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23 February 2024

John Perrins
Blue Sky Meats Ltd
729 Woodlands-Morton Mains Rd
MORTON MAINS 9871

Dear John,

RESPONSE TO ENVIRONMENT SOUTHLAND POST LODGEMENT QUESTIONS – BLUE SKY MEATS LAND DISCHARGE OF WASTEWATER AND BIOSOLIDS

1.0 Introduction

Blue Sky Meats Ltd (BSM) currently discharge wastewater from their Morton Mains red meat processing plant onto pastoral land under Environment Southland Resource Consent No. 201191-V1.
Pattle Delamore Partners Ltd (PDP) has provided technical assistance for an application to replace this consent, to irrigate treated wastewater and apply biosolids, which has been lodged with Environment Southland (ES). Stantec New Zealand (Stantec) on behalf of ES have requested clarification on the application. The issues raised refer to soil quality, receiving land availability and groundwater quality data. This letter provides detailed response to these issues highlighted to support the continuation of the consent process.

2.0 Issues 6 and 28 Soil Quality Assessment

Stantec have made the following comments, and requested the following additional information in relation to the soil remediation:

> ***The sodium adsorption ratio (SAR) data provided in Appendix F indicates low 'sodium hazard,' which means that the irrigation water will not cause damage to the soil porosity. If there has been historic damage to soil porosity due to cation exchange between water and the soil, addition of gypsum (or lime) could help (this is to balance the ratio between Na on one hand and Ca and Mg on the other).***
>
> ***The response indicates that the applicant will endeavour to maintain a minimum soil saturated hydraulic conductivity of 6 mm/hr. Conditions 21-24 provide for monitoring of Exchangeable Sodium Percentage (ESP) and hydraulic conductivity on an annual basis during May. The management actions specified in Conditions 23 and 24 are acceptable.***
>
> ***However, our question has not been fully addressed re: how much damage occurred previously and how this will initially be remediated.***

And,

> ***Methods have been provided but no timeframe for how long it will take to reinstate the land so that it can appropriately accept treated wastewater to minimise WQ effects in the groundwater and surface water.***

The technical assessment of environmental effects (AEE) prepared by PDP (2022) in support of the consent lodgement highlighted that previous irrigation of primary treated wastewater to land had caused adverse environmental effects to soil, such as increased pH, increased Olsen P, and increased Na, K, and exchangeable sodium percentage (ESP). This assessment also identified that low infiltration rates were likely a result of high fat, oil, and grease loads, rather than soil dispersion from increases in Na and K. The technical AEE presented recent soil testing where the soils had largely recovered due to improved treated wastewater quality, application of lime, mechanical aeration, and paddock reseeding.

The Land and Water Science Report (LWSR) (2021) was included in the application and provided soil chemistry analysis and measurements of soil infiltration rate at five different monitoring sites in the consent area, one of which was a control site (site 1) used as a stock holding area prior to BSM processing and does not receive treated wastewater irrigation. The 2023 update of this report provides additional information to respond to inquiries about soil quality and chemistry of the site. The following sections summarise soil chemistry monitoring results of the irrigated sites compared to the control section from both the 2023 LWSR's, provided in Appendix A, to demonstrate that the remediation and timeframes for reinstatement have already occurred between 2016 and 2020.

Without access to data prior to the land treatment activity occurring onsite, the question of "how much damage occurred" is best given by considering the monitoring results from land application areas against the control site. Infiltration data from LWSR (2023) has been summarised in Table 1 below during two time periods:

- 2011 – 2016, the first 5 years of record, where the soil infiltration rates were consistently low; and
- 2020 – 2023, the most recent four monitoring rounds, where soil infiltration rates are improved and stable.

Table 1: Summary of Soil Infiltration Results (mm/hr)

	Average	Median	95th Confidence Interval	Sample Size
Impacted Conditions (2011 – 2016)				
Control Area	158.8	138.5	96.8 - 220.9	6
Land Treatment Areas	4.2	3.0	2.0 - 6.3	12
Current Conditions (2020 - 2023)				
Control Area	93.3	94.0	23.5 – 163.0	4
Land Treatment Areas	133.8	99.5	69.6 - 197.9	16

Notes:
1. *95th percentile confidence interval were calculated for the sample using a Student's T distribution.*

This data indicates that during the period 2011 – 2016, the impact of the land treatment activity had reduced the average soil infiltration rates from between 96.8 – 220.9 mm/hr by one to two orders of magnitude, down to 2.0 – 6.3 mm/hr.

In 2017, BSM engaged specialists and began a programme of work to address this issue, which included:

- Wastewater Treatment Plant (WWTP) upgrades to remove fats, oil, and grease;
- Mechanical aeration of the soils;
- Regrassing paddocks;
- Minimising stock on the paddocks;
- Gypsum applications.

Since 2020, soil infiltration rates have been recovered and stable. The above data indicates that during the period 2020 – 2023, the impact of the land treatment activity on soil infiltration rates was negligible, with the average control site infiltration of 23.5 – 163.0 mm/hr being much the same as the average land treatment infiltration of 69.6 – 197.9 mm/hr. Therefore, PDP considers that the timeframe for recovery has occurred, and was approximately 4 years.

Exchangeable sodium percent (ESP) is discussed below as it is used to assess risk associated with cation imbalance. High concentrations of Na and K in the soil profile can cause degradation of soil structure, which in turn affects soil pore space and water movement. Adjusting Australian guidelines of acceptable levels of ESP, considering New Zealand soils are less prone to Na/K dispersion due to humid temperate climate, problems are unlikely if ESP remains below 5 - 6 %.

Table 2 below shows that the land treatment areas do have increased ESP relative to the control site. Average control site ESP is 1.1 %, being significantly lower than the average land treatment ESP of 4.3 – 4.4%. However, average ESP is still below 5%, and therefore unlikely to cause any soil structure issues. With continued land treatment activity, the soil ESP will continue to increase and will need ongoing monitoring and management via fertiliser applications (lime and gypsum) to maintain it below 5%. This is evidenced in the ESP data fluctuations, where ESP rises and then decreases with gypsum applications to within or near optimum range. Therefore, it should be considered that the timeframe for this is ongoing, and the land will only ever temporarily be 'reinstated' to pre-irrigation ESP levels while the land treatment activity is ongoing.

As indicated in the further information request, continued monitoring and management of ESP levels is proposed to be secured by consent conditions which Stantec considered to be acceptable.

Table 2: Summary of Exchangeable Sodium Percentage

	Average	Median	95th Confidence Interval	Sample Size
Control Area	1.1	1.2	1.1 - 1.1	14
Land Treatment Areas	4.3	4.7	4.3 - 4.4	48

Notes:

1. *95th percentile confidence interval were calculated for the sample using a Student's T distribution.*

Please note that ESP is above the optimal range at irrigation site two and is nearing the threshold at site three, that could result in soil structural damage, according to 2023 data. Under proposed condition 23 for BSP's consent site two would require remedial action as ESP is above 5 %.

Soil Olsen P (plant available phosphorus) was adequate at site one and site five. No site is below optimum values for pasture growth (22 mg/L), which is sufficient for the current land use. Sites 2, 3 and 4 were above optimum values for pasture growth (50 mg/L), posing a risk for phosphorus loss to surface water bodies. Site five, having been ploughed, had Olsen P levels within optimum range for pasture growth due to distribution of phosphorus deeper through the soil profile. All irrigated sites had higher Olsen P compared to the control site. This may not recover with the proposed operation, especially if access to third-party land is lost; however, the early implementation of riparian planting between irrigation sites and nearby surface water bodies, will ensure that there is no effect beyond the site boundary.

Soil pH values for 2023 show the soil to be slightly acid to moderately acid. All sites are within the optimal range (5.5 – 6.5) for pastoral land use. From 2022 to 2023, all irrigated sites decreased pH (decreased alkalinity) for all sites except the control site, given all irrigated sites received an application of gypsum.

Total Nitrogen (TN) ranged between 0.43 – 0.53% across the irrigated sites, while the control site was 0.56%. These sites are within the medium range for New Zealand soils, translating to a C:N ration of approximately 12 – 14 and considered an adequate range of mineralisable nitrogen adequate to meet pasture demands.

Therefore, timeframes for reinstatement are varied depending on the parameter being considered. However, the key parameters for receipt of wastewater: hydraulic conductivity and ESP, are fully recovered and subject to ongoing maintenance, respectively. Proposed consent condition will ensure these are maintained throughout the consent, and there are no apparent soil issues that would preclude the proposed land treatment activity.

3.0 Issue 32 Receiving Land Availability

Stantec have requested the following additional information in relation to the third-party owned land:

> ***Please provide detail regarding how the identified risk will be mitigated. For example, are there long term agreements in place with the third parties owning irrigation land, to allow the operation to continue for the proposed consent term (at minimum)? What measures are in place to avoid restriction of access to this land? Are there any contingencies in the event the third party owned land can no longer be used?***

The current agreement between BSM and third-party landowners is informal, with no future certainty of access. It is considered unlikely that BSM will be able to secure any long-term agreements, and that the relationship will only continue while there is mutual benefit.

The proposed consent conditions allow for use of the third-party land during the dry season only to maximise mutual benefit and encourage the informal agreement to continue. During the dry season:

- The third-party farmer will get benefit in pastoral growth from the irrigation and nutrient load.
- BSM can reduce their nutrient loads onto their own land.

However, although the third-party land is a part of the application, the assessed envelope of effects was on the basis that third-party land may not be available into the future. Maximum loading rates are calculated based on BSM owned land receiving all the wastewater and waste solids generated. A key finding in that assessment was that under the no access to third-party land scenario, phosphorus loading would be at an unsustainable level, and a riparian management plan was proposed to manage this and has now been implemented. The requirements for this riparian planting have also been secured by proposed condition 11.

The early implementation of the riparian planting provides resilience to the site if third-party access is lost.

4.0 Issue 65 Groundwater Quality Data

Data for TP at bore MW1D Downgradient is inconsistent. Applicant to check.

ES highlighted Total Phosphorus (TP) data from a groundwater monitoring bore appeared inconsistent. However, the results are correct and TP levels in the deep bore MW1D were high, compared to DRP and TN levels (refer to Hill Laboratory reports, attached). This may be a result of sediment entering the sample.

5.0 Limitations

This document has been prepared by Pattle Delamore Partners Limited (PDP) based on information provided by Blue Sky Meats Ltd and others (not directly contracted by PDP for the work), including Environment Southland. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the document. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

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Yours faithfully

PATTLE DELAMORE PARTNERS LIMITED

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Appendix 1: Soil Monitoring Reports

Blue Sky Meats Morton Mains Plant: Soil Monitoring Report 2021

Dr Lisa Pearson

Land and Water Science Report 2021/18
June 2021

Blue Sky Meats Morton Mains Plant: Soil Monitoring Report 2021

Prepared by
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Table of Contents

List of Figures

List of Tables

1 Introduction

Blue Sky Meats (NZ) Ltd hold a permit under consent number 201191 from Southland Regional Council (Environment Southland) to discharge meat processing and rendering plant wastewater to land via a spray irrigator at their Morton Mains Plant. Current soil monitoring requirements, as stipulated in Condition 13 of the discharge permit state the following:

The consent holder shall monitor soil on the site during the month of May each year as follows:

a) Samples shall be taken from, and the measurements made in, at least three wastewater irrigation sites (two in the Waikiwi soil and one site in the Waikiwi mottled soils), and at least one control site (in an area where effluent is not discharged).

b) Soil samples shall be analysed for the following:
- *Infiltration rate*
- *soil pH*
- *Exchangeable calcium*
- *Exchangeable magnesium*
- *Exchangeable potassium*
- *Exchangeable sodium*
- *Phosphorus (Olsen P)*
- *Cation Exchange Capacity*
- *Total nitrogen concentration*

Analysis shall include the calculation of exchangeable sodium percentage (ESP) values for each sample.

Soil sampling and infiltration measurement was undertaken by Land and Water Science (Dr Lisa Pearson and Michele Rutherford) and AquaTech Environmental Data Collection (Dianne Elliotte) on the 5 May 2021. This report summarises and interprets the soil monitoring data for 2021 for compliance with the conditions of the resource consent. Earlier data from Greenwood (2015; 2017) and Pearson (2018; 2019; 2020) is used for comparison and identification of any trends in the data from previous years.

2 Site Details and Observations

Blue Sky Meats (BSM) is located at 729 Woodlands-Morton Mains Rd, Morton Mains 9871. Soil monitoring was undertaken at previous soil monitoring locations, identified as 'Sites' in Greenwood (2015, 2017) and Pearson (2018, 2019, 2020) (Figure 1). Here we use coloured lines to represent soil sampling transect lines within the site area. Site transects are hereafter designated as 'sites' to maintain consistency with previous monitoring (Greenwood, 2017)[1]. Samples for soil chemistry are collected at 25-30 locations along the length of the transect line and soil infiltration measurements are made at the start, middle, and end of the transect line at each site.

[1] The term 'soil moisture site' (or SM-sites) refer to the 6 soil moisture tapes used by Blue Sky Meats for irrigation scheduling. Soil moisture site numbers are not related to the soil monitoring sites.

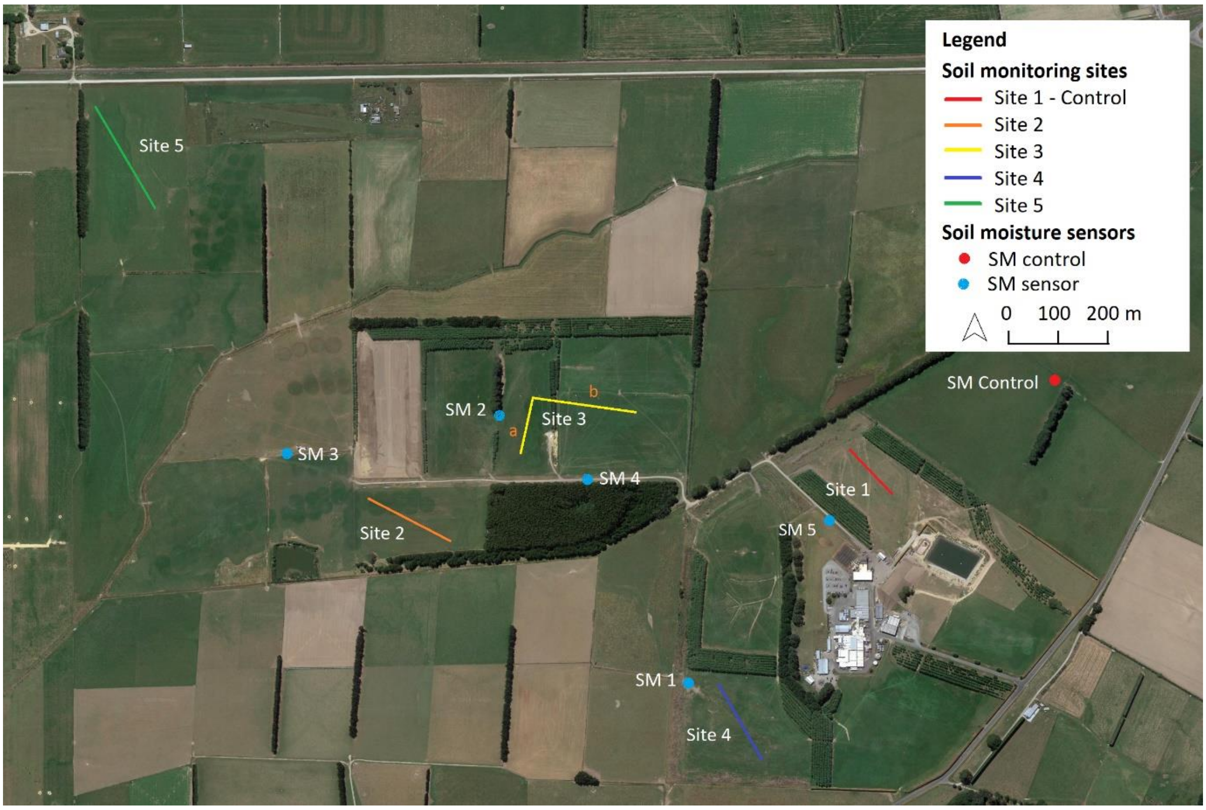

Figure 1: Soil sampling sites at Blue Sky Meats, Morton Mains Plant. Coloured transect lines show where soil samples were taken at the monitoring sites. Where SM Control and SM1 – 5 denote the location of in situ soil moisture (SM) instruments used for irrigation scheduling. Aerial photography is older than the second pond construction.

The control site (Site 1) is located to the north of the processing plant and is typically used as a stock holding area prior to processing. The soil at this site is identified as a Waikiwi deep silt loam which is a Typic Firm Brown soil under the New Zealand Soil Classification (NZSC). At the time of sampling, the paddock had relatively long grass cover and no stock (Figure 2).

Figure 2: Site 1 Control - shows the soil sample transect direction and infiltration test parallel to the pylons.

Sites 2, 3 and 5 are located to the northwest of the processing plant on Waikiwi deep silt loam soils.

Site 2 had long grass coverage which was patchy in places. There was no stock present at the time of sampling, but the paddock had been grazed 3 weeks earlier. The site had received wastewater discharge the day prior to sampling and overnight rain had left the soil saturated (Figure 3). The paddock had been recently aerated with rip lines visible across the land surface. Although wet, the soil maintained good structure and had numerous earthworms.


Figure 3: Site 2 northern end of transect and soil structure.

Site 3 is split across two paddocks, the western paddock (3a Figure 1) had good grass cover and no irrigation pods. Site 3a had been recently aerated. Two infiltration measurements were recorded in this paddock which required careful site selection to avoid the recent aeration rips. The eastern paddock had recently irrigated prior to sampling (3b Figure 1 and 4). Site 3b had patchy grass cover and recent aeration rips were not as obvious in this paddock. Site 3b was noticeably more compact and difficult to get the infiltration ring in the ground.


Figure 4: Site 3b southern end of transect and soil structure.

Site 4 is located to the south of the processing plant (Figure 1) on a Woodlands deep silt loam (Greenwood, 2017). Under the NZSC, Woodlands soils are classified as Mottled Firm Brown soils. This site has permanent irrigation points. There was good grass coverage at the time of sampling and no obvious aeration rips on the surface.

Figure 5: Site 4 southern end of transect and soil structure.

Site 5 located on Waikiwi deep silt loam soils had long grass with good coverage (Figure 6). In some areas near the north of the paddock, grass cover was patchy with minor surface ponding. The soil was slightly more compacted relative to other sites. Aeration rips were present in the paddock and required careful placement of soil infiltration equipment to avoid rips.

Figure 6: Site 5 southern end of transect and soil structure.

2.1 Antecedent Soil Conditions for Infiltration Testing

The rainfall recorded at Blue Sky Meats over the 3-month period prior to soil infiltration rate testing was 205.8 mm of which 9.8 mm was recorded in the week prior to sampling (Figure 7). Rainfall volume 3 months prior to sampling was similar to 2020, therefore soil chemical concentrations are likely comparable between the two sample dates. If rainfall is significantly higher, concentration decreases are likely due to leaching from the soil occurring.

Soil moisture conditions were indicated to be below field capacity at the time of sampling at both BSM and Environment Southland's 'Woodlands at Garvie Road' soil moisture monitoring site which is <5 km west from BSM (Figure 8). The soil at the ES monitoring site is the same soil series as Site 4 at BSM, Woodlands soil series, which is imperfectly drained.

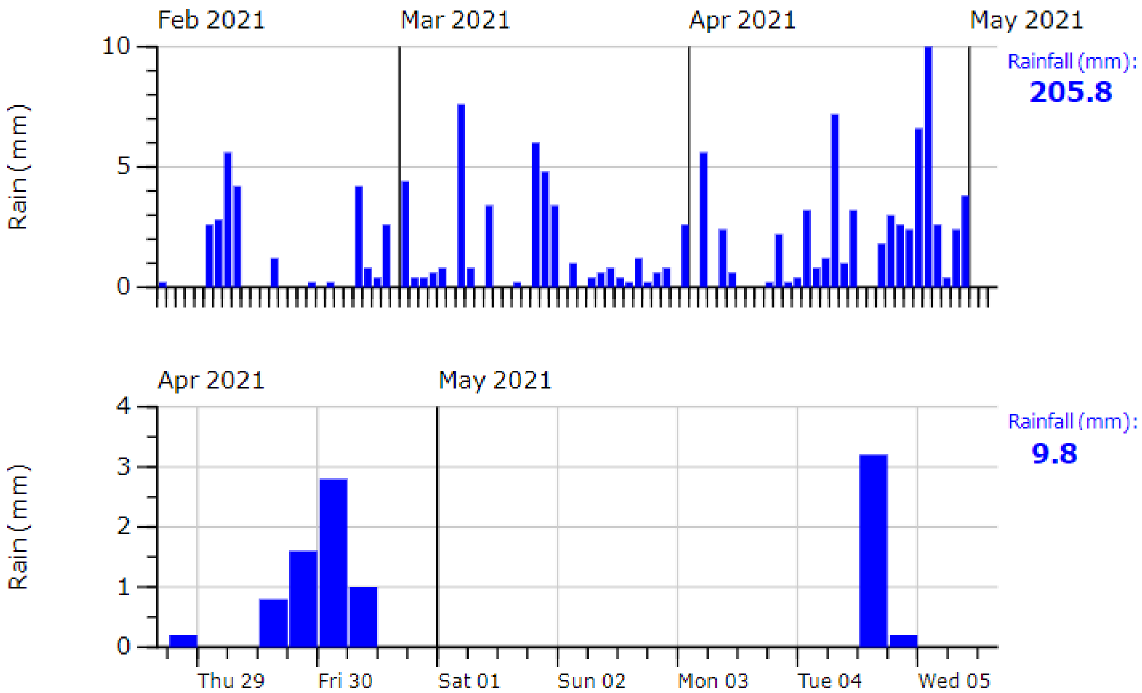

Figure 7: a) Total rainfall at Blue Sky Meats Processing Plant for 3 months prior to sampling and b) 1 week prior to sampling (Data from BSM Harvest system, accessed 7 May 2021).

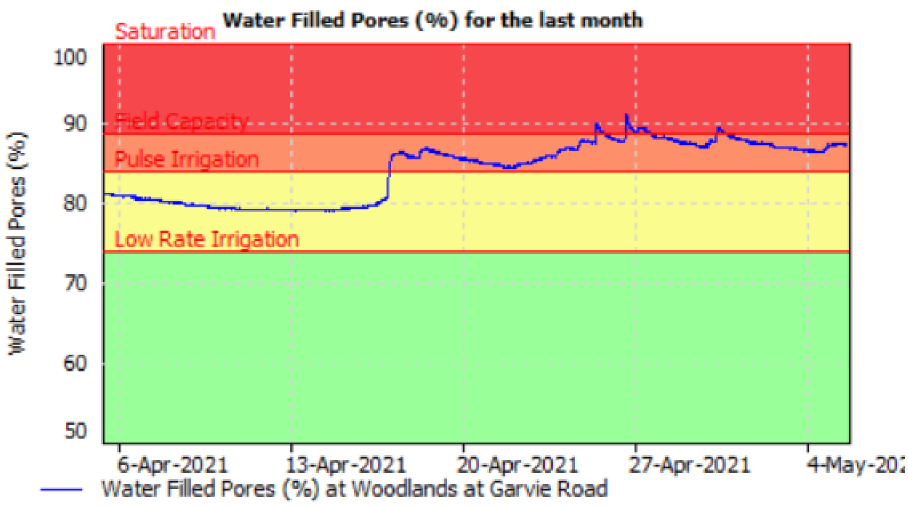

Figure 8: Soil moisture as percent water filled pores at Woodlands at Garvie Road prior to soil testing at Blue Sky Meats Processing Plant (Data sourced from http://gis.es.govt.nz/ accessed 6 May 2021).

There are six soil moisture sensors at the BSM Processing Plant that continuously record soil moisture as a percentage (%) and deficit (in mm). Soil moisture deficit is calculated from field capacity as defined by expert judgement. The location of the sensors and proximity to the soil monitoring sites are shown in Figure 1. The BSM soil moisture as a percentage ranged between 28 and 43% at the time of sampling (Figure 9). The soil moisture deficit at the SM control site was 13 mm (Figure 6). SM Sites 1 to 5 had a soil moisture deficit between 0 - 79 mm (Figure 9). The range in moisture deficit between sites is large and we recommend recalibration, especially for soil moisture site 2. If soil moisture deficits are not correctly calibrated to reflect soil moisture in the irrigation areas, irrigation volumes based on this information are likely to result in overirrigation.

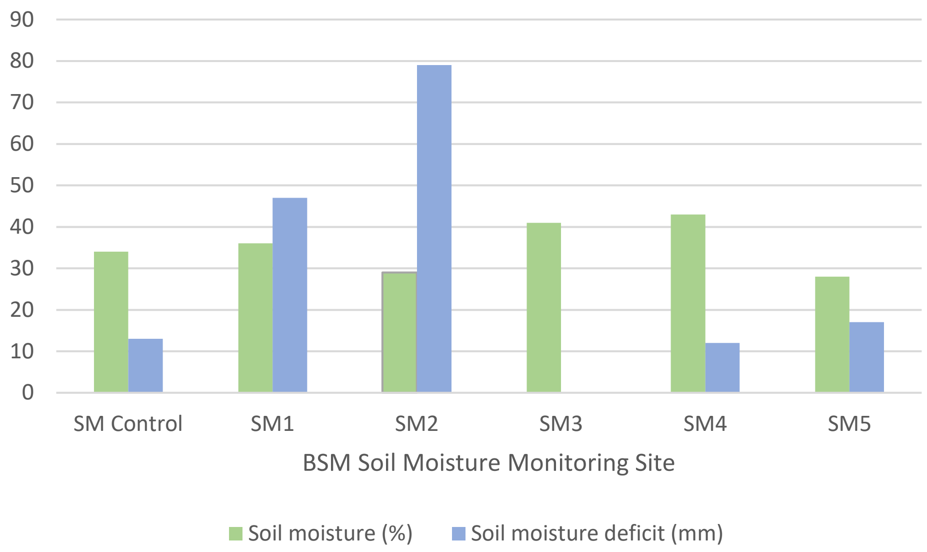

Figure 9: Soil moisture (%) and deficit (mm) from soil moisture sensors at Blue Sky Meats Processing Plant (see Figure 1 for sensor locations). Note sensor numbers are from Blue Sky Meats and are not the same as the soil monitoring sites.

3 Methods

3.1 Infiltration Rate

Soil infiltration rate was measured *in situ* on the 5 May 2021.

Infiltration rates were calculated using the double-ring infiltration method (Figure 10). The rings were inserted into the soil to a minimum depth of 1 cm, ensuring a tight seal with the soil. Both the inner and outer rings were filled with water until they slightly overflowed. A ruler was placed in the centre ring and the water depth recorded. Simultaneously, a timer was set for 15 minutes. After 15 minutes, the water depth remaining was measured, and the volume of water infiltrated calculated. If the soil infiltrated the total volume of water faster than the 15-minute period, the depth of water infiltrated, and time taken to infiltrate was recorded. Three repeat measures were taken at each site, near the start, middle and end of each transect line (Figure 1). The three measurements were used to calculate the mean, median, minimum, and maximum infiltration rate for each site. One measurement at Site 3 was removed due to suspected interference by aeration rips as results were significantly different to the other measurements for the site. The remaining 2 measurements (both in site 3A) were used to calculate the statistics for the site.

Figure 10: Double ring infiltration setup for soil infiltration testing. During use, both rings are filled up with water with only the inner ring measured. The reason for only measuring the inner ring is the outer ring may infiltrate much faster than the inner ring because there will be lateral movement of water around the cutter blade. This action also creates a seal for the inner ring and gives a much more accurate indication of the actual rate of infiltration at the location.

3.2 Soil Chemistry

Soil samples for chemical analysis were collected on the 5 May 2021.

Soil samples were collected at regular intervals along a transect at each site (1 - 5) as identified in Figure 1. Approximately 25 - 30 soil cores (~500 g) were collected to a depth of 7.5 cm from the soil surface and a composite sample per site sent for analysis. The composite soil samples were analysed at Hill Laboratories Ltd for the chemical analytes specified in the consent conditions (see section 1).

4 Results and Discussion

4.1 Infiltration Rate

All wastewater irrigation areas showed decreases in infiltration rate since the last soil monitoring in June 2020 (Figure 11). Soil infiltration rates across the wastewater irrigation areas ranged from 37 mm/hr to 187 mm/hr, with the control site recording 69 mm/hr (Site 1, Table 1). Mean infiltration rates for all sites were recorded as moderate (4-72mm) at site 1 and 4, and rapid (>72 mm/hr) at sites 2, 3, and 5 while individual measures ranged as low as 4mm/hr at Sites 2 and 4 which is considered slow. All sites recorded a large degree of variation across with some areas being saturated and others exhibiting rapid infiltration where the soil aeration was evident. The control site showed the least amount of variation.

As wastewater can have a high organic content, overloading an area can result in blockage of the soil macropores responsible for water transmission, as well as structural damage associated with irrigation of wastewater with a high concentration of monovalent cations (i.e., Na^+ and K^+, discussed further in Section 4.2.3). As the wastewater composition has improved in response to improved wastewater treatment, soil clogging rates are likely low. This is reflected in the improvements in infiltration rate in the last 3 years.

A limitation of *in situ* infiltration measures occurs when soils are at or near field capacity. Under these conditions the ability of the soil to drain is limited. Conversely, if the soils are dry they infiltrate a larger volume of water. Wet soil conditions are an important control over the ability of irrigated wastewater to infiltrate, with a strong seasonal bias towards lower infiltration rates during the cooler months of the year when evapotranspiration rates are low. Determining seasonal and annual average *in situ* infiltration rates would aid in irrigation scheduling.

Table 1: Mean, median, minimum, and maximum soil infiltration rates at the monitoring sites. Soil moisture deficit from Blue Sky Meats closest moisture sensor(s) at time of sampling.

Site	Mean (mm/hr)	Median (mm/hr)	Minimum (mm/hr)	Maximum (mm/hr)	Soil moisture deficit at closest sensor (mm)	Soil Moisture Sensor
1 Control	69	76	36	96	17	5
2	87	96	4	160	79 - 0	2 and 3
3*	100	-	40	160	12 - 79	4 and 2
4	37	28	4	80	47	1
5	187	232	72	257	-	-

* One measurement at site 3 was removed due to suspected interference by aeration rip. Remaining 2 measurements were used to calculate mean for the site.

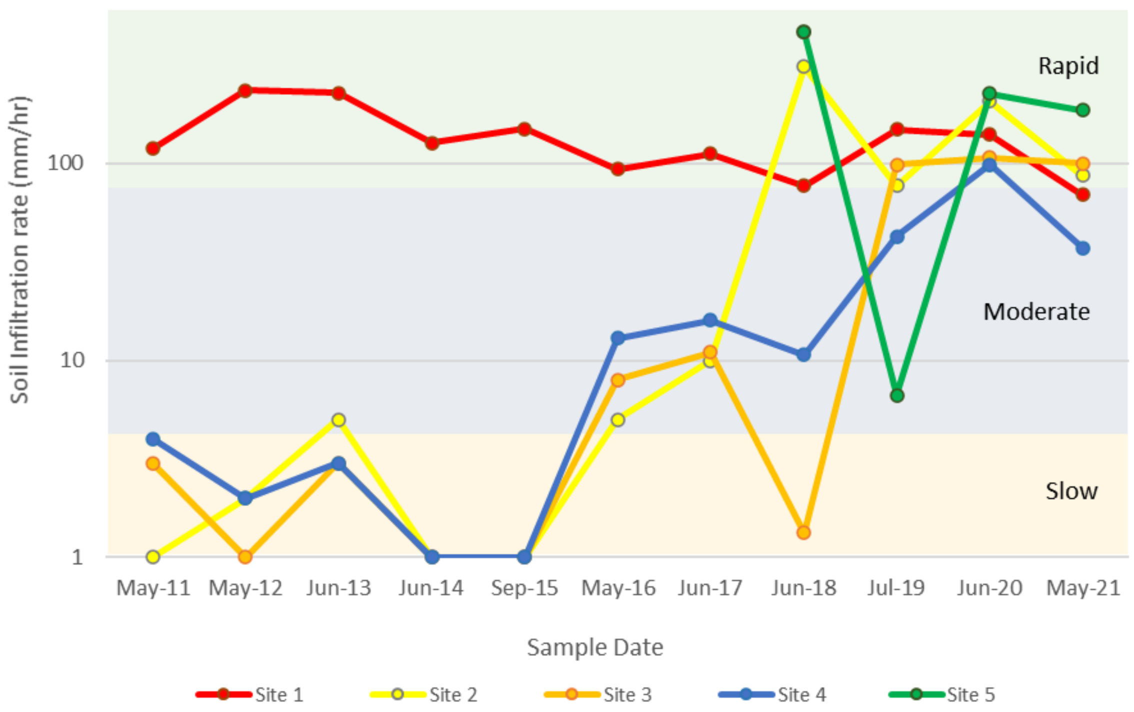

Figure 11: Log_{10} plot of mean infiltration rate at each site between 2011 and 2021. For historic monitoring data see Appendix A.

4.2 Soil Chemical Analysis

The results of the soil chemical analyses for 2021 from Hill Laboratories are provided in Table 2. Exchangeable sodium percent (ESP) was calculated using the milliequivalent (me/100g) sodium concentration divided by the cation exchange capacity (CEC). See Appendix B for Hill Laboratories Certificate of Analysis.

Table 2: Soil chemical analysis including the calculation of exchangeable sodium percent. Ca, Mg, K and Na results are reported as MAF quick test values. Site 1 control is shaded.

	pH	Ca (MAF)	Mg (MAF)	K (MAF)	Na (MAF)	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
Site 1	5.7	7	20	7	8	1.2	18	0.58	26
Site 2	6.2	5	18	21	54	8.1	18	0.51	72
Site 3	5.8	5	18	30	32	4.7	18	0.52	86
Site 4	6.4	7	13	33	49	7.5	17	0.48	52
Site 5	6.2	8	20	17	41	5.9	20	0.59	40

The soil monitoring results have been graphed against previous years monitoring for comparison and identification of any trends in the data and discussed further in the following subsections. See Appendix A for a table of historical results from Greenwood (2017) and Pearson (2018; 2019; 2020). The soil quality indicators for acidity (pH), fertility (Olsen P) and organic resources (Total N) are assessed against Landcare Research's SINDI: Soil Quality Indicators[2] online tool which compares the analytical results against the National Soils Database. Soil pH, Olsen P and Total N have been evaluated for a Brown soil (NZSC) under a dry stock land use. Cation exchange capacity and exchangeable bases are assessed against Blakemore et al. (1981) which provides ratings for the chemical properties of New Zealand soils, and McLaren and Cameron (1996) for soil quick test optimal pasture response.

4.2.1 Soil pH

Soil pH values for 2021 show the soil to be slightly to moderately acid (Blakemore et al., 1981) and are all within the optimal range of 5.5 - 6.5 for a pastoral land use (Landcare Research, SINDI online). Over the monitoring period, soil pH has varied less than 1 pH unit at all sites (Figure 12). The 2021 analysis shows a decrease in pH (increasing acidity) for Site 1 control, while Site 2, 4, and 5 showed an increase in pH (increasing alkalinity), and site 3 recorded no change since sampling in 2020 (Pearson, 2020).

[2] https://sindi.landcareresearch.co.nz/

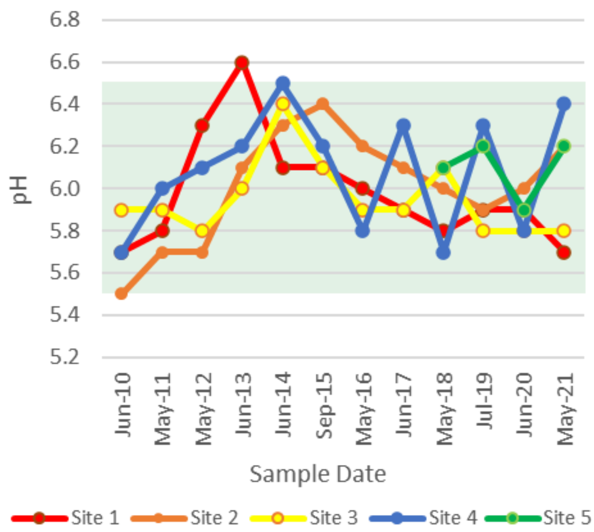

Figure 12: Soil pH results between 2010 and 2021. Green shading shows optimal range according to Landcare Research (SINDI online) for a Brown Soil under dry stock.

4.2.2 Nitrogen (N) and Phosphorus (P)

Total Nitrogen (TN), ranged between 0.48 - 0.59% across the wastewater irrigation sites (Table 2). The control site has a TN value of 0.58% (Table 2). Overall, these sites are all within the medium range for New Zealand soils (Blakemore et al., 1981). This range of mineralisable nitrogen is adequate to meet pasture demand and equates to a C:N ratio of approximately 12 - 14 (Landcare Research, SINDI online). All wastewater discharge sites (Sites 2-5) showed a decrease in TN from the monitoring undertaken in 2020 (Figure 13A; Pearson, 2020).

Soil Olsen P, a measure of the plant available phosphorus, was excessively high at discharge Sites 2 and 3 (72 and 86 mg/l, respectively), and high at discharge site 4 (52 mg/l). These sites all exceed recommended optimum values (Figure 13B). Site 5 is within the adequate range at 40 mg/L (Table 2). The control site also increased in Olsen P suggesting there was likely to be fertiliser applied to this area (and potentially others) during the year. An Olsen P of 26 mg/l is sufficient for the current land use. All sites, including the control, showed an increase in Olsen P from previous years monitoring (Figure 13B, Pearson, 2020). Areas with soil Olsen P values above the optimum have a significant risk of phosphorus leaching to both shallow ground- and surface water bodies. Good management practice is to use soil testing results to guide irrigation loading rates and any additional inputs (i.e., fertiliser).

High soil nutrient levels can be reduced by decreasing the load of nutrient going onto the land by:

- (i) spreading wastewater over a larger area;
- (ii) reducing its concentration in wastewater, and/or;
- (iii) by removing excess nutrient off-site in harvested plant material under a ‘cut and carry’ scenario.

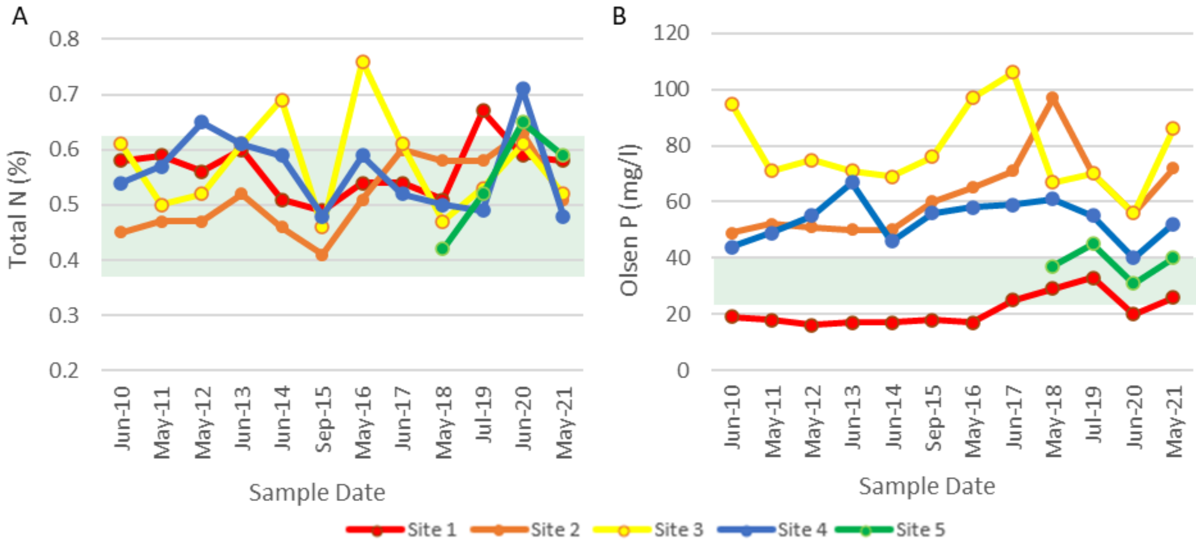

Figure 13: Total N and Olsen P results between 2010 and 2021. Green shading shows adequate range according to Landcare Research (SINDI online) for a Brown soil under dry stock. Values above this range are likely to be in excess of plant demand. There is a significant risk of leaching to waterways with excessive concentrations.

4.2.3 Macronutrients (Ca, Mg, Na, K)

Under normal soil pH conditions there is usually an overall excess of negative charge on the surface of soil particles onto which cations, calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}), are adsorbed. The area and density of exchange sites for cation attraction depends on the type of particles that make up the soil, with the least number of exchange sites on sand particles and the greatest number of exchange sites on clays. The amount of negative charge on clay hydroxy groups or organic matter is dependent on the pH of the surrounding solution, with a higher pH resulting in greater CEC. Cation exchange capacity (CEC) is the measure used to determine how many exchange sites a soil has (typically measured in milliequivalents per 100 grams, or me/100 g). For consistency with historical data from Greenwood (2017) and to demonstrate potential trends in the data, soil quick test MAF values have been presented in Table 2 and Figures 14 and 15. The CEC of the soil at BSM is within the typical range of a sedimentary soil (Figure 14; McLaren and Cameron, 1996).

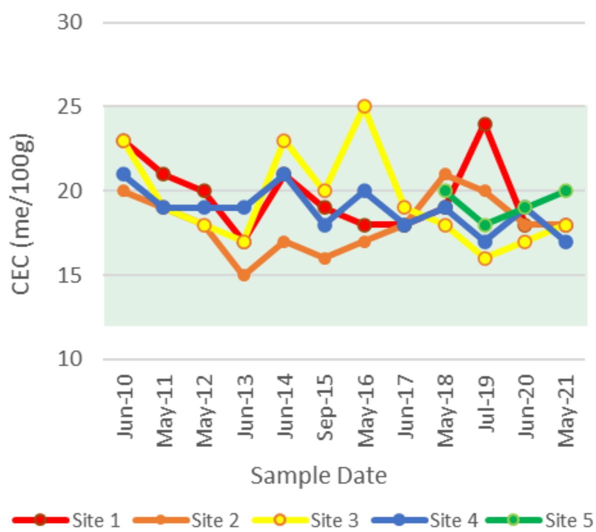

Figure 14: Cation Exchange Capacity (CEC) results between 2010 and 2021. Green shading shows the typical range for a sedimentary soil (McLaren and Cameron, 1996).

As not all the exchange sites of a soil are necessarily occupied by cations, the measure of the occupancy of the exchange sites by Ca, Mg, Na, and K is defined by percentage base saturation (BS) (%). The base saturation and milliequivalent concentrations for Ca, Mg, K and Na are presented in Table 3. Base Saturation is calculated by Hill Laboratories, along with CEC, and is a good way of assessing the balance between the macronutrients. Desirable base saturation levels for an agricultural land use are Ca 50 - 75%, Mg 5 -15%, K 2 - 5% and Na 1 - 2%. Low supply of macronutrients in the soil is likely to affect pasture yield, while oversupply can affect stock health with no pasture yield increase expected.

Table 3 shows the control site has base saturation levels within the range of typical agricultural soils, except for Ca which is lower. The wastewater discharge areas (Sites 2-5) have a higher K and Na base saturation than typical agricultural land, suggesting significant leaching of Ca and Mg. Divalent cations (Ca^{2+} and Mg^{2+}) are generally held more tightly on exchange sites than monovalent cations (K^+ and Na^+), however if monovalent cations are high in soil solution, as is typical in wastewater discharge areas, exchange can occur between K and Na, reducing the Ca and Mg on exchange sites. The leaching of the divalent cations Ca and Mg is a common feature of soils receiving large volumes of waste with elevated Na and K concentrations.

Table 3: Milliequivalent (me/100g) and Base Saturation (BS %) of Ca, Mg, K, and Na.

	Ca		Mg		K		Na		Total BS
	me.100g	BS (%)	me.100g	BS (%)	me.100g	BS (%)	me.100g	BS (%)	(%)
Site 1 (C)	6.8	39	1.15	6.5	0.45	2.6	0.22	1.2	49
Site 2	4.9	28	0.99	5.6	1.29	7.3	1.46	8.2	49
Site 3	4.5	25	0.99	5.4	1.75	9.7	0.85	4.7	44
Site 4	6.5	39	0.67	4	1.91	11.3	1.27	7.5	61
Site 5	8.5	42	1.17	5.8	1.08	5.4	1.17	5.8	59

Blakemore et al. (1981) provides a rating for exchangeable bases for New Zealand soils. This is a good benchmark to rate whether concentrations are naturally elevated at the control site (Site 1) or elevated due to wastewater application. Calcium values for the control site are within the medium range of 5-10 me.100g. The wastewater discharge areas Sites 4 and 5 are also within the medium range for New Zealand soils while Sites 2 and 3 are low (Figure 15A; Blakemore et al., 1981). Magnesium values are also non-limiting to plant uptake and all sites are in the high range for New Zealand soils (Figure 15B; Blakemore et al., 1981). All sites show an increase in Ca and Mg compared to 2020 results (Pearson, 2020). Sodium values are low at the control site (Site 1), and very high (>2 me.100g) at all wastewater discharge sites (Figure 12C; Blakemore et al., 1981). Potassium values are low at the control site (Site 1), high at Site 5 and very high at Sites 2-4 (Figure 15D; Blakemore et al., 1981).

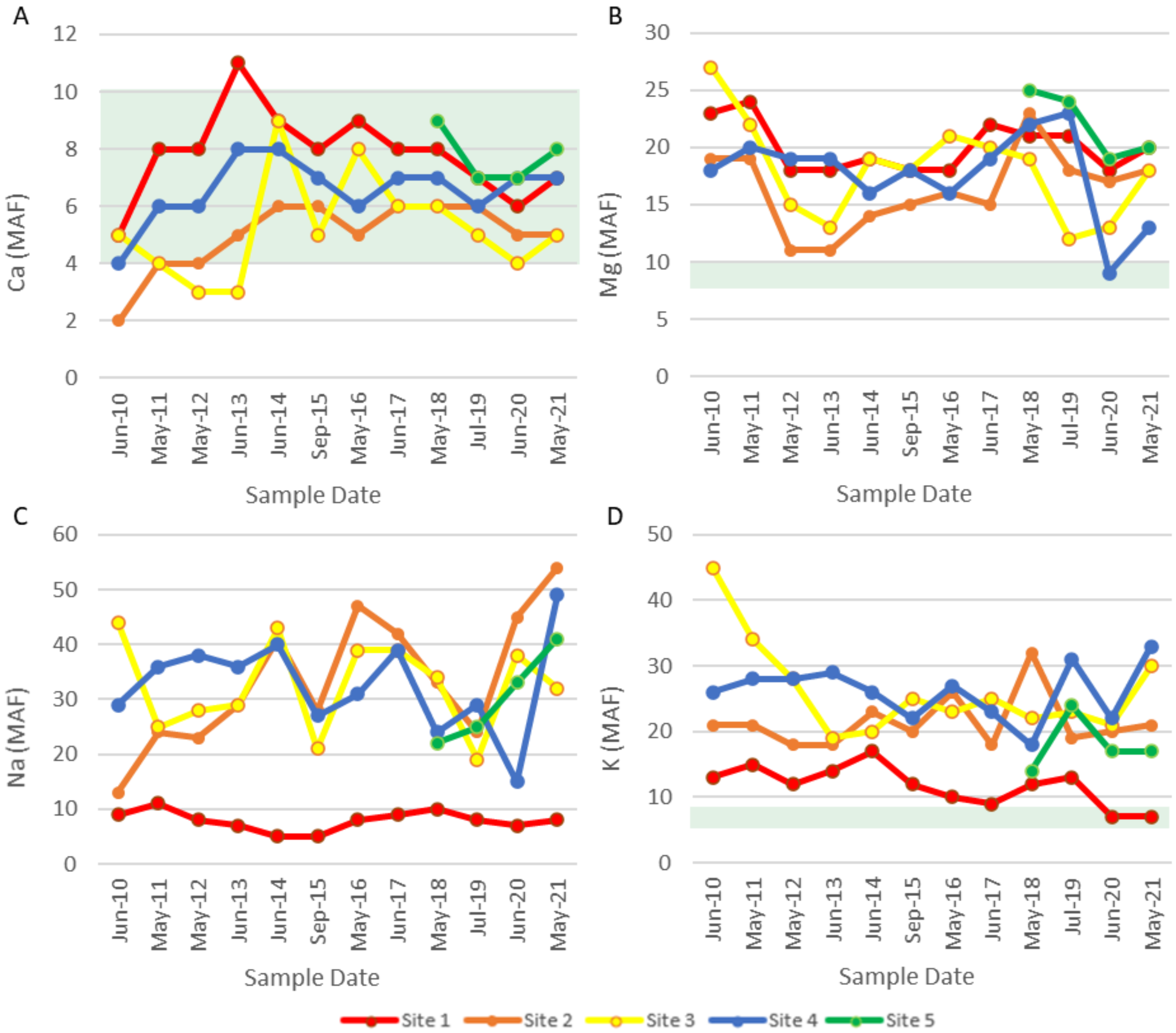

Figure 15: Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K) results between 2010 and 2021. Green shading shows an optimum range for plant growth according to McLaren and Cameron (1996). Values above the optimum range indicate plants are not limited by this macronutrient. Sodium is not required for plant growth, therefore does not have an optimum range for plant uptake (see section 4.2.4).

A significant environmental concern with the discharge of wastewater to land is the accumulation of monovalent cations, Na^+ and K^+ and the loss of divalent Ca^{2+} and Mg^{2+} in the soil profile and the resultant degradation of soil structure, which in turn affects aeration and water movement. Sodium assimilation by plants is low, therefore a management approach to mitigate the effects is often to leach the salt through the soil profile; however, this can have adverse effects on the environment via leaching of other nutrients, such as N and P. Sodium quick test values are elevated at all sites (37 - 54) compared to the control (8) (Table 2). Na concentrations have increased at Sites 1, 2, 4 and 5 and decreased at Site 4 since monitoring in 2020 (Figure 15C, Pearson, 2020). Exchangeable Na percent is used to assess risk and is discussed further in section 4.2.4.

Although plant uptake of K is typically high; plant requirements are often exceeded under typical wastewater applications. This is evident in elevated K quick test values (17 – 33) relative to the control site (7) (Table 2, Figure 15D). K has increased at most sites since the previous year's monitoring (Pearson, 2020). High K values can result in restricted magnesium uptake by plants. Herbage sampling for plant nutrients could be part of the annual monitoring if it was deemed important to ensure pasture and animal health was not under stress, however this is not considered necessary at this time.

4.2.4 Exchangeable Sodium Percent (ESP)

High concentrations of Na (and K) in the soil profile can cause degradation of soil structure, which in turn affects aeration and water movement (McLaren and Cameron, 1996). Most of the work on Na problems in soils has been undertaken in Australia and many of the guidelines are Australian based. New Zealand soils are generally less prone to Na/K dispersion problems than Australian soils because our humid temperate climate generally promotes leaching of soils to a degree that minimises accumulation of soluble salts within soil horizons. Therefore, using Australian guidelines can be considered conservative for NZ situations. Typically, problems are very unlikely if ESP remains below 5 - 6%. ESP has increased above optimal range at Sites 2, 4 and 5 and could result in soil structural damage (Figure 16). It is recommended that these concentrations be managed with annual applications of divalent cations, such as lime or gypsum. Given evidence of Ca and Mg leaching dolomite lime is likely to be a good option at Blue Sky Pastures.

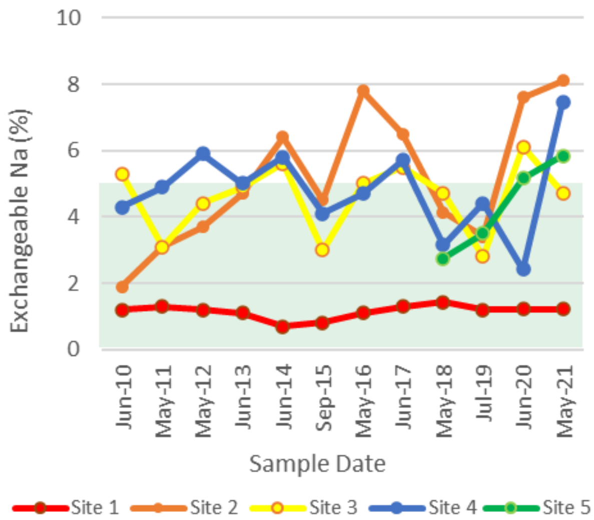

Figure 16: Exchangeable Na (ESP) results between 2010 and 2021.

5 Summary and Recommendations

Accumulation of nutrients in the soil may not harm the soil itself but can impact on plant and animal health and water quality if not appropriately monitored and managed. None of the changes to the soil from long-term irrigation at BSM appear to be detrimental to the long-term functioning of the soil and all are reversible.

Best management practice for managing nutrients in many wastewaters focuses on reducing leaching and runoff losses thereby retaining constituents, such as N and P, within the soil profile where the opportunity for retention by the soil matrix, removal via denitrification and assimilation by plants and microbial biomass is maximised. Excessive Na and K loading can deplete soils of Ca and Mg needed for maintenance of good soil structure and drainage and may also reduce soil pH. Utilising the maximum discharge area for irrigation (lower loading rates) and removal of excess nutrient via cut and carry type operations is the most suitable way of reducing nutrient leaching and preventing Na and K overloading. Regular liming can also prevent the accumulation of monovalent cations in the soil and regulate pH.

Comparisons with monitoring results from 2020 show decreases in soil infiltration at all sites. Olsen P concentrations have also increased at all sites and are at the upper range for optimum at sites 4 and 5, and at excessive concentrations in sites 2 and 3. Similar rainfall volumes were recorded three months prior to sampling this year compared to 2020, therefore the higher concentrations of Na and K are likely due wastewater loading (Pearson, 2020).

Irrigation rates should be regularly adjusted to account for soil infiltration rates, precipitation, and soil moisture conditions. Exceeding field capacity or irrigating on soils already above field capacity elevates the potential for surface ponding and runoff to occur to waterways. Soil moisture sensors at BSM are set to show a soil moisture deficit, which should be adjusted regularly according to field capacity assessments at the wastewater discharge sites. In addition, the hydraulic and organic loading of the wastewater applied should be regularly assessed to determine appropriate loading rates and irrigation return times for the discharge sites. Overloading the soil blocks pore space and is likely to result in in anaerobic soil conditions, ponding, and a reduction in the capacity of the soil to effectively treat the wastewater. This is likely to be occurring at Site 3 and recent aeration of the soil hasn’t resulted in any significant improvement from 2020. Ensuring application across the full irrigation area is recommended to avoid over saturating and loading soil. It is recommend that lime or gypsum is applied to lower the current soil sodium concentrations, which are above recommended guidelines.

6 References

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Appendix A: Historic Monitoring Data

Table A1: Soil infiltration rate measurements from Greenwood (2017) and Pearson (2018-2020). Results from 2021 are included for each site in bold.

	Site 1 - Control	Site 2	Site 3	Site 4	Site 5
May-11	119	1	3	4	
May-12	235	2	1	2	
Jun-13	228	5	3	3	
Jun-14	127	<1	<1	<1	
Sep-15	150	<1	<1	<1	
May-16	94	5	8	13	
Jun-17	112	10	11	16	
Jun-18	77	311	1	11	464
Jul-19	149	77	99	43	7
Jun-20	140	208	107	99	227
May-21	**69**	**87**	**100**	**37**	**187**

Table A2: Soil chemistry data from Greenwood (2017) and Pearson (2018-2020). Results from 2021 are included for each site in bold.

		pH	Ca	Mg	K	Na	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
Site 1	Jun-10	5.7	5	23	13	9	1.2	23	0.58	19
Control	May-11	5.8	8	24	15	11	1.3	21	0.59	18
	May-12	6.3	8	18	12	8	1.2	20	0.56	16
	Jun-13	6.6	11	18	14	7	1.1	17	0.60	17
	Jun-14	6.1	9	19	17	5	0.7	21	0.51	17
	Sep-15	6.1	8	18	12	5	0.8	19	0.49	18
	May-16	6.0	9	18	10	8	1.1	18	0.54	17
	Jun-17	5.9	8	22	9	9	1.3	18	0.54	25
	May-18	5.8	8	21	12	10	1.4	19	0.51	29
	Jul-19	5.9	7	21	13	8	1.2	24	0.67	33
	Jun-20	5.9	6	18	7	7	1.2	18	0.59	20
	May-21	**5.7**	**7**	**20**	**7**	**8**	**1.2**	**18**	**0.58**	**26**
Site 2	Jun-10	5.5	2	19	21	13	1.9	20	0.45	49
	May-11	5.7	4	19	21	24	3.1	19	0.47	52
	May-12	5.7	4	11	18	23	3.7	18	0.47	51
	Jun-13	6.1	5	11	18	29	4.7	15	0.52	50
	Jun-14	6.3	6	14	23	41	6.4	17	0.46	50
	Sep-15	6.4	6	15	20	28	4.5	16	0.41	60
	May-16	6.2	5	16	26	47	7.8	17	0.51	65
	Jun-17	6.1	6	15	18	42	6.5	18	0.60	71
	May-18	6.0	6	23	32	33	4.1	21	0.58	97
	Jul-19	5.9	6	18	19	24	3.4	20	0.58	70
	Jun-20	6.0	5	17	20	45	7.6	18	0.63	56
	May-21	**6.2**	**5**	**18**	**21**	**54**	**8.1**	**18**	**0.51**	**72**
Site 3	Jun-10	5.9	5	27	45	44	5.3	23	0.61	95
	May-11	5.9	4	22	34	25	3.1	19	0.50	71
	May-12	5.8	3	15	28	28	4.4	18	0.52	75
	Jun-13	6.0	3	13	19	29	4.9	17	0.61	71

	Jun-14	6.4	9	19	20	43	5.6	23	0.69	69
	Sep-15	6.1	5	18	25	21	3.0	20	0.46	76
	May-16	5.9	8	21	23	39	5.0	25	0.76	97
	Jun-17	5.9	6	20	25	39	5.5	19	0.61	106
	May-18	6.1	6	19	22	34	4.7	18	0.47	67
	Jul-19	5.8	5	12	23	19	2.8	16	0.53	70
	Jun-20	5.8	4	13	21	38	6.1	17	0.61	56
	May-21	**5.8**	**5**	**18**	**30**	**32**	**4.7**	**18**	**0.52**	**86**
Site 4	Jun-10	5.7	4	18	26	29	4.3	21	0.54	44
	May-11	6.0	6	20	28	36	4.9	19	0.57	49
	May-12	6.1	6	19	28	38	5.9	19	0.65	55
	Jun-13	6.2	8	19	29	36	5.0	19	0.61	67
	Jun-14	6.5	8	16	26	40	5.8	21	0.59	46
	Sep-15	6.2	7	18	22	27	4.1	18	0.48	56
	May-16	5.8	6	16	27	31	4.7	20	0.59	58
	Jun-17	6.3	7	19	23	39	5.7	18	0.52	59
	May-18	5.7	7	22	18	24	3.2	19	0.50	61
	May-18	5.7	7	22	18	24	3.2	19	0.50	61
	Jul-19	6.3	6	23	31	29	4.4	17	0.49	55
	Jun-20	5.8	7	9	22	15	2.4	19	0.71	40
	May-21	**6.4**	**7**	**13**	**33**	**49**	**7.5**	**17**	**0.48**	**52**
Site 5	May-18	6.1	9	25	14	22	2.8	20	0.42	37
	Jul-19	6.2	7	24	24	25	3.5	18	0.52	45
	Jun-20	5.9	7	19	17	33	5.2	19	0.65	31
	May-21	**6.2**	**8**	**20**	**17**	**41**	**5.9**	**20**	**0.59**	**40**

Appendix B: Hill Laboratory Results

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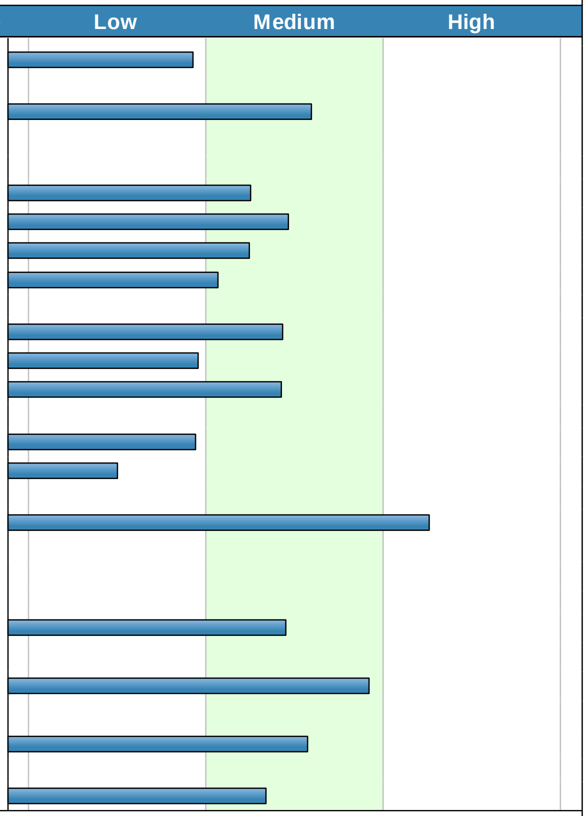
Certificate of Analysis

Client:	Land and Water Science Limited	**Lab No:**	2606092 shvpv1
Address:	90 Layard Street Invercargill 9810	**Date Received:**	07-May-2021
		Date Reported:	17-May-2021
		Quote No:	109755
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: Site 1 Control **Lab Number:** 2606092.1
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range
pH	pH Units	5.7	5.8 - 6.2
Olsen Phosphorus	mg/L	26	20 - 30
Anion Storage Capacity*	%	37	
Potassium	me/100g	0.45	0.40 - 0.60
Calcium	me/100g	6.8	4.0 - 10.0
Magnesium	me/100g	1.15	1.00 - 1.60
Sodium	me/100g	0.22	0.20 - 0.50
CEC	me/100g	18	12 - 25
Total Base Saturation	%	49	50 - 85
Volume Weight	g/mL	0.77	0.60 - 1.00
Sulphate Sulphur	mg/kg	10	10 - 12
Extractable Organic Sulphur*	mg/kg	10	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	276	150 - 250
Anaerobically Mineralisable N*	µg/g	239	
Organic Matter*	%	11.5	7.0 - 17.0
Total Carbon*	%	6.7	
Total Nitrogen*	%	0.58	0.30 - 0.60
C/N Ratio*		11.6	
Anaerobically Mineralisable N/Total N Ratio*	%	4.1	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,004	700 - 1600



Base Saturation %	K 2.6	Ca 39	Mg 6.5	Na 1.2
MAF Units	K 7	Ca 7	Mg 20	Na 8

The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information. IANZ Accreditation does not apply to comments and interpretations, i.e. the 'Range Levels' and subsequent graphs.

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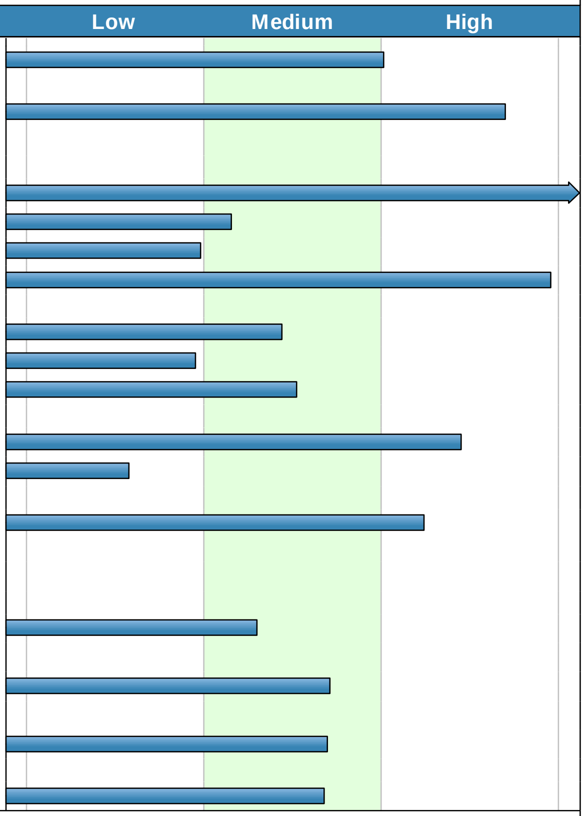
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: Site 2 **Lab Number:** 2606092.2
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range
pH	pH Units	6.2	5.8 - 6.2
Olsen Phosphorus	mg/L	72	20 - 30
Anion Storage Capacity*	%	43	
Potassium	me/100g	1.29	0.40 - 0.60
Calcium	me/100g	4.9	4.0 - 10.0
Magnesium	me/100g	0.99	1.00 - 1.60
Sodium	me/100g	1.46	0.20 - 0.50
CEC	me/100g	18	12 - 25
Total Base Saturation	%	49	50 - 85
Volume Weight	g/mL	0.81	0.60 - 1.00
Sulphate Sulphur	mg/kg	29	10 - 12
Extractable Organic Sulphur*	mg/kg	11	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	274	150 - 250
Anaerobically Mineralisable N*	µg/g	226	
Organic Matter*	%	10.0	7.0 - 17.0
Total Carbon*	%	5.8	
Total Nitrogen*	%	0.51	0.30 - 0.60
C/N Ratio*		11.3	
Anaerobically Mineralisable N/Total N Ratio*	%	4.4	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,311	700 - 1600



Base Saturation %	K 7.3	Ca 28	Mg 5.6	Na 8.2
MAF Units	K 21	Ca 5	Mg 18	Na 54

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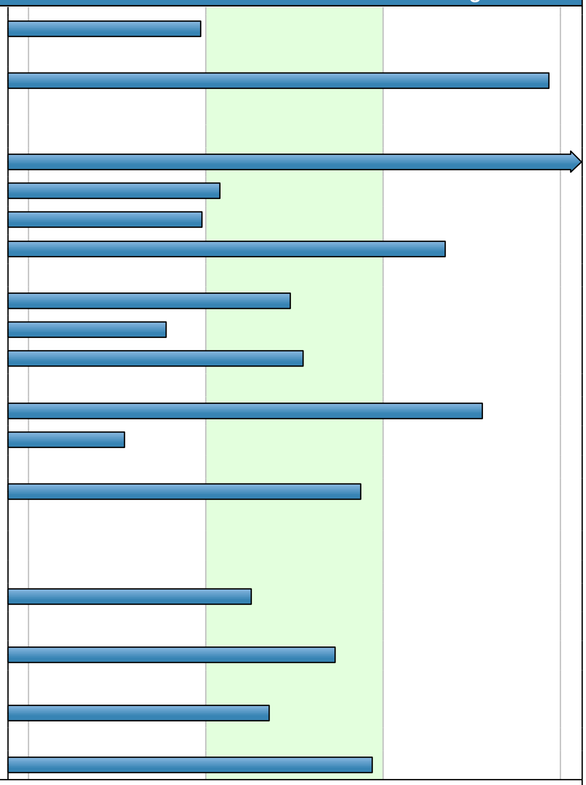
		Quote No:	109755
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: Site 3 **Lab Number:** 2606092.3
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range	Low	Medium	High
pH	pH Units	5.8	5.8 - 6.2			
Olsen Phosphorus	mg/L	86	20 - 30			
Anion Storage Capacity*	%	45				
Potassium	me/100g	1.75	0.40 - 0.60			
Calcium	me/100g	4.5	4.0 - 10.0			
Magnesium	me/100g	0.99	1.00 - 1.60			
Sodium	me/100g	0.85	0.20 - 0.50			
CEC	me/100g	18	12 - 25			
Total Base Saturation	%	44	50 - 85			
Volume Weight	g/mL	0.82	0.60 - 1.00			
Sulphate Sulphur	mg/kg	33	10 - 12			
Extractable Organic Sulphur*	mg/kg	10	15 - 20			
Potentially Available Nitrogen (15cm Depth)*	kg/ha	237	150 - 250			
Anaerobically Mineralisable N*	µg/g	193				
Organic Matter*	%	9.5	7.0 - 17.0			
Total Carbon*	%	5.5				
Total Nitrogen*	%	0.52	0.30 - 0.60			
C/N Ratio*		10.7				
Anaerobically Mineralisable N/Total N Ratio*	%	3.7	3.0 - 5.0			
'Total' Phosphorus	mg/kg	1,545	700 - 1600			
Base Saturation %		K 9.7	Ca 25	Mg 5.4	Na 4.7	
MAF Units		K 30	Ca 5	Mg 18	Na 32	



The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.
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Client:	Land and Water Science Limited	**Lab No:**	2606092	shvpv1
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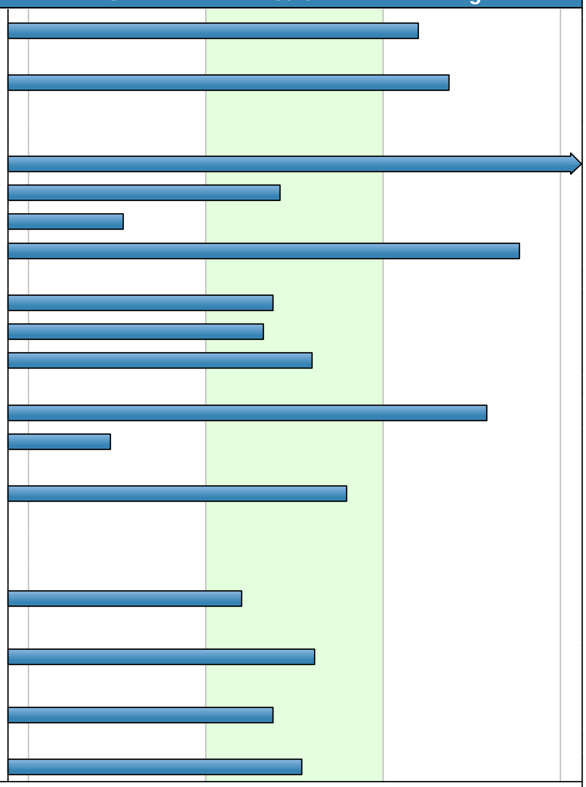
		Date Reported:	17-May-2021	
		Quote No:	109755	
		Order No:		
		Client Reference:		
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson	

Sample Name: Site 4 **Lab Number:** 2606092.4
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range
pH	pH Units	6.4	5.8 - 6.2
Olsen Phosphorus	mg/L	52	20 - 30
Anion Storage Capacity*	%	38	
Potassium	me/100g	1.91	0.40 - 0.60
Calcium	me/100g	6.5	4.0 - 10.0
Magnesium	me/100g	0.67	1.00 - 1.60
Sodium	me/100g	1.27	0.20 - 0.50
CEC	me/100g	17	12 - 25
Total Base Saturation	%	61	50 - 85
Volume Weight	g/mL	0.84	0.60 - 1.00
Sulphate Sulphur	mg/kg	34	10 - 12
Extractable Organic Sulphur*	mg/kg	10	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	230	150 - 250
Anaerobically Mineralisable N*	µg/g	182	
Organic Matter*	%	9.0	7.0 - 17.0
Total Carbon*	%	5.2	
Total Nitrogen*	%	0.48	0.30 - 0.60
C/N Ratio*		10.8	
Anaerobically Mineralisable N/Total N Ratio*	%	3.8	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,186	700 - 1600



Base Saturation %	K 11.3	Ca 39	Mg 4.0	Na 7.5
MAF Units	K 33	Ca 7	Mg 13	Na 49

The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.
IANZ Accreditation does not apply to comments and interpretations, i.e. the 'Range Levels' and subsequent graphs.

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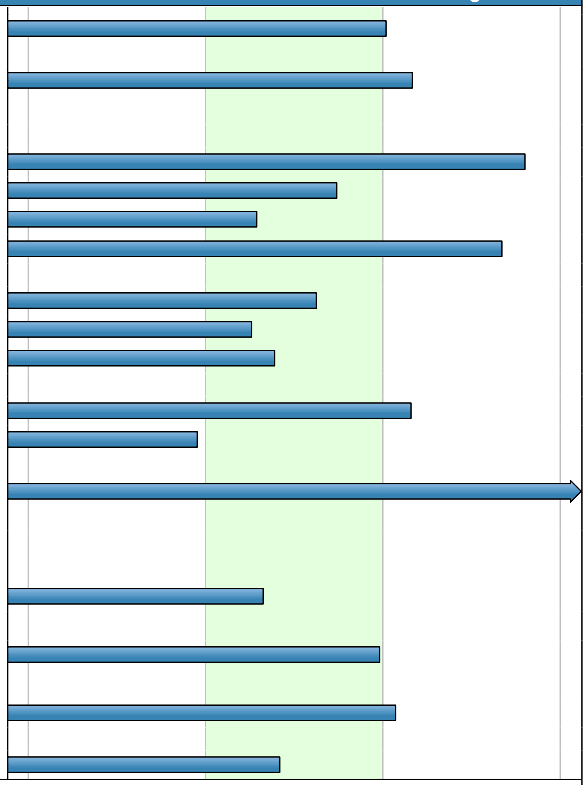
Certificate of Analysis

Client:	Land and Water Science Limited	**Lab No:**	2606092 shvpv1
Address:	90 Layard Street Invercargill 9810	**Date Received:**	07-May-2021
		Date Reported:	17-May-2021
		Quote No:	109755
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: Site 5 **Lab Number:** 2606092.5
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range
pH	pH Units	6.2	5.8 - 6.2
Olsen Phosphorus	mg/L	40	20 - 30
Anion Storage Capacity*	%	46	
Potassium	me/100g	1.08	0.40 - 0.60
Calcium	me/100g	8.5	4.0 - 10.0
Magnesium	me/100g	1.17	1.00 - 1.60
Sodium	me/100g	1.17	0.20 - 0.50
CEC	me/100g	20	12 - 25
Total Base Saturation	%	59	50 - 85
Volume Weight	g/mL	0.76	0.60 - 1.00
Sulphate Sulphur	mg/kg	18	10 - 12
Extractable Organic Sulphur*	mg/kg	15	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	363	150 - 250
Anaerobically Mineralisable N*	µg/g	320	
Organic Matter*	%	10.2	7.0 - 17.0
Total Carbon*	%	5.9	
Total Nitrogen*	%	0.59	0.30 - 0.60
C/N Ratio*		10.0	
Anaerobically Mineralisable N/Total N Ratio*	%	5.4	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,078	700 - 1600



Base Saturation %	K 5.4	Ca 42	Mg 5.8	Na 5.8
MAF Units	K 17	Ca 8	Mg 20	Na 41

The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.
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		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Soil Analysis Results

Sample Name:		Site 1 Control	Site 2	Site 3	Site 4	Site 5	
Lab Number:		2606092.1	2606092.2	2606092.3	2606092.4	2606092.5	
Sample Type:		SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	
Sample Type Code:		S1	S1	S1	S1	S1	
pH	pH Units	5.7	6.2	5.8	6.4	6.2	
Olsen Phosphorus	mg/L	26	72	86	52	40	
Anion Storage Capacity*	%	37	43	45	38	46	
Potassium	me/100g	0.45	1.29	1.75	1.91	1.08	
Potassium	%BS	2.6	7.3	9.7	11.3	5.4	
Potassium	MAF units	7	21	30	33	17	
Calcium	me/100g	6.8	4.9	4.5	6.5	8.5	
Calcium	%BS	39	28	25	39	42	
Calcium	MAF units	7	5	5	7	8	
Magnesium	me/100g	1.15	0.99	0.99	0.67	1.17	
Magnesium	%BS	6.5	5.6	5.4	4.0	5.8	
Magnesium	MAF units	20	18	18	13	20	
Sodium	me/100g	0.22	1.46	0.85	1.27	1.17	
Sodium	%BS	1.2	8.2	4.7	7.5	5.8	
Sodium	MAF units	8	54	32	49	41	
CEC	me/100g	18	18	18	17	20	
Total Base Saturation	%	49	49	44	61	59	
Volume Weight	g/mL	0.77	0.81	0.82	0.84	0.76	
Sulphate Sulphur	mg/kg	10	29	33	34	18	
Extractable Organic Sulphur*	mg/kg	10	11	10	10	15	
Potentially Available Nitrogen (15cm Depth)*	kg/ha	276	274	237	230	363	
Anaerobically Mineralisable N*	µg/g	239	226	193	182	320	
Organic Matter*	%	11.5	10.0	9.5	9.0	10.2	
Total Carbon*	%	6.7	5.8	5.5	5.2	5.9	
Total Nitrogen*	%	0.58	0.51	0.52	0.48	0.59	
C/N Ratio*		11.6	11.3	10.7	10.8	10.0	
Anaerobically Mineralisable N/Total N Ratio*	%	4.1	4.4	3.7	3.8	5.4	
'Total' Phosphorus	mg/kg	1,004	1,311	1,545	1,186	1,078	

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		Date Reported:	17-May-2021
		Quote No:	109755
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Analyst's Comments

Samples 1-9 Comment:
The medium or optimum range guidelines shown in the histogram report relate to sampling protocols as per Hill Laboratories' crop guides and are based on reference values where these are published. Results for samples collected to different depths than those described in the crop guide should be interpreted with caution.
For pastoral soils, the medium ranges are specific for a 75mm sample depth, but if a 150mm sampling depth is used the nutrient levels measured may appear low against these ranges, as nutrients are typically more concentrated in the top of the soil profile. These soil profile differences are altered upon cultivation or contouring.

Samples 1-9 Comment:
While soil Mg MAF levels of 8-10 (0.4 - 0.6 me/100g) are sufficient for pasture production, soil levels of 25-30 (1 - 1.6 me/100g) are required to ensure adequate Mg content in pasture for animal health (greater than 0.22% in the herbage).

Samples 1-9 Comment:
The Potentially Available Nitrogen (kg/ha) test above assumes the sample is taken to a 15 cm depth. If the depth is 7.5 cm, then the result reported above should be divided by two.
To calculate Potentially Available Nitrogen (as kgN/ha) for other sample depths use the reported Anaerobic Mineralisable Nitrogen (AMN) result in the following equation:
AN (kg/ha) = AMN (µg/g) x VW (g/ml) x sample depth (cm) x 0.1
Note that the AN and AMN results reported include the readily available Mineral N (NH4-N and NO3-N) fraction, which is typically quite low.

Samples 1-9 Comment:
Anion Storage Capacity (also known as Phosphate Retention) is an inherent property of the soil type and does not change. Phosphorus and sulphur fertiliser recommendations should take this value into account. Soils may be classified as Low (less than 30%), Medium (30-60%) or High (greater than 60%) ASC.

Samples 1-9 Comment:
The medium range shown describes typical 'Total' Phosphorus levels for mineral soils in New Zealand. The 'Total' P test has not been correlated against pasture growth response rates so should be interpreted along with other observations.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sample Registration*	Samples were registered according to instructions received.	-	1-9
Soil Prep (Dry & Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2mm screen.	-	1-9
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. In-house.	0.1 pH Units	1-9
Olsen Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry. In-house method.	1 mg/L	1-9
Sulphate Sulphur	0.02M Potassium phosphate extraction followed by Ion Chromatography. In-house.	1 mg/kg	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9

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Client:	Land and Water Science Limited	**Lab No:**	2606092 shvpv1
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		Date Reported:	17-May-2021
		Quote No:	109755
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	2 MAF units	1-9
Extractable Organic Sulphur*	Determined by NIR, calibration based on; 0.02M Potassium phosphate extraction. Total extractable S determined by ICP-OES from which the Sulphate-S is subtracted.	2 mg/kg	1-9
Potentially Available Nitrogen*	Determined by NIR, calibration based on Available N by Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample). Note that any Mineral N present is included in the AN/AMN result reported.	1 mg/L	1-9
Anaerobically Mineralisable N*	As for Potentially Available Nitrogen but reported as µg/g.	5 µg/g	1-9
Organic Matter*	Organic Matter is 1.72 x Total Carbon.	0.2 %	1-9
Anion Storage Capacity*	Determined by NIR, calibration based on; Equilibration with 1000 mg/L P solution followed by colorimetric analysis.	10 %	1-9
Total Carbon*	Determined by NIR, calibration based on Total Carbon by Dumas combustion.	0.1 %	1-9
Total Nitrogen*	Determined by NIR, calibration based on Total N by Dumas combustion.	0.04 %	1-9
'Total' Phosphorus	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-OES. (Total recoverable nutrients reported on a dry weight basis) The levels from this method are referred to as 'Totals' in quotation marks, as they will be a slight under-estimation of the true Totals for some elements. In-house.	65 mg/kg	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.01 me/100g	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.5 me/100g	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.04 me/100g	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.05 me/100g	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 %BS	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.2 %BS	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-9
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity. May be overestimated if soil contains high levels of soluble salts or carbonates. In-house.	2 me/100g	1-9
Total Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	5 %	1-9
Volume Weight	The weight/volume ratio of dried, ground soil. In-house.	0.01 g/mL	1-9

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 12-May-2021 and 17-May-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

W. M. Homewood.

Wendy Homewood
Operations Support - Agriculture

Blue Sky Pastures Morton Mains Plant: Soil Monitoring Report 2023

Dr Lisa Pearson

Land and Water Science Report 2023/11
June 2023

Blue Sky Pastures Morton Mains Plant: Soil Monitoring Report 2023

Prepared by
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Table of Contents

List of Figures

List of Tables

1 Introduction

Blue Sky Pastures (NZ) Ltd hold a permit under consent number 201191 from Southland Regional Council (Environment Southland) to discharge meat processing and rendering plant wastewater to land via a spray irrigator at their Morton Mains Plant. This consent is currently undergoing renewal and until finalised soil monitoring requirements, as stipulated in Condition 13 of the existing discharge permit, are required to be undertaken. The requirements state:

The consent holder shall monitor soil on the site during the month of May each year as follows:

a) *Samples shall be taken from, and the measurements made in, at least three wastewater irrigation sites (two in the Waikiwi soil and one site in the Waikiwi mottled soils), and at least one control site (in an area where effluent is not discharged).*

b) *Soil samples shall be analysed for the following:*
   - *Infiltration rate*
   - *soil pH*
   - *Exchangeable calcium*
   - *Exchangeable magnesium*
   - *Exchangeable potassium*
   - *Exchangeable sodium*
   - *Phosphorus (Olsen P)*
   - *Cation Exchange Capacity*
   - *Total nitrogen concentration*

   Analysis shall include the calculation of exchangeable sodium percentage (ESP) values for each sample.

Soil sampling and infiltration measurement was undertaken by Land and Water Science (Dr Lisa Pearson) and AquaTech (Dianne Elliotte) on the 15 May 2023. This report summarises and interprets the soil monitoring data for 2023 for compliance with the conditions of the resource consent. Earlier monitoring data from Greenwood (2015; 2017) and Pearson (2018-2022) is used for comparison and identification of any trends in the data from previous years.

2 Site Details and Observations

Blue Sky Pastures (BSP) is located at 729 Woodlands-Morton Mains Rd, Morton Mains 9871. Soil monitoring was undertaken at previous soil monitoring locations, identified as 'Sites' in Greenwood (2015) (Figure 1). Here we use coloured lines to represent soil sampling transect lines within the site area. Site transects are hereafter designated as 'sites' to maintain consistency with previous monitoring (Greenwood, 2017)[1]. Samples for soil chemistry are collected at 25-30 locations along the length of the transect line and soil infiltration measurements are made at the start, middle, and end of the transect line at each site.

[1] The term 'soil moisture site' (or SM-sites) refer to the 6 soil moisture tapes used by Blue Sky Meats for irrigation scheduling. Soil moisture site numbers are not related to the soil monitoring sites.

Figure 1: Soil sampling sites at Blue Sky Pastures, Morton Mains Plant. Coloured transect lines show where soil samples were taken at the monitoring sites. Where SM Control and SM1 – 5 denote the location of in situ soil moisture (SM) instruments used for irrigation scheduling. Note: Aerial photography is older than the second pond construction.

The control site (Site 1) is located to the north of the processing plant in the Pond paddock and is typically used as a stock holding area prior to processing. The soil at this site is identified as a Waikiwi deep silt loam which is a Typic Firm Brown soil under the New Zealand Soil Classification (NZSC). At the time of sampling, the paddock had moderate grass cover and no stock however sheep had been in paddock prior to sampling (Figure 2). The site also had a pile of aggregate material dumped in the southwest. Care was taken to avoid this area while sampling. No aeration had been undertaken.

Figure 2: Site 1 Control - shows the end of the sample transect and infiltration test parallel to the pylons.

Sites 2, 3 and 5 are located to the northwest of the processing plant on Waikiwi deep silt loam soils. Site 2 is located at BSP Paddock 6 and had long grass coverage with evidence of stock grazing in the paddock. The paddock had some wetter areas underfoot but was otherwise in good condition. The soil had good surficial structure with numerous earthworms. No aeration had been undertaken.

Figure 3: Site 2 northern end of transect. Irrigation is occurring in BSP paddock 1 prior to sampling.

Site 3 is split across two paddocks, the western paddock (3a Figure 1, BSP Paddock 3) had long grass cover with some wet areas indicating recent irrigation. Waste solids from the processing plant had recently been spread on this paddock. Two infiltration measurements were recorded in this paddock. Site 3b (BSP Paddock 1) was irrigated approximately 30 min prior to soil monitoring (see Figure 3). The area where irrigation occurred was avoided for monitoring. The paddock had shorter patchier grass cover and evidence of stock grazing. Site 3b was noticeably more compact than the neighbouring paddock. No aeration had been undertaken in either paddock.

Figure 4: Site 3a (top) and Site 3b (bottom) transect. Core is taken from Site 3b.

Site 4 is located to the south of the processing plant (Figure 1, BSP Cattle Yard) on a Woodlands deep silt loam (Greenwood, 2017). Under the NZSC, Woodlands soils are classified as Mottled Firm Brown soils. This site has permanent irrigation points. There was moderate grass coverage with some doc at the time of sampling and the paddock had not been irrigated for approximately 2 weeks (Figure 5). No aeration had been undertaken.

Figure 5: Site 4 near middle of transect north of irrigation points.

Site 5 located on Waikiwi deep silt loam soils had very long grass with good coverage (Figure 6, Railway Paddock). The paddock had been ploughed and resown since sampling in 2022. Sheep were moved into the paddock at the time of sampling.

Figure 6: Site 5 southern end of transect.

All soil monitoring sites (BSP Paddocks 6, 1, 2, 3, Cattle Yards, and Railway) received an application of gypsm in December 2022 at a rate recommended by the fertiliser supplier. No gypsum was applied at the control site.

2.1 Antecedent Soil Conditions for Infiltration Testing

The rainfall recorded at Blue Sky Pastures over the 3-month period prior to soil infiltration rate testing was 150.2 mm of which 25.4 mm was recorded in the week prior to sampling (Figure 7). The total rainfall volume 3 months prior to sampling was 37 mm less than 2022. If rainfall is significantly higher from year to year, concentration decreases are possible due to leaching from the soil occurring.

Soil moisture conditions were indicated to be below field capacity at the time of sampling according to Environment Southland's 'Woodlands at Garvie Road' soil moisture monitoring site which is <5 km west from BSM (Figure 8). The soil at the ES monitoring site is the same soil series as Site 4 at BSM, Woodlands soil series, which is imperfectly drained. Soil moisture deficit at the site was 30 mm (Figure 9).

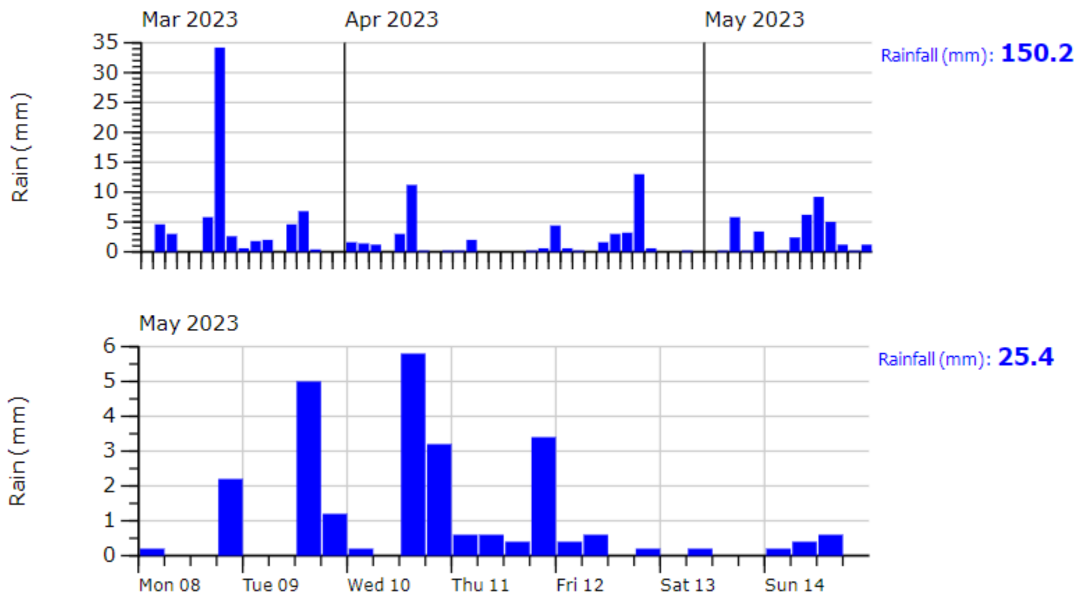

Figure 7: a) Total rainfall at Blue Sky Pastures Processing Plant for 3 months prior to sampling and b) 1 week prior to sampling (Data from BSM Harvest system, accessed 6 June 2023).

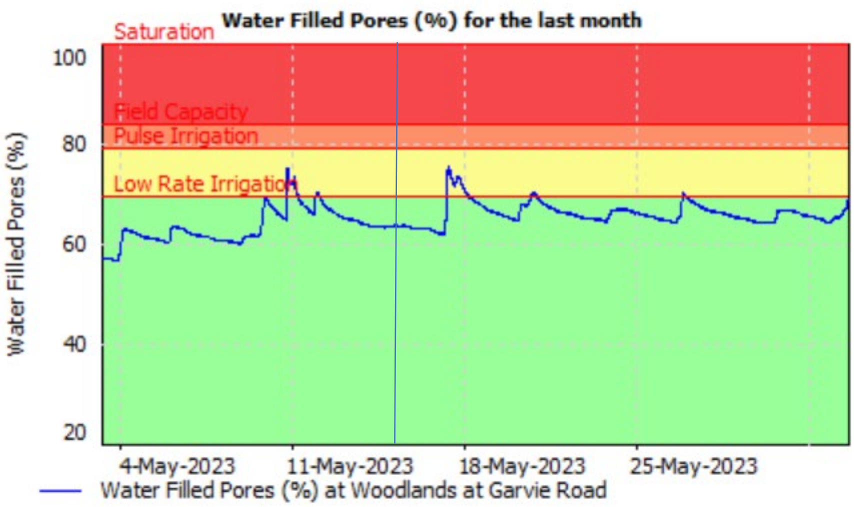

Figure 8: Soil moisture as percent water filled pores at Woodlands at Garvie Road. The date of soil monitoring is indicated by a vertical line (Data sourced from http://gis.es.govt.nz/ accessed 30 May 2023).

There are five soil moisture sensors at the BSM Processing Plant that continuously record soil moisture as a percentage (%) and deficit (in mm). Soil moisture deficit is calculated from field capacity as defined by expert judgement. The location of the sensors and proximity to the soil monitoring sites are shown in Figure 1. The BSM soil moisture as a percentage ranged between 32 and 40% at the time of sampling (Figure 9). There was 3 mm soil moisture deficit at the control site, indicating the soil was close to saturation near the leased land irrigation paddocks. It is recommended that soil moisture deficit be annually adjusted based on soil hydraulic conductivity measurements assessed at least once a year.

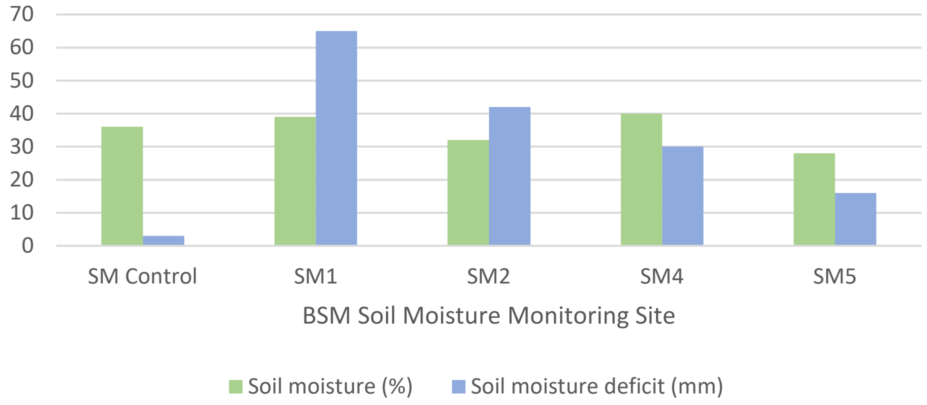

Figure 9: Soil moisture (%) and deficit (mm) from soil moisture sensors at Blue Sky Pastures Processing Plant (see Figure 1 for sensor locations). Note sensor numbers are from Blue Sky Pastures and are not the same as the soil monitoring sites. Soil Moisture sensor 3 is currently not operational.

3 Methods

3.1 Infiltration Rate

Soil infiltration rate was measured *in situ* on the 25th May 2022.

Infiltration rates were calculated using the double-ring infiltration method (Figure 10). The rings were inserted into the soil to a minimum depth of 1 cm, ensuring a tight seal with the soil. Both the inner and outer rings were filled with water until they slightly overflowed. A ruler was placed in the centre ring and the water depth recorded. Simultaneously, a timer was set for 15 minutes. After 15 minutes, the water depth remaining was measured, and the volume of water infiltrated calculated. If the soil infiltrated the total volume of water faster than the 15-minute period, the depth of water infiltrated, and time taken to infiltrate was recorded. Three repeat measures were taken at each site, near the start, middle and end of each transect line (Figure 10). The three measurements were used to calculate the mean, median, minimum, and maximum infiltration rate for each site.

Figure 10: Double ring infiltration setup for soil infiltration testing. During use, both rings are filled up with water with only the inner ring measured. The reason for only measuring the inner ring is the outer ring may infiltrate much faster than the inner ring because there will be lateral movement of water around the cutter blade. This action also creates a seal for the inner ring and gives a much more accurate indication of the actual rate of infiltration at the location.

3.2 Soil Chemistry

Soil samples for chemical analysis were collected on the 15th May 2023.

Soil samples were collected at regular intervals along a transect at each site (1 - 5) as identified in Figure 1. Approximately 25 - 30 soil cores (~500 g) were collected to a depth of 7.5 cm from the soil surface and a composite sample per site sent for analysis. The composite soil samples were analysed at Hill Laboratories Ltd for the chemical analytes specified in the consent conditions (see section 1).

4 Results and Discussion

4.1 Infiltration Rate

All wastewater irrigation areas showed no decline in infiltration rate since the last soil monitoring in May 2022 (Figure 11). Mean soil infiltration rates across the wastewater irrigation areas ranged from 12 mm/hr to 424 mm/hr, with the control site recording 119 mm/hr (Site 1, Table 1). Infiltration rates for all sites, except Site 4, were recorded as rapid (>72mm/hr) which is a significant improvement since 2022. Site 4 infiltration rate was moderate (between 4-72mm) and showed no improvement from monitoring in 2022. Individual measures at Site 4 ranged as low as 4mm/hr which is considered slow.

Table 1: Mean, median, minimum, and maximum soil infiltration rates at the monitoring sites. Soil moisture deficit from Blue Sky Pastures closest moisture sensor(s) at time of sampling. Soil moisture 3 unavailable.

Site	Mean (mm/hr)	Median (mm/hr)	Minimum (mm/hr)	Maximum (mm/hr)	Soil moisture deficit at closest sensor (mm)	Soil Moisture Sensor
1 Control	119	92	20	244	16	5
2	333	288	276	435	30	2 and 3*
3	194	184	64	333	42 - 30	4 and 2
4	12	12	4	20	65	1
5	424	300	271	700	-	3*

As wastewater can have a high organic content, overloading an area can result in blockage of the soil macropores responsible for water transmission, as well as structural damage associated with irrigation of wastewater with a high concentration of monovalent cations (i.e., Na^+ and K^+, discussed further in Section 4.2.3). As the wastewater composition has improved in response to improved wastewater treatment, soil clogging rates are likely low. All sites received an application of gypsum which likely contributed to an increase in infiltration rate from 2022. Site 5 had the largest improvement in infiltration contributed to both ploughing, resowing and gypsum application.

A limitation of *in situ* infiltration measures occurs when soils are at or near field capacity. Under these conditions the ability of the soil to drain is limited. Conversely, if the soils are dry they infiltrate a larger volume of water. Wet soil conditions are an important control over the ability of irrigated wastewater to infiltrate, with a strong seasonal bias towards lower infiltration rates during the cooler months of the year when evapotranspiration rates are low.

Therefore, the increase in soil infiltration is likely to be a result of a dry spring/summer period and the recent gypsum application. To maintain high levels of soil infiltration, regular maintenance of gypsum and long return periods for irrigation is recommended, especially coming into wetter seasons. The proposed conditions under the new discharge permit no longer stipulates an *in situ* method for soil infiltration testing and laboratory controlled infiltration testing will yield more reliable measurements in future. These measurements can also be used to adjust discharge volumes.

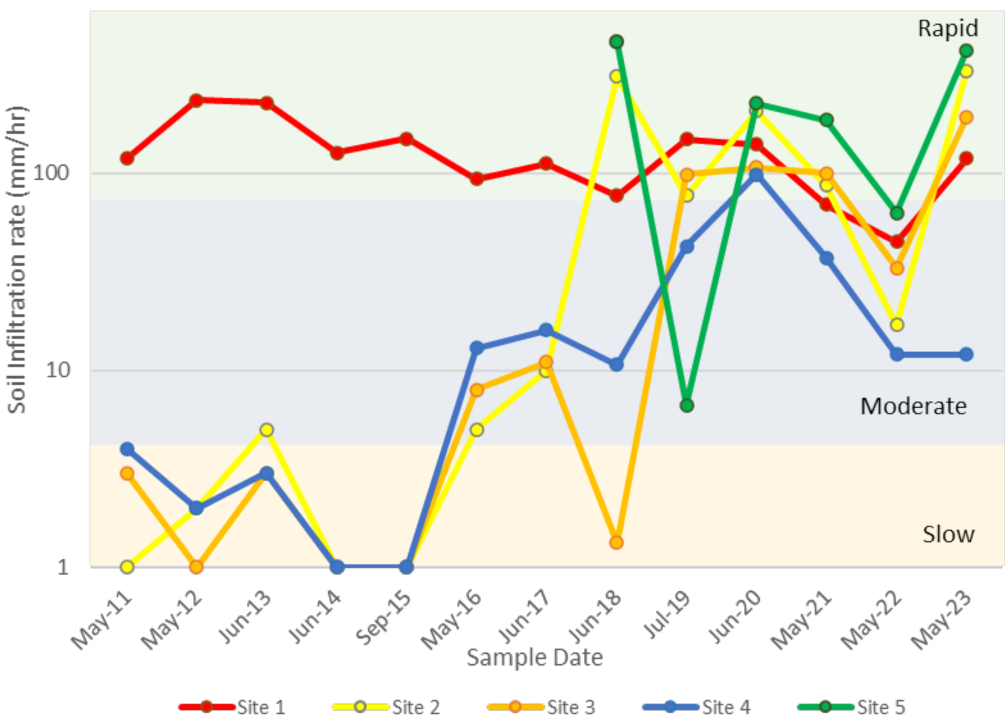

Figure 11: Log_{10} plot of mean infiltration rate at each site between 2011 and 2023. For historic monitoring data see Appendix A.

4.2 Soil Chemical Analysis

The results of the soil chemical analyses for 2023 from Hill Laboratories are provided in Table 2. Exchangeable sodium percent (ESP) was calculated using the milliequivalent (me/100g) sodium concentration divided by the cation exchange capacity (CEC) and expressed as a percentage. See Appendix B for Hill Laboratories Certificate of Analysis.

Table 2: Soil chemical analysis including the calculation of exchangeable sodium percent. Ca, Mg, K and Na results are reported as MAF quick test values. Site 1 control is shaded.

	pH	Ca (MAF)	Mg (MAF)	K (MAF)	Na (MAF)	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
Site 1	5.8	7	21	9	9	1.3	20	0.56	27
Site 2	6.1	7	16	20	38	5.5	20	0.52	76
Site 3	5.9	6	14	24	33	4.9	19	0.53	102
Site 4	6.2	9	14	26	17	2.6	19	0.48	63
Site 5	5.9	9	21	17	22	2.9	18	0.43	42

The soil monitoring results have been graphed against previous years monitoring for comparison and identification of any trends in the data and discussed further in the following subsections. See

Appendix A for a table of historical results from Greenwood (2017) and Pearson (2018-2022). The soil quality indicators for acidity (pH), fertility (Olsen P) and organic resources (Total N) are assessed against Landcare Research's SINDI: Soil Quality Indicators[2] online tool which compares the analytical results against the National Soils Database. Soil pH, Olsen P and Total N have been evaluated for a Brown soil (NZSC) under a dry stock land use. Cation exchange capacity and exchangeable bases are assessed against Blakemore et al. (1981) which provides ratings for the chemical properties of New Zealand soils, and McLaren and Cameron (1996) for soil quick test optimal pasture response.

4.2.1 Soil pH

Soil pH values for 2023 show the soil to be slightly acid to moderately acid (Blakemore et al., 1981). All sites are within the optimal range of 5.5 - 6.5 for a pastoral land use (Landcare Research, SINDI online).

Over the monitoring period, soil pH has ranged between 5.5 and 6.7 at all sites (Figure 12). The 2023 analysis shows a decrease in pH (decreasing alkalinity) for all sites except Site 1, which recorded no change since sampling in 2022 (Pearson, 2021). This decrease in pH is expected given all compliance sites received an application of gypsum.

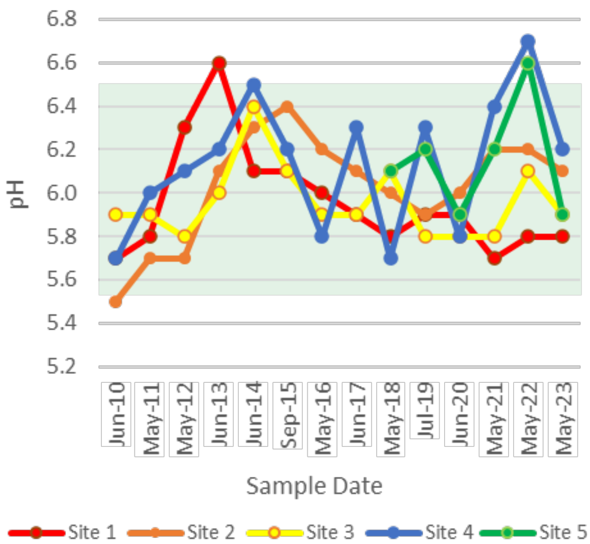

Figure 12: Soil pH results between 2010 and 2023. Green shading shows optimal range according to Landcare Research (SINDI online) for a Brown Soil under dry stock.

4.2.2 Nitrogen (N) and Phosphorus (P)

Total Nitrogen (TN), ranged between 0.43 - 0.53% across the wastewater irrigation sites (Table 2). The control site has a TN value of 0.56% (Table 2). Overall, these sites are all within the medium range for New Zealand soils (Blakemore et al., 1981). This range of mineralisable nitrogen is adequate to meet pasture demand and equates to a C:N ratio of approximately 12 - 14 (Landcare Research, SINDI online). Site 2 and 4 showed an increase in TN from the monitoring undertaken in 2022 (Figure 13A; Pearson, 2021).

Soil Olsen P, a measure of the plant available phosphorus, was adequate at the control Site 1 and Site 5. Soil Olsen P was high at Site 2 and 4 and excessive at Site 3 (Table 2). No site is below optimum values for pasture growth of 22 mg/L which is sufficient for the current land use (Figure

[2] https://sindi.landcareresearch.co.nz/

13B, Table 2). All discharge sites showed no increase in Olsen P from the previous years monitoring (Figure 13B, Pearson, 2022). The reduction in Site 5 was expected given the site was ploughed distributing phosphorus deeper through the soil profile. Areas with soil Olsen P values above the optimum have a significant risk of phosphorus leaching to both shallow ground- and surface water bodies. Good management practice is to use soil testing results to guide irrigation loading rates and any additional inputs (i.e., fertiliser).

High soil nutrient levels can be reduced by decreasing the load of nutrient going onto the land by:

- (i) spreading wastewater over a larger area;
- (ii) reducing its concentration in wastewater, and/or;
- (iii) by removing excess nutrient off-site in harvested plant material under a 'cut and carry' scenario.

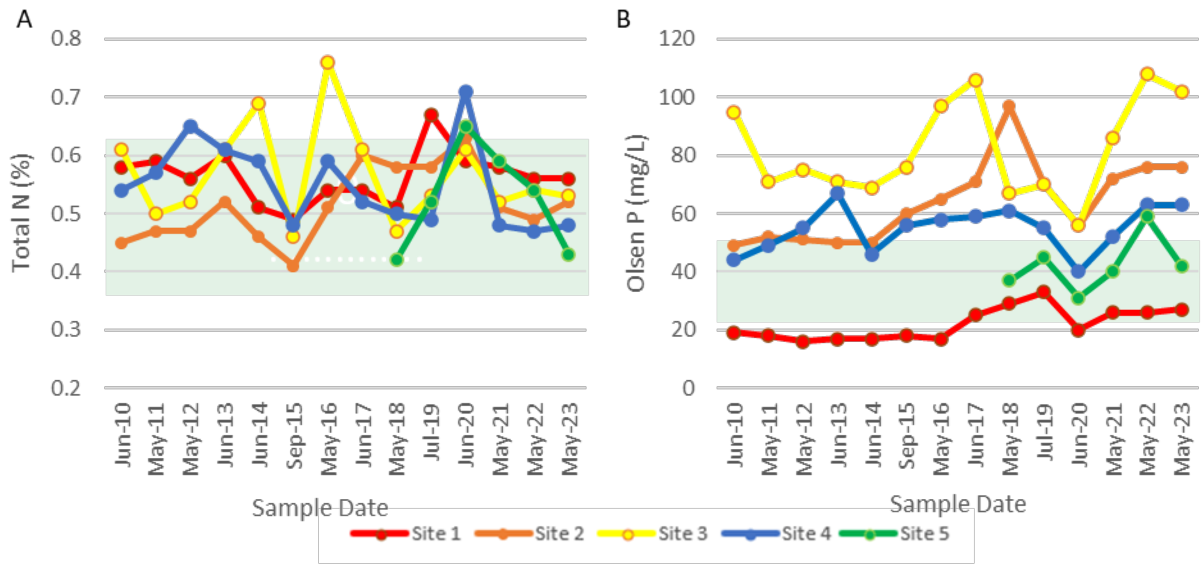

Figure 13: Total N and Olsen P results between 2010 and 2023. Green shading shows adequate range according to Landcare Research (SINDI online) for a Brown soil under dry stock. Values above this range are likely to be in excess of plant demand. There is a significant risk of leaching to waterways with excessive concentrations.

4.2.3 Macronutrients (Ca, Mg, Na, K)

Under normal soil pH conditions there is usually an overall excess of negative charge on the surface of soil particles onto which cations, calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+), are adsorbed. The area and density of exchange sites for cation attraction depends on the type of particles that make up the soil, with the least number of exchange sites on sand particles and the greatest number of exchange sites on clays. The amount of negative charge on clay hydroxy groups or organic matter is dependent on the pH of the surrounding solution, with a higher pH resulting in greater CEC. Cation exchange capacity (CEC) is the measure used to determine how many exchange sites a soil has (typically measured in milliequivalents per 100 grams, or me/100 g). The CEC of the soil at BSM is within the typical range of a sedimentary soil (Figure 14; McLaren and Cameron, 1996). For consistency with historical data from Greenwood (2017) and to demonstrate potential trends in the data, soil quick test MAF values for the macronutrients have been presented in Table 2 and Figure 15.

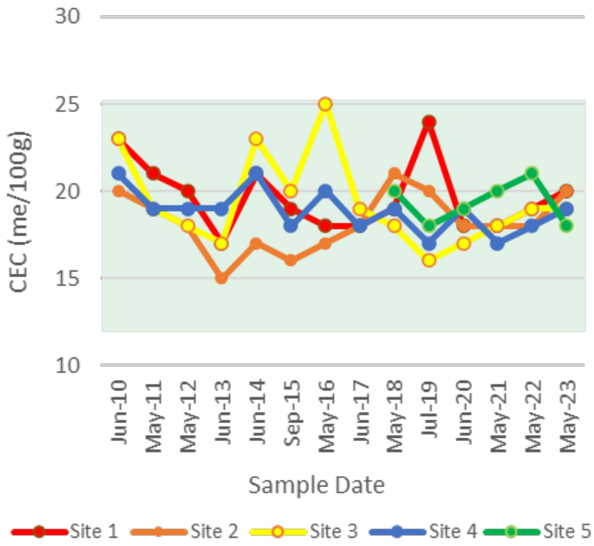

Figure 14: Cation Exchange Capacity (CEC) results between 2010 and 2023. Green shading shows the typical range for a sedimentary soil (McLaren and Cameron, 1996).

As not all the exchange sites of a soil are necessarily occupied by cations, the measure of the occupancy of the exchange sites by Ca, Mg, Na, and K is defined by percentage base saturation (BS) (%). The base saturation and milliequivalent concentrations for Ca, Mg, K and Na are presented in Table 3. Base Saturation is calculated by Hill Laboratories, along with CEC, and is a good way of assessing the balance between the macronutrients. Desirable base saturation levels for an agricultural land use are Ca 50 - 75%, Mg 5 -15%, K 2 - 5% and Na 1 - 2%. Low supply of macronutrients in the soil is likely to affect pasture yield, while oversupply can affect stock health with no pasture yield increase expected.

Table 3 shows the control site has base saturation levels within the range of typical agricultural soils. The wastewater discharge areas (Sites 2-5) have a higher K and Na base saturation than typical agricultural land, suggesting significant leaching of Ca and Mg. Divalent cations (Ca^{2+} and Mg^{2+}) are generally held more tightly on exchange sites than monovalent cations (K^{+} and Na^{+}), however if monovalent cations are high in soil solution, as is typical in wastewater discharge areas, exchange can occur between K and Na, reducing the Ca and Mg on exchange sites. The leaching of the divalent cations Ca and Mg is a common feature of soils receiving large volumes of waste with elevated Na and K concentrations.

Table 3: Milliequivalent (me/100g) and Base Saturation (BS %) of Ca, Mg, K, and Na.

	Ca		Mg		K		Na		Total BS
	me.100g	BS (%)	me.100g	BS (%)	me.100g	BS (%)	me.100g	BS (%)	(%)
Site 1 (C)	7.0	36	1.27	6.5	0.60	3.1	0.26	1.3	47
Site 2	8.0	40	0.95	4.8	1.32	6.7	1.10	5.6	58
Site 3	4.9	25	1.08	5.7	1.68	8.8	0.93	4.8	45
Site 4	9.7	52	0.84	4.5	1.68	9	0.50	2.7	68
Site 5	7.8	43	1.03	5.6	0.93	5.1	0.53	2.9	56

Blakemore et al. (1981) provides a rating for exchangeable bases for New Zealand soils. This is a good benchmark to rate whether concentrations are naturally elevated at the control site (Site 1) or elevated due to wastewater application. Calcium values for the control site are within the medium range of 5-10 me.100g. The wastewater discharge areas Sites 2, 4, and 5 are also within the medium range for New Zealand soils while Site 3 is low (Figure 15A; Blakemore et al., 1981). Magnesium values are also non-limiting to plant uptake and all sites are in the low to medium range for New Zealand soils (Figure 15B; Blakemore et al., 1981). All sites show similar or increases in Ca and Mg compared to 2022 results due to the application of gypsm (Pearson, 2022). Sodium values are low at the control site (Site 1), moderate at wastewater discharge Sites 4 and 5 and high at Sites 2 and 3 (Figure 12C; Blakemore et al., 1981). Potassium values are medium at the control site (Site 1), very high (> 1.2 me.100g) at wastewater discharge sites 2, 3, and 4 (Figure 15D; Blakemore et al., 1981). Manual manipulation of the soil at Site 5 would have redistributed the elevated Na and K deeper down the soil profile, however K remains high at Site 5.

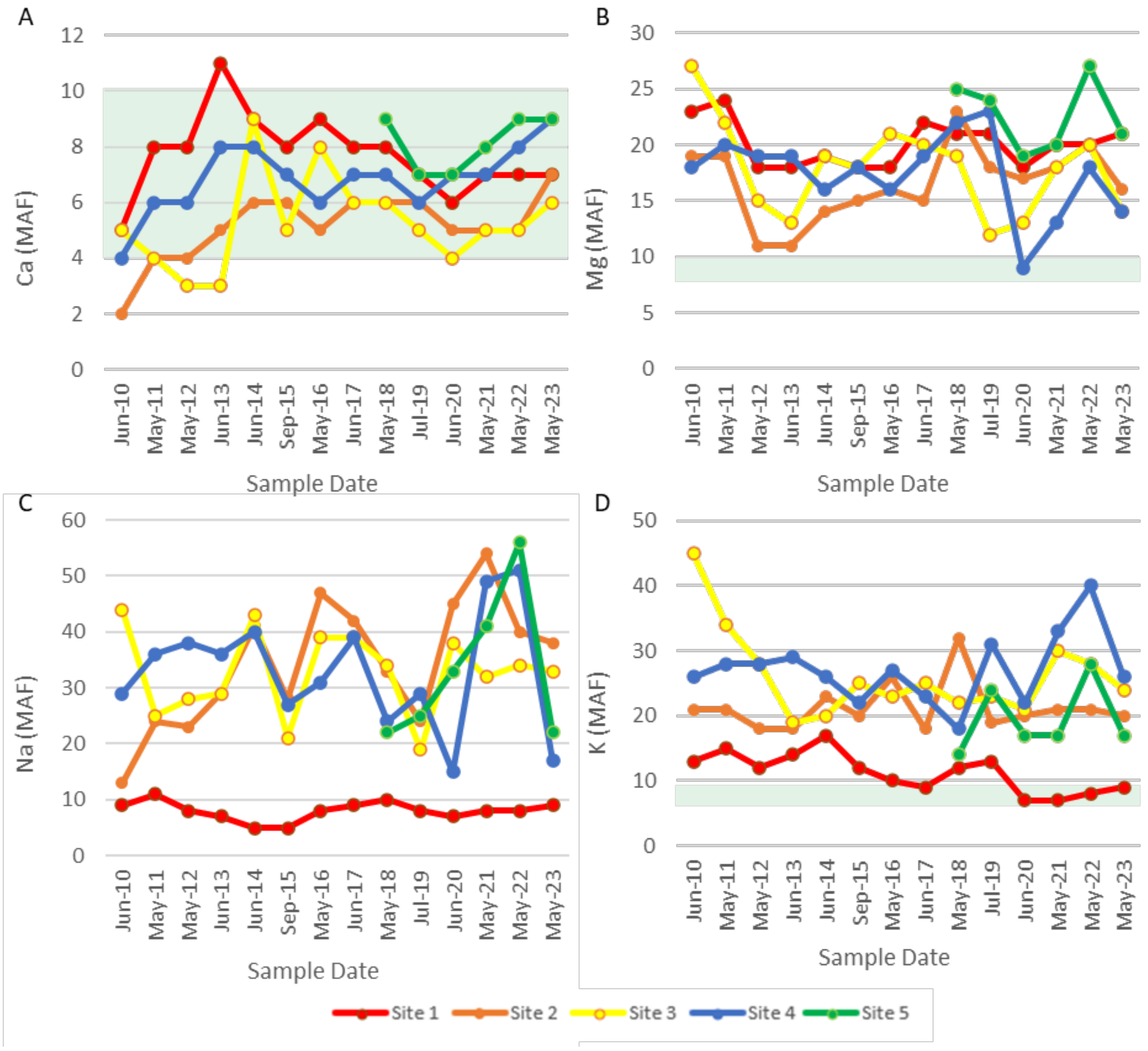

Figure 15: Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K) results between 2010 and 2023. Green shading shows an optimum range for plant growth according to McLaren and Cameron (1996). Values above the optimum range indicate plants are not limited by this macronutrient. Sodium is not required for plant growth, therefore does not have an optimum range for plant uptake (see section 4.2.4).

A significant environmental concern with the discharge of wastewater to land is the accumulation of monovalent cations, Na^+ and K^+ and the loss of divalent Ca^{2+} and Mg^{2+} in the soil profile and the resultant degradation of soil structure, which in turn affects aeration and water movement. Sodium assimilation by plants is low, therefore a management approach to mitigate the effects is often to leach the salt through the soil profile; however, this can have adverse effects on the environment via leaching of other nutrients, such as N and P. Sodium quick test values are elevated at all sites (17 – 38 MAF) compared to the control (9 MAF) (Table 2). Na concentrations have decreased at all wastewater discharge sites since monitoring in 2022 with the most significant decreases occurring at Sites 4 and 5 (Figure 15C, Pearson, 2022). Exchangeable Na percent is used to assess risk and is discussed further in section 4.2.4.

Although plant uptake of K is typically high; plant requirements are often exceeded under typical wastewater applications. This is evident in elevated K quick test values (17 – 26 MAF) relative to the control site (9 MAF) (Table 2, Figure 15D). K has decreased at all wastewater monitoring sites since the previous year's monitoring with the most significant decreases occurring at sites 4 and 5 (Pearson, 2022). High K values can result in restricted magnesium uptake by plants. Herbage sampling for plant nutrients could be part of the annual monitoring if it was deemed important to ensure pasture and animal health was not under stress, however this is not considered necessary at this time.

4.2.4 Exchangeable Sodium Percent (ESP)

High concentrations of Na (and K) in the soil profile can cause degradation of soil structure, which in turn affects aeration and water movement (McLaren and Cameron, 1996). Most of the work on Na problems in soils has been undertaken in Australia and many of the guidelines are Australian based. New Zealand soils are generally less prone to Na/K dispersion problems than Australian soils because our humid temperate climate generally promotes leaching of soils to a degree that minimises accumulation of soluble salts within soil horizons. Therefore, using Australian guidelines can be considered conservative for NZ situations. Typically, problems are very unlikely if ESP remains below 5 - 6%.

ESP is above optimal range at Site 2 and is nearing the threshold that could result in soil structural damage at Site 3 (Figure 16). Site 2 however has decreased over the past 2 years of monitoring (Figure 16). It is recommended that these concentrations be managed with annual applications of divalent cations, such as lime or gypsum. Given evidence of Ca and Mg leaching dolomite lime is likely to be a good option at Blue Sky Pastures when soil pH needs to be increased. Under proposed condition 23 for BSP's consent Site 2 (Paddock 6) would require remedial action as ESP is above 5%.

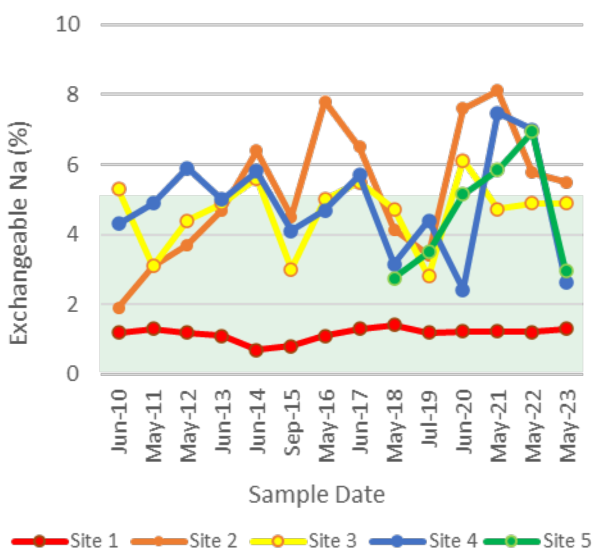

Figure 16: Exchangeable Na (ESP) results between 2010 and 2023.

5 Summary and Recommendations

Accumulation of nutrients in the soil may not harm the soil itself but can impact on plant and animal health and water quality if not appropriately monitored and managed. None of the changes to the soil from long-term irrigation at BSM appear to be detrimental to the long-term functioning of the soil and all are reversible.

Best management practice for managing nutrients in many wastewaters focuses on reducing leaching and runoff losses thereby retaining constituents, such as N and P, within the soil profile where the opportunity for retention by the soil matrix, removal via denitrification and assimilation by plants and microbial biomass is maximised. Excessive Na and K loading can deplete soils of Ca and Mg needed for maintenance of good soil structure and drainage and may also reduce soil pH.

Utilising the maximum discharge area for irrigation (lower loading rates) and removal of excess nutrient via cut and carry type operations is the most suitable way of reducing nutrient leaching and preventing Na and K overloading at the BSP site.

Comparisons with monitoring results from 2022 show increases in soil infiltration at all sites, except site 4 which recorded no change. The soil had also not been mechanically aerated this year, and it is recommended that aeration is undertaken when infiltration becomes limited to maintain soil structure.

For soil chemistry, Olsen P concentrations have decreased or remained the same at all discharge sites, however concentrations remain high (except Site 5) and are nearing or at excessive concentrations for pastoral growth. Total N is similar to last years monitoring result indicating nitrogen is not accumulating in the soil. This means it can be vulnerable to leaching if applied at high loading rates. Ensuring wastewater application across the full irrigation area is recommended to avoid over saturating and chemically loading the soil. The application of gypsum to the wastewater monitoring sites has shown significant improvement in overall soil quality and decreased Na and K base saturation. It is recommended that annual applications become part of BSP management for all wastewater irrigation paddocks. Site 2 requires remedial action under proposed condition 23 to reduce ESP below 5%.

Irrigation rates should be seasonally adjusted to account for soil infiltration rates, precipitation, and soil moisture conditions. Exceeding field capacity or irrigating on soils already above field capacity elevates the potential for surface ponding and runoff to occur to waterways. The hydraulic and organic loading of the wastewater applied should be regularly assessed to determine appropriate loading rates and irrigation return times for the discharge sites. The proposed consent conditions removing the requirement of *in situ* testing means that soil cores can be analysed under laboratory conditions and the results used for both compliance monitoring and informing farm management decisions.

6 References

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Appendix A: Historic Monitoring Data

Soil Infiltration

Table A1: Soil infiltration rate measurements from Greenwood (2017), Pearson (2018-2022) and this year's survey. Mean and median values are calculated from the long-term record and are shown for each site in bold.

	Site 1 - Control	Site 2	Site 3	Site 4	Site 5
May-11	119	1	3	4	
May-12	235	2	1	2	
Jun-13	228	5	3	3	
Jun-14	127	<1	<1	<1	
Sep-15	150	<1	<1	<1	
May-16	94	5	8	13	
Jun-17	112	10	11	16	
Jun-18	77	311	1	11	464
Jul-19	149	77	99	43	7
Jun-20	140	208	107	99	227
May-21	69	87	100	37	187
May-22	45	17	33	12	63
May-23	119	333	194	12	424
Average	128.1	81.4	43.2	19.5	228.6
Median	119.0	10.0	8.0	12.0	207.0

Soil Chemistry

Table A2: Soil chemistry data from Greenwood (2017), Pearson (2018-2022) and this year's survey. Mean and median values are calculated from the long-term record and are shown for each site in bold.

	Date	pH	Ca (MAF)	Mg (MAF)	K (MAF)	Na (MAF)	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
Site 1	Jun-10	5.7	5	23	13	9	1.2	23	0.58	19
Control	May-11	5.8	8	24	15	11	1.3	21	0.59	18
	May-12	6.3	8	18	12	8	1.2	20	0.56	16
	Jun-13	6.6	11	18	14	7	1.1	17	0.60	17
	Jun-14	6.1	9	19	17	5	0.7	21	0.51	17
	Sep-15	6.1	8	18	12	5	0.8	19	0.49	18
	May-16	6.0	9	18	10	8	1.1	18	0.54	17
	Jun-17	5.9	8	22	9	9	1.3	18	0.54	25
	May-18	5.8	8	21	12	10	1.4	19	0.51	29
	Jul-19	5.9	7	21	13	8	1.2	24	0.67	33
	Jun-20	5.9	6	18	7	7	1.2	18	0.59	20
	May-21	5.7	7	20	7	8	1.2	18	0.58	26
	May-22	5.8	7	20	8	8	0.0	19	0.56	26
	May-23	5.8	7	21	9	9	1.3	20	0.56	27
	Average	**6.0**	**7.7**	**20.1**	**11.3**	**8.0**	**1.1**	**19.6**	**0.6**	**22.0**
	Median	**5.9**	**8.0**	**20.0**	**12.0**	**8.0**	**1.2**	**19.0**	**0.6**	**19.5**
Site 2	Jun-10	5.5	2	19	21	13	1.9	20	0.45	49
	May-11	5.7	4	19	21	24	3.1	19	0.47	52
	May-12	5.7	4	11	18	23	3.7	18	0.47	51
	Jun-13	6.1	5	11	18	29	4.7	15	0.52	50
	Jun-14	6.3	6	14	23	41	6.4	17	0.46	50
	Sep-15	6.4	6	15	20	28	4.5	16	0.41	60
	May-16	6.2	5	16	26	47	7.8	17	0.51	65

	Date	pH	Ca (MAF)	Mg (MAF)	K (MAF)	Na (MAF)	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
	Jun-17	6.1	6	15	18	42	6.5	18	0.60	71
	May-18	6.0	6	23	32	33	4.1	21	0.58	97
	Jul-19	5.9	6	18	19	24	3.4	20	0.58	70
	Jun-20	6.0	5	17	20	45	7.6	18	0.63	56
	May-21	6.2	5	18	21	54	8.1	18	0.51	72
	May-22	6.2	5	20	21	40	0.0	18	0.49	76
	May-23	6.1	7	16	20	38	5.5	20	0.52	76
	Average	**6.0**	**5.1**	**16.6**	**21.3**	**34.4**	**4.8**	**18.2**	**0.5**	**63.9**
	Median	**6.1**	**5.0**	**16.5**	**20.5**	**35.5**	**4.6**	**18.0**	**0.5**	**62.5**
Site 3	Jun-10	5.9	5	27	45	44	5.3	23	0.61	95
	May-11	5.9	4	22	34	25	3.1	19	0.50	71
	May-12	5.8	3	15	28	28	4.4	18	0.52	75
	Jun-13	6.0	3	13	19	29	4.9	17	0.61	71
	Jun-14	6.4	9	19	20	43	5.6	23	0.69	69
	Sep-15	6.1	5	18	25	21	3.0	20	0.46	76
	May-16	5.9	8	21	23	39	5.0	25	0.76	97
	Jun-17	5.9	6	20	25	39	5.5	19	0.61	106
	May-18	6.1	6	19	22	34	4.7	18	0.47	67
	Jul-19	5.8	5	12	23	19	2.8	16	0.53	70
	Jun-20	5.8	4	13	21	38	6.1	17	0.61	56
	May-21	5.8	5	18	30	32	4.7	18	0.52	86
	May-22	6.1	5	20	28	34	0.0	19	0.54	108
	May-23	5.9	6	14	24	33	4.9	19	0.53	102
	Average	**6.0**	**5.3**	**17.9**	**26.2**	**32.7**	**4.3**	**19.4**	**0.6**	**82.1**
	Median	**5.9**	**5.0**	**18.5**	**24.5**	**33.5**	**4.8**	**19.0**	**0.5**	**75.5**
Site 4	Jun-10	5.7	4	18	26	29	4.3	21	0.54	44
	May-11	6.0	6	20	28	36	4.9	19	0.57	49
	May-12	6.1	6	19	28	38	5.9	19	0.65	55
	Jun-13	6.2	8	19	29	36	5.0	19	0.61	67
	Jun-14	6.5	8	16	26	40	5.8	21	0.59	46
	Sep-15	6.2	7	18	22	27	4.1	18	0.48	56
	May-16	5.8	6	16	27	31	4.7	20	0.59	58
	Jun-17	6.3	7	19	23	39	5.7	18	0.52	59
	May-18	5.7	7	22	18	24	3.2	19	0.50	61
	Jul-19	6.3	6	23	31	29	4.4	17	0.49	55
	Jun-20	5.8	7	9	22	15	2.4	19	0.71	40
	May-21	6.4	7	13	33	49	7.5	17	0.48	52
	May-22	6.7	8	18	40	51	0.0	18	0.47	63
	May-23	6.2	9	14	26	17	2.6	19	0.48	63
	Average	**6.1**	**6.9**	**17.4**	**27.1**	**32.9**	**4.3**	**18.9**	**0.5**	**54.9**
	Median	**6.2**	**7.0**	**18.0**	**26.5**	**33.5**	**4.6**	**19.0**	**0.5**	**55.5**
Site 5	May-18	6.1	9	25	14	22	2.8	20	0.42	37
	Jul-19	6.2	7	24	24	25	3.5	18	0.52	45
	Jun-20	5.9	7	19	17	33	5.2	19	0.65	31
	May-21	6.2	8	20	17	41	5.9	20	0.59	40
	May-22	6.6	9	27	28	56	0.0	21	0.54	59

	Date	pH	Ca (MAF)	Mg (MAF)	K (MAF)	Na (MAF)	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
	May-23	5.9	9	21	17	22	2.9	18	0.43	42
	Average	**6.2**	**8.2**	**22.7**	**19.5**	**33.2**	**3.4**	**19.3**	**0.5**	**42.3**
	Median	**6.2**	**8.5**	**22.5**	**17.0**	**29.0**	**3.2**	**19.5**	**0.5**	**41.0**

Appendix B: Hill Laboratory Results

Additional sites analysed for BSP have been removed from this report.

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TRIED, TESTED AND TRUSTED

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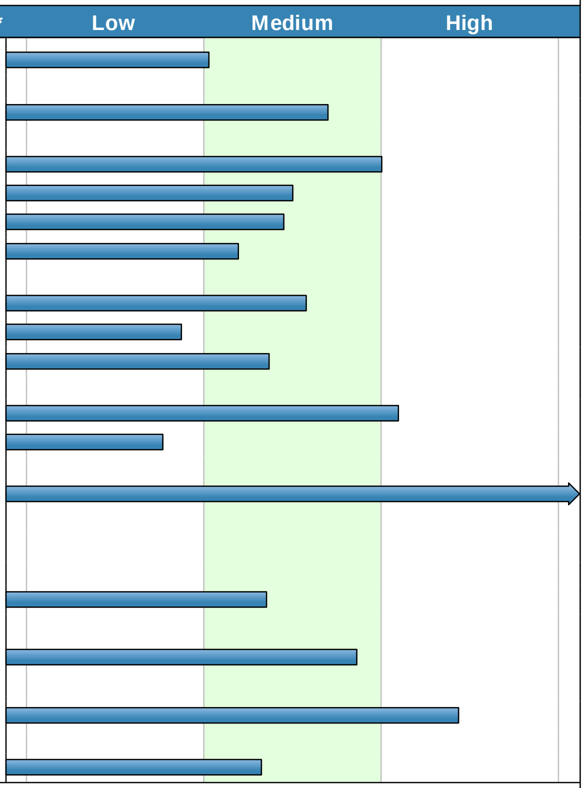
Certificate of Analysis

Client:	Land & Water Science Limited	**Lab No:**	3281381 shvpv1
Address:	231 Dee Street Avenal Invercargill 9810	**Date Received:**	19-May-2023
		Date Reported:	31-May-2023
		Quote No:	118039
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSM Control Site 1 **Lab Number:** 3281381.1
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range*
pH	pH Units	5.8	5.8 - 6.2
Olsen Phosphorus	mg/L	27	20 - 30
Potassium	me/100g	0.60	0.40 - 0.60
Calcium	me/100g	7.0	4.0 - 10.0
Magnesium	me/100g	1.27	1.00 - 1.60
Sodium	me/100g	0.26	0.20 - 0.50
CEC	me/100g	20	12 - 25
Total Base Saturation	%	47	50 - 85
Volume Weight	g/mL	0.75	0.60 - 1.00
Sulphate Sulphur	mg/kg	16	10 - 12
Extractable Organic Sulphur	mg/kg	13	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	450	150 - 250
Anaerobically Mineralisable N*	µg/g	402	
Organic Matter*	%	10.5	7.0 - 17.0
Total Carbon	%	6.1	
Total Nitrogen	%	0.56	0.30 - 0.60
C/N Ratio*		10.9	
Anaerobically Mineralisable N/Total N Ratio*	%	7.2	3.0 - 5.0
'Total' Phosphorus	mg/kg	992	700 - 1600
Base Saturation %		K 3.1 Ca 36	Mg 6.5 Na 1.3
MAF Units		K 9 Ca 7	Mg 21 Na 9



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Certificate of Analysis

Client:	Land & Water Science Limited	**Lab No:**	3281381 shvpv1
Address:	231 Dee Street Avenal Invercargill 9810	**Date Received:**	19-May-2023
		Date Reported:	31-May-2023
		Quote No:	118039
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSM Site 2 **Lab Number:** 3281381.2
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range*
pH	pH Units	6.1	5.8 - 6.2
Olsen Phosphorus	mg/L	76	20 - 30
Potassium	me/100g	1.32	0.40 - 0.60
Calcium	me/100g	8.0	4.0 - 10.0
Magnesium	me/100g	0.95	1.00 - 1.60
Sodium	me/100g	1.10	0.20 - 0.50
CEC	me/100g	20	12 - 25
Total Base Saturation	%	58	50 - 85
Volume Weight	g/mL	0.75	0.60 - 1.00
Sulphate Sulphur	mg/kg	84	10 - 12
Extractable Organic Sulphur	mg/kg	9	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	432	150 - 250
Anaerobically Mineralisable N*	µg/g	386	
Organic Matter*	%	9.6	7.0 - 17.0
Total Carbon	%	5.6	
Total Nitrogen	%	0.52	0.30 - 0.60
C/N Ratio*		10.6	
Anaerobically Mineralisable N/Total N Ratio*	%	7.4	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,433	700 - 1600

Base Saturation %	K 6.7	Ca 40	Mg 4.8	Na 5.6
MAF Units	K 20	Ca 7	Mg 16	Na 38

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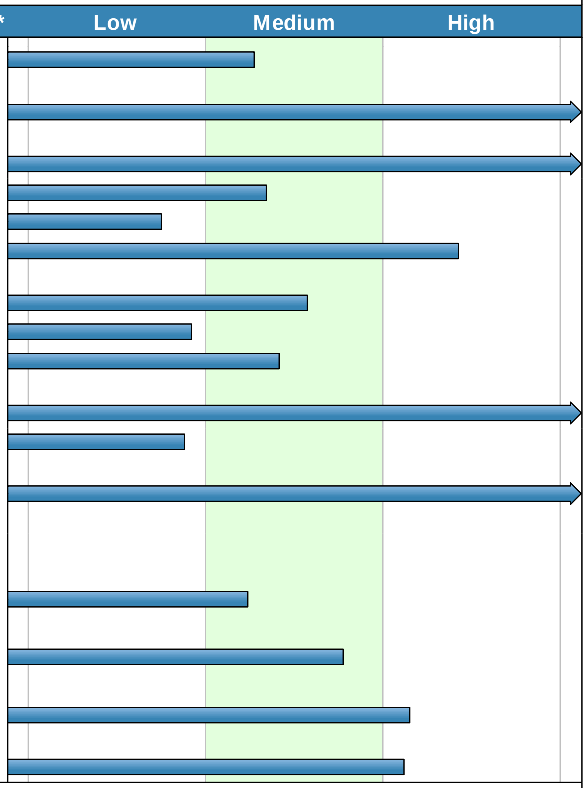
		Quote No:	118039
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSM Site 3 — **Lab Number:** 3281381.3
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range*
pH	pH Units	5.9	5.8 - 6.2
Olsen Phosphorus	mg/L	102	20 - 30
Potassium	me/100g	1.52	0.40 - 0.60
Calcium	me/100g	6.1	4.0 - 10.0
Magnesium	me/100g	0.82	1.00 - 1.60
Sodium	me/100g	0.93	0.20 - 0.50
CEC	me/100g	19	12 - 25
Total Base Saturation	%	48	50 - 85
Volume Weight	g/mL	0.77	0.60 - 1.00
Sulphate Sulphur	mg/kg	79	10 - 12
Extractable Organic Sulphur	mg/kg	14	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	353	150 - 250
Anaerobically Mineralisable N*	µg/g	307	
Organic Matter*	%	9.4	7.0 - 17.0
Total Carbon	%	5.4	
Total Nitrogen	%	0.53	0.30 - 0.60
C/N Ratio*		10.2	
Anaerobically Mineralisable N/Total N Ratio*	%	5.8	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,697	700 - 1600
Base Saturation %	K 7.8	Ca 31	Mg 4.2	Na 4.8
MAF Units	K 24	Ca 6	Mg 14	Na 33



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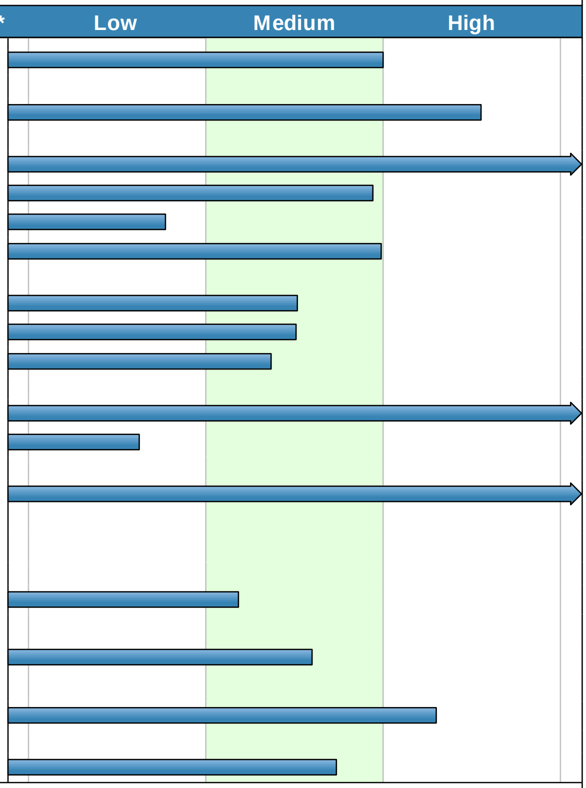
Certificate of Analysis

Client:	Land & Water Science Limited	**Lab No:**	3281381 shvpv1
Address:	231 Dee Street Avenal Invercargill 9810	**Date Received:**	19-May-2023
		Date Reported:	31-May-2023
		Quote No:	118039
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSM Site 4 **Lab Number:** 3281381.4
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range*
pH	pH Units	6.2	5.8 - 6.2
Olsen Phosphorus	mg/L	63	20 - 30
Potassium	me/100g	1.68	0.40 - 0.60
Calcium	me/100g	9.7	4.0 - 10.0
Magnesium	me/100g	0.84	1.00 - 1.60
Sodium	me/100g	0.50	0.20 - 0.50
CEC	me/100g	19	12 - 25
Total Base Saturation	%	68	50 - 85
Volume Weight	g/mL	0.75	0.60 - 1.00
Sulphate Sulphur	mg/kg	96	10 - 12
Extractable Organic Sulphur	mg/kg	11	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	350	150 - 250
Anaerobically Mineralisable N*	µg/g	313	
Organic Matter*	%	8.8	7.0 - 17.0
Total Carbon	%	5.1	
Total Nitrogen	%	0.48	0.30 - 0.60
C/N Ratio*		10.7	
Anaerobically Mineralisable N/Total N Ratio*	%	6.5	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,363	700 - 1600



Base Saturation %	K 9.0	Ca 52	Mg 4.5	Na 2.7
MAF Units	K 26	Ca 9	Mg 14	Na 17

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Client:	Land & Water Science Limited	**Lab No:**	3281381 shvpv1
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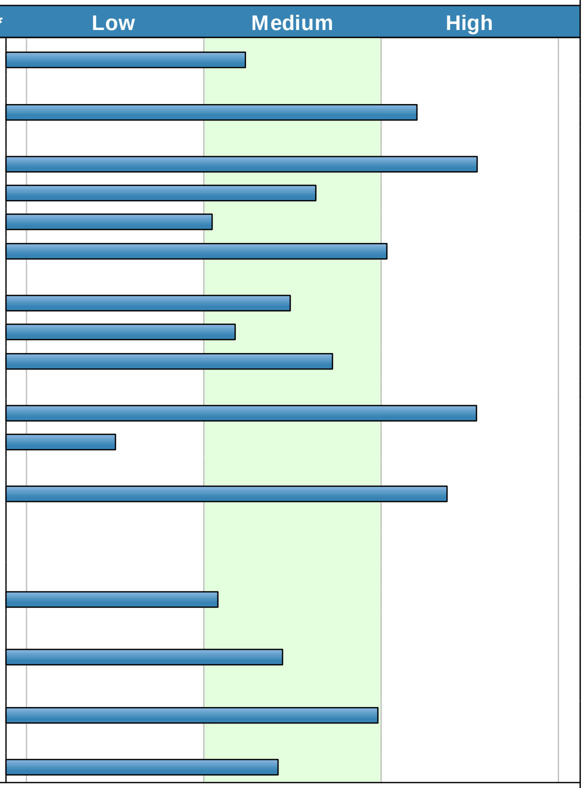
		Date Reported:	31-May-2023
		Quote No:	118039
		Order No:	
		Client Reference:	
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSM Site 5 **Lab Number:** 3281381.5
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range*
pH	pH Units	5.9	5.8 - 6.2
Olsen Phosphorus	mg/L	42	20 - 30
Potassium	me/100g	0.93	0.40 - 0.60
Calcium	me/100g	7.8	4.0 - 10.0
Magnesium	me/100g	1.03	1.00 - 1.60
Sodium	me/100g	0.53	0.20 - 0.50
CEC	me/100g	18	12 - 25
Total Base Saturation	%	56	50 - 85
Volume Weight	g/mL	0.89	0.60 - 1.00
Sulphate Sulphur	mg/kg	33	10 - 12
Extractable Organic Sulphur	mg/kg	10	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	287	150 - 250
Anaerobically Mineralisable N*	µg/g	215	
Organic Matter*	%	7.8	7.0 - 17.0
Total Carbon	%	4.5	
Total Nitrogen	%	0.43	0.30 - 0.60
C/N Ratio*		10.5	
Anaerobically Mineralisable N/Total N Ratio*	%	5.0	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,078	700 - 1600
Base Saturation %		K 5.1 Ca 43	Mg 5.6 Na 2.9
MAF Units		K 17 Ca 9	Mg 21 Na 22



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		Quote No:	118039	
		Order No:		
		Client Reference:		
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson	

Soil Analysis Results

Sample Name:		BSM Control Site 1	BSM Site 2	BSM Site 3	BSM Site 4	BSM Site 5	
Lab Number:		3281381.1	3281381.2	3281381.3	3281381.4	3281381.5	
Sample Type:		SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	
Sample Type Code:		S1	S1	S1	S1	S1	
pH	pH Units	5.8	6.1	5.9	6.2	5.9	
Olsen Phosphorus	mg/L	27	76	102	63	42	
Potassium	me/100g	0.60	1.32	1.52	1.68	0.93	
Potassium	%BS	3.1	6.7	7.8	9.0	5.1	
Potassium	MAF units	9	20	24	26	17	
Calcium	me/100g	7.0	8.0	6.1	9.7	7.8	
Calcium	%BS	36	40	31	52	43	
Calcium	MAF units	7	7	6	9	9	
Magnesium	me/100g	1.27	0.95	0.82	0.84	1.03	
Magnesium	%BS	6.5	4.8	4.2	4.5	5.6	
Magnesium	MAF units	21	16	14	14	21	
Sodium	me/100g	0.26	1.10	0.93	0.50	0.53	
Sodium	%BS	1.3	5.6	4.8	2.7	2.9	
Sodium	MAF units	9	38	33	17	22	
CEC	me/100g	20	20	19	19	18	
Total Base Saturation	%	47	58	48	68	56	
Volume Weight	g/mL	0.75	0.75	0.77	0.75	0.89	
Sulphate Sulphur	mg/kg	16	84	79	96	33	
Extractable Organic Sulphur	mg/kg	13	9	14	11	10	
Potentially Available Nitrogen (15cm Depth)*	kg/ha	450	432	353	350	287	
Anaerobically Mineralisable N*	µg/g	402	386	307	313	215	
Organic Matter*	%	10.5	9.6	9.4	8.8	7.8	
Total Carbon	%	6.1	5.6	5.4	5.1	4.5	
Total Nitrogen	%	0.56	0.52	0.53	0.48	0.43	
C/N Ratio*		10.9	10.6	10.2	10.7	10.5	
Anaerobically Mineralisable N/Total N Ratio*	%	7.2	7.4	5.8	6.5	5.0	
'Total' Phosphorus	mg/kg	992	1,433	1,697	1,363	1,078	

Client:	Land & Water Science Limited	**Lab No:**	3281381 shvpv1
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Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Analyst's Comments

Samples 1-9 Comment:
The medium or optimum range guidelines shown in the histogram report relate to sampling protocols as per Hill Laboratories' crop guides and are based on reference values where these are published. Results for samples collected to different depths than those described in the crop guide should be interpreted with caution.
For pastoral soils, the medium ranges are specific for a 75mm sample depth, but if a 150mm sampling depth is used the nutrient levels measured may appear low against these ranges, as nutrients are typically more concentrated in the top of the soil profile. These soil profile differences are altered upon cultivation or contouring.
Further explanation of the derivation of the medium and optimum ranges is available on request.

Samples 1-9 Comment:
While soil Mg MAF levels of 8-10 (0.4 - 0.6 me/100g) are sufficient for pasture production, soil levels of 25-30 (1 - 1.6 me/100g) are required to ensure adequate Mg content in pasture for animal health (greater than 0.22% in the herbage).

Samples 1-9 Comment:
The Potentially Available Nitrogen (kg/ha) test above assumes the sample is taken to a 15 cm depth. If the depth is 7.5 cm, then the result reported above should be divided by two.
To calculate Potentially Available Nitrogen (as kgN/ha) for other sample depths use the reported Anaerobic Mineralisable Nitrogen (AMN) result in the following equation:
AN (kg/ha) = AMN (µg/g) x VW (g/ml) x sample depth (cm) x 0.1
Note that the AN and AMN results reported include the readily available Mineral N (NH4-N and NO3-N) fraction, which is typically quite low.

Samples 1-9 Comment:
The medium range shown describes typical 'Total' Phosphorus levels for mineral soils in New Zealand. The 'Total' P test has not been correlated against pasture growth response rates so should be interpreted along with other observations.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sample Registration*	Samples were registered according to instructions received.	-	1-9
Soil Prep (Dry & Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2mm screen.	-	1-9
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. In-house.	0.1 pH Units	1-9
Olsen Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry. In-house method.	1 mg/L	1-9
Sulphate Sulphur	0.02M Potassium phosphate extraction followed by Ion Chromatography. In-house.	1 mg/kg	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	2 MAF units	1-9

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Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Extractable Organic Sulphur	0.02M Potassium phosphate extraction. Total extractable S is determined by ICP-OES from which the Sulphate-S is subtracted. In-house.	2 mg/kg	1-9
Potentially Available Nitrogen	Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample). Note that any Mineral N present is included in the AN/AMN result reported. In-house.	10 kg/ha	1-9
Anaerobically Mineralisable N*	As for Potentially Available Nitrogen but reported as µg/g.	5 µg/g	1-9
Organic Matter*	Organic Matter is 1.72 x Total Carbon.	0.2 %	1-9
Total Carbon	Dumas combustion. In-house.	0.1 %	1-9
Total Nitrogen	Dumas combustion. In-house.	0.04 %	1-9
'Total' Phosphorus	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-OES. (Total recoverable nutrients reported on a dry weight basis) The levels from this method are referred to as 'Totals' in quotation marks, as they will be a slight under-estimation of the true Totals for some elements. In-house.	65 mg/kg	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.01 me/100g	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.5 me/100g	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.04 me/100g	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.05 me/100g	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 %BS	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.2 %BS	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-9
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity. May be overestimated if soil contains high levels of soluble salts or carbonates. In-house.	2 me/100g	1-9
Total Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	5 %	1-9
Volume Weight	The weight/volume ratio of dried, ground soil. In-house.	0.01 g/mL	1-9

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 19-May-2023 and 31-May-2023. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Caroline Hill DipSc
Client Services Manager - Agriculture

Blue Sky Pastures Morton Mains Plant: Soil Monitoring Report 2022

Dr Lisa Pearson

Land and Water Science Report 2022/16
July 2022

Blue Sky Pastures Morton Mains Plant: Soil Monitoring Report 2022

Prepared by
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Table of Contents

List of Figures

List of Tables

1 Introduction

Blue Sky Pastures (NZ) Ltd hold a permit under consent number 201191 from Southland Regional Council (Environment Southland) to discharge meat processing and rendering plant wastewater to land via a spray irrigator at their Morton Mains Plant. Current soil monitoring requirements, as stipulated in Condition 13 of the discharge permit state the following:

The consent holder shall monitor soil on the site during the month of May each year as follows:

a) *Samples shall be taken from, and the measurements made in, at least three wastewater irrigation sites (two in the Waikiwi soil and one site in the Waikiwi mottled soils), and at least one control site (in an area where effluent is not discharged).*

b) *Soil samples shall be analysed for the following:*
   - *Infiltration rate*
   - *soil pH*
   - *Exchangeable calcium*
   - *Exchangeable magnesium*
   - *Exchangeable potassium*
   - *Exchangeable sodium*
   - *Phosphorus (Olsen P)*
   - *Cation Exchange Capacity*
   - *Total nitrogen concentration*

   Analysis shall include the calculation of exchangeable sodium percentage (ESP) values for each sample.

Soil sampling and infiltration measurement was undertaken by Land and Water Science (Dr Lisa Pearson) and Campbell Water Design (Tim Campbell) assisted by BSP Environmental Graduate, Jacob Read, on the 25 May 2021. This report summarises and interprets the soil monitoring data for 2022 for compliance with the conditions of the resource consent. Earlier monitoring data from Greenwood (2015; 2017) and Pearson (2018; 2019; 2020,2021) is used for comparison and identification of any trends in the data from previous years.

2 Site Details and Observations

Blue Sky Pastures (BSP) is located at 729 Woodlands-Morton Mains Rd, Morton Mains 9871. Soil monitoring was undertaken at previous soil monitoring locations, identified as 'Sites' in Greenwood (2015) (Figure 1). Here we use coloured lines to represent soil sampling transect lines within the site area. Site transects are hereafter designated as 'sites' to maintain consistency with previous monitoring (Greenwood, 2017)[1]. Samples for soil chemistry are collected at 25-30 locations along the length of the transect line and soil infiltration measurements are made at the start, middle, and end of the transect line at each site.

[1] The term 'soil moisture site' (or SM-sites) refer to the 6 soil moisture tapes used by Blue Sky Meats for irrigation scheduling. Soil moisture site numbers are not related to the soil monitoring sites.

Figure 1: Soil sampling sites at Blue Sky Pastures, Morton Mains Plant. Coloured transect lines show where soil samples were taken at the monitoring sites. Where SM Control and SM1 – 5 denote the location of in situ soil moisture (SM) instruments used for irrigation scheduling. Note: Aerial photography is older than the second pond construction.

The control site (Site 1) is located to the north of the processing plant and is typically used as a stock holding area prior to processing. The soil at this site is identified as a Waikiwi deep silt loam which is a Typic Firm Brown soil under the New Zealand Soil Classification (NZSC). At the time of sampling, the paddock had moderate grass cover and no stock (Figure 2). No aeration had been undertaken.

Figure 2: Site 1 Control - shows the end of the sample transect and infiltration test parallel to the pylons.

Sites 2, 3 and 5 are located to the northwest of the processing plant on Waikiwi deep silt loam soils. Site 2 had long grass coverage with evidence of stock grazing in the paddock. The site had not been irrigated on for 2 weeks, however overnight rain had left the soil saturated (Figure 3). The soil showed good structure with numerous earthworms. No aeration had been undertaken.

Figure 3: Site 2 northern end of transect.

Site 3 is split across two paddocks, the western paddock (3a Figure 1) had long grass cover. Two infiltration measurements were recorded in this paddock which was at or near saturation, limiting infiltration. Site 3b had shorter patchier grass cover and evidence of stock grazing. Site 3b was noticeably more compact than the neighbouring paddock. No aeration had been undertaken in either paddock.

Figure 4: Site 3a (top) and Site 3b (bottom) transect.

Site 4 is located to the south of the processing plant (Figure 1) on a Woodlands deep silt loam (Greenwood, 2017). Under the NZSC, Woodlands soils are classified as Mottled Firm Brown soils. This site has permanent irrigation points. There was good grass coverage at the time of sampling and surface ponding in the eastern side of the paddock. No aeration had been undertaken.

Figure 5: Site 4 southern end of transect.

Site 5 located on Waikiwi deep silt loam soils had long grass with good coverage (Figure 6). Surface ponding was evident in the swale and this area is avoided in the soil chemistry transect. The paddock had recently been used to spread muck from the processing plant (Figure 6). No aeration had been undertaken in this paddock.

Figure 6: Site 5 southern end of transect (left) and muck on grass surface (right).

2.1 Antecedent Soil Conditions for Infiltration Testing

The rainfall recorded at Blue Sky Pastures over the 3-month period prior to soil infiltration rate testing was 187.4 mm of which 50 mm was recorded in the week prior to sampling (Figure 7). The rainfall in the week prior to sampling was less than ideal and will likely have an impact on the infiltration testing. The total rainfall volume 3 months prior to sampling was similar to 2021, therefore soil chemical concentrations are likely comparable between the two sample dates. If rainfall is significantly higher, concentration decreases are possible due to leaching from the soil occurring. Southland was in drought over the summer of 2021/22.

Soil moisture conditions were indicated to be below field capacity at the time of sampling according to Environment Southland's 'Woodlands at Garvie Road' soil moisture monitoring site which is <5 km west from BSM (Figure 8). The soil at the ES monitoring site is the same soil series as Site 4 at BSM, Woodlands soil series, which is imperfectly drained. Soil moisture at the BSP site was significantly wetter (Figure 9).

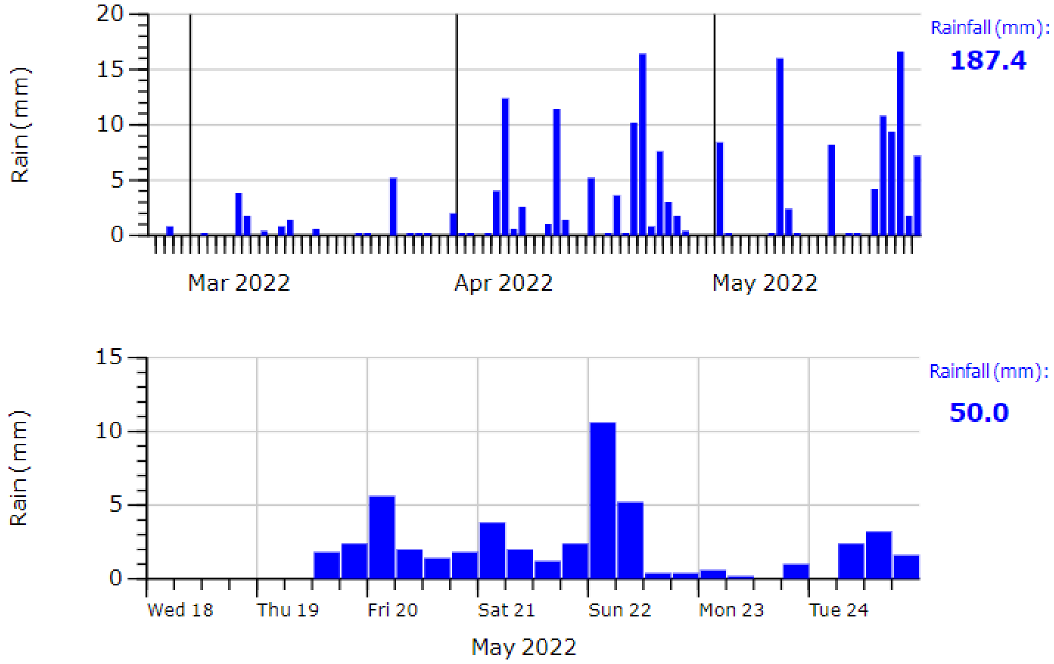

Figure 7: a) Total rainfall at Blue Sky Pastures Processing Plant for 3 months prior to sampling and b) 1 week prior to sampling (Data from BSM Harvest system, accessed 31 May 2022).

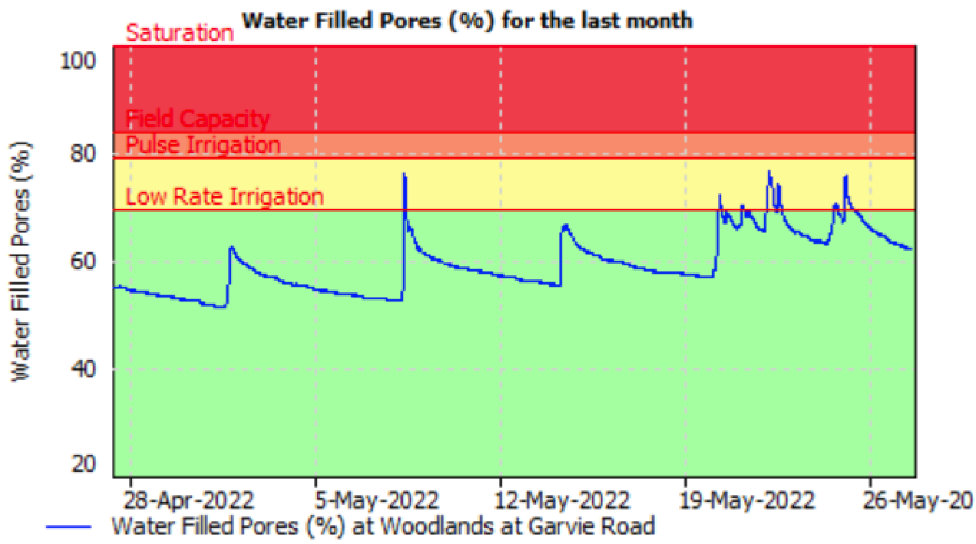

Figure 8: Soil moisture as percent water filled pores at Woodlands at Garvie Road prior to soil testing at Blue Sky Pastures Processing Plant (Data sourced from http://gis.es.govt.nz/ accessed 27 May 2022).

There are five soil moisture sensors at the BSM Processing Plant that continuously record soil moisture as a percentage (%) and deficit (in mm). Soil moisture deficit is calculated from field capacity as defined by expert judgement. The location of the sensors and proximity to the soil monitoring sites are shown in Figure 1. The BSM soil moisture as a percentage ranged between 30 and 52% at the time of sampling (Figure 9). There was no soil moisture deficit at the control site, site 1 and site 4 (Figure 6) indicating the soil was close to saturation at the site.

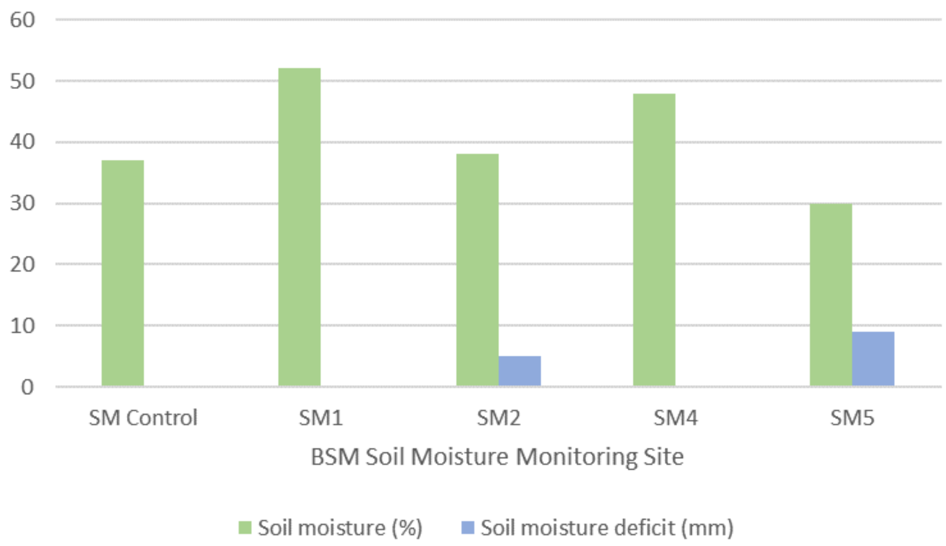

Figure 9: Soil moisture (%) and deficit (mm) from soil moisture sensors at Blue Sky Pastures Processing Plant (see Figure 1 for sensor locations). Note sensor numbers are from Blue Sky Pastures and are not the same as the soil monitoring sites. Soil Moisture sensor 3 is currently not operational.

3 Methods

3.1 Infiltration Rate

Soil infiltration rate was measured *in situ* on the 25th May 2022.

Infiltration rates were calculated using the double-ring infiltration method (Figure 10). The rings were inserted into the soil to a minimum depth of 1 cm, ensuring a tight seal with the soil. Both the inner and outer rings were filled with water until they slightly overflowed. A ruler was placed in the centre ring and the water depth recorded. Simultaneously, a timer was set for 15 minutes. After 15 minutes, the water depth remaining was measured, and the volume of water infiltrated calculated. If the soil infiltrated the total volume of water faster than the 15-minute period, the depth of water infiltrated, and time taken to infiltrate was recorded. Three repeat measures were taken at each site, near the start, middle and end of each transect line (Figure 1). The three measurements were used to calculate the mean, median, minimum, and maximum infiltration rate for each site. One measurement at Site 3 was removed due to suspected interference by aeration rips as results were significantly different to the other measurements for the site. The remaining 2 measurements (both in site 3A) were used to calculate the statistics for the site.

Figure 10: Double ring infiltration setup for soil infiltration testing. During use, both rings are filled up with water with only the inner ring measured. The reason for only measuring the inner ring is the outer ring may infiltrate much faster than the inner ring because there will be lateral movement of water around the cutter blade. This action also creates a seal for the inner ring and gives a much more accurate indication of the actual rate of infiltration at the location.

3.2 Soil Chemistry

Soil samples for chemical analysis were collected on the 25th May 2022.

Soil samples were collected at regular intervals along a transect at each site (1 - 5) as identified in Figure 1. Approximately 25 - 30 soil cores (~500 g) were collected to a depth of 7.5 cm from the soil surface and a composite sample per site sent for analysis. The composite soil samples were analysed at Hill Laboratories Ltd for the chemical analytes specified in the consent conditions (see section 1).

4 Results and Discussion

4.1 Infiltration Rate

All wastewater irrigation areas showed decreases in infiltration rate since the last soil monitoring in May 2021 (Figure 11). Soil infiltration rates across the wastewater irrigation areas ranged from 4 mm/hr to 104 mm/hr, with the control site recording 45 mm/hr (Site 1, Table 1). Mean infiltration rates for all sites were recorded as moderate (between 4-72mm) while individual measures ranged as low as 4mm/hr at Sites 2 and 4 which is considered 'slow'. All sites recorded a large degree of variation with some areas being saturated and others exhibiting moderate infiltration where the soil was better drained. The control site showed the least amount of variation.

As wastewater can have a high organic content, overloading an area can result in blockage of the soil macropores responsible for water transmission, as well as structural damage associated with irrigation of wastewater with a high concentration of monovalent cations (i.e., Na^+ and K^+, discussed further in Section 4.2.3). As the wastewater composition has improved in response to improved wastewater treatment, soil clogging rates are likely low.

A limitation of *in situ* infiltration measures occurs when soils are at or near field capacity. Under these conditions the ability of the soil to drain is limited. Conversely, if the soils are dry they infiltrate a larger volume of water. Wet soil conditions are an important control over the ability of irrigated wastewater to infiltrate, with a strong seasonal bias towards lower infiltration rates during the cooler months of the year when evapotranspiration rates are low. Determining seasonal and annual average *in situ* infiltration rates would aid in irrigation scheduling.

Therefore, the decrease in soil infiltration is likely to be caused by the recent rainfall than soil structural damage. However, the soils were significantly wetter than the Environment Southland monitoring site indicated for the surrounding region and indicates the return period for irrigation likely needs to be increased to allow for soils to dry, especially coming into wetter seasons.

Table 1: Mean, median, minimum, and maximum soil infiltration rates at the monitoring sites. Soil moisture deficit from Blue Sky Pastures closest moisture sensor(s) at time of sampling.

Site	Mean (mm/hr)	Median (mm/hr)	Minimum (mm/hr)	Maximum (mm/hr)	Soil moisture deficit at closest sensor (mm)	Soil Moisture Sensor
1 Control	45	44	40	52	9	5
2	17	4	4	44	5	2 and 3*
3	33	32	28	40	0 - 5	4 and 2
4	12	12	4	20	0	1
5	63	44	40	104	Not available	3*

Soil moisture 3 unavailable.

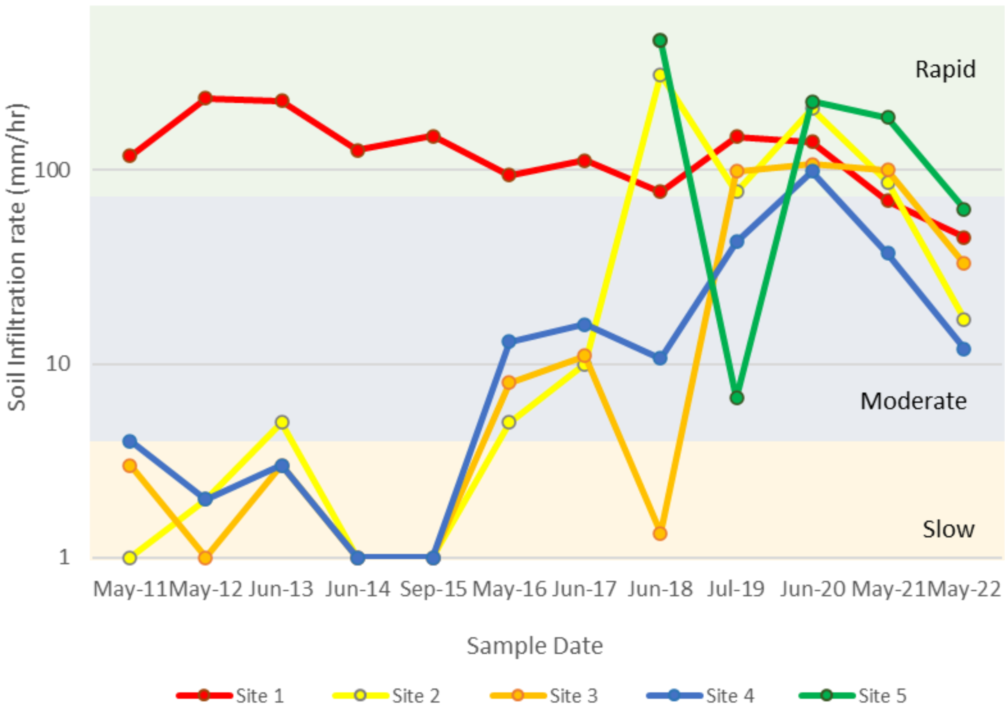

Figure 11: Log_{10} plot of mean infiltration rate at each site between 2011 and 2022. For historic monitoring data see Appendix A.

4.2 Soil Chemical Analysis

The results of the soil chemical analyses for 2022 from Hill Laboratories are provided in Table 2. Exchangeable sodium percent (ESP) was calculated using the milliequivalent (me/100g) sodium concentration divided by the cation exchange capacity (CEC) and expressed as a percentage. See Appendix B for Hill Laboratories Certificate of Analysis.

Table 2: Soil chemical analysis including the calculation of exchangeable sodium percent. Ca, Mg, K and Na results are reported as MAF quick test values. Site 1 control is shaded.

	pH	Ca (MAF)	Mg (MAF)	K (MAF)	Na (MAF)	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
Site 1	5.8	7	20	8	8	1.2	19	0.56	26
Site 2	6.2	5	20	21	40	5.8	18	0.49	76
Site 3	6.1	5	20	28	34	4.9	19	0.54	108
Site 4	6.7	8	18	40	51	7.0	18	0.47	63
Site 5	6.6	9	27	28	56	7.0	21	0.54	59

The soil monitoring results have been graphed against previous years monitoring for comparison and identification of any trends in the data and discussed further in the following subsections. See Appendix A for a table of historical results from Greenwood (2017) and Pearson (2018-2021). The soil quality indicators for acidity (pH), fertility (Olsen P) and organic resources (Total N) are assessed against Landcare Research's SINDI: Soil Quality Indicators[2] online tool which compares the analytical results against the National Soils Database. Soil pH, Olsen P and Total N have been evaluated for a Brown soil (NZSC) under a dry stock land use. Cation exchange capacity and exchangeable bases are assessed against Blakemore et al. (1981) which provides ratings for the chemical properties of New Zealand soils, and McLaren and Cameron (1996) for soil quick test optimal pasture response.

4.2.1 Soil pH

Soil pH values for 2022 show the soil to be near neutral to moderately acid (Blakemore et al., 1981). The control, Sites 2 and 3 are all within the optimal range of 5.5 - 6.5 for a pastoral land use, with Sites 4 and 5 slightly out of this range (Landcare Research, SINDI online). Soil pH in the near neutral to alkaline range are higher than necessary for productive pasture and above optimal growth. Further increases can lead to a loss of desirable pasture species. It is recommended that lime applications be reduced at these sites.

Over the monitoring period, soil pH has ranged between 5.5 and 6.7 at all sites (Figure 12). The 2022 analysis shows an increase in pH (increasing alkalinity) for all sites except Site 2, which recorded no change since sampling in 2021 (Pearson, 2021).

[2] https://sindi.landcareresearch.co.nz/

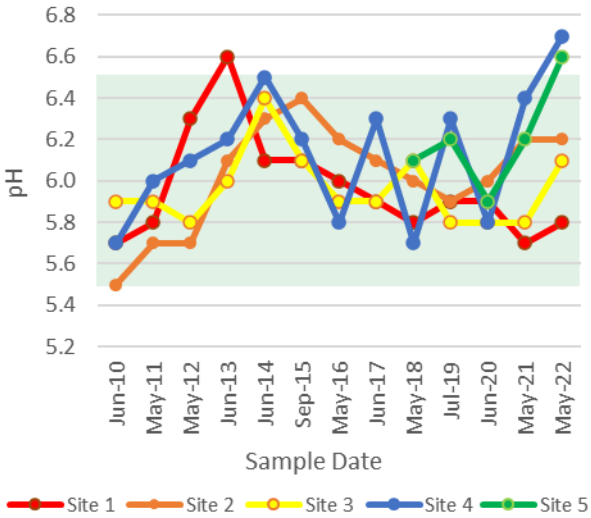

Figure 12: Soil pH results between 2010 and 2022. Green shading shows optimal range according to Landcare Research (SINDI online) for a Brown Soil under dry stock.

4.2.2 Nitrogen (N) and Phosphorus (P)

Total Nitrogen (TN), ranged between 0.47 - 0.56% across the wastewater irrigation sites (Table 2). The control site has a TN value of 0.56% (Table 2). Overall, these sites are all within the medium range for New Zealand soils (Blakemore et al., 1981). This range of mineralisable nitrogen is adequate to meet pasture demand and equates to a C:N ratio of approximately 10 - 12 (Landcare Research, SINDI online). Only site 3 showed an increase in TN from the monitoring undertaken in 2021 (Figure 13A; Pearson, 2021). As the nitrogen is not accumulating within the soil, it is important to interpret the soil N results with groundwater monitoring, to indicate if the nitrogen load is leached to groundwater.

Soil Olsen P, a measure of the plant available phosphorus, was excessively high at all discharge sites (ranging from 59 to 108 mg/l). These sites all exceed recommended optimum values for pasture growth (Figure 13B, Table 2). There was no change in Olsen P at the control site. An Olsen P of 26 mg/l is sufficient for the current land use. All discharge sites showed an increase in Olsen P from the previous year's monitoring (Figure 13B, Pearson, 2021). Areas with soil Olsen P values above the optimum have a significant risk of phosphorus leaching to both shallow ground- and surface water bodies. Good management practice is to use soil testing results to guide irrigation loading rates and any additional inputs (i.e., fertiliser).

High soil nutrient levels can be reduced by decreasing the load of nutrient going onto the land by:

- (i) spreading wastewater over a larger area;
- (ii) reducing its concentration in wastewater, and/or;
- (iii) by removing excess nutrient off-site in harvested plant material under a 'cut and carry' scenario.

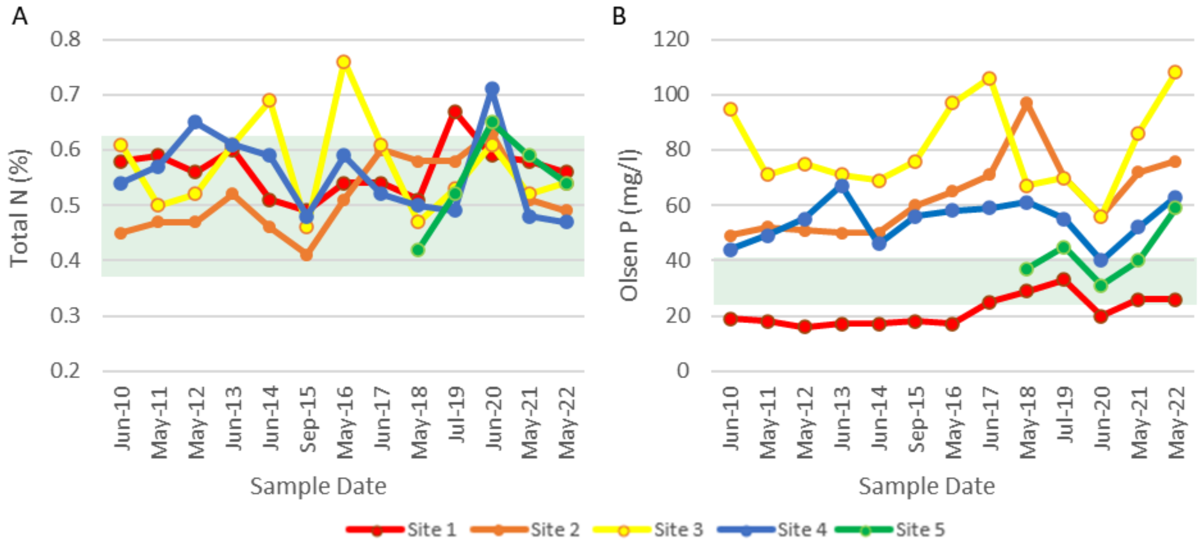

Figure 13: Total N and Olsen P results between 2010 and 2022. Green shading shows adequate range according to Landcare Research (SINDI online) for a Brown soil under dry stock. Values above this range are likely to be in excess of plant demand. There is a significant risk of leaching to waterways with excessive concentrations.

4.2.3 Macronutrients (Ca, Mg, Na, K)

Under normal soil pH conditions there is usually an overall excess of negative charge on the surface of soil particles onto which cations, calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}), are adsorbed. The area and density of exchange sites for cation attraction depends on the type of particles that make up the soil, with the least number of exchange sites on sand particles and the greatest number of exchange sites on clays. The amount of negative charge on clay hydroxy groups or organic matter is dependent on the pH of the surrounding solution, with a higher pH resulting in greater CEC. Cation exchange capacity (CEC) is the measure used to determine how many exchange sites a soil has (typically measured in milliequivalents per 100 grams, or me/100 g). For consistency with historical data from Greenwood (2017) and to demonstrate potential trends in the data, soil quick test MAF values have been presented in Table 2 and Figure 15. The CEC of the soil at BSM is within the typical range of a sedimentary soil (Figure 14; McLaren and Cameron, 1996).

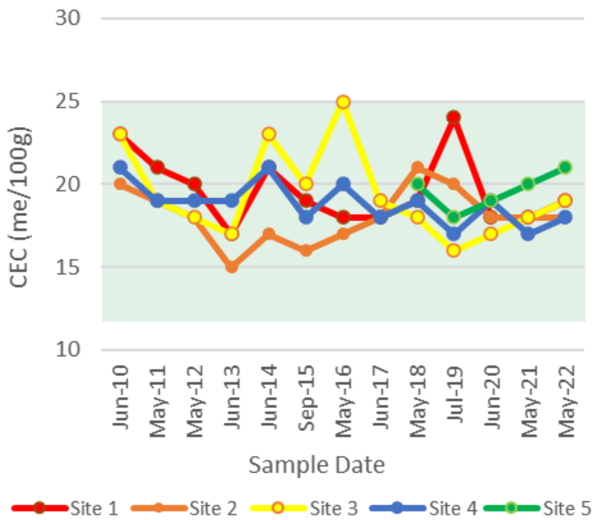

Figure 14: Cation Exchange Capacity (CEC) results between 2010 and 2022. Green shading shows the typical range for a sedimentary soil (McLaren and Cameron, 1996).

As not all the exchange sites of a soil are necessarily occupied by cations, the measure of the occupancy of the exchange sites by Ca, Mg, Na, and K is defined by percentage base saturation (BS) (%). The base saturation and milliequivalent concentrations for Ca, Mg, K and Na are presented in Table 3. Base Saturation is calculated by Hill Laboratories, along with CEC, and is a good way of assessing the balance between the macronutrients. Desirable base saturation levels for an agricultural land use are Ca 50 - 75%, Mg 5 -15%, K 2 - 5% and Na 1 - 2%. Low supply of macronutrients in the soil is likely to affect pasture yield, while oversupply can affect stock health with no pasture yield increase expected.

Table 3 shows the control site has base saturation levels within the range of typical agricultural soils, except for Ca which is lower. The wastewater discharge areas (Sites 2-5) have a higher K and Na base saturation than typical agricultural land, suggesting significant leaching of Ca and Mg. Divalent cations (Ca^{2+} and Mg^{2+}) are generally held more tightly on exchange sites than monovalent cations (K^+ and Na^+), however if monovalent cations are high in soil solution, as is typical in wastewater discharge areas, exchange can occur between K and Na, reducing the Ca and Mg on exchange sites. The leaching of the divalent cations Ca and Mg is a common feature of soils receiving large volumes of waste with elevated Na and K concentrations.

Table 3: Milliequivalent (me/100g) and Base Saturation (BS %) of Ca, Mg, K, and Na.

	Ca		Mg		K		Na		Total BS
	me.100g	BS (%)	me.100g	BS (%)	me.100g	BS (%)	me.100g	BS (%)	(%)
Site 1 (C)	7.2	37	1.21	6.3	0.52	2.7	0.23	1.2	48
Site 2	5.0	28	1.05	6.0	1.23	7.0	1.04	5.9	47
Site 3	4.9	25	1.08	5.7	1.68	8.8	0.93	4.8	45
Site 4	6.9	37	0.89	4.8	2.21	12	1.26	6.8	61
Site 5	9.0	43	1.41	6.7	1.60	7.6	1.46	6.9	64

Blakemore et al. (1981) provides a rating for exchangeable bases for New Zealand soils. This is a good benchmark to rate whether concentrations are naturally elevated at the control site (Site 1) or elevated due to wastewater application. Calcium values for the control site are within the medium range of 5-10 me.100g. The wastewater discharge areas Sites 4 and 5 are also within the medium range for New Zealand soils while Sites 2 and 3 are low (Figure 15A; Blakemore et al., 1981). Magnesium concentrations are also non-limiting to plant uptake and all sites are in the low to medium range for New Zealand soils (Figure 15B; Blakemore et al., 1981). All sites show similar or slight increases in Ca and Mg compared to 2021 results (Pearson, 2021). Sodium values are low at the control site (Site 1), and high (0.7-2.0 me.100g) at all wastewater discharge sites (Figure 12C; Blakemore et al., 1981). Potassium values are medium at the control site (Site 1), very high (> 1.2 me.100g) at all wastewater discharge sites Figure 15D; Blakemore et al., 1981).

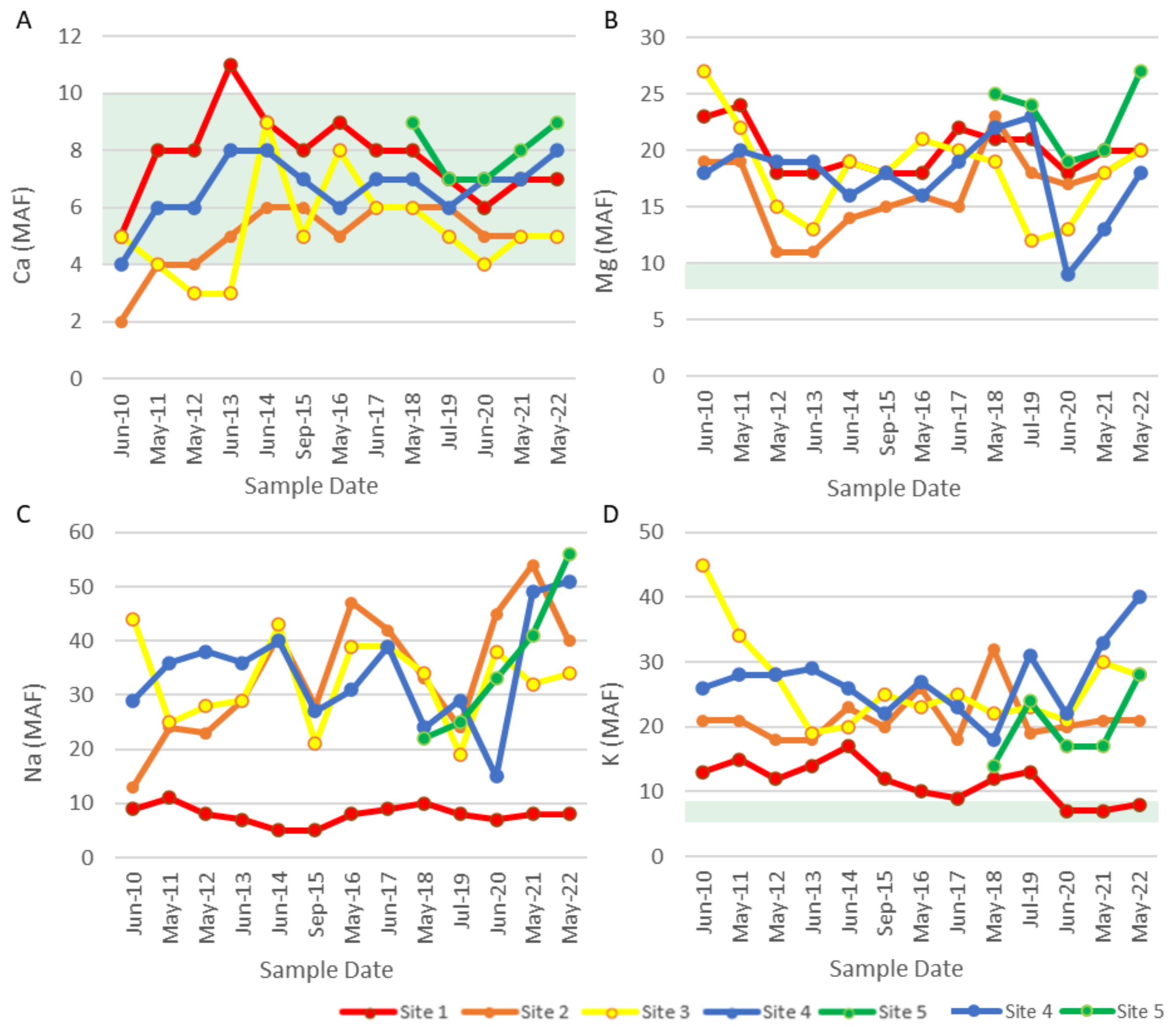

Figure 15: Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K) results between 2010 and 2022. Green shading shows an optimum range for plant growth according to McLaren and Cameron (1996). Values above the optimum range indicate plants are not limited by this macronutrient. Sodium is not required for plant growth, therefore does not have an optimum range for plant uptake (see section 4.2.4).

A significant environmental concern with the discharge of wastewater to land is the accumulation of monovalent cations, Na^+ and K^+ and the loss of divalent Ca^{2+} and Mg^{2+} in the soil profile and the resultant degradation of soil structure, which in turn affects aeration and water movement. Sodium assimilation by plants is low, therefore a management approach to mitigate the effects is often to leach the salt through the soil profile; however, this can have adverse effects on the environment via leaching of other nutrients, such as N and P. Sodium quick test values are elevated at all sites (34 – 56 MAF) compared to the control (8 MAF) (Table 2). Na concentrations have increased at Sites 3, 4 and 5 and decreased at Site 2 since monitoring in 2021 (Figure 15C, Pearson, 2020). Exchangeable Na percent is used to assess risk and is discussed further in section 4.2.4.

Although plant uptake of K is typically high; plant requirements are often exceeded under typical wastewater applications. This is evident in elevated K quick test values (21 – 40 MAF) relative to the control site (8 MAF) (Table 2, Figure 15D). K has increased at Sites 1, 4 and 5 since the previous year’s monitoring (Pearson, 2020). High K values can result in restricted magnesium uptake by plants. Herbage sampling for plant nutrients could be part of the annual monitoring if it was deemed important to ensure pasture and animal health was not under stress, however this is not considered necessary at this time.

4.2.4 Exchangeable Sodium Percent (ESP)

High concentrations of Na (and K) in the soil profile can cause degradation of soil structure, which in turn affects aeration and water movement (McLaren and Cameron, 1996). Most of the work on Na problems in soils has been undertaken in Australia and many of the guidelines are Australian based. New Zealand soils are generally less prone to Na/K dispersion problems than Australian soils because our humid temperate climate generally promotes leaching of soils to a degree that minimises accumulation of soluble salts within soil horizons. Therefore, using Australian guidelines can be considered conservative for NZ situations. Typically, problems are very unlikely if ESP remains below 5 - 6%.

ESP has increased above the optimal range at Sites 2, 4 and 5 could result in soil structural damage (Figure 16). This could be a result of the drought conditions in Southland over the summer months in addition to wastewater loading. It is recommended that these concentrations be managed with annual applications of divalent cations, such as lime or gypsum. Given evidence of Ca and Mg leaching dolomite lime is likely to be a good option at Blue Sky Pastures when soil pH needs to be increased.

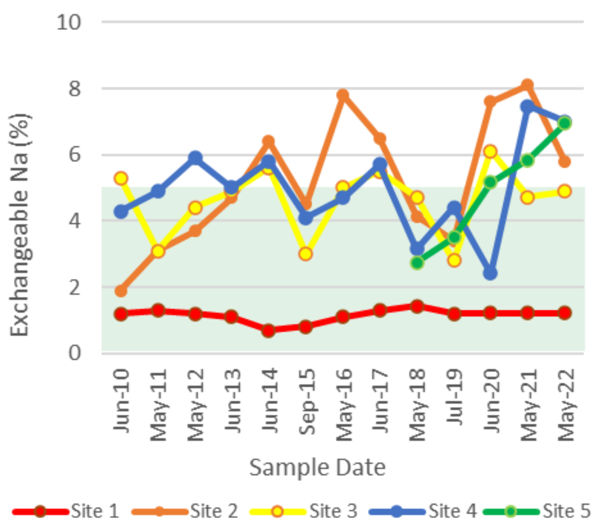

Figure 16: Exchangeable Na (ESP) results between 2010 and 2022.

5 Summary and Recommendations

Accumulation of nutrients in the soil may not harm the soil itself but can impact on plant and animal health and water quality if not appropriately monitored and managed. None of the changes to the soil from long-term irrigation at BSM appear to be detrimental to the long-term functioning of the soil and all are reversible.

Best management practice for managing nutrients in many wastewaters focuses on reducing leaching and runoff losses thereby retaining constituents, such as N and P, within the soil profile where the opportunity for retention by the soil matrix, removal via denitrification and assimilation by plants and microbial biomass is maximised. Excessive Na and K loading can deplete soils of Ca and Mg needed for maintenance of good soil structure and drainage and may also reduce soil pH.

Utilising the maximum discharge area for irrigation (lower loading rates) and removal of excess nutrient via cut and carry type operations is the most suitable way of reducing nutrient leaching and preventing Na and K overloading.

Comparisons with monitoring results from 2021 show decreases in soil infiltration at all sites. The soil moisture conditions at the time of sampling would likely have impacted this result, however given the dryness of the summer the soils should not have been as saturated this early into the autumn/winter months. The soil had also not been mechanically aerated this year, and it is recommended that aeration is undertaken at least annually to maintain soil structure.

For soil chemistry, Olsen P concentrations have increased at all discharge sites and are nearing or at excessive concentrations for pastoral growth. Similar rainfall volumes were recorded in the three months prior to sampling this year compared to 2021, therefore the higher concentrations of Na and K are likely due wastewater loading (Pearson, 2021). Ensuring application across the full irrigation area is recommended to avoid over saturating and loading the soil. These results should be interpreted alongside groundwater monitoring to assess whether the nitrogen that is not retain by the soil is being leached or removed by plant uptake.

Irrigation rates should be seasonally adjusted to account for soil infiltration rates, precipitation, and soil moisture conditions. Exceeding field capacity or irrigating on soils already above field capacity elevates the potential for surface ponding and runoff to occur to waterways. The hydraulic and organic loading of the wastewater applied should be regularly assessed to determine appropriate loading rates and irrigation return times for the discharge sites.

6 References

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Appendix A: Historic Monitoring Data

Soil Infiltration

Table A1: Soil infiltration rate measurements from Greenwood (2017), Pearson (2018-2021) and this year's survey. Mean and median values are calculated from the long-term record and are shown for each site in bold.

	Site 1 - Control	Site 2	Site 3	Site 4	Site 5
May-11	119	1	3	4	
May-12	235	2	1	2	
Jun-13	228	5	3	3	
Jun-14	127	<1	<1	<1	
Sep-15	150	<1	<1	<1	
May-16	94	5	8	13	
Jun-17	112	10	11	16	
Jun-18	77	311	1	11	464
Jul-19	149	77	99	43	7
Jun-20	140	208	107	99	227
May-21	69	87	100	37	187
May-22	45	17	33	12	63
Average	128.8	60.5	30.7	20.1	189.6
Median	123.0	7.5	5.5	11.3	187.0

Soil Chemistry

Table A2: Soil chemistry data from Greenwood (2017), Pearson (2018-2021) and this year's survey. Mean and median values are calculated from the long-term record and are shown for each site in bold.

	Date	pH	Ca	Mg	K	Na	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
Site 1	Jun-10	5.7	5	23	13	9	1.2	23	0.58	19
Control	May-11	5.8	8	24	15	11	1.3	21	0.59	18
	May-12	6.3	8	18	12	8	1.2	20	0.56	16
	Jun-13	6.6	11	18	14	7	1.1	17	0.60	17
	Jun-14	6.1	9	19	17	5	0.7	21	0.51	17
	Sep-15	6.1	8	18	12	5	0.8	19	0.49	18
	May-16	6.0	9	18	10	8	1.1	18	0.54	17
	Jun-17	5.9	8	22	9	9	1.3	18	0.54	25
	May-18	5.8	8	21	12	10	1.4	19	0.51	29
	Jul-19	5.9	7	21	13	8	1.2	24	0.67	33
	Jun-20	5.9	6	18	7	7	1.2	18	0.59	20
	May-21	5.7	7	20	7	8	1.2	18	0.58	26
	May-22	5.8	7	20	8	8	0.0	19	0.56	26
	Average	6.0	7.8	20.0	11.5	7.9	1.1	19.6	0.56	21.6
	Median	5.9	8.0	20.0	12.0	8.0	1.2	19.0	0.6	19.0
Site 2	Jun-10	5.5	2	19	21	13	1.9	20	0.45	49
	May-11	5.7	4	19	21	24	3.1	19	0.47	52
	May-12	5.7	4	11	18	23	3.7	18	0.47	51
	Jun-13	6.1	5	11	18	29	4.7	15	0.52	50
	Jun-14	6.3	6	14	23	41	6.4	17	0.46	50
	Sep-15	6.4	6	15	20	28	4.5	16	0.41	60
	May-16	6.2	5	16	26	47	7.8	17	0.51	65
	Jun-17	6.1	6	15	18	42	6.5	18	0.60	71
	May-18	6.0	6	23	32	33	4.1	21	0.58	97

	Date	pH	Ca	Mg	K	Na	ESP (%)	CEC (%)	Total N (%)	Olsen P (ug/ml)
	Jul-19	5.9	6	18	19	24	3.4	20	0.58	70
	Jun-20	6.0	5	17	20	45	7.6	18	0.63	56
	May-21	6.2	5	18	21	54	8.1	18	0.51	72
	May-22	6.2	5	20	21	40	0.0	18	0.49	76
	Average	6.0	5.0	16.6	21.4	34.1	4.8	18.1	0.51	63.0
	Median	6.1	5.0	17.0	21.0	33.0	4.5	18.0	0.51	60.0
Site 3	Jun-10	5.9	5	27	45	44	5.3	23	0.61	95
	May-11	5.9	4	22	34	25	3.1	19	0.50	71
	May-12	5.8	3	15	28	28	4.4	18	0.52	75
	Jun-13	6.0	3	13	19	29	4.9	17	0.61	71
	Jun-14	6.4	9	19	20	43	5.6	23	0.69	69
	Sep-15	6.1	5	18	25	21	3.0	20	0.46	76
	May-16	5.9	8	21	23	39	5.0	25	0.76	97
	Jun-17	5.9	6	20	25	39	5.5	19	0.61	106
	May-18	6.1	6	19	22	34	4.7	18	0.47	67
	Jul-19	5.8	5	12	23	19	2.8	16	0.53	70
	Jun-20	5.8	4	13	21	38	6.1	17	0.61	56
	May-21	5.8	5	18	30	32	4.7	18	0.52	86
	May-22	6.1	5	20	28	34	0.0	19	0.54	108
	Average	6.0	5.2	18.2	26.4	32.7	4.2	19.4	0.57	80.5
	Median	5.9	5.0	19.0	25.0	34.0	4.7	19.0	0.54	75.0
Site 4	Jun-10	5.7	4	18	26	29	4.3	21	0.54	44
	May-11	6.0	6	20	28	36	4.9	19	0.57	49
	May-12	6.1	6	19	28	38	5.9	19	0.65	55
	Jun-13	6.2	8	19	29	36	5.0	19	0.61	67
	Jun-14	6.5	8	16	26	40	5.8	21	0.59	46
	Sep-15	6.2	7	18	22	27	4.1	18	0.48	56
	May-16	5.8	6	16	27	31	4.7	20	0.59	58
	Jun-17	6.3	7	19	23	39	5.7	18	0.52	59
	May-18	5.7	7	22	18	24	3.2	19	0.50	61
	Jul-19	6.3	6	23	31	29	4.4	17	0.49	55
	Jun-20	5.8	7	9	22	15	2.4	19	0.71	40
	May-21	6.4	7	13	33	49	7.5	17	0.48	52
	May-22	6.7	8	18	40	51	0.0	18	0.47	63
	Average	6.1	6.7	17.7	27.2	34.2	4.4	18.8	0.55	54.2
	Median	6.2	7.0	18.0	27.0	36.0	4.7	19.0	0.54	55.0
Site 5	May-18	6.1	9	25	14	22	2.8	20	0.42	37
	Jul-19	6.2	7	24	24	25	3.5	18	0.52	45
	Jun-20	5.9	7	19	17	33	5.2	19	0.65	31
	May-21	6.2	8	20	17	41	5.9	20	0.59	40
	May-22	6.6	9	27	28	56	0.0	21	0.54	59
	Average	6.2	7.4	19.6	24.7	34.9	3.8	18.8	0.54	50.1
	Median	6.2	7.0	19.0	24.0	34.2	4.4	19.0	0.52	54.2

Appendix B: Hill Laboratory Results

Additional sites analysed for BSP have been removed from this report.

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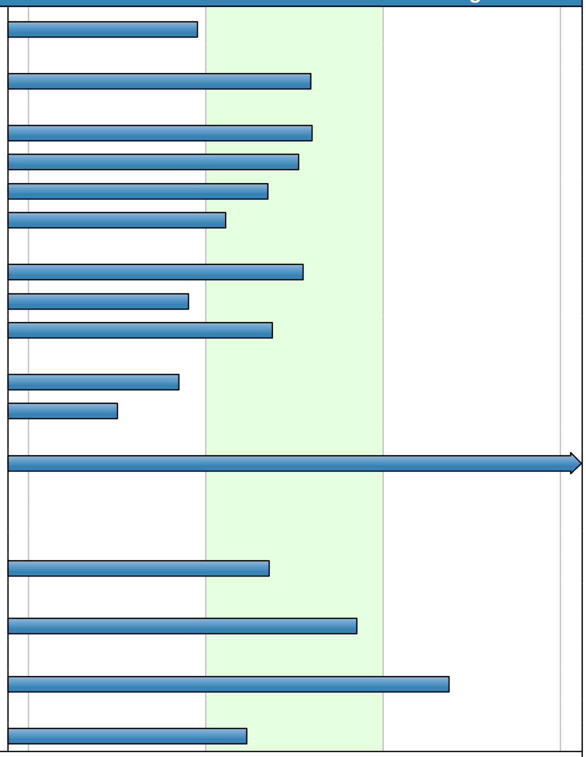
Certificate of Analysis

Client:	Land and Water Science Limited	**Lab No:**	3003752 shvpv1
Address:	90 Layard Street Invercargill 9810	**Date Received:**	01-Jun-2022
		Date Reported:	15-Jun-2022
		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSP Site 1 (C) **Lab Number:** 3003752.1
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range
pH	pH Units	5.8	5.8 - 6.2
Olsen Phosphorus	mg/L	26	20 - 30
Potassium	me/100g	0.52	0.40 - 0.60
Calcium	me/100g	7.2	4.0 - 10.0
Magnesium	me/100g	1.21	1.00 - 1.60
Sodium	me/100g	0.23	0.20 - 0.50
CEC	me/100g	19	12 - 25
Total Base Saturation	%	48	50 - 85
Volume Weight	g/mL	0.75	0.60 - 1.00
Sulphate Sulphur	mg/kg	9	10 - 12
Extractable Organic Sulphur	mg/kg	10	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	430	150 - 250
Anaerobically Mineralisable N*	µg/g	382	
Organic Matter*	%	10.6	7.0 - 17.0
Total Carbon	%	6.1	
Total Nitrogen	%	0.56	0.30 - 0.60
C/N Ratio*		11.0	
Anaerobically Mineralisable N/Total N Ratio*	%	6.9	3.0 - 5.0
'Total' Phosphorus	mg/kg	909	700 - 1600



	K	Ca	Mg	Na
Base Saturation %	K 2.7	Ca 37	Mg 6.3	Na 1.2
MAF Units	K 8	Ca 7	Mg 20	Na 8

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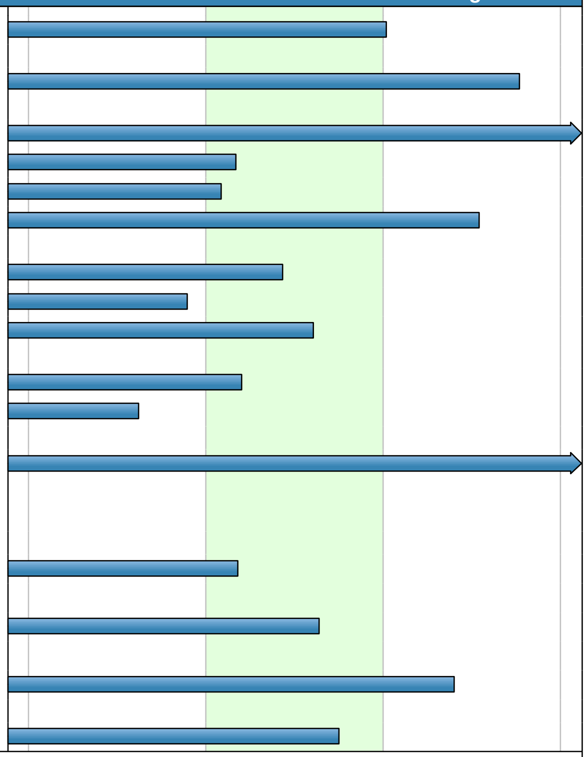
Address:	90 Layard Street Invercargill 9810	**Date Received:**	01-Jun-2022
		Date Reported:	15-Jun-2022
		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSP Site 2 **Lab Number:** 3003752.2
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range	Low	Medium	High
pH	pH Units	6.2	5.8 - 6.2			
Olsen Phosphorus	mg/L	76	20 - 30			
Potassium	me/100g	1.23	0.40 - 0.60			
Calcium	me/100g	5.0	4.0 - 10.0			
Magnesium	me/100g	1.05	1.00 - 1.60			
Sodium	me/100g	1.04	0.20 - 0.50			
CEC	me/100g	18	12 - 25			
Total Base Saturation	%	47	50 - 85			
Volume Weight	g/mL	0.84	0.60 - 1.00			
Sulphate Sulphur	mg/kg	10	10 - 12			
Extractable Organic Sulphur	mg/kg	11	15 - 20			
Potentially Available Nitrogen (15cm Depth)*	kg/ha	436	150 - 250			
Anaerobically Mineralisable N*	µg/g	345				
Organic Matter*	%	8.8	7.0 - 17.0			
Total Carbon	%	5.1				
Total Nitrogen	%	0.49	0.30 - 0.60			
C/N Ratio*		10.4				
Anaerobically Mineralisable N/Total N Ratio*	%	7.0	3.0 - 5.0			
'Total' Phosphorus	mg/kg	1,377	700 - 1600			
Base Saturation %		K 7.0	Ca 28	Mg 6.0	Na 5.9	
MAF Units		K 21	Ca 5	Mg 20	Na 40	



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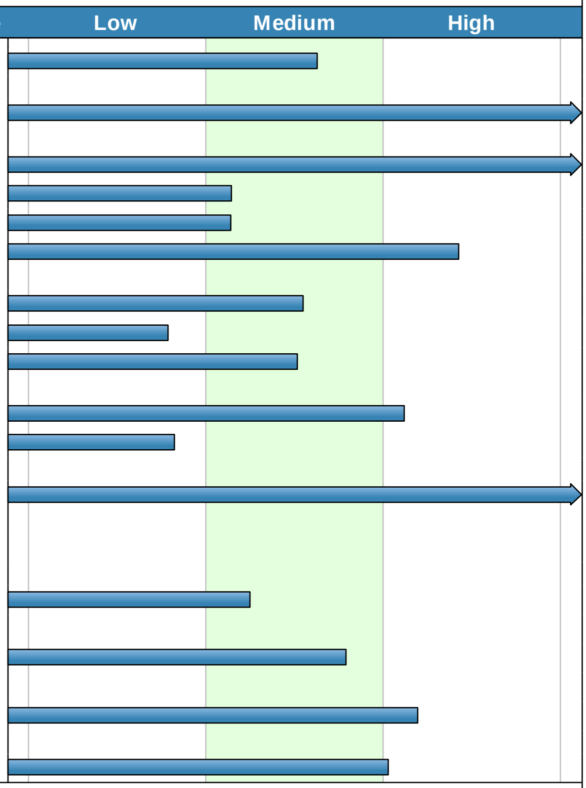
Certificate of Analysis

Client:	Land and Water Science Limited	**Lab No:**	3003752 shvpv1
Address:	90 Layard Street Invercargill 9810	**Date Received:**	01-Jun-2022
		Date Reported:	15-Jun-2022
		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSP Site 3 **Lab Number:** 3003752.3
Sample Type: SOIL Mixed Pasture (S1)

Analysis		Level Found	Medium Range
pH	pH Units	6.1	5.8 - 6.2
Olsen Phosphorus	mg/L	108	20 - 30
Potassium	me/100g	1.68	0.40 - 0.60
Calcium	me/100g	4.9	4.0 - 10.0
Magnesium	me/100g	1.08	1.00 - 1.60
Sodium	me/100g	0.93	0.20 - 0.50
CEC	me/100g	19	12 - 25
Total Base Saturation	%	45	50 - 85
Volume Weight	g/mL	0.81	0.60 - 1.00
Sulphate Sulphur	mg/kg	17	10 - 12
Extractable Organic Sulphur	mg/kg	13	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	389	150 - 250
Anaerobically Mineralisable N*	µg/g	322	
Organic Matter*	%	9.5	7.0 - 17.0
Total Carbon	%	5.5	
Total Nitrogen	%	0.54	0.30 - 0.60
C/N Ratio*		10.2	
Anaerobically Mineralisable N/Total N Ratio*	%	6.0	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,624	700 - 1600
Base Saturation %		K 8.8 Ca 25 Mg 5.7 Na 4.8	
MAF Units		K 28 Ca 5 Mg 20 Na 34	



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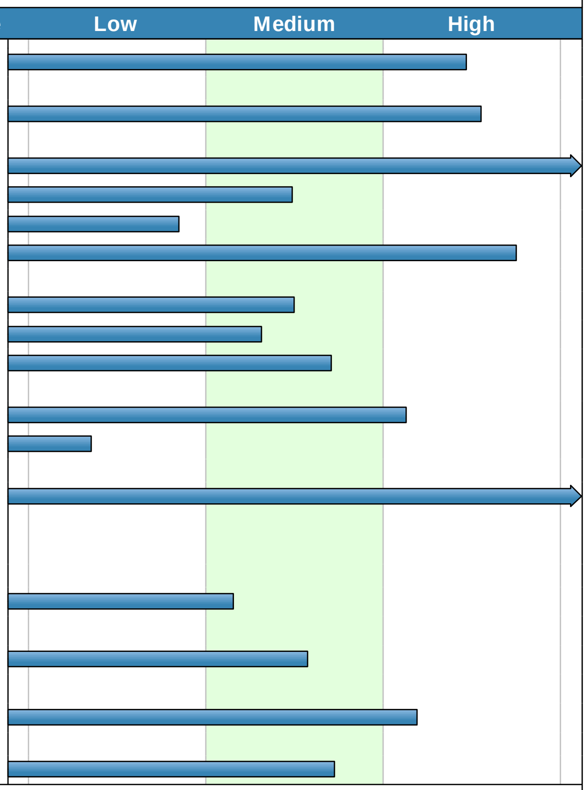
		Date Reported:	15-Jun-2022
		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSP Site 4 **Lab Number:** 3003752.4
Sample Type: SOIL Mixed Pasture (S1)

Analysis	Units	Level Found	Medium Range
pH	pH Units	6.7	5.8 - 6.2
Olsen Phosphorus	mg/L	63	20 - 30
Potassium	me/100g	2.21	0.40 - 0.60
Calcium	me/100g	6.9	4.0 - 10.0
Magnesium	me/100g	0.89	1.00 - 1.60
Sodium	me/100g	1.26	0.20 - 0.50
CEC	me/100g	18	12 - 25
Total Base Saturation	%	61	50 - 85
Volume Weight	g/mL	0.88	0.60 - 1.00
Sulphate Sulphur	mg/kg	17	10 - 12
Extractable Organic Sulphur	mg/kg	9	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	373	150 - 250
Anaerobically Mineralisable N*	µg/g	282	
Organic Matter*	%	8.5	7.0 - 17.0
Total Carbon	%	5.0	
Total Nitrogen	%	0.47	0.30 - 0.60
C/N Ratio*		10.5	
Anaerobically Mineralisable N/Total N Ratio*	%	6.0	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,354	700 - 1600



	K	Ca	Mg	Na
Base Saturation %	K 12.0	Ca 37	Mg 4.8	Na 6.8
MAF Units	K 40	Ca 8	Mg 18	Na 51

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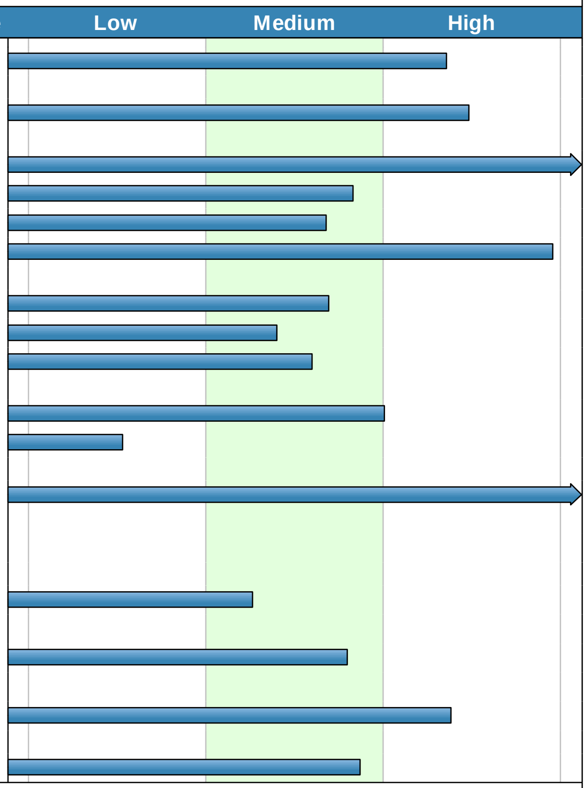
Client:	Land and Water Science Limited	**Lab No:**	3003752 shvpv1
Address:	90 Layard Street Invercargill 9810	**Date Received:**	01-Jun-2022
		Date Reported:	15-Jun-2022
		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Name: BSP Site 5 **Lab Number:** 3003752.5
Sample Type: SOIL Mixed Pasture (S1)

Analysis	Units	Level Found	Medium Range
pH	pH Units	6.6	5.8 - 6.2
Olsen Phosphorus	mg/L	59	20 - 30
Potassium	me/100g	1.60	0.40 - 0.60
Calcium	me/100g	9.0	4.0 - 10.0
Magnesium	me/100g	1.41	1.00 - 1.60
Sodium	me/100g	1.46	0.20 - 0.50
CEC	me/100g	21	12 - 25
Total Base Saturation	%	64	50 - 85
Volume Weight	g/mL	0.84	0.60 - 1.00
Sulphate Sulphur	mg/kg	12	10 - 12
Extractable Organic Sulphur	mg/kg	10	15 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	471	150 - 250
Anaerobically Mineralisable N*	µg/g	374	
Organic Matter*	%	9.6	7.0 - 17.0
Total Carbon	%	5.6	
Total Nitrogen	%	0.54	0.30 - 0.60
C/N Ratio*		10.3	
Anaerobically Mineralisable N/Total N Ratio*	%	6.9	3.0 - 5.0
'Total' Phosphorus	mg/kg	1,484	700 - 1600
Base Saturation %		K 7.6 Ca 43 Mg 6.7 Na 6.9	
MAF Units		K 28 Ca 9 Mg 27 Na 56	



Certificate of Analysis

Client:	Land and Water Science Limited	**Lab No:**	3003752 shvpv1
Address:	90 Layard Street Invercargill 9810	**Date Received:**	01-Jun-2022
		Date Reported:	15-Jun-2022
		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Soil Analysis Results

Sample Name:		BSP Site 1 (C)	BSP Site 2	BSP Site 3	BSP Site 4	BSP Site 5
Lab Number:		3003752.1	3003752.2	3003752.3	3003752.4	3003752.5
Sample Type:		SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture	SOIL Mixed Pasture
Sample Type Code:		S1	S1	S1	S1	S1
pH	pH Units	5.8	6.2	6.1	6.7	6.6
Olsen Phosphorus	mg/L	26	76	108	63	59
Potassium	me/100g	0.52	1.23	1.68	2.21	1.60
Potassium	%BS	2.7	7.0	8.8	12.0	7.6
Potassium	MAF units	8	21	28	40	28
Calcium	me/100g	7.2	5.0	4.9	6.9	9.0
Calcium	%BS	37	28	25	37	43
Calcium	MAF units	7	5	5	8	9
Magnesium	me/100g	1.21	1.05	1.08	0.89	1.41
Magnesium	%BS	6.3	6.0	5.7	4.8	6.7
Magnesium	MAF units	20	20	20	18	27
Sodium	me/100g	0.23	1.04	0.93	1.26	1.46
Sodium	%BS	1.2	5.9	4.8	6.8	6.9
Sodium	MAF units	8	40	34	51	56
CEC	me/100g	19	18	19	18	21
Total Base Saturation	%	48	47	45	61	64
Volume Weight	g/mL	0.75	0.84	0.81	0.88	0.84
Sulphate Sulphur	mg/kg	9	10	17	17	12
Extractable Organic Sulphur	mg/kg	10	11	13	9	10
Potentially Available Nitrogen (15cm Depth)*	kg/ha	430	436	389	373	471
Anaerobically Mineralisable N*	µg/g	382	345	322	282	374
Organic Matter*	%	10.6	8.8	9.5	8.5	9.6
Total Carbon	%	6.1	5.1	5.5	5.0	5.6
Total Nitrogen	%	0.56	0.49	0.54	0.47	0.54
C/N Ratio*		11.0	10.4	10.2	10.5	10.3
Anaerobically Mineralisable N/Total N Ratio*	%	6.9	7.0	6.0	6.0	6.9
'Total' Phosphorus	mg/kg	909	1,377	1,624	1,354	1,484

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		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Analyst's Comments

Samples 1-9 Comment:
The medium or optimum range guidelines shown in the histogram report relate to sampling protocols as per Hill Laboratories' crop guides and are based on reference values where these are published. Results for samples collected to different depths than those described in the crop guide should be interpreted with caution.
For pastoral soils, the medium ranges are specific for a 75mm sample depth, but if a 150mm sampling depth is used the nutrient levels measured may appear low against these ranges, as nutrients are typically more concentrated in the top of the soil profile. These soil profile differences are altered upon cultivation or contouring.
Further explanation of the derivation of the medium and optimum ranges is available on request.

Samples 1-9 Comment:
While soil Mg MAF levels of 8-10 (0.4 - 0.6 me/100g) are sufficient for pasture production, soil levels of 25-30 (1 - 1.6 me/100g) are required to ensure adequate Mg content in pasture for animal health (greater than 0.22% in the herbage).

Samples 1-9 Comment:
The Potentially Available Nitrogen (kg/ha) test above assumes the sample is taken to a 15 cm depth. If the depth is 7.5 cm, then the result reported above should be divided by two.
To calculate Potentially Available Nitrogen (as kgN/ha) for other sample depths use the reported Anaerobic Mineralisable Nitrogen (AMN) result in the following equation:
AN (kg/ha) = AMN (µg/g) x VW (g/ml) x sample depth (cm) x 0.1
Note that the AN and AMN results reported include the readily available Mineral N (NH4-N and NO3-N) fraction, which is typically quite low.

Samples 1-9 Comment:
The medium range shown describes typical 'Total' Phosphorus levels for mineral soils in New Zealand. The 'Total' P test has not been correlated against pasture growth response rates so should be interpreted along with other observations.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sample Registration*	Samples were registered according to instructions received.	-	1-9
Soil Prep (Dry & Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2mm screen.	-	1-9
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. In-house.	0.1 pH Units	1-9
Olsen Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry. In-house method.	1 mg/L	1-9
Sulphate Sulphur	0.02M Potassium phosphate extraction followed by Ion Chromatography. In-house.	1 mg/kg	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	2 MAF units	1-9

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		Quote No:	118039
		Order No:	
		Client Reference:	BSP22009
		Add. Client Ref:	Abattoir Treated Wastewater Disposal Area
Phone:	03 214 3003	**Submitted By:**	Lisa Pearson

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Extractable Organic Sulphur	0.02M Potassium phosphate extraction. Total extractable S is determined by ICP-OES from which the Sulphate-S is subtracted. In-house.	2 mg/kg	1-9
Potentially Available Nitrogen	Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample). Note that any Mineral N present is included in the AN/AMN result reported. In-house.	10 kg/ha	1-9
Anaerobically Mineralisable N*	As for Potentially Available Nitrogen but reported as µg/g.	5 µg/g	1-9
Organic Matter*	Organic Matter is 1.72 x Total Carbon.	0.2 %	1-9
Total Carbon	Dumas combustion. In-house.	0.1 %	1-9
Total Nitrogen	Dumas combustion. In-house.	0.04 %	1-9
'Total' Phosphorus	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-OES. (Total recoverable nutrients reported on a dry weight basis) The levels from this method are referred to as 'Totals' in quotation marks, as they will be a slight under-estimation of the true Totals for some elements. In-house.	65 mg/kg	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.01 me/100g	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.5 me/100g	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.04 me/100g	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.05 me/100g	1-9
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-9
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 %BS	1-9
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.2 %BS	1-9
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-9
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity. May be overestimated if soil contains high levels of soluble salts or carbonates. In-house.	2 me/100g	1-9
Total Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	5 %	1-9
Volume Weight	The weight/volume ratio of dried, ground soil. In-house.	0.01 g/mL	1-9

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 03-Jun-2022 and 15-Jun-2022. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Fiona Calvert
Market Sector Manager - Agriculture

Appendix 2: Hill Laboratory Groundwater Monitoring Reports

Hill Laboratories
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Certificate of Analysis

SPv1

Client:	Blue Sky Meats (NZ) Limited	**Lab No:**	2527626
Contact:	Paulus Smith	**Date Received:**	13-Feb-2021
	C/- Blue Sky Meats (NZ) Limited	**Date Reported:**	22-Feb-2021
	729 Woodlands Morton Mains Road	**Quote No:**	109678
	RD 1	**Order No:**	
	Invercargill 9871	**Client Reference:**	Labeled Blue Sky Pastures Bore water
		Submitted By:	Paulus Smith

Sample Type: Aqueous

Sample Name:		MW3U 12-Feb-2021 10:15 am	MW2D 12-Feb-2021 12:40 pm	MW1D 12-Feb-2021 11:50 am	MW1D Deep 12-Feb-2021 1:30 pm	MW3D 12-Feb-2021 1:00 pm
Lab Number:		2527626.1	2527626.2	2527626.3	2527626.4	2527626.5
pH	pH Units	6.0	6.4	6.4	5.9	6.4
Electrical Conductivity (EC)	mS/m	17.2	25.4	17.6	102.1	37.2
Total Sodium	g/m^3	28	22	21	50	39
Chloride	g/m^3	24	23	23	168	43
Total Nitrogen	g/m^3	11.5	0.33	5.6	47	7.3
Total Ammoniacal-N	g/m^3	0.012	< 0.010	0.28	< 0.010	< 0.010
Nitrite-N	g/m^3	< 0.002	< 0.002	0.004	0.005	0.74
Nitrate-N + Nitrite-N	g/m^3	4.2	0.24	0.004	47	1.06
Total Kjeldahl Nitrogen (TKN)	g/m^3	7.3	< 0.10	5.6	< 0.10	6.2
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	21	0.020	7.6	0.047	0.88
Escherichia coli	MPN / 100mL	2 [#1]	-	< 1 [#1]	-	4 [#3]
Escherichia coli	cfu / 100mL	-	10 [#2]	-	37 [#3]	-

Sample Name:		MW1U 12-Feb-2021 11:20 am	MW2U 12-Feb-2021 10:45 am			
Lab Number:		2527626.6	2527626.7			
pH	pH Units	5.8	5.7	-	-	-
Electrical Conductivity (EC)	mS/m	27.0	43.6	-	-	-
Total Sodium	g/m^3	32	49	-	-	-
Chloride	g/m^3	44	64	-	-	-
Total Nitrogen	g/m^3	12.4	9.1	-	-	-
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	-	-	-
Nitrite-N	g/m^3	0.003	0.011	-	-	-
Nitrate-N + Nitrite-N	g/m^3	8.8	8.1	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	3.7	1.01	-	-	-
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	-	-	-
Total Phosphorus	g/m^3	2.5	1.03	-	-	-
Escherichia coli	MPN / 100mL	< 1 [#1]	> 23 [#1]	-	-	-

Analyst's Comments

#1 Please interpret this microbiological result with caution as the sample was > 24 hours old at the time of testing in the laboratory. The sample is required to reach the laboratory with sufficient time to allow testing to commence within 24 hours of sampling.
Please interpret this result with caution as the sample was > 10 °C on receipt at the lab. The sample temperature is recommended by the laboratory's reference methods to be less than 10 °C on receipt at the laboratory (but not frozen). However, it is acknowledged that samples that are transported quickly to the laboratory after sampling, may not have been cooled to this temperature.

#2 Statistically estimated count based on the theoretical countable range for the stated method.
Please interpret this microbiological result with caution as the sample was > 24 hours old at the time of testing in the laboratory. The sample is required to reach the laboratory with sufficient time to allow testing to commence within 24 hours of sampling.
Please interpret this result with caution as the sample was > 10 °C on receipt at the lab. The sample temperature is recommended by the laboratory's reference methods to be less than 10 °C on receipt at the laboratory (but not frozen). However, it is acknowledged that samples that are transported quickly to the laboratory after sampling, may not have been cooled to this temperature.

#3 Please interpret this microbiological result with caution as the sample was > 24 hours old at the time of testing in the laboratory. The sample was receipted by the laboratory within 24 hrs of sample collection, but due to processing delays it was not processed within the required time frame. An investigation has been instigated.
Please interpret this result with caution as the sample was > 10 °C on receipt at the lab. The sample temperature is recommended by the laboratory's reference methods to be less than 10 °C on receipt at the laboratory (but not frozen). However, it is acknowledged that samples that are transported quickly to the laboratory after sampling, may not have been cooled to this temperature.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1-7
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1-7
pH	pH meter. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-7
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 23rd ed. 2017.	0.1 mS/m	1-7
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.021 g/m³	1-7
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m³	1-7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m³ is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m³, the Default Detection Limit for Total Nitrogen will be 0.11 g/m³. In-house calculation.	0.05 g/m³	1-7
Total Ammoniacal-N	Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23rd ed. 2017.	0.010 g/m³	1-7
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m³	1-7
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m³	1-7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) 23rd ed. 2017.	0.10 g/m³	1-7
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m³	1-7
Total Phosphorus	Total phosphorus digestion, auotmated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H 23rd ed. 2017.	0.002 g/m³	1-7
Escherichia coli	MPN count in LT Broth at 35°C for 48 hours, TBX Confirmation. Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9221 B & F (modified) 23rd ed. 2017.	1 MPN / 100mL	1, 3, 5-7

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 I 23rd ed. 2017.	1 cfu / 100mL	2, 4

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 15-Feb-2021 and 22-Feb-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Martin Cowell - BSc
Client Services Manager - Environmental

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Certificate of Analysis

Client:	Blue Sky Meats (NZ) Limited	**Lab No:**	2604649 SPv1
Contact:	Paulus Smith	**Date Received:**	06-May-2021
	C/- Blue Sky Meats (NZ) Limited	**Date Reported:**	11-May-2021
	729 Woodlands Morton Mains Road	**Quote No:**	109678
	RD 1	**Order No:**	
	Invercargill 9871	**Client Reference:**	Labeled Blue Sky Pastures Bore water
		Submitted By:	Paulus Smith

Sample Type: Aqueous

Sample Name:		MW3A School House 05-May-2021 9:00 am	MW2D Lane 05-May-2021 10:00 am	MW1D Deep Basil Deep 05-May-2021 8:00 am	Mw1D Basil 05-May-2021 8:30 am	MW3D Cattle Yard 05-May-2021 10:30 am
Lab Number:		2604649.1	2604649.2	2604649.3	2604649.4	2604649.5
pH	pH Units	6.2	7.0	6.7	6.6	6.5
Electrical Conductivity (EC)	mS/m	17.5	28.9	18.2	155.2	50.2
Total Sodium	g/m^3	26	23	23	59	55
Chloride	g/m^3	28	23	22	270	49
Total Nitrogen	g/m^3	8.5	0.48	1.5	75	21
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	0.20	< 0.010	0.079
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	0.023
Nitrate-N + Nitrite-N	g/m^3	3.4	0.40	< 0.002	75	18.7
Total Kjeldahl Nitrogen (TKN)	g/m^3	5.0	< 0.10	1.5	< 0.10	2.1
Dissolved Reactive Phosphorus	g/m^3	0.009	0.008	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	22	0.014	16.4	0.006	0.51
Escherichia coli	cfu / 100mL	3 #1	140 #1	< 1 #1	10 #1	560

Sample Name:		MW1U Cow Shed 05-May-2021 9:30 am	MW2U Ward 05-May-2021 11:00 am			
Lab Number:		2604649.6	2604649.7			
pH	pH Units	6.1	5.8	-	-	-
Electrical Conductivity (EC)	mS/m	28.6	70.9	-	-	-
Total Sodium	g/m^3	30	74	-	-	-
Chloride	g/m^3	45	143	-	-	-
Total Nitrogen	g/m^3	10.4	14.9	-	-	-
Total Ammoniacal-N	g/m^3	0.014	< 0.010	-	-	-
Nitrite-N	g/m^3	0.003	< 0.002	-	-	-
Nitrate-N + Nitrite-N	g/m^3	8.3	14.5	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	2.1	0.4	-	-	-
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	-	-	-
Total Phosphorus	g/m^3	0.52	0.31	-	-	-
Escherichia coli	cfu / 100mL	1 #1	9 #1	-	-	-

Analyst's Comments

#1 Statistically estimated count based on the theoretical countable range for the stated method.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-7
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1-7
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-7
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 23rd ed. 2017.	0.1 mS/m	1-7
Total Sodium	Nitric acid digestion, ICP-MS, screen level. APHA 3125 B 23rd ed. 2017.	0.42 g/m^3	1-7
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	1-7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-7
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23rd ed. 2017.	0.010 g/m^3	1-7
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-7
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) 23rd ed. 2017.	0.10 g/m^3	1-7
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m^3	1-7
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H 23rd ed. 2017.	0.002 g/m^3	1-7
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 I 23rd ed. 2017.	1 cfu / 100mL	1-7

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 06-May-2021 and 11-May-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Ara Heron BSc (Tech)
Client Services Manager - Environmental

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Certificate of Analysis

Client:	Blue Sky Meats (NZ) Limited	**Lab No:**	2698616 SPv1
Contact:	Paulus Smith	**Date Received:**	09-Sep-2021
	C/- Blue Sky Meats (NZ) Limited	**Date Reported:**	15-Sep-2021
	729 Woodlands Morton Mains Road	**Quote No:**	109678
	RD 1	**Order No:**	
	Invercargill 9871	**Client Reference:**	Labeled Blue Sky Pastures Bore water
		Submitted By:	Paulus Smith

Sample Type: Aqueous

Sample Name:		School House 08-Sep-2021 9:30 am	Lane 08-Sep-2021 10:30 am	Basil deep 08-Sep-2021 7:30 am	Basil 08-Sep-2021 8:00 am	Cattle Yards 08-Sep-2021 8:30 am
Lab Number:		2698616.1	2698616.2	2698616.3	2698616.4	2698616.5
pH	pH Units	6.3	7.0	6.6	6.6	6.8
Electrical Conductivity (EC)	mS/m	14.9	31.4	18.5	118.2	68.6
Total Sodium	g/m^3	16.8	23	22	54	93
Chloride	g/m^3	21	22	23	200	97
Total Nitrogen	g/m^3	5.4	0.67	2.2	59	26
Total Ammoniacal-N	g/m^3	0.034	< 0.010	0.142	< 0.010	< 0.010
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Nitrate-N + Nitrite-N	g/m^3	1.47	0.52	< 0.002	59	26
Total Kjeldahl Nitrogen (TKN)	g/m^3	3.9	0.15	2.2	< 0.10	0.31
Dissolved Reactive Phosphorus	g/m^3	0.011	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	6.6	0.017	6.1	0.073	0.023
Escherichia coli	cfu / 100mL	100 #1	11 #1	12 #1	2 #1	15 #1

Sample Name:		Cow Shed 08-Sep-2021 10:00 am	Wards 08-Sep-2021 9:00 am			
Lab Number:		2698616.6	2698616.7			
pH	pH Units	5.9	5.9	-	-	-
Electrical Conductivity (EC)	mS/m	28.1	32.4	-	-	-
Total Sodium	g/m^3	30	38	-	-	-
Chloride	g/m^3	45	33	-	-	-
Total Nitrogen	g/m^3	9.9	8.0	-	-	-
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	-	-	-
Nitrite-N	g/m^3	< 0.002	< 0.002	-	-	-
Nitrate-N + Nitrite-N	g/m^3	8.7	7.7	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	1.29	0.29	-	-	-
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	-	-	-
Total Phosphorus	g/m^3	0.62	0.006	-	-	-
Escherichia coli	cfu / 100mL	< 10 #1	5 #1	-	-	-

Analyst's Comments

#1 Statistically estimated count based on the theoretical countable range for the stated method.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-7
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1-7
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-7
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 23rd ed. 2017.	0.1 mS/m	1-7
Total Sodium	Nitric acid digestion, ICP-MS, screen level. APHA 3125 B 23rd ed. 2017.	0.42 g/m^3	1-7
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	1-7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-7
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23rd ed. 2017.	0.010 g/m^3	1-7
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-7
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) 23rd ed. 2017.	0.10 g/m^3	1-7
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m^3	1-7
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H 23rd ed. 2017.	0.002 g/m^3	1-7
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 I 23rd ed. 2017.	1 cfu / 100mL	1-7

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 09-Sep-2021 and 15-Sep-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

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Certificate of Analysis

Client:	Blue Sky Meats (NZ) Limited	**Lab No:**	2742884	SPv1
Contact:	Paulus Smith	**Date Received:**	22-Oct-2021	
	C/- Blue Sky Meats (NZ) Limited	**Date Reported:**	29-Oct-2021	
	729 Woodlands Morton Mains Road	**Quote No:**	109678	
	RD 1	**Order No:**		
	Invercargill 9871	**Client Reference:**	Labeled Blue Sky Pastures Bore water	
		Submitted By:	Paulus Smith	

Sample Type: Aqueous

Sample Name:		Cattle Yards 21-Oct-2021 7:30 am	Lane 21-Oct-2021 8:00 am	Basil deep 21-Oct-2021 8:30 am	Basil 21-Oct-2021 9:00 am	Cow Shed 21-Oct-2021 9:30 am
Lab Number:		2742884.1	2742884.2	2742884.3	2742884.4	2742884.5
pH	pH Units	6.9	7.0	7.2	6.5	6.6
Electrical Conductivity (EC)	mS/m	65.8	33.8	20.0	122.8	28.2
Total Sodium	g/m^3	87	21	21	57	29
Chloride	g/m^3	83	22	23	200	45
Total Nitrogen	g/m^3	27	0.50	0.15	57	9.2
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	0.139	< 0.010	< 0.010
Nitrite-N	g/m^3	0.006	0.003	< 0.02 [#2]	< 0.002	< 0.002
Nitrate-N + Nitrite-N	g/m^3	26	0.36	< 0.02 [#2]	57	9.1
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.37	0.14	0.15	< 0.10	< 0.10
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	0.008	< 0.004	< 0.004
Total Phosphorus	g/m^3	0.012	0.023	0.147	0.040	0.043
Escherichia coli	cfu / 100mL	800 [#1]	< 1 [#1]	< 1 [#1]	< 1 [#1]	< 1 [#1]

Sample Name:		Wards 21-Oct-2021 10:00 am	School House 21-Oct-2021 10:30 am			
Lab Number:		2742884.6	2742884.7			
pH	pH Units	5.8	5.8	-	-	-
Electrical Conductivity (EC)	mS/m	30.7	19.0	-	-	-
Total Sodium	g/m^3	37	25	-	-	-
Chloride	g/m^3	32	32	-	-	-
Total Nitrogen	g/m^3	8.0	5.8	-	-	-
Total Ammoniacal-N	g/m^3	< 0.010	0.031	-	-	-
Nitrite-N	g/m^3	< 0.002	< 0.002	-	-	-
Nitrate-N + Nitrite-N	g/m^3	7.7	4.5	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.32	1.38	-	-	-
Dissolved Reactive Phosphorus	g/m^3	< 0.004	0.011	-	-	-
Total Phosphorus	g/m^3	0.022	1.45	-	-	-
Escherichia coli	cfu / 100mL	45	30 [#1]	-	-	-

Analyst's Comments

[#1] Statistically estimated count based on the theoretical countable range for the stated method.

[#2] Severe matrix interferences required that a dilution be performed prior to analysis, resulting in a detection limit higher than that normally achieved for the NOxN /NO2N analysis.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-7
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1-7
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-7
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 23rd ed. 2017.	0.1 mS/m	1-7
Total Sodium	Nitric acid digestion, ICP-MS, screen level. APHA 3125 B 23rd ed. 2017.	0.42 g/m^3	1-7
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	1-7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-7
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23rd ed. 2017.	0.010 g/m^3	1-7
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-7
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) 23rd ed. 2017.	0.10 g/m^3	1-7
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m^3	1-7
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H 23rd ed. 2017.	0.002 g/m^3	1-7
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 I 23rd ed. 2017.	1 cfu / 100mL	1-7

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 22-Oct-2021 and 29-Oct-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

Carole Rodgers-Carroll

Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental

Hill Laboratories
TRIED, TESTED **AND TRUSTED**

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Certificate of Analysis

Client:	Blue Sky Meats (NZ) Limited	**Lab No:**	2776804	SPv1
Contact:	Paulus Smith C/- Blue Sky Meats (NZ) Limited 729 Woodlands Morton Mains Road RD 1 Invercargill 9871	**Date Received:**	24-Nov-2021	
		Date Reported:	01-Dec-2021	
		Quote No:	109678	
		Order No:		
		Client Reference:	Labeled Blue Sky Pastures Bore water	
		Submitted By:	Paulus Smith	

Sample Type: Aqueous

Sample Name:		School House 23-Nov-2021 9:00 am	Lane 23-Nov-2021 9:30 am	Basil Deep 23-Nov-2021 7:00 am	Basil 23-Nov-2021 7:30 am	Cattle Yards 23-Nov-2021 10:00 am
Lab Number:		2776804.1	2776804.2	2776804.3	2776804.4	2776804.5
pH	pH Units	6.3	6.8	7.0	6.4	6.9
Electrical Conductivity (EC)	mS/m	19.3	32.6	19.2	111.6	41.0
Total Sodium	g/m^3	23	22	22	52	44
Chloride	g/m^3	30	21	22	183	47
Total Nitrogen	g/m^3	6.6	0.41	0.82	51	10.8
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	0.162	< 0.010	< 0.010
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Nitrate-N + Nitrite-N	g/m^3	4.9	0.32	< 0.002	51	10.5
Total Kjeldahl Nitrogen (TKN)	g/m^3	1.67	< 0.10	0.82	< 0.10	0.26
Dissolved Reactive Phosphorus	g/m^3	0.005	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	3.0	0.022	3.1	0.030	0.036
Escherichia coli	cfu / 100mL	40 #1	10 #1	< 10 #2	< 10 #2	20 #1

Sample Name:		Cowshed 23-Nov-2021 8:00 am	Ward 23-Nov-2021 8:30 am			
Lab Number:		2776804.6	2776804.7			
pH	pH Units	6.3	6.0	-	-	-
Electrical Conductivity (EC)	mS/m	28.9	32.6	-	-	-
Total Sodium	g/m^3	29	38	-	-	-
Chloride	g/m^3	46	33	-	-	-
Total Nitrogen	g/m^3	9.9	6.4	-	-	-
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	-	-	-
Nitrite-N	g/m^3	< 0.002	< 0.002	-	-	-
Nitrate-N + Nitrite-N	g/m^3	9.0	6.2	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.91	0.23	-	-	-
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	-	-	-
Total Phosphorus	g/m^3	0.51	0.026	-	-	-
Escherichia coli	cfu / 100mL	< 10 #1	10 #1	-	-	-

Analyst's Comments

#1 Statistically estimated count based on the theoretical countable range for the stated method.

#2 Statistically estimated count based on the theoretical countable range for the stated method.
Please interpret this microbiological result with caution as the sample was > 24 hours old at the time of testing in the laboratory. The sample is required to reach the laboratory with sufficient time to allow testing to commence within 24 hours of sampling.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-7
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23^{rd} ed. 2017.	-	1-7
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 23^{rd} ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-7
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 23^{rd} ed. 2017.	0.1 mS/m	1-7
Total Sodium	Nitric acid digestion, ICP-MS, screen level. APHA 3125 B 23^{rd} ed. 2017.	0.42 g/m^3	1-7
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 23^{rd} ed. 2017.	0.5 g/m^3	1-7
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-7
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23^{rd} ed. 2017.	0.010 g/m^3	1-7
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23^{rd} ed. 2017.	0.002 g/m^3	1-7
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23^{rd} ed. 2017.	0.002 g/m^3	1-7
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) 23^{rd} ed. 2017.	0.10 g/m^3	1-7
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23^{rd} ed. 2017.	0.004 g/m^3	1-7
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H 23^{rd} ed. 2017.	0.002 g/m^3	1-7
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 I 23^{rd} ed. 2017.	1 cfu / 100mL	1-7

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 25-Nov-2021 and 01-Dec-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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