Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Orari Plains water quality addendum

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July 2019

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Summary

Background:
Desired outcomes for surface and groundwater quality are not being met in South Coastal Canterbury's Orari Plains. To better understand the nitrate nitrogen (NO_3-N) impacts of land-use change and intensification in the area, Environment Canterbury's existing Orari Plains integrated flow model (Durney *et al.,* 2019) has been updated to include finite difference solute transport modelling of NO_3-N.

Objectives:
The two primary objectives of the investigation were:
1. to update Environment Canterbury's calibrated Orari Plains model to include nutrient transport modelling;
2. to apply the calibrated model to simulate the potential effects of future land uses on the water budget and water quality within the Orari Plains.

What we did:
We updated the Orari Plains model to include advective-transport modelling, building upon the model presented in Durney *et al.* (2019) and Scott *et al.,* 2018. The conceptual understanding was translated into the water quality component of the Orari Plains MIKE SHE model, to which we applied a NO_3-N load based on Environment Canterbury's estimate of nutrient leaching under good farming practice. Given the load leaching layer represented the future rather than current conditions, only limited calibration was performed using water quality observation data. Instead, we decided to conserve the nutrient mass within the model when determining the water quality outcomes. We consider this to be a conservative approach to modelling nutrient transport.

What we found:
Despite the limited calibration, the model successfully produces a reasonable approximation of the water quality in surface water and groundwater across the Orari Plains.

What it means:
The model can be used to look at the impacts of various proposed land-use changes on groundwater and surface water quality for the Orari Plains. Analysis based on the NO_3-N results of this model should focus on the direction of change between the scenarios, rather than the absolute numbers.

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1 Introduction

Located in South Coastal Canterbury, the Orari Plains fall within the Orari-Temuka-Opihi-Pareora Canterbury Water Management Strategy zone. Desired outcomes for surface and groundwater quality are not being met in the Orari Plains. To ensure the long-term sustainability of these resources, we need a more detailed understanding of the hydrological processes in the catchment, along with a way to test the impacts of potential land use change. To this end, Environment Canterbury's existing MIKE SHE integrated flow model has been updated to include solute transport modelling of NO_3-N. This report documents the model update, building upon Environment Canterbury's MIKE SHE numerical modelling report on the Orari Plains (Durney *et al.,* 2019).

The MIKE SHE integrated flow model that was developed for the Orari catchment is a useful tool that has been further developed to incorporate water quality changes associated with land use. A benefit of an integrated model is that it captures the entire hydrological process inside one model; containing a river model, a groundwater model, a soil-water process model and solute transport model all inside the same tool. We decided to build an integrated model as we consider that groundwater and surface water should be managed as a single, interconnected system. This is particularly important in the Orari plains area since the Orari River loses thousands of litres of water every second to groundwater at the top of the plains, only to gain a large proportion back below State Highway 1.

The model extends from the foothills to the sea and covers the area between the Rangitata River and (to just north of) the Opihi River. The flow model was updated to include advection-dispersion solute transport modelling. This was done to:

1. assess the long term NO_3-N outlook for groundwater
2. assess the long term NO_3-N outlook for surface water
3. test land use change scenario impacts on both surface water and groundwater.

Ultimately, the model provides a framework to assess the relative magnitude of effects that different land use scenarios may have on the hydrologic system[1] (especially water quality).

2 Background

2.1 Sources and transport

In line with the OTOP Healthy Catchments project, our water quality modelling focuses on NO_3-N transport. NO_3-N is an important nutrient for plants and is often applied as fertiliser to improve plant growth; it is also a major component in animal excreta. A further NO_3-N source includes decaying organic matter in soils. Nitrogen in soils converts to nitrate, which is water soluble and can be transported into groundwaters and streams. In scientific reports, we often talk about nitrate-nitrogen (NO_3-N), which is the elemental nitrogen component of nitrate. The LWRP drinking water standard of 11.3 mg/l maximum allowable value (MAV) is in units of NO_3-N however in the New Zealand Drinking Water Standard (and often in international literature), this is quoted in units of nitrate (NO_3) which includes elemental oxygen. The equivalent value for MAV in these units is 50 mg/l NO_3. In Canterbury, the primary source of NO_3-N contamination is intensive agriculture (Scott *et al.,* 2018).

Scott *et al.* (2018) identify the reasons we care about NO_3-N levels in groundwater and surface water as:

- nitrogen is a plant nutrient, so it contributes to nuisance periphyton and macrophyte growth in streams/rivers, which can alter water quality to the point that it stresses ecological values.
- nitrogen is a factor in the growth of toxic cyanobacteria in waterways. Toxins from cyanobacterial blooms are harmful to human and animal health.

[1] In this report we consider the term 'hydrologic system' to be synonymous with the water cycle and not exclusive to surface water resources

- concentrations of NO_3-N in drinking water are harmful to human health. The NZ Drinking Water Standard (Ministry of Health, 2008) set a short-term MAV for NO_3 at 50 mg/l (11.3 mg/l NO_3-N).
- dependent on concentration, NO_3-N is toxic for aquatic life and can have chronic negative effects on aquatic life. The New Zealand national bottom line for NO_3-N toxicity in rivers is 6.9 mg/l annual median and 9.8 mg/l annual 95th percentile NO_3-N.

Webb *et al.* (2010) produced a document that details soil NO_3-N leaching risk for the Canterbury plains based on soil type; Figure 2-1 shows that the Orari Plains are particularly susceptible to NO_3-N leaching.

This risk map is supported by observation data from Environment Canterbury's groundwater monitoring arrays in some areas, which show that groundwater is already highly contaminated with NO_3-N (Figure 2-2), partially due to the industrial discharges from the Clandeboye Dairy Factory. However, data in other areas such as along the south-western margin of the Rangitata River suggest that, if there is significant leaching, then the concentrations are rapidly diluted by water from the Rangitata River.

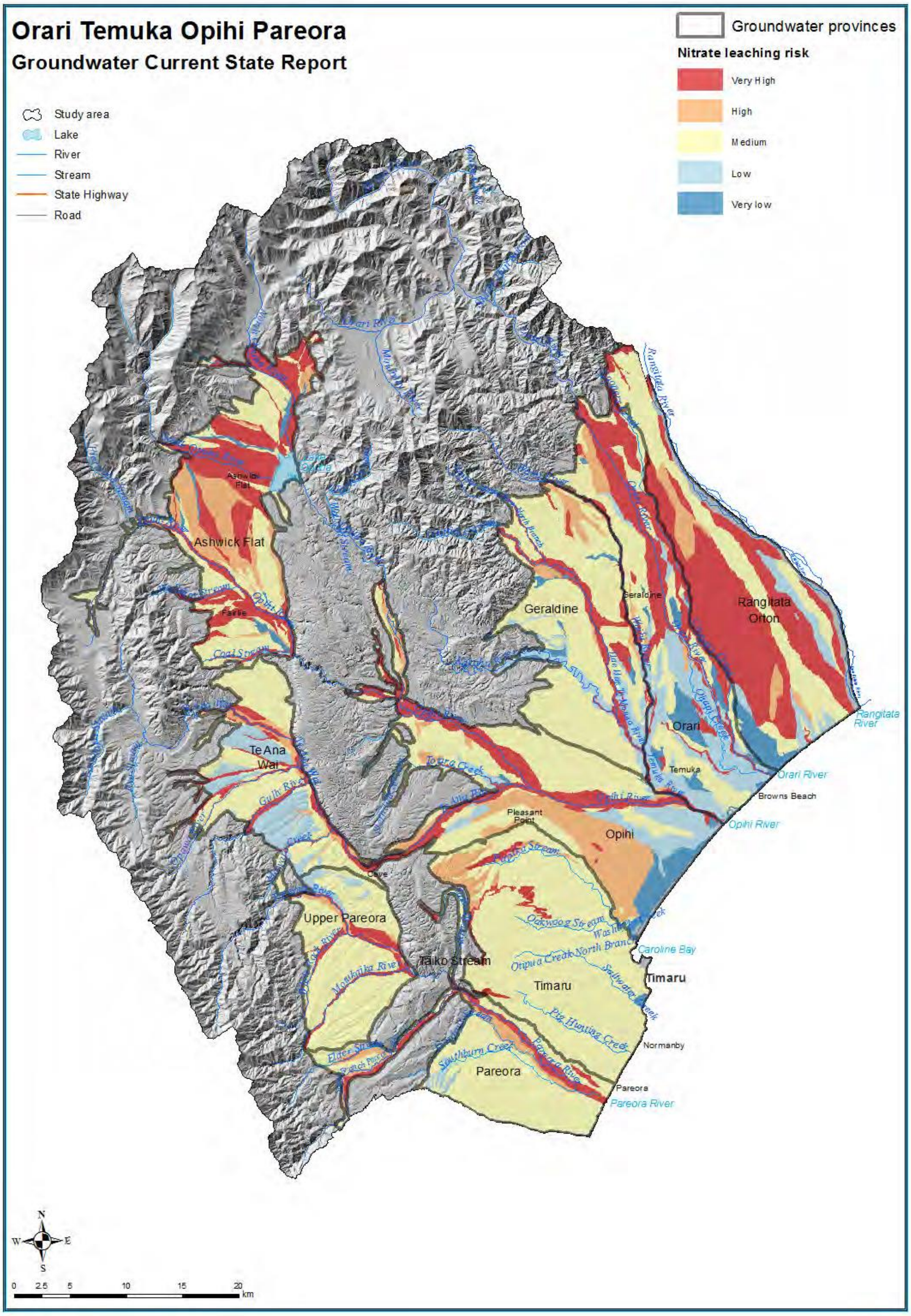

Figure 2-1: NO_3-N leaching risk map (Webb *et al.,* 2010)

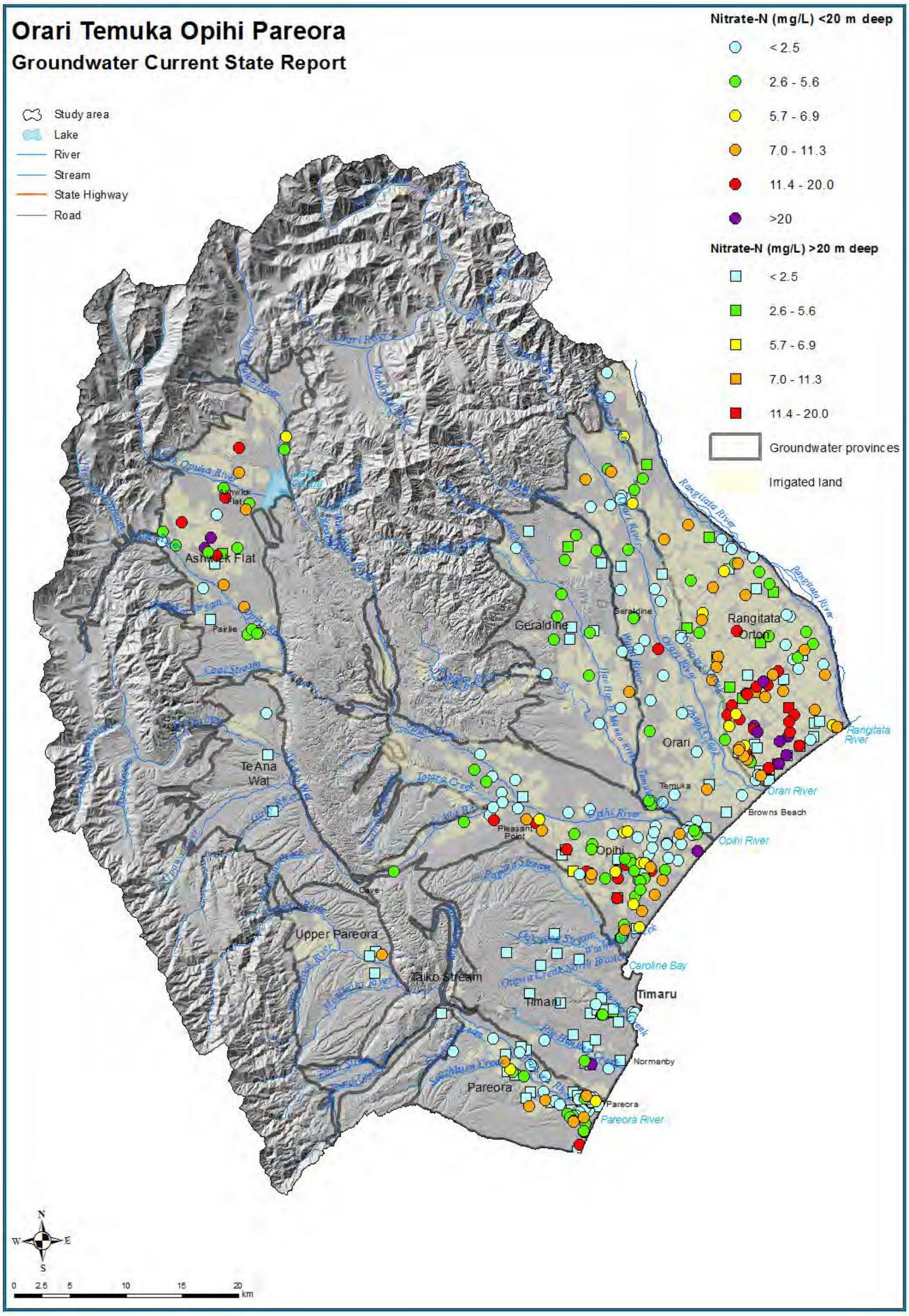

Figure 2-2: Maximum recorded NO_3-N concentrations (mg/l) (Scott *et al.,* 2018)

2.2 Surface water quality

NO_3-N concentrations in the Orari Plains vary spatially, temporally and with river type. The upper reaches of the Orari River have low NO_3-N concentrations, while NO_3-N concentrations in the spring-fed sites contrast greatly between the Ohapi Creek sites on the south side of the Orari River and the streams on the northern side. Sites that are north of the Orari River, such as McKinnon's Creek, Petries Drain and Rhodes Stream, have significantly higher NO_3-N concentrations than the lower Orari River and Ohapi Creek. Overall, the northern sites are near or exceed the national bottom line for NO_3-N, while those to the south maintain good water quality (Figure 2-3).

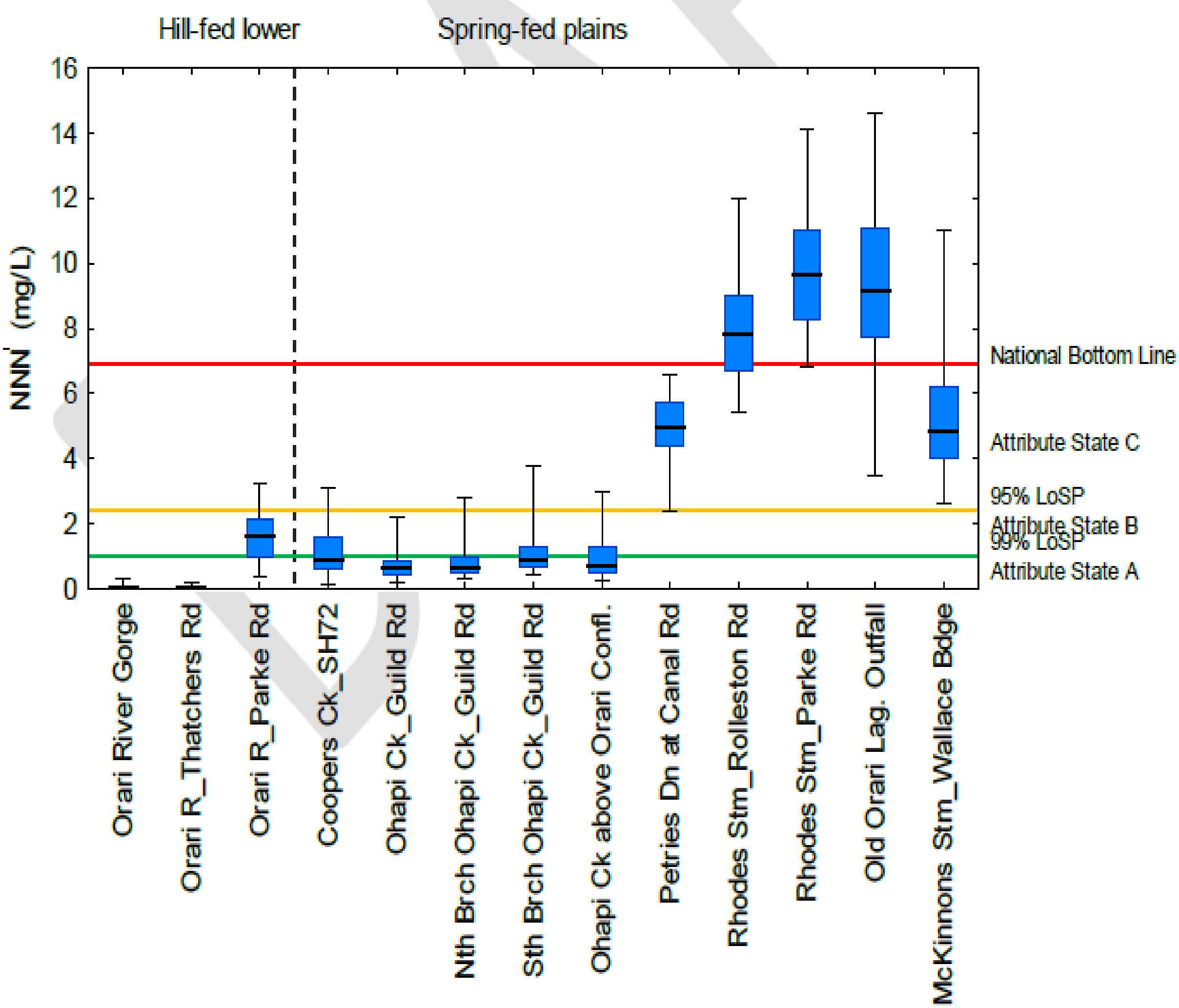

Figure 2-3: Surface water quality sites (Hayward *et al.,* 2016)

3 Model set-up and calibration

The flow model developed for the Orari Plains is fully transient, with results generated at a daily timestep. With the model already calibrated to surface and groundwater flows and exchanges, we focused, during this update, on ensuring this goodness of fit also translated to the water quality modelling. To test this, we modelled NO_3-N transport and accumulation across the Orari Plains.

3.1 Nutrient Mass Input data

The mass of NO_3-N leaching from the soils was based on estimated existing land-use (circa 2015) and the good farming practice leaching rates for each land use (Mojsilovic, 2019). The leaching data was compiled in the form of a GIS shapefile representing the average annual NO_3-N loss spatially from farming activities (Figure 3-1). This shapefile layer formed the basis for the OTOP "Current pathways" scenario, which sought to understand the impacts of consented activities and good farm management practices on the long-term outcomes for the catchment.

The average annual load (in units of kg/ha/yr NO_3-N) was translated into an average daily load per m^2 and applied to the model framework as an input load approximately 600 mm below the ground surface (i.e. below the root zone and in the unsaturated zone). Placing the load in the unsaturated zone allowed the model to calculate NO_3-N concentrations in recharge water, or from discharge due to groundwater upwelling. In the model, the load built up daily in the soil profile until recharge occurred. Essentially, the recharge water picks up the load and transports it through the unsaturated zone via piston flow until it reaches the saturated zone, where it is then transported by the groundwater flow model component. We specified the river water quality at the model inflow boundaries based on long-term monitoring data in the upstream locations of the respective rivers.

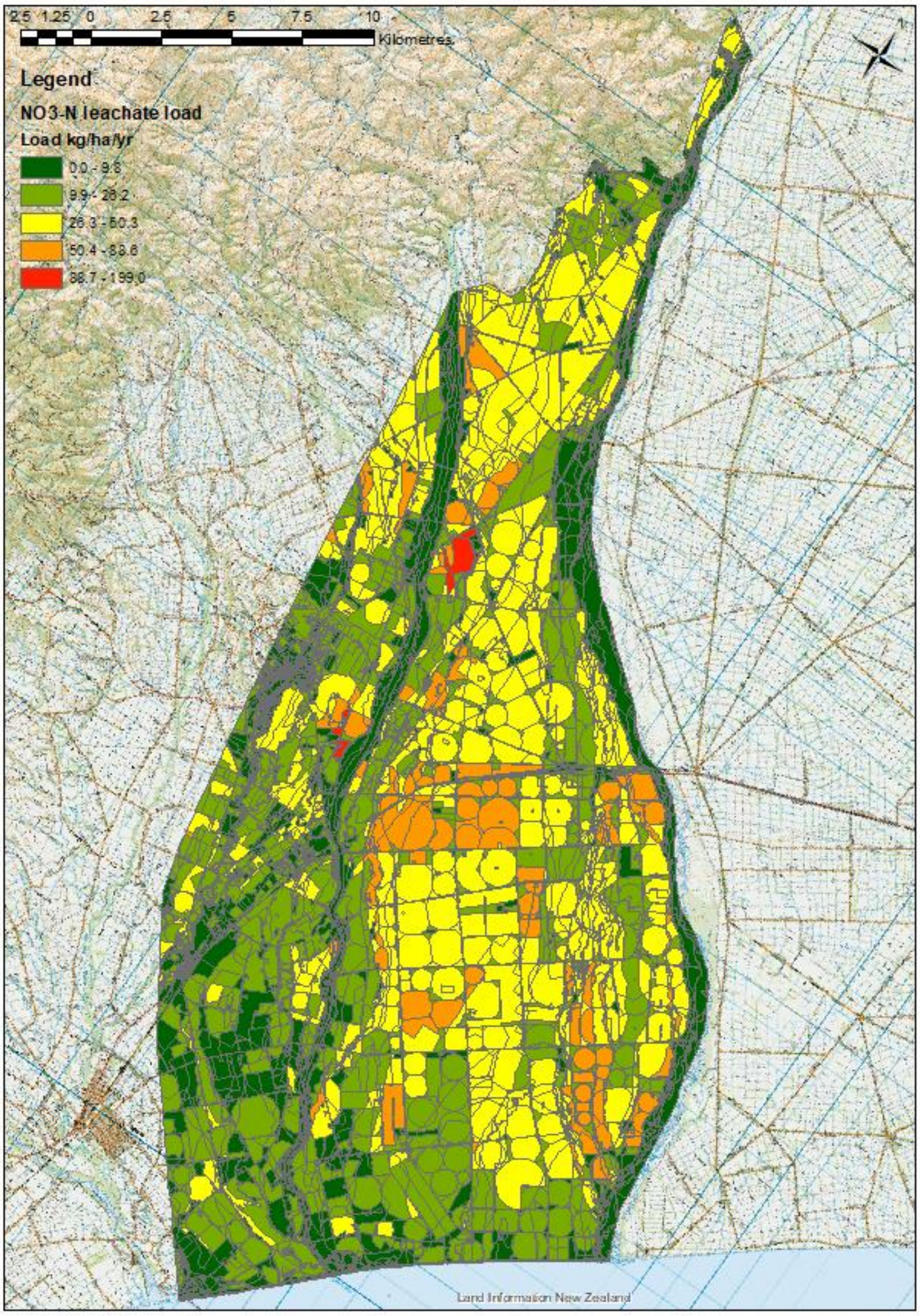

Figure 3-1: NO_3-N load from MGM OVERSEER modelling (Mojsilovic, 2019)

3.2 Model parameters

Known input concentrations would ideally be used to calibrate the transport model parameters to the observation data. However, at the time of modelling, no estimates of current or historic nutrient leaching rates were available. Instead, a scenario leaching load map of good farming practice based on OVERSEER outputs was employed to calibrate the transport model parameters. The authors understand that after this modelling exercise, an estimate of 30% higher loads has been made by Environment Canterbury. The new estimate of current practice leaching rates is based on investigations in the Waimakariri CWMS Zone, (pers comm. Zeb Etheridge. *Senior Groundwater Scientist at Environment Canterbury*, June 2018).

Based on feedback from Torsten Vammen Jacobsen (*Senior Hydrologist DHI*. *pers. Comm.* May 2015) we only attempted limited calibration of the transport model due to lack of historical data on NO_3-N leaching loads. Limited calibration (using porosity) was conducted to match residence time and nutrient breakthrough based the opinion of Environment Canterbury water quality scientists Shirley Hayward and Marta Scott (pers comm. 2016) and groundwater age for the shallow part of the aquifer. Following work conducted in support of the Managed Aquifer Recharge trial in Hinds, Ashburton (Durney, 2016), we incorporated dual porosity flow. Dual porosity flow means that one component of particle flow is faster than the other and brings our model results and conceptualisation in line with the findings of Dann *et al*. (2008), in that it enables capture of preferential flow channels.

We used dispersion parameters informed by MIKE SHE defaults and the expert advice of Henning Prommer (*Senior Principal Research Fellow, Faculty of Science, School of Earth Sciences, University of Western Australia. pers. comm.* September 2016). The dispersion coefficients were modelled as homogenous and isotropic across the model domain (at a value of 1e-5) and under the assumption that numerical dispersion controlled by model grid size will dwarf true dispersion.

Due to lack of field data on rates of nutrient loss from soils under various land use, combined with the scale of the integrated model, we decided to conserve the NO_3-N mass within the model, i.e. denitrification or other reactive processes (i.e. sorption) were not included. This approach means modelled results will be conservative and are likely to present an overestimate of groundwater NO_3-N concentrations and associated discharges to surface water. The limited calibration means that the model results presented are essentially those of a scenario that consists of:

- currently consented groundwater abstraction adjusted to meet provisions of existing plans and Environment Canterbury's Land and Water Regional Plan
- implementation of the Rangitata South Irrigation scheme
- planned minimum flows for the Orari River and Ohapi Creek
- on-farm good management practice
- estimated nutrient loss from existing farm types assuming good farming practice.

3.3 Results

Model calibration of the contaminant transport model has been assessed qualitatively, and despite calibration being limited to porosity, it produces reasonable results. The model results are comparable to the observations at most monitoring sites. Model results are compared to the latest and longer-term concentrations in Environment Canterbury's monitoring wells in Figure 3-2.

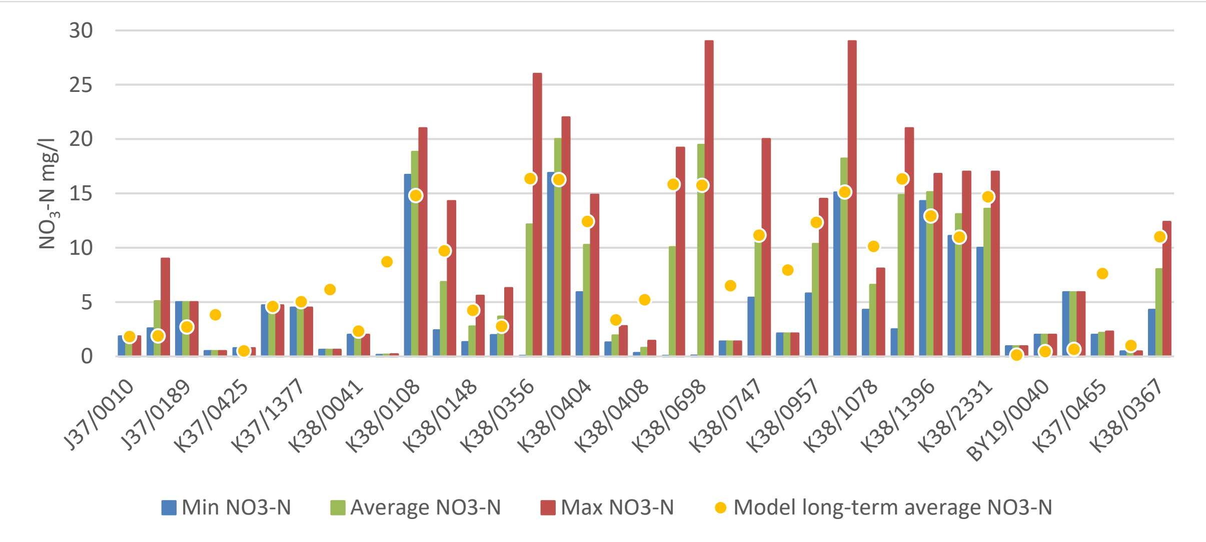

Figure 3-2: Observed NO_3-N concentrations compared to long-term model averages at Environment Canterbury monitoring wells

Figure 3-2 shows that without accounting for reactive processes, the modelled long-term average nitrate concentration under the good farming practice loadings is likely to be close to the average observed concentration in most Environment Canterbury monitoring wells.

Those wells where the modelled concentration is significantly greater than the observed maximum suggests that the groundwater system may still be under-representing the overlying land use effects or be demonstrating the effects of reactive chemical processes.

The model suggests that the shallow parts of the aquifer have a residence time in the order of zero to five years. Deeper parts of the aquifer respond much slower, taking around 100 to 150 years to reach equilibrium. Figure 3-3 provides a spatial representation of the model's first saturated zone layer compared to observations. Results along the southwestern margin of the Rangitata River tend to overpredict NO_3-N concentration and look to be closer to the leaching risk maps than observations. This suggests that the model is underpredicting the level of dilution from the Rangitata River in this area.

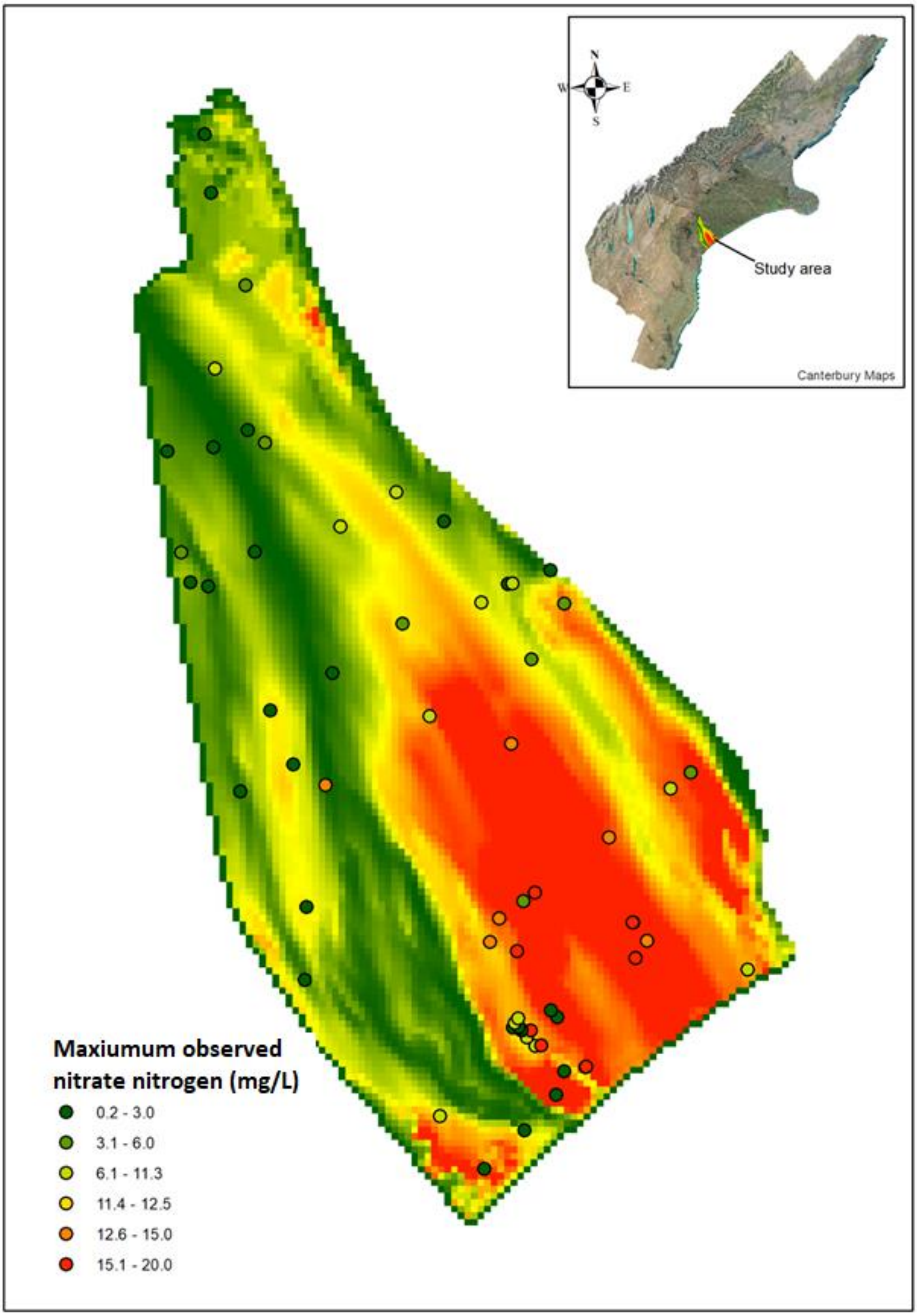

Figure 3-3: Long-term NO_3-N model outcome for the Orari Plains

Figure 3-4 shows the long-term average NO_3-N concentrations in the top 30 m of the aquifer as a result of MGM good management practice. Concentrations in deeper parts of the aquifer will be lower, as seen in Figure 3-5, which shows the estimated long-term NO_3-N concentrations 60-70 metres below ground level (m bgl).

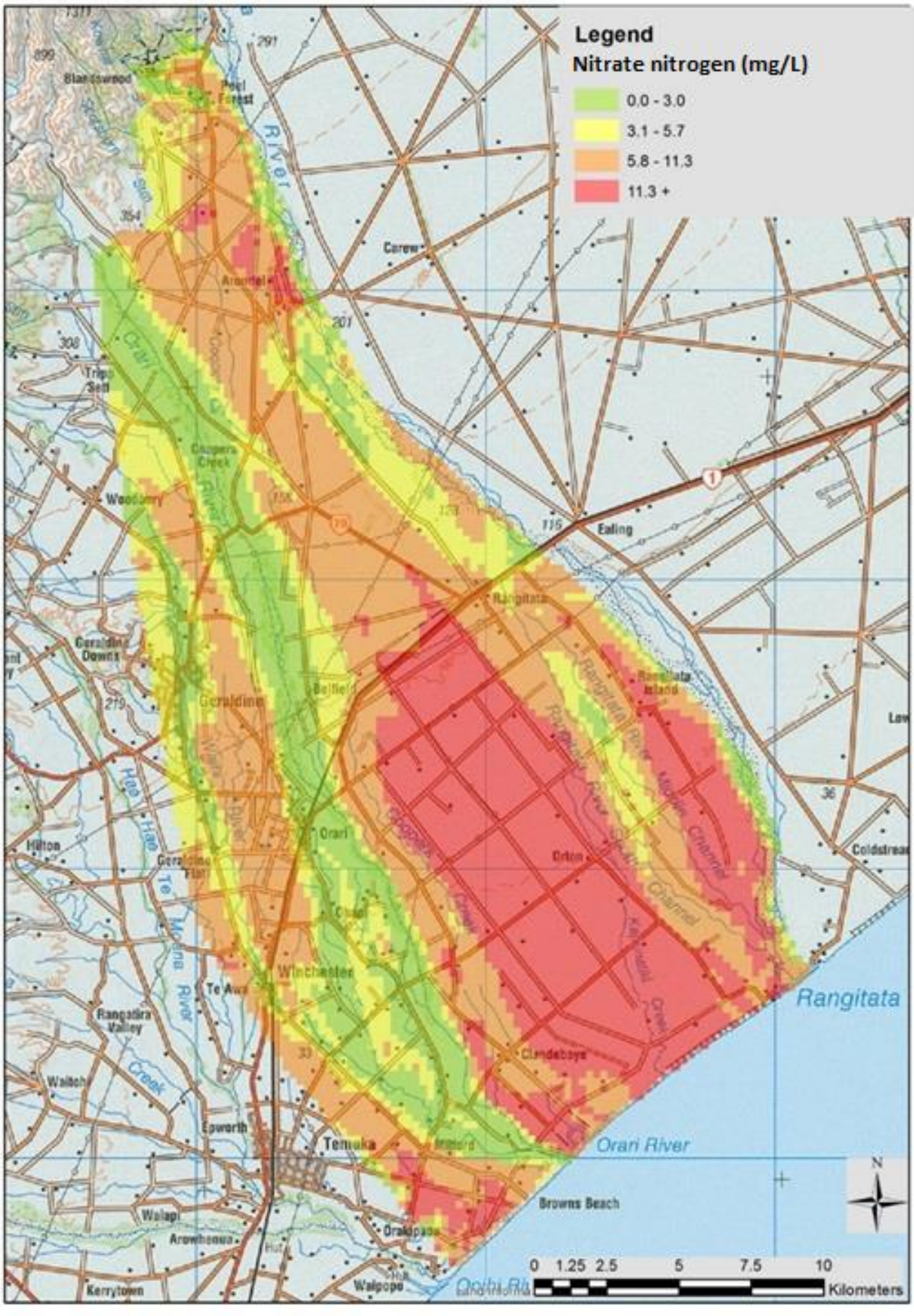

Figure 3-4: Long-term average NO_3-N concentration in shallow groundwater (<30 m bgl)

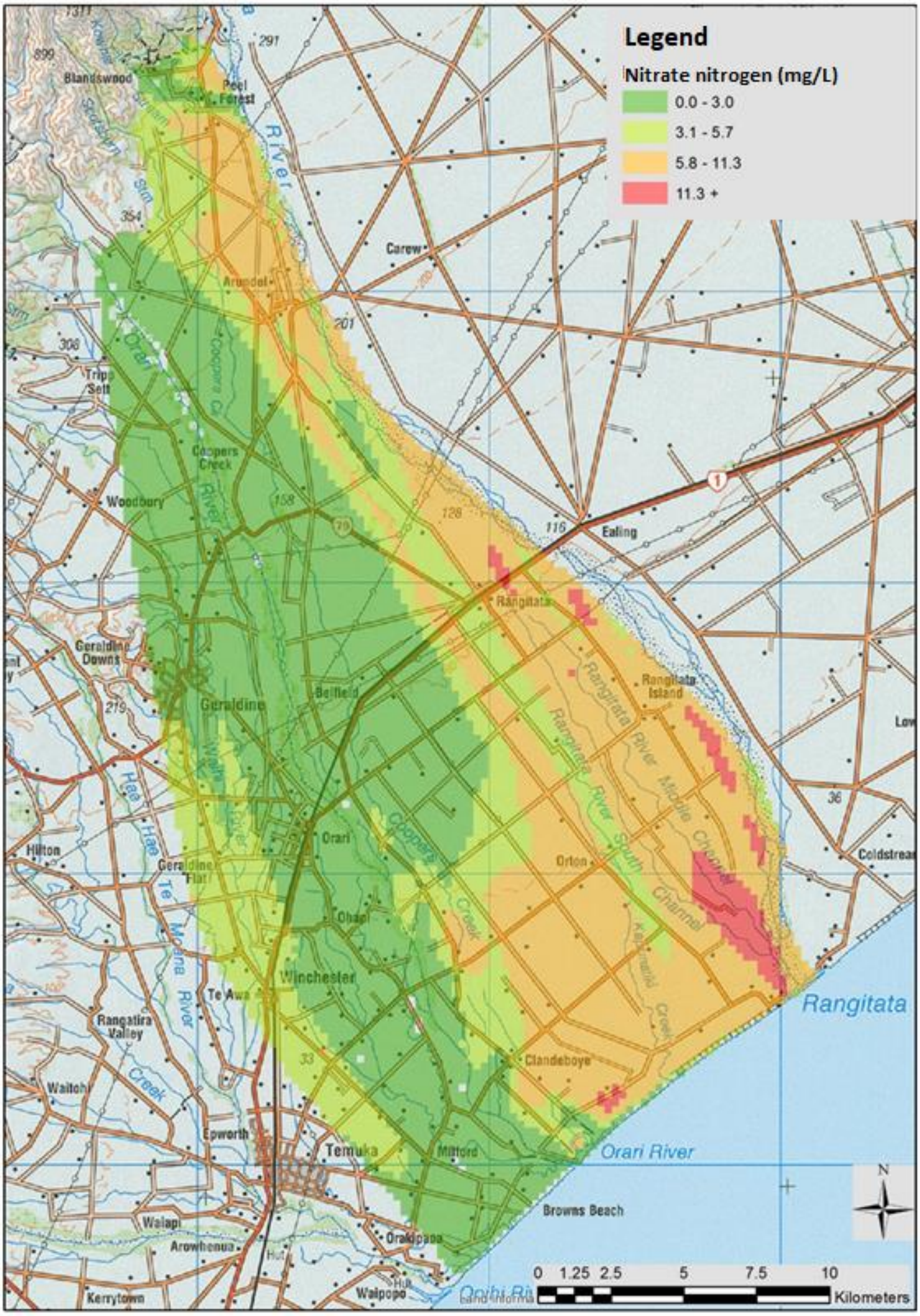

Figure 3-5: Long-term average NO_3-N concentrations in groundwater 60 -70 m bgl

3.4 Surface water quality

We compared the model results against three surface water quality sites in the catchment. Overall, the model appears to perform well against these sites, especially given the lack of instream water quality process modelling (e.g. plant uptake). Table 3-1 shows the modelled water quality compared to the observed concentrations at the three locations.

Table 3-1: Surface water observation site NO_3-N concentrations, observed and modelled

Observation site	Site number	Observed average NO_3-N	Current pathways long-term average NO_3-N
Ohapi Creek	SQ21047	1.0	1.4
Orari River (upstream of the confluence with Ohapi Creek)	SQ26633	1.6	2.0
Rhodes stream	SQ20545	10.1	10.2

4 Conclusions

Although the water quality transport model was reliant on modelled estimates of nutrient leaching inputs for sources of NO_3-N, and despite limited calibration, the contaminant transport model developed appears to perform well relative to recorded observations. In the absence of denitrification, sorption or reactive processes, the modelled NO_3-N over predictions suggest that full equilibrium conditions may not have been reached and that consequently, NO_3-N concentrations in groundwater may generally rise across the catchment, though groundwater close to the Orari River is expected to continue to be of good quality. In terms of predictions, the model performs well against spring-fed streams such as the Ohapi Creek, Rhodes Stream and the lower Orari River.

The model performance provides confidence that the model setup and functions are reasonable and hence can be used for catchment-scale water quality assessments in the relative change framework.

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