Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Waimakariri Land and Water Solutions Programme

Options and Solutions Assessment

Nitrate Management

Report No. R19/68
ISBN 978-1-98-859335-7 (print)
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A Kreleger
Z Etheridge

May 2019

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

	Name	Date
Prepared by :	*Amber Kreleger and* *Zeb Etheridge* *Senior Scientists*	18 April 2019
Reviewed by :	*Carl Hanson* *Groundwater Science Manager*	15 May 2019
External review by :	*Jens Rekker* *JH Rekker Consulting Ltd*	29 April 2019
Approved by:	*Tim Davie* *Chief Scientist*	24 May 2019

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200 Tuam Street
PO Box 345
Christchurch 8140
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru 7940
Phone (03) 687 7800
Fax (03) 687 7808

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

Executive summary

Background
The availability of safe and reliable drinking water, maintenance of the current high-quality drinking water from Christchurch's aquifers and surface water quality which supports aquatic life and mahinga kai were identified as Priority Outcomes by the Waimakariri Water Zone Committee. Management of nitrate is critical for all of these outcomes.

The problem
Nitrate concentrations currently breach drinking water limits and ecological toxicity thresholds in some wells and surface water bodies in the Waimakariri Canterbury Water Management Zone. Te Aka Aka (Ashley estuary) shows a moderate degree of eutrophication and the Ashley River/Rakahuri suffers from toxic cyanobacteria growth in the summer months. Nitrate concentrations are trending upwards in some water bodies. Nitrate concentrations are relatively low in some other parts of the Waimakariri zone, however, and concentrations are trending downwards in a few surface water courses.

What we did
We modelled nitrate losses below the root zone from land within the Waimakariri zone under a range of management scenarios and evaluated the uncertainty around these loss rate estimates. We developed a stochastic groundwater model which used the modelled nitrate loss rates to assess the possible range of surface water and groundwater nitrate concentrations that could occur under the management scenarios, when concentrations equilibrate with loss rates from land.

The zone committee used our modelling results in combination with economic, ecological and mahinga kai impact information to make recommendations (via their Zone Implementation Programme Addendum [ZIPA]) for a set of nitrate limits to be included in the Land and Water Regional Plan.

In order to achieve these nitrate limits the ZIPA has made nitrate management recommendations which include: going beyond Baseline Good Management Practice (GMP) nitrate loss reductions, reductions in the areas of land that can be used for winter grazing without a resource consent; and more detailed investigation of the feasibility of implementing Managed Aquifer Recharge (MAR) and Stream Augmentation to reduce nitrate concentrations. We used our modelling results in combination with some field investigation findings to evaluate the extent to which, and period within which, the recommended nitrate limits could be achieved.

What we found
Our modelling results and "first principles"/conceptual analysis showed that nitrate concentrations could increase significantly in some water bodies. This is mainly because the groundwater age in some receptors (e.g. water supply wells) predates recent land use intensification, i.e. there is a lag between land use change and the full effects of that change being seen. These results highlight the fact that, regardless of actions taken now or in the near future, nitrate concentrations in those receptors with long lag times are likely to get worse before they get better.

Contrary to previous assumptions, our modelling results showed that groundwater in the Waimakariri Water Zone is likely to flow under the Waimakariri River and into the Christchurch aquifer system. Nitrate concentrations in Christchurch's public drinking water supply wells are expected to increase because of this contribution from north of the Waimakariri River.

What it means
Our modelling results indicate that significant beyond Baseline GMP nitrate loss reductions will be required across a large area of the Waimakariri zone to meet the recommended nitrate limits. It could take a long time to achieve the limits and, in some instances, it may not be possible to achieve them unless the nitrate loss reduction requirements are extended to a wider set of properties. Implementation of on-the-ground actions, principally MAR and stream augmentation, could reduce the nitrate loss reduction requirements and the time taken to meet limits. These actions could also help to meet limits without expanding the requirements for nitrate loss reductions and deliver a broader set of ecological benefits associated with increased flows in surface water courses.

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Glossary

Report term	Definition
Alternative pathways scenarios	Possible land use configurations modelled to consider how to reach community outcomes. 1) 'Beyond Baseline GMP' nitrate-nitrogen losses are reduced by 10% or 20% for specified land uses every 10 years under a staged or adaptive approach as follows: • **10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP. • **20 kg/ha 10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha. • **20 kg/ha 10 & 20% beyond Baseline GMP** – Dairy reduce nitrate losses 20% and all other consented 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha. 2) Potential nitrogen loads and number of consents that would be required under a range of PA threshold options, e.g. a 25% reduction and 50% reduction in the threshold.
Baseline GMP loss rate	The average nitrogen loss rate below the root zone, as estimated by the Farm Portal, for the farming activity carried out during the nitrogen baseline period, if operated at good management practice.
COMAR	Cultural Opportunity, Mapping Assessment and Response. Shorthand for the Cultural Health Assessment report prepared by Dr Gail Tipa and Ngāi Tūāhuriri in 2016. Cultural Health Assessment report minimum flow, cultural allocation and nitrate limit recommendations are considered in this paper.
Current State	Condition of water resources that we currently see and measure.
Current Pathways Scenario (CP)	Condition of water resources, mahinga kai, stream health, social/recreational state and the local economy at some point in the future under the assumption that the current natural resource management regime and economic and social conditions continue along their current trajectory. Assume the hydrological and ecological system equilibrates with current land use, including any intensification that can occur under current Regional Plan and consent rules.
GAZ	A planning tool for determining an allocation limit and managing groundwater abstraction. GAZs are primarily based on areas of similar hydrogeology and recharge sources. Each GAZ has an allocation limit expressed as annual volume in cubic metres per year. Their boundaries are set out in Planning Maps in the LWRP.
GMP	Good Management Practice. Defined in PC5 as "the practices described in the document entitled "Industry-agreed Good Management Practices relating to water quality" - dated 18 September 2015."
interzone source area	Area from which the groundwater model predicts water will infiltrate and flow under the Waimakariri River toward the Christchurch aquifers.

Report term	Definition
LWRP	Land and Water Regional Plan. The regional plan for managing freshwater resources in Canterbury. The only regional plan for the Ashley catchment. The only regional plan for the Ashley catchment.
Limit	Defined in the NPS-FM. The maximum amount of resource use available.
Nitrate	In this report we use “nitrate” to refer to “nitrate-nitrogen” (or nitrate-N or NO_3-N). A nitrate-N concentration of 1 mg/L is equivalent to 4.43 mg/L nitrate (or NO_3). Therefore, the New Zealand Drinking Water Maximum Acceptable Value (MAV) of 11.3 mg/L nitrate-nitrogen is equivalent to 50 mg/L nitrate.
NPA	Nitrate Priority Area. Area where additional actions and controls are required to reduce nitrate discharges
NPS-FM	National Policy Statement for Freshwater Management. Central Government direction for how freshwater must be managed, regional councils must give effect to it when preparing freshwater plan changes. Requires limits to be set for quality and quantity, and water quality to be maintained or improved. Also sets “bands” in which nitrate concentrations (amongst other attributes) must be maintained.
PC5	Plan Change 5 (Nutrient Management & Waitaki) to the LWRP. Among other things, this plan change introduced “Good Management Practice” into the region-wide rulebook.
Receptor	A receiving water body that could be affected by contamination – e.g. a community water supply well, spring fed stream or estuary
Scenario	A possible land use configuration modelled to consider how to reach community outcomes. Exploration of alternatives/options/what ifs at whatever scale is useful to support the question being asked.
Stochastic model	A tool for estimating probability distributions of potential outcomes by allowing for random variation in one or more inputs over time. This type of model addresses uncertainty associated with data. While this approach still relies on underlying model assumptions to generate initial parameter estimates, it more clearly estimates the uncertainty associated with modelling and allows reflection of this in communications.
Target	Defined in the NPS-FM. Applies in the context of phasing out over-allocation. In summary, means a limit on resource use that is less than current allocation, to be achieved by a stated time in the future.
Nitrate threshold option for waterbodies outside of the Waimakariri Water Zone	Nitrate threshold options provide a point of reference, or a starting point indicating the scale of nitrate reductions that may be needed to enable land users in the Waimakariri Zone to play their part in maintaining the high quality of Christchurch groundwater and the Waimakariri River.
Waimakariri northern tributaries catchment	Area of Waimakariri River catchment within the Waimakariri CWMS zone that drains into the northern side of the Waimakariri River.

1 Introduction

1.1 Background

The Canterbury Water Management Strategy (CWMS) was developed by the Canterbury Mayoral Forum in 2008 as a collaboration between Te Rūnanga o Ngāi Tahu, Canterbury's 10 territorial authorities, Canterbury Regional Council (Environment Canterbury), in collaboration with industry, key stakeholders, agencies and the community. The aim of the strategy is: "to enable present and future generations to gain the greatest social, economic, recreational and cultural benefits from our water resources within an environmentally sustainable framework."

The CWMS Framework Document contains 10 target areas:

- ecosystem health/biodiversity
- natural character of braided rivers
- kaitiakitanga
- drinking water
- recreational and amenity opportunities
- water-use efficiency
- irrigated land area
- energy security and efficiency
- regional and national economies
- environmental limits

The CWMS established 10 Zone Committees across Canterbury, largely defined by territorial authority boundaries. The Zone Committees implement the strategy through collaboration, assessment of technical information and community feedback, and decision making. Each Zone Committee has developed a detailed 'Zone Implementation Programme' (ZIP) which includes a set of Priority Outcomes. Although Zone Implementation Programmes are not statutory documents, there is a clear expectation and commitment for the programmes to be implemented, resourced, and given effect to through both regulation and on the ground actions.

The Waimakariri Zone Implementation Programme Addendum (ZIPA), finalised in December 2018, builds on the original Zone Implementation Programme and provides recommendations to guide both the sub-region plan change to section 8 (Waimakariri) of the Canterbury Land and Water Regional Plan (LWRP), and actions to be advanced within the Waimakariri Water Zone (Waimakariri Zone) and the Waimakariri District Plan. These recommendations, the Waimakariri sub-region plan change, and the programme of actions are collectively referred to as the Waimakariri Land and Water Solutions Programme.

The ZIPA recommendations (referred to as the 'Solutions Package' in this report) comprise a mix of statutory actions (e.g. recommendations for nutrient limits, nitrate loss rates and consenting requirements) and non-statutory actions (e.g. monitoring, on the ground actions, education etc.).

The Waimakariri Land and Water Solutions Programme, which includes development of the ZIP and ZIPA documents and the broader process into which these elements were interwoven, is summarised in Figure 1-1. The process also included several interim community and stakeholder consultation stages (e.g. as part of the Current Stage and Current Pathways elements) which are not shown in this figure.

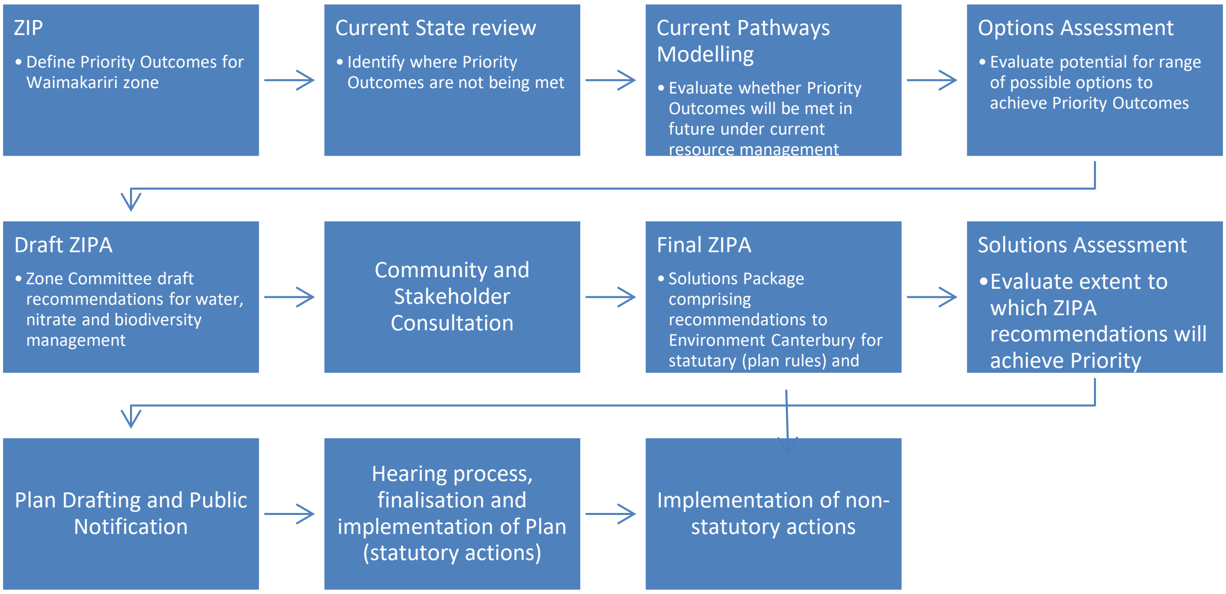

Figure 1-1: Roadmap for the Waimakariri Land and Water Solutions Programme

1.2 Key Zone Committee Priority Outcomes for nitrates

The ZIPA contains a collection of integrated actions and proposals that give effect to the vision and principals of the CWMS for the zone. These are embodied in the set of nine Priority Outcomes. The zone committee recognised five key areas as 'drivers of change' required to achieve these Priority Outcomes. One of these key drivers is reducing nitrates in the zone. We have described the key Priority Outcomes in section 1.2.1, 1.2.2 and 1.2.3 which will be supported by reducing nitrate emissions.

1.2.1 Safe and reliable drinking water

Priority Outcome 4 states that the zone has reliable drinking water, preferably from secure sources. Nearly all drinking water in the Waimakariri Zone is sourced from groundwater. There are approximately 2,750 private water supply wells in the zone, supplying water to ~9,600 people. The remaining 53,700 people are supplied by public water supply wells. This means that robust groundwater quality management is critical for Waimakariri Zone residents.

Priority Outcome 9 recommends that land and freshwater management in the Waimakariri Zone will, over time, support the maintenance of current high-quality drinking water from Christchurch's aquifers. This outcome recognises the connectivity between the Waimakariri and Christchurch aquifer systems and that nitrate concentrations in the Christchurch aquifer may increase, in the medium to long term, due to the nitrate load already moving through the system. The zone committee has explored options for nutrient management in the Waimakariri Zone, in order to "play their part" in maintaining the high quality of water in the Christchurch aquifers.

1.2.2 Surface water quality supports aquatic life and mahinga kai

Priority Outcome 1 strives for water quality and quantity of spring-fed streams that maintains or improves mahinga kai gathering and diverse aquatic life. Nitrate concentrations in the spring-fed streams will need to be improved or maintained to support abundant and diverse aquatic life (including native flora and fauna).

Priority Outcome 2 states that the Ashley River/Rakahuri is safe for contact recreation, has improved river habitat, fish passage, and customary use; and has flows that support natural coastal processes. Managing nitrate concentrations will be key for supporting aquatic life, customary use and mahinga kai gathering.

1.2.3 Optimal nutrient management

The zone committee envisions that optimal water and nutrient management is common practice within the zone (*Priority Outcome 7*). All land and water users practice management that minimises inputs of nutrients to water. Industry agreed Good Management Practices and Farm Environment Plans are adopted as everyday farm management tools.

1.3 Report purpose

The purpose of this report is to summarise current nitrate concentrations in the Waimakariri Zone, to explain how modelling was used to evaluate future nitrate concentrations under a range of management scenarios and to show how the Solutions Package particularly the Regional Plan rule recommendations for nitrate concentration limits, nitrate loss management and farming land use consent rules provided in the ZIPA, will achieve the Priority Outcomes defined by the Waimakariri Water Zone Committee (WWZC).

This report focuses on nitrate concentrations and loads; although we discuss these in relation to environmental limits (e.g. nitrate toxicity), we do not discuss the implications of our results for mahinga kai, stream health etc. These matters are addressed in Arthur *et al.* (2019).

1.4 Report context

A large-scale multi-disciplinary technical work programme was undertaken to support and inform the Waimakariri Land and Water Solutions Programme. It included assessments of cultural health, water quality, water quantity, biodiversity, the local economy, and social/recreational conditions within the zone. These assessments were undertaken to:

- understand the current state of the zone
- estimate outcomes if current resource management practices were to continue unaltered into the future (Current Pathways Scenario)
- explore future alternatives for resource management (Alternative Pathways Scenario)
- support the Zone Committee options assessment process
- evaluate the impact of the Solutions Package on cultural, environmental, social and economic values.

This process is summarised in Figure 1-2.

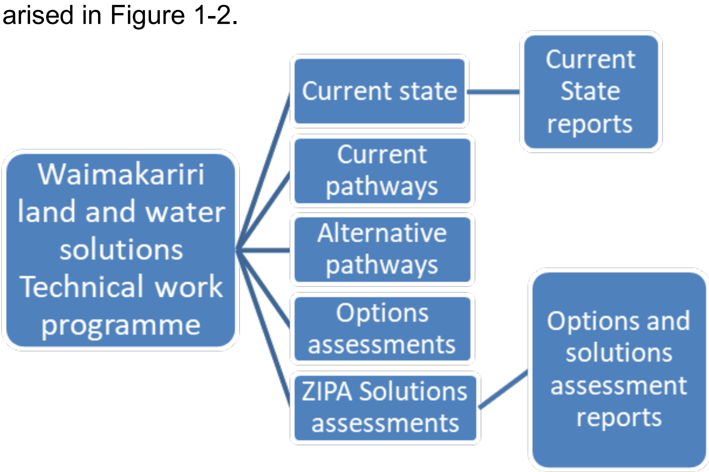

Figure 1-2: Summary of technical work programme

This Nitrate Management report is one of a series of technical reports which summarise and in some cases update Current State information (the main Current State reports, were written in 2016), document the modelling process and assess the results of management options and the ZIPA Solutions Package. These technical reports are summarised in a technical overview report (Etheridge and Whalen, 2019).

This Nitrate Management Report is also an important input for the technical report on Aquatic Ecology and Biodiversity (Arthur *et al.,* 2019), which assesses matters related to protecting and improving mahinga kai, aquatic ecosystem health and how these impact values related to biodiversity and recreation.

Components of the Social Assessment (Sparrow and Taylor, 2019), particularly those related to recreation and aesthetics, are also informed by the results of this report. Likewise, the economic outcome of some recommendations described in this report are detailed in Harris (2019) and relate mostly to the investments in drinking water treatment, farm management practices and land use change that are likely to be required to achieve the Priority Outcomes.

Two other important reports in the series are the Surface Water Quantity Options and Solutions Assessments report (Megaughin and Lintott, 2019) and the Cultural Health Assessment and Water Management report (hereby referred to as the COMAR (Cultural Opportunity Mapping, Assessment and Responses) report) prepared by Te Ngai Tūāhuriri and Tipa & Associates (2016). The first provides limits and modelling results for minimum flows and surface water allocations. The second provides information on mahinga kai outcomes for the zone. Values relating to the cultural importance of waterbodies, particularly the health and productivity of mahinga kai communities, are for the most part similar to those related to protecting water quality and ecosystem health in the zone. That is, when ecosystems flourish, as do the mahinga kai communities they support.

A collaborative, open and transparent approach was initiated at the beginning and carried throughout the entire process. Waimakariri Water Zone Committee, stakeholders, CWMS partners, community members and others were invited to participate in the development of the technical work scope and were updated periodically on technical work findings, progress and next steps.

1.5 Report structure

This technical report is structured as follows:

- Section 2 provides a general description of the current state for nitrate concentrations at the different receptors: drinking water wells and spring-fed streams in the Waimakariri Zone and community supply wells in Christchurch.
- Section 3 describes the methodology used to calculate the different nitrate management scenarios.
- Section 4 gives an overview of the nitrate limit options and management scenarios and the modelled future nitrate concentrations for these scenarios.
- Section 5 describes the ZIPA Solutions Package presented by the zone committee and the modelled future nitrate concentrations for the Solution Package. It also describes which on-the-ground actions can help reduce nitrates in the zone further.
- Section 6 summarises the main conclusions of our study.

2 Current state

2.1 General description

The Waimakariri Zone extends across the Ashley-Waimakariri Plain, north of the Waimakariri River to just south of the Kowai River (Figure 2-1). The zone includes the foothills which drain onto the Plains, including the Lees Valley. The north-western portion of the zone is hill and high country. These hills, including Mt Oxford, Mt Richardson, and Mt Thomas, dominate the zone's western landscape.

The Waimakariri Zone surface hydrology is characterised by the large alpine Waimakariri River along its southern boundary, the northern tributaries of the Waimakariri River (Kaiapoi River Catchment), the hill-fed Ashley River/Rakahuri and its tributaries and estuary (Te Aka Aka), the Ashley-Waimakariri Plain, the Loburn fan, and a network of spring fed streams and lagoons near the coast.

The Waimakariri Zone has a long history of farming land use. Some farming activities have released nitrogen to the environment which has leached into groundwater as nitrate. Nitrate concentrations were already high in some monitoring wells when we first began regular sampling on the Ashley-Waimakariri plains in the 1980s. Intensification of land use in the Eyre River catchment is causing an increase in nitrate in some wells and springs in the down-gradient Kaiapoi River catchment. Some of the nitrate load from the current and historical land use is likely still moving through the groundwater and yet to emerge to the surface waterways and to deeper wells. This lag between land use change and the arrival of associated nitrate concentration changes in groundwater means that we have not yet seen the full effects of land use intensification on water quality.

Recent science investigations (Etheridge and Hanson, 2019a) have concluded that a proportion of the Christchurch aquifer system is recharged by groundwater derived from north of the Waimakariri River. Christchurch City Council (CCC) owns community drinking water supply wells in this aquifer system.

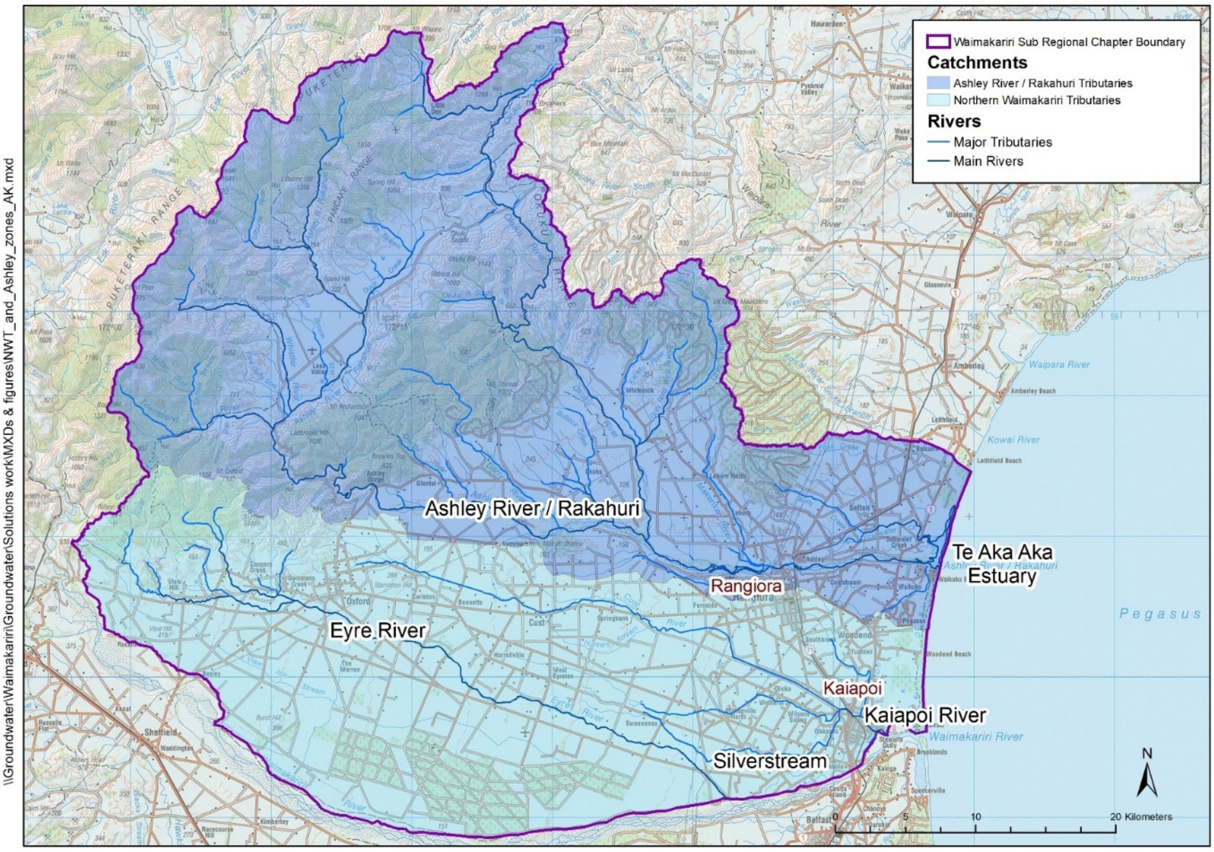

Figure 2-1: Orientation map for Waimakariri Water Zone

2.2 Conceptual zone hydrology

The natural surface water hydrology of the Waimakariri Zone is complex, however we have simplified it into its main elements and the connections between these elements (Figure 2-2). This shows how changes to water quantity and quality in any element influence subsequent elements. An understanding of this flow-on effect is critical to the decision making process for the zone (Megaughin and Hayward, 2016).

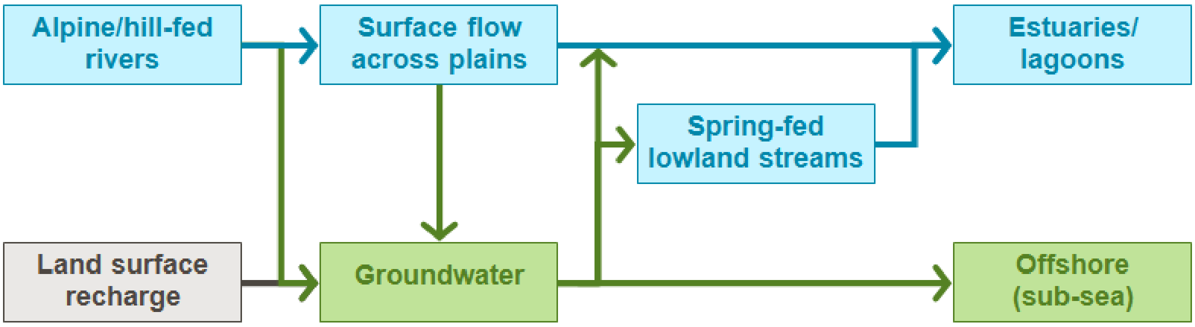

Figure 2-2: Conceptual natural zone hydrology

This conceptualisation is dominated by the larger watercourses (Waimakariri River and Ashley River/Rakahuri). The majority of their flow comes from high elevation catchments, and in the case of the Waimakariri River, the Main Divide. This water flows out of the hills, across the plains and out to sea, via river mouths.

As these larger watercourses exit the hills and flow on to the plains they also lose flow to ground; this recharges the aquifers beneath the plains. The smaller hill-fed rivers such as the Cust and Eyre Rivers also recharge the aquifers, although the water they contribute is less than that of the two larger rivers.

The water contained in the aquifers flows slowly towards the coast. Groundwater may return to the surface via springs that supply the lowland streams around Rangiora and Kaiapoi for example. Some of this water also enters the larger watercourses, which gain flow along their lower reaches. Some groundwater flow continues offshore.

The final element of this system is land surface recharge to groundwater. Naturally this occurs via rainfall directly on the plains, but recharge also occurs from the application of irrigation water and leakage from irrigation and stockwater infrastructure (not shown in this conceptualisation).

Connected to these systems, to a greater or lesser degree, are the standing waterbodies/wetlands of the zone. Wetlands, swamps, marshes, lagoons and man-made ponds generally have a delicate water balance and changes to any elements of the zone hydrology that are linked to such features will affect those water bodies.

Etheridge and Wong (2018) derived a groundwater budget for the Eyre River, Cust and Ashley Groundwater Allocation Zones (GAZ) (see explanation below) for the 2015 calendar year[1]. The budget includes both the natural and anthropogenic components of the hydrological system and shows the relative importance of the various recharge and discharge components (see Table 2-1).

[1] 2015 was a dry year, with land surface recharge (LSR) being 70% below average.

Table 2-1: Groundwater budget for 2015 calendar year for Eyre River, Cust and Ashley GAZs

In m³/s		Out m³/s	
LSR	2.5	Abstraction	2.7
SW losses	4.2	SW gains + inter-zone flow	6.0
Race losses	1.2	Offshore flow	0.9[2]
Depletion of storage	1.6		
Total	9.5		9.6

Groundwater allocation in the Waimakariri Zone is divided in five GAZs for resource management purposes. These GAZs are generally used in discussions about groundwater quantity, e.g. the availability of groundwater for groundwater users. They are also useful in describing spatial variability in groundwater quality within a GAZ. A map of the GAZs within the Waimakariri Zone is provided in Figure 2-3.

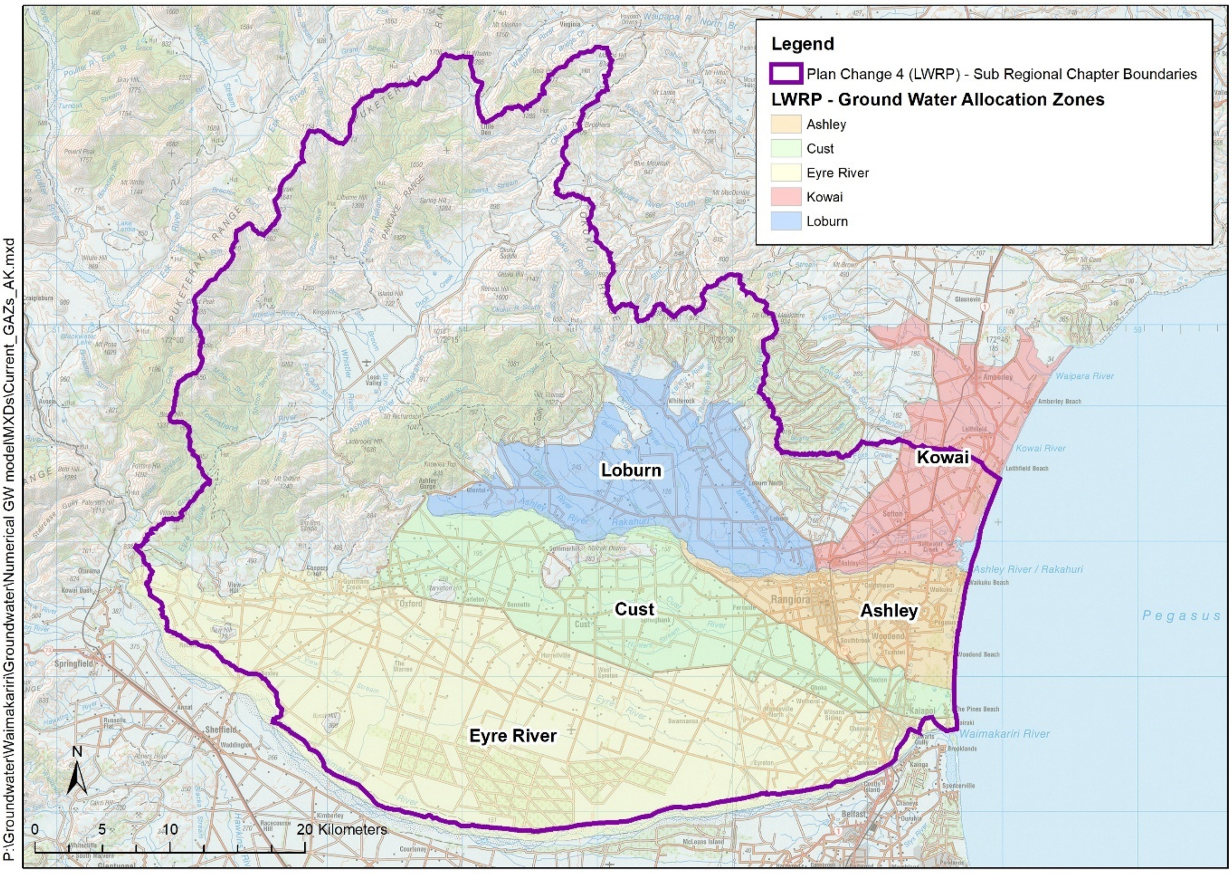

Figure 2-3: Current Groundwater Allocation Zones within the Waimakariri Zone as defined in the LWRP

[2] Assumes that unmeasured groundwater outflows to the spring-fed streams are lower in proportion with measured surface water gains

2.3 Groundwater quality - Nitrate

2.3.1 Nitrate concentrations

Diffuse sources of nitrogen leaching from land use are the main threat to groundwater quality in the Waimakariri Zone. Generally, nitrate[3] concentrations in shallow wells (<50 m) show significant seasonal variability, with seasonal spikes being approximately 1.6 times greater than the long-term average. Deeper wells (e.g. the majority of the community supply wells) show a more stable nitrate concentration, with limited seasonal variability (Scott *et. al.,* 2016).

Figure 2-4 shows an overview of the maximum recorded nitrate concentrations in all the groundwater wells with monitoring results in our database (since 1954). Some of those wells have only one sample, but we included them on the map to be able to give an indicative spatial overview.

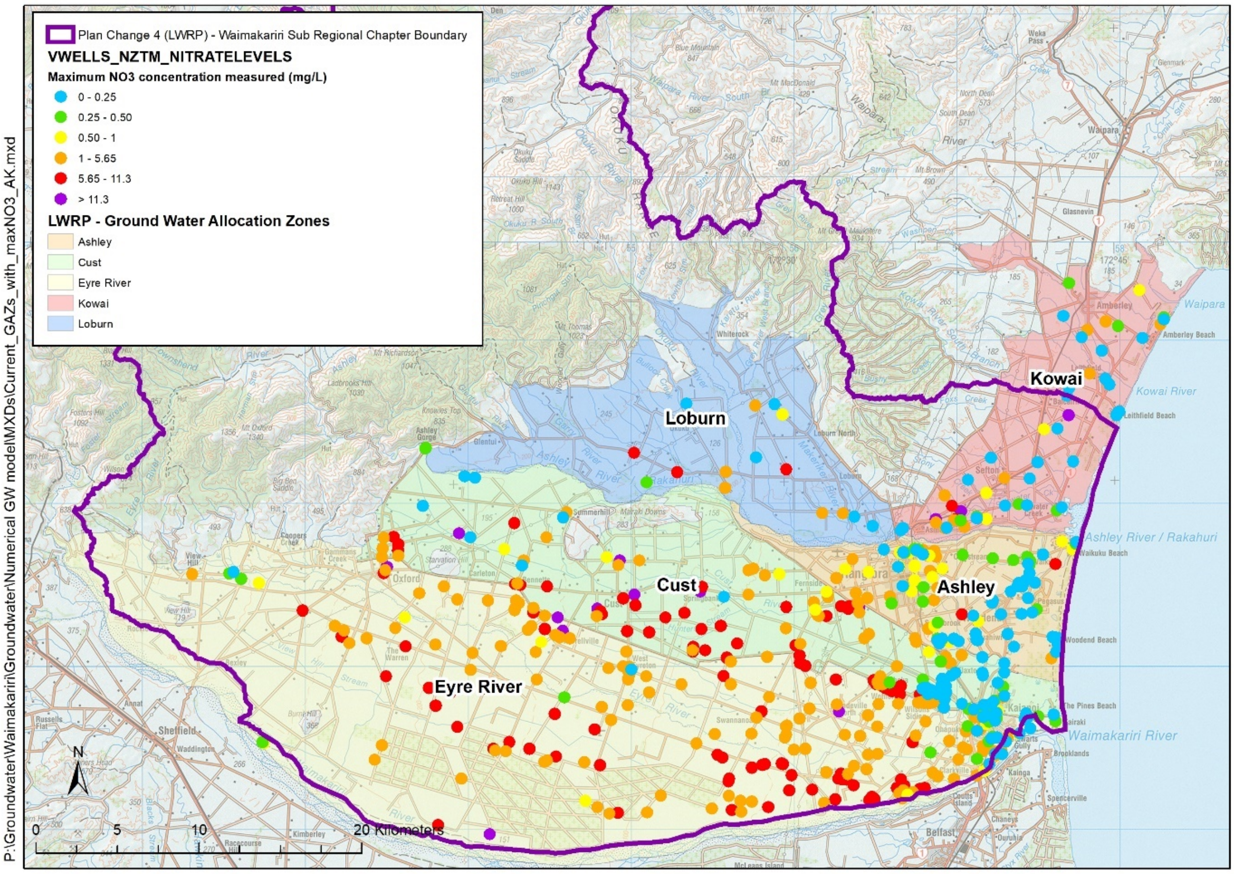

Figure 2-4: Measured maximum nitrate concentrations in groundwater wells (any kind of use) in the Waimakariri Zone

Nitrate[4] concentrations in 75% of the wells located in Cust and Eyre River GAZs exceed 1 mg/L, with ~30% exceeding 5.65 mg/L and 10 out of 339 wells (3%) exceeding the Drinking-water Standards New Zealand (DWSNZ) Maximum Acceptable Value (MAV) of 11.3 mg/L nitrate-nitrogen (N).

For the Loburn, Kowai and Ashley GAZs: ~70% of the wells have nitrate concentrations below 1 mg/L, mostly located in the Kowai and Ashley GAZs. Nitrate concentrations in approximately 25% of the wells are within 1.0-5.65 mg/L and ~5% have higher concentrations. These higher concentrations are found near the urban Rangiora and Ashley/Sefton area.

[3] In this report we use "nitrate" to refer to "nitrate-nitrogen" (or nitrate-N or NO_3-N). A nitrate-N concentration of 1 mg/L is equivalent to 4.43 mg/L nitrate (or NO_3). Therefore, the Drinking-water Standards New Zealand Maximum Acceptable Value (MAV) of 11.3 mg/L nitrate-nitrogen is equivalent to 50 mg/L nitrate.

[4] P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GW quality\Private_wells_ExWDC_CurrentGAZ.xlsx

Table 2-2 gives an overview of the nitrate concentrations per GAZ, based on the groundwater samples since 1954. Cust and Eyre River GAZs have the highest overall average and Ashley and Kowai GAZs the lowest. Given the low mean and low annual mean concentration it is likely that the maximum concentrations recorded for Cust, Eyre River and Kowai GAZs relate to point sources rather the diffuse source nitrate contamination.

Table 2-2: Nitrate Nitrogen concentration (mg/L) per Groundwater Allocation Zone (samples since 1954)[5]

GAZ	Number of sample sites	Number of samples	Nitrate Nitrogen concentration (mg/L)			
			Minimum	Maximum	Mean	Annual mean 2013-2017
Ashley	79	419	0.002	6.70	0.77	0.36
Cust	137	662	0.002	26.00	3.60	6.21
Eyre River	202	1389	0.005	18.30	3.53	3.88
Kowai	26	74	0.025	25.90	2.73	0.26
Loburn	16	122	0.05	9.80	2.26	4.40
Waimakariri Zone	460	2666	0.002	26.00	2.98	3.54

2.3.2 Nitrate trends

Our Current State of Groundwater Quality in the Waimakariri CWMS zone report (Scott *et al.,* 2016) noted that groundwater nitrate concentrations in two of our long term monitoring wells, at Eyrewell and Ohoka, are increasing. Concentrations have increased from around 6.5 mg/L to 7.5 mg/L nitrate at our monitoring site in Ohoka and from 4.5 to 7 mg/L at Eyrewell over the past 10 years. Data from the Springbank monitoring well near the Cust River show a decreasing trend in nitrate concentrations from near 16 mg/L to below the drinking-water MAV. Nitrate concentrations are generally increasing in the Kaiapoi River catchment.

Nitrate concentrations in groundwater are affected by both land use and climatic variability, with lower nitrate concentrations generally occurring during dryer periods since less nitrogen is flushed into the aquifer at these times. Prolonged dry periods (e.g. 2014-2017) can cause nitrate concentrations to decline, even where total nitrate discharges to the soil profile and vadose zone are increasing. Long delays (or lag times) can occur between land use change and the effects of the change being observed in a monitoring well or stream. These lags are caused by the slow movement of water through both the vadose zone and aquifer. A declining or increasing nitrate trend should therefore be interpreted with caution, and within the context of the other processes which affect groundwater and stream nitrate concentrations.

2.3.3 WDC Community Supply Schemes

The Waimakariri District Council (WDC) operates 16 public water supply schemes (Figure 2-5), with the Pines/Kairaki wells included in the Kaiapoi supply scheme, and Woodend Beach only supplying a holiday park. As of June 2018, 12 of the 16 schemes were compliant with the revised Drinking Water

[5] P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GWquality\Private_wells_ExWDC_CurrentGAZ.xlsx

Standard (DWSNZ 2008) (Waimakariri District Council, 2018a). The remaining four schemes have programmes of work set up to meet approved timeframes for compliance which are outlined in the District Council's Water Safety Plans for each scheme as summarised in Table 2-3. For example, Poyntzs Road will be connected to the West Eyreton supply wells by 2019 to make the supply scheme compliant with DWSNZ 2008. The same upgrade has been achieved for Summerhill in 2011 (Waimakariri District Council, 2018b). In Appendix 1 we describe the primary and secondary sources for all the WDC supply schemes.

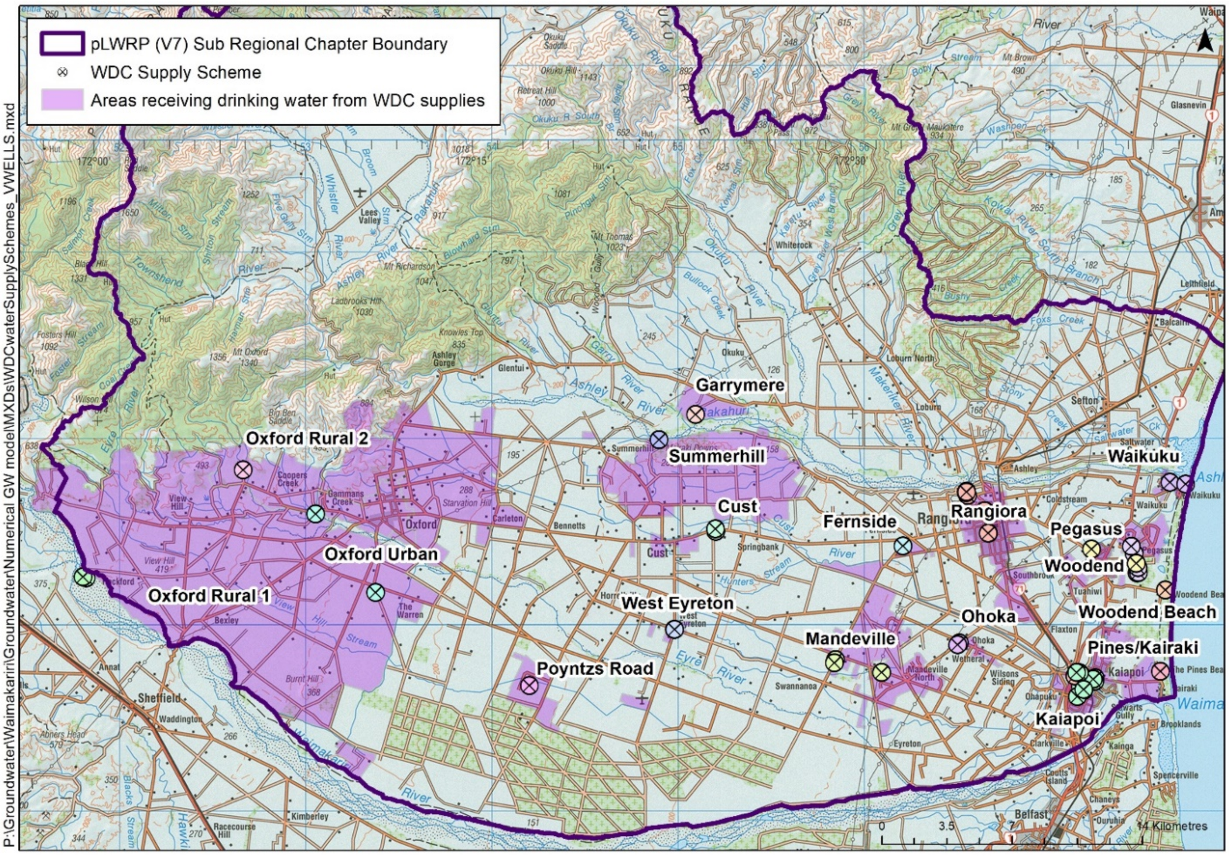

Figure 2-5: Waimakariri District Council Community supply wells

Table 2-3: Planned WDC scheme upgrades to comply with Drinking Water Standards 2008

Scheme	Upgrade Option	Timeframe
Waikuku	UV Treatment Installation and Drilling of Second Well	2017/18
Garrymere	Treatment Upgrade	2018/19
Oxford Rural No.1	Drill a new deep well	2018/19
Poyntzs Road	Connect to West Eyreton Scheme	2018/19

Some properties in the Waimakariri District north of the Ashley River (Sefton/Ashley/Loburn areas) are connected to the Ashley Rural Water Scheme which is administered by the Hurunui District Council and is effectively a surface water take.

WDC supplied us with recent (up to January 2018) nitrate measurements in their drinking water supply wells. The range in peak annual mean nitrate concentrations based on these measurements are presented in Table 2-4.

The measured nitrate concentrations are all below the drinking-water MAV. Poyntzs Road has nitrate concentrations higher than ½ MAV or 5.65 mg/l: hence this supply scheme is monitored monthly by WDC. Eight schemes have concentrations below 1.0 mg/L and another eight fall between 1.0 and 5.65 mg/L.

Table 2-4: Nitrate-nitrogen concentrations measured in WDC community supply wells

Drinking water supply scheme	Peak annual mean nitrate-nitrogen (mg/L) Range				
	<0.25	0.25 – 0.5	0.5 – 1.0	1.0 – 5.65	5.65 – 11.3
Cust		x			
Fernside[6]				x	
Garrymere		x			
Kaiapoi[7]				x	
Mandeville[6]				x	
Ohoka		x			
Oxford Rural 1				x	
Oxford Rural 2[8]				x	
Oxford Urban[8]				x	
Pegasus	x				
Pines/ Kairaki[7]		x			
Poyntzs Road					x
Rangiora				x	
Waikuku			x		
West Eyreton and Summerhill[9]				x	
Woodend	x				
Woodend Beach	x				

[6] The source for Mandeville was upgraded to supply Fernside in 2018.
[7] The Pines/Kairaki supply is connected to the Kaiapoi water supply since 2017 due to damage sustained to the Featherstone Ave headworks during the 2010/11 earthquakes.
[8] The source for Oxford Urban was upgraded to supply Oxford Rural 2 in 2018.
[9] The source for West Eyreton was upgraded to supply Summerhill in 2011.

2.3.4 Christchurch City Council Community Water Supply Schemes

Christchurch City Council (CCC) operates nine drinking water supply schemes that take groundwater from the aquifers underneath urban Christchurch (Figure 2-6), with a total of ~160 wells/bores. Groundwater nitrate concentrations in the deep Christchurch aquifer have been monitored in our long-term deep monitoring site at Russley Road since 1995. Two wells have been monitored: Well M35/6791, screened from 188 – 200 m depth, was monitored from 1995 to 2013, when the well was decommissioned by CCC. Monitoring has continued in nearby well M35/6040 (screened from 170 – 176 m depth) since that time. Monitoring results show that nitrate concentrations are increasing over time[10], but remain very low, between 0.1-0.8 mg/L (see graph in Figure 2-7).

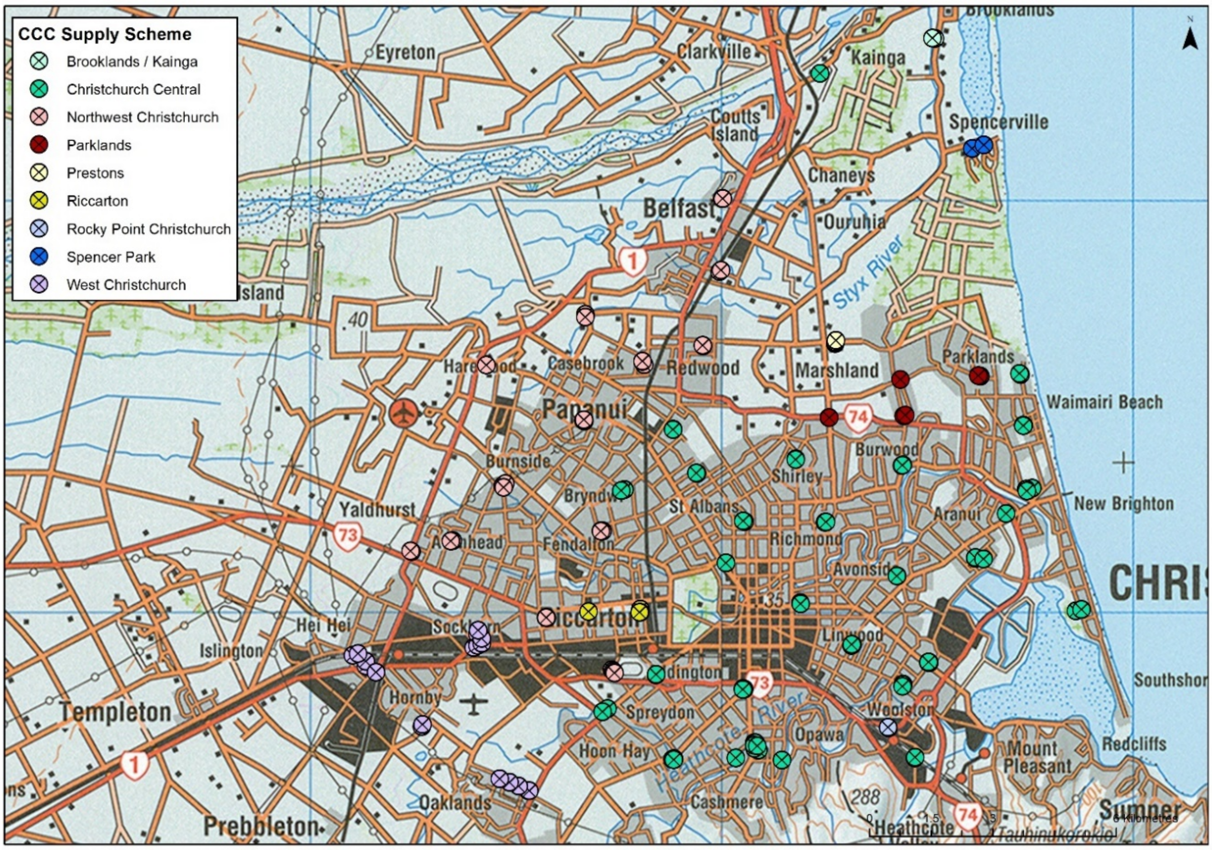

Figure 2-6: CCC Community Water Supply Schemes (urban area)[11]

[10] Statistical analysis of monitoring data undertaken by GNS found a Sen slope of 0.0044 mg/L per year over the 1995-2015 time period, with a p-value of 0.0045 (i.e., statistically significant at the 95% confidence level) for the Mann-Kendall test, seasonally adjusted, excluding outliers located outside a 4 times the median absolute deviation interval.

[11] P:\Groundwater\Waimakariri\Groundwater\Groundwater Quality\CCC nitrate monitoring data\CCC wells.csv

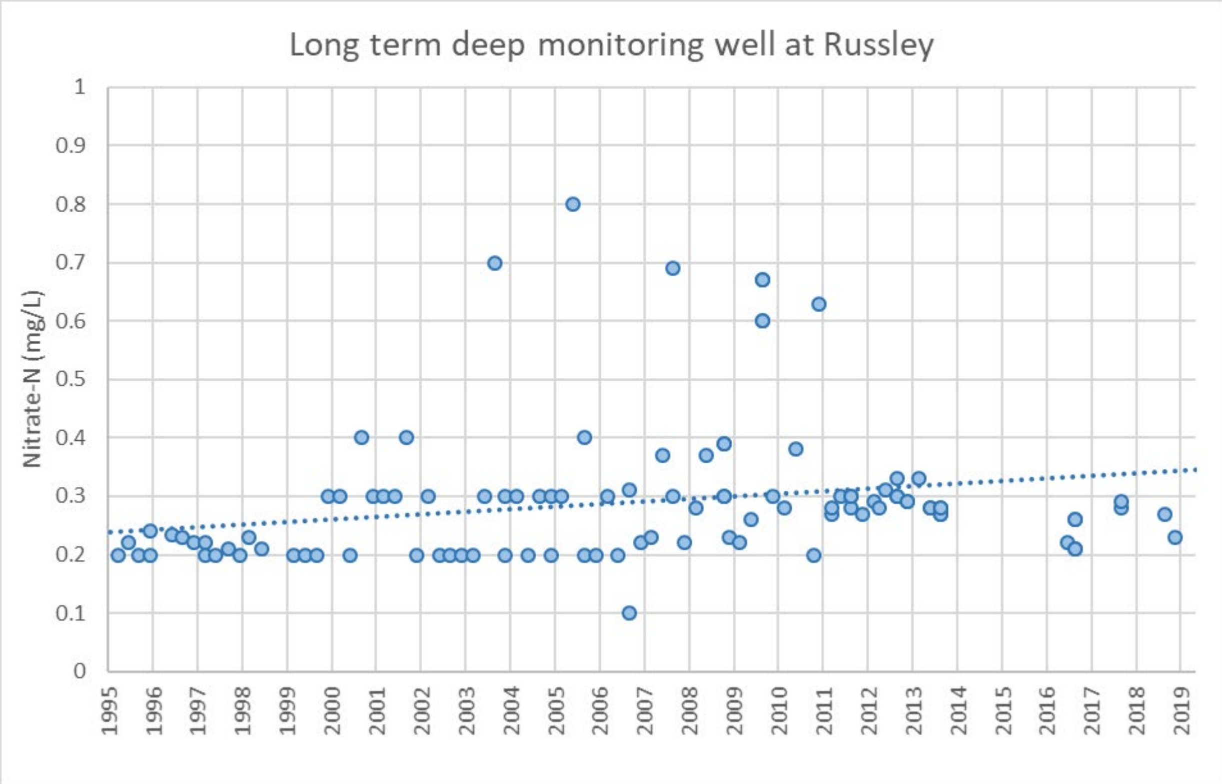

Figure 2-7: Nitrate concentrations in samples taken from Environment Canterbury's monitoring site at Russley Road[12]

Figure 2-8 shows the range in depths of the CCC Community Water Supply wells. We present combined nitrate concentration monitoring data from the CCC for their supply wells in Urban Christchurch[13] and recent monitoring data for CCC supply wells from our groundwater quality database in Figure 2-9. The data is grouped by the depth ranges of the CCC water supply wells. As can be seen from the graph, 100% of the samples were below the drinking-water MAV for nitrate.

[12] Internal data source: P:\Groundwater\Waimakariri\Groundwater\Groundwater Quality\CCC nitrate monitoring data\hilltop\CCC_wells_all_nitrate.xlsx

[13] Internal data source: P:\Groundwater\Christchurch West Melton\CCC_drinking_water_wells_Chemistry.xlsx

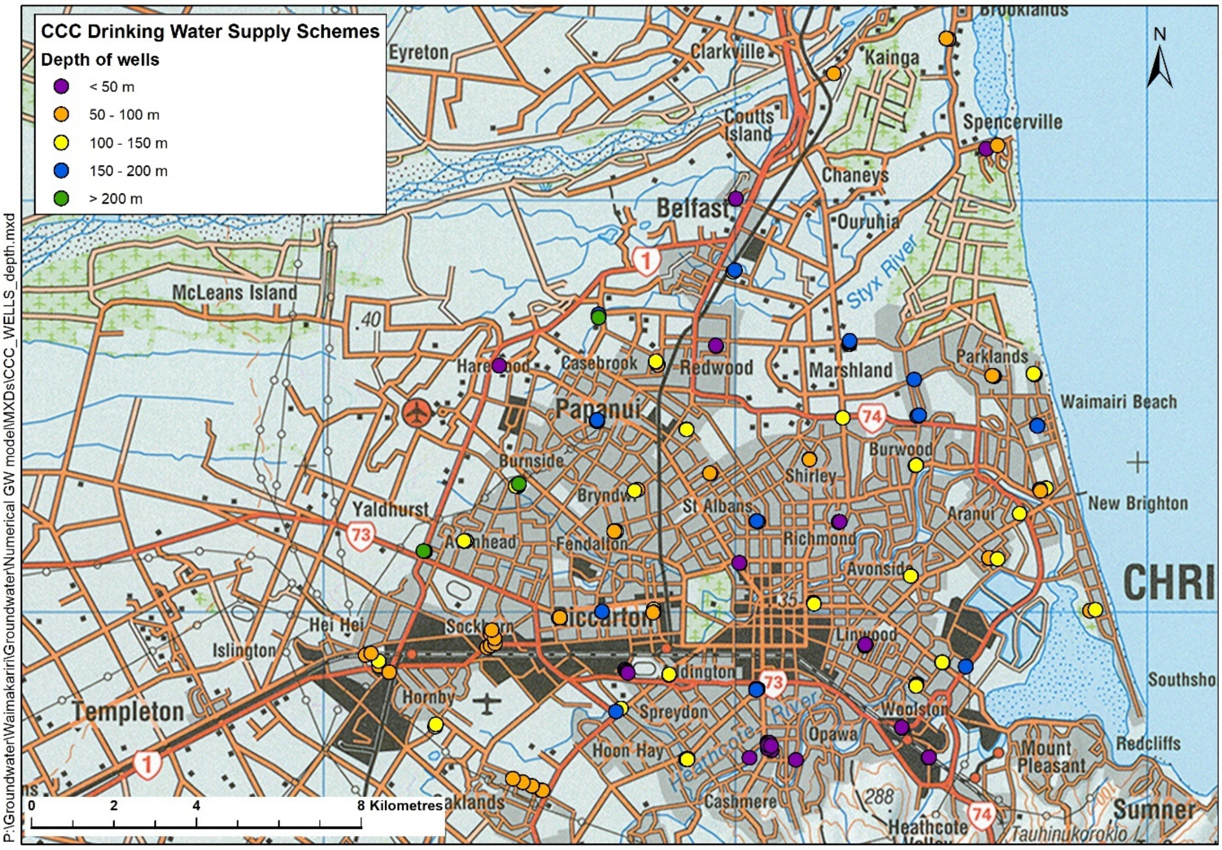

Figure 2-8: Depth of the CCC Community Water Supply Wells

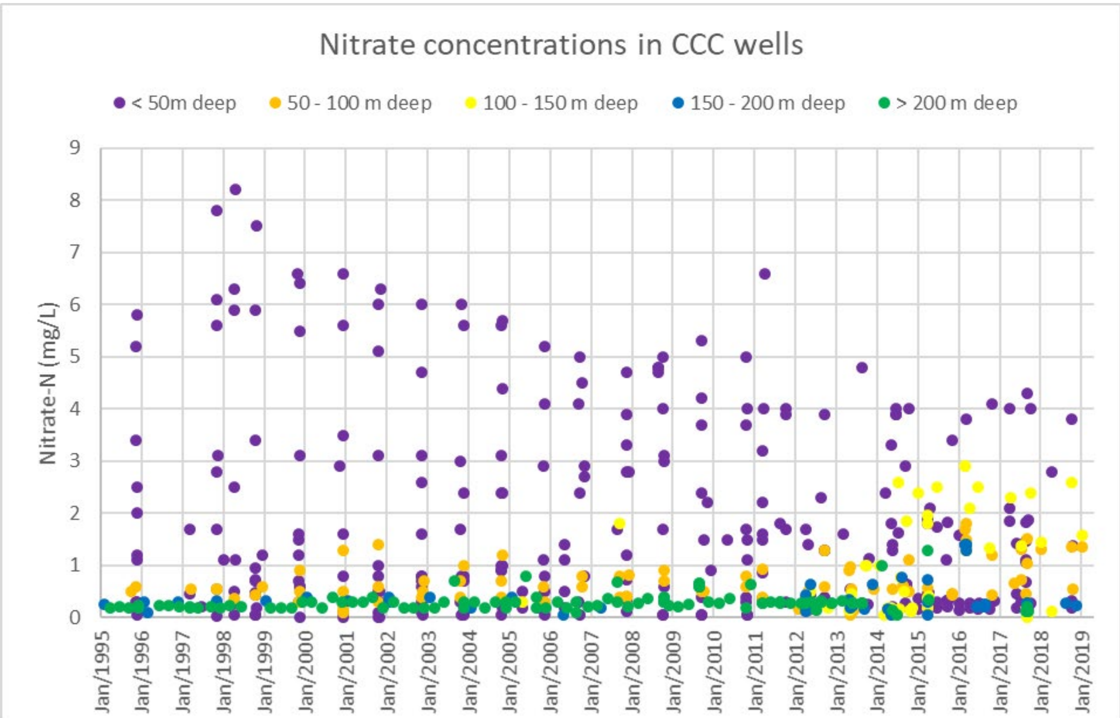

Figure 2-9: Measured nitrate (mg/L) in samples from CCC water supply wells 1995 – 2019 by depth

Shallow wells (< 50m deep) are generally influenced by local hydrogeology, surface water and nearby activities. Water levels and water quality react relative quickly to local changes, which is why the shallow CCC water supply wells show a significant variability in nitrate concentrations (see Figure 2-9). On average the nitrate concentration for shallow CCC water supply wells is 1.6 mg/L (see Table 2-5).

Deeper well nitrate concentrations are less variable and generally lower. Currently maximum nitrate concentrations in CCC water supply wells at a depth > 150 m are below 1.5 mg/L, with an average of 0.42 mg/L (spatially weighted).

The reduction in nitrate concentrations with depth correlates with generally increasing groundwater age with depth, although other factors (e.g. recharge source) could also be relevant. We discuss this further in Section 3.7.

Table 2-5: Nitrate concentrations (mg/L) in CCC water supply wells for different depth ranges for period 2008-2019[14]

Depth (m)	% of wells in depth range	Number of sampled wells	Number of samples	Minimum	Maximum	Average
< 50	20	30	141	0.05	6.6	1.63
50 - 100	25	22	55	0.05	1.8	0.58
100 - 150	35	35	56	0.05	2.9	0.49
150 - 200	15	16	32	0.05	1.4	0.42
> 200	5	6	49	0.05	1.3	0.42

2.3.5 Private water supply wells

There are approximately 2,750 active private drinking wells in the Waimakariri Northern Tributaries (WNT) catchment (see Figure 2-1 for catchment boundaries) listed in our Wells database; ~2,650 of these are located outside of WDC water reticulation areas. We have assumed that wells located within WDC water reticulation areas are not used for drinking water supply. While the exact population using these private wells is unknown, if we assume the New Zealand average of 2.6 people per household (Stats NZ data), approximately 6,900 people within the WNT catchment obtain potable water supplies from private wells. There are approximately 60,700 people in the WNT in total, so around 11% of population within the WNT obtain water from private supply wells and the other 89% from community supply wells owned by the WDC. In the WNT catchment the current long-term nitrate concentration for groundwater is generally close to or above 5.65 mg/L (½ MAV), as described in section 2.3.1 (refer to concentrations for the Cust and Eyre GAZs).

In the Ashley River/Rakahuri catchment there are ~170 active private drinking wells listed in our database, with a median depth of 18 m. That is only 6% of all the active private drinking water wells (~2,810) in the Waimakariri Zone. Based on groundwater quality monitoring results (described in section 2.3.1, refer to concentrations for the Ashley and Kowai GAZ) the current long-term nitrate concentration for groundwater in this catchment is generally below 5.65 mg/L (½ MAV).

There are ~2000 private water supply wells located in the Cust and Eyre River GAZs, ~730 in the Loburn and Ashley GAZs and ~80 in the Kowai GAZ. See Figure 2-10 for the locations of the private water supply wells within the GAZs.

[14] Internal data source: P:\Groundwater\Waimakariri\Groundwater\Groundwater Quality\CCC nitrate monitoring data\ hilltop\CCC_wells_all_nitrate.xlsx

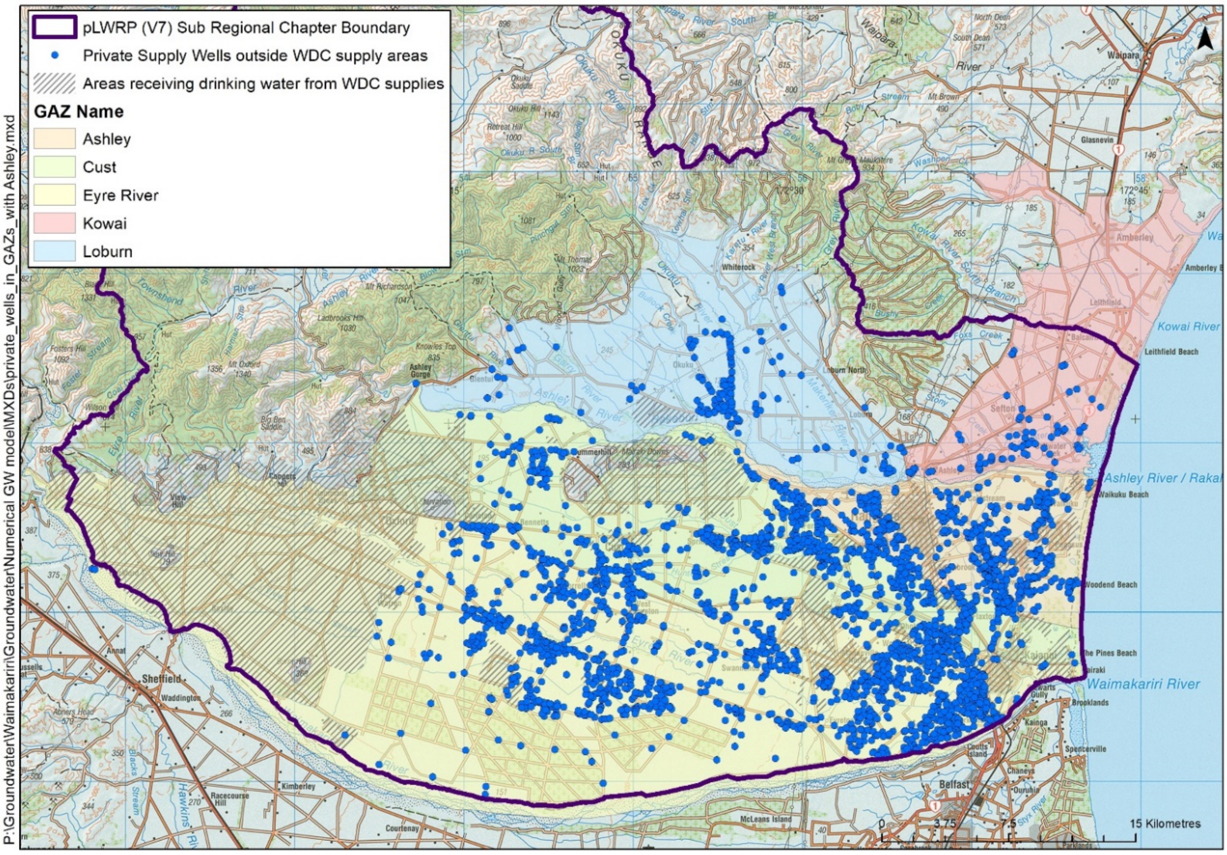

Figure 2-10: Private water supply wells (outside of WDC water reticulation areas) within the GAZs

We have gathered all the nitrate monitoring data (since 1954) for private water supply wells samples in our database. We presented the maximum measured nitrate concentrations for private wells (with nitrate data) in the Waimakariri Zone in Figure 2-11.

For the 182 wells presented in the map 6 wells (3%) have maximum concentrations exceeding the drinking-water MAV. In 48 wells (26%) the maximum concentration is between 5.65 – 11.3 mg/L and 128 wells (71%) show maximum nitrate concentrations below 5.65 mg/L. Based on feedback and concerns we received from members of the local community during the consultation process we know that there are more than 6 private water supply wells in which nitrate exceeds the drinking-water MAV.

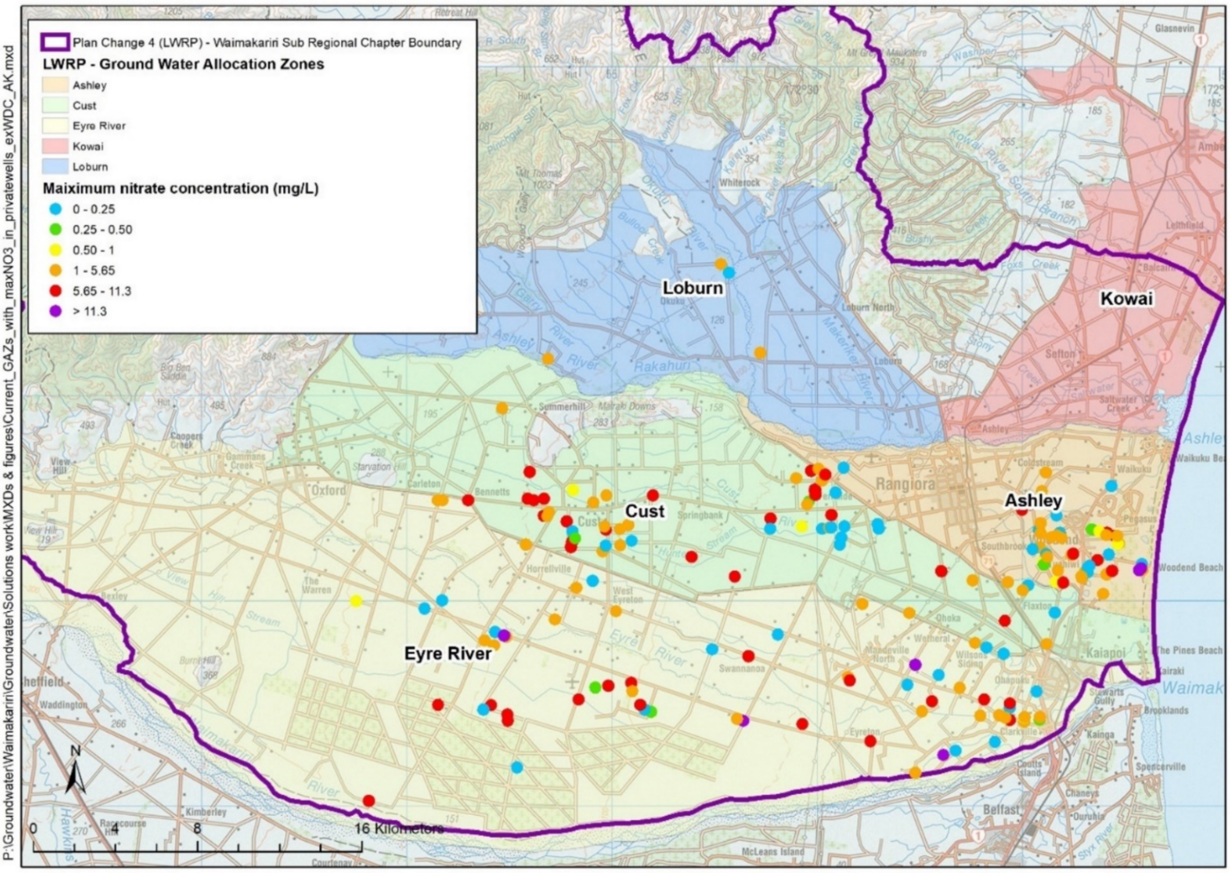

Figure 2-11: Measured maximum nitrate concentrations in private water supply wells in the Waimakariri Zone[15]

As can be seen when comparing Figure 2-10 with Figure 2-11, there is a large number of private water supply wells without nitrate concentration data. In order to estimate concentrations for all the private water supply wells in the Waimakariri Zone we used relationships between the ***mean*** nitrate concentration for all groundwater samples collected for the whole of the Canterbury plains in a given year and the percent of the samples in that year with nitrate concentrations exceeding 11.3 mg/L. This is useful for estimating drinking water nitrate MAV exceedances for areas in which we have too few samples to provide a clear picture of spatial variance (but have enough samples to provide an estimate of the mean concentration). We refer to Appendix 2 for an overview of the established relationships.

Based on the assessment in Appendix 2 we assume that this translates to a total of ~165 wells in the Cust, Eyre River and Loburn GAZs combined and ~90 wells for the Waimakariri Zone on its own. This difference is due to spatial variance of nitrate concentrations in the zone; local effects are playing their part in changing the spatial variance in nitrate concentrations compared to the spatial variance for the whole Waimakariri Zone or the Canterbury plains. Therefore we estimate that nitrate concentrations are likely to exceed the drinking water limit in 90-165 wells on some occasions.

[15] Internal data P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GW quality\Private_wells_ExWDC_CurrentGAZ.xlsx

2.4 Surface water quality

For this technical report we have distinguished three surface water allocation zones: spring-fed streams in the *Waimakariri northern tributaries catchment*, the *Ashley River/Rakahuri catchment* and the *Waimakariri River*. Refer to the map in Figure 2-12 for the orientation of the zones and spring-fed streams identified for this report. A short description of the catchments follows in the next sections. The values (ecological, cultural, recreational and economical) of all the assessed streams and rivers are described in the separate technical report 'Aquatic Ecology and Biodiversity' (Arthur *et al.,* 2019). The importance of these surface waters for mahinga kai is described in Te Ngāi Tūāhuriri and Tipu & Associates (2016). We have included our assessment of the trend in nitrate concentration for each catchment in Appendix 3. For the trend analysis we used a Seasonal Kendall test and slope analysis with median values in each season of 1 month. For each trend we have presented our confidence in the trend with a probability (%).

2.4.1 Waimakariri Northern tributaries catchment

We focused on the following spring-fed streams:

- Kaiapoi River/Silverstream
- Courtenay Stream
- Ohoka Stream
- Cust Main Drain
- Cam River

Kaiapoi River/Silverstream

The upper reaches of the Kaiapoi River, e.g. the section of watercourse from the springheads to the three streams confluence, is commonly referred to as Silverstream. Between Harpers Road and Island Road, Silverstream gains flow from many springs and small tributaries. Below Island Road the term 'Kaiapoi River' is used to define the section of watercourse from the three streams confluence to the Waimakariri River confluence. At this section the Kaiapoi River forms a large, deep and slow flowing tidally influenced channel. Unlike Silverstream, the Kaiapoi River becomes increasingly saline.

Nitrate concentrations in the Kaiapoi River/Silverstream are relatively high (exceeding the NPSFM (MfE, 2017 national bottom lines for nitrate toxicity (6.9 mg/L) at our Harpers Road monitoring site and show an increasing trend (see Table 2-6). We have not assessed nitrate concentrations in the lower reaches of the Kaiapoi River, where tidal water dynamics introduce significant complexities into nitrate concentration modelling, and the measured data record is much more limited.

Between 80-95% of the nitrate load reaching the river is likely to be sourced from dairy and dairy support land use (based on the land use map created by Lilburne *et al.* (2017, see 3.3.1).

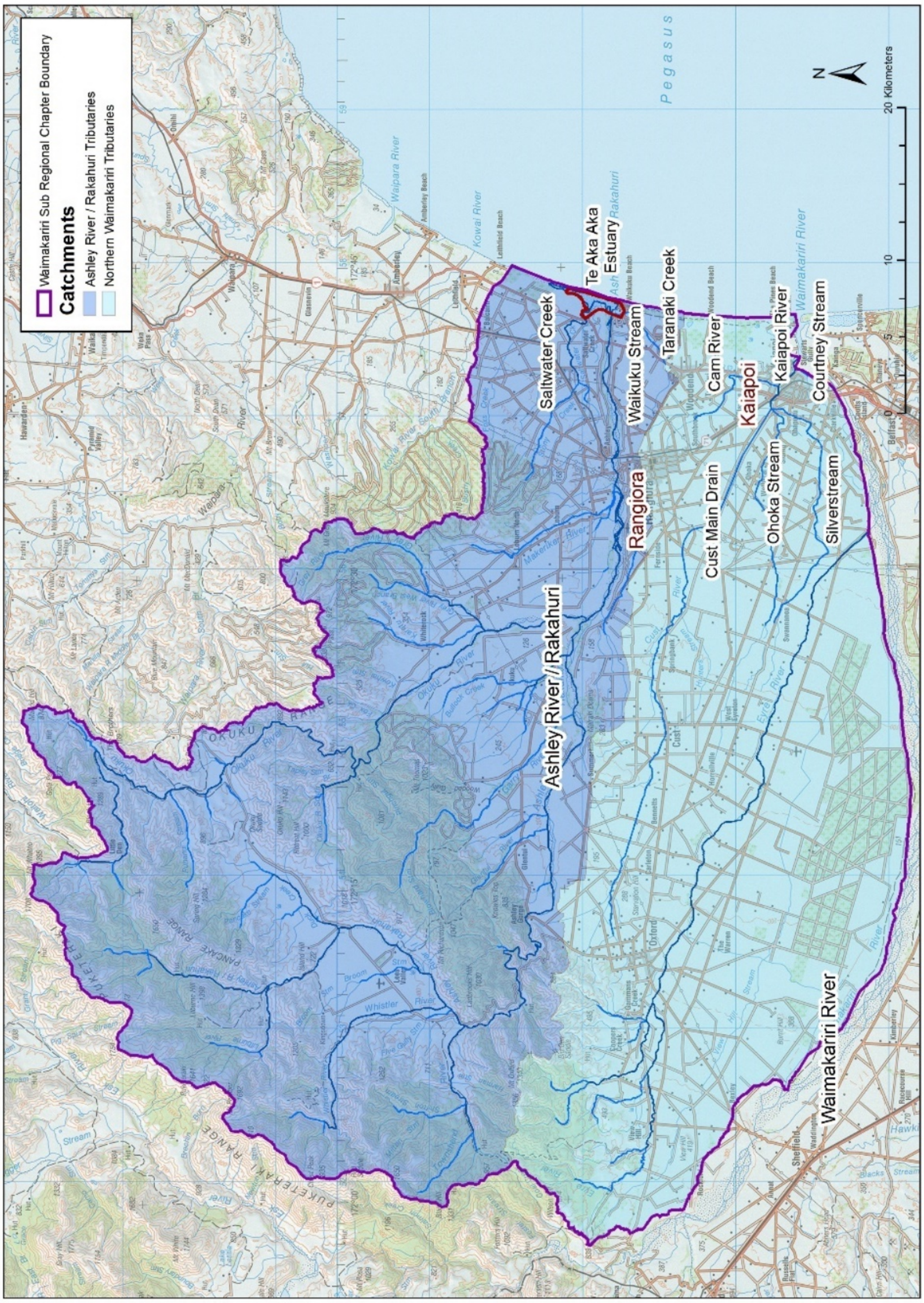

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Figure 2-12: Overview of the spring-fed streams in the major catchments within the Waimakariri Water Zone

Table 2-6: Current nitrate concentrations and trends: Northern Waimakariri Tributaries[16]

Stream	Peak annual median nitrate (mg/L)	Long term median nitrate (mg/L)	Trend 2009 – 2018 (% probability)
Silverstream[17] at Harpers Road	9.4	7.4	Increasing trend virtually certain (100%)
Silverstream[17] at Island Road	5.4	4.7	Increasing trend possible (88%)
Courtenay Stream	3.1	2.9	Uncertain, possibly upward[18]
Ohoka Stream	4.5	4.2	Decreasing trend very likely (99%)
Cust Main Drain	4.7	4.1	Increasing trend possible (88%)
Cam River	1.5	0.9	Increasing trend likely (91%)

Courtenay Stream
The Courtenay Stream is mostly slow flowing with a bed dominated by fine sediments. Kaikanui Stream, which flows into the lower reaches, functions primarily to convey stormwater. A short stretch of stream in the mid-reach still contains swift flows and exposed gravels. The nitrate concentrations in the river are relatively high, but below the national bottom line of 6.9 mg/L (see Table 2-6). Approximately 90% of the nitrate load reaching the river is likely to be sourced from dairy and dairy support land use.

Ohoka Stream
Ohoka Stream contains a modified catchment of straightened channels that drain historical wetlands. It contributes significant to flows to the Kaiapoi River and therefore strongly influences the river's values downstream. The nitrate concentrations in the river are relatively high, but below the national bottom line (see Table 2-6). Approximately 50% of the nitrate load reaching the river is likely to be sourced from dairy and dairy support land use.

Cust Main Drain
The Cust Main Drain is a modified form of the lower Cust River and, unlike the latter, flows year-round for the entirety of its length. Despite its modified state, the Cust Main Drain contains a gravel and cobble bed and very high ecological values. It provides fish passage for species migrating upstream into the Cust River during periods when flow is fully connected. The Cust Main Drain is a "priority river" for the development of esplanade under Waimakariri District Plan. The nitrate concentrations in the river are relatively high, but below the National Bottom Line of 6.9 mg/L (see Table 2-6). Approximately 50% of the nitrate load reaching the river is likely to be sourced from dairy and dairy support land use and 40% from intensive sheep and beef land use.

Cam River
The Cam River mainstem flows from tributaries that include the three Brooks (North, Middle and South Brooks) and Tuahiwi Drain. Along the river springs arise in, and flow through, Rangiora township. The catchment contains low nitrate levels relative to other northern Waimakariri spring-fed tributaries (see Table 2-6). Extensive rehabilitative efforts, such as bankside planting in the three brooks, is improving habitat quality and stream health at a smaller scale. The Cam River is a "priority river" for the development of esplanade under Waimakariri District Plan. Approximately 30% of the nitrate load reaching the river is likely to be sourced from dairy and dairy support land use and 40% from intensive sheep and beef land use.

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16 Refer to Appendix 3 for trend analysis results
17 The upper reaches of the Kaiapoi River, e.g. the section of watercourse from the springheads to the three streams confluence, is commonly referred to as Silverstream
18 No monitoring results available for Courtenay Stream during 2009 – 2018

2.4.2 Waimakariri River

The Waimakariri River is highly valued locally as well as regionally and nationally. It provides a wide array of services related to ecological function and natural character, cultural and customary use, recreational use, and amenity value. The Waimakariri Zone does not encompass the Waimakariri River per se, however groundwater and surface water flows from the Waimakariri Water Zone (e.g., Eyre and Kaiapoi River catchments) do impact the water and habitat quality in the Waimakariri River.. By way of example, Smiths Creek, a small lower north Waimakariri River bank tributary, discharges ~100 L/s of flow with ~ 6 mg/L of nitrate-N, i.e. around 20 tonnes/year, which equates to ~5% of the Waimakariri River N load at the Gorge monitoring site. This in itself is significant. Groundwater from the inland Waimakariri zone also seeps into river via the incised banks. Groundwater from the inland Waimakariri zone also seeps into the incised. Waimakariri River values are therefore influenced by land and water use in the Waimakariri Zone.

Nitrate concentrations in the river are relatively low, but there is an increasing trend in (see Table 2-7). Although concentrations are low in term of nitrate toxicity, they exceed the 0.1 mg/L indicative threshold for cyanobacteria growth. As such cyanobacteria blooms have been recorded as recently as 2019 (Arthur *et al.,* 2019). This highlights the susceptibility of the river to the effects of increasing nutrients.

Table 2-7: Current nitrate concentrations and trends: Waimakariri River[19]

Site	Peak annual median nitrate (mg/L)	Long term median nitrate (mg/L)	Trend 2009 – 2018 (% probability)
Gorge	0.1	0.07	Increasing trend possible (92%)
SH1	0.2	0.1	Increasing trend likely (95%)

The tidal reaches of the Waimakariri River and estuary (Brooklands Lagoon) fall outside of the Waimakariri Land and Water Solutions Programme scope and are not discussed in this report.

2.4.3 Ashley River/Rakahuri Catchment

In the Ashley River/Rakahuri catchment we focused on the Ashley River/Rakahuri and the following spring-fed streams:

- Saltwater Creek
- Waikuku Stream
- Taranaki Creek

All of these watercourses are groundwater-fed, with Taranaki Creek and Waikuku Stream being almost entirely spring-fed. We also included Te Aka Aka, which is the estuary of the Ashley River/ Rakahuri, in our assessment (see section 2.4.4). The surface water bodies within the Ashley River/Rakahuri catchment are of great importance to Ngāi Tūāhuriri, particularly the spring-fed streams and Te Aka Aka estuary.

Ashley River / Rakahuri
The Ashley River/Rakahuri catchment starts in the headwater above Lees Valley and extends to the coast. It includes the Okuku River and its tributaries. Around Lees Valley a number of hill-fed tributaries contribute to the main stem. As these pass through Lees Valley some water is lost to ground but reappears in the river at the entrance to the gorge. Below the gorge the river initially loses water to ground, going dry near Rangiora in typical summers. As the river approaches the coast flow returns from groundwater. The nitrate concentrations in the river are relatively low (see Table 2-8).

Saltwater Creek
Saltwater Creek drains a large area to the north of the Ashley River/Rakahuri. This includes some of the forested slopes of Mount Grey. The main channels of Saltwater Creek close to the Ashley

[19] Refer to Appendix 3 for trend analysis results

River/Rakahuri are spring-fed, with some of this spring water derived from the Ashley River/Rakahuri where it loses to groundwater further upstream. The tributaries further north are fed with runoff from local land and from the hillslopes behind. Many of these will be dry during the summer months. Saltwater Creek discharges into the Ashley River/Rakahuri estuary (Te Aka Aka). The nitrate concentrations in the river are relatively low (see Table 2-8).

Waikuku Stream
The Waikuku Stream drains a narrow strip of land south of the Ashley River/Rakahuri. Waikuku Stream is spring-fed, with much of the water coming from the Ashley River / Rakahuri. It discharges through tidal-gates into the Ashley River/Rakahuri near Leggitts Road. The nitrate concentrations in the river are relatively low (see Table 2-8).

Taranaki Creek
Taranaki Creek drains the area to the west and north of Woodend. It also drains Pegasus Township and Waikuku Beach. The upper reaches of Taranaki Creek are spring-fed with much of the water coming from the Ashley River/Rakahuri. Various other springs exist within the catchment that contribute to flow in the main channel. Additional flow comes from the wetlands and lagoons east of Pegasus township. The nitrate concentrations in the river are relatively low (see Table 2-8).

Table 2-8: Current nitrate concentrations and trends: Ashley River/Rakahuri catchment[20]

Stream	Peak annual median nitrate (mg/L)[21]	Long term median nitrate (mg/L)	Trend 2009 – 2018 (% probability)
Ashley River at Gorge	0.2	0.05	Decreasing trend virtually certain (100%)
Ashley River at SH1	0.3	0.2	Decreasing trend about as likely as not (74%)
Saltwater Ck	0.7	0.3	Decreasing trend about as likely as not (79%)
Waikuku Str	1.2	0.4	Increasing trend about as likely as not (67%)
Taranaki Ck	1.2	0.6	Increasing trend possible (91%)

[20] Refer to Appendix 3 for trend analysis results
[21] Maximum recorded annual median for 2008-2016 period.

2.4.4 Te Aka Aka

We refer to Bolton-Ritchie (2019a and 2019b) and Arthur *et al.* (2019) for a detailed description of Te Aka Aka. Te Aka Aka receives freshwater from the Ashley River/Rakahuri, Saltwater Creek, Taranaki Creek, Waikuku Stream and a number of small lowland creeks (Figure 2-13). Within the catchments of these rivers/creeks there are the urban areas of Rangiora, Woodend, Pegasus township and Waikuku. There is intensive rural land use within these catchments including an intensification of irrigated land. Te Aka Aka currently has one opening to the sea; the location of this opening does vary over time. The estuary has an extensive area of saltmarsh vegetation and non-vegetated intertidal sediments including the long area behind Ashworths Spit. The coastal marine area of Te Aka Aka is classified as an Area of Significant Natural Value (Environment Canterbury, 2012).

Figure 2-13: Aerial view (2012) of Te Aka Aka (Bolton-Ritchie, 2019a)

Nitrogen is typically the limiting nutrient for the growth of phytoplankton and algae in coastal and estuarine water. When there is plenty of nitrogen, and other growing conditions are right (such as water temperature and sunlight), these plants grow prolifically. This means that coastal water bodies such as Te Aka Aka can be highly sensitive to increases in nitrate influxes.

Field surveys have shown that within Te Aka Aka there are large areas of the fast-growing macroalgae species Ulva spp. and Gracilaria chilensis. Flushing of the estuary within a tidal cycle places some limits on the potential for excessive phytoplankton growth in the estuary, but if the estuary outlet was closed or occluded for a period of time due to coastal processes, flushing would reduce and the potential for excessive algal growth would increase.

The macroalgae distribution and sediment parameter field survey results (see Bolton-Ritchie, 2019a) suggest that:

- Saltwater Creek nutrients are causing macroalgae growth and effects on some sediment parameters along the margins of this creek;
- the small drains flowing into the western margin of the estuary are a source of nutrients causing macroalgae growth in the small channels in this area; and
- The Ashley River/Rakahuri is the likely source of nutrients causing macroalgae growth and effects on some sediment parameters in the southern part of the estuary. However, there may be some influence of Taranaki Creek water on these indicators here.

A set of tools for assessment of the trophic index of NZ estuaries was released for use in 2016 (Robertson *et al.,* 2016a, 2016b). The tools include:

- Determination of eutrophication susceptibility using physical parameters and nutrient load data, and
- use of monitoring indicators to assess the actual eutrophication band.

The tools define four eutrophication bands, as shown in Table 2-9.The macroalgae mapping results indicate that Te Aka Aka is currently within band B (moderate eutrophication) or C (high eutrophication).

Table 2-9: Eutrophication bands for estuary trophic status assessment

A Minimal Eutrophication	B Moderate Eutrophication	C High Eutrophication	D Very High Eutrophication
Ecological communities are healthy and resilient. *Primary Producers: dominated by seagrasses and microalgae. **Primary Producers: dominated by phytoplankton (diverse, low biomass). Water Column: high clarity, well-oxygenated. Sediment: well oxygenated, low organic matter, low sulphides and ammonia, diverse macrofaunal community with low abundance of enrichment tolerant species.	Ecological communities are slightly impacted by additional algal growth arising from nutrient levels that are elevated. *Primary Producers: seagrass/microalgae still present but increasing biomass opportunistic macroalgae. **Primary Producers: dominated by phytoplankton (moderate diversity and biomass). Water Column: moderate clarity, mod-poor DO esp at depth. Sediment: moderate oxygenation, organic matter, and sulphides, diverse macrofaunal community with increasing abundance of enrichment tolerant species.	*Ecological communities are highly impacted by macroalgal or phytoplankton biomass elevated well above natural conditions. Reduced water clarity likely to affect habitat available for native macrophytes. **Ecological communities are highly impacted by phytoplankton biomass elevated well above natural conditions. Reduced water clarity may affect deep seagrass beds. *Primary Producers: opportunistic macroalgal biomass high, seagrass cover low. Increasing phytoplankton where residence time long e.g. ICOLLs. **Primary Producers: dominated by phytoplankton (low diversity and high biomass). Water Column: low-moderate clarity, low DO, esp at depth. Sediment: poor oxygenation, high organic matter, and sulphides, macrofauna dominated by high abundance of enrichment tolerant species.	*Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover. **Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a nuisance algal bloom situation (often toxic). *Primary Producers: opportunistic macroalgal biomass very high or high/low cycles in response to toxicity, no seagrass. At very high nutrient loads, cyanobacterial mats may be present. Phytoplankton only high where residence time is long. **Primary Producers: dominated by nuisance phytoplankton (e.g cyanobacteria, picoplankton). Water Column: low clarity, deoxygenated at depth. Sediment: anoxic, very high organic matter, and sulphides, subsurface macrofauna very limited or absent. Eventually the sediments are devoid of macrofauna and are covered in mats of sulfur-oxidizing bacteria (i.e. *Beggiatoa*).

2.4.5 Coastal lagoons and wetlands

The coastal strip of land (between SH1 and the sea) stretching between the Waimakariri River and Te Aka Aka Estuary is a series of parallel dune systems with wetlands, streams, and lakes between them. Kairaki Creek and McIntosh Drain flow from broad areas of salt marsh including the Pines Beach wetlands, Tutaihara Trust holdings and Kaiapoi and Pegasus township wetland areas. Inland are a series of flooded and groundwater fed historic gravel pits that now form the Kaiapoi Lakes, and further to the north is Tūtaepatu Lagoon and the artificial groundwater-fed Lake Pegasus (Arthur *et al.,* 2019). Other than the Ashley Estuary (Te Aka Aka), coastal streams and wetlands were not included in this assessment. Arthur *et al.* (2019) note that:

- water quality data for these waterbodies is limited (partly due to tidal influences in some instances);
- land use is generally less intensive in the vicinity of these water bodies;
- low permeability near-surface sediments limit the egress of nitrogen-rich groundwater from intensive land uses further inland; and that
- anoxic conditions in groundwater and within the wetlands themselves are likely to attenuate nitrate in the near-coastal zone

This means that nitrate concentrations in these areas could not be easily or usefully assessed and modelled, and that the need for quantitative nitrate concentration assessment is less critical here.

3 Methodology

3.1 Context

In this section we explain the methodology we used to assess nitrate losses from the soil profile and the transport of nitrate through the groundwater system. The methodology underpins the subsequent Options, scenarios and management tools assessment (Section 4), which used the modelling tools documented here to help the WWZC explore the costs and benefits of a range of nitrate limit options and management strategies and tools. The ZIPA Solutions Package assessment (Section 5) is also founded on nitrate load and concentration modelling.

3.2 Overview

The main components of our methodology are:

- Soil nitrate loss modelling (Section 3.3)
- Development and optimisation of a deterministic steady state numerical groundwater model of the Waimakariri – Christchurch aquifer system (Section 3.4)
- Use of the groundwater model to evaluate transport pathways between the soil profile and key receptors (e.g. wells, spring-fed streams) and hence the recharge areas for these receptors (Section 3.5)
- Modelling of dilution of soil drainage water with low nitrate water sources in the aquifer along the transport pathways (Section 3.6)
- Evaluation of groundwater age data to provide an approximate basis for translating the modelled steady state nitrate concentrations into concentrations over time (Section 3.7)
- Quantitative uncertainty analysis for all of the above (Section 3.6)
- Comparison of model nitrate concentrations with measured data (i.e. “model validation”) (Section 3.9.2, Validation of model results)
- Discussion of modelling assumptions and limitations (Section 3.10)

Some of the key questions we needed to answer via the modelling study were:

1. Nitrate concentrations are increasing in some receptors and the effects of recent land use intensification in some parts of the zone are unlikely to have been observed to date. How high will nitrate concentrations be when they equilibrate with current land use (lag effect)?
2. Does groundwater from the Waimakariri zone flow beneath the Waimakariri River and into the Christchurch aquifer?
3. What effect will various nitrate management measures, such as implementation of GMP, have on nitrate concentrations in our key receptors?
4. What are the recharge areas for each of our receptors?
5. How much would we need to reduce the nitrate loss rate from land within these recharge areas in order to achieve a given nitrate concentration limit?

Further to point No. 1 above, our modelling approach aimed to provide estimates of nitrate concentrations in the surface water and groundwater receptors within our study area under steady state conditions. i.e. when concentrations equilibrate with current land use inputs. Because we know that significant and relatively recent land use intensification has occurred in some parts of the Waimakariri zone, and that the travel times between the land surface and some of the receptors can be very long, development of a tool which could evaluate steady state nitrate concentrations was a key requirement of our modelling approach.

3.3 Soil nitrate loss modelling

3.3.1 Spatial nitrate loss modelling

The process used to generate land use layers and associated rates of nitrate loss below the root zone[22] for the Waimakariri Zone is explained in Lilburne *et al.,* 2019 and summarised below.

A spatial modelling approach was used to classify and combine information on land use and management practices, climate, soil type, and a lookup table of expected nitrate losses for each farm type, climate and soil category (Lilburne *et al.,* 2019). This was done by developing a series of GIS (geographic information system) models to combine various data sources to generate a map of land use (Figure 3-1). The regionally available information was refined using local data where possible.

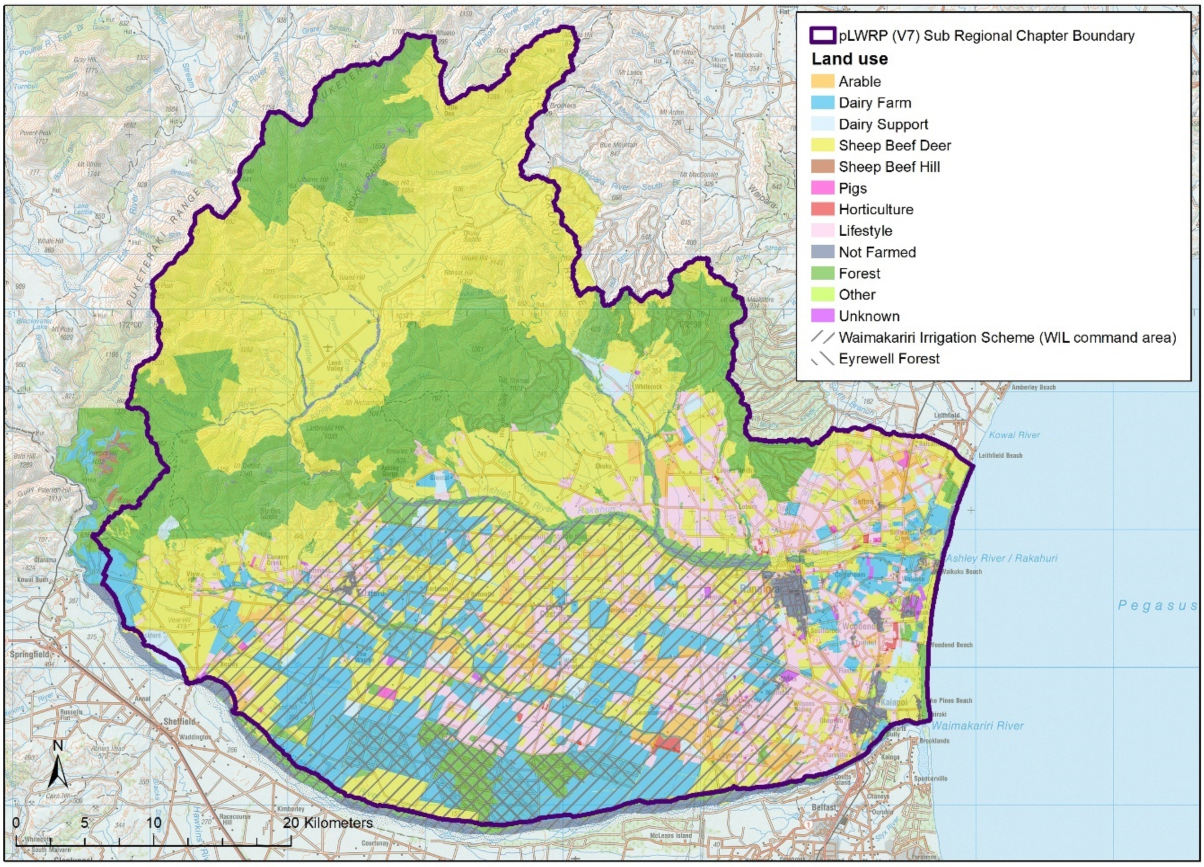


Figure 3-1: Land use at "Current State", as at 2016 (based on Lilburne *et al.,* 2019)

A lookup table of nitrate loss rates based on farm type was derived using a combination of values from the Matrix of Good Management (MGM, see Robson *et al.,* 2015) and the lookup table (Lilburne *et al.,* 2013) for farm types not covered by the MGM. The modelled land use intensity was estimated by extrapolating and totalling key data for some representative MGM farm types, e.g., stocking rate and milk solids production, across the land use map. Lifestyle properties were not included in the stock inventory of the land use map. This resulted in Figure 3-2, a map of nitrate loss rates for the Waimakariri Zone in the current state (with the assumption from OVERSEER® that Good Management Practices [GMP] are being applied).

Lilburne *et al.* (2019) also estimated the difference between soil nitrate loss rates under current management practices, i.e. before GMP (as defined in the LWRP) is fully implemented, and GMP. The modelling included soil drainage rate changes associated with the reduction in irrigation water losses that are occurring as irrigation efficiency improves under GMP, and the reduction in nitrogen load

[22] Internal location for Solutions assessments layer: P:\Groundwater\Waimakariri\Landuse\Shp\Results_24Nov2018.gdb\ zipa_28Nov18_ecanpp

leaching associated with improved irrigation efficiency and (to a lesser degree) improved fertiliser application management. Modelling results in Lilburne *et al.* (2019) show that although implementation of GMP is expected to reduce the nitrate loss load, the associated improvement in irrigation efficiency (and associated reduction in soil drainage rates) means that the OVERSEER® model outputs show an increase in nitrate concentrations in soil profile drainage water when GMP is implemented. This means that nitrate concentrations in the underlying groundwater can actually increase despite the nitrogen load reduction. This negative effect occurs in catchments where both land surface recharge from agricultural land is the dominant groundwater recharge component and where irrigation water is externally sourced[23] ; the reduction in nitrogen load can equate to a reduction in groundwater concentrations in areas where more than 50% of groundwater recharge is derived from low nitrate sources (e.g. alpine rivers) or where irrigation water is sourced from within the catchment. The highest nitrate concentrations occur in catchments where groundwater recharge is predominantly derived from intensively farmed land, however, and large areas of the Waimakariri zone are irrigated with an external water source (the Waimakariri River). This means that the potential for nitrate concentrations to increase following improvements in irrigation efficiency is widespread.

We excluded point sources of nitrate losses (e.g. dairy effluent ponds) from the nitrate load layer because they are negligible compared to the losses from intensively farmed land within the zone. Loe and Clarke (2017) inventoried all the point sources between the Ashley River/Rakahuri and Waimakariri River, based on the total amount of authorised waste water discharges (permitted or consented). These were mainly for dairy farm effluent ponds (10.4 t nitrate- nitrogen (N) per year) and centralised sewerage systems (19.1 t N per year). For on-site waste water treatment facilities they found 31.3 t N per year and these discharges were included in the model as part of the Lifestyle Block leaching rate estimate by Lilburne *et al.* (2019).

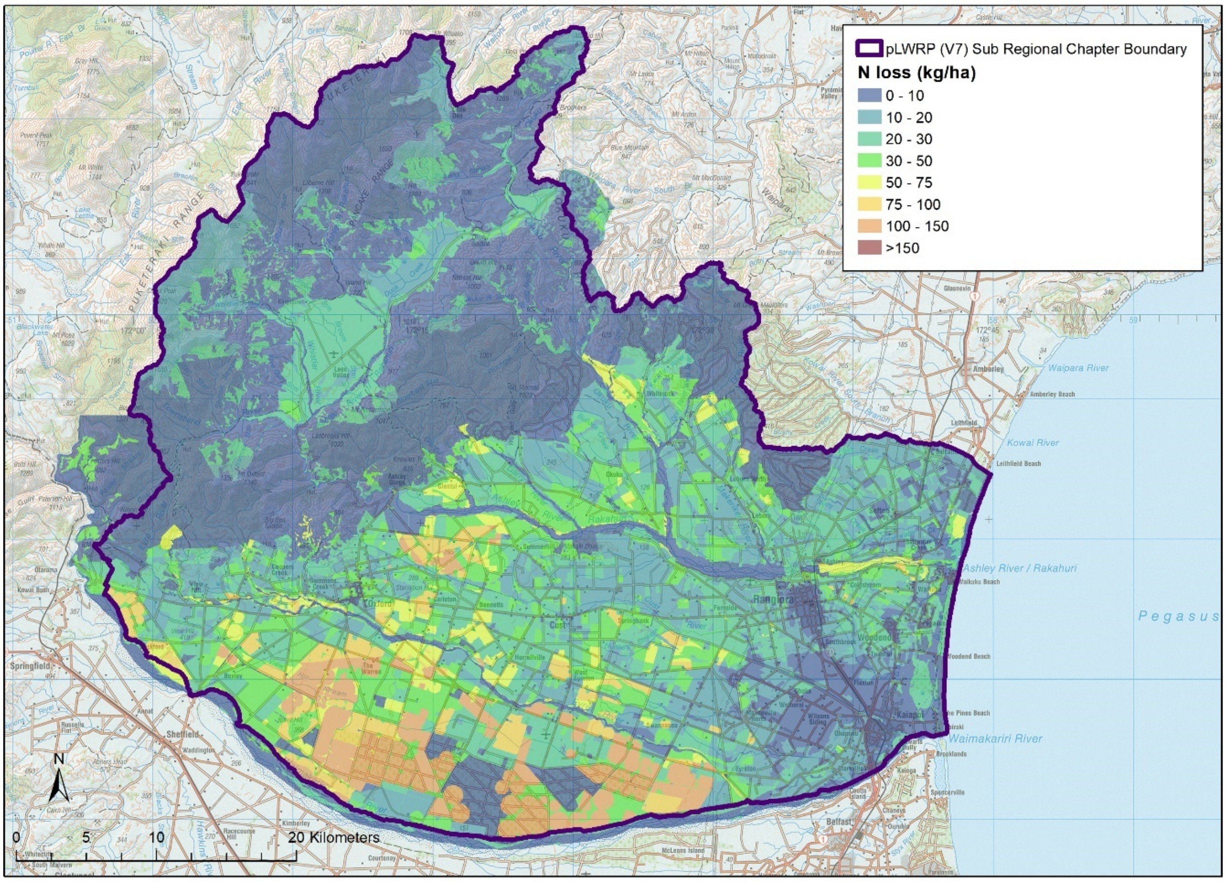


Figure 3-2: N losses (per year) below the root zone under land use in the 'Current State' (based on Lilburne *et al.,* 2019)

[23] e.g. use of Waimakariri River for irrigation within the Silverstream recharge area

Although our study and modelling did not include nitrate losses from land south of the Waimakariri River, we ran a sensitivity analysis under which a uniform 8 kg/ha/year N loss rate was applied to the Christchurch West Melton zone. The result of this analysis (discussed in Etheridge and Hanson, 2019a), showed that modelled Christchurch dep groundwater nitrate concentrations are not sensitive to N losses from land within the Christchurch West Melton zone.

3.3.2 Uncertainty analysis

The widespread view that use of OVERSEER®-derived N loss estimates to set catchment-scale nutrient limits is an inappropriate use of this tool needs to be addressed to inform stakeholder acceptance of these limits (Etheridge *et al.,* 2018). Accounting for uncertainty is the best way to deal with this issue, according to the authors. Uncertainty quantification also allows decision-makers to consider the likelihood that a proposed management approach will be successful and to understand the likelihood that model projections of future water quality will eventuate.

The Etheridge *et al.* (2018) study involved OVERSEER® experts from Ravensdown, Manaaki Whenua Landcare Research and Environment Canterbury, selected based on their familiarity with and standing within the stakeholder and scientific community. The study used a formal expert judgement elicitation framework (Sheffield Elicitation Framework, Oakley and O'Hagan, 2016) to approximately quantify uncertainty around catchment-scale modelled N loss rates.

Uncertainties included potential errors in data collection, classification, processing and/or detail not captured in the input layers. The nitrate loss rates look-up table was derived from farm-scale modelling with inherent uncertainties due to a narrow range of farm types (excluded lifestyle blocks), inputs to characterise each farm system, as well as functional errors in the model. We used the outputs of the Etheridge *et al.* (2018) study (included in Appendix 4) as part of our overall nitrate modelling uncertainty quantification process (see Section 3.6 for further details).

3.4 Groundwater model development programme

We undertook a three year collaborative groundwater model development programme[24] with the aim of providing a robust scientific tool for use in the Waimakariri Land and Water Solutions Programme. The main stages of the model development were:

1. Evaluation of the current (as of 2015) knowledge of the Waimakariri Zone hydrological system and identification of key gap areas
2. Field investigations and data analysis studies to address these gaps
3. Development of an initial numerical groundwater model
4. Further field investigations and data analysis
5. Finalisation of groundwater modelling

3.4.1 Knowledge gap studies

Dodson (2015) interviewed ten groundwater technical experts about their understanding of the Waimakariri groundwater system and held a workshop to discuss points of agreement and disagreement. The study identified a number of critical knowledge gaps, including:

- Offshore coastal discharge rates
- Groundwater flow beneath the Waimakariri River
- Effects of conversion of the former Eyrewell Forest into irrigated dairy farming on downstream nitrate concentrations
- Vulnerability of community water supply wells (e.g. Kaiapoi and Christchurch) to diffuse source nitrate contamination
- Lag times and nitrate attenuation in groundwater

[24] (September 2015 - November 2018)

- Hydraulic connection between shallow and deep productive water-bearing zones in the Eyre River GAZ

We undertook the following gap-filling investigations, initially based on the findings of Dodson (2015) and supplemented based on the emerging information requirements of the Waimakariri Land and Water Solutions Programme:

- Coastal groundwater discharge in the Waimakariri zone (Etheridge, 2019)
- Hydrostratigraphy of the Eyre River Groundwater Allocation Zone (PDP, 2016)
- Land-surface recharge calculations for Waimakariri groundwater model (Alkhaier, 2016)
- Ashley – Waimakariri Major Rivers Characterisation (Aqualinc, 2016)
- Ashley River/Rakahuri water budget (Etheridge, 2016)
- Potential for Nitrate attenuation in the Waimakariri coastal zone (Included in Etheridge and Hanson 2019a)
- Age tracer investigation for the Waimakariri spring-fed streams (Van der Raaij, 2016)
- Groundwater quality investigation, with sampling of ~120 wells in 2015-2016 and 30 wells in 2017
- Groundwater level surveys in 2016 and 2017

The findings of these studies are discussed in Etheridge and Hanson (2019a).

Other gaps, such as the effects of conversion of the former Eyrewell Forest into irrigated dairy farming, the vulnerability of community water supply wells to diffuse source nitrate contamination and groundwater flow beneath the Waimakariri River were addressed through our groundwater modelling study directly.

3.4.2 Groundwater model development

Numerical groundwater models are widely recognised within the scientific community as the best tool for exploring the complicated three-dimensional groundwater flow questions (such as those outlined in Section 3.1) that cannot be addressed using analytical methods and expert judgement alone. The four main stages of our groundwater model design and development process (which is described in detail in Etheridge and Hanson, 2019a) comprised:

1. Development of a conceptual model of the hydrological system
2. Collaborative design and development of a numerical groundwater model
3. Compilation of model inputs using data and expert panel knowledge and judgement
4. Optimisation of model parameters such that the model replicates measured data as closely as possible

Conceptual model
The main elements of our conceptual model were:

1. Evaluation of model water budget components:
    a. Water losses from irrigation and stockwater races
    b. Rainfall and irrigation-induced land surface recharge of the aquifer system
    c. Groundwater abstraction rates
    d. The distribution and rate of water exchange between surface water courses and the groundwater system
    e. The distribution and rate of offshore groundwater flow

2. Groundwater flow paths
    a. The hydrostratigraphy of the aquifer system and the orientation of preferential flow paths
3. Groundwater chemistry
    a. Presence and spatial distribution of nitrate attenuation potential (nitrate attenuation was assessed in a separate document, see discussion below)
    b. Geochemical indicators of nitrate dilution potential
    c. Groundwater age

Some of the key findings of our conceptual model development process were:

1. Water budget
    a. Water losses from the stockwater and irrigation race network are a significant component of the Waimakariri zone groundwater recharge budget
    b. Irrigation efficiency is likely to be relatively low (as of 2016) due to the poor reliability of the Waimakariri Irrigation Limited water supply and the ad-hoc approach to irrigation practised by farming in general. Inefficient irrigation is likely to represent a significant groundwater recharge source, particularly on light soils
    c. Groundwater abstraction rates were estimated to equate to ~40-50% of the consented volume in an average year
    d. The Ashley River/Rakahuri loses a significant amount of water (~5 m^3/s) to the aquifer in its lower reaches
    e. The Eyre River generally loses all of its water to ground in the upper/mid Waimakariri – Ashley plains; this also represents a significant groundwater recharge source
    f. The rate off offshore flow is likely to be low (< 0.3 m^3/s) along the Waimakariri zone coast between the Waimakariri River and Pegasus Town and much higher (1.4 – 5.1 m^3/s) to the north of Pegasus Town
2. Groundwater flow paths
    a. The Waimakariri River is likely to have followed a more northerly flow path at various times during the Holocene period, travelling across the Waimakariri – Ashley plains, sometimes discharging offshore near Pegasus Town. At other times is likely to have followed a south east flow path across the lower Waimakariri – Ashley plains, towards Christchurch. These former flow paths are likely to be associated with higher transmissivity deposits and a south-easterly orientated preferential flow paths in some parts of the aquifer.
    b. Water levels in adjacent deep and shallow wells in the inland plains area show significant differences, with rest water levels in deep wells being much lower than shallow wells. This steep downward hydraulic gradient is likely to be driven by recharge at the groundwater surface and lateral drainage in the highly transmissive deep aquifer (>150 m) across the Waimakariri – Ashley and broader central Canterbury Plains area.
3. Groundwater chemistry
    a. Nitrate attenuation potential, based on geochemistry data, is generally very low for the inland plains and high in some parts of the coastal and near coastal aquifer system.
    b. Field investigations suggest that nitrate attenuation potential is greatest within the low permeability organic silt and peat deposits and lowest in the high transmissivity sand and gravel deposits. This means that although the nitrate attenuation potential is high, much of the water flowing to wells and spring-fed streams could bypass the deposits in which attenuation can occur and hence the actual rate of nitrate attenuation may be much lower than the potential rate.

c. Our analysis of geochemistry data (stochastic End Member Mixing Analysis, EMMA, see Scott and Etheridge, 2017) showed that in some areas (e.g. parts of the Christchurch aquifer), groundwater contains a significant alpine river component (most likely from the Waimakariri River). Assuming that this composition continues in the future, nitrate concentrations associated with land surface recharge (LSR) from intensive land use will be diluted significantly. In other areas (e.g. some spring-fed streams), the alpine river component is very low with the water comprising almost entirely LSR. This signals a limited dilution potential.

d. The mean age of water in spring-fed streams in the Kaiapoi River/Silverstream catchment is relatively young (<10 years). This means that whilst a proportion of the water quality impacts associated with land use intensification that has occurred within the last 10 years may be apparent in current water quality monitoring data, the full effects of any such intensification are unlikely to have been seen. The effects of older land use intensification (e.g. 20-30 years) are likely to be well-represented, however.

e. The mean age of groundwater in some private water supply wells and in the deep community water supply wells is much older (e.g. >40 – 100 years, and many hundreds of years for the eastern Christchurch aquifer). This means that, depending on the alpine river dilution ratio, nitrate concentrations could increase significantly over time, as the effects of land use intensification become apparent. We discuss the concept of groundwater age further in Section 3.7.

The information and methods upon which these findings are based are discussed in more detail in Etheridge and Hanson (2019a).

Collaborative model design and development
Our groundwater model development process took place over two main phases:

Phase 1 ran from March 2016 to May 2017, during which time we:

1. Worked with our project partners (GNS Science) and external reviewers (TLAG[25]) to develop a conceptual model and a set of modelling inputs and assumptions
2. Built a numerical groundwater model which extended from the Ashley River/Rakahuri in the north to approximately 5 km south of the Waimakariri River, and from the foothills in the west to the Waimakariri zone coastline. The model was based on the set of agreed inputs and assumptions
3. Optimised the groundwater model against long term average stream and river flows and groundwater levels, such that model flows and water levels provided a reasonable approximation of measured data
4. Ran simulations with the model to assess flow paths and nitrate concentrations in our key receptors

The modelling results indicated that nitrate draining from intensively farmed land in some parts of the Ashley-Waimakariri plains could flow under the Waimakariri River and eventually cause a significant increase in nitrate concentrations in the Christchurch aquifer. We referred to this process as “interzone transfer”. In recognition of the significance of this modelled outcome and some of the limitations and data gaps in this first modelling phase, we initiated a second phase of modelling provide a more robust assessment of the potential for transport of nitrate from the Waimakariri zone into the Christchurch aquifer.

The main component parts of Phase 2 of modelling (undertaken between June and November 2017) were:

1. Identify critical gaps in information relating to the connectivity between the Waimakariri and Christchurch aquifer

[25] Technical Lead Advisory Group, particularly Peter Callander (PDP) – see Etheridge and Whalen (2019) for details

2. Appoint an expert panel to advise on and review our methods and findings
3. Meet with panel to discuss and agree upon critical gaps, investigation scope and method
4. Design and implement an extensive field investigation programme including installation of nine new wells, an extensive groundwater level survey and a groundwater quality sampling programme
5. Re-design and build the groundwater model
6. Convene an expert panel workshop to obtain views from the panel on inputs to the model, to ensure the suite of models could explore all conceptual models and parameters envisaged by the experts
7. Parameterise and calibrate a single groundwater model realisation[26] using expert panel knowledge in combination with the extensive archive of groundwater level, stream flow and aquifer property data held within our databases
8. Issue memos and convene meetings with the expert panel to explain and seek agreement on changes that needed to be made to the model for it to fit with observation data
9. Analyse all available data, including information obtained from the field investigation programme, and summarise in a series of memos for review by the expert panel
10. Hold an expert judgement workshop (27/10/17) using a formal elicitation framework to provide quantitative expert judgement-based estimates of the likelihood of interzone transfer (see Etheridge and Hanson 2019a for details). The expert panel were not shown any of the model results prior to this elicitation in order to ensure that they were not influenced by the modelled outcomes.
11. Finalise the model optimisation process to create a single model realisation which encapsulates expert knowledge and matches field observations within acceptable margins.
12. Implement a quantitative uncertainty analysis modelling process, which explores areas of the aquifer system in which we have no or limited information and creates thousands of different groundwater model parameter sets (or model iterations), which both encapsulate expert knowledge and fit observation data, to provide a tool by which the modelling results effects of our poor understanding of some aspects of the hydrological system can be explored. We discuss uncertainty analysis further in Section 3.6.
13. Run End Member Mixing MT3D transport simulations for ~2,000 model realisations to determine the modelled ratio of alpine river water to land surface recharge water in each realisation. Filter the model realisations using a “rejection sampling” approach, under which model realisations for which the model ratio of alpine river water to land surface recharge water falls outside of the likely range determined from stochastic EMMA in key receptors (Christchurch community water supply wells) were rejected. This left a suite of 165 model realisations to be used for predictive modelling.
14. Run steady-state model simulations with the 165 model realisations to assess the possible range of nitrate concentrations in key receptors.
15. Compare field data-based EMMA results to model results for those receptors not used in the original rejection sampling and develop clean water dilution scaling factors accordingly (see Section 3.9). We discuss our nitrate concentration modelling further in Section 3.6.

The expert panel comprised individuals from a range of backgrounds all of whom have extensive experience in the study area. They were:

- Four research scientists with previous and ongoing long-term research projects in the area (Scott Wilson & Jens Rekker [Lincoln Agritech], Lee Burberry [ESR] and Paul White [GNS])

[26] The groundwater model provides a receptacle for expert knowledge on the study area. We therefore worked closely with members of the expert panel to elicit their conceptual understanding of the groundwater system, and then incorporated this understanding into the model.

- Two consultants who between them provide consultancy services to a large proportion of the Waimakariri zone farming community and to Christchurch city stakeholders (John Talbot [Bowden Environmental], and Peter Callander [PDP])
- Environment Canterbury Groundwater Science staff (Carl Hanson, Zeb Etheridge[27])

As noted above, the model design and development process is explained in detail in Etheridge and Hanson (2019a). The model calibration and uncertainty analysis are presented in Hemmings *et al.* (2017) and Hemmings *et al*. (2018) respectively.

3.4.3 Groundwater modelling process outcome

In summary, the nitrate load modelling with quantitative uncertainty analysis and groundwater model design, development, optimisation, uncertainty analysis, rejection sampling and dilution ratio scaling process yielded a suite of 165 model realisations which met the following criteria:

- Encapsulated expert knowledge of the hydrological system, and retained this knowledge in the model unless the knowledge was inconsistent with measured data
- Were aligned (as closely as possible) with all measured water level, surface water flow, aquifer property and well log data
- Provided the appropriate ratio of low nitrate alpine river water to (relatively) high nitrate land surface recharge water in key receptors
- Provided a basis for evaluating groundwater flow paths, recharge zones and nitrate concentrations in key receptors in both the Waimakariri Zone and the Christchurch aquifer and quantified the uncertainty associated with these model projections.

3.4.4 Modelling domain exclusions

The Waimakariri River, Ashley River/Rakahuri and Te Aka Aka were not fully included in our numerical model domain. This was partly because incorporation of the full extent of these large catchments in the model would have been impractical and partly because nitrate transport to these waterbodies via overland and quickflow is important but not readily accounted for in a groundwater model. We therefore used a different nitrate modelling process for these waterbodies, as discussed in Section 3.6.2. We discuss the implications of using a modelling approach which excludes overland flow and quickflow in Section 3.8.

3.5 Transport pathways and recharge zone modelling

Determination of the likely recharge areas for our key receptors (e.g. Silverstream, community water supply wells) is required as a precursor to determination of the nitrate management actions required to achieve some of the WWZCs Priority Outcomes (Section 1.1).

We ran forward and backward particle tracking simulations using the MODPATH utility for the suite of 165 steady state model realisations. Etheridge and Hanson (2019a) provide a detailed explanation of this modelling process and how modelling results were applied. We discuss the issues associated with use of a steady state model for particle tracking in Section 3.10. Particle tracking results provided an indication of the likely recharge area for each receptor within our study area, which comprised:

- The main spring-fed streams in the Waimakariri zone
- Private water supply wells, grouped into 18 geographic areas (with some areas split into deep wells and shallow wells – discussed further below)
- 12 of the main Waimakariri District Council community water supply wells
- The Christchurch aquifer, split into three depth zones and six geographic areas

Because the Waimakariri River, Ashley River/Rakahuri and Te Aka Aka were not fully included in our numerical model we used the following approach to model them:

[27] Provided expert judgement in first two workshops, facilitated final workshop

1. Waimakariri River:
    a. Use groundwater model (particle tracking) to evaluate areas of land on north side of Waimakariri River which are likely to discharge groundwater to the river
    b. Nitrate loads in Waimakariri River losses to aquifer and in stock and irrigation race losses to ground were excluded from the model (these are insignificant relative to the very high nitrate loss rates from agricultural land here)
2. Ashley River/Rakahuri:
    a. Assume all nitrate load from hydrological catchment above Ashley Gorge discharges to the Ashley main stem
    b. Assume all nitrate load from the Loburn Fan hydrological catchment discharges to the Ashley main stem
    c. Use groundwater model (particle tracking) to evaluate areas of land on south side of Ashley River/Rakahuri which are likely to discharge groundwater to the river
    d. Account for nitrate load discharge to ground in lower Ashley River/Rakahuri reaches, where ~5 m^3/s of water loss has been estimated (these are more significant given the relatively low intensity of land use in the Ashley River/Rakahuri catchment)
3. Te Aka Aka:
    a. Use Saltwater Creek hydrological catchment and groundwater recharge catchment (defined via particle tracking) as a basis for estimating Saltwater Creek nitrate influx to estuary
    b. Evaluate extent of hydrological catchment for eastern part of estuary on the north bank and calculate nitrate load from this land
    c. Sum nitrate loads from Ashley main stem, Waikuku Stream, Taranaki Creek, Saltwater Creek and additional recharge area to north of estuary to determine total estuary N load

3.5.1 Waimakariri zone surface water recharge areas

Our groundwater recharge areas for the Waimakariri surface water courses based on particle tracking results are plotted in Figure 3-3. We note the following:

- The size of the recharge zones partly reflects the uncertainty range in the particle tracking results (Etheridge and Hanson, 2019a), with the recharge zone spatial extents being greater than the land area required to provide for a recharge rate commensurate with the measured stream flow rates (i.e. if the recharge zone area is multiplied by the average land surface recharge rate in the zone, the resultant flow volume would be greater than the measured stream flow volume). The size of the recharge zones also reflect stream flow rate, with larger streams requiring larger recharge areas to achieve the given flow rate.
- Some recharge areas overlap due to modelling uncertainty
- We do not expect all of the water draining from these areas to discharge to the surface water course in question. The purpose of the zones is to evaluate where nitrate management actions are most likely to impact nitrate concentrations in each surface water course. This also applies to the private water supply area, community water supply well and Christchurch aquifer recharge areas discussed below.

The surface water recharge zone gap in the inland plains area provides recharge to the Christchurch aquifer system and to some community and private water supply wells in the Waimakariri zone, as shown in subsequent sections of this report.

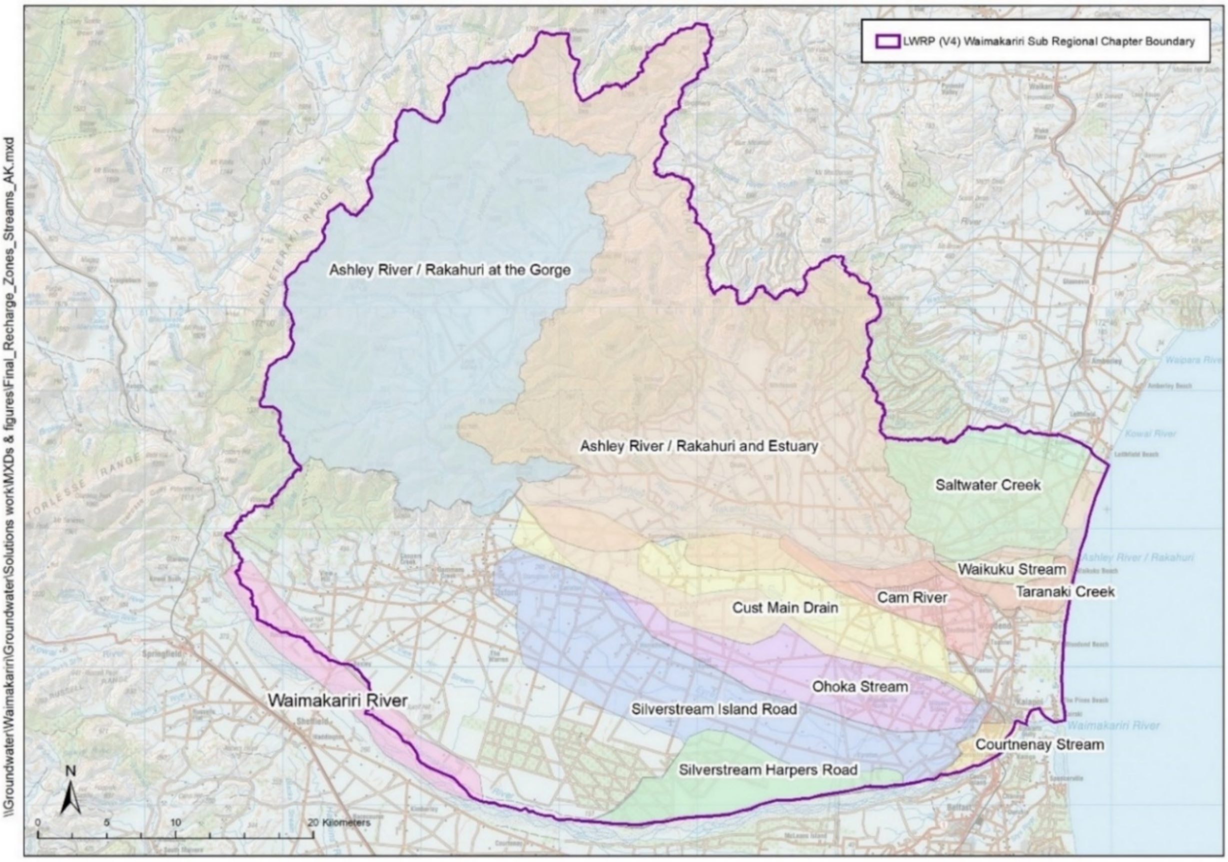


Figure 3-3: Modelled groundwater recharge zones for surface water courses (Waimakariri Northern Tributaries) and surface water and groundwater contributing catchments (Ashley Tributaries)[28]

3.5.2 Private Water Supply Areas (PWSA)

We divided the private water supply wells south of the Ashley River into 18 private water supply well areas (PWSA) as shown in Figure 3-4. The total number of private wells covered by the PWSAs is ~2,640. As discussed in section 2.3.1 and 2.3.5 groundwater nitrate concentrations in the Ashley River/Rakahuri catchment (which includes the Kowai, Loburn and Ashley GAZs) is generally below ½ MAV, with 70% of the sampled groundwater wells having maximum concentrations below 1.0 mg/L. Also, only 6% of all the private water supply wells in the Waimakariri Zone are located in this catchment. Therefore we have excluded most of the private wells north of the Ashley River/Rakahuri from the PWSAs and our nitrate assessment. Appendix 5 gives an overview of the number of wells in each PWSA and the estimated median nitrate concentration for each based on available groundwater samples in our database.

We modelled median nitrate concentrations on a PWSA basis because:

a) it would be impractical to model nitrate concentrations in each individual private water supply well; and
b) because our modelling resolution did not align with fine scale analysis of the individual private water supply well order.

[28] Recharge zone files can be found here: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Final Recharge Zones\SW Recharge Zones. Ashley River at Gorge is Lees Valley GAZ (GISPUBLIC.DBO.pLWRP_V7_GroundwaterAllocationZones) and Ashley River and Estuary is Major Ashley Catchment (GIS.DBO.CATCHMENTS_NZTM_CatchmentsMajor)

Although we did not explicitly model the Eyrewell PWSA, modelling results for the Eyreton PWSA, located immediately downgradient, are likely to provide a suitable proxy and were therefore used here.

The modelled recharge areas for the PWSAs are shown in Figure 3-5. As per the spring-fed streams, there is significant overlap for some of the PWSA recharge areas due to modelling uncertainty. The large extent of some of the recharge areas reflects both modelling uncertainty and the spatial extent of the PWSA area itself.

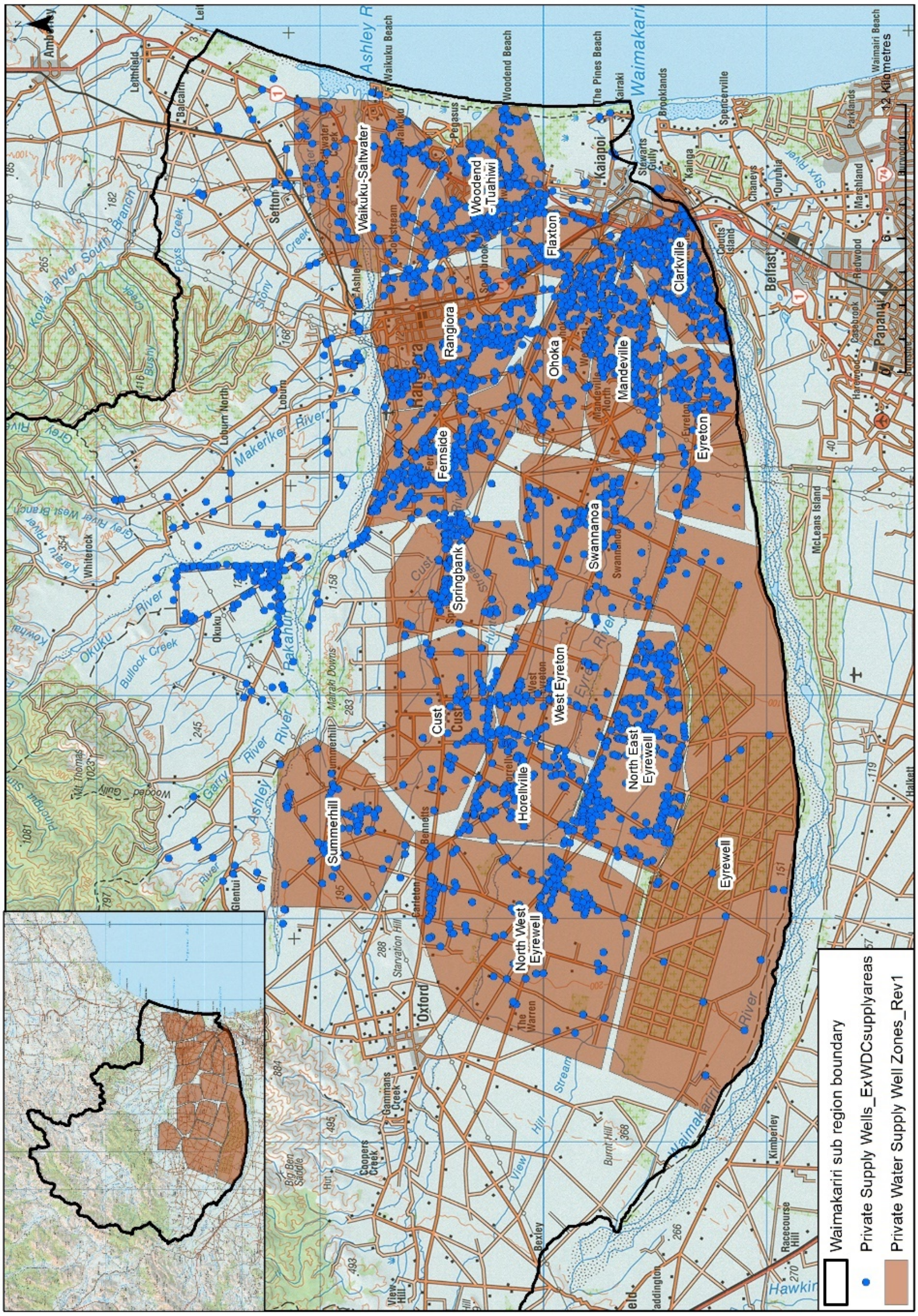
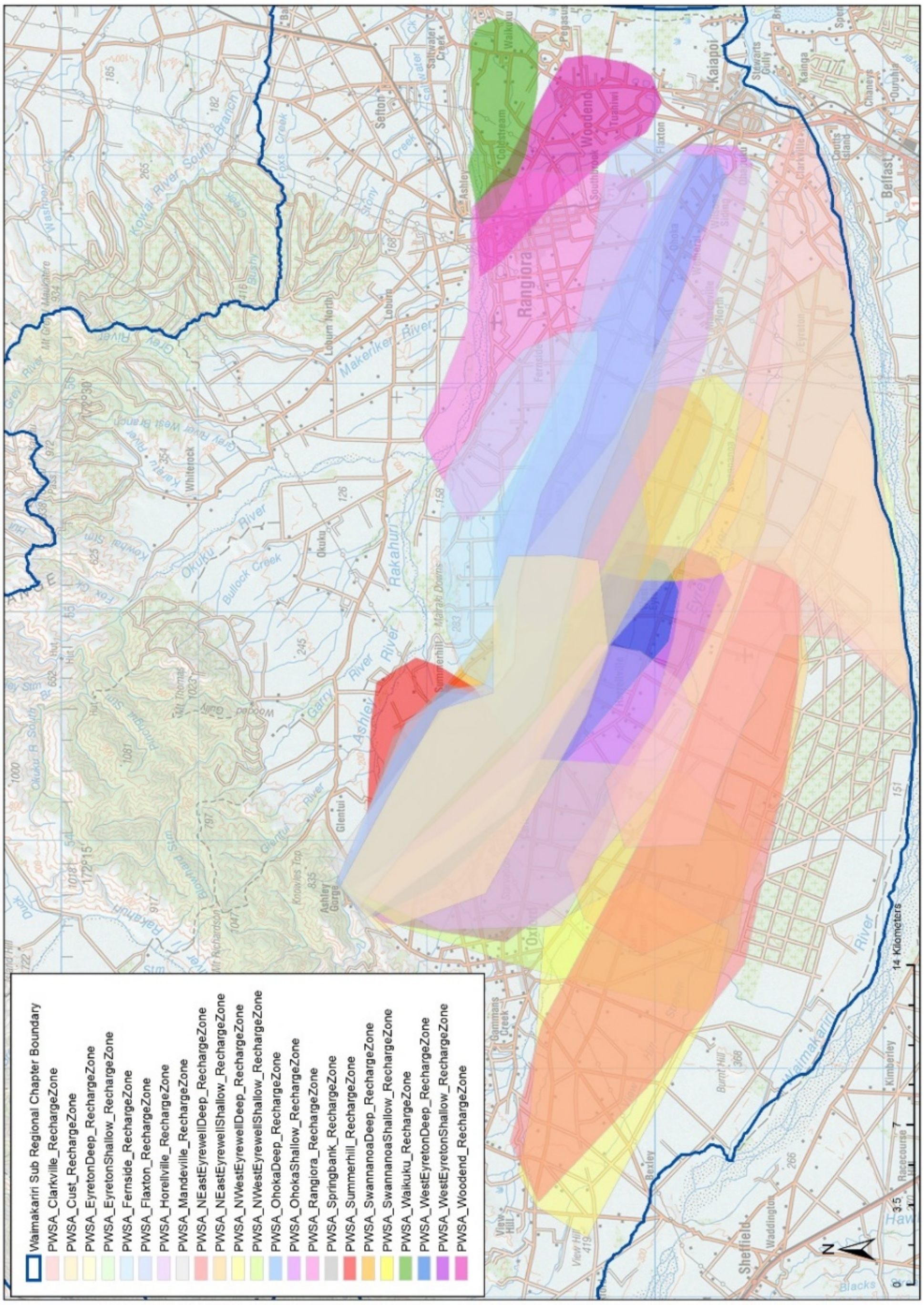


Figure 3-4: Private Water Supply Areas used in the groundwater model



\\Groundwater\Waimakariri\Groundwater\Solutions work\MXDs & figures\Final_Recharge_Zones_PWSA_AK.mxd

Figure 3-5: Modelled recharge zones for Private Water Supply Areas (PWSA)

3.5.3 WDC community water supply wells

We modelled 12 of the 16 Waimakariri District Council community water supply wells specifically and one implicitly[29]. The Oxford Rural 2 supply area is now sourced from Oxford Urban wells and the Summerhill supply area is now sourced from the Eyreton well (see Appendix 1). Of the remaining two supplies, Oxford Rural 1 and Garrymere are gallery wells adjacent to the Waimakariri and Ashley River/Rakahuri respectively (and are hence dominated by surface water, rather than groundwater, nitrate concentrations). These four water supplies are therefore excluded from the groundwater model assessments and don't have established (separate) groundwater recharge areas. Although Oxford Rural 1 is sourced from the Rockford Road deep well (since 2016), this well only supplies ~30% of the schemes current demand (Waimakariri District Council, 2018c), and was not included in our assessments.

As described in section 2.3.3, the Ashley Rural Water Scheme is administered by the Hurunui District Council and is effectively a surface water take. This water supply is therefore also excluded from the groundwater model assessments.

We have plotted the results of the MODPATH particle tracking-based recharge areas for the 12 WDC community supplies in Figure 3-6. As can be seen from this map, the recharge zones for the supply wells in the coastal area are disconnected from the wells, e.g. there is a gap between these wells and recharge areas for these wells. This is because these supply wells are located in the so called Coastal Confined Gravel Aquifer System, which means there are confining layers between the screens of the wells and the ground level. These confining layers restrict recharge in the vicinity of the wells and therefore the recharge areas for these wells are located at some distance from the wells where confined layers are absent.

3.5.4 The Christchurch aquifer

For modelling purposes we have divided the Christchurch aquifer into five community water supply areas (see Figure 3-7). The purpose of this somewhat arbitrary delineation is to provide an indication of how modelled nitrate concentrations vary spatially across the city.

In this technical report we will focus on the nitrate concentrations for the deep Christchurch aquifers (> 120 m) in three areas: *Western Christchurch, Central Christchurch and Eastern Christchurch* (see areas outlined in red in Figure 3-7). As explained in Etheridge and Hanson (2019a) it is the deep Christchurch aquifers that are likely to be recharged by groundwater originating from north of the Waimakariri River. Because offshore coastal discharge from the Christchurch aquifer is considered to be limited, the main outflows from the deep aquifer are groundwater abstraction and upward seepage of artesian water into the shallow aquifer system and thence spring-fed streams (e.g. the Avon River/Ōtākaro).

We used particle tracking to evaluate the likely recharge area for the deep Christchurch aquifer. We used a broad definition of the deep Christchurch aquifer (see "Interzone receptor area" in Figure 3-7 and Figure 3-8) in recognition of both the parts of the aquifer that are currently used for community water supply and the areas that could potentially be used for community supplies in the future. We have plotted the results of the particle tracking and associated recharge zone delineation in Figure 3-8 below. The results show that water infiltrating from a significant area of land (~34,000 ha) north of the Waimakariri River could drain into the Christchurch aquifer system. We have encapsulated this area within the Interzone Transfer Source Area polygon in Figure 3-8.

It is important to note that not all of the water infiltrating from land within the Interzone Transfer Source Area is expected to flow towards Christchurch, only some proportion of that water. Some of the water will be abstracted by wells within the Waimakariri zone, and some will follow pathways to Waimakariri zone spring-fed streams. The interzone source area therefore overlaps with the recharge areas we have delineated for some of the streams and wells within the Waimakariri zone (see section 3.5.2 and

[29] The results from the Pegasus wells were used as a proxy for the Woodend supply

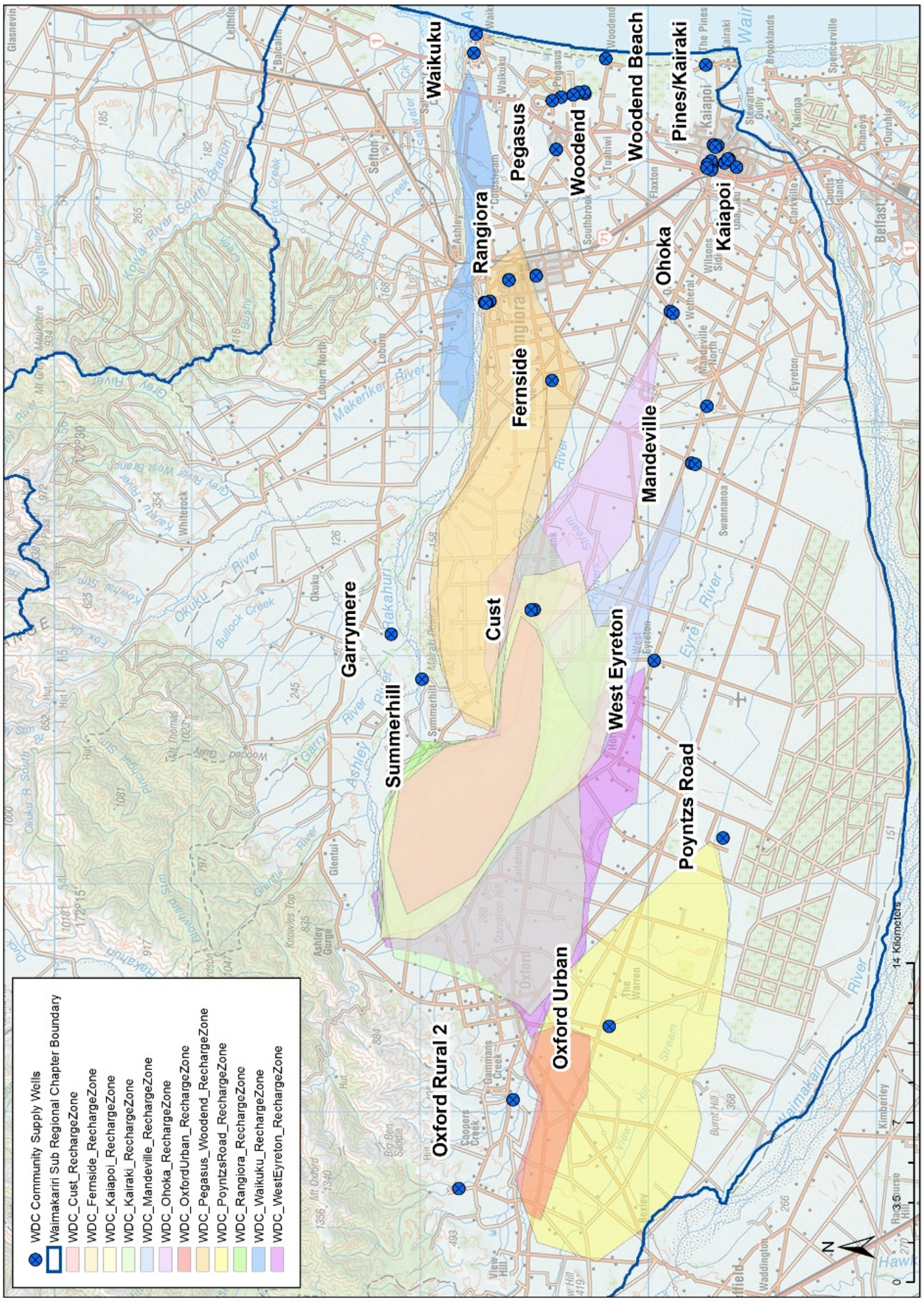
3.5.3). It was not possible[30] to delineate those parts of the Waimakariri zone in which a certain minimum proportion of the water is likely to drain towards Christchurch.

A number of the model realisations (less than 50% of the 165 total) indicate that some of the water infiltrating from land outside of the Interzone Transfer Source Area could flow into the Christchurch aquifer system. We have not included these areas within the delineated source zone because our analysis suggests that there is a low likelihood of this wider area contributing a significant proportion of its infiltration to Christchurch. The particle tracking results suggest that infiltration from land in the Springfield and Russells Flat area (west of the interzone) is likely to flow into the Christchurch aquifer system. The pathway for this is likely to be via the Waimakariri River. Any nitrate in this drainage water will be diluted significantly in the river.

It is noteworthy that the western boundary of the Christchurch-West Melton CWMS zone on the south bank of the Waimakariri River aligns closely with our groundwater modelling results. The CWMS zone boundary was based on previous analysis of shallow aquifer groundwater level data, and represents an inferred groundwater divide between the Christchurch and Selwyn Te Waihora aquifer systems. Although our recent groundwater modelling was based on a larger dataset and more recent information, the similarity of groundwater divide locations inferred from these two sets of information shows that our understanding of flow pathways in the shallow Christchurch aquifer system has not changed fundamentally.

Some of the irrigation and stock water race network outside of the delineated source areas (e.g. in Carleton/Bennetts area) is included within the high likelihood modelling results. This is a function of the modelling method, and can be ignored. Likewise, the area of land adjacent to the foothills north of Oxford, which is shown as being a recharge area for Christchurch in a high number of model realisations, is likely to be a modelling artefact associated with the boundary delineation.

[30] Within current time and information constraints



\\Groundwater\Waimakariri\Groundwater\Solutions work\MXDs & figures\Final_Recharge_Zones_WDC_Supplies_AK.mxd

Figure 3-6: Modelled recharge zones for WDC Community supply wells

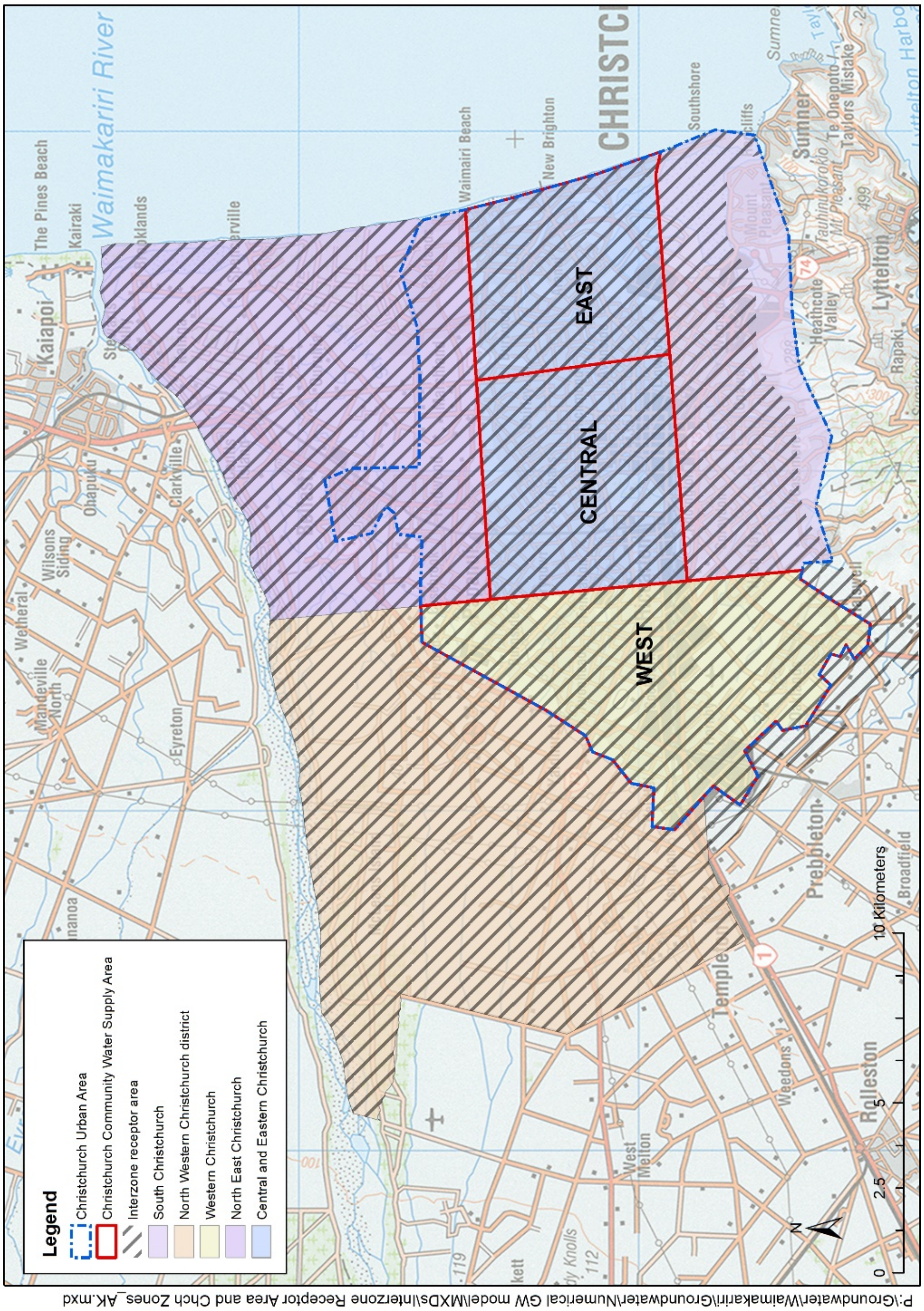
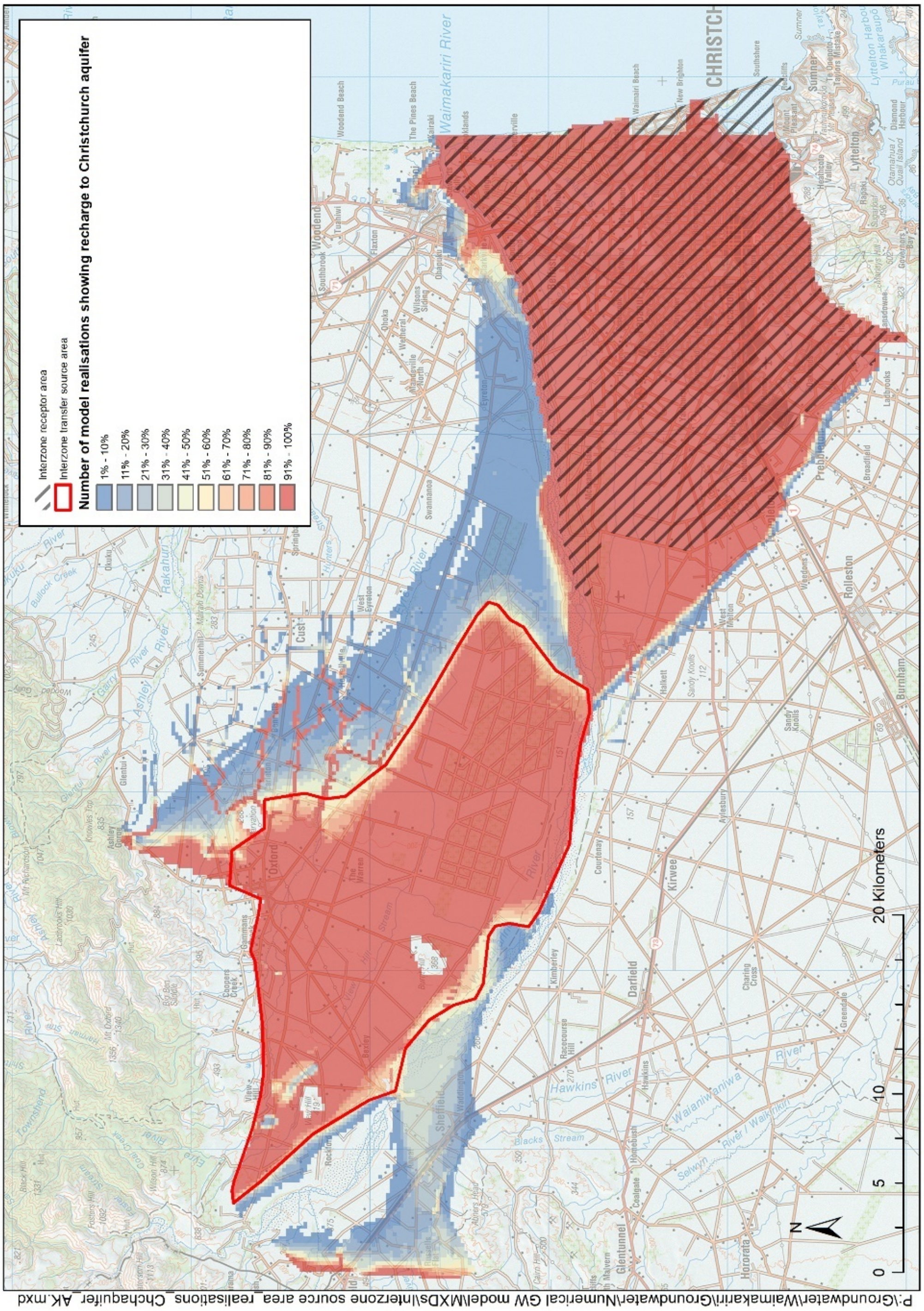


Figure 3-7: Christchurch community water supply areas as used in groundwater model



P:\Groundwater\Waimakariri\Groundwater\Numerical GW model\MXDs\Interzone source area_realisations_Chchaquifer_AK.mxd

Figure 3-8: Interzone transfer source area

3.6 Nitrate concentration modelling with quantitative uncertainty analysis

3.6.1 Methodology for receptors within model domain

Our model domain (and hence numerical model results) cover most of the WDC community water supply wells, the Waimakariri zone spring-fed streams and the Christchurch aquifer (not including the Christchurch spring-fed streams). Our modelled nitrate concentrations for these receptors are an estimate of what the true nitrate concentration will be under a given scenario under steady state conditions (see explanation below), and are subject to uncertainty. This uncertainty is created by:

- Uncertainty in the OVERSEER® modelling of nitrate loss rates from the soil profile
- Groundwater modelling uncertainty

Our quantitative uncertainty modelling yielded a nitrate concentration probability density function for each of the key receptors (Section 3.5) by using the standard error propagation method to combine the nitrate loss rate uncertainty (Section 3.3.2) and the groundwater modelling uncertainty (Section 3.4.2).

It should be noted that our nitrate concentration modelling uncertainty estimates are themselves also subject to some uncertainty because we do not have enough information to precisely quantify the level of uncertainty around all inputs to the model. The structure of our model is a gross simplification of the complex real world hydrological system and we were unable to simulate some of the biophysical processes such as nitrate attenuation. Nitrate attenuation is possible in the anoxic parts of the aquifer system with groundwater, for instance (as discussed previously in section 3.4.2) and this has not been considered in our modelling within this report because we cannot currently quantify it or determine whether it is likely to be a significant factor. Uncertainty about the uncertainty is referred to as second order uncertainty. We do not discuss this second order uncertainty in this document, but it is important to be aware that when we say there is a 95% probability for a given model result, for instance, the true level of certainty could be less (or greater) than the estimated probability.

Our stochastic modelling approach allows us to present the nitrate modelling results in terms of the percentage likelihood that the true value will be less than the modelled value. The 50th percentile is the middle point in the range of our modelling results, for instance. There is a 50% probability[31] that the true nitrate concentration will be higher than this modelled value and a 50% probability that the actual nitrate concentration will be lower. Further explanation is provided in Table 3-1 below.

Table 3-1: Explanation of model percentiles

Model results percentile	Probability that actual nitrate concentration will be **lower**	Probability that actual nitrate concentration will be **higher**
5th percentile	5%	95%
Median (50th percentile)	50%	50%
95th percentile	95%	5%

Because our groundwater model was run as a “steady state” simulation, the outputs of the model reflect conditions once nitrate concentrations in groundwater and surface water have reached equilibrium with the inputs (i.e. nitrate losses from the soil profile). We discuss this further in relation to groundwater age in Section 3.7.

We did not provide nitrate concentration results for the Cust River, relying instead on the Cust Main Drain as an integrator of nitrate in the Cust River and Cust Main Drain catchment.

[31] Noting the second order uncertainty discussed above

3.6.2 Method for Waimakariri River, Ashley River/Rakahuri and Te Aka Aka

We explained previously that the Waimakariri River, Ashley River/Rakahuri and Te Aka Aka were not fully included in our groundwater model and that we used a different nitrate modelling method for these receptors. Our uncertainty quantification method is summarised below.

Waimakariri River
Because we have not modelled N loads for the whole Waimakariri River catchment we used the following method for our nitrate scenario modelling:

- Roughly estimate Waimakariri River N loads at Gorge and SH1 monitoring sites using the mean annual flow (125 m^3/s) and the 15 year average nitrate concentration for samples collected at these two sites (~180 and 480 tonnes/year respectively)
- Calculate the N load for land within the Waimakariri Zone which is likely to drain into the Waimakariri River (see Section 3.5) for each nitrate management scenario
- Express the latter as a percentage of the former to show the scale of impact of Waimakariri zone-sourced nitrate on the Waimakariri River

Ashley River/Rakahuri
Although our groundwater model domain only included the Ashley River/Rakahuri between Ashley Gorge and the coast, and did not include the northern tributaries (e.g. Okuku River), our nitrate load layer covered the whole Ashley River/Rakahuri catchment. Our initial nitrate concentration modelling approach for the Ashley River/Rakahuri was therefore as follows:

- Use the catchment areas described in Section 3.5 (in conjunction with hydrological catchment for hill country areas where appropriate) in combination with the N load layer to evaluate N loads in the river at the Ashley Gorge[32] and SH1 monitoring sites
- Translate N loads into concentrations using flow monitoring records from these sites

However, our model validation (see Section 3.9) showed that the modelled N loads were significantly higher than measurement-based estimates. Although there is likely to be some lag between land use change and equilibrium nitrate concentrations in the Ashley River/Rakahuri (see Section 3.7 for discussion), we do not consider that this is likely to be a significant factor. Further analysis of the assumptions used to generate nitrogen load estimates from low intensity hill-country land use revealed that our model was likely to be overestimating N loads from the extensive areas of this land within the Ashley River/Rakahuri catchment. We therefore applied a 0.55 scaling factor to model loads in order to bring them into closer alignment with measurement-based loads for the highest N load year within our recent monitoring records. We discuss this further in Section 3.9.3.

The Ashley River/Rakahuri spring-fed streams (Taranaki Creek, Waikuku Stream and Saltwater Creek) were included in our model domain, but our model validation for these watercourses also showed a significant mismatch between model and measured data, which could not be attributed to lag times (which are likely to be <5 years – see Section 3.7). We therefore assumed that measured stream nitrate concentrations in these watercourses have equilibrated with current N load inputs from land within their catchments, and used the scaling factors commensurate with this assumption to adjust our model results for the nitrate load/management scenario N loads we modelled (discussed in Section 3.3).

Te Aka Aka
Nitrogen inputs to Te Aka Aka comprise the Ashley River/Rakahuri loads and spring-fed stream loads, which were modelled as above, plus the additional catchment area to the north of the estuary discussed in Section 3.5.1. We used the stochastic N load layer data generated via the method described in Section 3.3 to develop a probability density function of nitrate loads for the estuary. Bolton-Ritchie (2019b) explains the methodology she adopted to evaluate the eutrophication susceptibility of Te Aka Aka, using the nitrate load data in conjunction with the Estuarine Trophic Index (ETI) tool and the CLUES (Catchment Land Use Environmental Sustainability) Estuary tool (Dudley and Plew, 2018). Our model validation for Te Aka Aka (Section 3.9) showed that the median model results equated to a much

[32] Data: P:\Groundwater\Waimakariri\Current Pathways and Solutions N results\Current Pathways Results Spreadsheets\AshleyGorge_NResults.xlsx

higher level of eutrophication than that recorded in the recent field surveys undertaken by Bolton-Ritchie (2019b). The Ashley River/Rakahuri N load is the main component of the Te Aka Aka N load. A possible explanation for the lack of alignment between field observations and modelling results, therefore, is that that much of the Ashley River/Rakahuri N load could be carried offshore with a very limited estuary residence time and thus limited opportunity for macro-algal uptake. Detailed modelling of the estuarine dynamics would be required to resolve this uncertainty, as discussed in Bolton-Ritchie (2019b) and in Appendix 10. We found that our 5th percentile model results were more closely aligned with field survey results, and therefore used these in our scenarios modelling.

3.7 Groundwater age and lag-times

There is a lag in time between nitrogen leaching into the soil in one area and the increased nitrate concentrations ending up in a groundwater receptor downstream. This means that even when nitrogen leaching at the source is reduced, there is still nitrate "in the post", e.g. on its way to a receptor due to the time it takes to travel. Understanding groundwater travel times between the soil root zone and our key receptors helps us to address several important questions:

- Whether the effects of land use intensification are apparent in our water quality monitoring results. For instance, has some or all of the additional nitrate load from a given dairy conversion reached the downgradient spring-fed stream yet?
- How long will it take for our steady state modelling projections to be realised?
- How long will it take to before we see the water quality improvements associated with changes in land and water management practices?

Analysis of groundwater age data obtained by environmental isotope residence time determination helps us to answer these questions. The most commonly applied techniques to infer groundwater age use environmental tracers, such as the man-made gaseous compounds chlorofluorocarbons (CFCs) and sulphur-hexafluoride (SF6), or tritium and carbon 14. These tracers can be used to infer groundwater age due to their time-dependent input to the groundwater system via recharge and/or due to their time-dependent alteration by processes such as radioactive decay (Beyer *et al.,* 2014).

Groundwater drawn from a well or discharged to a spring-fed stream usually comprises a mixture of water of different ages. We refer to this as the *age distribution*. Part of the water has often moved slowly through the finer-grained, less permeable parts of the aquifer and is therefore older, whereas other parts have travelled more quickly through the most transmissive parts of the aquifer (e.g. the open framework gravels of former river channels) and is therefore younger. It is therefore useful to consider groundwater age in the following terms:

- Young fraction: this is the percentage of water in a well or stream sample which is less than a few years old (typically one year). If a water sample has a high fraction of water less than a few years old we would expect nitrate from land use intensification to start to arrive at the well or stream fairly quickly.
- Mean residence time, or mean age: this is the average age of water in a stream or well sample. This is the metric most commonly used when discussing groundwater age. Again, a young mean residence time would indicate that the effects of land use change on measured nitrate concentrations should start to be seen relatively quickly.
- Maximum age: this is the age of the oldest fraction of water in a sample. Knowledge of the maximum age allows us to understand how long it will take for nitrate concentrations in a stream or well to equilibrate with nitrate discharges from the land, but this knowledge is often lacking.

Whilst mean groundwater age can be evaluated with a reasonable degree of certainty if enough samples have been collected over a long period, determining the age distribution (e.g. young fraction and maximum age) is more challenging. Age distribution is typically estimated via mixing models that interpret isotope-derived age estimates; the choice of model and assumptions made when using that model can result in a wide range of estimates of the age distribution of a water sample. Age distribution can also vary significantly over time: water in a spring fed stream may comprise a high old water fraction after an extended dry period and a significant young fraction component after a wet period.

Because our knowledge of the age distribution of water in our key receptors is generally very limited we have used average groundwater age (mean residence time) as an indicator of lag-time. This assumption is likely to underestimate lag times to some degree, with the degree being dependant on the skewness and Standard Deviation of the age distribution. We compensated for this to some degree for the Kaiapoi River catchment spring-fed streams by using a 10 year lag time, which is longer than the likely mean residence time for most these waterbodies. The modelled aged distribution for these spring-fed streams is also strongly skewed towards younger ages, with a significant proportion of the water estimated to be <10 years old. (See GNS, 2016).

We have summarised our lag time estimates and the information sources upon which these were based in Table 3-2 and included more background information on groundwater age investigations and age distribution in Appendix 6.

Table 3-2: Mean lag times for drinking water and surface water

Receiving water body	Source	Lag time (years)
Private water supply wells	Van der Raaij, R.W. 2011. Age determination and hydrochemistry of groundwater from the Ashley – Waimakariri Plains, Canterbury, New Zealand. GNS Science Report 2011/02, 73p.	7-88
WDC community supply wells	Van der Raaij, R.W. 2011. Age determination and hydrochemistry of groundwater from the Ashley – Waimakariri Plains, Canterbury, New Zealand. GNS Science Report 2011/02, 73p.	6-100
CCC community supply wells	Stewart, M.K., 2012. A 40-year record of carbon-14 and tritium in the Christchurch groundwater system, New Zealand: Dating of young samples with carbon-14. Journal of Hydrology 430-431, p. 50-68.	200-1200
Waimakariri Northern Tributaries catchment and spring-fed streams	Van der Raaij, R.W. 2016. Tritium results and residence time interpretations for spring-fed streams in the Waimakariri Water Management Zone. GNS Letter report CR2016/99 LR	10
Ashley River/Rakahuri tributaries and spring-fed streams	Van der Raaij, R.W. 2011. Age determination and hydrochemistry of groundwater from the Ashley – Waimakariri Plains, Canterbury, New Zealand. GNS Science Report 2011/02, 73p. (shallow wells sampled near these watercourses)	<5

Numerical groundwater modelling could, in theory, have been used as an alternative approach for assessment of lag times. Some of the fundamental issues of age determination through groundwater modelling, however, are the requirement for information on the effective porosity of the aquifer (for which no local information is available) and the significant technical challenges associated with simulation of a dual porosity aquifer system[33]. These issues are compounded by uncertainties over aquifer hydraulic conductivity and recharge rates. Although it is possible to apply a range of effective porosity values (based on literature data) and a range of hydraulic conductivity values and recharge rates to a single porosity model (as per the model used in this study), the output of such modelling would be a crude estimate of the possible range of average groundwater ages in a given receptor. This output does not address the key lag time question, which relates to the time taken to reach steady state rather than the time taken to get half way there (as per the average age). Groundwater age estimates obtained from age tracer data are sometimes used to "calibrate" the model effective porosity value. The benefits of this approach over using the age tracer-based groundwater age estimates directly are questionable.

[33] Previous studies, e.g. Dann *et al.* (2008) have shown that the Canterbury aquifers behave as a dual porosity system. This means that whilst a significant proportion of the total aquifer throughflow often occurs through buried river channels comprising open framework gravels, the remainder of groundwater flow is through much lower permeability sediments. This creates multi-order of magnitude variabilities in groundwater transport velocities with associated wide groundwater age distributions. Our knowledge of the structure and hydraulic properties of this system is very poor, and large scale numerical simulation of dual porosity aquifers, even when these are well characterised, is challenging.

3.8 Nitrate scenario modelling methodology and assumptions

In Sections 4 and 5 we explain how we modelled various nitrate management scenarios to support the WWZC's decision-making process and to assess the extent to which implementation of the ZIPA recommendations are likely to achieve the Priority Outcomes. We used the following method and made the following assumptions during that modelling:

1. Our modelling assumes that nitrate transport through the aquifer is the predominant pathway between source (e.g. agricultural land) and receptor (e.g. spring fed streams). This is valid in the case of wells and spring-fed streams but is less true in the case of hill-fed rivers and streams (e.g. Ashley River/Rakahuri, Cust River), into which nitrate transport through overland and quickflow pathways are often more dominant. Incorrect representation of transport pathways in our modelling results is unlikely to compromise the results significantly, however. This is partly because our model results represent steady state annual medians[34] (and hence the nitrate concentration temporal variability associated with differing transport pathways is not important) and partly because we assume no nitrate attenuation in groundwater.
2. We have not accounted for instream nitrate uptake and hyporheic nitrate attenuation. We do not consider instream uptake to be an attenuation mechanism per se, because instream uptake and the associated macrophyte and periphyton growth are an effect rather than a mitigation factor. Given the high nitrate concentrations in many of the Waimakariri zone spring-fed streams, in-stream uptake is unlikely to increase if nitrate concentrations continue to increase in the future in any case. Arthur *et al.* (2019) conclude that hyporheic nitrate attenuation is unlikely to be significant.
3. Nitrate losses below the root zone were estimated for each scenario (See Lilburne *et al.,* 2019) and subsequently used to model nitrate concentrations in surface and groundwater. The uncertainties behind these estimations are explained in section 3.3.2.
4. When modelling Permitted Activity winter grazing threshold scenarios (see Section 4.4.3) we assumed that, in addition to the assumptions discussed in Lilburne *et al.* (2019), which account biophysical constraints for small block winter grazing, no new consents will be granted for winter grazing or irrigation in catchments where groundwater or surface water nitrate concentrations either currently exceed the recommended nitrate limits or are expected to do so in the future, after accounting for lag effects. We also applied this assumption to the Te Aka Aka catchment, given the sensitivity of this waterbody to additional nitrate discharges. Although in reality consents for winter grazing could be granted, the total nitrate loss from a property would need to be maintained within the 2009-2013 GMP Baseline (as specified in the LWRP) in the majority of cases; this would achieve the same end result, of minimising the potential for additional nitrate discharges to sensitive water bodies.
5. We have presented some of our nitrate modelling results as plots of nitrate concentrations over time. In order to produce these plots using currently available data (which comprises current annual median nitrate concentration estimates, modelled steady state concentrations and the estimates of mean residence time discussed above) we assumed a simple linear rate of change between current measured nitrate concentrations and the modelled steady state nitrate concentrations for the GMP and Current Pathways Scenarios (see 4.6.2). Our linearity assumption implies a uniform groundwater age distribution which is highly unlikely to be the case in reality. The actual age distribution for each receptor is unknown and likely to be variable both between receptors and over time. The outcome of these factors is that actual nitrate concentrations are unlikely to follow the modelled time series data. Nonetheless, we consider that the time series plots still provide useful information if used in the way we intend: to make an estimated comparison between nitrate concentration results for different scenarios . We discuss this further in Section 4.6.
6. Given our assumed uniform groundwater age distribution, our model results show relatively fast initial reductions in nitrate concentrations. This assumption also means that peak nitrate concentrations are always lower when N loss reductions are applied than they are otherwise, even in receptors with long mean residence times.

[34] Based on a gaussian distribution assumption, i.e. mean = median

7. The year by which steady state nitrate concentrations will be reached is assumed to be the full implementation date of a given nitrate management scenario (e.g. GMP by 2025) plus the lag-time specified for that receptor (See section 3.7 for the specified mean lag-times). If the a significant proportion of the water is older than the mean residence time (e.g. if the mean residence time is 10 years and 30% of the water is more than 20 years old), this approach will underestimate the time taken for actual nitrate concentrations to reach the modelled steady state concentration.
8. For the Alternative Pathways scenario 'Beyond Baseline GMP' N loss reduction rates (see Section 4.6.3) we have calculated the reduction in the nitrate concentration for each receptor per 10-year stage with our steady-state groundwater model. We assumed the first stage of the Alternative Pathway is implemented at the same time as GMP. This is a best case approach. A delay in implementation would mean that reductions in nitrate concentrations would also be delayed. This scenario does not exclude low nitrate emitters – e.g. all dairy farms reduce nitrate losses at the rates assumed for this scenario, regardless of how low their N loss rate might be. It takes Current Pathways modelling results as the starting point for the Beyond Baseline GMP reductions.
9. The calculated 10-year stage reduction is applied as a *linear reduction* until the zone committee target for that location has been reached.
10. We used a slightly different method for our Solutions Package modelling; we discuss this in Section 5.4.

3.9 Validation of model results

3.9.1 Alpine river/land surface recharge water dilution ratio

We explained earlier (Section 3.4.2) that we used an EMMA-based rejection sampling method to optimise our stochastic groundwater modelling to the range of low nitrate alpine river water dilution ratios inferred from our groundwater sampling data. The rejection sampling[35] was focused on data from Christchurch water supply wells in recognition of the importance of these receptors for Christchurch City. We therefore needed to validate the model dilution ratio for receptors north of the Waimakariri River, e.g. Silverstream and the Kaiapoi and Rangiora community water supply wells. We did this by comparing field data-based EMMA results to model-based EMMA results for the same receptors. Where the model ratio of (low nitrate) alpine river water fell outside of the likely range determined from field data, we used a scaling factor to adjust model nitrate results so that the appropriate amount of dilution was accounted for. The field-data based EMMA analysis for Silverstream at Harpers Road, for instance, gave a median of 23% alpine river water. Our numerical modelling-based EMMA analyses yielded an alpine river percentage of between 60-95%[36] (Figure 3-9). Model simulations with this very high alpine river component caused a significant underestimate of N concentrations in the Silverstream (model: 1-6 mg/L, current measured long-term median: 7.4 mg/L). To correct this defect, we built a linear regression between the modelled nitrate concentrations and the modelled alpine river component in each receptor with a significant modelled alpine river component (as per Figure 3-9). We used this regression equation to scale the modelled nitrate concentration using the alpine river component inferred from measured data.

[35] Under rejection sampling, model realisations for which the model ratio of alpine river water to land surface recharge water falls outside of the likely range determined from stochastic EMMA in key receptors (e.g. Christchurch community water supply wells) were rejected, as explained previously

[36] 5^{th} to 95^{th} percentile

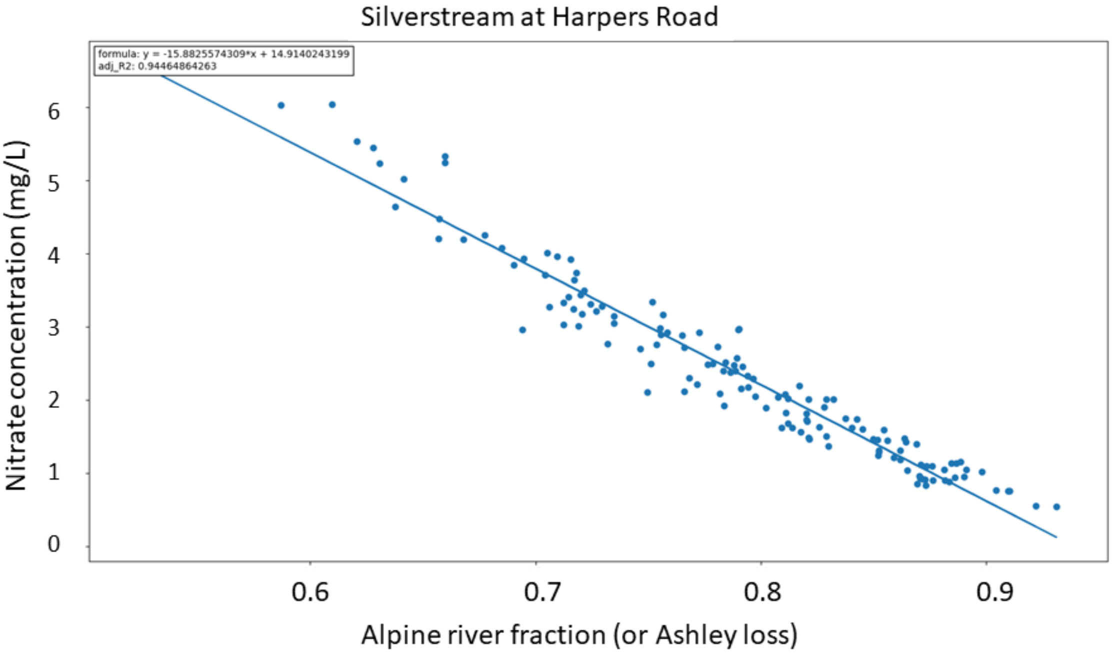


Figure 3-9: Raw modelled nitrate concentrations vs fraction of alpine river water in Silverstream at Harpers Road[37]

3.9.2 Model versus measured nitrate concentrations in groundwater and spring-fed streams

Having completed the EMMA-based model adjustments discussed above we compared model nitrate concentrations under current land and water management practices (CMP scenario, see Section 4.4.1) to measured spring-fed stream concentrations (Figure 3-10) and to sampling results from shallow wells located in areas where recent land use intensification has been minimal (Figure 3-11).

Although the 50th percentile model nitrate concentrations are generally higher than measured median concentrations in the Waimakariri Northern Tributaries catchment spring-fed streams, some of the differences relate to lag times and the recent land use intensification that has occurred in some catchments (e.g. Silverstream/Kaiapoi River, where nitrate concentrations are increasing and the effects of the Eyrewell Forest development are unlikely to have been realised as yet). Nitrate concentrations in 2016, when our water quality data analysis was undertaken, were also declining in some watercourses (e.g. Ohoka Stream and Cust Main Drain) which we attributed to the dry weather conditions in the preceding years. Nitrate concentrations have been much higher in more recent years (a declining trend is no longer apparent) and hence the measured concentrations are now closer to the model concentrations. On this basis it is reasonable for modelled nitrate concentrations based on Current Management Practice (CMP, see description in section 4.4.1) to be greater than measured concentrations.

[37] Internal data sources: P:\Groundwater\Waimakariri\Groundwater\Groundwater Quality\End member mixing model\SpringFedStreams4EM_ReachResults.csv for field data EMMA, P:\Groundwater\Waimakariri\Groundwater\Numerical GW model\Model simulations and results\ex_bd_va\n_results\waimak_per_results_at_points\stocastic_set_strs.csv for Model-based EMMA and P:\Groundwater\Waimakariri\Groundwater\Numerical GW model\Model simulations and results\ex_bd_va\n_results\n_vs_wai_regressions\streams

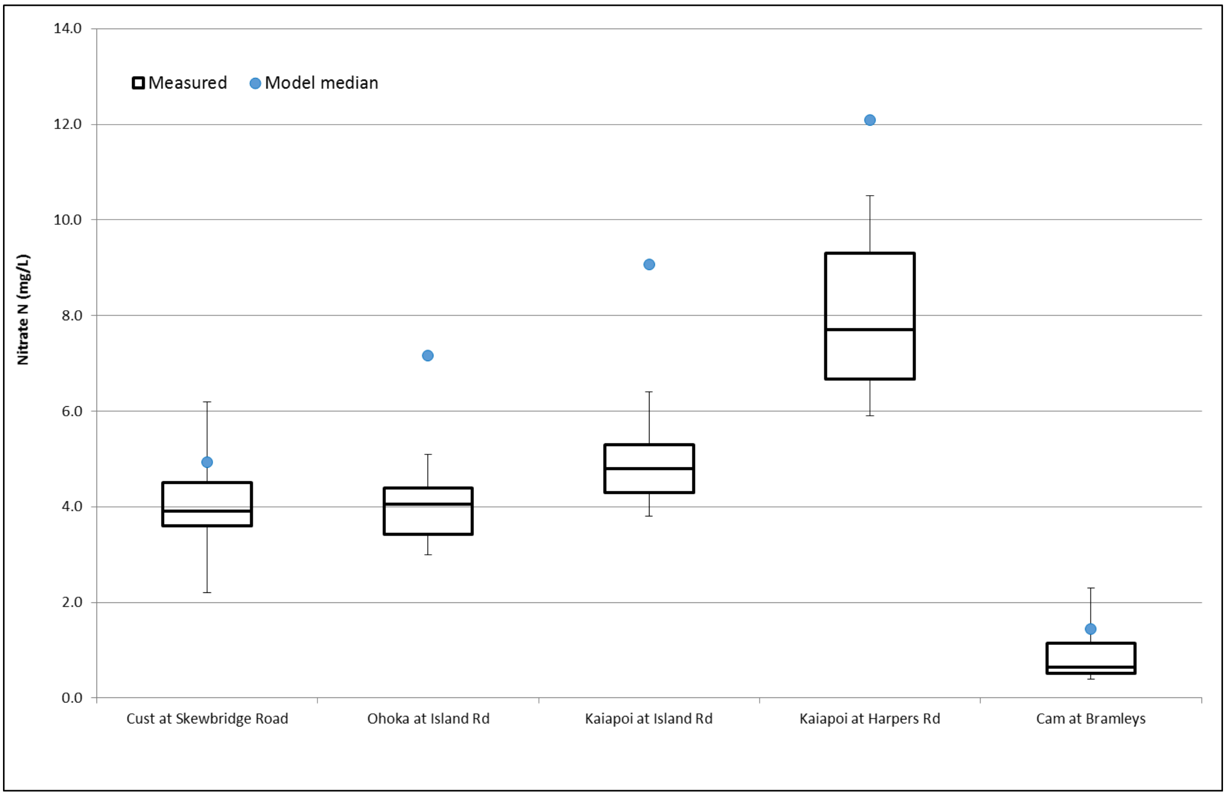


Figure 3-10: Measured and modelled (CMP, median) stream Nitrate

The model both over and under-predicts the nitrate concentration in the shallow monitoring wells we evaluated. However, our model was not designed to accurately simulate nitrate concentrations in individual private water supply wells and hence these overs and unders are to be expected. A more useful test of the model is whether the average model nitrate concentration across all of these wells is similar to the average measured data. The average model nitrate concentration for the 14 wells shown in Figure 3-11 is 5.1 mg/L; the average measured concentration is 4.9 mg/L. Model and measured results in these shallow wells, with limited lag effects, are therefore similar.

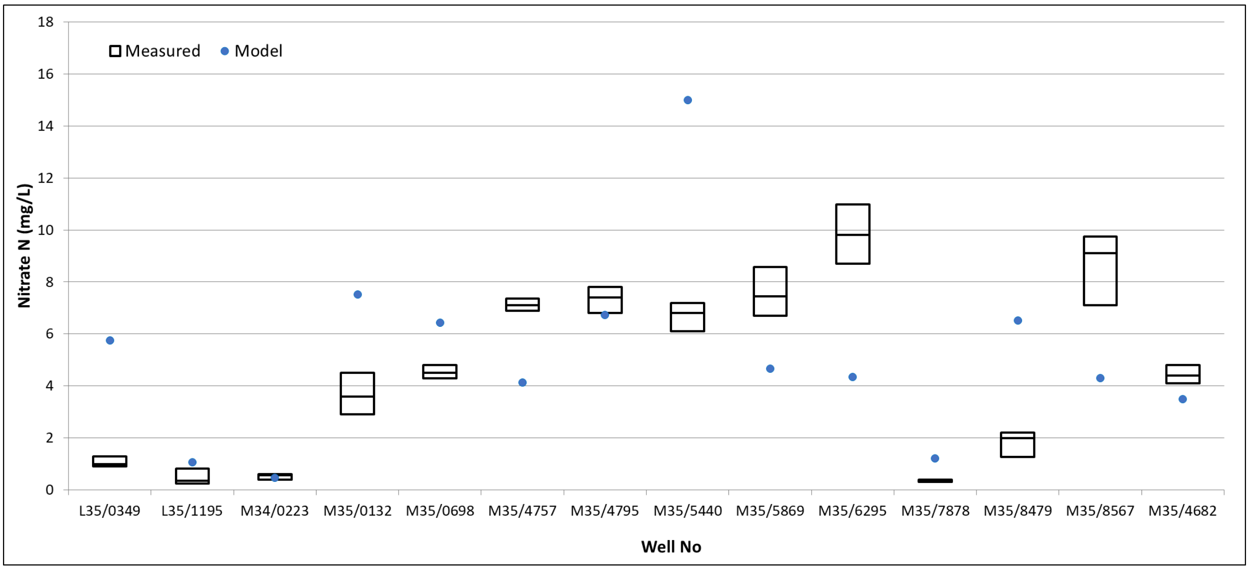


Figure 3-11: Measured and modelled (CMP, median) groundwater Nitrate in shallow wells

3.9.3 Ashley River/Rakahuri

Measurement-based N loads in Ashley River at the Gorge ranged between 11 and 108 tonnes/year over the 2010–2016 period with an average of 41 tonnes per year. Our original median modelled load, prior to the scaling discussed in section 3.6.2, was 180 tonnes/year. Use of a 0.55 scaling factor gives an N load of 98 tonnes/year, which is similar to the 2010-2016 maximum. Scaling model results to the maximum measured load (which occurred in 2012) is appropriate because environmental outcomes and assessment of whether targets are being met are based on the worst year, not long-term averages. We acknowledge the uncertainty associated with application of this crude scaling factor but nonetheless consider that our approach is the best solution to nitrate modelling in this catchment.

3.9.4 Nitrate load validation for Te Aka Aka

Our 5th and 95th percentile nitrate modelling results and the associated eutrophication susceptibility bands for Te Aka Aka are presented in Table 3-3.

The field measurements and observations discussed in Bolton-Ritchie (2019b) are consistent with classification of the estuary as band B with some evidence of band C conditions in certain areas (see section 2.4.4). Whilst our model results represent the highest nitrate load year between 2010 and 2016 (for reasons discussed above), our field surveys did not target the peak N load years. A field survey undertaken in 2012 (the highest measured N load year) could potentially have shown more significant eutrophication potential. On this basis the model results are not necessarily inconsistent with field observations. However, because the 5th percentile CLUES estuary tool assessment correlates most closely with observation data, we have assumed that these results provide the most useful indication of the outcome of each modelling scenario. Other modelling results are therefore greyed-out in Table 3-3 below. All of our modelling results for the options and solutions assessment (Sections 4 and 5) therefore only relate to the 5th percentile CLUES estuary tool assessment results.

Table 3-3: Summary of the current eutrophication bands (susceptibility) of Te Aka Aka

Modelled N load (tonnes/year)		CLUES Estuary tool eutrophication susceptibility band [tonnes/year]	
5th percentile	95th percentile	5th percentile	95th percentile
293	598	C [100-320)	D [>320]

3.10 Model limitations

Although we have discussed some key modelling limitations in the following paragraphs, we have not provided a comprehensive limitations review in this current report. Further information on model assumptions and limitations is provided in Etheridge and Hanson (2019a).

Because our model results represent the long-term average, they do not account for the inter-annual variability in nitrate concentrations associated with weather conditions. This is important because measured data from Silverstream at Harpers Road, for instance, show that the peak annual median nitrate concentration is roughly 30% greater than the long-term median. Correcting for this issue is problematic where nitrate concentrations are trending either up or downwards over time. The model results are therefore likely to under-predict stream nitrate concentrations in peak years, all else being equal. Seasonal variability also needs to be accounted for when evaluating model results for shallow wells. Our analysis of seasonal variability in shallow well nitrate concentrations, for instance, shows that peak annual concentrations are, on average, around 4 mg/L higher than annual average concentrations. This means that a modelled shallow groundwater nitrate concentration in excess 7.1 mg/L could mean that seasonal peak nitrate concentrations at that location exceed the drinking water limit of 11.3 mg/L.

Delineation of catchment boundaries using particle tracking with a steady state model means that the significant variations in flow directions that can occur between the irrigation season, when groundwater levels decline significantly, and late winter, when groundwater levels peak, are not accounted for. Our modelling results rely on the assumption that the groundwater gradients and flow paths associated with long term average water levels provide for a reasonable representation of net long term travel paths.

Modelling results assume that there is no attenuation of nitrate in groundwater, as discussed previously. This is a reasonable assumption for the inland plains, where our investigations and other research (e.g. Burbery, 2018, Close *et al.,* 2016) has found that the conditions required for groundwater nitrate attenuation are not present. Some attenuation is possible in the coastal zone, where anoxic groundwater and organic-rich sediments are present. Our investigations to date suggest that anoxic conditions and organic sediments may predominantly occur within low permeability sediments, which are by-passed by the majority of groundwater flow to wells and spring-fed streams. It is therefore not appropriate to account for any nitrate attenuation based on current knowledge. Nonetheless, we acknowledge the possibility that some nitrate attenuation could be occurring and if this is the case, the model projections of steady state nitrate concentrations may not be realised: actual steady state concentrations could be lower. We discuss this further in Kreleger and Etheridge (2019).

4 Options, scenarios and management tools assessment

4.1 Purpose

ZIPA recommendations for nitrate management controls were a key output of the Waimakariri Land and Water Solutions Programme. These recommendations have been used as a basis for drafting statutory Regional Plan rules for the Waimakariri Zone. We used the modelling methodology described in Section 3 to model nitrate concentrations in surface waters and groundwater and to explore the extent to which a range of nitrate limit options and management strategies and tools could help to achieve the Priority Outcomes. The information generated from this work underpinned the WWZC decision-making process.

The key zone-committee decisions relating to their ZIPA nitrate management recommendations were:

- nitrate limits;
- whether implementation of the current LWRP nitrate management regime (including the recent PC5 amendments [GMP]) is likely to achieve the WWZC Priority Outcomes;
- the magnitude of “beyond Baseline GMP” nitrate loss reductions required where just GMP is likely to be insufficient; and
- the extent to which higher rates of “beyond Baseline GMP” nitrate loss reductions could help to achieve nitrate targets and Priority Outcomes more quickly.

4.2 Structure

We have structured this report section as follows:

1. Summary of the nitrate limit options presented to the WWZC
2. Discussion of the nitrate management scenarios we explored with the WWZC
3. Assessment of nitrate limit options
4. Modelling results for the nitrate management options
5. Summary of proposed management areas

4.3 Nitrate limit options

4.3.1 Receptors within Waimakariri Zone

The nitrate limits generally used as determinants for water quality in the Waimakariri Zone are based on the New Zealand nitrate limits for drinking water and aquatic toxicity. Much lower limits can also be imposed, typically for hill-fed and alpine rivers, to reduce the risk of excessive periphyton growth. Nitrate concentrations above the drinking water MAV (11.3 mg/L) can be harmful to infants.

Elevated stream nitrate concentrations in surface waters can have toxicity effects on invertebrates and fish and cause nuisance periphyton growths in hill-fed streams and nuisance macrophyte growths in spring-fed streams. At high densities macrophytes and periphyton can reduce habitat availability for fish and invertebrates. Large macrophyte stands reduce stream hydraulic capacity, increase sediment deposition and alter diurnal oxygen and pH patterns. Nitrate toxicity limits are defined in the National Policy Statement for Freshwater Management (NPS-FM) 2014 as a series of concentration bands; these are discussed further in Arthur *et al.* (2019).

The nitrate limit options considered by the WWZC are summarised in Table 4-1.

Table 4-1: Nitrate concentration limit options for streams and groundwater in the Waimakariri Zone

Waterbody	Option name	Basis	Nitrate- N limit (mg/L)
Streams	Current measured	Maximum measured annual median	Varies
	National Bottom Line	Statutory obligation where concentrations already exceed 6.9 mg/L (or where concentrations are currently in NPS-FM C band, but are projected to rise above this)	6.9
	Fisheries protection	90% species protection with increased protection for salmonid spawning and rearing. This figure is within C band (2.4 – 6.9) of the NPS-FM.	3.8
	B band	Top of the NPS-FM B band. Statutory obligation to maintain within this figure if current concentrations are in B band now. Also 95% species protection.	2.4
	COMAR	Cultural Health Assessment report recommendation (Te Ngāi Tūāhuriri, 2016). Top of NPS-FM A band. Also 99% species protection	1.0
Ashley River/Rakahuri	Current measured	No deterioration from present	0.3 (Ashley River/Rakahuri at SH1)
	Periphyton control	Reduce proliferation of nuisance algal growth	0.1
Groundwater	Shallow well protection	Maximum annual average concentration in shallow wells at which peak seasonal concentrations are likely to be < drinking water limit (11.3 mg/L)	7.1[38]
	Current measured	Spatially averaged current measured nitrate concentration in northern Waimakariri River tributaries catchment monitoring wells from 2014 – 2017	4.1
		Spatially averaged current measured nitrate concentration for the Ashley and Kowai GAZs monitoring wells from 2014 – 2017	0.8
	LWRP	5.65 mg/L spatially averaged over area	5.65

4.3.2 Receptors outside of Waimakariri zone

The purpose of the nitrate limit options for the outside of the Waimakariri zone (Christchurch aquifer and Waimakariri River) differs from those considered for waterbodies within the zone. Within zone nitrate limit options are firm recommendations for concentrations that should be achieved in surface water and groundwater/drinking water supply wells. The limit options for the Christchurch aquifer

[38] See discussion in Section 4.5.1

provide an indicative threshold which can be used to show the scale of nitrate reductions that may be needed to enable land users in the Waimakariri zone to support Priority Outcome 9 (play their part in maintaining the high quality of Christchurch groundwater). The same logic applies to the Waimakariri River nitrate limit options. We have therefore referred to the Christchurch and Waimakariri River nitrate limit options as "thresholds" in this report. The thresholds considered for the Christchurch aquifers are given in Table 4-2 and the thresholds for the Waimakariri River in Table 4-3.

Table 4-2: Nitrate concentration threshold options for the deep Christchurch aquifers

Nitrate threshold option (mg/L N)	Rationale
0.6	Average current measured concentration in deep Christchurch aquifer
1.0	NPSFM A Band limit: protects 99% of aquatic species. Recognises that groundwater from deep Christchurch aquifer likely to ultimately discharge to spring-fed streams
2.4	NPSFM B Band limit: protects 95% of aquatic species. Recognises spring-fed stream connectivity as above.
3.8	Protects 90% of aquatic species. Recognises spring-fed stream connectivity as above.

Table 4-3: Nitrate concentration threshold options for the Waimakariri River

Option name	Basis	Nitrate- N limit (mg/L)
Current measured	No deterioration from present	0.2 (Waimakariri River at SH1) 0.1 (Waimakariri River at Gorge)
Periphyton control	Reduce proliferation of nuisance algal growth	0.1

4.4 Nitrate Management Scenarios

Our nitrate scenario assessment evaluated possible future nitrate concentrations under a range of management regimes, as follows :

- Current Management Practice (CMP)
- Good Management Practice (GMP)
- Plan Change 5, Permitted Activities (PC5PA) (full uptake of permitted activity rules for winter grazing and irrigation)
- Current Pathways (GMP and 50% uptake of permitted activity rules for winter grazing and irrigation)
- Alternative Pathways (individual assessment of reductions beyond Baseline GMP, winter grazing options, dryland farming and managed aquifer recharge/stream augmentation)

4.4.1 Current Management Practice and Good Management Practice

The Current Management Practice scenario (CMP) aimed to provide an estimate of nitrate loss rates prior to implementation of Good Management Practice (GMP, as defined in the LWRP). The purpose of this scenario was to assess the impact of GMP alone on nitrate concentrations.

The GMP scenario assessed surface water and groundwater nitrate concentrations under the assumptions that:

- Industry-agreed good management practices for nutrient management are fully implemented;

- Land use remains as per 2015 land use mapping, except for consented but unimplemented (in 2015) land use consents, which are assumed to be fully utilised (e.g. the Ngai Tahu Te Whenua Hou/Eyrewell Forest conversion);
- The impacts of nutrient loads "in the post" are realised (see previous discussion in section 3.7); and
- Land use intensification allowed for under Plan Change 5 (PC5) of the LWRP (which allows for limited areas of winter grazing and irrigation as a permitted activity [PA]) is excluded (this is discussed below in section 4.4.2).

4.4.2 PC5PA and Current Pathways

The LWRP Plan Change 5 Permitted Activity Rules (PC5PA) scenario assessed nitrate concentrations under the same assumptions as GMP plus full uptake of land use intensification (for winter grazing and irrigation) allowed for under the PC5PA.

The Current Pathways results represent the projected outcome of continuance along the current resource management trajectory. Current Pathways focusses on GMP and a 50% uptake of the land use intensification allowed for under the PC5PA. This scenario recognises that full uptake of winter grazing and irrigation on every property in the WNT catchment is very unlikely.

4.4.3 Alternative pathways scenario

The Alternative Pathways scenarios for nitrate loss mitigation explored the impacts of a set of alternative nitrate management approaches which would require farmers to reduce nitrate losses to a rate lower than their Baseline GMP rate[39]. We refer to these reductions as a percentage beyond Baseline GMP, and considered mitigation options that could be implemented to achieve them.

We also considered the feasibility of Managed Aquifer Recharge and Stream Augmentation as mitigation options and evaluated a range of alternative consenting thresholds for winter grazing to reduce the potential for increases N losses by Permitted Activity (see below).

Nitrate loss mitigation options
Information provided in Lilburne *et al.* (2019) shows that around 50% of the Waimakariri zone nitrate losses to surface water and groundwater are likely to be sourced from dairy farm land (see Figure 4-1). Sheep, beef and deer farming is also likely be a major contributor (34% of total zone N load). Other land use classes make relatively small contributions to the overall N load. These proportional contributions vary significantly on a catchment scale. Information provided in Etheridge and Hanson (2019b) shows that over 90% of the Silverstream N load is likely to be sourced from dairy farm land. The Cam River/Ruataniwha catchment N load is estimated to comprise 30% dairy and 60% sheep, beef and deer farm land sources.

[39] We use the term Baseline in this report to describe reduction of nitrate losses beyond the modelled GMP loss rate for the baseline period (2009-2013) specified in Plan Change 5 of the LWRP. See Glossary for further details.

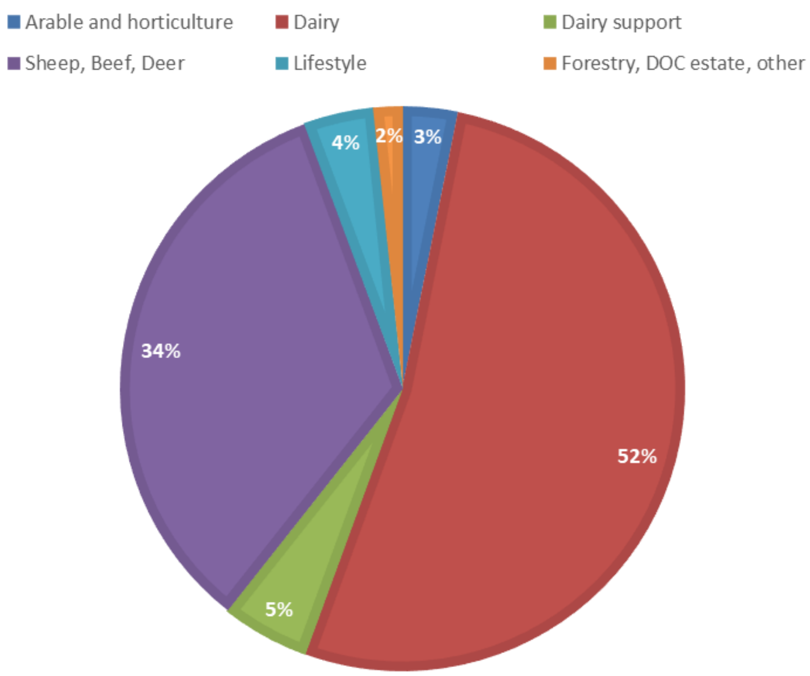


Figure 4-1: Nitrogen leaching load by land use class

Harris (2019) explains that whilst a number of beyond Baseline GMP nitrate loss reduction options are available for dairy farms, no specific options were identified for mitigating beyond GMP for mitigations for sheep and beef and arable. Given the major contribution of dairy farm N losses to the overall zone N load and the availability of mitigation options for these farms, the nitrate loss mitigation options assessment focused on dairy farms.

We identified three possible approaches to achieving beyond Baseline GMP nitrate loss rates for dairy farms in the Waimakariri zone:

1. *Farmers Panel mitigation:* analysis and Overseer modelling undertaken by the Waimakariri Farmers Reference Panel suggested that **N load reductions of up to 10% beyond Baseline GMP** can potentially be achieved on dairy farms and dairy support land without major economic impacts (see Fietje and Carmichael, 2018 – see Appendix 4). Because the ratio of dairy farms to non-dairy farms varies across the Waimakariri zone and because 10% is the maximum likely N load reduction that could be achieved using this package, we assumed that this mitigation option could achieve an N load reduction of between 3 and 7% on average when applied to catchments with mixed land use for our options modelling.
2. *Systems change mitigation:* Dairy NZ investigated a wider range of mitigations including options that involve infrastructure upgrades such as feed pads. This package of options generally achieves up to **~30% reduction in N losses beyond Baseline GMP** on dairy farms and dairy support land according to Overseer modelling results. We assumed that this mitigation option could achieve an N load reduction of between 7 and 20% on average when applied to catchments with mixed land use for our options modelling.
3. *Land use change:* we have assumed that an N load reduction **>30% beyond Baseline GMP** could only be achieved through land use change. Other mitigations are likely to become available over time, and hence the threshold for land use change may increase above 30% in the medium to long term.

The results for these three possible approaches give us an indication of the impact they have on nitrate loads and nitrate concentrations downstream at the receptors. The zone committee has used these results to make their final recommendations on how to reduce nitrates in the zone (see section 5). Harris (2019) explains that no specific mitigations were found for sheep and beef and arable farms, so replacement of grazing and arable land with forestry was used in his economic modelling for beyond Baseline GMP nitrate loss reductions for these farm types.

Beyond Baseline GMP nitrate loss reduction options
The three beyond Baseline GMP nitrate loss reduction options we considered were:

1. **10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP
2. **20 kg/ha + 10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.
3. **20 kg/ha + 10 & 20% beyond Baseline GMP** – Dairy reduce nitrate losses 20% and all other consented 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.

For each of these three options we assumed that nitrate losses from consented land are reduced by 10% or 20% (depending on the option) of the original 2009-2013 Baseline GMP load every 10 years under a staged approach.

For option 1 this means that if within a recharge zone a total nitrate loss reduction of 30% is required to meet the nitrate limit, and if 70% of the recharge zone nitrate load is sourced from consented landuse the average nitrate reduction rate would be 7% every 10 years for that recharge zone. Consented farmers would be required to undertake roughly four stages of reduction (i.e. ~40% total reduction) in order to achieve the overall 30% recharge zone reduction. Because the nitrate loss rate reduces over time under this approach, the percentage reduction relative to the leaching rate at the end of each 10 year stage increases. For example, taking a Baseline GMP loss rate of 50 kg/ha/year, a 10% reduction equates to 5 kg/ha/year. After 10 years, the nitrate loss rate would be 45 kg/ha/year; a 5 kg/ha/year loss reduction equates to 11% of 45 kg/ha/year.

Dryland farming option (Land use change mitigation)
For the Christchurch aquifers we have assessed a fourth alternative scenario: *dryland farming*[40]. This scenario explores potential nitrate concentrations in a hypothetical scenario under which the *average nitrate losses from the interzone source area* is reduced to 8 kg/ha per year by 2050 due to land use change (dairy to dryland). The purpose of this scenario was to provide information on the costs and benefits of a highly restrictive nitrate management regime for the interzone source area.

Winter grazing options
Plan Change 5 of the LWRP defined a set of land area thresholds beneath which a land use consent is not required for irrigation and winter grazing, i.e. the activity is classified as a Permitted Activity [PA]. Because these thresholds were defined for the whole of Canterbury, they may not be optimal for local circumstances in some parts of the region.

For spring-fed streams we assessed winter grazing options under more strict PA rules than those set by PC5 (which is now part of the LWRP but had not been adopted during the Waimakariri Land and Water Solutions technical work programme). Appendix 7 gives additional information on the winter grazing management options we explored.

We evaluated the potential nitrate loads and number of consents that would be required under a range of different PA threshold options, some of which are summarised in Table 4-4 below.

Table 4-4: PA Threshold options

Option	Winter grazing allowances based on property size (ha)				
	< 5	<10	10 – 100	100 – 1,000	>1,000
Draft ZIPA	No consent	5% of farm area	5% of farm area	5% of farm area	50 ha
Current Pathways/PC5	No consent	No consent	10 ha	10%	100 ha
Scenario 4	No consent	No consent	7.5 ha	7.5%	75 ha

[40] This scenario assumed no reduction of land surface recharge beyond Baseline GMP. While there would likely be a reduction of land surface recharge if irrigated land is converted back to dry stock/forestry (see Harris 2019 for details), this simplification is unlikely to effect the conclusions of our groundwater modelling.

Managed Aquifer Recharge and Stream Augmentation
Managed Aquifer Recharge (MAR) and Stream Augmentation (SA) are internationally well known methods for improving groundwater and surface water quantity and quality. MAR refers to the intentional recharge of water (groundwater, surface water or recycled water) to aquifers for subsequent use or environmental benefit and is commonly used as a measure to control over-abstraction, to restore the groundwater balance and to control saltwater intrusion. MAR has benefits for shallow groundwater nitrate concentrations in particular, which may be helpful where private drinking water supplies are drawn from shallow depths preferentially. Like MAR, SA also uses an external water source to enhance stream flows and/or surface water quality. The Waimakariri River has been identified as a potential SA source given its relatively low nitrate concentrations.

Although we undertook a successful infiltration test as a pre-cursor to a Managed Aquifer Recharge (MAR) trial in the Silverstream catchment (see Appendix 8 for summary), we concluded that the feasibility of MAR and SA have not yet been proven to a sufficient level of certainty for either to be put forward as a viable means of achieving nitrate reductions in streams and in particular groundwater used for drinking water supply in the Waimakariri zone. We emphasize that nitrate concentrations can be improved by MAR, but nitrogen loads are hardly affected by it.

We therefore assumed that reduction of nitrate loss rates from land is the only mechanism by which nitrate limits can be achieved with a sufficient level of certainty at the present time. This assumption can be revisited in the future, when more work has been undertaken to assess the feasibility of these alternative mitigation options.

4.5 Nitrate limit assessment and ZIPA recommendations

4.5.1 Assessment

Setting nitrate limits is a critical part of the Waimakariri Land and Water Solutions Programme because these define the standard for nitrate management across the zone. We presented the WWZC with three sets of possible nitrate limits to support their decision-making process. We referred to these scenarios in terms of the nitrate loss reductions that would be required to meet them, as follows:

Low reduction scenario: this is the most permissive set of limits and hence it causes the lowest level of economic impact of the three scenarios we looked at (see Harris, 2019 for further information). It allows for some deterioration of nitrate concentrations within existing National Objective Framework (NOF) bands for most streams. Of the surface watercourses, nitrate concentrations would only need to be reduced within the Silverstream/Kaiapoi River catchment under this option. We assumed that a nitrate limit of 5.65 mg/L (50% of the drinking water limit) would be targeted for the WDC community supply wells, and 7.1 mg/L for private supply wells. 7.1 mg/L is the maximum nitrate concentration at which seasonal nitrate spikes in shallow wells are likely to remain below the drinking water limit. The percentage reductions in nitrate discharges required to meet these limits are based on the 50th percentile (median) model results. This means that there is a 50% probability that the actual nitrate loss reductions required to achieve the limits will be higher than our assessment results suggest and a 50% probability that lower reductions will be required.

Middle reduction scenario: these limits are the same as the Low reduction scenario for most waterbodies but with the percentage nitrate reductions required being based on the 95th percentile model results. This scenario provides an indication of the nitrate loss reductions that would be required if true nitrate concentrations ultimately prove to be at the upper end of our modelled range. Nitrate concentration limits for the Cust Main Drain and Cam River are based on current measured concentrations. A reduction in nitrate discharges to the Waimakariri River would be required to reduce nuisance algal growth under this scenario. The limit for both WDC and private wells is 5.65 mg/L.

High reduction scenario: these limits would aim to restore nitrate concentrations at the Kaiapoi River/Silverstream at Harpers Road site to protect salmonid spawning, and nitrate concentrations in the lower Kaiapoi River, Ohoka Stream and Courtenay Stream would be maintained at present concentrations. The limits would aim to reduce nitrate concentrations in Cust Main Drain to the 90% species protection level to provide for increased protection for salmonid spawning and rearing in recognition of the high fishery value of this waterbody. This option would also aim to maintain nitrate concentrations at or reduce to 5.65 mg/L in all water supply wells in the catchment. Use of our

95th percentile model results means that the calculated beyond Baseline GMP N loss reductions for this scenario represent a worst case scenario with a 95% probability that the actual reductions needed would be less.

Major nitrate loss reductions would be required to achieve the COMAR stream nitrate concentration limit of 1.0 mg/L .

Full details of these scenarios and their implications for nitrate reductions under a range of modelled confidence intervals are presented in Etheridge and Hanson (2019b).

Christchurch aquifer
We evaluated the beyond Baseline GMP nitrate loss reduction required in the Christchurch aquifer recharge area for the various Christchurch nitrate thresholds. The main outcomes of this were:

- All thresholds considered by the WWZC and Christchurch West Melton Zone Committee were lower than the 5.65 mg/L (50% of the drinking water limit) threshold at which drinking water suppliers are required[41] to undertake monthly nitrate sampling and submit annual results to the Drinking Water Assessor for review.
- Comprehensive land use change, to a low intensity activity such as forestry, would be required to achieve the 0.6 mg/L threshold. Nitrate concentrations are expected to increase above this value due to loads “in the post”, even if all N losses ceased immediately.

[41] Under the New Zealand Drinking Water Standards

Table 4-5: Evaluation of Christchurch aquifer nitrate threshold options

Nitrate threshold option (mg/L N)	Rationale	Evaluation
0.6	Average current measured concentration in deep Christchurch aquifer	Modelling results indicate that an average nitrate loss reduction of around 90% beyond Baseline GMP could be required to achieve this. This could necessitate conversion of the whole Christchurch aquifer recharge area to forestry. Nitrate concentrations are expected to increase even if a forestry conversion was implemented immediately due to nitrogen loads already “in the post”.
1.0	NPSFM A Band limit: protects 99% of aquatic species. Recognises that groundwater from deep Christchurch aquifer likely to ultimately discharge to spring-fed streams	An average N loss reduction of 80% beyond Baseline GMP is likely to be required to achieve this target. Assessment results indicate that conversion of all irrigated land to low intensity sheep and beef farming and forestry could be necessary to achieve this limit. As per the option above, nitrate concentrations may still increase beyond this value due to loads “in the post”.
2.4	NPSFM B Band limit: protects 95% of aquatic species. Recognises spring-fed stream connectivity as above.	An average N loss reduction of 50% beyond Baseline GMP is likely to be required to achieve this target. This could potentially be achieved with less severe land use change, or potentially over a long period without land use change if new nitrate loss mitigation solutions are developed
3.8	Protects 90% of aquatic species. Recognises spring-fed stream connectivity as above.	30% beyond Baseline GMP N loss reduction required. Can be achieved without land use change and by using currently available N loss mitigation options.
>5.65		No modelled N loss reduction. All thresholds considered by the WWZC and Christchurch West Melton Zone Committee were lower than the 5.65 mg/L (50% of the drinking water limit)

4.5.2 ZIPA nitrate limit recommendations

The nitrate limits recommended by the WWZC are summarised in Table 4-6 (drinking water) and Table 4-7 (surface water).

The 3.8 mg/L threshold for Christchurch aims to maintain nitrate concentrations in Christchurch’s spring-fed streams, recognising that some attenuation may occur between the deep aquifer and spring discharge locations, and that deep groundwater is only one component of the spring-fed stream flows. Low nitrate water seepages from the Waimakariri River make up a significant proportion of the Avon River flows, for instance.

Table 4-6: Proposed nitrate limits by the zone committee for drinking water

Metric	Receptor	ZC limit[42] (mg/L)	Indicator	Future goal (mg/L)	Priority outcome (see section 1.2)
Nitrate-N	Private water supply wells	5.65	At least 50% of all samples collected from each private supply well area should meet the limit	All private drinking water supply wells should meet the Nitrate-nitrogen Drinking Water Standards at all times	(4) The zone has safe and reliable drinking water
	Community water supply wells Waimakariri District Council	5.65	100% of all samples collected from community supply wells should meet the limit, recognising that it may take some time to achieve this		
	Christchurch deep aquifer	3.8 (indicative threshold)	Average nitrate-nitrogen concentration in all samples collected from wells >80 m deep should be less than the limit	1.0	(9) Land and freshwater management in the Waimakariri Water Zone will, over time, support the maintenance of current high-quality drinking water from Christchurch's aquifers

[42] For the Christchurch Aquifers the limit is referred to as "threshold"

Table 4-7: Proposed nitrate limits by the zone committee for surface water

Metric	Receptor	ZC limit (mg/L)	Indicator[43]	Future goal (mg/L)	Priority outcome (see section 1.2)
Nitrate-N	Silverstream[17] at Harpers Road	6.9	Annual median concentration should reduce to below this limit over time	3.8	(1) Spring-fed streams maintain or improve mahinga kai gathering and diverse aquatic life
	Silverstream[17] at Island Road	6.9	Annual median concentration should remain below this limit	3.8	
	Courtenay Stream	3.8	Annual median concentration should remain below this limit	-	
	Ohoka Stream	3.8	Annual median concentration should reduce to below this limit over time	-	
	Cust Main Drain	3.8		-	
	Cam River / Ruataniwha	1.0		-	
Nitrate-N	Saltwater Creek	1.0	Annual median concentration should remain below this limit	-	(1) Spring-fed streams maintain or improve mahinga kai gathering and diverse aquatic life
	Waikuku Stream	1.0	Annual median concentration should reduce to below this limit over time	-	
	Taranaki Creek	1.0		-	
	Little Ashley Creek	1.0	Annual median concentration should remain below this limit	-	
	Ashley River/Rakahuri at Gorge	0.2		-	(2) The Ashley River/Rakahuri is safe for contact recreation, has improved river habitat, fish passage, and customary use; and has flows that support natural coastal processes
	Ashley River/Rakahuri at SH1	0.3		-	
Nitrate-N	Waimakariri River at SH1	0.2 (indicative threshold)	Waimakariri zone plays its part in preventing deterioration on Waimakariri water quality	0.1	(3) The Waimakariri River as a receiving environment is a healthy habitat for freshwater and coastal species, and is protected and managed as an outstanding natural landscape and recreation resource

4.6 Nitrate scenarios modelling results

4.6.1 Overview

In this section of the report we present the results of modelling undertaken to assess whether the nitrate management options and scenarios discussed in Section 4.4 could achieve the recommended nitrate limits. We have presented our results under the Current Pathways and Alternative Pathways headings. The former includes the GMP, PC5PA and Current Pathways scenarios described previously. The latter

[43] Based on current measured nitrate concentrations

comprises the modelling results of various beyond Baseline GMP percentage nitrate loss reduction rates. We discuss our results by receptor groups, e.g. private water supply wells, surface water and Te Aka Aka. For the Christchurch aquifer recharge area we also evaluated the potential nitrate concentrations associated the Dryland Farming scenario described above.

We have presented current measured nitrate concentrations, modelled future nitrate concentrations and the times at which these concentrations could occur after full implementation of each scenario.

We have assumed that the scenarios will be fully implemented by 2030 and have provided illustrative graphs of modelled nitrate concentrations over time in the various receptors in Appendix 9, based on the method described in Section 3.8. Refer to Appendix 9 for a glossary with the graphs.

4.6.2 Current Pathways

Private water supply wells

The median nitrate concentrations for the 23[44] private water supply areas (PWSAs) are currently below the zone committee limit of 5.65 mg/L (see Table 4-8). Under GMP, PC5PA and Current Pathways the concentrations are projected to increase until the lag time has been reached (see section 3.7 for an explanation of the lag times). All the PWSAs are expected to reach higher concentrations under the Current Pathways scenario. In 15 of the 23 modelled PWSAs the median concentrations are projected to exceed the zone committee limit of 5.65 mg/L under the GMP, PC5PA and Current Pathways scenarios when the lag-time has been reached. In the Eyreton PWSA concentrations in both deep and shallow wells are expected to exceed the MAV of 11.3 mg/L.

Although our analysis suggests that Priority Outcome 4 might not be achieved under the current management framework, it should be noted that the modelled nitrate results for private wells span a wide range. If the true results prove to be at the lower end of the modelled range, the 5.65 mg/L limit would be achieved in 21 of the 23 modelled PWSAs under the Current Pathways scenario. Conversely, if the true results proved to be at the upper end of the modelled range, exceedances of the 5.65 mg/L limit would be much more widespread and only 2 PWSAs would comply with the limit.

[44] including 6 deep PWSAs but excluding the Eyrewell PWSA, which was not modelled directly

Table 4-8: GMP and Current Pathways – Nitrate modelling results for PWSAs

PWSA	ZIPA limit[45] (mg/L)	Current measured (mg/L)	Lag time (year)	GMP (mg/L)	PC5PA (mg/L)	Current pathways (mg/L)
Clarkville	5.65	4.4 (0.5 – 9.4)	40	7.8 (4.7-11.1)	8.6 (5.2-12.2)	8.2 (5.0-11.7)
Cust	5.65	4.4 (0.05 – 8.8)	48	6.4 (3.7-9.3)	7.0 (4.1-10.2)	6.7 (3.9-9.7)
Eyreton (shallow)	5.65	5.2 (0.6 – 9.6)	45	11.9 (8.0-16.0)	12.6 (8.5-17.1)	12.3 (8.3-16.6)
Eyreton (deep)	5.65	5.2 (0.6 – 9.6)	75	15.0 (7.3-23.6)	15.4 (7.5-24.3)	15.2 (7.4-24.0)
Fernside	5.65	3.7 (0.04 – 8.8)	46	4.0 (1.8-6.4)	5.8 (2.6-9.2)	4.9 (2.2-7.8)
North East Eyrewell (shallow)	5.65	3.6 (0.7 – 7.0)	50	6.2 (2.3-12.7)	7.0 (2.7-14.4)	6.6 (2.5-13.6)
North East Eyrewell (deep)	5.65	3.6 (0.7 – 7.0)	70	7.1 (3.8-10.9)	7.9 (4.2-12.1)	7.5 (4.0-11.5)
Flaxton	5.65	4.4 (0.05 – 8.8)	36	3.2 (1.8-5.6)	3.9 (2.2-6.9)	3.5 (2.0-6.3)
Horellville	5.65	3.7 (0.04 – 8.8)	48	4.3 (2.0-6.8)	4.8 (2.3-7.6)	4.6 (2.2-7.2)
Mandeville	5.65	4.4 (0.05 – 8.8)	45	4.5 (2.2-8.4)	5.1 (2.5-9.5)	4.8 (2.3-8.9)
North West Eyrewell (shallow)	5.65	3.6 (0.7 – 7.0)	45	6.0 (2.0-11.9)	6.5 (2.1-13.0)	6.3 (2.0-12.5)
North West Eyrewell (deep)	5.65	3.6 (0.7 – 7.0)	75	7.3 (2.0-13.7)	8.1 (2.3-15.3)	7.7 (2.1-14.5)
Ohoka (shallow)	5.65	4.4 (0.05 – 8.8)	50	5.8 (3.7-8.0)	6.8 (4.4-9.4)	6.3 (4.0-8.7)
Ohoka (deep)	5.65	4.4 (0.05 – 8.8)	88	7.1 (4.2-10.3)	8.0 (4.7-11.6)	7.5 (4.4-10.9)
Rangiora	5.65	0.5 (0.3 – 0.7)	15	2.3 (0.4-5.6)	3.1 (0.5-7.8)	2.7 (0.4-6.7)
Springbank	5.65	3.7 (0.04 – 8.8)	45	6.2 (3.7-8.8)	7.1 (4.3-10.2)	6.6 (4.0-9.5)
Summerhill	5.65	3.7 (0.04 – 8.8)	70	9.9 (4.7-15.2)	11.0 (5.3-16.9)	10.4 (5.0-16.1)
Swannanoa (shallow)	5.65	3.7 (0.04 – 8.8)	45	6.7 (2.8-11.4)	7.5 (3.2-12.9)	7.1 (3.0-12.1)
Swannanoa (deep)	5.65	4.4 (0.05 – 8.8)	45	8.0 (4.2-11.9)	8.8 (4.6-13.1)	8.4 (4.4-12.5)
Waikuku	5.65	0.8 (0.03 – 3.8)	7	1.2 (0.6-3.4)	1.3 (0.6-3.7)	1.3 (0.6-3.5)
West Eyreton (shallow)	5.65	3.7 (0.04 – 8.8)	48	5.3 (2.6-10.5)	6.0 (3.0-11.7)	5.6 (2.8-11.1)
West Eyreton (deep)	5.65	3.7 (0.04 – 8.8)	66	6.1 (3.5-8.9)	6.6 (3.8-9.7)	6.3 (3.7-9.3)
Woodend - Tuahiwi	5.65	0.8 (0.03 – 3.8)	7	2.2 (0.6-5.2)	3.3 (0.9-7.6)	2.8 (0.8-6.4)

Purple – concentration exceeds ZIPA limit
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)

[45] At least 50% of all samples collected from each private supply well area should meet the limit

Tuahiwi marae
Nitrate concentrations in the Tuahiwi Marae supply well are currently low and are expected to stay well below 5.65 mg/L under the Current Pathways scenario, as shown in the illustrative graphs of modelled nitrate concentrations over time below (Figure 4-2).

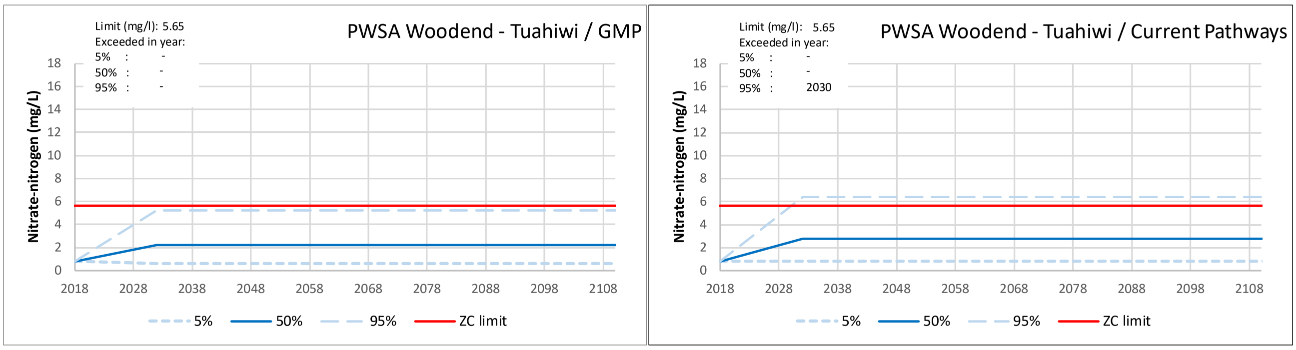


Figure 4-2: Indicative modelled nitrate concentrations for PWSA Woodend-Tuahiwi

WDC Community supply wells
The results for the WDC community supply wells are given in Table 4-9. Currently the mean nitrate concentrations are mostly below the zone committee limit of 5.65 mg/L except for Poyntzs Road. Under GMP, PC5PA and Current Pathways the concentrations are projected to increase until the lag time has been reached. The 50th percentile model concentrations under GMP and/or Current Pathways are projected to exceed the zone committee limit in seven of the WDC sites. We have added graphs with indicative modelled nitrate concentrations for WDC supplies Oxford Urban and Rangiora in Figure 4-3 as examples. Graphs for the Current Pathways scenario (and for some receptors also the GMP scenario) are provided in Appendix 9.

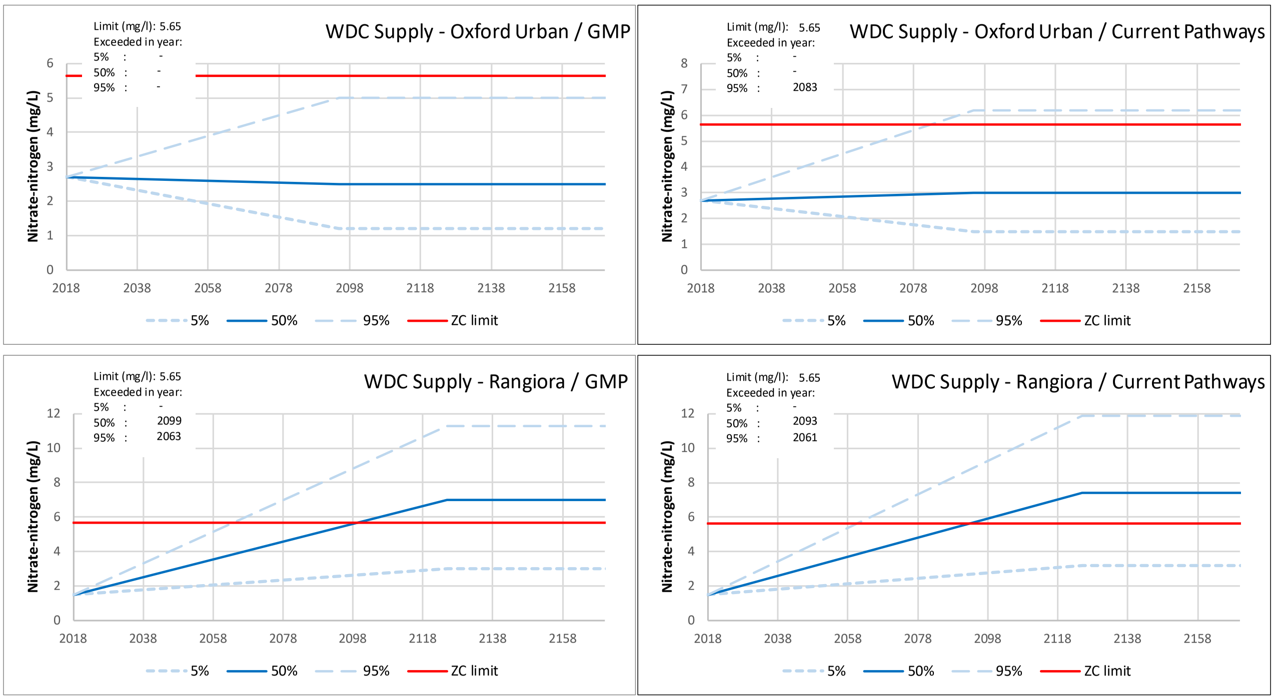


Figure 4-3: Indicative modelled nitrate concentrations for WDC Supplies Oxford Urban and Rangiora

Table 4-9: GMP and Current Pathways – Nitrate modelling results for WDC Drinking water supply wells

Site[46]	ZIPA limit[47] (mg/L)	Current measured (mg/L)	Lag time (year)	GMP (mg/L)	PC5PA (mg/L)	Current pathways (mg/L)
Cust	5.65	0.3	>80 (used 100)	6.0 (3.6-8.5)	6.8 (4.2-9.7)	6.4 (3.9-9.1)
Fernside	5.65	1.1	1/46[48] (used 20)	4.6 (2.4-6.6)	6.4 (3.4-9.4)	5.5 (2.9-8.0)
Kaiapoi	5.65	1.5	>80 (used 100)	6.4 (3.1-10.2)	7.1 (3.4-11.3)	6.8 (3.3-10.8)
Kairaki	5.65	0.4	>77 (used 100)	5.1 (3.1-7.5)	5.7 (3.5-8.3)	5.4 (3.3-7.9)
Mandeville	5.65	3.0	42	7.8 (4.9-11.2)	8.4 (5.3-12.1)	8.1 (5.1-11.7)
Ohoka	5.65	0.35	88	7.2 (4.3-10.4)	8.3 (5.0-11.9)	7.7 (4.7-11.1)
Oxford Urban	5.65	2.7	70	2.5 (1.2-5.0)	3.6 (1.7-7.4)	3.0 (1.5-6.2)
Pegasus/ Woodend	5.65	0.02	>83 (used 100)	2.5 (0.8-5.0)	3.9 (1.3-7.9)	3.2 (1.1-6.4)
Poyntzs Road	5.65	9.0	10	7.0 (4.5-10.4)	7.6 (4.8-11.3)	7.3 (4.6-10.9)
Rangiora	5.65	1.5	>80 (used 100)	7.0 (3.0-11.3)	7.8 (3.3-12.6)	7.4 (3.2-11.9)
Waikuku	5.65	0.7	<6 (used 6)	1.7 (1.0-3.0)	2.1 (1.2-3.9)	1.9 (1.1-3.4)
West Eyreton / Summerhill	5.65	2.0	66	5.7 (3.5-8.1)	6.0 (3.7-8.6)	5.8 (3.6-8.4)

Purple – concentration exceeds ZIPA limit
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)

[46] Internal model inputs data source: P:\Groundwater\Waimakariri\Groundwater\Numerical GW model\Model simulations and results\ex_bd_va\n_results\waimak_per_results_at_points\stocastic_set_wells.csv
[47] All water samples collected from WDC community supply wells should meet the limit, recognising that it may take some time to achieve this
[48] Age tracer results are ambiguous for this site and could be interpreted as either one year or 46 year mean residence time

Christchurch aquifer
The results for the Christchurch aquifer are given in Table 4-10. Currently the median nitrate concentrations are well below the zone committee threshold of 3.8 mg/L. Under GMP, PC5PA and Current Pathways the concentrations are projected to increase until the lag time has been reached (see section 3.7 for an explanation of the lag times). 50th percentile model concentrations exceed the threshold for all three area of the aquifer. We have added graphs with indicative modelled nitrate concentrations for concentrations for the West and Central areas of the Christchurch aquifer in Figure 4-4. A complete set of graphs is provided in Appendix 9.

Table 4-10: GMP and Current Pathways – Nitrate modelling results for Christchurch aquifer areas

Area	ZIPA threshold [49] (mg/L)	Current measured (mg/L)	Lag time (year)	GMP (mg/L)	PC5PA (mg/L)	Current pathways (mg/L)
West	3.8	0.3	200	4.0 (1.2 - 6.9)	4.2 (1.3 – 7.3)	4.1 (1.3 – 7.1)
Central	3.8	0.3	800	5.2 (3.4 – 7.4)	5.6 (3.6 – 7.9)	5.4 (3.5 – 7.6)
East	3.8	0.3	1200	5.2 (3.4 – 7.4)	5.6 (3.6 – 7.9)	5.4 (3.5 – 7.6)

Purple – concentration exceeds ZIPA threshold
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)

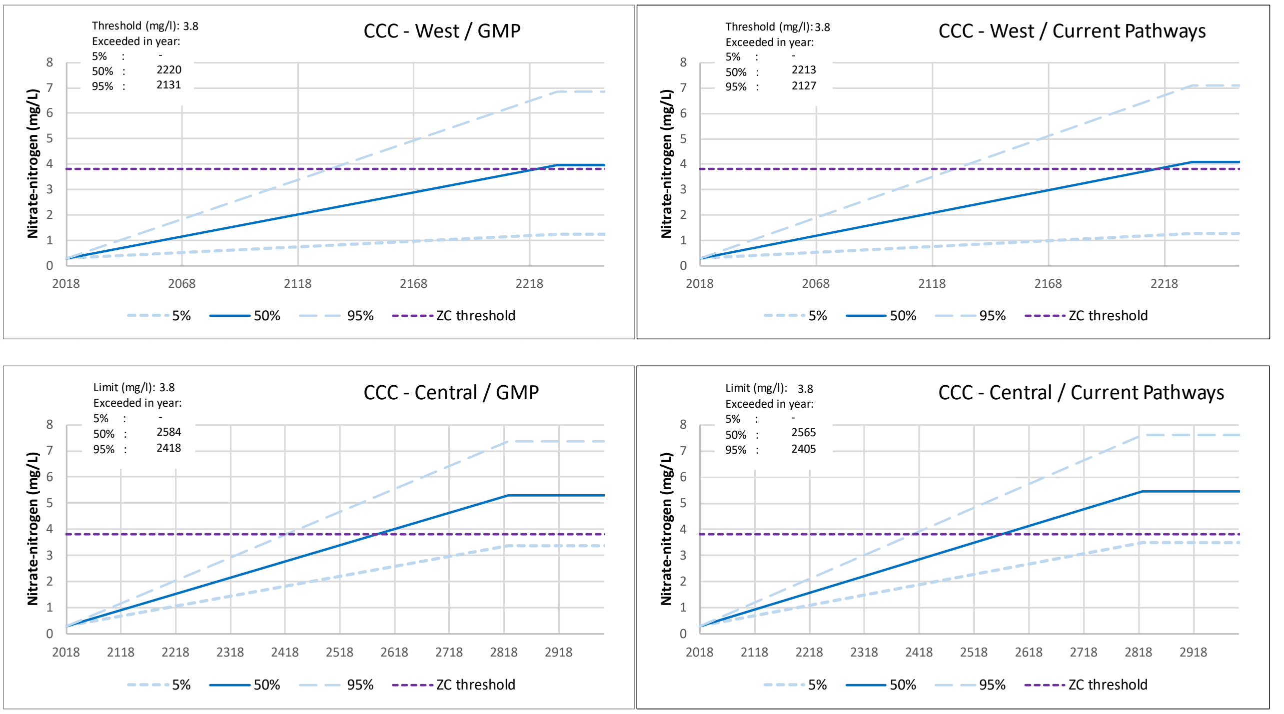


Figure 4-4: Indicative modelled nitrate concentrations for West and Central Christchurch aquifer

49 Average nitrate concentration in all samples collected from CCC wells >80 m deep should be less than the threshold

Conclusions for drinking water supply wells

The results from our groundwater model indicate that average nitrate concentrations in most drinking water supplies are likely to exceed the limits and threshold recommended by the WWZC under the current nutrient management regime. Section 4.6.3 describes the results of the Alternative Pathways scenario, within which we evaluated the nitrate loss reductions that may be required to meet the limits.

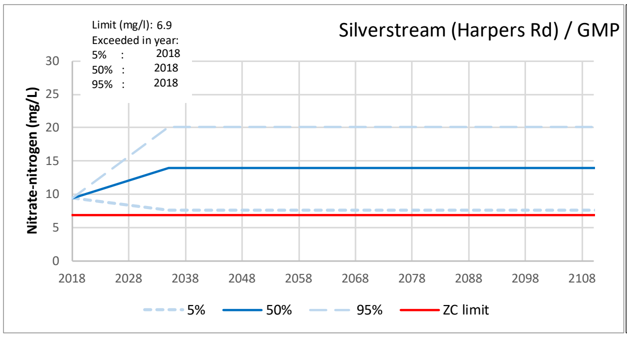
Surface water

Current nitrate concentrations exceed the limits recommended in the ZIPA in the following watercourses:

- Silverstream (Harpers Rd site)
- Ohoka Stream
- Cust Main Drain
- Cam River/Ruataniwha
- Waikuku Stream
- Taranaki Creek

Our modelling results for stream and river nitrate concentrations are presented in Table 4-11. Under GMP, PC5PA and Current Pathways the concentrations in all watercourses in the Kaiapoi River catchment (top half of table) are projected to increase until the lag time has been reached (see section 3.7 for an explanation of the lag times). Our model results indicate that these watercourses are likely to exceed the recommended limit for nitrate, except Cam River/Ruataniwha under GMP. By looking at the differences between the CMP and GMP model results (see Etheridge and Hanson, 2019b) we can see that even if there is no lag-driven increase in surface water nitrate concentrations, implementation of GMP is not expected to achieve the nitrate limits in Silverstream at Harpers Rd, Ohoka Stream and Cust Main Drain. The implication of this is that, regardless of our modelling results and uncertainty, beyond Baseline GMP N loss reductions will be required here. The only exception to this would be if GMP delivers significantly higher reductions in soil drainage nitrate *concentrations* than our modelling results suggest.

We have added graphs with indicative modelled nitrate concentrations for concentrations for Silverstream (at Harpers Road) in Figure 4-5. More graphs for the other spring-fed streams of the Waimakariri Northern Tributaries are provided in Appendix 9.



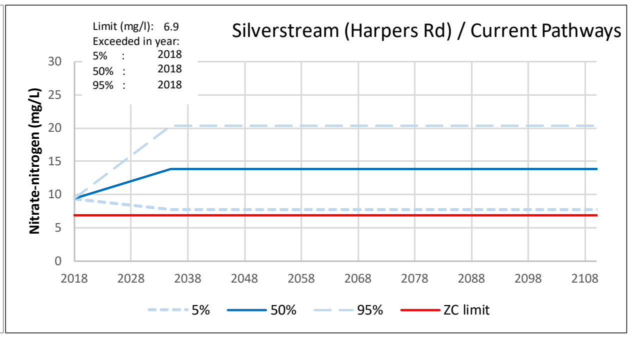


Figure 4-5: Indicative modelled nitrate concentrations for Silverstream at Harpers Road

Table 4-11: GMP and Current Pathways - Nitrate modelling results for surface water

Stream	ZC limit (mg/L)	Current measured (mg/L)	Lag time (year)	GMP (mg/L)	PC5PA (mg/L)	Current pathways (mg/L)
Silverstream[17] at Harpers Road	6.9	9.4	10	13.6 (7.6-20.1)	14.0 (7.8-20.6)	13.8 (7.7-20.3)
Silverstream[17] at Island Road	6.9	5.4	10	9.1 (5.5-12.8)	10.0 (6.0-14.1)	9.5 (5.7-13.5)
Courtenay Stream	3.8	3.1	10	4.5 (3.1-6.3)	5.0 (3.4-7.0)	4.7 (3.2-6.6)
Ohoka Stream	3.8	4.5	10	6.5 (3.9-9.3)	7.5 (4.5-10.6)	7.0 (4.2-10.0)
Cust Main Drain	3.8	4.7	10	5.6 (3.3-8.2)	6.9 (4.1-10.2)	6.2 (3.7-9.2)
Cam River	1.0	1.5	10	1.0 (0.6-1.6)	1.4 (0.9-2.3)	1.2 (0.8-1.9)
Ashley Gorge	0.2	0.2	10	0.19 (0.11-0.23)	0.19 (0.11-0.23)	0.19 (0.11-0.23)
Ashley SH1	0.3	0.3	10	0.27 (0.16-0.33)	0.37 (0.21-0.46)	0.31 (0.18-0.38)
Saltwater Ck	1.0	0.7	10	0.64 (0.39-0.80)	1.00 (0.61-1.24)	0.80 (0.49-0.99)
Waikuku Str	1.0	1.2	10	1.00 (0.61-1.10)	1.09 (0.67-1.20)	1.04 (0.63-1.15)
Taranaki Ck	1.0	1.2	10	1.03 (0.65-1.16)	1.19 (0.75-1.33)	1.10 (0.70-1.23)

Red – concentration exceeds ZIPA limit
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)

Modelling results for the Ashley River/Rakahuri catchment suggest that nitrate concentrations are unlikely to change significantly under the GMP, PC5PA and Current Pathways scenarios for most watercourses. A small increase is shown for Saltwater Creek, but nitrate concentrations remain below the proposed 1.0 mg/L limit for this watercourse.

Modelling results for the Norther Waimakariri Tributaries catchment suggest that implementation of GMP is expected to reduce nitrate concentrations in these watercourses. On the other hand the PC5PA and Current Pathways modelling results show that any improvements by GMP could be counteracted by the additional land use intensification that is allowed for as a Permitted Activity under the current LWRP rules.

Te Aka Aka
Our modelling results for Te Aka Aka are presented as nitrogen (N) loads and the eutrophication susceptibility bands (as per Dudley and Plew, 2018) in Table 4-12 below. Results are presented for the 5th percentile Clues-Estuary tool assessment band as discussed in Section 3.6.2. We refer to Appendix 10 for a full nitrate assessment for Te Aka Aka.

Table 4-12: Summary of the potential eutrophication bands (susceptibility) of Te Aka Aka

Scenario	Modelled N load **(t/year)**	CLUES Estuary tool eutrophication susceptibility	Band and N load (t/year)		
			A	B	C
			<42	42-100	100-320
	5th percentile	5th percentile	N load reduction required to achieve band		
Current MP	293	C	86%	66%	N/A
GMP	222	C	81%	55%	N/A
PC5PA	527	D	92%	81%	39%
Current pathways	374	D	89%	73%	15%

Modelling results indicate that successful implementation of GMP could reduce nitrate discharges to the estuary by 5-11%. Although this is unlikely to be sufficient to reduce N loads in the estuary to within the band B classification in the highest N load years, it would help to maintain the estuary within band B for more of the time.

Full or 50% uptake of the PC5PA winter grazing and extra irrigation allowances could potentially degrade the estuary to band D in the worst (highest N load) years, based on the 5th percentile CLUES Estuary tool eutrophication susceptibility results. Our analysis of the N load reductions required to achieve each ETI band under the four modelling scenarios (Table 4-12) indicates that major load reductions are likely to be required (e.g. 73% under Current Pathways to achieve B band) status at all times.

Conclusions for surface water
Our 50th percentile modelling results suggest that nitrate concentrations are likely to exceed the ZIPA limits for watercourses within the Kaiapoi River catchment under the Current Pathways scenarios. The implication of these results is that beyond Baseline GMP nitrate loss reductions will be required to meet the recommended nitrate limits. We discuss this further in Section 4.6.3. Furthermore, comparison of current measured nitrate concentrations and the ZIPA nitrate limits shows that beyond Baseline GMP N loss reductions are required to meet the limits, regardless of modelled projections of lag-driven nitrate concentration increases. Nitrate loads and eutrophication risks in Te Aka Aka are likely to increase under the Current Pathways scenarios. This is due to the additional land use intensification (principally winter grazing) that can occur as a Permitted Activity under PC5 of the LWRP.

4.6.3 Alternative pathways

For the Alternative Pathways scenario we assumed that the nitrate losses will be reduced by a set percentage of the 2009-2013 Baseline GMP N load every ten years, until the target (zone committee limit) is reached. The year by which the target will be reached is dependent on the nitrate reduction rate (%) per 10-year stage and the lag time (section 3.7). The assumptions used in these assessment are explained in section 3.8. Appendix 11 contains tables with the model results for all the receptors for the three beyond Baseline GMP nitrate loss reduction options:

1. **10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP
2. **20 kg/ha 10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.
3. **20 kg/ha 10 & 20% beyond Baseline GMP** – Dairy reduce nitrate losses 20% and all other consented 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.

Note that in some instances our 95th percentile model results show that >100% reductions would be required for dairy farms (i.e. more than 10 stages under 10% beyond GMP reductions or more than 5 stages under 20% beyond GMP reductions) because we have not capped the maximum feasible % reduction when generating the results. This means that, for areas where >90% reductions are being required beyond Baseline GMP reductions will not get the nitrate concentrations under the zone committee target for the 95th percentile model results).

Overall conclusions for this assessment are:

- although increasing the rate of beyond Baseline GMP N loss reductions would mean that nitrate limits are achieved more quickly, the inherent hydrological system lag times are the dominant driver in the time taken to meet limits;
- the reduction per 10 year stage results show significant variability depending on the amount of dairy landuse in the recharge zone of the receptor. E.G. a 20% reduction in dairy farm N losses in the Eyreton PWSA recharge area is likely to achieve an overall average 18.4% reduction here, due to the dominance of dairy farming land use in this area. The same reduction rate in the Fernside catchment would deliver a 1.4% average reduction due to the dominance of non-dairy farm land use here.
- Introducing a “nitrate floor” of 20 kg/ha below which beyond GMP nitrate reductions are not needed does in general not introduce a significant difference in the reductions achieved per 10 year stage, unless the recharge zone is dominated by consented land use with loss rates < 20kg/ha. This is only the case for a few receptors.

Private water supply wells

Our groundwater model results for the Alternative Pathways N loss reduction scenarios are presented in Appendix 11 and are summarised for a representative sub-set of the PWSAs in Table 4-13. Indicative nitrate time series plots for this representative sub-set are presented in Appendix 9 and Figure 4-6. Our modelling results indicate that:

- beyond Baseline GMP N loss reductions are likely to be required in order to meet the recommended nitrate limits for 15 of the PWSAs;
- of these, between ~10%-60% beyond Baseline GMP N loss reduction could be needed to reduce the projected Current Pathways nitrate concentrations for the zone to below the zone committee limit of 5.65 mg/L under the scenarios we modelled here.
- for those wells with projected nitrate concentrations in excess of the recommended limit, between 0.5-6 stages of nitrate reductions are likely to be required under these modelled scenarios (this which equates to a total of 5% to 60% beyond Baseline GMP N loss reduction for land owners;
- although increasing the rate of beyond Baseline GMP N loss reduction would mean that nitrate limits are achieved more quickly, the inherent hydrological system lag times are the dominant driver in the time taken to meet limits.

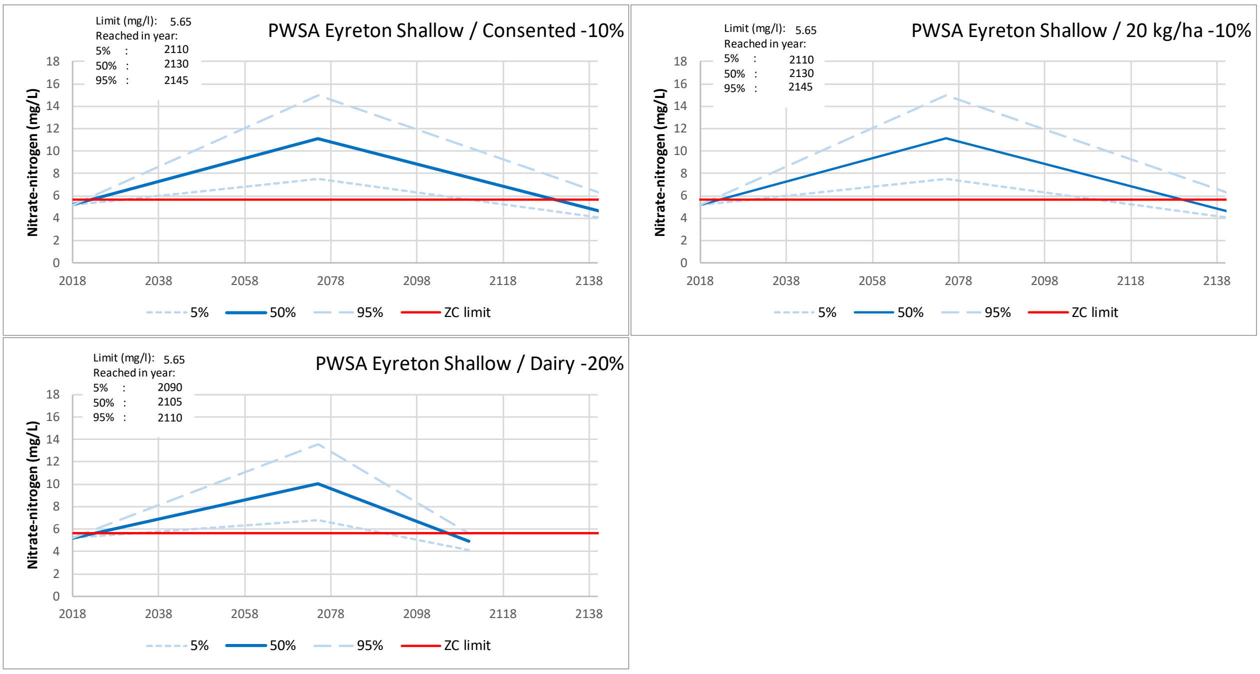


Figure 4-6: Indicative modelled nitrate concentrations for PWSA Eyreton (shallow)

Table 4-13: Alternative Pathways - Nitrate modelling results for PWSA

PWSA	ZC limit[50] (mg/L)	Current Pathways (mg/L)	Lag time (year)	Reduction needed (%)	Option	Beyond GMP reduction (%)	Number of 10yr-stages	Target reached (years)
Eyreton (shallow)	5.65	12.3 (8.3-16.6)	45	54.1 (31.9-66.0)	C-10	9.7%	5.6 (3.3-6.8)	100 (80-115)
					20kg-10	9.6%	5.6 (3.3-6.8)	100 (80-115)
					D-20	18.4%	3.0 (1.7-3.6)	75 (60-80)
Fernside	5.65	4.9 (2.2-7.8)	46	0 (0-27.6)	C-10	2.0%	0 (0-13.8)	0 (0-185)
					20kg-10	1.4%	0 (0-19.9)	0 (0-245)
					D-20	1.4%	0 (0-19.9)	0 (0-245)
North East Eyrewell (shallow)	5.65	6.6 (2.5-13.6)	50	14.4 (0-58.5)	C-10	9.0%	1.6 (0-6.5)	65 (0-115)
					20kg-10	8.8%	1.6 (0-6.6)	65 (0-115)
					D-20	15.7%	0.9 (0-3.7)	60 (0-85)
Summerhill	5.65	10.4 (5.0-16.1)	70	45.7 (0-64.9)	C-10	8.1%	5.6 (0-8.0)	125 (0-150)
					20kg-10	8.1%	5.7 (0-8.0)	125 (0-150)
					D-20	12.8%	3.6 (0-5.1)	105 (0-120)
Swannanoa (shallow)	5.65	7.1 (3.0-12.1)	45	20.4 (0-53.3)	C-10	8.9	2.3 (0-6.0)	70 (0-105)
					20kg-10	8.6	2.3 (0-6.1)	70 (0-105)
					D-20	13.9%	1.5 (0-3.8)	60 (0-85)

Purple – concentration exceeds ZC limit
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)
C-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use
20kg-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use with a nitrate loss higher than 20kg/ha
D-20 : GMP + staged nitrate reductions of 20% per 10 year for dairy and 10% per 10 year for all other consented land use with a nitrate loss higher than 20kg/ha
Target reached in “0” years means nitrate concentration will always be below ZC limit if this scenario is implemented
Years is years after full implementation

[50] At least 50% of all samples collected from each private supply well area should meet the limit

WDC Community supply wells

Our groundwater model results for the Alternative Pathways N loss reduction scenarios are presented in Appendix 11 and are summarised for a representative sub-set of the WDC water supply wells in Table 4-14. Indicative nitrate time series plots for this representative sub-set are presented in Appendix 9 and Figure 4-7. Our modelling results indicate that:

- Beyond Baseline GMP N loss reductions are likely to be required in the recharge zones of 7 WDC Community Supplies, or 6 if the Poyntzs Rd well is excluded (given that this is being replaced with an alternative supply by WDC in the near future);
- of these, between ~3%-30% beyond Baseline GMP N loss reduction could be needed to reduce the projected Current Pathways nitrate concentrations for the zone to below the zone committee limit of 5.65 mg/L under the scenarios we modelled here;
- for those wells with projected nitrate concentrations in excess of the recommended limit, between 0.5-4 stages of nitrate reductions are likely to be required under these modelled scenarios (this which equates to a total of 10% to 40% beyond Baseline GMP N loss reduction for land owners);
- as per the PWSAs although increasing the rate of beyond Baseline GMP N loss reduction would mean that nitrate limits are achieved more quickly, the inherent hydrological system lag times are the dominant driver in the time taken to meet limits.

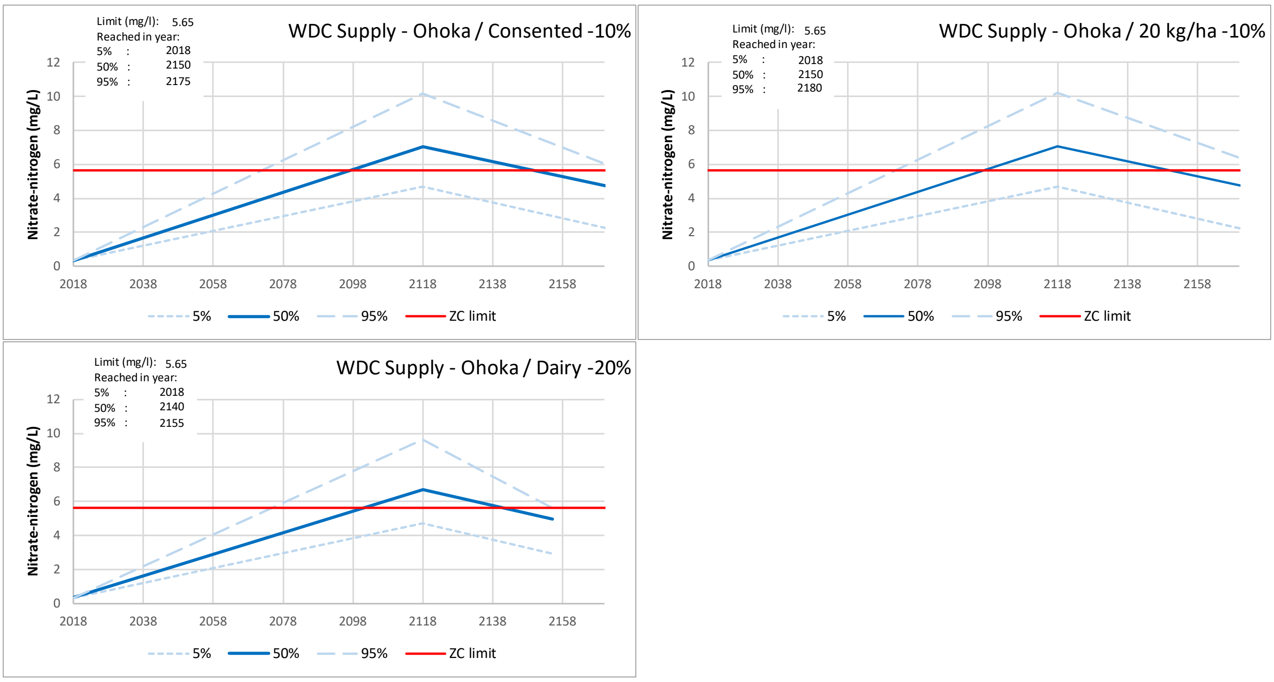


Figure 4-7: Indicative modelled nitrate concentrations for WDC Supply Ohoka

Table 4-14: Alternative Pathways - Nitrate modelling results for WDC Drinking water supply wells

Site	ZC limit[51] (mg/L)	Current Pathways (mg/L)	Lag time (year)	Reduction needed (%)	Option	Beyond GMP reduction (%)	Number of 10yr-stages	Target reached (years)
Ohoka	5.65	7.7 (4.7-11.1)	88	26.6 (0-49.1)	C-10	8.3%	3.2 (0-5.9)	120 (0-145)
					20kg-10	8.1%	3.3 (0-6.0)	120 (0-150)
					D-20	13.2%	2.0 (0-3.7)	110 (0-125)
Pegasus	5.65	3.2 (1.1-6.4)	>80 (used 100)	0 (0-11.7)	C-10	2.4%	0 (0-4.9)	0 (0-150)
					20kg-10	1.9%	0 (0-6.0)	0 (0-160)
					D-20	2.2%	0 (0-5.3)	0 (0-155)
West Eyreton	5.65	5.8 (3.6-8.4)	66	2.6 (0-32.7)	C-10	8.5%	0.3 (0-3.9)	70 (0-105)
					20kg-10	8.3%	0.3 (0-3.9)	70 (0-105)
					D-20	14%	0.2 (0-2.3)	70 (0-90)

Purple – concentration exceeds ZC limit
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)
C-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use
20kg-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use with a nitrate loss higher than 20kg/ha
D-20 : GMP + staged nitrate reductions of 20% per 10 year for dairy and 10% per 10 year for all other consented land use with a nitrate loss higher than 20kg/ha
Target reached in "0" years means nitrate concentration will always be below ZC limit if this scenario is implemented
Years is years after full implementation

Christchurch aquifer
Our Alternative Pathways scenario modelling results are summarised in Table 4-15; results for the dryland farming scenario are summarised in Table 4-16. Indicative nitrate time series plots are included in Appendix 9 and Figure 4-8. Our results show that:

- between ~10%-30% beyond Baseline GMP N loss reduction could be needed to reduce the projected Current Pathways nitrate concentrations for the zone to below the zone committee threshold of 3.8 mg/L under the scenarios we modelled here;
- between 1 and 3 stages of nitrate reductions are likely to be required under these modelled scenarios (this which equates to a 10% to 40% beyond Baseline GMP N loss reduction); and
- as per the PWSAs and WDC wells, although increasing the rate of beyond Baseline GMP N loss reduction would mean that nitrate limits are achieved more quickly, the inherent hydrological system lag times are the dominant driver in the time taken to meet limits;
- conversion of the entire 33,000 ha interzone source area into dryland farming could reduce the ultimate steady state nitrate concentration to under 1.5 mg/L. Although this is higher than current measured concentrations, it could maintain concentrations at below the 3.8 mg/L threshold (hence the "0" years target reached).

The economic impact of the dryland farming scenario is discussed in Harris (2019).

[51] All water samples collected from WDC community supply wells should meet the limit, recognising that it may take some time to achieve this

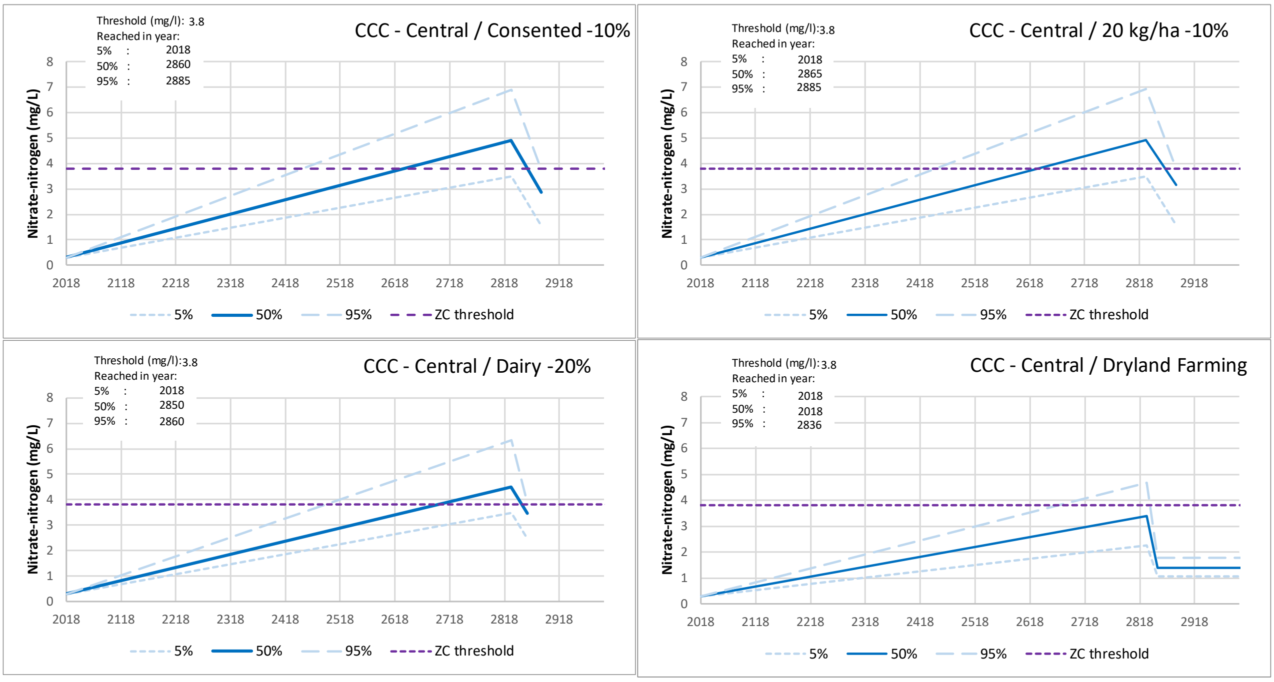


Figure 4-8: Indicative modelled nitrate concentrations for Central Christchurch deep aquifer

Table 4-15: Alternative Pathways - Nitrate modelling results for Christchurch aquifer

Site	ZC limit[52] (mg/L)	Current Pathways (mg/L)	Lag time (year)	Reduction needed (%)	Option	Beyond GMP reduction (%)	Number of 10yr-stages	Target reached (years)
West	3.8	3.97 (1.24 - 6.86)	200	7.3 (0-46.5)	C-10	9.2%	0.8 (0-5.1)	210 (0-250)
					20kg-10	8.8%	0.8 (0-5.3)	210 (0-255)
					D-20	16.6%	0.4 (0-2.8)	205 (0-230)
Central	3.8	5.24 (3.38 – 7.36)	800	29.6 (0-50.0)	C-10	9.2%	3.2 (0-5.5)	830 (0-855)
					20kg-10	8.8%	3.4 (0-5.7)	835 (0-855)
					D-20	16.6%	1.8 (0-3.0)	820 (0-830)
East	3.8	5.24 (3.38 – 7.36)	1200	29.6 (0-50.0)	C-10	9.2%	3.2 (0-5.5)	1230 (0-1255)
					20kg-10	8.8%	3.4 (0-5.7)	1235 (0-1255)
					D-20	16.6%	1.8 (0-3.0)	1220 (0-1230)

Purple – concentration exceeds ZC threshold
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)
C-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use
20kg-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use with a nitrate loss higher than 20kg/ha
D-20 : GMP + staged nitrate reductions of 20% per 10 year for dairy and 10% per 10 year for all other consented land use with a nitrate loss higher than 20kg/ha
Target reached in "0" years means nitrate concentration will always be below ZC limit if this scenario is implemented
Years is years after full implementation

[52] All water samples collected from CCC community supply wells should meet the limit, recognising that it may take some time to achieve this

Table 4-16: Dryland Farming scenario - Nitrate modelling results for Christchurch aquifer

Site	ZC threshold [53] (mg/L)	Current Pathways (mg/L)	Lag time (year)	Fully implemented by	Dryland Farming (mg/L)	Target reached (years)
West	3.8	3.97 (1.24 - 6.86)	200	2050	1.07 (0.44-1.72)	0 (0-210)
Central	3.8	5.24 (3.38 – 7.36)	800	2050	1.40 (1.07-1.78)	0 (0-810)
East	3.8	5.24 (3.38 – 7.36)	1200	2050	1.40 (1.07-1.78)	0 (0-1210)

Purple – concentration exceeds ZC threshold
Red – concentration exceeds MAV
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)
Target reached in "0" years means nitrate concentration will always be below ZC target if this scenario is implemented
Years is years after full implementation

[53] Average nitrate concentration in all samples collected from CCC wells >80 m deep should be less than the limit

Surface water
The results for the Alternative Pathways for representative spring-fed streams are presented in Appendix 11 and summarised for a representative sub-set in Table 4-17. Indicative time series plots are provided in Appendix 9 and Figure 4-9. Our results indicate that:

- Beyond Baseline GMP N loss reductions are likely to be required in the recharge zones of all the spring-fed streams, except for Saltwater Creek;
- between 5% to 50% beyond Baseline GMP N loss reduction could be required to reduce the projected Current Pathways nitrate concentrations for the zone to below the specific surface water zone committee limits under the scenarios we modelled here;
- between 0.5-6 stages of nitrate reductions are likely to be required under these modelled scenarios (this which equates to a total of 10% to 80% beyond Baseline GMP N loss reduction for land owners);
- the shorter spring-fed stream lag times mean that the time taken to achieve a target is more dependent on the lag time than is the case for drinking water wells.

Table 4-17: Alternative Pathways - Nitrate modelling results for surface water

Stream	ZC limit (mg/L)	Current Pathways (mg/L)	Lag time (year)	Reduction needed (%)	Option	Beyond GMP reduction (%)	Number of 10yr-stages	Target reached (years)
Silverstream[17] at Harpers Road	6.9	13.8 (7.7-20.3)	10	50.0 (10.4-66)	C-10	9.8%	5.1 (1.1-6.7)	60 (20-75)
					20kg-10	9.8%	5.1 (1.1-6.7)	60 (20-75)
					D-20	19.4%	2.6 (0.5-3.4)	35 (15-45)
Cust Main Drain	3.8	6.2 (3.7-9.2)	10	38.7 (0-58.7)	C-10	6.9%	5.7 (0-8.6)	65 (0-95)
					20kg-10	6.5%	6.0 (0-9.1)	70 (0-100))
					D-20	10.6%	3.6 (0-5.5)	45 (0-65)
Cam River	1.0	1.2 (0.8-1.9)	10	16.7 (0-47.4)	C-10	4.2%	3.9 (0-11.2)	50 (0-120)
					20kg-10	2.7%	6.3 (0-17.9)	75 (0-190)
					D-20	4.3%	3.8 (0-10.9)	50 (0-120)

Red – concentration exceeds ZC limit
Concentrations are presented in 50th percentile model results, with 5th and 95th percentile results between brackets, see section 3.6.1)
C-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use
20kg-10 : GMP + staged nitrate reductions of 10% per 10 year for all consented land use with a nitrate loss higher than 20kg/ha
D-20 : GMP + staged nitrate reductions of 20% per 10 year for dairy and 10% per 10 year for all other consented land use with a nitrate loss higher than 20kg/ha
Target reached in "0" years means nitrate concentration will always be below ZC limit if this scenario is implemented
Years is years after full implementation

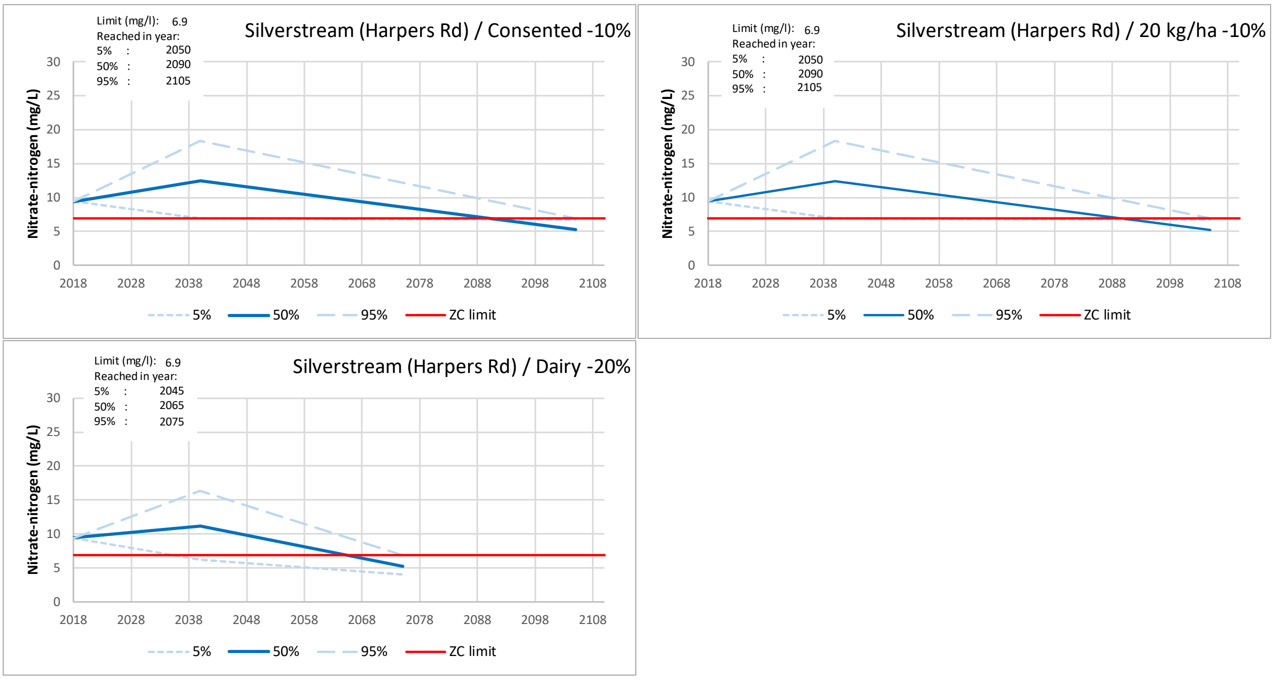


Figure 4-9: Indicative modelled nitrate concentrations for Silverstream at Harpers Road

Winter grazing options

Noting that uptake of the LWRP PC5 winter grazing PA allowances could cause a significant increase in nitrate in some water bodies, particularly Te Aka Aka, we modelled the nitrate loads for the various PA rule options discussed in Section 4.4.3 and presented the results as a percentage change from the Good Management Practice (GMP) N load[54] for eight stream catchments. Results are plotted in Figure 4-10 below. In all instances we assumed that 100% of the PA allowances are used. A detailed description of the assessment can be found in Appendix 7.

Focusing on the highly sensitive Te Aka Aka estuary, modelling results show[55] that:

- Nitrate discharges to the estuary from land without resource consent could be increased by ~30% under the current PC5 rules relative to the N load discharged from consented land, all assumed to be operating at Good Management Practice. This means that whilst successful implementation of GMP is expected to reduce nitrate discharges to the estuary by around 5-11% (see section 4.6.2), the land use intensification that can occur as a Permitted Activity under PC5 could offset this entirely and cause a total of >20% increase in nitrate discharges if the PA allowances were fully utilised by all eligible landowners.
- The N load increase would be reduced to ~15% under the Draft ZIPA option and ~25% under the Scenario 4 option.

The implications of these N loads for Te Aka Aka and other surface water bodies are discussed in more detail in Arthur *et al.* (2019). Bolton-Richie L. and Etheridge Z. (2018, Appendix 10) show that a 30% increase in nitrate discharges to the estuary could cause a significant increase in the eutrophication risk.

We have plotted the same data in Figure 4-11 under the 50% uptake scenario discussed above (i.e. the Current Pathways Scenario instead of PC5PA). N load increases in surface water bodies are more modest with a 50% uptake rate but are still significant in some water bodies such as Te Aka Aka, e.g. ~15% under Current Pathways.

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[54] See Lilburne *et al.*, 2019 for details on how GMP N loads were modelled
[55] Internal data source: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\AshleyCatchment_ZIPANSolnAssessment (version 1).xlsx

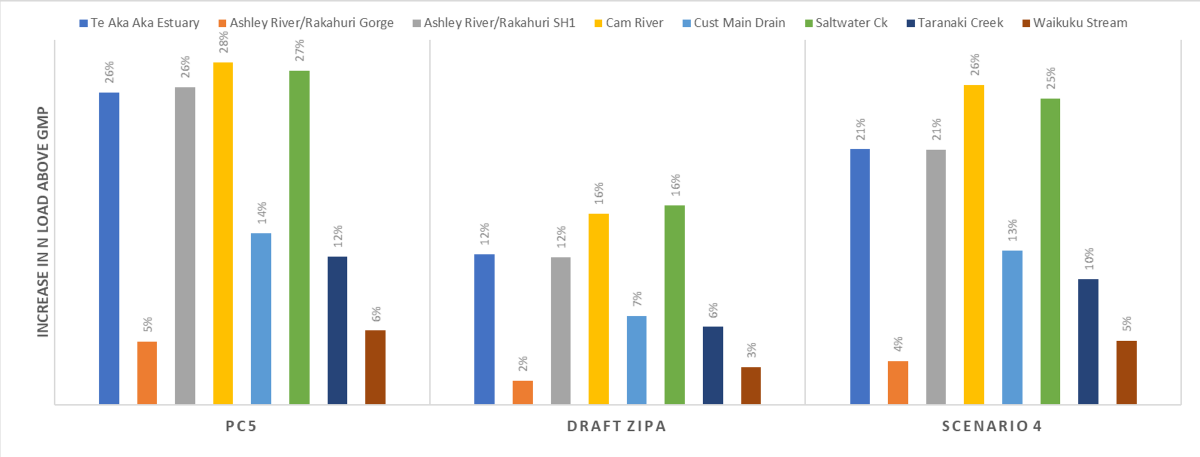

Figure 4-10: Changes in N loads under PA rule scenarios (100% uptake)

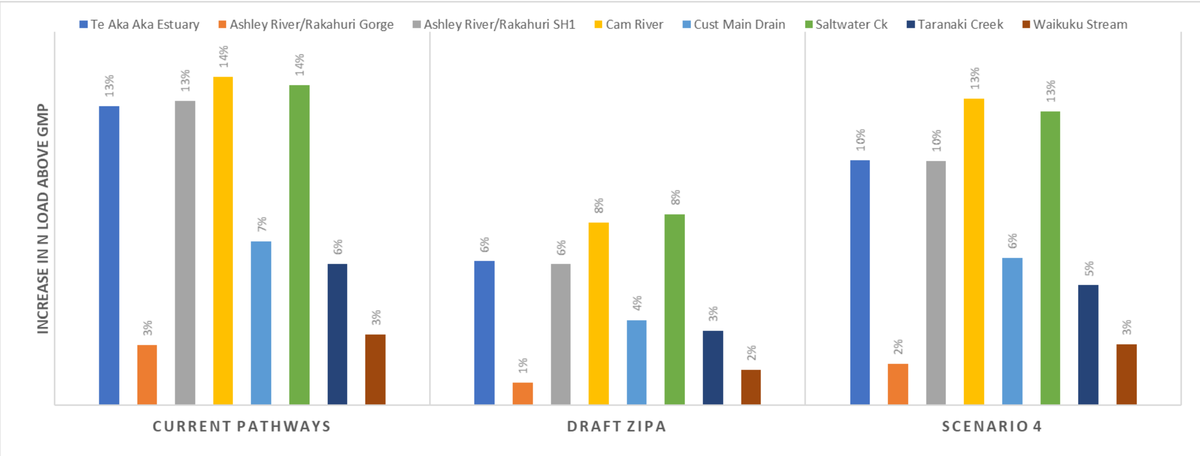

Figure 4-11: Changes in N loads under PA rule scenarios (50% uptake)

Lowering the PA threshold will *increase* the number of properties required to obtain resource consents and hence to produce Farm Environment Plans (FEPs) under the PC5 rules. A side effect of the reduced PA thresholds would therefore be:

- more rigorous management of both nitrate and the runoff contaminants (phosphorus, *E. coli* and sediment) on those properties; and
- additional costs for those properties which decide the undertake winter grazing and apply for a resource consent. The economic impact of the increased consent requirement associated with reduced PA rules is discussed in Harris (2019).

Our analysis[56] indicates that:

- Approximately 250 properties will need land use consent for irrigation and/or winter grazing within the Waimakariri zone under PC5;
- Scenario 4 would likely result in a small increase in the number of properties requiring consent (30 additional consents, i.e. ~280 in total)
- ~400 properties would need land use consent for irrigation and/or winter grazing under the Draft ZIPA winter grazing recommendation, an increase of roughly 150 consents.

Conclusions for surface water
A 20% reduction of nitrate losses by dairy farms and dairy related land use will have the most positive effect on predicted future nitrate concentrations at surface water receptors by reducing the time taken to achieve the recommended nitrate limits. Nitrate losses could increase significantly under the LWRP

[56] Internal data source: P:\Groundwater\Waimakariri\Landuse\Spreadsheet\PA rule ZIPA analysis_consentNos.xlsx

Permitted Activity rules (Plan Change 5) and offset nitrate loss reductions achieved with the staged reductions beyond GMP Baseline. Reducing the winter grazing area thresholds would provide a means by which these potential increases can be controlled.

4.7 Management areas

Arthur *et al.* (2019) evaluated the relative impact of the predominant surface water contaminants on stream health (and hence mahinga kai) and found that the contaminants which are mainly transported to waterways via surface runoff (i.e. the runoff contaminants) are the main driver in most waterways in the major Ashley River Catchment. Nitrate toxicity is a key driver of stream health in Silverstream, Ohoka Stream and Cust River/Cust Main Drain, e.g. the Waimakariri Northern Tributaries catchment.

This relative impact information was used by the zone committee, in combination with mapping of the main recharge areas for the Waimakariri zone receptors (see section 3.5), to understand where additional actions and controls are required to reduce nitrate discharges. The zone committee subsequently defined a Nitrate Priority Area (NPA) and a Runoff Priority Area (RPA),see Figure 4-12. The purpose of this division was to recognize that extra measures to reduce nitrates were required within the NPA for receptors to be able to reach the zone committee nitrate targets. These measures include beyond GMP N load reductions for farms within the NPA, as explained under our Alternative Pathways assessment (section 4.6.3).

The management areas were defined by:

1. Evaluating which contaminants are having the greatest impact in each water body (see Arthur *et al.,* 2019)
2. Grouping the surface water catchments where runoff contaminants are having the greatest impact and where nitrate toxicity effects are limited, and defining this area as the Runoff Priority Area (RPA)
3. Cutting the groundwater recharge zone for wells supplying water to more than 5,000 people and with a projected median nitrate concentration in excess of 5.56 mg/L under Current Pathways Scenario (see section 4.6.2) out of the RPA and including it in the NPA
4. Cutting areas of poorly drained soils out of the NPA Management Zone
5. Including the modelled Christchurch aquifer recharge zone within the NPA
6. Excluding the inland Waimakariri River catchment from the NPA

We have provided a series of maps which overlay the priority management area boundaries, soil drainage classes and surface water and groundwater catchments and recharge zones in Appendix 12. (This assessment was undertaken and the Appendix 12 maps produced in early 2018). The NPA boundary has since been modified slightly in Figure 4-12 to align with paddock boundaries where this could be done without deviating significantly from the modelling results-based boundary definition. The original and revised boundaries are shown in Appendix 12.

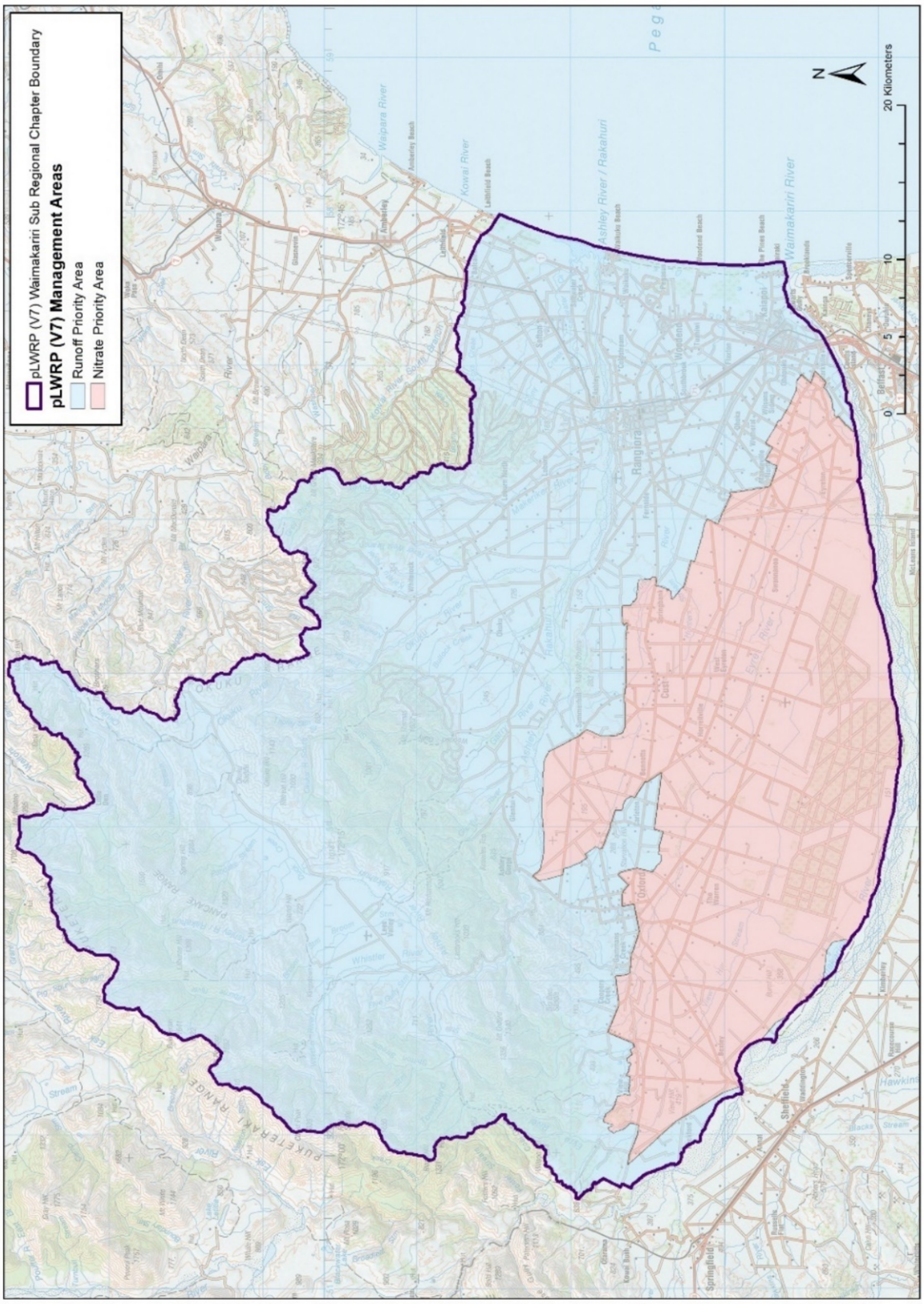

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Figure 4-12: Proposed Nitrate Priority Area

5 ZIPA Solutions Package assessment

5.1 Content and structure

In this section of the report we:

- describe the ZIPA nitrate management recommendations (referred to collectively as the Solutions Package) which aim to achieve the Priority Outcomes (section 1.2);
- present our modelling results to show how implementation of the statutory ZIPA recommendations for Beyond Baseline nitrate loss reductions will help to reduce surface water and groundwater nitrate concentrations;
- assess the benefits of the proposed PA winter grazing threshold reductions and the number of additional resource consents that could be required as a result of this change; and
- describe how on-the-ground actions could help to achieve the recommended nitrate limits.

5.2 Assessment results summary

Our assessment indicates that if the ZIPA nitrate management recommendations are implemented:

- nitrate concentrations in surface water and groundwater bodies recharged by the NPA area will reduce over time as a result of the beyond Baseline GMP N loss reductions;
- it is likely to take a long time to achieve the nitrate limits recommended by the WWZC in some receptors. Although this is predominantly due to lag effects, low rates of nitrate loss reduction is also a significant factor in catchments with mainly non-dairy land use and/or with only a small number of properties requiring land use consents and hence needing to reduce N losses;
- it may not be possible to achieve the surface water and groundwater limits recommended in the ZIPA in some receptors without requiring N loss reductions from land that does not require a resource consent under current LWRP rules and would not under the ZIPA recommendations;
- beyond Baseline GMP N loss reductions may ultimately be required for land which falls outside of the NPA in order to meet the ZIPA nitrate limits;
- nitrate concentrations in some receptors are likely to get worse before they get better due to lag effects;
- nitrate concentrations in receptors with short lag times and a high proportion of dairy land use could reduce relatively quickly (e.g. within the next 20 years); and
- implementation of GMP in line with current LWRP requirements is expected to reduce nitrate concentrations in the Ashley catchment. Although this reduction could be offset by the land use intensification that can occur under current LWRP Permitted Activity rules, the reduction in the winter grazing threshold recommended in the ZIPA will reduce the magnitude of this offset.
- successful implementation of non-statutory on-the-ground actions in parallel to the statutory N loss reductions could help to achieve nitrate limits more quickly and reduce the overall nitrate loss reduction requirements

We have presented our nitrate loss reduction modelling results in terms of the number of 10 year stages of beyond Baseline GMP reductions (see explanation in 5.3.1 below) that are likely to be required to achieve the ZIPA nitrate limits in the absence of on-the-ground actions. The 50th percentile model results indicate that:

- Zero to four 10-year reduction stages are likely to be required to achieve the WDC community water supply well nitrate limits
- Zero to five stages of reduction are likely to be required to achieve the private water supply well nitrate limits

- One to three stages of reduction are likely to be required to achieve the Christchurch aquifer indicative nitrate concentration thresholds (but the long inherent lag effects dwarf the length of these stages)
- Three to six reduction stages are likely to be required to achieve the spring-fed stream nitrate limits

5.3 ZIPA recommendations

5.3.1 Key statutory recommendations

Recommendations 3.15 and 3.18 of the ZIPA (and the associated Tables 3.2, 3.3 and 3.5 of the ZIPA) advise that Environment Canterbury should adopt nitrate limits for drinking water supply wells and streams in the Waimakariri section of the Land and Water Regional Plan. We presented these limits in section 4.5.2 and used these in our Nitrate Management Scenarios Assessment in section 4.6. We will also use these in our assessment of the ZIPA Solutions Package.

Recommendations 3.1 – 3.14 provide measures which aim to achieve the recommended nitrate limits. These recommendations essentially comprise ongoing staged reductions in nitrate losses from land with all the following characteristics:

- High nitrate loss rates;
- Located within the source/recharge zones of drinking water supply wells (and/or surface water body) receptors;
- Nitrate concentrations in the downgradient receptors do not meet the recommended limits at present and/or are unlikely to do so in the future, after accounting for nitrate loads already consented and/or travelling through the hydrological system towards these receptors (i.e. “in the post”).

The zone committee has proposed a staged approach to achieve the nitrate limits. They acknowledge that landowners will need time to make necessary adjustments to their farm practices. The zone committee proposes Baseline GMP (based on land use between 2009-2013) as the fixed starting point for a staged approach (*Rec 3.4*). Figure 5-1 illustrates the staged approach recommended by the zone committee.

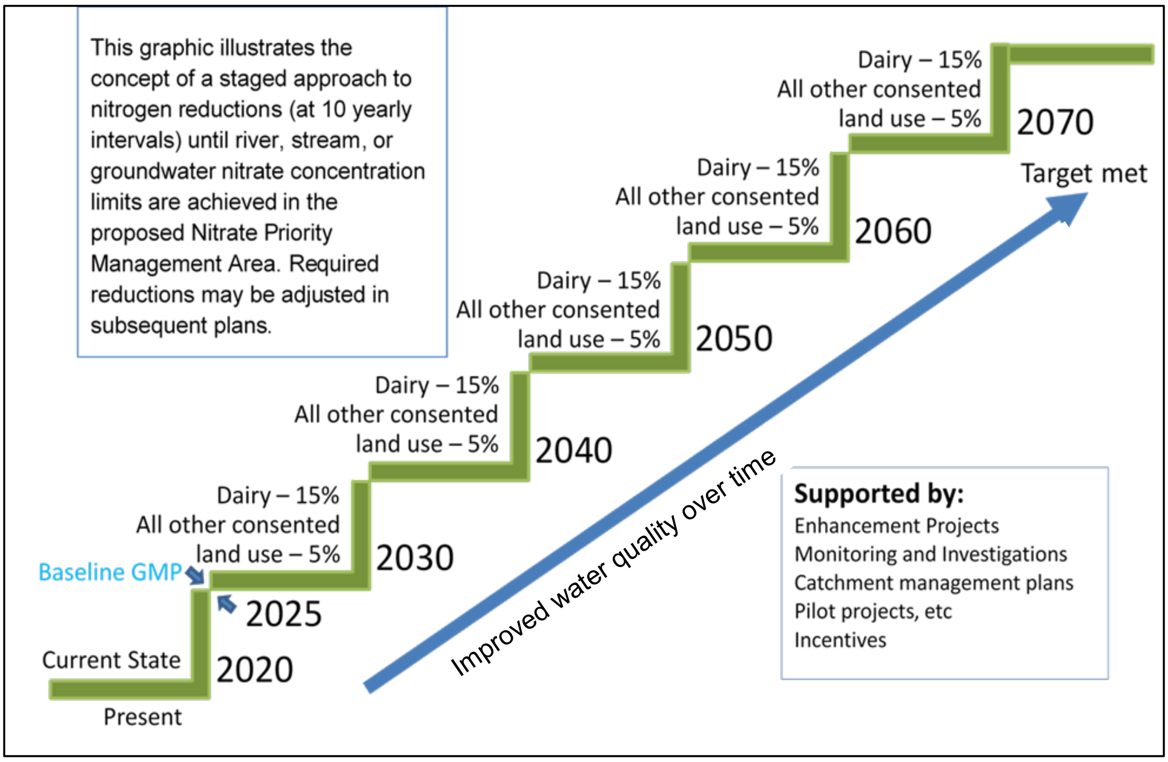

Figure 5-1: Proposed staged approach to nitrate reductions (adapted from ZIPA)

Beyond Baseline GMP N loss reductions only have to be achieved within the proposed Nitrate Priority Area (NPA) under the ZIPA recommendations, as the expectation is that landowners outside this area will focus on minimising overland flow of contaminants such as sediment, phosphate, nitrate and pathogens (*Rec 3.3*). We have presented the NPA in section 4.7 of this report.

The WWZC assumed full implementation of Baseline GMP in 2025 and a staged reduction of nitrate losses of 15% per 10 year period for land use classified as "dairy" (*Rec 3.5*) and 5% per 10 year for other consented land use (*Rec 3.6*) until the plan limits have been or are like to be met (*Rec 3.8*).

To avoid unreasonable impacts on low nitrate loss farming activities the zone committee proposed a "floor", below which further loss reductions beyond Baseline GMP are not required[57] (*Rec 3.10*).

The ZIPA proposes to restrict the rules for permitted activity winter grazing. This includes lowering the area threshold for properties subject to the farming rules to 5 ha (instead of 10 ha) and lowering the permitted winter grazing thresholds in the LWRP [as per Plan Change 5] (*Rec 3.11*).

5.3.2 Key non-statutory recommendations

The ZIPA includes various non-statutory recommendations, which we refer to as on-the-ground actions. The most important on-the-ground recommendations are **3.19** and **3.24**:

Rec 3.19 – recommends that Environment Canterbury makes sufficient resources available to enable significant improvements to continue to be made in the understanding of the Waimakariri Water Zone groundwater system and its connection with the Christchurch aquifer and spring-fed streams. The

[57] For simplicity, we modelled this as a 20 kg/ha threshold. The proposed LWRP plan rule uses a different threshold: Dairy farms where the reduction in N leaching rates associated with a 15% beyond Baseline reduction are less than 3 kg N/ha are not required to reduce nitrate losses; all other consented land uses where the reduction in N leaching rates associated with a 5% beyond Baseline reduction are less than 1 kg N/ha are not required to reduce nitrate losses. These two thresholds are mathematically equivalent for our modelling purposes.

outcome of this work should be an updated assessment of the direction of travel and likely future nitrate concentrations provided to the zone committee, partners and stakeholders in 2025.

This recommendation will allow us to give a better estimation of how land use changes in the Waimakariri Zone affect groundwater and surface water quality both within the zone and in Christchurch.

Rec 3.24 – recommends that the Zone Committee support the investigation and assessment of on-the-ground actions to address nitrate issues (for example, Managed Aquifer Recharge [MAR], stream augmentation, woodchip bioreactors, wetland creation, and water storage), including:

a) That Environment Canterbury undertake a zone-wide study to assess the feasibility, costs and measures required to implement appropriate actions (to be completed by the end of 2019) to inform the development of sub-catchment management plans.

b) That the Waimakariri section of the Land and Water Regional Plan should be assessed to ensure that these activities are enabled where appropriate in the Waimakariri Zone.

Other non-statutory recommendations that could help to achieve Priority Outcomes related to nitrate include:

Rec 3.7 - The zone committee encourage industry and local authorities to provide incentives to achieve nutrient reductions greater than the recommended reductions in this ZIP Addendum.

Rec 3.23 - That Environment Canterbury continues to work with sector and research groups to encourage the further development and implementation of tools and techniques to reduce nitrogen leaching.

Rec 3.16 - That Environment Canterbury, Waimakariri District Council and Canterbury District Health Board work together to:

a) develop a programme for testing and reporting of water quality in private drinking water supply wells, and

b) raise awareness of health impacts from high nitrates in drinking water.

Rec 3.17 - Environment Canterbury and Waimakariri District Council should consider provision of guidance and information regarding a minimum depth for new drinking water supply wells and well head security, to provide better water quality protection.

Rec 3.20 - That Environment Canterbury commences a review of the Waimakariri section of the Land and Water Regional Plan in 2030 to incorporate new information and understanding of:

a) how social, cultural, economic and environmental systems have responded and
b) whether we are on track to meet the plan nitrate limits.

Rec 3.22 - That Environment Canterbury works with the Waimakariri community and Ngāi Tūāhuriri Rūnanga, to respond accordingly to new information, emerging opportunities and technology, and review the Waimakariri section of the Land and Water Regional Plan at least every 10 years.

5.4 Nitrate loss reduction modelling results

5.4.1 Overview

The key questions addressed by our solutions assessment are:

1. How much will dairy and other consented land users need to reduce their nitrate losses in order to achieve the recommended nitrate limits?
2. Will the staged nitrate loss reductions be sufficient to achieve the recommended nitrate limits?
3. How long will it take to achieve the limits?

The amount of time needed to achieve the recommended nitrate concentration limits is dependent on the lag-time for each receptor, the total nitrate reduction needed and the reduction per 10-year stage.

Our modelling results for the ZIPA Solutions Package are presented in section 5.5 (Drinking water) and 5.6 (Surface water). We have used the Current Pathways scenario as baseline for this solution, which means that by 2025 GMP is fully implemented and that 50% of eligible landowners utilise their PA winter grazing allowances within reasonable biophysical constraints, as described in Lilburne *et al.* (2019). Our assessment considers the nitrate reductions associated with both the beyond Baseline GMP N loss reductions and the reduction in winter grazing PA allowances (section 5.8) recommended in the ZIPA.

5.4.2 Nitrate load reduction maps

We have produced a series of maps to provide an indication of the beyond Baseline GMP N loss reductions that would be required to meet the recommended nitrate limits for our for 50th percentile model results for dairy farms and for other consented land use. We presented these as the number of N loss reduction stages required to meet nitrate limits (Figure 5-2 and Figure 5-3) and the total percentage N loss reduction (relative to 2009-2013 Baseline GMP) required by consented dairy an non dairy landuse (Figure 5-4). Maps for the 5th and 95th percentile model results can be found in Appendix 13.

We generated the nitrate loss reduction maps by:

- calculating the percentage difference between the modelled Current Pathways nitrate concentration and the ZIPA nitrate limit or threshold in each receptor for the 50th percentile model results: this shows the required percentage reductions in nitrate concentrations at each receptor;
- running our groundwater model with a nitrate load layer based on the ZIPA N loss reduction rates (for one 10 year reduction stage) within the NPA and the recommended PA rule thresholds and comparing the results against the Current Pathways nitrate concentration results to determine the percentage concentration reduction achieved;
- determining the percentage concentration reduction achieved per 10 year N loss reduction stage within the NPA (excluding the PA rule change-based N loss reduction) for each receptor;
- and applying these percentages to each catchment area polygon. Where catchment areas for different receptors overlap (which is commonplace), the receptor requiring the greatest reduction drives the % reduction for the overlapping area on the map;
- calculating the number of reduction stages required to achieve the overall required concentration reduction. We have presented these reduction stages in fractions (Figure 5-2) as well as whole numbers (Figure 5-3), to indicate how far off the recharge zone area would be from the next stage, as 0.5 – 1.4 stages is one stage, 1.5 – 2.4 stages is two stages etc. This is important information as the jump between two stages means a difference of 15% in required beyond GMP N load reductions for dairy farmers;
- multiplying the number of stages by 15% for dairy and 5% for consented non-dairy to determine the total % reduction required by these land uses under the ZIPA recommendations; and
- where the total % reduction is >90%, plotting these areas as >90%.

Note that in some instances our 95th model results (see Appendix 13) show that >100% reductions would be required for dairy farms (i.e. more than 6.7 reduction stages) because we have not capped the maximum feasible % reduction when generating the maps. This means that, for areas where >90% reductions are shown as being required for dairy farms, non-dairy farms may need to make significantly greater N loss reductions than our results show.

For reference, information provided in Harris (2019) indicates that, based on currently available nitrate loss mitigation techniques and farm economics, N loss reductions in excess of 30% would render average dairy, sheep and beef and arable farms non-viable; land use change would need to occur.

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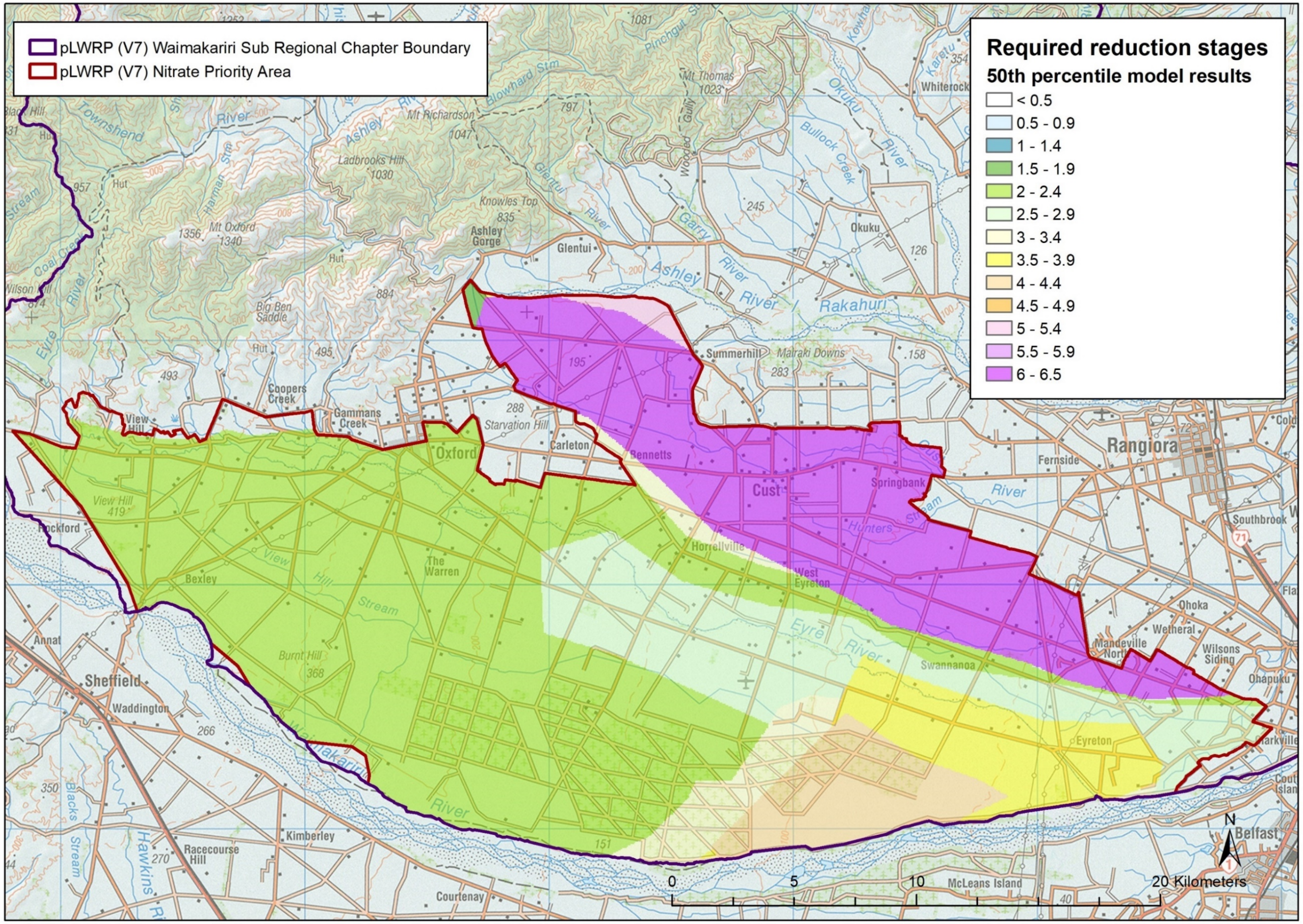

Figure 5-2: **50th percentile – N load reduction stages required at irrigated properties (dairy and dairy support) to reach ZIPA targets at receptors**

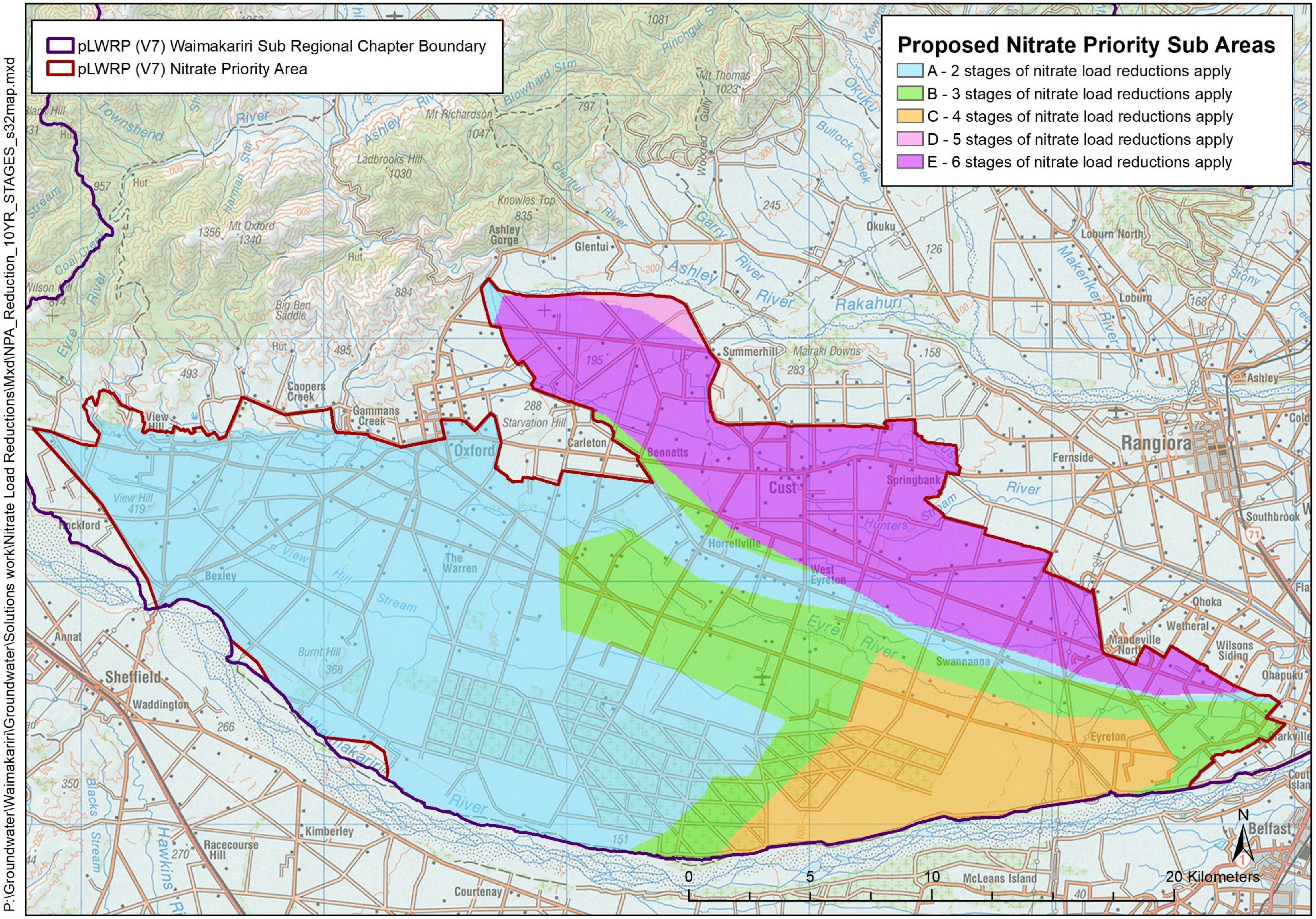

Figure 5-3: Proposed Nitrate Priority Sub Areas with required beyond GMP nitrate load reductions stages based on 50th percentile model results

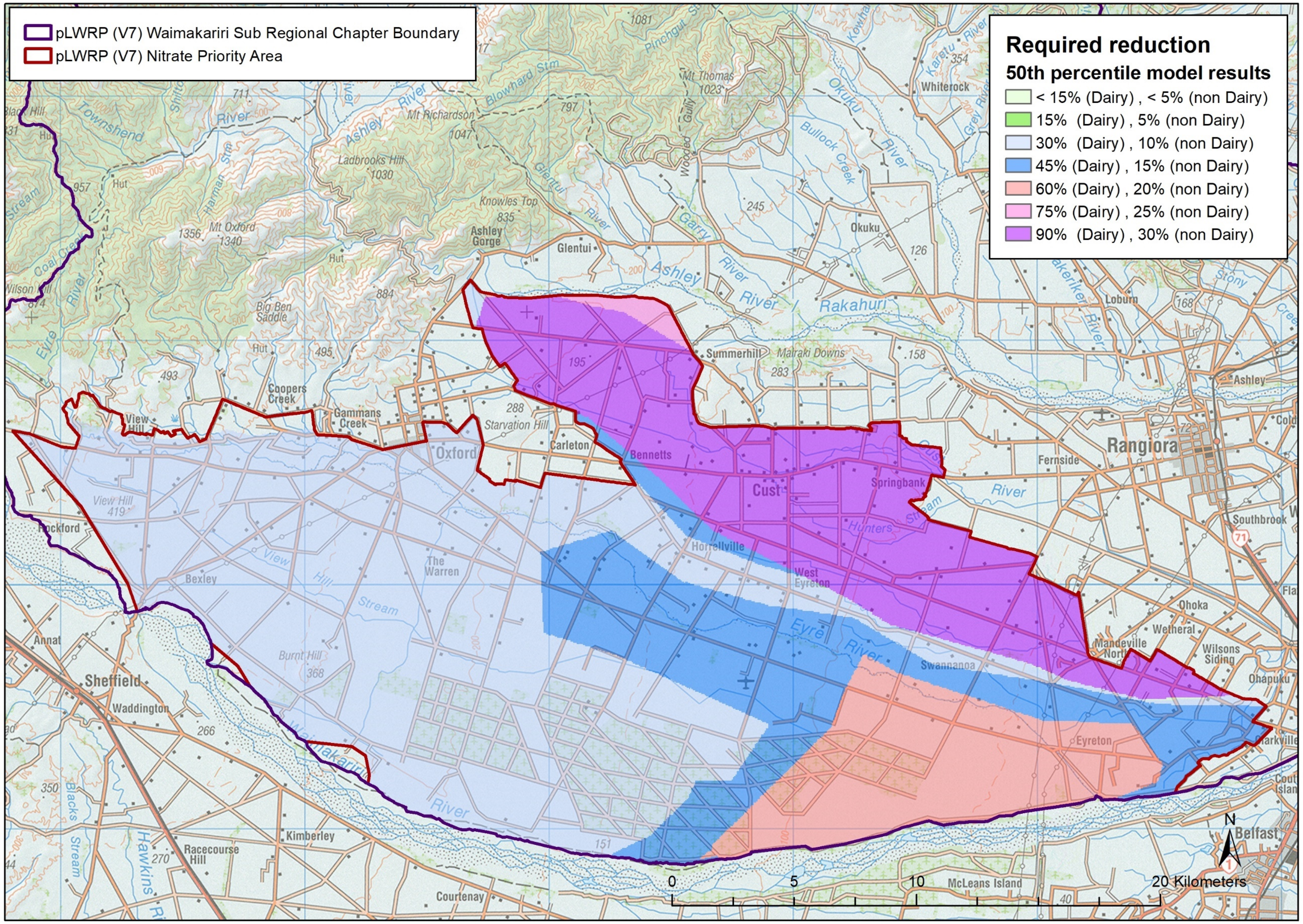

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Figure 5-4: 50th percentile – Percentage beyond GMP N load reductions required at irrigated dairy and non dairy properties to reach ZIPA targets at receptors

5.5 Statutory ZIPA recommendation modelling results for drinking water

5.5.1 Private Water Supply Areas (PWSA)

Modelled future nitrate concentrations in the PWSAs are presented in tables Appendix 13. Indicative nitrate time series plots are presented in Appendix 9 and Figure 5-5.

Our 50th percentile modelling results for the PWSAs suggest that in order to meet the ZIPA nitrate limit of 5.65 mg/L N as a median in each of the PWSAs:

- Beyond Baseline GMP N loss reductions are likely to be required in the recharge zones of 15 of the 23 PWSAs;
- Whilst 15 of the PWSAs will exceed the zone committee's nitrate concentration limit under Current Pathways, the ZIPA Solution Package reduces the median nitrate concentration in these PWSAs by~ 9.5% in the first stage and by ~8% for subsequent stages. Higher first stage reductions reflect the benefits of changing the PA winter grazing rules;
- For these 15 PWSAs, between 1 and 5 reduction stages would be required to reach the zone committee nitrate concentration limit for private wells; and
- For these 15 PWSAs it will take ~60 to ~125 years to reach the zone committee nitrate concentration limit for private wells.
- Nitrate loss reductions are not required for eight of the PWSAs (Fernside, Flaxton, Horellville, Mandeville, Rangiora, Waikuku, West Eyreton (shallow wells only) and Woodend) under our 50th percentile model projections (and Waikuku is the only PWSA that does not need any staged reductions under the 95th percentile model results). This means a total of 1305 private supply wells (49%) do not need a reduction under the 50th percentile (median) modelling results.

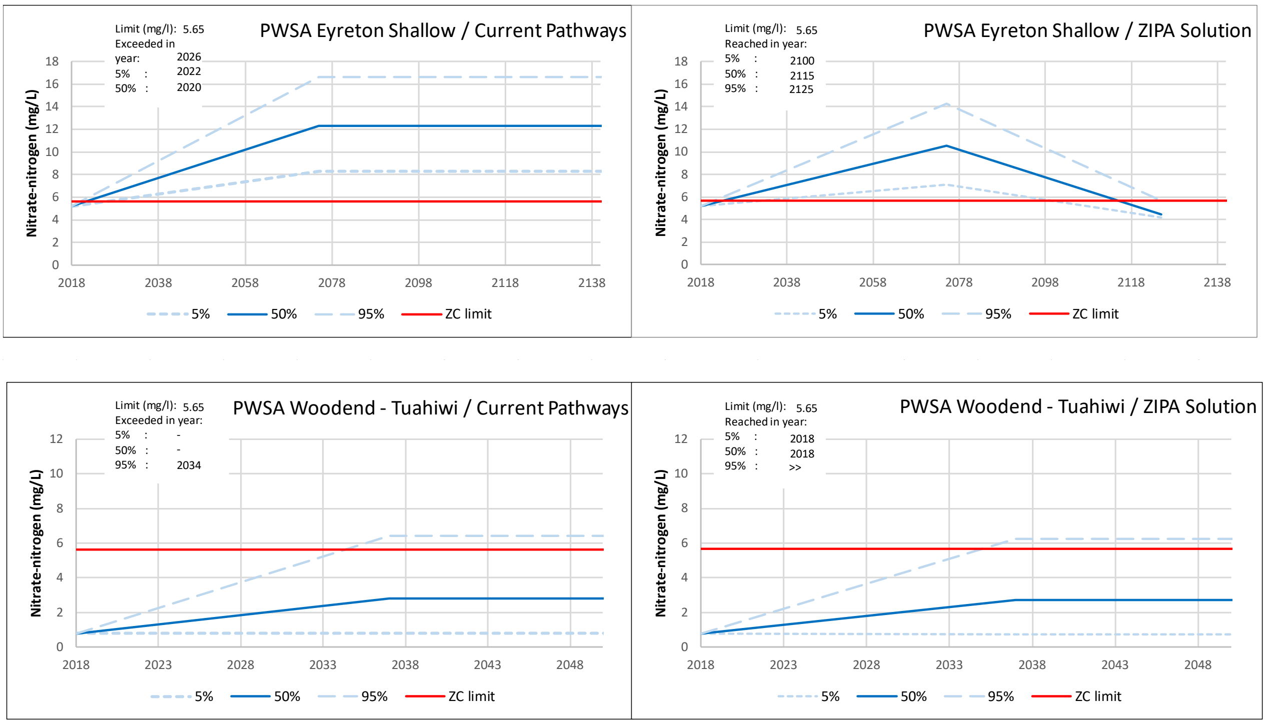


Figure 5-5: Indicative nitrate concentrations over time under Current Pathways and ZIPA solution for PWSA Eyreton Shallow and Woodend-Tuahiwi

There are 61 deep (>50 m) private water supply wells in total and 2,580 shallow wells. Of the deep wells, our modelling results indicate that 10% will still exceed the MAV for nitrate 50 years after implementation of the ZIPA Solutions Package. For the shallow wells this percentage is 8%. This shows that drilling deeper wells to avoid increasing nitrate concentrations is unlikely to be a viable solution in the long term.

The ZIPA nitrate target for private water supply wells indicates that 50% or more of the well samples within a PWSA should have nitrate concentrations below 5.65 mg/L. This recommendation per PWSA provides a higher degree of certainty in the number of wells exceeding the drinking water limit of 11.3 mg/L than the alternative approach using a larger spatial unit for evaluation (e.g. the entire Waimakariri Zone). This is apparent in the previous results presented in section 2.3.5: assessing the number of wells likely to breach the drinking water limit based on the ***mean*** nitrate concentration per GAZ gives a higher number of wells (160) than an equivalent calculation using the ***mean*** nitrate concentration for the whole Waimakariri zone (90 wells). This is because use of smaller spatial units mean that nitrate concentrations in private drinking water wells are addressed in all areas, including nitrate "hot-spot areas"; use of larger spatial units "averages-out" the hot-spot concentrations with low nitrate concentration areas (e.g. the area east of Rangiora, where the Ashley River/Rakahuri loses large volumes of low nitrate water to the aquifer).

In section 2.3.5 we presented graphs of the relationship between the measured ***mean*** annual nitrate concentration in the Canterbury Plains and the percentage of samples or wells that exceeded the nitrate limit of 11.3 mg/L. We have used the equivalent ***median*** nitrate relationship in conjunction with our 50^{th} percentile model results to estimate the percentage of samples or wells likely to exceed the zone committee nitrate limit of 5.65 mg/L for all of the PWSAs in combination (e.g. the entire Waimakariri Zone).

We have evaluated the impact of using smaller spatial units (the PWSAs) to assess compliance with a 5.65 mg/L median N limit current measured, Current Pathways and the ZIPA solution in Table 5-1. The results are presented for the entire Waimakariri Zone, but the concentrations are weighted by the numbers of wells per PWSA, therefore taking into account the local variance in nitrate concentrations. Appendix 14 gives an overview of the wells per PWSA that exceeded the nitrate drinking water MAV of 11.3 mg/L and the percent of samples per PWSA exceeding 5.65 mg/L.

The data presented in Table 5-1 suggest that the zone committee target (at least 50% of the well samples below 5.65 mg/L) for the private wells in the Waimakariri Zone is likely be met (or very close to) for all the presented scenarios.

Table 5-1: Estimated % of samples and wells that breach the zone committee limit for private supply wells and the Drinking Water MAV of 11.3 mg/L N based on median concentrations[58]

Scenario	Median based on PWSA wells[59]	% samples >5.65 mg/L	% samples > 11.3 mg/L	#wells > 5.65 mg/L	#wells > 11.3 mg/L
Current	3.1	26%	6%	720 (27%)	165 (6.2%)
Current Pathways	5.6	51%	11%	1,005 (38%)	270 (10.3%)
Zipa Solution 1 stage	5.1	46%	10%	940 (36%)	250 (9.4%)
Zipa Solution 2 stages	4.6	41%	9%	890 (34%)	230 (8.7%)
ZIPA Solution 5 stages	3.3	27%	6%	740 (28%)	170 (6.5%)

One key assumption for our assessment is that the spatial variance in nitrate concentrations within a PWSA is similar to that across the Canterbury Plains. In reality the spatial variability within each PWSA is different. The spatial resolution of our groundwater quality monitoring data are currently insufficient to assess local varience in nitrate concentrations . Recommendaiton 3.16 of the ZIPA proposes that Environment Canterbury, Waimakariri District Council and Canterbury District Health Board work together to develop a programme for testing and reporting of water quality in private drinking water supply wells. Implementation of this recommendation would provide the information required to resolve this critical area of uncertainty and the improved understanding could be used to inform nitrate limit-setting in a future review of the Waimakariri section of the LWRP. We provide more detailed information on modelling results for nitrate concentrations in private wells (per PWSA) in Appendix 14.

5.5.2 WDC Community Supply Wells

The modelled nitrate concentrations at the WDC Community Supply sites for the ZIPA Solutions Package are presented in Appendix 13. Indicative nitrate time series plots are presented in Appendix 9 and Figure 5-6.

Our 50th percentile modelling results suggest that:

- Beyond Baseline GMP N loss reductions are likely to be required in the recharge zones of 7 WDC Community Supplies, or 6 if the Poyntzs Rd well is excluded (given that this is being replaced with an alternative supply by WDC in the near future);
- Whilst half of the WDC Community Supply Schemes are expected to exceed the zone committee's nitrate concentration limit under Current Pathways, the ZIPA Solution Package reduces the median concentration at these WDC supply wells by ~9% in the first stage and by ~8% for subsequent stages. Higher first stage reductions reflect the benefits of changing the PA winter grazing rules;
- Between 1 and 5 reduction stages would be required to reach the zone committee nitrate concentration limit for those WDC community supply wells expected to exceed the ZIPA limit;

[58] Internal source: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Median Nitrate PWSA\PWSAWells_median_N.xlsx

[59] The median for the Waimakariri Zone has been calculated by multiplying the 50th percentile modelled median nitrate-N concentration for each PWSA by the number of wells in each PWSA and then dividing the result by the total number of PWSA wells (2,641).

- It could take ~30 to ~125 years to reach the zone committee nitrate concentration limit in WDC community supply wells expected to exceed the ZIPA limit.
- WDC supply Waikuku is the only community supply that does not need any reductions in the 5th, 50th and 95th percentile model results.

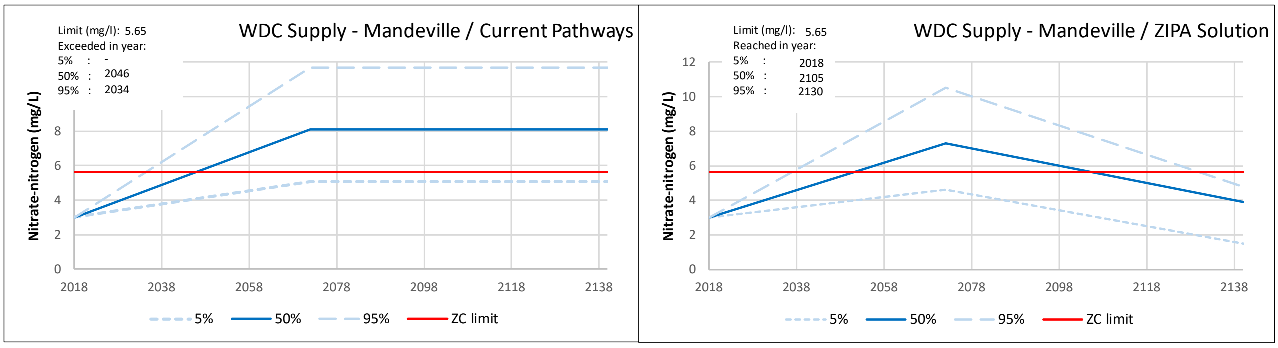


Figure 5-6: Indicative nitrate concentrations over time for WDC Supply Mandeville

5.5.3 Christchurch aquifer

Our modelled ZIPA Solutions Package nitrate concentrations and time taken to achieve the 3.8 mg/L Christchurch aquifer nitrate threshold[60] are presented in Appendix 13. Indicative nitrate time series plots are presented in Appendix 9 and Figure 5-7. We have also presented some sensitivity analysis modelling results in Figure 5-8 to provide an indication of the extent to which higher rates of nitrate loss reduction would improve the time taken to achieve the ZIPA nitrate threshold and reduce the magnitude of the peak nitrate concentration.

The 50th percentile model results suggest that:

- Two stages of reductions are likely to be required to achieve the threshold;
- Whilst nitrate concentrations in the Christchurch aquifer are expected to exceed the zone committee's nitrate concentration threshold under Current Pathways, the ZIPA Solution Package reduces the median concentration in the presented CCC community supply areas by ~12% in the first stage and by ~11% for subsequent stages. Higher first stage reductions reflect the benefits of changing the PA winter grazing rules;
- Depending on the lag-times, it could take between 205 years (West Christchurch) and 1225 years (East Christchurch) for nitrate concentrations to fall below the threshold; and
- Doubling the beyond Baseline GMP N loss reduction rate (from 15% and 5% for Dairy and non-dairy to 30% and 10%) could reduce peak nitrate concentrations by up to 0.7 mg/L and cause that nitrate concentrations fall back to within the 3.8 mg/L threshold ~10 years earlier than they would do under the ZIPA rates.

[60] in wells deeper than 80 m

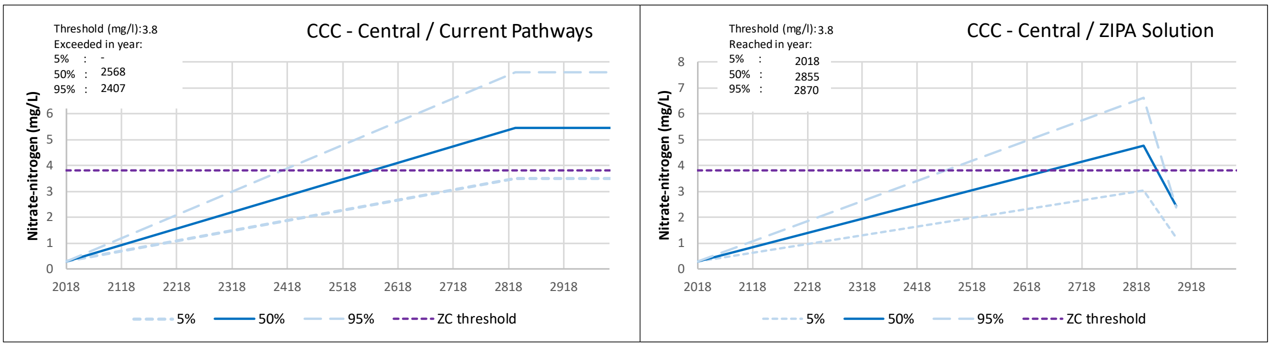


Figure 5-7: Indicative modelled nitrate concentrations for CCC Supply area Central

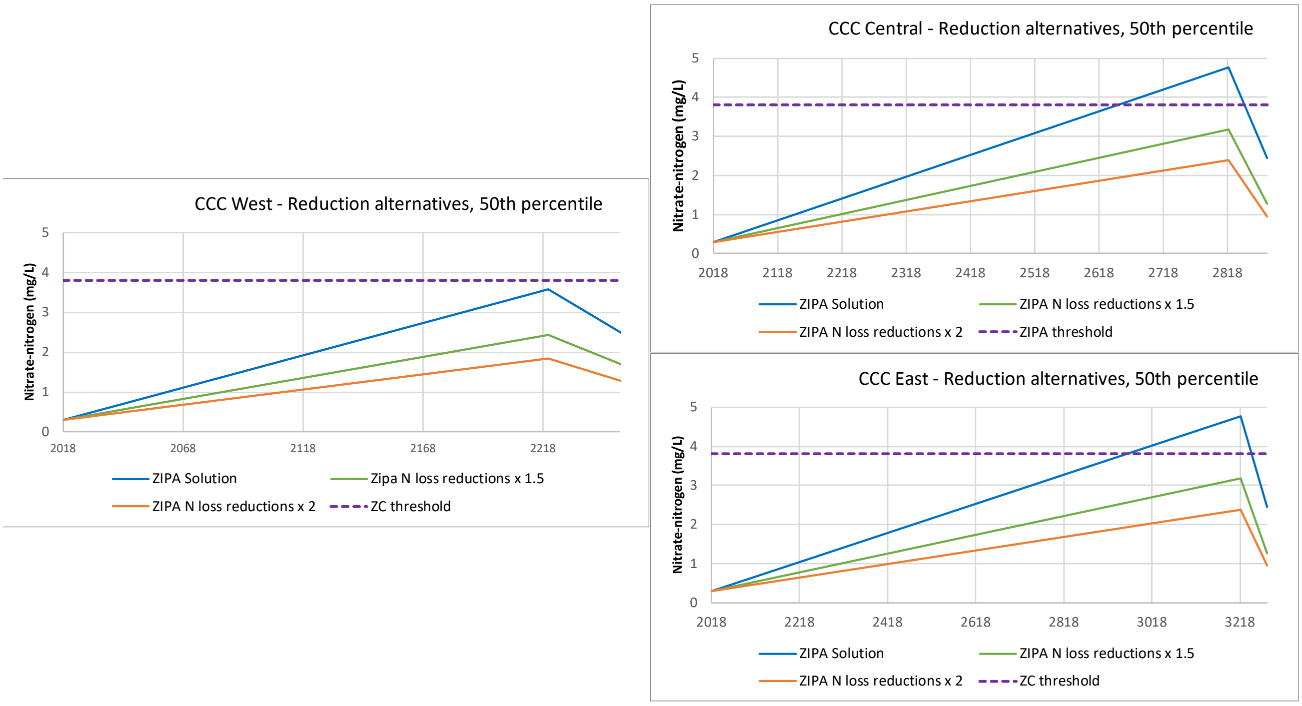


Figure 5-8: Sensitivity analysis results for increased nitrate loss reductions (x 1.5 and x 2)

5.6 Statutory ZIPA recommendation modelling results for Waimakariri Northern Tributaries

Our modelled nitrate concentrations for the Waimakariri Northern Tributaries catchment spring-fed streams are presented in Appendix 13. Indicative nitrate time series plots are presented in Appendix 9 and Figure 5-9.

Our 50th percentile modelling results for the spring-fed streams suggest that:

- Beyond Baseline GMP N loss reductions are likely to be required in the recharge zones of all the spring-fed streams, but only the recharge areas of Cust Main Drain, Silverstream (Harpers Road and Island Road) and Ohoka Stream are covered by the NPA;
- Whilst those four streams will exceed the zone committee's nitrate concentration limit under Current Pathways. The ZIPA Solution Package reduces the median concentration at these receptors by ~9.5% in the first stage and by ~8.5% for subsequent stages. Higher first stage reductions reflect the benefits of changing the PA winter grazing rules;

- Between 2 and 6.5 reduction stages would be required to reach the zone committee nitrate concentration limit for these four spring-fed stream;
- It is expected to take ~35 to ~75 years to reach the zone committee nitrate concentration limit these four spring-fed streams.
- The Cust Main Drain and Ohoka Stream results emphasise the need for implementation of the on-the-ground actions recommended by the zone committee in order to achieve targets earlier (see section 5.7).
- As the recharge zone for the Cam River is outside the NPA, the nitrate concentration at this receptor will not be able to reach the zone committee target of 1.0 mg/L (see Figure 5-9). This emphasises the need for implementation of the on-the-ground actions recommended by the zone committee in order to achieve targets without Beyond GMP reductions (see section 5.7).

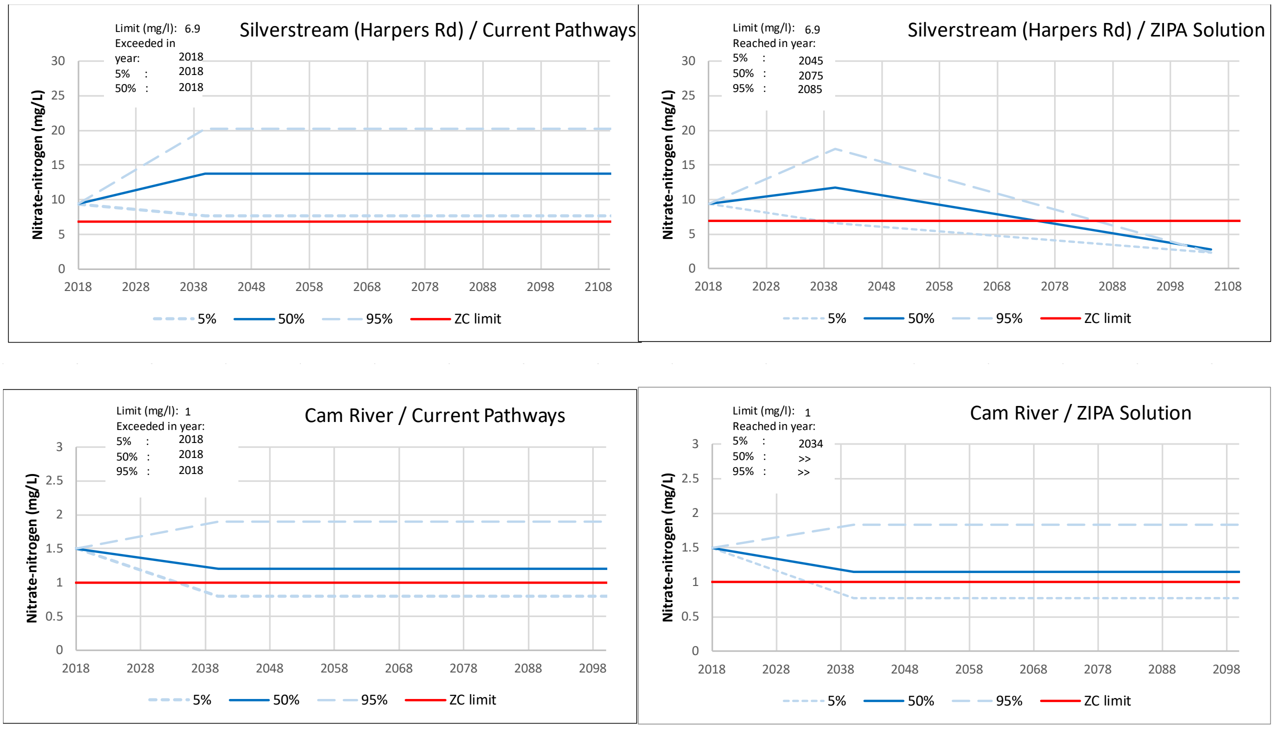


Figure 5-9: Indicative modelled nitrate concentrations for Silverstream at Harpers Road and Cam River

5.7 Non-statutory ZIPA recommendation assessment

Noting that, based on current N loss mitigation options:

1. land use change would be required to deliver N loss reductions in excess of 30% (see Harris, 2019); and that
2. >30% reductions are required across a large part of the Waimakariri zone according to our "middle of the road" modelling results,

on-the-ground actions such as described in section 4.4.3 (Managed Aquifer Recharge [MAR] and stream augmentation [SA]) are an important part of the solutions package and may be required in the long term to achieve the recommended limits.

A successful pre-MAR infiltration trial has already been completed in the Silverstream catchment (see Appendix 8); the trial is currently being extended into a MAR trial which has the potential to reduce the time taken to achieve the Silverstream and Kaiapoi River nitrate limits and the associated beyond Baseline GMP N loss reduction requirement significantly. Nitrate concentrations in water supply wells downgradient of the MAR trial site are also likely to reduce.

Megaughin and Lintott (2019) explain that Cust River (and hence Cust Main Drain) is likely to already be informally augmented by discharges from the Waimakariri Irrigation Limited and stockwater race network. Current Regional Plan Rules include provisions for further augmentation. The median flow of the Cust Main Drain is approximately 1 m^3/s; further augmentation with 0.2 m^3/s of low nitrate Waimakariri River water via the race network, for instance, could reduce nitrate concentrations by 20% which would reduce the beyond Baseline GMP N loss requirement by 50%.

Although more work is required to demonstrate feasibility, commit funding and develop a governance mechanism to deliver stream augmentation and MAR, the work already completed and infrastructure that is already in place mean that there is a genuine possibility of achieving nitrate limits more quickly, with fewer stages of beyond Baseline GMP N loss reductions, via on-the-ground actions.

In Section 3.9.3 we discussed the misalignment between modelled and measured nitrate concentrations in the Ashley River/Rakahuri, and the use of a crude scaling factor to resolve this. In Section 3.10 we discussed uncertainty around nitrate attenuation in the near coastal zone and the zero attenuation assumption used in our modelling results. Nitrate attenuation processes could limit the lag-related nitrate concentration increases projected in our modelling results which would mean that lower nitrate reduction losses from farmland are required to achieve the same end result.

Kreleger and Etheridge (2019) explore a series of non-statutory action, nitrate attenuation and Ashley River/Rakahuri nitrate load uncertainty scenarios to illustrate the effect of these factors on the nitrate loss reductions required to achieve the recommended nitrate concentration limits.

5.8 PA winter grazing thresholds

5.8.1 ZIPA recommendation

The ZIPA recommends the following winter grazing permitted activity [PA] rules (Table 5-2):

Table 5-2: Permitted activity rules under ZIPA Solutions Package

Option	Winter grazing allowances based on property size (ha)				
	< 5	<10	10 – 100	100 – 1,000	>1,000
ZIPA	No consent	5 ha	5 ha	5%	50 ha

5.8.2 Nitrate modelling results

We modelled the nitrate loads that could be discharged as a PA[61] under the ZIPA limits and presented the results as a percentage change from the Good Management Practice (GMP) N load[62] for eight stream catchments. Full details of this analysis are provided in Appendix 7 with key information from this appendix summarised below. Results for the ZIPA Solutions Package are plotted in Figure 5-10 below for both 50% and 100% uptake rate assumptions.

Focusing on the highly sensitive Te Aka Aka estuary, modelling results show[63] that the increase in nitrate load above GMP would be reduced from 30% under the current LWRP rules to ~15% under the ZIPA recommendation for 100% uptake of the PA rules and from 13% to ~10% for 50% uptake.

The implications of these N loads for Te Aka Aka and other surface water bodies are discussed in more detail in Arthur *et al.* (2019).

[61] Based on the assumptions discussed in Section 3.8
[62] See Lilburne *et al.,* 2019 for details on how GMP N loads were modelled
[63] Internal data source: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\AshleyCatchment_ZIPANSolnAssessment (version 1).xlsx

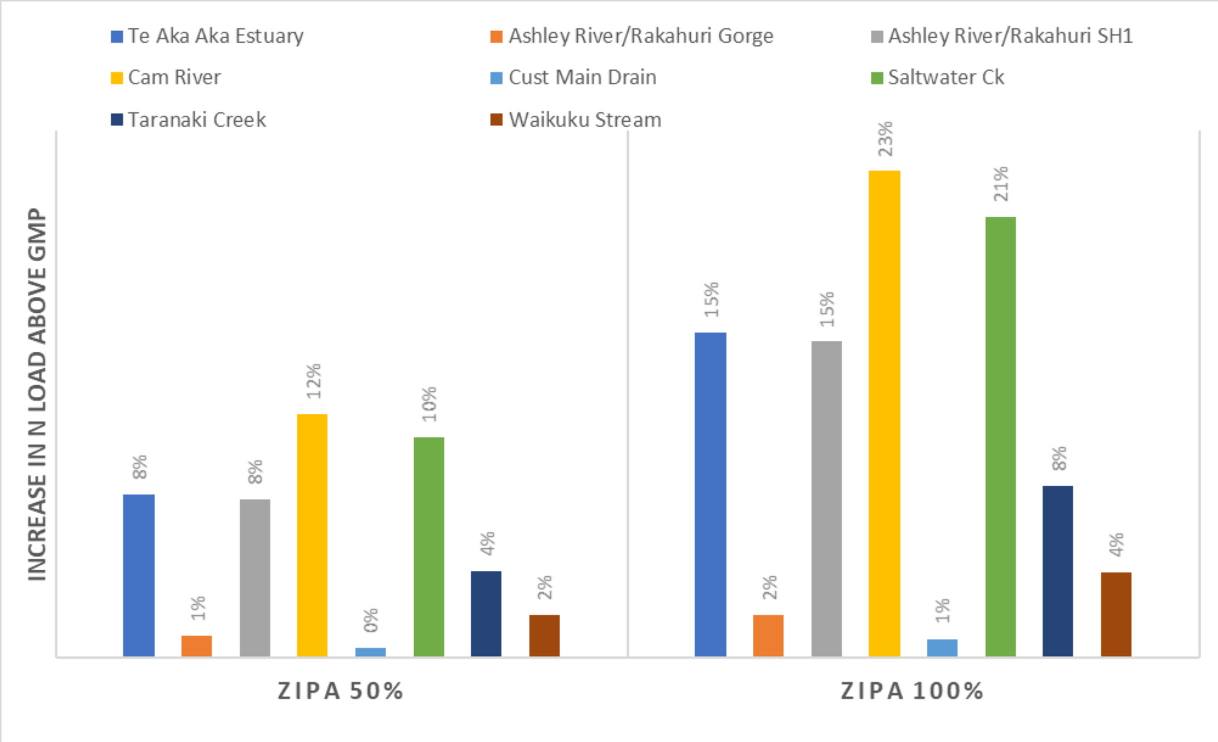


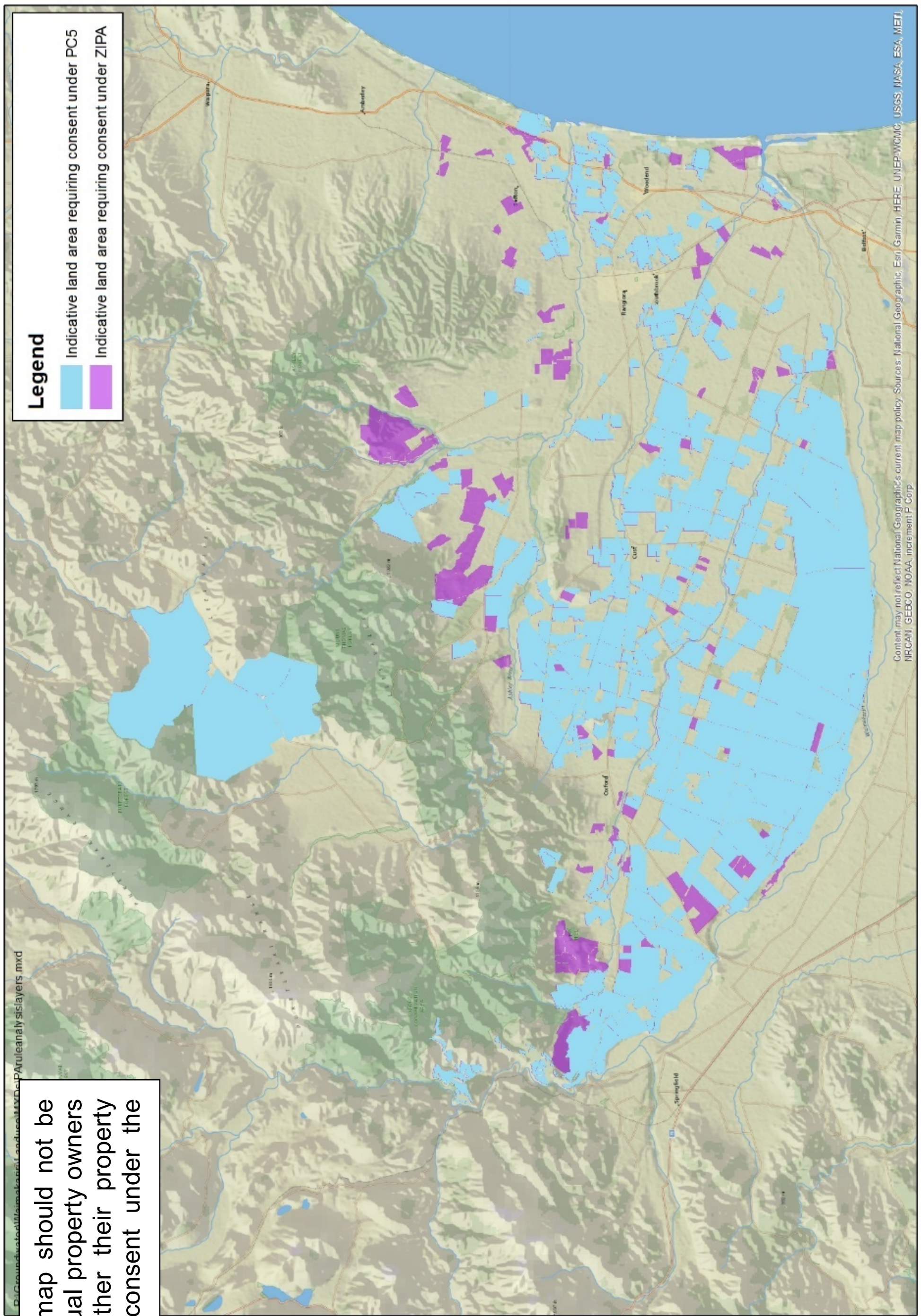
Figure 5-10: Increase in nitrate loads under 50% or 100% uptake of the permitted activity rules (PC5) under the ZIPA Solutions Package

5.8.3 Consenting requirements

Our analysis[64] indicates that around 260 properties would need land use consent for irrigation and/or winter grazing within the Waimakariri zone under the ZIPA Solutions Package (100% uptake), an increase of 50 consents relative to the current regional plan rules (LWRP with PC5), under which approximately 210 land use consents are required.

Figure 5-11 illustrates the effect of restricting the rules for winter grazing PA in the Waimakariri zone; the area of land requiring consent increases, with associated requirements for careful management of nutrients.

[64] Internal data source: P:\Groundwater\Waimakariri\Landuse\Spreadsheet\PA rule ZIPA analysis_consentNos.xlsx



Note that this map should not be used by individual property owners to assess whether their property would require consent under the

Figure 5-11: Indicative land area requiring a consent under LWRP – Plan Change 5 and under zone committee recommendations

6 Conclusions

The availability of safe and reliable drinking water, maintenance of the current high-quality drinking water from Christchurch's aquifers and surface water quality which supports aquatic life and mahinga kai were identified as Priority Outcomes by the Waimakariri Water Zone Committee. Management of nitrate is critical for all of these outcomes.

We analysed current nitrate concentrations and trends and found that nitrate concentrations breach drinking water limits and ecological toxicity thresholds in some wells and surface water bodies. Te Aka Aka shows a moderate degree of eutrophication and the Ashley River/Rakahuri (and to a less degree the Waimakariri River) suffers from toxic cyanobacteria growth in the summer months. Nitrate concentrations are trending upwards in some water bodies. Nitrate concentrations are relatively low in some other parts of the Waimakariri zone, however, and concentrations are trending downwards in a few surface water courses.

We modelled nitrate losses from land within the Waimakariri zone under a range of management scenarios and evaluated the uncertainty around these loss rate estimates. We developed a stochastic groundwater model which used the modelled nitrate loss rates to assess the possible range of surface water and groundwater nitrate concentrations that could occur under the management scenarios, when concentrations equilibrate with loss rates from land.

Our modelling results showed that nitrate concentrations could increase significantly in some water bodies. This is mainly because the groundwater age in some receptors (e.g. water supply wells). predates recent land use intensification, i.e. there is a lag between land use change and the full effects of that change being seen (steady state conditions). These results highlight the fact that, regardless of actions taken now or in the near future, nitrate concentrations in those receptors with long lag times are likely to get worse before they get better.

We compared our steady state model results to a range of possible surface water and groundwater nitrate limits and evaluated the reduction in nitrate loss rates that would be required to achieve these limits. The zone committee used our modelling results in combination economic, ecological and mahinga kai impact information to make recommendations (via their ZIPA) for a set of nitrate limits to be included in the Land and Water Regional Plan.

The nitrate management recommendations in the Waimakariri zone ZIPA also include beyond Baseline GMP nitrate loss reductions, reductions in the areas of land that can be used for winter grazing without a resource consent and more detailed investigation of the feasibility of implementing Managed Aquifer Recharge (MAR) and Stream Augmentation to reduce nitrate concentrations. We used our modelling results in combination with some field investigation findings to evaluate the extent to which, and period within which, the recommended nitrate limits could be achieved.

Our modelling results indicate that significant beyond Baseline GMP nitrate loss reductions are likely to be required across a large area of the Waimakariri zone to meet the recommended nitrate limits. It could take a long time to achieve the limits and, in some instances, it may not be possible to achieve them unless the nitrate loss reduction requirements are extended to a wider set of properties. Implementation of on-the-ground actions, principally MAR and stream augmentation could reduce the nitrate loss reduction requirements and the time taken to meet limits. These actions could also help to meet limits without expanding the requirements for nitrate loss reductions.

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Appendix 1. Overview Waimakariri District Council community supply schemes

This overview is based on the Water Supply Scheme Activity Management Plans written by the WDC for all its water supplies (2018). These can be downloaded via https://www.waimakariri.govt.nz/services/water-services/water-supply/water-supply-schemes.

Drinking water supply scheme	Primary Source (well number and depth)	Back up source (well number and depth)	Secure?
Cust	Springbank Well no.2 M35/2589, 73m	Springbank well no.1 M35/11544, 80m	Y
Fernside	See Mandeville		
Garrymere	M34/5518, 30m		N
Kaiapoi, Kairaki/Pines	M35/3529, 123m M35/8211, 122m M35/0847, 98m M35/5875, 107m M35/8242, 107m M35/0834, 136m	Rinaldi Ave, M35/0833, 74.3m	Y
Mandeville / Fernside	Two Chain Rd, no.1 M35/9021, 106.8m Two Chain Rd, no.2 M35/18638, 77m	Tram Rd, M35/5585, 22.6	N
Ohoka	Ohoka Well no.2, BW24/0262, 84.7m	Ohoka well no.1 M35/5609, 18.8m	Y (N back up)
Oxford Rural 1	Rockford Road No. 1 Gallery Well L35/0327 12m Rockford Road Deep Well BW22/0070 128m McPhedrons Road Well (not yet consented or commissioned) BW22/0088, 81m	Rockford Road No. 2 gallery well (non-secure surface water) L35/0576 6.6m	N
Oxford Rural 2	See Oxford Urban		
Oxford Urban / Oxford Rural 2	Domain Rd Well No. 1 L35/0850, 123m Domain Rd Well No. 2 BW22/0049, 135.4m	Coopers Creek Infiltration Gallery 3.0m Gammans Creek Supply L35/0071, 9.1m	Y (N back up)
Pegasus	Equestrian 1 M35/18017, 214m Equestrian 2	none	Y

Drinking water supply scheme	Primary Source (well number and depth)	Back up source (well number and depth)	Secure?
	M35/18018, 250m Equestrian 3 M35/18019, 138m Pegasus Well 1 M35/10908, 143m		
Poyntzs Road	Single well (programmed for upgrade in 2018/19) M35/0181, 29.3m	none	N
Rangiora[65]	Smith St (Kaiapoi) deep wells 1: M35/11199, 154.4m 2: M35/11908, 155.8m 3: M35/11910, 155m 4: M35/11909, 150.5m	Ayer St shallow wells Dudley Park shallow wells	Y (N back up)
Summerhill	See West Eyreton		
Waikuku	Kings Ave well M35/0474, 21.6m	Camping Ground well M35/9594, 24.6m	N
West Eyreton and Summerhill	West Eyreton well no. 2 M35/9566 98.3m	West Eyreton well no. 1 M35/0055 15.2m	Y (N back up)
Woodend[65]	Gladstone Rd well 1 M35/7524, 205.8m Gladstone Rd well 2 M35/11693, 210m	Chinnerys Rd No.2 M35/0470, 30.2m	Y (N back up)

[65] Currently Gladstone Road wells are the primary source for Woodend and the Equestrian Park wells are the primary wells for Pegasus. When the schemes are joined these would all be the primary wells

Appendix 2. Relationship between annual nitrate concentrations and samples above the drinking water MAV

In order to estimate concentrations for all the private water supply wells in the Waimakariri Zone we used relationships between the ***mean*** nitrate concentration for all groundwater samples collected for the whole of the Canterbury plains in a given year and the percent of the samples in that year with nitrate concentrations exceeding 11.3 mg/L. This is useful for estimating drinking water nitrate MAV exceedances for areas in which we have too few samples to provide a clear picture of spatial variance (but have enough samples to provide an estimate of the mean concentration) It is also a useful tool for understanding what spatially averaged model nitrate concentrations could mean for private water supply wells or groundwater wells in general in a modelled area. The graph below (Figure 1) shows the relationship between the ***mean*** nitrate concentration for all groundwater samples collected in a given year and the % of the samples in that year for which nitrate concentrations exceeded 11.3 mg/L. A similar relationship has been established between the annual mean nitrate concentrations and the ***percentage of wells*** in which nitrate might exceed 11.3 mg/L (Figure 2).

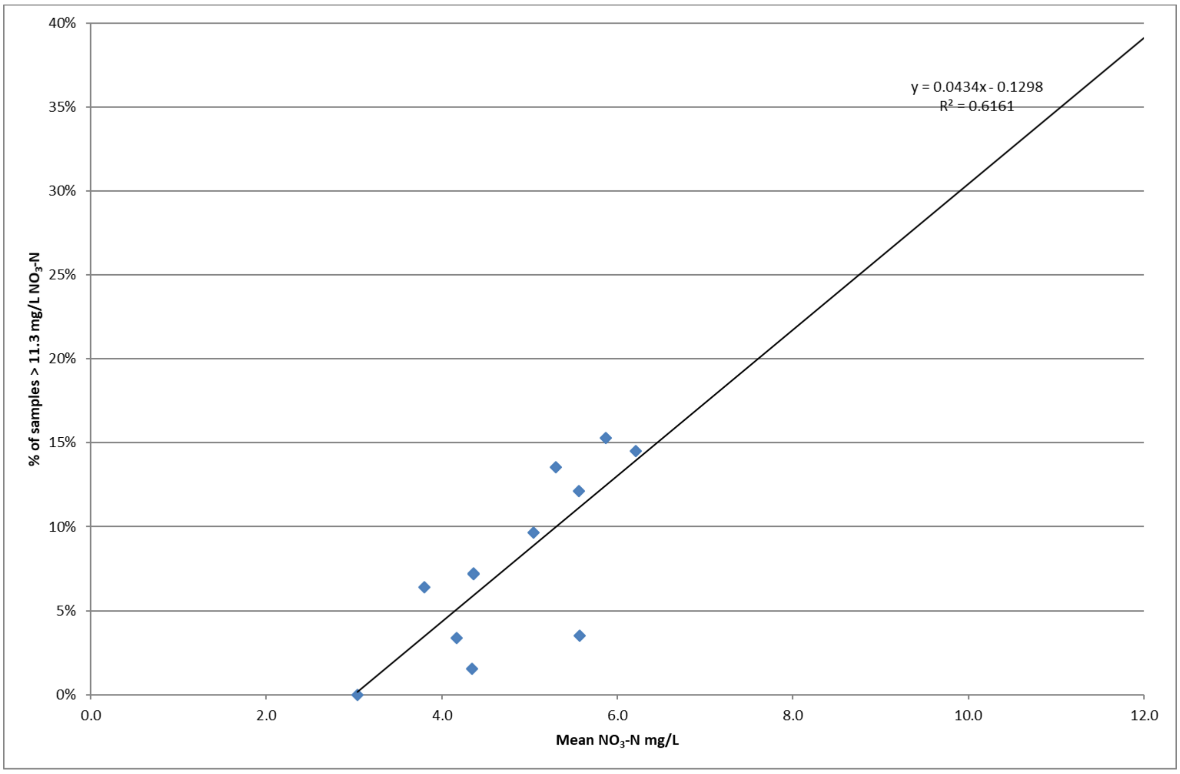

Figure 1 Mean nitrate concentration vs % of samples above the drinking water standard for nitrate of 11.3 mg/L[66]

[66] P:\Groundwater\Waimakariri\Groundwater\Groundwater Quality\Spreadsheets\Copy of Regional N data with N trends.xlsx

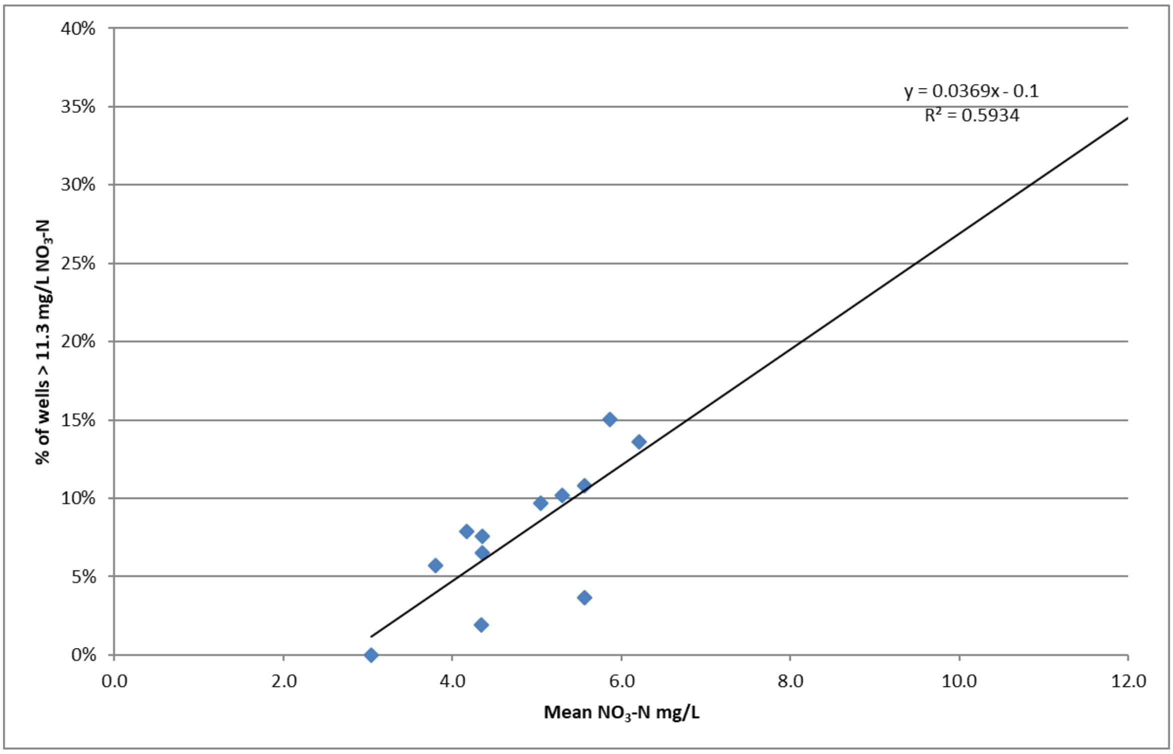

Figure 2 **Mean nitrate concentration vs % of wells with any sample above the drinking water MAV for nitrate of 11.3 mg/L[66]**

The mean nitrate concentration has been calculated for the each GAZ based on the available nitrate samples per GAZ. The extent to which these samples represent the spatial and temporal variability of water quality in the GAZs is uncertain as sampling times and locations were ad-hoc: a carefully designed and more comprehensive sampling programme would be required to improve the likelihood of obtaining a representative data set. We have used the 2013-2017 mean annual nitrate concentration in each GAZ (see Table 1) in combination with the regression equation shown in Figure 2 to estimate the percentage of wells in which nitrate is likely to exceed the nitrate MAV - either periodically or consistently. Results suggest that this could be 13% of the private wells for Cust GAZ, 4.4% for Eyre River GAZ and 6.3% for Loburn GAZ. We have also estimated the % of wells exceeding the MAV based on the mean annual nitrate concentration for the whole zone: 3.1 %.

Table 1 Percentage of drinking water samples and wells above MAV (11.3 mg/L) for nitrate (2013-2017)[67]

GAZ	Number of private water supply wells	Mean annual nitrate concentration (mg/L)	% of samples >11.3 mg/L based on Figure 1	% of wells>11.3 mg/L based on Figure 2	Number of wells>11.3 mg/L
Ashley	590	0.36	0	0	0
Cust	700	6.21	14.0%	13.0%	90
Eyre River	1,300	3.88	3.9%	4.4%	60
Kowai	80	0.26	0	0	0
Loburn	140	4.40	6.2%	6.3%	10
Total (all GAZs)					160
Waimakariri Zone	2,810	3.54	2.4%	3.1%	90*
* Due to the spatial variance of nitrate concentrations in the GAZs the total number of wells for the Waimakariri zone that exceed the MAV is lower based on the mean annual nitrate concentration for the whole zone compared to the mean annual nitrate concentrations per GAZ. This means that the number of wells exceeding the MAV lies between 90-160 wells.					

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Appendix 3. Surface water nitrate-N trend data

Assessment of trend using Seasonal Kendall test and slope analysis with median values in each season of 1 month

Seasons used in analysis are: January February March April May June July August September October November December

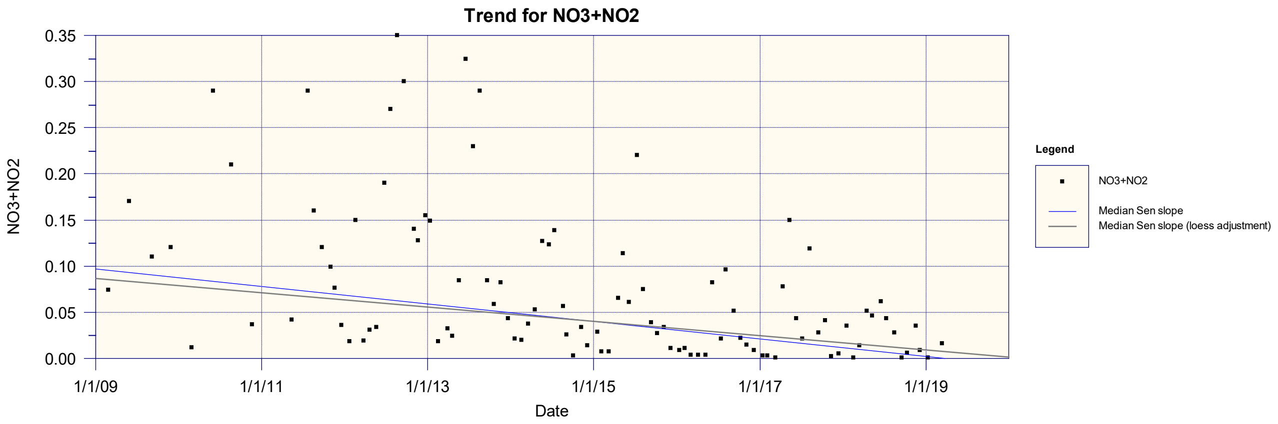
If the sample size is less than 10 small sample size probabilities are used otherwise a normal approximation is used to determine P value

Slope assessment excludes any censored values

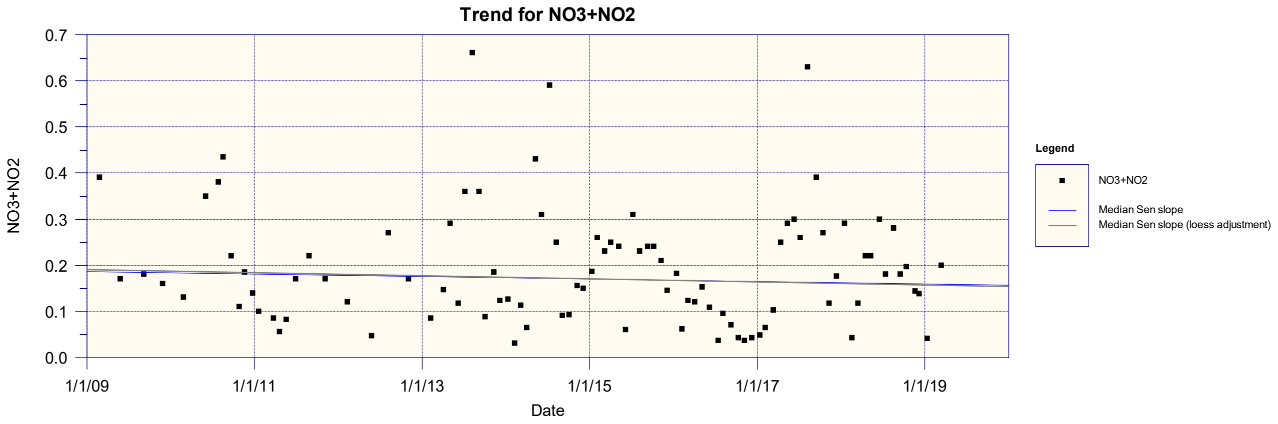
Site	Variable		Missing	Excluded	Non-detects	Samples used	Sampling period	Mean	Maximum	Minimum	Median	Kendall statistic	Variance	Z	P	Sen slope (annual)	Percent annual change	95% confidence limits for slope	Probability	Trend direction and confidence
Waimakariri River at Gorge	NO3NO2		1	0	0	119	14/1/09-12/12/18	0.09	0.23	0.03	0.08	67	1467	1.72	0.08	0	2.41	0.00 to 0.00	0.96	Increasing trend likely
Waimakariri River at Gorge	Adjusted for Flow		2	0	0	118	14/1/09-12/12/18	0.09	0.23	0.03	0.08	54	1434	1.4	0.16	0	1.83	0.00 to 0.00	0.92	Increasing trend possible
Waimakariri old highway bridge	NO3NO2		1	0	0	119	14/1/09-12/12/18	0.19	1	0.03	0.16	47	1467	1.2	0.23	0	1.91	0.00 to 0.01	0.89	Increasing trend possible
Waimakariri old highway bridge	Adjusted for Flow		1	0	0	119	14/1/09-12/12/18	0.19	1	0.03	0.16	65	1467	1.67	0.09	0	2.14	0.00 to 0.01	0.95	Increasing trend likely
Ashley River u/s Ashley Gorge Road	NO3NO2		0	0	0	101	24/2/09-12/3/19	0.07	0.35	0	0.04	-177	938.33	-5.75	0	-0.01	-23.07	-0.01 to -0.01	1.00	Decreasing trend virtually certain
Ashley River u/s Ashley Gorge Road	Adjusted for Flow		1	0	0	100	20/1/12-5/12/18	0.08	0.35	0	0.04	-161	920.33	-5.27	0	-0.01	-18.82	-0.01 to 0.00	1.00	Decreasing trend virtually certain
Ashley River 50m u/s SH1	NO3NO2		0	0	0	95	24/2/09-12/3/19	0.19	0.66	0.03	0.17	-21	803.67	-0.71	0.48	0	-1.62	-0.01 to 0.01	0.78	Decreasing trend about as likely as not
Ashley River 50m u/s SH1	Adjusted for Flow		13	0	0	82	18/1/11-11/12/17	0.2	0.66	0.03	0.17	-13	525.67	-0.52	0.6	0	-2.01	-0.01 to 0.01	0.74	Decreasing trend about as likely as not
Waikuku Stream d/s SH1	NO3NO2		0	0	0	71	25/2/09-13/11/18	0.58	1.69	0.04	0.48	11	513	0.44	0.66	0.02	3.14	-0.02 to 0.05	0.67	Increasing trend about as likely as not
Kaiapoi River u/s Harpers Road	NO3NO2		0	0	0	67	27/7/12-9/1/19	7.89	10.5	4.3	7.5	21	279.67	1.2	0.23	0.13	1.8	-0.23 to 0.37	0.88	Increasing trend possible
Kaiapoi River u/s Harpers Road	Adjusted for Flow		0	0	0	67	29/1/13-6/12/18	7.89	10.5	4.3	7.5	47	281.67	2.74	0.01	0.27	3.64	0.07 to 0.57	1	Increasing trend virtually certain
Kaiapoi River u/s Island Road	NO3NO2		0	0	0	100	25/2/09-9/1/19	4.85	6.4	3.5	4.8	36	905.33	1.16	0.24	0.03	0.7	-0.02 to 0.09	0.88	Increasing trend possible
Cust River u/s Skewbridge Road	NO3NO2		0	0	0	108	25/2/09-9/1/19	4.27	7.6	1.6	4.05	6	1111.33	0.15	0.88	0	0	-0.07 to 0.06	0.56	Trend unlikely
Cust River u/s Skewbridge Road	Adjusted for Flow		0	0	0	108	18/1/11-6/12/18	4.27	7.6	1.6	4.05	43	1123	1.25	0.21	0.07	1.66	-0.04 to 0.18	0.89	Increasing trend possible
Ohoka River u/s Island Road	NO3NO2		0	1	0	54	25/2/09-6/11/18	4.09	5.2	1.3	4.2	-48	447	-2.22	0.03	-0.04	-1.02	-0.08 to 0.00	0.99	Decreasing trend very likely
Cam River u/s Bramleys Road	NO3NO2		0	0	0	94	25/2/09-9/1/19	0.91	2.3	0.33	0.73	-9	805.67	-0.28	0.78	0	-0.51	-0.04 to 0.03	0.64	Trend unlikely
Cam River u/s Bramleys Road	Adjusted for Flow		0	0	0	94	18/1/11-6/12/18	0.91	2.3	0.33	0.73	52	810.67	1.79	0.07	0.05	7.22	0.00 to 0.13	0.96	Increasing trend likely
Taranaki Creek u/s Preeces Road	NO3NO2		0	0	0	71	25/2/09-13/11/18	0.7	1.53	0.12	0.66	31	515.67	1.32	0.19	0.03	4.87	-0.01 to 0.07	0.91	Increasing trend possible
Saltwater Creek at Factory Rd	NO3NO2		0	0	0	87	25/2/09-12/3/19	0.42	1.33	0.01	0.35	-21	683	-0.77	0.44	-0.01	-2.72	-0.03 to 0.01	0.79	Decreasing trend about as likely as not

Note: Cust River u/s Skewbridge Road is representative for Cust Main Drain as referred to in this technical report.

Ashly River/Rakahuri at the Gorge



Ashley River/Rakahuri at SH1



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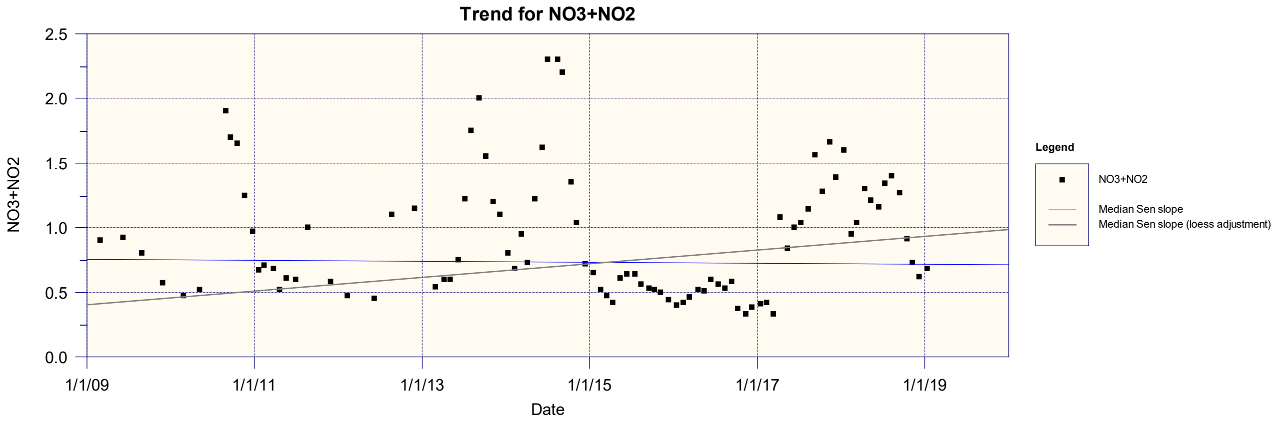
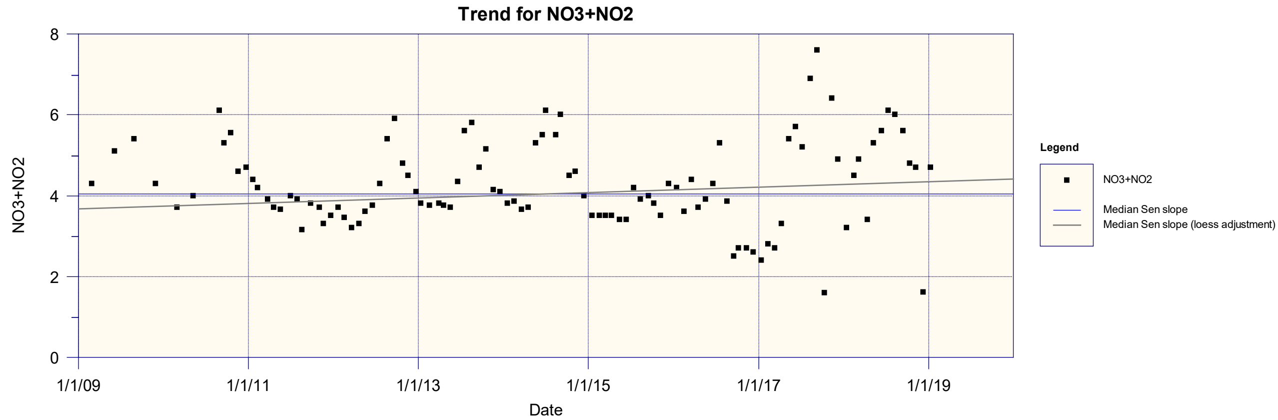
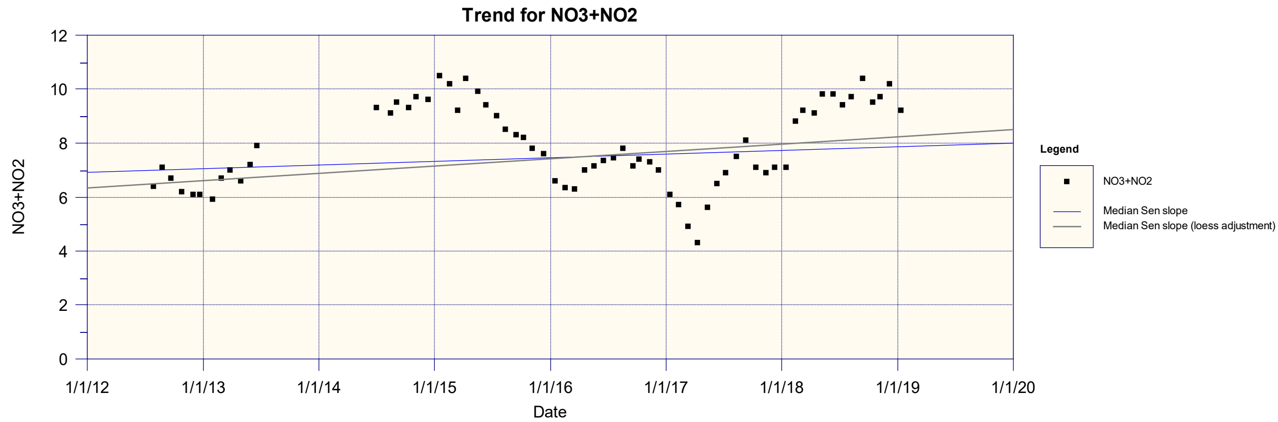


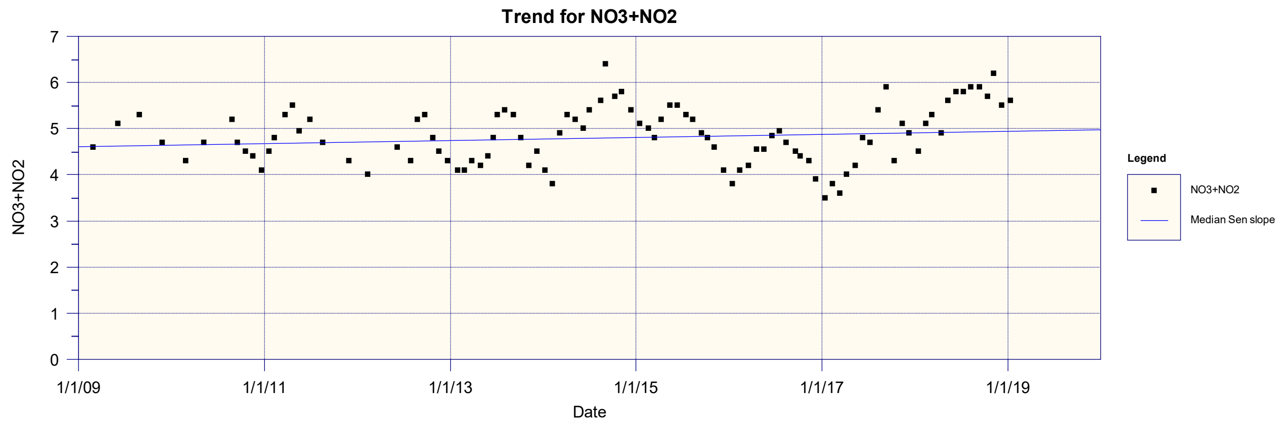
Cust River



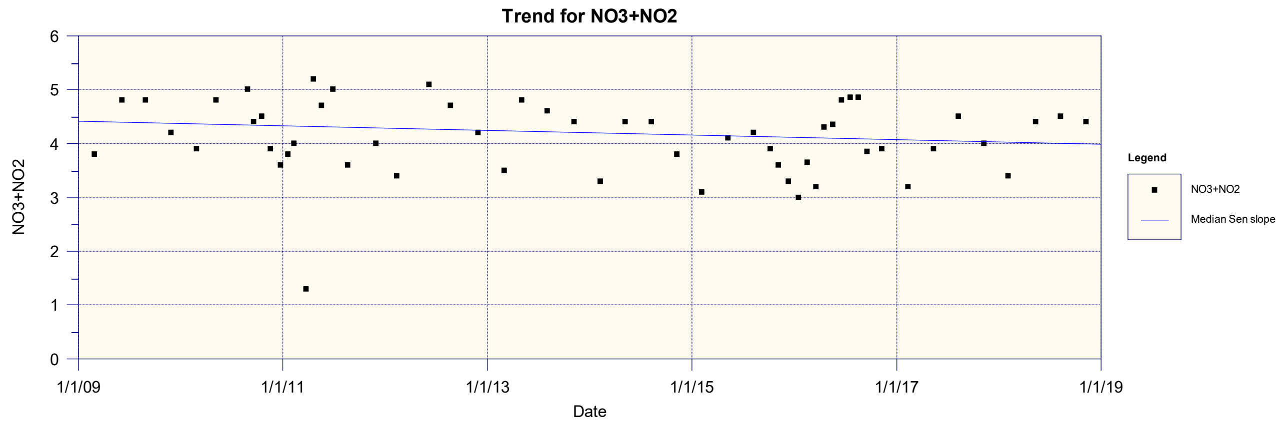
Silverstream at Harpers Road



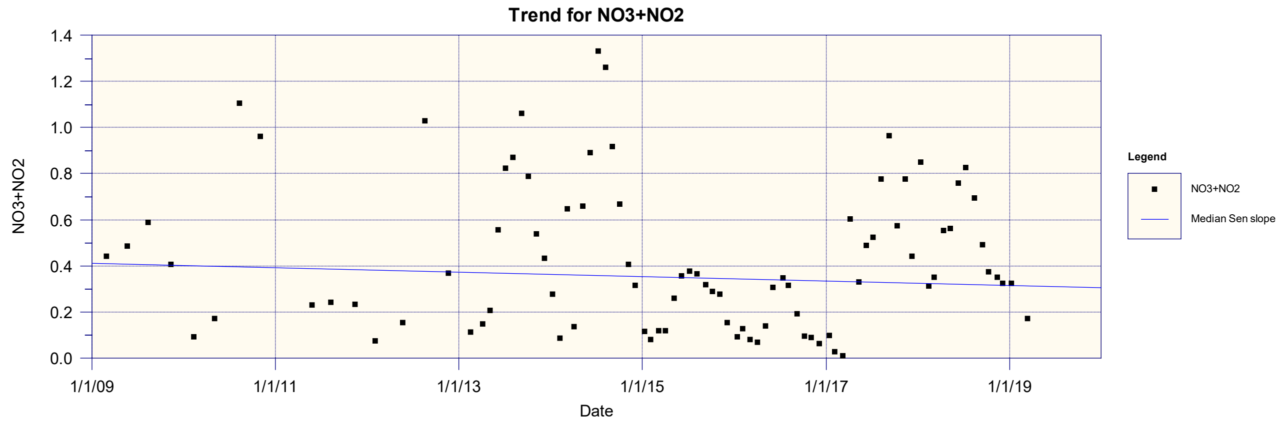
Silverstream at Island Road



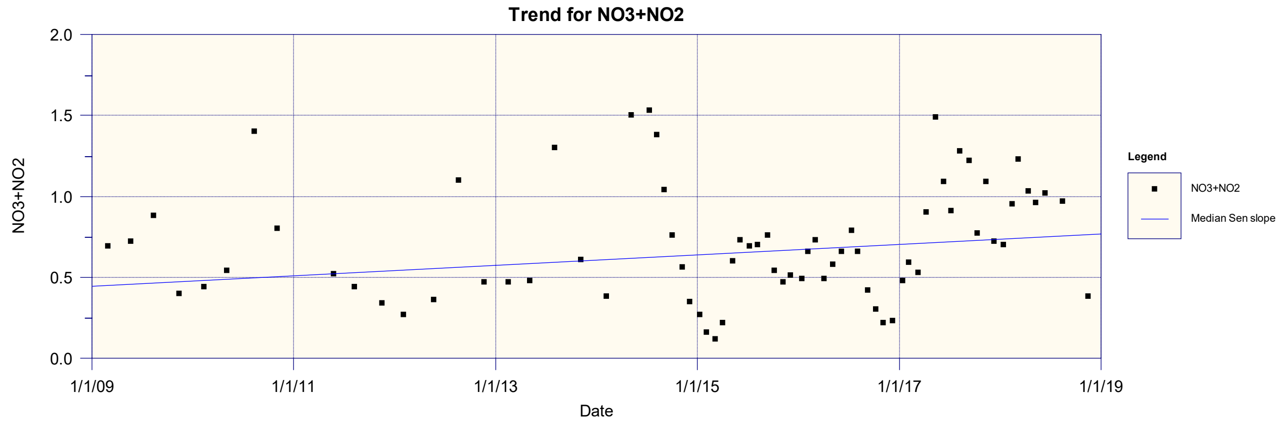
Ohoka Stream



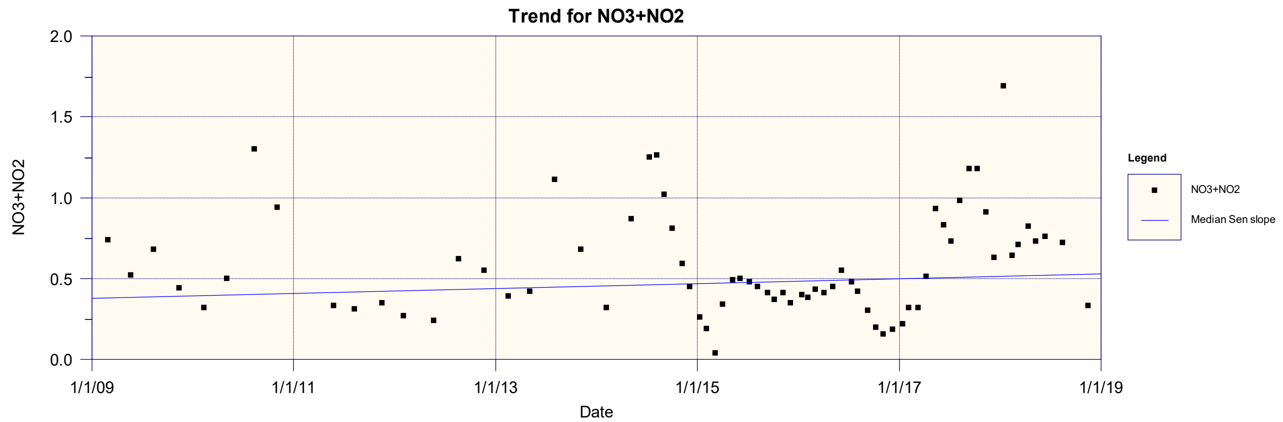
Salwater Creek



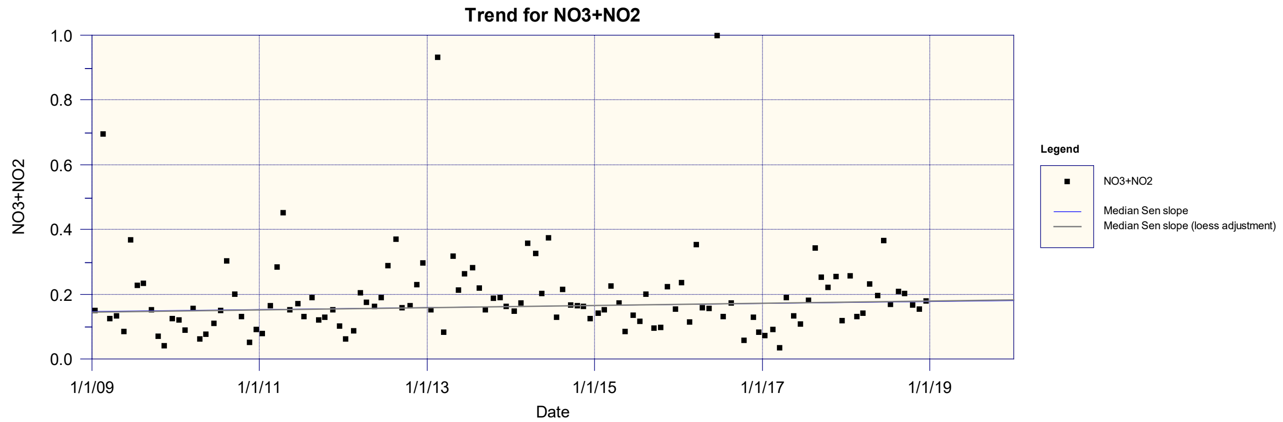
Taranaki Creek



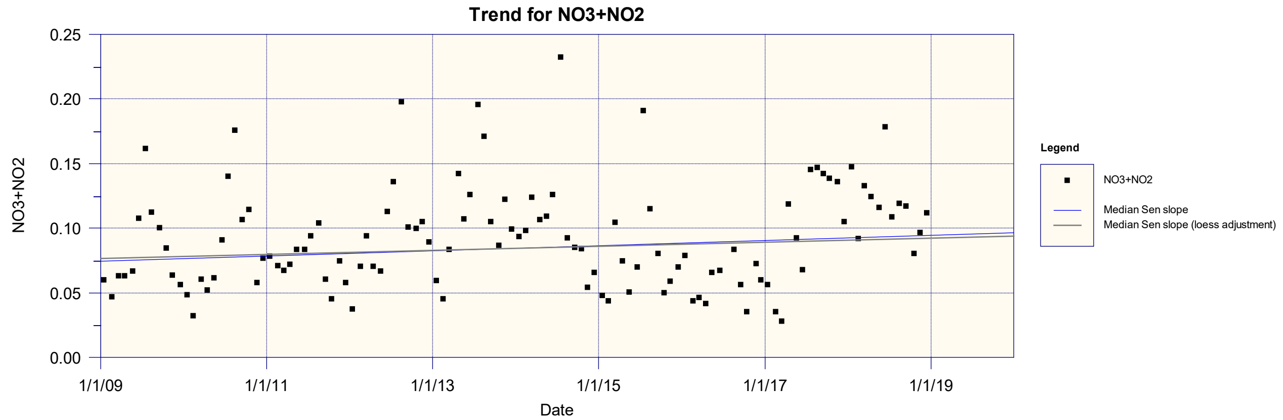
Waikuku Stream



Waimakariri River at SH1



Waimakariri River at Gorge



Appendix 4. Farmer Engagement in Farming Within Limits

Fietje, L., Carmichael, L. 2018. Farmer Engagement in Farming Within Limits. In: Farm environmental planning – Science, policy and practice. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No.31. Fertliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

FARMER ENGAGEMENT IN FARMING WITHIN LIMITS

Leo Fietje[1] and Lyn Carmichael[2]

[1]Principal Planning Advisor, Environment Canterbury,
P.O. Box 345, Christchurch 8140, New Zealand
[2]Planner, Environment Canterbury,
P.O. Box 345, Christchurch 8140, New Zealand

Introduction

The need for limits on loss of nutrients from the use of land has achieved considerable acceptance over recent years, but there are catchments for which capping losses at present levels may not be enough. This is envisaged in the National Policy Statement for Freshwater Management (NPS-FM 2014) which refers to both maintaining and improving water quality as a bottom line. The key pathways for reducing the impact of farming on water quality are the implementation of Industry-agreed Good Management Practices (GMPs), but what happens when this is not enough and we need to make further reductions? Is that feasible and if so at what cost?

There's no shortage of advice in the public arena, particularly around the benefits of reducing stocking rates and improving profitability for some farming sectors – but is it really that straight-forward?

To better understand this challenge, Environment Canterbury assembled two groups of farmers from separate planning zones that are each going through a process of establishing water quality outcomes and limits for their zones. Farmers were invited based on their reputation as respected and influential thought leaders covering the major farm types, along with industry representatives from DairyNZ, Beef + Lamb NZ, and Foundation for Arable Research. Meetings were generally held over dinner and lasted two to three hours, every four to six weeks. Each group established its own ground rules early on and while the groups never met as one, knowledge was exchanged between them

The results from both groups were presentations to the respective Zone Committees setting out the groups answers to the questions posed above and providing valuable information that will continue to be used in future decision-making. The work has highlighted the importance of considering all aspects when assessing mitigation options, including consequences of increasing the complexity of management, farming skill and resource required. Feedback from both Committees was very positive and both groups were recognised for their contributions.

1

Background

The Canterbury Water Management Strategy (CWMS, 2009) divides Canterbury into ten water management zones and empowers communities via their Zone Committees to have significant input into decisions made about the management of water within their respective zones. Three of these committees[1] are currently engaged in collaborative community processes to establish water quality and quantity limits that will inform plan changes to their respective sections of the Land and Water Regional Plan.

The key pathway for reducing the impact of farming on water quality is the implementation of Industry-agreed GMP. However,where it is uncertain whether water quality limits are likely to be met the collaborative processes will inevitably seek answers to questions around options and consequences for reducing impacts 'beyond' GMP.

Traditionally each industry sector, organisation or group would develop their own answers to these questions and argue why their conclusions should be preferred over those of others. This can become very negative and unhelpful for those seeking an honest understanding of options and consequences for reducing impacts beyond GMP. In a desire to better understand this challenge and actively seek a robust set of answers, lead farmers, industry representatives and farmer members of the respective Zone Committees were invited to establish reference groups within two of the zones (Waimakariri and Orari-Temuke-Opihi-Pareora) to investigate options and agree on consequences of further reductions in N loss from various farm types within their zones.

Methodology

The groups met over dinner every four to six weeks. While the Waimakariri reference group was established first, much of the modelling was completed concurrently, and the inputs and assumptions for the nutrient and financial budgets were reviewed and further refined by each group as the projects progressed.

The first meetings established the scope and key principles for the work undertaken, primarily:

- Focus on N loss;
- Only mitigations that can be quantified using OVERSEER®, either directly or via surrogates, would be considered;
- Full transparency and ability to have the information generated independently reviewed;
- Avoiding duplication and building on work previously carried out;
- Develop a consensus view;
- Use representative farm systems farming at GMP as a starting point; and
- Results must be robust and technically defensible

These are further discussed below.

[1] Waimakariri, Orari-Temuka-Opihi-Pareora (OTOP) and Hurunui-Waiau Zone Committees

2

Focus on N loss

While other contaminants can also move through the soil profile, N in the form of nitrate moves very effectively with soil drainage and that is a major pathway for N loss over much of Canterbury, especially the lighter soils over alluvial gravels which have undergone considerable development in recent decades. Other studies looked closer at nutrients and other contaminants lost primarily through surface runoff.

Only consider mitigations that can be quantified using OVERSEER

OVERSEER is the tool of choice for managing nutrient outputs in the Canterbury Region and elsewhere and generates quantifiable estimates of nutrient loss, enabling the generation of defensible cost-benefit estimates. However, in adopting this principle it was acknowledged that there are other mitigations for which early science and anecdotal evidence is encouraging in terms of potential for N mitigation. These include the use of alternative pasture species such as plantain, chicory, short-rotation ryegrass and fescue as well as emerging technology such as the use of N inhibitors.

Transparency and Independent Review

Throughout the process participants were encouraged to have the information generated independently reviewed. In our view that was critical in establishing trust between members of both groups, particularly given much of the information was generated by the authors working for a regulatory body. Given that most of the mitigations related to dairying properties there was a close working relationship with DairyNZ staff, particularly Taisekwa Chikazhe who reviewed the OVERSEER files and financial data.

In parallel with the above, DairyNZ carried out several case studies on actual properties within each Zone to provide information on the costs of getting from current to Industry-agreed GMP; and going 10, 20 and 30% beyond GMP for those same properties. This information was invaluable in answering questions around the extent to which representative farms could be used to inform impacts on actual farm systems.

Avoiding Duplication

Various reports and modelling of potential mitigations for N loss have been undertaken in Canterbury for previously completed sub-regional plan processes. The groups considered these reports and used the representative farms generated in previous processes as a starting point for developing zone specific representative farms.

The groups also considered the work undertaken for the Pastural 21 and Forages for Reduced Nitrate Leaching research programmes and presentations on this work were helpfully provided to the groups by DairyNZ staff.

3

Developing a consensus view

Virtual farms were developed and located within the catchments to best represent the mix of land use, management practices and farming environments within the two zones. The development of these virtual farms was critical to overcoming issues of confidentiality of information and for allowing full transparency of all the information used. However, the (confidential) case studies carried out by DairyNZ on actual farms were a necessary balance to ensure information generated was ground-truthed.

Developing consensus within the groups was important for both the process and the outcomes of the work completed. It was critical for consensus that all participants had full access to all the information generated through the process and could review the information used, including taking it away for review by their trusted advisors. The inputs for developing nutrient and financial budgets and representative farms were circulated both prior to and following the meetings. Meetings were an opportunity for discussion and debate – sometimes very robust – to ensure all views were tabled and evaluated and it is a credit to both groups that they could come to agreements and support the presentations of results to the respective Zone Committees.

Using Good Management Practice as a starting point

Given the focus on potential nutrient reductions 'beyond' GMP it was important to establish what this meant in modelling terms. Environment Canterbury had notified a Plan Change to the Land and Water Regional Plan to introduce the Industry-agreed GMP into its planning framework. This included a suite of OVERSEER modelling proxies which sought to translate the Industry-agreed GMPs into 'modelling speak'. While essential to ensure meaningful analysis and comparison with other studies, it was nevertheless not without its challenges particularly given the Plan Change process occurred during the time the farmer groups were meeting and one of the matters that attracted significant attention was the appropriateness of the modelling proxies. At the time of writing some of these proxies have been appealed, including the two (fertiliser and irrigation) with most impact on N loss estimates.

This is where the work carried out by DairyNZ was an invaluable contribution, in that it demonstrated the range of costs incurred by the case study farms in achieving GMP.

Ensuring results are robust and technically defensible

Extensive technical work and catchment based modelling has been undertaken in each zone and representative data on soils, land use and climate was sourced from the technical reports. Farm production, performance and financial data was sourced from industry and government databases to ensure the representative farms were representative – necessary given it was clear that both groups performed at an above average level and needed reminding of that from time to time when carrying out analysis that applied to properties intended to represent both above and below average properties.

4

Both groups included local farm consultants among the farmer representatives and staff from industry organisations DairyNZ, Beef and Lamb and the Foundation for Arable Research. In each zone local consultants and DairyNZ reviewed the nutrient budgets to ensure they were technically sound and the input from these reviews was incorporated into the final budgets.

Process

The process began with a 'brain dump' of 14 possible mitigations, each of which was modelled in OVERSEER and results reviewed. Many of these were subsequently removed for reasons such as:

- The modelling and financial analyses was already being carried out elsewhere – e.g. cow genetics, Pastoral 21 and Forages for Reduced N Leaching Projects;
- The modelling surrogates were not feasible or gave erroneous results – e.g. increased riparian margins – is reduction due to reduced cow numbers to compensate for loss of land, or increased width of margin?
- The modelling showed only either very small reductions or even increases in N loss.
- Complexity and uncertainty – for example where a mitigation resulted in less area needed for the same level of production with lower total N loss it was recognised that unless the area formerly used was factored into the analysis, particularly the new land use, results would be misleading.

The remainder were analysed for change in profit associated with the mitigation which initially involved the preparation of full farm financial budgets. Following the preparation of the initial budgets it was apparent that analysis of marginal costs and benefits was adequate to understand the impact. This reduced both workload and debate around inputs not affected by the mitigation.

Results

Table 1 sets out the initial 'brain dump' of possible mitigations beyond GMP along with the results of the initial analysis.

Table 1 Results of Initial Analysis of Possible Mitigation Options Beyond GMP

Possible Mitigation	Result of Initial Analysis
Higher genetic merit animals	Medium to long term option, research promising but feedback from industry = that it is too early to be 'bankable option'. Deleted.
Better feeding to improve condition score at calving	Requires low condition score cows to begin, not realistic. Deleted.
Replace grass silage with grain	Feasible option, but potential for health effects if introduced too quickly.
Replace grass silage with fodder beet	As above
Mop-up crop after winter feed	Only works on light land, good information available from trial work, no additional benefit in modelling. Deleted.
Reduce stock numbers	Key P21 outcome, considerable trial work at farmlet and whole-farm level so no additional benefit in modelling through this process. Deleted.
Winter cows on dairy platform using fodder beet	Needs whole-system evaluation including knowledge of what the land previously used for wintering will now be used for. Deleted
Spread effluent over larger area	No benefits in reduced N loss given N input unchanged. Possible benefit if there are issues with runoff and insufficient storage. Deleted.
Feed fodder beet for the last two months of milking	Modelling showed significant reductions available.
Substitute urea with slower release and ammonia ion fertilisers during shoulder periods	No change in modelled N loss. Deleted.
Restricted grazing to reduce urine deposition at high risk times	Modelling showed significant reductions available.
Increase riparian buffers	Only applicable to farms on heavy soils. Increase in riparian margin from one to five metres showed small reduction in estimated N loss but likely to show greater reductions for other contaminants separately analysed and greater still if margin followed land contour. Deleted.
Install wetland	As above re applicability and reductions in other contaminants. Deleted.

By establishing a starting point of all farming systems at GMP it was immediately apparent that there was limited ability for any significant reductions in N loss beyond GMP for systems other than dairy and dairy support. For dairy systems most of the N lost in leaching is from excess N excreted as urine patches. The mitigations that provided significant reductions in N loss beyond GMP worked in either of two ways: by reducing urinary N concentration; or reducing the number of urine patches deposited directly on the paddock.

Reducing the concentration of N in urine

In addition to the fodder beet and grain in Table 1 maize was also subsequently shown to reduce N loss when used as a supplement to replace grass silage. Importantly and somewhat surprisingly these three alternative supplements were shown to be extremely cost-effective when compared with grass silage, after taking account of factors such as:

- Moisture content;
- Cost of transport, storage and feeding out;
- Metabolizable energy (ME); and
- Feed wastage.

When all the above factors were considered the cost of lower-protein supplements ranged from 3.8 – 4.3 c/MJ of ME versus 5.4c/MJ of ME for grass silage. However, both groups raised issues with the use of alternative supplements that for some would preclude use despite the economic benefits. These included:

- Management complexity – compared with an all-grass and grass supplement system;
- Stock health – particularly transition from pasture to fodder beet and grain, long term effect of lower protein feds on overall body condition and effects of soil ingestion when feeding fodder beet;
- Crop reliability especially with possibility of late frosts;
- Effect of fodder beet on soil structure;

There was robust debate around the significance of these issues and level of management needed to overcome them hence they were simply listed as intangibles with no attempt made to evaluate or cost out. One of the main management challenges with low-protein feeds is found in the management of the transition from grass – there were several reports of cow deaths during this period, especially using fodder beet and to a lesser extent grain.

Integration into the farm system is also a challenge that was not fully explored. Fodder beet is not available for the entire milking period unless stored and when stored loses quality due to loss of leaf. Further if the quantity of low-protein supplements fed out exceed the quantity of grass silage fed out in the underlying base model, issues of pasture management and potential for perverse consequences such as the need for stocking rates to increase to maintain pasture quality need to be factored in.

Reducing the number of urine patches deposited directly on the paddock

Restricted grazing was modelled by incorporating a feed or standoff pad used for three hours, twice a day in the shoulder months. Cost of building the infrastructure is significant but can be halved if the herd is split in two shifts and the pad is used for 12 hours per day rather than six. At ~ $1,000 per cow place including approaches and tracking, with 3% for maintenance, 7% interest and 8% depreciation, cost per cow is $150/annum or half that if each cow place is used by two cows.

Reduction in estimated N loss

Table 2 shows the reduction in estimated N loss from the two mitigations options further analysed:

Table 2 Reduction in N loss from use of low protein supplements and restricted grazing

	Light Soils % reduction from base model	**Heavy Soils** % reduction from base model
Replace grass silage with grain	5	0
Replace grass silage with fodder beet	12	12
Replace grass silage with maize silage	5	0
Use fodder beet for last two months of milking	7	14
Restricted grazing in shoulder months	11	12

Other Results

During the process several other options were discussed and analysed to various degrees. These included early cessation of autumn irrigation and late-season applications of N fertiliser; heavy culling in April and rotating maize and short-rotation ryegrass through pasture blocks on the dairy platform. Some of these show promise that merits further investigation and analysis.

Conclusions

While the absence of 'silver bullet' solutions may be disappointing for those hoping there are multiple readily-available and affordable options for reducing N loss beyond GMP, the work described above shows this is not the case. Even the two groups of mitigations that emerged from the process are not without their challenges. Restricted grazing through the use of pads introduces a level of management complexity and cost; and similarly the use of alternative supplements introduces further management complexity with potential effects on animal health and other impacts including long-term impacts on soil structure and animal health. Understanding the 'unintended consequences' of options is invaluable and made possible only through the generosity of the two farmer reference groups – generous with their time and with their willingness to impart their knowledge and engage in debate.

The results and conclusions from these studies were presented to the respective zone committees, where they were well received and have informed decision making. The zone committees acknowledged and appreciated that the information was tested through the generous efforts of the leading farmers involved and the input from industry bodies, to ensure the results are credible and defensible.

References

Canterbury Water Management Strategy (2009). Canterbury Mayoral Forum, https://www.ecan.govt.nz/document/download/?uri=2105939

Industry-agreed Good Management Practices relating to water quality (2015). MGM Governance Group, https://www.canterburywater.farm/gmp/

National Policy Statement – Freshwater Management (2014). Ministry for the Environment, New Zealand.

Appendix 5. Current nitrate concentrations in PWSAs

PWSA	Number of private water supply wells	Calculated median nitrate concentrations (mg/L)
Clarkville	262	4.4
Cust	70	4.4
Eyreton Deep	6	5.2
Eyreton Shallow	93	5.2
Eyrewell	40	5.2
Fernside	198	3.7
Flaxton	69	4.4
Horellville	95	3.7
Mandeville	179	4.4
North East Eyrewell Deep	14	3.6
North East Eyrewell Shallow	246	3.6
North West Eyrewell Deep	3	3.6
North West Eyrewell shallow	138	3.6
Ohoka	26	4.4
Ohoka shallow	133	4.4
Rangiora	252	0.5
Springbank	104	3.7
Summerhill	67	3.7
Swannanoa Deep	4	4.4
Swannanoa Shallow	122	3.7
Waikuku	153	0.8
West Eyreton Deep	8	3.7
West Eyreton Shallow	56	0.7
Woodend - Tuahiwi	303	0.8
Total/overall median	2641	3.1

Appendix 6. Groundwater age investigations

A6.1 Christchurch groundwater age investigations

Stewart (2012)[68] evaluated age tracer data for the Christchurch aquifer system and concluded that prior to groundwater abstraction, the rate of turnover of water in the system was probably quite slow (i.e. the mean age was quite old). By the 1970's mean groundwater ages in the deep system had become relatively young right across Christchurch (with mean ages of 60–70 years) indicating mainly lateral inflow of young water driven by groundwater abstraction. Mean ages have gradually increased since then, showing increasing up-flow of much older water from depth. By 2006 a steep age gradient (from 300 years to 1400 years) had formed across Christchurch from west to east, suggesting that a large body of much older, deeper water is stored on the seaward side of the system where the deep aquifers are likely to be blind[69]. This offshore reservoir is expected to yield good quality water for many years, but eventually it is likely to be replaced or bypassed by younger (a few hundred years old) water which comprises a mixture of Waimakariri River water and land surface recharge from the inland plains (Stewart, 2012).

A6.2 Groundwater flow route

Our groundwater modelling suggests that nitrate will be transported downwards into the deep aquifer in the Waimakariri zone, and from there flow laterally towards the Christchurch aquifer. The model indicates that nitrate will be transported from the deep Christchurch aquifer upwards into the mid-depth and shallow parts of the aquifer system, driven by the upward hydraulic gradient in the artesian aquifer system. This means that knowledge of the groundwater ages in the deep aquifer will provide the best understanding of how long it will take for nitrate from the Waimakariri zone to travel into the Christchurch aquifer, assuming that the model results prove to be correct.

Stewart's conclusion that the very old water currently being drawn from the deep aquifer in the eastern and central parts of the system is likely to be replaced or bypassed by younger water, a few hundred years old, therefore provides useful information on how long it might take for nitrate concentrations in the Christchurch aquifer to increase as a result of land use intensification in the Waimakariri zone, but do not provide any insights into how long it would take for the full impact of this (i.e. when the full concentration increases projected by our modelling would occur).

A6.2 Groundwater age distribution

Figure 1 below plots modelled age distributions for water samples collected from 115 and 220 m deep wells to the west of Christchurch. The plots show results from three different mixing models: an Exponential Piston Model (EPM) and two Binary Mixing Models (BMM). The mean residence time (MRT, i.e. mean age) estimates are variable because the analysis is based on a single sample. Collection of more samples (5-10 years after each other) would reduce uncertainty over the mean age.

BMM Model results (green dashed lines on plots below) suggest that if land use intensification had occurred in the recharge area for these wells 20 years ago, for instance, we should have seen 30% of the nitrate concentration increase associated with that intensification by now in the 115 m deep well if either of the BMM results are correct. However, we would not expect nitrate concentrations to have increased at all yet if the EPM results are correct. We would expect the full effects of intensification to have occurred (i.e. steady state conditions) after 50 years if the EPM results are correct, but would not expect this to happen within 100 years if either of the BMM results are correct.

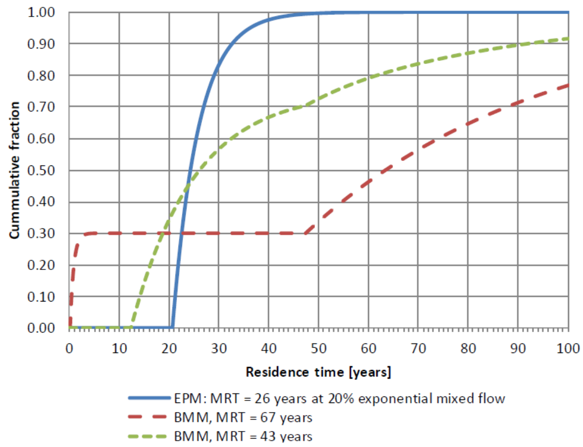
For the 220 m deep well, we would expect around 20% of the nitrate concentration increase associated with intensification 20 years ago to have occurred by now if either of the BMM results are correct but would not expect to have seen any change in concentrations based on the EPM results. Steady state conditions are not expected to occur within 100 years under any of these model results, but in all three

[68] Stewart, M.K., 2012. A 40-year record of carbon-14 and tritium in the Christchurch groundwater system, New Zealand: Dating of young samples with carbon-14. Journal of Hydrology 430-431, p. 50-68.

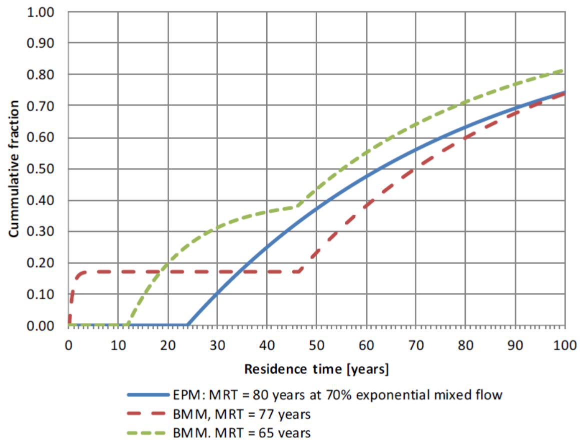
[69] i.e. the aquifers are believed to terminate offshore, which limits the rate of throughflow

cases we would expect to have measured 70-80% of the full nitrate concentration increase associated with the intensification within this timeframe.

These results do not represent the full spectrum of potential age distributions in these wells or other wells in the Christchurch aquifer system. We are currently working with GNS to improve our understanding of groundwater ages in the Christchurch aquifer systems using the results of an age tracer monitoring programme undertaken in 2017. Nonetheless, these results do provide some useful insights into the timing of possible nitrate increases.



115 m deep well



220 m deep well

Figure 1 Age distribution for two deep wells west of Christchurch (see text for explanation)

Considering the information above in the context of measured and modelled nitrate concentrations in the Christchurch aquifer system:

- Our modelling results are consistent with the current interpretation of the age tracer data (e.g. the fact that we do not see high nitrate concentrations at depth can be explained by the expected lag in the system.)
- If our modelling results are correct, the increasing nitrate concentration measured in the deep Russley wells represents the first arrival of nitrate in this area of the Christchurch aquifer system from the Waimakariri zone. Concentration increases in the Russley wells seem to start in 1999/2000. If the EPM model is correct the increase may be in response to land use intensification which started 20-30 years prior to that time (i.e. in the 1970's-1980's). If BMM model (green dashed lines) provides a better representation of the groundwater system the measured nitrate concentration increases could be in response to land use intensifications in the 1990's.
- The mean groundwater age in the deep aquifer beneath central and eastern parts of Christchurch is older than that in the Figure 1 wells (located west of the city). We would expect a wider distribution of ages as we move eastwards, with increasing distance from the inferred recharge zone north of the Waimakariri River. Whilst nitrate concentrations could start to increase in the next few decades, and may already be increasing beneath the city, mixing model results for the 220 m deep well west of Christchurch suggest that any increases are likely to occur gradually. We do not expect the full increases projected by our modelling to occur within 100 years.

Appendix 7. Winter grazing management options[70]

Date	2/11/18
To	Waimakariri Water Zone Committee
CC	
From	Zeb Etheridge

This Appendix is a formatted version of the Technical Memorandum presented to the WWZC, which was used in its deliberations and instructions to Environment Canterbury.

A7.1 Background

Plan Change 5 has defined a set of land area thresholds beneath which a land use consent is not required for irrigation and winter grazing (i.e. the activity is classified as a Permitted Activity [PA]). It has been recognised that because these thresholds were defined for the whole of Canterbury, they may not be optimal for local circumstances in some parts of the region.

Several matters have been raised regarding the current (PC5) PA rules for the Waimakariri zone:

- Consented land users in the proposed Nitrate Priority Area could potentially seek to achieve a proportion of the beyond Baseline GMP N loss reductions recommended by the zone committee by wintering their cattle outside of the NPA. Beyond Baseline GMP N loss reductions have not been recommended outside the NPA. The unintended consequence of the ZIPA recommendations if PC5PA rules are left unchanged could therefore be to “shift the problem”, potentially into the nitrate-sensitive Te Aka Aka catchment, rather than solving it.
- Alternatively, consented land holders within the NPA could, in theory, winter their stock on land which does not require consent within the NPA (such as small blocks or properties with little or no irrigation or winter grazing), in response to beyond Baseline GMP N loss reduction requirements for consented land. This would show an improvement in nitrate losses on paper (via Overseer budgets) but would not actually reduce nitrate discharges within the NPA.
- It could potentially become attractive for farmers to winter cattle off-farm across the broader region, to meet nitrate reduction requirements. We recognise that the Waimakariri Water Zone Committee does not wish to provide a rule framework which allows nitrate loads from other parts of the region to be transferred to the Waimakariri zone via winter grazing (although the likelihood of this may be low).
- Farmers who currently require land use consent in the NPA and are facing significant beyond Baseline GMP N loss reductions may need to “go further” in their nitrate reductions, to offset the increased nitrate discharges which are allowed for under the current PA rules. The potential outcome of this would be that while some farmers are working hard to reduce their N losses, others are able to increase them without requiring resource consent.

The zone committee received feedback from some parts of the farming community during the draft ZIPA consultation process regarding the cost impact of the requirement to obtain resource consent and undertake a nutrient budget and Farm Environment Plan. Impacts on small farms were highlighted. This is discussed in Harris (2019).

This memo provides an assessment of the potential increases in nitrate loads in several surface water bodies in the Waimakariri zone associated with the different winter grazing rule options considered by the Waimakariri Water Zone Committee (WWZC) and their final recommended solution. The number of additional resource consents that may be required is also assessed. The implications of the PA N loads and increased consent numbers on stream health, biodiversity and farm economics are discussed in separate documents which are referenced in this memo.

[70] Internal data source: https://punakorero/groups/plansec/WaimakAsh/research/Solutions/PA%20rules%20options%20and%20solutions%20assessment_final.docx?web=1

It is important to note that changing the PA rules would not necessarily mean that these discharges will not occur: land use consents could still be granted for the new properties wishing to undertake winter grazing in excess of the PA thresholds. However, the rules provide a mechanism by which nitrate discharges can be managed and reduced under future plan changes or when consents expire *if required*. Furthermore, if ongoing science work shows a significant eutrophication risk for the estuary, or unexpected nitrate concentration increases in other spring-fed streams, the appropriateness of issuing more winter grazing consents could be considered.

A7.2 Options and solutions assessment

The zone committee was provided with information on the potential nitrate loads and number of consents that would be required under a range of PA threshold options, some of which are summarised in Table 1 below. The zone committee received feedback on the Draft ZIPA option from stakeholders and the community as part of the Draft ZIPA consultation programme.

Table 1 PA Threshold Options

Option	Winter grazing allowances based on property size (ha)				
	< 5	<10	10 – 100	100 – 1,000	>1,000
Draft ZIPA	No consent	5%	5%	5%	50 ha
Current Pathways/PC5	No consent	No consent	10 ha	10%	100 ha
Scenario 4	No consent	No consent	7.5 ha	7.5%	75 ha
ZIPA	No consent	5 ha	5 ha	5%	50 ha

The “jumps” in the permitted winter grazing area under some of these scenarios were discussed by the zone committee, e.g: under the Draft ZIPA option a 5 ha property could, in theory, dedicate all 5 ha of land to winter grazing as a permitted activity, while a 50 ha property could only have 2.5 ha of winter grazing. This matter was considered by the zone committee, together with feedback received during the consultation process, when developing a final nitrate management solution for the Waimakariri zone (the ZIPA option in the table above). The likelihood of winter forage crop grazing on <10 ha properties was also deliberated.

A7.3 Modelling assumptions

The nitrate load modelling methodology and assumptions are discussed in detail by Lilburne et al. (2019). A summary of some of the key assumptions is provided below.

One key modelling assumption for the winter grazing nitrate management analysis relates to biophysical constraints for sustained long-term winter forage crop growth: land productivity limitations mean that it will not be feasible to use 100% of a small block (e.g. 10 ha) for winter grazing continuously. Only a proportion of this land would sustain winter grazing on rotation. The same rationale applies to the small to mid-sized blocks (10-100 h): e.g. a 15 ha block would not be able to sustain 10 ha of winter grazing under the PC5 allowance. Our modelling therefore assumed that the maximum area of long-term winter grazing that could be achieved on 10-100 ha blocks within reasonable biophysical constraints were the lower of 15% of the land area or 10 ha under the Current Pathways/PC5 option. This effectively means that blocks < 67 ha were assumed to use 15% of their land for winter forage crops and 67-100 ha blocks grow 10 ha of winter grazing. The lower of 15% or 5 ha for 10-100 ha blocks was used for the ZIPA Solutions Package discussed later in this memo.

Because the PC5 plan rules do not place constraints in the number of properties that can use the winter grazing allowance, we needed to assess N loads under the assumption that every eligible property uses their full allowance within the biophysical constraints outlined above. The results for this scenario are referred to as the PC5 option. However, we also recognise that 100% utilisation of these allowances is unlikely. We addressed this by considering another scenario, called Current Pathways, which assumes that only 50% of eligible properties use the PC5 winter grazing allowance. We took the same approach with the other options: we modelled the N load that could be discharged without requiring a resource consent if all eligible properties use their full allowance, and under the 50% uptake scenario.

The PC5 PA irrigation allowances were left unchanged under all options, since the additional N load associated with full utilisation of these allowances is relatively small and inconsequential. We assumed full utilisation of the irrigation PA allowances.

A7.4 N load analysis

We modelled the nitrate loads which could be discharged as a PA and presented the results as a percentage change from the Good Management Practice (GMP) N load[71] for eight stream catchments. Results are plotted in Figure 1 below. In all instances we assumed that 100% of the PA allowances are used.

Focusing on the highly sensitive Te Aka Aka estuary, modelling results show[72] that:

- Nitrate discharges to the estuary from land without resource consent could be increased by ~30% under the current PC5 rules relative to the N load discharged from consented land, all assumed to be operating at Good Management Practice
- The increase above GMP would be reduced to ~15% under the Draft ZIPA option and ~25% under the Scenario 4 option and ZIPA recommendation.

The implications of these N loads for Te Aka Aka and other surface water bodies are discussed in more detail in Arthur et al. (2019). Information provided in Appendix 10 shows that a 30% increase in nitrate discharges to the estuary could cause a significant increase in the eutrophication risk.

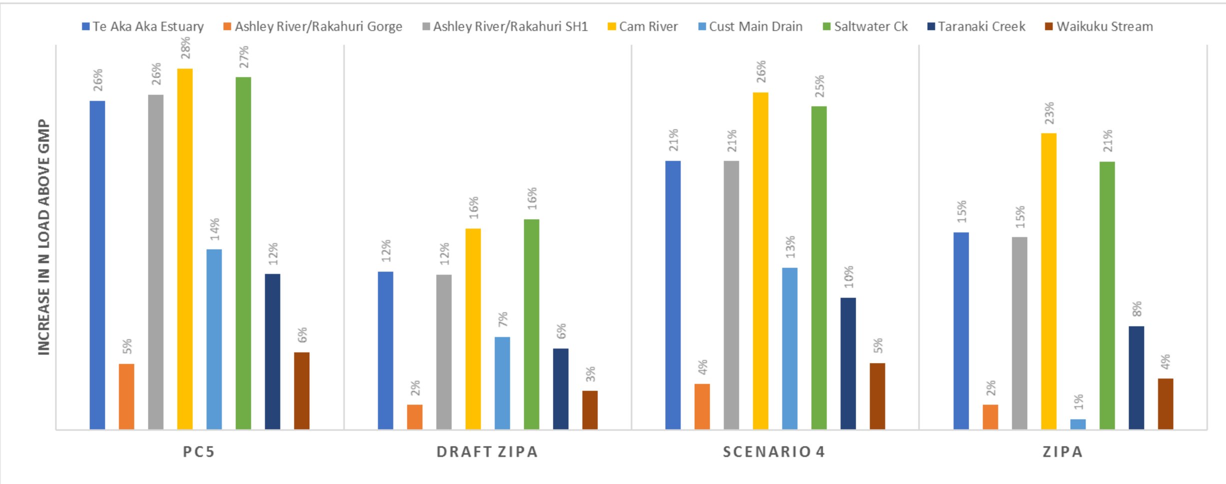


Figure 1 Changes in N loads under PA rule options and ZIPA solution – full uptake

We have plotted the same data in Figure 2 under the 50% uptake scenario discussed above. N load increases in surface water bodies are more modest with a 50% uptake rate but are still significant in some water bodies such as Te Aka Aka, e.g. ~15% under PC5. Again this is discussed further in Arthur et al. (2019).

71 See Lilburne et al., 2019 for details on how GMP N loads were modelled
72 Internal data source: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\AshleyCatchment_ZIPANSolnAssessment (version 1).xlsx

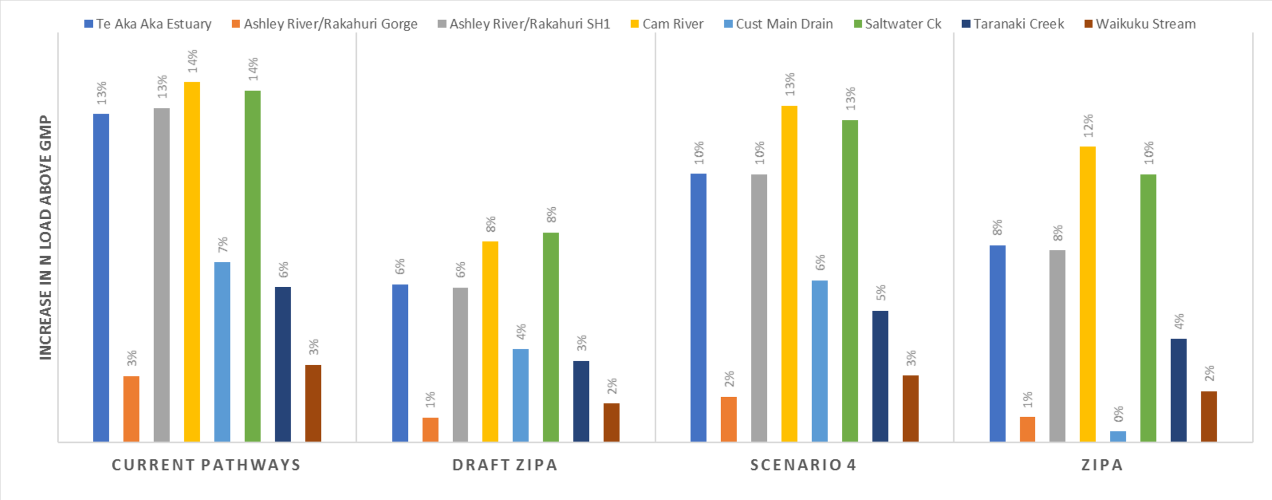


Figure 2 Changes in N loads under PA rule options and ZIPA solution – 50% uptake

A7.5 Number of consents

Lowering the PA threshold will increase the number of properties required to obtain resource consents and hence to produce Farm Environment Plans (FEPs) under the PC5 rules. A side effect of the reduced PA thresholds associated with the ZIPA recommendation would therefore be both more rigorous management of both nitrate and the runoff contaminants (phosphorus, E. coli and sediment) on those properties and additional costs for those properties which decide the undertake winter grazing and apply for a resource consent. The economic impact of the increased consent requirement associated with the ZIPA recommendation is discussed in Harris (2019).
Our analysis[73] indicates that (see Figure 3):

- Approximately 250 properties will need land use consent for irrigation and/or winter grazing within the Waimakariri zone under PC5;
- Scenario 4 would likely result in a small increase in the number of properties requiring consent (30 additional consents, i.e. ~280 in total)
- ~400 properties would need land use consent for irrigation and/or winter grazing under the Draft ZIPA winter grazing recommendation, an increase of roughly 150 consents
- Around 300 properties would need land use consent for irrigation and/or winter grazing within the Waimakariri zone under the ZIPA recommendation, an increase of 50 relative to the current regional plan rules.

Figure 4 shows the approximate areas of land which may require land use consent under current plan rules (PC5) and under the winter grazing rules recommended in the ZIPA.

[73] Internal data source: P:\Groundwater\Waimakariri\Landuse\Spreadsheet\PA rule ZIPA analysis_consentNos.xlsx

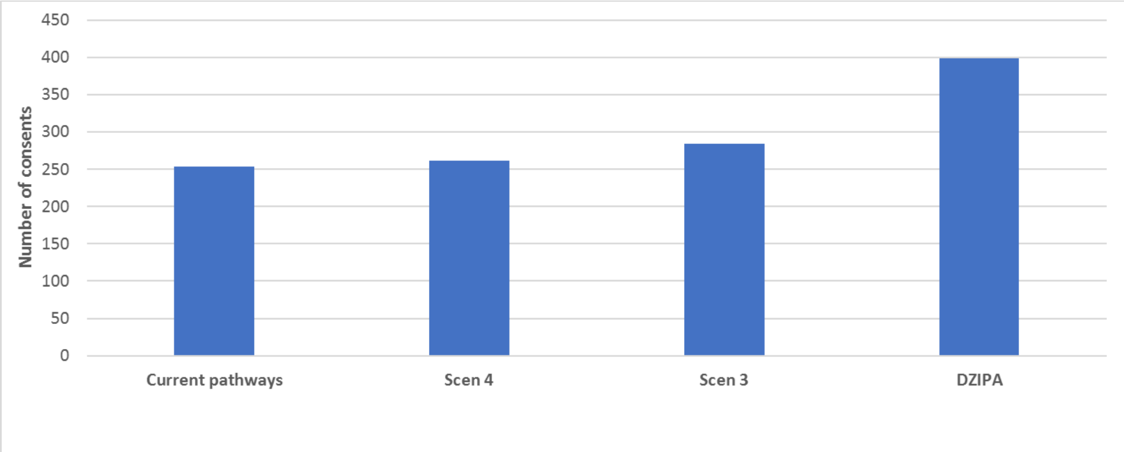


Figure 3 Number of consents required

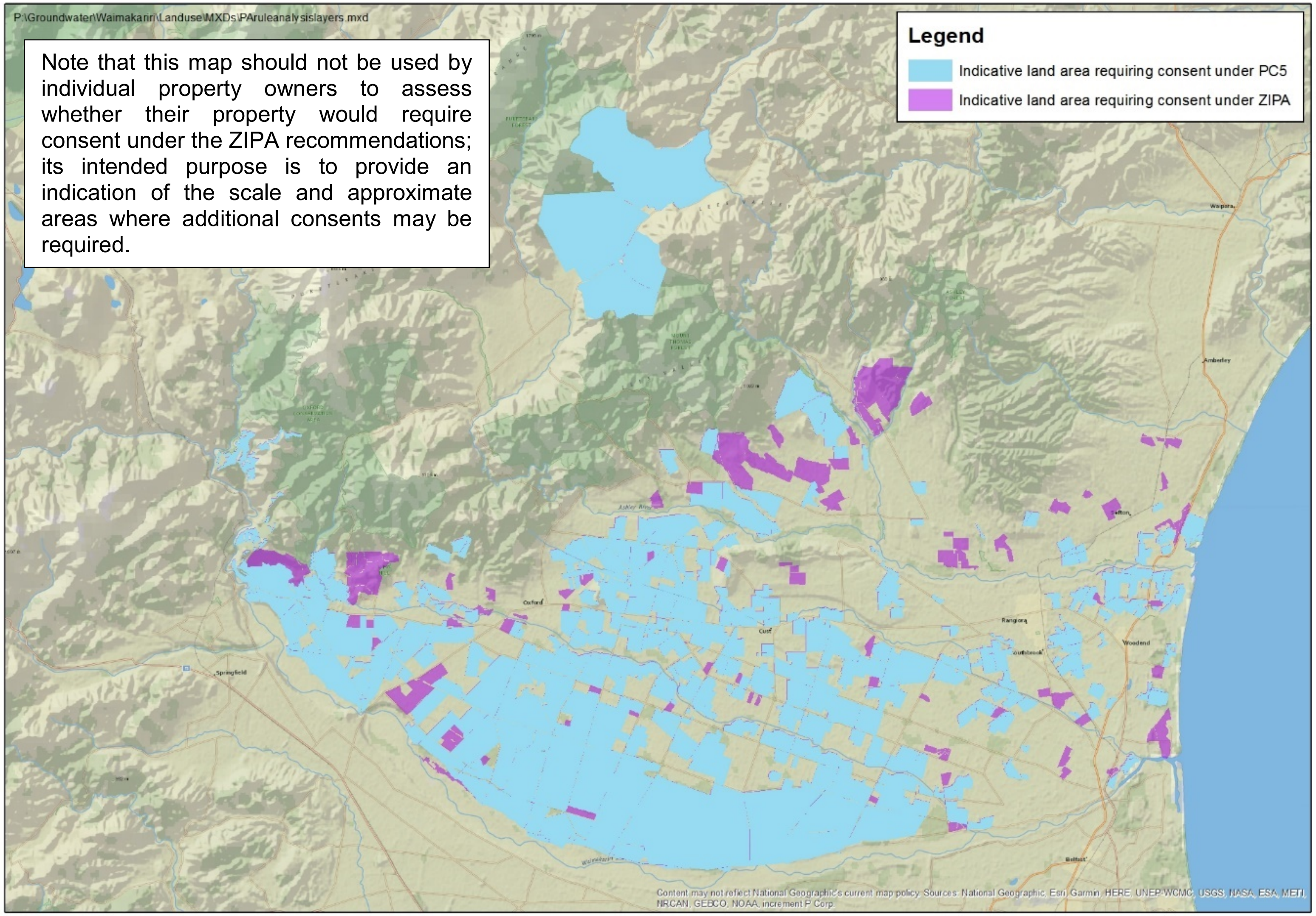


Figure 4 **Land use consent requirements under PC5 and Draft ZIPA recommendation**

Appendix 8. MAR Investigation - Infiltration Trial

Environment Canterbury and Waimakariri Irrigation Limited commenced a MAR investigation in the area upstream of Silverstream in August 2018. The investigation showed that ~100 L/s of clean Waimakariri River water could be infiltrated to ground using existing water race infrastructure and a relatively low-cost 150 m long trench (seeFigure 1) with limited mounding in the monitoring wells we installed adjacent to the trench (Figure 2). Low nitrate water discharged to this trench is likely to reach the spring heads feeding Silverstream and the Kaiapoi River within a few years. Given that the median Silverstream flow at Harpers Road is in the order of 400 L/s, augmentation of the current high-nitrate groundwater discharge to this stream with 100 L/s of clean water could reduce nitrate concentrations from the currently measured 10 mg/L to 7.5 mg/L within a few years if all of the recharged water reached Silverstream (although in reality some of the clean water may be drawn into downgradient abstraction wells and not reach the spring-fed streams). The MAR investigation results to date have therefore demonstrated that it may be possible to achieve the ZIPA nitrate limit in Silverstream much more quickly if MAR is successfully implemented in the Silverstream catchment. Several critical questions still need to be addressed, however, before MAR could be implemented on a broader scale to help achieve the WWZC Priority Outcomes:

- The number and spatial distribution of infiltration sites required to deliver nitrate concentration reductions in surface water and groundwater receptors has not yet been evaluated.
- The potential for an increase in groundwater-driven flooding risk needs to be assessed and appropriate mitigation developed, if needed, to manage these risks.
- The funding and management mechanisms required to build and operate a MAR scheme have also not yet been considered.

Figure 1 Infiltration trench at start of trial

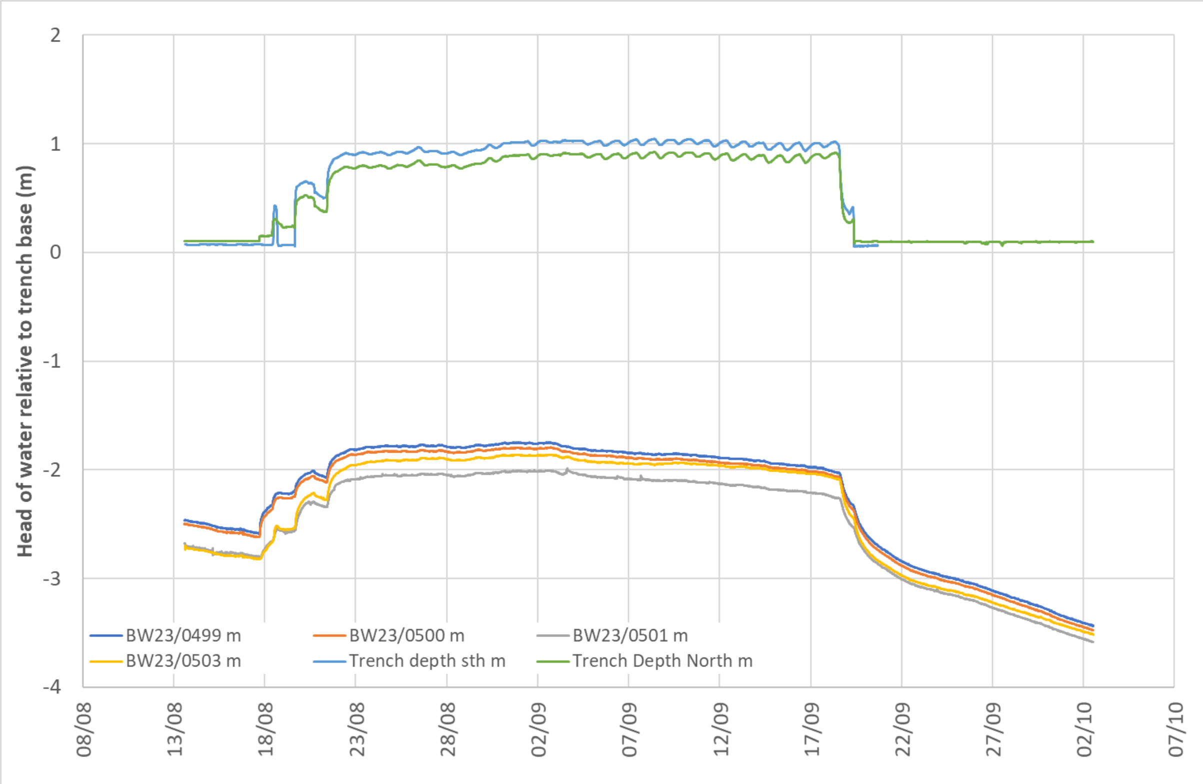


Figure 2 **Water levels in trench and piezometers adjacent to trench during test period (August-September 2018)**

Appendix 9. Nitrate modelling results

The graphs presented in this appendix show our nitrate concentration time series modelling results for all the drinking water wells and surface water bodies for the Current Pathways scenario and the ZIPA Solutions Package (see Section 5). Graphs for GMP and Alternative Pathways are only presented for a selection of receptors to indicate the general effect of these options on nitrate concentrations over time.

This appendix is structured as follows:

- A9.1 Nitrate time series for Private Water Supply Areas (PWSA)[74]
- A9.2 Nitrate time series for Waimakariri District Council (WDC) Community Supply Wells[75]
- A9.3 Nitrate time series for Christchurch City Council (CCC) Community Supply Wells[76]
- A9.4 Nitrate time series for Waimakariri Northern Tributaries[77]

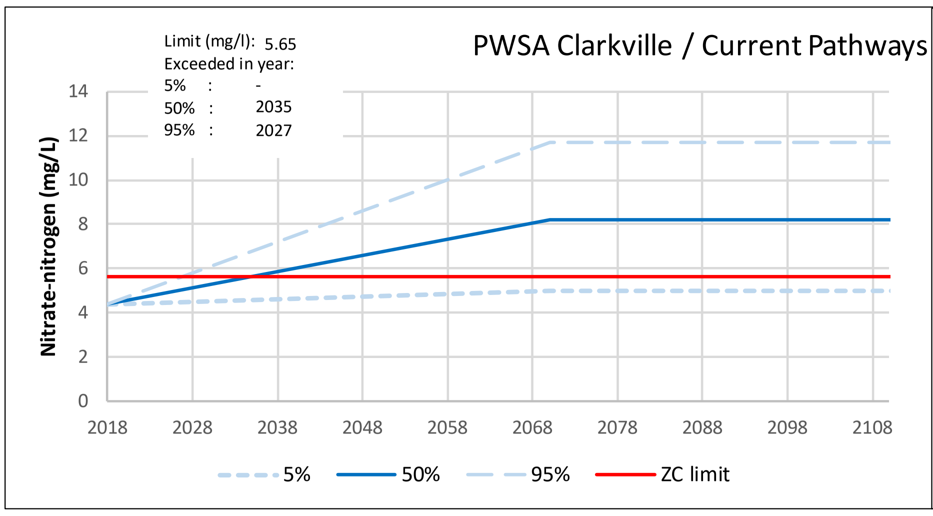
[74] P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GW quality\Options and solutions N results PWSA.xlsx
[75] P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GW quality\Options and solutions N results WDC Supply Wells.xlsx
[76] P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GW quality\Options and solutions N results CCC Supply Wells.xlsx
[77] P:\Groundwater\Waimakariri\Groundwater\Solutions work\Spreadsheets\GW quality\Options and solutions N results Surface water.xlsx

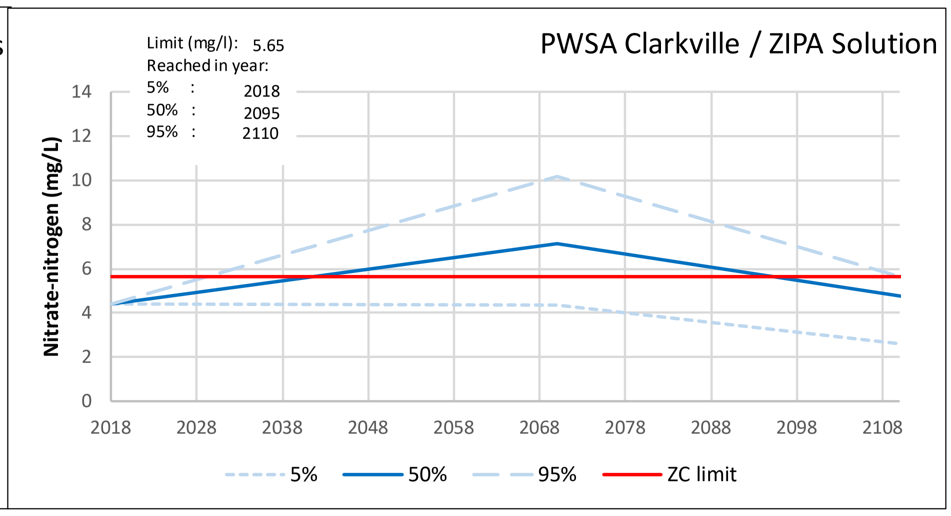
Glossary

5^{th}, 50^{th}, 95th	: Results are presented for our 50^{th} percentile model results, with the 5^{th} percentile and 95^{th} percentile results showing the band with (or uncertainty)
GMP	: Condition of water resources at some point in the future under the assumption that Good Management Practice regime, defined in PC5 as "the practices described in the document entitled "Industry-agreed Good Management Practices relating to water quality" - dated 18 September 2015.", are currently 100% adopted and continue along in the future.
Current Pathways	: Condition of water resources at some point in the future under the assumption that the current natural resource management regime and economic and social conditions continue along their current trajectory. Assume the hydrological and ecological system equilibrates with current land use, including any intensification that can occur under current Regional Plan and consent rules.
Consented -10%	:10% beyond Baseline GMP – all consented land use reduce nitrate losses 10% beyond Baseline GMP.
20kg/ha -10%	: 20 kg/ha + 10% beyond Baseline GMP – all consented land use reduce nitrate losses 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.
Dairy – 20%:	: 20 kg/ha + 10 & 20% beyond Baseline **GMP** – Dairy reduce nitrate losses 20% and all other consented 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.
Dryland Farming:	: Potential nitrate concentrations in a hypothetical scenario under which the *average nitrate losses from the interzone source area* is reduced to 8 kg/ha per year by 2050 due to land use change (dairy to dryland).
ZIPA Solution	: Condition of water resources at some point in the future after implementation of the statutory ZIPA recommendations.

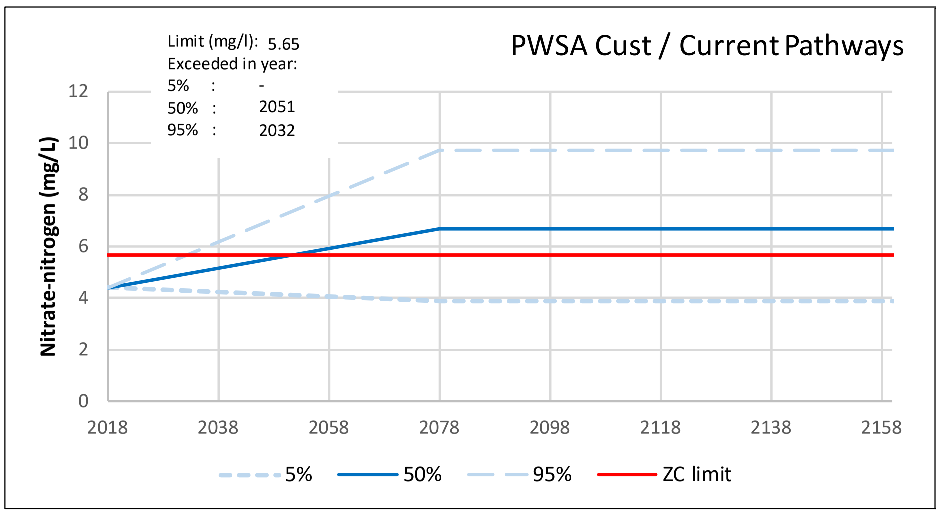
A9.1 Nitrate time series for Private Water Supply Areas (PWSA)

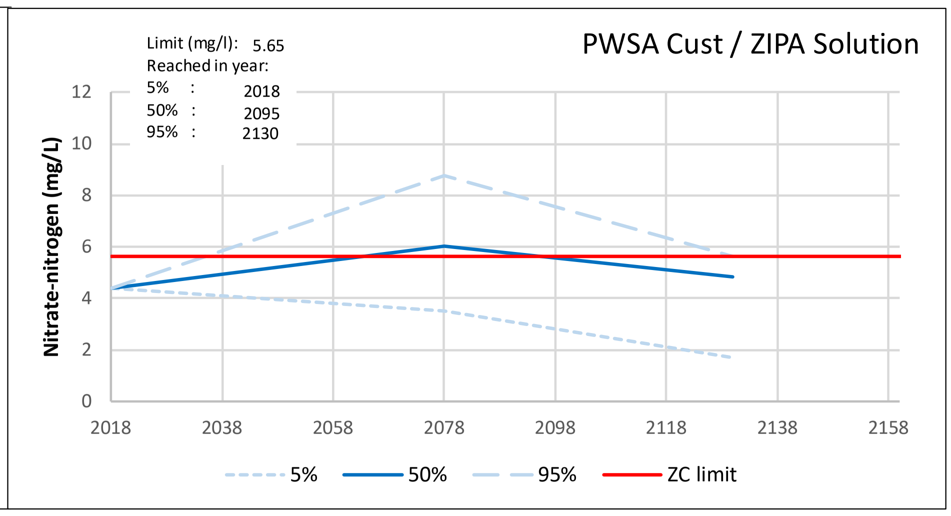
PWSA Clarkville



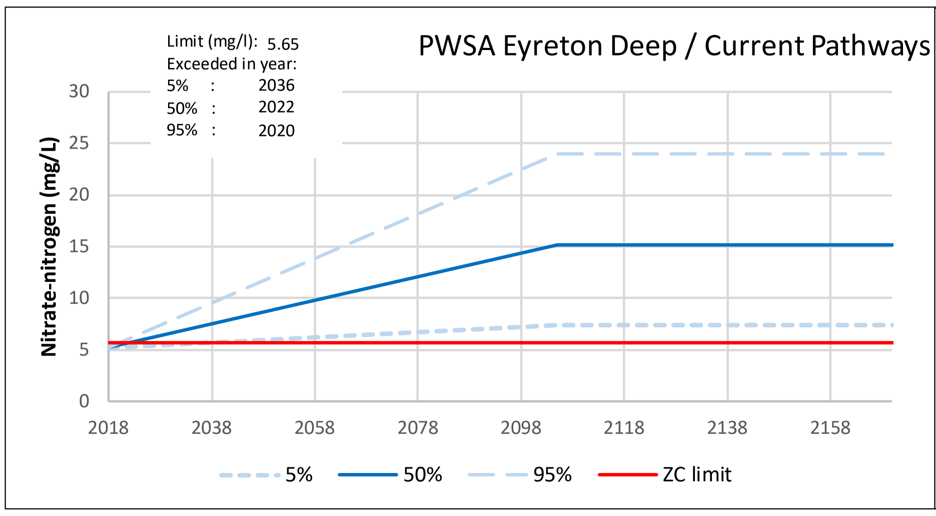


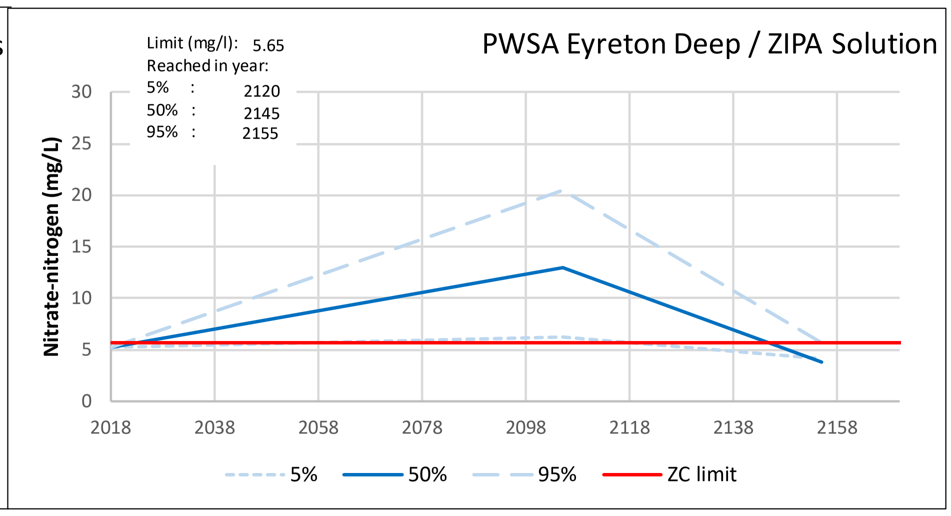
PWSA Cust



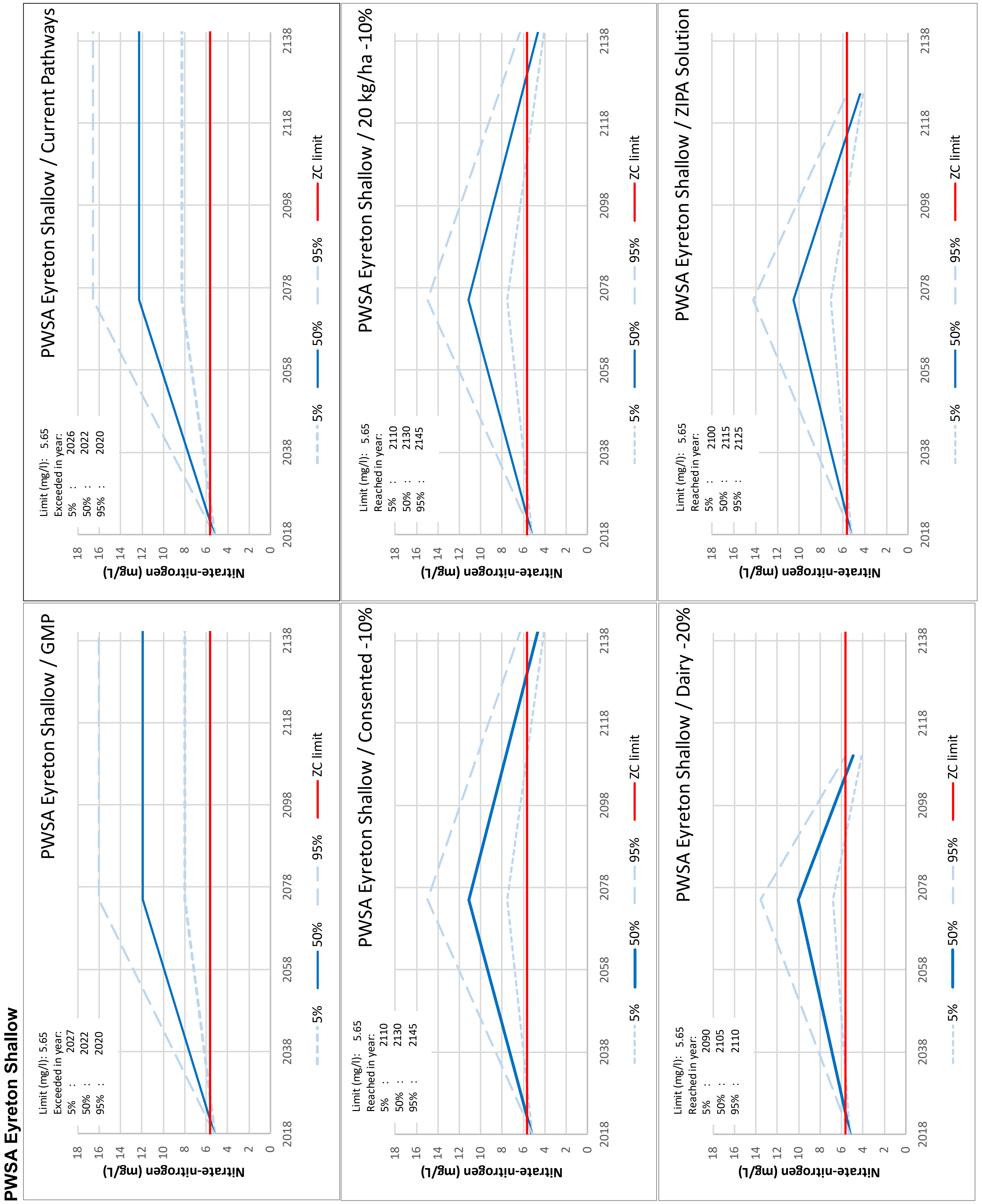


PWSA Eyreton Deep

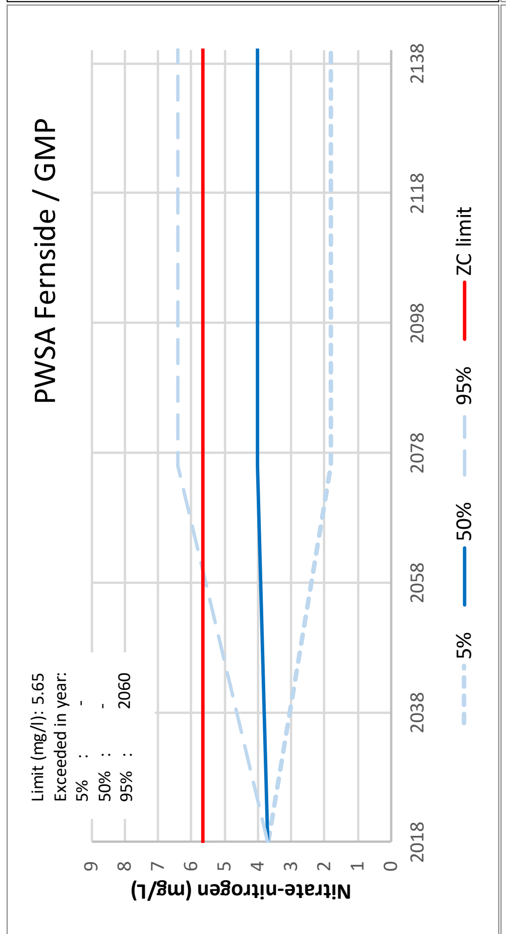


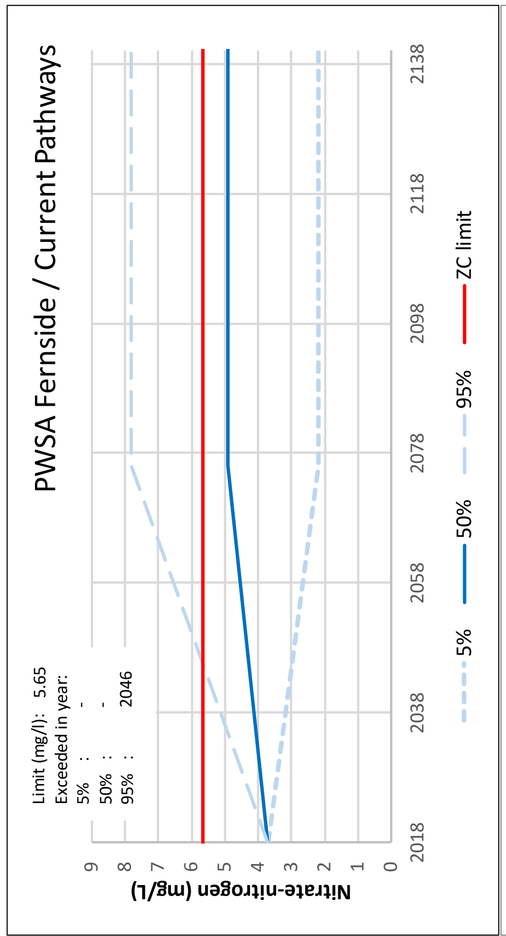


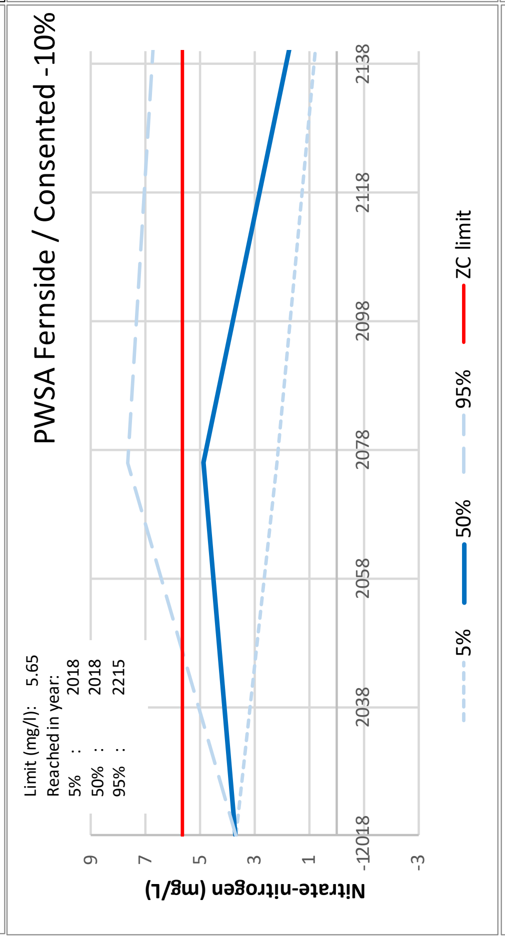
PWSA Eyreton Shallow

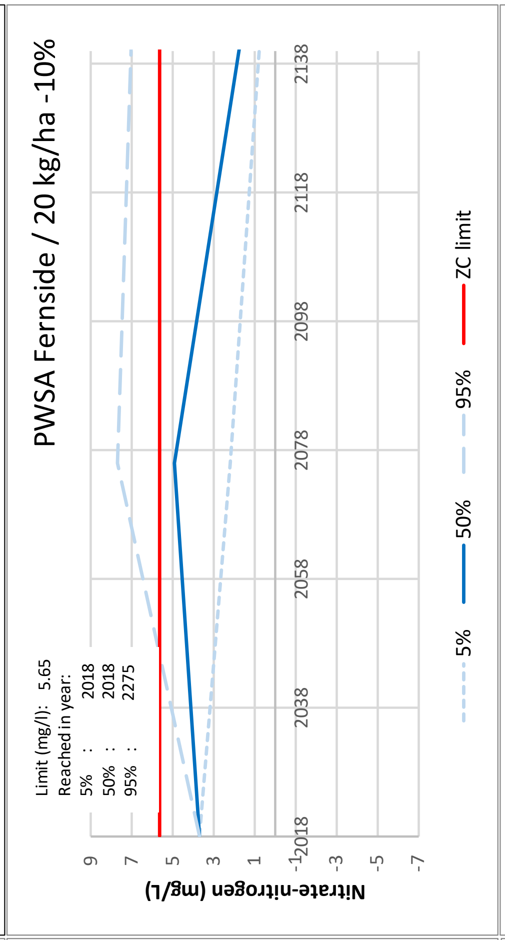


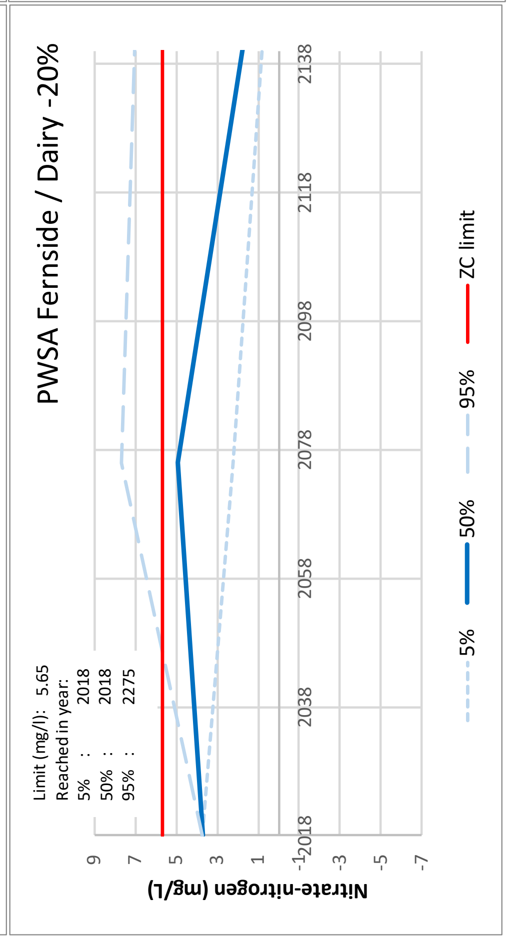
PWSA Fernside

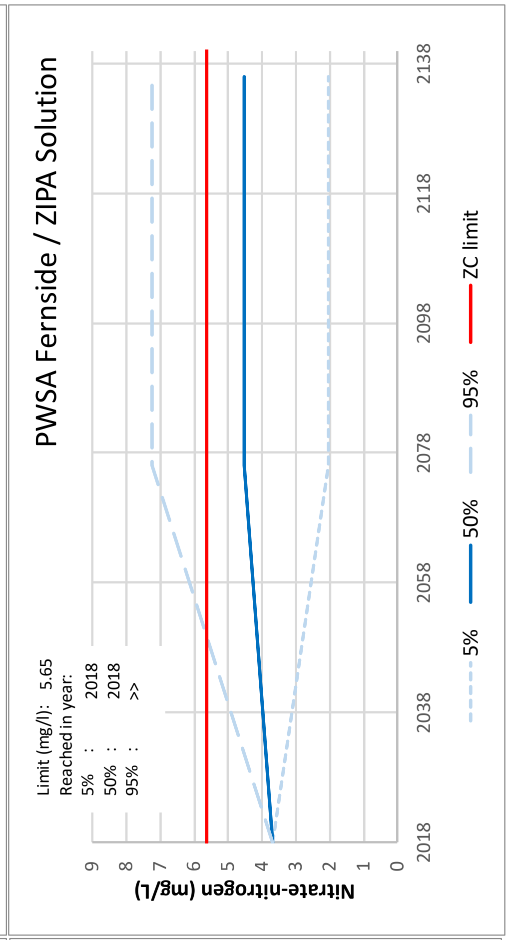




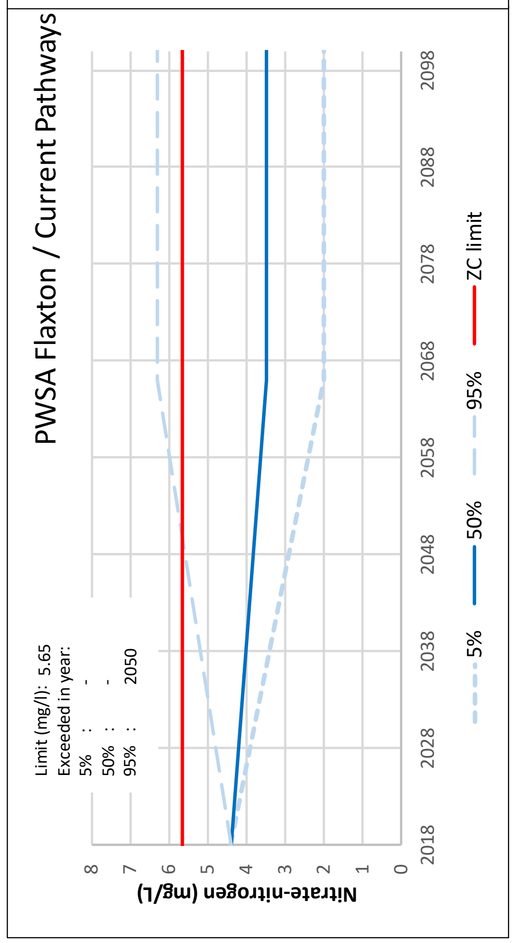


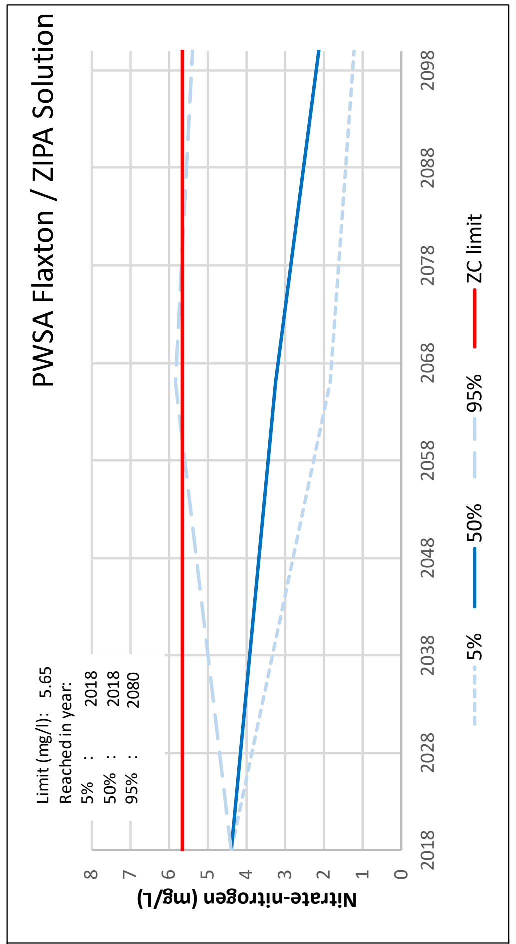






PWSA Flaxton





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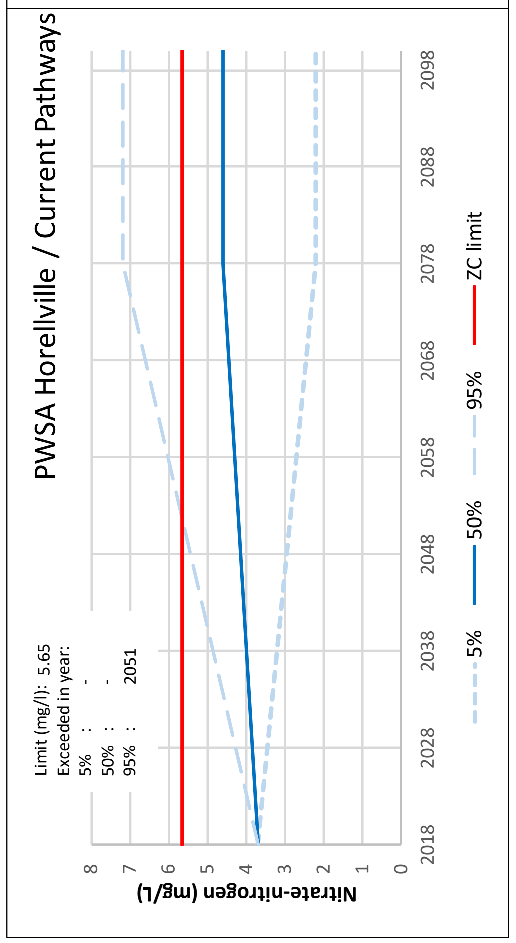
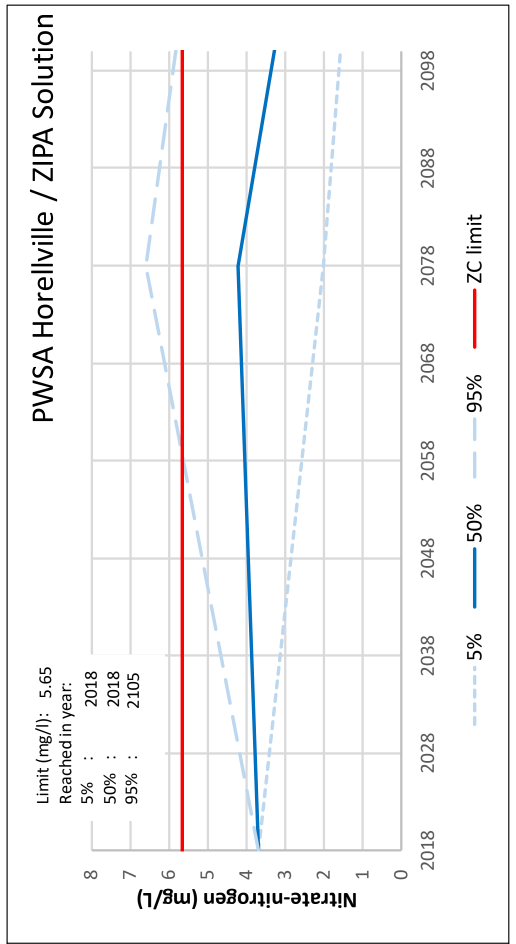
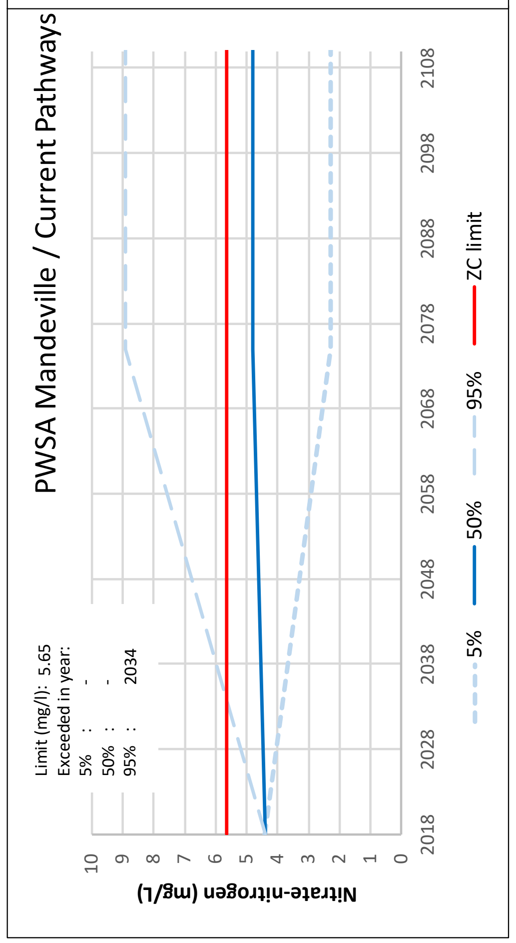
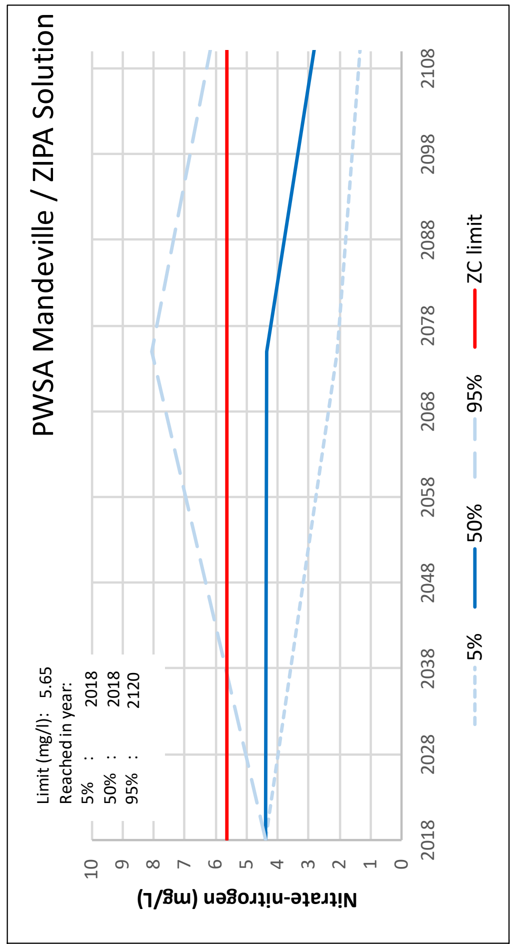


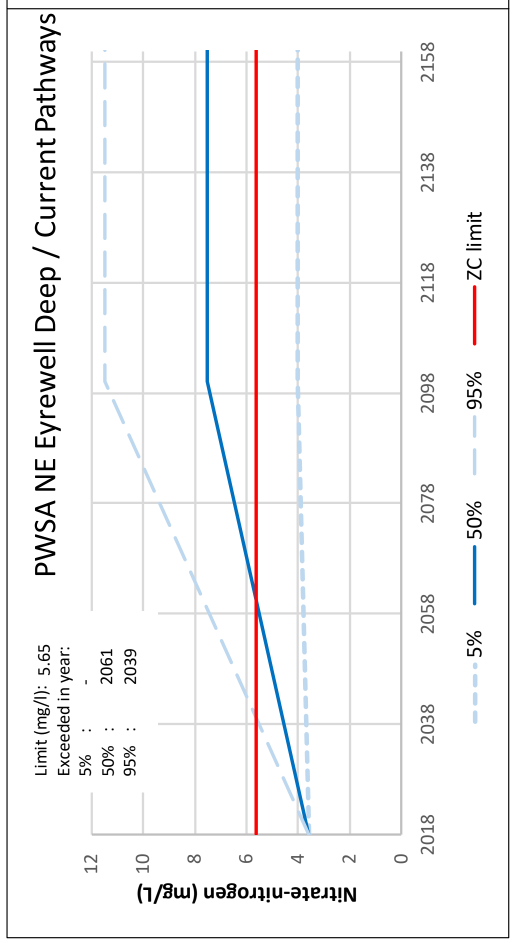


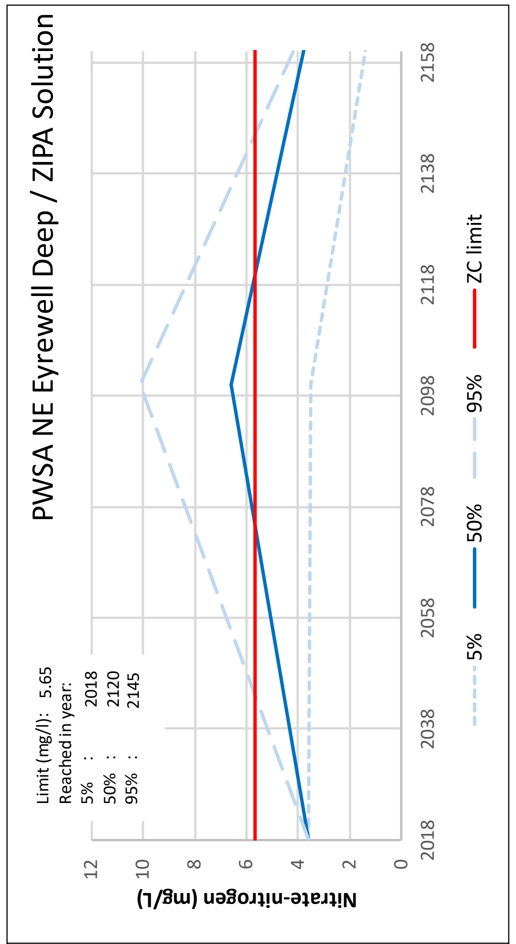
PWSA Mandeville





PWSA North-East Eyrewell (deep)





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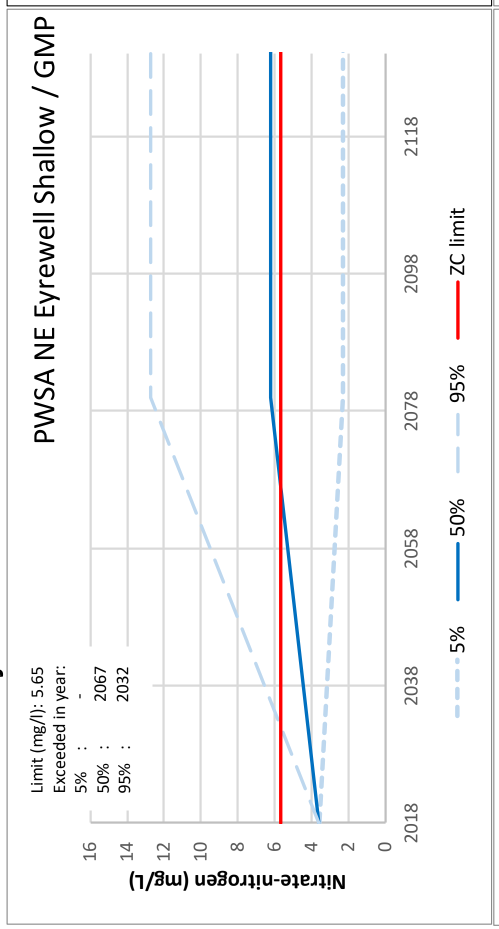

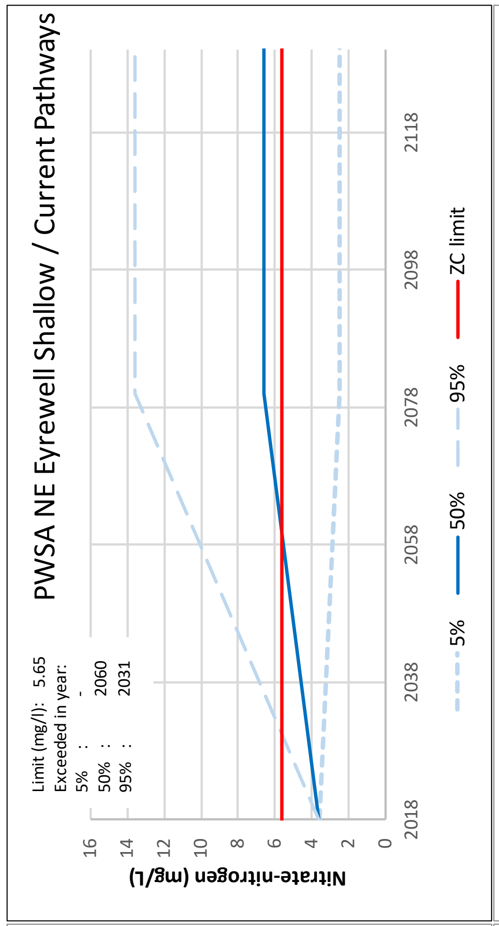

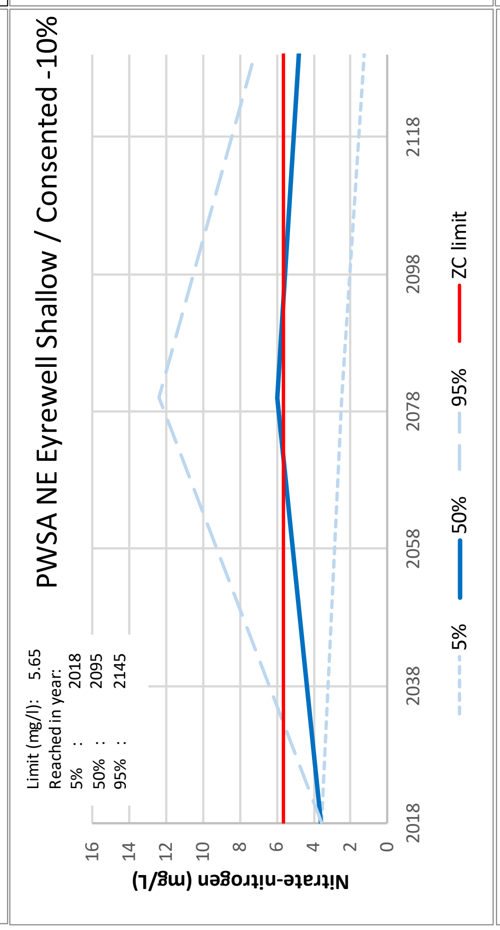

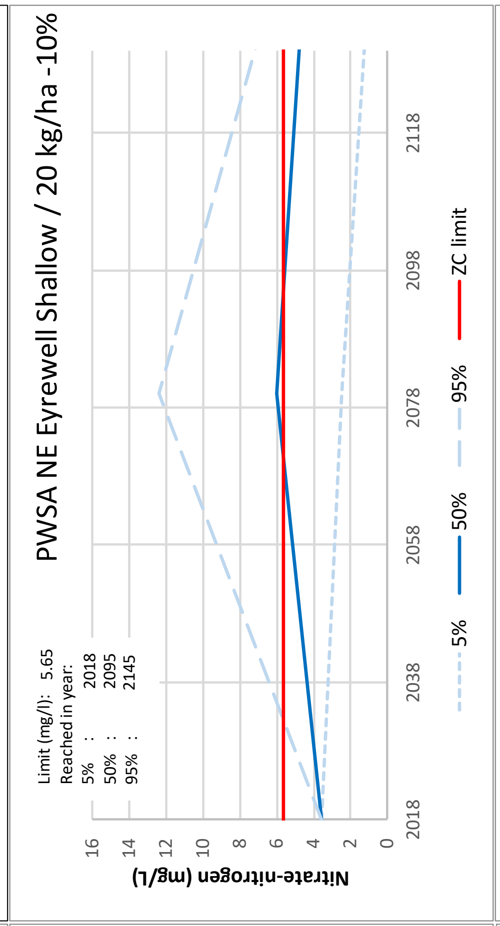

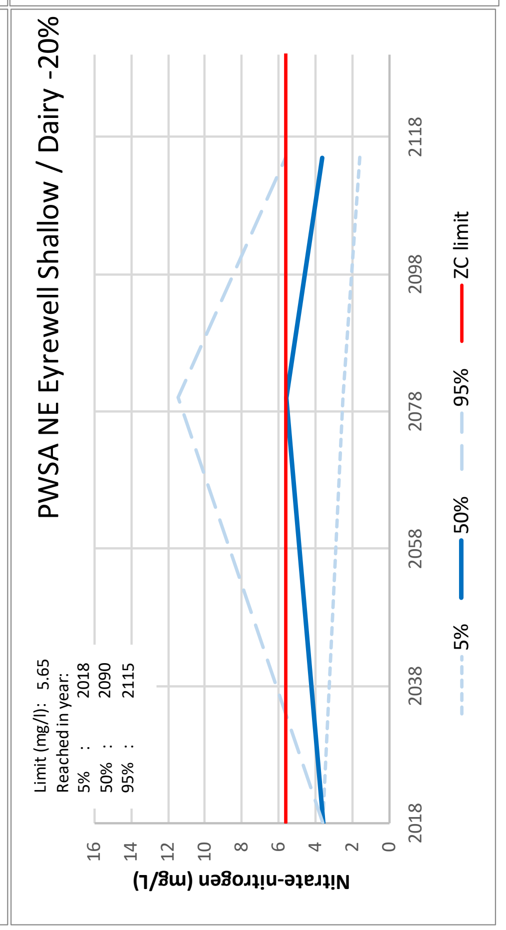

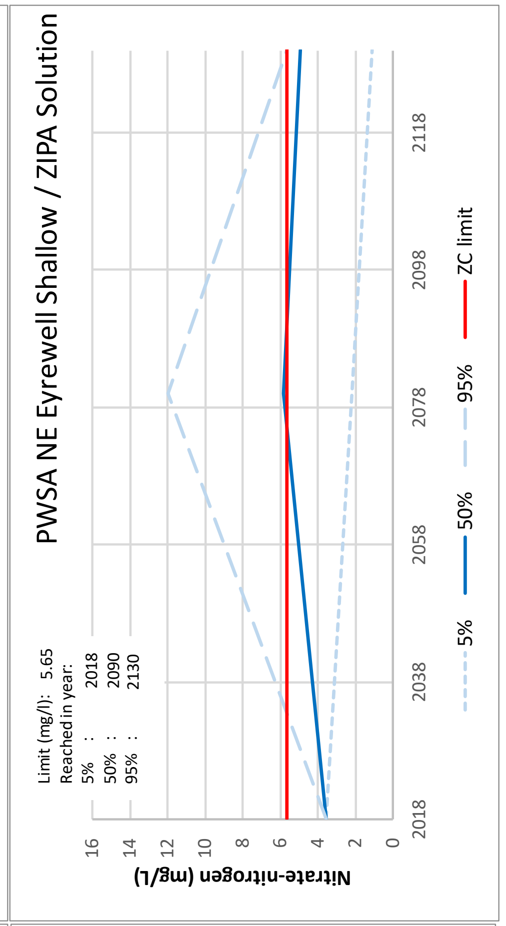

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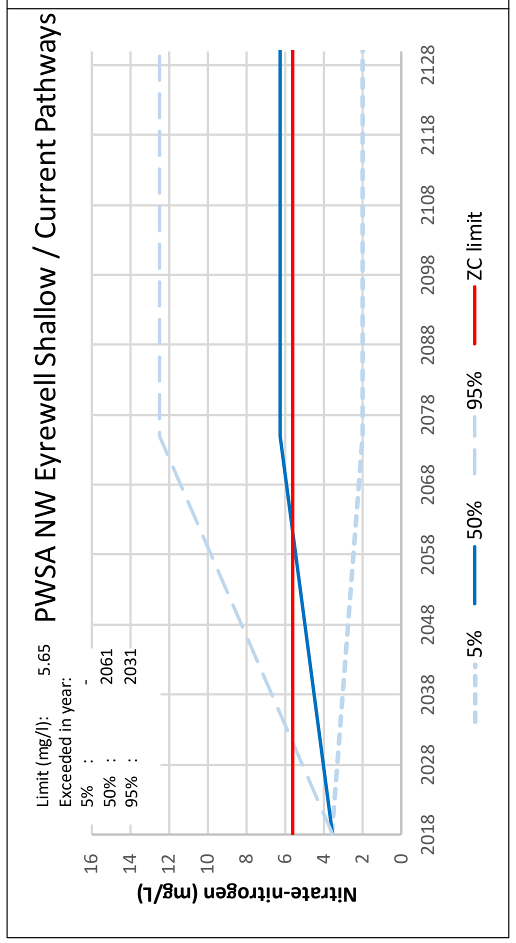

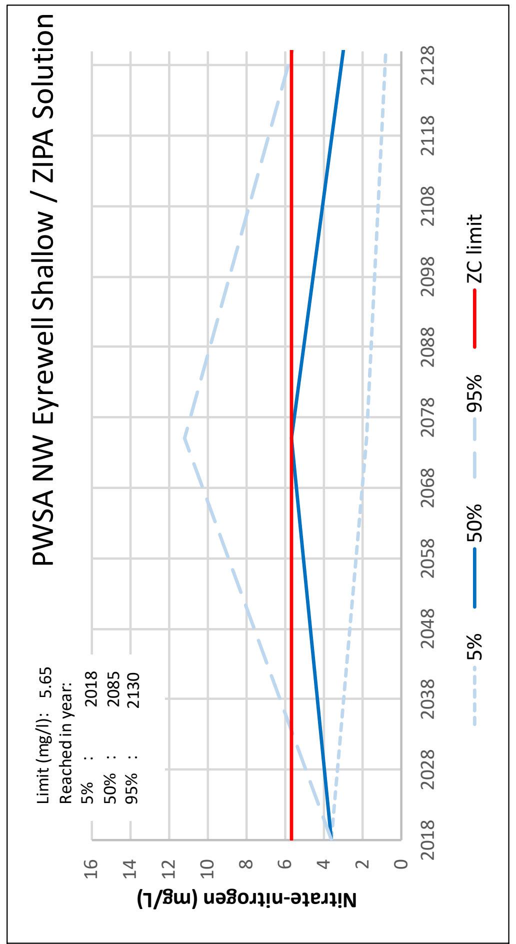

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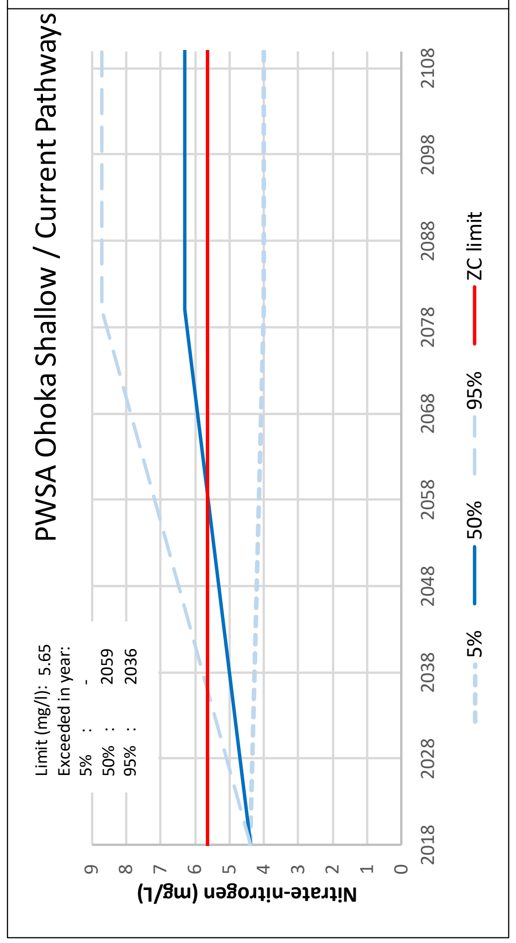

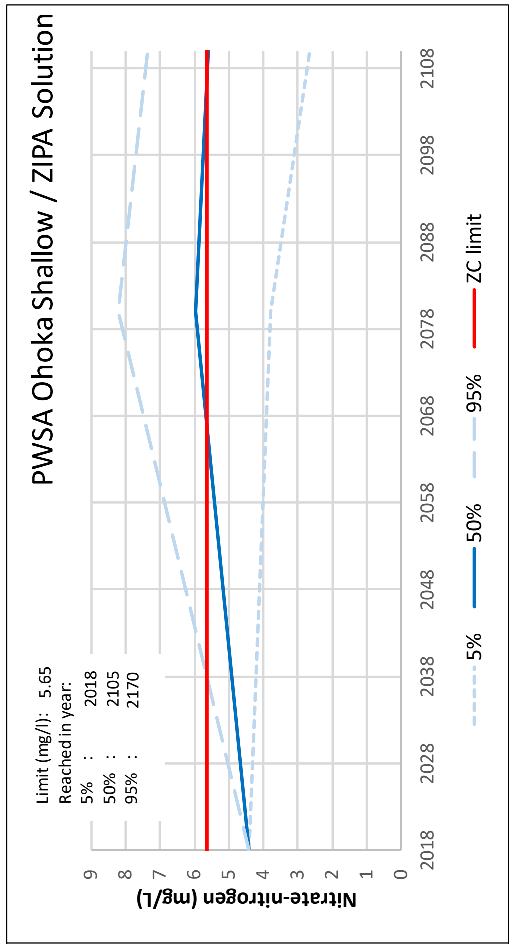

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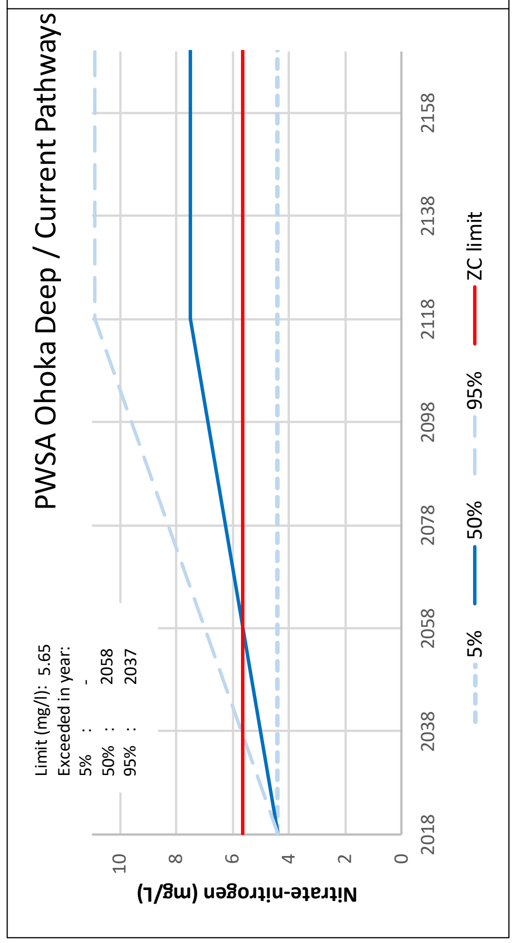

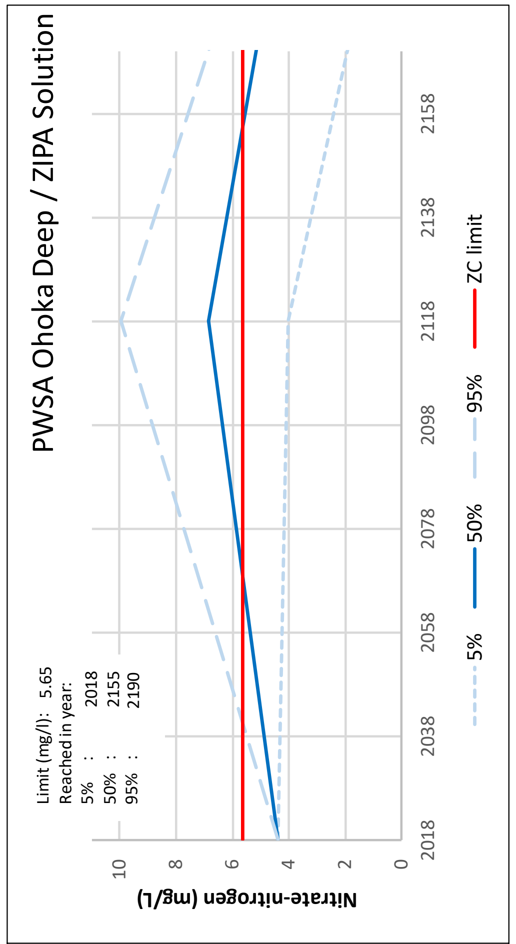

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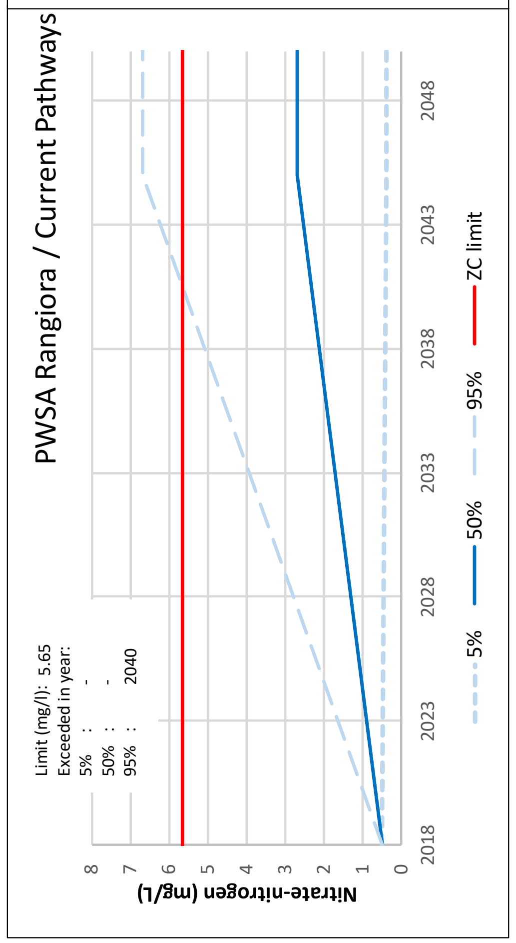

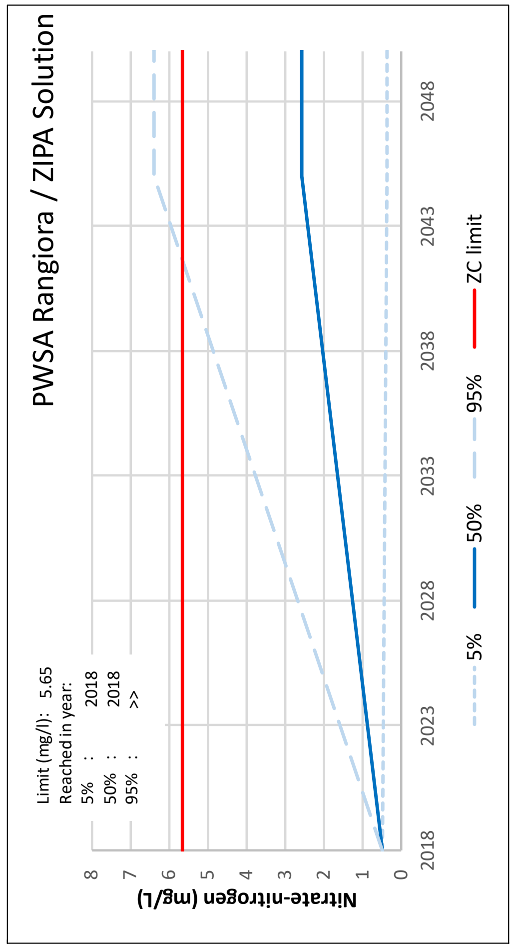

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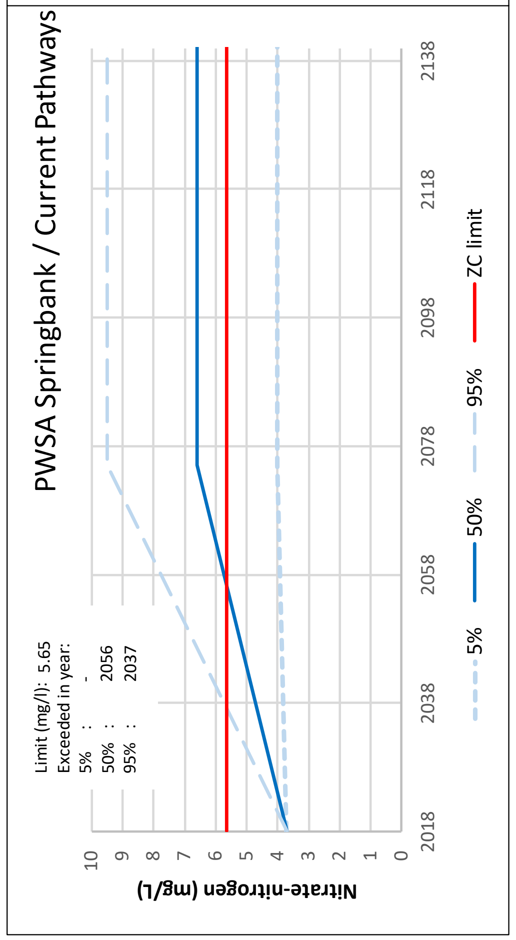
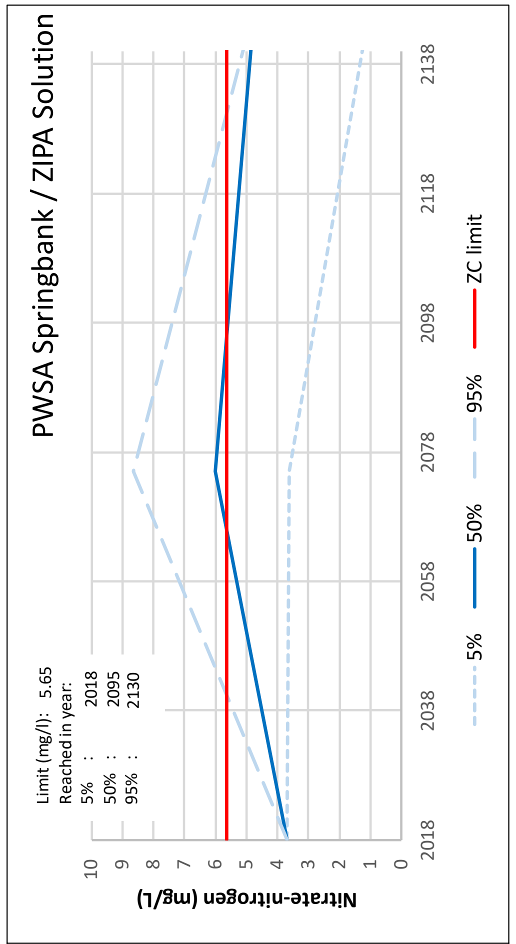
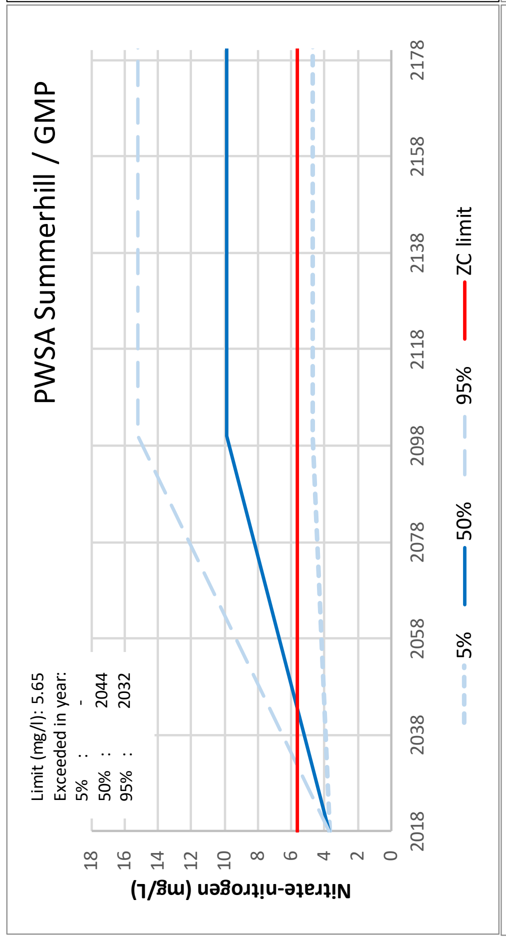
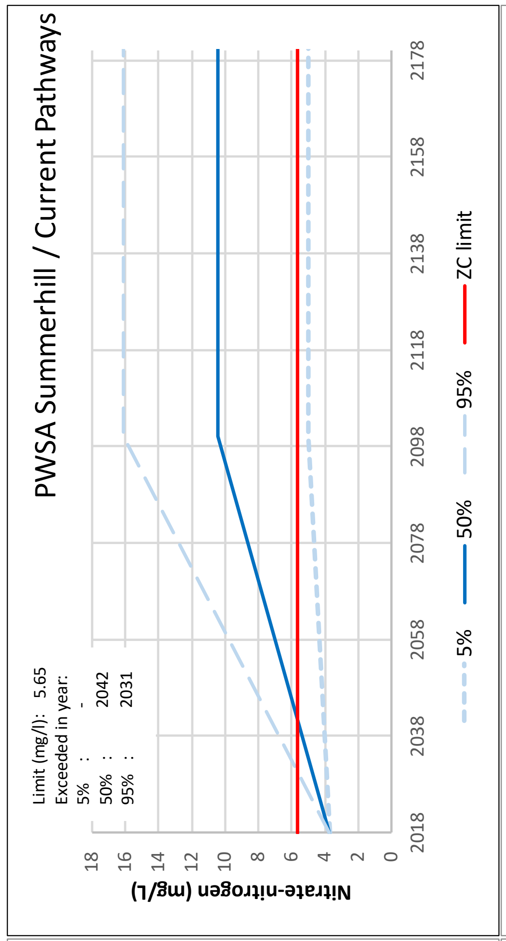
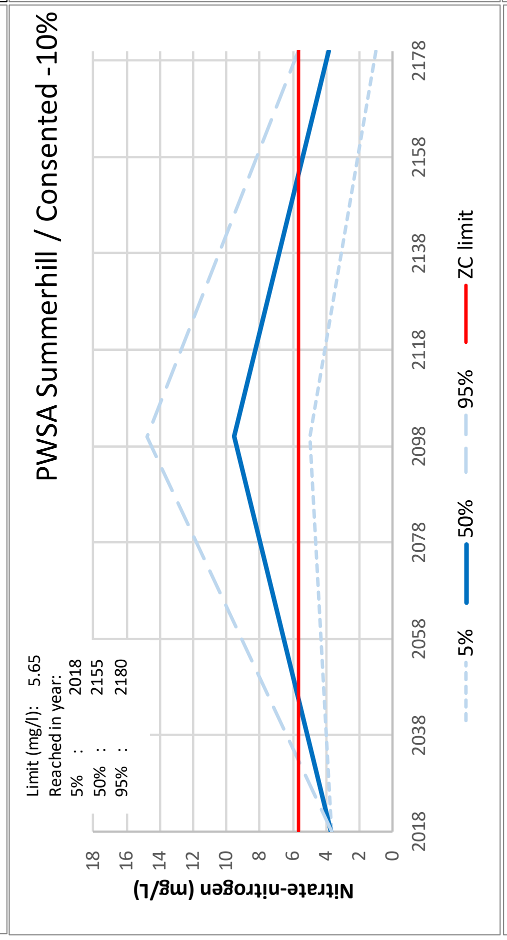


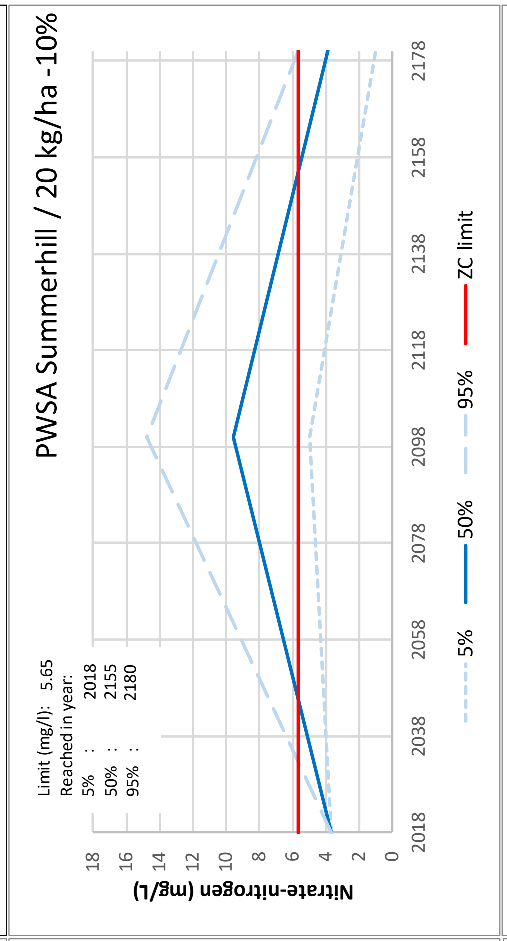


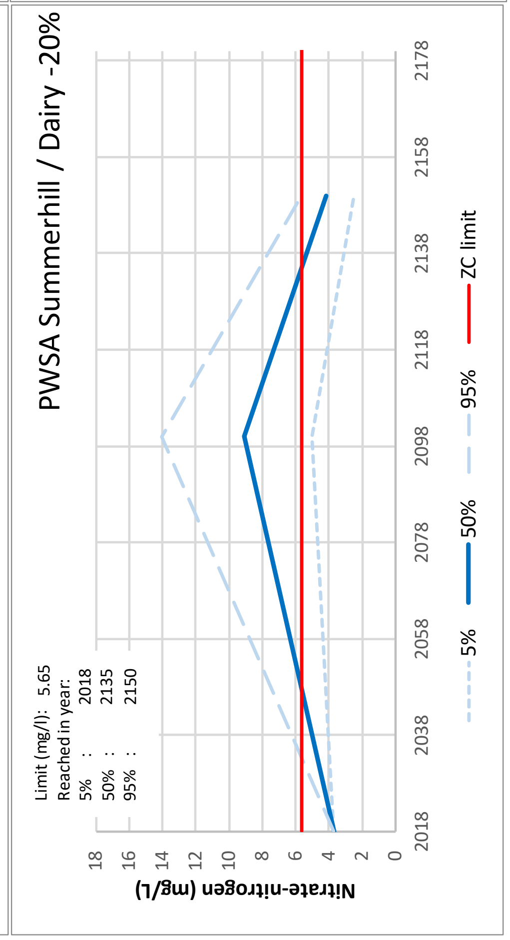
PWSA Summerhill

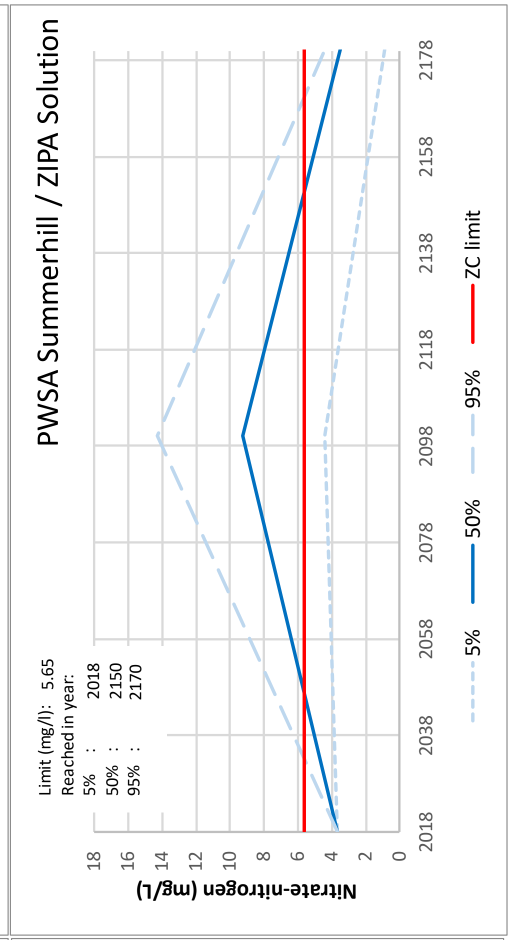




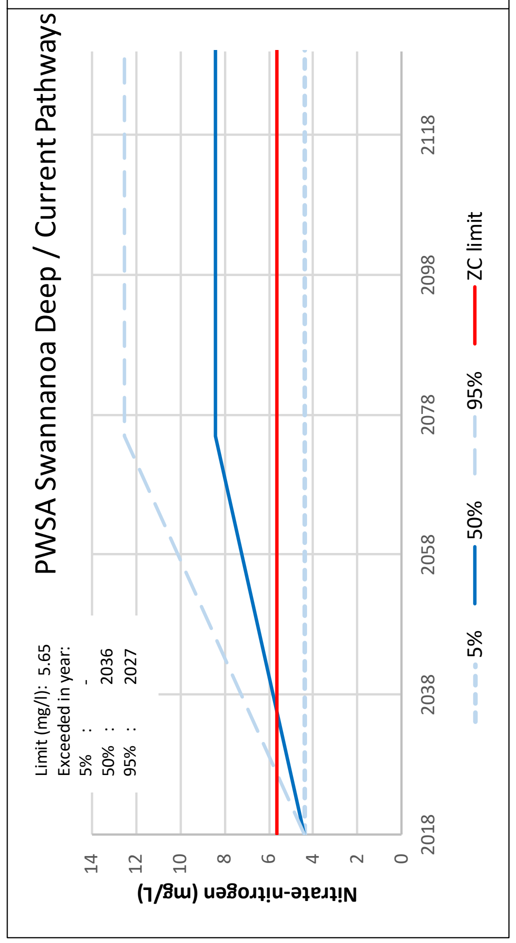


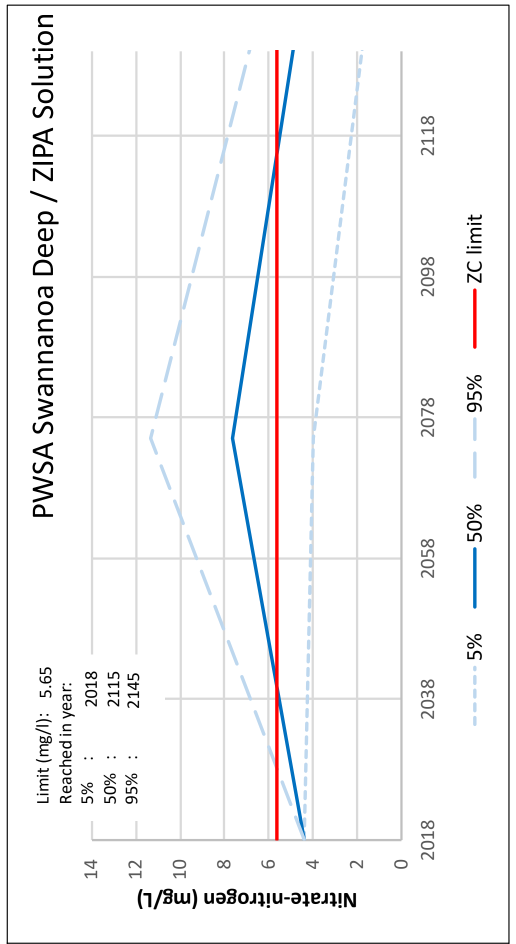




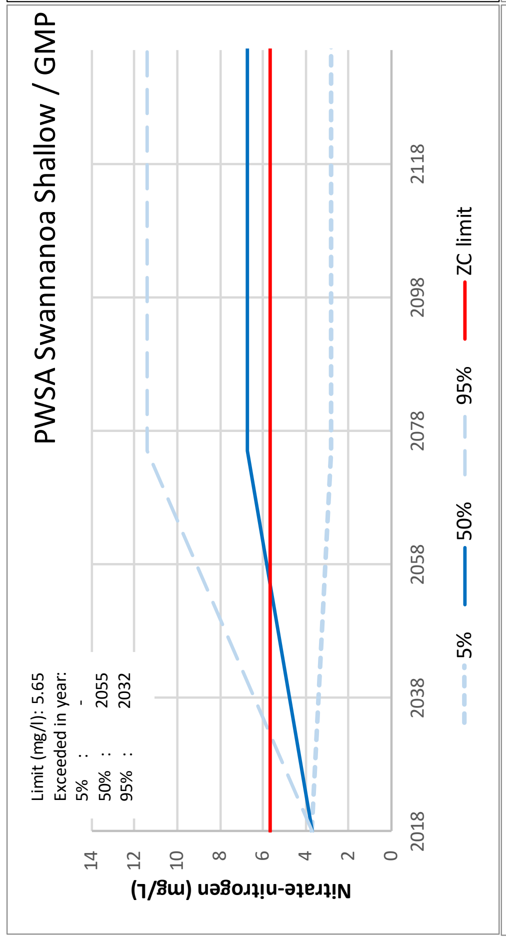


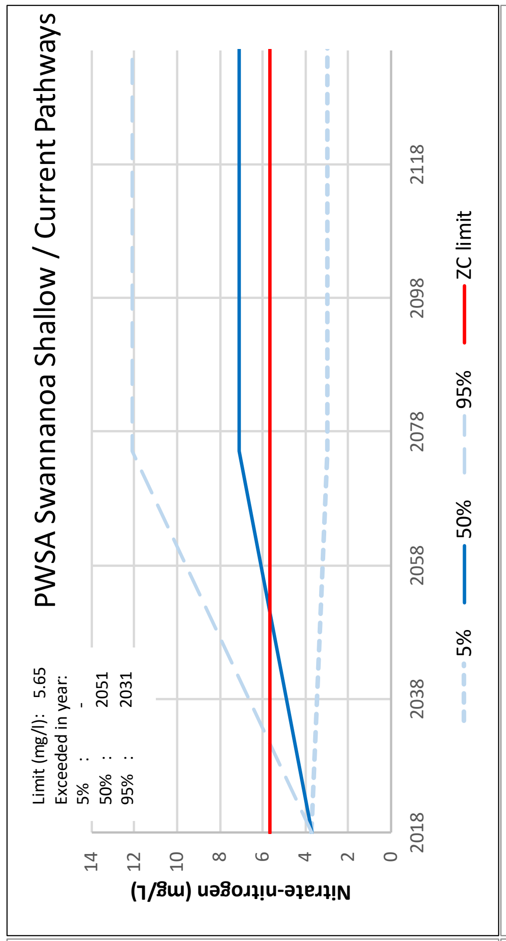
PWSA Swannanoa Deep

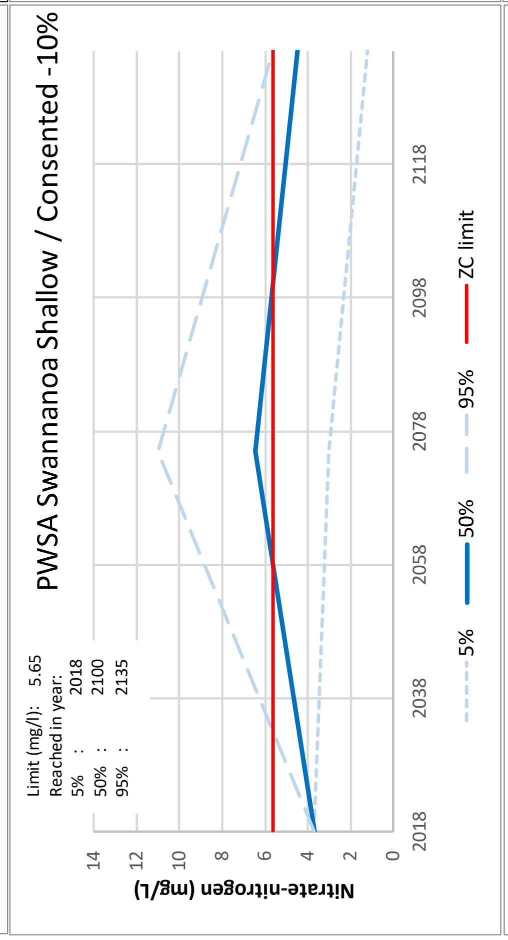


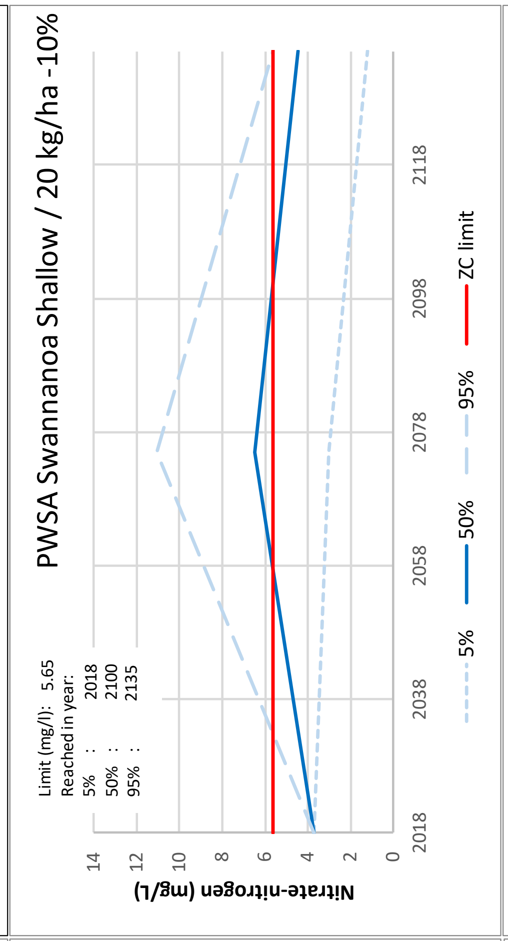


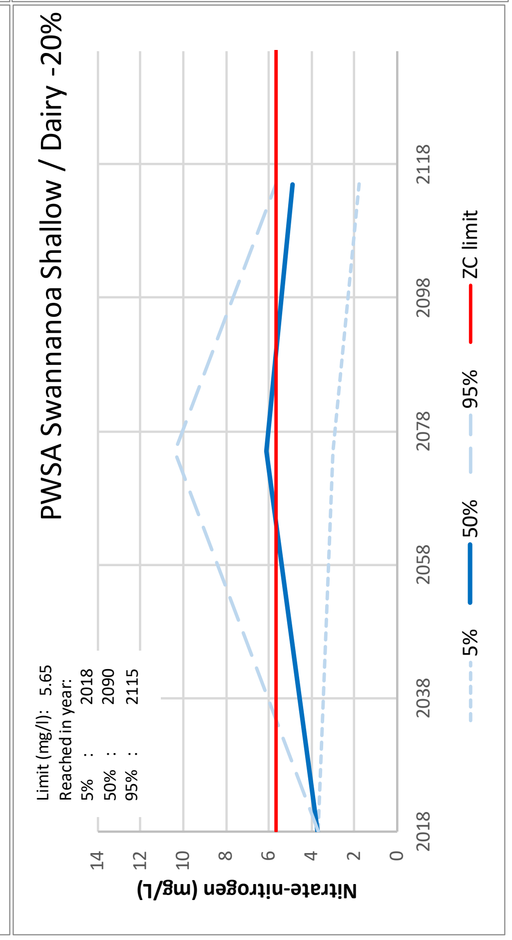
PWSA Swannanoa Shallow

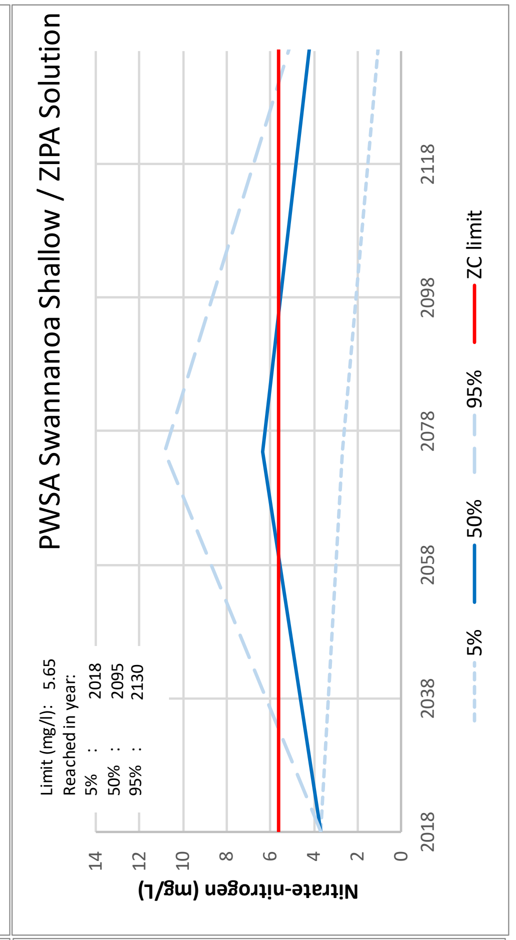




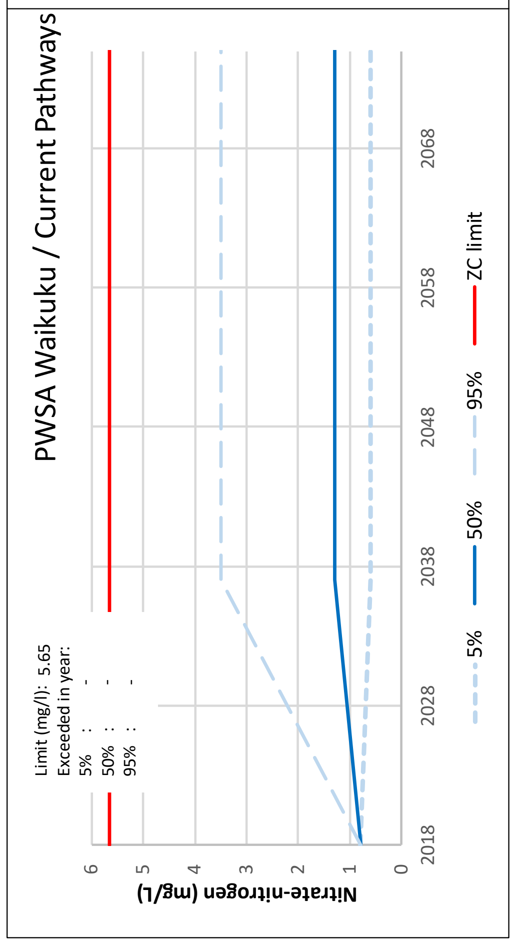


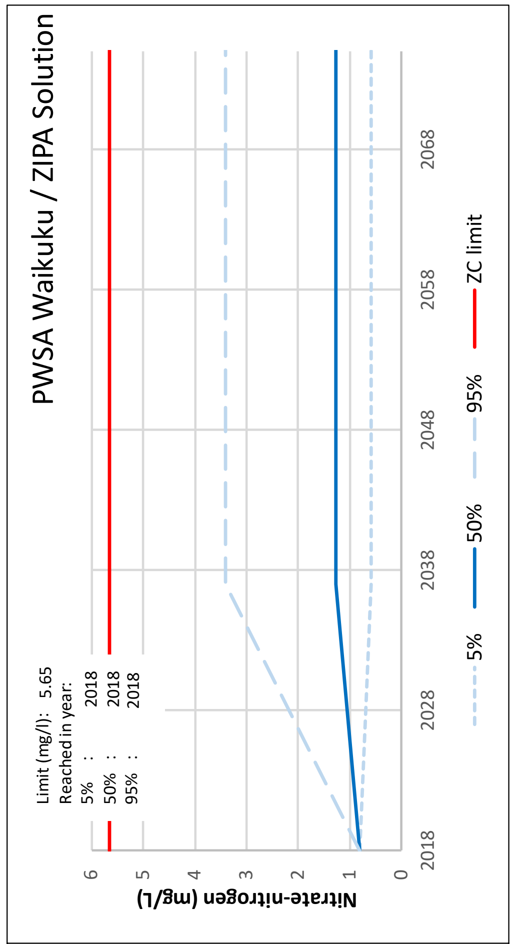




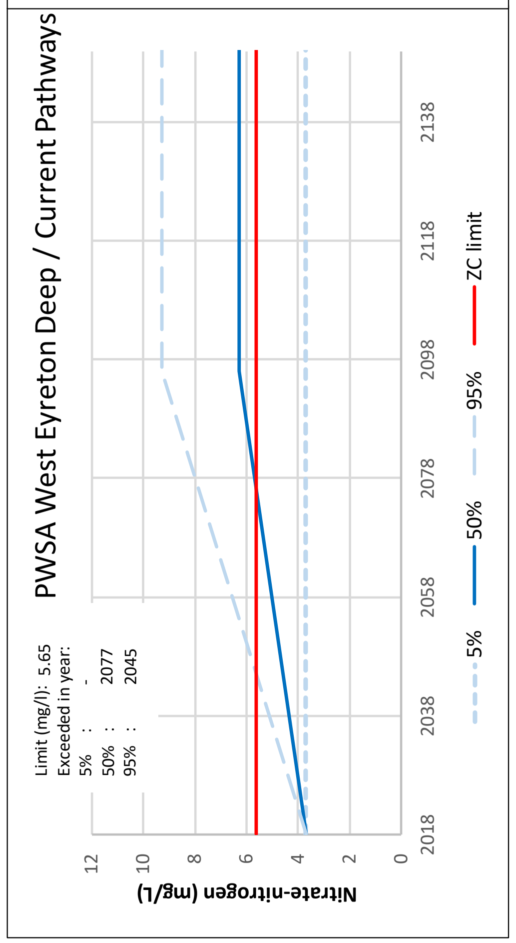


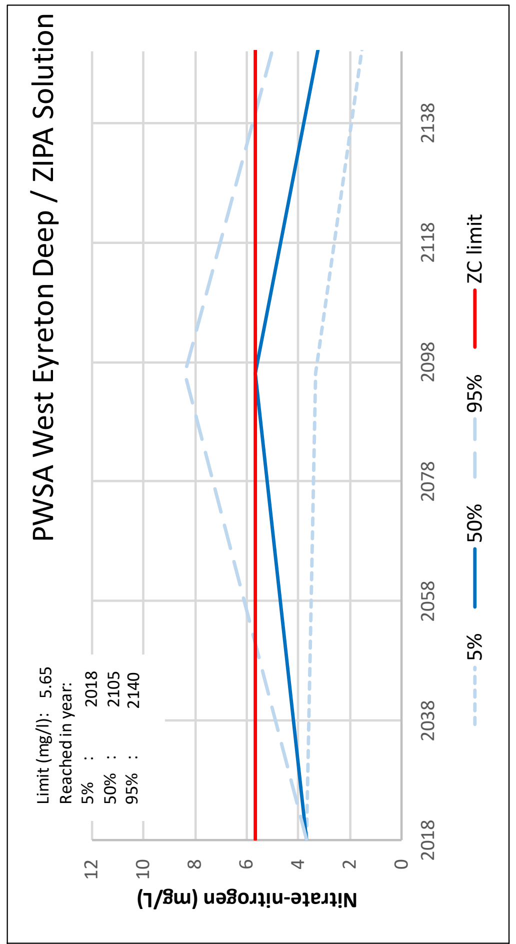
PWSA Waikuku



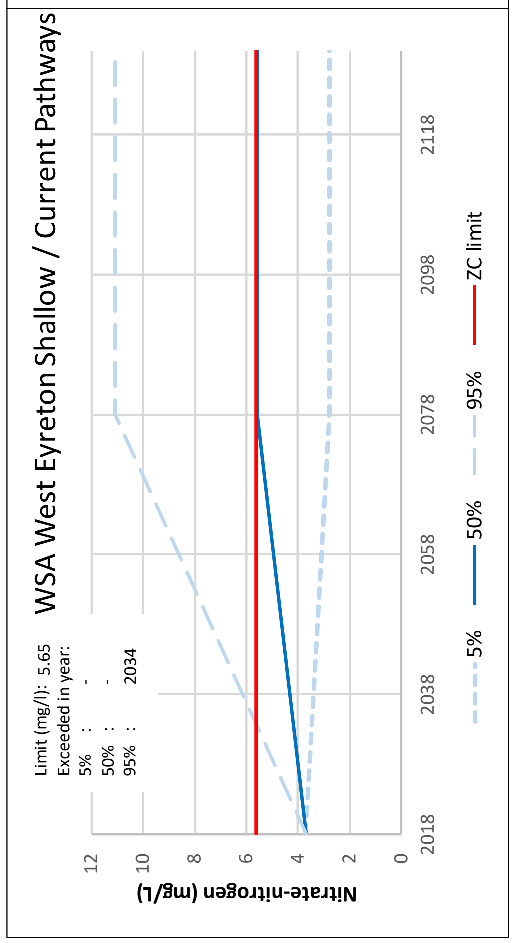


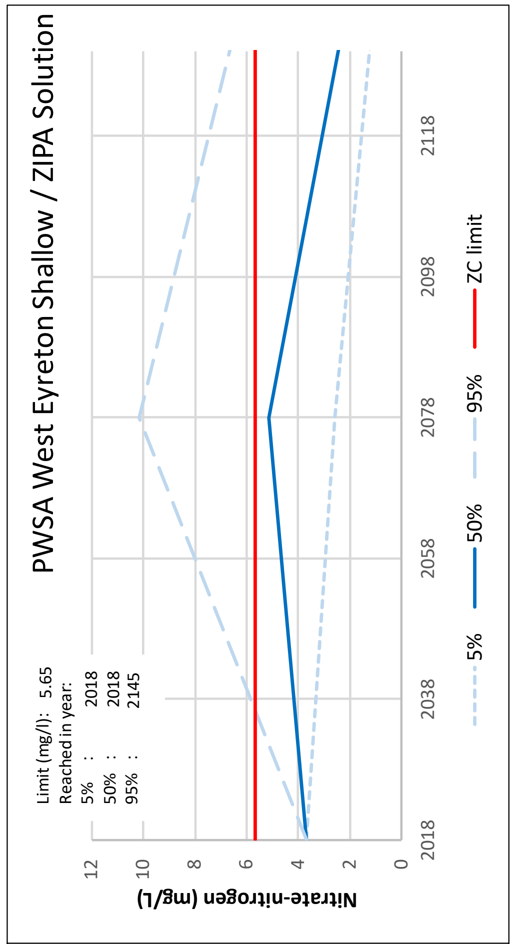
PWSA West Eyreton Deep



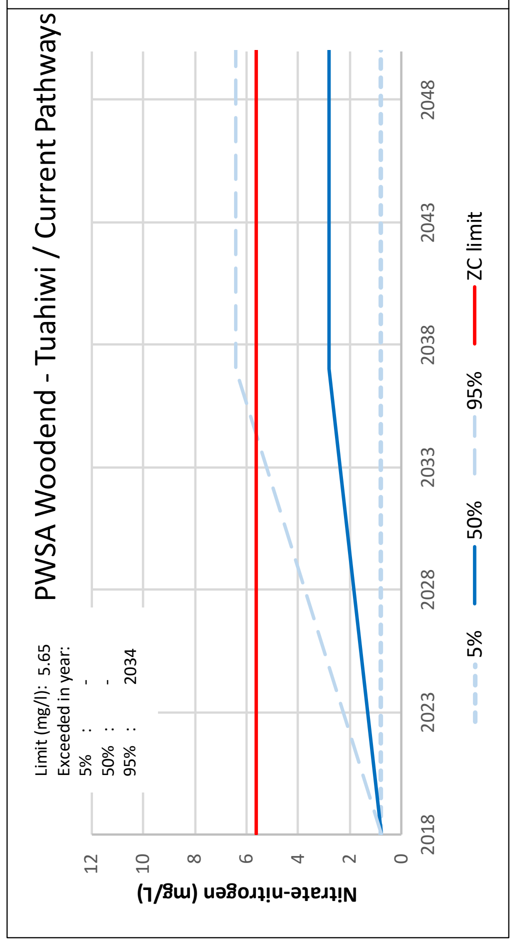


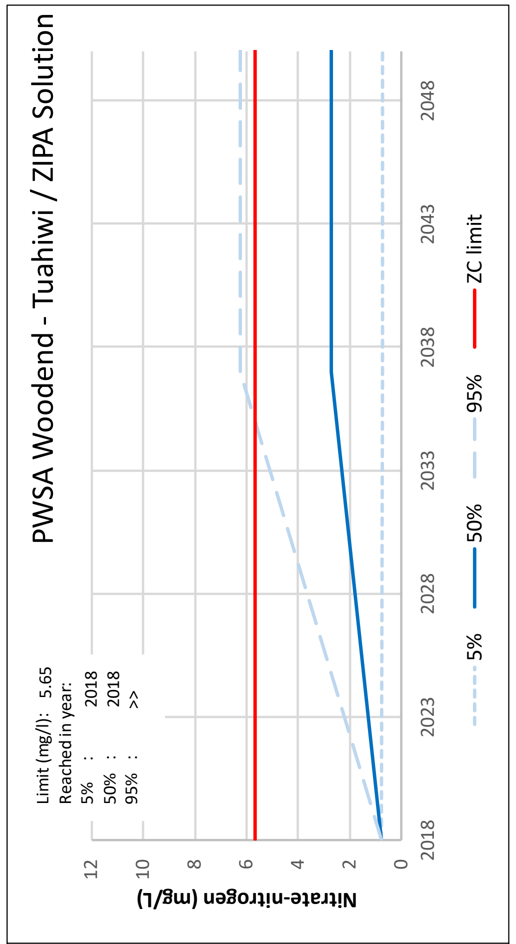
PWSA West Eyreton Shallow





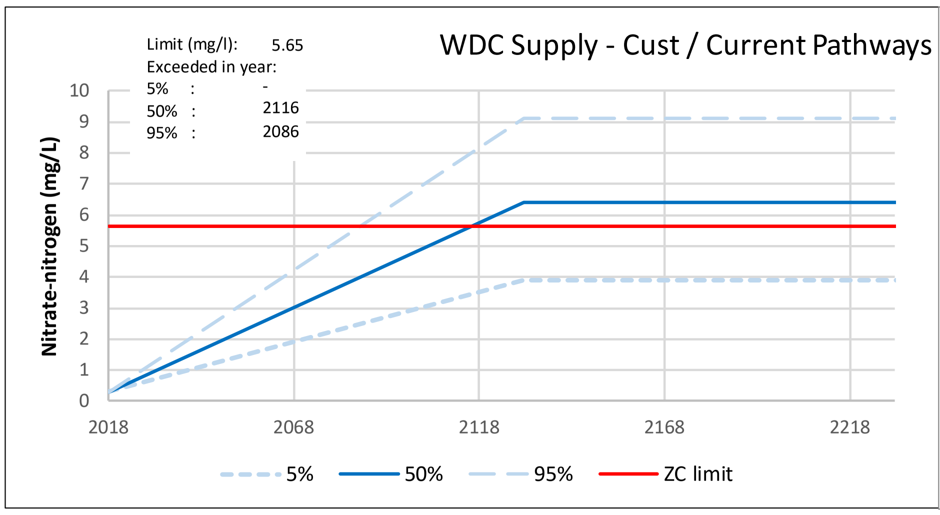
PWSA Woodend – Tuahiwi

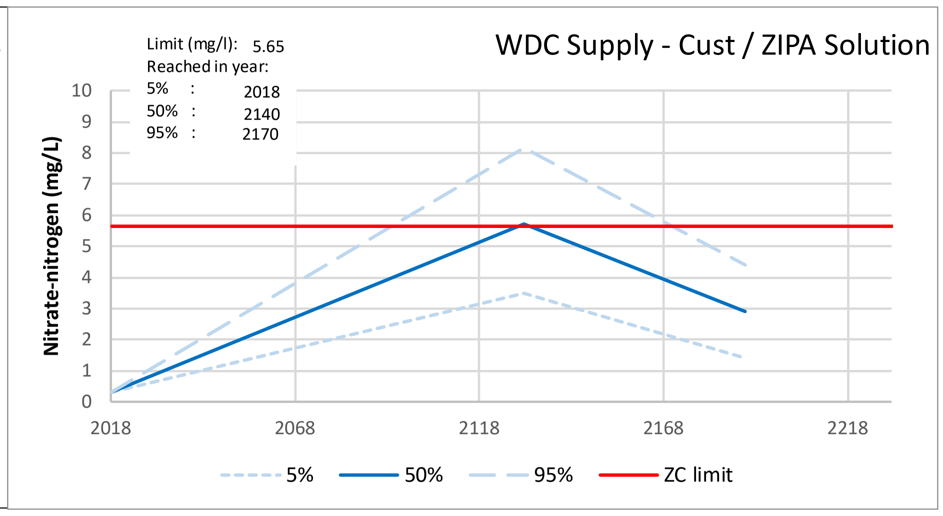




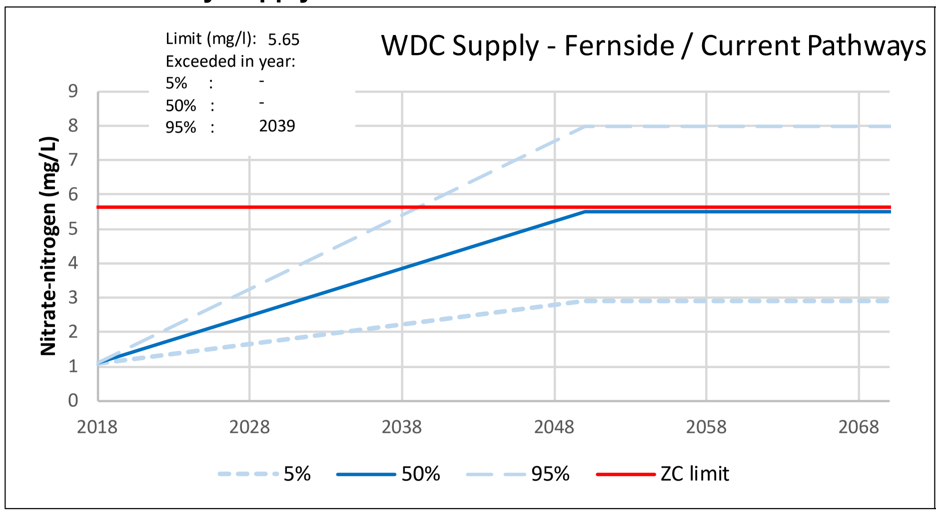
A9.2 Nitrate time series for Waimakariri District Council (WDC) Community Supply Wells

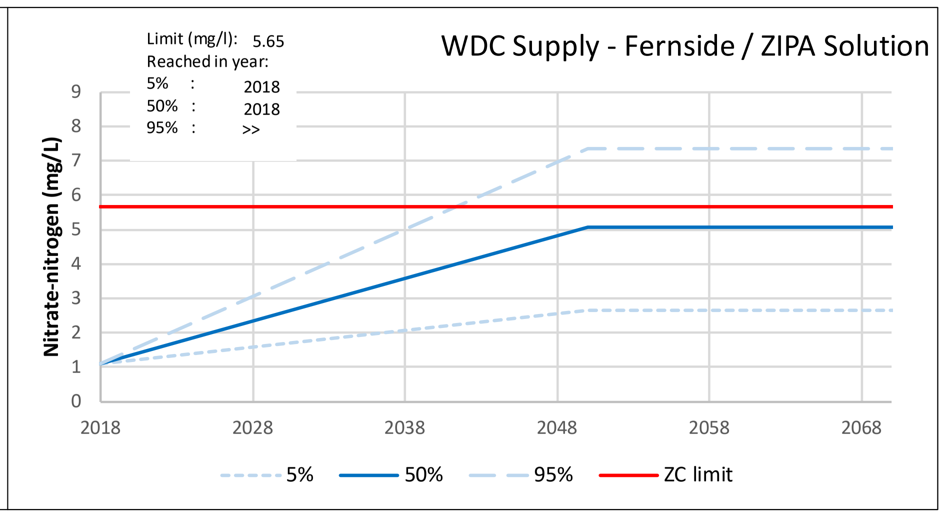
WDC Community Supply Wells - Cust



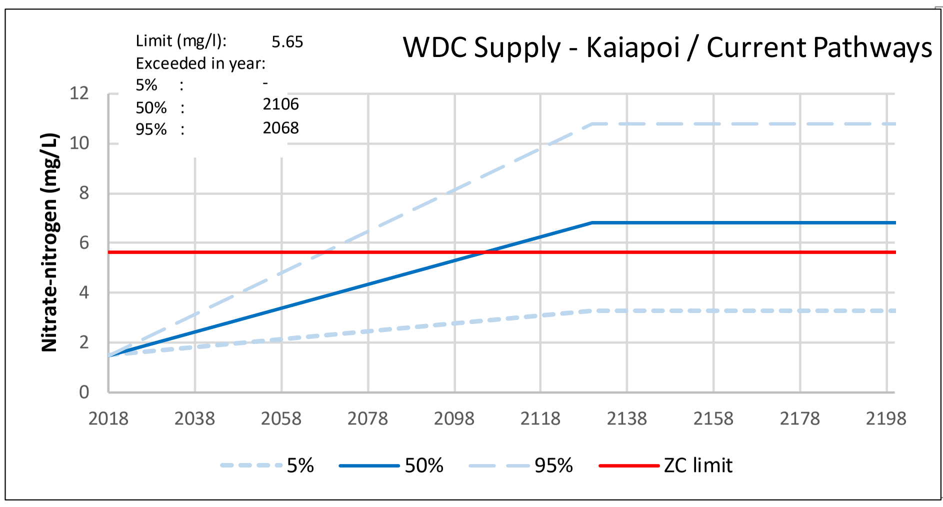


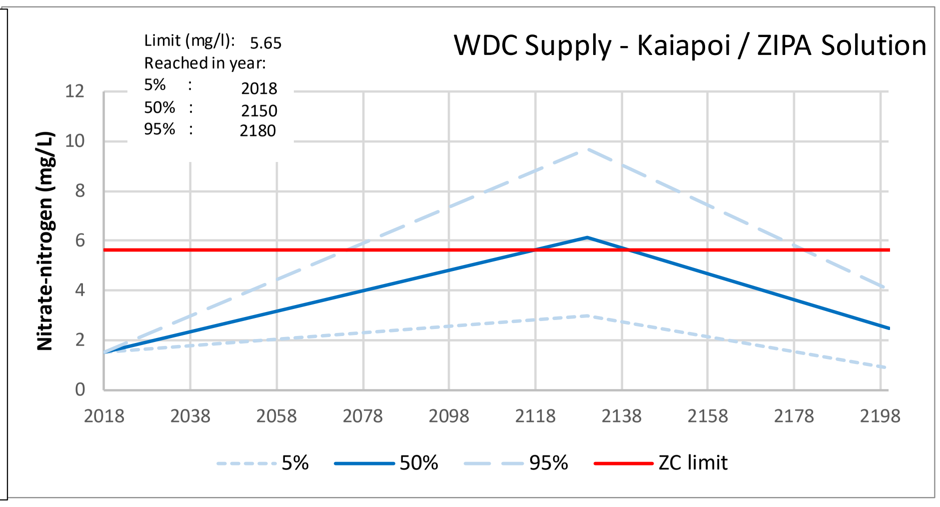
WDC Community Supply Wells - Fernside



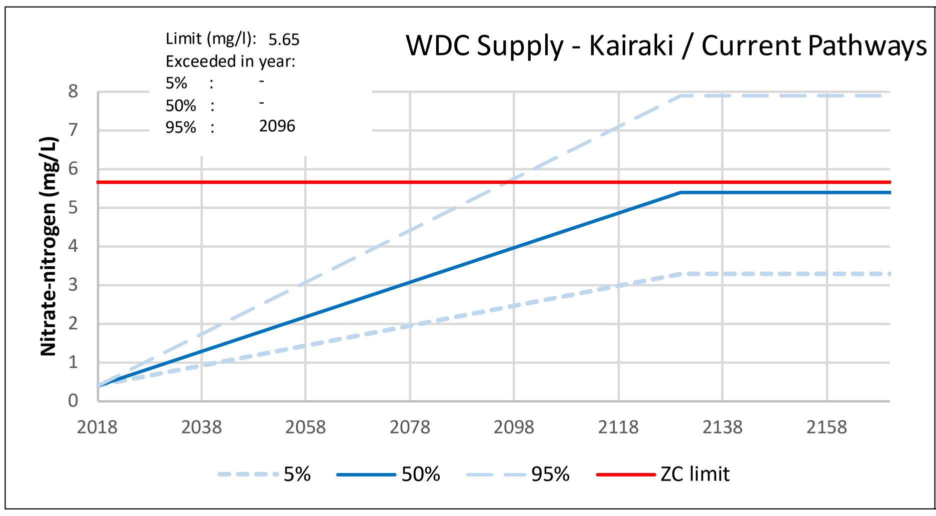


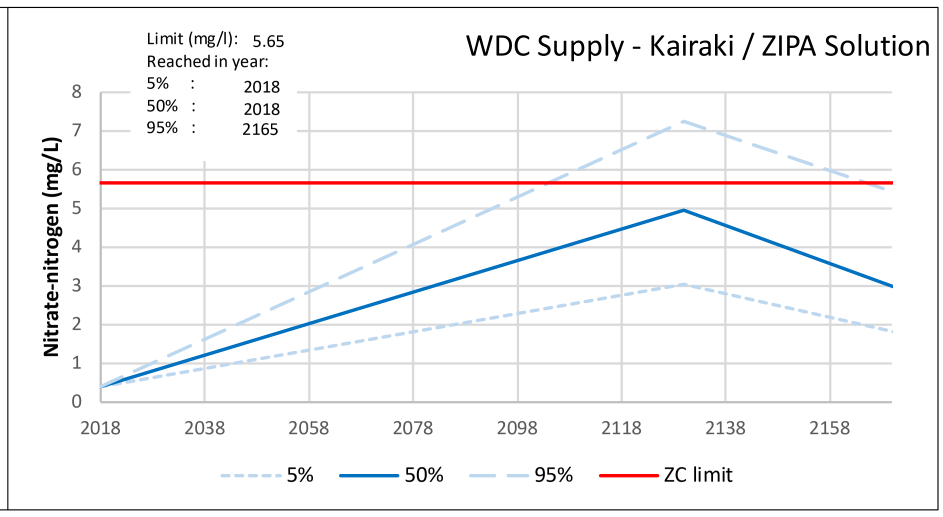
WDC Community Supply Wells Kaiapoi



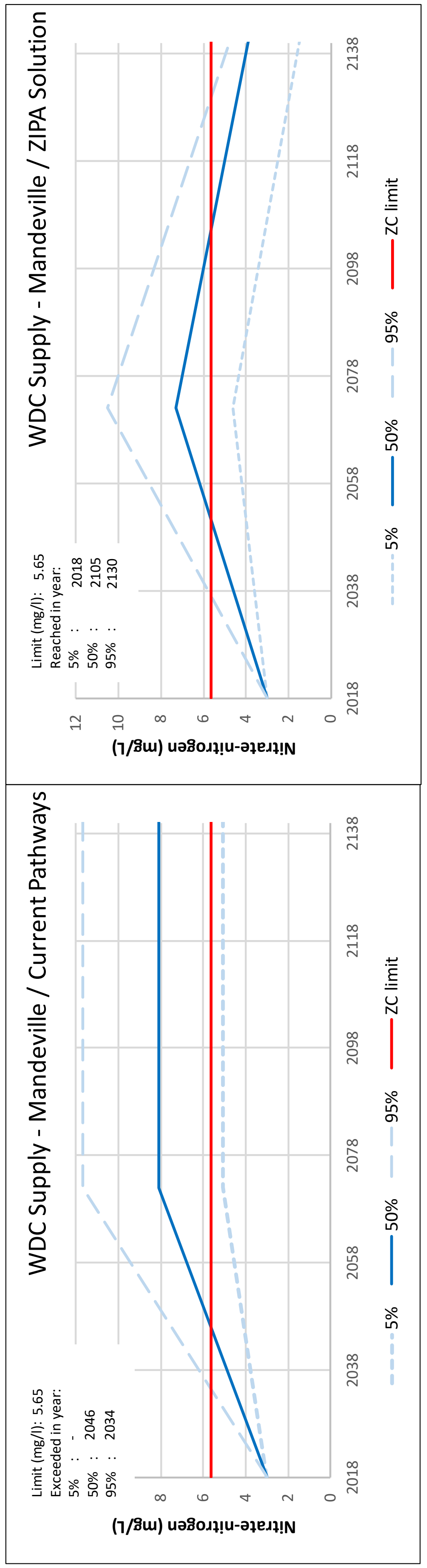


WDC Community Supply Wells – Kairaki

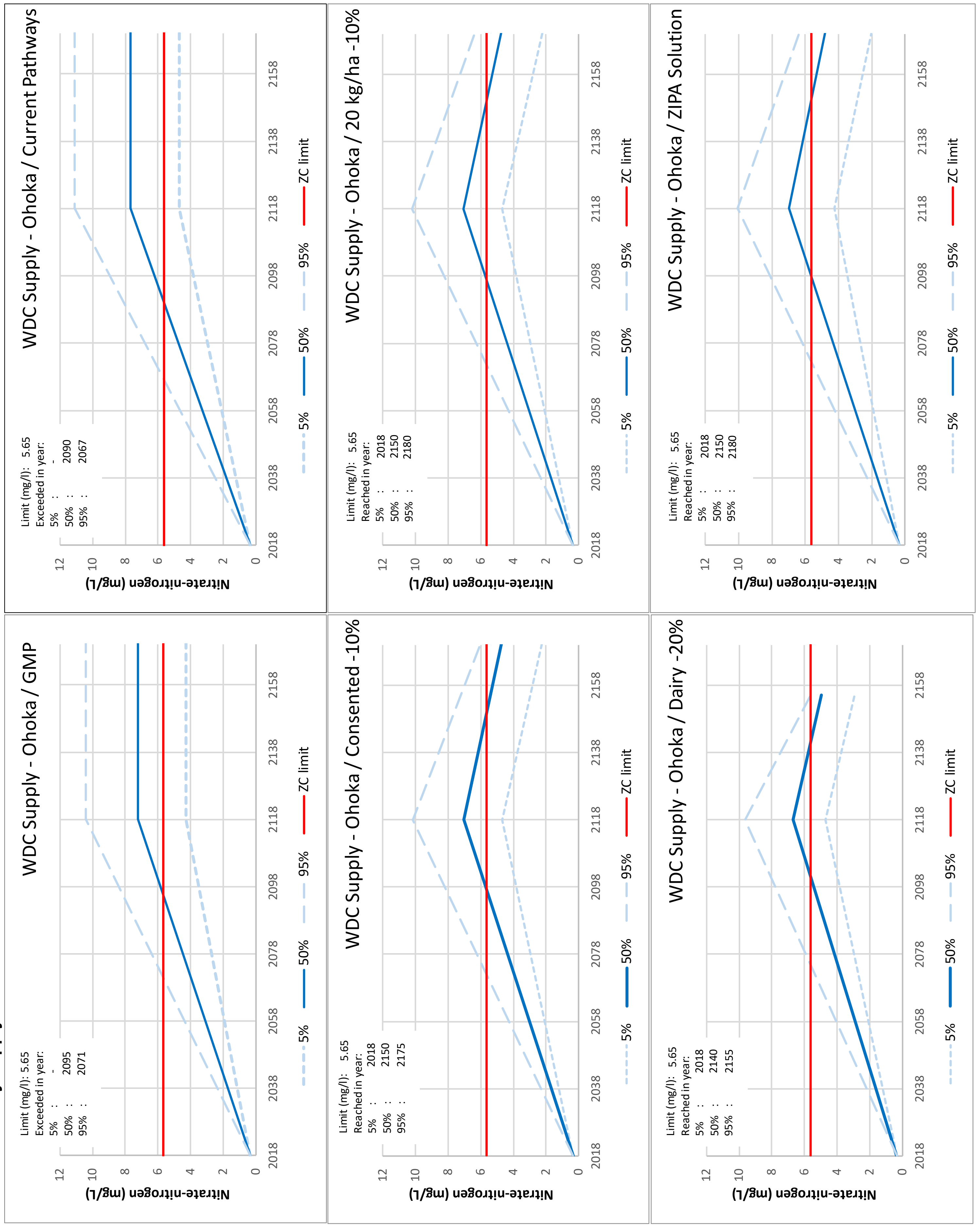




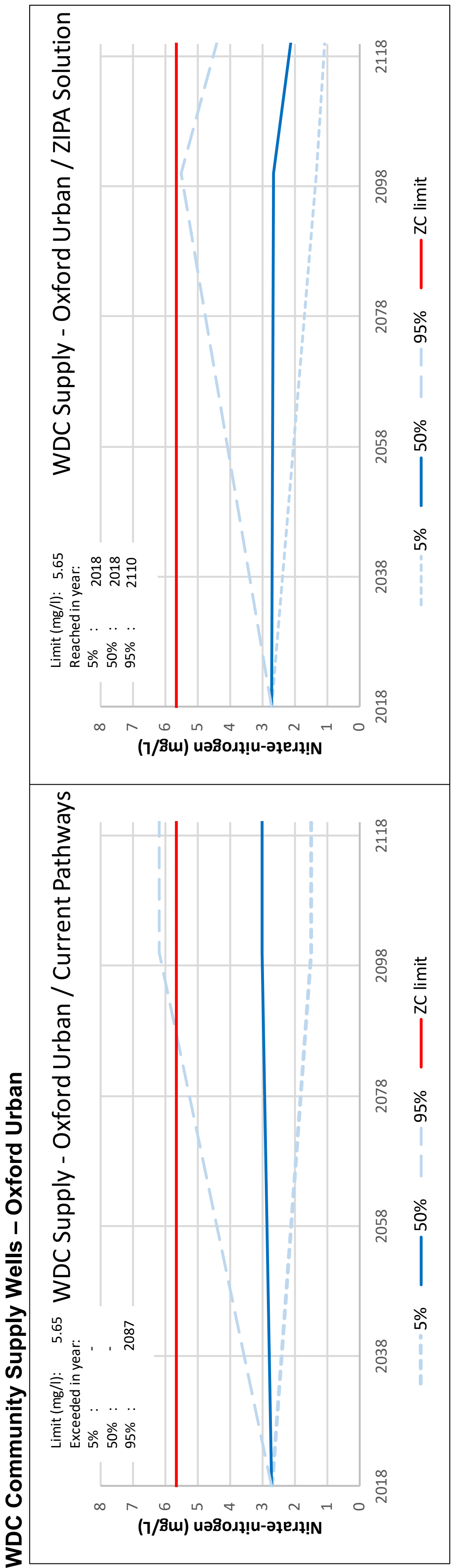
WDC Community Supply Wells – Mandeville



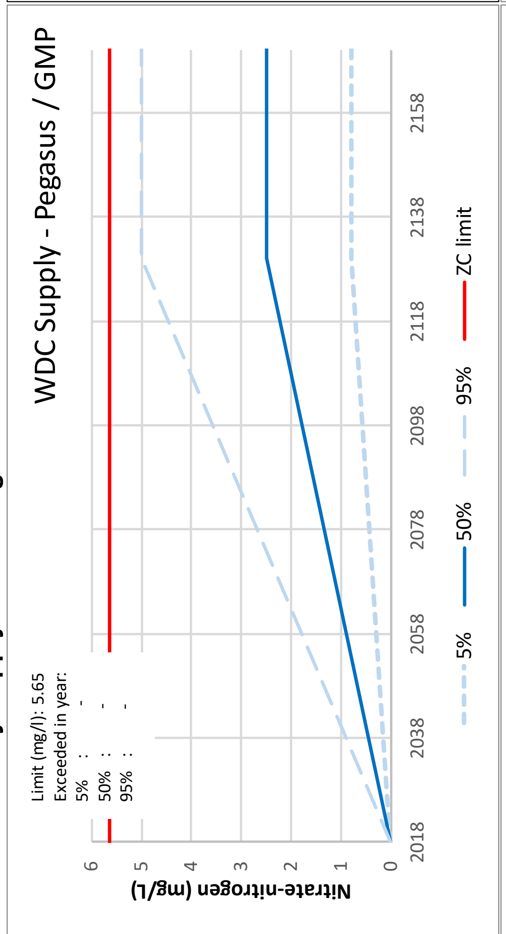
WDC Community Supply Wells - Ohoka

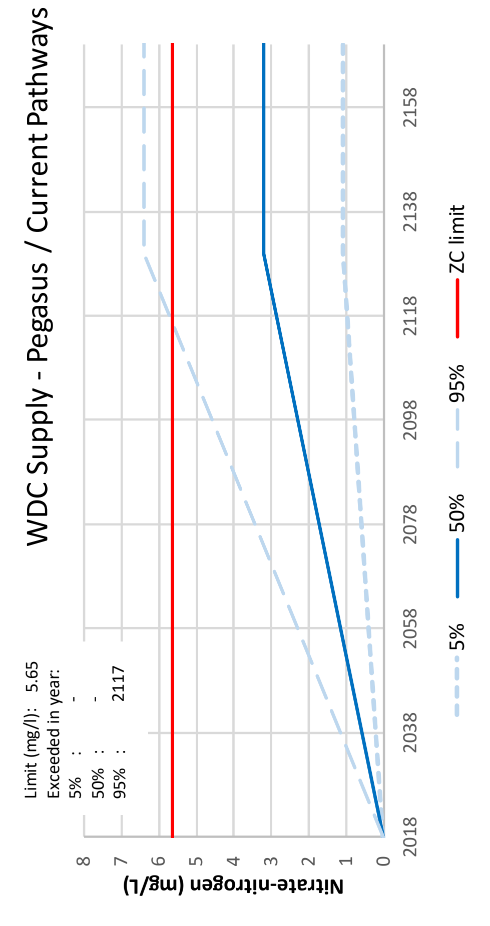


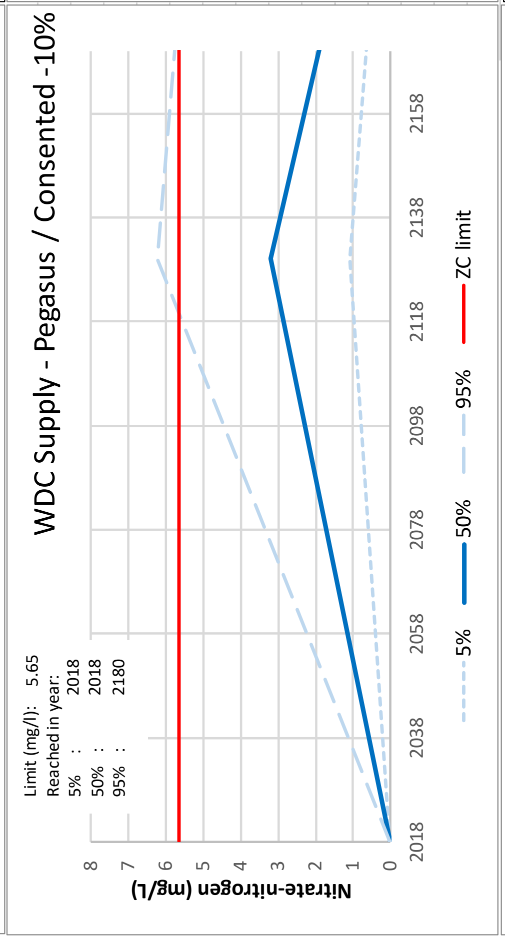
WDC Community Supply Wells – Oxford Urban

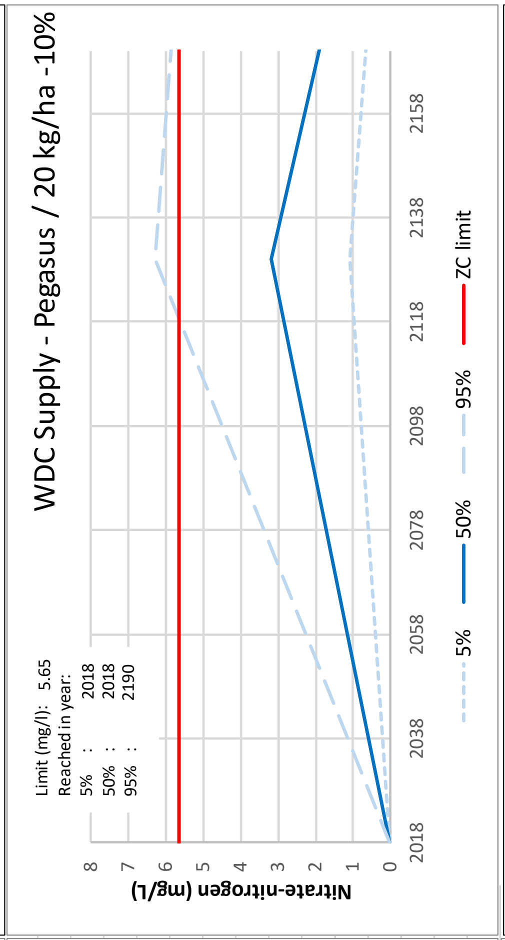


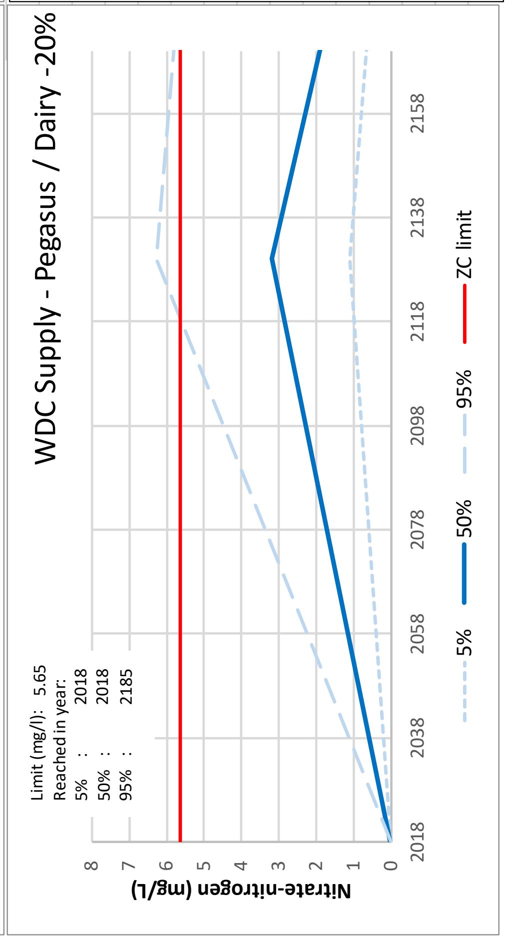
WDC Community Supply Wells - Pegasus

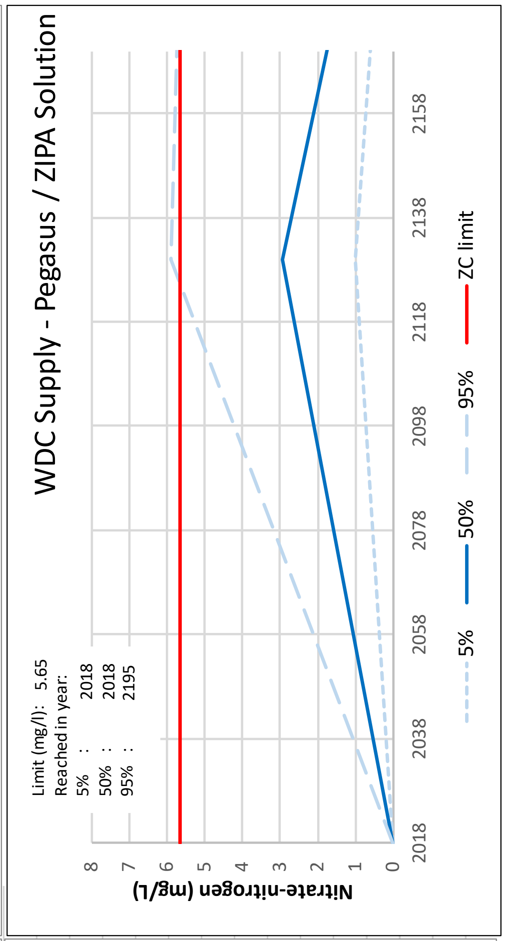




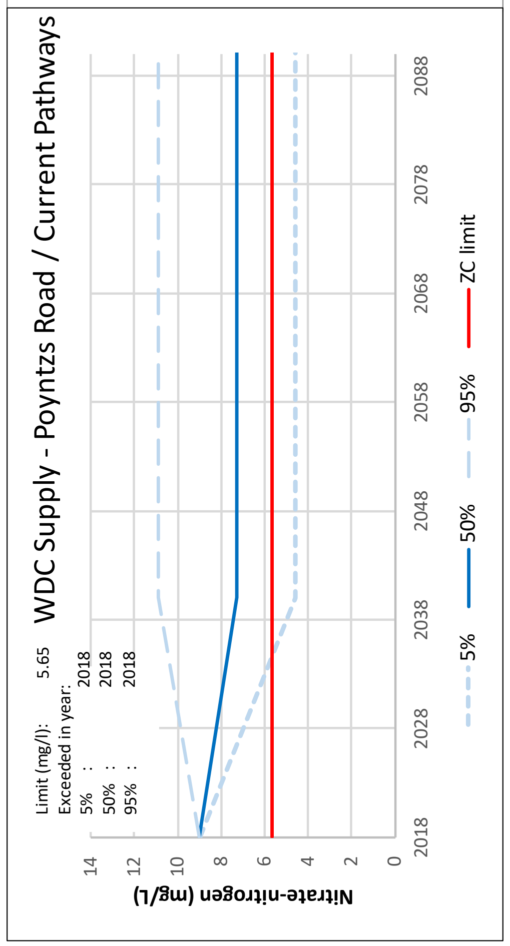


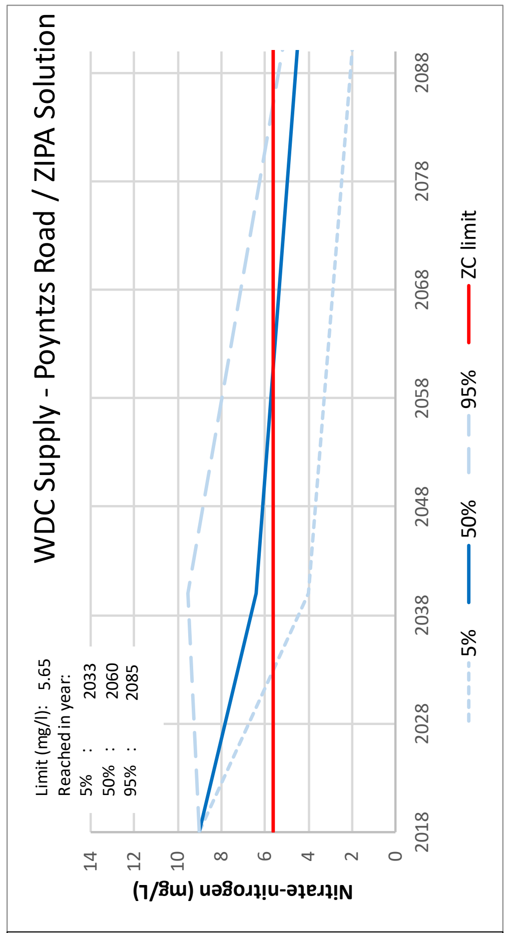




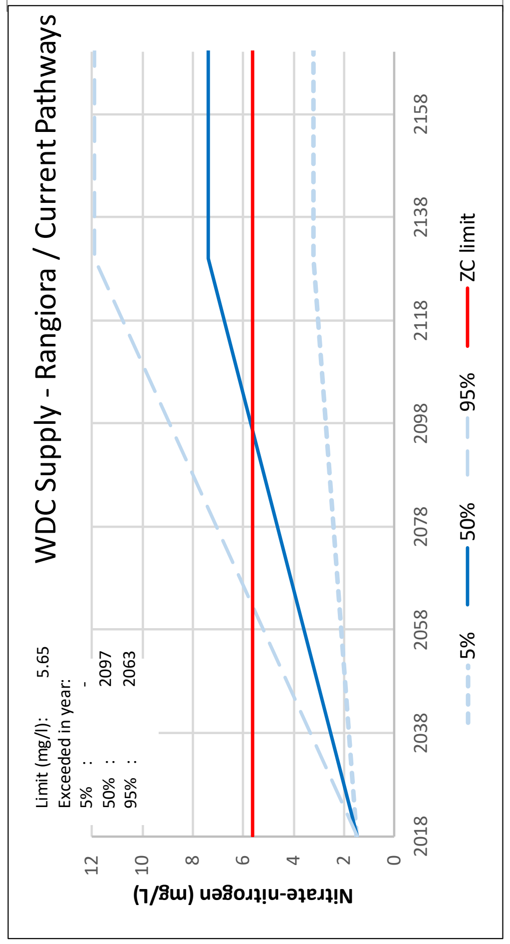


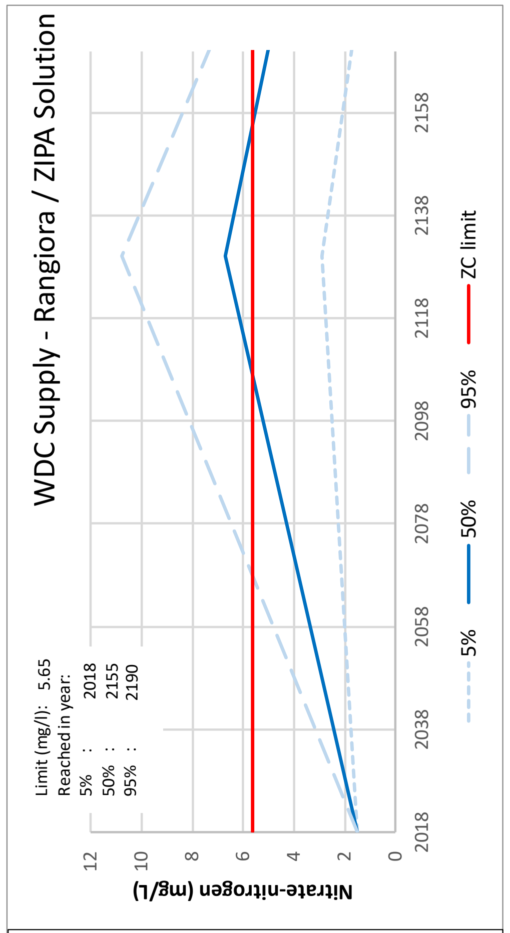
WDC Community Supply Wells – Poyntzs Road



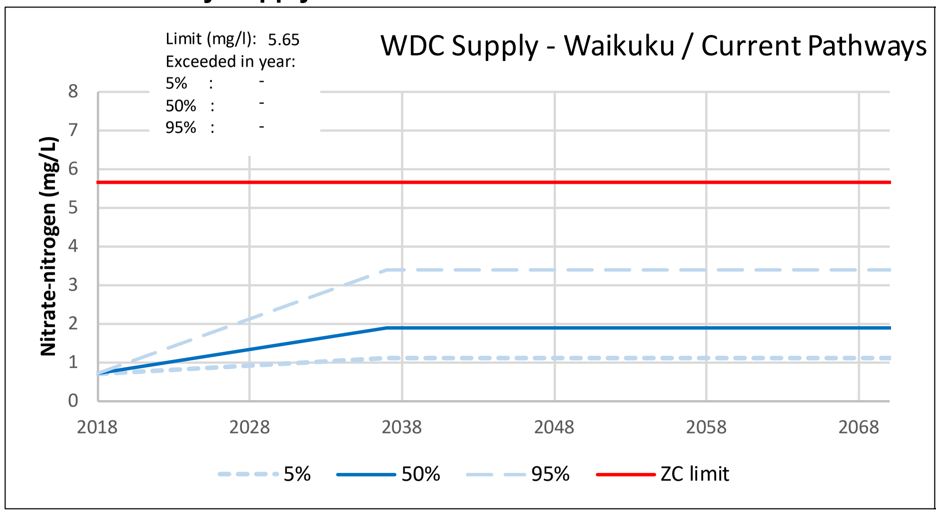


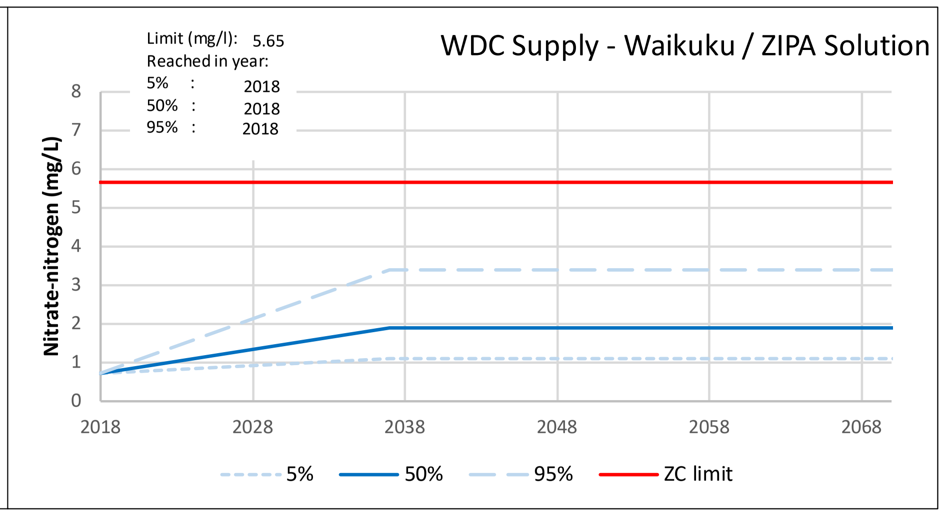
WDC Community Supply Wells – Rangiora



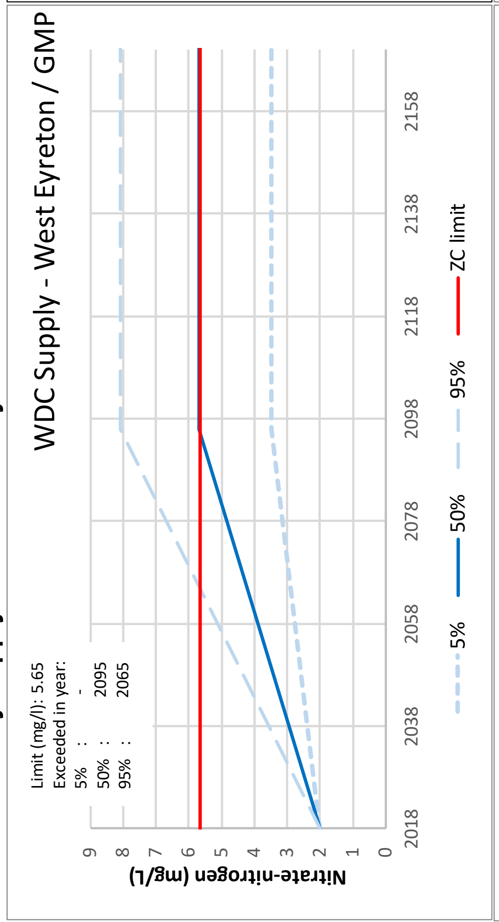


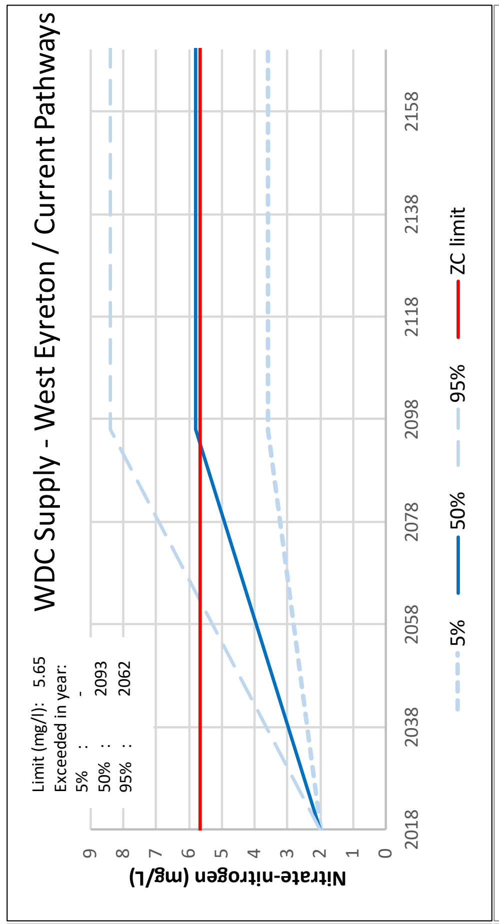
WDC Community Supply Wells – Waikuku

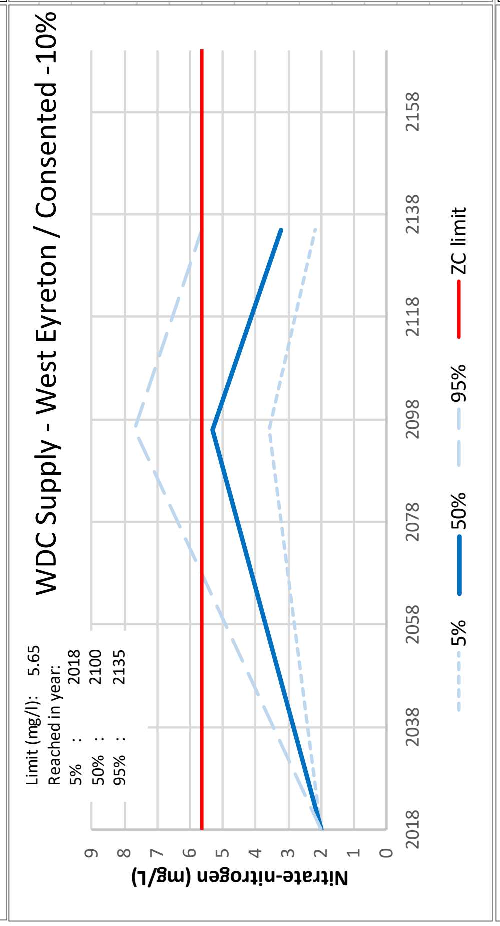


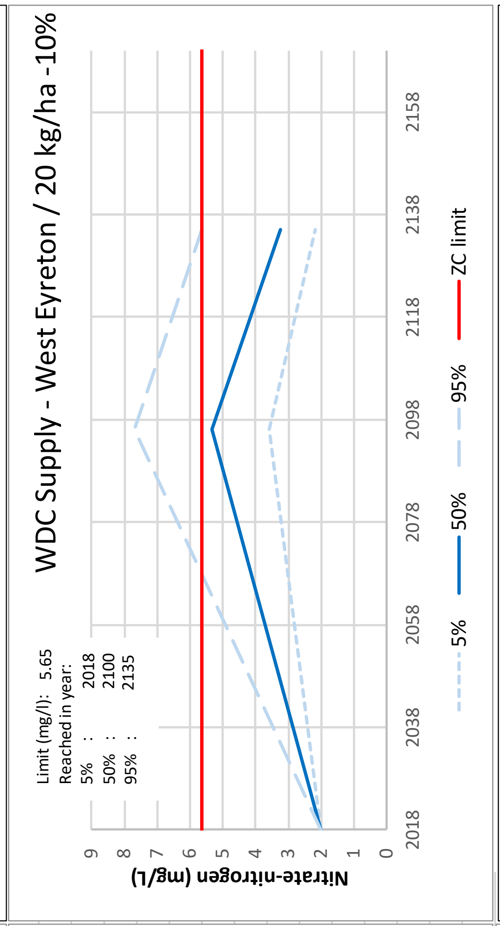


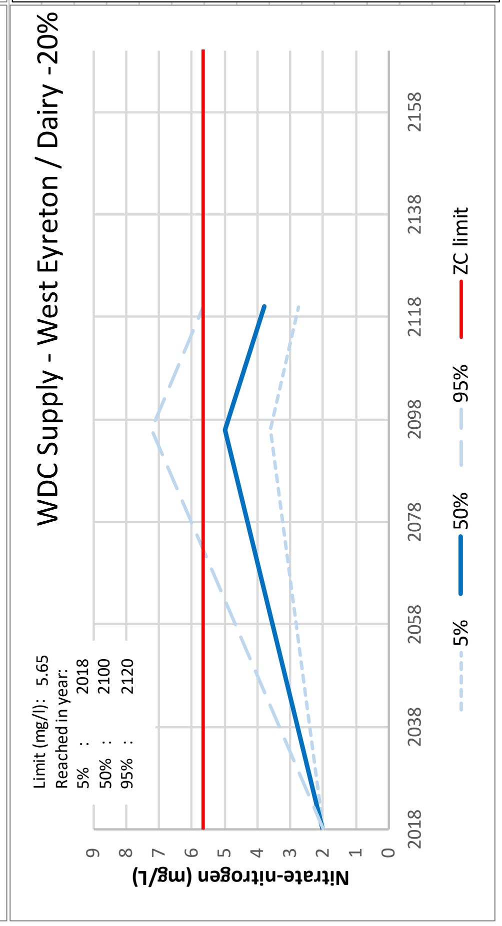
WDC Community Supply Wells – West Eyreton / Summerhill

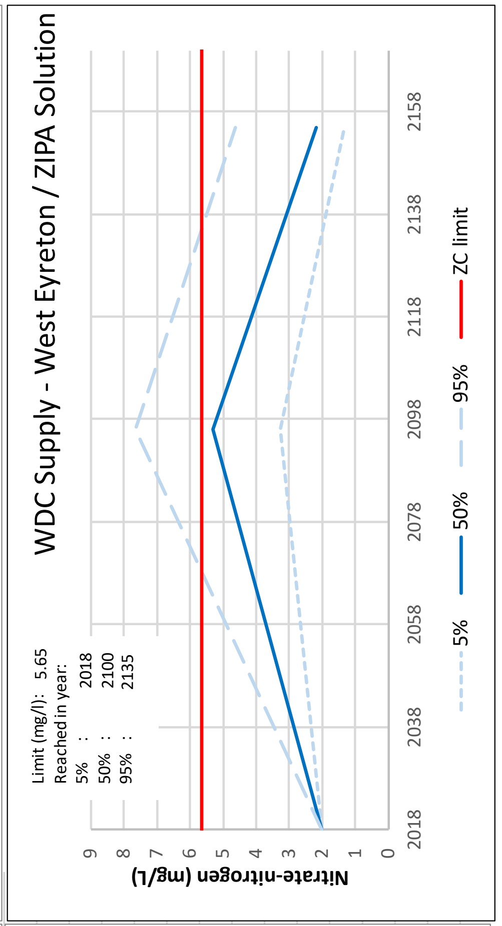






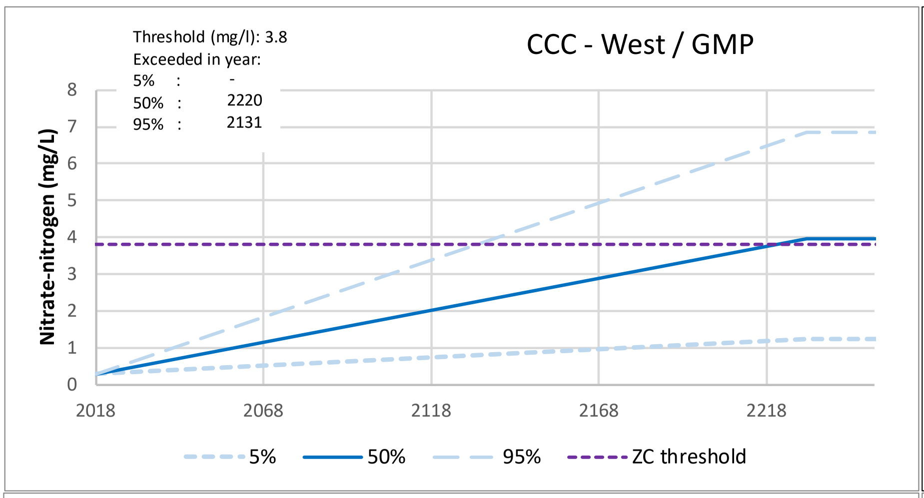


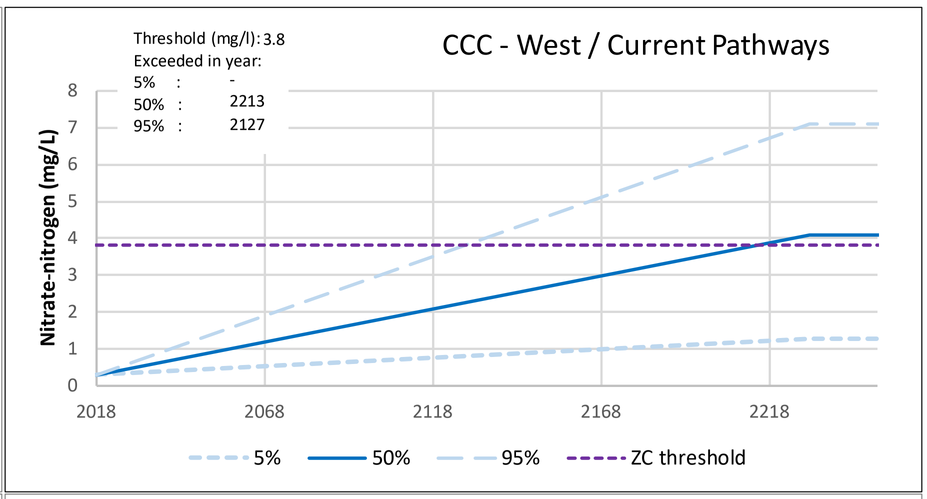


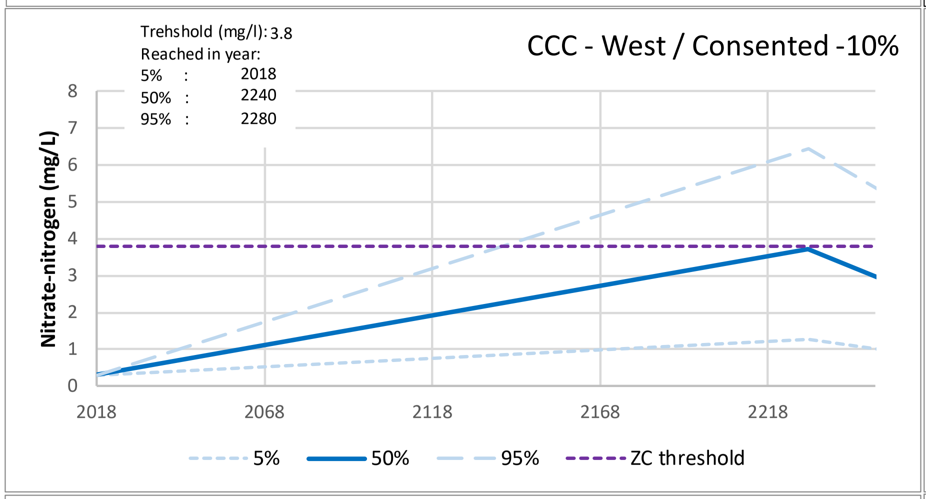


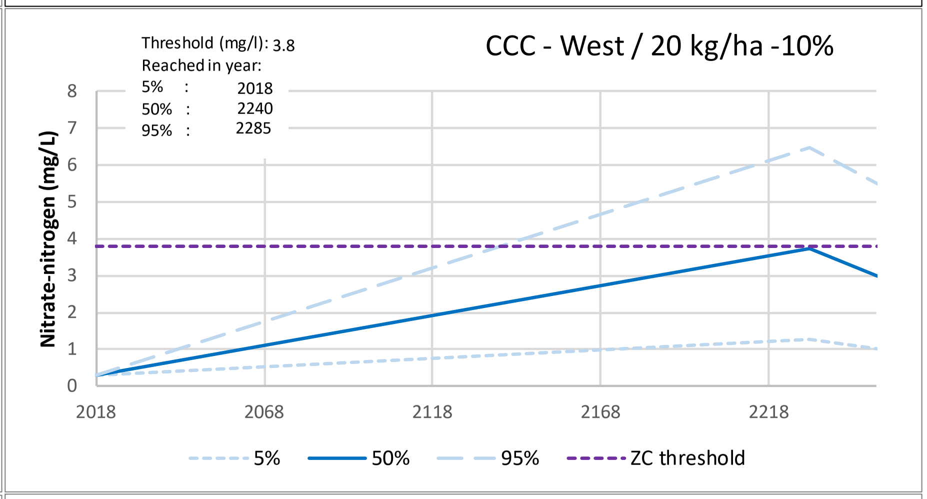
A9.3 Nitrate time series for Christchurch aquifer

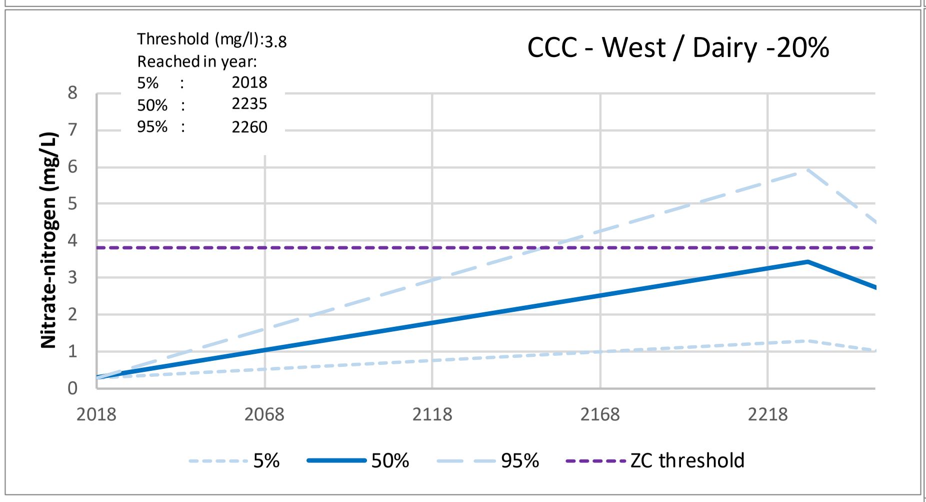
Christchurch aquifer – West

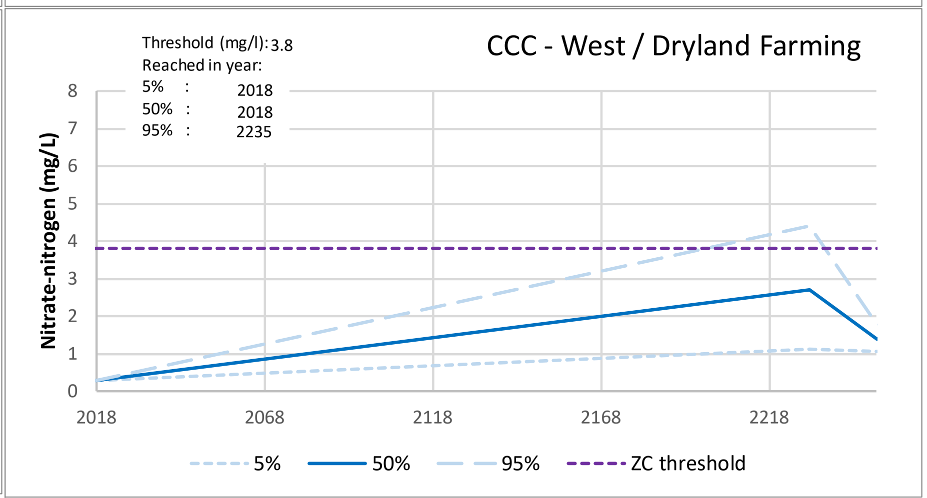


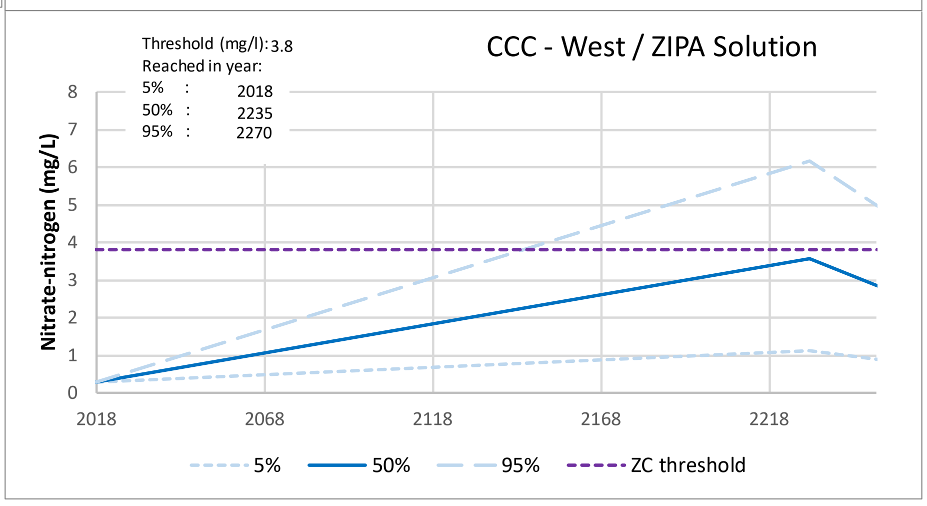






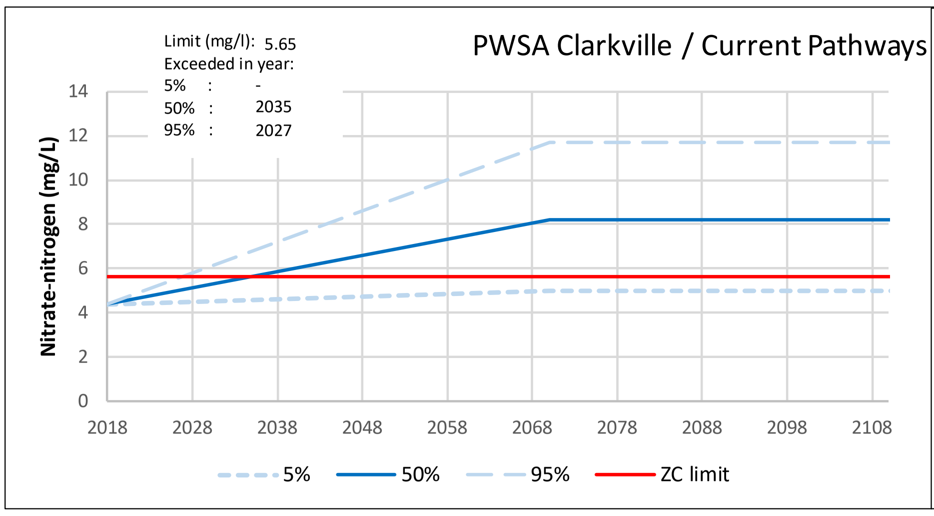


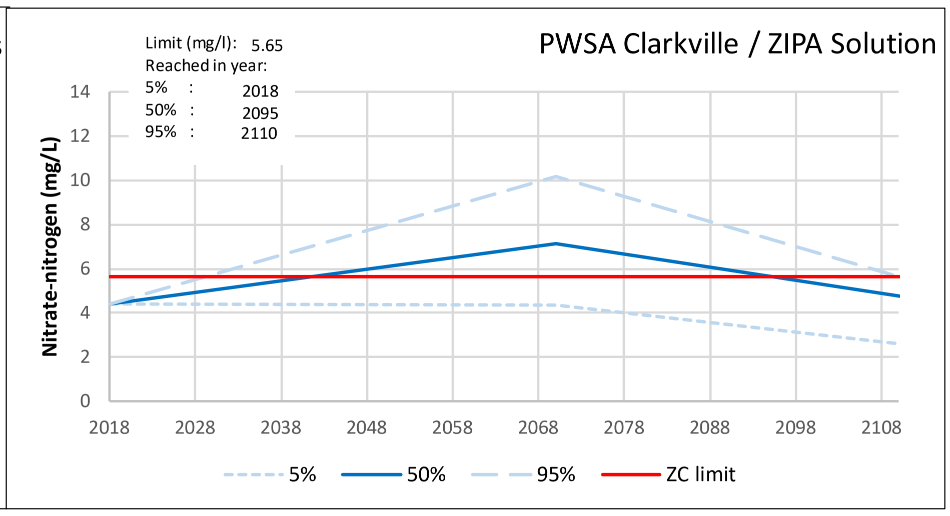




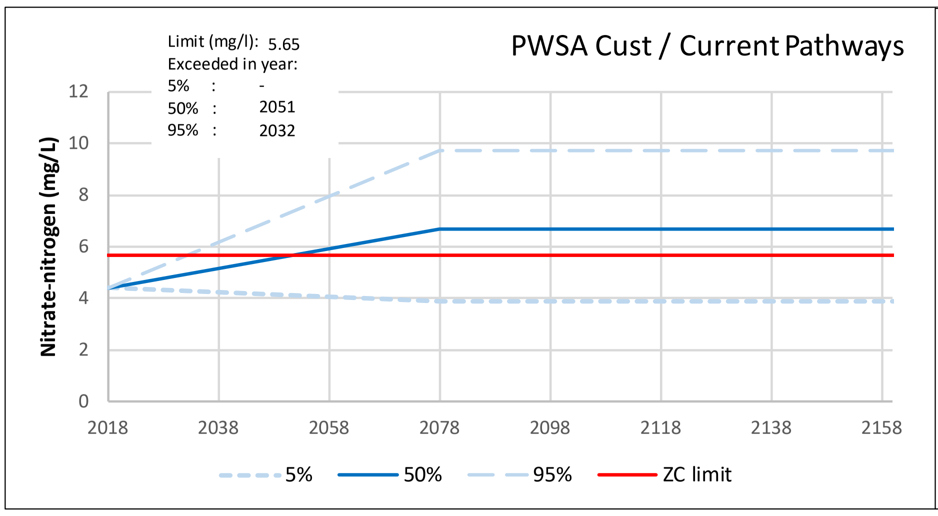
A9.1 Nitrate time series for Private Water Supply Areas (PWSA)

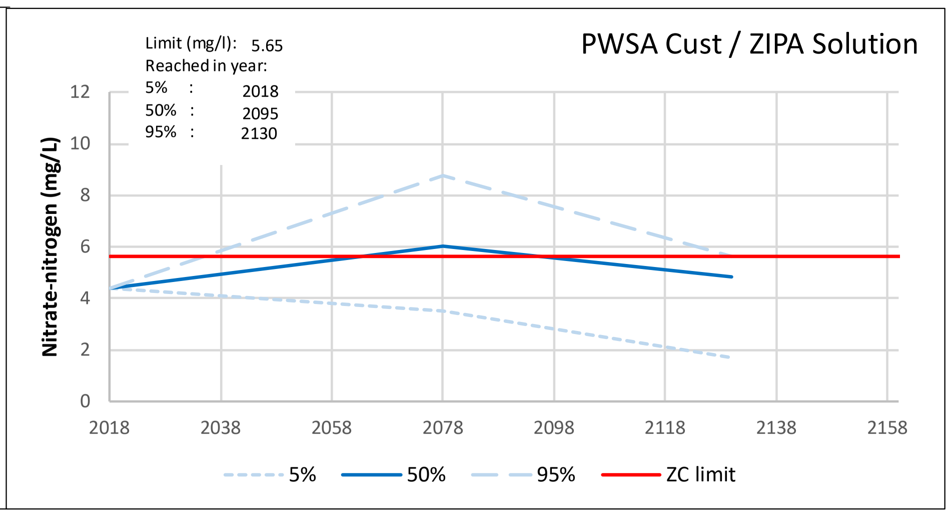
PWSA Clarkville



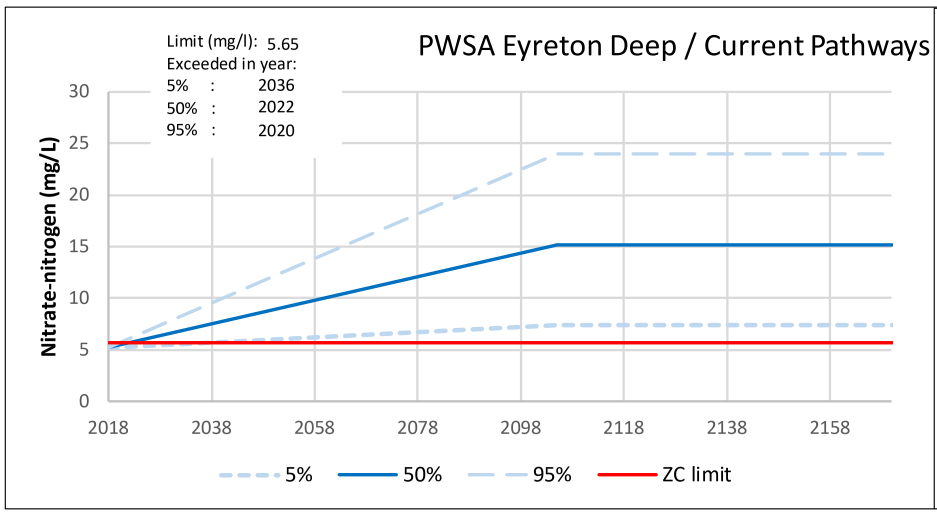


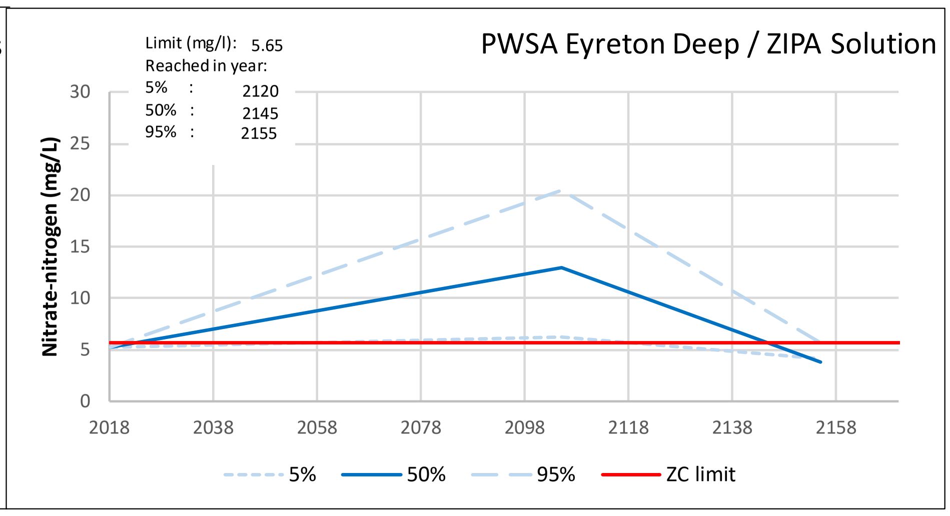
PWSA Cust



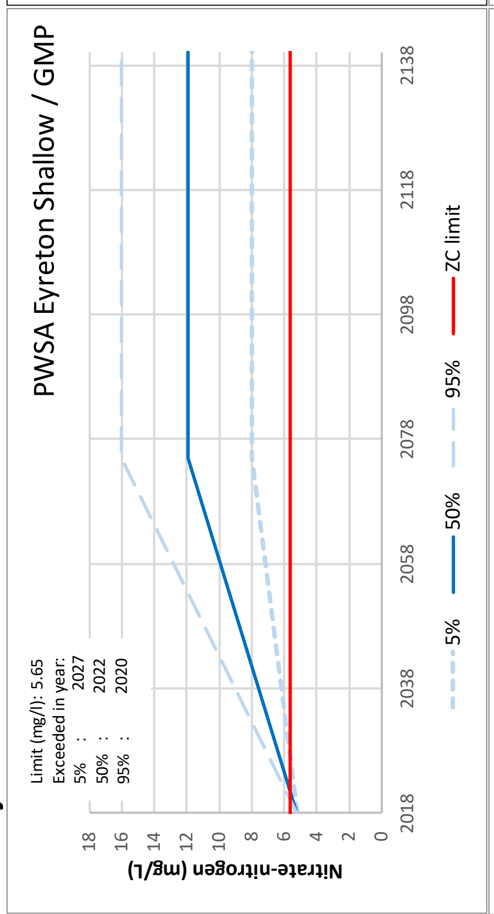


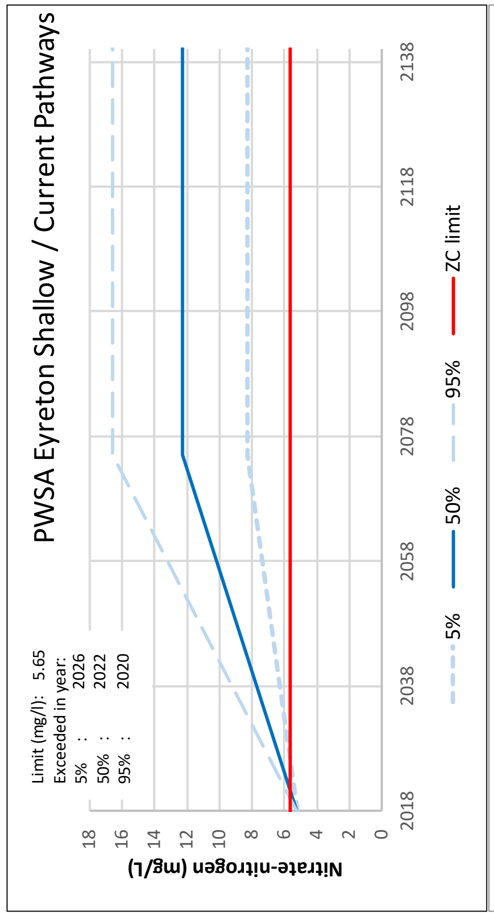
PWSA Eyreton Deep

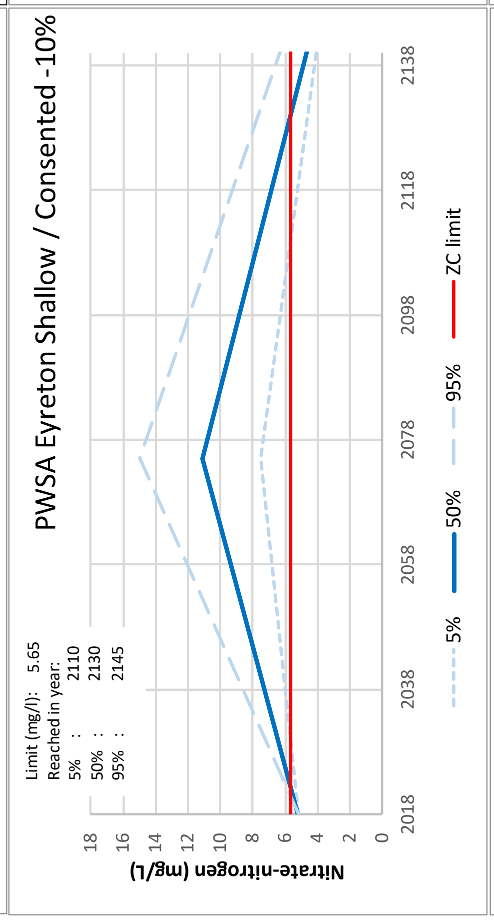


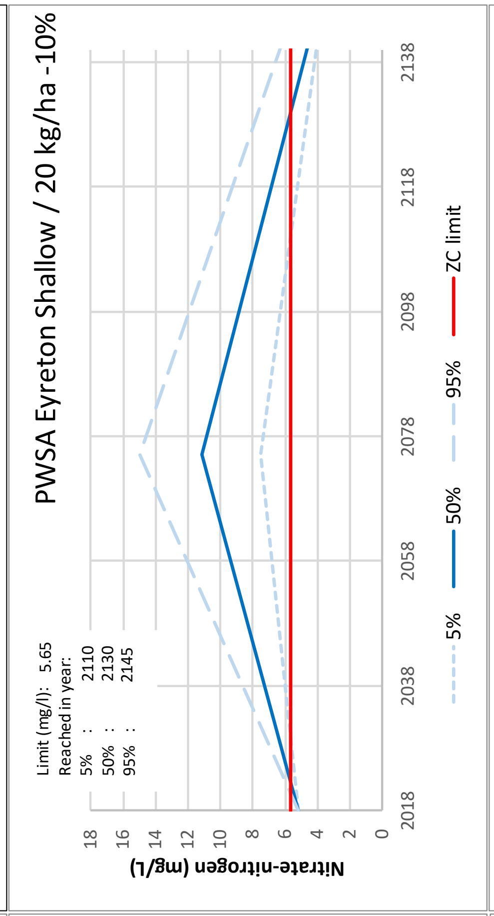


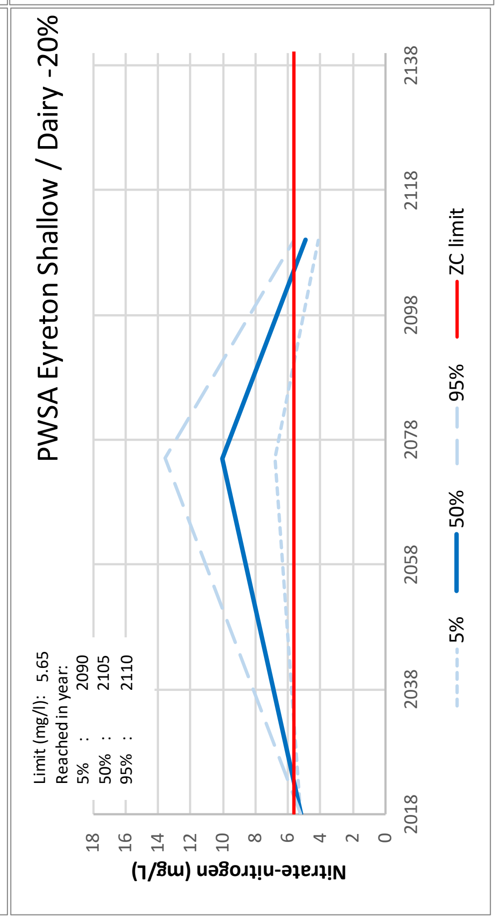
PWSA Eyreton Shallow

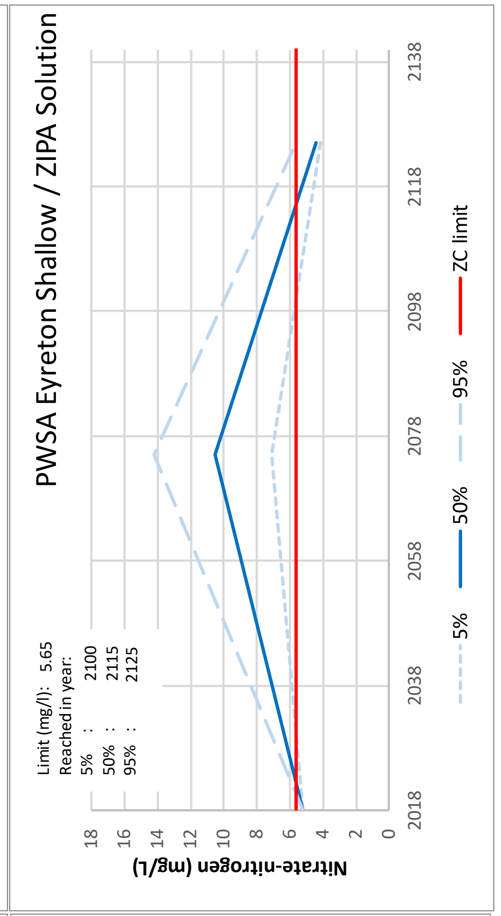




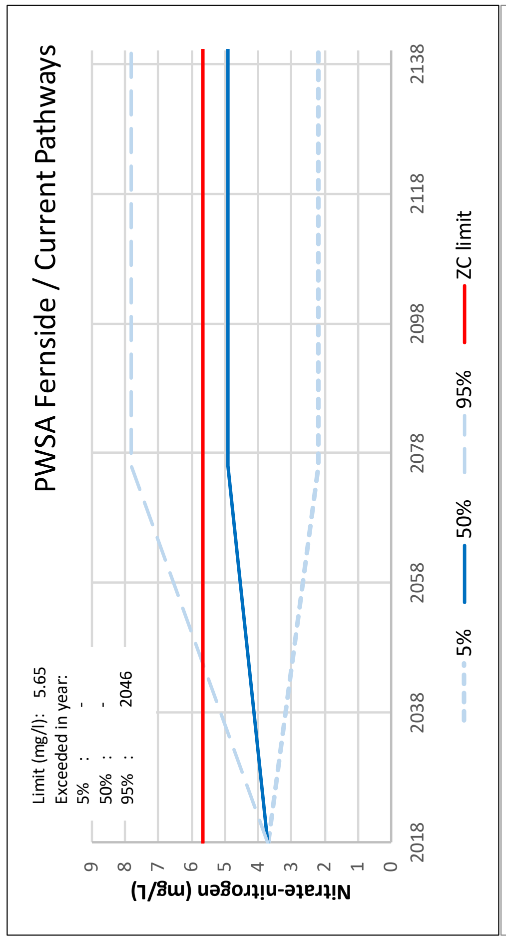


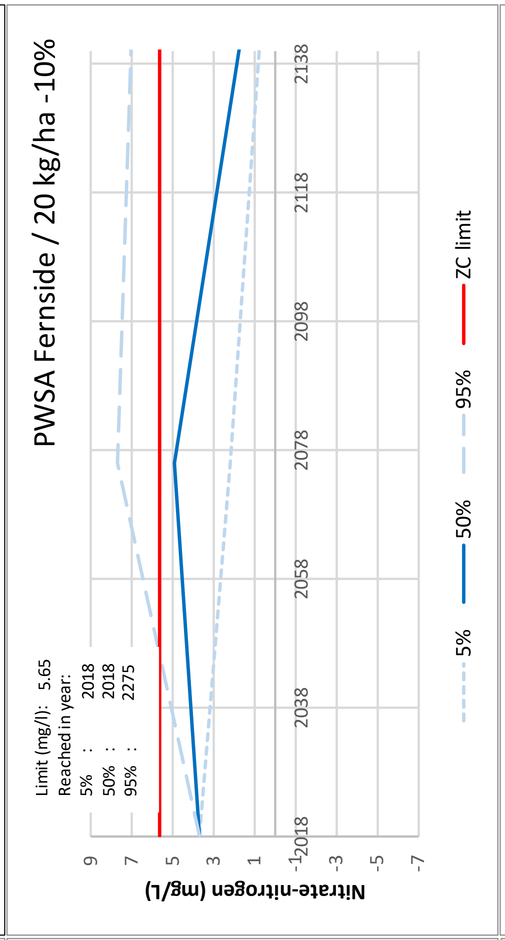


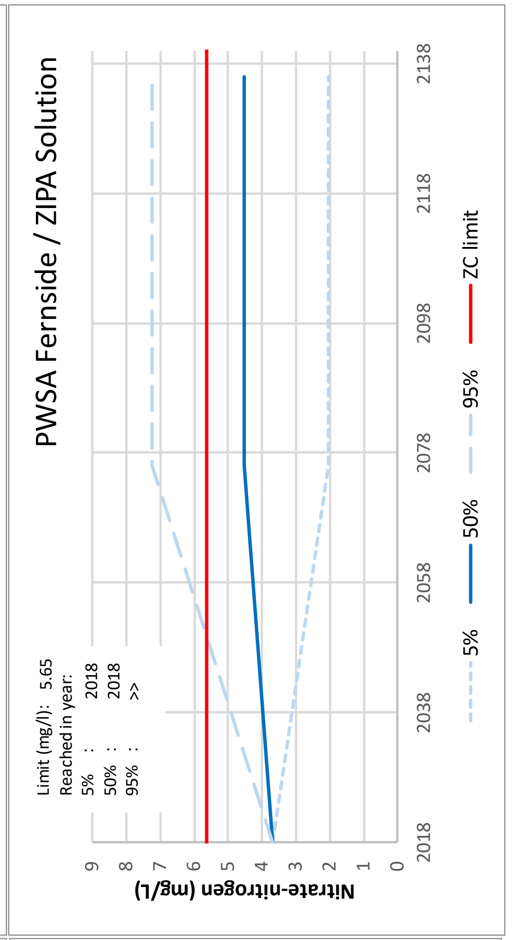


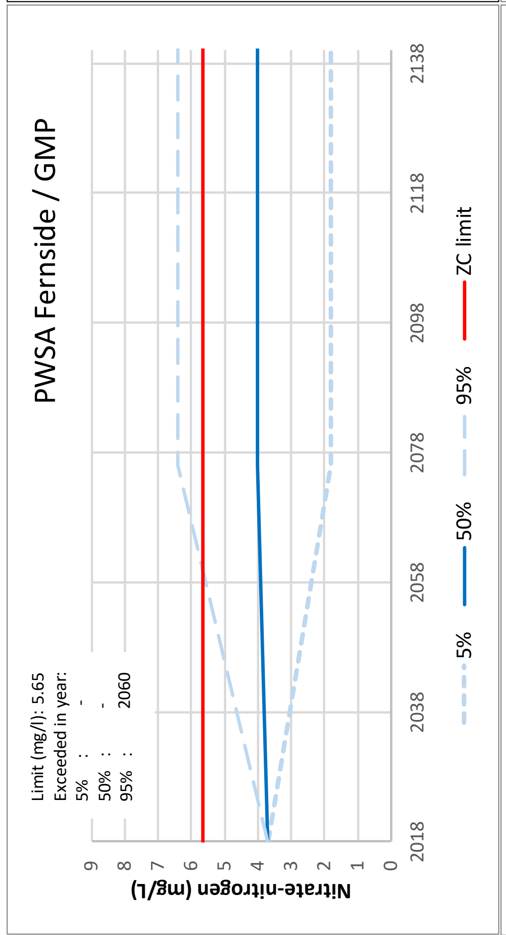


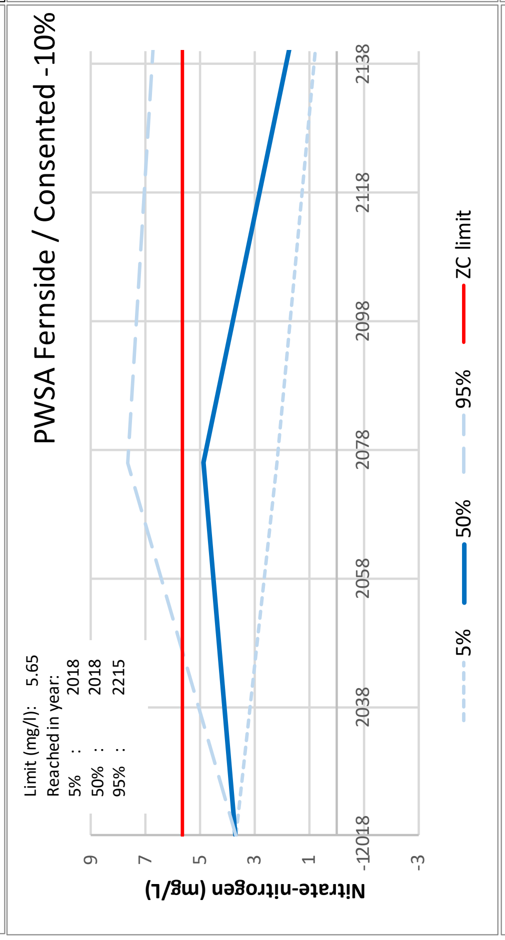
PWSA Fernside

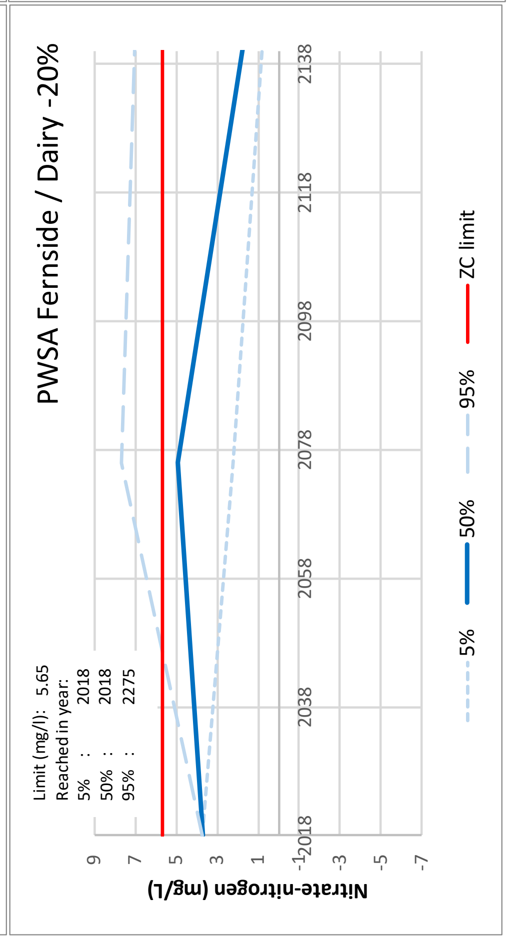




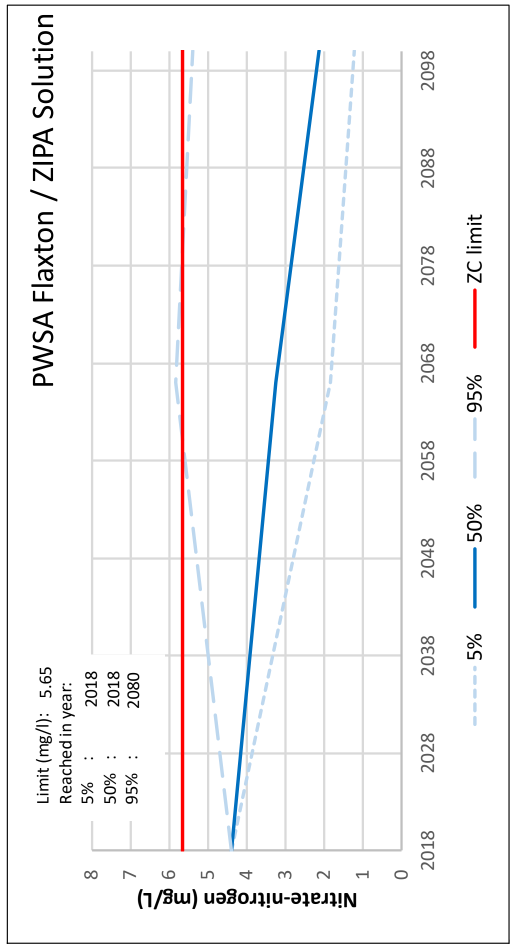


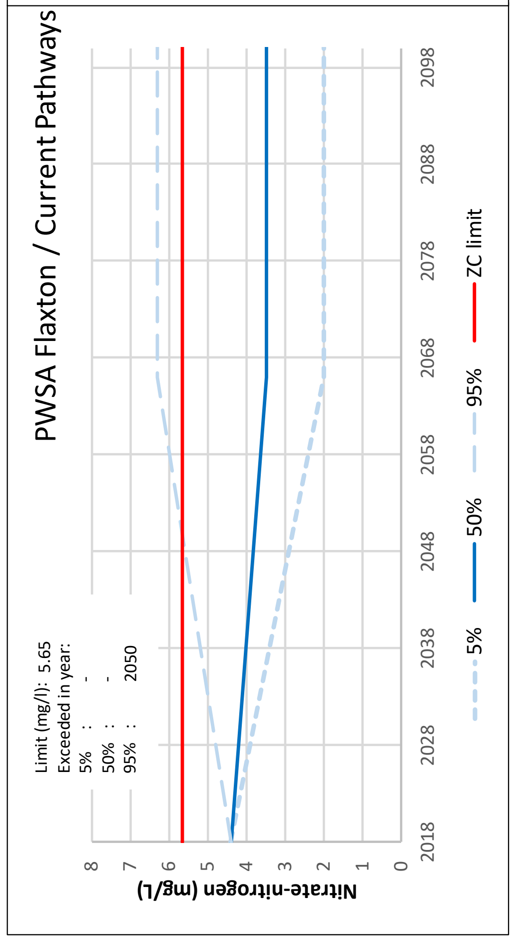




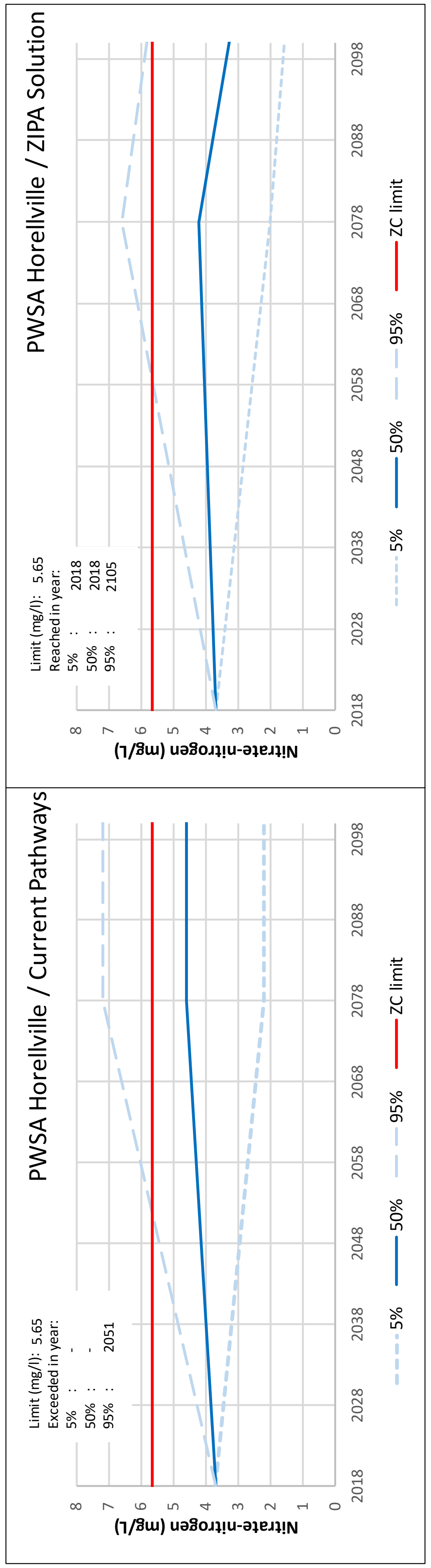


PWSA Flaxton

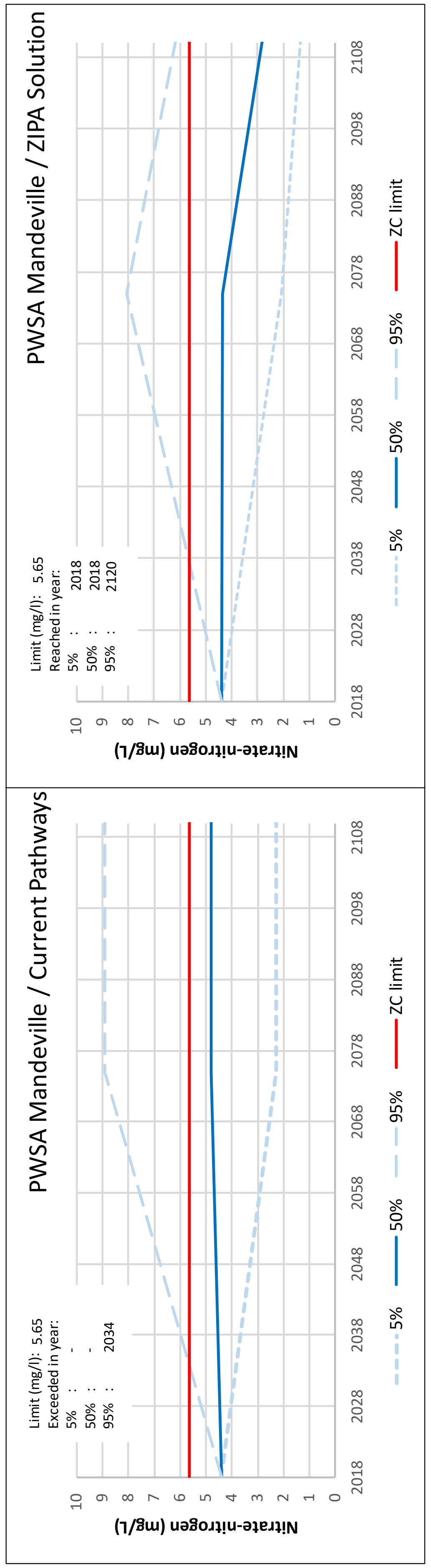




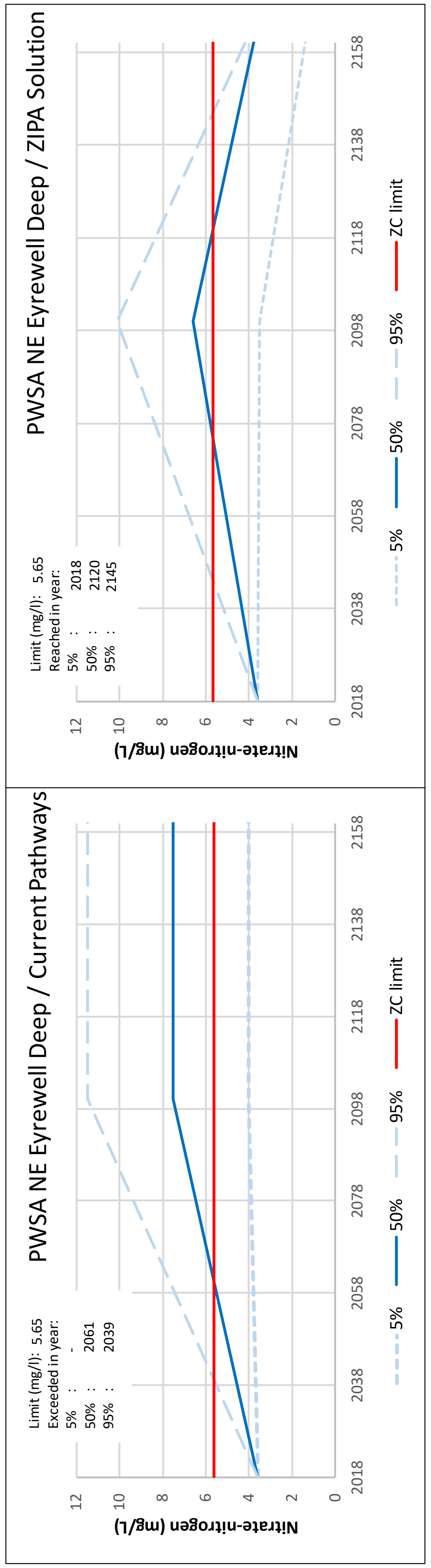
PWSA Horellville



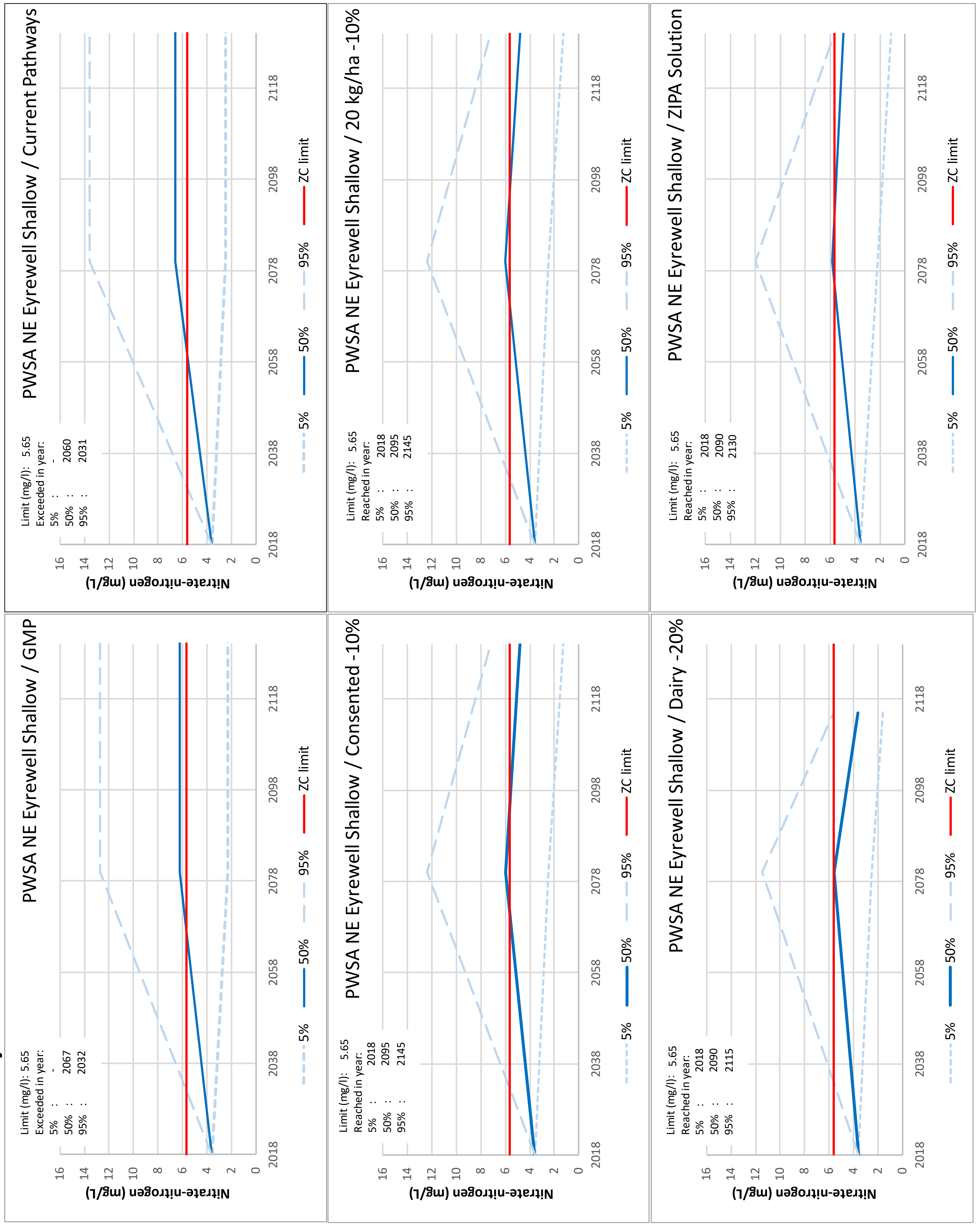
PWSA Mandeville



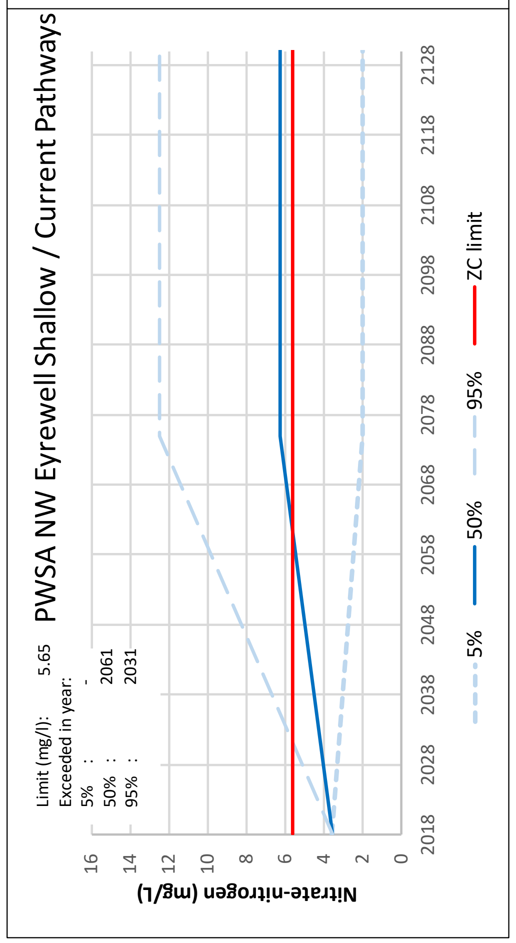
PWSA North-East Eyrewell (deep)

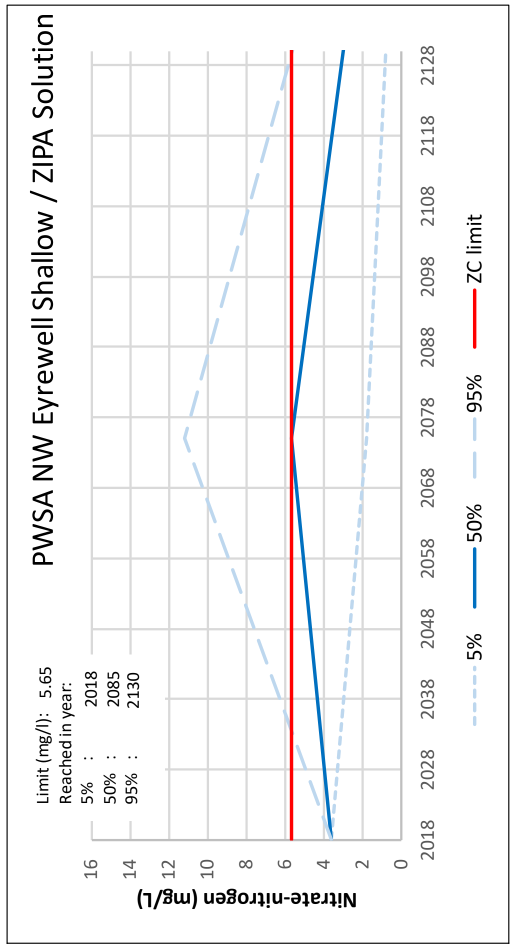


PWSA North-East Eyrewell Shallow

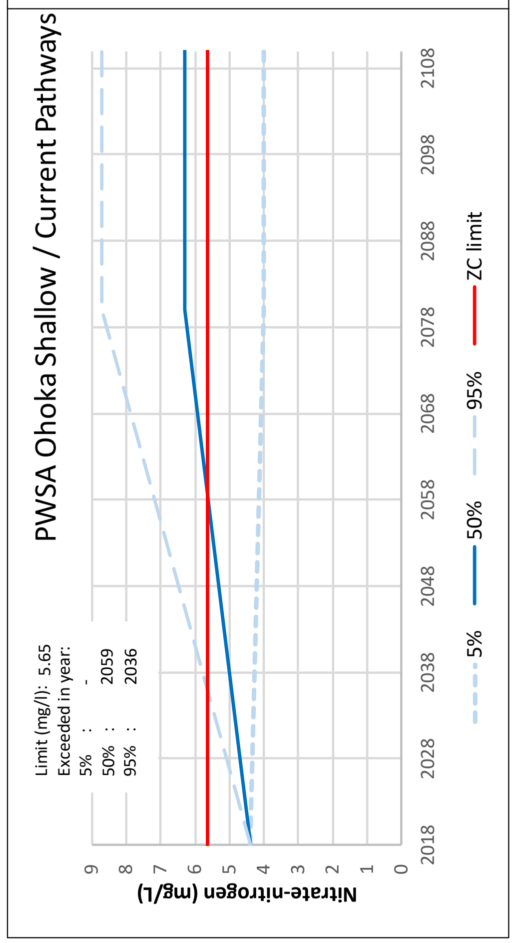


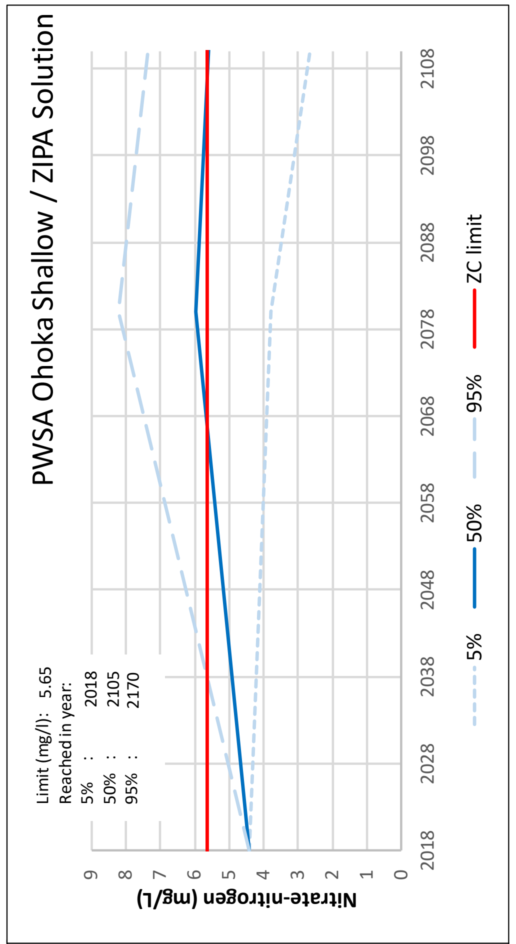
PWSA North-West Eyrewell (shallow)



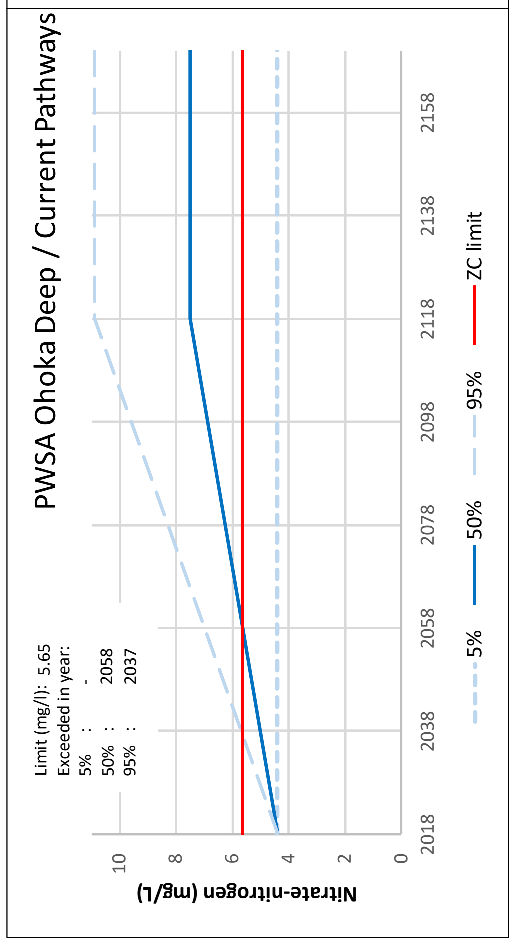


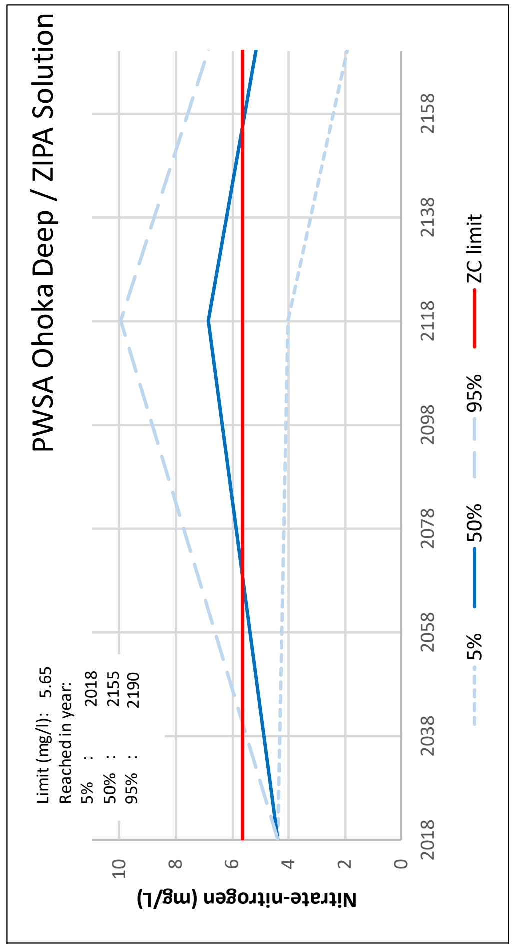
PWSA Ohoka (shallow)



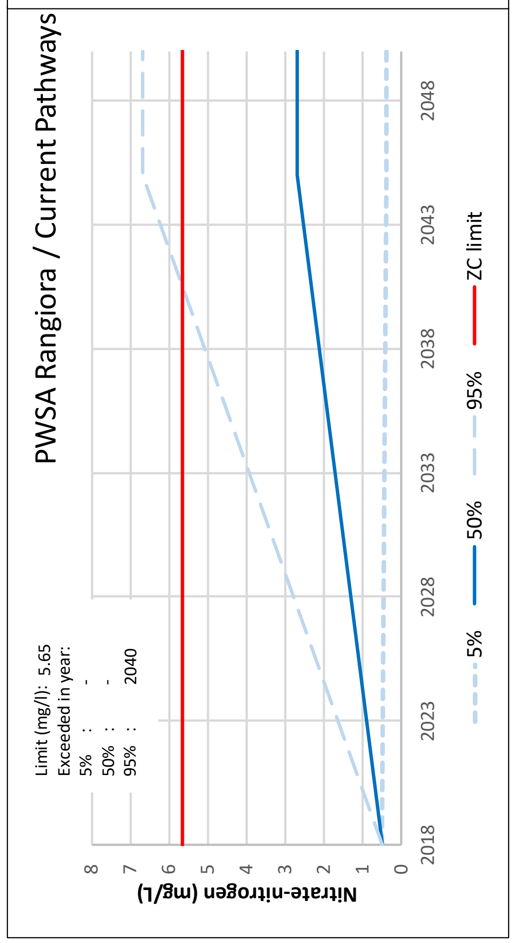


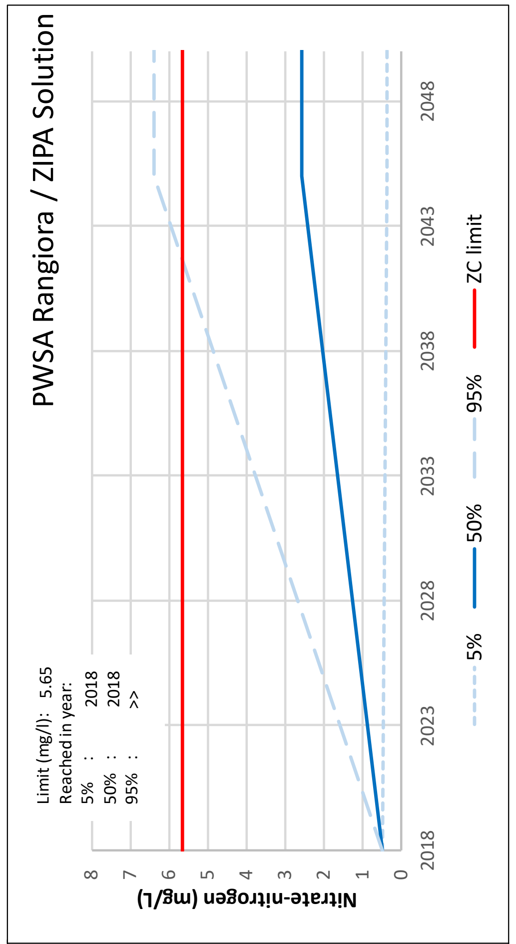
PWSA Ohoka (deep)



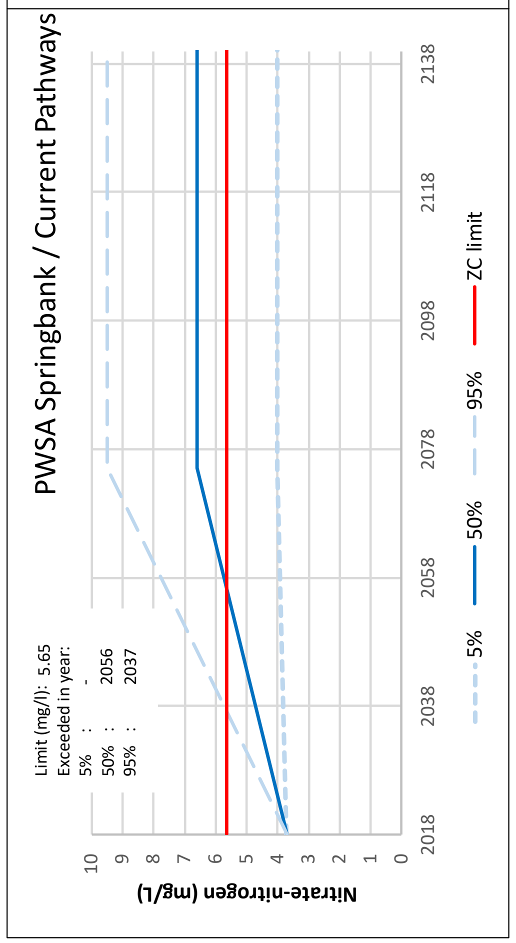


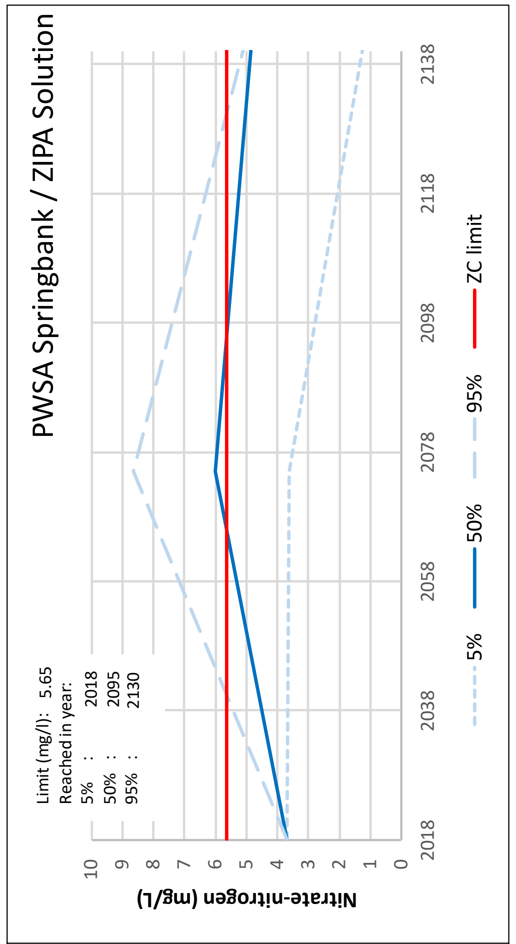
PWSA Rangiora



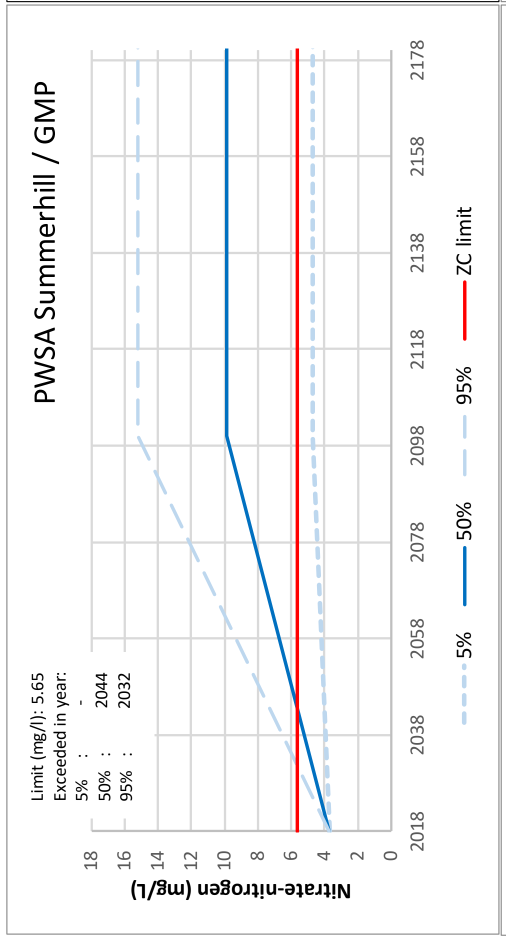


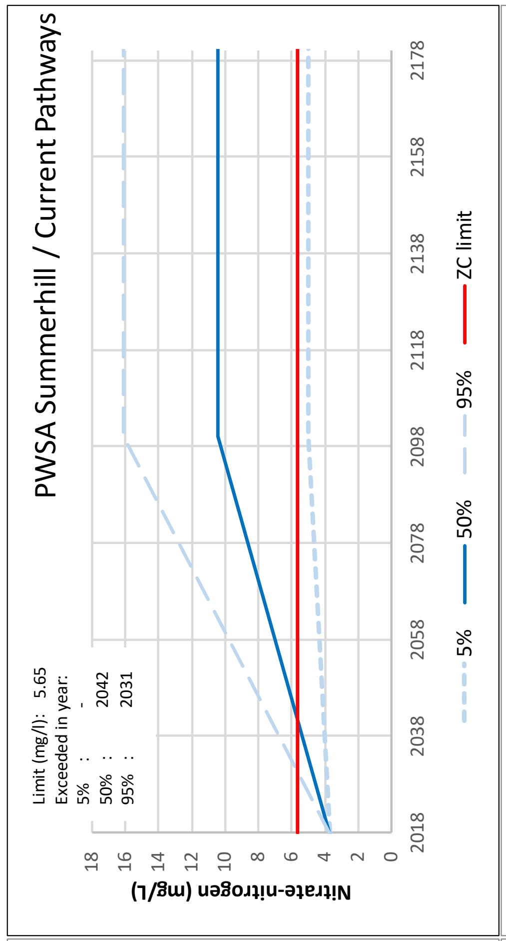
PWSA Springbank

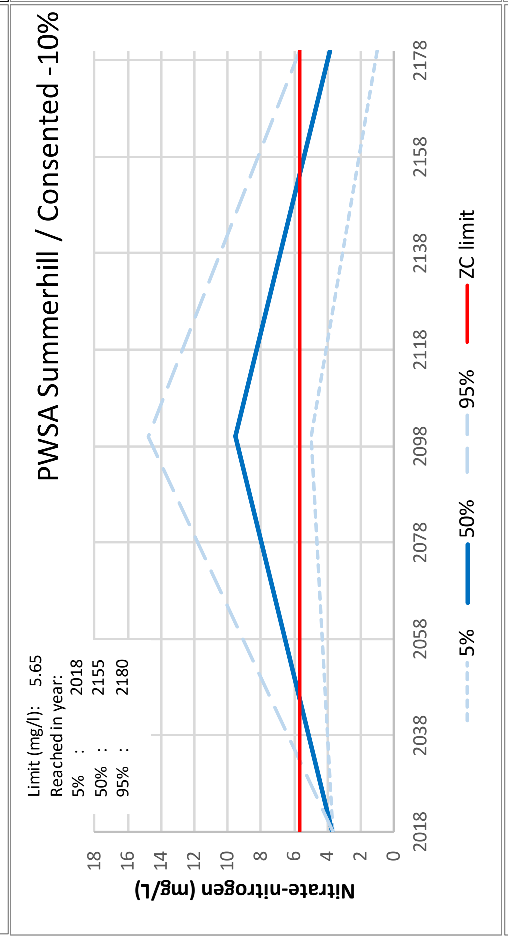


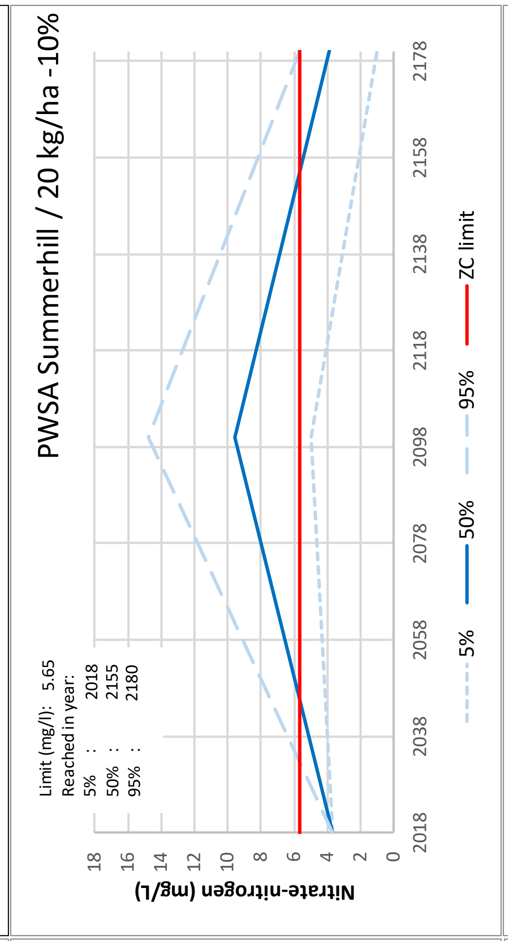


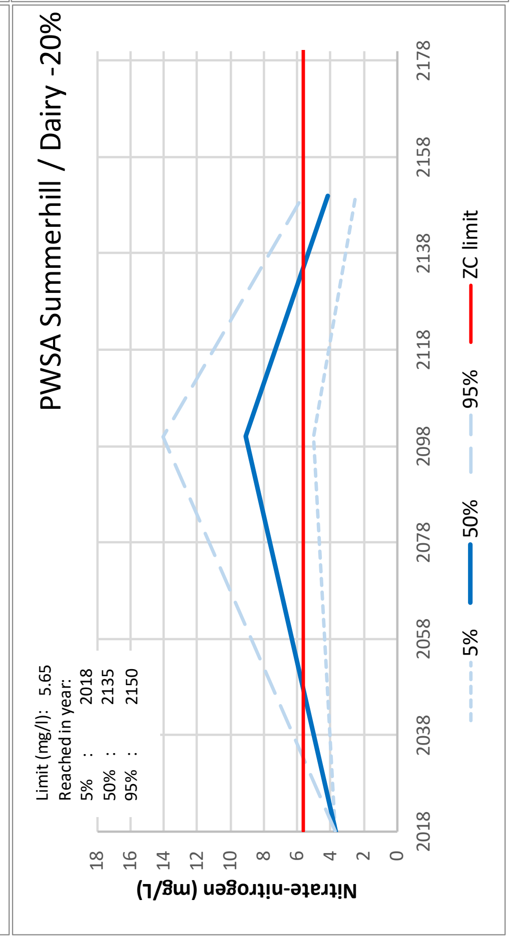
PWSA Summerhill

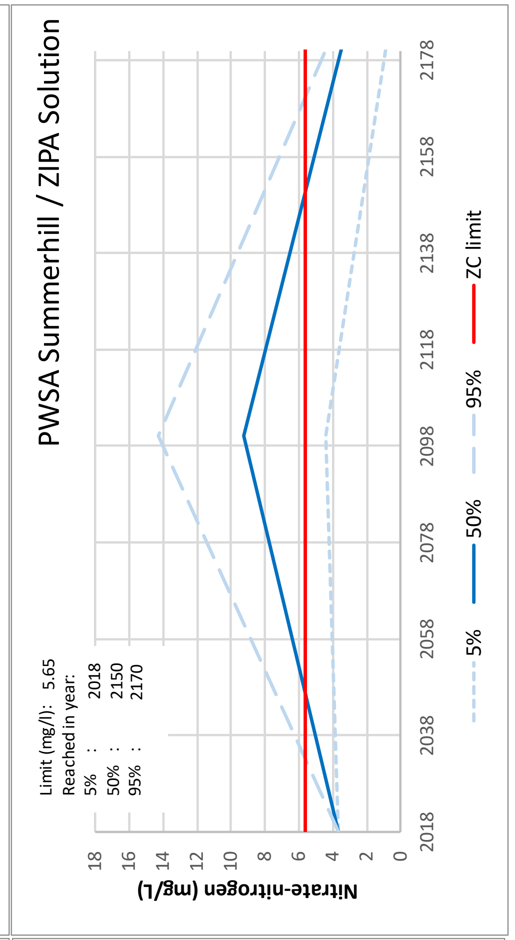




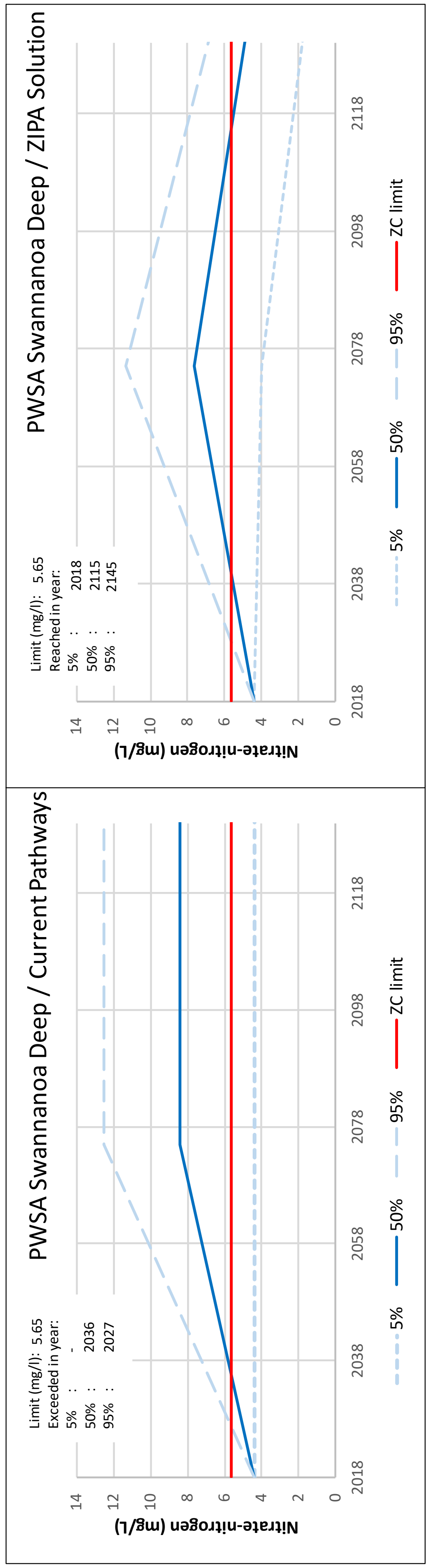




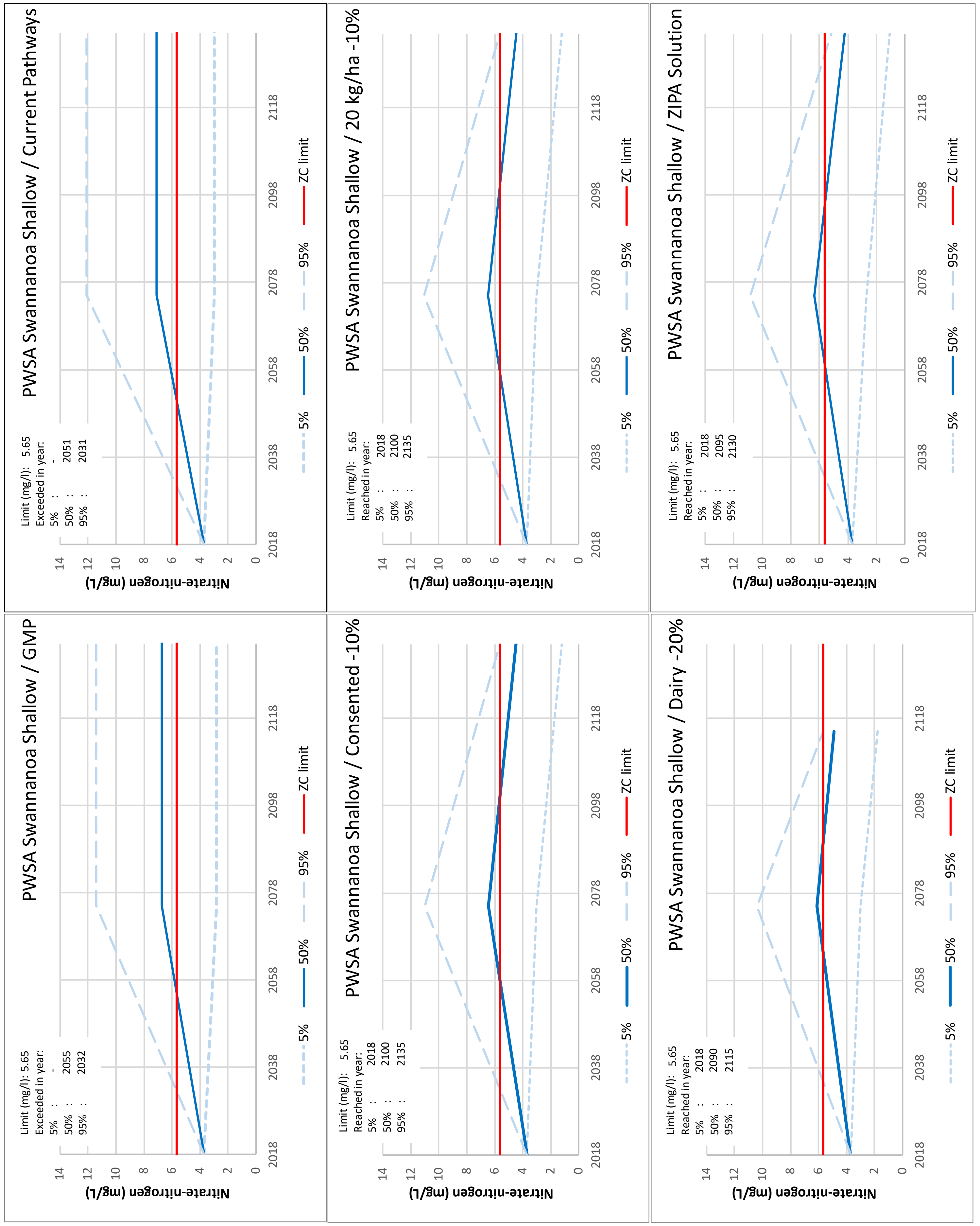




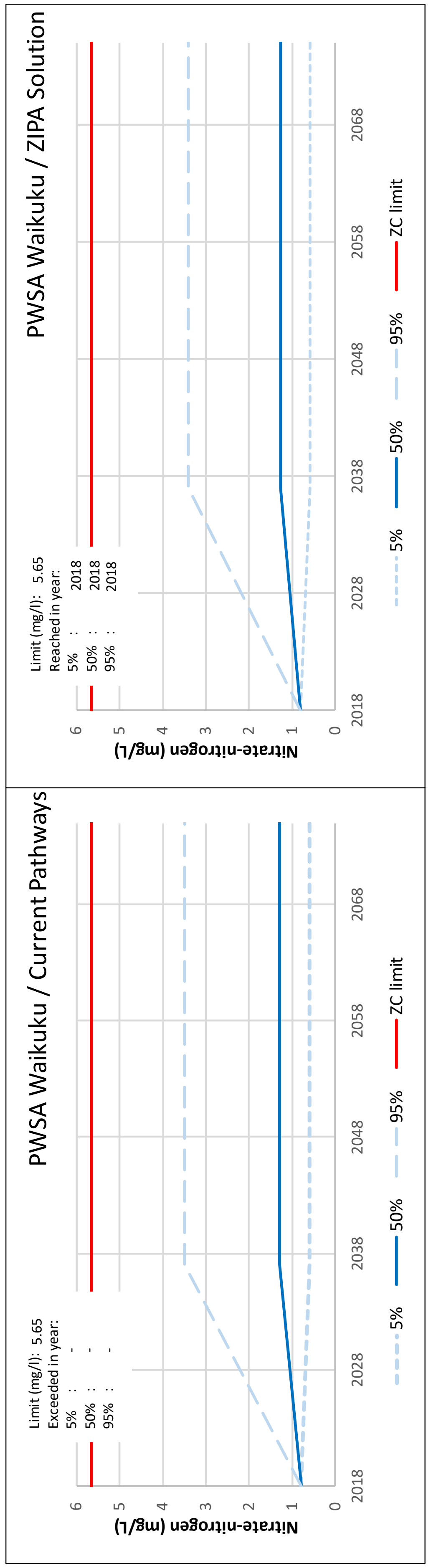
PWSA Swannanoa Deep



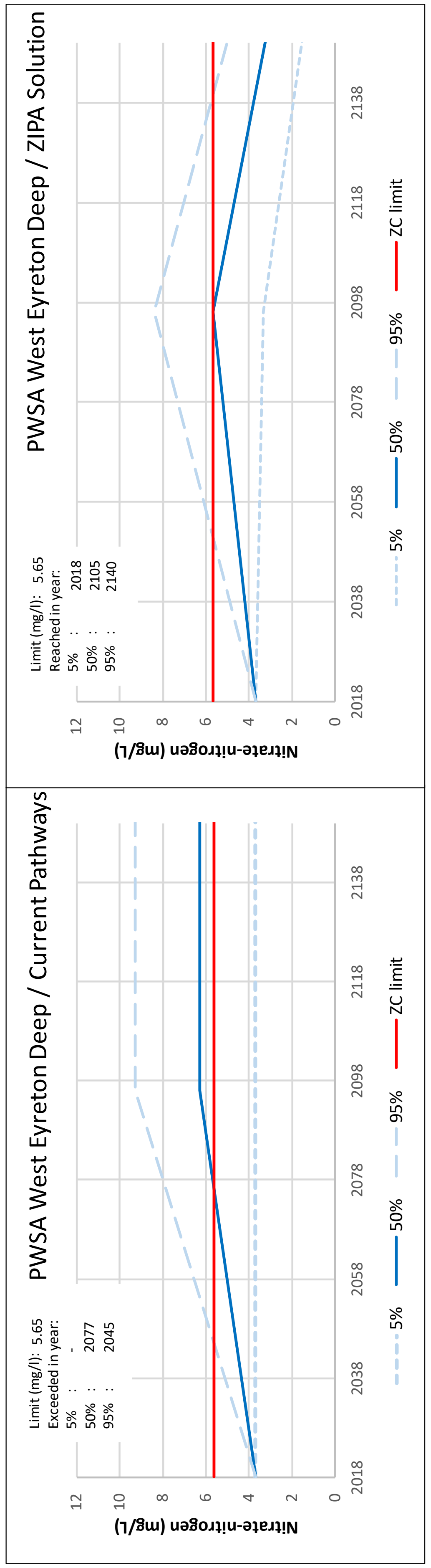
PWSA Swannanoa Shallow



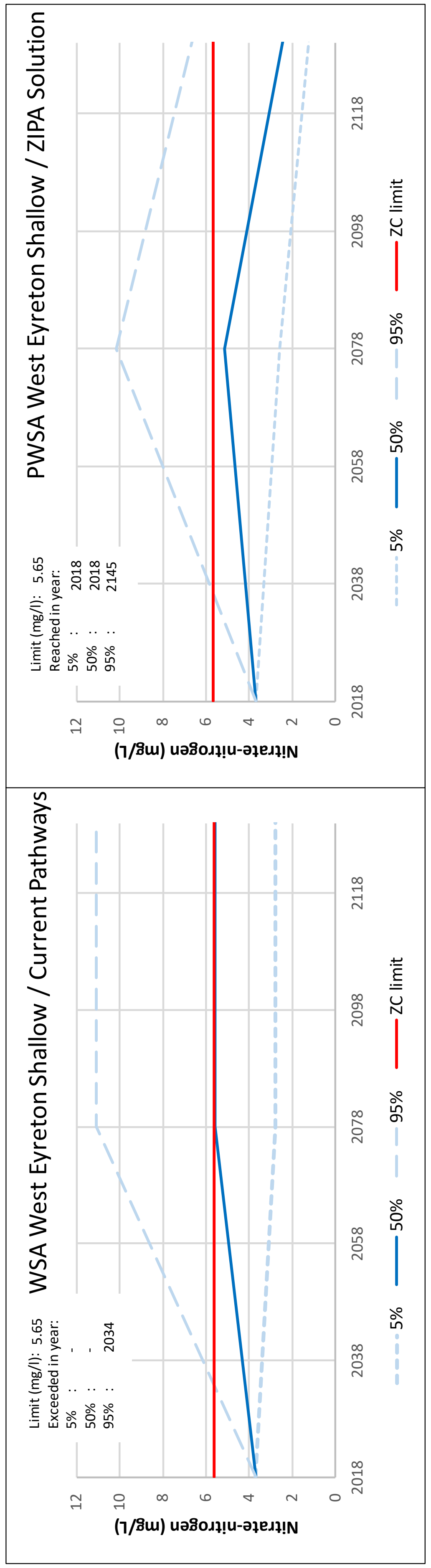
PWSA Waikuku



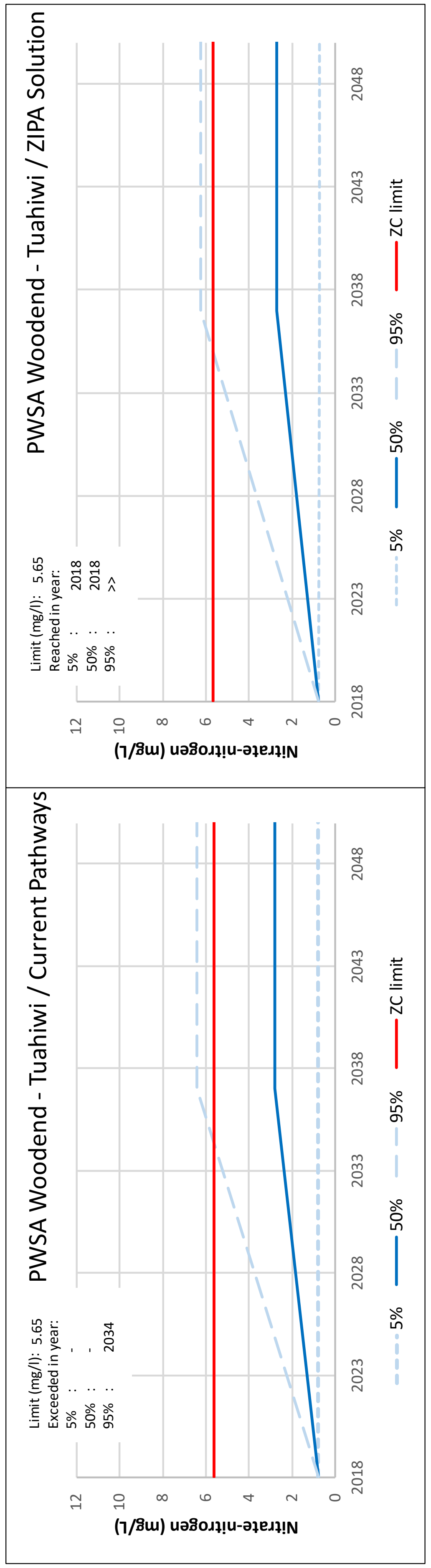
PWSA West Eyreton Deep



PWSA West Eyreton Shallow

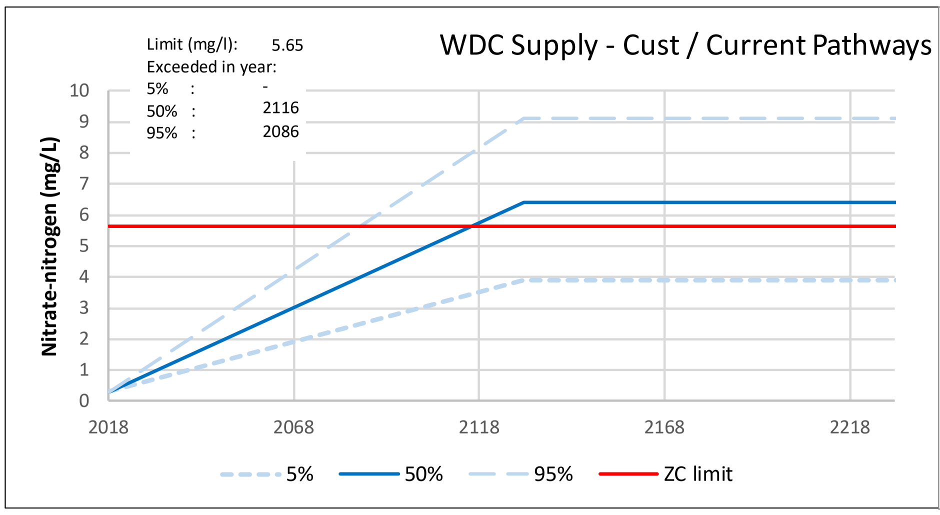


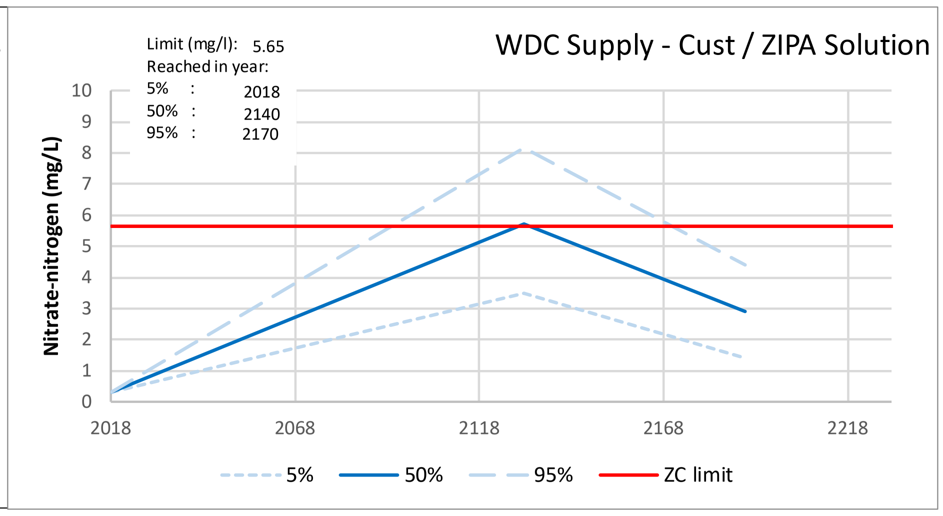
PWSA Woodend – Tuahiwi



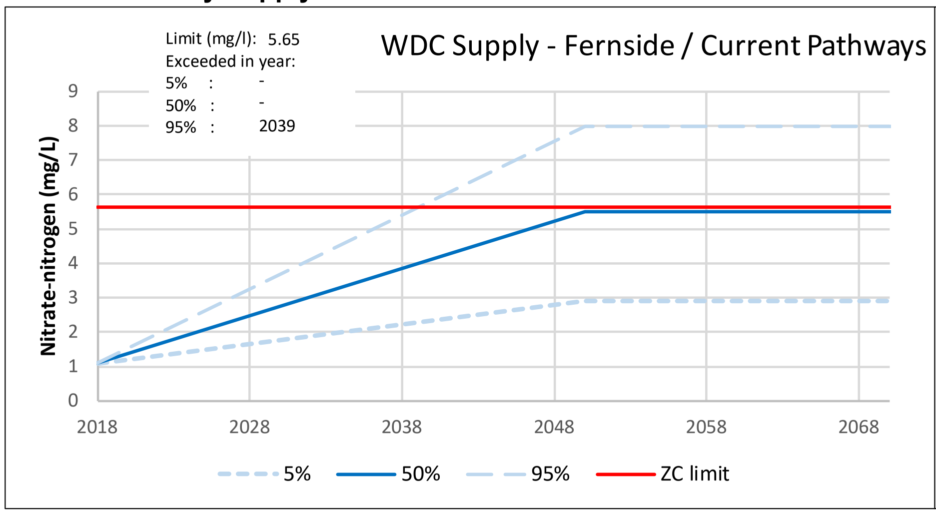
A9.2 Nitrate time series for Waimakariri District Council (WDC) Community Supply Wells

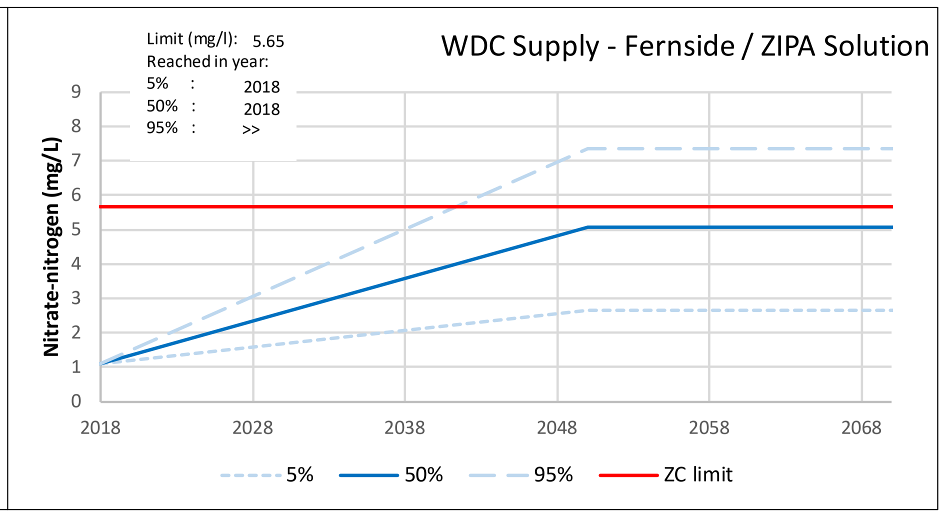
WDC Community Supply Wells - Cust



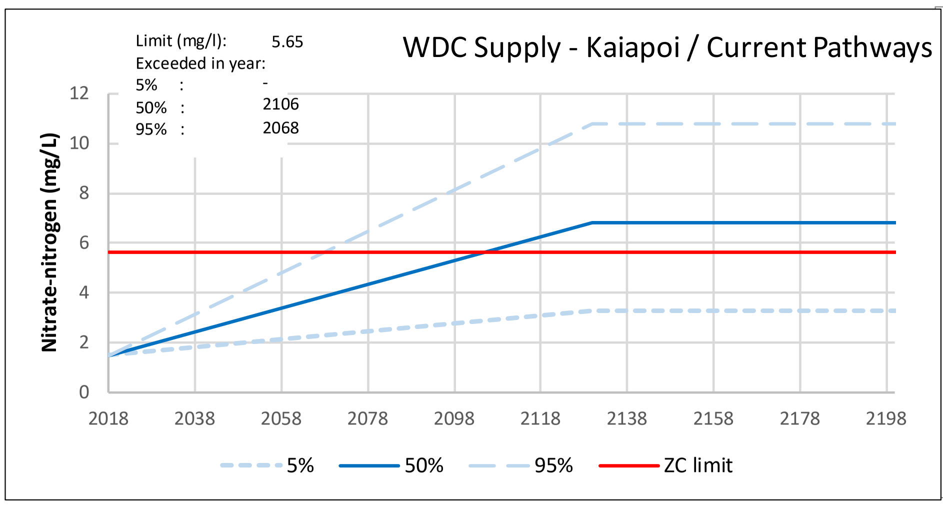


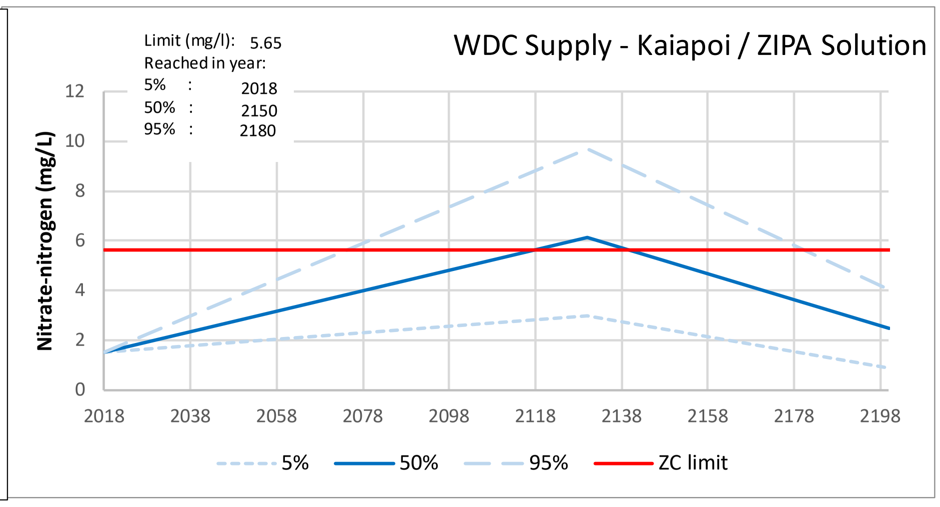
WDC Community Supply Wells - Fernside



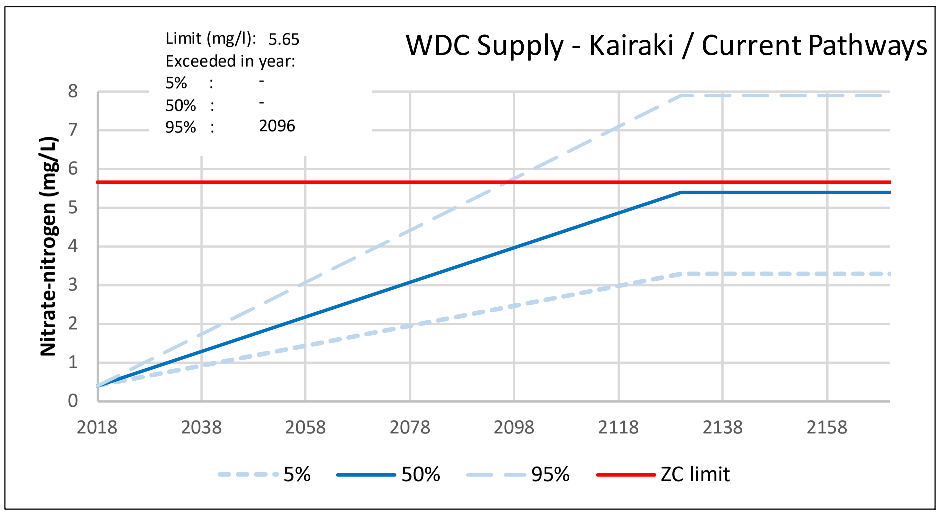


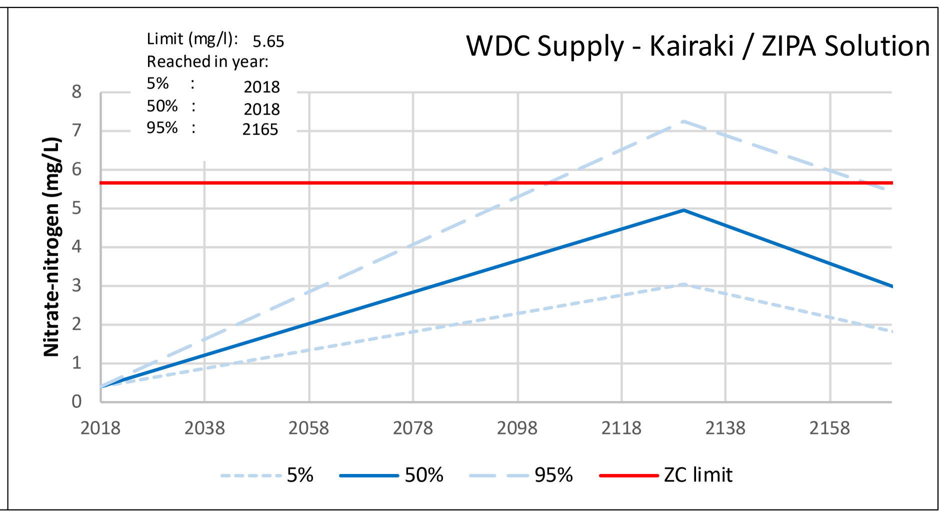
WDC Community Supply Wells Kaiapoi



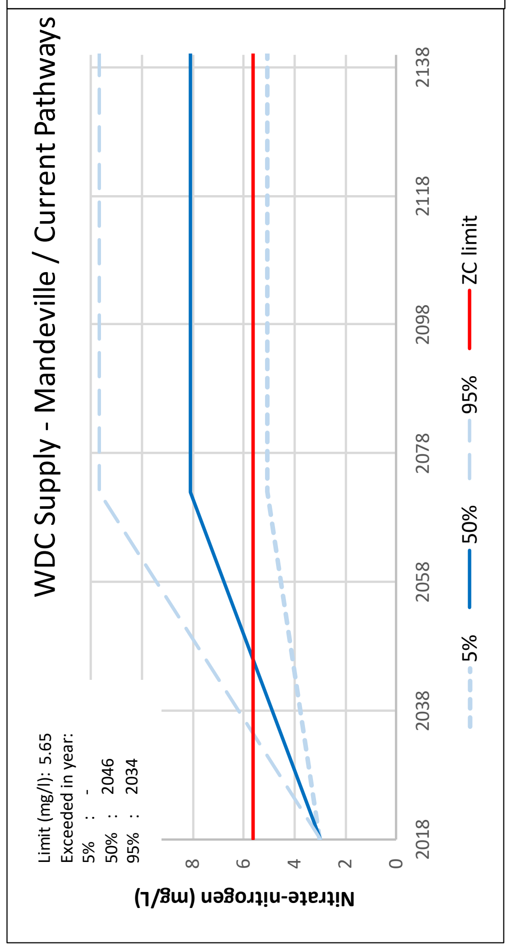


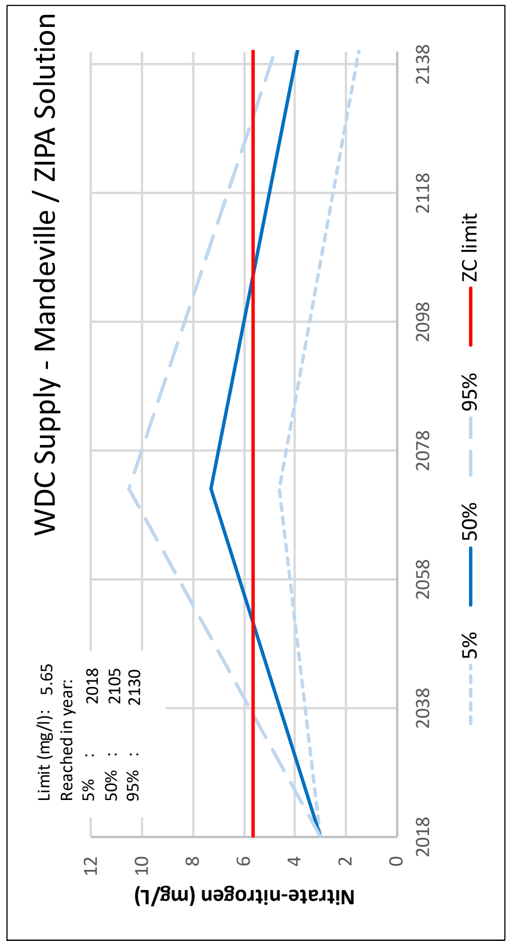
WDC Community Supply Wells – Kairaki



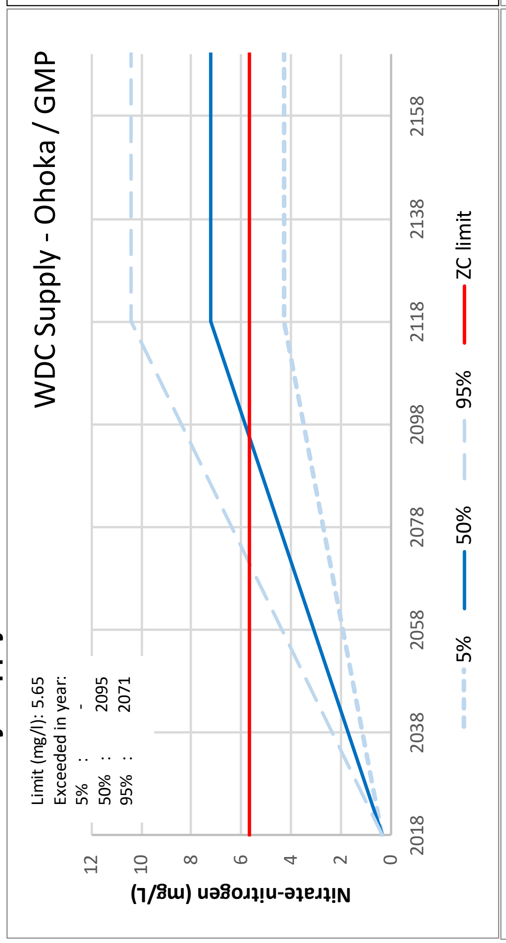


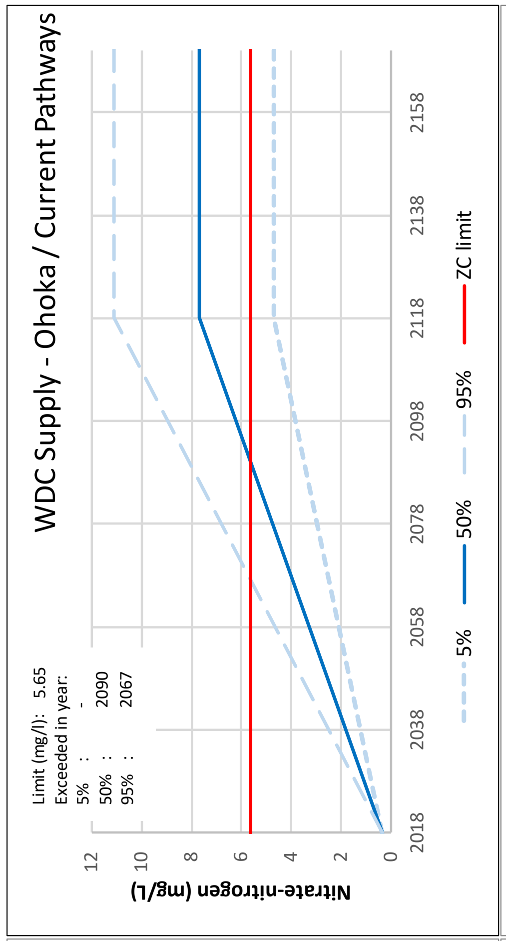
WDC Community Supply Wells – Mandeville

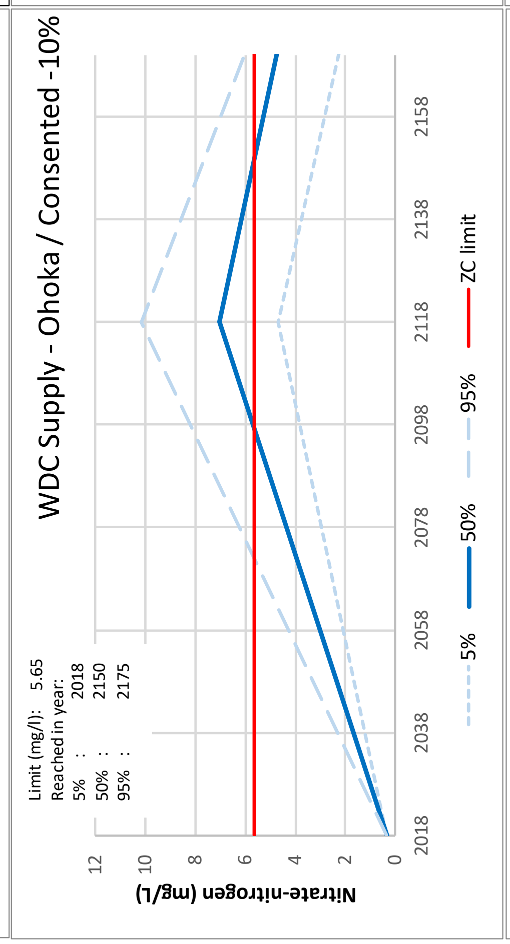


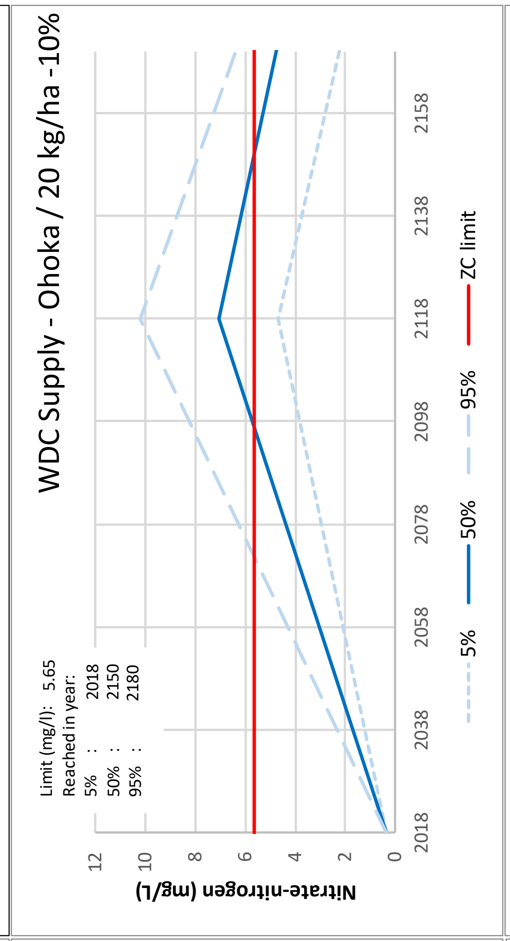


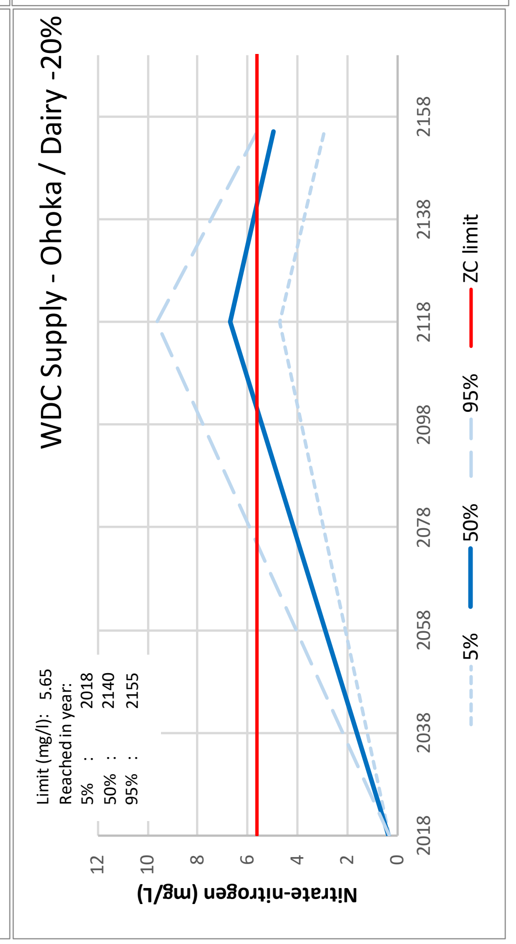
WDC Community Supply Wells - Ohoka

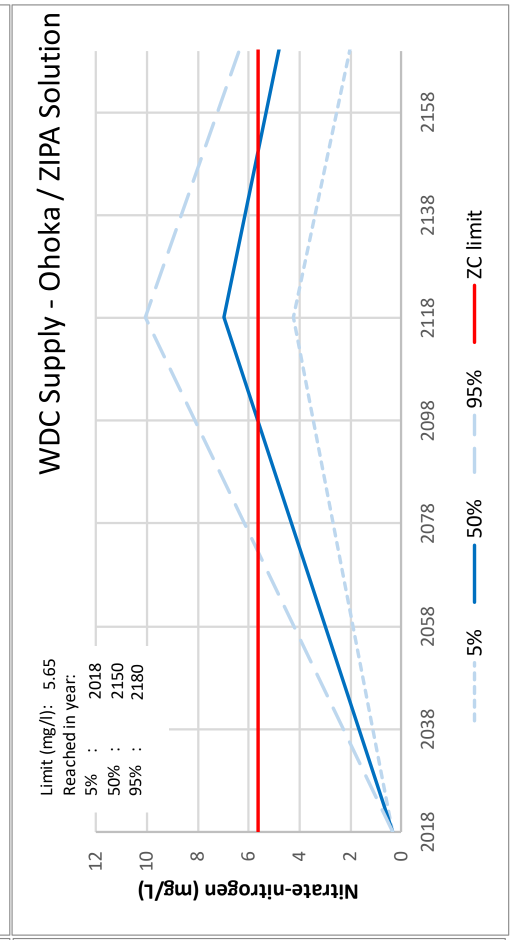




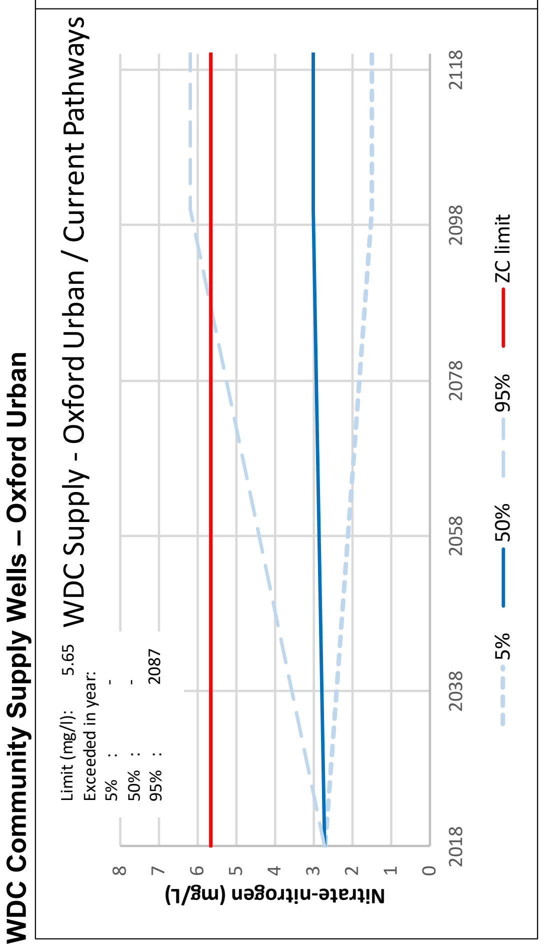


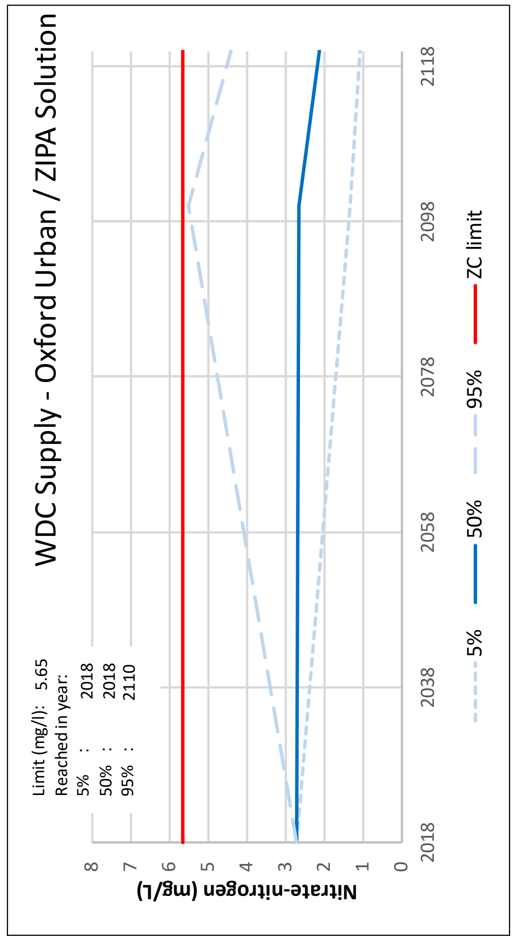




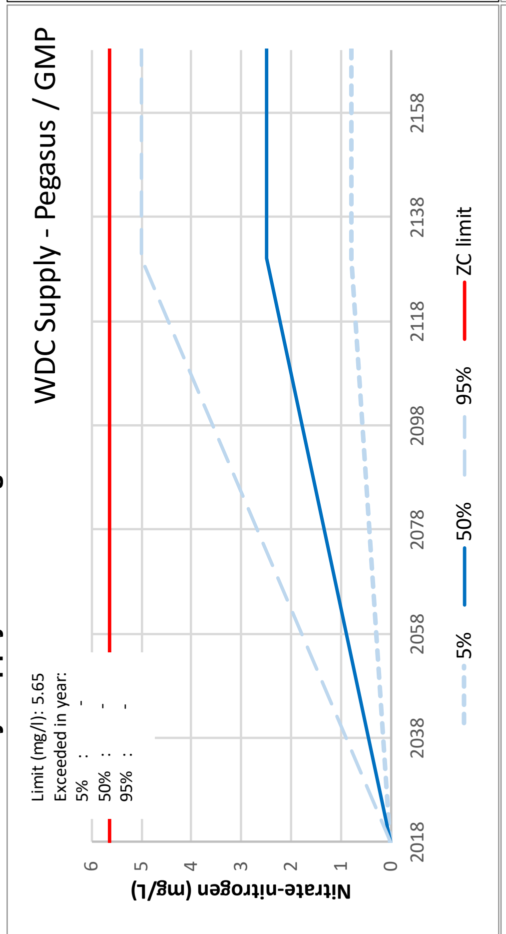


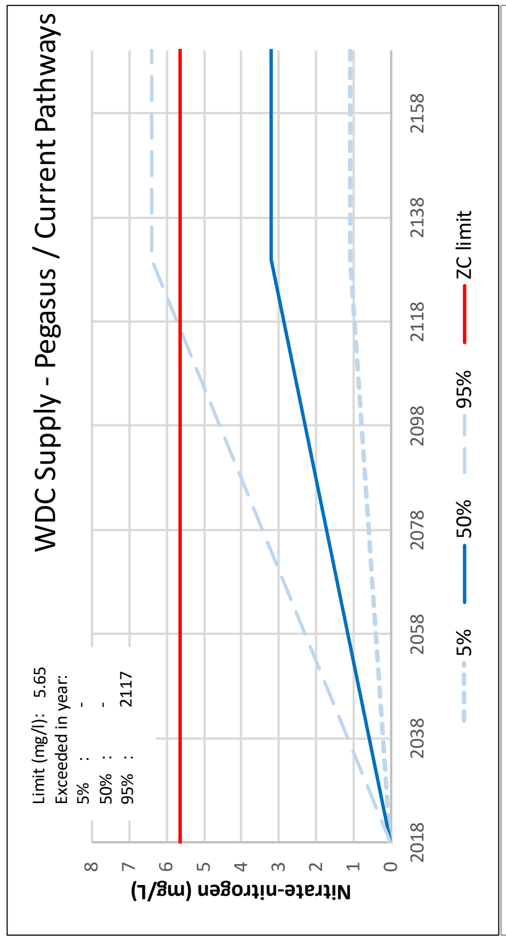
WDC Community Supply Wells – Oxford Urban

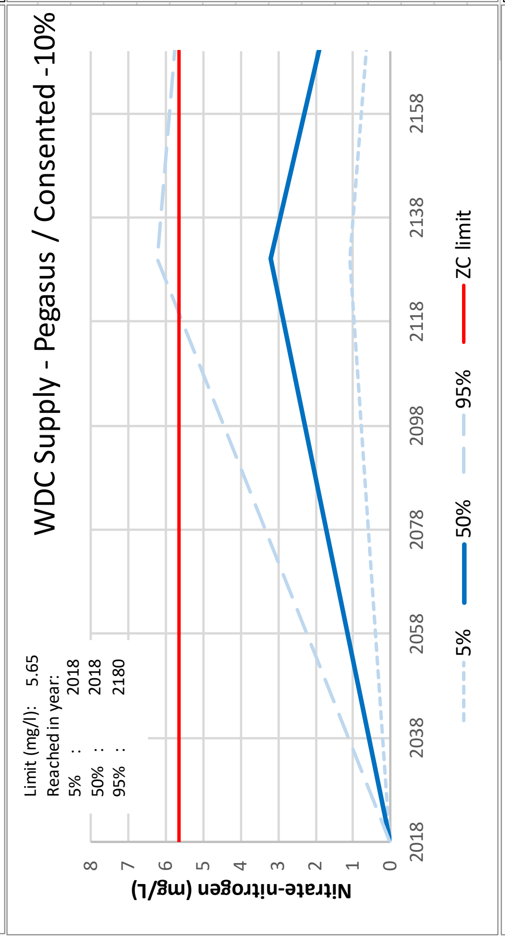


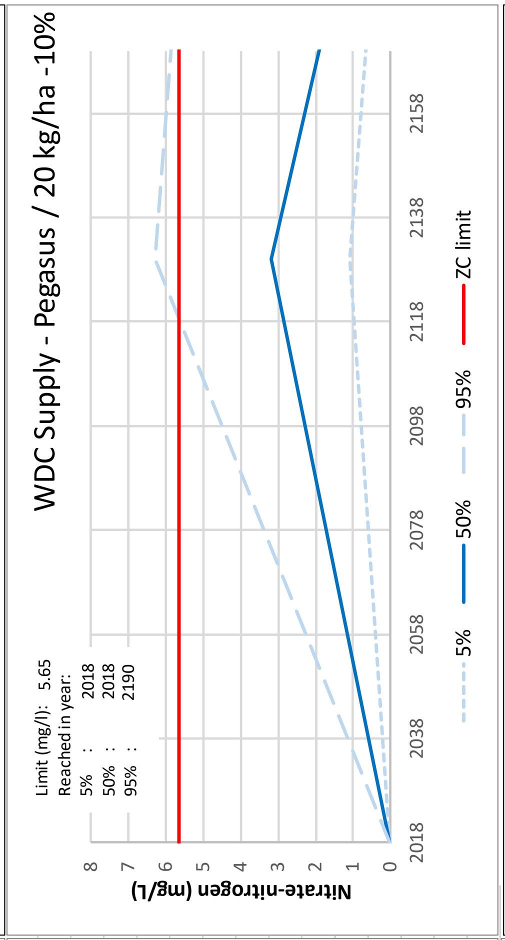


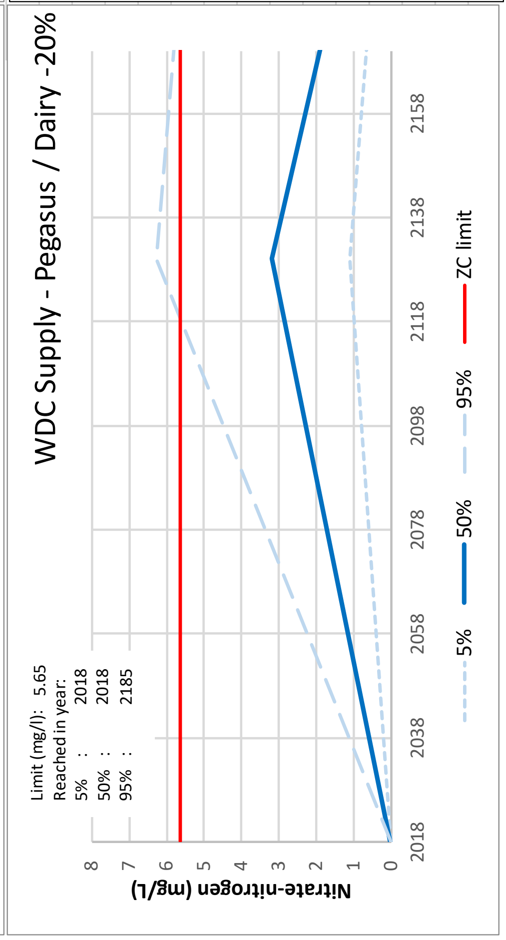
WDC Community Supply Wells - Pegasus

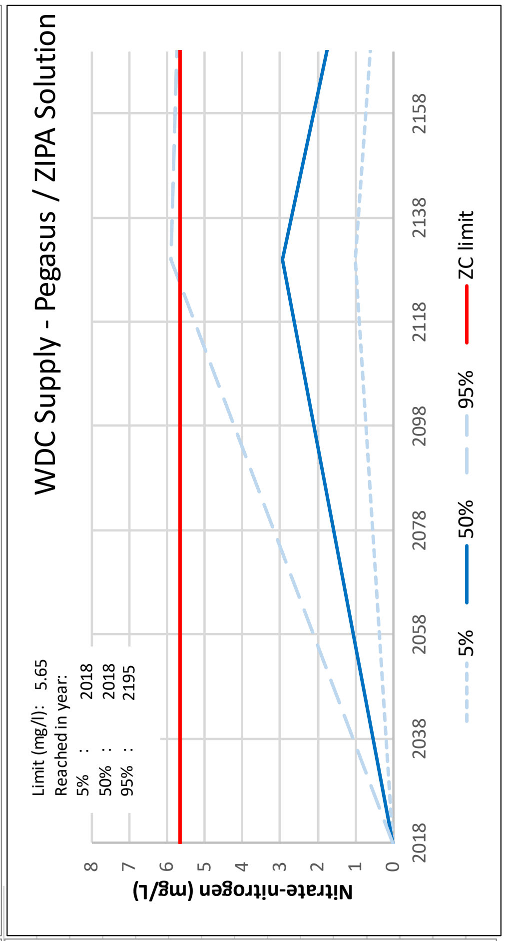




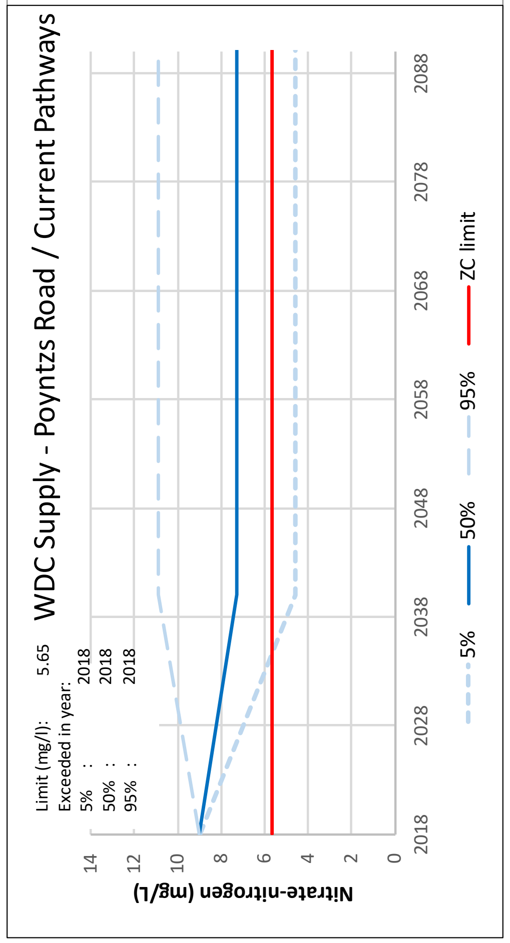


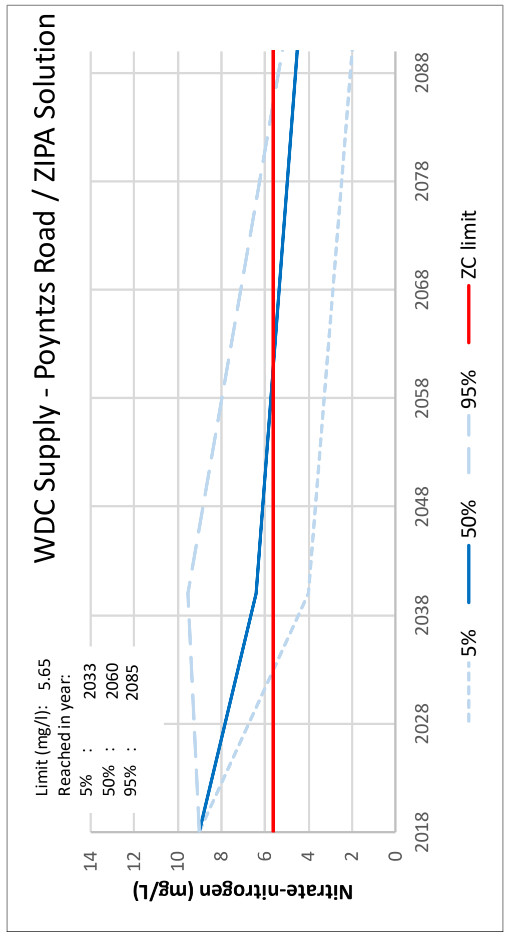




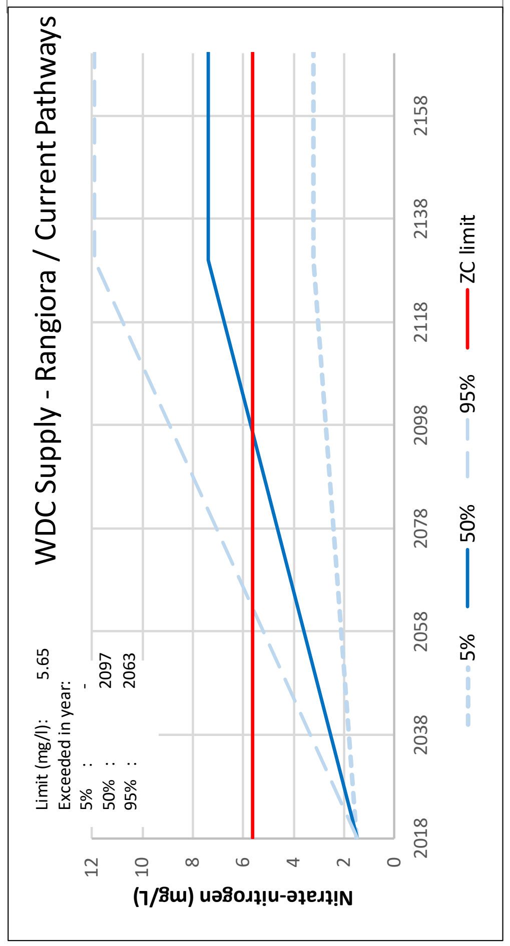


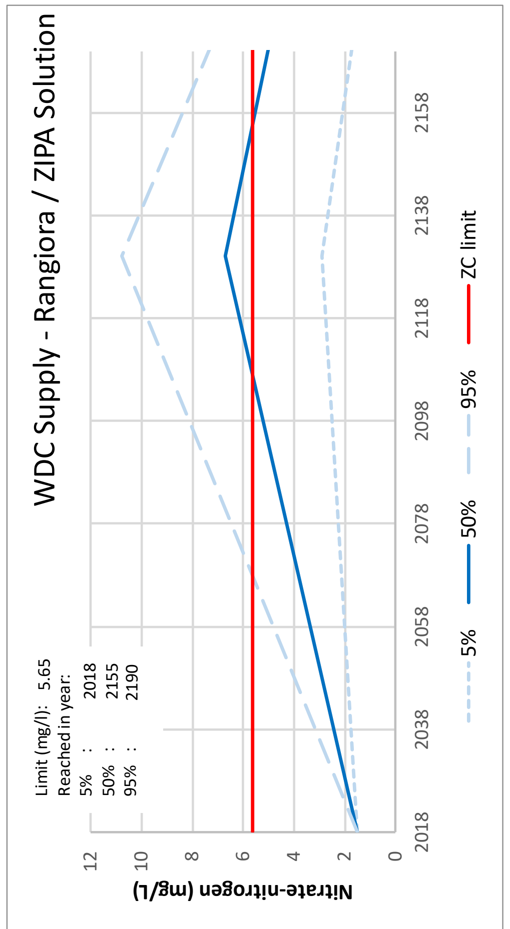
WDC Community Supply Wells – Poyntzs Road



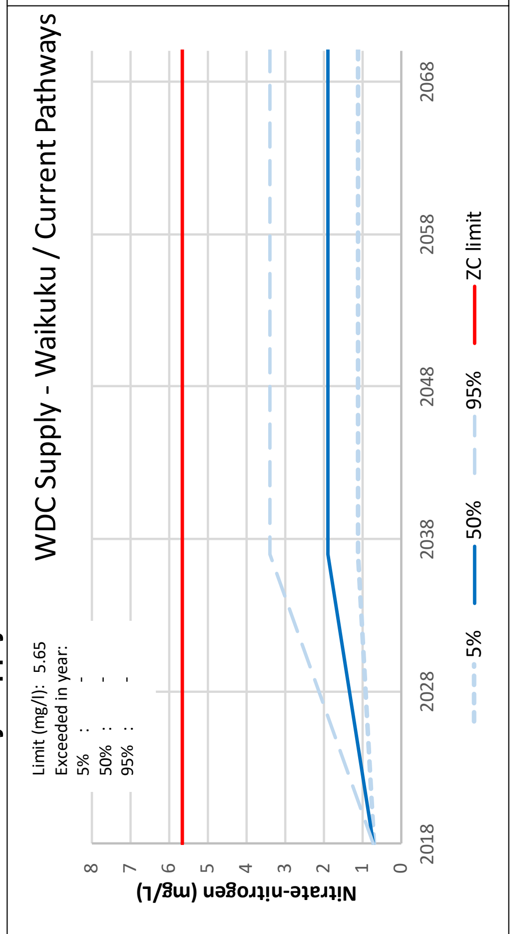


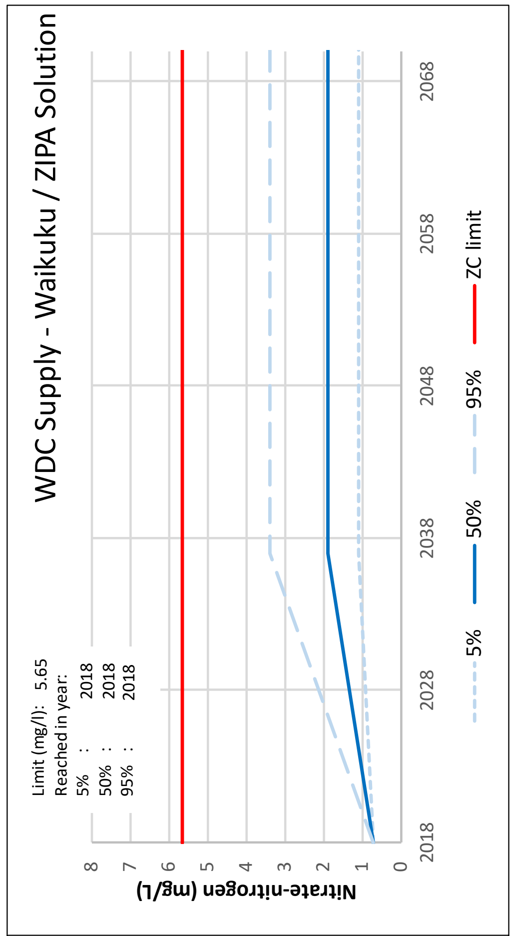
WDC Community Supply Wells – Rangiora



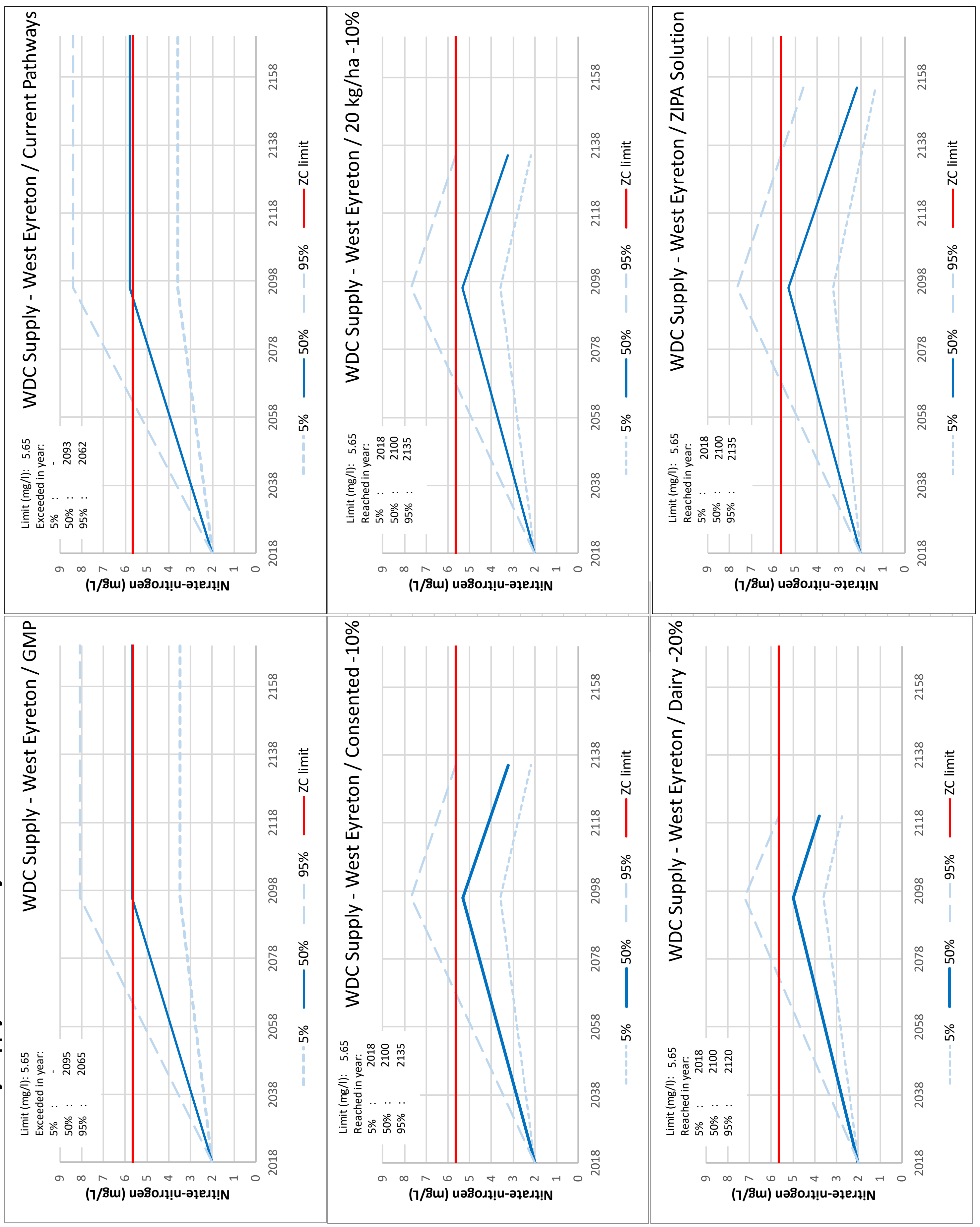


WDC Community Supply Wells – Waikuku



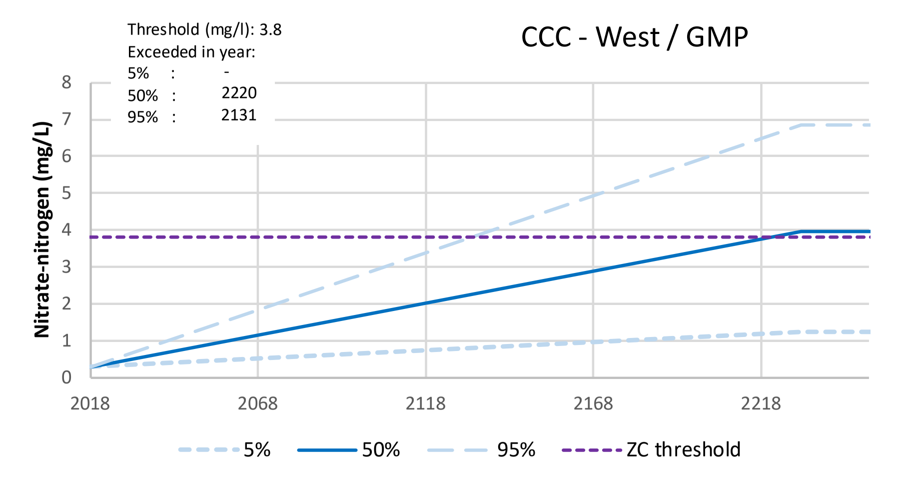


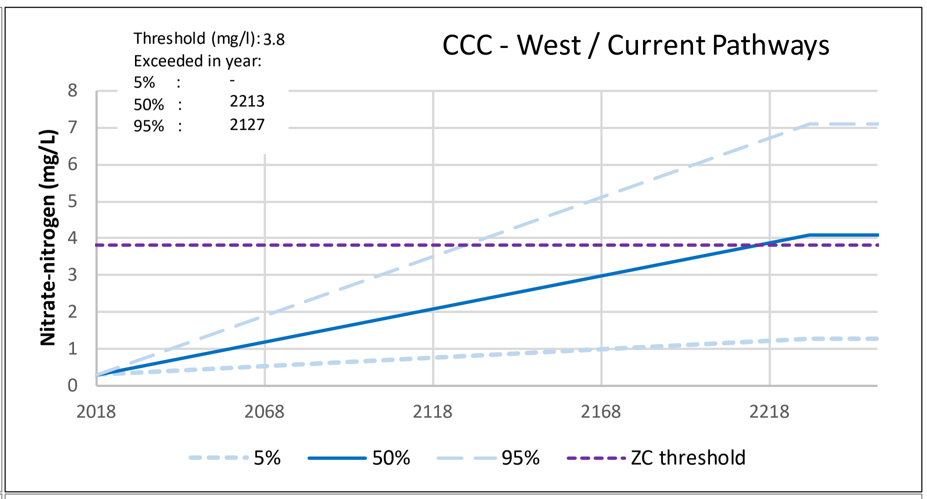
WDC Community Supply Wells – West Eyreton / Summerhill

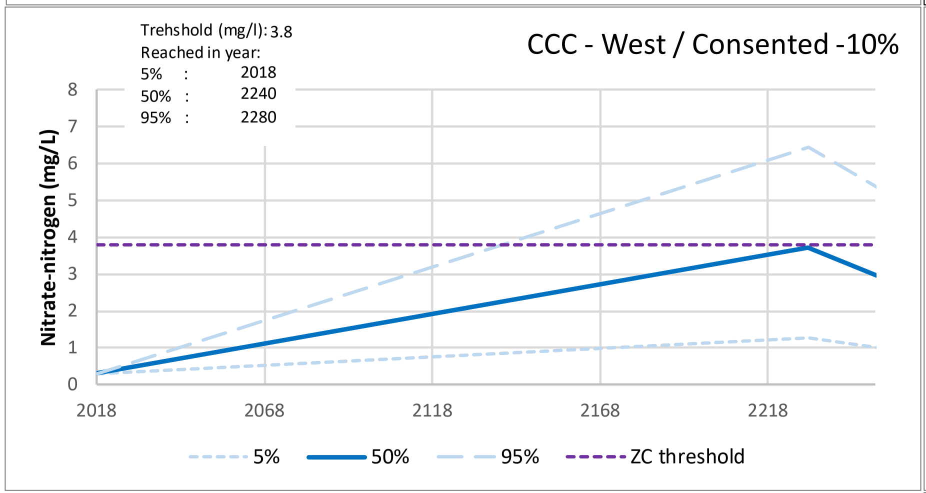


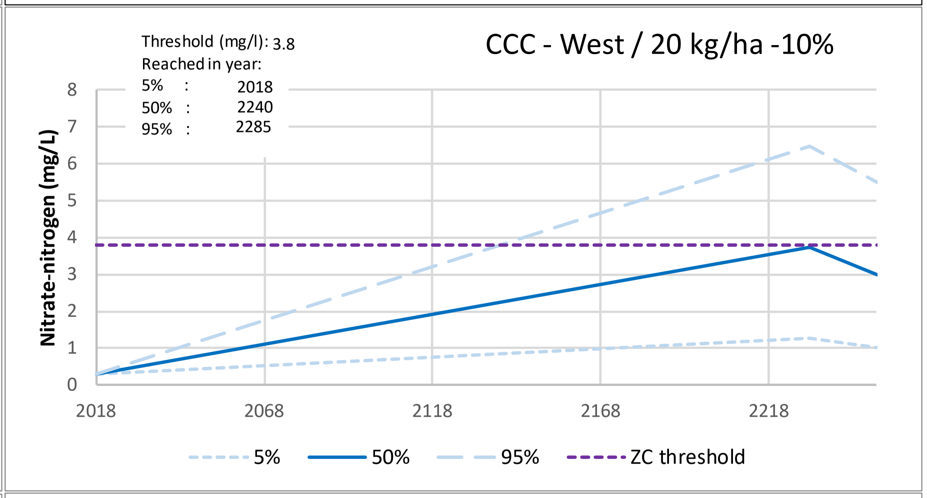
A9.3 Nitrate time series for Christchurch aquifer

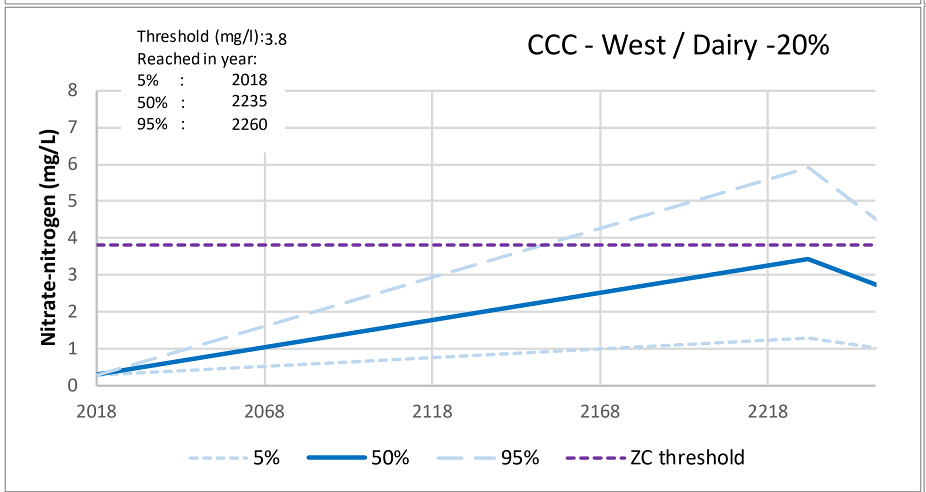
Christchurch aquifer – West

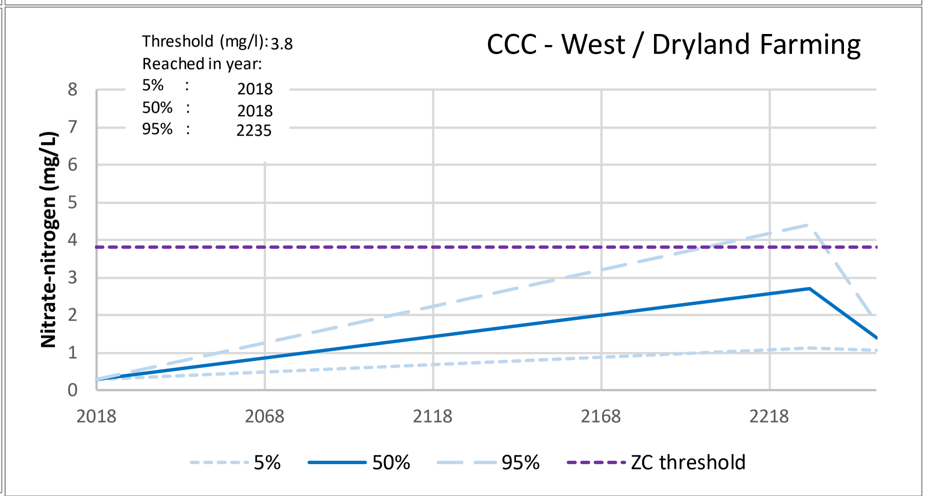


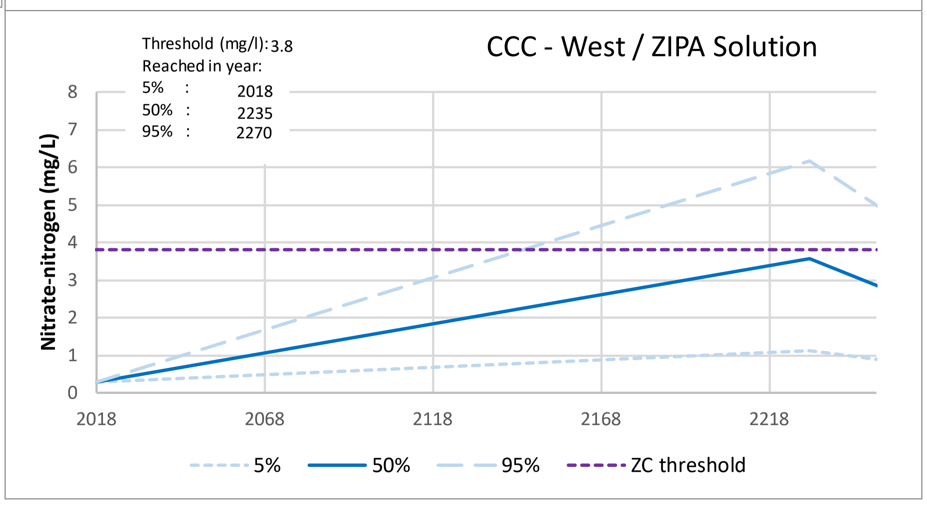




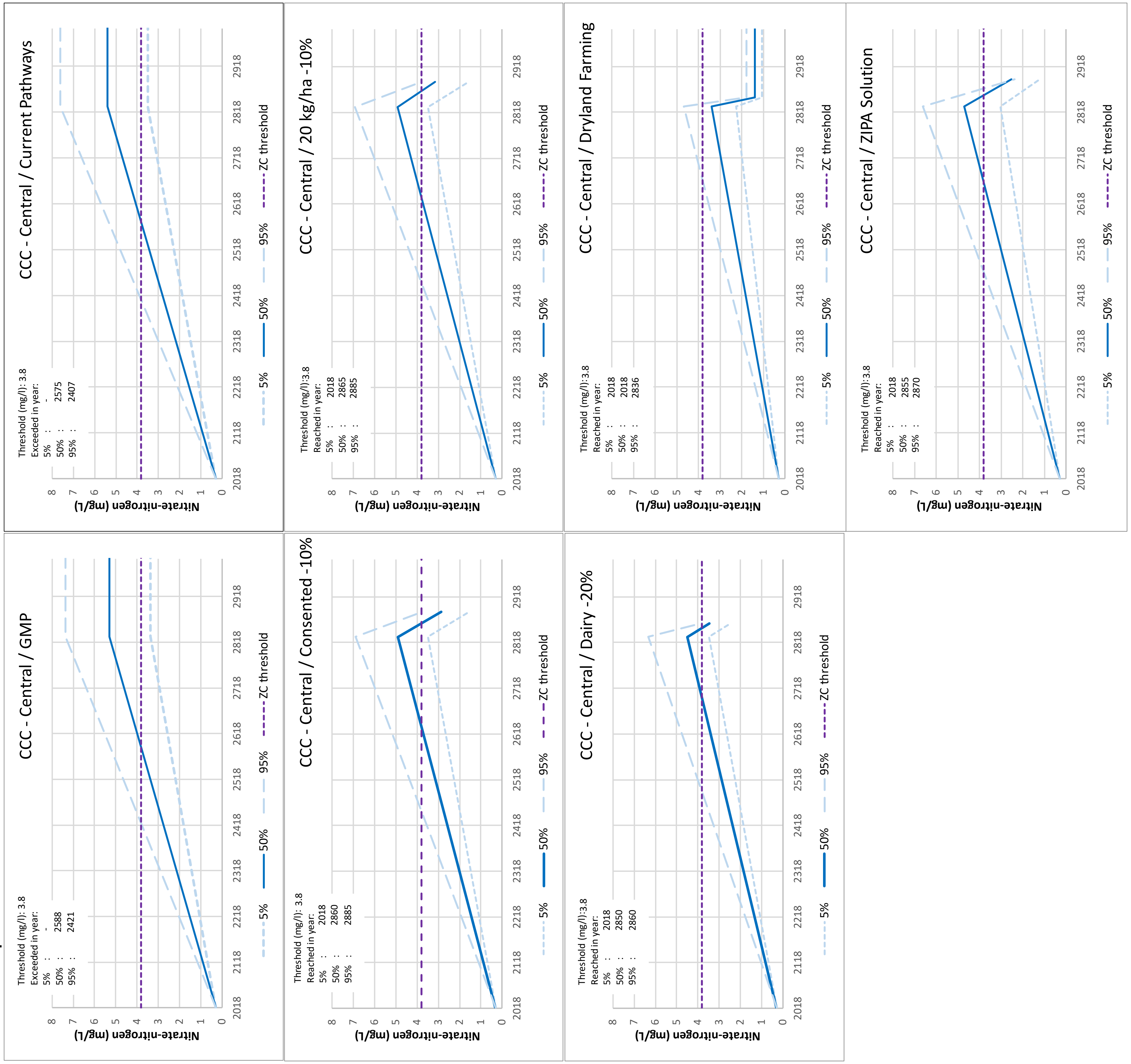




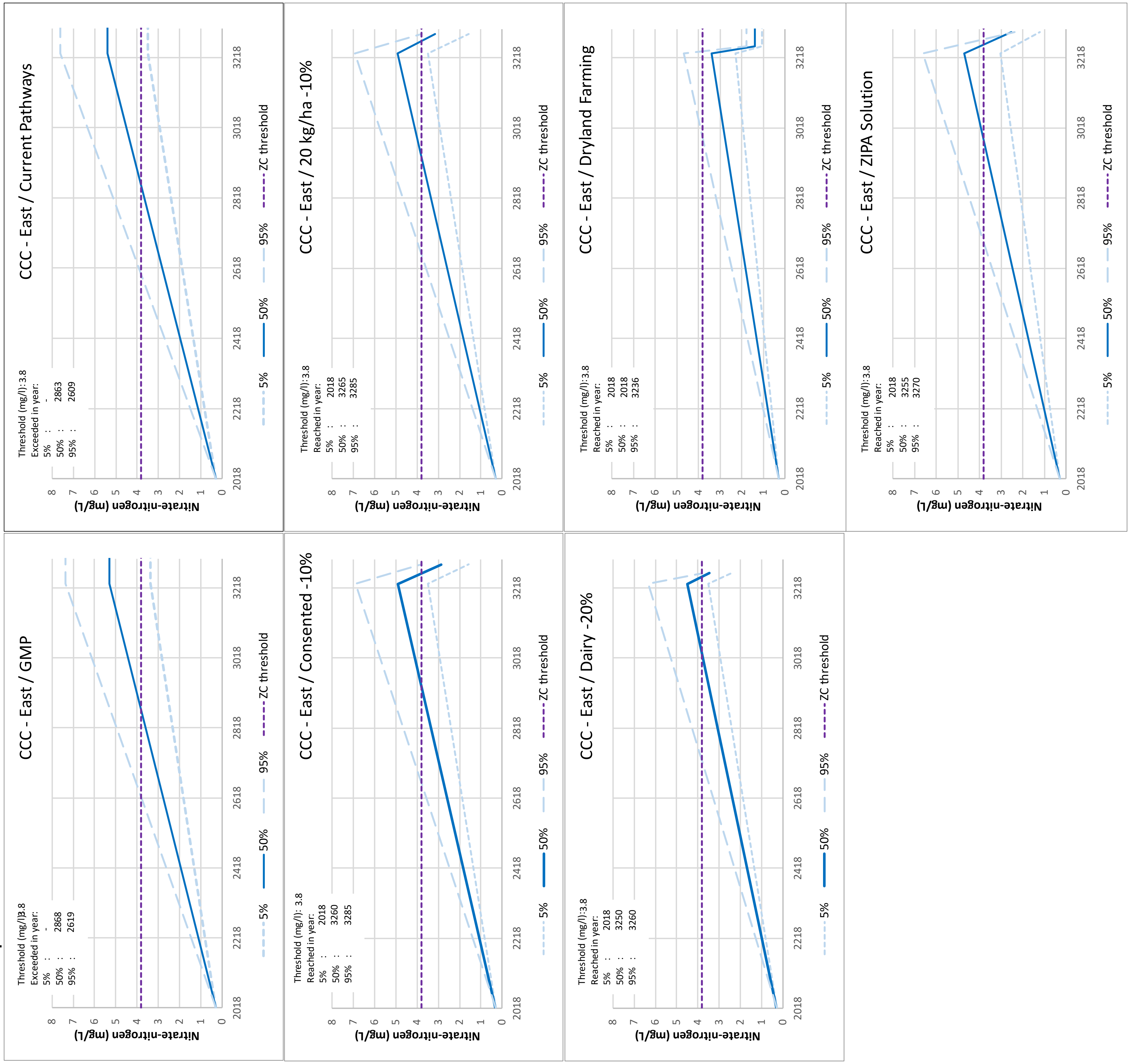




Christchurch aquifer – Central

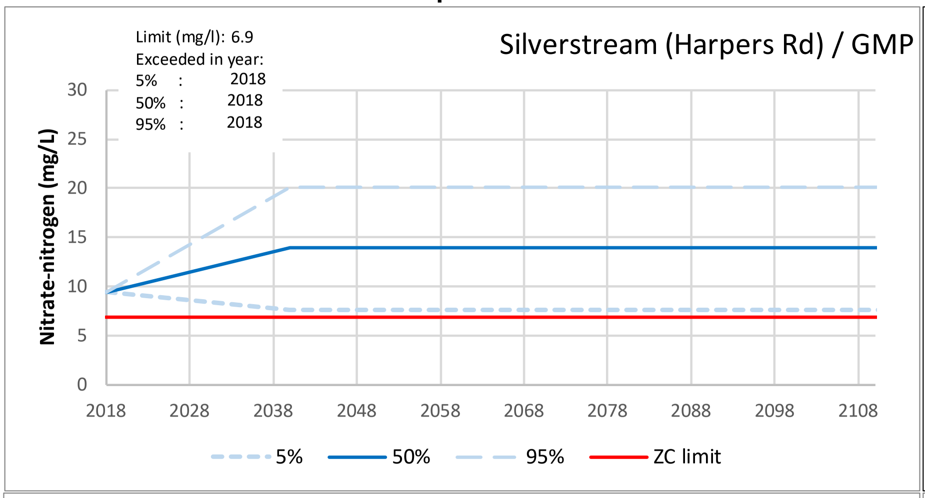


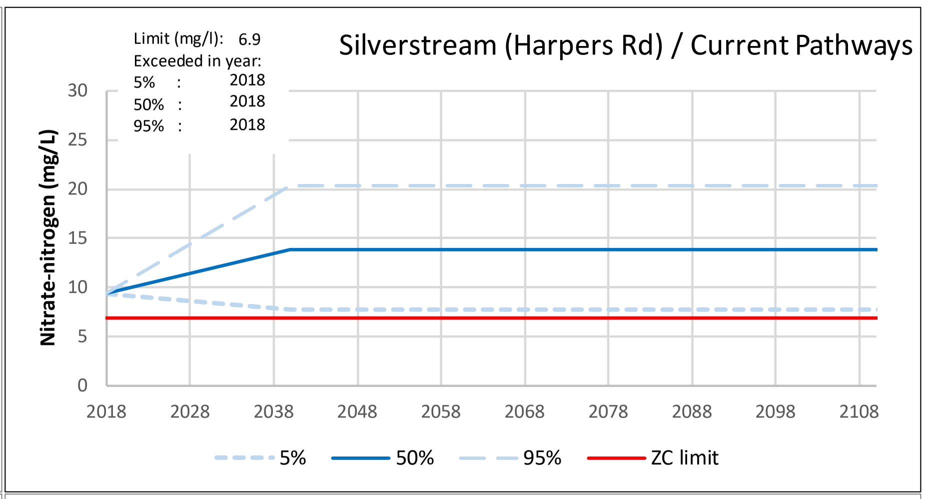
Christchurch aquifer – East

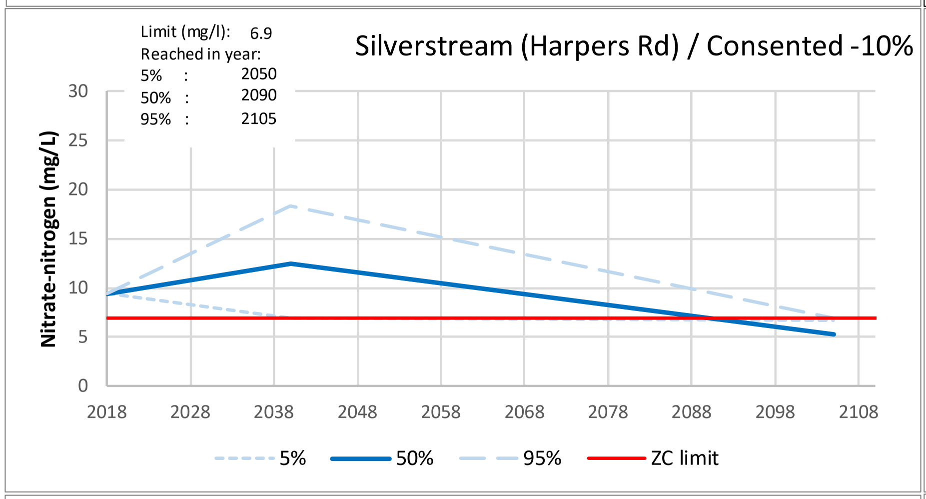


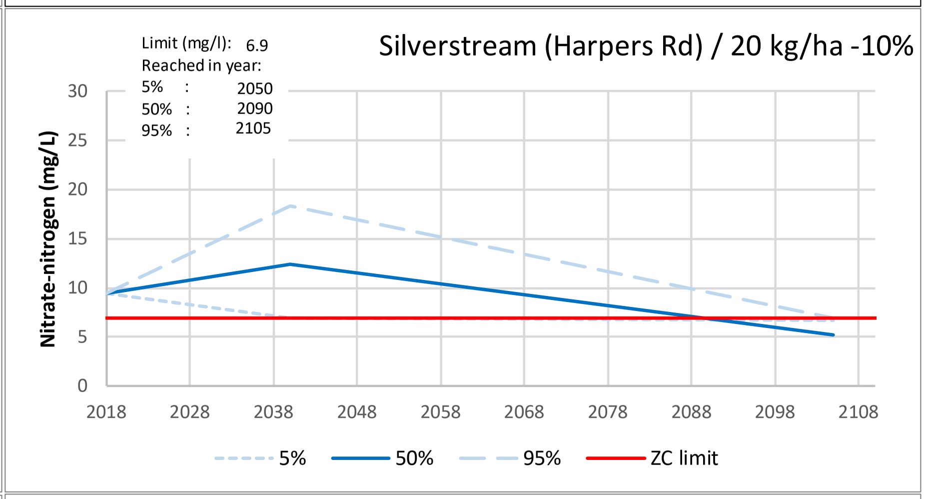
A9.4 Nitrate time series forWaimakariri Northern Tributaries

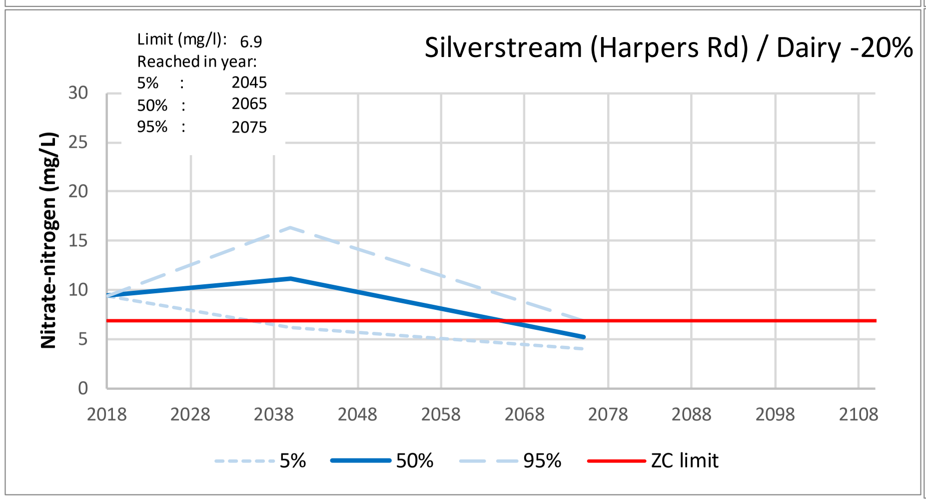
Surface water: Silverstream at Harpers Road

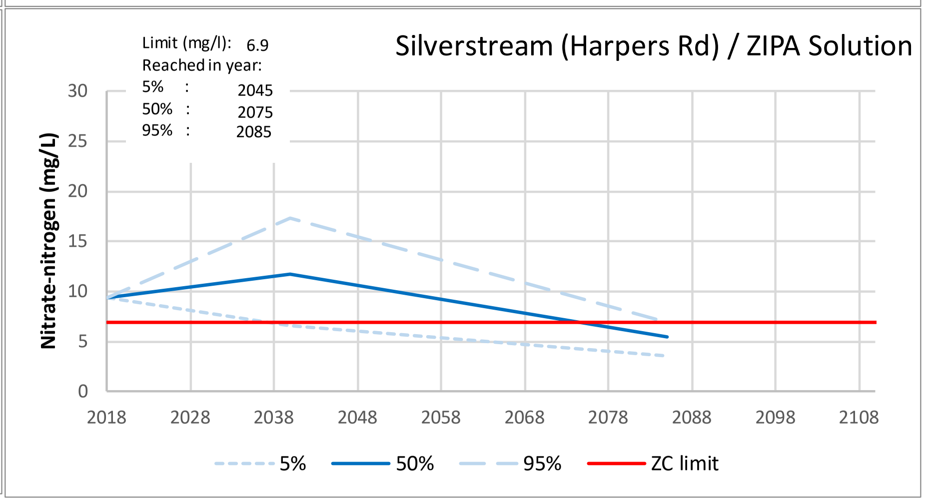




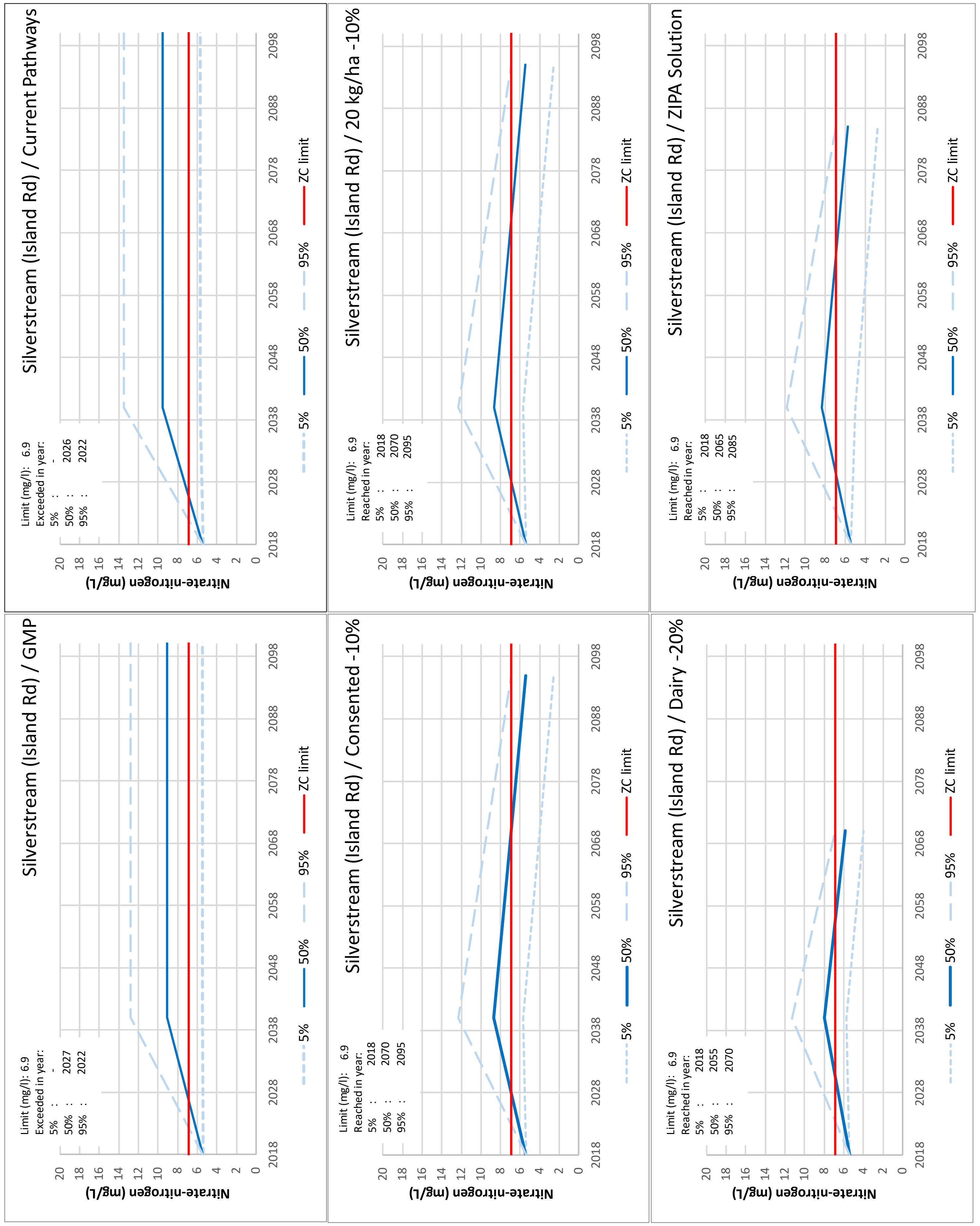




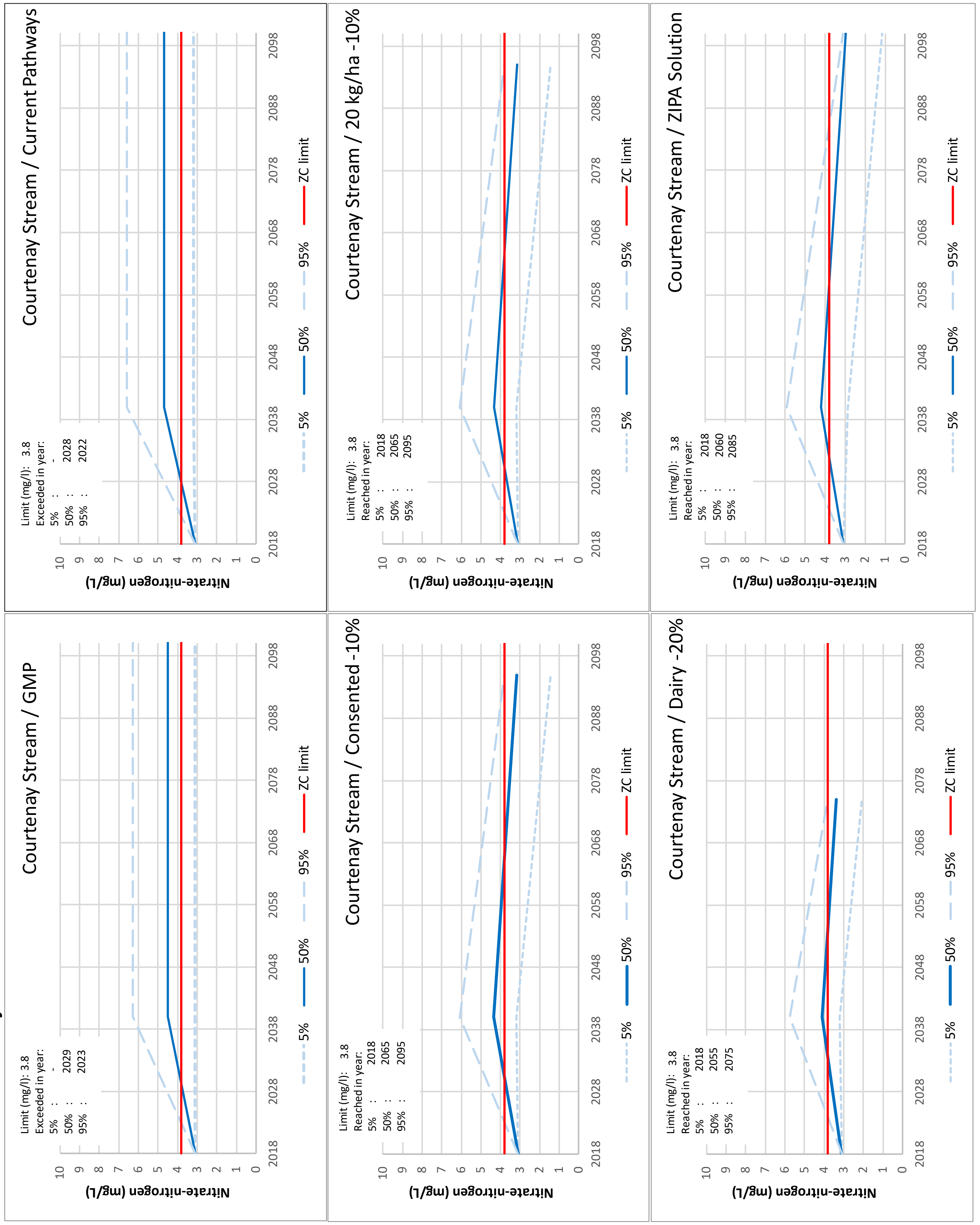




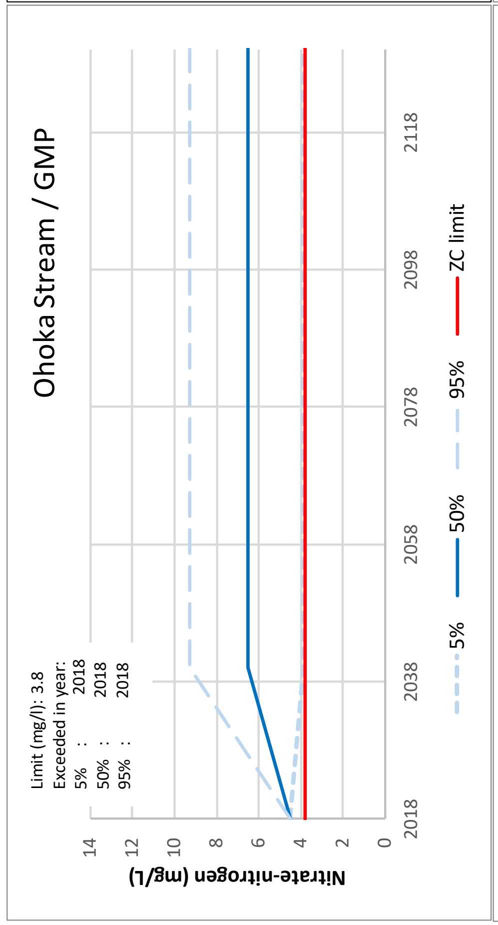
Surface water: Silverstream at Island Road

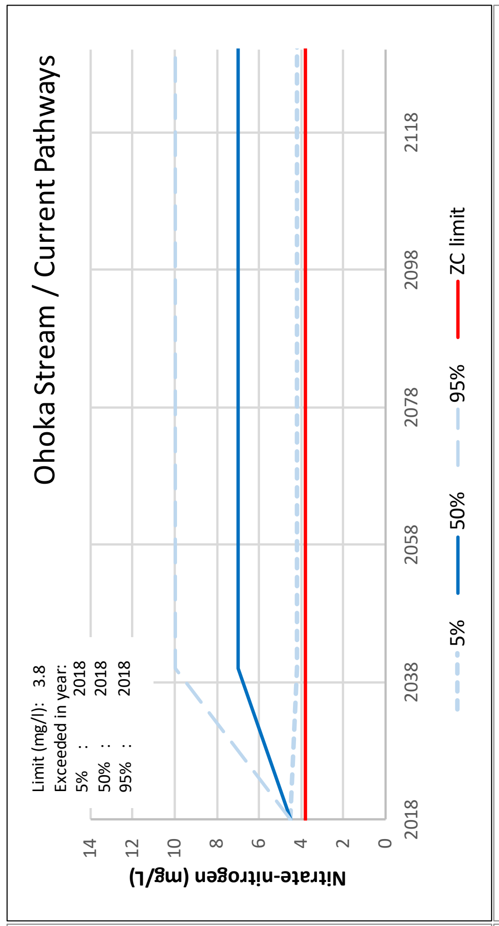


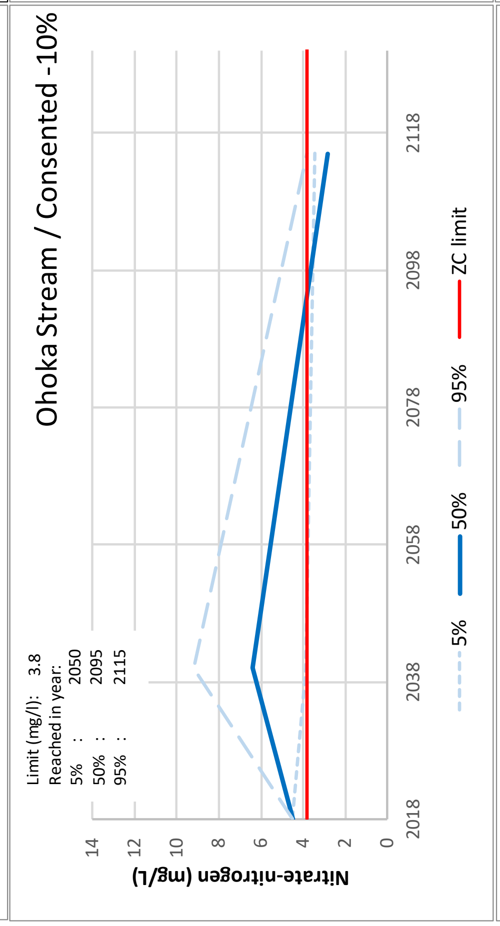
Surface water: Courtenay Stream

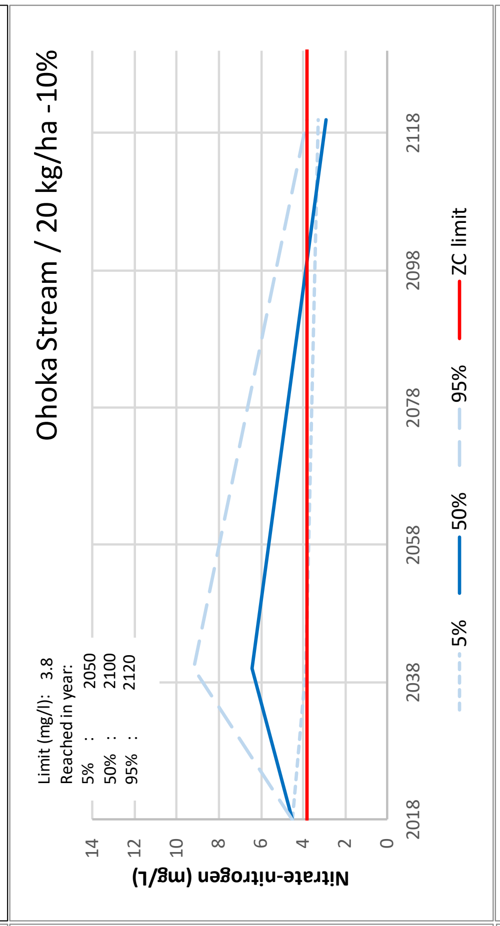


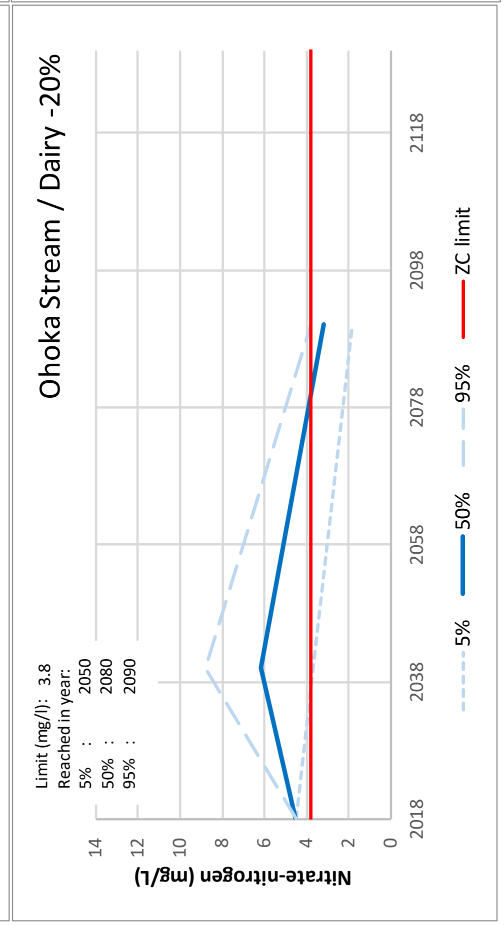
Surface water: Ohoka Stream

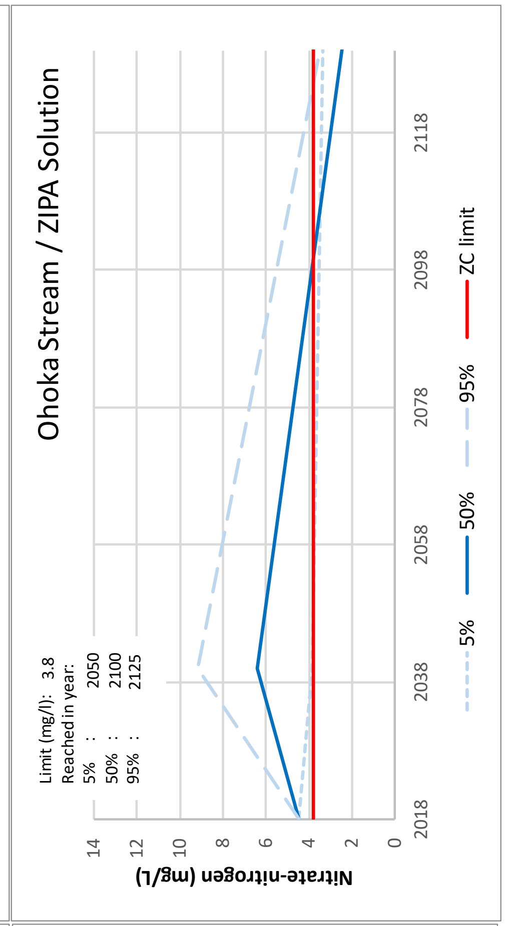




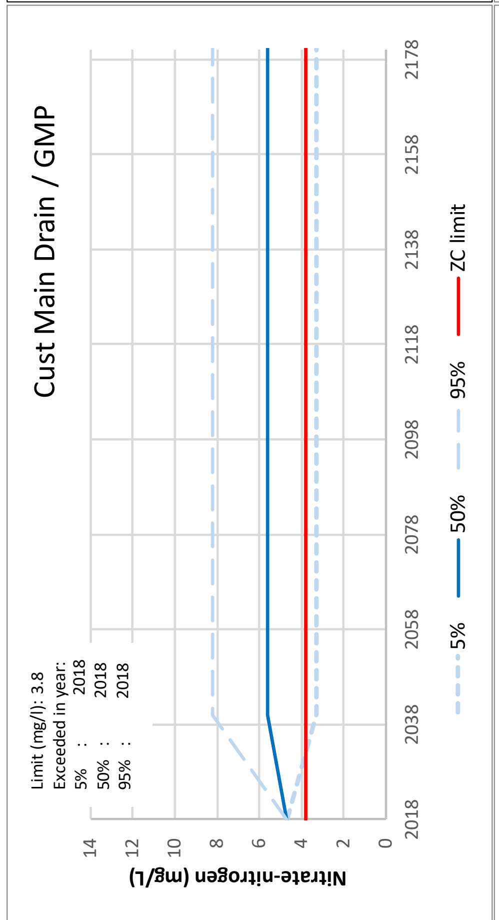


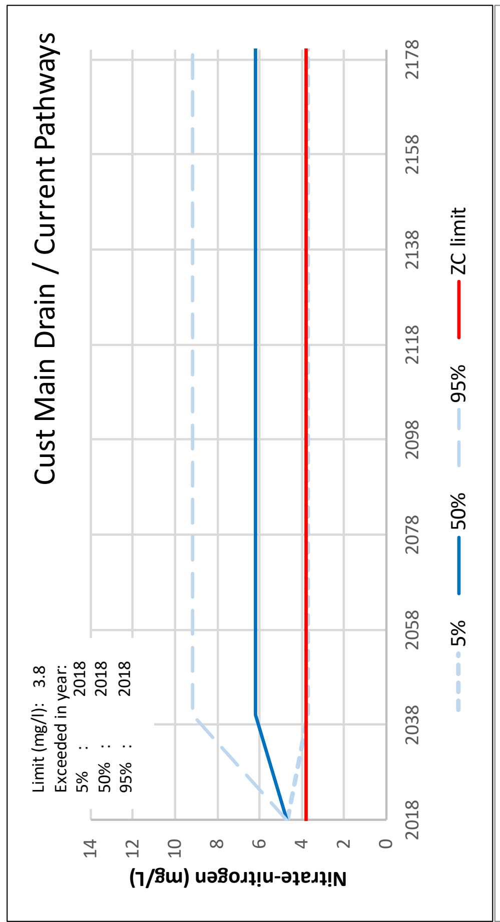


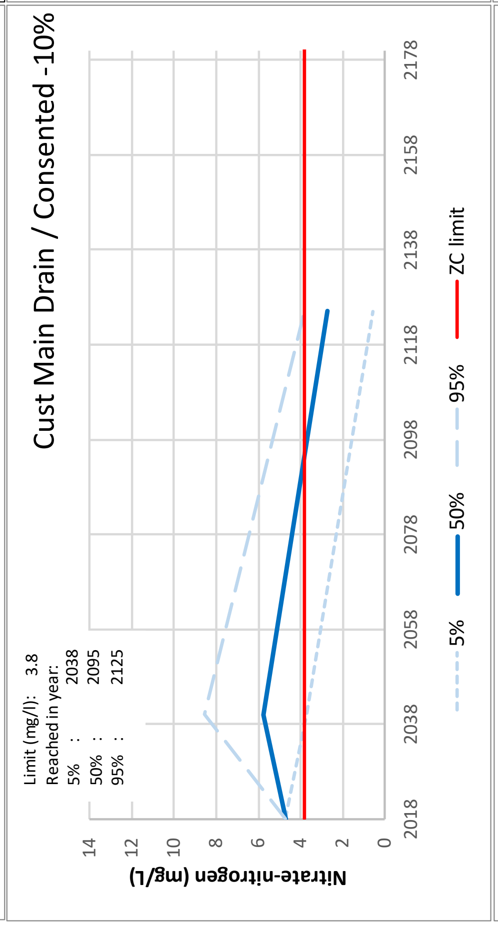


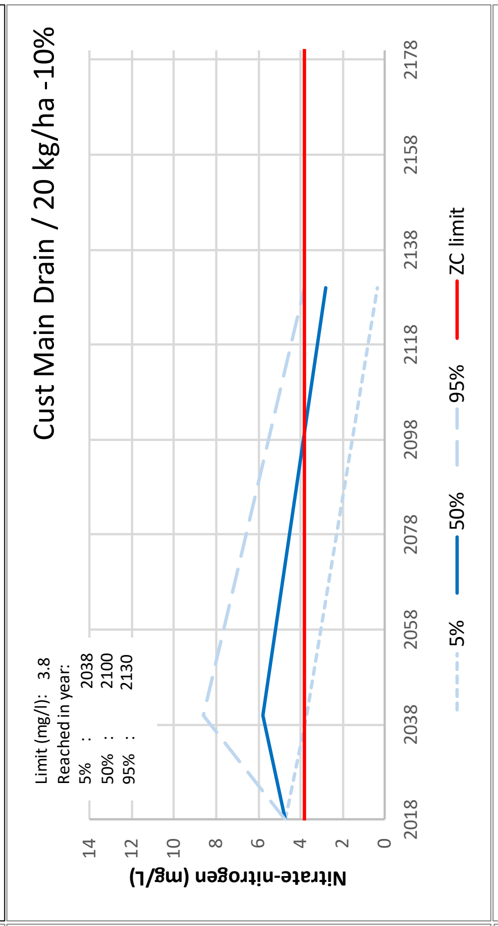


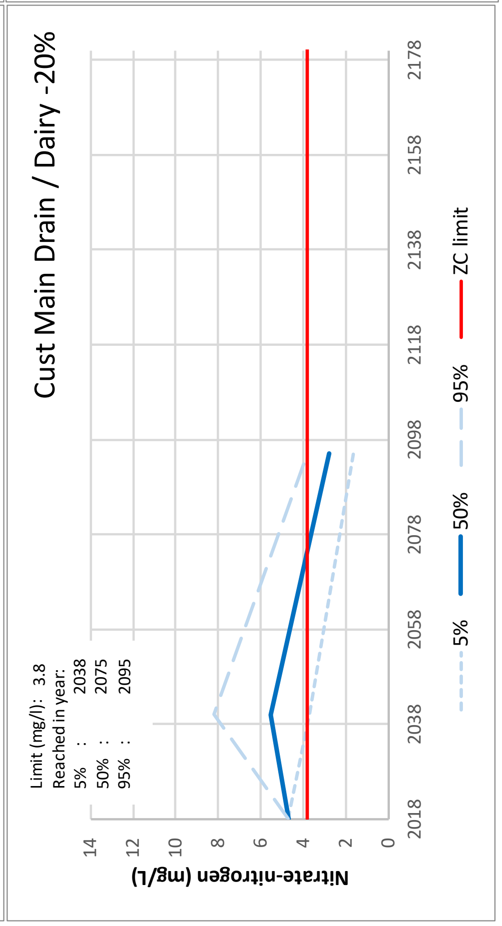
Surface water: Cust Main Drain

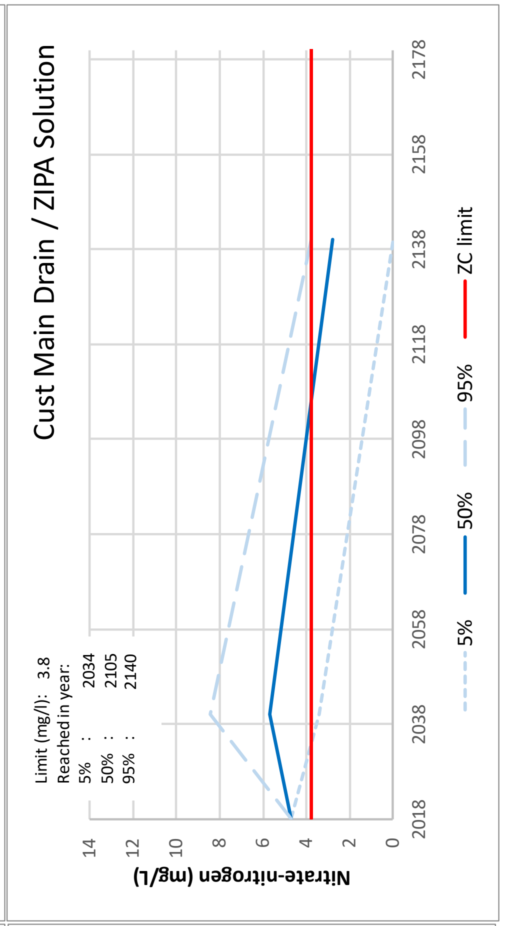




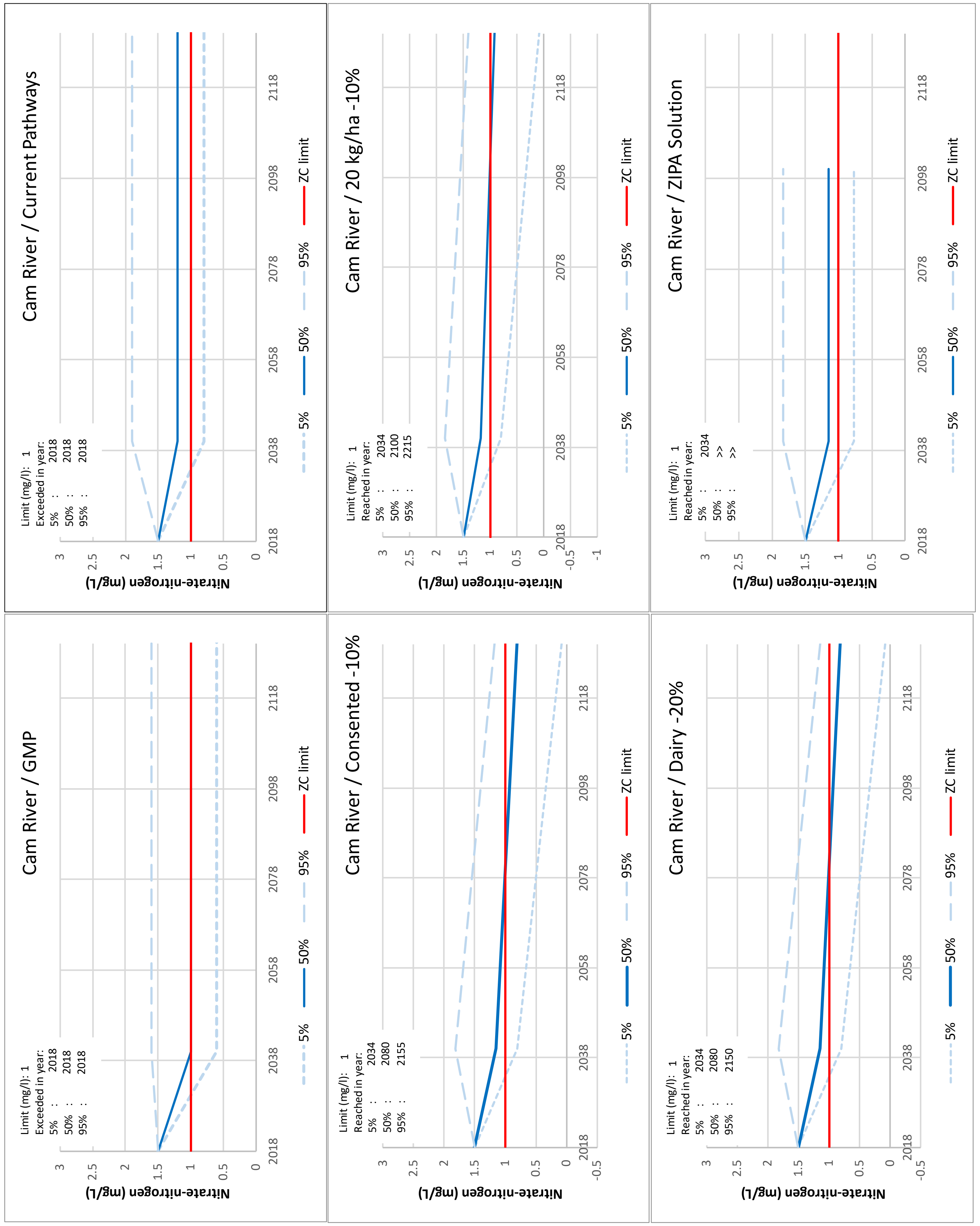








Surface water: Cam River



Appendix 10. Assessment of nitrate-N impacts in Te Aka Aka

Date	21 March 2018 Rev 1
To	Waimakariri Water Zone Committee
CC	
From	Dr Lesley Bolton-Ritchie and Zeb Etheridge

This Appendix is a formatted version of the Technical Memorandum presented to the WWZC, which was used in its deliberations and instructions to Environment Canterbury.

A10.1 Summary

Elevated nitrogen concentrations can cause excessive growth of fast-growing macroalgae species in estuaries. Macroalgae trap fine sediment, making the sediments muddier, can reduce dissolved oxygen levels in water and cause anoxic conditions in estuarine sediment. The abundance and diversity of estuarine species may decline in response to these effects.

Field investigations undertaken by Environment Canterbury suggest that Te Aka Aka is somewhere between slightly and highly impacted by excessive macroalgae growth, i.e. in the range of moderate to high eutrophication. However, there is significant spatial variability on impacts within the estuary. There is also likely to be year-to-year variability, as nitrate loads discharging to the estuary vary with weather and climate cycles.

Modelling results suggest that successful implementation of GMP could reduce the nitrate-N concentration in the estuary, but that the benefits of this are likely to be counteracted if land users within the catchment make use of the proposed Plan Change 5 Permitted Activity (PA) rules, which allow for additional winter grazing and irrigation. The Zone Committee may wish to consider the option of revising the PC5PA thresholds to reduce the potential for future increases in nitrate discharges to Te Aka Aka.

A major nitrate load reduction would be required in the Te Aka Aka catchment in order to reduce the eutrophication susceptibly of the estuary.

A10.2 Introduction

Nitrogen is typically the limiting nutrient for the growth of phytoplankton and algae in coastal and estuarine water. When there is plenty of nitrogen, and other growing conditions are right (such as water temperature and sunlight), these plants grow prolifically.

Prolific growth of macroalgae can cover intertidal sediments and cause the sediments to become anoxic. This means there is no oxygen to support the worms and other animals that live within the sediment and keep the sediment healthy. Anoxic sediment is black and emits a sulphurous odour.

Macroalgae smothers and eliminates seagrass and traps fine sediment particles such that the estuary could become muddier over time. The respiration of abundant macroalgae can lower/deplete the water of oxygen at night, when there is no oxygen production through photosynthesis. Depleted oxygen levels can result in the death of the animals that live in the water, such as fish.

When macroalgae die they can dislodge and either be carried out of the estuary or deposited on the shore or in backwaters. The breakdown of the algae in these locations by micro-organisms can deplete the water of oxygen which in turn can result in the death of the animals that live in the water, such as fish. The decaying macroalgae emits a strong odour.

Field surveys have shown that within Te Aka Aka there are large areas of the fast-growing macroalgae species *Ulva* spp. (Figure 1) and *Gracilaria chilensis* (Figure 2). Flushing of the estuary within a tidal cycle limits the potential for excessive phytoplankton growth in the estuary. There is no seagrass in Te Aka Aka.

The presence of macroalgae within an estuary is not entirely negative. *Ulva* spp. and *Gracilaria* provide habitat for a range of estuarine species such as topshells, hoppers and worms (Bressington, 2003). In turn this is food for the birds and fish that feed on these species. We have seen many birds including godwits, oyster catchers and spoonbills feeding in and around the edges of a dense bed of *Ulva* sp. within Te Aka Aka. But excessive growth of macroalgae over large areas of an estuary do cause ecological issues. The process of nutrient enrichment and excessive growth of plants and algae associated with this is called eutrophication.

Figure 1: *Ulva* sp. Within Te Aka Aka. 100% cover and a thick layer

Figure 2: *Gracilaria chilensis* within Te Aka Aka

A10.3 Current state

A set of tools for assessment of the trophic index of NZ estuaries was released for use in 2016 (Robertson *et al,* 2016a, 2016b). The tools include:

- Determination of the eutrophication susceptibility using physical and nutrient load data, and
- use of monitoring indicators to assess the actual eutrophication band.

The tools define four eutrophication bands, as shown in Table 1.

Table 1 Description of the four eutrophication categories

A Minimal Eutrophication	B Moderate Eutrophication	C High Eutrophication	D Very High Eutrophication
Ecological communities are healthy and resilient. *Primary Producers: dominated by seagrasses and microalgae. **Primary Producers: dominated by phytoplankton (diverse, low biomass). Water Column: high clarity, well-oxygenated. Sediment: well oxygenated, low organic matter, low sulphides and ammonia, diverse macrofaunal community with low abundance of enrichment tolerant species.	Ecological communities are slightly impacted by additional algal growth arising from nutrient levels that are elevated. *Primary Producers: seagrass/microalgae still present but increasing biomass opportunistic macroalgae. **Primary Producers: dominated by phytoplankton (moderate diversity and biomass). Water Column: moderate clarity, mod-poor DO esp at depth. Sediment: moderate oxygenation, organic matter, and sulphides, diverse macrofaunal community with increasing abundance of enrichment tolerant species.	*Ecological communities are highly impacted by macroalgal or phytoplankton biomass elevated well above natural conditions. Reduced water clarity likely to affect habitat available for native macrophytes. **Ecological communities are highly impacted by phytoplankton biomass elevated well above natural conditions. Reduced water clarity may affect deep seagrass beds. *Primary Producers: opportunistic macroalgal biomass high, seagrass cover low. Increasing phytoplankton where residence time long e.g. ICOLLs. **Primary Producers: dominated by phytoplankton (low diversity and high biomass). Water Column: low-moderate clarity, low DO, esp at depth. Sediment: poor oxygenation, high organic matter, and sulphides, macrofauna dominated by high abundance of enrichment tolerant species.	*Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover. **Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a nuisance algal bloom situation (often toxic). *Primary Producers: opportunistic macroalgal biomass very high or high/low cycles in response to toxicity, no seagrass. At very high nutrient loads, cyanobacterial mats may be present. Phytoplankton only high where residence time is long. **Primary Producers: dominated by nuisance phytoplankton (e.g cyanobacteria, picoplankton). Water Column: low clarity, deoxygenated at depth. Sediment: anoxic, very high organic matter, and sulphides, subsurface macrofauna very limited or absent. Eventually the sediments are devoid of macrofauna and are covered in mats of sulfur-oxidizing bacteria (i.e. *Beggiatoa*).

We have used monitoring indicators ((Robertson *et al,* 2016b) to assess the current eutrophication state of Te Aka Aka. This has involved mapping the extent of macroalgae within the estuary (2014 and 2018) as well as measuring several sediment parameters (2016/2017). The macroalgae mapping results (which evaluated the area of the estuary covered by macroalgae) indicate that Te Aka Aka is within band B. However, the sediment parameters results show that, depending on the sediment parameter and the location within the estuary, the band does vary (Figure 3).

The macroalgae distribution and sediment parameter results overall suggest that:

- Saltwater Creek nutrients are causing macroalgae growth and effects on some sediment parameters along the margins of this creek;
- the small drains flowing into the western margin of the estuary are a source of nutrients causing macroalgae growth in the small channels in this area; and
- The Ashley River/Rakahuri is the source of nutrients causing macroalgae growth and effects on some sediment parameters in the southern part of the estuary. However, it is likely that Taranaki Creek water also influences these indicators in this part of the estuary.

Figure 3: Sediment parameter assessment 2016/2017 A: Percent mud B: Total nitrogen C: Total organic carbon D: Redox
Symbols: Light Blue - ETI Band A, dark blue - ETI Band B, yellow - ETI Band C, Orange – ETI Band

A10.4 Modelling method and scenarios

Nitrogen (nitrate-N) load modelling was undertaken using a calibrated, peer-reviewed groundwater model together with an N load layer optimised to measured N loads at the Ashley Gorge site and subjected to uncertainty analysis by a panel of experts from industry, research organisations and Environment Canterbury. Modelling scenarios are summarised below.

Table 2 Model scenarios

Scenario name	Description	Purpose
CMP	Current Management Practice	Estimates nitrate-N concentrations/loads at steady state, when water quality equilibrates with current land use
GMP	Good Management Practice	Assess the benefits of implementation of industry-agreed good management practices on nitrate-N discharges
PC5PA	Proposed Plan Change 5 Permitted Activity Rules for winter grazing & irrigation	Assess the additional nitrate losses associated with additional winter grazing and irrigation permitted under the proposed PC5. Assumes full uptake of both allowances.
Current Pathways	Assumes 50% of the PA winter grazing and irrigation is implemented on the ground	Full uptake of the winter grazing and irrigation area on every property in the Ashley catchment is very unlikely. This scenario represents a more reasonable estimate of the possible ultimate outcome of the current management regime.

A10.5 Nutrient susceptibility modelling

Environment Canterbury contracted NIWA staff to evaluate the eutrophication susceptibility of Te Aka Aka using physical and nutrient load data and the CLUES (Catchment Land Use Environmental Sustainability) model for the model scenarios above. The nutrient load data were provided by Environment Canterbury and included nutrient loads for the model scenarios in Table 2.

Modelling results (Table 3) are presented as nitrogen (N) loads and the eutrophication susceptibility bands (Dudley and Plew, 2018). Results are presented for both the ETI tool 1 band and for the Clues-Estuary tool assessment band. Results are presented for 5th and 95th percentile estimates of nitrate loads based on the results of the expert panel uncertainty assessment.

The CMP results, which should reflect the current worst year N load, fall within band D under the ETI tool 1 assessment for both the 5th and 95th percentile N loads, and band C and D respectively for the assessment based on the CLUES estuary tool.

As noted above, field measurements and observations are consistent with classification of the estuary as band B with some evidence of band C conditions in certain areas. Model results represent the worst year nitrate load (since nitrogen controls should aim to maintain acceptable Nitrogen levels in all years, not just in average or below average N load years). On this basis the model results are not necessarily inconsistent with field observations.

Because the 5th percentile CLUES estuary tool assessment correlates the closest with observation data, we have assumed that these results provide the most useful indication of the outcome of each modelling scenario. Other modelling results are therefore greyed-out in Table 3. All discussion of modelling results from here on relates to the 5th percentile CLUES estuary tool assessment results.

Table 3 Summary of the potential eutrophication bands (susceptibility) of Te Aka

Scenario	Modelled N load **(t/year)**		ETI tool 1 eutrophication susceptibility		CLUES Estuary tool eutrophication susceptibility	
	5th percentile	95th percentile	5th percentile	95th percentile	5th percentile	95th percentile
CMP	293	598	D	D	C	D
GMP	222	504	D	D	C	D
PC5PA	527	809	D	D	D	D
Current pathways	374	656	D	D	D	D

Modelling results indicate that introduction of GMP will not be sufficient to reduce N loads in the estuary to within the band B classification in the highest N load years, but would likely help to maintain the estuary within band B for more of the time and therefore maintain and possibly improve estuarine health.

Full or 50% uptake of the PC5PA winter grazing and extra irrigation allowance could potentially degrade the estuary from C to band D in the worst (highest N load) years, based on the CLUES Estuary tool eutrophication susceptibility results. Significant degradation of the eutrophication state of the estuary is therefore *possible* under the current management regime. The Zone Committee may wish to consider the option of revising the PC5PA thresholds to reduce the potential for future increases in nitrate discharges to Te Aka Aka.

In the future the ideal outcome is that the eutrophication state of the estuary is maintained within band B and does not reach band C, even in high N load years. Analysis of the N load reductions required to achieve each the ETI band under the four modelling scenarios (Table 4) indicates that major load reductions (e.g. 73% under Current Pathways and 55% under the GMP scenario) may be required to achieve this.

Table 4 Annual loads required to meet ETI band

Scenario	Band and N load (t/year)			
	A	B	C	D
	<42 t/year	42-100 t/year	100 – 320 t/year	>320 t/year
	N load reduction required to achieve band			
CMP	86%	66%	N/A	N/A
GMP	81%	55%	N/A	N/A
PC5PA	92%	81%	39%	N/A
Current pathways	89%	73%	15%	N/A

Nitrogen management options for the estuary are presented in the Environment Canterbury document entitled *Setting and Achieving Flow, Allocation and Nitrate Limits in the Ashley/Rakahuri Catchment*.

A10.6 Future research and recommended monitoring

Further investigations could be undertaken in the future to:

- understand the variability in eutrophication susceptibility between average and high N load years.
- understand the relative impacts of N loads from different freshwater sources within the estuary catchment on eutrophication susceptibility
- model and understand the hydrodynamics of the estuary and the impact this has on nitrate outflows and macro algal growth.

We recommend long-term annual monitoring to assess the eutrophication band of Te Aka Aka. This should include:

- mapping of the macroalgae within Te Aka Aka – distribution, % cover
- sampling sediments and macroalgae at ~ 20 sites within Te Aka Aka to assess the ETI parameter values – redox, sediment total nitrogen, sediment total reactive phosphorus, sediment grain size, algae biomass.

A10.7 References

Bressington, M. 2003. The effects of macroalgal mats on the marine benthic fauna in the Avon-Heathcote Estuary. University of Canterbury M.Sc, thesis.

Dudley, B and Plew, D. 2018. Te Akaaka eutrophication susceptibility assessment. NIWA Client Report for Environment Canterbury. 2017041CH.

Robertson, B.M, Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T., Oliver, M. 2016a. NZ Estuary Trophic Index Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 47p.

Robertson, B.M, Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Oliver, M. 2016b. NZ Estuary Trophic Index Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 68p.

Appendix 11. Alternative Pathways tables modelling results

This appendix gives an overview[78] of the beyond baseline GMP reductions created with the three alternative pathway scenarios:

1. **10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP
2. **20 kg/ha + 10% beyond Baseline GMP** – all consented land use reduce nitrate losses 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.
3. **20 kg/ha + 10 & 20% beyond Baseline GMP** – Dairy reduce nitrate losses 20% and all other consented 10% beyond Baseline GMP if their nitrate loss at any stage is more than 20 kg/ha.

Legend for the tables:

5th, 50th, 95th:	Results are presented for our 50th percentile model results, with the 5th percentile and 95th percentile results showing the band with (or uncertainty)
CP:	Current Pathways Scenario
Concentration:	Nitrate-nitrogen in mg/L
Limit:	Nitrate-nitrogen in mg/L
Lag time:	time in years

Dark grey shading: the number of required 10-year stages will result in a beyond GMP reduction of more than 100%. As a the calculations have not been limited, this implies that these receptors might not reach the zone committee limit or threshold by just applying beyond GMP reductions.

Yellow Shading:No beyond GMP results available

[78] P:\Groundwater\Waimakariri\Landuse\Spreadsheet\NloadAlternativePathways.xlsx

Table 1 10% beyond Baseline GMP reductions for all consented land use

	CP concentration					Required concentration reduction			Beyond GMP	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
CCC Central	3.50	5.40	7.60	3.80	800	0.0%	29.6%	50.0%	9.2%	0.00	3.24	5.46	0	830	855	2018	2860	2885
CCC West	1.30	4.10	7.10	3.80	200	0.0%	7.3%	46.5%	9.2%	0.00	0.80	5.08	0	210	250	2018	2240	2280
CCC East	3.50	5.40	7.60	3.80	1200	0.0%	29.6%	50.0%	9.2%	0.00	3.24	5.46	0	1230	1255	2018	3260	3285
PWSA Clarkville	5.00	8.20	11.70	5.65	40	0.0%	31.1%	51.7%	9.1%	0.00	3.42	5.69	0	75	95	2018	2105	2125
PWSA Cust	3.90	6.70	9.70	5.65	48	0.0%	15.7%	41.8%	8.0%	0.00	1.96	5.21	0	70	100	2018	2100	2130
PWSA Eyreton Deep	4.70	15.20	24.00	5.65	75	0.0%	62.8%	76.5%	10.0%	0.00	6.29	7.66	0	140	150	2018	2170	2180
PWSA Eyreton Shallow	8.30	12.30	16.60	5.65	45	31.9%	54.1%	66.0%	9.7%	3.31	5.60	6.84	80	100	115	2110	2130	2145
PWSA Fernside	2.20	4.90	7.80	5.65	46	0.0%	0.0%	27.6%	2.0%	0.00	0.00	13.83	0	0	185	2018	2018	2215
PWSA Flaxton	2.00	3.50	6.30	5.65	36	0.0%	0.0%	10.3%	7.2%	0.00	0.00	1.43	0	0	50	2018	2018	2080
PWSA Horellville	2.20	4.60	7.20	5.65	48	0.0%	0.0%	21.5%	8.5%	0.00	0.00	2.52	0	0	75	2018	2018	2105
PWSA Mandeville	2.30	4.80	8.90	5.65	45	0.0%	0.0%	36.5%	7.9%	0.00	0.00	4.63	0	0	90	2018	2018	2120
PWSA N East Eyrewell Deep	4.00	7.50	11.50	5.65	70	0.0%	24.7%	50.9%	9.0%	0.00	2.76	5.68	0	100	125	2018	2130	2155
PWSA N East Eyrewell Shallow	2.50	6.60	13.60	5.65	50	0.0%	14.4%	58.5%	9.0%	0.00	1.60	6.51	0	65	115	2018	2095	2145
PWSA N West Eyrewell Deep	2.10	7.70	14.50	5.65	75	0.0%	26.6%	61.0%	8.7%	0.00	3.05	6.99	0	105	145	2018	2135	2175
PWSA N West Eyrewell Shallow	2.00	6.30	12.50	5.65	45	0.0%	10.3%	54.8%	8.8%	0.00	1.18	6.25	0	55	105	2018	2085	2135
PWSA Ohoka Deep	4.40	7.50	10.90	5.65	88	0.0%	24.7%	48.2%	7.7%	0.00	3.20	6.26	0	120	150	2018	2150	2180
PWSA Ohoka Shallow	4.00	6.30	8.70	5.65	50	0.0%	10.3%	35.1%	7.0%	0.00	1.47	4.99	0	65	100	2018	2095	2130
PWSA Rangiora	0.40	2.70	6.70	5.65	15	0.0%	0.0%	15.7%	3.7%	0.00	0.00	4.27	0	0	60	2018	2018	2090
PWSA Springbank	4.00	6.60	9.50	5.65	45	0.0%	14.4%	40.5%	7.7%	0.00	1.87	5.26	0	65	100	2018	2095	2130
PWSA Summerhill	5.00	10.40	16.10	5.65	70	0.0%	45.7%	64.9%	8.1%	0.00	5.64	8.01	0	125	150	2018	2155	2180
PWSA Swannanoa Deep	4.40	8.40	12.50	5.65	45	0.0%	32.7%	54.8%	8.0%	0.00	4.10	6.87	0	85	115	2018	2115	2145
PWSA Swannanoa Shallow	3.00	7.10	12.10	5.65	45	0.0%	20.4%	53.3%	8.9%	0.00	2.30	6.01	0	70	105	2018	2100	2135
PWSA Waikuku	0.60	1.30	3.50	5.65	7	0.0%	0.0%	0.0%	7.3%	0.00	0.00	0.00	0	0	0	2018	2018	2018
PWSA West Eyreton Deep	3.70	6.30	9.30	5.65	66	0.0%	10.3%	39.2%	8.6%	0.00	1.20	4.56	0	80	110	2018	2110	2140
PWSA West Eyreton Shallow	2.80	5.60	11.10	5.65	48	0.0%	0.0%	49.1%	8.5%	0.00	0.00	5.79	0	0	105	2018	2018	2135
PWSA Woodend	0.80	2.80	6.40	5.65	7	0.0%	0.0%	11.7%	4.7%	0.00	0.00	2.49	0	0	30	2018	2018	2060
Cam River	0.80	1.20	1.90	1.00	10	0.0%	16.7%	47.4%	4.2%	0.00	3.94	11.21	0	50	120	2018	2080	2150
Courtenay Stream	3.20	4.70	6.60	3.80	10	0.0%	19.1%	42.4%	7.8%	0.00	2.45	5.44	0	35	65	2018	2065	2095
Cust Main Drain	3.70	6.20	9.20	3.80	10	0.0%	38.7%	58.7%	6.9%	0.00	5.65	8.56	0	65	95	2018	2095	2125
Silverstream Harpers Rd	7.70	13.80	20.30	6.90	10	10.4%	50.0%	66.0%	9.8%	1.06	5.08	6.71	20	60	75	2050	2090	2105
Silverstream Island Rd	5.70	9.50	13.50	6.90	10	0.0%	27.4%	48.9%	8.9%	0.00	3.07	5.48	0	40	65	2018	2070	2095
Ohoka Stream	4.20	7.00	10.00	3.80	10	9.5%	45.7%	62.0%	8.2%	1.16	5.56	7.55	20	65	85	2050	2095	2115
Saltwater Creek	0.49	0.80	0.99	1.00	10	0.0%	0.0%	0.0%	2.3%	0.00	0.00	0.00	0	0	0	2018	2018	2018
Taranaki Creek	0.70	1.10	1.23	1.00	10	0.0%	9.1%	18.7%	6.5%	0.00	1.40	2.88	0	25	40	2018	2055	2070
Waikuku Stream	0.63	1.04	1.15	1.00	10	0.0%	3.8%	13.0%	7.1%	0.00	0.54	1.83	0	15	30	2018	2045	2060
WDC Cust	3.90	6.40	9.10	5.65	100	0.0%	11.7%	37.9%	8.7%	0.00	1.34	4.34	0	115	145	2018	2145	2175
WDC Fernside	2.90	5.50	8.00	5.65	20	0.0%	0.0%	29.4%	1.9%	0.00	0.00	15.70	0	0	175	2018	2018	2205
WDC Kaiapoi	3.30	6.80	10.80	5.65	100	0.0%	16.9%	47.7%	8.5%	0.00	2.00	5.64	0	120	155	2018	2150	2185
WDC Kairaki	3.30	5.40	7.90	5.65	100	0.0%	0.0%	28.5%	8.5%	0.00	0.00	3.36	0	0	135	2018	2018	2165
WDC Mandeville	5.10	8.10	11.70	5.65	42	0.0%	30.2%	51.7%	8.6%	0.00	3.50	5.99	0	75	100	2018	2105	2130
WDC Ohoka	4.70	7.70	11.10	5.65	88	0.0%	26.6%	49.1%	8.3%	0.00	3.20	5.90	0	120	145	2018	2150	2175
WDC Oxford Urban	1.50	3.00	6.20	5.65	70	0.0%	0.0%	8.9%	4.8%	0.00	0.00	1.86	0	0	90	2018	2018	2120
WDC Pegasus	1.10	3.20	6.40	5.65	100	0.0%	0.0%	11.7%	2.4%	0.00	0.00	4.86	0	0	150	2018	2018	2180
WDC Poyntzs Road	4.60	7.30	10.90	5.65	10	0.0%	22.6%	48.2%	8.7%	0.00	2.61	5.57	0	35	65	2018	2065	2095
WDC Rangiora	3.20	7.40	11.90	5.65	100	0.0%	23.6%	52.5%	8.3%	0.00	2.86	6.35	0	130	165	2018	2160	2195
WDC Waikuku	1.10	1.90	3.40	5.65	6	0.0%	0.0%	0.0%	5.3%	0.00	0.00	0.00	0	0	0	2018	2018	2018
WDC West Eyreton	3.60	5.80	8.40	5.65	66	0.0%	2.6%	32.7%	8.5%	0.00	0.31	3.86	0	70	105	2018	2100	2135

Table 2 10% beyond Baseline GMP reductions for all consented land use if their nitrate loss at any stage is more than 20 kg/ha

	CP concentration					Required concentration reduction			Beyond GMP	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
CCC Central	3.50	5.40	7.60	3.80	800	0.0%	29.6%	50.0%	8.8%	0.00	3.37	5.68	0	835	855	2018	2865	2885
CCC West	1.30	4.10	7.10	3.80	200	0.0%	7.3%	46.5%	8.8%	0.00	0.83	5.28	0	210	255	2018	2240	2285
CCC East	3.50	5.40	7.60	3.80	1200	0.0%	29.6%	50.0%	8.8%	0.00	3.37	5.68	0	1235	1255	2018	3265	3285
PWSA Clarkville	5.00	8.20	11.70	5.65	40	0.0%	31.1%	51.7%	9.0%	0.00	3.46	5.75	0	75	100	2018	2105	2130
PWSA Cust	3.90	6.70	9.70	5.65	48	0.0%	15.7%	41.8%	7.9%	0.00	1.98	5.28	0	70	100	2018	2100	2130
PWSA Eyreton Deep	4.70	15.20	24.00	5.65	75	0.0%	62.8%	76.5%	10.0%	0.00	6.29	7.66	0	140	150	2018	2170	2180
PWSA Eyreton Shallow	8.30	12.30	16.60	5.65	45	31.9%	54.1%	66.0%	9.6%	3.31	5.61	6.85	80	100	115	2110	2130	2145
PWSA Fernside	2.20	4.90	7.80	5.65	46	0.0%	0.0%	27.6%	1.4%	0.00	0.00	19.92	0	0	245	2018	2018	2275
PWSA Flaxton	2.00	3.50	6.30	5.65	36	0.0%	0.0%	10.3%	6.7%	0.00	0.00	1.55	0	0	50	2018	2018	2080
PWSA Horellville	2.20	4.60	7.20	5.65	48	0.0%	0.0%	21.5%	8.2%	0.00	0.00	2.61	0	0	75	2018	2018	2105
PWSA Mandeville	2.30	4.80	8.90	5.65	45	0.0%	0.0%	36.5%	7.7%	0.00	0.00	4.77	0	0	95	2018	2018	2125
PWSA N East Eyrewell Deep	4.00	7.50	11.50	5.65	70	0.0%	24.7%	50.9%	8.9%	0.00	2.78	5.72	0	100	125	2018	2130	2155
PWSA N East Eyrewell Shallow	2.50	6.60	13.60	5.65	50	0.0%	14.4%	58.5%	8.8%	0.00	1.63	6.61	0	65	115	2018	2095	2145
PWSA N West Eyrewell Deep	2.10	7.70	14.50	5.65	75	0.0%	26.6%	61.0%	8.5%	0.00	3.13	7.18	0	105	145	2018	2135	2175
PWSA N West Eyrewell Shallow	2.00	6.30	12.50	5.65	45	0.0%	10.3%	54.8%	8.6%	0.00	1.20	6.36	0	55	110	2018	2085	2140
PWSA Ohoka Deep	4.40	7.50	10.90	5.65	88	0.0%	24.7%	48.2%	7.3%	0.00	3.40	6.63	0	120	155	2018	2150	2185
PWSA Ohoka Shallow	4.00	6.30	8.70	5.65	50	0.0%	10.3%	35.1%	6.0%	0.00	1.71	5.80	0	65	110	2018	2095	2140
PWSA Rangiora	0.40	2.70	6.70	5.65	15	0.0%	0.0%	15.7%	2.7%	0.00	0.00	5.81	0	0	75	2018	2018	2105
PWSA Springbank	4.00	6.60	9.50	5.65	45	0.0%	14.4%	40.5%	7.5%	0.00	1.93	5.43	0	65	100	2018	2095	2130
PWSA Summerhill	5.00	10.40	16.10	5.65	70	0.0%	45.7%	64.9%	8.1%	0.00	5.65	8.03	0	125	150	2018	2155	2180
PWSA Swannanoa Deep	4.40	8.40	12.50	5.65	45	0.0%	32.7%	54.8%	7.8%	0.00	4.20	7.03	0	85	115	2018	2115	2145
PWSA Swannanoa Shallow	3.00	7.10	12.10	5.65	45	0.0%	20.4%	53.3%	8.6%	0.00	2.36	6.17	0	70	105	2018	2100	2135
PWSA Waikuku	0.60	1.30	3.50	5.65	7	0.0%	0.0%	0.0%	7.3%	0.00	0.00	0.00	0	0	0	2018	2018	2018
PWSA West Eyreton Deep	3.70	6.30	9.30	5.65	66	0.0%	10.3%	39.2%	8.5%	0.00	1.21	4.60	0	80	110	2018	2110	2140
PWSA West Eyreton Shallow	2.80	5.60	11.10	5.65	48	0.0%	0.0%	49.1%	8.3%	0.00	0.00	5.92	0	0	105	2018	2018	2135
PWSA Woodend	0.80	2.80	6.40	5.65	7	0.0%	0.0%	11.7%	3.9%	0.00	0.00	3.04	0	0	35	2018	2018	2065
Cam River	0.80	1.20	1.90	1.00	10	0.0%	16.7%	47.4%	2.7%	0.00	6.29	17.87	0	75	190	2018	2105	2220
Courtenay Stream	3.20	4.70	6.60	3.80	10	0.0%	19.1%	42.4%	7.7%	0.00	2.49	5.51	0	35	65	2018	2065	2095
Cust Main Drain	3.70	6.20	9.20	3.80	10	0.0%	38.7%	58.7%	6.5%	0.00	5.99	9.08	0	70	100	2018	2100	2130
Silverstream Harpers Rd	7.70	13.80	20.30	6.90	10	10.4%	50.0%	66.0%	9.8%	1.06	5.10	6.73	20	60	75	2050	2090	2105
Silverstream Island Rd	5.70	9.50	13.50	6.90	10	0.0%	27.4%	48.9%	8.8%	0.00	3.11	5.56	0	40	65	2018	2070	2095
Ohoka Stream	4.20	7.00	10.00	3.80	10	9.5%	45.7%	62.0%	7.8%	1.22	5.84	7.92	20	70	90	2050	2100	2120
Saltwater Creek	0.49	0.80	0.99	1.00	10	0.0%	0.0%	0.0%	2.0%	0.00	0.00	0.00	0	0	0	2018	2018	2018
Taranaki Creek	0.70	1.10	1.23	1.00	10	0.0%	9.1%	18.7%	6.5%	0.00	1.40	2.88	0	25	40	2018	2055	2070
Waikuku Stream	0.63	1.04	1.15	1.00	10	0.0%	3.8%	13.0%	7.1%	0.00	0.54	1.83	0	15	30	2018	2045	2060
WDC Cust	3.90	6.40	9.10	5.65	100	0.0%	11.7%	37.9%	8.7%	0.00	1.35	4.38	0	115	145	2018	2145	2175
WDC Fernside	2.90	5.50	8.00	5.65	20	0.0%	0.0%	29.4%	1.3%	0.00	0.00	21.77	0	0	240	2018	2018	2270
WDC Kaiapoi	3.30	6.80	10.80	5.65	100	0.0%	16.9%	47.7%	8.3%	0.00	2.03	5.73	0	120	155	2018	2150	2185
WDC Kairaki	3.30	5.40	7.90	5.65	100	0.0%	0.0%	28.5%	8.4%	0.00	0.00	3.39	0	0	135	2018	2018	2165
WDC Mandeville	5.10	8.10	11.70	5.65	42	0.0%	30.2%	51.7%	8.5%	0.00	3.54	6.06	0	75	105	2018	2105	2135
WDC Ohoka	4.70	7.70	11.10	5.65	88	0.0%	26.6%	49.1%	8.1%	0.00	3.27	6.04	0	120	150	2018	2150	2180
WDC Oxford Urban	1.50	3.00	6.20	5.65	70	0.0%	0.0%	8.9%	4.2%	0.00	0.00	2.11	0	0	90	2018	2018	2120
WDC Pegasus	1.10	3.20	6.40	5.65	100	0.0%	0.0%	11.7%	1.9%	0.00	0.00	6.09	0	0	160	2018	2018	2190
WDC Poyntzs Road	4.60	7.30	10.90	5.65	10	0.0%	22.6%	48.2%	8.4%	0.00	2.69	5.72	0	35	65	2018	2065	2095
WDC Rangiora	3.20	7.40	11.90	5.65	100	0.0%	23.6%	52.5%	8.1%	0.00	2.93	6.50	0	130	165	2018	2160	2195
WDC Waikuku	1.10	1.90	3.40	5.65	6	0.0%	0.0%	0.0%	5.3%	0.00	0.00	0.00	0	0	0	2018	2018	2018
WDC West Eyreton	3.60	5.80	8.40	5.65	66	0.0%	2.6%	32.7%	8.3%	0.00	0.31	3.92	0	70	105	2018	2100	2135

Table 3 20% beyond Baseline GMP reductions for consented dairy and 10 % for all other consented land use if their nitrate loss at any stage is more than 20 kg/ha

20 kg/ha 10% reduction beyond GMP	CP concentration					Required concentration reduction			Beyond GMP	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
CCC Central	3.50	5.40	7.60	3.80	800	0.0%	29.6%	50.0%	16.6%	0.00	1.79	3.02	0	820	830	2018	2850	2860
CCC West	1.30	4.10	7.10	3.80	200	0.0%	7.3%	46.5%	16.6%	0.00	0.44	2.81	0	205	230	2018	2235	2260
CCC East	3.50	5.40	7.60	3.80	1200	0.0%	29.6%	50.0%	16.6%	0.00	1.79	3.02	0	1220	1230	2018	3250	3260
PWSA Clarkville	5.00	8.20	11.70	5.65	40	0.0%	31.1%	51.7%	16.7%	0.00	1.86	3.09	0	60	70	2018	2090	2100
PWSA Cust	3.90	6.70	9.70	5.65	48	0.0%	15.7%	41.8%	12.3%	0.00	1.28	3.40	0	60	80	2018	2090	2110
PWSA Eyreton Deep	4.70	15.20	24.00	5.65	75	0.0%	62.8%	76.5%	20.0%	0.00	3.15	3.83	0	105	115	2018	2135	2145
PWSA Eyreton Shallow	8.30	12.30	16.60	5.65	45	31.9%	54.1%	66.0%	18.4%	1.74	2.95	3.59	60	75	80	2090	2105	2110
PWSA Fernside	2.20	4.90	7.80	5.65	46	0.0%	0.0%	27.6%	1.4%	0.00	0.00	19.92	0	0	245	2018	2018	2275
PWSA Flaxton	2.00	3.50	6.30	5.65	36	0.0%	0.0%	10.3%	10.7%	0.00	0.00	0.96	0	0	45	2018	2018	2075
PWSA Horellville	2.20	4.60	7.20	5.65	48	0.0%	0.0%	21.5%	13.8%	0.00	0.00	1.56	0	0	65	2018	2018	2095
PWSA Mandeville	2.30	4.80	8.90	5.65	45	0.0%	0.0%	36.5%	11.5%	0.00	0.00	3.17	0	0	75	2018	2018	2105
PWSA N East Eyrewell Deep	4.00	7.50	11.50	5.65	70	0.0%	24.7%	50.9%	15.8%	0.00	1.56	3.21	0	85	100	2018	2115	2130
PWSA N East Eyrewell Shallow	2.50	6.60	13.60	5.65	50	0.0%	14.4%	58.5%	15.7%	0.00	0.92	3.72	0	60	85	2018	2090	2115
PWSA N West Eyrewell Deep	2.10	7.70	14.50	5.65	75	0.0%	26.6%	61.0%	15.3%	0.00	1.73	3.98	0	90	115	2018	2120	2145
PWSA N West Eyrewell Shallow	2.00	6.30	12.50	5.65	45	0.0%	10.3%	54.8%	15.0%	0.00	0.69	3.64	0	50	80	2018	2080	2110
PWSA Ohoka Deep	4.40	7.50	10.90	5.65	88	0.0%	24.7%	48.2%	11.8%	0.00	2.10	4.09	0	110	130	2018	2140	2160
PWSA Ohoka Shallow	4.00	6.30	8.70	5.65	50	0.0%	10.3%	35.1%	9.7%	0.00	1.06	3.60	0	60	85	2018	2090	2115
PWSA Rangiora	0.40	2.70	6.70	5.65	15	0.0%	0.0%	15.7%	4.2%	0.00	0.00	3.73	0	0	50	2018	2018	2080
PWSA Springbank	4.00	6.60	9.50	5.65	45	0.0%	14.4%	40.5%	11.1%	0.00	1.29	3.64	0	60	80	2018	2090	2110
PWSA Summerhill	5.00	10.40	16.10	5.65	70	0.0%	45.7%	64.9%	12.8%	0.00	3.56	5.06	0	105	120	2018	2135	2150
PWSA Swannanoa Deep	4.40	8.40	12.50	5.65	45	0.0%	32.7%	54.8%	11.6%	0.00	2.82	4.72	0	75	90	2018	2105	2120
PWSA Swannanoa Shallow	3.00	7.10	12.10	5.65	45	0.0%	20.4%	53.3%	13.9%	0.00	1.47	3.83	0	60	85	2018	2090	2115
PWSA Waikuku	0.60	1.30	3.50	5.65	7	0.0%	0.0%	0.0%	14.4%	0.00	0.00	0.00	0	0	0	2018	2018	2018
PWSA West Eyreton Deep	3.70	6.30	9.30	5.65	66	0.0%	10.3%	39.2%	12.8%	0.00	0.81	3.07	0	75	95	2018	2105	2125
PWSA West Eyreton Shallow	2.80	5.60	11.10	5.65	48	0.0%	0.0%	49.1%	13.4%	0.00	0.00	3.65	0	0	85	2018	2018	2115
PWSA Woodend	0.80	2.80	6.40	5.65	7	0.0%	0.0%	11.7%	7.5%	0.00	0.00	1.57	0	0	25	2018	2018	2055
Cam River	0.80	1.20	1.90	1.00	10	0.0%	16.7%	47.4%	4.3%	0.00	3.84	10.93	0	50	120	2018	2080	2150
Courtenay Stream	3.20	4.70	6.60	3.80	10	0.0%	19.1%	42.4%	12.6%	0.00	1.52	3.37	0	25	45	2018	2055	2075
Cust Main Drain	3.70	6.20	9.20	3.80	10	0.0%	38.7%	58.7%	10.6%	0.00	3.64	5.53	0	45	65	2018	2075	2095
Silverstream Harpers Rd	7.70	13.80	20.30	6.90	10	10.4%	50.0%	66.0%	19.4%	0.53	2.57	3.39	15	35	45	2045	2065	2075
Silverstream Island Rd	5.70	9.50	13.50	6.90	10	0.0%	27.4%	48.9%	16.2%	0.00	1.69	3.03	0	25	40	2018	2055	2070
Ohoka Stream	4.20	7.00	10.00	3.80	10	9.5%	45.7%	62.0%	12.0%	0.79	3.80	5.15	20	50	60	2050	2080	2090
Saltwater Creek	0.49	0.80	0.99	1.00	10	0.0%	0.0%	0.0%	3.1%	0.00	0.00	0.00	0	0	0	2018	2018	2018
Taranaki Creek	0.70	1.10	1.23	1.00	10	0.0%	9.1%	18.7%	13.0%	0.00	0.70	1.44	0	15	25	2018	2045	2055
Waikuku Stream	0.63	1.04	1.15	1.00	10	0.0%	3.8%	13.0%	14.0%	0.00	0.28	0.93	0	15	20	2018	2045	2050
WDC Cust	3.90	6.40	9.10	5.65	100	0.0%	11.7%	37.9%	14.0%	0.00	0.84	2.71	0	110	125	2018	2140	2155
WDC Fernside	2.90	5.50	8.00	5.65	20	0.0%	0.0%	29.4%	1.3%	0.00	0.00	21.77	0	0	240	2018	2018	2270
WDC Kaiapoi	3.30	6.80	10.80	5.65	100	0.0%	16.9%	47.7%	13.1%	0.00	1.29	3.64	0	115	135	2018	2145	2165
WDC Kairaki	3.30	5.40	7.90	5.65	100	0.0%	0.0%	28.5%	13.6%	0.00	0.00	2.09	0	0	120	2018	2018	2150
WDC Mandeville	5.10	8.10	11.70	5.65	42	0.0%	30.2%	51.7%	13.2%	0.00	2.30	3.93	0	65	80	2018	2095	2110
WDC Ohoka	4.70	7.70	11.10	5.65	88	0.0%	26.6%	49.1%	13.2%	0.00	2.02	3.73	0	110	125	2018	2140	2155
WDC Oxford Urban	1.50	3.00	6.20	5.65	70	0.0%	0.0%	8.9%	5.0%	0.00	0.00	1.78	0	0	90	2018	2018	2120
WDC Pegasus	1.10	3.20	6.40	5.65	100	0.0%	0.0%	11.7%	2.2%	0.00	0.00	5.29	0	0	155	2018	2018	2185
WDC Poyntzs Road	4.60	7.30	10.90	5.65	10	0.0%	22.6%	48.2%	14.9%	0.00	1.52	3.23	0	25	40	2018	2055	2070
WDC Rangiora	3.20	7.40	11.90	5.65	100	0.0%	23.6%	52.5%	12.3%	0.00	1.92	4.26	0	120	145	2018	2150	2175
WDC Waikuku	1.10	1.90	3.40	5.65	6	0.0%	0.0%	0.0%	10.3%	0.00	0.00	0.00	0	0	0	2018	2018	2018
WDC West Eyreton	3.60	5.80	8.40	5.65	66	0.0%	2.6%	32.7%	14.0%	0.00	0.19	2.34	0	70	90	2018	2100	2120

Appendix 12. Delineation of the Nitrate Priority Area

Figure 1: Priority management areas with those water supply well groundwater recharge zones where nitrate is projected to exceed 5.65 mg/L N. Note: interzone source area not shown.

Figure 2: Priority management areas with surface water catchments. Runoff Priority Area (RPA) includes all surface water catchments except those which generally drains to ground (e.g. Eyre River), Silverstream (where nitrate management is a priority), and those water supply well recharge zones which supply water to more than 5,000 people.

Figure 3: Priority management areas with soil drainage layer overlain. Note: poorly drained soils generally fall within the RPA, with some exceptions (e.g. an area of poorly drained soils falls within the Kaiapoi and Rangiora water supply well recharge zone).

Figure 4: Adjustment of the boundary between the priority management areas. The proposed Nitrate Priority Area (NPA) is adjusted based on:

- property and/or paddock boundaries;
- the proposed change of the southern boundary of the Waimakariri Sub Region;
- boundaries of groundwater recharge zones used in the groundwater model (e.g. the boundary of the NPA has been cut back where it extended beyond groundwater recharge zone boundaries).

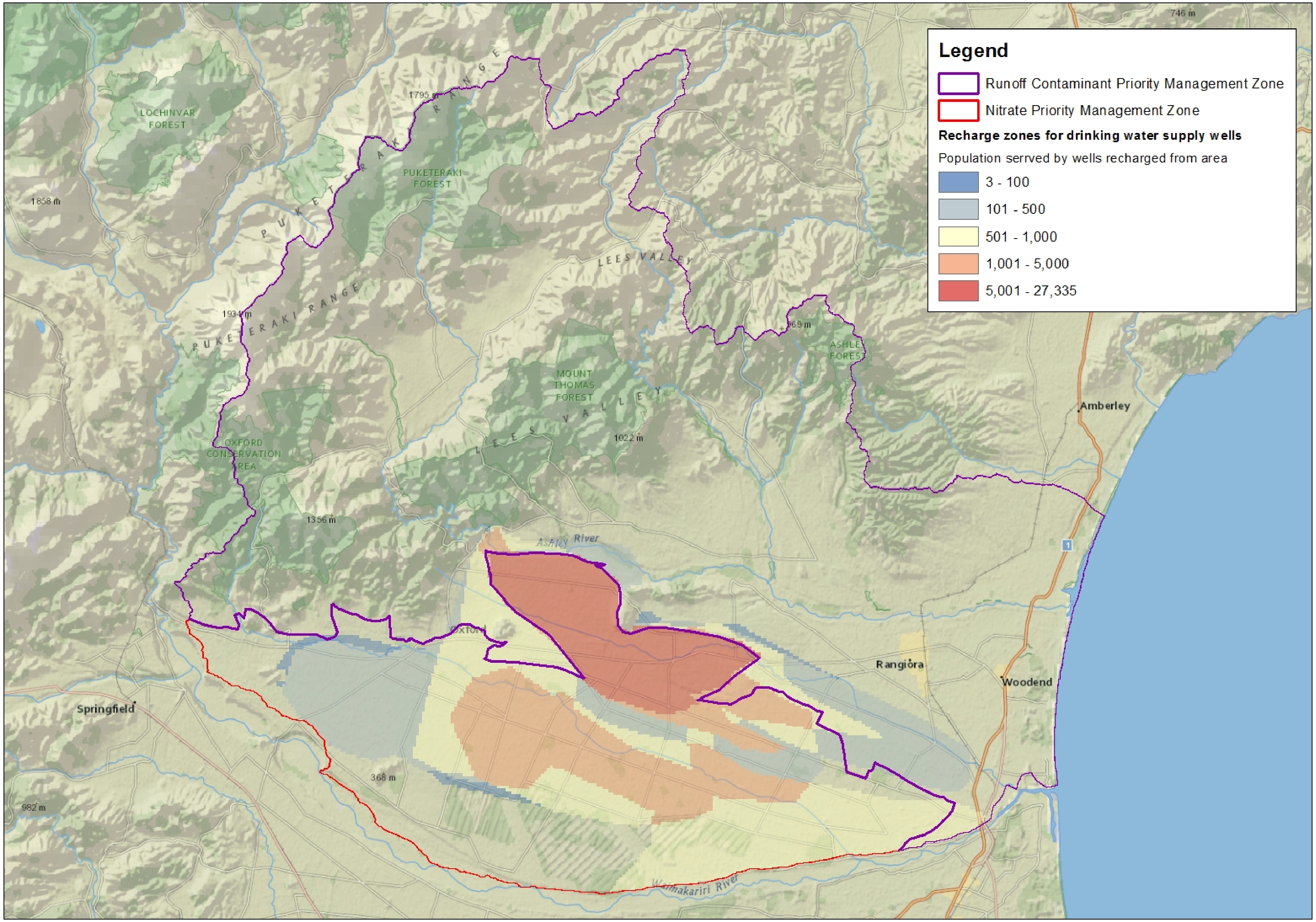


Figure 1 Priority management area with water supply well groundwater recharge zones where nitrate projected to exceed 5.65 mg/L N (interzone source area not shown)

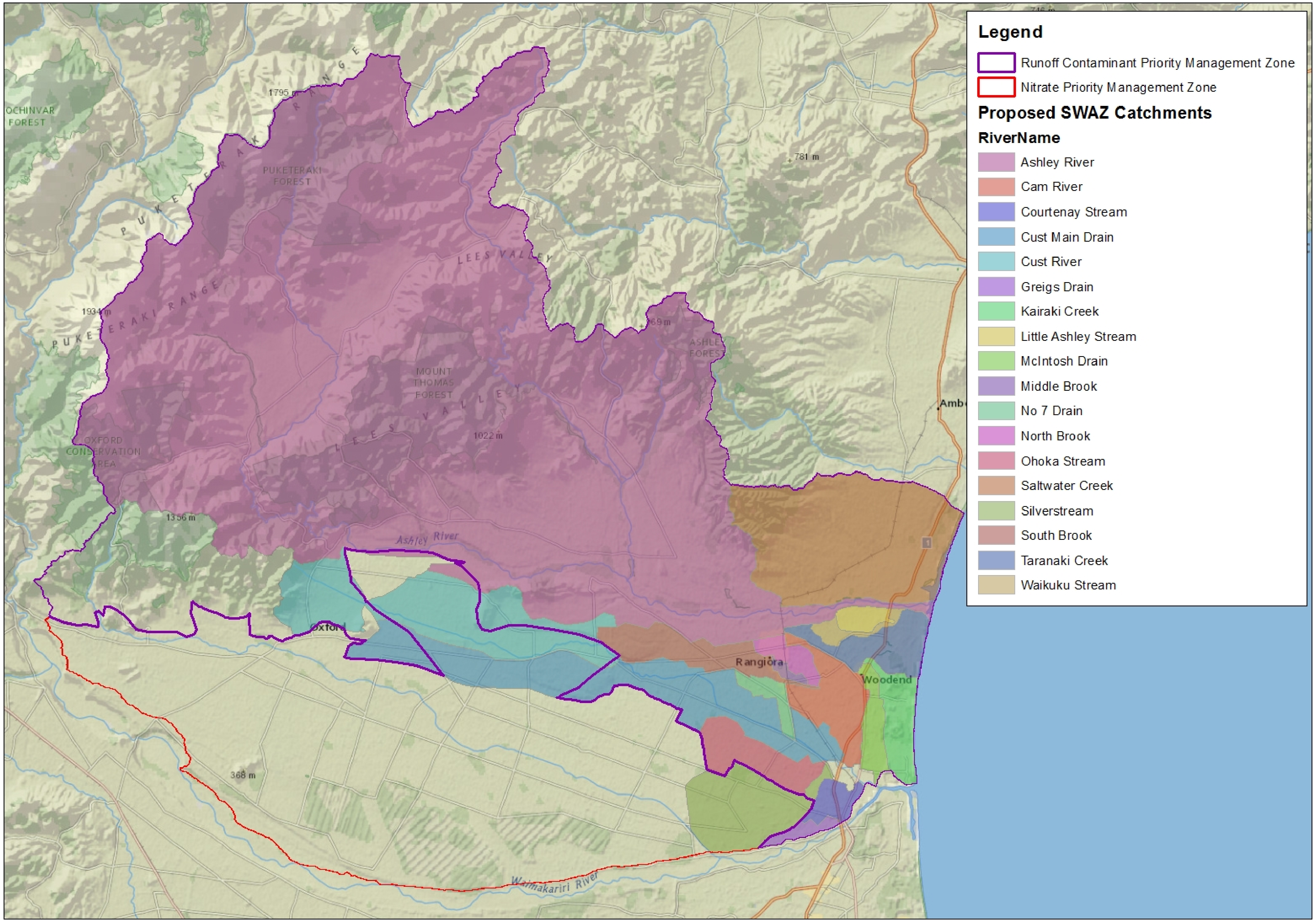


Figure 2 Priority management zones with surface water catchments

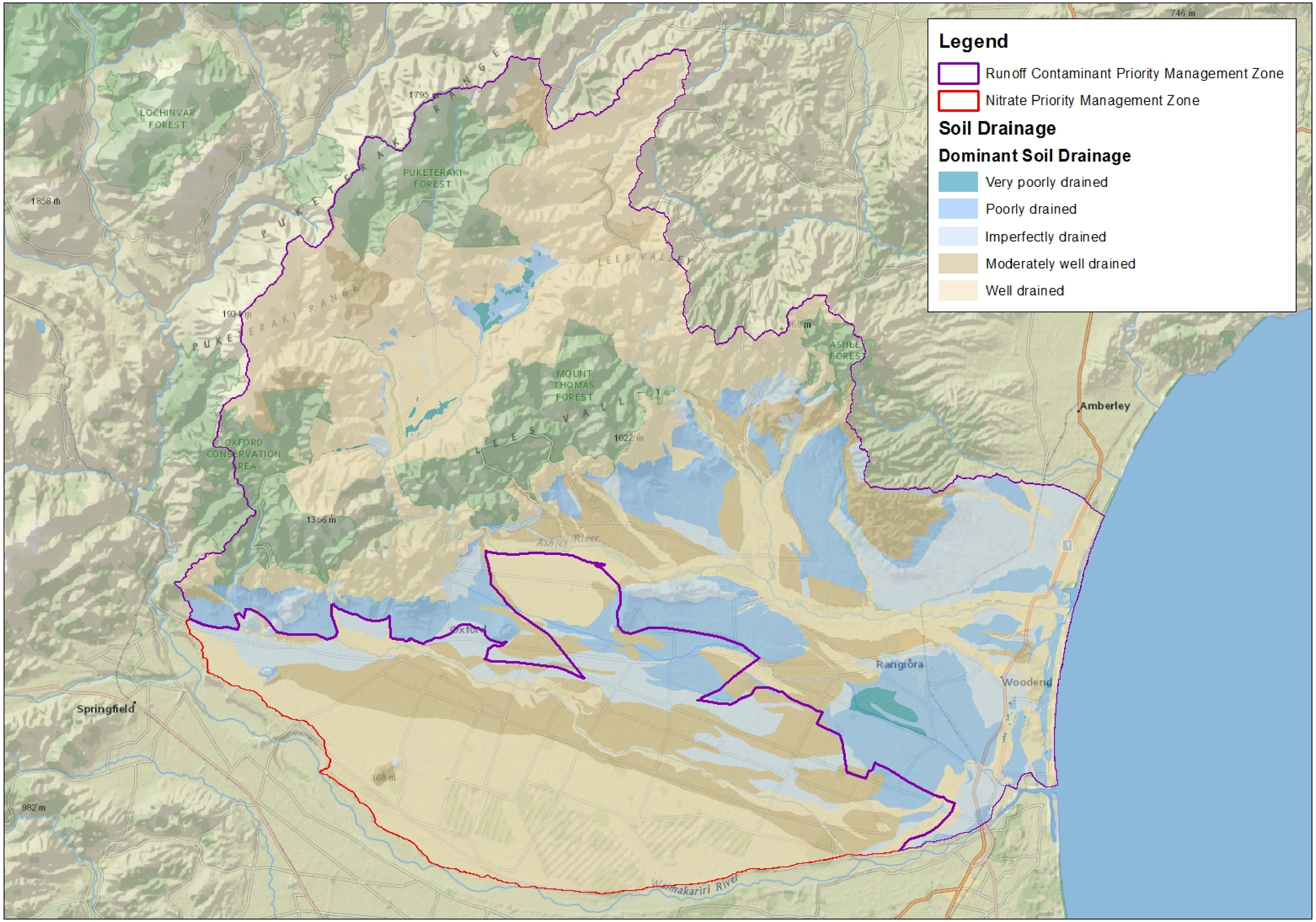


Figure 3 **Priority management zones with soil drainage**

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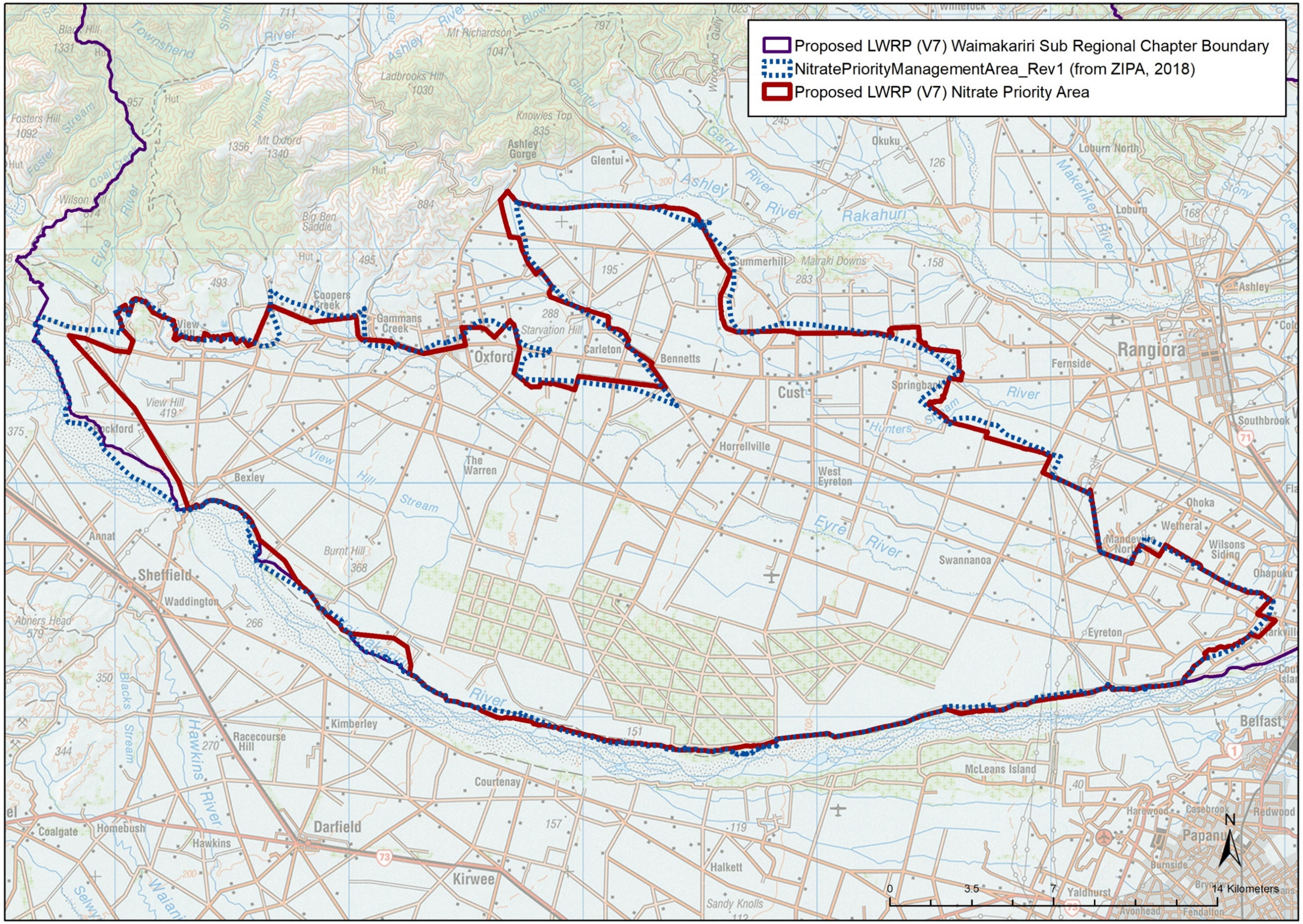


Figure 4 **Adjustment of the Nitrate Priority Management Area presented in the ZIPA to the Nitrate Priority Area for the proposed LWRP (V7)**

Appendix 13. Nitrate reductions achieved with ZIPA Solution Package

The tables in this Appendix give an overview of the nitrate reductions achieved under the ZIPA Solutions Package[79]. They form the background information for the staged nitrate load reduction maps in Section 5.4.2 (50th percentile model results) and the maps in this appendix (5th and 95th model results).
The assumed implementation year for the ZIPA Solution Package is 2030.

Legend for the tables:

5th, 50th, 95th:	Results are presented for our 50th percentile model results, with the 5th percentile and 95th percentile results showing the band with (or uncertainty)
CP:	Current Pathways Scenario
Concentration:	Nitrate-nitrogen in mg/L
Limit:	Nitrate-nitrogen in mg/L
Lag time:	time in years

Red highlighted values: represent receptors that fall (largely) outside the NPA and therefore will not have (or very minimal) staged reduction in N loss within their groundwater recharge zones. This means that any required reductions in nitrate concentrations at the receptor will not be achieved or only after a very long time.

[79] Internal data source: P:\Groundwater\Waimakariri\Landuse\Spreadsheet\NloadBreakDowneperLanduseClassPerRechargeArea.xlsx

Table 1 Nitrate reductions assessed for the CCC Water Supply Areas

	CP concentration					Required concentration reduction			ZIPA	Beyond	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	Reduction	GMP reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
CCC West	1.30	4.10	7.10	3.80	200	0.0%	7.3%	46.5%	12.8%	12.0%	0.0	0.6	3.8	0	205	240	2018	2235	2270
CCC Central	3.50	5.40	7.60	3.80	800	0.0%	29.6%	50.0%	12.8%	12.0%	0.0	2.4	4.1	0	825	840	2018	2855	2870
CCC East	3.50	5.40	7.60	3.80	1200	0.0%	29.6%	50.0%	12.8%	12.0%	0.0	2.4	4.1	0	1225	1240	2018	3255	3270

Table 2 Nitrate reductions assessed for the Private Water Supply Areas	CP concentration					Required concentration reduction			ZIPA	Beyond	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	Reduction	GMP reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
PWSA Clarkville	5.00	8.20	11.70	5.65	40	0.0%	31.1%	51.7%	13.0%	12.2%	0.0	2.5	4.2	0	65	80	2018	2095	2110
PWSA Cust	3.90	6.70	9.70	5.65	48	0.0%	15.7%	41.8%	9.7%	7.6%	0.0	1.8	5.2	0	65	100	2018	2095	2130
PWSA Eyreton Deep	4.70	15.20	24.00	5.65	75	0.0%	62.8%	76.5%	14.9%	14.9%	0.0	4.2	5.1	0	115	125	2018	2145	2155
PWSA Eyreton Shallow	8.30	12.30	16.60	5.65	45	31.9%	54.1%	66.0%	14.2%	13.6%	2.3	3.9	4.8	70	85	95	2100	2115	2125
PWSA Fernside	2.20	4.90	7.80	5.65	46	0.0%	0.0%	27.6%	7.4%	**0.1%**	0.0	0.0	**307.2**	0	0	3120	2018	2018	**5150**
PWSA Flaxton	2.00	3.50	6.30	5.65	36	0.0%	0.0%	10.3%	7.3%	4.9%	0.0	0.0	1.6	0	0	50	2018	2018	2080
PWSA Horellville	2.20	4.60	7.20	5.65	48	0.0%	0.0%	21.5%	8.4%	7.3%	0.0	0.0	2.8	0	0	75	2018	2018	2105
PWSA Mandeville	2.30	4.80	8.90	5.65	45	0.0%	0.0%	36.5%	9.3%	7.6%	0.0	0.0	4.6	0	0	90	2018	2018	2120
PWSA N East Eyrewell Deep	4.00	7.50	11.50	5.65	70	0.0%	24.7%	50.9%	12.2%	11.4%	0.0	2.1	4.4	0	90	115	2018	2120	2145
PWSA N East Eyrewell Shallow	2.50	6.60	13.60	5.65	50	0.0%	14.4%	58.5%	11.7%	11.3%	0.0	1.2	5.1	0	60	100	2018	2090	2130
PWSA N West Eyrewell Deep	2.10	7.70	14.50	5.65	75	0.0%	26.6%	61.0%	12.5%	11.2%	0.0	2.3	5.3	0	100	130	2018	2130	2160
PWSA N West Eyrewell Shallow	2.00	6.30	12.50	5.65	45	0.0%	10.3%	54.8%	10.3%	9.4%	0.0	1.0	5.7	0	55	100	2018	2085	2130
PWSA Ohoka Deep	4.40	7.50	10.90	5.65	88	0.0%	24.7%	48.2%	8.7%	6.5%	0.0	3.5	7.1	0	125	160	2018	2155	2190
PWSA Ohoka Shallow	4.00	6.30	8.70	5.65	50	0.0%	10.3%	35.1%	5.5%	3.7%	0.0	2.3	9.0	0	75	140	2018	2105	2170
PWSA Rangiora	0.40	2.70	6.70	5.65	15	0.0%	0.0%	15.7%	4.7%	**0.0%**									
PWSA Springbank	4.00	6.60	9.50	5.65	45	0.0%	14.4%	40.5%	9.0%	6.9%	0.0	1.8	5.6	0	65	100	2018	2095	2130
PWSA Summerhill	5.00	10.40	16.10	5.65	70	0.0%	45.7%	64.9%	11.3%	8.6%	0.0	5.0	7.3	0	120	145	2018	2150	2175
PWSA Swannanoa Deep	4.40	8.40	12.50	5.65	45	0.0%	32.7%	54.8%	9.3%	7.7%	0.0	4.1	6.9	0	85	115	2018	2115	2145
PWSA Swannanoa Shallow	3.00	7.10	12.10	5.65	45	0.0%	20.4%	53.3%	10.4%	9.6%	0.0	2.1	5.5	0	65	100	2018	2095	2130
PWSA Waikuku	0.60	1.30	3.50	5.65	7	0.0%	0.0%	0.0%	2.7%	**0.0%**									
PWSA West Eyreton Deep	3.70	6.30	9.30	5.65	66	0.0%	10.3%	39.2%	9.7%	8.4%	0.0	1.1	4.5	0	75	110	2018	2105	2140
PWSA West Eyreton Shallow	2.80	5.60	11.10	5.65	48	0.0%	0.0%	49.1%	8.4%	7.4%	0.0	0.0	6.5	0	0	115	2018	2018	2145
PWSA Woodend	0.80	2.80	6.40	5.65	7	0.0%	0.0%	11.7%	2.7%	**0.0%**									

Table 3 Nitrate reductions assessed for the spring-fed streams

	CP concentration					Required concentration reduction			ZIPA	Beyond	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	Reduction	GMP reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
Cam River	0.80	1.20	1.90	1.00	10	0.0%	16.7%	47.4%	3.7%	**0.0%**									
Courtenay Stream	3.20	4.70	6.60	3.80	10	0.0%	19.1%	42.4%	10.4%	9.8%	0.0	1.9	4.3	0	30	55	2018	2060	2085
Cust Main Drain	3.70	6.20	9.20	3.80	10	0.0%	38.7%	58.7%	8.4%	5.5%	0.0	6.4	10.2	0	75	110	2018	2105	2140
Silverstream Harpers Rd	7.70	13.80	20.30	6.90	10	10.4%	50.0%	66.0%	14.9%	14.5%	0.7	3.4	4.5	15	45	55	2045	2075	2085
Silverstream Island Rd	5.70	9.50	13.50	6.90	10	0.0%	27.4%	48.9%	12.0%	11.3%	0.0	2.4	4.3	0	35	55	2018	2065	2085
Ohoka Stream	4.20	7.00	10.00	3.80	10	9.5%	45.7%	62.0%	8.2%	7.2%	1.2	6.2	8.4	20	70	95	2050	2100	2125
Saltwater Creek	0.49	0.80	0.99	1.00	10	0.0%	0.0%	0.0%	4.3%	**0.0%**									
Taranaki Creek	0.70	1.10	1.23	1.00	10	0.0%	9.1%	18.7%	3.7%	**0.0%**									
Waikuku Stream	0.63	1.04	1.15	1.00	10	0.0%	3.8%	13.0%	2.0%	**0.0%**									

Table 4 Nitrate reductions assessed for the WDC drinking water supply schemes

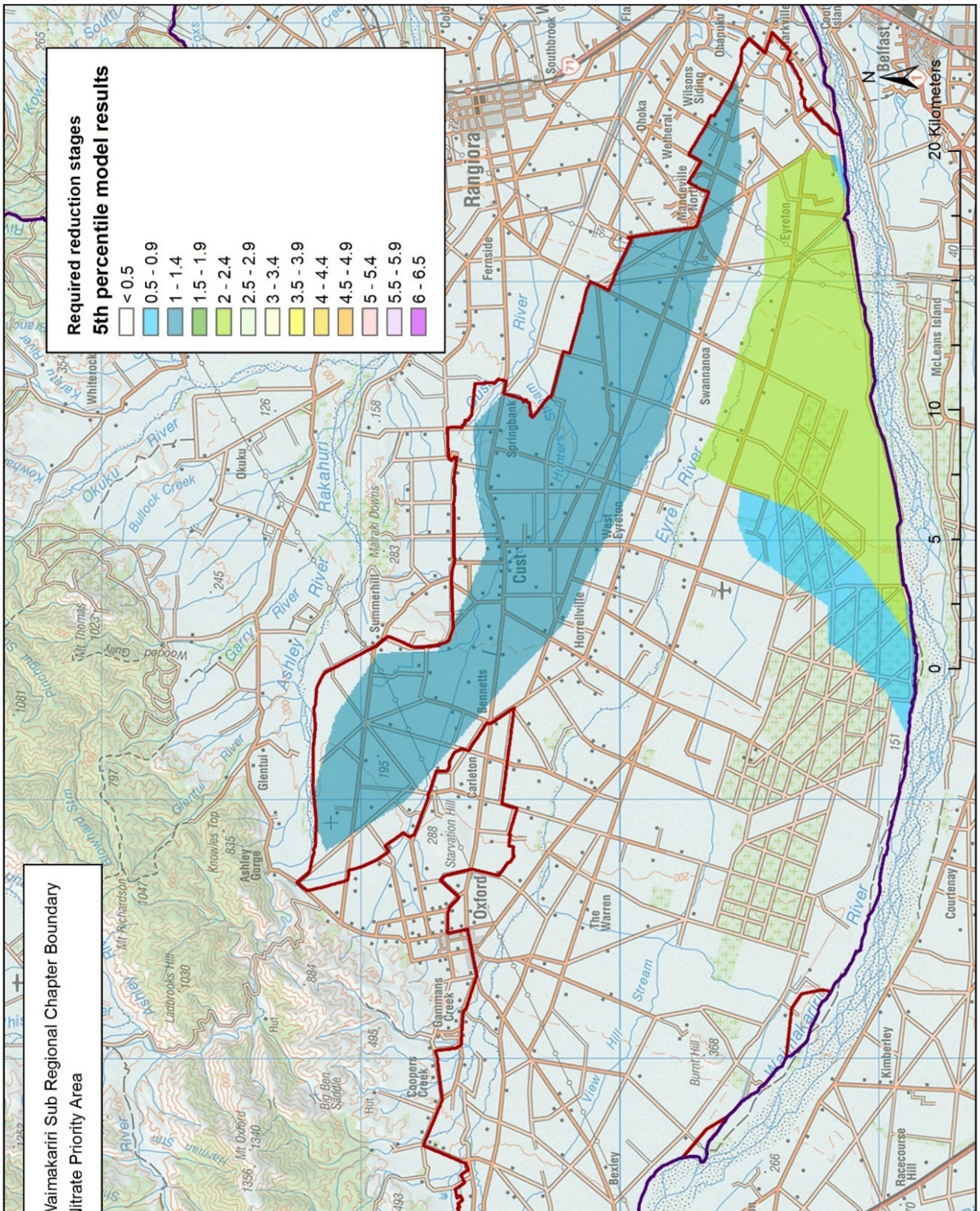
	CP concentration					Required concentration reduction			ZIPA	Beyond	10 year stages			years			year reached		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	Reduction	GMP reduction	5th	50th	95th	5th	50th	95th	5th	50th	95th
WDC Cust	3.90	6.40	9.10	5.65	100	0.0%	11.7%	37.9%	10.4%	9.6%	0.0	1.1	3.9	0	110	140	2018	2140	2170
WDC Fernside	2.90	5.50	8.00	5.65	20	0.0%	0.0%	29.4%	8.1%	**0.0%**									
WDC Kaiapoi	3.30	6.80	10.80	5.65	100	0.0%	16.9%	47.7%	10.1%	8.9%	0.0	1.8	5.2	0	120	150	2018	2150	2180
WDC Kairaki	3.30	5.40	7.90	5.65	100	0.0%	0.0%	28.5%	8.4%	7.5%	0.0	0.0	3.7	0	0	135	2018	2018	2165
WDC Mandeville	5.10	8.10	11.70	5.65	42	0.0%	30.2%	51.7%	9.9%	8.9%	0.0	3.3	5.7	0	75	100	2018	2105	2130
WDC Ohoka	4.70	7.70	11.10	5.65	88	0.0%	26.6%	49.1%	9.2%	7.9%	0.0	3.2	6.1	0	120	150	2018	2150	2180
WDC Oxford Urban	1.50	3.00	6.20	5.65	70	0.0%	0.0%	8.9%	11.1%	3.5%	0.0	0.0	0.8	0	0	80	2018	2018	2110
WDC Pegasus	1.10	3.20	6.40	5.65	100	0.0%	0.0%	11.7%	7.8%	0.7%	0.0	0.0	6.5	0	0	165	2018	2018	2195
WDC Poyntzs Road	4.60	7.30	10.90	5.65	10	0.0%	22.6%	48.2%	12.2%	10.8%	0.0	2.0	4.3	0	30	55	2018	2060	2085
WDC Rangiora	3.20	7.40	11.90	5.65	100	0.0%	23.6%	52.5%	9.5%	8.2%	0.0	2.7	6.2	0	125	160	2018	2155	2190
WDC Waikuku	1.10	1.90	3.40	5.65	6	0.0%	0.0%	0.0%	8.0%	**0.0%**									
WDC West Eyreton	3.60	5.80	8.40	5.65	66	0.0%	2.6%	32.7%	8.9%	7.7%	0.0	0.3	4.1	0	70	105	2018	2100	2135

The tables indicate that 50 years after implementation (after 5 stages) of the Solution Package there could still be receptors that require nitrate load reductions in their recharge areas:
For the 50th percentile results this results in 2 receptors needing more than 5 stages:

- Cust Main Drain
- Ohoka Stream

For the 95th percentile results this results in 15 receptors needing more than 5 stages:

- Cust Main Drain
- Ohoka Stream
- WDC Kaiapoi
- WDC Mandeville
- WDC Ohoka
- WDC Pegasus
- WDC Rangiora
- PWSA Cust
- PWSA Eyreton Deep
- PWSA North East Eyrewell (Shallow)
- PWSA North West Eyrewell (Deep and Shallow)
- PWSA Ohoka (Deep and Shallow)
- PWSA Summerhill
- PWSA Swannanoa (Deep and Shallow)
- PWSA West Eyreton (Shallow)


Required reduction stages
5th percentile model results
< 0.5
0.5 - 0.9
1 - 1.4
1.5 - 1.9
2 - 2.4
2.5 - 2.9
3 - 3.4
3.5 - 3.9
4 - 4.4
4.5 - 4.9
5 - 5.4
5.5 - 5.9
6 - 6.5
pLWRP (V7) Waimakariri Sub Regional Chapter Boundary
pLWRP (V7) Nitrate Priority Area
0 5 10 20 Kilometers
N
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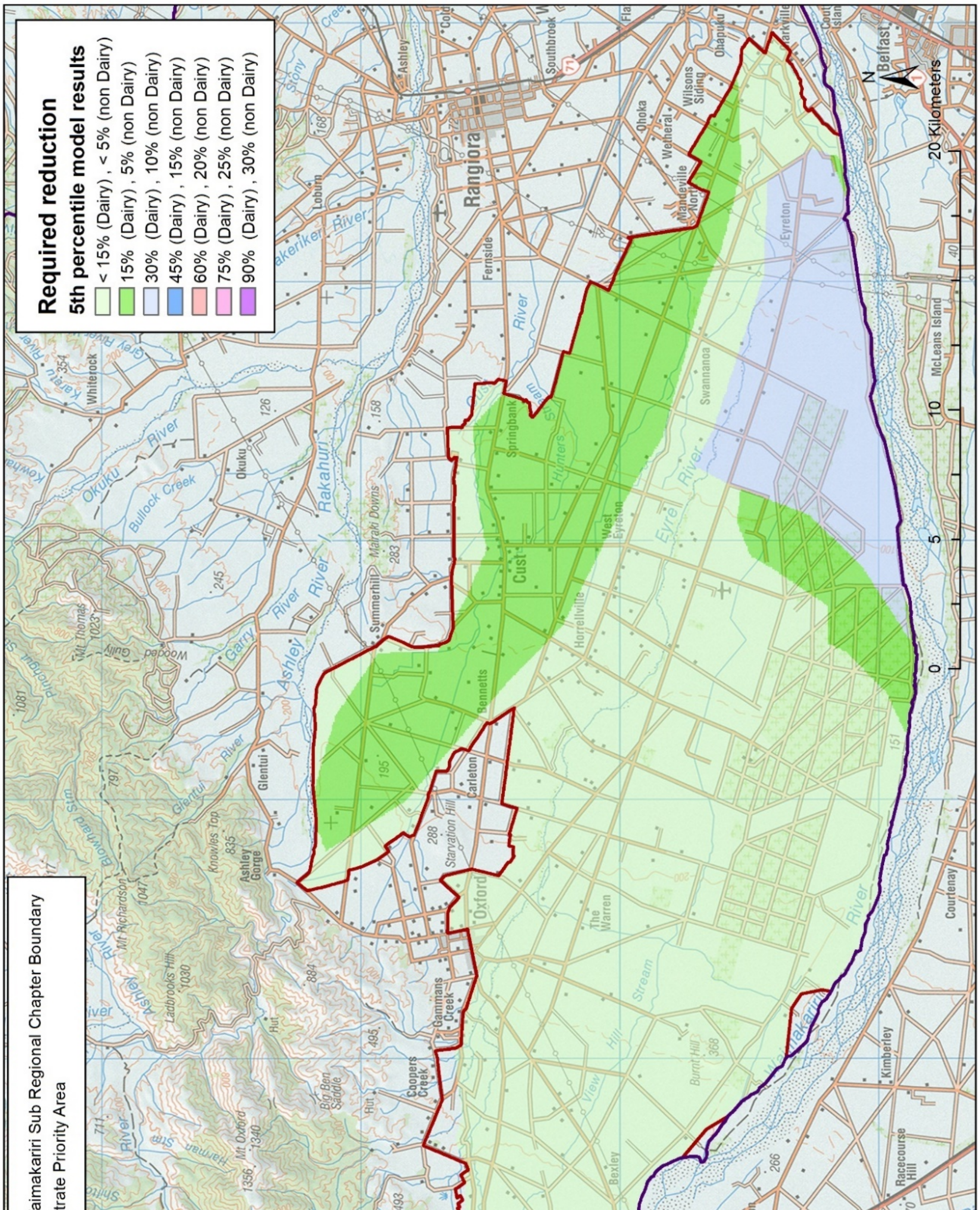

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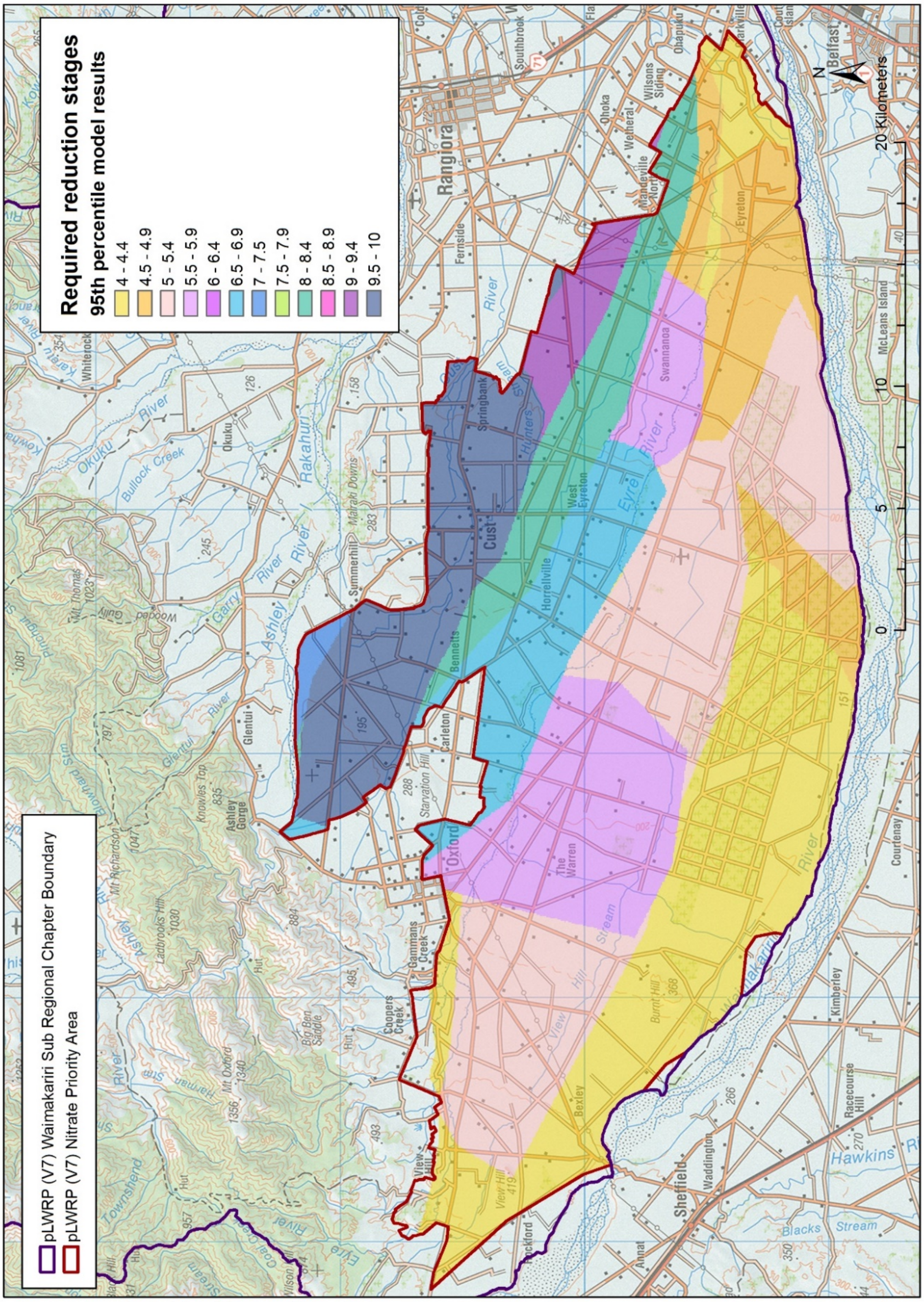

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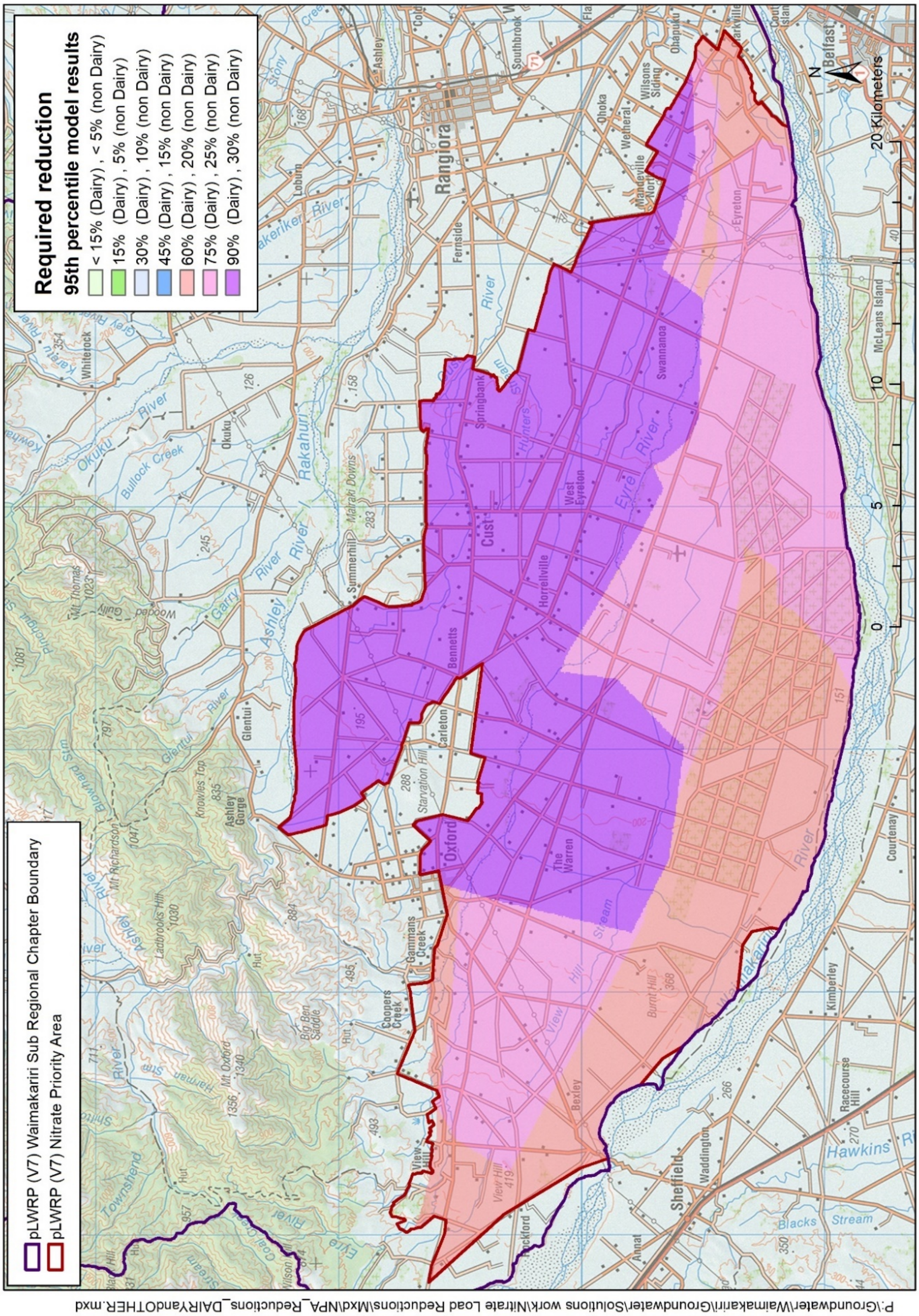
Required reduction
95th percentile model results
< 15% (Dairy) , < 5% (non Dairy)
15% (Dairy) , 5% (non Dairy)
30% (Dairy) , 10% (non Dairy)
45% (Dairy) , 15% (non Dairy)
60% (Dairy) , 20% (non Dairy)
75% (Dairy) , 25% (non Dairy)
90% (Dairy) , 30% (non Dairy)
pLWRP (V7) Waimakariri Sub Regional Chapter Boundary
pLWRP (V7) Nitrate Priority Area
N
0 5 10 20 Kilometers
Rangiora
Oxford
Cust
Sheffield
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	Concentrations for Current Pathways Scenario					Reduction required			ZIPA concentration after 10 years after lag-time			ZIPA concentration after 20 years after lag-time			ZIPA concentration after 50 years after lag-time		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
CCC West	1.30	4.10	7.10	3.80	200	0.0%	7.3%	46.5%	1.13	3.58	6.19	0.98	3.08	5.34	0.51	1.61	2.79
CCC Central	3.50	5.40	7.60	3.80	800	0.0%	29.6%	50.0%	3.05	4.71	6.63	2.63	4.06	5.72	1.37	2.12	2.98
CCC East	3.50	5.40	7.60	3.80	1200	0.0%	29.6%	50.0%	3.05	4.71	6.63	2.63	4.06	5.72	1.37	2.12	2.98
PWSA Clarkville	5.00	8.20	11.70	5.65	40	0.0%	31.1%	51.7%	4.35	7.14	10.18	3.74	6.13	8.75	1.90	3.12	4.45
PWSA Cust	3.90	6.70	9.70	5.65	48	0.0%	15.7%	41.8%	3.52	6.05	8.76	3.22	5.54	8.02	2.33	4.01	5.80
PWSA Eyreton Deep	4.70	15.20	24.00	5.65	75	0.0%	62.8%	76.5%	4.00	12.94	20.43	3.30	10.68	16.87	1.21	3.90	6.16
PWSA Eyreton Shallow	8.30	12.30	16.60	5.65	45	31.9%	54.1%	66.0%	7.12	10.55	14.24	6.00	8.89	11.99	2.62	3.88	5.24
PWSA Fernside	2.20	4.90	7.80	5.65	46	0.0%	0.0%	27.6%	2.04	4.54	7.22	2.04	4.53	7.22	2.03	4.52	7.20
PWSA Flaxton	2.00	3.50	6.30	5.65	36	0.0%	0.0%	10.3%	1.85	3.24	5.84	1.76	3.07	5.53	1.46	2.56	4.60
PWSA Horellville	2.20	4.60	7.20	5.65	48	0.0%	0.0%	21.5%	2.02	4.22	6.60	1.85	3.88	6.07	1.37	2.86	4.48
PWSA Mandeville	2.30	4.80	8.90	5.65	45	0.0%	0.0%	36.5%	2.09	4.35	8.07	1.91	3.98	7.39	1.38	2.89	5.35
PWSA N East Eyrewell Deep	4.00	7.50	11.50	5.65	70	0.0%	24.7%	50.9%	3.51	6.58	10.10	3.05	5.73	8.78	1.68	3.15	4.83
PWSA N East Eyrewell Shallow	2.50	6.60	13.60	5.65	50	0.0%	14.4%	58.5%	2.21	5.83	12.01	1.92	5.08	10.47	1.07	2.84	5.85
PWSA N West Eyrewell Deep	2.10	7.70	14.50	5.65	75	0.0%	26.6%	61.0%	1.84	6.73	12.68	1.60	5.87	11.06	0.90	3.28	6.18
PWSA N West Eyrewell Shallow	2.00	6.30	12.50	5.65	45	0.0%	10.3%	54.8%	1.79	5.65	11.21	1.61	5.06	10.04	1.04	3.29	6.52
PWSA Ohoka Deep	4.40	7.50	10.90	5.65	88	0.0%	24.7%	48.2%	4.02	6.85	9.96	3.73	6.36	9.25	2.87	4.90	7.12
PWSA Ohoka Shallow	4.00	6.30	8.70	5.65	50	0.0%	10.3%	35.1%	3.78	5.95	8.22	3.63	5.72	7.90	3.19	5.02	6.93
PWSA Rangiora	0.40	2.70	6.70	5.65	15	0.0%	0.0%	15.7%	0.38	2.57	6.38	0.38	2.57	6.38	0.38	2.57	6.38
PWSA Springbank	4.00	6.60	9.50	5.65	45	0.0%	14.4%	40.5%	3.64	6.01	8.64	3.36	5.55	7.99	2.54	4.18	6.02
PWSA Summerhill	5.00	10.40	16.10	5.65	70	0.0%	45.7%	64.9%	4.44	9.23	14.28	4.01	8.34	12.90	2.72	5.67	8.77
PWSA Swannanoa Deep	4.40	8.40	12.50	5.65	45	0.0%	32.7%	54.8%	3.99	7.62	11.34	3.65	6.97	10.38	2.64	5.04	7.50
PWSA Swannanoa Shallow	3.00	7.10	12.10	5.65	45	0.0%	20.4%	53.3%	2.69	6.36	10.84	2.40	5.69	9.69	1.54	3.65	6.22
PWSA Waikuku	0.60	1.30	3.50	5.65	7	0.0%	0.0%	0.0%	0.58	1.26	3.40	0.58	1.26	3.40	0.58	1.26	3.40
PWSA West Eyreton Deep	3.70	6.30	9.30	5.65	66	0.0%	10.3%	39.2%	3.34	5.69	8.40	3.03	5.16	7.62	2.10	3.58	5.28
PWSA West Eyreton Shallow	2.80	5.60	11.10	5.65	48	0.0%	0.0%	49.1%	2.56	5.13	10.17	2.36	4.71	9.34	1.73	3.46	6.86
PWSA Woodend	0.80	2.80	6.40	5.65	7	0.0%	0.0%	11.7%	0.78	2.72	6.22	0.78	2.72	6.22	0.78	2.72	6.22
Cam River	0.80	1.20	1.90	1.00	10	0.0%	16.7%	47.4%	0.77	1.16	1.83	0.77	1.16	1.83	0.77	1.16	1.83
Courtenay Stream	3.20	4.70	6.60	3.80	10	0.0%	19.1%	42.4%	3.11	4.57	6.42	3.11	4.57	6.42	3.11	4.57	6.42
Cust Main Drain	3.70	6.20	9.20	3.80	10	0.0%	38.7%	58.7%	3.39	5.68	8.43	3.19	5.34	7.92	2.58	4.32	6.41
Silverstream Harpers Rd	7.70	13.80	20.30	6.90	10	10.4%	50.0%	66.0%	6.55	11.74	17.28	5.43	9.74	14.32	2.07	3.72	5.46
Silverstream Island Rd	5.70	9.50	13.50	6.90	10	0.0%	27.4%	48.9%	5.02	8.36	11.88	4.37	7.29	10.36	2.44	4.07	5.79
Ohoka Stream	4.20	7.00	10.00	3.80	10	9.5%	45.7%	62.0%	3.85	6.42	9.18	3.55	5.92	8.45	2.64	4.40	6.29
Saltwater Creek	0.49	0.80	0.99	1.00	10	0.0%	0.0%	0.0%	0.47	0.77	0.95	0.47	0.77	0.95	0.47	0.77	0.95
Taranaki Creek	0.70	1.10	1.23	1.00	10	0.0%	9.1%	18.7%	0.67	1.06	1.18	0.67	1.06	1.18	0.67	1.06	1.18
Waikuku Stream	0.63	1.04	1.15	1.00	10	0.0%	3.8%	13.0%	0.62	1.02	1.13	0.62	1.02	1.13	0.62	1.02	1.13
WDC Cust	3.90	6.40	9.10	5.65	100	0.0%	11.7%	37.9%	3.49	5.73	8.15	3.12	5.12	7.28	1.99	3.27	4.65
WDC Fernside	2.90	5.50	8.00	5.65	20	0.0%	0.0%	29.4%	2.67	5.05	7.35	2.67	5.05	7.35	2.67	5.05	7.35
WDC Kaiapoi	3.30	6.80	10.80	5.65	100	0.0%	16.9%	47.7%	2.97	6.12	9.71	2.67	5.51	8.75	1.79	3.69	5.86
WDC Kairaki	3.30	5.40	7.90	5.65	100	0.0%	0.0%	28.5%	3.02	4.94	7.23	2.77	4.54	6.64	2.03	3.33	4.87
WDC Mandeville	5.10	8.10	11.70	5.65	42	0.0%	30.2%	51.7%	4.59	7.30	10.54	4.14	6.58	9.50	2.79	4.43	6.40
WDC Ohoka	4.70	7.70	11.10	5.65	88	0.0%	26.6%	49.1%	4.27	6.99	10.08	3.90	6.39	9.21	2.79	4.57	6.59
WDC Oxford Urban	1.50	3.00	6.20	5.65	70	0.0%	0.0%	8.9%	1.33	2.67	5.51	1.28	2.56	5.30	1.13	2.25	4.66

	Concentrations for Current Pathways Scenario					Reduction required			ZIPA concentration after 10 years after lag-time			ZIPA concentration after 20 years after lag-time			ZIPA concentration after 50 years after lag-time		
Receptor	5th	50th	95th	limit	lag-time	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
WDC Pegasus	1.10	3.20	6.40	5.65	100	0.0%	0.0%	11.7%	1.01	2.95	5.90	1.01	2.93	5.86	0.98	2.86	5.72
WDC Poyntzs Road	4.60	7.30	10.90	5.65	10	0.0%	22.6%	48.2%	4.04	6.41	9.57	3.54	5.62	8.40	2.05	3.26	4.86
WDC Rangiora	3.20	7.40	11.90	5.65	100	0.0%	23.6%	52.5%	2.89	6.69	10.77	2.63	6.08	9.78	1.84	4.25	6.84
WDC Waikuku	1.10	1.90	3.40	5.65	6	0.0%	0.0%	0.0%	1.01	1.75	3.13	1.01	1.75	3.13	1.01	1.75	3.13
WDC West Eyreton	3.60	5.80	8.40	5.65	66	0.0%	2.6%	32.7%	3.28	5.29	7.66	3.00	4.84	7.01	2.17	3.49	5.05

Appendix 14. Estimated percentage of samples per PWSA that breach the zone committee limit

In section 2.3.5 we presented graphs of the relationship between the measured ***mean*** annual nitrate concentration in the Canterbury Plains and the percentage of samples or wells that exceeded the nitrate limit of 11.3 mg/L. We have established an equivalent for the ***median*** annual nitrate concentration in the Canterbury Plains. If we assume the relationship established for the Canterbury Plains is equaly valid for the separate PWSAs[80] and our calculated 50th percentile model results, we can estimate the % of samples or wells that could exceed the drinking water MAV of 11.3 mg/L or ½MAV for different scenarios and the ZIPA Solutions Package for each PWSA (see Table 1 and Table 2).

The results in Table 1 indicate that in 13 PWSAs more than 10% of the wells will exceed the nitrate drinking water MAV after the first 10-y stage of the ZIPA solution package. After 50 years in only 6 PWSAs more than 10% of the wells will exceed the MAV (Eyreton Shallow and Deep, Eyrewell, Ohoka Deep, Summerhill and West Eyreton Deep). As can be seen in this table, there are not many deep private water supply wells at present in the Deep PWSAs. There are 61 deep (>50 m) private water supply wells in total and 2,580 shallow wells. Of the deep wells, our modelling results indicate that 10% will still exceed the MAV for nitrate 50 years after implementation of the ZIPA Solutions Package. For the shallow wells this percentage is 8%. This shows that drilling deeper wells to avoid increasing nitrate concentrations is unlikely to be a viable solution in the long term.

Table 1 Number of wells exceeding MAV (11.3 mg/L) for nitrate based on the median nitrate concentrations in the PWSA, ignoring local spatial variability[81]

PWSA	Number of wells in PWSA	Number of wells exceeding MAV				
		Current	Current Pathways	ZIPA, after 10 years	ZIPA, after 20 years	ZIPA, after 50 years
Clarkville	262	22	38	33	29	25
Cust	70	6	8	8	7	7
Eyreton Deep	6	1	2	1	1	1
Eyreton Shallow	93	9	20	17	14	12
Eyrewell	40	4	8	7	6	5
Fernside	198	14	18	17	17	17
Flaxton	69	6	5	4	4	4
Horellville	95	7	8	8	7	7
Mandeville	179	15	16	15	14	13
North East Eyrewell Deep	14	1	2	2	1	1
North East Eyrewell Shallow	246	17	29	26	23	20

[80] Which in reality may not be the case: the spatial variability in nitrate concentrations across the Canterbury Plains could be greater than that found in the much smaller PWSAs.

[81] Internal data source: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Median Nitrate PWSA\PWSAWells_median_N.xlsx

PWSA	Number of wells in PWSA	Number of wells exceeding MAV				
		Current	Current Pathways	ZIPA, after 10 years	ZIPA, after 20 years	ZIPA, after 50 years
North West Eyrewell Deep	3	0	0	0	0	0
North West Eyrewell shallow	138	10	16	14	13	12
Ohoka Deep	26	2	3	3	3	3
Ohoka Shallow	133	11	15	14	14	13
Rangiora	252	5	14	14	14	14
Springbank	104	7	12	11	11	10
Summerhill	67	5	12	11	10	9
Swannanoa Deep	4	0	1	1	0	0
Swannanoa Shallow	122	9	15	14	13	11
Waikuku	153	4	5	5	5	5
West Eyreton Deep	8	1	1	1	1	1
West Eyreton Shallow	56	1	6	5	5	5
Woodend - Tuahiwi	303	8	17	17	17	17
TOTAL Waimakariri Zone	2,641	165	271	248	229	212
Results in ***grey*** show where more than 10% of the wells in the PWSA are expected to exceed the MAV (11.3 mg/L) based on the relationship between modelled median nitrate concentrations in the PWSA and % of wells exceeding 11.3mg/L						

The results in Table 2 indicate that the number of well samples exceeding the proposed 5.65 mg/L limit is not expected to reduce significantly after the first stage of the ZIPA solution package. After 50 years the results are more promising: 17 of the 18 PWSAs that did not meet the zone committee target under Current Pathways, now do meet the target. Only PWSA Summerhill would still need further reductions.

Table 2 Estimated % of samples per PWSA that breach the zone committee limit[82]

PWSA	% of samples exceeding 5.65 mg/L				
	Current	Current Pathways	ZIPA after 10 years	ZIPA, after 20 years	ZIPA, after 50 years
Clarkville	35 - 50%	65 - 80%	65 - 80%	50 - 65%	20 - 35 %
Cust	35 - 50%	50 - 65%	50 - 65%	50 - 65%	20 - 35 %
Eyreton Deep	35 - 50%	> 80%	> 80%	> 80%	20 - 35 %
Eyreton Shallow	35 - 50%	> 80%	> 80%	> 80%	20 - 35 %
Eyrewell	35 - 50%	> 80%	> 80%	> 80%	20 - 35 %
Fernside	20 - 35 %	35 - 50%	35 - 50%	35 - 50%	35 - 50%
Flaxton	35 - 50%	20 - 35 %	20 - 35 %	20 - 35 %	20 - 35 %
Horellville	20 - 35 %	35 - 50%	35 - 50%	20 - 35 %	20 - 35 %
Mandeville	35 - 50%	35 - 50%	35 - 50%	20 - 35 %	20 - 35 %
North East Eyrewell Deep	20 - 35 %	65 - 80%	50 - 65%	50 - 65%	20 - 35 %
North East Eyrewell Shallow	20 - 35 %	50 - 65%	50 - 65%	35 - 50%	20 - 35 %
North West Eyrewell Deep	20 - 35 %	65 - 80%	50 - 65%	50 - 65%	20 - 35 %
North West Eyrewell shallow	20 - 35 %	50 - 65%	50 - 65%	35 - 50%	20 - 35 %
Ohoka Deep	35 - 50%	65 - 80%	50 - 65%	50 - 65%	35 - 50%
Ohoka Shallow	35 - 50%	50 - 65%	50 - 65%	50 - 65%	35 - 50%
Rangiora	< 20%	20 - 35 %	20 - 35 %	20 - 35 %	20 - 35 %
Springbank	20 - 35 %	50 - 65%	50 - 65%	50 - 65%	35 - 50%
Summerhill	20 - 35 %	> 80%	> 80%	65 - 80%	50 - 65%
Swannanoa Deep	35 - 50%	65 - 80%	65 - 80%	50 - 65%	35 - 50%
Swannanoa Shallow	20 - 35 %	65 - 80%	50 - 65%	50 - 65%	20 - 35 %
Waikuku	< 20%	< 20%	< 20%	< 20%	< 20%
West Eyreton Deep	20 - 35 %	50 - 65%	50 - 65%	35 - 50%	20 - 35 %
West Eyreton Shallow	< 20%	50 - 65%	35 - 50%	35 - 50%	20 - 35 %
Woodend - Tuahiwi	< 20%	20 - 35 %	20 - 35 %	20 - 35 %	20 - 35 %
TOTAL Waimakariri Zone	20 - 35 %	50 - 65%	35 - 50%	35 - 50%	20 - 35 %
Results in ***grey*** show where the zone committee target will be breached, e.g. where more than 50% of the water quality samples will exceed nitrate concentration of 5.65 mg/L.					

[82] Internal data source: P:\Groundwater\Waimakariri\Groundwater\Solutions work\Median Nitrate PWSA\PWSAWells_median_N.xlsx

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

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