Farming, Food and Health. First™
Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Nutrient losses within the Manuherikia Catchment

RE500/2015/016

June 2015

New Zealand's science. New Zealand's future.

Nutrient losses within the Manuherikia Catchment

Report prepared for Golder Associates (NZ) Limited

June 2015

Natalie Watkins, David Wheeler, Matthew Brown, Chris Smith and Harry Yoswara.

Table of Contents

EXECUTIVE SUMMARY

The Manuherikia Catchment Water Strategy Group was formed in 2011 to investigate the best way to utilise the water resource within the Manuherikia catchment for the joint benefit of the various farm enterprises and the environment. A feasibility study investigating how water could be used efficiently and sustainably is currently underway. AgResearch has been sub-contracted by Golder Associates (NZ) Limited (Golder) to contribute to the water quality assessment by providing OVERSEER® Nutrient Budget (hereafter referred to as OVERSEER) analysis and interpretation.

The purpose of this report is to describe the process undertaken using OVERSEER to assess current and potential nutrient losses from the Manuherikia catchment. The report outlines previous OVERSEER modelling within the Manuherikia catchment and then discusses a series of case study farms that were set-up to gain an understanding of current and future nutrient losses within the catchment under different irrigation management systems. The case study farms were then used in a catchment scaling-up process to produce catchment nutrient loss maps. Three scenarios were modelled 1) current land use and irrigation, 2) future land use with no increase in storage, but a move to more efficient irrigation and 3) future land use with potential maximum development associated with increased storage.

The analysis of the individual case study farms showed that 1) nutrient losses are strongly influenced by irrigation management practices and 2) an efficient irrigation system can have lower nutrient losses than an inefficient irrigation system. However, the influence of irrigation management on nutrient loss needs to be assessed on a case by case basis as there is still a strong interaction between stock type, management and nutrient loss susceptibility (particularly nitrogen (N) leaching). This interaction was highlighted in the catchment scale-up process. The inherent N leaching susceptibility maps, which are based solely on inherent climate and soil conditions and the irrigation GIS layer with no management information considered, showed that N leaching potential reduced as we moved from areas under contour (controlled) irrigation to area's under efficient irrigation systems.

When farm management information (i.e. the case study farms) was incorporated into the scaling up process to the catchment level, the differences in total N leaching losses between the 'current scenario' and the 'future – with storage scenario' are almost negligible. This highlights that the net impact (cumulative effect) of changes in an irrigation scheme in a catchment is a function of the changes in stock intensity (increase in dairy farming) and changes in the area irrigated and the water use efficiency of the

irrigation system. When comparing the 'current scenario' with the 'future – with storage scenario' we are seeing a reduction in the high (>30 kg N/ha/yr) N leaching categories (less red area's), coupled with an increase in the medium-high (11-30 kg N/ha/yr) N leaching categories. Overall the net effect is a minor decrease (0.4%) in total N losses.

The case study analysis results showed that soil P loss risk within the Manuherikia catchment is low. The case study farms showed that moving from 'current' inefficient irrigation systems to 'future' efficient irrigation systems reduced P loss, mainly from the reduced loss associated with irrigation outwash.

It is recommended that the results of the catchment scaling-up process are only assessed at a catchment level and not at the individual farm level. The nutrient loss maps have highlighted that accurate farm management data in terms of stock grazing timing, numbers and type is important to accurately reflect individual farm nutrient losses. The scaling-up process is based on a small number of generic OVERSEER farm management files and therefore a recommendation to improve estimates would be to establish a wider range of OVERSEER farm management files and improve allocation of the different OVERSEER farm management files to ensure these files are better allocated across the catchment to more accurately reflect the geographical spread of different farm management systems.

This highlights that the net impact (cumulative effect) of changes in an irrigation scheme in a catchment is a function of the changes in stock intensity (increase in dairy farming) and changes in the area irrigated and the water use efficiency of the irrigation system.

1. INTRODUCTION

A feasibility study is currently underway in the Manuherikia catchment with the aim of providing options for water storage and distribution for irrigation within the catchment, while ensuring Central Otago's economic and environmental interests are addressed. The Manuherikia catchment is located in Central Otago (Figure 1). The headwaters of the Manuherikia River are in the far north west of the Central Otago region, with the West Branch draining the eastern side of the St. Bathans Range, and the East Branch draining the western flanks of the Hawkdun Range. The river continues southwest through the wide Manuherikia Valley to its confluence with the Clutha River at Alexandra.

A key component of ensuring environmental interests are addressed is an understanding of current and potential nutrient losses from the Manuherikia catchment. AgResearch has been subcontracted by Golder Associates (NZ) Limited (Golder) to contribute to the water quality assessment by providing OVERSEER® Nutrient Budget Model *(*hereafter referred to as OVERSEER*)* analysis and interpretation. OVERSEER is an agricultural management tool which assists farmers in examining nutrient use and movement within a farm. OVERSEER calculates and estimates the nutrient flows in a farming system and can be used to identify where efficiencies in managing nutrients can be made, as well as the potential environmental impacts associated with losses via run-off, leaching, and greenhouse gas emissions (Wheeler *et al.,* 2003).

The aim of this report is to describe and interpret the OVERSEER analysis undertaken within the Manuherikia catchment at the individual case study farm level and in the scaling-up process to produce catchment nutrient loss maps. This report is structured in three parts; the first section covers previous OVERSEER modelling within the Manuherikia catchment, based on work completed by AgResearch for the Otago Regional Council (ORC), the second section outlines a series of case study farms that were set-up within the catchment and the final section covers the development of the Manuherikia catchment nutrient loss maps. Three scenarios were modelled to develop the catchment nutrient loss maps; 1) current land use and irrigation, 2) future land use with no increase in storage, but a move to more efficient irrigation and 3) future land use with potential maximum development associated with increased storage.

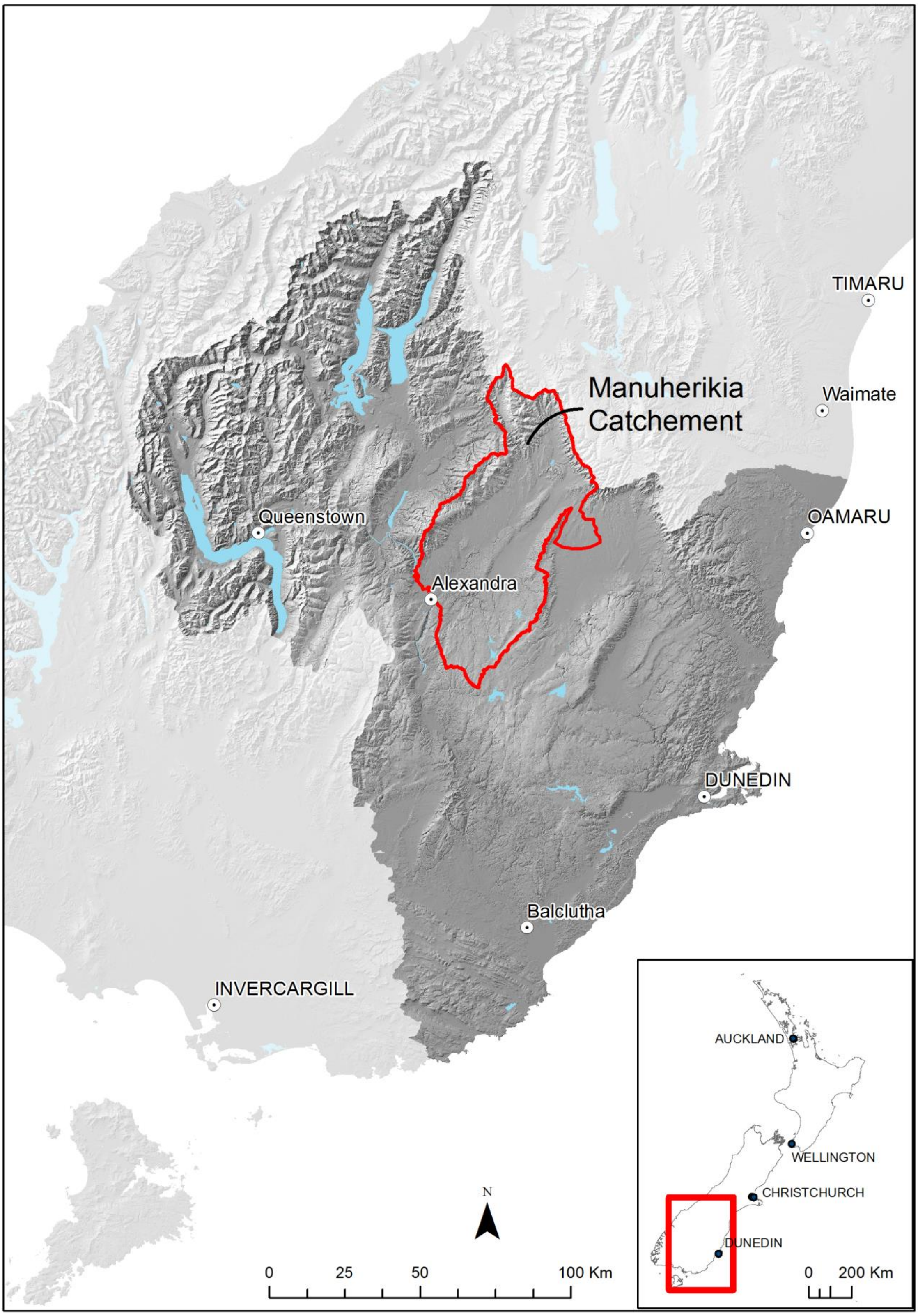


Figure 1: Location of the Manuherikia catchment in New Zealand

2. OVERSEER MODELLING WITHIN THE MANUHERIKIA CATCHMENT

2.1 Introduction to OVERSEER

OVERSEER allows nutrient budgets to be created for a large range of farm systems in New Zealand, from dairy farms to arable cropping and some horticultural operations. OVERSEER was developed with a set of key ground rules that are necessary to provide comparable results over time. For example, OVERSEER assumes the farm management system is constant, good management is practiced and the information entered into the model is reasonable and accurate.

One of the key features of OVERSEER is that it is based largely on information that farmers have or that can be readily obtained. Where this is not the case, suitable defaults are generally available. OVERSEER requires information about the farm at two scales: the farm scale and management block scale. At the farm scale the type of information required includes: location, types of enterprise (stock), structures present (feed-pads etc.) and feed supplements imported. Splitting the farm into management blocks is an essential part of correctly setting up the model. Management blocks within a farm system are defined as the sum of areas of the farm that are managed differently (e.g. irrigated, cropped, effluent applied), have different soil types, topography, fertiliser application rates or soil test values. At the management block scale the type of information OVERSEER requires includes: topography, climate conditions, soil type, pasture type, supplements used, fertiliser applied, irrigation applied or effluent management system. The nature of the information required will vary depending on the block type, i.e. pasture block or crop block (Wheeler and Shepherd 2013).

A key development focus for OVERSEER has been to incorporate a wide range of possible on-farm management practices including many that can be used to enhance nutrient use efficiency and/or mitigate environmental impacts. This ability to model different practices enables decisions to be made for farm management planning purposes.

The key strengths of OVERSEER is that it provides a very good indicator of farm nutrient 'balances' and nutrient management efficiencies. OVERSEER equips farmers to make sound decisions about nutrient management. Although OVERSEER can successfully model most farm systems, not all management practices can be accurately described.

OVERSEER can be used to assess nutrient losses from farm systems and catchment scale losses. OVERSEER can be used to determine catchment scale losses to the bottom of the root zone (60 cm; Wheeler and Shepherd 2013). However, to understand nutrient losses to groundwater, additional models are required that can determine nutrient transport through the vadose zone i.e. like 'Trim or CLUES'.

The Otago Regional Council plan change 6A (Water Quality) specifically refers to OVERSEER as the nutrient budgeting model that will be used to determine nutrient losses from a farm system. It is therefore likely, that the use of OVERSEER for all farm systems within the Otago region will increase significantly.

2.2 Otago Regional Council N leaching maps

An N leaching risk map for the whole Otago region was prepared by AgResearch for the ORC (Watkins, 2014). The intention was to provide information that would help better understand the influences of inherent soil and climate properties as well as their interaction with different land-use on N leaching. The process of developing the Otago region N leaching map is explained below.

AgResearch produced two maps focussing on N leaching losses for the Otago region. The first map utilised only the animal urine patch N sub-model within OVERSEER and the second map utilised the whole N model within OVERSEER (animal urine patch model + background N model). Within OVERSEER, N leaching is calculated by two processes; background N leaching losses and N leaching from animal urine patches. Background N leaching losses incorporate the effects of fertiliser use, effluent application and soil N cycling. The animal urine patch N model within OVERSEER is based on two components: 1) the amount of excreta (urine) N added and 2) the proportion of excreta N leached each month. In most pastoral farming situations, leaching from the animal urine patch is the dominant source of N loss.

N leaching losses are estimated monthly and reported annually within OVERSEER. Excreta (urine) N added is largely determined by management practices such as stock type and numbers, stock diet and timing of stock on pasture. The proportion of N leached each month is largely determined by site characteristics such as climate and soil properties that determine the drainage potential of that specific soil. A description of each map that was created is outlined below:

Map 1: Inherent N leaching risk from urine N inputs (Figure 3)

The aim of this map was to show the risk of N leaching specific to the urine N patch model within OVERSEER. A standardised input of urine N was assumed (100 kg N/ha), which meant that the proportion of N leached each month was only a function of the physical characteristics of the Otago region. No management effect i.e. different land use types, stock numbers or management practices were taken into consideration. The only management effect which was taken into consideration was the addition of the ORC GIS irrigation layer, due to the effect of irrigation on drainage. The purpose of this map was to highlight the areas of the region that are most at risk (sensitive) of N leaching regardless of existing or future management practices.

Map 2: Estimate of N leaching under existing land-use (Figure 4)

The aim of this map was to combine all relevant factors, including soil properties, rainfall/drainage, irrigation, stock numbers and type, existing land-use and management practices to produce a map of estimated N leaching for existing land-use. This map therefore utilised the background and urine patch N leaching models within OVERSEER.

The process to develop the maps, involved three key steps; OVERSEER files, geographic information systems (GIS) data and the development of a Dynamic Link Library (DLL) (Figure 2).

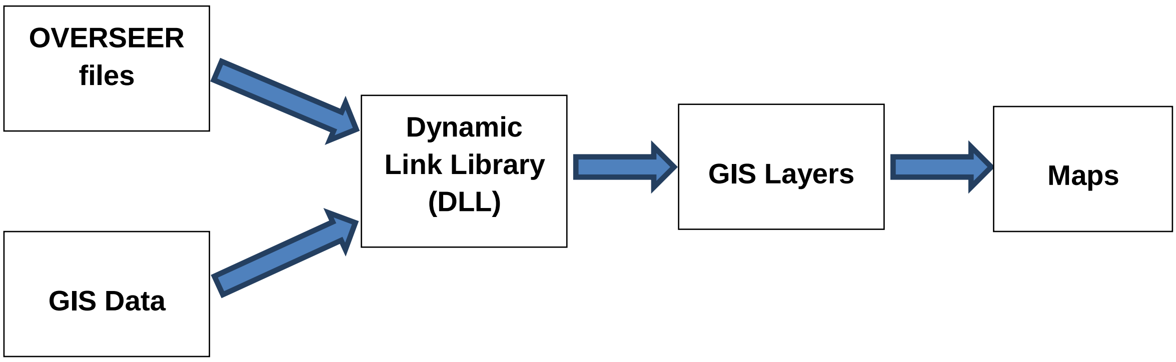


Figure 2: Overview of the process undertaken to develop the maps

A number of OVERSEER files were created using the development version of OVERSEER (February 2014). The development version was used as the methodology for creating links with the DLL was already understood and the urine N leaching risk factor could be included in the output. The dominant land uses chosen were based on Agribase™ data (2013). However, individual records may be older (as participating in Agribase™ is voluntary).

A large amount of the information required for the OVERSEER files was defined through the GIS layers or hard-coded in the DLL. The main information required in the establishment of the base OVERSEER files was an understanding of likely stock numbers and management practices to support the given farm systems.

The GIS layers used included Agribase™, GrowOtago (soil and climate information), Land use capability (LUC), slope and an irrigation layer supplied by the ORC. A number of the GIS layers were reclassified to reduce the size of the databases and processing times. The DLL used information from the OVERSEER files and input data from GIS layers. The DLL produced outputs of N loss, P loss and urine N leaching risk index, that were stored in a database table, which was then used to build the maps.

The two maps produced are shown in Figure 3 and 4. The inherent N leaching risk map (Figure 3) indicates that for the Manuherikia catchment the inherent risk of N leaching is low to moderate, this would likely be due to the climate of this region and the associated amount of expected drainage. The map showing estimates of N leaching under existing land use (Figure 4) indicates the Manuherikia catchment's current leaching losses are also in the low to moderate range.

A number of limitations exist based on how the ORC maps were developed and the quality of the information used; it is therefore crucial that these maps are only used for their original purpose of providing background information to better understand the influence of soil and climate features combined with land-use on N leaching risk. It is also important that the large scale of the map is taken into consideration. The current maps are definitely not applicable at a farm scale or even at most catchment scales as the level of input data is not specific enough. A number of steps could be undertaken to improve the quality of the maps, particularly for catchment scale modelling, where a much greater level of data resolution is essential.

Limitations and areas for future improvements for the ORC maps:

1. Allocation of representative farm systems across a region. Significant gaps exist in the Agribase™ data set, partly due to how data collection occurs (voluntary).
2. Farm system information within the OVERSEER files. Currently this is very generic and only a limited number of OVERSEER files were created to represent the farm systems within the Otago region.
3. Stock numbers: Improvements in the way stocking numbers are estimated and incorporated into the maps.

4. Irrigation entry into OVERSEER: Irrigation entered into OVERSEER is based on "best practice". This will be greatly overestimating the efficiency of these systems (therefore underestimating N leaching losses). Within the OVERSEER files created for the ORC work, irrigation was entered as method only i.e., no values were entered for irrigation rates applied. Using method only (leaving rates blank), means OVERSEER calculates the amount of irrigation water applied based on daily water balances required to replace the estimated soil water deficit. The calculated amounts are usually considerably less than actual irrigation rates applied on a long-term basis.
5. The irrigation GIS layer provided to us by ORC showed land parcels associated with water permits granted to take and use water for irrigation. The permits do not necessarily mean that the water is available and therefore able to be used. Furthermore, the irrigation GIS layer also doesn't differentiate between irrigation methods or provide information on the timing of irrigation events, as it does not distinguish between farmers who only get a limited amount of water over the shoulder periods and those who have reliable water all season, nor between centre pivot compared to border dyke. ORC and AgResearch decided the best approach for consistency was to assume all irrigation was via centre pivot and occurred between October and March. Irrigation rates within OVERSEER were left blank, which implies irrigation was applied as necessary to meet soil moisture deficit. This would underestimate the effects of irrigation in the region, in particular on border dyke irrigated land as this system is known to be less efficient.
6. Soil information: GrowOtago provides information on a limited range of soil properties. A wider range of soil properties, in particular better definition of areas with shallow stony soils, would improve estimates of N leaching. The use of S-Map will improve the quality of soil information, but at the time of the map development for ORC, S-map was not available for the Otago region.
7. To date there is a lack of research documenting N leaching losses from high (>1500 mm) and low (<600 mm) rainfall zones. This means that effect of rainfall is extrapolated out to these regions based on scientific principles. Further research in high and low rainfall zones would provide more information to calibrate and/or evaluate OVERSEER.

Improvements to the quality of land-use and management data are necessary before the map could be used to look at N leaching risks within specific catchments.

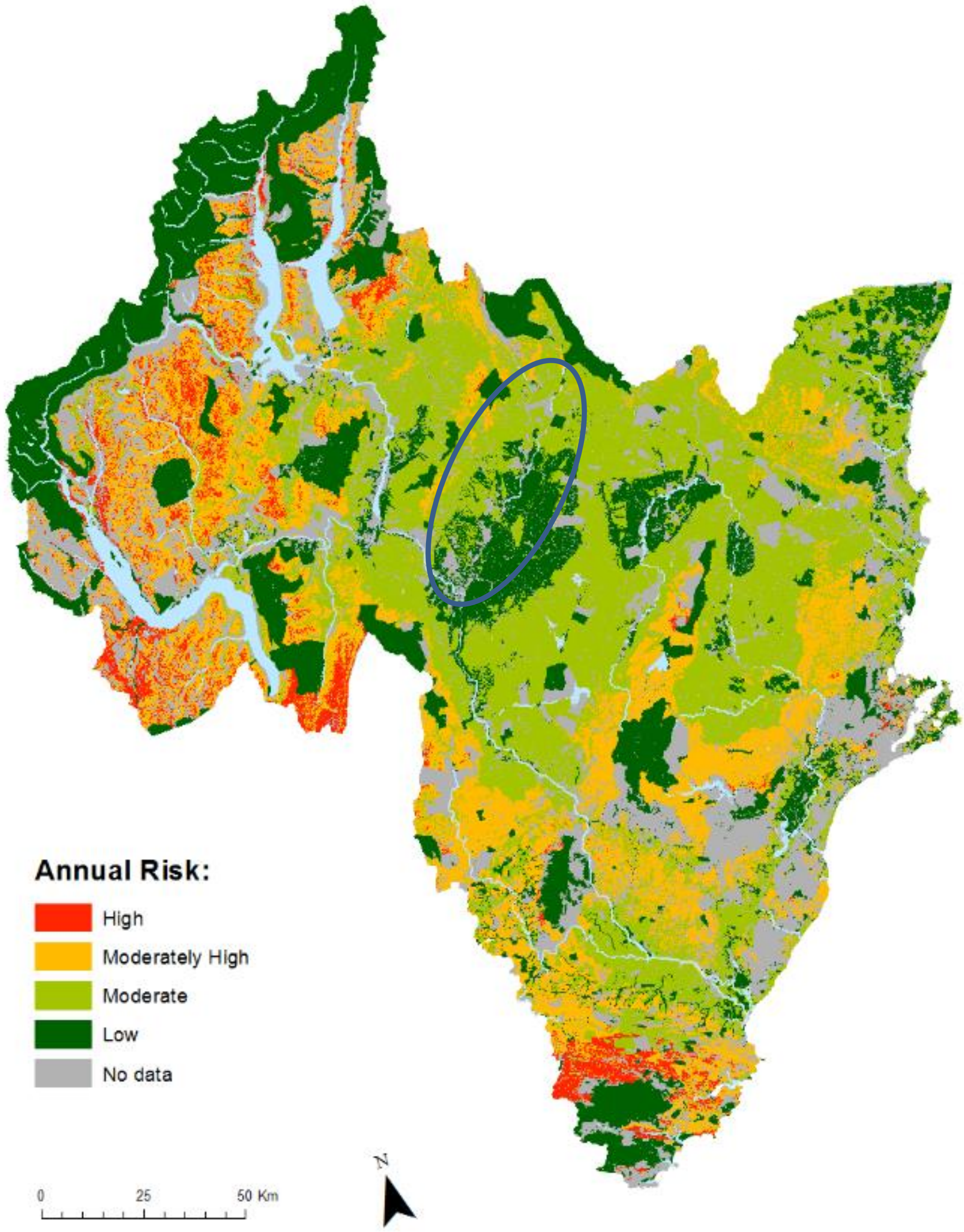


Figure 3: Inherent N leaching risk from urine N inputs. The blue circle approximately highlights the Manuherikia catchment.

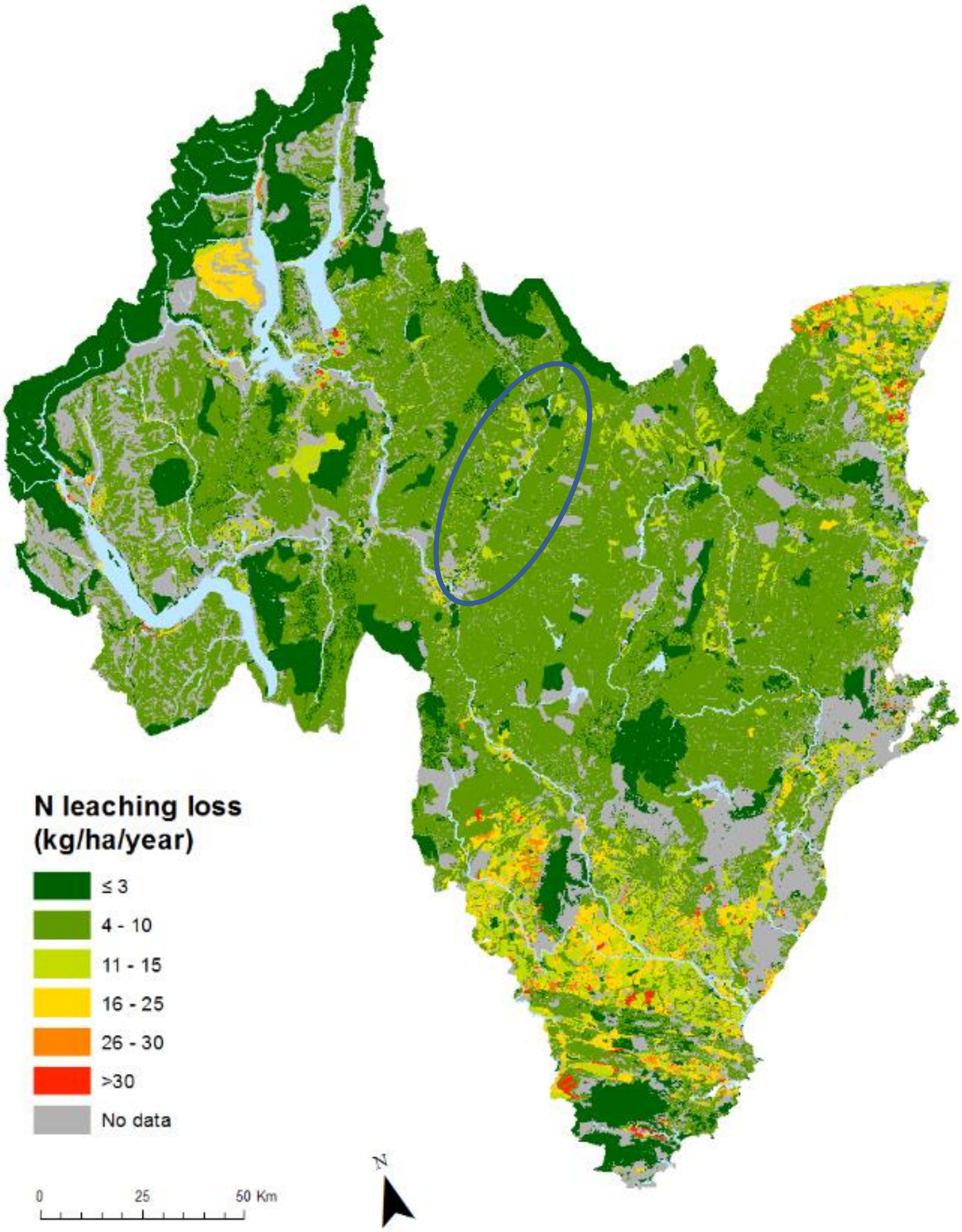


Figure 4: Estimate of N leaching under existing land use. The blue circle approximately highlights the Manuherikia catchment.

3. OVERSEER CASE STUDY FARMS

3.1 Introduction to case study farms

A number of case study farms were developed to gain an understanding of current and future nutrient losses within the catchment under different irrigation systems. The case study farms were also used in the scaling up process to produce the Manuherikia catchment nutrient loss maps. The sections below describe how the individual case study farm's OVERSEER files were developed and results reported in OVERSEER. Section 4 of this report describes the use of the case study farms in the scaling up process.

3.2 Creation of OVERSEER files

A number of OVERSEER files were created using the development version of OVERSEER (June 2015) to reflect the current and expected future farming systems in the Manuherikia catchment. The development version of OVERSEER was used because the methodology for creating the link with the dynamic link library (DLL) to develop the maps is understood. The outputs from the development version and the current publically available version of OVERSEER (6.2.0) will be very similar. The development version used and the publically available version of OVERSEER (6.2.0) have an updated irrigation module. The updated irrigation module has a wide range of management options available that can more accurately reflect on-farm irrigation practices.

The farm types chosen were based on information supplied by Compass Agribusiness Management Limited (Compass Agribusiness) in Arrowtown. The farm information and Farmax file (if available) was supplied to AgResearch to develop an OVERSEER file. The OVERSEER files created are listed in Table 1 and Appendix 1 outlines each farm system in more detail. The "OVERSEER Best Practice Input Standards" (OVERSEER, 2015) were followed to ensure the most appropriate information was obtained. OVERSEER defaults were used where necessary.

All farms were modelled as having similar effective farm areas, with the exception of the partially irrigated farm, where a large dry hill country block (800 ha) was also modelled as part of a 1000 ha farming operation. In terms of the individual case study farms, the climate and soil information was defined by the location of the farm used to develop the case study farm scenarios (Table 2). The climate station tool, based on NIWA virtual climate grid network, was used to determine rainfall. S-map (http://smap.landcareresearch.co.nz/home) was used to determine the predominant soil order. Irrigation information was provided by Golder. The current case study farms that were irrigated were assumed to have controlled flood irrigation with an application depth of 120 mm and a return period of 42 days. The future case study farms were assumed to have centre pivot irrigation systems with a trigger point at 60% of profile available water (PAW) and a target (refill point) of 95% PAW. Irrigation information is described in Table 3. All the remaining farm management information was determined by Compass Agribusiness (Appendix 1).

Table 1: Brief description of the OVERSEER files created

Farm Types	Farm Descriptions
<u>Current Farms</u>	
Existing dryland sheep	400 ha sheep farm, no irrigation, no crops.
Existing irrigated sheep	400 ha sheep farm, all irrigated (controlled flood), fodder crop grown (turnips).
Existing irrigated dairy support	400 ha dairy support farm, all irrigated (controlled flood), fodder crop grown (kale).
Existing irrigated mixed arable	400 ha mixed arable, all irrigated (controlled flood), sheep, barley and wheat.
Existing irrigated partially irrigated	1000 ha sheep farm, 200 ha irrigated (controlled flood), fodder crop (turnips) and 800 ha dryland.
<u>Future farms</u>	
Efficient irrigated dairy (also used as current system dairy farm)	400 ha dairy farm, all pivot irrigated. Friesen/Jersey cross cows (1280 at peak), 411 kg MS/cow, imports PKE, barley & silage, and a fodderbeet crop grown that is grazed in April, May, August and September..
Efficient irrigated sheep	400 ha, all irrigated (pivot), fodder crop grown (turnips).
Efficient irrigated dairy support	400 ha, all irrigated (pivot), fodder crop grown (kale).
Efficient irrigated mixed arable	400 ha mixed arable, all irrigated (pivot), sheep, ryegrass seed, barley, kale and wheat.
Efficient partially irrigated	1000 ha sheep farm, 200 ha irrigated with fodder crop (turnips) and 800 ha dryland.

Table 2: Climate and soil information for the case study farms

Farm Type	Location	Rainfall (mm/yr)	Annual PET (mm/yr)	Mean annual temp (°C)	Dominant Soil Order	Soil PAW* (mm to 60 cm)
Current farms						
Existing irrigated dryland sheep	Downs	550	912	9.4	Pallic	93
Existing irrigated sheep	Omakau MaWhinney	498	913	9.7	Gley	130
Existing irrigated dairy support	Omakau	423	912	9.6	Semi-arid	92
Existing irrigated mixed arable	Keddel	392	874	10.5	Semi-arid	92
Existing partially irrigated sheep	Hawkdun	596	873	8.9	Pallic	93
Future farms						
Efficient irrigated dairy	Omakau	423	912	9.6	Semi-arid	93
Efficient irrigated sheep	Omakau MaWhinney	498	913	9.7	Gley	130
Efficient irrigated dairy support	Omakau	423	912	9.6	Semi-arid	92
Efficient irrigated mixed arable	Keddel	392	874	10.5	Semi-arid	92
Efficient partially irrigated sheep	Hawkdun	596	873	8.9	Pallic	93

*Soil profile available water (PAW) for pasture blocks only

Table 3: Irrigation information used in the OVERSEER file development

	Irrigation type	Timing	Application depth	Return period	Trigger Point*
Current farms	Controlled flood	October – April	120 mm	42 days	n/a
Future farms	Centre Pivot	September - April	n/a	n/a	Trigger = 60 Target = 95

*Trigger point defines the soil water content that triggers and irrigation event. In the above table the trigger point is profile available water (PAW) at 60% and the target PAW is 95%. PAW is defined as the rainfall equivalent depth of 'total available water' within a specified depth in the soil.

3.3 OVERSEER nutrient budget results

The core of OVERSEER is a nutrient budget. A nutrient budget is a table of nutrient inputs and outputs moving into and from a particular physical identity (farm or blocks within a farm) throughout the year. In terms of outputs of a nutrient, this report focused on nutrient loss to water. Within OVERSEER this is defined as 'losses in water calculated to the 'edge of field', i.e. from the bottom of the root zone for leaching (60 cm) and from the paddock in surface run-off to second order streams. Attenuation processes in water bodies within the farm and beyond are not included. The exception is that attenuation in wetlands and riparian strips up to the stream bank edge are considered within the farm boundary if these are entered into OVERSEER (Wheeler and Shepherd, 2013). When describing the case study farms, wetlands and riparian strips were not included in our OVERSEER analysis.

The OVERSEER nutrient budget report further breaks down N and P loss to water into a series of sub categories. These sub categories are defined in Table 4 for N and P loss. These definitions help in explaining the breakdown of N and P loss to water from the case study farms.

Table 4: Definitions of sub categories of N and P loss to water

Title	Definition	
	Nitrogen to water	**Phosphorus to water**
Leaching – urine patches	The leaching of N from animal urine patches	n/a
Leaching – other	The leaching of N from inter-urine areas (incorporates the effects of dung, fertiliser and effluent and other N input sources and soil N cycling)	Losses of P from farm structures i.e. yards/races
Runoff	The removal of nutrients from the land via overland flow	
Outwash	N and P discharged from irrigation outwash (i.e. surface runoff caused by irrigation), based on soil Olsen P level.	

The OVERSEER nutrient budget results for the case study farms are shown in Table 5. These results are reported from the farm scenario nutrient budget reports. Table 5 shows the total N and P loss for the individual farms along with drainage.

Table 5: OVERSEER nutrient budget results for the case study farms

Farm Type	Total Nitrogen loss (kg N/ha/yr)	Total Phosphorous loss (kg P/ha/yr)	Drainage (mm/yr)
Current farms			
Existing dryland sheep	3	0.1	61
Existing irrigated sheep	14	2.8	386
Existing irrigated dairy support	37	3.2	424
Existing irrigated mixed arable	63	3.2	550
Existing partially irrigated sheep	9	0.8	539
Future farms			
Efficient irrigated dairy	12	1.4	75
Efficient irrigated sheep	6	0.8	98
Efficient irrigated dairy support	9	0.8	80
Efficient irrigated mixed arable	8	0.2	69
Efficient partially irrigated sheep	4	0.2	110

Table 5 highlights that nutrient losses from the current irrigated farms are higher than the nutrient losses from the future irrigated farms. The existing irrigated sheep nutrient budget reported a total N leaching loss value of 14 kg N/ha/yr. The breakdown of this leaching value was 5 kg N/ha/yr originating from the urine patch and 3 kg N/ha/yr leaching from other sources. For the existing irrigated sheep farm N losses from the irrigation outwash were 5 kg N/ha/yr and the remaining 1 kg N/ha/yr was from N runoff. The total P losses from the existing irrigated sheep nutrient budget were 2.8 kg P/ha/yr, with P runoff being the largest contributor (1.7 kg P/ha/yr) and 1.0 kg P/ha/yr from irrigation outwash. When comparing the existing irrigated sheep farm to the future irrigated sheep nutrient budget total N leaching has been reduced to 6 kg N/ha/yr. The breakdown of the leaching value was 1 kg N/ha/yr from the urine patch and 5 kg N/ha/yr from other sources. Total P losses were reduced to 0.8 kg P/ha/yr, with runoff still the largest source. The future irrigated sheep farm has moved from controlled flood irrigation to efficient centre pivot irrigation. This has removed nutrient losses as a result of irrigation outwash. Irrigation outwash was a significant source of nutrient losses in all the current irrigated farm systems.

The existing dairy support nutrient budget reported a total N leaching value of 37 kg N/ha/yr. The largest proportion of this was from the urine patch (21 kg N/ha/yr) with N leaching other contributing 10 kg N/ha/yr and the remaining N loss from irrigation outwash. With farms that graze dairy cows we would expect that the highest proportion of N loss would be attributed to N losses from the urine patch, particularly if the cows are grazed on the property during high risk months for N leaching (late autumn/early winter). The total P loss from the existing dairy support nutrient budget was 3.2 kg P/ha/yr, with runoff being the largest contributor (2.0 kg P/ha/yr), followed by irrigation outwash. When comparing the existing dairy support nutrient budget to the future dairy support nutrient budget total N leaching has been reduced to 9 kg N/ha/yr. The largest contributor was leaching from the urine patch (6 kg N/ha/yr), with ‘leaching other’ at 3 kg N/ha/yr. Total P losses were reduced to 0.8 kg P/ha/yr. Runoff is still the largest contributor at 0.7 kg P/ha/yr, with the remaining loss being ‘leaching-other’.

The existing mixed arable nutrient budget reported a total N leaching value of 63 kg N/ha/yr, with the largest proportion coming from leaching other sources (55 kg N/ha/yr). The remaining N loss was equally split between leaching from the urine patch and irrigation outwash. In cropping systems the highest proportion of N loss is generally attributed to leaching from other sources (mineralisation of N). There is also a contribution from animals grazing crops in situ and this can be significant if the timing of grazing occurs in late autumn/early winter. The total P losses from the existing mixed arable nutrient budget were 3.2 kg P/ha/yr, with the largest source from P runoff.

Irrigation outwash contributed 1.2 kg P/ha/yr and leaching other 0.1 kg P/ha/yr. When comparing this to the future mixed arable nutrient budget N leaching has been reduced to 10 kg N/ha/yr, with leaching from other sources still the largest contributor at 9 kg N/ha/yr and the remaining N loss from leaching urine patches. Total P losses were reduced to 0.2 kg P/ha/yr, which was all attributed to P runoff.

The existing partially irrigated nutrient budget reported a total N leaching value of 9 kg N/ha/yr. The amount of N leaching depended on source with 3 kg N/ha/yr estimated as derived from the urine patch, 5 kg N/h/yr from other sources and 1 kg N/ha/yr from irrigation outwash. The total P losses from the existing partially irrigated nutrient budget were 0.8 kg P/ha/yr, with runoff the largest source (0.6 kg P/ha/yr) and the remaining P loss from irrigation outwash. When comparing the existing partially irrigated nutrient budget to the future partially irrigated nutrient budget N leaching has been reduced to 4 kg N/ha/yr, with 1 kg N/ha/yr from leaching from the urine patch and the remainder leaching from other sources. Total P losses were reduced to 0.2 kg P/ha/yr, which was all attributed to less P runoff.

The existing dryland sheep farm system was accounted for under the current farm scenarios only. Nutrient losses from this system were very low reflecting the low intensity of farming, with total N loss at 3 kg N/ha/yr and total P loss at 0.1 kg P/ha/yr. The efficient dairy farm system was only accounted for under the future farm scenarios, as it was assumed that all current dairy farms within the catchment were operating at the efficient end of the scale in terms of irrigation i.e. they had centre pivots and soil moisture assessment techniques in place to guide irrigation applications. The nutrient budget for the dairy farm with efficient irrigation reported a total N loss value of 12 kg N/ha/yr and a total P loss value of 1.4 kg N/ha/yr.

3.4 Discussion and Conclusion

The case study nutrient budget results indicated that nutrient losses from the current irrigated farms are higher than from the future irrigated farms. Nitrogen losses were reduced by 57 to 87% depending on the farm system and P losses were reduced by 71 to 94%. The main reasons for the reduction in nutrient losses was attributed to more efficient irrigation systems that were accounted for in the future irrigated farms. The current irrigated farms were all set up with controlled flood irrigation applied to an application depth of 120 mm with a return period of 42 days. This represents a relatively inefficient system and the drainage values shown in Table 5 reflect this. Drainage values for the current irrigated farms range from 386 to 550 mm/yr. Drainage without irrigation on these farms according to OVERSEER ranges from 0 to 170 mm/yr for the case study farms. This highlights that an inefficient irrigation system is dramatically increasing the amount of water draining through the soil profile, which is leading to higher leaching nutrient losses. The future farms were all set up with centre pivot irrigation which applied irrigation once a trigger of 60% PAW was reached and refilled the profile to a target of 95% PAW. This reflects an efficient irrigation system as shown in the drainage values in Table 5, where drainage values range from 69 to 110 mm/yr. This closely aligned to what OVERSEER showed as the natural soil drainage rates without irrigation (0 to 61 mm/yr) for the case study farms.

When interpreting these results it is important to take into account the two irrigation systems represented at the current and future farm level are showcasing the 'least efficient' and the 'most efficient' systems and therefore represent the two extremes of nutrient loss. In reality most farming practices will probably sit somewhere within the continuum between least efficient and most efficient irrigation systems. The modelling of the case study farm scenarios utilised the latest version of OVERSEER, which has an updated irrigation module that models a greater range of irrigation management systems and irrigation rules. This allowed greater flexibility in representing individual farm irrigation management practices.

Alongside the impact of different irrigation systems on reducing soil drainage, the changing of irrigation systems (from controlled flood to centre pivot) removed the nutrient losses associated with outwash. Outwash refers to the nutrient discharged from irrigation outwash. Outwash can also be reduced by better management of the irrigation system. A centre pivot irrigation system does not have outwash and this represented a reduction in N losses from between 1 to 6 kg N/ha/yr and a reduction in P losses from between 0.2 to 1.2 kg P/ha/yr depending on the farming system.

A further consideration when interpreting these results is to understand that the case study farms although representative still reflect a very small range of likely farm management systems practiced in the Manuherikia catchment. Differences in farm management systems can have a large influence on total nutrient losses. Key farm management drivers of N losses are stocking type and rate, stock management and feeding, fertiliser use, effluent management, cropping practices and irrigation management. Key farm management drivers of P losses are fertiliser use, effluent management, stock management and feeding, cropping practices, artificial drainage and irrigation management. Nutrient loss numbers are also reflective of the inherent farm nutrient loss susceptibility. Key 'inherent' drivers of N losses are drainage, climate, and soil type. Key 'inherent' drivers of P losses are topography, climate and soil properties (Selbie, *et al*., 2013).

In summary, nutrient losses are strongly influenced by irrigation management practices. An efficient irrigation system, even with potentially higher stocking rates, can have lower nutrient losses than an inefficient irrigation system with a low stocking rate. However, this needs to be assessed on a farm by farm basis. The current and future case study farms showcase the two extremes of irrigation management, from inefficient current controlled flood irrigation farms to efficient future centre pivot irrigation farms. Nitrogen reductions of between 57 and 87% and P reductions of between 71 and 94% can be achieved as a result of improving the efficiency of the on-farm irrigation systems.

4. DEVELOPMENT OF THE MANUHERIKIA CATCHMENT NUTRIENT LOSS MAPS

The development of the Manuherikia catchment nutrient loss maps involved the modelling of three scenarios 1) current land use and irrigation – ‘current’, 2) future land use with no increase in storage, but a move to more efficient irrigation – ‘future without storage’ and 3) future land use with potential maximum development associated with increased storage – ‘future with storage’.

4.1 Key differences between the ORC nutrient loss maps and the Manuherikia catchment nutrient loss maps

Section 2 of this report outlined the process undertaken to produce the ORC nutrient loss risk maps. A similar process was undertaken to produce the Manuherikia catchment nutrient loss maps, however a number of key differences exist:

- The OVERSEER model used to develop the ORC farm management files was based on an older development version of OVERSEER. The development version used to create the Manuherikia catchment farm management files had a new irrigation model. This new irrigation model allowed greater flexibility around irrigation systems and management.
- The Manuherikia catchment OVERSEER farm management files were created based on farm management data specific to the Manuherikia catchment. The ORC OVERSEER farm management files were created based on generic farm management data for the whole ORC region.
- The ORC maps were based on GrowOtago soil data, for the Manuherikia catchment maps we were able to move to S-map data for a proportion of the catchment. GrowOtago was still used where S-map was not available.
- The Agribase layer used to allocate land use across the catchment was revised for the Manuherikia catchment maps to more accurately reflect current and potential future land uses with the catchment.
- The irrigation layer provided was more representative of current and future irrigation systems. The ORC irrigation layer was based on land parcels associated with water permits granted to take and use water for irrigation and all irrigation systems were assumed to be centre pivot and operating under best practice.

4.2 Development of the Dynamic Link Library

A dynamic link library (DLL) was created using the development version of OVERSEER (June 2015). The development version of OVERSEER is a building block of the publically available version of OVERSEER. The development version was used as the methodology for creating the links with the DLL was already understood. The outputs from the development version and the current publically available version of OVERSEER (6.2.0) will be very similar. The DLL used information from the OVERSEER files and input data from GIS layers. The output from the DLL is stored on a database table, which is used to build the maps based on the development of the GIS layers (section 4.4).

4.3 OVERSEER files used in scaling up process

A description of the OVERSEER files generated for the Manuherikia catchment was described in Section 3 of this report and Appendix 1. In the scaling-up process the OVERSEER files are used to determine farm management systems only. The GIS layers provide site specific information for a given polygon (irrigation system, soil attributes, climate attributes and land use). The DLL brings in the appropriate OVERSEER file to match land use and irrigation system. Therefore the OVERSEER file used for a given polygon is a function of the land use of that polygon and the irrigation system of that polygon. Table 6 shows the sources of information for the required OVERSEER inputs to highlight the difference between what information is sourced from the OVERSEER file and what information is sourced from the DLL and GIS layers.

In addition to the OVERSEER files generated specifically for the Manuherikia catchment, AgResearch created OVERSEER files for the three farming systems listed below from similar sources that were used to develop the N leaching maps for the ORC.

1. OVERSEER deer farm file
2. OVERSEER orchard farm file
3. OVERSEER vineyard farm file

No OVERSEER files were created for beef farms or sheep and beef farms. Discussions with Compass Agribusiness and Golder determined that straight beef farms were not a major enterprise in the catchment and Compass Agribusiness were not looking at any beef farms in their economic analysis. It was therefore agreed that any land use showing up as beef in Agribase™ would be linked to the OVERSEER dairy support farm management system OVERSEER file and any land use showing up as sheep and beef would be linked to the OVERSEER sheep management system OVERSEER file.

Table 6: Source of information required to create OVERSEER data set

Main OVERSEER Inputs	Source	Place information implemented
Stock numbers	As supplied by Compass Agribusiness	OVERSEER
Stock production	As supplied by Compass Agribusiness	OVERSEER
Distance from the coast	GIS layer	GIS
Topography	Slope from Landcare 15 m DEM	GIS
Climate information	GrowOtago	GIS
Soil information	S-map, GrowOtago and NZFSL	GIS
Soil tests	As supplied by Compass Agribusiness or default OVERSEER values	OVERSEER
Soil drainage	S-map and GrowOtago	DLL
Fertiliser	As supplied by Compass Agribusiness	OVERSEER
Crop information	As supplied by Compass Agribusiness	OVERSEER
Irrigation information	Irrigation GIS layer supplied by Golder	GIS and DLL
Pasture type	As supplied by Compass Agribusiness	OVERSEER
Supplements	As supplied by Compass Agribusiness	OVERSEER
Effluent management	As supplied by Compass Agribusiness	OVERSEER

4.4 Development of the GIS layers

A number of the GIS layers were reclassified to reduce the size of the databases and processing times (Table 8). Mean annual rainfall and mean annual air temperatures were sourced from the NIWA-produced GrowOtago climate layers. Rainfall was reclassed into 13, 50 or 100 mm breaks using a modified natural breaks (Jenks) method. Air temperature was reclassed to even 0.5°C breaks into 13 classes.

Irrigated areas were supplied by Golder and integrated into the land use spatial layer (Appendix 5, 6 and 7). The development of the 'current' and 'future' with and without storage irrigation layers is described in a report by Golder, 2015. Recent aerial photographs were used to identify the areas currently irrigated which were checked against irrigation scheme records and some field checking. The irrigated areas were classified into four irrigation systems by Golder. Table 7 shows how these different systems were set-up in OVERSEER for the scaling-up process.

1. Efficient Spray – variable and low application rate/depth systems including centre pivots, drip, trickle and other orchard vineyard systems.
2. Medium Spray – higher application rate/depth systems including travelling irrigators (guns, rotating boons etc.) K-line and solid set for pasture situations.
3. Medium Flood – border strips.
4. Contour Irrigation.

Table 7: Irrigation systems used in the scaling up process

	Irrigation type	Timing	Application depth (mm)	Return period	Trigger point
Efficient spray	Centre Pivot	Sep-April	n/a	n/a	Trigger = 60% Target = 95%
Medium spray	Centre Pivot	Sep-April	50	12	n/a
Medium flood	Border dyke	Oct-April	80	28	n/a
Contour irrigation	Controlled flood	Oct-April	120	42	n/a

Within the scaling up process irrigation of crops and pasture were treated the same with the exception of medium flood irrigation. When cropping occurred under this irrigation system it was changed in OVERSEER to travelling irrigator, no outwash with a soil moisture trigger value of <50% of PAW, with 80 mm depth of application and minimum return period of 28 days.

The first three irrigation types were relatively easy to identify from aerial photography. Other areas of obvious irrigation were assigned contour irrigation which is the dominant (area wise) irrigation type in the catchment. The 'current' irrigation map was then updated to represent 'future' irrigation scenarios (with and without storage). The with storage future scenario represents large scale irrigation development (i.e. a large raise of Falls Dam and a new Mt Ida Dam) and increased spray irrigation on-farm. The without storage future scenario represents the fact that even with no improvement in water supply reliability, increased spray irrigation on-farm is expected as current irrigators continue to move from flood to spray irrigation. In developing the future scenarios properties were assumed to be fully irrigated with only one irrigation type. In practice individual properties will not be fully irrigated (lane ways, buildings, shelter belts etc.) and multiple irrigation types are often used (i.e. centre pivot with k-line or long laterals at the corners), however at a catchment level the 'future' irrigation maps are considered an appropriate representation.

For the development of the current map, Agribase™ was used as the source of farm descriptions in the Manuherikia catchment. Table 9 shows the Agribase™ categories used and the associated OVERSEER file or default value used. Compass Agribusiness and Golder reviewed the Agribase™ layer and modified it to better reflect current land use within the Manuherikia catchment. Appendix 2 shows the Agribase™ layer used in the development of the current nutrient loss maps. The Agribase™ land use layer was modified further by Compass Agribusiness and Golder to produce the 'future' with and without storage land use layers (Appendix 3 and 4). The future land use layer with storage was based on what land use could look like under a potential maximum irrigation development scenario (i.e. a large raise of Falls Dam and a new Mt Ida Dam). The 'future' land use layers were developed to be consistent with the catchment economic assessments undertaken as part of the wider feasibility study.

Landcare Research S-map was used for the intensively farmed river plains and a mix of GrowOtago and the New Zealand Fundamental Soils Layer (NZSFL) was used for the remaining upland areas. Additional S-map attributes were supplied by Landcare Research to provide the DLL with more spatially refined parameters. These include:

- Soil Order
- Soil Drainage
- Topsoil Texture
- Topsoil Stoniness
- Lower Profile Texture
- Lower Profile Nonstandard Layer
- Root Depth
- Impeded Layer Depth

The GrowOtago upland soils were supplied only with soil order, therefore soil drainage was taken from NZFSL using a geographic overlay.

Table 8: GIS datasets used

Data set name	Source	Type	Pre-processing
Agribase™	AsureQuality	Polygon	Reclassification of farm type. Some land covers removed and land use revised to better reflect current and potential land use
Rainfall	GrowOtago	Raster*	Convert to polygon. Classification of annual range
Temperature	GrowOtago	Raster	Convert to polygon
Slope	Landcare Research	Raster	Convert to polygon. Reclassed to match OVERSEER
Soil	GrowOtago/S-Map	Polygon	Soil descriptions were reclassed to soil order
Irrigation	Golder	Polygon	Merge

*Raster refers to a rectangle grid of pixels

Table 9: Agribase™ categories and associated OVERSEER file or default value used

Agribase™ Category	OVERSEER file used or default value used		
	Efficient spray and Medium spray	**Medium flood and Contour (poor flood)**	**No irrigation**
Sheep	Efficient irrigated sheep	Existing irrigated sheep	Existing dryland sheep
Dairy	Efficient irrigated dairy	N/A	N/A
Arable Cropping	Efficient irrigated mixed arable	Existing mixed arable	N/A
Sheep and Beef	Efficient irrigated sheep	Existing irrigated sheep	Existing dryland sheep
Beef	Efficient irrigated dairy support	Existing dairy support	N/A
Dairy Dry Stock (Support)	Efficient irrigated dairy support	Existing dairy support	N/A
Deer	Otago Deer Farm		N/A
Orchard	Otago Orchard Farm		N/A
Vegetable	Otago Orchard Farm		N/A
Vineyard	Otago Vineyard Farm		N/A
Forestry	Assign background value (3 kg N/ha/yr)		
Native	Assign background value (3 kg N/ha/yr)		
Lifestyle blocks	Assign background value (3 kg N/ha/yr)		
Other	Assign background value (3 kg N/ha/yr)		
Park/golf course	Assign background value (3 kg N/ha/yr)		
Track/paper road	Assign background value (3 kg N/ha/yr)		
Riverbed	Assign background value (3 kg N/ha/yr)		
Reservoir	Leave as marked reservoir on the map		
Road	Leave as marked road on the map		
Urban	Leave as marked urban on the map		

5. MANUHERIKIA CATCHMENT NUTRIENT LOSS MAPS

Three scenarios were modelled 1) current land use and irrigation, 2) future land use with no increase in storage, but a move to more efficient irrigation and 3) future land use with potential maximum development associated with increased storage. From the three scenarios nine maps were created:

1) **Inherent N leaching susceptibility from urine N inputs (Three maps - Figure 5a, b and c).**

   The urine N leaching susceptibility maps are based on the urine N leaching risk index. This is an index based on the proportion of N that can leach from a standardised 'block' urine N input of 100 kg N/ha/month and is determined using the physical characteristics of the site (i.e. soil, climate, topography and irrigation). Management information such as, different land use types, stock numbers and management practices are not taken into consideration. The only management effect taken into consideration is the addition of the GIS irrigation layers, due to the effect of irrigation on drainage. The scale used to create the bands for this map is a unitless measure (susceptibility index) and hence no units are supplied on the map.

2) **Estimate of N leaching under a scenario of current and future land uses (Three maps - Figure 6a, b and c).**

   Estimate of N leaching under a scenario of current and future average land use combines the N leaching susceptibility map with management information (i.e. different land uses, stock numbers and management practices), and includes losses of N to water from other sources such as N leaching from the OVERSEER background N model, direct deposition by animals in streams, and outwash losses. These maps utilise the OVERSEER files created and GIS layers to take account of different management effects across the Manuherikia catchment.

3) **Estimate of soil P loss susceptibility under a scenario of current and future land uses (Three maps - Figure 7a, b and c).**

   The estimate of soil P loss risk maps for the current and future land use scenarios combines the physical characteristics of the catchment (climate, soil, topography; McDowell *et al*. 2005) with some management effects (Olsen P values and deer behaviour). These maps utilise the OVERSEER files created (only for Olsen P values and deer behaviour) and GIS layers.

5.1 Inherent N leaching susceptibility from urine N inputs

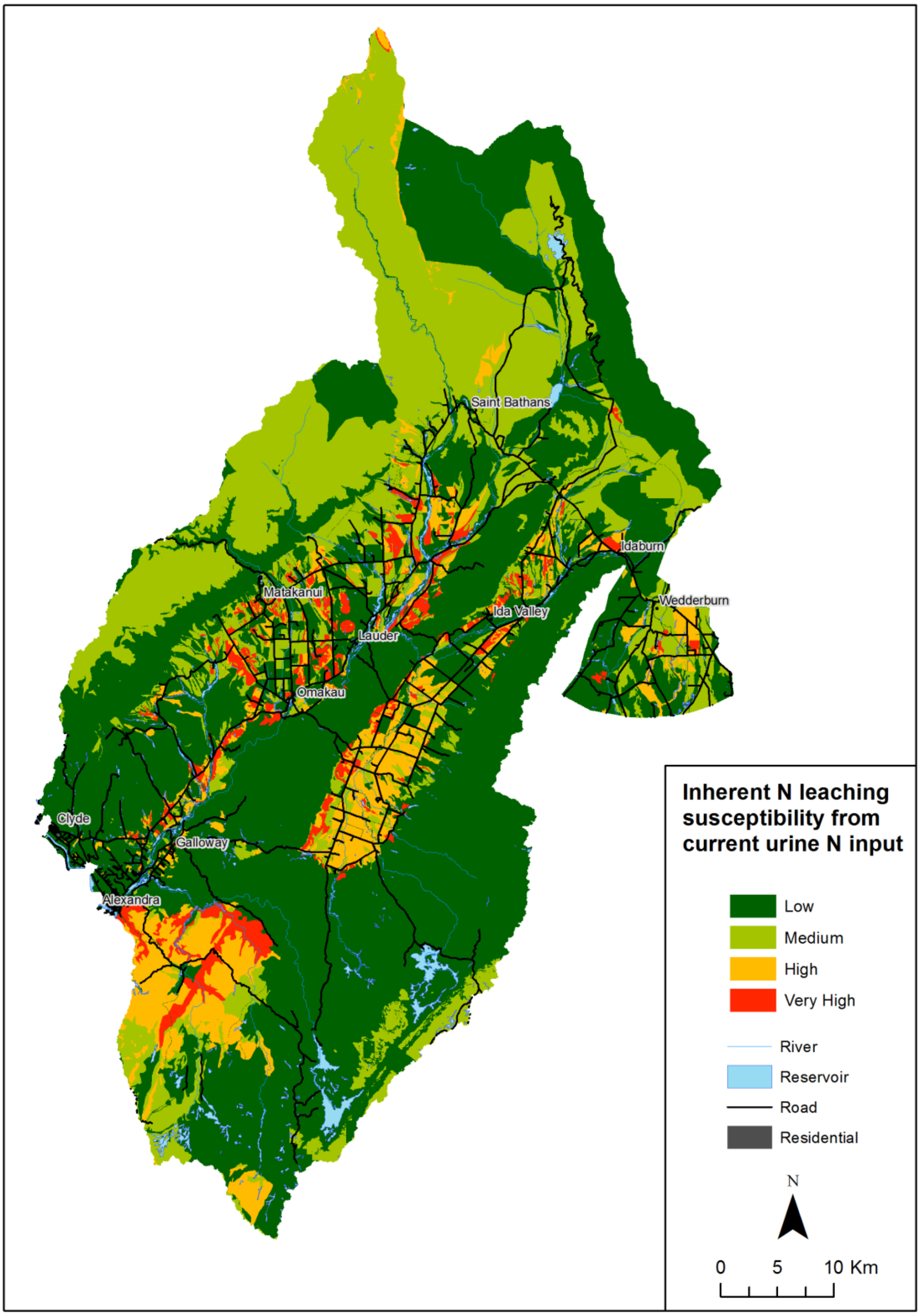


Figure 5a: Inherent N leaching susceptibility from the 'current scenario' urine N inputs for the Manuherikia catchment.

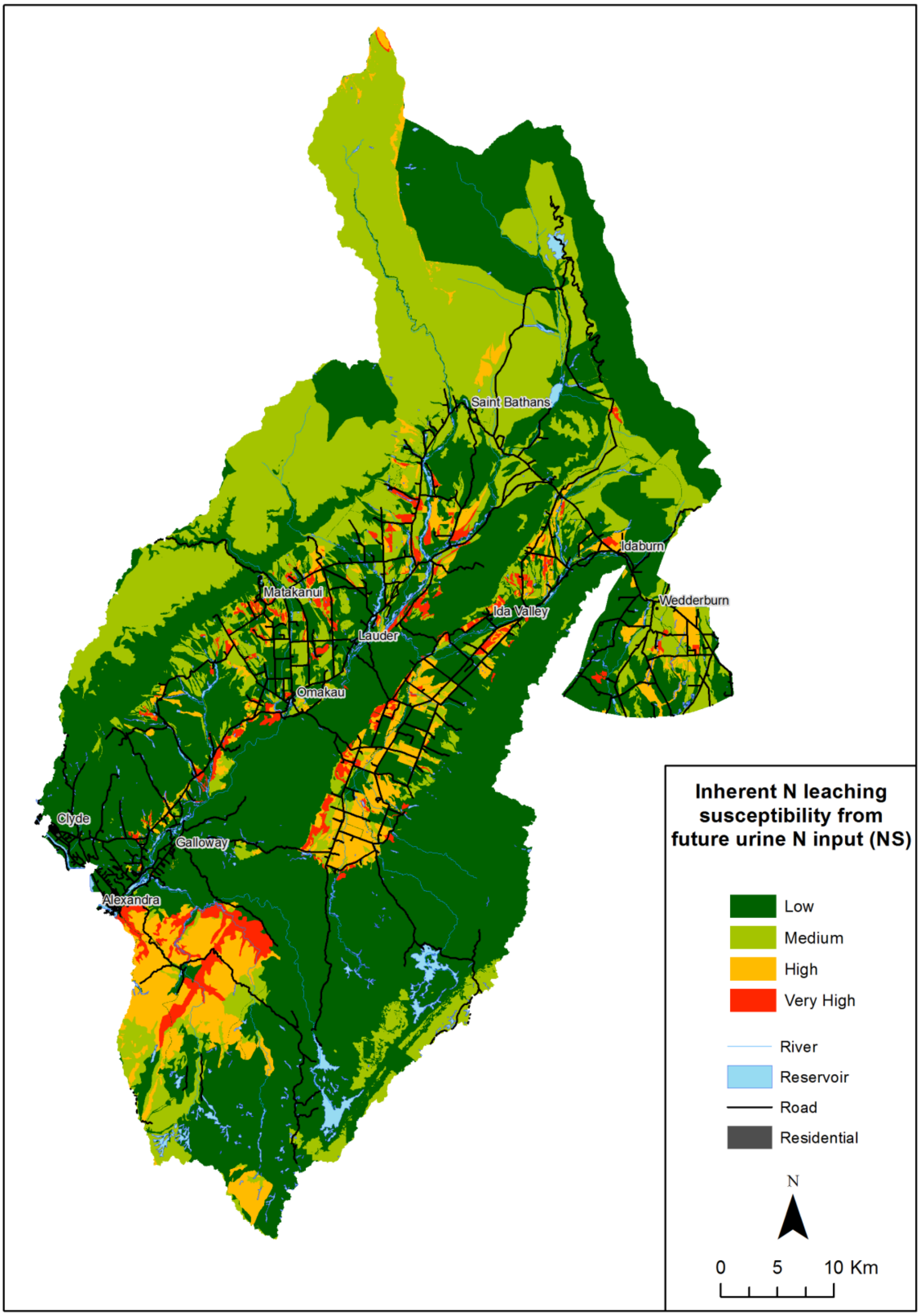


Figure 5b: Inherent N leaching susceptibility from the 'future – without storage scenario' urine N inputs for the Manuherikia catchment.

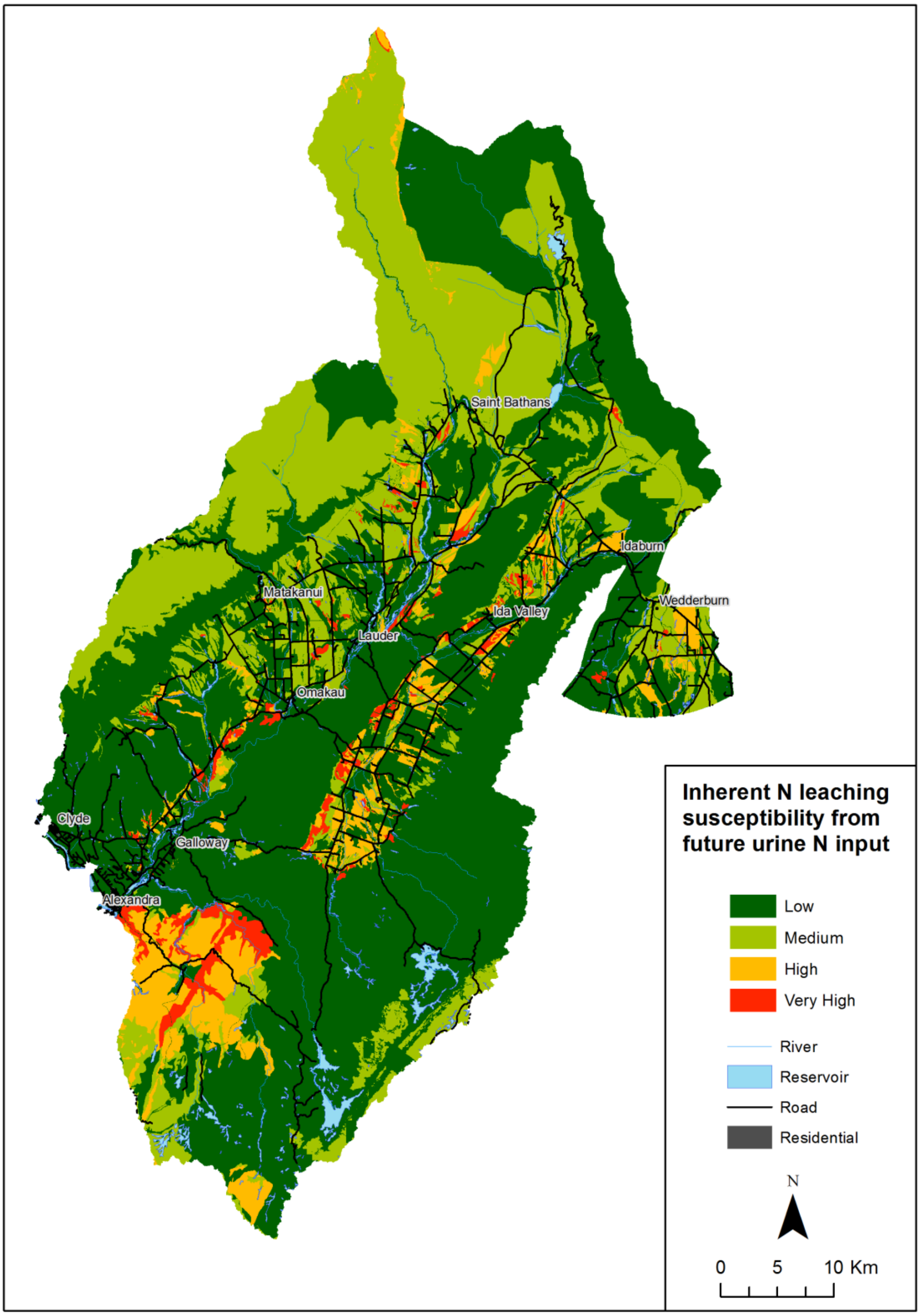


Figure 5c: Inherent N leaching susceptibility from the 'future – with storage scenario' urine N inputs for the Manuherikia catchment.

Key assumptions made for all three maps (Figure 5a, b and c)

- Standardised input of urine N assumed
- No management effect is taken into consideration (except irrigation as supplied by Golder)
- GrowOtago and S-map soil information used and GrowOtago climate information.

5.2 Estimate of N leaching under a scenario of current and future land use for the Manuherikia catchment

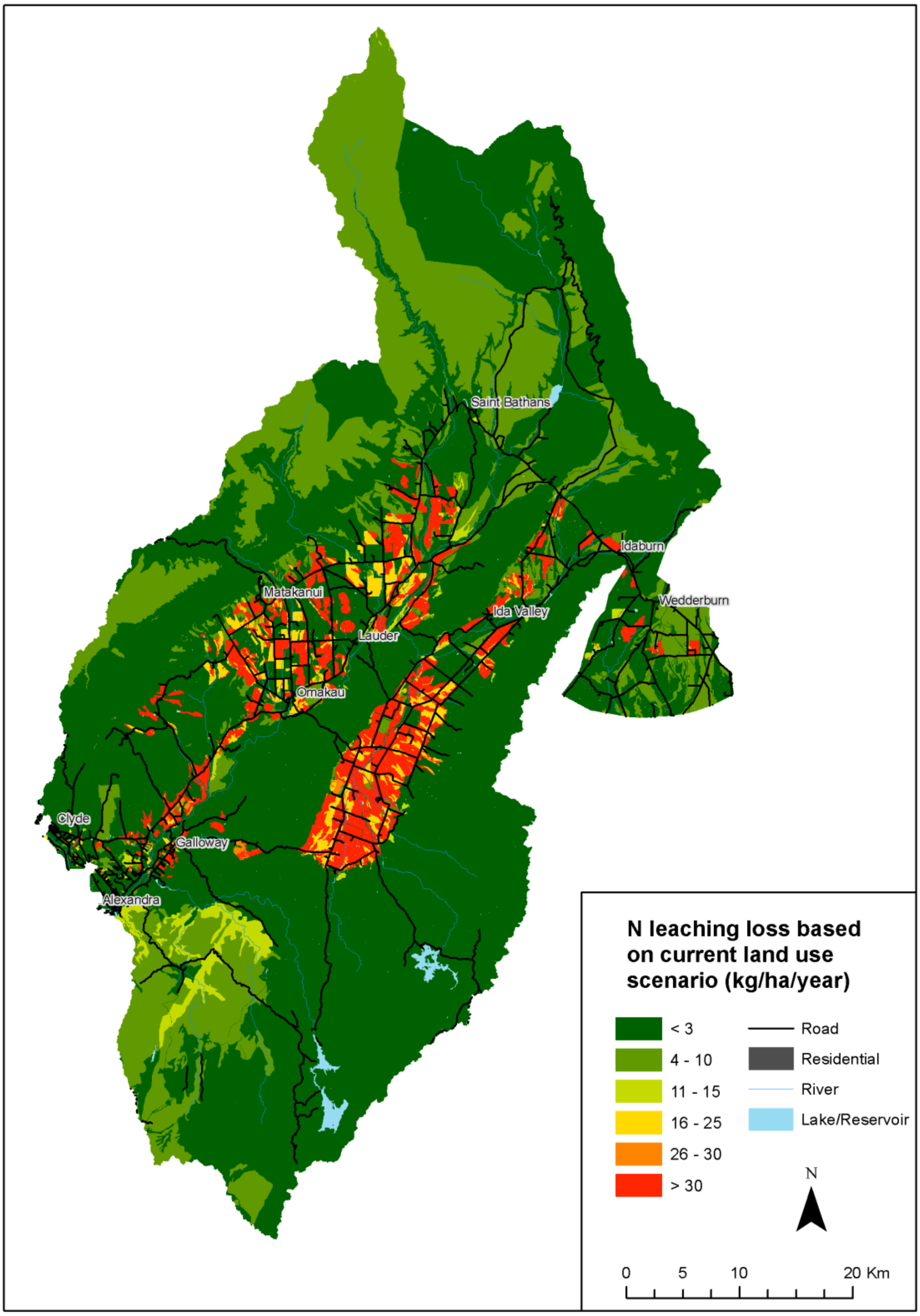


Figure 6a: Estimate of N leaching under a scenario 'current' land use for the Manuherikia catchment.

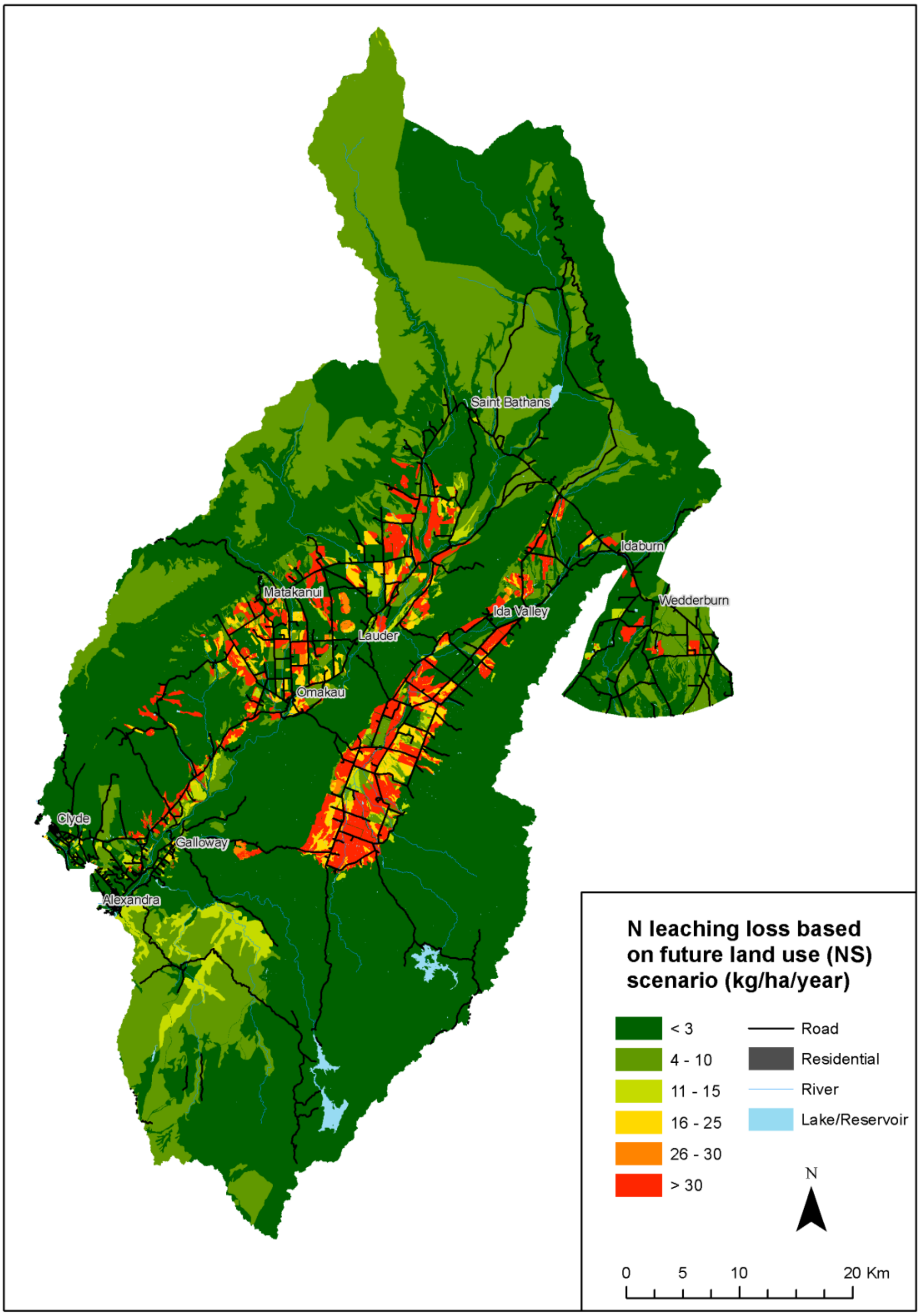


Figure 6b: Estimate of N leaching under a scenario 'future – without storage' land use for the Manuherikia catchment.

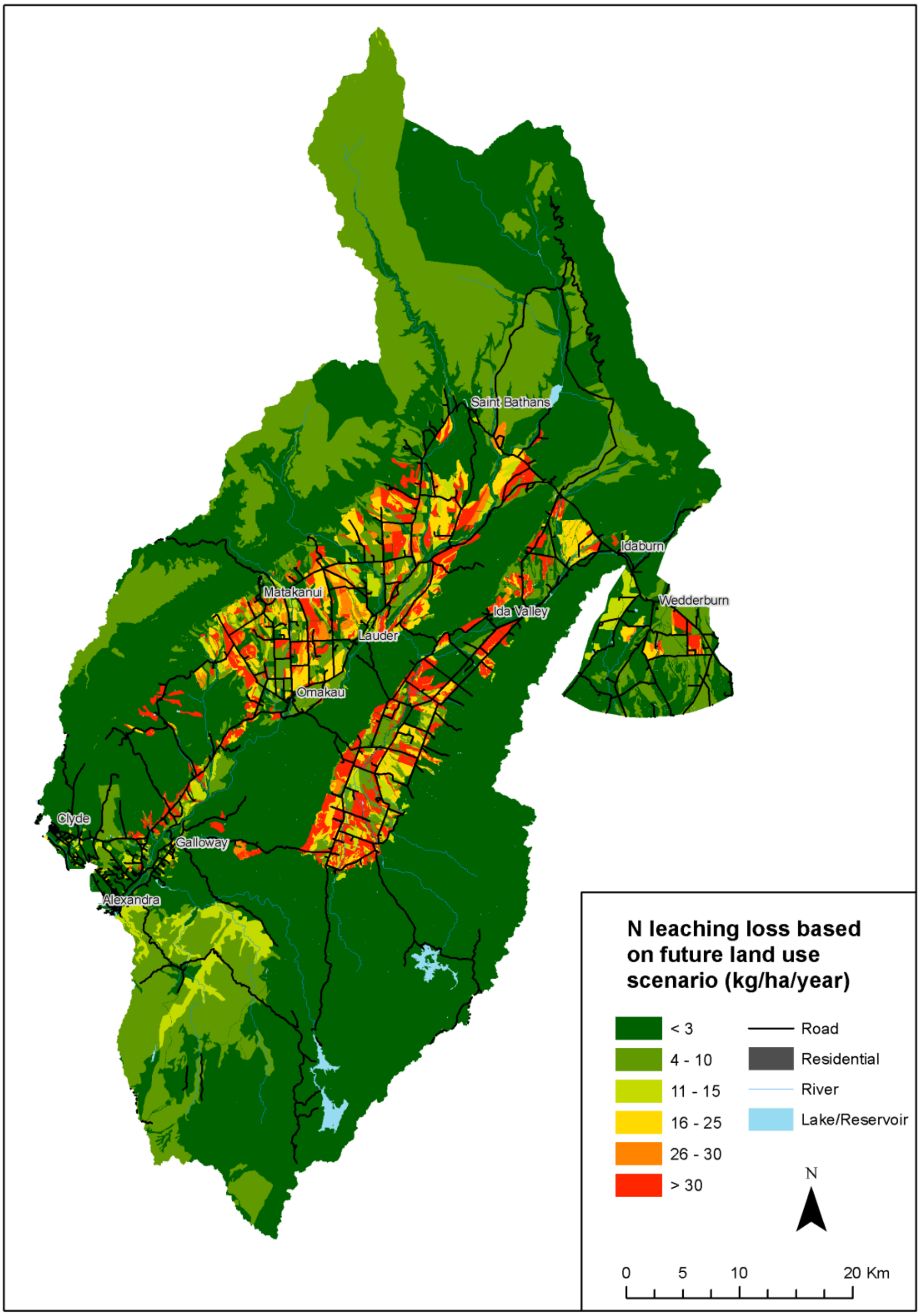


Figure 6c: Estimate of N leaching under a scenario 'future – with storage' land use for the Manuherikia catchment.

Key assumption made for all three maps (Figure 6a, b and c)

- Revised Agribase land use layer was used to allocate farm types across the region
- OVERSEER files created covered limited farm management systems
- GrowOtago and S-map soil information used and GrowOtago climate information.

5.3 Estimate of soil P loss susceptibility under a scenario of current and future land use for the Manuherikia catchment

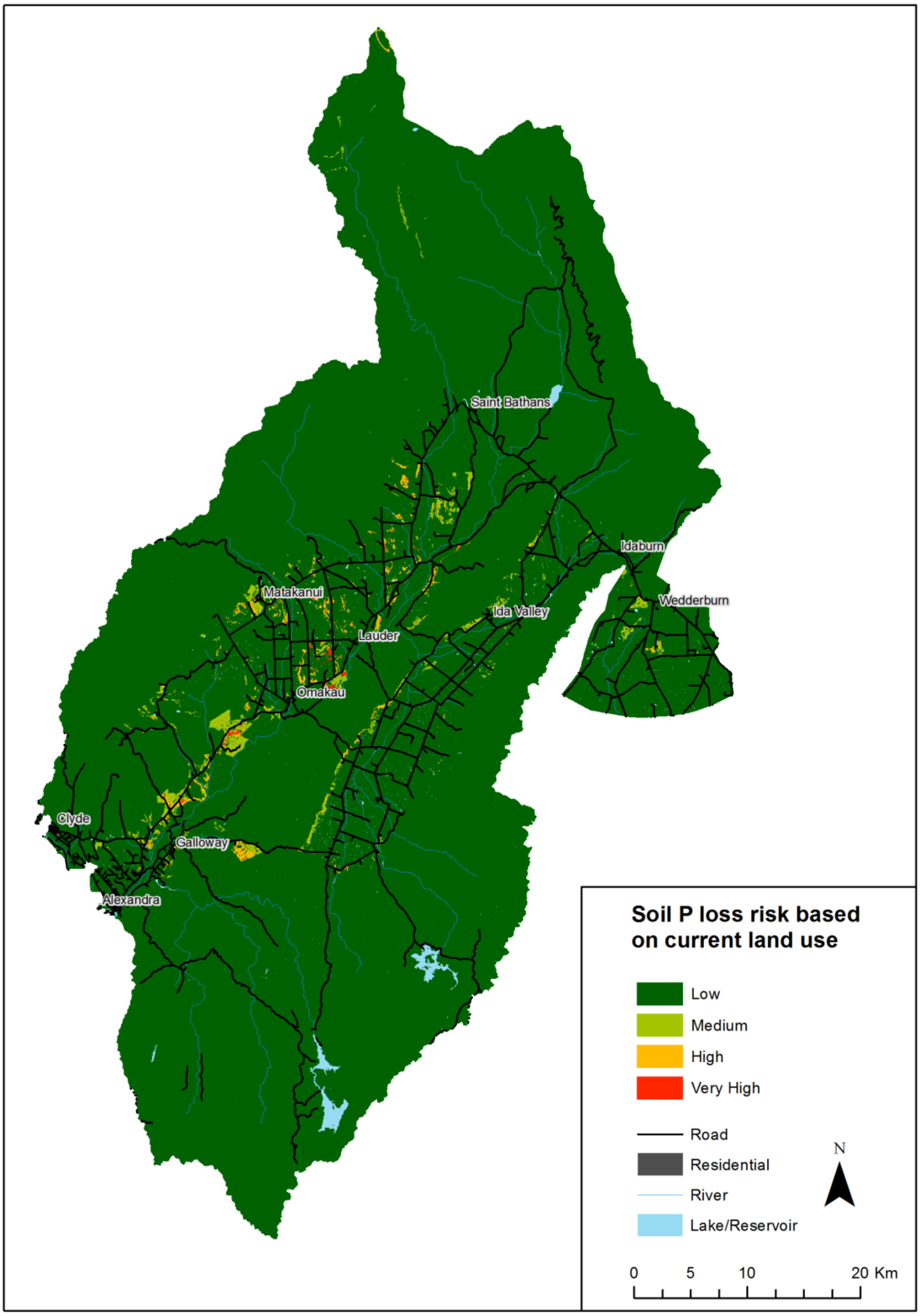


Figure 7a: Estimate of soil P loss susceptibility under a scenario of 'current' land use for the Manuherikia catchment.

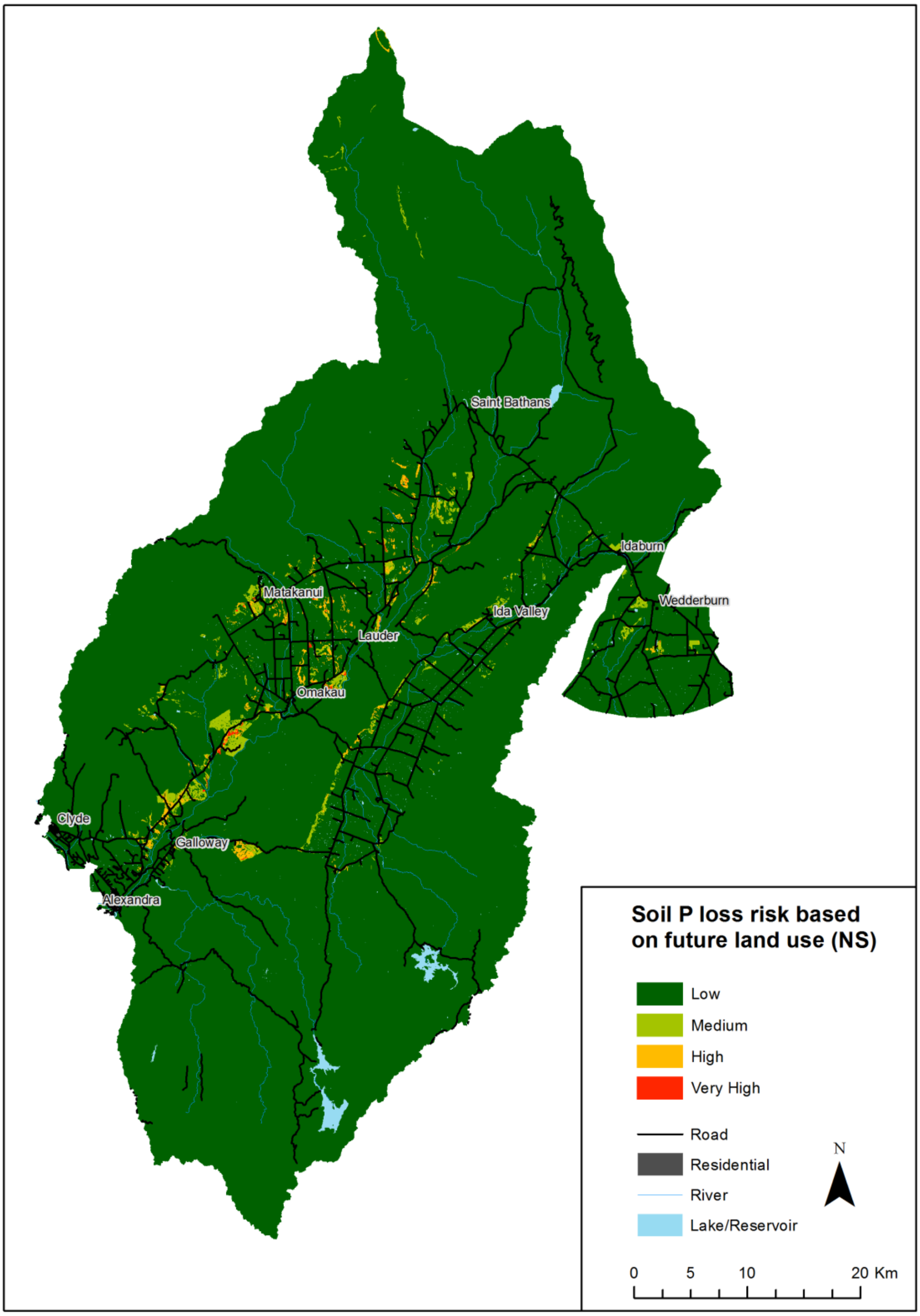


Figure 7b: Estimate of soil P loss susceptibility under a scenario of 'future – without storage' land use for the Manuherikia catchment.

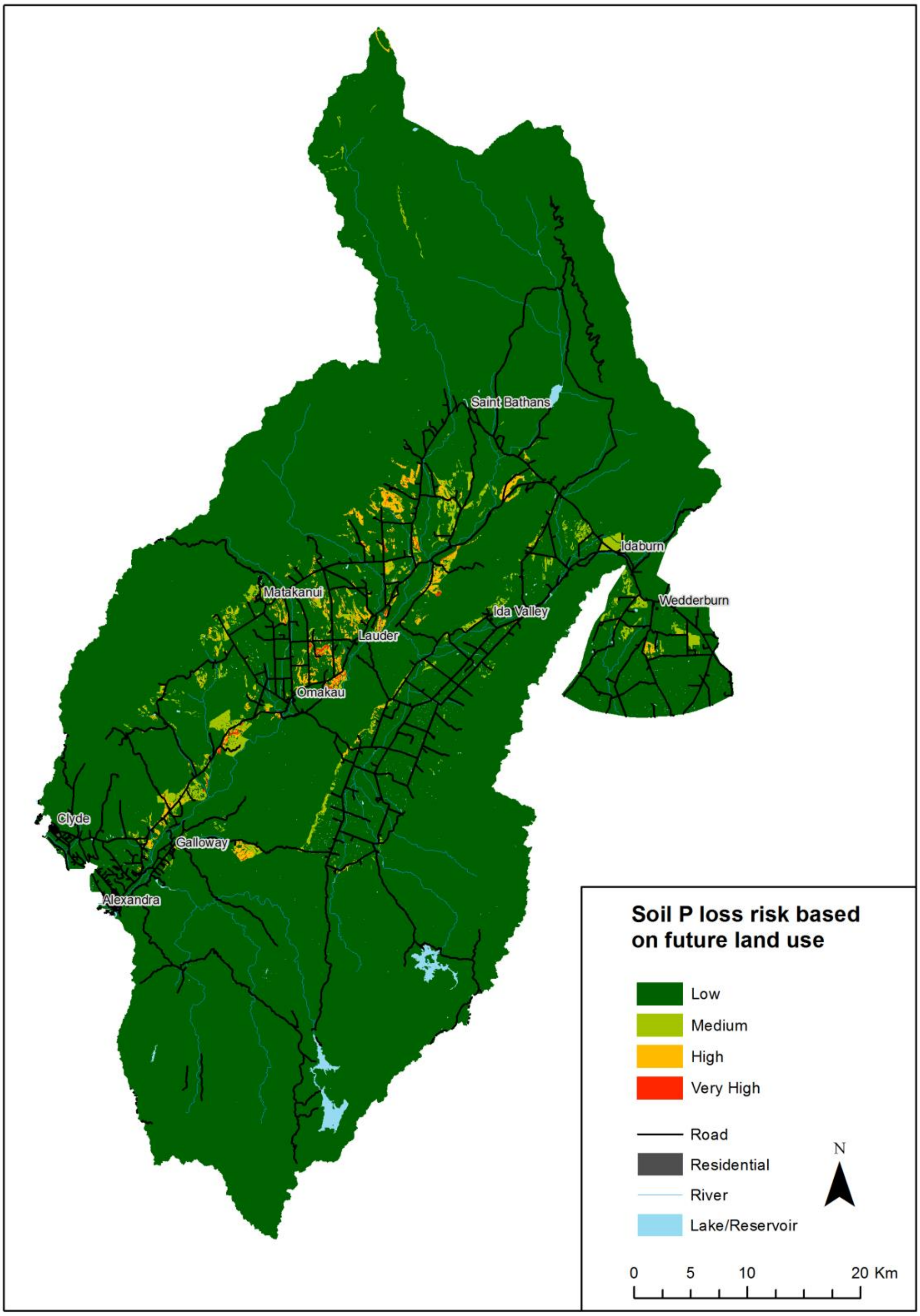


Figure 7c: Estimate of soil P loss susceptibility under a scenario of 'future – with storage' land use for the Manuherikia catchment.

Key assumptions made for all three maps (Figure 7a, b and c)

- Revised Agribase land use layer was used to allocate farm types across the region
- OVERSEER files created covered limited farm management systems
- GrowOtago and S-map soil information used and GrowOtago climate information.

5.4 Discussion around map features

5.4.1 Inherent urine N leaching susceptibility maps

The inherent urine N leaching susceptibility maps (Figure 5a, b and c) show the potential susceptibility of urine N to leaching below the root zone (60 cm) due to climate conditions and soil characteristics of the catchment. The urine N leaching susceptibility maps do not take into consideration different land management practices, with the exception of the irrigation layer which is included. The irrigation layer is included due to the impact of irrigation on soil drainage. There are three maps due to different irrigation layers for the current and future with and without storage scenarios and the only differences between the maps is the irrigation layer i.e. climate and soil conditions remain constant.

When comparing the three maps the only difference in N leaching susceptibility is found in the irrigation zones as expected. As you move from the current to the future with and without storage irrigation zone the N leaching susceptibility reduces (i.e. less red areas in the irrigation zones). The highest risk of inherent N leaching is found in the current scenario (Figure 5a), with the lowest risk found in the future – with storage scenario (Figure 5c). The change in N leaching susceptibility is driven by future irrigation zones predominantly using more efficient irrigation systems and therefore the impact on drainage is less and subsequently the N leaching risk is lower. A key aspect of efficient irrigation systems is to apply irrigation based on soil water content. A wide range of irrigation technology exists to achieve this. However, water supply contracts need to be aligned so that water availability aligns with water requirements as determined by soil moisture monitoring.

Areas outside the irrigation zones that have high N leaching susceptibility are primarily driven by soil characteristics. Rainfall plays a minor role on influencing N leaching susceptibility within this catchment as generally rainfall is low and therefore the impact on soil drainage is low. Red areas on the maps are generally associated with areas where the soil has a low available water capacity and are therefore more susceptible to drainage (i.e. leaching). Outside the irrigation zones the N leaching susceptibility is low to medium for the majority of the catchment. A few exceptions exist, where N leaching susceptibility is high to very high. The area to the east of Alexandra is an example of this situation. A major difference in this region relates to the S-map attributes for rooting depth and impeded layers. An over-estimation of N leaching susceptibility may be occurring here, due to the shallow impeded layer and rooting depth and the current OVERSEER model not dealing with the lateral movement of drainage as well as it should. This area of very high susceptibility should be treated with caution until further work is done, which is outside the scope of this report.

5.4.2 Estimate of N leaching maps

The estimate of N leaching maps (Figure 6a, b and c) combine the urine N leaching susceptibility map with the current and future land use information (i.e. OVERSEER files) to provide estimates of N leached below the root zone (60 cm). As with the N leaching susceptibility maps the main focus of change is on the irrigation zones. No change in land use occurs outside the irrigation zone between the current and future maps and therefore no change in N leaching occurs outside the irrigation zones.

Focusing on the irrigation zones, results indicate that the differences in total N leaching losses between the 'current scenario' and the 'future – with storage scenario' are almost negligible (Table 10). The 'current scenario' has a higher proportion of areas with N leaching values >30 kg N/ha/yr (Figure 6a), and as we move to the 'future – with storage scenario', the proportion of areas with high (>30 kg N/ha/yr) decreases, however we see an increase in the N leaching categories 11 – 30 kg N/ha/yr (Figure 6c). This aligns with the irrigation layer (Appendix 7), which shows an increase in the amount of areas under irrigation in the 'future – with storage scenario'. The irrigation systems in the 'future – with storage scenario' are efficient irrigation systems, but the cumulative effect of an increase in areas under irrigation is shown through the larger proportion of the irrigated catchments now showing N leaching values within the category 11 – 30 kg N/ha/yr. This highlights that despite an efficient irrigation system, which without the influence of land use type and stock management can reduce N leaching (section 5.4.1), if you introduce stock there is a strong interaction between stock type and management and N leaching susceptibility. In general adding irrigation results in increased stock numbers or results in changing land use (i.e. to dairy farming). Both these situations can lead to increased urine N deposition. Alongside this, the addition of irrigation water increases the risk of drainage, although this risk is lower with more efficient systems. The net impact of an irrigation scheme in a catchment is the sum of these 4 processes:

1) Efficient irrigation systems reducing the risk of N leaching;
2) Irrigation resulting in increasing stock intensity thereby, increasing the risk of N leaching;
3) Fertiliser use – N fertiliser use only has a small effect of N losses, the major effect is through increased production as a result of N fertiliser application;
4) Interaction between the effect of irrigation management practices on drainage and hence the urine N susceptibility to leaching loss (Wheeler and Bright, 2015).

Table 10: Total N leaching load from the three modelled scenarios

Scenario	Total N leaching load (kg N/ha/yr)
Current	162,194
Future – without storage	151,684
Future – with storage	161,527

Figure 6a, b and c are based on typical farm management practices for a given land use. In practice there is a wide range of farm management practices and hence the N leaching from an individual property will be different to those depicted in the maps. However, this work does highlight three factors that affect N loss:

1) Site characteristics (soil and climate) as illustrated by the inherent urine N leaching susceptibility maps (Figure 5a, b and c),
2) Efficiency of the irrigation system, as illustrated by the case study farms (Section 3),
3) Farm management systems, for example, OVERSEER assumes the N losses are higher under dairy than sheep.

5.4.3 Estimate of soil P loss susceptibility maps

The soil P loss susceptibility maps (Figure 7a, b and c) show that generally the susceptibility of soil P loss within the Manuherikia catchment is low. One of the main reasons for this is that soil properties and climate within this catchment result in a low occurrence of surface runoff. Where runoff has the potential to occur within the catchment, a low susceptibility is still showing on the maps due to low soil Olsen P levels. The Olsen P levels used in the OVERSEER files were the OVERSEER default value for sheep farms and for the dairy farm an Olsen P value of 24 was provided. A wider range of Olsen P values will alter the susceptibility. A further reason for low soil P loss susceptibility showing in the Manuherikia catchment relates to the anion storage capacity (ASC) values, also known as P retention, used. Within OVERSEER the ASC were left as default as other sources of data were not available at the time. This meant that ASC were based on the ASC value associated with a given soil order. It is expected that ASC values of soils within the Manuherikia catchment will vary, with ASC on some soils being very low. These maps should be treated with caution until more refined information on the range of soil Olsen P levels are included and until ASC estimates for the range of soil orders in the catchment are better refined.

In OVERSEER, a significant contributor to P loss can be direct deposition of P by animals in stream, and P lost in irrigation outwash. Within the OVERSEER files we assumed no animals (dairy) had access to streams. Access by sheep to streams is not an option in OVERSEER. The contributions from incidental losses from fertiliser or effluent applications, or deer behaviour are included in the OVERSEER model estimate total P loss, but are not included in soil P risk index that was used to produce these two maps. Therefore this may also be causing an underestimation of P loss susceptibility, as this can be a significant source of P loss.

6. LIMITATIONS AND FUTURE IMPROVEMENTS

6.1 Limitations

A number of limitations exist based on how the maps were developed and the quality of the information used. It is also important that the catchment scale of the map is taken into consideration. The map is not designed to be applicable at a farm scale as the level of input data is not specific enough. A greater understanding of the range of farm management systems within the catchment would need to be understood and associated OVERSEER files created to represent the wider range of management systems likely in the catchment. Summaries of key limitations of the maps are provided below:

- The OVERSEER files created only take into consideration a limited number of farm management systems. Therefore, the OVERSEER files created will not fully represent the wide range of farm management practices and farm systems likely in the Manuherikia catchment.
- Quality of the database inputs used. For example, Agribase™ (October 2013) was used to determine the allocation of farm types across the region. However, there are still gaps in this data set and interpretation of the different farm types to fit the identified categories was required. Some records are out of date and some areas are actively farmed but not captured due to the method of data collection (voluntary survey). This limitation has mostly been mitigated by integrating local knowledge from agricultural consultants to revise the Agribase™ layers for the current and future scenarios.
- Irrigation limitations – the range of irrigation management systems covers the majority of irrigation systems, but not all possible irrigation systems. The current irrigation model in OVERSEER is based on current understanding of N leaching. However, N cycling under irrigation needs to be better understood. Recent work (Wheeler and Bright, 2015) suggests that the monthly profile of urine N leaching risk may vary between dryland, efficient and less efficient irrigation systems. Further research on N cycling in irrigated pastures is required.
- The current OVERSEER irrigation module doesn't account for the increased runoff (including overland flow and subsurface lateral flow) that would likely be associated with rolling topography and this may lead to an underestimation of P losses on rolling topography that is irrigated.
- GrowOtago soil information was used where S-map was not available in the catchment. Moving to S-map when it becomes available for the whole catchment will improve the quality of soil information. Only a limited range of soil properties were available within GrowOtago. A wider range of soil properties, in

particular better definition of areas with shallow stony soils, would improve estimates of N leaching.

- All soil properties are based on databases and hence historical data. Changes in soil properties due to management (i.e. irrigation can increase soil organic matter) may not be reflected in these databases.
- Currently anion storage capacity (ASC) is based on the OVERSEER default associated with the soil order selected. A more refined estimate of ASC for the soil orders within the catchment would better refine estimates of P losses.
- To date there is a lack of research documenting N leaching losses from high (>1500 mm) and low (<600 mm) rainfall zones. This means that the effect of rainfall is extrapolated out to these regions based on scientific principles. Further research in high and low rainfall zones would provide more information to calibrate and/or evaluate OVERSEER.
- The majority of spatial data is collected at national or regional scale (e.g.1:50,000), therefore using the data set for property-level analysis would not be appropriate and is not recommended.
- OVERSEER determines nutrient loss to the bottom of the root zone (60cm). Therefore, to understand nutrient losses to groundwater additional models are required that can determine nutrient transport through the vadose zone.

6.2 Future improvements

A number of steps could be undertaken to improve the quality of the catchment nutrient loss estimates. However, part of any consideration of potential improvements should address the scale of information needed. Initial improvements could include the following:

- A greater understanding of the range of farm management systems within the catchment and associated OVERSEER files created to represent the wider range of management systems likely in the catchment.
- Utilise S-map (when available for the whole Manuherikia catchment) to derive better soil information (e.g. soil depth). This will better describe soil drainage patterns which will in turn improve estimates.
- Farm system descriptions – establish a wider range of farm management systems to improve the dataset of the OVERSEER files. This will help accurately reflect nutrient losses based on varied farm management systems and not always based on ‘best practise’.

7. IMPLICATION FOR IRRIGATION SCHEME

This work indicates that on individual farms;

- There will be an increase in N leaching below the root zone due to increased productivity because of irrigation.
- Irrigation can be managed to reduce this impact on a farm scale. A key aspect of efficient irrigation systems is to apply irrigation based on soil water content and a wide range of irrigation technology exists to achieve this. Recent work (Wheeler and Bright 2015) indicates that this is more important when irrigating soils with low PAW and irrigating during the shoulder periods (beginning and end of the irrigation season). Water supply contracts need to be aligned so that water availability aligns with water requirements based on soil moisture monitoring. This situation has been recognised in development of the Ruataniwha irrigation scheme.

On a catchment scale;

- The effect of irrigation can be reduced by substituting inefficient systems for more efficient use of water.
- The actual catchment discharge below the root zone may differ depending on how individual farmers change their management practices under irrigation, and the impact of irrigation on non-irrigated land (for example, dairy grazers).
- The modelling work was based on farm descriptions that are typical of the catchment, and irrigation scenarios are based on best estimates of current and future practices. The future irrigation scenario recognises both increased efficiency and substitution of less efficient management systems with more efficient systems.
- Improved estimation would require farm specific information, including management (animal and irrigation) and soil information.
- Given these constraints, the approach taken is similar to that for modelling discharges of N below the root zone used in the Ruataniwha irrigation scheme, except that an updated version of OVERSEER model was used. In the Ruataniwha irrigation scheme, these discharges were linked to catchment hydrology model (Trim model), whereas this work only considers N leached below the root zone.

It is important to note that:

- This work only determines N loss below the root zone. This work makes no comments on the effect on the receiving waters (lakes, rivers, etc.).
- Result may change as the model is updated or improved data sources (e.g. soils data) are obtained.

8. CONCLUSION

The OVERSEER analysis within the Manuherikia catchment showed that nutrient losses are strongly influenced by irrigation management practices. An efficient irrigation system generally has lower nutrient losses than an inefficient irrigation system (all things being equal). A key aspect of efficient irrigation systems is to apply irrigation based on soil water content and a wide range of irrigation technology exists to achieve this. However, water supply contracts need to be aligned so that water availability aligns with water requirements based on soil moisture monitoring. This situation has been recognised in development of the Ruataniwha irrigation scheme.

The current and future case study farms are showcasing the two extremes of irrigation management, from inefficient current controlled flood irrigated farms to efficient future centre pivot irrigated farms. The OVERSEER analysis showed that for the case study farms reductions in N leaching of between 57 and 87% and total P loss reductions of between 71 and 94% can be achieved as a result of improving the efficiency of irrigation systems.

However, the scaling process highlights that there is a strong interaction between stock type, management and N leaching susceptibility. Increasing the efficiency of irrigation systems, reduces the risk of N leaching, but the change in area irrigated and stock management due to irrigation, in particular grazing timing, stock numbers and stock type, are important as this increases the amount of urine N deposited. Therefore, the net impact of an irrigation scheme in a catchment is a function of the efficiency of the irrigation system, stock intensity and the interaction between the effect of irrigation management practices on drainage and hence the urine N susceptibility to leaching loss. Within the Manuherikia catchment we are seeing a negligible decrease of about 0.4% as we move from the 'current scenario' to the 'future – with storage scenario'.

OVERSEER determines nutrient losses to the bottom of the root zone (60 cm). Therefore, to understand nutrient losses to groundwater additional models are required that can determine nutrient transport through the vadose zone. It is also recommended that the results of the catchment scaling-up process are only assessed at a catchment level and not at the individual farm level. The nutrient loss maps have highlighted that accurate farm management data in terms of stock grazing timing, numbers and type is critically important to accurately reflect individual farm nutrient losses. The scaling-up process is based on a small number of generic OVERSEER farm management files. Therefore, it is recommended that estimates be improved by building a wider range of OVERSEER farm management files and better allocation of these files across the catchment to more accurately reflect the geographic spread of different farm management systems.

9. ACKNOWLEDGEMENTS

We wish to thank the following people who have made valuable contributions towards the development of this report: Ian Lloyd (Golder Associates (NZ) Limited), Bruce Hamilton and Ben Gardyne (Compass Agribusiness Management Limited) and Geoff Mercer and Seth Laurenson (AgResearch) for reviewing the report.

10. REFERENCES

Golder, 2015: Manuherikia Catchment Water Strategy Group - Irrigation distribution report. Client report Manuherikia Catchment Water Strategy Group.

McDowell, R.W.; Monaghan, R.M and D.M Wheeler. 2005: Modelling phosphorus losses from pastoral farming systems in New Zealand. New Zealand Journal of Agricultural Research, 48: 131–141.

Selbie, D.R.; Watkins, N.L.; Wheeler, D.M and M.A Shepherd. 2013: Understanding the distribution and fate of nitrogen and phosphorus in OVERSEER®. *Proceedings of the New Zealand Grassland Association 75:113-118.*

Overseer. 2015: Overseer: Best practice data input standards. Overseer version 6.2.0. Overseer Management Services Ltd, Wellington.

Watkins, N.L.; Wheeler, D.M.; Monaghan, R.M., Brown, M and H. Yoswara. 2014: Nitrogen leaching maps for the Otago Region. Client Report prepared for Otago Regional Council.

Wheeler, D.M.; Ledgard, S.F.; de Klein, C.A.M.; Monaghan, R.M.; Carey, P.L.; McDowell, R.W and K.L Johns. 2003: OVERSEER® nutrient budgets – moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association 65*: 191-194.

Wheeler, D.M and M.A Shepherd. 2012. Introduction. Technical Manual for the description of the OVERSEER® model. Accessed from www.OVERSEER.org.nz/OVERSEERModel/Information/Technicalmanual on 19 February 2015. pp.7.

Wheeler, D.M and J. Bright. 2015. Irrigation in OVERSEER®. In: Moving farm systems to improved nutrient attenuation. (Eds L.D. Currie and L.L. Burkitt). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8 pages.

Appendix 1: Detailed Case Study Farm Descriptions

Dryland Sheep farm

This farm consisted of two blocks, 200 ha flat block and 200 ha rolling block, with no winter crops grown. The farm was not irrigated and pasture production was 3.5 t DM/ha allowing a stocking rate of 4.4 SU/ha. Pasture type was ryegrass – white clover with 150 t DM of balage made on the flat block area each year. Fertiliser inputs amounted to 250 kg/ha of Ballance Superten applied in February. Soil test results were the OVERSEER default values.

Existing sheep farm

This sheep farm was created with 150 ha rolling country and 200 ha flat land with 50 ha of direct drilled winter forage crops (Turnips) producing 8.0 t DM/ha rotating round the flat area. The turnip crop is grazed by sheep in June, July and August. Pasture production is 8.8 t DM/ha/year allowing a stocking rate of 10.5 SU/ha. Pasture type is ryegrass – white clover and 150 t DM of balage is made on the flat area each year. Fertiliser inputs are 300 kg/ha 15% potash Superten applied in February to both the pasture blocks and in January to the winter crop block. Irrigation of the pasture and crop blocks is controlled flood irrigation (120 mm application depth and 42 day return period) and occurs from October to April. Soil test results were the OVERSEER default values.

Existing dairy support

This farm was created as two equal areas of rolling and flat land with both being 180 ha in size, the farm included a 40 ha non-productive area also. A 37 ha direct drilled kale crop producing 10 t/ha for winter grazing rotated around both the flat and rolling blocks. Stock grazing on the property consisted of 680 Friesian Jersey cross animals which came onto the property at 4 months of age and left at 22 months of age. Irrigation for both blocks is controlled flood irrigation from October to April (120 mm application depth and 42 day return period). Pasture production of 9.7 t DM/ha/year. Balage (200 t DM) is made on the flat area. Fertiliser inputs are 300 kg/ha 15% potash Superten applied in February to the pasture and 400 kg/ha DAP applied in December to the crop area. Soil test results were the OVERSEER default values.

Existing Mixed arable

This 400 ha controlled flood irrigated arable farm consisted of 200 ha pasture, 100 ha of wheat following a barley crop and 100 ha of barley sown out of pasture. The wheat was sown in April and harvested February, while the barley was sown in October and harvested in March. Fertiliser inputs to the wheat were 200 kg/ha 20% potash DAP sulphur super at sowing in April, and 40 kg N as urea in October and November.

Fertiliser inputs to the barley crops are 200 kg/ha 20% potash DAP sulphur super at sowing in October, and 30 kg N as urea in December and January. Wheat yields were 6 t grain/ha with all straw removed, while barley yields were 5 t/ha grain again with all straw removed. Pasture production was 7.7 t DM/ha ryegrass/white clover, allowing for a stocking rate of 5.2 SU/ha (sheep). Fertiliser input to the pasture was 200 kg/ha Superten applied in February. Soil test results were the OVERSEER default values.

Existing partially irrigated

This sheep farm consisted of 200 ha controlled flood irrigated flat land, and 800 ha of dryland easy hill country, with 40 ha of winter crops (8 t DM/ha turnips) rotating round the flat area. Pasture was ryegrass/white clover for the flats land and unimproved tussock grasslands for the hill country. Pasture production was 7.3 t DM/ha for the flat land and 2.2 t DM/ha for the easy hill country, with 100 t DM of balage made on the flats. This production allowed for a stocking rate of 4.2 SU/ha, with monthly animal numbers taken from the supplied Farmax file. Fertiliser inputs were 300 kg/ha 15% potash Superten applied in February to the flats, including the forage crop, and 150 kg super 10 to the hill country. Soil test results were the OVERSEER default values.

Future irrigated dairy

This is a 400 ha irrigated dairy farm with 200 ha of flat land (of which 100 ha has effluent spread) and 200 ha of rolling country. Irrigation was applied by centre pivot to the whole farm. Stock numbers were entered monthly, as supplied, with a peak of 1280 milked. Milk solids are 1315 kg/ha and milk production per cow is 411 kg MS/cow. Pasture production is 16.3 T DM/ha, with 384 T DM of silage made on the effluent area. Supplements imported onto the farm consisted of 128 T DM of silage which was fed on all pastoral blocks and 256 T of PKE and 256 T of barley, both of which were fed in the milking shed. Effluent was stored in a holding pond and applied to the effluent block at a medium rate of 12-24 mm. Fertiliser application consisted of 350 kg/ha 15% potash Superten applied in August to the whole farm. The effluent block also received 250 kg/ha 10% potash Superten in January. Urea (30 kg N/ha) was applied to the non-effluent areas in September, November, January, February, March and May, and to the effluent area in September February and April only. A fodder beet crop was grown on 20 ha on flat land. The fodder beet crop was sown in November with a yield of 28 T/ha DM. The fodder beet crop was grazed in April, May, August and September. The area was resown back into pasture in October. At sowing of the fodder beet crop 180 kg/ha of Cropzeal 16N was applied with 40 kg N/ha applied in December and February. Dairy cows were grazed off the farm in June and July, with 50% of the herd off in August also. Soil test information was supplied by Compass Agribusiness, Olsen P value was 24 mg/L.

Future irrigated sheep farm

This is a 400 ha irrigated sheep and beef farm with 200 ha of flat land and 200 ha of rolling country. 60 ha of turnips was sown in December, producing 10 T DM/ha grown for winter forage on the flat land, 30 ha of which was entered as rotating round the flat land and 30 ha of which was entered as a designated crop block. This was done as OVERSEER only accepts fodder crops that are <25% of the block area. Pasture production was 18.5 T DM/ha on both the flat and rolling country which gave a stocking rate of 20.4 SU/ha. Stock numbers were entered monthly sheep numbers supplied from the farm Farmax file. Balage (75 T DM) was made on the flat and rolling block and fed out over the whole farm. Irrigation was applied by centre pivot. Fertiliser inputs were 350 kg/ha 15% potash Superten applied in February to all pastoral blocks with 300 kg DAP applied in December and 50 kg N/ha as urea applied in January to the turnips.

Future irrigated dairy support

This is a 400 ha irrigated dairy support farm with 200 ha of flat land and 200 ha of rolling country. A 100 ha winter kale crop block producing 15 T DM/ha rotated through both the flat and rolling country. Pasture production was 15.1 T DM/ha and allowed a stocking rate of 16.9 SU/ha of 1024 Friesian Jersey Cross dairy grazers, arriving as calves and staying for 2 years. Monthly stock numbers were entered into OVERSEER from the supplied Farmax file. Silage (300 T DM) was made on the flat land and fed out over the whole farm. Irrigation was applied by centre pivot from September to April. Fertiliser inputs were 350 kg/Ha 15% potash Superten applied in February to pastoral areas and 400 kg DAP applied in October at sowing to the kale crop.

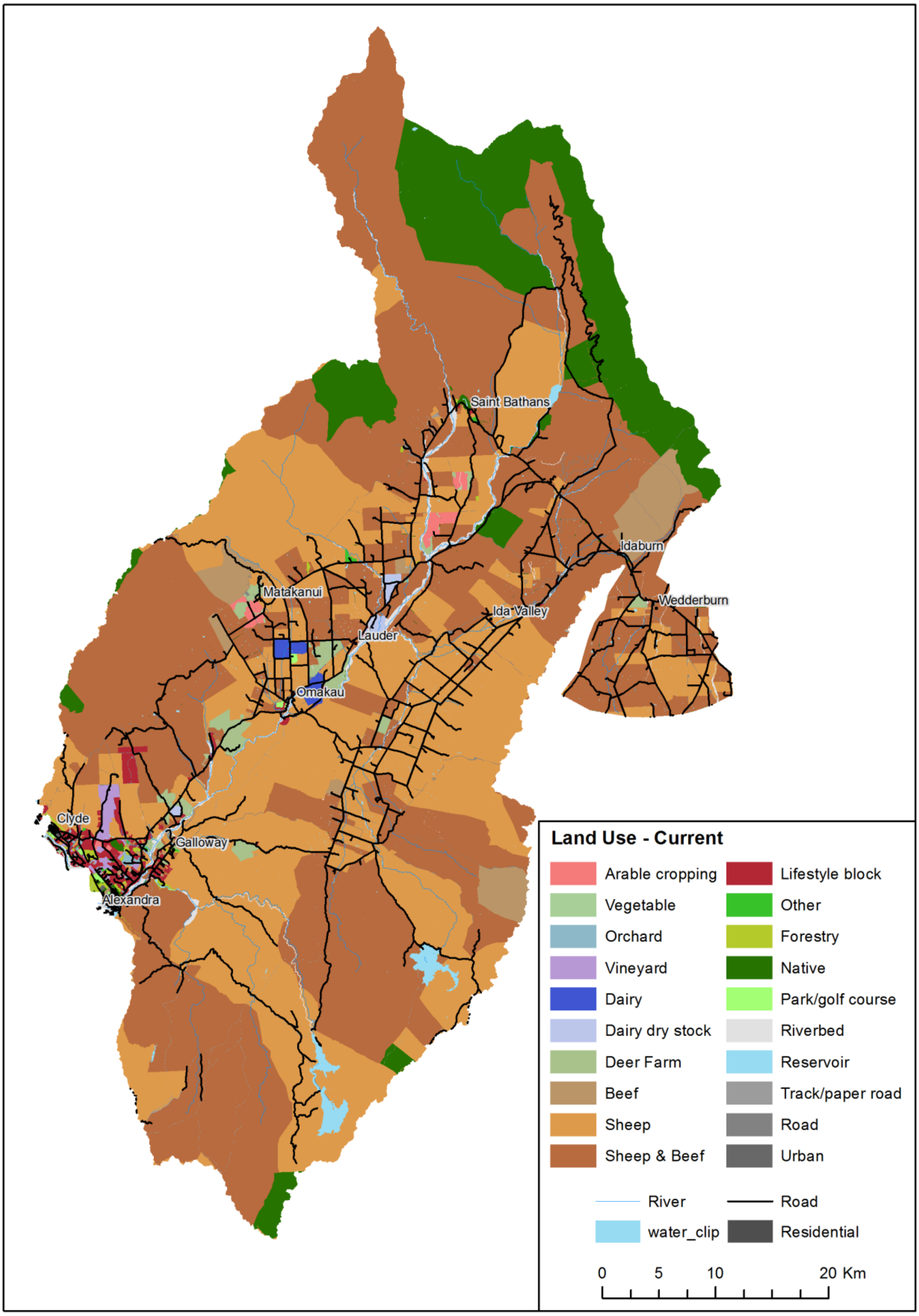
Future arable

This is a 400 ha irrigated mixed arable farm. Approximately 30% (120ha) of the land is in wheat, 30% in barley 15% in grass seed and the remainder in pasture. The wheat rotation is pasture – barley – wheat with the barley sown in October and the wheat in April. The barley rotation is 100 ha pasture – barley and 20 ha pasture – kale – barley, with the barley from pasture sown in October and the kale sown in November followed be barley the following October. The ryegrass seed rotation is wheat – ryegrass – pasture. With the ryegrass seed crop sown in April and harvested the following January. Crop yields are wheat 9 t/ha grain plus straw removed; barley 8 t/ha grain plus straw removed; ryegrass seed 1.5 t/ha seed and kale 12 t DM/ha. The grazed pasture produces 16.3 T DM allowing a stocking rate of 7.1 SU/ha over the whole farm and 28 SU/ha over the pastoral area using 1600 Texel sheep with 140% lambing and 50% (200) of the hogget's mated. Irrigation is via centre pivot and applied from September to April. Fertiliser application to the pasture was 300 kg/ha 15% potash Superten applied in February. For the wheat crops fertiliser is 300 kg/ha 20% potash DAP sulphur super at sowing in October, and 60 kg N as urea in October and December. Fertiliser applied to the barley paddocks was 300 kg/ha 20% potash DAP sulphur super at sowing in October, and 50 kg N as urea in December and January. For the ryegrass seed crop 150 kg/ha 20% potash DAP sulphur super was applied at sowing in April and 50 kg N as urea in August followed by 60 kg N as urea in October. The kale was sown with 200 kg/ha DAP followed by 50 kg N/ha as urea in January and March.

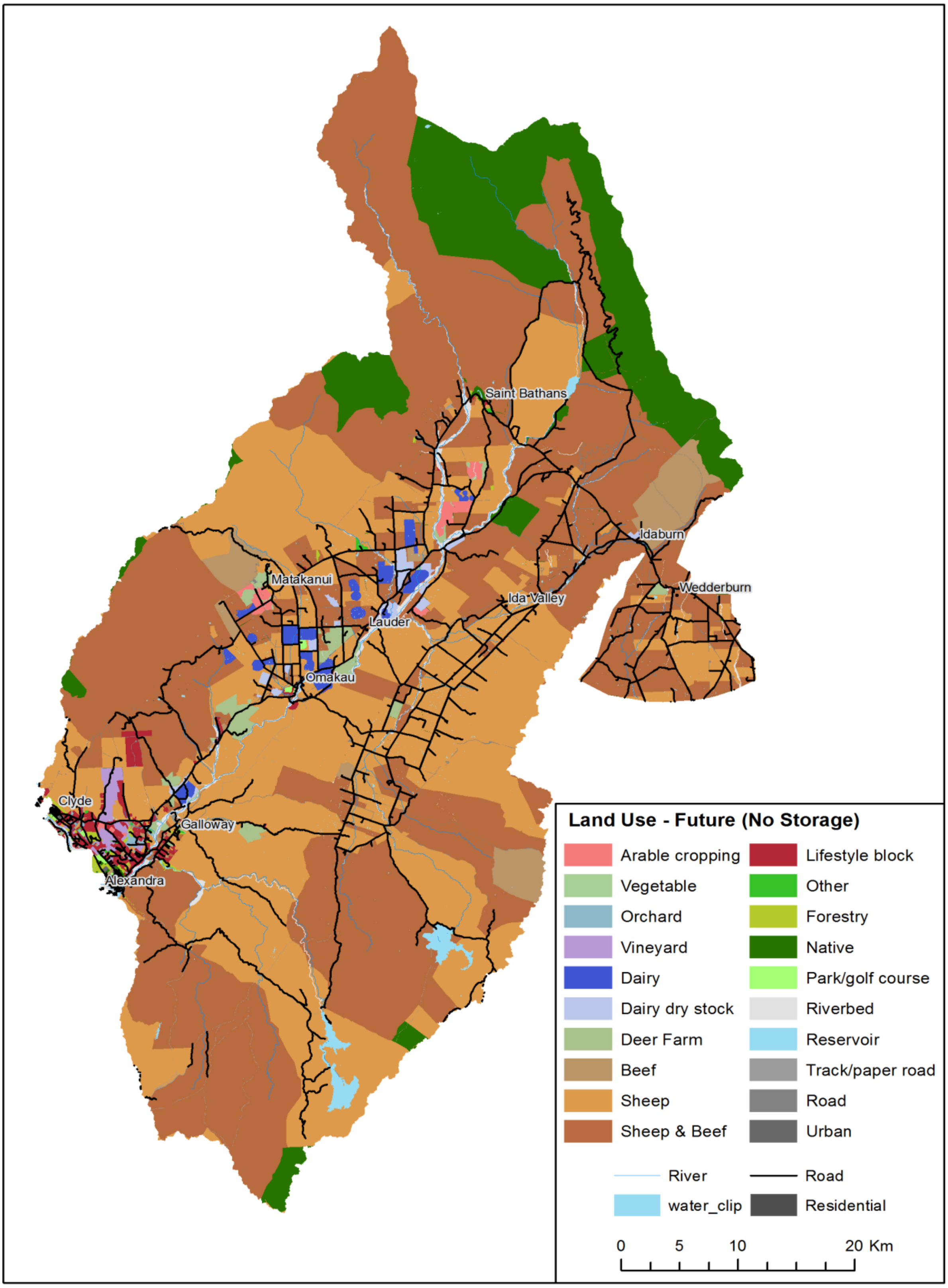
Future partially irrigated

This sheep farm consisted of 200 ha centre pivot irrigated flat land, and 800 ha of dryland easy hill country, with 35 ha of winter crops (15 T DM/ha turnips) rotating round the flat area. Pasture on the flat area was ryegrass/white clover producing 16.2 T DM/ha with 50 T balage made. Pasture on the easy hill country was entered as Browntop and produced 3.2 T DM/ha. Stocking rate was 7.4 SU/ha with monthly sheep numbers taken from supplied Farmax file. Fertiliser inputs were 350 kg/ha 15% potash sulphur Superten applied in February for the flat land and 150 kg/ha Superten for the hill block. The winter turnip block received 200 kg DAP/ha at sowing in January with a further 50 kg N/ha as urea in February.

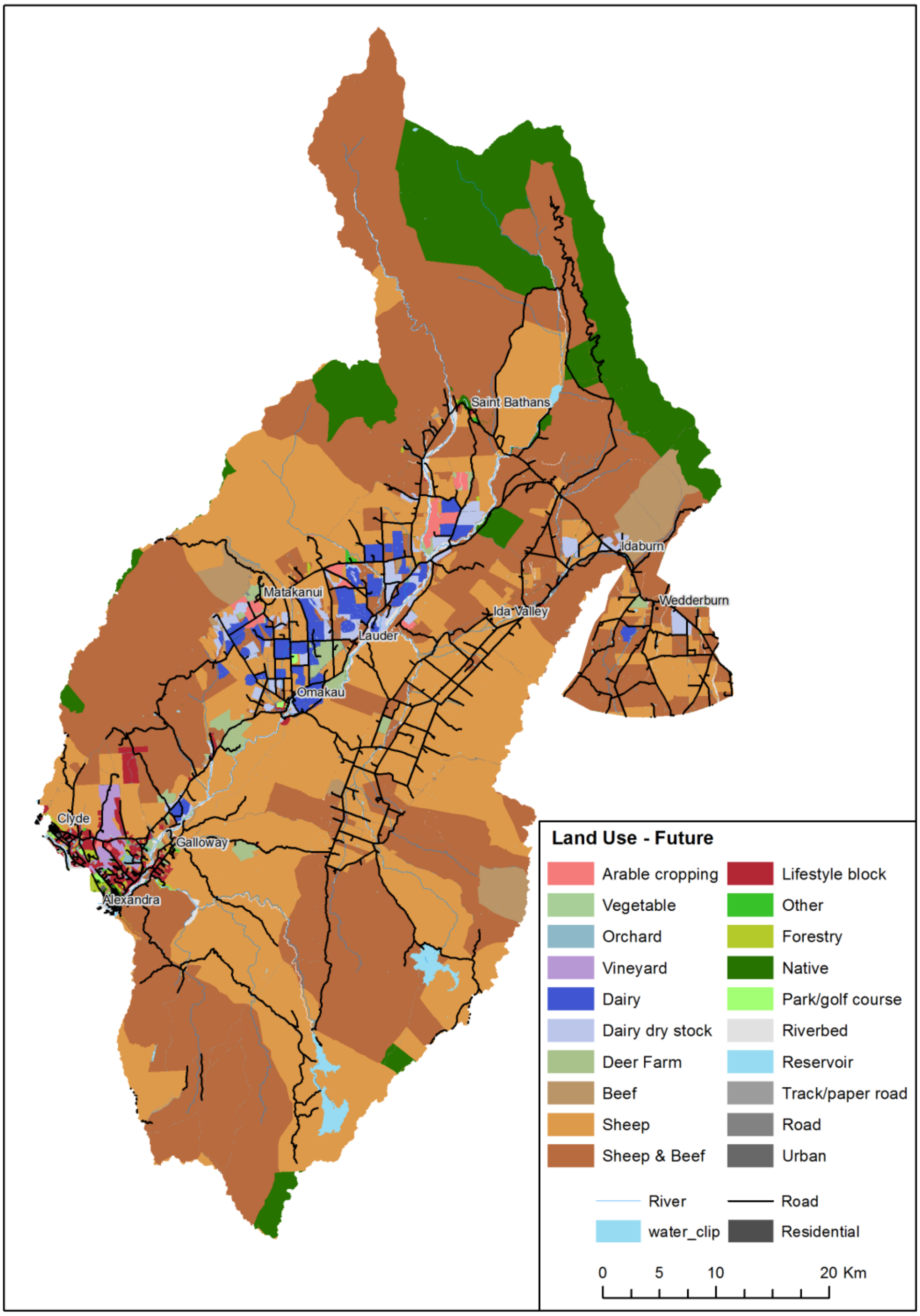
Appendix 2: Revised Agribase™ layer 'current' land use



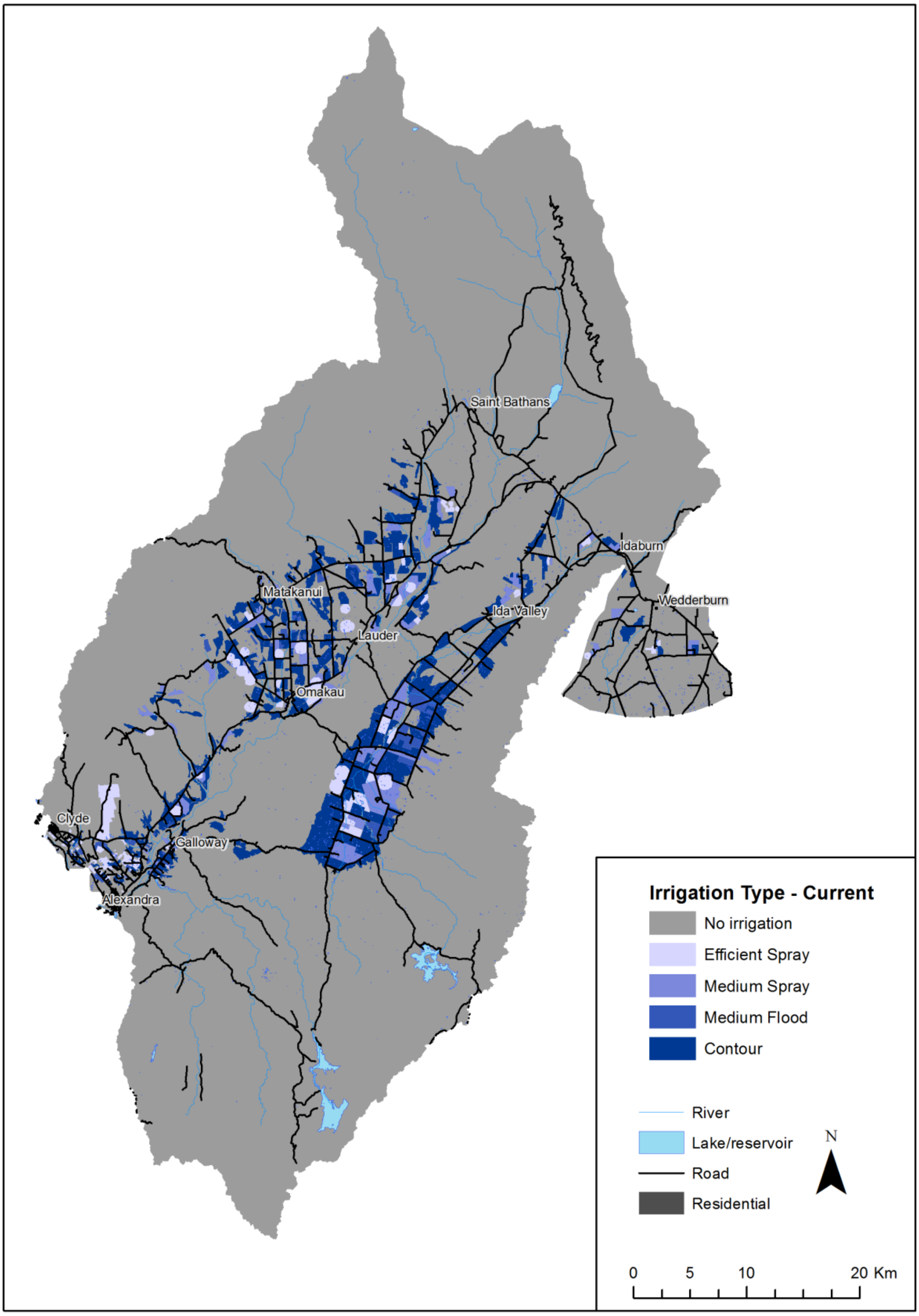
Appendix 3: Revised Agribase™ layer 'future - without storage' land use



Appendix 4: Revised Agribase™ layer 'future – with storage' land use

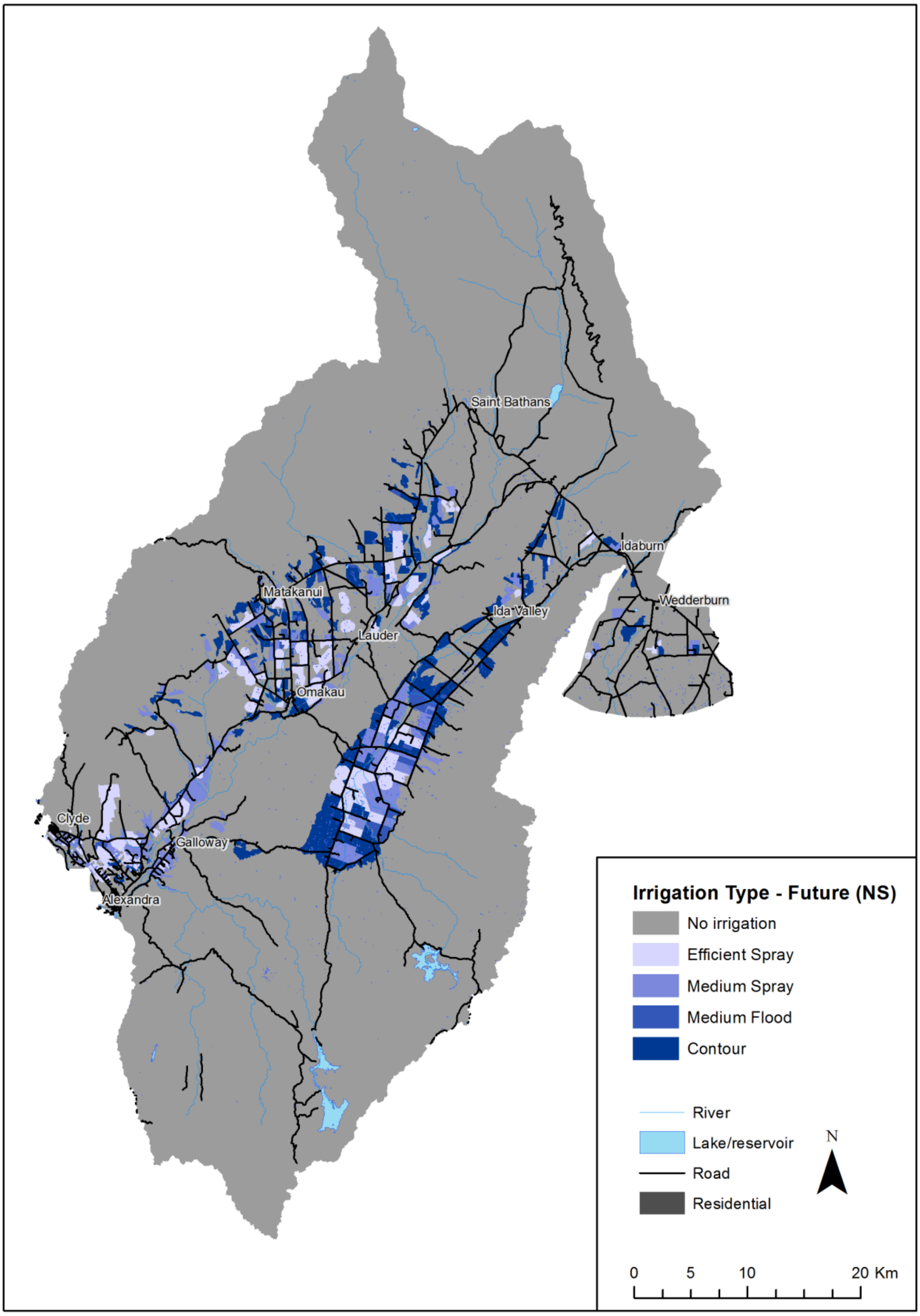


Appendix 5: Irrigation layer 'current'



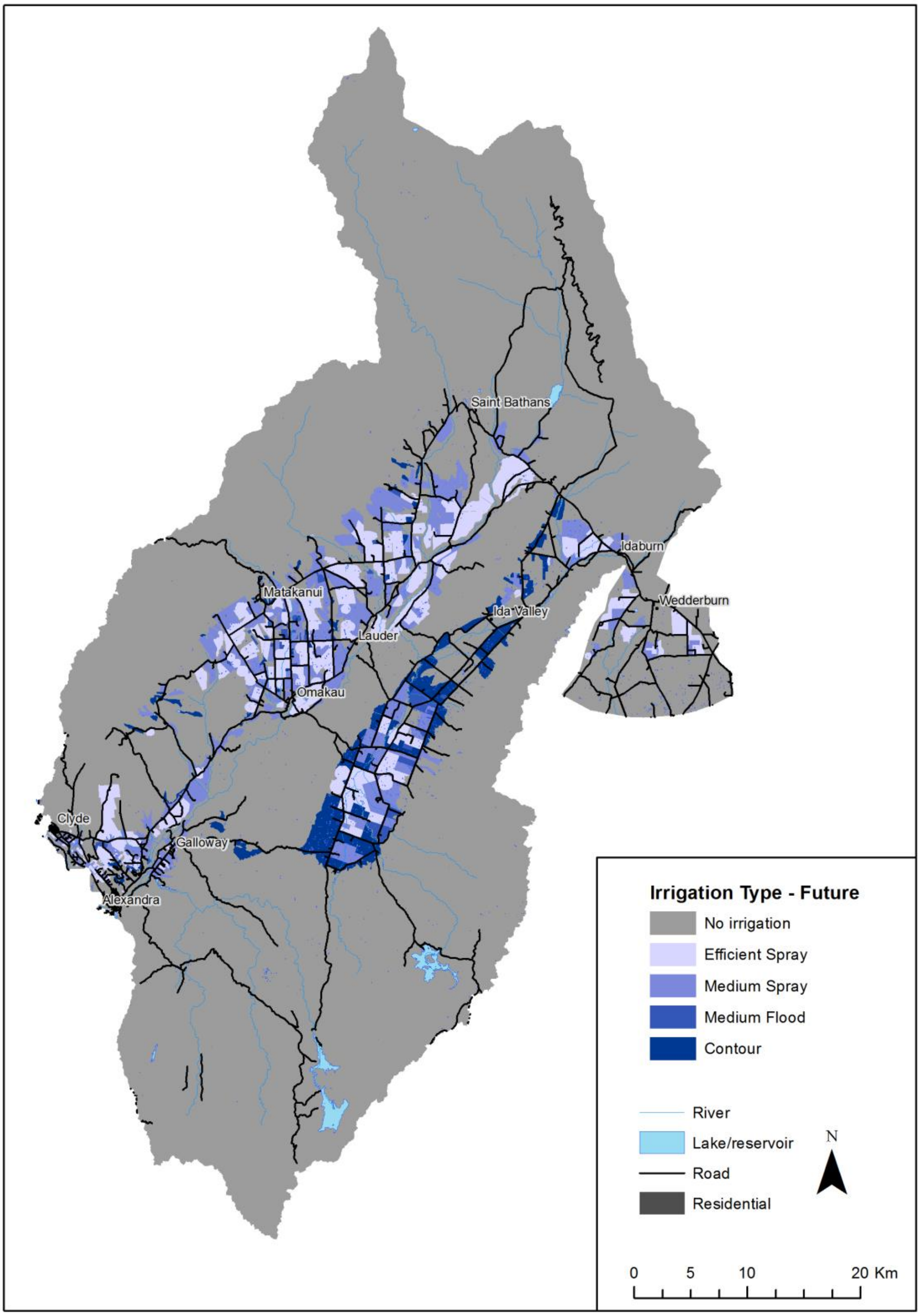
* Irrigation layer supplied by Golder (Golder, 2015)

Appendix 6: Irrigation layer ‘future – without storage’



* Irrigation layer supplied by Golder (Golder, 2015)

Appendix 7: Irrigation layer 'future – with storage'



* Irrigation layer supplied by Golder (Golder, 2015)