Physiographics of Southland: Soil zone controls over freshwater quality and chemistry

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A key outcome of the Physiographics of Southland project was to identify and characterise soil zone control over freshwater chemistry in Southland.

The physiographic concept

Water quality and chemistry are variable in both space and time, despite similar or identical land use practices. Variability is linked to hydrological and biogeochemical factors, which vary depending on landscape characteristics.

A conceptual model was developed to explain variation in regional freshwater. Hydrochemical data were used to identify four key drivers (landscape attributes) controlling freshwater chemical variation (Figure 1). We found two of these drivers to be intimately linked to the soil zone: 'landform age and parent material composition' and 'soil and aquifer reduction potential'. We concluded that these drivers exert a strong control over the freshwater chemical variation in Southland.

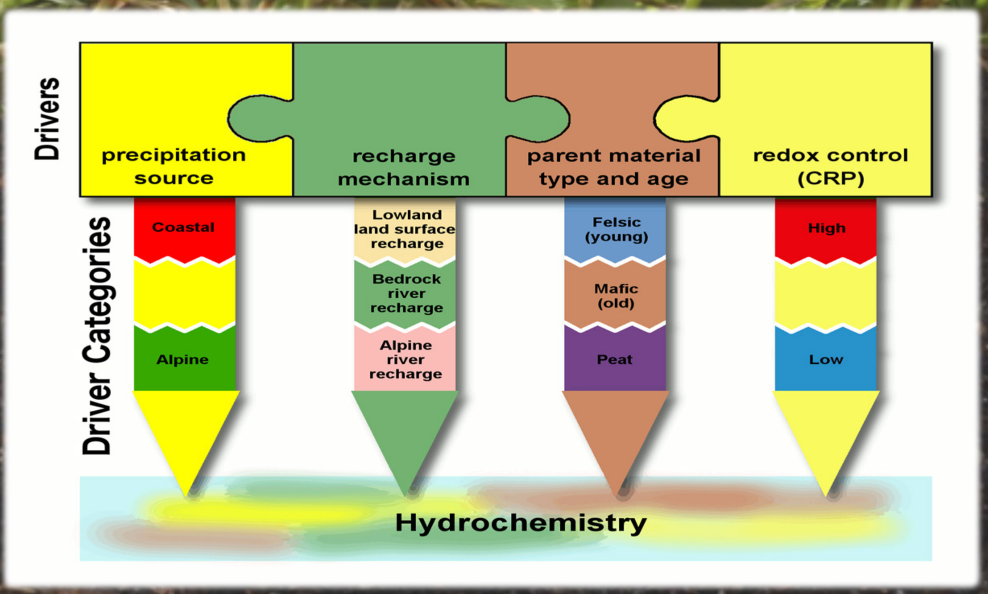

Figure 1: The physiographic conceptual model, depicted as the four key drivers making up parts of the hydrochemistry puzzle. Drivers are: precipitation source (composition and volume of precipitation); recharge mechanism (the process in which the water was recharged); parent material type and age (the degree of weathering and parent material composition); and redox control (the reduction potential of the soils and aquifers)

DRIVER: Landform Age and Parent Material Composition

Hydrochemistry in Southland's ground and surface waters is highly influenced by fast soil and unsaturated zone reactions (Figure 2). The degree of weathering and the mineralogical composition of soil controls clay development and organic matter content. Subsequently, this controls the occurrence of fast biogeochemical reactions in the soil zone, such as ion exchange, sorption and redox. Biochemical reactions and resulting soil properties heavily influence the chemistry of infiltrating water.

The majority of Southland's freshwater systems consist of soil zones, shallow aquifers and surface waters that are highly hydraulically connected. This results in relatively rapid water transit times through soils and aquifers to surface rivers and streams (Chanut, 2014; Daughney et al., 2015).

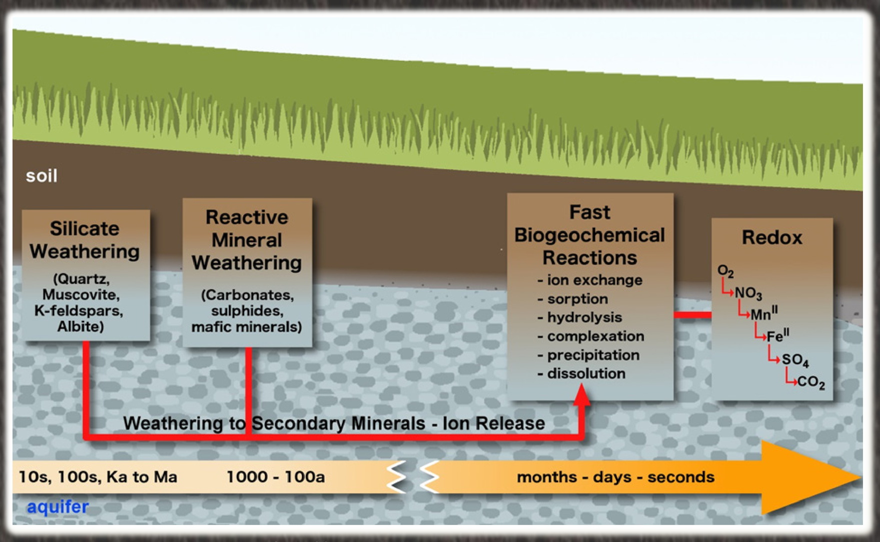

Figure 2: Depiction of differing biogeochemical reactions that occur over varying timescales within the soil and unsaturated zone.

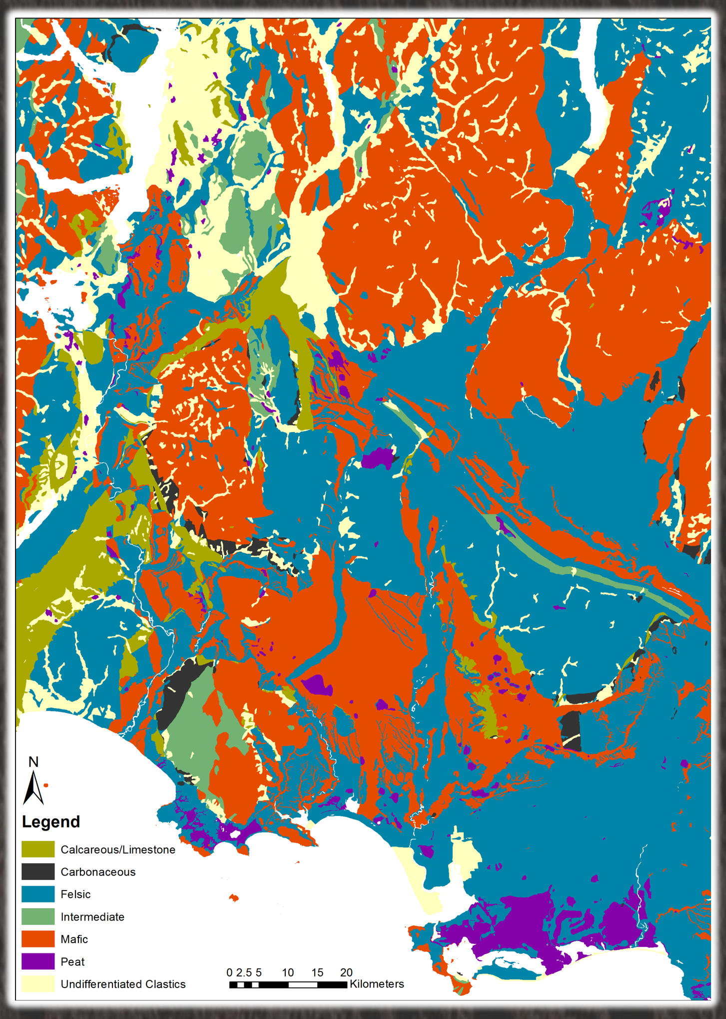

Figure 3: Southland parent material composition map (surface). Landform age classification is not shown.

Mapping the driver

'Landform age and parent material composition' was characterised and mapped using existing information within QMap (Heron, 2014) and TopoClimate South (2001). Figure 3 shows the classification of Southland by approximate composition. Mapping the *surface* environment utilised soil and geological information, while *subsurface* mapping utilised geological information only.

DRIVER: Soil and Aquifer Reduction Potential

The soil zone exerts by far the greatest control over the variability in regional soil-influenced ground- and surface water redox signatures for 90% of Southland's aquifers. This is due to the short interaction times and relatively inert nature of the majority of Southlands aquifer materials. Therefore, the soil zone has significant control over groundwater nitrate concentrations and redox signatures across the region.

For example, within poorly drained soils there is often sufficient residence time and decoupling from an atmospheric source of oxygen for the evolution of reducing conditions. This results in the ecological succession of terminal electron-accepting processes including NO_3 reduction (denitrification) (Figure 4).

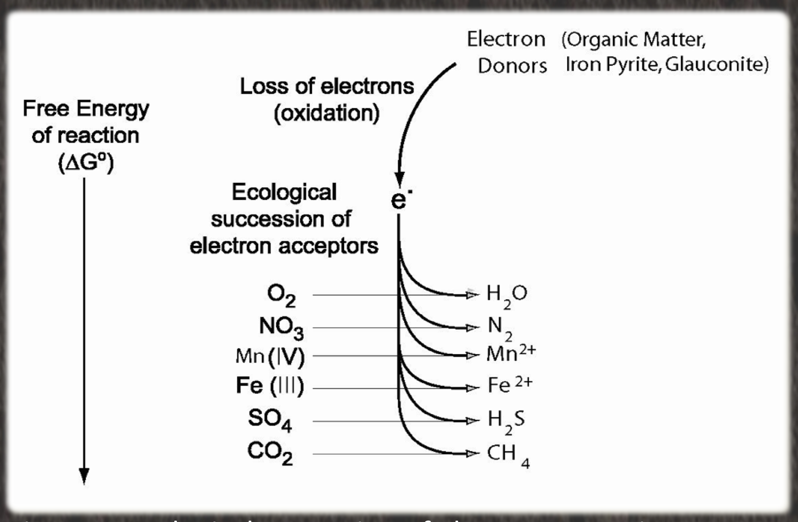

Figure 4: Ecological succession of electron-accepting processes and sequential production of final products in natural waters.

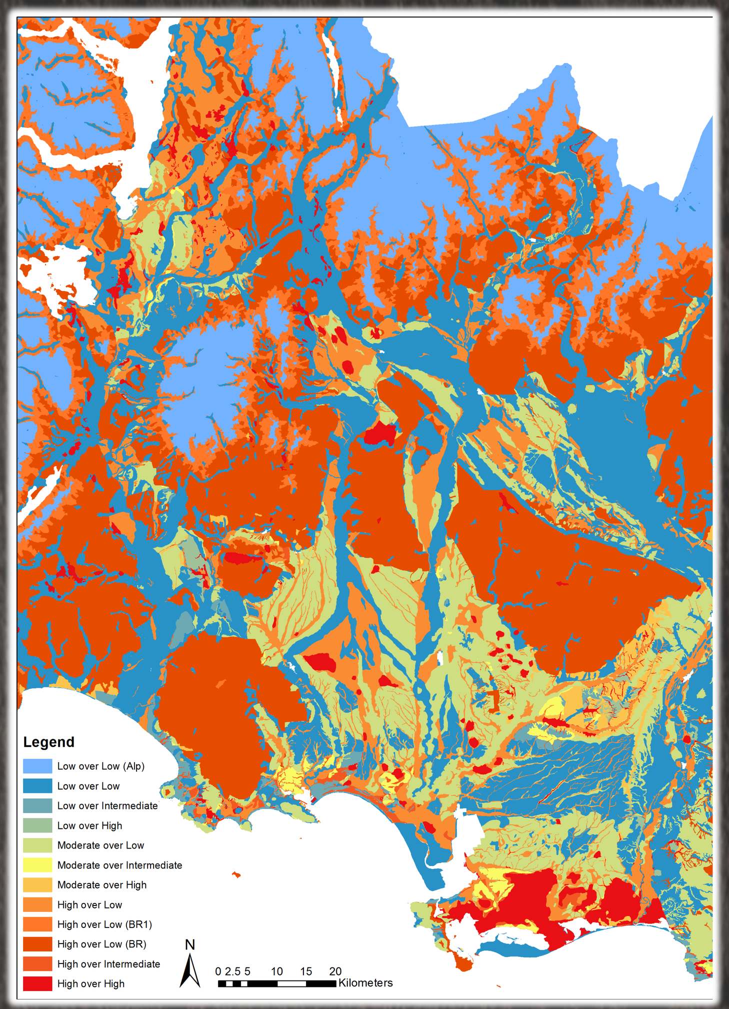

Figure 5: Southland reduction potential map.

Mapping the driver

We used the qualitative soil and geological 'denitrification' assessments of Killick et al. (2014) and Rissmann (2011) respectively to classify Southland by combined soil and aquifer reduction potential (Figure 5). During their assessment Killick et al. (2014) used soil hydraulic properties and soil carbon abundance information within TopoClimate South (2001) to estimate reduction potential. Rissmann (2011) used geological information in QMap (Heron, 2014) to infer reduction potential of aquifer materials.

Further links between soils and freshwater

$\delta^{13}C$-DIC signatures for surface waters (SW), tile drain waters (TD) and groundwaters (GW) were similar and clustered toward a soil organic carbon signature (c. -24 to -34‰) (Figure 6). We found the opposite for precipitation (PPT), which was more enriched in ^{13}C. This indicated a soil organic carbon source and supported the link between the soil zone and Southland freshwaters. Inevitably degassing occurs, especially in TD and SW causing ^{13}C enrichment.

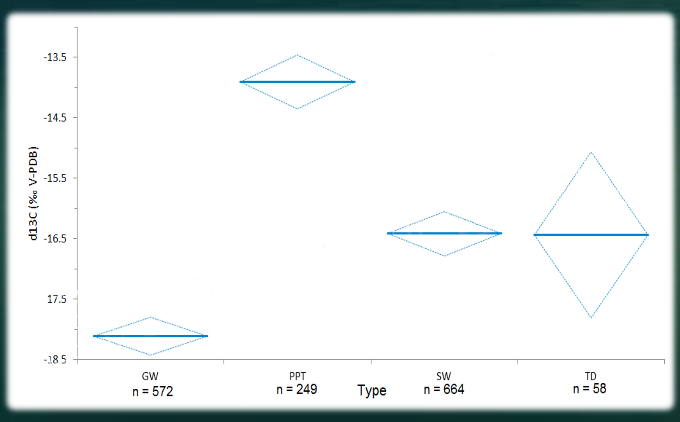

Figure 6: Mean plot for $\delta^{13}C$-DIC of Southland waters. Grouped by water type. The solid line depicts the mean, the extent of the diamond encompasses the 95th percentile.

The Physiographic Zones

For planning purposes, simplified physiographic zones were delineated utilising the understanding of Southland hydrochemical drivers. The mapping utilised existing information about soils, geology, topography and hydrology to delineate the region into areas with similar inherent properties that influence water quality outcomes (N, P, Sediment, *E.coli)* (Figure 7).

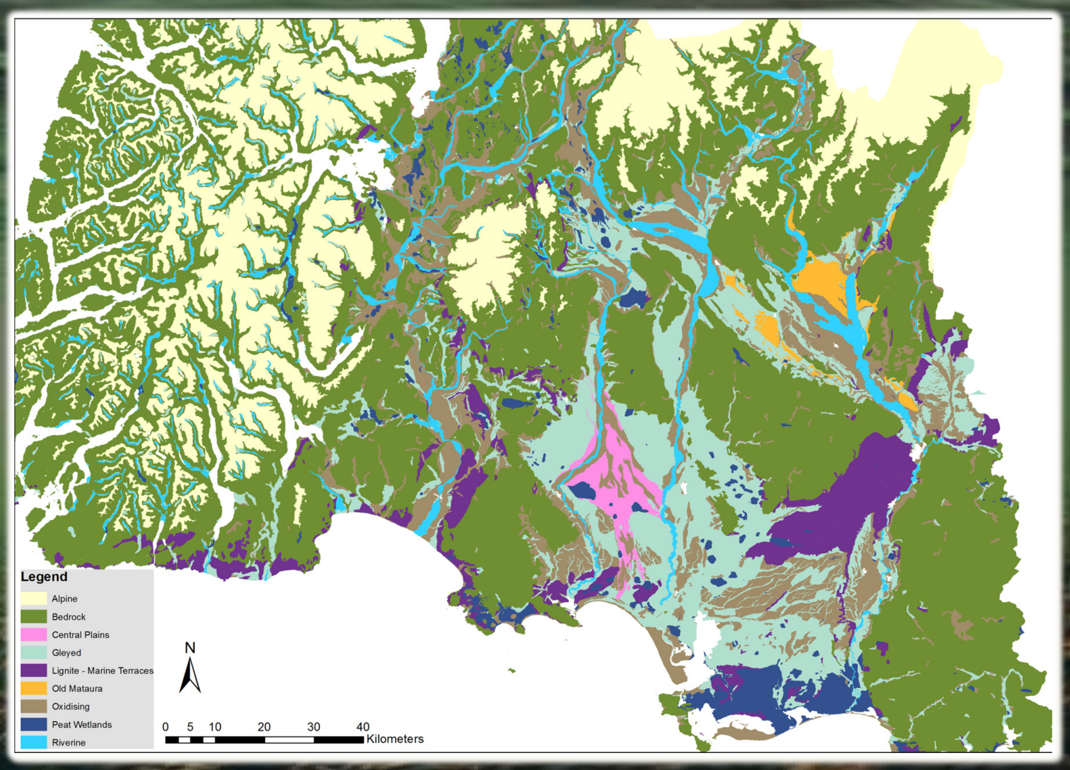

Figure 7: Simplified physiographic zones for Southland. Soil properties such as drainage characteristics and the reduction potential were critical in the development of these zones.

Acknowledgements
Many thanks to Ton Snelder, Tim Ellis, Travis Horton, Jenny Webster-Brown, Scott Larned, Richard McDowell, Troy Baisden, Peter Almond, Tim Clough, Sephrah Rayner and Mark Schallenberg for contribution of knowledge and resources.

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