Overland Flow risk in Southland

Technical Report

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Executive Summary

Overland flow, along with deep drainage and subsurface (including artificial) drainage are the three main pathways for the transport of contaminants from land to water. Overland flow (surface runoff) can occur through two processes. Firstly, when the soils become saturated, which is most common in low lying areas and during the wetter months; or secondly if the rainfall intensity exceeds the rate that water can infiltrate the soil, which can be caused by animal treading damage restricting soil permeability. Overland flow is likely to originate within gullies due to the natural convergence of rainfall and saturation of soil. Overland flow traveling over agricultural land can contribute significant quantities of contaminants, such as nitrogen, phosphorus, sediment and faecal bacteria to waterways.

This investigation assesses the likelihood of overland flow occurring from land surfaces across Southland. This assessment is to be used with the Physiographic Units to allow for the identification of variants within a defined unit, where overland flow may be a dominant or an insignificant contaminant pathway for the unit. The aim is to improve on the knowledge of flow pathways across Southland to guide targeted mitigation approaches for contaminant loss.

To estimate the overland flow risk from a surface, two factors (texture and slaking/dispersion) were combined to give a hydrologic index for the soil, which is multiplied by a slope factor and expressed as a percentage of effective annual rainfall. The hydrological index represents the likelihood of overland flow occurring due to the soils properties, while the slope index indicates whether the topography is a significant factor. This approach to estimating overland flow is used by the model Overseer® to quantify phosphorus loss from agricultural systems.

For most of the agriculturally productive areas of Southland, the risk of overland flow is typically less than 10 % of annual rainfall. However, agricultural land is a significant source of contaminants, which can be easily picked up and transported by overland flow events. Between May to November, when soils are likely to be saturated, the risk that contaminants will be transported to waterways by overland flow is high. The risk to the receiving environment is also high as only small quantities of these contaminants can have significant ecological impacts on the waterbody.

Overland flow risk is lowest (>2 %) on the flat, well developed, deep, loess or gravel-dominated soils of lowland Southland, parts of the northern plains and Te Anau basin. However, if the land is not well managed, the risk of overland flow increases. Published research has shown land use and management practices, such as subsurface artificial drainage, grazing management, stocking rate and vegetation have a significant influence on the occurrence of overland flow.

Overland flow is the dominant pathway for rainfall over the Fiordland area of Southland, potentially accounting for more than 35 % of effective rainfall. The steep slopes and shallow, weakly developed soils are the major contributing factors to the loss. However, due to the pristine nature of the catchment, any overland flow occurring is unlikely to transport significant quantities of contaminants to waterways.

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1. Introduction

Overland flow (surface runoff), along with deep drainage (leaching) and subsurface drainage (tile-mole) are the three main pathways for the transport of contaminants from land to water (Figure 1). Overland flow occurs when soils become saturated (saturation-excess overland flow) (Srinivasan et al., 2002), which is most common in low lying areas, or if the rainfall intensity exceeds the soil infiltration rate (infiltration-excess overland flow; Hortonian overland flow) (Horton, 1940) and can be caused by animal treading damage restricting soil permeability. On flat land, infiltration excess overland flow will result in surface ponding (Needelman et al., 2004). Overland flow is likely to originate within gullies due to the natural convergence of rainfall and saturation of soil. Therefore, the amount, duration and intensity of the rainfall event, along with the rate that the water can infiltrate the soil and the ability of any artificial drainage system to remove excess water affects how water is transported from the area.

Studies show overland flow from pastures grazed by cattle are enriched in P (dissolved and particulate), sediment, faecal bacteria and ammonium-N (Smith and Monaghan, 2003; Goldsmith and Ryder, 2013; Orchiston et al., 2013; Curran Cournane et al., 2011; McKergow et al, 2007). Critical source areas are typically located near stream channels or in low infiltration areas and gullies that are connected to the stream channel (Goldsmith and Ryder, 2013). The period with the highest risk for overland flow in Southland is between May and November (Smith and Monaghan, 2003; McDowell et al. 2005; Monaghan et al, 2016).

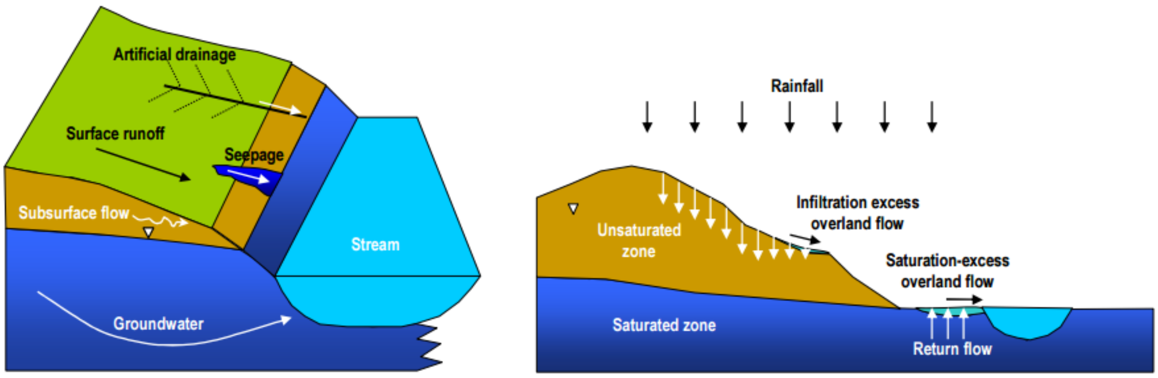

Figure 1: Water pathways from pasture to streams (left) and surface runoff generated by infiltration-excess and saturation-excess overland flow (from McKergow et al. 2007).

The objective of this investigation is to assess the likelihood of overland flow occurring from surfaces across Southland. This assessment of overland flow is to be used with the Physiographic Units to allow for the identification of variants within a defined unit, where overland flow may be a dominant or an insignificant contaminant pathway. The aim is to improve our knowledge of flow pathways across Southland to better guide targeted mitigation approaches for contaminant loss. The method used to determine overland flow is based on the soil properties of texture and slaking/dispersion along with position in the landscape. This approach to estimating overland flow is used by the Overseer® model to calculate phosphorus loss from agricultural systems, as described in McDowell et al. (2005).

2. Method

2.1. Soil GIS maps

Soil GIS maps were obtained from three sources and combined to create one GIS Soil layer for Southland. Topoclimate South (2001) mapped soil types in Southland and extensively described the soil properties for each. The mapping was undertaken at a 1:50,000 scale and covered approximately 825,000 hectares of intensively farmed land. To extend coverage of Southland soils beyond the extent of Topoclimate South, soil information from Wallace County (O'Bryne, 1986) and Land Resource Inventory (LRI) (DSIR, 1968) soil maps were used. See Appendix 1 for a map of NZSC Soil Orders in Southland.

The output of this study is a GIS Overland flow layer which is located on Environment Southland's server as follows: M:\GIS\Projects\ArcMap\Environmental Info\Tile Drain Sampling\Lisa files for TileDrains\Overland flow soils.

2.2. Overland flow potential

To estimate the potential for overland flow occurring, two factors (texture and slaking/dispersion) were combined to give a hydrologic index for the soil (eq. 1), which is multiplied by a slope index (eq. 2) and expressed as a percentage of effective annual rainfall.

Hydrologic index = texture index x slaking and dispersion index (1)

Index of overland flow risk (% of rainfall) = (Hydrologic index x Slope index) x 100 (2)

Hydrologic index is based on the U.S. Department of Agriculture (USDA) curve number method for determining soil hydrologic class and uses soil texture as a basis for drainage, and therefore an indication of the likely potential for saturation excess overland flow. There is a higher potential for overland flow in fine textured soils than coarse textured soils. The slaking/dispersion factor takes into account the susceptibility for soil damage to influence the soil hydrology. Flow pathways through the soil profile are limited with increased susceptibility to slaking and/or soil dispersion causing reduced infiltration and consequently more overland flow. The relative slaking and dispersion potentials of New Zealand soils are taken from Hewitt and Shepherd (1997), with mean values from McDowell et al. (2005) (Table 1). The product of the texture and slaking/dispersion indices gives an estimate of hydrologic index whereby soils with a higher hydrologic index have a greater potential for overland flow.

To calculate the hydrologic index of Topoclimate South soil polygons which contained multiple soils, the hydrologic index of the individual soil series was weighted by the percentage of the soil series within a polygon prior to calculating the hydrologic index. The percentages of soils within a polygon were obtained from S-Map Online (Landcare Research). This level of precision was not possible with Wallace County or LRI soil polygons.

Soil polygons that contained shallow or stony soils with mixed bedrock in Wallace County and LRI were assessed for hydrologic index using a similar method to the Topoclimate South mixed soil polygons. The hydrologic index of the polygon was determined by calculating the hydrologic index of the soil and assigning a value of 1.0 for bedrock. For polygons that contained one soil and bedrock the weighting of 60:40 was assigned. The first soil was deemed to be the dominant soil. For polygons that contained two soils and bedrock a weighting of 50:30:20 was assigned and the hydrologic index calculated accordingly. Polygons with no soil information and described as ‘permanent ice’ by LRI were assigned a hydrological index value of 1.0.

Table 1: Soil texture and mean slaking/dispersion indices for calculating hydrologic index.

Soil texture	Texture Index	Mean slaking/dispersion index	S/D Index
Sand, Loamy sand	0.2	Oxidic, Allophanic, Brown, Melanic	0.2
Sandy loam, Loam	0.4	Granular, Gley	0.4
Silt loam, Sandy clay loam	0.6	Recent, Raw, Pallic	0.6
Clay loam, Silty clay loam, Sandy clay, Peaty loam	0.8	Ultic, Semiarid, Organic	0.8
Silty clay, Clay, Peat	1	Pumice, Podzol	1

The slope index was calculated by using the assigned ratings from McDowell et al. (2005) for flat, rolling, easy hill and steep to produce a slope index curve (Figure 2). Additional slope indices at 4 to 5 degree intervals were determined from the curve for each of the LRI slope classes (Table 2). The slope classifications for the soil polygons were sourced from the Topoclimate South data or calculated from Environment Southland’s 8 m Digital Elevation Model (DEM) for Wallace County and LRI soil polygons by averaging the slope within each mapped soil polygon.

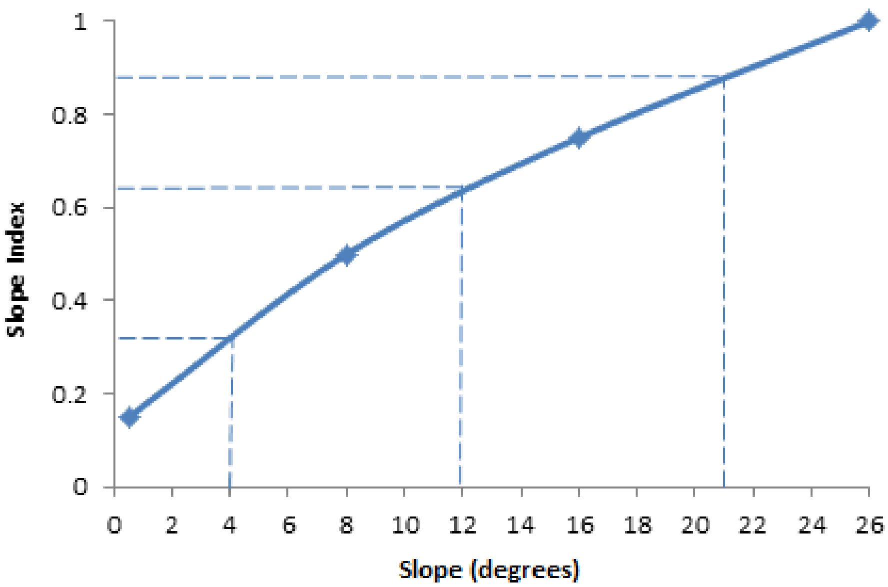

Figure 2: Generation of slope factors from McDowell et al. (2005).

Table 2: Slope index.

Slope	Range (degrees)	LRI Slope Class	Slope Index
Flat	0 - 3.99	A	0.150
Undulating	4 - 7.99	B	0.325
Gently rolling	8 - 11.99	C	0.500
Rolling	12 – 15.99	C	0.635
Strongly rolling	16 - 20.99	D	0.750
Moderately steep	21 - 25.99	E	0.875
Steep	26 - 35.99	F	1.000
Very steep	> 36	G	1.000

3. Results and Discussion

The highest risk areas for overland flow in Southland occur on very steep, weakly developed shallow soils of the Fiordland area (Figure 3). Fiordland contains many areas of sparsely vegetated, exposed or bare ground, which increases the likelihood of overland flow occurring. Overland flow predominates with greater than 35 % of the flow pathway for this part of the region. On Raw soils, bedrock and areas with permanent ice, overland flow is the only flow pathway; however on permanent ice precipitation is likely to fall as snow.

The areas of lowest risk of overland flow are the intensively farmed, flat areas of lowland Southland (around Invercargill, Woodlands and Tussock Creek), parts of the plains north of the Hokonui Hills (Riversdale and Wendonside) and parts of the Te Anau basin (Figure 3). The soils on the lowland plains are dominated by deeply developed (> 1 m), well drained Brown soils formed on loess parent materials or gravely substrates (Crops for Southland, 2002). In northern Southland and the Te Anau basin the soils are shallow (20 – 45 cm depth), well drained Brown soils with similar parent materials (Crops for Southland, 2002). These areas are typically flat to undulating, which results in an overland flow risk of less than 2 % of rainfall in these areas.

The main agricultural land in Southland (surveyed by the Topoclimate South project), which is predominantly flat to rolling, typically has a loss by overland flow of less than 10 % (Figure 3). However, this area is a significant source of contaminants due to the intensity of agriculture, and representing overland flow as an annual loss misrepresents the risk of contaminants leaving via this pathway as seasonal effects are minimised. The 10 % of annual rainfall as overland flow may be lost during a small number of weather events between May and November (Smith and Monaghan, 2003; McDowell et al. 2005; Monaghan et al, in press).

Pallic soils, with naturally higher bulk densities and often poor drainage, which occur around Mossburn Hill, East dome, Waikaia and the foothills of Mount Linton have potential losses of overland flow in the range of 12-36 %, which during the high risk months of winter/spring will produce significant overland flows. As the majority of these areas are under native bush and forestry, the actual loss by overland flow may be minimised. Perch-gley Pallic soils (such as Waikoikoi and Pukemutu soils) located around the central lowland plains on undulating topography (see Appendix 1), have a lower risk of overland flow occurring (5.4 % of rainfall). However, even though overland flow volumes are small relative to rainfall, due to the intensive land use the contaminant load transported to waterways via this pathway is ecologically significant.

West Dome, Piano Flat, Mt Linton and Mavora are predominantly Brown or Melanic soils with silty loam textures which have a reduced the risk of overland flow when compared to Pallic soils. Typically, 12 % of rainfall was estimated to be lost via overland flow, which increases to 50 % on steeper slopes where soils are shallow and bed rock is exposed (Figure 3).

In the east of the region, Podzol soils in the Catlins on rolling to steep topography, have a high risk of overland flow occurring (approximately 30-50 % of rainfall). Podzol soils that occur around the lower Waiau and Longwood forest on strongly rolling to steep areas also have a greater potential of producing overland flow similar to that of the Catlins (Figure 3).

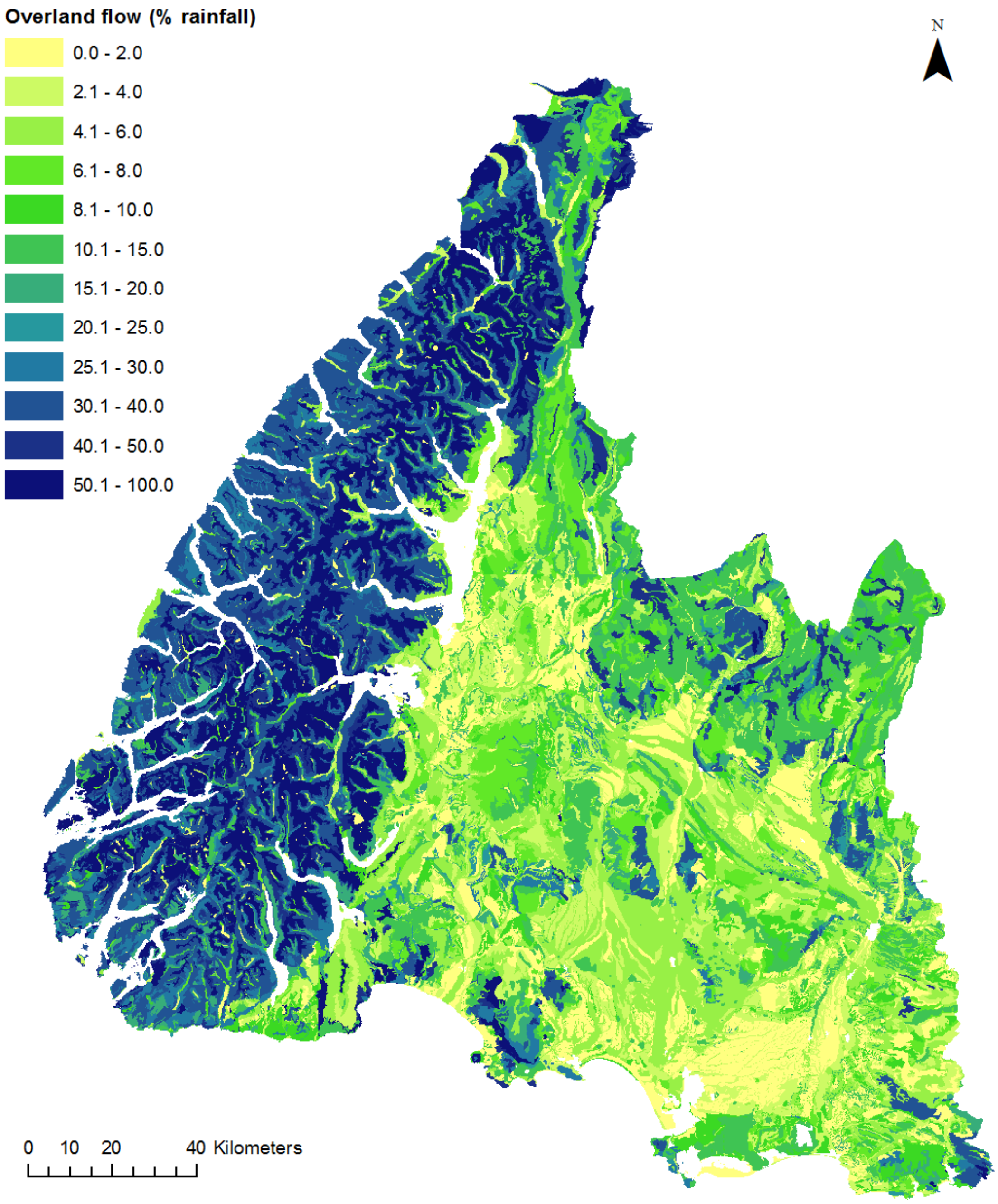

Figure 3: Index of overland flow risk expressed as percentage of effective rainfall (Note: Scale bar is not uniformly graded).

Comparison of the hydrologic and slope index maps allows for better understanding of the mechanism determining overland flow risk (Figures 4 and 5). The hydrological index represents the likelihood of overland flow occurring due to soil properties, while the slope index indicates whether topography is a significant factor. For example, the Hokonui Hills are predominantly silt loam Brown soils with a hydrologic index of 0.12 and when combined with the slope factor, produces overland flow values ranging between 2 and 36 %. Therefore, slope is the dominant factor controlling the likelihood of overland flow occurring in the Hokonui Hills. Conversely, in the central plains, which have a low slope index of 0.1, the soil properties are the dominant factor controlling the risk of overland flow occurring. The soils in this area are predominantly Typic or Orthic Gleys, Argillic-fragic or Perch-gley Pallics and Mottled Brown soils with silt loam textures resulting in a hydrologic index of 0.25 to 0.4 and an overland flow risk of 2.3 to 10 %.

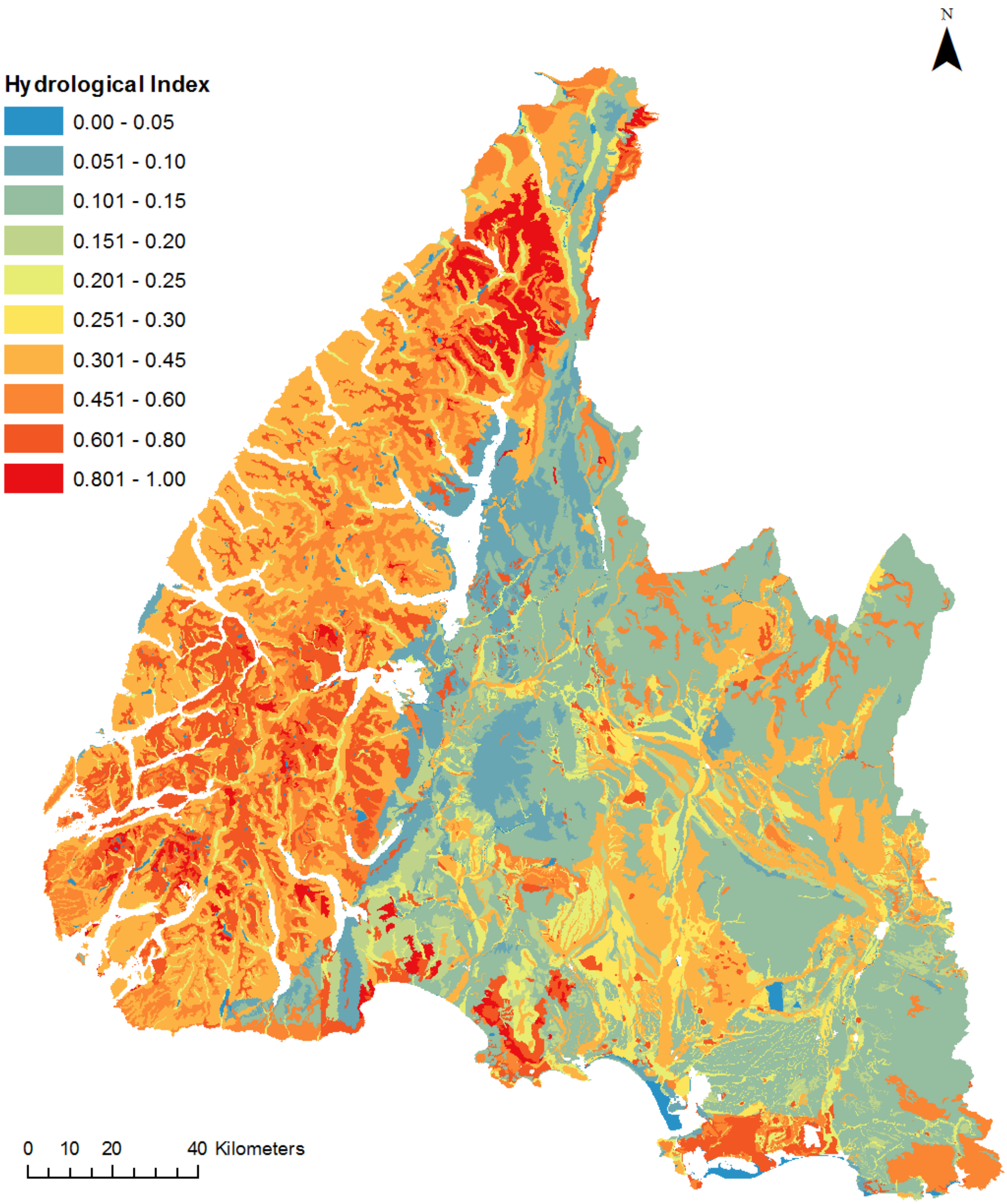

Figure 4: Hydrological index which shows the likelihood of overland flow occurring due to the soil properties (Note: Scale bar is not uniformly graded).

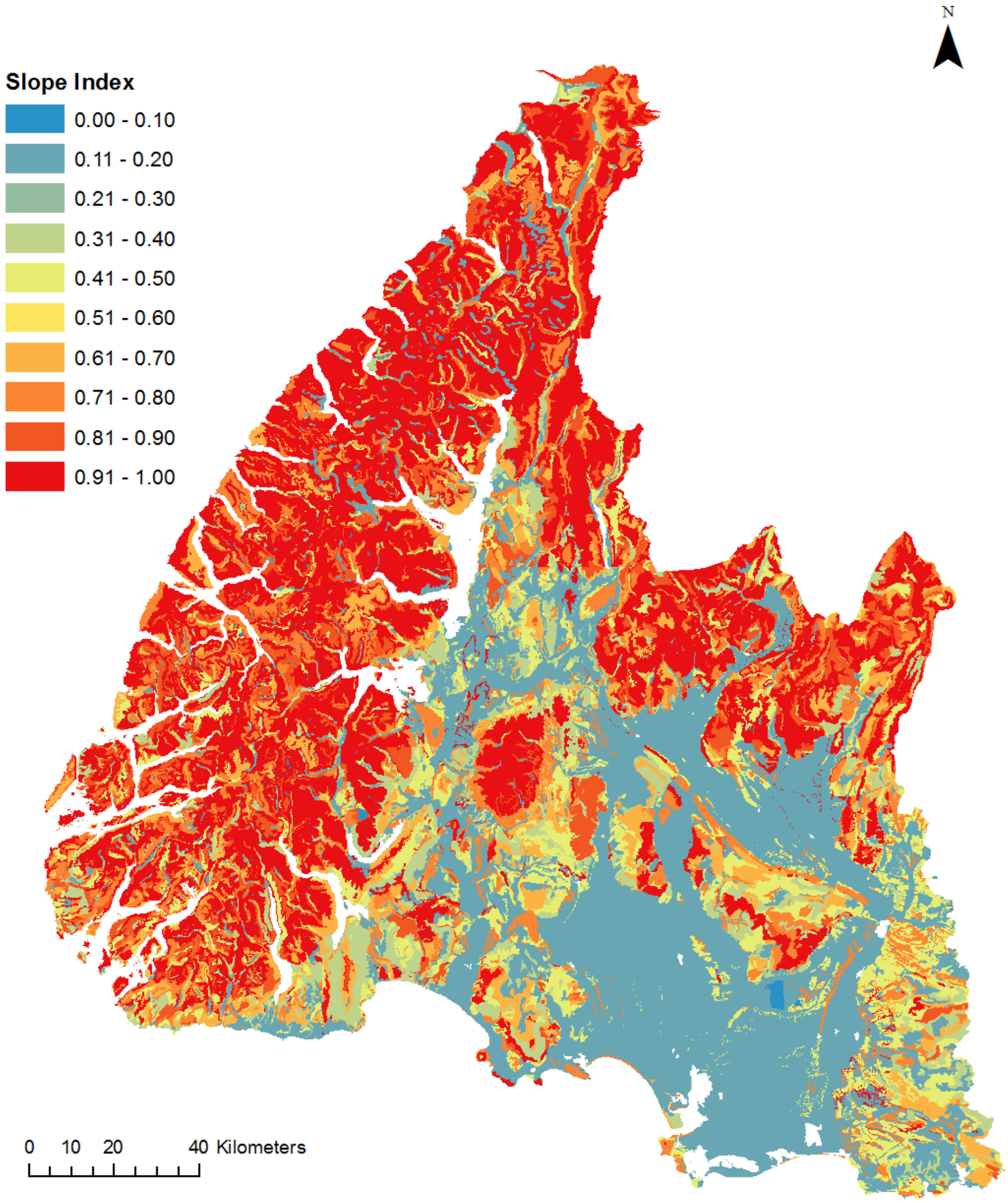

Figure 5: Slope index which shows the likelihood of overland flow occurring due to slope.

Comparison of the overland flow risk assessment with field studies show the predicted value was within the range of measured studies undertaken at Edendale and Tussock Creek in Southland (Table 3; Smith and Monaghan, 2003, Monaghan et al. in press). The studies measured overland flow on drained and undrained plots and under a low (2.0 cows ha^{-1}) and high (3.1 cows ha^{-1}) stocking density at Edendale. Smith and Monaghan (2003) found the likelihood of overland flow occurring was reduced by mole-pipe drainage and reduced stocking rate at Edendale. At Tussock Creek there was no significant difference between drained and undrained study plots (Monaghan et al. in press). In other studies, the link between soil structure/quality and overland flow risk show significant negative relationships between soil physical properties, such as decreasing macroporosity and saturated hydraulic conductivity (K_{sat}), and the increased concentrations or loads of dissolved reactive phosphorus, total phosphorus or suspended solids discharged in overland flow (Curran Cournane et al. 2011, McDowell and Houlbrook, 2009 and McDowell et al, 2003). Drewry and Paton (2000) reported reducing stocking rate by excluding cows for selected grazing can significantly improve water infiltration within the top 0-5 cm of the soil, and thus reduce the risk of overland flow occurring.

Table 3: Overland flow prediction compared to published studies. Smith and Monaghan (2003) show minimum and maximum overland flow range under a stocking density of 2.0 – 3.1 cows ha^{-1}.

	Smith and Monaghan (2003)		**Monaghan et al. (2016)**	
Site	Edendale - Undrained		Tussock Creek	
Study date	1998 - 2000		2002-2003	
Rainfall (mm yr^{-1})	915		1040	
Slope (degrees)	3		2	
Soil texture	Silt loam		Silt loam	
Soil Series	Waikoikoi-Arthurton		Pukemutu	
NZSC Classification	Fragic Perch-gley Pallic - Pallic Firm Brown		Argillic-mottled Fragic Pallic	
Drainage	Undrained	Drained	Undrained	Drained
Minimum OF (mm yr^{-1})	1.4 - 5.1	0.1 - 0.8	58	44
Maximum OF (mm yr^{-1})	10.5 - 43.4	5.1 - 5.2	115	125
OF (% rainfall)	0.15 - 4.75	0.01 - 0.09	6.3 - 9.9	4.7 - 10.8
Overland flow prediction				
Hydrologic index		0.26		0.36
Slope index		0.15		0.15
Overland flow risk (% rainfall)		3.9		5.4
Overland flow (mm yr^{-1})		36		56

This risk assessment is does not take into account the potential for overland flow to occur due to differences in land uses, management practices or vegetation cover. An increase in heavier stock with the conversion of sheep and beef farms to dairy is likely to result in increased soil bulk density, decreased porosity and potentially the creation of pans at plough depth over time, increasing the risk of infiltration-excess overland flow. Winter grazing practices, where stock are grazed on fodder crops/bare ground, during times when soils are saturated, cause pugging and treading damage to the soil, which will increase the likelihood of overland flow. Tian et al. (1998) and Nguyen et al. (1998) suggested cattle grazing could have a detrimental effect on water infiltration rate into the soil, lasting for up to 6 months. Observations of surface ponding occurring across lowland Southland have increased markedly over the past 15 years as land use has intensified (Gary Morgan, Principal Land Sustainability Officer - Environment Southland, pers com). Vegetation cover in some areas may reduce the likelihood of overland flow occurring from a land surface. For example, tall tussocks and alpine grasses in upper catchments intercept rainfall and minimise overland flow. Conversely, the lack of vegetation on a land surfaces will increase the risk of overland flow occurring from an area and the use of buffer strips from agricultural land is recommended (Monaghan et al. 2010).

Areas that are not well represented by the overland flow assessment are non-agricultural areas and areas where boundaries of two data sources are joined. The ability to assess overland flow occurring in non-agricultural areas is limited by the USDA curve number method for determining hydrologic class, which was determined on agricultural soils and may not relate to soils under non-agricultural land uses. The errors associated with the joining of two data sources are minimal and do not significantly affect the overall impression of where overland flow is likely to occur across Southland. The accuracy of these maps will be improved with updated soils maps in future.

4. Conclusion

This assessment provides the likelihood of overland flow occurring from surfaces across Southland based on soil properties and position in the landscape. Comparison of the hydrologic and slope index maps can be used to elucidate the mechanism determining overland flow risk from an area, as hydrological index represents the likelihood of overland flow occurring due to soil properties, while the slope index indicates whether topography is a significant factor. The ability to predict the likelihood of overland flow occurring from non-agricultural land uses is limited as the ratings applied to soil properties were developed under agricultural systems.

For most of the agriculturally productive areas of Southland, the risk of overland flow is typically less than 10 %. However, agricultural land is a significant source of contaminants (i.e. nitrogen, phosphorus, sediment and faecal organisms), which can be easily picked up and transported by overland flow events. Between May to November, when soils are likely to be saturated, the risk of contaminant transport to waterways by overland flow is high and only small quantities of these contaminants can have significant ecological impacts on the receiving waterways.

Overland flow risk is lowest (< 2 % of rainfall) on the flat, well developed, deep, loess or gravel-dominated soils of lowland Southland, parts of the northern plains and Te Anau basin. However, if the land is not well managed, the risk of overland flow increases. Published research has shown land use and management practices, such as subsurface artificial drainage, grazing management, stocking rate and vegetation have a significant influence on overland flow yields.

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Appendix 1: Map of NZSC Soil Orders