State of the Environment Monitoring
Nitrates in Shallow Groundwater
2002 to 2012
Technical Report 2014–48

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Executive summary

Excess nutrient inputs as a result of various land use activities pose a pollution threat to freshwater resources within the Taranaki region and across New Zealand. Nitrate contamination of groundwater has been linked primarily to agricultural land use activities, particularly the expansion and intensification of the dairy industry.

The consumption of water with high nitrate concentrations can have implications for human and animal health. The Ministry of Health (MoH) sets a Maximum Acceptable Value (MAV) for nitrate concentration in drinking water of 11.3 mg/L (as NO3-N). The MAV value for nitrates is set out in the Drinking Water Standards for New Zealand 2005 (revised 2008). (It should be noted that the MoH notes that water containing up to double this level is still safe even for infants).[1]

Groundwater with high nitrate concentrations can also contribute to elevated nutrient loads in surface water systems, which can result in excessive algal growth and eutrophication. Nitrate can also be toxic to in-stream fauna.

The Taranaki Regional Council (the Council) monitors the concentration of nitrate in groundwater as part of its overall State of the Environment Monitoring Programme. Typically, sampling surveys are carried out on a five yearly basis. Each five yearly sampling survey consists of four sampling rounds (one round per season) being carried out over a 12 monthly period.

The following report details the results of the most recent nitrates survey undertaken by the Council, which was carried out during the 2011-12 monitoring period. A total of 74 sites were sampled during the survey, intended to provide a representative distribution of sampling sites across the region's predominant shallow aquifers.

The results of the 2011-12 nitrates survey can be summarised as follows:

- In total 74 sites were sampled and 272 individual samples obtained.
- Nitrate concentrations across all samples ranged from 0.005 mg/L to 26.1 mg/L NNN (at site GND1112).
- The mean nitrate concentration of all samples was 3.45 mg/L NNN; the median was 2.51 mg/L NNN.
- The MAV for nitrate in drinking water (11.3 mg/L) was exceeded in 10 samples collected at various times from a total of six separate sites. This represents 4% of all samples. 8% of the 74 wells sampled had one or more samples exceeding the MAV level.

The results of the 2011-12 nitrates survey compare favourably with the results of recent groundwater surveys carried out in other areas of New Zealand with intensive dairy farming land use, including Waikato (WRC 2012) and Canterbury (Environment Canterbury 2013).

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[1] *Annual Report on Drinking-water Quality 2012-2013*, Ministry of Health 2014, pg 24

Of the 74 sites sampled during the 2011-12 survey, 56 of these sites had also been sampled during the during the previous 2002-03 and 2006-07 surveys. The data from these 56 sites was used to assess trends in nitrate concentration over the 10 year period from 2002 to 2012. The results of the trend analysis indicate:

- Measured nitrate concentrations at 41 of the 56 sites (or 73%) were stable during the 2002 to 2012 period;
- Applying statistical analysis, 7 sites (or 13%) displayed an increasing trend (deterioration) in nitrate concentrations.
- 8 sites (or 14%) displayed declining trend (improvement) in nitrate concentrations.
- The number of sites where there was an exceedance of the MAV has reduced in each survey;
- The number of individual samples exceeding the MAV has reduced in each survey;
- The number of samples exceeding the MAV, as a percentage of the number of all samples collected in each survey, is showing an overall reduction across the three surveys; and
- The majority of sites had their highest NNN concentration measured in the first survey, and there is a clear pattern emerging of fewer sites having their peak NNN concentrations recorded during more recent surveys.

Overall, nitrate concentrations in Taranaki groundwater have remained relatively stable over the period 2002 to 2012. The stability in groundwater nitrate concentrations is a positive result for the region given the observed increases in farm productivity over the same period. In addition, there are also consistent indications of improvements (reductions) in peak groundwater nitrate concentrations over the same period (as demonstrated by the results outlined above).

Acknowledgement: Dr Roland Stenger of Lincoln Agritech has provided guidance on and review of this report during its preparation. His contributions are acknowledged and appreciated. However, the contents of the report as presented remain the responsibility of the Council.

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1. Introduction

1.1 What's the issue?

Excess nutrient inputs as a result of various land use activities pose a pollution threat to freshwater resources within the Taranaki region and across New Zealand. Nitrate contamination of groundwater has been linked primarily to agricultural land use activities, particularly the expansion and intensification of the dairy industry. In order to maximise the profits gained from dairying operations, farmers look to improve farm productivity. Increasing farm productivity generally requires additional inputs, such as fertiliser, supplementary feeds and water, which can result in increased nutrient losses (PCE, 2013). Once present in groundwater systems, nitrate is highly mobile, and elevated concentrations can often be found long distances down gradient of a contamination source.

The consumption of water with high nitrate concentrations can have implications for both human and animal health. The Drinking Water Standards for New Zealand (Ministry of Health, 2008) set a Maximum Acceptable Value (MAV) for nitrate concentration in drinking water of 11.3 mg/L (as NO_3-N).While extremely rare, the consumption of nitrate laden water by bottle fed infants has the potential to contribute to a blood disorder known as methemoglobinemia or "blue baby syndrome." It should be noted that the Ministry of Health advises that, based on World Health Organisation information and findings, drinking water with up to double this concentration of nitrates is still safe even for infants. '*The World Health Organization's Guidelines for Drinking-water Quality (2011) notes that waters with nitrate concentrations up to twice the maximum acceptable value are safe for infants, provided the water is microbiologically safe.* '[2]

Stock health can also be at risk when animals consume water nitrate concentrations in excess of 40 mg/L NO_3-N, in combination with high nitrate feeds.

The contamination of groundwater with nitrate also has the potential to result in the degradation of surface water systems that receive groundwater baseflow. The nutrient enrichment of surface water systems can lead to excessive algal growth and eutrophication under certain combinations of environmental conditions.

1.2 Structure of this report

The following report contains 7 sections as follows:

- Section 1 is an introductory and background section. It provides general information about nitrates in groundwater.
- Section 2 provides specific details of the 'Nitrates in Shallow Groundwater Monitoring Programme.'
- Section 3 provides background information on the physical environment of the Taranaki region.
- Section 4 provides details of agricultural land use and land use trends across the Taranaki region.

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[2] '*Annual Report on Drinking-water Quality 2012-2013*, Ministry of Health 2014, pg 24

- Section 5 presents the groundwater nitrate data collected by the Council.
- Section 6 presents provides and interpretation of the data collected by the Council and draws conclusions based on the results.
- Section 7 concludes the report with recommendations to be implemented in the next monitoring period.

A glossary of common abbreviations and scientific terms, and a bibliography, are included at the end of the report.

2. Nitrates in Shallow Groundwater Monitoring Programme

2.1 Objectives

The Nitrates in Shallow Groundwater Monitoring Programme (the nitrates programme) aims to:

- Monitor nitrate concentrations in shallow groundwater at a selected number of sites across the region;
- Assess groundwater nitrate concentrations for compliance with relevant guidelines and standards;
- Monitor temporal changes and trends in nitrate concentrations at each monitoring site;
- Monitor spatial trends in nitrate concentrations across the region;
- Identify natural or human induced spatial and temporal trends; and
- Assess effectiveness of groundwater management objectives and policies for the region.

2.2 Statutory framework

The Resource Management Act 1991 (RMA) requires the Council to monitor and report on the overall state of the environment within the Taranaki region. To meet this requirement, the Council undertakes a comprehensive programme of monitoring across all areas of the region's natural environment. The nitrates programme is part of Council's overall State of the Environment Monitoring (SEM) programme.

Several policies developed and enforced by the Council are aimed at reducing the effects of nutrient inputs on groundwater and protecting the quality of the regions groundwater resources. Key policy documents include the Regional Policy Statement for Taranaki (RPS) and the Regional Freshwater Plan for Taranaki (RFWP).
The RPS promotes the sustainable management of groundwater so that adverse effects on groundwater quality from the discharge of contaminants can be avoided, remedied or mitigated. The RPS states that the Council will:

"recognise local nitrate contamination of shallow groundwater aquifers as an inevitable product of intensive agricultural production and promote land management practices, including those related to the discharge of contaminants to land and the application of nitrogen based fertilisers to land, which have the effect of reducing levels of this contamination."

Policy 6.3.1 of the RFWP outlines management practices aimed at maintaining and enhancing water quality by reducing diffuse source contamination. With respect to nitrates in groundwater, Policy 6.3.1 encourages and promotes land use practices which avoid, remedy or mitigate adverse effects on fresh water quality. In addition, Appendix VIIA of the RFWP contains information on good management practices for the discharge of farm effluent to land and provides general guidance on the best practicable option for preventing or minimising adverse effects on the environment from the discharge of effluent to land.

Overriding regional policy in any case, section 15(1)(b) of the RMA states that:

"no person may discharge any contaminant onto or into land in circumstances which may result in that contaminant (or any other contaminant emanating as a result of natural processes from that contaminant) entering water, unless the discharge is expressly allowed by a national environmental standard or other regulations, a rule in a regional plan as well as a rule in a proposed regional plan for the same region (if there is one), or a resource consent."

The Council has taken a number of prosecutions under the RMA, where it believed an effluent discharge may have resulted in contaminants entering groundwater.

The results and assessment of the data gathered as part of the nitrates programme allow the Council to determine how well it is meeting the objectives and statutory requirements set out in the RPS, RFWP and the RMA.

2.3 Programme overview

The nitrates programme is the primary SEM programme for the monitoring of nitrate concentrations in shallow groundwater. Typically, sampling surveys are carried out on a five yearly basis. Each five yearly sampling survey consists of four sampling rounds (one round per season) being carried out over a 12 month period.

The nitrate concentrations measured at each site as part of the nitrates programme are assessed against the MAV limit for nitrate as set out in the DWSNZ.

The following report details the results of the most recent nitrates survey undertaken by the Council during the 2011-12 monitoring period and is the third SEM nitrates report produced by the Council. The report compares the results of 2011-12 survey with the results of previous surveys carried out during the 2002-03 and 2006-07 monitoring periods. The last nitrates programme report was published by the Council in 2009.

2.4 Monitoring sites

The number of sites sampled during groundwater nitrates surveys has varied over the course of the programme. Sampled sites have typically included those sampled specifically as part of the nitrates surveys and additional sites where groundwater samples have been obtained and analysed for nitrate concentrations as part of consent compliance monitoring programmes.

As part of the 2011-12 survey, a total of 74 sites were sampled. Of the 74 sites sampled, 56 of these sites had also been sampled during the 2002-03 and 2006-07 surveys.

The sites sampled during the 2011-12 survey were geographically distributed across the region (Figure 1). Sampling sites selected for inclusion in the programme included a range of wells, bores and springs, intended to provide an all-encompassing distribution of sampling sites across the region's predominant shallow aquifers.

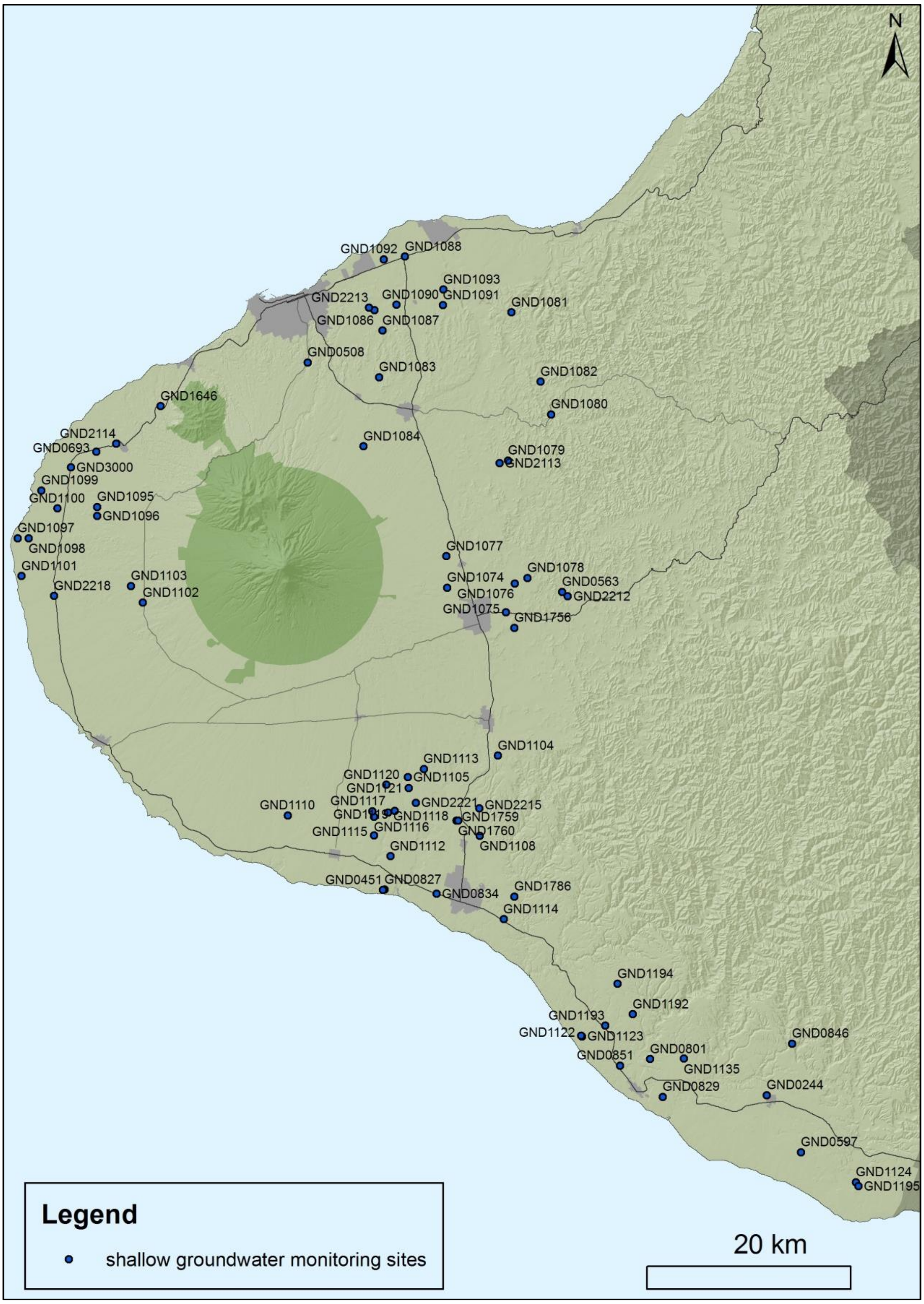

Figure 1 Location of sampling sites sampled during the 2011-12 survey

The nitrates programme is designed to focus on assessing the nitrate concentration in shallow groundwater, as it is the most susceptible to contamination from land use activities. As such, approximately 64% of sites sampled during the 2011-2012 survey were shallower than 10 m in depth. The water level depth across all sites sampled ranged from 0 m to 52.4 m, with a mean depth of 3.5 m (all measurements below ground level). In some instances, the overall depth of a sampling site and water level could not be confirmed as access to the actual bore or well was not possible. In addition, spring discharges sampled as part of the survey have not been assigned a depth measurement. The depth distribution of the sites sampled in the 2011-12 survey is illustrated in Figure 2.

The specific details of each monitoring site included in the 2011-12 survey are included in Appendix I.

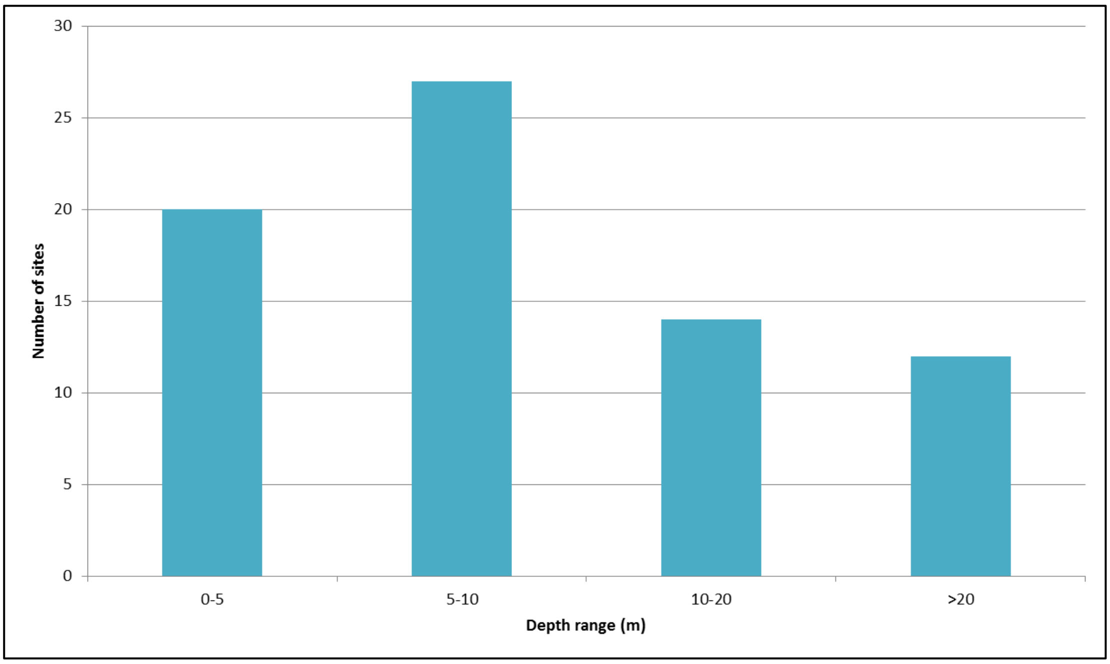

Figure 2 Depth of sites selected for inclusion in the 2011-12 survey (m below ground level)

2.5 Sample collection

Groundwater sampling was carried out by the Council in accordance with the procedures set out in the National Protocol for State of the Environment Groundwater Sampling in New Zealand (2006), as outlined in Appendix II.

Wells and/or bores in regular use were not purged prior to sampling as regular usage ensures that 'fresh' groundwater is being continuously drawn to the well or bore from the surrounding aquifer. In the event that the well or bore was not in regular use, purging was carried out prior to sampling to ensure the sample obtained was representative of the surrounding aquifer.

Where possible, groundwater samples were obtained directly from the well or bore using a bailer. If access to the well or bore itself was not possible, samples were obtained from a sample point at the surface. Samples from springs were obtained directly from the discharge point.

2.6 Sample analysis

Groundwater samples collected were analysed in the Council's IANZ accredited laboratory. The range of analyses carried out by the laboratory, and the respective limit of detection (LOD), are outlined below in Table 1.

Table 1 Details of sample analytes and LOD

Analyte	Abbreviation	LOD (mg/L)
Nitrate	NO_3-N	0.001
Nitrite	NO_2-N	0.001
Nitrite/nitrate nitrogen	NNN	0.01
Faecal coliforms	N/A	N/A
E.coli	N/A	N/A

2.7 Data interpretation

The nitrate results being referred to in this report are nitrate-nitrite nitrogen (NNN) concentrations. Collectively, nitrate (NO_3) and nitrite (NO_2) are also referred to as total oxidised nitrogen. Typically, the nitrite contribution to the NNN value is so low it represents an insignificant proportion of the total oxidised nitrogen species in Taranaki groundwater. Where available, NNN concentrations are used in the analysis of data collected in the nitrates programme. Where NNN analysis has not been carried out, NO_3-N concentrations have been used as a substitute for NNN, or NNN has been calculated by adding measured concentrations of NO_3-N and NO_2-N. Where measured concentrations of NNN, NO_3-N or NO_2-N were below the laboratory's limit of detection (LOD), a value of half the LOD is used in the analysis.

Summary statistics, including the maximum, minimum, mean and median are used to describe nitrate concentrations at each site sampled during the 2011-12 survey. The concentrations of nitrates observed at each site are also compared with the MAV value for nitrate. Box plots are used to illustrate the statistical summaries of results from each sample site.

Data collected from the 56 sites that were sampled during each of the 2011-12, 2006-07 and 2002-03 nitrate surveys has been used to assess whether there are any statistically significant improvements or deterioration in nitrate concentrations at each site.

In order to assess trends, linear trendlines were fitted to time-series data of nitrate concentrations at each site. The co-efficient of determination (R^2) for each trendline was calculated to determine how well the fitted trendline describes the data. R^2 values range from 0 to 1, the higher the R^2 value, the better the fit between the data plotted in the time series and the trendline, and the more likely there is a statistically significant trend in the data. For the purposes of the trend analysis in this report, R^2 values above 0.4 were deemed as significant. Where an increasing or decreasing trend in nitrate concentrations at a particular site is observed, the absolute value of the trend (NNN in mg/L/yr) was also calculated.

2.8 Programme audit and review

During the course of the period being reported, the Council engaged Pattle Delamore Partners Limited (PDP) to carry out an audit of the Council's groundwater SEM programmes. PDP issued a report (PDP audit report) of their audit findings in October 2011. The report concluded by stating that "*the (groundwater SEM) programmes are generally considered to be robust and effective for state of the environment monitoring*." The PDP audit report did however outline a number of areas where they believed the nitrates programme could benefit from changes. The recommended changes can be summarised as follows:

- Common objectives should be developed across SEM programmes and standardised where possible.
- Monitoring for nitrates should be carried out quarterly each year.
- New monitoring sites should be established in higher risk areas, developing robust spatial coverage.
- Data analysis should match the level of data available (i.e. detailed trend analysis on small data sets should be avoided).
- Data interpretation and analysis should be peer reviewed.
- A consistent reporting format should be developed between SEM programmes.

In 2013, Dr Roland Stenger of Lincoln Agritech provided additional commentary and guidance to the Council on the design and implementation of the regional groundwater programme in future.

The recommendations regarding reporting, data analysis and interpretation, and peer review have been implemented in compiling this report. A revised sampling regime will be implemented and will commence during the 2013-2014 monitoring period.

3. The Taranaki region

3.1 Climate

The Taranaki climate is dictated by its westerly position, its mid-latitude location and its topography. The Taranaki climate is generally sunny and windy, with moderate temperatures and regular rainfall throughout the year. Average annual rainfall volumes across the region range from less than 1,000 mm along some southern coastal margins to in excess of 7,000 mm on the upper slopes of Mount Taranaki. Rainfall volumes also increase with elevation in the Taranaki hill country (Figure 3). The high rainfall volumes across Taranaki result in high rainfall surpluses across Taranaki (rainfall – potential evapotranspiration), particularly at higher elevation.

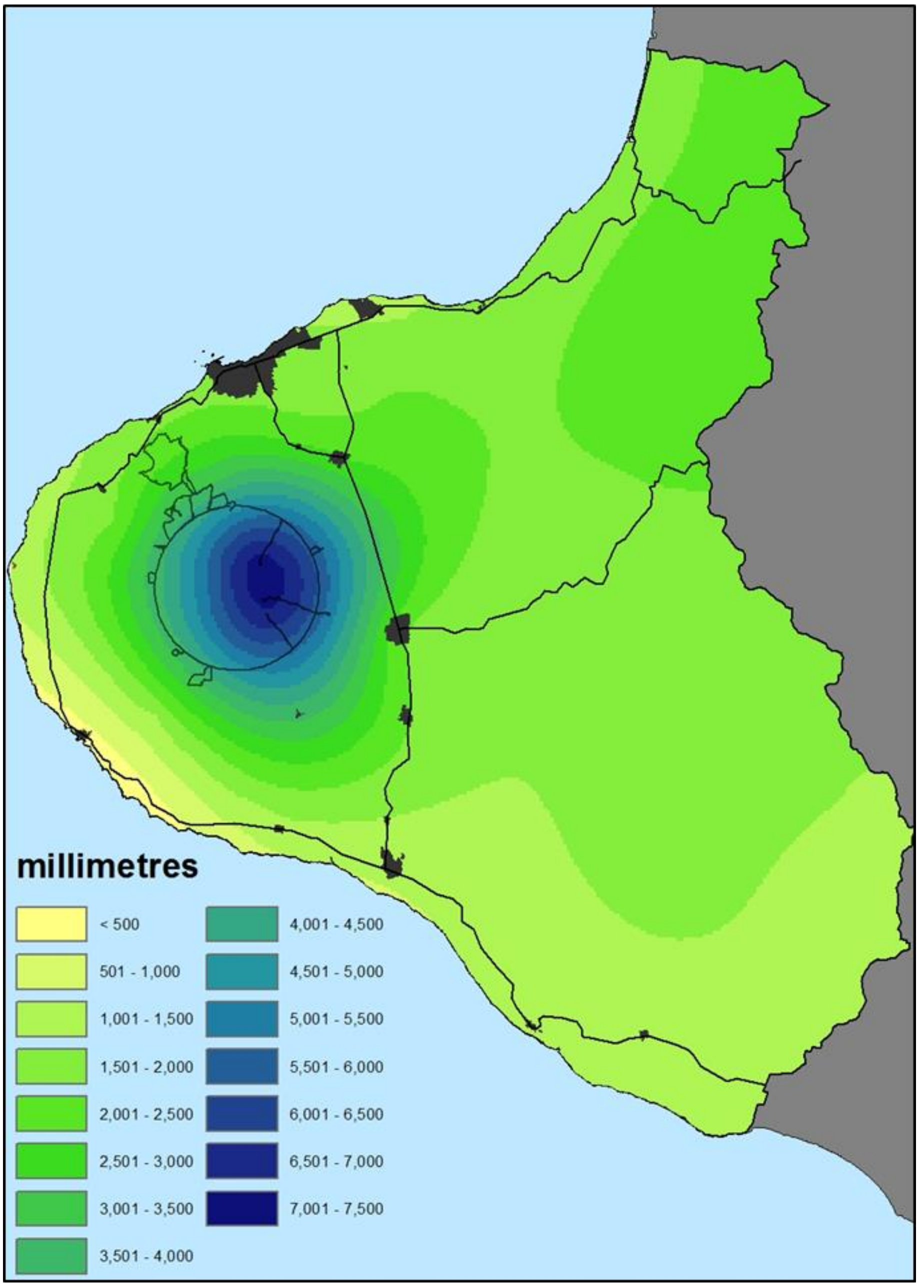

Figure 3 Average annual rainfall volumes for Taranaki 2008 to 2013 (TRC)

3.2 Geology

The dominant geological features within the Taranaki region are the andesitic cone of Mount Taranaki (2,518 m) and the surrounding volcanic ring plain. Other features include the elevated area of dissected hill country to the east (eastern hill country) and the uplifted Marine Terrace formations along the regions coastal boundaries.

The north-south trending Taranaki Boundary Fault Zone marks the boundary between the Taranaki basin to the west and the up-thrown Tertiary sediments of the eastern hill country. Within the Taranaki basin, the down-thrown Tertiary formations are of a wide extent. The Tertiary formations are unconformably overlain by Quaternary volcanic deposits from Mount Taranaki and earlier volcanic centres, forming the extensive ringplain.

Figure 4 illustrates the spatial variation in top-rock geology across the Taranaki Region.

3.3 Soils

Allophanic soils predominate across the Taranaki region area as a result of historical volcanic activity and depositional events. As each volcanic cone was built up by successive eruptions, natural erosion and lahar flows stripped away much of the volcanic debris and redistributed it as an apron, known as a ringplain. In addition, significant volumes of ash and tephra were deposited on the ringplain area during these successive volcanic events.

The drainage capacity of the soils within the ringplain area is variable due to the variations in soil depositional sequence and structure. In different areas of the ringplain the effects of erosional deposition and ash fall can vary. Laharic deposition is more prevalent on the western side of the ringplain, resulting in the presence of stones and boulders. These deposits are often cemented resulting in impeded drainage. To the east and north of the ringplain ash fall deposits are much deeper and are typically free draining.

Some of the poorly drained soils in the western area of the ringplain also suffer impeded drainage due to the presence of hard iron oxide layers in the subsoil. The iron oxide layers are created by the lateral seepage of iron dissolved from andesitic rocks on the slopes of Mount Taranaki.

Soils in the eastern hill country have been derived from the weathering of underlying parent material which includes mudstones, siltstones and sandstones. Some areas are overlain by a thin covering of volcanic tephra, however much of the volcanic deposits have eroded away, particularly on steeper slopes.

The soils of the Marine Terraces to the north and south of the region are the most versatile and productive in Taranaki. The distance of these areas from the volcanic ringplain mean they did not receive laharic flows during erosional events.

Figure 5 illustrates the distribution of the major soil types within the Taranaki region.

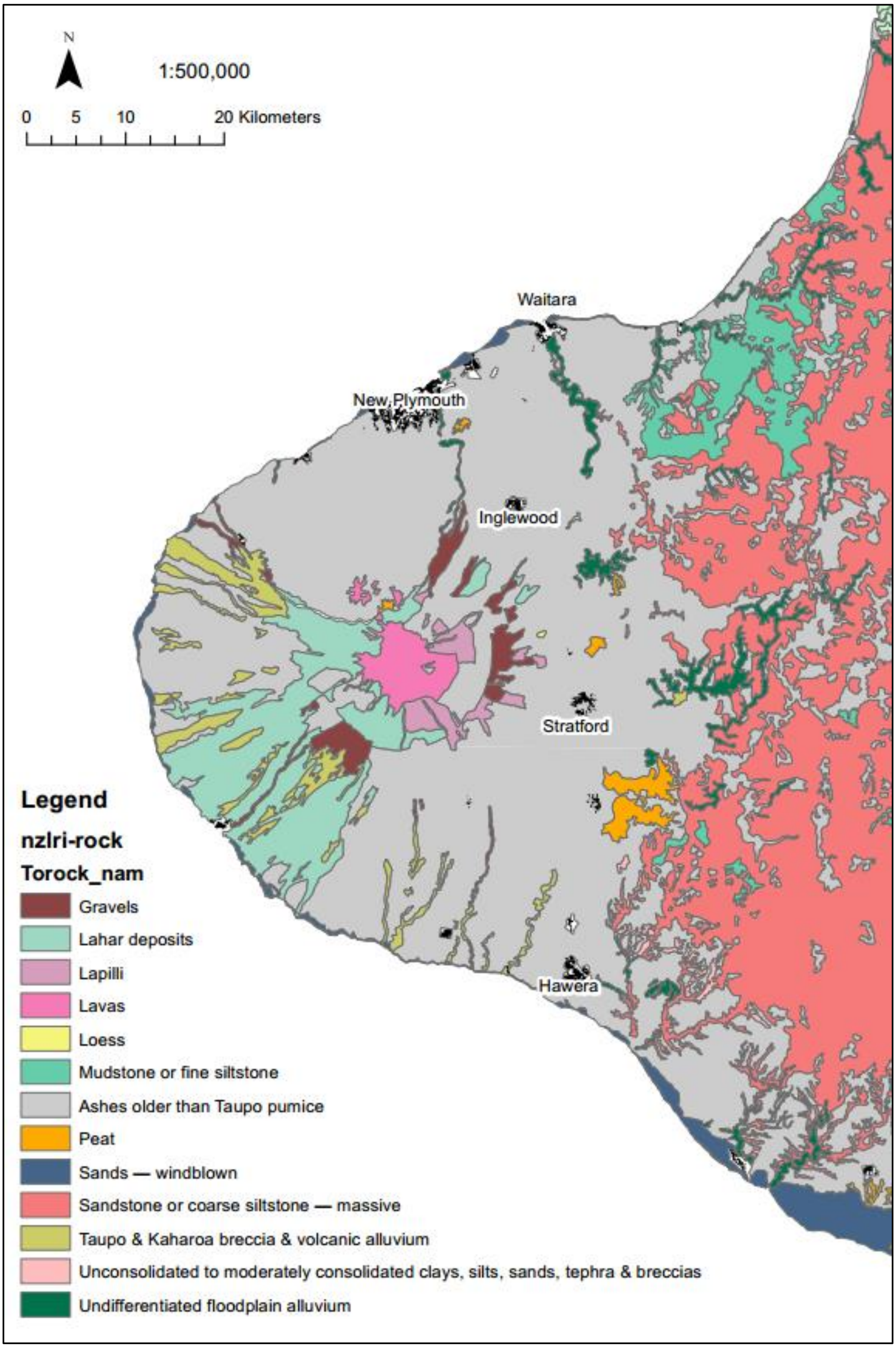

Figure 4 Top-rock geology of the Taranaki region (Newsome et al. 2008)

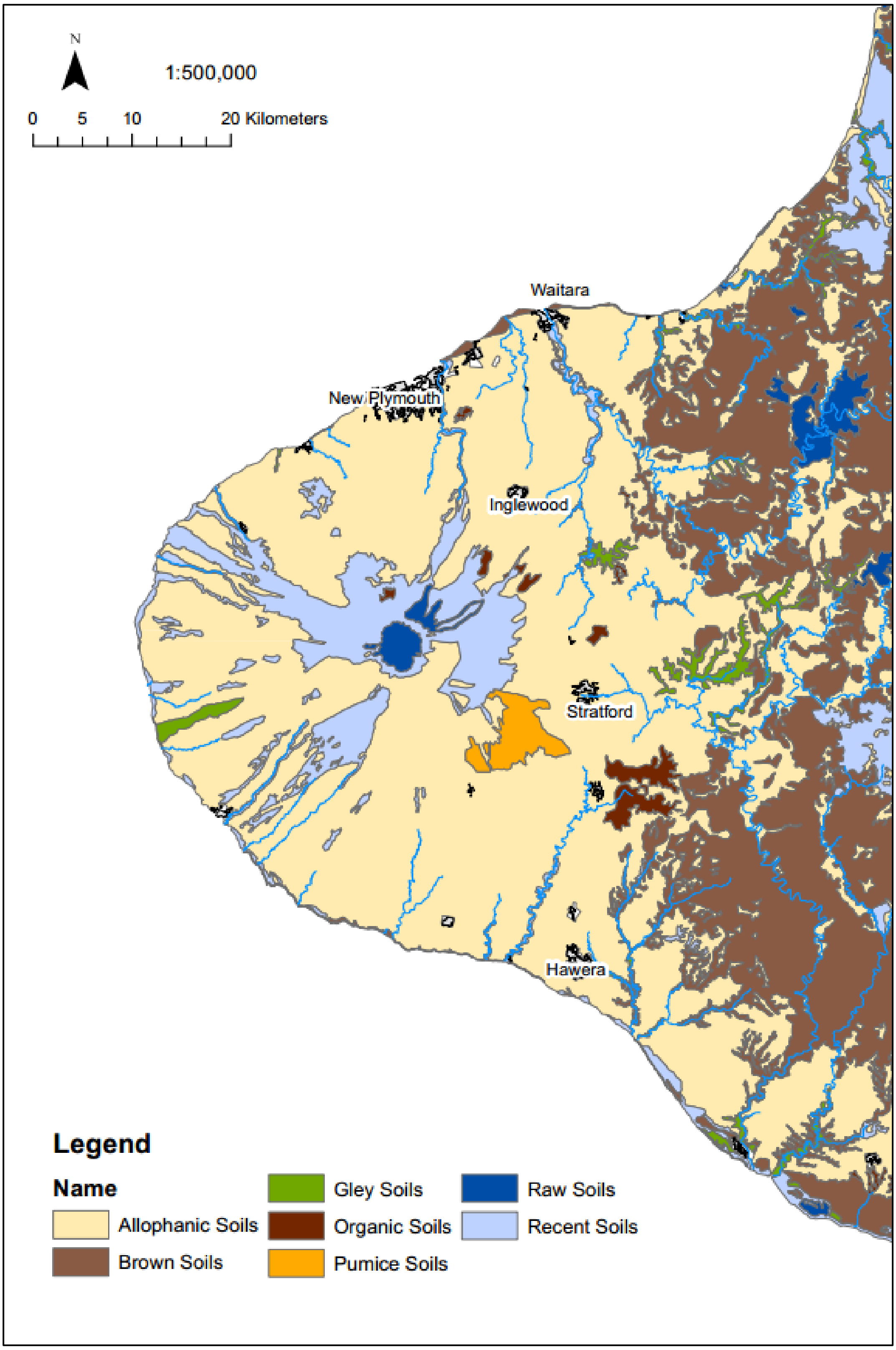

Figure 5 Distribution of soil types across the Taranaki region (Newsome et al. 2008)

3.4 Shallow groundwater resources

Groundwater resources within the Taranaki region can be differentiated between shallow unconfined aquifers, and deeper confined or semi-confined aquifers. The major shallow aquifers within the region are those contained within the Taranaki volcanic and Marine Terrace deposits. The major confined aquifers within the region include the Whenuakura and Matemateaonga Formation aquifers.

The Taranaki volcanic deposits cover a wide area of the Taranaki region, extending from the coastal boundary in the west, to the Tertiary deposits of the Taranaki basin in the east, and bounded to the north and south by the Quaternary marine terrace deposits. The Taranaki volcanic deposits contain both coarse material (sands, breccia and agglomerates) and fine material (clay, tuff and ash), resulting in irregular lithologies and anisotropic hydrogeologic conditions (Taylor and Evans, 1999). These result in a complex system of unconfined, perched and semi confined aquifers within the volcanic deposits. The water table within the ring plain area is typically encountered between 1 to 10 m below ground level, with seasonal variations in water table depth of up to 5 m. Groundwater flow generally reflects surface topography and flows radially from Mount Taranaki. Recharge to the Taranaki volcanic aquifers is mainly by rainfall infiltration, with additional contributions from stream and river bed leakage. Groundwater within the shallow volcanics aquifers is thought to be relatively ‘young’ water due to the predominant recharge mechanisms. Tritium dating of shallow groundwater abstracted from bores within the Taranaki volcanic deposits indicated water less than 2 years old (TRC, 2008)

The marine terrace deposits occur on coastal areas south of Hawera and to a lesser extent, the coastal areas north of New Plymouth. Basal units are typically marine sands often with conglomerate or shell layers, grading upward to terrestrial sediments. The marine terrace sediments range up to about 40 m in thickness and contain multiple unconfined aquifers. The water table within the marine terraces generally lies between 1 to 15 m below ground level, and follows a subdued reflection of surface topography. Recharge to the marine terrace aquifers is primarily by rainfall infiltration. The composition and quality of groundwater from the Marine terrace aquifers is variable, as are well yields. Groundwater within the marine terrace aquifers is also thought to be relatively ‘young’ water.

The majority of groundwater abstractions in the Taranaki region are from the shallow Taranaki volcanic deposits and Marine Terrace aquifers. Water abstracted from these aquifers is used for a variety of purposes including domestic and stock water supplies, general farm and industrial use. Potential usages for shallow groundwater can be restricted due to the variable composition and quality of the water (e.g. high natural iron content) and typically low yields. These shallow groundwater resources are also the most vulnerable to contamination by land use activities due to their proximity to the ground surface.

While significantly fewer bores target the deeper Whenuakura and Matemateaonga Formation aquifers, they provide the greatest volume of groundwater used within the Taranaki Region. The Whenuakura and Matemateaonga Formation aquifers generally provide better quality water and much higher yields than from the shallow unconfined aquifers of the Taranaki volcanic and Marine Terrace aquifers. Recharge to the Whenuakura and Matemateaonga Formation aquifers is not well understood. Some recharge may occur via the overlying unconfined volcanic and marine terrace deposits and also where the formations are exposed at the surface. The Whenuakura and Matemateaonga Formation aquifers are much less susceptible to contamination from land use activities due to their depth and predominantly confined nature. Groundwater within these aquifer systems is generally much older than water within overlying unconfined aquifers and, in some cases, is tens of thousands of years old (Taylor and Evans, 1999).

The distribution of the major aquifer units of the Taranaki region is illustrated below in Figure 6.

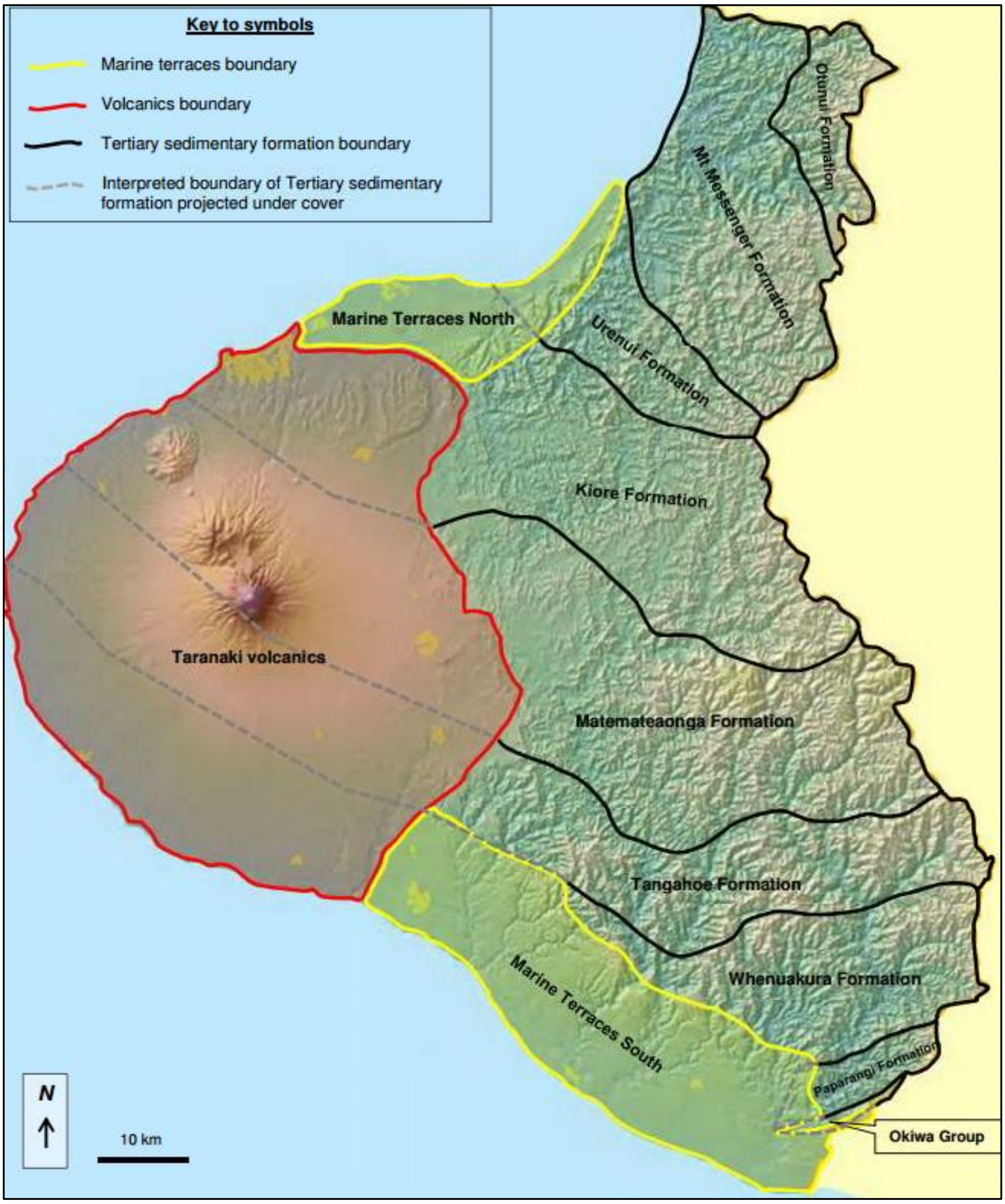

Figure 6 Distribution of the aquifer units across the Taranaki region (Brown 2013)

4. Agricultural land use in Taranaki

Dairy farming is the dominant agricultural land use within the Taranaki region. The New Zealand Dairy Statistics (published by LIC and Dairy NZ) for the 2011-12 year indicate that the total area utilised for dairy farming in the Taranaki region is 170,968 hectares. The region supports a total of 1,731 dairy herds comprising a total of 484,204 cows. The average stocking rate across the region is 2.83 cows per hectare and average milk-solids production is 358 kg per cow. The Taranaki region accounts for approximately 10.4% of the national herd and 10.3% of the national milk-solids production.

In terms of regional distribution, the highest number of cows are located in South Taranaki (312,823), followed by the New Plymouth (110,970) and Stratford (60,411) districts. The average stocking rates in each respective district are 2.94, 2.63 and 2.69 cows per hectare.

Dairy statistics for the Taranaki region indicate that from 2002 to 2012, the total area of land utilised for dairy farming in the region has decreased by 12,542 hectares. The total number of herds has also decreased by 421, while total cow numbers have remained stable (Figure 7). As the reduction in farmed area has not been matched by a reduction in cow numbers, the average stocking rate for Taranaki has increased slightly from 2.71 to 2.83 cows per hectare over the period 2002 to 2012. Average milk-solids production across the region also increased from 296 to 358 kg per cow over the same period.

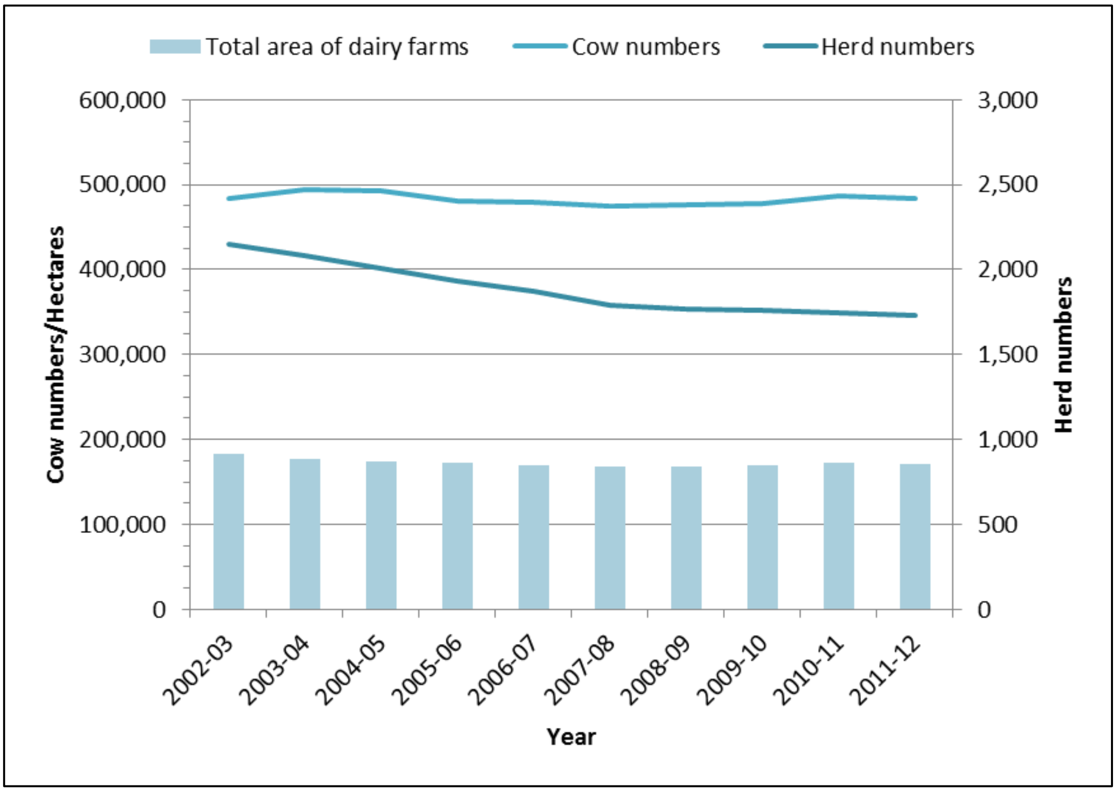

Figure 7 Dairy statistics for the Taranaki region (2002 to 2012)

Overall, the dairy statistics for the Taranaki region indicate a minor intensification in dairy farming activity in the region over the period 2002 to 2012, but do indicate an increase in farm productivity over the same period. The most notable increases have been in the South Taranaki district.

The levels of dairy farming expansion and intensification are predicated to increase across New Zealand and within the Taranaki region. The Land Use in Rural New Zealand Model (LURNZ), developed by Motu Economic and Public Policy Research (Motu), predicates that by 2020, the area of land utilised for dairy farming within Taranaki will increase by 17,700 hectares in comparison to 2008 levels (Parliamentary Commissioner for the Environment (PCE) 2013). Since 2008 however, there has only been an additional 2,687 hectares converted to dairy farm area in Taranaki region (Figure 7). Further rapid expansion would be required over the next eight years (2012 to 2020) if the modelled level of dairy farming land use in 2020 was to eventuate.

In addition to dairy farming, sheep and beef farming also plays an important part in the regional economy. There are approximately 880 sheep and beef farms in Taranaki which stock approximately 679,000 sheep and 131,000 beef cattle. Other smaller scale industries producing effluent for disposal to land include piggeries, poultry and goat farming operations.

4.1 Effluent discharge consents

The Council issues resource consents for the disposal of effluent to land and/or water under Section 87(e) of the RMA. As of 30 June 2012, the total number of consents held for the disposal of effluent to land and/or water was 954. This total number includes consents for dairy, piggery, poultry and goat effluent discharges. The number and range of consents issued by the Council for effluent discharges from 2002 to 2012 is illustrated below in Figure 8.

Overall there is a gradual increase in the number of consents discharging to land in preference to water. While this leads to an improvement in surface water quality, it concurrently increases nutrient loading on soil and thus groundwater, unless nutrients are otherwise managed.

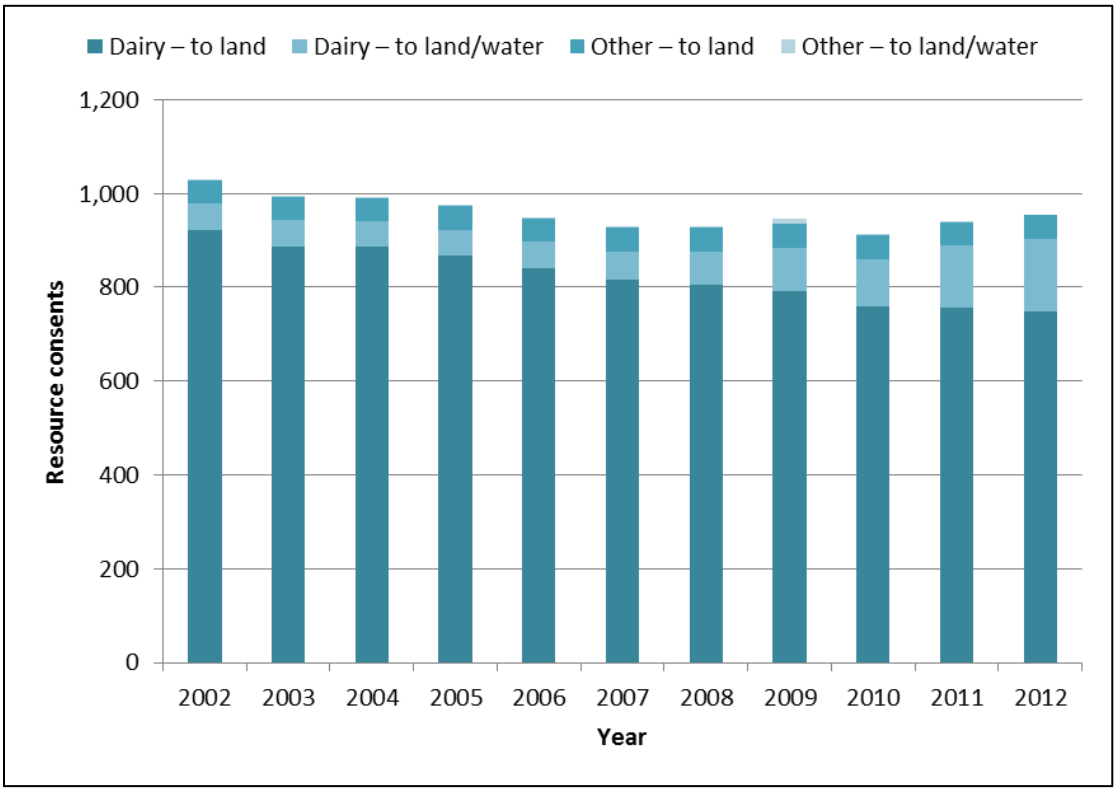

Figure 8 Number of resource consents held for the discharge of effluent (2002 to 2012)

5. Results

5.1 Results of 2011-12 nitrates survey

The results of the 2011-12 nitrates survey represent the current state of Taranaki groundwater with respect to nitrate concentrations and can be summarised as follows:

- In total 74 sites were sampled and 272 individual samples obtained.
- Nitrate concentrations across all samples ranged from 0.005 mg/L to 26.1 mg/L NNN (at site GND1112).
- The mean nitrate concentration of all samples was 3.45 mg/L NNN; the median was 2.51 mg/L NNN.
- 76% of sites had a maximum measured NNN concentration less than 50% of the MAV for nitrate.
- The MAV for nitrate in drinking water was exceeded in 10 samples collected at various times from a total of six separate sites. This represents 4% of all samples. 8% of the 74 wells sampled had one or more samples exceeding the MAV level.

The summary statistics for nitrate concentrations measured in shallow groundwater are shown in Table 2. Site locations are illustrated in Figure 1.

Table 2 Summary NNN concentration statistics for sites sampled in 2011-12 survey

Site	Samples	Min (NNN)	Max (NNN)	Mean (NNN)	Median (NNN)
GND0244	2	0.005	0.005	0.005	0.005
GND0451	2	0.005	0.080	0.043	0.043
GND0508	4	0.500	0.710	0.623	0.640
GND0563	1	0.040	0.040	0.040	0.040
GND0597	4	0.005	0.005	0.005	0.005
GND0693	4	0.050	4.500	1.200	0.125
GND0801	3	1.900	6.250	4.180	4.390
GND0827	4	1.250	1.340	1.278	1.260
GND0829	4	4.580	6.710	5.688	5.730
GND0834	4	0.560	2.660	1.743	1.875
GND0846	4	0.190	5.260	3.375	4.025
GND0851	4	2.370	3.410	2.905	2.920
GND1074	4	2.480	2.670	2.570	2.565
GND1075	4	0.650	1.020	0.835	0.835
GND1076	4	0.170	0.690	0.383	0.335
GND1077	4	1.160	1.570	1.388	1.410
GND1078	4	0.970	1.190	1.075	1.070
GND1079	4	1.000	1.300	1.145	1.140
GND1080	4	0.005	0.410	0.106	0.005
GND1081	4	0.340	2.890	2.113	2.610
GND1082	4	1.690	5.450	4.208	4.845
GND1083	4	1.060	1.560	1.308	1.305
GND1084	2	0.880	2.760	1.820	1.820
GND1086	4	1.400	4.050	2.125	1.525
GND1087	4	5.290	5.940	5.483	5.350

Site	Samples	Min (NNN)	Max (NNN)	Mean (NNN)	Median (NNN)
GND1088	4	0.690	1.040	0.840	0.815
GND1090	4	1.960	6.780	3.818	3.265
GND1091	4	1.770	1.960	1.885	1.905
GND1092	4	4.760	9.890	8.093	8.860
GND1093	4	2.070	2.970	2.308	2.095
GND1095	4	2.690	2.870	2.793	2.805
GND1096	4	1.650	2.510	2.215	2.350
GND1097	4	0.270	2.470	1.258	1.145
GND1098	4	1.670	2.230	1.890	1.830
GND1099	4	0.490	1.250	0.835	0.800
GND1100	4	2.400	3.080	2.720	2.700
GND1101	4	8.070	12.400	10.793	11.350
GND1102	4	0.005	0.005	0.005	0.005
GND1103	3	2.920	3.340	3.077	2.970
GND1104	4	3.880	5.640	5.053	5.345
GND1105	4	5.820	17.100	11.165	10.870
GND1108	4	10.000	12.600	10.750	10.200
GND1110	4	7.200	10.200	8.705	8.710
GND1112	4	16.600	26.100	22.375	23.400
GND1113	4	4.830	5.630	5.100	4.970
GND1114	4	2.950	8.530	5.265	4.790
GND1115	4	2.090	3.030	2.555	2.550
GND1116	4	4.510	6.050	5.053	4.825
GND1117	4	1.530	2.750	2.073	2.005
GND1118	4	7.580	11.500	9.610	9.680
GND1119	4	5.640	7.520	6.540	6.500
GND1120	4	1.960	3.710	2.848	2.860
GND1121	4	0.005	7.000	3.094	2.685
GND1122	4	0.015	1.020	0.484	0.450
GND1123	4	6.590	16.400	9.725	7.955
GND1124	4	4.780	7.140	5.553	5.145
GND1135	4	0.020	0.890	0.343	0.230
GND1192	4	2.920	3.500	3.195	3.180
GND1193	4	4.070	4.750	4.423	4.435
GND1194	4	1.850	2.720	2.355	2.425
GND1195	4	0.005	0.005	0.005	0.005
GND1646	1	0.170	0.170	0.170	0.170
GND1756	1	1.300	1.300	1.300	1.300
GND1759	2	2.390	3.070	2.730	2.730
GND1760	2	3.000	6.430	4.715	4.715
GND1786	4	0.530	1.100	0.795	0.775
GND2113	4	0.005	0.130	0.036	0.005
GND2114	2	0.005	0.040	0.023	0.023
GND2212	4	0.005	0.005	0.005	0.005
GND2213	4	2.360	2.990	2.735	2.795
GND2215	4	4.040	5.160	4.635	4.670
GND2218	4	3.160	5.420	4.185	4.080
GND2221	4	3.200	5.290	4.300	4.355
GND3000	3	2.390	3.200	2.830	2.900

The maximum nitrate concentrations measured at each site during the 2011-12 survey are plotted as a proportion of the drinking water MAV for nitrate in Figure 9. The spatial distribution of these sites is illustrated in Figure 10.

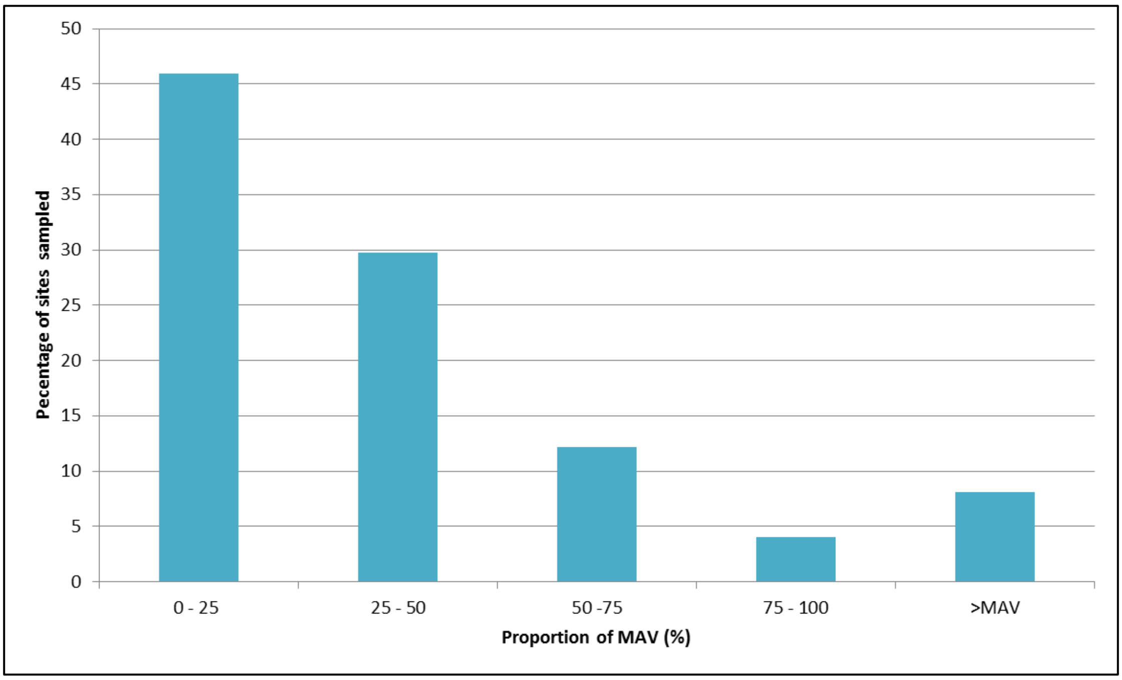

Figure 9 Maximum NNN concentrations as a proportion of MAV

The median, interquartile range, non-outlier range, outliers and extremes for nitrate are illustrated in Figure 11. The MAV value for nitrate in drinking water is included (red line) for comparison with measured concentrations.

The data from 2011-12 nitrates survey is included in Appendix III.

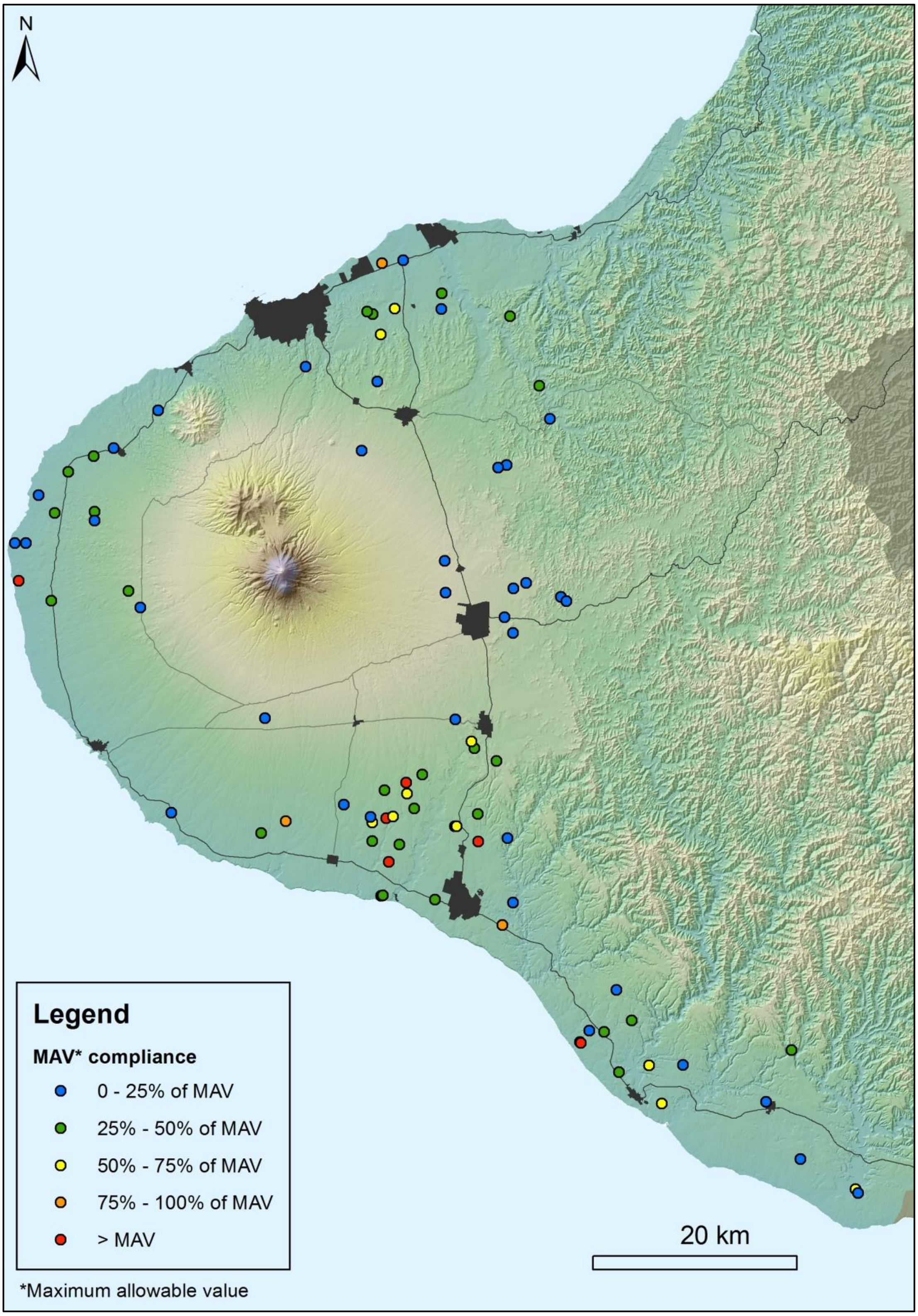

Figure 10 Spatial distribution of maximum nitrate concentrations measured during 2011-12 as a percentage proportion of the MAV

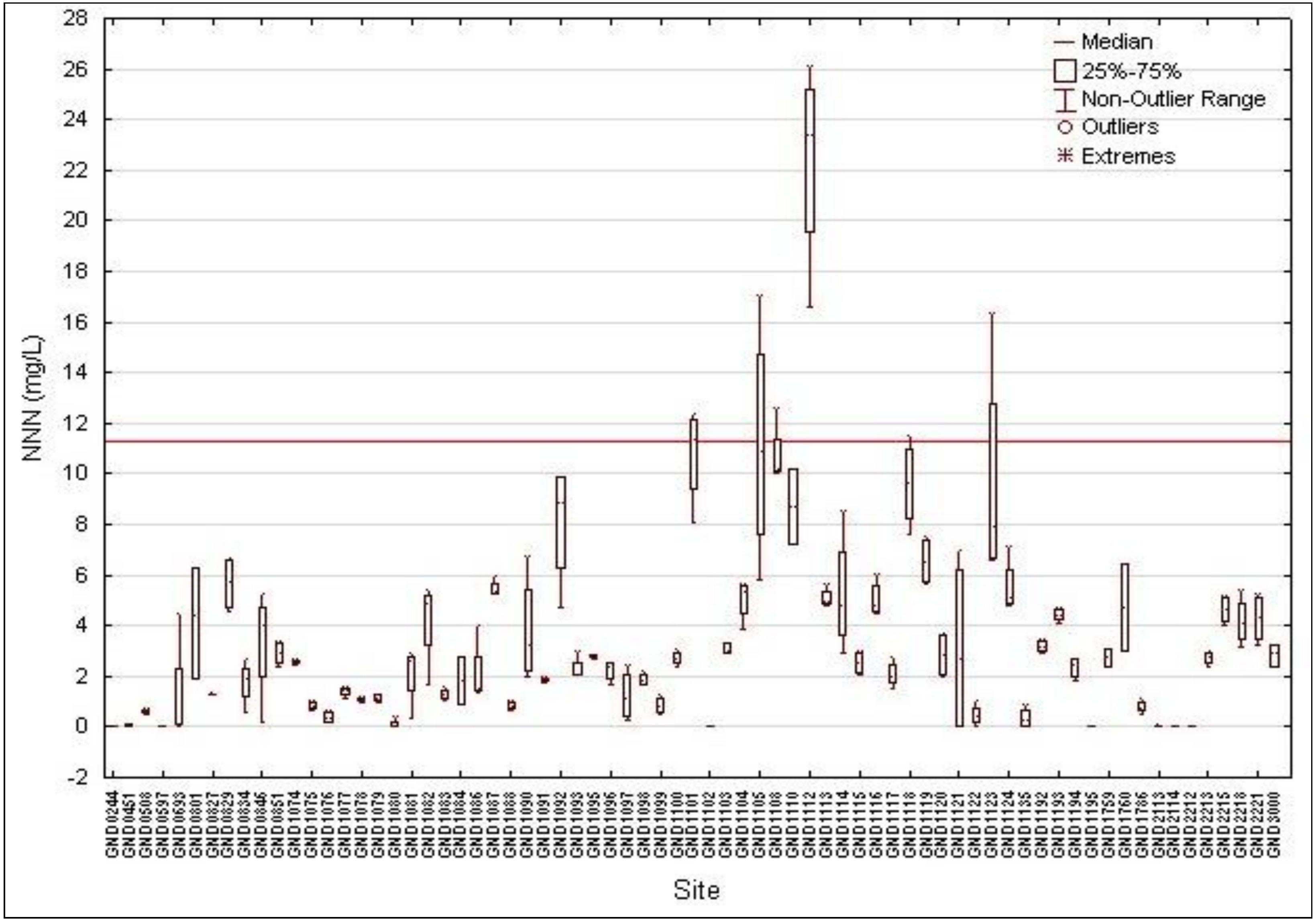

Figure 11 Box plot of NNN summary statistics for each site sampled in the 2011-12 nitrates survey

5.2 Trend analysis 2002 to 2012

Data collected from the 56 sites that were sampled during each of the 2011-12, 2006-07 and 2002-03 nitrate surveys has been used in comparisons to assess whether there are any statistically significant improvements or deterioration in nitrate concentrations, or more general indications thereof, over the period 2002 to 2012.

Table 3 provides details of the results of the monitoring carried out at each of the 56 sites over the period 2002 to 2012. In summary, the data indicates:

- The number of sites where there was an exceedance of the MAV has reduced in each survey;
- The number of individual samples exceeding the MAV has reduced in each survey;
- The number of samples exceeding the MAV, as a percentage of the number of all samples collected in each survey, is showing an overall reduction across the three surveys; and
- The majority of sites had their highest NNN concentration measured in the first survey, and there is a clear pattern emerging of fewer sites having their peak NNN concentrations recorded during more recent surveys.

Table 3 Results of NNN concentration trend analysis (2002 to 2012)

Period	**2002-03**	**2006-07**	**2011-12**
Number of sites sampled	56	56	56
Number of samples	307	214	220
Annual mean nitrate	4.00	4.20	3.81
Annual median nitrate	2.68	2.39	2.67
Number of sites with a MAV exceedance	10 (18%)	9 (16%)	6 (11%)
Number of samples exceeding MAV	26 (8%)	25 (12%)	11 (5%)
Survey when a site's maximum NNN concentration was measured	28 (50%)	16 (29%)	12 (21%)

The data collected between 2002 and 2012 was also statistically analysed to rigorously identify and evaluate trends in NNN concentrations at each individual site. The trends were quantified by calculating the average change in NNN concentrations (in mg/L/yr.) over the data record. The results are presented in Table 4. In summary, the data analysis indicates:

- Measured nitrate concentrations at 41 of the 56 sites (or 73%) were stable during the 2002 to 2012 period;
- A statistically significant trend in nitrate concentration was only detected at 15 sites (or 27%).
- 7 of the 15 sites (or 13% of all sites) displayed an increasing trend (deterioration) nitrate concentrations.
- 8 of the 15 sites (or 14% of all sites) displayed declining trend (improvement) in nitrate concentrations.

Table 4 Results of site specific NNN concentration trend analysis (2002 to 2012)

Site	Samples	Min (NNN)	Max (NNN)	Mean (NNN)	Median (NNN)	R2 value	Trend	Change in NNN (mg/L per year)	Any samples > MAV
GND0597	13	0.005	0.120	0.022	0.005	0.269			
GND0801	12	0.005	6.250	2.668	2.820	0.041			
GND0827	36	1.250	4.900	2.321	2.370	0.030			
GND0829	13	3.940	7.840	6.030	6.530	0.316			
GND0834	39	0.560	7.880	4.054	3.630	0.185			
GND0846	13	0.190	5.260	2.045	1.570	0.482	▲	**0.26**	
GND0851	13	2.090	3.470	2.964	3.130	0.040			
GND1074	13	1.600	2.670	2.132	2.160	0.854	▲	**0.11**	
GND1075	13	0.650	4.680	1.835	1.490	0.640	▼	**0.22**	
GND1076	13	0.170	1.540	0.932	0.860	0.668	▼	**0.11**	
GND1077	13	1.160	1.700	1.453	1.480	0.005			
GND1078	13	0.100	1.660	1.085	1.080	0.029			
GND1079*	13	0.005	1.750	1.322	1.430	0.260	▼	**0.07**	
GND1080	13	0.005	0.540	0.130	0.010	0.129			
GND1081	13	0.340	2.890	2.234	2.520	0.074			
GND1082	13	1.330	6.760	4.742	4.880	0.131			
GND1083	13	0.500	2.020	1.068	1.050	0.069			
GND1084	10	0.880	3.200	1.816	1.465	0.127			
GND1086	12	0.030	5.620	2.947	2.765	0.351			
GND1087	13	5.290	7.090	6.190	6.300	0.661	▼	**0.11**	
GND1088	14	0.320	4.600	2.044	2.015	0.450	▼	**0.22**	
GND1090	13	0.430	6.780	2.269	1.960	0.433	▲	**0.26**	
GND1091	13	1.650	2.130	1.859	1.880	0.013			
GND1092	13	1.730	9.890	6.435	6.740	0.222			
GND1093	14	0.680	2.970	1.609	1.560	0.464	▲	**0.11**	
GND1095	13	1.140	3.300	2.453	2.790	0.045			
GND1096	13	1.280	3.270	2.180	2.200	0.011			
GND1097	13	0.070	4.020	1.797	1.700	0.380			
GND1098	13	0.330	4.110	1.989	1.720	0.000			
GND1099	13	0.280	12.200	2.019	0.980	0.181			Y
GND1100	13	0.070	6.610	2.766	2.450	0.149			
GND1101	13	8.070	30.300	13.344	11.900	0.026			Y
GND1102	13	0.005	0.010	0.005	0.005	0.001			
GND1103	12	2.920	5.780	3.854	3.400	0.475	▼	**0.15**	
GND1104	13	3.880	7.400	5.930	5.880	0.247			
GND1105	13	3.220	17.800	9.497	9.340	0.100			Y
GND1108	13	10.000	15.800	12.685	12.600	0.241			Y
GND1110	14	6.050	13.500	10.094	10.200	0.128			Y
GND1112	14	8.730	26.100	17.095	16.550	0.729	▲	**1.00**	Y
GND1113	13	0.130	5.630	3.210	4.830	0.735	▲	**0.50**	
GND1114	13	2.830	24.300	7.225	5.310	0.007			Y
GND1115	13	2.090	10.500	5.663	5.850	0.542	▼	**0.47**	
GND1116	13	0.600	9.720	4.698	4.600	0.001			
GND1117	14	0.910	26.700	3.576	1.800	0.001			Y
GND1118	13	6.610	16.100	10.327	10.300	0.065			Y
GND1119	13	2.240	17.300	9.358	7.760	0.133			Y
GND1120	14	0.220	4.730	2.831	2.790	0.004			

Site	Samples	Min (NNN)	Max (NNN)	Mean (NNN)	Median (NNN)	R2 value	Trend	Change in NNN (mg/L per year)	Any samples > MAV
GND1121	13	0.005	15.100	5.410	3.410	0.317			Y
GND1122	13	0.015	1.020	0.429	0.400	0.038			
GND1123	13	2.820	16.400	6.607	5.290	0.308			Y
GND1124	13	4.780	8.920	6.835	7.140	0.641	▼	0.26	
GND1135	13	0.020	2.300	0.789	0.570	0.065			
GND1192	13	2.140	5.370	3.619	3.350	0.164			
GND1193	13	0.017	4.750	1.984	1.460	0.790	▲	0.37	
GND1194	13	1.850	14.200	3.400	2.470	0.129			Y
GND1195	13	0.005	0.100	0.015	0.005	0.210			

* An outlier exists in the data set for this site, which when removed, results in an R^2 value of 0.9. As such, this site has been included in the list of sites indicating decreasing nitrate concentrations.

The time-series plots for the sites displaying statistically significant increasing trends in nitrate concentration are included below in Figures 12 to 18, and those displaying a decreasing trend in Figures 19 to 26. The time-series plots for all other sites are included in Appendix IV.

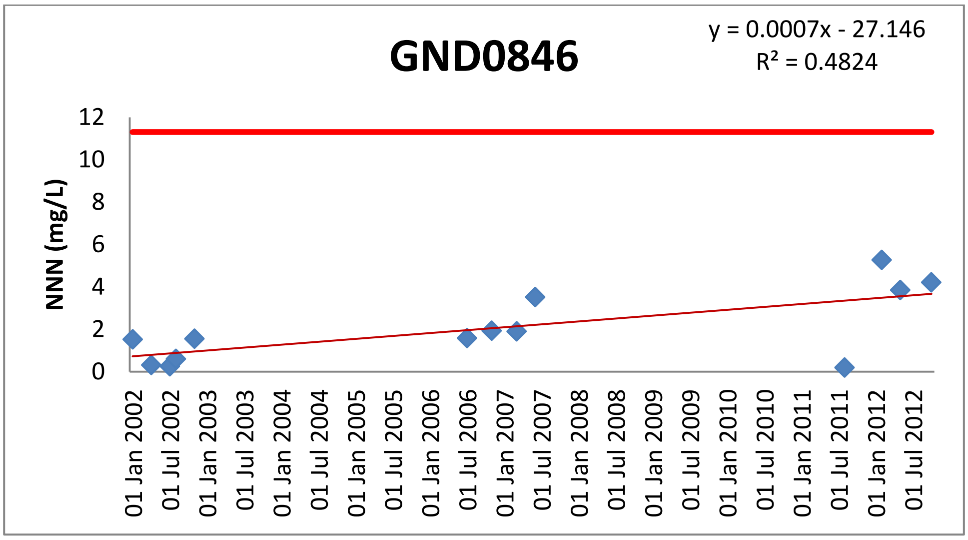

Figure 12 GND0846: Time-series plot of NNN concentrations 2002 to 2012

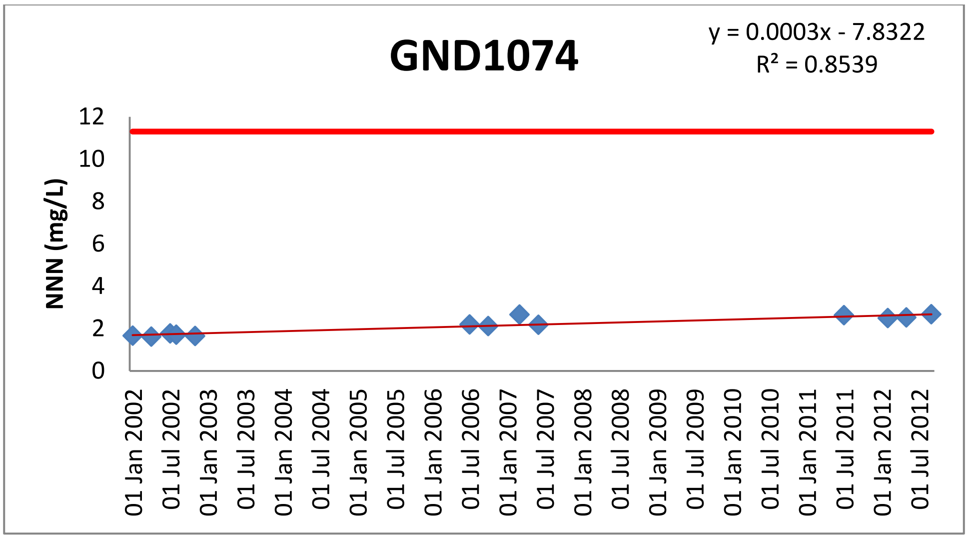

Figure 13 GND1047: Time-series plot of NNN concentrations 2002 to 2012

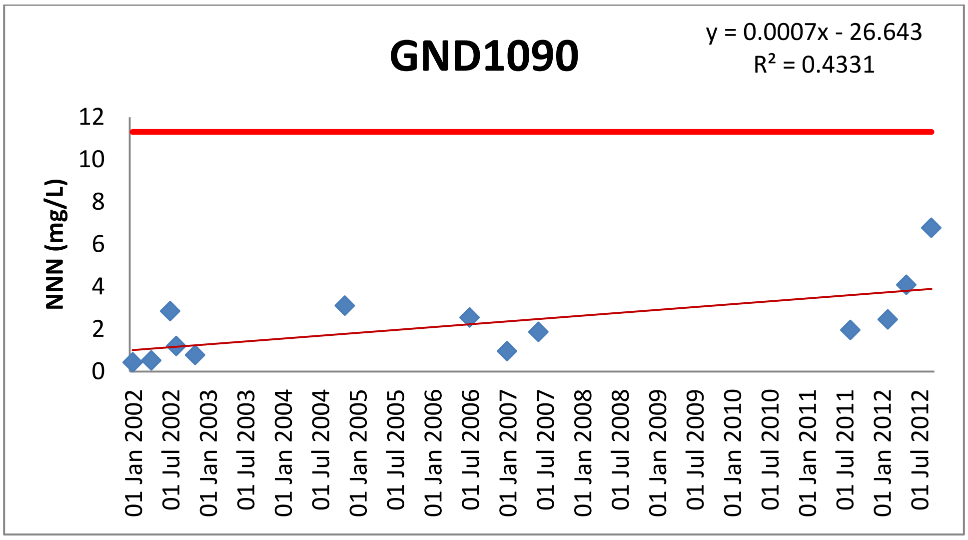

Figure 14 GND1090: Time-series plot of NNN concentrations 2002 to 2012

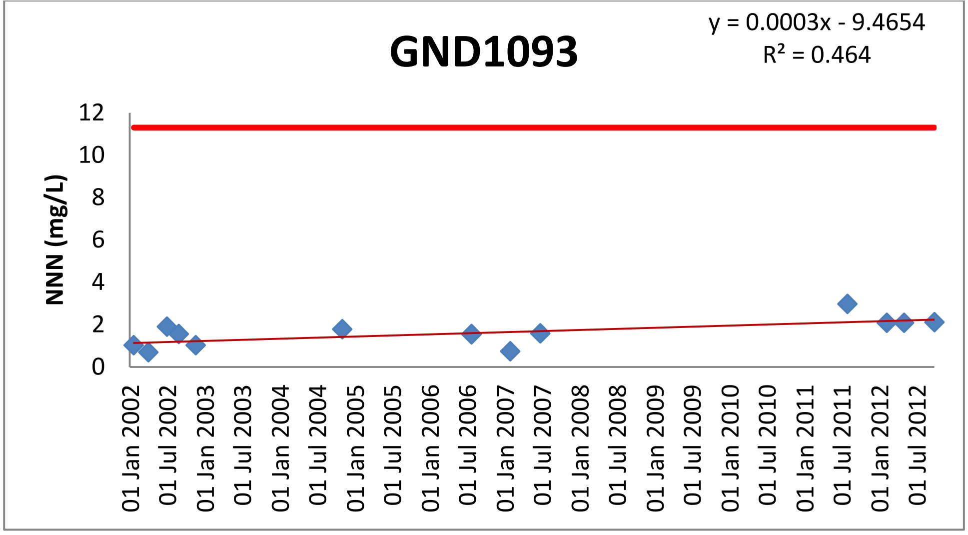

Figure 15 GND1093: Time-series plot of NNN concentrations 2002 to 2012

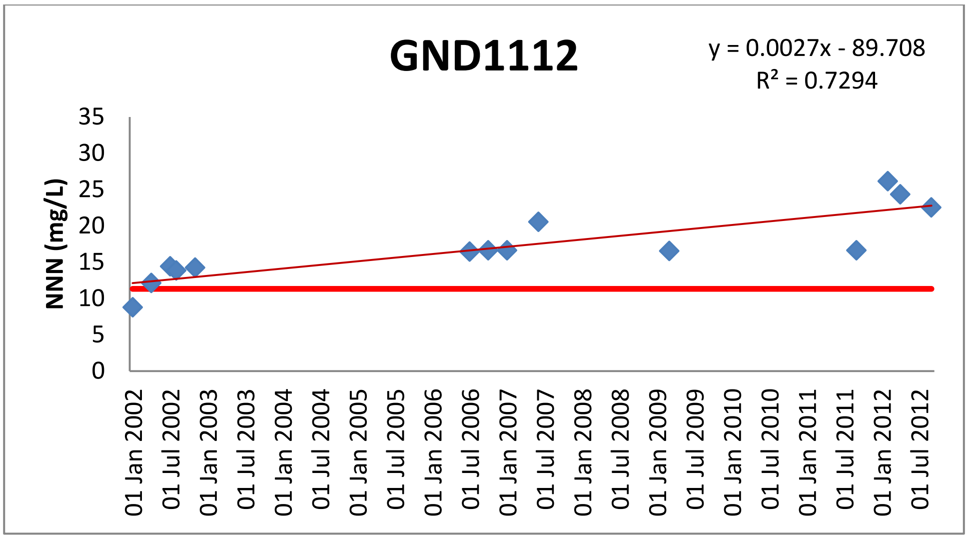

Figure 16 GND1112: Time-series plot of NNN concentrations 2002 to 2012

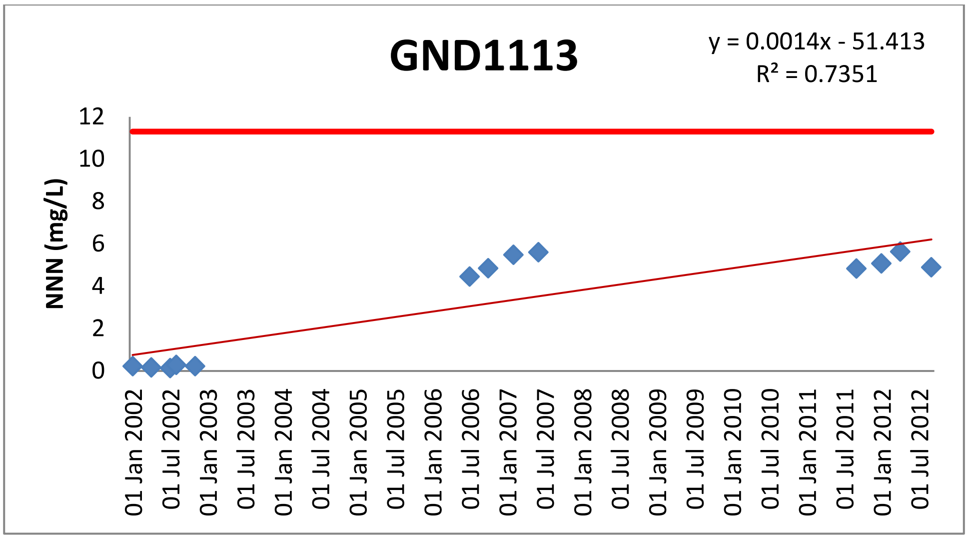

Figure 17 GND1113: Time-series plot of NNN concentrations 2002 to 2012

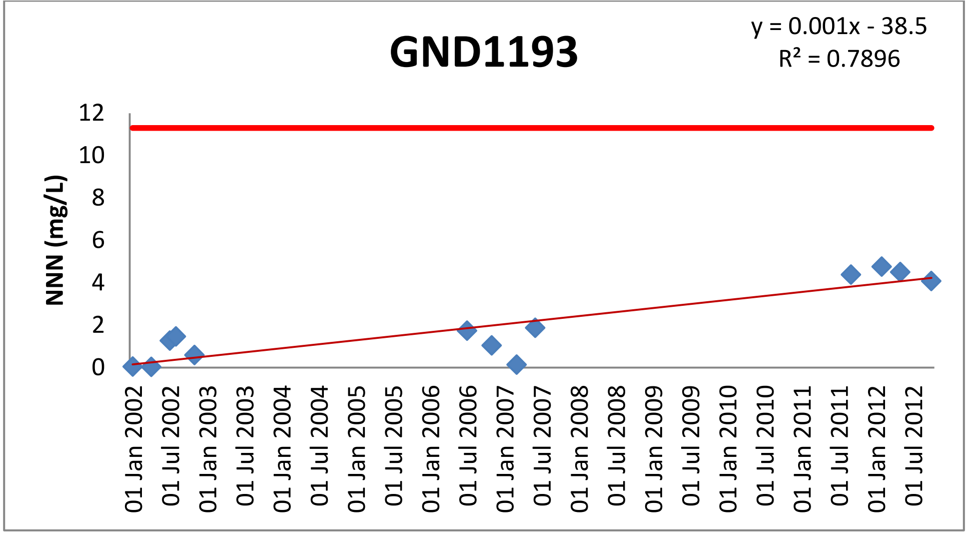

Figure 18 GND1193: Time-series plot of NNN concentrations 2002 to 2012

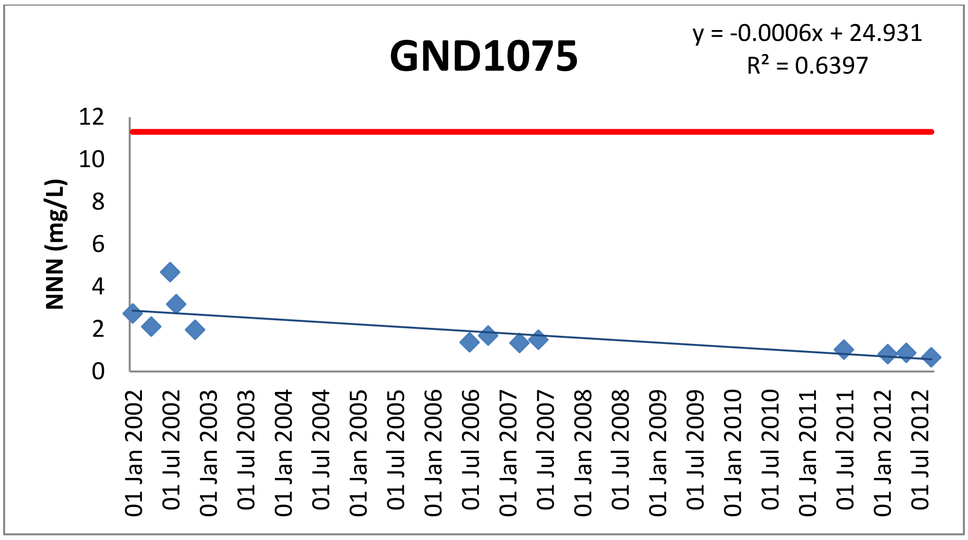

Figure 19 GND1075: Time-series plot of NNN concentrations 2002 to 2012

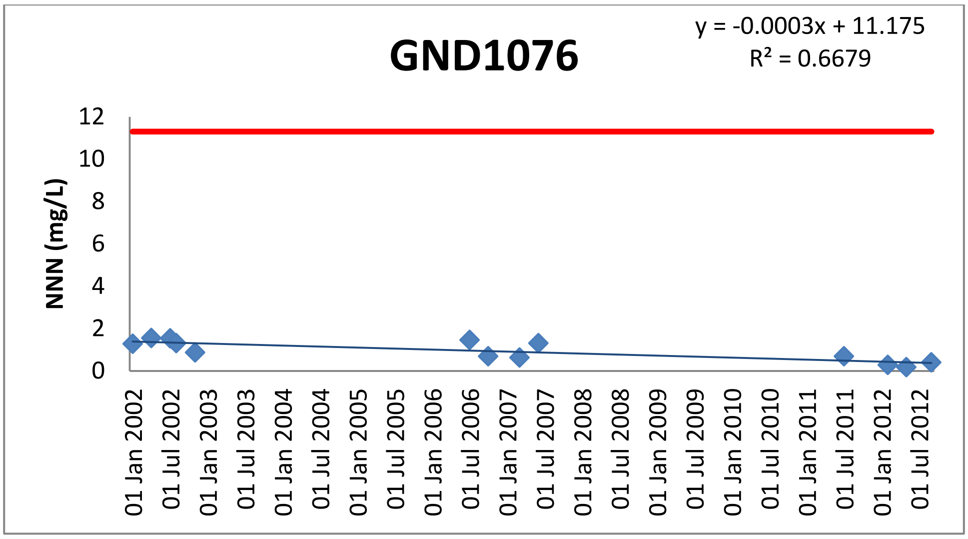

Figure 20 GND1076: Time-series plot of NNN concentrations 2002 to 2012

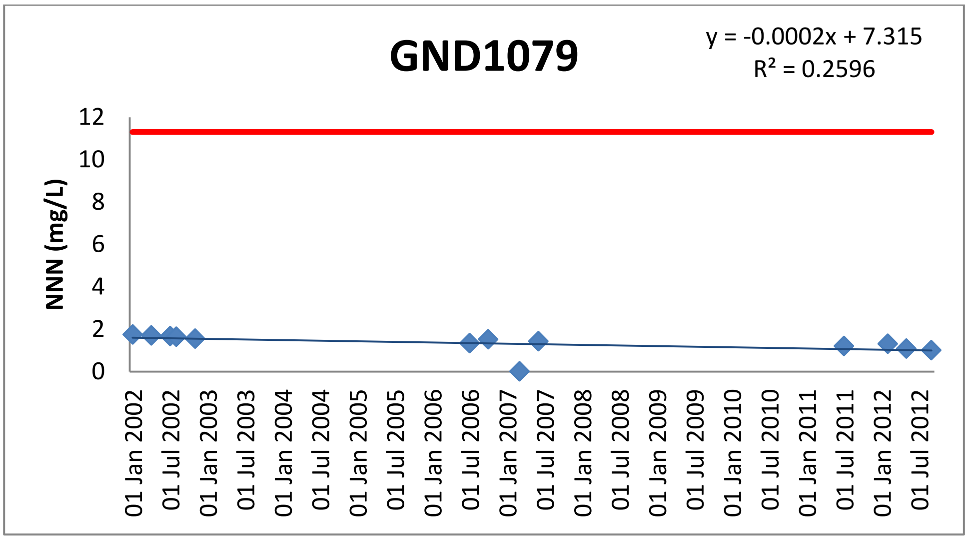

Figure 21 GND1079: Time-series plot of NNN concentrations 2002 to 2012

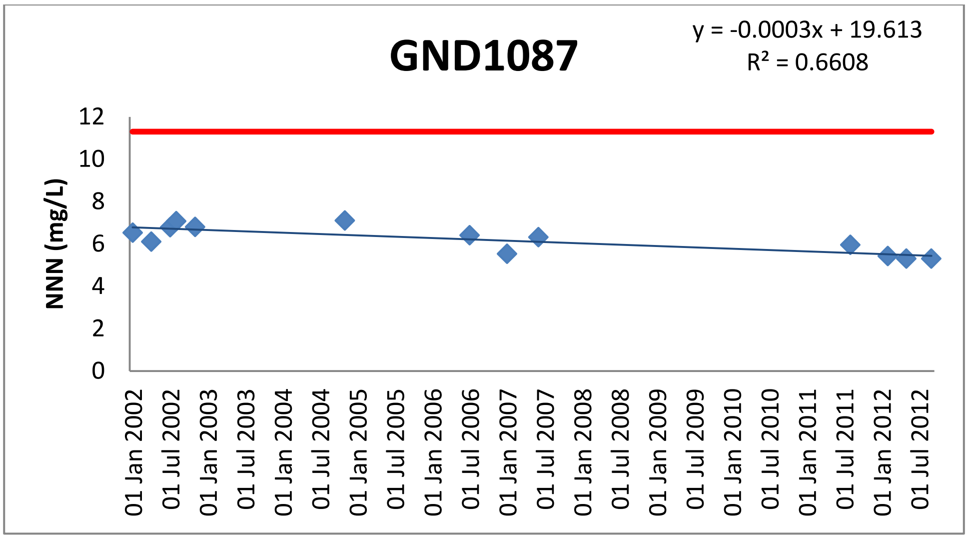

Figure 22 GND1087: Time-series plot of NNN concentrations 2002 to 2012

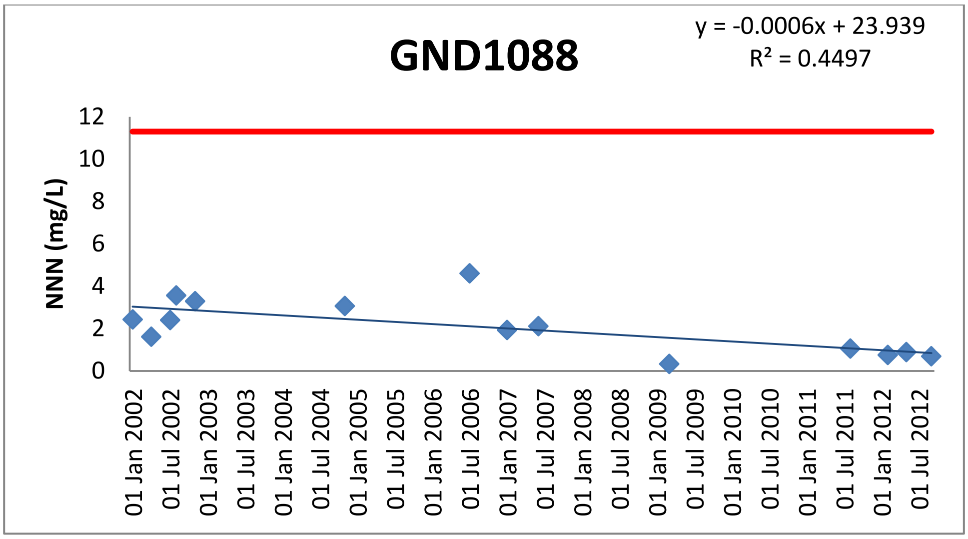

Figure 23 GND1088: Time-series plot of NNN concentrations 2002 to 2012

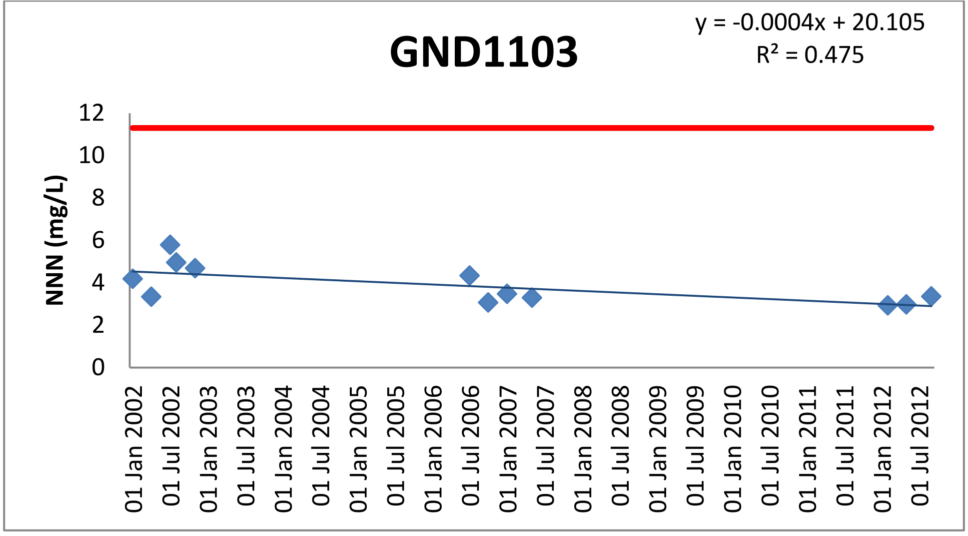

Figure 24 GND1103: Time-series plot of NNN concentrations 2002 to 2012

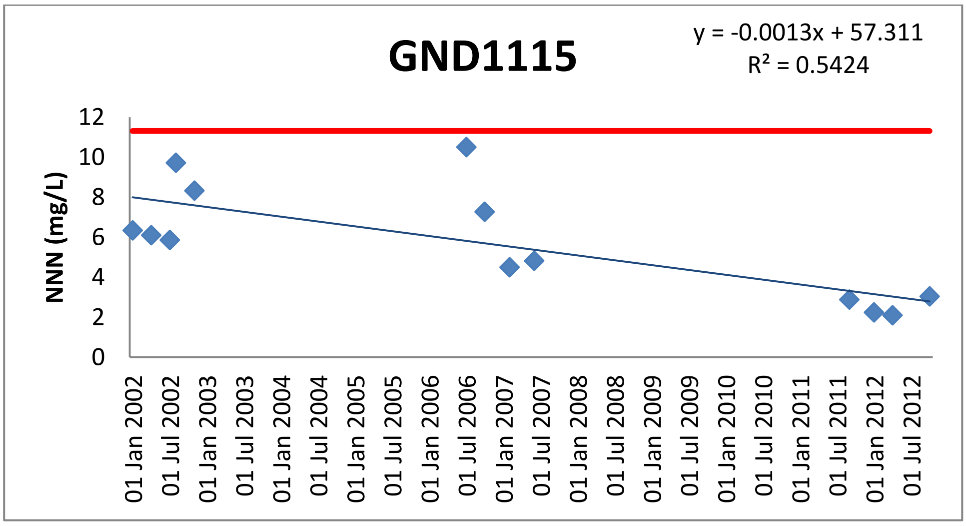

Figure 25 GND1115: Time-series plot of NNN concentrations 2002 to 2012

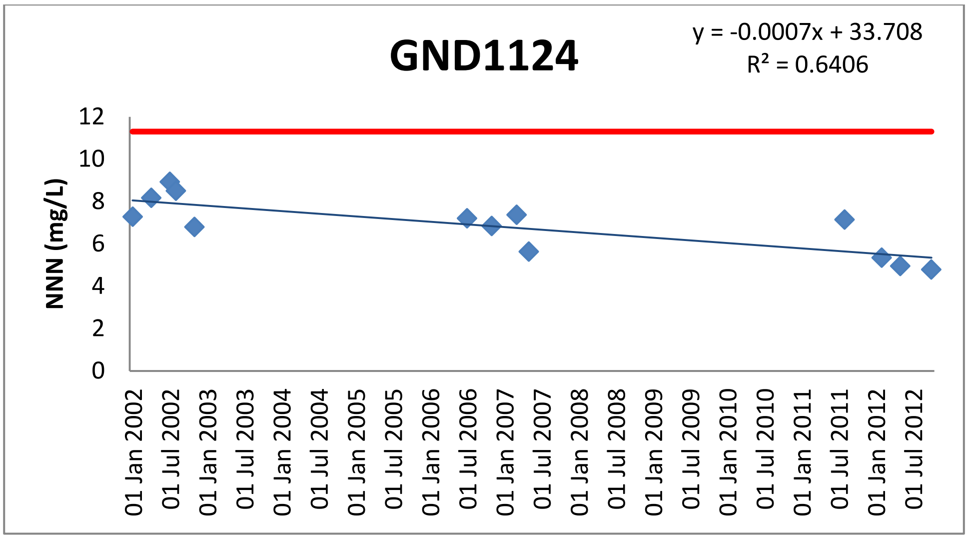

Figure 26 GND1124: Time-series plot of NNN concentrations 2002 to 2012

To further assess regional trends in groundwater nitrate concentrations, the annual mean and median nitrate concentrations of all groundwater samples collected by the Council for the three surveys over the period 2002 to 2012 were calculated. The total number of sites sampled includes those sampled as part of consent compliance monitoring programmes, in addition to those sampled during nitrates surveys. After collating the data it was apparent that there was a large variation in the number of samples obtained for nitrate analysis during each monitoring year. Unsurprisingly, the years that the greatest numbers of samples were obtained coincided with the years during which the five yearly nitrate surveys were carried out. Only data collected during these years (2002-03, 2006-07 and 2011-12) were included in the trend analysis, as the data sets from other years were deemed too small for inclusion. The results of the calculations are presented below in Table 5 and are plotted in Figure 27.

Table 5 Mean and median groundwater nitrate concentrations (2002 to 2012)

Period	2002-03	2006-07	2011-12
Number of samples	375	263	272
Annual mean nitrate	3.96	3.73	3.45
Annual median nitrate	2.68	2.11	2.51

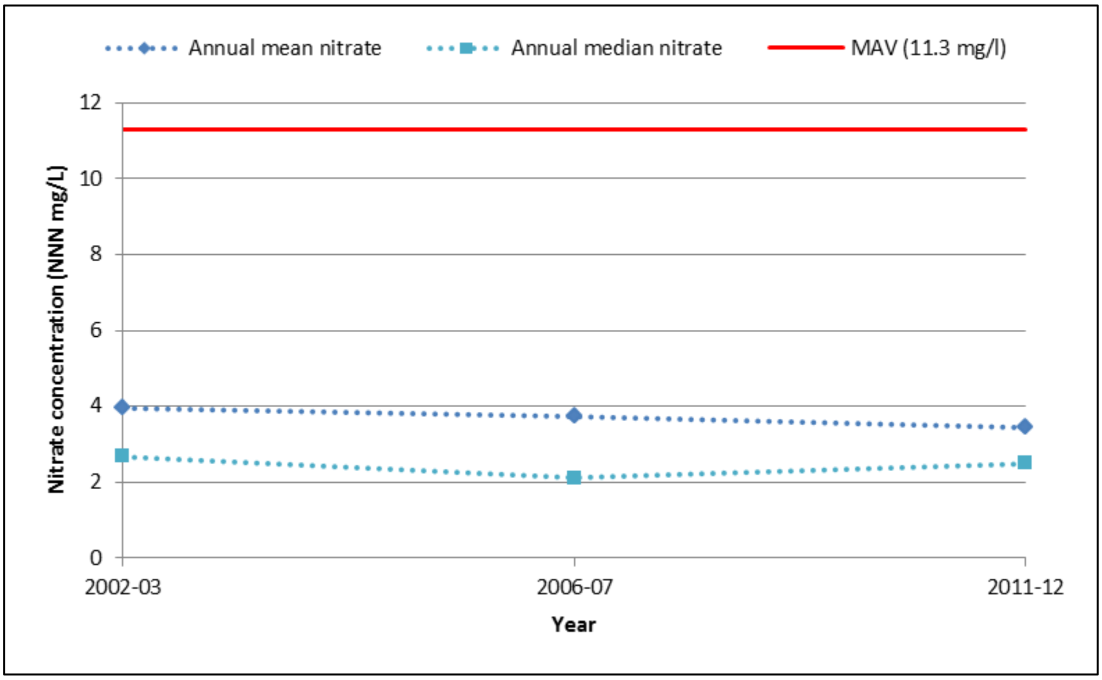

Figure 27 Annual mean and median groundwater nitrate concentrations 2002 to 2012

6. Discussion

The most recent nitrates survey was carried out during the 2011-12 monitoring period and involved sampling shallow groundwater at 74 sites across the region. 56 of the 74 sites had also been sampled during previous nitrate surveys carried out in the 2002-03 and 2006-07 monitoring periods.

The trend analysis carried out indicates that sites showing statistically significant improvement or deterioration in nitrate concentrations are similar in number. There is also no distinguishable geographical pattern in the location of sites displaying trend (Figure 28), indicating that trends in nitrate concentration are being driven by localised rather than regional scale land use activities.

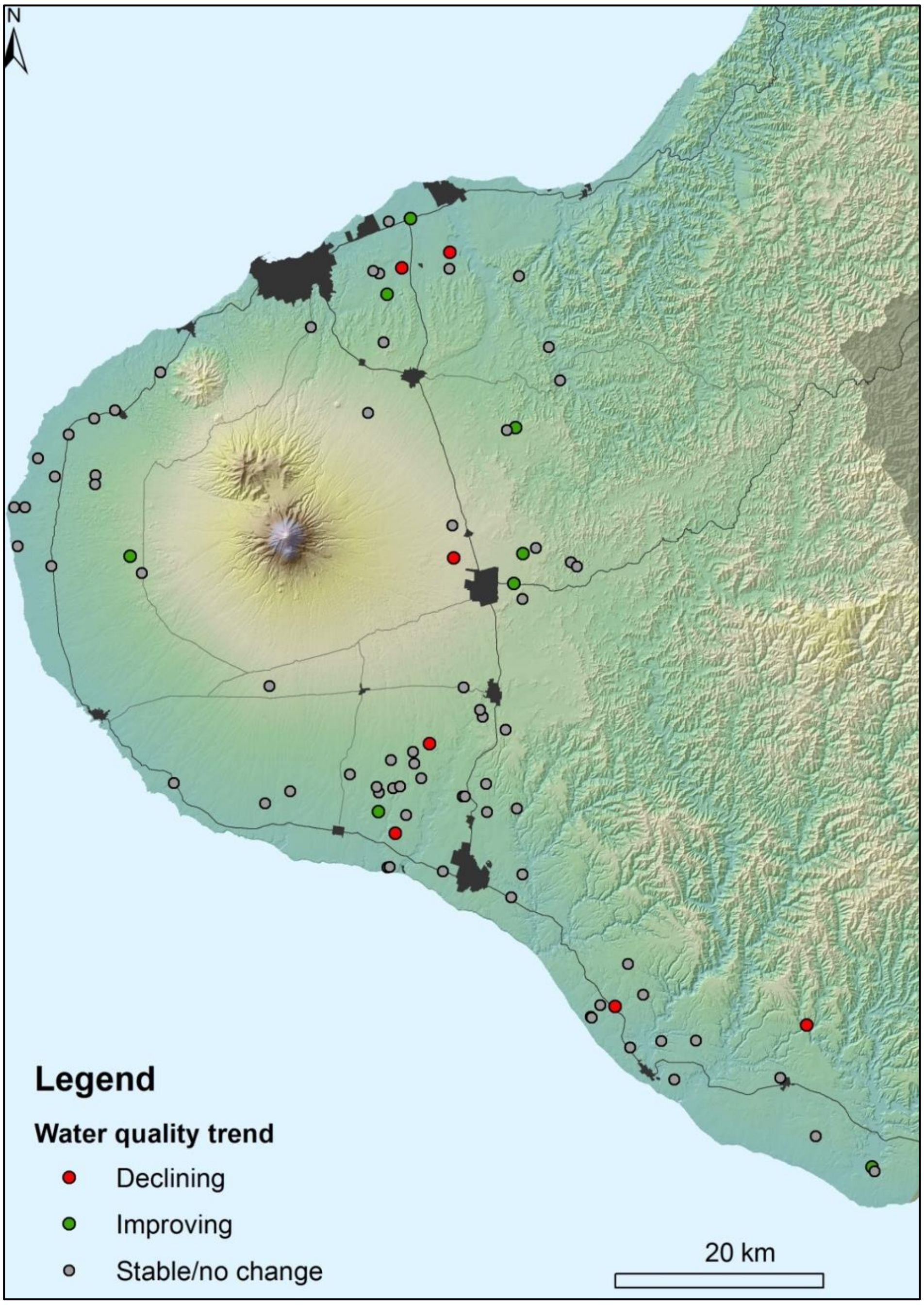

Figure 28 Spatial distribution of wells indicating trends in nitrate concentrations

Overall, nitrate concentrations in Taranaki groundwater have remained relatively stable over the period 2002 to 2012. The stability in groundwater nitrate concentrations is a positive result for the region given that stocking rates have intensified slightly and productivity per hectare has increased some 21% over the same period. In addition, there are also consistent indications of improvements (reductions) in peak groundwater nitrate concentrations over the same period.

6.1 National and regional comparisons

A number of models have been produced in an attempt to quantify the volume and flow of nutrients within various catchments and regions across New Zealand. Dymond et al. (2013) calculated the nitrate losses per animal for every soil and climate combination in New Zealand using the OVERSEER® model. Estimates of nitrate leaching for the Taranaki region were among the highest in the country; exceeding 40 kg of nitrate ha^{-1} yr^{-1} across most areas of the region. Other regions with high modelled rates of nitrate leaching included the Waikato, Bay of Plenty, and Canterbury regions; all regions with extensive areas of intensive dairying land use.

Given the high rate of nitrate leaching modelled by Dymond et al. (2013), it could be expected that groundwater nitrate concentrations across Taranaki would also be high. However, the data gathered as part of the nitrates programme does not support this assumption. The results of the 2011-12 nitrates survey compare favourably with the results of recent groundwater surveys carried out in other areas of New Zealand, including Waikato (WRC, 2012) and Canterbury (Environment Canterbury, 2013) (Figure 30).

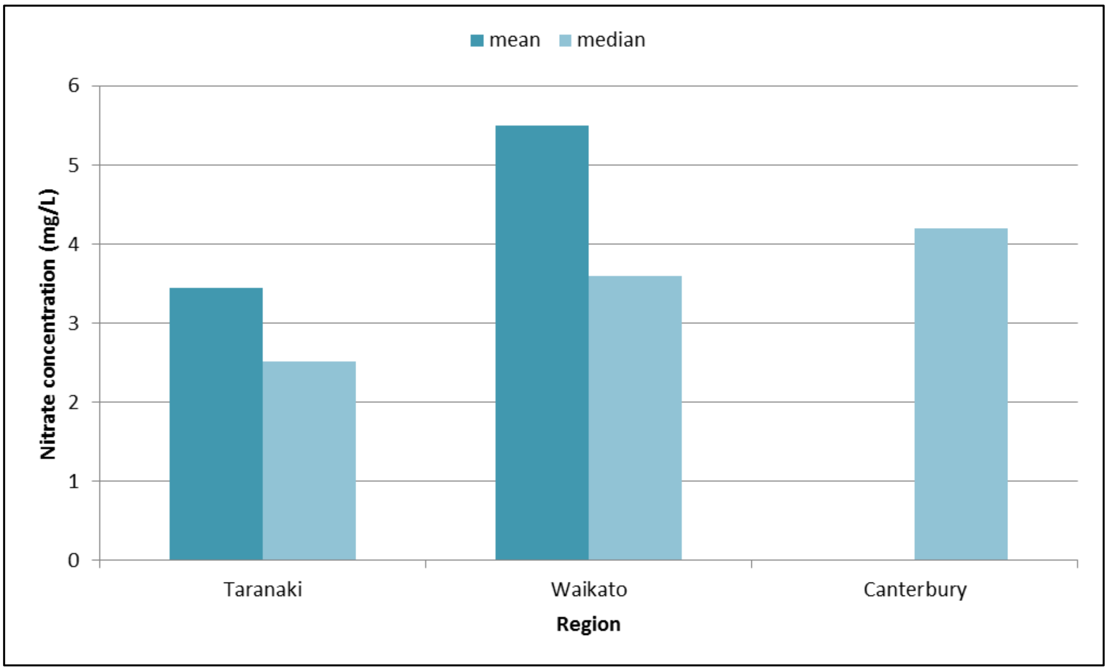

Figure 29 Regional comparisons of mean and median groundwater nitrate concentrations

The apparent contrast in modelled nitrate leaching rates and groundwater nitrate concentrations measured across Taranaki may be due to the dilution of leachate by high rainfall surpluses, subsurface attenuation processes (denitrification), or deficiencies in the model itself [Field measurements of pasture losses in Taranaki by

Roach & Morton (2005) indicated actual nitrate leaching rates significantly lower than those predicted in modelling by Dymond et al., (2013)].

6.2 Groundwater denitrification

To date, research into denitrification in groundwater systems within New Zealand has been limited (Stenger et al., 2013). However, the occurrence and impacts of denitrification in groundwater systems has been widely studied in many northern hemisphere countries. Research carried out in the northern German state of Lower Saxony indicates that, when averaged across the state, nearly half of the initial nitrate in land surface recharge is denitrified in the groundwater system (Meyer & Elbracht, 2012). Within New Zealand, research carried out in the Toenepi catchment (Waikato) indicates that approximately 45% of the nitrate lost from the root zone within the catchment was attenuated by denitrification (Woodward et al., 2013).

The occurrence and impacts of denitrification within groundwater systems in Taranaki has not yet been studied. However, reduced conditions are evident in three of the five Taranaki wells sampled as part of the National Groundwater Monitoring Programme and up to 13 wells sampled by the Council in the nitrates programme between 2002 and 2012 have been suspected to draw at least temporarily reduced groundwater (using NNN concentrations ≤0.1 mg/L as an indicator). Changes to the nitrates programme (section 2.8) are intended to provide suitable data to assess if conditions are favourable for denitrification in shallow Taranaki groundwater across a wide area or are localised. Understanding the occurrence and magnitude of denitrification in shallow groundwater will assist in resource management and land use planning across Taranaki.

6.3 Potential impacts on surface water systems

It is also important to note that while groundwater nitrate concentrations across the Taranaki region are generally low when compared to MAV values for drinking water, somewhat more stringent nitrate limits are applicable to surface water systems given the different considerations that come into play. The surface water quality limits being developed in New Zealand as part of the National Objectives Framework stipulate lower (more stringent) nitrate concentrations for surface water bodies than the standards for drinking water. These more stringent water quality limits are important to consider, particularly in areas where shallow groundwater discharge provides significant baseflow to surface water systems. *The National Policy Statement for Freshwater Management 2014* (gazetted on 4 July 2014) stipulates that the annual median nitrate concentrations in surface water must be below 6.9 mg/L of nitrogen present as nitrate, with 95% of samples remaining below 9.8 mg N/L ('national bottom line'). Surface waters in Taranaki are already well below these limits, and trends show reductions in nitrate and other nitrogen species[3]. However, as a conservative approach to ensuring satisfactory water quality in the region, it remains important to ensure nitrate concentrations in groundwater are not only well below MAV limits, but also ensure that surface water quality is being maintained or enhanced.

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[3] *Freshwater Physicochemical Programme State of the Environment Monitoring Annual Report 2012-2013*, Technical report 2013-49, Taranaki Regional Council March 2014

7. Recommendations

It is recommended:

1. THAT the results of the analysis presented in this report be noted for inclusion in the next 'State of the Environment' report to be prepared by the Council.

2. THAT the revised sampling regime (section 2.8) proposed to commence in the forthcoming monitoring period be adopted.

3. THAT annual reviews of data collected be carried out to assess the suitability of sites selected for inclusion in the revised nitrates programme and that the range of parameters being analysed for is sufficient;

4. THAT more site observation data such as land use and site activities be recorded during sampling visits to allow nitrate concentrations to be assessed and interpreted against these;

5. THAT consideration is given to attempting to delineate the capture zone of each sampling site, so nitrate results can be assessed against land use activities within the capture zone of each site.

Glossary of common terms and abbreviations

The following abbreviations and terms may be used within this report:

Aquifer	A permeable water-bearing geological formation through which water moves under natural conditions and which yields water to wells at a sufficient rate to be a practical source of water supply.
Bailer	A device for removing groundwater from a well or bore.
Bore	Bore means a hole drilled into the ground and completed for the abstraction of water or hydrocarbons to a depth of greater than 20 metres below the ground surface.
Co-efficient of determination	Statistical measure of how well data points fit a statistical model (denoted R^2 and pronounced R squared).
Confined aquifer	means when an impermeable formation, such as clay, overlies anaquifer so that air and water are no longer in contact and the pressure is no longer equal to atmospheric pressure. Water in a well will stand at a different level to the water-table.
Denitrification	A microbially facilitated process of nitrate reduction.
DWSNZ	Drinking Water Standards for New Zealand 2005 (revised 2008).
Effluent	Liquid waste including slurries.
Eutrophication	The ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, to an aquatic system.
Fertiliser	Substance used, or suitable for, sustaining or increasing the growth, productivity, or quality of plants by its application to those plants or the soil in which they grow or will grow; and includes a substance imported, manufactured, or being manufactured, with the intention that it be so.
Interquartile range	In descriptive statistics, the interquartile range (IQR), also called the midspread or middle fifty, is a measure of statistical dispersion, being equal to the difference between the upper and lower quartiles.
Leaching	The loss of mineral and organic solutes through percolation
MAV	Maximum Acceptable Value (taken from DWSNZ).
Non-outlier range	The range of data values which fall below the upper outlier limit and above the lower outlier limit.
NO_2	Nitrite.
NO_3	Nitrate.
Objective	A statement of a desired and specific environmental outcome.
Outlier	An outlier is an observation point that is distant from other observations. An outlier may be due to variability in the measurement or it may indicate an error.
Oxidation state	See Redox
Policy	A specific statement that guides or directs decision making. A policy indicates a commitment to a general course of action in working towards the achievement of an objective.
Purging	The removal of groundwater from a well or bore prior to obtaining a sample.
Recharge	The addition of water from other sources to an aquifer, e.g., seepage from rivers, percolation of rainfall.

Redox	Redox (reduction-oxidation) reactions include all chemical reactions in which atoms have their oxidation state changed; in general, redox reactions involve the transfer of electrons between species. Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom, or ion. Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom, or ion.
Resource consent	Refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15).
RFWP	Regional Freshwater Plan for Taranaki (2001).
RMA	Resource Management Act (1991) and including all subsequent amendments.
RPS	Regional Policy Statement.
Time-series	A sequence of data points measured at successive points in time over a specified time intervals.
Trendline	A line on a graph showing the general direction that a group of data points are following.
Unconfined aquifer	Groundwater which is freely connected to the atmosphere and which is free to rise and fall in the saturated zone, or water of an unconfined aquifer, or water under water table conditions.
Well	A hole dug, augured or drilled, tapping the water-table or springs to a depth of 20 metres or less below the ground surface.
Yield	The volume of water per unit of time able to be abstracted from a bore or well.

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Appendix I

Sampling site details

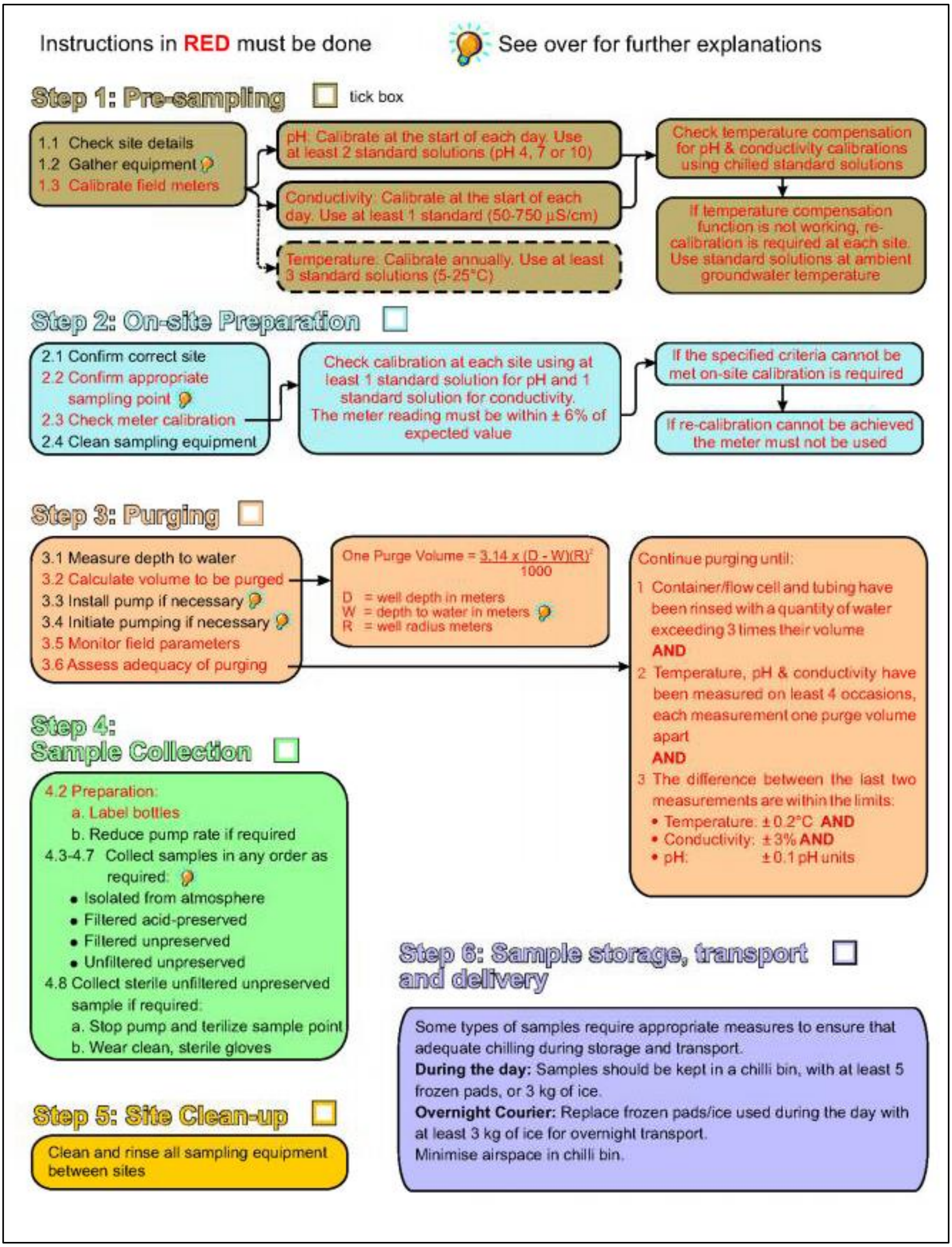
Site	Altitude (masl)	Total depth (m)	Construction	Primary use	Screen detail		Static water level	
					Top (mbgl)	Bottom (mbgl)	High (mbgl)	Low (mbgl)
GND0244	70	127.1	Drilled - screened	Public Water Supply	121	127.1	52.4	52.4
GND0451		171.3	Drilled - open ended casing	Irrigation-pasture	64	171.3	4.2	5.5
GND0508	120	14	Drilled - screened	Monitoring Bore (piezometer)	2.2	8.6	5.7	
GND0563		77.7	Drilled - open ended casing	Domestic Water Supply	72.1	77.7		
GND0597	51	32.3	Drilled - screened	Domestic Water Supply	28.9	32.3	13.1	
GND0693	70	96	Drilled - open ended casing	Stock	42.7	96	3.26	
GND0801	57	10	Dug - lined	Stock and Domestic (both)			6.2	
GND0827	35	8	Dug - unlined	Domestic Water Supply	0	8	3.2	
GND0829	49	5.2	Bored or augered - unlined	Stock and Domestic (both)	0	5.2	2	
GND0834	84	7		Domestic Water Supply	0	7	1.2	2
GND0846	180	1	Spring	Domestic Water Supply			0	0
GND0851	38	2	Spring	Domestic Water Supply			0	0
GND1074	370	11.7	Dug - lined	Stock and Domestic (both)			6.9	
GND1075	270	7	Dug - lined	Stock and Domestic (both)			1.3	
GND1076	320	6.5	Dug - lined	Domestic Water Supply			0.7	
GND1077	360	0	Spring	Stock and Domestic (both)			0	0
GND1078	275	6.3	Pit	Stock and Domestic (both)			1.4	
GND1079	200	6.1	Pit	Stock	0	6.1	1.8	
GND1080	100	3.5	Dug - lined	Stock and Domestic (both)			2.1	
GND1081	140	4.9		Stock and Domestic (both)			0.86	
GND1082	105	3.6	Dug - unlined	Stock	0	3.6	1.17	
GND1083	195	40	Dug - unlined	Stock	0	40	3.7	
GND1084	310	6.7	Dug - unlined	Stock	0	6.7	1.5	
GND1086	70	50	Dug - lined	Stock and Domestic (both)	0	6.7	1.5	
GND1087	100	4	Dug - unlined	Stock	0	4	1.9	

Site	Altitude (masl)	Total depth (m)	Construction	Primary use	Screen detail		Static water level	
					Top (mbgl)	Bottom (mbgl)	High (mbgl)	Low (mbgl)
GND1088	30	3.6	Pit	Stock and Domestic (both)	0	3.6	2.1	
GND1090	75	6.2	Dug - unlined	Industrial (Commercial)			0	
GND1091	95	7.5	Dug - lined	Stock and Domestic (both)	0	6.2	0.8	
GND1092	30	14.2	Dug - lined	Unused			2.7	
GND1093	75	1.9	Bored or augered - unlined	Stock and Domestic (both)			0.2	
GND1095	105	7.5	Dug - lined	Stock			1.1	
GND1096	120	0	Spring	Stock			0.7	
GND1097	14	5.7	Dug - lined	Stock and Domestic (both)			1.4	
GND1098	32	5.7	Dug - lined	Domestic Water Supply			2	
GND1099	28	4.7	Dug - lined	Stock and Domestic (both)			1.9	
GND1100	49	4.57		Stock and Domestic (both)			1.7	
GND1101	20	5.5	Dug - lined	Stock			1.7	
GND1102	235	3.4	Dug - lined	Stock			1.56	
GND1103	195	4.7	Dug - unlined	Stock and Domestic (both)			2.1	
GND1104	213	9.2	Dug - lined	Stock and Domestic (both)			0.3	
GND1105	190	7.2		Domestic Water Supply			3.1	
GND1108	118	8.3	Dug - lined	Stock and Domestic (both)			4.3	
GND1110	90	4.3	Dug - lined	Stock	0	4.3	1.8	
GND1112	95	12.2	Dug - unlined	Stock and Domestic (both)	0	12.2	3.2	10.5
GND1113	185	17	Dug - lined	Stock			3.8	
GND1114	95	5.6		Stock			3.3	
GND1115	110	11.7	Dug - lined	Stock			5.2	
GND1116	131	11.7	Dug - lined	Stock and Domestic (both)			3.6	
GND1117	128	8	Dug - lined	Stock and Domestic (both)			3	
GND1118	123	13	Dug - unlined	Stock and Domestic (both)			3.6	
GND1119	115	20.1		Stock			5.1	

Site	Altitude (masl)	Total depth (m)	Construction	Primary use	Screen detail		Static water level	
					Top (mbgl)	Bottom (mbgl)	High (mbgl)	Low (mbgl)
GND1120	155	7.1	Dug - lined	Stock and Domestic (both)			0.8	
GND1121	150	18	Drilled - open ended casing	Stock and Domestic (both)			5.44	
GND1122	49	147	Bored or augered - lined	Stock and Domestic (both)	90			
GND1123	31	5.78	Dug - unlined	Unused			1	
GND1124	11	0	Spring	Industrial (Commercial)			0	0
GND1135	75	18.6	Drilled - screened	Domestic Water Supply	12.6	15.5	9	
GND1192	115	4.6	Pit	Stock			1.6	
GND1193	60	3.7	Spring	Stock			2.2	
GND1194	145	7.02		Domestic Water Supply			1.3	
GND1195	20	153.3	Drilled - screened	Industrial (Commercial)	141.1	153.3	14.3	
GND1646	60	18	Drilled - open ended casing	Industrial (Commercial)				
GND1756	250	5	Bored or augered - unlined	Stock and Domestic (both)			1.9	
GND1759		8	Bored or augered - unlined	Stock and Domestic (both)			3.5	
GND1760		9					4.26	
GND1786	82	5	Bored or augered - unlined	Stock and Domestic (both)			0.7	
GND2113		21					1.7	
GND2114	80	41.9	Drilled - screened	Industrial (Commercial)	34.4	41.9		
GND2212		0						
GND2213	80	10.1					5.9	
GND2215	140	11.75	Dug - lined	Domestic Water Supply			6.6	
GND2218	50	8.35					1.4	
GND2221		15.46					4.6	
GND3000		6.74	Dug - unlined	Stock			0.9	2.1

Appendix II

Groundwater sampling procedures



Instructions in **RED** must be done

💡 See over for further explanations

Step 1: Pre-sampling ☐ tick box

1.1 Check site details
1.2 Gather equipment 💡
1.3 Calibrate field meters

pH: Calibrate at the start of each day. Use at least 2 standard solutions (pH 4, 7 or 10)

Conductivity: Calibrate at the start of each day. Use at least 1 standard (50-750 µS/cm)

Temperature: Calibrate annually. Use at least 3 standard solutions (5-25°C)

Check temperature compensation for pH & conductivity calibrations using chilled standard solutions

If temperature compensation function is not working, re-calibration is required at each site. Use standard solutions at ambient groundwater temperature

Step 2: On-site Preparation ☐

2.1 Confirm correct site
2.2 Confirm appropriate sampling point 💡
2.3 Check meter calibration
2.4 Clean sampling equipment

Check calibration at each site using at least 1 standard solution for pH and 1 standard solution for conductivity. The meter reading must be within ± 6% of expected value

If the specified criteria cannot be met on-site calibration is required

If re-calibration cannot be achieved the meter must not be used

Step 3: Purging ☐

3.1 Measure depth to water
3.2 Calculate volume to be purged
3.3 Install pump if necessary 💡
3.4 Initiate pumping if necessary 💡
3.5 Monitor field parameters
3.6 Assess adequacy of purging

One Purge Volume = $\frac{3.14 \times (D - W)(R)^2}{1000}$

D = well depth in meters
W = depth to water in meters 💡
R = well radius meters

Continue purging until:

1. Container/flow cell and tubing have been rinsed with a quantity of water exceeding 3 times their volume
AND
2. Temperature, pH & conductivity have been measured on least 4 occasions, each measurement one purge volume apart
AND
3. The difference between the last two measurements are within the limits:
   - Temperature: ± 0.2°C **AND**
   - Conductivity: ± 3% **AND**
   - pH: ± 0.1 pH units

Step 4: Sample Collection ☐

4.2 Preparation:
  a. Label bottles
  b. Reduce pump rate if required
4.3-4.7 Collect samples in any order as required: 💡
- Isolated from atmosphere
- Filtered acid-preserved
- Filtered unpreserved
- Unfiltered unpreserved

4.8 Collect sterile unfiltered unpreserved sample if required:
  a. Stop pump and terilize sample point
  b. Wear clean, sterile gloves

Step 5: Site Clean-up ☐

Clean and rinse all sampling equipment between sites

Step 6: Sample storage, transport and delivery ☐

Some types of samples require appropriate measures to ensure that adequate chilling during storage and transport.
During the day: Samples should be kept in a chilli bin, with at least 5 frozen pads, or 3 kg of ice.
Overnight Courier: Replace frozen pads/ice used during the day with at least 3 kg of ice for overnight transport.
Minimise airspace in chilli bin.

From: Ministry for the Environment (2006)

Appendix III

2011-12 monitoring results

Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND0244	TRC121381	08 May 2012	Year 2012	Autumn	09:50	<0.01	
GND0244	TRC123081	01 Oct 2012	Year 2012	Spring	10:00	<0.01	
GND0451	TRC100210	30 Mar 2009	Year 2009	Autumn	12:00		0.1
GND0451	TRC100215	15 Jul 2009	Year 2009	Winter	12:00		0.046
GND0451	TRC112260	20 Sep 2011	Year 2011	Spring	13:10	<0.01	
GND0451	TRC120326	01 Feb 2012	Year 2012	Summer	11:00	0.08	
GND0508	TRC100198	25 Sep 2008	Year 2008	Spring	12:00		1
GND0508	TRC100205	15 Jan 2009	Year 2009	Summer	12:00		1.2
GND0508	TRC100209	30 Mar 2009	Year 2009	Autumn	12:00		1.1
GND0508	TRC100214	15 Jul 2009	Year 2009	Winter	12:00		0.94
GND0508	TRC100219	10 Nov 2009	Year 2009	Spring	12:00		0.89
GND0508	TRC111916	27 Jul 2011	Year 2011	winter	11:02	0.71	
GND0508	TRC120442	09 Feb 2012	Year 2012	Summer	11:45	0.5	
GND0508	TRC121334	02 May 2012	Year 2012	Autumn	13:25	0.66	
GND0508	TRC123035	27 Sep 2012	Year 2012	Spring	13:05	0.62	
GND0563	TRC100195	16 Jun 2008	Year 2008	Winter	12:00		0.002
GND0563	TRC100199	25 Sep 2008	Year 2008	Spring	12:00		0.002
GND0563	TRC100202	15 Jan 2009	Year 2009	Summer	12:00		0.004
GND0563	TRC100206	30 Mar 2009	Year 2009	Autumn	12:00		0.002
GND0563	TRC100211	15 Jul 2009	Year 2009	Winter	12:00		0.046
GND0563	TRC100216	10 Nov 2009	Year 2009	Spring	12:00		0.03
GND0563	TRC112261	20 Sep 2011	Year 2011	Spring	10:45	0.04	
GND0597	TRC112073	29 Aug 2011	Year 2011	winter	14:10	<0.01	
GND0597	TRC120560	14 Feb 2012	Year 2012	Summer	10:20	<0.01	
GND0597	TRC121378	08 May 2012	Year 2012	Autumn	11:15	<0.01	
GND0597	TRC123085	01 Oct 2012	Year 2012	Spring	12:10	<0.01	
GND0693	TRC111918	27 Jul 2011	Year 2011	winter	13:56	4.5	
GND0693	TRC120448	09 Feb 2012	Year 2012	Summer	10:55	0.14	
GND0693	TRC121333	02 May 2012	Year 2012	Autumn	14:10	0.11	
GND0693	TRC123039	27 Sep 2012	Year 2012	Spring	14:35	0.05	
GND0801	TRC112093	30 Aug 2011	Year 2011	winter	13:18	4.39	
GND0801	TRC120538	14 Feb 2012	Year 2012	Summer	11:50	6.25	
GND0801	TRC121349	03 May 2012	Year 2012	Autumn	11:10	1.9	
GND0827	TRC100196	16 Jul 2008	Year 2008	Winter	12:00		2
GND0827	TRC100200	25 Sep 2008	Year 2008	Spring	12:00		2.6
GND0827	TRC100203	15 Jan 2009	Year 2009	Summer	12:00		2.4
GND0827	TRC100207	30 Mar 2009	Year 2009	Autumn	12:00		2.8
GND0827	TRC100212	15 Jul 2009	Year 2009	Winter	12:00		4.9
GND0827	TRC100217	10 Nov 2009	Year 2009	Spring	12:00		2.8
GND0827	TRC112259	20 Sep 2011	Year 2011	Spring	12:40	1.34	
GND0827	TRC120325	01 Feb 2012	Year 2012	Summer	10:25	1.25	
GND0827	TRC121301	30 Apr 2012	Year 2012	Autumn	11:45	1.27	

Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND0827	TRC122969	24 Sep 2012	Year 2012	Spring	11:55	1.25	
GND0829	TRC112091	30 Aug 2011	Year 2011	winter	12:18	4.93	
GND0829	TRC120537	14 Feb 2012	Year 2012	Summer	11:00	6.71	
GND0829	TRC121347	03 May 2012	Year 2012	Autumn	12:20	6.53	
GND0829	TRC123092	01 Oct 2012	Year 2012	Spring	12:45	4.58	
GND0834	TRC090860	06 Mar 2009	Year 2009	Autumn	13:12	4.11	
GND0834	TRC112213	15 Sep 2011	Year 2011	Spring	14:10	1.81	
GND0834	TRC120324	01 Feb 2012	Year 2012	Summer	10:05	0.56	
GND0834	TRC121300	30 Apr 2012	Year 2012	Autumn	11:30	2.66	
GND0834	TRC122968	24 Sep 2012	Year 2012	Spring	11:20	1.94	
GND0846	TRC112074	29 Aug 2011	Year 2011	winter	15:02	0.19	
GND0846	TRC120559	14 Feb 2012	Year 2012	Summer	09:20	5.26	
GND0846	TRC121377	08 May 2012	Year 2012	Autumn	10:40	3.85	
GND0846	TRC123082	01 Oct 2012	Year 2012	Spring	10:20	4.2	
GND0851	TRC112094	30 Aug 2011	Year 2011	winter	14:23	3.17	
GND0851	TRC120536	14 Feb 2012	Year 2012	Summer	10:15	2.67	
GND0851	TRC121346	03 May 2012	Year 2012	Autumn	10:20	2.37	
GND0851	TRC123091	01 Oct 2012	Year 2012	Spring	12:25	3.41	
GND1074	TRC111909	21 Jul 2011	Year 2011	winter	11:42	2.62	
GND1074	TRC120337	02 Feb 2012	Year 2012	Summer	10:20	2.48	
GND1074	TRC121327	02 May 2012	Year 2012	Autumn	08:55	2.51	
GND1074	TRC122961	24 Sep 2012	Year 2012	Spring	10:55	2.67	
GND1075	TRC111900	19 Jul 2011	Year 2011	winter	14:19	1.02	
GND1075	TRC120332	02 Feb 2012	Year 2012	Summer	07:48	0.8	
GND1075	TRC121311	01 May 2012	Year 2012	Autumn	08:50	0.87	
GND1075	TRC122956	24 Sep 2012	Year 2012	Spring	09:15	0.65	
GND1076	TRC111901	19 Jul 2011	Year 2011	winter	15:10	0.69	
GND1076	TRC120333	02 Feb 2012	Year 2012	Summer	08:15	0.27	
GND1076	TRC121312	01 May 2012	Year 2012	Autumn	09:10	0.17	
GND1076	TRC122957	24 Sep 2012	Year 2012	Spring	09:35	0.4	
GND1077	TRC111910	21 Jul 2011	Year 2011	winter	12:46	1.57	
GND1077	TRC120336	02 Feb 2012	Year 2012	Summer	10:00	1.38	
GND1077	TRC121315	01 May 2012	Year 2012	Autumn	10:45	1.44	
GND1077	TRC122960	24 Sep 2012	Year 2012	Spring	11:10	1.16	
GND1078	TRC111899	19 Jul 2011	Year 2011	winter	13:38	0.97	
GND1078	TRC120334	02 Feb 2012	Year 2012	Summer	08:34	1.19	
GND1078	TRC121313	01 May 2012	Year 2012	Autumn	09:30	1.08	
GND1078	TRC122958	24 Sep 2012	Year 2012	Spring	09:55	1.06	
GND1079	TRC111906	20 Jul 2011	Year 2011	winter	14:25	1.2	
GND1079	TRC120451	10 Feb 2012	Year 2012	Summer	09:30	1.3	
GND1079	TRC121357	03 May 2012	Year 2012	Autumn	11:40	1.08	
GND1079	TRC123059	28 Sep 2012	Year 2012	Spring	12:00	1	

Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND1080	TRC111904	20 Jul 2011	Year 2011	winter	13:16	0.41	
GND1080	TRC120446	09 Feb 2012	Year 2012	Summer	14:55	<0.01	
GND1080	TRC121356	03 May 2012	Year 2012	Autumn	10:35	<0.01	
GND1080	TRC123057	28 Sep 2012	Year 2012	Spring	12:40	<0.01	
GND1081	TRC111902	20 Jul 2011	Year 2011	winter	11:05	2.7	
GND1081	TRC120403	09 Feb 2012	Year 2012	Summer	11:50	0.34	
GND1081	TRC121317	01 May 2012	Year 2012	Autumn	12:10	2.52	
GND1081	TRC123116	03 Oct 2012	Year 2012	Spring	09:40	2.89	
GND1082	TRC111903	20 Jul 2011	Year 2011	winter	12:25	1.69	
GND1082	TRC120445	09 Feb 2012	Year 2012	Summer	14:10	5.45	
GND1082	TRC121355	03 May 2012	Year 2012	Autumn	11:00	4.81	
GND1082	TRC123118	03 Oct 2012	Year 2012	Spring	10:30	4.88	
GND1083	TRC111911	21 Jul 2011	Year 2011	winter	14:12	1.06	
GND1083	TRC120339	02 Feb 2012	Year 2012	Summer	11:30	1.34	
GND1083	TRC121316	01 May 2012	Year 2012	Autumn	11:20	1.27	
GND1083	TRC122962	24 Sep 2012	Year 2012	Spring	11:35	1.56	
GND1084	TRC111907	20 Jul 2011	Year 2011	winter	15:18	2.76	
GND1084	TRC120338	02 Feb 2012	Year 2012	Summer	10:55	0.88	
GND1086	TRC111927	01 Aug 2011	Year 2011	winter	13:06	1.4	
GND1086	TRC120453	10 Feb 2012	Year 2012	Summer	11:00	1.54	
GND1086	TRC121332	02 May 2012	Year 2012	Autumn	12:40	4.05	
GND1086	TRC123032	27 Sep 2012	Year 2012	Spring	11:40	1.51	
GND1087	TRC111925	01 Aug 2011	Year 2011	winter	11:02	5.94	
GND1087	TRC120444	09 Feb 2012	Year 2012	Summer	13:20	5.41	
GND1087	TRC121336	02 May 2012	Year 2012	Autumn	11:50	5.29	
GND1087	TRC123033	27 Sep 2012	Year 2012	Spring	12:00	5.29	
GND1088	TRC090857	06 Mar 2009	Year 2009	Autumn	09:52	0.32	
GND1088	TRC111929	01 Aug 2011	Year 2011	winter	14:10	1.04	
GND1088	TRC120400	09 Feb 2012	Year 2012	Summer	13:00	0.75	
GND1088	TRC121329	02 May 2012	Year 2012	Autumn	10:35	0.88	
GND1088	TRC123029	27 Sep 2012	Year 2012	Spring	10:25	0.69	
GND1090	TRC111932	02 Aug 2011	Year 2011	winter	12:38	1.96	
GND1090	TRC120401	09 Feb 2012	Year 2012	Summer	13:40	2.45	
GND1090	TRC121331	02 May 2012	Year 2012	Autumn	10:55	4.08	
GND1090	TRC123034	27 Sep 2012	Year 2012	Spring	12:30	6.78	
GND1091	TRC111933	02 Aug 2011	Year 2011	winter	13:10	1.77	
GND1091	TRC120404	09 Feb 2012	Year 2012	Summer	12:20	1.93	
GND1091	TRC121318	01 May 2012	Year 2012	Autumn	11:50	1.88	
GND1091	TRC123117	03 Oct 2012	Year 2012	Spring	09:20	1.96	
GND1092	TRC111928	01 Aug 2011	Year 2011	winter	13:46	9.89	
GND1092	TRC120399	09 Feb 2012	Year 2012	Summer	13:20	9.88	
GND1092	TRC121330	02 May 2012	Year 2012	Autumn	10:20	4.76	

Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND1092	TRC123030	27 Sep 2012	Year 2012	Spring	10:45	7.84	
GND1093	TRC111930	01 Aug 2011	Year 2011	winter	14:33	2.97	
GND1093	TRC120402	09 Feb 2012	Year 2012	Summer	13:40	2.07	
GND1093	TRC121328	02 May 2012	Year 2012	Autumn	09:45	2.08	
GND1093	TRC123028	27 Sep 2012	Year 2012	Spring	10:00	2.11	
GND1095	TRC111937	03 Aug 2011	Year 2011	winter	11:30	2.87	
GND1095	TRC120622	20 Feb 2012	Year 2012	Summer	11:35	2.8	
GND1095	TRC121453	16 May 2012	Year 2012	Autumn	11:35	2.81	
GND1095	TRC123047	28 Sep 2012	Year 2012	Spring	10:00	2.69	
GND1096	TRC111936	03 Aug 2011	Year 2011	winter	10:40	2.5	
GND1096	TRC120621	20 Feb 2012	Year 2012	Summer	12:00	1.65	
GND1096	TRC121454	16 May 2012	Year 2012	Autumn	11:50	2.2	
GND1096	TRC123048	28 Sep 2012	Year 2012	Spring	10:10	2.51	
GND1097	TRC111939	03 Aug 2011	Year 2011	winter	12:55	2.47	
GND1097	TRC120614	20 Feb 2012	Year 2012	Summer	10:45	0.59	
GND1097	TRC121442	11 May 2012	Year 2012	Autumn	11:45	0.27	
GND1097	TRC123050	28 Sep 2012	Year 2012	Spring	10:50	1.7	
GND1098	TRC111938	03 Aug 2011	Year 2011	winter	12:10	2.23	
GND1098	TRC120623	20 Feb 2012	Year 2012	Summer	10:25	1.67	
GND1098	TRC121441	11 May 2012	Year 2012	Autumn	11:25	1.72	
GND1098	TRC123049	28 Sep 2012	Year 2012	Spring	10:40	1.94	
GND1099	TRC111919	27 Jul 2011	Year 2011	winter	14:30	1.25	
GND1099	TRC120618	20 Feb 2012	Year 2012	Summer	12:30	0.49	
GND1099	TRC121455	16 May 2012	Year 2012	Autumn	11:15	0.64	
GND1099	TRC123040	27 Sep 2012	Year 2012	Spring	14:55	0.96	
GND1100	TRC111920	27 Jul 2011	Year 2011	winter	14:56	2.67	
GND1100	TRC120619	20 Feb 2012	Year 2012	Summer	11:15	2.73	
GND1100	TRC121452	16 May 2012	Year 2012	Autumn	12:20	3.08	
GND1100	TRC123041	27 Sep 2012	Year 2012	Spring	15:05	2.4	
GND1101	TRC111940	03 Aug 2011	Year 2011	winter	13:35	8.07	
GND1101	TRC120615	20 Feb 2012	Year 2012	Summer	09:10	12.4	
GND1101	TRC121440	11 May 2012	Year 2012	Autumn	10:45	11.9	
GND1101	TRC123051	28 Sep 2012	Year 2012	Spring	11:20	10.8	
GND1102	TRC112039	23 Aug 2011	Year 2011	winter	11:30	<0.01	
GND1102	TRC120616	20 Feb 2012	Year 2012	Summer	08:20	<0.01	
GND1102	TRC121438	11 May 2012	Year 2012	Autumn	09:35	<0.01	
GND1102	TRC123054	28 Sep 2012	Year 2012	Spring	12:40	<0.01	
GND1103	TRC112040	23 Aug 2011	Year 2011	winter	11:56	No result	
GND1103	TRC120617	20 Feb 2012	Year 2012	Summer	08:35	2.92	
GND1103	TRC121439	11 May 2012	Year 2012	Autumn	10:00	2.97	
GND1103	TRC123053	28 Sep 2012	Year 2012	Spring	12:15	3.34	
GND1104	TRC112178	13 Sep 2011	Year 2011	Spring	12:50	5.53	

Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND1104	TRC120319	01 Feb 2012	Year 2012	Summer	07:50	5.16	
GND1104	TRC121295	30 Apr 2012	Year 2012	Autumn	09:15	5.64	
GND1104	TRC122963	24 Sep 2012	Year 2012	Spring	09:15	3.88	
GND1105	TRC112179	13 Sep 2011	Year 2011	Spring	13:35	17.1	
GND1105	TRC120295	31 Jan 2012	Year 2012	Summer	08:25	9.34	
GND1105	TRC121285	27 Apr 2012	Year 2012	Autumn	09:45	5.82	
GND1105	TRC123001	26 Sep 2012	Year 2012	Spring	12:40	12.4	
GND1108	TRC112276	22 Sep 2011	Year 2011	Spring	12:40	12.6	
GND1108	TRC120321	01 Feb 2012	Year 2012	Summer	08:45	10	
GND1108	TRC121297	30 Apr 2012	Year 2012	Autumn	09:45	10.2	
GND1108	TRC122964	24 Sep 2012	Year 2012	Spring	09:45	10.2	
GND1110	TRC090845	05 Mar 2009	Year 2009	Autumn	14:14	9.1	
GND1110	TRC112042	23 Aug 2011	Year 2011	winter	14:30	7.22	
GND1110	TRC120328	01 Feb 2012	Year 2012	Summer	11:45	7.2	
GND1110	TRC121303	30 Apr 2012	Year 2012	Autumn	12:20	10.2	
GND1110	TRC122971	24 Sep 2012	Year 2012	Spring	12:45	10.2	
GND1112	TRC090817	04 Mar 2009	Year 2009	Autumn	13:35	16.5	
GND1112	TRC112238	19 Sep 2011	Year 2011	Spring	11:40	16.6	
GND1112	TRC120327	01 Feb 2012	Year 2012	Summer	11:20	26.1	
GND1112	TRC121302	30 Apr 2012	Year 2012	Autumn	12:45	24.3	
GND1112	TRC122970	24 Sep 2012	Year 2012	Spring	12:10	22.5	
GND1113	TRC112181	13 Sep 2011	Year 2011	Spring	14:55	4.83	
GND1113	TRC120294	31 Jan 2012	Year 2012	Summer	08:05	5.06	
GND1113	TRC121284	27 Apr 2012	Year 2012	Autumn	09:15	5.63	
GND1113	TRC123000	26 Sep 2012	Year 2012	Spring	12:25	4.88	
GND1114	TRC112275	22 Sep 2011	Year 2011	Spring	11:20	8.53	
GND1114	TRC120323	01 Feb 2012	Year 2012	Summer	09:45	4.27	
GND1114	TRC121299	30 Apr 2012	Year 2012	Autumn	11:00	2.95	
GND1114	TRC122967	24 Sep 2012	Year 2012	Spring	10:30	5.31	
GND1115	TRC112239	19 Sep 2011	Year 2011	Spring	12:10	2.87	
GND1115	TRC120299	31 Jan 2012	Year 2012	Summer	09:50	2.23	
GND1115	TRC121289	27 Apr 2012	Year 2012	Autumn	11:05	2.09	
GND1115	TRC123077	01 Oct 2012	Year 2012	Spring	13:35	3.03	
GND1116	TRC112240	19 Sep 2011	Year 2011	Spring	12:45	4.51	
GND1116	TRC120300	31 Jan 2012	Year 2012	Summer	10:05	4.6	
GND1116	TRC121290	27 Apr 2012	Year 2012	Autumn	11:20	6.05	
GND1116	TRC123006	26 Sep 2012	Year 2012	Spring	14:15	5.05	
GND1117	TRC090818	04 Mar 2009	Year 2009	Autumn	14:14	1.22	
GND1117	TRC112241	19 Sep 2011	Year 2011	Spring	13:15	1.53	
GND1117	TRC120301	31 Jan 2012	Year 2012	Summer	10:25	2.75	
GND1117	TRC121291	27 Apr 2012	Year 2012	Autumn	11:45	1.9	
GND1117	TRC123007	26 Sep 2012	Year 2012	Spring	14:35	2.11	

Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND1118	TRC112242	19 Sep 2011	Year 2011	Spring	13:55	7.58	
GND1118	TRC120302	31 Jan 2012	Year 2012	Summer	10:45	8.86	
GND1118	TRC121292	27 Apr 2012	Year 2012	Autumn	12:00	11.5	
GND1118	TRC123008	26 Sep 2012	Year 2012	Spring	14:55	10.5	
GND1119	TRC112243	19 Sep 2011	Year 2011	Spring	14:49	5.64	
GND1119	TRC120298	31 Jan 2012	Year 2012	Summer	09:35	5.78	
GND1119	TRC121288	27 Apr 2012	Year 2012	Autumn	10:45	7.22	
GND1119	TRC123005	26 Sep 2012	Year 2012	Spring	13:55	7.52	
GND1120	TRC090816	04 Mar 2009	Year 2009	Autumn	12:25	1.67	
GND1120	TRC112180	13 Sep 2011	Year 2011	Spring	14:20	3.71	
GND1120	TRC120303	31 Jan 2012	Year 2012	Summer	11:00	2.14	
GND1120	TRC121293	27 Apr 2012	Year 2012	Autumn	12:25	3.58	
GND1120	TRC123009	26 Sep 2012	Year 2012	Spring	15:20	1.96	
GND1121	TRC112279	22 Sep 2011	Year 2011	Spring	14:40	0.01	
GND1121	TRC120296	31 Jan 2012	Year 2012	Summer	08:46	<0.01	
GND1121	TRC121286	27 Apr 2012	Year 2012	Autumn	10:00	5.36	
GND1121	TRC123002	26 Sep 2012	Year 2012	Spring	13:10	7	
GND1122	TRC112106	01 Sep 2011	Year 2011	Spring	13:05	0.015	
GND1122	TRC120532	14 Feb 2012	Year 2012	Summer	12:45	0.5	
GND1122	TRC121351	03 May 2012	Year 2012	Autumn	12:50	0.4	
GND1122	TRC123086	01 Oct 2012	Year 2012	Spring	10:45	1.02	
GND1123	TRC112107	01 Sep 2011	Year 2011	Spring	12:48	16.4	
GND1123	TRC120533	14 Feb 2012	Year 2012	Summer	12:55	6.59	
GND1123	TRC121352	03 May 2012	Year 2012	Autumn	12:55	6.71	
GND1123	TRC123087	01 Oct 2012	Year 2012	Spring	10:55	9.2	
GND1124	TRC112072	29 Aug 2011	Year 2011	winter	13:10	7.14	
GND1124	TRC120561	14 Feb 2012	Year 2012	Summer	10:40	5.34	
GND1124	TRC121379	08 May 2012	Year 2012	Autumn	12:10	4.95	
GND1124	TRC123084	01 Oct 2012	Year 2012	Spring	11:30	4.78	
GND1135	TRC112092	30 Aug 2011	Year 2011	winter	12:50	0.89	
GND1135	TRC120539	14 Feb 2012	Year 2012	Summer	11:25	0.02	
GND1135	TRC121348	03 May 2012	Year 2012	Autumn	11:45	0.02	
GND1135	TRC123094	01 Oct 2012	Year 2012	Spring	13:15	0.44	
GND1192	TRC112109	01 Sep 2011	Year 2011	Spring	14:40	3.35	
GND1192	TRC120535	14 Feb 2012	Year 2012	Summer	09:40	2.92	
GND1192	TRC121345	03 May 2012	Year 2012	Autumn	09:50	3.5	
GND1192	TRC123090	01 Oct 2012	Year 2012	Spring	11:55	3.01	
GND1193	TRC112108	01 Sep 2011	Year 2011	Spring	13:42	4.37	
GND1193	TRC120540	14 Feb 2012	Year 2012	Summer	12:30	4.75	
GND1193	TRC121350	03 May 2012	Year 2012	Autumn	09:30	4.5	
GND1193	TRC123088	01 Oct 2012	Year 2012	Spring	11:15	4.07	
GND1194	TRC112110	01 Sep 2011	Year 2011	Spring	15:15	2.72	

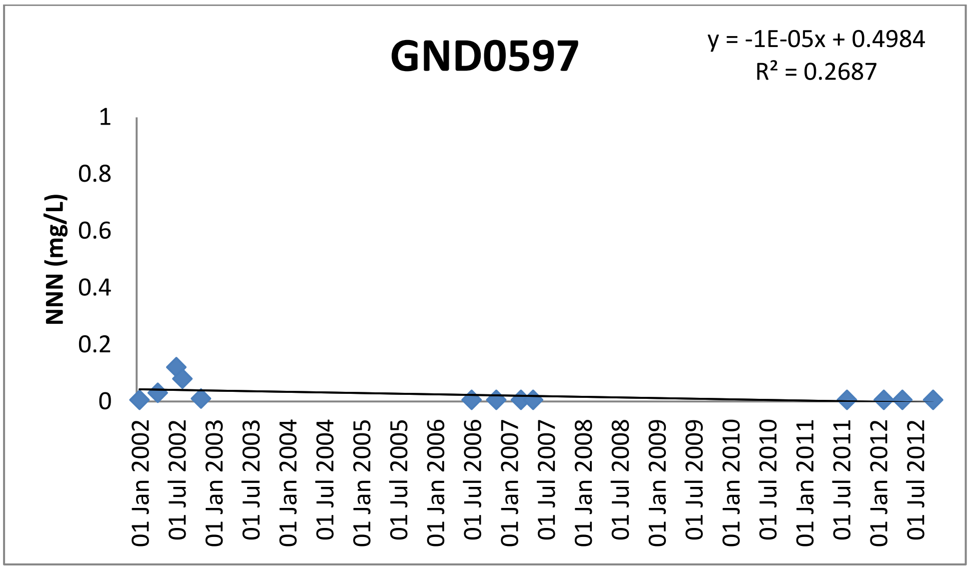
Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND1194	TRC120534	14 Feb 2012	Year 2012	Summer	13:10	2.67	
GND1194	TRC121353	03 May 2012	Year 2012	Autumn	13:25	2.18	
GND1194	TRC123089	01 Oct 2012	Year 2012	Spring	11:35	1.85	
GND1195	TRC112071	29 Aug 2011	Year 2011	winter	13:00	<0.01	
GND1195	TRC120562	14 Feb 2012	Year 2012	Summer	11:00	<0.01	
GND1195	TRC121380	08 May 2012	Year 2012	Autumn	12:50	<0.01	
GND1195	TRC123083	01 Oct 2012	Year 2012	Spring	11:00	<0.01	
GND1646	TRC120449	09 Feb 2012	Year 2012	Summer	10:00	0.17	
GND1756	TRC111908	21 Jul 2011	Year 2011	winter	10:50	1.3	
GND1759	TRC121296	30 Apr 2012	Year 2012	Autumn	10:05	2.39	
GND1759	TRC122965	24 Sep 2012	Year 2012	Spring	10:05	3.07	
GND1760	TRC112277	22 Sep 2011	Year 2011	Spring	13:18	6.43	
GND1760	TRC120320	01 Feb 2012	Year 2012	Summer	08:25	3	
GND1786	TRC112214	15 Sep 2011	Year 2011	Spring	15:25	1.1	
GND1786	TRC120322	01 Feb 2012	Year 2012	Summer	09:25	0.79	
GND1786	TRC121298	30 Apr 2012	Year 2012	Autumn	10:35	0.53	
GND1786	TRC122966	24 Sep 2012	Year 2012	Spring	10:55	0.76	
GND2113	TRC111905	20 Jul 2011	Year 2011	winter	13:50	0.13	
GND2113	TRC120452	10 Feb 2012	Year 2012	Summer	10:00	<0.01	
GND2113	TRC121358	03 May 2012	Year 2012	Autumn	09:10	<0.01	
GND2113	TRC123060	28 Sep 2012	Year 2012	Spring	13:50	<0.01	
GND2114	TRC111917	27 Jul 2011	Year 2011	winter	13:01	<0.01	
GND2114	TRC120447	09 Feb 2012	Year 2012	Summer	10:25	0.04	
GND2212	TRC111898	19 Jul 2011	Year 2011	winter	12:05	<0.01	
GND2212	TRC120335	02 Feb 2012	Year 2012	Summer	09:10	<0.01	
GND2212	TRC121314	01 May 2012	Year 2012	Autumn	10:05	<0.01	
GND2212	TRC122959	24 Sep 2012	Year 2012	Spring	10:18	<0.01	
GND2213	TRC111926	01 Aug 2011	Year 2011	winter	12:18	2.36	
GND2213	TRC120443	09 Feb 2012	Year 2012	Summer	12:45	2.68	
GND2213	TRC121335	02 May 2012	Year 2012	Autumn	12:05	2.99	
GND2213	TRC123031	27 Sep 2012	Year 2012	Spring	11:10	2.91	
GND2215	TRC111934	02 Aug 2011	Year 2011	winter	14:50	5.02	
GND2215	TRC120531	14 Feb 2012	Year 2012	Summer	08:35	5.16	
GND2215	TRC121344	03 May 2012	Year 2012	Autumn	08:55	4.04	
GND2215	TRC123076	01 Oct 2012	Year 2012	Spring	08:50	4.32	
GND2218	TRC112041	23 Aug 2011	Year 2011	winter	13:01	3.16	
GND2218	TRC120563	15 Feb 2012	Year 2012	Summer	13:10	5.42	
GND2218	TRC121437	11 May 2012	Year 2012	Autumn	10:20	4.31	
GND2218	TRC123052	28 Sep 2012	Year 2012	Spring	11:50	3.85	
GND2221	TRC112278	22 Sep 2011	Year 2011	Spring	14:01	5.29	
GND2221	TRC120297	31 Jan 2012	Year 2012	Summer	09:15	3.74	
GND2221	TRC121287	27 Apr 2012	Year 2012	Autumn	10:30	3.2	

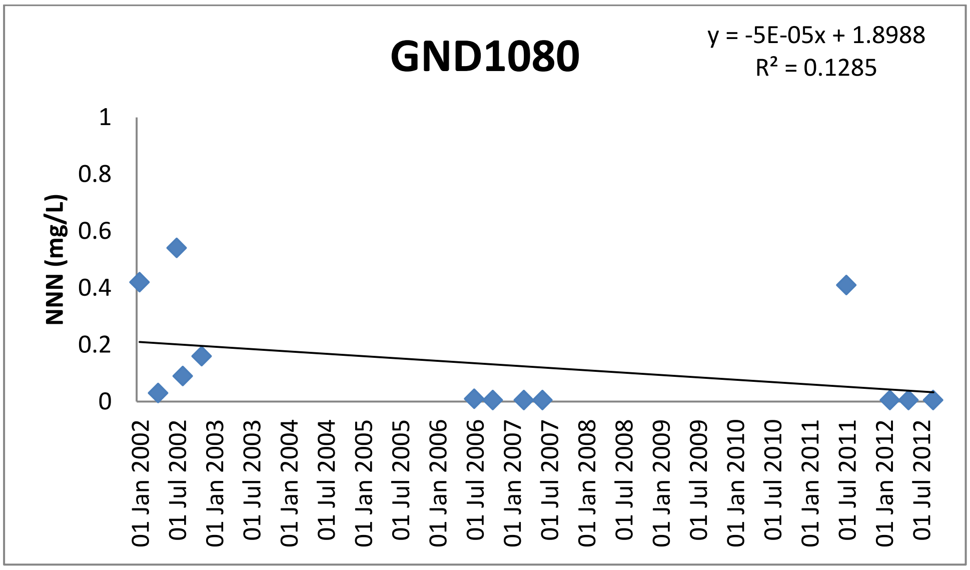
Site	**Sample**	**Date**	**Year**	**Season**	**Time**	**NNN**	**NO_3-N**
GND2221	TRC123004	26 Sep 2012	Year 2012	Spring	13:30	4.97	
GND3000	TRC090858	06 Mar 2009	Year 2009	Autumn	10:50	3.51	
GND3000	TRC120620	20 Feb 2012	Year 2012	Summer	13:30	2.39	
GND3000	TRC121443	11 May 2012	Year 2012	Autumn	12:05	2.9	
GND3000	TRC123046	28 Sep 2012	Year 2012	Spring	09:50	3.2	

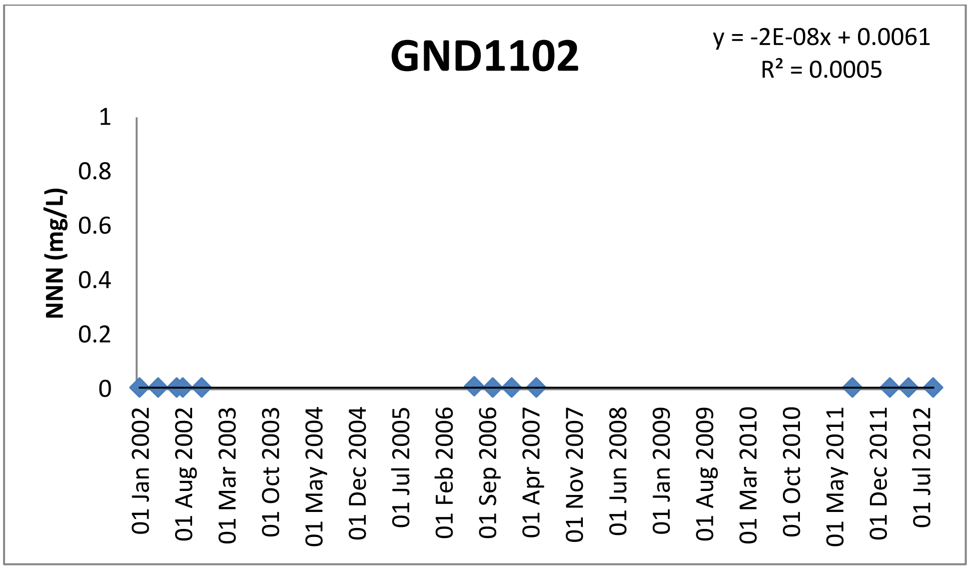
Appendix IV

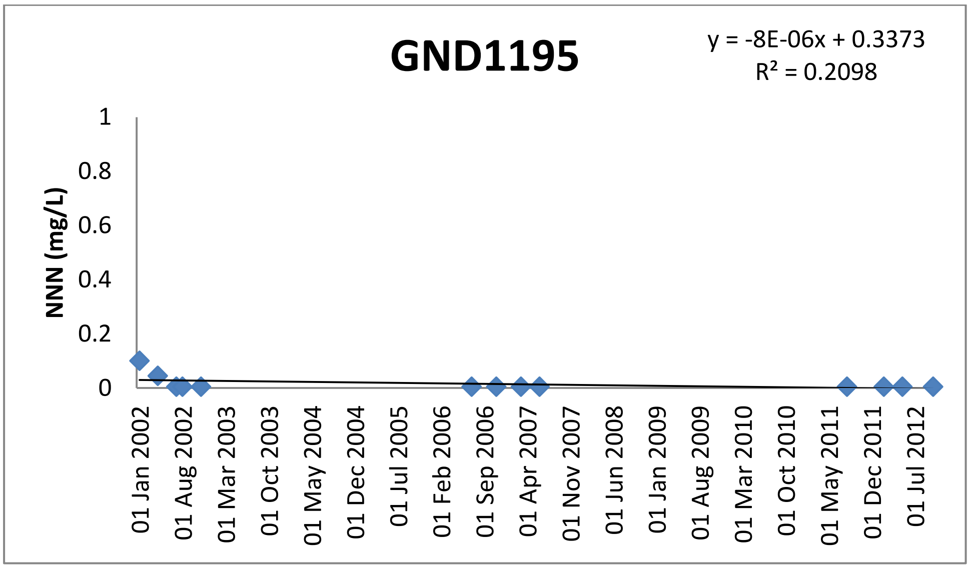
2002-2012 time-series plots

0 - 1 mg/L NNN concentration range:

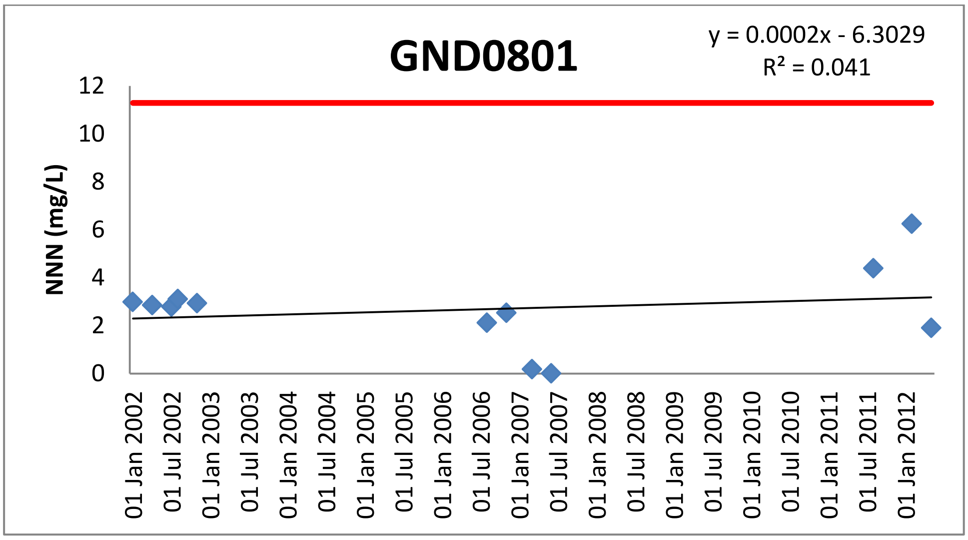


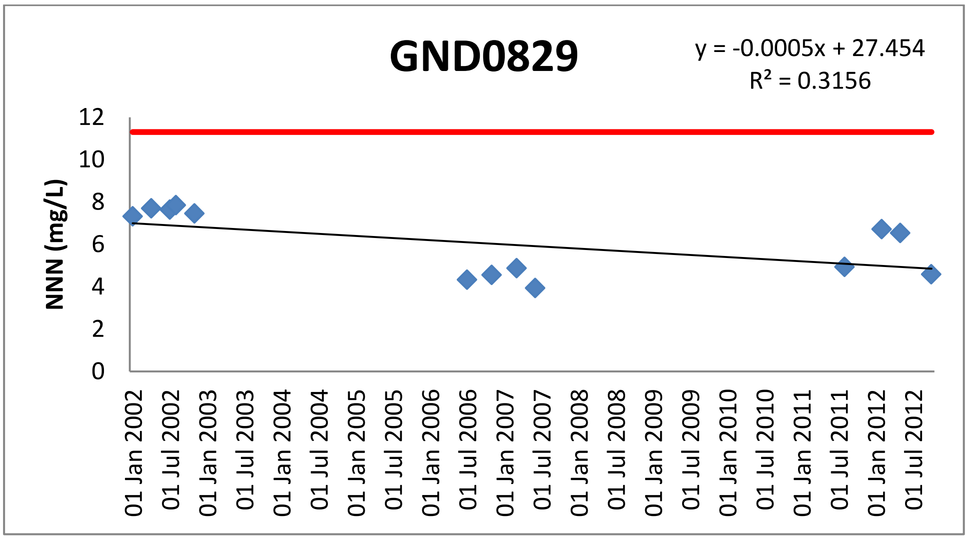


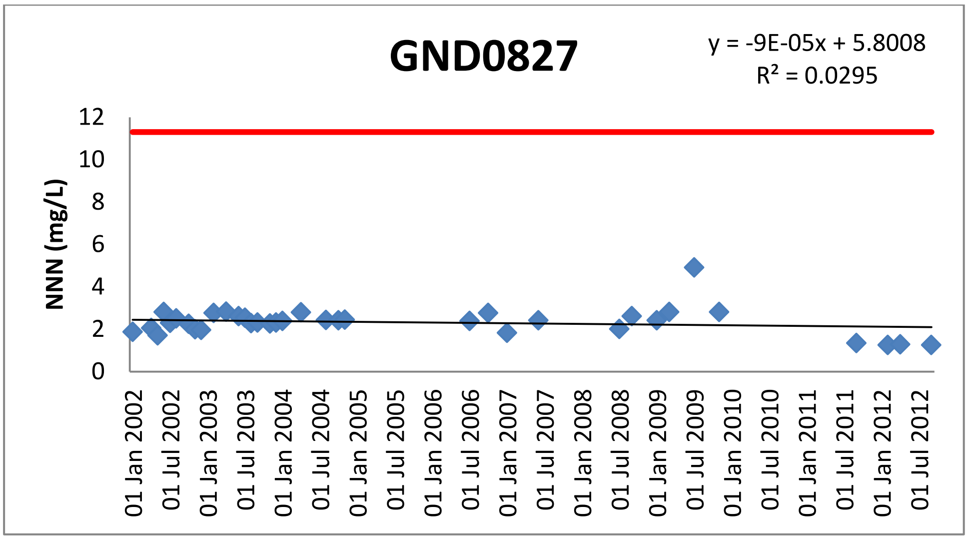


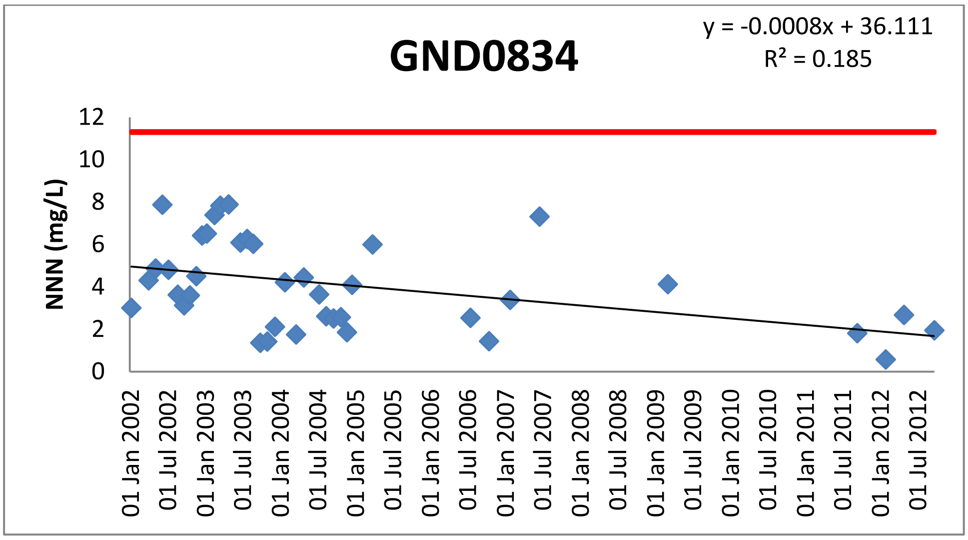

GND1195
y = -8E-06x + 0.3373
R² = 0.2098
NNN (mg/L)
1
0.8
0.6
0.4
0.2
0
01 Jan 2002
01 Aug 2002
01 Mar 2003
01 Oct 2003
01 May 2004
01 Dec 2004
01 Jul 2005
01 Feb 2006
01 Sep 2006
01 Apr 2007
01 Nov 2007
01 Jun 2008
01 Jan 2009
01 Aug 2009
01 Mar 2010
01 Oct 2010
01 May 2011
01 Dec 2011
01 Jul 2012

0 - 12 mg/L NNN concentration range (red line = MAV):








GND0834
y = -0.0008x + 36.111
R² = 0.185
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
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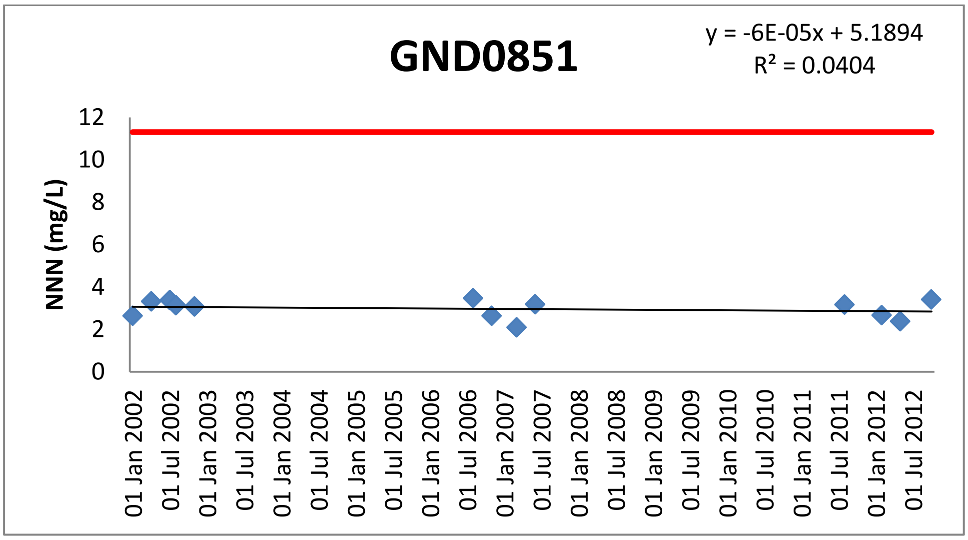
GND0851
y = -6E-05x + 5.1894
R² = 0.0404
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
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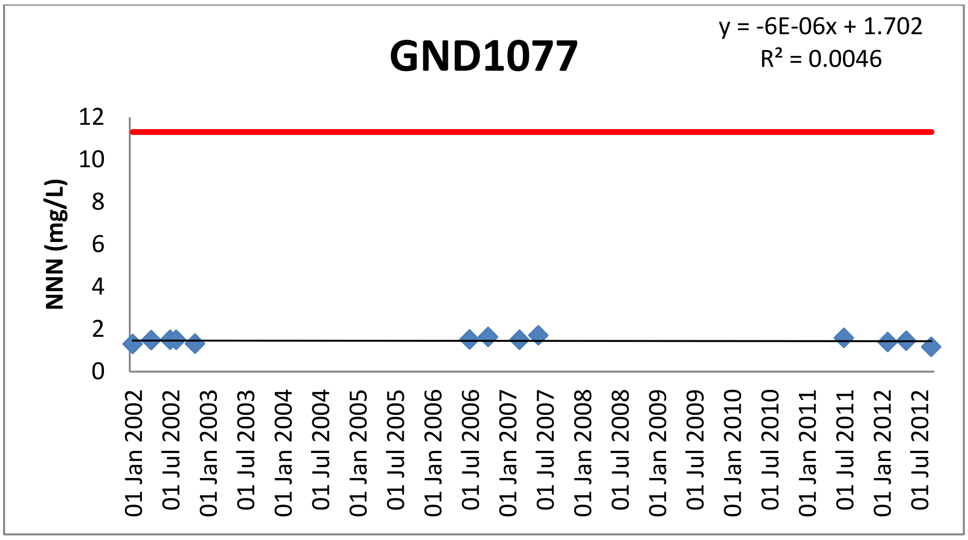
GND1077
y = -6E-06x + 1.702
R² = 0.0046
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
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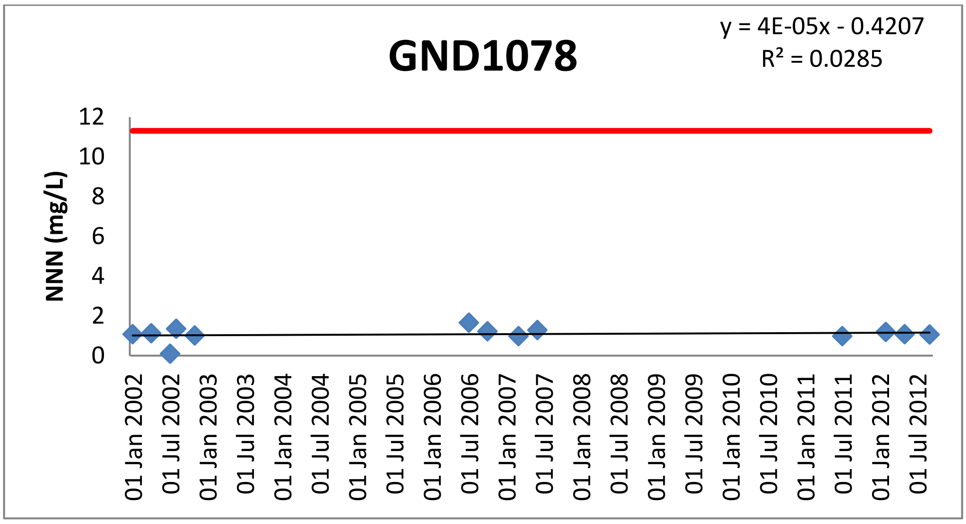
GND1078
y = 4E-05x - 0.4207
R² = 0.0285
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
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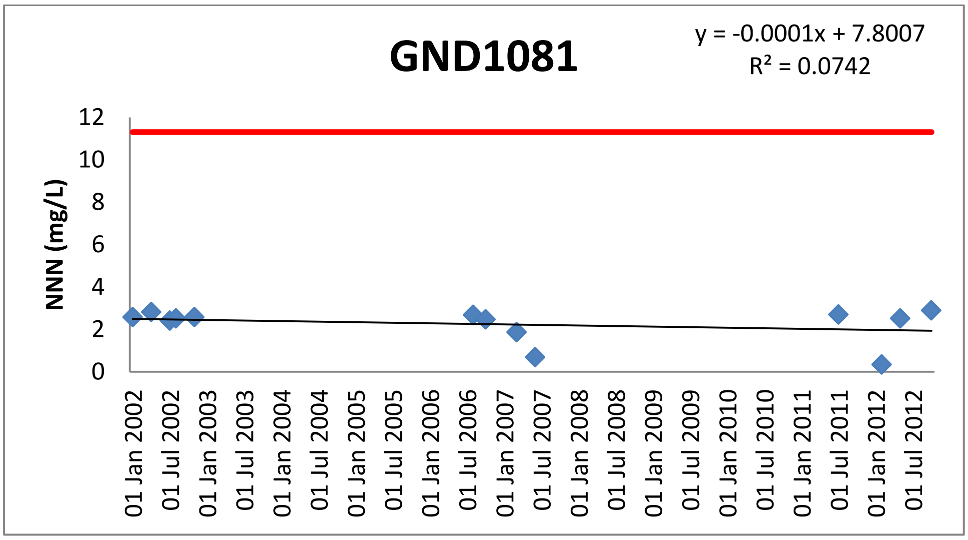
GND1081
y = -0.0001x + 7.8007
R² = 0.0742
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
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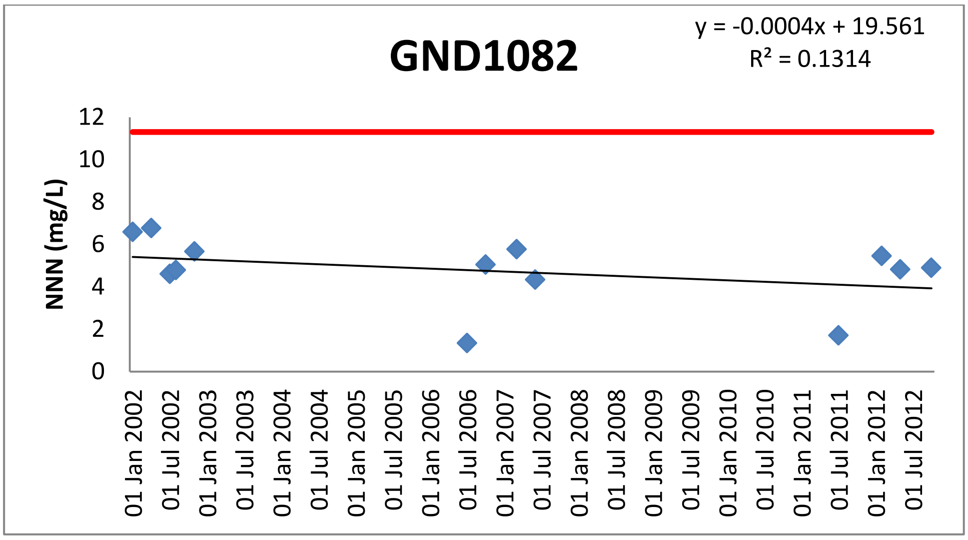
GND1082
y = -0.0004x + 19.561
R² = 0.1314
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
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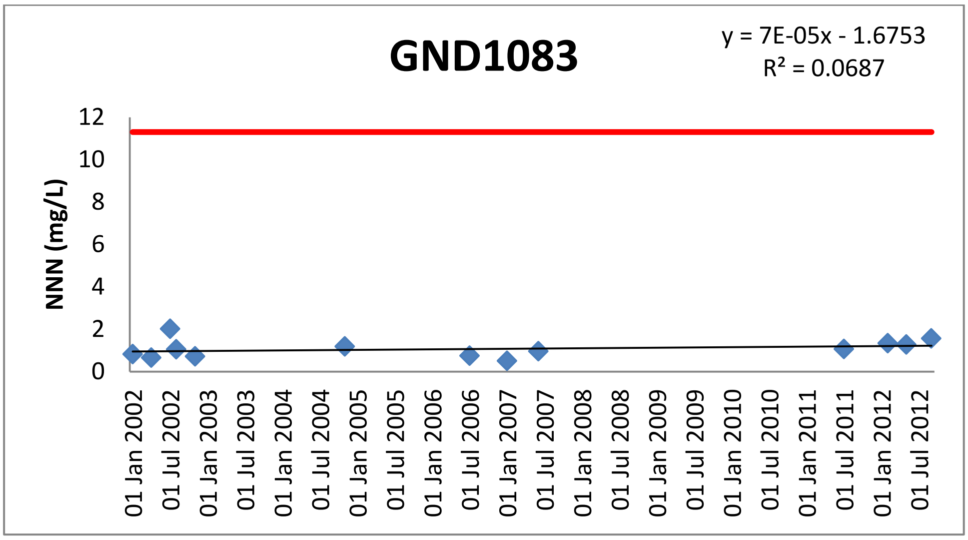
GND1083
y = 7E-05x - 1.6753
R² = 0.0687
NNN (mg/L)
0
2
4
6
8
10
12
01 Jan 2002
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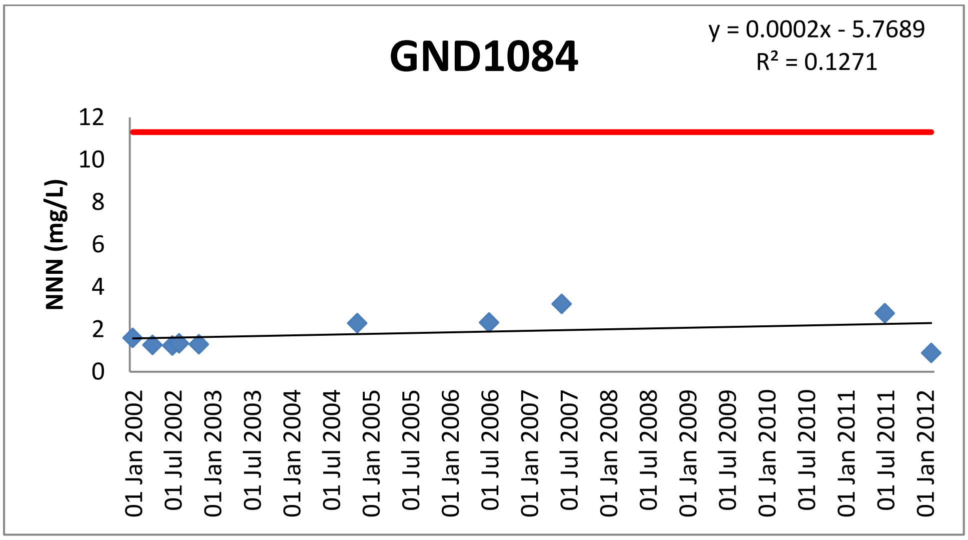
GND1084
y = 0.0002x - 5.7689
R² = 0.1271
NNN (mg/L)
0
2
4
6
8
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12
01 Jan 2002
01 Jul 2002
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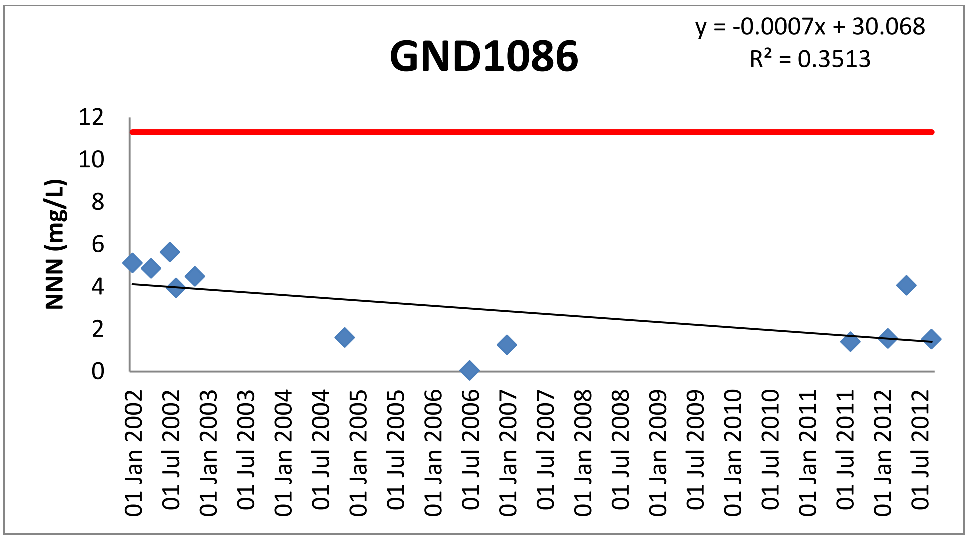
GND1086
y = -0.0007x + 30.068
R² = 0.3513
NNN (mg/L)
0
2
4
6
8
10
12
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
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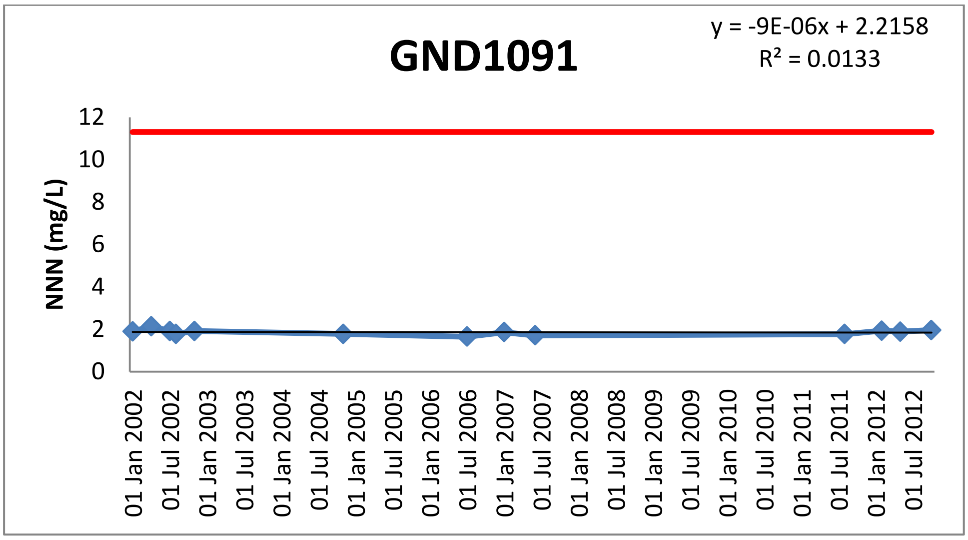
GND1091
y = -9E-06x + 2.2158
R² = 0.0133
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
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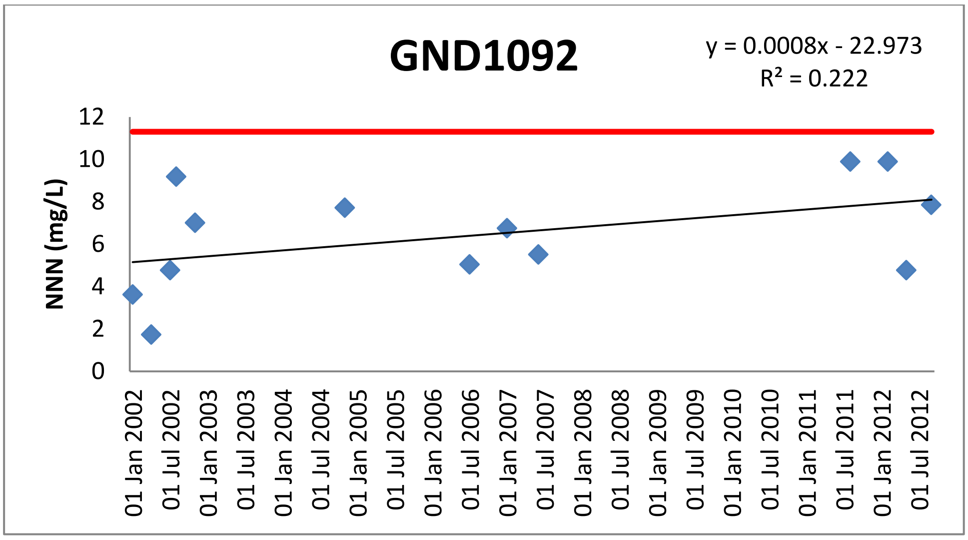
GND1092
y = 0.0008x - 22.973
R² = 0.222
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
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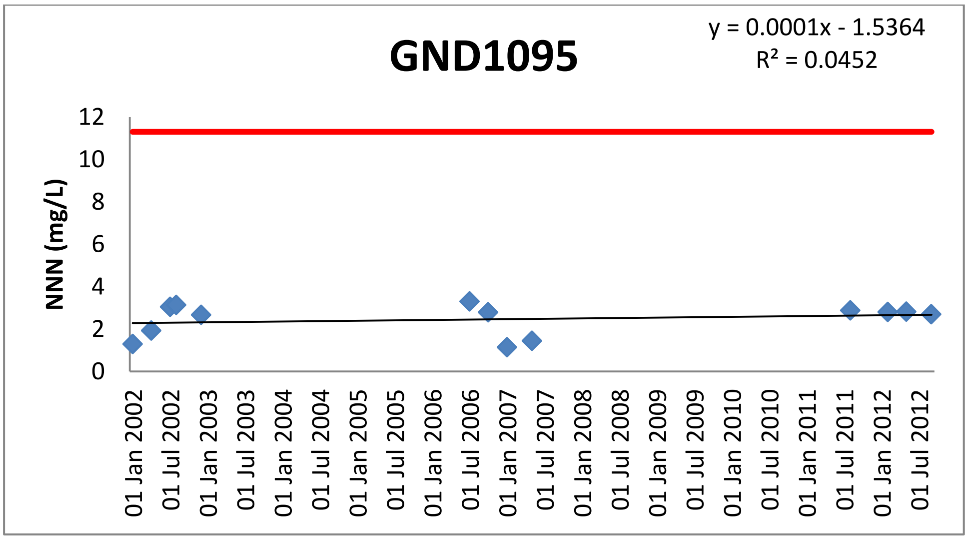
GND1095
y = 0.0001x - 1.5364
R² = 0.0452
NNN (mg/L)
12
10
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6
4
2
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
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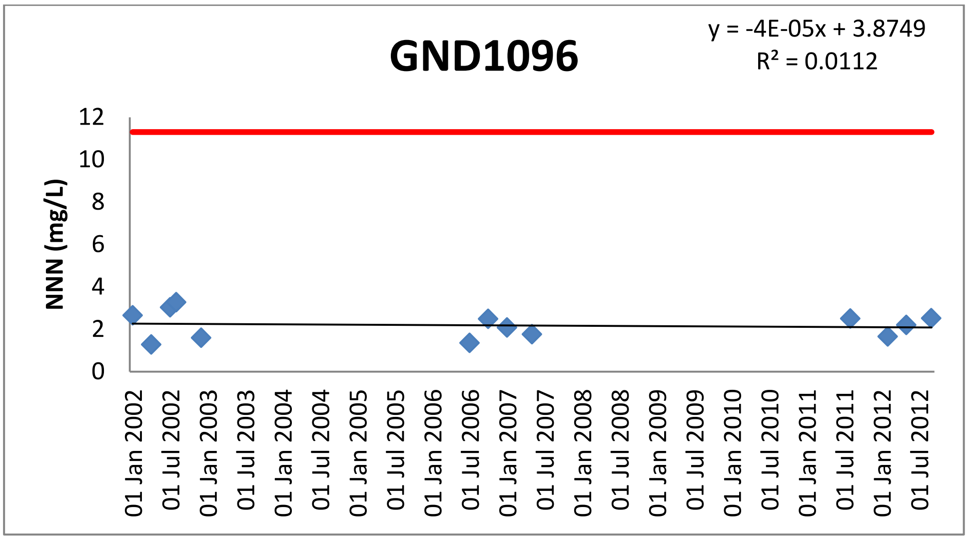
GND1096
y = -4E-05x + 3.8749
R² = 0.0112
NNN (mg/L)
0
2
4
6
8
10
12
01 Jan 2002
01 Jul 2002
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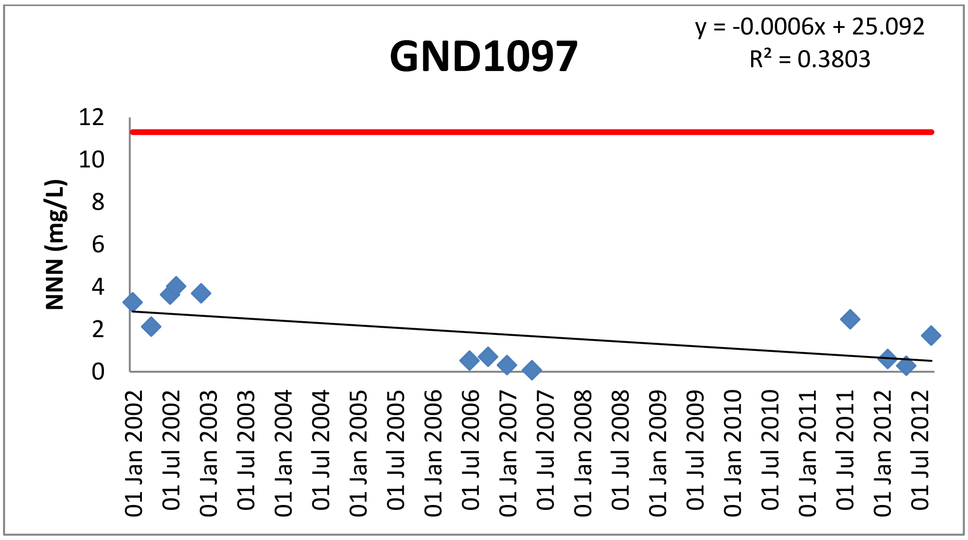
GND1097
y = -0.0006x + 25.092
R² = 0.3803
NNN (mg/L)
0
2
4
6
8
10
12
01 Jan 2002
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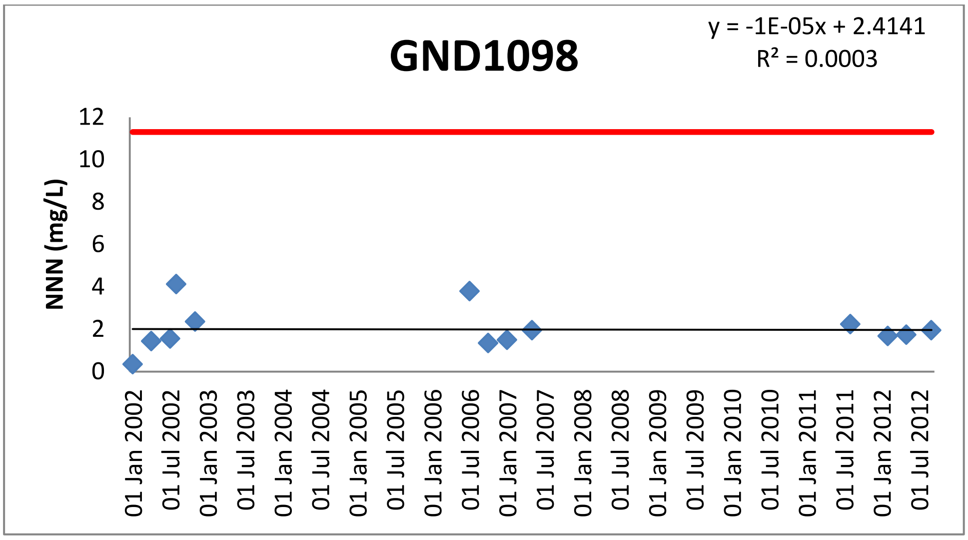
GND1098
y = -1E-05x + 2.4141
R² = 0.0003
NNN (mg/L)
0
2
4
6
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12
01 Jan 2002
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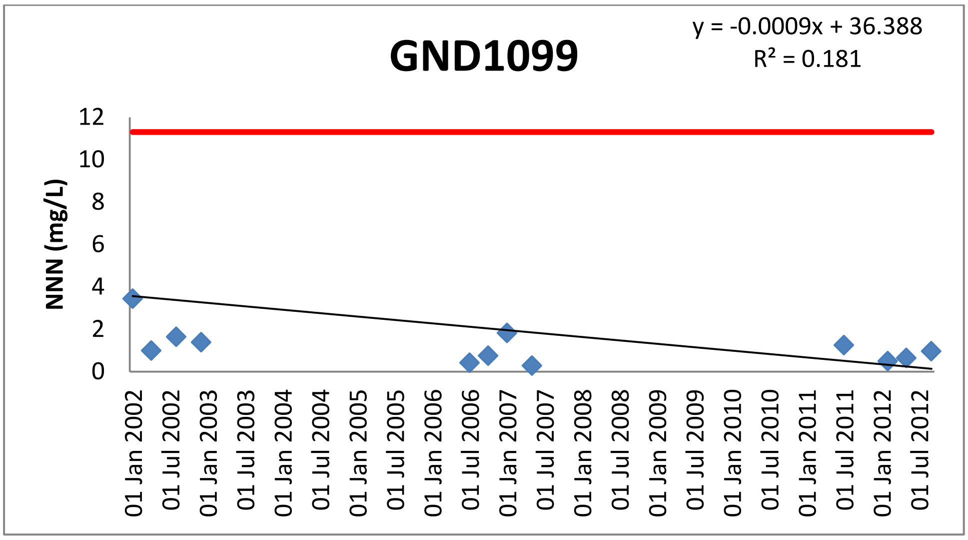
GND1099
y = -0.0009x + 36.388
R² = 0.181
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
01 Jul 2004
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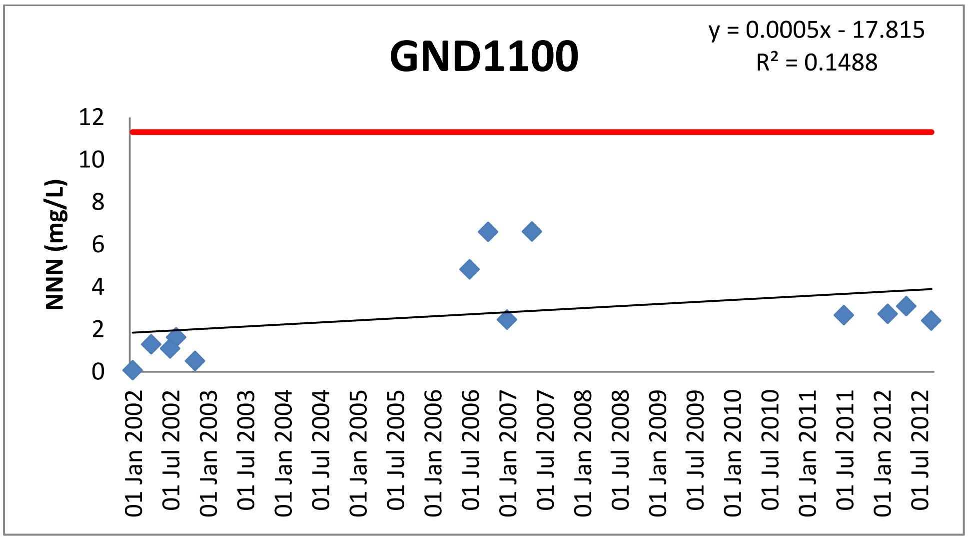
GND1100
y = 0.0005x - 17.815
R² = 0.1488
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
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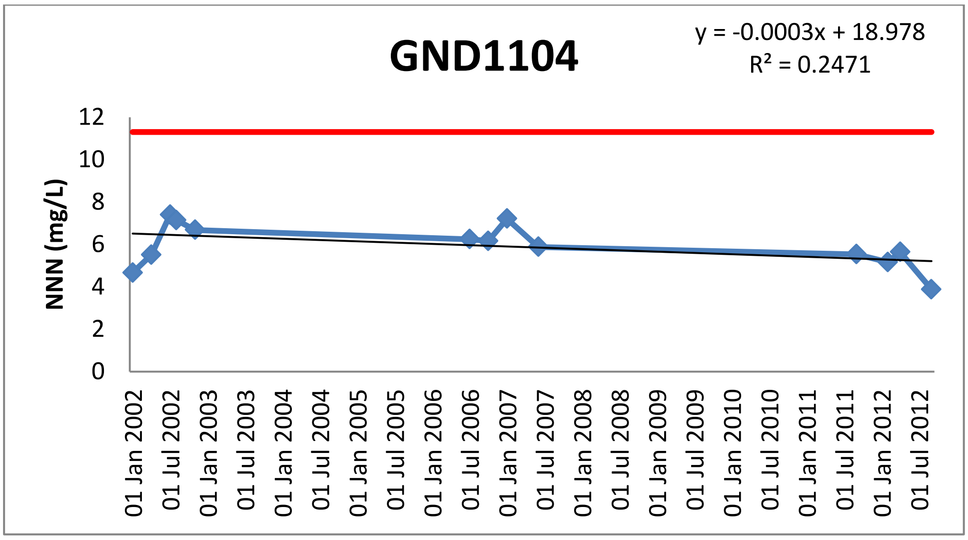
GND1104
y = -0.0003x + 18.978
R² = 0.2471
NNN (mg/L)
12
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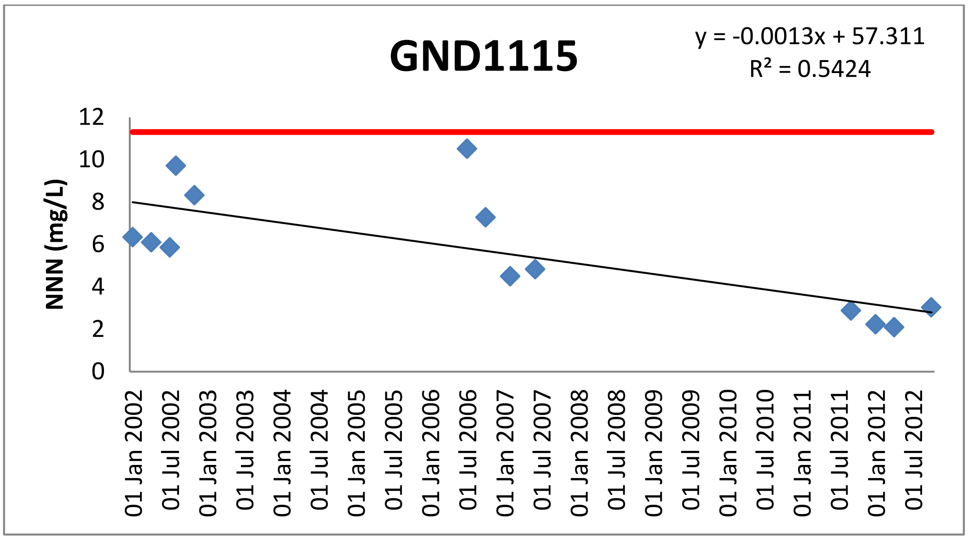
GND1115
y = -0.0013x + 57.311
R² = 0.5424
NNN (mg/L)
0
2
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12
01 Jan 2002
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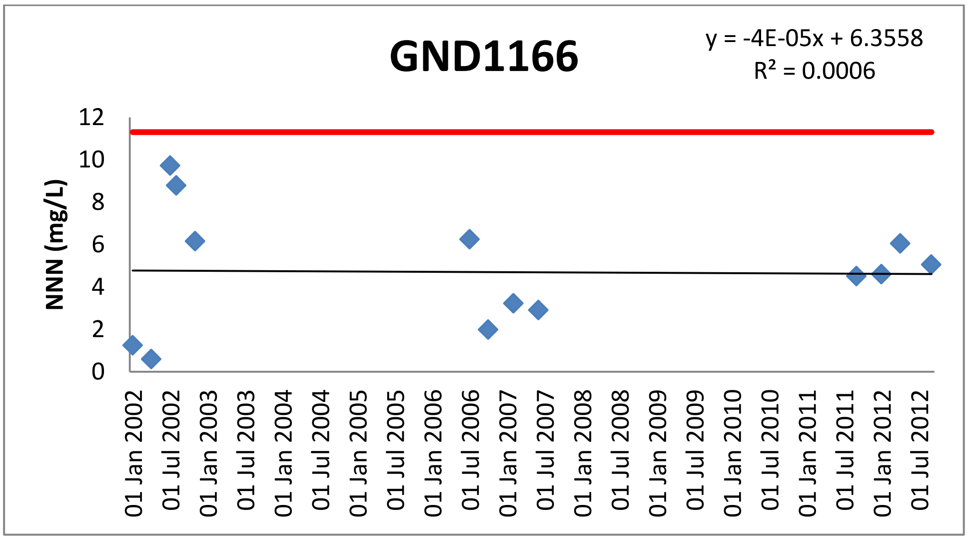
GND1166
y = -4E-05x + 6.3558
R² = 0.0006
NNN (mg/L)
0
2
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12
01 Jan 2002
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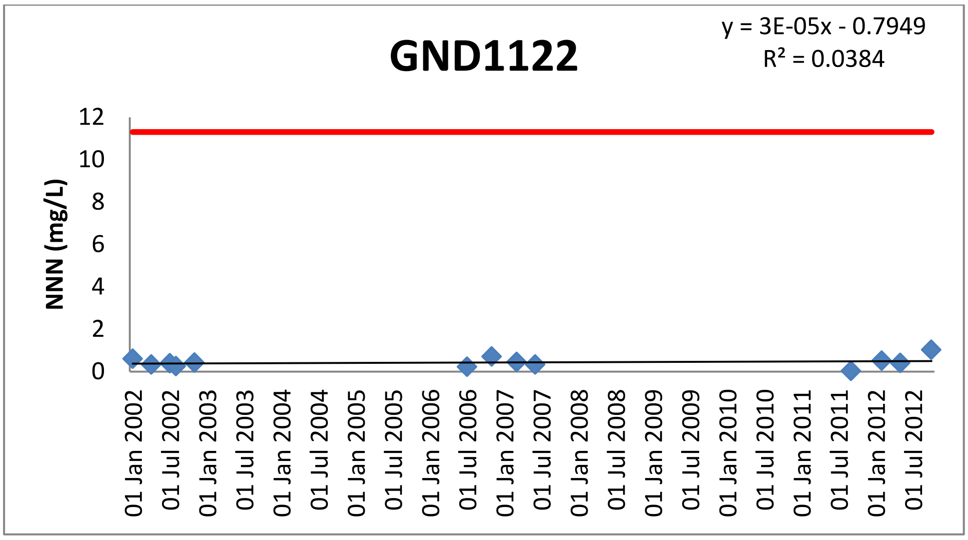
GND1122
y = 3E-05x - 0.7949
R² = 0.0384
NNN (mg/L)
0
2
4
6
8
10
12
01 Jan 2002
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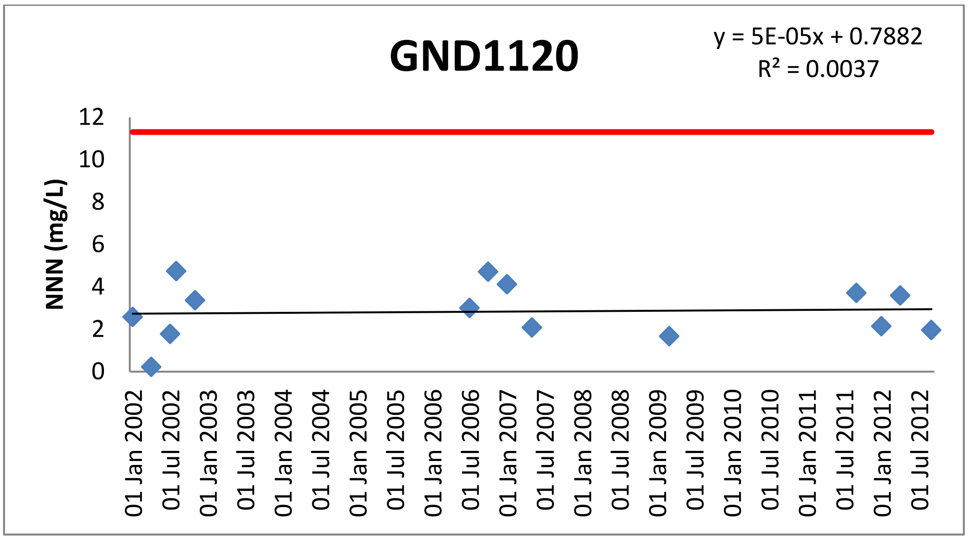
GND1120
y = 5E-05x + 0.7882
R² = 0.0037
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
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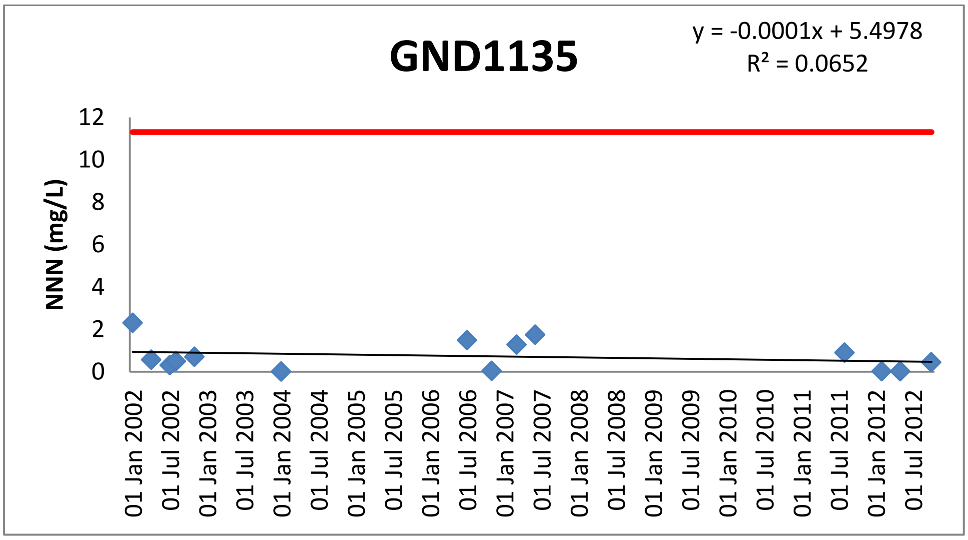
GND1135
y = -0.0001x + 5.4978
R² = 0.0652
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
01 Jul 2004
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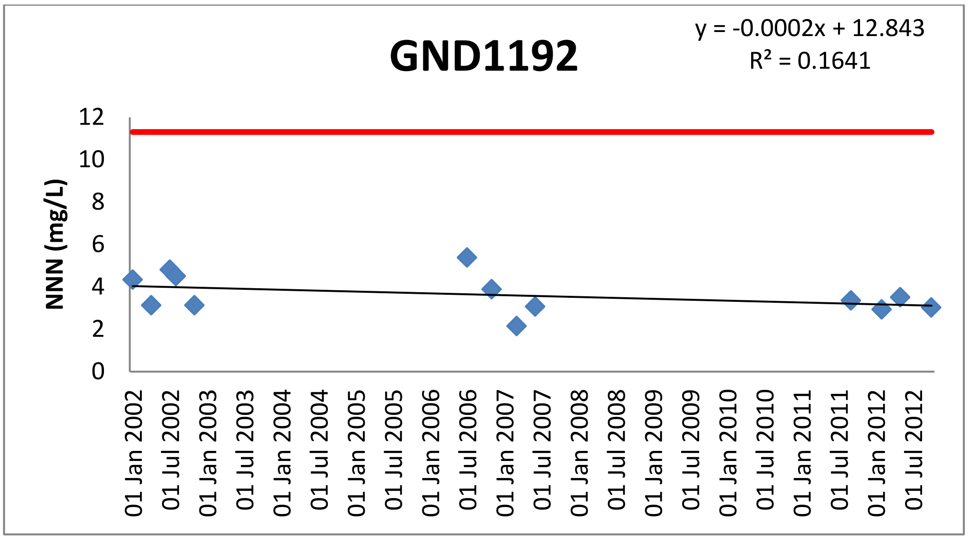
GND1192
y = -0.0002x + 12.843
R² = 0.1641
NNN (mg/L)
12
10
8
6
4
2
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
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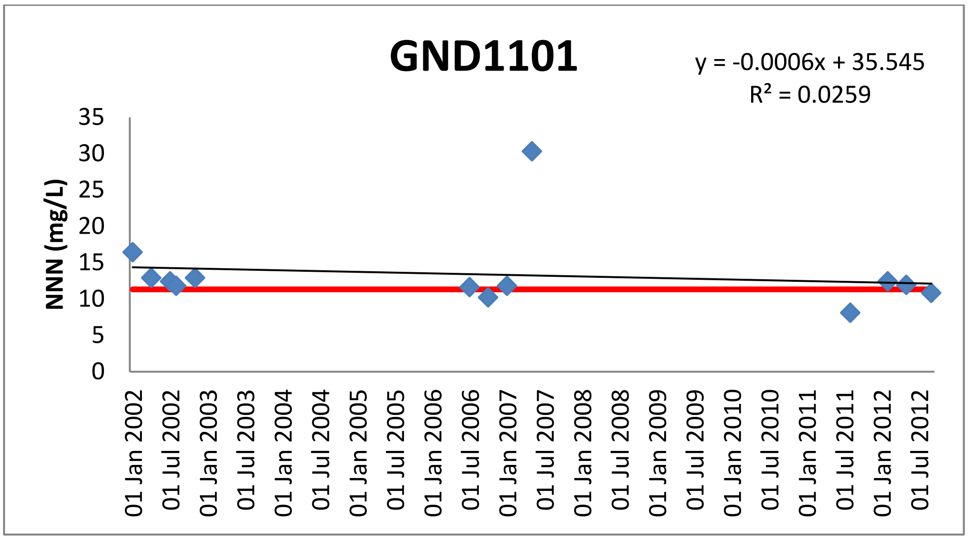
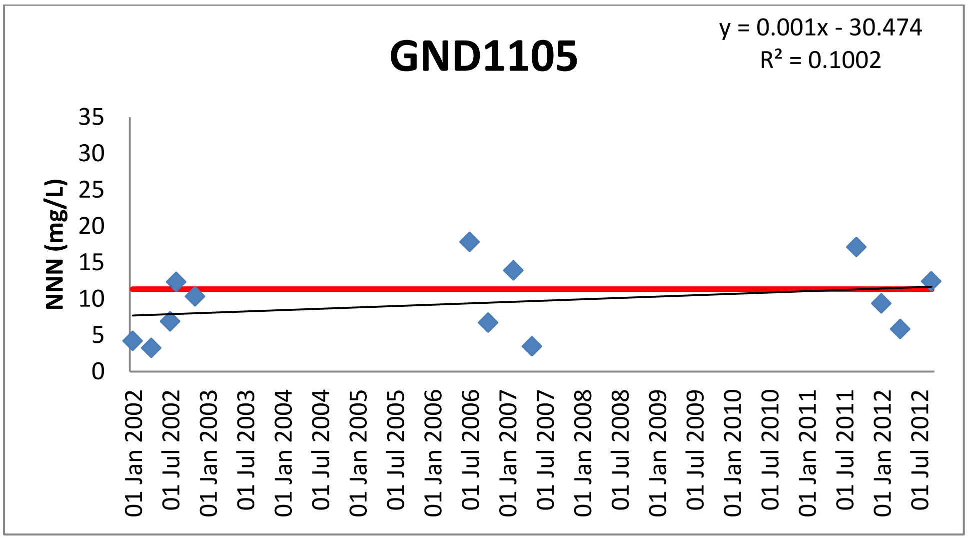
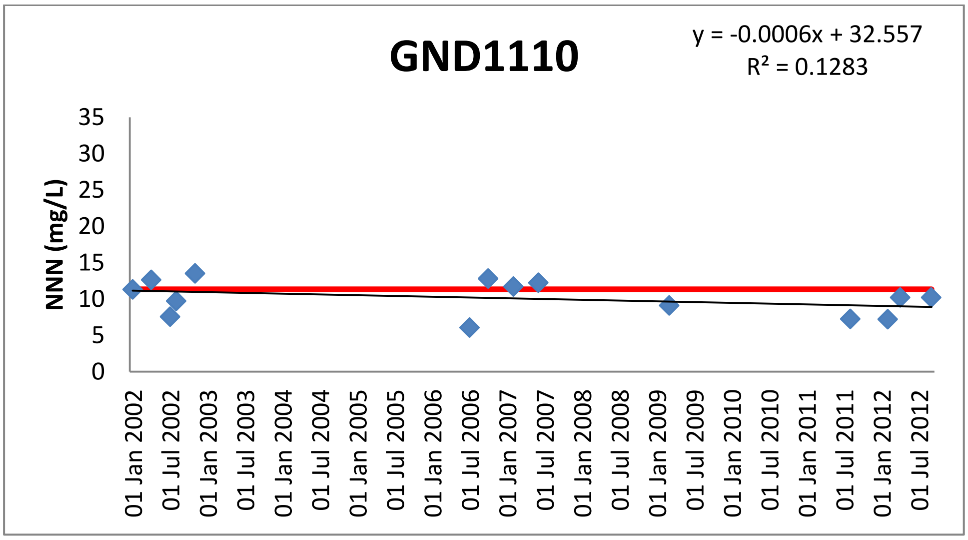
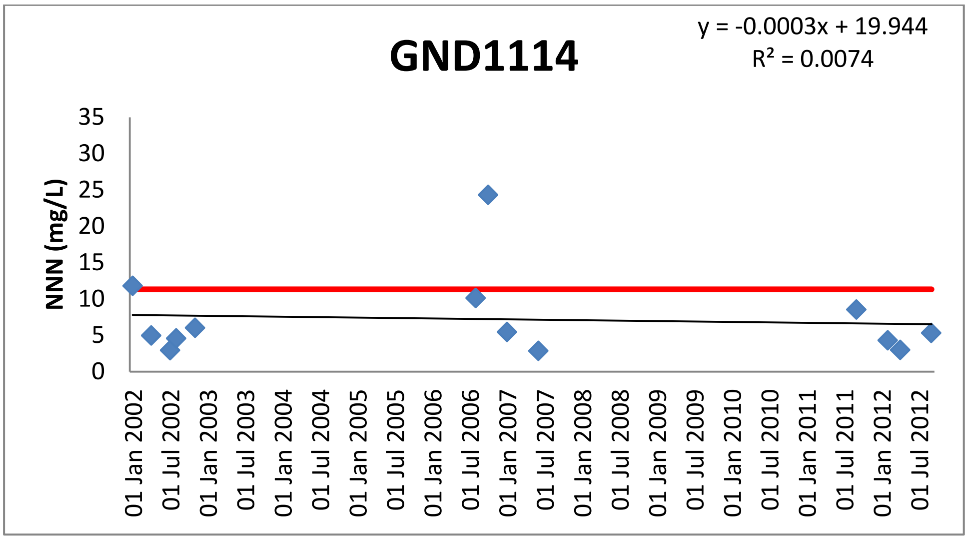
0 - 35 mg/L NNN concentration range (red line = MAV):








GND1114
y = -0.0003x + 19.944
R² = 0.0074
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
01 Jul 2004
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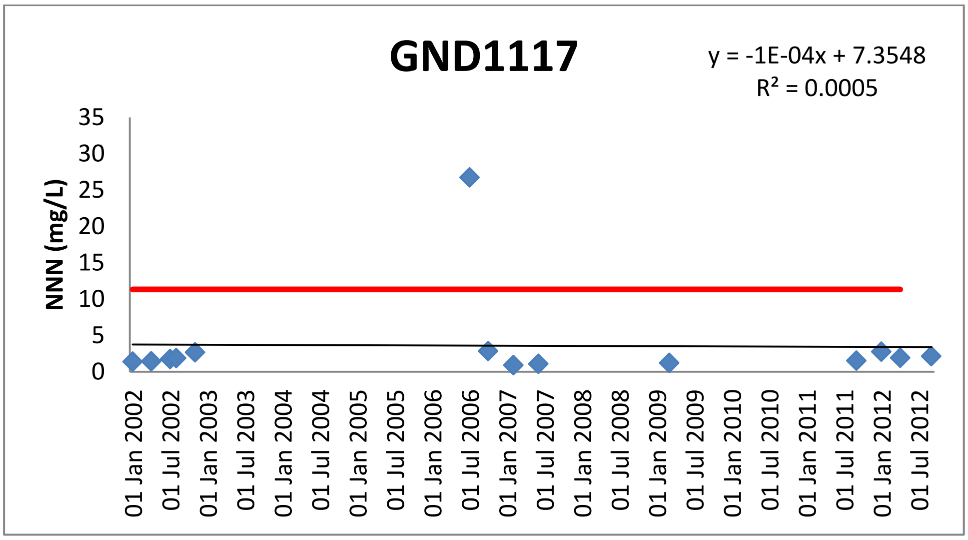
GND1117
y = -1E-04x + 7.3548
R² = 0.0005
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
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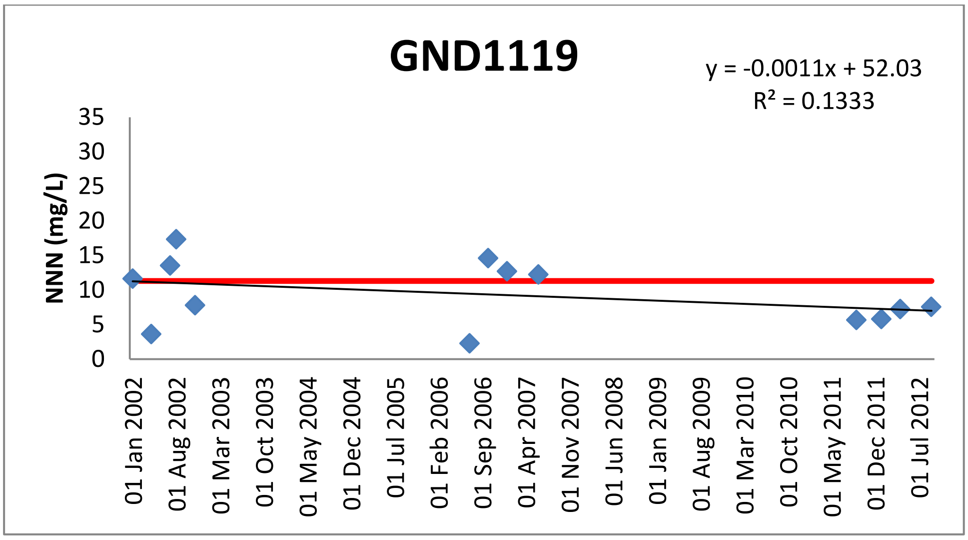
GND1119
y = -0.0011x + 52.03
R² = 0.1333
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Aug 2002
01 Mar 2003
01 Oct 2003
01 May 2004
01 Dec 2004
01 Jul 2005
01 Feb 2006
01 Sep 2006
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01 Nov 2007
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01 Aug 2009
01 Mar 2010
01 Oct 2010
01 May 2011
01 Dec 2011
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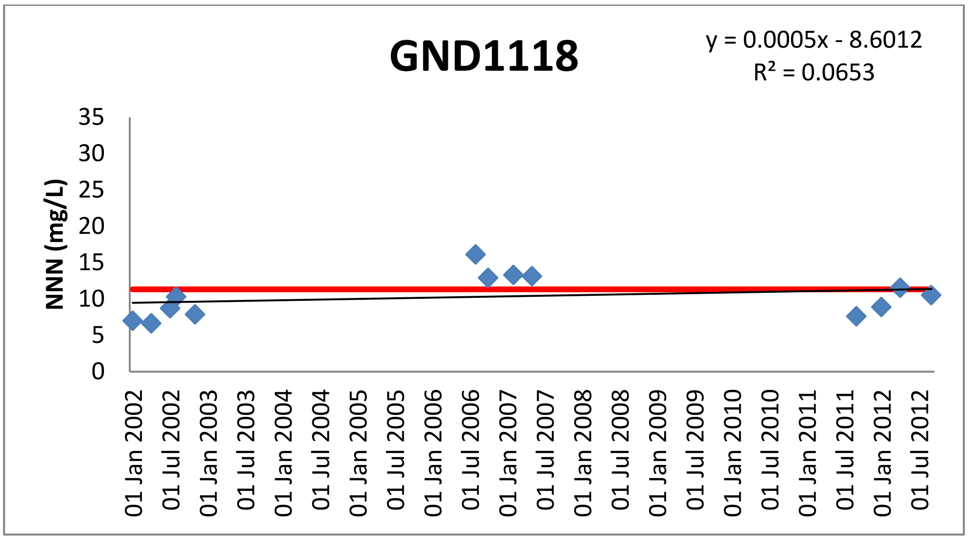
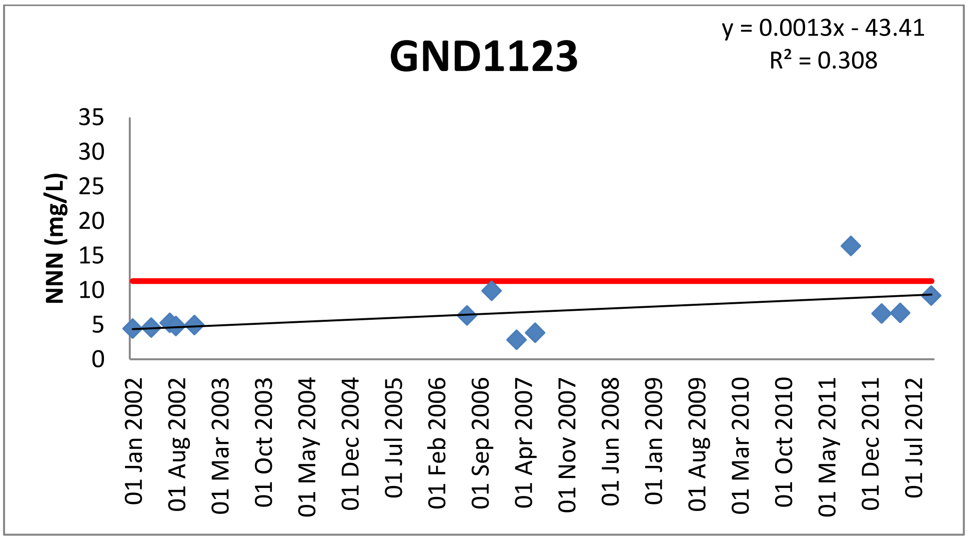
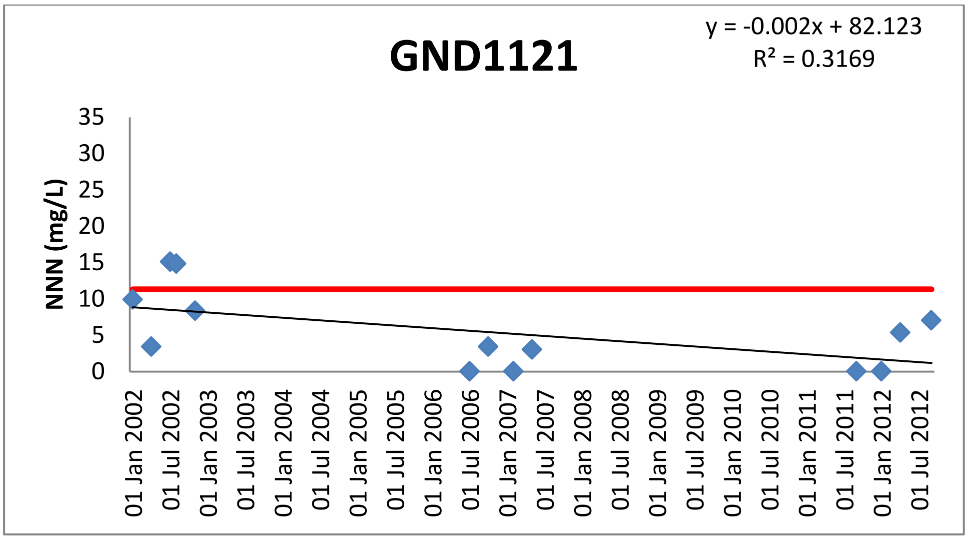
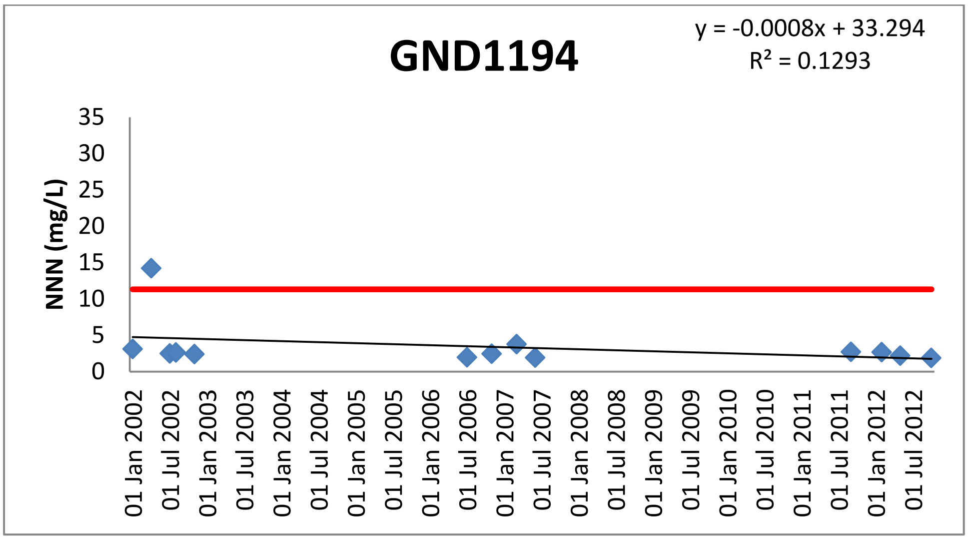

GND1118
y = 0.0005x - 8.6012
R² = 0.0653
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
01 Jul 2004
01 Jan 2005
01 Jul 2005
01 Jan 2006
01 Jul 2006
01 Jan 2007
01 Jul 2007
01 Jan 2008
01 Jul 2008
01 Jan 2009
01 Jul 2009
01 Jan 2010
01 Jul 2010
01 Jan 2011
01 Jul 2011
01 Jan 2012
01 Jul 2012


GND1123
y = 0.0013x - 43.41
R² = 0.308
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Aug 2002
01 Mar 2003
01 Oct 2003
01 May 2004
01 Dec 2004
01 Jul 2005
01 Feb 2006
01 Sep 2006
01 Apr 2007
01 Nov 2007
01 Jun 2008
01 Jan 2009
01 Aug 2009
01 Mar 2010
01 Oct 2010
01 May 2011
01 Dec 2011
01 Jul 2012


GND1121
y = -0.002x + 82.123
R² = 0.3169
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
01 Jul 2004
01 Jan 2005
01 Jul 2005
01 Jan 2006
01 Jul 2006
01 Jan 2007
01 Jul 2007
01 Jan 2008
01 Jul 2008
01 Jan 2009
01 Jul 2009
01 Jan 2010
01 Jul 2010
01 Jan 2011
01 Jul 2011
01 Jan 2012
01 Jul 2012

GND1194
y = -0.0008x + 33.294
R² = 0.1293
NNN (mg/L)
35
30
25
20
15
10
5
0
01 Jan 2002
01 Jul 2002
01 Jan 2003
01 Jul 2003
01 Jan 2004
01 Jul 2004
01 Jan 2005
01 Jul 2005
01 Jan 2006
01 Jul 2006
01 Jan 2007
01 Jul 2007
01 Jan 2008
01 Jul 2008
01 Jan 2009
01 Jul 2009
01 Jan 2010
01 Jul 2010
01 Jan 2011
01 Jul 2011
01 Jan 2012
01 Jul 2012