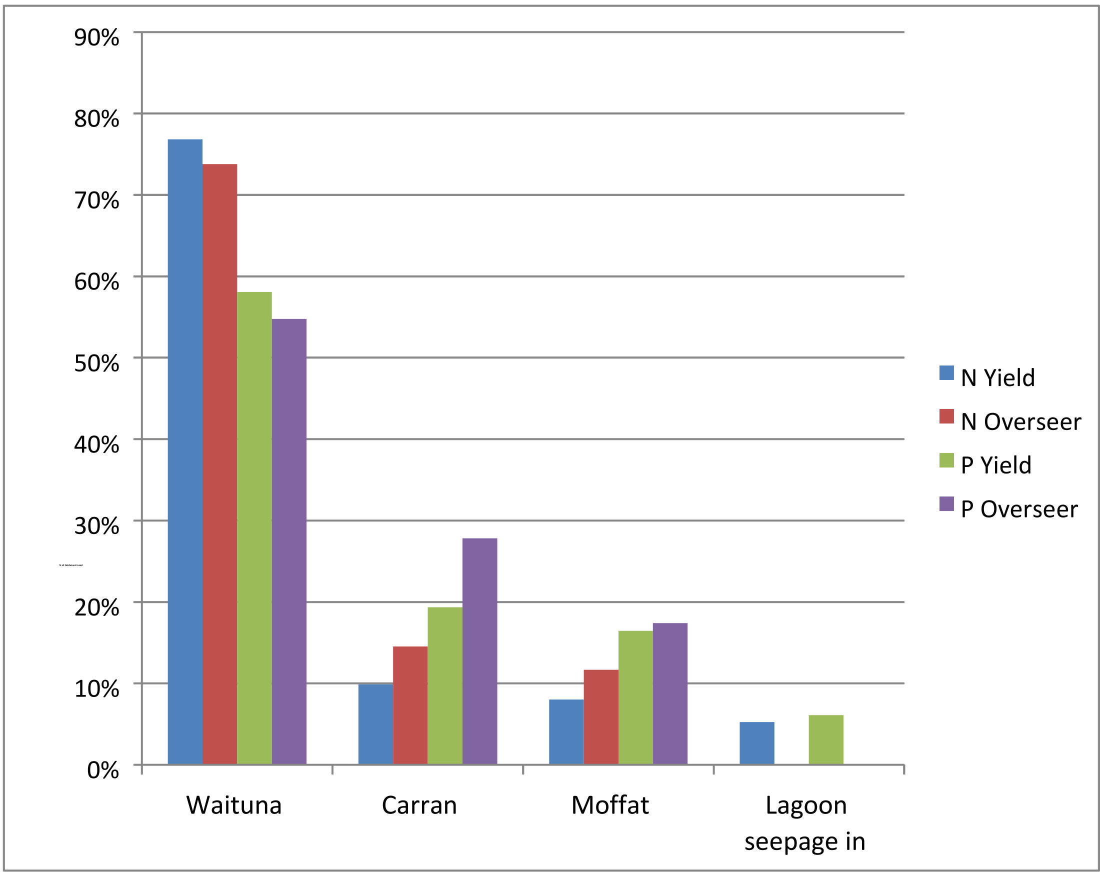

Figure 1. Estimated proportion of total catchment load of nutrient losses from the creeks in the Waituna catchment predicted from stream yield data from Diffuse Sources & NIWA (2012) and Overseer® modelling by Ross Monaghan (AgResearch – presented to the CTG).

Two catchment-scale models have been used in the Waituna catchment, the aforementioned CLUES and the Soil and Water Assessment Tool (SWAT). Each model has particular strengths and weaknesses (Elliott, 2012). The lagoon model used by the LTG requires estimates of the daily volume of water and nutrient loads to the lagoon to operate. The SWAT model operates on a daily time step, while CLUES estimates annual loads, and therefore SWAT has been used in the catchment to support the lagoon model. However, SWAT is unable to accurately reflect the range of mitigations that could be applied on farms in the catchment (Elliott, 2012). In contrast, the CLUES model can account for most mitigation options, but will still struggle to model the effects of wintering cows on fodder crops (Elliott, 2012). Therefore, it is recommended to use a modelling approach that is more resolved – both spatially and in terms of land management – than the current version of CLUES (Elliott, 2012).

Mitigation options

A number of mitigation options have been proposed as useful for reducing nutrient and sediment losses to the Waituna Lagoon. Some of the key options are fencing off of waterways, improving farm dairy effluent (FDE) management, maintaining soil Olsen P levels at or below agronomic optimums and better management of winter/spring forage crops (McDowell et al., 2011; Muirhead & Rutherford, 2007; Robson et al., 2011). In addition to forage crops grazed in winter, forage crops are grazed in spring to transition cows back onto pasture when coming back onto the milking platform from elsewhere. A one year study in the northern part of the catchment showed that these spring grazed forage crops lose a similar load of nutrients and sediment as winter grazed forage crops (McDowell et al., 2011). However, Dennis et al. (2012) showed that delaying the return of the cows to the milking platform or removing spring forage crops and good pasture management was financially no different than utilising a spring forage crop, but would result in less contaminant loss in surface runoff. Methods such as filter strips, wetlands and sediment traps have been reviewed as options for the Waituna catchment (Hamill et al., 2012). However, these methods only work on the water leaving the farm that actually passes through the structure. The effectiveness of filter strips in removing contaminants from surface runoff in the Waituna catchment will be limited due to the extensive artificial drainage network that will result in a large proportion of flow bypassing the filter strips. The artificial drainage network does help collect water that can be directed to wetlands. However, there are physical limitations on where wetlands can be placed in catchments and NIWA have a project to identify where these could be applied in Waituna (see section 3.2). More detailed descriptions of various mitigation options can be found in Monaghan et al. (2010).

Managing drains

Artificial drainage functions by lowering the water table in the soils of the drained area. For the drains to function correctly there must be sufficient fall for the water to drain away from the land. The Waituna catchment contains an extensive network of open and sub-surface drains that direct drainage water from the farm to the stream network and the lagoon. This network of drains and creeks accumulates sediment that restricts the flow of drainage water. Regular cleaning of drains and creeks is required to maintain the necessary fall for efficient drainage of farmland (Olsen, 2012). The process of mechanically cleaning the drains disturbs the stream channel and results in increased sediment in the water downstream of the activity (Ballantine & Hughes, 2012).

Estimates of losses of sediment and nutrients to the Lagoon from the Waituna Creek in 2012 has been conducted on samples collected during drain cleaning activities (Ballantine and Hughes, 2012). Based on long-term data from the Waituna Creek the expected sediment load during the 7 week period of drain clearing activity was 22 tonnes. However, the actual load based on intensive sampling during this period was estimated at 550 tonnes (Ballantine and Hughes, 2012). The annual average sediment load is estimated at 895 tonnes (Diffuse Sources & NIWA, 2012). As the annual load is derived from a relationship between sediment concentration and flow it would not include flow-independent inputs such as drain cleaning. This is clearly a source of sediment enrichment to the lagoon that is not currently accounted for. Relative to the increases in sediment loads the nutrient load from drain clearing was much less at 17% and 3% for total P and total N, respectively. Drain cleaning is conducted under low summer flows, to enable the diggers to operate effectively, and the large pulse of sediment into the lagoon at this time may have a significant effect on lagoon health compared to at other times of year. Drain clearing in the majority of the Waituna Creek catchment currently occurs every 3 years. Thought should be given to rescheduling cleaning to a time of year when the effect on lagoon heath would be mitigated (e.g. to coincide cleaning with opening of the lagoon or when water clarity is not critical for submerged macrophytes).

A key question regarding drain cleaning is where the material in the creeks is coming from. If we can prevent the material from getting into the creek then we reduce the need for drain cleaning and its associated effects. There are two predominant sources of the sediment that accumulates in the stream network; (a) erosion of soil from the paddock surface or decomposing mole-tile channels that is transported via surface runoff and drainage to open drains and streams (Goldsmith & Ryder, 2013) and (b) erosion of the stream banks. The management response to reducing these different sources is different, and therefore it is important to determine the relative importance of each source before attempting to put mitigations in place. The purpose of the sediment finger-printing project (Section 3.2) is to determine the relative proportion of sediment lost from topsoil, subsoil, creek banks and creek beds before deciding on a course of action to reduce sediment loads to the creek network.

As well as cleaning creeks, a lot of cleaning also occurs on the artificial drainage network in each farm (Olsen, 2012). Assessing the impact of drain cleaning in these smaller drain networks is much harder. A potential option to mitigate nitrogen, phosphorus and sediment losses from these small drains to larger creeks is the use of peak runoff control (PRC) structures (McDowell et al., 2012a). PRC structures are a series of bunds and culverts in the outlet of open drains that act to store and slow down the flow of water in the drains. These PRC structures have the potential to reduce sediment and phosphorus loads by settling out of sediment in the drains and to reduce nitrogen loads by increasing denitrification (McDowell et al., 2012a). If the majority of the sediment in the creek network is from erosion of the paddocks, then these PRC structures could more effectively trap the sediment closer to the farm reducing the need for drain cleaning in the larger creeks. Furthermore, the PRC structures could act like the clearing of alternative 50m sections of the drains (Greer et al., 2012), reducing the impact when drain clearing does occur i.e. the sediment disturbed in cleaning one section could be retained in the next PRC structure downstream.

3.2 Projects still being conducted

There are a number of projects still being conducted in the Waituna catchment, the results of which will further help guide the selection of appropriate mitigation options to achieve the target nutrient loads to ensure the long-term sustainability of the lagoon.

There is a sediment finger-printing project being conducted by AgResearch with funding from Environment Southland. The aim of this project is to determine the relative sources of the sediment in the creeks to ensure that mitigations are targeted at the largest sources. The results of this project are due at the end of September, 2013. In relation to this, Environment Southland have additional work looking at creek bank reconstruction (rock protection and bank rebattering) and monitoring of the impacts from this work.

There is also a project measuring nutrient losses from Organic soils being conducted by AgResearch with funding from DairyNZ. Most of the data on nutrient losses measured from high organic matter soils in NZ have been conducted on Organic soils from the Waikato, which contain a relatively high amount of Al-containing allophane. The Allophane in these Waikato Organic soils is a result of volcanic ash inputs and this embodies these soils with a relatively high P retention (> 50%). Nutrient loss estimates for Organic soils in Overseer® is based on these Waikato studies. There is concern that the nutrient (particularly P) losses from the Organic soils in the Waituna could be much higher that measured in the Waikato studies due to poor P-retention (commonly <5%). This 2 year project aims to measure actual losses of nitrogen and phosphorus from Organic soils in the Waituna catchment. The results of this project will be delivered to DairyNZ in December, 2013.

NIWA are conducting a project on wetlands for Environment Southland. The aim of this work is to determine where wetlands could be sited to optimise the removal of N from stream flow and to estimate the proportion of the catchment were wetlands could intercept and treat drainage water from the farms. This project is due for completion in July 2013.

DairyNZ funded a workshop that was held on the 10th May in Invercargill in conjunction with Environment Southland. The aim of this workshop was to bring together scientists, farmers and rural professionals to discuss appropriate good management practices (GMPs) for the Waituna catchment with a focus on implementing them. There was good discussion and clarification around the practical difficulties and barriers of implementing GMPs on farms. A report on this workshop by AgResearch is due to DairyNZ in July 2013.

Environment Southland is working on updating the catchment boundary using the LIDAR data collected in 2011.

3.3 Potential knowledge gaps that have not yet been addressed

As discussed in section 3.2 there is a lack of knowledge of nutrient losses from the Organic and Podzol soils in the Waituna catchment. The irrigation of farm dairy effluent (FDE) to land is also a potential source of P losses from dairy farm systems (Monaghan et al., 2010). The losses of P from FDE irrigation to the Organic and Podzol soils in the Waituna may be significant but is unknown.

A recent report for Environment Southland has highlighted significant knowledge gaps around winter management of animals (Monaghan, 2012). This work also highlights that soils with a high risk of losing nitrogen will have a low risk of losing phosphorus and sediment and vice versa. Thus, there is no "ideal" soil type for animal wintering (Monaghan, 2012).

There is work underway in the catchment to improve the stability of creek banks to reduce bank erosion (Anon, 2013). While there is a reasonable body of reports providing advice on managing stream banks (Ballantine & Hughes, 2012; Goldsmith et al., 2013), there is very little data that quantifies how much a specific method will reduce sediment losses. Therefore, it may be difficult to accurately predict sediment loads and the effect of mitigation options.

4. Estimates of natural baselines

A key issue in the management of aquatic systems is the establishment of reference conditions. Reference conditions can be defined as the chemical, physical or biological conditions that can be expected in streams and rivers with minimal or no anthropogenic influence. In the Waituna context this answers the question, "what would the water quality be like in the creeks if there was no human activity, or how much of an effect on water quality are human activities having"? This recognises that even if there is no human activity in the catchment there will still be a level of nutrients and sediment naturally in the creeks. There are two approaches that can be used in the Waituna catchment. The first is comparing data from an impacted stream with a stream that is not now, nor has historically been impacted. Sites that meet this criterion are referred to as in minimally disturbed condition (MDC; McDowell et al., 2012b). The key factor with this approach is that the un-impacted reference stream must drain a similar landscape, climate and soil type as the impacted streams to make a valid comparison. In the Waituna catchment the Craws Creek provides a suitable reference site for the remainder of Carran Creek and for Moffat Creek which collectively drain a large part of the lower catchment.

A comparison of the Craws Creek MDC site with Carran and Moffat creeks shows that the median concentrations are much less at the MDC site (Figure 2). The differences are greatest for nitrate and least for DRP. Both nitrate and DRP originate from farming practices. However, losses of DRP at the MDC site also reflect an anaerobic groundwater source under Organic soils (Rissmann et al., 2012). Compared to DRP, median total phosphorus (TP) concentrations were far greater in Carran and Moffat creeks than in the MDC site. This reflects the dominance of particulate-associated P within TP losses and the enhanced loss of suspended solids (TSS) (Figure 2).

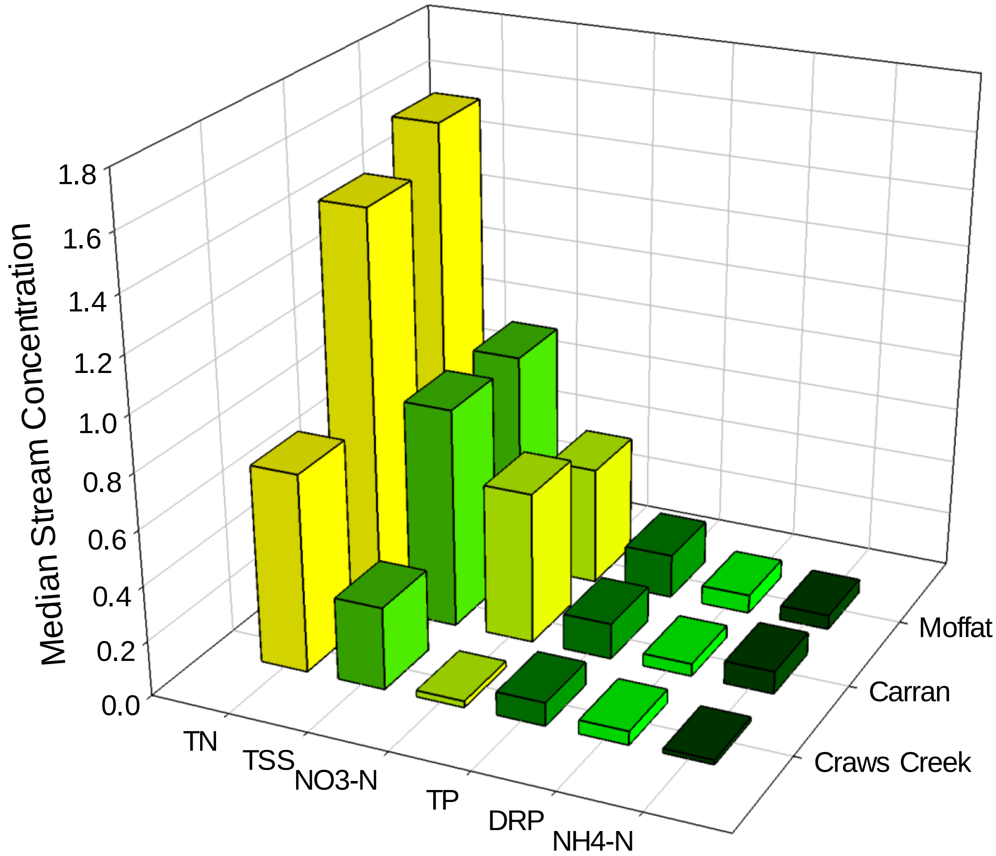

Figure 2. Median concentration of water quality indicators for the Moffat, Carran and (MDC site) Craws Creeks. The concentration units are cg L^{-1} for TSS and mg L^{-1} for all other contaminants.

The Waituna Creek as a whole is not amenable to comparison with a MDC site due to the significant change in geology between the upper and lower parts of the catchment (Rissmann et al., 2012). However, the data collected from the Mokotua Road site on the Waituna Creek could be used, as at this point the creek drains predominantly Brown soils. Due to the high suitability of the Brown soil types for agricultural production there are no remnants of this landscape left in Southland that represent suitable reference conditions.

Another method that can be used to estimate reference conditions is to compile data from other regions that represent similar climatic, hydrological conditions and geology as represented by the river environment classification (REC; Snelder and Biggs, 2002). This analysis was recently completed using data from over 1000 sites throughout NZ (McDowell et al., 2012b). In the REC system the Waituna creek above Mokotua is classified as a cool-dry climate`, lowland stream with soft sedimentary geology. This classification was used to determine the expected reference conditions for the upper part of the catchment. The median concentrations for the predicted natural state of the upper Waituna Creek are much less than the current state of the Creek (Figure 3).

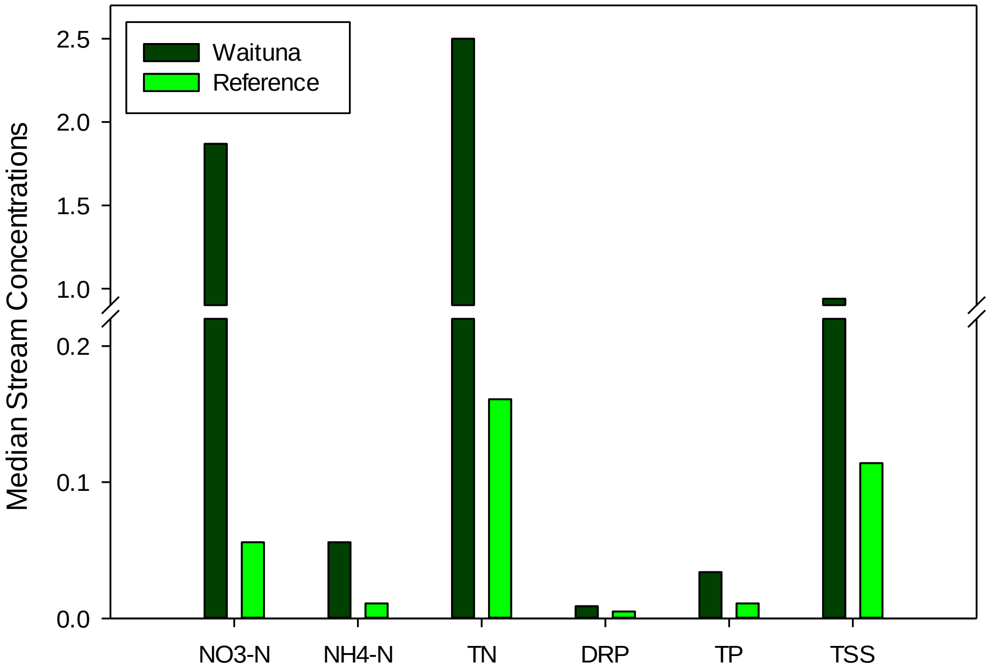

Figure 3. Comparison of median concentrations of water quality indicators for the Waituna Creek at Mokotua and predicted reference conditions. The concentration units are cg L^{-1} for TSS and mg L^{-1} for all other contaminants.

Comparison of the current water quality data from the Waituna catchment with reference conditions indicate the creeks are impacted by agricultural land use (Figures 2 and 3). However, the fact that the current levels are much higher than reference conditions means that there is potential to reduce loads through appropriate mitigations.

5. Overseer® Modelling

5.1 Purpose of the Overseer® Modelling

The CTG has been charged with developing an understanding of where the nutrient and sediment loads from the catchment are coming from and the potential for these loads to be reduced. Thus, detailed Overseer® modelling runs were conducted to help identify the potential sources of nitrogen and phosphorus and to gauge the potential for mitigation. The modelled data is presented for the different farm systems and soil types, so that the losses per hectare can be put into a speadsheet with areas of land use and soil type for the catchment, to predict farm scale losses for the catchment (i.e. ignoring the scaling effect of in stream attenuation). This analysis can be used as a quick check to see how easy or difficult it will be for farms to achieve the catchment level targets that will be proposed by the Lagoon Technical Committee.

5.2 Methods

The detailed methods and data used in the Overseer® analyses can be found in the Appendix. Briefly, to identify sources of nitrogen and phosphorus in the catchment Overseer® modelling was conducted using a matrix of 6 farm types by 4 soil types. The 4 main soil types in the catchment (Brown, Gley, Podzol and Organic) were modelled separately to identify any soil type effect. The 6 farm types were comprised of 3 dairying and 3 dry-stock farm types. The 3 dairy farm types were based on the DairyNZ farm systems 2, 3 and 4 and will give an indication of the expected nutrient losses from these three levels of intensification of dairy farms (DairyNZ, 2013). The 3 dry-stock farms were based on a sheep only, a sheep & beef operation and a sheep farm that grazed dairy cows during the winter on a forage crop. The level of inputs, stocking rates etc…for the farm systems modelled were circulated to the industries working in the Waituna catchment and modified based on their experience of workable farming systems in the catchment. All farm systems were also modelled using FarmMax to ensure that they were profitable and would grow the appropriate amount of feed for the numbers of animals.

To generate an indication of the potential to mitigate losses of nutrients from these 24 combinations of farm systems and soil types, a series of mitigation bundles were applied to each farm system. The mitigation bundles were labelled none, easy, middling and difficult. The farms modelled with no mitigation bundle applied would represent a worst case scenario with little thought given to environmental concerns. We do not expect any farms to actually be managed in this manner but the modelled data does provide a useful reference point of what could happen. Individual mitigations were grouped into the bundles according to the criteria below.

Easy. These mitigations are considered to be well proven, low cost, and are generally accepted as current best practice. Most of these mitigations are included in the Clean Streams Accord and as such should represent current typical farms in the dairy industry.
Middling. These mitigation options require more thought, planning or capital expense to implement.

Difficult. These mitigations can be difficult to implement on farms. They may require significant capital investment and can involve a major change in how the land is farmed.

These classifications of easy to difficult are based on discussions with farmers; however, the results may be different for specific farms. For example, wetlands are considered a middling mitigation for farmers to implement in this report but (due to specific landscape features) may be difficult or impossible to implement on an individual farm.

5.3 Results and Discussion

For farms with no mitigation options applied, the nitrogen losses from dairy farms are much higher than for sheep or sheep & beef farms (Figure 4). Sheep farms with no mitigation options, but winter dairy cows have intermediate nitrogen losses reflecting the high nitrogen losses from forage crops (Figure 4 and Monaghan, 2012). While the nitrogen losses for the dairy farming systems without mitigations is high, the potential for mitigating these losses is also high as indicated by the large spread of data points (Figure 4). While applying the easy bundle of mitigation options reduced the nitrogen losses by 15-25% on the dairy farms, this level of N losses should reflect current good practice in the catchment.

The application of the middling bundle of mitigations reduced nitrogen losses on dairy farms by 10-40%, but in practice this may be difficult to achieve. The key driver of this reduction in nitrogen losses is the establishment of a wetland that is able to capture and treat 50% of the drainage water leaving a farm (see Appendix). With the high level of artificial drainage in the Waituna catchment this magnitude of water capture is possible, but difficult to achieve. The ability for wetlands to deliver this level of treatment for farms in the Waituna is the focus of the NIWA led project (see section 3.2). The application of the difficult bundle of mitigations includes the use of restricted grazing practices in the autumn (see Appendix). To implement restricted grazing requires the building of specific farm infrastructure (such as stand-off pads, effluent capture and management systems) and careful management to maintain pasture productivity. All of this will require a significant investment in capital equipment and staff training to implement. This may not be practical on all farms. Furthermore, the investment in capital equipment is typically followed with an increase in stocking rate to help pay for the investment. An increased stocking rate can lead to increased losses from other parts of the farm which partially offset any of the environmental gains from the investment (Laurenson et al., 2012).

The effect of soil type on N losses is much stronger on the dairy farms with no mitigations applied than with the difficult mitigation options applied (Figure 4). This reflects the mitigations targeting the leaky parts of the whole farm system. For the different dairy farm systems, losses of nitrogen increase as the farms are intensified from system 2 to system 3 farms (Figure 4). However, intensifying from system 3 to 4 does not appear to increase losses of nitrogen due to the system 4 farm collecting some of the dung and urine on the feed pad (Appendix 1).

Losses of nitrogen from the dry-stock farming systems start at a lower level than the dairy farms but are more difficult to mitigate (Figure 4). The effect of soil type on nitrogen losses is clearly seen with the losses being greatest for the Brown soils and lowest for the Organic soils. It is clear from the modelling analysis that the mitigation with the largest effect on nitrogen losses from the dry-stock farms is the wetlands. The easy mitigation bundle had little effect due to the low levels of fertilizer use on the base farms (Figure 4 and Appendix). For the dry-stock farms, the only mitigation option in the difficult bundle is using a beef cattle feed pad which only applies to the sheep and beef farm system. We assumed that a dairy farm investing in off-pasture infrastructure would put this on the milking platform, not the winter runoff. Therefore, there is no data for the difficult mitigation bundle for the sheep and sheep & dairy farm systems.

For the dairy farming systems (with the exception of the Organic soils) it will not be easy to reduce farm nitrogen losses below 15 kg ha^{-1} y^{-1} (Figure 4). For the dry-stock farm systems, achieving nitrogen losses below 15 kg ha^{-1} y^{-1} would require identifying areas in the catchment where wetlands are most effective at removing nitrogen and not grazing dairy cows during the winter (Figure 4).

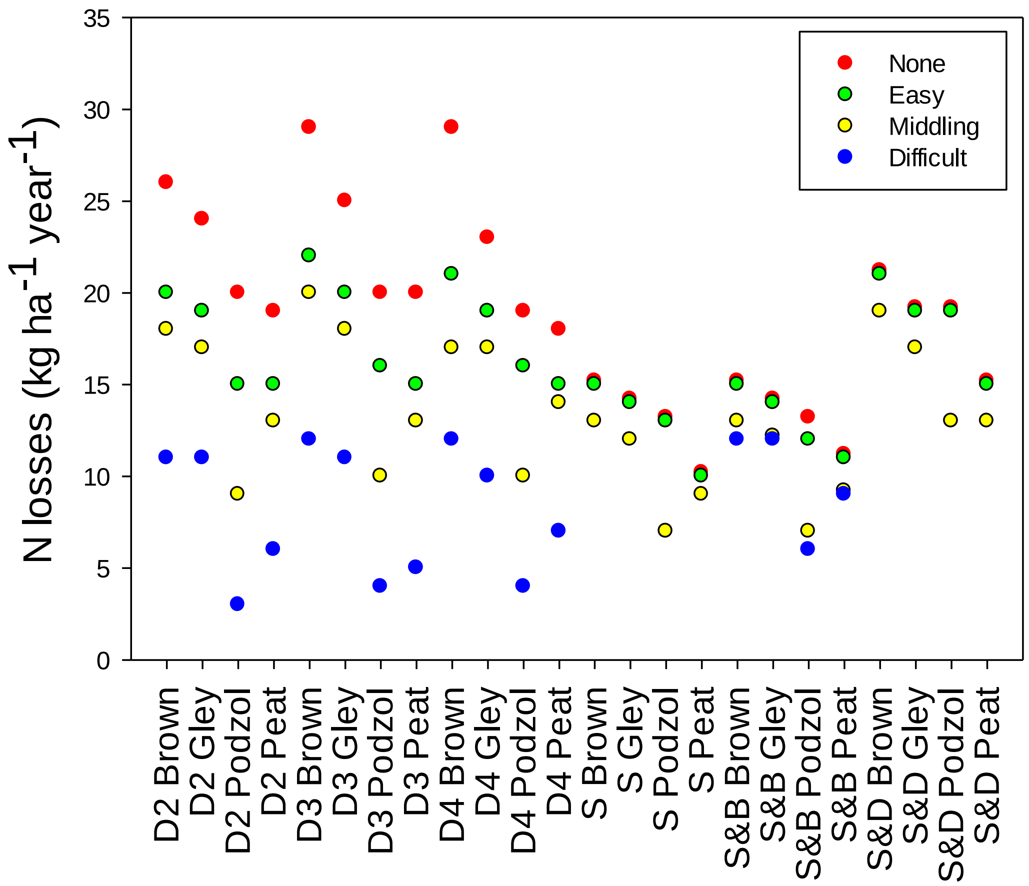

Figure 4. Predicted nitrogen losses from the 24 combinations of 6 farming systems and 4 soil types modelled in the Waituna catchment. D2 = dairy farm system 2, D3 = dairy farm system 3, D4 = dairy farm system 4, S = sheep farm, S&B = sheep and beef farm and S&D = sheep farm with dairy cows grazed during winter. Coloured circles that overlap are modelled as the same nitrogen losses.

For predicted phosphorus losses from farms in the Waituna there was a strong soil type effect with much higher losses from the Organic soils than the other soil types (Figure 5). The high P losses from the Organic soils in this study, compared to the data in Robson et al. (2011), is a result of lowering the anion storage capacity (ASC – aka P retention) property of the Organic soil setting in Overseer® to 2% which was based on recent unpublished work on these soils in the catchment. The phosphorus losses from the dairy farm systems are higher than for the dry-stock systems. Using the mitigation options identified, the ability to mitigate phosphorus losses is less than for nitrogen losses (Figures 4 & 5). In the dry-stock farm systems none of the mitigations chosen had a large effect on P losses. For the dairy farm systems the mitigations in the "easy" bundle (fencing streams and FDE management) had a large effect on P losses but the "middling" and "difficult" bundles had no effect on P losses (Figure 5). If the easy dairy mitigation options (FDE management and fenced streams) are already well implemented in the Waituna then this implies that we do not have any other mitigation options in the Overseer model that can reflect reduced P losses from the catchment. There are other mitigation options that will have the potential to reduce P losses (McDowell and Nash, 2012) but these mitigations are not currently available in Overseer. This has implications for how the effect of these mitigations can be accounted for when setting farm scale limits to achieve the overall catchment limits. Additional work is required to match suitable options to mitigate phosphorus loss to the Waituna catchment. However, if current contracted work identifies, as hypothesized, the Organic soils as a potential hot spot of phosphorus loss this may enable mitigation by land use change to be better targeted.

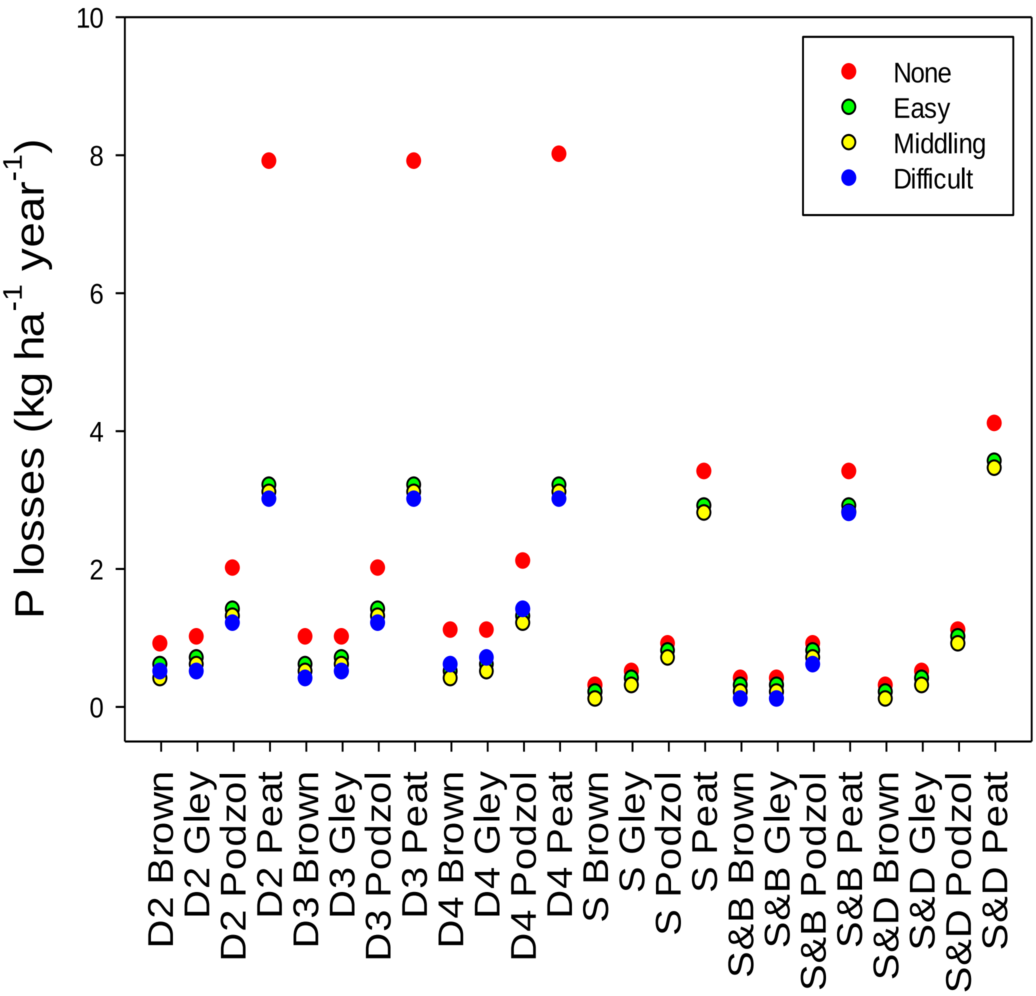

Figure 5. Predicted phosphorus losses from the 24 combinations of 6 farming systems and 4 soil types modelled in the Waituna catchment. D2 = dairy farm system 2, D3 = dairy farm system 3, D4 = dairy farm system 4, S = sheep farm, S&B = sheep and beef farm and S&D = sheep farm with dairy cows grazed during winter. Coloured circles that overlap are modelled as the same phosphorus losses.

5.4 Overseer® Modelling Conclusions

- Nitrogen and phosphorus losses from dairy farms are typically higher than losses from dry-stock farms.
- There is potential to reduce nitrogen losses from the dairy farm systems, but this will require the implementation of difficult and complex mitigation options.
- The effectiveness of wetlands will be critical to realizing the potential reductions of nitrogen losses in the catchment. The NIWA report on wetlands will provide clarity on the mitigation potential of wetlands in the Waituna catchment.
- Phosphorus losses are strongly affected by soil type.
- The high P losses from dairy farm systems can be reduced using the easy mitigations of FDE management and fencing off of streams. However, if these mitigations are already well implemented in the catchment then current mitigations to further reduce P losses may be limited to changes in land use. Additional work is required to identify and model the effect of mitigation strategies appropriate to the Waituna catchment.
- If the catchment level nitrogen and phosphorus limits from the Lagoon Technical Group require the implementation of middling or difficult mitigation options on farms, then a detailed technical and economic feasibility analysis should be conducted on individual farms.
- There are some mitigation options that would be of value in the Waituna catchment that are not available in the Overseer® model. Careful thought will need to be given to how these mitigations could be included in the catchment targets.

6. General Conclusions

- The Waituna Lagoon in Southland is recognised as a highly valued and unique wetland-lagoon complex that is under threat of eutrophication.
- The Waituna is a wet catchment with significant surplus rainfall and hence requires artificial drainage to maintain high agricultural production.
- The northern zone of the catchment with the freer draining Brown soil types will be the dominant area for nitrogen losses from the catchment.
- In contrast, the poorer draining and low phosphorus retention Organic (and some Podzol) soils in the southern zone will be the dominant area for phosphorus losses.

- The sediment concentrations and loads are low (relative to other catchments in New Zealand), but historical sedimentation rates are high in the lagoon perhaps due to sediment released during drain cleaning.
- Estimates of the natural baselines of sediment and nutrient loads to the lagoon indicate that current levels are much higher than would be expected from the catchments prior to development for farming.
- Overseer® modelling of various farm systems in the catchment indicates that nitrogen and phosphorus losses from dairy farms are typically higher than losses from dry-stock farms.
- There is potential to reduce nitrogen losses from the dairy farm systems, but this will require the implementation of difficult and complex mitigation options. The effectiveness of wetlands will be critical to realizing the potential reductions of nitrogen losses in the catchment.
- The high phosphorus losses from dairy farm systems can be reduced using the easy mitigations of FDE management and fencing off of streams. However, if these mitigations are already well implemented in the catchment then current mitigations to further reduce P losses may be limited to changes in land use.
- There are some mitigation options that would be of value in the Waituna catchment that are not available in the Overseer® model. Careful thought will need to be given to how these mitigations could be included in the framework used to meet catchment targets.
- If the catchment level nitrogen and phosphorus limits from the Lagoon Technical Group require the implementation of middling or difficult mitigation options on farms (or other options not yet modelled), then a detailed technical and economic feasibility analysis should conducted on individual farms.
- If lagoon monitoring indicated that the lagoon was in a potentially vulnerable state during the summer low flows then consideration could be given to delaying drain cleaning activities to a time when the effect is weak.
- There are some science knowledge gaps in relation to: 1) farm dairy effluent irrigation on the poorly draining Podzol and Organic soils in the catchment; 2). losses of nutrients from winter grazing practices for drystock animals; and 3) managing stream banks to prevent bank erosion.

7. Recommendations

1. The results of the sediment finger-printing project are used to decide on a strategy for reducing the sediment inputs to the drains and creeks to reduce the amount of drain clearing needed.

2. The results from the nutrient loss study are used to calibrate Overseer® outputs.
3. Future Overseer® data, and that contained in this report, are used with the spatial data to generate maps of potential nutrient losses from farms in the catchment for a range of mitigation scenarios including easy and more appropriate options with the current land use and with land use change.
4. NIWA to utilise this data in a spatially resolved CLUES modelling of the catchment to account for in-stream attenuation and delivery to the lagoon as recommended in Elliott (2012).
5. The results of steps 2 to 4 are used to inform a discussion with the Waituna community on the key challenges faced by the community if they are to achieve the targets set by the Lagoon Technical Group. These challenges are likely to include:
    a. Achieving the desired lagoon values at the recommended catchment nutrient targets.
    b. The economic cost of implementing mitigations and/or land use change in the catchment.
    c. The implications of time lags required to implement changes.

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9. Appendix One: Potential OVERSEER® mitigation options available to reduce N and P losses in the Waituna Catchment

New Zealand's science. New Zealand's future.

Potential OVERSEER® mitigation options available to reduce N and P losses in the Waituna Catchment

Report prepared for Richard Muirhead, AgResearch

June 2013

Geoff Mercer and Natalie Watkins

9.1 Background

Information was supplied describing the dairy and non-dairy farms with no mitigations implemented. A full description of each farm was not available so assumptions have been made. No assessment of the farm description entered into *Overseer*® has been made to confirm that the description is realistic and represents a feasible, workable farm system. Assumptions made when setting up the base farm files are outlined in sections 9.3 and 9.5.

Mitigations were prepared as described in terms of bundles (Easy, Middling and Difficult) and were applied cumulatively. Mitigations applied are outlined in sections 9.4 and 9.6. Nutrients other than N and P were not considered when developing the mitigations.

9.2 Impact of mitigation bundles on N & P losses

Estimates of N leaching and P runoff losses from the whole farm including N removed by the fenced wetland are presented in Tables A1 and A2. N removed by the wetland is included in the total N loss values.

Table A1: N and P Losses from dairy farm systems with and without mitigation bundles implemented

Farm system			Wetland N removed	N Losses		P Losses	
	Soil Grp	Mitigation	kg N/yr	kg N/yr	kg N/ha/yr	kg P/yr	kg P/ha/yr
System 2	Brown	None	-	4946	26	177	0.9
		Easy	-	3838	20	86	0.5
		Middling	341	3386	18	84	0.4
		Difficult	187	2013	11	89	0.5
System 2	Gley	None	-	4633	24	192	1.0
		Easy	-	3668	19	109	0.6
		Middling	302	3268	17	108	0.6
		Difficult	182	2095	11	112	0.6
System 2	Podzol	None	-	3791	20	386	2.0
		Easy	-	2883	15	246	1.3
		Middling	1048	1756	9	243	1.3
		Difficult	868	664	3	248	1.3
System 2	Organic	None	-	3637	19	267	7.9
		Easy	-	2782	15	156	3.1

Farm system	Soil Grp	Mitigation	Wetland N removed kg N/yr	N Losses kg N/yr	N Losses kg N/ha/yr	P Losses kg P/yr	P Losses kg P/ha/yr
	Organic	Middling	253	2452	13	154	3.1
		Difficult	108	1217	6	159	3.1
System 3	Brown	None	-	5457	29	190	1.0
		Easy	-	4260	22	92	0.5
		Middling	379	3771	20	90	0.5
		Difficult	201	2188	12	96	0.5
System 3	Gley	None	-	4720	25	192	1.0
		Easy	-	3743	20	109	0.6
		Middling	309	3343	18	108	0.6
		Difficult	181	2098	11	112	0.6
System 3	Podzol	None	-	3886	20	386	2.0
		Easy	-	2966	16	246	1.3
		Middling	1048	1846	10	243	1.3
		Difficult	868	676	4	248	1.3
System 3	Organic	None	-	3724	20	267	7.9
		Easy	-	2866	15	157	3.1
		Middling	261	2535	13	155	3.1
		Difficult	108	1225	6	160	3.1
System 4	Brown	None	-	5437	29	209	1.1
		Easy	-	3937	21	100	0.5
		Middling	319	3303	17	98	0.5
		Difficult	180	2236	12	114	0.6
System 4	Gley	None	-	4414	23	200	1.1
		Easy	-	3568	19	115	0.6
		Middling	294	3208	17	114	0.6
		Difficult	151	1953	10	126	0.7
System 4	Podzol	None	-	3701	19	398	2.1
		Easy	-	2947	16	252	1.3
		Middling	1048	1849	10	249	1.3
		Difficult	821	800	4	263	1.4
System 4	Organic	None	-	3473	18	278	8.0
		Easy	-	2899	15	163	3.1
		Middling	264	2586	14	161	3.1
		Difficult	101	1337	7	174	3.1

Table A2: N and P Losses from dry-stock farms with and without mitigation bundles implemented

Farm system			Wetland N removed	N Losses		P Losses	
	Soil Grp	Mitigation	kg N/yr	kg N/yr	kg N/ha/yr	kg P/yr	kg P/ha/yr
Sheep	Brown	None	-	2821	15	33	0.2
		Easy	-	2827	15	32	0.2
		Middling	251	2430	13	32	0.2
Sheep	Gley	None	-	2566	14	73	0.4
		Easy	-	2570	14	70	0.4
		Middling	217	2219	12	69	0.4
Sheep	Podzol	None	-	2440	13	155	0.8
		Easy	-	2446	13	151	0.8
		Middling	1048	1277	7	150	0.8
Sheep	Organic	None	-	1990	10	125	3.4
		Easy	-	1994	10	119	2.9
		Middling	181	1691	9	118	2.8
Sheep & beef	Brown	None	-	2889	15	33	0.2
		Easy	-	2895	15	32	0.2
		Middling	256	2477	13	32	0.2
		Difficult	244	2364	12	32	0.2
Sheep & beef	Gley	None	-	2645	14	73	0.4
		Easy	-	2649	14	70	0.4
		Middling	220	2250	12	69	0.4
		Difficult	213	2187	12	69	0.4
Sheep & beef	Podzol	None	-	2498	13	156	0.8
		Easy	-	2505	13	149	0.8
		Middling	1048	1295	7	149	0.8
		Difficult	1048	1226	6	149	0.8
Sheep & beef	Organic	None	-	2064	11	125	3.4
		Easy	-	2068	11	119	2.9
		Middling	184	1717	9	118	2.8
		Difficult	177	1659	9	118	2.8
Sheep & dairy	Brown	None	-	4005	21	37	0.2
		Easy	-	4016	21	36	0.2
		Middling	366	3563	19	35	0.2
Sheep & dairy	Gley	None	-	3650	19	86	0.5
		Easy	-	3658	19	82	0.4
		Middling	274	3291	17	81	0.4
Sheep & dairy	Podzol	None	-	3631	19	189	1.0
		Easy	-	3644	19	184	1.0
		Middling	1049	2519	13	182	1.0
Sheep & dairy	Organic	None	-	2849	15	149	4.1
		Easy	-	2858	15	143	3.5
		Middling	265	2510	13	141	3.5

9.3 Farm Information Supplied

A range of *Overseer*® data inputs were supplied for both the dairy farms and sheep and beef farms (Tables A3 and A4).

Table A3: *Overseer*® Dairy Farm Inputs

	System 2	System 2	System 3	System 3	System 4	System 4
Soil Types	Brown	Other*	Brown	Other*	Brown	Other*
Drainage	Mole/tile	Other drains	Mole/tile	Other drains	Mole/tile	Other drains
Rainfall (mm/yr)	1000	1100	1000	1100	1000	1100
Farm area (ha)	190	190	190	190	190	190
Non-effluent block (ha)	142	142	137	137	134	134
Effluent block (ha)	48	48	53	53	56	56
Supplements imported - silage/balage (T)	0	0	192	144	290	218
Supplements imported - PKE (T)	0	0	0	0	425	320
N Fertiliser (kg N/ha)	150	150	150	150	150	150
P Fertiliser (kg P/ha)	32	32	32	32	32	32
P as imported supplement (kg P/ha)	0	0	3	2	17	12
Cows (peak milked)	570	470	635	477	656	493
MS (kg/ha)	1083	893	1279	961	1457	1094
MS (kg/cow)	361	359	381	380	420	420
Lactation length (days)	259	259	266	266	273	273
Winter management cows off farm for x days	80	80	80	80	80	80
Winter management infrastructure	None	None	None	None	Feedpad	Feedpad

*Other = Gley, Organic and Podzol soil types (Organic soils had ASC set to 2%)

Table A4: *Overseer*® Sheep and Beef Farm Inputs

	Sheep only	Sheep only	Sheep & Beef	Sheep & Beef	Sheep & Dairy support	Sheep & Dairy support
Soil Types	Brown	Other*	Brown	Other*	Brown	Other*
Drainage	Mole/tile	Other drains	Mole/tile	Other drains	Mole/tile	Other drains
Rainfall (mm/yr)	1000	1100	1000	1100	1000	1100
Farm area (ha)	190	190	190	190	190	190
Stocking rate (SU/ha)	14.7	12.3	14.7	12.3	15.5	12.1
Sheep (SU)	2812	2280	2531	2052	1727	1458
Beef (SU)	0	0	47	38	0	0
Dairy cows (90 grazing on forage crop)	0	0	0	0	620	470
Spring N Fertiliser (kg N/ha) (applied to only 33 ha)	28	28	28	28	28	28
P Fertiliser (kg P/ha)	18	18	18	18	18	18
Swede Forage Crop (ha)	28	22	28	22	38	36

*Other = Gley, Organic and Podzol soil types (Organic soils had ASC set to 2%)

All crops and supplements are made and fed out on-farm for sheep only, sheep and beef and sheep and dairy support, except for sheep and dairy support on Brown soil where an additional 125 big bales of hay are purchased.

9.4 Dairy Farm Assumptions – No mitigations implemented

Dairy herd

Peak cow numbers:	Not constant over the year
Breed:	Friesian
Calving:	6 August
Once a day milking:	During drying off
Replacements:	Off farm from weaning
Wintering off:	100% off in June and July, 67% off in May (to account for cows off for 20 days during the month = 80 days off farm)

Farm Blocks

Topography:	Flat (0 - 7°)
Location:	Invercargill
Distance from coast:	
Brown Soils	10 km
Other Soils	5 km
Soil texture group (lower profile):	Medium
Pugging occurs during:	Winter
Soil tests:	*Overseer*® default values (Olsen P: 30)
Pasture:	Ryegrass/white clover
Stream access:	Stock have access to streams
Effluent system:	Spray from sump Application method (slow <24 mm)
Supplements imported:	Weights are specified on a dry weight basis Silage is fed out on the feed pad (system 4) if present, otherwise evenly on all pastoral blocks (system 3) PKE is fed out on the feed pad (system 4 only)

Feed pad (system 4 only):

All supplements are fed out on the feed pad; none on pasture

Month on feed Pad:	August to end of April – 100% of cows
Time on feed Pad:	2 hours on pad; 22 hours on pasture
Feed pad effluent:	Manure removal method (Scraping no water) Solids separated and applied to Main block in October and March following uncovered storage for five months. Liquid effluent added to FDE

Fertiliser: Urea applied – 50 kg N in March, August and October

Phosphorus applied – September 32 kg P

9.5 Dairy Farms – Mitigation bundles

Dairy Easy Bundle

- Stock are excluded from streams
- Improve FDE management:
    - A holding pond is installed which separates solids and has adequate storage.
    - Effluent is applied at a low rate from the beginning of October to the end of March.
    - Solids are applied separately after 3 months storage (open to rain) in October and March.
    - Pond solids/sludge are applied to the Main Pasture block in March.
- Improved nutrient management:
    - P fertiliser is applied in November as RPR to the Main Pasture and Effluent blocks at maintenance levels to maintain an Olsen P of 30 mg/ml.
    - N fertiliser is applied in January, September and November at 50 kg N/ha per application.
    - The effluent block on the brown soil system 4 farm was too small and exceeded the recommended 150 kg N/ha/yr, therefore the effluent block size was increased slightly. No extension of the effluent block is required for the system 4 farm on other soil types.

Dairy Middle Bundle

- Develop and maintain a 2 ha fenced high performing wetland with the following characteristics:
    - Fenced, well vegetated wetland through which water always flows
    - Surface flow well distributed with no channelization
    - Dominated by sedges and reeds; may contain flaxes and willows
    - Catchment area = 50% of the farm drains into wetlands on the farm
    - High catchment convergence
    - The aquitard depth, i.e. the depth to the soil layer Impervious to water, is greater than 5 metres
- Reduce the stocking rate and improve per animal performance:
    - Reduce stocking rate by 10% and increase per animal milk production

- Reduce replacement rate from 23% to 21%
- With no change to per-hectare pasture production, breed and imported supplements, it is assumed that the farm can manage pasture production to meet day to day animal requirements.

Dairy Difficult Bundle

System 2 and 3 farms:

- Use a wintering pad to implement a restricted grazing strategy as follows:
    - All dairy cows on the pad from March to early May (71 days)
    - On the pad 4 hours/day; on pasture for the remaining 20 hours
    - Manure is removed by scraping and applied to the Main block in October following storage open to rain for three months
    - Liquid effluent is managed by the FDE system
    - Feed available for feed pad: 2 kg DM/cow/day

System 4 farms:

- Use an animal shelter / barn as follows:
    - Cows use barn throughout the year. All supplements are fed out on feeding apron
    - Mid May to July – in barn all the time
    - August to early May – 3 hours in the shelter, 21 hours on pasture
    - Manure is removed by scraping and liquid managed by the FDE system
- Solid effluent from the dairy and wintering pad, including separated solids are spread evenly over the effective area.
    - FDE pond solids are spread in October
    - Separated solids from the dairy are spread in March and October
    - Solids from the wintering pad are spread in October
- The effluent block on the system 4 farm on gley and brown soils was too small and exceeded the recommended 150 kg N/ha/yr. The effluent block size on both farm systems were increased.

All farms:

- Imported supplements to support housing systems / feed pad as follows

	Amount (tonnes DM)					
	System 2		System 3		System 4	
Supplement	Brown	Other	Brown	Other	Brown	Other
Palm kernel meal	73	60	81	61	425	320
Grass silage					510	380

9.6 Dry-stock farms assumptions – No mitigations implemented

Livestock

Sheep:

Breed:	Romney
Lambing:	15 September
Weaning:	15 December
Greasy Wool:	5 kg / RSU sheep

Opening and closing livestock balances are the same.

Overseer® default live weights have been used unless specified.

Ewe weaning percentage is read as the number of lambs weaned as a percentage of mixed age ewes in July.

25% of breeding ewes are culled on scanning June/July and 10% on docking at the end of October. The remainder are culled at the time replacements are aged into the mob at the end of November.

Other sheep are assumed to be mixed age breeding rams on-farm all year.

Lambs other than replacements are sold to works at the end of each month from December to March having reached a live weight of 41 kg

The percentage of lambs sold to works at the end of each month is given in the table below:

Month	%
December	8
January	17
February	25
March	50

*Percentages are rounded to the nearest whole number

Beef cattle:

Breed:	Dairy-beef cross

Purchased 6 month old weaners in March and retained until sold to works the end of April the following year on reaching a target live weight of 625 kg (*Overseer*® default).

Dairy grazers:

Breed:	Friesian

Mature pregnant mixed age dairy cows.

Farm Blocks

Block set up:	Two pastoral blocks: one that receives N fertiliser (33 ha) and a second which doesn't (157 ha). A Swede crop rotates through the latter.
Topography:	Flat (0 - 7°)
Distance from coast:	
Brown Soils	10 km
Other Soils	5 km
Soil texture group (lower profile):	Medium
Pugging:	Occasional
Soil tests:	*Overseer*® default values for tests other than Olsen P Olsen P: Sheep & Beef = 23; Dairy support = 27
Stream access:	Stock has access to streams
Pasture:	Ryegrass / white clover
Fertiliser:	Urea applied – 28 kg N in September (spring) Phosphorus applied –18 kg P in November
Supplements imported:	Big bales of hay are 10 bale equivalents (200 kg each) and fed out to beef and dairy grazers on the fodder crop
Supplements made:	Hay and baleage made on 157 ha block and fed out over the entire farm
Swede Crop:	Sown in November, Defoliated during May, June & July. Re-sown back into pasture in September. Block left bare during August. Cultivation is direct drill

9.7 Dry-stock farms – Mitigation bundles

Dry-stock Easy Bundle

- Apply maintenance P fertiliser using low water soluble P fertilisers. *Overseer*® was used to determine the amount of fertiliser required and this was applied as RPR to the effective area.

Dry-stock Middling Bundle

- Retire two ha of the larger of the two pastoral blocks and build a fenced artificial wetland with the following characteristics:
    - Fenced, well vegetated wetland through which water always flows
    - Surface flow well distributed with no channelization
    - Dominated by sedges and reeds; may contain flaxes and willows
    - Catchment area = 50% of the farm drains into wetlands on the farm
    - High catchment convergence
    - The aquitard depth, i.e. the depth to the soil layer Impervious to water, is greater than 5 metres
- Exclude livestock from streams: *Overseer*® only considers the effects of the exclusion of dairy or beef animals from streams and stream banks. No account is available for other animal types such as sheep.
- Reduce the stocking rate and improved animal performance by reaching the following targets for:

  Sheep:
    - Reduce breeding ewes by 5%
    - Increase lambing percentage from 129 to 140%
    - Increase weight gain of store lambs and sell them earlier at the same target live weight (41 kg) as described below:

Month	% Before	% Now
December	8	32
January	17	32
February	25	32
March	50	4

    - Purchase store lambs in December at 3 months of age at 21 kg live weight and sell to works at a target live weight of 41 kg

Farm Type	Soil Group	Lambs Purchased
Sheep	Brown	840
Sheep	Other	790
Sheep and beef	Brown	520
Sheep and beef	Other	545
Sheep and dairy support	Brown	725
Sheep and dairy support	Other	480

Beef cattle:

- Increase weight gain and sell two months early at a greater live weight as described in the table below:

Description	Before	Now
Month sold	April	February
Sale live weight (kg)	525	585

Dairy grazers:

- No change

Dry-stock Difficult Bundle

- Applicable only to farms with beef cattle, i.e. sheep and beef farms
- The description of the feed pad is as follows:
  - *Overseer*® does not support feed pad for beef cattle so this has been entered into *Overseer*® as a uncovered wintering pad
  - All beef cattle use the feed pad for on average four hours per day with unrestricted access to the feeding apron from the beginning of March to the end of August. For the remainder of the day they are on pasture.
  - The resting pad has a carbon rich surface which is lined with effluent captured in a tank. Liquid from the feeding apron is also drained to a tank. Liquid effluent is applied at a low rate (< 12 mm/hr) to the larger of the two effluent blocks in November
  - The resting pad and feeding apron are scraped regularly and solids stored open to rain for approximately three months before being applied in October to the larger of the two pastoral blocks.
- Make all baleage on the larger of the two pastoral blocks and feed to beef cattle on the feed pad to provide 80% of animal feed requirements. Amounts of supplement are as described below:

	Amount (tonnes)	
Supplements	Brown	Other
Baleage	62	55

- There are losses associated with the making and feeding out of baleage on the feed pad. Consequently the target live weight of R2 beef sold to work is reduced from 585 to 550 kg.