On-site Wastewater Groundwater Quality Risk

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by

Hamish Ogilvie, Clinton Rissmann, Brydon Hughes and George Ledgard

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Community Summary

On-site treatment is utilised as the primary means of domestic wastewater disposal in unsewered areas of Southland. Effluent from on-site wastewater treatment systems contains elevated levels of nutrients and microbial contaminants which have the potential to affect water quality in receiving waters.

To identify the potential risk to groundwater quality associated with on-site wastewater disposal, a simple risk assessment was developed using key criteria identified by ESR (2006) including:

- Soil drainage characteristics
- Depth to groundwater
- Density of on-site wastewater systems

Soil drainage characteristics and the associated potential for transport of contaminants through the unsaturated zone to the water table were evaluated using the nutrient leaching vulnerability index developed for the Topoclimate soil mapping project. This index assesses the relative risk of nutrients from the land surface reaching the underlying water table based on soil water holding and drainage properties. This index was considered to also provide a reasonable proxy for the relative risk of microbial contaminants reaching groundwater. The leaching vulnerability index was combined with the depth to groundwater to provide an overall assessment of groundwater quality risk shown in **Figure 1** below.

Potential cumulative effects on groundwater quality are increased in areas with a high density of on-site treatment systems. Due to the limited information available to determine the location of existing on-site wastewater treatment systems in Southland, an assessment of the relative density of these systems was undertaken using property information held by Environment Southland. The resulting map, shown in **Figure 2**, highlights the relatively high density of on-site wastewater disposal systems in several small unsewered townships including Waikaia, Mossburn, Centre Bush, Colac Bay and Orepuki.

The risk map shows potential risks to groundwater quality associated with on-site wastewater disposal vary with geographic location across Southland. Areas with the highest groundwater quality risk tend to be those with permeable soils overlying a shallow water table while areas with lower permeability soils or deeper water tables typically exhibit a lower risk. This spatial variation in water quality risk could be utilised to develop recommendations or standards for system design to reduce risks in particular areas. However, definition of appropriate design standards is likely to require specialist engineering input and may require further refinement or on-ground validation of the assessment methodology.

On-site wastewater treatment has the potential to adversely affect water quality at a local scale. This risk is increased in situations where the receiving environment for wastewater discharge (i.e. groundwater) is also the source for a potable water supply. Although declining through the natural processes of filtration and die-off, concentrations of microbial contaminants in wastewater can be transported in the groundwater system down gradient of the disposal area. Bores and wells located in this zone have an elevated risk of microbial contamination. Implementation of appropriate set-back distances from wells utilised for potable supply is therefore an important consideration to mitigate health risks associated microbial contamination associated with on-site wastewater disposal.

At a larger scale, on-site wastewater systems may also contribute to the cumulative nutrient loading to the groundwater system. However, the loading from individual on-site treatment systems tend to be very low compared to inputs from other land uses such as intensive agriculture. As a result, elevated nutrient concentrations associated with on-site wastewater discharge are likely to only occur where there is a high density of systems.

Although areas with poorly drained soils tend to have a lower risk to groundwater quality, unless designed and maintained in accordance with relevant standards, on-site wastewater treatment in such areas can increase risks to surface water, particularly where runoff or drainage to surface water may occur.

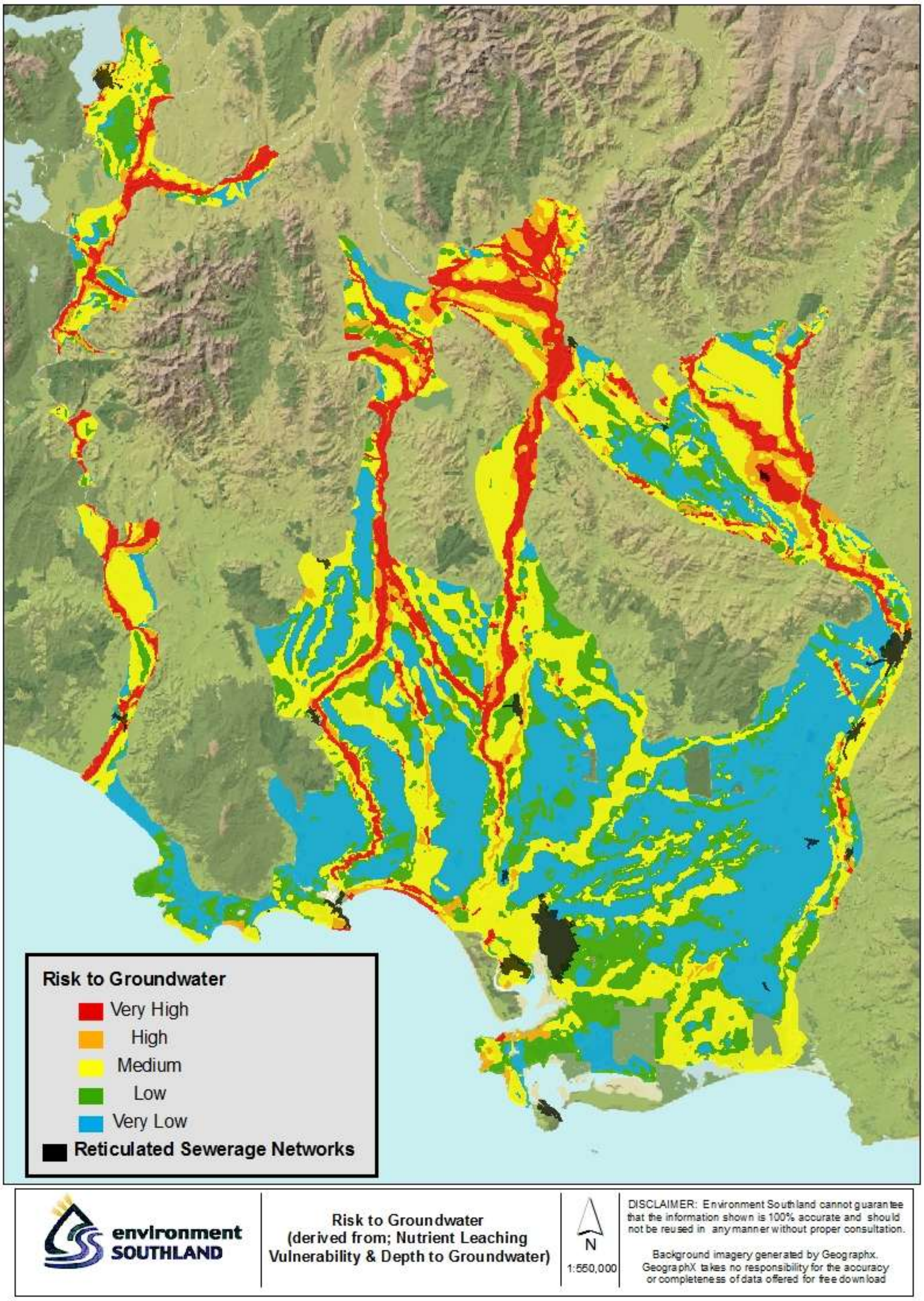

Figure 1. Risks to groundwater quality associated with on-site wastewater disposal

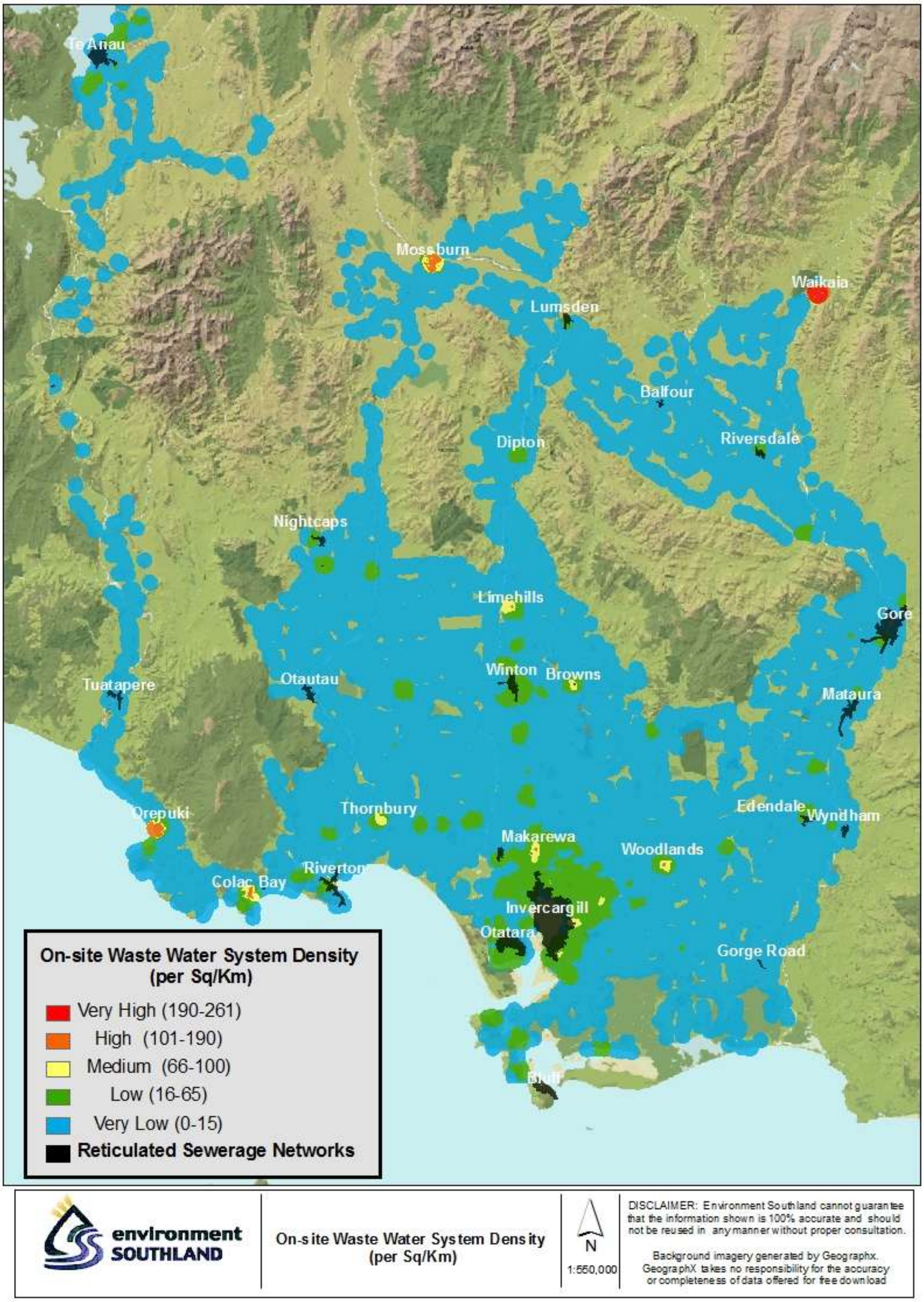

Figure 2. Estimated density of on-site wastewater treatment systems in the Southland Region

1. Introduction

On-site treatment is utilised as the primary means of domestic wastewater disposal in unsewered areas of Southland. Effluent from on-site wastewater treatment systems contains elevated levels of nutrients and microbial contaminants which have the potential to affect water quality in receiving waters.

In most instances, the low density of on-site wastewater treatment installations combined with effluent treatment occurring during soil infiltration means the risks to receiving waters are comparatively low. The overall nutrient loading from on-site wastewater disposal is typically minor compared to that associated with intensive farming practices. However, microbial contaminants (bacteria and viruses) have the potential to affect water quality on a local scale and may pose a risk to potable water supplies where bores and wells are located too close to a wastewater disposal system.

1.1 On-site wastewater disposal systems

On-site wastewater disposal systems provide treatment of domestic wastewater via discharge to ground within the property of origin. A range of on-site systems are available, designed to treat wastewater to varying degrees before final discharge to the environment.

Septic tanks are the most common form of on-site wastewater treatment utilised in Southland. These systems have two primary components, a solids settling tank (i.e. the septic tank) and a disposal field typically comprising soakage trenches or driplines as illustrated in **Figure 1** below. In septic tank systems a majority of effluent treatment occurs within the soil underlying the disposal area with the primary function of the septic tank being the removal of solids that may otherwise reduce drainage within the disposal field.

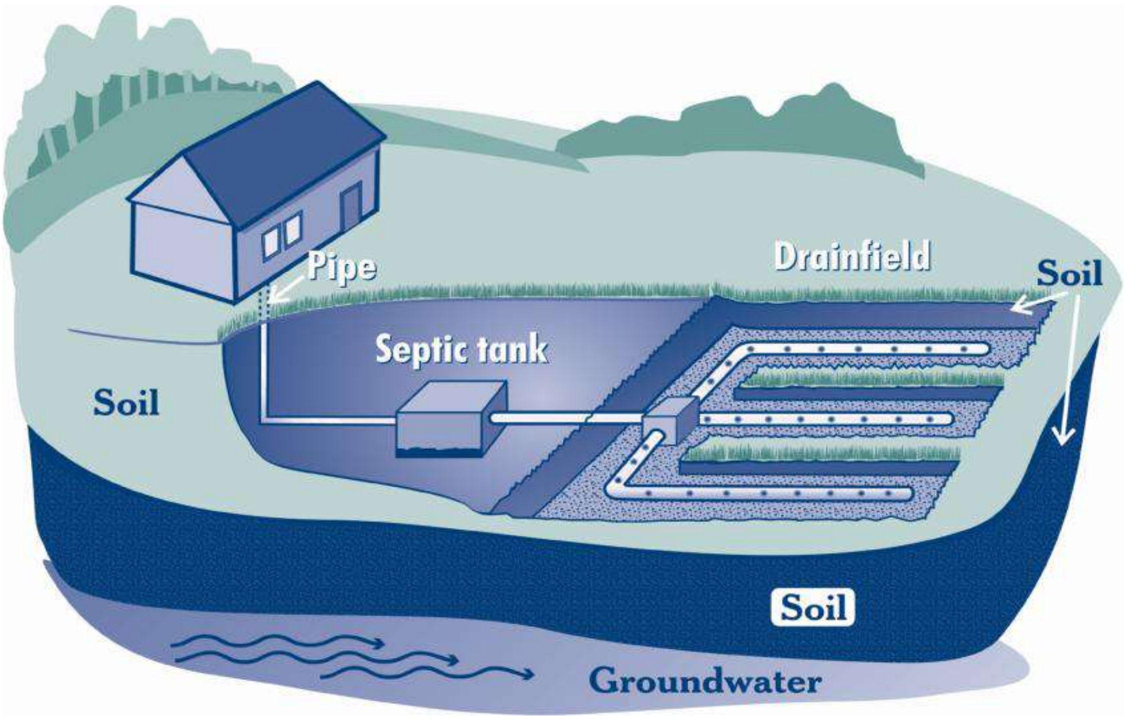

Figure 1. Schematic illustration of a typical on-site wastewater treatment system[1]

[1] From www.waternz.org.nz

As a result, the physical characteristics of the soil into which effluent is discharged has a significant influence on overall treatment effectiveness. If soils are highly permeable, or the groundwater table is high, effluent can rapidly infiltrate to underlying groundwater. Conversely, if soils are poorly drained and hydraulic loadings too high, effluent may pond on the land surface creating a health hazard or move laterally through the soil and discharge directly into surface water.

1.2 Potential water quality effects

On-site wastewater disposal has the potential to adversely impact on water quality in the receiving environment. Primary contaminants of concern include nutrients (nitrogen and phosphorus), microbial contaminants (bacteria and viruses) and various organic and inorganic chemicals (ranging from pharmaceuticals to organic compounds contained in household cleaners and other domestic products).

A majority of nitrogen in domestic effluent occurs in the form of organic nitrogen or as ammonia. Within a septic tank concentrations of organic nitrogen are reduced by the removal of solids but anoxic conditions mean little nitrification occurs to convert ammonia to nitrate. Once discharged to the soil treatment system, ammonia is typically converted relatively rapidly to nitrate which is highly soluble in water and is readily transported through the soil zone into underlying groundwater.

Domestic wastewater can potentially contain high loadings of a wide range of microbial contaminants including bacteria and viruses. The primary mechanisms for removal of these pathogens is within the soil treatment system where treatment occurs by way of:

- Filtration - the physical removal of contaminants in infiltrating wastewater as a result of retention by soil and unsaturated zone sediments[2]. While the extent of filtration is influenced by soil and unsaturated texture, a component of filtration is often associated with biological growths within these sediments;
- Retention - once outside a host, microbial contaminants have a restricted duration over which they remain viable. This 'die-off' process varies significantly between different micro-organisms. Die-off is often relatively rapid for bacteria (of the order of hours to days) but may be considerably slower for viruses (days to weeks). As a result, the time taken for effluent to infiltrate through the vadose (unsaturated) zone can have a significant influence of the flux of microbial contaminants reaching groundwater.

Chemical contaminants in domestic wastewater vary considerably depending on source characteristics. A majority of such contaminants occur at relatively low concentrations and many (especially organic compounds) are strongly adsorbed by organic carbon or degraded by biological activity within the disposal field. However, other compounds may be conservative and have the potential to infiltrate through the soil zone to reach underlying groundwater.

Overall, the primary water quality effects associated with on-site wastewater disposal are:

- A contribution to cumulative nutrient loadings to groundwater;
- A potential source of microbial contaminants (including pathogens such as bacteria and viruses).

For a majority of soil types in Southland, the typical phosphorus loadings in on-site wastewater are not considered to be a major issue due to limited mobility of phosphorus in aerobic environments. However, nitrogen loadings in septic tank effluent (typically around 10 grams per person per day (Potts and Elwood, 2000)) will contribute to

[2] Some on site systems employ filter beds (usually of sand) or more complex man made filter media but these are the exception rather than the rule.

cumulative loadings from surrounding land use as a majority of this loading is converted to the soluble nitrate form in the disposal field. These loadings however, are minimal relative to that associated with intensive agriculture.

Input of microbial contaminants to groundwater is a potential issue on a local scale where bores and wells are situated in close proximity to a wastewater disposal field. In this case, microbial contaminants remaining viable after infiltration through the unsaturated zone may be transported relatively rapidly to drinking water supplies, many of which are untreated.

Numerous studies have been undertaken in New Zealand and overseas (e.g. Pang 2009, Wall *et.al.* 2008, Pang *et al.* 2005) which show that due to natural processes of filtration, adsorption and die-off, groundwater contamination by micro-organisms tends to be localised near the contaminant source, except in exceptional circumstances where groundwater flow rates are particularly rapid or when viruses attach themselves to colloids. As a consequence, the majority of instances of contamination by micro-organisms are attributed to localised impacts down gradient of point source discharges (such as a septic tank or effluent disposal area) or where the wellhead is poorly constructed or maintained allowing contaminants from the land surface to enter the water supply.

1.3 Project objective

The objective of this project is to provide a regional-scale assessment of the relative risk of on-site wastewater disposal to groundwater across Southland. The assessment will enable identification of areas where existing on-site wastewater disposal practices present an elevated risk to water quality and provide a basis to identify priority areas for further work or policy development to ensure environmental and health effects are appropriately managed.

1.4 Methodology

The methodology adopted for the project includes a GIS-based assessment of the hydraulic connectivity between the surface environment and shallow unconfined aquifers to identify the risk of contaminants from on-site wastewater disposal reaching the groundwater receiving environment. The assessment has resulted in the production of two maps as described below:

- A map of the potential density of on-site wastewater treatment systems to identify areas where the greatest concentrations of on-site systems occur; and
- A map of groundwater risk associated with on-site wastewater disposal which combines an assessment of nutrient leaching vulnerability with estimated depth to groundwater.

2. Methodology

Several different approaches to estimating groundwater contamination risk associated with on-site wastewater discharge were investigated for this project. These approaches ranged from quantitative rankings of groundwater vulnerability (e.g. the DRASTIC model developed by the USEPA[3]) through to more specific assessments of health and environmental risks associated with on-site wastewater disposal (e.g. the New South Wales Local Government On-site Sewage Risk Assessment Model[4]).

However, due to limitations on available data and associated uncertainties when applying relatively complex models an alternative approach was adopted to provide a simple assessment of groundwater quality risk associated with on-site wastewater disposal in the Southland Region based on key criteria identified by ESR (2006). These criteria include:

- Soil drainage characteristics
- Depth to groundwater
- Density of on-site wastewater systems

The assessment methodology adopted combined readily available regional-scale assessments of soil characteristics and depth to groundwater to produce an assessment of on-site wastewater groundwater quality risk based on intrinsic soil and hydrogeological properties. A separate map of septic tank density was also produced to identify areas where a high concentration of on-site wastewater systems may increase the potential for groundwater contamination to occur.

2.1 On-site wastewater (OSWW) groundwater quality risk assessment

The assessment of groundwater quality risk associated with on-site wastewater treatment was compiled by combining the nutrient leaching vulnerability index developed for the Topoclimate Soils of Southland project with an assessment of spatial variations in depth to groundwater.

2.1.1 Nutrient leaching vulnerability

A ranking of nutrient leaching vulnerability in Southland was undertaken by AgResearch for Crops for Southland in 2003 utilising soil data collected for the Topoclimate project. This rating assessed the potential for excess nutrients to leach beyond the root zone and contaminate the underlying groundwater resource based on the inherent soil properties of the root zone. The soil characteristics used to construct the nutrient leaching vulnerability rating included:

Total Available Water (TAW): the total amount of water available to plants within the rooting depth. TAW is the water that occurs between field capacity (10 kPa) and wilting point (1500 kPa) and determines the relative volume of leaching below the root zone of different soils.

Drainage Class: drainage class was used to determine the probability that the soil profile will be saturated with water and experience anaerobic conditions. Under anaerobic conditions nitrate is transformed into gaseous forms of

[3] http://yosemite.epa.gov/water/owrccatalog.nsf/epanumber/9f6b7f250b4fbc4585256b0600723559?opendocument

[4] http://www.dlg.nsw.gov.au/dlg/dlghome/dlg_osras.asp

nitrogen (denitrification) and is lost to the atmosphere. The classification of drainage class assumes that there has been minimal management intervention with drainage networks to improve the drainage status of the soil.

Soil Permeability: soil permeability was used to determine the rate of transmission of nutrients through the soil. Soil layers with slow permeability retard the rate of transmission providing a longer residence time for biodegradation and sorption and result in the formation of anaerobic conditions for denitrification in perched water tables.

The Topoclimate nutrient leaching vulnerability assessment is based on an assumption that poorly drained soils lead to anaerobic soil conditions which favour partial or complete denitrification. However, the same poorly drained soil conditions typically occur in fine-grained soils which exhibit low vertical infiltration rates. Such conditions also favour the filtration and natural die-off of microbial contaminants. As a consequence, the Topoclimate nutrient leaching vulnerability assessment is considered to provide a reasonable proxy for the overall potential for a range of contaminants associated with on-site wastewater disposal to infiltrate through the soil zone to reach underlying groundwater.

Figure 2 shows the spatial distribution of nutrient leaching vulnerability classes calculated for the Southland Region. Where soil units contained more than one soil type the highest leaching vulnerability for all component soil types was adopted for the entire soil unit following the ranking outlined in **Table 1 below.**

Table 1. Classification of nutrient leaching vulnerability for the Topoclimate soil assessment.

Soil Characteristics			Nutrient Leaching Risk	
Drainage Class[a]	TAW (mm)[b]	Permeability[c]	Class	Weighting
Poor	>130	s, m, r	Slight	1
Poor	60-130	s		
Imperfect	>130	s		
Poor	60-130	m, r	Moderate	2
Poor	<60	s, m, r		
Imperfect	>130	m, r		
Imperfect	60-130	s		
Well	>130	m, s		
Imperfect	60-130	m, r	Severe	3
Imperfect	<60	s		
Well	>130	r		
Well	60-130	s, m		
Imperfect	<60	m, r	Very Severe	4
Well	60-130	r		
Well	<60	s, m, r		

[a] Drainage class based on the criteria of Milne *et al.* (1995)

[b] Total available water (mm) - difference in water content between -10 kPa and -1,500 kPa

[c] Permeability: slow (s) <4 mm/hr, moderate (m) = 4 to 72 mm/hr, rapid (r) >72 mm/hr

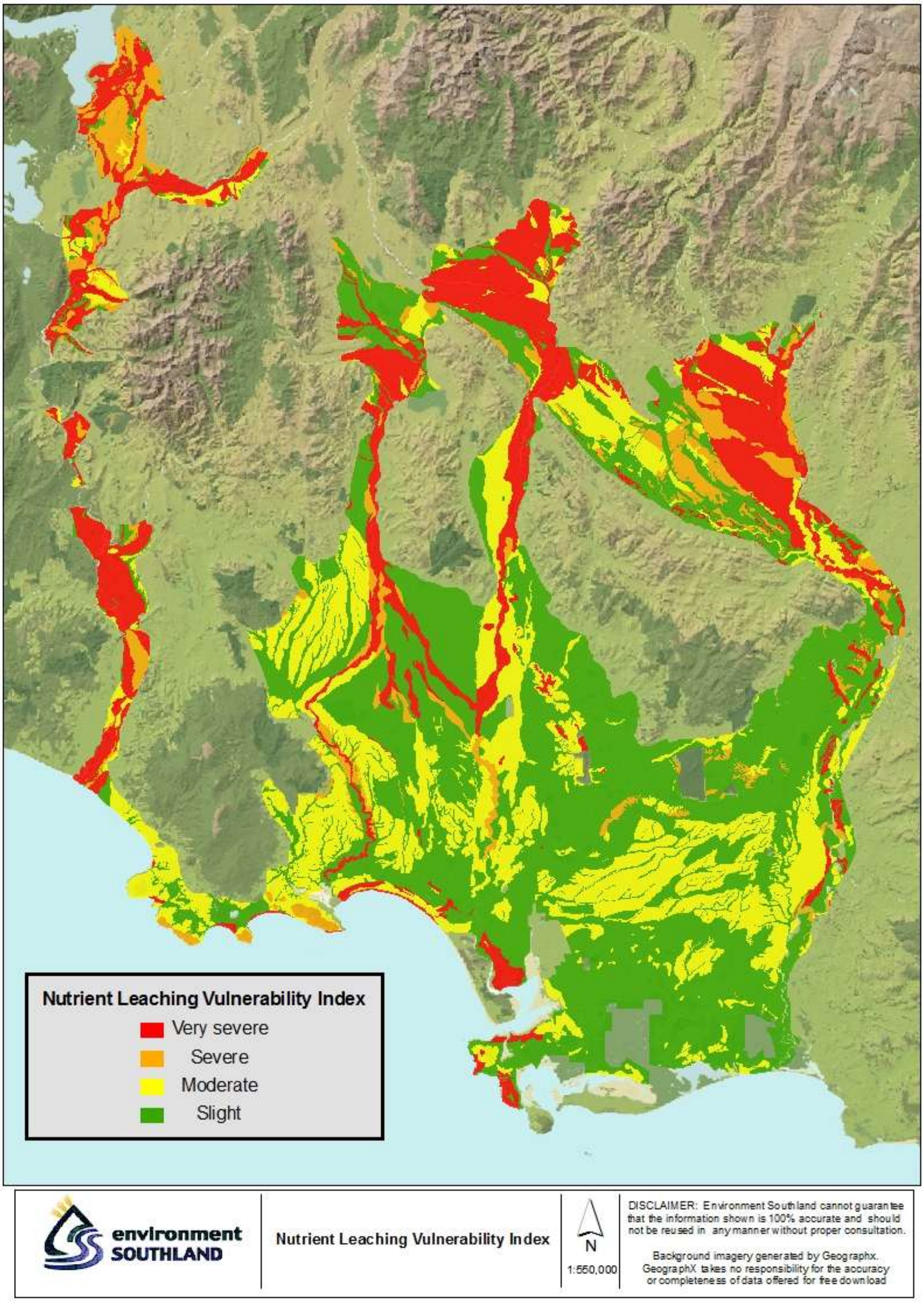

Figure 2. Topoclimate nutrient leaching vulnerability index

It is noted that the soil characteristics utilised to develop the nutrient leaching vulnerability do not include consideration of preferential (bypass) flow as a mechanism for soil moisture infiltration through the unsaturated zone. Preferential flow occurs via continuous or semi-continuous cracks or channels extending vertically through a soil profile as a result of shrink/swell behaviour, earthwork activity or plant roots. Water is able to infiltrate rapidly through these features thus bypassing infiltration through the soil mass.

Also, the assumption that the nutrient leaching vulnerability represents a reasonable representation of the potential for transport of nutrients and contaminants through the soil assumes the full soil profile is available for infiltration. On-site wastewater systems utilising forms of drainage that bypass the soil or unsaturated zone (e.g. soak holes) will have an elevated risk of groundwater contamination due to bypass flow, while those utilising tile drains have an elevated risk to surface water quality. The extent to which alternative disposal methods (soak hole or tile drains) are utilised for on-site wastewater disposal in Southland is unknown.

2.1.1 Depth to groundwater

The regional depth to groundwater coverage represents an approximation of the likely 'average' depth to groundwater across the region.

The depth to groundwater coverage was developed for Environment Southland based on a spatial interpolation of groundwater level data held by Environment Southland including piezometric survey results, baseline groundwater level monitoring data and static water levels recorded in the Wells database. This data was augmented by data points added to reflect known areas along rivers and streams where hydraulic connection is known to exist between groundwater and surface water and the depth to the water table is interpreted to vary across topographical features (e.g. terrace margins, gulleys etc).

For the purposes of the OSWW groundwater risk assessment the depth to groundwater coverage was divided into the classes shown in Table 2 below, the spatial distribution of which are illustrated shown in Figure 3.

Table 2. Depth to groundwater classification

Category	Depth to groundwater (m below ground)	Weighting
Very Low	>5.01	1
Low	3.01 - 5.0	2
Moderate	2.01 - 3.0	3
High	0.91 - 2.0	4
Very High	<0.9	5

It is noted that the regional depth to groundwater coverage is such that it does not identify areas where a shallow or perched water table may be present in the soil profile. In some areas low permeability layers within the soil or sub-soil can impede drainage to the extent that the soil becomes fully saturated (particularly during high rainfall conditions). The presence of such conditions may have a significant influence on the function of on-site wastewater treatment systems. However, the typical effect of such conditions is to increase the potential for ponding or lateral flow and/or runoff to surface water rather than risks to groundwater quality.

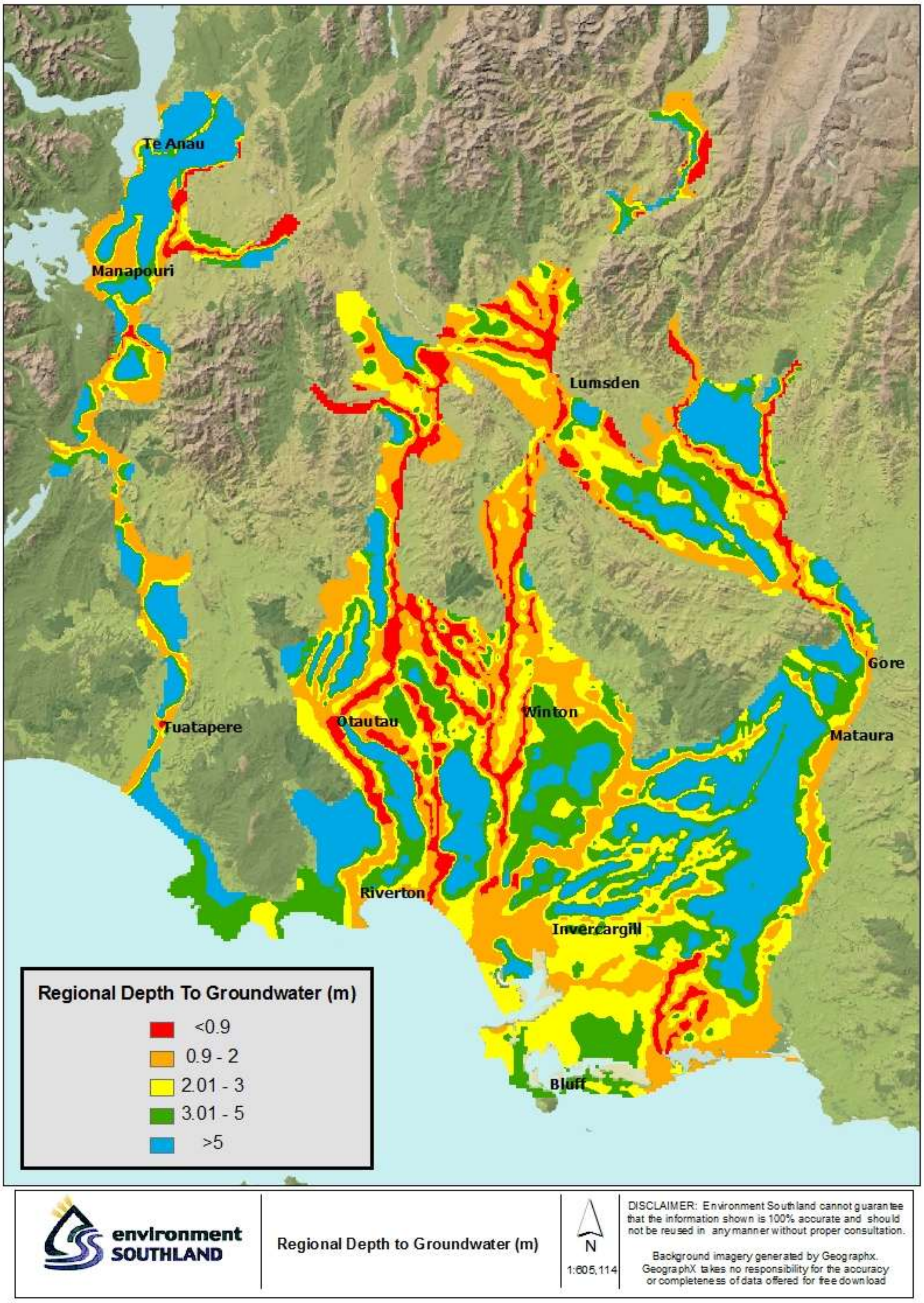

Figure 3. Regional depth to groundwater

2.1.3 Results

To produce the final OSWW groundwater risk rating the weighted rankings for nutrient leaching vulnerability and depth to groundwater were intersected using ARC GIS software following the scheme outlined in **Table 3**.

Table 3. Combined nitrate leaching vulnerability and depth to groundwater rankings

		Depth to Groundwater (m)				
Nitrate Leaching Risk		<0.9	0.9 - 2.0	2.0 - 3.0	3.0 - 5.0	>5.0
Classification	Weighting	5	4	3	2	1
Slight	1	6	5	4	3	2
Moderate	2	7	6	5	4	3
Severe	3	8	7	6	5	4
Very Severe	4	9	8	7	6	5

The risk rankings for individual polygons were then re-classified following the scheme outlined in **Table 4** and the dissolve function used to combine polygons with identical attributes to produce the final OSWW groundwater risk assessment shown in **Figure 4** below.

Table 4. Re-classification of OSWW groundwater risk

Ranking	OSWW Groundwater Risk
2 - 3	Very Low
4	Low
5 - 6	Medium
7	High
8 - 9	Very High

The risk assessment highlights areas along the main river systems as having an increased risk of groundwater contamination from on-site wastewater disposal. The elevated risk in these areas is associated with the typically thin, permeable soils overlying a shallow water table.

It is noted the OSWW groundwater risk assessment does not consider the fate of contaminants once they reach the water table. A majority of areas identified as having an elevated risk overlie moderate to high permeability aquifers along the major river systems. In these hydrogeological conditions, the relatively high groundwater flux moving through the aquifer system tends to dilute nutrient loadings relatively rapidly. In contrast, the relatively rapid groundwater flow in these settings increases the potential for transport of microbial contaminants down gradient of the source.

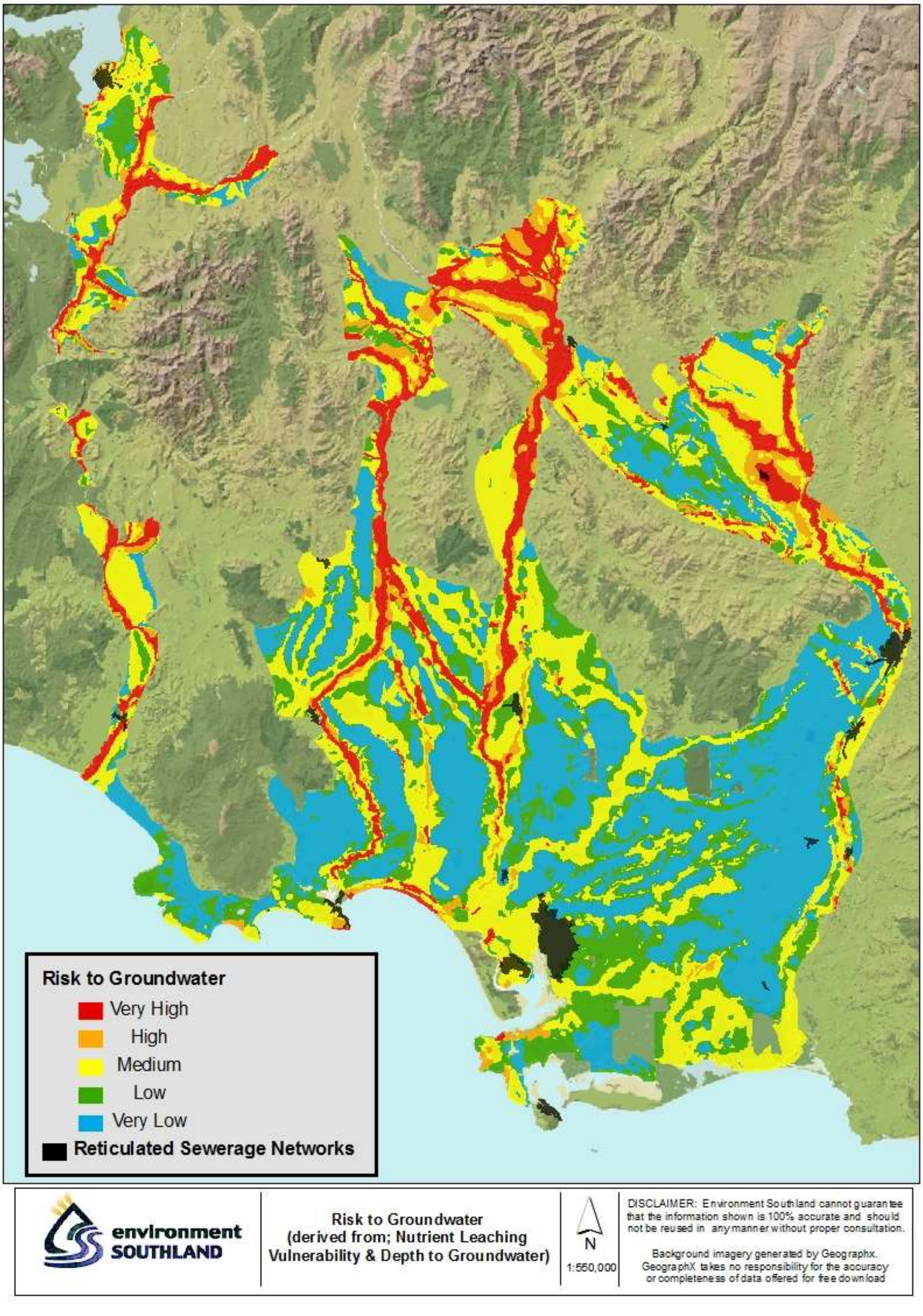

Figure 4. OSWW groundwater risk assessment

2.2 Septic tank density

At the current time no reliable database exists to identify the location of on-site wastewater systems in the Southland Region. As the potential for cumulative effects on water quality is increased in areas with a high density of these installations, this information is important to be able to identify priority areas for future investigation, monitoring or management initiatives.

For this purpose a map of potential density of on-site wastewater treatment systems was developed from the address points layer. This layer contains an entry for each registered dwelling based on records compiled by Land Information New Zealand (LINZ). For areas outside the identified boundaries of existing sewage reticulation, each address point was assumed to represent the location of an on-site wastewater treatment system in the vicinity of the primary dwelling.

The spatial density of on-site wastewater treatment systems was then calculated by counting the number of adjacent address points (each corresponding to a potential on-site wastewater treatment system) within a radius of 565 metres (equivalent to a 1 square kilometre area) of each address point. The nominal density of on-site wastewater treatment systems was then created using the inverse distance weighting (IDW) method in ArcGIS. Results of this assessment were ranked according to the scheme shown in **Table 5.** The resulting spatial coverage is illustrated in **Figure 5** below.

Table 5. Classification of on-site wastewater treatment system density

Category	System density (per km^2)	Weighting
Very Low	0 - 15	1
Low	16 - 65	2
Moderate	65 - 100	3
High	101 - 190	4
Very High	>191	5

The assessment clearly identifies the existence of a relatively high concentration of on-site wastewater treatment systems in small unsewered townships including Waikaia, Mossburn, Centre Bush, Colac Bay and Orepuki and highlights the elevated density in areas with significant numbers of lifestyle blocks around the fringes of Invercargill and Winton. The elevated density of systems is inferred to increase the overall risk of localised groundwater contamination in these areas.

In semi-urban areas, it is noted that the address points layer is likely to provide a conservative assessment of the potential number of septic tanks as it includes land parcels in subdivisions which may not have dwellings. In contrast, it is also recognised that in rural areas a single address point may include multiple on-site wastewater systems installed for a primary dwelling as well as other occupied dwellings on the property (e.g. dairy sheds, worker accommodation etc). However, in the absence of alternative data, the address points layer is considered to provide the best available data set to define the location and density of on-site wastewater disposal systems in Southland.

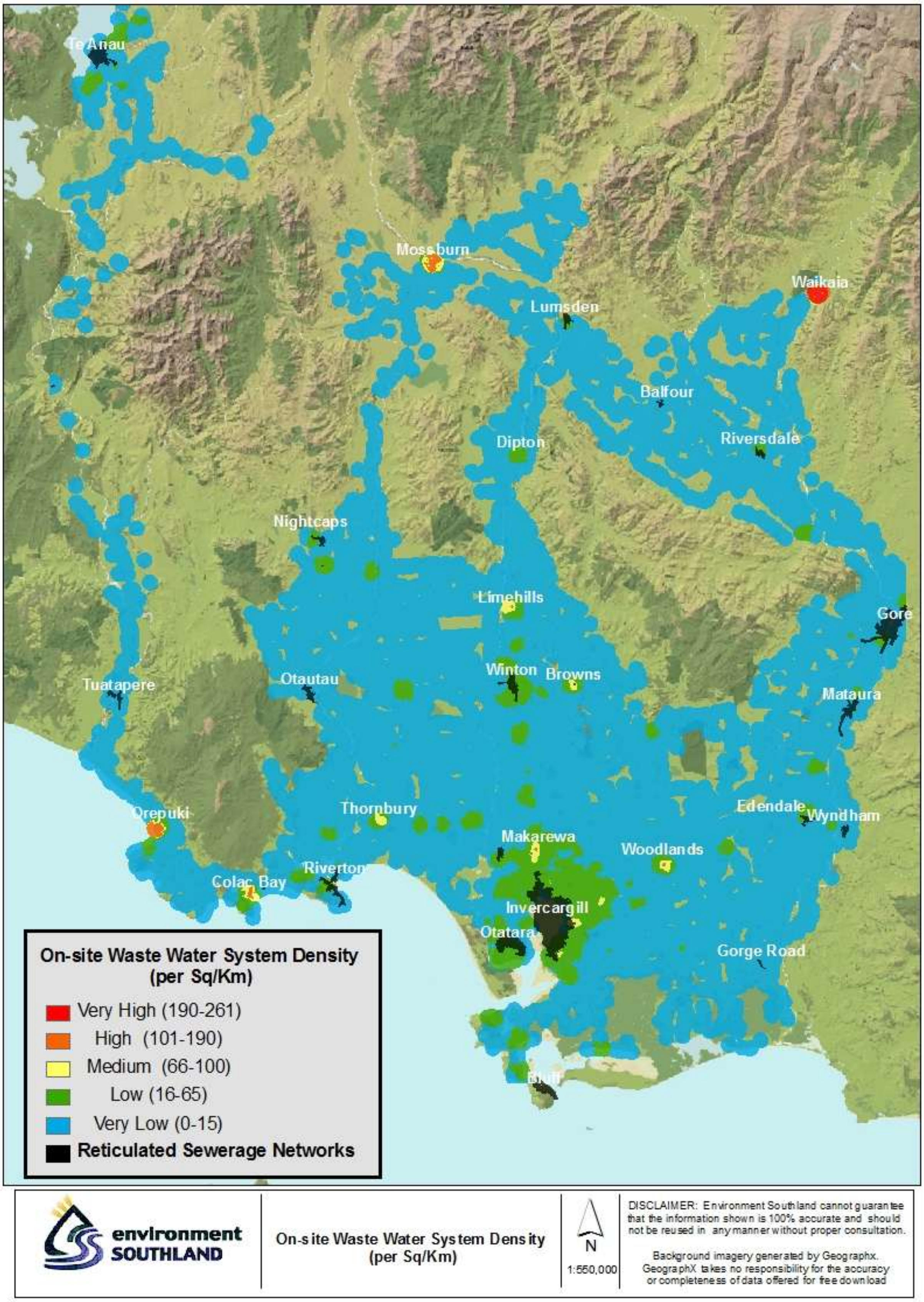

Figure 5. Calculated density of on-site wastewater treatment systems in Southland

3. Summary

On-site wastewater disposal has the potential to adversely impact on water quality in the receiving environment. The primary contaminants of concern include nutrients (nitrogen and phosphorus) and pathogenic micro-organisms (bacteria and viruses).

Water quality effects associated with on-site wastewater treatment have the potential to adversely affect water quality at a local scale. The risk associated with localised water quality impacts is increased in situations where the receiving environment for wastewater discharge (i.e. groundwater) is also the source for a potable water supply. Although declining through the natural processes of filtration and die-off, concentrations of microbial contaminants in wastewater can be transported in the groundwater system down gradient of the source. Bores and wells located in this zone have an elevated risk of microbial contamination.

At a larger scale, on-site wastewater systems also contribute to the cumulative nutrient loadings to aquifer systems. However, the net nutrient loading from individual on-site treatment systems is very low compared to inputs from other land uses such as intensive agriculture. As a result, elevated nutrient concentrations associated with on-site wastewater discharge are likely to only be an issue where there is a high density of systems.

As long as on-site wastewater treatment systems are installed and maintained in accordance with relevant standards (e.g. AS/NZS 1547) they provide a cost-effective means of domestic wastewater disposal across a majority of the Southland Region and appropriately manage risks to public health and the environment. However, in some physical settings on-site wastewater disposal systems have an elevated potential to result in adverse effects on receiving water quality. Key factors identified which influence the potential nature and scale of scale of such effects include:

- The physical characteristics of the soil surrounding the disposal field;
- The depth to groundwater
- The density of on-site wastewater treatment systems.

This report provides a simple assessment of potential risks to groundwater quality based on a combination of these factors. This assessment is intended to enable identification of areas of elevated groundwater quality risk associated with on-site wastewater discharge either associated with inherent soil and hydrogeological properties or the density of treatment systems. In combination, these assessments can be utilised to identify areas of highest risk to inform future targeted investigations and monitoring to determine the scale and magnitude of water quality effects associated with on-site wastewater disposal.

The OSWW groundwater risk assessment shows potential risks to groundwater quality associated with on-site wastewater disposal vary with geographic location across Southland. Overall, areas with the highest groundwater quality risk tend to be those with permeable soils overlying a shallow water table while areas with lower permeability soils or deeper water tables show a lower risk. This spatial variation in water quality risk could be utilised to develop standards for system design to reduce potential effects in higher risk areas. However, definition of appropriate design standards is likely to require specialist engineering input and may require further refinement or on-ground validation of the assessment methodology.

One situation highlighted by the OSWW groundwater risk assessment is the elevated potential for localised microbial contamination of drinking water supplies in areas where contaminants can reach groundwater and be transported down gradient of the source. In these areas determination of appropriate set-back distances, between on-site wastewater treatment and bores and wells may be an important consideration for future policy development (e.g. using the ESR (2010) guidelines). In the case of registered community drinking water sources consideration of future policy development could extend to appropriate set-back distances and/or system design to minimise potential risks to potable water supplies.

The OSWW groundwater risk assessment is solely focussed on risks to groundwater quality associated with on-site wastewater disposal. The assessment does not consider risks to surface water quality associated with poor soil drainage, or the presence of perched water tables or proximity to artificial (typically mole or tile) drainage. Assessment of surface water risks would require further work to develop an appropriate assessment methodology however, due to the reliance on soil drainage to characterise nutrient leaching risk, surface water risk is likely to some extent to be the inverse of groundwater risk.

The assessment also does not consider the fate of contaminants once they enter the groundwater system. As previously noted, due to their different characteristics the scale and magnitude of groundwater contamination potentially resulting from on-site wastewater disposal may be very different for nutrients and microbial contaminants in a similar hydrogeological environment. Improved definition of contaminant fate would require additional assessment of contamination attenuation and transport in the groundwater system.

4. References

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