Physiographic Environments of New Zealand

Information Document for Regional Councils

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Abstract

The Physiographic Environments of New Zealand (PENZ) a two-year project (mid 2017- mid 2019) that links fresh water to the land. Understanding this relationship is crucially important as it is a major influence over water composition, and hence quality. Landscape features can account for more than twice the variability in water quality than land use alone. For this reason, it is important to include landscape attributes in any attempt to explain 'how' and 'why' water quality varies across a catchment or region. The Physiographic Science turns existing thinking on its head because it uses the signals in water to trace the water's journey through the landscape. The project is made possible through collaboration and funding from Our Land and Water National Science Challenge and Regional Authorities. The regions currently undertaking physiographic mapping are Northland, Auckland, Waikato, Bay of Plenty, Manawatu-Wanganui, and Canterbury.

For regions around NZ that have opted to join the project, national and regional water composition and quality data sets are used in conjunction with existing geospatial layers to map the set of processes (hydrological and redox) that control the spatial variability of water. The method uses scientifically rigorous techniques to bring together data for climate, topography, geology, soils, and hydrological controls with analytical chemistry at a national scale. It will also be ground-tested using expert local knowledge. The resulting product will be "Physiographic Environments of New Zealand" – a freely-accessible, high resolution map that explains the 'how' and 'why' water quality varies spatially.

The method used in the project has been peer-reviewed both nationally and internationally (Rissmann et al., 2016). It was also ratified by Our Land and Water National Science Challenge, which has provided partial funding for the project. Unlike the crown research institutes and universities also involved in the national science challenges, this project is being developed out of an independent consultancy, and hence the need to obtain Regional Council support and funding to map each region.

This document presents a high-level overview of the physiographic science including a general introduction to the methodology, data requirements from regional authorities, and introduces the project team and affiliations. Also included in this document is a project timeline for deliverables and funding structure.

1 Introduction

Water quality can vary spatially across the landscape, even when there is similar land uses or pressures in a catchment. These differences in water quality occur because of the natural spatial variation in the physical landscape, which alters the composition of the water through coupled physical, chemical and biological processes. The water composition (of dissolved and particulate constituents) provides information about its origin, the pathway it has travelled and the processes to which it has been subjected. Of most significance to surface water quality are the processes occurring in the soil zone and shallow unconfined aquifers, as they are highly connected hydrologically to surface water (Figure 1). Identifying, mapping, and classifying these landscape features across an area forms the basis of the physiographic approach, making it possible to accurately predict the water chemistry of shallow groundwater and surface water. For example, all regional ground water nitrate, phosphorus and *E. coli* hotspots were accurately identified and constrained spatially for the Southland region (Rissmann, 2012; Rissmann et al., 2012; Snelder et al., 2016).

The physiographic approach was developed at Environment Southland, led by Dr Clint Rissmann, alongside policy development for the regional plan. The **Physiographic Environments of New Zealand** project takes this research a step further by producing a national scientific classification for knowledge transfer, independent from policy development. The physiographic approach is based on peer reviewed scientific principles, applicable not just to Southland but the whole of New Zealand and many other regions of the world (Peters, 1994; Clark and Fritz, 1997; Kendall and O'Donnell, 1998; Indamar, 2012; and others). Currently, the physiographic framework is being used for the Waituna Catchment for Living Water, a Department of Conservation and Fonterra partnership, to provide a basis for targeted investments to mitigate losses from farms across the catchment.

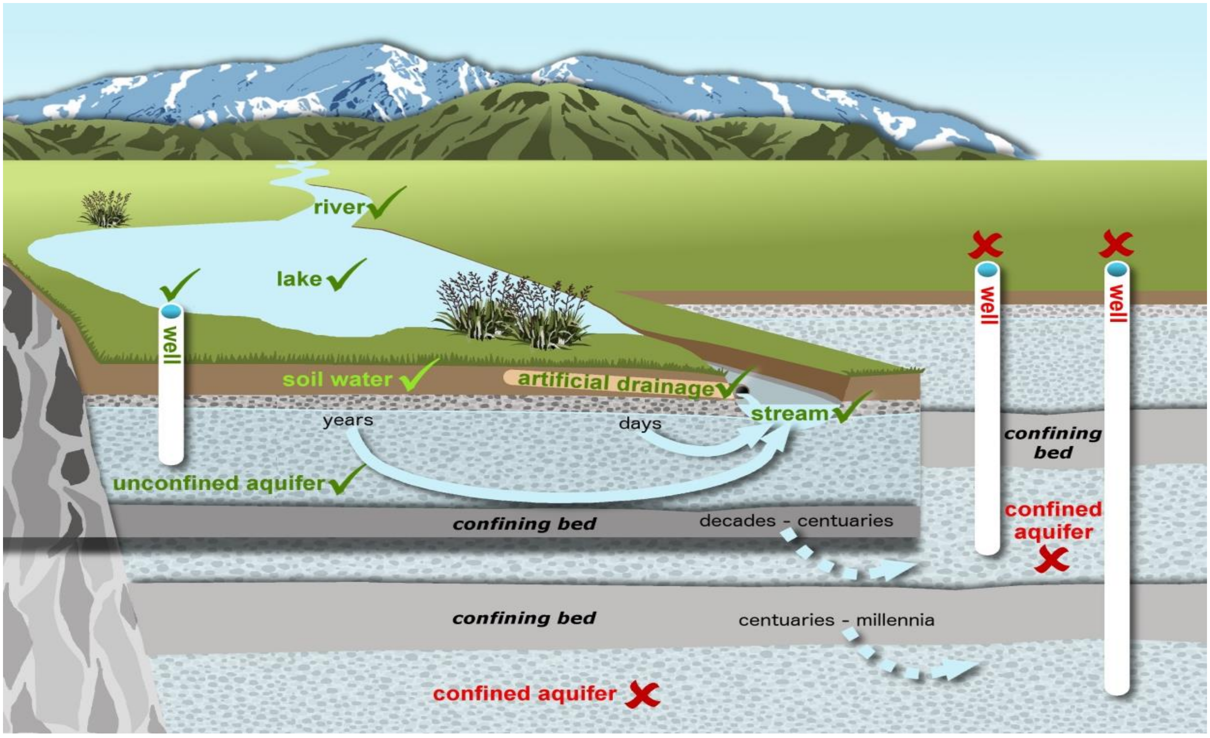

Figure 1: Illustration of the connectivity of water resources, including soil water, surface and shallow groundwater. The green tick marks show the hydrologically connected settings included in the physiographic approach, red crosses identify settings that are excluded.

1.1 National Policy Statement for Freshwater Management

Under the National Policy Statement for Freshwater Management (NPS-FM; MfE, 2014), regional authorities are required to maintain or improve water quality through regional plans to set freshwater objectives and limits. Local authorities must ensure there are appropriate controls on land use, discharges and water takes to meet a freshwater objective for both water quantity and quality.

The need for regional authorities to understand the major drivers of water quality outcomes and inherent risk is critical for planning purposes, resource consent activities, and targeted locations for cost-effective water management strategies (or mitigations). Objective A1 of the NPS-FM requires councils to adopt a **holistic** or **whole catchment** response using a variety of tools and methods. The physiographic conceptual framework provides a tool for councils to effectively manage to freshwater objectives for a catchment/region.

1.2 Benefit of Physiographic Science

Physiographic Environments provide a visual, spatial platform to explain 'how' and 'why' water composition, water quality state, and inherent water quality risks vary across a landscape or catchment (Rissmann et al., 2018; Pearson et al., 2018). They can be used to understand the controls and estimate the concentration of redox sensitive species (dissolved oxygen, nitrate, nitrite, ammonia, dissolved manganese, dissolved iron, sulphate) and indirectly sensitive species, such as soluble forms of phosphorus. Sediment and microbial contaminants are not directly included in the assessment; however Physiographic Environments can discriminate between clarity, turbidity and microbial (*E. coli*) risk between mapped environments (Snelder et al., 2016). A sediment specific physiographic layer is currently being developed for Northland Regional Council.

Physiographic Environments can be used in a wide range of applications across a regional authority; including resource consent applications for assessment of environmental effects, informing land management decisions and farm environmental plans to target mitigation approaches, and assisting with future policy and planning. The Physiographic Environments provide context to existing empirical models (such as Overseer Nutrient Budgets, CLUES, LUCI and other catchment models), as they are based on a recognition of those soil features that are most critical to water quality outcomes and that may not be recognised or incorporated within existing geospatial layers. For this reason, Physiographic Environments allow for a more rigorous spatial understanding of the fate of contaminants once they leave the root zone. This includes their subsequent transport and attenuation potential prior to reaching a water body. Water quality mitigation approaches can therefore be targeted to the Physiographic Environment, thus optimising expenditure and increasing success.

Physiographic Environments are useful for:

- Improving understanding of the processes driving surface and groundwater quality, particularly variation in water quality patterns in the region
- Better understanding of risks of land uses to water bodies
- Identification or refinement of freshwater management units under the National Policy Statement for Freshwater Management 2014,
- Setting of freshwater quality objectives and limits,
- Development of appropriate (i.e. targeted and effective) regulatory and non-regulatory land management initiatives for maintaining and improving water quality.

1.3 Scale

The physiographic approach explains water quality variation in small (greater than 2nd order) to large order drainage basins and local scale aquifers. The 'Physiographics of Southland' could explain and accurately estimate longitudinal variation in surface and shallow groundwater across Southland, including locating all groundwater hotspots (for nitrogen, phosphorus and E. coli), and most importantly explain why they form where they do, despite often similar land use pressures.

At the farm scale, physiographic environments work by providing key context to the farm setting and the underlying controls over water quality outcomes. For Southland, Dr Ross Monaghan, Senior Scientist at AgResearch, used the physiographic zones to tailor mitigations to each zone, which Environment Southland's farm extension team use to provide context to the advice they give to farmers.

2 Project Affiliations and Support

PENZ will be primarily developed by a Project Team at Land and Water Science, and in affiliation with Our Land and Water National Science Challenge and Regional Authorities. The project relies on funding and guidance from Regional Councils across New Zealand and without their input it is not possible to classify every region. The roles of each of these groups is outlined below.

2.1 Project Team

The research and development of PENZ will be undertaken at Land and Water Science, led by Dr Clint Rissmann.

The key people involved at LWS are:

- Dr Clint Rissmann – Project Leader, Director, and Adjunct Senior Fellow at the Waterways Centre for Freshwater Management, University of Canterbury and Lincoln University.
- Dr Lisa Pearson – Project Manager, Lead Environmental and Earth Scientist
- Dr Monique Beyer – Environmental Engineer and Hydrologist
- Mr Matt Couldrey – GIS Analysist and Environmental Scientist
- Ms Jessie Lindsay – GIS Analyst and Environmental Scientist

2.2 Our Land and Water National Science Challenge

Physiographic Environments of New Zealand project is incorporated with the Our Land and Water (OLW) National Science Challenge, which aims "to enhance primary sector production and productivity while maintaining and improving our land and water quality for future generations". The project integrates directly with two key challenge themes, **Sources and Flows** - Lead by Dr MS Srinivasan and Dr Richard Muirhead, and **Land Use Suitability** - Lead by Dr Scott Larned and Professor Richard McDowell. A key requirement of the PENZ project is the alignment and integration of this work with the Sources and Flows and Land Use Suitability themes.

2.3 Regional Authorities

A key requirement of the PENZ programme has been to obtain co-funding from regional authorities throughout New Zealand, to facilitate application of the physiographic approach in as many regions as possible. Physiographic mapping for contracted regions in the North Island commenced in early 2018, including development of hydrological process attribute and redox process attribute layers.

The project also requires experts from the regional authorities for local expert knowledge and supply of regional water quality datasets for validation and ground truthing of the final product. Regional council input will help shape the final outputs.

The councils currently involved with the project are:

- Northland Regional Council
- Auckland Council
- Waikato Regional Council
- Bay of Plenty Regional Council
- Horizons Regional Council
- Environment Canterbury

In addition, a high-resolution sediment layer is currently being undertaken for Northland Regional Council due to the particular importance of sediment loss for the region. This work leverages off existing geospatial layers including a radiometric survey of the region.

3 Current Applications and Relevant Work

This section details other projects and scoping work that has been undertaken in regions and catchments around NZ.

3.1 Living Water (Department of Conservation and Fonterra Cooperative)

Over the past year we have been collaborating with Living Water (DOC/Fonterra Partnership) and local landowners to undertake high-resolution physiographic mapping of the Waituna Catchment, Southland (Rissmann et al., 2018a; Pearson et al., 2018a; Pearson et al., 2018b; Rissmann and Beyer, 2018). The key aim of the project was to support water quality and biodiversity investment decisions for the catchment, and to assist the partnership in achieving their aim of *"finding solutions to enable farming, freshwater, and healthy ecosystems to thrive side-by-side"*. To achieve this, we created high-resolution physiographic science process-attribute layers for the catchment (Figure 2). The hydrological and redox process-attribute layers were identified to be the key controls over water quality outcomes in the Waituna Catchment.

Two Story Maps (online interactive maps) were produced for the catchment, which show the physiographic maps and natural variation in mobility of nitrogen (nitrate, organic N), phosphorus (dissolved reactive and particulate), sediment, and microbes.

Story Map 1: Background and Technical Information
https://e3s.maps.arcgis.com/apps/MapJournal/index.html?appid=0c0fc1fa5afa423eb63d85bd9a1ec980

Story Map 2: Physiographic Maps and Inherent Risk
https://e3s.maps.arcgis.com/apps/MapJournal/index.html?appid=73571ecdd1e14f3eb3d07166952b897d

Additional information on the application of the physiographic approach to the Waituna Catchment can be found in a recently published paper (Rissmann et al., 2018b), which was presented at the Massey University, Fertilizer and Lime Research Centre Workshop.

http://flrc.massey.ac.nz/workshops/18/Manuscripts/Paper_Rissmann_2018.pdf.

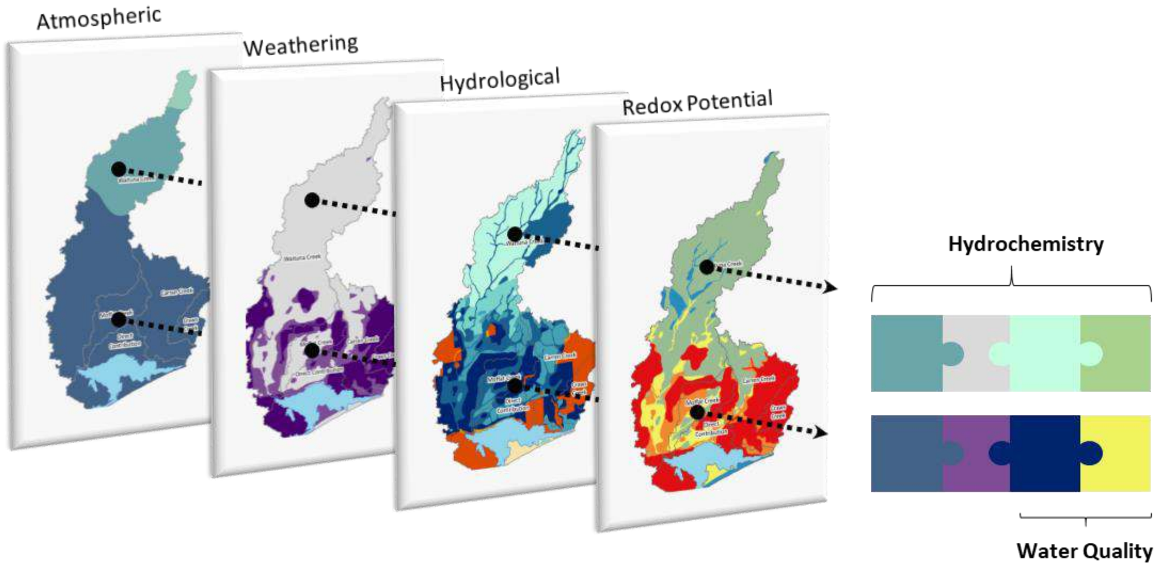

Figure 2: Example of the physiographic mapping undertaken for the Waituna Catchment, Southland (Rissmann et al. 2018b).

3.2 Sustainable Farming Fund

Over the next six months we are particularly looking forward to collaborating with numerous industry and local stakeholders on the Ministry for Primary Industries, Sustainable Farming Fund Project (2018 – 2021) which commences in July 2018. Through this project, we aim to work with farmers, industry groups, and community groups to establish a spatial platform to allow landowners to access mapping layers developed through the physiographic science approach. Ultimately, this will allow industry groups and landowners to better understand the landscape controls on water quality, and to have the required information to implement management procedures to allow for the maintenance and improvement of water quality. Examples of 'on the ground' management practices that can be implemented and which are informed by physiographic science include: land use management practices (e.g., changes to nutrient and stock rates and inputs), implementation of physical mitigation measures (e.g., riparian planting of waterways; peak runoff structures to reduce sediment during high flow/rainfall events), optimisation of the timing of fertiliser and Farm Dairy Effluent irrigation, and provision of spatial context to existing farm extension programmes.

For more information on this project see the SFF application in Appendix 1 or contact Lisa at Land and Water Science (lisa@landwatersci.net).

3.3 Envirolink Advice Grants (Waterways Centre for Freshwater Management, University of Canterbury and Lincoln University)

3.3.1 Suitability of national datasets for physiographic mapping

An Envirolink medium advice grant was completed for Northland Regional Council to assess the suitability of national datasets for physiographic mapping for the region (Rissmann et al., 2017). Attributes within national soil (FSL, SMAP), geological (NZLRI, QMAP), topographical (DEM), and hydrological (REC) datasets were identified to recognise landscape gradients specific to water quality. These attributes were compared against radiometric imagery which is a direct measure of the spatial heterogeneity of the land surface and is relevant to deciphering the key landscape controls over water quality. While the project was specific to Northland, the findings have been incorporated into the physiographic methodology for the national application.

3.3.2 Small advice grants

Envirolink small advice grants regarding provision of technical advice were undertaken for Marlborough, Tasman District Council (Lovett and Rissmann, 2018a) and West Coast Regional Council (Lovett and Rissmann, 2018b). The primary aims of these projects were to engage with regional council staff to transfer knowledge on the application of physiographics to the respective regions. This engagement was essential to allow regional council staff to better understand the physiographic approach, the work required in application of the science, and potential benefits for water resources management at a regional and catchment scale.

4 Physiographic Approach – Overview of Methodology

Identifying the landscape features which control the spatial variation in water quality is the basis of the physiographic method (Rissmann et al., 2016). Landscape features can account for more than twice the variability in water quality than land use alone (Johnson et al., 1997; Hale et al., 2003; Dow et al., 2005; King et al., 2005; Shiels, 2010; Becker et al., 2014). Natural **gradients** in landscape features, which we term **attributes**, govern the variation in the key **processes** that determine water composition, water quality outcomes and risk. For example, it is widely recognised that soil zone denitrification is driven by gradients in soil drainage class. While poor water quality is unlikely to occur in the absence of intensive land use, similar intensities of land use don't always result in the same water quality issues if the underlying landscape attributes are different (e.g. different assemblages of soils, geology and hydrology).

The physiographic method involves mapping the gradients in the processes governing variation in water composition as individual **process-attribute layers (PAL)** using GIS mapping software. National and international literature provides evidence that most differences in water quality outcomes, for a given land use pressure, across a landscape can be explained through the combination of **hydrology** and **redox** processes alone. The application of the physiographic method nationally will involve the development of these two key PALs, which are described further in the following sections. Other processes that control variation in water composition are atmospheric and weathering (erosion and deposition). These processes are necessary for a detailed understanding of water composition (e.g. hydrochemical facies and mineral saturation indices); however, they are not directly linked to water quality (i.e. nutrients, sediment, and microbiological indicators).

The signals in water (chemistry) are used to verify the effective properties of the landscape. This process is important for: (i) linking landscape compartments (i.e., land surface, soil, aquifer, surface waters); (ii) understanding the relative significance of each compartment over water composition, and; (iii) refining pre-existing maps of landscape attributes that may not have been mapped with water in mind, or do not contain the key attributes governing water quality outcomes.

With this integrated perspective in mind, the ultimate aim of the physiographic method is to produce a number of classed process-attribute GIS layers that depict the spatial coupling between process signals in water and landscape attribute gradients. The steps for physiographic mapping of the landscape are summarised in Figure 3.

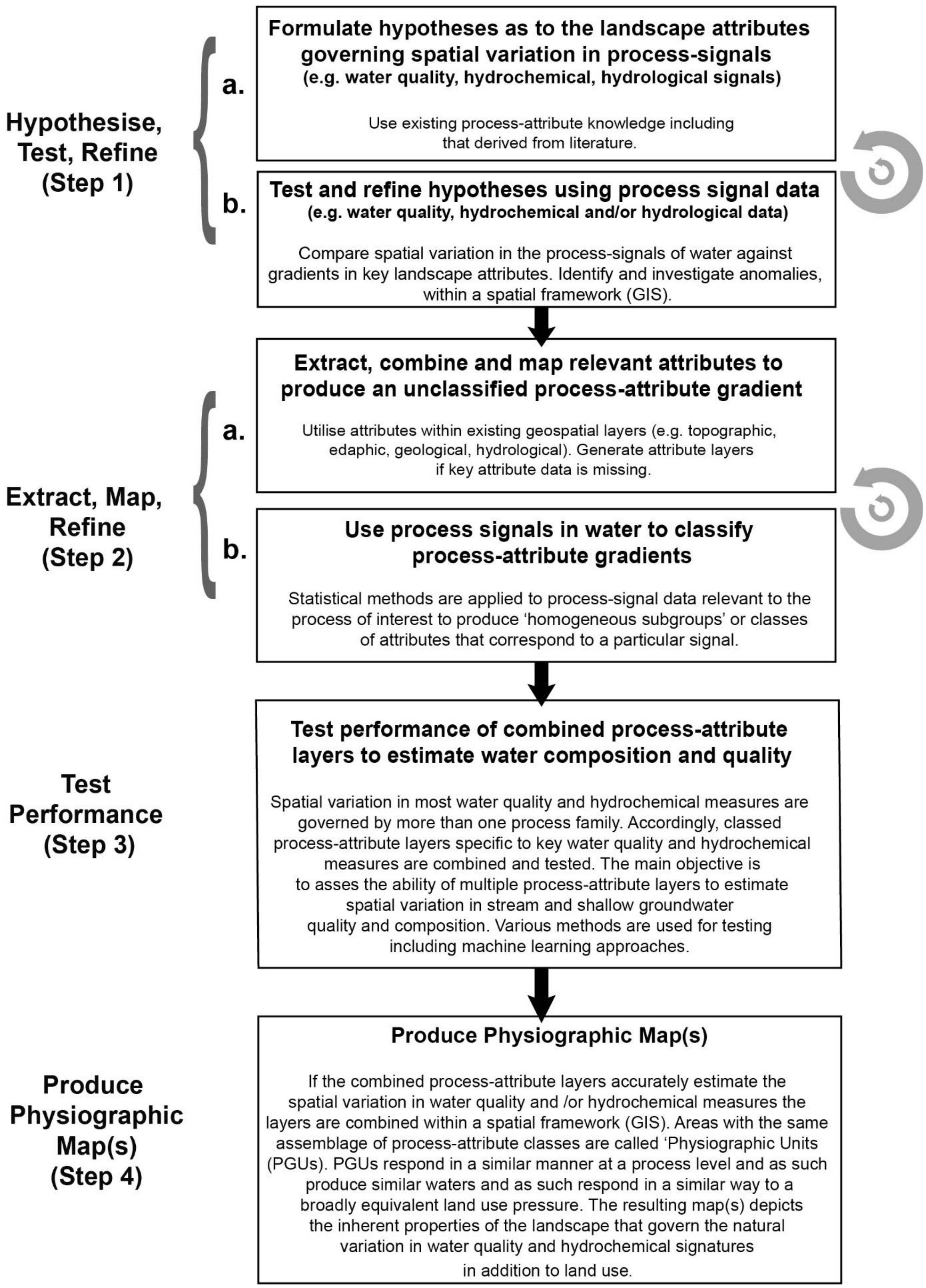

Figure 3: Summary of steps to develop the physiographic mapping method (Rissmann et al. in prep.).

4.1 Hydrological Process-Attribute Layer (H-PAL)

The **hydrological PAL** represents the landscape controls over:

- Water source - where the water in a stream or aquifer originates from i.e. alpine, hill country, lowland precipitation altitude and age.
- Recharge mechanism - the broad scale mechanism/process by which water reaches an aquifer or stream i.e. proximal land surface recharge or distal.
- Water pathway - fine scale mechanism/process controlling the pathway water takes i.e. bypass flow, overland flow, lateral drainage and deep drainage (Figure 4).

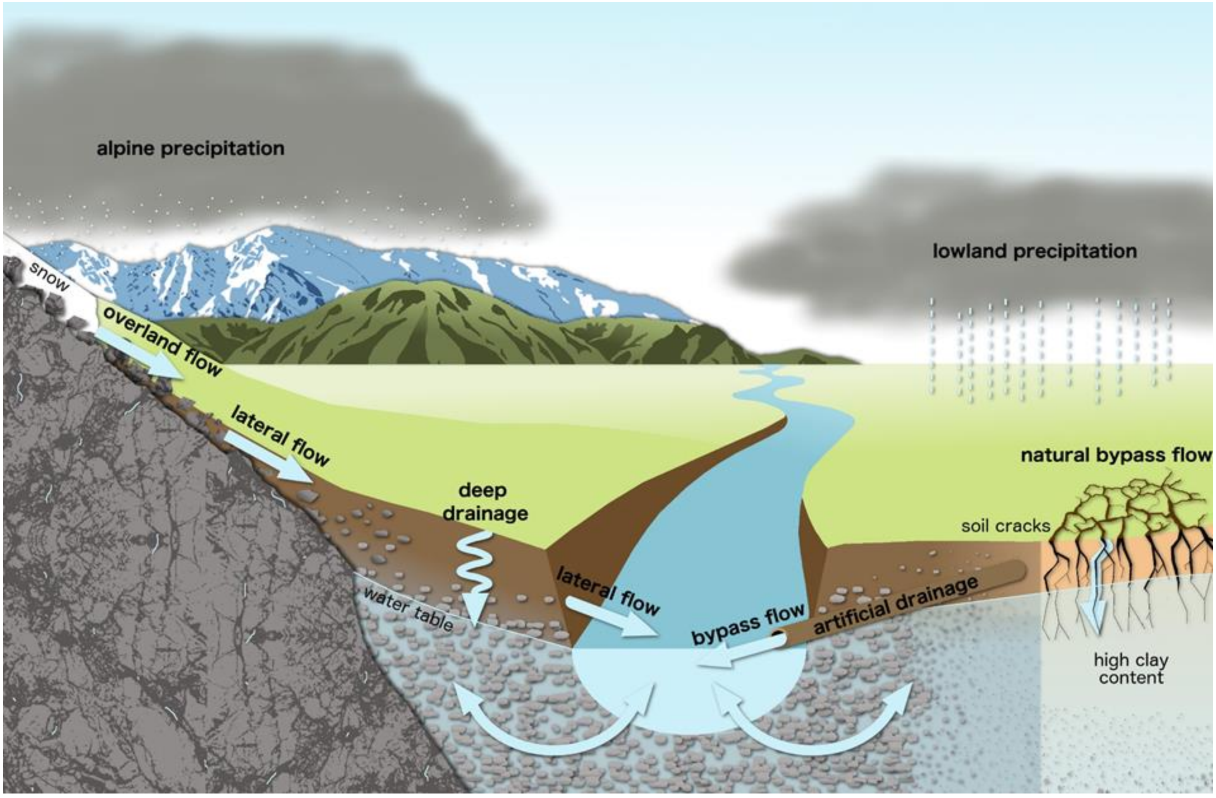

Figure 4: Fine scale hydrological pathways.

For example, a physical attribute, such as soil texture (or particle size), is one control over the water pathway through the landscape (Figure 5). A coarse textured gravel is at one end of the gradient, where water can move rapidly down through the soil (by deep drainage) and surface runoff (overland flow) is uncommon. As the soil particles weather (decreasing in size) to silt and clay size fractions at the other end of the gradient, the hydrological pathway changes. Finer textured soils typically have a slower permeability or infiltration rate (<4mm/hr), which means that deep drainage occurs more slowly, lateral and overland flow dominate, and water is retained in the soil for longer. Overland flow is highest where there is bedrock and little to no soil development. Another example of a physical attribute that controls hydrological processes is soil drainage. Soil drainage can vary from well to poorly drained. Well drained soils are typically coarse or uniformly textured, while poorly drained soils are typically fine textured (i.e. clay).

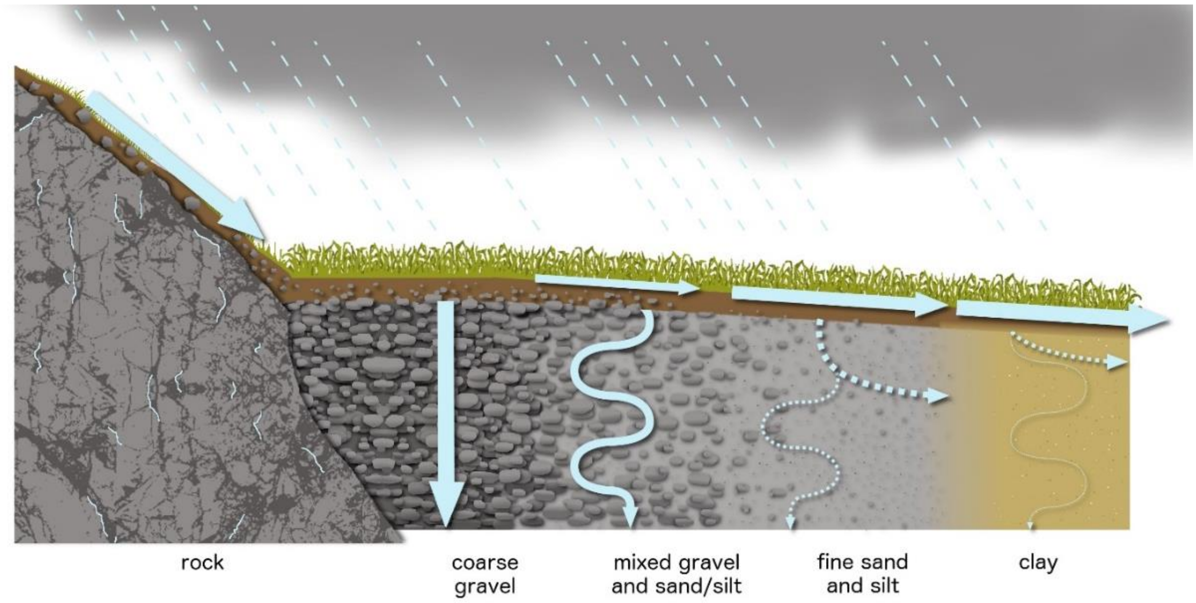

Figure 5: Soil texture gradient in the unsaturated zone controlling deep drainage, lateral flow and overland flow.

4.2 Redox Process-Attribute Layer (R-PAL)

The **redox PAL** represents the combined influence of:

- Soil (unsaturated zone) oxidation-reduction potential.
- Geological (aquifer) oxidation-reduction potential.

Redox processes are a type of **chemical process** in soil and shallow groundwater that govern a multitude of parameters including but not limited to: the concentration of the dissolved forms of nitrate and nitrite, oxygen, manganese, iron, sulphate, and heavy metals. Redox also indirectly controls the leachability and mobility of P species in soils, aquifers and subsequently surface waters.

The physical attributes of soil and geology such as those identified above, can be used to explain biogeochemical processes occurring in the landscape, as they are important for the oxidation-reduction (**redox) process** (Figure 6). In basic terms, the redox state is characterised as the presence of oxygen (oxic) or absence (anoxic) of oxygen, however it is more accurately described as chemical reactions which involve the transfer of electrons. The chemical species which loses the electron (increase in oxidation state) is oxidised, while the chemical species that gains the electron (decrease in oxidation state) is reduced. Typically, well drained soils are characterised as oxidising, while poorly drained soils are characterised as reducing.

Denitrification is a redox reaction that deals specifically with the transformation of nitrogen, in which oxidised nitrogen (nitrate, NO_3^-) accepts an electron and is reduced to nitrous oxide (NO or N_2O) or nitrogen gas (N_2). Denitrification is also a **biological process** as microbes (bacteria) drive the chemical process.

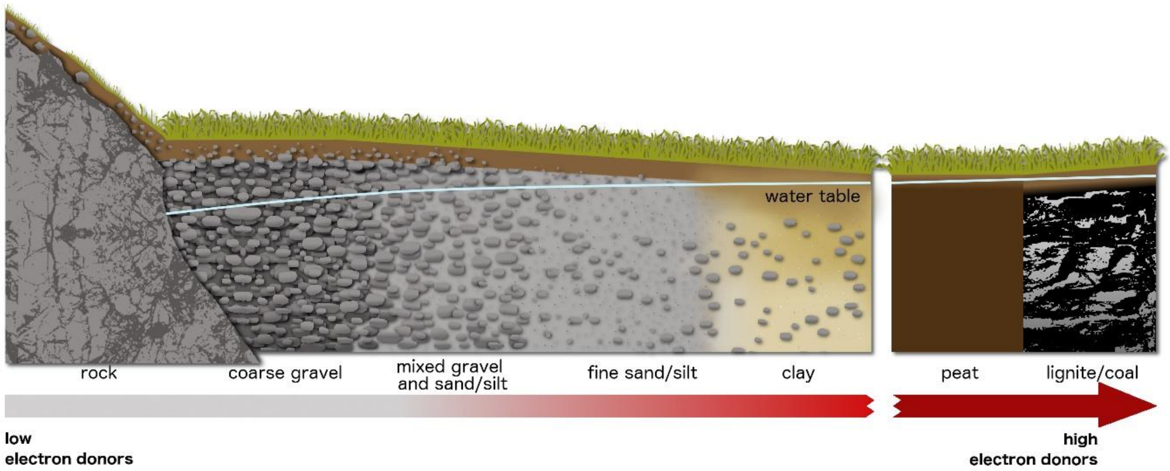

Figure 6: Redox process attribute gradient controlling denitrification, solubility, leachability and mobility of redox sensitive species in soils, aquifers and surface water.

Mapping of these physical attributes at high resolution allows a site-specific understanding of the processes occurring which influence water quality. Such information is important to a range of environmental concerns including low dissolved oxygen in surface waters, where leached nitrate is likely to be removed by denitrification, where phosphorus is likely to be leached and/or more mobile within soils and aquifers. A spatially refined redox PAL will also enable an understanding of where shallow groundwater is likely to contain elevated manganese, iron, and arsenic (in areas with arsenic bearing minerals), limiting its potential as a drinking water source. Soil zone redox processes, in conjunction with nitrogen load, also determine the magnitude of soil zone greenhouse gas emissions, such as nitrous oxide, methane and carbon dioxide.

4.3 Physiographic Environments – Conceptual Model

Physical, chemical and biological attributes are inherently coupled within a landscape, which means that similar settings in the landscape have a similar combination of attributes and can be used to form the basis of **Physiographic Environments**. If a set of attributes are known, the ability to predict other attributes or water composition increases (becomes statistically significant).

Before physiographic environments can be delineated, we first need to **let the water tell the story**. Given water composition evolves as it passes through the landscape, the chemical composition of the water can be analysed to tell the waters story – what landscape has it passed through? What processes have altered its chemistry? The presence or absence of chemical signatures (including particulate material) in the water reveals the **process-attribute gradients** the water has experienced along its path prior to reaching the point where the water body was sampled. This is critical in validating not only the mapped attributes used to define the physiographic boundaries, but also ensures we're not imposing a pre-determined framework on the environment. If inconsistencies are identified, it's not the water composition that is incorrect, it's our understanding of the processes that have occurred in the environment that need to be refined.

The gradients across the process-attribute layers are subsequently grouped into **classes**, delineated statistically by the water quality and chemical data using cluster analysis (Rissmann et al. 2016). The number of classes is determined by statistical significance. Each **class** represents a unique combination of physical, chemical and biological attributes. This is completed for each process-attribute layer (H-PAL, R-PAL). In order to estimate water quality indicators (e.g. DRP), governed by one or more key processes (e.g., hydrology and redox) it is necessary to combine and intersect each classed PAL using GIS spatial software. Combining the PALs allows those areas with similar controls over water composition and quality (assemblages of process-attribute classes) to be identified. These areas are termed **Physiographic Environments**.

The real power of the physiographic environments arises when a capture zone (watershed) is overlaid. Figure 7 presents an example of classes from the Aparima Catchment in Southland. Points A, B and C are surface water sampling points. The pie charts present the proportion of each Physiographic Environment (or 'Physiographic Unit') on an area basis within the capture zone of each surface water sampling point. Here the proportion of each class within a streams capture zone determines the water quality signals at the sampling point. Further, quantifying the proportion of a Physiographic Environment unit within each capture zone is able to accurately estimate the longitudinal variation in water quality along the stream reach. In Southland, physiographic mapping is so accurate that it can be used to estimate water composition for stream reaches without monitoring data (Snelder and Dey, 2016).

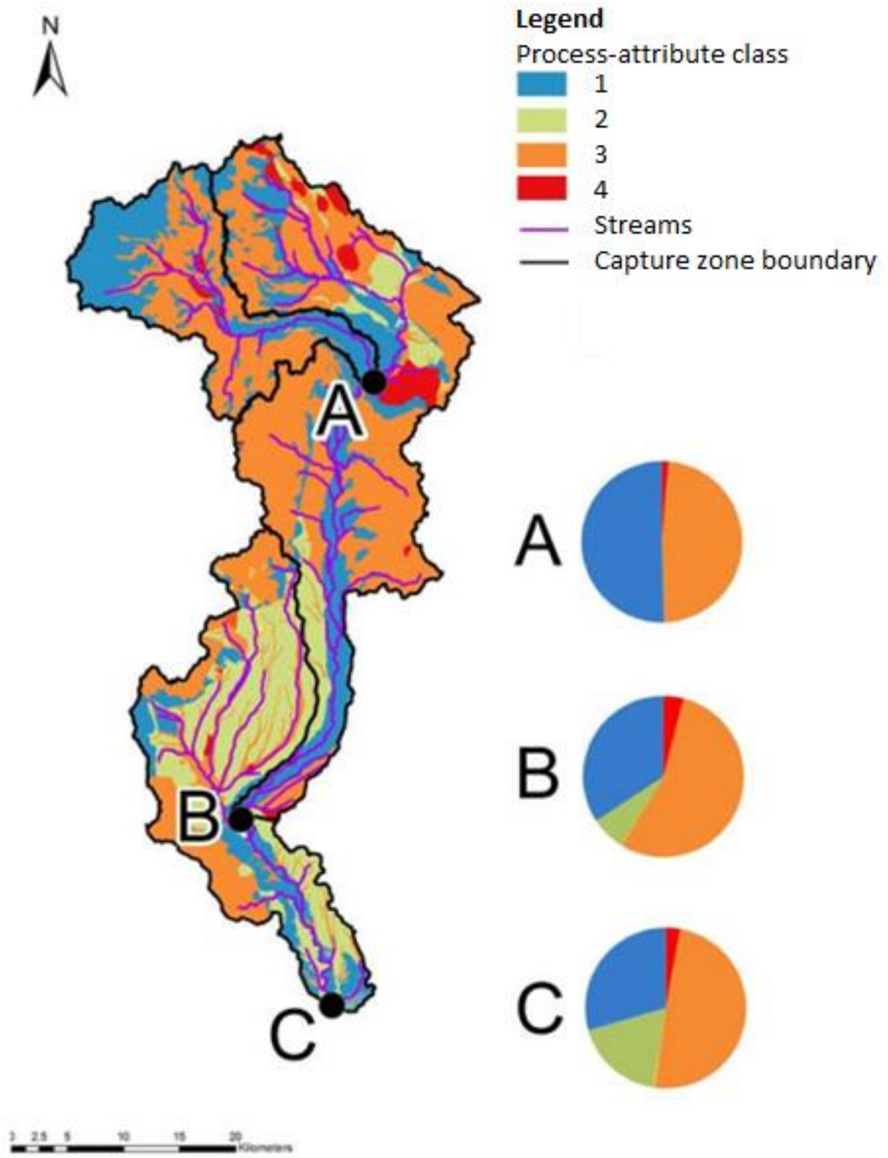

Figure 7: Physiographic classes in the Aparima Catchment, Southland.

4.4 Validation and Performance Testing

Physiographic process-attribute layers (PALs) and Physiographic Environments are the product of a water driven, statistically guided, classification of process-attribute gradients. As such, each PAL can also be used as a standalone layer. There are three ways the to assess the ability of Physiographic Environments to estimate surface and shallow ground water quality:

1. A hierarchical stratification of water data by PAL classes that proceeds by manually sorting water quality site data according to PAL classes (Rissmann et al., 2016);
2. A statistical assessment of the ability of Physiographic Environments and/or PAL classes to predict water parameters (Snelder and Dey, 2016), and;
3. A statistical assessment of the between zone variation in water quality (Snelder et al., 2016).

Performance testing of the outcomes of the Physiographics of Southland provided evidence that water composition (and quality) varied in a highly consistent manner according to the proportion of a given physiographic unit within a capture zone. The accuracy of the method for estimating surface water composition likely reflects:

- The well-mixed/integrated nature of stream flow which may be viewed as a weighted mean of the drainage area.
- Evaluation against steady-state values (i.e. medians).
- The observation that the water compositional data set for each surface water site was broadly representative of the known flow range.

For aquifer systems, physiographic mapping was able to accurately identify and constrain the spatial extent of previously defined groundwater nitrate, phosphorus and *E. coli* hotspots (Rissmann, 2012; Rissmann et al., 2012; Snelder and Dey, 2016). The water source (recharge altitude), recharge mechanism and redox setting were also accurately estimated for regional, unconfined aquifer systems.

5 Data Requirements

PENZ requires regional water quality data and national spatial datasets to produce the national classification. The spatial datasets are maintained by Crown Research Institutes and are typically freely available for download and use. Others require data agreements with the host organisation. Local and regional expert knowledge is required to improve the resolution of the data available.

5.1 Water quality data

The soil zone and shallow unconfined aquifers exert the most influence on surface water quality, as they are highly connected hydrologically to surface water. Therefore, it is critical that the **same analytes are measured in both surface and groundwater samples** to allow the controls over water composition to be understood.

5.1.1 PENZ Test Set

For classification and validation of the PALs and Physiographic Environments, water samples should be collected and analysed for the analytes identified in Table 1. These analytes are those that are hydrologically conservative or redox sensitive. Hill Laboratories test set details are included in Appendix 2 of this document.

Table 1: Surface and groundwater chemical analytes needed for classification and validation of PALs.

	Hydrological PAL	**Redox PAL**
Surface water (field or lab filtered sample)	Alkalinity (Total) Sodium (dissolved) Potassium (dissolved) Calcium (dissolved) Magnesium (dissolved) Silica (dissolved reactive) Boron (dissolved) Bromide Fluoride* Iodine (dissolved)*	Dissolved Oxygen Iron (dissolved) Manganese (dissolved) Sulphate
Surface water (sample not filtered in field)	Nitrogen (Total Kjeldahl) Electrical Conductivity Chloride Dissolved non-purgeable Organic Carbon	Nitrogen (Nitrate+Nitrite)
Groundwater	Alkalinity (Total) Sodium (dissolved) Potassium (dissolved) Calcium (dissolved) Magnesium (dissolved) Silica (dissolved reactive) Boron (dissolved) Bromide Nitrogen (Total Kjeldahl) Electrical Conductivity Chloride Dissolved non-purgeable Organic Carbon	Dissolved Oxygen Iron (dissolved) Manganese (dissolved) Sulphate Nitrogen (Nitrate+Nitrite)

* Non-essential analytes

The groundwater test set is the same as the National Groundwater Monitoring Programme (NGMP), operated by GNS Science in collaboration with regional authorities. The only additional analyte is a field measurement of dissolved oxygen.

We recommend that each Regional Council complete **3 surface water** sampling runs and **2 for groundwater** to aid with classification of the hydrological and redox gradients, with each sample analysed for their usual water quality suite plus the set of parameters outlined in Table 1.

Surface water sampling events should be completed for each of the following **flow** conditions:

- Low (baseflow)
- Median
- High

Groundwater sampling of unconfined aquifers and/or artesian aquifers connected to surface water bodies should be during the following **water level** conditions:

- High (winter/early spring)
- Low (summer/early autumn)

Note that the groundwater levels should be recorded prior to sampling. Bore construction information (screen depth, final depth, bore logs) should be provided for each sampled bore if available.

5.1.2 Historical SOE or other water quality data

To supplement the PENZ test set and aid in validation any additional surface or groundwater water quality data can be used. If a sub-set of the regions SOE network was sampled for PENZ, please provide data for all other sites in the region (ideally a 5-10-year data record).

5.2 Spatial data

As physiographic environments extend through the soil zone and unconfined shallow aquifers, a combination of existing national spatial datasets can be used to identify and map the necessary process-attribute gradients for a region.

The following existing national datasets can be used to delineate the spatial boundaries of attributes at a national level:

- Digital elevation model (8m DEM) - topography
- River environment classification (REC1-3) – river lines
- NIWA Virtual Climate Network – climate, precipitation
- NZLRI - soils, geology, topography
- S-Map - soils (incomplete national coverage)
- QMAP - geology and land surface age
- GNS Science Isoscape – stable isotopes of precipitation
- GNS Science Aquifer Potential
- Land cover database (LCDB4.1)

These datasets can be augmented by Regional Council data if necessary.

5.3 Local and regional expert knowledge

While the national datasets provide a good basis for mapping (especially for national coverage and consistency), they can be limited by the spatial scale of the original surveys. For example, during the development of the 'Physiographics of Southland', the water chemistry data for surface and groundwater samples near Edendale identified that there must be strong electron donors (i.e. lignite geology), due to strongly reducing groundwater signatures, including the absence of elevated nitrate in the water, however these lignite deposits were not mapped in the geological data from QMAP. **Local and expert regional knowledge** is therefore key for interpretation and understanding small scale inconsistencies between the water signature and the mapped attributes to be able to produce the most spatially accurate map from a water quality perspective for each region.

6 Project Deliverables

The PENZ project will be completed over **two years** starting July 2017 to the end of June 2019. Year 1 will focus on the science development followed by Year 2 application and regional validation. As part of the funding requirement for Our Land and Water (OLW), quarterly project milestone reporting to the OLW Directorate is required.

The key deliverables for PENZ are a combination of geospatial layers, technical report(s) and scientific journal articles.

The GIS layers will be produced for each collaborating region of New Zealand are:

1. Hydrological Process-Attribute Layer – water source, recharge mechanism and flow pathway maps
2. Redox Process-Attribute Layer – unsaturated and shallow saturated zone redox maps
3. Physiographic Environments for New Zealand – areas with similar hydrological and redox classes for which water quality risk (N, P, S, M) is similar.

The layers will be available as GIS shapefiles in addition to a web or application-based portal, such as Google Earth. A supporting technical report will accompany the geospatial layers.

We initially had planned user guides and technical information sheets to support the Physiographic Environments of New Zealand Map to be developed through an Envirolink Tool Grant (approximately 260K). However, the application submitted in 2017 was unsuccessful. It is possible to resubmit this application in October 2018 with increased Regional Council support.

Our Land and Water requires the publication of a method paper to be published in an international scientific journal. In February 2018, we presented at the Fertilizer and Lime Research Centre's annual conference introducing a method for integrated landscape mapping of water quality controls for farm planning (Rissmann et al., 2018). This concept paper, along with the work undertaken in the regions will be used to produce the final version.

7 Proposed Funding Structure for PENZ

The funding requirements are set out below and include a request to proceed with an initial investment from each region. The planned funding structure for the project is summarised in Table 2[1]. Operating concurrently with Year 2 of the PENZ project is a **Sustainable Farming Fund Project** to make the physiographic science accessible and relevant to farmers. See Section 3.2 and Appendix 1 for more information on this project.

As the national application of the Physiographic approach is being undertaken by a private consultancy, Land and Water Science Limited, we need to request partial payment in advance to cover project costs. Envirolink grants are available for eligible councils. Two medium advice grants ($20,000)[2] would be required to produce the 2 PALs and an unclassed Physiographic Environments layer for a region.

Table 2: Current Funding Structure

Project Phase	Funding Source	Contribution	Subtotal
Year 1: Science Development	Our Land and Water NSC	$70k	$160,000
	Regional Councils (currently 6 regions)	$15k per council* – $90,000	
Year 2: Application and Validation	Our Land and Water NSC	$30k	$120,000
	Regional Councils (currently 6 regions)	$15k per council* – $90,000	

* eligible councils can use Medium Advice Envirolink Grants

[1] Funding structure does not reflect the timing of project costs and expenditure.
[2] Includes overheads for the Waterways Centre of $5,000.

8 Actions required by each Regional Council

- Contact **Lisa Pearson** at Land and Water Science, Invercargill at lisa@landwatersci.net or on (03) 214 3003 for further information or to arrange a contract for your region.
- Add the additional analytes to the regional SOE water quality sampling for a minimum of 3 surface water quality runs and 2 groundwater quality runs.
- Provide both surface and groundwater historic water quality data for the region (ideally 5-10-year period).
- Eligible councils can request the Envirolink templates drafted for the PENZ project.

9 Testimonials

"The Physiographic Approach is a unique and holistic methodology that has revealed insights yet unrecognised into the drivers of water hydrochemistry and quality."

Peter Almond, Associate Professor - Soil and Physical Sciences,
Faculty of Agriculture and Life Sciences
Lincoln University

"The project entitled "Physiographics of Southland" is a remarkable achievement in interdisciplinary water quality research. Just because of the data-intensive work using state-of-the-art GIS, the project is laudable. What is more significant is its use of a large amount of research-quality data to identify mechanisms that control surface water and shallow groundwater quality, and not simply use the data for some form of black-box statistical analysis. I find the approach taken here compelling and a significant advance on other interdisciplinary approaches worldwide. It is strongly research-based, and pushes the state-of-the-art in terms of field science, data collection, and data analysis."

Professor Mark Milke
Department of Engineering and Natural Resources,
University of Canterbury

10 Acknowledgements

We would like to acknowledge the contribution Environment Southland has made to this research. The Physiographic approach was developed by the Science Team, as part of the Southland Science Programme over several years. For more information on the 'Physiographics of Southland' see http://waterandland.es.govt.nz/southland-science/physiographic-zones.

The conceptual graphics used in this document and those from the Physiographics of Southland were produced by Janet Hodgetts, SciArt.

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Appendix 1 – Sustainable Farming Fund (SFF) Application

Project Overview

Title	Response
Project Number	405475
Project Title	Farmer interface for Physiographic Environments
Proposed Start Date	01/07/2018
Proposed End Date	30/06/2021
Amount Requested	$444,200.00
Sector	Arable;Aquaculture;Dairy;Fibre;Forestry;Horticulture;Meat;Viticulture;Poultry
Sub Sector	Grasslands;Vegetables;Grain;Floriculture;Seed Crops;Cattle;Goats;Sheep;Alpaca;Indigenous;Berry fruit;Kiwifruit;Pip fruit;Tree crops;Beef Cattle;Deer;Pigs;Wine;Vines;Geese;Commercial Forestry;Farm Forestry
Region	National
Topic	Decision Mgmt & Support;Farm Management;Nutrient Management;Soil Management;Water Quality
Applicant Group Name	Land and Water Science Ltd.

Project Details

Project Summary

This project aims to improve water quality by placing state-of-the-art science into the hands of farmers, and into the heart of their land use decisions. **Physiographic Environments of New Zealand** (PENZ) shows farmers how potential contaminants are likely to travel within their farm boundaries, allowing farmers to consider what actions they can take to minimise water contamination risks. Under this project we would work with the primary industry groups to create a free web-based spatial platform to help inform farmers land use decisions. The intent is that this platform would be utilised by individual farmers, farmer-led catchment groups and be adopted into industry's extension programmes, to leverage off their existing extension activities. At the completion of this project, we want farmers, their industry groups and other trusted advisers to be using the rich information sources, available to them for the first time in an accessible way, to make informed land use decisions that optimise their natural capital and minimise as far as possible the impacts of their land use on the environment.

Physiographic Environments of New Zealand (PENZ) is a three-year, Our Land and Water (OLW) affiliated project that uses a forensic approach to identify links between water and the land to produce a map of 'how' and 'why' water quality outcomes vary across a catchment (surface water), aquifer (groundwater), region, or country. Natural variation in landscape features often account for ***more than twice the variability in water quality than land use alone[1].*** This means that despite similar land use pressures, the impact that land use has on water quality (e.g. nitrate build-up in groundwater) is significantly influenced by differences in climate, topography, geology and soil properties. With this knowledge, it is possible to match practical on-the-ground actions and mitigations for nitrogen, phosphorus, sediment and microbes with the water quality setting. An understanding of the role landscape variability has over water quality is crucially important to all land-based primary producers trying to reduce their environmental footprint.

To put the science directly into the hands of farmers, farmers need a simple, easy to access way of viewing their farm's water quality setting and water quality risk in the context of their local catchment. An open-access web-based platform will be used to provide land parcel, and in places paddock scale, specific information of the controls over water quality outcomes, through: (i) connecting the land parcel to stream and aquifer networks; (ii) supplying information on the water quality related properties of soil and where relevant shallow aquifers (e.g., denitrification potential of soils and shallow aquifers, P-retention of soils and aquifers); (iii) mapping the pathways at which contaminants leave a property (i.e., deep drainage to ground water, lateral soil zone flow including that associated with artificial drainage and overland flow path ways), and; (iv) a summary of the water quality risk profile for the land parcel that can be used to inform land management approaches and mitigation options.

This application to Sustainable Farming Fund (SFF) is to take the PENZ science directly to farmers in a way that is practical and easily accessible. The fundamental research component of the PENZ project is being funded from other sources, including the Our Land and Water National Science Challenge. To test the method to take the science to farmers, Southland would be used as the case study region, with local farmers and catchment group leaders within the Pourakino (southwestern Southland), Wendonside (north-east) Waituna (south-eastern) and Five Rivers (central northern) catchments leading the extension of the science. Industry and Environment Southland extension staff will support the farmers in this work and will incorporate the outputs with existing initiatives to optimise the delivery of their farm environment plans and mitigation support programmes. Farmer led co-development of an interface for the PENZ science across Southland will occur over Years 1 and 2 of the project, followed by a national roll out in Year 3 to coincide with the completion of the Physiographic Environments of New Zealand, Our Land and Water, National Science Challenge Project.

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[1] Johnson et al., 1997; Hale et al., 2003; Dow et al., 2005; King et al., 2005; Shiels, 2010; Becker et al., 2014; Rissmann et al., 2016.

Problem or Opportunity

Under the National Policy Statement for Freshwater Management (NPS-FM; MfE, 2014), regional authorities are required to maintain or improve water quality through regional plans that set freshwater objectives and limits. There are a range of impacts for farmers faced with land use controls and/or defined contaminant loss limits, including on farm profitability. A recent study in Southland showed the evaluation of the farming system, development of environmental plans and the impact on profitability by meeting proposed water quality limits is complex and potentially very costly (Moran, et al. 2017).

The over-simplification of landscape variability is a key limitation in existing numerical models used to estimate leaching losses and contaminant transport to water [1]. This over-simplification inhibits the ability of a land owner to identify which mitigations on the land will be most effective at reducing water quality impacts which means farmers do not have the tools they need to prioritise actions. The Physiographic Environments will provide important context to existing 'black-box' models (such as Overseer Nutrient Budgets, CLUES, LUCI etc.), as they are based on direct measures of water quality and identify the landscape features that are most critical to water quality outcomes. Physiographic Environments allow for a more heterogenous and, thereby more rigorous spatial understanding of the fate of contaminants once they leave the root zone. This includes their subsequent transport and attenuation potential prior to reaching a water body. Water quality mitigation approaches can therefore be targeted to the Physiographic Environment, thus optimising expenditure and increasing success.

A farmer designed and led, user-friendly, open-source platform is required to place this knowledge directly in the hands of farmers to best match environmental mitigations to the water quality setting of their land. Such knowledge reduces the financial risk of over investing in inappropriate strategies or technologies and lowers the risk of regulatory non-compliance. Southland Farmers and Catchment groups, Fonterra, Beef and Lamb New Zealand, Living Water (DOC-Fonterra partnership), Deer NZ, Foundation for Arable Research (FAR), have committed to using these proposed outputs to better match their existing extension programmes to the natural water quality setting.

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[1] Duncan et al., 2014; Rissmann et al., 2016; Moran, et al. 2017.

Project Deliverables

With the requested funding, we would:

- Develop a farmer-friendly web-based spatial platform that compliments existing environmental and mitigation programmes offered through industry and community good extension and support programmes.
- Produce a user guide for farmers
- Produce technical and non-technical information sheets to explain the science of each physiographic environment for farm professionals and decision-makers.

Deliverables for the PENZ science (not funded by SSF but link directly with this project) are:

- Map Physiographic Environments of New Zealand (PENZ)
- Production of three scientific journal articles to ensure that the PENZ science has been through rigorous international peer review.

The components of this interface are the web-based map viewer and data access platform with farmer-friendly information sheets and technical documentation. The specifications and design of each component will be led by a steering group of key Southland farmers and farmer-led catchment groups, with support from local industry representatives, scientists and IT experts over Year 1 and 2 of the project. Scientific input to the steering group will be provided via the PENZ project team and industry extension and research leaders. In Year 3, following sign-off by the farmer-led steering group, the refined platform will be rolled out nationally to coincide with completion of the national-scale PENZ project. At the end of the project, there will be a web-based spatial platform, informed by the science and designed by farmers, that provides knowledge of the water quality setting and the associated risk profile for all of New Zealand, providing farmers with the tools they need to prioritise actions.

Innovation

Leaders of the National Science Challenge, OLW commented that the Physiographic Science 'illuminates the black box' that is the landscape level controls over water quality by explicitly linking the landscape to water quality outcomes. In awarding the contestable funding, OLW leaders noted both the absence of any equivalent platform and the high potential impact for New Zealand.

Prof. Mark Milke (Department of Engineering and Natural Resources, University of Canterbury) comments: “The project entitled “Physiographics of Southland” is a remarkable achievement in interdisciplinary water quality research. Just because of the data-intensive work using state-of-the-art GIS, the project is laudable. What is more significant is its use of a large amount of research-quality data to identify mechanisms that control surface water and shallow groundwater quality, and not simply use the data for some form of black-box statistical analysis. I find the approach taken here compelling and a significant advance on other interdisciplinary approaches worldwide. It is strongly research-based, and pushes the state-of-the-art in terms of field science, data collection, and data analysis.”

The Physiographic approach was described by Associate Professor Peter Almond (Soil and Physical Sciences, Lincoln University) as “a unique and holistic methodology that has revealed insights yet unrecognised into the drivers of water hydrochemistry and quality.”

There is also interest from Australian and US researchers in this novel approach.

Although, the science component of this work is recognised as being highly innovative the ability to deliver a spatially refined platform to support sustainable production by helping farmers target preventative actions and prioritise mitigation is where the true value of this work lies. To this end the provision of a highly accessible web-based spatial platform that compliments existing farm extension initiatives and underpins strategic planning has the potential to place New Zealand's primary production sector at the forefront of innovative and sustainable production. In doing so, it will be the first spatially based platform specifically designed to link farm systems environmental management with the water quality setting at the land parcel level.

Project Outcomes

The outcomes of placing the PENZ science in the hands of farmers will be significant and enduring. The proposed project will give a strong and independent evidence base for targeted locations for on-farm mitigations. Giving this understanding to farmers, and the industry groups supporting them, will "put the ball back in their court", should increase their ability to develop and better target mitigations packages that are both effective and least cost. The economic value of improving knowledge in this area cannot be overstated, and will ultimately play a part in improving New Zealand's competitive advantage in its export markets.

At the completion of this project, we want farmers, their industry groups, and trusted advisors to be using the information sources to make informed land use decisions that optimise their natural capital and manage the impacts of their land use on the environment by virtue of providing information that can capture landscape variability farmers are intimately aware of. Aligning with farmers' 'ways of knowing' fosters high prospects for uptake (Duncan, 2016). Through direct engagement with farmers and with commitment from industry to use the platform for targeted farm extension programmes, this project will provide a tangible pathway towards improving the sustainability of farm systems and directly demonstrating the value of farmer-led actions to improve water quality outcomes across Southland and ultimately the rest of New Zealand. This work will be particularly significant for regions with water quality issues or areas where agriculture is a primary industry. It will also help guide investment opportunities in existing and new farm businesses by integrating farm systems/management with environmental sustainability. Embedding this knowledge within the broader primary producer tool box for future farm systems via farmer led linkages to water quality science and direct integration with industry extension programmes, will ensure the impact of this work will persist beyond the 3-year project plan. The anticipated long-term outcome is that farmers will be using PENZ on a regular basis to better target preventative actions and prioritise on-farm practices. This means that in the long-term, required water quality outcomes will be achieved sooner. This will have benefits for all of New Zealand, its brand and political leaders that are being criticised for taking too long to address the issues.

Risks and Mitigation

There are several risks associated with the proposed project:

1. Complexity of the Science: The science behind the physiographic context is complex and requires people to expand their understanding of the controls over water quality to those beyond the root zone, land use and land parcel scale. This risk will be mitigated by having farmers lead and associated industry groups support, the design of the spatial platform including supporting documents (e.g., user guide, technical sheets and information packages).
2. Perception of Competition: The proposed web-based spatial platform, although unique, may be seen as competing with existing decision support tools. This would be incorrect as the niche of the proposed platform is around better defining the landscape and fine scale flow path controls over water quality in order to further support existing tools. For example, this platform would complement existing tools such as Overseer, S-Map and CLUES by providing a refined water quality

context that directly links land to surface and shallow ground water. As there is no equivalent platform, this risk will be mitigated through the development of delivery plans that directly address the niche of the proposed spatial platform as well as clearly defining the pathway by which it will interface with existing decision support tools.

3. Industry Input: The investment and uptake by industry and the NZ Landcare Trust of the proposed spatial platform is critical to the utility of the spatial platform beyond the Southland region. Therefore, industry will need to be comfortable with the relevance and utility of the platform development in Southland to farmers across New Zealand. These risks will be mitigated by inviting industry to develop delivery plans relevant to their existing extension activities in a manner that support and reflect their organisational philosophies.
4. Information Technology: The technical design of the spatial platform will require considerable IT support. Consensus as who will host the site, ongoing costs for the site maintenance and the degree of accessibility of the data provided to farmers (e.g., can farmers directly down load the information) will be a key focus of the 1st year of the project. IT support will be provided via technical partners associated with Land and Water Science, Lincoln University, University of Canterbury and Digital Stock Ltd, Southland.
5. Alignment: There may be concerns that the outputs of the PENZ mapping project may not align with the fine scale variation of soils on the ground. The risk of misalignment is mitigated by the unique way PENZ science maps water quality settings. Specifically, the water itself (its signatures) forms the basis for the PENZ mapping approach as they provide by far the greatest insight over which landscape attributes (e.g. soil hydrology not soil series) are relevant to a given setting. The evidence for the accuracy and relevance of this approach is the unprecedented accuracy with which the PENZ platform was able to predict surface and shallow ground water across Southland[1] The accuracy of the PENZ approach reflects its departure from traditional top-down, water quality risk frameworks and 'black box' models that do not ask the water what attributes of the soil, geology or hydrology are directly relevant to water quality outcomes. There is also a need to communicate the role of soils over water quality outcomes more effectively. For example, we will explain that soil order or soil series scale mapping, which farmers are most familiar with, is not well correlated with water quality variation. For example, although there are c. 220 soil series (local soil names) mapped for Southland the majority fall within 8 key soil hydrological groups that have similar hydrological characteristics (e.g. soil permeability, macropore features, depth to slowly permeable horizon and drainage class characteristics). These soil hydrological families are associated with similar controls over the pathway water takes and the capacity of the soil to denitrify and/or retain phosphorus. Communication of these concepts and others, as they pertain to the role of the landscape over water quality outcomes, in a manner that is easily understood, will be part of the farmer led co-development of the PENZ spatial platform.

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[1] The success of the physiographic science and the invitation by OLW Directorate (Mr Ken Taylor and Prof. Rich McDowell) and OLW Research Theme Leaders, was due to the demonstration that this method was able to estimate in stream and shallow ground water quality and composition better than any existing approach applied in New Zealand.

Contribution to Sustainability

Land-based economic sectors such as agriculture, horticulture and forestry are increasingly facing the challenge of becoming more sustainable while remaining profitable. Nowhere is this transformational challenge highlighted more than with fresh water, which is a vital resource across all primary production systems. Recent cross-industry economic research in Southland into on-farm mitigations for improving water quality found that mitigating environmental effects are likely to have considerable implications on farm profitability (Moran et al., 2017). It also found that some farms have less capacity (both physically and financially) to reduce their environment effects than others – making "sustainability" seem overwhelming. Moran et al. (2017) underlined the importance of variability in environmental conditions across the landscape, and the complexity and diversity within the agricultural sector. This research and the fact that variation in landscape attributes is responsible for the majority of variation in water quality outcomes highlights the potential value of the proposed project to guide implementation of farm or paddock specific mitigations that are most likely to succeed at least cost.

Giving farmers a tool to target preventative actions and prioritise water quality mitigation that can deliver environmental improvements sooner and at least cost is economically and socially beneficial and a major contribution to sustainability.

Community of Interest

Farmers, farm catchment group leaders, regional and national primary industry representatives, local iwi, extension officers at Environment Southland Regional Council, Our Land and Water National Science Challenge, and associated research institutes make up the community of interest for this project.

The project will be led through a **Steering Group** of key Southland farmers, including leaders of the Pourakino, Wendonside, Waituna and Five Rivers Catchment Groups, in conjunction with technical support from Dr Rissmann (Director, Land and Water Science).

Land and Water Science
The research and development of the PENZ science will be undertaken at Land and Water Science, led by Dr Clint Rissmann**.** LWS scientists have a wide range of skills covering hydrology, geology, soils, geomorphology, geochemistry, hydrogeology, engineering, statistics, GIS mapping and analysis, science communication and project management.

Our Land and Water National Science Challenge
Physiographic Environments of New Zealand (PENZ) project is incorporated with the Our Land and Water National Science Challenge. The objective of the challenge is "to enhance primary sector production and productivity while maintaining and improving our land and water quality for future generations". The main role of the National Science Challenge is to integrate with the NZ science community and ensure the science is developed to a high standard and published in high-ranking scientific journals. The PENZ project integrates directly with key challenge themes, Sources and Flows Land Use Suitability and Next Generation (Farm) Systems.

New Zealand Landcare Trust
NZ Landcare Trust works with farmers, landowners and community groups to improve the sustainability of our landscapes and waterways. Their aim is "Sustainable land management through community involvement" by building good relationships based on trust and mutual respect. Regional and Project Coordinators understand the needs of farmers and rural communities, and work closely with them. The trust is also appointing a Southland Catchment Group Coordinator who will work closely with the farmer led steering group. The role and experience NZ Landcare Trust is essential to the PENZ project to help facilitate knowledge transfer directly to farmers, landowners and community groups. They have 20 years' experience working collaboratively with farmers and communities to solve local issues. They have facilitated a number of SFF projects with a particular emphasis on catchment management to improve water and soil. NZ Landcare Trust staff are trusted and respected by sector groups and farmers and have been involved in development of cross sector matrices of good management practices, extension programmes, and production of farmer friendly publications.

Fonterra Co-operative Group
Fonterra has several initiatives that will link directly with the outputs of PENZ. The Less Footprint programme is a Research and Development programme focused on providing cutting edge solutions to the Fonterra business and its farmers to minimise the impact the Co-operative has on the environment. This includes research into reducing greenhouse gas emissions and providing new technology to enable Fonterra farmers to produce more with less, while having a reduced impact on the environment. Having a clear understanding of the Physiographic Environment a farm sits in will aid in the research being undertaken to

reduce the environmental footprint of dairy farming.

The Farm Source Sustainable Dairying Programme, Tiaki, replaces Supply Fonterra which was a change programme designed to move farmers towards more sustainable farming practices by setting a clear set of minimum standards in the fields of effluent management, waterway fencing and nitrogen management. Tiaki is a new programme that enables Fonterra farmers to tap into specialised regional knowledge, expertise and services to support best practice farm management, proactively stay ahead of regulatory requirements and satisfy evolving consumer and market expectations. The programme is led by a network of sustainable dairying advisers and one of the key offerings to farmers are farm environment plans that are targeted to the regional requirements and landscape of the farm. The PENZ project would give Fonterra the ability to significantly enhance the effectiveness of its Farm Environment Plan by developing mitigations in conjunction with farmers based on how the land interacts with the surrounding water, thus potentially enabling less actions that are significantly more effective, resulting in less cost to the farmer and greater environmental improvements. Fonterra is also an Accountable Partner to the Sustainable Dairying Water Accord whose purpose is to enhance the overall performance of dairy farming as it effects freshwater.

Living Water
Living Water is a Fonterra and Department of Conservation partnership, with the aim of improving biodiversity and water quality at five significant catchments where intensive dairying exists. Currently, the PENZ science is being applied to the Waituna Catchment in Southland, to provide a basis for targeted investments to mitigate losses from farms in the catchment. The learnings from the Waituna case study will help guide the implementation of the PENZ project if this SFF bid is successful.

Foundation of Arable Research
Assisting farmers to mitigate the potential negative effects of some farming practices on the environment is a top priority for FAR. FAR's research and extension strategy is developed in conjunction with growers and industry with emphasis on developing a balanced portfolio to address issues facing cropping farmers in both short and long-term time frames. The PENZ project aligns directly with one of FAR’s key research goals – to build better and more robust farms, with a strong environmental focus. The PENZ science will support several current projects, including NCheck, Farm Environment Plans and developing Good Management Practices for the industry. FAR encourages collaborative investment in research and extension with other industry groups or companies both nationally and internationally.

Beef + Lamb New Zealand
Taking care of our environment is a strategic priority for B+LNZ. Farmers having easy access to and using good and trusted environmental information is critical to success. Targeted and informed environment extension programmes will be enhanced through integrated farm scale catchment mapping and information on priorities to improve natural resource management. Integrating that kind of information into existing work such as Farm Environment Planning and its component parts such as managing stock near water, soil conservation, nutrient management, and biodiversity initiatives will help to evolve the conversation from identifying those actions at a farm scale to understanding how those actions fit within a set of catchment priorities and interventions. Informed, strong and supported farmer leadership at a farm and catchment scale has been identified as one of the critical pathways to improved environmental outcomes. The development and availability of an information hub like PENZ at a farm scale will inform farmer decision making and extension programmes, consistently and at scale.

Deer Industry New Zealand
The Passion2Profit (P2P) strategy of Deer Industry NZ aims to help farmers improve their farming systems so they become more profitable making the deer industry as a whole more competitive with alternative land uses. DINZ uses Deer Hub, to assist with productivity objectives, farm and environment, and engagement with their farmers. This hub could interface directly with the PENZ outputs to refine their existing environment management system. This system is known as Land and Environment Planning ('LEP'), and is aligned with Beef + Lamb New Zealand. DINZ also has a Deer Farmers Landcare Manual, which has principles and practical tips that have been trialed and developed by deer farmers for deer farmers. Farmers currently use the Manual to help minimise or eliminate any adverse environment effects of deer on the farm environment (such as wallowing, fence pacing and nutrient loss), and to help build the industry's

reputation for sustainability.

Other Industries
We would also like to have representation from HortNZ and plantation forestry for this project. If this bid is successful, we will extend the invitation to these industries.

Science Community
There are a large community of NZ scientists with interests in this project. Waterways Centre for Freshwater Management, University of Canterbury and Lincoln University scientists will provide scientific input directly into this project.

The PENZ project team is also supported by a Technical Advisory Group, most of whom provide in kind advice. The members and affiliations of this group are: Dr Ton Snelder (Land Water People), Dr MS Srinivasan (NIWA), Dr Peter Almond (Lincoln University), Dr Sam Carrick (Landcare Research), Prof. Jenny Webster-Brown (University of Canterbury), Dr Christian Zammit (NIWA), Dr Travis Horton (University of Canterbury), Mr David Barrell (GNS), Dr Matthew Leybourne (Queens University, Canada), Dr Troy Basiden (GNS), Mr Ian Lynn (Landcare Research), and Mr Nick Ward (Environment Southland).

Environment Southland
The project will also be supported by Environment Southland, Regional Council, through their land sustainability (farm extension). The Land Sustainability team offer individual on-farm advice, as well as organise field days and work with community groups to increase awareness of land management issues and good environmental practices. The PENZ outputs will ensure advice provided by the team is tailored to each physiographic environment and will be incorporated in their Focus Activity Farm Plans.

Knowledge Sharing and Extension

This proposal is focussed on taking relevant water quality science directly to farmers. The results will be communicated in a manner that is farmer friendly and easily accessible via the Southland Farmers Steering group. Industry and the New Zealand Landcare Trust will focus on ensuring the relevance of the outputs developed in Southland are relevant to farmers across New Zealand.

The benefits to the community of interest will include site-specific information on the water quality setting and associated risk profiles for each physiographic environment. This knowledge will be used to improve the specificity of existing and future farm environmental and farm systems thinking including provision of a refined platform for guiding mitigation. This will include provision of water quality information at a land parcel, aquifer and catchment level. This information will directly inform industry extension programmes and as is currently being used with the Waituna Catchment with Living Water, will guide investment in fencing, planting and design and placement of mitigations.

Industry organisations and the Landcare Trust will work to support and integrate the farmer designed outputs with existing extension and farm research programmes. These include Fonterra's Less Footprint Research Programme, Fonterra's Farm Source Sustainable Dairying Programme (Tiaki), Beef + Lamb's farm environment plans, Deer Industry NZ's Passion to Profit and Deer Research Platforms, Foundation of Arable Research (FAR) environmental and extension platforms, Department of Conservation-Fonterra's Living Water Partnership. Land and Water Science will engage directly with the Science community through Our Land and Water National Science Challenge, and associated research themes, Waterways Centre for Freshwater Management, University of Canterbury and Lincoln University.

The key people from each stakeholder group is as follows:

- Steering group: David Diprose (Dairy Farmer Southland and Pourakino Catchment Group Leader); Raewyn Van Gool (Dairy Farmer, Dairy Environment Leader and Waituna Catchment Farmer); Sean Wilkins (Wilkins Farming Ltd. - Sheep and Beef, Deer, Dairy, Cropping and Grazing; Wendonside Catchment Group Leader), David Clark (Sheep and Deer Farmer, Five Rivers Catchment Group

Leader, Ballance Farm Environment Awards recipient, Southland, 2017); Graeme McKenzie (Dairy Chairman of Federated Farmers, Southland).

- Land and Water Science: Dr Clint Rissmann (Director, PENZ Science Lead) and Dr Lisa Pearson (Lead Earth and Environmental Scientist, PENZ project manager)
- New Zealand Landcare Trust: appointed Southland Farmer Catchment Group Coordinator (22 catchment groups regionally) and Janet Gregory (Canterbury Regional Coordinator/South Island Team Leader).
- Our Land and Water National Science Challenge: Ken Taylor (Director), Professor Richard McDowell (Chief Scientist), Dr MS Srinivasan and Dr Richard Muirhead (Sources and Flows), Dr Scott Larned (Land Use Suitability), and Dr Robyn Dynes (Next Generation Farm Systems).
- Fonterra: Dr Mike Scarsbrook (Fonterra Less Footprint Programme), Cain Duncan (Southland Sustainable Dairy Advisor, Farm Source)
- Living Water (DOC-Fonterra Partnership): Carolyn Mortland (Director, Social Responsibility, Fonterra); Mike Slater (Deputy Director General Operations, Department of Conservation); Nicki Atkinson (Science Technical Lead); Matt Highway (Fonterra/Living Water National Farm Extension Manager).
- Foundation of Arable Research: Diana Mathers (Research Manager – Farm Systems)
- Beef+LambNZ: Matt Harcombe (Environment Programme Manager) and Julia Beijeman (Environment Policy Manager - South Island)
- Deer Industry NZ: Lindsay Fung (Environmental Policy Manager)
- Environment Southland Regional Council: Jonathan Streat (Director of Operations and Strategy and Farm Extension)
- Waterways Centre for Freshwater Management, University of Canterbury and Lincoln University: Professor Jenny Webster-Brown (Director)
- Lincoln University: Associate Professor Peter Almond (Soil and Physical Sciences Department) and Dr Ronlyn Duncan (Environmental Management Department)
- The project steering group will also work to incorporate key horticulture and forestry leaders operating in Southland.

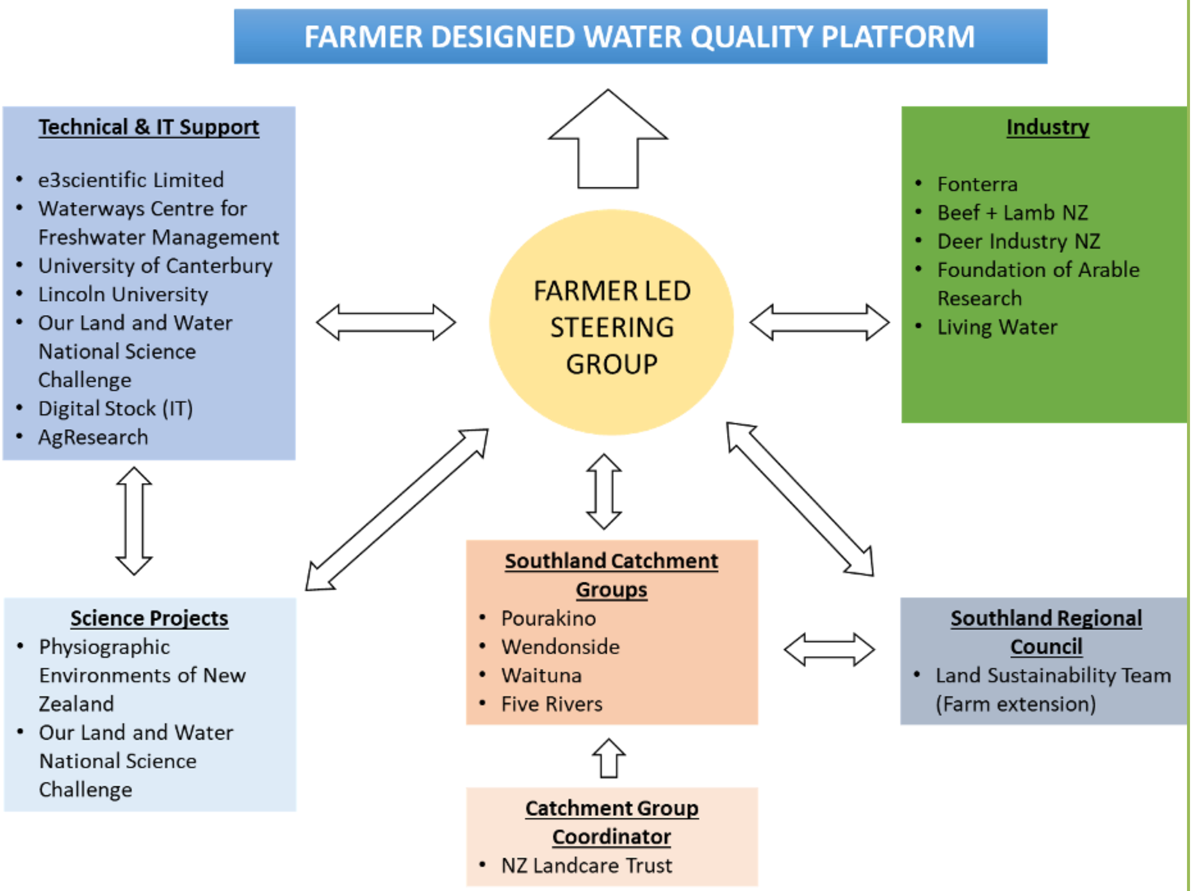
Related Work

The proposed web-based spatial platform for water quality is a new concept. However, it builds upon an existing science developed for the Southland region by Dr Rissmann. The science from a number of disciplines that PENZ uniquely brings together is well established in the academic literature. The work links to catchment group desires for more refined information on the controls over water quality, interfaces directly with existing industry research, farm extension and National Science Challenges initiatives under Our Land and Water.

To our knowledge there is no equivalent science and as such an equivalent spatial platform available regionally, nationally or internationally.

Methodological Rationale and Project Design

The proposal design is based around a farmer-led engagement structure that is designed to produce a farmer-specific water quality platform for the land parcel and in places the paddock scale (Figure 1). The specifications and design of each deliverable will be led by a Steering group of key Southland farmers and farmer-led catchment groups, with support from local industry representatives, scientists and IT experts over Year 1 and 2 of the project. Scientific input to the steering group will be provided via the PENZ project team and industry extension and research leaders. In Year 3, following sign-off by the farmer-led steering group, the refined platform will be rolled out nationally through industry and the Landcare Trust. At the end of the project, there will be a web-based spatial platform, informed by the science and designed by farmers, that provides knowledge of the water quality setting and the associated risk profile for all of New Zealand providing farmers with the tools they need to prioritise on farm actions.



The key steps for the project are as follows:

1. Establish a Steering Group

A steering group comprised of primary industry and community good groups listed in this application will be set up to ensure that:

- The OLW-PENZ science outputs are placed directly into the hands of primary producers,
- The information provided as farmer-friendly information and technical sheets, and user guide documentation is highly accessible and directly relevant to the needs of primary producers, and;
- The web-based spatial platform is designed in a manner that it is able to interface with existing extension programmes and platforms.

Key farmers will be nominated by the New Zealand Landcare Trust and primary industry groups to sit on the steering group and guide implementation. Farmers confirmed for this project are David Diprose (Dairy Farmer Southland and Pourakino Catchment Group Leader), Raewyn Van Gool (Dairy Farmer, Dairy Environment Leader and Waituna Catchment Farmer), Sean Wilkins (Wilkins Farming Ltd. - Sheep and Beef, Deer, Dairy, Cropping and Grazing; Wendonside Catchment Group Leader), David Clark, (Sheep and Deer Farmer, Five Rivers Catchment Group Leader), and Graeme McKenzie (Dairy Chairman of Federated Farmers, Southland). The farmer representatives will have **technical support from the PENZ project team, led by Dr Rissmann** (Director, Land and Water Science) and Dr Lisa Pearson (PENZ project manager, Land and Water Science). Representatives from each industry make up the remainder of the steering group. Environment Southland extension staff will also attend and support the steering group and regional development of the proposed spatial platform. We anticipate that the steering group will meet 4 times per year and be augmented by smaller working groups and both formal and informal (over a cuppa and/or on the phone) communication.

2. Run workshops

Collectively, we want the web-based tool to be as practical as possible. This will include 4 half-day formal workshops at the start of the project to ensure the outputs will add value to farmers and make real change on-ground. The key theme of these workshops will focus on the accessibility of the information to primary producers, including the ability of the spatial platform to interface with existing environmental programmes and technologies. Due to the national scale of the PENZ project and the spatial nature of the work, the provision of a spatial platform of land parcel and paddock scale resolution requires the development and hosting of a specialised geospatial database. Database development will run alongside the science development.

3. Develop a delivery plan
At the heart of the delivery of PENZ science to primary producers will be the development of a delivery plan in partnership with each respective industry and community good group identified in this application. The delivery plan will evolve out of the farmer led steering group. For each primary producer involved in the proposed implementation project, a design and delivery pathway will be developed by each industry in collaboration with nominated farmers and the PENZ, OLW project team.

The key value of the delivery plan will be in identifying the added value that can be provided through combining the PENZ spatial outputs with existing sustainable farming initiatives as well as for future strategic environmental planning. At the end of year 1 of the proposed programme there will be a detailed integration road map and implementation plan that outlines the linkages between the PENZ-OLW-SFF project and both existing initiatives and future aspirations.

4. Design web-based spatial platform
The general concept of the web-based PENZ spatial platform ('PENZ-WEB' or relevant name decided upon by farmers) is access to the Physiographic Environments map of water quality controls, which farmers can view, manipulate and download with 'point and click' accessibility. The web platform will contain descriptions of the key landscape water quality 'settings' and the associated water quality risk profiles for each physiographic environment. Topographic, hydrological (water shed boundaries, aquifer and stream network) and fine scale flow-paths layers can be selected and deselected by the user.

The agreed concept is that the spatial platform will include the ability to identify the farm by a selection of land parcel boundaries. From this selection, a summary report can be produced on the relevant water quality settings and the associated water quality risk profiles for the physiographic environments identified in the selected parcels. The summary includes a physiographic environment map output, proportional and percentage areas of each environment, the risk profiles for the soil and shallow aquifers associated with each setting including information as to the broader hydrological linkages to the stream networks and where relevant shallow aquifer systems.
The same summary-reporting function will be provided for catchments (>8 km^2) and aquifers to help inform the range and general composition of the water quality settings for a given catchment. Catchment selection will be scalable, meaning summary reports can be provided for large (e.g., the Mataura River, Waikato River etc) as well as tributaries or catchments which discharge directly to surface water bodies, such as lakes and estuaries (e.g. Waituna and Pourakino Catchments). The ability to provide local scale water quality context to an individual property has been identified as of critical importance by the farmers in this application.

Given the national scale of the project, the design and hosting of this spatial platform requires considerable investment in geospatial database design and infrastructure. Conversations with Digital Stock, a well-respected Southland IT and innovation company, indicate little barrier to web-based development and if of relevance a smart phone based platform for farmers.

5. Develop user guide and technical information sheets
The user guide, technical and info sheets will accompany the web-based platform as part of the 'point and click' accessibility. The user guide will provide a farmer specific overview of the project and information on how to access and use PENZ. Embedded in the web platform will be 'hints' and 'guides' based on recognised 'point and click' technologies so as to guide the user. The user guide will also include a section describing the key landscape water quality 'settings' and the consequent water quality risk profiles associated with each setting. The user guide will be further support by a series of technical sheets that describe in detail the character of each given water quality setting mapped by the PENZ project, namely:

- Landscape characteristics – topography (elevation, slope), geology, climate
- Surface zone characteristics – dilution potential, surface waterways, overland flow
- Soil zone characteristics – NZSC soil orders, textures, reduction (denitrification) potential, artificial drainage, lateral drainage
- Saturated zone characteristics – groundwater levels, groundwater discharge, reduction potential, deep drainage
- Water quality implications – influencing factors, water quality issues for surface and ground water, and key hydrochemical features.

An example of some Technical Information Sheets, produced for the Environment Southland extension team are available at http://waterandland.es.govt.nz/southland-science/physiographic-zones/physiographics-and-farm-management. The Technical sheets have been written for farm professionals and decision-makers. They describe generalised water quality risks associated with individual physiographic zones and their variants, and a summary of mitigation aims. Examples of 'Fact Sheets' of a less technical nature are also available http://waterandland.es.govt.nz/southland-science/physiographic-zones/introduction. A user guide was also written to support these documents (Hughes and Wilson, 2016). It is important to note that the spatial resolution of the mapping for the PENZ project will be of much finer scale than currently used by Environment Southland. The science will sit outside of any regulatory framework and be provided directly to farmers but will be a key tool in achieving and, it is hoped, going beyond their regulatory obligations.

6. National roll-out

Following sign-off by the farmer-led steering group, the refined platform will be rolled out nationally through industry and the Landcare Trust in Year 3 of the project. This will occur through the integration the spatial platform with industries extension programmes (see community of interest section). The national roll-out will follow the delivery plan (Step 3).

7. Science deliverables (developed alongside the spatial platform)

While not deliverables to be funded by the Sustainable Farming Fund, it is important for the uses to know that the PENZ OLW has specific science deliverables which ensure the science is as robust as possible. The most important of these deliverables being the **Physiographic Environments of New Zealand Map,** developed by a project team at Land and Water Science and supported by a Technical Advisory Group of NZ Scientists. The project team report progress directly to the Our Land and Water National Science Challenge, and interfaces with a number of their key research scientists. OLW require the publication of three papers in high ranking, international scientific journals on the methodology, application and performance of physiographic environments nationally. The proposed journal papers are as follows:

1. Physiographic method – article that provides a transparent step-by-step guide to mapping a region or countries physiographic settings governing water composition and quality. This also includes a measure of the performance of the physiographic platform to estimate in stream and shallow ground water quality (i.e., the concentration of contaminants). [Here it is important to note that the performance of the Southland Physiographic Science platform to estimate surface and shallow ground water quality was more accurate than any existing numerical or classification (i.e., REC) based water quality platform currently in use (Snelder et al., 2016; Rissmann et al., 2016). The exceptional performance of the physiographic platform to estimate surface and shallow ground water quality was a key factor in the invite by OLW to submit a bid for national application].
2. The application and validation of the physiographic method to estimate water quality variation across the 15 key regions of New Zealand. Specifically, the relative proportion of physiographic settings by region can be used to understand why there is strong inter-regional variation in water quality outcomes.
3. The use and effectiveness of land parcel scale physiographic information to guide land use management and tools selection for mitigation of land use losses. This paper will be co-authored with Southland farmers and primary industry partners listed in this application.

These outputs will ensure that the PENZ science has been through rigorous international review. The web-based platform will make these publications available to interested persons, without the need for journal subscriptions.

Other information

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Appendix 2 - Hill Laboratory Test Sets

Surface water

Surface water – Sample bottle unfiltered in the field. The shading indicates necessary tests for the hydrological PAL (blue) and redox PAL (red) classification.

Test Name	Lab Method	Lab Method Description	Lab Test Name	Units
E. Coli (CFU)	E. Coli (CFU)	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, MUG Confirmation	ECmfCHCH;ECmfH	cfu / 100mL
Faecal Coliforms (mf)	Faecal Coliforms (mf)	Membrane Filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation	FCmfCHCH;FCmfH	cfu / 100mL
Nitrogen (Total Kjeldahl)	TKN	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser.	TKN;TKNs	g/m3
Phosphorus (Total)	TP	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser.	TP;TPs;	g/m3
Nitrogen (Total)	TN	Calculation: TKN + Nitrate-N + Nitrite-N	TN;TNt	g/m3
pH	pH	pH meter.	pH;pHCHCH;pHmanual;pH;pHCHCH_man	pH Units
Turbidity	Turbidity	Analysis using a Hach 2100 Turbidity meter.	TurbCHCH;Turb	NTU
Electrical Conductivity	ECuS_OnlyCHCH	Conductivity meter, 25deg;C.	ECuS_OnlyCHCH; EC; ECuS;EC_msm;ECmanual;ECuS_OnlyH	uS/cm
Phosphorus (Dissolved Reactive)	Dissolved Reactive Phosphorus	Molybdenum blue colorimetry. Discrete Analyser.	DRPchH;DRP;DRPt;DRPtchH;DRPtreq;DRPchH_KL;DRP_KL	g/m3
Chloride	Chloride	Ferric thiocyanate colorimetry. Discrete Analyser.	ClChH;Cl;Clic;ClicChH	g/m3
Nitrogen (Total Ammonical)	Ammoniacal Nitrogen	Phenol/hypochlorite colorimetry. Discrete Analyser.	NH4NchH;NH4N;AMN;NH4Nt;NH4tchH;NH4NchH_KL;NH4N_KL	g/m3
Nitrogen (Nitrite)	Nitrite Nitrogen	Automated Azo dye colorimetry, Flow injection analyser.	NO2NchH;NO2N; NO2NsChH;NO2N_old;NO2NchH_old;NO2NsChH	g/m3
Nitrogen (Nitrate+Nitrite)-Combined	NOxN	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser.	NOxNchH;NOxN;NOxNsChH;NOxNchH_old;NOxN_old;NOxNs	g/m3
Nitrogen (Nitrate)	NO3N	Calculation: (Nitrate-N + Nitrite-N) - NO2N.	NO3N;NO3	g/m3
Dissolved Non-Purgeable Organic Carbon (DNPOC)	DNPOC	Filtered sample. Dilution with aqueous TMAH solution. ICP-MS determination.	DNPOC; DNPOCnew	g/m3

Surface water – Sample bottle field filtered. The shading indicates necessary tests for the hydrological PAL (blue) and redox PAL (red) classification. Green shading is used to indicate additional analytes for H-PAL development (non-essential).

Test Name	Lab Method	Lab Method Description	Lab Test Name	Units
Iron (Dissolved)	Iron (Dissolved)	Filtered sample, ICP-MS, trace level.	FeDt;FeTDXuSal;FeTDt	g/m3
Magnesium (Dissolved)	MgDt	NULL	MgDt;MgTDt	g/m3
Manganese (Dissolved)	Manganese (Dissolved)	Filtered sample, ICP-MS, trace level.	MnDt;MnTDXuSal;MnTDt	g/m3
Potassium (Dissolved)	K_Dt	NULL	K_Dt;K_TDt;K_Dt;K_TDt	g/m3
Sodium (Dissolved)	NaDt	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	NaDt;NaTDt	g/m3
Fluoride	F	Direct measurement, ion selective electrode.	F	g/m3
% Difference in Ion Balance	%DiffIonBalD	Calculation from Sum of Anions and Cations	%DiffIonBalD	%
Hardness	Hard	NULL	Hard	g/m3 as CaCO3
Anions (Total)	AnBal	Calculation: sum of anions as mEquiv/L	AnBal	meq/L
Cations (Total)	CatBalD	Calculation: sum of cations as mEquiv/L	CatBalD	meq/L
Alkalinity (Total)	Alkalinity (Total)	Titration to pH 4.5 (M-alkalinity), autotitrator.	AlkCHCH;Alk;AlkCHCH_man	g/m3 as CaCO3
Silica (Dissolved Reactive)	Reactive Silica	Heteropoly blue colorimetry. Discrete analyser.	SilicaChH;Silica	g/m3 as SiO2
Sulphate	Sulphate	Ion Chromatography.	SO4chH;SO4	g/m3
Boron (Dissolved)	Boron (Dissolved)	0.45µm filtration, ICP-MS, trace level	B_Dt;B_TDt;	g/m3
Calcium (Dissolved)	CaDt	NULL	CaDt; CaTDt	g/m3
Bicarbonate Alkalinity	AlkHCO3	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates.	AlkHCO3	g/m3 as CaCO3
Carbonate Alkalinity	AlkCO3	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates.	AlkCO3	g/m3 as CaCO3
Iodine (Dissolved)	Dissolved Iodine	Filtered sample. Dilution with aqueous TMAH solution. ICP-MS	I_Dt;I_DtchH	g/m3
Bromide	Bromide	Filtered sample. Ion Chromatography.	Br;BrChH	g/m3

Groundwater

Groundwater analytes to be measured including a field measurement of dissolved oxygen. The shading indicates necessary tests for the hydrological PAL (blue) and redox PAL (red) classification. Green shading is used to indicate additional analytes for H-PAL development (non-essential).

Test	Analyte Name	Analyte Code	Method	Method Text
Alkalinity (Bicarbonate)	Bicarbonate Alkalinity	AlkHCO3_gm3CaCO3	AlkHCO3	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 22nd ed. 2012.
Alkalinity (Carbonate)	Carbonate Alkalinity	AlkCO3_gm3CaCO3	AlkCO3	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 22nd ed. 2012.
Alkalinity (Total)	Total Alkalinity	Alk_gm3CaCO3	Alkalinity (Total)	Titration to pH 4.5 (M-alkalinity), autotitrator. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.
Anions (Total)	Sum of Anions	AnBal_meqL	AnBal	Calculation: sum of anions as mEquiv/L calculated from Alkalinity (bicarbonate), Chloride and Sulphate. Nitrate-N, Nitrite-N. Fluoride, Dissolved Reactive Phosphorus and Cyanide also included in calculation if available. APHA 1030 E 22nd ed. 2012.
Boron (Dissolved)	Dissolved Boron	B_D_gm3	Boron (Dissolved)	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Bromide (Dissolved)	Bromide	Br__gm3	Bromide	Filtered sample. Ion Chromatography. APHA 4110 B 22nd ed. 2012.
Calcium (Dissolved)	Dissolved Calcium	CaD_gm3	CaDt	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Carbon (Dissolved Organic)	Dissolved Organic Carbon (DOC)	DOC_gm3	DOC	Filtered sample, Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) 22nd ed. 2012.
Cations (Total)	Sum of Cations	CatBalD_meqL	CatBalD	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH (H+) also included in calculation if available. APHA 1030 E 22nd ed. 2012.
Chloride (Total)	Chloride	Cl_gm3	Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl- E (modified from continuous flow analysis) 22nd ed. 2012.
Conductivity (Lab)	Electrical Conductivity (EC)	EC_uScm	ECuS_OnlyCHCH	Conductivity meter, 25Â°C. Analysed at Hill Laboratories - Chemistry; 101C Waterloo Road, Christchurch. APHA 2510 B 22nd ed. 2012.
E-Coli <MPN>	Escherichia coli	ECmpnQT_MPN100ml	E.Coli (MPN_QT)	MPN count using Colilert (Incubated at 35Â°C for 24 hours), or Colilert 18 (Incubated at 35Â°C for 18 hours), Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9223 B, 22nd ed. 2012.
Fluoride (Total)	Fluoride	F_gm3	F	Direct measurement, ion selective electrode. APHA 4500-F- C 22nd ed. 2012.

Hardness (Total)	Total Hardness	Hard_gm3CaCO3	Hard	Calculation from Calcium and Magnesium. APHA 2340 B 22nd ed. 2012.
Iodine (Dissolved)	Dissolved Iodine	I_D_gm3	Dissolved Iodine	Filtered sample. Dilution with aqueous TMAH solution. ICP-MS determination. APHA 3125 B 22nd ed. 2012.
Ion Balance	% Difference in Ion Balance	%DiffIonBal_%	%DiffIonBalD	Calculation from Sum of Anions and Cations. Please note: The result reported for the '% Difference in Ion Balance' is an absolute difference between the 'Sum of Anions' and 'Sum of Cations' based on the formula taken from APHA. This does not indicate whether the 'Sum of Anions' or the 'Sum of Cations' produced a higher value. APHA 1030 E 22nd ed. 2012.
Iron (Dissolved)	Dissolved Iron	FeD_gm3	Iron (Dissolved)	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Magnesium (Dissolved)	Dissolved Magnesium	MgD_gm3	MgDt	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Manganese (Dissolved)	Dissolved Manganese	MnD_gm3	Manganese (Dissolved)	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Nitrogen (Nitrate Nitrite)	Nitrate-N + Nitrite-N	NOxN_gm3	NOxN	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).
Nitrogen (Nitrate)	Nitrate-N	NO3N_gm3	NO3N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.
Nitrogen (Nitrite)	Nitrite-N	NO2N_gm3	Nitrite Nitrogen	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).
Nitrogen (Total Ammoniacal)	Total Ammoniacal-N	NH4N_gm3	Ammoniacal Nitrogen	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH3 F (modified from manual analysis) 22nd ed. 2012.
Nitrogen (Total Kjeldahl)	Total Kjeldahl Nitrogen (TKN)	TKN_gm3	TKN	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH3 F (modified) 22nd ed. 2012.
Nitrogen (Total)	Total Nitrogen	N_T_gm3	TN	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.
Phosphorus (Dissolved Reactive)	Dissolved Reactive Phosphorus	DRP_gm3	Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.
Phosphorus (Total)	Total Phosphorus	P_T_gm3	TP	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate

				interference from arsenic present in the sample. NWASCA, Water & soil Miscellaneous Publication No. 38, 1982.
Potassium (Dissolved)	Dissolved Potassium	K_D_gm3	K_Dt	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Silica (Dissolved Reactive)	Reactive Silica	SiO2R_gm3SiO2	Reactive Silica	Filtered sample. Heteropoly blue colorimetry. Discrete analyser. APHA 4500-SiO2 F (modified from flow injection analysis) 22nd ed. 2012.
Sodium (Dissolved)	Dissolved Sodium	NaD_gm3	NaDt	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.
Sulphate (Total)	Sulphate	SO4_gm3	Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B 22nd ed. 2012.
Sulphide (Total)	Total Sulphide	S2_gm3	S2	Sulphide distillation. Automated methylene blue colorimetry, discrete analyser. APHA 4500-S2- I 21st ed. 2005 (modified).
pH (Lab)	pH	pH	pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H+ B 22nd ed. 2012. 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.