# Potential for controlled drainage to decrease nitrogen and phosphorus losses to Waituna Lagoon

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# Client Report

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**Client: Environment Southland**

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**Contents**

# Summary

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 increased 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-rich 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, phosphorus and sediment mitigation potential of the structures within the Waituna Lagoon catchment.

# 1 Introduction

Coastal marine environments that receive excess nutrients (primarily nitrogen and phosphorus) from wastewater discharge, atmospheric deposition and agricultural runoff often show symptoms of eutrophication (McGlathery et al., 2007). This process is characterised by an accelerated production of organic matter in the form of phytoplankton blooms followed by microbial decomposition of the organic matter and excessive oxygen consumption (Mackay, 1992). Eutrophication has been associated with many pervasive ecological and socio-economic problems including the presence of nuisance or harmful algal blooms, large-scale fish kills, changes in benthic macrofauna community structure, and economic loses to tourism, fishing and real estate (Carpenter et al., 1998).

The Waituna Lagoon in Southland, New Zealand is exhibiting symptoms of eutrophication as a consequence of the high nutrient load entering the Lagoon in runoff water from intensive agricultural land use within the catchment (~20,000 ha). The problem is exacerbated by the narrow opening of the Lagoon, which allows only intermittent flushing of the water with the sea and a recirculation of nutrients within the Lagoon. The Waituna Lagoon is highly valued as a habitat for birds and for recreation including fishing, duck-shooting, boating and walking. The Southland Regional Council has initiated an emergency response for decreasing the load of nitrogen and phosphorus to the Lagoon.

Much of this nitrogen and phosphorus is transported to the Lagoon in runoff and drainage water and entrained in sediment. Drainage of agricultural fields generally decreases surface runoff and soil water content by allowing excess water to flow away from the field. However, drainage, as opposed to surface runoff, can transport a greater proportion of nitrogen and phosphorus in dissolved (filterable), and immediately available, forms (McDowell et al., 2004). Additional particulate losses can occur if mole drains collapse or erosion of open channels occurs (McDowell et al., 2004; Smith and Huang, 2010). The nitrogen and phosphorus entrained within particulates can become available when particles settle out in the Lagoon.

Given the potential harm nitrogen, phosphorus, and sediment can have on the Lagoon, work has focused on strategies to mitigate their loss. Although many on-farm strategies may be effective in decreasing the contaminant load to the Lagoon (e.g. Robson et al., 2011), additional "off-farm" measures are required in order to meet current targets to decrease nitrogen and phosphorus inputs to the Lagoon by 50% (Robertson et al., 2011). Controlled drainage is an off-farm strategy that might be suitable in reaching part of this target.

Loads of nitrogen, phosphorus and sediment leaving the drainage system are believed to be decreased by slowing flow rates and inducing sedimentation and denitrification (Wesstrom and

Messing, 2009). To achieve this, controlled drainage systems restrict or prevent discharge from agricultural field drains by the installation of adjustable weirs, flashboards or variable weed clearance protocols. Provided topographic and soil characteristics are taken into account when decreasing pollutant loads, drainage can be altered to improve the yield of different crops by draining soil in wet months and retaining moisture during dry periods. After taking the cost of capital and on-going maintenance costs into account, the installation of controlled drainage could increase on-farm profitability. This report therefore aims to:

1) Provide a brief review of the literature around the efficacy of controlled drainage systems in decreasing nitrogen and phosphorus loads (some consideration is also given to sediment);
2) Provide commentary on the suitability of controlled drainage systems for use in the Waituna Lagoon catchment; and
3) Outline a design process and give brief recommendations for a plan to implement the testing of a controlled drainage system within the catchment (if a suitable system is found).

# 2 Benefits and disadvantages of controlled drainage

A summary of the benefits and caveats (around suitability to the Waituna Lagoon catchment) associated with traditional controlled drainage systems are given in Table 1. However, specific examples and discussion relating to the mitigation of nitrogen, phosphorus and sediment are listed below.

Decreased nitrate loads have been reported between comparisons of free draining and controlled drainage systems. In Italy, Bonaiti and Borin (2010) reported decreases in drainage volumes of 77% and nitrate loads of 70%. Similarly, decreases in nitrate loads (76.5 - 85%) were reported by Wesstrom and Messing (2009) by the installation of controlled drainage devices in 4 areas of Southern Sweden, and of 96-98% in Arkansas, USA by Kronger et al (2011). In addition to decreasing the load of nitrate lost, some workers have also identified a decrease in nitrate concentrations lost from controlled drainage systems (Ng et al 2002; Lalonde et al., 1996; Bohlen and Villapondo, 2011).

For phosphorus, both Tan and Zang (2010) and Wesstrom and Messing (2009) found significant decreases in phosphorus loads were driven by decreased losses of particulate phosphorus. They attributed this to lower flow rates and a rise in the water table (i.e. water column in open channel drains), allowing sedimentation, and decrease in suspended sediment concentrations, to occur.

In a review of controlled drainage systems, Skaggs and Youssef (2008) concluded that the decrease in nitrate loads were due to less drainage based on the fact that the percentage decrease in flow and nitrate loads were the same. However, decreased flow rates and an increased water table height also increase the likelihood of anoxia and denitrification (Singh et al., 2006). Denitrification results in the loss of nitrogen as di-nitrogen or nitrous oxice gasses; the later is a greenhouse gas 300 times more potent than $CO_2$. The loss of nitrogen as a gas could decrease the concentration of nitrate in the water column. However, the contribution of denitrification to decreasing nitrogen losses in controlled drainage systems is unclear. On a positive note, both, Kliewer and Gilliam (1995) and Elmi et al. (2002) suggest that $N_2O$ (not $N_2$) emissions are not significantly increased by controlled drainage. Measurements by Kliewer and Gilliam (1995) in a controlled drainage system illustrated that $N_2O$ production only accounted for 2% of denitrification potential. It was thought that the increased soil moisture, brought about by controlled drainage, not only increased the potential for denitrification, but also the residence time of nitrous oxide in the soil thereby providing greater opportunity for its reduction to $N_2$.

The altered hydrology and anoxic conditions created by controlled drainage also have implications for the mobility of phosphorus. For example, although overall loads of phosphorus loss over 5 years were decreased in a controlled, versus freely, draining system, Tan and Zhang (2011) found that the concentrations of most phosphorus forms (dissolved un-reactive phosphorus, particulate phosphorus and total phosphorus) in surface runoff and of dissolved reactive phosphorus in subsurface drainage, increased. Anoxic conditions, caused by elevated water tables, create conditions conducive to the reduction of iron and aluminium oxides and the mobilisation of associated phosphates into dissolved forms. The implications for water quality are two-fold: 1) dissolved phosphorus species (including many unreactive forms) are immediately available to periphyton and hence controlled drainage may increase periphyton coverage in streams a rivers, but 2) the much lower particulate phosphorus loss from controlled drainage systems means that there may be less phosphorus reaching (and possibly released under anoxic conditions) the Lagoon. The beneficial effect of sedimentation of particulate phosphorus will be enhanced by low flow rates and hence maximised in areas of little topographical variation (i.e. flat). A slope of <1-2% is often highlighted as a prerequisite for successful controlled drainage systems (Joel et al., 2009).

Hydrologically, increased soil moisture and the decrease in overall drainage of a controlled drainage system are countered by increases in other mechanisms of water loss from the system notably: evapotranspiration, surface runoff and deep and lateral seepage (Zhuan-xi et al., 2009). Tan and Zhang (2011) found that the volume of surface runoff in a controlled drainage system increased in comparison to surface runoff from a paired free draining system. Additional hydrological simulations using DRAINMOD found that surface runoff generally increased when controlled drainage was used (Singh et al., 2006). Increased surface runoff will result in greater loss of phosphorus, ammoniacal-nitrogen and sediment, but will depend on soil type and management. For instance, phosphorus is bound to the soil in proportion to the concentration of Al- and Fe-oxides in the soil (measured as anion storage capacity; McDowell and Condron, 2004).

Most soils will therefore tend to exhibit phosphorus enrichment in the topsoil due to applications of fertiliser or effluent. Strong binding in the topsoil means that P-enrichment decreases with depth and results in stratification of Olsen P concentrations in the top 2-cm of soil that are 2-3 times greater than Olsen P determined on the same core to 7.5-cm depth (Haygarth et al., 1998). An exception might be organic soils that tend to have low anion storage capacity and therefore less stratification. However, this may become a problem due to the enrichment of deeper soil layers, which, especially for organic soils coupled with a high water table, may lead to dissolution and increased losses of dissolved P in a controlled drainage system compared to a freely draining system.

Soil type will also affect the potential for denitrification to decrease nitrogen losses under controlled drainage. Specifically, those soils rich in carbon will exhibit denitrification when inundated. In the Waituna catchment, this is commonly seen by nitrate rich and poor groundwater in the upper and lower pats of the catchment that have Brown and Organic (or carbon-rich organic horizons in Podzol or Gley soils), respectively (Rissman and Wilson, 2012).

Under the same land use and rainfall, the potential for erosion is a function of soil texture and organic matter, generally decreasing as texture becomes coarser and organic matter concentration increases (Dymond, 2010; Hewitt and Shepherd, 1997). Among the soils reviewed by Hewitt and Shepherd (1997) relevant to the Waituna Lagoon catchment, Gley and Podzol soils had a greater dispersion and slaking potential than Brown soils. These two factors combine to yield a measure of the vulnerability to structural degradation, and are also a component of erosion potential. Additional work has also shown that dispersion is a key factor in the potential loss and sedimentation of particulate phosphorus, with highly dispersive soils likely to maintain particulate-bound phosphorus concentrations in the water column for longer than those soils that do not readily disperse (Withers et al., 2009). Unfortunately, no New Zealand data is available on the potential for erosion of Organic soils, or their dispersion potential vis-à-vis P losses. A question also arises of the relative enrichment of particulate-bound phosphorus relative to soil Olsen P, and hence how this would interact with sedimentation rates?

Changing flow rates may enhance sedimentation or denitrification rates resulting in decreases in nitrogen and phosphorus losses in the order of 30-40%, but a raised water table also increases crop yields (e.g. corn [*Zea mays* L.] or soybean [*Glycine max* L.] yields (Deal et al., 1986; Mejia et al., 2000). With root systems extending beyond 1-m deep in the soil, many crops like corn are able to utilise a large soil volume for soil P, but also to tap into a raised water table that, with careful management, avoids strongly stratified topsoil and therefore the potential for P dissolution. In New Zealand, a controlled drainage system may have potential to improve yields of deeply rooted plants like corn. However, the suitability of the system for grazed pasture is of more interest. Although periods of drought occur in the Waituna catchment, and hence there would be some benefit of maintaining a higher water table for the establishment of forage crops, the environmental implications likely outweigh the agronomic benefit. Pasture plants tend to be shallow rooted. As a result, the water table would have to be maintained near the soil surface to avoid water stress. This increases the likelihood of drainage water coming in contact with P-rich topsoil, and surface runoff losses due to a decreased capacity of the system to adsorb rainfall and runoff events. Perhaps the overriding consideration is data from an unpublished study by Fonterra in the Waikato which concluded that raising the water table also increased the likelihood of pasture damage by pugging and therefore was to be avoided (John Russell, *pers. comm.*).

**Table 1**. Summary of the potential effects and suitability of controlled drainage in the Waituna Lagoon catchment.

| Effect | Caveat | Suitability in the Waituna Lagoon catchment |
|---|---|---|
| Less flow through open channel drainage network | 1. Potential for greater frequency of surface runoff and localised flooding.<br>2. Less flow through drainage network may decrease flushing within drains and increase the residence time of nutrients in the Lagoon if not balanced by nutrient poor seepage into the Lagoon via groundwater. | Hydrologically, the technology is better suited to headwaters in the upper catchment where the potential for flooding is less. |
| Decreased nitrogen loss | 1. There is potential for the pathway of nitrate loss to be driven from the surface drainage network into groundwater.<br>2. Losses only decreased where drainage was decreased and denitrification potential was maximised. | Greatest potential for decreasing nitrate is in the Brown soils of the upper catchment as opposed to the lower catchment where denitrification is naturally high and the likelihood of decreasing drainage volumes less. |
| Decreased phosphorus loss | 1. Increased dissolved P losses result, which could increase periphyton growth. Unless this is balanced by decreased particulate phosphorus losses it could result in a net increase in P load.<br>2. High water table increases the risk of coming into contact with P-rich topsoil. | Greater dispersion and erosion potential of soils in lower half of catchment imply greater potential to decrease P losses compared to upper catchment, but has to be balanced by the risk of losses via greater surface runoff/flooding. |
| Decreased sediment loss | 1. Dependant on soil type – e.g. Podzol and Gley soils more erosion prone than Brown soils.<br>2. Effect greatest where sedimentation potential enhanced i.e. flat topography (low flows) and deep water column. | Although net decrease in sediment loss potential is greater in the lower than upper catchment (soil type and topography), there is a greater risk of surface runoff and pasture damage. |
| Improved forage yield | 1. Only likely for deep rooted species<br>2. Maintaining high water table for the benefit of drought relief of pasture or better establishment of forage crops increases likelihood of interaction with P-rich topsoil. | Improved forage yields and profitability are unlikely considering the cost of installation and maintenance of a controlled drainage system. Further work is required to access the cost-benefit of a controlled drainage system. |

# 3 Peak Runoff Control

Peak Runoff Control (PRC) is a newer form of controlled drainage that is designed to be most effective during large peak runoff events. Unlike traditional controlled drainage systems where water is maintained in a “pseudo” wetland area for long periods of time (e.g. 80 days), a PRC structure generally only retains water for 1-5 days during periods of high flow, thereby allowing for sedimentation (some ponding and denitrification, see below), and decreases the risk of flooding. The PRC structure consists of an earth embankment with two plastic outflow pipes (three are sometimes used with larger diameter pipes located at higher levels); a control pipe is located near the bottom of the ditch to allow some ponding under normal flows, and an emergency outflow pipe is located at a depth below the soil surface commensurate with the desired detention (i.e. residence) time (Fig. 1).

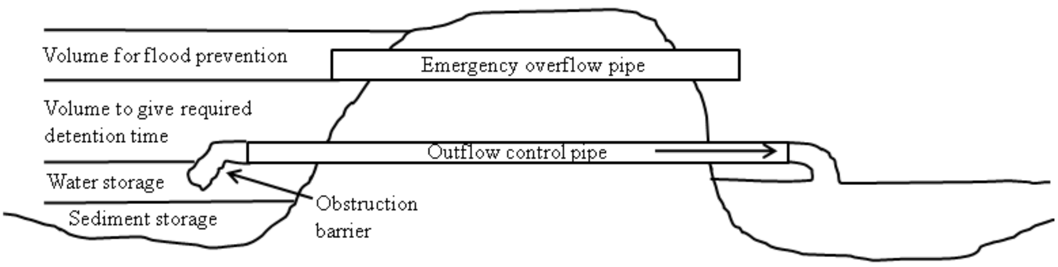


**Fig. 1.** Diagram of a peak runoff control (PRC) structure. Modified from Marttila and Kløve (2010).

PRC structures are currently being used overseas for decreasing storm flows and sediment and nutrient transport in peatland forestry. They have also been tested in some urban and agricultural sites. The method is based on the concept that runoff events are temporally retained in a ditch network using a set of control pipes that regulate flow, which decreases the load of suspended solids and suspended solids-bound nutrients (total nitrogen and phosphorus) by improving conditions for sedimentation. Some denitrification is also expected from the body of standing water below the bottom pipe. In a peatland forest in central Finland, Marttila and Kløve (2010) found that the PRC method decreased suspended solids load by 86% and the storm flow load of nitrogen by 65% and phosphorus by 67%, respectively. At another peat site in Finland, peak flows were decreased by 27-87%, suspended solids load by 61-94%, nitrogen by 45-91%, and phosphorus by 47-88% (Marttila and Kløve, 2009). There is also some evidence to indicate that PRC also decreases bank erosion and improves downstream aquatic habitat conditions (Marttila, 2010).

PRC structures are relatively cheap to construct and can be installed easily during ditch network maintenance operations. The main problem affecting the function of PRC structures is clogged pipes. Therefore, an obstruction barrier is often fitted to the outflow control pipe to keep the mouth of the pipe underwater and prevent floating debris from entering the pipe (Fig. 1). Debris can also be prevented from entering the pipes by arranging the pipes so that they are inclined with the lower end containing the obstruction barrier located at the inflow end of the barrier (Marttila, 2010).

The effectiveness of PRC structures for enhancing water protection depends on how well a structure is designed. The design needs to account for catchment topography (e.g. slope), the volume of runoff to be retained, the rate of the runoff, and the detention capacity of the drained network behind the structure. A well-designed PRC structure will have a good balance and control of flow velocities and water detention time. It will control runoff without overflowing or using the emergency outflow pipe during most peak runoff events. It will also provide increased settling conditions of SS and prevent erosion or resuspension of bed sediments by keeping the water flow velocity low without affecting drainage conditions (Marttila, 2010). Debris aside, problems affecting the PRC structure function are generally associated with an insufficient detention volume or an oversized control pipe (Marttila et al., 2010).

# 4 Principles for designing a PRC structure

PRC structures can be designed using a five step processes as outlined in Kløve (2000) and Marttila (2010): The first step is to determine the catchment area, the maximum rainfall during extreme storm events and the maximum runoff generated. Sediment transport and erosion are most likely to occur when storm events or snowmelt generate high water flows and it is necessary to know how much water the structure must hold.

Next, the location of the PRC structure in the catchment and drainage area should be determined. The PRC method has the potential to decrease soil drainage by increasing the water table and surface soil moisture, albeit less than traditional controlled drainage systems (Hökkä et al., 2011), so this must be taken into consideration when selecting a location for the PRC structure. The bed sediment particle size (and potential for re-suspension) should also be considered, along with the structures angle to the stream and spacing between individual structures. Although there is little existing information on their influence on PRC structure performance, stream order (i.e. flow lag times) and soil type within the catchment may also be considered. Furthermore, PRC structures should preferably not be installed in areas where they will interfere with fish migration.

The third step in designing a PRC structure is to calculate the peak runoff from the structure and determine the control pipe diameter. Runoff from the PRC structure is calculated using hydrological data according to the following equation:

$$Q = CA\sqrt{2gh} \qquad (1)$$

where $A$ is the cross-sectional area ($m^2$) of the control pipe, $g$ is the gravitational acceleration (9.81 m $s^{-1}$), $h$ is the difference between the headwater and tailwater elevations (m), and $C$ is a loss coefficient (loss at entry ($C_{in}$) + loss at outflow ($C_{out}$) + loss inside pipe ($C_{friction}$ = $f$L/D, where $f$ is a friction factor, L is the pipe length, and D is the pipe diameter). The friction factor for smooth pipes is generally assumed to be 0.02 (Kløve, 2000). This value is estimated using the Darcy-Weisbach equation and Moody's diagram for Reynold's numbers between $10^4$ and $10^5$. Kløve (2000) observed C to be 0.5 at Pohjansuo peat mine in central Finland.

The optimum control pipe diameter can be calculated using an iteration process and continuous relationships between the outflow and detention storage (Marttila et al., 2010):

$$\frac{I_t+I_{t+\Delta t}}{2}\Delta t - \frac{O_t+O_{t+\Delta t}}{2}\Delta t = V_{t+\Delta t} - V_t \qquad (2)$$

where $I_t$, $O_t$ and $V_t$ are water inflow, outflow and storage volume rates at time $t$.

Runoff from the PRC structure can also be estimated when the catchment area (ha), the storm event size (mm runoff), the storage volume of the retention basin ($m^3$), and the retention time (days) of the water are known (refer to accompanying Excel spreadsheet). Runoff can then be entered into equation 1 to determine the cross-sectional area of the control pipe and in turn, the control pipe diameter. The information generated by the equations can be used to create a nomogram (refer to Seuna (1983) for further information).

A nomogram is presented in Fig. 2 for a 20 mm rainfall event, using a detention time of 2 days, a difference in the headwater and tailwater elevations of 0.3 m, a loss coefficient of 0.5, and a detention storage volume of 225 $m^3$. According to this model, a 0.10 m diameter pipe would be suitable for a catchment area of 10 ha and this would create a water outflow rate of 0.01 $m^3$ $s^{-1}$. A slightly larger diameter pipe (0.15 m) would be necessary for a larger catchment area (20 ha) to create a larger water outflow rate (0.02 $m^3$ $s^{-1}$).

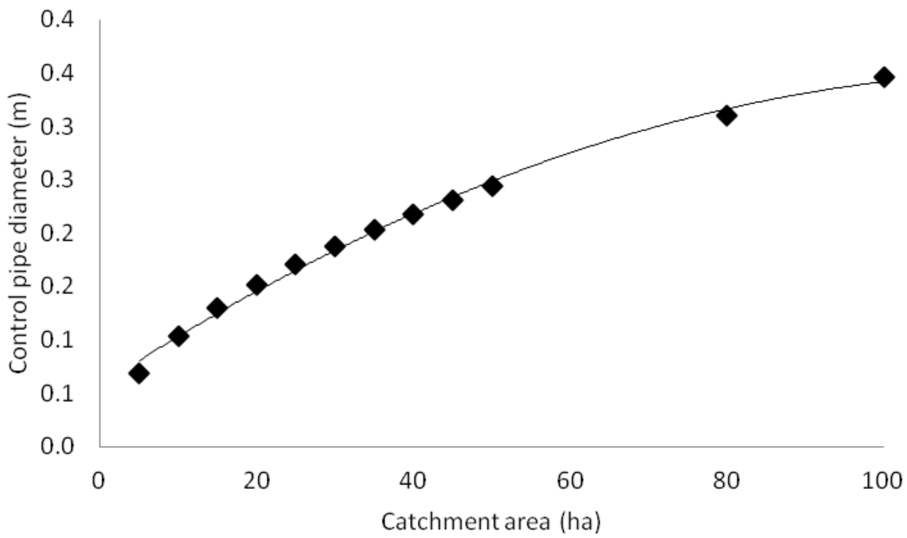


**Fig. 2**. Control pipe dimensioning for various catchment areas using a detention time of 2 days, a difference in the headwater and tailwater elevations of 0.3 m, a loss coefficient of 0.5, and a detention storage volume of 225 $m^3$.

In five peatland forestry drainage areas (3.5-132 ha catchment areas) in central Finland, Marttila et al. 2010 calculated optimum control pipe diameters between 0.05 and 0.2 m using a detention time of 1-2 days, a difference between headwater and tailwater elevations of 0.3 m, and maximum detention volumes of 286-3129 $m^3$. A detention time of ~24 hours is usually sufficient for sediment removal, but nutrient decreases requires a slightly longer retention time of >48 hours (Iowa storm water management manual, 2009).

The fourth step in designing a PRC structure is to adjust the detention time, based on critical flow velocities of bed sediments, so that no erosion of the bed deposits occurs. Where no information is available on flow bed velocities and potential resuspension, step four can be omitted from the design process.

The last step in designing a PRC structure is to test the effect of the structure against observed runoff values. Marttila et al. (2010) found that the peak runoff retention varied widely among the five central Finland peatland catchment areas studied. Accordingly, extreme rainfall events (>65 mm) resulted in retentions between 75 and 100%, while moderate rainfall (20-30 mm) resulted in only 20-80 % retention (Marttila et al., 2010). Once the structure is installed, if there are problems with retention, the diameter of the control pipe can be decreased at the outflow end to slow the water flow rate if necessary. Water samples can be collected at a distance upslope of the inflow and near the outflow ends of the control pipe to test the efficiency in removing suspended solids and suspended solids-bound nutrients.

## 4.1 Comparison with controlled drainage in agricultural and urban systems

PRC, which has been applied to peatland forestry, is different from the controlled drainage methods commonly used in agricultural systems where a permanent pool of water behind a weir structure maintains the water table at a near-constant level. While both systems have the benefit of enhancing water quality, unlike PRC, traditional controlled drainage methods (e.g. constructed wetlands, wet detention) are not specifically designed to attenuate water flow and SS-bound nutrient transport during large storm events. In traditional controlled drainage systems, water is maintained in a large wetland area for a long period of time (e.g. 80 days) compared to the retention of water in a PRC system (~1-5 days). The longer retention time of the traditional controlled drainage method allows for increased biological uptake and biogeochemical cycling of nutrients and provision of wildlife habitat. However, traditional controlled drainage requires a larger land footprint than PRC and has other negative effects (e.g. flooding, see above). The effect of traditional controlled drainage systems in decreasing total nitrogen and phosphorus concentrations in drainage outflow varies widely depending on many factors including soil type, rainfall, the type of drainage system and the management intensity (Evans et al., 2011). When selecting the best drainage method to use in a specific area it is important to assess the characteristics of the drainage area and desired impact of the drainage method on receiving waters.

Eastern North Carolina is a region that has benefited largely from the introduction of PRC structures within agricultural systems (Evans et al., 2007) and urban areas (City of Raleigh 2002). North Carolina has many estuaries and freshwater streams which are vulnerable to nutrient enrichment from agricultural and urban runoff within the catchments. Consequently, the North Carolina Agricultural Cost Share Program seeks to promote PRC as a method of controlled drainage, which has benefits for both agricultural production and water quality, by providing financial incentives for farmers who adopt the practice (Evans et al., 2011). Storm water PRC devices have also been installed in urban areas to decrease pollutants and detain runoff associated with development (e.g. impervious surfaces such as buildings and roads). Given the benefits that PRC has had on downstream water quality in North Carolina, and in peat soils in Finland, there may be potential that it could be used to decrease nitrogen, phosphorus and sediment loads to the Waituna Lagoon.

## 4.2 Establishment of plants and ongoing maintenance

Since constructed wetlands function best when emergent plants are established (Tanner et al., 2010), it is fair to assume that retention basins associated with PRC structures might also benefit from the establishment of plants. Plants help decrease erosion, enhance wildlife and aesthetic values, and produce organic matter which can be used as an energy source to support microbial processes such as denitrification. Plants can be established in all areas of the PRC flooded zone below the bottom pipe, shallow margins and embankments. High inputs of fine soil particles can cause silt to accumulate in the retention pond bed which can smother plants and increase water turbidity. Therefore, regular maintenance of the drainage ditch by removing sediments with excavator machinery is generally recommended. Frequent visual inspection of the pipes to check for blockages from plants or debris is also recommended (Tanner et al., 2010).

# 5 Recommendations

Although no controlled drainage system is guaranteed to decrease the load of nutrients and sediment to the Waituna Lagooon, the PRC system appears to maximise the potential for decreasing losses while minimising adverse effects associated with the attenuation of runoff in pastoral systems (e.g. the potential for flooding or prolonged soil moisture). The five steps outlined above for the design of a PRC structure can, for the Waituna Lagoon catchment, be distilled into two steps:

1) Given the variability of soil types within the catchment, work needs to be conducted to determine the desired retention time and storage at low flows to maximise the sedimentation of phosphorus and suspended solids and potential for denitrification, respectively. This should focus on a survey of the relative dispersion and deposition potential of the four major soil types in the catchment (Brown, Gley, Organic and Podzol) over a range of Olsen P concentrations;
2) Analysis of LIDAR, stream and meterolgocial data needs to determine the optimal location of PRC structures according to the detention time from step 1 above (realtive to soil type) and the required PRC catchment, storage and maximum runoff (via equations 1 and 2; see Excel spreadhseet) to avoid flooding. This data will also be useful to determine the frequency of innundation and hence potential for denitrification (and dissolution of DRP).

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