Te Rūnanga o Ngāi Tahu c/- Boffa Miskell

Osborne Drain

Hydrology and Water Quality

July 2015

Executive summary

Te Rūnanga o Ngāi Tahu, and a working party (Department of Conservation, Environment Canterbury and Selwyn District Council), commissioned this work to provide independent advice on Selwyn District Council's proposal to obtain a new consent to discharge land drainage and stormwater from Osbornes Drain into Te Waihora / Lake Ellesmere. This hydrological and water quality assessment was one of three parcels of expert technical advice for this work, conducted by GHD Limited, Boffa Miskell Ltd, and Lowe Environmental Impact.

The main objectives of this assessment was to improve the understanding of the physical characteristics of the Osbornes Drain network, and based on the understanding of the physical system, comment on the effectiveness (or otherwise) of the proposed water quality improvements suggested in the PDP Report (or any alternative measures) for achieving acceptable water quality standards for the discharge from Osbornes Drain.

Osbornes Drain is likely to receive more than 60% of its inflow via surface runoff from the surrounding land. Lateral seepage from the water table into the drain comprises a smaller proportion of the inflow to the drain. However, a full water balance for the drain system has not been calculated. Management of the runoff and nutrients contained in the runoff will have a positive effect on the water quality in the drain, and the quality of the discharge to Te Waihora / Lake Ellesmere. Further removal of sediments and organic material in the drain would assist with improving water quality in the short term. However, unless the quality of the runoff is better managed, further intervention within the drain system will likely be required.

The implementation of land management controls as described in LEI (2015) will likely improve the water quality in the drain system. In addition, creation of wetland systems within the drain or immediately adjacent to the drain would also improve water quality, removing nitrogen and phosphorus. However, further work is required to be undertaken to better understand the hydraulics of the drain system to enable a more thorough analysis of this option to be presented.

Setting of water quality limits is likely to be required before the outcomes of the various management options/strategies have an opportunity to be reflected in monitoring data. It is important to recognise that the drainage system is very different to the spring fed streams, and the water quality outcomes should take this into account, particularly given that the primary source of contaminants is considered to be from land surface run-off. The limits should also focus on continual improvement to the quality of the water within the drain, which will consequently improve the quality of the water discharged to Te Waihora / Lake Ellesmere. Therefore, the setting of water quality limits should focus on key contaminants of concern, namely phosphorus and nitrogen.

It is considered that establishing a monitoring regime that routinely reports the quality of the water within the drain and the improvements made over time is required to support decisions on drainage management options. This is critical to informing the success or otherwise of implementing various drain and land management options in the future.

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1. Introduction

This work was commissioned to provide Te Rūnanga o Ngāi Tahu, and a working party of the Department of Conservation (DoC), Environment Canterbury (ECan) and Selwyn District Council (SDC), with independent advice on SDC's proposal to obtain a new consent to discharge land drainage and stormwater from Osbornes Drain into Te Waihora/Lake Ellesmere.

The overall objectives of this work were to provide a more specific (and scientifically robust) basis for:

a. the development of acceptable water quality standards for the discharge from Osbornes Drain into Te Waihora / Lake Ellesmere; and

b. understanding the effectiveness of the water quality improvements suggested in the 2013 PDP Report (or any alternative measures) for achieving acceptable water quality standards for the discharge from Osbornes Drain and, thereby, ecological and cultural benefits for the downstream wetlands and lake.

To achieve this the following three parcels of expert technical (scientific) advice were undertaken:

a. Mitigation Measures Assessment, Lowe Environmental Impact (LEI), addressing the agricultural/soil aspects of the existing land use practices, in order to provide recommendations of viable on-farm mitigation measures and give Te Rūnanga a better understanding regarding the effectiveness of the proposed (or alternative) measures for reducing nutrient and sediment losses into ground and/or surface waters;

b. Hydrology and Water Quality Assessment, GHD Limited, addressing groundwater and surface water quality, in particular evaluating the potential effectiveness of in-drain mitigation measures and the on-farm mitigation strategies recommended by LEI.

c. Ecology Assessment, Boffa Miskell Limited, addressing the ecological condition of Osbornes Drain, the downstream wetland area and the immediate margins of Te Waihora; the likely effects of the discharges from Osbornes Drain on the values of these areas; and recommendations regarding the potential ecological impact of mitigation measures.

1.1 Background

The Osborne drainage scheme is a network of about 9 km of drains operating over 1620 ha of farmland, draining into Te Waihora / Lake Ellesmere in the vicinity of Greenpark Huts (Hudsons Road). The drain network maintenance is the responsibility of SDC, which is seeking to renew a resource consent to discharge water from the drain into Te Waihora / Lake Ellesmere. The water within the drain cannot flow freely into Te Waihora / Lake Ellesmere, which requires the SDC to operate a pump at the downstream end of the catchment to maintain low water levels and to remove flood waters. A description of this process is provided in Section 2 of this report.

Water quality sampling indicates high nitrogen and phosphorus concentrations, low dissolved oxygen and occasional elevated turbidity. Elevated nutrients are also present in the sediments. The water quality environment is characterised as poor or very poor based on ECan's Water Quality Index. This is the lowest ECan grade assessed for monitored tributaries to the lake.

Pattle Delamore Partners Limited (PDP) prepared a draft report (referred to as PDP, 2013) for SDC[1] which considered:

- The current quality of Osbornes Drain, including in drain water quality, sediment quality, quality of discharges to the drain and the impact of these on the wetlands that the drain directly discharges to and Te Waihora/Lake Ellesmere;
- Proposed improvement measures for Osbornes Drain including expected percentage reductions (or similar) of key water quality parameters and impact of these on the wetlands that the drain directly discharges to and Te Waihora/Lake Ellesmere;
- Identification of any further work that needs to be undertaken to improve the quality in Osbornes Drain;
- Recommendations relating to the potential design of Farm Plans, including, but not limited to, the inclusion of on farm or community wetlands (and recommended species etc.) for treatment of the land drainage water before it enters the drain and the associated anticipated benefits (and likely timeframes) of implementing such a tool to achieve short and long term goals for the drain.

1.2 Project Objective

The purpose of this work was to:

- Improve the understanding of the physical characteristics of the Osbornes Drain network; and
- Based on the understanding of the physical system, comment on the effectiveness (or otherwise) of the proposed water quality improvements suggested in the PDP Report (or any alternative measures) for achieving acceptable water quality standards for the discharge from Osbornes Drain.

1.3 Scope of work

The scope of work for this project was:

- Review the PDP report and proposed mitigation measures; and
- Provide a conceptual model of the Osbornes Drain catchment.

1.4 Report structure

The report has been structured as follows:

- Description of the Environmental Setting
- Conceptual Understanding
- Review of PDP (2013) draft report
- Recommendations

[1] Pattle Delamore Partners Ltd, 2013. *Osbornes Drain Water Quality Improvements*. Draft Report. Prepared for Selwyn District Council, December 2013.

1.5 Limitations

This report: has been prepared by GHD for Te Rūnanga o Ngāi Tahu and may only be used and relied on by Te Rūnanga o Ngāi Tahu for the purpose agreed between GHD and the Te Rūnanga o Ngāi Tahu as set out in section 1 of this report.

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The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

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2. Environmental Setting

2.1 Introduction

Robinson and Meredith (2013, Draft) investigated the water and sediment quality of Osbornes Drain, and while the report is still in draft format, the data obtained from the investigation is useful to this project.

The drainage network and pumping scheme was constructed in 1967-1968 for the purpose of reclaiming land that was essentially a shallow bay of Te Waihora/ Lake Ellesmere, which was submerged during periods of elevated lake levels (Robinson and Meredith, 2013). The drainage system was coupled with a series of stop banks that prevented the lake from inundating the drained land, a pump house, and a downstream discharge channel that conveyed the water through a wetland before discharging to the Lake (Robinson and Meredith, 2013).

There are other drains in the vicinity that were likely constructed at the same time, which flow directly into Te Waihora/ Lake Ellesmere under gravity. Figure A1, Appendix A, shows the drainage network.

Taylor (1996) provides a comprehensive review of the natural resources of Te Waihora/ Lake Ellesmere, including influent stream quality and quantities. However, the Obsornes Drain network is not discussed in Taylor (1996). More recently, Environment Canterbury (2013) provided a discussion on the restoration of the lake ecosystem, which highlights the importance of managing/reducing nutrient inflows to the lake. It also provides several recommendations/ approaches to manage land that surrounds the lake. Some of the points raised in the report are discussed in Section 5, where they are relevant to the Osbornes Drain system.

2.2 Soils

The catchment is low lying with a very gradual grade towards Te Waihora / Lake Ellesmere. The soils within the catchment are associated with lake deposits. A review of the soils data (S-map) contained on ECan's GIS identifies the soils as deep, poorly drained soils largely comprising the Motukarara deep silty loam and Greenpark deep sandy loam.

The heavy nature of the soils indicates the potential for poor vertical drainage through the soil profile, resulting in surface runoff.

2.3 Hydrology

The drain network receives inflows from direct rainfall, runoff from roadside drainage, lateral movement of sub-soil drainage, and stormwater runoff from the adjacent farm land. The following provides an overview of the drainage system extent and functionality. This is considered to be a high level review of the drain system and management approach. A more detailed investigation into the operation of the Pump House pumps and water levels may be required to be undertaken at a later date. Groundwater seepage is discussed in section 3.5 below.

2.3.1 Drainage Network

Osbornes Drain network consists of a main drain that is aligned essentially in a NW-SE direction, with the head of the drain observed at or about Dalys Road. There are a series of drainage laterals that connect into the main drain which are generally aligned in SW – NE direction. The laterals are generally situated along the road verges of Mathews Road, Jarvis Road, Gammacks Road and the bottom end of Hudsons Road. The laterals were observed during the site visit of 20 April 2015 to be heavily vegetated with shallow stagnant water present in the drains (Plates 1 to 3).

Each lateral receives surface inflows from the surrounding land during periods of surface run off. The inflow drains are generally elevated above the main drain (Plate 3). Appendix A provides an overview of the drainage network.

Robinson and Meredith (2013) provide a description of the drain profile in the vicinity of the Pump House pond and up to 2.5 km upstream on the main drain. Robinson and Meredith (2013) noted that the drain profile was essentially a box shape, with the drain having a near uniform width of 5 m for most of its length. The widest point of the drain was immediately upstream of the Pump House, where the drain is approximately 30 m wide forming a ponded area (Plate 4). It was also noted that during periods of no discharge the drain acted as a reservoir, with the pond area storing the greatest volume of water with the stored volume per meter of water way decreasing upstream. Importantly, Robinson and Meredith (2013) calculated that approximately half of the stored volume of water in the drain was within the ponded area immediately upstream of the Pump House.

Plate 1 Gammacks Road Lateral Drain – Looking SW

Plate 2 Jarvis Road Lateral Drain – Looking NE

Plate 3 Land drain into Hudsons Road Lateral

Plate 4 Pump House Pond

2.3.2 Halswell River

Lateral movement of water from the Halswell River into the drain could occur, as there is a difference in water level (i.e. hydraulic head) between the drain and the river immediately above the Pump House. However, the short distance between the two water bodies suggests that if significant seepage was occurring then the waters would exhibit similar chemical characteristics (and hydraulic head). The Halswell River has an average nitrate-nitrogen concentration an order of magnitude higher than recorded in the drain, although the total nitrogen concentrations are similar.

Based on the water chemistry data the Halswell River is considered to be independent from Osbornes Drain.

2.3.3 Pump House

The operation of the pumps[2] at the lower end of the drain network controls the water depth and velocity of flow within the drains. Records provided by SDC show the operational water levels for the pumps has varied since 2013, with water levels in the drain being maintained at a lower level now compared to 2013. Graphs showing water levels, pump operation, and estimated discharge volumes are provided in Appendix B.

The current operational levels indicate that water levels in the drain immediately upstream of the Pump House fluctuate by approximately 0.4 m, with the high level trigger set at approximately -2.3 m above mean sea level (amsl[3]) and a low level cut off of approximately -2.7 m amsl. The data suggests that the water levels were maintained at a higher level in 2013, with an upper pump initiation level of approximately -2.0 m amsl and a lower cut off level of approximately -2.4 m amsl.

Typically the pumps were operated from less than 10 minutes to several hours at a time, several times per day. The average pumping duration for the entire record was approximately 41 minutes, with the median duration of 10 minutes. However, since October 2014 the average pumping duration was approximately 11 minutes with the median approximately eight minutes. There was a consequential increase in the frequency of pumping associated with maintaining the lower water level in the drain, with the pumps switching on up to eight times per day during the latter part of 2014, decreasing to two to four times per day on average over the past summer.

The shorter duration of pumping is likely associated with maintaining water levels in the Pump House pond lower than previous operational levels, resulting in a potential reduction in the volume of water that is required to be removed per pumping event. However, the discharge rates from the pump house were not monitored. Therefore, the estimate of the volumetric discharge provided below were based on the pump specification sheets provided by SDC (noting that wear on the pump impellors has reduced the pumping capacity – pers. Comm. Murray England, 29 May 2015), and the estimated discharge rate provided in Robinson and Meredith (2013) of 0.45 m^3/s per pump.

During winter months one of the pumps may be operational continuously for several days to maintain water levels in the drain and to prevent sustained flooding of adjacent land. During these periods the discharge rate can be in the order of 0.45-0.5 m^3/s. Figure 1 provides an estimate of volume discharge per event and the cumulative discharge from the drain between October 2013 and April 2015.

[2] There are two pumps installed at the Pump House, consisting of Crompton Parkinson 50Hp pumps with a specified capacity of 31.5 cusecs each (i.e. 0.89m3/s).
[3] It was assumed that the reference point for the staff gauge used by SDC was mean sea level.

Based on the available data the pumps have discharged approximately 3.37 Million cubic metres of water over a period of 570 days. This equates to an average daily discharge of approximately 0.069 m^3/s, with a median discharge of approximately 0.025 m^3/s. Since September 2014 the mean daily discharge was approximately 0.033 m^3/s, with a median daily discharge of approximately 0.024 m^3/s. Compared to the spring fed streams that discharge into Te Waihora / Lake Ellesmere, the drain would be considered to be a minor contributor in terms of flow (as shown in Table 1 below).

Table 1: Flows recorded or calculated by Environment Canterbury for nine streams that are routinely monitored. Source: Hansen, 2014.

Stream Flow Gauging Site	Min (m^3/s)	Max (m^3/s)	Average (m^3/s)	% of flow to Te Waihora
Selwyn - Waimakariri streams				
Halswell River at McCartneys Bridge	0.6	10.5	1.4	14%
L II Stream at Pannetts	0.8	7.2	2	19%
Selwyn River / Waikirikiri at Coes Ford	0.1	203.4	3	29%
Irwell River at Lake Road	0	3.8	0.7	7%
Hanmer Rd Drain at Lake Road	0.1	5.2	0.3	3%
Selwyn - Rakaia streams				
Boggy Creek at Lake Road	0.1	3.3	0.2	2%
Doyleston Drain at Lake Road	0	4.9	0.2	2%
Harts Creek at Lower Lake Road	0.6	15.4	1.4	14%
Waikekewai Creek at Gullivers Road	0	1.4	0.1	1%
subtotal - monitored streams			9.2	90%
other streams and drains			1	10%
Total flow to Te Waihora			**10.2**	**100%**

The inflows to the Pump House drain since September 2014 have been relatively steady, suggesting a potential groundwater base flow rate into the drain network. Based only on the length of the main drain up to Gammacks Road (i.e. 2.5 km), this would equate to a seepage rate of approximately 0.01 L/s/m.

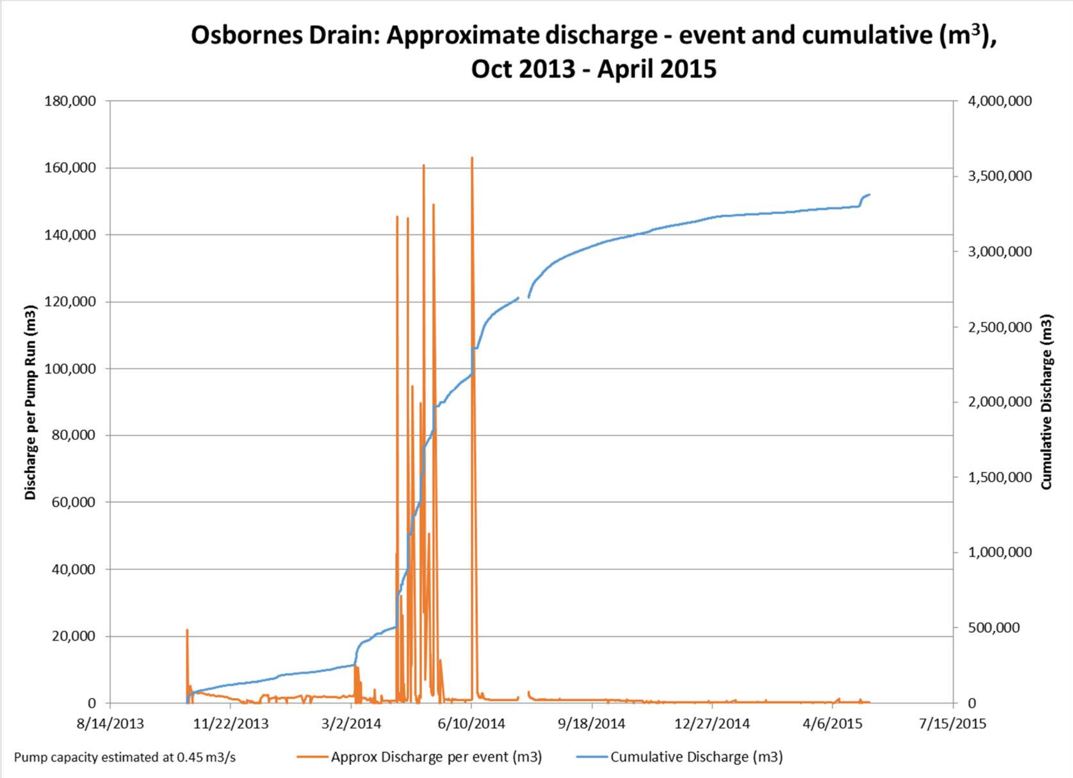

Figure 1 Osbornes Drain estimated discharge (2013-2015)

However, during the site visit of 20 April 2015 it was observed that the backflow flap valves were allowing some water from the downstream channel to flow back into the Pump House pond area. As the downstream flap values were observed to be allowing some backflow of water into the Pump House pond, estimates of lateral seepage from the groundwater system in the drain network provided above (i.e. 0.01 L/s/m) are considered indicative only. Some maintenance on the flap valves may address this issue.

High Flow Events

The water level data at the Pump House also illustrates instances where the water levels rose above the typical operational range, indicating flood events (Figure 2 and 3). Most events correspond with preceding rainfall of more than 20 mm/day. The elevated water levels are typically short in duration, with the event in July 2014 lasting for approximately 7 days above the operational high of -2.3 m asml (Figure 4). The July event is notable for the pumps not being used to lower water levels. This is likely a response to increased water levels in the lake and possible surrounding flooding issues, restricting the Council's ability to pump water from the drain. However, the variance in water levels between 18 July and 28 July (where the data indicates that the pumps were not operational) indicates that some removal of water from the catchment occurred.

The longest period of continuous pumping was approximately 100 hours, between 10 and 14 June 2014 (Figure 5). During this period it is estimated that approximately 163,141 m^3 of water was discharge from the drain. During this period there was approximately 35 mm of rainfall recorded at Lincoln. Water levels in the drain increased at the Pump House by approximately 0.7 m, peaking at -2 m amsl on 11 June, before the continuous pumping decreased water levels to the low cut off level of -2.7 m amsl on 14 June.

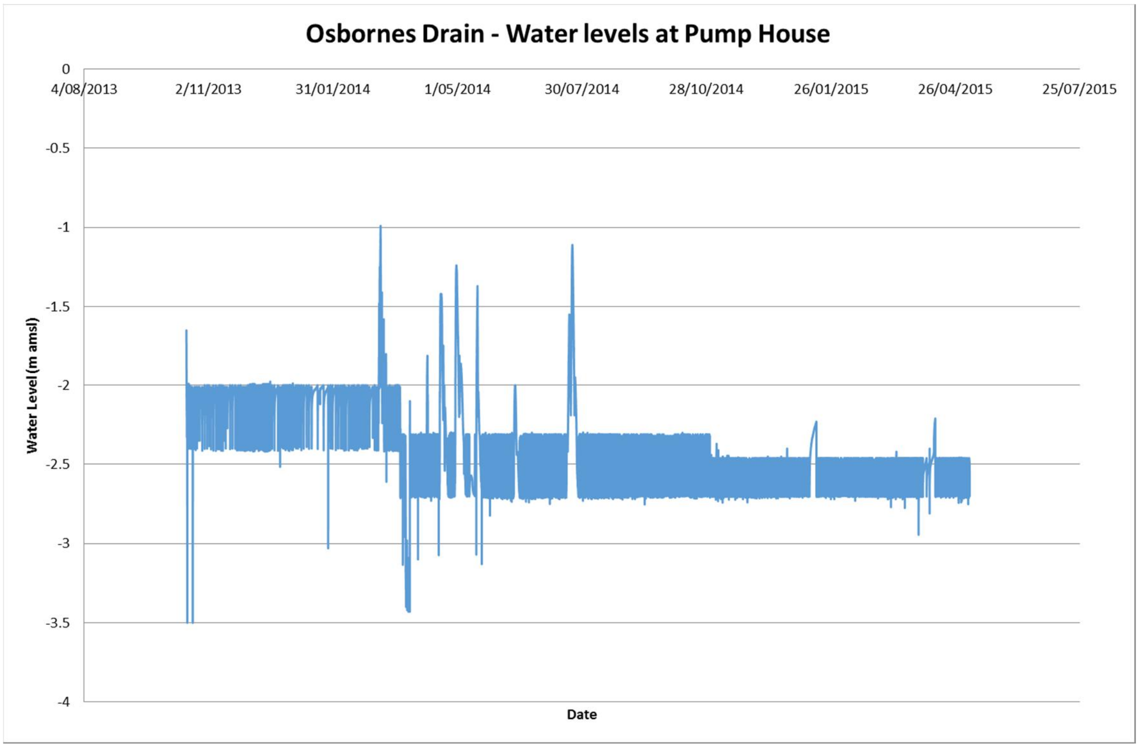

Figure 2 Water Levels at the Pump House (measured by SDC)

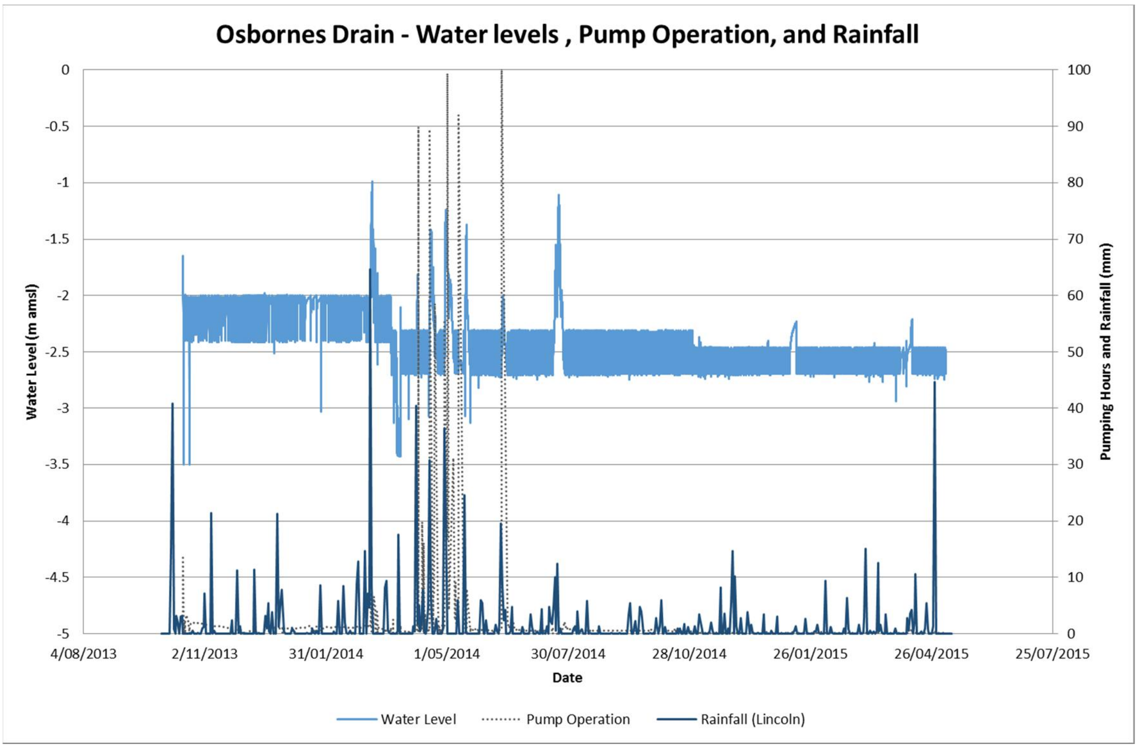

Figure 3 Water Levels, Pumping Duration, and Rainfall events

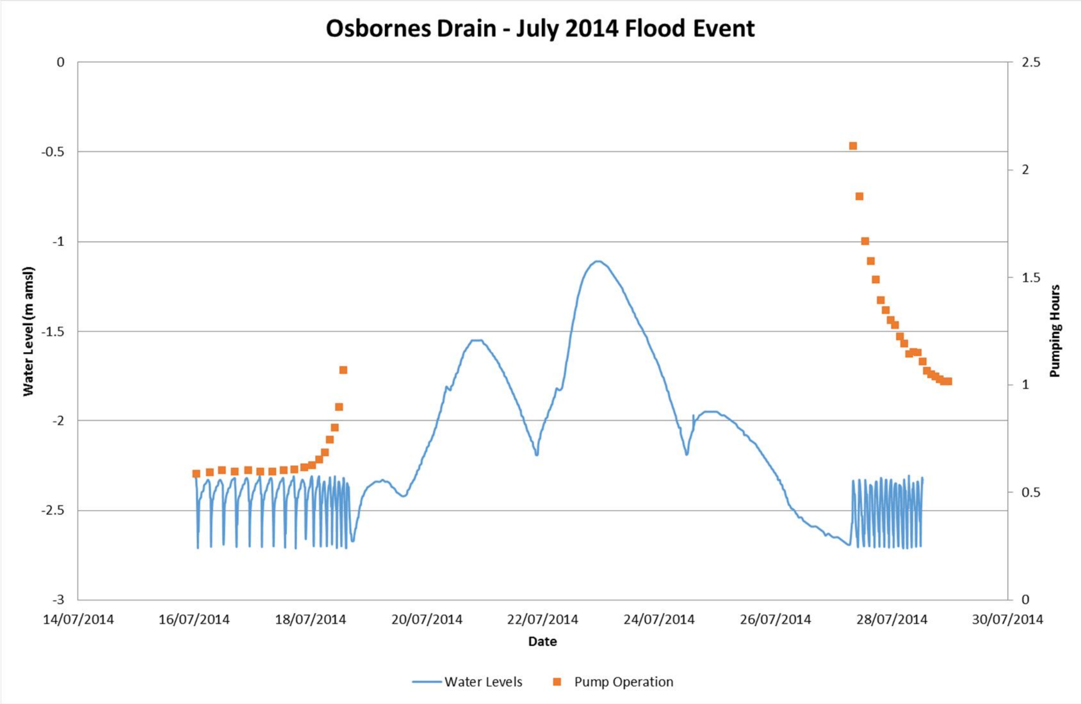

Figure 4 Water Levels at the Pump House – July 2014

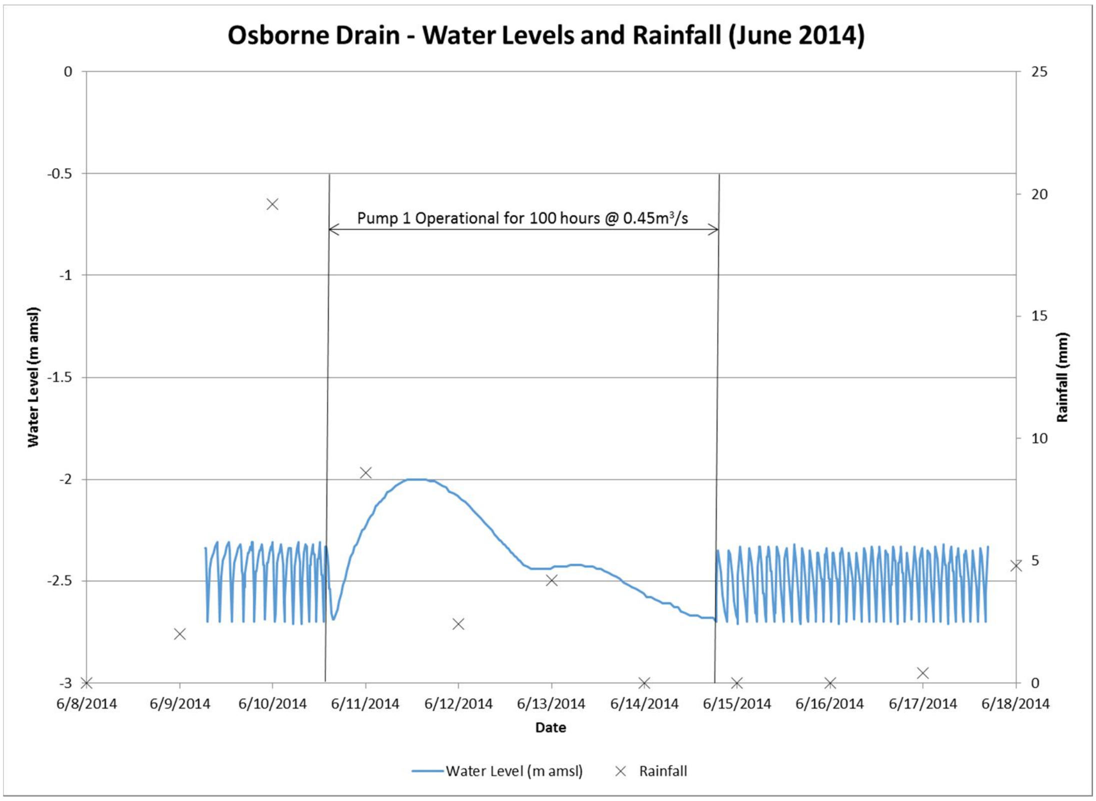

Figure 5 Water Levels at the Pump House – June 2014

An estimate of flood inflows versus base flow has been undertaken to estimate the proportion of high-flow events. As an initial estimate it was considered that pumping durations in excess of 1 hour would represent inflow to the drainage system that would likely be driven by overland flow. Based on this approach approximately 61% of the total volume discharged from the drain was associated with pumping events that lasted more than an hour. This suggests that discharge events that are likely to be associated with runoff accounts for more than 60% of the total volume discharged.

While this approach is simplistic, it does indicate that the majority of inflow to the drain is likely to be from overland flow.

2.4 Geology

The surficial geology was mapped as lacustrine silt, mud, sand and peat, with the main rock type being sand (Forsyth *et al.,* 2008). An area of dune sands was identified in the area of Hudsons Road and Jarvis Road, and running along the length of Ridge Road. The depth of the lake deposits is not known. However, a review of bore logs from 18 wells installed within the catchment indicate variable material in the upper 20 m of the profile, with sands, clays, and peats which act to confine the Riccarton Gravel aquifer all identified in the logs at varying thicknesses. The well logs indicate that there is a general trend of sand material in the upper 5 m with low permeability silt and clays underlying the sand material.

A scraping of the bank of Osbornes Drain in the vicinity of the Pump House pond illustrates the nature of the sediments that underlie the soils (Plate 5). The exposed material is fine grained, with stratification (layering) apparent in the photograph. The cutting is free of gravel or coarse sand material, indicating the likelihood of low vertical hydraulic conductivity associated with fine grained sands, silts, clays and organic matter.

Plate 5 Osbornes Drain - Bank cutting upstream of Pump House pond

2.5 Hydrogeology

The sandy nature of the surficial material will enable infiltration of rain into the subsoil. However, the lower permeability of the silts, clays and peats combined with the upward vertical hydraulic gradient of the Riccarton Gravel aquifer will restrict the vertical infiltration of drainage water. Furthermore, the water levels in the lake will likely influence the water table conditions around the lake margins, further restricting vertical movement of drainage water. Under natural conditions this would likely result in a water table that would be close to ground surface, creating swamp/marsh conditions.

The drainage system has likely lowered the water table in the immediate vicinity of the drains, but the lateral movement of water is expected to be slow given the inferred flat hydraulic gradient. The presence of the confining material at or about 5 m below ground level (bgl) will restrict the upward movement of water into the drainage system from the Riccarton Gravels, with the drain network absent of any spring discharges of substance. Therefore, the regional groundwater system within the Osbornes Drain catchment is largely isolated from the drainage system, with a water table aquifer likely to be present within the thin sand deposits.

There is no information available on the hydraulic conductivity of the sand material. However, Freeze and Cherry (1979) suggest that hydraulic conductivity of a sand to silty sand matrix is likely to be between 1×10^{-7} m/s to 1×10^{-3} m/s. The hydraulic gradient of the water table is also unknown. However, based on the surface grade it is likely to be in the order of 0.0002 (i.e. a very flat gradient). On this basis irrespective of the potential for relatively high hydraulic conductivity associated with clean sand lenses, due to the very flat hydraulic gradient, groundwater discharge to the drain and lake is expected to be very small.

The groundwater system within the catchment is characterised as follows:

- Confining sediments restrict vertical movement of water between regional aquifers and the water table;
- Hydraulic conductivity is likely to be consistent with sand to silty sand matrix;
- The water table hydraulic gradient is likely to be very low;
- Lateral inflow of groundwater from the water table into the drain system is likely to be low; and
- Discharge to the lake from the water table is expected to be small from this catchment compared to spring fed streams.

Seepage of groundwater associated with land surface drainage within the catchment is likely to occur, but the rate of discharge to the drains is expected to be limited relative to the stormwater runoff from the surrounding land and on-farm drainage networks.

2.6 Water Quality

Water quality data presented in Robinson and Meredith (2013), PDP (2013), and SDC data provided for the Pump House pond were reviewed. In addition, water quality sample results from the drains and streams that discharge into Te Waihora / Lake Ellesmere between June 2011 and July 2012 provided by SDC were also reviewed. The following observations were made:

- The nutrients within Osbornes Drain are present in different proportions to other spring fed streams sampled in the district, with higher organic nitrogen (organic – N), Total Phosphorus (TP), and Dissolved Reactive Phosphorus (DRP) concentrations.
- Conductivity measured in the drain network is higher in the drain than the spring fed streams, reflecting the interaction between lacustrine derived soils and drainage water in the Osbornes Drain catchment.
- Dissolved oxygen (DO) concentrations in the drain network are lower than the spring fed streams in the catchment, with DO saturation typically below 50%, with some results during summer months below 20% DO.
- Total Suspended Solids (TSS) are generally higher than the spring fed streams.
- The water quality of the Osbornes Drain reflects the slower flows with higher organic material producing an environment that is more closely associated with swamps/marshland rather than spring fed systems.

2.6.1 Discussion

The following provides a brief discussion of the possible linkages between the water quality measured in the drain and surrounding catchment.

Compared to the spring fed streams that discharge to Te Waihora / Lake Ellesmere the Osborne Drain network exhibits a very different water chemistry. This is likely due to the physical differences between the systems, with the drain network receiving lateral seepage and runoff from the land, while the spring fed streams receive groundwater inflow from the spring discharges. Groundwater discharging into spring fed systems is generally higher in Dissolved Inorganic Nitrogen (DIN) and lower in DRP concentrations. Furthermore, the flow within the spring fed streams is generally consistent (compared to the drain), maintaining a natural discharge to the lake at all times.

The Osbornes Drain catchment hydrology indicates that more than 60% of the inflows are likely to be derived from runoff from the surrounding land. The site visit identified a number of lateral drains which act to convey water from the pastoral land into the drains. Runoff is likely to contribute organic matter, sediment, and nutrients to the drain system. Lateral seepage into the drain is slow but may contribute DRP and DIN.

The organic matter, sediments and nutrients within the runoff water provides the basis for the elevated concentrations of TP, organic – N, sediment and organic matter (OM). This provides a source of nutrients to the drain water, which may already be in dissolved form or solid form (including particulate matter) which enables macrophytes and algae to proliferate. The organic growth within the drain tends to constrict flow, promote further sedimentation, and contribute to organic matter build up (from runoff and die off of instream macrophytes). This in turn affects the DO concentration / % saturation within the drain.

The higher proportion of organic – N to dissolved forms (DIN) suggest that the nitrogen within the drain is associated with runoff and the prevalence of organic material within the drain itself. Robinson and Meredith (2013) state that the dominant water quality components of Osbornes drain are associated with decomposed organic material. Conversion of the organic – N to DIN is limited by the low DO concentrations within the drain (PDP, 2013); Robinson and Meredith, 2013).

The concentration of Phosphorus in the drain water is typically an order of magnitude greater than the concentrations observed in Te Waihora / Lake Ellesmere and the spring fed streams (e.g. the Halswell River). Phosphorus is likely to enter the drain attached to soil particles or as effluent that is within surface runoff water. Once in the drain network the slow flow rate and the presence of macrophytes including weeds, grasses, and other organic material will enhance settlement of the sediment bound phosphorus.

Under anoxic conditions microbial activity converts the sediment bound P into its soluble form (i.e. dissolved reactive phosphorus). DRP is readily available for plant uptake and at the right proportions with DIN can lead to algal blooms. The high concentrations of TP and DRP in the drain will also support growth of plant matter in the drain.

The balance of nutrients, dissolved oxygen concentrations, organic matter and sedimentation within the drain is reflective of the physical characteristics of the drain system and surrounding interaction with the land. Environment Canterbury (2013) considered that the high DRP concentrations in the drain were likely to be associated with the development of anoxic conditions in the shallow groundwater system adjacent to the drain, which results in higher DRP concentrations in groundwater being discharged in to the drain. However, this pathway is considered secondary to the effects of direct runoff from the surrounding land, depositing sediment bound P within the drain to be converted later to DRP under anoxic conditions within the drain. It is noted that the concentration of DRP in shallow groundwater seepage has not previously been quantified.

2.7 Summary

A review of the available information indicates that Osbornes Drain receives inflows from rainfall runoff from the surrounding catchment. Initial estimates suggest rainfall runoff provides more than 60% of the discharge volume to Te Waihora / Lake Ellesmere. Groundwater from the deeper coastal confined aquifer system is unlikely to contribute measureable volumes of water, whilst lateral seepage from the shallow water table is likely to also be very small. The quality of the groundwater seepage is not known. However, the water quality within the drain is more likely to be affected by the runoff events that convey organic matter, nutrients and sediment into the drain.

The flat drain profile and the low seepage rate provide an opportunity for the organic matter and sediment to settle on the bed of the drain, supporting macrophyte and algae growth. This in turn acts to further restrict flow, enhance sedimentation, decrease DO levels, and enable the conversion of sediment bound P to DRP (and inhibit the conversion of organic – N to DIN).

3. Conceptual Understanding

3.1 Overview

The following provides the current conceptual understanding of the physical system based on the information reviewed. The following is an interpretation of the data as it currently stands, and with new information the conceptual understanding of the system should be updated.

The main components of the physical system are:

- Soils are sandy in nature and require the introduction of organic matter to improve soil health (Robinson and Meredith, 2013);
- Soils are characterised as being deep, poorly drained, silt to sandy silt loams, which restricts the vertical infiltration of rain, particularly during heavy and sustained rainfall events (Land Care NZ S-Soils Map, ECan GIS);
- Infiltration of rainfall through the soil horizon is further limited by the shallow water table. During high water table conditions rainfall runoff will occur;
- Rainfall runoff is directed to lateral drains that cross the land surface, which discharge into the main Osbornes Drain. Based on an initial assessment approximately 60% of the discharge from the drainage system is associated with rainfall runoff within the catchment;
- Runoff is likely to contain nutrients in the form of Phosphorus bound to sediment and Nitrogen and Phosphorus in animal waste;
- The source of organic – N and Phosphorus may also be from farm losses of organic fertilisers applied to the land;
- Groundwater inflow from the regional system is unlikely to occur;
- Lateral movement of sub-soil drainage will occur, but the low hydraulic gradient and low hydraulic conductivity means that inflows to the drain are likely to be very slow. An initial estimate of the main drain suggests a seepage rate of 0.01 l/s/m in the main drain;
- Lateral movement of water from the Halswell River into the main drain could occur but inflows are likely to be very low;
- Runoff contributes a significant proportion of nutrients to the drainage system, which supports macrophyte growth in the drain;
- Existing vegetation in the drain restricts flow and enables sedimentation to occur;
- Existing vegetation also contributes to organic matter build up in the drain;
- Low dissolved oxygen concentrations are likely to be associated with the low flows, the high organic matter, and the level of nutrients present in the drain;
- The low DO concentrations enable the particle bound P to be converted into DRP; and
- The Pump House pond water level controls the water movement in the main drain and has a significant control on functioning of the system;

A conceptual model of the system has been sketched to illustrate the various interactions between nutrient pathways and the drain (Figure 6) and for the Pump House pond (Figure 7). The conceptual models illustrate the inflows of phosphorus and organic – N from land surface runoff which circumvents the existing bank vegetation/filters via piped discharges. Organic matter builds up in the drain and contributes to the lower DO, low conversion of DIN, and higher DRP concentrations. The Pump House operation reflects the intention of the rock weirs to provide a barrier to sediment entering the pond, but at higher water levels it is expected that some sediment and nutrients will bypass the weirs.

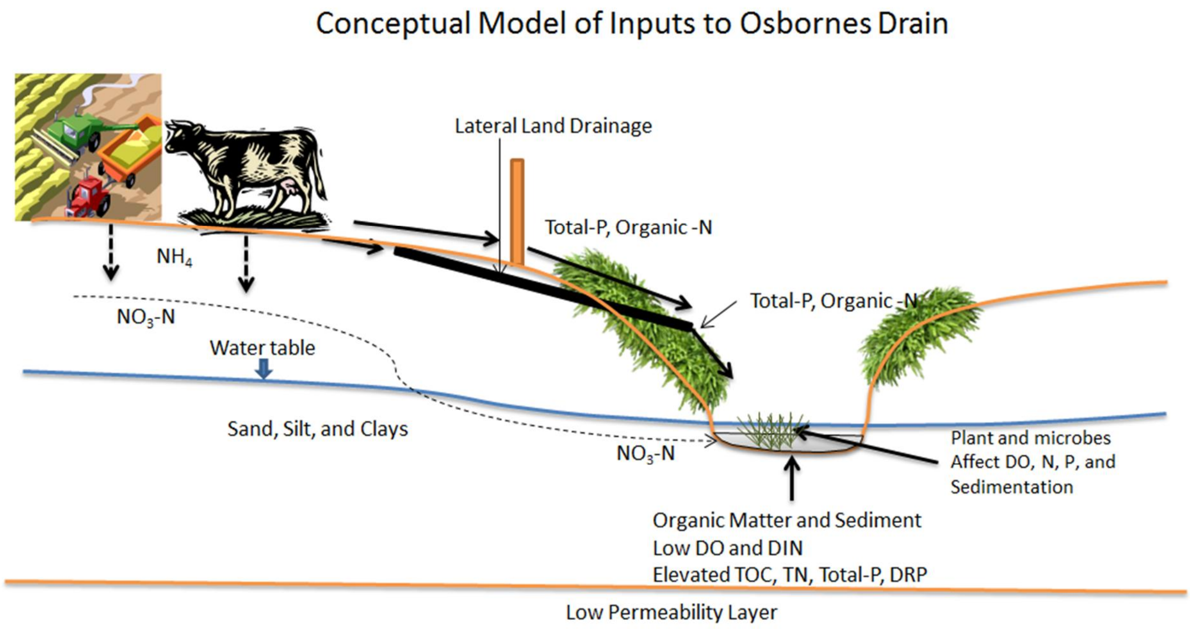

Figure 6 - Conceptual Model of Drain System

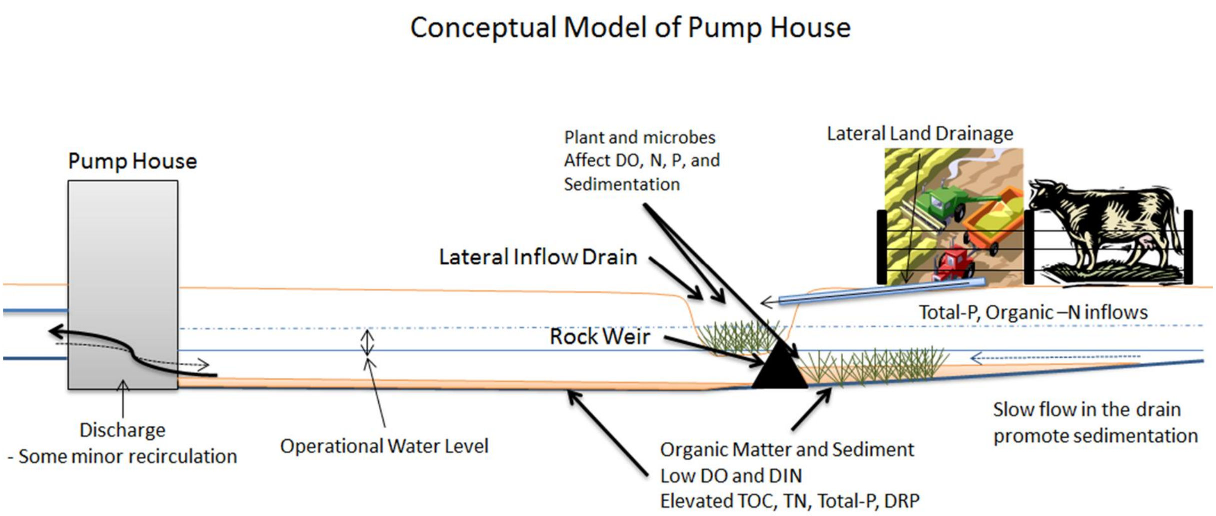

Figure 7 - Conceptual Model of Pump House

4. Review of PDP Draft (2013) Report

4.1 Introduction

SDC engaged PDP to assist with understanding the water quality in the drain network and how the water quality could be improved under a range of potential improvement measures. The following provides a review of the PDP report as it relates to the characterisation of the drain system and the potential mitigation measures that were outlined in Appendix H of their report.

4.2 Environmental Setting

Section 1.1 of the PDP draft report provides a brief description of the environmental setting of Osbornes Drain. The report notes that the drain is situated within an area of low permeability sediments that form part of the coastal confining layers for deeper gravel aquifers. Based on the presence of the confining sediments PDP considered that the water in the drain is primarily fed from surface water and shallow groundwater derived from the local catchment. In addition, PDP considered that the movement of deeper groundwater into the drain would be limited by the presence of the confining sediments, and any inflow from inland groundwater that contains nutrients would be attenuated by the low permeability sediments.

On that basis PDP considered that the primary source of water and contaminants within the drain is most likely to be derived from the local catchment area.

The brief description provided in PDP (2013) is reasonable for a high level characterisation of the drainage system and its contributing catchment. However, a more developed conceptual model of the drainage system would assist with the interpretation of the water quality results obtained from the drainage network. A conceptual model would also assist with the derivation of appropriate water quality targets for the drainage network, ensuring that water quality targets and management options for the drain system are appropriate for the physical system.

A more detailed description of the environmental setting is provided in Section 2, with a conceptual model of the drainage network and contributing catchment presented in Section 3.

4.3 Water Quality

PDP (2013) classified the drain network according to its Water Quality Index (WQI) based on data measured by Environment Canterbury (Robinson and Meredith, 2013). The WQI scores in the report for the drain indicate a degraded system, with poor to very poor water quality. Water quality tended to improve towards the lower end of the drain, but was still rated poor using the WQI.

The report also compared the results of the water quality sampling undertaken by Robinson and Meredith (2013) against guidelines values from the Natural Resources Regional Plan (NRRP) and ANZECC (2000).

The analysis undertaken in PDP (2013) identified the following:

- Total Phosphorus (TP) concentrations are more than 100% above the ANZECC guideline value of 0.033 mg/L;
- Dissolved Reactive Phosphorus (DRP) concentrations are more than 100% above the NRRP guideline value of 0.016 mg/L;
- Total Nitrogen (TN) concentrations are more than 100% above the ANZECC guideline value of 0.614 mg/L;

- Dissolved Inorganic Nitrogen (DIN) concentrations are below the NRRP guideline value of 1.5 mg/L;
- Ammoniacal – N (NH_4-N) concentrations exceed guideline value in the upper part of the catchment, and is below the guideline value in the lower catchment (NRRP guideline value of < 0.9 mg/L); and
- Dissolved oxygen (DO) concentrations are below guideline values, but this is variable throughout the catchment.

The concentration of TP and DRP was highlighted to be of most concern in the drain system, as Te Waihora / Lake Ellesmere is considered to be phosphorus limited.

The report indicates that the surrounding land use and the physical characteristics of the drain system and Pump House contribute to the water quality within the drain system.

4.4 Improvement Options – (PDP, 2013 - Appendix H)

A series of options to improve the water quality in Osbornes Drain were presented in Section 5 and Appendix H of PDP (2013). The report broadly quantified the likely success or otherwise of each mitigation option by assigning a percentage change to the water quality parameter as a potential outcome. The report acknowledged the variability that could be experienced for each water quality parameter as a result of implementation of some/all of the management options.

The PDP (2013) report provided a hierarchy for the implementation of improvement measures, which have been replicated as follows:

- Step 1: Implement farmer education, implement individual farm management plans and riparian management strategies;
- Step 2: Remove contaminated sediment (as identified by a sampling survey) downstream of the pump station and for a short section upstream of the pump station. Install a weir to restrict the movement of upstream contaminated sediments into the excavated area. (Appropriate planning of this mitigation is required, with particular attention and detail to timing of year and consideration of potential impacts on the receiving environment if high flows were to occur immediately after earthworks);
- Step 3: Establish base flow augmentation using artesian bore water and instalment of a minimum flow meter;
- Step 4: Monitor water quality changes. Only consider recirculation or aerators if steps 1 – 3 do not show an improvement
- Step 5: Once implementation of farm management plans has reduced contaminant input to an acceptable level then complete excavation of other contaminated sediments.

Appendix H of PDP (2013) provided an assessment of the likely water quality improvements that could be achieved through the application of various management options. Our review of the options presented in PDP (2013), as they relate to water quality improvements in the drain network from the implementation of the improvement measures above, are provided in Appendix C of this report (GHD, 2015). Whereas, PDP (2013) options that relate more specifically to on farm mitigation are addressed in the accompanying Mitigation Measures Report by LEI (2015).

Our review focused on two options:

- Removal of the sediment from the main drain upstream of the Pump House; and
- The introduction of groundwater to augment flow in the drain network.

The use of aerators or recirculation was not considered in detail within this report.

4.4.1 Sediment Removal

PDP (2013) generally noted that the sediment removal processes would result in an increase to the drain cross-sectional area, which would generally reduce flow velocities within the drain and enable sedimentation to occur. PDP (2013) considered that the potential effects on key water quality parameters were:

- Dissolved oxygen concentrations would reduce due to increases in water temperature in the drain from the increase in cross-sectional area and reductions in flow, driving biological activity to consume DO.
- Nitrogen concentrations would improve only slightly as the lower velocities would promote sedimentation, of which 13% of the organic nitrogen was understood to be in solid form;
- Phosphorus concentrations would improve by 30%-50% as lower velocities would promote sedimentation, of which 47% of phosphorus is in particulate form.
- TSS would also decrease with a lower velocity.

The removal of sediment from the main drain, upstream of the Pump House to Gammacks Road, took place in April 2015 (as described in Section 4.5). The removal of sediment and organic matter from the drain is expected to have an immediate improvement to a range of water quality parameters within the area of works. However, it is unlikely that the removal of sediment would alter the cross-sectional area significantly to have a marked effect on the water temperature already experienced in the drain system. It is also unlikely that the sediment removal will improve DO concentrations over the long term. It is considered that DO concentrations would return to low levels in the drain. The lower DO is a concern as it enables particulate bound P to be converted by biological processes into DRP, which is plant available. However, counter to this is that conversion of organic – N to soluble inorganic forms of nitrogen (DIN) is currently limited.

Flows within the drain network are typically very slow (unless in flood), which enables organic material and sediment to accumulate in the drain. The removal of sediment is unlikely to reduce the flow velocity to promote further sedimentation of suspended solids as described in PDP (2013). In the short term the absence of weeds and other organic material from the drain will likely improve flow efficiency towards the Pump House. Therefore, any influent contaminants from the surrounding land could be discharged to the lake more readily. This may not be desirable for the long term management of the water quality of the Lake.

There is a concern that connecting water quality improvements with lower water velocities within the drain, which allow for settling of the suspended solids (which contain particulate bound P), does not account for the potential sink created for future conversion of P to DRP under low dissolved oxygen conditions. This could continue to contribute DRP within the drain water, which could be discharged to the Lake.

The source of the organic material and sediment is more than likely associated with lateral runoff of stormwater and subsoil drainage from the surrounding land. Unless the inputs to the drain system are more effectively managed (e.g. via on farm management tools – see LEI, 2015) to avoid sedimentation and the build-up of organic matter, the improvements made to the water quality parameters from the sediment removal are unlikely to be sustained. More regular drain cleaning operations may be required to minimise the build-up of key contaminants within the drain network, in particular sediment bound P and organic nitrogen. Reuse of the dredged sediment on surrounding land is an option to recycle nutrients, provided that buffers are created to avoid recirculation of the nutrients back to the drain system. However, long term sediment removal and drain maintenance is likely to have long-lasting negative effects on the ecology of Osbornes Drain, which may not be desirable if a goal of any improvements options is also to improve the ecology (Boffa Miskell 2015).

4.4.2 Drain Flow Augmentation with Groundwater

Step 3 of the management approach outlined in PDP (2013) was to introduce groundwater to the drain network from a series of artesian wells. The purpose of the augmentation of flow in the drain would be to increase through flow, increase wetted area (i.e. increase water depth), and improve dissolved oxygen concentrations.

PDP (2013) considered that the potential effects on key water quality parameters were:

- With sufficient augmentation stagnation of water within the drain would be addressed and as a result could provide for some minor improvement in the DO concentrations.
- Nitrogen concentrations would reduce due to low concentrations of dissolved inorganic nitrogen in groundwater used to augment flows, which would dilute the overall concentration of nitrogen in the drain.
- Phosphorus concentrations in the drain would reduce due to low concentrations of dissolved reactive phosphorus in groundwater used to augment flows. The augmentation of drain flows with groundwater would dilute the overall concentration of phosphorus in the drain.
- Total suspended solids would also be reduced with augmentation of drain flows with low TSS groundwater.

A review of groundwater quality data from wells installed in the Riccarton Gravel aquifer (i.e. >30 m below ground level) that are located within the Osbornes Drain catchment indicates that groundwater quality is of a high standard, with very low DIN and DRP concentrations. Therefore, the introduction of groundwater would achieve the outcomes that PDP (2013) indicated. However, dissolved oxygen concentrations in groundwater are at or near zero, with evidence of elevated dissolved metals (i.e. iron and magnesium). Improvement to DO concentrations within the drain system would require additional engineering to introduce oxygen into the water. This could be achieved through the use of baffles on the discharge and weirs in the drain system to oxygenate the water. However, there is a risk that dissolved iron and manganese within the groundwater could immediately oxidise once pumped into surface water and drop out of solution, which bacteria feed upon causing sludge and discolouration of the water. A more thorough review of the water chemistry of the shallow aquifer would be required to confirm this.

While the introduction of groundwater to the drain network would likely dilute the concentration of nutrients it would not reduce the mass of nutrients in the system. When combined with a method to increase the dissolved oxygen concentration of the water the augmentation may prevent the conversion of particulate bound P to DRP. However, it would likely provide for oxidisation of the organic – N to forms that are plant available (i.e. DIN). This would result in concentrations of nitrate-nitrogen being the dominant form of nitrogen in the drain (as is observed in the adjacent Halswell River).

The augmentation of flows in the drain network following the sediment removal has the potential to achieve the outcomes presented in PDP (2013). However, it must be coupled with improvements to land management practices (i.e. on farm management tools – see LEI 2015) to avoid significant recontamination of the drain network. There are concerns that the introduction of groundwater to the drain network only masks the issue of land management and sediment and nutrient loss.

4.5 Recent Activities

It is not known the extent to which the action plan outlined in PDP (2013) has been implemented to date, particularly with reference to the introduction of farm management plans and farmer education. However, the removal of sediment from the main drain upstream of the Pump House to Gammacks Road was undertaken by SDC during April 2015. There was no removal of sediment downstream of the Pump House. Boffa Miskell was present during the dredging process, with a fish recovery operation undertaken during the dredging works. Boffa Miskell has reported the observations of the fish recovery, while SDC collected a series of sediment samples for laboratory analysis (BML, 2015).

It appears that approximately 0.2-0.3 m depth of material was removed from the bed of the drain. The material removed was inspected during a site visit undertaken by the project team on 20 April 2015. The material was characterised in the field as being predominantly fine to medium sand with trace of silt, blue in colour, with organic material interspersed in the dredged spoil. Some spoil was noted as being sandy silt, with traces of clay, blue in colour. The resulting bed material appeared to be sand based. However, at the upper end of the drain near Gammacks Road the bed material appeared to be sand but once disturbed the material immediately below the surface indicated black organic material being present.

It was also noted that small rock weir structures were installed immediately upstream of the Pump House, in the vicinity of the main drain entering the ponding area of the Pump House and the Hudson collector drain inflow point (Plate 6). The purpose of the rock weirs was to assist with sediment accumulation (PDP, 2015). PDP (2015) provided results of composite samples taken from four locations above the weir, separated into three sampling depth ranges (i.e. 0 m - 0.2 m, 0.3 m -0.5 m, and 0.8 m-1.0 m). As the samples from the four sites were combined for laboratory analysis, analysis of spatial differences in sediment quality or the functionality of the weirs cannot be made. However, the data indicated that the top layer (i.e. 0 m – 0.2 m) contained the highest concentration of nutrients, total organic carbon, and organic matter. Therefore, the removal of sediment from the drain has likely removed a high proportion of the organic matter from the drain and associated nutrients.

Plate 6 Pump House pond - rock weirs

Further testing of water and sediment quality should be undertaken to determine the effectiveness of the removal of sediment from the drain. Composite sampling should not be used to characterise sediment quality in the drain as it does not enable site specific characterisation of the sediment to be undertaken. Instead, maintaining a stable monitoring network site for both sediment and water quality is recommended.

5. Recommendations

The following provides some comments/recommendations that may assist to further understand how the drainage system functions, which could inform the future management of the drain system and the discharge to Te Waihora / Lake Ellesmere. These steps could be used to inform the setting of water quality targets associated with the discharge from the drain system to the Lake.

Environmental Monitoring/Investigations

Environmental monitoring and some additional investigations would enable the relationships between inputs and outputs to be better defined. It is recommended that the following are undertaken over the next 12 – 24 months:

- Establish a drain monitoring network to be used to benchmark changes in sediment and water quality as improvements to catchment management are implemented (the monitoring network in Robinson and Meredith (2013) is considered suitable);
- Sample water quality at regular intervals (i.e. monthly) for nutrients (i.e. TN, TKN, DIN (NH_4-N, NO_3-N, NO_2-N), TP, DRP) and DO, and quarterly for organic matter, sediment depth (accumulation), and other constituents (i.e. OM, TOC, Metals including Fe and Mg);
- Investigate areas within the catchment to enhance sediment removal and polishing of water before it reaches the Pump House pond (i.e. areas for wetland creation);
- Investigate quality of shallow groundwater (i.e. <5 m) within the catchment for DIN (NH_4-N, NO_3-N, NO_2-N), DRP, DO, Fe, and Mn;
- Undertake hydraulic testing of the shallow water table and soil infiltration rates;
- Investigate sedimentation rates and determine the potential frequency of sediment removal;
- Undertake catchment runoff modelling to quantify inflow and potential storage volume requirements (residence time in the drain to improve water quality); and
- Investigate improvements for riparian and drain management to improve instream water quality, which may have consequential benefits to instream fauna (see BML, 2015).

Engineering Work/Controls

Engineering works could be undertaken to improve functionality of the drain system, including:

- Undertake maintenance on the Pump House downstream flap valves to prevent recirculation of water;
- Investigate the benefits of installing concrete broad crested weirs to control water and sediment movement into the Pump House pond (i.e. replace rock weirs);
- Undertake preliminary hydraulic design of constructed wetlands in areas identified as suitable to develop as wetland treatment/buffering; and
- Install flow meters on the pumps to quantify volumes of water being discharged (set up with telemetry).

Water Quality Improvements / Management

The following approaches would also enable the catchment water quality to be continually improved and managed. It is recommended that the following measures undertaken within the next five years:

- Implement on-farm management tools (discussed in LEI, 2015) to reduce inflows of nutrients to the drain;
- Set water quality limits/targets for the drain system based on a more thorough understanding of the system that reflect the physical environment of the drain; and
- Provide tool for continuous feedback to the community and stakeholders to communicate the actions and outcomes of the various strategies and monitoring undertaken in the catchment.

6. Summary

Setting of water quality limits is likely to be required before the outcomes of the various management options/strategies have an opportunity to be reflected in monitoring data. It is important to recognise that the drainage system is very different to the spring fed streams, and the water quality outcomes should take this into account. The limits should also focus on continual improvement to discharge water quality and focus on key contaminants of concern, namely phosphorus and nitrogen.

It is noted that the existing drain environment appears to control DIN concentrations at levels that are well below the NRRP guideline values for spring fed lowland streams. However, increasing the DO concentrations to address the higher DRP concentrations (by limiting further conversion of particulate bound P to DRP) is likely to have a consequential effect of increasing DIN concentrations. Minimising increases in DRP load to the lake system is important given that the lake is phosphorus limited. The on-farm management options discussed in LEI (2015) focus on achieving this outcome.

Reducing the influent contaminant mass to the drain system by implementing on-farm management tools and providing for some buffering/filtering of runoff water before it enters the drain was recommended in PDP (2013). If this is not possible, then changes to the functioning of the drain system should be investigated further. However, it is considered that significantly changing the existing chemical balance in the drain by introducing groundwater to dilute concentrations and increase DO concentrations should not be undertaken at this point. It is the quality of the discharge that is considered more important to manage rather than the quality in the drain network (although one affects the other).

7. References

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PDP (2015): Sediment quality of sub-surface sediments within the upper reaches of Osborne Drain. Letter to SDC, Murray England – Strategic Asset Manager, Date 08 January 2015. Reference No: C02363507.

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Appendices

Appendix A – Location Map

Content

Figure 8: Osbornes Drain

Appendix B – Pump House Data

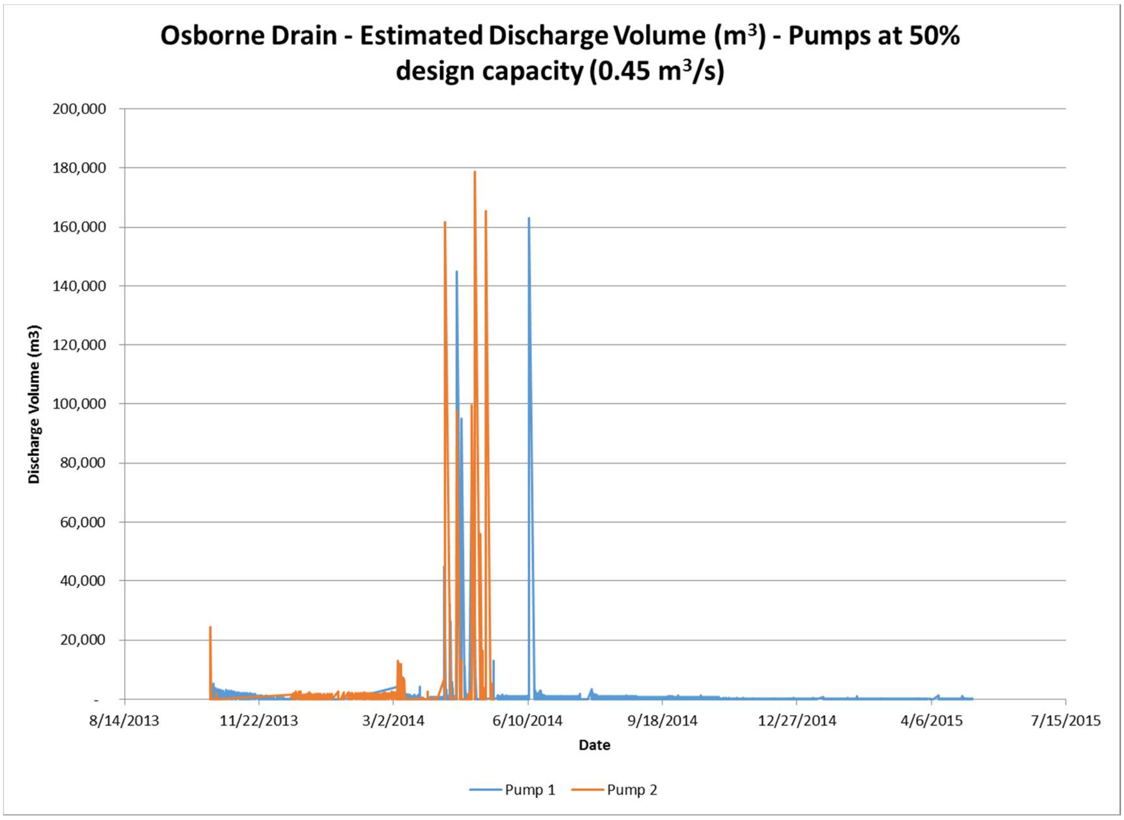

Figure 9 Pump Discharge at 0.45 m^3/s

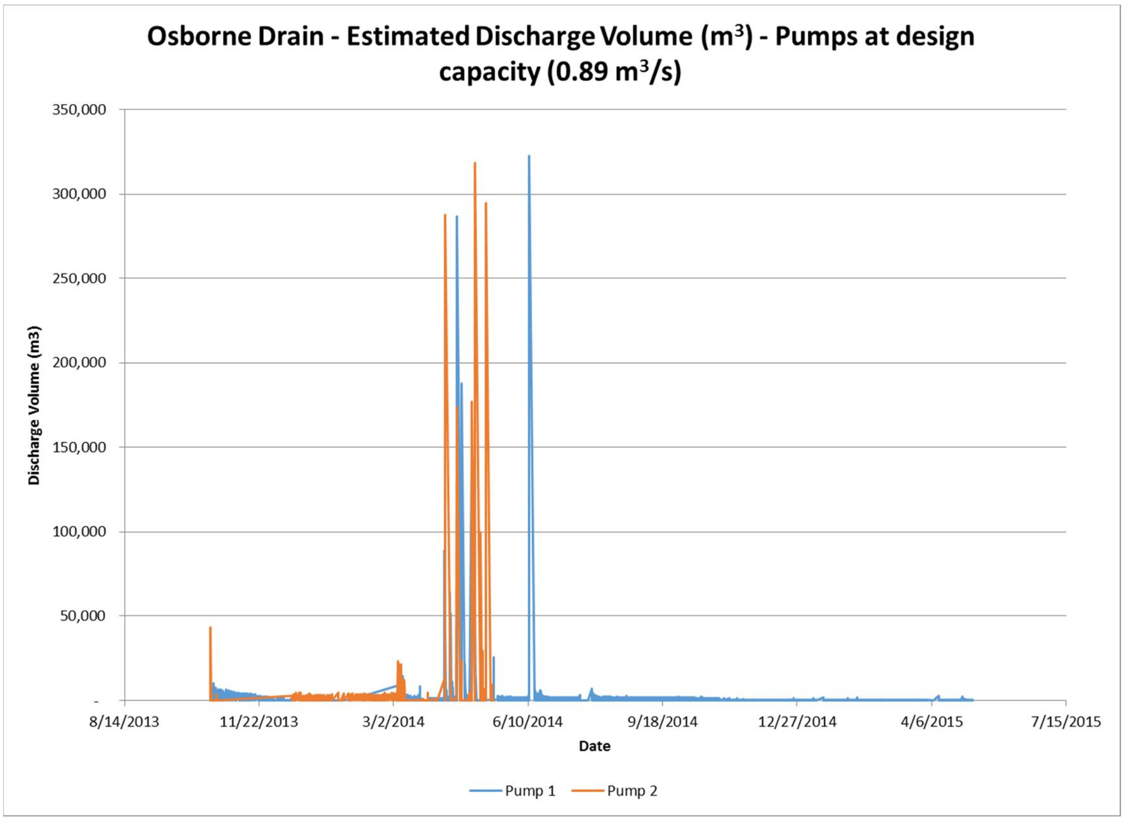

Figure 10 Pump Discharge at 0.89 m^3/s (design capacity)

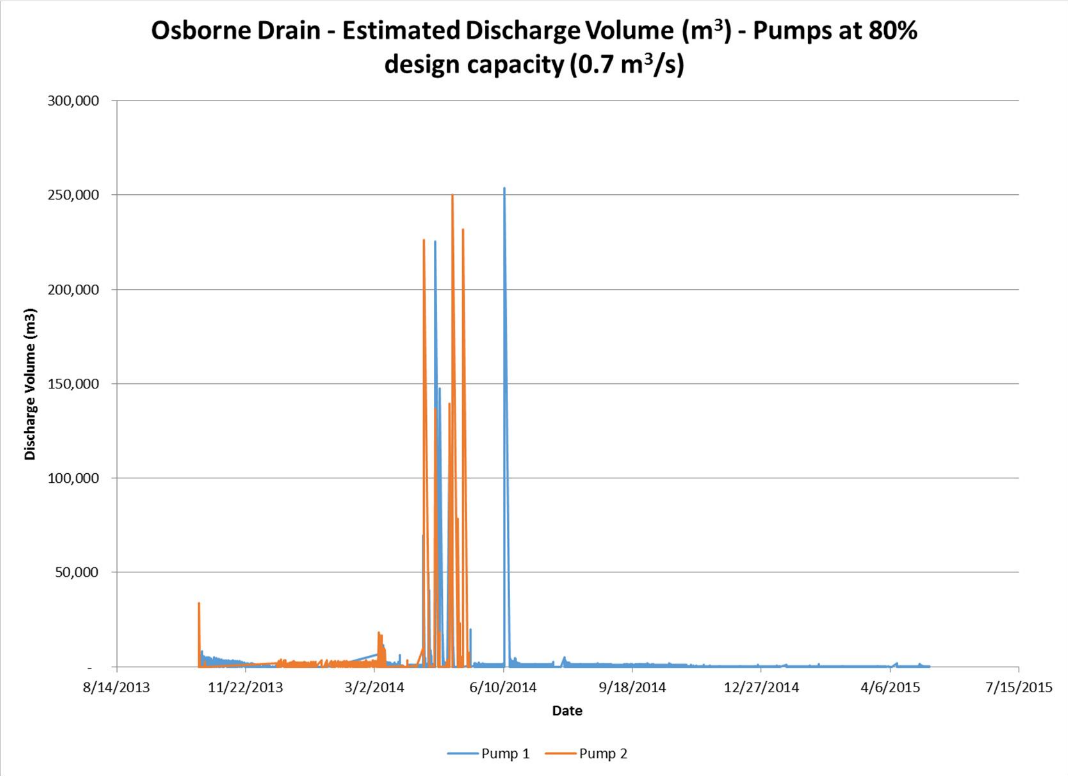

Figure 11 Pump Discharge at 0.7 m^3/s (80% design capacity)

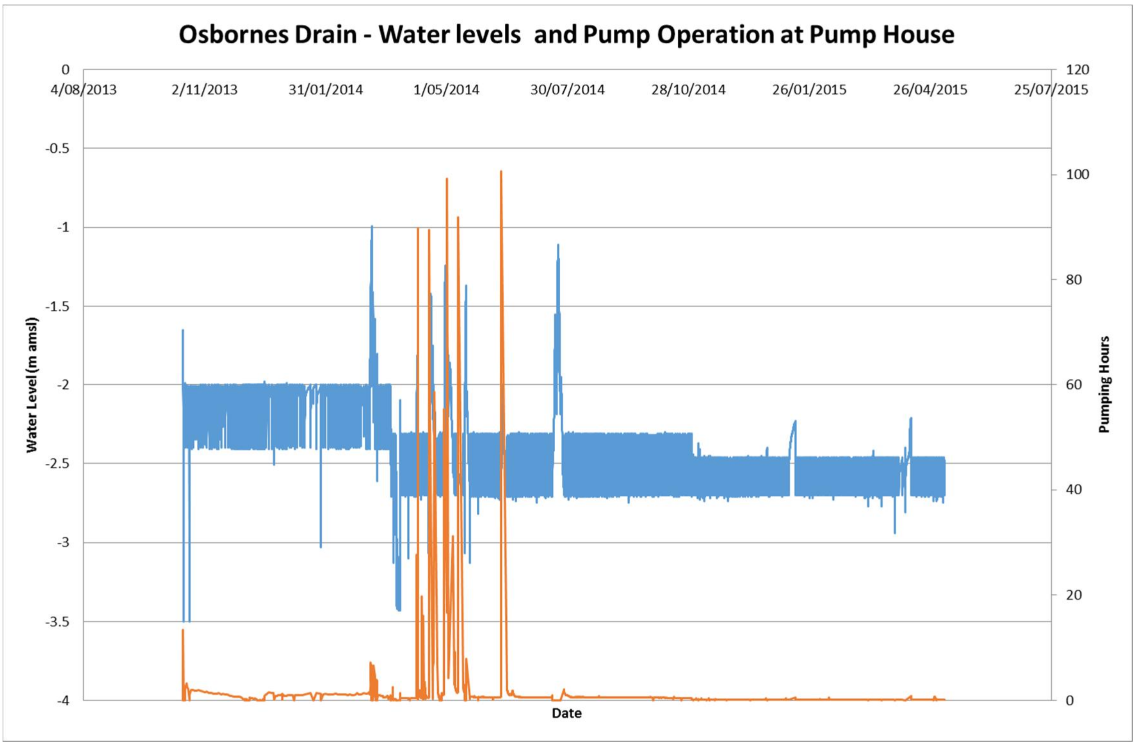

Figure 12 Pump operation and water levels

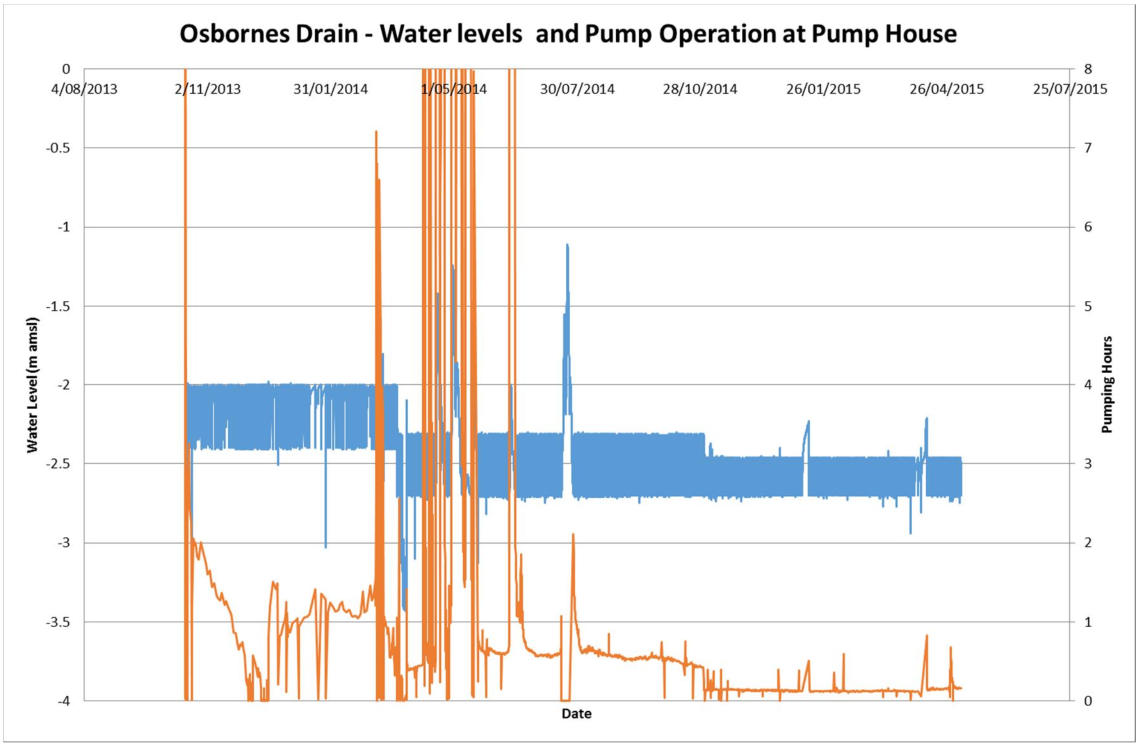

Figure 13 Pump operation (< 8 hours) and water levels

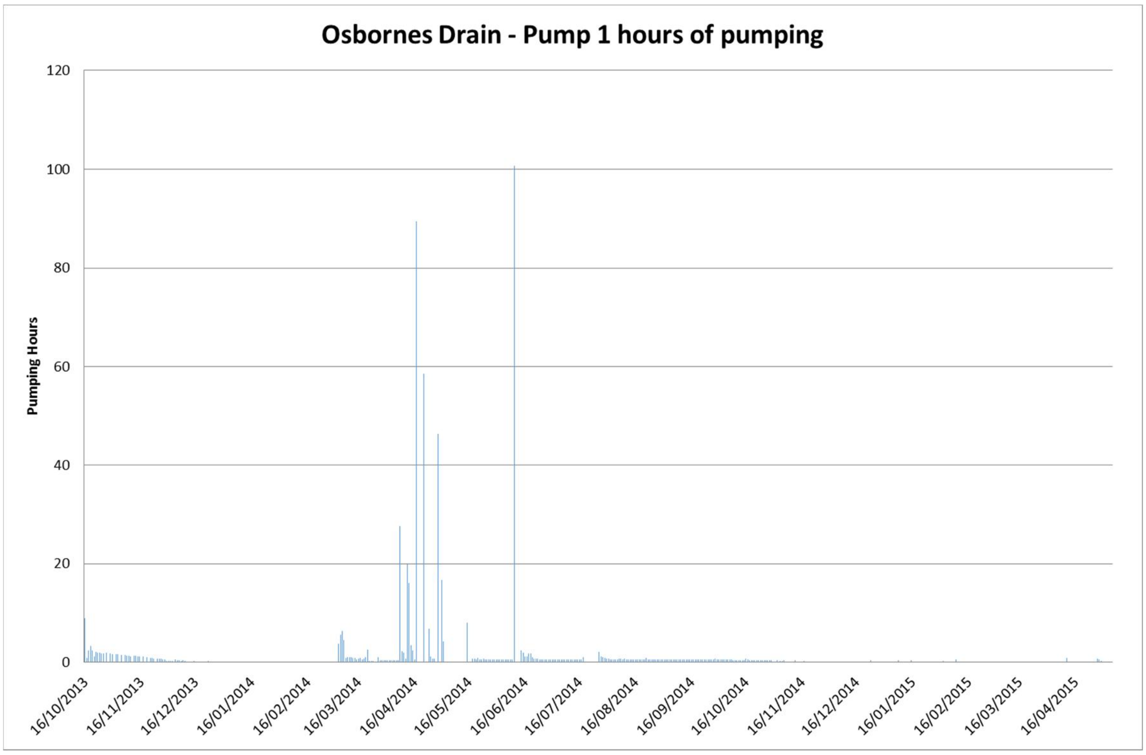

Figure 14 Pump 1 operational hours

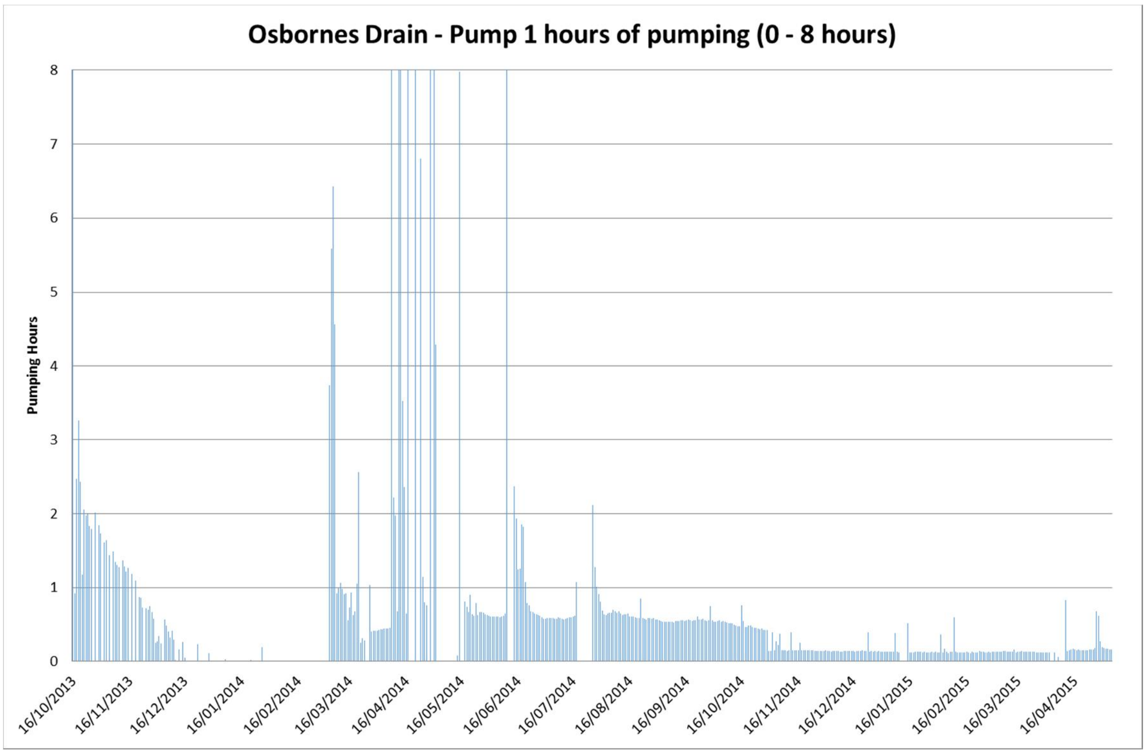

Figure 15 Pump 1 operational hours (< 8 hours)

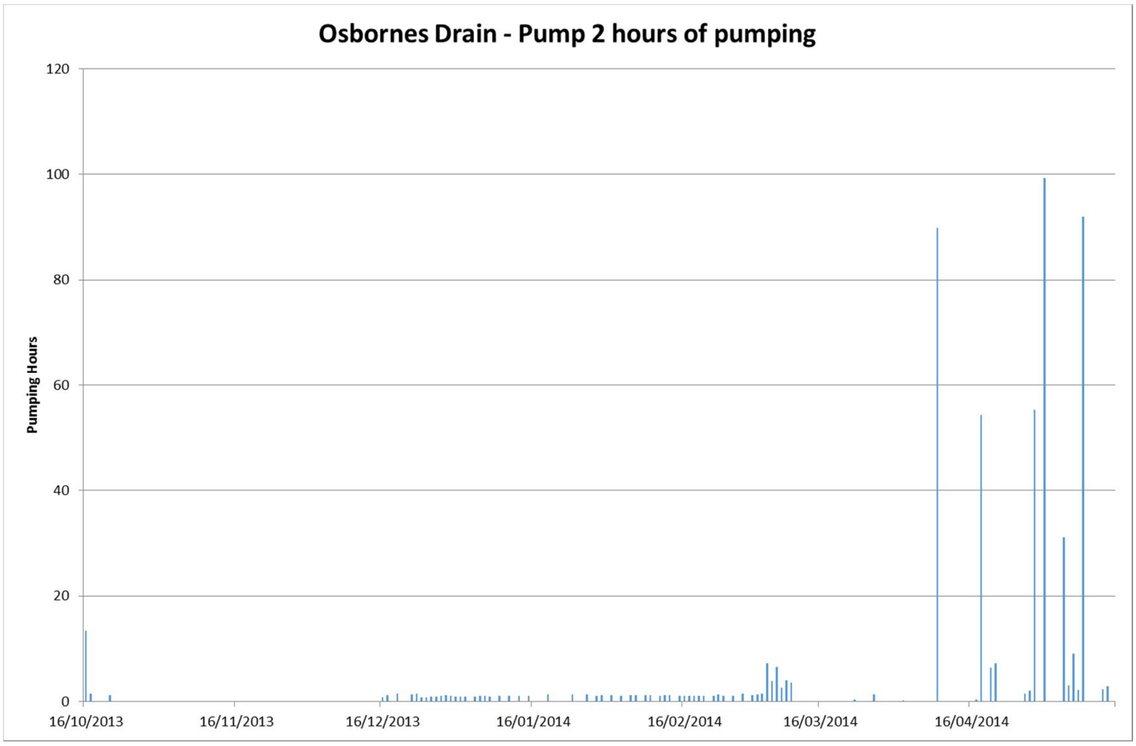

Figure 16 Pump 2 operational hours

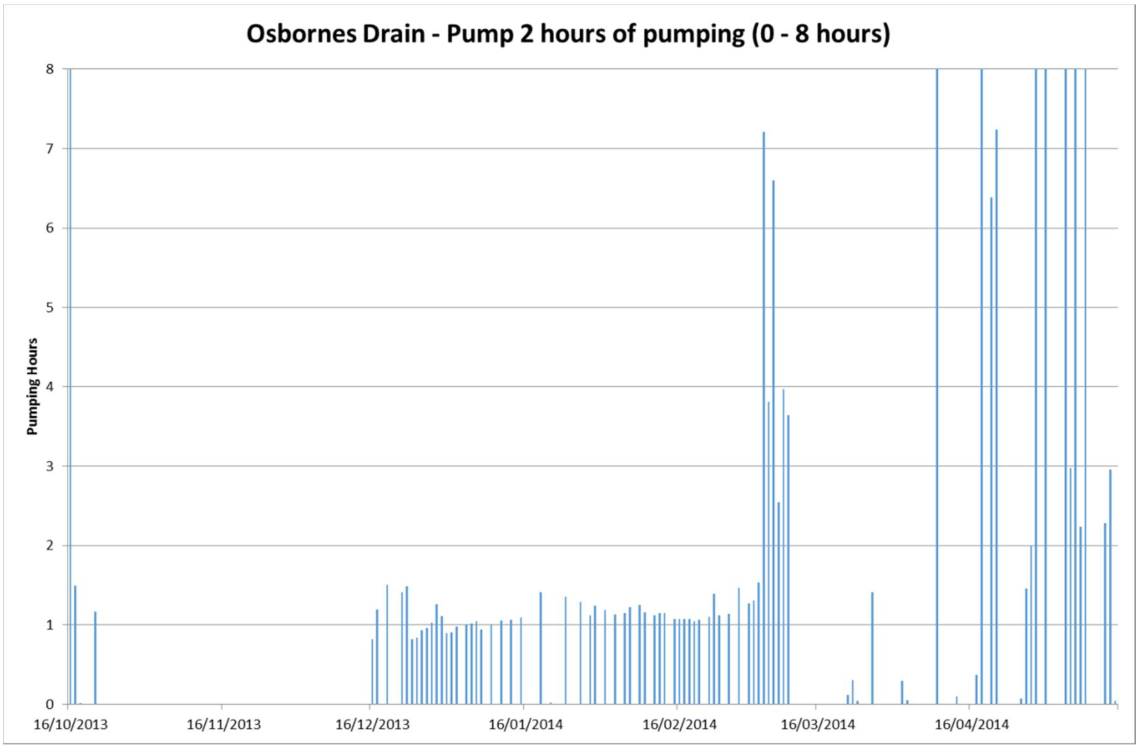

Figure 17 Pump 2 operational hours (< 8 hours)

Appendix C – Review of PDP (2013)

Improvement Measure	Key WQ Indicators	PDP % Change	PDP Recommendation/Comment	GHD Review Comments
Remove sediment from drain upstream of Pump House	Temperature	Minus 20-50%		The effect is largely associated with how the levels in the drain network are maintained (i.e. Pump House operational control levels). Given the incised nature of the drain network, increasing the wetted perimeter of the drain is unlikely to be a significant factor, so the reduction in velocity, turbulence, and the consequential increase in residence time is likely to be over stated. Dredging is likely to result in a lowering of the invert of the drain bed which could affect the longitudinal grade to the Pump House and hence affect flow velocities, water depth, and residence time. However, these effects are likely to be controlled largely by the pumping schedule at the Pump House.
	DO	Short term effect Minus 20%-50%	PDP considered that potential reductions in DO associated with increases in water temperature in drain from the increase in cross-sectional area and reductions in flow, driving biological activity to consume DO could arise.	DO concentrations vary spatially and temporally, with low DO saturation generally observed upstream of the Pump House lagoon area (i.e. <20%), so removal of sediment and associated decaying organic matter could improve DO concentrations immediately. However, a lack of flow through the system combined with a return of instream vegetation/organic matter would generally return DO concentrations to current levels.
	TN and Dissolved N	Limited improvement 0-5%	PDP noted that increased removal of nitrogen would occur if increased sedimentation rates are provided. However, PDP considered that since only 13% of N is in particulate form and that increased sedimentation is unlikely to significantly affect particulate N in the water column, the changes are likely to be small.	Based on the WQ data there is unlikely to be any significant change to dissolved N (NNN) associated with the dredging. There could be a short term increase in concentrations associated with a potential increase in DO following dredging, allowing for the oxidisation of ammoniacal – N. But this is unlikely to remain for long. Organic N comprises the bulk of the nitrogen found in the water samples. We didn't have access to the laboratory data but the summary information presented in ECan (2012) indicates that the filtered N is primarily in organic form associated with decaying organic matter. The removal of organic matter from the drains associated with dredging is likely to have some improvement on Total – N, including the organic component. However, further work to on farm systems would be required to limit a return to the current situation. That said, organic material growing in the drain and on the banks may continue to contribute to organic N content in the drain over time.
	Total P and DRP	Net improvement 30%-50%	PDP noted that increased removal of P would occur if increased sedimentation rates are provided. PDP considered that 47% of P is in particulate form so changes to improve sedimentation occurred (associated with lowering velocities and TSS removal).	Potential for immediate improvement in Total P and DRP associated with removal of P bound to sediments in the drain. P has likely entered drain through land drainage already bound to sediment (i.e. runoff into the drainage system). DRP released under anoxic conditions, so removing the sediment bound P would ultimately reduce DRP concentrations. However, unless runoff from the surrounding land is not managed, sediment bound P will return to the drain and DRP concentrations will increase over time.
	TSS	Good Improvement 50%-75%	PDP considered that the reduction in velocities in the drain would enhance sedimentation and reduce suspended solid concentrations.	TSS in the drain will be dependent on the control of run-off from surrounding land use, stability of the bed and banks of the drain network, and the water level that is maintained at the Pump House. Management of farm runoff will provide some long term benefits to TSS concentrations in the drain, however, during flood events the drain is still likely to experience high TSS.
	Visual Appearance and Odour, including turbidity	Short term improvements in clarity. Short term reduction in odour, increasing over time.	PDP noted that the removal of sediment from the drain would reduce water velocities and improve clarity and over the long term odour issues would improve.	Agree that in the short term the visual clarity would improve as the organic matter in the drain is removed. Odour issues would arise during the dredging process associated with exposing anoxic sediment and organic material to aerobic conditions. Overtime the visual clarity could reduce unless the drain is maintained with regular dredging of organic matter. The frequency of the dredging would depend on the riparian and on farm management.
	Heavy Metals	Minus 20% to zero	PDP noted that if anoxic conditions are removed then the sulphide reducing bacteria would also be removed, resulting in a reduction in the heavy metal removal rates until anoxic conditions returned.	There was limited information in the PDP report to characterise the heavy metal contamination and likely sources in the drain. However, heavy metals typically sorb to sediments (i.e. sands and silts) and under anoxic conditions bacteria will consume certain metals to further reduce concentrations. However, from a dissolved metals perspective the removal of the sediment effectively removes a potential source of contaminants to the lake. Where the material is disposed of does require careful consideration.

Improvement Measure	Key WQ Indicators	PDP % Change	PDP Recommendation/Comment	GHD Review Comments
Base Flow Augmentation	Temperature	Limited Improvement 0%-5%	PDP considered that the introduction of groundwater which has a typical temperature of 13-15 deg. C may have minor improvements in drain water temp during long hot spells. PDP noted that the drain temperature is generally below 13 deg C.	The data reviewed supports the view that groundwater temperatures may be slightly higher than the median and mean values recorded throughout the drain network. However, during the summer periods where inflows are likely to be low (to nil) the water temperatures are likely to be elevated. The introduction of groundwater to augment flows during summer periods would likely address the spikes in temperature, provided that sufficient through flow is maintained. Base flow augmentation therefore could avoid temperature extremes in the drain network.
	DO	Minor improvement 10% -30%	PDP note that with sufficient augmentation stagnation of water within the drain would be addressed and as a result could provide for some minor improvement in the DO concentrations.	DO concentrations in groundwater within the coastal confined aquifer system are typically at or about zero. The aquifer conditions in the Riccarton gravels and deeper are typically reducing with no dissolved oxygen and potential for elevated dissolved metals (iron and manganese) to be introduced to the drain environment. Some aeration of the groundwater at the point of discharge could increase DO concentrations (i.e. use of baffles/aerators) could address this issue.
	TN and Dissolved N	Minor improvement 10% -30%	PDP note that ECan report (Robinson and Meredith, 2013) suggests that groundwater has lower nitrogen concentration than present in the drain, and therefore augmentation would provide some dilution and improvement in nitrogen concentrations.	There is no reference in the ECan report to groundwater quality in the coastal confined aquifer system in this area. However, low NNN concentrations are likely to be present in the aquifers due to low to zero to low DO producing reducing conditions. This is unlike the spring discharge zone which is west of the drain network, which receives shallow groundwater which has been recharged from land surface drainage and contains elevated NNN concentrations and reasonable levels of DO. Groundwater quality from several wells in the catchment confirm low DO, NNN at or below detection limits, and presence of dissolved metals. However, introduction of groundwater containing low NNN would only have a small benefit to reducing nitrogen concentrations in the drain, largely due to the existing low NNN concentrations (mean and median concentrations <0.3-0.6 mg/L). Nevertheless, the introduction of low NNN groundwater would dilute Total N concentrations in the drain.
	Total P and DRP	Minor improvement 10% -30%	PDP note that ECan report (Robinson and Meredith, 2013) suggests that groundwater has lower phosphorus concentration than present in the drain, and therefore augmentation would provide some dilution and improvement in phosphorus concentrations.	As above. Groundwater has low DRP despite the low DO concentrations. This is associated with phosphorus loss cycle being largely associated with runoff from the land in the form of sediment bound P, with DRP being released from sediment bound P under low DO conditions in the drain. Therefore, the introduction of groundwater into the drain network would dilute DRP concentrations. However, it would not address the potential ongoing source of DRP which is the sediment in the drain and the land runoff from the surrounding land use.
	TSS	Minor improvement 10% -30%	PDP note that ECan report (Robinson and Meredith, 2013) suggests that groundwater has lower TSS concentration than present in the drain, and therefore augmentation would provide some dilution and improvement in TSS concentrations.	As above. Groundwater is likely to have low TSS but this is not routinely sampled for (i.e. field samples are generally filtered for TSS before laboratory analysis as dissolved fraction is what is typically what is of most interest). As a consequence the augmentation of the drain with groundwater may reduce TSS concentrations in the drain. However, increased velocities in the drain associated with maintaining a constant flow in the drain may keep suspended solids in suspension for longer.
	Visual Appearance and Odour, including turbidity	Minor improvement to odour 10% -30% No improvement to clarity or turbidity (may be negative 20%)	PDP considered that odour would improve as areas within the drain that are anoxic will reduce. However, the increased through flow will reduce residence time and not enable settling of sediment.	Increased flow in the drain could reduce areas where anoxic conditions prevail. However, the groundwater has a low DO concentration so there would need to be aeration of the groundwater discharge to increase DO concentrations throughout the network. This could also be managed through the introduction of weirs or structures that aerates the flow.
	Heavy Metals	Unknown due to lack of data but potential for improvement (10%-30%)	PDP consider that metals are likely to be present in groundwater but at lower concentrations. Therefore, it was considered that augmentation could dilute existing concentrations of heavy metals in the drain network.	There was limited information in PDP (2013) to characterise the heavy metal contamination and likely sources in the drain. However, heavy metals typically sorb to sediments (i.e. sands and silts) and under anoxic conditions bacteria will consume certain metals to further reduce concentrations. However, from a dissolved metals perspective augmentation of drain water with groundwater could introduce iron and magnesium to the drain system, resulting in a potential for iron bacteria to be present in the drain, resulting in a brown staining in the drain. During the site visit there was evidence of iron pan/staining in the shallow soils in a recently cut drain.

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