Singh, R., Elwan, A., Horne, D., Manderson, A., Patterson, M., Roygard, J., 2017. Predicting land-based nitrogen loads and attenuation in the Rangitikei River catchment – the model development. In: *Science and policy: nutrient management challenges for the next generation.* (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13 pages.

PREDICTING LAND-BASED NITROGEN LOADS AND ATTENUATION IN THE RANGITIKEI RIVER CATCHMENT – THE MODEL DEVELOPMENT

Ranvir Singh[1], Ahmed Elwan[1], Dave Horne[1], Andrew Manderson[2], Maree Patterson[3], and Jon Roygard[3]

[1]*Fertilizer and Lime Research Centre, Massey University, Palmerston North*
[2]*Landcare Research, Palmerston North,*
[3]*Horizons Regional Council, Palmerston North*
E-mail: R.Singh@massey.ac.nz

Abstract

Under the National Policy Statement for Freshwater Management 2014 (NPSFM), Regional Councils are required to produce a set of 'freshwater resource accounts' for defined individual Freshwater Management Units (FMUs) in their regions. This requires establishment of a freshwater quality accounting system which is based on measured, modelled or estimated loads of relevant water contaminants in groundwater and surface water bodies.

Nutrient budgeting tools (such as Overseer NB) have been developed to account for nutrient flows and losses from farming systems. However, these models mostly account for nutrient flows within the farm boundary and predict nutrients losses from the root zone. Catchment characteristics like topography, rainfall, the nature of the vadose zone, underlying geology, and subsurface geochemistry may further affect the transport and transformation of nutrients such as nitrate-nitrogen (NO_3-N) along flow pathways from farms to rivers and lakes.

We investigated and developed a simple model to account for the influence of different soil types and underlying geology on the transformation of nitrogen (N) in the Rangitikei River catchment. The main soil and rock types of the catchment were classified into low, moderate and high N attenuation capacities, depending on their texture, drainage rate and carbon content. These N attenuation capacity classes were assigned nitrogen attenuation values in order to predict soluble inorganic nitrogen (SIN) loads to the river. The river SIN loads predicted in this manner were compared with the SIN loads measured in the river.

We found that the SIN loads measured in the river were significantly smaller than the estimates of the quantities of nitrogen leached from the root zone. The prediction of SIN loads in the river was improved by incorporating the spatial effects of both of the different soil types and underlying geologies on N attenuation in the subsurface environment of the Rangitikei River catchment.

1. Introduction and Objectives

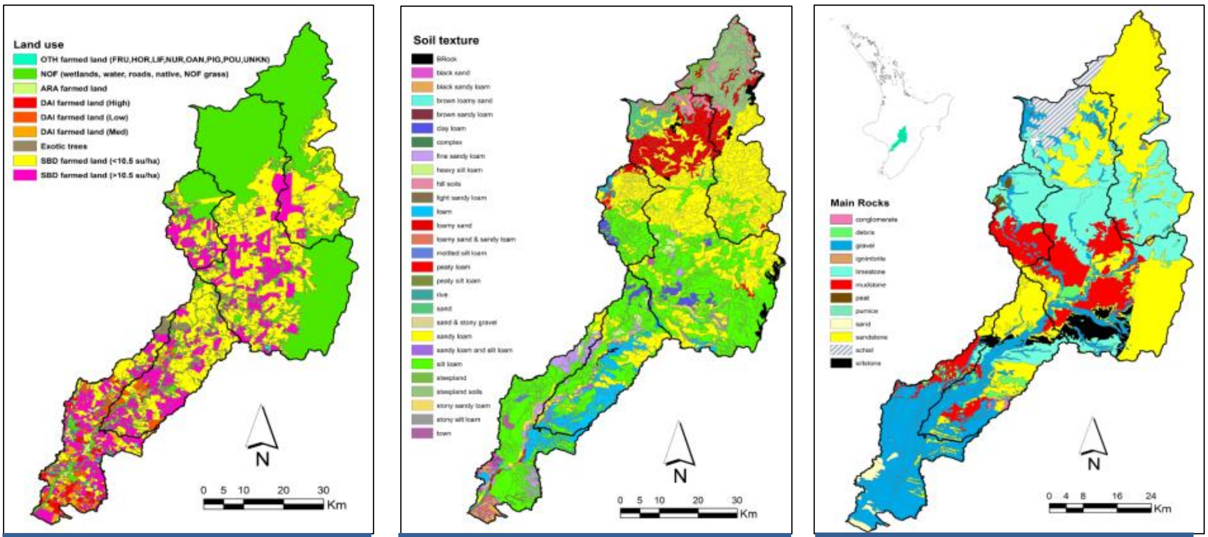
Elevated levels of nutrients such as nitrogen (N) and phosphorus (P) in surface waters are of increasing concern because of their effects on the degradation of freshwater quality and ecosystems health. Intensive agricultural activities are generally associated with runoff and/or leaching of these nutrients (N & P) from soils to receiving freshwater bodies in agricultural landscape (Di & Camerson, 2002; Monaghan *et al*., 2005; Roygard *et al*., 2012). Unfortunately, applications of fertilizer especially where these are applied in excessive amounts, intensive cropping, pastoral grazing and associated animal urine patches, and farm effluent spreading have the potential to increase nutrient leaching and/or runoff from agricultural soils (Di & Cameron, 2002; Wang *et al.*, 2004). Pastoral grazed systems are identified as inherently leaky with respect to nitrogen, the key nutrient implicated in the deterioration of surface and ground water quality in New Zealand's agricultural catchments.

The National Policy Statement for Freshwater Management (NPS-FM) requires Regional Councils to produce a set of 'freshwater accounts' every 5 years for individual Freshwater Management Units "FMUs" (Ministry for the Environment, 2014). This requires establishment of a freshwater quality accounting system which is based on measured, modelled or estimated loads of relevant water contaminants in groundwater and surface water bodies. Nutrient budgeting tools (such as Overseer NB) have been developed to account for nutrient flows and losses from farming systems. However, these models mostly account for nutrient flows within the farm boundary and predict nutrients losses from the root zone (which Overseer NB sets at a depth of only 60 cm for pasture). Catchment characteristics like topography, rainfall, the nature of the vadose zone, underlying geology, and subsurface geochemistry may further affect the transport and transformation of nutrients such as nitrate-nitrogen (NO_3-N) along flow pathways from farms to rivers and lakes (Stenger *et al.*, 2014; Singh *et al.*, 2014; Elwan *et al.*, 2015).

We analysed estimates of nitrogen flows and its potential attenuation in the Rangitikei catchment (Singh *et al.*, 2017). We investigated and developed a simple model to account for the influence of different soil types and underlying geology on nitrogen attenuation and prediction of land-based soluble inorganic nitrogen (SIN) loadings in the Rangitikei River. This hydrogeologic-based model was further used (Horne *et al.*, 2017) to simulate a number of scenarios to evaluate the potential of redesigning land use patterns and practices in a coordinated fashion by spatially aligning intensive land use with high nitrogen attenuation pathways, i.e. 'matching landuse with land suitability', to increase agricultural production while reducing the effects on the river water quality.

2. Study Area – Rangitikei River Catchment

The Rangitikei catchment covers an area of around 3887 km^2 in the lower part of the North Island of New Zealand (Figure 1). The major land use categories are sheep/beef/dairy (~50%) and NOF "i.e. Blocks not otherwise used for farming, such as indigenous forest" (~42%) (Figure 1a). There are approximately 18,000 ha of dairy farms and 1,100 ha of arable farmed land mainly in the lower parts of the catchment. The major soil types in the catchment are silt loam (~36%), sandy loam (~30%) and loam/loamy sand (~13%) (Newsome et al., 2008) (Figure 1b). The major rock types in the catchment are sandstone (~32%), limestone (~23%), gravel (~22%) and mudstone (~12%) (QMAP; Heron, 2014) (Figure 1c).



Major land use - Sheep/beef/dairy (~50%) ; and NOF "i.e. Blocks not otherwise used for farming" (~42%). ~ 18,000 ha of dairy farming and 1,100 ha of arable farmed land mainly in the lower parts of the catchment.

Major soil types are silt loam (~36%), sandy loam (~30%) and loam/loamy sand (~13%)

Major rock types in the catchment are sandstone (~32%), limestone (~23%), gravel (~22%) and mudstone (~12%)

Figure 1: The Rangitikei catchment and the distribution of its main land use, soil texture and rock types. In the landuse layer, ARA = Arable farm; NOF = Blocks not otherwise used for farming; DAI = Dairy farm; OTH farm + <10ha = Other farm type (minor) + pastoral farms <10ha; and SBD = Sheep/beef/deer farm.

3. Estimates of Nitrogen Loads in the Rangitikei River

Horizons Regional Council (HRC) monitors flow and several water quality parameters including nitrate-nitrogen (NO_3^--N), soluble inorganic nitrogen (SIN) and total nitrogen (TN) at five sites in the Rangitikei River (Figure 2). The water quality parameters are sampled and analysed at a monthly frequency while the river flow is recorded continuously every 15 minutes. Table 1 summarizes the durations of the monthly water quality parameters and continuous river flow records available and used for the five sub-catchments in the Rangitikei catchment.

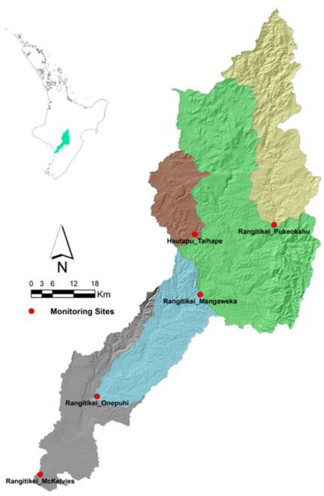


Table 1: Records of river flow and water quality parameters monitored by HRC at each monitoring site on the Rangitikei River.

Site	River Flow ($m^3 s^{-1}$)*	Water Quality Parameters ($mg L^{-1}$)**
Rangitikei_Pukeokahu	March-1999 to June-2015	July-2008 to June-2015
Hautapu_Taihape	July-1993 to June-2015	July-2008 to June-2015
Rangitikei_Mangaweka	July-1993 to June-2015	July-2008 to June-2015
Rangitikei_Onepuhi	July-1993 to June-2015	July-2008 to June-2015
Rangitikei_McKelvies	July-1993 to June-2015	July-2008 to June-2015

* Continuous (every 15 minutes) river flow ($m^3 s^{-1}$)

** Monthly water quality parameters ($mg L^{-1}$) including nitrate-nitrogen, ammoniacal-nitrogen and total nitrogen

Figure 2: Location of river flow and water quality monitoring sites in the Rangitikei catchment.

A number of methods have been developed to quantify contaminant loads in streams and river using infrequent (monthly) river water quality measurements and frequent river flow measurements. These methods can be categorized into average, ratio estimator, regression (or rating curve), stratification and planning level load estimation methods (Quilbé *et al.*, 2006). Recently, Elwan *et al.*, (201X) reviewed and assessed the influence of different sampling frequencies and load estimation methods on the quantification of annual contaminant loads of nitrate-nitrogen (NO_3^--N), soluble inorganic nitrogen (SIN), total nitrogen (TN), dissolved reactive phosphorus (DRP), total phosphorus (TP), and total suspended solids (TSS) in the Manawatu River at Teachers College monitoring site in Palmerston North. Elwan *et al.*, (201X) found that, for monthly water quality sampling, the Flow Stratified (FS) method (mainly used by Horizons Regional Council) resulted into low bias (calculated as the difference between estimated load and reference "true" load) of 1% for SIN and -10% for TN at the study site.

Using the measured continuous river flow (m^3 s^{-1}) and monthly concentrations of nitrogen (NO_3^--N, SIN and TN) (mg L^{-1}) (Table 1), we applied the Flow Stratified (FS) method to estimate average annual loads of NO_3^--N, SIN and TN (t yr^{-1}) at the five monitoring sites in the Rangitikei River (Figure 3). The average annual SIN load was estimated to increase from 33 t yr^{-1} at the Pukeokahu site (in upper parts of the catchment) to 592 t yr^{-1} at the McKelvies site (near the coast). Figure 3 suggests that most of the SIN load in the river was in the form of nitrate-nitrogen (NO_3^--N).

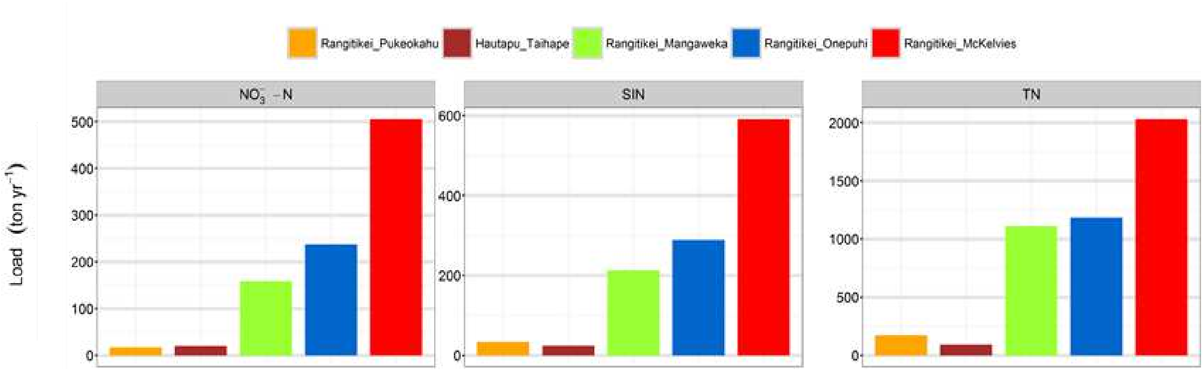


Figure 3: Estimates of cumulative average annual loads (t yr^{-1}) of nitrate-nitrogen (NO_3^--N), soluble inorganic nitrogen (SIN) and total nitrogen (TN) at five monitoring site in the Rangitikei River.

The calculated average annual nitrogen loads in the river (Figure 3) included both point sources (e.g. treated wastewater discharges) and diffuse sources (e.g. farms runoff/leaching) contributions to the river load. HRC calculated and provided the contribution of point source SIN loads in different sub-catchments of the Rangitikei catchment (Source: Ms. Amy Shears, personnel communication). The point sources SIN loads were subtracted from the river SIN loads (Figure 3) to calculate the diffuse (non-point sources) SIN loads in the river received from different sub-catchments of the Rangitikei catchment (Figure 4). Note that Figure 4 presents the average annual nitrogen loads received from the individual sub-catchments (contributing to each monitoring site) whereas Figure 3 presents cumulative average annual nitrogen loads (t yr^{-1}) at each monitoring site.

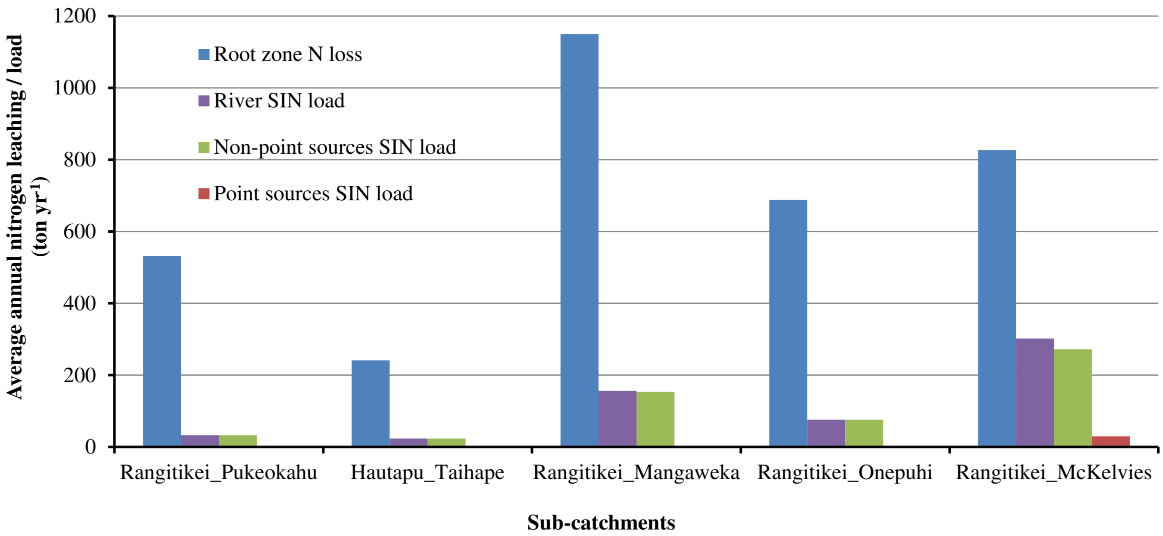


Figure 4: Estimates of average annual root-zone nitrogen loss and river soluble inorganic nitrogen (SIN) loads (t yr^{-1}) in different sub-catchments of the Rangitikei River.

The average annual SIN load to the river was estimated to range from 33 t yr^{-1} received from Rangitikei_ Pukeokahu sub-catchment (in the upper parts of the catchment), to 302 t yr^{-1} received from the Rangitikei_McKelvies sub-catchment (in the lower parts of the catchment). The Rangitikei River is estimated to receive on average 94% of its average annual SIN loads from diffuse sources, varying from 90% in the Rangitikei_Mckelives sub-catchment to approximately 100% in the Rangitikei_Pukeokahu, Hautapu_Taihape and Rangitikei_Onepuhi sub-catchments.

The average annual SIN load from diffuse sources was estimated to range from 33 t yr^{-1} received from Rangitikei_ Pukeokahu sub-catchment, to 272 t yr^{-1} received from the Rangitikei_McKelvies sub-catchment, with a total of 559 t yr^{-1} for the whole Rangitikei catchment. The rate of SIN loading from diffuse sources increased longitudinally, from 0.4 kg ha^{-1} yr^{-1} in the Rangitikei_Pukeokahu where landuse is mostly extensive to 4.5 kg ha^{-1} yr^{-1} in the more intensively farmed Rangitikei_McKelvies sub-catchment. The overall diffuse SIN loading rate for the entire Rangitikei catchment is estimated at 1.4 kg ha^{-1} yr^{-1}.

4. **Estimates of Nitrogen Leaching from Agriculture and Other Areas**

Manderson *et al.*, (2016) used spatially–informed Overseer nutrient budget modelling to estimate N leaching (N-loss) (kg N ha^{-1} yr^{-1}) from the majority of agricultural land uses, and reference N-loss values from literature for the remaining non-agricultural areas (forestry, natural areas, urban) to estimate average annual nitrogen leaching (N-loss) Rangitikei catchment. OVERSEER® version 6.2.2 (Wheeler et al., 2003) was used, and the reference N-loss values for the non-agricultural areas were sourced from the literature e.g. Lilburne *et al.*, 2013; Ledgard, 2014; Monaghan *et al.*, 2009; Parfitt *et al.*, 201; Wheeler *et al.*, 2010.

Figure 5 reproduces the estimates of average N-loss from the root zone of the main land uses in the Rangitikei catchment (Manderson *et al.*, 2016). The estimates of average annual N-losses varied under different land uses, and within a landuse type. The average annual N-losses were estimated to be highest at 37 kg N ha^{-1}yr^{-1} under high intensity dairy farming, followed by 28 and 22 kg N $ha^{-1}yr^{-1}$ under medium and low intensity dairy farming, receptively. The average annual N-losses were estimated to be from 9 to 11 kg N ha^{-1} yr^{-1} under sheep, beef and deer grazing, 13 kg N ha^{-1} yr^{-1} under arable farming, and 10 kg N ha^{-1} yr^{-1} under other farming activities (Figure 5). Reference N-loss values of 1.9 kg N ha^{-1} yr^{-1} for forestry and 1.8 kg N ha^{-1} yr^{-1} for NOF were used (Manderson et al., 2016). These estimates of N-losses were used at the block level along with the area (ha) of each block to quantify the root zone N loss in each of the five Rangitikei sub-catchments (Figure 4). The average annual root zone N loss is estimated to range from 241 t yr^{-1} in the Hautapu_Taihape sub-cathcment, to 1150 t yr^{-1} in the Rangitikei_Mangaweka sub-catchment (Figure 4). This summed to an estimate of a total of 3437 t yr^{-1} of average annual nitrogen leached from the root zone of different land uses in the catchment.

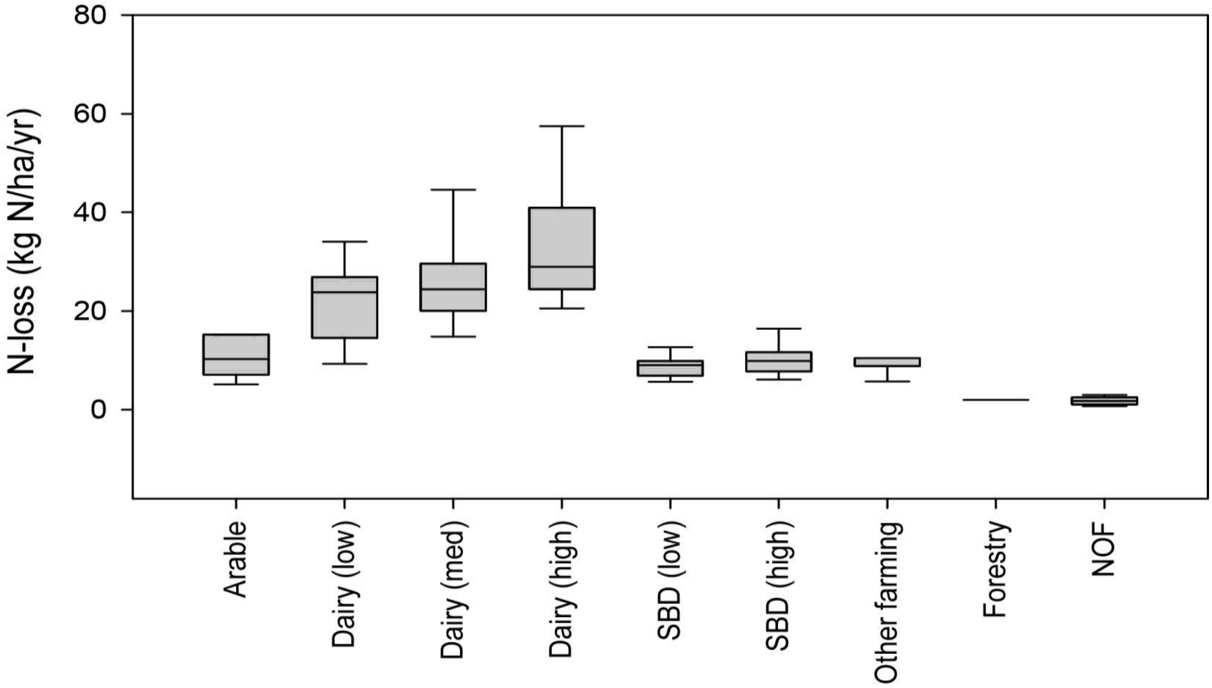


Figure 5: Estimates of average annual root-zone nitrogen leaching (N-loss) under different landuse in the Rangitikei River (Source: Manderson et al. 2016).

5. **Modelling Land-based Nitrogen Loads to the Rangitikei River**

Nutrient budgeting tools (such as Overseer NB) account for nutrient flows within the farm boundary and predict nutrients losses from the root zone. They do not account for the effects of catchment characteristics such as underlying geology and subsurface geochemistry on the transport and transformation of nutrients such as nitrate-nitrogen (NO_3-N) along flow pathways from farms to rivers and lakes. Figure 4 clearly highlights the signficant differences between the estimates of average annual root zone nitrogen losses and SIN loads in the river in different sub-catchments of the Rangitikei catchment. On the catchment-scale, the average annual root zone nitrogen loss of 3437 t yr^{-1} is estimated to be approximatley six times greater than the average annual river SIN load of 559 t yr^{-1} from diffuse sources. This suggests an average annual nitrogen reduction or attenuation of 84% in the Rangitikei catchment. This average annual nitrogen attenuation varied from 67% in the Rangitikei_McKelvies sub-catcment to 94% in the Rangitikei_Pukeokahu sub-cathcment

(Figure 4). Elwan *et al.* (2015) found similar spatial variation in the nitrogen attenuation capacity among different sub-catchments in the Tararua area of the Manawatu River.

Leached nitrogen from agricultural soils may or may not contribute to the nitrogen loads of surface waters, depending upon the groundwater – surface water interaction and transformations or attenuation of leached NO_3^--N in flow pathways from farms to receiving surface waters (Stenger *et al.*, 2014; Singh *et al.*, 2014). Rivas *et al.* (2014) and Collins *et al.* (2016) have assessed groundwater redox conditions in Tararua and lower Rangitikei areas, respectively, and both studies identified a potential or capacity for spatially variable denitrification in the subsurface environment. Elwan *et al.* (2015) assessed this spatial nitrogen attenuation capacity as positively correlated with fine textured soils (e.g. clay loams), but negatively correlated with both well-drained soils (e.g. soils with drainage class 5, in the Fundamental Soil Layer "FSL") in the Tararua area of the Manawatu River.

In-stream uptake of nitrogen by biological growths such as periphyton could also significantly affect flows and, therefore, measurements of SIN in streams and rivers (Heathwaite, 1993).

We developed a simple hydrogeologic model (Eq. 1) to account for spatial effects of different land units (soil and rock types) and in-stream nitrogen attenuation to predict SIN loads in the river. The model developed by Elwan *et al.* (2015) was updated to account not only for the variable nitrogen attenuation capacities of different rock types but also for different soil types and in-stream uptake of nitrogen, as follows:

$$River\ SIN\ load\ = m\left[\sum_{i=1}^{n} A_i * N_i * \left(1 - AF_{N_{RT}}\right)\left(1 - AF_{N_{ST}}\right)\right] - N_{up} \qquad \text{(Eq. 1)}$$

Where:
$\boldsymbol{m}$ = Conversion factor;
$\boldsymbol{A_i}$ = Area of land use type (ha);
$\boldsymbol{N_i}$ = Nitrogen loss rate for different land use type (kg ha^{-1} yr^{-1});
$\boldsymbol{AF_{N_{RT}}}$ = Nitrogen attenuation capacity (factor) for different rock types;
$\boldsymbol{AF_{N_{ST}}}$ = Nitrogen attenuation capacity (factor) for different soil types; and
$\boldsymbol{N_{up}}$ = In-stream nitrogen uptake (t yr^{-1}).

5.1 Estimates of in-stream nitrogen uptake in the Rangitikei River

In-stream uptake by biological growth such as periphyton could convert significant amounts of soluble inorganic nitrogen (NO_3-N, NO_2-N and NH_4+-N) to organic N in stream and rivers (Heathwaite, 1993). However, neither direct measurements of this uptake or locally calibrated models to estimate in-stream nitrogen uptake by periphyton growth were available.. Hence, we developed a simple model to estimate potential dissolved inorganic nitrogen uptake by periphyton in streams and rivers, as follows:

$$N_{up} = m * (f_n * AI * P) * (f_p * W) \quad \text{(Eq. 2)}$$

Where:

N_{up} = In-stream N uptake ($t\ yr^{-1}$);

m = Conversion factor;

W = Wetted area of stream/river bed (m^2);

f_p = Periphyton cover fraction (-);

P = Periphyton growth (mg *Chl-a*/m^2);

AI = Autotrophic Index (i.e. ratio of periphyton biomass (ash-free dry mass) to Chl-a) (-); and

f_n = Periphyton biomass N content fraction (-).

We applied the simple in-stream nitrogen uptake model (Eq. 2) to estimate the (potential) average annual in-stream nitrogen uptake by periphyton in different sub-catchments of the Rangitikei River. The average wetted area of streams and river bed (*W*) for each sub-catchment was calculated by multiplying the estimates of channel length (m) and wetted perimeter (m) of medium to large streams (stream order 2 and above) in the sub-catchment. The average stream channel wetted perimeters for different stream orders were estimated based on streamflow gauging conducted by HRC in the Rangitikei catchment. The average periphyton cover fraction was estimated at 0.60 based on long-term periphyton measurements in the Rangitikei River (Kilroy *et al.*, 2016). The measurements of *chlorophyll-a* (*Chl-a*) accounts (predominantly) for amounts of autotrophic (periphyton algae) growth in streams and rivers (Biggs and Kilroy, 2000). A maximum of 3 - 4 accruals of 200 mg *Chl-a*/m^2 were assumed to occur giving a total of 600 - 800 mg *Chl-a*/m^2 of potential periphyton growth per year in the river. The autotrophic index (*AI*) measures the ratio of periphyton biomass (ash-free dry mass) to *Chl-a* measured in streams and rivers. Biggs and Kilroy, (2000) suggest that "stream periphyton communities (dominated by algae) usually contain 1 – 2% (by weight) of *chlorophyll-a* giving *AI* values of 50 – 100". The *AI* values > 400 are suggested as indicative of periphyton communities affected by non-autotrophic matters (organic pollution) (Biggs and Kilroy, 2000). There were no measurements available for periphyton biomass (ash-free dry mass) or *AI* values in the Rangitikei River. Hence, a range of *AI* values were used from 50 – 400 as a sensitivity analysis to assess the likely quantity of in-stream N uptake in different sub-catchments of the Rangitikei River. A value of 0.05 was used for the content of nitrogen in periphyton biomass.

Depending on the values assumed for periphyton growth (600 - 800 mg *Chl-a*/m^2) and *AI* values (from 50 – 400), the potential in-stream nitrogen uptake was estimated between 18 to 194 ton yr^{-1} in the Rangitikei catchment. This highlights a high level of uncertainly around instream nitrogen uptake in the catchment. However, a potential in-stream nitrogen uptake of 18 to 194 ton yr^{-1} equates to between <1 to 5.7% of the estimated total nitrogen loss (3437 t yr^{-1}) from the root zone in the catchment (Figure 4). Thus in-stream uptake is not a major contributor to the 84% reduction in nitrogen loads that occurs between the root zone and the monitoring sites in the river (Figure 4). Given the high level of uncertainly and its relatively small magnitude, the in-stream nitrogen uptake was not accounted for in subsequent analyses and development of the hydrogeologic model (Eq. 1) to predict SIN loads in the river.

5.2 Effects of soils and rock types on land-based nitrogen loads in the Rangitikei River

The effects of soils and underlying geology on land-based SIN loads were evaluated by developing and applying four versions of the hydrogeologic model (Eq. 1) (neglecting the in-stream nitrogen uptake term), as follows:

Model 1 - Uniform nitrogen attenuation factor

$$River\ SIN\ load\ (ton\ \mathrm{yr}^{-1}) = m\sum_{i=1}^{n} A_i * N_i * (1 - AF_{N\,0.5})$$

Model 2 - Variable nitrogen attenuation factor (soil types only – *FSL* layer)

$$River\ SIN\ load\ (ton\ \mathrm{yr}^{-1}) = m\sum_{i=1}^{n} A_i * N_i * (1 - AF_{N\,ST})$$

Model 3 - Variable nitrogen attenuation factor (rock types only - *QMAP* layer)

$$River\ SIN\ load\ (ton\ \mathrm{yr}^{-1}) = m\sum_{i=1}^{n} A_i * N_i * (1 - AF_{N\,RT})$$

Model 4 - Variable nitrogen attenuation factor (soil and rock types – *FSL* and *QMAP* layers)

$$River\ SIN\ load\ (ton\ \mathrm{yr}^{-1}) = m\sum_{i=1}^{n} A_i * N_i * (1 - AF_{N\,RT})(1 - AF_{N\,ST})$$

Where:

$\boldsymbol{m}$	= Conversion factor;
$\boldsymbol{A_i}$	= Area of different land use type (ha);
$\boldsymbol{N_i}$	= Estimates of nitrogen loss rate (kg ha^{-1} yr^{-1}) for different land use types;
$\boldsymbol{AF_N}$	= Subsurface nitrogen attenuation capacity (fraction) specific to soil types ($AF_{N\,ST}$) and rock types ($AF_{N\,RT}$)

The “Model 1” simply used a value of 0.5 for AF_N to simulate a uniform nitrogen attenuation capacity across the sub-catchments. This is a common approach used in translating the estimates of average annual root-zone nitrogen losses to river nitrogen loads in agricultural catchments (e.g. Roygard and Clark, 2012). The other three models used variable nitrogen attenuation factors based on only soils types “Model 2” or rock types “Model 3”, or a combination of both soils and rock types “Model 4”. For these models, the Rangitikei sub-catchments soil types (based on the Fundamental Soil Layer “FSL”; Newsome et al., 2008) and rock types (based on the QMAP; Heron, 2014) were classified into three nitrogen attenuation capacity categories (i.e. ‘high’, ‘medium’ and ‘low’). This categorisation was based on; geological material, texture, carbon content, and drainage characteristics. These classes were assigned different nitrogen attenuation factors ranging from 0.1 – 0.3 for the low category (e.g. stony sandy loam, sand, and sand & stony gravel, carbon class 5, drainage classes 4&5, gravels), 0.35 – 0.6 for the medium category (e.g. sandy loam and loam, carbon classes 3&4, drainage class 3, sandstone and limestone), and 0.70 – 0.85 for the high category (e.g. heavy silt loam, clay loam and peaty loam, carbon classes 1&2, drainage classes 1&2, mudstone and peat).

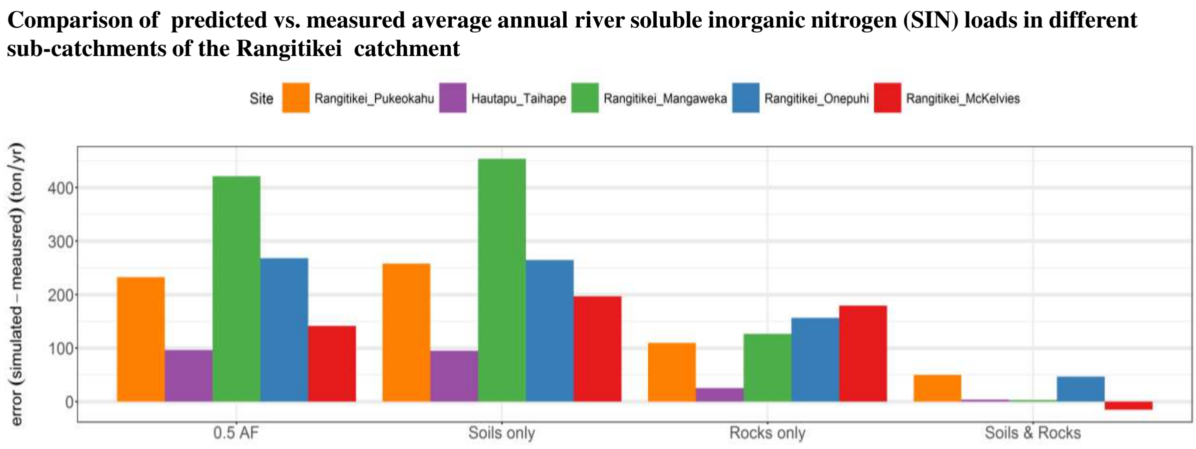


Figure 6: Differences between predicted and measured average annual river soluble inorganic nitrogen (SIN) loads (t yr^{-1}) in different sub-catchments of the Rangitikei River.

Figure 6 compares the predicted and measured average annual river SIN loads (t yr^{-1}) in different sub-catchments of the Rangitikei catchment. The "Model 1", using a uniform value for AF_N of 0.5, over-predicted the river SIN loads in the different sub-catchments. The differences between the predicted and measured river SIN loads varied from 97 to 421 t yr^{-1} in the different sub-catchments with an overall over-prediction of 1,161 t yr^{-1} (207%) for the whole Rangitikei catchment. The "Model 2", using variable values of AF_N for soils only, did not result in improved predictions of river SIN loads, but the "Model 3", using variable values of AF_N for rocks only, did improve the predictions of river SIN loads in the different sub-catchments.

However, "Model 4", using combined variable values of AF_N for soils and rocks types, resulted in markedly better predictions of average annual river SIN loads (t yr^{-1}) in the different sub-catchments of the Rangitikei River (Figure 6). The differences between the predicted and measured river SIN loads varied from -15 to +50 t yr^{-1} in the different sub-catchments with an overall over-prediction of only 88 t yr^{-1} (16%) for the whole Rangitikei catchment. This stresses the importance of different hydrogeologic settings (soil and rock types) in effecting nitrogen flows and its potential attenuation from farms to streams and rivers in the catchment.

6. Conclusions and Recommendations

Catchment-scale accounting of nitrogen flows in the Rangitikei River catchment suggests that soluble inorganic nitrogen (SIN) loads measured in the river (at 559 t yr^{-1}) are significantly smaller (about 84%) than the estimates of nitrogen leached from the root zone (at 3437 t yr^{-1}). This average annual nitrogen attenuation varied from 67% in the Rangitikei_McKelvies sub-catcment to 94% in the Rangitikei_Pukeokahu sub-cathcment.

The estimates of potential in-stream nitrogen uptake by periphyton were estimated to account for between <1 to 5.7% of the estimated total nitrogen loss (3437 t yr^{-1}) from the root zone in the catchment.

A series of models were evaluated for their ability to predict SIN loads to the Rangitikei river. The best predictions of SIN loads in the river were made when the spatial effects of both soil types and underlying geologies on nitrogen attenuation in the subsurface environment were incorporated in the model.

This clearly suggests that the effects of catchment characteristics such as soil type, underlying geology, and subsurface geochemistry should be considered in prediction and accounting of nitrogen flows and its potential attenatuon from farms to receiving surface water bodies in agricultural catchments. Further research is needed to better understand and model effects of catchment characteristics on spatial variations of nitrogen attenuation capacity in subsurface environment in agricutural catchments. Maps of this varibale nitorgen attenuation capacity will also be the basis of the tools and the planing required to spatially aligning intensive landuse practices with high nitrogen attenuation pathways, i.e. 'matching landuse with land suitability', in order to minimise the impacts of agricultural production on receiving water quality.

References

Biggs, B.J.F., Kilroy, C., 2000. Stream periphyton monitoring manual. Christchurch, New Zealand.

Collins, S. B., Singh, R., Rivas, A., Palmer, A., Horne, D., Roygard, J. & Matthews, A., 2016. Assessment of nitrogen flow pathways and its potential attenuation in shallow groundwaters in the lower Rangitikei catchment. In: *Integrated nutrient and water management for sustainable farming*. (Eds L. D. Currie and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 14 pages.

Di, H. J., & Cameron, K. C. (2002). Nitrate leaching in temperate agroecosystems: Sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems 64*(3), 237–256.

Elwan, A., Singh, R., Horne, D., Roygard, J., & Clothier, B., 2015. Nitrogen attenuation factor: can it tell a astory about nutrients in different subsurface environments? In: *Moving farm systems to improved attenuation*. (Eds L.D. Currie and L. L. Burkitt). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Elwan, A., Singh, R., Patterson, M., Roygard, J., Horne, D., Clothier, B., Jones, G., 201X. Influence of sampling frequency and calculation methods on calculation of annual river nutrient and suspended solids loads: A case study of the Manawatu River, New Zealand. *Submitted for peer-review journal publication*.

Heathwaite, A.L., 1993. Nitrogen cycling in surface waters and lakes. In: Burt, T.P., Heathwaite, A.L., Trudgill, S.T. (Eds.), *Nitrate Processes, Patterns and Management*. John Wiley & Sons Ltd.

Heron, D.W. (custodian), 2014. Geological Map of New Zealand 1:250 000. GNS Science Geological Map 1. Lower Hutt, New Zealand.

Horne, D., Elwan, A., Singh, R., Manderson, A., Patterson, M., Roygard, J., 2017. Predicting land-based nitrogen loads and attenuation in the Rangitikei River catchment – the implications for landuse. In: *Science and policy: nutrient management challenges for the next generation*. (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Kilroy, C., Wesh, J., Chakraborty, M., Brown, L., Watson, B., Patterson, M., Patterson, M., Shell, T., 2016. Periphyton in the Manawatu - Whanganui region State, trends and seasonality, 2009-2015. Horizons Report 2016/EXT/1494.

Ledgard, G., 2014. An inventory of nitrogen and phosphorus losses from rural land uses in the Southland region. In: *Nutrient management for the farm, catchment and* community. (Eds L.D. Currie and C.L Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Lilburne, L., Webb, T., Robson, M., Watkins, N., 2013. Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury. Environment Canterbury Regional Council.

Manderson, A., Lilburne, L., Vetrova, V., 2016. Spatial Overseer N-loss modelling for the Rangitikei Catchment. Unpublished Landcare Research report for DairyNZ. Palmerston North.

Ministry for the Environment, 2014; A guide to freshwater accounting under the National Policy Statement for Freshwater Management 2014. Publication No. ME1206, Ministry for the Environment, New Zealand.

Monaghan, R.M., Semadeni-Davies, A., Muirhead, R.W., Elliott, S., Shankar, U., 2009. Land use and land management risks to water quality in Southland. AgResearch Client Report for Environment Southland, 88 p.

Monaghan, R. M., Pat, R. J., Smith, L. C., Drewry, J. J., & Littlejohn, R.P., 2005. The impacts of nitrogen fertilisation and increased stocking rate on pasture yield, soil physical condition and nutrient losses in drainage from a cattle grazed pasture. *New Zealand Journal of Agricultural Research* 48, 227–240.

Newsome, P.F.J., Wilde, R.H., Willoughby, E.J., 2008. Land and resource information system spatial data layers: Data dictionary. doi:10.7931/DL1V88

Parfitt , R.L., Stevenson, B.A., Dymond, J.R., Schipper, L.A., Baisden W.T., Ballantine, D.J., 2012. Nitrogen inputs and outputs for New Zealand from 1990 to 2010 at national and regional scales. *New Zealand Journal of Agricultural Research* 55:3, 241-262.

Quilbé, R., Rousseau, A.N., Duchemin, M., Poulin, A., Gangbazo, G., Villeneuve, J.-P., 2006. Selecting a calculation method to estimate sediment and nutrient loads in streams: Application to the Beaurivage River (Québec, Canada). *Journal of Hydrology* 326, 295–310. doi:10.1016/j.jhydrol.2005.11.008

Rivas, A., Singh, R., Bishop, P., Horne, D., Roygard, J., & Hedley, M., 2014. Measuring denitrification in the subsurface environment of the Manawatu River catchment. In: *Nutrient management for the farm, catchment and community*. (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Roygard, J., Clark, M., 2012. Supplementary Statement by Jon Roygard and Maree Clark on Nutrient Load Scenarios and Methodology. Palmerst North.

Roygard, J.K.F., McArthur, K.J., Clark, M.E., 2012. Diffuse contributions dominate over point sources of soluble nutrients in two sub-catchments of the Manawatu River, New Zealand. *New Zealand Journal Marine and Freshwwater Research* 46, 219–241. doi:10.1080/00288330.2011.632425

Singh, R., Rivas, A., Espanto, P., Elwan, A., Horne, D., Roygard, J., Matthews, A., Clothier, B., 2014. Assessment of transport and transformation of nitrogen in the subsurface environment of Manawatu River catchment- work in progress. In: *Nutrient management for the farm, catchment and community*. (Eds L.D. Currie and L. L. Burkitt). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Singh, R., Elwan, A., and Horne, D., 2017. Nitrogen Accunting in the Rangitikei catchment. Massey FLRC Report to Horizons Regional Council. Under review.

Stenger, R., Clague, J., Woodward, S., Moorhead, B., Wilson, S., Shokri, A., Wohling, T., Canard, H., 2014. Root zone losses are just the beginning. In: *Nutrient management for the farm, catchment and* community. (Eds L.D. Currie and C.L Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Wang, H., Magesan, G. N., & Bolan, N. S., 2004. An overview of the environmental effects of land application of farm effluents. *New Zealand Journal of Agricultural Research 47(4),* 389-403. doi: 10.1080/00288233.2004.9513608

Wheeler, D.M., Ledgard, S.F., de Klein, C.A.M., Monaghan, R.M., Carey,P.L., McDowell, R.W., Johns, K.L., 2003. OVERSEERTM nutrient budgets—moving towards on-farm resource accounting. *Proc. NZ Grassland Association* 65, 191–194.

Wheeler, D.M., MacCormick, A. & Wheeler, S.L., 2010. Description of the house block model within OVERSEER® Nutrient Budgets. In: Farming's future – minimising footprints and maximising margins. Occasional Report No. 23., Palmerston North, New Zealand, Fertiliser and Lime Research Centre, Massey University.