Land and Water Science
61c Leet Street
Invercargill 9810
New Zealand

03 214 3003
www.landwaterscience.co.nz

25th June 2019

Technical Assessment of APP-20191230: Cashmere Bay Dairy

Prepared by: Dr Clint Rissmann and Dr Lisa Pearson

Internal review by: Dr Monique Beyer

1 Scope of Works

Environment Southland Consents Officer Mr Alex Erceg has contracted Land and Water Science Ltd to undertake a review of the application from Cashmere Bay Limited (APP-20191230) and provision of technical advice on the effects of the proposed activity as specified below:

1. What effects, including cumulative effects, would the proposed activity (land use consent application APP-20191230) as a whole have on the groundwater quality in the receiving environment;
2. What effects would the proposed land use change, specifically converting an organic sheep farm to a dairy farm, have on the groundwater in the receiving environment;
3. To what extent would the proposed activities affect the nitrate hotspots in the vicinity of the property, including cumulative effects, with particular regard to the hotspot beneath the property;
4. In regards to the groundwater nitrate levels beneath the property, what is/are the likely causes of the nitrate levels, including how the nitrate hotspots to the east of the property interacts with and may contribute to the groundwater quality beneath the property; and
5. What is the level of hydraulic connection to surface water in regards to contaminant movement from the aquifer to surface water, and what are the likely effects of the proposed

activity on surface water quality that is recharged from the groundwater, down gradient from the applicant's property?

The above technical requirements are reordered to firstly address the contextual questions around the causes of elevated groundwater nitrate (4) and the hydraulic connection (5) of the aquifers underlying the property to surface waters within and down gradient from the applicant's property. These requirements necessitate a review and evaluation of the current environmental setting of the property in question, including the proposed inclusion of the sheep block.

Following an assessment of the environmental setting, the effect of the proposed activity over the environment will be assessed. Specifically, requirement 2 will be evaluated in terms of the effect of the proposed activity over existing nitrate hotspots beneath the property (3) and as a whole (1) both in terms of acute and cumulative effects.

Review of the AEE provided by LandPro for application APP-20191230 is provided in Section 5 of this letter report.

2 Data

Land and Water Science Ltd provided the following data request to Environment Southland:

1. Time series (minimum of a 10-year period) groundwater quality and level data for the property and surrounds including any surface water or tile drain or open ditch monitoring for the property. An emphasis was placed on data associated with the Knapdale and Croydon groundwater management zones given the location of the property.
2. Bore depth, drilled depth, screen interval, aquifer confinement status and aquifer type (terrace, riparian, lowland etc).

Land and Water Science sourced the following:

1. High-resolution physiographic layers Rissmann et al., (2019) for Southland developed as part of the National Science Challenge, Our Land Water.
2. NASA Shuttle Radar Topography (NASA Shuttle) is preferred to the region 8 m DEM as it is derived from actual measures of the land surface and as such has better vertical resolution.
3. Topoclimate South
4. Radiometric survey imagery (Block F) provided by New Zealand Petroleum and Minerals (NZP&M Database).
5. Topo50 polylines: terrace lines, drain centrelines, river centrelines.
6. QMAP
7. River Environment Classification

3 Environmental Setting

3.1 Property Location

The property is located at 145 Jaffray Rd, Gore (RD7) approximately 22 km northwest from the town of Gore (Figure 1).

There are two blocks defined under the existing land use activity, the milking platform (purple) and the leased runoff block (green). The proposed activity incorporates the sheep block (yellow) into the farm area.

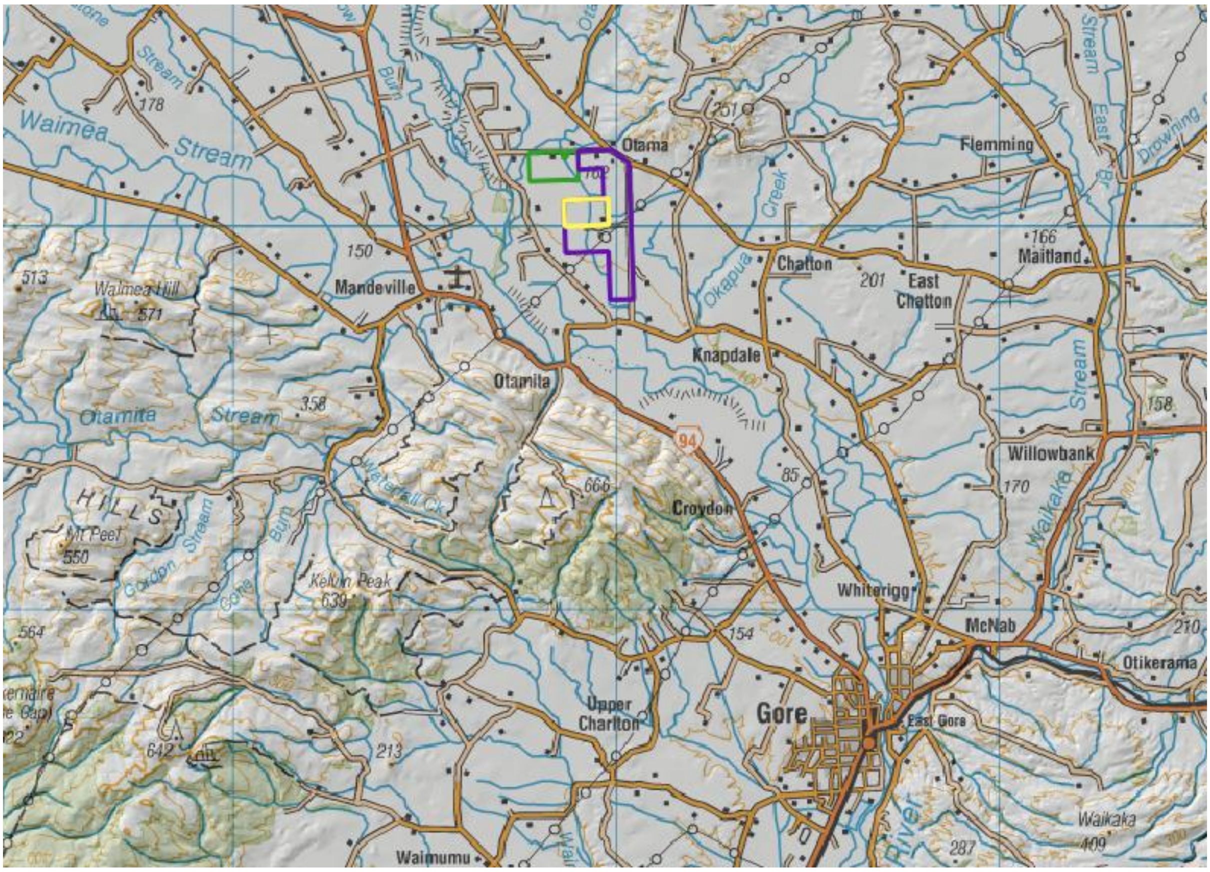

Figure 1: Property location of dairy milking platform (purple), leased runoff block (green), and the new sheep block (yellow) over Topo250 map.

3.2 Geological Setting

The existing dairy platform and proposed 'sheep block' is situated across a flight of alluvial terraces that flank the eastern boundary of the Mataura Valley (Figure 2). Terrace age decreases with proximity to the Mataura River from Q6 to Q1 age (0.25 – 0.01 Million years). A transect through the property reveals a fall of ~50 m from Otama Rd road to the property boundary (Figure 3).

Geological records suggest a mix of weathered schist and greywacke overlain by loess across the most easterly and oldest terraces (Q4 – Q6). To the west terrace age, degree of weathering and loess thickness reputedly decrease reflecting the relative youthfulness of the Q2a terrace associated with the western portion of the property. West of the property boundary, towards the floodplain of the Mataura River, geomorphic surface age again decreases (Q1). Here the Mataura River and its floodplain is described as a modern postglacial flood plain compromised of unconsolidated gravel, sand, silt, clay, and minor peat.

Notably, the alluvial terraces that form the eastern portion of the property are closer to the rocks of the Dun Mountain-Matai Terrane and exhibit radiometric signatures consistent with a mix of felsic and ultra-mafic sediments. To the east the younger and lower lying Q2a terrace, that constitutes the western extent of the property and the bulk of the sheep block, shows characteristically more felsic radiometric signatures typical of loess derived from weathered Caples Group sandstones. Southwest of the property boundary the modern-day floodplain of the Mataura River exhibits a potassium rich signature typical of active floodplains and a dominant headwater bedrock source associated with the Mataura Ranges.

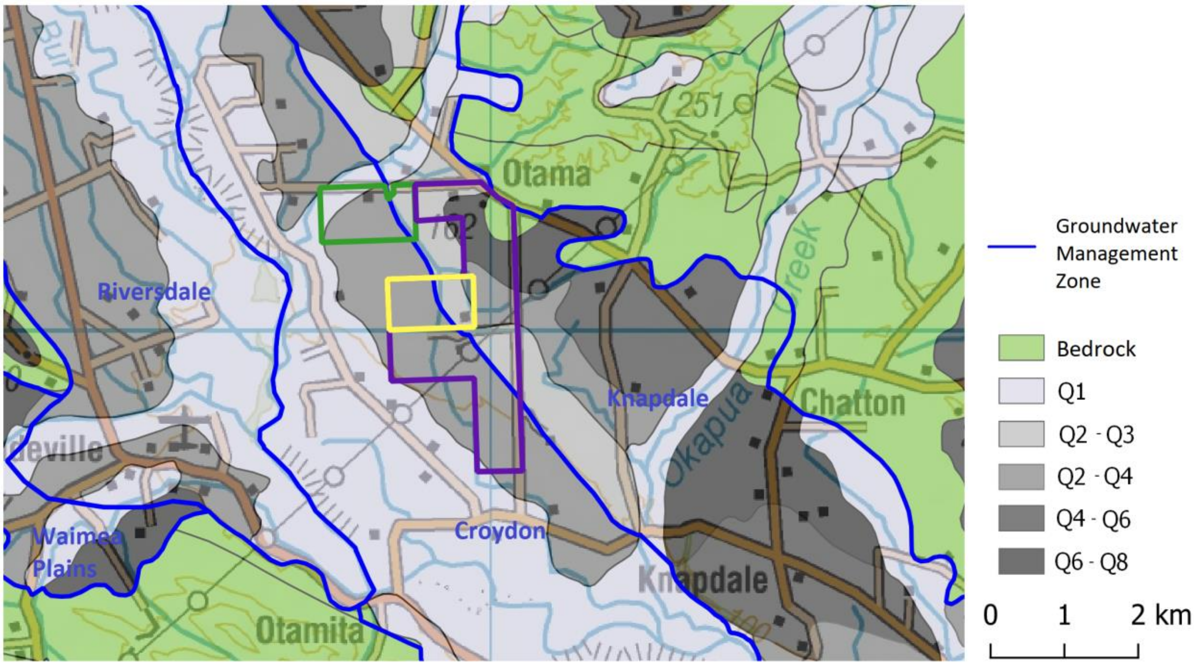

Figure 2: Geological age of the alluvial terraces across the Cashmere Bay Dairy property with the youngest terrace (Q1) shown as light grey and the oldest in dark grey (Q6-Q8). The property spans the Knapdale and Croydon Groundwater Management Zones. The property is identified as the dairy milking platform (purple), leased runoff block (green), and the new sheep block (yellow).

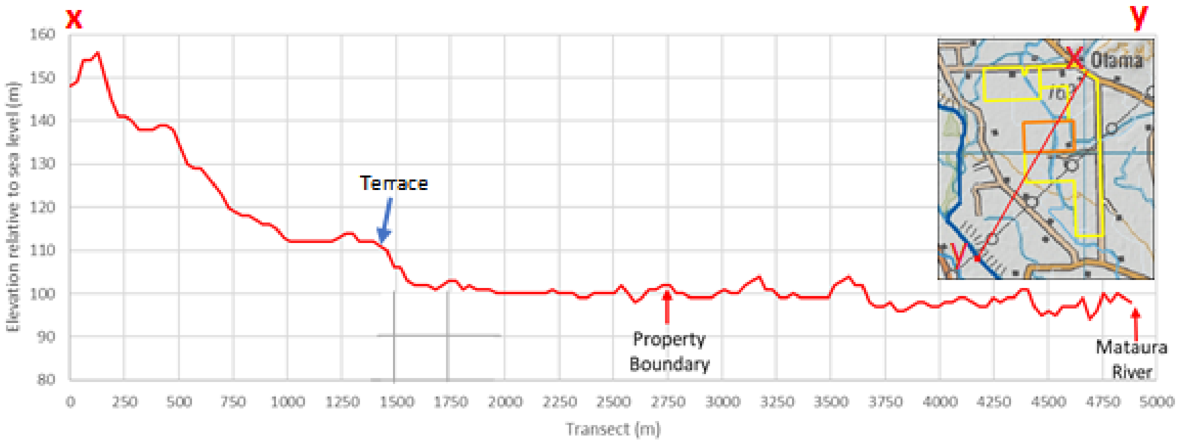

Figure 3: Transect across Cashmere Bay Dairy and Sheep Block (NASA Radar Topography). Otama (left) to Mataura River (Right). Existing milking platform is shown in yellow and the sheep block in orange.

3.3 Soils

Approximately 82% or 364.8 Ha of the dairy platform is mapped as well drained and moderately permeable Mataura and Oreti soils (Figure 4). The remaining 18% is associated with poorly drained Fleming and Jacobstown soils characterised by slow infiltration rates (<4 mm/hr). The proposed 'sheep block' is distinct from the dairy platform having a much larger proportion, i.e., 32 Ha (40%), of poorly drained Fleming (Perch-gley Pallic) and Jacobstown (Orthic Acidic Gley) soils.

The well drained Oreti and Mataura soils are expected to play an important role over aquifer recharge, poorly drained Fleming and Jacobstown soils, assuming that they do not crack in response to soil moisture deficit, are considered less important. Rather, these poorly drained soils are considered more likely to export soil water laterally as subsurface or overland flow to the drainage network and unnamed creek.

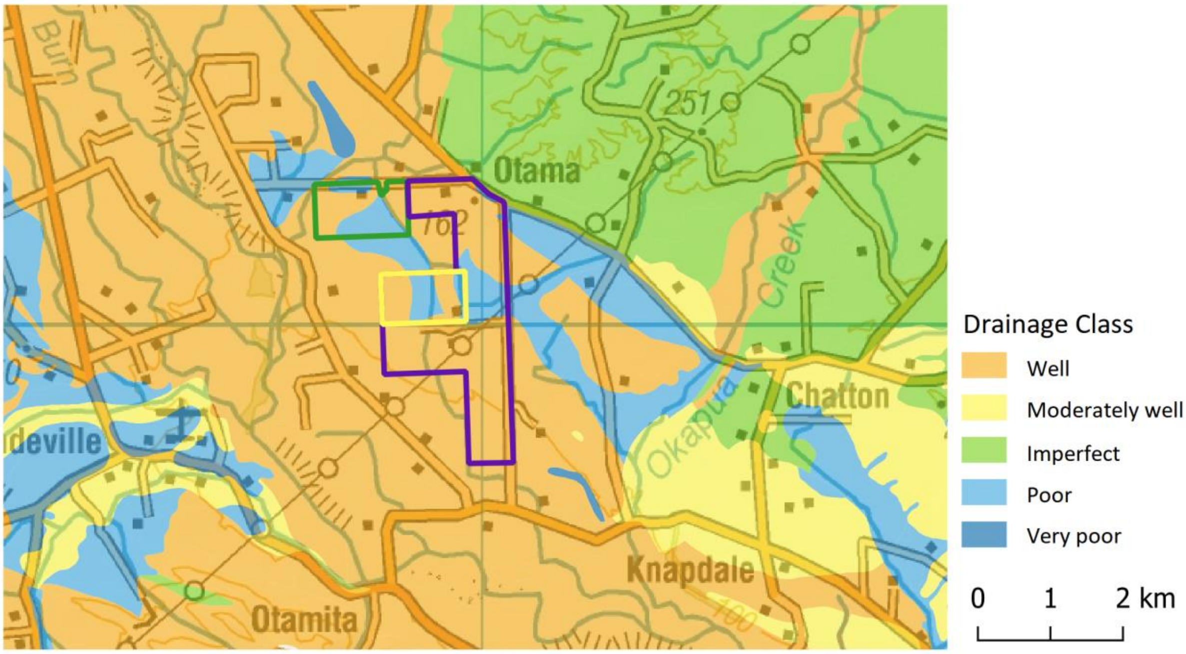

Figure 4: Soil drainage across the Cashmere Bay Dairy property. The property is identified as the dairy milking platform (purple), leased runoff block (green), and the new sheep block (yellow).

3.4 Reduction and Oxidation Processes

Soil redox potential is an important control over nitrate leaching to the aquifers underlying the milking platform and 'sheep block.' Approximately 60% of the 'sheep-block' is associated with well drained Mataura and Oreti soils. Oreti soils are classified as having a very severe nitrate leaching risk and Mataura soils as having a moderate leaching risk by TopoClimate South Soil Survey. Work on groundwater hotspot mapping and physiographics across the region identifies a strong association between well drained soils and aquifers that are not flushed by alpine recharge (see Rissmann et al., 2016; Hughes et al., 2016). The 40% of poorly drained soils across the proposed 'sheep block' favours soil zone denitrification. However, these soils have a higher risk of lateral and overland transport of contaminants to the surface water network (Rissmann et al., 2019).

Geological reduction potential can be highly variable in complex alluvial aquifer systems, especially those associated with geologically recent over bank deposits. However, older terrace remnants tend to exhibit higher oxidation status than more recent deposits, perhaps reflecting the oxidation of electron donors within the aquifer in response to large volumes of oxygen rich recharge over successive millennia (Rissmann, 2012; Rissmann et al., 2019). The latter is especially common of aquifer systems overlain by well drained and relatively permeable soil materials.

3.5 Hydrological Setting

3.5.1 Surface Water Network

A schematic of the surface water drainage network is provided in Figure 5. It denotes an unnamed creek which drains the eastern hills and enters the property on the eastern boundary. The creek is thought to turn south running through the 'sheep block' and western most paddocks of the dairy platform before exiting the property adjacent to the east-west running Dillon Rd. South of Otamita Rd the unnamed creek joins the Mataura River around Knapdale. It is estimated that approximately 8 km of the main stem of the unnamed tributary runs through or adjacent to the property. Numerous small tributaries and open ditch drains criss-cross the property (Attachment D Tiaki Farm Environment Plan).

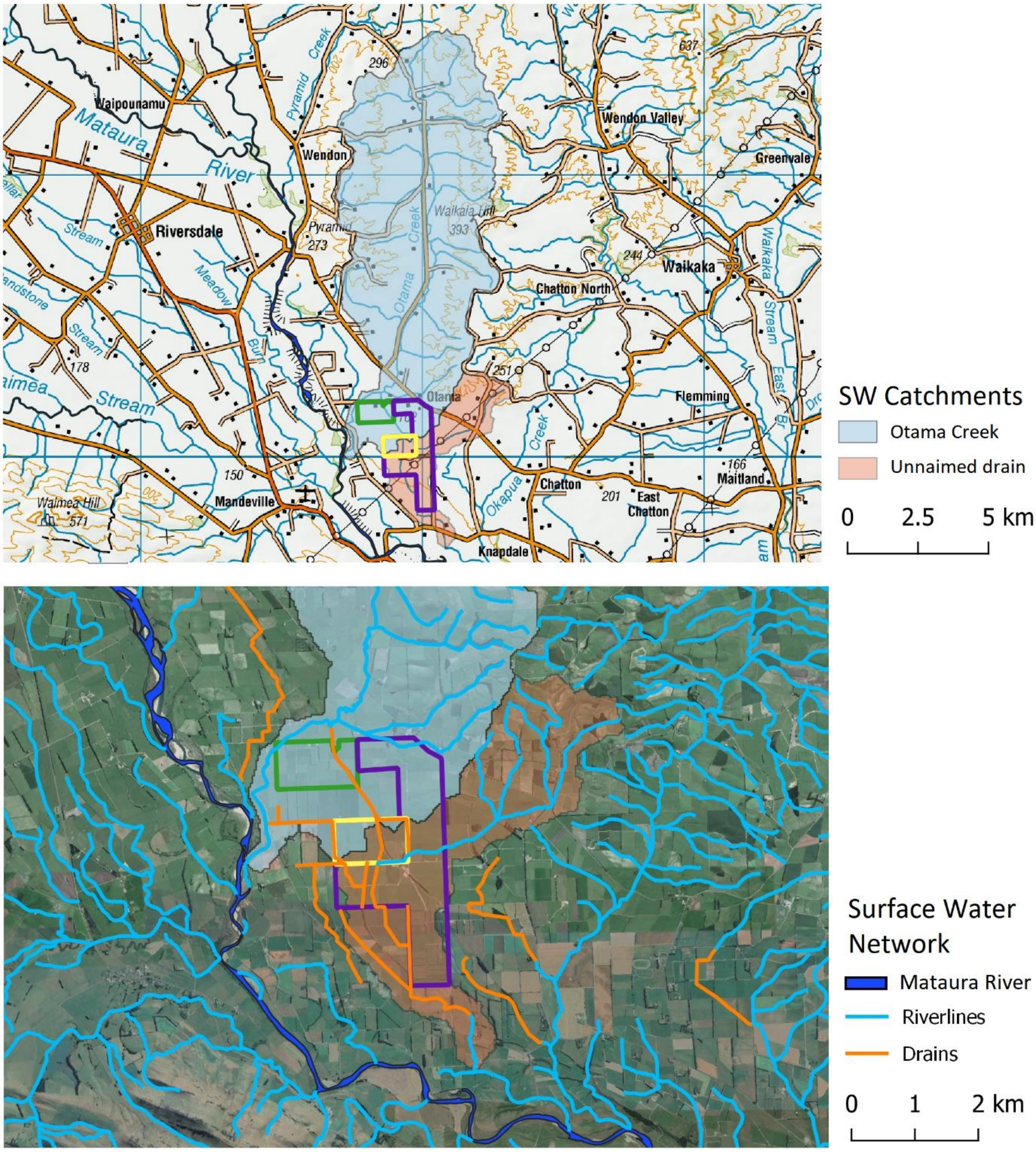

Figure 5: Surface water catchments (top) and waterways (bottom) across the Cashmere Bay Dairy property. The north of the property contributes to the Otama Creek (blue catchment area) while the south of the property drains into an unnamed drain on the property (orange catchment area). The property is identified as the dairy milking platform (purple), leased runoff block (green), and the new sheep block (yellow).

3.5.2 Groundwater

Groundwater Management Zones

Through the middle of the property a terrace riser subdivides the older more elevated easterly terraces from the younger (Q2a) and lower lying westerly terrace. The same terrace riser constitutes a geological and hydrogeological divide that separates the Knapdale and Croydon groundwater management zones (Figure 2; Hughes, 2012; Environment Southland). The Knapdale aquifer is characterised as a terrace aquifer system that receives the bulk of its recharge from local rainfall whereas the Croydon aquifer is thought to receive a proportion of its recharge from the Mataura River, with aquifer permeability and hydraulic connectivity (and hence flushing) thought to increase with proximity to the main stem of the river and its modern-day floodplain (Hughes, 2012; Environment Southland).

Groundwater Level

Groundwater level data within or bordering the property shows a decrease in water table depth across the property that coincides with the terrace riser subdividing the Knapdale and Croydon groundwater management zones (Figure 6). Wells F45/0444 and F45/0445, which occur on the elevated terraces of the Knapdale aquifer, had initial static water levels of -11.4 m below ground level. Wells F45/0634 and F45/0172 which occur on the lower and more easterly (Q2a) terrace within the Croydon aquifer system had initial static water levels of -2.53 and -2.26 m bgl, respectively. Wells F45/0182 and F45/0173 occur close to the eastern boundary of the Knapdale aquifer and show intermediate static water levels of -4.8 and -5.0 m bgl, respectively. The shallowing of the water table towards the Mataura River is consistent with trends observed by Hughes (2012) who noted a strong topographic control over aquifer level associated with terrace landforms and proximity to the active floodplain of the Mataura River.

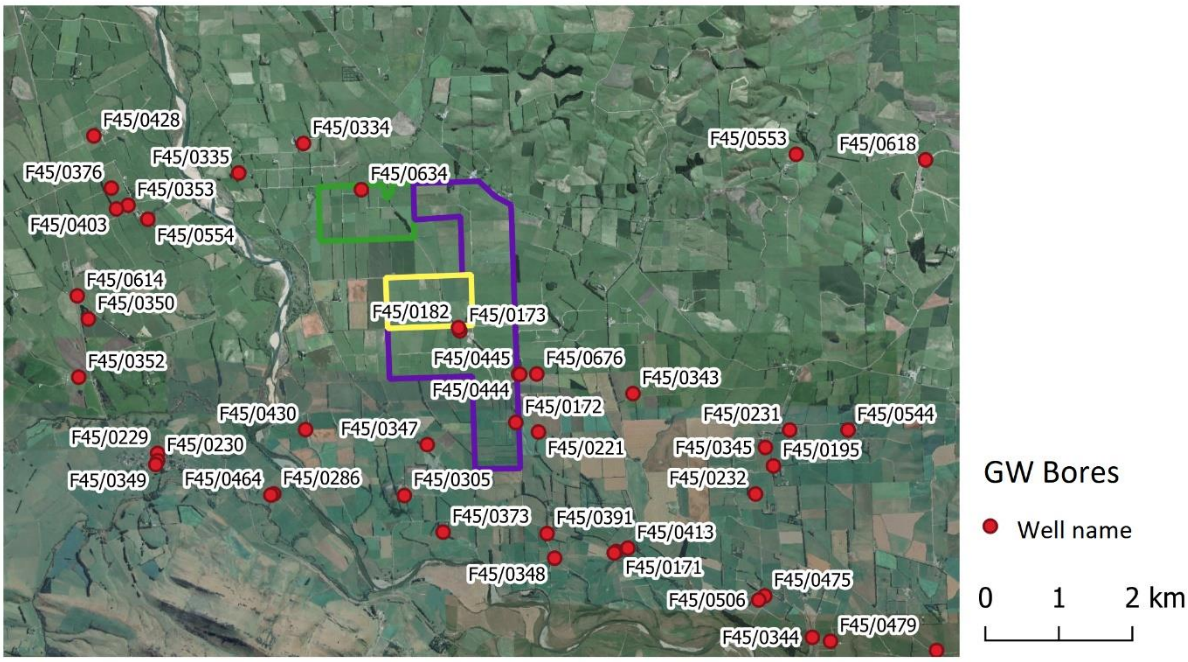

Figure 6: Bore (well) locations near the Cashmere Bay Dairy property. The property is identified as the dairy milking platform (purple), leased runoff block (green), and the new sheep block (yellow).

Groundwater levels for a 19-year period reported for wells F45/0172 and F45/0173 support the general pattern of a shallowing water table towards the Mataura River and also highlight an average seasonal variation in water table on the magnitude of ~1 m for wells F45/0172 and 2.3 m for F45/0173 (Environment Southland Data). Groundwater level data for these two wells fit within the general framework for the Knapdale and Croydon aquifers with maximum groundwater levels occurring in winter (typically July/August) and minimum levels in early Autumn (March/April) (Hughes, 2012; Environment Southland Data). As with studies of groundwater baseflow contribution to the Waimea Stream in the nearby Waimea valley, peak groundwater contribution to stream flow coincides with maximum aquifer levels during July/August (Rissmann and Pearson, 2018). As aquifer levels decline over the warmer months the volumetric contribution to stream flow wanes and, in the instance of an extended dry period or 'drought', streams may dry up completely. Groundwater age is also expected to increase within the stream channel as the water table decays reflecting the decanting of younger groundwater first (Rissmann and Pearson, 2018).

Groundwater flow direction

A piezometric survey of the Knapdale and Crydon aquifers indicates a strong topographic control associated with terrace remnants adjacent to the eastern hills with a more concentric groundwater flow path occurring at lower elevations across the Mataura River and its floodplain (Hughes, 2012; Environment Southland). Significant subsurface flow of shallow groundwater perpendicular to the terraces towards the Mataura River is thought to be less of a control over aquifer export than drainage via the varied network of open ditches and the numerous small streams and tributaries that occur across the property (Figure 7). At deeper levels the slow movement of older more evolved groundwater towards the Mataura River is considered an important process. The hydrological setting is discussed in more detail below.

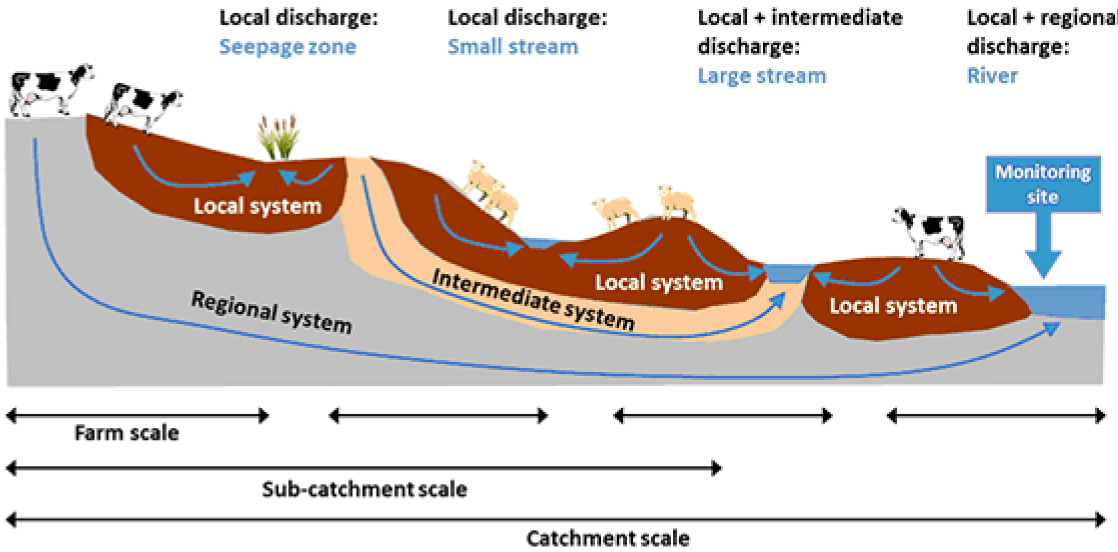

Figure 7: The shallow and relatively fast pathways that are often crucial for nitrogen transfers at the sub-catchment scale. Image: Lincoln Agritech.

Connectivity to the Mataura River

As anticipated, there is little evidence in median chloride (Cl), bromide (Br), alkalinity, sodium (Na) or electrical conductivity (200 – 224 µS/cm) for dilution by the Mataura River across the Knapdale aquifer side of the property (wells F45/0182, F45/0173, F45/0444, F45/0455, F45/0343, F45/0676). Furthermore, despite being within the Croydon aquifer, wells F45/0634, F45/0221 and F45/0172 show no evidence of alpine derived recharge with Cl, Br, Na, alkalinity and/or electrical conductivity values (c. 200 – 220 μS/cm) comparable to those in shallow wells on the older elevated terraces to the east. Well F45/0347 just beyond the eastern most margin of the property and the extent of the Q2a terrace shows a median electrical conductivity value of 261.0 μS/cm, once again indicating little evidence for dilution by the Mataura River. However, 800 m further east of the Q2a terrace boundary within the floodplain of the modern-day Mataura River, wells F45/0305 and F45/0373 show evidence for some dilution by river water with conductivity dropping to values of 115.8 – 150 μS/cm.

Limited hydrological connectivity at shallow levels in the Mataura River is consistent with the hydrogeological setting of the dairy platform and proposed 'sheep block' along the eastern most margin of the Croydon aquifer in association with the alluvial terrace aquifer that appears to pre-date the current floodplain of the Mataura River (Hughes, 2012). Despite limited evidence for shallow hydraulic connectivity to the Mataura and its floodplain, aquifer permeability is expected to be higher for the younger and more westerly Q2a terrace that underlies the majority of the western portion of the property due to its relative youthfulness (Hughes, 2012).

Groundwater Nitrate Hotspots

Groundwater quality data for the property and surrounds indicate an association between well drained Oreti and Mataura soils and elevated groundwater nitrate. This includes the observation of elevated groundwater nitrate in bores associated with the eastern and most elevated terraces that flank the Mataura valley south of Pyramid and parallel to the Mataura River and its floodplain towards Whiterigg in the south. The main reason for these hotspots is intensive land use occurring in association with well drained soils overlying oxidising aquifers that are not flushed by alpine or hill country derived streams.

Across the wider Knapdale and Croydon groundwater management zones the oldest terrace remnants are often associated with the highest groundwater nitrate concentrations reflecting lower aquifer permeability and electron donor abundance due to weathering. Under this setting nitrate concentrations may accumulate to high levels, often in excess of the New Zealand Drinking Water (NZDW) standard of 11.3 mg/L NO_3-N. Younger terraces often exhibit greater permeability and lower redox potentials, despite still being oxidising. Greater permeability equates to faster turnover of water within the aquifer which typically limits NO_3-N accumulation to concentrations less than the NZDWS.

However, in the vicinity of the Cashmere Bay property there is considerable time series variation evident in groundwater NO_3-N concentrations. Time series variation is most likely due to cycles of recharge and flushing with a noted positive correlation (r^2 0.76) between electrical conductivity and NO_3-N concentrations for the majority of bores of relevance (Figure 8). Plots of individual wells show similar positive correlations. Spatial variation in the location of high intensity wintering practices are also know to influence temporal variability (Monaghan, 2012; Rissmann et al., 2012). Specifically, maximum NO_3-N concentrations are associated with the highest conductivity values indicating concentrated recharge to the aquifer.

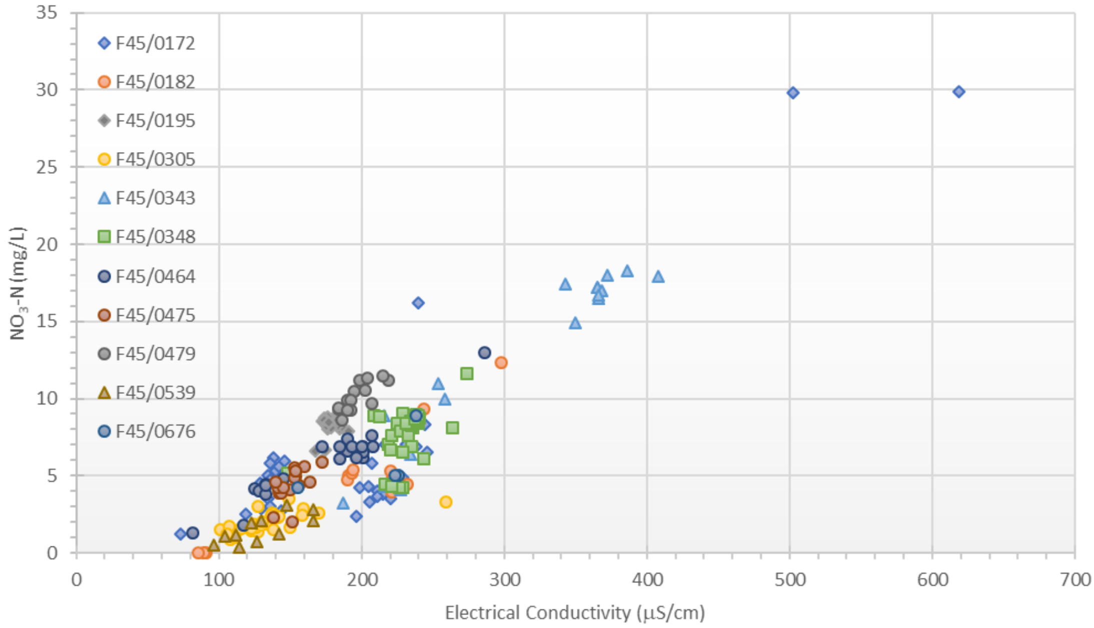

Figure 8: Nitrate (mg/L) and Electrical Conductivity (uS/cm) for the wells surrounding Cashmere Bay Dairy.

The strong correlation between conductivity and NO_3-N also extends to major ions such as Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-} and alkalinity, which are commonly elevated in recharge across areas of intensive land use. Such signatures have been observed in response to flushing events following extended periods of dry weather (Rissmann et al., 2012; Smith and Monaghan, 2013). This is especially true of areas of wintering which may sustain high conductivity and NO_3-N concentrations in drainage waters for an extended period post wintering (Monaghan, 2012; Monaghan et al., 2013; Pearson et al., 2016 and references therein). The lag between a flushing event and the time for drainage water to reach the aquifer will vary according to unsaturated zone thickness, soil hydrological properties and climatic factors (Wilson et al., 2014). Following recharge, the proportion of recent drainage that leaves via the stream network will then depend upon aquifer level and the degree of connectivity to the drainage network. Unfortunately, dipped levels at the time of water quality sampling do not appear to have been archived so that a quantitative assessment of the relationship between water level, conductivity and NO_3-N concentration cannot be undertaken.

Groundwater nitrate (NO_3-N) model

A simple model of the drivers of spatial variation in median groundwater NO_3-N across the Knapdale, Croydon and Riversdale groundwater management zones was generated using the method of Rissmann et al. (2019). The model is predictive and based on the use of environmental correlation whereby physical attributes known to govern the key hydrological and redox processes driving variation in water quality and composition are used as environmental covariates. A total of 34 bores of <20 m depth comprising >200 samples of groundwater NO_3-N were extracted, including those wells occurring within the dairy platform (i.e., F45/0182, F45/0173, F45/0172, F45/0634; Figure 9). For each well a 200 m radius was generated as a capture zone and numeric scores for rainfall source (ATM), recharge domain (RCD), soil matrix drainage to the aquifer (DD), soil matrix bypass (BP), geological (aquifer) reduction potential (GRP), soil reduction potential (SRP) and land use intensity (LUI) were quantified[1]. Well depth and initial static water level were also retained as environmental

[1] Each of these layers was produced as part of a high-resolution physiographic mapping project for Southland (see Rissmann et al., 2019).

covariates. Numeric scores for each layer were then tabulated for each well along with well depth, initial static water level and median NO_3-N concentration.

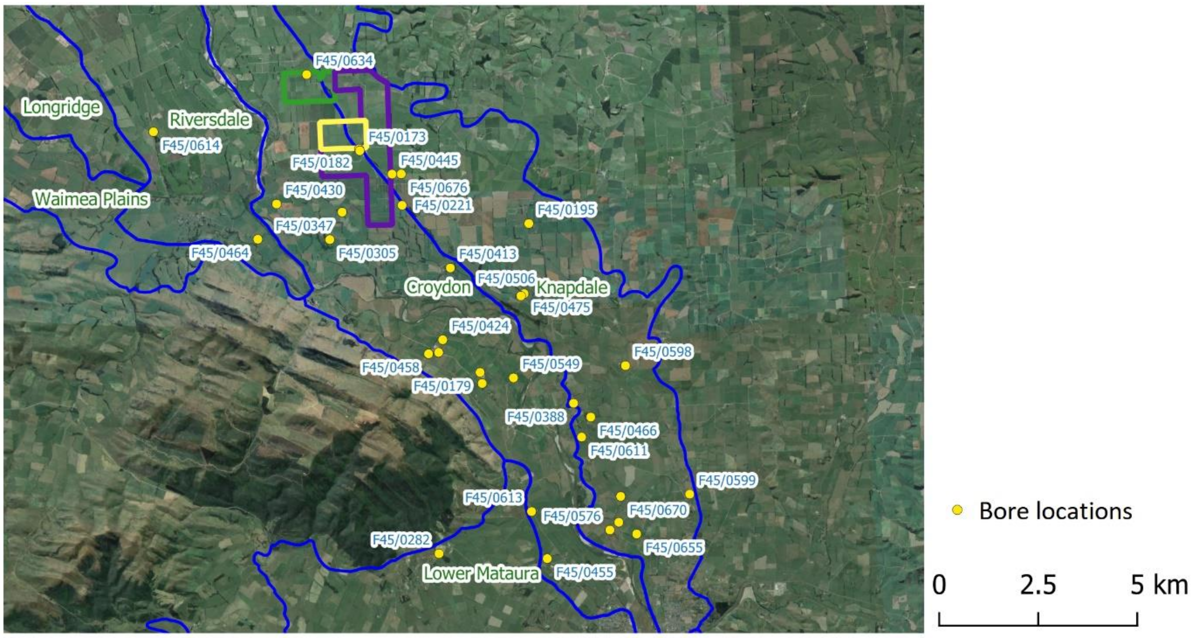

Figure 9: Shallow (<20 m bgl) groundwater wells (yellow)used for model development. All of these wells have recorded depth and initial static water level. Blue outlines depict the extent of Southland's groundwater management zones. The property is identified as the dairy milking platform (purple), leased runoff block (green), and the new sheep block (yellow).

The tabulated data was then imported into the machine intelligence software package Eureqa (version 1.24.0; Schmidt and Lipson, 2015) which utilises symbolic regression (SR) as the genetic programming algorithm, Pareto front optimisation for model selection, provides measures of predictor sensitivity and magnitude, and cross validates by splitting the data via a disjunctive approach where the training and validation data sets are kept separate (e.g. 90% training: 10% validation with a random shuffle before splitting the data; Schmidt and Lipson, 2009, 2015; Dubčáková, 2011).

Modelling proceeds by identifying the most sensitive layers for explaining spatial variation in groundwater NO_3-N across the modelled area. Importantly, if an environmental covariate offers little explanatory power, relative to others, it is automatically excluded during the evolutionary process. After numerous iterations, the SR algorithm returns a set of models (i.e. explicit mathematical functions) that explain the spatial variation in groundwater NO_3-N as a function of one or more environmental covariates. The sensitivity ('importance') of a given environmental covariate is defined according to its relative impact over the estimation of NO_3-N concentration. A positive magnitude occurs when increases in a numeric score for an environmental covariate lead to increases in NO_3-N, and vice-versa for a negative magnitude. Model complexity and accuracy is assessed by the goodness of fit (R^2), correlation coefficient (r), root mean squared error (RMSE) and mean absolute error (MAE) methods (Schmidt and Lipson, 2009, 2015; Dubčáková, 2011). Model selection was guided by the trade-off between R^2 and model simplicity using Pareto front optimisation.

Model performance metrics include a cross-validated R^2 of 0.77 and are summarised in Table 1. The top 5 models retained SRP, GRP, LUI, well depth (Dz), DD and ATM as important predictors (Table 2). Of these predictors the redox layers SRP and GRP were collectively the most sensitive layers for estimating spatial variation in NO_3-N. Land use intensity (LUI) was the 3rd most important estimator followed by well depth (Dz). Deep soil matrix drainage to the aquifer (DD) and rainfall source (ATM) were important albeit less sensitive predictors. Importantly, the model response is consistent with established understanding of NO_3-N dynamics across Southland but also elsewhere (Rissmann, 2011, Rissmann et al., 2016). Specifically, NO_3-N decreases as soil (SRP) and geological (GRP) increase and increases as LUI increases. NO_3-N concentration also decreases with well depth but not in all instances.

Table 1:. Model performance metrics. R^2 is the cross-validated model fit.

R^2 Goodness of Fit	0.768
Correlation Coefficient	0.881
Maximum Error	1.754
Mean Squared Error	0.212
Mean Absolute Error	0.267
Coefficients	7
Complexity	110

Table 2: Model sensitivity analysis - drivers of variation in groundwater NO_3-N.

Variable	Sensitivity	% Positive	Positive Magnitude	% Negative	Negative Magnitude
SRP	1.2017	4%	9.3621	96%	0.89944
GRP	1.0927	0%	0	100%	1.0927
LUI	0.81783	79%	0.76368	21%	1.0164
Dz	0.41472	38%	0.31002	62%	0.47916
DD	0.27982	100%	0.27982	0%	0
ATM	0.22688	100%	0.22688	0%	0

The findings of this simple model support the general interpretation that the physiographic setting of the property in conjunction with a relatively high intensity operation are likely the dominant drivers of elevated NO_3-N beneath the property. Limitations of this approach include the averaged nature of the land use intensity layer and the relatively small number of wells used to generate the model.

4 Environmental Assessment of Proposed Activity

Following from above and with regards to the groundwater nitrate levels beneath the property, the likely causes of elevated nitrate levels reflect the combination of intensive land use and the physiographic setting. Specifically, well drained soils overlying oxidising aquifers are recharged exclusively by rainfall recharge. This pattern of elevated groundwater NO_3-N is not isolated to the Cashmere Bay Ltd property but is a common feature of similar physiographic settings and high intensity land use activities across the region (Rissmann et al., 2016; Hughes et al., 2016).

Although possible, we consider it unlikely that upgradient land use is the dominant control over nitrate concentrations beneath the dairy platform. Our reasons for this include:

1. The majority of shallow and high NO_3-N groundwater is likely to discharge through the ephemeral stream, unnamed creek and open drain networks during periods of elevated groundwater level and soil moisture status. Groundwater movement associated with sub-regional flow from east to west towards the Mataura River is likely to occur at deeper levels.
2. Water quality associated with Well F45/0172 likely reflects what is a very localised signal. Specifically, the bore is shallow (i.e., 4.6 m deep) has a correspondingly shallow water table

(initial SWL of -2.6 m bgl but as shallow as -0.5 m bgl; Environment Southland Data) and is overlain by a well-drained soil. Therefore, during peak groundwater levels the aquifer and soil are in direct contact. Furthermore, the data for upgradient well F45/0676 is hydrochemically distinct (major cations and anions) from F45/0172, indicating a different evolutionary history.

3. The current intensity of consented land use within this setting is sufficient on its own to generate elevated groundwater NO_3-Nin the order of that observed in well F45/0182 (max 12.3 mg/L) in the middle of the property. Specifically, the occurrence of elevated groundwater NO_3-N within similar physiographic settings and land use intensity regionally is well recognised.
4. Wells F45/0676, F45/0444, F45/0445, F45/0343 and F45/0221 to the east of the property contain lower maximum conductivity and NO_3-N concentrations than recorded in F47/0172. Specifically, well F45/0172 has peak NO_3-N concentrations that are at least 10 mg/L NO_3-N lower than well F45/0172.

In terms of the level of hydraulic connection of aquifers beneath the dairy platform and the proposed 'sheep block' to the surface water network we consider it likely that:

1. Young NO_3-N rich groundwater is exported to the ephemeral stream, unnamed creek and open ditch network during periods of peak aquifer level during the wet periods of the year - mainly winter but whenever aquifer level is elevated. This water subsequently moves down gradient via the stream network before discharging to the Mataura River.
2. The streams most likely to be impacted by discharge of elevated NO_3-N groundwaters are the unnamed creek that runs through the property, the various small ephemeral tributaries across the western portion of the property and the stream network down gradient from the property.
3. However, we consider it likely that there is little aquifer discharge via the open ditch, unnamed tributary and ephemeral stream network during the drier months of the year when the underlying water table falls below the level of the ephemeral water courses, unnamed creek, and open ditch drains. This likely restricts the majority of NO_3-N export to the wetter months of the year (winter/early spring), which is when dilution within the Mataura River is likely to be at a maximum.

The observation of significant temporal variation in aquifer conductivity and NO_3-N concentration in conjunction with seasonal variation in water table, support a dynamic system of recharge and export across the property and the wider terrace aquifer setting (see also Hughes, 2012). Therefore, on the basis of the physiographic setting, groundwater monitoring data, the modelling present here and equivalent settings regionally, it is considered likely that NO_3-N concentrations delivered to the stream network could be significantly in excess of both the ANZECC and periodically the National Objective Framework Guidelines for surface waters. However, due to a lack of monitoring data the concentration of NO_3-N exported to open drains across the property during periods of peak drainage is currently unknown.

5 Review of AEE and Proposed Activity

With regards to Cashmere Bay Dairy Limited Resource Consent Application to the Southland Regional Council (Environment Southland) we provide the following review. The report was prepared by Mike Freeman (BSc, PhD) & Grace Baldwin (MMAg Systems) with review by Tanya Copeland of Landpro and subsequently by the landowner George Raymond. We provide comment for each section of the report. Here we provide comment in response to the claims of the applicant as it pertains to key water quality issues. A summary of review comments is also provided.

5.1 Details of the Proposal (Section 2)

The details of the proposal outline the general location of the property and the proposed farm boundary incorporating the 'sheep-block.' The legal details of the dairy farm are tabulated, and a discussion is provided of existing land use. Reference is made to discharge Permit AUTH-301811-V2 and Water Permit AUTH-301812-V2.

On page 5 section 2.2.2 it is stated that "*that the consented number of cows, 1,000, will not increase following the proposed expansion of the dairy platform, and the applicant will continue to operate under Discharge Permit AUTH-301811-V2 and Water Permit AUTH-301812-V2 upon the granting of the land use consent for farming. No farm dairy effluent is proposed to be discharged to the Sheep Block. No changes are proposed to the existing discharge and water permits, as the consented maximum number of cows is not changing*."

The proposed activity Section 2.2.5. states that a "*Consent is sought to incorporate a new 80 ha (approx.) block of land located between Otama Flat Road and Jaffray Road (adjacent to the existing property), to add to the existing farm for dairying and milking of up to a maximum of the currently consented number of 1,000 cows. This block has previously been used as an organic sheep farm, but it is proposed that it now be incorporated into the dairy platform and is labelled as the 'Sheep Block' for the purposes of this application. The Sheep Block will be utilised as part of the dairy platform for grazing of pasture and winter crops*."

5.2 Description of Existing Environment (Section 3)

Land use, topography and climate are briefly presented. Water resources are broadly defined but no integrated schematic of the drain or stream network is provided. The overview of surface water quality is at a high level and considered unsuited to the scale of the activity. Specifically, it utilises the Land Air Water Aotearoa (LAWA) website and references the State and Trend at the Waikaia River at Waipounamu Bridge Monitoring Site (nearest upstream LAWA monitoring site) and Gore Monitoring Site (nearest downstream LAWA monitoring site). Source: LAWA data – up to December 2017.

The authors state that: "*The monitoring results indicate that water quality on the mainstem of the Mataura River is generally similar between the upstream and downstream and with the exception of microbiological quality, is largely consistent with the regional plan objectives. Most of the variables measured, with the exception of ammoniacal N and dissolved reactive P, have indicated higher concentrations at the downstream site. However, an increase in river nutrient concentrations moving downstream is normally found in lowland New Zealand rivers. At both monitoring sites (Waipounamu Bridge Road and Gore), dissolved reactive phosphorus concentrations are below the relevant ANZECC trigger value of 0.010 g/m^3 while nitrate N concentrations at both sites exceed the trigger value of 0.444 g/m^3 (for 'slightly disturbed lowland streams', Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000)*."

The authors summarise "*the surface water quality monitoring data does not indicate a significant deterioration in water quality moving downstream between these two sites in the Mataura River system. However, data is not available for all local tributaries, and information from many land use and water quality investigations in Southland highlight the need to minimise contaminant loss from land into water bodies to ensure that the water quality of rivers remains consistent with the relevant objectives in the relevant statutory planning provisions (See Section 6)*."

We agree that a lack of data for small order surface waterbodies is limiting but raise the importance of a more localised consideration of water quality if a meaningful assessment of effects is to be developed. Specifically, although the property does occur within the Mataura Catchment FMU we question the relevance of using the two sites on the Mataura River as the basis for a meaningful summary of water quality within the vicinity of the property. Rather we note that water quality effects associated with a given property are best assessed at a local scale if they are to be relevant (see also McDowell et al., 2017).

In terms of groundwater we agree with the general description of the hydrogeological environment underlying the property. However, note that the aquifer systems are more accurately defined as terrace aquifers not lowland. The authors note that "*Generally, groundwater quality within the Knapdale GMZ complies with limits set in the Drinking Water Standards for New Zealand (DWSNZ). However, it has been established since at least 2012 that areas of groundwater in the KGMZ have significantly elevated nitrate-nitrogen concentrations.*" They also note that "*The most likely reasons for these elevated concentrations are a combination of the pastoral and arable land together with shallow unconfined groundwater with limited saturated aquifer thickness (generally less than 10m), local rainfall as the primary recharge, and the moderate to low permeability of the aquifer. These factors have been identified in a number of reports on groundwater quality in Southland."* Soil and aquifer redox status as determined in the above technical discussion are also primary controls over water quality in the vicinity of the property and need to be given an appropriate level of consideration.

The applicant goes on to note that *"The trend over time for groundwater nitrate nitrogen in the wider area is illustrated in the following figure. This illustrates relatively stable concentrations of nitrate-nitrogen in bores in the area with the exception of groundwater from bore F45/0343.*" However, due to the lack of any quantitative evaluation of trend we raise questions around the legitimacy of the interpretation provided here. We also note the following statement "*We emphasise that groundwater flow in this area is reported as being primarily south by south-west. And therefore, Cashmere Bay Dairy will definitely not be contributing to the hotspot at F45/0343 and highly unlikely to be contributing to any significant extent to the hotspot at F45/0172.*" Whilst we agree the current dairy operation is unlikely to be a factor influencing elevated NO_3-N in well F45/0343 to the east of the property we do note it is further evidence that elevated groundwater NO_3-N is a common feature of this particular physiographic setting. Further, we disagree with the statement that Cashmere Bay Dairy is "*highly unlikely to be contributing to any significant extent to the hotspot at F45/0172"* and refer to the above technical assessment for a likely localised (dairy platform) influence over instances of elevated groundwater NO_3-N in both wells F45/0172 and F45/0182 and equivalent settings regionally.

In terms of the contribution to the Toetoes/Fortrose Harbour and estuary we agree that it is challenging to directly link the activities at any one property to overall deterioration. Rather, we suggest that an assessment of effects over ground and surface water bodies associated with the property is a far more relevant basis for any AEE. As such we question the relevance of an assessment of a small-scale property against estuarine trophic status due to issues of scaling. Soils and physiographic zones are discussed and summarised in table 5.

5.3 Assessment of Environmental Effects (Section 6)

Section 6 provides an assessment of environmental effects (AEE) on the environment resulting from the proposal to incorporate the Sheep Block into the existing dairy platform. The assessment "*assesses the farming activity in its entirety and doesn't use a permitted baseline approach to the* *assessment i.e., does not exclude those adverse effects on water quality authorised by permitted activity rules (as indicated by PSWLP Policy 39)*."

The AEE is based on the combination of Overseer and Good Management Practices (GMP). Table 9 details the "*Potential effects and mitigation measures (which include many GMPs indicated in ES GMP Factsheets) that will be adopted for the existing and proposed activities.*" With regards to winter grazing Table 9 does not specify whether intensive winter grazing will occur on the 'sheep-block' although it is mentioned earlier under section 2 (Details of the Proposal).

Overseer modelling and a subsequent review by Irricon resource solutions is provided. "*The data inputs into the model were based on the 'actual lawful use of the land' for the past three years for the dairy platform and runoff, as opposed to modelling consented maximums*." The review identifies a number of concerns regarding the inputs and outputs of the Overseer modelling. In particular, the high pasture production for all blocks relative to Southland data, the variance in effluent area between reported and modelled budgets, and a difference in fertilizer application to fodder crops. Overall Irricon rate the robustness of the nutrient budgets as medium.

The Overseer modelling for the sheep block shows an increase in N loss from 16 kg/ha/yr in 2017/18 to 30kg/ha/yr under the proposed activity, while the dairy platform decreases from 45 kg/ha/yr in 2017/18 to 39kg/ha/yr. However due to the above concerns raised by Irricon, the modelled scenarios may not be an accurate representation of current or proposed activities. Other issues surround the inherent uncertainty associated with Overseer modelling in terms of the level of confidence associated with the reported differences in NO_3-N leaching losses between current and proposed activities reported in the AEE.

The modelling suggests that "*Nitrogen losses to water are most likely to occur in the Gleyed, Bedrock/Hill Country and Old Mataura Physiographic Zones, via both artificial drainage and overland flow pathways*." We also expect NO_3-N losses from the Oxidising Physiographic Zone, which makes up 66% of the property, to be elevated and are surprised this is not noted. The overall conclusion of the modelling was "*the range of proposed mitigation measures to be implemented means that there is a high level of certainty that the actual loss of N to water will be less with the proposed development (sheep-block inclusion) compared to the average situation prior to the addition of the 80 ha sheep block*." Similarly, "*The proposed addition of the Sheep Block results in an Overseer modelled increase in the total amount of P loss to water across the whole farm from 299 kg P/yr to 317 kg P/yr. A very small increase of 18kg. This is a 6% increase in total P loss over the property. As noted for the N loss to water estimates the predevelopment P loss estimate does not include losses associated with off-site wintering. The modelled increase is primarily because Overseer assumes more laneways because of the overall increase in area of 80 ha*."

The AEE subsequently assesses the reduction in modelled P losses through a number of GMP that are not currently modelled by Overseer. It suggests a large reduction in P loss on the order of >29.5 kg. We do not disagree with this assessment if all actions noted in the application and attached Tiaki FEMP are implemented. The AEE goes on to consider winter grazing noting that an increase of 70 cows under the proposed activity. The increased contribution from additional grazing is averaged against the increased land area provided by the 'sheep-block' noting that the area (7.3% of the land holding) meets the permitted activity requirements under Rule 20(a)(iii) of the PSWLP.

Section 6.4 assesses the specific contaminant loss and cumulative effects of freshwater and ***Section 6.5*** discusses the potential cumulative effects on the Toetoes/Fortrose Harbour Estuary. In these important sections the authors of the report state that: "*The background existing nitrate nitrogen concentrations in groundwater are relatively high as indicated earlier in this report. However, the* *mitigation measures included in the FEMP reflected in the Overseer modelling strongly indicate that the proposed inclusion of the 80ha block in the dairy farm will contribute to a small reduction in the overall nitrogen load in the area. In addition, because wintering off will be brought onto the milking platform N and P losses in locations where wintering was previously undertaken will also be reduced. The effect of this will be an extremely small reduction in the concentrations of nitrate nitrogen in local groundwater and an extremely small reduction in total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved reactive phosphorus in surface waters downstream of the property*." Overall, we agree that due to an increase in land area associated with the proposed sheep-block and no increase in cow numbers that the farm system is unlikely to result in a change in the current intensity of land use across the dairy platform – assuming the lease block is retained for the duration of the proposed consent. However, we note that there is likely to be an increase in NO_3-N leaching rates across the 'sheep-block' if incorporated into the dairy platform and used as a site for intensive wintering. In section 6.6 the applicant appears to agree that "*the change from an organic sheep farm to becoming part of an extended dairy farm is highly likely to increase the losses of nitrogen to groundwater from this block compared to losses that would have occurred while the block was run as an organic sheep block*." Further that "*it is highly likely that there will be an increase in contaminant loss to water from the sheep block's proposed use compared to its use as an organic sheep farm*."

Yet the authors go on to state that: "*As indicated earlier in this report the reductions of N and P loss from this property will be insignificant on the basis of one property within relatively large groundwater and surface water catchments. There would be no measurable change in either local or distant receiving water quality as a consequence of the GMPs and additional mitigation implemented on this property. Measurable enhancements in groundwater and surface water quality N concentrations or surface water quality P concentrations would only be achieved through a broader catchment approach to water quality management. This means that if equivalent measures were undertaken more broadly across the catchments, the suitability of groundwater would improve as a source of drinking water and the nutrient regime in surface waters would be compatible with a reduction in plant biomass e.g., periphyton. The overall effect of the changes in land use on the property would be a small contribution towards a reduction in existing adverse effects associated with nitrogen and phosphorus in water*." Once again, we agree that measurable effects at a surface water catchment scale i.e., Mataura FMU are unlikely to be detectable. However, we do not agree that localised changes, as a consequence of additional mitigations or GMPs, many not listed here, would not have an effect on local ground or surface water quality. For example, wintering barns or feed pads and staggered winter grazing can significantly reduce local NO_3-N leaching losses to aquifers (Monaghan et al., 2012; Monaghan, 2012; Chrystal et al., 2012). Further, detention bunds and peak runoff control structures have a published track record of significantly reducing nutrient and sediment losses to waterways (McDowell et al., 2012; Clarke, 2013, Couldrey et al., 2018; Living Water, 2018; Dorner et al., 2018).

In terms of sediment and microorganism the authors note that "*the s.88 response letter asks for an assessment that shows "annual amount of sediment and microbiological contaminants discharged from the landholding will be no greater than the last 5 years prior to the application being made".* They respond by stating *"It is not practicable to quantify the annual amount of sediment discharged from the property over the last five years, nor is it practicable to quantify the amount of sediment that would result after implementation of all the mitigation measures. However, there are sufficient relevant research and case studies that enable us to conclude that there will be a substantial and, if implemented as part of a catchment-wide programme, significant improvement in relevant water quality variables (e.g., black disc, turbidity and sediment deposition) in receiving waters. The overall effect of the changes in land use on the property would be a reduction in existing adverse effects associated with sediment in water e.g., reduction in smothering of stream bed macroinvertebrate communities."* We note that it is possible to estimate sediment and sediment bound reductions in N and P going forward if investments are made in monitoring of sediment retention on the property (McDowell et al., 2012; Clarke, 2013). Overall, we agree that it is difficult to provide any meaningful assessment of cumulative effects on the Mataura Catchment and the Toetoes/Fortrose Harbour and Estuary. However, we do not agree that significant improvement in the quality of localised ground and surface water associated with the property cannot be achieved.

Section 6.6 discusses Adverse effects on and from specific blocks on the property. The applicant notes that "*We have been informed by Environment Southland that before this application will be considered complete under Section 88 of the RMA it must include an "…assessment of effects from the entire landholding on the receiving environment, including an assessment from each block (run-off, dairy platform and sheep block) individually;" and it must include "…an assessment of effects resulting from the proposed change in land use (organic sheep farm to dairy farm) on the new block*". *We have examined both the surface water sub-catchments and groundwater flow direction for the area and the relevant planning provisions and cannot identify an effects or statutory/policy basis for attempting to separate out the Sheep Block and estimate contaminant losses from that block in isolation from other blocks. Similarly, we cannot see any effects-based reason or robust statutory/policy basis for separating out the runoff block or the balance of the milking platform. If the property contained a catchment boundary, we could see a rationale for separating out an assessment based on those catchments. Rule 20 requires resource consent application to use land for a farming activity and the focus is on the whole landholding. We address the policy matters in Section 7 of this report*."

Further that: "*Notwithstanding these concerns, we acknowledge that the change from an organic sheep farm to becoming part of an extended dairy farm is highly likely to increase the losses of nitrogen to groundwater from this block compared to losses that would have occurred while the block was run as an organic sheep block. However, the modelling and mitigation to be applied to the whole property means that we are very confident that for the property as a whole there will be a reduction in nitrogen and all other contaminant losses to water from the whole property. Therefore, it is highly likely that there will be an increase in contaminant loss to water from the sheep block's proposed use compared to its use as an organic sheep farm. However, we are very confident that the proposed range of good management practices and mitigation above and beyond these GMPs will more than offset these adverse effects*."

In response, we do not agree that there will be a significant overall reduction in NO_3-N leaching losses across the property. Rather, on the evidence presented here we expect losses to be similar overall. Further, we do expect that there will be a localised increase in NO_3-N concentrations in the aquifer beneath the 'sheep-block' if used for wintering. This is consistent with studies into the localised effects of winter grazing over NO_3-N leaching losses by AgResearch at Five Rivers and Tussock Creek (Smith and Monaghan, 2013, Monaghan et al., 2013) and recognition of the physiographic setting and shallow water table across the western terrace. Further, given that groundwater NO_3-N concentrations are on occasion exceeding the NZDWS, as high as 29.8 mg/L NO_3-N, it is our opinion that consideration should be given to alternative mitigations focussed on the reduction of NO_3-N leaching associated with wintering on well-drained soils. However, we do agree that there will likely be a decrease in sediment, P and potentially microbial losses to surface waterways if the full suite of mitigations outlined in this report are implemented.

The authors conclude that they *"…do not consider that there would be any benefit in analysing the Overseer modelling to try and separate before and after scenarios on the basis of the three components (Sheep Block, Run-off Block & Milking Platform) of the proposed farm.*" Although we think modelling of NO_3-N losses from the sheep-block would indeed be instructive for better understanding the potential impact on groundwater beneath the 'sheep-block', especially under a proposed wintering scenario, we do not think it would add much value if such modelling did not consider the need to implement mitigations for NO_3-N leaching from well drained soils.

Section 6.9 discusses schedule 4 of the RMA that requires "*an assessment of environmental effects must include a description of any possible alternative locations or methods for undertaking the activity if it is likely that the activity will result in any significant adverse effect on the environment and/or if the activity includes the discharge of contaminants*." The applicant states that "*The proposed dairy expansion activity as described in this report will not result in significant adverse effects on the environment. However, for completeness, an assessment of alternatives is provided*." In our opinion this is inconsistent with the physiographic setting and evidence from groundwater monitoring on the property for NO_3-N concentrations that already exceed the NZDWS under the current activity. Furthermore, in our opinion wintering on well drained soils across the sheep-block is likely to result in a localised increase in groundwater NO_3-N. Alternatives, including spatial relocation options that would result in a significant net decrease in local NO_3-N leaching to underlying aquifers have not been put forward.

6 Conclusion

We conclude that the AEE undertaken for the proposed activity fails to recognise or acknowledge localised effects associated with intensive farming under a physiographic setting prone to the development of groundwater NO_3-N hotspots. **Although we agree that 'overall' the increase in NO_3-N leaching losses is likely to be small, due to an increase in the area of the dairy platform, we do expect localised increases in groundwater NO_3-N to occur beneath the well-drained soils of the sheep-block if this consent were to be granted.** We agree that the suite of mitigations proposed for sediment and P are likely to have a net benefit.

A key question arises as to what the change in the per unit area land use intensity and associated groundwater NO_3-N concentrations be if the lease block were to become unavailable?

a. Will wintering be off-site under this scenario or on-site?

We conclude by suggesting that consideration should be given to mitigations that limit NO_3-N leaching losses from the well-drained soils to aquifers beneath the property. In particular, thought should be given to limiting NO_3-N losses from proposed wintering activities. If not, we expect NO_3-N concentrations to increase beneath the proposed sheep-block.

Dr Clint Rissmann
Director
Land and Water Science Ltd

Dr Lisa Pearson
Lead Earth and Environmental Scientist
Land and Water Science Ltd

References

Chrystal, J.M., Monaghan, R.M., Dalley, D., and Styles, T. (2012) Assessments of N leaching losses from six case study dairy farms using contrasting approaches to cow wintering. Proceedings of the New Zealand Grassland Association 74: 51-56. https://www.grassland.org.nz/publications/nzgrassland_publication_2269.pdf

Clarke, D.T. (2013). The performance of Detainment Bunds (DBs) for attenuating phosphorus and sediment loss from pastoral farmland. Unpublished MSc thesis, Department of Biological Sciences, University of Waikato, Hamilton, New Zealand.

Couldrey, M., Pearson, L., Rissmann, C., and Newe, H. (2018). Peak runoff control for farm contaminant retention in the Waituna Catchment. Land and Water Science Report 2018/12. 53p.

Dorner, J., Doole, G.J., Bermeo, S., and Paterson, J. (2018). Economic assessment of options to mitigate sediment loss from New Zealand agriculture – in the context of managing freshwater quality. Pay of Plenty Regional Council 2018/07. https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/Sediment-review-full.PDF

Dubčáková, R. (2011). Eureqa: software review. Genetic programming and evolvable machines, 12(2): 173-178.

Hughes, B. (2012). Knapdale Groundwater Zone Technical Report. Liquid Earth Report prepared for Environment Southland. https://www.goredc.govt.nz/assets/documents/coopers-wells/2012-hughes-knapdale.pdf

Hughes, B., Wilson, K., Rissmann, C., Rodway, E. (2016). Physiographics of Southland: Development and application of a classification system for managing land use effects on water quality in Southland Technical Report November 2016. Publication No 2016/11. Version 2 – Final.

Living Water. (2018). Detention Bund Project. https://www.livingwater.net.nz/assets/sm/upload/z5/vz/su/fr/Detention%20bunds%20trial%20case%20study%20July%202018.pdf

McDowell, R.W., Gongol, C., and Woodward, B. (2012). Potential for controlled drainage to decrease nitrogen and phosphorus losses to Waituna Lagoon. AgResearch Report for Environment Southland. Christchurch, New Zealand.

McDowell, R.W., Cox, N., and Snelder, T.H. (2017). Assessing the yield and load of contaminants with stream order: would policy requiring livestock to be fenced out of high-order streams decrease catchment contaminant loads? Journal of Environmental Quality. https://landwaterpeople.co.nz/wp-content/uploads/2018/02/Consideration-of-proposed-fencing-rules-in-New-Zealand-with-respect-to-contaminant-generation-at-the-national-scale.pdf

Monaghan, R.M., Semadeni-Davies, A., Muirhead, R.W., Elliott, S., and Shankar, U. (2010). Land use and land management risks to water quality in Southland. AgResearch Report prepared fro Environment Southland. http://envirolink.govt.nz/assets/Envirolink/885-ESRC230-Land-use-and-land-management-risks-to-water-quality-in-Southland.pdf

Monaghan, R.M. (2012). The impacts of animal wintering on water and soil quality. AgResearch Report prepared for Environment Southland. RE500/2012/029. 45p.

Monaghan, R.M., Smith, L.C., and DeKlein, C.A.M. (2013). Nitrate leaching and nitrous oxide emissions from a winter forage crop in southern New Zealand. Agriculture, Ecosystems and Environment 175: 29-38.

Pearson, L., Couldrey, M. and Rodway, E. (2016). Spatial analysis of winter forage cropping in Southland and the implications for water quality management. Environment Southland Technical Report 2016-13. 57p. https://www.es.govt.nz/Document%20Library/Research%20and%20reports/Land%20and%20soil%20reports/Technical%20Report%20-%20Spatial%20analysis%20of%20winter%20forage%20cropping%20in%20Southland%20(PDF).pdf

Rissmann, C. (2011). Regional Mapping of Groundwater Denitrification Potential and Aquifer Sensitivity, 2011-12, 38p. https://doi.org/10.13140/2.1.3412.5606.

Rissmann C., Wilson, K., and Hughes, B. (2012). Waituna Catchment Groundwater Response. Environment Southland Technical Report 2012-04. 101p. https://www.es.govt.nz/Document%20Library/Research%20and%20reports/Groundwater%20reports/waituna_technical_report_2012.pdf

Rissmann, C. and Pearson, L. (2018). Identifying Pollutant Sources within the Waimea Catchment: Applying hydrochemical tracers to surface water time series data. Land and Water Science Report 2018/15. p54.

Rissmann, C., Rodway, E., Beyer, M., Hodgetts, J., Pearson, L., Killick, M., Marapara, T.R., Akbaripasand, A., Hodson, R., Dare, J., Millar, R., Ellis, T., Lawton, M., Ward, N., Hughes, B., Wilson, K., McMecking, J., Horton, T., May, D., and Kees, L. (2016). Physiographics of Southland Part 1: Delineation of key drivers of regional hydrochemistry and water quality. Environment Southland Technical Report No. 2016/3. Invercargill, New Zealand.

Rissmann, C.W.F., Pearson, L.K., Beyer, M., Couldrey, M.A., Lindsay, J.L., Martin, A.P., Baisden, W.T., Clough, T.J., Horton T.W., and Webster-Brown, J.G. (2019). A hydrochemically guided landscape classification system for modelling spatial variation in multiple water quality indices: Process-attribute mapping. Science of the Total Environment 672: 815-833. https://doi.org/10.1016/j.scitotenv.2019.03.492.

Schmidt, M., and Lipson, H. (2009). Symbolic regression of implicit equations. Genetic Programming Theory and Practice. https://doi.org/doi:10.1007/978-1-4419-1626-6_5

Schmidt, M. and Lipson, H. (2015). Eureqa (Version 1.24. 0).

Smith, C. and Monaghan, R. (2013). Comparing OVERSEER estimates of N leaching from grazed winter forage crops with results from Southland trial sites. AgResearch Report prepared for Environment Southland. RE500/2013/123. 6p.

Wilson, S., Chanut, P., Rissmann, C., Ledgard, G. (2014). Estimating time lags for nitrate response in shallow Southland groundwater. Environment Southland and Lincoln Agritech Technical Report 2014-03. https://www.es.govt.nz/Document%20Library/Research%20and%20reports/Groundwater%20reports/estimating_time_lags_for_nitrate_response_in_shallow_southland_groundwater.pdf