NITROGEN ATTENUATION FACTOR: CAN IT TELL A STORY ABOUT THE JOURNEY OF NUTRIENTS IN DIFFERENT SUBSURFACE ENVIRONMENTS?

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Abstract

Catchment characteristics such as land use, topography, rainfall, soil texture and underlying geology may affect the transport and transformation of nutrients runoff and/or leached from farms to surface and ground waters. Therefore, it is important to identify these characteristics for an improved understanding of the spatial and temporal variations observed in nutrient concentrations and their influence on water quality at a catchment scale. A number of studies have investigated the relationship between catchment characteristics and surface water quality (mainly nitrate concentration). However, none of these studies have investigated the relationship between the nitrogen attenuation factor AF_N (decrease in nitrogen leaving the root zone, by different processes in the subsurface environment, to the river sampling site at the outlet of the catchment) and catchment characteristics. There is considerable interest in nitrogen attenuation in the 'sensitive' sub-catchments of the Manawatu River catchment such as the Tararua Groundwater Management Zone (TGWMZ) covering 3192 km^2 on the eastern side of the Ruahine and Tararua Ranges. Few studies have calculated the AF_N for specific sub-catchments and there is no study which determines the spatial distribution of the AF_N throughout the TGWMZ.

The main objectives of this study were two-fold; (1) to define and quantify the spatial variation of the AF_N throughout the TGWMZ, and (2) to evaluate the relationship between AF_N and catchment characteristics of the TGWMZ. A total of 15 surface water quality monitoring sites in the TGWMZ were used in ArcMap to delineate the contributing area 'sub-catchments' upstream of these sites. The shapefiles resulting from this delineation were then used to extract the key characteristics of each sub-catchment. The AF_N for each sub-catchment was calculated based on the root zone nitrogen leaching (estimated by adding up the land use area multiplied by the average nitrogen leaching rate of each main land use in the sub-catchment) and the river nitrogen load (estimated by using the measured monthly soluble inorganic nitrogen concentrations and daily water flow) at the outlet of the sub-catchment. Finally, the relationship between various sub-catchment characteristics and the AF_N values was evaluated using regression analysis.

We found that the AF_N varied from 0.29 (Makuri at Tuscan Hills and Kumeti at Te Rehunga sub-catchments) to 0.75 (Manawatu at Weber Rd and Raparapawai at Jackson Rd sub-catchments) with an average of 0.58 for the whole of TGWMZ (i.e. the Manawatu River at the Upper Gorge monitoring site). The regression analysis between AF_N and sub-catchment characteristics showed that the fine textured soils (e.g. clay loam) has a positive relationship with the AF_N (R^2=0.37, p <0.05). On the other hand, the AF_N has a negative relationship with

the well-drained soils (e.g. soils with drainage class 5 in the Fundamental Soil Layer "FSL") (R^2= -0.35, p <0.05) and the Base Flow Index "*BFI*" (R^2= -0.31, p <0.05). The AF_N values showed a spatial correlation with the redox status of the groundwater in the TGWMZ. Thus, the AF_N is a promising catchment descriptor that could infer information about catchment characteristics and its capacity to attenuate nitrogen runoff and/or leached from farms to surface and ground waters.

Introduction

Increased population and associated land use change are putting pressures on freshwater resources through water abstractions and eutrophication (Pimentel *et al*., 2004). Eutrophication is defined as the process through which water bodies became enriched in nutrients (mainly nitrogen and phosphorus) (Smith *et al*. 1999; Smith, 1998). Increased levels of nutrients in freshwater resources may cause severe problems such as oxygen deficiency, changes in pH levels, loss of biodiversity, and degradation of water quality (Carpenter *et al*., 1998; Davis & Koop, 2001; Gillingham & Thorrold, 2000; Ledgard *et al*., 1999; Monaghan & Smith, 2004; Monaghan *et al*., 2005). Thus, a sound understanding of sources, transport and fate of nutrients lost from farms to rivers and lakes is crucial to manage and mitigate any adverse impacts of agricultural intensification on water quality and freshwater ecosystems.

Catchment characteristics, like land use, topography, rainfall, soil type and underlying geology may affect the transport and transformation of nutrients runoff and/or leached from farms to surface and ground waters (Young *et al*., 1996). A full identification of these characteristics and their subsequent modifications, either natural or anthropogenic, is required for a better understanding of the spatial and temporal variations observed in nutrient concentrations and their influence on water quality at a catchment scale (Barlow *et al*., 2009; Heathwaite & Johnes, 1996; Quinn, 2004). Thus, the catchment scale studies are inevitable for land use and management decisions (Heathwaite & Johnes, 1996).

A number of studies have investigated the relationship between catchment characteristics and surface water quality. All these studies have found significant correlations between different catchment characteristics (e.g. soil texture, soil drainage, base flow index and geology) and the river water quality (mainly nitrate concentration) (Davies & Neal, 2007; Jarvie, Oguchi, and Neal 2002; Meynendonckx *et al*. 2006; Schilling & Lutz 2004; Thornton & Dise 1998). However, none of these studies have assessed the relationship between different catchment characteristics and their capacity to attenuate 'reduce' nitrogen lost from farms to rivers and lakes.

In New Zealand, Alexander *et al*. (2002) calculated the landscape yield (kg ha^{-1} yr^{-1}) and watershed yield (kg ha^{-1} yr^{-1}) for the Waikato river system. Based on their results, Clothier *et al*. (2007) calculated the nitrogen transmission factors ($\mathfrak{R}$; nutrient load in the river divided by nitrogen leaching from the root zone) for the Waikato river system and its sub-catchments which varied from 0.25 to 0.61. Using the river water quality and flow data and average nitrogen leaching rates from farms, Clothier *et al*. (2007) calculated the nitrogen transmission factor ($\mathfrak{R}$) for sheep/beef and dairy areas to be 0.50 in the upper parts of the Manawatu catchment. However, these studies also did not investigate the relationship between different catchment characteristics and their capacity to attenuate 'reduce' nitrogen lost from farms to the river. There is a need for an improved understanding about the spatial variation of nitrogen attenuation factor AF_N and how it is influenced by different catchment characteristics. Therefore, the main goals of this study were to (1) define and quantify the spatial variation of nitrogen attenuation 'reduction' capacity, and (2) evaluate the relationship between the nitrogen attenuation 'reduction' capacity and the catchment characteristics in the TGWMZ of the Manawatu River catchment.

Materials and Methods

Nitrogen can be attenuated 'reduced' by different biogeochemical processes (e.g. denitrification, uptake, and assimilation) on its journey after leaching from the soil profile 'root zone' till it reaches the sampling point at the catchment outlet. The nitrogen attenuation 'reduction' capacity of a catchment can be assessed by comparing the estimates of nitrogen leached from the root zone to the measured nitrogen load in the river in the catchment (Ausseil, 2012; Clothier *et al*., 2007; Roygard & Clark, 2012). We defined and quantified the nitrogen attenuation 'reduction' capacity as the nitrogen attenuation factor (Singh *et al*., 2014), noted as AF_N, as follows:

$$AF_N = \frac{L_d - L_r}{L_d} \quad \text{(Eq. 1)}$$

Where:

$\mathrm{L_d} = \sum_{\mathrm{i}}^{\mathrm{n}} A_i * N_i$ (Eq. 2); and $L_r = m \sum_{i=1}^{n^*} \left(Q_{avg} * C_{avg}\right)_i * \left(\frac{\bar{N}}{n^*}\right)$ (Eq. 3)

L_d = Nitrogen leaching from the root zone (M/T);
L_r = Soluble inorganic nitrogen load in the river (M/T);
A_i = Area of land use type (L^2);
N_i = Average annual nitrogen loss rate for land use type ($M/L^2/T$);
m = Conversion factor to convert the calculated values into a specific unit;
Q_{avg} = Average flow (L^3/T) of the *i*th flow decile bin;
C_{avg} = Average soluble inorganic nitrogen concentration (M/L^3) of the *i*th flow decile bin;
n^* = Number of flow decile bins; and
$\bar{N}$ = Expected population size (365 for a year; 366 on leap years).

According to this definition, the value of AF_N varies from 0 to 1, with 0 implying no nitrogen attenuation and 1 indicating a complete nitrogen attenuation. Thus, AF_N of 0.60 indicates that 60% of nitrogen is attenuated along its flow pathway, after leaching from the root zone and before reaching the river.

We quantified the nitrogen attenuation factor, AF_N based on the estimates of nitrogen leaching from the root zone and the nitrogen load measured in the river at 15 sites in the Tararua Ground Water Management Zone (GWMZ) of the Manawatu River catchment (Fig. 1). TGWMZ is located in the upper part of The Manawatu River catchment, to the East of the Manawatu gorge, and covers an area of 3192 km^2 (Fig. 1). The topography in the TGWMZ varies from 60 m to 1497 m with an average of 316 m above msl. The major soil texture types are the silt loam (53%) and sandy loam (16%), and the major rock types are mudstone (42%) and gravel (31%). The dominant land use types are the sheep/beef farming (64%), native cover (17%) and dairy (16%).

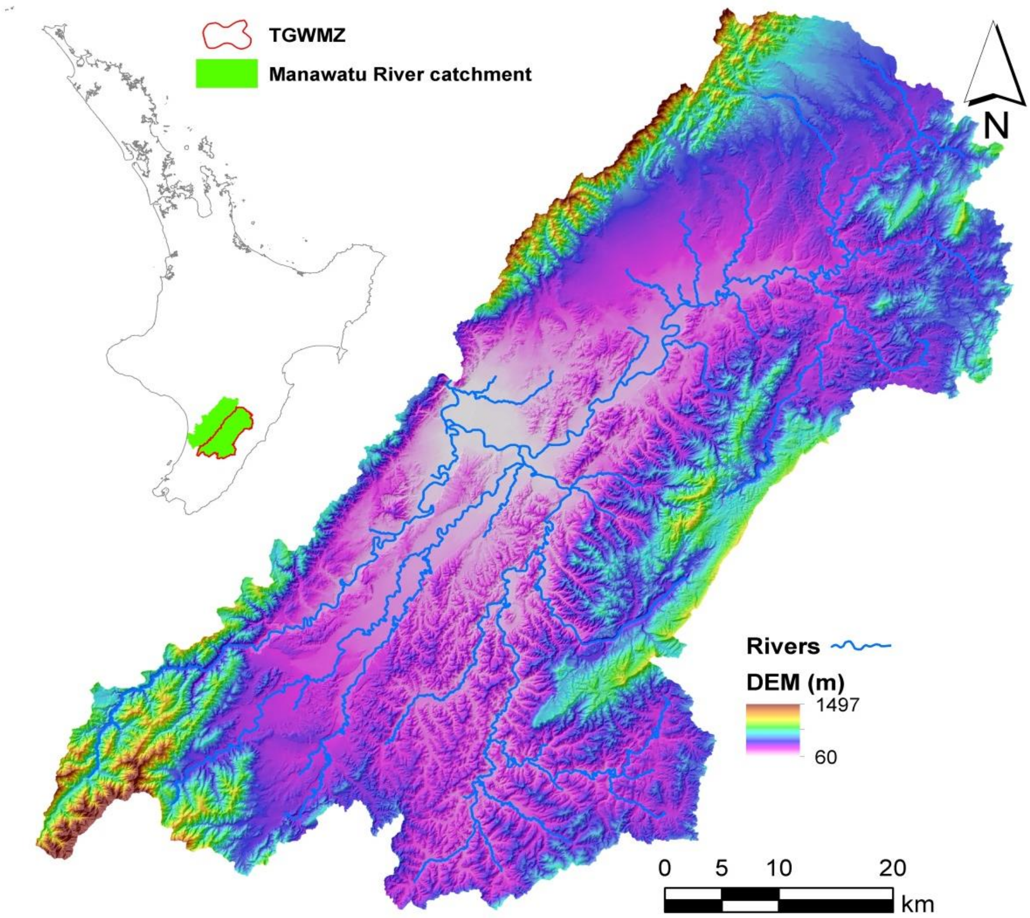

Figure 1: Location and topography of the Tararua Groundwater Management Zone (TGWMZ) in the Manawatu River catchment. Inset shows the location of the TGWMZ in the Manawatu River catchment in the North Island, NZ.

Horizons Regional Council (HRC) monitors water quality and river flow at a number of sites across the region including Manawatu River catchment. We used 15 water quality and river flow monitoring sites in the TGWMZ to delineate their contributing areas 'sub-catchments' upstream of each site. The resulting shapefiles from the delineation process were used to extract the characteristics of each sub-catchment (e.g. soil types, rock types, and land use). We got the various geographic information layers, used to extract sub-catchment characteristics, from different sources. The digital elevation model (DEM) and the soil map (Fundamental Soil Layer "FSL") were obtained from the Land Resource Information System (LRIS) Portal (https://lris.scinfo.org.nz/). The geological layers (QMAP) were obtained from the Institute of Geological and Nuclear Sciences Limited (GNS Science). HRC provided the land use map of 2013. HRC also provided the 15 minutes measurements of river flow (derived from the stage-discharge relationship) recorded at the study sites. In addition, HRC also provided the monthly measured water quality parameters (e.g. ammoniacal-nitrogen, nitrate-nitrogen and nitrite-nitrogen) at the study sites. We used the available flow and water quality data for 25 years (from 1990 to 2014) to calculate the soluble nitrogen load in the river.

A number of calculation methods has been developed to use the limited water quality data and frequent river flow measurements to estimate nutrient loads in the rivers L_r. Flow stratified average method (FS) has been used in many studies in New Zealand to calculate nutrient loads in streams and rivers (Roygard & McArthur, 2008; Roygard *et al*., 2012; Roygard & Clark, 2012). As its name implies, the FS method illustrates the application of stratification (dividing the flow data in homogeneous classes/bins) to the averaging methods (one of the methods used to calculate annual nutrient loads in the river). According to Roygard & Clark (2012), this method stratifies the river flow into 10 equal flow categories (flow decile bins) based on the flow exceedance percentile. Then, the measured nutrient concentrations are assigned to the flow decile bin which contains the flow value at the time of sampling. For each flow decile bin, the nutrient load is calculated by multiplying the average flow by the average nutrient concentration for the bin. Afterwards, the load of each decile bin is multiplied by 36.5 days as each flow bin represents 10% of the record. Finally, the nutrient loads for all decile bins are summed to calculate the total annual nutrient load (Eq. 3).

The robustness of the FS method (Eq. 3) stems from its ability to: (1) investigate how measured loads fluctuate with different flows; (2) calculate the relative contributions from point sources and non-point sources to the load in each flow decile bin; and (3) estimate the loads that occur below flood flows (the highest 20% of the flows or flows that occur 20% of the time or less) (Roygard & McArthur, 2008; Roygard *et al*., 2012; Roygard & Clark, 2012). Many authors suggested that using a composite nutrient load calculation method such as FS method increases the accuracy and precision in the nutrient load estimation (Aulenbach & Hooper, 2006; Quilbé *et al*., 2006; Richards, 1998). Elwan *et al*., (2014) evaluated different nutrient load calculation methods and found that the FS method resulted in the lowest bias and root mean square error (*RMSE*) in estimating the annual nutrient loads for different water quality parameters at various sampling frequencies in the Manawatu River at the Teachers college site in Palmerston North, NZ. Thus, we used the FS method in this study to calculate the average annual soluble nitrogen river load L_r (ton yr^{-1}) for each sub-catchment, using the available monthly water quality (ammoniacal-nitrogen, nitrate-nitrogen and nitrite-nitrogen concentrations) and 15 minutes river flow data from 1990 to 2014 for the study sites in the TGWMZ.

The quantification of AF_N (Eq. 1) for each sub-catchment also requires estimates of the nitrogen leaching from the root zone (L_d; Eq. 2). The nitrogen leaching from the root zone (L_d; Eq. 2) was calculated through (1) assigning average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) for each land use type; (2) multiplying the assigned average annual nitrogen loss rate N (kg ha^{-1} yr^{-1}) by the area A (ha) of each land use in the sub-catchment; and (3) adding up all land uses contribution for each sub-catchment to get the total average annual nitrogen leaching from the root zone L_d (ton yr^{-1}) for the sub-catchment. The major land use areas in the TGWMZ are sheep/beef (204,884 ha), native cover (53,998 ha) and dairy (49,856 ha). The average annual nitrogen leaching rates N (kg ha^{-1} yr^{-1}) for each land use were obtained from Roygard & Clark (2012), i.e. 2.4 from native cover, 4 from exotic cover, 50.5 from cropping, 80 from horticulture, 3 from built-up/other areas, and 16 from sheep/beef. The average annual nitrogen leaching rate N (kg ha^{-1} yr^{-1}) from dairy was assigned as 33.9 based on the average value from all simulated N loss (kg ha^{-1} yr^{-1}) from the dairy farms in the Mangatainoka catchment (HRC, 2015, pers. comm.).

The collected geographical information such as land use, soil types, rock types, topography (DEM), rainfall and river flow records were used to extract key physical characteristics of each-sub-catchment in the study area. The average daily river flow records were used to separate the base flow (i.e. groundwater component in the river flow) from the total river flow. Base flow was separated from the river flow using the local minimum method of the of the Web-based Hydrograph Analysis Tool (WHAT) system (Lim *et al*., 2005). Then, base flow index (*BFI*) was calculated by dividing the base flow with the total stream flow. Finally, a regression analysis was conducted in R (R Core Team, 2013) to evaluate the relationships between different catchment characteristics and estimated AF_N values across the TGWMZ.

Results and discussion

The estimated nitrogen attenuation factor AF_N, for the 15 sub-catchments in the TGWMZ (Fig. 2), ranges from 0.29 (Makuri at Tuscan Hills and Kumeti at Te Rehunga sub-catchments) to 0.75 (Manawatu at Weber Rd and Raparapawai at Jackson Rd sub-catchments). The AF_N for the whole TGWMZ (i.e. Manawatu at Upper Gorge site) was estimated at 0.58, suggesting that about 58% of the nitrogen leached from the root zone is attenuated 'reduced' before flowing out of the TGWMZ. These estimated AF_N values for the TGWMZ match well with the AF_N values in other catchments in New Zealand which ranges from 0.3 to 0.7 (Alexander *et al*., 2002; Clothier *et al*., 2007; Roygard & Clark, 2012). The AF_N values derived from table 10 in Alexander *et al*. (2002) ranges from 0.39 for Waipa to 0.75 for Taupo with an average of 0.45 for the whole Waikato River System.

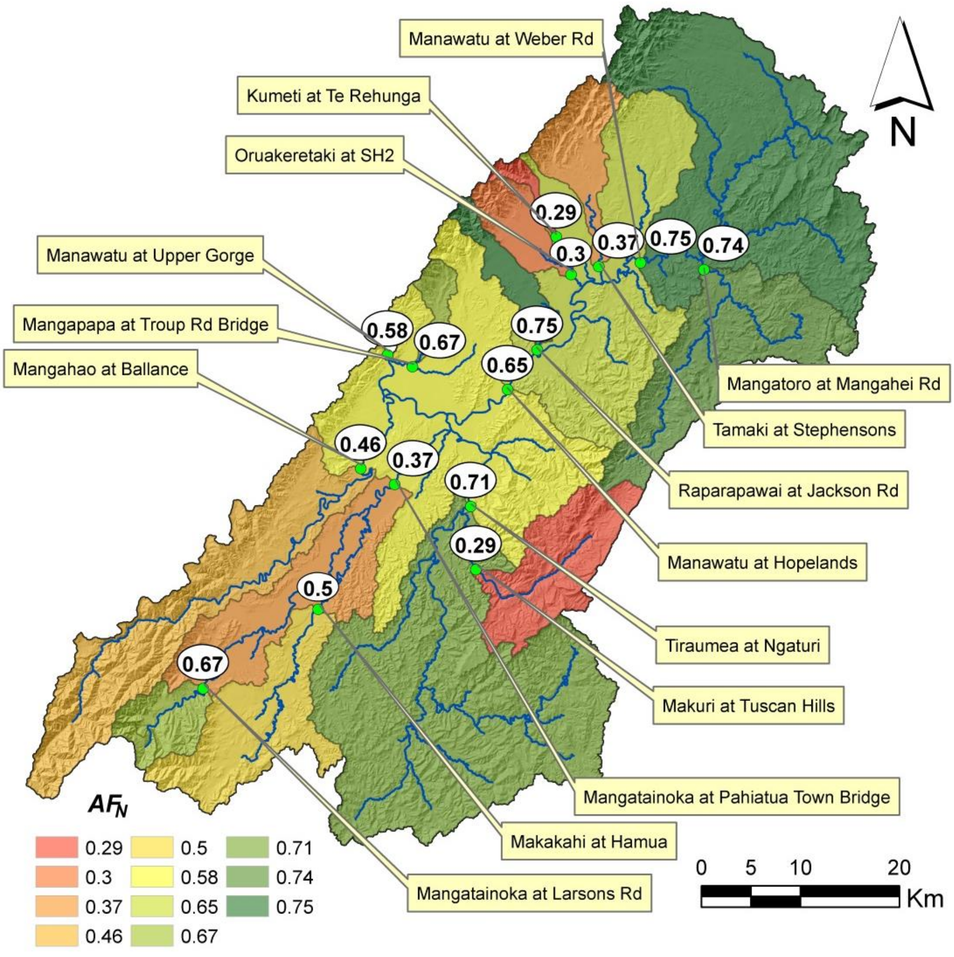

Figure 2: Spatial distribution of the nitrogen attenuation factor for 15 sub-catchments in the Tararua Groundwater Management Zone (TGWMZ).

According to the equations (1, 2 and 3), the uncertainty associated with the AF_N values for all sub-catchments in the TGWMZ are due to either the land use area A (ha), the average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) for each land use type, and/or the average annual river nitrogen load estimation L_r (ton yr^{-1}). Elwan *et al*., (2014) assessed the uncertainty in the annual river load estimates L_r (ton yr^{-1}) as a result of different sampling frequency and nutrient load estimation methods using the daily measurements of water quality parameters (including soluble inorganic nitrogen) at the Manawatu teachers college site from May 2010 to April 2011. According to Elwan *et al*., (2014), the flow stratified average method (FS) resulted into very low bias, i.e. -1.56 % of the true load for soluble nitrogen in case of monthly sampling frequency. Thus, the river nitrogen load estimation is not considered as the main source of uncertainty in estimating AF_N values for different sub-catchments in the TGWMZ.

The average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) for major land uses (i.e. native cover, sheep/beef, and dairy) are considered to be a major source of uncertainty in the estimation of AF_N values in the TGWMZ. The uncertainty in average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) from other minor land use types is expected to have a minor influence on the estimates of AF_N values for different sub-catchments in the TGWMZ. For instance, if the average annual nitrogen loss rate N of 80 (kg ha^{-1} yr^{-1}) for horticulture land use was varied by ± 30%, the AF_N values remained the same. Similarly, if the average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) for cropping, built-up and exotic cover land uses were varied by ± 30%, the AF_N values remained almost the same without any significant changes. This is due to the small area of these land uses in different sub-catchments of the TGWMZ.

On the contrary, the uncertainty in the average annual nitrogen loss rate N (kg ha^{-1} yr^{-1}) for land uses with large areas may result in large influence on the estimates of AF_N values for different sub-catchments in the TGWMZ. For instance, if the average annual nitrogen loss rate N of 2.4 kg ha^{-1} yr^{-1} for native cover was varied by +30%, the resulting AF_N values changed from 0.29 to 0.32 (0.26 in case of -30% variation) for the Kumeti at Te Rehunga sub-catchment, and from 0.46 to 0.49 (0.44 in case of -30% variation) for the Mangahao at Balance Rd sub-catchment. This is due to the large area of the native cover in these sub-catchments which accounts for 65% and 66% of the total area in the sub-catchments, respectively. Similarly, if the average annual nitrogen loss rate N of 33.9 kg ha^{-1} yr^{-1} for dairy land use was varied by + 30%, the AF_N values changed from 0.30 to 0.43 (0.10 in case of -30% variation) for the Oruakeretaki at SH2 sub-catchment, from 0.29 to 0.41 (0.10 in case of -30% variation) for the Kumeti at Te Rehunga sub-catchment, and from 0.37 to 0.47 (0.23 in case of -30% variation) for the Mangatainoka at Pahiatua Town Bridge sub-catchment. If the average annual nitrogen loss rate N of 16.0 kg ha^{-1} yr^{-1} for sheep/beef land use was varied by + 30%, the AF_N values changed from 0.29 to 0.45 (0 in case of -30% variation) for the Makuri at Tuscan Hills sub-catchment, from 0.37 to 0.44 (0.28 in case of -30% variation) for the Tamaki at Stephensons sub-catchment, and from 0.37 to 0.43 (0.29 in case of -30% variation) for the Mangatainoka at Pahiatua Town Bridge sub-catchment. The another source of uncertainty in the estimates of the AF_N values could be changes in land use, particularly major land uses in the TGWMZ along with higher average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) (e.g. 33.9 kg ha^{-1} yr^{-1} for dairy and 16 kg ha^{-1} yr^{-1} for sheep/beef) over the time period considered from 1990 to 2014. Due to the limited data available, we could not account for changes in the land use throughout the period of study (from 1990 to 2014).

Regardless of the uncertainty associated, the estimates of AF_N values suggest a significant nitrogen attenuation 'reduction' capacity in the TGWMZ, and this capacity appears to be spatially variable across the sub-catchments. This is also supported by the variations in the redox status of the groundwater observed in the TGWMZ as outlined in Rivas *et al*. (2014). As shown in figure (3) below, sub-catchments with higher AF_N values (i.e. high capacity to attenuate nitrogen) have mostly wells in the reducing conditions. On the contrary, sub-catchments with lower AF_N values (i.e. less capacity to attenuate nitrogen) have mostly wells in the oxidizing conditions.

A linear regression analysis between the estimated AF_N values and various sub-catchments characteristics showed that there is a negative relationship between AF_N and the percentage of well-drained soils (e.g. soils with drainage class 5 in the FSL) in the sub-catchments (R^2=-0.35, p <0.05) (Table 1). The well-drained soils are characterized by high infiltration capacity and as a result faster movement of water (i.e. shorter travel time to groundwater) which will result in less denitrification (Meynendonckx *et al*. 2006; Mueller *et al*., 1997). Thus, the sub-catchments or catchments characterized by larger proportions of well-drained soils are expected to have lower capacity to attenuate nitrogen flow from farms to rivers and lakes. One the other hand, the fine textured soils (e.g. clay loam) showed a positive relationship with the AF_N values (R^2=0.37, p <0.05) (Table 1). The slow movement of water in fine textured soils implies longer travel 'residence' time and thus enough time for denitrification to take place. Thus, the sub-catchments or catchments with larger proportions of fine textured soils are expected to have higher capacity to attenuate nitrogen flow from farms to rivers and lakes.

The underlying geology is further expected to have a major influence on flow and travel time of water from farms to rivers and lakes in a catchment (Güler & Thyne, 2004). Base flow index *BFI* is considered as a catchment descriptor that can indicate the influence of geology on water flow pathways (Smakhtin, 2001). Higher values of *BFI* indicate permeable catchments, whereas lower values of *BFI* indicate impermeable catchments (Lacey & Grayson, 1998; Tallaksen & Van Lanen, 2004). Davies & Neal (2007) found positive relationship between mean nitrate concentration and *BFI* in catchments across the UK. This could be explained by catchment permeability and associated groundwater residence time. As higher values of *BFI* indicate permeable catchments, it is expected to have less groundwater residence time in these permeable catchments, less time for denitrification and as a result high levels of nutrient concentration in the rivers. If *BFI* has positive relationship with nitrogen concentration in rivers, it implies that *BFI* should have negative relationship with the nitrogen attenuation capacity of the catchment (i.e. AF_N). That is what we found in our study that the AF_N has a negative relationship with *BFI* (R^2= -0.31, p <0.05) (Table 1). Thus, the sub-catchments or catchments with relatively lower permeability are expected to have higher capacity to attenuate nitrogen flow from farms to rivers and lakes.

Table 1: Results of linear regression analysis between the AF_N values and catchments characteristics

Catchment Characteristics	AF_N	
	R^2	p
Well-drained (e.g. soils with drainage class 5) soils*	-0.35	<0.05
Fine textured (e.g. clay loam) soils	0.37	<0.05
Base Flow Index (*BFI*)	-0.31	<0.05

*Soils with drainage class 5, in the Fundamental Soil Layer "FSL", are well-drained soils.

Conclusions

Assessment and management of water quality in agricultural catchments require better understanding of sources, transport, transformation and fate of nutrients (N & P) run-off and leaching from farms to river and lakes. Many studies have assessed the relationship between different water quality parameters in the rivers and different catchment characteristics. However, none of these studies have considered estimating the attenuation 'reduction' of nitrogen on its way from farms to river and lakes, and how this correlates with the catchment characteristics. We defined and quantified the nitrogen attenuation factor AF_N for 15 sub-catchments in the TGWMZ and further investigated its relationship with different sub-catchment characteristics through a regression analysis.

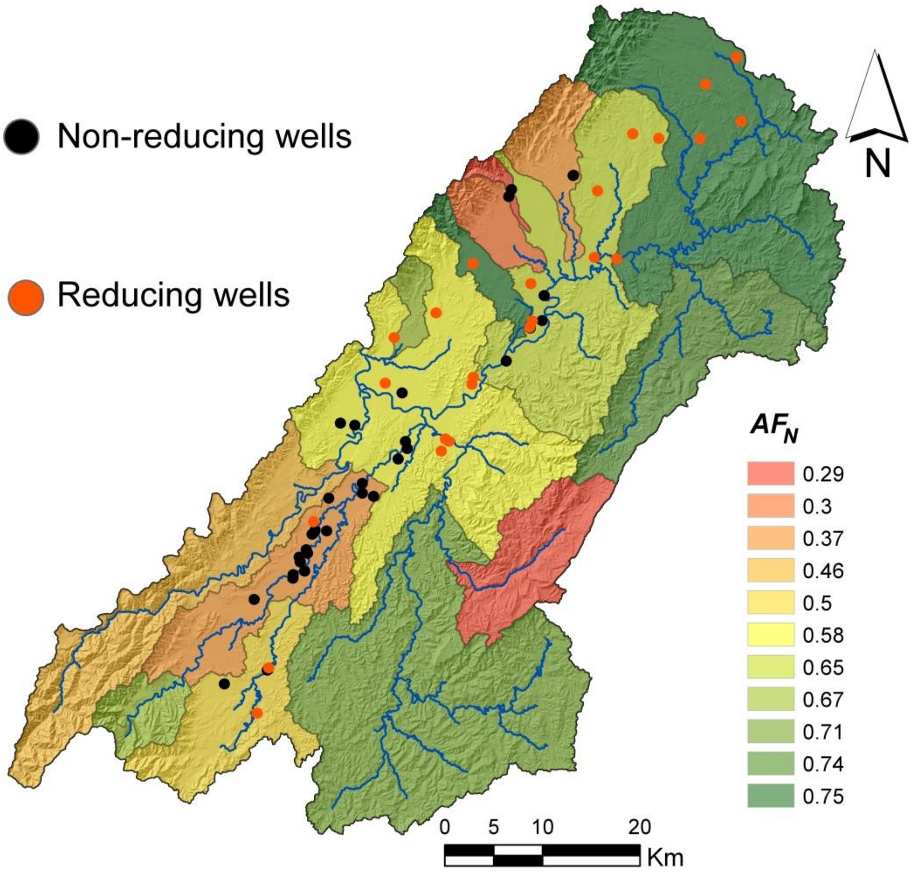

Figure 3: The AF_N values for all sub-catchments in the TGWMZ match with the redox status of the groundwater (Rivas *et al*., 2014). Wells in the reducing conditions are mainly located in sub-catchments with the high AF_N values (green catchments), whereas wells in the oxidising conditions are located in sub-catchments with the low AF_N values.

Our results showed that the AF_N values differ spatially from one sub-catchment to another as a function of the sub-catchment characteristics. The estimated AF_N values varied from 0.29 to 0.75 for the 15 sub-catchments with an overall value of 0.58 for the whole TGWMZ. The variations in estimates of AF_N values showed a spatially correlation with the redox status of the groundwater in different sub-catchments. We found that sub-catchments with higher capacity to attenuate nitrogen (i.e. higher AF_N values) are dominated by wells in the reducing conditions. On the contrary, sub-catchments with lower capacity to attenuate nitrogen (i.e. lower AF_N values) are dominated by wells in the oxidizing conditions.

A regression analysis showed that the AF_N values have a positive relationship with the fine textured soils (e.g. clay loam) whereas it has a negative relationship with well-drained soils and base flow index (*BFI*) for different sub-catchments in the TGWMZ. This suggests that permeable sub-catchment or catchments characterized by well-drained soils and relatively high permeability underlying geology results in larger and faster movement of water as groundwater, i.e. higher base flow and less time in the subsurface for denitrification and consequently higher levels of nitrogen in the river (i.e. low AF_N). On the contrary, sub-catchments or catchments characterized by fine textured soils and relatively lower permeability underlying geology results in less and slower movement of water as groundwater, i.e. lower base flow and more time in the subsurface for denitrification and consequently lower levels of nitrogen in the river (i.e. higher AF_N). We hypothesize that the AF_N is a catchment descriptor that can quantify the nitrogen attenuation 'reduction' capacity at sub-catchment or catchment scale, and that different AF_N values are associated with sub-catchment or catchments with different characteristics. This needs more research to reduce uncertainty in quantification of the AF_N for different sub-catchments in NZ agricultural catchments. We plan to further calculate sub-catchment and catchment level water balance and evaluate that there is no bypass flow at the water quality monitoring site (to ensure that the delineated surface water catchment match with the groundwater catchment). In addition, more field measurements are required for better estimates of the average annual nitrogen loss rates N (kg ha^{-1} yr^{-1}) for larger and intensive land use types, i.e. native cover, sheep/beef and dairy. Furthermore, we recommend that the changes in land use (mainly sheep/beef and dairy) over time to be assessed and evaluate the uncertainty associated with these changes on the AF_N values and its relationship with different catchment characteristics.

Acknowledgments

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