# Synthesising water convergent zones for optimised farm contaminant mitigation

Adaption of the LUCI framework to map spatially explicit pathways for overland flow convergence in Waituna Catchment

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## Summary

Overland flow is cited as a key pathway for land based contamination to waterways in New Zealand and other parts around the world (McDowell, 2006; Deakin et al., 2016). However, ephemeral overland flow pathways generally converge before they reach a significant surface waterway or recharge groundwater. If mapped, the enhanced knowledge of these drainage pathways and areas of convergence across the landscape would assist regional councils and farmers to identify and prioritise where nutrient run-off could most effectively be mitigated for water quality improvement. This project evaluates whether Convergent Zone Mapping can be developed reliably through integrating existing information (high resolution Digital Elevation Models (DEMs), the River Environment Classification, soil data) to provide a hierarchy of place based priorities for applying mitigation strategies. The evaluation was carried out using the Land Use Capability Indicator (LUCI) modelling tool in the Waituna catchment in the Southland region of New Zealand. The LUCI tool was augmented to produce additional outputs that target zones of high accumulation of water, sediment and/or nutrients and Strahler stream networks and individual stream reaches of subcatchments. Areas of water convergence were identified to be widespread around the Waituna catchment. However, at large scale, priority should be placed where the cumulative flow is high, and this coincides with the fifth Strahler order. At farm scale priority should focus on all areas of flow convergence. Low lying areas where there was no water convergence are mostly covered by forest land cover types or are intercepted by these land cover types which mitigate overlandflow.

## 1. Introduction

Environment Southland has developed a comprehensive regional science programme to understand the landscape and its capacity for primary production while meeting the requirements of the National Policy Statement for Freshwater Management[1] (NPSFM). Policy being developed within Environment Southland, based on this science, will require farmers to mitigate contaminant losses to waterways, in order to "maintain or improve" water quality. Farmers must be provided with information that can assist them to optimally mitigate contaminant loss to meet environmental requirements essential for Southland's economy.

Targeted mitigation is therefore a key strategy for optimum land management. All major contaminants, nitrates, phosphorus, microbes and sediment are subject to periodic transport overland during rainfall events and consequently end up in waterways. Trying to protect the waterways through extensive riparian margins with ecological or engineering buffers is unlikely to ever be feasible. Therefore, it is necessary to find where protection of the Waterways provides the most benefit. The delineation of target areas for protection of waterways will provide useful guidance for devising appropriate and cost-effective mitigation strategies.

Overland flow is cited as a key pathway for land based contamination to waterways (McDowell, 2006; Deakin et al., 2016). However, ephemeral overland flow pathways generally converge before they reach a significant surface waterway or recharge groundwater (Helmers et al., 2005). If mapped, the enhanced knowledge of these drainage pathways and areas of convergence across the landscape would assist council and farmers to identify and prioritise where nutrient run-off could most effectively be mitigated.

This project evaluates whether Convergent Zone Mapping can be developed reliably through integrating existing information (high resolution Digital Elevation Models (DEMs), the River Environment Classification, soil data) to provide a hierarchy of place based priorities for applying mitigation strategies. The evaluation was carried out in the Waituna catchment.

Currently, there is no unified tool for convergent zone mapping that we are aware of, although the Land Use Capability Indicator (LUCI) identifies flow accumulation (convergent) pathways as a more integrated mitigation tool box (Jackson et al., 2013). The LUCI framework was used to support this

[1] The NPSFM provides direction about how local authorities should carry out their responsibilities under the Resource Management Act 1991 for managing fresh water. It's particularly important for regional councils, as it directs them to consider specific matters and to meet certain requirements when they are developing regional plans for fresh water.

mapping in Waituna catchment. The ultimate goal is to apply convergence zone mapping regionally as part of Environment Southland's NPSFM if it passes proof of concept in the Waituna catchment. Waituna catchment was chosen as a test site because of data richness, as it is one of the most intensively studied catchments in Southland. Moreover, it has a similar range in relief to other lowland catchments across Southland but not the same obvious topography as hill country or alpine areas. Therefore, if convergent zone mapping works within the Waituna Catchment it is likely to work across much of Southland.

## 2. Description of the LUCI model

LUCI is an ecosystem services support framework extended from the Polyscape framework (Jackson et al., 2013). It is a GIS-based negotiation tool that explores and indicates the capability of a landscape to deliver ecosystem services which vary as a result of changes in land management. Services considered include flood risk management, carbon sequestration, nitrate loading, sediment delivery, erosion management, agricultural production and biodiversity conservation through habitat connectivity. LUCI enables the visualisation of impacts that different decisions have on the delivery of the ecosystem services. It identifies areas of high existing value in terms of ecosystem service provision, areas where maximum benefits can be achieved following certain interventions and areas where intervention could reduce optimum delivery of services. Interventions for ecosystem service delivery are prioritised based on the area they affect as a whole, not just the areas directly modified.

Most LUCI algorithm calculations and valuations are produced at the resolution of a digital elevation model (DEM): many of its models require this resolution due to its topographical routing capabilities. Applications to date suggest that 5-10m DEMs provide sufficient resolution for making decisions at the field scale (Jackson et al., 2013; Ballinger, 2011; Marapara, 2016; Trodahl et al., 2017), and this is the scale used in this study. The potential of the landscape to provide benefits is a function of both the biophysical properties of individual landscape elements and their configuration. Both are respected in LUCI where possible. For example, the hydrology, sediment and chemical routing algorithms are based on physical principles of hillslope flow, taking information on the storage and permeability capacity of elements within the landscape from soil and land use data and honoring physical thresholds and mass balance constraints. LUCI discretizes hydrological response units within the landscape according to similarity of their hydraulic properties and preserves spatially explicit topographical routing. Implications of keeping the "status quo" or potential scenarios of land management change can then be evaluated under different meteorological or climatic events (e.g. flood return periods, rainfall events, droughts), cascading water through the hydrological response units using a “fill and spill” approach. These and other component algorithms are designed to be fast-running while maintaining physical consistency and fine spatial detail. This allows it to operate from subfield scale to catchment, or even national scale, simultaneously. It analyses and communicates the spatial pattern of individual service provision and tradeoffs/synergies between desired outcomes at detailed resolutions and provides suggestions on where management change could be most efficiently targeted to meet water quality targets while maintaining production.

Maps, tables and other outputs are generated by the LUCI water quality models allowing exploration of water flow and sediment, total nitrogen (TN) or total phosphorus (TP) loads and concentrations both in-stream and on land. A traffic-light system is generally used to distinguish between categorisations or hierarchies. In the context of water quality, this can seem counter-intuitive as rather than flagging a problem, red implies a significant “good” is present. Specifically, red implies high existing service provision, suggesting to practitioners and decision makers that they should STOP and think carefully before making any changes to land placed in this categorisation (bright and dark red distinguish between very high and moderately high existing service provision respectively). Orange suggests existing provision is poor but there is also negligible opportunity to significantly improve provision. These areas are flagged as not worthy of significant effort for either preservation or change. Green areas denote a “green light” to proceed with change as there is negligible existing service provision combined with an opportunity to significantly enhance service provision. Bright green suggests a higher opportunity to enhance service provision than dark green (both still being categorised as significant).

# 3. Methodology

## 3.1. Study site description

The Waituna catchment was chosen as the study site for convergent zone mapping. The catchment comprises of five sub-catchments, namely, Waituna creek, Moffat creek, Carrack creek, Craws creek and Lagoon margins catchment.

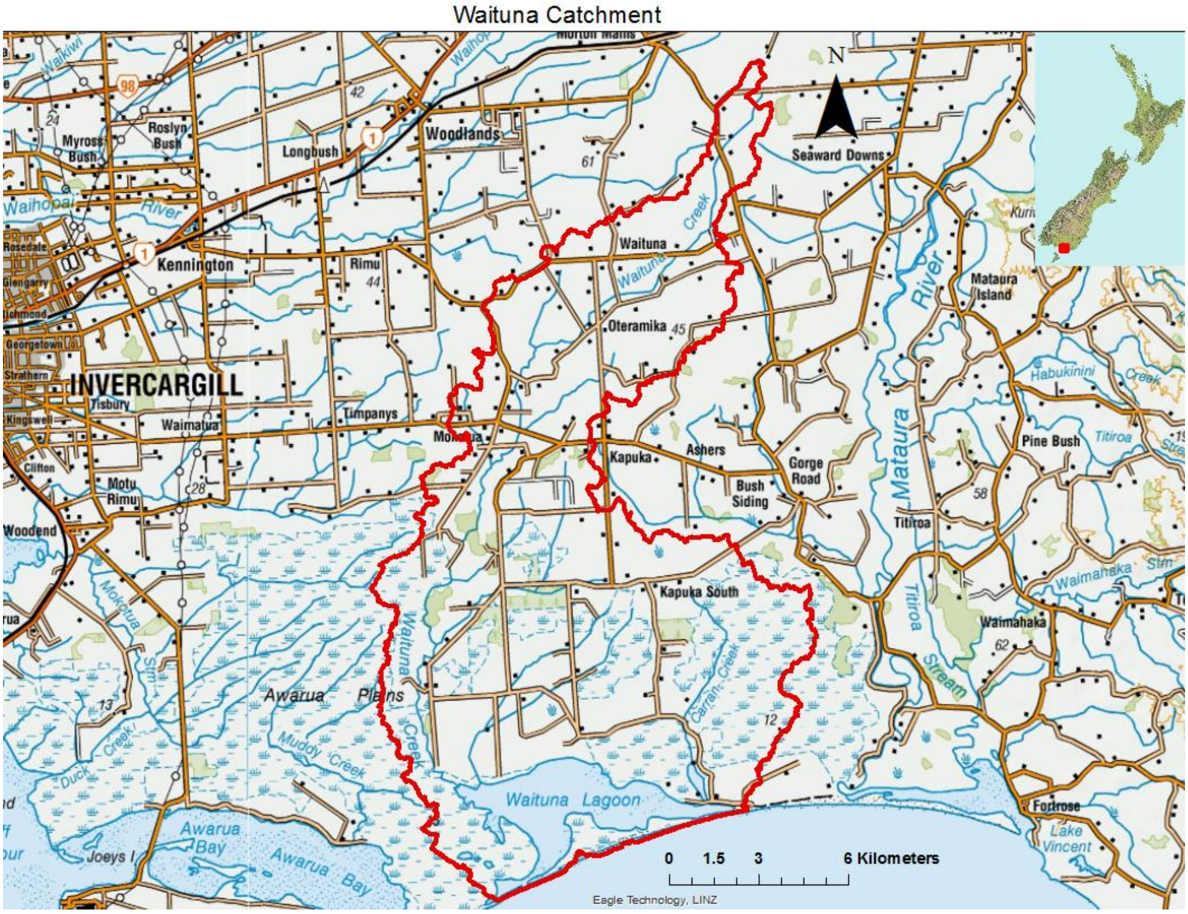


Figure 1 Map showing location of Waituna catchment

### 3.1.1 Rainfall

Rainfall in the catchment is fairly evenly distributed throughout the year, ranging from 960 to 1190 mm per year. Rainfall events, including higher intensity rainfall events that promote runoff are more common during the summer and spring period. Daily Potential Evapotranspiration (PET) is also highest during summer (4 mm) and lowest during winter (0.4 mm). The very low winter PET results in soil moisture levels that are close to saturation during July to September for most soils in the catchment. The catchment is more prone to surface runoff during high intensity rainfall events that occur during the summer period.

### 3.1.2 Topography

The topography of the Waituna catchment is fairly flat. Slope ranges from 0 to 10 degrees. Elevation ranges from 69 m in the far north of the catchment down to sea level in the south, over a linear distance of 27.5 km. Within this range there are some clear topographic features which manifest as distinct breaks in slope on an otherwise subdued terrain.

### 3.1.3 Landuse

The most widespread land use within the Waituna catchment is high production pasture (63%), followed by herbaceous freshwater vegetation associated with peatlands (15.3%). The LCDB-4.1 database shows a shift from 62% to 63% in high production grassland from 1996 to 2012. This change was accompanied by a small increase in low production grassland and a small decrease in freshwater vegetation, gorse and Manuka. Soils impart a fundamental control on drainage in the Waituna catchment. This is partly due to the thin unsaturated zone that exists throughout much of the catchment, including the upper Waituna Creek sub-catchment. By definition and supported by shallow bore water level measurements, the unsaturated zone is thin in the lower catchment, adjoining wetlands, and Waituna Lagoon. The unsaturated zone thickens slightly towards the upper catchment, but the rising base of the shallow gravel aquifer keeps the water table close to the land surface. Having a thin unsaturated zone and moderate to high hydraulic conductivity in the shallow gravel aquifer, means the drainage of soils would impart quite direct connection between the soil profile and the underlying aquifer.

### 3.1.4 Soils

Soils in Waituna catchment were better characterised by the Topoclimate survey of the late 1990s – 2000s (Hewitt et al, 2012).

The catchment is dominated by brown soils which cover 35% of the land area. These soils are imperfectly drained with the exception of the Waikiwi typic firm brown soil, which is well-drained. The next most abundant soil is the organic soil order, which is found in 32% of the catchment area. These soils have the potential for high phosphorous leaching.

Gley soils, associated with saturated anoxic conditions, cover 20% of the catchment. Podzols are the least abundant soil order in the Waituna catchment. The four podzols found in the catchment are all classed as pan podzols, and are imperfectly drained. Soils that are considered to have potential for nitrate leaching due to their high drainage rates or lower PAW are highlighted in blue. These soils are classed in S-Map as having a medium susceptibility for nitrate to leach beyond the root zone into groundwater. As outlined in the following, we also think the Waikiwi soils may be susceptible to nitrate leaching, partly on the basis of elevated nitrate nitrogen concentration in the shallow aquifer beneath areas of Waikiwi soils.

The Waikiwi soils are classed as having a low leaching vulnerability in the S-Map database, but are classed as vulnerable to leaching to groundwater in the Topoclimate database. Waikiwi series soils are the only soil type in the catchment which are considered to be well-drained. This suggests that they are more prone to nutrient loss through drainage, and are more likely to drain to groundwater rather than near-surface routing to tile drains. Accordingly, nitrate accumulation vulnerability in underlying shallow, oxic groundwater is largely associated with Waikiwi soils in the Waituna catchment.

Gley soils are a good indicator of prevailing saturated conditions, and the Waimairi, Longbeach and Eureka soils are all orthic gleys, which form in shallow groundwater conditions. These soils are quite widespread south of Caesar Road (see Orientation Map), indicating that the regional water table in the alluvial gravels approaches the land surface in the vicinity of Caesar Road. In addition to gley soils, the shallow water table manifests in the emergence of spring-fed tributaries of Waituna Creek (Maher Creek) and also at the headwaters of the Carran and Moffat Creeks. In the lower catchment, shallow water table areas, the soil types are either gley, podzol or organic.

### 3.1.5 Waituna Lagoon

Waituna Lagoon is an ~1.5m deep brackish, coastal lagoon that is fed by three creeks, drains into the sea through a managed opening and is cut off from coastal waters by a pea-gravel coastal barrier. The lagoon occupies an area of 1350 ha which is part of a 20 000ha internationally recognised Awarua wetland (Lincoln Agritech Report, 2016).

### 3.1.6 Ground water and subsurface drainage influence on the lagoon

Groundwater flow decreases from north to south as a function of the decline in land surface elevation. Groundwater was envisaged to play a minor role in the transport of nutrient loads within the Waituna catchment (Rissmann et al., 2012). The primary recharge input to the Waituna catchment groundwater system occurs via infiltration of local rainfall. Significant water discharge occurs via baseflow into Waituna Lagoon with a component of outflow directly into the lagoon or offshore (Rissmann et al., 2012).

## 3.2. Data used for LUCI modelling in the Waituna catchment

Input data covering the extent of the catchment was gathered. This included digital elevation model (DEM), stream network, land use/ cover and soil data.

### 3.2.1 Digital elevation model

Topographical attributes such as elevation and slope influence the speed and direction of water flow. When modelling water flow and accumulation, these attributes can be represented by a DEM. Therefore, precise representation of areas of flow convergence is influenced by the quality of the DEM. The quality of the DEM is in turn determined by the resolution (horizontal and vertical) at which the data is presented, the source or procedure used for measuring elevation, interpolation method, topography of the represented landscape, density and location of sampling points (Thompson et al., 2001). These factors are critical for modelling on gentle sloping or flat surfaces, where low resolution or otherwise inaccurate DEMs may inaccurately represent hydrological parameters, e.g. cause a reduction in the number and length of channels per area or otherwise misrepresent flow directions in the landscape (Thieken et al., 1999; Thompson et al., 2001).

Algorithm calculations in LUCI are produced at the resolution of a DEM, therefore DEM sources of varying grid sizes determine the accurate representation of the flat topography. Moreover, using elevation data acquired from different sources is critical for determining the reliability of the data sources and for exploring the accurate representation of the surface especially in landscapes where thick vegetation might interfere with the capture of true ground elevation. This study used an 8m horizontal resolution DEM, with a vertical precision of ~ 0.15-0.2m. The DEM was produced from resampling the 15m National DEM and combining it with LiDAR data.

### 3.2.2 Catchment boundary

The Waituna catchment boundary was provided by Environment Southland. However, the boundary was not consistent with the DEM and we had to discard some areas that did not produce Strahler stream order for convergent zone mapping, particularly on the margins on the west of the boundary.

### 3.2.3 Stream network and rainfall data

LUCI automatically generated a raster of stream network based on the calculation of flow direction and accumulation on the filled DEM. For rainfall data, average annual values were used. It is reasonable to assume uniform rainfall at the small scale of tens of hectares.

### 3.2.4 Land cover and soil data

Land cover/use and soil data sets that were used were derived from the New Zealand Land Cover Database 4.1 (LCDB-4.1) and the New Zealand Land Resource Inventory data base (NZLRI) respectively. The LCDB-4.1 is based on a remote sensing satellite imagery acquired in 2011-2012.

The NZLRI data base includes the fundamental soil layers (FSL) which contain soil attributes of the various land parcels in New Zealand. The soil attributes include drainage, soil moisture properties, chemistry, physical characteristics and environment parameters (Newsome et al., 2008). These attributes are important for the determination of water flow and retention in a landscape.

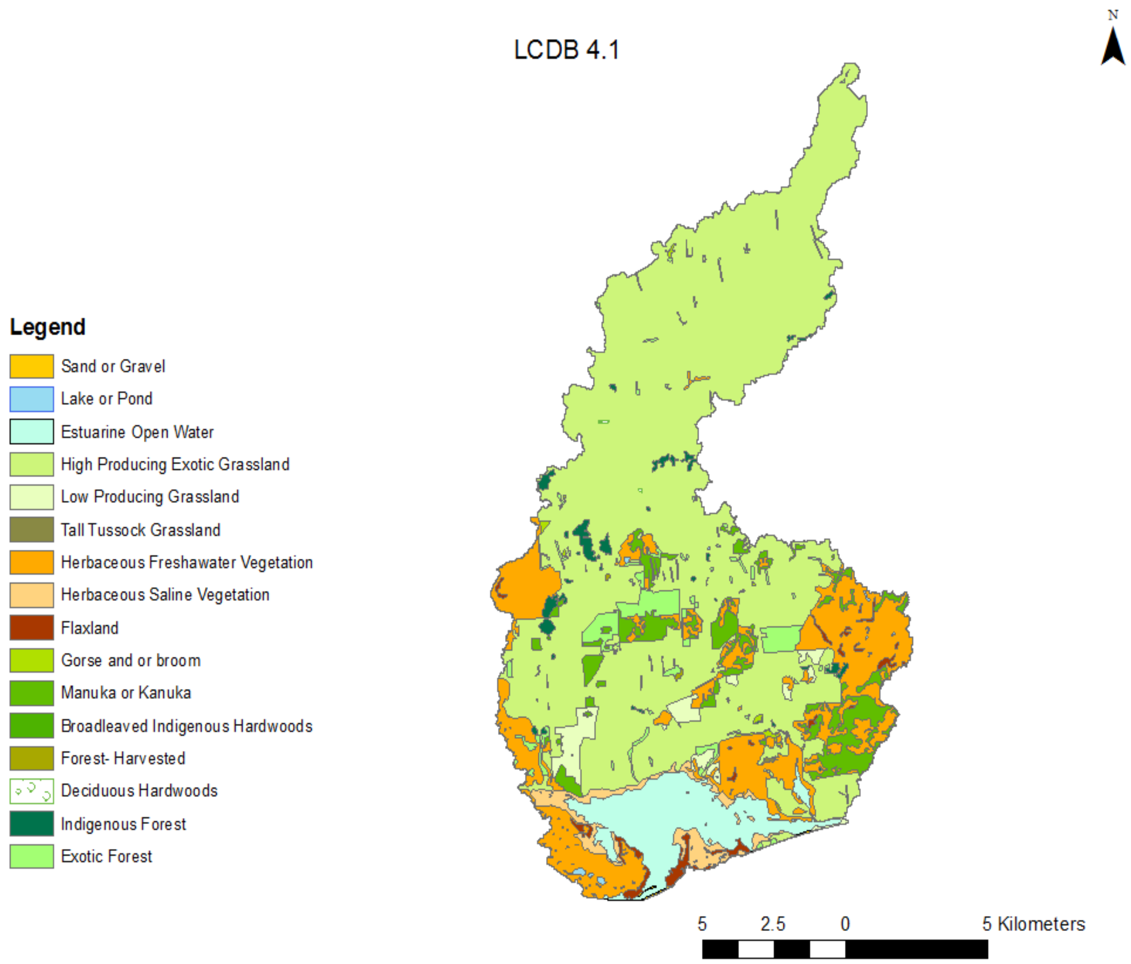


Figure 2 Map showing land cover of Waituna catchment as depicted by LCDB 4.1

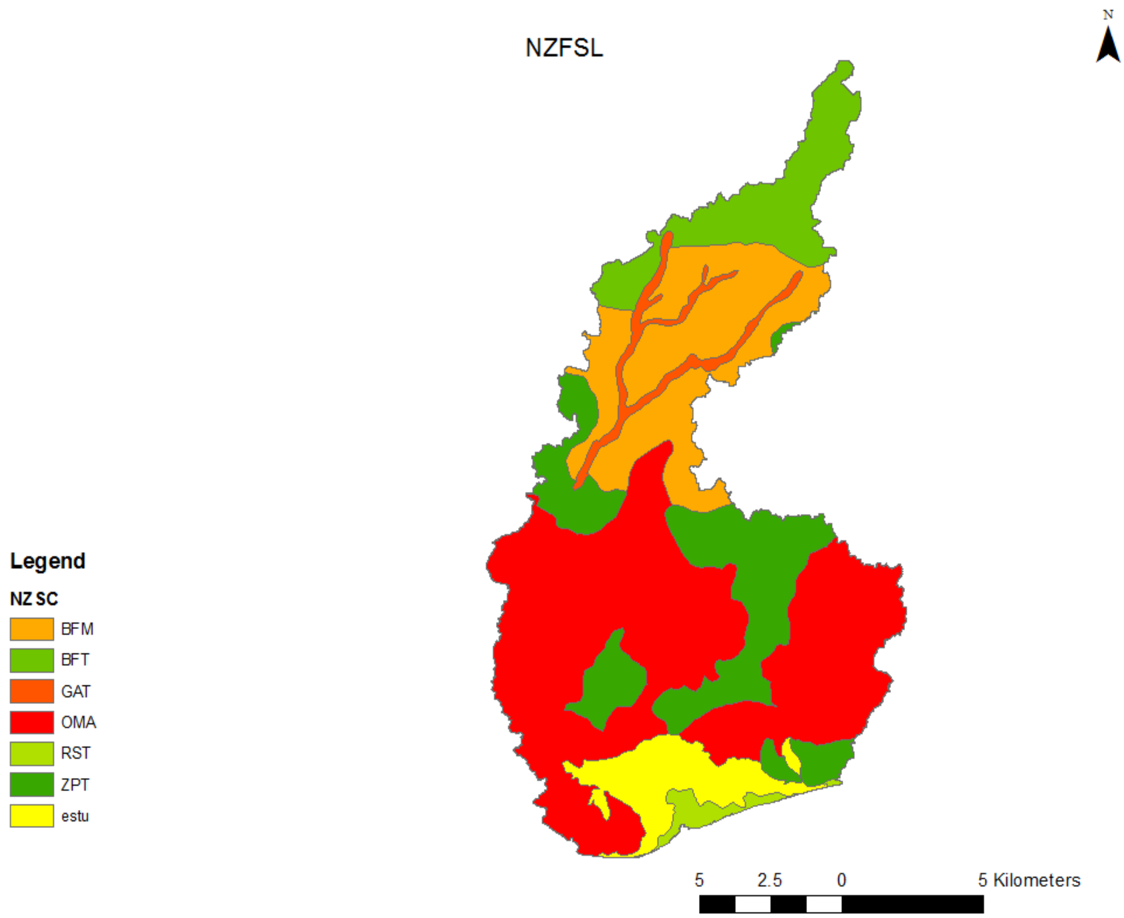


Figure 3 Soils in Waituna as depicted by the New Zealand fundamentals soil layer

## 3.3. Convergent zone modelling in LUCI

The flow and convergence of water transporting contaminants in landscapes is a function of climate, topography, soil type, geology, area of water bodies, land use and land cover type among others. A combination of impermeable compacted soils, high rainfall, uphill runoff contributing areas and impermeable bedrock geology results in high incidence of fast moving overland flow and rapid throughflow, raising the risk of significant flow and contaminants converging before reaching surface water bodies. In contrast, permeable soils overlying permeable bedrock and, receiving flow from uphill areas have the capacity to absorb and store much of this fast-moving overland flow and reduce flow convergence risk. On impermeable soils, flow attenuation can be achieved by practising land use management strategies such as tree planting or tillage changes that ameliorate soil properties for better water storage.

The LUCI tool evaluates flow accumulation based on physical principles of hillslope flow. The tool utilises a digital elevation model, stream network data, gridded rainfall data, land use and soil data as inputs. It derives information on permeability and storage capacity of elements within the landscape from soil and land use data. Overland flow attenuation is interpreted as a reduction in the flow reaching surface water bodies during large rainfall events. Based on the permeability and storage information, LUCI considers volumetric constraints on readily and total available plant water, infiltration capacity, maximum drainage rate, and drainable water holding capacity (the capacity of soil to hold water between field capacity and complete saturation). LUCI then discretises units within the landscape according to similarity of their hydraulic properties and spatially explicit topographical routing.

Using gridded annual or flood duration rainfall and evaporation data inputs, LUCI then calculates the average annual flow rates, or average flood flow rates (LUCI tools help document, www.lucitools.org). Alternatively, stream network data can be used if rainfall data is unavailable. This water is routed through the landscape using a bespoke algorithm that considers the aforementioned volumetric constraints on infiltration, drainage and available water. The direction of this routing is enabled by hydrologically conditioning the digital elevation model of the landscape. In this simple form, ignoring temporal variations in flow, all land use or soil types that absorb water, provide significant mitigation and are treated as of high existing value (sinks), and areas that are intercepted by these features are considered to be mitigated (Jackson et al., 2013). Impermeable areas where a large amount of unmitigated flow directly routes to water bodies are flagged as zones of convergence and target areas for change. Parameters to define thresholds for the “corrected” flow accumulation values are used to categorise priority areas for targeting change (Jackson et al., 2013). The default parameters were used in this application, assuming that landscape areas accumulating five times more water than was provided directly to them by rain are areas of least convergence, while areas accumulating more than twenty times the rainfall are areas of high convergence.

As part of this project, LUCI was augmented to produce Strahler stream networks[2] and additional outputs that target zones of high accumulation of water, sediment and/or nutrients. These output layers can be used to clip out zones of the landscape where the mass of interest is converging, to help with identification of areas with high mitigation potential. They are provided in vector (polygon) as well as raster form. These new outputs provide the key masks required to identify and target overland flow and rapid near-surface soil flow “convergence zones” in the landscape. They can also be interrogated in combination with the various physiographic data layers to explore land use suitability, impact of soils and geology, etc.

[2] The measure of relative size of streams. Streams are classified based on the size and number of tributaries. A stream with no tributaries is classified as first order. Stream order increases when streams of the same order intersect. When two first order streams merge, they form a third order stream. A third order stream only becomes a fourth order when it merges with another third order stream.

### 3.2.5 Sub-surface drainage network and groundwater level layers in convergence zone mapping

While the above convergence zone analysis targets overland flow and rapid near-surface soil flow as dominant pathways for contaminants, there are also other pathways such as drains and groundwater which if connecting to the convergence zones, provide further pathways that could transport a significant amount of contaminants. Areas where convergence zones interact with artificial drains are a concern. Tile drains are a necessity for maintenance of productivity of high producing pastures (which are typical of Waituna catchment. The risk of contaminant translocation is compounded where such sub-surface drainage is connected to the zones of convergence. Additionally, the risk of contaminant translocation also increases when there's a connection between convergence zones and groundwater. The shallower the groundwater, the more likely the connection to convergence zones and the higher the volume of water transporting contaminants.

At the time of this analysis, we lacked robust groundwater level and sub-surface drainage layers. However, for proof of concept and to provide a more complete tool for further convergence zone analysis work, we created artificial drainage and groundwater level layers from a combination of limited available data and interpolation methods. We used these to demonstrate a methodology to assess the relationship between convergence zones and subsurface drainage and groundwater dynamics. This additional functionality has also been built into the LUCI model; however, it is important to note that due to the data limitation, the assessment and results are only indicative.

Point groundwater data was provided by Environment Southland as height below surface. We interpolated groundwater depth using Inverse Distance Weight and Nearest Neighbour methods (3-point search for both) to produce maps of groundwater level. The two are shown to make the point that different interpolation methods produce different results; for demonstration purposes, we then carried out the following analysis using the IDW-interpolated groundwater level map. For robust results, the interpolation or model would need to be carried out by a groundwater expert with appropriate knowledge of the groundwater system, or a similar map produced by an appropriately validated groundwater model of the area.

Areas with groundwater level (GWL) < 3m were considered as connected to convergence zones; GWL 3-6m, moderately connected, and > 6m disconnected from convergence zones.

A subsurface drainage data layer was also provided by Environment Southland, derived from a combination of their physiographic information over the catchment and expert knowledge, with similar caveats to the groundwater level layer described earlier; for robust results, further time and mapping effort would be needed. The layer is an indication of the density of tile drains, from high to no artificial drainage in the catchment.

## 4. Results and Discussion

Convergence zone modelling output (Figure 4) shows that areas of very high convergence which accumulate 20 times more water than is provided to them by rain, are wide spread in the catchment. Areas of high convergence (accumulating 5 times more water) contribute cumulative flow to the very high convergent areas. High and very high water convergence areas are abundant throughout the catchment except on a few land parcels covered by deciduous hardwoods, indigenous forest, exotic forest, manuka or kanuka, flax and the lagoon (Appendix 1). Forest land cover types can reduce runoff and water accumulation through high interception and enhanced infiltration into the soil (Farley et al., 2005; Marshall et al., 2009; Archer et al., 2013; Marapara, 2016). This explains the absence of convergence zones in some low producing grassland areas that are intercepted by exotic forests and manuka/kanuka (Appendix 1).

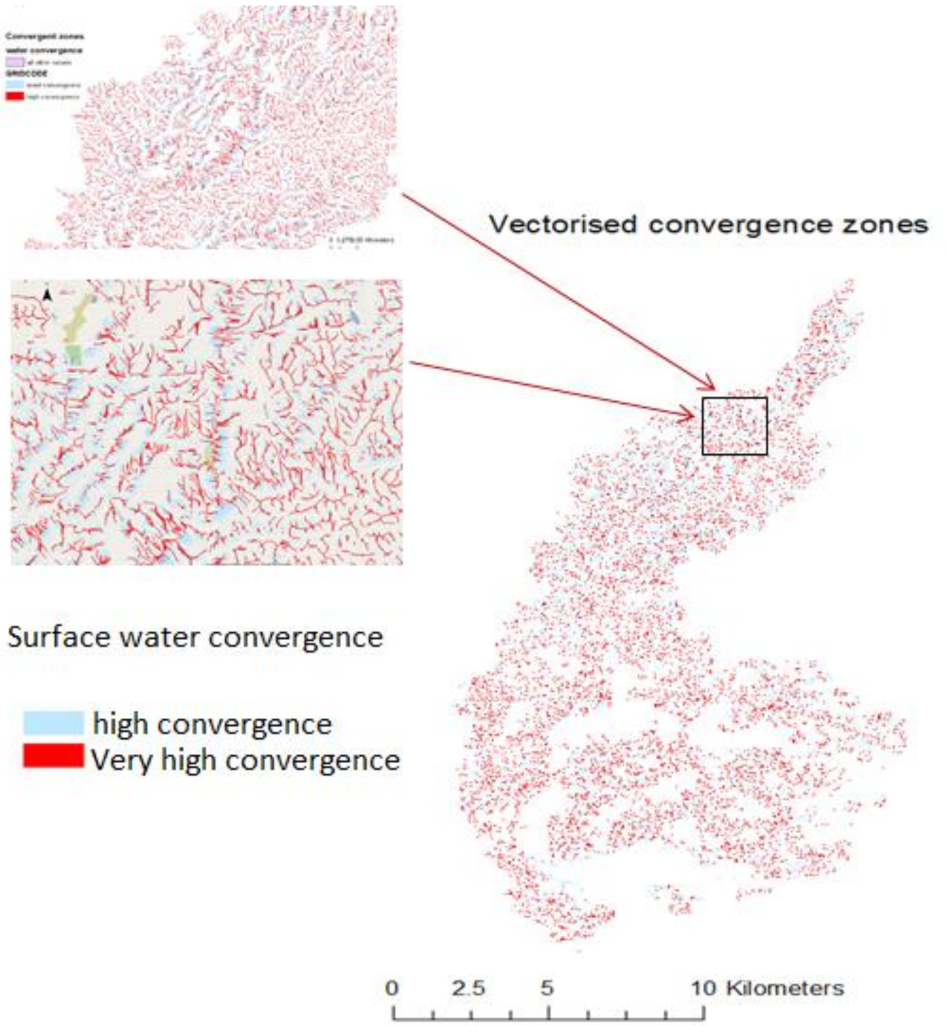


Figure 4 Areas of high and very high Convergence zones

Stream network delineation produced six Strahler orders (Figure 5). The upper catchment is dominated by 1-3 Strahler orders, while 1-5 orders dominate the west of the catchment, up to the 4th order on the east and up to the 6th order on the south. This is attributed generally to the low slope gradient in the south of the catchment where a larger order of stream networks exist. Strahler orders 1,2 and 3 are associated with average flows <0.1m$^3$/s, while order 4 is associated with 0.1-1m$^3$/s and orders 5 and 6 are associated with 1-10 m$^3$/s (Appendix 2).

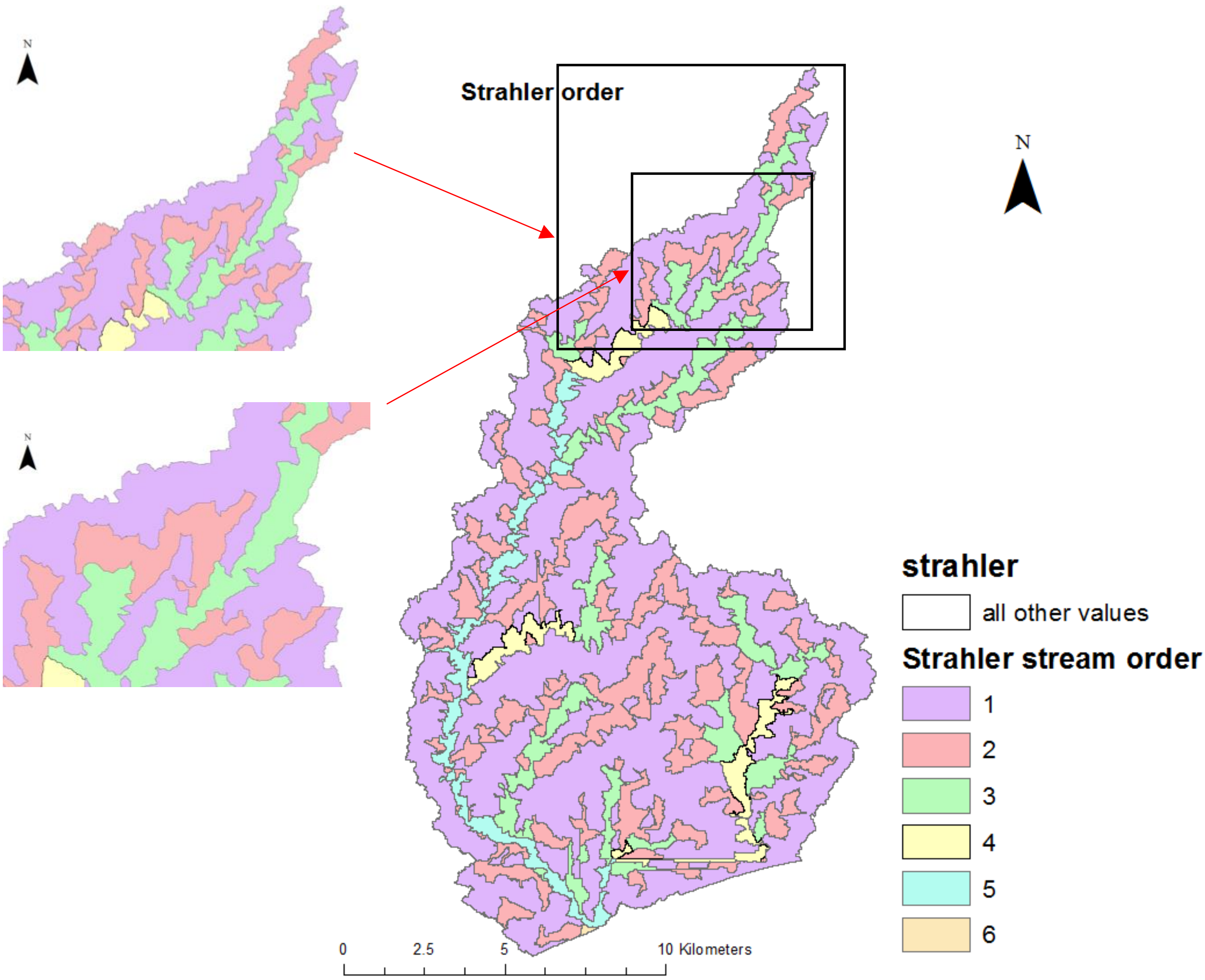


Figure 5 Stream network

Zones of high and very high convergence exist within all strahler orders across the catchment (Figure 6). Mitigation at catchment scale should however, target convergence zones in high Strahler order areas, particularly the 5th order where the average cumulative flow is high (1-10 $m^3/s$) (Figure 6; Appendix 2). At small (farm) scale, mitigation strategies can target convergence zones in whatever strahler order available.

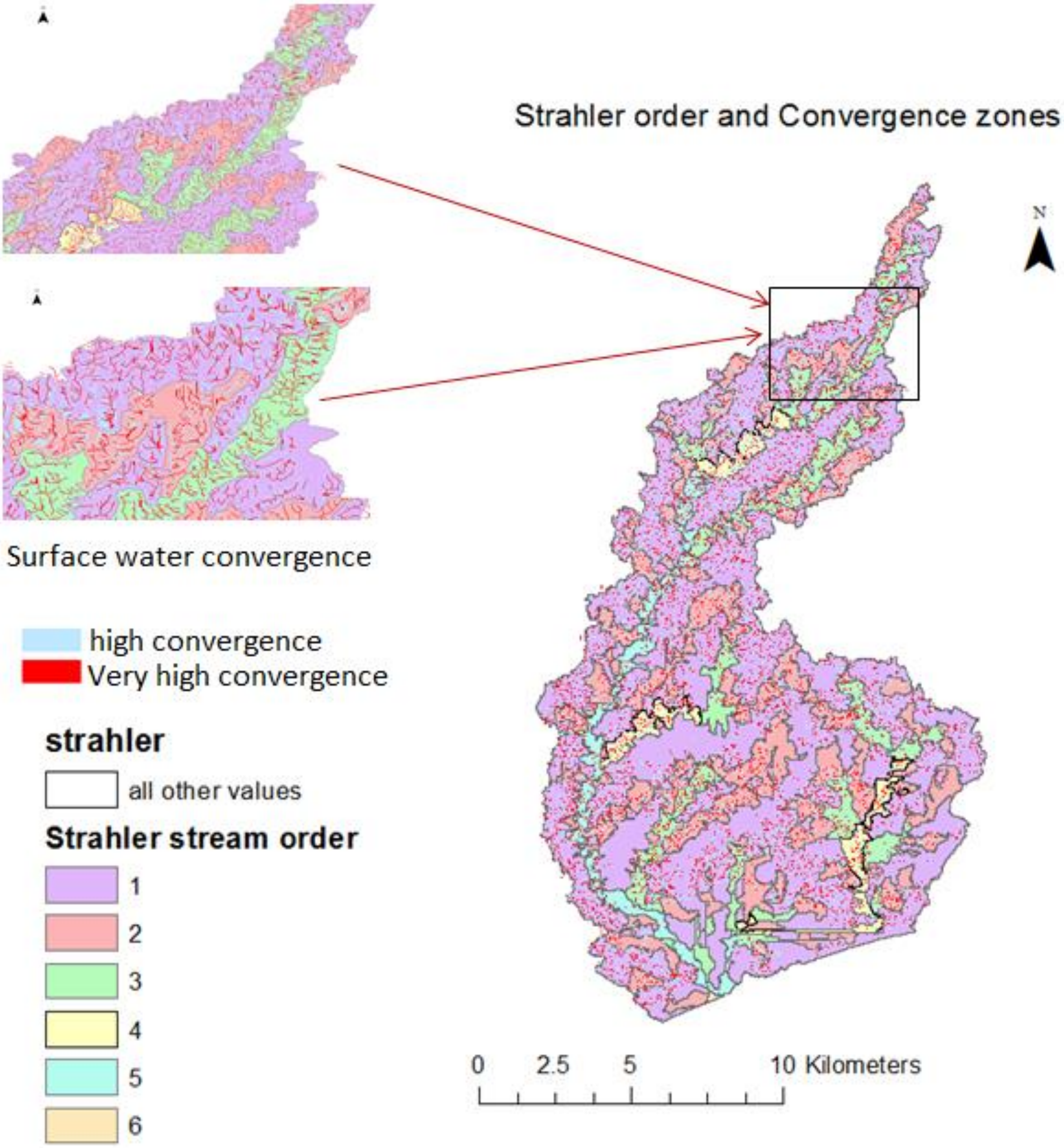


Figure 6 Map showing zones of convergence and Strahler stream order

## 4.1. Ground water level and artificial sub-surface drainage coincidence with convergence zones

The following results identifying where shallow groundwater and/or artificial subsurface drains interact with convergence zones are only indicative due to data limitations, and simplifications to generate proof of concept maps as discussed early. Notwithstanding this, areas where convergence zones coincide with shallow ground water are flagged as areas at high risk of significant contaminant loss to ground water (Figure 7, Appendix 3). These areas are most common in the northern, central and southern regions of the catchment (Figure 7, Appendix 3). Priority for mitigating groundwater contamination should focus on these areas (Figure 7). Of particular importance is the high risk of groundwater contamination in the area adjacent to the lagoon which is likely to be the source of pollutants for the lagoon (Figure 7, Appendix 3). This correlates with other research that has highlighted that discharge occurs via baseflow into Waituna Lagoon with a component of outflow directly into the lagoon or offshore (Rissmann et al., 2012).

Areas of high subsurface drainage density are scattered throughout the catchment, and particularly prolific in the southern region of the catchment (Figure 8, Appendix 4). Where surface convergence zones interact with high density of subsurface drains there is a high risk of contaminant loss to the drains. Drainage from these areas is likely to rapidly end up in the lagoon (Figure 8). It would be beneficial to target mitigations for water quality improvement in these areas, particularly to prevent further deterioration of the lagoon.

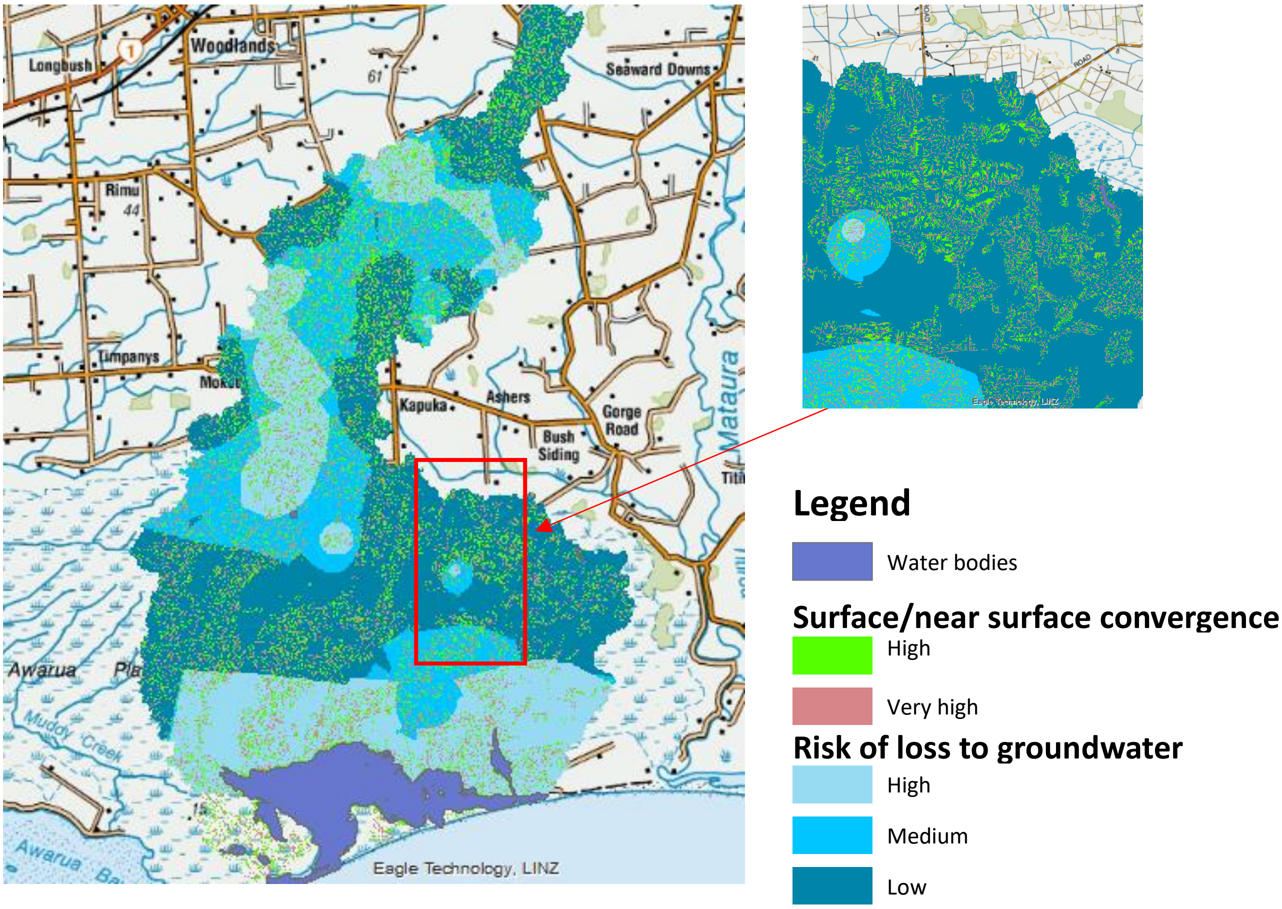


Figure 7 Ground water and convergence zones interaction

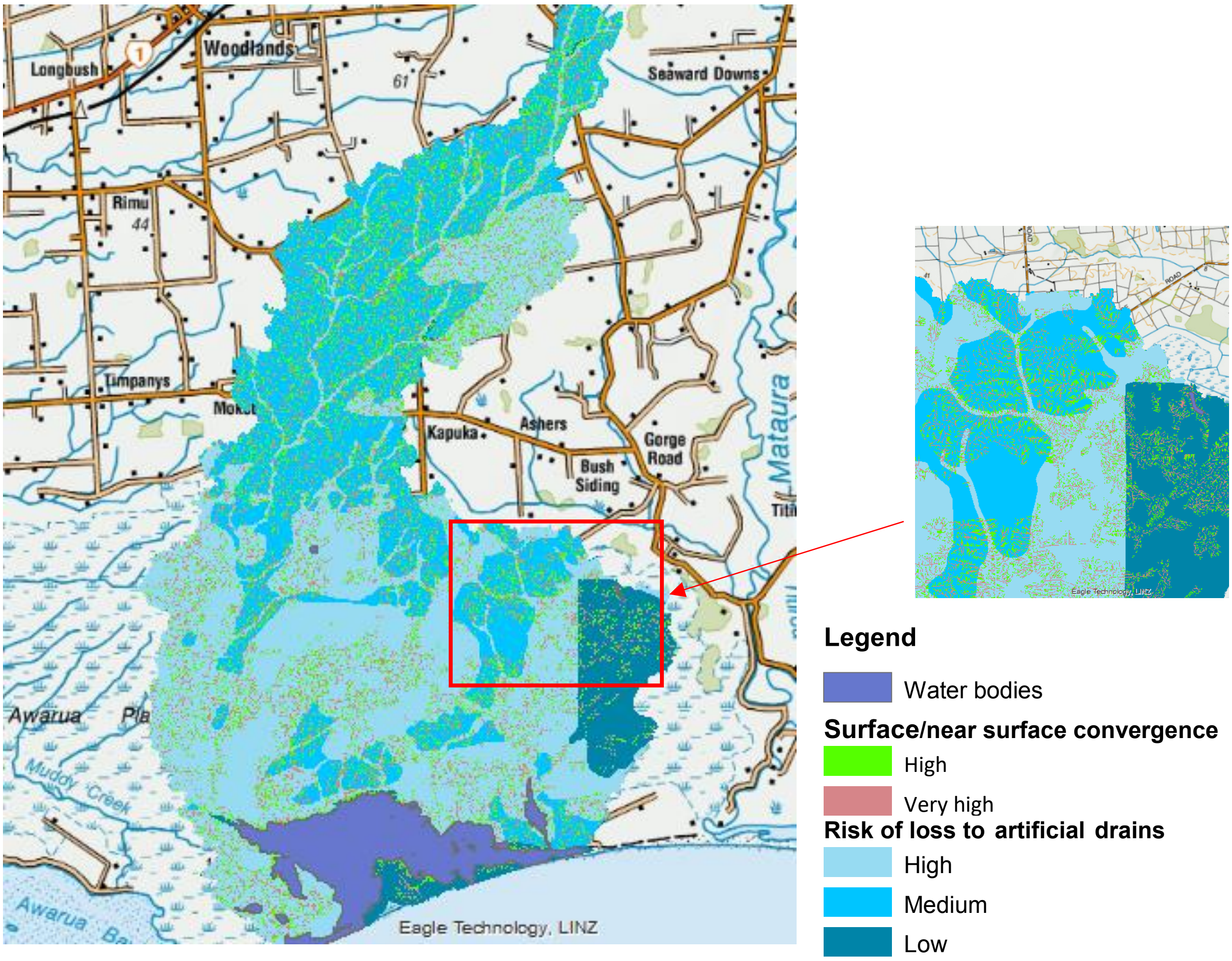


Figure 8 Subsurface drainage and convergence zones

## 5. Conclusion and Recommendations

The Land Use Capability Indicator (LUCI) tool was augmented to produce additional outputs that target zones of high accumulation of surface and near-subsurface water, sediment and/or nutrients, further distinguishing contributions to Strahler stream networks of various orders and individual stream reaches of sub-catchments. These output layers can be used to clip out zones of the landscape where the mass of interest is converging, to help with identification of areas with high mitigation potential. They are provided in vector (polygon) form, along with supplementary raster data if desired. They can also be interrogated in combination with the various physiographic data layers to explore land use suitability, impact of soils and geology, etc. Areas of water convergence were identified to be widespread around the Waituna catchment. However, priority should be placed where the cumulative flow is high, and this coincides with the fifth Strahler order. Low lying areas where there was no water convergence are mostly covered by forest land cover types or are intercepted by these land cover types which mitigate overlandflow. The LUCI modelling tool can potentially be adopted for convergent zone modelling at regional level if appropriate input data is available.

Although the surface and rapid near-surface soil flow pathways targeted in the main analysis are generally likely to provide a good indication of potential for efficient mitigation targeting, the method would be further enhanced by also considering where such pathways coincide with shallow groundwater and/or artificial subsurface drainage. Where artificial drainage coincides, the risk of significant contamination reaching waterways is further increased. In the case of groundwater connections being achieved, there may be either positive or negative implications for contaminant transport depending on the flow paths and chemical transformations particles encounter enroute to surface water bodies again. We recommend the improvement of subsurface representation by inclusion of robust tile drainage and spatially explicit groundwater depth data to maximise the information provided by this research. This will enable evaluation of how artificial sub-surface drainage and groundwater affects convergence zones and inturn help in decision making for optimum contaminant management.

A programme of careful groundtruthing to establish any discrepancies between predictions and observations in the Waituna catchment would be useful. However, previous work in NZ and elsewhere suggests that as long as soil and topographical inputs are reasonably accurate, LUCI generally performs very well in predicting near surface water accumulation.

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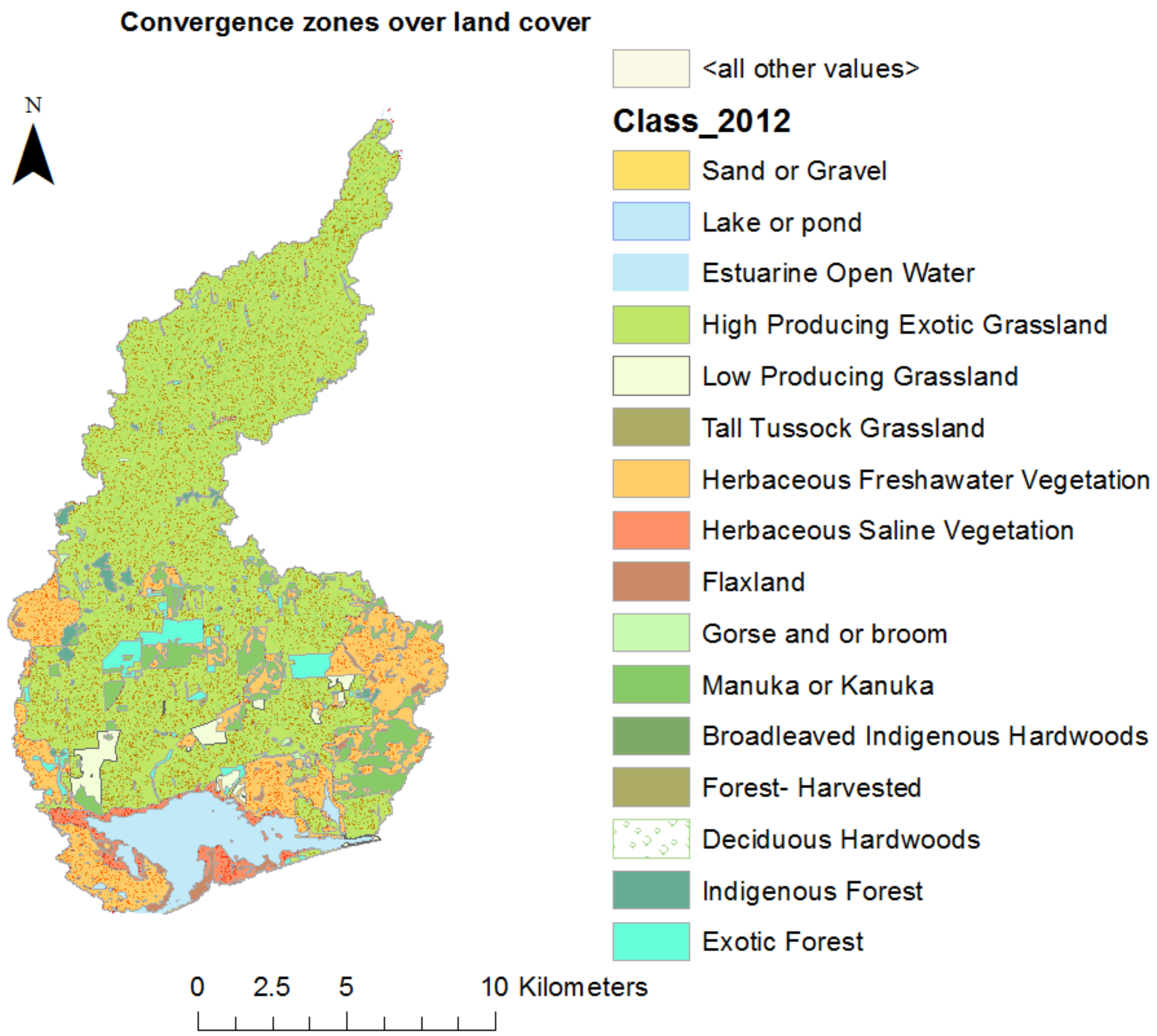
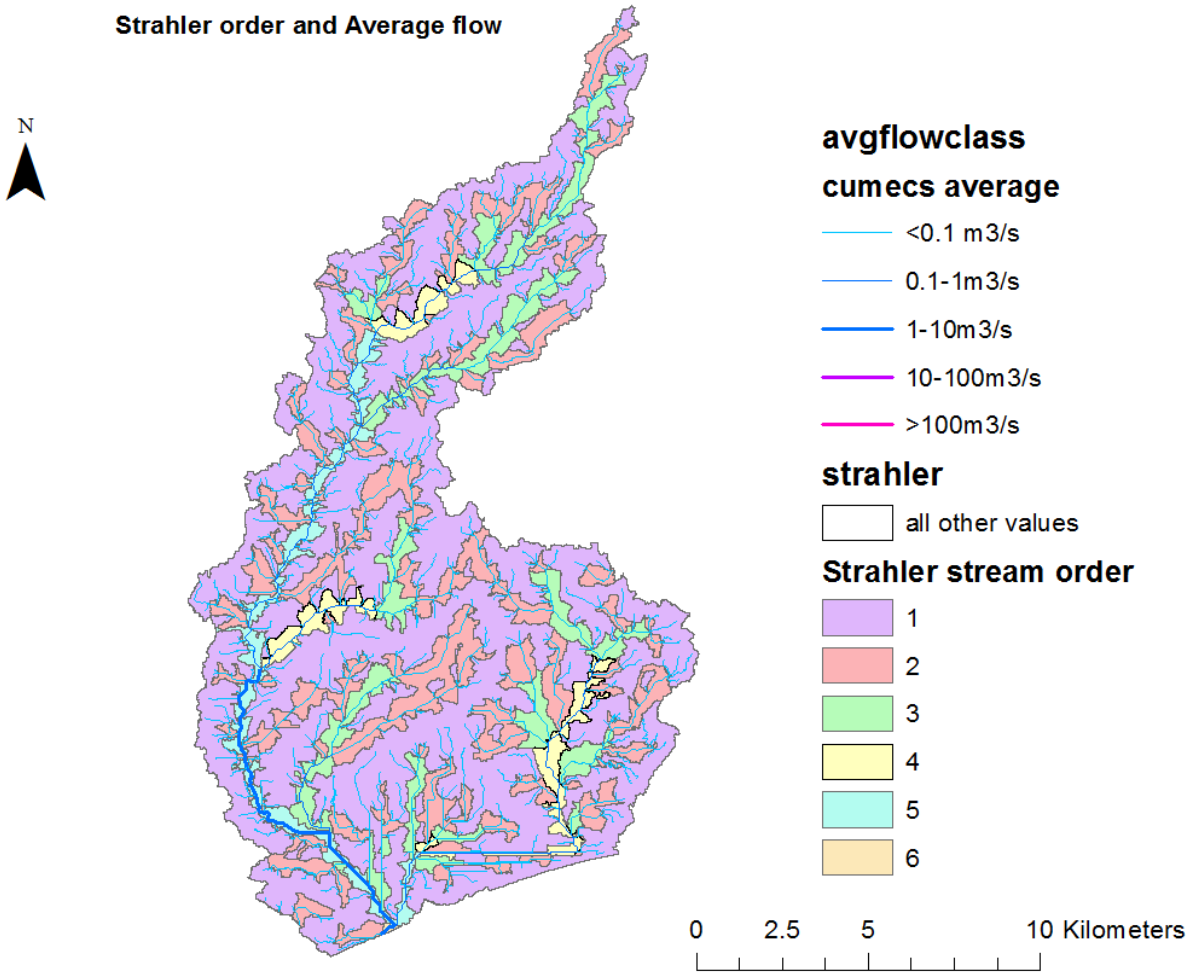
# 7. Appendices

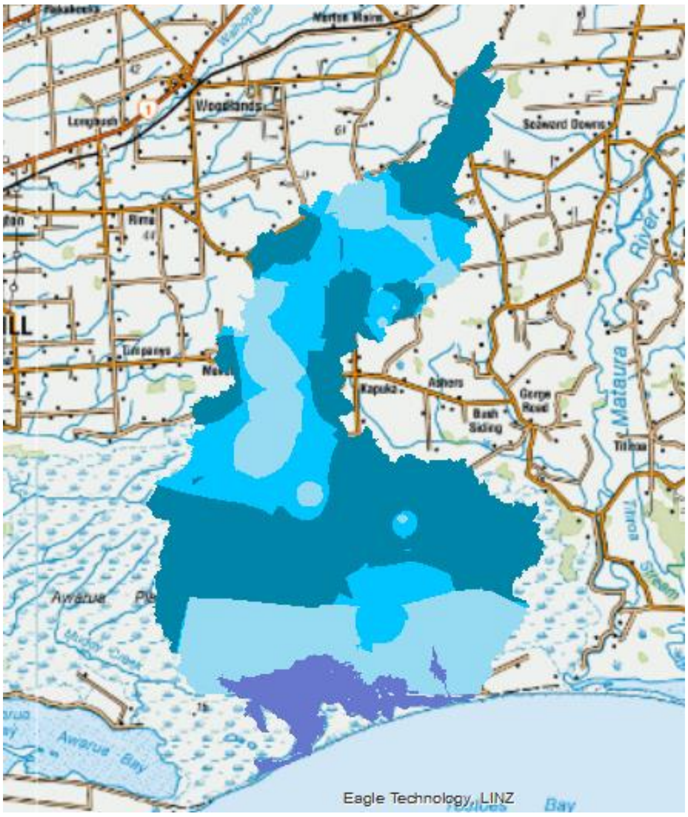
Appendix 1



Appendix 2


Strahler order and Average flow
N
avgflowclass
cumecs average
<0.1 m3/s
0.1-1m3/s
1-10m3/s
10-100m3/s
>100m3/s
strahler
all other values
Strahler stream order
1
2
3
4
5
6
0 2.5 5 10 Kilometers

Appendix 3




IDW

## Legend

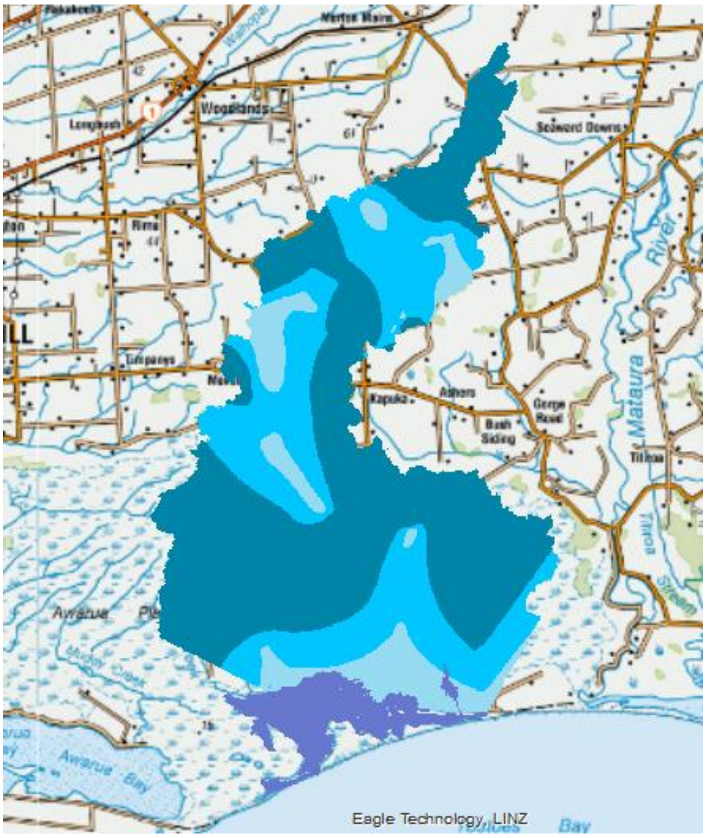
Water bodies

## Risk of loss to groundwater

High

Medium

Low




Nearest neighbour

Appendix 4

Artificial drainage