Fourth Northern Malheur County Groundwater Management Area Nitrate Trend Analysis Report

Submitted to: Northern Malheur County Groundwater Management Committee

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State of Oregon
Department of Environmental Quality

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Executive Summary

Introduction

This document describes the fourth trend analysis of groundwater nitrate concentrations in the Northern Malheur County Groundwater Management Area (NMC GWMA). The NMC GWMA was declared in 1989 after widespread groundwater nitrate contamination was identified that had resulted primarily from nonpoint source activities. The Oregon Department of Environmental Quality (DEQ), a citizen's advisory committee, and a local interagency advisory committee created an Action Plan for reducing the groundwater nitrate concentrations to acceptable levels. The Action Plan identifies specific "measures" to gauge the success of changes in the area. The measures that relate to nitrate concentrations and trends are the subject of this report.

Purpose of the Study

The purpose of this study is to determine, through an analysis of NMC GWMA water quality data, if the water quality measures of Action Plan success have been met.

Conclusions

The major conclusions drawn from this study are:

- The Action Plan goal of achieving an area-wide nitrate concentration of 7 milligrams per liter (mg/l) with a 75% confidence level has not yet been met. The area-wide mean and median concentrations are 12.5 and 9.9 mg/l, respectively.
- Although not all monitoring stations in the GWMA exhibit decreasing nitrate trends, the multiple lines of evidence suggesting improving water quality (including the statistically significant decreasing area-wide trend) provide sufficient evidence to conclude there has been an overall improvement in groundwater nitrate concentrations from 1991 through 2012. Therefore, the second measure of Action Plan success has been met.
- Continued and perhaps expanded best management practice (BMP) implementation is needed to attain and maintain water quality improvements.

Based on the conclusions stated above, the following recommendations are made. These recommendations are grouped according to the responsible parties.

Groundwater Management Committee and Malheur County SWCD

- As appropriate and as resources provided allow, evaluate the possibility of point source contributions in the vicinity of wells with increasing nitrate trends.
- As available and appropriate, provide financial and technical support to assist in the continued research, documentation, and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

DEQ

- Continue to sample the existing well network (i.e., the 36 wells and 2 surface water bodies) four times per year for nitrate to maintain the water quality database.
- Perform another formal trend analysis of nitrate concentrations in 2017 using cadmium reduction nitrate data collected through December 2016.
- As available and appropriate, provide financial and technical support to assist in the continued research and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

Registered Professional Geologist Seal

In accordance with Oregon Revised Statutes (ORS) Chapter 672.505 to 672.705, specifically ORS 672.605 that states:

"All drawings, reports, or other geologic papers or documents, involving geologic work as defined in ORS 672.505 to 672.705 which shall have been prepared or approved by a registered geologist or a subordinate employee under the direction of a registered geologist for the use of or for delivery to any person or for public record within this state shall be signed by the registered geologist and impressed with the seal or the seal of a nonresident practicing under the provisions of ORS 672.505 to 672.705, either of which shall indicate responsibility for them.",

I hereby acknowledge that the document cited below was prepared by me.

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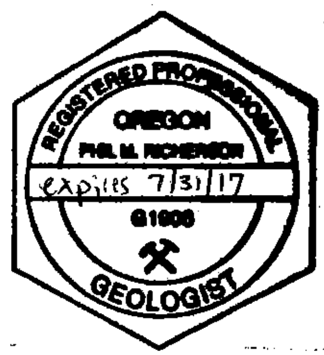


1. Introduction

The Northern Malheur County Groundwater Management Area (NMC GWMA) was declared in 1989 after widespread groundwater nitrate contamination was identified that had resulted primarily from nonpoint source activities. The Oregon Department of Environmental Quality (DEQ), a citizen's advisory committee, and a local interagency advisory committee created an Action Plan for reducing the groundwater nitrate concentrations to acceptable levels. The Action Plan identifies specific "measures" to gauge the success of changes in the area. The measures that relate to nitrate concentrations and trends are the subject of this report.

1.1 Establishment of the Northern Malheur County Groundwater Management Area

Oregon's Groundwater Protection Act of 1989 (Oregon Administrative Rules Chaper 340, Division 40) requires the DEQ to declare a Groundwater Management Area (GWMA) if area-wide groundwater contamination, caused primarily by nonpoint source pollution, exceeds certain trigger levels.

Nonpoint source pollution of groundwater results from contaminants coming from diffuse land use practices, rather than from discrete sources such as a pipe or ditch. The contaminants of nonpoint source pollution can be the same as from point source pollution, and can include sediment, nutrients, pesticides, metals, and petroleum products. The sources of nonpoint source pollution can include construction sites, agricultural areas, forests, stream banks, roads, and residential areas.

The Groundwater Protection Act also requires the establishment of a local Groundwater Management Area Committee comprised of affected and interested parties. The committee works with and advises the state agencies that are required to develop an action plan that will reduce groundwater contamination in the area.

The NMC GWMA was declared in 1989 after groundwater contamination was identified in an 115,000-acre (180 square mile) area in the northeastern portion of the county where land use is dominated by irrigated agriculture. The GWMA boundary starts at the mouths of the Malheur and Owyhee Rivers where they converge with the Snake River and extend to the uppermost irrigation canals. The approximate location of the NMC GWMA is indicated in Figure 1-1. The locations of the 36 wells and 2 surface water sample locations used to collect water quality data for this trend analysis are within this area (Figure 1-2). Three wells have very few additional data points since the previous trend analysis. One well owner withdrew his well from the sampling program in 2001. The well pump at another well broke in 2000 and was not replaced. The well pump at the third well only works sporadically and has not been replaced.

Groundwater samples from private water wells identified nitrate contamination and the presence of the pesticide dacthal (also known as dimethyl tetrachloroterephthalate or DCPA) and its breakdown products (hereafter known as DCPA & metabolites). Traditional fertilizer and agricultural chemical application practices are believed to be the main source of the contamination. Other possible sources of nitrate identified in the GWMA include residential lawn care, on-site sewage systems (i.e., septic tanks and leach lines), confined animal feedlot operations, bulk fertilizer storage facilities, and other possible sources.

Sampling confirmed that most of the contaminated groundwater is present in the shallow alluvial sand and gravel aquifer, which receives a large proportion of its recharge from canal leakage and irrigation water. Therefore, the shallow aquifer is the focus of efforts to restore groundwater quality in Northern Malheur County.

1.2 Northern Malheur County Groundwater Management Area Action Plan

The Northern Malheur County Groundwater Management Action Plan, hereafter referred to as the Action Plan (Malheur County Groundwater Management Committee, 1991) was developed to reduce existing contamination and prevent further contamination of groundwater in the GWMA. The Northern Malheur County Groundwater Management Committee, the Technical Advisory Subcommittee, and representatives from the DEQ, the Oregon Department of Agriculture (ODA), the Oregon Water Resources Department (OWRD), the Oregon Department of Human Services (formerly known as the Oregon Health Division), and Oregon State University (OSU) conducted an 18-month effort ending with approval of an Action Plan focused on reducing groundwater contamination in the GWMA. The Action Plan is available online at
http://www.deq.state.or.us/wq/groundwater/docs/nmcgwma/actionplan.pdf

The Action Plan includes detailed information on water quality, identification of contaminant sources, and recommendations for implementation of Best Management Practices (BMPs) to improve groundwater quality. This approach allows farmers to customize a sequence or system of available BMPs to their individual farm operations. The Committee chose to implement the Action Plan on a voluntary basis recognizing that individuals, businesses, organizations, and governments will, if given adequate information and encouragement, take positive actions and adopt or modify practices and activities to reduce contaminant loading to groundwater.

As part of implementation of the Action plan, a network of 36 wells (mostly private drinking water and irrigation wells) and 2 surface water bodies is currently sampled every other month for analysis of nitrate and DCPA & metabolites. Approximately once a year, these wells and surface water bodies are sampled for a larger list of analytes including major ions, metals, and additional pesticides. The nitrate data provide the basis for this study. The nitrate data (along with the results of the trend analysis) are graphically indicated in Appendix A. A table correlating the DEQ well designation to the Oregon Water Resources Department well designation is also included in Appendix A.

In May 2011, three amendments were made to the Action Plan. The memorandum documenting the amendments is included in Appendix B and summarized below. Amendment #1 allows the use of the Seasonal Kendall method for evaluating trends. Amendment #2 removed the unattainable goal of an area-wide nitrate concentration of 7 mg/l by July 1, 2000. Amendment #3 reduced the sample frequency from six times per year to four times per year.

Comments received during preparation of this report prompted an evaluation of nitrate concentrations and trends versus groundwater levels and water delivered to irrigators. Results of that investigation are in Appendix C.

1.3 Purpose of this Study

The purpose of this study is to determine, through an analysis of NMC GWMA nitrate data, if the water quality measures of Action Plan success have been met.

1.4 Measures of Action Plan Success

The Action Plan specifies four specific ways to gauge success. Three of these are related to water quality concentrations or trends (i.e., changes in groundwater quality over time) in response to adoption of BMPs. The fourth measure of success involves “other indicators of progress” (i.e., the adoption of BMPs). These measures of success are reiterated below.

The Action Plan will be considered successful if:

(1) A trend analysis indicates, at a 75% confidence level, that the level of the nitrate monitoring data for the entire management area is 7 mg/l; or
(2) A statistically significant downward trend can be demonstrated at the 80% confidence level; or
(3) Other indicators show progress toward this goal. Other indicators of progress may include but are not limited to the following:
- number of producers adopting farm plans;
- an increase in utilization of soil testing to improve fertilization practices;
- an increase in efficiency of nitrogen fertilizer application: timing, placement, form, & rate;
- an increase in irrigation efficiency, reducing deep percolation;
- a vadose zone drilling project demonstrating decrease in concentrations of nitrate;
- number of water quality practices being applied; and
- Ontario Hydrologic Unit Area reports and evaluations of progress and effectiveness.

The first two measures of Action Plan success (i.e., those related to water quality trends) are discussed in this report. The third measure of success will be discussed in a future document.

1.5 Principles of Trend Analysis

The principles of trend analysis are discussed in Section 2.0 of the December 2003 document titled “Northern Malheur County Groundwater Management Area Trend Analysis”. This document, as well as other Northern Malheur County GWMA documents, is available at http://www.deq.state.or.us/wq/groundwater/nmcgwma.htm

2. Determination of Analysis Software and Nitrate Data Set

2.1 Software Selection

The trend analysis software used in this analysis was Minitab version 16 by Minitab, Inc. and macros written by Dr. Dennis Helsel and Dr. Edward Gilroy (both retired from the United States Geological Survey). The use of product names is for information purposes only. DEQ does not advocate the use of any particular software.

2.2 Nitrate Data Set

The following sections discuss the timeframe of the nitrate data set (i.e., the inclusive dates), which data to include in the analysis, the steps taken to prepare the data for analysis, and the wells not included in the analysis.

2.2.1 Timeframe of the Nitrate Data Set

The Action Plan requires that nitrate trend analyses include data from July 1, 1991 until the date of the analysis. In accordance with the Action Plan, only data collected after July 1, 1991 were used in this study. This is not necessarily consistent with previous trend analyses (see Appendix C of the December 2003 nitrate trend analysis document for more details). This effectively means the first data points from most monitoring stations are from August 1991. The data set for this study includes 21½ years of data from July 1991 through November 2012.

2.2.2 Nitrate Data Set Preparation

The starting point for the data used in this evaluation was the input files from the previous trend analysis. Additional data from DEQ's laboratory database were then added to the electronic files. Certain steps were taken to prepare the data so that the trend analysis could be conducted. These steps included the following:

- Results from duplicate samples were averaged into one value.
- The data were visually examined for obvious outliers and potential transcription errors. If a data point was suspected of being an error, efforts were made to trace the data back to the original laboratory report to confirm the result. Statistical outliers were not deleted from the data set.

2.2.3 Wells Not Included in Analysis

Two wells that were included in the first three trend analyses are not included in the fourth trend analysis because they are no longer being sampled. These two wells (MAL119 and MAL211) are no longer sampled. The owner of well MAL119 decided to end their participation in the groundwater sampling program in April 2001. The owner of well MAL211 decided to remove the pump from the well in April 2000.

3. Methods

The methods selected for evaluation of water quality data were based on the Action Plan, recommendations from previous studies, and literature research. The methods used to evaluate nitrate trends are discussed below.

3.1 Data Set Statistics

Table 4-1 lists specific aspects of the nitrate data set from each well. The standard statistics include starting date, ending date, minimum, maximum, median, number of samples, and percent non-detected. In addition to the standard statistics, two statistics important to trend analyses (seasonality and serial correlation) are also identified.

Seasonality is when data values tend to vary according to season, and are related to some seasonal variation such as precipitation or temperature. The seasonality of the data set was evaluated using the non-parametric Kruskal-Wallis test of equal medians. The data set was determined to show seasonality if the median of one time frame (e.g., all the April data) showed a statistically significant difference from other time frames at a 90% confidence level.

Serial correlation (or autocorrelation) is when there is correlation between observations of a time series indicating each value is not truly an independent measurement. In other words, a value is influenced by the previous value. Serial correlation of the data set was evaluated by calculating autocorrelations between a specific value and other values in the series at specific “lags” (lag 1 is the next value in the series while lag 2 is the value after the next value). The plot of autocorrelations versus lags (surrounded by an envelope indicating bounds for statistical significance) is called the autocorrelation function. The data set was determined to show serial correlation if any of the autocorrelations exceeded the 5% significance level envelope. The presence or absence of serial correlation dictated whether the trend technique used was the Seasonal Kendall test or the Seasonal Kendall test with Serial Correlation Correction.

3.2 Analysis of Data where Nitrate Was Not Detected

Results from three wells were sometimes reported as below the nitrate detection limit (i.e., <0.005 mg/l). One well exhibited a small amount of “non-detected” values (4% or less). Two wells exhibited a significant amount of non-detected values (40% or 61%). For those wells with some non-detected values, two values were entered into the electronic files for each result. The first value was the measured concentration for detected concentrations or the detection limit for non-detected values. The second value was a code indicating if the first value represents a detected concentration or the detection limit for a non-detected observation.

The data where nitrate was not detected were recorded in this manner to allow more statistically robust evaluations of data set characteristics and trends. The procedures recommended in Helsel (2005) for computing summary statistics and calculating trends were followed using macros written by Dr. Helsel for use within Minitab. These include the following:

- For wells with a small amount of non-detected values, the mean and median were calculated by the Kaplan-Meier method using the KMStats macro.
- For wells with a significant amount of non-detected values, the mean and median were calculated by the Maximum Likelihood Estimation method using the MLEBoot macro.
- Trends at wells with non-detected values were calculated by the Akritas-Theil-Sen version of Kendall’s robust line fit. The Turnbull estimate of median residual is used as the intercept. This is a nonparametric regression line based on Kendall’s tau correlation coefficient. The ATS macro was used for these calculations.
- Seasonality at wells with non-detected values was evaluated using the nonparametric Kruskal-Wallis test for comparing medians. The CensKW macro was used for these calculations.

3.3 Trend Analyses at Individual Wells

Nitrate results from wells with no non-detected values were analyzed for a monotonic trend using the Seasonal Kendall test. The Seasonal Kendall test was developed by the USGS in the 1980s and has become the most frequently used test for trends in the environmental sciences (Helsel, et.al. 2006). The Seasonal Kendall test performs separate tests for trends in each season, and then combines the results into one overall linear trend result. A variation of the Seasonal Kendall test that accounts for serial correlation was used when serial correlation was evident in the data set. The effect of using the Seasonal Kendall test that accounts for serial correlation is a lower confidence level in the estimated trend. The slope of the trend is not affected.

The Seasonal Kendall test accounts for seasonality by computing the Mann-Kendall test on each season separately, and then combining the results. For example, February data are compared only to February data. No comparisons are made across seasonal boundaries. The overall Seasonal Kendall trend slope is computed as the median of all slopes between data points within the same season. No cross-season slopes contribute to the overall estimate of the Seasonal Kendall trend slope. This slope is the median rate of change over time. This overall result reflects whether there is a trend with time for that location, blocking out all seasonal differences in the pattern of change (Helsel and Frans, 2006). The Seaken macro written by Dr. Helsel for use within Minitab was used to calculate trends at individual wells. Results of the individual well trend analyses are discussed in Section 4.1.

In addition to calculating the monotonic trends at each well, LOWESS lines through the data were also calculated for each well. LOWESS stands for LOcally WEighted Scatterplot Smoothing (Cleveland et al., 1979). It is not a monotonic trend analysis technique. It is a data smoothing algorithm that uses a moving window superimposed over a graph of the data, with analyses being performed with each move, to produce a smoothed relationship between the two variables. Data near the center of the moving window influences the smoothed value more than those farther away. The smoothed relationship is then plotted as the LOWESS line. It provides a graphical depiction of the underlying structure of the data. LOWESS lines are included on each of the NMC GWMA time series plots in Appendix A.

An advantage of LOWESS is that no model, such as a linear or quadratic function, is assumed prior to computing a smoothed line. As such, LOWESS is an exploratory tool for discerning the form of relationship between y and x. Because no model form is assumed, the data describe the pattern of dependence of y on x. LOWESS is particularly useful to emphasize the shape of the relationship between two variables on a scatterplot of moderate to large sample size.

Because a LOWESS line reflects the underlying pattern of the data and is not fitting a straight line through the data as all monotonic trend techniques do, it allows an evaluation of changes over time. For example, a monotonic trend analysis result may indicate a statistically significant downward trend in a water quality variable over a 10-year time frame. However, the LOWESS line may suggest that the water quality variable decreased for 8 years and increased during the last 2 years. As another example, a monotonic trend analysis result may not identify a statistically significant trend in a water quality variable over a 10-year time frame. However, the LOWESS line may suggest that the water quality variable increased for 5 years then decreased for 5 years. These observations might be valuable and would not be apparent from a monotonic trend analyses.

3.4 Evaluation of Area-Wide Trend

The measures of Action Plan success regarding water quality trends relate to changes "for the entire management area." A variation of the Seasonal Kendall test called the Regional Kendall test was used to evaluate the area-wide trend.

Helsel and Frans (2006) describe the test as follows. The Regional Kendall test is a test to determine whether a consistent pattern of trend occurs across an entire area, at multiple locations. The Regional Kendall test substitutes location for season and computes the equivalent of the Seasonal Kendall test. The Regional Kendall test looks for consistency in the direction of trend at each location, and tests whether there is evidence for a general trend in a consistent direction throughout the region. Patterns at an individual location occurring in the same direction as the regional trend provide some evidence toward a significant regional trend, even if there is insufficient evidence of trend for that one location.

The Seaken macro written by Dr. Helsel for use within Minitab was used to calculate the linear area-wide trend. Results of the area-wide nitrate trend analysis are discussed in Section 4.2.

4. Results

Results of the analysis of nitrate trends at individual wells as well as on an area-wide basis are discussed below. The discussion of individual nitrate trends consists of three aspects: the trend at each well, trends versus geographic location, and trends versus well depth.

4.1 Nitrate Trends at Individual Wells

A basic component of the evaluation of trends at individual wells is the time versus concentration graph. Time versus nitrate concentration graphs at each well are included in Appendix A. Also included on the graphs in Appendix A are the monotonic trends from the previous and current analyses as well as a LOWESS line (which provides an indication of the general pattern of the data).

4.1.1 Nitrate Trends at Each Well

Results of nitrate trend analyses at individual wells include two basic pieces of information for each test performed: a slope value and a confidence level. The slope indicates the direction and magnitude of the trend while the confidence level indicates the statistical certainty of the result. Trends are either increasing (i.e., have a positive slope), decreasing (i.e., have a negative slope), or flat (i.e., have a slope of zero). For NMC GWMA studies, test results with confidence levels less than 80% are considered “statistically insignificant”. This does not mean that the concentrations observed at these wells are insignificant or unworthy of attention. Instead, this means that the statistical test could not identify a linear trend with a high degree of assurance. All statistically insignificant trends are grouped together in this report. Statistically significant trends are divided into increasing or decreasing trends in this report (there were no flat trends identified).

Table 4-1 includes summary statistics for each of the 36 currently sampled wells and summarizes the nitrate trend at each well. An examination of Table 4-1 reveals 10 increasing trends (28%), 19 decreasing trends (53%), and 7 statistically insignificant trends (19%). Of the statistically significant trends, several trends are approximately 0.1 part per million (ppm) per year or less, and may not be physically meaningful.

Figure 4-1 illustrates the LOWESS lines and trend lines through the nitrate data at all network sampling locations. Each graph on Figure 4-1 is at the same scale to allow a direct comparison of trends between locations. Useful information can be gained by comparing trend lines with LOWESS lines. For example, the monotonic trend at well MAL062 is decreasing, but the LOWESS line indicates an increasing then decreasing trend. As another example, the monotonic trend at well MAL106 is decreasing, but the LOWESS line indicates the trend decreased steeply for several years but is now gently increasing.

It is noteworthy that two of the seven wells exhibiting statistically insignificant trends have average nitrate concentrations above the target concentration of 7 ppm. As previously stated, the fact that a statistically significant linear trend cannot be drawn through the data does not mean the concentrations are insignificant or unworthy of attention. It is also noteworthy that the 10 ppm drinking water standard for nitrate was exceeded at least once at 28 of the 36 wells; and that the average nitrate concentration exceeded the drinking water standard at 18 of the 36 wells (Table 4-1).

The fact that statistically significant trends cannot be drawn through the data at some wells indicates that the data are not “well behaved” (i.e., the data exhibit significant variability) and may suggest a shift in trend direction within the data set. For example, the LOWESS line through well MAL136 data (page A-23 in Appendix A) displays a decreasing then increasing pattern. The trend test is unable to draw a statistically significant line through these data.

In conclusion, the monotonic trends at individual wells are predominately decreasing but also include increasing and statistically insignificant trends. Examination of LOWESS lines through the nitrate data illustrates more subtle changes in concentration over time. Trends are often more complicated than a straight line. Water quality changes seen in the data are smoothed by the LOWESS line and distilled to a straight line by the trend analysis. The smoothing often highlights changes over time while a straight line over-simplifies changes.

Determining why specific wells exhibit high concentrations and/or steeply increasing trends could provide useful information in identifying BMPs that could reduce nonpoint source pollution and/or identifying point source contamination sources that should be addressed. Shallow wells can be affected by both point source and nonpoint source nitrate contamination. For example, well MAL126 located in Vale was likely affected by a formerly active bulk fertilizer plant located nearby.

4.1.2 Nitrate Trends versus Geographic Location

Figures 4-2 and 4-3 illustrate the nitrate trends and average nitrate concentrations at each well. Symbols are placed at well locations indicating the trend direction and magnitude on Figure 4-2. Colors and numbers are placed at well locations indicating the average nitrate concentration on Figure 4-3.

An examination of Figures 4-2 and 4-3 illustrates the following observations:

- The Ontario/Cairo Junction area has predominantly decreasing trends at wells with moderate and elevated nitrate levels,
- The Pioneer School area (the area north of Payette, Idaho) has predominantly decreasing trends at wells with elevated nitrate levels,
- The area north of Nyssa has an almost even mix of increasing and decreasing trends at wells with elevated nitrate levels,
- The Vale area has predominantly decreasing trends at wells with predominantly low nitrate levels (one well has elevated nitrate concentrations),
- The Owyhee River area wells exhibits predominantly increasing trends, but also a statistically insignificant trend at wells with generally low nitrate levels; the surface water samples exhibit either a decreasing or increasing trend at low nitrate levels, and
- The Annex area has both decreasing and increasing trends at wells with moderate to elevated nitrate levels.

The most dramatic increase and decrease in nitrate concentrations occurred in close proximity to one another, illustrating that large differences in nitrate trends occur over short distances. The largest decreasing trend is -1.55 part per million per year (ppm/yr) at well MAL218 located north of Nyssa. The largest increasing trend is 0.57 ppm/yr at well MAL078. Wells MAL218 and MAL078 are located a few hundred yards away from each other.

Possible explanations for this variability include influences from residential land uses (lawn and garden fertilization practices and septic systems), undocumented fertilizer spills, and uneven soil characteristics and fertilizer application rates causing uneven leaching to groundwater.

4.1.3 Nitrate Concentrations and Trends versus Well Depth

Figure 4-4 is a plot of nitrate concentrations and trends versus well depth. Figure 4-4a plots well depth versus the average nitrate concentration from 1991 through 2009. Figure 4-4b plots well depth versus nitrate trend from 1991 through 2009. The symbols indicate which aquifer the wells tap.

The total depth of two wells is unknown. The cased depth[1] of ten wells is unknown. Several of the deep wells being sampled have relatively shallow cased depths and can capture water from any productive zone between the cased depth and total depth. For example, the deepest well sampled (MAL005) is 210 feet deep with a cased depth of 81 feet (i.e., the open portion of well MAL005 extends from 81 feet to 210 feet). Similarly, two of the other three wells deeper than 100 feet also have long open sections. Construction details of the other deep well are not known.

[1] Cased depth is the depth to which solid casing is extended in the borehole. It marks the shallowest portion of the open hole or screened portion of the well.

As indicated by Figure 4-4a, the highest average concentrations are at wells MAL047 and MAL062, which are about 75 to 80 feet deep. The casing depth for well MAL047 is 45 feet while the casing depth for well MAL062 is unknown. The four wells deeper than 100 feet have relatively low average nitrate concentrations (i.e., less than 7 mg/l).

As indicated by Figure 4-4b, the shallower wells exhibit the steepest trends (both increasing and decreasing) while the deeper wells exhibit smaller magnitude trends. Increasing, decreasing, and statistically insignificant trends are exhibited by wells in each aquifer. The largest decreasing trends are in wells screening a portion of both aquifers. A Sand & Gravel aquifer well has a slightly smaller decreasing trend. The largest increasing trends are in Sand & Gravel Aquifer wells.

Figure 4-4 illustates the fact that the two wells with the highest average concentrations (MAL047 and MAL062) are among the steepest decreasing trends. It is also worth noting that most of the trends, as well as the steepest trends are decreasing trends.

In conclusion, shallow wells exhibit the greatest magnitude of trends while deeper wells exhibit smaller trends. This is likely because application of nitrate fertilizer and irrigation water, as well as BMP implementation, occurs at land surface thus creating greater responses in near-surface wells.

4.2 Area-Wide Trends

Figure 4-5 illustrates the data used to evaluate the area-wide trend as well as the results of the evaluation. Figure 4-5 consists of four stacks of data points each year. Each of these stacks of data points represents one sampling event and contains one data point for each well sampled during that event. The well network was sampled every other month from 1991 through 2009. However, due to budgetary constraints, the wells were sampled only four times per year beginning in 2010. The wells are no longer sampled in June and December but are still sampled in February, April, August, and October (i.e., “quarterly”). Figure 4-5 shows that most of the samples from all sampling events are less than 30 ppm with many less than 20 ppm. Without considering trends, the average value of the 2,645 data points is 12.5 ppm while the median value is 9.9 ppm.

It is not appropriate to directly compare these statistics to similar statistics from previous trend analysis reports because previous reports include data from two wells that are no longer sampled (MAL119 and MAL218) but also included data from June and December while the current report does not. However, a comparison of the “quarterly” data (i.e., not including June and December) through 2009 from the 36 currently sampled wells shows the median value is also 9.9 ppm but the average value is 12.8. The lower average concentration indicates an improvement from the timeframe of the previous trend analysis report.

The area-wide trend was estimated using the Regional Kendall test for trend. The Regional Kendall test was set up such that each “well / month sampled” combination was defined as a “season.” For example, each sample from well MAL005 sampled in February of any year was designated as belonging to season “MAL005Feb.” MAL005Feb contains 18 data points. Nitrate results from all wells were individually grouped by season resulting in 140 “well-seasons” with enough data to compute slopes. The data were evaluated to estimate a trend for each “season,” then the individual trends were combined into an area-wide trend.

The Regional Kendall test estimated the area-wide trend to be -0.06 ppm/yr at a 99% confidence level. This result is illustrated in Figure 4-5. This result is important in that it satisfies the third measure of Action Plan success, which calls for a statistically significant downward trend to be demonstrated at the 80% confidence level.

The LOWESS line through all the data is also illustrated in Figure 4-5. The LOWESS line slightly decreases throughout the 1991 through 2012 timeframe but is nearly steady in the mid 2000’s.

EPA (2006) states “there must be consistency in behavioral characteristics across sites over time in order for a single summary statement to be valid across all sampling locations” and “if the stations exhibit approximate trends in the same direction with comparable slopes, then a single summary statement across stations is valid”. The author contacted EPA regarding this statement (Warren, 2006) and was told that the comment was written as a precautionary statement since the document was written for non-statisticians. The intent was to ensure that statistical techniques are not misused and that results are not misinterpreted. Although not all monitoring stations in the GWMA exhibit decreasing nitrate trends, the statistically significant decreasing area-wide nitrate trend and decreasing LOWESS line indicates there has been an overall improvement in groundwater nitrate concentrations from 1991 through 2010.

4.2.1 Regional Kendall Trends by Month

Figure 4-6 illustrates the Regional Kendall trend slopes at each well by month in two different ways. Figure 4-6a is a bar chart showing the number of increasing, decreasing, and flat trends per month. Figure 4-6b is a box and whisker plot showing the nitrate trend slope distribution and median per month. Also indicated in Figure 4-6b is the total number of increasing, decreasing, and flat slopes along with their mean and median slope values.

Figure 4-6 illustrates several aspects of the monthly nitrate trends that suggest improving water quality throughout the GWMA. These include:

- there are more decreasing trends than increasing trends (i.e., 90 decreasing trends versus 49 increasing trends),
- each month exhibits predominantly decreasing trends (e.g., February exhibited 19 decreasing trends, 13 increasing trends, and 0 flat trends), and
- the decreasing trends are steeper than the increasing trends (i.e., the median decrease is -0.34 ppm/yr while the median increase is 0.14 ppm/yr).

It is interesting to note that the most decreasing trends and fewest increasing trends occurred in August and October (Figure 4-6a).

A possible explanation for the dominance of decreasing trends during the summer and fall is dilution from canal water. A large percentage of the irrigation water applied in August is likely used by plants and/or lost to evaporation, with a smaller proportion leaching to groundwater as compared to other times of year. By October, almost all irrigation has ceased but canals still have water. Because most recharge to the aquifer is from leaky canals and percolation through fields, recharge during the fall is likely mostly from canal leakage. Because canal water is generally lower in nitrate than groundwater, the decreasing trends in August and October may be reflecting the larger percentage of canal water entering the groundwater system versus water percolating through irrigated fields. Further investigation into this possible explanation would involve evaluating the proximity of canals to wells exhibiting decreasing trends in the fall, the relative difference between groundwater and canal water elevation (to determine whether the canal is gaining or losing water) as well as the quality of the water in the canal throughout the year.

Another possible explanation for this pattern is a reduction in fall nitrogen fertilization in the GWMA. If this pattern becomes more pronounced in the future, it might be useful to evaluate whether or not water quality improvements are occurring where the reductions in fall fertilization are occurring. The ability to directly link BMP implementation to groundwater quality improvement would be a significant finding and a useful education and outreach tool. As such, it would illustrate the importance and benefit of BMP implementation to growers as well as the general public. However, documentation of the location and timing of fertilizer application over time would be needed to evaluate this possibility.

Other possible factors involved in the dominance of decreasing trends during the summer and fall include the elapsed time since nitrate was applied to fields, seasonal soil moisture profile changes, and more time for plant uptake of nitrate.

4.2.3 Conceptual Model of Area-Wide Nitrate Trend

During the previous trend analyses, a conceptual model was developed to explain how an area-wide trend might develop in response to BMP implementation. This conceptual model is illustrated in Figure 4-7. It is important to note that the axes in Figure 4-7 are relative scales. No values are included or implied.

In the NMC GWMA, this conceptual model is best suited to the flood plains closest to perennial streams (e.g., the Malheur and Owyhee Rivers). Areas outside these flood plains that now contain groundwater likely contained little water prior to the introduction of irrigated agriculture.

As illustrated in Figure 4-7, the conceptual model assumes nitrate concentrations were at some low steady-state background concentration prior to the introduction of agriculture. During the early years of agriculture, over-fertilization and over-irrigation cause the accumulation of nitrate in the unsaturated zone beyond the reach of plants and a dramatic increase of nitrate concentrations in groundwater. As BMPs that improve fertilization and irrigation practices are implemented, the nitrate loading at land surface decreases but the nitrate in the unsaturated zone beyond the reach of plants persists. As time progresses under BMP implementation, the nitrate in the unsaturated zone continues to leach, thus maintaining the increase of groundwater nitrate concentrations, but at a slower rate. When a sufficient amount of nitrate has moved through the system and fertilization and irrigation closely approximates crop needs, nitrate concentrations in groundwater stabilize. Eventually, under continued improvement and expansion of BMPs, groundwater quality gradually improves as the majority of remaining nitrate moves out of the unsaturated zone and through the groundwater system. Ultimately, nitrate concentrations are expected to reach a new steady-state concentration likely higher than the original background concentration (Figure 4-7).

An explanation for the slightly decreasing area-wide trend calculated in the previous three studies is consistent with the conceptual model if these data reflect the portion of the conceptual model curve that has flattened out and beginning to decline (Figure 4-7). The measures of success in the Action Plan requiring area-wide nitrate concentrations of 7 ppm, or even a statistically significant downward trend, within five years of BMP implementation were overly optimistic. It is clear that a longer time frame will be required for both of these measures of success to be met.

5. Comparison of Nitrate Concentrations and Trends

This section compares nitrate concentrations and trends in two ways: by comparing the bi-monthly data to quarterly data to ensure compatibility between analyses, and by comparing nitrate concentrations and trends over time (at individual wells and on an area-wide basis). The last sub-section describes indications of improving or worsening water quality based on the changes in nitrate concentrations and trends.

5.1 Comparison of Bi-Monthly Data to Quarterly Data

This section describes a comparison of the data collected before and after the sampling frequency was changed, and draws conclusions regarding the effect of the change on summary statistics and trends calculated.

As indicated in Section 4.2, budgetary constraints prompted DEQ to reduce the sampling frequency from six times per year (i.e., bi-monthly) to four times per year (i.e., quarterly) at the beginning of 2010. At the time, DEQ evaluated which months could be eliminated from the sampling program with the least amount of influence on the resulting statistics. In other words, which data could be eliminated from the data set and still result in calculated trends and summary statistics that are nearly the same as those using all the data? After testing several scenarios, it was decided that eliminating the June and December sampling events should have the least affect on the overall characteristics of the data set as well as the conclusions drawn from evaluating the data set.

The differences between the quarterly and bi-monthly data sets from 1991 through 2009 are summarized in Table 5-1 and discussed below. In summary, very little differences were observed when the quarterly and bi-monthly data sets from 1991 through 2009 were compared. This indicates the quarerly data collected from 2010 forward can be added to the previous data, because statistical consistency is maintained.
Summary statistics and trends at individual wells, as well as the area-wide trend were calculated using the quarterly data. These results were compared to the results of the first trend analysis to evaluate the effect of the change on summary statistics and trends.

In general, there were either no differences or very little differences observed in the calculated statistics and trends. Specific details are described below.

5.1.1 Trends at Individual Wells

As indicated in Table 5-1, there was no difference in the total number of increasing, decreasing, flat, and statistically insignificant trends. In addition, the direction of the trend at each individual well did not change. There were, however, some differences in the slope of trends at individual wells. The largest difference (0.22 ppm/yr) was at well MAL126. Both trends are statistically insignificant. Four other wells (MAL047, MAL218, MAL106, and MAL078) showed differences of 0.06 to 0.08 ppm/yr. The relative percent difference (RPD) between the calculated trends was less than 7% at these wells. The slopes at 13 wells did not change. In summary, with the exception of one statistically insignificant trend (MAL126), there is very little difference in the individual well trends calculated using the two data sets.

5.1.2 Average and Median Concentrations at Individual Wells

Slight differences in average concentrations were observed at most wells: 14 wells had higher means using the quarterly data set, 21 wells had lower means using the quarterly data set, and 1 well showed no difference. The average of the differences was 0.02 ppm. The largest difference (0.96 ppm) was at MAL126, which is also the well that showed the largest difference in calculated trend. The RPD between the means at this well is 3%. Two other wells (MAL106 and MAL101) showed a difference of greater than 0.5 ppm, but the RPD was less than 7%.

Overall, very little difference was observed in average concentrations when the two data sets are compared (Table 5-1).

Slight differences in median concentrations were also observed at most wells: 11 wells had higher medians using the quarterly data set, 16 wells had lower medians using the quarterly data set, 9 wells showed no difference. The average of the differences was 0.02 ppm. The largest difference (2.05 ppm) was at well MAL047. The RPD between the medians is 8%. Three other wells (MAL062, MAL106, and MAL035) showed a difference greater than 0.5 ppm. The RPD was less than 7% except for MAL106. With the exception of well MAL106, very little difference was observed in median concentrations when the two data sets are compared.

5.1.3 Maximum and Minimum Concentrations at Individual Wells

When the bi-monthly data set is compared to the quarterly data set at the 36 wells, the quarterly data set misses 10 minimum concentrations and 11 maximum concentrations that were observed in the bi-monthly data set. This indicates the bi-monthly data set captures more variability in nitrate concentrations than the quarterly data set.

5.1.4 Area-Wide Trend

Figure 5-1illustrates the area-wide trends calculated using both the bi-monthly data set and the quarterly data set. As indicated in Figure 5-1, there is very little difference between the trends calculated with the two different data sets. This indicates the change in sample frequency (i.e., switching from bi-monthly to quarterly sampling) did not appreciably change the estimation of the area-wide trend slope. This allows a direct comparison of past and future area-wide trend estimates.

The bi-monthly data set began in August 1991 and ended in December 2009. Because it takes a few years of sampling to accumulate enough data to calculate a statistically significant trend[2], the first trend illustrated in Figure 5-1 is through 1995. This trend as well as the next six trends (i.e., through 2001) was flat (i.e., slope of zero). Some of these trends are statistically significant while others are statistically insignificant (Figure 5-1). The trend through 2002 is the first decreasing trend. Subsequent trends are also decreasing. The slope of the area-wide trend get steeper (i.e., decreasing more) through 2009 when it reaches the steepest slope yet observed (-0.080 ppm/yr). The next three years continue to show a decreasing trend, but the slope of the decreasing trend is getting less steep. The area-wide trend through 2012 is -0.060 ppm/yr.

5.2 Comparison of Nitrate Concentrations and Trends over Time

5.2.1 Comparison of Annual Average and Annual Median Concentrations Over Time

Figure 5-2 shows the change in area-wide nitrate concentrations over time by using the annual average and annual median nitrate concentrations. In order to not skew the comparison, the June and December data collected prior to 2010 were removed from the data set so that each year’s average or median was calculated with only four sampling events per year.

As shown in Figure 5-2, the annual average nitrate concentration fluctuates from year to year but decreased more than 4 ppm over 20 years. The annual average nitrate concentration was 14.8 ppm in 1993 and 10.5 ppm in 2012. Similarly, the annual median nitrate concentration fluctuates from year to year but decreased about 2.5 ppm over 20 years. The annual median nitrate concentration was 12 ppm in 1993 and was 9.5 ppm in 2012.

[2] DEQ uses an 80% confidence level as a cut off for statistical significance. In other words, trends with a confidence level of 80% or higher are deemed statistically significant while trends with a confidence level of 79% or lower are deemed statistically insignificant.

It is noteworthy that both the annual average and annual median nitrate concentrations are above the 7 ppm GWMA Trigger Level[3]. The annual average nitrate concentration also remains above the 10 ppm federal drinking water standard for nitrate.

5.2.2 Comparison of Monthly Trends between Analyses

The technique used to calculate the area-wide trend involves calculating monthly trends at each well. Figure 5-3 and Table 5-2 illustrate these monthly trends obtained from the four nitrate trend analyses reports conducted to date. In general, Figure 5-3 and Table 5-2 illustrate the switch from predominantly increasing trends (during the first analysis) to predominantly decreasing trends (during subsequent analyses).

Figure 5-3 illustrates the general observation that there have been fewer increasing monthly trends over the years. This generality fits precisely for June and August in which fewer increasing trends were observed during each analysis. However, the number of increasing trends in February decreased from the first to second analysis, then held steady during the third and fourth analysis. The number of increasing trends in April, October and December is lower in 2005, 2009, and 2012 than in 1999 but do not steadily decrease like June and August (Figure 5-3).

Figure 5-3 also illustrates the general observation that there have been more decreasing monthly trends over the years. As with increasing trends, the number of decreasing trends in June and August steadily increase with each analysis. The number of decreasing trends in February, April, October and December is higher in 2005, 2009, and 2012 than in 1999 but do not steadily increase like June and August (Figure 5-3).

The general observation of fewer increasing nitrate trends over time along with more decreasing trends over time is an indication of general improvement in groundwater nitrate contamination.

Table 5-2 presents the same information as Figure 5-3, but in tabular format. In this format, other observations are more evident. For example, the shaded cells in Table 5-2 (indicating the dominant trend direction) illustrate the following indications of improving nitrate concentrations with time:

- The overall dominant trend direction was increasing in the first analysis, but decreasing in the second, third, and fourth analyses,
- The dominant trend direction was increasing in 5 of the 6 months in the first analysis, but decreasing in 6 of 6 months in the second and third analyses, and in 4 of 4 months during the fourth analysis, and
- Decreasing trends are steeper than increasing trends in all four analyses.

5.2.3 Changes in Annual Area-Wide Nitrate Trend Slopes

The change in annual area-wide nitrate trend slopes is shown in Figure 5-1 and discussed in Section 5.1.4 in the context of comparing the bi-monthly data set to the quarterly data set. In that discussion, it was concluded that the change in sample frequency (i.e., switching from bi-monthly to quarterly sampling) did not appreciably change the estimation of the area-wide trend slope, thus allowing a direct comparison of past and future area-wide trend estimates.

As indicated in Figure 5-1, the area-wide trend slope was flat (i.e., a slope of zero) during the late 1990's then began to decrease in about 2002. The trend steepened for the next several years, reaching a maximum slope in 2009. The next three years also show decreasing trends but at a less steep slope. The twelve years of decreasing area-wide nitrate concentrations meets the Action Plan goal of a decreasing nitrate trend.

[3] Oregon's Groundwater Quality Protection Rules (OAR Chapter 340 - Division 040) defines 7 mg/l (or 7 ppm) as the concentration at which a groundwater management area designation is triggered.

5.3 Indications of Improving and Worsening Water Quality

Some of the changes in nitrate statistics and trends between the first and fourth trend analyses are summarized in Table 5-3 as indications of improving or worsening water quality. Table 5-3 includes more indications of improving water quality than worsening water quality. Furthermore, the indications considered most important (e.g., the area-wide trend, the number of individual increasing and decreasing trends) all suggest improving water quality.

The information in Table 5-3 can also be stated as follows:

- the overall area-wide nitrate trend changed from a statistically insignificant flat trend to a statistically significant slightly declining trend,
- the area-wide nitrate trends by month exhibit more decreasing trends than increasing trends, every month exhibits predominantly decreasing trends, and the decreasing trends are steeper than the increasing trends,
- there are more wells showing decreasing nitrate trends,
- there are fewer wells showing increasing trends,
- the average slope of all nitrate trends decreased,
- more monitoring stations exhibited new minimum concentrations (63%) than new maximum concentrations (50%),
- more monitoring stations exhibited lower mean nitrate concentrations (60%) than higher mean concentrations (39%),
- more monitoring stations exhibited lower mean nitrate concentrations (63%) than higher mean concentrations (37%), and
- the area-wide mean and median nitrate concentrations were lower.

In previous analyses, the change in slope at individual wells was used as one indicator of improving or worsening water quality. For example, if an increasing trend became more steeply increasing, that change was deemed an indication of worsening water quality. Similarly, if a decreasing trend became less steeply decreasing, that change was deemed an indication of worsening water quality. During the current analysis, it became evident that this metric is not always appropriate with decreasing trends. For example, page A-20 of Appendix A shows well MAL125 exhibited a decreasing trend through 1999 with a slope of -0.60 ppm/yr. The trend through 2012 was also decreasing, but at a rate of -0.38 ppm/yr. Although the trend slope is decreasing at a less steep angle, it is not really a sign of worsening water quality because the actual concentrations are starting to level off at a relatively low value. While the other variations of this indicator still appear appropriate (i.e., increasing trends getting steeper is an indicator of worsening water quality, increasing trends getting less steep is an indicator of improving water quality, and decreasing trends getting steeper is an indication of improving water quality), it was decided to stop using changes in slopes at individual wells as an indicator of improving or worsening water quality.

Although not all monitoring stations in the GWMA exhibit decreasing nitrate trends, the multiple lines of evidence suggesting improving water quality discussed above (including the statistically significant decreasing area-wide trend) provide sufficient evidence to conclude there has been an overall improvement in groundwater nitrate concentrations from 1991 through 2012.

6. Conclusions and Recommendations

6.1 Conclusions

Based on the information presented in this report, the following conclusions were drawn from this study:

- The Action Plan goal of achieving an area-wide nitrate concentration of 7 mg/l with a 75% confidence level has not yet been met. The area-wide mean and median concentrations are 12.5 and 9.9 mg/l, respectively.
- Although not all monitoring stations in the GWMA exhibit decreasing nitrate trends, the multiple lines of evidence suggesting improving water quality (including the statistically significant decreasing area-wide trend) provide sufficient evidence to conclude there has been an overall improvement in groundwater nitrate concentrations from 1991 through 2012. Therefore, the second measure of Action Plan success has been met.
- Continued and perhaps expanded BMP implementation is needed to attain and maintain water quality improvements.
- Conclusions from an evaluation of nitrate concentrations and trends versus groundwater levels, water delivered to irrigators, and precipitation include:
    - Groundwater levels at most of the OWRD wells are increasing over time, show seasonality with water levels highest in the third quarter, and water level trends do not appear to be related to total well depth or geographic location.
    - Nitrate concentrations and trends observed at the GWMA wells do not appear to be influenced by the volume of water released from the Owyhee Dam or the volume of water delivered to irrigators.
    - Nitrate concentrations do not appear to to respond to annual precipitation variations. The lack of correlation is likely due to the fact that the volume of irrigation water applied is several times greater than the volume of precipitation.

6.2 Recommendations

Based on the conclusions stated above, the following recommendations are made. These recommendations are grouped according to the responsible parties.

Groundwater Management Committee and Malheur County SWCD

- As appropriate and as resources provided allow, evaluate the possibility of point source contributions in the vicinity of wells with increasing nitrate trends.
- As available and appropriate, provide financial and technical support to assist in the continued research, documentation, and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

DEQ

- Continue to sample the existing well network (i.e., the 36 wells and 2 surface water bodies) four times per year for nitrate to maintain the water quality database.
- Perform another formal trend analysis of nitrate concentrations in 2017 using cadmium reduction nitrate data collected through December 2016.

- As available and appropriate, provide financial and technical support to assist in the continued research and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

7. References

Cleveland, W.S., 1979, Robust Locally Weighted Regression and Smoothing Scatterplots: *J. Am. Stat. Assoc. 74*, 829-836.

EPA, 2006. Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9S, EPA/240/B-06/003. 190 pgs.

Helsel, D.R., 2005. Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, New Jersey. 250 pg.

Helsel, D.R., and L.M. Frans, 2006. Regional Kendall Test For Trend, *Environmental Science & Technology, Vol. 40, No. 13*, pg 4066-4073.

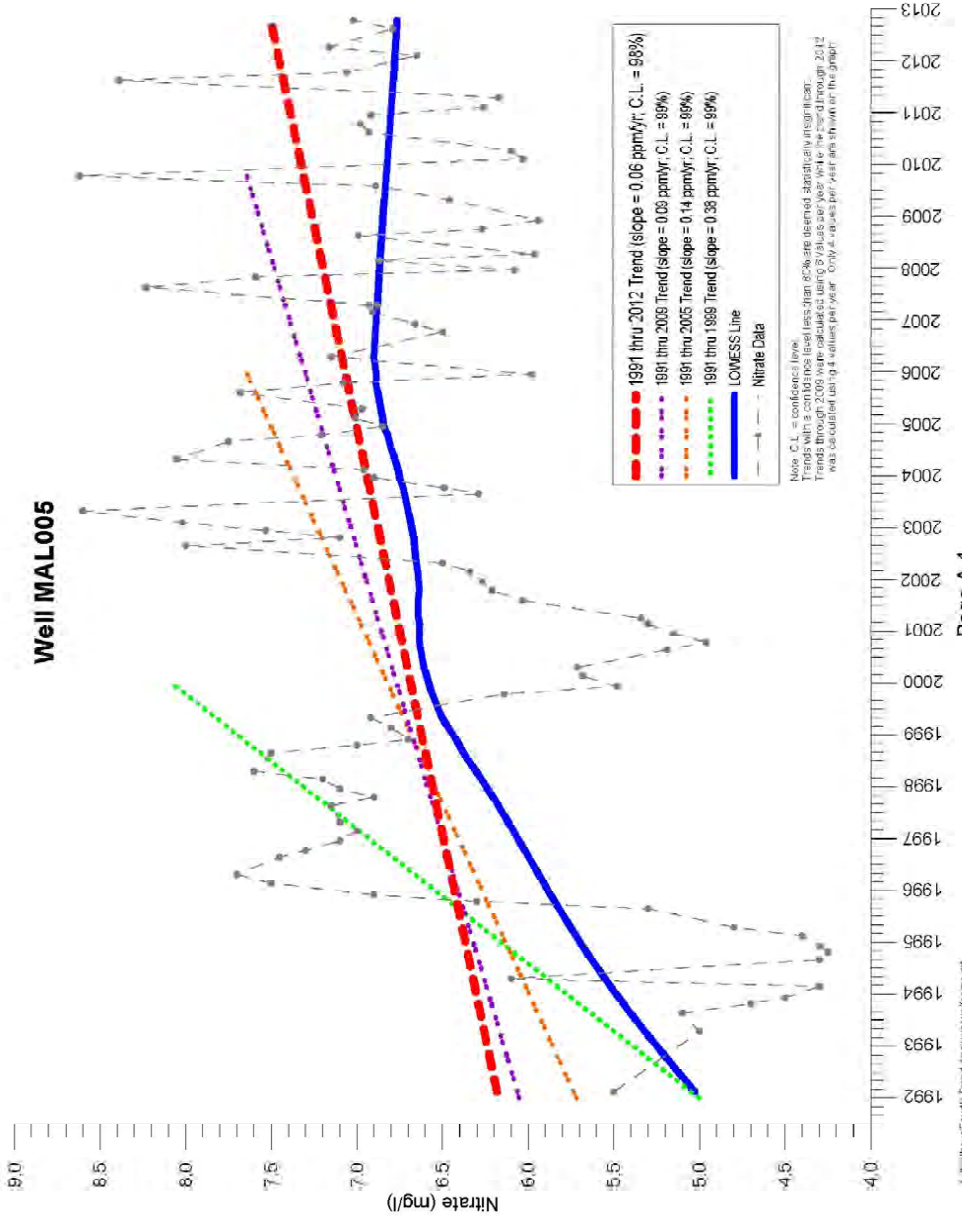
Helsel, D.R., Mueller, D.K., and Slack, J.R. 2006. Computer Program for the Kendall Family of Trend Tests. U.S. Geological Survey Scientific Investigations Report 2005-5275, 4 p.

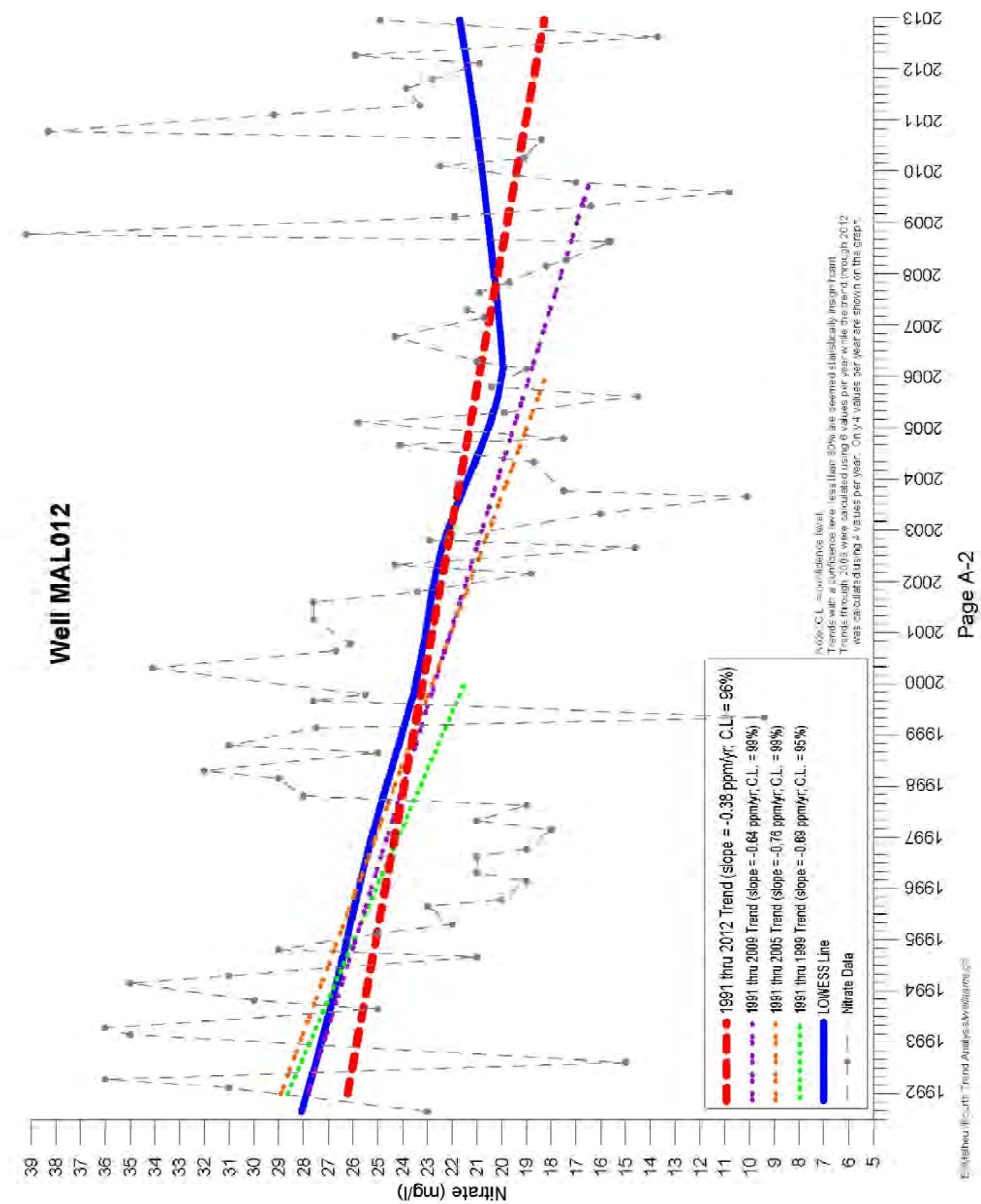
Malheur County Groundwater Management Committee, 1991. Northern Malheur County Groundwater Management Action Plan, State of Oregon Department of Environmental Quality.

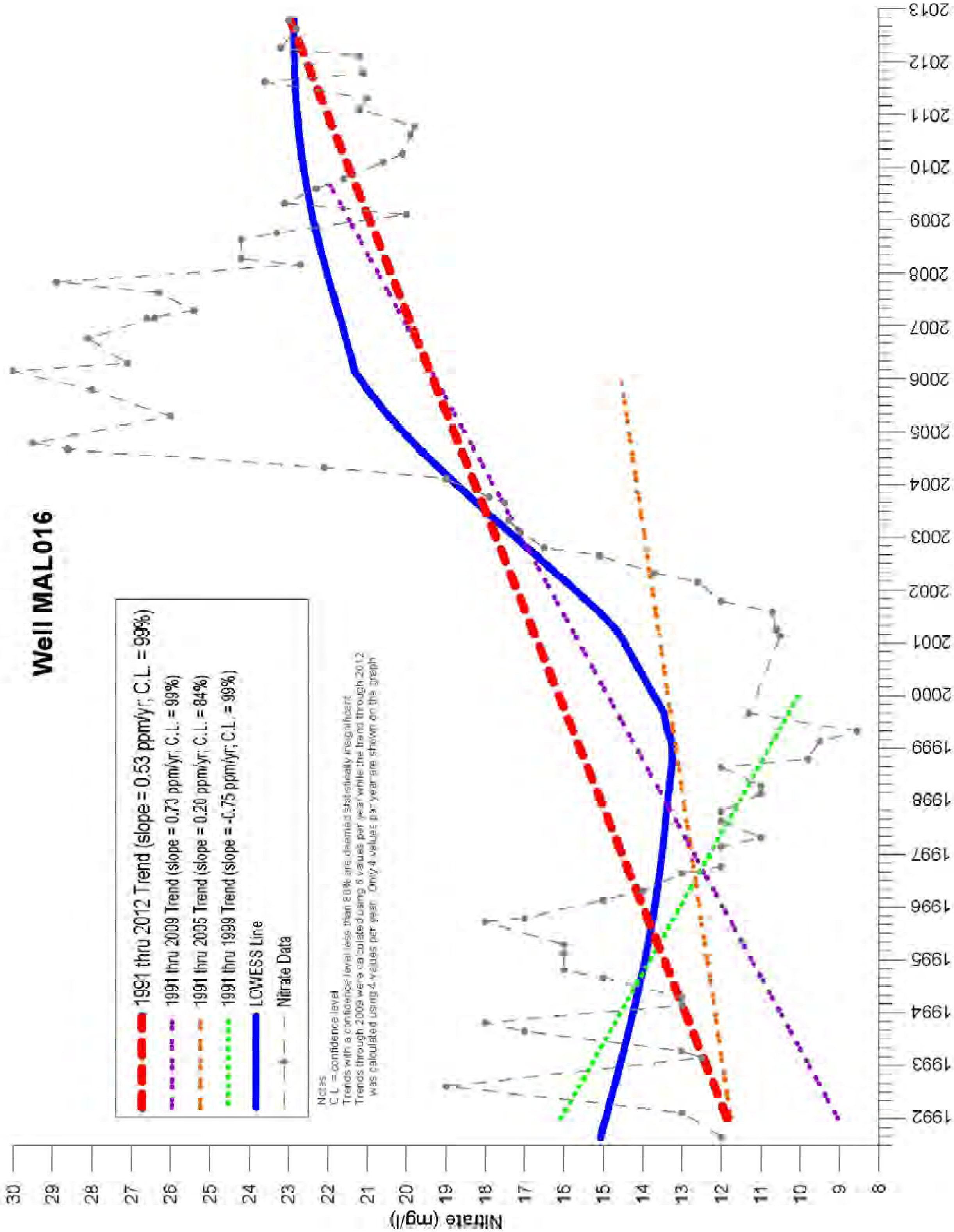
Warren, John, 2006. Personal communication with John Warren of the Quality Staff of the US EPA Office of Environmental Information. August 9, 2006.

Appendix A

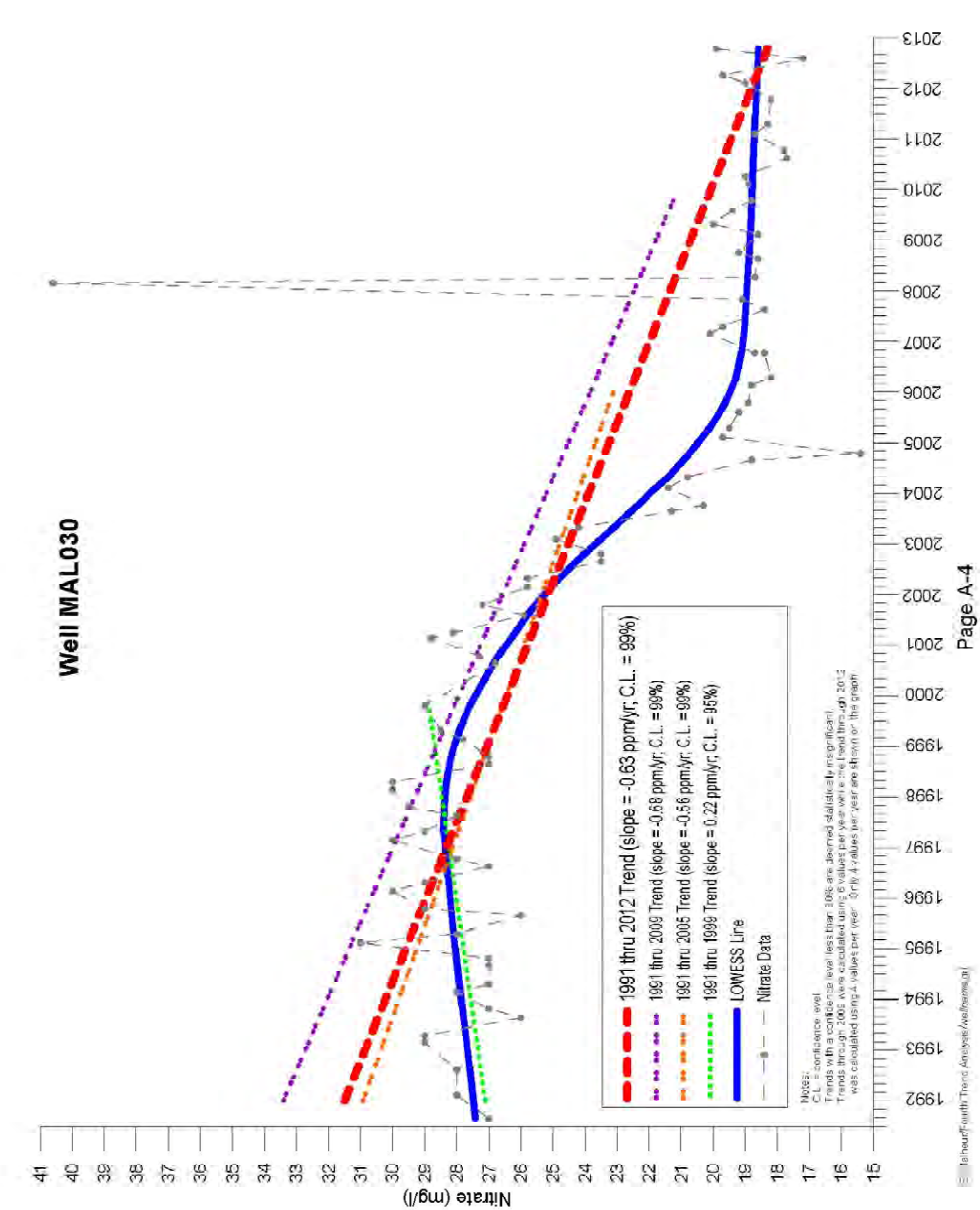
Time versus Concentration Graphs
&
Well Construction Details

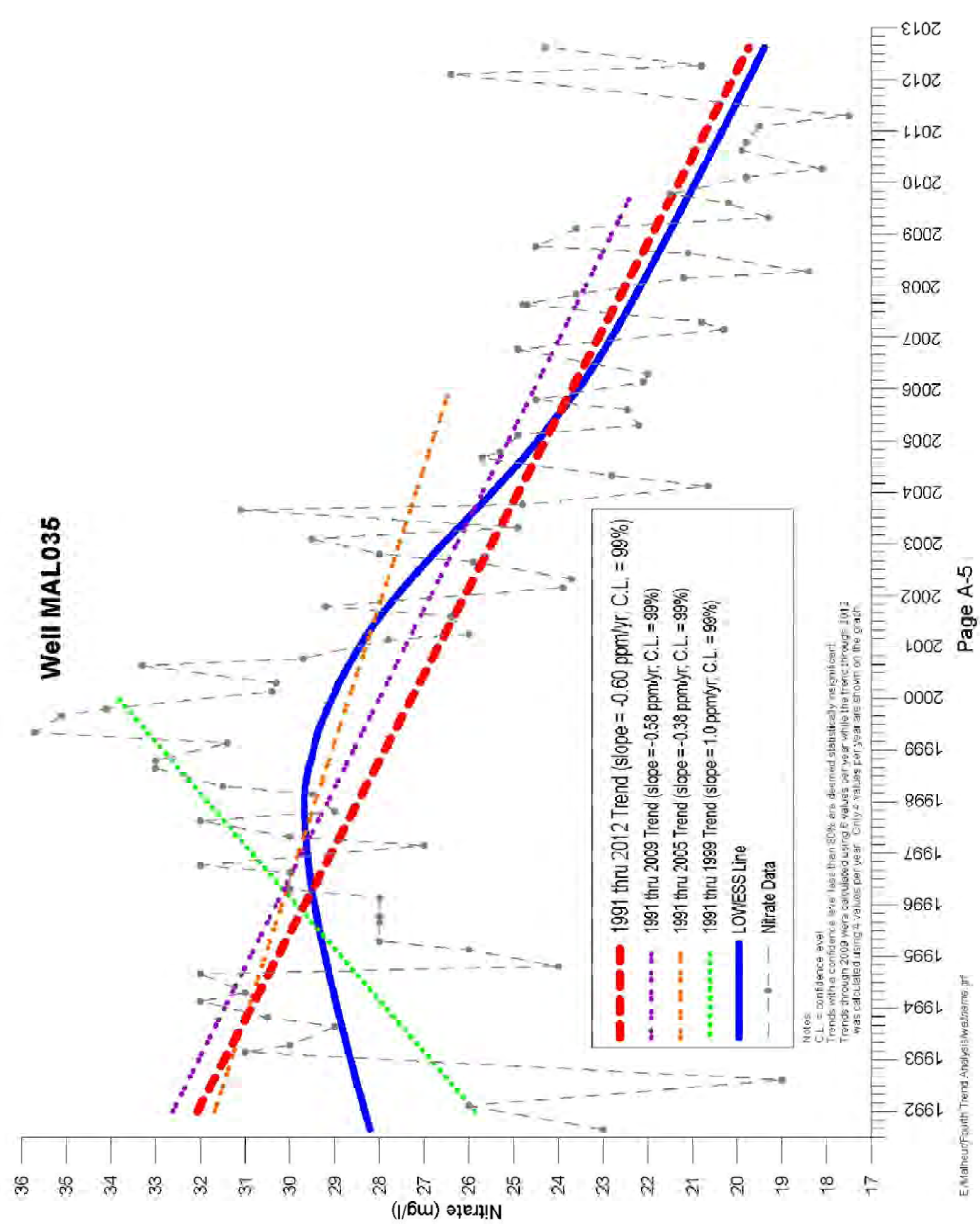

Well MAL005
Nitrate (mg/l)
1991 thru 2012 Trend (slope = 0.06 ppm/yr; C.L. = 98%)
1991 thru 2009 Trend (slope = 0.09 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = 0.14 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.38 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Page A-1

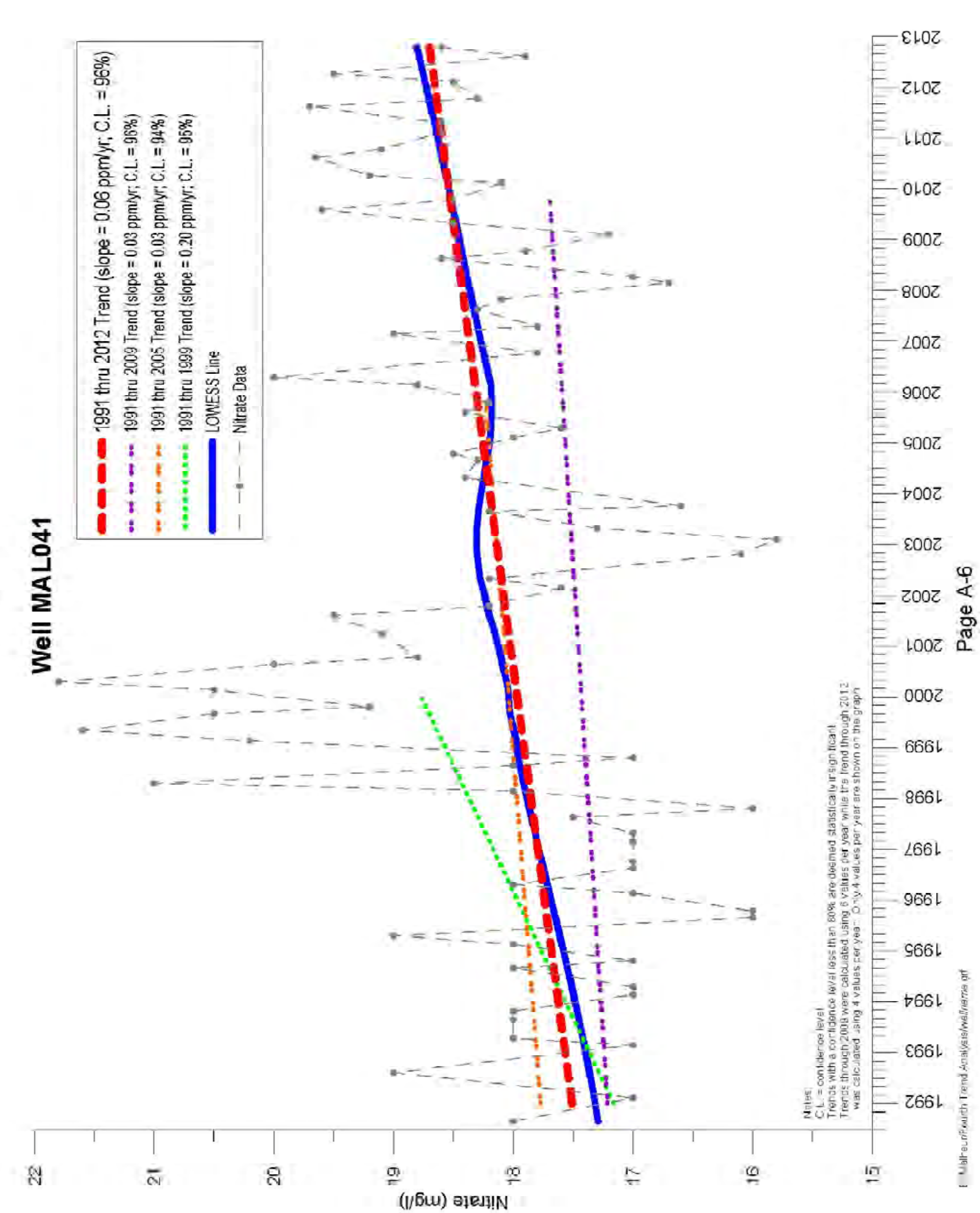

Well MAL012
Nitrate (mg/l)
1991 thru 2012 Trend (slope = -0.38 ppm/yr; C.L. = 96%)
1991 thru 2009 Trend (slope = -0.64 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.76 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.69 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Note: C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Page A-2

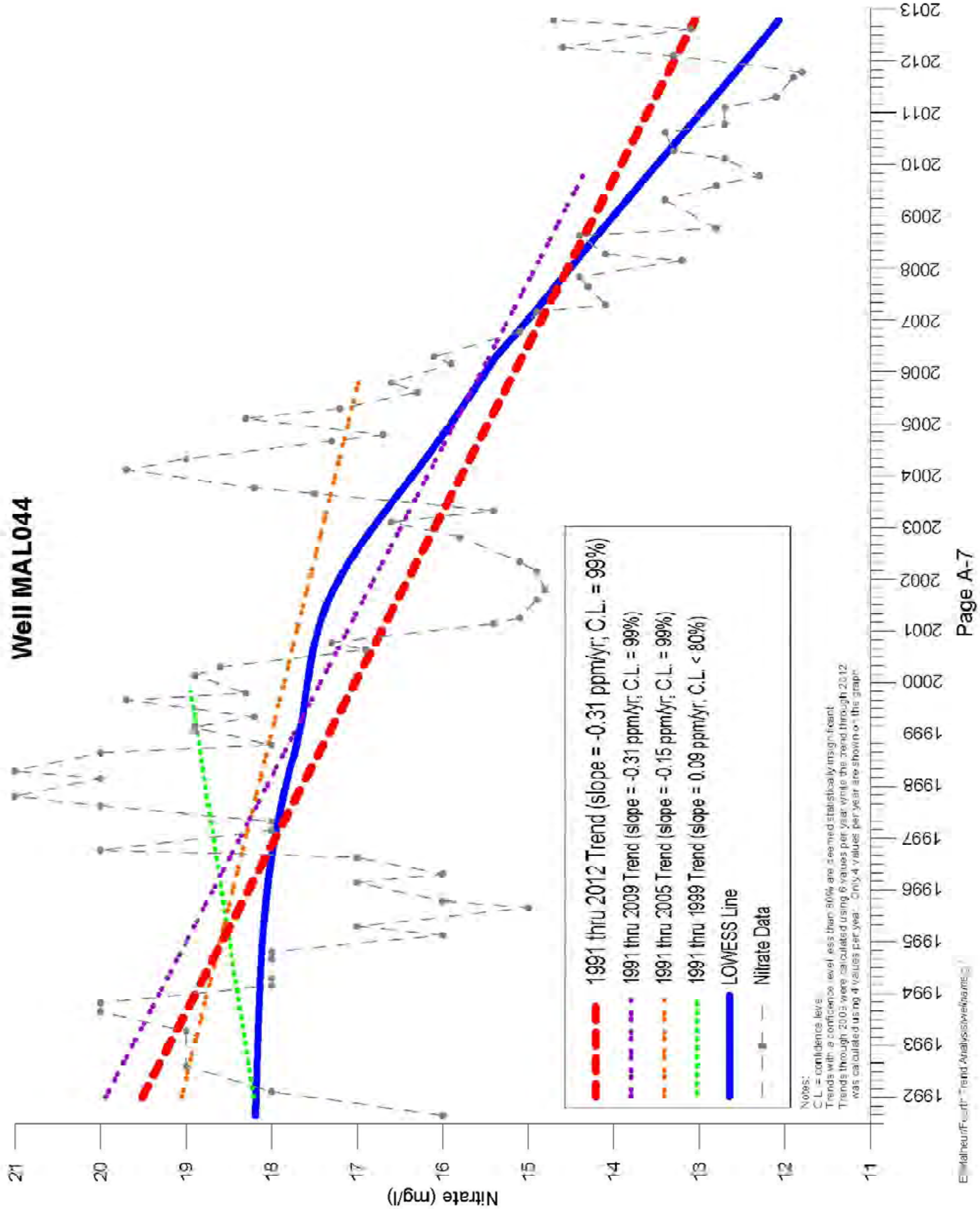

Well MAL016
1991 thru 2012 Trend (slope = 0.53 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = 0.73 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = 0.20 ppm/yr; C.L. = 84%)
1991 thru 1999 Trend (slope = -0.75 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on this graph
Nitrate (mg/l)

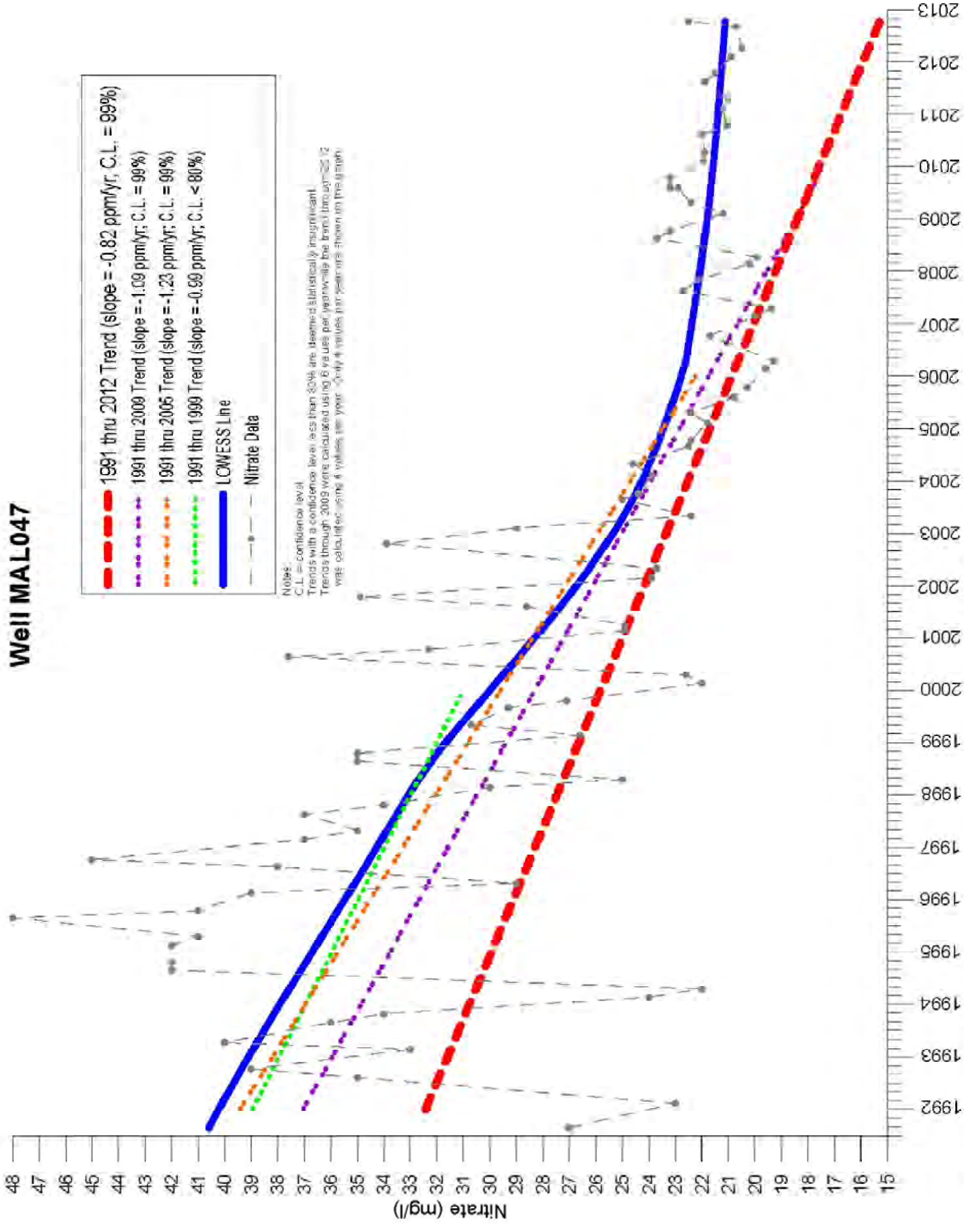
Page A-3


Well MAL030
Nitrate (mg/l)
1991 thru 2012 Trend (slope = -0.63 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.68 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.56 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.22 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Page A-4

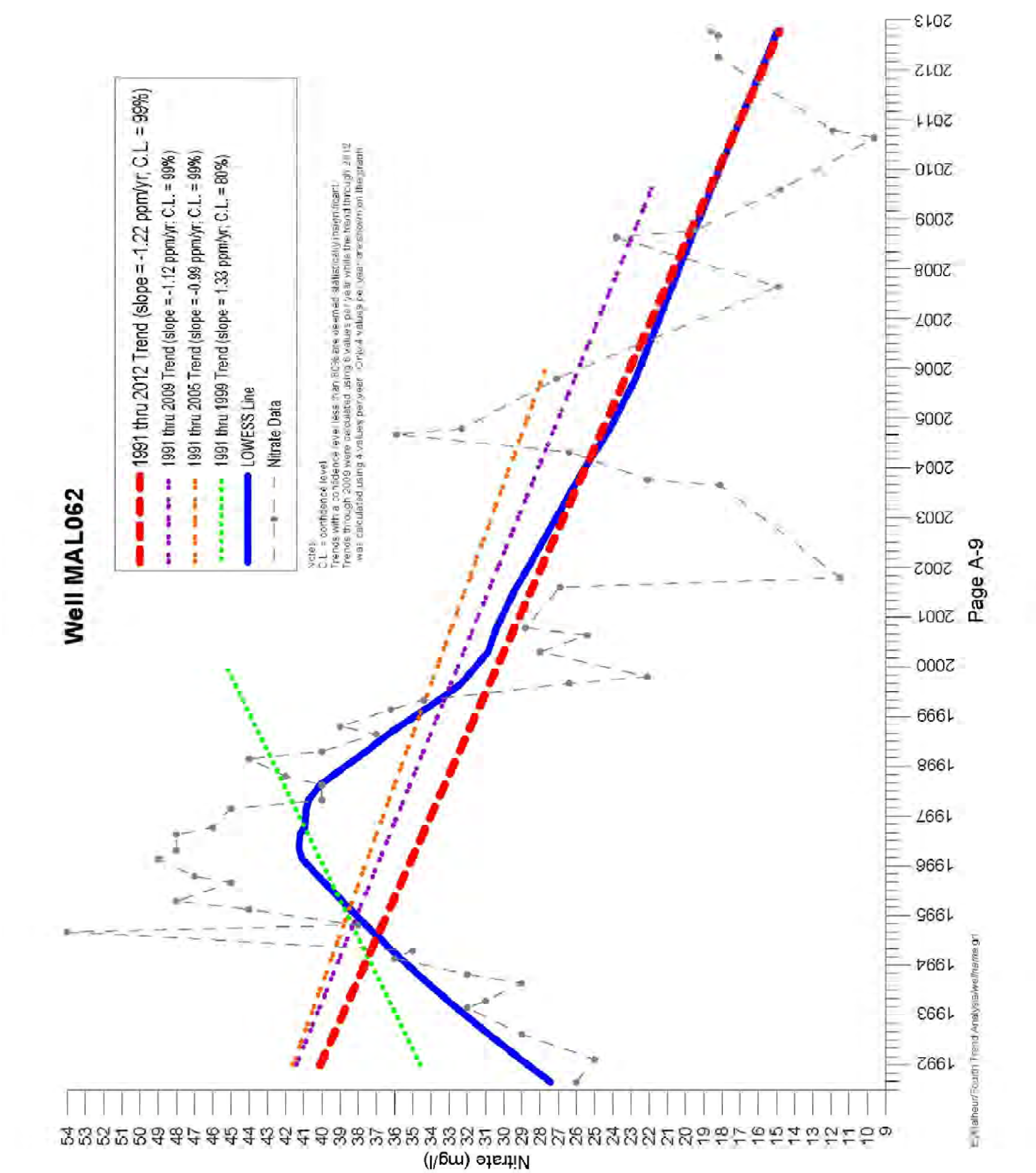

Well MAL035
Nitrate (mg/l)
1991 thru 2012 Trend (slope = -0.60 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.58 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.38 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 1.0 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Page A-5


Well MAL041
1991 thru 2012 Trend (slope = 0.06 ppm/yr; C.L. = 96%)
1991 thru 2009 Trend (slope = 0.03 ppm/yr; C.L. = 96%)
1991 thru 2005 Trend (slope = 0.03 ppm/yr; C.L. = 94%)
1991 thru 1999 Trend (slope = 0.20 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
22
21
20
19
18
17
16
15
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant
Trends through 2008 were calculated using 6 values per year while the trend through 2012 was calculated using 4 values per year. Only 4 values per year are shown on the graph
Page A-6

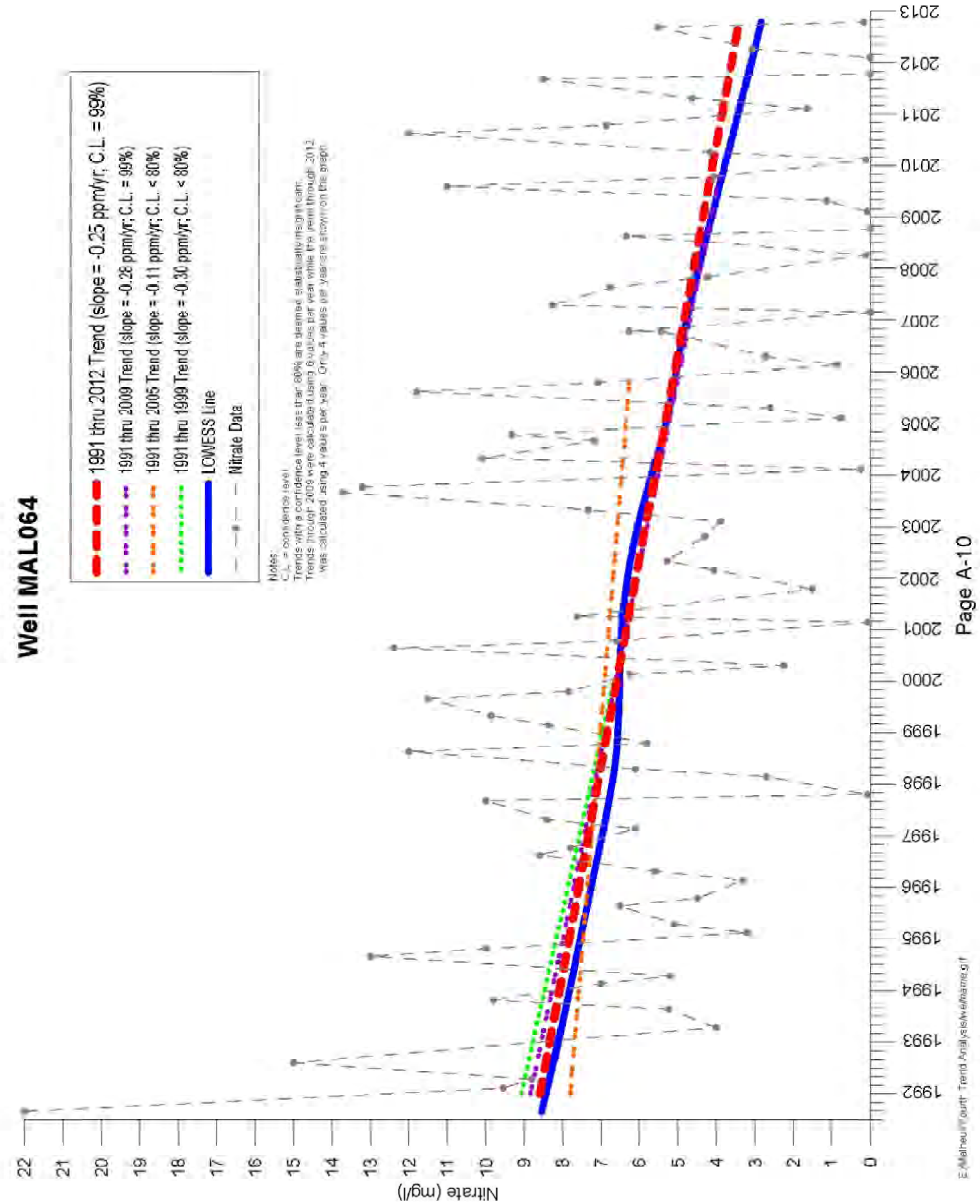

Well MAL044
1991 thru 2012 Trend (slope = -0.31 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.31 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.15 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.09 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
Page A-7


Well MAL047
1991 thru 2012 Trend (slope = -0.82 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -1.09 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -1.23 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.99 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Nitrate (mg/l)
48 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

Page A-8


Well MAL062
1991 thru 2012 Trend (slope = -1.22 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -1.12 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.99 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 1.33 ppm/yr; C.L. = 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Nitrate (mg/l)
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Page A-9


Well MAL064
1991 thru 2012 Trend (slope = -0.25 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.28 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.11 ppm/yr; C.L. < 80%)
1991 thru 1999 Trend (slope = -0.30 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1992
1993
1994
1995
1996
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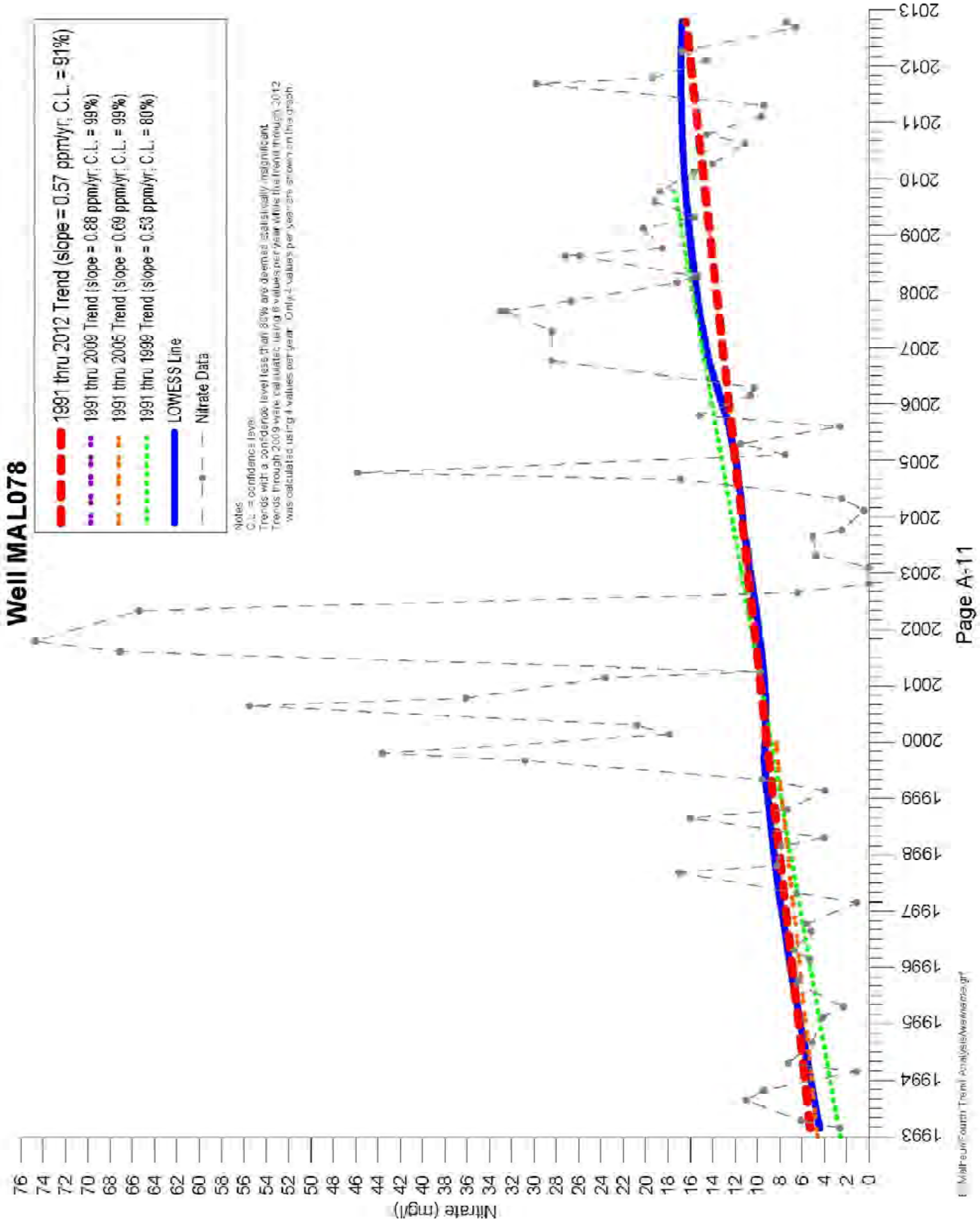
2006
2007
2008
2009
2010
2011
2012
2013
Page A-10


Well MAL078
1991 thru 2012 Trend (slope = 0.57 ppm/yr; C.L. = 91%)
1991 thru 2009 Trend (slope = 0.88 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = 0.69 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.53 ppm/yr; C.L. = 80%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

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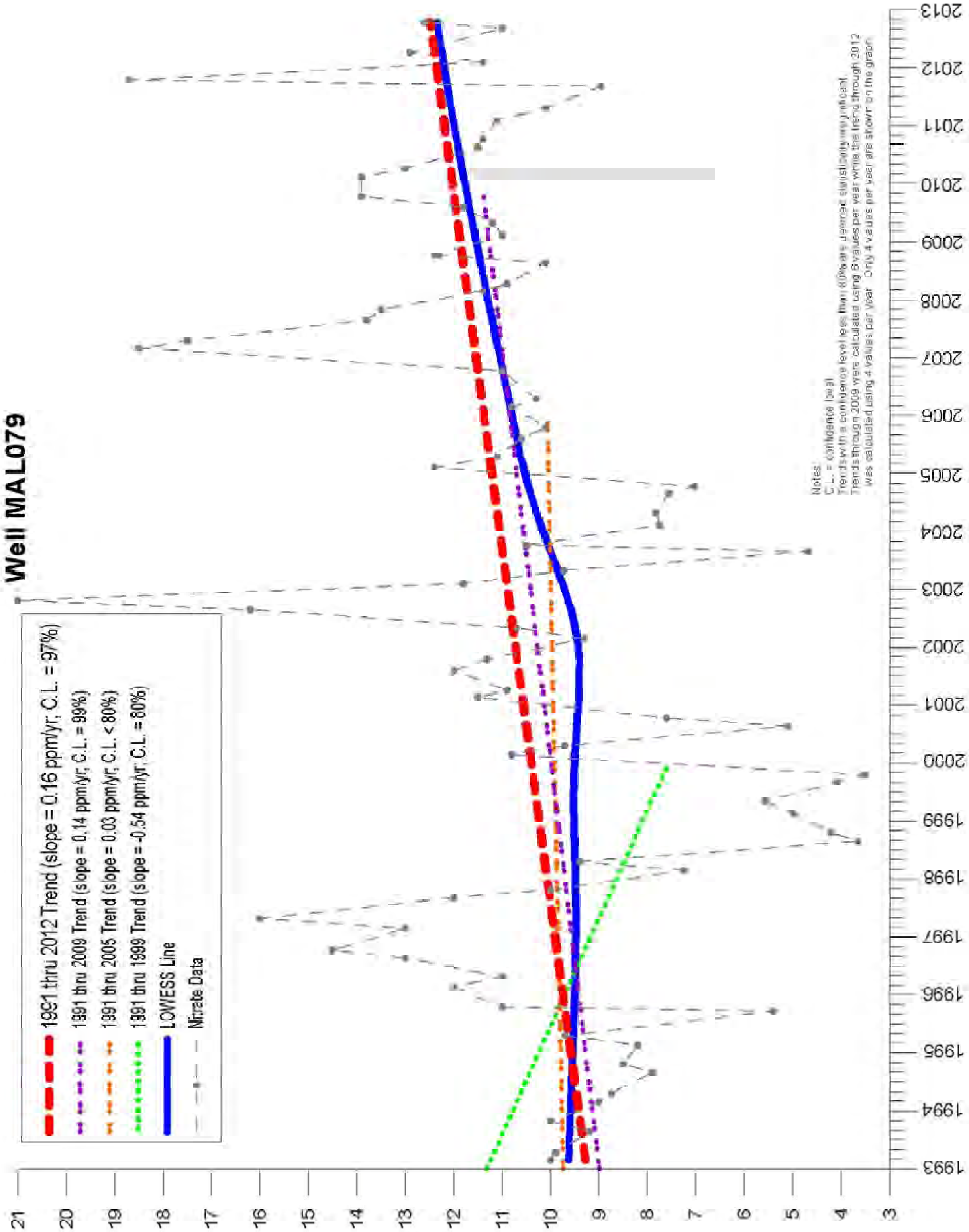
Well MAL079
1991 thru 2012 Trend (slope = 0.16 ppm/yr; C.L. = 97%)
1991 thru 2009 Trend (slope = 0.14 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = 0.03 ppm/yr; C.L. < 80%)
1991 thru 1999 Trend (slope = -0.54 ppm/yr; C.L. = 80%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 8 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.

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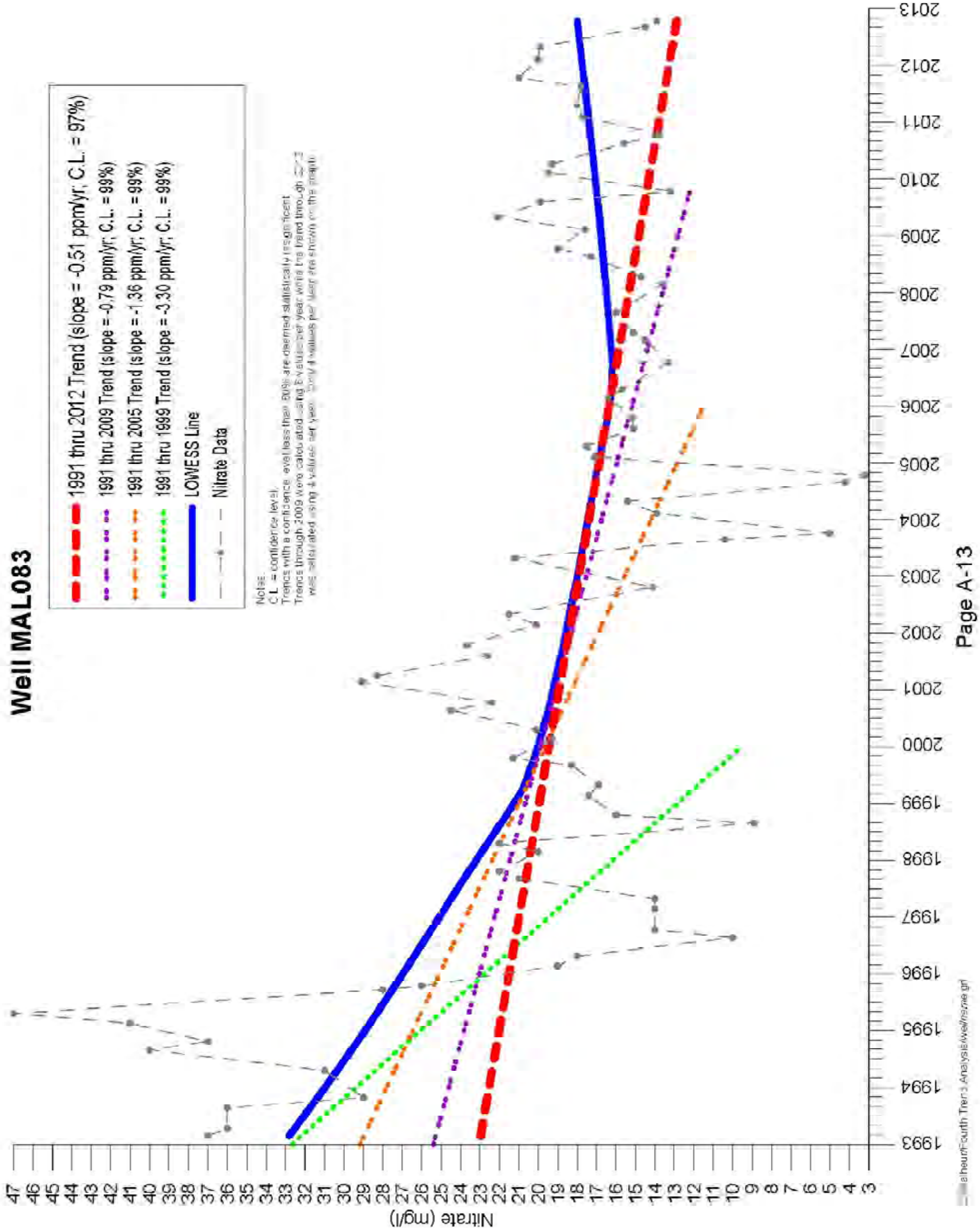
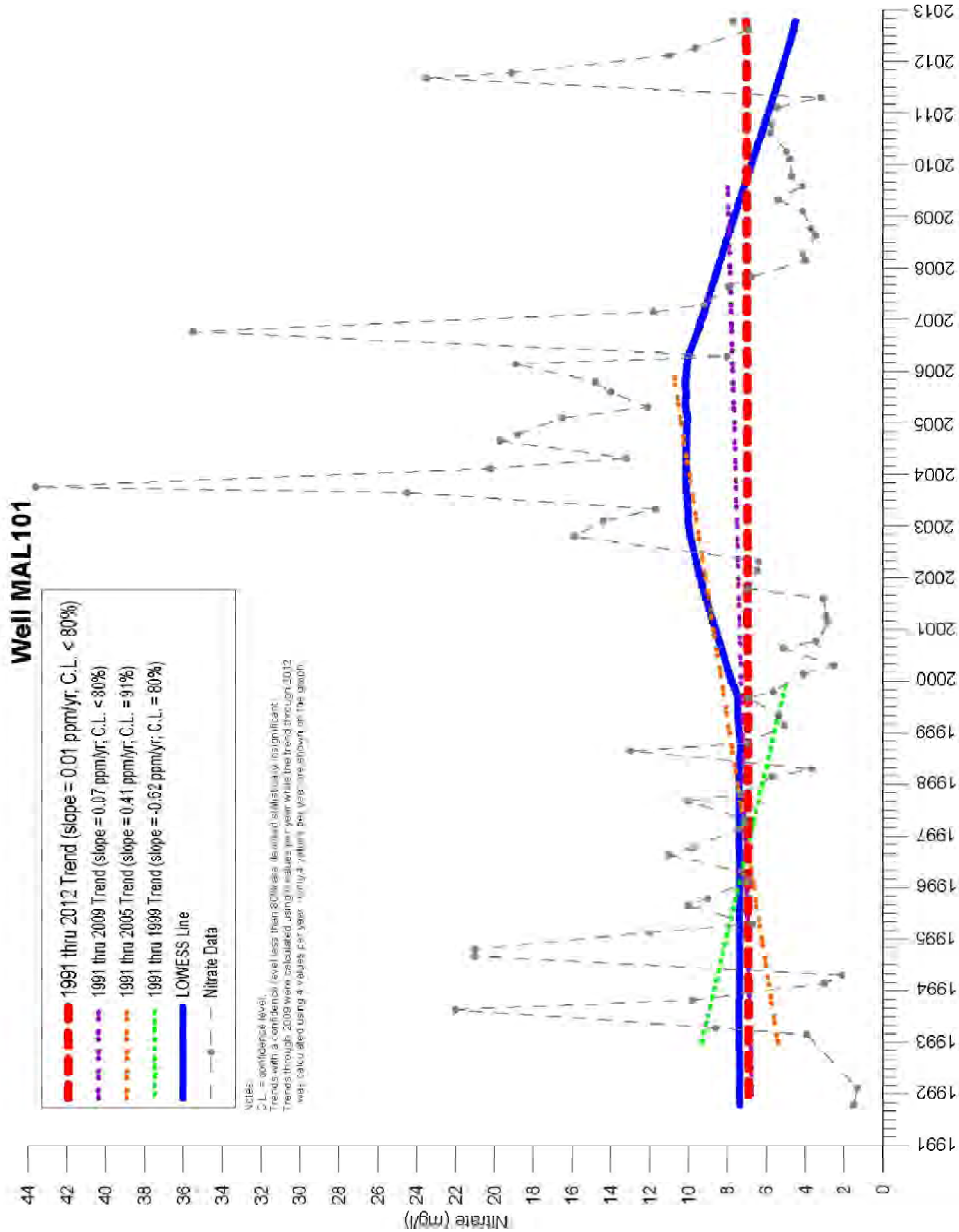
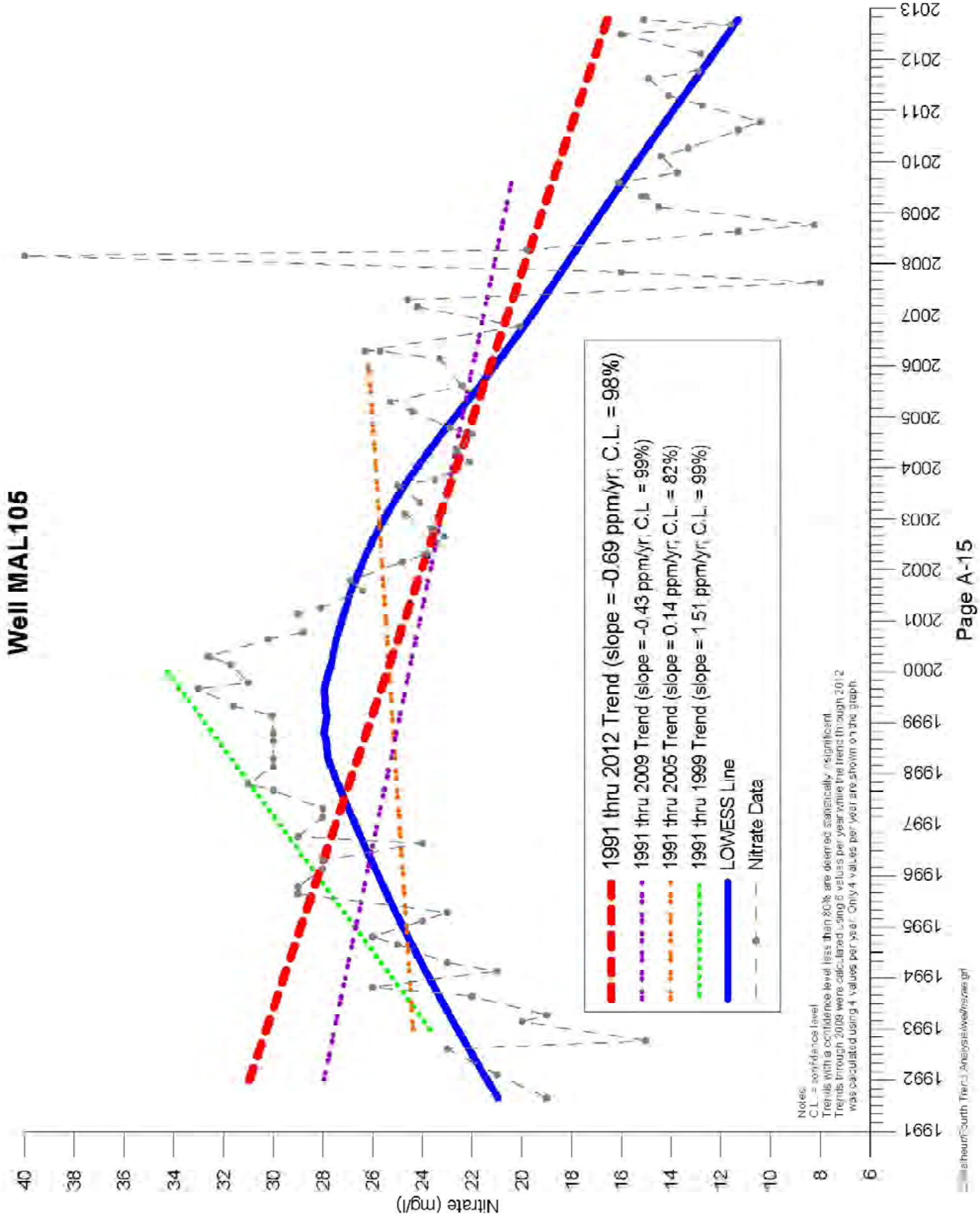


Well MAL083
1991 thru 2012 Trend (slope = -0.51 ppm/yr; C.L. = 97%)
1991 thru 2009 Trend (slope = -0.79 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -1.36 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -3.30 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Nitrate (mg/l)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Page A-13


Well MAL101
1991 thru 2012 Trend (slope = 0.01 ppm/yr; C.L. < 80%)
1991 thru 2009 Trend (slope = 0.07 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = 0.41 ppm/yr; C.L. = 91%)
1991 thru 1999 Trend (slope = -0.62 ppm/yr; C.L. = 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using n values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Page A-14


Well MAL105
1991 thru 2012 Trend (slope = -0.69 ppm/yr; C.L. = 98%)
1991 thru 2009 Trend (slope = -0.43 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = 0.14 ppm/yr; C.L. = 82%)
1991 thru 1999 Trend (slope = 1.51 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.

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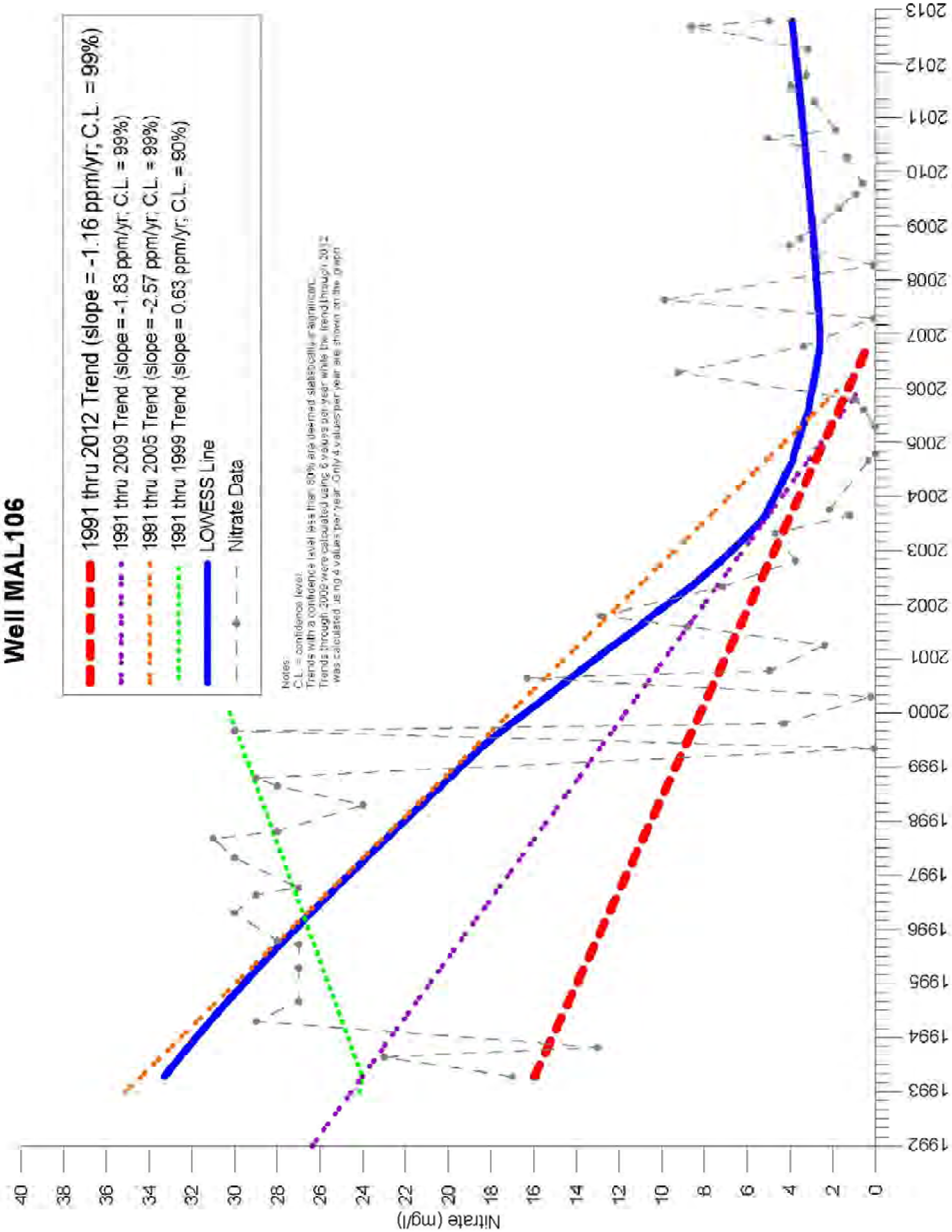
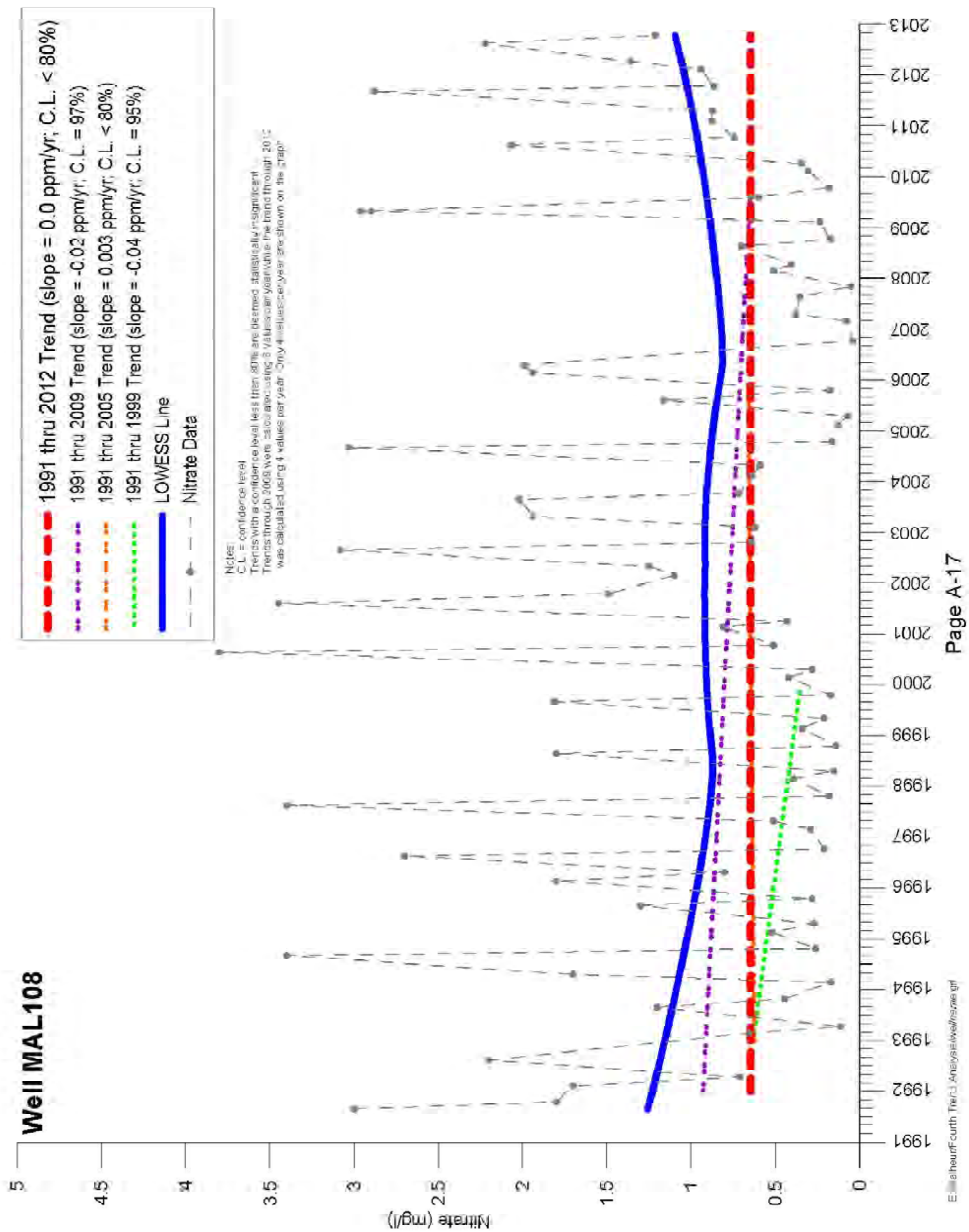
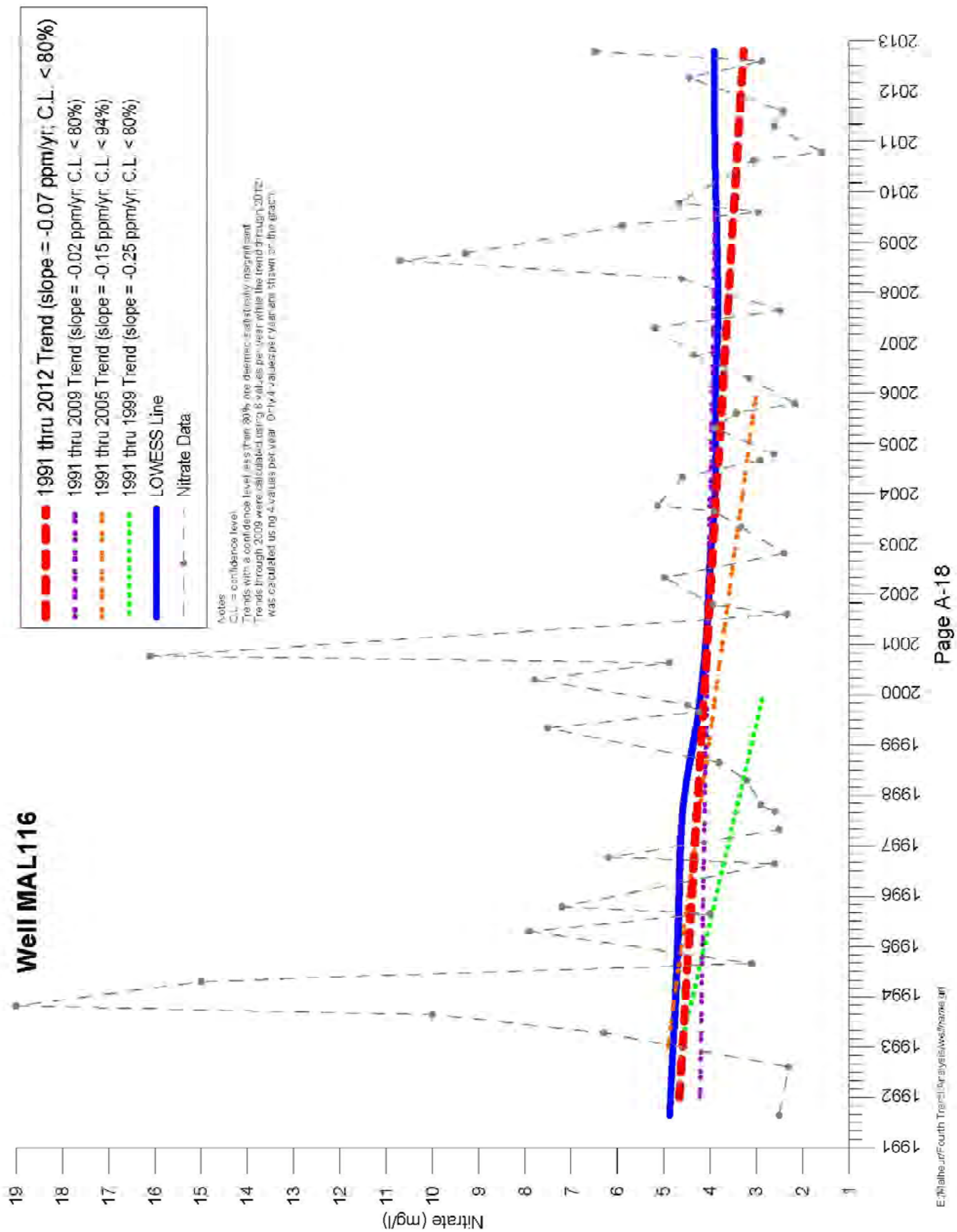


Well MAL106
1991 thru 2012 Trend (slope = -1.16 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -1.83 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -2.57 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.63 ppm/yr; C.L. = 90%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Page A-16


Well MAL108
1991 thru 2012 Trend (slope = 0.0 ppm/yr; C.L. < 80%)
1991 thru 2009 Trend (slope = -0.02 ppm/yr; C.L. = 97%)
1991 thru 2005 Trend (slope = 0.003 ppm/yr; C.L. < 80%)
1991 thru 1999 Trend (slope = -0.04 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
Page A-17


Well MAL116
1991 thru 2012 Trend (slope = -0.07 ppm/yr; C.L. < 80%)
1991 thru 2009 Trend (slope = -0.02 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = -0.15 ppm/yr; C.L. < 94%)
1991 thru 1999 Trend (slope = -0.25 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes
C.L. = confidence level
Nitrate (mg/l)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

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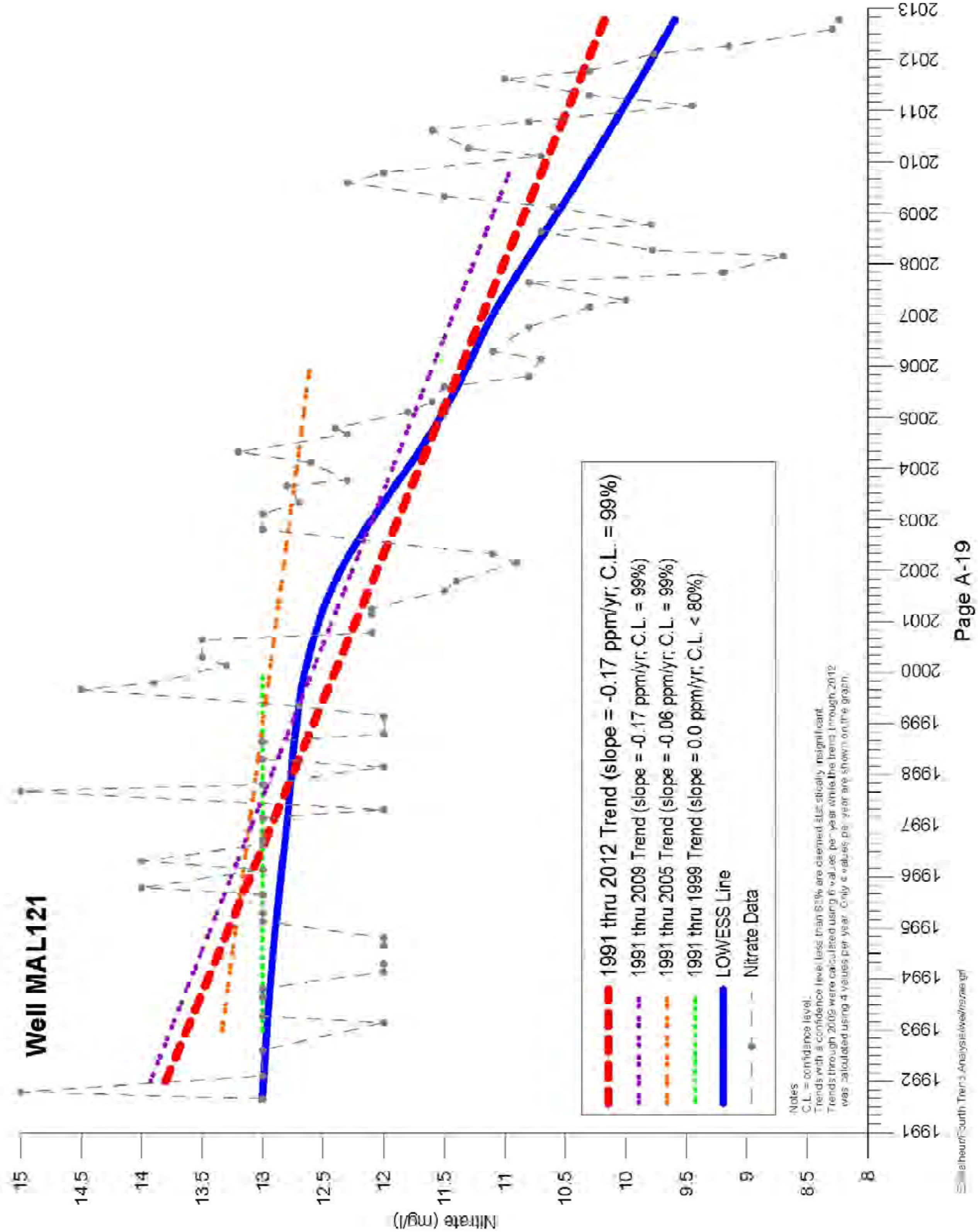
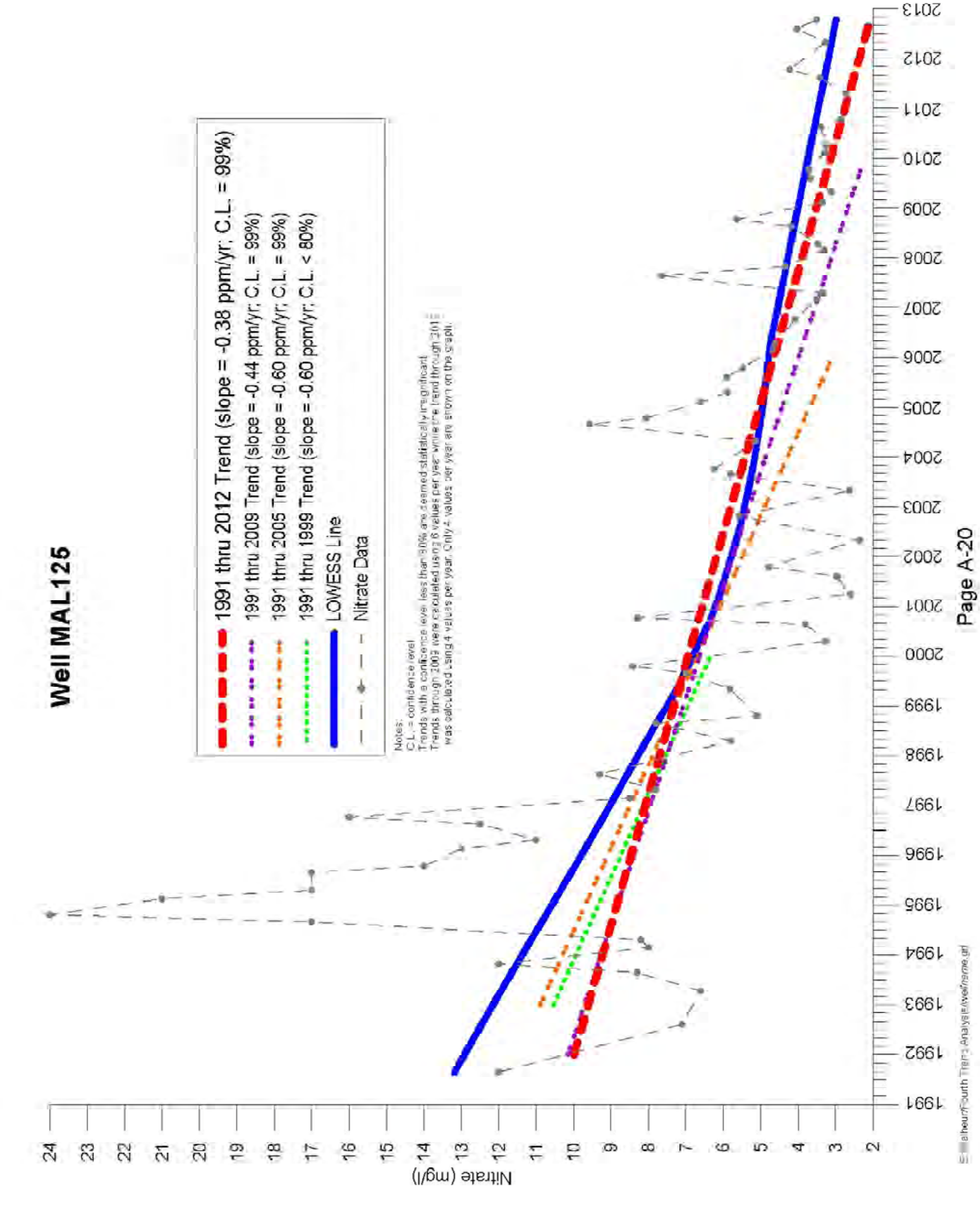
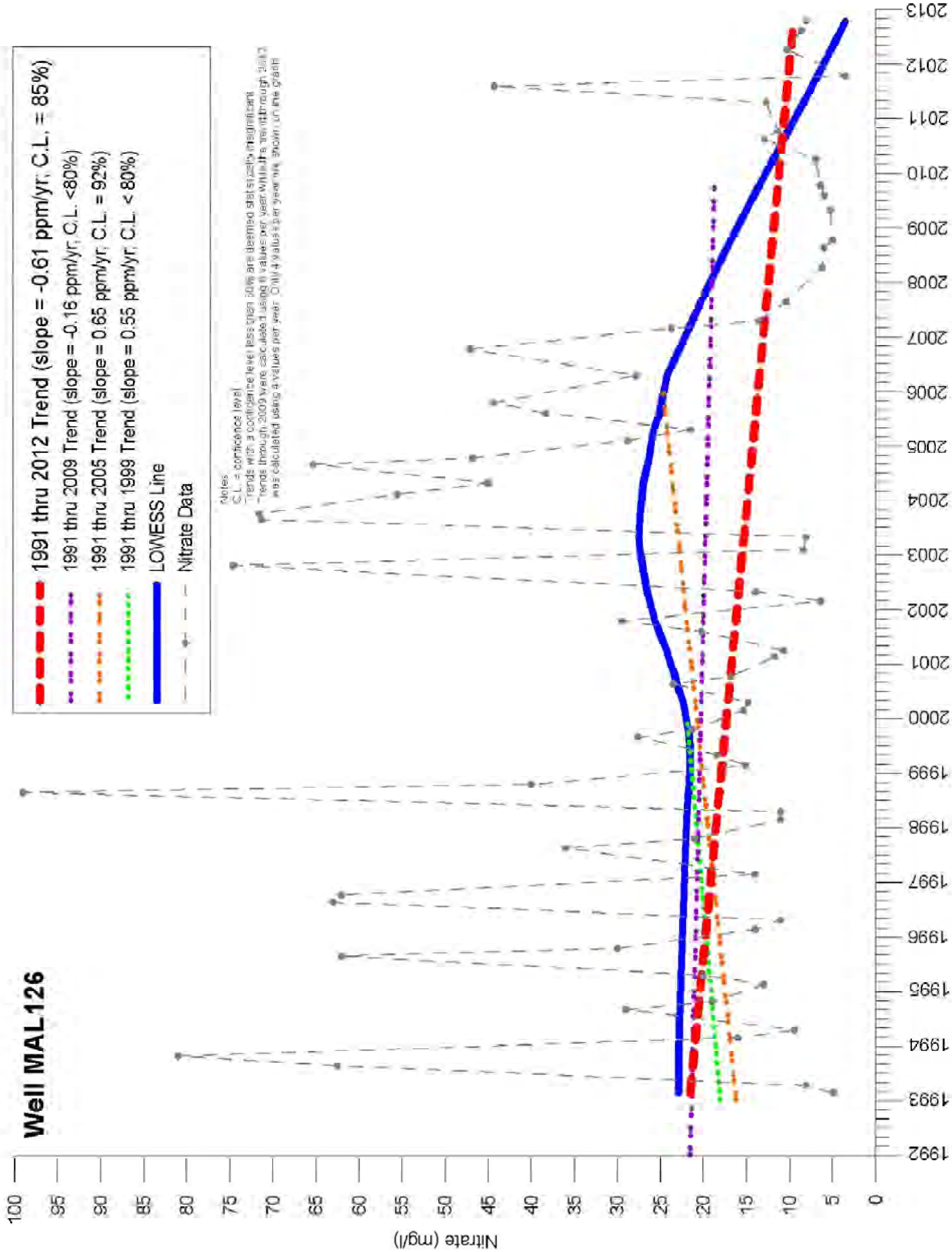

Well MAL121
Nitrate (mg/l)
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
8
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
1991 thru 2012 Trend (slope = -0.17 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.17 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.06 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.0 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Page A-19


Well MAL125
1991 thru 2012 Trend (slope = -0.38 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.44 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.60 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.60 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Page A-20


Well MAL126
1991 thru 2012 Trend (slope = -0.61 ppm/yr; C.L. = 85%)
1991 thru 2009 Trend (slope = -0.16 ppm/yr; C.L. <80%)
1991 thru 2005 Trend (slope = 0.65 ppm/yr; C.L. = 92%)
1991 thru 1999 Trend (slope = 0.55 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

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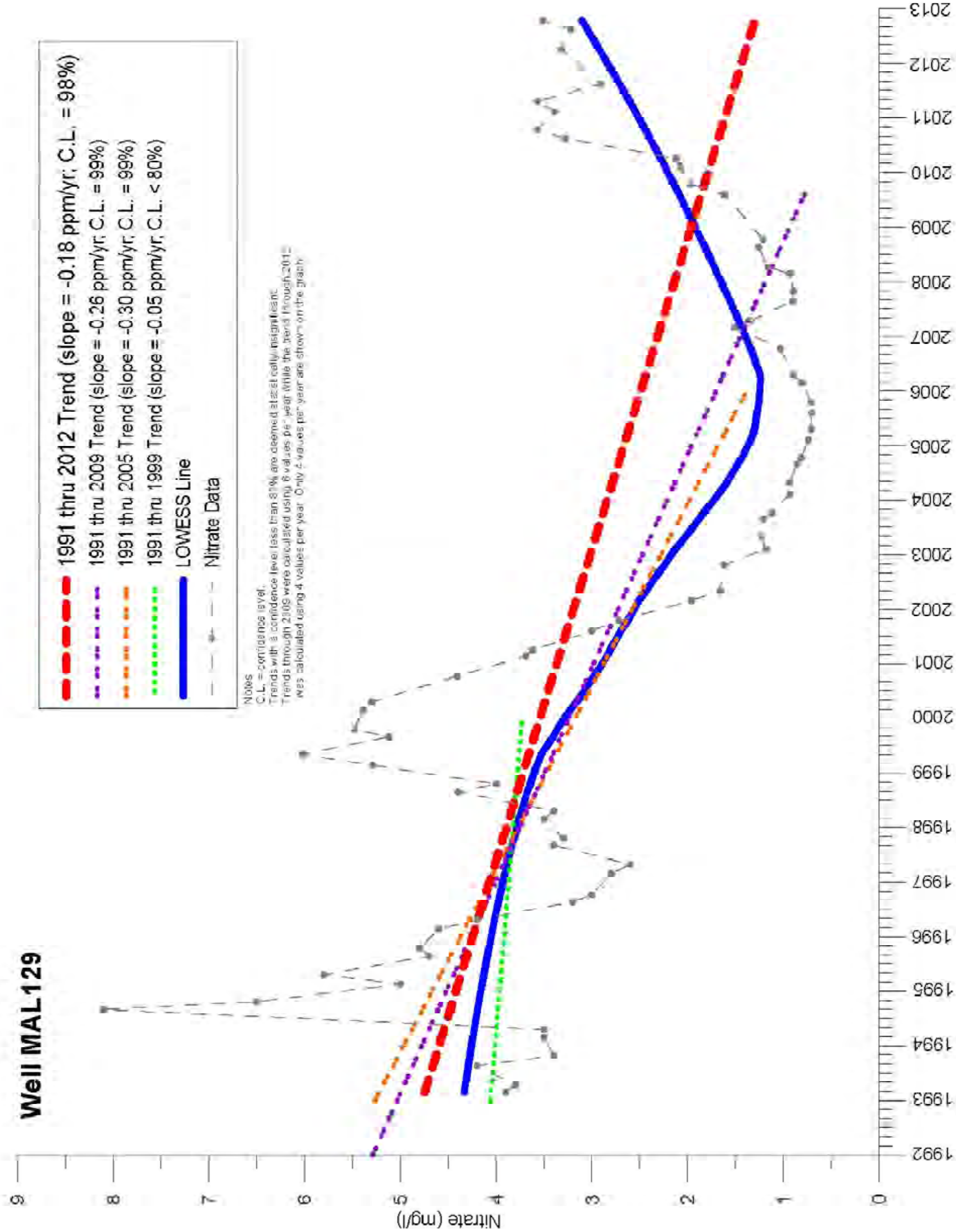
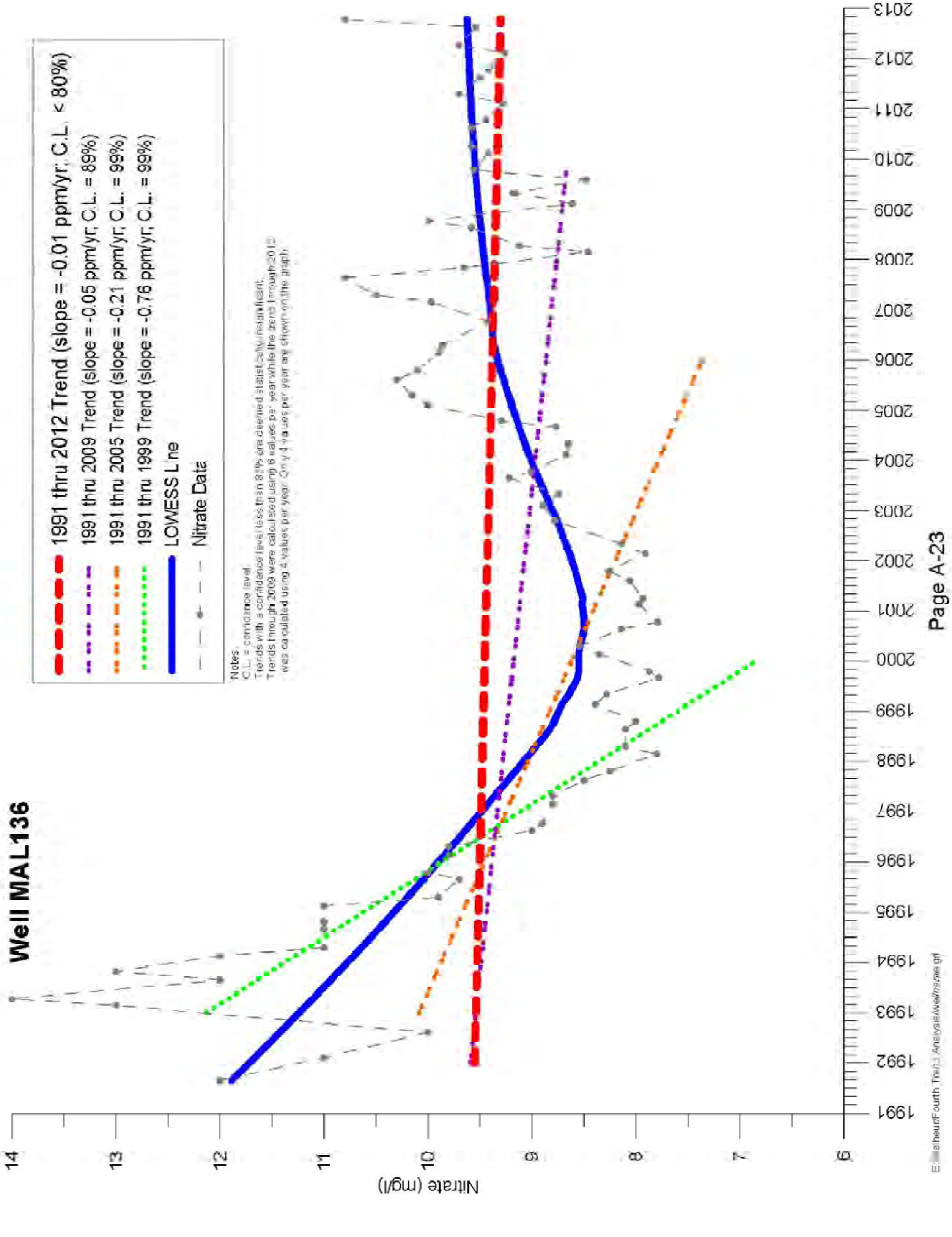

Well MAL129
1991 thru 2012 Trend (slope = -0.18 ppm/yr; C.L. = 98%)
1991 thru 2009 Trend (slope = -0.26 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.30 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.05 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
0
1
2
3
4
5
6
7
8
9
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Page A-22



Well MAL136
1991 thru 2012 Trend (slope = -0.01 ppm/yr; C.L. < 80%)
1991 thru 2009 Trend (slope = -0.05 ppm/yr; C.L. = 89%)
1991 thru 2005 Trend (slope = -0.21 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.76 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012 was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
14
13
12
11
10
9
8
7
6
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

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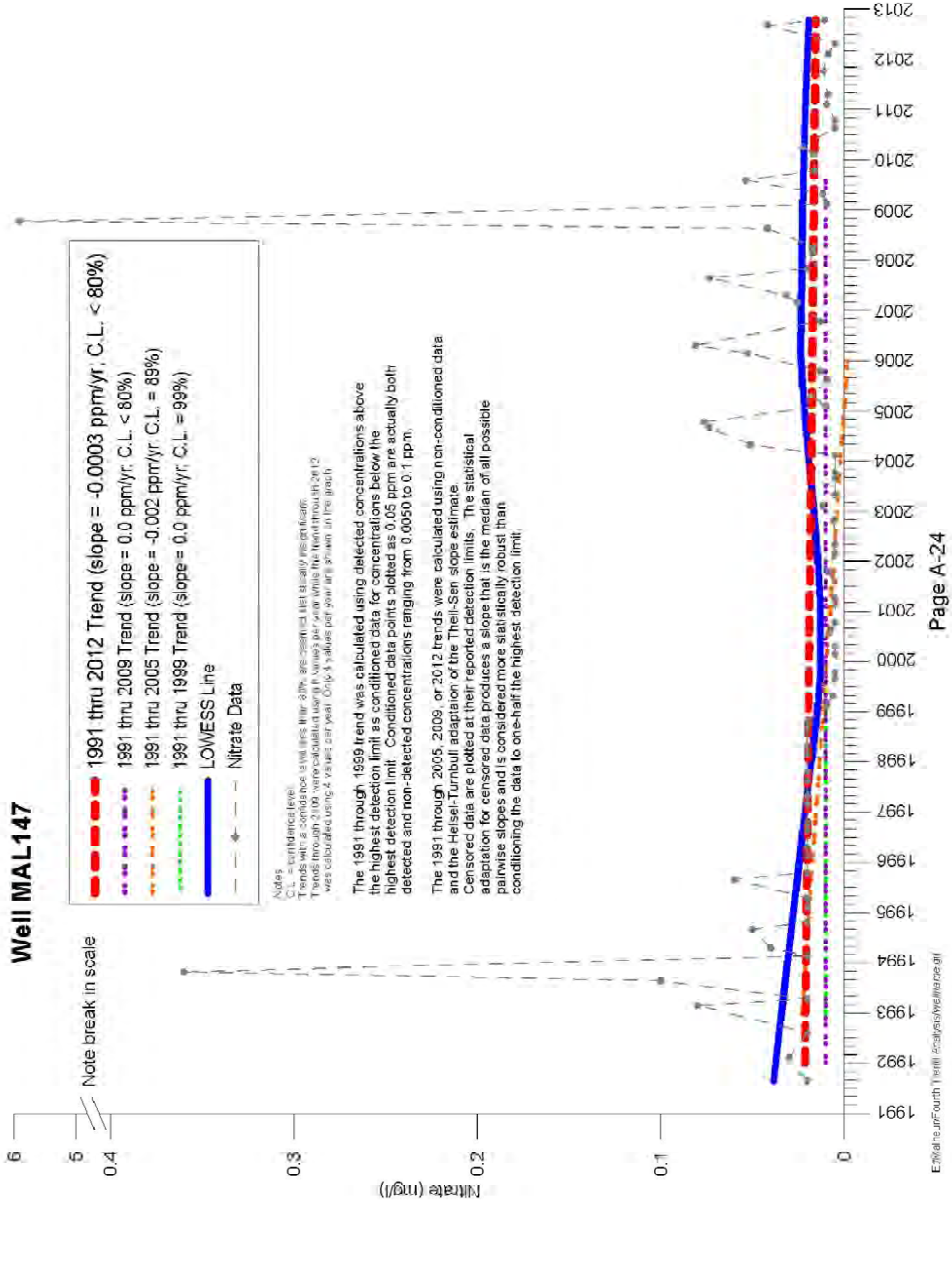
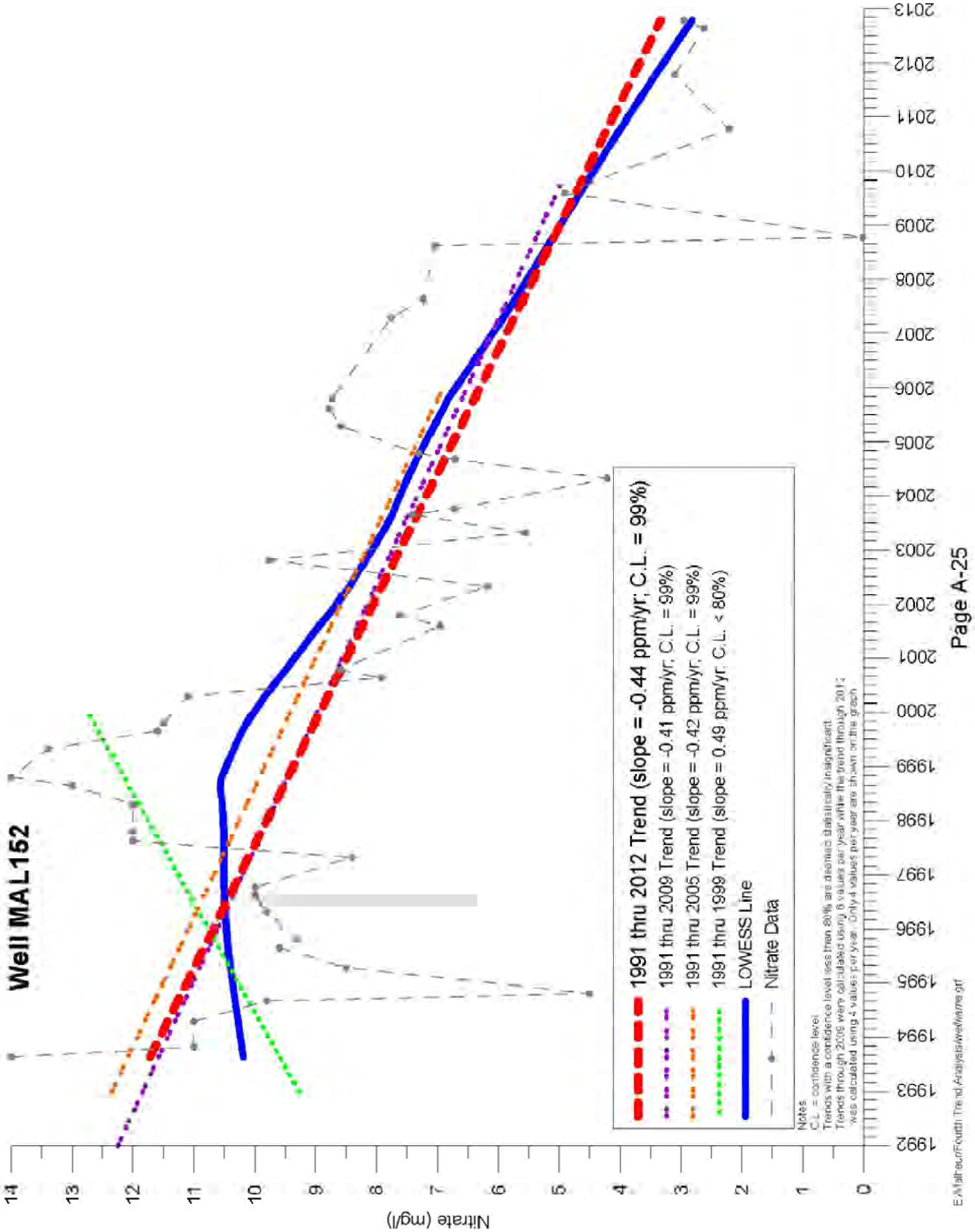
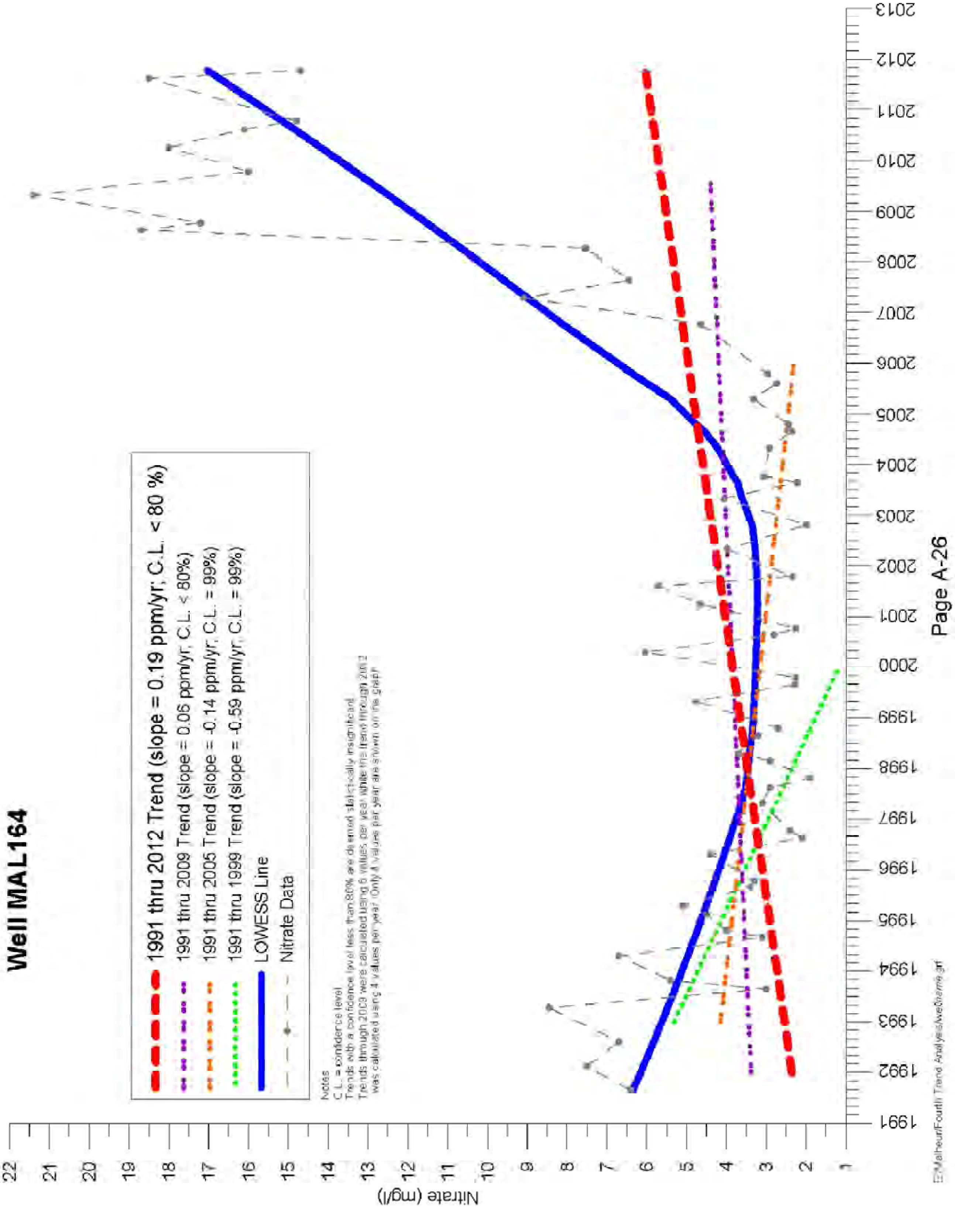


Well MAL147
Note break in scale
1991 thru 2012 Trend (slope = -0.0003 ppm/yr; C.L. < 80%)
1991 thru 2009 Trend (slope = 0.0 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = -0.002 ppm/yr; C.L. = 89%)
1991 thru 1999 Trend (slope = 0.0 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
The 1991 through 1999 trend was calculated using detected concentrations above the highest detection limit as conditioned data for concentrations below the highest detection limit. Conditioned data points plotted as 0.05 ppm are actually both detected and non-detected concentrations ranging from 0.0050 to 0.1 ppm.
The 1991 through 2005, 2009, or 2012 trends were calculated using non-conditioned data and the Helsel-Turnbull adaptaion of the Theil-Sen slope estimate. Censored data are plotted at their reported detection limits. The statistical adaptation for censored data produces a slope that is the median of all possible pairwise slopes and is considered more statistically robust than conditioning the data to one-half the highest detection limit.
Nitrate (mg/l)
6
5
0.4
0.3
0.2
0.1
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Page A-24


Well MAL152
1991 thru 2012 Trend (slope = -0.44 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.41 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.42 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.49 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
Page A-25


Well MAL164
1991 thru 2012 Trend (slope = 0.19 ppm/yr; C.L. < 80 %)
1991 thru 2009 Trend (slope = 0.06 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = -0.14 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.59 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

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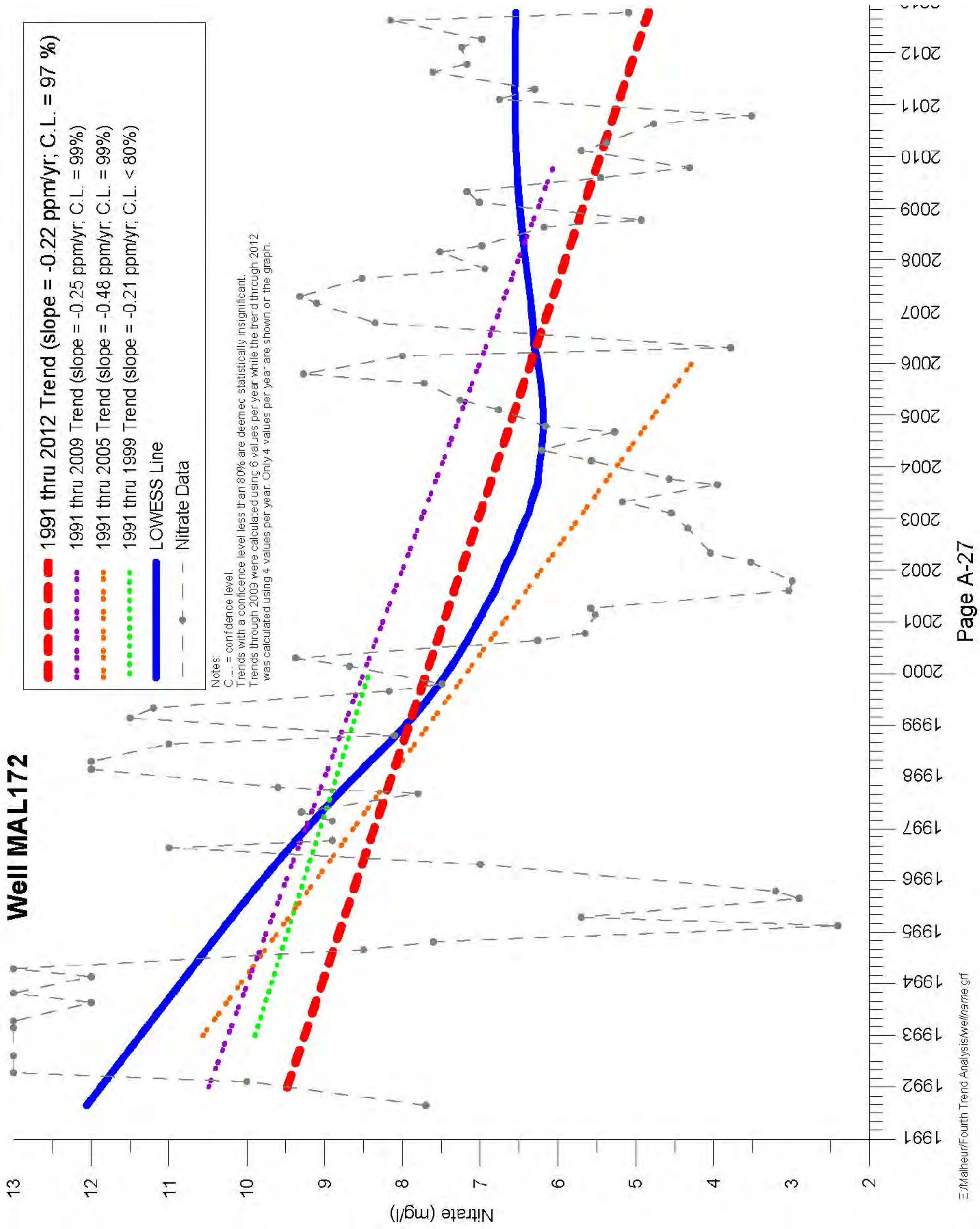
Well MAL172
1991 thru 2012 Trend (slope = -0.22 ppm/yr; C.L. = 97 %)
1991 thru 2009 Trend (slope = -0.25 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.48 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.21 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
13
12
11
10
9
8
7
6
5
4
3
2
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Page A-27
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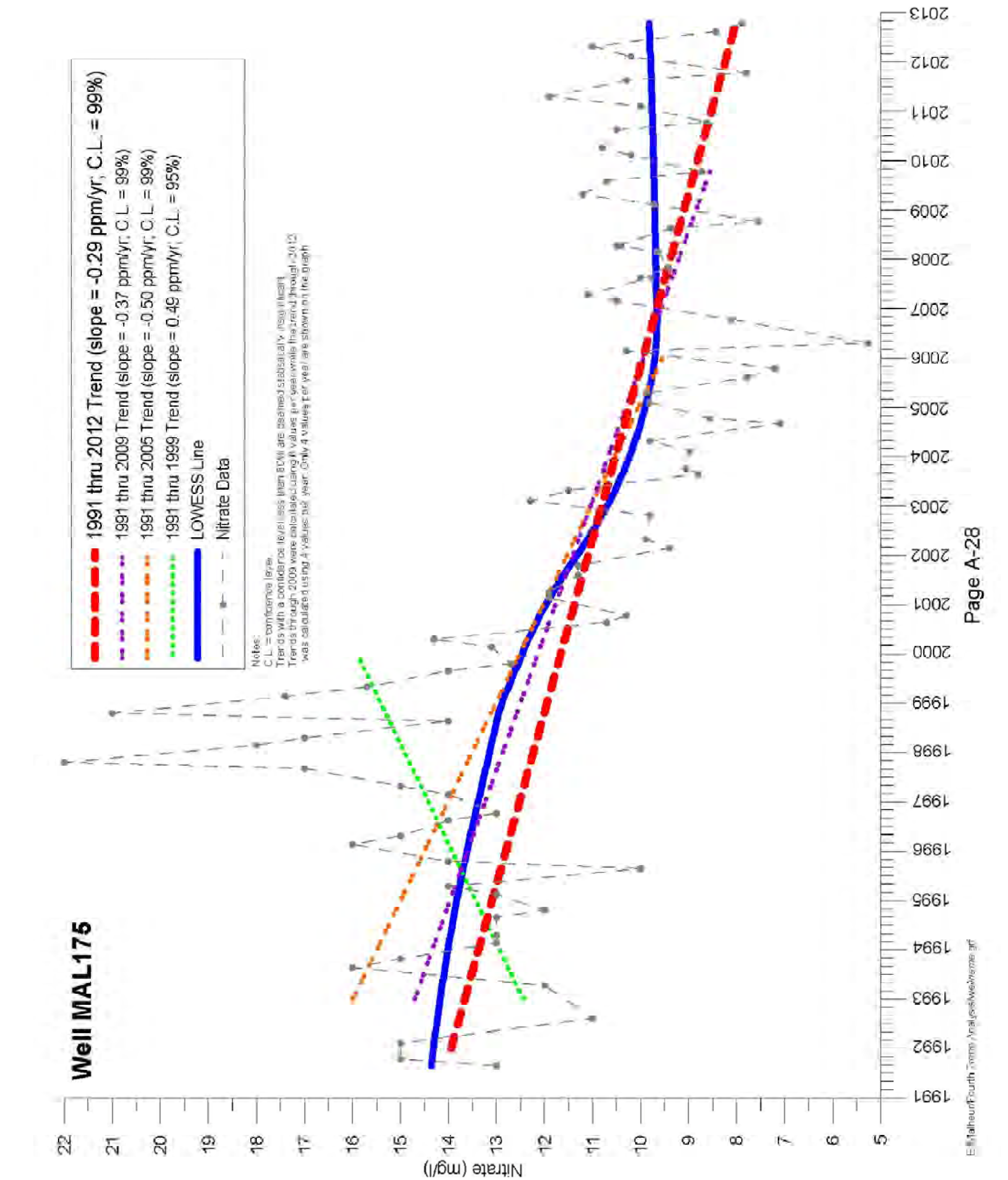
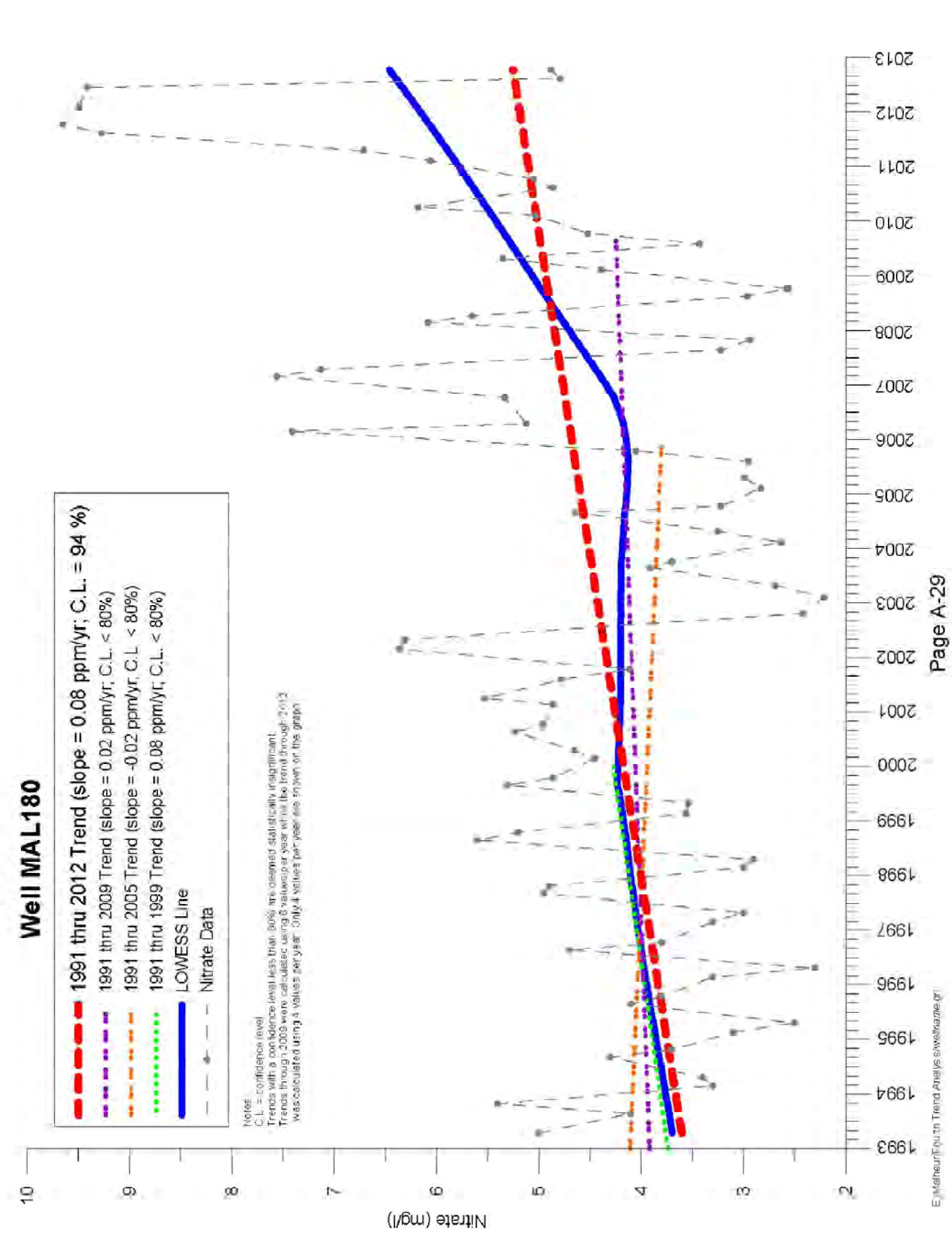
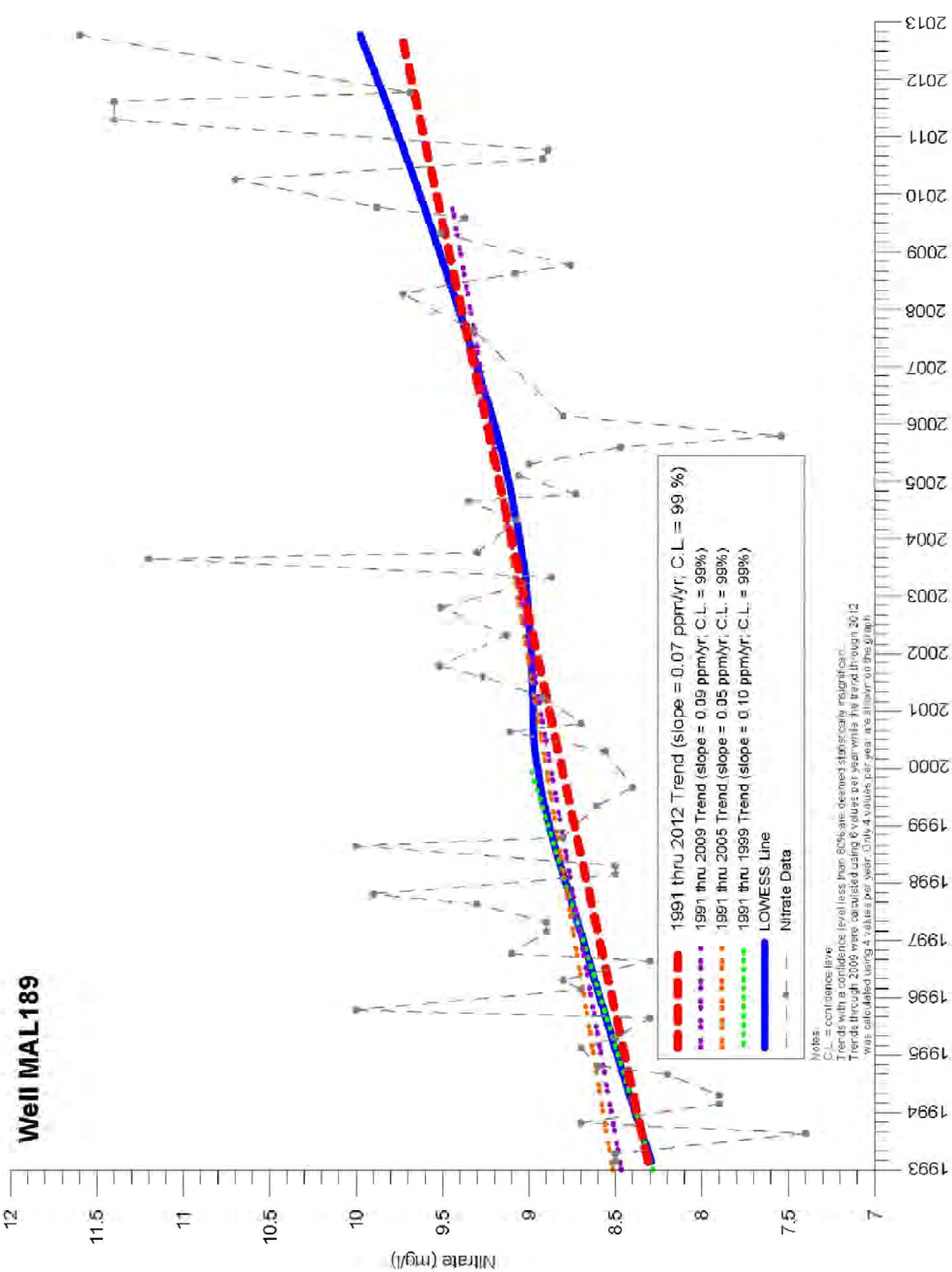

Well MAL175
1991 thru 2012 Trend (slope = -0.29 ppm/yr; C.L. = 99%)
1991 thru 2009 Trend (slope = -0.37 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.50 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.49 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 8 values per year while the trend through 2012 was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Page A-28


Well MAL180
1991 thru 2012 Trend (slope = 0.08 ppm/yr; C.L. = 94 %)
1991 thru 2009 Trend (slope = 0.02 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = -0.02 ppm/yr; C.L. < 80%)
1991 thru 1999 Trend (slope = 0.08 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph
Nitrate (mg/l)
10
9
8
7
6
5
4
3
2
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Page A-29


Well MAL189
Nitrate (mg/l)
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
1991 thru 2012 Trend (slope = 0.07 ppm/yr; C.L = 99 %)
1991 thru 2009 Trend (slope = 0.09 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = 0.05 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.10 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.

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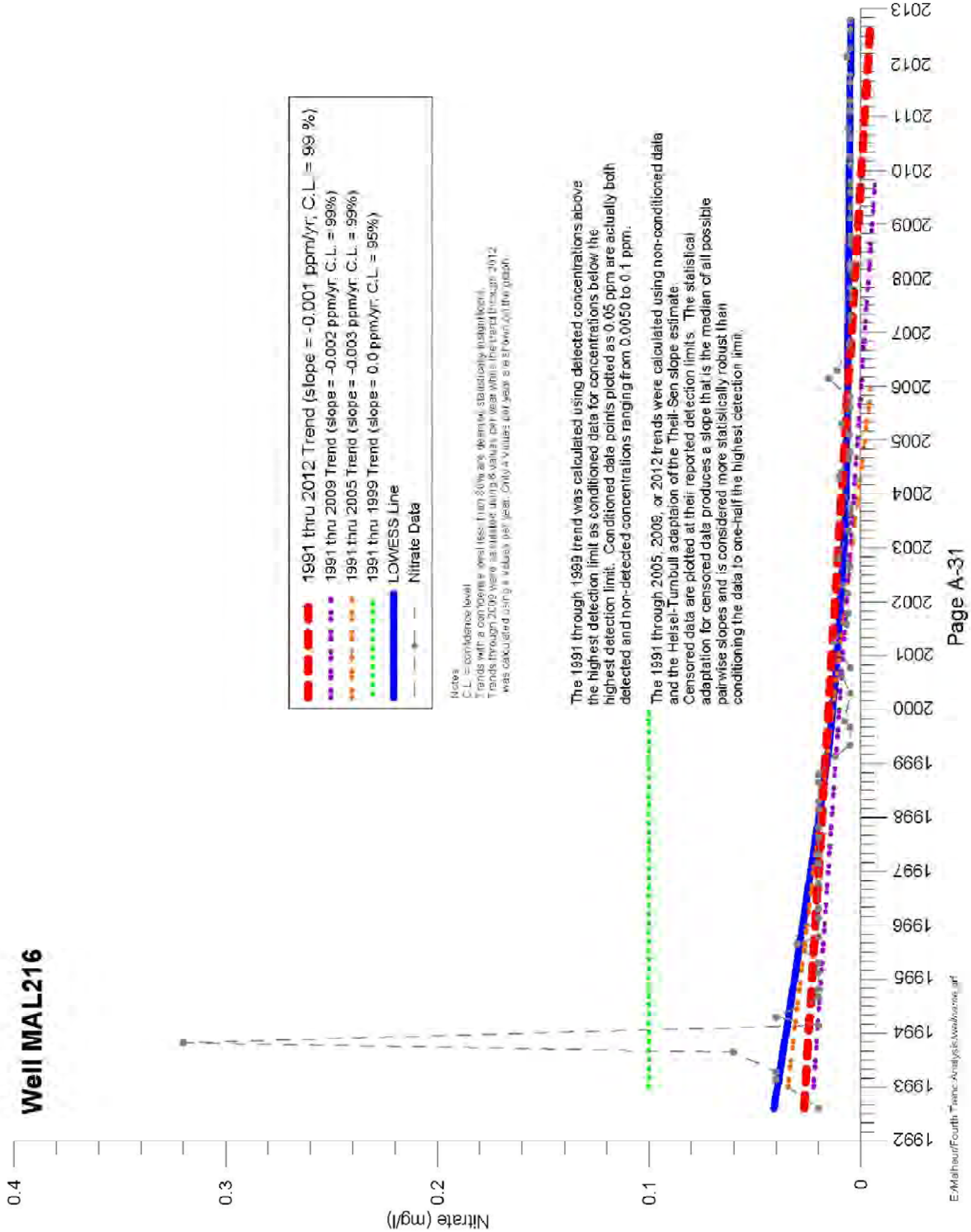
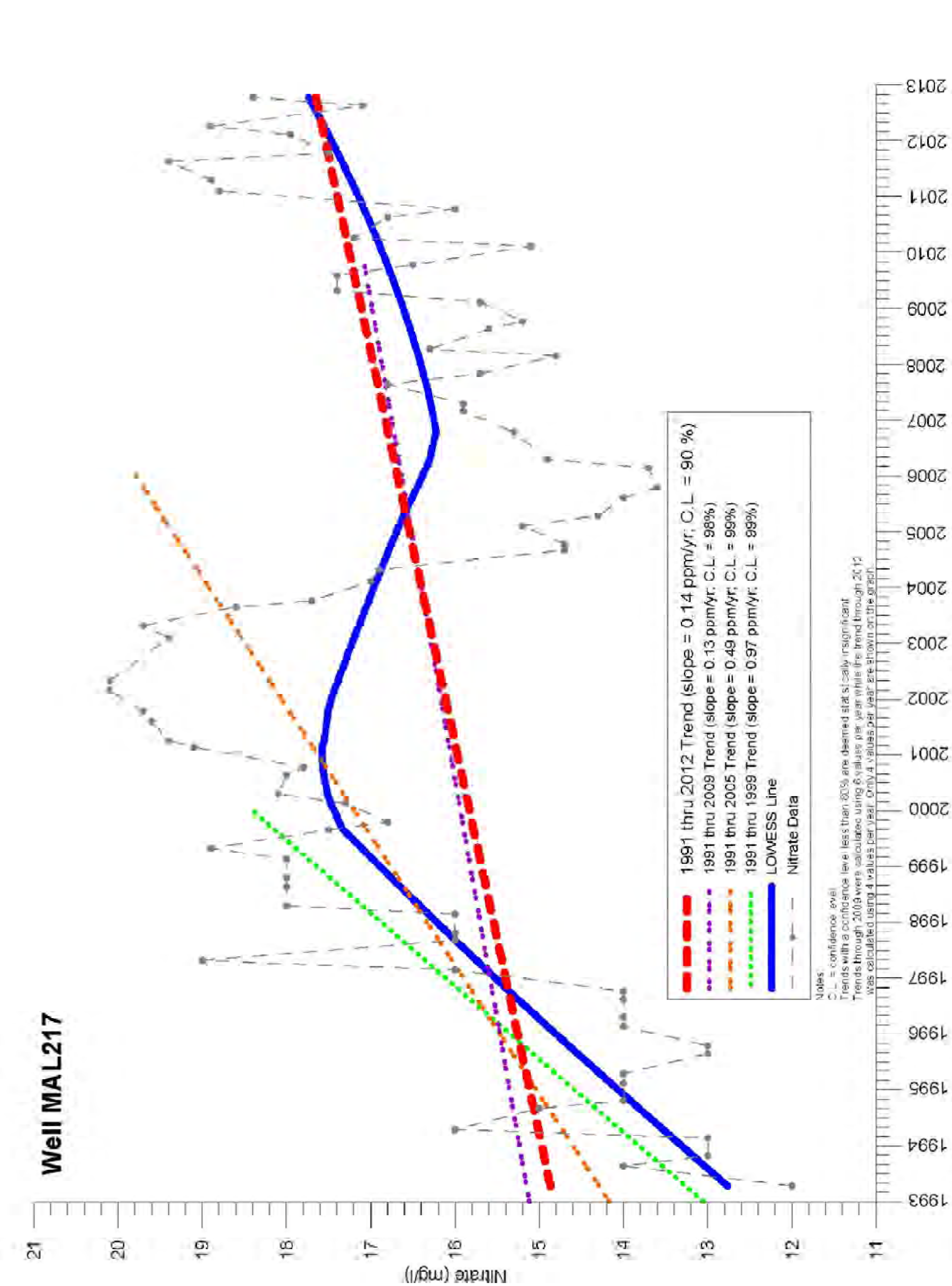
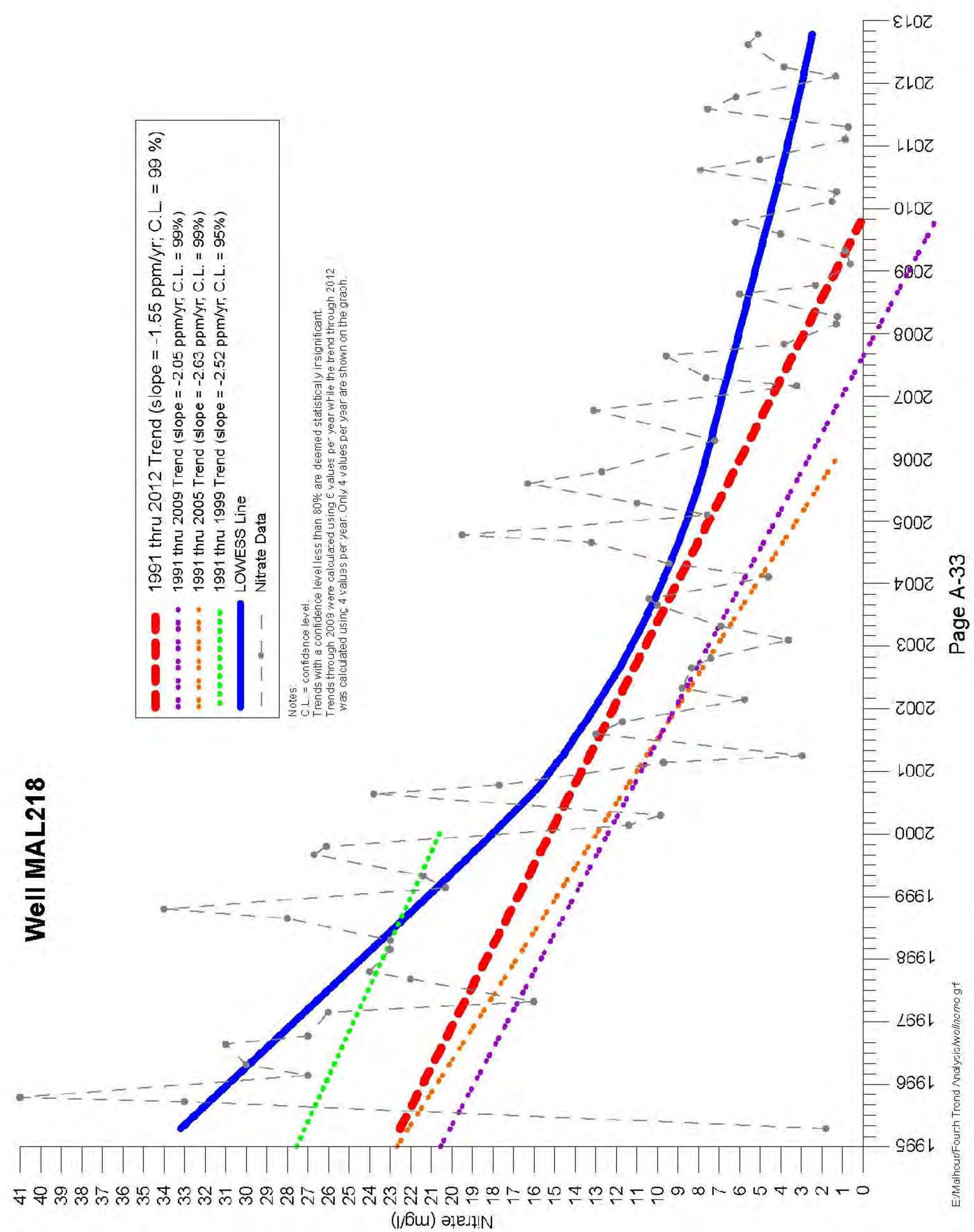
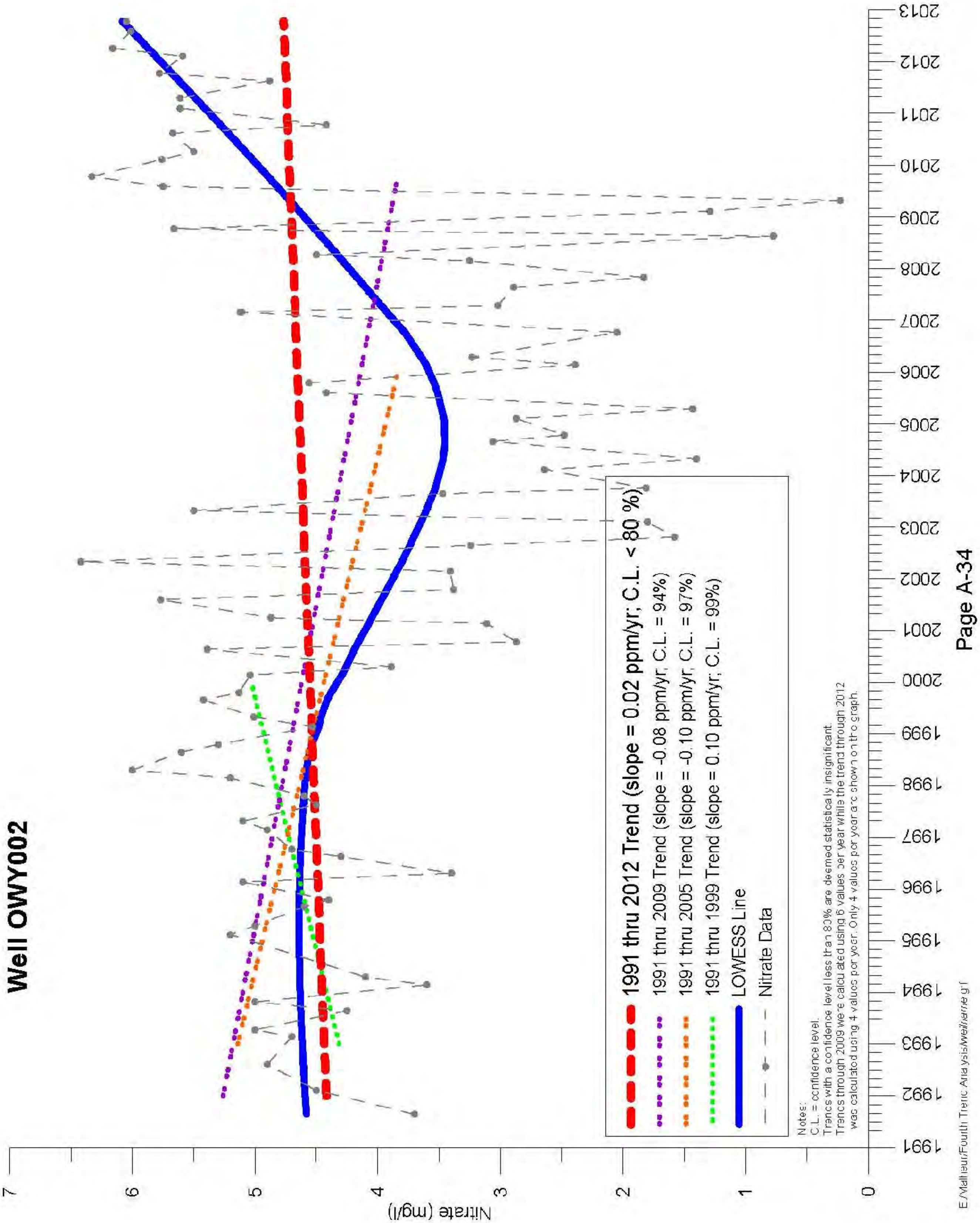

Well MAL216
1991 thru 2012 Trend (slope = -0.001 ppm/yr; C.L. = 99 %)
1991 thru 2009 Trend (slope = -0.002 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.003 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.0 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Notes
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 8 values per year while the trend through 2012 was calculated using 4 values per year. Only 4 values per year are shown on the graph.
The 1991 through 1999 trend was calculated using detected concentrations above the highest detection limit as conditioned data for concentrations below the highest detection limit. Conditioned data points plotted as 0.05 ppm are actually both detected and non-detected concentrations ranging from 0.0050 to 0.1 ppm.
The 1991 through 2005, 2009, or 2012 trends were calculated using non-conditioned data and the Helsel-Turnbull adaptation of the Theil-Sen slope estimate. Censored data are plotted at their reported detection limits. The statistical adaptation for censored data produces a slope that is the median of all possible pairwise slopes and is considered more statistically robust than conditioning the data to one-half the highest detection limit.
Nitrate (mg/l)
0.4
0.3
0.2
0.1
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Page A-31

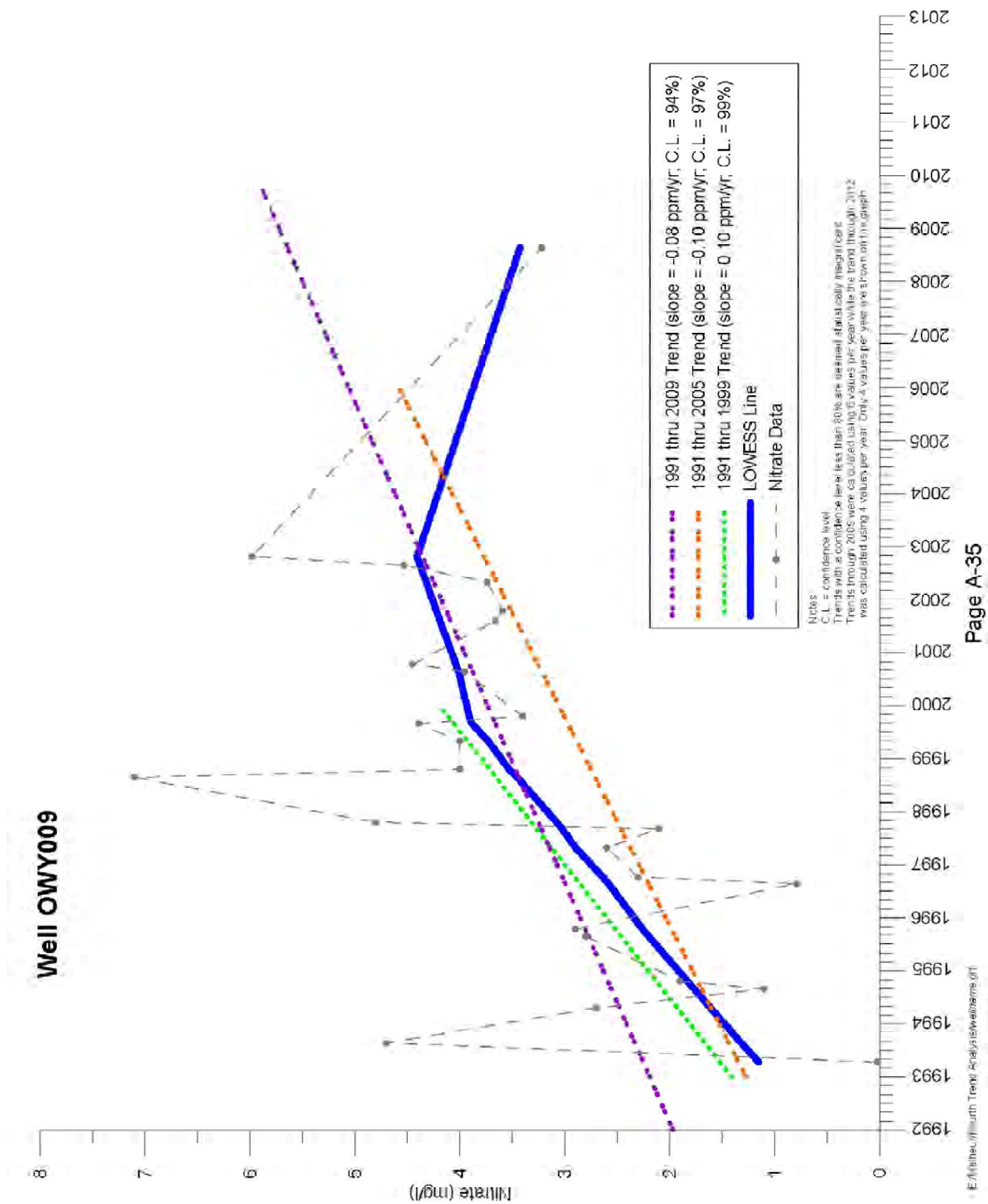

Well MAL217
Nitrate (mg/l)
21
20
19
18
17
16
15
14
13
12
11
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
1991 thru 2012 Trend (slope = 0.14 ppm/yr; C.L. = 90 %)
1991 thru 2009 Trend (slope = 0.13 ppm/yr; C.L. = 98%)
1991 thru 2005 Trend (slope = 0.49 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.97 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.

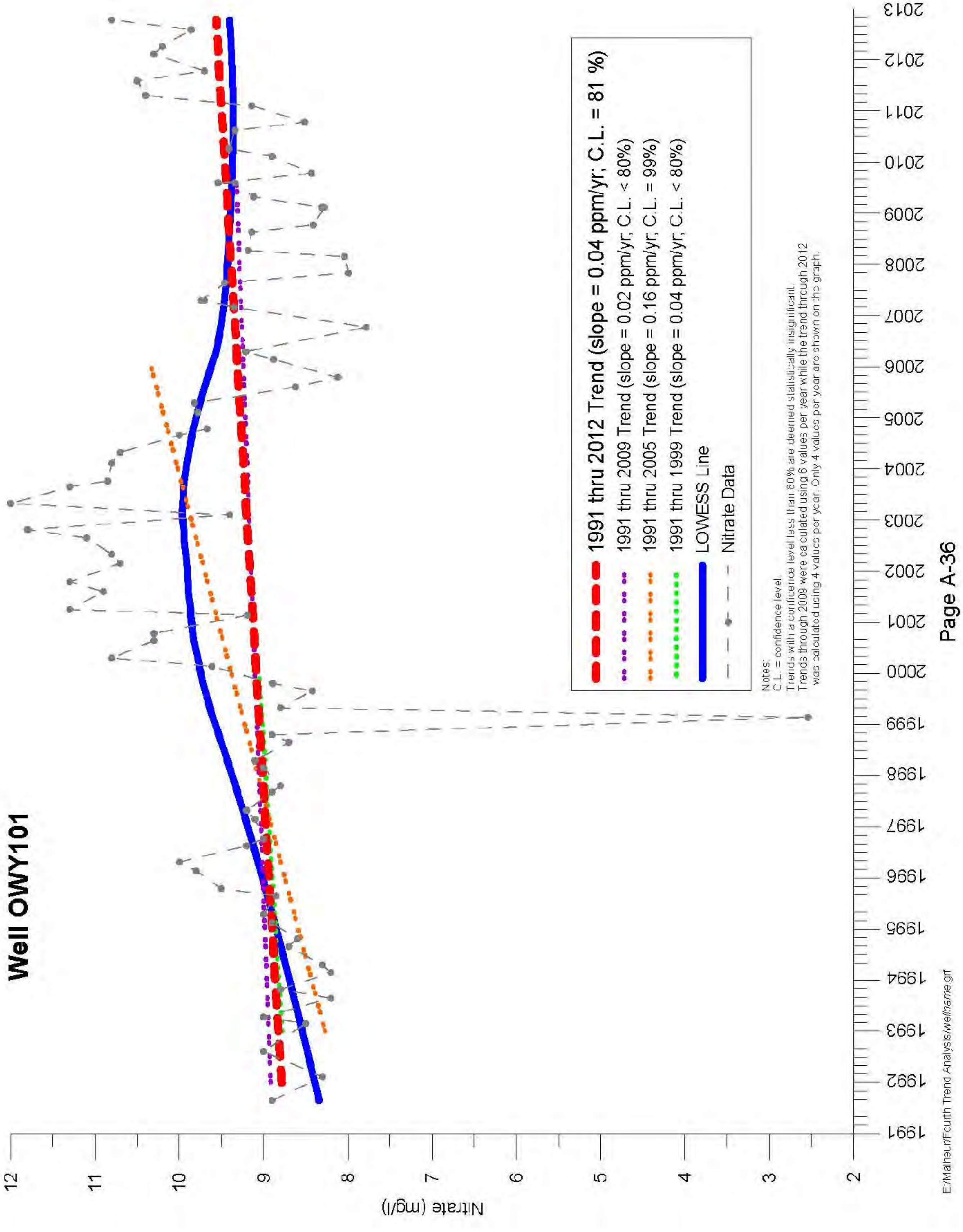
Page A-32


Well MAL218
1991 thru 2012 Trend (slope = -1.55 ppm/yr; C.L. = 99 %)
1991 thru 2009 Trend (slope = -2.05 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -2.63 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -2.52 ppm/yr; C.L. = 95%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
E:/Malheur/Fourth Trend Analysis/wellnomo.grf

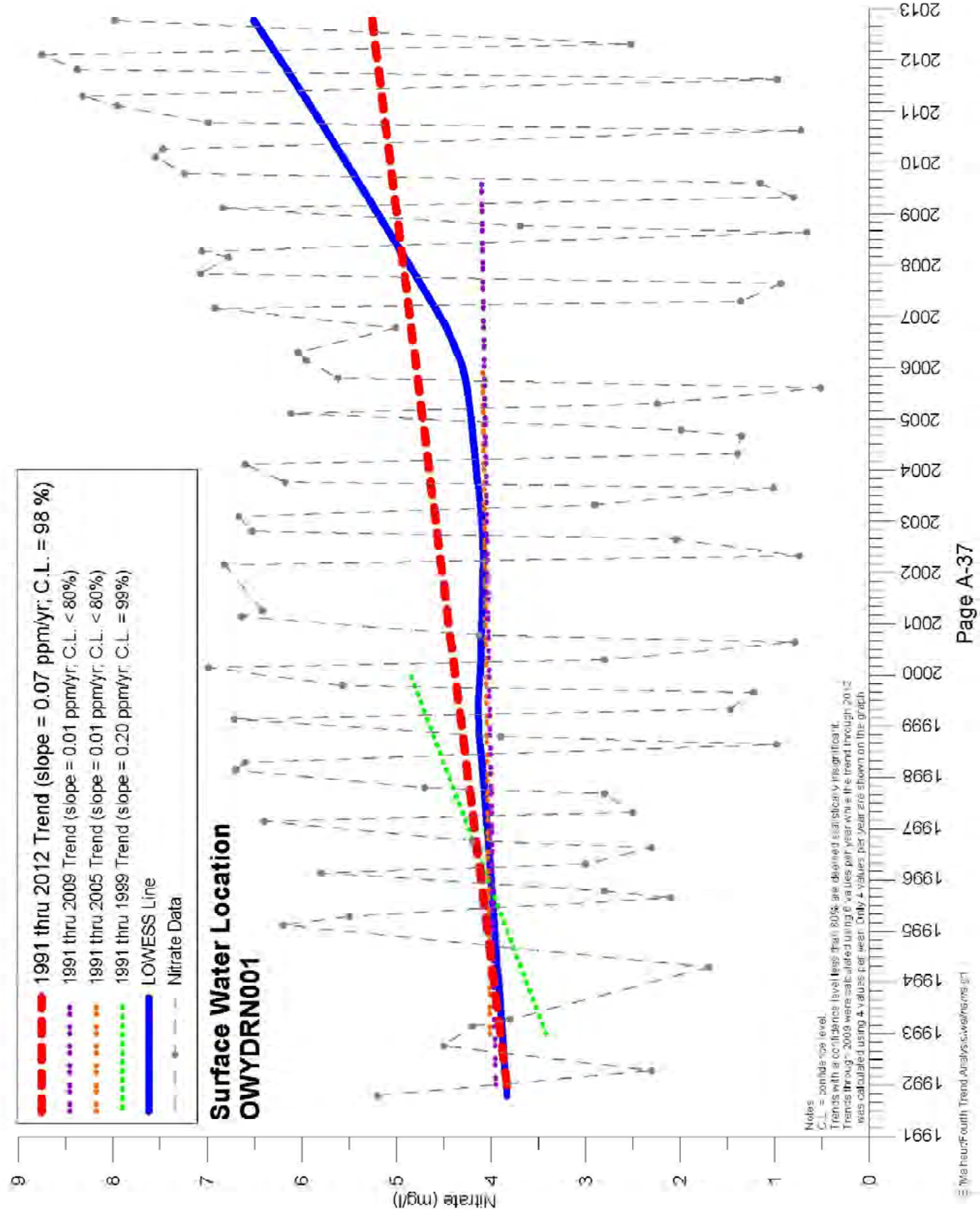
Page A-33


Well OWY002
Nitrate (mg/l)
0
1
2
3
4
5
6
7
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
1991 thru 2012 Trend (slope = 0.02 ppm/yr; C.L. < 80 %)
1991 thru 2009 Trend (slope = -0.08 ppm/yr; C.L. = 94%)
1991 thru 2005 Trend (slope = -0.10 ppm/yr; C.L. = 97%)
1991 thru 1999 Trend (slope = 0.10 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Page A-34


Well OWY009
1991 thru 2009 Trend (slope = -0.08 ppm/yr; C.L. = 94%)
1991 thru 2005 Trend (slope = -0.10 ppm/yr; C.L. = 97%)
1991 thru 1999 Trend (slope = 0.10 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Notes
C.L. = confidence level
Nitrate (mg/l)
0
1
2
3
4
5
6
7
8
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Page A-35


Well OWY101
1991 thru 2012 Trend (slope = 0.04 ppm/yr; C.L. = 81 %)
1991 thru 2009 Trend (slope = 0.02 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = 0.16 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = 0.04 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Nitrate (mg/l)
12
11
10
9
8
7
6
5
4
3
2
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
E:/Malheur/Fourth Trend Analysis/wellname.grf

Page A-36


1991 thru 2012 Trend (slope = 0.07 ppm/yr; C.L. = 98 %)
1991 thru 2009 Trend (slope = 0.01 ppm/yr; C.L. < 80%)
1991 thru 2005 Trend (slope = 0.01 ppm/yr; C.L. < 80%)
1991 thru 1989 Trend (slope = 0.20 ppm/yr; C.L. = 99%)
LOWESS Line
Nitrate Data
Surface Water Location
OWYDRN001
Nitrate (mg/l)
0
1
2
3
4
5
6
7
8
9
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Notes:
C.L. = confidence level.
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
Page A-37

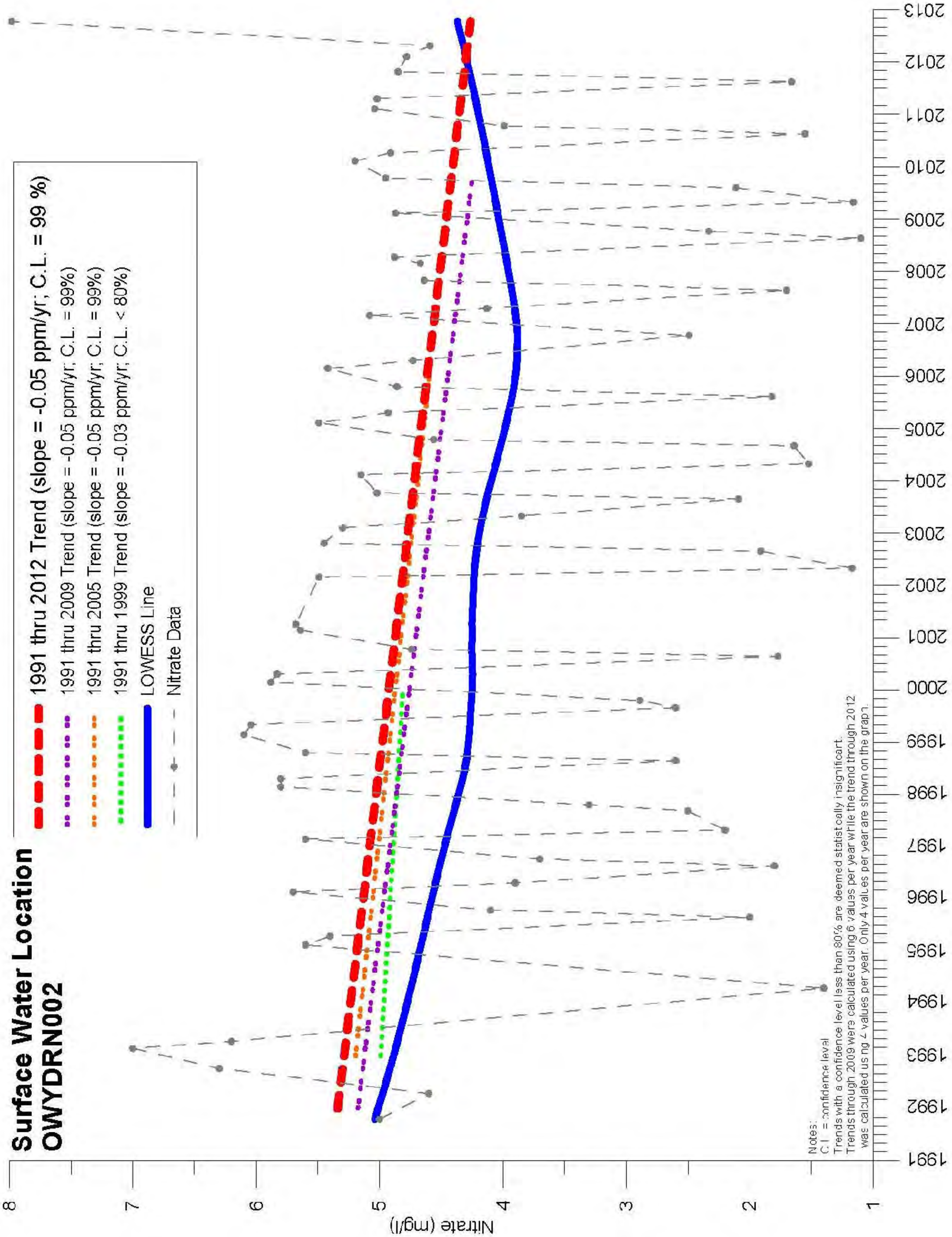

Surface Water Location
OWYDRN002
1991 thru 2012 Trend (slope = -0.05 ppm/yr; C.L. = 99 %)
1991 thru 2009 Trend (slope = -0.05 ppm/yr; C.L. = 99%)
1991 thru 2005 Trend (slope = -0.05 ppm/yr; C.L. = 99%)
1991 thru 1999 Trend (slope = -0.03 ppm/yr; C.L. < 80%)
LOWESS Line
Nitrate Data
Nitrate (mg/l)
1
2
3
4
5
6
7
8
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Notes:
C.L. = confidence level
Trends with a confidence level less than 80% are deemed statistically insignificant.
Trends through 2009 were calculated using 6 values per year while the trend through 2012
was calculated using 4 values per year. Only 4 values per year are shown on the graph.
E:/Malheur/Fourth Trend Analysis/wellname.grf

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Table A-1
Well Construction Details
Fourth Northern Malheur County GWMA Trend Analysis Report

DEQ Well ID	OWRD Well ID	Total Depth	Open Interval	Aquifer Tapped	Static Depth to Water
MAL005	MALH 626	210	81 – 210	Glenns Ferry FM	60
MAL012	MALH 1188	59	43 – 59	Sand & Gravel	27
MAL016	MALH 1606	35	20 – 35	Sand & Gravel	12
MAL030	MALH1496	65	50 – 65	Sand & Gravel	35
MAL035	?	?		Both S&G and Glenns Ferry FM	
MAL041	MALH 1703	61	55 – 61	Sand & Gravel	22
MAL044	MALH 1718	85	36 – 46; 51 – 85	Both S&G and Glenns Ferry FM	25
MAL047	MALH 1695	75	45 – 52; 56 – 75	Both S&G and Glenns Ferry FM	20
MAL062	?	?	?	Both S&G and Glenns Ferry FM	
MAL064	MALH 539	55	30 – 55	Glenns Ferry FM	15
MAL078	MALH 1936	25	23 – 25	Sand & Gravel	10
MAL079	?	?	?	Sand & Gravel	
MAL083	MALH 1731	55	27 – 55	Glenns Ferry FM	20
MAL101	MALH 1212	25	20 – 25	Sand & Gravel	10
MAL105	MALH 1195	39	39	Sand & Gravel	20
MAL106	?	?	?	Sand & Gravel	
MAL108	MALH 1927	44	25 – 40	Sand & Gravel	17
MAL116	MALH 898	38	24 – 38	Sand & Gravel	14
MAL119	MALH 1706	38	35 – 38	Sand & Gravel	12
MAL121	MALH 1213	33	31 – 33	Sand & Gravel	12
MAL125	MALH 923	35	29 – 34	Sand & Gravel	12
MAL126	?			Sand & Gravel	
MAL129	MALH 1004	30	25 – 30	Sand & Gravel	14
MAL136	MALH 1207	40	37 – 40	Sand & Gravel	12
MAL147	MALH 461	145	90 – 105; 134 – 139	Glenns Ferry FM	16
MAL152	MALH 469	32	24 – 32	Sand & Gravel	11
MAL164	?	145	?	Glenns Ferry FM	
MAL172	MALH 190	33	30 – 33	Sand & Gravel	11
MAL175	MALH 334	65	24 – 65	Glenns Ferry FM	15
MAL180	MALH 1154	25	24 – 25	Glenns Ferry FM	10
MAL189	MALH 1211	38	18 – 38	Sand & Gravel	9
MAL211	?	?	?	Sand & Gravel	
MAL216	MALH 2526	175	81 – 175	Glenns Ferry FM	27.5
MAL217	?	?	?	Sand & Gravel	
MAL218	MALH 3044	37	32 – 37	Both S&G and Glenns Ferry FM	20
OWY002	?	?	?	Sand & Gravel	
OWY009	MALH 2143	30	23 – 60	Glenns Ferry FM	9
OWY101	MALH 51463	60	?	Sand & Gravel	

Appendix B

Summary of Action Plan Amendments

State of Oregon
Department of Environmental Quality — Memorandum

To: Northern Malheur County GWMA Committee — **Date:** May 23, 2011

From: Phil Richerson – Nonpoint Source Hydrogeologist

Section: Eastern Region Water Quality Program

Subject: Northern Malheur County GWMA Action Plan Amendments

In accordance with the recommendations of the Third Northern Malheur County GWMA Nitrate Trend Analysis Report, and in response to decreases in the Department of Environmental Quality's (DEQ's) budget and expanding monitoring needs, the following amendments to the Northern Malheur County Groundwater Management Area Action Plan are made.

Amendment #1 – In accordance with the recommendations of the Third Northern Malheur County GWMA Nitrate Trend Analysis Report, the use of the Seasonal Kendall method (and the variation known as the Regional Kendall method) for the evaluation of water quality trends is allowed rather than requiring the use of the ordinary least squares method.

The Seasonal Kendall method was developed by the United States Geological Survey in the 1980s and has since become the most frequently used test for trends in the environmental sciences (Helsel, 2006). Environmental data sets often do not conform to the assumptions required by the ordinary least squared method, but can be evaluated using the Seasonal Kendall method without violating assumptions.

Amendment #2 - In accordance with the recommendations of the Third Northern Malheur County GWMA Nitrate Trend Analysis Report, the unattainable goal of an area-wide nitrate concentration of 7 mg/l by July 1, 2000 is removed from the Action Plan.

Amendment #3 – In response to decreases in DEQ's budget and expanding monitoring requirements, the sample frequency is reduced from six times per year to four times per year. Sampling will no longer be conducted during June and December. Sampling will continue during the months of February, April, August, and October.

Figure 1 illustrates the differences in area-wide nitrate trends, annual average nitrate concentrations, and annual median nitrate concentrations between the full data set (i.e., using all data collected) and a data set trimmed of all June and December data.

Figure 1 illustrates the trends, annual averages, and annual medians are very similar between the full data set and the trimmed data set. This similarity suggests there will be no significant reduction in the ability to detect area-wide trends using four sampling event per year versus six sampling events per year.

Bibliography

Helsel, D. a. (2006). Regional Kendall Test for Trend. *Environmental Science & Technology*, *40* (13), 4066-4073.

Page **1** of **2**

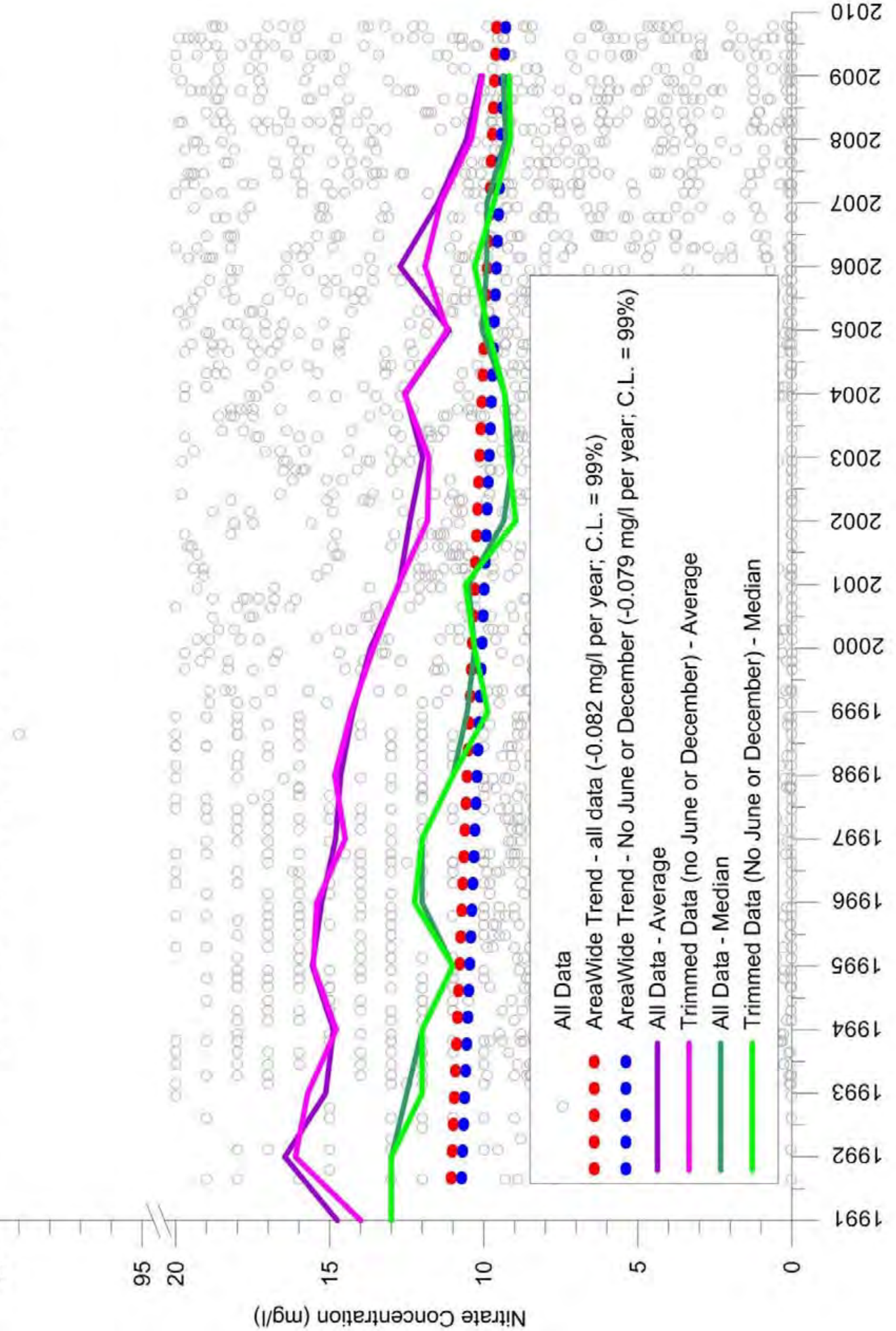

Figure 1
Comparison of Trends and Summary Statistics Between Full Data Set and Trimmed Data Set
Northern Malheur County Groundwater Management Area

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Appendix C

Evaluation of Nitrate Concentrations and Trends versus Groundwater Levels, Water Delivered to Irrigators, and Precipitation

Introduction

Comments received during preparation of the fourth Northern Malheur County GWMA trend analysis report prompted an evaluation of nitrate concentrations and trends versus groundwater levels, water delivered to irrigators, and precipitation. Results of that investigation are described below.

Groundwater Level Trends

In order to investigate a potential relationship between groundwater nitrate concentrations and groundwater levels, a trend analysis was performed on water levels from 11 wells within the GWMA at which the Oregon Water Resources Department regularly measures water levels[4]. For the purpose of this discussion, the wells regularly sampled for nitrate are called the GWMA wells while the wells regularly monitored for water levels are called the OWRD wells. Results of the trend analysis are summarized in Table C-1, illustrated in the graphs at the end of this Appendix, and described below. It should be noted that the lines on the graphs drawn through the data are LOWESS lines rather than monotonic trend lines. LOWESS lines provide an estimation of the overall changes within a data set as opposed to the best fitting linear trend line.

As indicated in Table C-1, the OWRD wells ranged in depth from 73 to 1,236 feet deep with average water level depths of 6.5 to 37 feet. The GWMA wells range from 25 to 210 feet deep with 75% of them being less than 65 feet deep. Even though static water levels in the OWRD wells are likely similar to water levels within the GWMA wells (which are not routinely measured), water levels and trends observed in the deeper wells may not be representative of shallower water levels and trends.

Water Level Seasonality

The water level data sets were evaluated for the presence of seasonality. For this evaluation, a data set was declared to show seasonality if the Kruskal-Wallis test identified a statistically significant difference between the median water level in one quarter versus other quarters at a 90% confidence level. Seasonality in water levels could be caused by natural fluctuations in aquifer recharge and/or fluctuations in groundwater pumping. Table C-1 indicates that nine of the eleven wells exhibited seasonality. In the data sets that showed seasonality, water levels were generally highest in the third quarter (6 of 9 wells) and lowest in the first half of the year (4 wells are lowest in the first quarter and 3 wells are lowest in the second quarter).

The fact that most wells exhibited high water levels during the third quarter when water diversion and delivery is at its peak suggests the aquifer is receiving significant recharge from diverted surface water. This observsation is consistent with the Oregon Water Resources Department's hydrogeologic characterization of the area (Ground Water Report #34, Hydrogeology of the Ontario Area, Malheur County, Oregon) prepared by Marshall Gannett which states, in part, "the shallow aquifer is recharged by infiltration of local precipitation, snow melt, leakage of irrigation canals and ditches, and by deep percolation of irrigation water. Conveyance and application of irrigation water is the biggest source of recharge".

Overall Water Level Trends

The period of record for water levels is not the same for all eleven OWRD wells. Most periods of record begin in the 1960s although one well has no measurements before 1997. Ten of the OWRD wells have data since 1990 (i.e., the timeframe in which the GWMA wells were sampled). Trends calculated using the entire period of record (i.e., the overall trend) included six increasing trends, three decreasing trends, and two statistically insignificant trends (Table C-1). The magnitude of the trends is on the order of tenths or hundredths of feet per year. The steepest increasing trend was 0.12 ft/yr (at well MALH1678; the deepest well analyzed) while the steepest decreasing trend was 0.24 ft/yr (at well MALH220; a medium-depth well).

Trends Since 1990

Trends calculated using only measurements since 1990 were, with two exceptions, in the same direction but with steeper slopes (Table C-1). The two exceptions (wells MALH1062 and MALH252) showed the trend since 1990 was in the opposite direction, and steeper, than the overall trend.

[4] Because the wells sampled for nitrate are plumbed into existing water delivery systems, measuring water levels in those wells is not easily done and is not done during routine sampling.

As shown in Table C-1, there does not appear to be a strong relationship between water level trend and total well depth. For instance, increasing trends were observed at the shallowest wells and the deepest wells with decreasing trends observed at wells about 250 feet deep.

Figure C-1 shows the locations of the 10 wells with measurements since 1990 along with the calculated trend and the wells total depth. As indicated in Figure C-1, there does not appear to be a relationship between water level trend and geographic location. The decreasing trends (including the three statistically insignificant trends with negative slopes) are at wells close to wells showing increasing trends.

In conclusion, groundwater levels at most of the OWRD wells are increasing over time, show seasonality with water levels highest in the third quarter; and water level trends do not appear to be related to total well depth or geographic location.

Nitrate Concentrations and Trends versus Water Delivered to Irrigators

In order to investigate a potential relationship between groundwater nitrate concentrations and the amount of water delivered to irrigators, water delivery information provided by the Owyhee Irrigation District was compared to nitrate concentrations and trends. Information provided by the OID included total volume released from the dam from 1991 through 2013 (except 1996) and the total allotment given to each grower from 1997 through 2014.

Nitrate Concentrations versus Water Delivered to Irrigators

Figure C-2 plots the information provided by OID versus the nitrate concentrations measured at the GWMA wells currently being sampled. In Figure C-2, individual nitrate concentrations are shown as small circles. Because many of the highest individual nitrate concentrations are from a single well (i.e., MAL126), all concentrations from well MAL126 are indicated with a small red plus sign. The Third Northern Malheur County GWMA Nitrate Trend Analysis Report concluded that historical storage and handling of bulk fertilizers at the Simplot Soil Builders site in Vale contributed to the elevated nitrate concentrations at nearby well MAL126.

The volume of water released during each year is superimposed on the nitrate data as vertical bars. The annual allotment is indicated beneath each bar. The three years in which less than the total allotment was provided are shaded darker than other years.

Figure C-2 illustrates that most years (19 of 22) had less than 600,000 acre-ft released from the Owyhee dam. Only 25% of years had less than 425,000 acre-ft released from the dam. The three years with the largest volume released from the dam include 1993 (791,579 acre-ft), 2006 (1,359,074 acre-ft), and 2011 (927,448). The average volume released from the dam is 543,864 acre-ft while the median is slightly smaller (521,833 acre-ft). Figure C-2 also illustrates that the full allotment was given to growers in all years reported except 2003, 2005, and 2013.

It is interesting to note that nitrate concentrations in general, and at well MAL126 specifically, began to decrease before the very wet year in 2006. The dry years of 2003 and 2005 as well as the very wet year of 2006 do not appear to affect individual nitrate concentrations at the GWMA wells. In other words, the volume of water released from the Owyhee dam does not appear to influence groundwater nitrate concentrations in the GWMA wells.

Nitrate Trends versus Water Delivered to Irrigators

Figure C-3 plots the information provided by OID versus the area-wide nitrate trends calculated using the GWMA wells. Figure C-3 includes the area-wide trends calculated with two slightly different data sets[5]. The two estimates of the area-wide trend are very similar in the years that they overlap. The area-wide trend was flat for the first decade or so (i.e., 1991 through 2001). The area-wide trend started decreasing in 2002 and got steeper each year through 2009 (Figure C-3). The last three years in which the area-wide trend was calculated remain decreasing (i.e., a negative slope) but were less steeply decreasing.

[5] One data set includes all 38 GWMA wells and six values per year while the second data set includes only the 36 currently sampled wells and only four values per year.

As with Figure C-2, the volume of water released during each year is superimposed on the area-wide nitrate trend as vertical bars. The annual allotment is indicated above each bar. The three years in which less than the total allotment was provided are shaded darker than other years. Figure C-3 illustrates that the two dry years (2003 and 2005) and the very wet year (2006) appear to have no influence on the area-wide nitrate trend. The steepening of the area-wide decreasing trend stopped in 2009, which both follows and preceeds three “normal” water delivery years.

In conclusion, nitrate concentrations and trends observed at the GWMA wells do not appear to be influenced by the volume of water released from the Owyhee Dam or the volume of water delivered to irrigators.

Nitrate Trends versus Precipitation

Figure C-4 shows the annual precipitation at six sites within the GWMA from 1987 through 2013. The annual precipitation at these six sites ranged from 1.06 inches (at Ontario KSRV in 2013) to 16.27 inches at Ontario KSRV in 2005). The average annual precipitation at these six sites over this time frame ranged 8.63 inches at Vale to 9.97 inches at the Malheur Experiment Station (MES). The average annual precipitation at all six sites is 9.01 inches.

As previously indicated, the typical irrigation water allotment provided by OID is 4 acre-feet per acre with equals 48 inches of precipitation. The amount of water applied as irrigation far exceeds the amount of water supplied by precipitation.

Figure C-5 shows the nitrate concentrations from the GWMA wells as small circles with the data from well MAL216 highlighted as plus signs. The average annual precipitation at the six sites within the GWMA is superimposed on the nitrate plot as a bar plot. Horizontal lines on the graph indicate the 27-year average precipitation at the six sites, at the site with the lowest annual precipitation (Owyhee Dam), and at the site with the highest annual precipitation (Malheur Experiment Station).

Figure C-5 shows that, in general, the mid- to late-1990s were close to or above average precipitation years, as well as the periods from 2003 through 2006 and from 2009 through 2011. In general, the late 1980s through early 1990s were below average as was the period from 2001 through 2004 and from 2007 to 2008. More specifically, the years 1993, 1995, 1996, 1998, 2005, and 2010 were the wettest of the 27 years while 1990, 2002, 2007, 2008, and 2013 were the driest of the 27 years (Figure C-5).

Figure C-5 indicates the nitrate data set as a whole does not respond to variations in annual precipitation. For example, there are many nitrate data points in the 20 to 45 mg/l range during the relatively wet period of the 1993 through 1998, but not during the relatively wet period of 2004 through 2006 or during the wet year of 2010. In contrast, the nitrate concentrations generally decline regardless of the average annual precipitation. This lack of correlation suggests annual precipitation is not a dominant factor in groundwater nitrate concentrations. The lack of correlation is likely due to the fact that the volume of irrigation water applied is several times greater than the volume of precipitation.

As with the entire data set, the nitrate concentrations at well MAL216 do not appear to respond to annual precipitation variations. For example, well MAL216 exhibited its highest concentrations during the relatively wet period of 1993 through 1996 but also during the relatively dry years of 2002 and 2003. Similarly, the well showed higher nitrate concentrations during the relatively wet years of 2004 through 2006 than during the relatively dry years of 2007 and 2008. While nitrate concentrations at well MAL216 do not appear to be related to annual precipitation, it is possible that nitrate concentrations at other wells could respond to variations in precipitation.

Figure C-1
Water Level Trends at OWRD Wells
Fourth Northern Malheur County GWMA Nitrate Trend Analysis Report

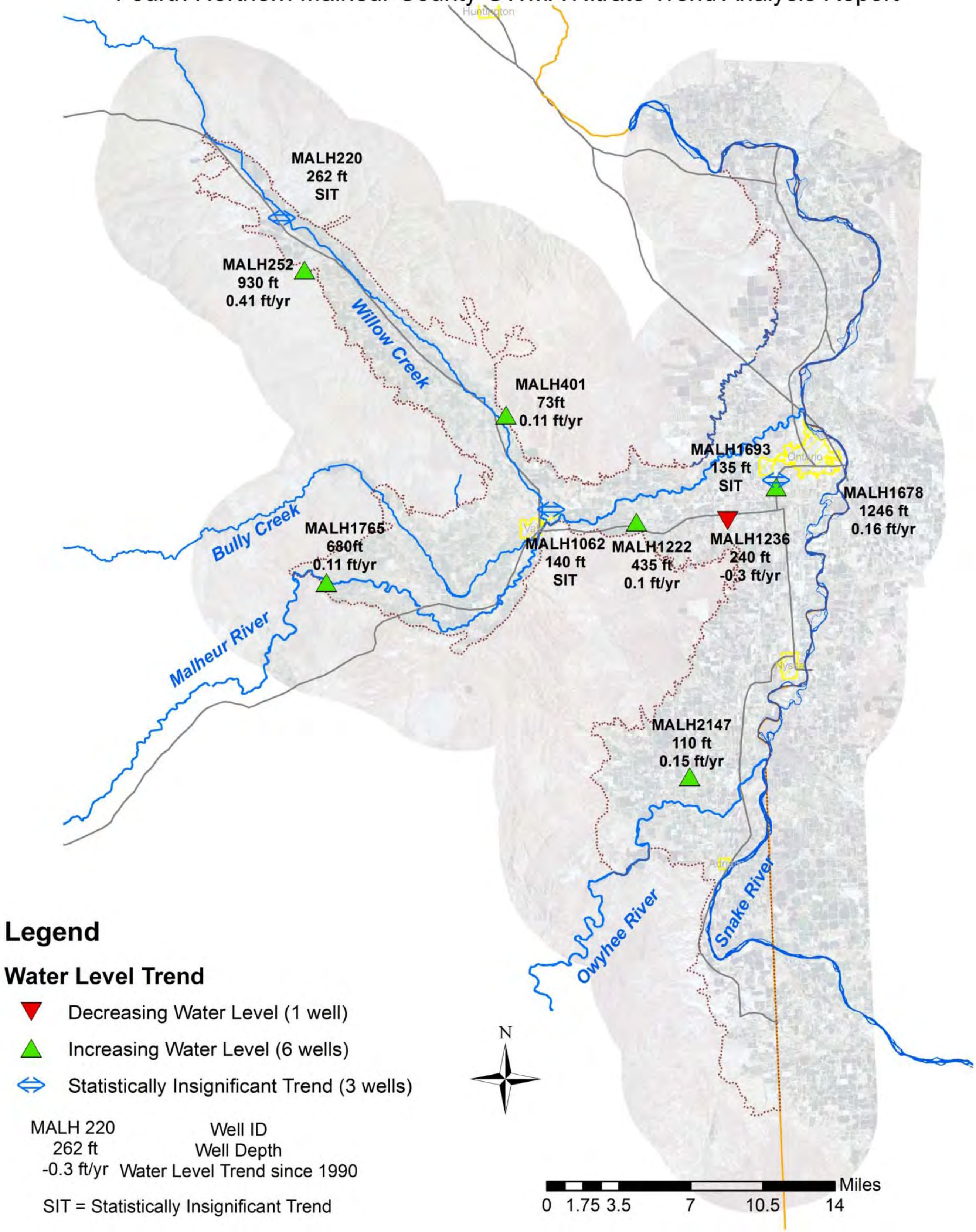


Figure C-2
Nitrate Concentrations Versus Water Released from Owyhee Dam
Fourth Northern Malheur County GWMA Nitrate Trend Analysis Report

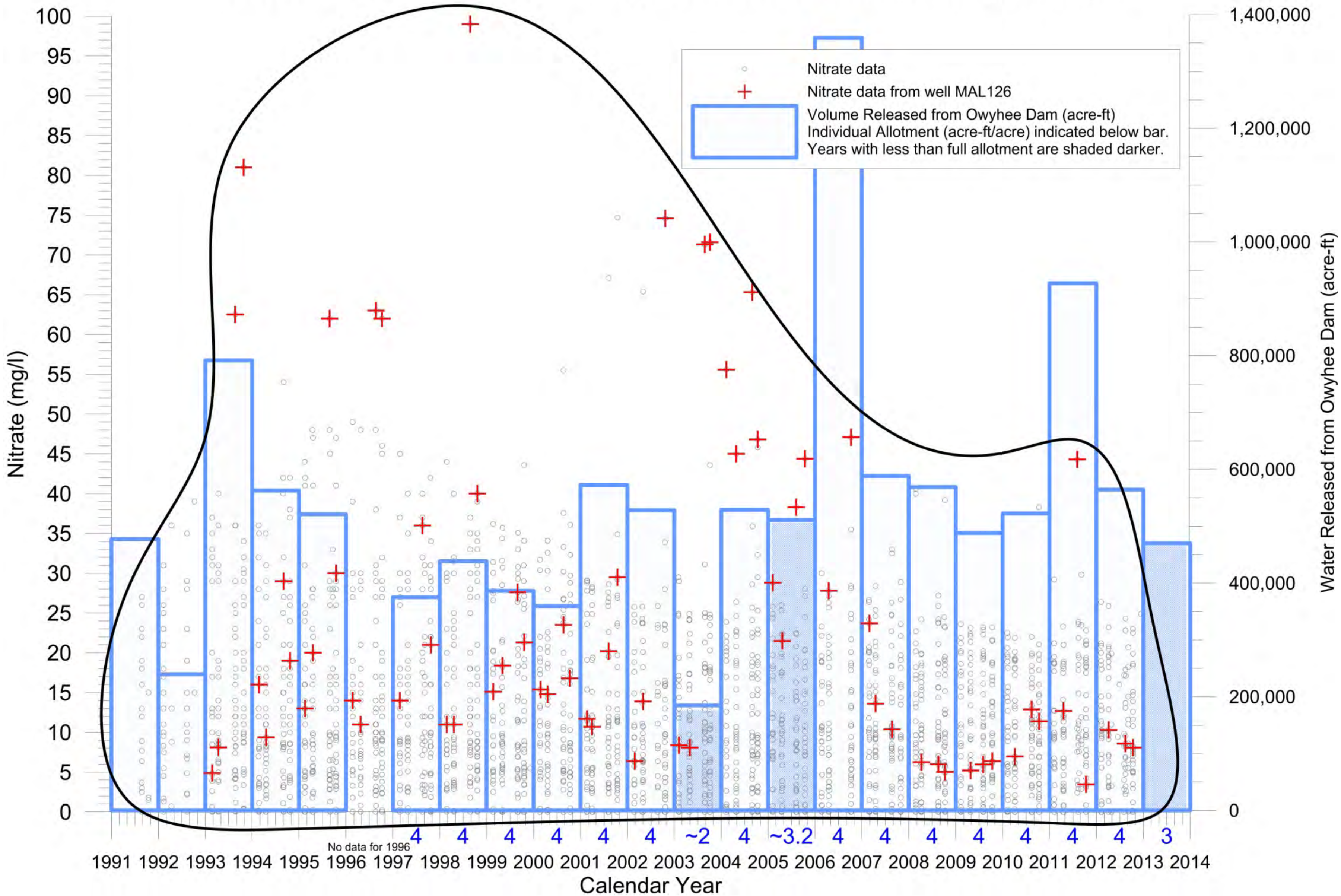
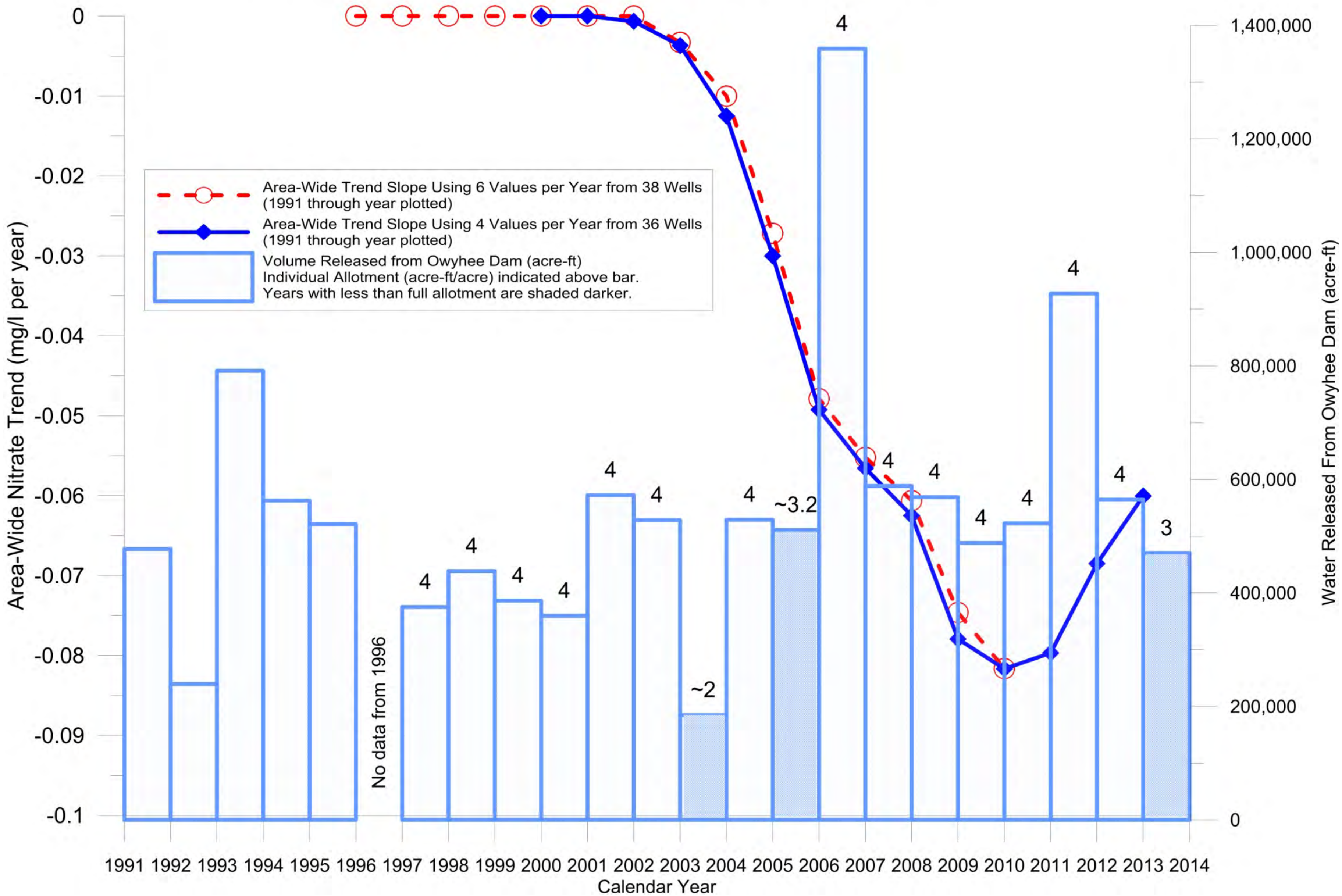


Figure C-3
Annual Area-Wide Nitrate Trend versus Water Released From Owyhee Dam
Fourth Northern Malheur County GWMA Nitrate Trend Analysis Report



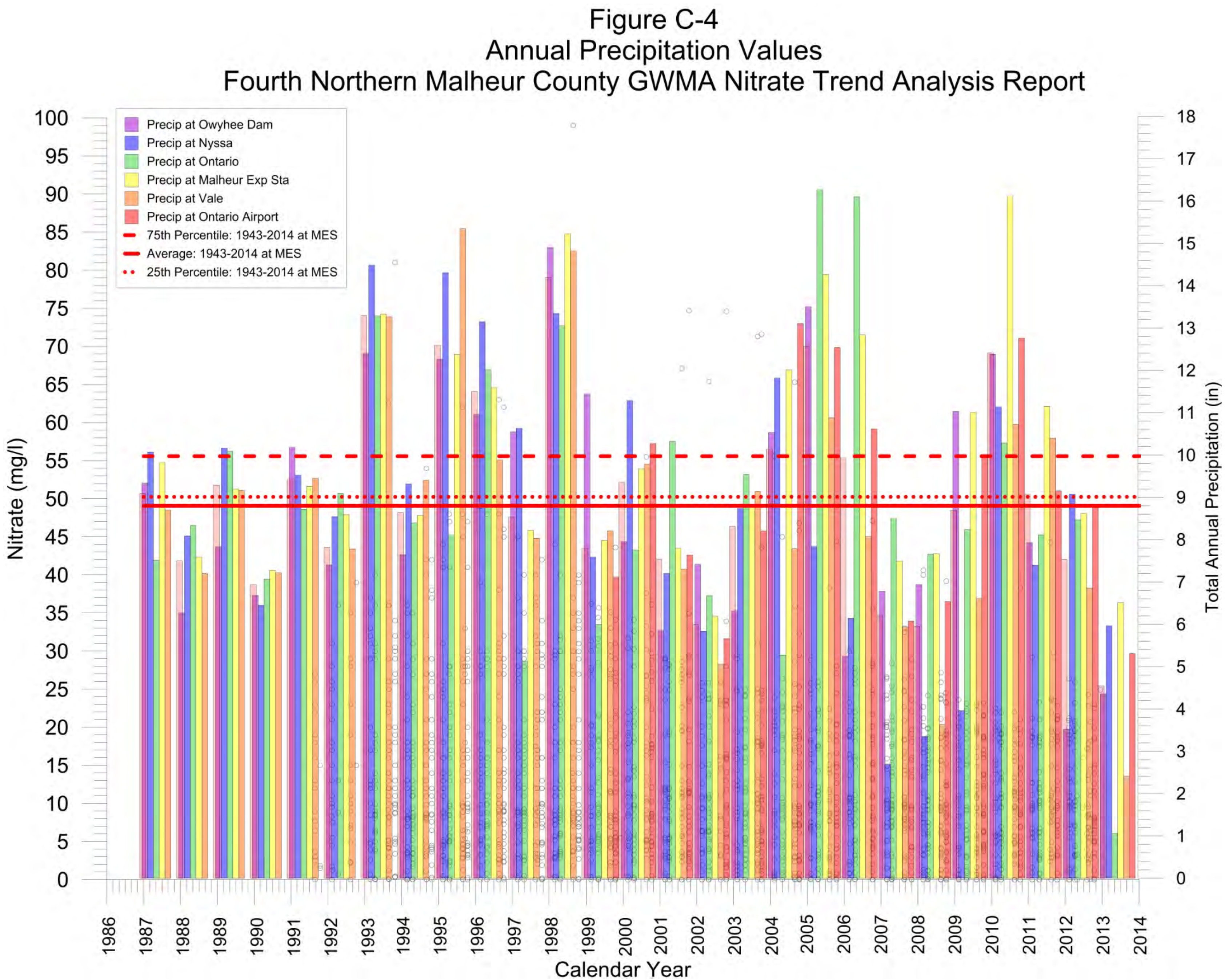


Figure C-4
Annual Precipitation Values
Fourth Northern Malheur County GWMA Nitrate Trend Analysis Report
Precip at Owyhee Dam
Precip at Nyssa
Precip at Ontario
Precip at Malheur Exp Sta
Precip at Vale
Precip at Ontario Airport
75th Percentile: 1943-2014 at MES
Average: 1943-2014 at MES
25th Percentile: 1943-2014 at MES
Nitrate (mg/l)
Total Annual Precipitation (in)
Calendar Year
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
1986
1987
1988
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1990
1991
1992
1993
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2010
2011
2012
2013
2014

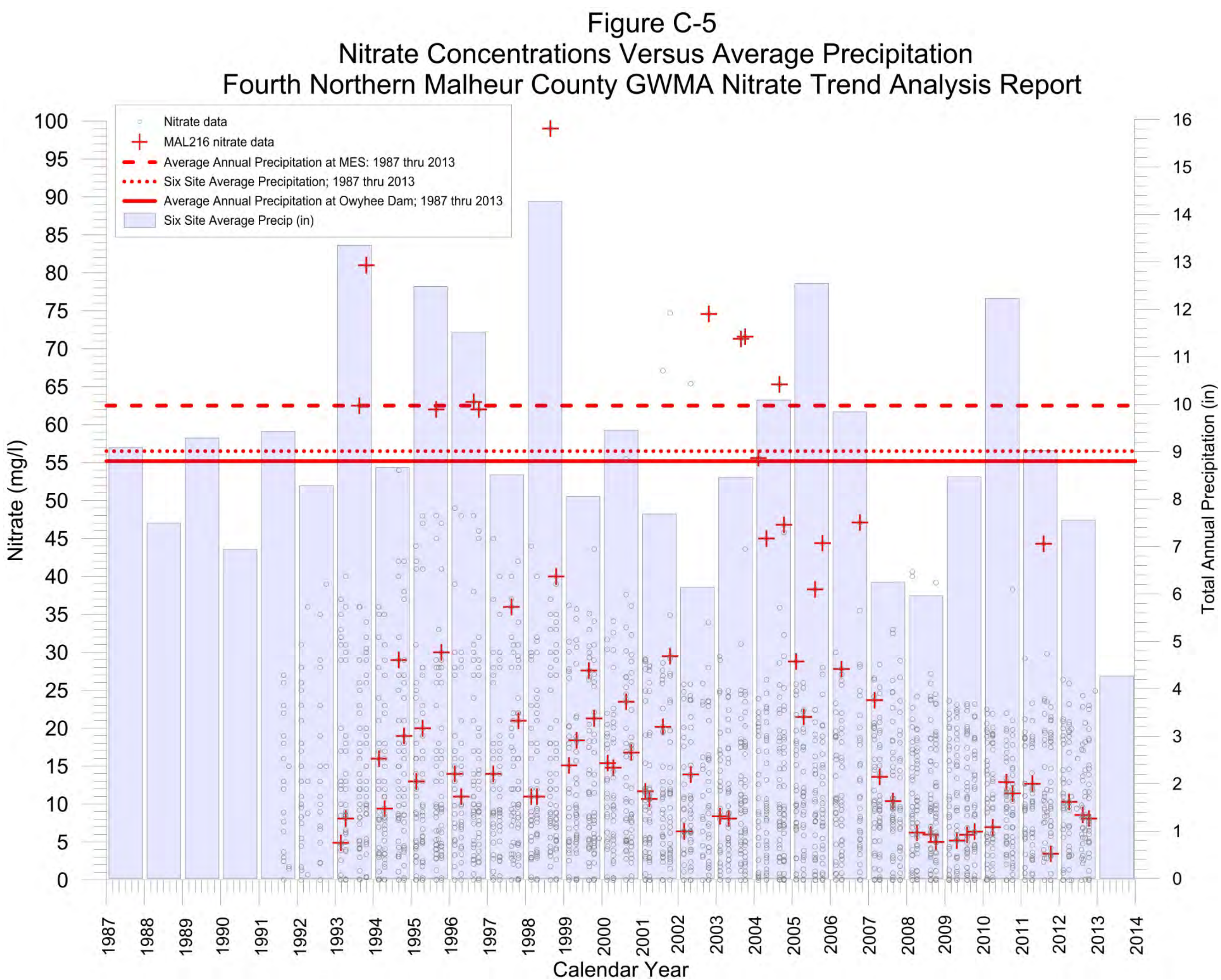


Figure C-5
Nitrate Concentrations Versus Average Precipitation
Fourth Northern Malheur County GWMA Nitrate Trend Analysis Report
Nitrate data
MAL216 nitrate data
Average Annual Precipitation at MES: 1987 thru 2013
Six Site Average Precipitation; 1987 thru 2013
Average Annual Precipitation at Owyhee Dam; 1987 thru 2013
Six Site Average Precip (in)
Nitrate (mg/l)
Total Annual Precipitation (in)
Calendar Year

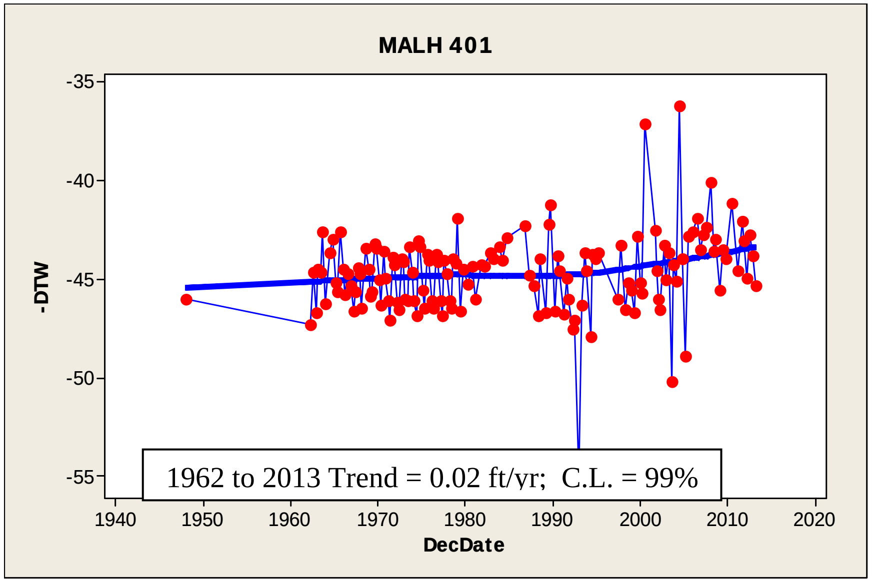
Table C-1
Summary of Water Level Data at OWRD's Wells in NMC GWMA
Fourth Northern Malheur County Groundwater Management Area Nitrate Trend Analysis Report

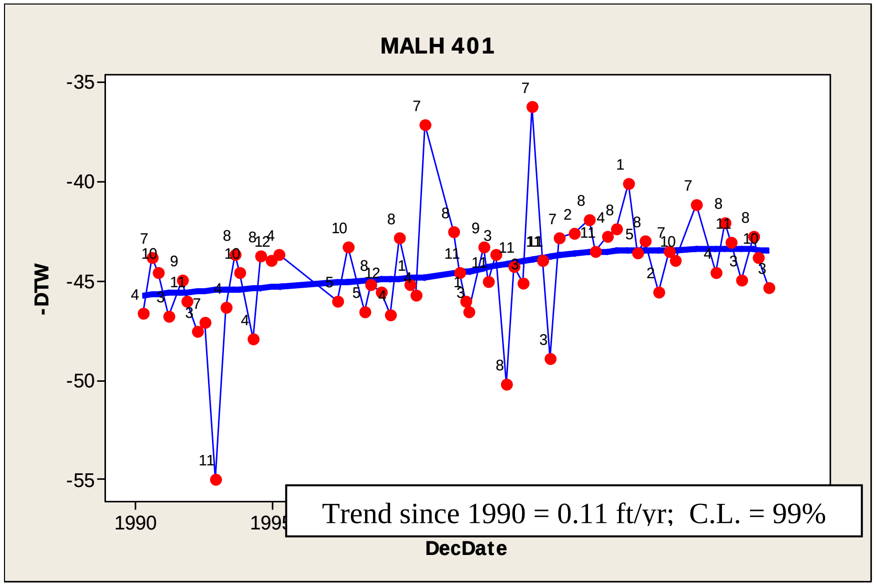
							Overall Trend			Trend Since 1990		
Well ID	Total Depth	Avg Depth to Water	Period of Record	Seasonality?	Seasonal High	Seasonal Low	slope (ft/yr)	Conf Level	Trend	slope (ft/yr)	Conf Level	Trend
MALH 401	73	45	1962 - 2013	Yes	Q3	Q2	0.02	99%	Increasing	0.11	99%	Increasing
MALH 689	86	37	1962 - 1987	Yes	Q3	Q1	0.10	99%	Increasing	na	na	na
MALH 2147	110	10.8	1962 - 2013	Yes	Q3	Q2	0.06	99%	Increasing	0.15	99%	Increasing
MALH 1693	135	10.4	1950 - 1993	Yes	Q3	Q2	-0.004	34%	SIT	-0.46	61%	SIT
MALH 1062	140	8.1	1962 - 2013	Yes	Q3	Q1	0.002	22%	SIT	-0.03	60%	SIT
MALH 1236	240	18	1962 - 2012	Yes	Q4	Q1	-0.12	99%	Decreasing	-0.30	99%	Decreasing
MALH 220	262	15.3	1965 - 2000	Yes	Q1	Q3	-0.24	99%	Decreasing	-0.30	35%	SIT
MALH 1222	435	10.6	1962 - 2013	Yes	Q3	Q1	0.08	99%	Increasing	0.10	99%	Increasing
MALH 1765	680	6.5	1961 - 2013	No			0.03	99%	Increasing	0.11	99%	Increasing
MALH 252	930	27.6	1962 - 2012	Yes	Q2	Q4	-0.07	96%	Decreasing	0.41	99%	Increasing
MALH 1678	1246	11.6	1997 - 2013	No			0.12	96%	Increasing	0.16	80%	Increasing

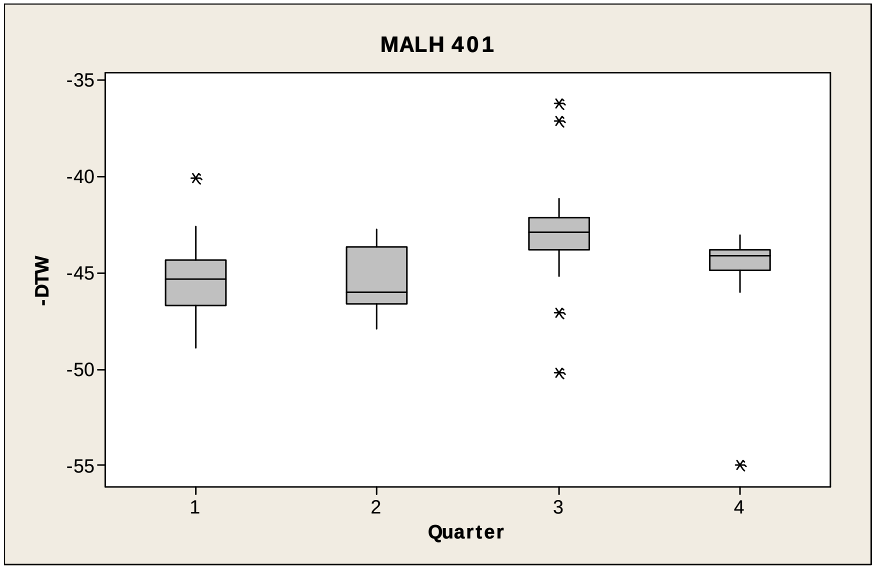
Note:
A well was declared to exhibit seasonality if the Kruskal-Wallis test identified a statistically significant difference between the median water level in one quarter versus other quarters at a 90% confidence level.

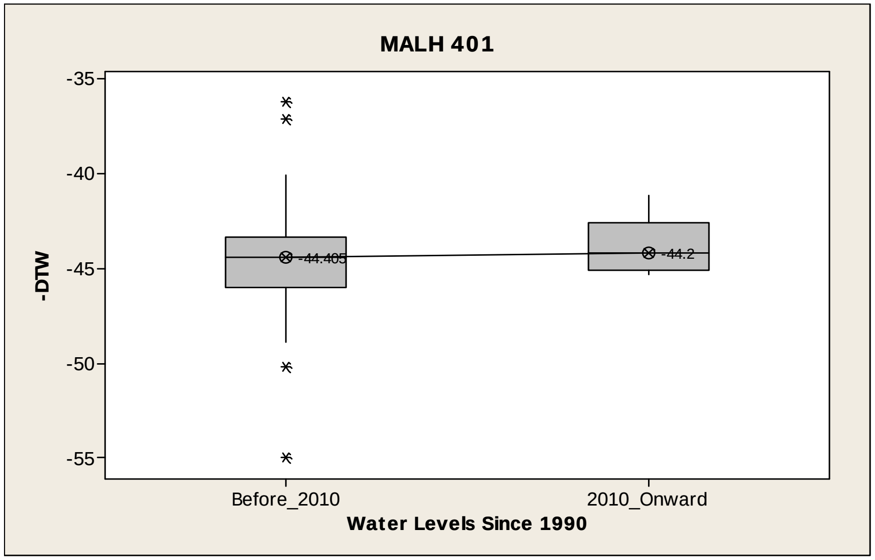
# increasing trends =	6
# decreasing trends =	2
# statistically insignificant trends =	2

8 Statistically Significant Trends	average slope =	0.06
	median slope =	0.11
	max slope =	0.41

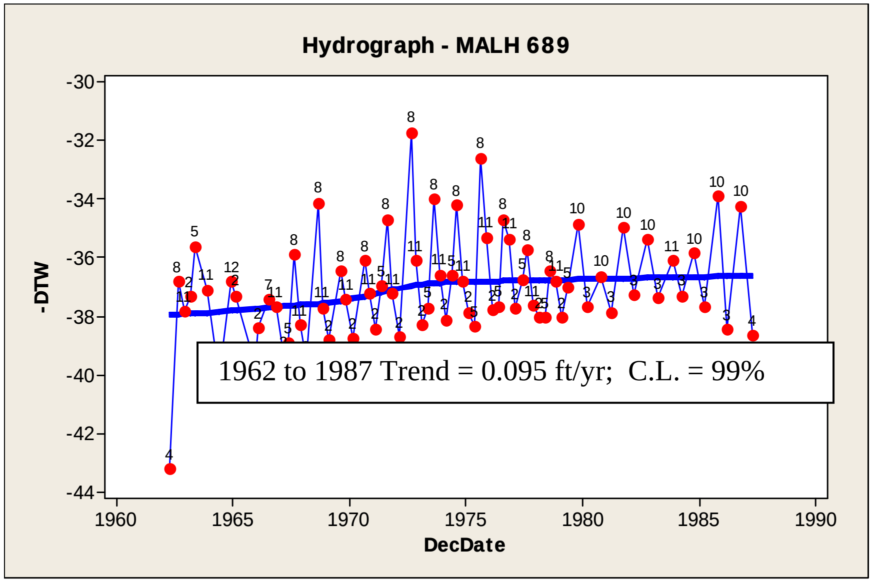


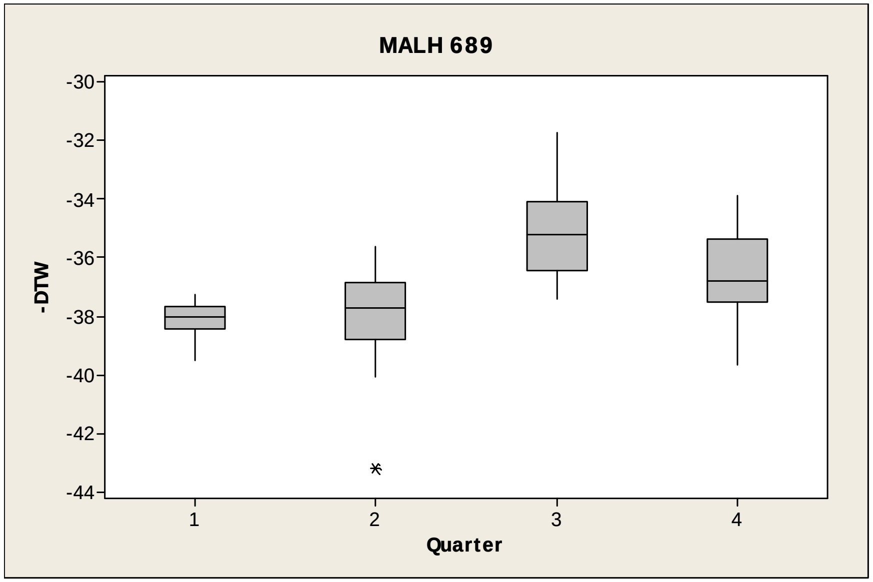




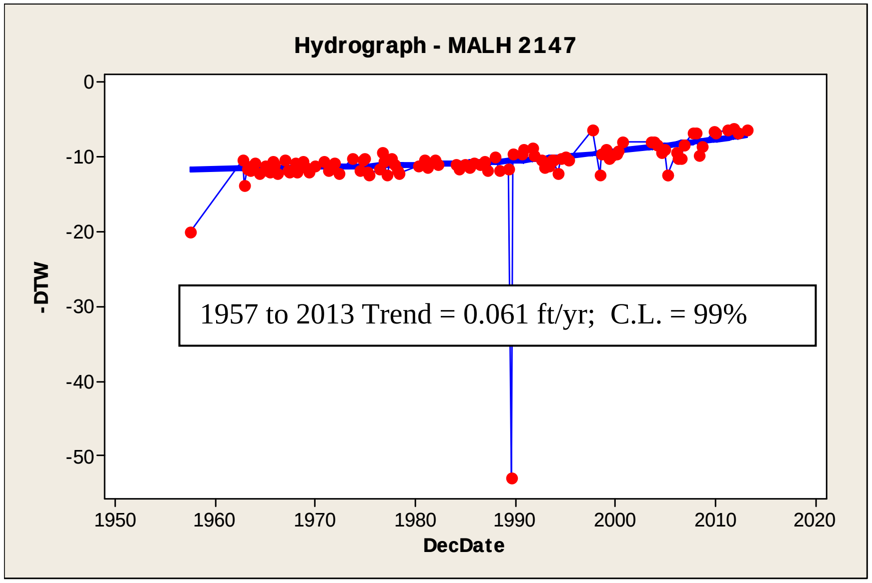


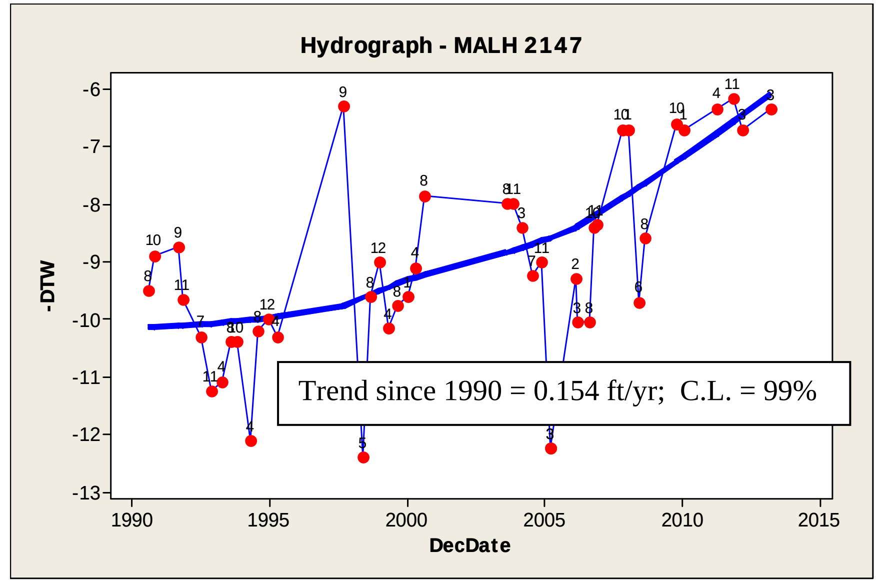
MALH 401 Period of Record = 1962 - 2013
Total Depth = 73 ft
Average depth to water = 45 ft
Shows a very slight statistically significant increasing water level trend since 1962, and a steeper increasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the second quarter and highest in the third quarter.
Shows a slight but not statistically significant difference between water levels between 1990 to 2009 and from 2010 to 2013.

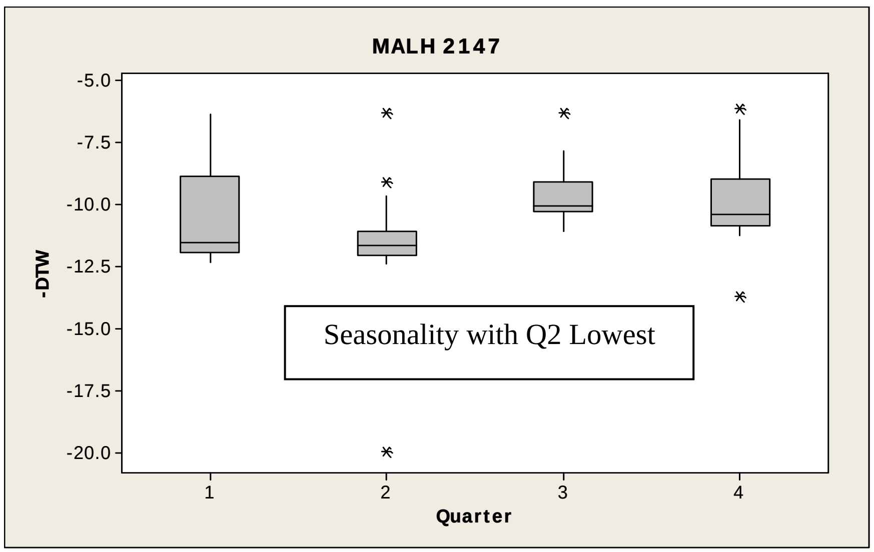


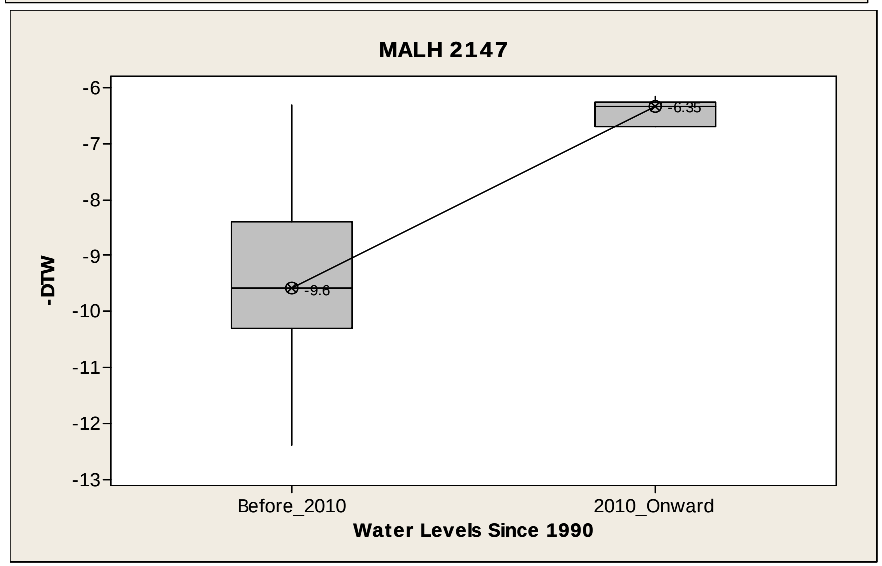


MALH 689 Period of Record = 1962 - 1987
Total Depth = 86 ft
Average depth to water = 37 ft
Shows a statistically significant increasing water level trend from 1962 through 1987. No measurements after 1987.
Shows statistically significant seasonality with water levels highest in the third quarter.

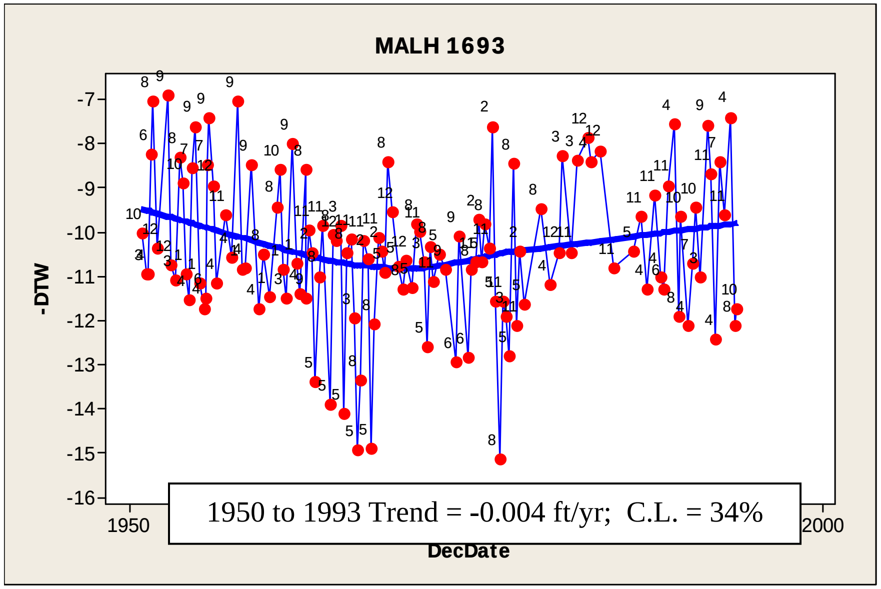


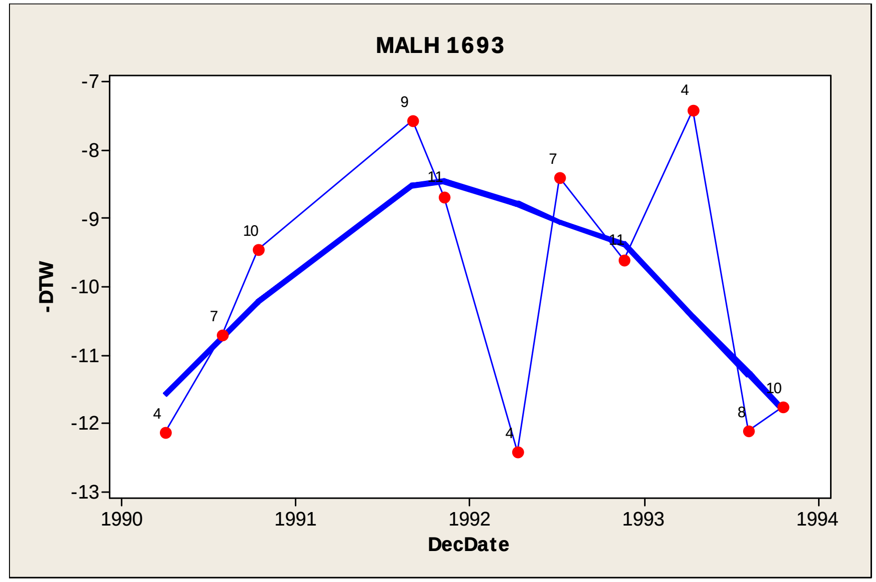




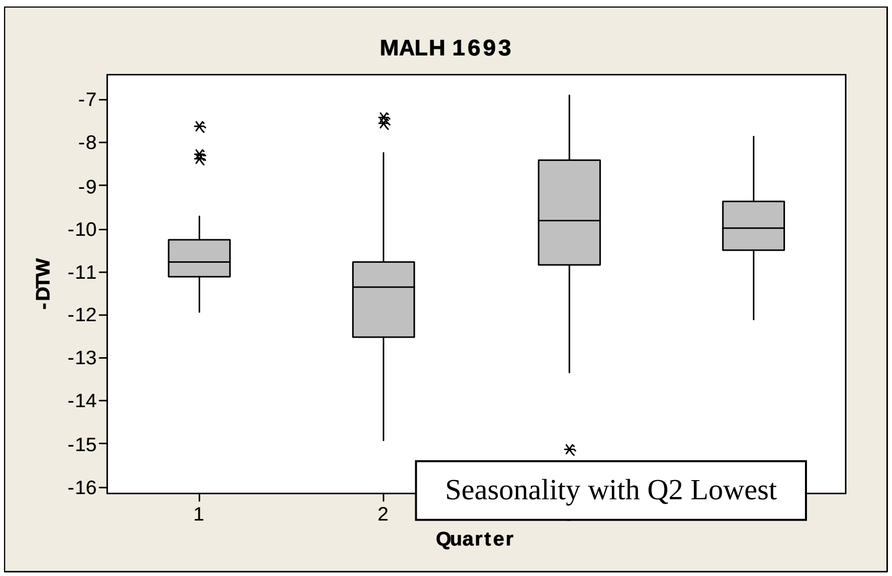


MALH 2147 Period of Record = 1957 - 2013
Total Depth = 110 ft
Average depth to water = 11 ft
Shows a slight statistically significant increasing water level trend since 1962, and a steeper increasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the second quarter.
Shows a statistically significant difference between water levels between 1990 to 2009 and from 2010 to 2013.



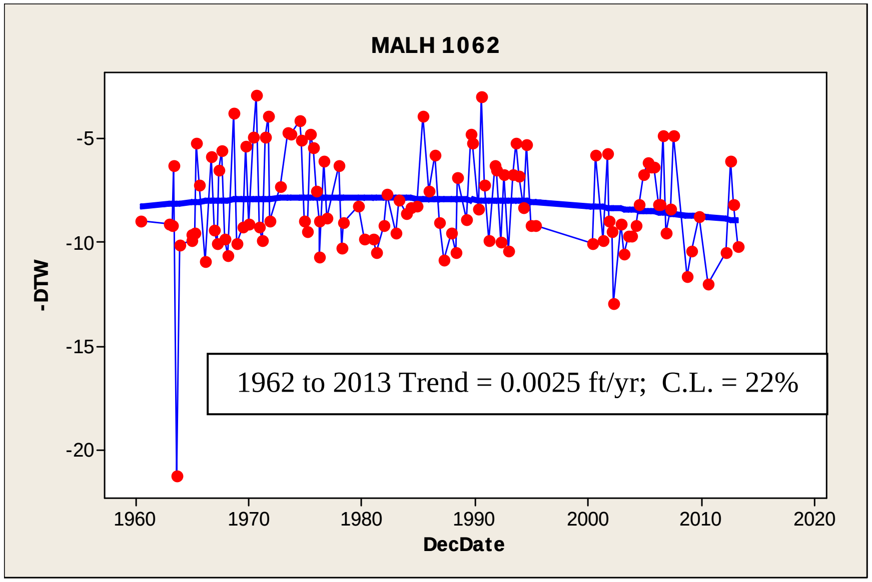


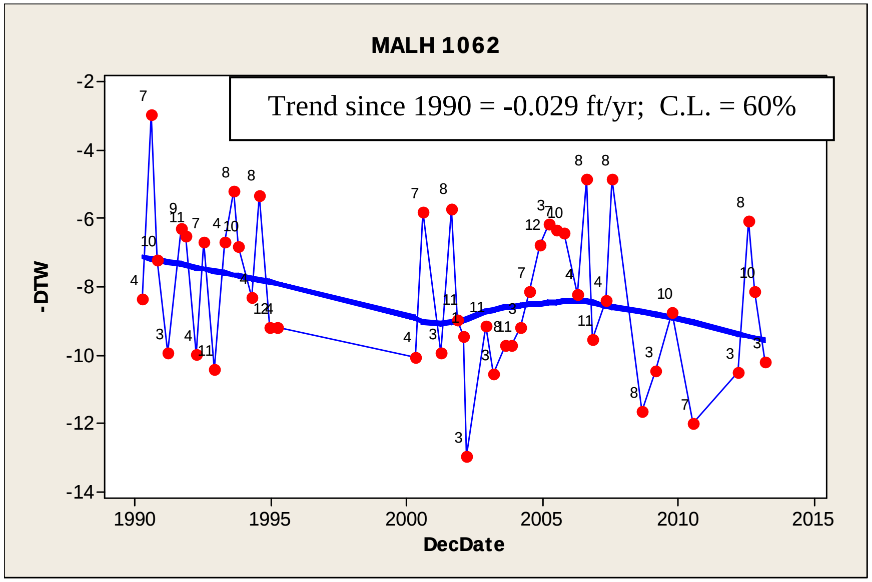
Trend since 1990 = -0.462 ft/yr; C.L. = 61%

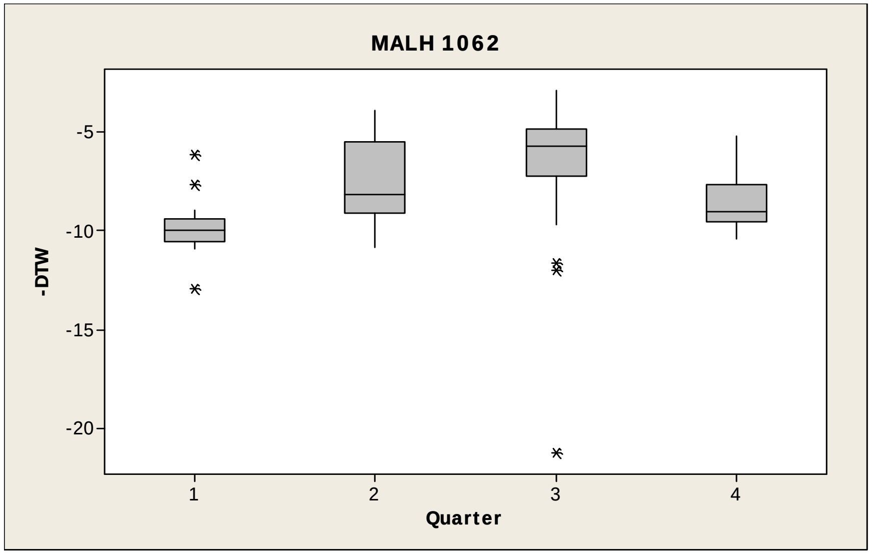


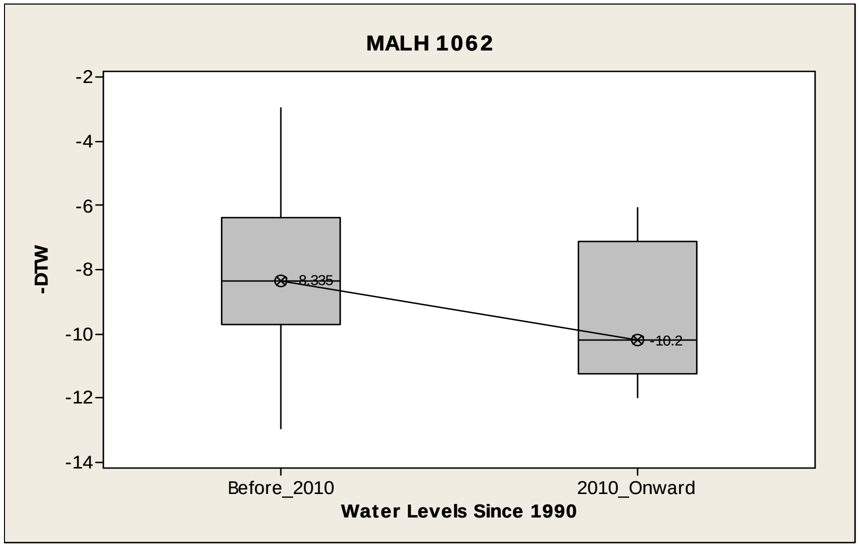
No measurements made after 1993.

MALH 1693 Period of Record = 1950 - 1993
Total Depth = 135 ft
Average depth to water = 10 ft
Shows a very slight statistically insignificant decreasing water level trend since 1950, and a steeper statistically insignificant decreasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the second quarter and highest in the third quarter.

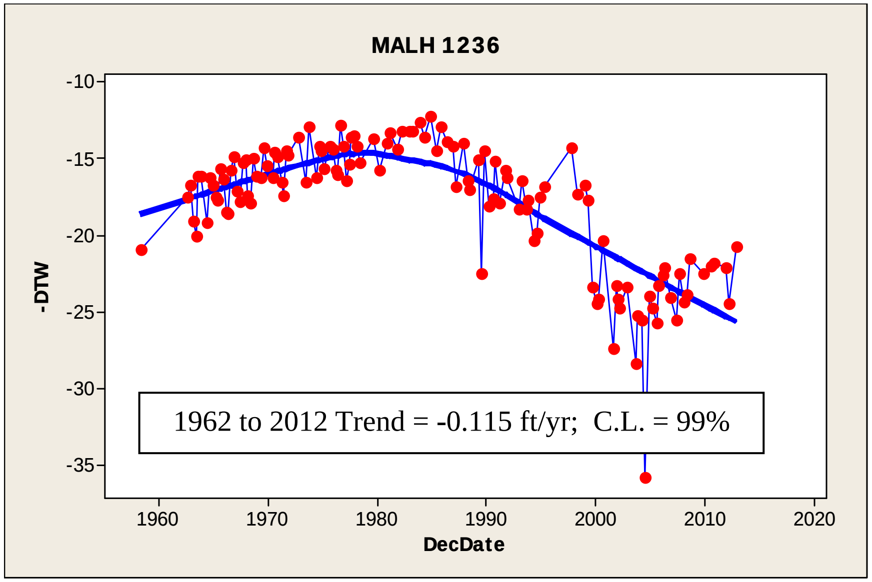


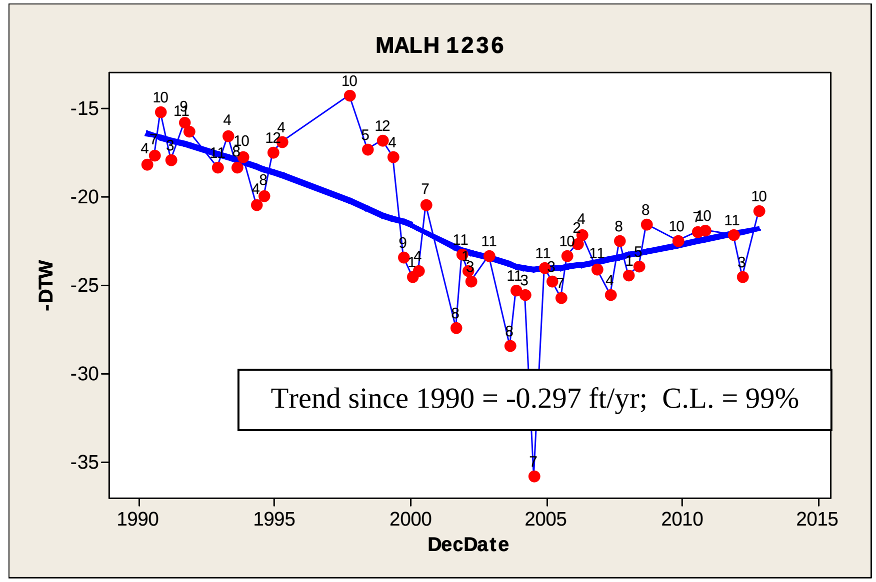


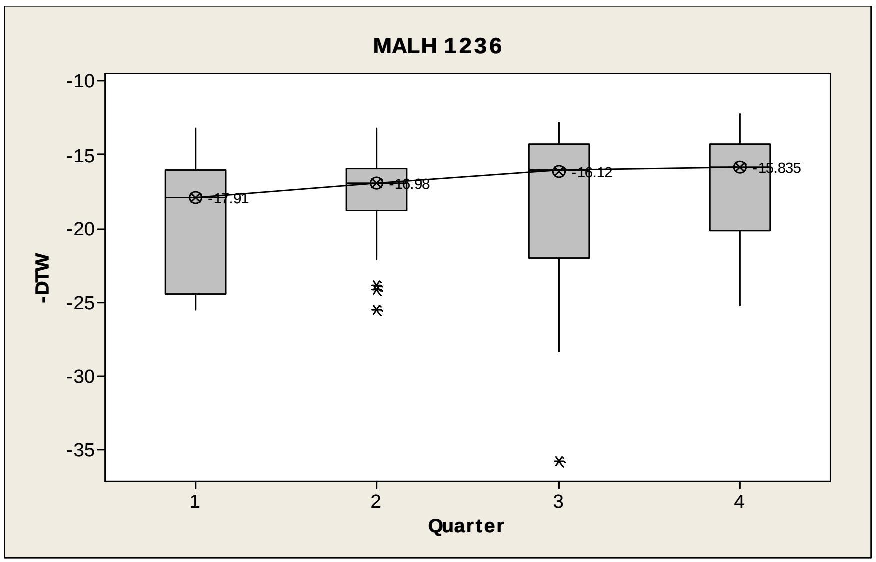


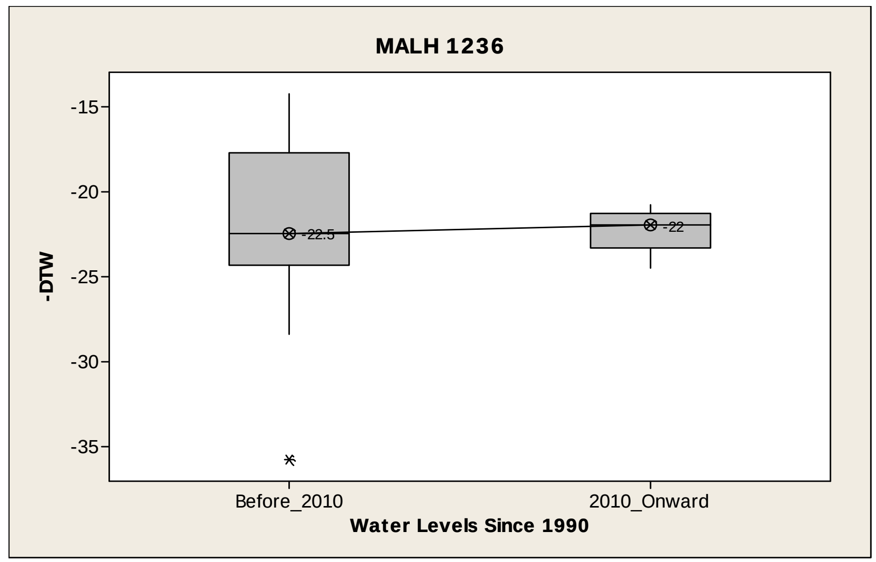


MALH 1062 Period of Record = 1962 - 2013
Total Depth = 140 ft
Average depth to water = 8 ft
Shows a statistically significant very slight increasing water level trend since 1962, and a statistically insignificant slightly decreasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the first quarter and highest in the third quarter.
Shows a statistically insignificant difference between water levels between 1990 to 2009 and from 2010 to 2013.

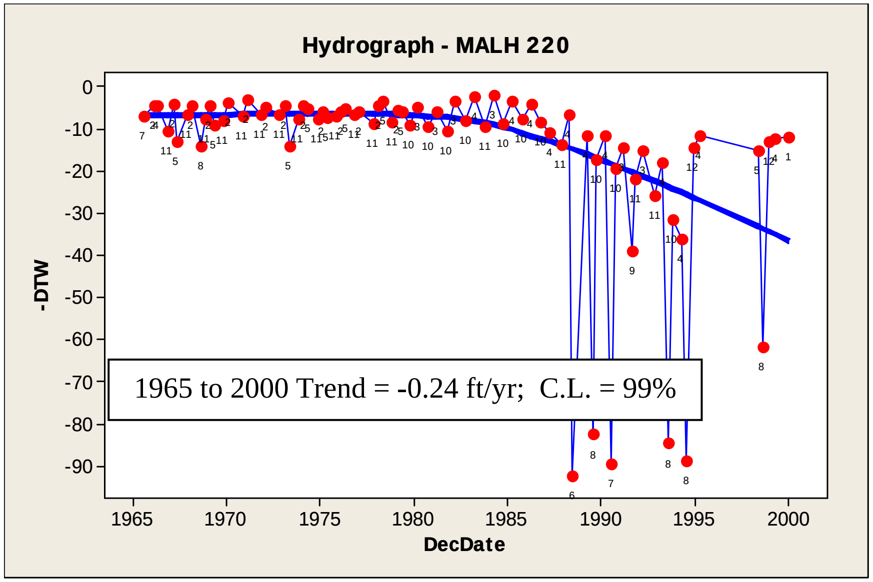


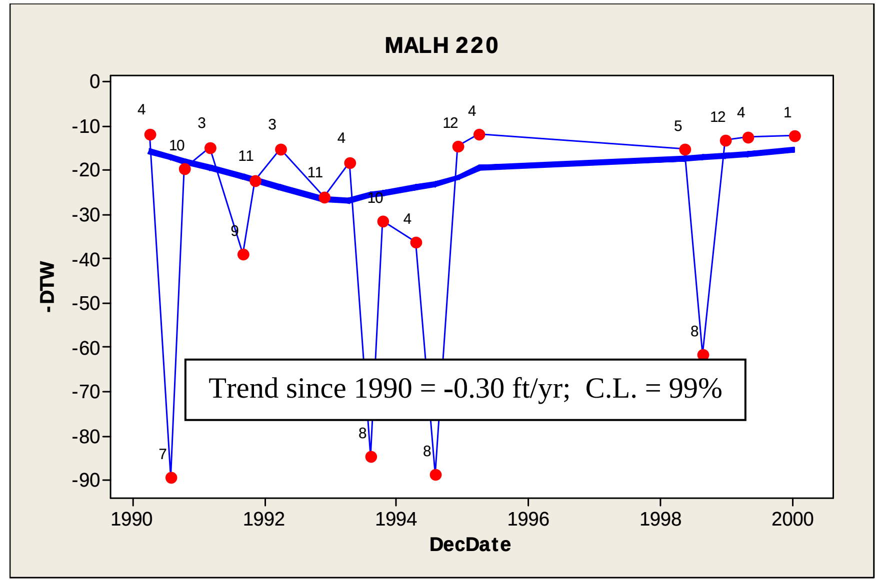


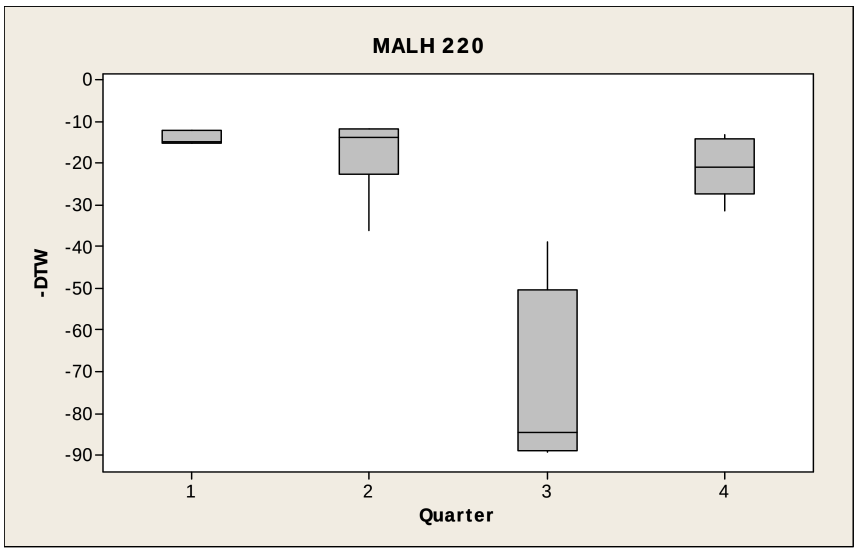




MALH 1236 Period of Record = 1962 - 2012
Total Depth = 240 ft
Average depth to water = 18 ft
Shows a statistically significant decreasing water level trend since 1962, and a steeper decreasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the first quarter and highest in the fourth quarter.
Shows a statistically insignificant difference between water levels between 1990 to 2009 and from 2010 to 2013.

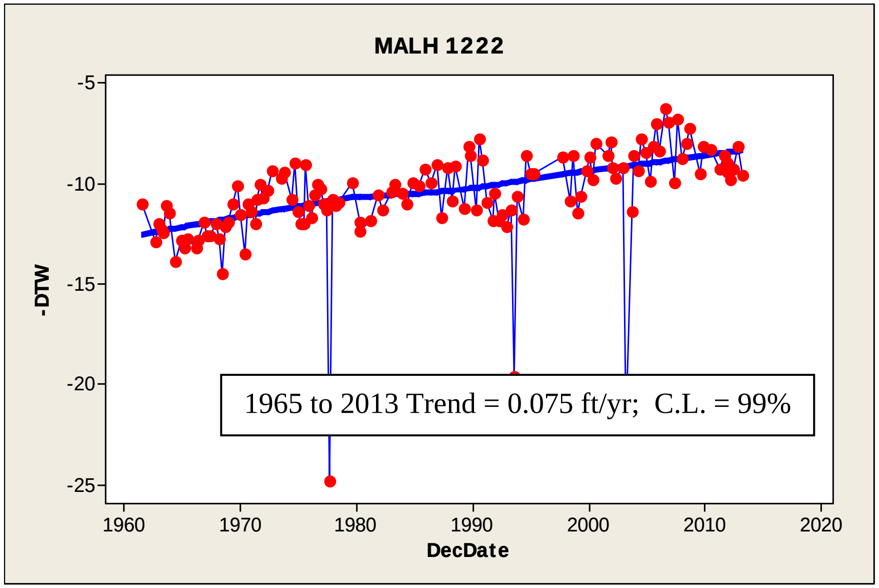


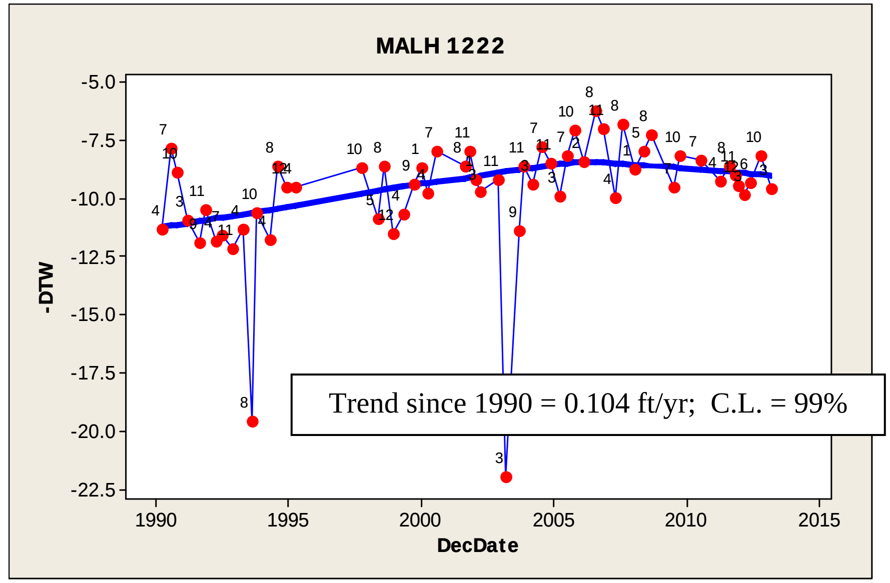


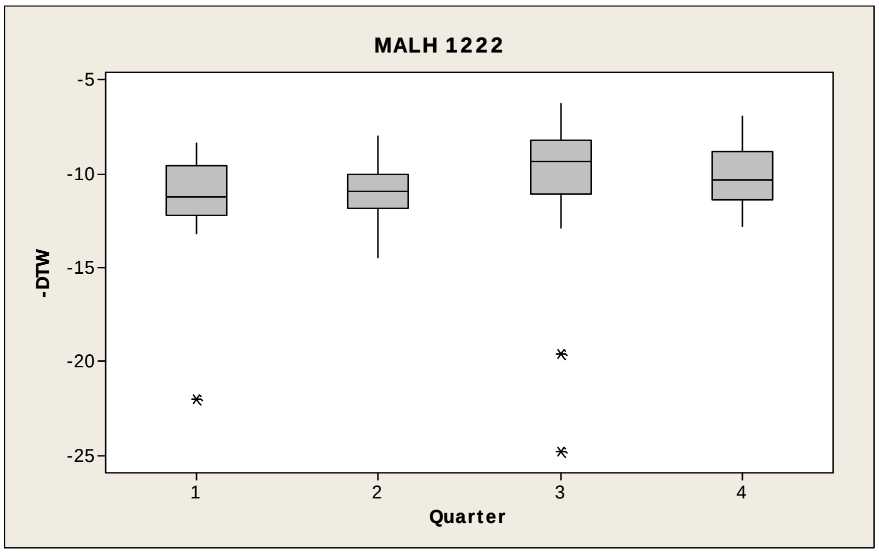


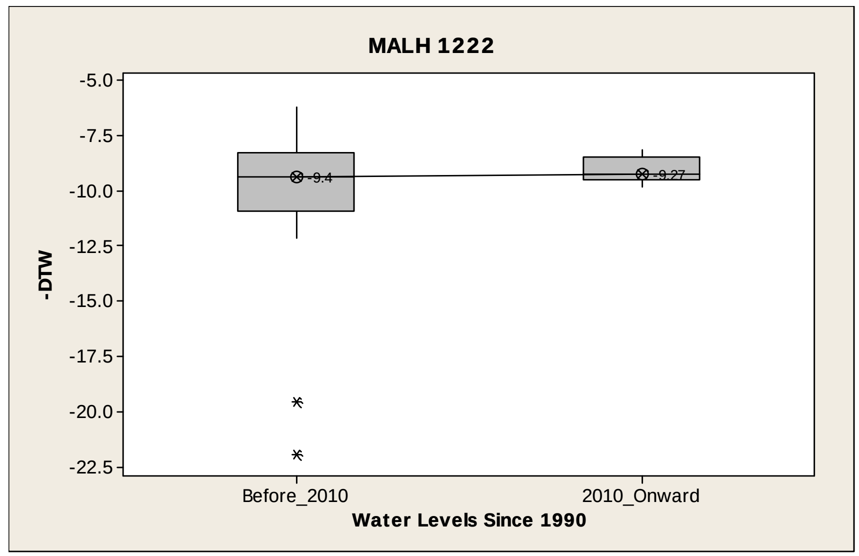
No water level measurements since 2000.

MALH 220 Period of Record = 1965 - 2000
Total Depth = 262 ft
Average depth to water = 15 ft
Shows a statistically significant decreasing water level trend since 1965, and a steeper decreasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the third quarter.

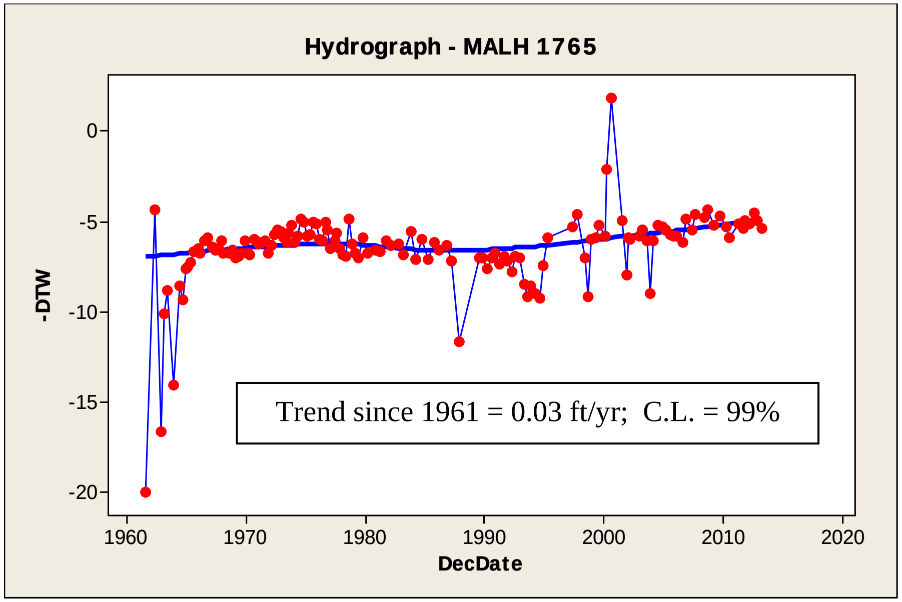


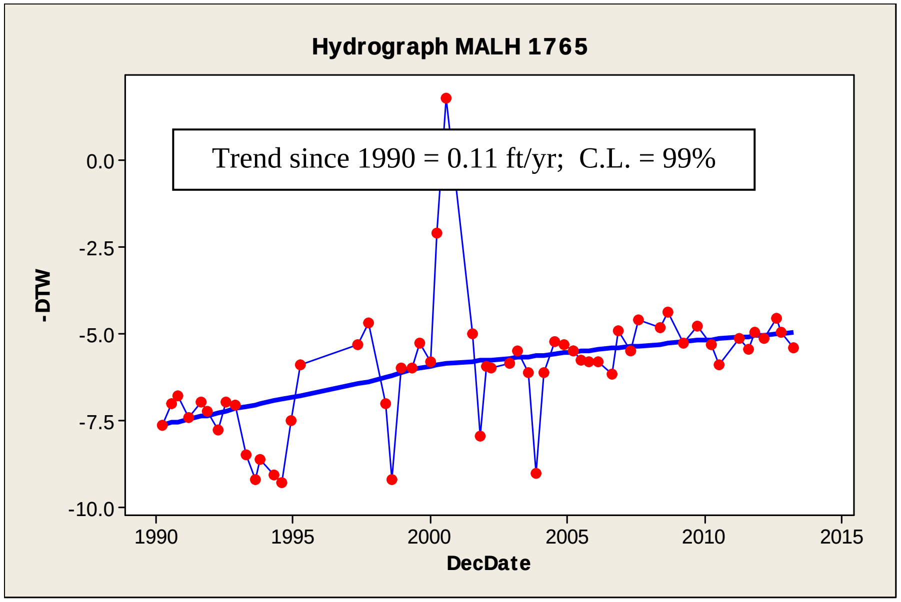


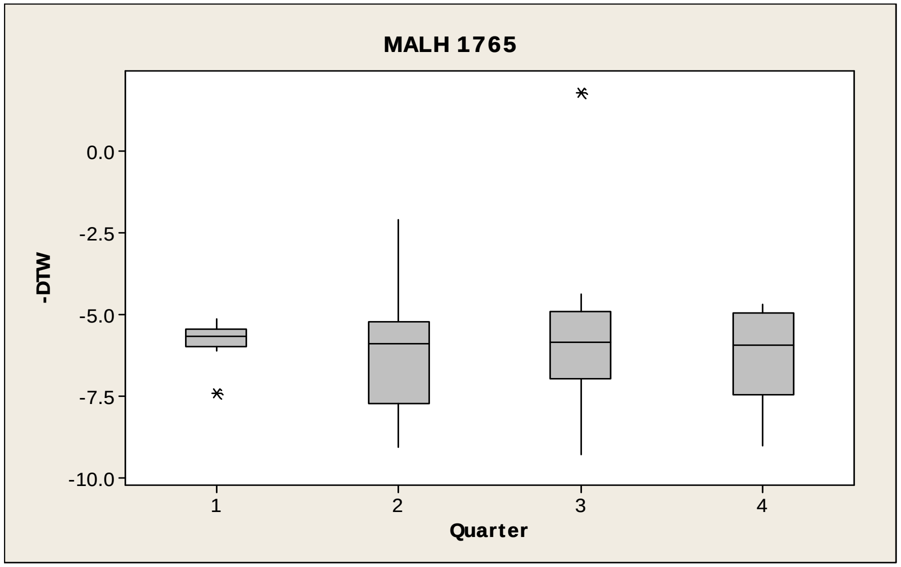


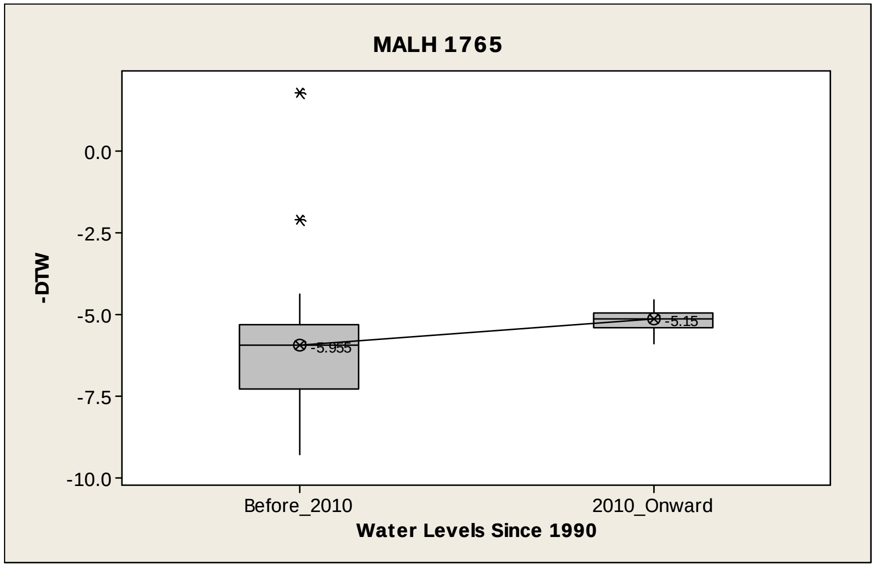


MALH 1222 Period of Record = 1962 - 2013
Total Depth = 435 ft
Average depth to water = 11 ft
Shows a slight statistically significant increasing water level trend since 1962, and a similar increasing trend since 1990.
Shows statistically significant seasonality with water levels lowest in the first quarter and highest in the third quarter.
Shows no statistical difference between water levels between 1990 to 2009 and from 2010 to 2013.

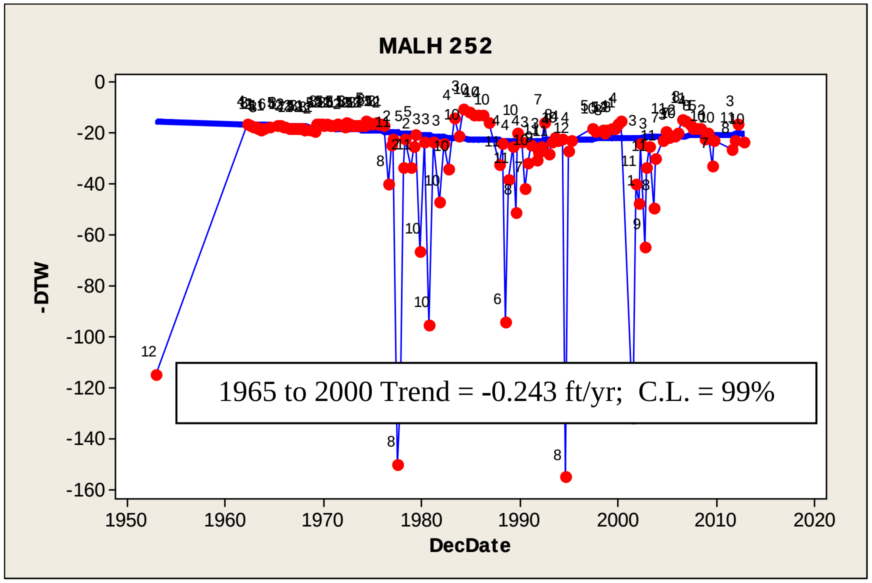


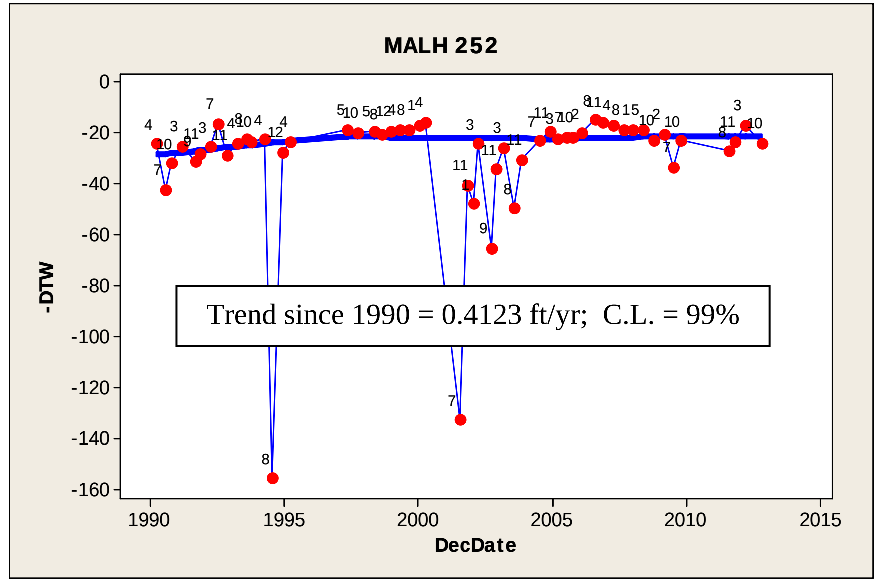


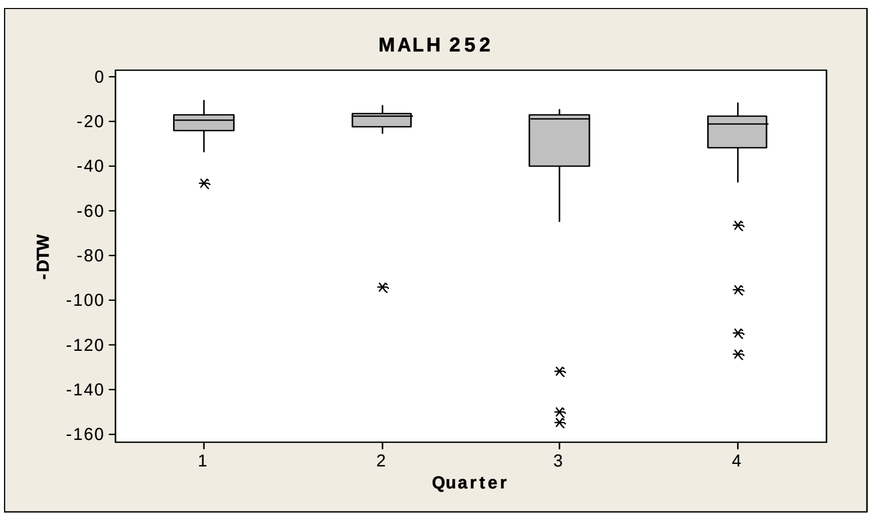


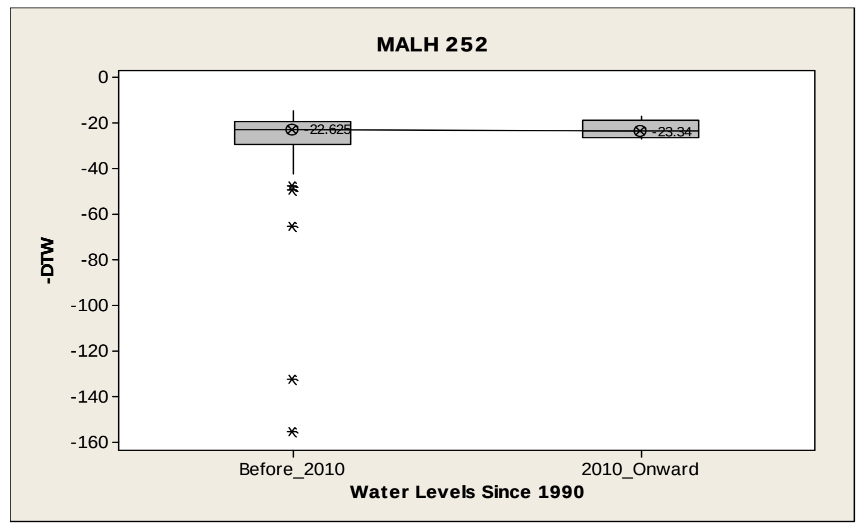


MALH 1765 Period of Record = 1961 - 2013
Total Depth = 680 ft
Average depth to water = 7 ft
Shows a very slight statistically significant increasing water level trend since 1961, and a steeper increasing trend since 1990.
Shows no statistically significant seasonality.
Shows a statistical difference between water levels between 1990 to 2009 and from 2010 to 2013 with later water levels being higher.

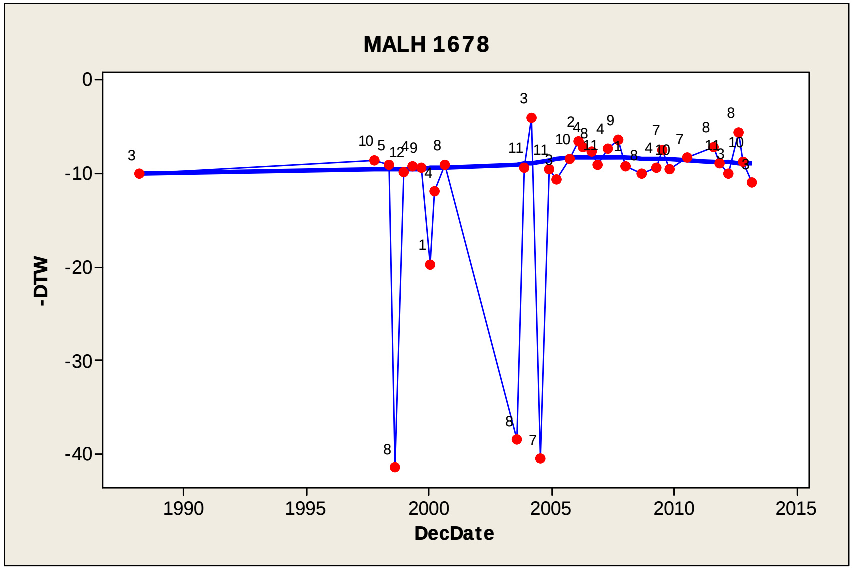


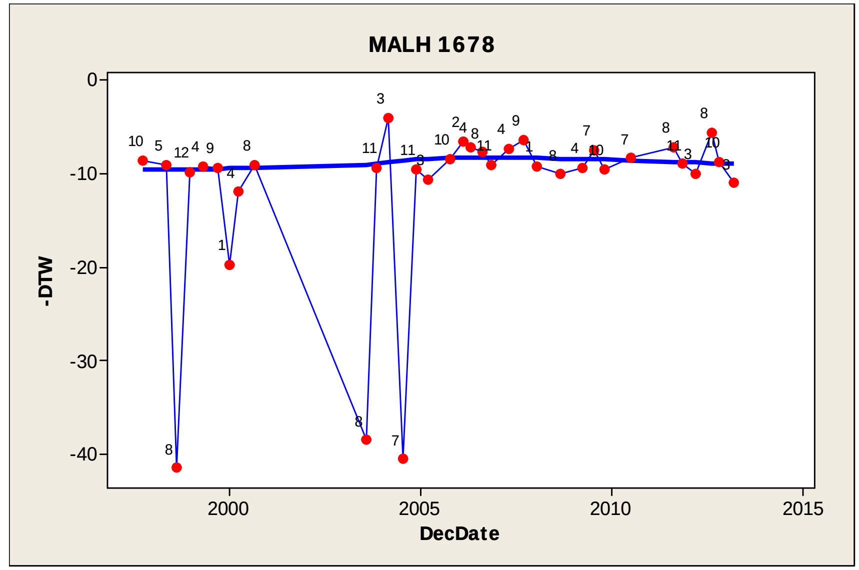


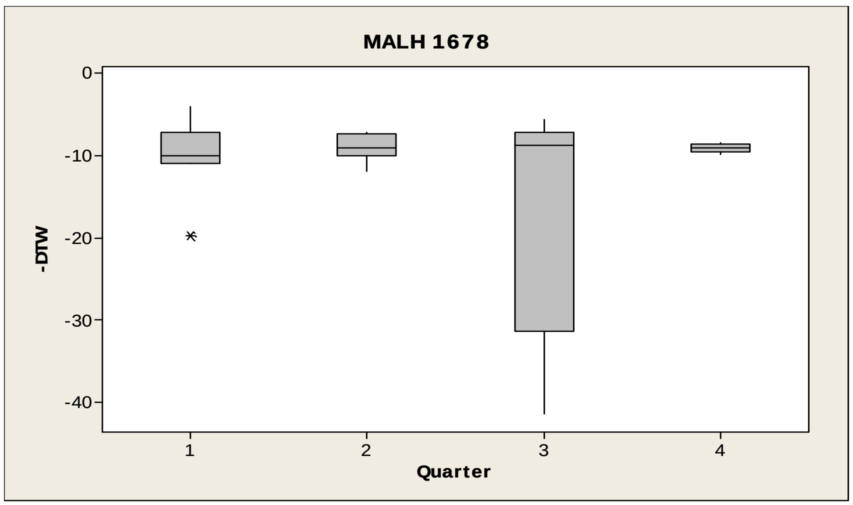


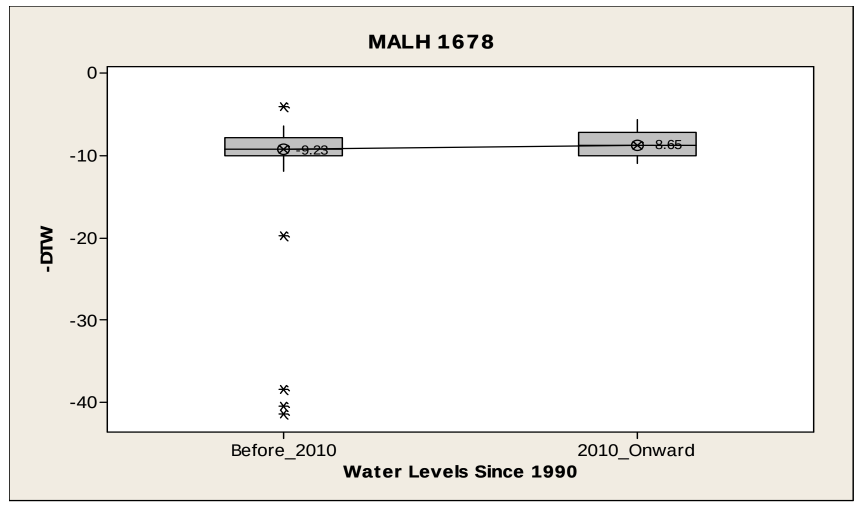


MALH 252 Period of Record = 1962 - 2012
Total Depth = 930 ft
Average depth to water = 28 ft
Shows a very slight statistically significant decreasing water level trend since 1962, but an increasing trend since 1990.
Shows statistically significant seasonality with water levels highest in the second quarter and lowest in the fourth quarter.
Shows no statistical difference between water levels between 1990 to 2009 and from 2010 to 2013.









MALH 1678 Period of Record = 1988 - 2013
Total Depth = 1246 ft
Average depth to water = 12 ft
Shows a statistically significant increasing water level trend since 1988, and a similar increasing trend since 1990.
Shows no statistically significant seasonality.
Shows no statistical difference between water levels between 1990 to 2009 and from 2010 to 2013.