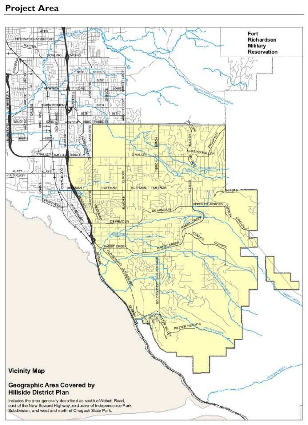

Status of Anchorage Hillside Well Water: Nitrates Study

December 2011

Ted Moore, P.E.,
James A. Munter, CGWP, CPG,
and Ian Moore

Commissioned by the Anchorage Hillside's
Home And Landowners Organization (HALO, Inc.)
anchoragehalo.org

Area-G
Home
And
Landowners
Organization, Inc.

P.O. Box 110096
Anchorage, AK 99511-0096

December 1, 2011

The large lot lifestyle on the Anchorage Hillside has been under the watchful eye of the Home And Landowners Organization (HALO, Inc.) since 1969. A big part of life up here is getting our water from wells. Anyone who drinks well water should pay attention to its quality and the quality of neighboring wells.

The Hillside District Plan recommends a Well Water Protection Program. HALO didn't want to wait for the MOA to get around to this so we took it on ourselves to do the initial step of looking at the quality of our water now. This study provides that information and more.

There are a variety of things to watch for in well water. One main indicator of water quality is the level of nitrates. This study analyzed all available private and public well nitrate data, including records from over 2,900 wells, for the Anchorage Hillside between 1989 and 2010 to identify areas with elevated nitrates and determine nitrate trends over time.

The report concludes that the long-term viability of on-site well and wastewater systems on the Anchorage Hillside is good. The current practice of letting the tiny number of individual well owners with elevated nitrate levels develop solutions best suited to their unique situation seems to be the best practical approach.

The study shows that nitrate levels vary significantly across the Hillside, sometimes within a very short distance. While the vast majority of wells have insignificant levels of nitrates, the levels in many wells are increasing, but at generally low and varying rates. More good news is indications that recent requirements for well grouting and bedrock sealing appear to have positive benefits.

There is a common concern that the use of septic systems risks tainting our water supply. This study did not find a correlation between septic system use and nitrates.

The report provides a list of things that could be looked at more closely and provides a list of suggestions for the future. These include changes in Municipality of Anchorage and DEC routines and education of Hillside residents.

At this point, the quality of our water looks good.

Drink up!

Wayne Westberg
Chair

Status of Anchorage Hillside Well Water: Nitrates Study

December 2011

By Ted Moore, P.E.[1], James A. Munter, CGWP, CPG[2], and Ian Moore[3]

Executive Summary:

This report presents an analysis of nitrate data collected from single family and public-supply wells on the Anchorage Hillside. It is intended to be the first in a series of periodic reports that track nitrate concentrations in local aquifers over time in an effort to better understand ongoing changes in nitrates in groundwater aquifers used for water supply and to facilitate actions to alleviate or prevent problems related to elevated nitrates before they become serious.

This study was commissioned by the Home and Landowner's Organization, Inc. (HALO), as part of its Hillside District Plan (HDP) Implementation Program. This study analyzed all available private and public well nitrate data, including records from over 2,900 wells, for the Anchorage Hillside between 1989 and 2010 to identify areas with elevated nitrates and determine nitrate trends over time. Observed nitrate levels vary significantly across the Hillside, sometimes within a very short distance. The nitrate levels from most Hillside wells are below levels commonly attributable to human activities; however some wells have nitrate levels approaching nationally accepted Maximum Contaminant Levels (MCLs) of 10 mg/l. Nitrate levels in many wells on the Hillside are increasing, but at generally low and varying rates. For example, 38% of 47 public water system wells on the Hillside have low but increasing trends of nitrates that are statistically significant, i.e the trends are not likely the result of randomness. Examination of data from 144 private wells with 4 or more nitrate analyses shows a similar pattern of significant numbers of wells with increasing nitrate trends while many other wells are virtually nitrate-free.

The study also examined existing data to evaluate potential sources of nitrate contamination and avenues for elevated nitrates to get into drinking water aquifers and/or directly into wells. There appears to be some statistically significant correlation between shallower aquifers and elevated nitrates. Recently-enacted changes that require well grouting and bedrock sealing during well construction may be having positive benefits in reducing nitrate levels in wells. There does not appear to be any simple correlation between septic system usage and nitrates: many areas with relatively dense septic system usage exhibit lower nitrate patterns than other areas with larger lots and lower septic system densities.

The report concludes that the long-term viability of on-site well and wastewater systems on the Anchorage Hillside is not significantly diminished on the basis of existing nitrate trends and concentrations. The current practice of letting the tiny number of individual well owners with elevated nitrate levels develop solutions best suited to their unique situation seems to be the best practical approach.

The report makes a number of recommendations for further work to improve long-term management of nitrates in the Hillside area including:

(1) Work with the Municipality of Anchorage and State agencies to improve the quality and usability of water quality and well data;

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(2) Develop targeted sampling programs to investigate variability in the nitrate data;

(3) Contract with UAA to do nitrogen isotope or other studies to identify sources of nitrates in drinking water;

(4) Educate the public about the nature of nitrates in Hillside aquifers, ways to reduce sources of nitrates, and ways to maintain the viability of wells as long-term sources of water supply on the Hillside;

(5) Periodically revisit studies such as this (approximately every 3 to 5 yrs) to evaluate nitrate trends and spatial patterns on the Anchorage Hillside; and

(6) Broaden the scope of future water-quality studies to be Municipality-wide and include other contaminants such as arsenic.

I. Background of this study:

This report presents an analysis of nitrate data collected from single family and public-supply wells on the Anchorage Hillside. It is intended to be the first in a series of periodic reports that track nitrate concentrations in local aquifers over time, in an effort to better understand ongoing changes in nitrates in groundwater aquifers used for water supply, and to facilitate actions to alleviate or prevent problems related to elevated nitrates before they become serious.

This study was commissioned by the Home and Landowner's Organization, Inc. (HALO), as part of its Hillside District Plan (HDP) Implementation Program. The project study area coincides with the boundaries of the HDP.

Acknowledgements: The project team is deeply indebted to Patricia Hansen, a Hillside resident and statistician, for her invaluable work in analyzing and graphing plots from the large body of available data.

Nitrates as a contaminant in drinking water:

The nitrate ion (NO_3^-) is the most commonly occurring form of nitrogen found in groundwater. Potential sources of nitrates in groundwater include septic systems, lawn and garden fertilizer, animal manure, and natural fixation of nitrogen gas from the atmosphere by plants. From a national perspective, elevated nitrates in groundwater most commonly occur in agricultural areas where large amounts of nitrogen fertilizer are used, but high nitrate levels can also be found in areas with concentrations of septic systems, large-animal waste, or municipal sewage disposal. Nitrates can be fixed from the atmosphere by microbes associated with the root systems of alders (which are abundant on the Hillside). Once nitrates make it into groundwater they tend to travel with the groundwater because they do not significantly bind to soil particles or break down chemically.

The U.S. Environmental Protection Agency and the State of Alaska have established a Maximum Contaminant Level (MCL) for nitrates of 10 milligrams per liter (mg/L) in public water systems. Neither agency regulates water supplies from wells serving single family homes or from small community water systems serving fewer than 25 people. While the Municipality of Anchorage has not formally adopted a nitrate MCL, it uses the EPA standard of 10 mg/L in issuing Certificates of On-Site Approval (COSAs) for wells serving single family homes. Owners of wells with more than 10 mg/L of nitrates are required to perform investigative and perhaps rehabilitative work on the well. High nitrate levels are of concern because they are known to cause a rare but potentially fatal condition in infants known as infant methemoglobinemia. Excessive levels of nitrate can be removed from drinking water by reverse osmosis treatment.

Naturally occurring nitrate concentrations in ground waters of the U.S. are typically less than 2 mg/L (Mueller and others, 1995). A nitrate level of 3 mg/l is sometimes used as a threshold level indicating human influences (Bristol Environmental Services Corporation (hereafter termed Bristol), 1997). Nitrate levels greater than 3 mg/l in wells are not uncommon in drinking water wells on the Anchorage Hillside. Numerous water samples collected from wells located at high elevations near the Chugach State Park boundary have shown elevated nitrates, indicating that it is possible that nitrate values higher than 3 mg/L may occur naturally in some areas, perhaps due to fixation by alders. On the other hand, a much greater number of wells throughout the Hillside area exhibit nitrates below 0.1 mg/L.

Elsewhere in the U.S. Federally mandated groundwater management areas (GWMAs) have been established in a number of locations around the country where nitrates in drinking water have been identified as an issue of particular concern. These include locations in the Southern Willamette Valley, the Columbia Basin, San Diego County, California and Wisconsin. Each of these areas is primarily agricultural where the predominant source of nitrates is from chemical fertilizer. Typical incidence of nitrates in wells tested in these GWMAs is >20% exceeding the 10 mg/l standard, with maximum nitrates in the 30 mg/l to 40 mg/l range. Elevated nitrate incidence is even greater in many European countries.

Anchorage Hillside aquifers:

Except for areas served by the Anchorage Water and Wastewater Utility, almost all the water used for domestic, commercial, and institutional use in the Anchorage Hillside area is local groundwater from wells. There are estimated to be more than 6000 wells tapping glacial and bedrock sources of groundwater in the area. Groundwater moves slowly from its area of recharge from rain or melting snow to its point of use or area of discharge. In the Cook Inlet area, "much of the water pumped by domestic and public-supply wells may have traveled less than 10 miles, and the trip may have taken as short a time as a few days or as long as several decades" (Glass, 2002). To understand how water can move from the surface to recharge aquifers tapped by wells in relatively short timeframes, the U.S Geological Survey studied 30 wells in the Cook Inlet Basin, including wells in the Anchorage Hillside area, and found that 93 percent of the wells contained some modern groundwater (Glass, 2002). Modern groundwater is groundwater recharged after the beginning of atmospheric testing of thermonuclear explosives in the early 1950's. This testing left identifiable concentrations of tritium (an isotope of hydrogen and a component of water molecules) in the global hydrosphere, some of which now appears in most well water in the Anchorage area. Thus, if other contaminants such as nitrates are introduced into recharging waters, they may also be found in well water.

Aquifers on the Anchorage Hillside consist of two principal types – glacial or glaciofluvial aquifers and bedrock aquifers. Glacial or glaciofluvial aquifers occur generally in the lower-elevation areas of the Hillside, although there is considerable variability. These aquifers commonly consist of relatively thin and discontinuous layers of sand and gravel found beneath and within thicker layers of silty glacial sediments known as till. The till transmits water from the land surface in recharge areas to deeper aquifers, but generally does not yield much water to a well bore. Almost the entire Hillside study area is a recharge area for groundwater.

Bedrock in the Hillside area mostly consists of hard and dense metamorphic rocks such as argillite, greywacke (a silty metamorphic sandstone), and conglomerate. Water occurs in these rock types in fractures and sometimes in weathering zones at the bedrock surface beneath glacial deposits. In many areas of the upper Hillside, bedrock is exposed or occurs very near the land surface. Recharge to bedrock aquifers also occurs in the areas where bedrock is close to the land surface. Figure 1 provides a generalized hydrogeologic diagram of aquifers in the Anchorage area.

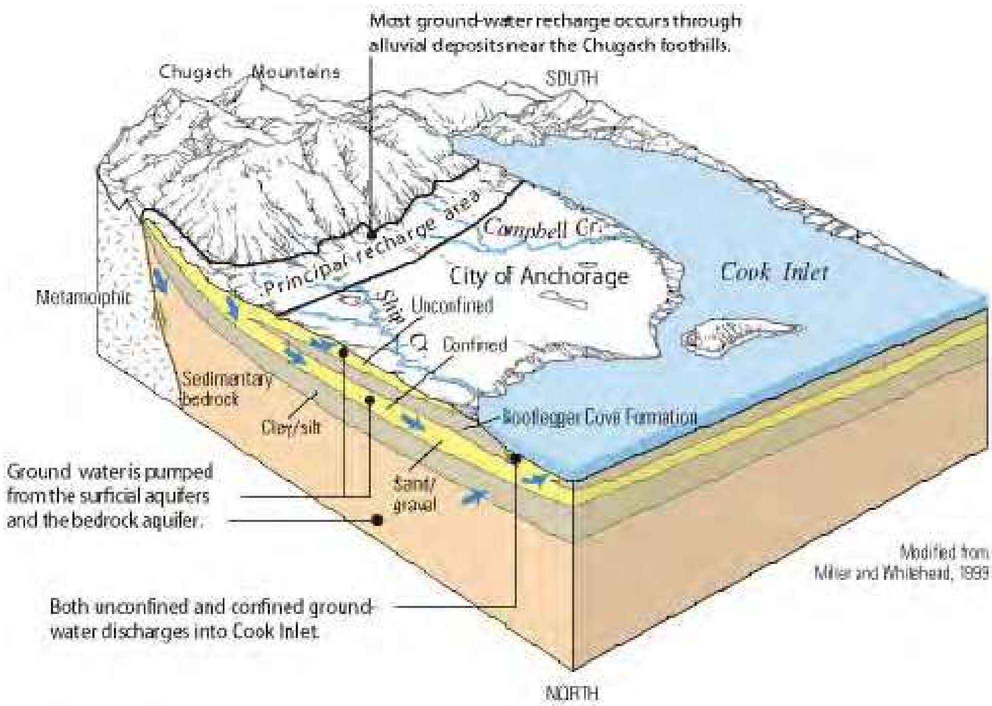


Figure 1. Generalized hydrogeological depiction of groundwater recharge zones in the Anchorage area.

II. Previous Studies of Hillside Nitrates:

Three different studies of nitrates in groundwater on the Anchorage Hillside have been conducted in recent years. Bristol (1997) found that approximately 18 percent of wells on the Hillside showed nitrates above 3 mg/L, and were concentrated in several distinct regions on the Hillside. Repeat sampling of some wells indicated that gradual increases in nitrate concentrations in groundwater may be occurring at some sites. Most of the Anchorage Hillside showed reported nitrate concentrations less than 0.5 mg/L nitrates, and even in areas with elevated nitrates, local variations created highly irregular patterns of apparent nitrate concentrations.

Montgomery Watson (2000) performed a detailed analysis of nitrate data along with other physical and hydrogeologic data for an area that exhibited variable nitrate values near the intersection of Hillside Drive and DeArmoun Road. The statistical correlation analysis using nine different factors and a separate hydrogeologic analysis failed to identify any significant correlations, trends, or predictors of nitrate occurrence.

Larsen Consulting Group and the Boutet Company (2007) produced a map as part of the draft Hillside District Plan, which indicated nitrate concentrations similar to that produced by Bristol (1997). This map was based on data collected between 1998 and 2007. The map was not included in the final version of the plan adopted by the Municipality of Anchorage.

Unlike the present study, both previous nitrate concentration maps used graphical techniques to smooth the nitrate data and show generalized trends, rather than specific nitrate data on a lot-by-lot basis, where considerable variation exists. Comparison of the two maps shows a high degree of similarity, both in the locations of areas where nitrates are elevated and in the degree of elevation of nitrates throughout the Hillside area. The nitrate trends for data collected prior to 1997 are not readily distinguishable from the trends for data collected during the subsequent 10 years.

III. Hillside Water Quality Data Sources:

All water quality data used to prepare this report was submitted by well operators to public agencies and is available in public databases. The data used to evaluate Hillside water quality for this report are derived from two primary sources. These are:

A. COSA database of single-family wells: Water quality data are collected by the Municipality of Anchorage as part of their Certificate of On-Site Approval (COSA) program. With few exceptions, a COSA certificate is required by Municipal ordinance to be issued prior to any transfer of title of any single-family residence that is served by an on-site well or wastewater disposal system. Water quality data that have been collected through this program includes coliform bacteria, nitrates, and arsenic. COSA water quality data records dating back to 1989 are maintained in a Municipal data base, which was made available to the authors of this report. As of the February, 2011, retrieval date, this database contained 9,578 COSA records on 5917 different wells throughout the Municipality, of which 4,791 records on 2,907 different wells fall within the boundaries of the HDP study area.

In addition to water quality data, the Municipal COSA database contains limited additional information pertaining to well yield and static water level. Prior to 2008, the Municipality entered more well information from the COSA sheets into the database including the date drilled, total depth, and casing depth as well as several other parameters related to the wastewater disposal system on the lot. The exact location of the well on the lot has never been documented in the database. For mapping purposes in this study, the authors have treated nitrate data as being applicable to entire lot upon which a single-family well is drilled.

The study authors expended a considerable amount of effort correcting numerous data entry problems pertaining to the COSA nitrate data and resolving discrepancies in the database. Many of these discrepancies turned out to be simple data entry mistakes in water-quality test results or property identification. We were able to identify and correct a large number of these mistakes and thereby include the nitrate data from those wells in this study. There were many instances where nitrate levels below the laboratory's minimum reporting limit were entered incorrectly as 0 instead of as the minimum reporting limit. Over the time period spanned by the data, the minimum reporting limit varied between 0.1, 0.2, and 0.5 mg/l. In order to maximize consistency, the study authors converted all nitrate values recorded as 0 in the database to the minimum reporting limit believed to be in effect on the date that the sample was tested. In a few instances where recorded nitrate levels appeared unrealistically high, we checked the original data and found decimal point errors.

One potential drawback to the COSA database is that nitrate readings in excess of 10 mg/l may tend to be under-reported. Nitrate measurements on the Hillside that exceed the 10 mg/l standard are quite rare; however readings at a number of locations approach that standard. Until recently, the Municipality would not issue COSAs where the nitrate level exceeded 10 mg/l. In such situations, the applicant had to either resample in an attempt to get a lower test result, or modify the well in an attempt to reduce the nitrate value.

This large body of water-quality data for single-family wells provides a good overview of the spatial distribution of nitrate levels across the Hillside. Because the data spans more than a 21-year period, it also allows time trends in nitrate levels to be evaluated; however, since these nitrate data are only collected when a house is sold, the specific wells sampled are not the same each year.

Many private wells do not show up in the COSA database at all because the houses they serve were not sold during that period, and so no nitrate level is known. Other private wells appear in the database multiple times, due to numerous re-sales of the same property. The most nitrate values for any private well in the database is eight. Wells with multiple nitrate tests allow time trends to be evaluated for those specific wells, although the data points may be irregularly spaced.

B. Drinking Water Watch (DWW) database of nitrates in water from public wells: Water quality data for large public water systems are required to be regularly submitted to the Alaska Department of Conservation. There are more than 47 public water systems located within (or in close proximity to) the Hillside study area. These systems typically serve more than 25 individuals in separate residential homes or apartments, or buildings such as offices, businesses, schools, or churches. Water-quality data for each of these wells collected during the period from 1993 through 2011 is posted on ADEC's "Drinking Water Watch" website. Most of these wells are sampled annually, and a few are tested more frequently. The water quality information available on this website includes bacteria, nitrates and arsenic, plus a suite of other potential contaminants. There is also limited information regarding the water system operator and the sampling point used.

As with the COSA data there are numerous inconsistencies in data entry, particularly where the test result was below the lab's minimum reporting level. In these situations the field is sometimes left blank, sometimes has a zero and sometimes lists the minimum reporting limit. In using these data the study authors adjusted zero and blank nitrate values to the minimum reporting limit believed to be in effect on the date of the sample. No other changes were made to the data extracted from the DWW database.

There are numerous Class C public supply wells (wells serving two or more residences, but less than 25 individuals) in the study area, but there is no reliable source of water quality data for these. They are not routinely required to report either to the State or the Municipality. While these wells are technically still under State jurisdiction, the DEC stopped actively monitoring their water quality several years ago and does not enter or maintain Class "C" well water quality data in their Drinking Water Watch website. The Municipality collects nitrate and arsenic data from these small community wells as part of its COSA process for single family homes served by these wells, but does not reliably enter the data into its COSA database.

IV. Spatial distribution of nitrate levels in Hillside wells:

Figure 2 is a map of the Hillside study area with each lot for which at least one nitrate test was performed color coded to show its measured nitrate level. There are a total of 2907 different lots served by single-family wells on the Hillside with available nitrate data. Where more than one nitrate sample has been collected for a particular lot, the lot's color code indicates the most recent nitrate level observation.

This figure also depicts the locations of 47 public wells serving community water systems on the Hillside. A few of these public wells are located just outside the HDP area, but they have also been included. The location of each of the public wells is indicated by a circle that is color coded to depict the most recent nitrate level at the site.

From Figure 2 it can be seen that nitrate concentrations are not uniform across the Hillside study area. However, despite significant local variations, patterns of nitrate concentration are apparent. With a few exceptions, the overwhelming majority of nitrate observations in the mid- and lower-Hillside area are less than or equal to 2.5 mg/l. The majority of the higher nitrate concentrations fall within areas that can be loosely described as:

- The Furrow Creek area in the Huffman Road-Elmore Road vicinity;
- The Potter Creek area east of Goldenview Drive;
- The vicinity of Abbott Road-Birch Road; and
- In the vicinity of Hillside Drive between Abbott and DeArmoun Roads and extending eastward.

However, even within these areas, significant unexplained variability exists between adjacent and nearby lots. Many lots in these areas exhibit low to moderate nitrates. Conversely, there are scattered instances of lots with elevated nitrate concentrations in the remaining area of the Hillside where generally low nitrate levels prevail.

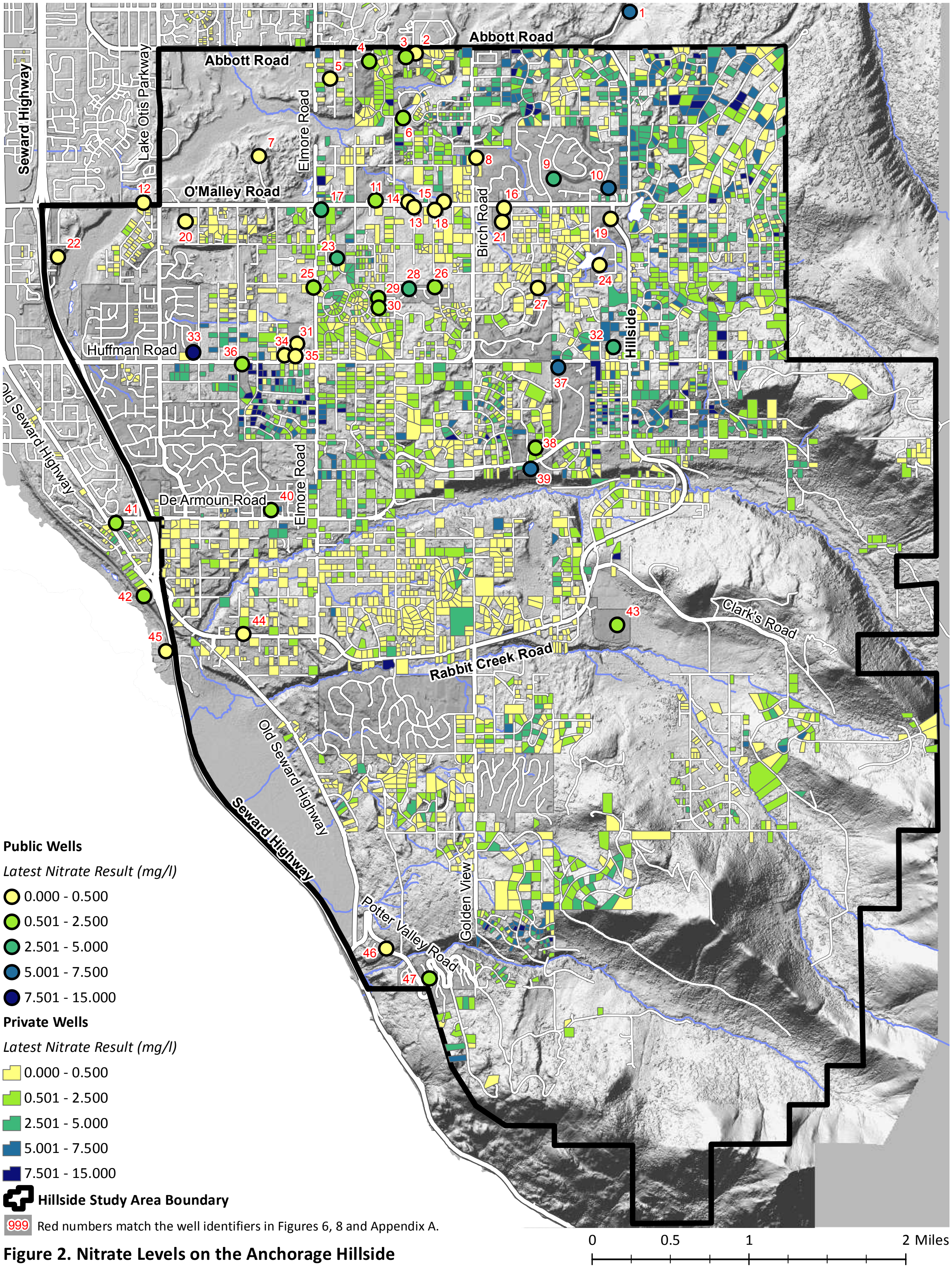


Figure 2. Nitrate Levels on the Anchorage Hillside

Figure 3 is a bar graph of all available nitrate test results for all single family wells on the Hillside. This graph illustrates the frequency of nitrate observations in five different concentration groups that correspond to the color codes used on Figure 2. It includes all 4791 nitrate tests reported on 2907 different Hillside wells between 1989 and 2010. Overall, 42% of the tests showed less than or equal to 0.5 mg/l nitrate, 32% had more than 0.5 but less than or equal to 2.5 mg/l nitrate, 17% had more than 2.5 but less than or equal to 5.0 mg/l nitrate, 7% had more than 5.0 but less than or equal to 7.5 mg/l nitrate and 2% had greater than 7.5 mg/l nitrate. Only 0.2% of the reported tests exceeded the 10 mg/l nitrate MCL.

For comparison to the findings of Bristol (1997), which found that 18 percent of wells exceeded 3.0 mg/L, this study finds that 22 percent of tests overall, and 23 percent of tests considering only the most recent test for any well, were above 3.0 mg/L nitrates.

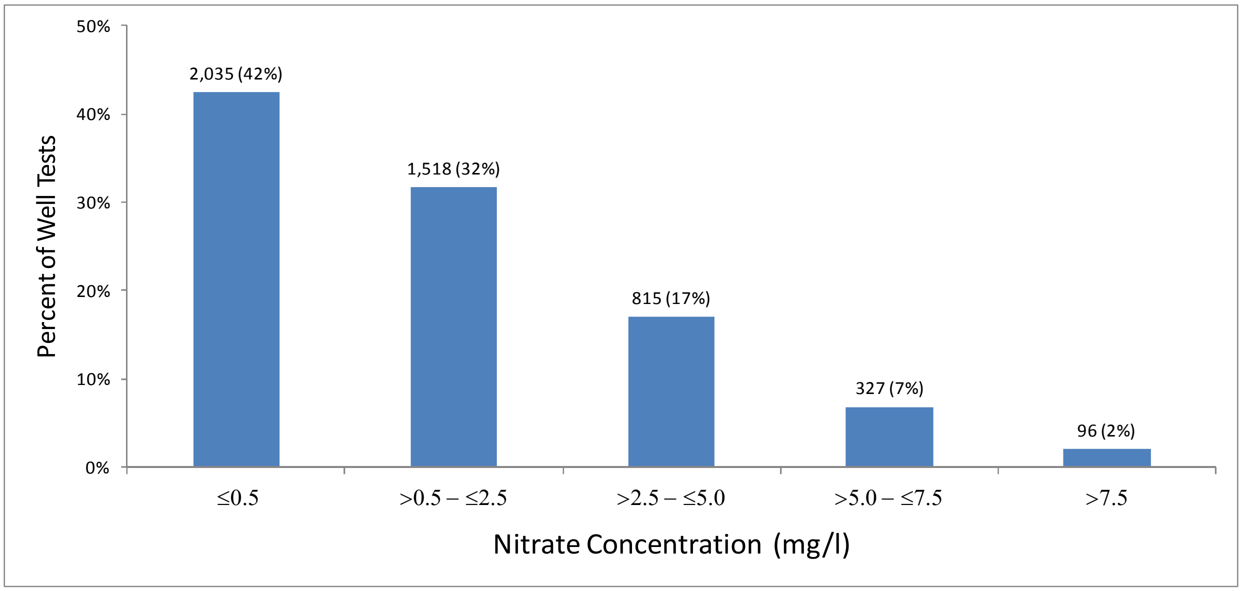


Figure 3. Frequency of nitrates in well water in the Hillside study area.

V. Time trends of nitrates in Hillside wells:

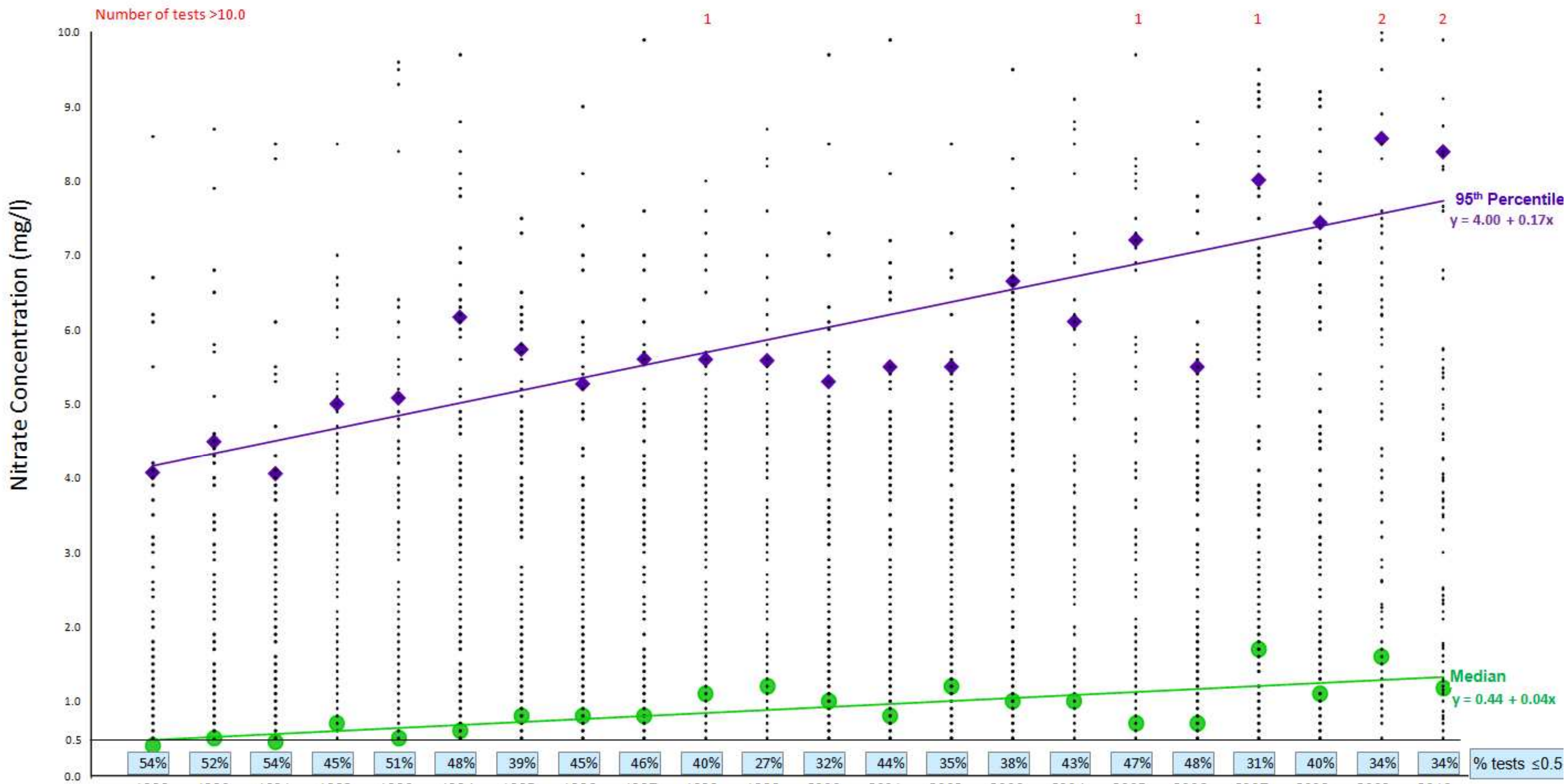
A. Nitrate trends in composite data for all private wells on the Hillside: The COSA nitrate database, containing almost 5000 nitrate tests on almost 3000 different wells spanning a 21-year period, provides a huge resource of data on what is happening to nitrate levels on the Anchorage Hillside over time. It should be noted that because the nitrate samples were collected only in conjunction with home sales, the number of well tests conducted each year is not the same, nor is the distribution of tests across the Hillside. However, with an average of over 200 Hillside homes being sold each year, it can be safely assumed that the general distribution of tests across the Hillside is reasonably consistent.

Figure 4 is a plot of the annual distribution of nitrate levels in all private well tests between 1989 and 2010. It should be noted that multiple nitrate levels for some wells are included on this plot, due to the property having being sold a number of times over the years.

Green circles depict the median nitrate level observed each year and purple diamonds depict the 95th percentile nitrate. Trend lines are drawn on the graph to indicate how the median nitrate value and the 95th percentile nitrate have changed over time. The numbers inside the blue shaded boxes just above the bottom of the graph represent the percent of nitrate tests that were at or below a nominal 0.5 mg/l, which during some periods was the minimum reporting limit used by the testing laboratories.

Figure 4 shows that the median nitrate level trend is gradually increasing at a rate of 0.04 mg/l per year, but is still less than 2.0 mg/l. The nitrate level trend of the 95th percentile samples is increasing at a higher rate of 0.17 mg/l per year and is now between 8 and 9 mg/l.

Figure 5 is a plot illustrating the annual frequency of nitrate tests that exceeded the various nitrate level thresholds used in other plots. This shows that the frequency of observations exceeding any particular level is increasing at a little less than one percent per year. The frequency of nitrate observations over 7.5 mg/l did not start increasing (above a low background level) until approximately 2003, so its regression line is based on the data from 2003 to 2010. In 2010, approximately 10% of all nitrate tests taken that year exceeded 7.5 mg/l.



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Number of Well Tests	147	203	250	321	283	267	234	234	200	218	224	236	241	236	230	219	199	221	193	158	157	120
Median	0.4	0.5	0.5	0.7	0.5	0.6	0.8	0.8	0.8	1.1	1.2	1.0	0.8	1.2	1.0	1.0	0.7	0.7	1.7	1.1	1.6	1.2
95th Percentile	4.1	4.5	4.1	5.0	5.1	6.2	5.7	5.3	5.6	5.6	5.6	5.3	5.5	5.5	6.7	6.1	7.2	5.5	8.0	7.4	8.6	8.4

Figure 4. Annual distribution of nitrate levels observed in single-family well

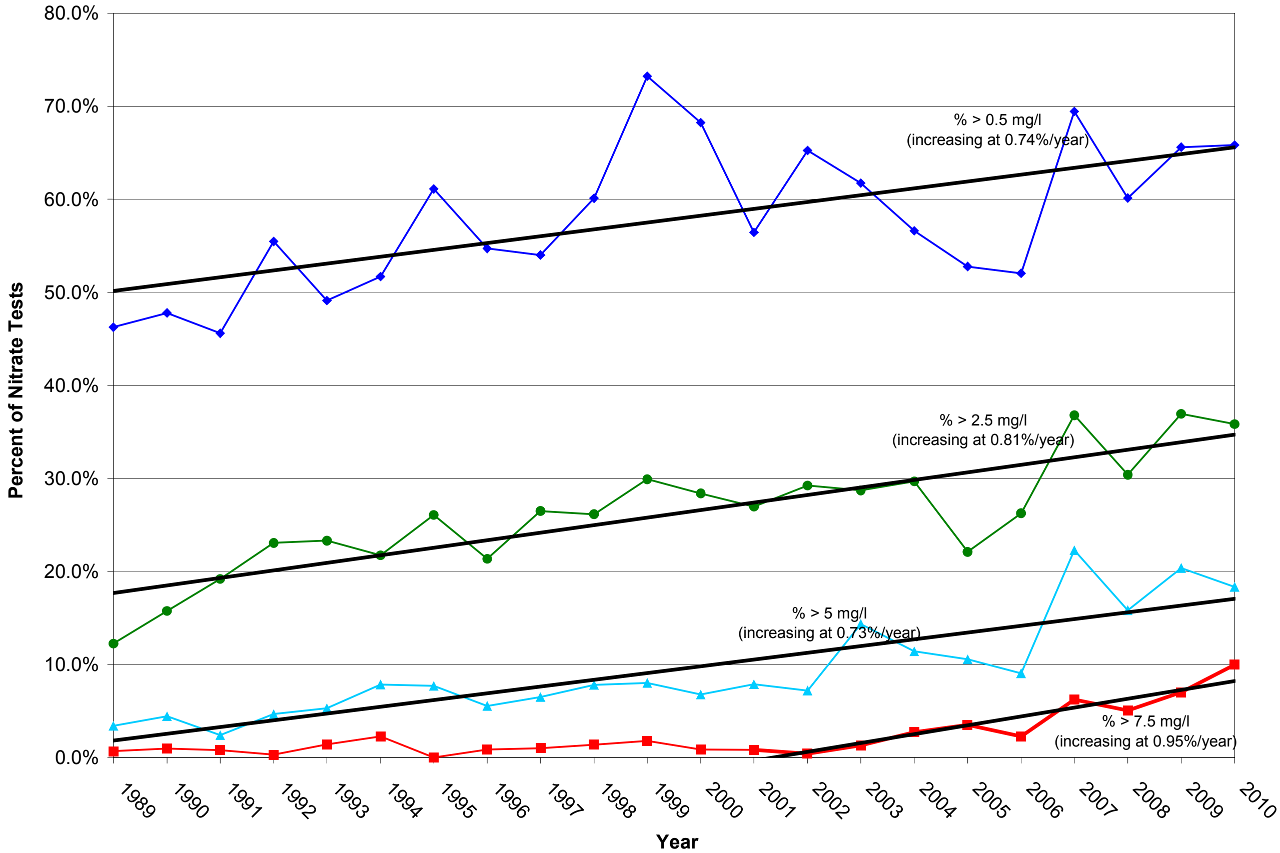


Figure 5. Annual frequency of nitrates greater than specified levels in all tests of private wells

B. Nitrate trends in Hillside public wells: Public water systems provide a particularly useful source of data for evaluating time trends of nitrate concentrations on the Hillside. This is because water samples are collected from the same source and tested on a regular basis. The DEC's Drinking Water Watch (DWW) website provides public access to these test results.

Numerous reported nitrate concentrations in the DWW database unfortunately are blank or are reported as zero. While ADEC stands behind the accuracy of its database, the study authors believe that at least some of these blank readings may be the result of data reporting errors and do not reflect valid nitrate values. As was done with the COSA nitrate data, the study authors converted blank and zero values in the database to the minimum reporting limit in effect at the time the sample was taken.

In a few instances, specific reported nitrate values (outliers) departed significantly from trends that appeared to be established by the bulk of the data; however, point-by-point data validation of individual data points was beyond the scope of this study. Thus, in plotting nitrate trends for public wells, none of these apparent outliers were removed. In many (but not all) cases, the effect of retaining these apparent outliers does not significantly affect the overall trend.

A linear regression analysis was performed on nitrate data from 47 community water systems. Criteria for selecting the water systems to include were as follows:

- At least 4 nitrate analyses were available;
- Data had to be collected over at least a 5-year period; and
- The most recent data point could not be more than 7 years old.

The rate of change in nitrate concentration for each public well (the slope of the linear regression line) is plotted in Figure 6 and the individual plots for each well are provided in Appendix A. In addition to the slope of the line, a determination was made as to how well the regression line fit the data points. The measure used in this determination was the root mean square error (RMSE), which is a measure of the average variance of all the data points from the regression line. Based on visual interpretation of the individual plots for each of the public water systems, the study authors selected a RMSE value of < 0.75 mg/l as an indicator that the regression line is a good fit to the data.

The slopes with RMSE's greater than 0.75 are denoted with a gray symbol in contrast to the blue symbol used for the rest of the slopes.

A determination was made as to whether the slopes of the trend lines were statistically significant or not compared to a zero slope, or flat line. The test for statistical significance is used to identify trends that are unlikely to have been produced by chance, using a probability of 1 in 20 for the test criterion. Of the 47 systems, 18 systems, or 38 percent, were found to have statistically significant positive slopes, including all 15 systems with slopes greater than 0.05 mg/l/year (Figure 6).

Detailed plots of each system, including data points used to generate each line, are included in Appendix A.

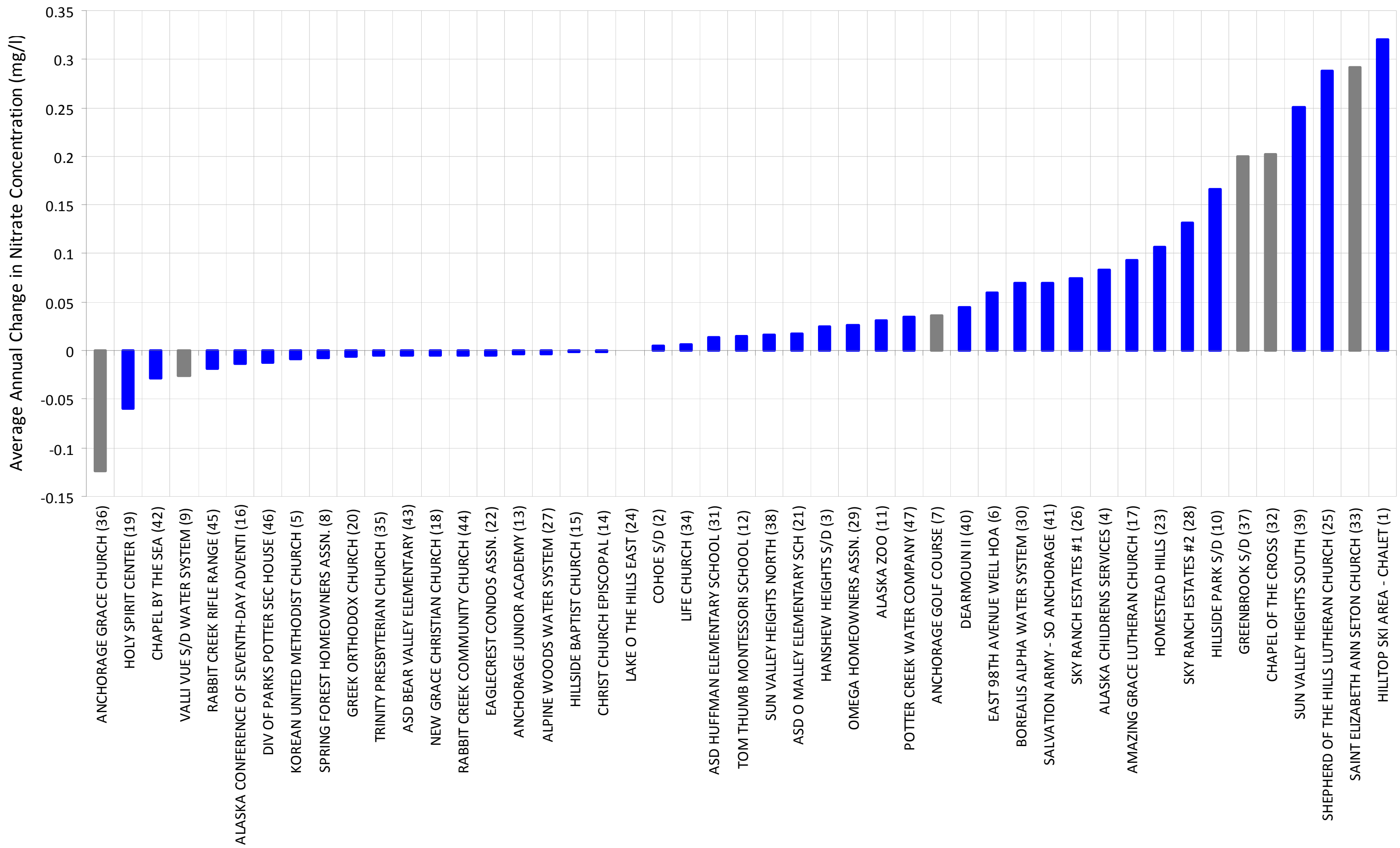


Figure 6. Bar graph depicting nitrate trends at 47 Hillside public wells. Locations of wells are shown in Figures 2 and 10 using the well identifier shown after the system name.

In preparing Figure 6, the wells were sorted in order of increasing slope of the trend. As an aid to locating a specific public well on the map, a number was appended to the name of each public well (Figure 2), with numbers generally increasing from north to south.

More than half of the public water systems show an increasing trend of nitrates with time, and some show increases at rates significantly greater than the trend of median nitrate values from private wells of 0.04 mg/l per year. Overall, the data show that, while many systems remain essentially nitrate-free, average trend rates of nitrate increases of 0.1 mg/l per year or more are exhibited by 20 percent (or 9) of the 47 public water systems.

Figure 7a plots the linear regression lines for nitrate trends at all 47 public water systems. This graph shows a surprising clustering of systems into a set of six higher-slope and higher-nitrate systems and a larger set of 40 lower- or negative-slope and lower-nitrate systems. One system shows a higher slope, but still low nitrate levels. The reason(s) for this bimodal clustering of systems is (are) not known. Except for the seven higher-slope systems, it would take decades for any of the other 40 systems to reach nitrates levels that would typically be cause for concern, should present trends continue.

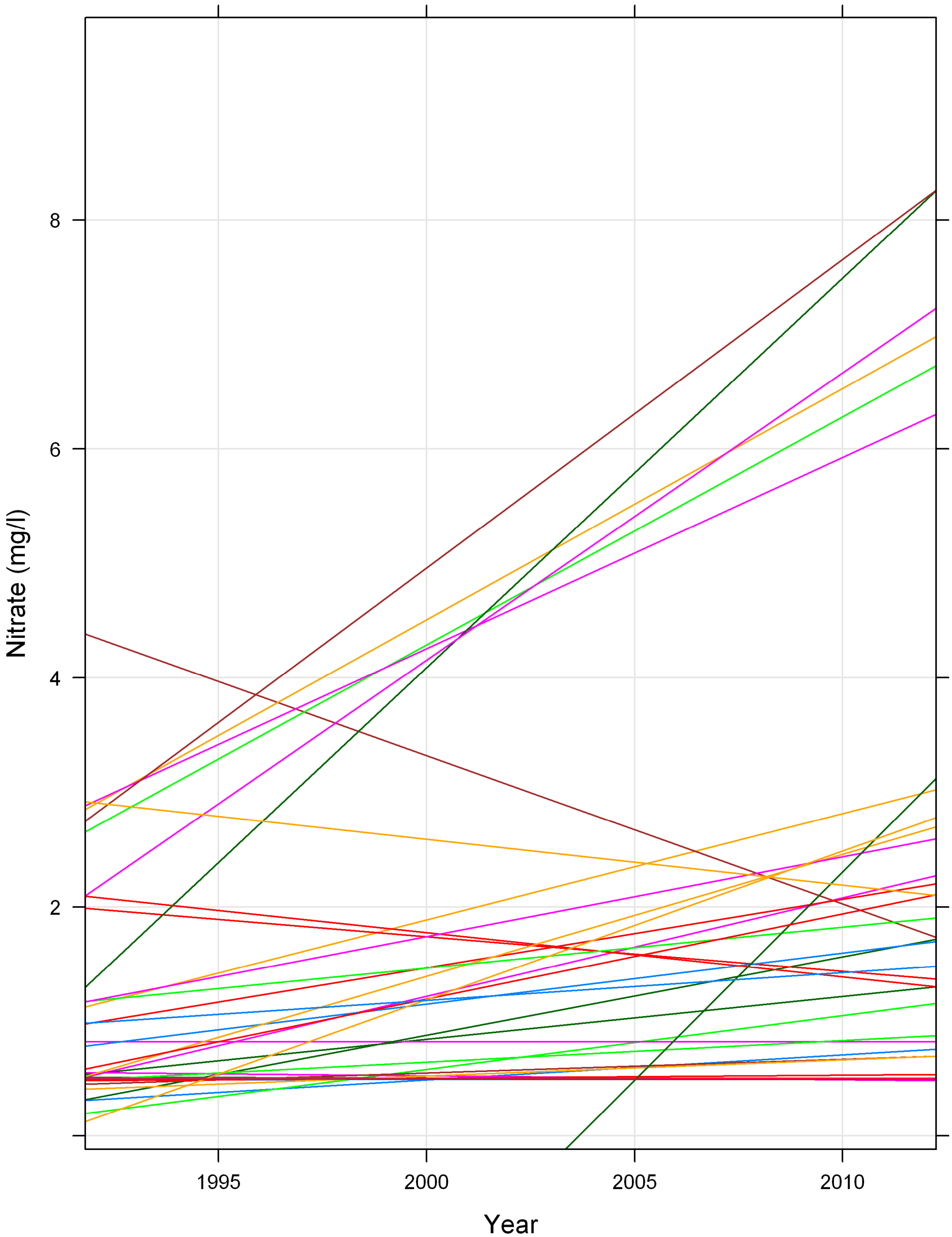


Figure 7a. Plot of nitrate trend lines of 47 Hillside public wells and levels of nitrates.

Another way of illustrating the increasing values of nitrates in many public water systems is shown in Figure 7b. Figure 7b shows a plot of the latest nitrate value at a public water system plotted against the average annual change in nitrate concentration for that system. Qualitatively, the plot generally shows that wells with higher nitrate trends also tend to have higher nitrate levels. Also, a cluster of systems show virtually no change in nitrates over time and their latest nitrate values are below 1.0 mg/L.

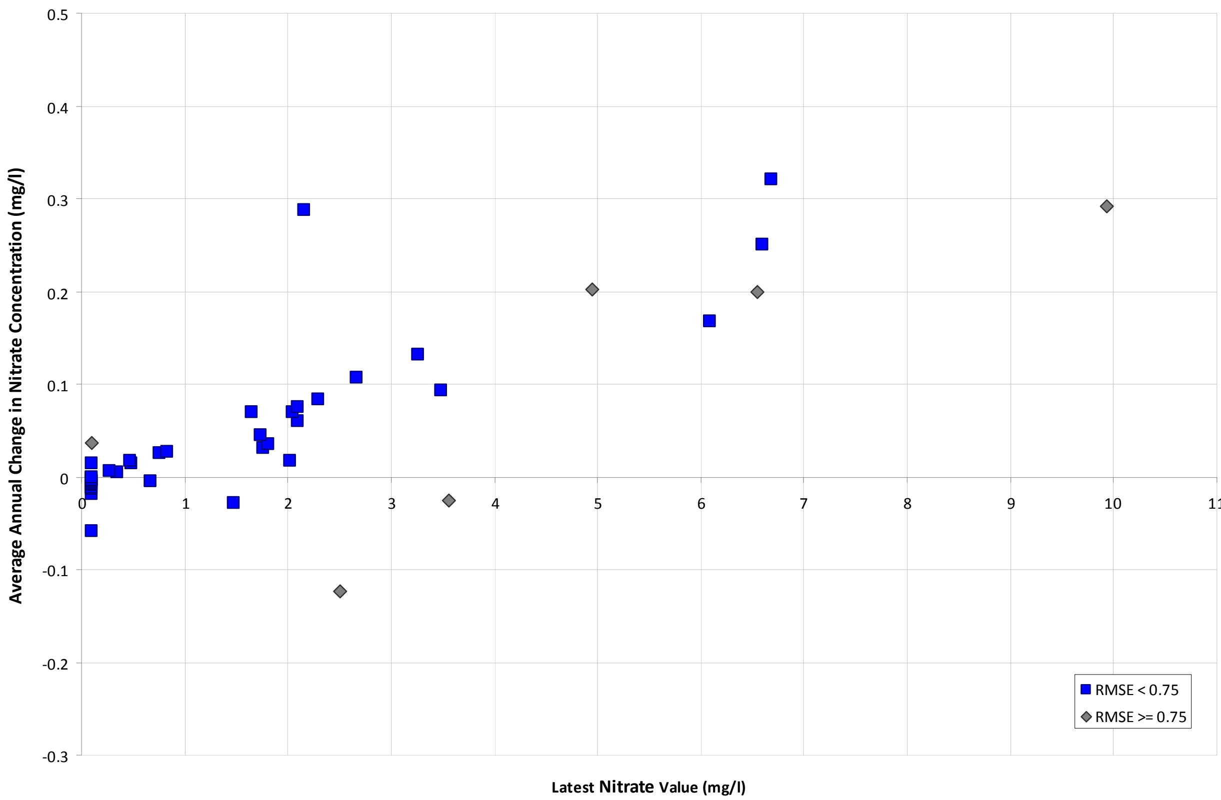


Figure 7b. Plot showing nitrate trends vs latest observed nitrate value in public wells.

C. Nitrate trends for individual Hillside private wells with 4 or more nitrate tests: Private wells are much more numerous than community wells and potentially broaden our understanding of nitrate trends over time. We found 144 private wells that meet the following criteria:

- At least 4 nitrate analyses were available;
- Data had to be collected over at least a 5 year period; and
- The most recent sample could not be more than 7 years old.

A regression analysis was performed on data from these systems to create trend lines. The average annual rate of change in nitrate concentration for each private well (the slope of the linear regression line) is plotted in Figure 8 and the individual plots are provided in Appendix A. In addition to the slope of the line, a determination was made as to how well the regression line fit the data points. As was done with public wells, the measure used in this determination was the root mean square error (RMSE), and a RMSE value of < 0.75 mg/l was used as an indicator that the regression line is a good fit to the data.

Although the nitrate data for private wells is more variable than for community wells, it is also more difficult to determine which outliers should be removed, so the authors did not remove any data points, except where listed nitrate values exceeded any reasonable value, and could be corrected by review of actual lab reports.

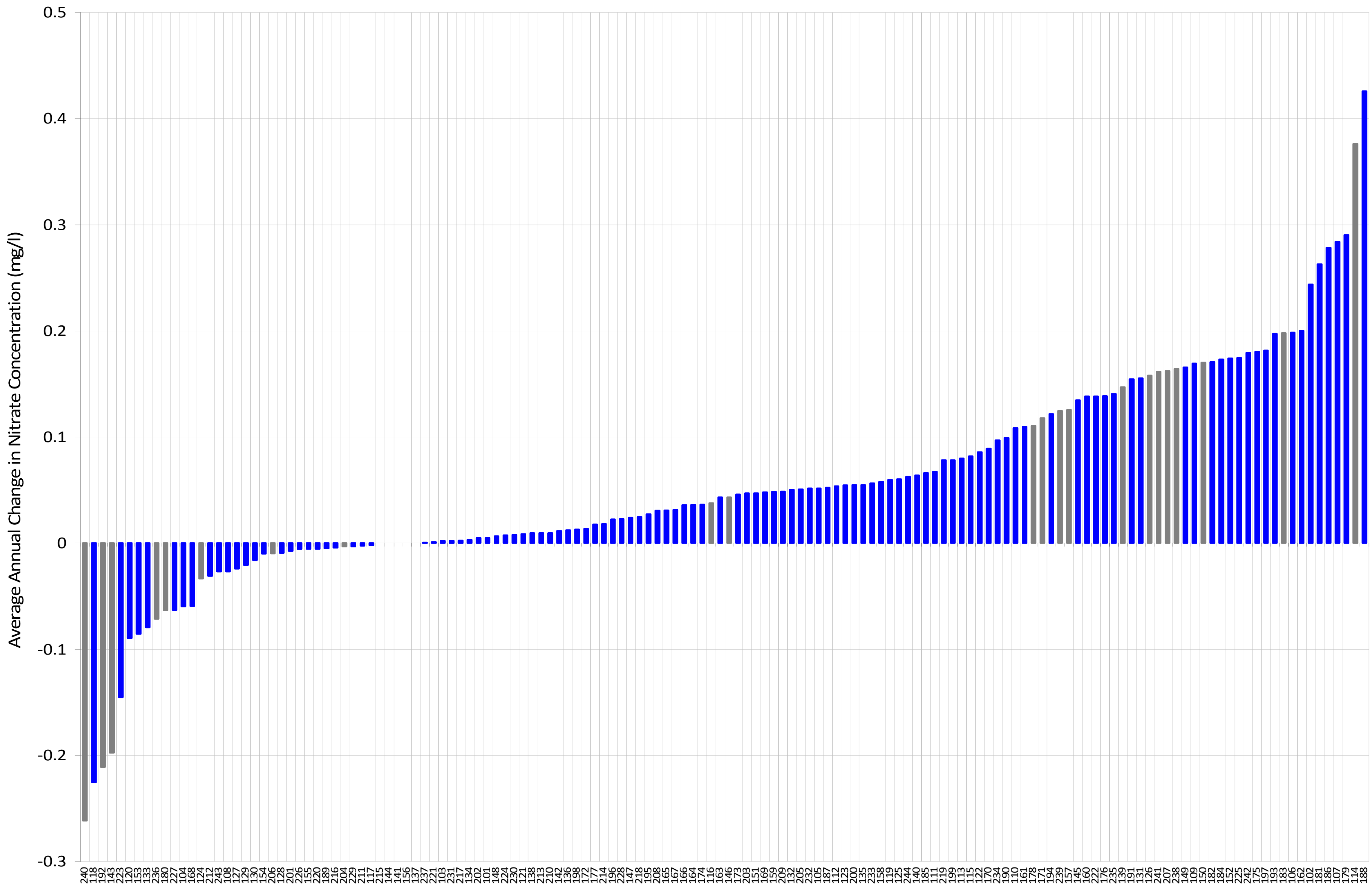


Figure 8. Bar graph depicting nitrate trends at Hillside private wells with 4 or more tests. Individual plots are provided in Appendix A and locations of systems are shown on figure 10 using the well number shown.

Trend line slopes with MSE's greater than 0.75 are denoted with gray in contrast to the blue color used for the rest of the slopes. In general the nitrate levels reported for private wells seem to have less consistent values and to show less consistent trends over time than nitrate levels observed in wells serving community water systems. One possible explanation for this observation is that the aquifers feeding private wells are subjected to less steady pumping, since consumption is dictated by the demands of a single family. Also, since most of the private well water samples were collected shortly prior to a home sale, many of the homes may have been vacant for some time prior to sample collection, resulting in little or no water usage in the days immediately preceding the test.

Considering all wells shown in Figure 8, 28 percent of them, or 40 wells, showed nitrate trend line increases of 0.1 mg/L per year or more. This is a slightly higher percentage than for public wells, and is likely a result of the fewer data points (and therefore higher uncertainty on the trends) available for most of the private wells.

Figure 9a show the nitrate trends at all 144 private wells with 4 or more nitrate values. This plot shows a rather chaotic mix of trend lines. Three observations stand out. First, the greatest concentration of trend lines is for systems that have low slopes and low nitrates (less than 1 mg/L). Second, there appear to be significantly more positive slopes than negative slopes. Third, there are a few trend lines that reach into the 8-10 mg/L nitrate range (or higher). If these trend lines continue, more systems will enter that range, and more systems will show trends lines crossing the 10 mg/L MCL.

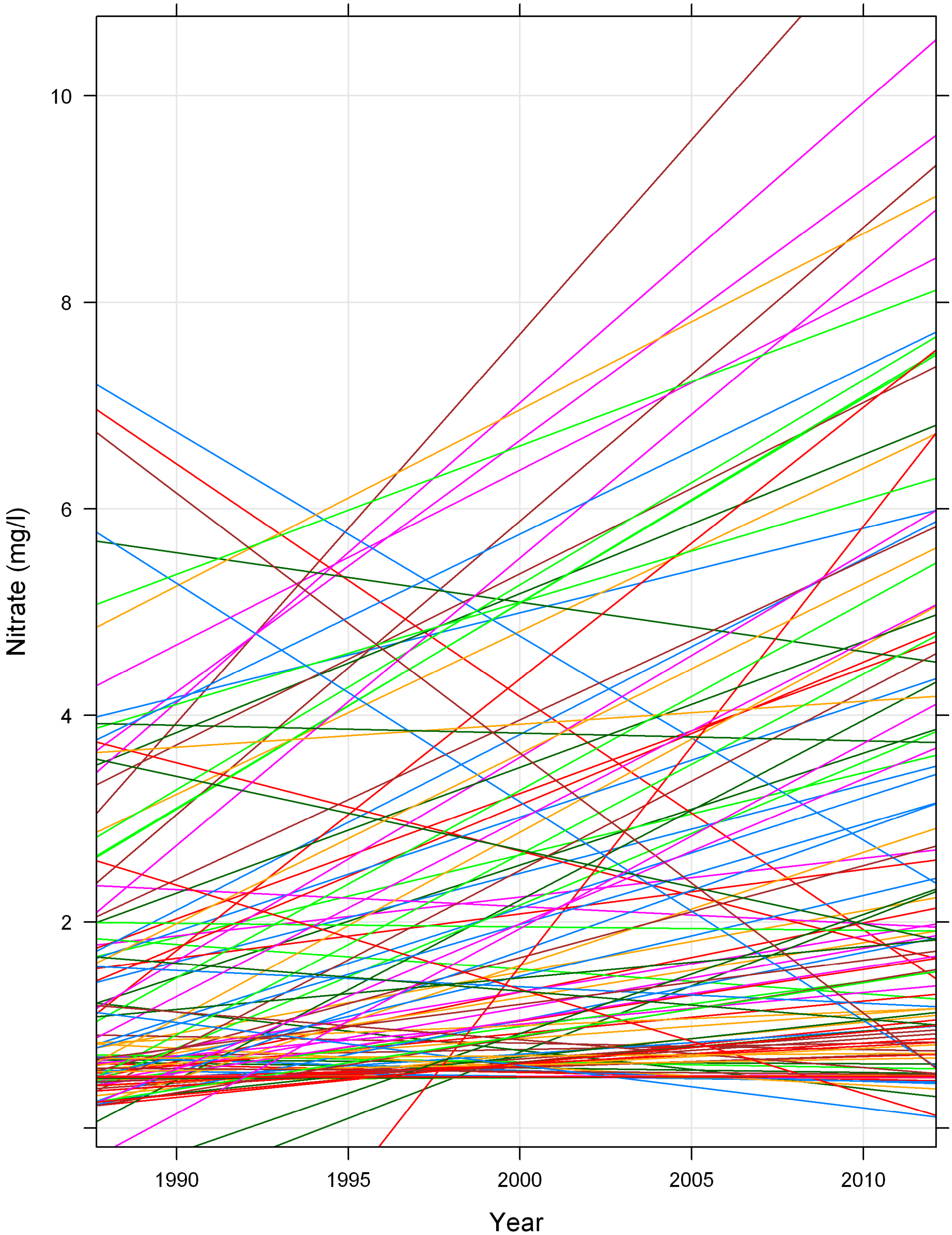


Figure 9a. Plot of nitrate trend lines at private wells with 4 or more tests and levels of nitrates.

Figure 9b shows another way of illustrating the increasing values of nitrates in many private wells. This figure shows a plot of the latest nitrate value at a private well plotted against the average annual change in nitrate concentration for that well. Similar to Figure 7b, the plot generally shows that wells with higher nitrate trends also tend to have higher nitrate levels. Also, a cluster of systems show virtually no change in nitrates over time and their latest nitrate values are below 1.0 mg/L.

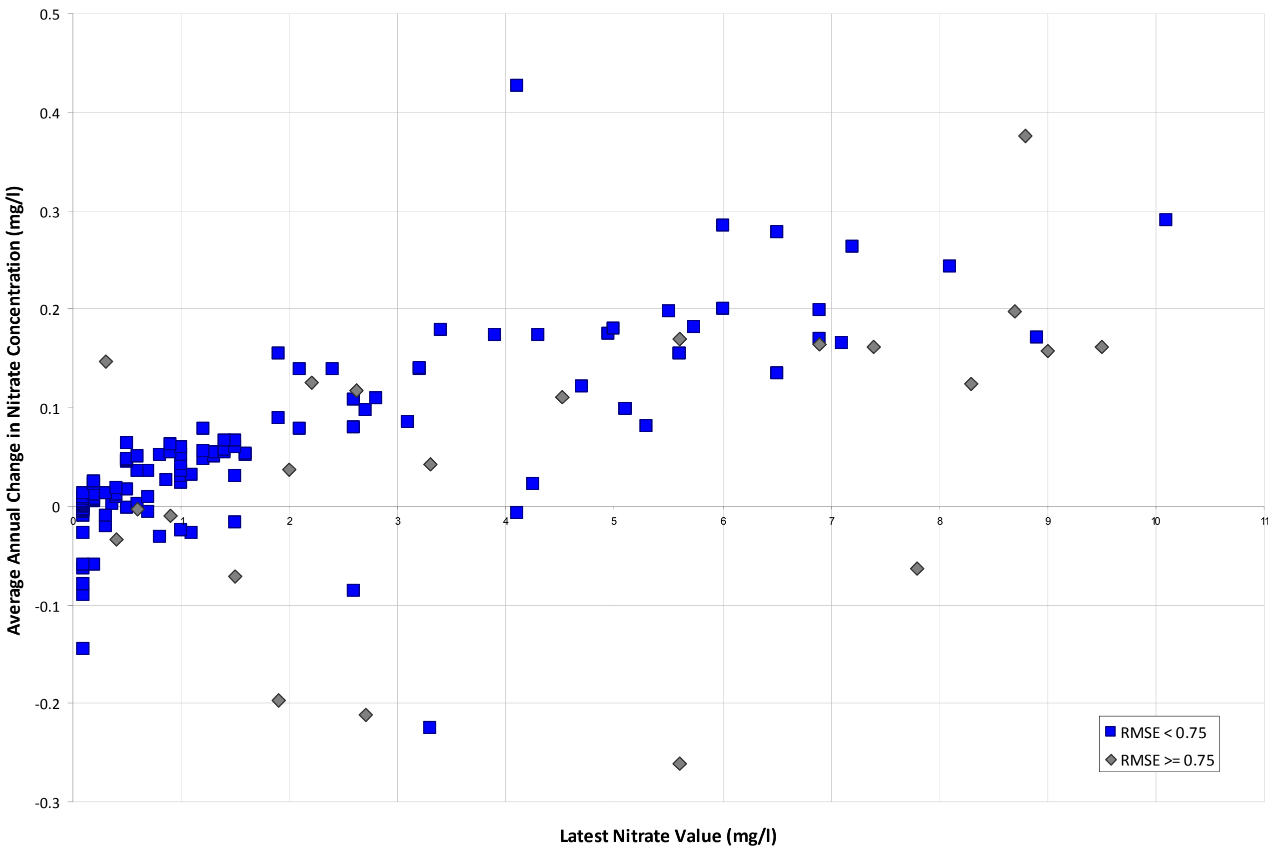


Figure 9b. Plot showing nitrate trends vs. latest observed nitrate value in private wells.

D. Spatial distribution of nitrate trends in Hillside area wells: Figure 10 is a map showing trends at all public wells and private wells with 4 or more nitrate tests. This figure shows that both public and private wells with positive slopes greater than 0.05 mg/l/yr are distributed throughout the Hillside area and that it is difficult to discern any particular areas of concentration.

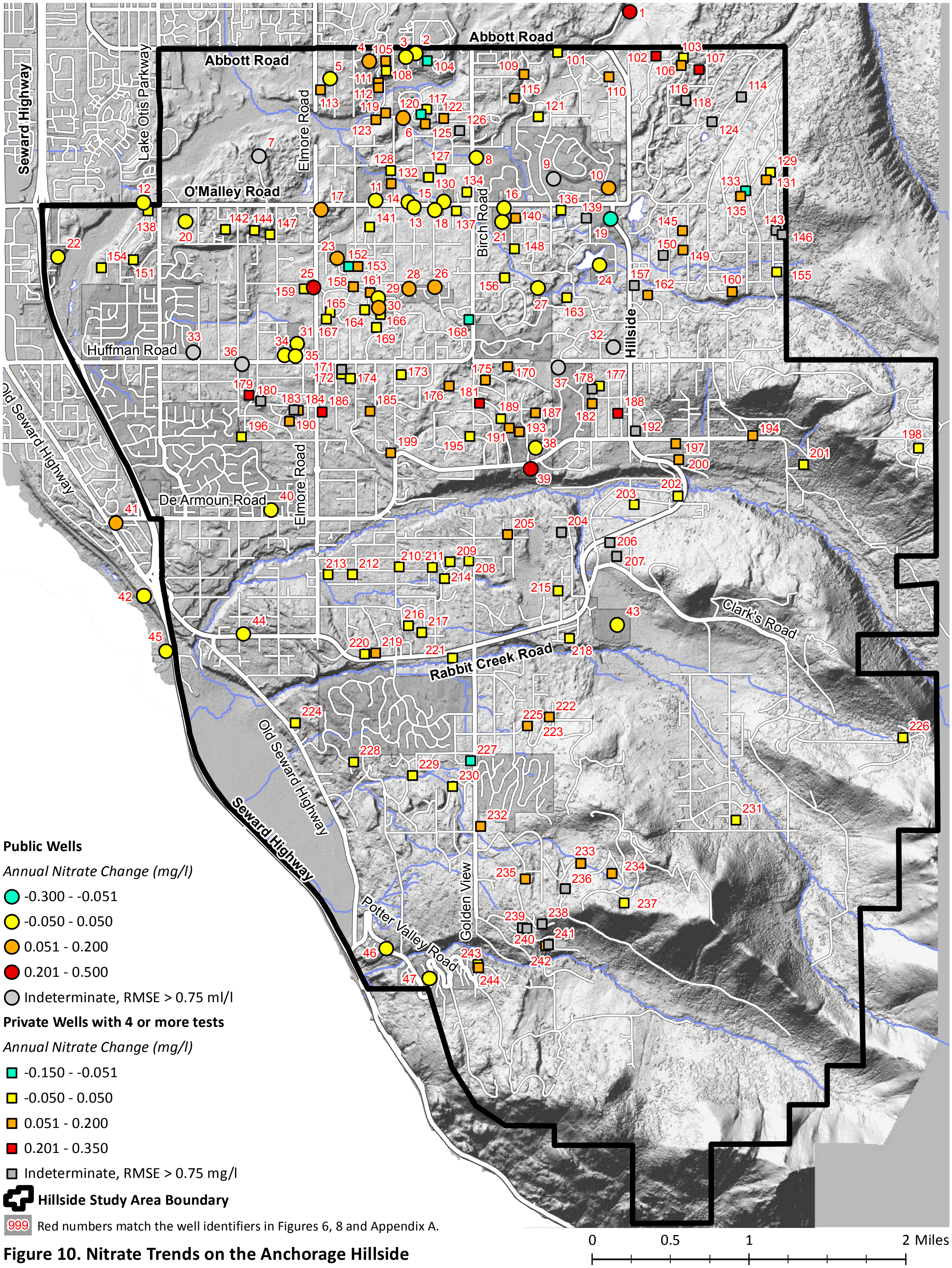


Figure 10. Nitrate Trends on the Anchorage Hillside

VI. Discussion of quantifiable factors potentially affecting nitrate concentrations in Hillside wells:

A limited statistical review of several quantifiable factors that could have an influence on nitrate levels was performed as part of this study. The results are summarized below.

- Well depth and well casing depth: It seems reasonable to expect that deeper aquifers would have greater protection from overlying nitrate sources, all other factors being equal. Both well depth and well casing depth were found to have a small but statistically significant correlation with reported nitrate levels, with deeper wells and deeper casing correlating with lower nitrate levels (see Appendix B).

- Well age: While a statistical analysis suggested that older wells were found to have a small but statistically significant correlation with higher nitrate levels (see Appendix B), other data were conflicting, so no conclusion can be drawn at the present time on this factor.

- Well grouting: On 8/13/96 the Municipal well drilling ordinance was changed to require all wells to be dry grouted (to prevent surface water infiltration around the bore hole) at the time they were drilled. To see if any effect of this ordinance could be observed, Table 1 and Figure 11 compare nitrate levels observed in tests done after 8/13/96 on wells drilled before and after the effective date of the ordinance. Except for 2008, each of the years between 1997 and 2008 showed that the median nitrate level in wells that had been drilled prior to 8/13/96 was approximately 0.5 mg/l higher than in wells that had been drilled after 8/13/96. This suggests that using dry grout to seal around the outside of the bore hole has had some effect on reducing nitrate levels.

Table 1. Comparison of nitrates in wells drilled before and after well dry-grouting requirements

	Median Nitrate Concentration (mg/l)	
YEAR	Not Grouted	Grouted
1997	1.0	0.5
1998	1.1	0.9
1999	1. 5	0.6
2000	1.1	0.8
2001	0.9	0.6
2002	1.2	0.6
2003	1.0	0.7
2004	1.2	0.2
2005	0.8	0.3
2006	1.1	0.3
2007	2.1	0.8
2008	1.1	1.05

Note: The well completion date was not recorded in 2009 and 2010

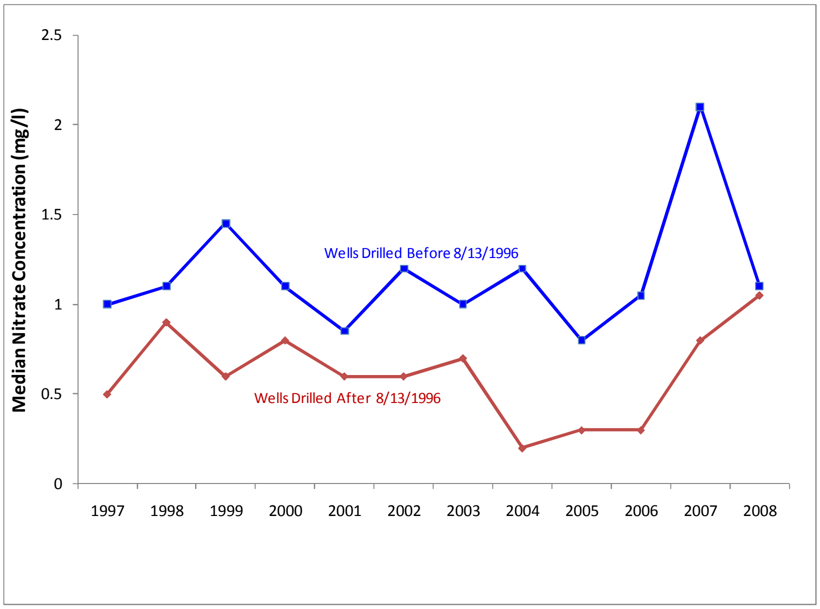


Figure 11. Comparison of nitrates in wells drilled before and after well dry-grouting requirements.

- Sealing bedrock wells: On 1/1/2006 the Municipal well drilling ordinance was changed to require that all wells that encountered bedrock shallower than 40 feet should have oversized boreholes drilled into the bedrock and sealed with bentonite slurry or granules. The study authors wanted to compare nitrate levels in wells with shallow bedrock that were drilled before and after the effective date of the ordinance, however very little data was available to do so, because an **unfortunate** decision was made in 2008 to no longer enter the well drilling date into the COSA database. Despite the fact that there are only 6 samples from Hillside bedrock wells with recorded completion dates after 1/1/2006 and 14 samples Municipal-wide, there appears to be an indication that this bedrock sealing procedure significantly reduces nitrates. The median nitrate level in the sealed wells was 0.1 mg/l, whereas the median nitrate levels for unsealed wells encountering shallow bedrock were 1.5 and 1.3 mg/l for the Hillside and Municipal-wide areas, respectively.

Table 2. Comparison of nitrates in wells encountering shallow bedrock constructed before and after 2006 grouting requirements.

Date of Well Completion	Number of Well Tests (Hillside Only)	Median nitrate value (mg/L)
After 1/1/2006	6	0.1
Before 1/1/2006	99	1.5

Date of Well Completion	Number of Well Tests (Muni-wide)	Median nitrate value (mg/L)
After 1/1/2006	14	0.1
Before 1/1/2006	197	1.3

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- Septic system use and density: Practically the entire Hillside area is served exclusively by on-site septic systems. As can be seen from the nitrate patterns shown in Figure 2, the uniformity in septic system usage does not correlate well with the highly irregular patterns of nitrates in well water. For example, nitrates are not seen to uniformly increase, as one might expect, in down gradient directions from increasing numbers of septic systems upgradient. Also, there does not appear to be any simple correlation between septic system usage and nitrates; many areas with relatively dense septic systems exhibit lower nitrate patterns than other areas with larger lots and lower septic system densities. This suggests that factors other than septic system usage control the distribution and occurrence of nitrates in many areas. A primary possible factor is that local aquifers may have varying susceptibility to nitrates in different areas.

- Geologic variability: Groundwater in the Hillside area commonly occurs in multiple permeable horizons at any given location. Adjacent wells can tap aquifers or bedrock fractures at very different depths. Different strata can have different concentrations of nitrates. This parameter could not be analyzed because available databases do not include stratigraphic information from the well driller's logs.

- Well yield: A localized nitrate source may have less potential impact on a high-yield well than a low-yield well because of greater dilution in larger or more permeable aquifers.   No statistically significant correlation was observed between well yield and observed nitrate levels.

- Soil absorption system type: Shallow impermeable strata could keep nitrates in the aerobic zone and therefore subject to plant uptake, or cause nitrate-laden groundwater to become surface water – thereby protecting deeper aquifers from nitrate contamination.   While the nitrate database does not contain soil information directly, it does contain a description of the absorption system type used – in general beds, mounds and drainfields are installed over shallow impermeable strata or a shallow water table, whereas trenches and seepage pits are used where the permeable stratum is thicker. While the median nitrate levels observed in wells located on lots served by beds, mounds and drainfields is slightly lower than on lots served by trenches and seepage pits, the data are not conclusive that there is a correlation.

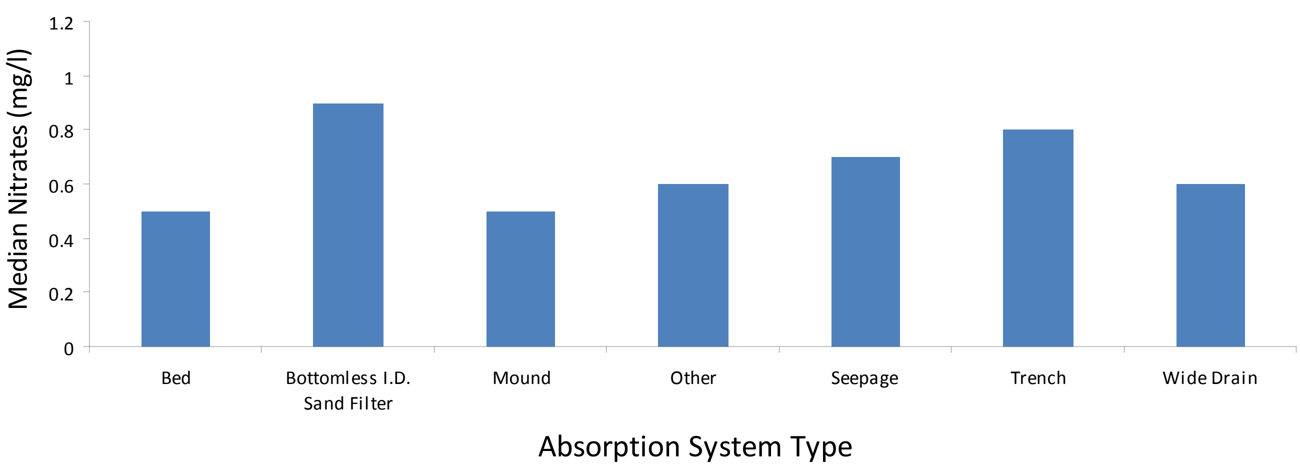

Figure 12. Median nitrate values on lots with different types of septic systems.

- Seasonal variations: Shallow aquifers tend to contain higher nitrates and may only be active during periods of high recharge, such as during and shortly after spring breakup or fall rains. On the other hand, higher levels of precipitation could tend to dilute the nitrates in an aquifer. No significant correlation was found between median nitrate levels and the month during which the sample was collected.

- Sampling methodologies: If a well is pumped only briefly prior to sample collection then the sample may be reflective of water in the well casing or just outside of it, whereas if a well is subjected to prolonged pumping prior to sample collection, the sample may be more representative of water in the larger aquifer. Information on sampling methodologies is not available in the nitrate database.

- Data entry error: Numerous instances of data entry error were identified and corrected as part of this study; however there may be additional sources of error.

VII. Findings and Conclusions:

From a global, or even a national perspective, the nitrate levels presently being observed on the Anchorage Hillside should not be a major cause for short-term concern for most well owners. Approximately 9% of wells tested showed nitrate levels of >5 mg/L, which is half the MCL of nitrate of 10 mg/L for public water supplies. With only 0.2% of wells having nitrates in excess 10 mg/l, and the maximum recorded nitrate level less than 15 mg/l, the current nitrate levels in wells on the Anchorage Hillside (where large scale agriculture is absent) presents significantly less cause for concern than in many communities around the world. Nevertheless, the fact that nitrates are increasing at many locations means that nitrate levels should not be ignored. Many public water systems (18 of 47 systems analyzed) were found to have statistically significant increases in nitrate concentrations with time, and many private wells were also found to have increasing trends of nitrates.

Many water systems remain essentially nitrate-free, and the median rate of increase for most systems is less than 0.1 mg/L per year, which means that it will be decades before most of these systems approach levels meriting urgent concern, assuming present trends continue. Some systems, however, are increasing at a sufficient rate that owners are at risk (again assuming that present trends continue) of approaching or exceeding nationally-established MCLs for nitrates within timeframes of less than 10 years.

Nevertheless, the number of systems where nitrate values present a near-term problem for well owners is tiny compared to the total number of water systems, and the current method of letting individual well owners develop solutions best suited to their unique situation seems to be the best practical approach.

Existing data about nitrates in Anchorage Hillside groundwater shows that levels and rates of increase are low. Thus, there is no reason to conclude that the long-term viability of on-site well and wastewater systems on the Anchorage Hillside is diminished on the basis of existing nitrate trends and concentrations.

Based on this study we have been able to quantify nitrate levels in private and public wells on the Hillside, and also what trends have been observed in nitrate levels over the past 20+ years.

There are, however, many unanswered questions pertaining to nitrates on the Anchorage Hillside that this study has been unable to address due to lack of available data. These include:

(1) What are the primary sources of the nitrates found in Hillside wells? Because nitrate levels are increasing in many Hillside areas, it seems reasonable to conclude that the increases are attributable to human activity. However, how much of this increase is attributable to septic system usage vs. other sources of nitrates such as lawn and garden fertilizer or horse stables. This is an important question that warrants in-depth analysis. See recommendations.

(2) Why do certain distinct subareas of the Hillside exhibit elevated nitrate levels compared to others? There is little apparent correlation between development density and observed nitrate levels. In fact, many of the subareas that exhibit the highest nitrate levels are on the upper Hillside where lots are generally larger and human influences less concentrated. These upper Hillside areas with elevated nitrates, some of which are along pronounced ridges, have little or no human development activities occurring upslope or near them where the aquifers are recharged.

(3) How do the observed nitrates get into the aquifers? Most Hillside wells tap confined aquifers, which means that the aquifers are overlain by low-permeability rock or soil layers. The presence of these materials means that nitrate contamination originating near the surface on a lot is unlikely to make its way into the aquifer being tapped by the well on the lot. Poorly sealed bedrock wells, and the aquifer in the vicinity of such wells, on the other hand, can potentially be contaminated by nitrates originating in water often encountered flowing along the shallow surface of fractured bedrock.

(4) What happens to nitrates in an aquifer as it moves along? Wells in much of the mid-Hillside area downslope of the high nitrate areas of the upper Hillside exhibit low or non-detectable nitrates. Are nitrates in these wells somehow becoming cleansed or diluted, or do they tap totally different aquifers that are too deep to be tapped by upper Hillside wells? Do the high-nitrate aquifers being tapped by upper Hillside wells "daylight" out into surface water where plants can take up the nitrates?

(5) Where do the nitrates encountered in the Lower Huffman/Elmore Road area originate? Development in this area is neither denser nor of a lower standard than adjacent areas located upslope which exhibit significantly lower nitrates.

(6) What is the explanation for the often significant variability between nitrate levels observed in wells on adjacent lots and/or sometimes in the same well when repeat samples are collected? (See recommendation for targeted sampling program)

VIII. Recommendations for future work:

Following are specific suggestions for further work, generally arranged in order of those of greatest ease of implementation and importance.

A. Institute database changes to improve the accuracy of water quality data.

1. Municipal COSA database improvements:

The Municipal COSA database provides a valuable source of nitrate (and coliform and arsenic) data for private wells on the Anchorage Hillside (and other areas of the Municipality).   With the following changes to the data entry process the accuracy and usefulness of this resource could significantly enhanced.   Each of the recommended data entry fields is contained on the existing COSA data submittals, and many of these have been entered in the past.

Our overall primary recommendation is that the Municipality should consider requiring engineers to submit all the data required for their COSA applications using an on-line form that could be entered into the COSA database after approval. This way the engineer would be accountable for the validity of the information that was in the database and the Municipal staff would only have to review the content (as they currently do) without having to re-keypunch it. It would take some effort initially to set up the system, but after it was working it should save the Municipality money and would almost certainly result in more accurate and complete data collection. Pending this overhaul of how the Municipality processes data, or in some cases as part of such a system, the following detailed recommendations are provided:

a. To reduce data entry errors, the data entry form should be formatted to resemble insofar as possible the COSA data sheet from which the data are being extracted.
b. The data entry fields should be properly formatted for numbers, dates, or text.
c. To ensure that actual data are entered, contaminant data fields should never contain a default value.
d. With the exception of coliform bacteria, contaminant levels should never be entered as zero. For each contaminant there should be: (1) a field to enter the laboratory MRL; (2) a yes/no field to show whether the reported value was </= the MRL; and (3) a field to enter the reported contaminant concentration.
e. Contaminant concentrations should always be entered using the same number of decimal places as reported by the testing laboratory.
f. To reduce data entry error, the data entry form should incorporate an automatic warning whenever a value entered is outside the expected or possible range.
g. The date that the water sample was collected should be entered.
h. Well drilling data including date drilled, total depth, casing depth, highest casing perforation (if any), well yield, and static water level should be entered.
i. Data should be collected about the results and effectiveness of any well rehabilitation work designed to reduce nitrates in wells. A well rehabilitation report should be required from those who perform such services.
j. The parcel ID number should be entered.
k. Nitrate and arsenic water quality test data collected for Class "C" wells should also be entered.
l. Data should be proof-checked by someone other than the original data entry person prior to uploading to the database.

2. DEC Drinking Water Watch (DWW) database improvements:

Recognizing that Drinking Water Watch is a National program that was not developed locally, the overall format probably cannot be changed significantly. However, based on the study author's experience in using the database, data entry procedures can and should be changed to reduce errors and improve the quality of the data in the database.
a. Whenever a sample is tested both the "concentration level" and the "reporting level" should be entered consistently into the data base. These fields should never be zero, or left blank.
b. Care should be taken to ensure the units used are consistent, and that duplicate entry of the same data is avoided, particularly with different units.
c. Care should be taken to ensure that the actual date that the sample was collected is shown. While this was not observed to be a problem with nitrate results, it was with other analytes such as lead.
d. Ideally, data entry should be proofed at the time of entry to ensure its accuracy, and instances where the data deviates substantially from expected trends should be evaluated and/or follow-up samples collected, tested and entered into the database.

B. Investigate local nitrate variability through further analysis and/or targeted sampling programs:

Between the Municipal COSA database and the State DWW database there is a tremendous pool of nitrate data continuously being generated for the Anchorage Hillside, so no additional area-wide nitrate sampling program is needed. There are, however, numerous areas of high variability in the available nitrate data which warrant further investigation. Understanding the reasons behind this variability will help enhance the credibility of the database and perhaps lead to a better understanding of nitrates on the Hillside.

Within the identified subareas where nitrate levels tend to be high there are numerous lots where nitrate levels are much lower as can be readily seen on Figure 2. The explanations for these differences are unknown. One approach would be to perform a detailed analysis of well log data in these subareas to see if different aquifers are being tapped, or other hydrological explanation can be found. A second approach would be to institute a targeted sampling program to collect simultaneous nitrate data from numerous wells in the subarea (including wells not presently in the COSA database) to determine if the nitrate differentials are still present, and if they are the result of differences in sampling dates, sampling procedures, well construction, or some other factor.

Similarly, in the broad areas where nitrates tend to be low, a few isolated lots show much higher nitrates. In these situations also, similar analyses of well logs and/or targeted sampling programs would likely yield useful insights into what is going on.

Thirdly, on some lots extreme variability is observed between different nitrate samples collected from the same well, sometimes within a very short time span. A targeted sampling program could investigate whether the causative factor is related to the season during which the sample was collected, the amount of water that was pumped from the well prior to sample collection, or some other sampling protocol.

C. Undertake a research program to determine the sources of nitrates in Anchorage well water:

Before considering instituting measures designed to reduce nitrate levels, it is essential to be confident that one knows the source of the nitrates that occur in drinking water. At this time, there is no hard evidence conclusively linking elevated nitrate levels on the Hillside to contamination from septic systems – or to inadequate well drilling practices. In addition to wastewater disposal systems, other potential sources of nitrates in wells on the Anchorage Hillside include lawn and garden fertilizer, horse manure and natural fixation of atmospheric nitrogen.

Isotope analysis of both nitrogen and oxygen can be used to differentiate between sources of contaminants. This approach is based on the fact that a tiny percentage of each element occurs naturally as a heavier isotope. The ratio of the heavier isotope to the “normal” isotope of each element is modified differently as it goes through different chemical or biological processes. Useful insights as to nitrate’s origin can be gained through comparing the ratios of stable isotopes of nitrogen and oxygen in nitrates. The analysis is complicated and the results are not always definitive, particularly when several different sources occur simultaneously. However, isotope analysis is a well-documented technique that has been successfully used in many similar situations around the country. Anchorage is in the fortunate position of having an isotope laboratory located at UAA. The authors of this report recommend that this type of analysis would make an excellent UAA research project.

In addition to isotope analysis, many researchers have also used trace organic compounds from pharmaceuticals and household and consumer products such as caffeine to identify influences from septic systems on local groundwater. UAA also has the capability to perform studies in this area.

D. Outreach programs for public education:

Elevated nitrates can cause difficulties for homeowners by reducing marketability of property or endangering a safe water supply. Fortunately these types of problems affect only a very tiny minority of systems. The current practice of allowing system owners to manage their own situation through industry-standard practices of well sealing, rehabilitation, deepening, well re-drilling, or even connecting to a neighboring well are practical and effective solutions. Technical information should be made available to well owners about the nature and efficacy of these solutions.

Elevated nitrates potentially affect people throughout broad areas of the Anchorage Hillside and neighborhood-wide understanding of the situation and how to address it is important. This is achievable through:

- Dissemination of study findings so more people understand the situation;
- Minimization and proper application of lawn and garden fertilizer;
- Appropriate management of waste from large animals;
- Support use of innovative low-nitrate septic systems in certain areas;
- Support periodic reviews of on-site water and wastewater ordinances. This could include re-evaluating requirements for high-nitrate wells, requiring submittals of well rehabilitation work, and other items;
- Reassurance of the long-term viability of on-site water wells across most or all of the Anchorage Hillside; and
- Support for continuing efforts to study and report on nitrate trends and source evaluation.

E. Periodically update this report:

This report provides a snapshot of the nitrate levels presently being observed on the Hillside and evaluates trends that are evident over the past 20 years. Because the addition of a single year's additional data is unlikely to significantly change either of these, it seems reasonable to schedule periodic updates of this type of report at approximately 3 to 5-year intervals. In the meantime, it will be more important to focus nitrate study efforts on determining the actual sources of nitrates in Anchorage well water and on sub-area analysis and targeted sampling programs to figure out what is causing localized variability of nitrate levels.

F. Broaden the scope of future drinking water analyses to be Municipality-wide and include other contaminants:

Water quality concerns pertaining to wells on the Anchorage Hillside apply equally to all wells across the Anchorage area. Data available on the Municipal COSA database and the State Drinking Water Watch database is not limited to the Hillside area, so with little additional effort the same types of analyses could be performed on a city-wide basis - or on any other subarea of the Municipality. Approximately one half of the nitrate data in the COSA database pertains to the Hillside area; other large areas within the Municipality that contain high densities of on-site wells and septic systems are the Eagle River to Eklutna area and the Sand Lake area. Other smaller areas include Stuckagain Heights and Bird Creek. Most of these areas share geological characteristics similar to those found on the Hillside, so looking at the broader picture of the Municipality as a whole should improve understanding of the issues, both on the Hillside and across the rest of the Municipality.

Nitrate contamination is the major concern on the Hillside; however nitrates are only one aspect of the larger issue of well water quality in Anchorage. Arsenic is another contaminant that is known to occur in many drinking water wells in Anchorage, particularly in the Sand Lake area. Unlike nitrates (where levels in excess of the 10 mg/l MCL are rare) arsenic levels measured in Sand Lake area wells frequently exceed the National and State MCL of 10 micrograms per liter, often by a factor of 2 or more. Each of the major data sources utilized in this study contains citywide data on arsenic, and the DEC drinking water website watch contains extensive data on a broad spectrum of additional contaminants. It only makes sense to tap these data sources for increased understanding of all known contaminants.

G. Evaluate and upgrade well log database

The Alaska Department of Natural Resources maintains a website called WELTS (Well Log Tracking System) that contains copies of driller's logs for many drinking water wells in Alaska. Unfortunately, the format of the WELTS data does not allow specific well data to be systematically retrieved.

Information in WELTS regarding a well's location does not include the Municipal PID#, which is useful for linking data to records in the Municipality database.

The WELTS record for a well contains a pdf of the driller's log, but only the driller's name, owner's name, well location, date drilled and total well depth are typed into separate fields. In order to be useable for a study such as this all the driller's log information including casing depth, static water level, well yield, depths of formations penetrated, and depths of casing perforations would need to be entered into searchable data fields. At the time WELTS was set up, this more comprehensive database function was provided by the U.S. Geological Survey's Ground Water Site Inventory (GWSI) system. This system currently contains many well logs for the Hillside area, but by no means is it comprehensive.

There should be an evaluation of database needs for the Hillside area (and, actually, the entire Municipality and the State as a whole) and a plan should be prepared and implemented to upgrade and maintain a suitable well log database.

IX. Glossary

Aquifer

A permeable formation that stores and transmits groundwater in sufficient quantity to supply wells or springs.

Confined aquifer

An aquifer that lies between two relatively impermeable rock or sedimentary units. The static water level in a well tapping a confined aquifer will always rise in the casing above the level where the aquifer is encountered.

Confining bed or unit

a body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

COSA

Certificate of On-site System Approval. A certificate required by the Municipality of Anchorage indicating approval of wells and/or wastewater disposal systems prior to sale of single family dwellings in Anchorage.

DWW

Drinking Water Watch. A database operated in Alaska by the Alaska Department of Environmental Conservation Drinking Water Program that contains water quality data on public water supply systems.

Glaciofluvial

Pertaining to streams fed by melting glaciers, or to the deposits and landforms produced produved by such streams.

Groundwater

Water within the earth that supplies wells and springs; water in the zone of saturation where all openings in rocks and soil are filled, the upper surface of which forms the water table.

Linear Regression Analysis

A technique in which a straight line is fitted to a set of data points to measure the effect of a single independent variable. The slope of the line is the measured impact of that variable.

MCL

Maximum Contaminant Level. Highest allowable concentration of certain contaminants in water delivered to a user of public drinking water supply.

Mean square error

The mean of the squares of all the deviations between the observed values and the predicted values.

Mg/L or mg/l

Milligrams of a substance contained in one liter of liquid. At low concentrations typical of fresh water, it is numerically equal to parts per million (ppm).

Nitrate

A negatively charged ion composed of one atom of nitrogen (N) and three atoms of oxygen (O); the chemical symbol for nitrate is NO_3^-.

Outliers

Observations that appear to be inconsistent with the rest of the data.

p value

p value is associated with a test statistic (such as in this paper a regression line slope). It is "the probability, if the test statistic really were distributed as it would be under the null hypothesis (such as in this paper a flat slope), of observing a test statistic as extreme as, or more extreme than, the one actually observed.

The smaller the p value, the more strongly the test rejects the null hypothesis, that is, the hypothesis being tested.

A p-value of 0.05 or less (or 1 in 20 or less) rejects the null hypothesis "at the 5% level" that is, the statistical assumptions used imply that only 5% of the time would the supposed statistical process produce a finding this extreme if the null hypothesis were true.

Root mean square error

The square root of the mean square error. A statistical measure of how well a predictive line fits the data. It has the same units as the parameter being analyzed.

Unconfined aquifer

An aquifer that has a water table. The static water level in a well tapping an unconfined aquifer will not rise in the casing above the level where the aquifer is encountered.

Water table

The upper surface of the zone of saturation on which the water pressure in the porous medium equals atmospheric pressure.

Zone of aeration

A region below the Earth's surface that is marked by the presence of both water and air in the pores of rocks and soil.

Zone of saturation

A region that lies below the zone of aeration and is marked by the presence of water and the absence of air in the pores of rocks and soil.

X. References

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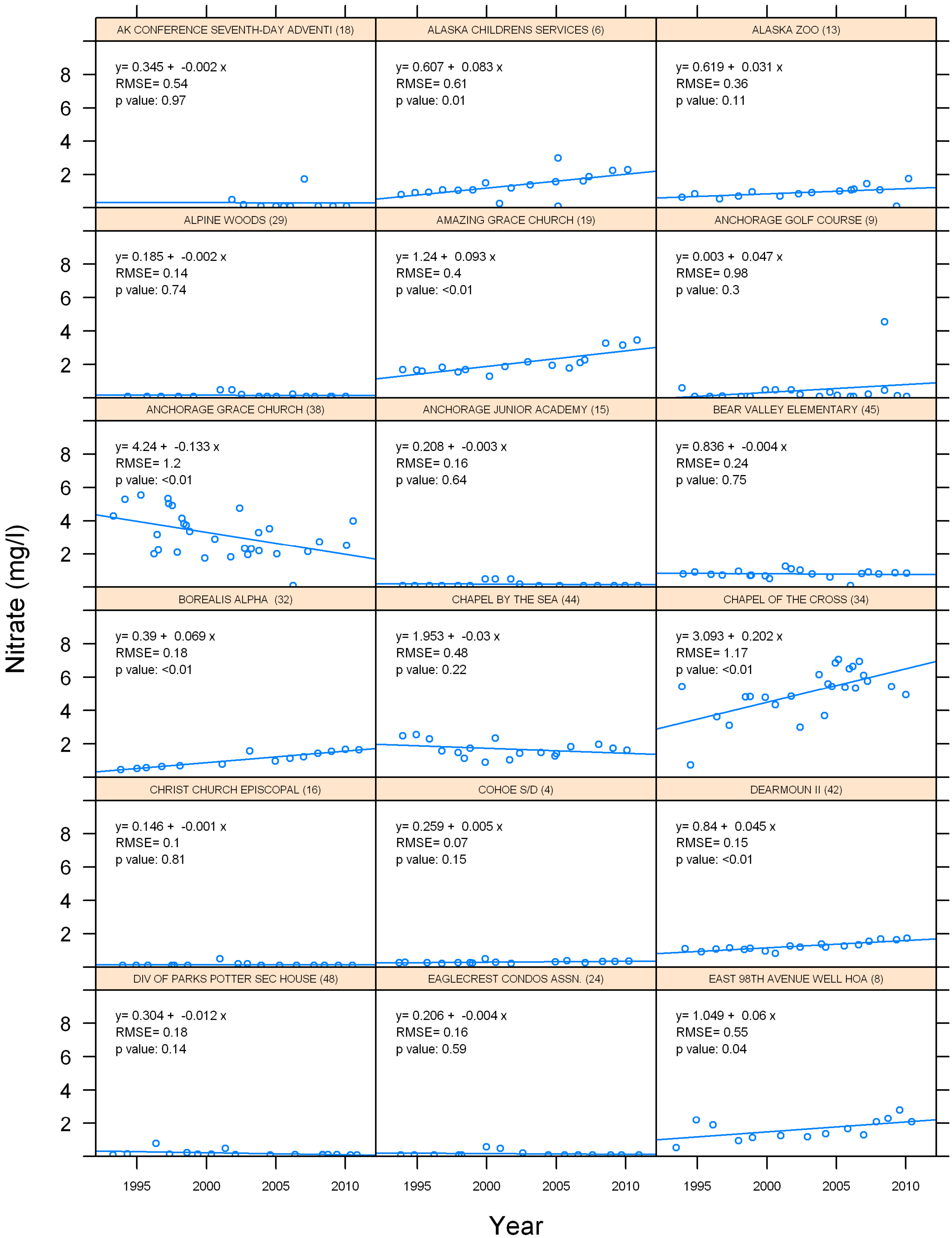
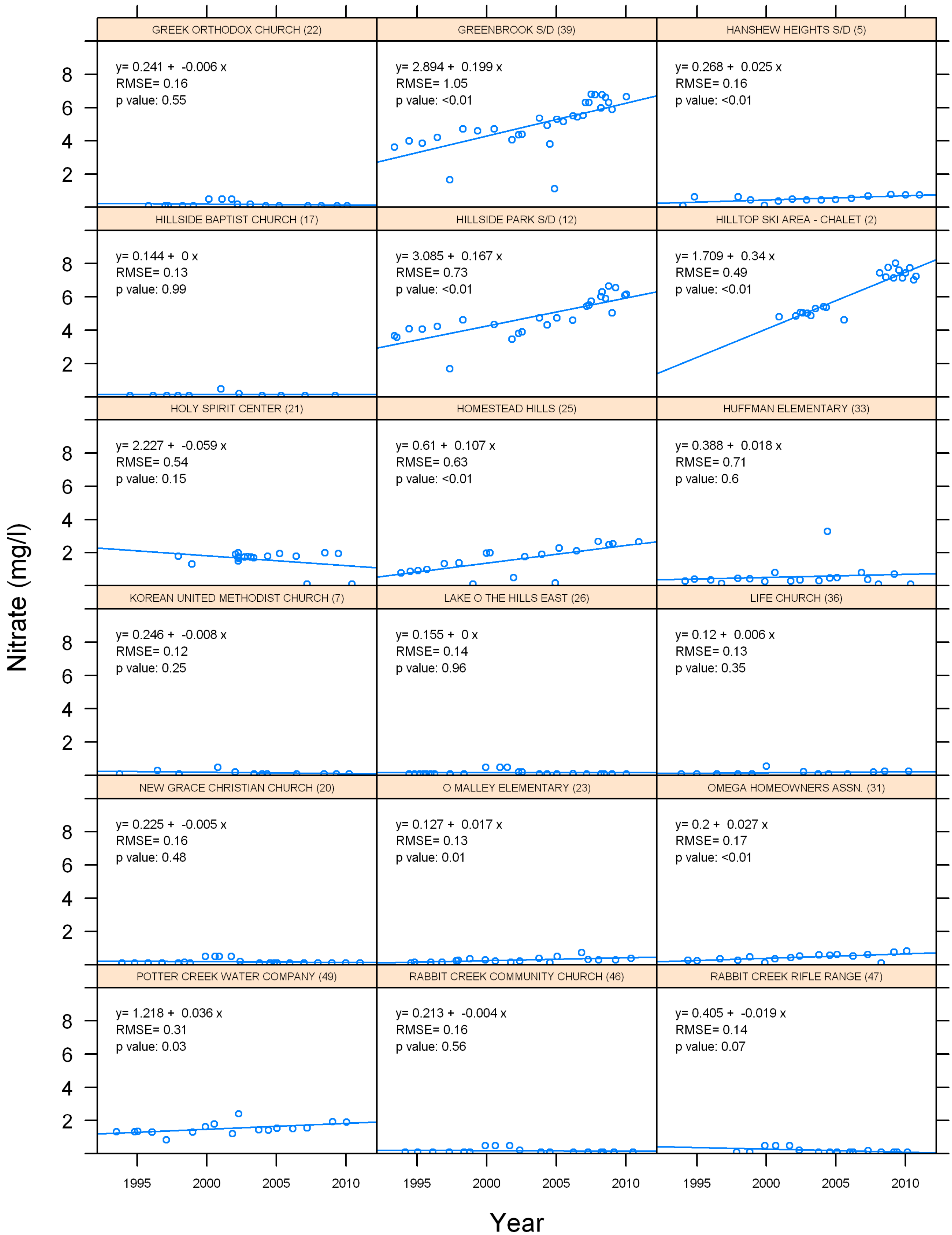
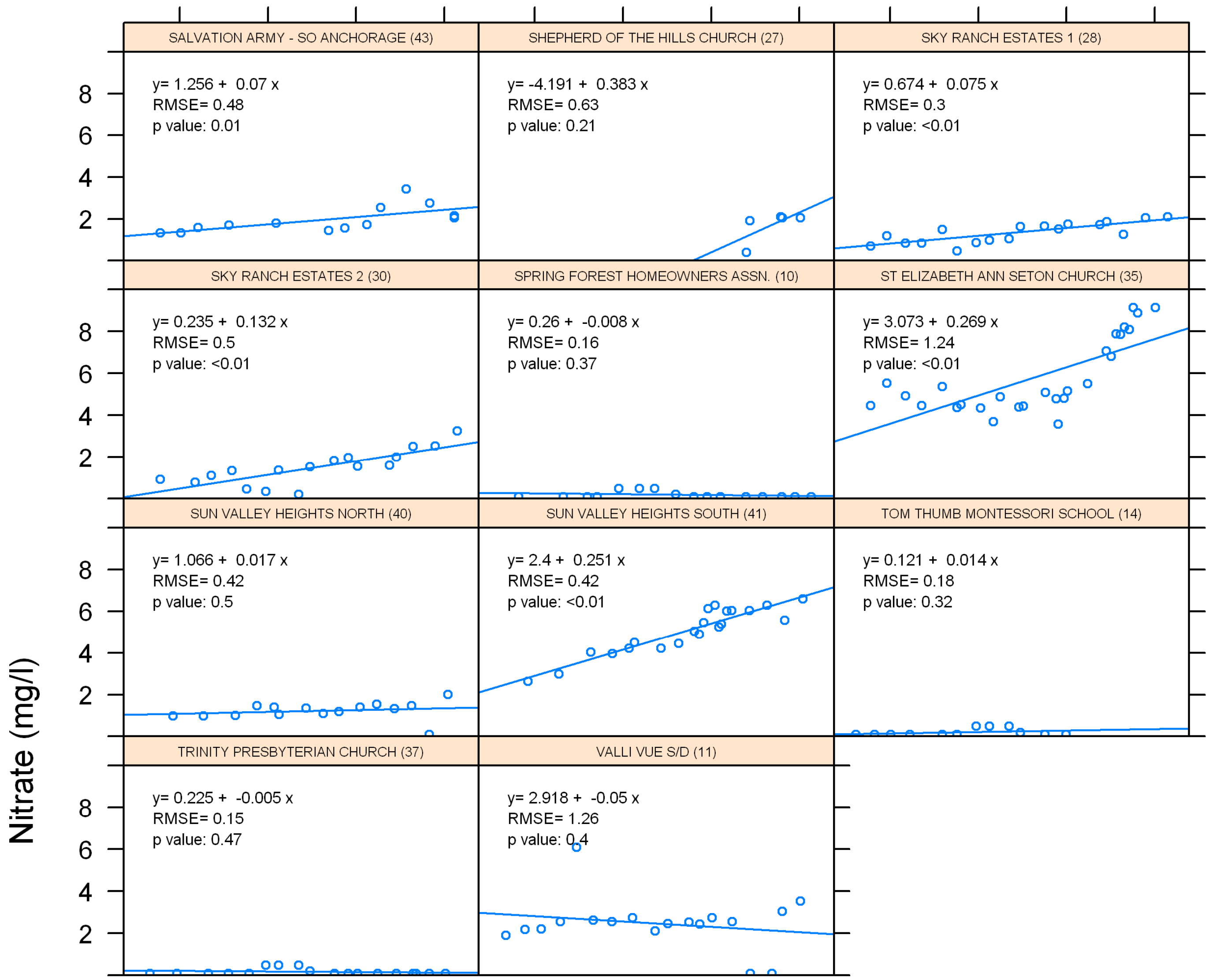
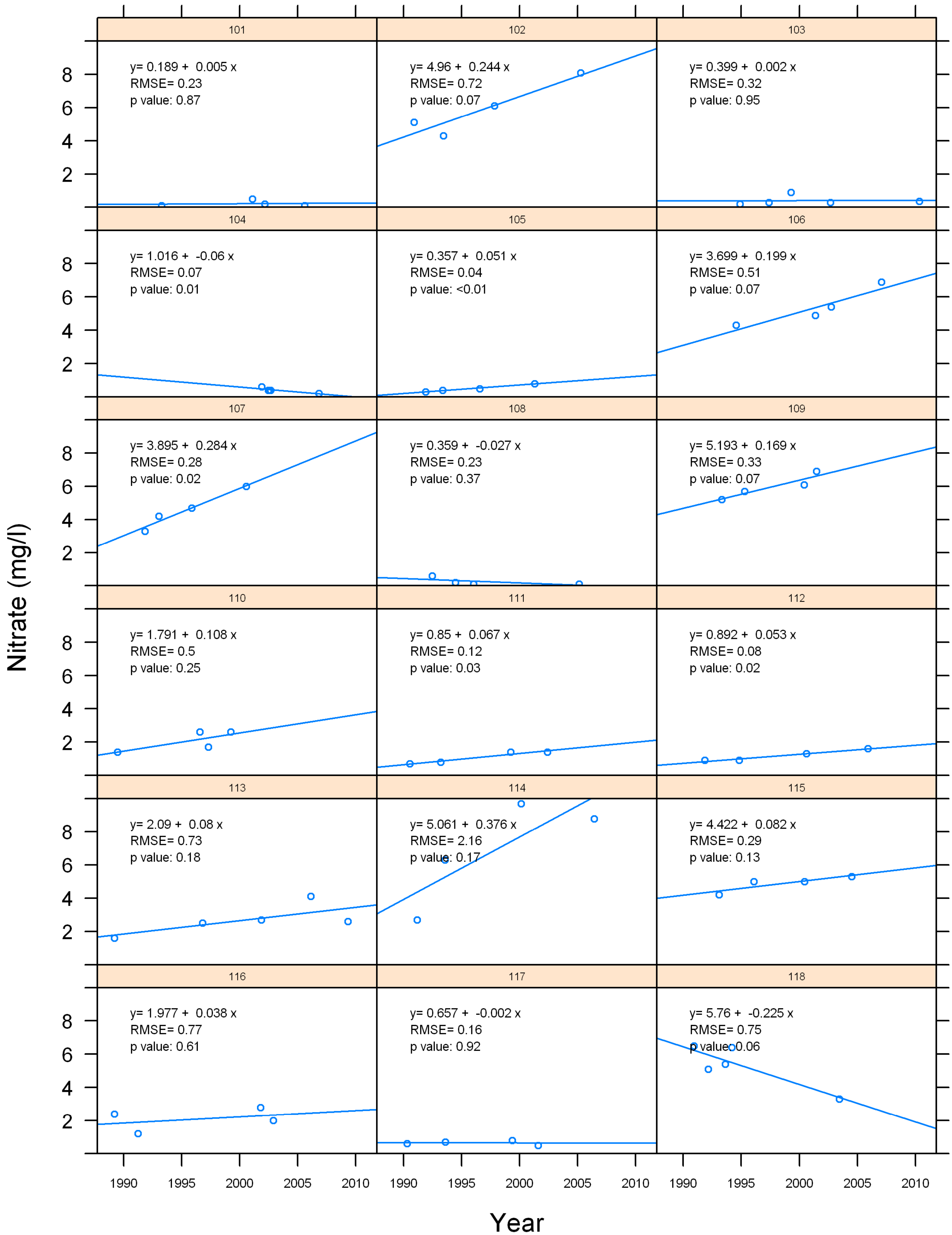
Appendix A

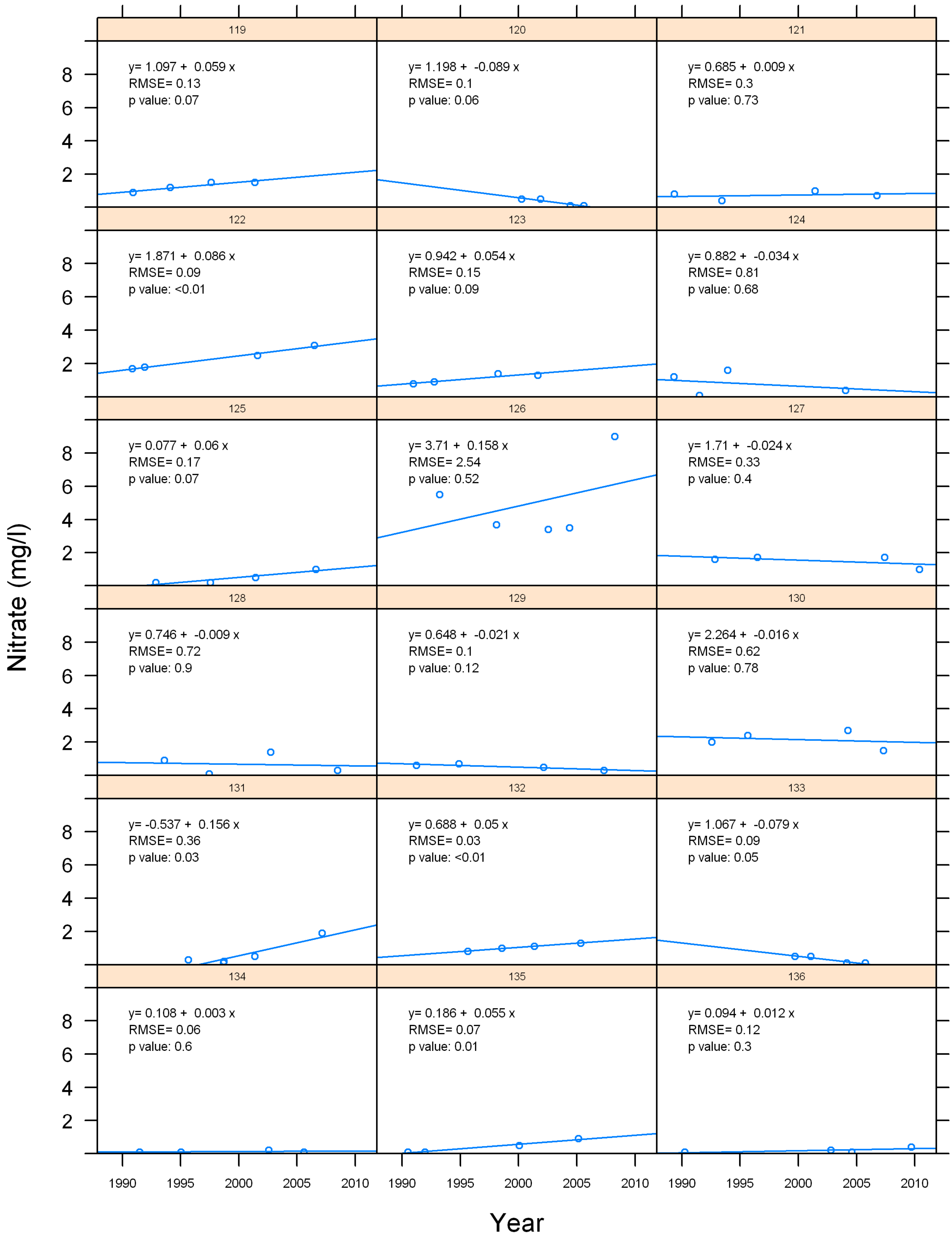
Regression graphs for public and private wells

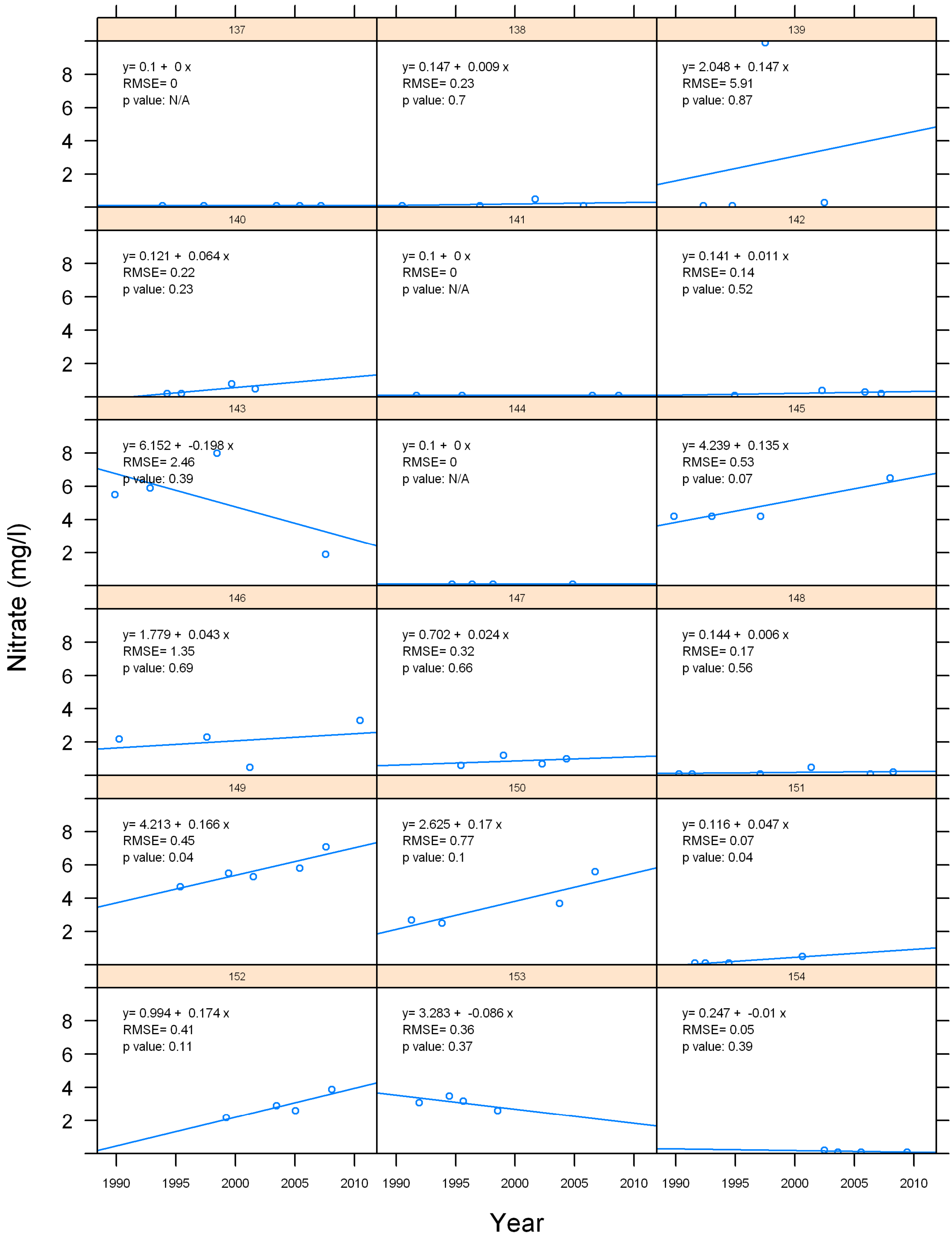

AK CONFERENCE SEVENTH-DAY ADVENTI (18)
y= 0.345 + -0.002 x
RMSE= 0.54
p value: 0.97
ALASKA CHILDRENS SERVICES (6)
y= 0.607 + 0.083 x
RMSE= 0.61
p value: 0.01
ALASKA ZOO (13)
y= 0.619 + 0.031 x
RMSE= 0.36
p value: 0.11
ALPINE WOODS (29)
y= 0.185 + -0.002 x
RMSE= 0.14
p value: 0.74
AMAZING GRACE CHURCH (19)
y= 1.24 + 0.093 x
RMSE= 0.4
p value: <0.01
ANCHORAGE GOLF COURSE (9)
y= 0.003 + 0.047 x
RMSE= 0.98
p value: 0.3
ANCHORAGE GRACE CHURCH (38)
y= 4.24 + -0.133 x
RMSE= 1.2
p value: <0.01
ANCHORAGE JUNIOR ACADEMY (15)
y= 0.208 + -0.003 x
RMSE= 0.16
p value: 0.64
BEAR VALLEY ELEMENTARY (45)
y= 0.836 + -0.004 x
RMSE= 0.24
p value: 0.75
BOREALIS ALPHA (32)
y= 0.39 + 0.069 x
RMSE= 0.18
p value: <0.01
CHAPEL BY THE SEA (44)
y= 1.953 + -0.03 x
RMSE= 0.48
p value: 0.22
CHAPEL OF THE CROSS (34)
y= 3.093 + 0.202 x
RMSE= 1.17
p value: <0.01
CHRIST CHURCH EPISCOPAL (16)
y= 0.146 + -0.001 x
RMSE= 0.1
p value: 0.81
COHOE S/D (4)
y= 0.259 + 0.005 x
RMSE= 0.07
p value: 0.15
DEARMOUN II (42)
y= 0.84 + 0.045 x
RMSE= 0.15
p value: <0.01
DIV OF PARKS POTTER SEC HOUSE (48)
y= 0.304 + -0.012 x
RMSE= 0.18
p value: 0.14
EAGLECREST CONDOS ASSN. (24)
y= 0.206 + -0.004 x
RMSE= 0.16
p value: 0.59
EAST 98TH AVENUE WELL HOA (8)
y= 1.049 + 0.06 x
RMSE= 0.55
p value: 0.04
Nitrate (mg/l)
2
4
6
8
1995
2000
2005
2010
Year

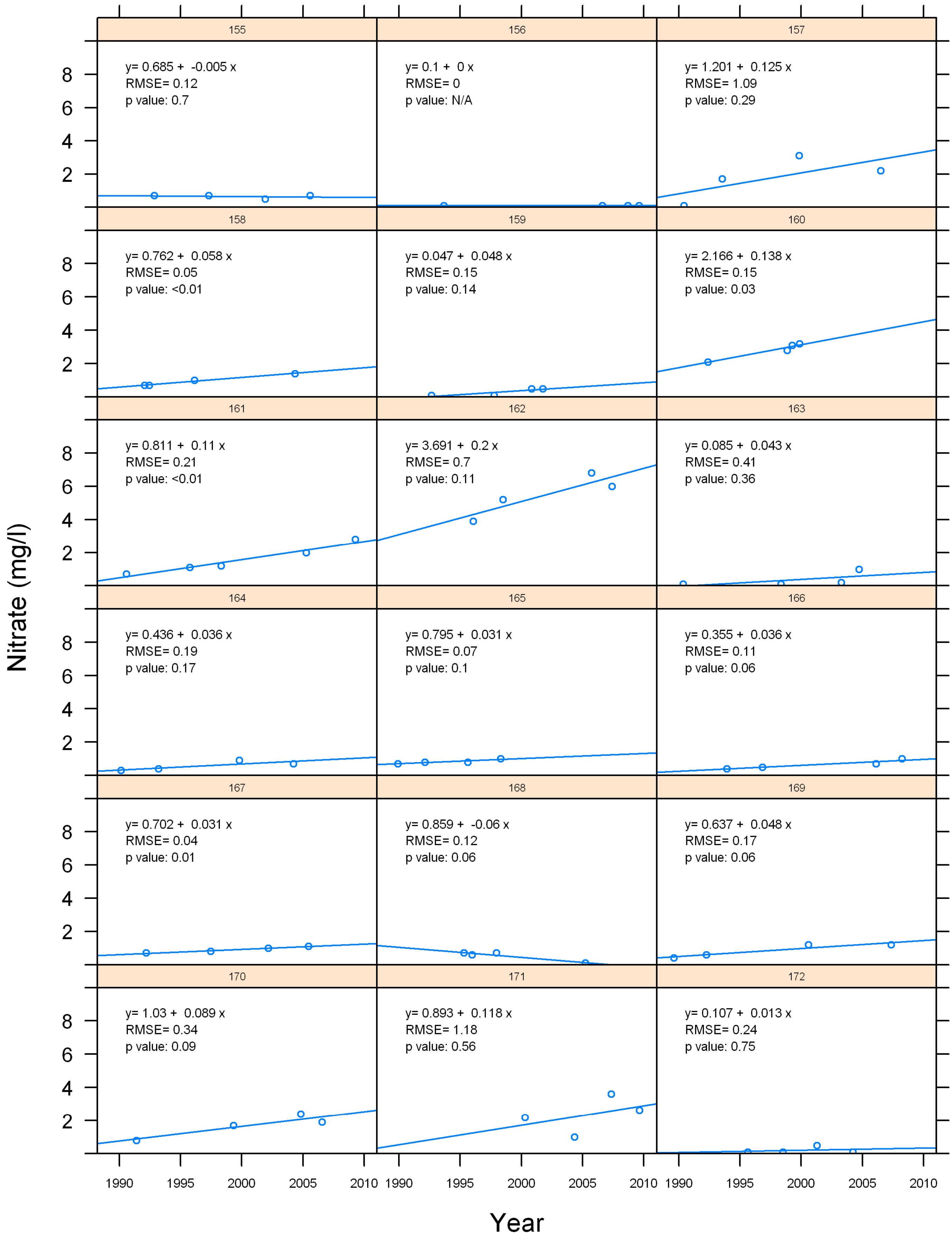

GREEK ORTHODOX CHURCH (22)
y= 0.241 + -0.006 x
RMSE= 0.16
p value: 0.55
GREENBROOK S/D (39)
y= 2.894 + 0.199 x
RMSE= 1.05
p value: <0.01
HANSHEW HEIGHTS S/D (5)
y= 0.268 + 0.025 x
RMSE= 0.16
p value: <0.01
HILLSIDE BAPTIST CHURCH (17)
y= 0.144 + 0 x
RMSE= 0.13
p value: 0.99
HILLSIDE PARK S/D (12)
y= 3.085 + 0.167 x
RMSE= 0.73
p value: <0.01
HILLTOP SKI AREA - CHALET (2)
y= 1.709 + 0.34 x
RMSE= 0.49
p value: <0.01
HOLY SPIRIT CENTER (21)
y= 2.227 + -0.059 x
RMSE= 0.54
p value: 0.15
HOMESTEAD HILLS (25)
y= 0.61 + 0.107 x
RMSE= 0.63
p value: <0.01
HUFFMAN ELEMENTARY (33)
y= 0.388 + 0.018 x
RMSE= 0.71
p value: 0.6
KOREAN UNITED METHODIST CHURCH (7)
y= 0.246 + -0.008 x
RMSE= 0.12
p value: 0.25
LAKE O THE HILLS EAST (26)
y= 0.155 + 0 x
RMSE= 0.14
p value: 0.96
LIFE CHURCH (36)
y= 0.12 + 0.006 x
RMSE= 0.13
p value: 0.35
NEW GRACE CHRISTIAN CHURCH (20)
y= 0.225 + -0.005 x
RMSE= 0.16
p value: 0.48
O MALLEY ELEMENTARY (23)
y= 0.127 + 0.017 x
RMSE= 0.13
p value: 0.01
OMEGA HOMEOWNERS ASSN. (31)
y= 0.2 + 0.027 x
RMSE= 0.17
p value: <0.01
POTTER CREEK WATER COMPANY (49)
y= 1.218 + 0.036 x
RMSE= 0.31
p value: 0.03
RABBIT CREEK COMMUNITY CHURCH (46)
y= 0.213 + -0.004 x
RMSE= 0.16
p value: 0.56
RABBIT CREEK RIFLE RANGE (47)
y= 0.405 + -0.019 x
RMSE= 0.14
p value: 0.07
2
4
6
8
1995
2000
2005
2010
Nitrate (mg/l)
Year


Nitrate (mg/l)
SALVATION ARMY - SO ANCHORAGE (43)
y= 1.256 + 0.07 x
RMSE= 0.48
p value: 0.01
SHEPHERD OF THE HILLS CHURCH (27)
y= -4.191 + 0.383 x
RMSE= 0.63
p value: 0.21
SKY RANCH ESTATES 1 (28)
y= 0.674 + 0.075 x
RMSE= 0.3
p value: <0.01
SKY RANCH ESTATES 2 (30)
y= 0.235 + 0.132 x
RMSE= 0.5
p value: <0.01
SPRING FOREST HOMEOWNERS ASSN. (10)
y= 0.26 + -0.008 x
RMSE= 0.16
p value: 0.37
ST ELIZABETH ANN SETON CHURCH (35)
y= 3.073 + 0.269 x
RMSE= 1.24
p value: <0.01
SUN VALLEY HEIGHTS NORTH (40)
y= 1.066 + 0.017 x
RMSE= 0.42
p value: 0.5
SUN VALLEY HEIGHTS SOUTH (41)
y= 2.4 + 0.251 x
RMSE= 0.42
p value: <0.01
TOM THUMB MONTESSORI SCHOOL (14)
y= 0.121 + 0.014 x
RMSE= 0.18
p value: 0.32
TRINITY PRESBYTERIAN CHURCH (37)
y= 0.225 + -0.005 x
RMSE= 0.15
p value: 0.47
VALLI VUE S/D (11)
y= 2.918 + -0.05 x
RMSE= 1.26
p value: 0.4
2
4
6
8

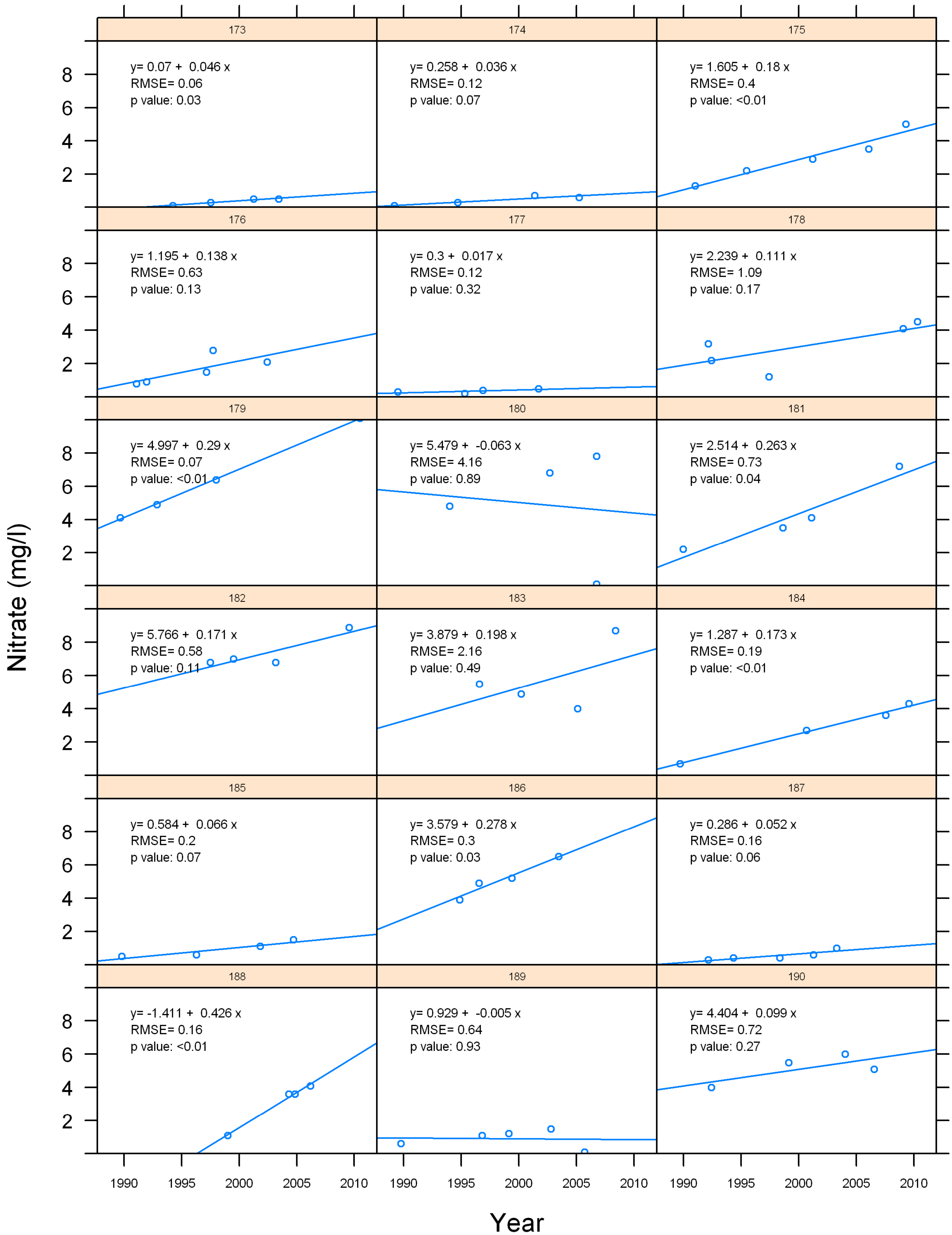

Nitrate (mg/l)
Year
101
y= 0.189 + 0.005 x
RMSE= 0.23
p value: 0.87
102
y= 4.96 + 0.244 x
RMSE= 0.72
p value: 0.07
103
y= 0.399 + 0.002 x
RMSE= 0.32
p value: 0.95
104
y= 1.016 + -0.06 x
RMSE= 0.07
p value: 0.01
105
y= 0.357 + 0.051 x
RMSE= 0.04
p value: <0.01
106
y= 3.699 + 0.199 x
RMSE= 0.51
p value: 0.07
107
y= 3.895 + 0.284 x
RMSE= 0.28
p value: 0.02
108
y= 0.359 + -0.027 x
RMSE= 0.23
p value: 0.37
109
y= 5.193 + 0.169 x
RMSE= 0.33
p value: 0.07
110
y= 1.791 + 0.108 x
RMSE= 0.5
p value: 0.25
111
y= 0.85 + 0.067 x
RMSE= 0.12
p value: 0.03
112
y= 0.892 + 0.053 x
RMSE= 0.08
p value: 0.02
113
y= 2.09 + 0.08 x
RMSE= 0.73
p value: 0.18
114
y= 5.061 + 0.376 x
RMSE= 2.16
p value: 0.17
115
y= 4.422 + 0.082 x
RMSE= 0.29
p value: 0.13
116
y= 1.977 + 0.038 x
RMSE= 0.77
p value: 0.61
117
y= 0.657 + -0.002 x
RMSE= 0.16
p value: 0.92
118
y= 5.76 + -0.225 x
RMSE= 0.75
p value: 0.06

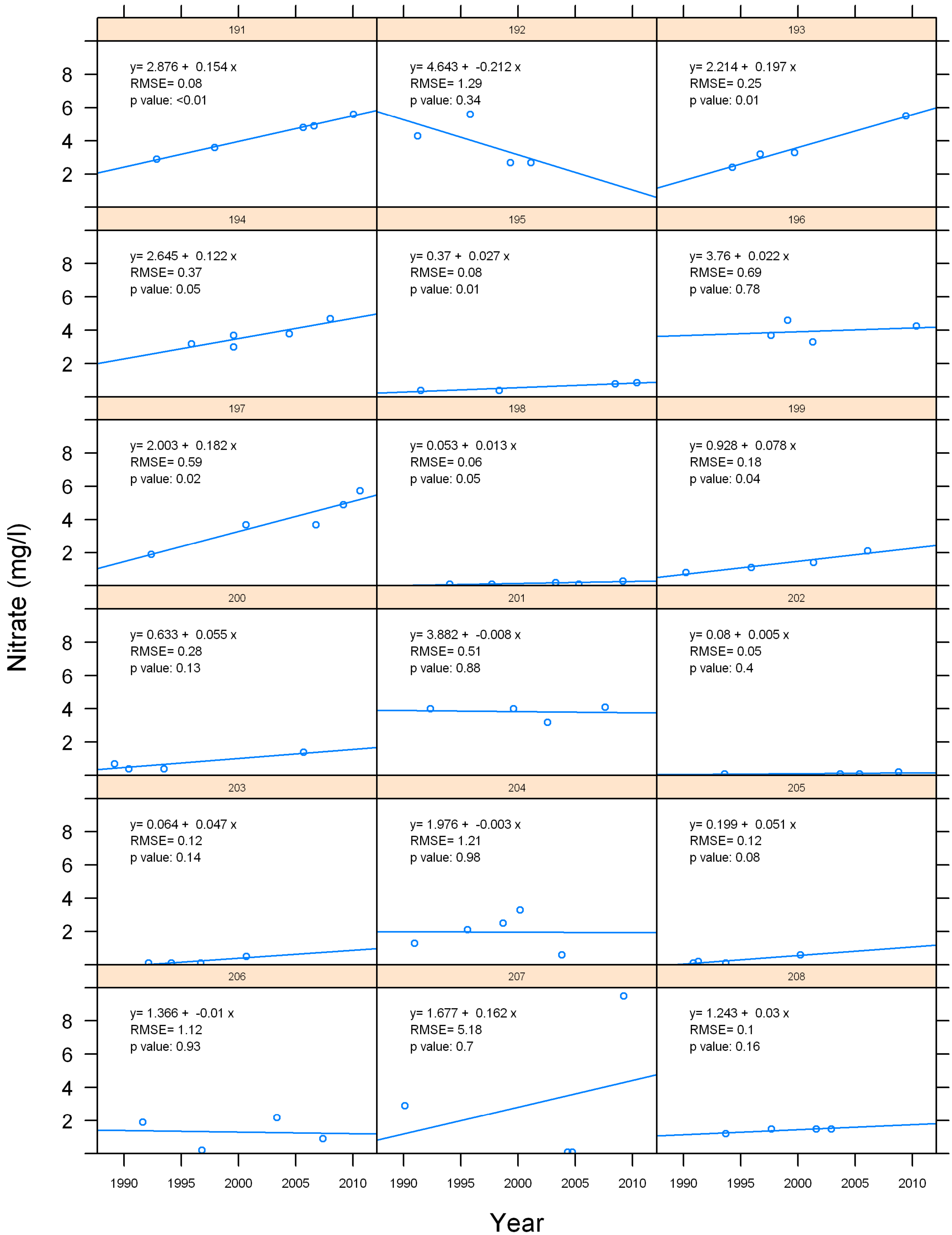

119
y= 1.097 + 0.059 x
RMSE= 0.13
p value: 0.07
120
y= 1.198 + -0.089 x
RMSE= 0.1
p value: 0.06
121
y= 0.685 + 0.009 x
RMSE= 0.3
p value: 0.73
122
y= 1.871 + 0.086 x
RMSE= 0.09
p value: <0.01
123
y= 0.942 + 0.054 x
RMSE= 0.15
p value: 0.09
124
y= 0.882 + -0.034 x
RMSE= 0.81
p value: 0.68
125
y= 0.077 + 0.06 x
RMSE= 0.17
p value: 0.07
126
y= 3.71 + 0.158 x
RMSE= 2.54
p value: 0.52
127
y= 1.71 + -0.024 x
RMSE= 0.33
p value: 0.4
128
y= 0.746 + -0.009 x
RMSE= 0.72
p value: 0.9
129
y= 0.648 + -0.021 x
RMSE= 0.1
p value: 0.12
130
y= 2.264 + -0.016 x
RMSE= 0.62
p value: 0.78
131
y= -0.537 + 0.156 x
RMSE= 0.36
p value: 0.03
132
y= 0.688 + 0.05 x
RMSE= 0.03
p value: <0.01
133
y= 1.067 + -0.079 x
RMSE= 0.09
p value: 0.05
134
y= 0.108 + 0.003 x
RMSE= 0.06
p value: 0.6
135
y= 0.186 + 0.055 x
RMSE= 0.07
p value: 0.01
136
y= 0.094 + 0.012 x
RMSE= 0.12
p value: 0.3
Nitrate (mg/l)
2
4
6
8
1990
1995
2000
2005
2010
Year

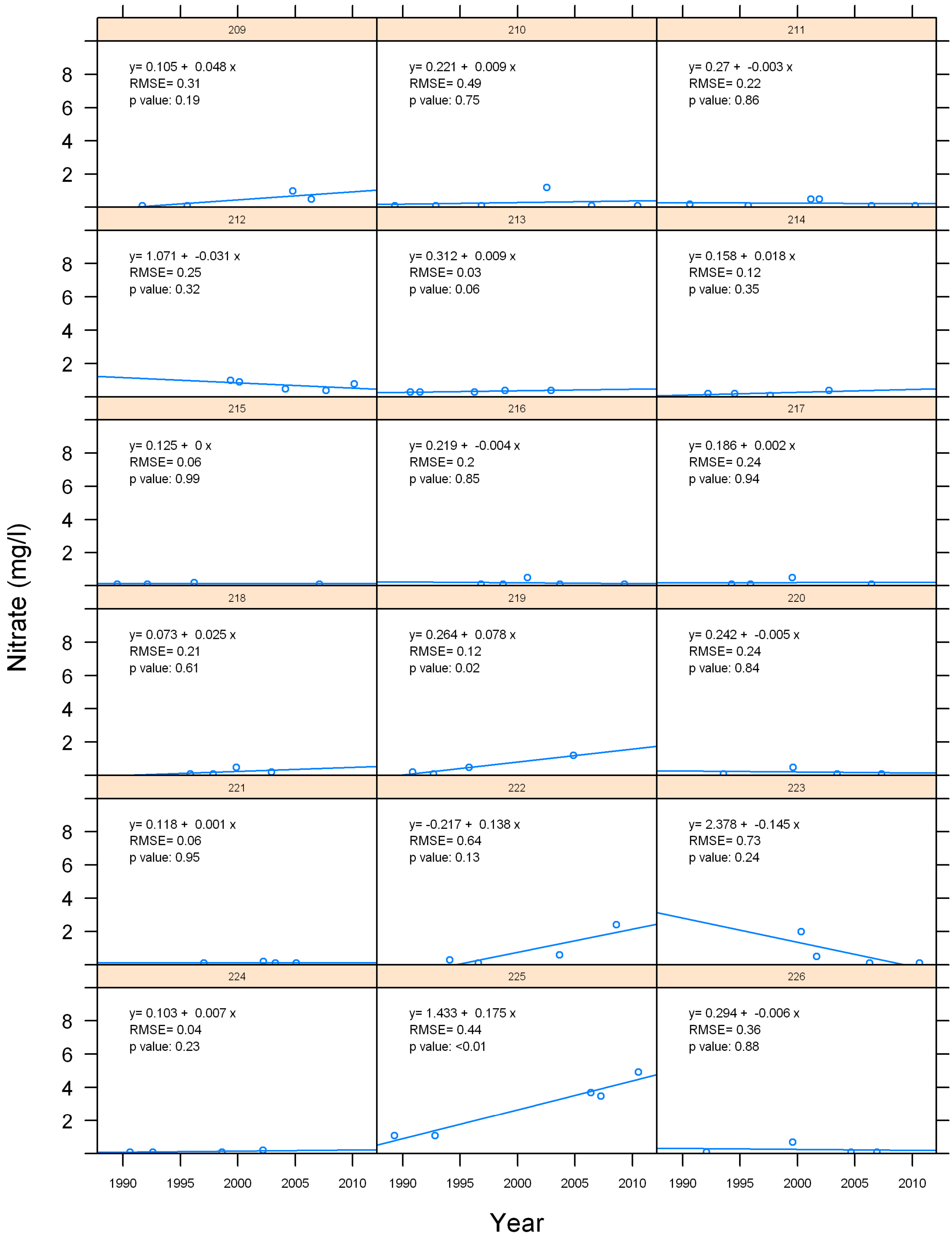

137
y= 0.1 + 0 x
RMSE= 0
p value: N/A
138
y= 0.147 + 0.009 x
RMSE= 0.23
p value: 0.7
139
y= 2.048 + 0.147 x
RMSE= 5.91
p value: 0.87
140
y= 0.121 + 0.064 x
RMSE= 0.22
p value: 0.23
141
y= 0.1 + 0 x
RMSE= 0
p value: N/A
142
y= 0.141 + 0.011 x
RMSE= 0.14
p value: 0.52
143
y= 6.152 + -0.198 x
RMSE= 2.46
p value: 0.39
144
y= 0.1 + 0 x
RMSE= 0
p value: N/A
145
y= 4.239 + 0.135 x
RMSE= 0.53
p value: 0.07
146
y= 1.779 + 0.043 x
RMSE= 1.35
p value: 0.69
147
y= 0.702 + 0.024 x
RMSE= 0.32
p value: 0.66
148
y= 0.144 + 0.006 x
RMSE= 0.17
p value: 0.56
149
y= 4.213 + 0.166 x
RMSE= 0.45
p value: 0.04
150
y= 2.625 + 0.17 x
RMSE= 0.77
p value: 0.1
151
y= 0.116 + 0.047 x
RMSE= 0.07
p value: 0.04
152
y= 0.994 + 0.174 x
RMSE= 0.41
p value: 0.11
153
y= 3.283 + -0.086 x
RMSE= 0.36
p value: 0.37
154
y= 0.247 + -0.01 x
RMSE= 0.05
p value: 0.39
Nitrate (mg/l)
Year
2
4
6
8
1990
1995
2000
2005
2010

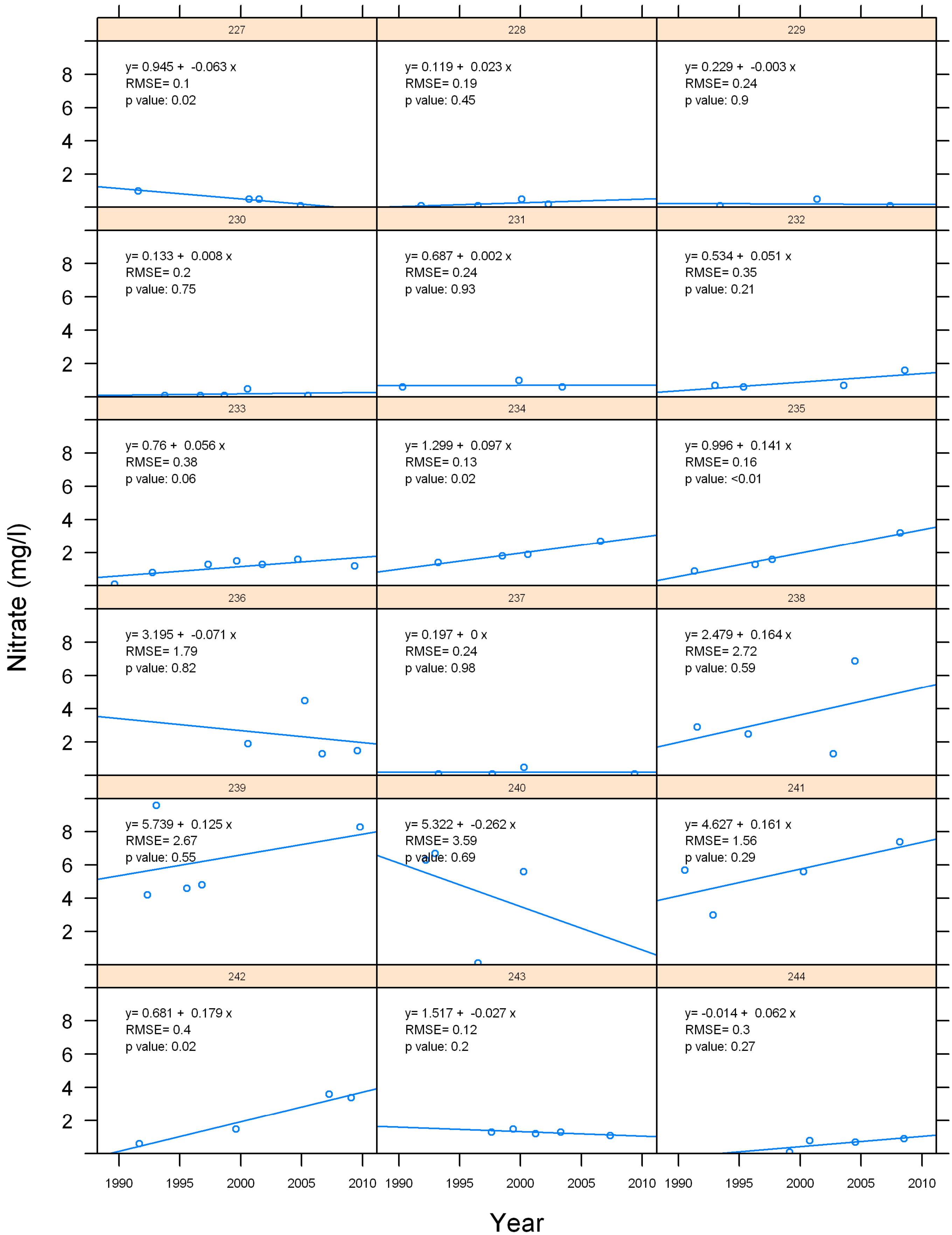


155
y= 0.685 + -0.005 x
RMSE= 0.12
p value: 0.7
156
y= 0.1 + 0 x
RMSE= 0
p value: N/A
157
y= 1.201 + 0.125 x
RMSE= 1.09
p value: 0.29
158
y= 0.762 + 0.058 x
RMSE= 0.05
p value: <0.01
159
y= 0.047 + 0.048 x
RMSE= 0.15
p value: 0.14
160
y= 2.166 + 0.138 x
RMSE= 0.15
p value: 0.03
161
y= 0.811 + 0.11 x
RMSE= 0.21
p value: <0.01
162
y= 3.691 + 0.2 x
RMSE= 0.7
p value: 0.11
163
y= 0.085 + 0.043 x
RMSE= 0.41
p value: 0.36
164
y= 0.436 + 0.036 x
RMSE= 0.19
p value: 0.17
165
y= 0.795 + 0.031 x
RMSE= 0.07
p value: 0.1
166
y= 0.355 + 0.036 x
RMSE= 0.11
p value: 0.06
167
y= 0.702 + 0.031 x
RMSE= 0.04
p value: 0.01
168
y= 0.859 + -0.06 x
RMSE= 0.12
p value: 0.06
169
y= 0.637 + 0.048 x
RMSE= 0.17
p value: 0.06
170
y= 1.03 + 0.089 x
RMSE= 0.34
p value: 0.09
171
y= 0.893 + 0.118 x
RMSE= 1.18
p value: 0.56
172
y= 0.107 + 0.013 x
RMSE= 0.24
p value: 0.75
Nitrate (mg/l)
2
4
6
8
1990
1995
2000
2005
2010
Year


173
y= 0.07 + 0.046 x
RMSE= 0.06
p value: 0.03
174
y= 0.258 + 0.036 x
RMSE= 0.12
p value: 0.07
175
y= 1.605 + 0.18 x
RMSE= 0.4
p value: <0.01
176
y= 1.195 + 0.138 x
RMSE= 0.63
p value: 0.13
177
y= 0.3 + 0.017 x
RMSE= 0.12
p value: 0.32
178
y= 2.239 + 0.111 x
RMSE= 1.09
p value: 0.17
179
y= 4.997 + 0.29 x
RMSE= 0.07
p value: <0.01
180
y= 5.479 + -0.063 x
RMSE= 4.16
p value: 0.89
181
y= 2.514 + 0.263 x
RMSE= 0.73
p value: 0.04
182
y= 5.766 + 0.171 x
RMSE= 0.58
p value: 0.11
183
y= 3.879 + 0.198 x
RMSE= 2.16
p value: 0.49
184
y= 1.287 + 0.173 x
RMSE= 0.19
p value: <0.01
185
y= 0.584 + 0.066 x
RMSE= 0.2
p value: 0.07
186
y= 3.579 + 0.278 x
RMSE= 0.3
p value: 0.03
187
y= 0.286 + 0.052 x
RMSE= 0.16
p value: 0.06
188
y= -1.411 + 0.426 x
RMSE= 0.16
p value: <0.01
189
y= 0.929 + -0.005 x
RMSE= 0.64
p value: 0.93
190
y= 4.404 + 0.099 x
RMSE= 0.72
p value: 0.27
Nitrate (mg/l)
Year


191
y= 2.876 + 0.154 x
RMSE= 0.08
p value: <0.01
192
y= 4.643 + -0.212 x
RMSE= 1.29
p value: 0.34
193
y= 2.214 + 0.197 x
RMSE= 0.25
p value: 0.01
194
y= 2.645 + 0.122 x
RMSE= 0.37
p value: 0.05
195
y= 0.37 + 0.027 x
RMSE= 0.08
p value: 0.01
196
y= 3.76 + 0.022 x
RMSE= 0.69
p value: 0.78
197
y= 2.003 + 0.182 x
RMSE= 0.59
p value: 0.02
198
y= 0.053 + 0.013 x
RMSE= 0.06
p value: 0.05
199
y= 0.928 + 0.078 x
RMSE= 0.18
p value: 0.04
200
y= 0.633 + 0.055 x
RMSE= 0.28
p value: 0.13
201
y= 3.882 + -0.008 x
RMSE= 0.51
p value: 0.88
202
y= 0.08 + 0.005 x
RMSE= 0.05
p value: 0.4
203
y= 0.064 + 0.047 x
RMSE= 0.12
p value: 0.14
204
y= 1.976 + -0.003 x
RMSE= 1.21
p value: 0.98
205
y= 0.199 + 0.051 x
RMSE= 0.12
p value: 0.08
206
y= 1.366 + -0.01 x
RMSE= 1.12
p value: 0.93
207
y= 1.677 + 0.162 x
RMSE= 5.18
p value: 0.7
208
y= 1.243 + 0.03 x
RMSE= 0.1
p value: 0.16
Nitrate (mg/l)
2
4
6
8
1990
1995
2000
2005
2010
Year


209
y= 0.105 + 0.048 x
RMSE= 0.31
p value: 0.19
210
y= 0.221 + 0.009 x
RMSE= 0.49
p value: 0.75
211
y= 0.27 + -0.003 x
RMSE= 0.22
p value: 0.86
212
y= 1.071 + -0.031 x
RMSE= 0.25
p value: 0.32
213
y= 0.312 + 0.009 x
RMSE= 0.03
p value: 0.06
214
y= 0.158 + 0.018 x
RMSE= 0.12
p value: 0.35
215
y= 0.125 + 0 x
RMSE= 0.06
p value: 0.99
216
y= 0.219 + -0.004 x
RMSE= 0.2
p value: 0.85
217
y= 0.186 + 0.002 x
RMSE= 0.24
p value: 0.94
218
y= 0.073 + 0.025 x
RMSE= 0.21
p value: 0.61
219
y= 0.264 + 0.078 x
RMSE= 0.12
p value: 0.02
220
y= 0.242 + -0.005 x
RMSE= 0.24
p value: 0.84
221
y= 0.118 + 0.001 x
RMSE= 0.06
p value: 0.95
222
y= -0.217 + 0.138 x
RMSE= 0.64
p value: 0.13
223
y= 2.378 + -0.145 x
RMSE= 0.73
p value: 0.24
224
y= 0.103 + 0.007 x
RMSE= 0.04
p value: 0.23
225
y= 1.433 + 0.175 x
RMSE= 0.44
p value: <0.01
226
y= 0.294 + -0.006 x
RMSE= 0.36
p value: 0.88
Nitrate (mg/l)
2
4
6
8
1990
1995
2000
2005
2010
Year


227
y= 0.945 + -0.063 x
RMSE= 0.1
p value: 0.02
228
y= 0.119 + 0.023 x
RMSE= 0.19
p value: 0.45
229
y= 0.229 + -0.003 x
RMSE= 0.24
p value: 0.9
230
y= 0.133 + 0.008 x
RMSE= 0.2
p value: 0.75
231
y= 0.687 + 0.002 x
RMSE= 0.24
p value: 0.93
232
y= 0.534 + 0.051 x
RMSE= 0.35
p value: 0.21
233
y= 0.76 + 0.056 x
RMSE= 0.38
p value: 0.06
234
y= 1.299 + 0.097 x
RMSE= 0.13
p value: 0.02
235
y= 0.996 + 0.141 x
RMSE= 0.16
p value: <0.01
236
y= 3.195 + -0.071 x
RMSE= 1.79
p value: 0.82
237
y= 0.197 + 0 x
RMSE= 0.24
p value: 0.98
238
y= 2.479 + 0.164 x
RMSE= 2.72
p value: 0.59
239
y= 5.739 + 0.125 x
RMSE= 2.67
p value: 0.55
240
y= 5.322 + -0.262 x
RMSE= 3.59
p value: 0.69
241
y= 4.627 + 0.161 x
RMSE= 1.56
p value: 0.29
242
y= 0.681 + 0.179 x
RMSE= 0.4
p value: 0.02
243
y= 1.517 + -0.027 x
RMSE= 0.12
p value: 0.2
244
y= -0.014 + 0.062 x
RMSE= 0.3
p value: 0.27
Nitrate (mg/l)
Year

Appendix B
Factors potentially affecting reported nitrate concentrations in Hillside wells

Definitions:
GE=greater than or equal to
LT = less than
EQ = equal to
GT=greater than
LE = less than or equal to

1. Analysis of factors that might have an effect on the level of nitrates

   Data

   - Used the well data from all locations, not just the Hillside
   - Last nitrate measurement only – if a location had multiple tests only the last one was used in the analysis.
   - The following modifications were made to the data to eliminate influential observations:
     - All zero nitrate values were set to the minimum detection limit;

     - IF WellDepth GE 550 THEN WellDepth = MISSING;
     - IF WellDepth LT 40 THEN WellDepth = MISSING;

     - IF WellYield EQ 0 THEN WellYield = MISSING;
     - IF WellYield GT 40 THEN WellYield = 40;

     - IF WellCasingDepth EQ 0 THEN WellCasingDepth = MISSING;
     - IF WellCasingDepth GE 550 THEN WellCasingDepth = MISSING;

     - Age = YEAR(LAST_TESTDATE) - YEAR(WELLDRILLEDDATE);
     - IF Age LE 0 THEN AGE = = MISSING;
     - IF AGE GE 38 THEN AGE = 38;

Analysis

This was a bit more complicated than I would like and I am not sure how much you want to include in the report.
Because the data has a lot of values at the detection limit regular regression analysis, which assumes the data is normally distributed, is not appropriate. I analyzed the data with a *conditional* model.

The analysis consists of four stages.

1. create two sets of data from the original:

    a) Presence Dataset: shows whether or not nitrates were present above minimum detection limits; This data set contains all observation (all locations regardless of nitrate level).
    A new variable *Presence* was created: *Presence* = 1 for detectable nitrate values and *Presence* = 0 for values at or below the detection limit.

    b) Nitrate Dataset: this dataset is a subset of the Presence Dataset, it only includes those wells with detectable nitrate concentrations (*Presence* = 1).

2. model the Presence Dataset using logistic regression.
   This will answer the question: What variables affect the presence of nitrate level above detection?

3. model the Nitrate Dataset using ordinary regression.
   This will answer the question: When nitrates are present, what variables affect the level nitrate?

4. Combining the two models (stage 2 and 3) to estimate the expected nitrate level for a specific set of values of the explanatory variables.

The explanatory variable examined for both models included:

Soil Absorption Rate
Well_Age
Well Yield
Well Depth
Well Casing Depth;

Results

What variables affect the presence of nitrate level above detection?

Three variables; Well Age, Well Depth, and Well Casing Depth had a significant effect on whether a well had nitrates above the detection limit.

Variable	Estimate	P value
Well Age	0.022	0.01
Well Depth	-0.001	0.03
Well Casing Depth	-0.002	0.03

While some of the variables were significant, the model really didn't fit the data, which is to say there are other factors affecting the level of nitrates that are not in the database (like maybe distance from some source of nitrogen).

Results

- When nitrates are present, what variables affect the level nitrate?

  Three variables; Well Age, Well Depth, and Well Casing Depth had a significant effect on nitrate levels given the well had a nitrate level above detection.

Variable	Estimate	P value	If a well have nitrate levels above 0.5
Well Age	0.026	<0.01	For every year older the well was, the nitrate levels increased an average of 0.022 mg/l
Well Depth	-0.001	<0.01	As Well Depth increased the level of nitrates decreased
Well Casing Depth	-0.002	<0.01	As Well Casing Depth increased the level of nitrates decreased

While some of the variables were significant, the model really didn't fit the data, which is to say there are other factors affecting the level of nitrates that are not in the database (like maybe distance from some source of nitrogen).