Factors Affecting Contaminant Loss in Overland Flow

Technical Review

prepared by

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Environment Southland

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Cover photo (G. Ryder): Example of drainage works to convey overland flow from farm land to the Waipahi River, South Otago.

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Table of Contents

1. Introduction

1.1 What is overland flow?

Overland flow (or surface run-off) is water that flows horizontally across land after rainfall (or snow melt or effluent application) of sufficient intensity to exceed the soil's capacity to absorb water. This may occur either because the soil is saturated (saturation-excess overland flow) or its infiltration capacity has been exceeded (infiltration-excess overland flow or Hortonian overland flow[1]). Overland flow can occur as sheet flow or more commonly become channelized, which increases its energy and erosion potential.

1.2 Overland flow and contaminant transport to surface waters

Water in streams and rivers is derived from baseflow (the relatively stable discharge of groundwater to rivers and streams), interflow (water moving laterally through the unsaturated soil zone) and overland flow. The contribution of overland flow is greatest during or immediately following a rainfall event. Stream flow declines over time following rain events as contributions of overland flow and interflow decline and groundwater discharge (base flow) comprises an increasing portion of stream discharge (Ledgard and Hughes 2012).

Overland flow has the potential to adversely affect surface water ecology and water quality through the transport and contribution of contaminants. The four main potential contaminants in rural environments are nitrogen, phosphorus (both nutrients), sediment and faecal micro-organisms. Contaminants on the soil surface or within soil particles are transported to watercourses in suspension or dissolved within overland flow.

Overland flow can be a significant source of sediment through soil erosion, particularly in hill-country catchments where slope strongly influences water movement and the mobilisation of contaminants. Nutrients and faecal micro-organisms are also transported to watercourses in overland flow. Generally the main pathway of phosphorus loss, aside from direct deposition, is through overland

[1] Soil infiltration rate is affected by natural soil structure and physical damage caused by, for example, animal grazing. Surface water can quickly appear above slow infiltration rate soils depending on rainfall (or irrigation) intensity and land gradient. This infiltration-excess water is referred to as overland flow when the gradient creates water movement, or ponded water when the surface gradient is flat.

flow (although subsurface losses can also be high in some circumstances, particularly where artificial subsurface drainage is present). Phosphorus can be transported either in particulate form (bound to sediment) or by being dissolved in water. The dominant form of phosphorus transport in overland flow depends on flow mechanism and land use (McDowell 2008). For example, total phosphorus (TP) losses from hill pasture are significantly higher than for other land uses due to the greater potential for overland flow with accompanying mobilisation of sediment and other particulate material (Ledgard and Hughes 2012). Faecal bacteria (*Escherichia coli* or *E. coli*[2]) are mainly lost from land via overland flow, although losses to artificial subsurface drainage (e.g., tile, mole, Novaflow) can also be relatively high (Monaghan *et al.* 2010). The dominant pathway for nitrogen loss is through soil leaching, with overland flow of particulate nitrogen occurring only where there are high levels of soil erosion.

McKergow *et al.* (2007) investigated the relative importance of overland flow paths in transporting suspended sediment, total nitrogen and total phosphorus for seven generic scenarios for dairy, intensive sheep/beef and hill country sheep/beef farms (Table 1). The scenarios were loosely based on monitored research catchments for a variety of landscapes and farming types (e.g., Bog Burn, Toenepi, Whatawhata, etc.). Table 1 shows estimates of overland flow-path dominance in relation to other flow paths (i.e., subsurface, drain and groundwater flows) and the proportion of the total paddock load of each pollutant carried in overland flow for each scenario. Dominance of the overland flow path was greatest for scenarios with heavy subsoil and/or rolling-steep topography. Overland flow made an important contribution to suspended sediment load for all scenarios. Total nitrogen and total phosphorus loads are mostly contributed through subsurface, drain and groundwater flow paths, except for the ‘intensive sheep/beef heavy subsoil’ scenario where 25-50% of the total nitrogen load was contributed through overland flow.

[2] *E. coli* is a type of bacteria that is usually found the lower intestine of warm-blooded organisms. It is used as an indicator of faecal contamination of waterways and as an indicator of the risk of exposure to disease-causing micro-organisms.

Table 1 *Percentage dominance of the overland flow path (relative to other flow paths i.e. subsurface, drain and groundwater flows) and percentage of the total paddock load of suspended sediment, total nitrogen and total phosphorus contributed by the overland flow path for seven different model farm scenarios (adapted from Tables 9 and 11 McKergow* et al. *2007).*

Model farm scenario	Topography / soil / artificial drainage	Overland flow path dominance (%)	Percentage of total load (%)		
			Suspended sediment	Total nitrogen	Total phosphorus
Intensive dairy, well drained	Flat / well drained / no	< 5	> 50	0	0
Dairy, heavy subsoil	Flat, easy / poorly drained, heavy subsoil / yes	10 - 20	25 - 50	1 - 10	0
Dairy, moderately well drained	Flat, easy / moderately well drained / yes	5 - 10	25 - 50	0	0
Intensive sheep/beef, well drained	Rolling / well drained / no	5 - 10	> 50	0	0
Intensive sheep/beef, heavy subsoil	Rolling / heavy subsoil / yes	20 - 50	25 - 50	25 - 50	1 - 10
Hill country sheep/beef, well drained	Rolling-steep / well drained topsoil / no	10 - 20	> 50	1 - 10	1 - 10
Hill country sheep/beef, poorly drained	Rolling-steep / poorly drained / no	10 - 20	> 50	1 - 10	1 - 10

This review examines how overland flow, and therefore the potential for contaminant loss to water, is influenced by climate, landscape and land management factors. Ultimately the environmental effects of contaminant loss to overland flow will depend on the amount that enters watercourses and the sensitivity of the receiving environment. Factors that influence this were examined in an earlier review on the environmental effects of activities within the riparian zone (Ryder Consulting 2012).

1.3 Report objectives

Environment Southland commissioned a technical review of the climate, landscape and land management factors that influence contaminant loss through overland flow, focussing on the four main potential contaminants in rural environments; nitrogen, phosphorus, sediment and faecal micro-organisms. The review includes the following components:

1. A review of available information on factors that influence contaminant loss through overland flow, including:
    a. Soil type.
    b. Slope.
    c. Rainfall intensity and frequency.
    d. Vegetation type.
    e. Grazing.
    f. Stock wintering.
    g. Hard surfaces.
    h. Irrigation.
    i. Cultivation
    j. Fertiliser application.
2. Examples of case studies, from Southland where possible, demonstrating the influence of these factors.
3. A qualitative examination of the impact of climate change on overland flow.
4. A summary of the relative influence of factors that influence overland flow identifying the key issues and priorities.

2. Influences of contaminant loss in overland flow

2.1 Soil type

2.1.1 Effects/processes

Soil type is very important as it influences both the potential for overland flow to occur and also how readily contaminants are lost from soil to overland flow. Some soils have naturally limited drainage capacity (influenced by soil texture, pore continuity and proximity to water table), and may be vulnerable to compaction and structural damage, which reduces water infiltration increasing overland flow potential. Different soils also have differing abilities to retain nutrients. For example, the rate at which phosphorus dissolves from soil into solution depends on the soil's phosphorus sorption strength (i.e., soil phosphorus retention) and surface area (McDowell 2008). Sandy soils and peat soils (such as those found in parts of the Waituna catchment in Southland) have little phosphorus retention ability and are therefore vulnerable to phosphorus loss (McDowell 2008, Robson *et al.* 2011).

2.1.2 Reference material

'Crops for Southland' (2003) have produced a summary of the typical average properties of each of the approximately 175 soil types that have been mapped in Southland. Information is provided on key physical (e.g., aeration, permeability) and fertility properties (e.g., soil phosphorus retention levels, indication of likely fertiliser responses). The summary also includes a system of rating soils according to their relative vulnerability to, or the level of risk of, environmental impacts that may adversely affect sustainable land use. The 'sustainable management indictors' that relate to overland flow potential are:

- Structural compaction – the vulnerability of the soil to structural degradation, the ability of the soil to maintain its capacity to store water.
- Topsoil erodibility by water – the inherent erodibility of a soil. The actual risk of erosion will depend on the nature and interaction of factors such as rainfall intensity, slope, vegetation cover, and conservation management techniques.
- Waterlogging – the risk of a soil having a high water table, which may increase the risk of overland flow and structural compaction.

Southland soil types vary in their vulnerability to the factors above[3]. For example, those soils that fall within the New Zealand soil Order classification of 'Pallic' (e.g., Northope, Otama) are prone to structural compaction and also waterlogging, however they are generally less prone to waterlogging than 'Gley' soils (e.g., Acton, Makarewa), which are poorly drained soils found predominantly in low lying areas. The risk of a soil becoming degraded ultimately depends on the environmental and management conditions at a site.

2.1.3 Case studies

McDowell *et al*. (2003b) determined how phosphorus loss in overland flow (artificial rainfall) varied between six Southland pastoral soil types – Woodlands (Mottled Firm Brown), Waikiwi (Typic Firm Brown), Matura (Typic Orphic Recent), Northope (Mottled Immature Pallic), Pukemutu (Argillic-mottled Fragic Pallic), and Waikoikoi (Mottled Fragic Pallic). The magnitude of phosphorus loss appeared to be influenced by soil pedological origin, with lower dissolved reactive phosphorus (DRP) concentrations measured in overland flow from the Brown soils, compared to the less weathered Recent and Pallic soils.

Houlbrooke and Monaghan (2009) used the Overseer® model to investigate how phosphorus loss varied for a range of farm dairy effluent management practices on two Southland soil types; the poorly drained Pukemutu silt loam (Fragic Pallic) and the well-drained Gore stony silt loam (Orthic Brown). Phosphorus loss was greatest from the Pukemutu soil, with effluent application using a slow speed travelling irrigator contributing 5 kg P/ha/year; in contrast the equivalent loss from the Gore soil was only 0.2 kg P/ha/year. Improvements in irrigation management reduced the phosphorus loss on both soil types, with the greatest reductions achieved through the use of deferred irrigation with a low application rate irrigator.

Robson *et al.* (2011) also used the Overseer® nutrient budgeting model to investigate how losses of nitrogen and phosphorus from example dairy and sheep and beef farms varied under different management practices and soil types. Soil type had an important effect on the magnitude of contaminant losses, more so for phosphorus than nitrogen, and also influenced the relative importance of different

[3] Location maps and technical information on Southland soil types is provided at http://www.southlandnz.com/Home/Land-People/Environment-Land-Information/Southland-Soils

sources and pathways of loss for contaminants. For both farm types, nitrogen leaching from urine patches deposited onto pastures and grazed winter forage crop paddocks were more important nitrogen sources than overland flow, although losses of nitrogen from urine and dung deposited in or near unfenced watercourses were also potentially significant. Nitrogen losses were greatest from freely drained soils than poorly drained soils (i.e., Brown > Podzol > Peat > Gley) (Figure 1). Phosphorus loss showed a different pattern (i.e., Peat > Podzol > Gley > Brown), however the authors noted that the paucity of information available on phosphorus losses from Peat, Podzol and Gley soils may have influenced their estimates (Figure 2). For both farm types (dairy, and sheep and beef), winter forage crop grazing, stock access to watercourses and soil phosphorus were all important sources of phosphorus loss. Direct phosphorus loss from recently applied farm dairy effluent via both overland flow and subsurface drainage pathways were also important sources of phosphorus loss from the model dairy farm.

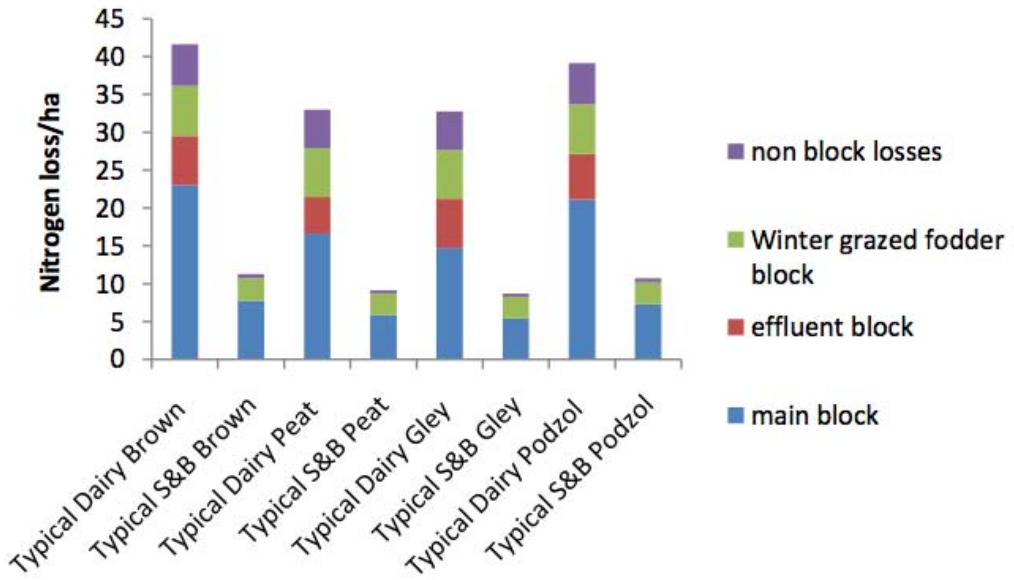

Figure 1 *Estimated annual nitrogen losses (via all pathways) from the example dairy or sheep and beef (S&B) system on Brown, Peat, Gley and Podzol soils (kg N/ha/year). From Robson* et al. *(2011).*

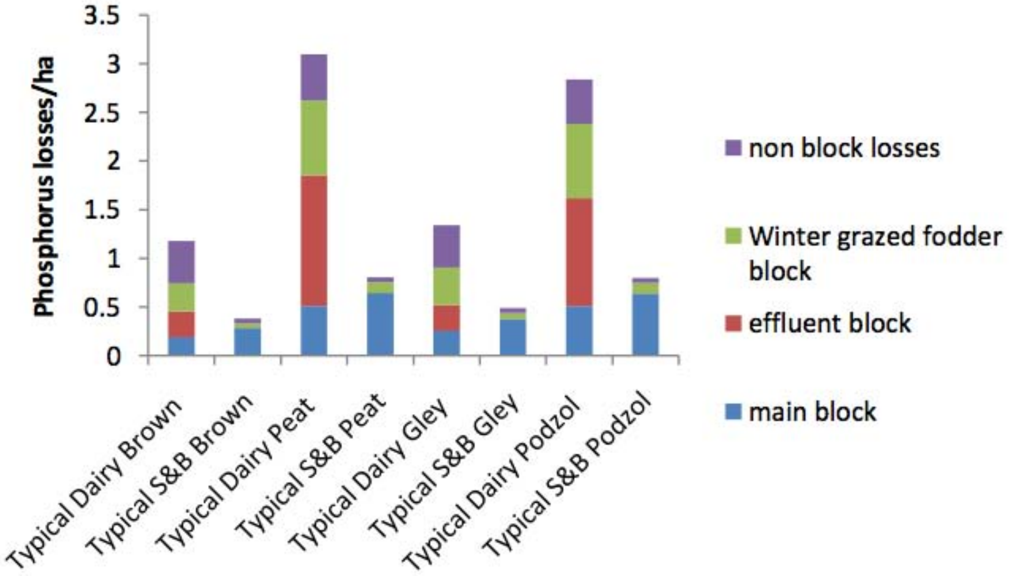

Figure 2 *Estimated annual phosphorus losses (via all pathways) from the example dairy or sheep and beef (S&B) system on Brown, Peat, Gley and Podzol soils (kg P/ha/year). From Robson* et al. *(2011).*

2.2 Slope

2.2.1 Effects/processes

Land slope influences both the volume and velocity of overland flow. Steeper slopes have higher flow velocities resulting in reduced infiltration potential and therefore a higher potential for overland flow, and also greater energy and erosive power to mobilise and transport contaminants.

2.2.2 Reference material

Research on the effect of slope on overland flow, independent of other influences, is limited. However, it is recognized that the greatest potential for overland flow (either saturation- or infiltration-excess) occurs where sloping land, low soil infiltration rates and wet soil conditions combine (McDowell *et al.* 2008 cited in Houlbrooke and Monaghan 2009). This combination of factors is present in some areas of Southland where there are intensive dairy farming operations on rolling land (c. >7° slope) with low surface infiltration. Application of farm dairy effluent in these areas presents a high risk of overland flow and contaminant loss if not appropriately managed (Houlbrooke and Monaghan 2009). Deer farming on sloping land also presents a high risk of contaminant loss as erosion caused by deer wallowing and pacing exposes soil, increasing the potential for nutrient and sediment lost to overland flow (Monaghan *et al.* 2010). Modelled estimates of phosphorus and nitrogen loss in the Bog Burn catchment (Southland) were found to be higher for deer than sheep grazing on hill country, and phosphorus losses for deer grazing on hill country were also higher than that of high input dairy grazing on flatter land (note though that nitrogen loss was lower) (Monaghan *et al.* 2010).

Ahuja *et al*. (1982) used soil boxes and simulated rainfall to assess the effects of soil slope length, degree of slope, soil cover and storm size on soluble phosphorus in overland flow. They found that the concentration of soluble phosphorus in runoff water was appreciably influenced by all of the above variables. The degree of slope and soil cover primarily influenced the effective soil mass that interacts with rainfall and runoff waters, while the slope length influenced both the soil mass and water/soil ratio (and thus the kinetics of phosphorus release).

2.2.3 Case studies

Giercuszkiewicz-Bajtlik (1990, cited in Sharpley 1995) investigated how phosphorus loss varied with land slope in Poland. Phosphorus loss from flat arable land (slope <5%) was approximately 45% lower than that from hilly arable land (slope 5-20%). For forested land phosphorus loss varied little between flat and mountainous land (slope >20%).

McDowell *et al.* (2003a) (cited in McDowell 2006) examined the losses of sediment and phosphorus from small bounded plots at two positions on a hillslope on a South Otago farm (recently converted from sheep and beef cattle grazing to dairy). Results showed that losses from grazed cropland were about four times that lost from ungrazed pasture and twice that lost from ungrazed cropland. Losses from steep (20%) plots near the stream channel were about twice that from plots on gently rolling (<5%) land at the top of the slope.

On shallower sloping land (average slope of 3°, range 0-4°) in eastern Southland (Edendale), Smith and Monaghan (2003) investigated overland flow losses in cattle grazed pastures. In this study, drained soils had significantly less overland flow with most overland flow occurring in winter and spring.

A two year study by Drewry and Paton (2005) investigated the effects of winter brassica forage crop grazing treatments on soil physical properties on a Fragic Pallic soil, susceptible to compaction, in South Otago. Micro-topography differences between hump and hoof-hollow areas were found to differ in saturated hydraulic conductivity, with very low saturated hydraulic conductivity values in hoof-hollow areas compared with hump areas. Overall, cropping with on-off grazing and, with some exceptions, crop grazing with a back-fence, were found to have some merit for reducing damage to soil physical properties compared with current practice.

Houlbrooke *et al.* (2006, cited in Houlbrooke and Monaghan 2009) observed that application of farm dairy effluent by a rotating travelling irrigator on wet, sloping land, with poor surface infiltration resulted in 78% of the irrigated volume being lost to overland flow. The loss was lower (44%) when a low flow rate irrigation system (K-line) was used.

Nguyen *et al.* (1998) assessed cattle treading damage on steep slopes in the central North Island. Results of this study showed a significant increase in the transport of suspended solids, total Kjeldahl nitrogen, and total phosphorus from plots subjected to heavy treading damage during simulated runoff. On the steep inter-track zone, damaged areas had a 46% lower infiltration rate, and runoff from these areas contained on average 87% more sediment, and 89% more nitrogen and 94% more phosphorus compared with undamaged areas. Overall conclusions from the investigation were that a two to three day winter treading event could increase soil bulk density, reduce soil macroporosity and total porosity, and increase contaminant runoff for a considerable period following grazing. In general, soil damage due to stock treading on easy slopes (15–24°) had no effect on runoff of sediment and nutrients, whereas on steeper slopes (28–39°), treading damage generated greater losses of soil, phosphate and nitrogen (Nguyen *at al.* 1998).

2.3 Rainfall intensity and frequency

2.3.1 Effects/processes

The intensity and frequency of rainfall events influences the volume of overland flow and therefore also of contaminant losses. Typically, most overland flow events occur in winter and spring, with frequent rainfall events and high soil moisture levels allowing saturation-excess overland flow to occur more readily. High intensity events have more energy and erosive power to mobilise and transport contaminants through overland flow than low intensity storms that result in subsurface flow (McDowell 2012).

2.3.2 Reference material

Research in New Zealand and overseas has demonstrated that the magnitude of contaminant loss is related to the intensity of the event and therefore the volume of overland flow generated (Smith and Monaghan 2003, Sharpley *et al.* 2008). Although larger storm events result in greater contaminant loss they occur less frequently and therefore their contribution to contaminant loss over a longer period is less than that of smaller events that occur more frequently (Sharpley *et al.* 2008). During large or long rainfall events the rate of contaminant loss to overland flow may also decrease through time as all available contaminants are removed from the surface. This occurs more often with overland flow than subsurface flow, as the period of time when soil and water are in contact is shorter (Koopmans *et al.* 2002 cited in McDowell 2008). As intensity and frequency of rainfall events vary seasonally and also locally in the Southland region the number and size of overland flow events and therefore the potential for contaminant loss will vary.

2.3.3 Case studies

Smith and Monaghan (2003) measured overland flow and contaminant loss on drained (mole-tile) and undrained cattle-grazed plots over a three-year period at a farm near Edendale, Southland. Overland flow occurred when rainfall exceeded the infiltration rate of the soil and occurred mostly in winter and spring. The amounts of nitrogen and phosphorus lost via overland flow tended to reflect the overland flow volumes. Total overland flow was between two to seven times higher from undrained than drained soil, and contaminant losses in overland flow were also greater from undrained than drained soil. These differences were particularly apparent when several overland flow events occurred in one month, or where large single events occurred within a month.

Sharpley *et al.* (2008) quantified the effect of storm size on phosphorus loss in overland flow from a catchment in Pennsylvania (United States of America). Storm flows made up only 32% of catchment flows, however they contributed 65% of dissolved reactive phosphorus losses and 76% of total phosphorus losses, through overland flow (surface or near surface flow). Large storms (greater than 10 year return period) contributed more phosphorus than small storms, however as they occurred infrequently this comprised only about 20% of phosphorus losses over the ten year study period. Almost 77% of phosphorus was lost during the more frequently occurring lower intensity storms (with a return period of 5 years or less). Therefore management practices that minimize the risk of phosphorus loss from more frequent low intensity storms may be an effective management strategy (Sharpley *et al.* 2008).

2.4 Vegetation type

2.4.1 Effects/processes

Significant changes have occurred to New Zealand's vegetative cover over its recent history with native forest, scrub, tussock and wetlands being developed to pasture, cropping, forestry and other agriculture, horticulture and urban vegetation types. Vegetation has an important influence on overland flow by intercepting and preventing rainfall from reaching the soil surface thereby reducing the potential for overland flow (Rowe 2003). If overland flow does occur, vegetation cover slows its progress, reducing its energy and therefore erosive potential. Vegetation can also reduce nutrient loss by intercepting, retaining and transforming nutrients in overland flows (e.g., riparian buffers). There are a wide range of land uses in Southland, including beef, dairy, deer and sheep farming, cropping, horticulture and forestry. As vegetation type varies among these different land uses there is also variation in overland flow potential.

2.4.2 Reference material

As different land uses and vegetation types tend to be associated with particular soil types and land slopes, it is difficult to independently assess the influence of vegetation type on overland flow. For example, most cropping land use in New Zealand occurs on flat to gently rolling slopes and as a result overland flow potential is lower than that of forestry, which tends to be associated with steeper slopes. Most New Zealand research on overland flow variation with vegetation type has focussed on differences between exotic pine plantations and pasture.

Despite the steeper slopes and therefore higher potential for overland flow, studies have shown that forest vegetation intercepts significant amounts of rainfall thereby reducing overland flow and as a result the potential for contaminant loss (Menneer *et al.* 2004). Fahey (1994) reported that conversion of pasture to pine plantation (5-10 years after planting) reduced water yield by 30-50%, and conversion from tussock grassland to forest reduced yields by 25-30% (the smaller reduction with tussock conversion probably reflecting the greater water inception potential of tussock over pasture grass). Other forms of tall vegetation (e.g., gorse, manuka) will also reduce water yields, but not to the same extent as forest establishment (Fahey 1994). A review by Rowe *et al*. (2002) found that interception storage capacity of precipitation by woody vegetation (e.g., conifers, beech, kanuka and snow tussock) tends to be in the order of 2mm. This review also found that while trees are considered to extract moisture from soils to greater depths than pasture, evidence does show that pasture can extract moisture over 150cm down the profile and at similar depths to trees. Both trees and pasture prefer to extract moisture from the top 60cm or so of the soil profile Rowe *at al*. 2002).

Sediment yields from established forest are approximately half that from pasture. After the trees are harvested this may increase by 3-4 times, however when considered over the lifetime of a forestry plantation sediment losses from pasture are likely to be greater (Fahey *et al.* 2004). In general, the conversion of pasture to forest reduces inputs of sediment, nutrients and pathogens to watercourses and creates conditions similar to that under native forest (Fahey *et al.* 2004).

2.4.3 Case studies

Smith (1987) observed as results of an eight year study that water yields from four Taieri River catchments (Otago) were approximately 43% greater from pasture catchments than exotic forest catchments.

Fahey and Marden (2000) compared the suspended sediment load from a pasture catchment and a mature exotic plantation forest in Hawke's Bay over a 29-month period, including nine storm events. Sediment yield in the pasture catchment was found to be almost 2.5 times that of the forest catchment, and between one quarter and a third of the total suspended sediment was contributed by one storm.

Matthaei *et al*. (2006) assessed fine sediment cover in three second-order Otago streams with four categories of catchment development (ungrazed tussock grasslands, grazed pasture, dairying and deer farming). Fine sediment cover was found to be different between these land uses, being lowest in tussock (7%), intermediate in pasture (30%) and dairy (47%) and highest in deer streams (88%).

Quinn and Stroud (2002) measured water quality at monthly intervals for 2-5 years on nine Waikato streams draining catchments with pasture, pine plantation and native forest land uses. The study area was dominated by steep (>30°) to hilly (17-20°) topography with yellow brown earth soils and patches of yellow brown loam soils. While the study did not specifically look at overland flow, they found that the export of suspended solids and nutrients (except DRP) from the pasture catchment was 4 to 15 fold higher during the winters of 1995 and 1996 than winter 1997 when rainfall was half the normal level. Streams draining native forest had lower temperature, sediment and nutrient concentrations (except DRP), and higher water clarity, than those draining pine forest and pasture. Pasture streams had the highest concentrations of nitrogen species and also showed the greatest variation in water quality attributes in relation to season and flow (Quinn and Stroud 2002).

At a national scale, Larned *et al*. (2004) assessed New Zealand's surface water quality status using four land-cover classes (native forest, plantation forest, pastoral and urban). Water quality state was found to vary widely within these land-cover classes. *E. coli* and dissolved nitrogen and phosphorus concentrations in the pastoral and urban classes were 2-7 times higher than in the native and plantation forest classes, and median water clarity in the pastoral and urban classes was 40-70% lower than in the native and plantation forest classes. Water quality state in the pastoral class was not statistically different from that of the urban class, and water quality state in the plantation forest class was not statistically different from that of the native forest class. Significant trends in low-elevation rivers were limited to four parameters: flow (trending down in all instance), and temperature, clarity and conductivity (trending up in all instances).

2.5 Grazing

2.5.1 Effects/processes

Grazing can increase the potential for overland flow to occur and also for contaminants to be lost from soil to overland flow. The treading action of grazing animals on land can damage the soil, causing compaction and pugging and decreasing infiltration rates. Grazing animals also damage plant cells exposing nutrients, and they deposit dung on pasture providing an additional source of contaminants to overland flow (McDowell 2008).

2.5.2 Reference material

Research has demonstrated that grazing animals damage soil, reducing macroporosity and infiltration rates, and increasing overland flow (e.g., Elliot and Carlson 2004, McDowell *et al.* 2003, McDowell *et al.* 2005). The vulnerability of soils to damage varies among soil types and with local conditions. Heavy animals such as cattle generally cause more treading damage, but smaller animals can cause severe local effects (e.g., soil trampling by deer along fence lines) (McDowell 2008). The amount and rate of dung decomposition and incorporation into the soil, also varies depending on animal type, diet and climate conditions (McDowell 2008), and in general *E. coli* concentrations in overland flow decrease as the interval between grazing and overland flow increases (Monaghan *et al.* 2010).

Confounding factors have therefore made it difficult to compare the effects of different grazing animals on contaminant loss in overland flow. However, a grazing trial designed to eliminate any variability due to soil type, slope, climate, stocking rate, and behavioural issues demonstrated that phosphorus and suspended sediment losses in overland flow did not differ significantly between grazing cattle, sheep and deer (Curran Cournane *et al.* 2011). Grazing management to reduce contaminant loss is therefore important regardless of stock type.

2.5.3 Case studies

Curran Cournane *et al.* (2011) investigated the impact cattle, sheep and deer have on soil physical quality and losses of phosphorus and suspended sediment in overland flow from grazed pasture in a two year trial conducted on the AgResearch Invermay farm near Mosgiel (Otago). Field conditions were maintained the same for each stock type treatment to eliminate any variability due to soil type, slope, climate and stocking rate, and sufficient feed was provided to prevent behavioural issues like fence-line pacing. Soil physical quality was found to be poorer in late winter than summer, and most overland flow and the greatest phosphorus loads were derived from saturation-excess conditions in winter. Only small volumes of overland flow were generated from infiltration-excess conditions during spring/summer, and these were lower than loads lost via infiltration-excess runoff from impervious areas like track, lanes and stock camping areas (see Section 2.7). However, although the spring/summer loads were small the phosphorus concentrations were high and therefore pose an environmental risk at a time when low stream flows, warm temperatures and high light conditions may favour nuisance algal growths. Soil physical data indicated differences between stock types (cattle having the greatest negative effects on soil structure), and increases in phosphorus and suspended sediment concentrations and loads with decreases in macroporosity, saturated hydraulic conductivity and time since grazing. However, these differences had no impact on phosphorus and suspended sediment losses in overland flow between stock types.

2.6 Stock wintering

2.6.1 Effects/processes

Most overland flow events occur in winter and spring, with frequent rainfall events and high soil moisture levels allowing saturation-excess overland flow to occur more readily. Stock management systems during winter can involve the restriction of animals to a localized area for an extended period of time (e.g., winter forage crop grazing). As a result stock wintering practices can cause the exposure of bare ground, treading damage, and effluent accumulation. These factors all increase the potential for contaminant loss, through increasing the surface area of sediment exposed to overland flow, compacting soil and decreasing its capacity for water storage (reducing infiltration and therefore increasing overland flow potential), and increasing the density of faecal material, respectively. During winter overland flow also generally occurs over a larger area than during drier periods, when only soils adjacent to water are likely to be saturated (McDowell 2012). In combination these factors indicate a potentially high risk of contaminant transport to watercourses through overland flow in winter.

2.6.2 Reference material

Repeat use of an area for winter grazing can damage soil structure (especially in vulnerable soils such as Pallic and Grey soil orders) and consequently increase the risk of contaminant losses in overland flow (McDowell *et al.* 2003). Phosphorus and sediment have been found to be the main contaminants lost to overland flow during wintering, with nitrogen being lost mainly through subsurface pathways (McDowell *et al.* 2003, 2005, McDowell and Houlbrooke 2008). Despite much research on phosphorus loss from agricultural soils, defining contributions from overland flow is still difficult because of problems associated with spatial and temporal variability (Monaghan *et al.* 2010). Monaghan *et al.* (2010) reviewed available information on phosphorus and sediment losses and concluded that generally losses from winter grazed forage crops are greater than those from sheep grazed pasture, and are greater from cattle-grazed winter crops than sheep-grazed winter crops. Winter grazing is therefore an important source of phosphorus and sediment loss, however more research is required as losses show large variability depending on wintering practises and local conditions (e.g., soil, slope, rainfall). More research is also needed to understand the role of overland flow from grazed winter forage crops as a source of *E. coli* (Monaghan *et al.* 2010).

2.6.3 Case studies

McDowell and Stevens (2008) examined how the loss of contaminants in overland flow varied between two red deer wintering systems in Lumsden (Southland). Contaminant concentrations (dissolved reactive phosphorus, total dissolved phosphorus, total phosphorus, particulate phosphorus, suspended sediment, ammonium-nitrogen, nitrate+nitrite-nitrogen, and *E. coli*) were measured before and after deer grazing on a pasture or a forage crop (swede). Contaminant losses were greater after grazing than before and generally greater from the forage crop than the pasture, the exception was dissolved reactive phosphorus, which was lost in similar quantities from both wintering systems.

McDowell *et al.* (2005) investigated how different dairy cow grazing regimes on winter forage crops (brassica) effected soil physical properties, and sediment, phosphorus and *E. coli* loss to overland flow in the Dull Burn catchment (South Otago). Unrestricted grazing (24 hours per day) resulted in treading damage to the soil and increased both loads and concentrations of suspended sediment, *E. coli* and phosphorus loss in overland flow, relative to the ungrazed treatment. In contrast, when cows were restricted to only one three hour grazing period (to simulate break feeding, where animals graze a proportion of the crop at a time) suspended sediment, *E. coli* and phosphorus loads were similar to ungrazed pasture. Greater contaminant loss with unrestricted grazing was attributed to added soil disturbance and dung deposition.

The impacts of forage crop cattle wintering has been monitored at Telford Farm in South Otago. This study (reported in Monaghan in prep.) involved two small headwater catchments, each approx. 2 ha in area, that had been monitored since June 2011 for yields of sediment, phosphorus and *E. coli* in overland flow and subsurface drainage. Both catchments were managed similarly in 2011 as a calibration step; in 2012, one catchment was grazed as per suggested good management practice whereby the catchment gully was protected from the heavy animal treading that typically occurs during winter. This protected area represented 2% of the total paddock area. The other catchment was managed as a control treatment where typical grazing practice (grazed from the bottom of the catchment without back-fencing) was employed and the gully was left un-protected from grazing and soil treading damage.

Preliminary findings found that the heavy treading damage caused by cows grazing in the control treatment reduced soil infiltration rates and caused more water to exit the paddock in overland flow, resulting in relatively large yields of sediment. Measurements and observations suggest that much of the sediment and phosphorus loss originates from within the gully where, i) the water is flowing over the soil surface and ii) soil aggregation is greatly reduced. Yields of water, sediment and phosphorus in overland flow were greatly reduced in the catchment that has been grazed according to 'Good Management Practice'. Back-fencing forage crop breaks helps minimise the amount of soil damage incurred and surface runoff produced.

2.7 Hard surfaces

2.7.1 Effects/processes

Overland flow occurs more rapidly from impervious surfaces, which do not allow water to enter the soil. Any activity that reduces the ability of water to infiltrate soil will increase the potential for infiltration-excess overland flow. Agricultural land use examples include hard surface formation by concreting or gravel application and soil compaction due to stock treading (e.g., at yards, lands, tracks, gateways, troughs). Hard surfaces are also often high stock use areas, therefore in addition to increased potential for overland flow, contaminant presence is often high. Overland flow that occurs as a result of limited soil infiltration rate has a greater capacity than saturation-excess overland flow to detach and move soil particles and therefore to transport contaminants to watercourses (Kleinman *et al*., 2006 cited in McDowell

2012).

2.7.2 Reference material

The contribution of overland flow from hard surfaces as a source of contaminants to watercourses has recently been highlighted in New Zealand (McDowell 2012). Studies have focussed on dairy farms and found that in particular phosphorus and sediment loss from hard surfaces can be substantial, and is of particular concern in summer when low stream flows, warm temperatures and high light conditions may favour nuisance algal growth (Lucci *et al.* 2010 and 2012, McDowell 2007, Monaghan and Smith 2012).

2.7.3 Case studies

Over a two-year period Monaghan and Smith (2012) measured the concentrations and loads of contaminants transferred to watercourses in overland flow discharging directly from seven laneways on four dairy farms in the Bog Burn catchment (Southland). Overland flow tended to occur when rainfall exceeded 20mm in summer and 10mm in winter (Figure 3). The volume of overland flow was greatest on a concrete laneway surface and lowest on a laneway surface that consisted of soft, porous fines.

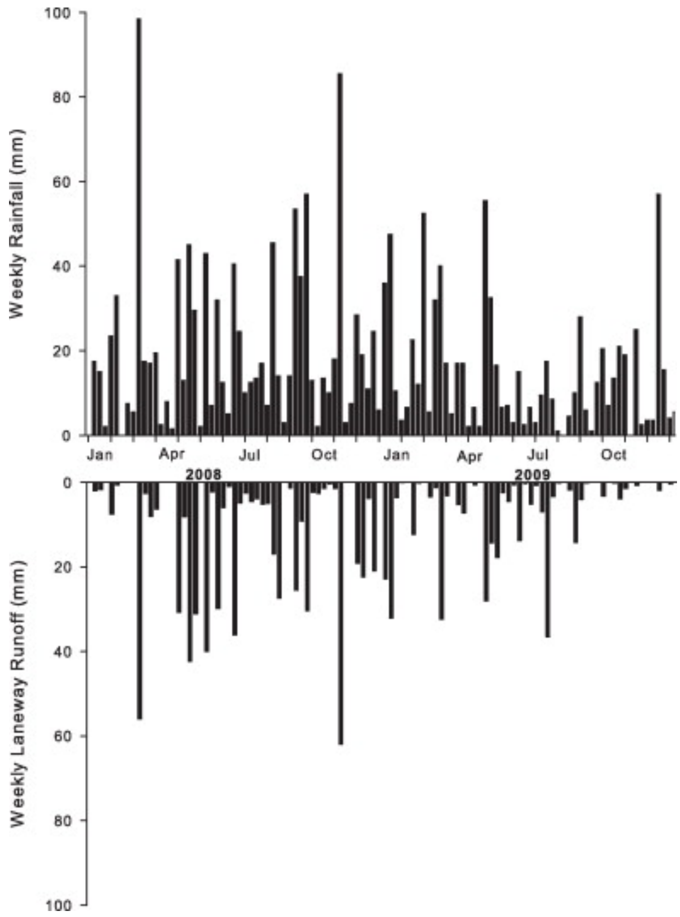

Figure 3 *Weekly rainfall and laneway overland flow depths for the duration of measurement (January 2008–December 2009). Overland flow values are averages measured at sampling sites 3–9 (redrawn from Monaghan and Smith 2012).*

The concentration of nutrients, sediment and *E. coli* in overland flow samples was very high compared to that measured in catchment or paddock discharges, and was similar to that found in farm dairy effluent. Contaminant loads in overland flow varied somewhat among months, seasons and also locations within the farm, in the most part probably due to variation in the quantity and freshness of cow excreta. Monaghan and Smith (2012) calculated that overland flow from dairy farm tracks and lanes would account for less than 1% of the annual loads of total phosphorus, dissolved reactive phosphorus, total soluble nitrogen and total suspended solids discharged from the Bog Burn catchment. However, during summer the proportional contribution is greater, when overland flow from lanes could contribute between 4 and 76% of total phosphorus loads, or between 6 and 100% of total suspended solid loads, assuming that 5 or 100% of laneway areas discharge directly to Bog Burn stream, respectively. *E. coli* in overland flow from lanes may account for all the *E. coli* discharged from the catchment during summer (although there are factors that confound this assessment). This study demonstrates the importance of infiltration excess overland flow from laneways as a source of potential contaminants to watercourses during summer when low stream flows, warm temperatures and high light conditions may favour nuisance algal growths.

Lucci *et al.* (2012) found in their study of a dairy catchment in Hillend (South Otago) that mean concentrations of phosphorus and suspended sediment in overland flow were highest from laneways, followed by the area around watering troughs, and lowest from pasture. The loss of dissolved reactive phosphorus and total dissolved phosphorus was highest from trough sites in summer, coinciding with the time of major use. However, the load from the trough was typically less than 10% of the total load for all phosphorus and sediment lost from the catchment, implying that even under saturated conditions, the contribution from the trough areas would be of minor importance. Calculations suggested that up to 89% of the dissolved reactive phosphorus load was contributed by the laneway when overland flow was likely. For laneways the loss of dissolved reactive phosphorus and total phosphorus was high during summer rainfall events and in autumn, possibly due to the summer accumulation of dung during warm, dry summer conditions that limit decomposition. Like Monaghan and Smith's (2012), Lucci *et al.*'s (2012) study therefore demonstrated the potential importance of contaminant loss from laneways during summer.

2.8 Irrigation

2.8.1 Effects/processes

The application of water to land through irrigation is a potential source of overland flow, however irrigation should not necessarily increase overland flow unless water is applied at too great a rate (i.e., inefficiently) and/or on already wet or sloping land. Overland flow is more likely to occur with flood or border dyke irrigation, which are generally less efficient than spray irrigation methods (e.g., centre pivot, rotary boom). However, on dairy farms spray irrigation is commonly used as a means of disposing of farm dairy effluent to land and there is a high risk of contaminants entering watercourses through overland flow if this effluent application it is not managed appropriately.

2.8.2 Reference material

The potential for excessive irrigation to result in overland flow is well understood in New Zealand. The efficient design and regulation of irrigation systems has received a lot of attention, particularly with the use of irrigators to apply farm dairy effluent to pasture. The use of deferred irrigation, which allows effluent application to be delayed until a time when the overland flow potential is lower, can reduce phosphorus losses by a third (McDowell *et al*. 2008). In a South Otago study (Houlbrooke 2006), the use of low rate K-line irrigation systems to apply dairy effluent (application rate 4 mm per hour) resulted in lower overland flow volumes, and lower concentrations and loss of contaminants, than that of rotary travelling irrigator application systems (application rate 132 mm per hour). The main effect of irrigation on contaminant losses is to allow increased intensification and therefore urinary inputs of nitrogen, however nitrogen is primarily loss through leaching rather than overland flow pathways (Monaghan *et al.* 2010).

2.8.3 Case studies

McDowell and Houlbrooke (2008) investigated nitrogen, phosphorus and sediment loss from cattle- and sheep-grazed irrigated (fixed K-Line pods) winter forage crops and irrigated pasture grazed by sheep at a site in North Otago. During the study period (February 2007 to March 2008) 21 overland flow events were recorded and eight of these were caused by irrigation (which took place during October to April). Overland flow volumes were greater from the winter forage crop plots (35 mm) than pasture plots (13 mm), and from the cattle (45 mm) than sheep (25 mm) grazed winter forage plots. As sub-surface flow volumes varied little between treatments overland flow probably occurred via saturation-excess conditions, rather than infiltration-excess, although differences in overland flow in the cattle grazed plots compared to the sheep grazed plots was likely due to decreased macroporosity due to treading damage. Overland flow was the main mechanism for phosphorus and sediment loss, in contrast nitrogen losses primarily occurred through sub-surface flow. Approximately 30% of phosphorus losses and 32-37% of sediment losses from the cropped plots occurred during irrigation. In general phosphorus losses from cattle grazed crop plots were twice that of sheep grazed crop plots, and seven times that of sheep-grazed pasture. Sediment loss was greatest from cattle grazed forage crops, followed by sheep grazed crops and lowest from sheep grazed pasture. Lower phosphorus and sediment loss from pasture than forage crops probably reflected animal disturbance of the soil and the filtration of particles in overland flow by grasses. This study demonstrates that irrigation can lead to over-watering and overland flow, especially when soil infiltration rates are decreased due to treading and compaction.

In a follow-up study McDowell and Houlbrooke (2009) demonstrated that the contribution of irrigation water to overland flow, as a result of saturation-excess conditions, was greatest under cattle crop (20% of total) compared with sheep crop (15%) and sheep pasture (11%). McDowell and Houlbrooke (2009) concluded that these differences were probably an effect of soil physical condition and highlighted the importance of accurate irrigation scheduling to keep soil moisture below field capacity.

Monaghan *et al.* (2010) illustrated the relative importance of overland flow compared to other pathways of nitrogen, phosphorus and *E. coli* losses using model Southland dairy and sheep farms (using the Bog Burn catchment and soils as a case study setting). Unrestricted stock access to watercourses was allowed for in the models, and on the dairy farm dairy effluent was disposed of by irrigation to land. For both model farms, overland flow pathways provided the smallest contribution of nitrogen (dairy farm 5%, sheep farm 8%), with the majority of losses occurring through subsurface artificial drainage (mole-pipe) (Figures 4 and 5). Phosphorus losses in overland flow from the dairy farm (18%) were smaller than those due to direct deposition of faecal material in watercourses (50%) and losses through subsurface drainage (21%) (Figure 4). However, for the sheep farm overland flow, direct deposition and drainage pathway phosphorus losses were all approximately equal (Figure 5). Drainage of farm dairy effluent by preferential flow through mole-pipe drains (47%) and direct deposition (26%) contributed the majority of *E. coli* losses from the dairy farm, with overland flow (18%) representing a much smaller source (Figure 4). In contrast, on the sheep farm, overland flow was the major pathway of *E. coli* losses from dung deposition on pasture (60%) (Figure 5). The model farms illustrate the relative contribution that overland flow pathways make to contaminant losses on an annual basis, however it is noted that they do not adequately account for spatial and temporal variation in pathways and effects (Monaghan *et al.* 2010).

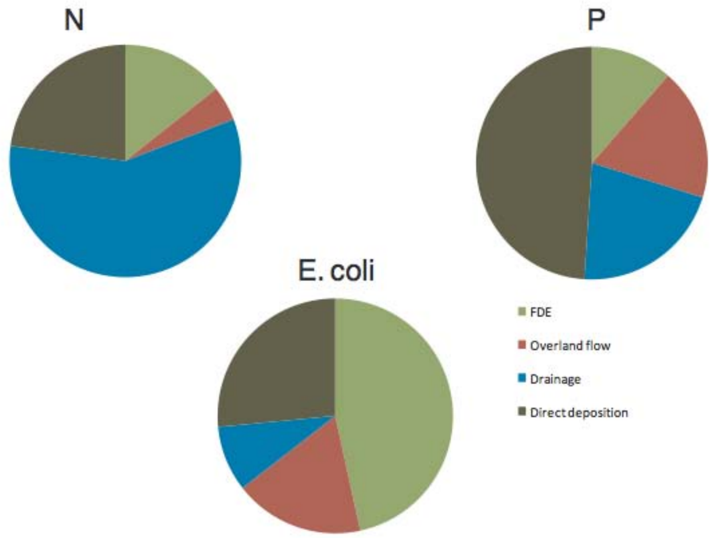

Figure 4 *Estimated sources of nitrogen, phosphorus and* E. coli *discharges to water from a Bog Burn dairy farm: (i) direct deposition of faeces to un-fenced streams, (ii) drainage, (iii) overland flow, and (iv) incidental losses of contaminants due to the preferential flow of farm dairy effluent (FDE) through mole-pipe drains (one month pond storage assumed). Note that un-restricted access of cows to streams has been assumed to demonstrate the large potential effect this can have on whole-farm contaminant losses. From Monaghan* et al. *2010.*

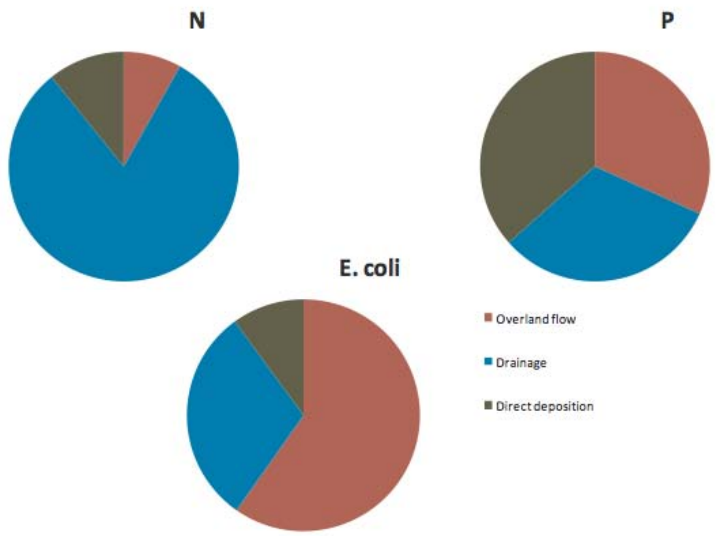

Figure 5 *Estimated sources of nitrogen, phosphorus and* E. coli *discharges to water from a Southland sheep farm: (i) direct deposition of faeces to un-fenced streams (deposition of 0.7% of excreta assumed), (ii) drainage, and (iii) overland flow. Note that un-restricted access of sheep to streams has been assumed to demonstrate the potential effect this can have on whole-farm contaminant losses. From Monaghan* et al. *2010.*

2.9 Cultivation

2.9.1 Effects/processes

Overland flow from undisturbed soils generally carries little sediment. However, when cultivation removes vegetation cover from large areas there is a potential for storm events to cause surface erosion. Most cultivation in New Zealand occurs on flat land, which reduces the opportunity for surface erosion. However, where cultivation does occur on sloping land, especially in association with fertiliser application, there is a high risk of contaminant transport in overland flow occurring during storm events. In addition to introducing sediment to water, soil particles may carry particulate bound nutrients.

A review for Environment Southland by Monaghan *et al*. (2010) found that losses of phosphorus and sediment from the mixed cropping farms depend heavily on management factors such as cultivation of slopes, sowing up and down slopes and leaving soil exposed during periods of surplus rainfall. Conversely, the use of good environmental management practices (GEPs) such as contour ploughing, cover crops, and expert fertiliser decision support tools may help to decrease losses.

In general, sediment contamination of streams is most pronounced on cropping and horticultural land where cultivation occurs close to the edge of streams and drains, and where depressions that serve as temporary drainage channels during rain are cultivated and left exposed to surface runoff (MfE 2001). The impact of these cultivation practices is magnified where cultivation takes place on a slope: the steeper and longer the slope the greater the erosive force of the runoff (MfE 2001).

2.9.2 Reference material

There has been limited research on contaminant loss from cultivated crop land in New Zealand. Research focuses primarily on nitrogen and phosphorus losses through leaching (e.g., McDowell and Monaghan 2002) with less information on sediment and phosphorus losses in overland flow from cultivated land (Monaghan *et al.* 2010). Losses depend on local conditions and management factors such as slope, rainfall event frequency, cover crop use, contour ploughing (in contrast to cropping in vertical rows up a slope) and cultivation setbacks from waterways (Monaghan *et al.* 2010). More research is needed on how cultivation associated with intensive horticultural operations influences contaminant loss, especially as this industry is expanding in Southland (Monaghan *et al.* 2010).

2.9.3 Case studies

Wallbrink *et al.* (2003) examined how sediment and sediment bound phosphorus loss varied between three land uses in Australia (Bundella Creek, New South Wales) – cultivated (slope 0-8%), pasture (slope 2-20%) and forestry (slope 8-20%). On a per unit area basis sediment and sediment bound phosphorus mobilisation from the surface of cultivated land exceeded that from pastures by factors of approximately 84 and 42, respectively. For comparison, sediment and sediment bound phosphorus mobilisation from forests exceeded that from pastures by factors of approximately 9 and 8, respectively. The highest concentrations of phosphorus were recorded during storm events and probably included some fertiliser sourced phosphorus.

2.10 Fertiliser application

2.10.1 Effects/processes

Fertiliser application primarily aims to replenish nutrient levels in the soil, however as it takes some time to enter the soil there is a risk that a rainfall event will occur shortly after application and some nutrients will be lost to overland flow. The magnitude of nutrient loss will vary however depending on the amount and timing of the rainfall after fertilization application and on the rate, time and method of fertiliser application, land vegetative cover, the ability of the soil to absorb nutrients and also on the form and solubility of the fertiliser.

2.10.2 Reference material

There have been numerous studies of phosphorus loss in overland flow following fertiliser application in New Zealand (e.g., Gillingham and Gray 2006, McDowell *et al.* 2003 a and b, McDowell *et al.* 2010). Direct losses of phosphorus are commonly low and only increase if phosphorus is applied during wet months, on steeply sloping ground[4], and/or immediately before a rainfall event. McDowell *et al*. (2007) estimated that approximately 10% of annual phosphorus losses in overland flow from dairy grazed pastures were attributable to fertiliser application (following best practices), however phosphorus losses from fertiliser application on hill-country slopes may be greater (McDowell *et al.* 2010). The risk of phosphorus loss is greatest in the period immediately following superphosphate fertiliser application and

[4] Moderate to steep slopes are regarded as being >15 degrees (Ledgard and Hughes 2012).

declines with time as phosphorus is taken up into the soil. The time taken for fertiliser to be incorporated into the soil depends on soil type and climatic conditions, and has been reported to range from 7 to 60 days (mean 21 days) (McDowell *et al.* 2010). Superphosphate fertiliser is typically applied during summer, therefore the risk of overland flow occurring following application is generally lower than during wetter times of the year. If phosphorus is lost to overland flow it is primarily in its soluble form (i.e., dissolved reactive phosphorus) rather than as particles. However, particulate phosphorus loss can occur on steep slopes, where rainfall is intense and/or where fertiliser is applied to cultivated soils. The use of less soluble reactive phosphorus rock rather than superphosphate (superphosphate is greater than 90% water soluble, while reactive phosphate rock is less than 1% water soluble) reduces the risk of phosphorus loss occurring, particularly in the period immediately following fertiliser application (McDowell 2003a, McDowell *et al.* 2010). However, on gently sloping dairy pastures at least, if good management practice are used in superphosphate application (e.g., not applying during wet periods) then the difference in phosphorus loss between the two fertiliser types is likely to be minimal (McDowell 2003a).

Nitrogen fertiliser application has increased in New Zealand in recent times with the expansion of dairy farming in New Zealand. Nitrogen is typically applied as either Urea or Ammonium (i.e., ammonium sulphate, ammonium nitrate) fertilisers. Relatively little nitrogen fertiliser is applied to sheep pastures and hill country, as sufficient nitrogen is supplied through biological nitrogen fixation by clover. Research on nitrogen fertiliser application has confirmed that if best practice is followed in terms of amount and timing of application little direct loss of nitrogen fertiliser occurs in grazing systems and the main source of nitrogen loss is through subsurface pathways rather than overland flow (Monaghan *et al.* 2005).

2.10.3 Case studies

McDowell *et al.* (2003a) determined the loss of phosphorus to overland flow (artificial rainfall) following application of several different rates of superphosphate application (0 to 376 kg phosphorus/ha/year) and compared that to phosphorus loss following applications of the less soluble reactive phosphate rock (RPR, 175 kg phosphorus/ha/year). The trial was undertaken at the Winchmore Irrigation Research Station near Ashburton on replicate turf layers with different phosphorus fertilization histories and treatments. Concentrations of phosphorus fractions (dissolved reactive phosphorus, total dissolved phosphorus, and total phosphorus) in overland flow increased with increasing phosphorus application rate. Phosphorus was mainly lost in its soluble form as dissolved reactive phosphorus rather than as particulate phosphorus. Dissolved reactive phosphorus losses following fertiliser application were at least 20% higher than background phosphorus loss levels. Phosphorus loss in overland flow decreased with time following superphosphate application. Considerably greater concentrations of phosphorus were measured in overland flow collected from soils fertilised with superphosphate than from those fertilised with RPR. The potential for phosphorus loss was higher from superphosphate than RPR soon after fertilization (approximately within 60 days), however in the medium to long term the potential for phosphorus loss from the two fertiliser types was similar. If good management practices are observed the differences between RPR and superphosphate use is therefore minimal.

Smith and Monaghan (2003) investigated the effects of nitrogen fertiliser application (400 kg nitrogen/ha/year urea) on nitrogen losses in overland flow on dairy pastures near Edendale (Southland). Fertiliser application had little effect on ammonium nitrogen concentrations in overland flow during autumn and winter, however, from late August concentrations significantly increased following fertiliser application, although this appeared to be more closely related to grazing than fertiliser application date. Nitrate-nitrogen concentrations in overland flow were more variable and few differences were related to fertiliser application. A subsequent study at the same site found that losses of nitrogen in overland flow were low relative to that measured in subsurface drainage, and that management aimed at reducing nitrogen losses should target subsurface drainage systems rather than overland flow (Monaghan *et al.* 2005). As there was little direct loss of applied nitrogen fertiliser during the trial it was suggested that nitrogen reductions may be achieved by reducing total nitrogen inputs or reducing animal excreta-nitrogen losses, rather than focusing on adjustments to fertiliser timing, form or pattern of splitting annual applications (Monaghan *et al.* 2005).

3. Potential climate change effects in Southland – why include it?

The Ministry for the Environment provides climate change predictions for each region of New Zealand[5]. These predictions are dependent on future greenhouse gas emissions, which are uncertain, and the models that are used to make the predictions also vary in their sensitivity to the emissions. Predictions of future climate therefore provide an indication of the range of conditions that may be experienced, rather than absolute predictions, however they provide a useful basis for understanding how climate change could affect future overland flow contaminant loss in Southland.

By the end of the century, Southland is predicted to be warmer, with air temperatures expected to be approximately 2°C higher and the number of days that maximum temperatures exceed 25°C increasing by 30 days. Southland will also be wetter, particularly in winter and spring, with very heavy rainfall events becoming more frequent. For example, in Invercargill average annual rainfall is predicted to increase by 4% by 2040 and 7% by 2090, with winter rainfall increasing by 10% by 2040 and 18% by 2090. The intensity of storms will decrease in summer and increase in winter, with an increase in the frequency of extreme winds, particularly westerly winds.

Climate change could therefore have a significant impact on overland flow and associated contaminant loss potential in Southland, depending on the location. Parts of Southland that are already dry may become drier, potentially decreasing overland flow, however in other areas there may be increases in average annual rainfall. Increases in storm intensity are expected to increase the risk of overland flow and erosion, and therefore also of contaminant transport to watercourses. A qualitative assessment of how climate change may affect influences on overland flow has therefore been presented below.

Soil type

Climate change may provide opportunities for land use change and grazing intensification in some parts of Southland. Depending on the soil type present in an area, increased intensification may increase structural degradation reducing water

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[5] http://www.mfe.govt.nz/issues/climate/about/climate-change-affect-regions/southland.html

infiltration and increasing overland flow potential.

Slope

Climate change will not alter land slope and therefore there will be no change to overland flow potential from sloping land. However, climate change associated changes to land use activities on sloping land or increases in rainfall or storm intensity could increase overland flow and also erosion.

Rainfall intensity and frequency

The intensity and frequency of rainfall events influences the volume and erosive power of overland flows. Any climate change related increases or decreases in rainfall or storm intensity are expected to have a corresponding effect on overland flows. Drainage installation will counteract any overland flow increases.

Vegetation type

Climate change may provide opportunities for new crops to be grown in some parts of Southland, resulting in changes to vegetation type. Any development that reduces vegetation cover, in particular tall vegetation cover, will increase overland flow potential.

Grazing

Climate change may result in land use intensification in some areas. Grazing animals can damage soil, decreasing infiltration rates and increasing overland flow potential. In general, increasing intensification is also likely to increase contaminant supply and therefore potential loss to overland flow.

Stock wintering

Predicted increases in rainfall or storm intensity in Southland due to climate change, particularly in winter and spring, is likely to increase the already high potential for overland flow to occur through saturation-excess conditions in winter. As with grazing, any increases in land use intensification will decrease infiltration rate and increase contaminant supply and potential loss to overland flow.

Hard surfaces

If land use intensity does not change in the interim, then more rainfall will provide increased dilution of contaminants within overland flow from hard surfaces, potentially reducing effects on watercourses. However, if land use intensifies, the quantity (load) of a contaminant may also increase, potentially increasing environmental effects on watercourses.

Irrigation

Climate change may result in some parts of Southland becoming drier, in which case irrigation demand may increase. However, if irrigation is applied efficiently and at an appropriate rate increased irrigation will not necessarily increase overland flow. Conversely, some parts of Southland may become wetter reducing the need for irrigation. Potentially of more concern is climate change related opportunities for increased land intensification resulting in increased farm dairy effluent disposal through irrigation and therefore increased potential for contaminant loss in overland flow if not appropriately managed.

Cultivation

Climate change may allow land use change, including opportunities for growing new crops or expending cropping into new areas. Such land use changes are likely to involve increased cultivation and potentially also increased fertiliser use. In combination with potential climate change associated increases in rainfall or storm intensity this could increase sediment and nutrient loss in overland flow.

Fertiliser application

Climate change may result in land use intensification in some areas, potentially increasing fertiliser application. If not managed appropriately, and in combination with increased rainfall, this will increase nutrient loss in overland flow.

4. Environmental effects matrices

The information presented in Section 2 explains how overland flow, and therefore the potential for contaminant loss to water, is influenced by climate, landscape and land management factors. The potential influence of these factors on overland flow and associated contaminant loss has been summarized in a table that allows the relative effects of each to be visually compared (Table 2). This is a simplified interpretation and therefore is not able to account for the spatial and temporal variability in overland flow and associated contaminant loss, nor potential interactions among some of the factors. However, the presentation of the information in this way does allow some key issues and priorities for the management of overland flow in Southland to be identified. The first three influences listed in Table 2 - soil type, slope and rainfall intensity and frequency – relate to climate and landscape factors, while the remaining factors relate to land management practices.

Soil type

Soil type is a very important determinant of overland flow potential and also contaminant loss. Soils have their own natural limitations to infiltration capacity, and vary in their vulnerability to damage from different land management practices and therefore soil type should be a primary consideration when evaluating the potential impact of a land use change.

Slope

Land slope determines both the volume and velocity of overland flow, and the combination of elevated slope, low soil infiltration rates and wet soil conditions present a high potential for overland flow and contaminant loss. Slope length also influences contaminant loss. This combination of factors is present in some areas of Southland where there are intensive dairy farming operations and therefore application of farm dairy effluent in these areas present a high risk of contaminant loss. Deer farming on sloping land also increases the risk of phosphorus and sediment loss through erosion.

Rainfall intensity and frequency

The intensity and frequency of rainfall events influences the volume of overland flow, with high intensity events having more energy and erosive power to mobilise and transport contaminants. Any climate change related increases in rainfall and storm intensity would therefore increase overland flow potential.

Vegetation type

Vegetation type has a direct effect on overland flow and contaminant loss potential. Tall and dense vegetation intercepts and prevents rainfall from reaching the soil surface reducing the potential for overland flow, slows overland flow thereby reducing its erosive potential, and also reduces contaminant loss by intercepting, retaining and transforming nutrients.

Grazing

The main influence of grazing on overland flow potential is to reduce soil water infiltration rates through treading damage thereby increasing overland flow. The vulnerability of soils to damage varies among soil types, as noted above, and with local conditions. The presence of grazing animals also increases the potential for contaminant losses through increasing urine and faecal inputs. Recent research has shown that, when all other factors are equal, phosphorus and sediment losses do not differ significantly between stock types (i.e., cattle, sheep, deer), and therefore grazing management to reduce contaminant loss is important regardless of stock type. Heavy animals such as cattle generally cause more treading damage, but smaller animals can cause severe local effects.

Stock wintering

Most overland flow events occur in winter and spring, and stock management systems during winter that involve the restriction of animals to a localized area for an extended period of time can result in a significant increase in the potential for overland flow and contaminant loss (primarily phosphorus and sediment) during this critical period. Restricted wintering practices exacerbate this risk by increasing the surface area of sediment exposed to overland flow, compacting soil and decreasing its capacity for water storage, and increasing the density of faecal material. More research is required to determine how contaminant losses vary depending on wintering practices and local conditions, and to understand the role of overland flow from wintering areas as a source of faecal micro-organisms. A summary of this work is currently being prepared for Environment Southland (Monaghan in prep.).

Hard surfaces

Contaminant losses through overland flow from hard surfaces (e.g., yards, lands, tracks, gateways, troughs) have been shown to be substantial and are of particular concern when they occur in summer when low stream flows, warm temperatures and high light conditions may favour nuisance algal growth in watercourses.

Irrigation

The application of water to land through irrigation is a potential source of overland flow, however irrigation should not necessarily increase overland flow unless water is applied at too great a rate and/or on already wet or sloping land. However, if spray irrigation includes the disposal of farm dairy effluent, and it is not appropriately managed, there is a high risk of contaminants entering watercourses through overland flow. Contaminant losses appear highly dependent on the irrigation method employed. Phosphorus, nitrogen, sediment and faecal micro-organisms may all be lost in overland flow, however the main effect of irrigation on contaminant losses is to allow increased grazing intensification and therefore urinary inputs of nitrogen (although nitrogen is primarily loss through leaching rather than overland flow pathways).

Cultivation

Cultivation has little influence on the potential for overland flow and most cultivation takes place on flat land, which reduces overland flow and surface erosion potential. However, where cultivation does occur on sloping land, especially in association with fertiliser application, there is a high risk of sediment transport occurring during storm events. In addition to introducing sediment to water, soil particles may also carry particulate bound nutrients. More research is required on how cultivation associated with intensive horticultural operations influences contaminant loss, especially as this industry is expanding in Southland.

Fertiliser application

Fertiliser application aims to replenish nutrient levels in the soil, however there is a risk that a rainfall event will occur shortly after application and some nutrients will be lost to overland flow. The magnitude of nutrient loss varies depending on the amount and timing of the rainfall after fertilization application and on the rate, time and method of fertiliser application, land vegetative cover, the ability of the soil to absorb nutrients and also on the form and solubility of the fertiliser. The use of less soluble reactive phosphorus rock rather than superphosphate reduces the risk of phosphorus loss occurring, particularly in the period immediately following fertiliser application. However, if best practice is followed in terms of amount and timing of application the risk of any direct loss of phosphorus or nitrogen fertiliser can be minimized. Additionally, the main source of nitrogen loss is through subsurface pathways, therefore the risk of nitrogen fertiliser in overland flow is low.

Table 2 *Influence of various climate, landscape and land management factors on overland flow potential and associated risk of contaminant loss in overland flow. Greater number of crosses = greater effect. Knowledge of microbial losses in overland flow is limited for some factors therefore question marks have been included where appropriate.*

Influence	Type	Overland flow	Relative risk of contaminant loss in overland flow			
			Nutrients		Sediment	Microbial
			N	P		
Soil type	Poorly drained	More	x	xxx	xxx	xxx ?
	Freely drained	Less	x	x	x	x
Slope	Steeper	More	xx	xx	xx	xx ?
	Shallower	Less	x	x	x	x
Rainfall intensity and frequency	Heavier	More	xx	xx	xx	xx ?
	Lighter	Less	x	x	x	x
Vegetation type	Shorter/ Thinner	More	xx	xx	xx	xx
	Taller/ Denser	Less	x	x	x	x
Grazing	Present	More	x	xx	xx	xx
	Absent	Less	x	x	x	x
Wintering	Present	More	x	xxx	xxx	xxx ?
	Absent	Less	x	x	x	x
Hard surfaces	More compacted	More	xx	xxx	xxx	xxx
	Less compacted	Less	x	x	x	x

Influence	Type	Overland flow	Relative risk of contaminant loss in overland flow			
			Nutrients		Sediment	Microbial
			N	P		
Irrigation (water)	High application rate	More	x	xx	xx	xx ?
	Low application rate	Less	x	x	x	x
Irrigation (effluent)	Rotating gun	More	xxx	xxx	-	xxx ?
	K-Line	Small increase	x	x	-	xx ?
Cultivation	Present	No change	x	xx	xx	x ?
	Absent	No change	x	x	x	x
Fertiliser application - phosphorus	High application rate	No change	-	xx	-	-
	Low application rate	No change	-	x	-	-
Fertiliser application - nitrogen	High application rate	No change	x	-	-	-

As indicated above, Table 2 is not able to account for the spatial and temporal variation in overland flow potential or interactions among some factors. However, an interactive map produced by Environment Southland (available at http://gis.es.govt.nz/), showing how land slope and soil type varies across the region, provides an indication of how two important influences of overland flow potential may interact to increase the risk of contaminant loss. The map was developed to illustrate the potential risk of contaminant loss from farm dairy effluent application, however it could also apply to contaminant loss in overland flow associated with other land use activities such as fertiliser application, cultivation and/or wintering (Figure 6). Where sloping land combines with low filtration rate soils, the risk of overland flow occurring is higher relative to well-drained flat land.

Land use across the Southland region was surveyed and mapped in 2008 (Figure 7, a repeat survey was being undertaken in 2012). High and low producing grassland dominates the developed area of the region (Figure 7). Any further development of forest to grassland or the conversion of grassland to cropping is likely to increase overland flow potential (as indicated in Table 2). The greatest risk occurs where sloping land, low soil infiltration rates and wet soil conditions combine. Any land management changes in these areas should therefore be carefully evaluated. Consideration of additional climate and landscape information (e.g., rainfall intensity and frequency, vegetation type, land use capability) for an area would also assist in determining overland flow potential.

This review has examined how overland flow, and therefore the potential for contaminant loss to watercourses, is influenced by climate, landscape and land management factors. Ultimately all water and contaminants that flow from the land and into watercourses must pass through the riparian zone ((with the exception of some groundwater and artificial drainage flows which bypass the riparian zone completely to enter surface waters directly) and therefore how this area is managed is an important determinant of the actual amount of contaminant loss to watercourses through overland flow. Fencing of the riparian zone prevents stock access and reduces the risk of nutrient and faecal micro-organisms loss to overland flow from urine and dung deposited directly adjacent to the watercourse. Restricting stock access to the riparian zone can also reduce overland flow potential and sediment losses by preventing soil damage and erosion. In addition, the presence of ungrazed riparian vegetation (depending on extent and composition) can reduce contaminant inputs by intercepting, retaining and/or transforming nutrients, faecal micro-organisms and sediments in overland flow. More detail on riparian zone management is provided in an earlier review that examined the environmental effects of activities within the riparian zone (Ryder Consulting 2012).

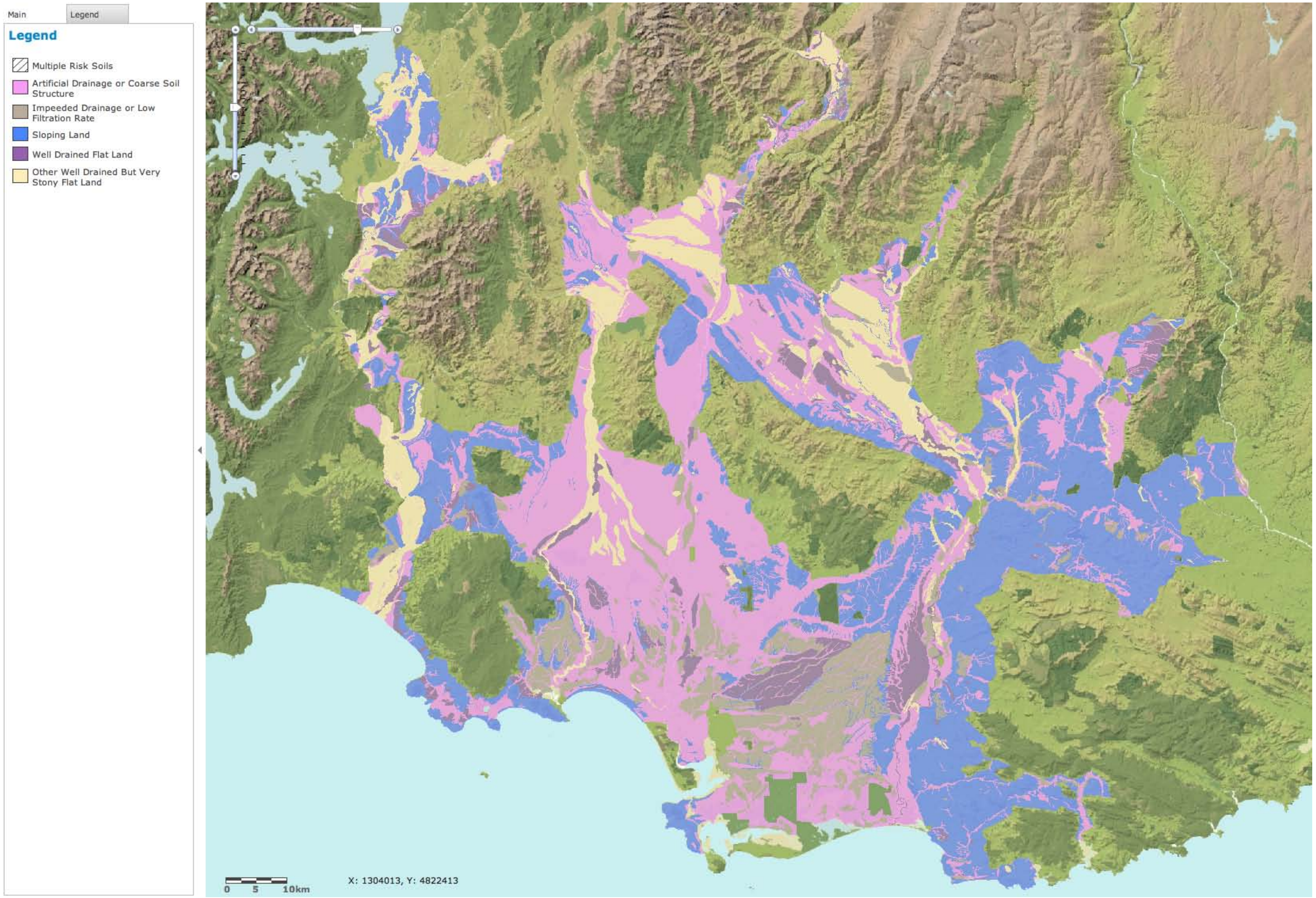

Figure 6 *Map of Southland showing how land slope and soil type could combine to influence the risk of contaminant loss from farm dairy effluent application in different areas. An version of this map that can be interrogated is available on-line via Environment Southland's Beacon mapping service at [http://gis.es.govt.nz/.](http://gis.es.govt.nz/)*

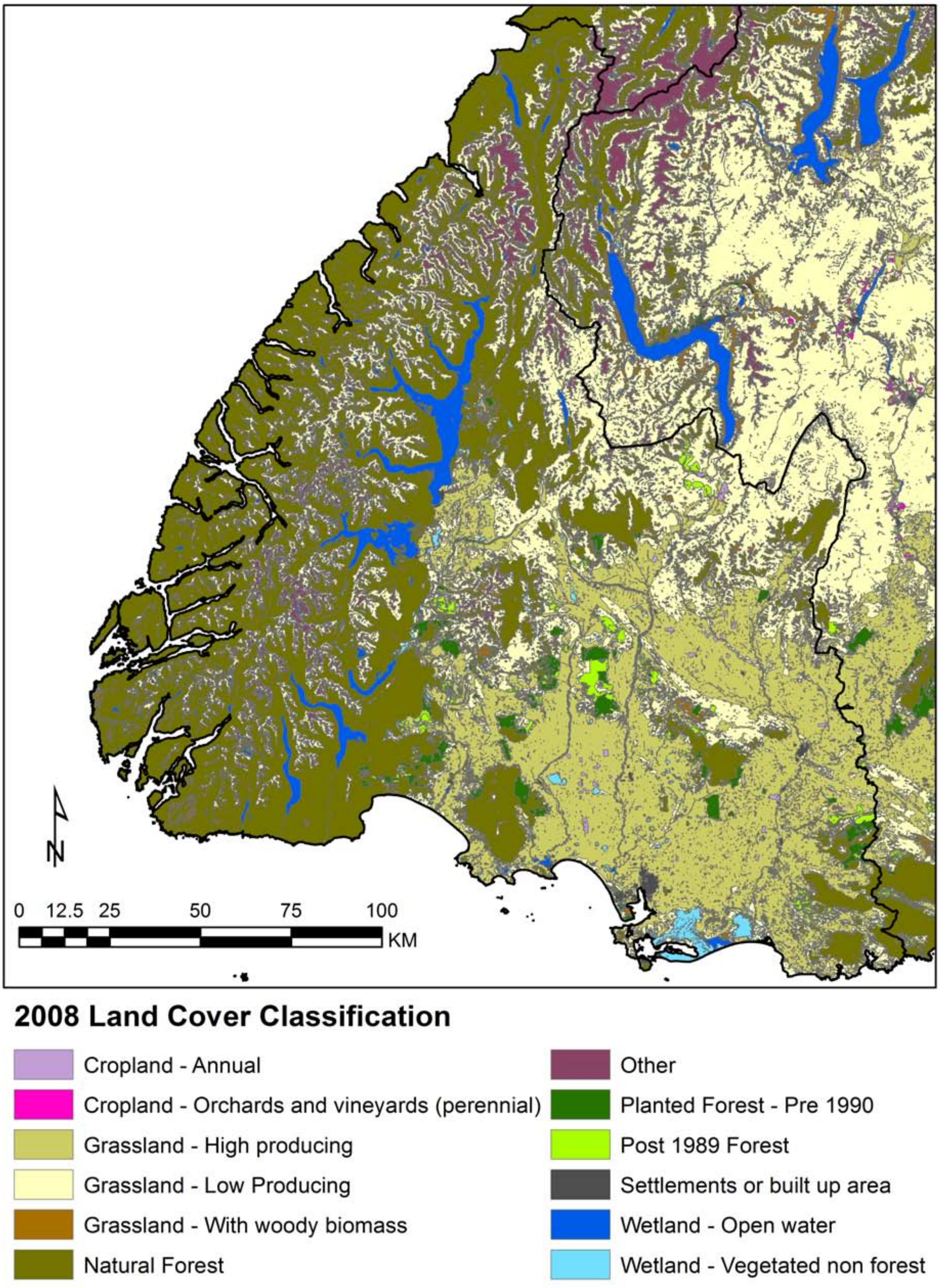

Figure 7 *Southland land cover classification in 2008, from the New Zealand Land Cover Database (data available from the Ministry for the Environment).*

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