# Nitrogen Yields into the Tauranga Harbour based on sub-catchment land use

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Christopher Paul Morcom

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# Abstract

Changes in land use and management practices can have significant impacts on freshwater, estuarine and marine environments. In order to preserve the economic, cultural, recreational, and ecological value of these environments, it is important that the effects of land use change on water quality are well understood. This thesis examines the nitrogen yield into the Tauranga Harbour, on the east coast of the North Island of New Zealand. The Soil and Water Assessment Tool (SWAT) model was used to examine the nitrogen yield from the Wairoa River under the present land use, as well as two hypothetical scenarios consisting of either only indigenous forest or agriculture. The Wairoa River represents more than 50 percent of discharge into the harbour. In addition to the numerical modelling, recorded data from a number of catchments in the area were also analysed to examine the spatial distribution of nitrogen yield into the Tauranga harbour. Analysis of both the simulation output and recorded data shows an increase in nitrogen yield with increased agricultural area. The recorded data also shows a strong relationship between urban and industrial area and nitrogen concentration. Long term trends are difficult to determine using the recorded data due to the high variability in nitrogen yield that is shown in the SWAT model output. Model outputs from different land use scenarios show changes in the temporal cycle of nitrogen yield. Increased agricultural area caused nitrogen yields to increase during winter, and decrease during summer. Increasing the indigenous forest area had the opposite effect, reducing nitrogen yield over winter, and increasing yield over summer.

In memory of my loving father,

Keith Charles Morcom

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# 1 Introduction

Anthropogenic activities can have significant impacts on the health of waterways, estuaries, and the coastal environment, from increased sedimentation to contamination by toxins and pollution by nutrients (Scholes, 2005). These environments each serve as important economic and recreational resources, and also support a wide variety of aquatic ecosystems. Over recent decades intensification and development of agriculture has prompted a significant amount of research into nitrogen leaching from pastoral soils. However only a limited amount of research has been conducted in New Zealand on the effect changes to land use have on nitrogen yield to the coastal environment. In order to preserve coastal ecosystems, and ensure that the coastal zone is able to be used for recreation by future generations, it is vital that planners understand how different land uses affect nutrient yields to the coastal environment.

This research aims to add to the understanding of how changes in land use affect nitrogen yields to the coastal environment in New Zealand. In particular the relationship between the area of a catchment that is in either native forest or agriculture and nitrogen yield is investigated. To achieve this goal nitrogen yields from subcatchments of the Tauranga Harbour will be examined. Taugranga harbour is located on the east coast of New Zealand’s North Island. The Soil and Water Assessment Tool (SWAT) model was used to simulate discharge, nitrate, nitrite, and ammonium yield from the Wairoa River, the largest river that discharges into the Tauranga harbour. The output form model scenarios with different land use will be analysed to examine the effect native forest and agriculture have on nitrogen yield.

In addition to numerical modelling using the SWAT model, water samples were collected from rivers within the study area between November 2011 and February 2013. The concentrations of these water samples were measured and the results analysed to show the spatial and temporal distribution of different nutrients entering Tauranga harbour. In addition to the data collected during this study, historical data from the Bay of Plenty Regional Council was analysed to give a wider perspective on the nitrogen input into the harbour. These two datasets are compared and combined to assess the recorded nitrogen yield into Tauranga Harbour.

This thesis first presents a review of literature pertaining to the aims of this study in chapter 2. Topics covered are the importance of nitrogen in the coastal environment, the sources and losses of nitrogen from different land uses, previous studies using both observed data and numerical models, and an overview of SWATs history, strengths and weaknesses, and studies that have applied SWAT to different catchments.

The methods used for the different stages of this research are then outlined in detail in chapter 3. Sampling and water analysis methods are described. The setup of the SWAT model is described in chapter 3.4, and the setup of the required input data is explained in chapter 4, and the methods used to calibrate the model are described.

Results from obtained from both the recorded data and model scenarios are presented and discussed in chapter's 5 and 6 respectively. And finally conclusions are drawn on the effects agriculture and forest have on nitrogen yield with regard to both simulated and recorded data, and the suitability of SWAT for aiding policy makers in decision making is discussed in Chapter 7.

The results of this research will aid policy makers in understanding the importance of urban and industrial, agricultural, and indigenous forest in driving nitrogen yields. This research will also aid in sampling design with regard to quantifying the difference in nitrogen yields between high and low discharges.

# 2 Literature Review

## 2.1 Importance of nitrogen in the coastal environment

The coastal environment can be influenced by many different contaminants that can affect both water quality and ecological health. Development in and near the coastal environment can have significant impacts on the condition of estuaries, from increased sedimentation, contamination by toxins and pollution by nutrients (Scholes, 2005). Nitrogen is an important nutrient contributing to degradation of estuaries and harbours. Increased inputs of nitrogen to the coastal environment have been linked to several problems throughout the globe. Impacts from increased nitrogen largely manifest themselves in the form of eutrophication (Burkholder *et al*., 2006; Boyton *et al*., 1995; Howarth *et al*., 1996). Furthermore, it has been shown that lowering the flushing time, and thus nitrogen concentration, can reduce the concentration of algae in an estuary (Lillebø *et al*., 2005). Changes to land use within the catchment of an estuary and climate have been found to be responsible for long-term changes in nitrogen concentration in estuaries. Individual rainfall events cause high river discharge resulting in a short term increase in nitrogen concentration with a time lag of several hours. Years with higher rainfall also correspond to higher nitrogen concentrations (Caffrey *et al*., 2007). The main changes in land use that cause increased nitrogen concentrations are reduction in the amount of forest, and increased agriculture and horticulture (Caffrey *et al*., 2007; Heggie & Savage, 2009).

The Tauranga Harbour has been subjected to many changes to both its catchment and the harbour itself. More recently the response of the harbour to these changes has become a growing concern. This has largely been due to periodic extensive blooms of sea lettuce (*Ulva spp*.). These blooms have negative impacts on biological, recreational and commercial uses of the harbour. The causes of these *Ulva* blooms are still not completely understood. However Park (2011) concluded that the spatial distribution of terrestrial nutrient inputs correlated with the concentration of nutrients within the organic tissue, but not with the overall *Ulva* abundance. It was found that the effect of El nino and La nina events on water temperature had the strongest correlation with *Ulva* abundance, with higher abundance occurring during El nino years.

## 2.2 Inputs of nitrogen

Nitrogen inputs can be divided into 3 main groups: atmospheric deposition, biological fixation and fertilizer application. Atmospheric deposition is divided into wet and dry deposition. Wet deposition is nitrogen that enters the soil with rainfall, whereas dry deposition occurs when nitrogen as $NO_x$ gas is absorbed from the atmosphere by plants or water, or by deposition of particles on which nitrogen has accumulated (Heggie & Savage, 2009). Atmospheric deposition of nitrogen is low and has been estimated to be between 1 and 2 kg N $ha^{-1}$ $yr^{-1}$, however deposition directly to an estuary can be significant. (Parfitt *et al.*, 2006; Scholes, 2005; Kinney & Valiela, 2011).

Fertilizer is applied to commercial crops to increase productivity. Fertiliser application to pasture in New Zealand varies from 3 kg N $ha^{-1}$ $yr^{-1}$ to 34 kg N $ha^{-1}$ $yr^{-1}$, with the highest values being for intensive dairy farming (Parfitt *et al.*, 2006; Parfitt *et al.*, 2012). Application rate of nitrogen on commercial crops is somewhat higher than this with a national average of 85 kg N $ha^{-1}$ $yr^{-1}$. Nitrogen applied as fertilizer is stored in plants and soil, leached to ground water or lost as gas (Heggie & Savage, 2009).

Biological fixation by legumes is one of the largest inputs of nitrogen in New Zealand. The main contributor to biologically fixed nitrogen is white clover in pasture, which can fix between 29 to 75 kg N $ha^{-1}$ $yr^{-1}$. The amount of nitrogen fixed by legumes in pasture is reduced by application of fertilizer (Parfitt *et al.*, 2012). Strips of grass between trees in orchards also contain legumes that can fix nitrogen at a rate of 30 kg N $ha^{-1}$ $yr^{-1}$. Forest plantations often contain legumes for a number of years before the canopy of the plantation closes over. These legumes are usually present for approximately 5 years, during which they fix nitrogen at a rate of 40 kg N $ha^{-1}$ $yr^{-1}$ (Parfitt *et al.*, 2006). Broom and gorse are commonly found in low productivity pastures and can fix nitrogen at rates of 110 kg N $ha^{-1}$ $yr^{-1}$ and 30 kg N $ha^{-1}$ $yr^{-1}$ respectively. Nationally, the coverage of gorse is much greater than broom so the combined rate of nitrogen fixation by both broom and gorse can be assumed to be 30 kg N $ha^{-1}$ $yr^{-1}$ (Parfitt *et al*., 2006). Leguminous trees and grains can have highly variable rates of nitrogen fixation. Leguminous trees can fix nitrogen at between 43 and 581 kg N $ha^{-1}$ $yr^{-1}$ and grains between 15 and 210 kg N $ha^{-1}$ $yr^{-1}$ (Heggie & Savage, 2009).

Some other inputs of nitrogen are industry, wastewater, imported feed to farms, and urban development (Alexander *et al*., 2002). In areas with a higher density of anthropogenic activities, waste water can contribute up to 50 % of the nitrogen that is discharged to the coastal environment making it the largest input of nitrogen in some systems (Kinney & Valiela, 2011). Effluent from livestock can be excluded large scale nitrogen yields models as the nitrogen is simply being recycled within the system and has already been accounted for by the other inputs of nitrogen (Heggie & Savage, 2009).

## 2.3 Losses of nitrogen

During transport through a catchment loss of nitrogen is attenuated by a range of processes at different stages during transport. Heggie and Savage (2009) partitioned these losses into 3 groups: losses in soil, losses in the vadose zone and losses in the aquifer. The largest loss of nitrogen is by denitrification by microbes which occurs at virtually all stages of transport through a catchment (Boyton *et al*., 1995; Nowicki *et al*., 1999). Denitrification is largest in pastoral soils that are well irrigated and fertilized with rates averaging 13 kg N $ha^{-1}$ $yr^{-1}$. Denitrification in forests is usually much lower than in pasture, with the majority of forests having denitrification rates of <1 kg N $ha^{-1}$ $yr^{-1}$ (Barton *et al*., 1999). Another gaseous loss of nitrogen is volatilization. Volatilization is an important factor when concerning fertilizer inputs as a large portion of the nitrogen can be lost before entering the soil (Heggie & Savage, 2009). Similarly, volatilization can also occur from urine excreted from livestock (Hunter & Walton, 2008).

Uptake by plants can lead to significant attenuation of the nitrogen that is moving through a catchment (Howarth *et al*., 1996). A large proportion of the nitrogen that is taken up by plants is recycled within the system. As a result losses of nitrogen to plants can be assumed to occur only when either biomass is increasing, or when nitrogen is removed as produce. For example Parfitt *et al*. (2006) assumed that native forests were at equilibrium and so there was no net loss of nitrogen. In contrast exotic plantation forests were estimated to take up 15 kg N $ha^{-1}$ $yr^{-1}$.

Many papers discuss erosion as a loss of nitrogen. In the case of nitrogen yields to the coastal environment, erosion can be considered an output rather than a loss. This subtle difference in terminology is due to the area of interest of different studies. For studies concerned with nitrogen leaching from soils the removal of nitrogen with eroded sediment is considered a loss. Whereas when nitrogen yield from a catchment is of interest the eroded sediment either is redeposited further down the catchment, or is transported out of the catchment as either suspended sediment or bedload. Thus any nitrogen removed from the catchment by this mechanism is simply another form of nitrogen output. (Parfitt *et al*., 2006).

The amount of nitrogen that leaves a catchment clearly depends on the land use within a catchment. Inputs that have the largest influence vary significantly throughout the globe (Howarth *et al*., 1996; Boyton *et al*, 1995; Parfitt *et al*, 2006). In highly populated areas wastewater is often the largest input of nitrogen (Kinney & Valiela, 2011). In New Zealand the population is low enough that wastewater is less important and in some cases can be ignored due to only a negligible amount remaining after being taken up by plants or lost via denitrification (Heggie & Savage, 2009). Agriculture and horticulture are often associated with high inputs of fertilizer, which can often make them the most important input of nitrogen. Furthermore clearing of native forest can release large amounts of stored nitrogen leading to a temporary increase in yields to the coastal environment (Heggie & Savage, 2009; Parfitt *et al*., 2006).

## 2.4 Previous nitrogen studies

Dymond *et al.* (2013) found that total nitrogen leaching in many parts of the Bay of Plenty was greater than 30 kg $ha^{-1}$ $yr^{-1}$. Nationally, the Waikato, Taranaki, Bay of Plenty, and Canterbury have the highest nitrogen leaching rates and therefore may have more of an influence on waterways. However, most North Island regions, including the Bay of Plenty, are showing temporal trend of decreasing nitrogen leaching rates.

Heggie and Savage (2009) found a strong positive relationship between the nitrogen yield from a catchment, and the percentage of catchment area in agriculture. Calculated nitrogen yields varied from 1 kg $ha^{-1}$ $yr^{-1}$ in catchments with 0% agriculture to 17 kg $ha^{-1}$ $yr^{-1}$ in a catchment with 91.2% agriculture (Heggie & Savage, 2009).

Environment Bay of Plenty, now known as Bay of Plenty Regional Council, conducted a monitoring program that spanned from 1990 to 2008 and covered over 40 streams and rivers in the Bay of Plenty region. Twelve of these sites showed an increase in total nitrogen over 1% per year, and 11 sites showed an increase in nitrate and nitrite over 1% per year. It was noted that these increasing trends occurred in catchments that were influenced by agricultural land uses. However some catchments that are influenced by agriculture showed a decreasing trend in total nitrogen (Scholes & McIntosh, 2009).

In the harbour itself, the Rocky, Kopurererua and Waimapu streams have higher nitrogen levels than other streams in the harbour. For Rocky stream this was attributed to the high amount of biomass in the stream’s slow moving water. The Omanawa stream in the Wairoa river system also had higher nitrogen levels than other tributaries in the system (such as the Ngamuwahine stream). In all cases, much of the total nitrogen was in the form of nitrate and nitrite, indicating agriculture as the source of the nitrogen (Scholes & McIntosh, 2009).

Trends in nitrogen concentration varied between catchments. The Waitao Stream, Rocky stream, and Waipapa River showed a signifigant decrease in total nitrogen and nitrate and nitrite oxides of nitrogen. While the Kopurererua River, Omanawa River, and Wairoa River showed significant increases in total nitrogen and the oxides of nitrogen. The Waimapu River, Ngamuwahine Stream, and Aongatete River show no significant trend (Scholes & McIntosh, 2009).

As mentioned earlier, the data that the above trends were derived from was collected over nearly two decades, providing a large spatial and temporal coverage. However the frequency of the monitoring and sample collection was often very low. Typically a river would be sampled somewhere between one and seven times per year. Due to the infrequency of the data, the significance of the detected trends could be brought into question.

## 2.5 Existing models

Using models to investigate nutrient yields into the coastal environment and the oceans is not a new concept. Many models have been created that calculate nutrient loading over a range of spatial and temporal scales. Nitrogen loads over annual time scales are most common as event driven and seasonal variability can be ignored allowing averages of input and loss rates to be used (Lampman *et al*., 1999). Northern hemisphere models range from calculating nitrogen loads for the entire North Atlantic Ocean, to single catchments and estuaries (Howarth *et al*., 1996; Kinney & Valiela, 2011). A common approach to modelling nitrogen yields is to first assess the inputs of nitrogen that occur within the area of interest, and then to attenuate nitrogen concentration in order to calculate an output to the coast. For this method, estimates of nitrogen input and loss rates for all the environments within the area of interest are needed, although for larger areas some generalizations can be made (Howarth *et al*., 1996; Kinney & Valiela, 2011). Kinney and Valiela (2011) and Hunter and Walton (2008) used this method to calculate the proportions of nitrogen loading from different land uses in Great South Bay, Florida and the Johnstone River system in north eastern Australia respectively. Howarth *et al*. (1996) also use a far more generalized form of this method to calculate the nitrogen fluxes for the entire North Atlantic Ocean. For both these models the areas of interest could be divided into sub catchments or areas, thus simplifying the model.

An alternative to the above approach to modelling nitrogen fluxes is to use a statistical approach. Statistically based models have the benefit of requiring less input data than process-based models. Smith *et al*. (1997) used the SPARROW model (Spatially referenced regressions of contaminant transport on watershed attributes) to assess regional total phosphorus, and nitrogen outflows in the United States. SPARROW was later improved by Smith *et al*. (2005) who used data from 496 sites to calibrate the model. This model was then able to use population and runoff as independent variables to estimate nitrogen loading with an $R^2$ value close to 0.8. Calibration of models can also be achieved by another method that also considers algorithm complexity and the number of land uses as calibration parameters. Walton & Hunter (2009) found that in some cases the number of land uses could be reduced by combining land uses, and simplfying calculations so that some parameters could be removed. These changes had no significant effect on the accuracy of the model and allowed land use effects to be isolated over much shorter time steps than could be achieved by regression analysis (Walton & Hunter, 2009).

For New Zealand, there are a wide variety of models that have been developed to simulate nitrogen loss from soil. The scale of these models varies both temporally and spatially, ranging from annual averages to less than daily temporal scales, and regional to paddock spatial scales catered for (Cichota & Snow, 2009). The SPARROW model has been adapted to calculate nitrogen loads in streams for the entire country. To achieve this, the model was calibrated with data from a national water quality monitoring network composed of 77 sampling points. This network does not include catchments that are less than 10 $km^2$, and so results for small catchments must be used with caution. Using SPARROW, the output of nitrogen to the coast was calculated to be 44% of the nitrogen that entered streams, giving a value of 167,700 t $yr^{-1}$ (Elliott *et al*., 2005). At the farm scale the most popular model is OVERSEER. OVERSEER calculates nitrogen leaching at one meter below the surface and was developed so that it could be used with information that is readily available to farmers, allowing for nitrogen budgets to be calculated for individual farms (Elliott *et al*., 2005).

Despite the amount of research that has been conducted on nitrogen leaching from soils, very few models have been developed for New Zealand that calculate the loss of nitrogen to the coast. One model that does calculate nitrogen loss to the coast is the SCENY model. The SCENY model was developed for several estuaries in southern New Zealand and uses GIS to calculate the average annual nitrogen yield from a single catchment. The model achieves this by assessing inputs from each land use within the catchments, then attenuating the amount of nitrogen as it is transported through the catchment. Results from this model have been found to agree well other models (Heggie & Savage, 2009).

In recent years, catchment scale models have begun to make use of Geographical Information Systems (GIS) as a means of managing spatial data for use in hydrographical and nutrient runoff modelling. Two such models are the Soil and Water Assessment Tool (SWAT) and Catchment Land Use for Environmental Sustainability (CLUES) model (Elliott S. , 2012). It should be noted here that SWAT is not a GIS based model, but a Fortran program. However, the GIS extension ArcSWAT can be used to manage the data sets and create input files that are needed for SWAT to run. CLUES was developed by the National Institute of Water and Atmospheric Research (NIWA) specifically to be applied to New Zealand and combines model components from NIWA, Landcare Research, AgResearch, and Plant and Food Research. Two of the main components of CLUES are simplified versions of SPARROW and OVERSEER to calculate nutrient generation from a variety of land uses and to estimate nutrient leaching from pasture respectively (Elliott S. , 2012; Cichota & Snow, 2009). CLUES has been used in several studies in New Zealand. Some benefits of CLUES are that it is freely available online from NIWA and comes preloaded with input data sets to allow easy setup of model scenarios. Some drawbacks of CLUES are that it provides only annual nutrient loads and a lagged effect of past land uses is not taken into account. Farm scale inputs such as effluent application cannot be included by the simplified version of OVERSEER that is used by CLUES. CLUES also does not provide any means to assess catchment nutrient sources, and so is unable to answer questions such as what land use is providing the majority of the nutrients (Elliott S. , 2012). The most important differences between SWAT and CLUES are that SWAT provides outputs at daily time steps and sources of nutrients can be traced to their origin. One of the major drawbacks of SWAT however is it’s need for a large amount of input data (Elliott S. , 2012). Default datasets are provided only for the United States (Winchell *et al.*, 2010).

This means that for models outside the US, the user must obtain the required data and create multiple databases for SWAT to run. SWAT is described in more detail below.

## 2.6 Soil and Water Assessment Tool (SWAT)

### 2.6.1 Development History

The SWAT model is the most recent model to come out of approximately 30 years of model development by the United States Department of Agriculture's Agricultural Research Service (USDA ARS). SWAT was developed to improve on the Simulator for Water Resources in Rural Basins (SWRRB) model, which was in turn created by combining several existing USDA ARS models. The Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model was used to include a daily rainfall and hydrology component in SWRRB. A component of the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model was used to simulate the fate of pesticides. And the Environmental Impact Policy Climate (EPIC) model was used to account for effects of crop growth (Gassman *et al*., 2007). SWRRB was then coupled with the Routing Outputs to Outlet (ROTO) model to assess the downstream effect of management practices. There was an issue with this model setup due to SWRRB allowing a maximum of only 10 subbasins. To overcome this limitation, the output of multiple SWRRB runs could be fed into the ROTO model. Although this was an effective solution to the problem, managing multiple SWRRB input and output datasets was awkward and undesirable. And so SWAT was created by merging ROTO and SWRRB into one model (Gassman *et al*., 2007).

### 2.6.2 SWAT model overview

SWAT is a physically based, basin scale model that operates on a continuous daily time step to predict the effects of land use management on nutrients, agrichemicals, sediment and water (Gassman *et al*., 2007). Watersheds are divided into several subwatersheds containing only one stream reach. Subwatersheds are then further divided into hydrological response units (HRU) consisting of unique combinations of soil type, land use and slope. HRU’s are not spatially defined but are represented as a percentage of the corresponding subwatersheds area (Gassman *et al*, 2007; Winchell *et al*., 2010; Neitsch *et al*., 2009). Model input files can then be defined at three different levels: watershed, subbasin, and HRU. Watershed level inputs contain information that is used to model processes that are consistent throughout the entire watershed. For example the method used to estimate evapotranspiration is defined at the watershed level as it remains the same for all HRU’s in the watershed. Subbasin level inputs are set at the same value for all HRU’s in a given subbasin. Climate data such as precipitation and maximum and minimum temperature are examples of subbasin level input data. Information pertaining to the reach of a subbasin is also defined at this level as each subbasin contains only one reach. HRU level inputs contain information unique to specific HRU’s such as management operations, and land use and soil parameters. There are some input files that do not fit into any of the above levels such as point source inputs or weather generator data which can be located outside the modelled catchment (Arnold *et al*., 2010).

### 2.6.3 SWAT strengths, weaknesses, and sensitivities

Despite the wide use of SWAT, it is still important to examine how successful past studies have been and what the strengths of weaknesses of the model are. The ability of SWAT to simulate effects on water discharge and quality has been assessed in several different studies. The first matter to be considered is the level of detail in elevation, soil and land use data that is required to produce accurate results. Chaplot (2005) found that DEM resolutions of 50 meters produced the most accurate results, with no improvement obtained from higher resolutions. The use of coarser resolutions resulted in minor changes in flow, and had a significant effect on nitrogen and sediment yields. It was hypothesised that effect on nitrogen and sediment yields is the result of an underestimation of slope angles when calculated from coarse DEM grids (Chaplot, 2005). The scale of soil maps used has a high impact on the quality of model outputs. A map scale of 1:25,000 has been found to be sufficient, whereas larger scale maps result in inaccurate results. (Chaplot, 2005; Muttiah & Wurbs, 2002; Romanowicz *et al*., 2005).

Techniques used in the preprocessing and parameterisation of soil and land use data can also have a significant effect on model performance (Geza & McCray, 2008). Parameterisation of soil data is best done by soil texture and hydrological properties before processing the data for entry into a soil database. Care should be taken when processing both land use and soil data, ensuring that both have been parameterised properly before averaging and entry into soil and land use databases (Romanowicz *et al*., 2005; Mulungu & Munishi, 2007). In addtion, the quality of rainfall data used to force the model is highly important. Rainfall stations need to be located in or near the watershed in order to provide representitive data (Dixon & Earls, 2012). Variables that discharge is particularly sensitive to are the runoff curve number (CN2), available water constant, and saturated hydraulic conductivity (Mulungu & Munishi, 2007). Variables that inorganic nitrogen is sensitive to are initial nutirent concentration in soils and fertilizer application rates (Grizzetti *et al*., 205; Winchell *et al*., 2010).

### 2.6.4 SWAT application in New Zealand

Although SWAT has been used in many different studies in other parts of the globe, there have been very few studies that have used the model in New Zealand. One reasons that SWAT has not been selected in favour of other models is because some models have been developed specifically for New Zealand (Cichota & Snow, 2009). CLUES (Catchment Land use for Environmental Sustainability) is one such model. Elliott (2012) compared SWAT and CLUES in an effort to assess the ability of the models to provide information used to make land management decisions in the Waituna lagoon catchment. The study concluded that the best solution was to use both models in conjunction with each other. This decision was made largely due to the differences in the two models. SWAT is far more complex than CLUES which, while resulting in a more detailed analysis of a catchment, also means more effort is required to create a working model and the output can difficult for decision makers to understand and interpret. In contrast, CLUES is quite simplistic and models can be set up without much difficulty, but there is a heavy reliance on external calculations to accurately assess some practices. Furthermore the simplicity of CLUES means that some processes are not simulated as well as in SWAT (Elliott S. , 2012).

**Table 2.1: Percent coverage of major land uses for each scenario (modified from Cao *et al.*, 2008)**

| Scenario | Pasture (%) | Indigenous Forest (%) | Planted Forest (%) | Scrub (%) |
|---|---|---|---|---|
| Present day | 17.9 | 36.84 | 26.61 | 9.92 |
| Prehistoric | - | 87.94 | - | 11.72 |
| Potential pine | 0.84 | 36.83 | 50.13 | 3.49 |

The SWAT model was used by Cao *et al*. (2008) to assess the effect changes in land use on discharge in the Motueka River. Three land use scenarios were modelled: present day land use, prehistoric land use, and a maximum potential pine plantation land use. Dominant land uses for the three scenarios are shown in Table 2.1. The model was calibrated and validated for present day land use using discharge data from 1990 to 2000. Model performance varied throughout the catchment with $R^2$ values ranging from 0.41 to 0.82. The calibrated model was then run for the two additional land use scenarios. The modelled discharges from these three scenarios were then compared to assess how the different land uses affected flow. The changes in water balance under prehistoric and potential pine land uses compared to present day land use are shown in Table 2.2. The results show that both prehistoric and potential pine scenarios cause an increase in evapotranspiration and a decrease in flow. The effects were found to vary in some of the lower order tributaries. Total water yields were reduced by 1.4% to 10.8% for the prehistoric scenario, and 0.17% to 15.7 % for the potential pine scenario.

**Table 2.2: Annual average percent change in evapotranspiration, quick flow, base flow, and total water yield compared with present day land use (adapted from Cao *et al.*, 2008).**

| Land use | Δ ET (%) | Δ Quick flow (%) | Δ Base flow (%) | Δ Total water yield (%) |
|---|---|---|---|---|
| Prehistoric | +7.5 | -7.7 | -3.9 | -5.5 |
| Potential Pine | +5.9 | -3.4 | -4.5 | -4.5 |

# 3 Methods

## 3.1 Site Description

This study was conducted on subcatchments of the Tauranga Harbour on the east coast of New Zealand's North Island. The harbour is enclosed by Matakana Island. Matakana Island formed by Holocene sand spit extension and fore dune accretion upon Pleistocene tephra covered terraces (Shepherd *et al.*, 1997). The harbour can be divided in to a northern harbour and a southern harbour, each with its own entrance at their respective ends of Matakana Island. The two halves, although joined by a small channel at high tide can for the most part be considered as separate systems (Tay, 2011). This study focuses on catchments that discharge into the southern harbour as it is the most affected by anthroprogenic activity.

To the west of the harbour, the mainland is characterised by low lying plains beneath the high hills of the Kaimai ranges. The Kaimai ranges are thought to have formed in the Early Miocene (20–15 ma) during the Kaikoura Orogeny. The underlying geology of the mainland consists of the Waiteariki Ignimbrite and associated tuff in hilly areas, and aluvial sand and gravel in low lying areas (Suggate *et al.*, 1987).

Land use was taken from the land cover database verson one (LCDB1). More information on LCDB1 is provided in chapter 4.1.3. The distribution of land uses in the area are shown in Figure 3.1 and land use areas for the entire harbour catchment and the southern harbour only are shown in Table 3.1 and Table 3.2 respectively. From these tables we can see that overall the main land uses are exotic grassland (agriculture) and indigenous forest, with a notable proportion of the area used for orchards, pine forests, and a small amount of built up urban area. When only the southern harbour catchment is considered, there is a slight decrease in the proportion of agricultural land, and a slight increase in indigenous forest and built up areas. These changes in proportion reflect that the largest urban areas, Tauranga City and Mount Maunganui, are located in the southern harbour. Also,

**Table 3.1: Land cover areas for the entire Tauranga Harbour catchment**

| LCDB1 Name | Area (ha) | Area (%) |
|---|---|---|
| Afforestation (imaged post LCDB 1) | 483.29 | 0.37 |
| Broadleaved Indigenous Hardwoods | 1170.26 | 0.89 |
| Built-up Area | 4818.33 | 3.65 |
| Coastal Sand and Gravel | 249.68 | 0.19 |
| Deciduous Hardwoods | 170.35 | 0.13 |
| Estuarine Open Water | 1784.39 | 1.35 |
| Forest Harvested | 1058.18 | 0.80 |
| Gorse and Broom | 690.93 | 0.52 |
| Herbaceous Freshwater Vegetation | 270.33 | 0.20 |
| Herbaceous Saline Vegetation | 763.98 | 0.58 |
| High Producing Exotic Grassland | 44984.72 | 34.05 |
| Indigenous Forest | 49534.53 | 37.50 |
| Lake and Pond | 93.40 | 0.07 |
| Landslide | 3.12 | <0.01 |
| Low Producing Grassland | 441.15 | 0.33 |
| Major Shelterbelts | 175.91 | 0.13 |
| Mangrove | 831.40 | 0.63 |
| Manuka and or Kanuka | 1348.15 | 1.02 |
| Mixed Exotic Shrubland | 59.72 | 0.05 |
| Orchard and Other Perennial Crops | 8202.99 | 6.21 |
| Other Exotic Forest | 1048.88 | 0.79 |
| Pine Forest - Closed Canopy | 10895.36 | 8.25 |
| Pine Forest - Open Canopy | 1381.04 | 1.05 |
| River | 105.13 | 0.08 |
| River and Lakeshore Gravel and Rock | 0.09 | <0.01 |
| Short-rotation Cropland | 418.14 | 0.32 |
| Surface Mine | 99.78 | 0.08 |
| Transport Infrastructure | 34.00 | 0.03 |
| Urban Parkland/ Open Space | 966.93 | 0.73 |
| Vineyard | 17.77 | 0.01 |
| **Total** | **132101.92** | **100** |

the catchment of the Wairoa river which is the largest in the harbour is largly covered by native forest.

Soils were parameterised by soil series. The distribution of the different soils is shown in Figure 3.2. For more details on the parameterisation refer to chapter 4.1.4.

The catchments in the southern harbour are shown in Figure 3.3. The catchments for which a SWAT model was made are that of the Wairoa River and the Waimapu River. The Wairoa River was chosen because it is the largest catchment in the Tauranga harbour. Both catchments have more nitrogen concentration data available than other catchments, allowing better calibration and verification.

**Table 3.2: Land cover areas for the southern harbour catchment**

| LCDB1 Name | Area (ha) | Area (%) |
|---|---|---|
| Afforestation (imaged post LCDB 1) | 435.29 | 0.42 |
| Broadleaved Indigenous Hardwoods | 802.52 | 0.77 |
| Built-up Area | 4505.72 | 4.31 |
| Coastal Sand and Gravel | 124.73 | 0.12 |
| Deciduous Hardwoods | 137.67 | 0.13 |
| Estuarine Open Water | 1723.37 | 1.65 |
| Forest Harvested | 255.65 | 0.24 |
| Gorse and Broom | 588.62 | 0.56 |
| Herbaceous Freshwater Vegetation | 22.73 | 0.02 |
| Herbaceous Saline Vegetation | 514.84 | 0.49 |
| High Producing Exotic Grassland | 35465.38 | 33.96 |
| Indigenous Forest | 41311.46 | 39.56 |
| Lake and Pond | 73.97 | 0.07 |
| Landslide | 1.22 | 0.00 |
| Low Producing Grassland | 417.24 | 0.40 |
| Major Shelterbelts | 130.50 | 0.12 |
| Mangrove | 424.15 | 0.41 |
| Manuka and or Kanuka | 989.94 | 0.95 |
| Mixed Exotic Shrubland | 55.67 | 0.05 |
| Orchard and Other Perennial Crops | 5037.22 | 4.82 |
| Other Exotic Forest | 770.73 | 0.74 |
| Pine Forest - Closed Canopy | 8746.80 | 8.38 |
| Pine Forest - Open Canopy | 541.94 | 0.52 |
| River | 95.51 | 0.09 |
| River and Lakeshore Gravel and Rock | 0.09 | 0.00 |
| Short-rotation Cropland | 220.23 | 0.21 |
| Surface Mine | 77.21 | 0.07 |
| Transport Infrastructure | 17.51 | 0.02 |
| Urban Parkland/ Open Space | 917.24 | 0.88 |
| Vineyard | 17.77 | 0.02 |
| **Total** | **104422.91** | **100** |

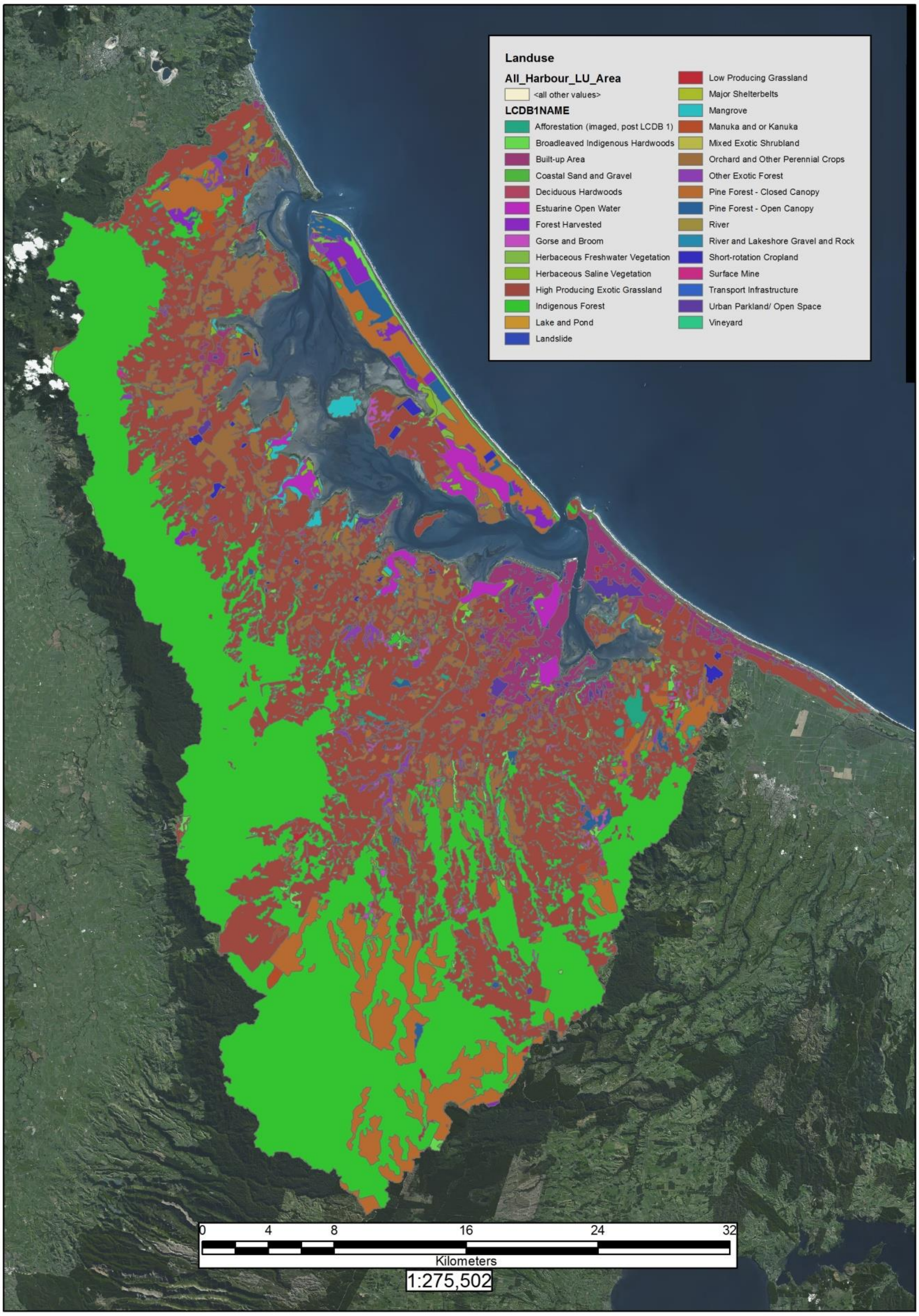


**Figure 3.1: Distribution of Land use in the Tauranga Harbour catchment.**

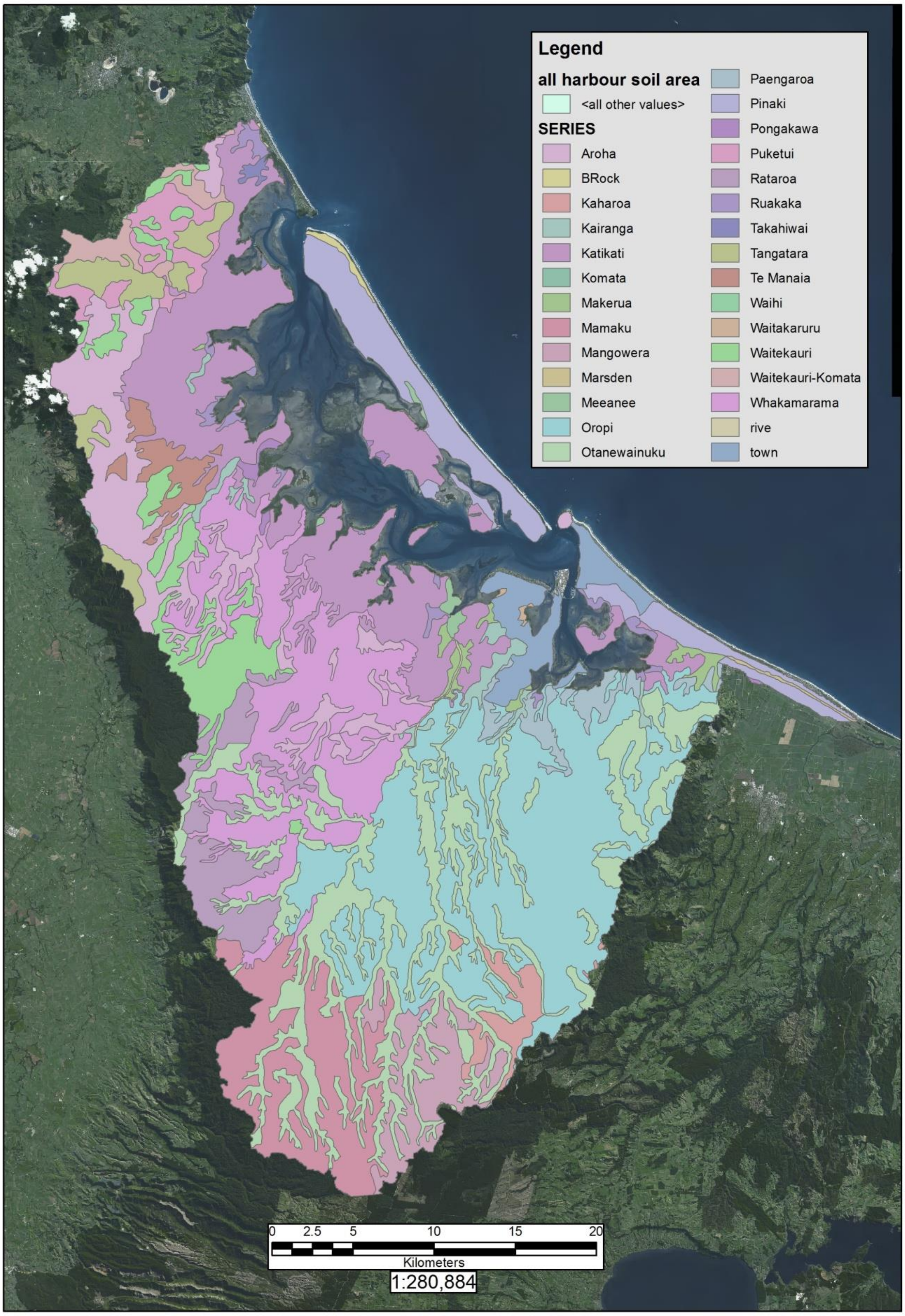


**Figure 3.2: Distribution of soils in the Tauranga Harbour catchment.**

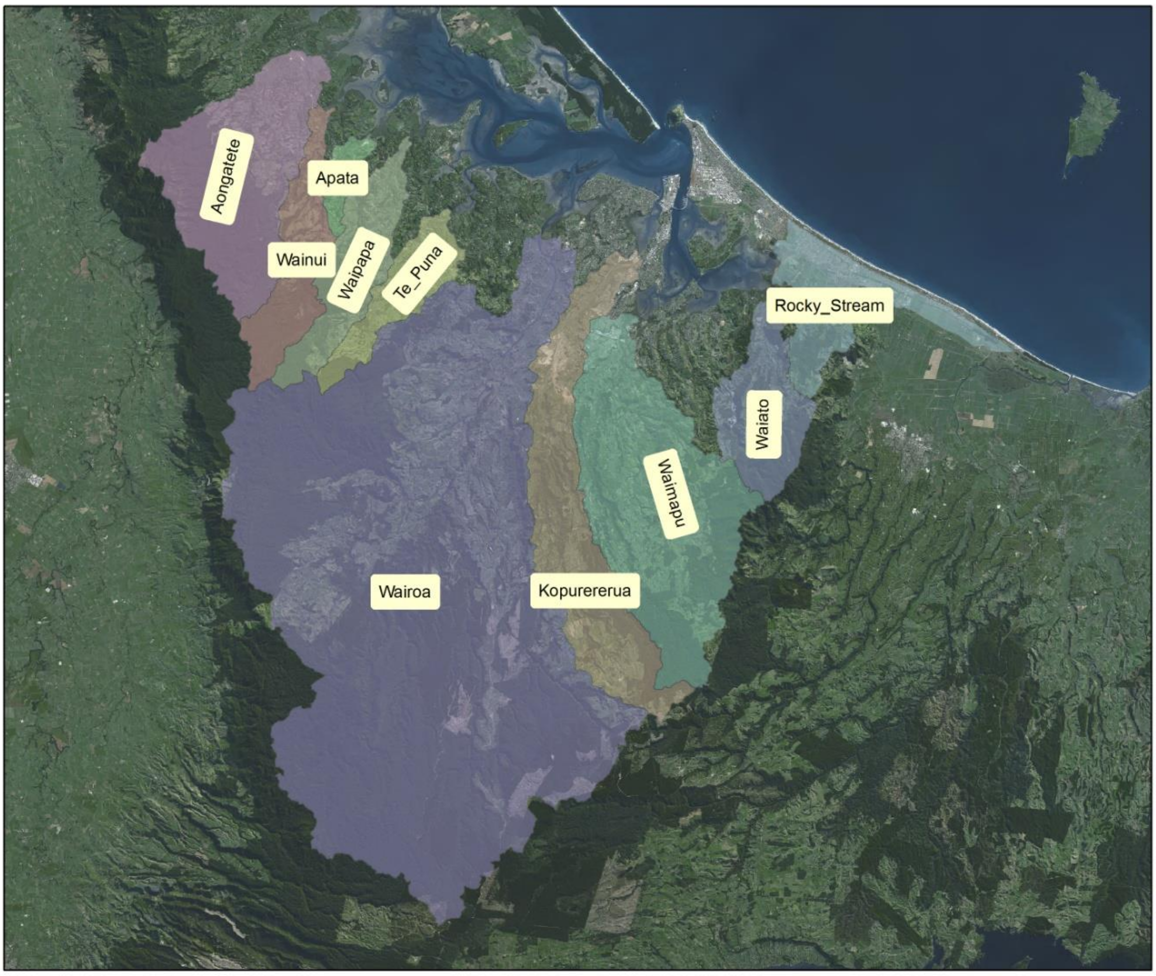


**Figure 3.3: The main catchments of the southern Tauranga Harbour.**

## 3.2 Field Sampling

A sampling program was undertaken to collect data for the purpose of describing the variability of nitrogen concentration between rivers. Samples were collected on 5 separate days between the 22nd of November 2011 and the 12th of December 2012. Sampling locations are shown in Figure 3.4. These sampling sites are from subcatchments that make up the majority of the southern harbours catchment. The site locations were chosen based on ease of access and proximity to the Harbour. An ideal sampling site was close to the mouth of a river to ensure samples were representative of the entire catchment, but far enough inland to ensure there was no influence from the saline water from the Harbour.

Sampling equipment was acid washed with 10% HCl and rinsed with deionised water prior to each day's sampling. Equipment was also triple rinsed with sample water before collection of a sample. Equipment that was reused was rinsed with deionised water between sites. Samples were collected by taking water from a river with a 1L plastic jug. The water was then taken from the jug with 60 ml syringes and transferred to 50 ml sterile sample tubes. A typical sample was approximately 45 ml in volume to ensure room in the tube for freezing of the sample. At each sampling site two unfiltered samples and two filtered samples were collected. Filtered samples were collected using 1.2 μm glass microfiber filters; these filters were stored for possible analysis of chlorophyll content in aluminium foil to avoid photodegradation of the sample. Both water and chlorophyll samples were immediately put on ice while in the field, and frozen at the end of the day until thawed for subsampling and analysis. Each tube was labelled with the date and time the sample was collected, the site ID number, the site name, and whether the sample was filtered or unfiltered. On some sampling trips, temperature and salinity was also measured.


**Figure 3.4: Sample collection locations.**

## 3.3 Nitrogen sample analysis

Analysis of water samples collected during field sampling were analysed for phosphate, ammonia, nitrite, and total oxides of nitrogen using flow injection analysis (FIA). Preparation for an FIA run first begins with acid washing all glassware that is to be used. Proper cleaning of glassware is necessary to ensure no contamination of either the calibration standards, or the chemicals used for the nutrient analysis occurs. Glassware is soaked in 10% HCl for several hours, triple rinsed in ultra-pure water, and left to air dry. Latex gloves are worn when handling any samples, glassware, or reagents. Many of the reagents are toxic and must only be opened in a fume hood. Once the glassware is clean reagents and calibration standards can be prepared. All solutions are made with ultra-pure water.

Once the calibration standards have been made, the FIA auto analyser can be calibrated and then samples analysed. However the calibration should be examined before running samples. Also, calibration standards can be re-analysed during the sample run to check for drift in the readings made by the auto analyser.

### 3.3.1 Reagents

The FIA method used requires that reagents need to be made for each of the nutrients that is analysed. The exception being Nitrite and $NO_x$ which use the same chemicals (the difference between the two channels is that the $NO_x$ channel contains a cadmium column that reduces $NO_3$ to $NO_2$). The reagents for each method, and how they were prepared are listed below.

#### 3.3.1.1 Ammonia reagents

Buffer solution: In a 1L schott bottle, dissolve 30.0g sodium hydroxide (NaOH), 25.0g disodium EDTA and 67.0g sodium phosphate dibasic heptahydrate ($Na_2HPO_4 \cdot 7H_2O$) in about 900mL water.  Dilute to mark and invert to mix.

Salicylate – nitroprussid color reagent: In a 1L schott bottle, dissolve 144g sodium salicylate [salicylate acid sodium salt, $C_6H_4(OH)(COO)Na$] and 3.5g sodium nitroprusside ($Na_2Fe(CN)_5NO \cdot 2H_2O$) in about 800mL water. Dilute to mark and invert three times. Store in a light proof bottle. Prepare fresh weekly.

Hypochlorite: In a 1L schott bottle, dilute 60mL Janola (4-6% sodium hypochlorite ($NaClO$)) to the mark with water. Invert three times. Prepare fresh daily

#### 3.3.1.2 Phosphorous reagents

Reagent 1: Stock ammonia molybdate solution. In a 1L schott bottle dissolve 40.0 g ammonia molybdate tetrahydrate [$(NH_4)_6Mo_7O_{24}.4H_2O$] in approximately 800 mL DI water. Dilute to the mark and place on a magnetic stirrer to dissolve. Stir for four hours on a stir plate to dissolve. Store in plastic and refrigerate.

Reagent 2: Stock antimony potassium tartrate solution. In a 1 L schott bottle, dissolve 3.0 g antimony potassium tartrate (potassium antimonyl tartrate hemihydrate $K(SbO)C_2H_4O_6 \cdot 1/2H_2O$) or 3.22g of antimony potassium tartrate (potassium antimonyl tartrate trihydrate $C_8H_4O_{12}$ $K_2Sb_2 \cdot 3H2O$) in approximately 800 mL water. Dilute to the mark and mix with a magnetic stirrer until dissolved. Store in a dark bottle and refrigerate.

Molybdate color reagent: In a fume hood to the 1L schott bottle add 35 mL concentrated sulfuric acid to approximately 500 mL DI water (CAUTION: The solution will get hot). Swirl to mix. When cool, add 72 mL antimony potassium tartrate solution (Reagent 2) and 213 mL ammonia molybdate solution (Reagent 1). Dilute to the mark with DI water and invert to mix.

Ascorbic acid reducing solution: In a 1L schott bottle dissolve 60.0 g granular ascorbic acid in about 700 mL DI water. Add 1.0 g sodium lauryl sulfate ($CH_3(CH_2)_{11}OSO_3Na$). Dilute to the mark with DI water and invert to mix. Prepare fresh on day of run.

#### 3.3.1.3 NOx Reagents

Ammonia chloride buffer: (CAUTION: Fumes) In a fume hood, to the 2.5L bottle add about 1250mL DI water, 252mL concentrated hydrochloric acid (HCl), and 247mL liquid ammonia ($NH_4OH$ aka ammonia solution). Add 2.5 g disodium EDTA, dissolve and dilute to mark. Invert to mix. Adjust to pH 8.5 with HCl or NaOH 15N solution.

15N NaOH solution: Add 150g NaOH very slowly to 250mL of MQ water. CAUTION: The solution will get very hot! Swirl until dissolved. Cool and store in plastic.

Sulfanilamide Colour Reagent: To a 1 L schott bottle add about 600 mL DI water. Then add 100 mL 85% phosphoric acid ($H_3PO_4$), 40.0 g sulfanilamide and 1.0 g N-(1-naphthyl)-ethylenediamine dihydrochloride (NED). Shake to wet, and stir with stir bar to dissolve for 30 min. Dilute to the mark, and invert to mix. Store the reagent in a dark bottle.

### 3.3.2 Calibration standards

Two sets of calibration standards are made. One set of combined standards for phosphate, ammonia, and $NO_x$, nnd another set for nitrite. The combined calibration standards are made from a stock standard with a concentration of 1000 mg/L of P, N (as NH3) and N as (NO3-). To make the stock standard add to a 1L volumetric flask the following:

$4.390 \pm 0.002$g $KH_2PO_4$

$3.819 \pm 0.002$g $NH_4Cl$

$7.218 \pm 0.002$g $KNO_3$

Fill the flask to the mark with ultra-pure water and mix thoroughly.

Intermediate standards with concentrations of 20 mg/L and 1 mg/L are made in order to make the final calibration standards easier to prepare. The 20 mg/L (20 STD) is made by adding 2 ml of stock standard to a 100 mL volumetric flask.

Dilute to the mark with ultra-pure water and mix thoroughly. The 1 mg/L (1 STD) is made by adding 5 ml of 20 STD to a 100 mL volumetric flask. Dilute to the mark with ultra-pure water and mix thoroughly.

Calibration standards are can then be prepared from the intermediate standards. Table 3.3 shows the concentration of the standard concentrations and the volume of the indicated intermediate standard that is used. All calibration standards are made in a 250 mL volumetric flask

**Table 3.3: Intimidate standards and the weights used to make the calibration standards used.**

| Intimidate standard | Amount used (g) | Final concentration (mg/L) |
|---|---|---|
| 20 STD | 9.375 | 0.75 |
| 20 STD | 6.25 | 0.5 |
| 1 STD | 25 | 0.1 |
| 1 STD | 12.5 | 0.05 |
| 1 STD | 2.5 | 0.01 |
| 1 STD | 1.25 | 0.005 |

The nitrite calibration standards were made from a stock standard with a concentration of 500 mg/L. The stock standard was made by adding 0.6161 ± 0.0005 g of $NaNO_2$ to a 250 mL volumetric flak. Ultra-pure water is then added up to the mark and the solution is thoroughly mixed.

From the stock standard a 10 mg/L intimidate standard (10 STD) is made. 20 mL of the stock is added to a 1 L volumetric flask, ultra-pure water is added up to the mark, and the solution is mixed thoroughly.

Finally the calibration standards are made using the weights of 10 STD indicated in Table 3.4. The 0.005 mg/L standard can also be made using 1.25 g of the 1 mg/L standard.

**Table 3.4: Weights of 10 STD used and the final concentration of the nitrite calibration standards.**

| Amount used (g) | Final concentration (mg/L) |
|---|---|
| 25 | 1 |
| 12.5 | 0.5 |
| 2.5 | 0.1 |
| 1.25 | 0.05 |
| 0.25 | 0.01 |
| 0.125 | 0.005 |

## 3.4 Model Setup

SWAT models used in this study were set up following the steps outlined in the ArcSWAT interface user's manual (Winchell *et al*., 2010). The process of setting up a SWAT model can be devided into three segments; watershed delineation, HRU definition, and writing input tables.

### 3.4.1 Watershed Delineation

Watershed delineation was done using a 25 meter DEM grid. The DEM was clipped to a size slightly larger than the catchment area prior to being loaded into being the interface. Known stream locations were taken from the River Enhancement Classification (REC) database (Snelder *et al*., 2004). The subbasin threshold area was then adjusted so that the delineated streams matched the known stream locations as closely as possible.

Once an acceptable subbasin and stream delineation had been acquired the subbasin outlet were edited. During this stage, outputs of any streams that had been delineated that do not exist in reality were deleted to reduce the number of subbasins. The output for the entire catchment was then selected and the watershed and subbasins were automatically delineated by the software. As there are no reservoirs in the modelled catchments, the subbasin parameters (such as area, slope statistics, and stream routing variables) can then be calculated and the watershed delineation dialog exited.

### 3.4.2 HRU definition

HRU definition consists of three stages: land use, soil, and slope definition. Land use and soil definition both require a land use/soil GIS shapefile to be loaded into the ArcSWAT interface. For the land use layer, the shape file contained an ID number for each soil. The user then assigned the SWAT land use (from either the crop of urban database) that corresponds to the layers ID number must be selected. For the soil layer, "name" was selected as the soil identifier. In much the same manner as for land use, soils form the user soils database were then assigned to their corresponding soil ID numbers. For slope definition, the multiple slope classes option was chosen and three slope classes were defined. For each catchment the range of each slope class was varied until a uniform distribution of classes was obtained.

The final stage of the HRU definition is to set the HRU threshold values. For all three layers, a threshold value of 10 Ha was used. Using an absolute value instead of a percentage of subbasin area simplified the model by removing small units from the modelling framework and preventing an excessive number HRU's from being created.

### 3.4.3 Write Input tables

The ArcSWAT dropdown menu "Write input files" is used to first define the weather data, and then write the input files required by SWAT. For more information on the preparation of the weather data see chapter 4.2.

Before the weather data can be loaded into ArcSWAT, the folder structure of the weather data tables must be properly organised. The correct folder structure consists of a primary folder containing the weather generator locations table and subsequent folders for each type of weather data (precipitation, temperature, wind, solar radiation, and relative humidity). Each of these subsequent folders must contain the weather station locations table, and all the data tables for that weather type.

Once the folder structure of the weather data is properly organised the user can then load the data into ArcSWAT. The first file to be loaded must be the weather generator locations table. To do this, under the weather generator data tab of the wether data definition window, the user much select "Custom Database" and then browse to the weather generator locations table. Next the user can load each of the weather datasets in any order. For each weather type, under the corresponding tab, the user must select the weather type stations option (other than simulation) and browse to the weather station locations table for that weather type. For precipitation data the user needs to define the precipitation data time step as either daily or sub-daily. Daily precipitation data was used for this study.

Once the locations tables for all the weather types have been loaded the SWAT input files can be written. For this study the option to write all files was used rather than writing each file type individually. ArcSWAT also gives the user to use default values for Mannings N and heat unit inputs. These default values are only suitable within the United States and so custom values were used. The software then proceeds to write all the required input files. When prompted, values for Mannings N and heat units were defined as 0.075 and 600 respectively.

Once the software has finished writing the input files the user can setup and run the default SWAT simulation.

### 3.4.4 Setup and run SWAT simulation

The dialog used to run SWAT is found under the SWAT Simulation menu. In this dialog the start and end dates were set to 31/05/1996 and 08/02/2002 respectively. The printout settings were set to daily. The variable NYSKIP was set to 1. NYSKIP causes SWAT to refrain from printing the output for the number of years specified, allowing that time period to be used as a warm up period for the model. In this case the NYSKIP value of 1 causes the first output point to be the 01/01/1997. All other parameters are left as default.

Once the run parameters have been set the “Setup SWAT Run” button can be pressed. This will write the selected properties to the SWAT input files, and cause the “Run SWAT” button to become selectable. However before the model is run, the user can make final changes to any input files. For this study the file.cio file was edited to limit the number of parameters printed to the output. rch file. To do this file.cio in the Default folder was opened and the line under “Reach output variables:” was edited so that the first four zeroes are replaced with 2, 13, 15, and 17 respectively. The file was saved and closed, and the model run by pressing the “Run SWAT” button in the setup and run SWAT model simulation dialog.

# 4 ArcSWAT Input data

## 4.1 GIS Data

ArcSWAT requires several layers of data to delineate both the watershed and hydrological response units. These layers consist of a digital elevation model, land cover and soil type. In this study, the optional input of known stream locations was also used. The following sections will describe these datasets in detail.

### 4.1.1 Digital elevation model

The digital elevation model (DEM) used was has a 20 by 20 meter resolution for the whole North Island. This layer was clipped to the study area in order to reduce computation times when using GIS. The clipped DEM is then used to delineate streams, watersheds, and the longest possible path of the streams during floods. A mask covering only the catchment of interest was used to further clip the DEM and reduce processing times.

### 4.1.2 Known stream locations

In some areas the, slope in the DEM is too low to accurately delineate streams. To overcome this issue, the option to input a GIS layer showing known stream locations was utilised. The reach layers from the River Enhancement Classification (REC) database were downloaded and clipped to the catchments used in this study. These new layers were then loaded into the ArcSWAT interface during the watershed delineation process. ArcSWAT then used these data to “burn in” stream locations. The result was a far more accurate delineation of subbasins than would have otherwise been achieved.

### 4.1.3 Land cover

Land cover data was obtained from the Ministry for the Environments Land Cover Database 2 (LCDB2). This database is a hierarchical development on Land Cover Database 1 (LCDB1), increasing the number of classes from 18 to 61. LCDB1 was derived from satellite imagery that was obtained during 1996 and

1997 with a map accuracy of 93.9 percent. Both LCDB1 and LCDB2 have a minimum mapping unit size of 1 ha (Ministry for the Environment, 2007).

### 4.1.4 Soils

To describe the spatial distribution of different soil types and their properties, SWAT requires a soils shape file to be loaded into the interface. This shape file does not contain the parameters of the soil, but rather only contains a soil identification number (OBJECTID). The soil parameters themselves must be appended to the user soils database. The user then assigns the correct soil names to the ID numbers during HRU definition.

**Table 4.1: Soil variables required by SWAT and their description. * required for each soil layer.**

| Variable name | Variable description |
|---|---|
| OBJECTID | Soil type unique identifier |
| SNAM | Soil name |
| HYDGRP | Soil hydrologic group |
| NLYRS | Number of layers in soil profile |
| SOL_ZMX | Maximum rooting depth of soil profile |
| ANION_EXCL | Fraction of porosity from which anions are excluded |
| SOL_CRK | Potential maximum volume of cracks in soil profile |
| SOL_Z* | Depth from soil surface to bottom of layer |
| SOL_BD* | Soil moist bulk density |
| SOL_AWC* | Soil layer available water content |
| SOL_K* | Saturated hydraulic conductivity |
| SOL_CBN* | Organic carbon content |
| CLAY* | Clay content |
| SILT* | Silt content |
| SAND* | Sand content |
| ROCK* | Rock fragment content |
| SOL_ALB* | Moist soil albedo |
| ULSE_K* | ULSE equation soil erodibility factor |
| SOL_EC* | Electrical conductivity |

For this study, the land resource inventory (LRI) spatial soil data layer was used to describe the spatial distribution of soils (Newsome *et al*., 2000). The LRI soil data shape file containd data on a wide verity of peramaters such as soil chemical, porductivity, drainage, parent material, and textural properties. Despite this wide range of available data, many of the variables required by SWAT were included. Where possible, required variables that were not found in the database were estimated from the available data. Table 4.1 shows a list of all the variables that are required by SWAT.

Soils were parameterised by soil series. Due to the high degree of variability present in soil properties in many cases it was necessary to average all the values for a given parameter before calculation of the value required for the user soils database. In retrospect, it would be more useful to parameterise soils by a parameter intrinsic to the behaviour of the soil such as textural class, rather than by soil series. The following sections describe the methods used to calculate each soil variable. A more detailed description of the variables and how they are used by the model can be found in the SWAT user manual (Winchell *et al*., 2010), SWAT input/output manual (Arnold *et al*., 2010), and SWAT theory manual (Neitsch *et al*., 2009).

#### 4.1.4.1 OBJECTID and SNAM

Both SNAM and OBJECTID were very easily defined. OBJECTID is an identification number for each soil type and is automatically created by the software when the soil parameters are appended to the database. SNAM is simply the name that is to be used for the soil type in the user soils database. For this study SNAM was the name of the soil series. It should be noted that the user needs to keep track of which polygons, or rather, the ID number in the attributes table of the polygons, correspond to which soil type. This is because during HRU definition the user must pair the ID numbers of the soil polygons with the name entered in SNAM.

#### 4.1.4.2 HYDGRP

The HYDGRP variable defines the soils hydrologic group. The U.S. Natural Resource Conservation Service classifies a soil into one of four hydrologic groups based on infiltration characteristics under storm conditions. Soil characteristics that affect infiltration rates are saturated hydraulic conductivity, depth to the water table, and depth to a slowly permeable layer. The four hydrologic groups are shown in

Table 4.2.

Because the LRI database did not contain any data on infiltration rates or depth to water table, the hydrologic group was estimated from the drainage class of the soil. Well drained soils were placed in group A, moderately well in group B, imperfect and poor in group C, and very poorly drained soils in group D (Newsome *et al*., 2000).

**Table 4.2: Soil hydrologic group definition. Taken from Arnold *et al*., 2010.**

| Group | Characteristics |
|---|---|
| A | Soils having high infiltration rates when thoroughly wetted, consisting chiefly of sands of gravel that are deep and well to excessively drained. These soils have a high rate of water transmission (low runoff potential). |
| B | Soils having moderate infiltration rates when thoroughly wetted, chiefly moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission. |
| C | Soils having slow infiltration rates when thoroughly wetted, Chiefly with a layer that impedes the downward movement of water or of moderately fine to fine texture and a slow infiltration rate. These soils have a slow rate of water transmission (high runoff potential). |
| D | Soils having very slow infiltration rates when thoroughly wetted, chiefly clay soils with a high swelling potential; soils with a high permanent water table; soil with a clay pan or clay layer at or near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission. |

#### 4.1.4.3 NLYRS

NLYRS is simply the number of layers of the soil in the database. The LRI database did not contain any data pertaining to the number of layers of the soil, so initially only one soil layer was defined. The number of soil layers was then changed during calibration of the model. During calibration, each layer for a given soil series had identical values for all parameters except for SOL_Z, which defines the depth to the bottom of the layer.

#### 4.1.4.4 SOL_ZMX

The variable SOL_ZMX specifies the maximum rooting depth of the soil profile. Values for SOL_ZMX were able to be taking directly from the LRI database variable PRD_MAX. Specific values for PRD_MAX varied within an each soil series. As a result the mean value for PRD_MAX was calculated for each soil series before being entered into the user soils database.

#### 4.1.4.5 ANION_EXCL

ANION_EXCL is the fraction of porosity from which anions are excluded via repulsion by the net negative charge that is possessed by most soil minerals. ANION_EXCL has important implications for anion transport as it excludes anions from the slowest moving portions of soil water (Arnold *et al.*, 2010). No data was available in the LRI database that was able to be used to calculate a value for ANION_EXCL. It was observed that existing soils in the SWAT database all used the default value of 0.5 for ANION_EXCL, and so the default was used for all soils used in this model as well.

#### 4.1.4.6 SOL_CRK

SOL_CRK defines the maximum potential crack volume of the soil profile. The crack volume is defined as a fraction of the total soil volume. No data was available in the LRI database that was able to be used to calculate a value for SOL_CRK. It was observed that existing soils in the SWAT database all used the default value of 0.5 for SOL_CRK, and so the default was used for all soils used in this model as well.

#### 4.1.4.7 SOL_Z

The value for SOL_Z defines the depth from the soil surface to the bottom of the soil layer. A value for SOL_Z must be defined for each layer of a soil type. As only one soil layer was initially defined the sole entry for SOL_Z for each soil series was set to the maximum depth of the soil profile. The LRI database variable DSLO_MID was used to define the depth of the soil profile as it is the average depth to a slowly permeable horizon. The mean value for DSLO_MID from all instances of a soil series was originally used for SOL_Z.

The number of soil layers was varied during model calibration. Changing the number of soil layers also required each soil layer to possess a different value for SOL_Z, with increasing values for deeper layers. For each layer of a given soil series, a value was calculated that was a proportion of the initial value for SOL_Z. layer one would have a SOL_Z value of 10 % the initial value, layer two would have a SOL_Z value of 20% the initial value and so on. The SOL_Z for the last layer in the soil profile was set to the initial SOL_Z for the soil series; the average depth to a slowly permeable horizon.

#### 4.1.4.8 SOL_BD

SOL_BD is the moist soil bulk density, expressed as the ratio of the mass of the solid particles to the total volume of the soil. The LRI database did not contain any data on bulk density. Instead the bulk density was estimated using the soil textural class, macroporosity, and particle densities. Soil textural classes were taken from the Landcare Research online soils database. Soil macroporosity was taken from the LRI database variable MPOR_S MID. Typical particle densities for different textural classes were taken from the My Agriculture Information Bank.

For each soil series, the bulk density was calculated as $(1 - MPOR)p_b$ where MPOR is the average macroporosity (measured as a percentage of soil volume) for the soil series, and $\rho_p$ is a typical particle density for the soils textural class. Some soil series could not be found on the online soils database. For these soils the average of all calculated bulk densities was used.

#### 4.1.4.9 SOL_AWC

The available water content of the soil is defined by SOL_AWC. SOL_AWC was calculated using the LRIS variables PRAW_MID (profile readily available water) and PROD_MID (potential rooting depth) as PRAW_MID/PROD_MID.

#### 4.1.4.10 SOL_K

SOL_K is the saturated hydraulic conductivity of the soil layer. No data on hydraulic conductivity was available in the LRI database. Instead a typical saturated hydraulic conductivity for the soils textural class was used. Table 4.3 shows hydraulic conductivity used for each textural class.

**Table 4.3: Typical saturated hydraulic conductivity ($K_{sat}$) for different textural classes. Adapted from the Argonne national laboratory (2012).**

| texture | $K_{sat}$ (m/yr) | $K_{sat}$ (mm/hr) |
|---|---|---|
| Sand | 5550 | 633.13 |
| Loamy sand | 4930 | 562.4 |
| Sandy loam | 1090 | 124.3 |
| Silty loam | 227 | 25.9 |
| Loam | 219 | 24.98 |
| Sandy clay loam | 199 | 22.7 |
| Silty clay loam | 53.6 | 6.11 |
| Clay loam | 77.3 | 8.82 |
| Sandy clay | 68.4 | 7.82 |
| Silty clay | 32.1 | 3.66 |
| Clay | 40.5 | 4.62 |
| Rock | 5.0005 | 0.57 |
| Gravel | 5005000 | 570956 |

#### 4.1.4.11 SOL_CBN

SOL_CBN defines the organic carbon content of the soil as a percentage of soil weight. SOL_CBN is analogous to the LRI parameter CARBON_MID.

#### 4.1.4.12 CLAY, SILT, SAND

The variables CLAY, SILT, and SAND define the percent of soil particles that are sand, silt, or clay as a percentage of soil weight (excluding gravel). Table 4.4 shows the grain sizes of each particle type. Soil textural class was used to estimate the percent sand silt and clay of each soil. Table 4.5 shows the percent sand silt and clay for each soil textural class. For soils where no textural class could be found, the average of all calculated values was used.

**Table 4.4: upper and lower diameters of sand, silt, and clay particles.**

| | Lower bound (mm) | Upper bound (mm) |
|---|---|---|
| Sand | 0.05 | 2.0 |
| Silt | 0.002 | 0.05 |
| Clay | - | 0.002 |

**Table 4.5: Percent sand, silt, and clay of different textural classes.**

| | % Sand | % Silt | % Clay |
|---|---|---|---|
| Sand | 95 | 2.5 | 2.5 |
| Loamy sand | 85 | 10 | 5 |
| Sandy loam | 70 | 20 | 10 |
| Sandy silty loam | 40 | 40 | 20 |
| Silty loam | 25 | 65 | 10 |
| Loam | 40 | 40 | 20 |
| Sandy clay loam | 60 | 10 | 30 |
| Silty clay loam | 10 | 55 | 35 |
| Clay loam | 30 | 35 | 35 |
| Sandy clay | 55 | 5 | 40 |
| Silty clay | 5 | 45 | 50 |
| Clay | 20 | 20 | 60 |

### 4.1.4.13 ROCK

The rock fragment content of the soil is defined by the variable ROCK as a percentage of total soil weight. Rock fragments are defined as particles bigger than 2 mm in diameter. The LRI soil database parameter GRAV_MID contains the soil gravel content as a percentage of soil volume. As no other data was available on the rock content of the soil the gravel the values from GRAV_MID were used for ROCK in the user soils database.

### 4.1.4.14 SOL_ALB

The variable SOL_ALB defines the moist soil albedo. The albedo of the soil is defined as the ratio of light that is reflected by an object to the amount that is incident upon it. No data could be found on the moist soil albedo of New Zealand soils. Existing soils in the SWAT soils database do contain data for SOL_ALB. The mean of all these existing values was calculated and used as SOL_ALB for all new soils being entered in the user soils database.

#### 4.1.4.15 USLE_K

USLE_K defines the USLE (Universal Soil Loss Equation) soil erodibility (K) factor. Arnold *et al* (2010) provide detailed instructions on two methods to calculate USLE_K. This study calculated USLE_K using the equation:

$$K_{USLE} = \frac{0.00021 \cdot M^{1.14} \cdot (12 - OM) + 3.25 \cdot (c_{soilstr} - 2) + 2.5 \cdot \left(c_{perm} - 3\right)}{100}$$

where $K_{usle}$ is the soil erodibility factor, M is the particle-size parameter, OM is the percent organic matter, $c_{soilstr}$ is the soil structure code, and $c_{perm}$ is the profile permeability class.

The particle-size parameter (M) was calculated as:

$$M = \left(m_{silt} + m_{vfs}\right) \cdot (100 - m_c)$$

where $m_{silt}$, $m_{vfs}$, and $m_c$ are the percent silt, very fine sand, and clay content of the soil. See chapter 4.1.4.12 for more information the sand, silt and clay soil content.

The percent organic matter content of the soil (OM) was calculated as

$$OM = 1.72 \cdot orgC$$

where orgC is the percent organic carbon content. The organic carbon content of the soil was taken from the LRI database parameter CARBON_MID.

For $C_{soilstr}$ all soils were assumed to medium or coarse granular texture, which has the soil structure code 3 (Arnold *et al.*, 2010).

Values for $c_{perm}$ were derived using the saturated hydraulic conductivity (SOL_K) from chapter 4.1.4.10. Table 4.6 shows the classification codes for $c_{perm}$ and the hydraulic conductivity they correspond to.

**Table 4.6: Values for $c_{perm}$ and their corresponding saturated hydraulic conductivity.**

| $c_{perm}$ | SOL_K (mm/hr) |
|---|---|
| 1 | >150 |
| 2 | 50-150 |
| 3 | 15-50 |
| 4 | 5-15 |
| 5 | 1-5 |
| 6 | <1 |

#### 4.1.4.16 SOL_EC

SOL_EC is the electrical conductivity of the soil. No data for electrical conductivity could be found for New Zealand soils. However all predefined soils in the SWAT database all have a SOL_EC value of zero. Furthermore, the SWAT2009 input/output documentation lists SOL_EC as not currently active. Thus SOL_EC was set to zero for all soil types.

## 4.2 Weather data

Weather data required to force the ArcSWAT model was obtained from NIWA's online database CliFlo. Data on precipitation, wind speed, maximum and minimum temperature, and relative humidity between 1990 and 2012 were obtained from a number of monitoring stations located within or near the study area. The specific site locations and temporal coverage varied for each of the datasets; specific locations and coverage for each dataset is covered in the corresponding section below. Given the large time periods that the data sets cover, missing data points were inevitable. The techniques used to fill in missing data varied between the different datasets and are also explained in the corresponding section below.

### 4.2.1 Precipitation data

Precipitation is the only compulsory weather dataset required by ArcSWAT. However, outside of the United States where there are no built in weather stations, all weather data types are required to be supplied by the user. Initially daily precipitation from 18 stations around the study area was obtained. However it became apparent that three of these stations were duplications of other stations, so a total of 15 stations were used. The location of each station and their temporal coverage is shown in Table 4.7.

Gap filling of the precipitation was done using linear regression. Correlation coefficients and regression slopes were calculated by regressing observations at each of the sites against observations at all other sites wherever these observations were collected at the same time. The regression was forced through the origin to avoid predicting a constant low precipitation during periods where there was no precipitation. For each site with missing data points the slope and intercept from the remaining site with the best correlation was used to predict missing values. To reduce the influence of outliers resulting from high rainfall, the log of the data was used to calculate the regression coefficients. Complete tables showing the calculated correlation coefficients, slope and intercepts can be found in Appendix 1.

**Table 4.7: Precipitation Station information.**

| Station Name | Agent Number | Latitude (dec.deg) | Longitude (dec.deg) | Height (m) | Start Date | End Date |
|---|---|---|---|---|---|---|
| Wharawhara Water Stn | 1567 | -37.57227 | 175.86206 | 132 | 01/01/1990 | 01/02/2012 |
| Katikati 2 | 1569 | -37.547 | 175.945 | 2 | 01/01/1990 | 01/12/2004 |
| Tauranga 4 | 1611 | -37.677 | 176.165 | 2 | 01/01/1990 | 01/03/2012 |
| Tauranga Aero | 1612 | -37.67242 | 176.19635 | 0 | 01/01/1990 | 01/02/1996 |
| Tauranga Aero Aws | 1615 | -37.673 | 176.196 | 4 | 02/06/1990 | 15/04/2012 |
| Whakamarama | 1617 | -37.73206 | 176.00218 | 255 | 01/01/1990 | 01/03/2012 |
| Oropi Water Treatment Plant | 1625 | -37.76974 | 176.13911 | 77 | 01/01/1990 | 01/03/2012 |
| Te Puke Randell Place | 1630 | -37.796 | 176.324 | 396 | 02/06/1990 | 01/11/2004 |
| Mclaren Falls | 1633 | -37.803 | 176.039 | 122 | 01/01/1990 | 01/11/1995 |
| Te Puke Edr | 1646 | -37.82 | 176.322 | 91 | 01/01/1990 | 02/09/1996 |
| Maniatutu | 1648 | -37.85126 | 176.4554 | 64 | 01/01/1990 | 01/06/2007 |
| Te Ranga | 1656 | -37.903 | 176.272 | 335 | 01/01/1990 | 01/05/2000 |
| Te Puke Ews | 12428 | -37.822 | 176.324 | 91 | 01/06/1996 | 15/04/2012 |
| Lloyd Mandeno | 17080 | -37.855 | 176.029 | 275 | 02/11/1997 | 01/02/2005 |
| Athenree 2 | 18638 | -37.453 | 175.919 | 4 | 02/10/2000 | 01/03/2012 |

### 4.2.2 Temperature data

Maximum and minimum daily temperature data from four stations were obtained to aid in estimating evaporation in the model. The locations of the four sites and their temporal coverage are shown Table 4.8.

Filling in missing data was done by calculating the mean maximum and minimum temperature for each Julian day for each site independently. Using the mean maximum and minimum for a given Julian day was possible due to the data having a strong annual cycle. Plots showing the gap filled data can be found in Appendix 1.

**Table 4.8: temperature station information**

| Name | Agent Number | Latitude (dec.deg) | Longitude (dec.deg) | Height (m) | Start Date | End Date |
|---|---|---|---|---|---|---|
| Te Puke Ews | 12428 | -37.822 | 176.324 | 91 | 01/06/1996 | 03/11/2011 |
| Paeroa Aws | 1547 | -37.373 | 175.684 | 18 | 01/10/1990 | 27/04/2011 |
| Katikati 2 | 1569 | -37.547 | 175.945 | 2 | 02/01/1990 | 19/06/2004 |
| Tauranga Aero Aws | 1615 | -37.673 | 176.196 | 4 | 01/06/1990 | 29/11/2011 |

### 4.2.3 Wind data

Daily wind speed was obtained from three stations to aid in estimating evaporation. Locations and temporal coverage of these sites are shown in Table 4.9.

**Table 4.9: Wind data station information.**

| Name | Agent Number | Latitude (dec.deg) | Longitude (dec.deg) | Height (m) | Start Date | End Date |
|---|---|---|---|---|---|---|
| Tauranga Aerodrome | 1614 | -37.67239 | 176.19671 | 4 | 01/01/1990 | 04/10/1996 |
| Tauranga Aero Aws | 1615 | -37.673 | 176.196 | 4 | 01/01/1990 | 20/03/2008 |
| Tauranga Harbour | 1610 | -37.64282 | 176.18149 | 3 | 01/01/1990 | 22/06/1995 |

**Table 4.10: $r^2$ and slope calculated between each wind data set.**

| | $r^2$ | | | Slope | | |
|---|---|---|---|---|---|---|
| | 1610 | 1614 | 1615 | 1610 | 1614 | 1615 |
| 1610 | 1 | 0.995 | 0.990 | 1 | 0.938 | 0.950 |
| 1614 | 0.995 | 1 | 0.992 | 1.061 | 1 | 0.997 |
| 1615 | 0.990 | 0.992 | 1 | 1.042 | 0.996 | 1 |

Gap filling of the wind data was done using linear regression, in much the same way as precipitation. Correlation coefficients and regression slope were calculated between both sites where there were coincident data. The fitted line was forced through the origin to prevent negative values from occurring. For each missing data point the calculated slope was then used to predict missing values. Table 4.10 shows the calculated correlation coefficients and slopes. Plots of the gap filled data can be found in Appendix 1.

### 4.2.4 Relative humidity data

Hourly relative humidity data were only available from one site in the study area in hourly recordings. The location and temporal coverage of the data are shown in Table 4.11. To obtain daily relative humidity, the mean of the hourly data was calculated for each day.

Due to relative humidity only being available from one site, it was not possible to use linear regression to predict missing values as was done with wind and precipitation. Instead the mean relative humidity of each Julian day was calculated to fill in missing data. A plot showing the gap filled relative humidity data can be found in Appendix 1.

**Table 4.11: Relative humidity station information.**

| Name | Agent Number | Latitude (dec.deg) | Longitude (dec.deg) | Height (m) | Start Date | End Date |
|---|---|---|---|---|---|---|
| Te Puke Ews | 12428 | -37.882 | 276.324 | 176.32 | 01/06/1996 | 01/08/2002 |

### 4.2.5 Weather generator database

In the case of missing values in any of the weather input files, SWAT is able to gap fill the missing data. In order to do so SWAT needs some data and statistical information on each weather type at each weather station. These data are entered into the user weather generator database. Table 4.12 lists the variables that are required by the user weather generator database. Many of the variables require that a value be calculated for each month of the year, using the entire dataset. For example, TMPMX1 would be the average maximum temperature for January over the entire dataset. All variables were calculated using the method outlined in Arnold, *et al*. 2010, chapter 12 SWAT input data: .WGN.

**Table 4.12: Variables required by the user weather generator database. "(mon)" indicates a variable that must be calculated for each month of the year.**

| Variable name | Description |
|---|---|
| STATION | Weather station name |
| WLATITUDE | Latitude of weather station |
| WLONGITUDE | Longitude of weather station |
| WELEV | Elevation of weather station |
| RAIN_YRS | Number of years of rain data |
| TMPMX(mon) | Mean daily maximum air temperature |
| TMPMN(mon) | Mean daily minimum air temperature |
| TMPSTDMX(mon) | Standard deviation of daily maximum air temperature |
| TMPSTDMN(mon) | Standard deviation of daily minimum air temperature |
| PCPMM(mon) | Mean total precipitation |
| PCPSTD(mon) | Standard deviation of precipitation data |
| PCPSKW(mon) | Skew coefficient of precipitation data |
| PR_W1_(mon) | Probability of a wet day following a dry day |
| PR_W2_(mon) | Probability of a wet day following a wet day |
| PCPD(mon) | Average number of days of precipitation |
| RAINHHMX(mon) | Maximum 0.5 hour rainfall |
| SOLARAV(mon) | Average daily solar radiation |
| DEWPT(mon) | Average daily dew point temperature |
| WNDAV(mon) | Average daily wind speed |

## 4.3 Model calibration

Calibration of the SWAT model was done by manually changing individual variables and comparing the output to observed data. In most cases the manual calibration helper that is included in ArcSWAT was used to make these changes. The manual calibration helper allows a variable to be replaced with, multiplied by, or added to a value defined by the user. The specified change can be applied to all or a specific combination of subbasins, soil types, land uses, and slopes. Observed data were provided by the Bay of Plenty Regional Council. Calibration of the SWAT model was done in two stages; discharge calibration, and nitrogen calibration.

The first variable that was varied in order to calibrate discharge was NLYRS, the number of soil layers for each soil type in the user soils database. Originally only one layer was entered into the user soils database as no data on the number of soil layers was available. However a single soil layer cannot produce accurate results as many important calculations within SWAT, such as denitrification, and ground water percolation, depend on there being a number of different layers. To correct this soil layers were added to this database that are identical to the original layer, but have different soil layer depths. The number of layers was varied and the simulated discharge, and nitrate and nitrite compared to the recorded discharge and nitrogen data. Seven soil layers most closely resembled the simulated discharge and nitrogen output, and so was used for all other model calibration runs.

Simulated discharge was further calibrated by manually changing the variables GW_Delay, SOL_K, and SOL_Awc using the manual calibration helper. Initially, each variable was changed one at a time and its effect on the simulated discharge examined individually. Then the SWAT was run using combinations of the different values that improved the accuracy of the simulated discharge the most. After each model run regression statistics were calculated between the simulated and observed data. Table 4.13 lists the change to each variable that was used in the calibrated model. Figure 4.1 shows a plot of the calibrated simulated discharge and observed discharge, and the regression plot of observed vs. simulated discharge.

**Table 4.13: Variables and the changes applied to them in the manual calibration helper used to calibrate discharge.**

| Variable | Operation | Value |
|---|---|---|
| GW_Delay | Replace | 60 |
| SOL_K | Multiply | 0.1 |
| SOL_Awc | Multiply | 0.1 |

Nitrogen calibration was done in two stages. The first is the same as was used for calibrating discharge output of the model. The second stage involved calibrating the management operations that are applied to different land uses. For the first stage, the variables NPERCO (Nitrogen percolation coefficient), CDN (denitrification rate coefficient), and SDNCO (Denitrification threshold water content) were used for calibrate nitrogen output. Table 4.14 shows each of these variables, the operation applied in the manual calibration helper, and the value that was used.

**Table 4.14: Variables and the changes applied to them in the manual calibration helper used to calibrate nitrogen.**

| Variable | Operation | Value |
|---|---|---|
| NPERCO | Replace | 0.2 |
| CDN | Replace | 0.1 |
| SDNCO | Replace | 0.9 |

Calibrating management operations was also done by a trial and error process, similar to discharge and stage one of nitrogen calibration. Management operations can be changed using the edit subbasin inputs dialog under the edit SWAT input drop down menu. Management operations can be changed for a specific land use by selecting .mgt as the input table to edit, then selecting the subbasin, land use, soil, and slope of a HRU that contains the land use of interest. Management operations are found under the operations tab of the edit management parameters window. Once the desired edits have been made, changes can be extended to other HRUs by clicking the extend management operations check box and the extend edits to selected HRUs check box. The HRUs that are to have the edits extended to can then be selected by choosing their corresponding subbasins, land uses, soils and slopes, and clicking OK. To ensure the edits have been applied to the input files properly all input files should be rewritten using the Rewrite SWAT input files dialog under the Edit SWAT input drop down menu.

A variety of different management practices were applied to the different land uses, and the management practices that produced the nitrogen output the fit the observed data the best were chosen for the calibrated model. In the end, default management practices were used for all land uses except general agriculture (AGRL). Native forest is mature by default, which is also assumed to be true for native forest in reality. Other land uses, apart from agriculture, occur in only small amounts and thus only have a very minor effect on nitrogen.

Three management practices were applied to agricultural land uses; a plant/begin growing season operation, a grazing operation, and a continuous fertilisation operation. The plant/begin growing season operation initializes the growing of pasture. All parameters were left as default, with heat unit scheduling set at 0.15, the plant ID set to Agricultural land-Generic, heat units to maturity set to 600, and all other values set to zero, which SWAT replaces with the default value of a given parameter when executing. The values used for the continuous fertilisation and grazing operations are shown in Table 4.15.and Table 4.16 respectively.

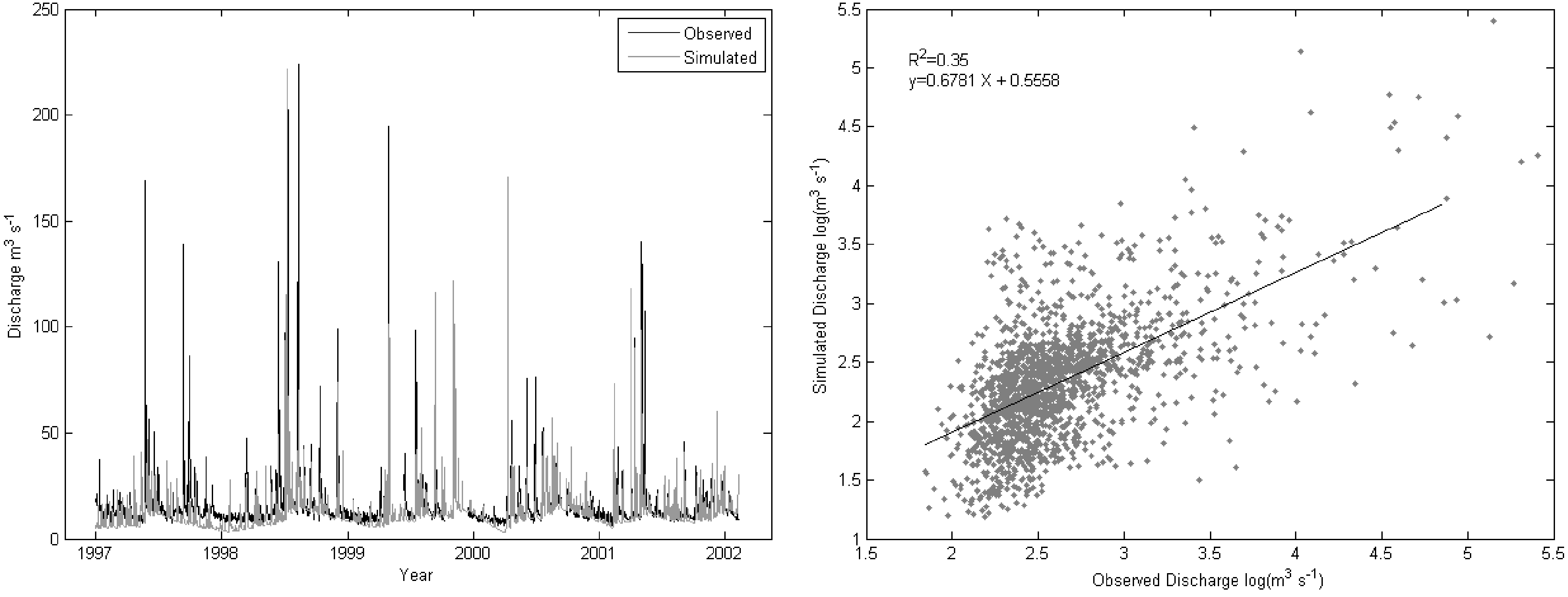


**Figure 4.1: Time series and scatter plots of observed vs. simulated discharge.**

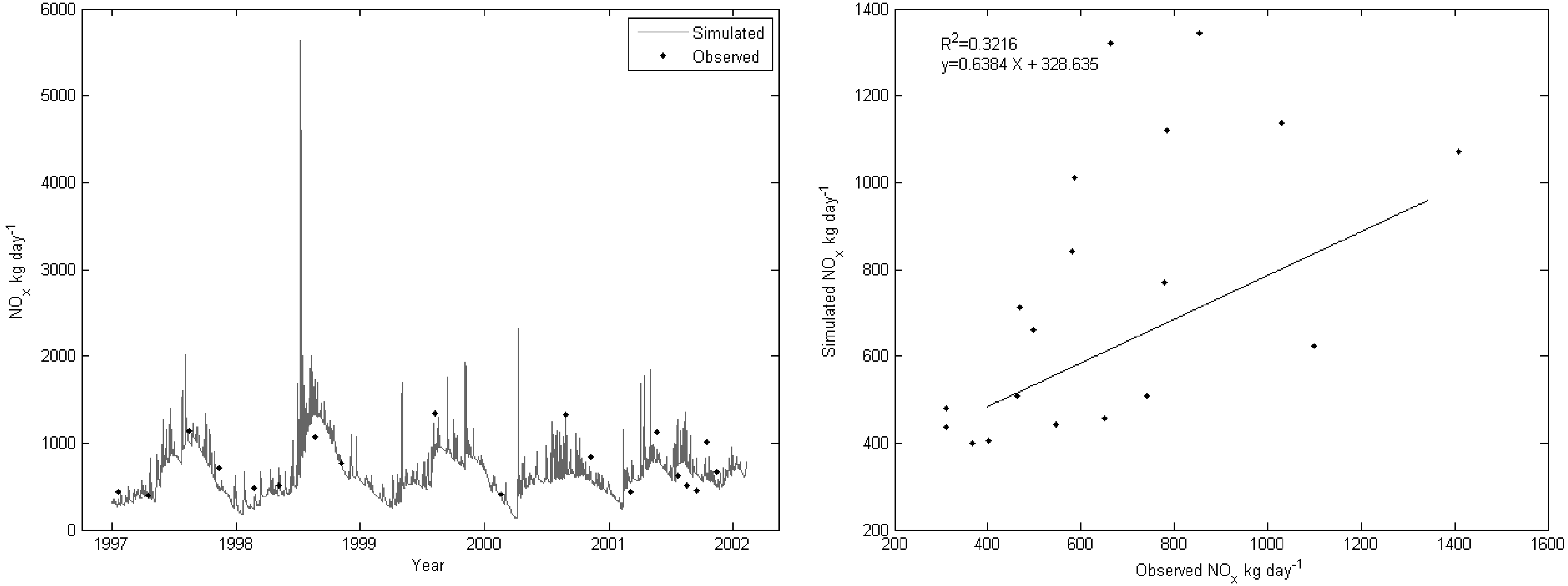


**Figure 4.2: Time series and scatter plots of observed vs. simulated nitrate and nitrite.**

**Table 4.15: Values used in the AGRL continuous fertilisation operation.**

| Variable | Value |
|---|---|
| Heat unit scheduling | 0.15 |
| CFRT_ID | Urea |
| FERT_DAYS | 1 |
| IFRT_FREQ | 1 |
| CFRT_KG | 38 |

**Table 4.16: Values used in the AGRL grazing operation.**

| Variable | Value |
|---|---|
| Manure ID | Beef fresh manure |
| Heat unit scheduling | 0.15 |
| GRZ_DAYS | 3 |
| BIO_EAT | 1128 |
| BIO_TRMP | 72 |
| Manure kg | 0 |

Figure 4.1 and Figure 4.2 time series and scatter plots of recorded against simulated discharge and nitrogen respectively. The f statistic, p value and $R^2$ calculated from the linear regression between observed and simulated discharge (Q) and $NO_x$ is shown in Table 4.17. Here we can see that although only 35% of the variation in observed discharge is explained by the simulated discharge, the relationship between the datasets is highly significant. Similarly, with the $NO_x$ data only 32% of the variation is explained by the regression model, but there is still a significant relationship in the data at the 0.05 level. The implication being that the calibrated SWAT model is poor at simulating small scale events such as individual storms, but is able to simulate long term trends such as seasonal variation or annual averages relatively successfully.

**Table 4.17: regression statistics from observed vs. simulated discharge and $NO_x$.**

| | $R^2$ | F | P |
|---|---|---|---|
| Q | 0.3501 | 913.6666 | <0.0001 |
| $NO_x$ | 0.3216 | 8.0595 | 0.0113 |

## 4.1 Model scenarios

Two different SWAT model scenarios were produced and run in addition to the calibrated model. The first was a pre human settlement scenario, where the only land use in the catchment is indigenous forest. The second scenario was “worst case” scenario, where the only land use present in the catchment was agriculture.

Scenarios could not be made by loading modified land use layers into HRU definition dialog due to an error in the software. Instead the different scenarios were produced by changing the management operations of the catchments HRUs, and thus changing the type of land use that is initialized when SWAT begins running. The management operations for indigenous forest land use (FRSE) and agricultural land use (AGRL) management operations were saved in the management operations editor. The management operations then loaded into a different HRU, and extended to all other HRUs. An exception is the water land use (WATR), which was left unchanged to preserve features such as large rivers in the model scenarios. Once the management operations had been changed the SWAT model was setup and run, and the output saved for analysis.

# 5 Recorded data

The rivers and streams in the Bay of Plenty have a range of economic, ecological, recreational, and cultural values. The Bay of Plenty Regional Council aims to maintain the water quality of these rivers and streams so that they are able support the aquatic ecosystems that dwell within them, the water is suitable for municipal supply purposes as well as recreation (such as swimming), and the water quality is prevented from deteriorating (Scholes & McIntosh, 2009). Thus it is vital that the Bay of Plenty closely monitors these rivers and streams, and uses the collected data to make informed management decisions, and identify the factors that drive spatial variation in nutrient yield.

In addition to nutrient data presented by the Bay of Plenty Regional Council, water samples were collected and analysed as part of this study. The sampling program of this study included many of the streams that discharge into the Tauranga Harbour that are monitored by the Bay of Plenty Regional Council, as well as some additional streams that are not monitored. The sites that these data were collected from are shown in Figure 5.1. The Bay of Plenty Regional Council also collects samples from the same location as Aongatete A, however this point cannot be seen in Figure 5.1 due to the points overlapping. These data were collected to investigate the spatial and temporal distribution of nitrogen yield, and for comparison to the data collected by Bay of Plenty Regional Council

This chapter presents these datasets, compares the two datasets to one another, investigates the spatial and temporal trends they display, and draws conclusions on what might be the cause of the spatial and temporal trends, as well as the ability of these datasets to detect such trends.

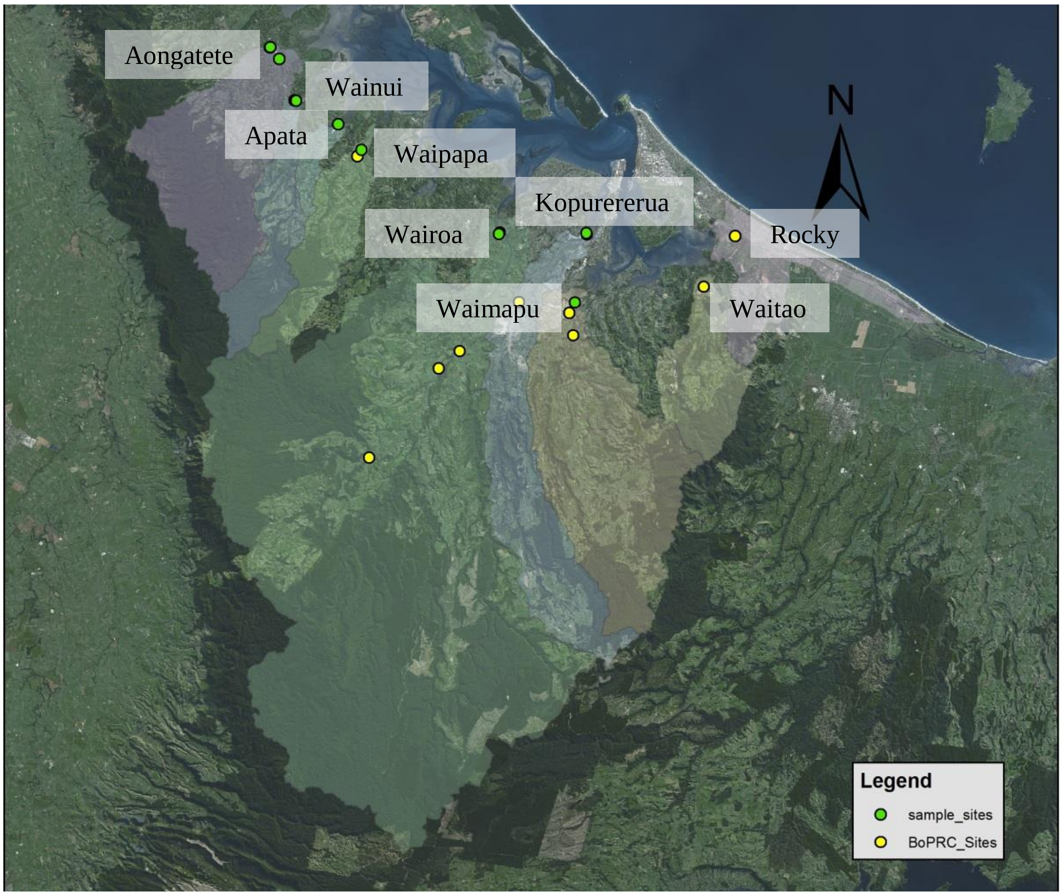


**Figure 5.1: Sample collection locations for the both the data collected by Bay of Plenty Regional Council (yellow), and the data collected as part of this study (green) in the catchments that are shown in Figure 3.3.**

## 5.1 Mean concentration

The mean concentrations of ammonia and the total oxides of nitrogen ($NO_x$) from both data collected as part of this study, and data collected as part of the Bay of Plenty Regional Council monitoring program are shown in Table 5.1. Nitrite concentrations are omitted from this table as they are in the order of three decimal places, and so are considered negligible.

In Table 5.1 the highest ammonia concentrations were found in the Apata and Kopurererua streams at 0.034 g $m^{-3}$ and 0.032 g $m^{-3}$ respectively, and the lowest ammonia concentration was found in the Waipapa River at 0.009 g $m^{-3}$. The highest $NO_x$ concentration was found in the Kopurererua Stream at 0.8 g $m^{-3}$, and the lowest concentrations were found in the Aongatete and Wainui rivers with concentrations of 0.205 g $m^{-3}$ and 0.219 g $m^{-3}$ respectively. It should be noted that

**Table 5.1: Mean ammonia and total oxide of nitrogen concentration recorded during this study and mean ammonium oxide of nitrogen concentration collected by Bay of Plenty Regional Council.**

| | This Study | | BoPRC | |
|---|---|---|---|---|
| | $NH_3$ (g m$^{-3}$) | $NO_x$ (g m$^{-3}$) | $NH_4$ (g m$^{-3}$) | $NO_x$ (g m$^{-3}$) |
| Aongatete | 0.014 | 0.205 | 0.009 | 0.287 |
| Wainui | 0.027 | 0.219 | 0.03 | 0.294 |
| Apata | 0.034 | 0.596 | - | - |
| Waipapa | 0.009 | 0.453 | 0.02 | 0.471 |
| Wairoa | 0.016 | 0.298 | 0.018 | 0.396 |
| Kopurererua | 0.032 | 0.800 | 0.109 | 0.889 |
| Waimapu | 0.019 | 0.672 | 0.035 | 0.698 |
| Waitao | - | - | 0.033 | 0.423 |
| Rocky | - | - | 0.171 | 0.864 |

in an effort to quantify the nitrogen yield into the harbour, the nitrogen concentrations for the Aongatete River are the average of the concentrations obtained from both the Aongatete A and B sites shown in Figure 3.4.

The highest mean ammonium concentration that was found by the Bay of Plenty Regional Council in Table 5.1 was found in the Rocky Stream at 0.171 g m$^{-3}$, followed by the Kopurererua Stream at 0.109 g m$^{-3}$. The lowest ammonium concentration in Table 5.1is from the Aongatete River at 0.009 g m$^{-3}$. The highest $NO_x$ concentrations found by the Bay of Plenty Regional Council are also from the Kopurererua and Rocky streams at 0.889 g m$^{-3}$ and 0.864 g m$^{-3}$ respectively. The lowest $NO_x$ concentrations in Table 5.1 are from the Aongatete and Wainui rivers with concentrations of 0.287 g m$^{-3}$ and 0.294 g m$^{-3}$ respectively.

Comparison between the mean concentrations from Bay of Plenty Regional Councils monitoring data, and data collected as part of this study in Table 5.1 shows that, for rivers that are common to both data sets, the concentrations are very similar. Unfortunately the Rocky Stream and Apata Stream, both of which have quite high concentrations of nitrogen are not included in both datasets, and cannot be compared.

The mean ammonium, ammonia, and $NO_x$ concentrations across all streams from both datasets are 0.052 g m$^{-3}$, 0.022 g m$^{-3}$, and 0.473 g m$^{-3}$ respectively. When these mean concentrations are coupled with the sum of mean discharge from all streams in both datasets of 48.56 m$^{3}$ s$^{-1}$ the average annual yields are

79216 kg $yr^{-1}$ of ammonium (0.08 Gg), 33088 kg $yr^{-1}$ (0.03Gg) of ammonia, and 723955100 kg $yr^{-1}$ (0.72 Gg) of $NO_x$. The cumulative area of all the catchments considered here is 84487 ha, which gives the specific yields 0.94 kg $ha^{-1}$ $yr^{-1}$ of ammonium, 0.94 kg $ha^{-1}$ $yr^{-1}$ of ammonia, and 8.57 kg $ha^{-1}$ $yr^{-1}$ of $NO_x$. If this specific yield is scaled up by the area of the entire Bay of Plenty (12271 $km^2$ (Parfitt, *et al*. 2006)) we get a yield of 1.15 Gg $yr^{-1}$ ammonium, 0.48 Gg $yr^{-1}$ ammonia and 10.51 Gg $yr^{-1}$ $NO_x$.

Dymond, *et al*. (2013) reported that many areas in the Bay of Plenty had nitrate yields greater than 30 kg $ha^{-1}$ $yr^{-1}$, although most of the areas that had such high nitrate yields were outside of the Tauranga Harbour catchment. Many areas within the Tauranga harbour catchment had lower nitrate yields ranging from 0 to 2 kg $ha^{-1}$ $yr^{-1}$, to 10 to 15 kg $ha^{-1}$ $yr^{-1}$ (Dymond, *et al*. 2013). The yield calculated above of 8.57 kg $ha^{-1}$ $yr^{-1}$ $NO_x$ is much lower than these values reported by Dymond, *et al*. 2013, further suporting that most of the areas that produce the highest nitrate yeilds are located outside of the Tauranga Harbour catchment.

Parfitt *et al*. (2012) estimated a total nitrogen output to the ocean from the Bay of Plenty in 2010 of 5Gg, which equates to a total nitrogen yield of 4.07 kg $ha^{-1}$ $yr^{-1}$. However, this estimate includes organic and particulate nitrogen. Guideline nutrient concentrations indicate that $NO_x$ makes up 2/3 of total nitrogen (Larned, *et al*. 2004). Adjusting the yield estimated by Parfitt *et al*. (2012) by this ratio gives a $NO_x$ yield of 2.72 kg $ha^{-1}$ $yr^{-1}$, which is considerably smaller than the $NO_x$ yield calculated from the recorded data presented in Table 5.1.

Parfitt *et al*. (2006) estimated nitrogen losses to the ocean, lakes, and reservoirs to be 63 Gg $yr^{-1}$. Using the same logic as was applied to the estimate from Parfitt *et al*. (2012) a $NO_x$ yield of 2.32 72 kg $ha^{-1}$ $yr^{-1}$ is calculated. This value is again considerably smaller than the $NO_x$ yields presented in this study.

Heggie & Savage (2009) simulated total nitrogen yields ranging from 1 kg $ha^{-1}$ $yr^{-1}$ from catchments with no agriculture, to 17 kg $ha^{-1}$ $yr^{-1}$ from a catchment with 91.2 percent agriculture. A catchment with 46.4 percent agriculture (a similar percentage to many of the catchments in Tauranga Harbour) had a total nitrogen yield of 9 kg ha$^{-1}$ yr$^{-1}$. Assuming $NO_x$ is accounts for 2/3 of total nitrogen, these values give $NO_x$ yields of 0.667 kg ha$^{-1}$ yr$^{-1}$ from a catchment with no agriculture, 6 kg ha$^{-1}$ yr$^{-1}$ from a catchment with 46.4 percent agriculture, and 11.3 kg ha$^{-1}$ yr$^{-1}$ from a catchment with 91.2. Given these values the data presented in Table 5.1 fall between the data Heggie & Savage (2009) present for catchments with 46.4 and 91.2 percent agriculture.

## 5.2 Temporal variation

Plots of the raw data that was collected by the Bay of Plenty Regional Council are presented in Appendix 2. The dataset from Bay of Plenty Regional Council contains many large gaps, and no discharge data is available for the Wairoa or Waimapu rivers. However there are some trends that can be seen in the data that is provided. Discharge, $NO_x$, and total kjehldahl nitrogen (TKN) all display a seasonal cycle, with lower values in the summer higher values in the winter. Ammonium values are typically very low, and in some rivers there is no observable temporal cycle. However in other cases ammonium displays a seasonal cycle that is out of phase with discharge, $NO_x$, and TKN. In all cases, there is no observable long term trend in the time series plots.

Scholes & McIntosh (2009) reported long term trends in the Bay of Plenty Regional Council nutrient data using linear regression. The trends that were calculated for rivers and streams that discharge into the southern Tauranga Harbour are summarised in Table 5.2, with trends that were deemed statically

**Table 5.2: Summary of the temporal trends in nitrogen concentration of rivers discharging into the southern Tauranga Harbour, with significant trends shown in bold. Data recorded by Bay of Plenty Regional Council between 1989 and 2008 (Adapted from Scholes & McIntosh, 2009).**

| | TN (%/year) | $NO_x$ (%/year) | $NH_4$ (%/year) |
|---|---|---|---|
| Rocky Stream | **-9.42** | -3.95 | -10.34 |
| Waitao Stream | **-3.52** | **-4.55** | **-3.76** |
| Waimapu River | -2.61 | 0.85 | 0.83 |
| Kopurererua Stream | **0.72** | **1.45** | -1.43 |
| Ngamuwahine Stream | 0.68 | -0.32 | **3.33** |
| Wairoa River | **0.97** | **0.95** | 0 |
| Waipapa River | **-2.54** | **-2.32** | **-4** |
| Aongetete River | -0.5 | -3.67 | -2.67 |

significant ($p$<0.05) shown in bold. From table Table 5.2 we can see that over the monitoring period, three sites had a significant decrease in total nitrogen (TN), two decreased in $NO_x$, and two decreased in ammonium ($NH_4$). Rocky Stream experienced the largest decrease in TN at -9.42 % per year. Two sites showed a significant increase in TN, another two increased in $NO_x$, and only one showed a significant increase in $NH_4$. The increase in $NH_3$ in the Ngamuwahine Stream was attributed to an increase in flow. The authors state that had the trend analysis for this stream been done taking the change in discharge into account, it is likely no significant trend would have been found (Scholes & McIntosh, 2009).

As mentioned earlier, the data that these trends were derived from (shown in Appendix 2) was collected sporadically, sometimes with several years passing with no data being collected. Furthermore, during periods when a river or stream was being regularly monitored, the sampling frequency would typically consist of five to ten samples per year. Therefore the degree to which the sample population represents the true variation of the nutrient concentrations is questionable. In order to investigate this issue, data were randomly selected from the calibrated SWAT model output. Seven data points for discharge, nitrate, ammonium, and nitrite were randomly selected for each complete year of the SWAT simulation. Linear regression coefficients were then calculated from these randomly selected data points, and the calculated slope recorded. The process was repeated until 100 slopes had been calculated for each data type. The histograms of these slopes, presented in Figure 5.2, show that in all cases slopes are distributed about zero. Table 5.3 shows the mean and median slope for each data type, all of which are close to zero. Therefore, although the trends calculated by Scholes & McIntosh (2009) might be significant, the sample population is from which those trends were derived are not representative of reality, and do not adequately capture the natural variation in discharge and nutrient concentration.

Raw data collected from rivers during the sampling program carried out during this study can be found in Appendix 3. The mean concentration across all streams from each sampling day is shown in Table 5.4. In Table 5.4 $NO_x$ consistently has the highest concentration by an order of magnitude. Ammonia

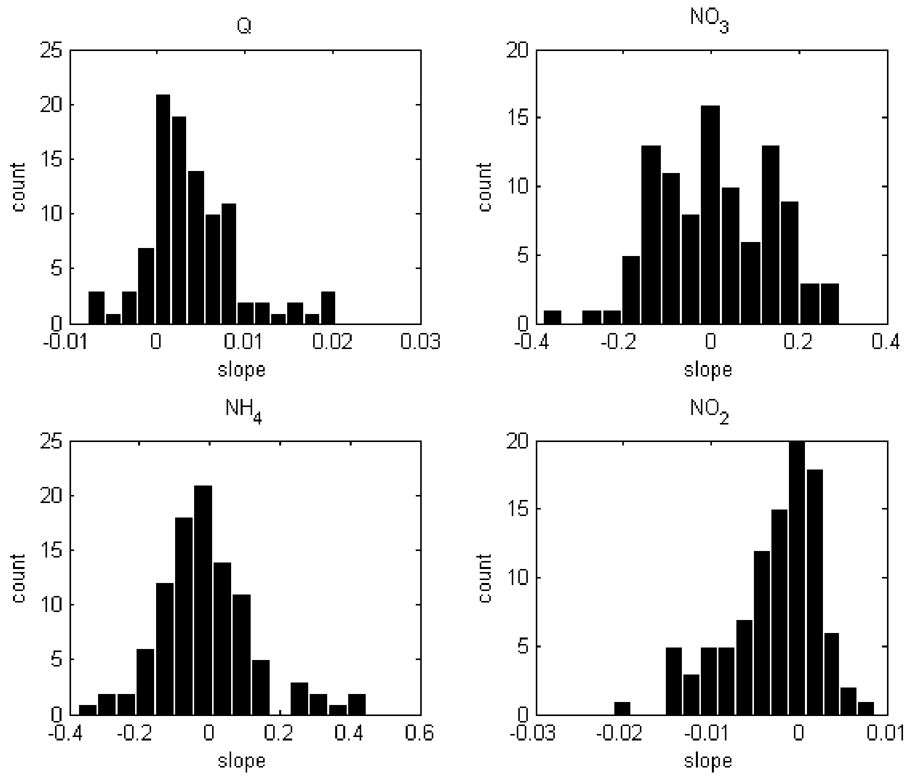


**Figure 5.2: Histograms of the slopes generated by regressing randomly selected points of discharge, nitrate, ammonium, and nitrite, with time.**

**Table 5.3: Mean and median slopes calculated from 100 randomly selected sub-datasets of discharge, nitrate, ammonium, and nitrite.**

| | Mean | Median |
|---|---|---|
| Discharge | 0.0034 | 0.0035 |
| Nitrate | -0.0050 | 0.0058 |
| Ammonium | -0.0221 | -0.0122 |
| Nitrite | -0.0015 | -0.0005 |

**Table 5.4: Mean ammonia, phosphate, nitrate and nitrite, and nitrite only concentration on each collection date across all sampling stations.**

| Date collected | Ammonium ($g\ m^{-3}$) | Phosphate ($g\ m^{-3}$) | $NO_x$ ($g\ m^{-3}$) | Nitrite ($g\ m^{-3}$) |
|---|---|---|---|---|
| 22/11/2011 | 0.027 | 0.010 | 0.413 | 0.005 |
| 24/01/2012 | 0.022 | 0.008 | 0.538 | 0.004 |
| 19/07/2012 | 0.014 | 0.004 | 0.649 | 0.004 |
| 27/09/2012 | 0.016 | 0.005 | 0.416 | 0.004 |
| 12/12/2012 | 0.014 | 0.005 | 0.266 | 0.004 |
| 8/02/2013 | 0.029 | 0.008 | 0.286 | 0.004 |

has the second highest concentrations, followed by phosphate, and nitrite has the lowest concentrations. Phosphate and nitrite often have similar concentrations, however they are consistently very low, and can be considered negligible.

Table 5.4 indicates that ammonium and phosphate levels decrease over winter and increase during summer, $NO_x$ levels appear to do the opposite, increasing in winter and decreasing in summer, and nitrite concentrations have no cycle. Given the apparent cycle in $NO_x$ and absence of a cycle in nitrite, it follows that the seasonal cycle in $NO_x$ is driven by a cycle in nitrate.

## 5.3 Spatial variation

The average nitrogen concentrations that were presented in Table 5.1 show that different catchments that are in close proximity to each other can have large variation in nitrogen concentration. It is therefore important to identify what causes this variation. Appendix 4 contains all the land classification database one (LCDB1) land uses for the catchments that discharge into the southern Tauranga harbour and the area of each land use in square meters and as percentages of catchment area. To simplify analysis, the number of land uses per catchment was reduced by combining similar land uses together. All types of forest were combined into a “forest” land use. All types of agriculture and horticulture were combined into a “productive land” land use. Urban, industrial, and transportation land uses were combined into an “urban/industrial” land use. Any land uses that did not fall into any of the three above land uses were combined into an ‘other’ land use. The areas of these new land use classifications then plotted against the mean ammonium, $NO_x$, and TKN concentration for each river and stream that was recorded by the Bay of Plenty Regional Council in Figure 5.3. From Figure 5.3 we can see that there is a negative relationship between the percent forest and ammonium, $NO_x$, and to a lesser degree TKN. Productive land area appears to have a positive relationship with $NO_x$, and possibly ammonium

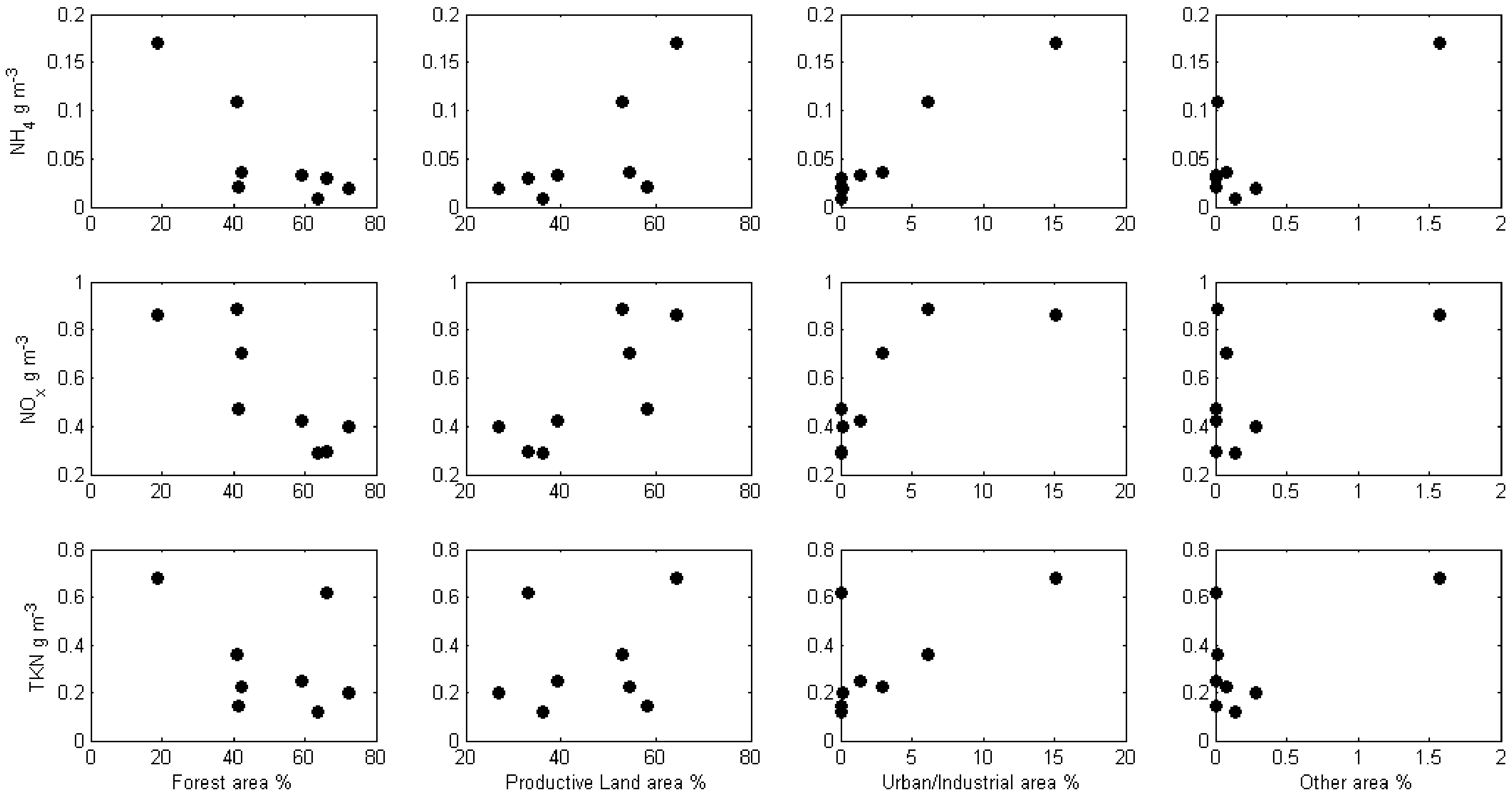


**Figure 5.3: Mean ammonium, $NO_x$, and TKN from BoPRC against the percent area forest, productive land, urban/industrial, and other land uses.**

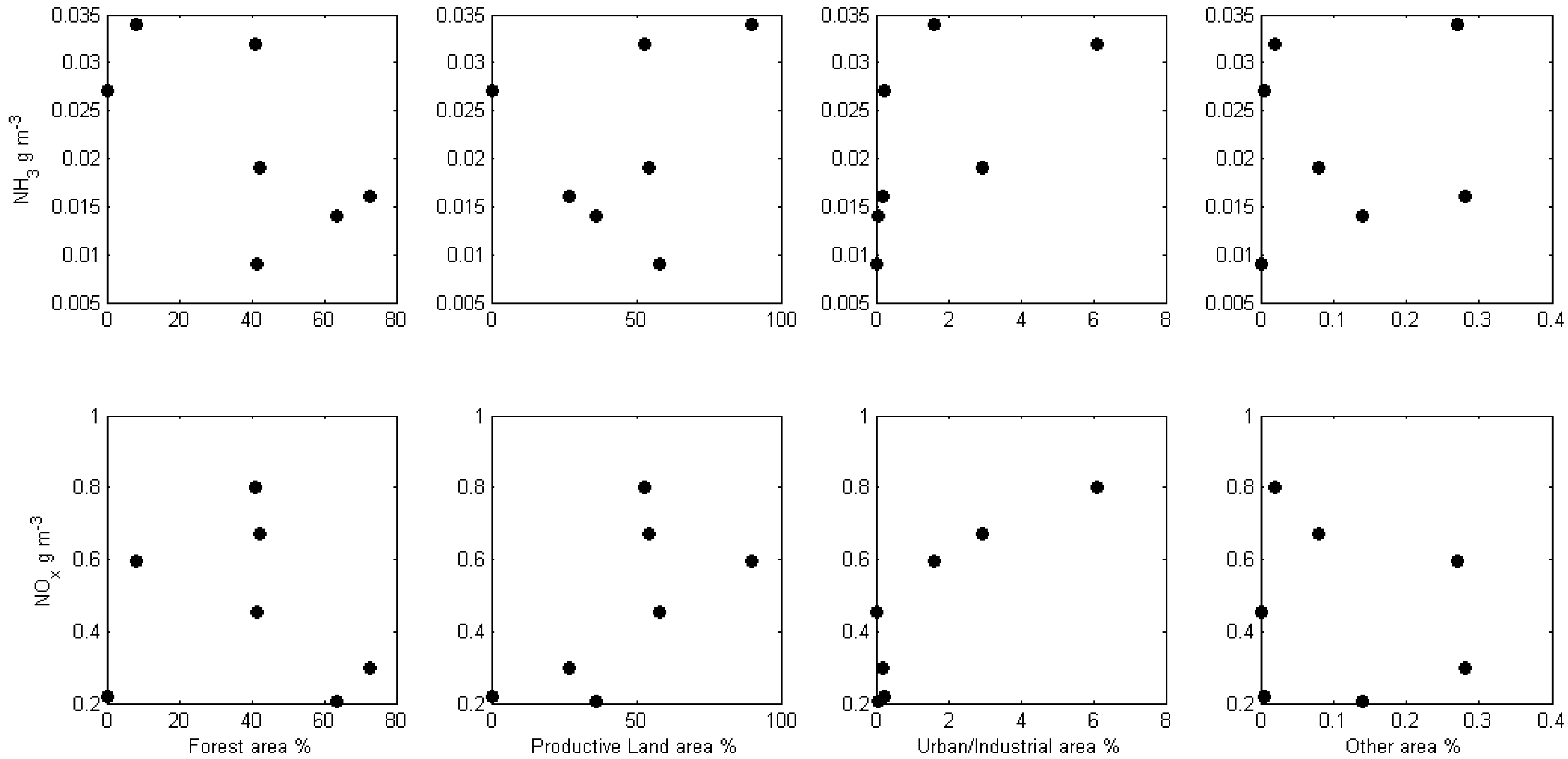


**Figure 5.4: Mean ammonia and $NO_x$, concentrations from data collected with this study against the percent area forest, productive land, urban/industrial, and other land uses.**

concentration. There does not appear to be any relationship between TKN and productive land area. The percent urban and industrial area appears to have the strongest relationship to nitrogen concentration. Ammonia, $NO_x$, and TKN all appear to have a positive relationship with urban and industrial area. Again, TKN has the weakest of these relationships, but if outliers are omitted the relationship appears to be very strong. No relationship is apparent between the "other" land use and any of the nitrogen species

The mean concentrations of ammonia and $NO_x$ from each stream sampled in conjunction with this study are also plotted against the simplified land use areas in Figure 5.4. In Figure 5.4 the percentage forest area may have a weak negative relationship with ammonia, but there is no apparent trend with $NO_x$. In contrast the percentage area of productive land has a possible positive relationship with $NO_x$ and does not show any relationship with ammonia. Both ammonia and $NO_x$ appear to have a positive relationship with the percentage of urban and industrial area. Figure 5.4 shows no relationship between either ammonia or $NO_x$ and the "other" land use.

**Table 5.5: Rivers and streams with the highest average nitrogen concentrations, their percentage forest, productive land, and urban and industrial, and their average $NO_x$ and ammonia concentrations.**

| | Forest % | Productive % | Urban % | $NO_x$ g $m^{-3}$ | NH4 g $m^{-3}$ |
|---|---|---|---|---|---|
| Apata | 8.24 | 89.88 | 1.61 | 0.60 | 0.03 |
| Kopurererua | 40.96 | 52.92 | 6.10 | 0.84 | 0.07 |
| Rocky | 18.76 | 64.53 | 15.07 | 0.86 | 0.17 |
| Waimapu | 42.45 | 54.38 | 2.93 | 0.69 | 0.03 |

The simplified land use areas, and $NO_x$ and ammonium concentrations of the catchments that had the highest nitrogen concentrations are shown in Table 5.5. Here we can see that all four of these catchments have over 50 percent productive land, and less than 50 percent forest. The Apata catchment has the most extreme difference in forest and productive land areas by a large margin at 89.88 percent productive and 8.24 percent forest. The Rocky Stream and Kopurererua Stream both have the highest percentage urban and industrial area. The Rocky Stream and Kopurererua Stream also have the Highest NOx concentrations. The Rocky Stream, which has the highest percentage urban and

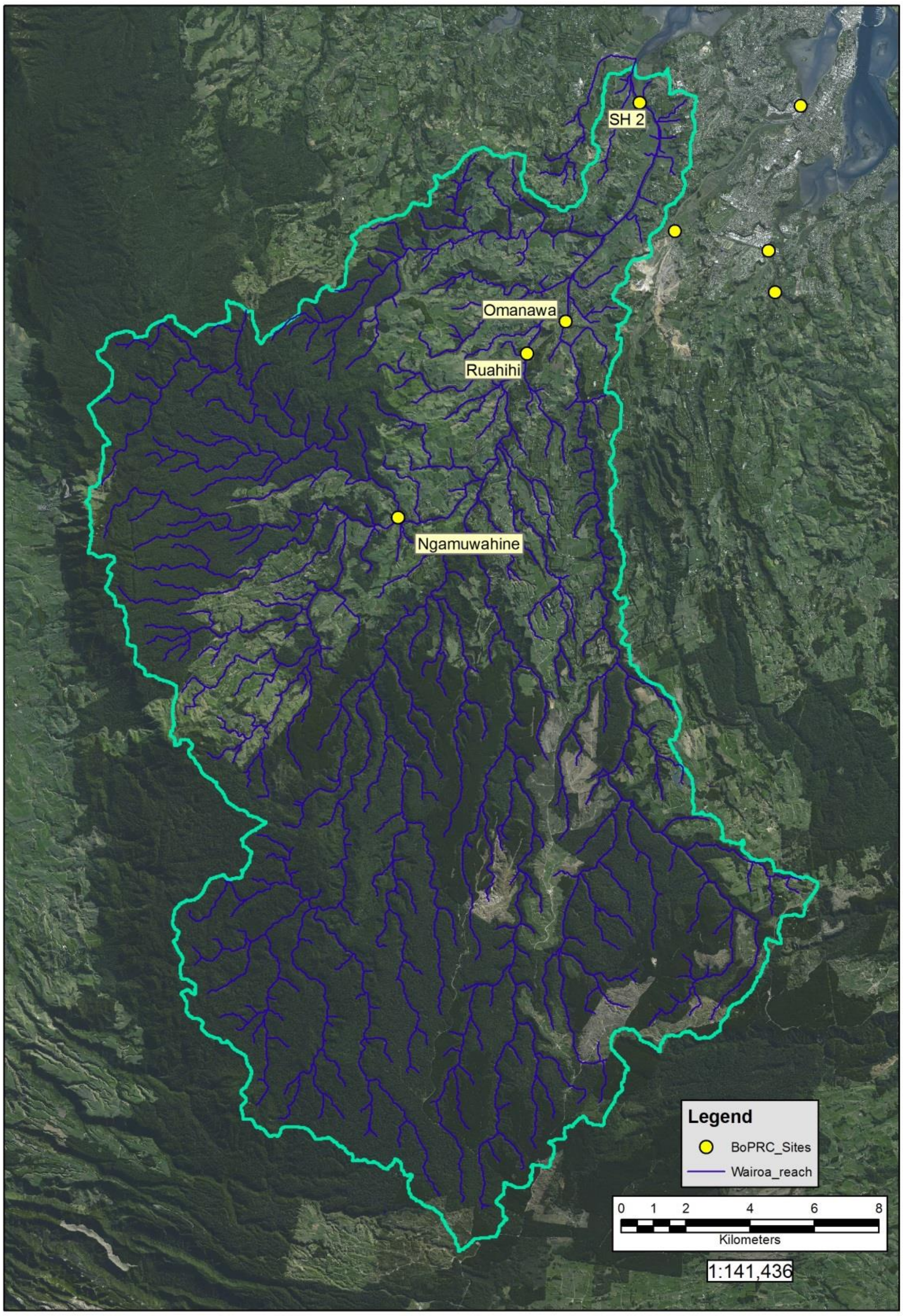


**Figure 5.5: Map of Bay of Plenty Regional Council monitoring sites within the catchment of the Wairoa River.**

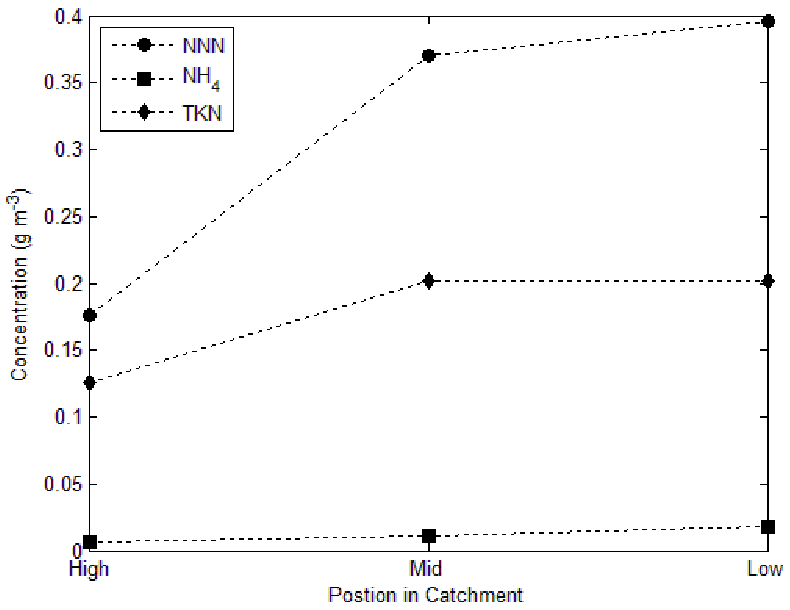


**Figure 5.6: NNN, $NH_4$, and TKN concentrations at high, mid, and low points in the Wairoa River catchment.**

industrial area by a factor of approximately two, also has the highest ammonium concentration.

To further investigate the relationship between land use and nitrogen yield, data collected from three sites within the catchment of the Wairoa River by the Bay of Plenty Regional Council were compared. The three sites are the Ngamuwahine, Ruahihi, and SH 2 sites shown in Figure 5.5, and represent high, mid and low positions in the catchment respectively. The Ngamuwahine streams catchment is dominated by indigenous forest, thus has a higher relative amount of forest than the rest of the Wairoa catchment. The Ruahihi station is located in the middle of the catchment, downstream of the Ruahihi power station. The final station is at the very bottom of the catchment at State Highway 2 (SH 2), close to the mouth of the Wairoa River. Together these three sites provide a transition from a catchment dominated by forest with lower amounts of agriculture, to a catchment with approximately even amounts of indigenous forest and agriculture (Scholes & McIntosh, 2009). Figure 5.6 indicates the concentration of nitrogen at these three sites tends to increase lower in the catchment. Such an increase suggests that water entering the river lower in the catchment contains more nitrogen per unit volume than water sourced higher in the catchment. This increase in nitrogen may be in response to an increase in the relative amount of agricultural land lower in the catchment. Figure 5.6 also suggests that the effect is strongest on NNN than it is on TKN, and is weakest on $NH_4$.

## 5.4 Discussion

The average nitrogen concentration from datasets collected by the Bay of Plenty Regional Council and in conjunction with this study compared well to each other. However, the average nitrogen yield that was calculated from these concentrations was consistently less than regional and national scale estimates from the literature. The difference in the calculated and estimated specific nitrogen yields suggests that catchments that discharge into the southern Tauranga Harbour produce lower specific nitrogen yields than would be considered typical for both the Bay of Plenty, and New Zealand. Dymond, *et al.* (2013) suggested that this might be the case, showing that the majority of land uses that produced high nitrogen yields in the Bay of Plenty were situated outside of the Tauranga Harbour catchment.

The temporal variation in nitrogen concentration shown in the data provided by Bay of Plenty Regional Council, and in the data collected as part of this study, both display a seasonal cycle. $NO_x$ and TKN concentrations both display a cycle that is in phase with discharge, increasing in the winter and decreasing in the summer. In some rivers and streams, ammonium concentrations are so low that no cycle can be observed. However some rivers and streams do display a seasonal cycle that is out of phase with $NO_x$ and TKN, where concentrations increase during summer, and decrease during winter. These seasonal cycles suggest that $NO_x$ and TKN concentrations are positively influenced by the seasonal cycle in base flow, whereas ammonium appears to have a negative relationship to either basefow or $NO_x$ and/or, TKN concentration.

Long term temporal trends that were calculated by Scholes & McIntosh (2009) (summarised in Table 5.2) suggest that several rivers and streams show a statistically significant increase or decrease over time. However, the slopes that were calculated from 100 datasets composed of data that was randomly selected from the calibrated SWAT output at a similar frequency to the Bay of Plenty Regional Councils monitoring program. These slopes all showed a distribution about zero (Figure 5.2). These results show that sampling frequencies used in the monitoring programs from both the Bay of Plenty Regional Council and this study are insufficient for detecting long term trends. Therefore, although regression statistics produced from such monitoring programs may suggest a significant trend, the data used are not an adequate representation of reality.

There are a variety of relationships suggested between nitrogen concentration and different land uses in Figure 5.3 and Figure 5.4. The relationships between different land uses and nitrogen concentrations were more pronounced in the data collected by the Bay of Plenty Regional Council than in data collected during this study. The most likely reason for the Regional Council's data producing more pronounced relationships is the fact that it is a much larger data set. Ammonium, ammonia, and $NO_x$ concentrations show a negative relationship with forest area, and a positive relationship with productive land area. TKN did not show a clear relationship to either forest or productive land areas. Figure 5.6 further supports the hypothesis that $NO_x$ and ammonia concentrations increase under productive land and decrease under forest. Figure 5.6 also suggests that TKN follows the same relationship with forest and productive land area. Ammonia, ammonium, $NO_x$, and TKN all show a positive relationship with urban and industrial land area. Furthermore, the relationships observed with regard to urban and industrial land area appear to be the strongest out of all the simplified land uses plotted in Figure 5.3 and Figure 5.4. Of the three nitrogen species, ammonia has the strongest relationship with urban and industrial land area. Furthermore, urban and industrial land uses only cover a small percentage of the catchments monitored, indicating that only a small amount of urban and industrial land area can have a large impact on the nitrogen concentration. No relationship was observed with the "other" land use, indicating that the three other simplified land uses are responsible for the major differences in nitrogen concentration between different catchments.

The apparent strength of the observed relationships with the three main land uses can be ranked, with urban and industrial area having the strongest relationship, productive land area having the second strongest relationship, and forest having the weakest relationship. These ranks correspond do the distance from the river mouth the different land uses typically occur. Urban and industrial land uses typically occur close to the coast, and so are usually concentrated at or near river mouths. Agriculture and horticulture are typically found further from river mouths midway up a catchment. Finally, both native and exotic forests are typically found in the steeper hills high in a catchment. Therefore it is possible that, for example, forest has a very strong relationship with nitrogen concentration. However due to forest occurring far from the river mouth, the influence it has on nitrogen concentration is masked by nitrogen derived from other land uses closer to the river mouth.

## 5.5 Conclusions

The data collected by Bay of Plenty Regional Council and the data collected as part of this research show that catchments discharging into the Tauranga Harbour produce lower nitrogen yields than is reported in Dymond, *et al*. (2013). Calculated specific nitrogen yields were higher than estimated yields for both the Bay of Plenty (Parfitt, *et al*. 2012) and New Zealand (Parfitt, *et al*. 2006).

$NO_x$ and TKN appear to have a seasonal cycle where concentrations increase over winter and decrease during summer. Ammonium appears to have a seasonal cycle that is out of phase with $NO_x$ and TKN, where ammonium concentrations increase during summer and decrease during winter.

Long term trends are unable to be accurately detected using the sampling frequency of the Bay of Plenty Regional Council monitoring program and the monitoring program for this study. The natural variation in nitrogen concentrations is high, and such monitoring programs are unable to adequately represent the natural system. Therefore long term temporal trends that are derived from such datasets are most likely due to random noise.

Urban and industrial land uses have the strongest effect on nitrogen concentrations. Catchments with a higher percentage urban and industrial area correspond to a higher nitrogen concentration. The percentage agriculture and horticulture has a similar yet less obvious relationship to nitrogen concentration. The percentage forest appears to also affect nitrogen concentrations, with higher concentrations corresponding to lower catchments with a lower percentage forest. It is speculated that the relative importance of urban and industrial land area, agricultural and horticultural land area, and forested area in determining nitrogen concentration may be due to the proximity of each land use group to a river mouth, rather than the intrinsic properties of each land use group.

# 6 SWAT output

Due to the low frequency and intermittent collection of the recorded data it is difficult to provide any insight into seasonal and storm variations. Understanding the seasonal and event driven variation can be used to aid design of water quality monitoring programs, assist setting water quality targets, and help predict when water quality targets will be achieved. Although numerical model predictions are not perfect, they can provide insight into scenarios that are not otherwise possible to predict. Process based models such as SWAT are able to simulate scenarios beyond the available data with more confidence than statistical or data based models.

In addition to the calibrated present day scenario, two hypothetical scenarios were also run using SWAT. These were a natural state scenario, with the only land use in the catchment being indigenous forest, and a worst case scenario, where the only land use in the catchment is agriculture. The forest only scenario was chosen because many regional councils aim to restore their lakes and rivers to the state they were in prior to European settlement, which this scenario simulates. The agriculture only scenario was chosen as a result of the increase in agriculture that has been observed over the past few decades. This agriculture only scenario represents the extreme case that would occur if agriculture continues to be developed unabated. Together, these scenarios represent the extreme cases of land use change that could possibly occur.

The following sections presents the results obtained from the above SWAT model scenarios. These results are analysed to investigate and draw conclusions on the affect that the simulated land use changes would have on nitrogen yield.

## 6.1 Results

Figure 6.1, Figure 6.2, and Figure 6.3 show time series plots of the SWAT output for the present day, forest only, and agriculture only scenarios respectively. Overall, the lowest nitrogen yield was obtained from the forest only scenario, followed by the present day scenario, and the highest nitrogen yield was produced by the agriculture. Due to sediment loading not being calibrated, organic nitrogen yields, which often is bound to sediment particles, are not presented. For all three plots discharge remains almost identical with only minor differences observable in the time series plots. For all three scenarios, discharge displays a seasonal cycle in base flow, increasing during winter and decreasing during summer. Large peaks occur in response to storm events. Years without large storms, such as 1997, show less of a seasonal trend than years that receive more rainfall.

Nitrate yield shows the strongest seasonal cycle of the three nutrients output from the model. Seasonal variation in nitrate yield shows a similar timing as the cycle in discharge, increasing in winter and decreasing in summer. However nitrate cycles appear to be less affected by the occurrence of storm events, although most storm events do result in a spike in nitrate yield. There is a large difference in the nitrate yield between the three scenarios. The farm only scenario produced nitrate yields approximately twice that of the forest only scenario, and approximately 1.5 times that of the present day scenario.

Ammonium yield is zero during low flow conditions, and only spikes during flood events, resulting in no seasonal cycle. The difference in ammonium yield between the different scenarios is the largest of any of the three nutrients. The forest only scenario has the smallest ammonium. The present day scenario produces an ammonium yield which, during storm events, produces ammonium yields approximately one order of magnitude larger than the yield from the forest only scenario. The agriculture only scenario produced an ammonium yield approximately another order of magnitude larger than that from the present day scenario.

Nitrite yield is the lowest of the three nitrogen species and is similar to ammonium yield in that it is solely event driven, and is zero during periods of low flow. The overall magnitude of nitrite yield follows the same pattern as ammonium did, with the agriculture only scenario producing the highest yield, and the forest only scenario producing the lowest yield. The magnitude of the difference between each scenario is much less than ammonium. The present day yield is approximately twice that of the forest only scenario. Nitrite yield from the

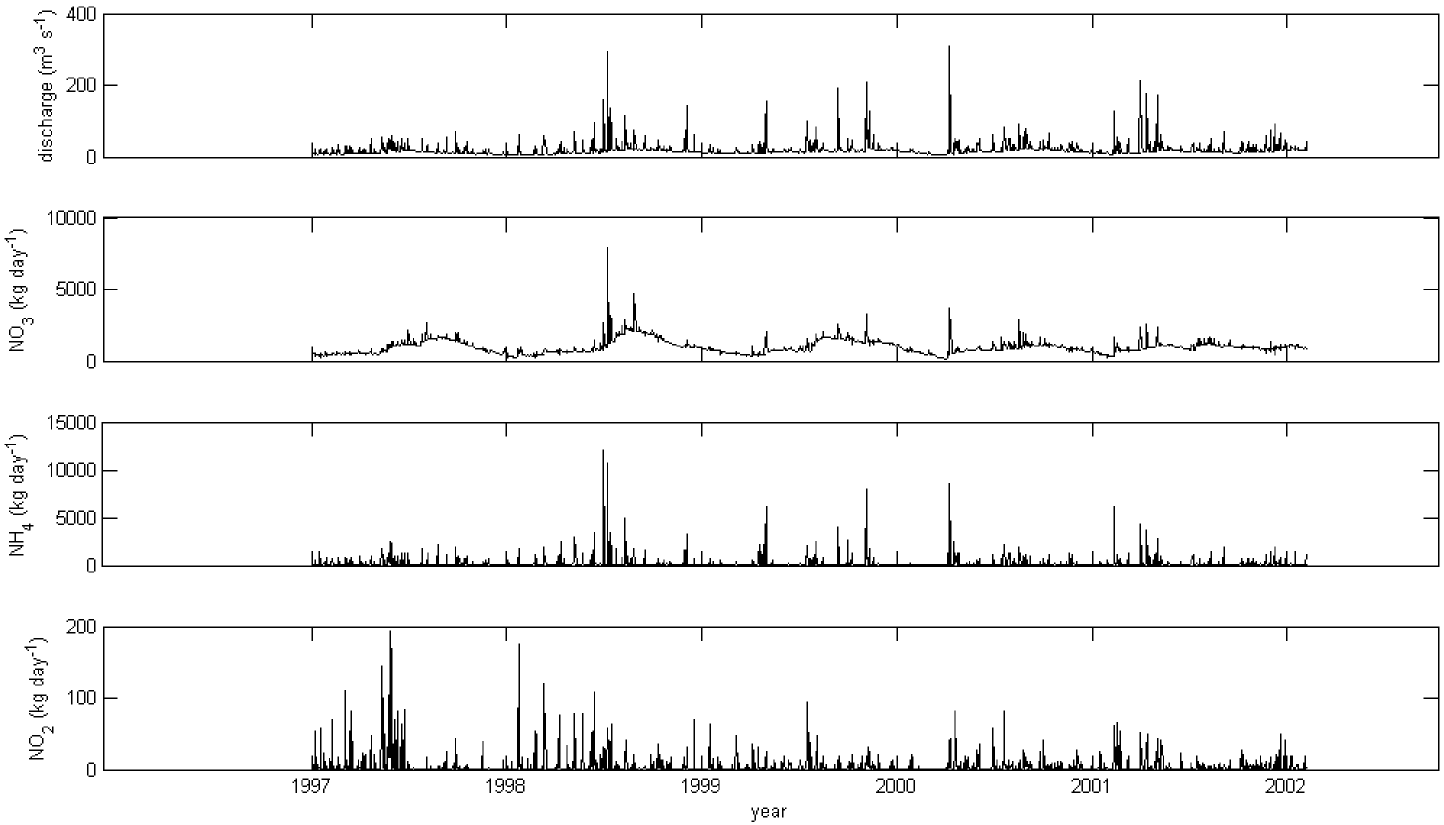


**Figure 6.1: SWAT discharge, nitrate, ammonium, and nitrite output for the present day scenario**

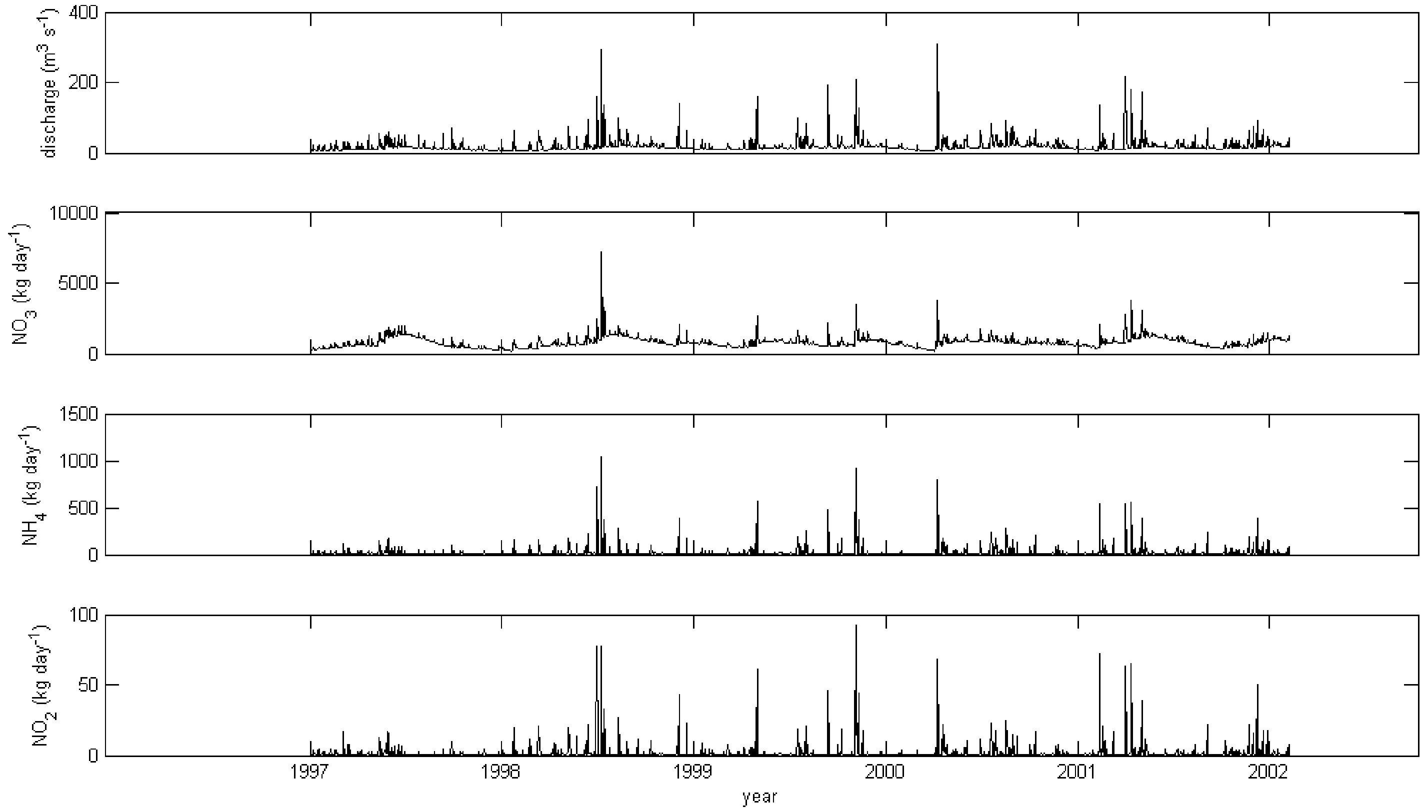


**Figure 6.2: SWAT discharge, nitrate, ammonium, and nitrite output for the forest only scenario**

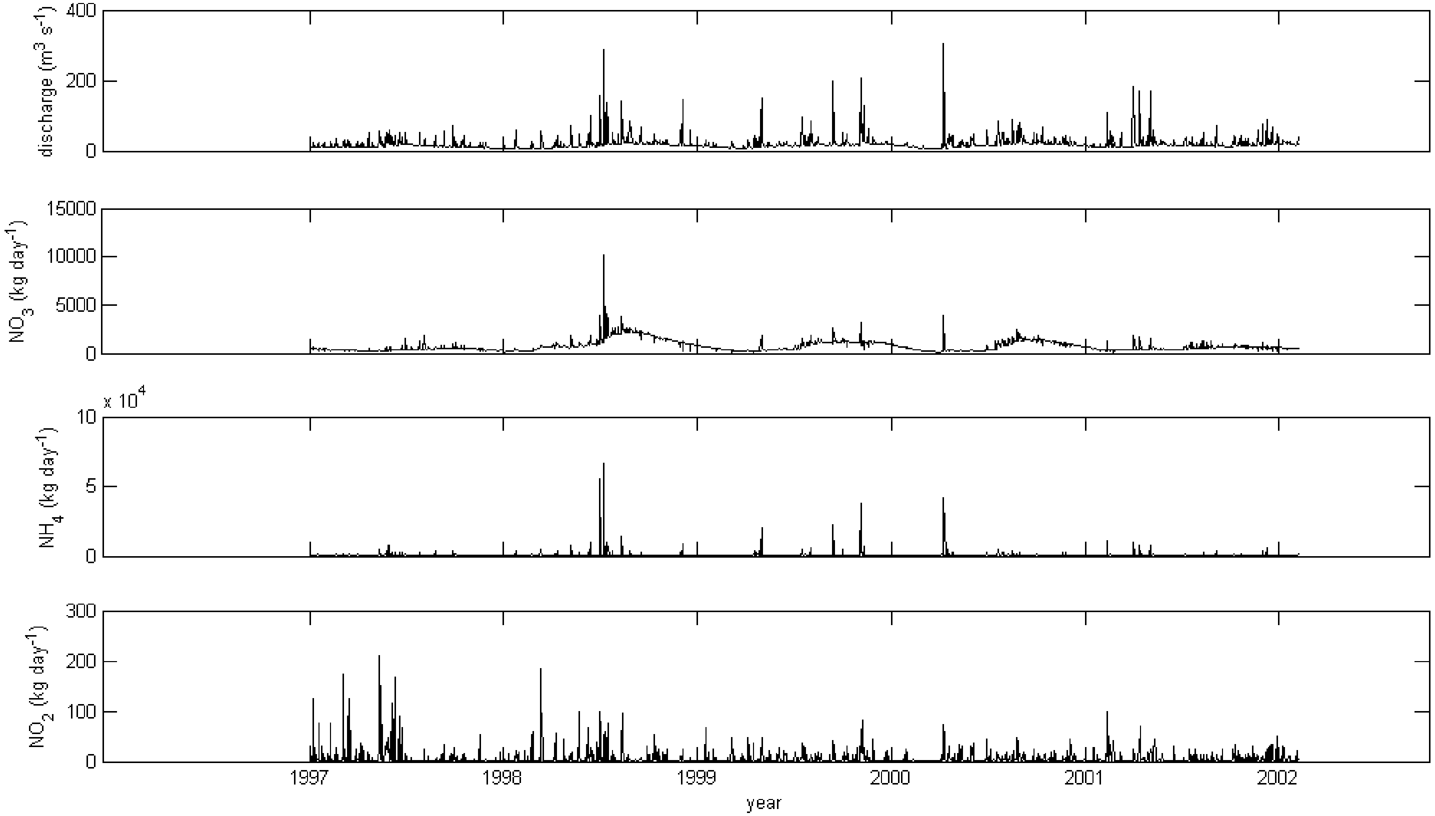


**Figure 6.3: SWAT discharge, nitrate, ammonium, and nitrite output for the agriculture only scenario**

agriculture scenario is fifty percent larger than the present day scenario. The temporal distribution of large nitrite yield events differs between the scenarios as well. Both the present day and agriculture only scenarios have their largest nitrite events during the first two years of simulation and then much lower yields for the rest of the simulation period. However the temporal distribution of the forest only scenario nitrite yield is the opposite, with the yields in the first two years much less than the rest of the simulation.

The average annual specific nitrate, ammonium, and nitrite yields from the three scenarios are shown in Table 6.1. Here we can see that the forest only scenario produced the lowest ammonium, and nitrite yield, and the agriculture only scenario produced the lowest nitrate yield. The highest ammonium and nitrite yields were produced by the agriculture only scenario, and the highest nitrate yield produced by the present day scenario. The decrease in nitrate from the present day scenario to the agriculture only scenario is more than offset by the increase in ammonium, meaning the total aqueous nitrogen yield from the agriculture only scenario is higher than that from the present day scenario.

**Table 6.1: mean specific nitrate, ammonium, and nitrite yield from the present day, forest only, and agriculture only SWAT model scenarios.**

| | Nitrate (kg $ha^{-1}$ $yr^{-1}$) | Ammonium (kg $ha^{-1}$ $yr^{-1}$) | Nitrite (kg $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|
| Present day | 7.92 | 1.44 | 0.04 |
| Forrest only | 6.55 | 0.14 | 0.01 |
| Agriculture only | 5.9 | 3.38 | 0.05 |

To further investigate how the model scenarios changed from the present day scenario the data in figures Figure 6.2 and Figure 6.3 were subtracted from the data in Figure 6.1. The differences between the present day and the forest only scenarios are shown in Figure 6.4, and the differences between the present day and agriculture only scenarios are shown in Figure 6.5.

From Figure 6.4, we can see that the change in discharge between the present day and forest only scenarios displays a cyclical behaviour. There is an increase in base flow during the summer months at the beginning of each year, followed by a decrease in base flow over winter during the later parts of the year. For the most part, storm events produce a difference in discharge of a larger magnitude in the same direction as the difference in base flow. However the cycle in the difference in peak discharge is slightly out of phase with the difference in base flow. Peak discharge difference will change from negative to positive (and vice versa) before base flow. The phase relationship between the cycle in the difference in peak discharge and the cycle in base flow difference indicates that the peak discharge cycle drives the base flow cycle.

The difference in discharge between the present day and agriculture only scenarios also displays a seasonal cycle. However the cycle in the difference in discharge shown in Figure 6.5 is out of phase with the discharge cycle in Figure 6.4. Instead the discharge in the agricultural only scenario is higher than the discharge of the present day scenario in winter and lower in summer.

Nitrate shows a similar trend to discharge in Figure 6.4. The difference between the present day and forest only nitrate yield becomes more positive during summer and more negative in winter. Storm events almost exclusively cause the nitrate difference to become more positive. The Nitrate plot in Figure 6.5 also follows a similar cycle to its corresponding discharge. However the cycle of the difference in nitrate yield between the present and agricultural only scenarios is much less obvious than the cycle observed in Figure 6.4. For example the nitrate yield from the agricultural scenario was consistently less than the nitrate yield from the present day scenario throughout 1997, and is mostly larger for 1998.

The difference in ammonium is negative for the majority of storm events in Figure 6.4, and positive for the majority of storm events in Figure 6.5. In both cases, the difference in ammonium is zero outside of periods of high discharge, due to the ammonium yield being zero in all scenarios during such times.

Differences in nitrite yield between scenarios are similar to the differences in ammonium yield. Nitrite differences shown in Figure 6.4 are zero during periods of low discharge, and are negative for most flood events. There are however more positive values than for ammonium in the same figure. These positive differences often have a much larger magnitude than the more common

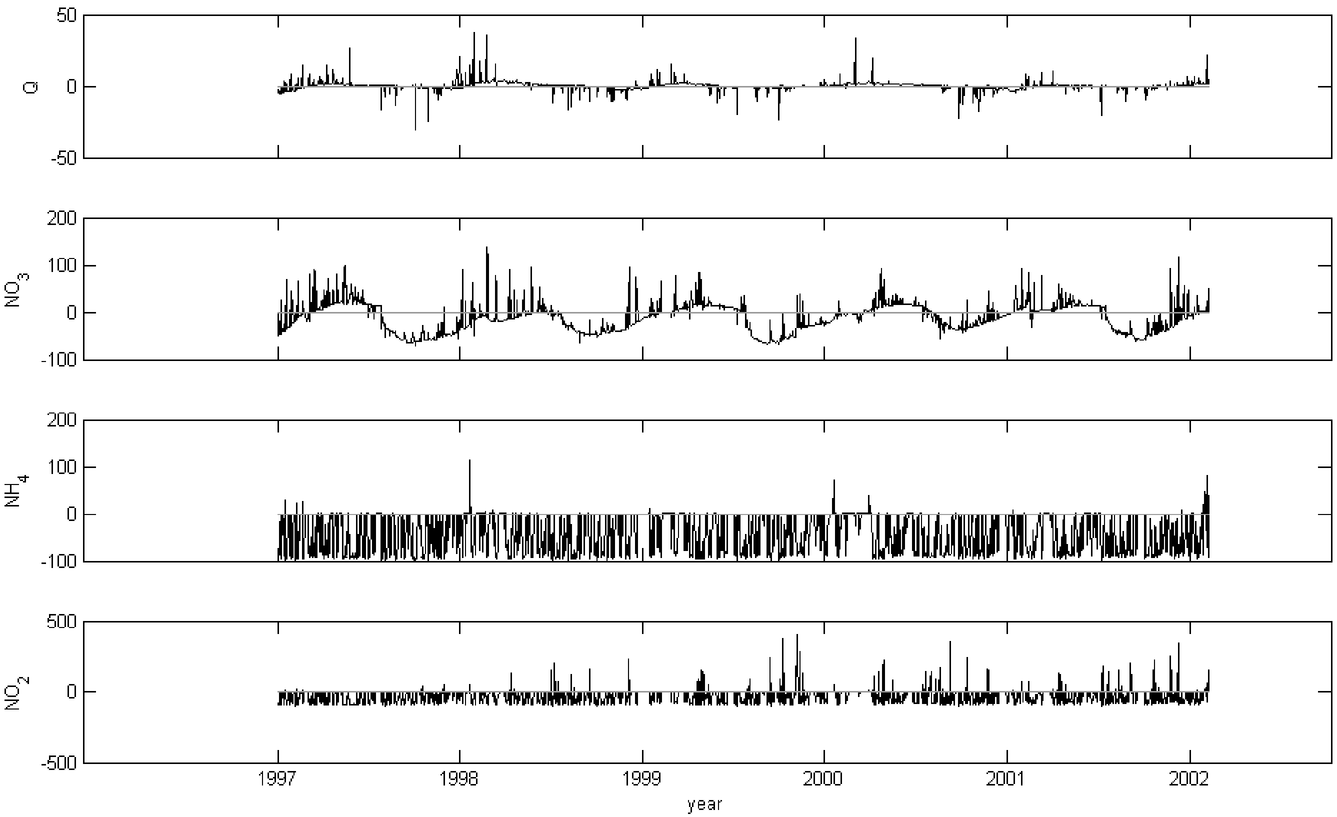


**Figure 6.4: Change in discharge, nitrate, ammonium, and nitrite from the present day scenario, to the forest only scenario.**

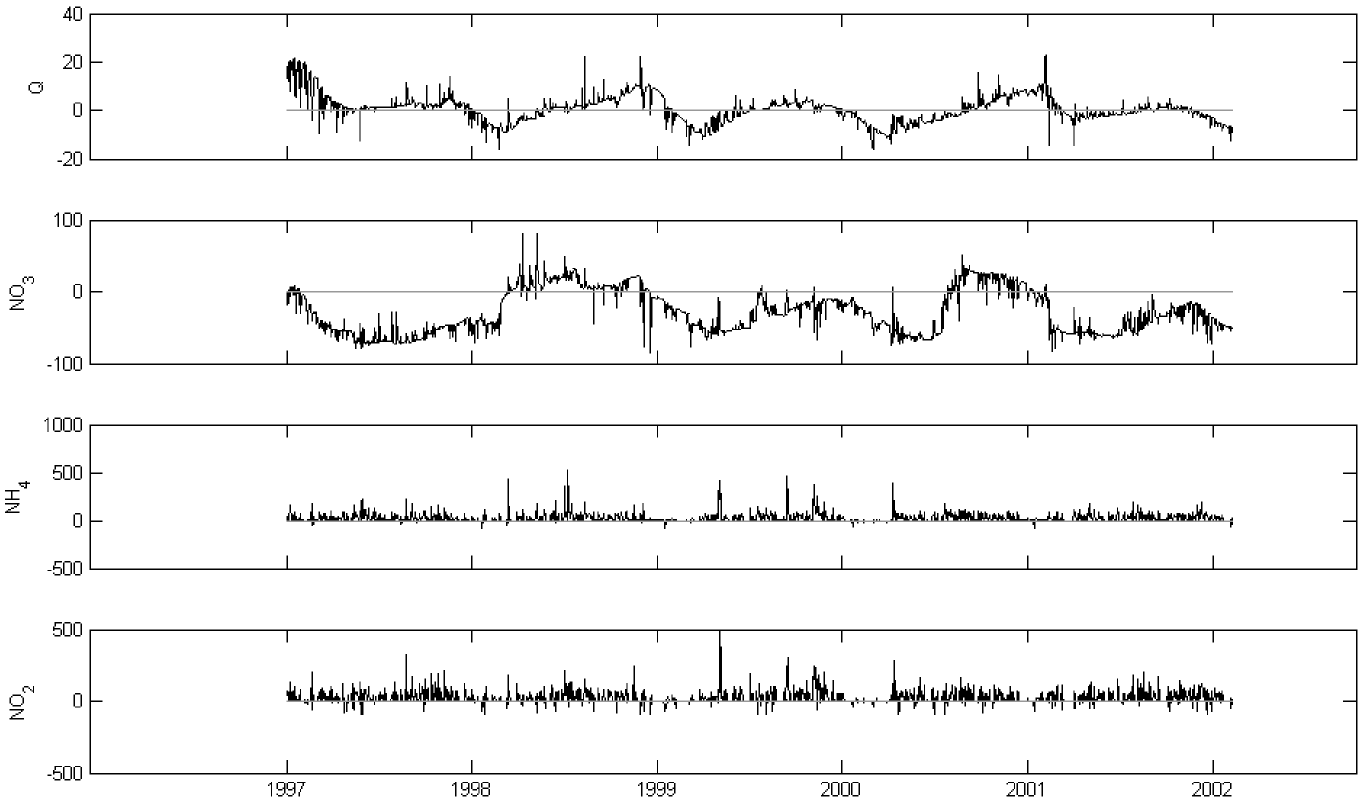


**Figure 6.5: Change in discharge, nitrate, ammonium, and nitrite from the present day scenario, to the agriculture only scenario.**

negative values. The nitrate difference plot in Figure 6.5 is also similar to the corresponding ammonium plot. The majority of storm events have a positive difference, there is zero difference during periods of low flow, and negative values are more common than in the ammonium plot of the same figure.

Overall the effect of land use on nitrogen yield is consistent with the results found by Heggie and Savage ( 2009). The forest only scenario produced lower nitrogen yields than the present day scenario. In turn, the present day scenario nitrogen yields were exceeded by the agriculture only scenarios nitrogen yields. The vegetation in the forest only scenario was mature, and so did not take up nitrogen from the soil. In contrast the pasture in the agriculture only scenario is permanently immature due to grazing, and so does take up nutrients from the soil. However the addition of fertiliser, along with excretion from animals, causes an increased amount of nitrogen to be leached from the soil and ground water, and transported into rivers and streams.

The differences between the scenarios appear to be largely driven by the effect the different land uses have on discharge. The forest only scenario appears to increase the storage of water, and slow transport of water from its source as rainfall to streams and rivers. An increase in travel time explains the cycle in discharge shown in Figure 6.4. During the winter when precipitation is higher, more of rain is stored in the catchment and relaced slower to rivers and streams than in the present day scenario. Increasing stored water over winter in turn causes the difference in discharge to become more negative. Then during summer months when precipitation is lower the stored water is slowly released, causing the difference in discharge to become more positive. The opposite occurs in the agriculture only scenario. Water is transported to streams and rivers faster than in the present day scenario, causing the difference in discharge to become more positive during winter and more negative during summer.

The difference in nitrate between scenarios tends to cycle in phase with the difference in discharge. When discharge is higher, the nitrate yield is also higher. However the nitrate plot in Figure 6.5 displays a much less pronounced cycle than in Figure 6.4. The variability of the nitrate plot is possibly caused by the superposition of two relationships on top of each other, one being the annual discharge cycle, and the other being the long term relationship between precipitation and discharge. For example 1997 had low precipitation. Although the expected cycle in discharge is still present, the lower precipitation causes the long term discharge to be lower overall. The lower discharge in turn causes the nitrate yield to be lower as well. This effect of low precipitation is not seen in Figure 6.4 because the additional water stored by the indigenous forest that is being delivered to rivers and streams maintains the cycle in nitrate yield.

In order to quantify how much nitrogen is discharged from the catchment by discharges of different magnitudes Figure 6.6 and Figure 6.7 were plotted. Both figures show the percentage of the total yield of each nitrogen species that leaves the catchment in events that were of the corresponding discharge or less. Figure 6.6 corresponds to the forest only scenario, and Figure 6.7 to the agriculture only scenario. In both Figure 6.6 and Figure 6.7 the bulk of all three nitrogen species leaves the catchment in events that are at the low end of the full spectrum of discharge values. This observation appears contradictory to Figure 6.1, where it is observed that high discharge events produce much larger nitrogen yields than low flow events. This discrepancy is due to the relative number of high and low flow events. The number of days that have a discharge that would be considered base flow far exceeds the number of flood events. Thus the lower nitrogen yield of low discharge events is counteracted by the sheer number of low discharge events.

In Figure 6.6 we can see events with the magnitude of the mean discharge (19 $m^3 s^{-1}$) or less account for approximately 60 percent of nitrate, and approximately ten percent of ammonium and nitrite. Discharges of 147 $m^3 s^{-1}$ (the one year flood event) or less account for approximately 79 percent of ammonium and nitrite, and 97 percent of nitrate. No events of the magnitude of the 10 year flood event occur during the simulation period.

Figure 6.7 shows that for the agriculture only scenario, the mean discharge or lower accounted for 58 percent of nitrate, 20 percent of nitrite, and 3.8 percent of ammonium. Discharges of the one year flood event or less accounted for 97

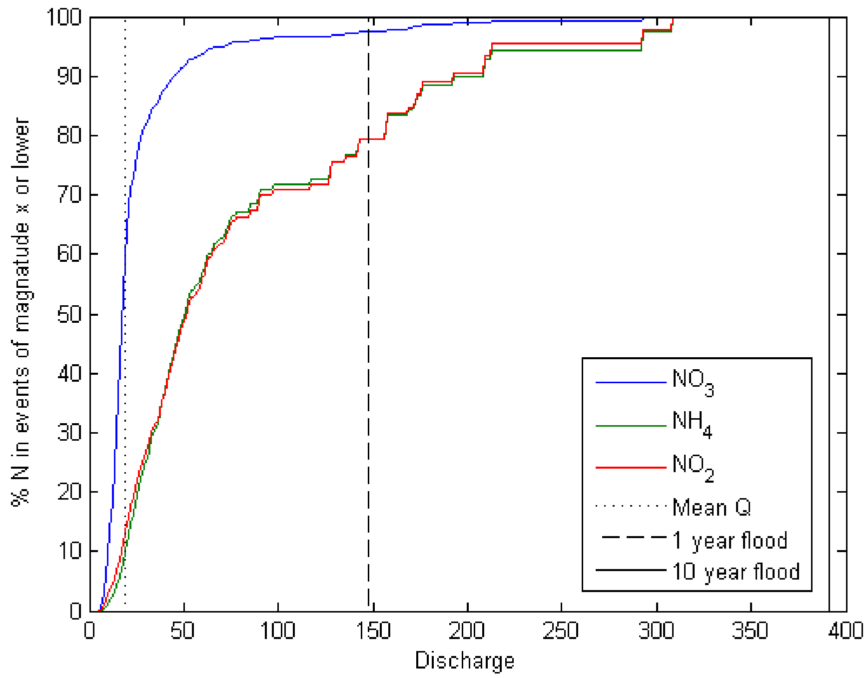


**Figure 6.6: The percent of nitrate, ammonium, and nitrite that is discharged from the Wairoa catchment in discharge events of a given magnitude or less under the forest only scenario, and the mean, 1 year flood, and 10 year flood event discharge.**

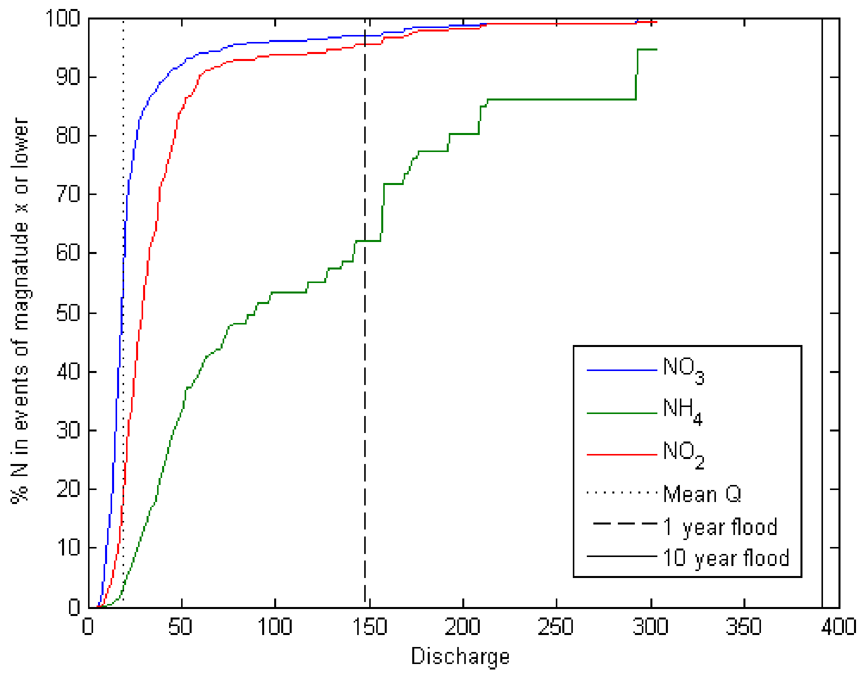


**Figure 6.7: the percent of nitrate, ammonium, and nitrite that is discharged from the Wairoa catchment in discharge events of a given magnitude or less under the forest only scenario, and the mean, 1 year flood, and 10 year flood event discharge.**

percent of nitrate, 95.4 percent of nitrite, and 62.3 percent of ammonium. Again, no 10 year flood events occurred during the simulation period.

The main differences between Figure 6.6 are Figure 6.7 are the distribution of ammonium and nitrite. In Figure 6.6 both ammonium and nitrite follow a very similar distribution to each other. However, in Figure 6.7 far more nitrite is discharged in lower magnitude events, whereas the distribution of ammonium shifts to more being discharged in higher magnitude events. A possible cause for this difference is the relationship between agriculture, nutrient concentration, and discharge that was observed in Figure 6.5. Under agriculture, the transport of water through the soil and into rivers and streams is faster. Furthermore there are more nutrients available in the agriculture scenario from fertiliser and animal excretion. During low flow conditions, ammonium is oxidised into nitrite and nitrate, thus more nitrite is present in low flow events in the agriculture scenario. It then follows that during high discharge, the travel time of the water is reduced, giving less time for ammonium to be oxidised, thus increasing the amount of ammonium present during periods of high discharge.

## 6.2 Discussion

The SWAT outputs for the present day, forest only, and agriculture only scenarios all have the same relative proportions of the different nitrogen species. Nitrate is the largest, followed by ammonium, and finally nitrite has the lowest concentrations. These relative proportions are due to ammonium and nitrite being oxidised into nitrate by bacteria.

All three scenarios also have similar temporal variations. Discharge and nitrate appear to cycle in phase with each other. Higher discharge and nitrate values occur during the winter, while summer produces lower discharge and nitrate yields. Ammonium and nitrite however are driven purely by storm events, with negligible amounts being discharged during low flow. The temporal distribution of storms then leads to there being a slight seasonal cycle in ammonium and nitrite, with increasing frequency during winter. However this seasonal cycle is much less obvious than the cycle in nitrate. Peak discharge events also correspond to peak nitrate yield.

The differences between the present day and forest only scenarios show an overall decrease in the concentration of nitrate, nitrite, and ammonium. In contrast, the difference between the present day and agriculture only scenarios shows an increase in ammonium yield and a very slight increase in nitrite yield. The nitrate yield from the agriculture only scenario is less than the yield from the present day scenario. The increase in ammonium that was observed between the present day and agriculture only scenarios is larger than the decrease that was observed in nitrate, giving an overall increase in nitrogen yield from the agriculture only scenario.

The reduced nitrogen yields that were produced by the forest only scenario are easily explained by the reduced nitrogen input that results by eliminating the agricultural area. Similarly the increased ammonium and nitrite output that were produced can be explained by the increase in nitrogen input from fertiliser and animal excretion. However the reduction in nitrate yield that resulted from the agriculture only scenario is counter-intuitive. To understand this we must also consider the affect agriculture was observed to have on discharge. The agriculture only scenario appeared to increase the speed at which water was transported through the soil. The result is that the amount of water stored in the soil is reduced, base flow is reduced, and quick flow is increased. Due to the majority of days having base flow, and this base flow being reduced, the overall yield of nitrate is reduced. However the increased quick flow also reduces the nitrate yield. The higher flow velocities that occur under increased quick flow reduces the time available for bacteria to oxidise ammonium and nitrite to nitrate. Thus the nitrate yield during quick flow is also reduced. The effect of agriculture on discharge, and therefore the relative concentrations of ammonium, nitrate, and nitrite also help explain the increase in ammonium and nitrite that was observed in the agriculture only scenario.

There is also temporal variation in the difference between discharge and nitrogen yield from the present day scenario, and forest and agriculture only scenarios. The difference in discharge and nitrate between the present day and forest only scenario tends to become more positive during summer and more negative during summer. In contrast, the difference in discharge and nitrate between the present day and agriculture only scenario tends to become more positive during winter and more negative during summer. These cycles can be explained by the effect of each scenario on water storage. The forest only scenario increases water storage. This stored water is slowly discharged between storm events. As a result, base flow is higher over summer and lower over winter. The opposite occurs under the agriculture only scenario where the reduced storage causes discharge to be higher in winter and lower in summer.

The agriculture only scenario appears to be more sensitive to long term precipitation trends. Due to water being transported to rivers and streams faster under agriculture, and the resulting decrease in water storage, the discharge (and by extension nitrate yield) is greatly reduced during years where perception is low.

The event magnitude distributions of nitrite and ammonium yields differ greatly between the agriculture and forest only scenarios. In the forest only scenario both nitrite and ammonium yields have very similar event magnitude distributions. However in the agriculture only scenario more nitrite is discharged during low magnitude events, and more ammonium is discharged in high magnitude events. The change in the nitrite distribution is explained by the increased nitrogen input and the number of low magnitude events to high magnitude events. The increased nitrogen input ensures there is more nitrite available for transport, and the high number of low magnitude events outweighs the higher nitrite yield in high magnitude events. Thus more nitrite is discharged in low magnitude events. The increased proportion of ammonium that is discharged in high magnitude events can be mostly explained by the increased nitrogen input and the relationship between ammonium concentration and flow velocity. The increased nitrogen input supplies more ammonium to the catchment. The increased flow velocity that occurs during high magnitude events gives bacteria less time to oxidise ammonium, resulting in higher ammonium concentrations in high magnitude events. Furthermore, the effect the increase in peak flow that is observed in the agriculture only scenario will further increase the flow velocity, and therefore the ammonium concentration and yield in high magnitude events.

Dymond *et al.* (2013) report nitrate leaching from portions of the Bay of Plenty over 30 kg $ha^{-1}$ $yr^{-1}$. These values are much higher than the yields produced by all three SWAT scenarios. However, the lower nitrate yields Dymond *et al.* (2013) reported for other areas in the Bay of Plenty are similar to the SWAT scenario outputs.

Heggie and Savage (2009) reported nitrogen yields of 17 kg $ha^{-1}$ $yr^{-1}$ from catchment with a high percentage of agriculture, and 1 kg $ha^{-1}$ $yr^{-1}$ from a catchment containing no agriculture. These results differ from the results produced by SWAT, with the agriculture only scenario yielding 9.33 kg $ha^{-1}$ $yr^{-1}$ of nitrogen and the forest only scenario yielding 6.7 kg $ha^{-1}$ $yr^{-1}$. Both these differences remain when the additional nitrogen that discharged from catchments in the form of organic nitrogen is considered. The differences between results reported by Heggie and Savage (2009) and the results obtained from SWAT suggest that the SWAT model is not as sensitive to changes in agricultural and forest land use areas relative to the SCENY model, with SWAT producing a higher nitrogen yield from forest and a lower nitrogen yield from agriculture. Alternately these differences could be due to differences in climate between the two studies, or different intrinsic qualities of the catchments, such as slope or soil texture. The overall changes in nitrogen yield in response to land use changes are the same between both SWAT and SCENY, with increased agricultural area resulting in a higher nitrogen yield.

Estimated dissolved inorganic nitrogen yields for the Bay of Plenty (Parfitt, *et al*. 2012) and New Zealand (Parfitt, *et al*. 2006) of 2.72 17 kg $ha^{-1}$ $yr^{-1}$ and 2.32 17 kg $ha^{-1}$ $yr^{-1}$ respectively are both lower than dissolved inorganic nitrogen yields produced by all three SWAT scenarios. These estimates are derived by assuming dissolved inorganic nitrogen accounts for 66 percent of total nitrogen. The difference between these estimated values and the average output from SWAT suggest that either SWAT may predict nitrogen yields that are two high, or the estimated nitrogen yields in Parfitt, *et al*. (2006) and Parfitt, *et al*. (2012) underestimate nitrogen yield.

## 6.3 Conclusions

The SWAT model output for the forest only scenario is lower than the output from the present day scenario, and the output from the agriculture only scenario is higher than the output from the present day scenario. The decrease in nitrogen yield produced by the forest only scenario was shown by all nitrogen species that were simulated. The agriculture only scenario produced increases in ammonium and nitrite, but a decrease in nitrate. The increase in ammonium was larger than the decrease in nitrate, resulting in the overall increase in nitrogen.

All three scenarios show similar temporal variation in discharge and nitrogen yield. Discharge and nitrate show a seasonal cycle, where values increase over winter, and decrease over summer, and peak values occur during storm events. Nitrite and ammonium show no major seasonal cycle, only produce low yields during periods of relatively low flow, and peak values during storm events.

The agriculture only scenario appears to transport rainfall to streams and rivers quicker than the present day scenario, resulting in higher peak discharge and lower base flow. The effects of this difference in discharge have several impacts on the temporal cycles of discharge and yield of different nitrogen species. The reduced volume of water stored in the catchment results in lower discharge and nitrate yields over summer, and higher discharge and nitrate yields over winter. The reduced amount of stored water also causes the effects of long period of low precipitation. Years with low precipitation produced much lower discharge and nitrate yields.

The forest only scenario has the opposite effect on discharge, increasing the time taken for precipitation to be transported to rivers and streams. The resulting increase in water stored in the catchment then causes discharge and ammonium to be higher in summer and lower in winter.

When compared to the forest only scenario, the agriculture only scenario caused a larger proportion of ammonium to be discharged in high magnitude events. This increase is attributed to higher nitrogen input and increased quick flow velocity. In contrast, a larger proportion of nitrite to be discharged in lower magnitude events under the agriculture only scenario due to the increased nitrogen input and the relative frequency of low flow events to flood events.

The simulated nitrogen yields were lower than the larger yields for the Bay of Plenty presented by Dymond *et al.* (2013), but were similar to lower nitrogen yields that were also found in the region. Heggie and Savage (2009) also reported higher nitrogen yields from catchments with a high percentage of agriculture, and low nitrogen yields from catchments with low percentage agriculture. However, the nitrogen yield Heggie and Savage (2009) reported from catchments with low amounts of agriculture were lower than the results from the forest only scenario, and vice versa for catchments with a high amount of agriculture. The nitrogen yields produced by all three SWAT scenarios were lower than the estimated yields for the Bay of Plenty and New Zealand produced by Parfitt, *et al*. (2006) and Parfitt, *et al*. (2012).

# 7 Conclusions

Recorded nitrogen data observed in this study combined with Bay of Plenty Regional Councils observations shows that mean dissolved inorganic nitrogen yields into the southern Tauranga Harbour are 0.39 kg ha$^{-1}$ yr$^{-1}$ for ammonia, 0.94 kg ha$^{-1}$ yr$^{-1}$ for ammonium, and 8.57 kg ha$^{-1}$ yr$^{-1}$ for $NO_x$. These nitrogen yields are lower than the highest nitrogen yields reported for the Bay of Plenty region by Dymond, *et al*. (2013), but match some of the lower nitrogen yields that are reported for other catchments in the area. Nitrogen yields that were estimated by Parfitt *et al*. (2006) and Parfitt *et al*. (2012) for the Bay of Plenty region were lower than yields that were calculated from the observations.

The spatial distribution of nitrogen concentration appears to have a strong positive relationship with the proportion of a catchment that has urban or industrial land uses. Furthermore, it appears that only a small proportion of a catchment needs to be in urban or industrial land use to have a large effect on the nitrogen concentration. However the apparent strength of urban and industrial areas ability to influence nitrogen concentration may be due to these land uses being concentrated close to river mouths near the coast, allowing little opportunity for denitrification. A slightly weaker positive relationship was also observed with nitrogen concentration and the proportion of catchment area in agriculture and horticulture. The proportion of catchment area in forest has a negative relationship with nitrogen concentration.

Long term temporal trends are difficult to determine with data that is collected at low frequency, such as the datasets used in this study. The random variation in nitrogen yields is high, and so sporadically and infrequently collected data is unable to adequately capture the real situation and distinguish trends from random noise.

The SWAT outputs from the present day, forest only, and agriculture only scenarios indicate that increasing the amount of agriculture in a catchment will also increase the nitrogen yield of the catchment. In all three scenarios discharge and nitrate show seasonal cycles with higher values in the winter and lower values in the summer. Ammonium and nitrite have very low yields during low discharge, and peak to high yields during storms. Discharge and nitrate yield also produce peak values during storms.

Results presented by Heggie & Savage, (2009) also show an increase in nitrogen with increased agriculture. However, the nitrogen yield from the forest only scenario was higher than the results presented by Heggie & Savage, (2009) for a similar catchment. Furthermore, the nitrogen yield from the agriculture only scenario was lower than a similar catchment modelled by Heggie & Savage, (2009). This comparison suggests that SWAT may have overestimated the nitrogen yield from forest, and underestimated the nitrogen yield from agriculture, reducing the sensitivity of the simulated nitrogen yield to changes in catchment. However, Heggie & Savage, (2009) simulated catchment in a colder environment, which may also cause different nitrogen yields.

Increasing the amount of agriculture in SWAT appears to reduce the time it takes for precipitation to be transported to streams and rivers. As a result, quick flow is increased, base flow is decreased, and the amount of water stored in the catchment is reduced. The increased quick flow also increases the nitrogen yield during storms, and the reduced base flow results in reduced nitrogen yield at low discharge. Reducing the amount of stored water in turn effects the temporal cycles of discharge and nitrate yield from the catchment. Increased agriculture area causes the cycles in both discharge and nitrate increase further over winter and decrease further over summer. The reduction in stored water also renders the catchment more sensitive to long periods of low precipitation, further reducing discharge and nitrate yield during dry years.

Increasing the area of indigenous forest in SWAT had the opposite effect to increasing the area of agriculture. The average time taken for precipitation to be transported into streams and rivers is increased, leading to a larger amount of water stored in the catchment. The stored water is slowly released to streams and rivers, which causes discharge and nitrate yield to increase over summer, and decrease over winter. The increased time taken for water to enter streams and rivers results in lower peak discharge and higher base flow, which in turn reduces nitrogen yield during storms and increases nitrogen yield during low discharge. The increased water storage also reduces the catchments sensitivity to long periods of low precipitation, increasing discharge and nitrate yield during dry years.

Increasing the agricultural area in SWAT caused a larger proportion of nitrite to be discharged in low magnitude events. Whereas increasing the agricultural area caused a larger amount of ammonium to be discharged in high magnitude events. The increased proportion of nitrite in low magnitude events is attributed to higher nitrogen inputs as a result of increased agriculture, and the number of low discharge events being much greater than high discharge events. The increased amount of ammonium discharged in high magnitude events is attributed to the increased nitrogen input, and the increased quick flow reducing the time available for the ammonium to be oxidised to nitrate.

The SWAT model appears to be able to simulate discharge and nitrogen yields under different land use regimes with reasonable accuracy. Furthermore the wide range of land uses and management practices that are able to be simulated by SWAT make the model an ideal tool for regional councils to use in aiding policy and decision making. The ArcSWAT extension for the ArcMap GIS software provides a far more user friendly and intuitive means of managing the vast quantity of input data that is required by SWAT. However using the ArcSWAT extension still requires a lot of time to achieve a working model. Furthermore the use of the ArcSWAT extension reduces the knowledge of SWAT that the user requires, which can increase the difficulty in trouble shooting problems and cause more errors to go unnoticed. The wide range of parameters that are output by SWAT would also be of great use to regional councils. However each set of output values (discharge, nitrogen, phosphorus, sediment, etc.) must be calibrated individually, further increasing the amount of time and quantity of recorded data required to produce a calibrated model. All these factors should be considered carefully by researchers and council members when considering SWAT as a tool for modelling nutrient yield.

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# Appendix 1

This appendix contains tables A1 and A2 showing the calculated correlation coefficients and slope used for gap filling the precipitation data respectively. Plots of gap filled data for maximum and minimum temperature, wind, and relative humidity are shown in figures A1, A2 and A3.

**Table A1: R squared values for linear regression between each set of precipitation data. Missing values result from datasets with no overlap. R squares of 1 are either from a site regressed against its self, or from duplicate sites.**

| | 1567 | 1569 | 1587 | 1589 | 1611 | 1612 | 1615 | 1617 | 1625 | 1630 | 1633 | 1636 | 1646 | 1648 | 1656 | 17080 | 18638 | 12428 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1567 | 1.000 | 0.986 | 0.980 | 0.980 | 0.980 | 0.985 | 0.983 | 0.980 | 0.980 | 0.984 | 0.985 | 0.986 | 0.986 | 0.980 | 0.983 | 0.975 | 0.979 | 0.980 |
| 1569 | 0.986 | 1.000 | 0.987 | 0.987 | 0.987 | 0.992 | 0.994 | 0.988 | 0.989 | 0.991 | 0.988 | 0.991 | 0.991 | 0.990 | 0.984 | 0.982 | 0.992 | 0.991 |
| 1587 | 0.980 | 0.987 | 1.000 | 1.000 | 1.000 | 0.988 | 0.986 | 0.984 | 0.985 | 0.989 | 0.989 | 0.989 | 0.989 | 0.986 | 0.987 | 0.980 | 0.977 | 0.985 |
| 1589 | 0.980 | 0.987 | 1.000 | 1.000 | 1.000 | 0.988 | 0.986 | 0.984 | 0.985 | 0.989 | 0.989 | 0.989 | 0.989 | 0.986 | 0.987 | 0.980 | 0.977 | 0.985 |
| 1611 | 0.980 | 0.987 | 1.000 | 1.000 | 1.000 | 0.988 | 0.986 | 0.984 | 0.985 | 0.989 | 0.989 | 0.989 | 0.989 | 0.986 | 0.987 | 0.980 | 0.977 | 0.985 |
| 1612 | 0.985 | 0.992 | 0.988 | 0.988 | 0.988 | 1.000 | 0.998 | 0.988 | 0.989 | 0.995 | 0.988 | 0.993 | 0.993 | 0.993 | 0.987 | - | - | - |
| 1615 | 0.983 | 0.994 | 0.986 | 0.986 | 0.986 | 0.998 | 1.000 | 0.988 | 0.993 | 0.995 | 0.990 | 0.995 | 0.995 | 0.992 | 0.987 | 0.984 | 0.988 | 0.995 |
| 1617 | 0.980 | 0.988 | 0.984 | 0.984 | 0.984 | 0.988 | 0.988 | 1.000 | 0.989 | 0.989 | 0.990 | 0.990 | 0.990 | 0.985 | 0.987 | 0.982 | 0.983 | 0.989 |
| 1625 | 0.980 | 0.989 | 0.985 | 0.985 | 0.985 | 0.989 | 0.993 | 0.989 | 1.000 | 0.987 | 0.987 | 0.990 | 0.990 | 0.989 | 0.987 | 0.986 | 0.985 | 0.995 |
| 1630 | 0.984 | 0.991 | 0.989 | 0.989 | 0.989 | 0.995 | 0.995 | 0.989 | 0.987 | 1.000 | 0.991 | 0.997 | 0.998 | 0.996 | 0.991 | - | - | - |
| 1633 | 0.985 | 0.988 | 0.989 | 0.989 | 0.989 | 0.988 | 0.990 | 0.990 | 0.987 | 0.991 | 1.000 | 0.991 | 0.991 | 0.989 | 0.989 | - | - | - |
| 1636 | 0.986 | 0.991 | 0.989 | 0.989 | 0.989 | 0.993 | 0.995 | 0.990 | 0.990 | 0.997 | 0.991 | 1.000 | 1.000 | 0.996 | 0.993 | - | - | 1.000 |
| 1646 | 0.986 | 0.991 | 0.989 | 0.989 | 0.989 | 0.993 | 0.995 | 0.990 | 0.990 | 0.998 | 0.991 | 1.000 | 1.000 | 0.996 | 0.993 | - | - | 1.000 |
| 1648 | 0.980 | 0.990 | 0.986 | 0.986 | 0.986 | 0.993 | 0.992 | 0.985 | 0.989 | 0.996 | 0.989 | 0.996 | 0.996 | 1.000 | 0.989 | 0.983 | 0.980 | 0.992 |
| 1656 | 0.983 | 0.984 | 0.987 | 0.987 | 0.987 | 0.987 | 0.987 | 0.987 | 0.987 | 0.991 | 0.989 | 0.993 | 0.993 | 0.989 | 1.000 | 0.985 | - | 0.990 |
| 17080 | 0.975 | 0.982 | 0.980 | 0.980 | 0.980 | - | 0.984 | 0.982 | 0.986 | - | - | - | - | 0.983 | 0.985 | 1.000 | 0.977 | 0.985 |
| 18638 | 0.979 | 0.992 | 0.977 | 0.977 | 0.977 | - | 0.988 | 0.983 | 0.985 | - | - | - | - | 0.980 | - | 0.977 | 1.000 | 0.985 |
| 12428 | 0.980 | 0.991 | 0.985 | 0.985 | 0.985 | - | 0.995 | 0.989 | 0.995 | - | - | 1.000 | 1.000 | 0.992 | 0.990 | 0.985 | 0.985 | 1.000 |

**Table A2: Slope values for linear regression between each set of precipitation data. Missing values result from datasets with no overlap.**

| | 1567 | 1569 | 1587 | 1589 | 1611 | 1612 | 1615 | 1617 | 1625 | 1630 | 1633 | 1636 | 1646 | 1648 | 1656 | 17080 | 18638 | 12428 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1567 | 1.000 | 0.952 | 0.969 | 0.969 | 0.969 | 0.935 | 0.940 | 0.981 | 0.964 | 0.946 | 0.977 | 0.955 | 0.955 | 0.949 | 0.981 | 0.981 | 0.969 | 0.961 |
| 1569 | 1.036 | 1.000 | 1.013 | 1.013 | 1.013 | 0.980 | 0.986 | 1.028 | 1.009 | 0.996 | 1.023 | 1.004 | 1.004 | 0.994 | 1.031 | 1.018 | 1.005 | 1.007 |
| 1587 | 1.011 | 0.975 | 1.000 | 1.000 | 1.000 | 0.959 | 0.958 | 1.001 | 0.982 | 0.967 | 1.003 | 0.982 | 0.982 | 0.969 | 1.007 | 1.004 | 0.981 | 0.977 |
| 1589 | 1.011 | 0.975 | 1.000 | 1.000 | 1.000 | 0.959 | 0.958 | 1.001 | 0.982 | 0.967 | 1.003 | 0.982 | 0.982 | 0.969 | 1.007 | 1.004 | 0.981 | 0.977 |
| 1611 | 1.011 | 0.975 | 1.000 | 1.000 | 1.000 | 0.959 | 0.958 | 1.001 | 0.982 | 0.967 | 1.003 | 0.982 | 0.982 | 0.969 | 1.007 | 1.004 | 0.981 | 0.977 |
| 1612 | 1.054 | 1.012 | 1.031 | 1.031 | 1.031 | 1.000 | 1.001 | 1.043 | 1.024 | 1.012 | 1.040 | 1.019 | 1.019 | 1.007 | 1.042 | - | - | - |
| 1615 | 1.045 | 1.008 | 1.029 | 1.029 | 1.029 | 0.997 | 1.000 | 1.039 | 1.023 | 1.010 | 1.038 | 1.017 | 1.017 | 1.005 | 1.040 | 1.033 | 1.022 | 1.018 |
| 1617 | 0.999 | 0.961 | 0.983 | 0.983 | 0.983 | 0.948 | 0.951 | 1.000 | 0.976 | 0.962 | 0.993 | 0.970 | 0.970 | 0.959 | 0.995 | 0.983 | 0.976 | 0.972 |
| 1625 | 1.017 | 0.980 | 1.002 | 1.002 | 1.002 | 0.966 | 0.971 | 1.013 | 1.000 | 0.977 | 1.011 | 0.988 | 0.988 | 0.979 | 1.015 | 1.007 | 0.993 | 0.993 |
| 1630 | 1.041 | 0.995 | 1.023 | 1.023 | 1.023 | 0.983 | 0.985 | 1.029 | 1.011 | 1.000 | 1.027 | 1.007 | 1.007 | 0.991 | 1.027 | - | - | - |
| 1633 | 1.008 | 0.966 | 0.987 | 0.987 | 0.987 | 0.950 | 0.954 | 0.997 | 0.977 | 0.965 | 1.000 | 0.971 | 0.971 | 0.959 | 0.996 | - | - | - |
| 1636 | 1.032 | 0.987 | 1.007 | 1.007 | 1.007 | 0.975 | 0.978 | 1.020 | 1.002 | 0.990 | 1.021 | 1.000 | 1.000 | 0.986 | 1.021 | - | - | 1.004 |
| 1646 | 1.033 | 0.987 | 1.007 | 1.007 | 1.007 | 0.975 | 0.978 | 1.021 | 1.002 | 0.991 | 1.021 | 1.000 | 1.000 | 0.987 | 1.022 | - | - | 1.004 |
| 1648 | 1.033 | 0.995 | 1.018 | 1.018 | 1.018 | 0.986 | 0.987 | 1.027 | 1.011 | 1.005 | 1.031 | 1.010 | 1.009 | 1.000 | 1.031 | 1.020 | 1.005 | 1.005 |
| 1656 | 1.003 | 0.955 | 0.980 | 0.980 | 0.980 | 0.947 | 0.949 | 0.992 | 0.973 | 0.964 | 0.994 | 0.972 | 0.972 | 0.959 | 1.000 | 0.973 | - | 0.967 |
| 17080 | 0.994 | 0.965 | 0.975 | 0.975 | 0.975 | - | 0.952 | 0.999 | 0.979 | - | - | - | - | 0.963 | 1.012 | 1.000 | 0.971 | 0.972 |
| 18638 | 1.011 | 0.988 | 0.996 | 0.996 | 0.996 | - | 0.967 | 1.007 | 0.992 | - | - | - | - | 0.975 | - | 1.006 | 1.000 | 0.987 |
| 12428 | 1.021 | 0.985 | 1.008 | 1.008 | 1.008 | - | 0.977 | 1.017 | 1.002 | - | - | 0.996 | 0.996 | 0.987 | 1.023 | 1.014 | 0.999 | 1.000 |

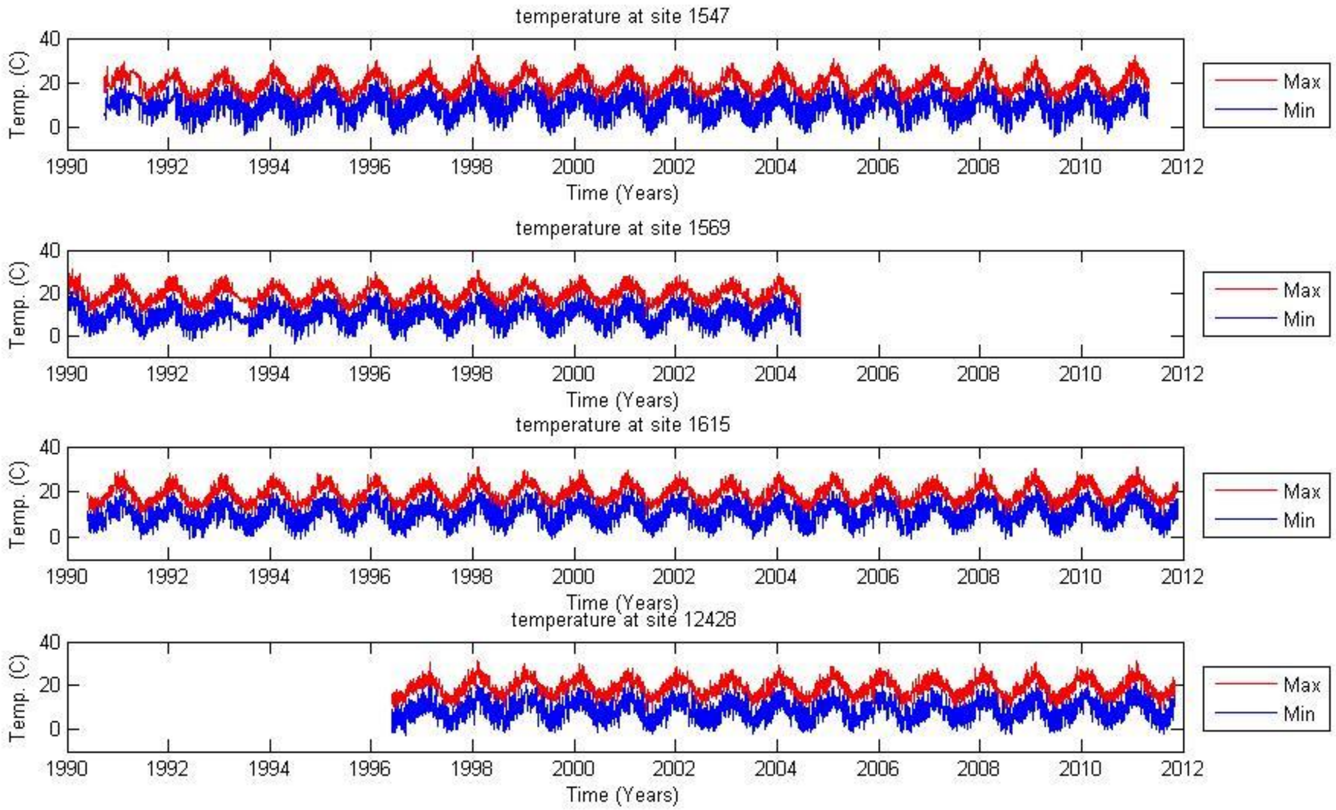



**Figure A 1: Gap filled maximum and minimum temperature from site 1547, 1569, 1615 and 12428.**

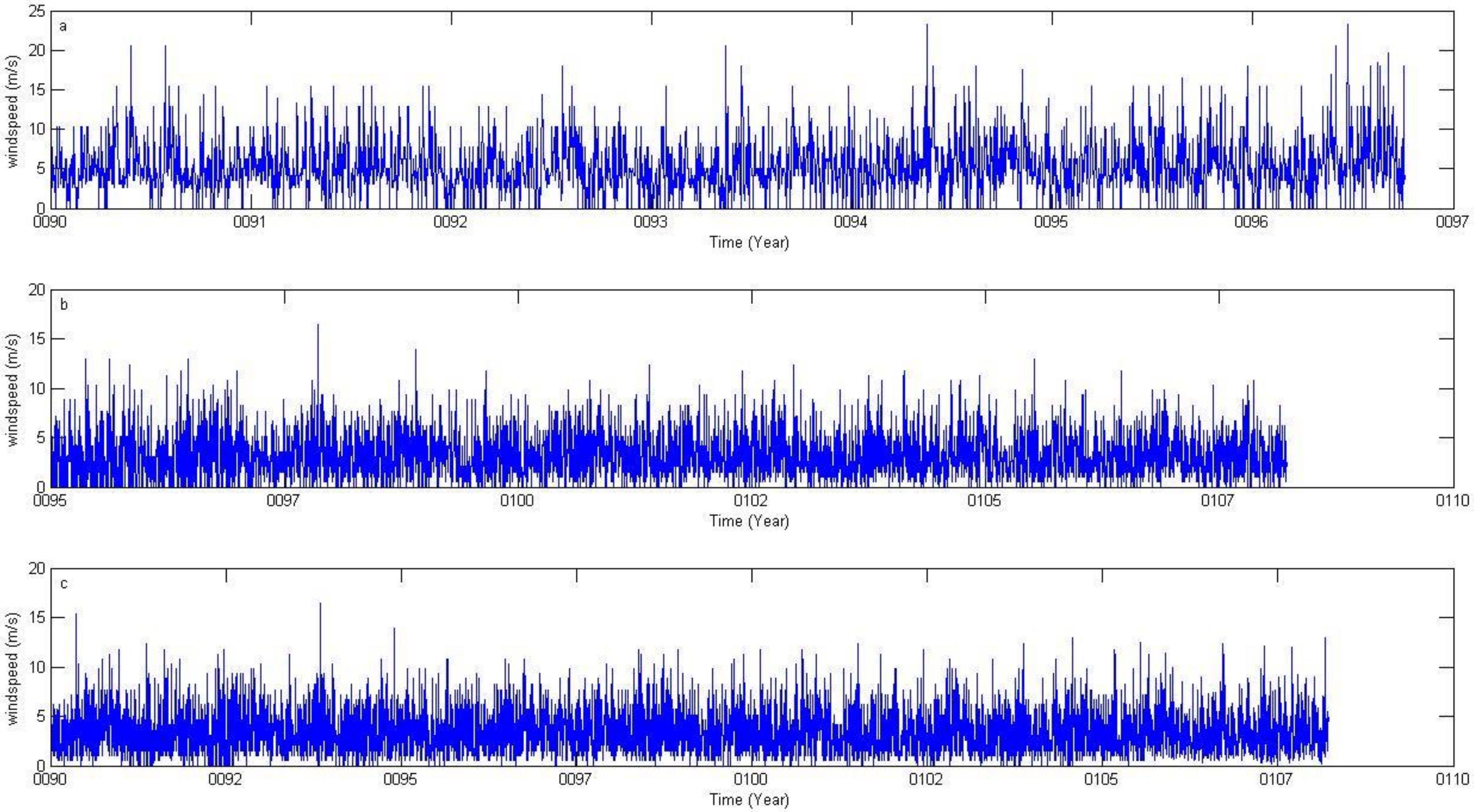



**Figure A 2: Gap filled wind data from sites (a) 1610, (b) 1614, and (c) 1615.**

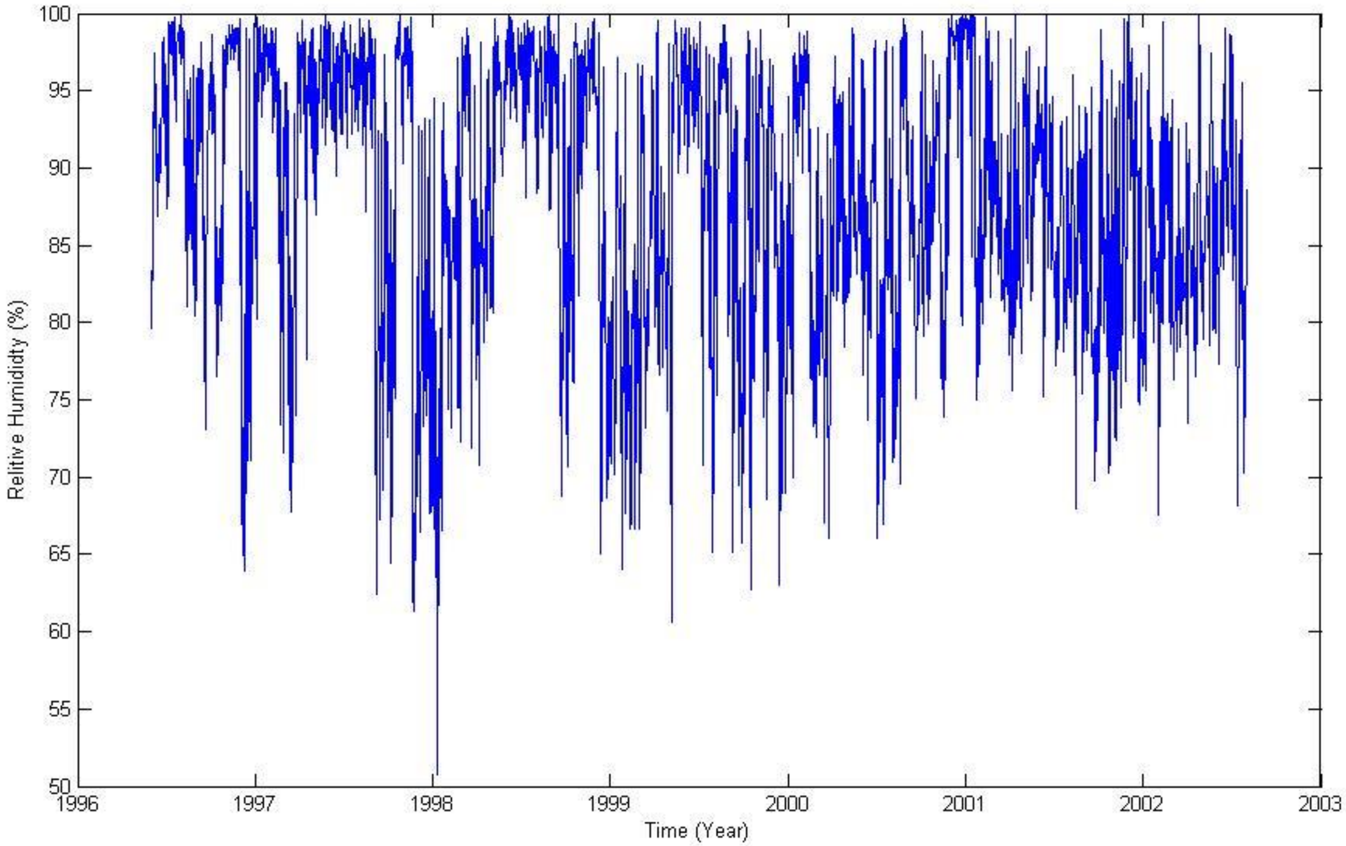
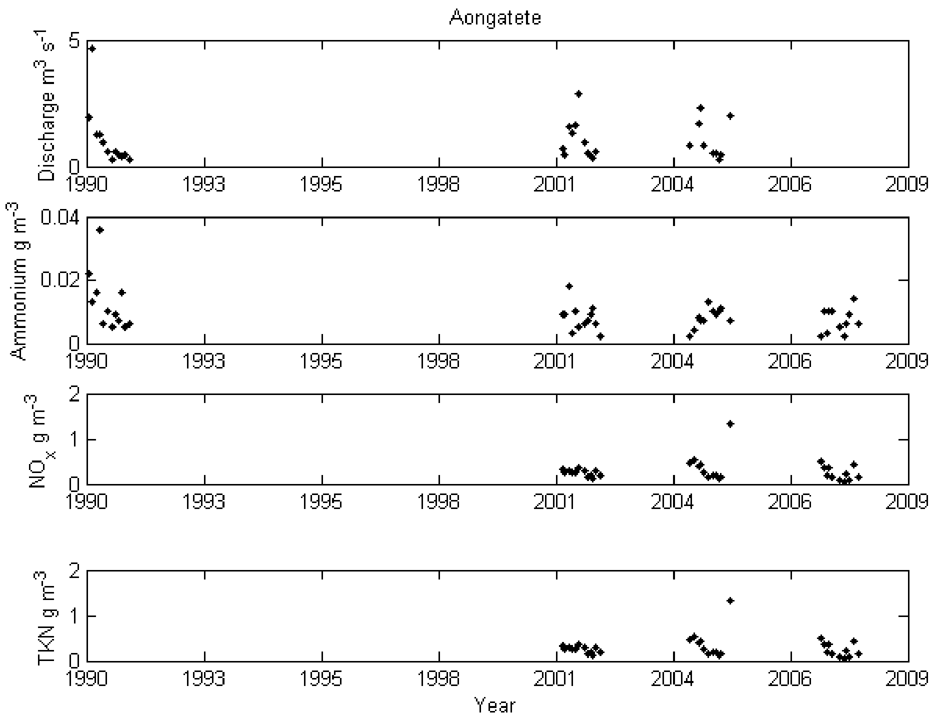
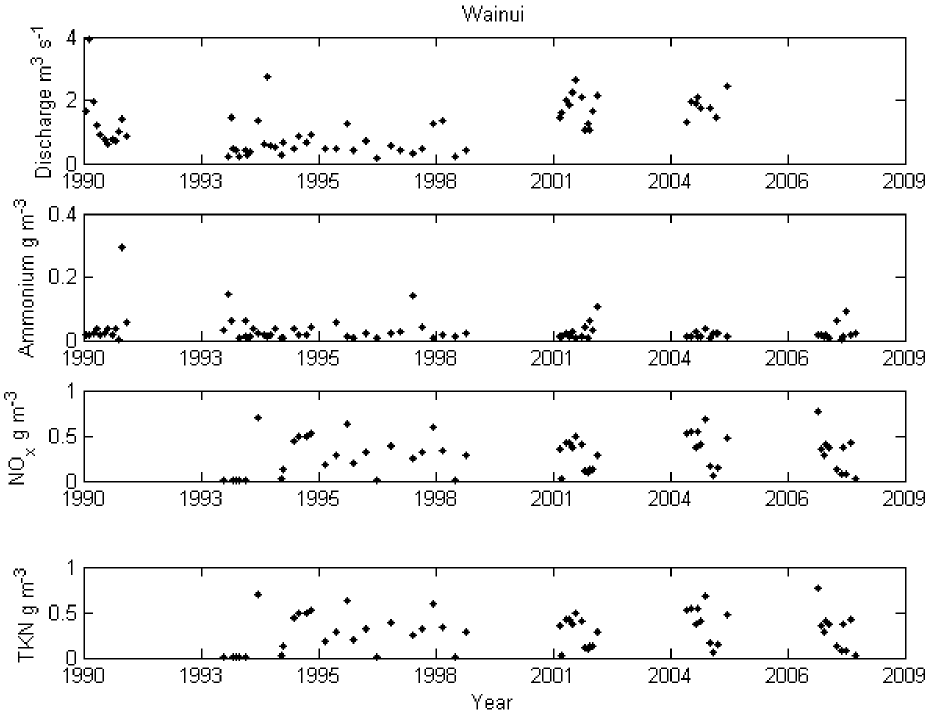


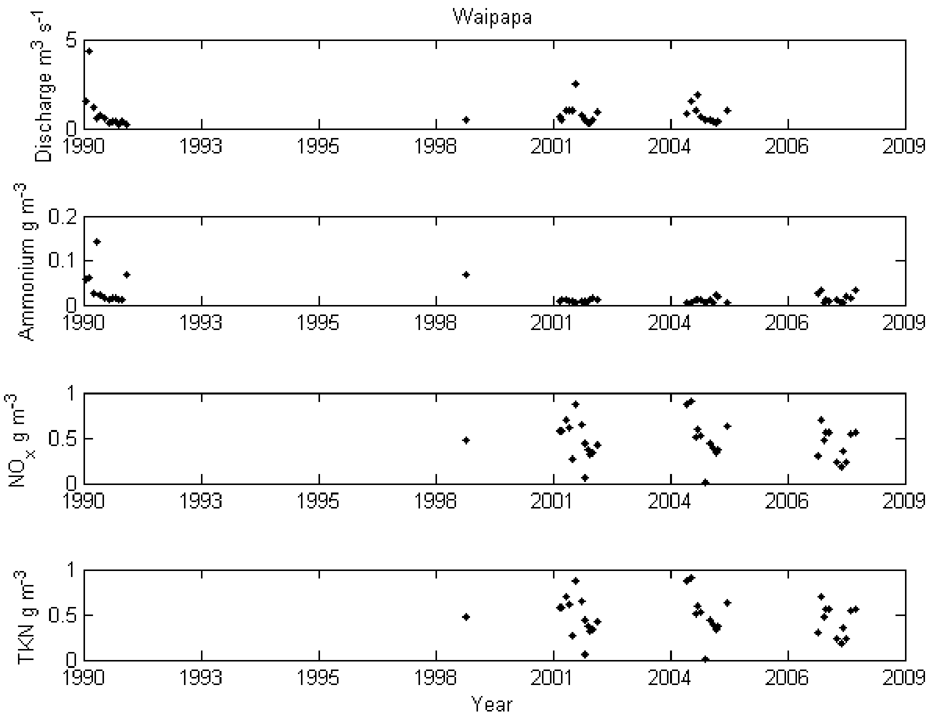

**Figure A 3: Gap filled relative humidity**

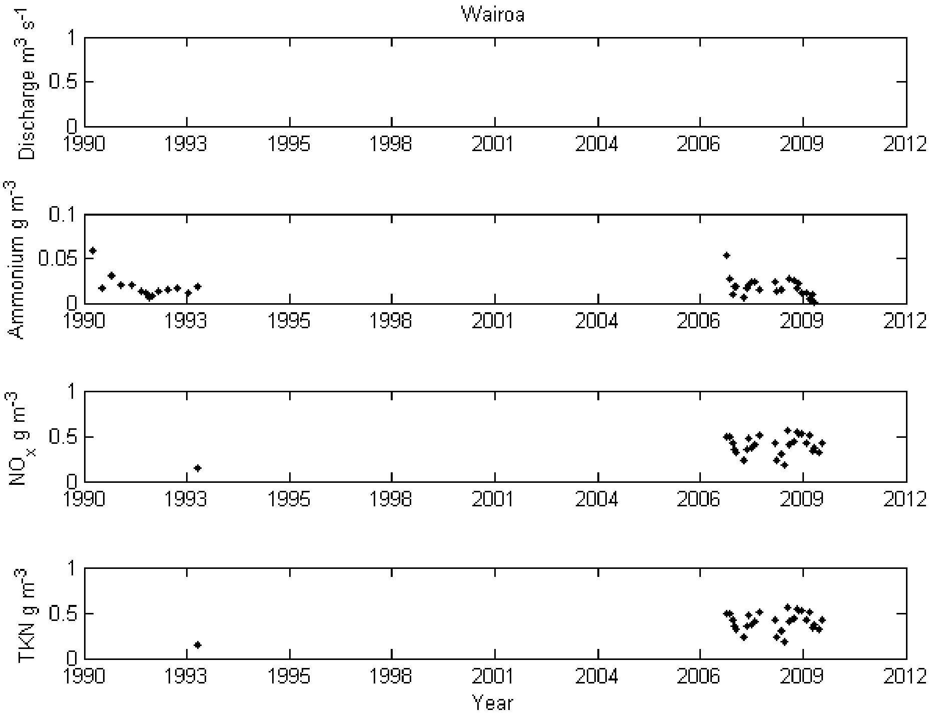
# Appendix 2

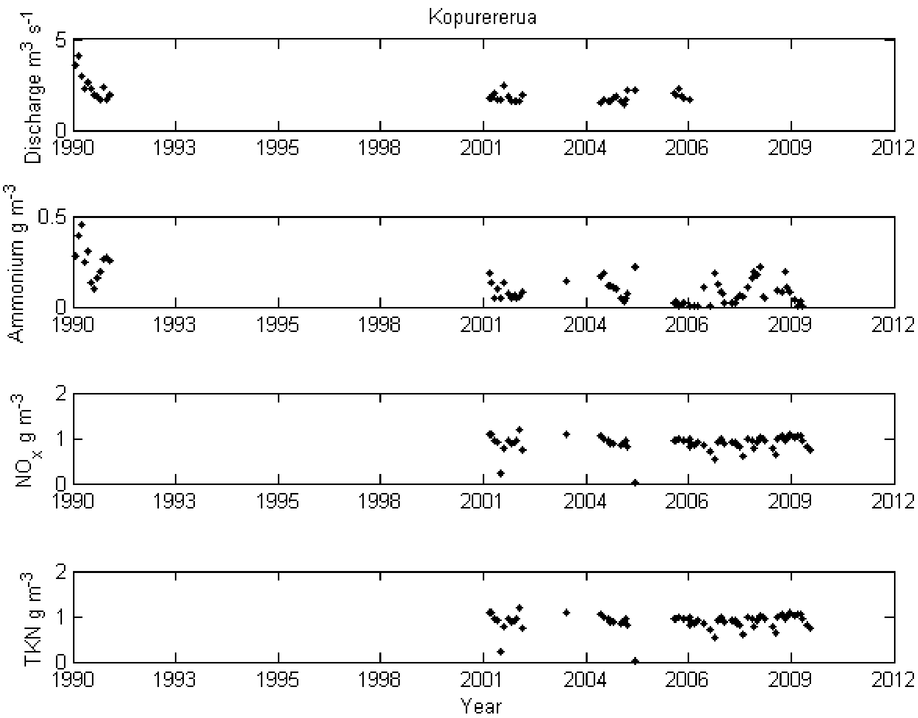
This appendix contains plots of the raw data collected by the Bay of Plenty Regional Council. The river that the data was collected from is shown in the plot titles.

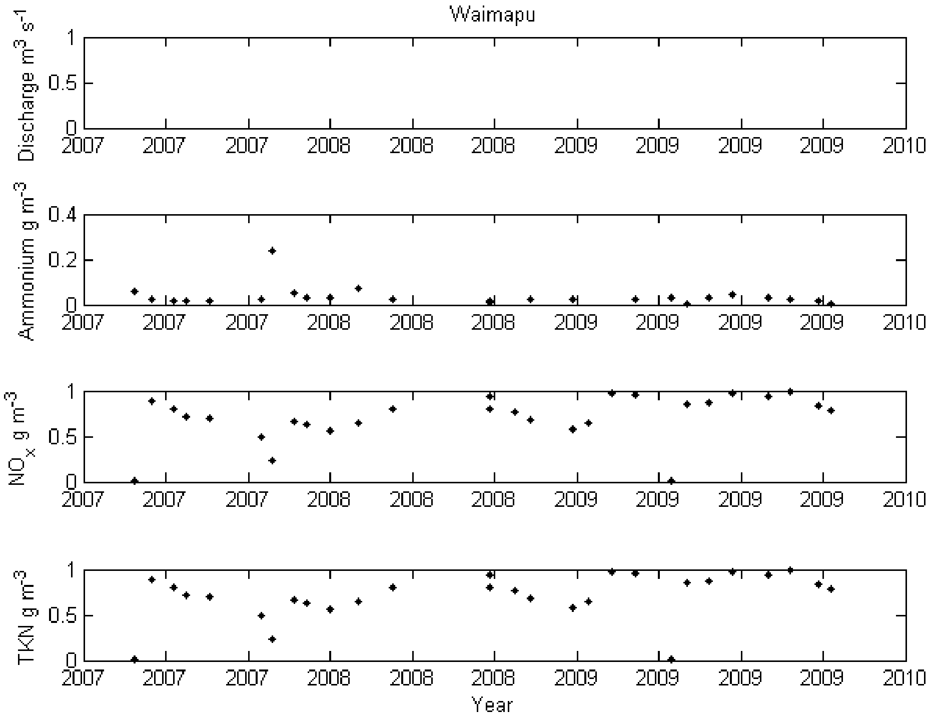


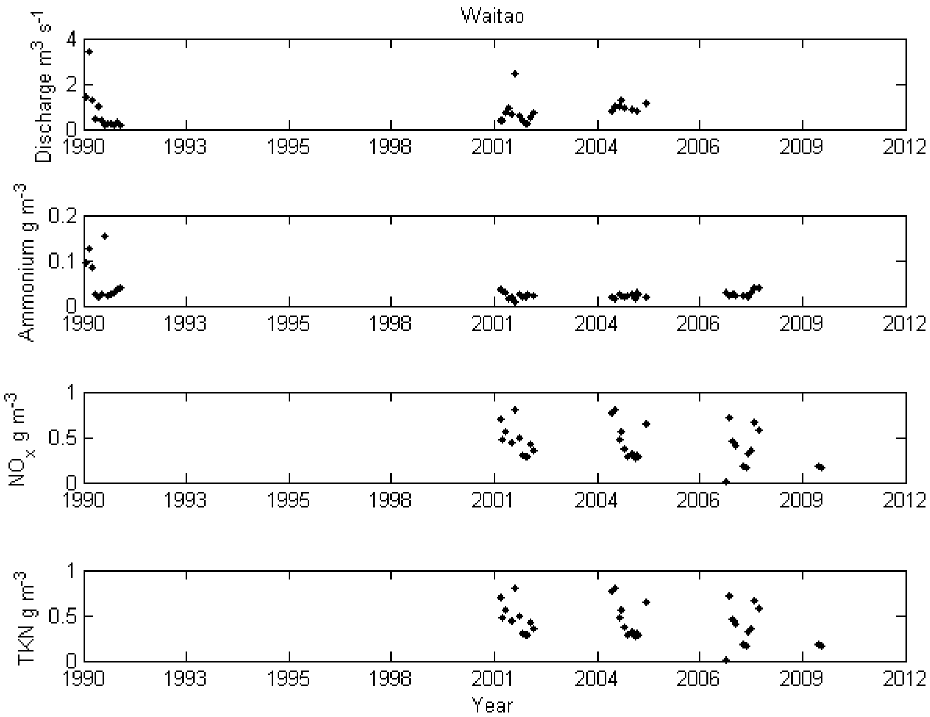

Wainui
Discharge $m^3$ $s^{-1}$
Ammonium g $m^{-3}$
$NO_x$ g $m^{-3}$
TKN g $m^{-3}$
Year

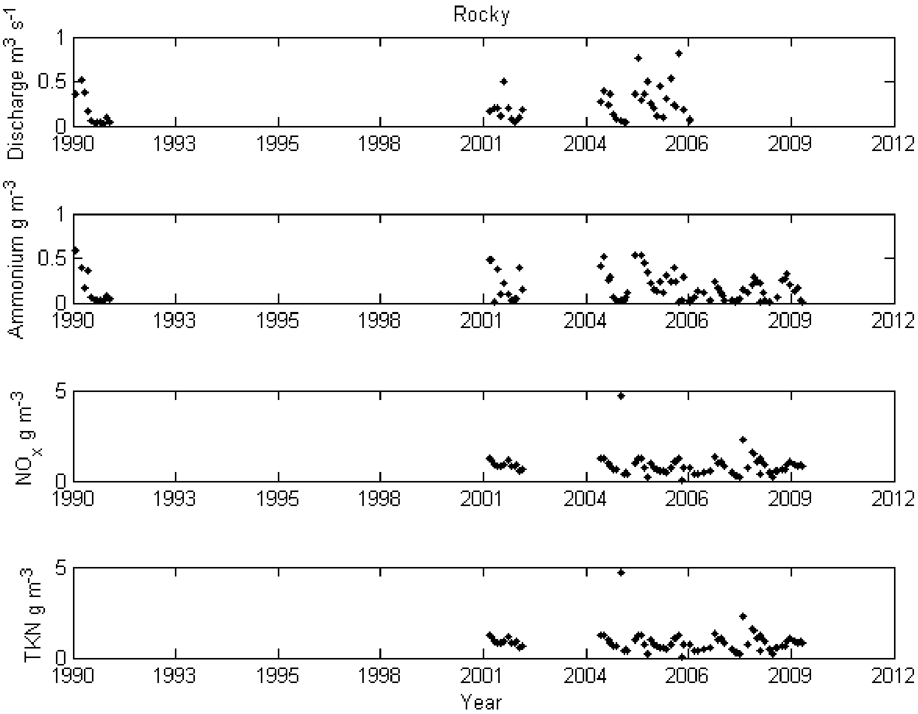

Waipapa
Discharge $m^3$ $s^{-1}$
Ammonium g $m^{-3}$
$NO_x$ g $m^{-3}$
TKN g $m^{-3}$
Year


Wairoa
Discharge m3 s-1
Ammonium g m-3
NOx g m-3
TKN g m-3
1990
1993
1995
1998
2001
2004
2006
2009
2012
Year


Kopurererua
Discharge m3 s-1
Ammonium g m-3
NOx g m-3
TKN g m-3
1990
1993
1995
1998
2001
2004
2006
2009
2012
Year


Waimapu
Discharge m3 s-1
Ammonium g m-3
NOx g m-3
TKN g m-3
Year
2007
2008
2009
2010


Waitao
Discharge m3 s-1
Ammonium g m-3
NOx g m-3
TKN g m-3
Year
1990
1993
1995
1998
2001
2004
2006
2009
2012


Rocky
Discharge m$^3$ s$^{-1}$
Ammonium g m$^{-3}$
NO$_x$ g m$^{-3}$
TKN g m$^{-3}$
1990
1993
1995
1998
2001
2004
2006
2009
2012
Year

# Appendix 3

This appendix contains recorded nutrient data that was collected during the sampling program that was carried out in conjunction with this study.

| river | date | time | Ammonia (mg/L) | Phosphate (mg/L) | NOx (mg/L) | Nitrite (mg/L) |
|---|---|---|---|---|---|---|
| Aongetete A | 22/11/2011 | 12:35 | 0.01269 | 0.003614 | 0.1934 | 0.003371 |
| Aongetete A | 24/01/2012 | 17:22 | 0.008408 | 0.004222 | 0.289 | 0.003861 |
| Aongetete A | 19/07/2012 | 11:10 | 0.002829 | 0.0008463 | 0.4101 | 0.002946 |
| Aongetete A | 27/09/2012 | 12:10 | 0.002944 | 0.001494 | 0.1857 | 0.00321 |
| Aongetete A | 12/12/2012 | 15:20 | 0.004439 | 0.001508 | 0.1269 | 0.003604 |
| Aongetete A | 8/02/2013 | 13:15 | 0.005628 | 0.002957 | 0.1051 | 0.004144 |
| Aongetete B | 22/11/2011 | 15:01 | 0.03281 | 0.006868 | 0.1023 | 0.003823 |
| Aongetete B | 24/01/2012 | 18:00 | 0.02622 | 0.007083 | 0.2172 | 0.004111 |
| Aongetete B | 19/07/2012 | 11:25 | 0.005209 | 0.00289 | 0.4902 | 0.003435 |
| Aongetete B | 27/09/2012 | 12:30 | 0.009411 | 0.004591 | 0.1997 | 0.003591 |
| Aongetete B | 12/12/2012 | 15:45 | 0.02253 | 0.003869 | 0.09818 | 0.004043 |
| Aongetete B | 8/02/2013 | 13:37 | 0.02898 | 0.005203 | 0.03726 | 0.003794 |
| Apata | 22/11/2011 | 13:15 | 0.03615 | 0.002297 | 0.6975 | 0.004281 |
| Apata | 24/01/2012 | 16:20 | 0.04108 | 0.002701 | 0.8947 | 0.004271 |
| Apata | 19/07/2012 | 10:25 | 0.01339 | 0.001312 | 0.9116 | 0.003801 |
| Apata | 27/09/2012 | 11:30 | 0.02596 | 0.002356 | 0.7527 | 0.004352 |
| Apata | 12/12/2012 | 14:00 | 0.0201 | 0.007329 | 0.2475 | 0.004845 |
| Apata | 8/02/2013 | 12:15 | 0.06842 | 0.004903 | 0.06996 | 0.003247 |
| Kopurererua | 22/11/2011 | 11:00 | 0.04868 | 0.0171 | 0.8258 | 0.008211 |
| Kopurererua | 24/01/2012 | 13:15 | 0.02034 | 0.01505 | 0.8275 | 0.004767 |
| Kopurererua | 19/07/2012 | 8:45 | 0.0491 | 0.0106 | 1.041 | 0.006296 |
| Kopurererua | 27/09/2012 | 9:52 | 0.05059 | 0.008606 | 0.6341 | 0.00793 |
| Kopurererua | 12/12/2012 | 12:29 | 0.01095 | 0.008404 | 0.7095 | 0.005394 |
| Kopurererua | 8/02/2013 | 10:35 | 0.01345 | 0.01102 | 0.7633 | 0.004764 |
| Te puna | 22/11/2011 | 12:05 | 0.01739 | 0.008692 | 0.2747 | 0.006462 |
| Waimapu | 22/11/2011 | 10:45 | 0.02484 | 0.0106 | 0.7014 | 0.004415 |
| Waimapu | 24/01/2012 | 11:09 | 0.01812 | 0.007137 | 0.7105 | 0.004275 |
| Waimapu | 19/07/2012 | 8:10 | 0.01556 | 0.007139 | 0.9409 | 0.004499 |
| Waimapu | 27/09/2012 | 8:45 | 0.01321 | 0.007536 | 0.5349 | 0.003859 |
| Waimapu | 12/12/2012 | 11:46 | 0.02301 | 0.009247 | 0.5005 | 0.004958 |
| Waimapu | 8/02/2013 | 9:50 | 0.02137 | 0.009803 | 0.6457 | 0.003987 |
| Wainui | 22/11/2011 | 13:55 | 0.04406 | 0.02062 | 0.07696 | 0.007241 |
| Wainui | 24/01/2012 | 16:56 | 0.02542 | 0.008283 | 0.2852 | 0.004858 |
| Wainui | 19/07/2012 | 10:50 | 0.002065 | 0.0009307 | 0.2604 | 0.002844 |
| Wainui | 27/09/2012 | 11:55 | 0.01497 | 0.005513 | 0.5531 | 0.003978 |
| Wainui | 12/12/2012 | 14:57 | 0.01554 | 0.002562 | 0.07673 | 0.004231 |
| Wainui | 8/02/2013 | 12:50 | 0.05838 | 0.007465 | 0.05982 | 0.004352 |
| Waipapa | 22/11/2011 | 12:30 | 0.01482 | 0.01626 | 0.4846 | 0.004031 |
| Waipapa | 24/01/2012 | 15:20 | 0.01271 | 0.01063 | 0.7644 | 0.004407 |
| Waipapa | 19/07/2012 | 10:00 | 0.005911 | 0.003685 | 0.6707 | 0.003256 |
| Waipapa | 27/09/2012 | 10:55 | 0.005934 | 0.005226 | 0.3805 | 0.003252 |
| Waipapa | 12/12/2012 | 1:45 | 0.004821 | 0.005904 | 0.1706 | 0.003515 |
| Waipapa | 8/02/2013 | 11:35 | 0.009146 | 0.0152 | 0.2484 | 0.00415 |
| Wairoa | 22/11/2011 | 11:25 | 0.01173 | 0.007535 | 0.3596 | 0.00394 |
| Wairoa | 24/01/2012 | 14:03 | 0.02352 | 0.007237 | 0.315 | 0.004611 |
| Wairoa | 19/07/2012 | 9:20 | 0.0155 | 0.005249 | 0.4709 | 0.003814 |
| Wairoa | 27/09/2012 | 10:23 | 0.003638 | 0.002163 | 0.08972 | 0.002817 |
| Wairoa | 12/12/2012 | 12:35 | 0.01412 | 0.00371 | 0.1961 | 0.003846 |
| Wairoa | 8/02/2013 | 11:00 | 0.02991 | 0.005851 | 0.3563 | 0.004518 |

# Appendix 4

This appendix contains the percent area of each land use within the catchments of the rivers that discharge into the Tauranga southern harbour.

**Aongatete River**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 115424.1 | 0.16 |
| Broadleaved Indigenous Hardwoods | 90256.2 | 0.12 |
| Built-up Area | 35200.97 | 0.05 |
| Deciduous Hardwoods | 112037.9 | 0.15 |
| Estuarine Open Water | 101573.6 | 0.14 |
| Forest Harvested | 658455.6 | 0.89 |
| Gorse and Broom | 14009.11 | 0.02 |
| Herbaceous Saline Vegetation | 1077.872 | 0.00 |
| High Producing Exotic Grassland | 22424000 | 30.33 |
| Indigenous Forest | 45393486 | 61.40 |
| Low Producing Grassland | 72234.85 | 0.10 |
| Major Shelterbelts | 62804.88 | 0.08 |
| Manuka and or Kanuka | 401761.8 | 0.54 |
| Orchard and Other Perennial Crops | 3881992 | 5.25 |
| Other Exotic Forest | 139426.4 | 0.19 |
| Pine Forest - Closed Canopy | 27522.22 | 0.04 |
| Short-rotation Cropland | 383563.9 | 0.52 |
| Transport Infrastructure | 14425.93 | 0.02 |

**Wainui River**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 18914.87168 | 0.06 |
| Broadleaved Indigenous Hardwoods | 228216.5011 | 0.75 |
| Deciduous Hardwoods | 19059.77136 | 0.06 |
| Gorse and Broom | 16752.78083 | 0.06 |
| Herbaceous Saline Vegetation | 93382.94165 | 0.31 |
| High Producing Exotic Grassland | 9554121.125 | 31.55 |
| Indigenous Forest | 18667425.91 | 61.65 |
| Low Producing Grassland | 131035.4556 | 0.43 |
| Major Shelterbelts | 18698.34666 | 0.06 |
| Mangrove | 12933.72083 | 0.04 |
| Manuka and or Kanuka | 853797.0839 | 2.82 |
| Orchard and Other Perennial Crops | 337245.3103 | 1.11 |
| Other Exotic Forest | 17001.71321 | 0.06 |
| Pine Forest - Closed Canopy | 136899.8056 | 0.45 |
| Pine Forest - Open Canopy | 139744.9394 | 0.46 |

| | | |
|---|---|---|
| Short-rotation Cropland | 34848.29541 | 0.12 |

**Waipapa River**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 112539.6 | 0.35 |
| Gorse and Broom | 86657.58 | 0.27 |
| Herbaceous Saline Vegetation | 108014.4 | 0.33 |
| High Producing Exotic Grassland | 16176049 | 50.11 |
| Indigenous Forest | 11773285 | 36.47 |
| Low Producing Grassland | 70422.02 | 0.22 |
| Manuka and or Kanuka | 85644.17 | 0.27 |
| Orchard and Other Perennial Crops | 2458590 | 7.62 |
| Other Exotic Forest | 101295 | 0.31 |
| Pine Forest - Closed Canopy | 933964.3 | 2.89 |
| Pine Forest - Open Canopy | 356744.8 | 1.11 |
| Short-rotation Cropland | 15503.84 | 0.05 |

**Wairoa River**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 937143.43 | 0.21 |
| Broadleaved Indigenous Hardwoods | 2070523.6 | 0.46 |
| Built-up Area | 768274.31 | 0.17 |
| Deciduous Hardwoods | 187916.46 | 0.04 |
| Forest Harvested | 151317.66 | 0.03 |
| Gorse and Broom | 2134077.4 | 0.47 |
| Herbaceous Saline Vegetation | 68030.438 | 0.01 |
| High Producing Exotic Grassland | 110343840 | 24.29 |
| Indigenous Forest | 258133664 | 56.83 |
| Lake and Pond | 443944.95 | 0.10 |
| Landslide | 12232.526 | 0.00 |
| Low Producing Grassland | 936395.91 | 0.21 |
| Major Shelterbelts | 575755.94 | 0.13 |
| Manuka and or Kanuka | 2630874.1 | 0.58 |
| Orchard and Other Perennial Crops | 8915180.8 | 1.96 |
| Other Exotic Forest | 2715345.3 | 0.60 |
| Pine Forest - Closed Canopy | 60810161 | 13.39 |
| Pine Forest - Open Canopy | 1420089.2 | 0.31 |
| River | 823488.69 | 0.18 |
| Transport Infrastructure | 25792.05 | 0.01 |
| Urban Parkland/ Open Space | 127464.04 | 0.03 |

**Kopurererua Stream**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 21692.71 | 0.03 |
| Broadleaved Indigenous Hardwoods | 763155.7 | 1.04 |
| Built-up Area | 3552227 | 4.85 |
| Deciduous Hardwoods | 66609.18 | 0.09 |
| Estuarine Open Water | 1002.214 | 0.00 |
| Gorse and Broom | 370787.8 | 0.51 |
| Herbaceous Saline Vegetation | 13959.73 | 0.02 |
| High Producing Exotic Grassland | 33550658 | 45.79 |
| Indigenous Forest | 23900644 | 32.62 |
| Low Producing Grassland | 157220 | 0.21 |
| Major Shelterbelts | 80622.3 | 0.11 |
| Mangrove | 885.94 | 0.00 |
| Manuka and or Kanuka | 1086229 | 1.48 |
| Orchard and Other Perennial Crops | 4577574 | 6.25 |
| Other Exotic Forest | 721749.1 | 0.99 |
| Pine Forest - Closed Canopy | 3193926 | 4.36 |
| Pine Forest - Open Canopy | 174335.2 | 0.24 |
| Short-rotation Cropland | 118266 | 0.16 |
| Surface Mine | 95374.46 | 0.13 |
| Transport Infrastructure | 8314.08 | 0.01 |
| Urban Parkland/ Open Space | 812473.2 | 1.11 |

**Waimapu River**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 175679.1 | 0.16 |
| Broadleaved Indigenous Hardwoods | 1012255 | 0.94 |
| Built-up Area | 2475459 | 2.31 |
| Deciduous Hardwoods | 146923 | 0.14 |
| Estuarine Open Water | 75704.6 | 0.07 |
| Gorse and Broom | 1254767 | 1.17 |
| Herbaceous Saline Vegetation | 179307.8 | 0.17 |
| High Producing Exotic Grassland | 50620449 | 47.22 |
| Indigenous Forest | 35317854 | 32.94 |
| Lake and Pond | 10886.76 | 0.01 |
| Low Producing Grassland | 205663.3 | 0.19 |
| Major Shelterbelts | 105253.7 | 0.10 |
| Manuka and or Kanuka | 1557127 | 1.45 |
| Orchard and Other Perennial Crops | 6019258 | 5.61 |
| Other Exotic Forest | 620050.2 | 0.58 |
| Pine Forest - Closed Canopy | 4956860 | 4.62 |
| Pine Forest - Open Canopy | 1616774 | 1.51 |
| Short-rotation Cropland | 20642.92 | 0.02 |

| | | |
|---|---|---|
| Surface Mine | 157799 | 0.15 |
| Transport Infrastructure | 25012.34 | 0.02 |
| Urban Parkland/ Open Space | 479148.3 | 0.45 |
| Vineyard | 177710.3 | 0.17 |

**Waitao River**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 753795.3 | 2.28 |
| Broadleaved Indigenous Hardwoods | 213488.9 | 0.65 |
| Built-up Area | 10700.7 | 0.03 |
| Gorse and Broom | 203491.3 | 0.62 |
| Herbaceous Saline Vegetation | 35171.05 | 0.11 |
| High Producing Exotic Grassland | 12103129 | 36.67 |
| Indigenous Forest | 12727653 | 38.57 |
| Low Producing Grassland | 296404 | 0.90 |
| Major Shelterbelts | 48154.49 | 0.15 |
| Manuka and or Kanuka | 1029036 | 3.12 |
| Orchard and Other Perennial Crops | 381807.9 | 1.16 |
| Other Exotic Forest | 226562.6 | 0.69 |
| Pine Forest - Closed Canopy | 3767323 | 11.42 |
| Pine Forest - Open Canopy | 766827.1 | 2.32 |
| Surface Mine | 438903.8 | 1.33 |

**Rocky Steam**

| LCDB1 Name | Area ($m^2$) | % area |
|---|---|---|
| Afforestation (imaged, post LCDB 1) | 559991.8 | 1.61 |
| Broadleaved Indigenous Hardwoods | 316150.3 | 0.91 |
| Built-up Area | 4818070 | 13.83 |
| Coastal Sand and Gravel | 15334.69 | 0.04 |
| Deciduous Hardwoods | 10492.03 | 0.03 |
| Gorse and Broom | 495201.4 | 1.42 |
| Herbaceous Saline Vegetation | 23150.12 | 0.07 |
| High Producing Exotic Grassland | 19173176 | 55.03 |
| Indigenous Forest | 891005.9 | 2.56 |
| Lake and Pond | 88898.63 | 0.26 |
| Low Producing Grassland | 712933.1 | 2.05 |
| Major Shelterbelts | 71816.71 | 0.21 |
| Manuka and or Kanuka | 378999.7 | 1.09 |
| Mixed Exotic Shrubland | 442516.2 | 1.27 |
| Orchard and Other Perennial Crops | 1142619 | 3.28 |
| Other Exotic Forest | 13837.09 | 0.04 |
| Pine Forest - Closed Canopy | 4060434 | 11.65 |
| Pine Forest - Open Canopy | 234042.6 | 0.67 |
| River and Lakeshore Gravel and Rock | 899.2221 | 0.00 |

| | | |
|---|---|---|
| Short-rotation Cropland | 957847.1 | 2.75 |
| Transport Infrastructure | 14847.25 | 0.04 |
| Urban Parkland/ Open Space | 418994.7 | 1.20 |