IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of the proposed Variation 2 to the Proposed Canterbury Land and Water Regional Plan - Section 13 Ashburton

STATEMENT OF PRIMARY EVIDENCE OF PETER BROWN FOR FONTERRA CO-OPERATIVE GROUP LIMITED AND DAIRYNZ LIMITED

15 MAY 2015

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1. INTRODUCTION

1.1 My full name is Peter Derek Brown. I am a soil and water engineer and currently hold the position of Senior Water Resource Engineer with Aqualinc Research Ltd ("**Aqualinc**").

Qualifications and experience

1.2 I hold a Bachelor of Engineering (Hons) and PhD from the University of Canterbury. I am a Chartered and APEC Engineer.

1.3 I have over 12 years' experience in water resources and irrigation-related work in the Canterbury region. I have specific expertise in assessing the impacts of irrigation on water quantity and quality. I have been involved in assessing the catchment scale impacts of irrigation proposals on water quality in a number of locations in the South Island including South Canterbury, the Manuherikia Valley, the Hurunui and Waiau catchments, and the Mackenzie Basin.

1.4 I work regularly with many of the irrigation schemes in Canterbury and Otago on a range of issues including Asset Management Systems, Farm Environmental Plan GIS systems, irrigation design reviews, root zone nutrient load estimation, scheme expansion, open channel flow automation, and hydrological modelling.

1.5 I also have expertise in soil water balance modelling, including field validation using water meter, soil moisture probes and lysimeter data.

Background

1.6 My involvement in the proposed Variation 2 to the Canterbury Land and Water Regional Plan - Section 13 Ashburton ("**Variation 2**") commenced in March 2014. My involvement includes undertaking a technical review of the water quality issues in the Lower Hinds/Hekeao Plains Area for DairyNZ, providing updated spatial maps of irrigated area, land use and drainage, and spatially modelling the impact different calculation methods have on catchment nitrogen loads and concentrations.

1.7 I am familiar with the provisions of Variation 2 to which these proceedings relate. In preparing my evidence I have reviewed the relevant parts of the section 32 Report and the section 42A Report.

1.8 I have also read the evidence of Ms Hayward.

Code of Conduct

1.9 I have read the Code of Conduct for expert witnesses contained in the Environment Court's Practice Note as updated in 2014 and agree to comply with it. In that regard, I confirm that this evidence is within my area of expertise, except where I state that I am relying on the evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed in this evidence.

2. SCOPE OF EVIDENCE

2.1 In my evidence I have been asked to:

(a) Prepare farm scale mapping of current irrigated area and system type, and the extent of the future area that can be irrigated;

(b) Identify the current land use;

(c) Calculate the root zone drainage using a soil water balance model;

(d) Prepare maps of the root zone nitrogen loss using two different methods;

(e) Undertake a spatial comparison between calculated root zone drainage nitrate concentrations and measured concentrations in the groundwater;

(f) Explain the sharp change in the rate of increase in nitrate concentrations in shallow groundwater since 2000; and

(g) Estimate the lag time between when land surface changes occur and when the bulk of the impact is measured in groundwater concentrations.

3. EXECUTIVE SUMMARY

3.1 Key conclusions from my analysis of the Lower Hinds/Hekeao Plains Area are:

(a) There is currently 93,000 ha (±3,000) of irrigated land within the total area of 127,000 ha. This estimate is higher than that estimated by Environment Canterbury in 2011, reflecting in part the development that has occurred over the last four years.

(b) Land availability constraints will limit the maximum additional irrigation that could occur to approximately 19,000 ha (±5,500). This is less than the 30,000 ha allowed for in Variation 2 and reflects in part the irrigation development that has already occurred since 2011.

(c) Currently about 60% (77,000 ha) of the total land area is dairy or dairy support. This compares with Environment Canterbury's 2011 estimate of 48% (61,000 ha) dairy or dairy support.

(d) There are large differences in estimated farm and catchment nitrate root zone load losses, depending on which version of Overseer is used and how drainage under irrigation is modelled. If the method through which the load is calculated in the Plan is different to that which is used to measure compliance it will lead to confusion and unintended outcomes. Since Overseer 6.1 will not be able to be used for compliance, the Plan numbers need to be revised and the reference to the total load in the catchment of 4,500 t-N/y needs to be deleted.

(e) While there are large differences in nitrate load estimates, the root zone nitrate concentrations calculated using Overseer 6.1 and 6.2 are similar.

(f) The sharp increase in nitrate concentrations in shallow groundwater, particularly since 2000, is due to a combination of factors, including an increase in the area of dairying, an increase in the irrigated area, and borderdyke to spray irrigation conversions.

(g) I estimate that nitrate lag times, for the majority of impacts to be measured in shallow groundwater, are at most 3 to 5 years. My opinion is based on the rapid change in groundwater concentrations in response to land surface changes, and the relatively good agreement between predicted root zone drainage nitrate concentrations and current concentrations in groundwater.

3.2 The differences between my recent analysis and that undertaken by Environment Canterbury are summarised in Table 1 below:

Table 1: Comparison between ECan and DairyNZ Land Uses analyses

Parameter	**ECan analyses (Scott & MRB 2013)**	**DairyNZ/Fonterra analyses (Brown 2015)**
Irrigated area	84,700 ha in 2011	91,300 ha in 2013
Potential new irrigation	30,000 ha in 2011	19,000 ha in 2015
Area of dairying	39,400 ha in 2011	49,000 ha in 2014
Total area in dairy or dairy support	61,000 ha in 2011	77,000 ha in 2015
Root zone drainage	287 mm/y	369 mm/y
Catchment N load	4,500 t-N/y in 2011 using Overseer 6.1	5,300 to 6,500 t-N/y in 2014 using Aqualinc & Overseer 6.2
Root zone nitrate N concentration	12.5 mg/L in 2011 using Overseer 6.1	11.2-13.9 mg/L in 2014 using Aqualinc & Overseer 6.2 methods
Land surface to groundwater lag time	Up to 10-20 years	Up to 3 to 5 years

4. FARM SCALE MAPPING OF CURRENT IRRIGATED AREA, SYSTEM TYPE AND AREA OF FUTURE NEW IRRIGATION

Irrigated area

4.1 Irrigated areas including system type were mapped under my supervision. This process involves mapping farm irrigation systems using farm boundaries, high resolution aerial photographs, resource consents, and multispectral satellite imagery ("**NDVI**"). In my view this is a more accurate and detailed method than was used for Environment Canterbury's original 2011 analysis. That analysis primarily relied on NDVI at a gross farm scale, which is typically only about 75% accurate on a farm by farm basis.

4.2 The mapped area in my evidence reflects the 2013 status. A summary of areas by type is included in Table 1. I estimate that the total irrigated area of 91,340 ha is accurate to ±3%. This is the net actual area, not gross farm area, since it excludes non-effective farm areas such as corners, buildings and tracks. There is little remaining borderdyke irrigation. Pivot irrigation is dominant on the lighter soils and Roto-Rainer irrigation dominant on the heavy soils nearer the coast.

Table 2: Irrigated area by type in 2013 in the Lower Hinds/Hekeao Plains Area

Irrigation system type	Area (ha)	% of total
Pivot or linear pivot	45,810	50
Roto-Rainer or Turbo-Rainer	22,340	24
Gun	4,280	5
K-line or long lateral	4,200	5
Borderdyke	4,660	5
Unknown*	10,050	11
Total	**91,340**	**100**
*Where the system type could not be identified from aerial photos, the system is most likely to be either K-line or Gun		

4.3 Based on my knowledge of the area and historic trends since 2013, I estimate there has probably been another 1,000 – 2,000 ha of borderdyke to spray irrigation conversions, and 1,000 – 2,000 ha of new irrigation. I therefore estimate that the current irrigated area as at 2015 is 93,000 ha (±3,000).

4.4 My 2013 estimate is 7,000 ha higher than that estimated by Environment Canterbury in 2011, reflecting in part the development that has occurred from 2011 to 2013.

Maximum additional irrigation

4.5 I also assessed the maximum amount of new irrigation that could occur. Of the remaining 34,000 ha of dryland (being 127,000 ha in total minus the 93,000 ha of irrigated land), not all of this can be physically irrigated. About 7,300 ha is non-agricultural land such as river margins, roads, ponds and urban areas. In addition, farms are never 100% irrigated, with some non-effective areas for corners, buildings, tracks and trees. Taking into account these land availability constraints, I estimate at most 19,000 ha (±5,500) of new irrigation could occur. Water distribution (i.e. supply) constraints will further limit the land that could be developed, perhaps by another 2,000 ha. This estimate of 19,000 ha is less than the 30,000 ha allowed for in Variation 2 and reflects in part the substantial irrigation development that has already occurred since 2011. My assessment of maximum additional irrigation area is set out in Table 3 below.

Table 3 - Maximum potential new irrigation calculations

ID	Land use category	Lower (ha)	Upper (ha)	Average (ha)	Comments
1	Non-agricultural (e.g. river margins, roads, ponds, urban)	7,320	7,320	7,320	
2	Trees on private land	800	800	800	LCDB4 (2012). Assume at most 1/2 area could be cleared for irrigation.
3	On-farm non-effective areas (corners, buildings, tracks etc)	11,900	5,900	8,900	5-10% of gross farm area
4	Existing irrigation 2013	94,000	89,000	91,500	2013 estimate ±3%
5	New irrigation 2013-2015	2,000	1,000	1,500	
6	Total geometric area	127,010	127,010	127,010	
	Maximum potential new irrigation	**13,390**	**24,390**	**18,890**	ID6 - (ID1,ID3,ID4,ID5) + ID2/2

4.6 There have been large changes in the type and extent of irrigation since 2000. In 2000 the majority of the two main irrigation schemes, Mayfield Hinds and Valetta, were irrigated borderdyke systems (about 24,000 ha). Over the last 15 years most of this borderdyke irrigation has been converted to pivot irrigation. There has also been a significant expansion in the irrigated area, with water from groundwater, lowland drains, water savings from existing schemes, and the Barhill Chertsey Irrigation scheme.

4.7 Further details of the methods and maps of the irrigated area are provided in **Appendix A**.

5. CURRENT LAND USE TYPE

5.1 Land use by farm as it existed in 2014 was mapped under my supervision. This land use mapping used legal boundaries and property ownership information from Land Information New Zealand, high resolution aerial photographs, Environment Canterbury's resource consents database, local industry expert knowledge, the Land Cover Database version 4.0, and Environment Canterbury's 2011 land use estimates (MRB 2013, Scott 2013a). The multiple independent sources of information mean that I have a reasonably high degree of confidence in this mapping. I expect the mapping accuracy to be similar to or better than Environment Canterbury's 2011 analysis, because for the majority of the area I did not need to rely on Agribase data, which is a less accurate data source.

5.2 Land use categories were developed in conjunction with Ms Hayward of DairyNZ. Many predominantly arable/cropping farms in the Hinds Plains Area include a portion of dairy wintering. To account for these systems we asked the local experts to identify farms that had primary and secondary land uses, and the approximate proportion of the farm dedicated to those land uses. Areas by land use are summarised in Table 4. Dairy and dairy support clearly dominate land use, accounting for about 60% of the Lower Hinds/Hekeao Plains Area.

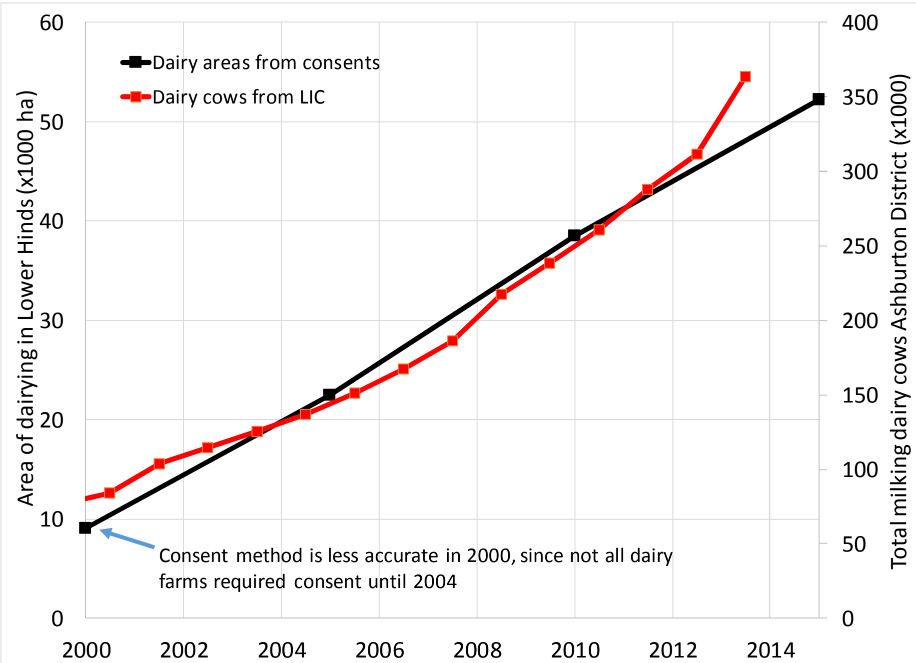
Table 4: 2014 Land use in the Lower Hinds/Hekeao Plains by area

Land use	**Area (ha)**			**% of total**
	Primary	**Secondary**	**Total**	
Dairy	49,089		49,089	39%
Dairy support including wintering	17,048		17,048	13%
Dairy support, no wintering	4,699	806	5,505	4%
Dairy wintering		4,994	4,994	4%
Dairy sub-total			**76,636**	**60%**
Beef (<30% sheep)	1,823	14	1,837	1%
Sheep (>70% sheep)	4,786	126	4,911	4%
Sheep and beef (30-70% sheep)	6,254		6,254	5%
Deer	996	140	1,136	1%
Sheep and beef, deer sub-total			**14,138**	**11%**
Arable/cropping	22,759	1,936	24,695	19%
Mixed use farms	1,253		1,253	1%
Horticulture	171		171	<1%
Pig	163		163	<1%
Other land uses	60		60	<1%
Lifestyle	1,781		1,781	1%
Low-N (trees, roads etc.)	8,111		8,111	6%
Other sub total			**36,234**	**29%**
Total			**127,008**	

5.3 My analysis shows that in 2014 dairy farms accounted for about 40% (49,000 ha) of the total area. Because dairy sheds were clearly visible from aerial photographs, with consents providing secondary confirmation, I have a high degree of confidence in this analysis. This estimate is 10,000 ha greater than Environment Canterbury's 2011 estimate, with the difference mainly due to conversions from 2011 to 2014.

5.4 I wished to understand how the area of dairying in the Lower Hinds Area has changed over time. To do this, I used the date that discharge consents were given effect to (where available) or issued, together with farm boundaries, to estimate the change in the dairying area over the last 15 years. Results in Figure 1 indicate that about 75-80% of the dairy development in the Lower Hinds/Hekeao Plains Area has occurred since 2000, at a fairly constant rate of about 2,800 ha per year. Dairy cow numbers from Livestock Improvement Corporation/DairyNZ for the whole Ashburton District show a similar trend.

Figure 1: Changes in dairy farming area with time (approx.)



5.5 Further land use method details and maps are provided in **Appendix B**.

6. CALCULATE OF ROOT ZONE DRAINAGE

6.1 I used my maps of rainfall, soil, irrigation area and type, together with a soil water balance model, to map root zone drainage. The soil water balance model I used was AusFarm, a biophysical model of temperate climate pastoral systems. I did not specifically model cropping systems, but rather assumed cropping drainage would be similar to pasture. Cropping drainage is more difficult to model because it requires knowledge of where and when different crop rotations occur. While this simplification may result in small differences in the total catchment drainage estimates, I do not expect it will have a material influence on my key conclusions.

6.2 I split the Lower Hinds/Hekeao Plains Area into three different rainfall zones based on mean annual rainfall isohyets from NIWA. I used three rainfall stations to represent each zone. I scaled the time series data from the rainfall stations slightly, so the mean annual rainfall for the time series was exactly equal to the mid-point of the zone. Rainfall zones are summarised in Table 5. Evapotranspiration information for all three zones was from the Winchmore climate station.

Table 5: Rainfall zones for the Lower Hinds/Hekeao Plains Area

Rainfall zone		**Representative rainfall station**	
Mean annual rainfall range	% of zone area	Name	Mean annual rainfall (mm)
600-700	23%	Coldstream	624
700-800	54%	Winchmore	737
>800	23%	Springburn	904

6.3 Soil information was provided by Landcare Research in March 2014. I grouped soils by the Landcare/Environment Canterbury soil code. The soil map differs from the data used by Scott (2013a), due to changes in the S-Map database in mid-2013. Soils are predominately "light" free draining lismores.

6.4 I modelled how different irrigation systems result in different amounts of drainage. I expected the drainage depths from AusFarm to be similar to Overseer 6.2 values. Overseer 6.2 uses another Aqualinc soil water balance model IrriCalc to calculate applied irrigation. IrriCalc and AusFarm produce very similar estimates, given the same inputs. The total calculated annual average drainage volume for the Lower Hinds/Hekeao Plains Area was 469 Mm^3, which is an average drainage of 369 mm per ha over the 127,000 ha. This value is about 30% higher than Environment Canterbury's estimated average drainage of 287 mm (Scott 2014). The difference is because Environment Canterbury estimates are based on Overseer 6.1, which under estimates irrigation requirements and drainage depths for irrigation, particularly on light soils.

6.5 Climate, soil and drainage method details and maps are included in **Appendix C**.

7. MAPPING THE ROOT ZONE NITROGEN LOSS

7.1 I used my maps of rainfall, soil, irrigation area and type, and drainage depth, together with a nitrate lookup table, to map root zone nitrate losses.

7.2 The Hinds look-up table was developed by DairyNZ and is described by Ms Hayward in her evidence. This table was developed as a coarse breakdown of the major land uses/soil/rainfall combinations based on Overseer 6.1 estimates of nitrate loads, nitrate concentrations and drainage values. I have referred to this data as the "DNZ base look-up table values".

7.3 In developing our estimates of nitrate loads for the Lower Hinds/Hekeao Plains Area, I employed two methods of adjusting for drainage and load deficiencies in Overseer 6.1 (see Table 6). The method I have termed "DNZ/Aqualinc" uses the DairyNZ base look-up table values, and applies a drainage correction factor. The drainage depth is assumed to be what I calculated using AusFarm. The nitrate concentration assumes any increase in drainage (relative to the base table) has half the concentration of the base table. The nitrate load is the nitrate concentration multiplied by the drainage depth. All of this analysis is done spatially at a sub-farm scale, with a unique nitrate load and concentration, and drainage depth, for each unique rainfall-soil-land use-irrigation type polygon.

Table 6: Root zone load and calculation methods.

Method	Drainage depth	Concentration
Overseer 6.1	Refer MRB (2013)	
DNZ/Aqualinc	AusFarm	Increase drainage 1/2 concentration of base table
DNZ/Overseer 6.2	AusFarm	DNZ base table

7.4 The reason for the "DNZ/Aqualinc" concentration adjustment factor is that there is evidence that inefficient irrigation systems (such as borderdyke) result in higher nitrate loads but lower concentrations from the root zone. The drainage and concentration adjustment method is the same method that is likely to be used in the Hurunui and Waiau Catchments for catchment nutrient. This method has received "buy-in" from all major stakeholders, including Environment Canterbury, in these catchments. This method generally results in higher loads (relative to Overseer 6.1) but lower concentrations.

7.5 The method I have termed "DNZ/Overseer 6.2" uses the DairyNZ base look-up table values, and applies a drainage correction factor. The drainage depth is from AusFarm while the nitrate concentration is equal to the base look-up table value. I have termed the method "DNZ/Overseer 6.2" because I expect it to be an approximation of this new version of Overseer. The core assumption is that Overseer 6.2 will have drainage depths similar to my AusFarm values, but concentrations will be similar to Overseer 6.1. These assumptions are based on preliminary DairyNZ analysis, which compared Overseer 6.1 and 6.2, and indicated that while loads can increase significantly between the two versions (particularly under irrigation on light soils), concentrations are similar. The DNZ/Overseer 6.2 method results in the highest load of the three methods.

7.6 These drainage adjustments mean my nitrogen load estimates account, at much finer resolution compared with the base tables, how irrigation type, rainfall and soils influence nitrate loads. This is because my drainage map spatially considers all of the irrigation type, rainfall and soil combinations.

7.7 Calculated nitrate losses are presented in Table 7. While there are large differences in the loads between the methods, concentrations remain similar. Further details of the method, and maps of load and concentration, are included in **Appendix D**.

Table 7: Root zone nitrate losses

Method	Catchment drainage		Nitrate loss		Root-zone drainage concentration
	mm/y	Mm^3/y	t-N/y	kg-N/ha/y	mg-N/l
DNZ/Aqualinc	369	469	5,267	41.5	11.2
DNZ/Overseer 6.2	369	469	6,508	51.2	13.9
Environment Canterbury 2011 (Scott 2013, MRB 2013)	*287*	*364*	*4,524*	*35.7*	*12.5*

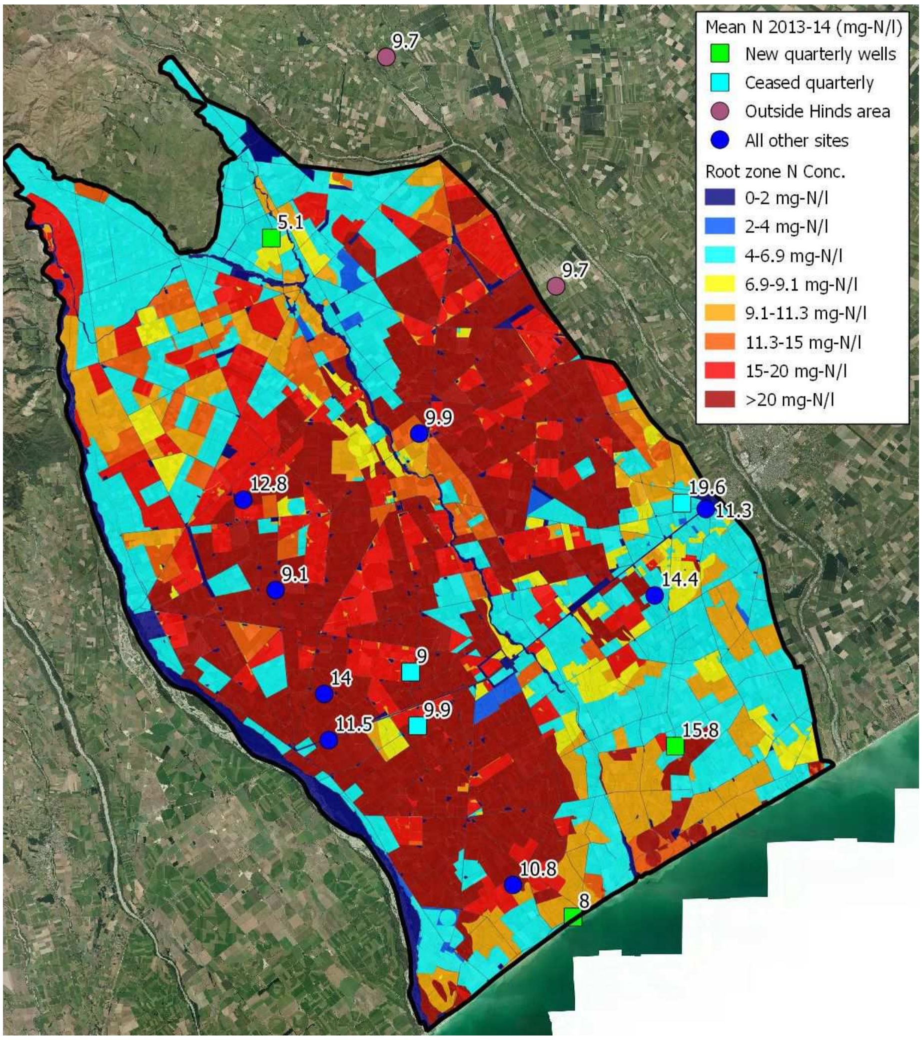
7.8 This modelling illustrates there are large differences in estimated farm and catchment nitrate load losses, depending on which version of

Overseer is used and how drainage under irrigation is modelled. DNZ/Overseer 6.2 loads are significantly higher than those estimated by Overseer 6.1 on light free-draining soils under irrigation. As the Lower Hinds/Hekeao Plains Area is dominated by irrigation on light free-draining soils, using Overseer 6.2 will have a major impact on the catchment load estimate. Were Overseer 6.2 used to recalculate Environment Canterbury's 2011 load, I would expect the calculated load to be roughly 30% greater (ie 5,900 t-N/ha compared to 4,524 t-N/ha), since drainage is likely to increase by about 30%.

7.9 This analysis highlights the importance of developing a consistent and objective load calculation method, and getting consensus across the catchment to use this same method to calculate compliance. If the method through which the load is calculated in the Regional Plan is different to that which is used to measure compliance it will lead to confusion and unintended outcomes. Similarly, if more than one method is used for compliance, or the method keeps changing with new versions of Overseer, the uncertainty or "noise" in catchment load estimates will make it very difficult to measure any real change in the catchment load over time. Since Overseer 6.1 will not be able to be used for compliance, in my opinion the reference to the total load in the catchment (ie 4,500 t-N/ha) needs to be deleted. I do not consider that any total annual load should be included until there is more certainly and consistency in how loads are calculated. Until then, rather than a total nitrate load, I would recommend using a "percentage reduction" description. In other words, rather than referring to a total target load of [x], the target should be to reduce nitrate load in the Catchment by [x]%.

7.10 Maps in **Appendix D** and Figure 2 illustrate that load and concentration across the zone is far from uniform. There are two distinct areas of high load and concentration, corresponding approximately to the Mayfield Hinds and Valetta Irrigation schemes. The high loads are the result of a combination of a high proportion of dairying and irrigation on light free draining soils. The maps illustrate how the calculated root zone concentrations compare with measured groundwater concentrations.

Figure 2: DNZ/Overseer 6.2 concentration



7.11 Measured groundwater concentrations in the 13 quarterly monitoring bores for the 2013/14 season was 10.9 mg-N/l. These bores appear to be appropriately positioned to capture the average nitrate concentrations across the zone. I estimate there is roughly about 120 Mm^3 per year of clean water recharge in the zone from irrigation and stock water races: 3.5 m^3/s associated with Mayfield Hinds Irrigation distribution[1] and 1.5 m^3/s from stock water races.[2] This would suggest that root zone drainage is diluted with around 20% of clean low nitrate race water. Therefore, an average shallow groundwater concentration of 10.9 would correspond to average root zone concentrations of 13.1 mg-N/l. This is within the range of (and close to the average of my two methods) of the

1 From previous work I have done for this irrigation scheme.

2 In 2007 Weir estimated there was 2.3 m^3/s of stock water recharge in the Ashburton-Rangitata zone. Some of this will be outside the Lower Hinds zone, and some of the races may no longer be in use, hence the lower value of 1.5 m^3/s. The Rangitata Diversion Race and surface water also provide clean water recharge.

calculated catchment root zone concentration of 11.2 – 13.9 mg-N/l (see paragraph 7.7).

8. WHY HAS THERE HAS BEEN A SHARP INCREASE IN GROUNDWATER NITRATES SINCE 2000?

8.1 Ms Hayward discusses in her evidence how groundwater concentrations have changed with time. She explains that there is a sharp change in the rate of increase in nitrate concentrations in shallow groundwater from 2000 – 2006, with the inflection point varying from bore to bore.

8.2 Conversions to dairying and an increase in the irrigated area can both be expected to increase the nitrate concentrations in drainage water. While borderdyke to spray conversions generally decrease nitrate loads (given the same land use), drainage concentrations generally increase. For example, this response is evident from water quality monitoring in the Amuri Basin in the Hurunui, where borderdyke to spray irrigation conversions have reduced the nitrate load from the basin but increased shallow groundwater concentrations. I suspect this is because of the higher stocking rates under spray systems and the lack of dilution from lower nitrate macro-pore bypass flow.

8.3 Both the increase in dairy conversions and the change from borderdyke to spray irrigation systems have primarily occurred since 2000. Since 2000 there has also been a significant increase in the area of irrigation. These land surface changes in time appear to closely follow the measured changes in groundwater. The implication is that shallow groundwater concentrations respond rapidly to land surface changes.

9. WHAT IS THE APPROXIMATE GROUNDWATER NITRATE LAG TIME?

9.1 The observations that land surface changes result in rapid changes in groundwater nitrate concentrations, and the close agreement between calculated root zone nitrate concentrations and groundwater concentrations, indicate that the lag times for the aquifer in the Lower Hinds/Hekeao Plains Area are much shorter than in many other parts of Canterbury. My opinion based on these observations is that the lag time, for the majority of land surface impacts to be measured in shallow groundwater, are at most 3 to 5 years. My opinion is the lag times are much shorter than the estimate of up to 10 to 20 years predicted by Scott (2013b).

Peter Brown
15 May 2015

References

MRB (2013). "Hinds catchment nutrient and on-farm economic modelling". Macfarlane Rural Business Ltd, December 2013. Environment Canterbury Technical Report No. R13/109. ISBN 978-1-927284-22-3.

Scott (2013a) "Hinds Plains water quality modelling for limit setting process". Environment Canterbury Report No. R13/93. ISBN 978-1-927274-38-5

Scott (2013b) "Lag times in the Hinds catchment". Internal Environment Canterbury memorandum dated 31 July 2013.

Scott (2014). "Hinds Plains water quality modelling – adjustment to the model and final catchment load calculations". Internal Environment Canterbury memorandum dated 3 April 2014.

Appendix A: Irrigated area mapping

The method is the same as that used to map irrigated area for other Water Management Strategy Zones for Environment Canterbury. For the Lower Hinds/Hekeao Plains Area the aerial photos are predominately from the summer of 2012/13, while multi-spectral satellite imagery is from March 2014.

Aqualinc's method for mapping irrigated area in Canterbury

(1) **Farm boundary extents.**
Map the approximate extent of farm boundaries using land ownership and title GIS data from LINZ.

(2) **Irrigation systems clearly visible from photos**
This step involves mapping the irrigation systems that are visible from high resolution aerial photos (0.5m pixel size or less). We also map the travelling irrigator units (e.g. Roto-Rainers, Linear Booms, Lateral pivots, Big Guns). We map the full extent that the irrigation system is designed to irrigate, not the actual area irrigated at the time of the photo. The system type is estimated by a range of factors including irrigation design considerations, property boundary limitations, visually sighting of travelling irrigators, and markings on the ground (e.g. wheel tracks, irrigation patterns). Where more than one set of images are available we cross-reference between imagery. This process identifies 80-90% of the irrigated area with a high degree of accuracy.

(3) **Areas with irrigation consents**
In GIS we combine the farm boundaries layer with Environment Canterbury consent records of irrigation consents (surface takes, groundwater takes, irrigated areas and irrigation scheme extents) and land slope. From this we identify farms and areas with water consents, and land slope less than 15°, which could potentially be irrigated.

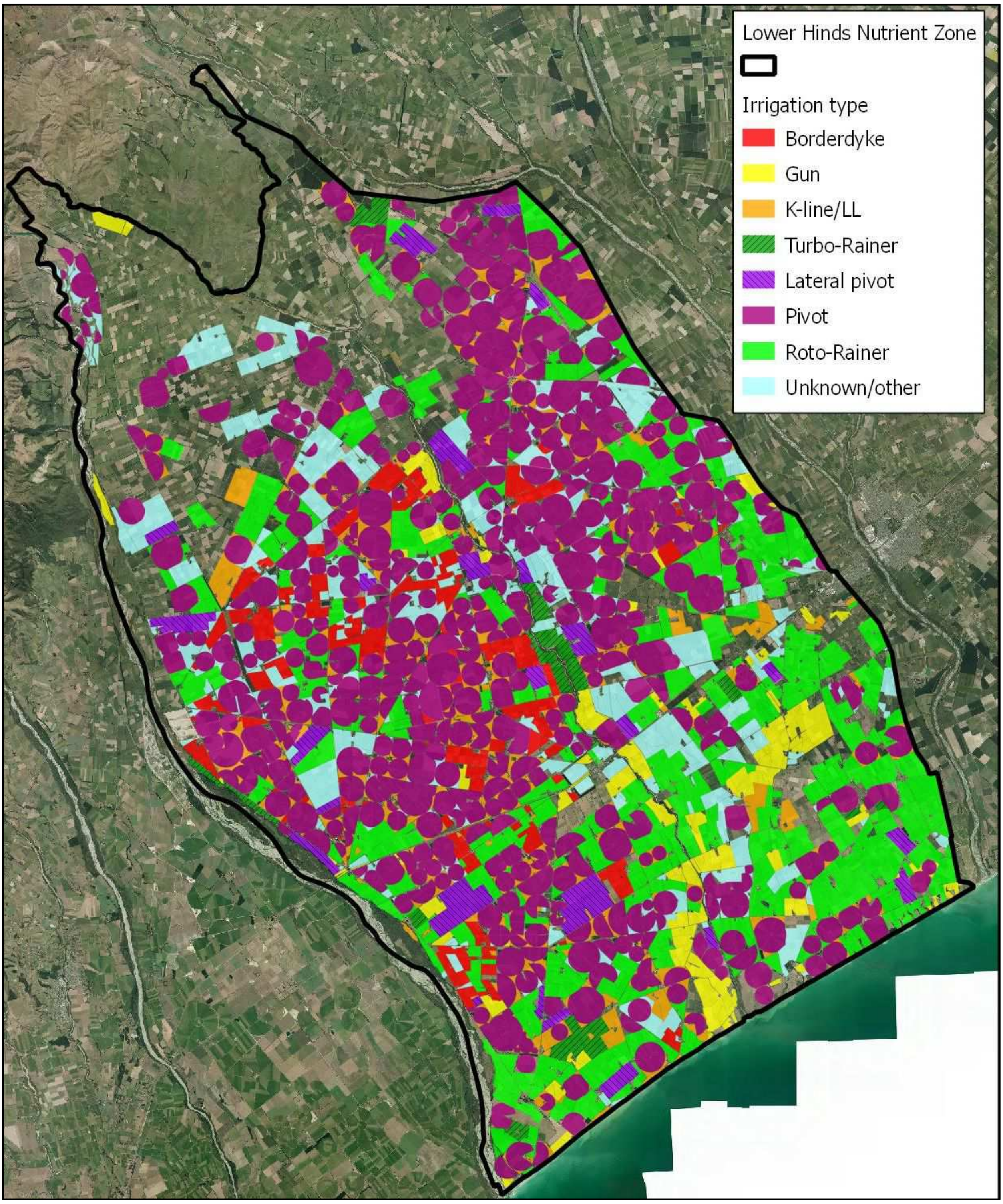
(4) **Multi-spectral satellite analysis**
We map the normalised difference vegetation index (NDVI) from Landsat imagery from January to March. We use images where there is a strong contrast between actively growing vegetation (which are likely irrigated) and dry areas.

(5) **Combine irrigation consents and NDVI analysis**
We combined results from steps (3) and (4) to map the remaining 10-20% of the irrigated area. We manually map these areas, giving consideration to irrigation design and farm boundary limitations.

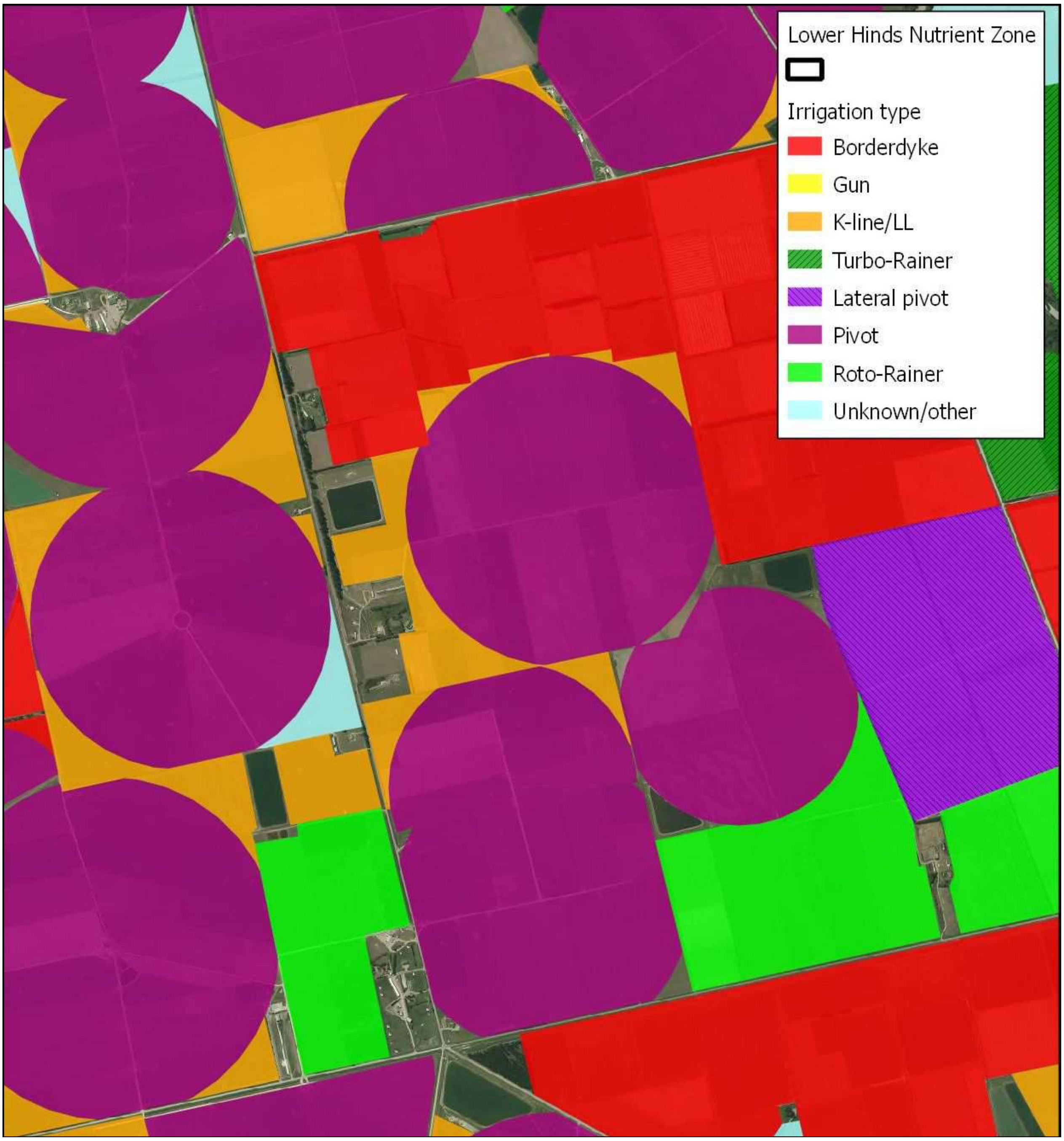
(6) **StatsNZ survey**
We cross-reference the total irrigated area for the territorial authority with StatsNZ 30 June 2012 agricultural survey results. We give consideration to irrigation development that has occurred since June 2012.

This method is particularly effective in Canterbury because: (1) the vast majority of the irrigation systems are permanent installations; (2) there is a high proportion of pivot irrigation, lateral pivots, and Roto-Rainer irrigation, which can all be mapped with a high degree of confidence from aerial photos; and (3) in a dry year for most irrigated areas in Canterbury there is a reasonable NDVI contrast between irrigated and unirrigated areas.

Lower Hinds nutrient zone 2013 Irrigated area



Irrigated area farm scale example



Appendix B: Land use (2014)

Method

Farm boundaries were estimated using Land Information New Zealand's land ownership database. Land parcels within 200 m of another parcel owned by the same entity were assumed to be part of the same farming unit. Farms separated by more than 200 m were assumed to be a different unit even if they were owned by the same entity. Where ownership of adjacent land parcels was effectively the same party, but under a different name (e.g. company name verses individual names) these were assumed to be part of the same farming unit. I expect these boundaries to be a reasonable representation of farming units at a catchment scale.

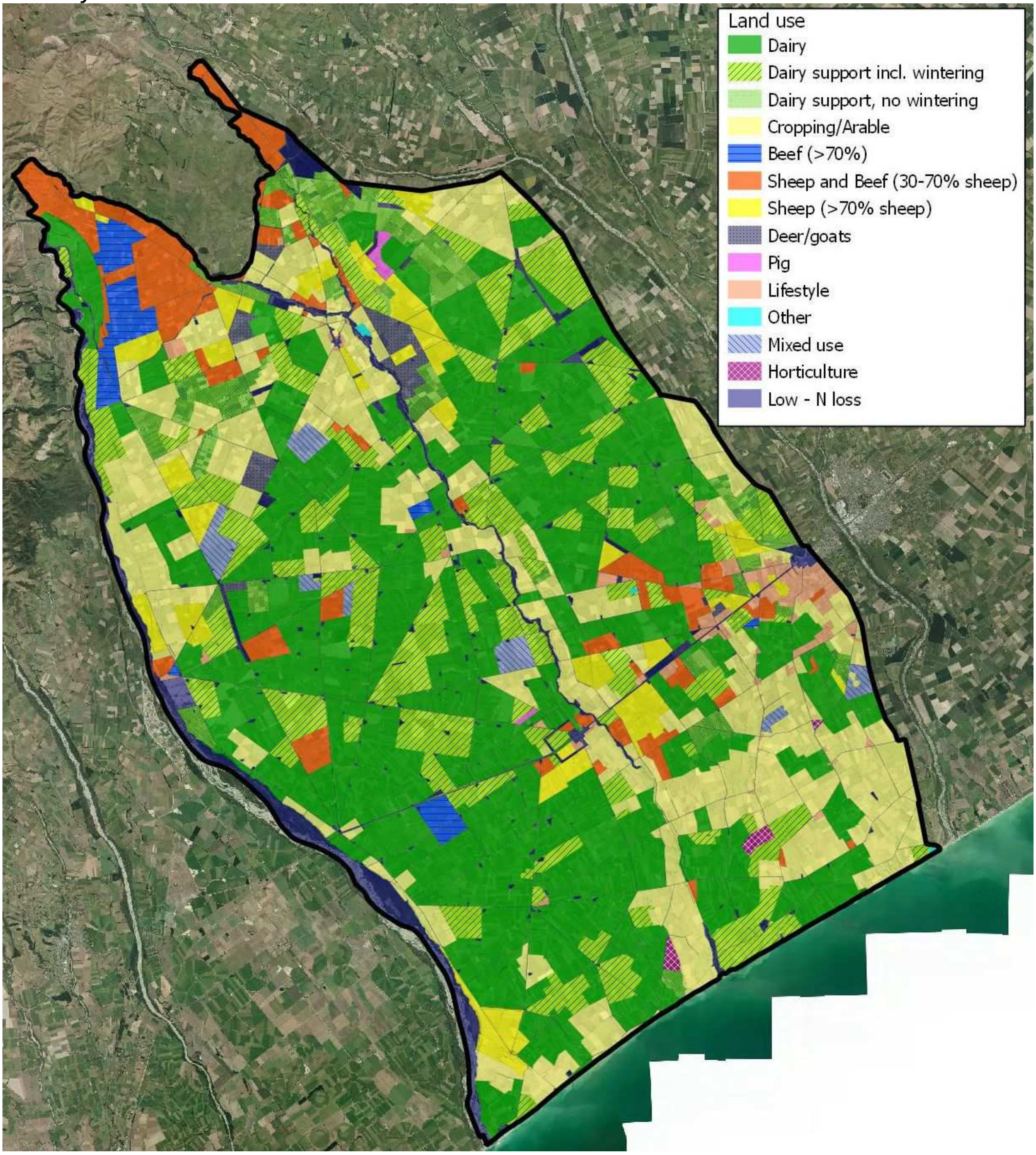
Dairy farms were mapped using a combination of Environment Canterbury's consents database (since every dairy shed requires an effluent discharge consent), aerial photographs, and local knowledge. Land use for the bulk of the remaining farms was identified by local industry experts, Reuben Edkins, Rab McDowell, George Lumsden, and Phil Everest. The local experts were able to identify the broad land use (e.g. sheep and beef, arable/dairy support) with a high degree of confidence for most farms. For the small number of farms where our experts could not confidently determine land use (about 7% of the total Study Area), Environment Canterbury's 2011 land use classifications were used.

Many predominantly arable/cropping farms on the Hinds Plains included a portion of Dairy Wintering. Ms Hayward considered it was important to capture the portion of Dairy Wintering, as this land use typically leaches more nitrogen than arable/cropping practices. The local experts were able to identify farms that had primary and secondary land uses, and the approximate proportion of the farm dedicated to those land uses.

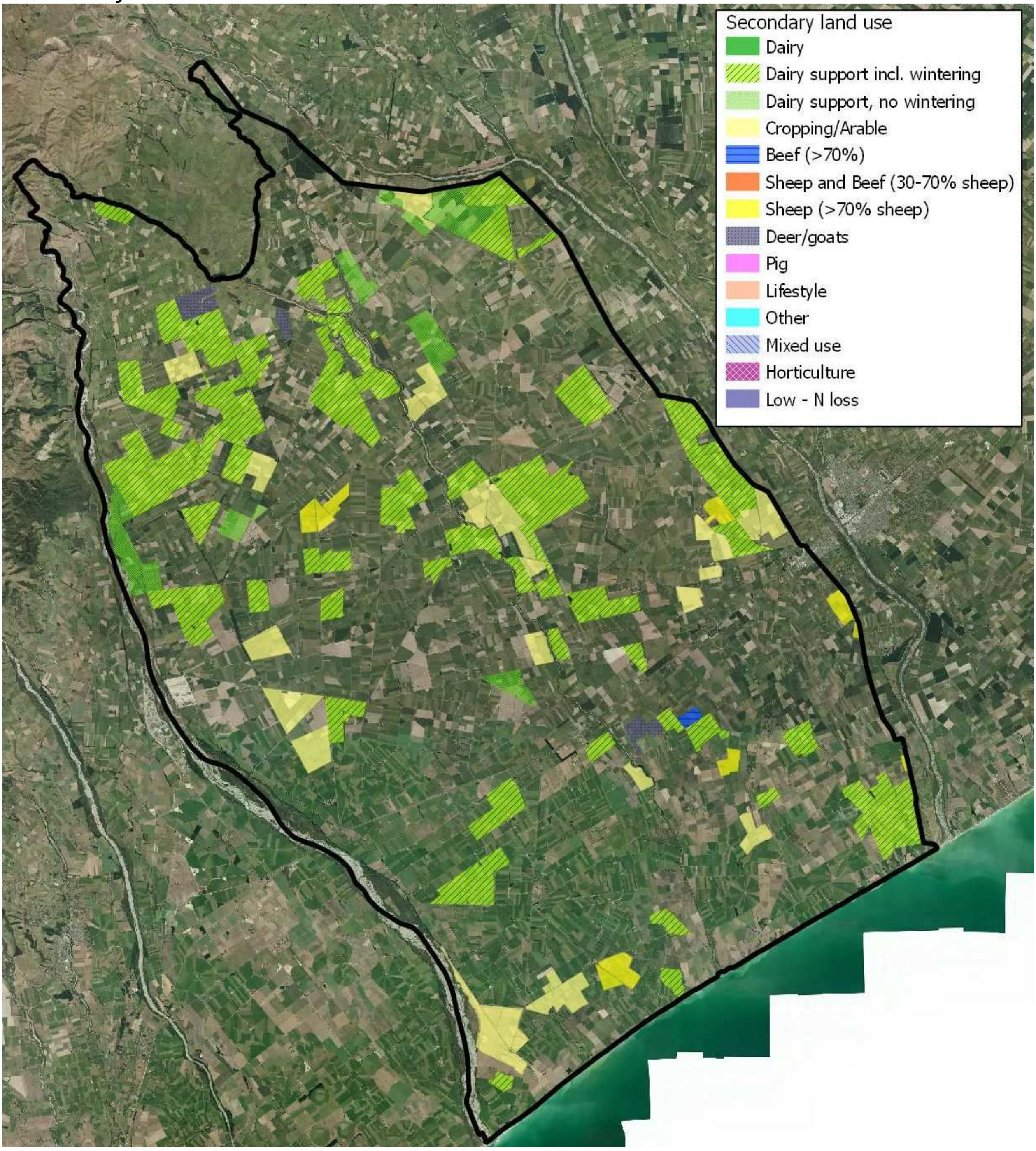
Ms Hayward assumed that "dairy wintering" as a secondary land use was more intensive than "dairy support including wintering" as a primary land use, and these categories were mapped accordingly. "Dairy support, no wintering" farms were classified as farms where the primary activities were calf and heifer raising, and cropping to support dairy farms, but little or no dairy wintering was thought to occur.

Land with very low nitrogen losses, such as road margins, trees and scrub, river margins, and urban areas, where identified from the Land Cover Database 4.0, aerial photographs, and from legal road boundaries. These areas accounted for 6% of the Study Area. These areas were assumed to leach ~2 kg N/ha/yr.

Primary Land Use

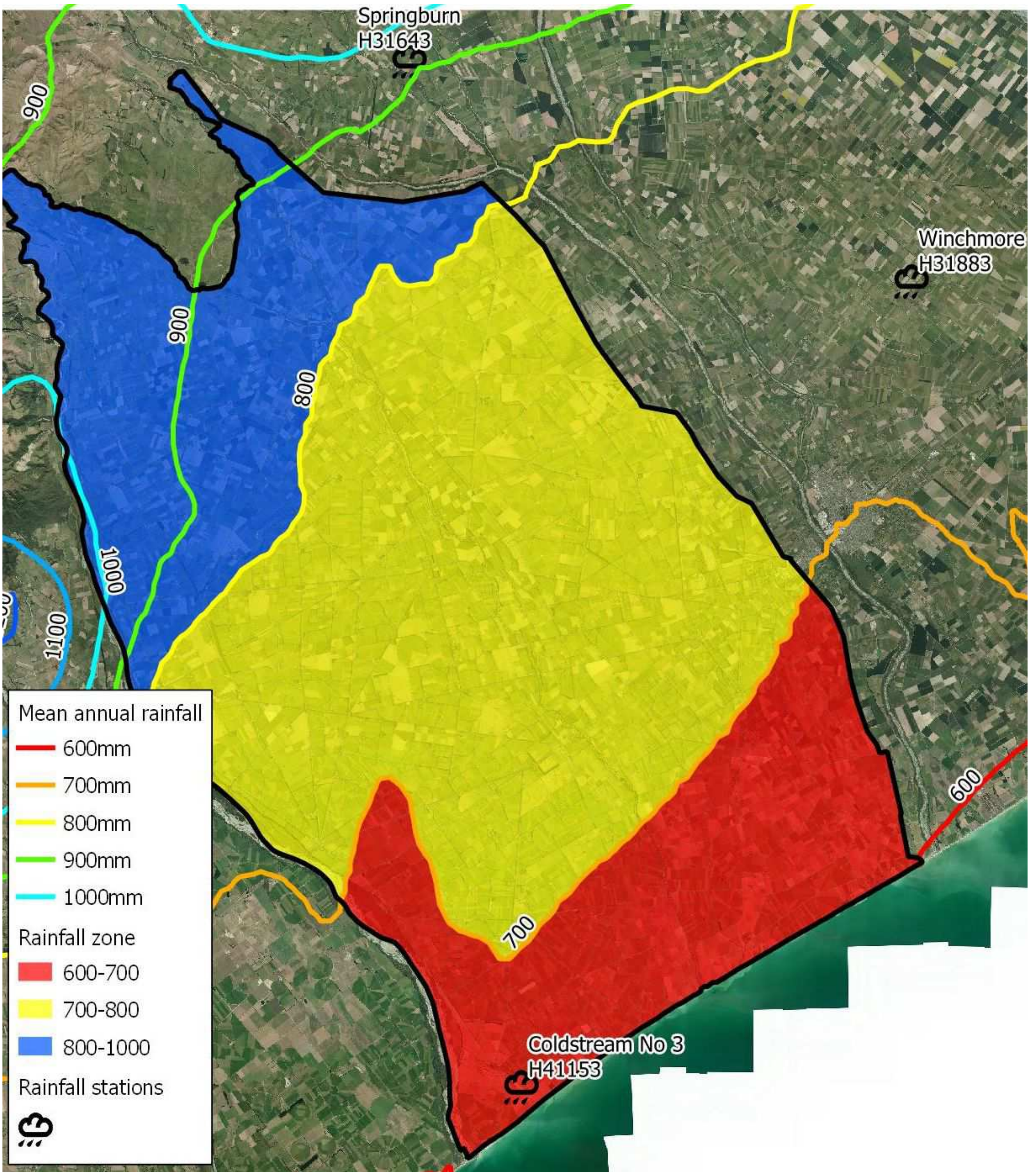


Secondary Land Use

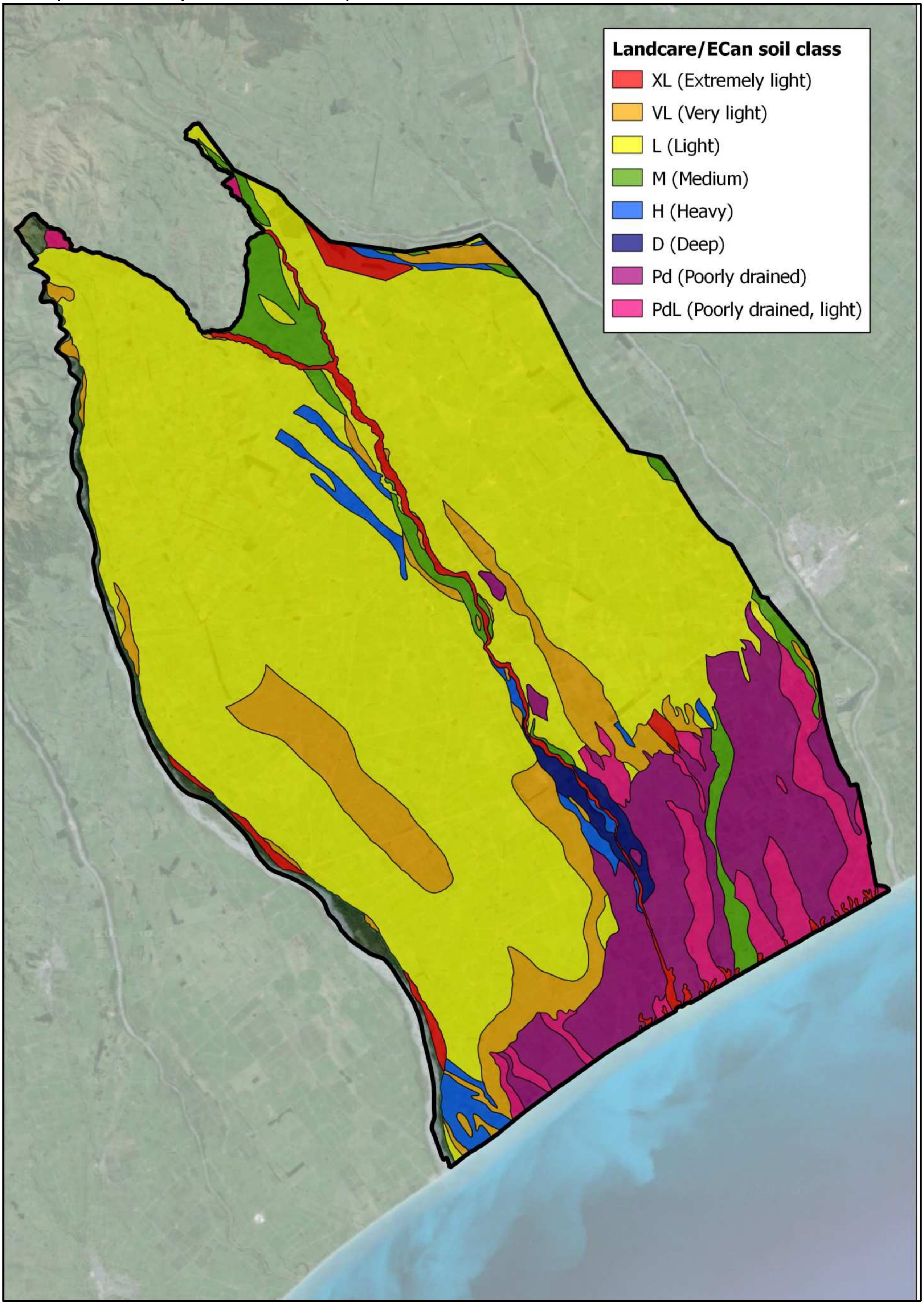


Appendix C: Root zone drainage

Rainfall zones



S-Map soil class (Landcare, 2014)



S-Map soil distribution

Soil code	Description	Area	
		Ha	% of total
XL	Extremely light	2,790	2%
VL	Very light	10,620	8%
L	Light	83,060	65%
M	Medium	4,470	4%
H	Heavy	2,480	2%
D	Deep	1,070	1%
Pd	Poorly drained	14,330	11%
PdL	Poorly drained, light	5,560	5%
-	No SMap data*	2,620	2%
Total		**127,000**	**100%**
*Where no S-Map data was available "Light" soils were assumed			

AusFarm soil parameters

Code	Dominate soil	PAW 60cm(1) (mm)	SHC(2) (mm/d)
VL, XL	VL	50	2000
L	L	65	1000
M	M	90	200
H, D, Pd PdL	Pd	140	200
(1) Profile available water to 60cm. Value for modelling from S-Map datasheet for dominant soil. (2) Saturated hydraulic conductivity.			

AusFarm irrigation parameters

Dominate soil	Depth (mm)	Return period (days)	Supply rate (mm/d)	Trigger soil moisture deficit (mm)	Application efficiency
	Pivot/lateral + cropping gun				
VL	13.5	3	4.5	20	80%
L	18	4	4.5	25	80%
M	18	4	4.5	30	85%
Pd	20	5	4.0	40	85%
	Rotorainer/kline + pasture gun + unknown				
VL	50	10	5.0	25	50%(1)(2)
L	50	10	5.0	30	60%(1)(2)
M	60	12	5.0	40	67%(1)(2)
Pd	60	12	5.0	60	80%
	Borderdyke				
VL	78.4	14	5.6	25	32%(1)
L	78.4	14	5.6	30	38%(1)
M	78.4	14	5.6	40	51%(1)
Pd	78.4	14	5.6	60	76%(1)
	(1) Values indicative. Calculated dynamically in AusFarm (2) For cropping 80% efficiency was assumed, since arable farmers tend to use water much more sparingly				

Irrigation season: 15 September to 30 April

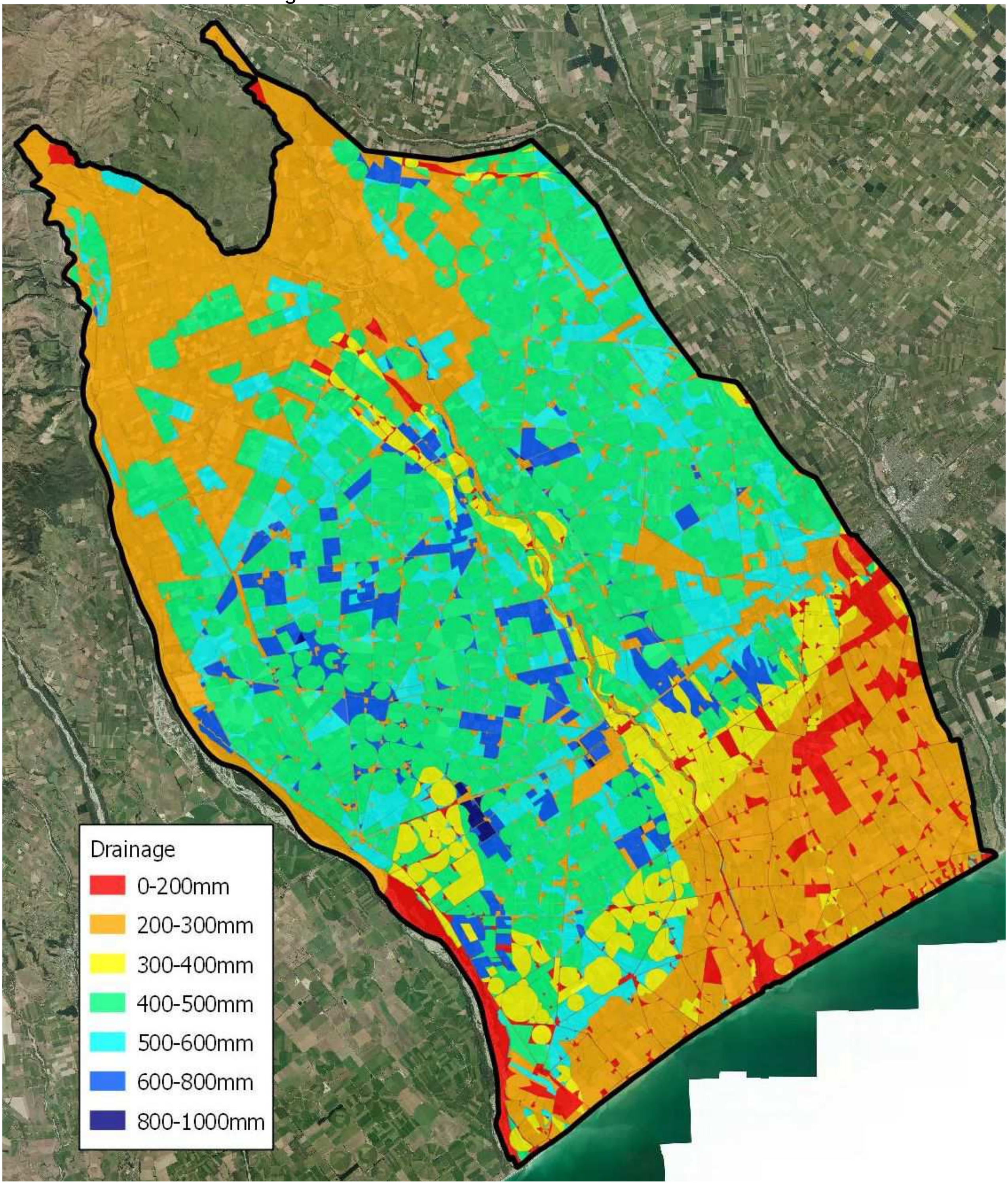
Calculated average annual irrigation depths using AusFarm (mm)

Soil PAW (mm)	Soil class	MAR=650mm	MAR=750mm	MAR=875mm
Pivot/Lateral				
50	XL/VL	570	517	458
65	L	557	486	427
90	M	498	428	365
140	H, D, Pd, PdL	465	388	333
Rotorainer/K-line/Gun(1)				
50	XL/VL	763	693	633
65	L	665	576	531
90	M	563	489	431
140	H, D, Pd, PdL	480	380	339
Borderdyke				
50	XL/VL	962	882	827
65	L	890	788	735
90	M	686	596	533
140	H, D, Pd, PdL	510	402	370
(1) For spray irrigated cropping refer to pivot/lateral values				

Calculated average annual drainage depths using AusFarm (mm)

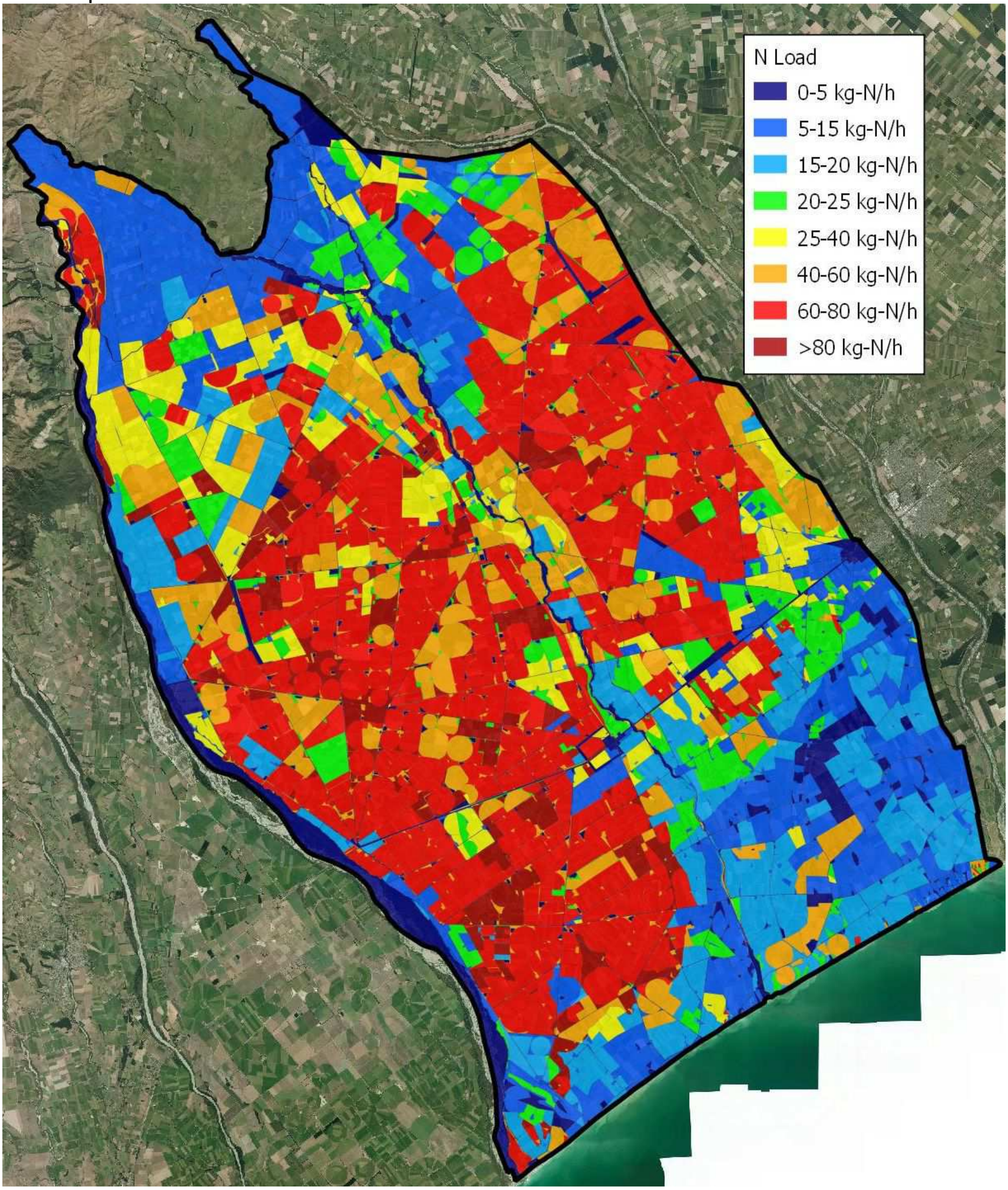
Soil PAW (mm)	Soil class	MAR=650mm	MAR=750mm	MAR=875mm
Pivot/Lateral				
50	XL/VL	373	443	479
65	L	357	415	447
90	M	293	351	382
140	H, D, Pd, PdL	263	322	354
Rotorainer/K-line/Gun(1)				
50	XL/VL	568	626	657
65	L	467	511	554
90	M	364	427	453
140	H, D, Pd, PdL	288	332	367
Borderdyke				
50	XL/VL	802	847	872
65	L	704	733	765
90	M	489	535	556
140	H, D, Pd, PdL	321	360	401
Dryland				
50	XL/VL	166	233	274
65	L	147	213	253
90	M	118	181	220
140	H, D, Pd, PdL	84	147	184
(1) For spray irrigated cropping refer to pivot/lateral values				

Calculated AusFarm drainage

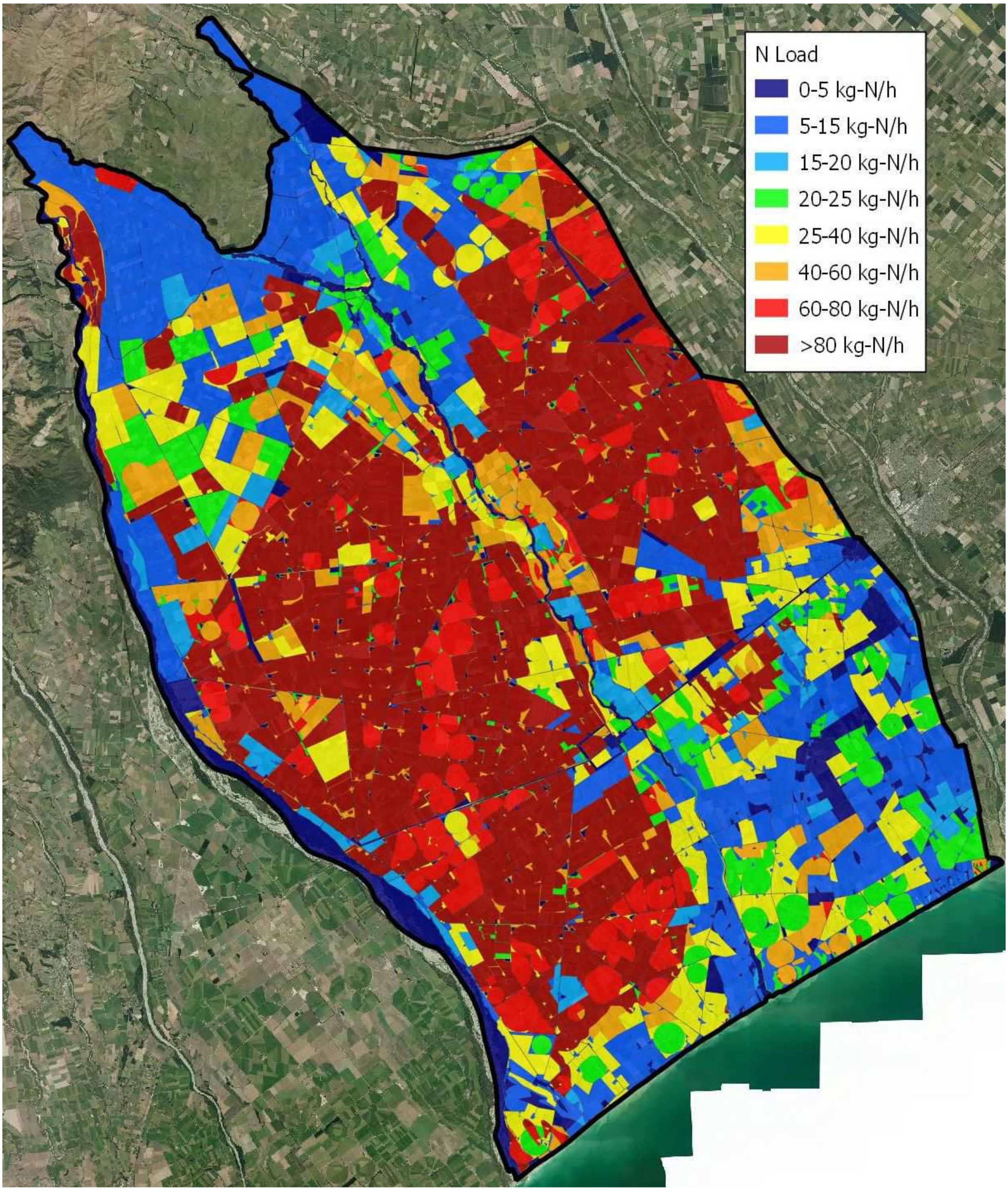


Appendix D: Root zone nitrate losses

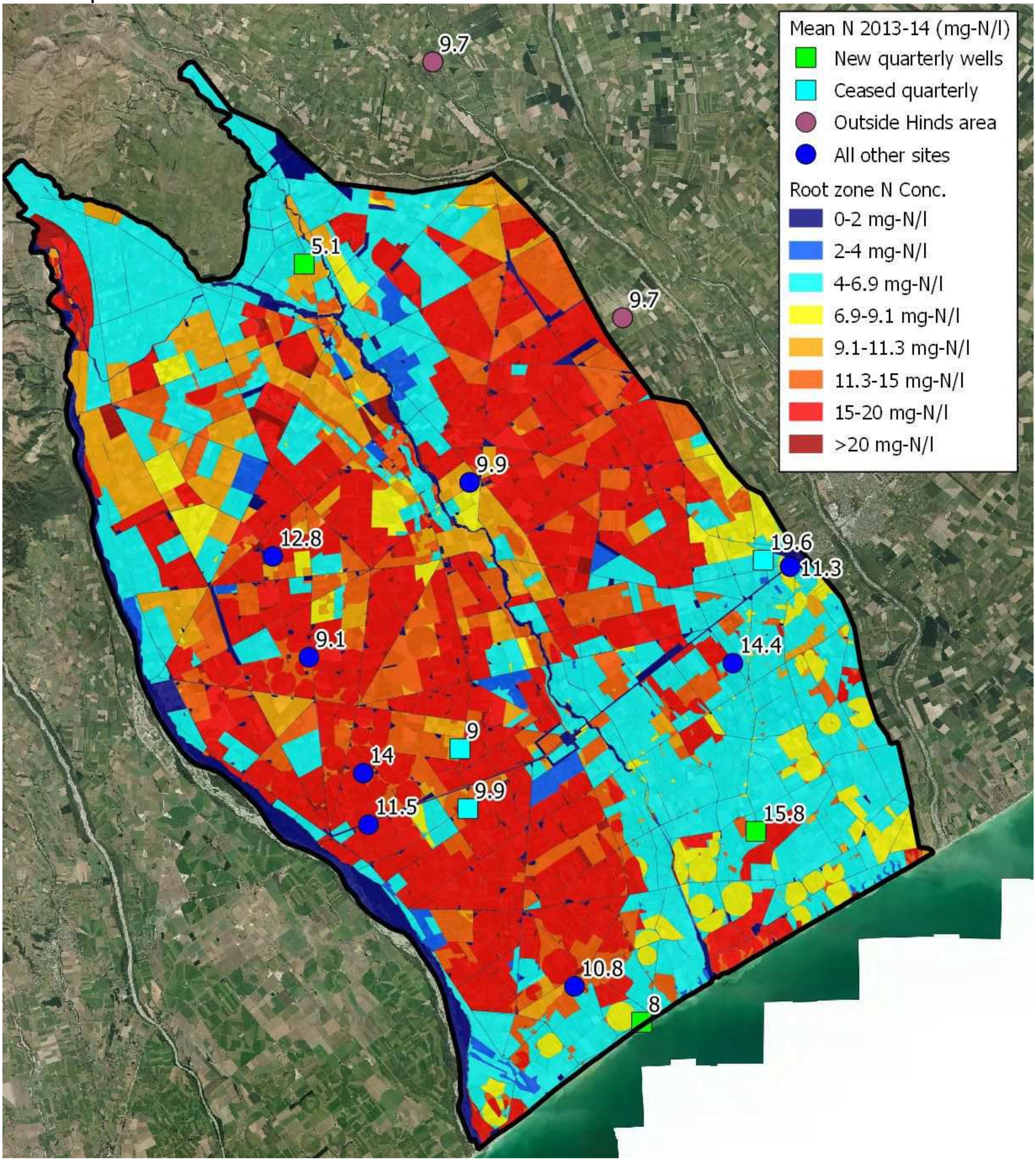
DNZ/Aqualinc load



DNZ/Overseer 6.2 load



DNZ/Aqualinc concentration



DNZ/Overseer 6.2 concentration