Evaluation of the physiographic method for the Tasman Region

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1 Introduction

This report has been prepared by Land and Water Science Ltd., on behalf of the Waterways Centre for Freshwater Management, for Tasman District Council, through an Envirolink Small Advice Grant (1840-WCRC170). The work undertaken in this project provides Tasman District Council with a foundation for which the physiographic approach can be applied within the region. The physiographic approach has a range of applications including assisting Tasman District Council to effectively manage and improve the quality of freshwater resources as required under the NPS-Freshwater Management (MFE, 2014). Overall, the physiographic method seeks to explain 'how' and 'why' water quality varies across a region by identifying the gradients driving key landscape processes that govern water quality outcomes and risk (Rissmann et al., 2016). The importance of understanding the role of the landscape reflects the observation that whilst land use is a prerequisite for poor water quality outcomes, it is the inherent physical, chemical and biological characteristics (attributes) of a landscape that are often responsible for a larger proportion (more than two times) of the variation in water quality outcomes (Johnson et al., 1997; Hale et al., 2004; Dow et al., 2006; Rissmann et al., 2016). This is particularly true for landscapes in New Zealand, which are characterised by steep gradients in chemical, physical and biological landscape attributes (Close and Davis-Colley, 1990; Rissmann et al., 2016).

Tasman District Council are particularly interested in using the physiographic approach to determine the origin of non-point source contaminants at a paddock scale. For example, the physiographic approach could be used to inform sources of contamination in locations where there are known or potential issues with water quality and aquatic ecology, which will in turn enable farmers to develop effective tools to reduce contamination. In addition, it is anticipated that an indication of the relative importance of each contaminant source will be achieved, allowing for prioritisation of contaminant reduction. Tasman District Council has expressed an interest in application of the physiographic method for the entire region and has identified specific areas of concern regarding water quality where the approach would be particularly valuable. These areas include the Waimea Plains in the Waimea Freshwater Management Zone, and Waikoropupu Springs in the Takaka Freshwater Management Zone.

The primary aim of this project was to identify the effort required for application of the physiographic approach in the Tasman Region. To achieve this, the following objectives were set: 1) assess existing environmental datasets (e.g., spatial and temporal data availability) to determine the current available datasets, and allow for identification of 'data gaps'; 2) develop a monitoring programme that would be sufficient to provide datasets to allow for application of the physiographic approach in the Tasman Region (at a regional and catchment scale); and 3) identify the methodology required to determine and apportion contaminant sources. Consideration of the spatial scale (e.g. farm, catchment, or regional) for which the physiographic method could be applied in the Tasman Region in relation to the intended application (e.g., contaminant tracking), was also presented.

2 Environmental setting

The Tasman Region covers an area of approximately 9,700 km^2 and is composed of the Tasman District (9,656 km^2) and Nelson City (42 km^2). The Tasman Region extends from Golden Bay in the west and Nelson City in the east and is bounded by the Upper Buller and Maruia Rivers to the south (James and McCallum, 2015). For purposes of water resource management, the Tasman Region was divided into five surface water management areas which include Aorere, Takaka, Motueka, Waimea, and Buller areas (Figure 1). Subsequently, Freshwater Management Units (FMUs) have been developed in the Waimea and Takaka Catchments to meet requirements of the NPS-FM (2014). Development of FMUs for the other freshwater management areas are in progress. Land-use within the Tasman District has a very high proportion of indigenous forest (60%), with pasture (17%) and exotic the other main land cover (9%) (James and McCallum, 2015). It has been estimated that approximately 12,000 Ha within the Tasman region is irrigated (Ministry for the Environment, 2018a).

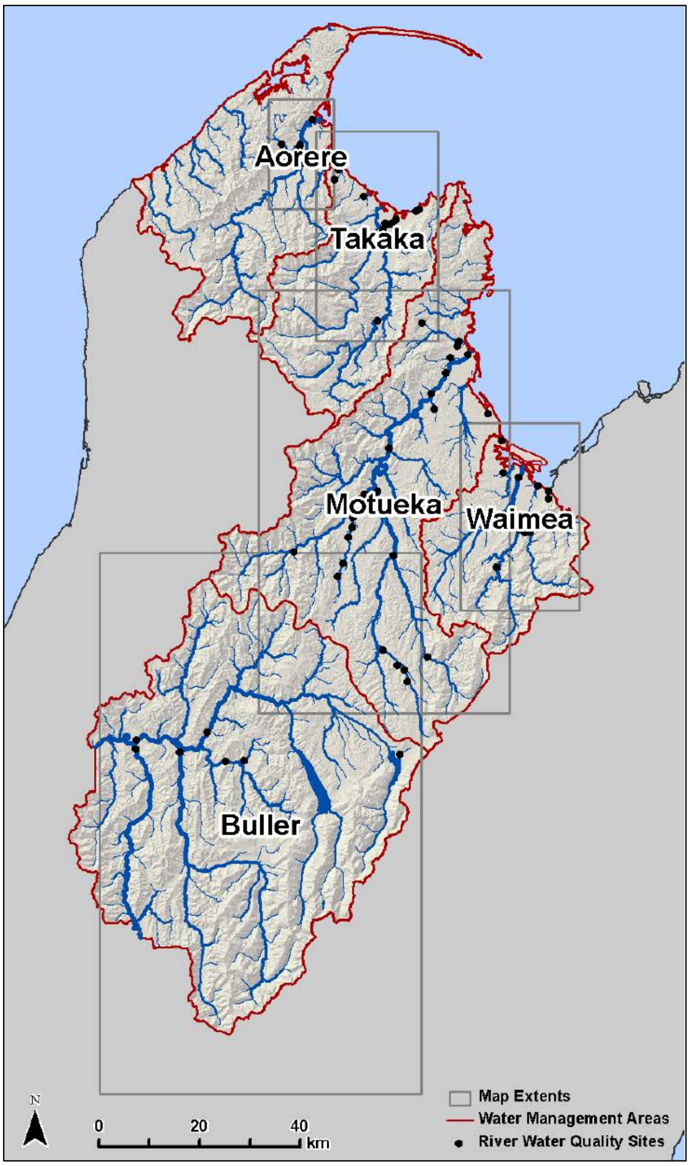

Figure 1: Location of Tasman District freshwater management areas (James and McCallum, 2015).

The Waimea Plains are located at the coastal margin of the Waimea catchment and cover an area of 75 km^2 (Thomas, 2001). The Waimea Plains were formed from late Quaternary gravels, which were deposited in the terraces and floodplains by the Waimea River and major tributaries including the Wairoa River and Wai-iti River (Thomas, 2001). Soils within the Waimea Plains are highly productive, and primarily support dairy, market gardening, horticulture and viticulture land-uses. Three major aquifers, including the Lower Confined, Upper Confined, and Appelby Gravel unconfined, and two minor aquifers including the Hope confined and Hope unconfined, occur beneath the Waimea Plains. Spring-fed streams in the Waimea Plains have very high nitrate concentrations. For example, nitrate concentration in Pearl, Borck and Niemann Creeks ranges from 3 – 10 g/m^3 of NO_3-N. High nitrate concentrations have been thought to cause prolific and extensive algae growth, resulting in a range of negative ecological effects (James and McCallum, 2015). In addition, the Burton Ale and James Cutting Creeks near Collingwood have the highest phosphorus concentrations in the region and suffer from high cover of filamentous green algae (James and McCallum, 2015).

The Takaka Valley catchment covers an area of 928 km^2 and includes a number of river catchments (e.g., Waingaro, Anatoki, Motupipi, and Waikoropupu Rivers). The three primary aquifers in the Takaka Valley are distinct due to lithology and geology, and include the Arthur Marble, Takaka Limestone, and Takaka Valley unconfined gravel. The Arthur Marble Aquifer system has formed in Ordovician Arthur Marble, and is the primary karstic system in the Takaka Valley covering an area of 180 km^2. The Arthur Marble Aquifer system is overlain in places by alluvial gravels and impervious Tertiary formations. Considerable concern has been expressed by Golden Bay residents, local iwi/hapū and the wider community regarding the risk of nutrient and faecal contamination of Waikoropupu Springs. There is potential that a high proportion of contaminant load may be entering the groundwater system and the springs via uncontrolled runoff into sinkholes. Application of the physiographic method may provide insights to assist with identifying shallow/surficial pathways of contaminant ingress.

3 Physiographic Concept

The fundamental basis of the physiographic approach is the recognition and mapping of gradients in those key landscape attributes that control variation in water quality outcomes, in addition to land use. For example, gradients in soil drainage class are known to strongly influence the degree to which nitrate is attenuated via denitrification (Webb et al., 2010; Killick et al., 2015; Beyer et al., 2016; Beyer and Rissmann, 2016); gradients in soil permeability and depth to slowly permeable (<4 mm/hr) layer determine the pathway water takes across the landscape and influence the potential for entrainment of contaminants via subsurface drainage and overland flow (Nash et al., 2002; Vidon and Hill, 2004; Soana et al., 2017) and; gradients in hydrological connectivity also determine the flushing potential of aquifers, streams, estuaries and lagoons (Volk et al., 2006; Larsen, 2012; Roselli et al., 2013; Outram et al., 2016). An understanding of the landscape level controls that govern variability in those key attributes that drive spatial variation in water quality, therefore, is fundamental to the physiographic approach (Figure 2) (Rissmann et al., 2016).

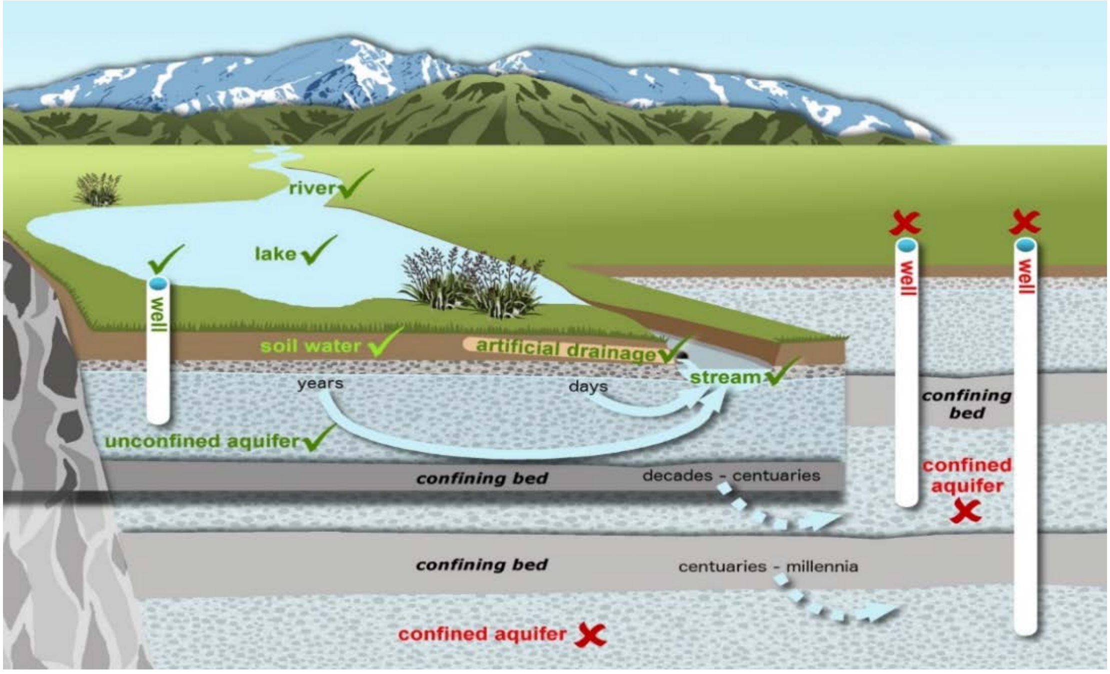

Figure 2: Illustration of the connectivity of near-surface water resources (Rissmann et al., 2016; Hughes et al., 2016). Green tick marks show hydrologically connected settings included in the physiographic approach, whereas red crosses identify settings that are excluded.

Water quality can vary spatially across the landscape, even when there are similar land uses or pressures in a catchment. These differences occur because of natural spatial variation in landscape attributes, which alters the composition of the water through coupled physical, chemical and biological processes. Previous research has demonstrated that spatial variation in landscape attributes can account for more than twice the variability in water quality than land use alone (Johnson et al., 1997; Hale et al., 2004; King et al., 2005; Dow et al., 2006; Shiels, 2010; Becker et al., 2014). The role of landscape variability over water quality outcomes is especially true for countries such as New Zealand, which is often recognised as one of the most complex geological regions in the world (Johnson et al., 1997).

Until recently, a systematic approach to mapping the integrated landscape controls over surface and shallow groundwater quality in New Zealand has been lacking. A conceptual overview of the Physiographic Method for identifying and mapping the critical attributes of the landscape that determine spatial variation in water quality outcomes is presented in Figure 1. The Physiographic Method provides a greater opportunity to target and implement mitigations that are environmentally- and cost- effective, in addition to providing critical context to calibrate existing tools that seek to better understand and model land use losses (SFF, 2017). Additional detail on the physiographic method can be obtain the key references including: Physiographics of Southland Project (Rissmann et al., 2016; Hughes et al., 2016); Physiographic Environments of New Zealand Information Document for Regional Councils (Rissmann and Pearson 2018); physiographic mapping for the Waituna Catchment (Rissmann et al., 2018). The physiographic method is proposed to have a natural home in supporting existing tools that seek to understand and minimise land use losses by providing critical context as to the role of the landscape over spatial variation in surface and shallow groundwater.

4 Physiographic Method for Tasman Region

4.1 Scoping of an environmental monitoring programme

An assessment of environmental monitoring requirements that are required to provide sufficient datasets for application of the physiographic approach in the Tasman Region was undertaken. This scoping included assessment of current available datasets; identification of knowledge gaps in the current dataset and recommendations for additional data required, including the number and type of parameters to be sampled, sampling frequency, numbers of samples, and specific analytes; sampling methodology (where complex sampling is required); and sampling staging. The monitoring programme scoping was undertaken using all available datasets provided by Tasman District Council and a literature review.

4.1.1 Surface water datasets

Tasman District Council commenced State of the Environment (SOE) surface water monitoring in 2000 (Tasman District Council, 2018). SOE monitoring sites are distributed between the five freshwater management areas of Aorere, Takaka, Motueka, Waimea, and Buller (Table 1). All 29 current SOE monitoring sites have been sampled monthly since July 2016. Prior to that the majority of sites were sampled quarterly during baseflow conditions. It was assumed that for low-frequency baseflow conditions that variability in water quality resulting from rainfall and higher flow events is not captured. Therefore, it is likely to take a lot longer to identify longer term water quality trends in comparison to operation of a sampling strategy that incorporates variations in river flow. Monthly sampling is undertaken at eight key sites which are generally located near the seaward mouth of major rivers, including the Waimea, Motueka (three sites), Sherry, Takaka, Aorere, Kaituna, and Buller Rivers.

Table 1: Summary of Tasman District Council surface water monitoring, in the context of Water Management Area (WMA), Freshwater Management Unit (FMU), and monitoring sites (2010-14).

WMA	Main catchments	FMU	No. sites (2010-14)	Reference sites
Aorere	Aorere, Kaituna, Parapara, Puponga	-	5	Kaituna River @ 500 m u/s of track
Takaka	Takaka, Te Waikoropupū, Motupipi	2014	15	Takaka at Harwoods
Motueka	Motueka, Moutere, Riwaka, Able Tasman Coast	-	24	Hunters @ Kikiwa, Motueka @ Gorge, Riwaka @ Northbranch and Wangapeka @ 5km u/s Dart
Waimea	Waimea, Wai-iti Waimea Inlet tributaries	2014 (ex. Waimea Inlet east arm)	12	Reservoir Ck at Marlborough Cres and Wairoa u/s Pig Valley are both far upstream in the catchment but have plantation forestry upstream.
Buller	Buller, Nelson Lakes, Owen, Matiri, Mangles, Matakitaki, Maruia Valley	-	8	-

In addition to the SOE monitoring network, Tasman District Council undertakes water quality sampling at a range of other sites at a range of temporal and spatial resolutions. Tasman District Council currently operates 54 surface water monitoring sites, three less than the 57 monitoring sites in 2015. SOE samples are analysed for a range of water quality parameters (Table 2).

Table 2: Summary of SOE water quality parameters, statistics used, and method reference source (James and McCallum, 2015).

Attribute	Statistic	Units	Source
Water clarity	Single measurement	m	-
Turbidity	Single measurement	NTU	ANZECC and ARMCANZ (2000)
Re-suspendable solids	Shuffle score (1 to 5)	N/A	-
Dissolved oxygen concentration	7-day mean min and lowest 1-day min	g/m^3	NPSFM (2014)
Water Temperature	Midpoint of daily mean and max	^{o}C	Davies-Colley et al. (2013)
pH	Single measurement	N/A	-
Ammonia-N	Annual: median and max	g/m^3	NPSFM (2014)
Nitrate-N	Annual: median and 95th percentile	g/m^3	NPSFM (2014)
Dissolved reactive phosphorus	Single measurement	g/m^3	ANZECC and ARMCANZ (2000)
E. coli	Annual median and 95th percentile	CFU/100 ml	NPSFM (2014)
Macroinvertebrates	MCI and SQMCI	N/A	Stark and Maxted (2007)
Phormidium	Percentage cover	%	MfE (2009)
Filamentous green algae	Percentage cover	%	Biggs and Kilroy (2000)
Periphyton	Periphyton score (1 to 10)	N/A	-

4.1.2 Groundwater datasets

Tasman District Council currently maintains water quality sampling for approximately 20 groundwater monitoring sites (Tasman District Council, 2018; Stevens, 2010). Eleven of these sites are included in the SOE and National Groundwater Monitoring Programme (NGMP) monitoring programmes, and an additional seven sites are included in SOE monitoring only (Table 3). SOE and NGMP samples are collected quarterly and analysed for a suite of selected water quality parameters (Stevens, 2010). The groundwater monitoring sites are distributed throughout the main groundwater environments in the region and include: nine sites on unconfined alluvial aquifers; two sites on confined alluvial aquifers; three sites on confined sedimentary aquifers; and two sites on karst aquifers. SOE and NGMP monitoring sites form the basis of long-term monitoring in the region.

Table 3: Summary of National Groundwater Monitoring Programme (NGMP) and State of Environment (SOE) monitoring sites in the Tasman District, including dates of sample availability.

Site	**Dates**	**Network**
GW 23759 - Collingwood	2015 - present	TDC SOE
GW 5027 - Le Comte	2002 - 2016	TDC SOE
GW 6342 - Takaka Fire	2000 - present	TDC SOE
GW 6601 - Central Takaka Water Bore	1990 - present	NGMP
GW Fish Creek Spring	1991 - present	TDC SOE
GW Pupu Main Spring	1986 - present	NGMP
GW 23604 - Bensemann	2009 - present	NGMP
GW 3314 - Bensemann	1990 - 2009	NGMP
GW 23806 - Tapawera	2013 - present	TDC SOE
GW 3115 - Drummond	1983 - present	NGMP
GW 3216 - Ngati Raru	1983 - present	NGMP
GW 3393 - Kildrummy	1998 - present	TDC SOE
GW 8054 - Middletons	2000 - present	TDC SOE
GW 8404 - Wrattens	1988 - present	NGMP
GW 8407 - Williams	1987 - present	NGMP
GW 23658 - TDC Prod 1 Murchison	2011 - present	TDC SOE
GW 114 - TDC Roadside	1976 - present	TDC SOE
GW 1392 - Spring Grove	2000 - present	TDC SOE
GW 32 - TDC	1976 - present	NGMP
GW 37 - Gardner	1984 - present	NGMP
GW 802 - Waiwest	1996 - present	NGMP
GW 997 - McCliskies	2000 - present	TDC SOE

* at times data collected during the identified period is regular (e.g., monthly, quarterly), however this is inconsistent between sites due to changes in the monitoring programme.

Tasman District Council also collects and holds a range of other groundwater quality datasets on the environmental database. Datasets include those collected in systematic surveys, one-off datasets (e.g., from drilling), resource consent compliance, and those collected by external organisations. Tasman District Council has been involved in several national surveys of pesticides in New Zealand groundwaters coordinated by the Institute of Environmental Science and Research Limited (ESR) (Close and Skinner, 2011). The pesticide surveys have been undertaken has at four yearly intervals since 1990, and Tasman District Council first contributed to this project in 1998. In 2006, 15 unconfined groundwater sites across the Waimea, Moutere and Motueka plains were sampled (Stevens, 2007), and in 2014 the survey included 10 bores[1]. In addition, stable isotope and groundwater dating datasets have been

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[1] It is understood that additional isotope samples from 2017 are available, and this data will be included in the data request for the Waimea WMA.

analysed by GNS Science for a range of studies (e.g., van der Raaij and Baisden, 2011; Appendix A).

4.1.3 Land use datasets

The primary basis for land use datasets for the Tasman Region is the national scale Land Cover Database (LCDB) (Ministry for the Environment, 2018b). More detailed land-use datasets exist for catchments in the Tasman Region, including that of the Waimea Plains presented in Fenemor et al. (2016).

4.1.4 Soil datasets

Four main soil surveys have been undertaken in the Tasman Region and subsequent soil maps have been produced (Tasman District Council, 2018). A summary of the primary soil maps and surveys are presented in Table 4. These studies have allowed for more than 140 different soil types to be identified in the Tasman Region. In addition, Tasman District Council initiated SOE monitoring for soils in 2000 which includes 35 sites on different soil types and land uses (Tasman District Council, 2018). The recent (2011 – 2017) high resolution soil mapping undertaken by the Tasman District Council is regarded as a valuable resource for physiographic mapping as it provides property level relevance over water quality controls. The 2017 Waimea Plains soil mapping survey filled significant knowledge gaps and provided the council with increased confidence in defining: soil types; Land Use Capability (LUC) extent and boundaries; and irrigation requirements (Tasman District Council, 2018). Recently, sampling by Tasman District of Ranzau and Waimea soils (those that have the highest leaching rates) has included a ~20 parameter suite of analytes, including nitrate. This data is currently unpublished but hopefully will be available for the mapping project (Simmons unpublished data).

Table 4: Summary of the primary soil surveys and maps that are available for the Tasman Region, including extent, a description of the project, and the scale of the maps.

Title	**Extent**	**Description**	**Scale and detail**
Waimea Plains Soil Survey (2017)	6,500 ha; Lower Queen Street, Redwood Valley, Waimea West, Brightwater, and Central Plains	4,497 soil pits and augers used to identify soil type and properties; soil extent identified using topography, land use, and vegetation	1:16,000 sufficient detail to provide accurate soil and land management information to land owners
Golden Bay Soil Survey (2016)	Takaka township, East Takaka and Motupipi, Puramahoi Coastal area and Kotinga	information gathered on each soil includes a profile description and land productivity rating	1:20,000 indicate soil type, variability, potential uses and physical characteristics (texture, structure and drainage)
General Soil Survey of the South Island (1968)	All of New Zealand	This was carried out to give an overall picture of soil pattern and to provide basic information for predicting future land use and broad fertility needs on a national basis	1:250,000 (4 miles to 1 inch)
Soils and Agriculture of the Waimea County (1966)	Includes: surveys of the flood plains and lower terraces; reconnaissance surveys for the General Soil Survey of the South Island.	a number of surveys and maps compiled from 1920's – 1960's	1:127,000 Reconnaissance surveys; to classify soils for tobacco culture

4.1.5 Other relevant datasets

Modelling of nitrate–nitrogen (NO_3-N) leaching losses was carried out using the SPASMO model for 40 years to 2013 (e.g., 1973 – 2013) by Fenemor et al. (2016). The modelling was undertaken using land uses of apples, grapes, outdoor vegetables, and dairy land uses on the four major soil series of the Waimea Plains (Table 5). Results indicated the highest nutrient leaching rates were from dairy (24 – 69 kg/N/ha/yr) and outdoor vegetables (16 – 51 kg/N/ha/yr) (Table 4.2). Total calculated nitrate loss below the soil root zone for the Waimea lowland catchment was 287 t/yr. The top six largest contributors by land use are pasture, forest, dairy, outdoor vegetables, grapes, and pipfruit. The top three soil series from which the nitrogen originates were Rosedale, Ranzau, and Waimea (Table 6).

Table 5: Summary of estimated nutrient losses from the soil zone for the predominant land uses in the lower Waimea Plains catchment (Fenemor et al., 2016).

	Dairy	Apples	Grapes	Outdoor vegetables	Other pasture*	Forest & scrub†
N-NO_3 loss kgN/ha/yr	24–69	3–18	4–18	16–51	10.7	2.5

* represents SPASMO modelled losses for extensive sheep and beef farming

† an adopted average value from literature

Key findings from Fenemor et al., (2016) were that: 1) modelling indicated little difference between nitrate losses for the same land use with or without irrigation, however irrigation allowed for more intensive land use, which subsequently produces higher nutrient losses; 2) soil water-holding capacity is a much greater determinant of nitrogen losses than irrigation; 3) plains soils generating highest nitrate leaching rates were Ranzau, Waimea, and Wakatu (in order); and 4) total modelled nitrate loss from the 40,600 ha of the lowland Waimea catchments was 287 t/yr. Soil loss information provided here is valuable with the physiographic connecting root zone loss estimates to signals in shallow aquifers and connected streams, thereby providing a platform for assessing the realised load.

Table 6: Average modelled nitrate-nitrogen losses from SPASMO modelling summarised for six Waimea catchment land uses and four soil groups, kg N/ha/yr (Fenemor et al., 2016)

Land Use/ Farm System	Ranzau soil	Waimea & Motupiko soils	Wakatu & Dovedale soils	Richmond & Heslington soils	Proxy soil for S&Beef includes all other soils	Proxy soil for Forest & scrub
Dairy pasture	68.8	63.4	65.6	24.0		
Apples (also applied here to berries, hops, kiwifruit, avocados)	18.3	6.6	9.3	3.1		
Grapes (also applied to olives, small nuts)	18.3	9.8	13.6	4.3		
Outdoor vegetables (also applied to nurseries, non-sealed glasshouses)	51.4	33.0	31.9	16.0		
Other pasture/lifestyle block/non-agricultural (assumes extensive sheep & beef land use)					10.7	
Forest, scrub						2.5

4.2 Additional data required

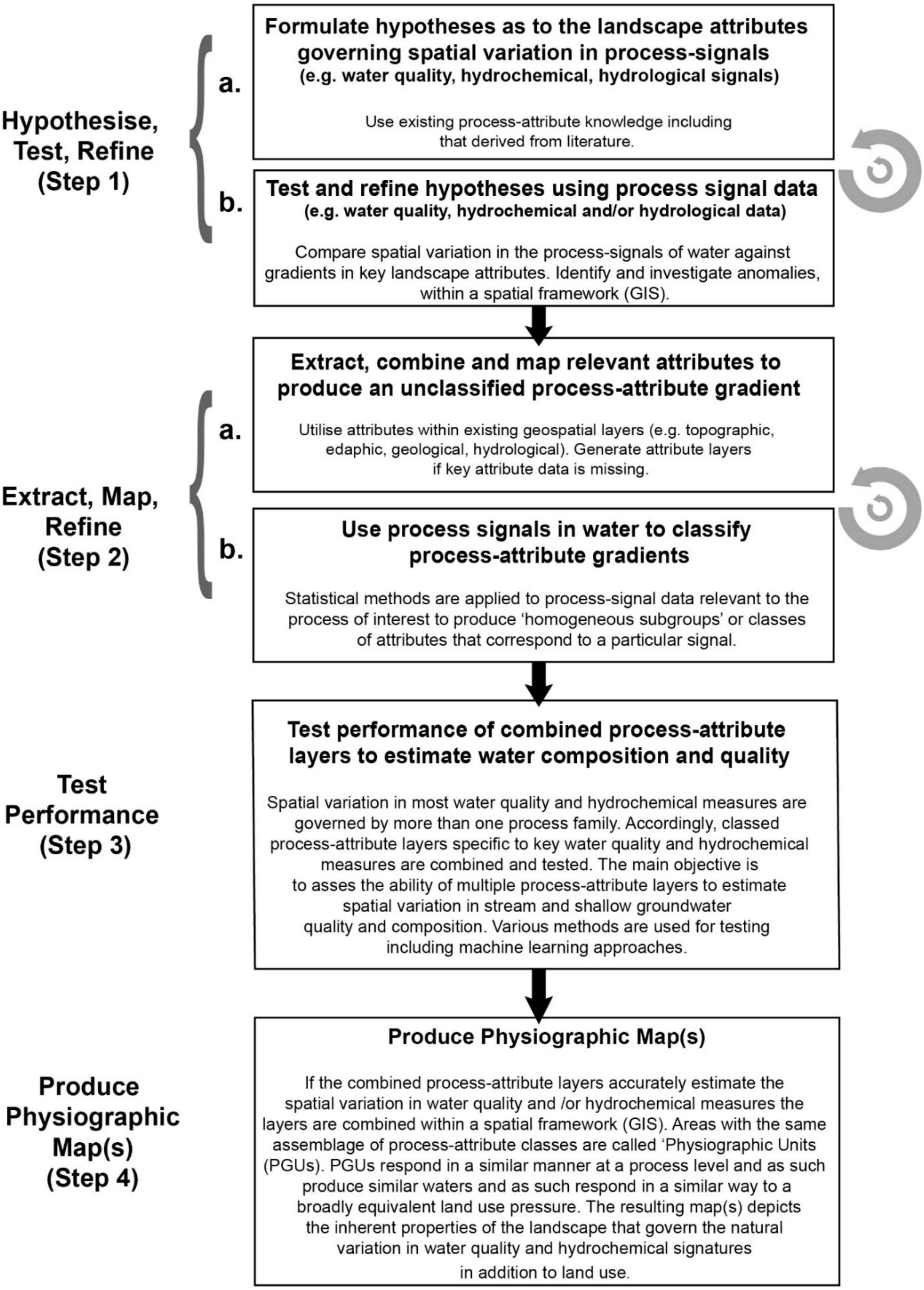
For the physiographic mapping approach, it is important to collect a number of ‘source’ water signatures. These are to provide context to hydrochemical, biogeochemical and water quality indicators. For example, water quality in lowland area receiving significant input from alpine or hill country catchments are often strongly buffered by inputs of pristine water. Such samples may include five samples of headwaters across ‘representative catchments.’ In Southland, headwater samples were taken from alpine areas (above the tree line) during the winter months. Samples were also taken from streams that originate in hill country areas, do not have an alpine source, to provide key constraint over the composition of these different source waters.

5 Methodology to determine and apportion contaminant sources.

It is widely recognised in hydrochemical and geochemical literature that there are four key process families governing the composition of fresh water - atmospheric, hydrological, redox and weathering (Moldan and Černý, 1994; Clark and Fritz, 1997; Güler and Thyne, 2004; Kendall and McDonnell, 2008; Tratnyek et al., 2012). Of these process families, hydrological and redox processes are often considered the most significant in governing variation in water quality outcomes (Moldan and Černý, 1994; Langmuir, 1997; Wieder et al., 2004; Tratnyek et al., 2012; Eriksson, 2012). The fundamental premise of the physiographic approach is that spatial variation in water composition (quality and hydrochemistry) can be understood by identifying and mapping the spatial coupling between *process signals* in water and *landscape attributes*.

For example, spatial variation in the concentration of sodium (Na), chloride (Cl), and the stable isotopes of water ($\delta^{18}O/\delta^{2}H\text{-}H_2O$, V-SMOW) in precipitation (*atmospheric process signals*) are known to be governed by altitude and distance from the coast (*landscape attributes*) (Clark and Fritz, 1997); spatial variation in the Na, Cl and $\delta D/\delta^{18}O$ in surface and shallow groundwater (*hydrological process signals*) are known to vary according to water source and connectivity between recharge domains (*landscape attribute*) (Clark and Fritz, 1997; Kendall and McDonnell, 2008; Inamdar, 2011); spatial variation in groundwater pH and hence alkalinity (*weathering process signals*) are governed by the acid neutralising capacity (ANC) (*landscape attribute*) of soil and rock, as well as its degree of weathering (Wright, 1988; Moldan and Černý, 1994; Giller and Malmqvist, 2004; Lydersen et al., 2004), and; aquifer reduction potential (*redox process signals*) varies according to the abundance of electron donors within an aquifer (*attribute*) (Krantz and Powars, 2002; McMahon and Chapelle, 2008; Rissmann, 2011; Beyer et al., 2016; Wilson et al., 2018).

The signals in water 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.



Formulate hypotheses as to the landscape attributes governing spatial variation in process-signals (e.g. water quality, hydrochemical, hydrological signals)

Use existing process-attribute knowledge including that derived from literature.

Test and refine hypotheses using process signal data (e.g. water quality, hydrochemical and/or hydrological data)

Compare spatial variation in the process-signals of water against gradients in key landscape attributes. Identify and investigate anomalies, within a spatial framework (GIS).

Extract, combine and map relevant attributes to produce an unclassified process-attribute gradient

Utilise attributes within existing geospatial layers (e.g. topographic, edaphic, geological, hydrological). Generate attribute layers if key attribute data is missing.

Use process signals in water to classify process-attribute gradients

Statistical methods are applied to process-signal data relevant to the process of interest to produce 'homogeneous subgroups' or classes of attributes that correspond to a particular signal.

Test performance of combined process-attribute layers to estimate water composition and quality

Spatial variation in most water quality and hydrochemical measures are governed by more than one process family. Accordingly, classed process-attribute layers specific to key water quality and hydrochemical measures are combined and tested. The main objective is to asses the ability of multiple process-attribute layers to estimate spatial variation in stream and shallow groundwater quality and composition. Various methods are used for testing including machine learning approaches.

Produce Physiographic Map(s)

If the combined process-attribute layers accurately estimate the spatial variation in water quality and /or hydrochemical measures the layers are combined within a spatial framework (GIS). Areas with the same assemblage of process-attribute classes are called 'Physiographic Units (PGUs). PGUs respond in a similar manner at a process level and as such produce similar waters and as such respond in a similar way to a broadly equivalent land use pressure. The resulting map(s) depicts the inherent properties of the landscape that govern the natural variation in water quality and hydrochemical signatures in addition to land use.

Figure 3: Summary of steps to develop the physiographic mapping method (Rissmann et al. 2018).

The fundamental basis of the physiographic method (e.g., understanding spatial variation in water composition (quality and hydrochemistry) through coupling between *process signals* in water and *landscape attributes*) can be used to inform water quality in the Tasman region. For example, the following inferences can be made:

- groundwater from the Arthur Marble Aquifer system would be expected to contain high levels of calcium and carbonate, high pH, strongly oxidising;
- soil water drainage from imperfectly to poor drained soils (e.g. Mahana, Motukarara soil series) would be expected to exhibit lower soil NO_3^- drainage losses relative to well drained (e.g. Ranzau soils);
- Differences in soil drainage class, soil texture and slope also influence overland flow pathways and influence P retention;
- Local coal measures and peat swamps occurring close or at the surface also strongly influence nutrient attenuation and are critical features of a region to integrate into a physiographic layer.

It is important to highlight that although data availability is spatially and temporally sparse in many areas of the Tasman Region, any available historical data (including one-off measurements or short- term datasets) is extremely useful for application of the physiographic method. This is due to the ability to infer likely variation at process level from inferred from landscape relationships. For example, historical NO_3^-, conductivity, DO or phosphorus data, in conjunction with can provide useful insight over the redox conditions, P sorption and water source dynamics. Historical data of this nature was used, in conjunction with a more evolved hydrochemical data set, for physiographic mapping of the Southland region.

6 Application of physiographic approach to Tasman

6.1 Consideration of scale

Another strength of the physiographic method is the ability to apply it at a range of scales including property, catchment, regional, and national scales. There are a number of considerations to make when selecting which scale to apply the method, including: 1) costs for assessing data availability and collating datasets; 2) costs associated with collection and analysis of additional hydrochemical sampling; and 3) GIS processing. Much of the GIS processing is the same for a catchment or regional scale, however collection of additional hydrochemical data is necessary for the classification and validation of the approach.

Accordingly, when considering collection of new datasets, in locations where additional water quality data is required, then the scale at which the method will be applied will be of far greater importance. For example, the cost associated with collation of existing datasets at the catchment scale will be less than collection at the regional scale. Another benefit of application of the physiographic method at the catchment scale, is that it can be directed at a particular land-use and or water quality issue. In the interim, Tasman District Regional Council have opted to stage investment in the necessary sampling and have identified the Waimea WMA as a priority catchment.

6.2 Recommendations based on current knowledge

An initial evaluation of existing environmental datasets (e.g., surface water, groundwater, soil layers) indicate sufficient spatial and temporal coverage for multi-scale (e.g., regional, catchment) physiographic mapping are available for the Tasman District. Areas of higher data availability may be suitable for higher resolution physiographic mapping (e.g., sub-catchment and farm scale). The rationale for progressing physiographic mapping of the Waimea WMA is provided below. These steps will largely be the same for other catchments in the Tasman District, although the number of water sources may vary (e.g. some catchments will not have alpine contributions). The following steps are recommended to provide a basis for undertaking physiographic mapping in the Waimea WMA:

1. Collate Historical Data: Extract and collate all available datasets (e.g., SOE, one-off and project samples, consent monitoring data) for groundwater and surface water from within the Waimea WMA. Every historical source of water compositional (e.g., quality and hydrochemical) data should be considered including one-off samples, or samples with a low number of parameters. For example, a single measurement of nitrate (NO_3^-) and conductivity, when used in conjunction with landscape setting can provide useful information over redox process and water source. 'Old' (>10 years) data is useful as this data is useful for understanding process signals not state and trend. For groundwater data well depth, aquifer confinement status (if available), aquifer type (e.g., riparian, fractured rock, alluvium, fractured rock, coal measures, carbonate, terrace, lowland) should be appended to the sample.

If Tasman District Council collect data from across the region that share similar geological, hydrological and ecological settings then these can be used to augment data for the Waimea WMA, specifically:

i. Monitoring of any 'true' hill country streams close to their source that share similar geology and hydrology to those within the Waimea WMA; and
ii. Monitoring of any 'true' alpine streams above the tree line.

Provision of any historical datasets will greatly assist in production of an 'uncalibrated Physiographic Map' that can be used to guide sampling of an extended suite for full calibration.

2. Development of an uncalibrated Physiographic map: An 'uncalibrated physiographic map' for the entire region will be developed in GIS using available information. This map can subsequently be calibrated when new environmental data is procured. It is recommended that Tasman District Council wait until the 'uncalibrated physiographic map' has been produced to undertake groundwater sampling and selected source water sampling (as described below). This is because information in the map can be used to inform locations and guide groundwater and selected source water sampling since these samples are primarily influenced by the combined role of the soil-aquifer system over hydrological pathway and redox. Sampling for other surface waters can be undertaken prior to development of the 'uncalibrated Physiographic Map', as described below.

3. Water Source Sampling: Identify and collect, if of relevance to the catchment of interest, the four key water source samples that underpin the physiographic approach:

i. Alpine streams (i.e. above tree line) – can be undertaken independent of 'Physiographic Mapping'.
ii. Hill country streams - significant hill country streams that do not have an alpine headwater - can be undertaken independent of 'Physiographic Mapping'.
iii. Lowland streams and aquifers, exclusively recharged by local precipitation with no alpine or hill country sourced contributions – following production of and 'uncalibrated Physiographic Map'.
iv. Mixed streams and aquifers, hill country streams with an alpine head water, Waimea River, riparian aquifers - following production of and 'uncalibrated Physiographic Map'.

Samples from each of the main source waters supplying the lowland Waimea Plains within the Waimea WMA are essential to un-mix and apportion the source of water and contaminants for streams and aquifers of mixed provenance. 'Significant' headwater streams are those that are considered most representative of the source of water - those streams that make the dominant volumetric contribution to lowland streams and aquifer systems of the Waimea WMA. Streams or shallow aquifers associated with significant anthropogenic signals (e.g., elevation of one or more of the following: N, P, S, M) should also be included, even if their volumetric contribution is relatively low. It is well known that a small contribution of highly contaminated waters can have a profound effect on overall water quality. Selection of sites is best guided by local knowledge.

3A. Sampling prior to availability of the 'uncalibrated Physiographic Map'

3.1: Headwater Sources: Identifying significant headwater tributaries/streams supplying water to the Waimea Plains is critical, specifically:

i. The source of waters from alpine areas (i.e., above the tree line); and
ii. The source of waters from true hill country areas – significant hill country streams that are not associated with an alpine headwater.

This sampling work can be completed early on as sampling is purely guided by the location of a headwater in 'Alpine' (i.e., above the tree line) and true Hill Country catchments. The number of samples to be taken will depend on the number of significant headwater streams feeding the Waimea Plains. Although Tasman District Council science personnel are better placed to decide on the most appropriate number of samples, an idealised spatial depiction of sampling sites for 'Alpine' headwater sources for the Waimea WMA can be provided based on information in Figure 4. Alpine samples are 'one-offs' and best collected during winter months.

For 'true' hill country streams that supply significant water volumes or contaminant loads to lowland areas, it is optimal to obtain samples at low, median, and high flow; and to sample the stream upgradient of or close to where it discharges onto an alluvial plain. A spatial depiction of potential sampling sites for headwater sources for the Waimea WMA can be determined based on local knowledge and information provided in Figure 4.

3.2: Lowland and Alpine-Hill Mixed waters: Streams with an alpine headwater normally drain areas of forested (or at least historically forested/tussock grassland) hill country before flowing onto an alluvial plain. These streams are a mix of alpine and hill country waters and are important to sample, especially if they contribute significantly to flow in the lowland reaches of streams or drive aquifer recharge.

Lowland areas such as the Waimea Plains receive water from Alpine, Hill and LSR. Sampling main stem rivers and tributaries that contain a mixed (Alpine-Hill-Lowland) water signal is critical for separating and explaining longitudinal variation in surface water quality and composition but also spatial variation between streams.

Again, historical data is an important source of information. However, if there are no or few sampling sites along main stem rivers (e.g. a sampling site at the bottom of the catchment but not along the middle or upper section of a main stem river) then establishment of sampling sites along the longitudinal reach of the river is important. Addition of extended analytes to key sites within this area is important. For surface water this will require three repeat samples for key sites at low, median, and high flow.

3B. Sampling following availability of the ‘uncalibrated Physiographic Map’

3.3: Samples of surface water and groundwater in areas of land surface recharge (LSR): These waters show little, if any, evidence of connection to alpine or hill country waters are the third main type of water to sample. These surface waters are most commonly associated with lowland aquifer systems that are also recharged by local precipitation. These areas typically occur in areas of higher intensity land use and as such have some historical monitoring associated with them. For surface water this will require three repeat samples for key sites at low, median and ‘high’ flow. For groundwater, sampling shallow bores when groundwater level is at its highest and once again when the water table is at its lowest is recommended.

3.4 Groundwater sampling: Economically important aquifers are often missing from Alpine and Hill Country areas; and the majority of shallow groundwater is associated with areas of valley infill and outwash surfaces. However, fractured rock aquifers are important to include where bedrock occurs at or near the surface. Therefore, the ‘uncalibrated Physiographic Map’ should be used to guide identification of groundwater sampling sites. The key focus of physiographic mapping is on sampling ecologically important groundwater as this component is most likely to supply streams as baseflow. Accordingly, aquifer confinement status along with well depth are two critical considerations when selecting wells for sampling. Groundwater signatures in baseflow commonly change in response to groundwater level changes, with younger often less-evolved groundwaters discharging to streams during and following periods of peak aquifer levels (e.g., during wettest months) (Inamdar et al., 2011). During periods of low aquifer level (e.g., during drier months) baseflow is commonly comprised of older, and often hydrochemically more evolved water. For this reason, sampling shallow bores when groundwater is at its highest water table and once again when the water table is at its lowest is recommended.

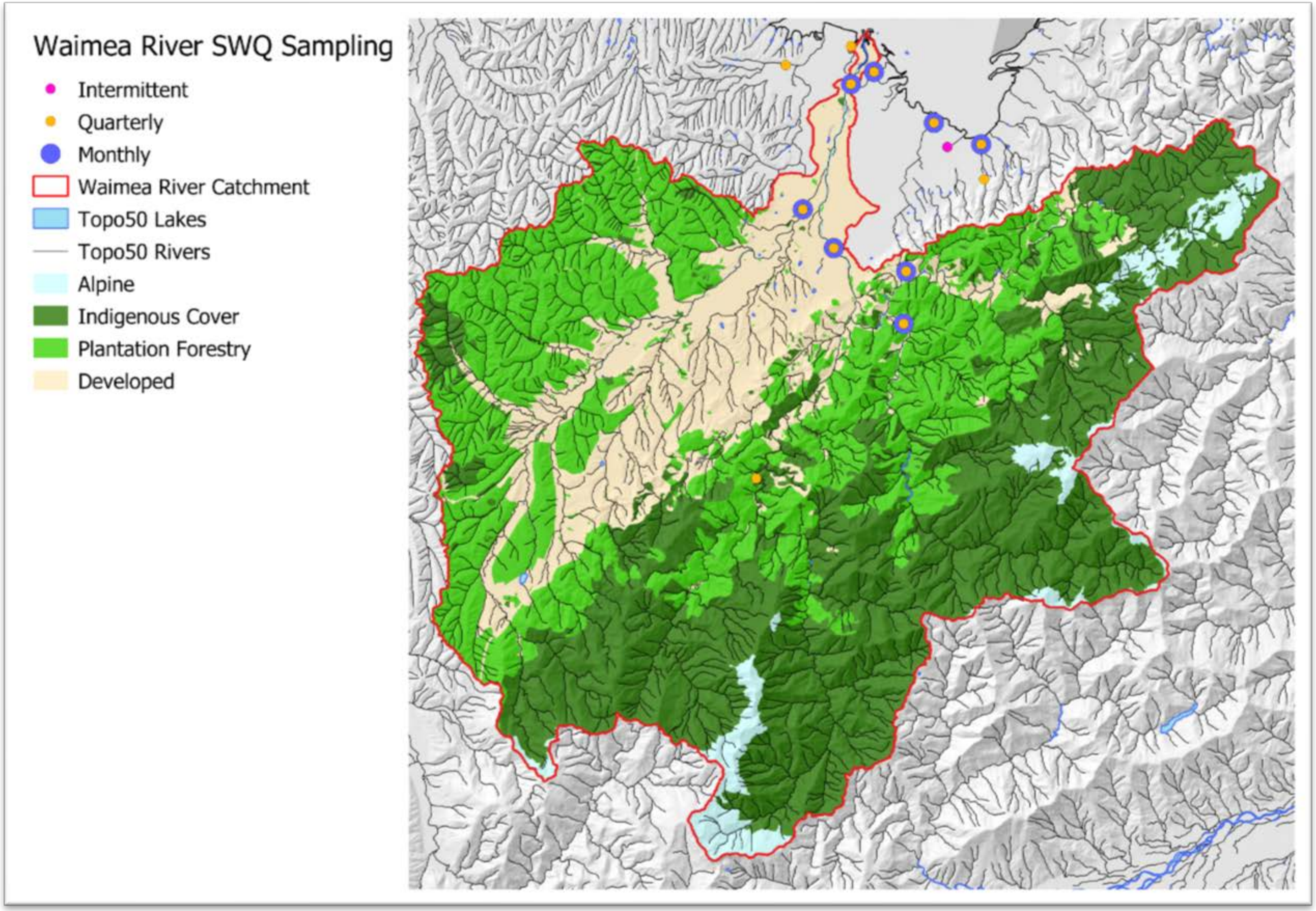


Figure 4: Map of the Waimea Catchment including land cover, location of previous and existing sampling sites, and frequency of sampling.

6.3 Estimate of additional sampling required

Recent soil mapping undertaken by Tasman District Council (2017) adds extra value and accuracy to the approach in areas of the highest intensity land use, the high resolution of the is mapping is a considerable advantage relative to some other regions of New Zealand. Additional sampling required by Tasman District Council will be dependent on whether the physiographic method is to be undertaken at the regional or catchment scale. An estimated number of additional water quality samples required (in addition to existing sampling) would be six surface water and six shallow groundwater samples per management region. The total number of samples for each catchment would be dependent on the hydrological system and the current monitoring sites.

The key consideration for the Tasman District Council is whether they embark upon catchment or regional scale physiographic mapping. Specifically, the GIS processing effort is largely the same for the entire region, but collation of historical data sets and additional sampling of surface and shallow groundwater analytes are more affordable at the catchment scale. Therefore, it is recommended that Tasman District Council undertake regional scale GIS mapping to produce an unvalidated physiographic model. Following this, one to three key catchments can be selected to prioritise physiographic sampling for validation and refinement. The value of this approach is the that uncalibrated mapping provides a platform for targeted sampling within the target area(s), thereby minimising sampling cost. Other catchments or unvalidated physiographic settings can then be strategically sampled over a longer period. This approach enables some direct outputs for the region to occur rapidly and adds value to the larger region by providing better insight into the key physiographic settings that require compositional sampling and enables a better assessment of the number of locations for sampling.

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APPENDIX A: EXISTING DATA INVENTORY

A1 Surface water and groundwater datasets

Table A1: Summary of surface water quality monitoring sites in the Aorere Water Management Area.

Catchment	River	Interval	Dates
Aorere	Aorere @ Devils Boot	Quarterly	2000 – 2016
	Aorere @ Le Conte	Quarterly	2000 – 2011
		Monthly	2011 – present
	Clay Ck.	Intermittent	-
Kaituna	Kaituna @ u/s track start	Monthly	2000 – 2001
		Monthly	2013 – present
		Quarterly	2005 – 2013
	Kaituna @ Sollys Rd.	Quarterly	2000 – 2016
		Monthly	2016 – present
Mackay	Mackay Ck.	Intermittent	-
Burton Ale	Burton Ale Ck.	Intermittent	-
James Cutting	James Cutting Ck.	Intermittent	-
Pakawau	Pakawau Ck.	Intermittent	-
	Pakawau-Puponga Ck	Intermittent	-

Table A2: Summary of surface water quality monitoring sites in the Takaka Freshwater Management Unit.

Catchment	River	Interval	Dates
Takaka	Takaka @ Harwoods	Quarterly	2000 – 2016
	Takaka @ Lindsay's Br	Monthly	2016 – present
	Takaka @ Kotinga	Monthly	2000 – 2013
		Quarterly	2013 – present
	Waingaro @ Hanging Rock	Quarterly	2000 – 2010
Te Waikoropupū	Te Waikoropupū Springs	Intermittent	-
Lake Killarney	Lake Killarney	Intermittent	-
Motupipi	Motupipi @ Reilly Br.	Quarterly	2000 – 2016
		Monthly	2016 – present
		Continuous [DO, ºC, EC, flow]	2007 – present
	Powell Ck. @ Reilly Br.	Quarterly	2005 – present
	Te Kaukau	Intermittent	-
Other Golden Bay	Winter Ck. @ 50 m u/s Totaranui	Quarterly	2000 – 2016
	Pohara Ck.	Intermittent	-
	Onahau	Intermittent	2005 – 2016
	Puremahia Stream	Intermittent	-
Onekaka	Onekaka u/s Ironstone Ck.	Quarterly	2000 – 2016
	Onekaka @ Shambala	Monthy	2016 – present
Tukurua	Tukurua @ Playground	Weekly in summer [faecal indicator]	2010 - present

Table A3: Summary of surface water quality monitoring sites in the Waimea Water Management Area.

Catchment	River	Interval	Dates
Waimea	Waimea @ SH60	Quarterly	2000 – 2013
		Monthly	2013 – present
	Wairoa @ Irvines	Quarterly	2000 – 2013
		Monthly	2013 – present
	Lee @ Meads Br.	Quarterly	2000 – 2013
		Monthly	2013 – present
	Roding @ Twin Br.	Quarterly	2000 – 2013
		Monthly	2013 – present
	Wairoa @ Pig Valley	Quarterly	2000 – Jun 2016
	Wai-iti @ Livingston	Quarterly	2000 – Jun 2016
		Monthly	Jul 2016 – present
Wai-iti	Reservoir @ d/s Salisbury Rd.	Quarterly	2000 – 2013
		Monthly	2013 – present
Wai-iti	Reservoir @ u/s Marlborough Ck.	Quarterly	2000 – Jul 2016
Jimmy-Lee	Jimmy-Lee Ck. @ 35 Beach Rd.	Intermittent	-
Borck	Borck @ 400 m d/s Lower Queen St.	Quarterly	Apr 2013 – June 2016
		Monthly	June 2016 – present
Neimann	Neimann @ 600 m u/s Landsdown Rd.	Quarterly	Apr 2013 – June 2016
		Monthly	July 2016 – present
Pearl	Pearl @ u/s tide gate	Quarterly	Jul 2013 – Jun 2016
Redwood Valley	Redwood Valley Stream @ Greenacres Rd.	Quarterly	2005 – Jun 2016
Seaton Valley	Seaton Valley Stream	Quarterly	Feb 2006 – Jun 2016

Table A4: Summary of surface water quality monitoring sites in the Buller Freshwater Management Unit.

Catchment	River	Interval	Dates
Black Valley	Black Valley Stream	Monthly	2000 - present
Buller River	Buller @ Longford	Monthly	1989 – present
	Buller @ O'Sullivans	Intermittent	-
Mangles	Mangles @ Gorge	Quarterly	2000 - present
Matakitaki	Matakitaki	Intermittent	-
Murchison	Murchison Ck.	Quarterly	2005 – present
Doughboy	Doughboy Ck.	Intermittent	-
Hinehaka	Hinehaka	Intermittent	-
Maruia	Maruia @ 1 km u/s Buller	Intermittent	-

Table A5: Summary of surface water quality monitoring sites in the Motueka Water Management Area.

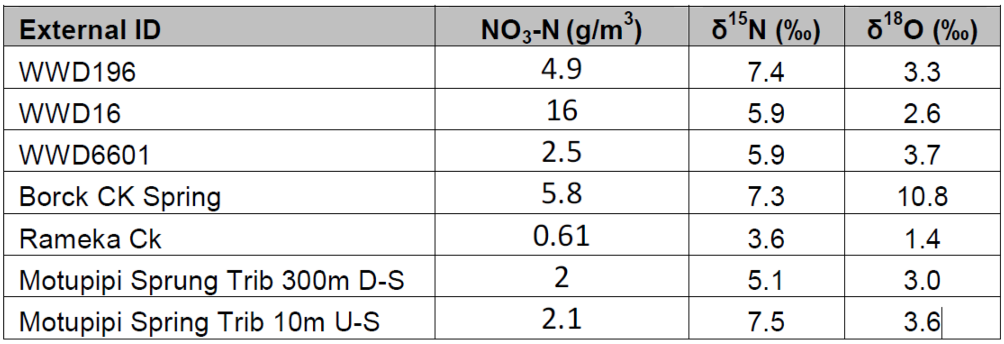
Catchment	River	Interval	Dates
Moutere Inlet	Tasman Valley Stream	Quarterly	Feb 2006 – present
Moutere River	Moutere @ Riverside	Quarterly	Aug 2012 – present
	Old House Ck. @ Central Rd.	Intermittent	-
	Moutere @ Kelling Rd.	Intermittent	-
	Old Moutere (Blue Ck.)	Intermittent	
Motueka	Motueka @ Gorge	Monthly	1989 – present
		Quarterly	2000 – present
	Motueka @ u/s Wangapeka	Quarterly	2000 – present
	Motueka @ Woodstock	Monthly	1989 – present
		Quarterly	2000 – present
	Motueka @ Woodmans Bend	Quarterly	2000 – present
	Motueka @ SH60 (mouth)	Quarterly	2000 – 2013
		Monthly	2013 – present
Sherry	Sherry @ Blue Rock	Quarterly	2000 – present
		Monthly	2000 – present
	Sherry @ Matariki Br	Intermittent	-
	Sherry @ u/s Cave Ck	Intermittent	-
Wangapeka	Wangapeka @ Walter Peak	Quarterly	2000 – present
	Wangapeka @ 5 km u/s Dart	Intermittent	-
Tadmor	Tadmor	Intermittent	-
Glenrae	Glenrae	Intermittent	-
Kohatu	‘Old School Ck.’	Intermittent	-
Hinetai	Hinetai Ck.	Intermittent	-
Motupiko	Motupiko @ Christies	Quarterly	2000 – present
	Motupiko @ u/s Motueka	Quarterly	2006 – present
Kikiwa	Kikiwa Ck.	Quarterly	2000 – present
	Graham Ck.	Quarterly	2000 – present
	Hunter Ck.	Quarterly	2000 – present
Waiwhero	Waiwhero @ Cemetery	Quarterly	2000 – present
Motueka Creeks	Moon, Doctors, Thorpe, Woodlands	Intermittent	-
Little Sydney	Little Sydney @ Factory Road	Quarterly	2000 – June 2016
Riwaka	Riwaka @ Northbranch source	Quarterly	2000 – June 2016
	Riwaka @ Hickmotts	Quarterly	2000 – June 2016
		Monthly	2016 – present

Table A4: Summary of Tasman District Council groundwater monitoring sites, periods of dataset collection and identification of monitoring network.

Site	E	N	Dates*	Network
GW 23759 - Collingwood	1569844	5497860	2015 - present	TDC SOE
GW 5027 - Le Comte	1569886	5497800	2002 - 2016	TDC SOE
GW 6342 - Takaka Fire	1583672	5477057	2000 - present	TDC SOE
GW 6601 - Central Takaka Bore	1584626	5474911	1990 - present	NGMP
GW Fish Creek Spring	1580500	5477883	1991 - present	TDC SOE
GW Pupu Main Spring	1580495	5478098	1986 - present	NGMP
GW 23604 - Bensemann	1601735	5447713	2009 - present	NGMP
GW 3314 - Bensemann	1601854	5447711	1990 - 2009	NGMP
GW 23806 - Tapawera	1585170	5417375	2013 - present	TDC SOE
GW 3115 - Drummond	1599189	5451291	1983 - present	NGMP
GW 3216 - Ngati Raru	1599940	1599940	1983 - present	NGMP
GW 3393 - Kildrummy	1599978	5446169	1998 - present	TDC SOE
GW 8054 - Middletons	1607560	5430487	2000 - present	TDC SOE
GW 8404 - Wrattens	1598704	5442843	1988 - present	NGMP
GW 8407 - Williams	1599141	5439685	1987 - present	NGMP
GW 23658 - TDC Prod 1 Murchison	1543548	5371895	2011 - present	TDC SOE
GW 114 - TDC Roadside	1610324	5419792	1976 - present	TDC SOE
GW 1392 - Spring Grove	1605907	5417667	2000 - present	TDC SOE
GW 32 - TDC	1613959	5425351	1976 - present	NGMP
GW 37 - Gardner	1611852	5423288	1984 - present	NGMP
GW 802 - Waiwest	1611246	5426481	1996 - present	NGMP
GW 997 - McCliskies	1609013	5427614	2000 - present	TDC SOE

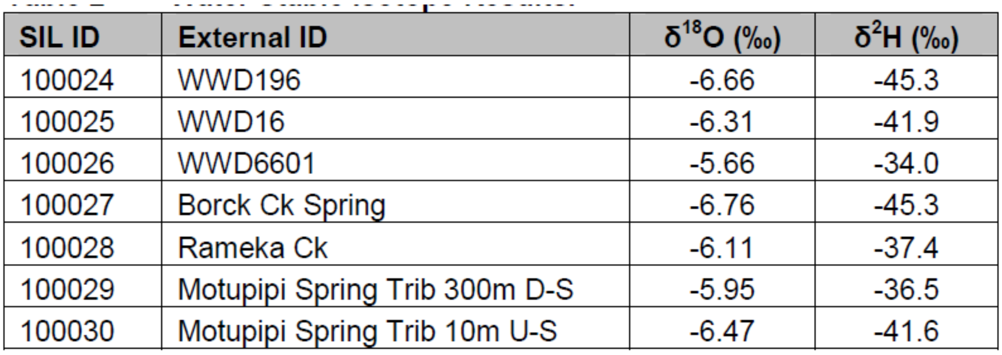
* at times data collected during the identified period is regular (e.g., monthly, quarterly), however this is inconsistent between sites due to changes in the monitoring programme.

Table A5: Nitrate sample isotope results (van der Raaij and Baisden, 2015).



External ID	NO_3-N (g/m^3)	δ^{15}N (‰)	δ^{18}O (‰)
WWD196	4.9	7.4	3.3
WWD16	16	5.9	2.6
WWD6601	2.5	5.9	3.7
Borck CK Spring	5.8	7.3	10.8
Rameka Ck	0.61	3.6	1.4
Motupipi Sprung Trib 300m D-S	2	5.1	3.0
Motupipi Spring Trib 10m U-S	2.1	7.5	3.6

Table A6: Water stable isotope results (van der Raaij and Baisden, 2015).



SIL ID	External ID	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)
100024	WWD196	-6.66	-45.3
100025	WWD16	-6.31	-41.9
100026	WWD6601	-5.66	-34.0
100027	Borck Ck Spring	-6.76	-45.3
100028	Rameka Ck	-6.11	-37.4
100029	Motupipi Spring Trib 300m D-S	-5.95	-36.5
100030	Motupipi Spring Trib 10m U-S	-6.47	-41.6