Jan 22, 2025

Groundwater Nitrate Trend Analysis

Lower Umatilla Basin Groundwater Management Area Well Network

This document was prepared by
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Acknowledgements

The author would like to acknowledge the valuable input received through discussions and manuscript review from numerous colleagues at the Oregon Department of Environmental Quality, the Oregon Department of Water Resources, the Oregon Health Authority, the Oregon Department of Agriculture, the United States Geological Survey, and Oregon State University Department of Statistics. This report is better because of their input. Thank you all.

List of Acronyms

AWQMS	Ambient Water Quality Monitoring System
CAFO	Confined Animal Feeding Operation
CRBG	Columbia River Basalt Group
DEQ	Department of Environmental Quality
DOGAMI	Department of Geology and Mineral Industries
GIS	Geographic Information System
GWMA	Groundwater Management Area
LOESS	Local Regression
LUBGWMA	Lower Umatilla Basin Groundwater Management Area
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
mg/L/yr	milligrams per liter per year
MML	Maximum Measurable Level
NMCGWMA	Northern Malheur County Groundwater Management Area
ODA	Oregon Department of Agriculture
OHA	Oregon Health Authority
OWRD	Oregon Water Resources Department

Executive Summary

Purpose of this Report

This report summarizes groundwater nitrate concentrations and trends from 30 domestic wells, two irrigation wells, and one industrial well within the Lower Umatilla Basin Groundwater Management Area well network sampled over a period of 32 years. It is a partial update to the 2012 document titled "Analysis of Groundwater Nitrate Concentrations in the Lower Umatilla Basin Groundwater Management Area," which concluded that the goal of decreasing nitrate trends throughout the LUBGWMA by the end of 2009 was not met. A companion report to this report is planned that will evaluate nitrate concentrations in groundwater at the permitted facilities in the LUBGWMA where data is available.

Background

Oregon's Groundwater Protection Act of 1989 directs the Oregon Department of Environmental Quality to declare a Groundwater Management Area if area-wide groundwater contamination, caused primarily by nonpoint source pollution, exceeds certain trigger levels. In the case of nitrate, the trigger level is 7 milligrams per liter. DEQ declared the LUBGWMA in 1990 after groundwater nitrate contamination was identified beneath a 352,000-acre area in northern Umatilla and Morrow counties.

Summary of findings

Key findings of this trend analysis include:

Nitrate drinking water standard exceeded in the area – Nitrate concentrations at about 40% of the network wells recently (and about 32% as a long-term average) exceed the 10 mg/L drinking water standard. Nitrate concentrations at some wells fluctuate seasonally and/or over multi-year cycles by more than 10 mg/L.

Complex nitrate distribution – While the highest concentrations and steepest trends occur in the western part of the well network, high concentrations are found throughout the area and no predictive geographic pattern is evident. Some groups of wells show commonalities in nitrate concentrations and trends, but proximity is not necessarily predictive. Average nitrate concentrations above 10 mg/L are observed in 10 wells ranging in depth from 40 feet to 100 feet. Some groups of wells show reductions in nitrate concentrations with depth, but ties in total well depths result in a weak correlation coefficient between well depth and nitrate concentration.

Overall increasing nitrate trend, with some decreases – Indications of an overall increasing nitrate trend throughout the network include (1) increase in network-wide annual median, average, and maximum concentrations, (2) the generally more numerous and steeper increasing trends than decreasing trends at individual wells, and (3) the network-wide trend is slightly increasing.

Nitrate concentrations fluctuate and some wells show seasonality – Over the 32-year period, nitrate concentrations at individual wells fluctuated between 0.13 mg/L and 69.7 mg/L with two-thirds of the wells fluctuating less than 10 mg/L. About half of the wells exhibit nitrate seasonality but not all show the same timing. Even so, nitrate was typically higher in Spring than in Fall.

Nitrate leaching is likely still occurring – The continued increase of nitrate concentrations at many wells and in the network as a whole indicate current nitrate leaching is likely.

Some changes in nitrate suggest land use changes – Steep trends, single abrupt changes, or multiple changes in nitrate concentrations at some wells suggest the possibility of changes in land use and indicate the potential for groundwater quality improvements based on changes in surface activities.

Enhancement of network needed – The network of wells regularly sampled by DEQ does not cover the entire LUBGWMA. However, there is significant geographic overlap between the 33-well network and over 1,800 wells tested as part of OHA's LUBGWMA Public Health Project.

The geographic area that the LUBGWMA well network represents should be determined. In addition, an effort should be made to form a larger well network capable of monitoring the entire LUBGWMA by expanding the existing well network with new strategically placed monitoring wells and/or including data from other regularly sampled wells at permitted facilities. An expanded network would improve understanding of regional groundwater quality and could lead to a better understanding of influences from surface activities.

Registered Professional Geologist Seal

In accordance with Oregon Revised Statutes 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.

Document Title: Groundwater Nitrate Trend Analysis - Lower Umatilla Basin Groundwater Management Area Well Network

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Document Date: Date: January 22, 2025

expires 8/1/2025

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1.0 Introduction

This report summarizes groundwater nitrate concentrations and trends from wells within the Lower Umatilla Basin Groundwater Management Area well network. A graphical analysis of general water quality was also completed. In addition, the Oregon Health Authority shared results from recent sampling in the area to allow a comparison with nitrate concentrations from the LUBGWMA well network. The groundwater quality data in this report for general water quality analysis and trend analysis came from the network of wells established by the Oregon Department of Environmental Quality in 1991 to monitor groundwater nitrate concentrations in the LUBGWMA. Most wells are private domestic wells with one industrial well and two irrigation wells currently included in the network. The nitrate and general chemistry data used in the analysis were generated by the DEQ lab and are available through DEQ's Ambient Water Quality Monitoring System AWQMS. Appendix A details the procedure used to download the data and prepare it for trend analysis.

This section discusses the establishment of the LUBGWMA, purpose of this report, previous evaluations, geologic setting, hydrogeologic setting, establishment and evolution of the well network, a prior review of statistical methods and conclusions, well network representativeness in general, and limitations and biases of the LUBGWMA well network.

1.1 Establishment of the LUBGWMA

Oregon's Groundwater Protection Act of 1989 directs the Oregon Department of Environmental Quality to declare a Groundwater Management Area if area-wide groundwater contamination, caused primarily by nonpoint source pollution, exceeds certain trigger levels. Maximum Measurable Levels found in OAR-340-040-0090 Tables 4A, 4B, 5, and 6 are used to trigger designation of a groundwater management area when concentrations are detected on an area-wide basis which exceed 70 percent of the nitrate MML or 50 percent of other MMLs. In the case of nitrate, the trigger level is 7 milligrams per liter.

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.

Nitrate is also a naturally occurring compound. Nitrate concentrations in natural groundwaters are usually less than 2 mg/L (Mueller et. al., 1995; Mueller and Helsel, 1996). Nolan et. al., (2002) used 4 mg/L as a threshold to indicate anthropogenic effects when evaluating the probability of nitrate contamination of recently recharged groundwater in the U.S.

DEQ declared the LUBGWMA in 1990 after groundwater nitrate contamination was identified through multiple sources including monitoring wells at permitted facilities, public water supplies, locally conducted surveys, and DEQ assessment work of domestic wells conducted in 1986 and 1987. The LUBGWMA is a 352,000-acre area (562 square miles) in the northern portions of Umatilla and Morrow counties that overlies the alluvial aquifer (Figure 1).

1.2 Purpose of this Report

The purpose of this report is to evaluate the groundwater nitrate concentrations and trends observed in the LUBGWMA Well Network. The network was established by DEQ in September 1991. Wells evaluated in this report include 30 domestic wells, two irrigation wells, and one industrial well.

This report is a partial update to the 2012 document titled “Analysis of Groundwater Nitrate Concentrations in the Lower Umatilla Basin Groundwater Management Area” (DEQ, 2012) which is summarized in Section 1.3 of this report.

A companion report to the current report is planned that will evaluate groundwater nitrate concentrations at the permitted facilities in the LUBGWMA that monitor groundwater nitrate concentrations (i.e., food processing wastewater application sites, Confined Animal Feeding Operation waste application sites, municipal domestic waste application sites, landfills, and public supply wells).

1.3 Previous Evaluations

As part of the LUBGWMA process, DEQ analyzed groundwater nitrate trends at over 100 wells located at permitted food processing wastewater land application sites for three timeframes: through 2001, through 2005, and through 2009 (DEQ, 2004, DEQ, 2007, and DEQ, 2011).

In 2012, DEQ evaluated groundwater nitrate concentrations from seven sources and approximately 650 wells (DEQ, 2012). Results of that evaluation are summarized below.

DEQ (2012) evaluated 32 wells in DEQ’s LUBGWMA Well Network, 113 monitoring wells and irrigation wells at food processor land application sites, 15 monitoring wells at a CAFO, three Public Supply wells, approximately 100 wells during three synoptic events, five monitoring wells at the former Umatilla Army Depot landfill, and 372 wells in the Domestic Well Testing Act and Real Estate Transaction database managed by Oregon Health Authority.

Each group of data contained wells with nitrate concentrations so low that no contamination from human activities is evident. Each group also contained wells with nitrate concentrations that exceed the 7 mg/L GWMA trigger level and the 10 mg/L drinking water standard. At least three of these groups contained wells with maximum concentrations greater than 100 mg/L. About 40% of the wells exhibited nitrate concentrations above 7 mg/L.

Nitrate trends were calculated at 201 wells. The timeframe of each data set was different but 95% of the data sets ended in late 2009. Half of the wells analyzed (51%) exhibited an increasing trend (i.e., high confidence of a positive slope) while 24% exhibited a decreasing trend (i.e., high confidence of a negative slope), 1% exhibited a flat trend (i.e., high confidence of a slope of zero), and 24% exhibited statistically insignificant trends (i.e., low confidence regardless of slope).

While not a calculated trend, a comparison of nitrate concentrations at 98 wells sampled 17 years apart during the first and third synoptic sampling events showed 54% increased, 24% decreased, and 22% did not change.

The proportions of increasing, decreasing, and statistically insignificant trends within the network of 32 wells regularly sampled by DEQ were very similar to the proportions of all 201 wells tested, as well as the comparison of the 98 synoptic sampling event wells.

The primary conclusion was that the goal of decreasing nitrate trends throughout the GWMA by the end of 2009 was not met.

1.4 Geologic Setting

Figure 2 is a geologic map of the LUBGWMA showing the geologic units at land surface. The figure utilizes GIS files from the Oregon Department of Geology and Mineral Industries-DOGAMI (2020) which are based on Madin and Geitgey (2007).

The geologic units exposed at land surface in order of increasing age include the Quaternary-aged deposits (eolian sand and ash, alluvium, and Missoula Flood Deposits), the Miocene/Pliocene-aged Alkali Canyon Formation, and the Miocene-aged Columbia River Basalt Group.

1.4.1 Missoula Flood Deposits

Quaternary-aged catastrophic Missoula Flood deposits dominate the LUBGWMA. Multiple failures of a glacial ice dam that contained glacial Lake Missoula resulted in catastrophic floodwaters repeatedly inundating the area up to an elevation of approximately 1,000 feet. The most recent catastrophic flood is estimated to be 15,000 to 13,000 years ago (Mullineaux et.al., 1978; Waitt, 1985). Sediments left behind include silt, sand, gravel, and boulder-sized particles. The floods scoured some areas, leaving bare bedrock scabland in some instances (east of Hermiston) enlarging drainages (Butter Creek southeast of Echo) and building huge bars (Coyote Coulee on the Umatilla Army Depot). Maximum thickness is approximately 150 feet but thickness is more commonly 15 to 50 feet (Madin and Geitgey, 2007).

1.4.2 Eolian Sand and Ash

The Missoula Flood deposits are blanketed by scattered deposits of Quaternary-aged wind-blown deposits of sand and silt reworked from older Missoula Flood deposits, and airfall volcanic ash deposits (Madin and Geitgey, 2007). These eolian deposits cover about half of the LUBGWMA.

1.4.3 Alluvium

Holocene-aged sand, silt, and gravel deposits were deposited along the channels and floodplains of Butter Creek and Umatilla River drainages. These deposits are generally unconsolidated and range in thickness less than ten feet to over fifty feet (Madin and Geitgey, 2007).

1.4.4 Alkali Canyon Formation

Underlying the quaternary-aged deposits is the upper Miocene to Pliocene-aged Alkali Canyon Formation. The Alkali Canyon Formation consists of interbedded fluvial (from a river) and lacustrine (from a lake) sedimentary rocks deposited on top of the underlying basalt flows of the Miocene-aged Columbia River Basalt Group. Maximum thickness observed in well logs is 360 feet (Madin and Geitgey, 2007).

1.4.5 Columbia River Basalt Group

Miocene-aged basalt flows of the CRBG that crop out in the LUBGWMA include the Saddle Mountains Basalt Formation (including its Elephant Mountain Member, Pomona Member, and Umatilla Member) and the undifferentiated Wanapum Basalt Formation (DOGAMI, 2020). Individual units are defined based on stratigraphic position, geochemistry, magnetic polarity, and petrography. Basalt outcrops can be found along the Columbia River, along the Service Anticline (including Emigrant Buttes, Hermiston Butte, and Umatilla Butte), along the margins of the Umatilla River downstream of Three-Mile Dam, in the southeast corner of the LUBGWMA adjacent to the Umatilla River upstream of Echo, and along Six Mile Canyon.

1.5 Hydrogeologic Setting

The Quaternary-aged sedimentary deposits (primarily the Missoula Flood Deposits but also the Alluvium and Eolian Deposits) along with the Alkali Canyon Formation and where hydraulically connected, the uppermost fractured portion of the Elephant Mountain Basalt flow collectively comprise the Alluvial Aquifer (Grondin, et.al., 1995). Because the aquifer contains more than just alluvium, the more accurate term “Sedimentary Aquifer System” is currently used by the Oregon Water Resources Department to describe this aquifer. For consistency with previous DEQ reports, the term ‘Alluvial Aquifer” is used in this document.

Alluvial sediments associated with Butter Creek and the Umatilla River occur in their respective flood plains. The Umatilla River is hydraulically connected to the alluvial aquifer between the cities of Echo and Umatilla where the river is in contact with alluvial sediments (OWRD, 2003). At Butter Creek, the river begins to progressively downcut through the aquifer until it reaches basalt bedrock at Three-Mile Dam. Natural springs occur in the lower reaches of the river indicating the aquifer discharges to the river. Other instances of groundwater/surface water interactions have been documented in the LUBGWMA.

Unconfined and confined conditions occur within the Alluvial Aquifer while confined conditions dominate in the Basalt Aquifers. The Basalt Aquifer System consists of the CRBG flows beneath the uppermost dense flow interior, and is considered to contain multiple aquifers, generally indicated by changes in hydraulic head. For brevity, the term Basalt Aquifers is used in this document.

Erosional windows through the Alkali Canyon Formation into the underlying basalt flows that were caused by the Missoula Floods have been documented in the LUBGWMA by Grondin et.al., (1995) and others. These erosional windows allow exchange of water between these aquifers that are typically hydraulically separate.

1.6 Establishment and Evolution of Well Network

This section describes the well selection process, how the network has changed over time, network well use and construction, approaches to evaluate the representativeness of a well network, and the limitations and biases of the LUBGWMA network.

1.6.1 Well Selection Process

The groundwater quality assessment portion of the LUBGWMA characterization completed by DEQ, OWRD, and OHA in the early 1990's included a 15-month reconnaissance phase focused on (1) understanding the general chemistry of local groundwater, (2) identifying the list and concentration range of contaminants, (3) identifying the extent of groundwater contamination, and (4) help to establish the project boundary limits. The GWMA program did not have funds allocated for well installation so existing wells were used for the characterization.

The reconnaissance involved sampling 198 existing wells. Based on those results, a subset of the wells was selected as the bi-monthly network to determine seasonal variability and trends. The well network consisted of 35 wells for routine sampling (every other month) plus five wells to be sampled if field time allowed.

The bi-monthly network wells were chosen for their hydrogeological placement, geographic location, and groundwater chemistry characteristics. The selection process used a predetermined two-step process.

In step 1, a list of candidate wells was compiled using the following criteria:

1. The well was located and observed by OWRD and/or DEQ staff during the reconnaissance phase of the investigation,
2. The well was completed in alluvium only or was completed in a single basalt water-bearing zone, and
3. The well appeared accessible throughout the year for sampling.

In step 2, a final list of wells was selected if the well met one or more of the following:

1. The well is a member of a group of wells positioned along a groundwater flow path.
2. The well provides data for an isolated geographic location.
3. Groundwater from the well had moderate to high levels of nitrate.
4. The well had confirmed levels of pesticides or volatile organic compounds detected.

A system for well identification was developed by DEQ in the 1990's for wells used in the LUBGWMA characterization. The DEQ system involves using the prefix "UMA" and sequential numbers. The OWRD well identification system involves using the first four letters of the county in which the well was installed (e.g., "UMAT" or "MORR") and sequential numbers. DEQ continues to use the "UMA" system in subsequent LUBGWMA reports, including this report.

1.6.2 Well Network Over Time

DEQ began sampling the bi-monthly network of 38 private wells in September 1991. Most of the wells are in the Alluvial Aquifer but a few are in the Basalt Aquifer. Most of the wells in the network are private drinking water wells but it does contain two irrigation wells and one industrial well.

This well network was sampled every other month from September 1991 through November 2009. Starting in 2010, this well network was sampled four times per year (i.e., January and July events were dropped). From this point on, the bi-monthly well network was referred to as the LUBGWMA well network.

Since 1991, some well owners have decided to end their participation, while other wells are no longer in use. In summary, ten wells were dropped from the network while two wells were added. Changes to the well network are summarized below.

Well ID	Included in Analysis?	Date Added	Date Dropped	Average Nitrate Concentration when dropped (mg/L)	Nitrate Trend direction when dropped	Nitrate Trend Magnitude when dropped (mg/L/yr)
UMA066	No	Sep-91	Sep-02	7.55	Increasing	0.24
UMA088	No	Oct-91	Nov-02	15.3	Increasing	0.4
UMA039	No	Oct-91	Sep-04	2.94	Increasing	0.27
UMA058	No	Oct-91	Nov-04	13.1	Decreasing	-0.61
UMA122	No	Oct-91	Sep-05	20.5	Increasing	1.56
UMA085	No	Oct-91	Jul-07	32.4	Increasing	1.46
UMA028	No	Oct-91	Nov-08	3.1	Increasing	0.3
UMA046	Yes	Oct-91	Sep-18	1	Decreasing	-0.01
UMA047	Yes	Oct-91	May-19	3.4	Increasing	0.06
UMA312	No	Mar-12	Nov-19	7.9	statistically insignificant	0.15
UMA313	Yes	Mar-12	still active	--	--	--

Note: Statistically insignificant trends had a confidence level of <80%.

The well network currently consists of 33 wells, with 29 wells sampled consistently since 1991. These 29 wells are termed the long-term wells in this report. These 29 wells were also included in larger synoptic sampling events where between 108 and 207 wells were sampled in 1992, 2003, 2009, and 2015.

Figure 3 shows the locations of the wells currently in the network and identifies the aquifer tapped by each well. Figure 3 also shows the network as nine groups of wells that are discussed in Section 3.8.

1.6.3 Network Well Use and Construction

Most wells are private domestic wells but one industrial and two irrigation wells are currently included in the network. The wells included in the network (unlike monitoring wells which typically target the water table) were drilled to a depth at which a sufficient water supply for the well owner's needs was encountered.

The open interval of a well is the portion of the well with perforations, screen, or open hole that allows water to enter the well casing. The open interval for one well is unknown; only the total depth is known. The closer the open interval is to land surface, the shorter the path is for surface contaminants to enter the well making depth to open interval one potential variable influencing nitrate concentration at a well. Depth to the top of the open interval in these wells ranges from 17.5 feet to 171.5 feet and averages about 58 feet.

Eleven of the network wells (all of which are in coarse-grained Missoula Flood Deposits) have solid casing driven to the total depth of the well, and are open only to the aquifer at the bottom of the well, and effectively have an open interval of zero. Open intervals for other network wells range from 1 foot to 167 feet. Twenty-one wells (including the wells with solid casing) have open interval lengths of 11 feet or less. Five wells have an open interval of 25 to 50 feet. Another five wells have an open interval of 50 to 100 feet. One well has an open interval of 167 feet.

The bottom of the open interval approximates a well's total depth. The bottom of the open interval in network wells range from 22.5 feet to 185 feet and average 82 feet.

1.7 Review of Statistical Methods and Conclusions

1.7.1 2012 Review by OSU Statistician

As part of a 2012 Oregon Department of Agriculture Fertilizer Research Program grant awarded to GSI Water Solutions, Inc. on behalf of the LUBGWMA Irrigated Agriculture Sub-Committee, OSU statistician Dr. Alix I. Gitelman reviewed the statistical methods used and conclusions made by DEQ in four LUBGWMA documents. In her February 2013 report, Dr. Gitelman identified three main statistical issues that she felt had the biggest impact on the overall message conveyed by the documents she reviewed: (1) "the lack of probability sampling (or in its place substantive arguments about the representativeness of the sampled wells), (2) the oversimplification of results by tabulations of increasing/decreasing trends without accounting for their magnitude and/or practical significance, and (3) a lack of focus on the 2000 to 2009 period for critical evaluation of the efficacy of the Action Plan".

She also stated “Unaddressed, these three issues combine to provide an overall negative view of the LUBGWMA in terms of nitrate concentrations. It remains unclear what the true picture of nitrate concentrations in the GWMA is today, but I believe that much of what the DEQ has reported over the last ten years should be tempered and qualified by language that reflects some of the issues I have described in this report. I provide recommendations corresponding to each of the main issues below. More than a re-analysis of the statistics, the DEQ reports could benefit from clear enumeration of all the assumptions that go into drawing inferences from sampled wells to the entire GWMA, that are involved with tabulating results and that justify the appropriate timeframe for analysis”.

The assumptions and determinations made by DEQ that address Dr. Gitelman’s comments are briefly addressed below and further explained in Section 2.2 of this document.

DEQ acknowledges the importance of considering both trend direction and magnitude when tabulating results and does so in this analysis.

DEQ believes the timeframe of the groundwater nitrate concentration data evaluated was appropriate then and now. It is worth noting that in response to the review, DEQ calculated a network-wide trend using only groundwater nitrate data from 2000 with the 31 wells in the network at that time. The network-wide trend from 2000 through 2003, 2004, 2005, 2006, 2007, and 2009 were statistically insignificant trends with a slope of zero or increasing at less than 0.002 mg/L/yr. The trend from 2000 through 2008 was statistically significant and increasing at 0.002 mg/L/yr.

Trends from 2000 through 2009 had similar magnitudes but lower statistical significance than trends from 1991 through 2009. Using the 31 current wells at the time, the statistically significant trend was increasing at 0.004 mg/L/yr. Including data from seven wells that had been dropped from the network from 2002 through 2008 (i.e., using 38 wells), the statistically significant trend was increasing at 0.017 mg/L/yr.

DEQ acknowledges the well networks were not established using rigorous statistical or mathematical techniques. The representativeness issue highlighted by Dr. Gitelman results from practical limits on DEQ’s capacity. With greater resources, DEQ could have met more rigorous design parameters at the onset of the monitoring program. Four approaches to evaluate the representativeness of groundwater monitoring networks are described in Section 1.8.

1.7.2 2024 Review by OSU Statistician

As part of the review process for this report, OSU Statistician Dr. Yuan Jiang was hired by DEQ to review this report. Based on Dr. Jiang’s comments, additional work was conducted to address the comments and is incorporated into this report.

Dr. Jiang provided initial comments in October 2024. Dr. Jiang concluded “In general, statistical methodologies are appropriately applied and statistical conclusions are appropriately drawn in this report”. His comments then focused on “pitfalls or inadequacies” in the report.

DEQ provided a response to comments in December 2024. In January 2025, Dr. Jiang indicated he found DEQ's responses satisfactory but had two very minor observations regarding statistical test assumptions. DEQ adequately addressed those comments in January 2025.

Six themes were identified in Dr. Jiang's comments. They are reiterated below with a summary of DEQ's response. A copy of Dr. Jiang's full comments and DEQ's full response is available upon request.

Comment Theme #1 - The representativeness of the selected wells to the GWMA is unclear.

Response #1 - The known limitations and biases of the network are acknowledged in Section 1.9, including that it does not cover the entire LUBGWMA. The term network-wide trends was used, but the report does not conclude results from the network are applicable to the entire GWMA.

In Section 1.2, a companion report to the current report is noted that will evaluate groundwater nitrate concentrations at permitted facilities in the LUBGWMA. Recommendations of the current report include (1) evaluating the geographic area that the LUBGWMA well network represents and (2) establishing a larger network capable of monitoring the entire LUBGWMA noting it could be done by expanding the existing well network with new strategically placed monitoring wells and/or including data from other regularly sampled wells at permitted facilities.

Comment Theme #2 – It was highly recommended that statistical test assumptions be stated, and a discussion included as to how the current data satisfies the assumptions.

Response #2 - Appendix B of this report lists the statistical test assumptions along with a discussion of how the data analyzed fit the assumptions and/or how some results were affected by not meeting test assumptions.

Comment Theme #3 - Spatial dependence of nitrate concentrations and trends should be discussed.

Response #3 - The spatial dependence of nitrate concentrations was evaluated both visually and statistically. Methods are described in Section 2.2.7. Results are described in Section 3.4. In summary, no evidence of spatial dependence was identified.

Comment Theme #4 - Multiple hypothesis testing should be accounted for in trend tests and the other statistical tests conducted. Such adjustments to trend tests would reduce the confidence level but not affect the slope.

Response #4 – In preparing this response, multiple statistical resources were reviewed to assess the concern for multiple hypothesis testing associated with the procedures and data sets used in this analysis. In summary, corrections for multiple hypothesis testing were identified and are included in the test used to evaluate seasonality and to compare the DEQ and OHA data sets, but not for the tests used to evaluate trends.

Specifically, the R function cen1way used to perform the Peto-Peto one-factor test to evaluate seasonality at individual wells and differences between the DEQ and OHA data sets uses the Benjamini & Hochberg (1995) method of adjusting p-values. However, no documentation that multiple hypothesis testing is a concern when conducting groundwater quality trend analyses was found. Therefore, no adjustments to p-values for the trend test results were made.

Comment Theme #5 – It was noted that to rule out confounding factors and effects of exogenous variables such as temperature and precipitation, a potential solution is to identify, measure, and incorporate exogenous variables into the trend tests.

Response #5 - While the investigation and documentation of variables other than time that affect groundwater nitrate concentrations would likely inform the understanding of nitrate leaching and groundwater nitrate concentrations in the LUBGWMA, the purpose of this trend analysis was to assess changes in groundwater nitrate concentrations over time rather than to assess the cause(s) of the changes in groundwater nitrate concentrations. An investigation of exogenous variables is beyond the scope of this report.

It is important to note that performing a trend test that includes an exogenous variable does not negate the value of the simpler trend test without an exogenous variable, it simply adds to the ability to discern and potentially explain the trend that is taking place (Helsel, et. al., 2020).

Researchers have shown that the influences of temperature and precipitation on groundwater nitrate concentrations can be either positive (i.e., result in lower nitrate leaching) or negative (i.e., result in higher nitrate leaching). Further complicating the issue, the relationships between meteorological variables and groundwater nitrate concentrations in natural systems have been altered in the LUBGWMA by irrigation systems and practices. While typical irrigation rates are about two to seven times higher than average precipitation rates, different crops require different amounts of water, so the amount of water applied per field is not constant over time. Accurately estimating hydraulic inputs for all irrigated crops within the LUBGWMA for the 32-year timeframe of the trend analysis would be a difficult task. In addition, factors other than hydraulic input and temperature have been shown to be as predictive or more predictive of groundwater nitrate concentrations.

Helsel et. al., (2020) discusses the importance and difficulties of discriminating between long-term trends attributable to human activity and "long-term persistence" resulting from the chaotic behavior of the land-atmosphere-ocean system that often manifests itself as a quasi-periodic oscillation existing across a wide range of time scales from years to centuries or millennia. They note that long-term persistence and short-term serial correlation will result in a higher probability of type I errors than otherwise expected. They also note that most hydrologic variables are responding to a mix of human activity and natural forces and that assessing that mixture is critical to projecting future conditions. However, they point out there is no simple solution to the problem of distinguishing persistence and human-caused trends, and that statistical tools will need to continue to evolve and improve until they are cognizant of the atmospheric and watershed processes that drive the changes that would exist even in the absence of human interventions. Finally, they note that without long-term high-frequency datasets (at least a few dozen samples per year for more than 30 years), it will continue to be difficult to sort out natural long-term variations, shorter-term serial correlation, and trends owing to changes in human activity. Their advice is to be cognizant of these issues in designing a trend analysis and explaining the meaning of the results.

Comment Theme #6 - When comparing OHA and DEQ data sets, the statistical independence of all observations in each data set, across all wells, and over all time points should be evaluated.

Response #6 - Given the noted differences between the ODA and OHA data sets and the discussion of independence in Helsel, et. al., (2020), the assumption of statistical independence is considered to be met.

1.8 Well Network Representativeness

The representativeness of a groundwater monitoring network depends, in part, on the objectives of the monitoring. A groundwater monitoring network can be considered representative if information collected from the monitoring network adequately answers the question that prompted creation of the monitoring network.

The LUBGWMA Well Network was expanded in 2012 when DEQ added two wells near Irrigon: one near the Columbia River and one near a basalt well already in the network. However, subsequent budget constraints resulted in less frequent sampling and no resources available for additional expansion or optimization of the well network.

1.8.1 Optimization of Subset of Possible Sampling Locations

Farlin et. al., (2019) presents a method to assess and improve the representativeness of an existing regional groundwater monitoring network. The method optimizes sampling locations from a larger choice of possible locations based on the distribution of desethyl atrazine (a ubiquitous pesticide transformation contaminant assumed to be indicative of diffuse agricultural pollution) and solute transport time. They note the ideal groundwater quality monitoring network allows for the detection of significant improvements of water quality, and closely approximates the true unknown mean concentration of the considered aquifer.

Farlin et. al. (2019) also notes the purpose of monitoring networks is not only to assess the chemical status of the groundwater body at a given time, but also to follow trends in that status over time and relate them to land use or land management changes. Since a delayed response of groundwater bodies by weeks, months or even years can be expected given the typical groundwater flow rates, an efficient monitoring network should allow a timely recognition of any improvement or deterioration in water quality, implying stations should be placed close to the pollution sources, but must also capture the rate of change of such improvement or deterioration at the scale of the groundwater body, (i.e. stations should also cover the range of groundwater transit times from the pollutant sources to the outlet, with some stations close to the sources and others closer to the outlet).

1.8.2 Statistically Generating Representative Sampling Sites

Arnold, et. al., (2009) focuses on designing a well network to characterize water quality in the High Plains aquifer of Colorado beneath areas of irrigated agriculture. A 30-well network was designed to provide for statistical representation of water-quality conditions by using a computerized technique to generate randomly distributed potential groundwater sampling sites based on aquifer extent, extent of irrigated agricultural land, depth to water from land surface, and saturated thickness.

Arnold et. al., (2009) designed and installed a well network to monitor recently recharged groundwater near the water table in areas of irrigated agriculture in the saturated portions of the High Plains aquifer of Colorado. Based on the State's goal of "reducing negative effects to groundwater and the environment by improving the management of agricultural chemicals and to ensure that groundwater remains safe for domestic and livestock consumption by preventing contamination", they guided their site selection process by only considering sites to drill wells in areas of irrigated agriculture where the depth to water allowed a particular drilling technique that limits introduction of drilling fluids into the aquifer and the aquifer exhibited a substantial saturated thickness providing the potential for long-term monitoring. Potential areas of irrigated lands to monitor were also aggregated into larger polygons if they were within a certain distance (1.24 miles) of each other. Drilling locations were created using a computerized technique that generates randomly distributed sites within areas fitting their criteria (within areas of irrigated agriculture where depth to water is less than 200 feet and saturated thickness is greater than 50 feet).

1.8.3 Contaminant Release Detection Networks

Nielson (1991) focuses on designing groundwater monitoring networks for regulated facilities where the goal of the network is to be able to detect impacts from facility operations, typically by comparing the quality of water entering and exiting the site (i.e., upgradient and downgradient comparisons). The site selection process uses information on facility features, geologic characteristics, and hydraulic characteristics to develop a conceptual model to illustrate the distribution of geologic materials at the site and their effect on groundwater flow direction and speed.

Gibbons (1994) examines multiple problematic issues inherent in the analysis of groundwater monitoring data. Much of the focus of the book relates to release detection networks.

1.8.4 Summary

Over the past thirty years, scientific literature on well network design and optimization has grown significantly (Farlin, et. al., 2019). As summarized in Daughney et. al. (2012), the different methods span a continuum going from purely data-based to purely process-based, blending different statistical and mathematical approaches with hydraulic, hydrologic and GIS-based modelling. Mathematical tools used include geostatistical techniques, principal components and cluster analysis, entropy, or Bayesian optimization methods and the use of groundwater flow models.

The LUBGWMA well network was not established using such rigorous statistical or mathematical techniques. Factors suggesting some degree of the representativeness of the LUBGWMA well network include:

- The network includes wells with low, medium, and high nitrate concentrations.
- The network includes wells located in multiple hydrogeologic settings.
- A large percentage of the area has one dominant land cover: cultivated crops.

1.9 Limitations and Biases of Network

Limitations and biases of the network include:

- The network was not developed through modern rigorous statistical methods so the representativeness of the network for the region was not statistically established.
- All instances of a particular land use are not being monitored. Different wells monitoring the same land use in different places can show different results.
- The network does not cover the entire LUBGWMA, including the westernmost 14 miles.
- The network relies almost exclusively on domestic wells and the cooperation of their owners. The reliance on privately-owned domestic wells limits the certainty of long-term well access and biases the network towards monitoring a deeper portion of the aquifer rather than near the water table where surface contaminants are more concentrated and detectable earlier.
- Property ownership changes and other factors have resulted in wells being dropped from the network.
- The selection criteria of moderate to high nitrate concentration or the detection of pesticides or Volatile Organic Compounds biases the network towards more contaminated wells.
- Nitrate sources are variable and change over time. Factors that affect groundwater nitrate concentrations include aquifer type, well depth, depth to water, soil drainage characteristics, aquifer type, amount of rainfall, amount of irrigation, amount of nitrogen applied, and denitrification in the subsurface. Some of these factors are non-changing (i.e., well depth and soil characteristics) while others can change without human involvement (e.g., precipitation and depth to water) while others are controlled by man (e.g., amount of irrigation and nitrogen applied). Since precipitation is a minor fraction of Alluvial Aquifer recharge in the LUBGWMA (Grondin et.al., 1995), variations in precipitation are not expected to be driving forces in groundwater nitrate concentrations. Changes in land use (primarily the amount, timing, and form of nitrogen and irrigation water applied to the surface) is likely the most important factor in groundwater nitrate variability that is controllable by humans.

2.0 Methods

This section describes the approach to the graphical analysis of general water quality and the statistical approach to nitrate trend analysis.

2.1 Graphical Analysis of General Water Quality

Piper (1944) and Piper (1953) proposed a graphic procedure to illustrate the sources of dissolved constituents in water and how they can mix. The procedure is based on the idea that most natural waters contain cations and anions in chemical equilibrium, and that the dominant ions are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride.

The Piper diagram is a projection of two ternary diagrams (one each for cations and anions) onto a diamond. The diamond can be separated into regions based on the dominant cations and anions in the water sample. These regions represent different hydrochemical facies or water types.

Two-component mixing can be seen on a Piper diagram. If two waters mix, the composition of the mixture will lie on a straight line joining the two end members (i.e., the two waters being mixed). The relative amount of each end member is inversely proportional to the distance of the mixture from that end member.

A query of DEQ’s AWQMS was performed that included results of all analytes from the current well network for the timeframe of this study (i.e., September 1991 through December 2023). Analytes required for Piper diagrams were culled from the query results and put into the chemical analysis spreadsheet AqQA to create Piper diagrams.

Results from each well from the most recent four sampling events that contained all the required analytes were plotted on a Piper diagram to assess general water types and general water quality stability.

2.2 Statistical Approach to Nitrate Trend Analysis

This section describes the rationale for using the particular statistical approach for this trend analysis. Aspects discussed include lessons learned from previous analyses, the specific methods used in this analysis, the timeframe of the data used, the choice of confidence level, analysis of data when nitrate is not detected, evaluation of serial correlation, evaluation of spatial correlation, and a discussion of statistical significance versus practical significance.

2.2.1 Lessons Learned from Northern Malheur County GWMA

The Northern Malheur County Groundwater Management Area was declared in 1989. The December 1991 NMCGWMA Action Plan included several measures of Action Plan success, including a statistically significant downward trend at the 80% confidence level. Evaluating this goal prompted DEQ to further review the statistical literature and evaluate various trend analysis techniques. As part of this analysis, multiple data sets were evaluated using several different techniques to determine how the analysis should be conducted. DEQ learned that using different trend analysis techniques causes differences in the calculated trends. The fact that using different trend analysis techniques produced different trends has two major implications:

1) it underscores the importance of using a technique that accommodates the complicating aspects of water quality data sets (e.g., missing data, non-normal distributions, and censored data), and
2) it suggests that the exclusive use of one technique that is appropriate for all data set characteristics would produce a more comparable set of results for comparisons made between wells and over time by eliminating variations in trend estimates produced by using multiple methods. The results would be more comparable both between wells for any given time (e.g., compare simultaneous trends in different areas), and at the same well at two different times (e.g., comparing a current trend to a past trend at a particular well).

Based on the literature view and testing of multiple trend analysis techniques, DEQ adopted the Seasonal-Kendall technique as the method to be used to evaluate water quality trends in the NMCGWMA and later in the LUBGWMA.

The Seasonal-Kendall technique (developed by the USGS in the 1980s specifically to accommodate seasonality) has become the most frequently used test for trends in the environmental sciences. It accounts for seasonality by computing the Mann-Kendall test on each season separately, and then combining the results (Helsel, et. al., 2020). In addition, environmental data sets often do not conform to the assumptions required by other tests but can be evaluated using the Seasonal-Kendall method without violating assumptions.

2.2.2 Specific Methods Used

This section describes the specific statistical methods used in this analysis. Appendix B is a list of the statistical test assumptions along with a discussion of how the data analyzed fit the assumptions and/or how some results were affected by not meeting test assumptions.

Water quality data are usually skewed so that the concentrations do not follow a normal distribution. For example, groundwater nitrate concentrations in this data set range from near zero (< 0.005 mg/L) to over 70 mg/L. Approximately one-third of the nitrate concentrations in this data set are less than 3 mg/L but none are less than zero. This clumping of results near (but not less than) zero illustrates their non-normal distribution. Based partly on that data set feature, non-parametric procedures including the Seasonal Kendall test and Kruskal-Wallis test were used for this analysis.

2.2.2.1 Seasonal Kendal Test for Linear Trends at Individual Wells

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. The final 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 Seasonal Kendall Test on Censored Data was selected for this trend analysis based on lessons learned in the NMCGWMA, the widespread usage of the Seasonal Kendall Test in environmental science investigations, recommendations in EPA (2006), and subsequent advancements in statistical testing of censored data (Helsel (2005) and Helsel (2011)).

The test counts the numbers of sequential increases and decreases in concentration across multiple years of data, conducting the test individually within each season and then combining the results into one overall test for trend (Frans and Helsel, 2005). Seasons or years with more data will have more influence on the outcome than less represented seasons or years.

The censeaken function found in the NADA2 R package was used to conduct the Seasonal Kendall test. The NADA2 package contains methods described in Helsel (2011) and courses and videos at http://practicalstats.com.

2.2.2.2 Regional Kendall Test for Linear Trend in the Network

The Seasonal Kendall Test used on individual wells was modified from its seasonal (i.e., quarterly) version into a regional version. A region in this context is a group of wells screened in the same aquifer (i.e., Alluvial or Basalt). Seasons for these Regional Kendall Tests were defined as a combination of well ID and quarter sampled.

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 substitute’s 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.

Trend tests are conducted at each season. Kendall’s S statistic for each well is then summed with other well ID/quarter seasons, so that the overall test determined if there was a consistent trend throughout that region (i.e., group of wells).

The censeaken function found in the NADA2 R package was used to perform the Regional Kendall test. The NADA2 package contains methods described in Helsel (2011) and courses and videos at http://practicalstats.com.

2.2.2.3 LOESS Line for Changes Within a Data Set

In addition to calculating the monotonic trends at each well, smoothed lines through the data were also calculated for each well. The smoothing technique called Local Regression (often called LOESS) was used to calculate these lines. LOESS is not a monotonic trend analysis technique. LOESS is a weighted least-squares method of placing a curve of the dependent variable through the center of a data set (Cleveland, et. al., 1992). In other words, it is a 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 a LOESS line. It provides a graphical depiction of the underlying structure of the data. The curve follows the general shape and direction of the data over time and defines the central tendency of the data. While a monotonic trend (such as the Seasonal Kendall test) estimates the change across the whole data set, the LOESS line estimates the change within the data set.

An advantage of LOESS is that no model, such as a linear or quadratic function, is assumed prior to computing a smoothed line. As such, LOESS 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. LOESS is particularly useful to emphasize the shape of the relationship between two variables on a scatterplot of moderate to large sample size.

Because a LOESS 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 within the data set. For example, a monotonic trend analysis result may indicate a statistically significant downward trend in a water quality variable over a 10-year period. However, the LOESS 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 period. However, the LOESS 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 analysis alone.

LOESS lines in this report were generated by the graphing software Grapher. The method fits simple polynomial models to localized subsets of data. The fits are defined by the percentage of data used in the calculation, the chosen algorithm, and whether the fit is linear or quadratic. Settings used in this report were a linear function was fit to a moving data span of 25% (25% to 50% are typical values) using a redescending M estimator with Tukey’s biweight or bisquare function.

2.2.2.4 Kruskal-Wallis and Peto-Peto Tests for Group Differences

The Kruskal-Wallis test is a non-parametric method for testing whether samples originate from the same distribution. It is the non-parametric equivalent of the one-way analysis of variance. It can be used for comparing two or more independent samples of equal or different sample sizes (Hollander and Wolfe, 1973). The nonparametric Kruskal-Wallis test was used to evaluate the presence of nitrate seasonality by comparing quarterly nitrate values. The Kruskal.test function found in the R package stats was used to perform the Kruskal-Wallis test.

The nonparametric Peto-Peto test extends the Kruskal-Wallis test to censored data by testing differences in cumulative distribution functions between groups (Peto and Peto, 1972; Benjamini and Hochberg, 1995; Helsel, 2011). The Peto-Peto test was used to evaluate the presence of nitrate seasonality in data sets with censored data and also to evaluate differences between the LUBGWMA Network results and OHA’s LUBGWMA Public Health Project (see Section 2.5).

The cen1way function found in the NADA2 R package was used to perform the Peto-Peto test. The NADA2 package contains methods described in Helsel (2011) and courses and videos at http://practicalstats.com.

2.2.2.5 Kendall's Tau for Correlation

The correlation between two variables (e.g., average nitrate concentration and total well depth) was evaluated using the non-parametric Kendall's Tau Correlation Coefficient. The cor.test function found in the R stats package was used to calculate Kendall's tau-b (with adjustments for ties) and the associated p-value.

2.2.3 Timeframe of Data

Agricultural practices across the LUBGWMA have been slowly changing since the groundwater nitrate contamination was identified in the early 1990s. The perception by the late 1990s was that there was a high level of adoption of best management practices by the food processors and the irrigated agriculture community. It has been suggested that statistical analysis should focus on data since 2000.

Routine sampling of the LUBGWMA Well Network began in September 1991. DEQ's view is that the goal of this statistical analysis is to evaluate the long-term changes in groundwater nitrate concentrations and that is best done using the entire data set from the well network.

The network was originally targeted for sampling in the six odd-numbered months (i.e., January, March, May, July, September, and November). Due to budget restrictions, sampling frequency was reduced starting in 2011 to include only the target months of March, May, September, and November.

The data used in this analysis includes 3,174 samples collected during 124 sampling events. Due to the pandemic, no sampling event occurred in 2020, May 2021, or September 2021.

Eleven sampling events were not fully completed within the target month. Six events were completed within one or two days of the target month. Four events were conducted within four to eight days of the target month. One event was conducted within fifteen days of the target month. In addition to samples collected in the target months of March, May, September, and November, 219 samples collected in April, June, October, and December as part of routine sampling events in the target months were included in this analysis. No results from January, July, or August were used in this analysis. Appendix A details the procedure used to download the data from AWQMS and to prepare the data for statistical analysis.

2.2.4 Choice of Confidence Level

One of the water quality goals (i.e., Measure of Action Plan Success) in the NMCGWMA Action Plan was that a statistically significant downward trend be demonstrated at the 80% confidence level. No magnitude of change was specified. DEQ chose to use a confidence level of 80% for that water quality goal. DEQ also uses an 80% confidence level for trend analyses of surface water quality data. An 80% confidence level essentially makes a trend easier to detect and harder to miss. The effect of using an 80% confidence level rather than a higher confidence level also made it easier to achieve the water quality goal of a decreasing trend. To maintain consistency, its use was continued in evaluating LUBGWMA data.

Larger data sets typically result in trend estimates with higher confidence levels. This analysis includes over 100 sample results for most wells, which generates calculated trends with a confidence level of 99% or higher for most wells. Trend estimates from this analysis typically have a very high confidence level (i.e., >99%). Three have very low confidence level (i.e., < 50%) while one has a confidence level in the 80% to 90% range.

2.2.5 Analysis of Data Where Nitrate Was Not Detected

Results from some wells were sometimes reported as below the nitrate detection limit (e.g., <0.005 mg/L). In the statistical literature, results reported as below the detection limit are called "censored". 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) and Helsel (2011) for computing summary statistics and calculating trends were followed using R functions written by Dr. Helsel and others. These include the following:

- For wells with less than 50% censored data, the mean and median were calculated by the Regression on Order of Statistics method using the R function censtats found in the NADA R package.
- For wells with a more than 50% censored data, the mean and median were determined by comparing to percentiles (e.g., if the middle-ranked value was <0.005 mg/L, then the median value is reported as <0.005 mg/L.
- Trends at wells with non-detected values were calculated by the censeaken function found in the NADA2 R package.

2.2.6 Serial Autocorrelation

Serial autocorrelation is the dependence of a particular result on the prior result. This violates the statistical assumption that each data point is independent and can happen when samples are collected too close in time. If serial correlation is present in a data set and not accounted for, the reported confidence level could be too high. Neither the trend slope or direction is affected. The potential for serial correlation within the LUBGWMA well network data set was evaluated in 2013 when the network was sampled six times per year. Those results showed that accounting for potential serial correlation made very little difference in the calculated trends.

In summary, with one exception the confidence level dropped for several wells but remained statistically significant. One decreasing trend was moved to the statistically insignificant category. Serial correlation is not expected to be a significant issue in this data set and was not evaluated.

2.2.7 Spatial Autocorrelation

Spatial autocorrelation refers to the correlation among values of a variable that can be strictly attributable to their relatively close locational positions. This can violate the statistical assumption of independence.

Spatial autocorrelation of nitrate concentrations was evaluated both visually and statistically. Visual evaluation was performed by examining nitrate concentration graphs of the wells spaced closest together for similarities. Statistical evaluation was performed using the Global Moran's I tool in ArcGIS Pro. The tool "measures spatial autocorrelation based on both feature locations and feature values simultaneously. Given a set of features and an associated attribute, it evaluates whether the pattern expressed is clustered, dispersed, or random. The tool calculates the Moran's I Index value and both a z-score and p-value to evaluate the significance of that index." The tool results will not be reliable with less than 30 features (ESRI, 2024).

Positive Moran's I Index values suggest similar values are clustered together while negative values mean similar values are more spatially dispersed than random. However, Moran's Index signs are only meaningful if Moran's I is statistically significant (i.e., the p-value is less than the chosen significance level).

The November 2023 nitrate values from the network wells were evaluated with the tool using the Inverse Distance Squared Spatial Relationship Conceptualization (most appropriate with continuous data or to model processes where the closer two features are in space, the more likely they are to interact with or influence each other), the Euclidean Distance Method (appropriate for modeling continuous data such as groundwater nitrate concentrations), and a significance level of 0.10 (i.e., a confidence level of 90%).

2.2.8 Statistical Significance versus Practical Significance

DEQ uses statistical significance as a bright line for evaluating trend direction. A trend is either increasing (a positive slope and high confidence level), decreasing (a negative slope and high confidence level), or statistically insignificant (low confidence level regardless of slope). A statistically significant trend can have a very small slope. This could mean something can have statistical significance and regulatory significance but be practically insignificant. A statistically significant trend that is slightly increasing would not meet the compliance goal of a decreasing trend, but a statistically significant slightly decreasing trend would. Either trend might arguably be called practically insignificant.

2.3 Trend Analysis at Individual Wells

The Seasonal Kendall test was performed on each of the 33 wells currently in the LUBGWMA network. Trends at individual wells were then summarized by frequency and magnitude. The number of trends in each of three groups were compared: (1) small trends being those with a slope up to 0.1 mg/L/yr (2) medium trends being those with a slope of 0.1 to 0.5 mg/L/yr, and (3) large trends being those with a slope greater than 0.5 mg/L/yr.

2.4 Nitrate Concentration and Trends by Well Group

Figure 3 shows the 33 wells in the network split into nine groups of wells based on geographic proximity. Each group has two, three, four, five, or seven wells. Well depth, nitrate concentrations, trends, and seasonality of the wells within each group are compared and contrasted.

2.5 Comparison to LUBGWMA Public Health Project Data

2.5.1 Establishment of LUBGWMA Public Health Project

Following a local public health emergency declaration by Morrow County in June 2022, OHA was tasked by the Governor's Office and the Oregon Legislature in late 2022 to work with partners to alert residents to the potential health risks of nitrates and offer access to safe water. The effort is called the LUBGWMA Public Health Project. The project includes outreach and education to alert residents to the health risk, water sample collection and laboratory testing, delivery of bottled water and installation of kitchen-tap water treatment systems. Partners include Morrow and Umatilla County Health Departments, Oregon Department of Human Services, and a number of local community-based organizations (Goldfarb, 2024).

The domestic well sampling portion of OHA's LUBGWMA Public Health Project began in March 2023 following direction from the Governor and legislature to identify well-dependent households in the LUBGWMA where residents are at risk of exposure to nitrate in drinking water and cooking water at levels above the 10 mg/L drinking water standard. More information about this initiative, which offers free well water testing, point-of-use reverse osmosis treatment systems, and water delivery, is available at testmywell.oregon.gov. The OHA Domestic Well Safety Program historically has been limited to outreach and education to well owners but was directed and resourced to deliver services to specific groups of domestic well owners in the LUBGWMA.

2.5.2 Nitrate Data Set

Between March 2023 and September 25, 2024, OHA accumulated 2,392 nitrate test results from 1,872 households out of roughly 3,300 well-dependent households in the LUBGWMA. The households were identified by OHA and partners through a door-to-door canvassing effort in Summer 2023. In June 2024, OHA initiated quarterly retesting for one year at households whose initial results were between 5 mg/L and 9.99 mg/L to evaluate seasonal fluctuations. If these households remain below 10 mg/L after one year of testing, they will be shifted to an annual retesting schedule. Households in other tiers are able to receive free annual nitrate tests.

Some errors (such as results submitted more than once or incorrect addresses) were identified and corrected in the database of results. Additional errors are anticipated but OHA believes the majority of the data are accurate (Goldfarb, 2024). At the time this report was prepared, the LUBGWMA Public Health Project website included maps showing the single highest nitrate result obtained from March 2023 through September 30, 2024.

2.5.3 Comparisons Made

In addition to comparing aspects of the datasets like purpose, number of samples, and timeframe, the statistical distribution of nitrate concentrations and geographical distribution of sample locations were compared.

OHA provided DEQ with a copy of their data through September 25, 2024 (minus personal identification information) which allowed DEQ to compare some characteristics of the data sets including number of wells sampled, number of results, length, and timeframe. The Peto-Peto test (which evaluates whether one group is shifted higher than another by evaluating their cumulative distribution functions) was used to test for differences between the data sets. Average values from each data set were estimated using the Kaplan-Meir method.

A map was also prepared showing the geographic overlap between the data sets. In addition, the percentage of each data set collected in each of the six zip codes within the LUBGWMA was compared.

3.0 Results

This section describes the LUBGWMA well network data set, the general water quality types of network wells, the evaluation of serial autocorrelation, LUBGWMA Well Network nitrate concentrations and trends, and the comparison of LUBGWMA Well Network data to the LUBGWMA Public Health Project Data.

3.1 Description of Data Set

The data used in this analysis consists largely of quarterly measurements of groundwater nitrate concentrations over a 32-year period. On occasion, samples were analyzed for a larger list of constituents including general chemistry analytes, volatile organic compounds and pesticides. Results of the general chemistry and nitrate monitoring are discussed below.

3.2 General Water Quality Type

Figure 4 is a Piper Diagram showing results from the four most recent sampling events that contained all the analytes required to make a Piper diagram (i.e., July 2005, November 2005, March 2006, and September 2009). Total Alkalinity has not been an analyte since November 2009 so wells UMA312 and UMA313 added in 2012 are not included in the Piper diagram.

Figure 4 shows most samples from the network wells at that time fall within the Calcium +Magnesium / Bicarbonate ($Ca+Mg/HCO_3$) water type field. However, Alluvial Aquifer well UMA056 plots by itself in the mixed water type closest to the Sodium + Potassium / Sulfate + Chloride ($Na+K/SO_4+Cl$) water type field. The well is located about 800 feet north of the Furnish Ditch and about 500 feet east of a lateral. However, nitrate concentrations do not show seasonality and were about 5 to 6 mg/L at the time the general chemistry analytes were quantified. Another unusual aspect of well UMA056 is that very high dissolved oxygen levels and degassing have been observed during sampling. The cause for the unusual observations regarding general chemistry and degassing at UMA056 is not known.

Another example of water samples plotting outside the $Ca+Mg/HCO_3$ water type include the Basalt Aquifer well UMA029 which plots largely as a Calcium + Magnesium / Sulfate + Chloride ($Ca+Mg$ / SO_4+Cl) water type mixing towards $Ca+Mg/HCO_3$ water type in the last sample. As described later, this well has elevated nitrate concentrations. The well log indicates water levels observed during drilling suggest a downward flow potential.

Appendix C contains Piper diagrams for each individual well plus three diagrams showing a particular group of wells. The figures show that most wells have results that form a tight cluster on a Piper diagram showing a consistent water quality over that timeframe.

Exceptions to the tight clustering include the two irrigation wells and the industrial well. The figure in Appendix C with wells UMA160, UMA191, and UMA198 shows the general chemistry of the irrigation well UMA191 and the industrial well UMA198 plot predominantly as $Ca+Mg/HCO_3$ water type but mixing towards $Na+K/HCO_3$ water type. Similarly, Alluvial Aquifer irrigation well UMA160 plots as Na+K/HCO_3) water type mixing towards Ca+Mg/HCO_3 water type. Rather than progressing in a straight line which suggests a consistent change in water quality, these samples bounce back and forth along a line suggesting the mixing of different quality waters.

3.3 November 2023 Nitrate Concentrations

The most recent sampling event included in this analysis was conducted in November 2023 when 30 wells were sampled. Figure 5 shows the results of the November 2023 sampling event. Concentrations ranged from < 0.005 mg/L to 67.8 mg/L. Eighteen of the wells sampled (60%) were below the 10 mg/L Federal Maximum Contaminant Level for drinking water, which is also the Oregon Numerical Groundwater Quality Reference Level for nitrate found in OAR 340-040-0020 Table 1.

Although the highest nitrate concentrations observed are in the western half of the network, no clear geographic pattern to nitrate concentrations is evident. Instead, large differences in nitrate concentration occur within relatively short distances. For example, the well with the highest observed concentration (67.8 mg/L at UMA198) is about 1.5 miles from the nearest well (UMA094) which had 4.66 mg/L nitrate.

Another example of nitrate variability within a small portion of the LUBGWMA is the group of six wells near Irrigon. Within a radius of about a mile, nitrate concentrations of 0.0829, 5.29, 5.56, 8.04, 10.3, and 32 mg/L were observed.

3.4 Evaluation of Spatial Autocorrelation

As indicated in Section 2.2.7, both a visual and a statistical evaluation of nitrate concentrations were performed to evaluate spatial autocorrelation. Nitrate concentration graphs of the wells closest together were visually examined for similarities. The November 2023 nitrate concentrations were used to statistically evaluate spatial autocorrelation. Results of the visual and statistical evaluation of spatial autocorrelation are discussed below and indicate no evidence of spatial autocorrelation was identified.

3.4.1 Visual Evaluation

The two network wells closest to each other are the Basalt Aquifer well UMA164 and the Alluvial Aquifer well UMA312 near Irrigon. The wells are less than 500 feet apart with about 27 feet separating their open intervals. As shown in Figure 14, they show similar overall trends (UMA164 is increasing while UMA312 is a statistically insignificant increasing trend) but nitrate concentrations are higher in the Alluvial Aquifer well (median about 8 mg/L) than the Basalt Aquifer well (median during the same time frame about 5 mg/L) and LOESS lines are dissimilar. The nitrate concentrations over time at these nearby wells in two different aquifers do not appear to be dependent on each other. It is worth noting that UMA312 is no longer part of the well network because it was only sampled from March 2012 to November 2019 and is therefore unlikely to be included in future trend analyses.

The next closest wells include three Alluvial Aquifer wells near Irrigon (UMA033, UMA034, and UMA313) located within the same hydrostratigraphic unit (i.e., coarse-grained Missoula Flood Deposits) about 2600 to 2700 feet apart. UMA313 is located about 500 feet from the Columbia River and exhibits low (<1 mg/L) and decreasing nitrate concentrations while UMA033 and UMA034 have increasing nitrate concentrations that average 7.4 mg/L and 4.2 mg/L, respectively. UMA034 shows seasonality and multi-year cycles while the other two wells do not.

Nitrate concentrations over time in these three wells within the same hydrostratigraphic unit do not appear to be dependent on each other.

3.4.2 Statistical Evaluation

The Global Moran's I Index test results include a Moran's Index of 0.22, a z-score of 1.57, and a p-value of 0.1168. The test conclusion is that "the pattern does not appear to be significantly different than random". In other words, no spatial autocorrelation was identified in the well network. Therefore, the assumption of independence is not adversely affected by the locations of the wells in the LUBGWMA network.

3.5 Nitrate Summary Statistics

This section describes the range and average nitrate concentration at individual wells, plus the median, average, and maximum value observed in the 29 long-term wells over time.

3.5.1 Concentration Range

Table 1 shows nitrate concentrations, trends, and seasonality at the LUBGWMA Network wells. As shown in Table 1, over the 32-year monitoring period nitrate concentrations have been as low as non-detectable (<0.005 mg/L) to as high as 75.5 mg/L. Three wells have 1% or 2% of results below detection limit. One has about 12% non-detects, another has 91% non-detects.

The range of nitrate concentrations observed at an individual well (i.e., the maximum concentration at the well minus the minimum concentration at the well) varied from 0.1 mg/L (at UMA187) to 69.7 mg/L (at UMA198; Table 1). The middle half of the ranked ranges is from 4.6 mg/L to 27.6 mg/L. The median range is 9.0 mg/L.

3.5.2 Average Concentrations

Figure 6 shows the average nitrate concentration at each well from September 1991 through November 2023, or the entire data set for wells with shorter timeframes. See Table 1 for timeframes. Average nitrate concentrations ranged from <0.005 mg/L at UMA187 to 40.5 mg/L at UMA029. Twenty-two wells (67%) have average nitrate concentrations of less than 10 mg/L.

As with the November 2023 concentrations, the highest average nitrate concentrations are observed are in the western half of the network with no clear geographic pattern evident. Instead, large differences in average nitrate concentration occur within relatively short distances.

3.5.3 Nitrate Statistics by Year

Figure 7 shows three nitrate summary statistics for the 29 long-term wells over time: median, average, and maximum value. If, as happened often, all 29 long-term wells were sampled four times in a particular year, the annual statistics are based on 116 results. The median, average, and maximum value from every well sampled during each year are plotted on Figure 7. A LOESS line is drawn through the annual values. Note the break in scale from 15 to 35 mg/L and the change in scale for maximum concentrations.

In summary, annual median, annual average, and annual maximum nitrate concentrations increased over the 32-year period. The overall increasing annual median, average, and maximum nitrate concentrations suggest an overall increase in nitrate within the network (Figure 7).

More specifically, the annual median nitrate concentration generally increased over time and fluctuated between 3.8 mg/L (in 1994) and 7 mg/L (in 2017). The LOESS line through annual median concentrations increases from about less than 5 mg/L to about 6.6 mg/L (Figure 7).

The annual average nitrate concentration generally increased over time and fluctuated between 8.1 mg/L (in 1994) and 13.3 mg/L (in 2023). The LOESS line through annual average concentrations fluctuates but generally increases from about 8.7 mg/L to about 13.3 mg/L.

The annual maximum nitrate concentration generally increased over time and fluctuated between 38.8 mg/L (in 2009) and 75.5 mg/L (in 2023). The LOESS line through the annual maximum concentration fluctuate until about 2020 when it increases more steeply.

3.6 Nitrate Seasonality

Using differences between quarterly nitrate values as a metric, 14 of the 33 wells (42%) exhibited nitrate seasonality, defined here as a statistically significant difference in quarterly nitrate concentrations at a 90% confidence level by either the Kruskal-Wallis test (for those datasets with no censored data) or the Peto-Peto test (for those datasets with censored data). All but one well that showed seasonality (UMA106) are Alluvial Aquifer wells.

It is worth noting that because sample frequency was reduced from six times per year to four times per year by dropping two sampling events, “quarterly” sampling events now occur either two months apart (Q1 to Q2 and Q3 to Q4) or four months apart (Q2 to Q3 and Q4 to Q1).

Nine different combinations of quarterly highs and lows were observed. The most common annual pattern occurred at four wells (29%) when nitrate ranked highest to lowest from Q2 to Q1 to Q3 to Q4. In other words, nitrate was typically higher in March and May than in September and November.

The second most common annual pattern occurred when nitrate ranked highest to lowest from Q1 to Q2 to either Q3 (2 wells) or Q4 (2 wells) to either Q3 or Q4.

Overall, ten of the 14 wells (71%) showed highs in either March (Q1) or May (Q2) and lows in either September (Q3) or November (Q4). In summary, for the wells exhibiting seasonality, nitrate is typically higher in March and May than in September and November.

Figure 8 illustrates the range of quarterly median nitrate concentrations at the wells showing seasonality.

The wells are arranged in Figure 8 from left to right according to increasing depth to the well's open interval. The depth to the top of the open interval is noted for each well. The well with the shallowest depth to open interval is UMA191 (17.5 ft). The well with the deepest depth to open interval is UMA094 (101 ft). No correlation between well depth and the amount of seasonal nitrate fluctuation is apparent in Figure 8. The wells with the largest seasonal fluctuations occur in wells with depth to open interval ranging from 40 to 80 feet below land surface.

Because ties affect the correlation coefficient's absolute value, significant ties in the wells' depth to open interval (6 of 14 wells had tied values) resulted in a statistically insignificant correlation coefficient (tau = 0.101; p=0.62) which may or may not reflect a true lack of correlation between amount of seasonality and depth to open interval.

While not evaluated in this report, it is possible that proximity to surface water features (including canals) could be correlated with nitrate seasonality.

3.7 Nitrate Trends

A basic component of the evaluation of trends is the time versus concentration graph. Time versus nitrate concentration graphs for each well are included as Appendix D. Also included on the graphs in Appendix D are the monotonic trends (showing the overall change) and a LOESS line (showing general patterns within the data). Appendix D also contains one page with the LOESS line and trend line at all 33 wells at the same scale on one page.

Trend analysis results 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). As discussed previously, test results with confidence levels less than 80% are considered "statistically insignificant" for LUBGWMA studies. 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 regardless of slope value. Some trends calculated in this study were very small (a few thousands of a part per million per year) but no trends had a slope of zero. Trends of very small magnitude could arguably be called effectively flat. See Section 2.2.8 for a discussion of statistical significance versus practical significance.

3.7.1 Individual Well Trends

Trends by Statistical Significance and Direction - Results of nitrate trend analyses at individual wells are summarized in Table 1. Only considering the statistical significance and direction of the 33 wells, 18 show increasing trends, 12 show decreasing trends, and 3 show statistically insignificant trends. The steepest increasing trend (1.20 mg/L/yr) was observed at UMA198. The steepest decreasing trend (-0.42 mg/L/yr) was observed at UMA029. It is noteworthy that two of the three wells exhibiting statistically insignificant trends have average nitrate concentrations above the LUBGWMA target concentration of 7 mg/L.

Trends by Direction and Magnitude - Table 2 summarizes nitrate trends of the 29 long-term wells by direction and magnitude by parsing increasing, decreasing, and statistically insignificant trends by magnitude into three categories: small (up to 0.1 mg/L/yr), medium (0.1 to 0.5 mg/L/yr), and large (greater than 0.5 mg/L/yr). In summary, increasing trends are more numerous and steeper than decreasing trends.

When viewed by direction, there are more increasing trends than decreasing trends (17 vs 10; 59% vs 35%). When viewed by average magnitude, average increasing trends are steeper than average decreasing trends (0.29 mg/L/yr vs -0.14 mg/L/yr).

When viewed by direction and magnitude, the following observations were made:

- Small trends – Increasing trends are more numerous (10 vs 4) but the average slopes are equal (0.05 mg/L/yr) vs -0.05 mg/L/yr).
- Medium trends – Decreasing trends are more numerous (6 vs 4), but less steep than increasing trends (average -0.21 mg/L/yr vs 0.34 mg/L/yr).
- Large trends – All large trends are increasing and average 1.01 mg/L/yr. It is noteworthy that the four largest trends (and seven out of the top ten largest trends) are increasing.

Figure 9 shows the nitrate trends at individual wells by magnitude. The largest increasing trends and largest decreasing trends are in the western half of the network. The three largest increasing trends include the Alluvial Aquifer industrial well UMA198 (1.20 mg/L/yr) and the Alluvial Aquifer domestic wells UMA180 (1.05 mg/L/yr) and UMA201 (0.79 mg/L/yr). The three largest decreasing trends are at the Basalt Aquifer domestic well UMA029 (-0.42 mg/L/yr), Alluvial Aquifer domestic well UMA133 (-0.38 mg/L/yr), and Alluvial Aquifer domestic well UMA144 (-0.12 mg/L/yr).

Correlation between nitrate and well depth - Significant ties in well depths (13 wells tied at 5 depths) resulted in a weak negative correlation between well depth and average nitrate concentration (Kendall’s tau = -0.174; p=0.158) and between well depth and trend slope (Kendall’s tau = -0.178; p=0.149). Ties in well depths are given less weight in the correlation coefficient calculation resulting in a smaller absolute value compared to a scenario with no ties, even if the underlying relationship between variables remains the same. In other words, any true correlation between nitrate concentration and depth may not be observable with this well network.

3.7.2 Network-Wide Trends

Rather than as individual wells, Table 3 shows the nitrate concentrations, trends, and seasonality of the network wells as a whole (all 33 wells) and as three subsets: the 29 long-term wells, the 26 long-term alluvial wells, and the 3 long-term basalt wells.

The trends in Table 3 were calculated using the Regional Kendall technique using the Well ID/Quarter Sampled as the season. As indicated in Table 3, the network-wide trend was increasing at about 0.03 to 0.04 mg/L/yr in each group of wells. The network-wide trend using the 29 long-term wells and the entire dataset (increasing at 0.04 mg/L/yr) best fits the assumptions of the test so it is viewed as the best estimate of the network-wide trend.

Figure 10 shows the 3,431 nitrate results from the 29 long-term wells over the 32-year period with the network-wide trend and LOESS lines drawn through the data. It is noteworthy that all concentrations exceeding 45 mg/L are from the well with the steepest increasing trend (UMA198) and the steepest decreasing trend (UMA029). The lack of data in 2020 and fewer than normal results from 2021 (particularly from wells with high concentrations and increasing trends) are possible causes of the recent dip in the LOESS line.

3.7.3 Network-Wide Nitrate Trends Over Time

Figure 11 shows the Network-wide trend over time utilizing the 29 long-term wells. The trend through 2023 (noted as 0.038) is the 0.04 mg/L/yr network-wide trend discussed above. The trend through previous years was calculated by sequentially deleting the most recent year of data and recalculating the trend. Note that no samples were collected in 2020 and fewer than normal samples were collected in 2021.

In summary, the network-wide trend has been slightly increasing (about 0.03 to 0.09 mg/L/yr) since enough data were collected to calculate a statistically significant trend (i.e., since 1999).

Trends including data through 2002 and longer are more robust estimates than those for shorter timeframes because all 116 seasons (29 wells sampled 4 times per year) are used in the calculations from 2002 forward. The effect of dropping seasons is to underemphasize results from those seasons. Seasons dropped from the analysis came largely from one well (UMA180) sampled in Q1 and Q4, and were all less than 2 mg/L. Therefore, the effect of dropping seasons with low values (which generally characterizes what was done up through 2001) is to underemphasize low values during those timeframes and potentially overestimate the trend slope.

3.7.4 Implications of Increasing Nitrate Concentrations

Recent nitrate concentrations shown in Figure 5, average nitrate concentrations shown in Figure 6, and short-term changes in nitrate concentrations shown by LOESS lines in Appendix D are useful to place these long-term trends into context. The continued increase of nitrate concentrations at many wells, and in the network as a whole, indicate current nitrate leaching is likely.

As summarized below, current nitrate leaching has been predicted and observed by researchers including Hitt and Nolan (2005), Wang, et al., (2015), Almasri and Kaluarachchi (2004), Weitzman, et al., (2022), and Weitzman, et al., (2024).

Studies such as Hitt and Nolan (2005) show that the likelihood of nitrate contamination of shallow groundwater is greatest in areas with high nitrogen input and well-drained surficial soils that overlie unconsolidated sand and gravel aquifers. They determined that increases in these six variables associated with nitrogen input and aquifer susceptibility increase the probability of nitrate leaching: nitrogen fertilizer applications, agricultural land use, population density, well-drained soils, depth to seasonally high-water table, and unconsolidated sand and gravel aquifers. They point out that the central Columbia Plateau is an area where their model matches observed conditions in that high median predicted probability of nitrate contamination corresponds to a high observed proportion of wells with nitrate concentrations greater than 4 mg/L. They also note that “nitrate can persist in groundwater for decades and accumulate to high levels as more nitrogen is applied to the land surface every year”.

Both regional and international studies have indicated nitrogen loading to the land surface every year produces elevated groundwater nitrate concentrations that can persist in groundwater for decades and accumulate to high levels.

Wang, et al., (2015) cites seven studies from around the world that have shown agricultural activities are a significant source of surface and groundwater pollution due to long-term and excessive fertilizer use.

Almasri and Kaluarachchi (2004) assessed nitrate concentrations in Whatcom County Washington and noted that areas with nitrate concentrations above the drinking water standard are characterized by heavy agricultural activities. Their analysis showed that high nitrate presence corresponds to areas with both high ground water recharge and high on-ground nitrogen loading. They concluded “the trend of long-term nitrate concentration remained elevated in shallow aquifers due to the persistent on-ground nitrogen loadings produced by agriculture-related land use practices”.

Recent studies in western Oregon using stable isotopes of nitrate and water showed less than half of nitrogen fertilizer applied to a corn crop (about 44%) was removed in crop harvest, about 27% was stored in the soil within the rooting zone, and about 29% was leached below the rooting zone (Weitzman et al., 2022). Of the 29% that was leached below 3.0 m, about 11% was recently-applied fertilizer and about 18% was fertilizer from previous applications that had been microbially-processed in the vadose zone and remobilized (Weitzman, et al., 2024).

3.8 Nitrate by Well Group

Figure 3 shows the well network divided into nine groups of wells based on geographic proximity. Figures 12 through 22 show the nitrate concentration graphs for the nine groups of wells. The open intervals, nitrate concentrations, nitrate trends, LOESS lines, nitrate seasonality, and any other pertinent observations regarding the wells in each group are summarized below. Unless otherwise stated, wells are Alluvial Aquifer domestic wells.

3.8.1 Group 1 – Two Boardman Area Wells

Figure 12 shows the nitrate concentration graphs for the two Boardman area wells UMA029 and UMA201. In summary, they have high concentrations (>90% above 10 mg/L) but are in different aquifers and show dissimilar trends.

Open Intervals - The open intervals are very different lengths and overlap in depth from land surface but they are completed in different aquifers. UMA029 is a Basalt Aquifer well with a longer than average open interval of 34 to 100 feet below land surface. UMA201 is an Alluvial Aquifer well with a short open interval of 80 to 85 feet below land surface.

Concentrations - All nitrate results from UMA029 and 90% of nitrate results from UMA201 exceed 10 mg/L. UMA029 has the highest average nitrate concentration in the network (40.5 mg/L).

Trends - UMA029 shows a medium decreasing trend (-0.42 mg/L/yr) while UMA201 shows a large increasing trend (0.79 mg/L/yr).

LOESS Lines – The UMA029 LOESS line suggests almost decadal cycles prior to about 2007 when typical concentrations were 45 to 50 mg/L. Concentrations dropped to about 30 mg/L from about 2007 to 2011 before rising to about 40 mg/L by 2024.

The UMA201 LOESS line increases over time with some multi-year cycles. Both LOESS lines show concentrations generally increasing from about 30 to 40 mg/L over the last decade.

Seasonality – UMA029 does not show seasonality, but UMA201 shows seasonality with nitrate highest in Q1 and lowest in Q3. About 10% of UMA201 results are less than 10 mg/L and occur between 2014 and 2020, largely in Fall but also in Spring. These low values likely contribute to the detection of statistically significant seasonality based on quarterly medians because otherwise a steep trend can mask differences in quarterly median values.

3.8.2 Group 2 –Three Wells South/Southwest of Irrigon

Figure 13 shows the nitrate concentration graphs for three wells south-southwest of Irrigon. In summary, these average depth wells have elevated nitrate concentrations (two average more than 10 mg/L), and a mix of trends (one small increasing trend with multiple changes through the years, one large increasing trend, and one medium decreasing trend).

Open Intervals – These wells are about average in depth and either have a short open interval (79.5-85.5 flbs at UMA160) or no open interval (UMA144 open at 57 feet below land surface; UMA180 open at 47 feet below land surface).

Concentrations – All three wells have a maximum concentration exceeding 25 mg/L. Two of three wells (UMA144 and UMA180) have average concentrations exceeding 10 mg/L.

Trends – Two wells are increasing while the third is decreasing. UMA180 shows a large increasing trend that steepens around 2005. The irrigation well UMA160 shows a small increasing trend largely driven by significantly higher concentrations from 2002 into 2013 and more recent elevated concentrations. UMA144 shows a medium decreasing trend.

LOESS Lines – The LOESS line for UMA144 generally decreases and suggests subtle multi-year cycles. The LOESS line for UMA180 generally increases with some fluctuations. The LOESS line for UMA160 shows multiple changes through the years; flat from 1991 until about 1998 when it increases until about 2005 then decreases to about 2016 then increase again through 2024.

Seasonality – Only UMA144 shows seasonality; with nitrate highest in Q1 and lowest in Q3. 2008 was uncharacteristic in that nitrate did not peak in Q1 but increased in Q2 and Q3 (to 42.3 mg/L) before dropping 24.5 mg/L in Q4 to 17.8 mg/L. This larger than usual and out of synch fluctuation suggest something unusual occurred in 2008.

3.8.3 Group 3 – Five Wells in and West of Irrigon

Figure 14 shows the nitrate concentration graphs for five wells in and west of Irrigon. In summary, nitrate concentrations are generally less than 10 mg/L with nitrate trends generally increasing. The low nitrate concentrations at UMA313 could be affected by the nearby low-nitrate Columbia River[1].

The Basalt Aquifer well UMA164 and the Alluvial Aquifer well 312 are located approximately 500 feet apart with about 27 feet separating their open intervals. They show similar trends (UMA164 is increasing while UMA312 is a statistically insignificant increasing trend) but nitrate concentrations are higher in the Alluvial Aquifer well (median about 8 mg/L) than the Basalt Aquifer well (median during the same time frame about 5 mg/L).

Open Intervals – The four Alluvial Aquifer wells are average in depth, have relatively similar open intervals, and range from 40 feet to 80 feet below land surface. The Basalt Aquifer well UMA164 is deeper with an open interval of 88 to 175 feet below land surface.

Concentrations – All nitrate concentrations from four wells and 95% of results from the fifth well are below 10 mg/L.

[1] DEQ collected surface water samples at six locations in the Columbia River adjacent to the LUBGWMA in September 2009. Nitrate values ranged from 0.0205 mg/L to 0.0825 mg/L and averaged about 0.065 mg/L.

Trends – The three long-term wells (including the Basalt Aquifer well UMA164) show small increasing trends. One of the short-term wells (UMA312) shows generally increasing concentrations but a statistically insignificant trend. The short-term well UMA313 is located less than 500 feet from the Columbia River and shows low and decreasing nitrate concentrations. The low nitrate concentrations at the well could be affected by the nearby low-nitrate River.

LOESS Lines – Overall, the LOESS lines at the three long-term wells generally increase, with the UMA034 LOESS line showing multi-year cycles while it generally increases. The LOESS lines at the short-term wells are slowly decreasing at UMA313 and increasing then decreasing at UMA312.

Seasonality – One of the five wells (UMA034) shows seasonality; with nitrate highest in Q1 and lowest in Q4.

3.8.4 Group 4 – Three Wells in and West of Umatilla

Figure 15 shows the nitrate concentration graphs for three wells in and west of Umatilla. In summary, nitrate at wells west of City limits are above 10 mg/L and increasing while nitrate at the well within City limits is below 10 mg/L and decreasing.

Open Intervals – The wells west of the City limits are open to gravels at 40 feet below land surface and 57 feet below land surface. The well within City limits (UMA038) is open to gravels at 57 feet below land surface.

Concentrations – With two exceptions, nitrate concentrations at the wells west of City limits are greater than 10 mg/L. Nitrate at the well within City limits is less than 10 mg/L. The two wells west of the city (UMA103 and UMA096) average 23.1 mg/L and 33.1 mg/L respectively, while the well within the city (UMA038) averages 2.9 mg/L.

Trends – Wells west of City limits (UMA096 and UMA103) exhibit medium increasing trends while the well within City limits (UMA038) exhibits a small decreasing trend.

LOESS Lines – The LOESS lines for the two wells west of City limits are generally increasing while the LOESS line through the well within the city limits is generally decreasing.

Seasonality – Wells UMA038 and UMA096 exhibit seasonality with nitrate highest in Q2 and lowest in Q4.

3.8.5 Group 5 – Seven Wells East of Hermiston

Group 5 consists of seven wells east of Hermiston. The seven wells are plotted as two subgroups based on nitrate concentration: Group 5a with higher nitrate concentrations than Group 5b. Figure 16 shows the nitrate concentration graphs for Group 5a - three wells east of Hermiston.

Group 5a wells largely surround the other four wells in Group 5 but have significantly higher concentrations. Two wells show seasonality (but with different timing) while all three wells show evidence of multi-year cycles. A relatively abrupt increase in nitrate concentrations at UMA110 around 2007 suggest a change in nearby land use.

Group 5a Open Intervals – The open intervals for these relatively shallow wells are relatively short (at most 11 feet) and get progressively deeper with UMA110 the shallowest and UMA156 the deepest (31-42 feet below land surface at UMA110; 44-45 feet below land surface at UMA109; 47-54 feet below land surface at UMA156).

Group 5a Concentrations – The shallower wells (UMA110 and UMA109) have an average nitrate concentration less than 10 mg/L but are increasing and currently exceed 10 mg/L. The deepest well (UMA156) fluctuates between about 4 mg/L to 32 mg/L and averages 18.5 mg/L.

Group 5a Trends – Two wells (UMA109 and UMA110) show medium increasing trends while the third well (UMA156) shows a statistically insignificant trend.

Group 5a LOESS Lines – The UMA109 LOESS line generally increases but suggests multi-year cycles prior to about 2014. The UMA110 LOESS line generally increases through multi-year cycles with a significant increase in concentrations around 2007. UMA156 exhibits a statistically insignificant trend but the LOESS line shows fluctuations of multi-year frequency, perhaps related to land use or climatic changes.

Group 5a Seasonality – Two of the three wells show seasonality, but with different timing.

UMA109 shows seasonality with nitrate concentrations highest in Q2 (followed closely by Q1) and lowest in Q4 (followed closely by Q3).

The deepest well (UMA156) shows substantial seasonality with nitrate concentrations highest in Q4 (followed closely by Q1) and lowest in Q3. An example of rapid changes in nitrate concentration at UMA156 is when nitrate dropped 24 mg/L from March to May 1999 (Figure 16).

UMA110 shows no seasonality but that may be masked by a noteworthy change in nitrate concentrations around 2007. Until 2007, almost all nitrate concentrations at UMA110 were less than 10 mg/L with annual maximums in Q3. Since 2008, almost all nitrate concentrations are above 10 mg/L with most annual maximums in Q1. The changes at UMA110 are more evident in the standalone time series plot of UMA110 in Appendix D. The changes in nitrate concentration and timing of seasonality suggests a change in nearby land use.

Figure 17 shows the nitrate concentration graphs for Group 5b – Four wells East of Hermiston. These wells (three Alluvial Aquifer wells and one Basalt Aquifer well) are largely surrounded by the other three wells in Group 5 but have significantly lower concentrations. UMA046 was last sampled in September 2018.

Group 5b wells are deeper and have lower nitrate concentrations than Group 5a wells. Two wells exhibit small increasing trends while the other two exhibit small decreasing trends. Three of the four wells exhibit seasonality but with different timing.

Group 5b Open Intervals - The open intervals of these wells are a little deeper than those in Group 5a (29-72 feet below land surface at UMA056; open at 50 feet below land surface at UMA116; 60-110 at UMA046; 58 to 115 feet below land surface at UMA106).

Group 5b Concentrations – All concentrations are less than 7.5 mg/L.

Group 5b Trends – Two wells (the Basalt Aquifer well UMA106 and UMA116) show small increasing trends while the other two wells (UMA046 and UMA056) show small decreasing trends.

Group 5b LOESS Lines – The UMA116 LOESS line suggests multi-year cycles while the other three LOESS lines show more gradual changes.

Group 5b Seasonality – The Basalt Aquifer well UMA106 and two of three Alluvial Aquifer wells (UMA116 and UMA046) show nitrate seasonality but with different timing (Figure 8).

3.8.6 Group 6 – Two Wells in Stanfield

Figure 18 shows the nitrate concentration graphs for Group 6 – Two Wells in Stanfield. These wells are about 0.4 miles apart. In summary, nitrate concentrations at these wells are low and show small increasing trends. A relatively abrupt increase in nitrate concentrations at UMA048 around 2010 suggest a change in nearby land use.

Open Intervals – Their open intervals overlap in depths but they are completed in different aquifers. UMA048 is an alluvial well with a 26-foot open interval from 59 to 85 feet below land surface. UMA047 is a basalt well with a 77-foot open interval from 68 to 145 feet below land surface.

Concentrations – All nitrate concentrations at these wells are less than 5 mg/L. Similar to UMA110 in Group 5, UMA048 shows two different ranges of nitrate concentrations. Nitrate concentrations fluctuated seasonally about 0.5 mg/L and averaged less than 2 mg/L until about 2009. Nitrate concentrations then rose to about 3 mg/L by 2012 and since then has exhibited larger seasonal fluctuations of a different timing than before and averaged about 3 mg/L. The changes at UMA048 are more evident in the standalone time series plot of UMA048 in Appendix D. UMA047 was last sampled in May 2019. A relatively abrupt increase in nitrate concentrations at UMA048 around 2010 suggest a change in nearby land use.

General Chemistry - While samples from both wells fall within the Ca+Mg HCO_3 water type field on the Piper diagram, they plot in separate distinct groups within the field (see individual diagrams in Appendix C). This separation shows the general chemistry of the alluvial aquifer well is distinct from the nearby Basalt Aquifer well.

Trends – Both wells show small increasing trends.

LOESS Lines – The UMA047 LOESS line gradually increases through May 2019 (when it was last sampled). The UMA048 LOESS line is relatively flat through about 2008 then increases through about 2014 when it levels off.

Seasonality – Neither well shows seasonality.

3.8.7 Group 7 – Four Butter Creek and Umatilla River Flood Plain Wells

Figure 19 shows the nitrate concentration graphs for Group 7 – Four Butter Creek and Umatilla River Flood Plain Wells. In summary, the four wells show low nitrate concentrations but concentrations in the shallower Umatilla River flood plain wells are higher than in the deeper Butter Creek flood plain wells. The deepest well has a very high rate of non-detected values plus some indications of a reducing environment.

Open Intervals – The two wells in the Umatilla River Flood Plain (UMA190 and UMA191) are shallower than the two in the Butter Creek flood plain (UMA185 and UMA187). UMA190 and UMA191 have open intervals no deeper than 25 feet below land surface while UMA185 and UMA187 have open intervals extending past 100 feet below land surface (17.5-22.5 feet below land surface at UMA191; open at 25 at UMA190; 25-100 at UMA187; 80-112 at UMA185).

Concentrations – All four of these wells show low nitrate concentrations but concentrations in the shallower Umatilla River flood plain wells are higher than in the deeper Butter Creek flood plain wells. UMA191 is an irrigation well located about 65 feet from the City of Echo wastewater lagoon. With one exception, all nitrate results from all four wells were less than 10 mg/L.

Butter Creek flood plain well UMA185 has very low concentrations (less than 0.2 mg/L). Butter Creek flood plain well UMA187 has a very high rate of non-detected values (91%) plus some indications of a reducing environment (e.g., negative Oxidation Reduction Potential values, sulfur odor, and detectable levels of ammonia.

Trends – Two wells (UMA185 and UMA190) show small increasing trends. UMA191 shows a statistically insignificant trend. UMA187 shows a small decreasing trend. The few detected values prior to 2010 combined with a lower detection limit since 1999 results in a very slightly decreasing trend. The changes at UMA185 and UMA187 are more evident in the standalone nitrate concentration graphs in Appendix D.

LOESS Lines – The UMA190 LOESS line fluctuates but stays below 4 mg/L until about 2020. It increases from less than 1 mg/L in about 2018 to over 6 mg/L by 2024. LOESS lines at the other three wells are relatively flat.

Seasonality – UMA191 shows the greatest variability of the flood plain wells, and exhibits seasonality with nitrate concentrations highest in Q2 (followed closely by Q1) and lowest in Q4.

3.8.8 Group 8 – Four Wells West of Hermiston

Figure 20 shows the nitrate concentration graphs for Group 8 – Four Wells West of Hermiston. In summary, these four wells show elevated nitrate concentrations with average values ranging from 8.2 mg/L to 27.1 mg/L. The industrial well UMA198 shows the highest average nitrate concentration of these wells and steepest trend in the network (1.2 mg/L/yr). The average nitrate concentrations at the domestic wells decrease with depth but have dissimilar trends and seasonality. A lag in seasonality may represent travel time through the vadose zone.

Open Intervals – The group includes three domestic wells and one industrial well. The industrial well UMA198 has 36 feet of open interval (perforated casing from 70 to 100 feet below land surface and open hole construction from 104 to 110) feet below land surface while the domestic wells are cased into gravel at 40 feet below land surface (UMA119), 80 feet below land surface (UMA084) and 101 feet below land surface (UMA094) with an open interval of zero.

Concentrations – Most nitrate concentrations at the four wells ranged from about 5 mg/L to 20 mg/L (with some at UMA198 higher) until about 2009 when nitrate at UMA198 increased beyond the range of the other three wells.

Trends – Two wells exhibit increasing trends: UMA198 exhibits the largest increasing trend (1.2 mg/L/yr) while UMA119 exhibits a small increasing trend. Two wells exhibit decreasing trends: a medium decreasing trend at UMA084 and a small decreasing trend at UMA094.

LOESS Lines – The LOESS lines largely overlap until about 2009 when the UMA198 LOESS line increases beyond the range of the other three wells. The LOESS lines are similar (particularly UMA084 and UMA094) and suggest multi-year cycles within the annual variability.

Seasonality – Three of the four wells (UMA119, UMA084, and UMA094) exhibit seasonality but with different timing. The shallowest well (UMA119) exhibits highest nitrate concentrations in Q1 and lowest in Q3 while the deeper wells exhibit highest nitrate concentrations in Q3 and lowest in Q1 (UMA084) or Q2 (UMA094). The lag in nitrate seasonality may represent travel time through the vadose zone.

Figure 21 shows the nitrate concentration graphs for the three domestic wells in Group 8 and illustrate the following observations.

Average nitrate concentrations decrease with the depth of these wells (13.2 mg/L at 40 feet below land surface, to 9.9 mg/L at 80 feet below land surface, and to 8.2 mg/L at 101 feet below land surface). UMA119 has average nitrate concentrations above 10 mg/L, higher nitrate concentrations in Q1 and Q2, and show an increasing trend. The other wells (UMA084 and UMA094) are different in that they are a bit deeper, have average nitrate concentrations below 10 mg/L, have the opposite seasonality (i.e., higher nitrate concentrations in Q3 and Q4), and show decreasing trends.

3.8.9 Group 9 – Three Wells South of Umatilla Depot

Figure 22 shows the nitrate concentration graphs for Group 9 – Three Wells South of Umatilla Depot. In summary, all three wells show medium decreasing trends, but two wells show nitrate concentrations less than 10 mg/L while the third (UMA133) has 95% of results greater than 10 mg/L. The LOESS line through UMA133 highlights a recent increase in nitrate concentrations.

Open Intervals – One well (UMA133) is 80 feet deep but no well log could be found so its construction details are unknown. The other two wells are similar in depth but have very different open intervals. One is 1.5 feet long (171.5 to 173 feet below land surface at UMA168) while the other is 167 feet long (18 to 185 feet below land surface at UMA112).

Concentrations – All nitrate results at UMA168 and UMA112 are less than 6 mg/L while 95% of nitrate results at UMA133 exceed 10 mg/L.

Trends – All three wells show medium decreasing trends.

LOESS Lines – The UMA133 LOESS line illustrates an early increase in nitrate concentrations until about 1998 followed by a decrease until about 2016 when in then increased through 2024. The UMA112 and UMA168 LOESS lines (better illustrated by the stand-alone graphs in Appendix D) generally decrease through multi-year cycles.

Seasonality – None of these three wells exhibit seasonality.

3.9 Potential Effect of Long-Term Persistence

As discussed in Section 1.7.2, an important but challenging factor in the evaluation of long-term trends caused by human activity is the concept of “long-term-persistence” manifesting as quasi-periodic oscillations of natural hydrologic processes. Most hydrologic variables are responding to a mix of human activity and natural forces, but adequate statistical tools and data sets do not yet exist that would allow distinguishing between human-caused trends and long-term persistence.

The effect of not distinguishing between human-caused trends and cyclic hydrologic processes includes an increase in the possibility of Type I errors (i.e., concluding there is a statistically significant human-caused trend when there is not) and limiting the ability to project future conditions (Helsel, et al., 2020).

In summary, the groundwater nitrate concentrations in the LUBGWMA are as measured. However, the factors controlling changes in nitrate concentrations may be complex. As discussed above, multi-year oscillations in nitrate concentrations were observed at about 40% of network wells suggesting the possible influences of changes in land use and/or climatic changes expressed as long-term persistence. If long-term persistence is a substantial factor, the confidence level of statistical tests evaluating changes in nitrate concentration may be inappropriately elevated. However, the very small p-values associated with most trends in this report (commonly 0.0002) indicate p-values could increase by three orders of magnitude and trends would still be considered statistically significant. Therefore, the statistical significance of trends described in this report is robust and rather resilient to potential decreases due to the influences of long-term persistence.

3.10 Comparison to LUBGWMA Public Health Project Data

This section describes the similarities and differences between the two data sets, compares the nitrate values in each data set, and describes the geographic overlap of the two data sets.

3.10.1 Similarities and Differences Between Data Sets

OHA's LUBGWMA Public Health Project data set and DEQ's LUBGWMA Well Network data set are similar in that they focus on domestic wells in the LUBGWMA but they also have notable differences including purpose, timeframe, sample locations, sample frequency, known aquifer tapped, data quality, and ability to fully capture seasonality These differences are discussed below and summarized in Table 4.

Purpose - The purpose of the DEQ network is to monitor groundwater nitrate concentrations and trends. The purpose of the OHA sampling effort is to identify well-dependent households with water at levels above the 10 mg/L drinking water standard.

Timeframe, Locations, and Frequency – The DEQ data set has more total data points over a much longer timeframe, but the OHA data set has over fifty times more wells represented. More specifically, the OHA data set typically includes one sample per well but can contain several samples per well from over 1,800 of the estimated 3,300 domestic well households in the LUBGWMA collected over a span of less than two years for a total of over 3,000 individual nitrate results. In contrast, the DEQ data set typically includes over 100 samples from each of the 30 domestic wells, two irrigation wells, and one industrial well collected over a span of 32 years for a total of 3,721 individual nitrate results.

Aquifer Tapped - The DEQ data set has 90% Alluvial Aquifer wells and 10% Basalt Aquifer wells. The OHA data set identifies thirteen well logs in OWRD's well log database with one Alluvial Aquifer well, 10 Basalt Aquifer wells, and two that appear to be the weathered basalt at the base of the Alluvial Aquifer system. This observation suggests the potential for the OHA data set to have a higher percentage of basalt wells, but the very low percentage of known well logs (<1%) does not allow a conclusion to be drawn.

Because the sources of nitrate contamination are at or near land surface, properly constructed Basalt Aquifer wells typically have lower nitrate concentrations than Alluvial Aquifer wells. The LUBGWMA well network currently includes three basalt wells with an overall median concentration of 4.6 and an average of 15.1 mg/L. However, one well has been as high as 61.3 mg/L and averages 40.5 mg/L, but the other two average 1.1 mg/L and 4.4 mg/L.

As a group, the ten basalt wells in the OHA data set have generally lower nitrate concentrations that range from non-detected to 21.7 mg/L with a median of 4.8 mg/L and an average of 5.9 mg/L.

Data Quality – The DEQ data are collected under more rigorous Quality Assurance / Quality Control procedures than the OHA data, so they are viewed as higher quality data. Obvious errors noted in the OHA data set include misspelled city names, zip codes not matching city names, and well log numbers that do not appear in the OWRD well log database. The OHA data set also includes some nitrate values of treated water that were not flagged as such.

Seasonality - The OHA data set contains multiple samples for some wells but one sample for most wells (average number of samples per well is 1.3) so it does not fully capture seasonal variations. The DEQ data set includes quarterly sampling for all wells and does capture seasonal variations.

Nitrate concentrations fluctuate seasonally at about half of the LUBGWMA Network wells and are known to fluctuate as much as 25 mg/L between quarterly measurements at some wells. Most wells sampled as part of OHA's project have not been sampled enough to adequately characterize seasonality.

3.10.2 Comparison of Nitrate Values

Table 4 summarizes the data set characteristics described above (e.g., timeframe, sample locations, sample frequency, aquifer tapped) along with a comparison of the nitrate concentrations and geographic extent of the data sets. The treated water samples identified in the data set are not included in this comparison.

Degree of Censoring – Thirty one percent of the OHA results are reported as non-detects as compared to 3.4% of the DEQ results. Most OHA non-detected values are reported as "0" or "ND" with only 5% of the OHA non-detected values including a detection limit (0.25 mg/L). This uncertainty limits the accuracy of calculating an average but does allow calculation of the 40th through 100th percentile.

Comparison of Nitrate Concentrations - As shown in Table 4, the 2,392 results from 1,872 wells in the OHA data set have a median value of 5.1 mg/L an average around 8.2 mg/L (see table footnote for details), a 75th percentile of 9.5 mg/L, a maximum value of 94.8 mg/L. Twenty three percent of results are above the 10 mg/L drinking water standard.

Table 4 shows the DEQ data set also has a median value of 5.1 mg/L but has a higher average (9.6 mg/L), higher 75th percentile (13.1 mg/L), and higher percentage of samples above 10 mg/L (31%), but a lower maximum value observed (75.5 mg/L). The Peto-Peto tests used to evaluate differences between the data sets were run using the reported detection limits and seven different assumed detection limits (ranging from 0.005 to 5.0 mg/L). All test results show very low p-values which indicate there is a difference between the two data sets. This difference is reflected in the higher values in the DEQ data set for the 40th, 60th, 70th, 80th, and 90th percentiles.

3.10.3 Geographic Overlap of Data Sets

Figure 23 is a map showing the geographic overlap of the LUBGWMA well network and the highest single nitrate result from each household in OHA's LUBGWMA Public Health Project data set through September 2024.

Figure 23 shows that domestic wells are not evenly distributed throughout the LUBGWMA. There are large areas within the LUBGWMA that do not have many domestic wells (i.e., Boardman Bombing Range, Umatilla Depot, the area west of Sixmile Canyon). Figure 23 also shows there is substantial geographic overlap between the two data sets. As shown in Table 4, the zip codes with the highest and second highest percentage of samples in both networks are Hermiston followed by Irrigon.

3.10.4 Conclusions

In conclusion, the OHA and DEQ data sets are similar in their focus on domestic wells, significant overlap in area tested, and overall median nitrate concentration. However, the data sets are different in their purpose, timeframe, sample locations, sample frequency, known aquifer tapped, data quality, and ability to fully capture seasonality. While both data sets share the same median value (5.1 mg/L), the OHA data set has the highest maximum value observed (94.8 mg/L vs 75.5 mg/L), and the DEQ data set has a higher average and upper percentile concentrations. This shows the DEQ data set is generally shifted higher than the OHA data set. The noted differences between how, why, where, and when samples are collected likely contribute to the differences observed in nitrate concentrations.

4.0 Conclusions and Recommendations

4.1 Conclusions

This section provides conclusions regarding the well network, the general water quality of wells within the network, and nitrate concentrations and trends.

1. **The network includes the relevant hydrostratigraphic units**. The hydrostratigraphic units within the Alluvial Aquifer capable of hosting a productive well are represented in this network.

2. **There is one dominant general water quality type.** Most network wells plot on the Piper diagram as Calcium Magnesium Bicarbonate water types. One well is a Sodium Potassium Chloride water type while another well plots largely as a Calcium Magnesium Chloride water type. The irrigation wells and industrial well plot along a line suggesting mixing of different quality water.

3. **No geographic pattern of groundwater nitrate is evident.** While the highest concentrations and steepest trends (both increasing and decreasing) occur in the western part of the well network, high concentrations are found throughout the area and no predictive geographic pattern is evident. Large differences in nitrate concentrations and trends occur within distances of a few miles.

4. **Proximity is not necessarily predictive**. While some wells in some geographic groups show commonalities, wells within groups may or may not have similar nitrate concentrations, seasonality, and trends. No spatial autocorrelation was found indicating wells are statistically independent.

5. **Nitrate drinking water standard exceeded in the area**. Most wells have nitrate detected in every sample. Three wells have a low amount of non-detected values while one well has 91% non-detected values. The most recent sampling event included in this analysis was conducted in November 2023 when 30 wells were sampled and concentrations ranged from <0.005 mg/L to 67.8 mg/L. Twelve of the wells sampled (40%) were above the 10 mg/L drinking water standard. Half of the wells were above the 7 mg/L GWMA trigger level.

   Over the 32-year monitoring period, nitrate results were reported from non-detectable (<0.005 mg/L) to 75.5 mg/L. Average nitrate concentrations ranged from 0.01 mg/L to 40.5 mg/L. Twenty-two wells (67%) have average nitrate concentrations of less than 10 mg/L.

   While three wells show maximum concentrations between 40 and 45 mg/L, all concentrations above 45 mg/L were detected at either the well with the steepest increasing trend (UMA190) or the one with the steepest decreasing trend (UMA029).

6. **Network wells in city limits have low nitrate**. All concentrations at the five wells located within or adjacent to a city limits (i.e., two in Stanfield, two in Irrigon, and one in Umatilla) are less than 10 mg/L. No network wells are in or adjacent to Hermiston or Echo city limits.

7. **Nitrate concentrations fluctuate -** Over the 32-year monitoring period, the range of nitrate concentrations at an individual well varied from 0.13 mg/L (at UMA187) to 69.7 mg/L (at UMA198). Thirteen wells (45%) fluctuated less than 10 mg/L, 19 wells (66%) fluctuated less than 20 mg/L, and 28 wells (97%) fluctuated less than 41 mg/L.

8. **Some wells show nitrate seasonality**. Fourteen network wells (42%) exhibit nitrate seasonality but not all show the same timing. Even so, nitrate was typically higher in March and May than in September and November. However, significant ties in the wells' depth to open interval resulted in a statistically insignificant correlation coefficient (tau = 0.101; p=0.62) which may or may not reflect a true lack of correlation between amount of seasonality and depth to open interval.

9. **Weak correlation with well depth -** While some groups of wells show nitrate concentrations lessen with depth, significant ties in well depth resulted in a weak negative correlation between well depth and average nitrate concentration, meaning any true correlation between nitrate concentration and depth may not be observable with the well network. The 17 wells with maximum nitrate concentration exceeding 10 mg/L range in depth from 25 feet to 110 feet. Average nitrate concentrations above 10 mg/L are observed in 10 wells ranging in depth from 40 feet to 100 feet.

10. **Annual summary statistics show nitrate is generally increasing -** Annual median, annual average, and annual maximum nitrate concentrations increased over the 32-year period suggesting an overall increase in nitrate within the network.

11. **Nitrate trends at individual wells show nitrate is generally increasing** – The steepest increasing trend (1.20 mg/L/yr) was observed west of Hermiston at the industrial well UMA098. The steepest decreasing trend (-0.42 mg/L/yr) was observed south of Boardman at the Basalt Aquifer well UMA029.

    At the 29 long-term wells, increasing trends are more numerous (17 vs 10) and, on average, steeper than decreasing trends (0.29 mg/L/yr vs -0.14 mg/L/yr).

    When viewed by magnitude and direction:
    - Small trends (up to 0.1 mg/L/yr) – Increasing trends are more numerous (10 vs 4) but average slopes are equal (0.05 mg/L/yr vs -0.05 mg/L/yr).
    - Medium trends (0.1 to 0.5 mg/L/yr) – Decreasing trends are more numerous (6 vs 4) but less steep than increasing trends (-0.21 mg/L/yr vs 0.34 mg/L/yr),
    - Large trends (greater than 0.5 mg/L/yr) – All three large trends are increasing and average 1.01 mg/L/yr.

12. **Network-wide nitrate trend continues to increase** – The Network-wide trend from 1991 through 2023 was increasing at about 0.03 to 0.04 mg/L/yr when viewed as all 33 wells, the 29 long-term wells, the 26 long-term Alluvial Aquifer wells, and the 3 long-term Basalt Aquifer wells. The network-wide trend using the 29 long-term wells (increasing at 0.04 mg/L/yr) best fits the test assumptions, so it is viewed as the best estimate of a network-wide trend. The network-wide trend using the 29 long-term wells has been slightly increasing (0.03 to 0.09 mg/L/yr) since enough data were collected to calculate a statistically significant trend (i.e., since 1999).

13. **Nitrate leaching is likely still occurring** – The continued increase of nitrate concentrations at many wells and in the network as a whole indicate current nitrate leaching is likely.

14. **Nitrate concentrations and trends may differ by well use** – The two irrigation wells average below 10 mg/L and exhibit small increasing trends (which is within the range of domestic wells) but the one industrial well located in an agricultural field west of Hermiston exhibits the highest concentrations and steepest increasing trend in the network.

15. **Nitrate concentrations and trends may differ by aquifer** – Slightly more than half of the 30 alluvial aquifer wells have exceeded 10 mg/L at least once while nine wells average above 10 mg/L. Six of those nine wells show increasing trends, two show decreasing trends, and one shows a statistically insignificant trend. Three of the four basalt wells show low but increasing concentrations while the fourth shows high but decreasing concentrations.

16. **Some changes in nitrate suggest land use changes** – Steep trends, single abrupt changes, or multiple changes in nitrate suggest the possibility of changes in land use and indicate the potential for groundwater quality improvements based on changes in surface activities.

17. **Long-term trends may not be predictive of near-term future** - Given the appearance of multi-year cycles suggested by LOESS lines, LOESS lines through the last ten years of data may be better predictors of the next few years than linear trends through all 32 years of data.

18. **There are similarities and differences with OHA's LUBGWMA Public Health Project data** - The OHA and DEQ data sets are similar in their focus on domestic wells, significant overlap in area tested, and overall median nitrate concentration. However, the data sets are different in their purpose, timeframe, sample locations, sample frequency, known aquifer tapped, data quality, and ability to fully capture seasonality. While both data sets share the same median value (5.1 mg/L), the OHA data set has the highest maximum value observed (94.8 mg/L vs 75.5 mg/L), and the DEQ data set has a higher average and upper percentile concentrations. This shows the DEQ data set is generally shifted higher than the OHA data set. The noted differences between how, why, where, and when sampled are collected likely contribute to the differences observed in nitrate concentrations.

19. **The geographic area that the LUBGWMA Well Network represents is not established**. Budget restrictions at the onset of the monitoring effort required the well selection criteria to rely on private wells in continuous use which resulted in the network being created largely of domestic wells predominantly located in the eastern/northeastern two-thirds of the LUBGWMA. The geographic extent of the network limits its usefulness as a predictor in other parts of the LUBGWMA.

4.2 Recommendations

Based on the conclusions above, the following recommendations are made:

1. Continue quarterly sampling of the LUBGWMA well network.

2. Periodically sample LUBGWMA network wells for general chemistry parameters and evaluate water types and potential mixing of waters.

3. Assess the possible correlation of seasonality and water quality with proximity to surface water features including canals.

4. Conduct another synoptic sampling event targeting the same wells sampled in previous synoptic sampling events.

5. Evaluate the geographic area that the LUBGWMA well network represents. Such efforts could include performing statistical evaluations such as geostatistical analysis.

6. An effort should be made to form a larger well network capable of monitoring the entire LUBGWMA. This could be done by expanding the existing well network with new strategically placed monitoring wells and/or including data from other regularly sampled wells at permitted facilities. An expanded network would improve understanding of regional groundwater quality and could lead to a better understanding of influences from surface activities.

7. Support data collection and research efforts to better understand and minimize nitrate leaching from all sources in the LUBGWMA.

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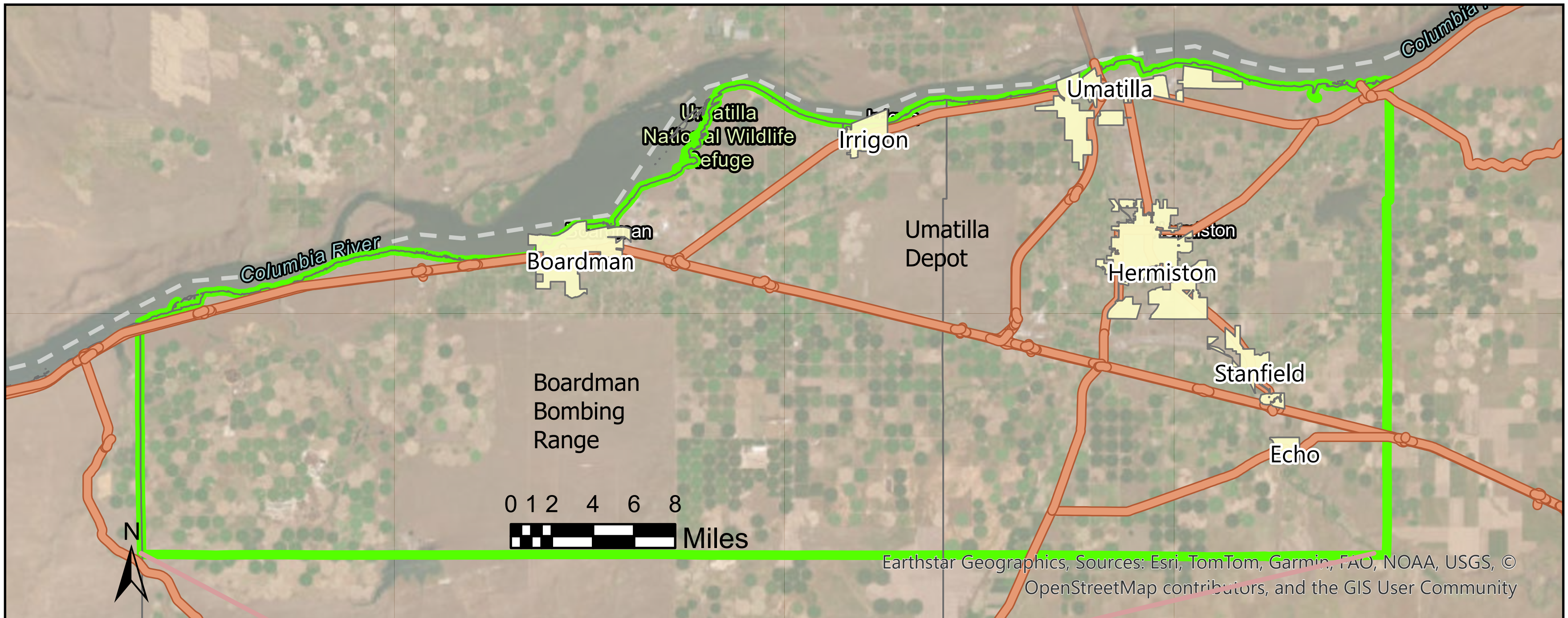
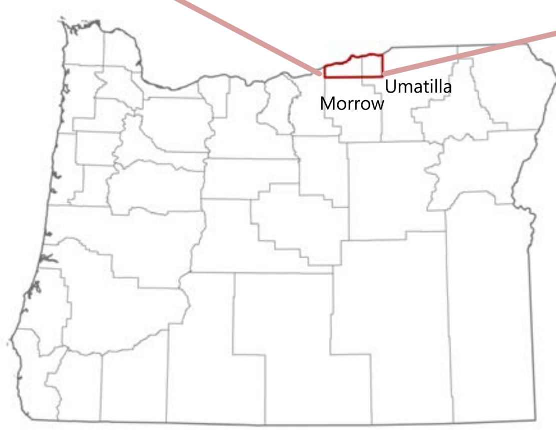
Figure 1
LUBGWMA Location Map
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network





Lower Umatilla Basin Groundwater Management Area Boundaries

North: Columbia River
South: 2N/3N Township Boundary
East: 29E/30E Range Boundary
West: 22E/23E Range Boundary

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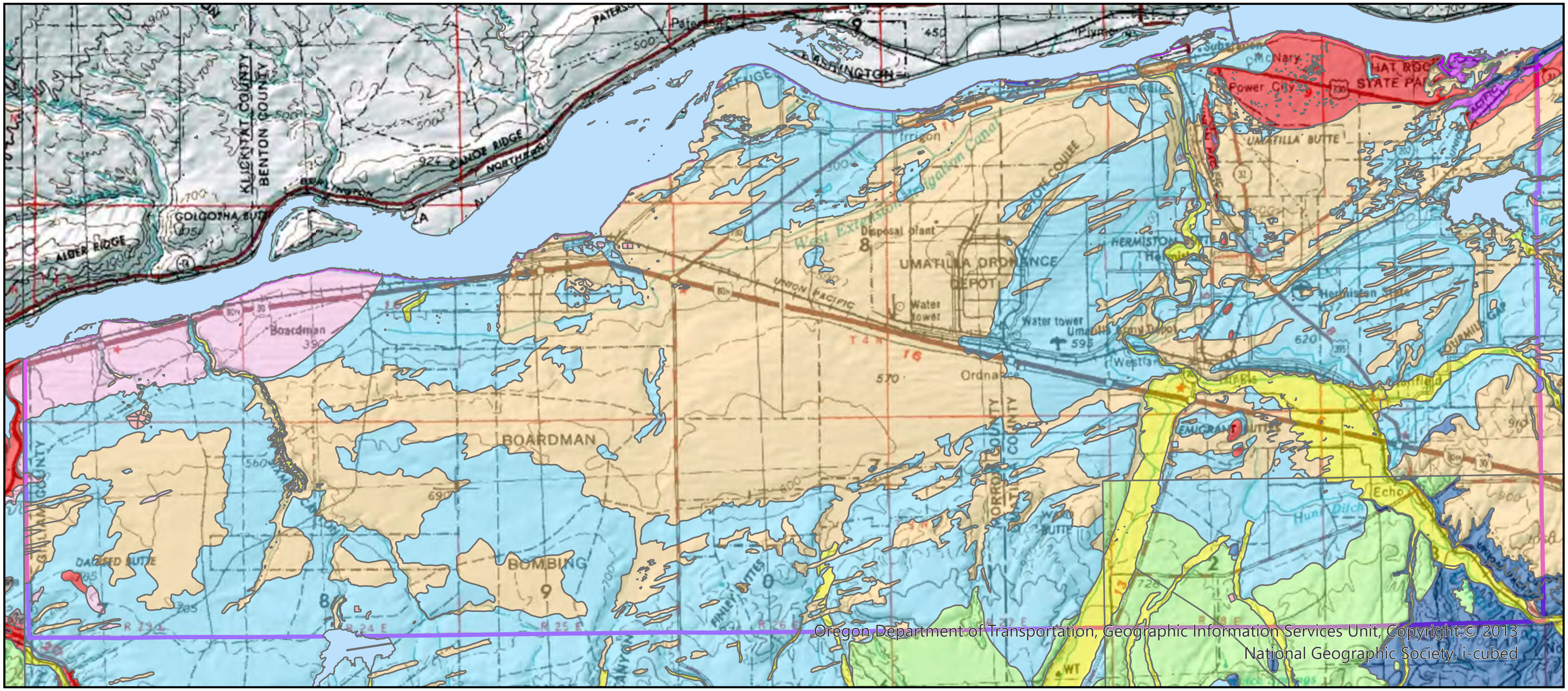
Figure 2
Geologic Map of the LUBGWMA
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network



Geologic Unit at Land Surface

Quaternary Sedimentary Deposits

- Alluvium
- Eolian Deposits
- Missoula Flood Deposits

Miocene/Pliocene Sedimentary Rocks

- Alkali Canyon Formation

Miocene Columbia River Basalt Group

Saddle Mountains Basalt

- Elephant Mountain Member
- Pomona Member
- Umatilla Member
- Wanapum Basalt (Undifferentiated)

0 1.5 3 6 9 12 Miles

N

Source: DOGAMI (2020) OGDC-7

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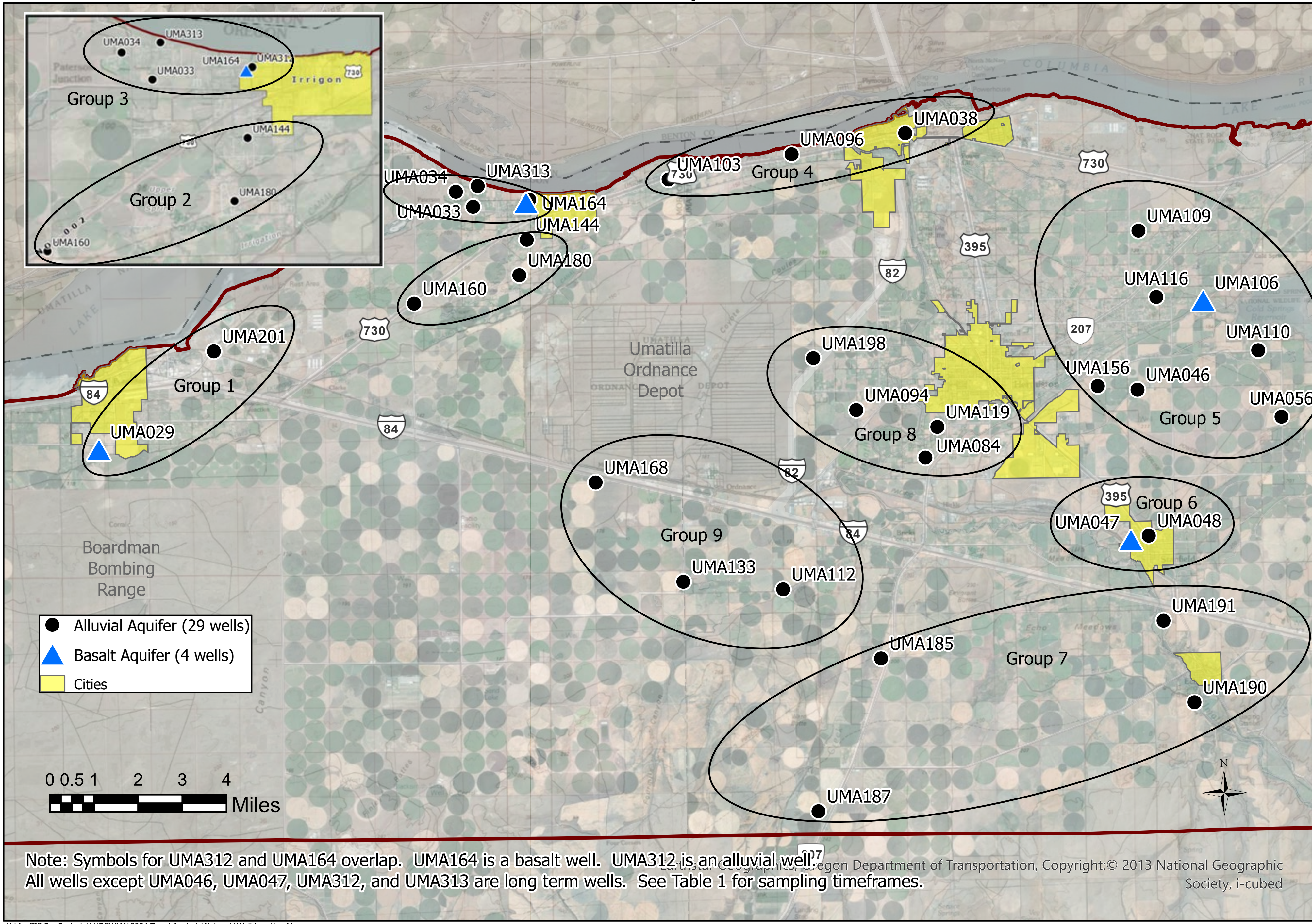
Figure 3
Well Location Map
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network



U:\ArcGIS Pro Projects\LUBGWMA\2024 Trend Analysis\Network\Well Location Map.aprx

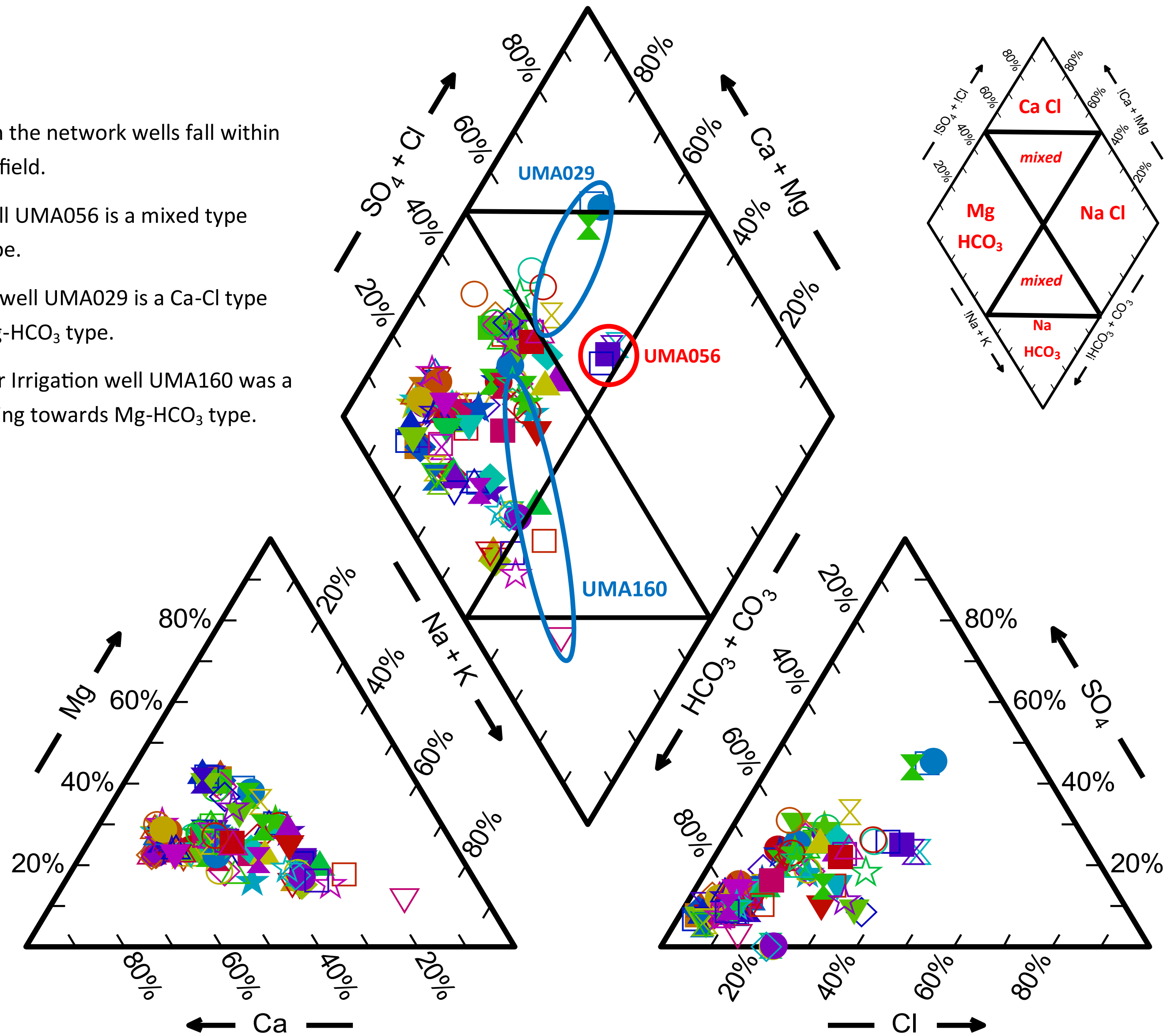
Figure 4
Piper Diagram of Network Wells
Groundwater Nitrate Trend Analysis—LUBGWMA Well Network

Most samples from the network wells fall within the Mg-HCO_3 type field.

Alluvial Aquifer well UMA056 is a mixed type closest to Na-Cl type.

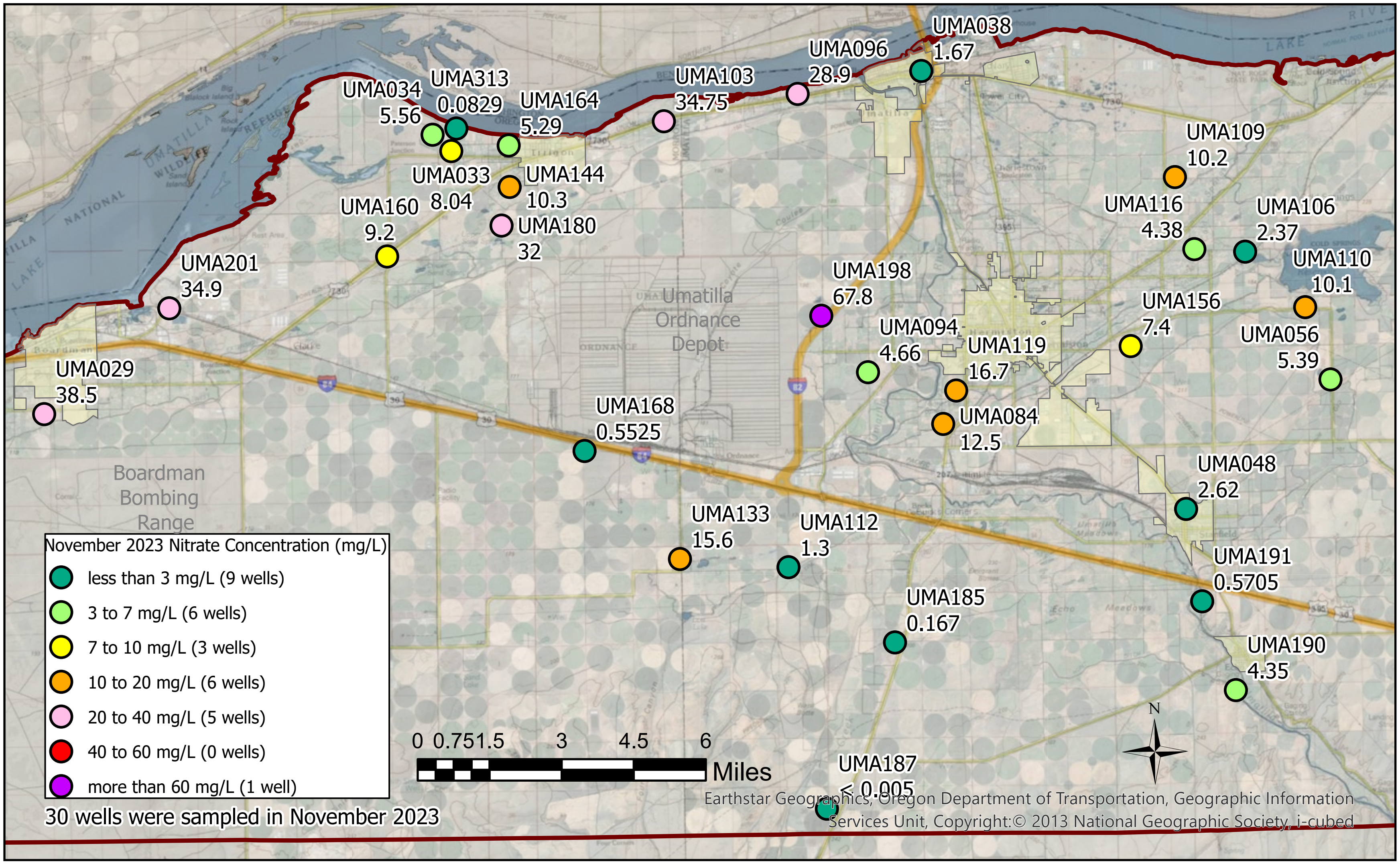
The Basalt Aquifer well UMA029 is a Ca-Cl type mixing towards Mg-HCO_3 type.

The Alluvial Aquifer Irrigation well UMA160 was a Na-HCO_3 type mixing towards Mg-HCO_3 type.



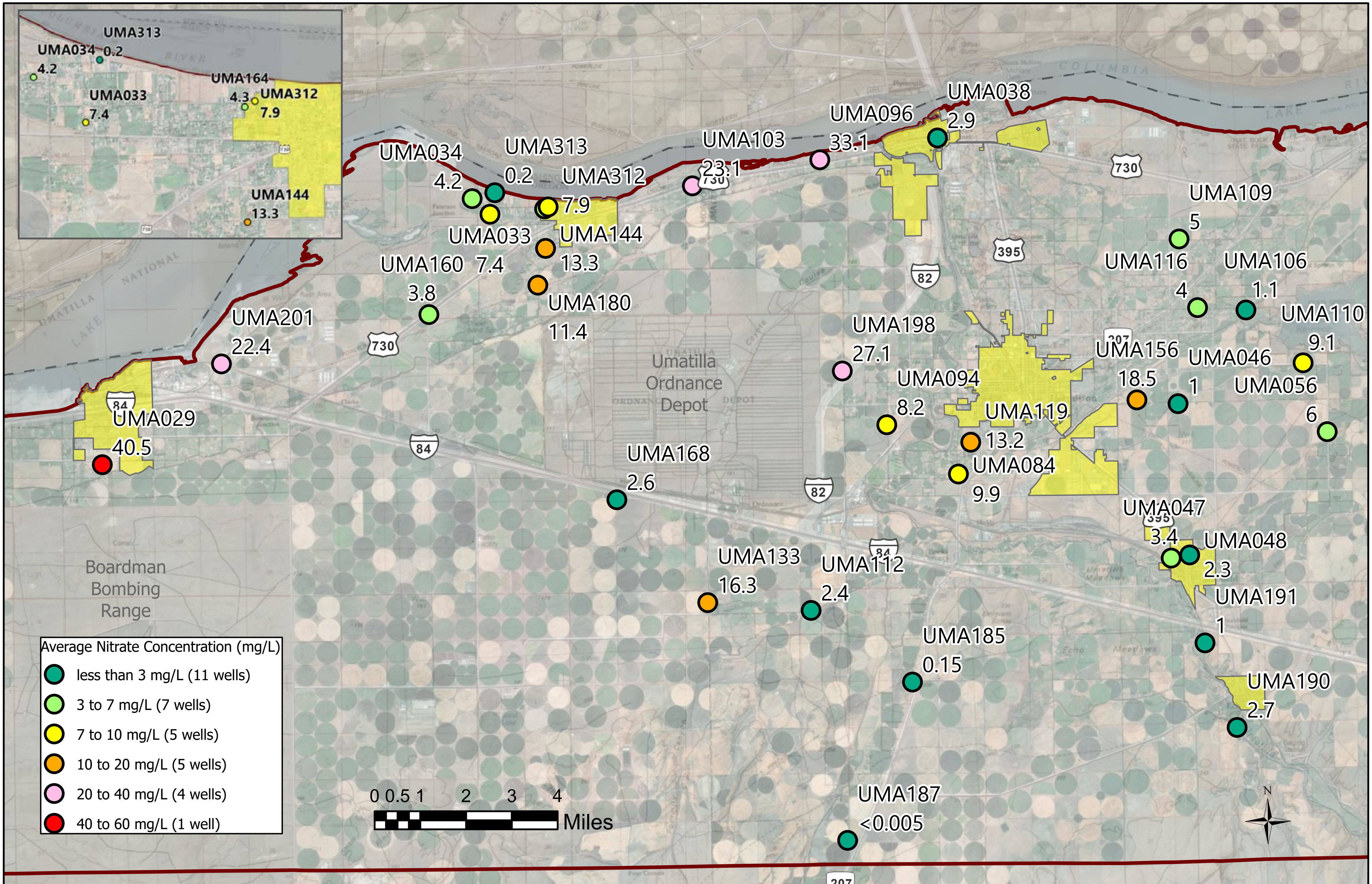
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events for the Network wells at that time.

Figure 5
November 2023 Nitrate Concentrations
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network



U:\ArcGISProProjects\LUBGWMA\2024 Trend Analysis\Network\November 2023 Nitrate Concentrations.aprx

Figure 6
Average Nitrate Concentrations
Groundwater Nitrate Trend Analysis - LUBGWMA Network



Notes: Symbols for UMA312 and UMA164 overlap. See inset map for more details.
Averages at 29 wells are from September 1991 through November 2023. Averages at four wells are shorter. See Table 1 for sampling timeframes.

U:\ArcGIS Pro Projects\LUBGWMA\2024 Trend Analysis\Network\Average Nitrate Concentrations with Closeup Map.aprx

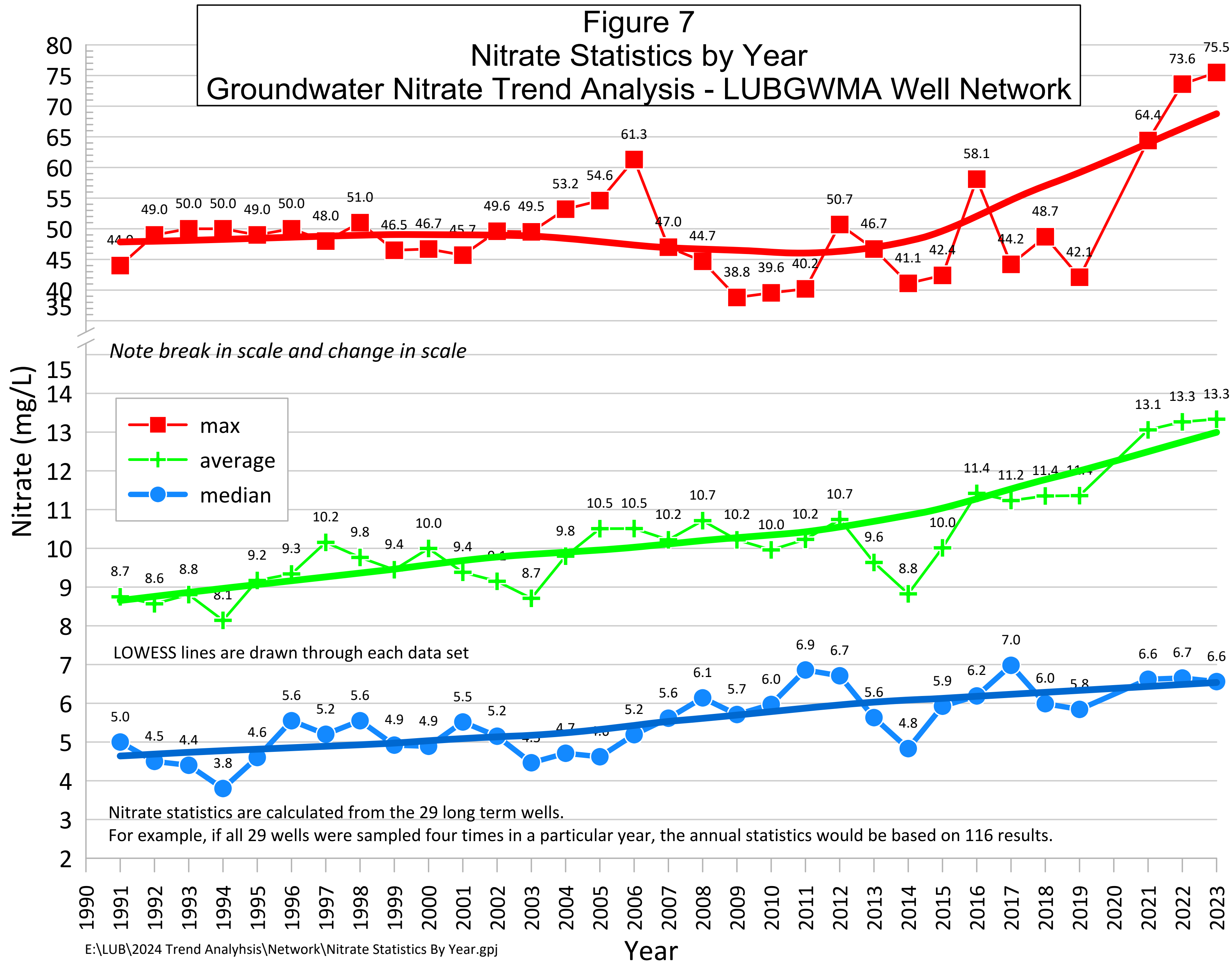


Figure 7
Nitrate Statistics by Year
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network
Note break in scale and change in scale
max
average
median
LOWESS lines are drawn through each data set
Nitrate statistics are calculated from the 29 long term wells.
For example, if all 29 wells were sampled four times in a particular year, the annual statistics would be based on 116 results.
Nitrate (mg/L)
Year
E:\LUB\2024 Trend Analyhsis\Network\Nitrate Statistics By Year.gpj

Figure 8
Nitrate Seasonality
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

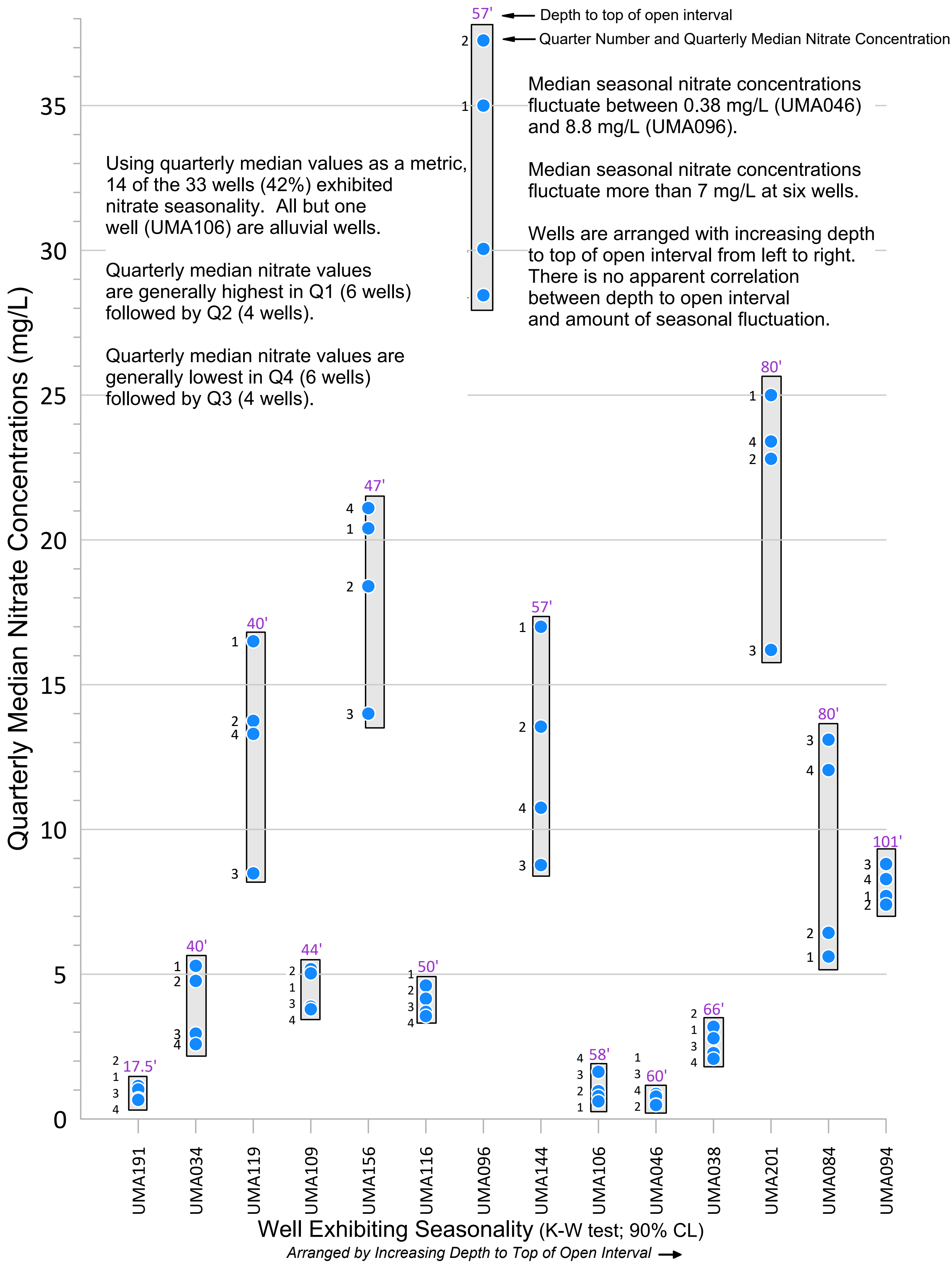
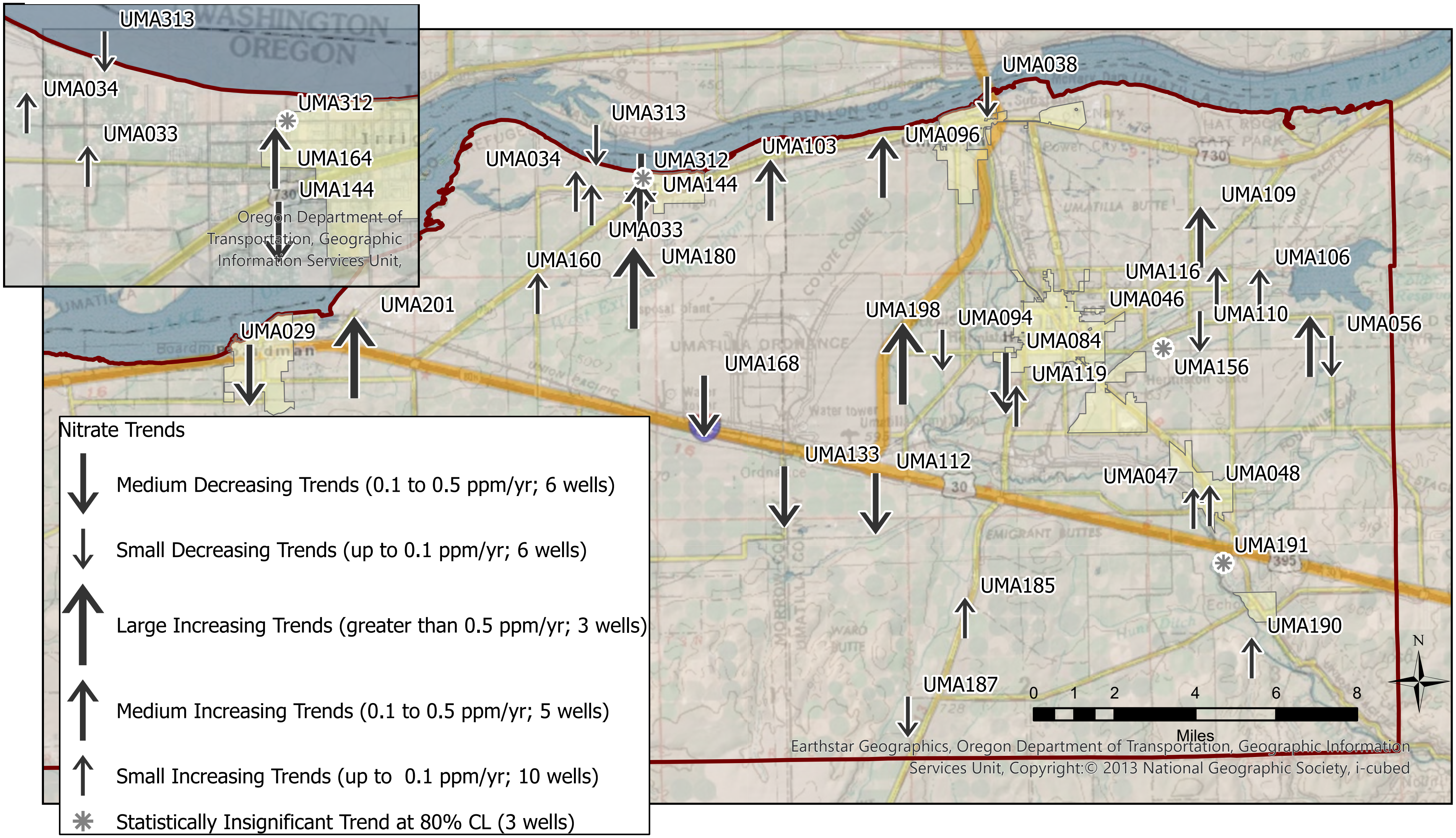


Figure 9
Nitrate Trends at Individual Wells
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network



Notes:
(1) Symbols for UMA312 and UMA164 overlap. See inset map for more details.
(2) Trends at 29 wells are from September 1991 through November 2023. Trends at four wells are shorter. See Table 1 for timeframes and trend slope.
(3) Recent nitrate concentrations shown in Figure 5, average nitrate concentrations shown in Figure 6, and short-term changes in nitrate concentrations shown by LOESS lines in Appendix D are useful to place long-term trends into context.

Figure 10
Network-Wide Trend
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

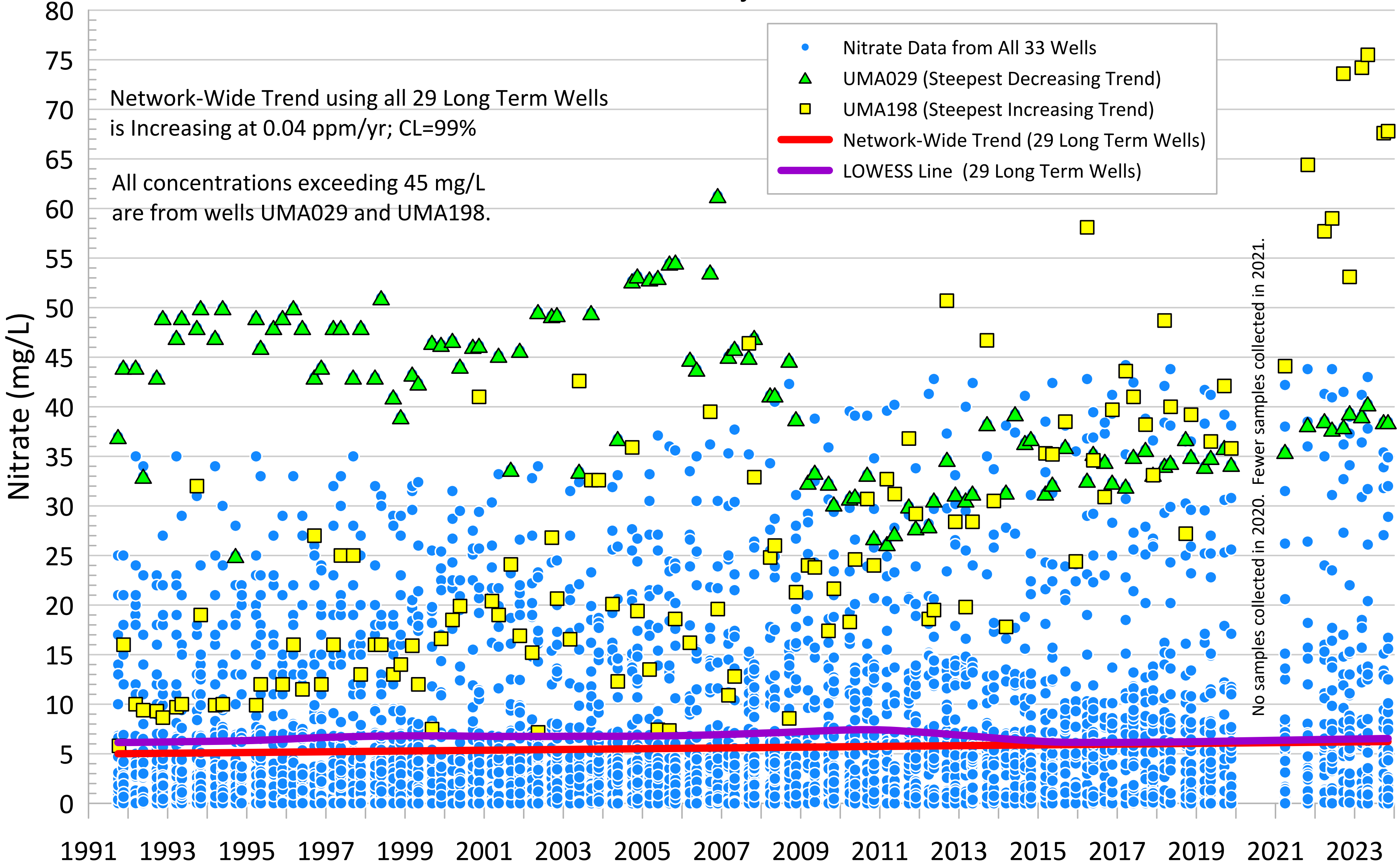


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Figure 11
Network-Wide Trend Over Time
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

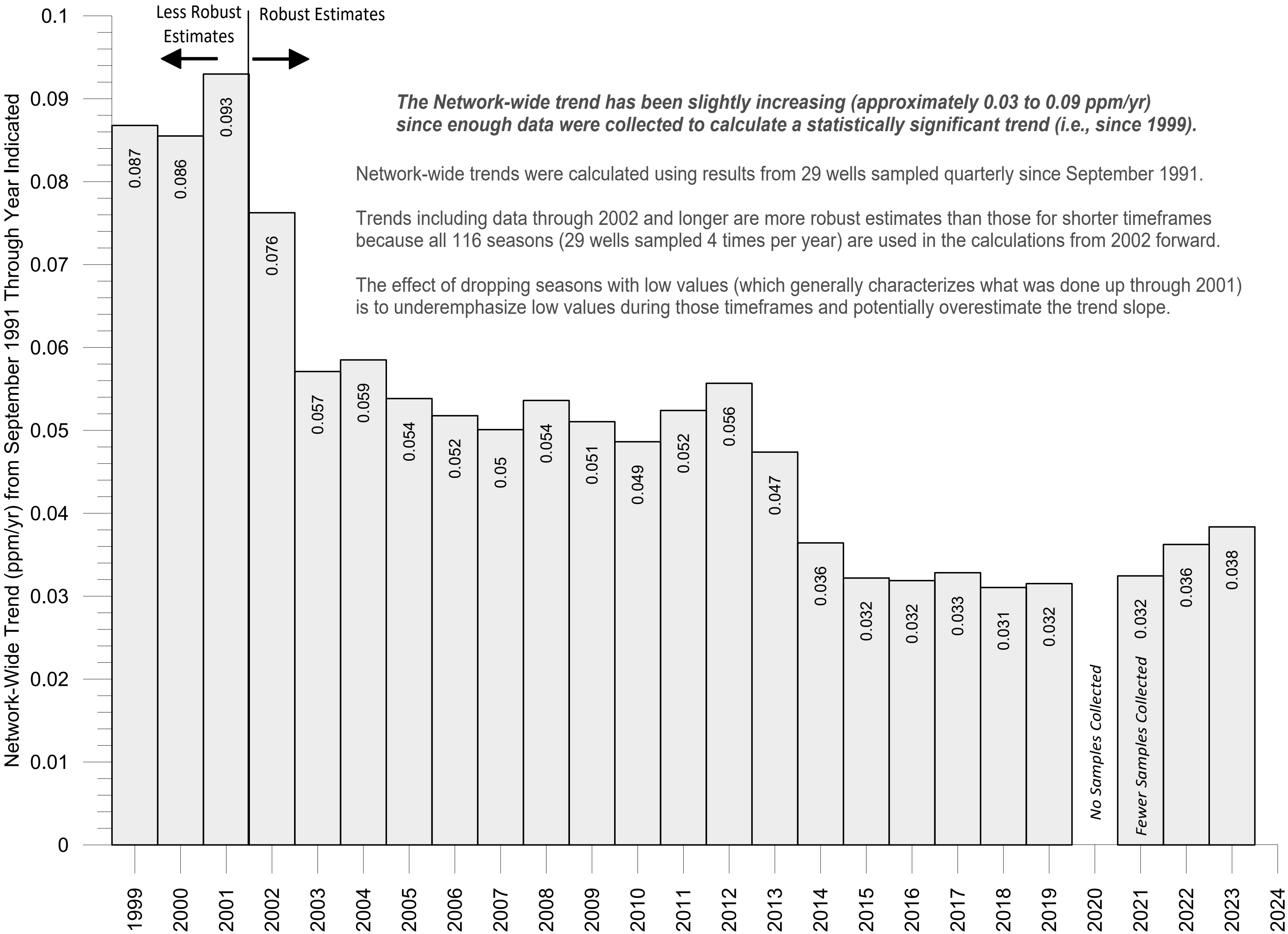

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Figure 12
Nitrate Concentrations at Group 1 - Two Boardman Area Wells
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

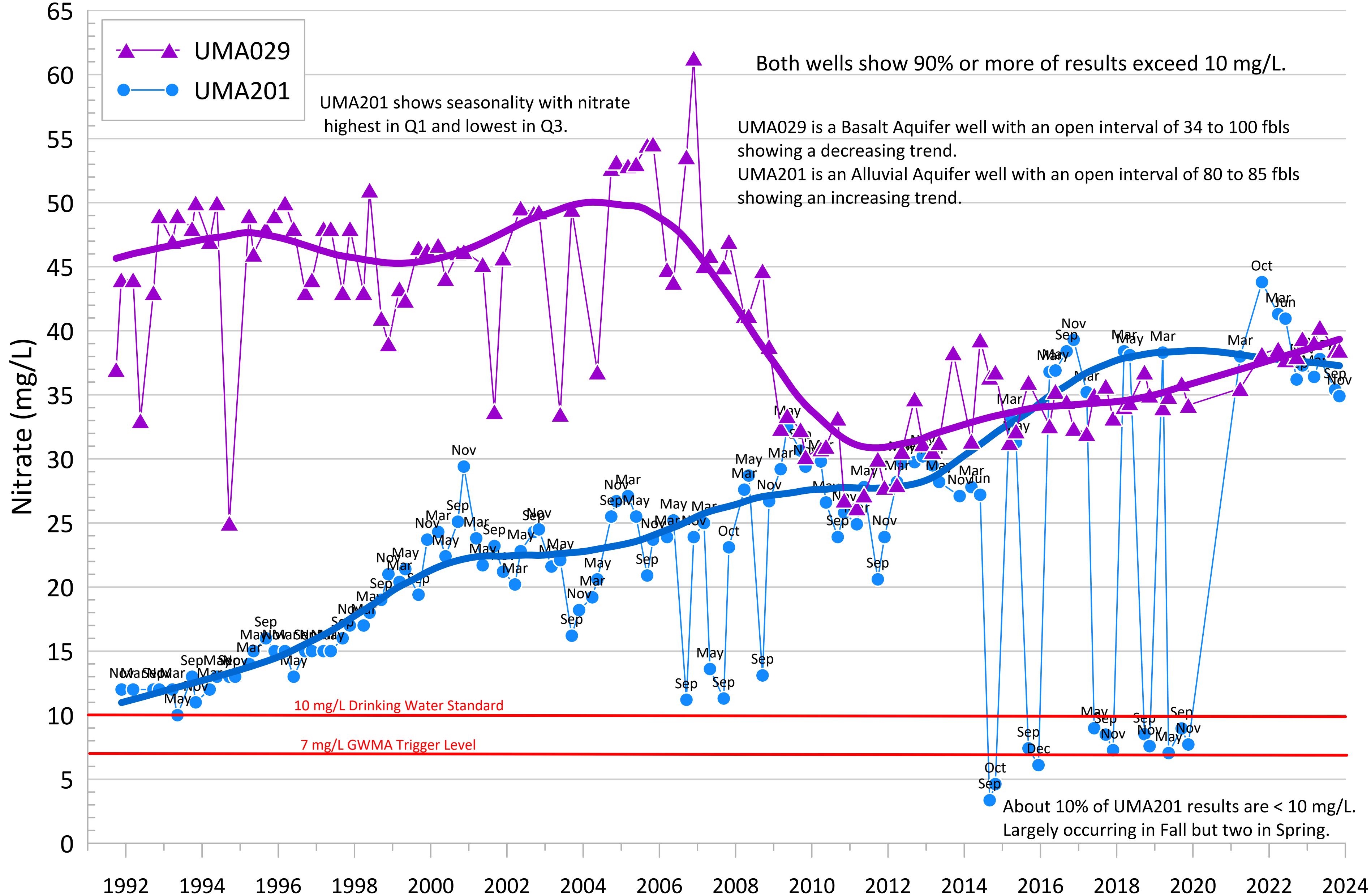
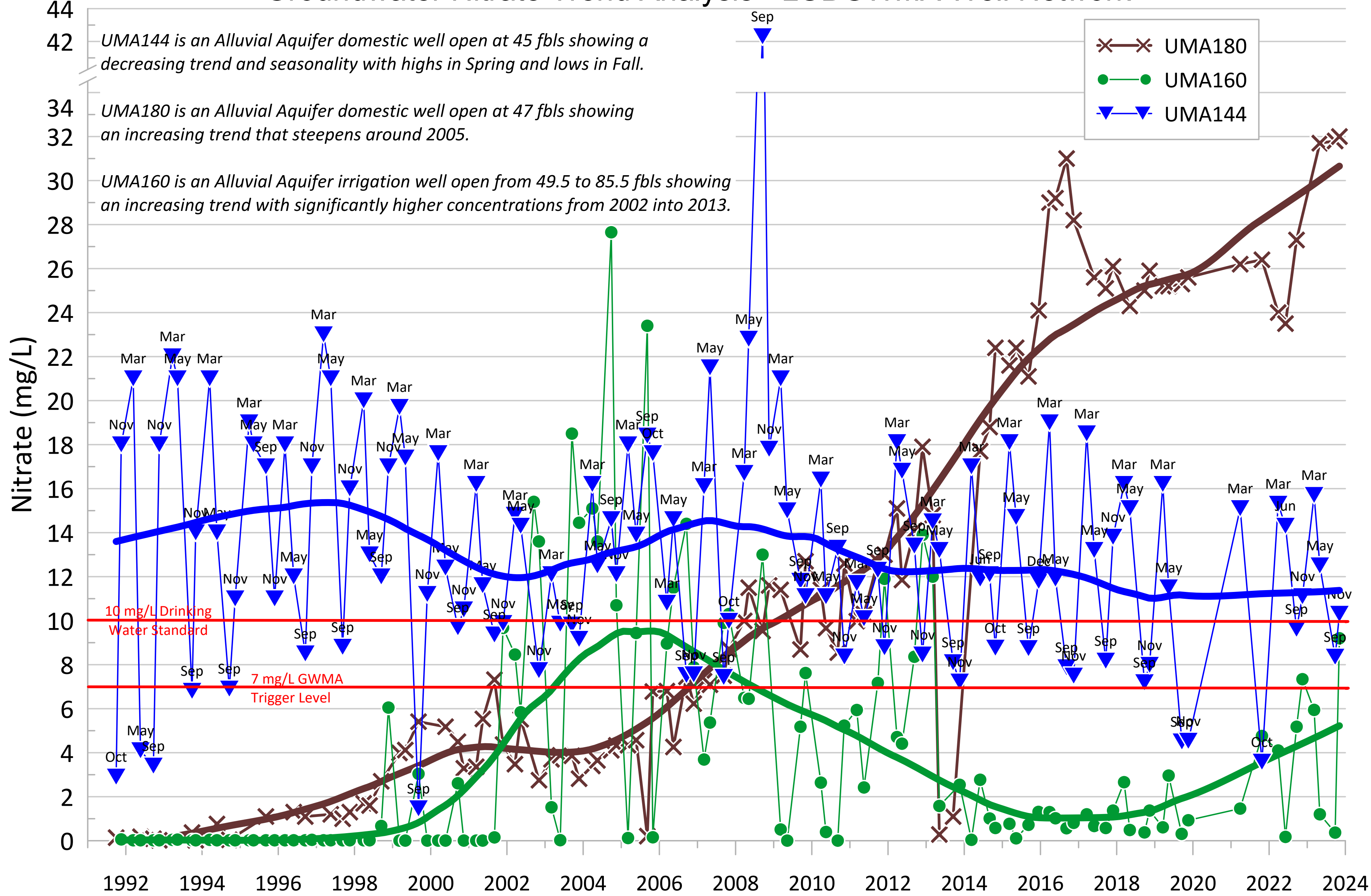


Figure 13
Nitrate Concentrations at Group 2 - Three Wells S-SW of Irrigon
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network



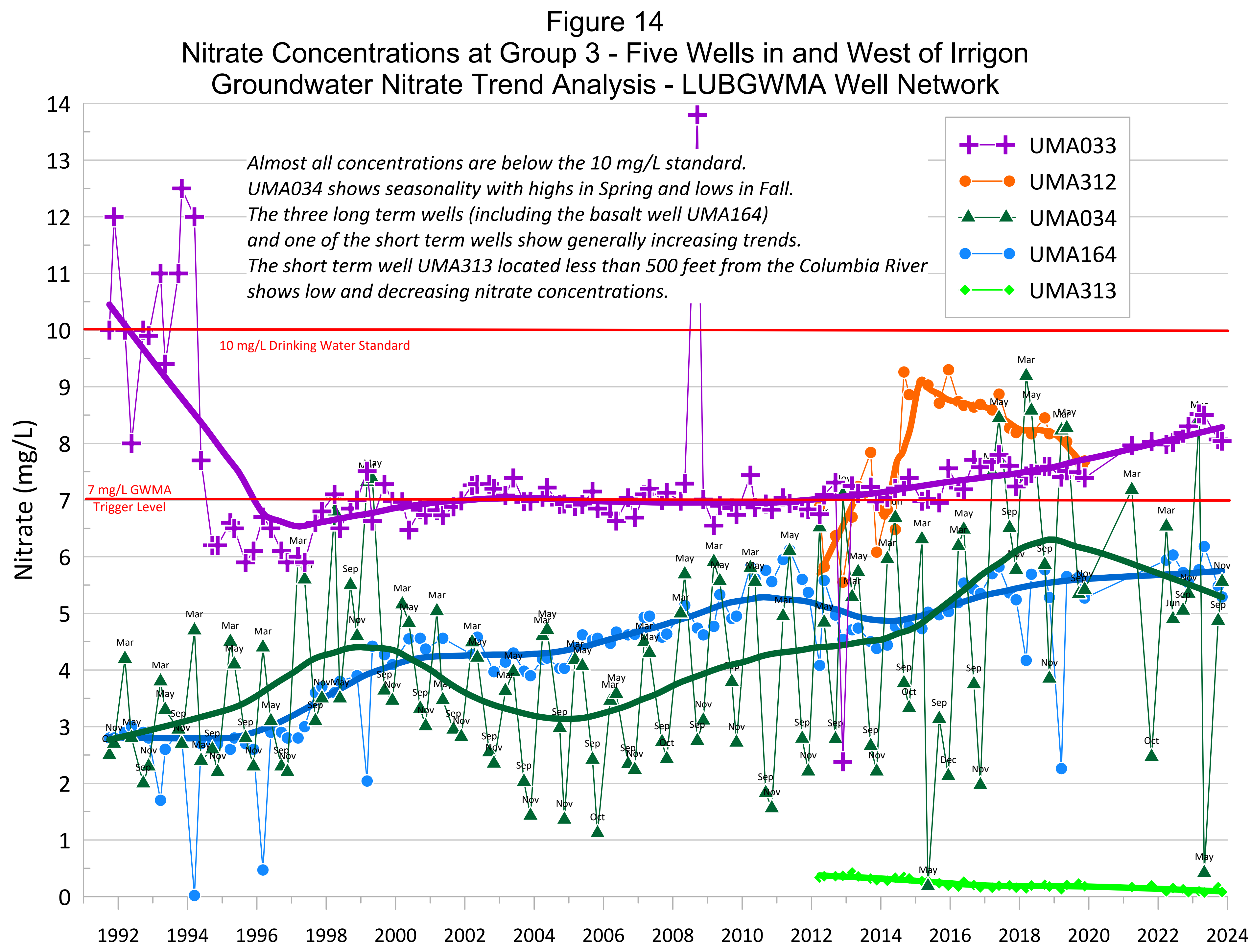


Figure 14
Nitrate Concentrations at Group 3 - Five Wells in and West of Irrigon
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network
Almost all concentrations are below the 10 mg/L standard.
UMA034 shows seasonality with highs in Spring and lows in Fall.
The three long term wells (including the basalt well UMA164)
and one of the short term wells show generally increasing trends.
The short term well UMA313 located less than 500 feet from the Columbia River
shows low and decreasing nitrate concentrations.
10 mg/L Drinking Water Standard
7 mg/L GWMA
Trigger Level
Nitrate (mg/L)
UMA033
UMA312
UMA034
UMA164
UMA313

Figure 15
Nitrate Concentrations at Group 4 - Three Wells in and West of Umatilla
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

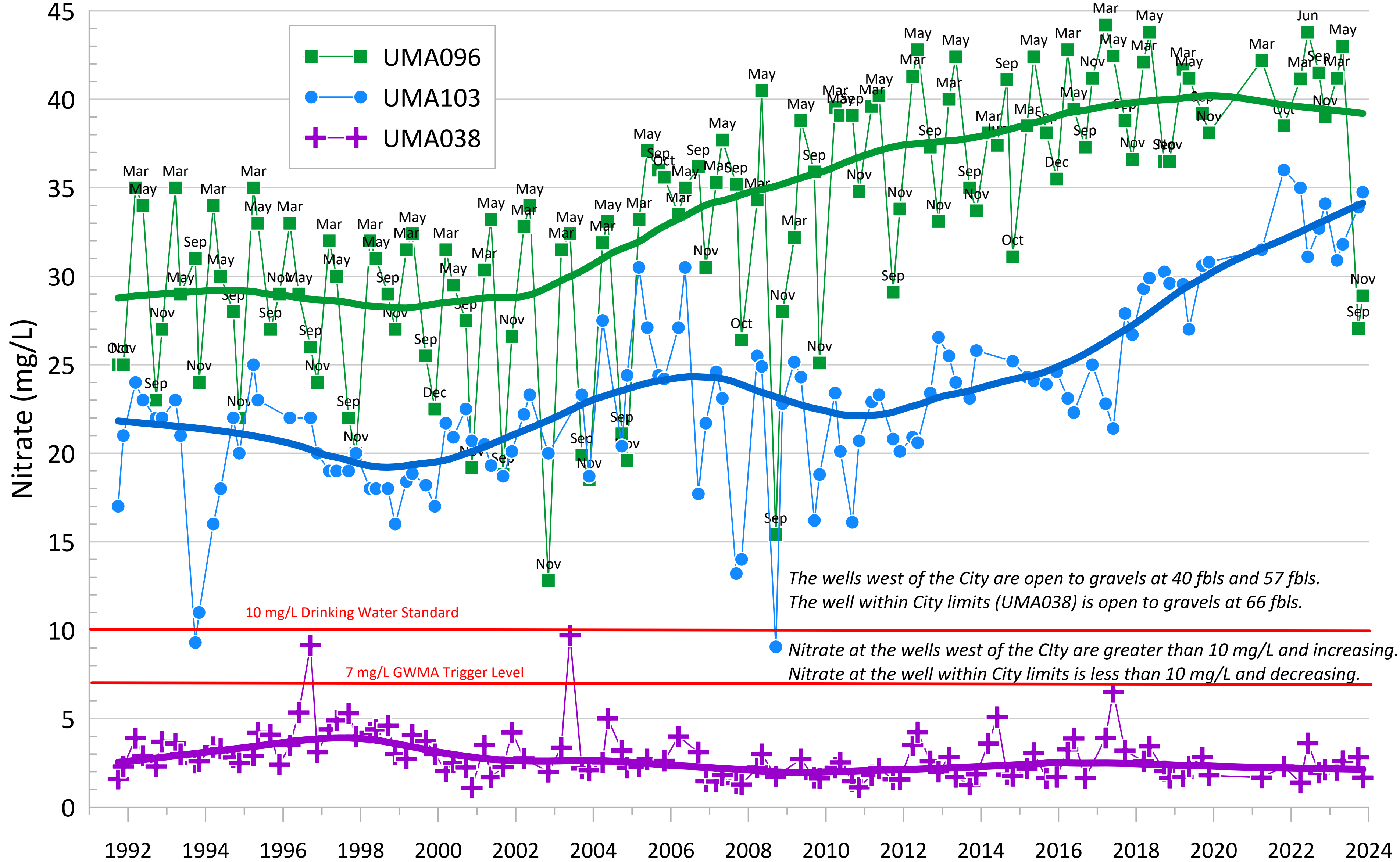


Figure 16
Nitrate Concentrations at Group 5a - Three Wells East of Hermiston
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

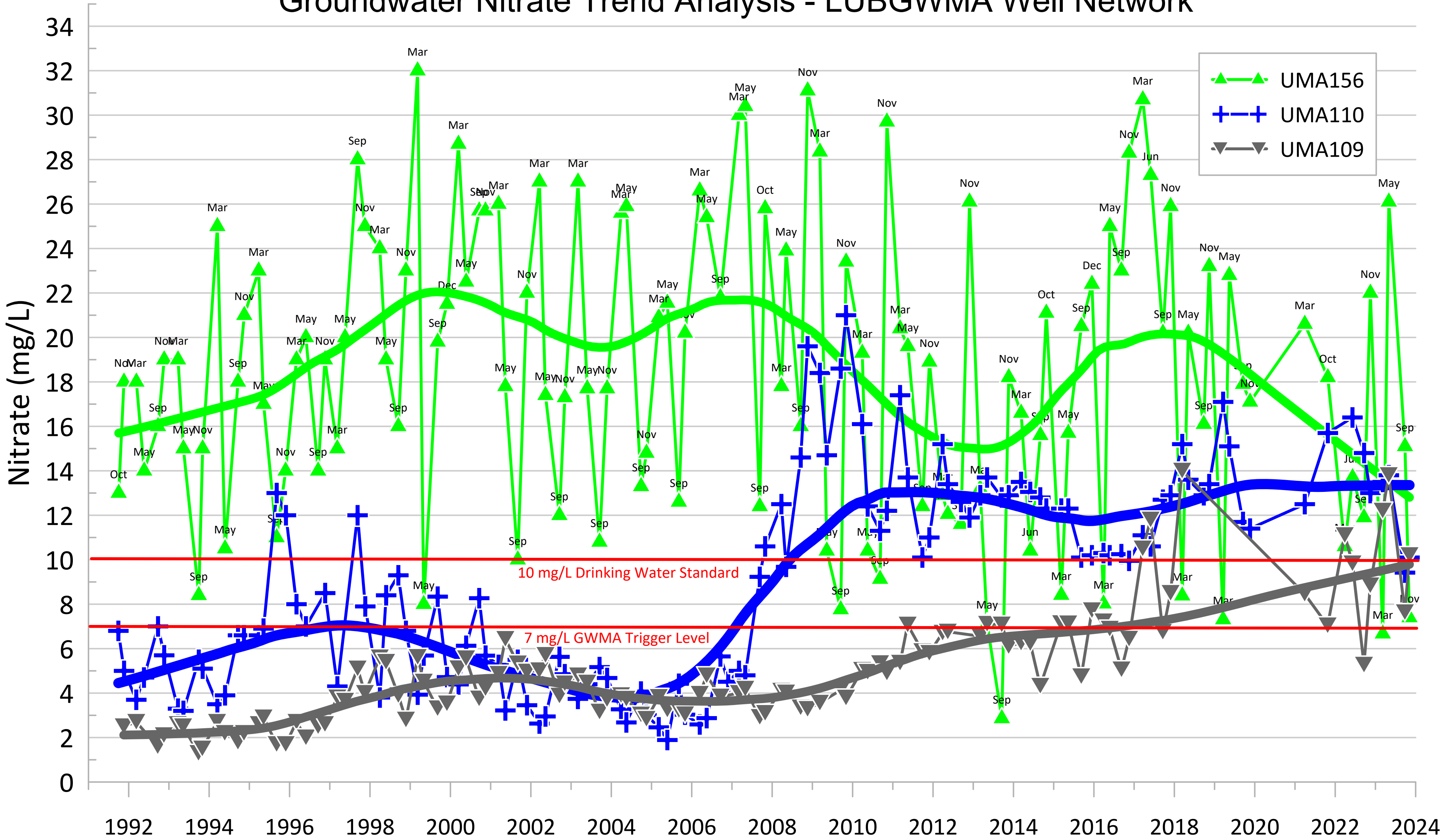


Figure 17
Nitrate Concentrations at Group 5b - Four Wells East of Hermiston
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

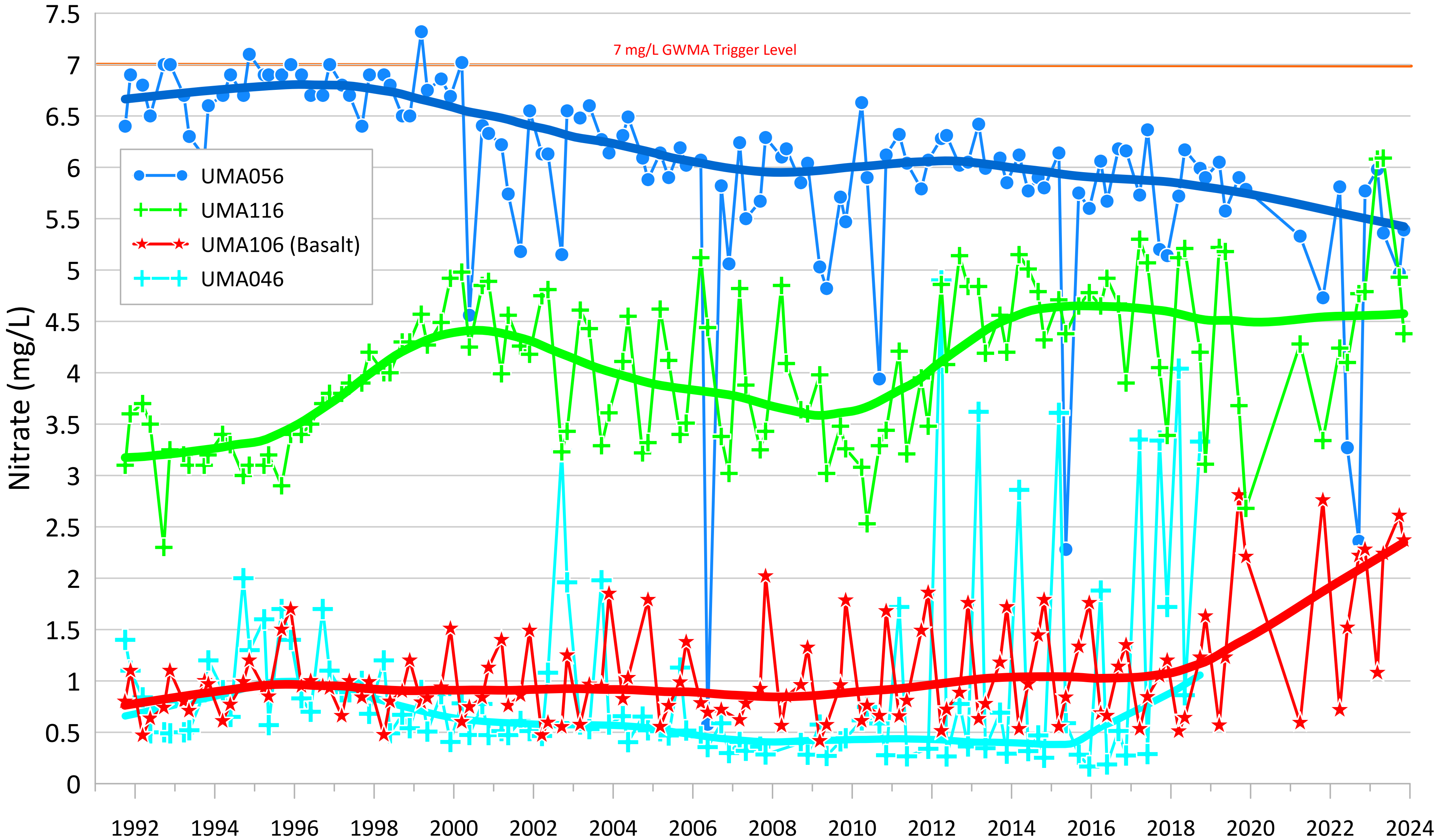


Figure 18
Nitrate Concentrations at Group 6 - Two Wells in Stanfield
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

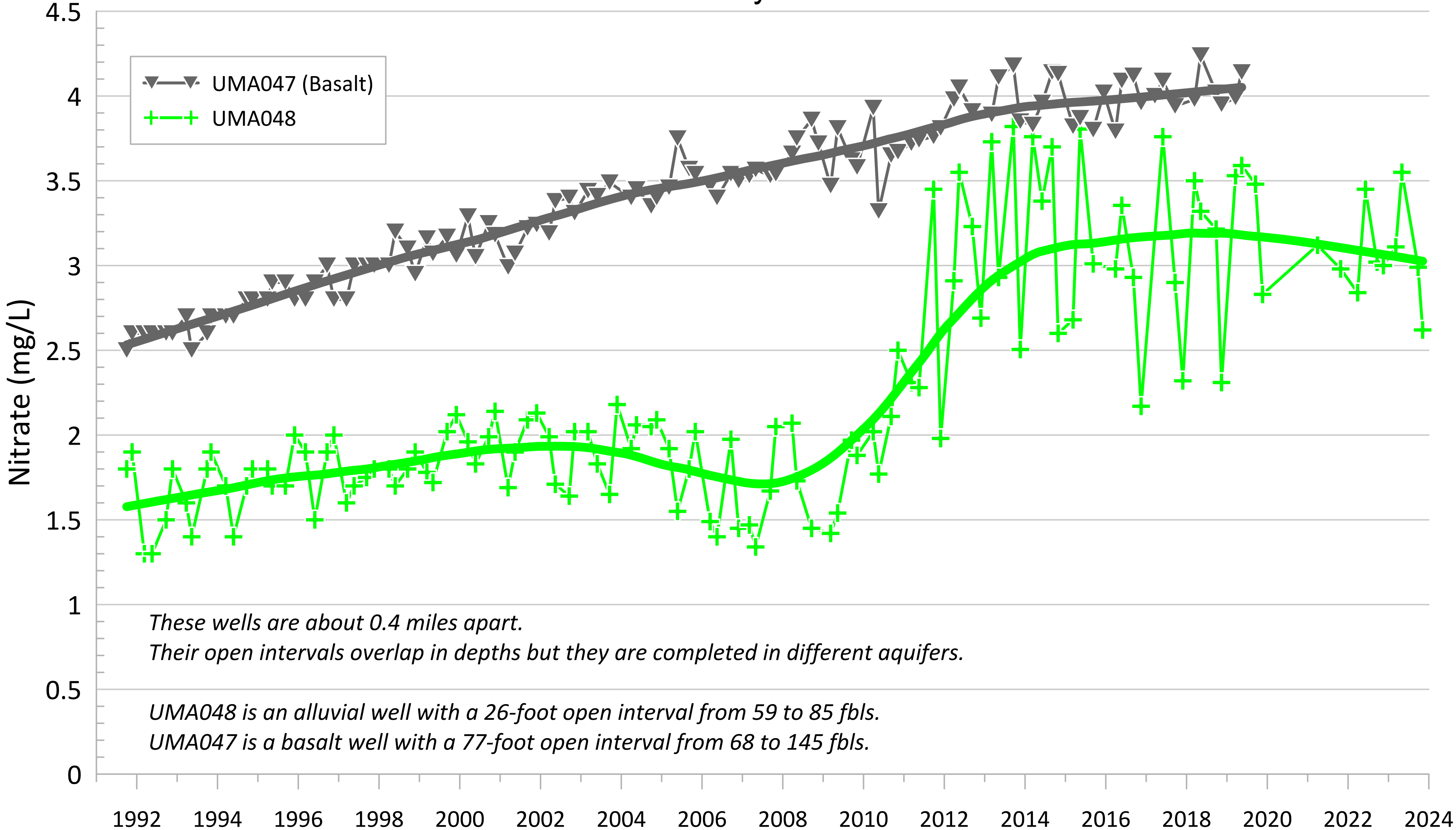


Figure 19
Nitrate Concentrations at Group 7 - Four Butter Creek and Umatilla River Flood Plain Wells
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

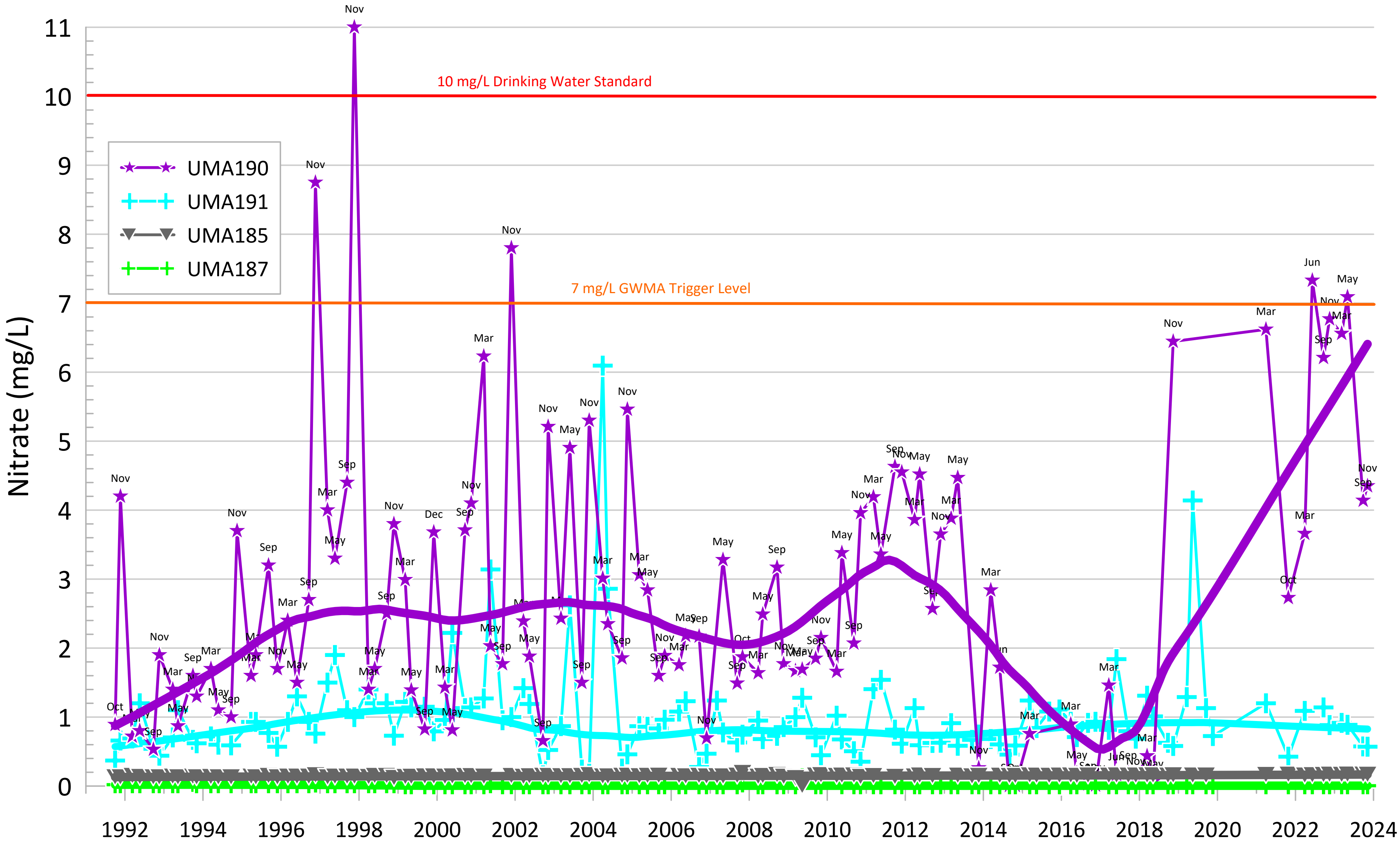


Figure 20
Nitrate Concentrations at Group 8 - Four Wells West of Hermiston
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

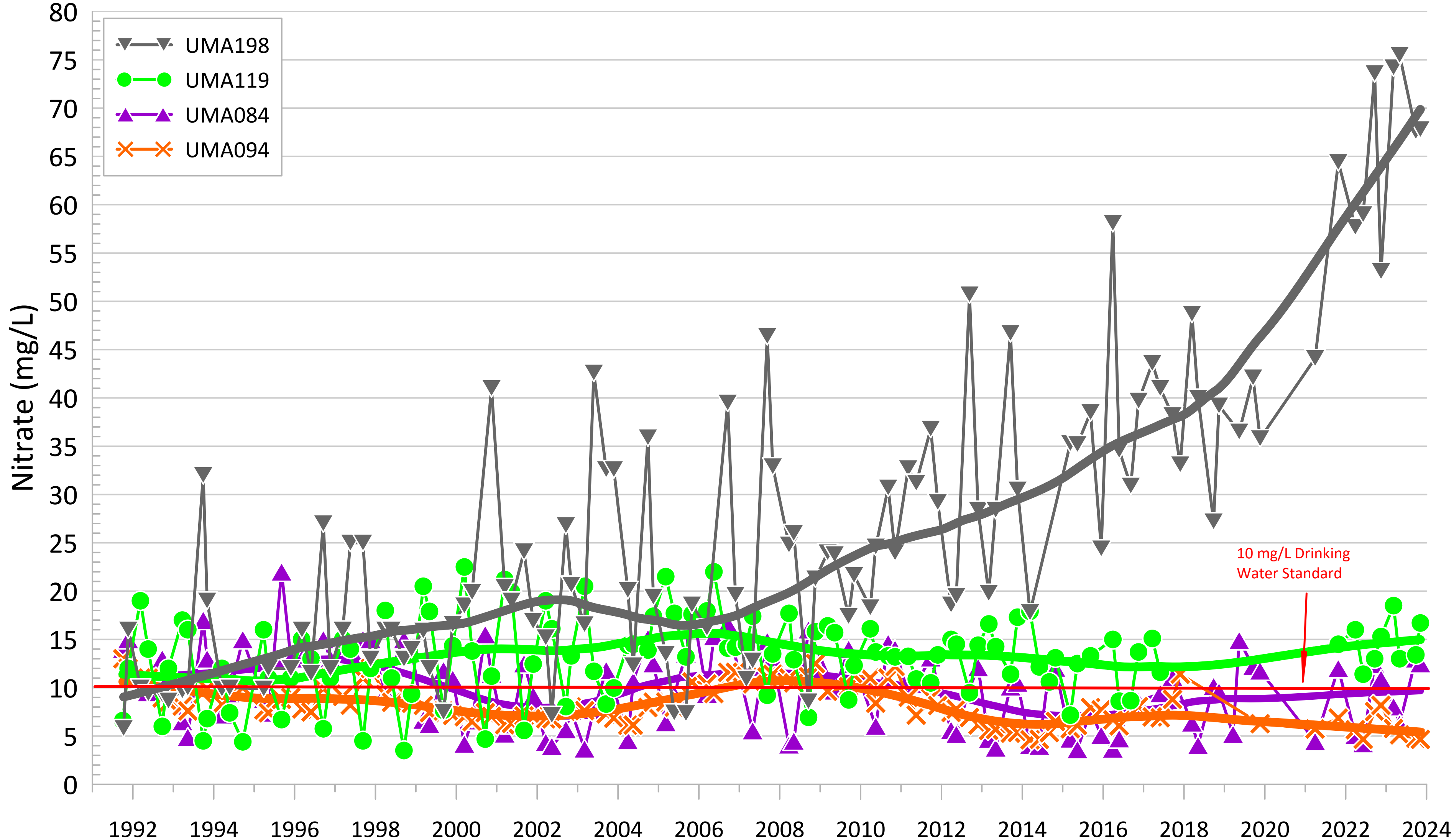


Figure 21
Nitrate Concentrations at Group 8 - Three of Four Wells West of Hermiston
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

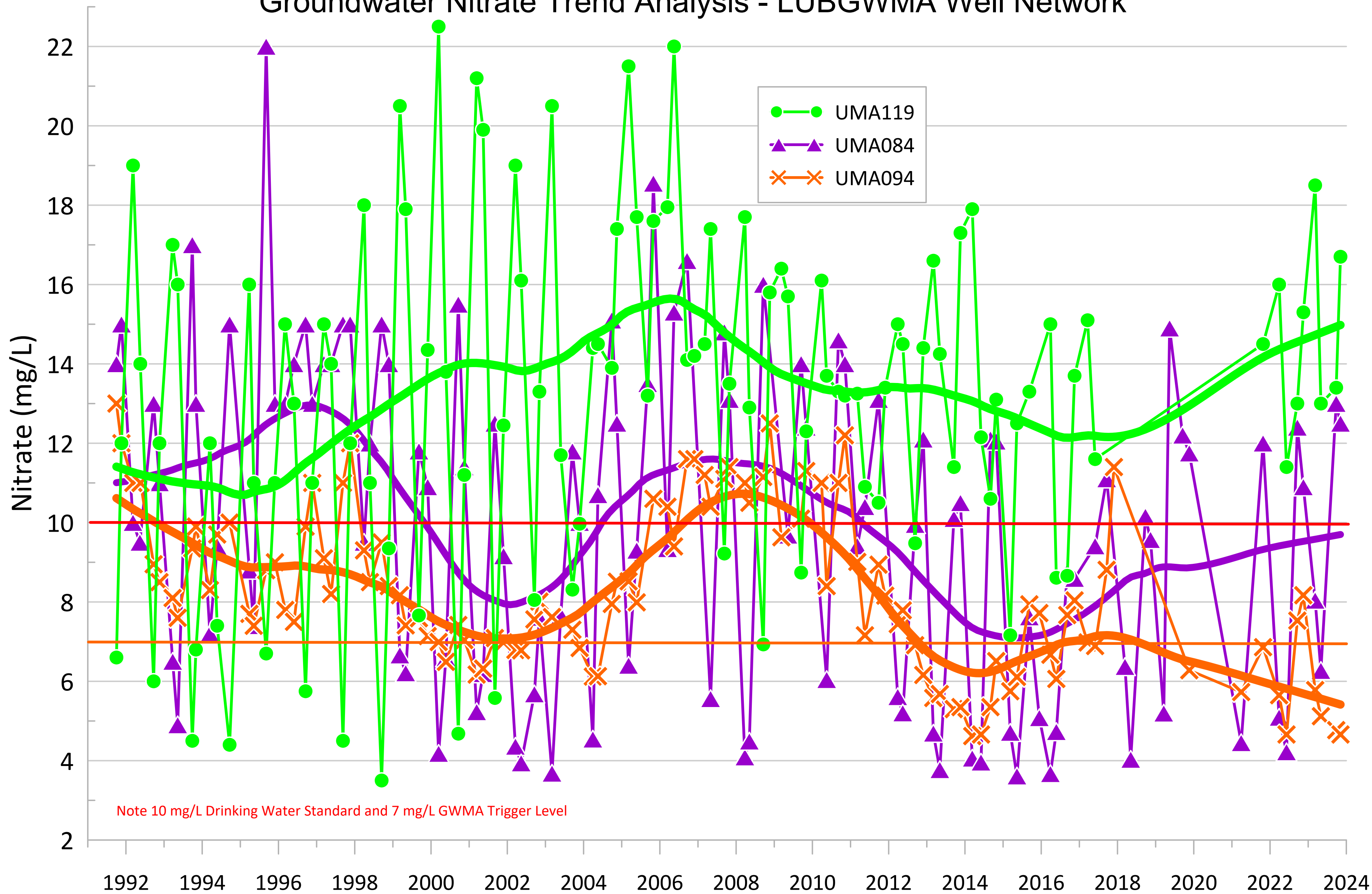


Figure 22
Nitrate Concentrations at Group 9 - Three Wells South of Umatilla Depot
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

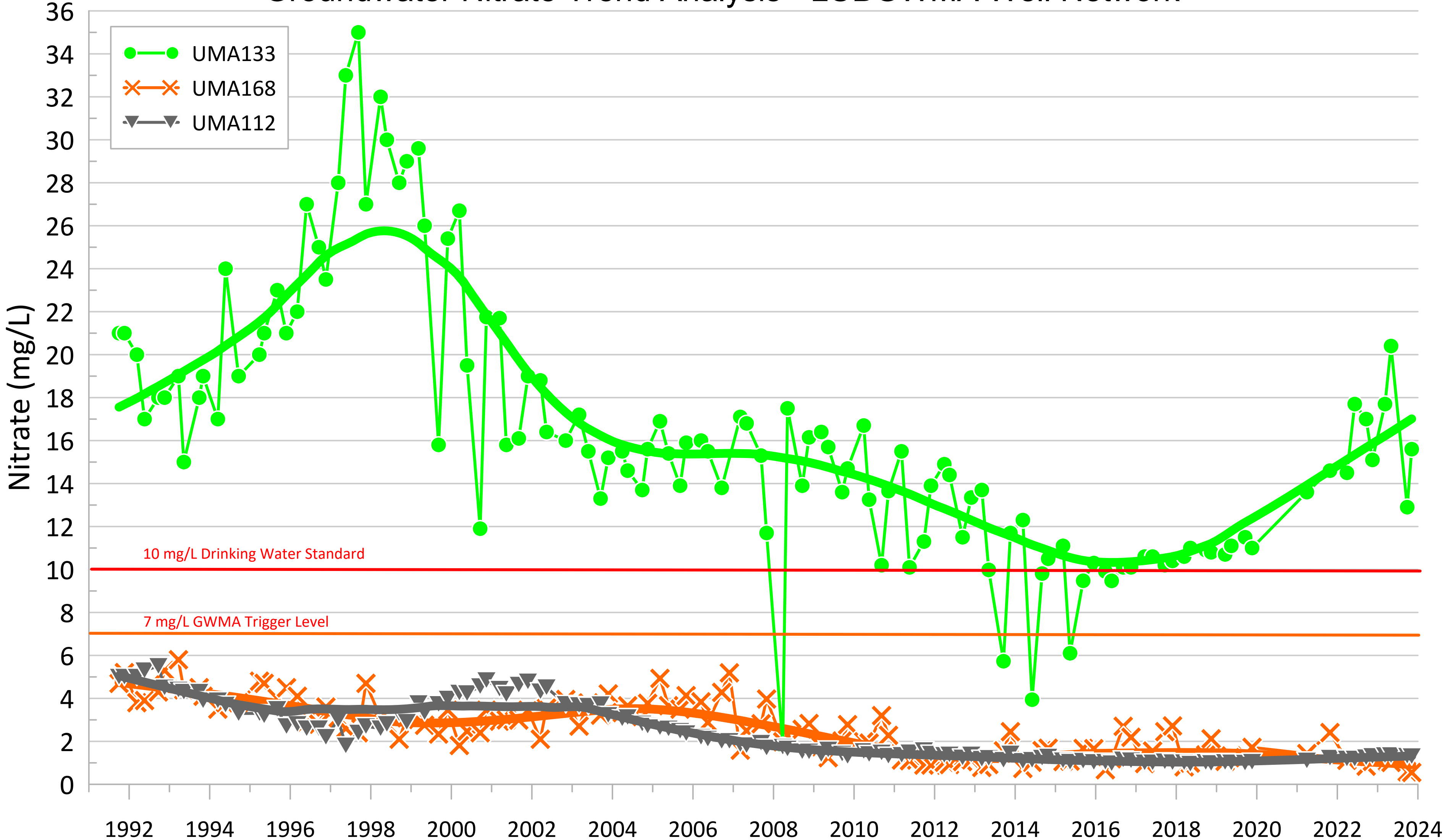
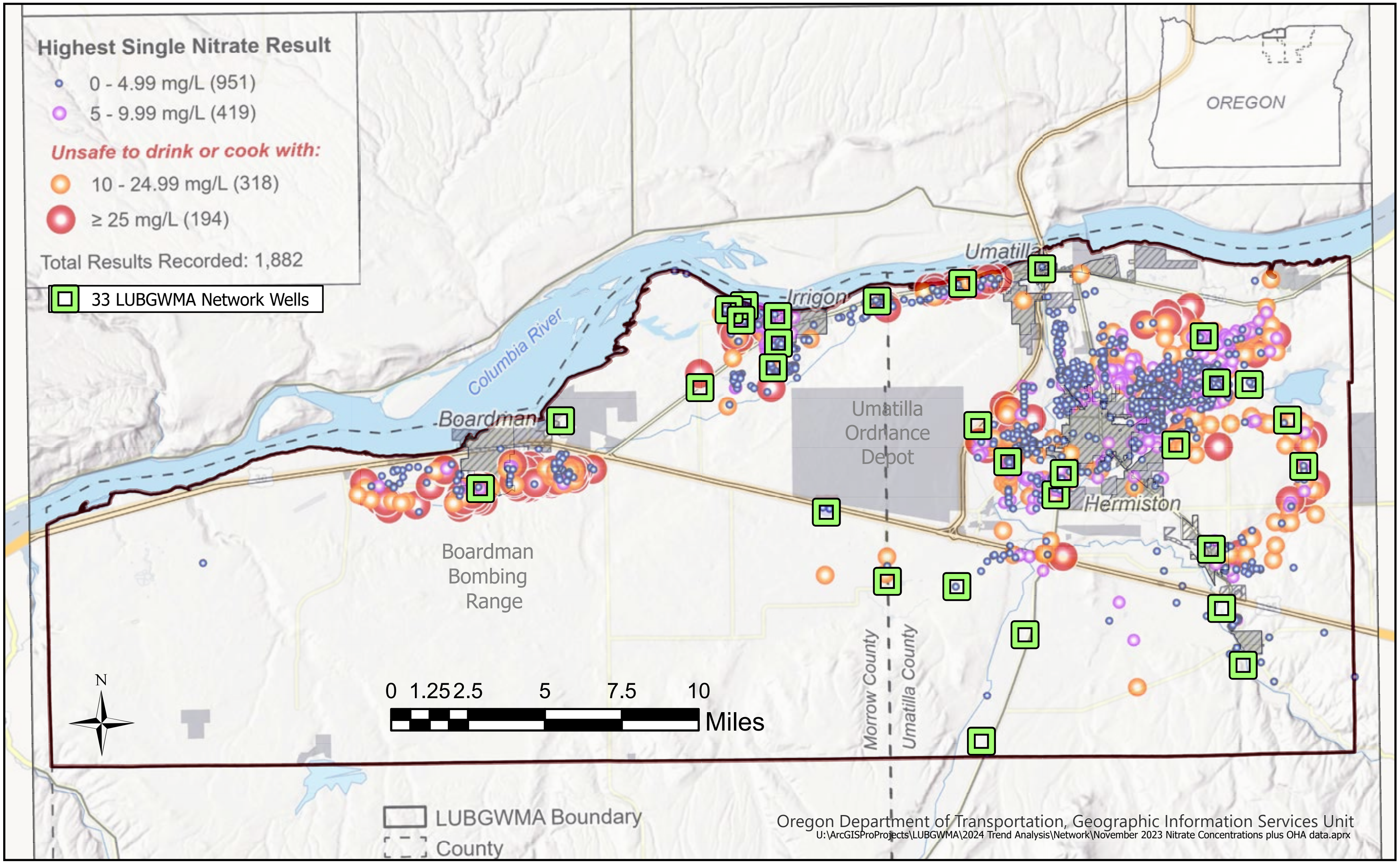


Figure 23
Overlap of LUBGWMA Well Network with OHA Data
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network



This figure superimposes the LUBGWMA Network well locations onto the map of highest single nitrate results through September 2024 from OHA's LUBGWMA website https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/SOURCEWATER/DOMESTICWELLSAFETY/Pages/Data.aspx.

Table 1
Nitrate Concentrations, Trends, and Seasonality at Individual Wells
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

Well ID	Aquifer	Well Use	Data Set Statistics											Trend Analysis Results				Seasonality ?
			Starting Date	Ending Date	Data Set Length (Yr)	n	# BDL	% BDL	Min (mg/L)	Median (mg/L)	Average (mg/L)	Max (mg/L)	Range (mg/L)	Direction	Slope (mg/L/yr)	p-value	Confidence Level	
UMA029	Basalt	domestic	10/1/1991	11/6/2023	32.1	116	0	0	25.0	39.4	40.5	61.3	36.3	Decreasing	-0.42	4E-04	99.96%	No
UMA033	Alluvial	domestic	10/1/1991	11/6/2023	32.1	124	0	0	2.4	7.1	7.4	13.8	11.4	Increasing	0.03	2E-04	99.98%	No
UMA034	Alluvial	domestic	10/1/1991	11/6/2023	32.1	124	0	0	0.2	3.8	4.2	9.2	9.0	Increasing	0.08	2E-04	99.98%	Yes
UMA038	Alluvial	domestic	10/2/1991	11/7/2023	32.1	116	0	0	1.1	2.6	2.9	9.7	8.6	Decreasing	-0.04	4E-04	99.96%	Yes
UMA046	*Alluvial*	*domestic*	*10/3/1991*	*9/26/2018*	*27.0*	*106*	*0*	*0*	*0.2*	*0.6*	*1.0*	*4.9*	*4.7*	*Decreasing*	*-0.01*	*2E-04*	*99.98%*	*Yes*
UMA047	*Basalt*	*domestic*	*10/3/1991*	*5/15/2019*	*27.6*	*109*	*0*	*0*	*2.5*	*3.5*	*3.4*	*4.2*	*1.7*	*Increasing*	*0.06*	*2E-04*	*99.98%*	*No*
UMA048	Alluvial	domestic	10/3/1991	11/7/2023	32.1	121	0	0	1.3	2.0	2.3	3.8	2.5	Increasing	0.05	2E-04	99.98%	No
UMA056	Alluvial	domestic	10/3/1991	11/7/2023	32.1	124	0	0	0.6	6.1	6.0	7.3	6.7	Decreasing	-0.04	2E-04	99.98%	No
UMA084	Alluvial	domestic	10/3/1991	11/7/2023	32.1	115	0	0	3.6	10.0	9.9	22.0	18.4	Decreasing	-0.11	2E-04	99.98%	Yes
UMA094	Alluvial	domestic	10/3/1991	11/7/2023	32.1	113	0	0	4.6	8.0	8.2	13.0	8.4	Decreasing	-0.10	2E-04	99.98%	Yes
UMA096	Alluvial	domestic	10/1/1991	11/7/2023	32.1	123	0	0	12.8	33.8	33.1	44.2	31.4	Increasing	0.48	2E-04	99.98%	Yes
UMA103	Alluvial	domestic	10/1/1991	11/6/2023	32.1	113	0	0	9.1	22.9	23.1	36.0	26.9	Increasing	0.37	2E-04	99.98%	No
UMA106	Basalt	domestic	9/30/1991	11/7/2023	32.1	122	0	0	0.4	0.9	1.1	2.8	2.4	Increasing	0.01	2E-04	99.98%	Yes
UMA109	Alluvial	domestic	11/18/1991	11/7/2023	32.0	110	0	0	1.3	4.4	5.0	14.0	12.7	Increasing	0.20	2E-04	99.98%	Yes
UMA110	Alluvial	domestic	9/30/1991	11/7/2023	32.1	121	0	0	1.9	9.4	9.1	21.0	19.1	Increasing	0.31	2E-04	99.98%	No
UMA112	Alluvial	domestic	10/2/1991	11/7/2023	32.1	122	0	0	0.9	1.8	2.4	5.5	4.6	Decreasing	-0.11	2E-04	99.98%	No
UMA116	Alluvial	domestic	10/3/1991	11/7/2023	32.1	124	0	0	2.3	4.1	4.0	6.1	3.8	Increasing	0.04	2E-04	99.98%	Yes
UMA119	Alluvial	domestic	10/3/1991	11/7/2023	32.1	111	0	0	3.5	13.4	13.2	22.5	19.0	Increasing	0.07	9E-03	99.14%	Yes
UMA133	Alluvial	domestic	10/2/1991	11/7/2023	32.1	121	0	0	1.8	15.5	16.3	35.0	33.2	Decreasing	-0.38	2E-04	99.98%	No
UMA144	Alluvial	domestic	10/1/1991	11/6/2023	32.1	123	0	0	1.5	12.5	13.3	42.3	40.8	Decreasing	-0.12	2E-03	99.82%	Yes
UMA156	Alluvial	domestic	10/3/1991	11/7/2023	32.1	123	0	0	2.9	18.9	18.5	32.0	29.1	no significant trend	-0.04	9E-01	10.22%	Yes
UMA160	Alluvial	irrigation	11/19/1991	11/6/2023	32.0	121	15	12%	< 0.005	1.0	3.8	27.7	27.6	Increasing	0.05	4E-04	99.96%	No
UMA164	Basalt	domestic	10/1/1991	11/6/2023	32.1	116	1	1%	< 0.02	4.6	4.3	6.2	6.2	Increasing	0.10	2E-04	99.98%	No
UMA168	Alluvial	domestic	10/2/1991	11/7/2023	32.1	121	0	0	0.6	2.6	2.6	5.8	5.2	Decreasing	-0.11	2E-04	99.98%	No
UMA180	Alluvial	domestic	10/1/1991	11/6/2023	32.1	101	1	1%	< 0.02	7.5	11.4	32.0	32.0	Increasing	1.05	2E-04	99.98%	No
UMA185	Alluvial	domestic	10/2/1991	11/7/2023	32.1	112	0	0	0.006	0.149	0.15	0.19	0.187	Increasing	0.001	2E-04	99.98%	No
UMA187	Alluvial	domestic	10/2/1991	11/7/2023	32.1	122	111	91%	< 0.005	<0.005	<0.005	0.13	0.1	Decreasing	-0.001	2E-03	99.80%	No
UMA190	Alluvial	domestic	10/2/1991	11/7/2023	32.1	114	2	2%	< 0.005	2.2	2.7	11.0	11.0	Increasing	0.03	1E-01	87.88%	No
UMA191	Alluvial	irrigation	10/2/1991	11/7/2023	32.1	122	0	0	0.2	0.9	1.0	6.1	5.9	no significant trend	-0.001	9E-01	14.72%	Yes
UMA198	Alluvial	industrial	10/10/1991	11/7/2023	32.1	115	0	0	5.8	24.0	27.1	75.5	69.7	Increasing	1.20	2E-04	99.98%	No
UMA201	Alluvial	domestic	11/22/1991	11/6/2023	32.0	121	0	0	3.4	23.1	22.4	43.8	40.4	Increasing	0.79	2E-04	99.98%	Yes
UMA312	*Alluvial*	*domestic*	*3/27/2012*	*11/19/2019*	*7.7*	*31*	*0*	*0*	*5.6*	*8.2*	*7.9*	*9.3*	*3.8*	no significant trend	*0.15*	*5E-01*	*47.24%*	*No*
UMA313	*Alluvial*	*domestic*	*3/27/2012*	*11/6/2023*	*11.6*	*42*	*0*	*0*	*0.073*	*0.2*	*0.2*	*0.4*	*0.4*	*Decreasing*	*-0.02*	*2E-04*	*99.98%*	*No*

Note: Long Term wells include all 33 wells minus *UMA046, UMA047, UMA312, and UMA313.*

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Table 2
Nitrate Trends by Magnitude
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

Trend Magnitude	# of Wells with Increasing Trends	Average slope of Increasing Trends (ppm/yr)	# of Wells with Decreasing Trends	Average slope of Decreasing Trends (ppm/yr)	# of Wells with Statistically Insignificant Trends	Average slope of Statistically Insignificant Trends (ppm/yr)
Small (up to 0.1 mg/L/yr)	**10**	0.05	4	-0.05	2	-0.02
Medium (0.1 to 0.5 mg/L/yr)	4	**0.34**	**6**	-0.21		
Large (greater than 0.5 mg/L/yr)	**3**	**1.01**				
TOTAL	**17**		10		2	
OVERALL AVERAGE		**0.29**		-0.14		-0.02

Note: This table only compares the 29 Long Term wells (i.e., those that were sampled September 1991 through November 2023)

bold = Larger number of wells or steeper trend

Summary

Increasing trends are generally more numerous and steeper than decreasing trends.

Parsed By Direction

Trends by Direction - There are more increasing trends than decreasing trends (17 vs 10; 59% vs 35%)

Trends by Average Magnitude - Average increasing trends are steeper than average decreasing trends (0.29 mg/L/yr vs -0.14 mg/L/yr).

Parsed By Direction and Magnitude

Small Trends - Increasing trends are more numerous (10 vs 4) but the average slopes are equal (0.05 mg/L/yr vs -0.05 mg/L/yr).

Medium Trends - Decreasing trends are more numerous (6 vs 4), but less steep than increasing trends (average -0.21 mg/L/yr vs 0.34 mg/L/yr).

Large Trends - All large trends are increasing and average 1.01 mg/L/yr. The 4 largest trends (and 7 of the 10 largest trends) are increasing.

E:\LUB\2024 Trend Analysis\LUBGWMA Network\[R output.xlsx]Table 2

Table 3
Nitrate Concentrations, Trends, and Seasonality of Well Groups
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

Well Group	Aquifer	Well Use	Data Set Statistics										Trend Analysis Results				Seasonality?
			Starting Date	Ending Date	Data Set Length (Yr)	n	# BDL	% BDL	Min	Median	Average	Max	Direction	Slope (ppm/yr)	p-value	Confidence Level	
All 33 wells	Both	mix	9/30/1991	11/7/2023	32.1	3719	130	0	< 0.005	5.1	9.6	75.5	Increasing	0.03	2E-04	99.98%	Yes
29 LT wells	Both	mix	9/30/1991	11/7/2023	32.1	3431	130	0	< 0.005	5.7	10.2	75.5	Increasing	0.04	2E-04	99.98%	Yes
3 LT Basalt wells	Basalt	domestic	9/30/1991	11/7/2023	32.1	354	1	0	< 0.020	4.6	15.1	61.3	Increasing	0.03	2E-04	99.98%	Yes
26 LT Alluvial wells	Alluvial	mix	9/30/1991	11/7/2023	32.1	3077	129	0	< 0.005	6.0	9.6	75.5	Increasing	0.04	2E-04	99.98%	Yes

Note: LT (Long Term) wells include all 33 wells minus *UMA046, UMA047, UMA312, and UMA313.*

E:\LUB\2024 Trend Analysis\LUBGWMA Network\[R output.xlsx]Table 3

Table 4
Comparison of DEQ and OHA Data Sets
Groundwater Nitrate Trend Analysis - LUBGWMA Well Network

	Data Set	DEQ	OHA
Data Set Characteristics	# Wells	33	1,872
	# Results	3,719	2,392
	Time Frame	Sep 91 - Nov 23	Mar 23 - Sep 24
	Data Set Length	32 years	1.5 years
	Percentage of Samples from Alluvial Aquifer	~10%	unknown (2)
Nitrate Concentrations	Non-Detected Values	3.4%	31%
	40th Percentile (mg/L)	3.7	2.5
	50th Percentile or Median (mg/L)	5.1	5.1
	Average (mg/L)	9.6	~ 8.2 (1)
	% above 10 mg/L	31%	23%
	75th Percentile (mg/L)	13.1	9.5
	Maximum (mg/L)	75.5	94.8
Geographic Distribuion of Samples	% from Hermiston Zip Code	30%	58%
	% from Irrigon Zip Code	27%	19%
	% from Boardman Zip Code	6%	13%
	% from Stanfield Zip Code	18%	5%
	% from Umatilla Zip Code	6%	4%
	% from Echo Zip Code	12%	2%

(1) The Peto-Peto test was used to evaluate differences in the data sets cumulative distribution functions while the mean was estimated by the Kaplan-Meir method. The tests were run using the reported detection limits and seven different assumed detection limits (ranging from 0.005 to 5.0 mg/L). All show differences between the groups with the DEQ data set mean = 9.6 mg/L and OHA mean = 8.1 to 9.0 mg/L. Assuming a detection limit of 0.5 mg/L (twice the reported detection limit) or lower is applicable for samples with unreported detection limits, the average is estimated to be 8.1 to 8.2 mg/L.

(2) Of the 1,872 well sampled, 13 reported their OWRD Well Log ID. One well is an Alluvial Aquifer well. Eleven wells were basalt wells. Two wells appear to tap the weathered basalt at the base of the Alluvial Aquifer. This observation suggests the potential for the OHA data set to have a higher percentage of basalt wells, but the very low percentage of known well logs (<1%) does not allow a conclusion to be drawn.

E:\LUB\2024 Trend Analysis\OHA Data\[OHA data through Sep25 2024.xlsx]Table 4

Appendix A

Data Download Procedure

Data Download Procedure

The following steps detail the procedure used in the LUBGWMA Well Network Trend Analysis.

1. *Download data* –
    a. Go to the Oregon DEQ Water Quality Monitoring Data website and sign in using the default orpublic username.
    b. Select the Standard (Abbreviated) export option, and default search criteria.
    c. Click the Select individual monitoring. Choose the option to Paste in the monitoring location IDs and, with OREGONDEQ as the selected Organization, paste the following IDs.

    16100-ORDEQ 16096-ORDEQ 16019-ORDEQ 16024-ORDEQ 16023-ORDEQ 16154-ORDEQ 16134-ORDEQ 16170-ORDEQ 16093-ORDEQ 16086-ORDEQ 16158-ORDEQ 16123-ORDEQ 16102-ORDEQ 16175-ORDEQ 16181-ORDEQ 16180-ORDEQ 16177-ORDEQ 16028-ORDEQ 16038-ORDEQ 16046-ORDEQ 16036-ORDEQ 16146-ORDEQ 16106-ORDEQ 16109-ORDEQ 16074-ORDEQ 16037-ORDEQ 16084-ORDEQ 16188-ORDEQ 16099-ORDEQ 16150-ORDEQ 16191-ORDEQ 36979-ORDEQ 36964-ORDEQ

    d. Click the Organization ID box in the top banner to select the locations.
    e. On the Other Search Criteria tab, uncheck the Metrics and Indexes boxes
    f. Enter absolute date range of 09-01-1991 to 12-31-2023
    g. In the Activity Type (specific) pull down menu, select Check All
    h. On the Parameters tab, check the box for Select individual parameters, then check the Nitrate + Nitrite box.
    i. Click the Export Data button. The data is exported to a downloadable spreadsheet.
2. Save the exported data into a spreadsheet called AWQMS export.xlsx. Rename the Results worksheet as AWQMS export. Copy worksheet into a new worksheet named “Trimmed”
3. *Trim Data Set* -
    a. Delete the empty row 1.
    b. Delete the following empty or unnecessary columns:
        i. Empty columns - Project ID2, Project ID3, Activity Conducting Organization1, Relative Depth, Depth/Height, Depth/Height Unit, Top Depth/Height, Top Depth/Height Unit, Bottom Depth/Height, Bottom Depth/Height Measure Unit, Data Logger Line, CAS#, Result Qualifier 2, Result Qualifier 3, Result Qualifier 4, Result Qualifier 5, Result Qualifier 6, Detection Condition, Precision, Bias, Confidence Interval, Upper Confidence Limit, Lower Confidence Limit, Substance Dilution Factor1, Analysis Start Date
        ii. Unnecessary columns - Organization ID, Activity ID, Monitoring Location State, Monitoring Location Type, Activity Start Time, Activity Media, Sample Collection Method ID, Sample Collection Method Context, Sample Collection Method Name, Result Status, Data Quality Level, Characteristic Name, Method Speciation , Sample Fraction, Result Value Type, Results Unit, Detection Limit Type1, Detection Limit Value1, Detection Limit Unit1, Detection Limit Type2, Detection Limit Value2, Detection Limit Unit2, Analytical Method ID, Analytical Method Context, Analytical Method Name, Laboratory Name

c. Rename the "Result Value" column to "Nitrate" and the "Activity Start Date" column to "Date"
d. The network was originally sampled in the six odd-numbered months (e.g., January, March, May, July, September, and November) but was subsequently reduced to sampling only in March, May, September, and November. No results from January, July, or August were used in this analysis (i.e., deleted from the query results). To do so,
    i. Insert three columns to the right of the Date column, then using the Data > Text to Columns function, parse the Dates into Month, Day, and Year. Name the columns and format them as General.
    ii. Sort the data set by Month, then by Day, then by Year. Delete the 580 January results, 645 July results, and one August result.
e. Well UMA312 was sampled on 5/1/2012 as part of the City of Irrigon's drinking water source water protection project. Sort the data set by Project ID1, then delete the Drinking Water Source result. That well was also sampled later that month as part of a regularly scheduled sampling event.

4. *Historical LASAR Data* – The Project ID1 for most results are identified as "Groundwater Management Areas" but 69 results from 5/14/1992 through 3/15/94 are identified as Historical LASAR Data. These data points were part of the regular sampling events so they were kept in the query results.
5. *Identify Replicates* – As part of the QA/QC plan, duplicate samples (i.e., collected from the same well on the same day) are periodically collected. They are termed "Sample – Routine" and "Quality Control Sample – Field Replicate" in AWQMS.
    a. The data were sorted by Activity Type, then a column called Dup 1 was added with a value of 1 entered for the Field Replicate samples.
    b. The data were sorted by Monitoring Location Name, then date. A column called Date Check was added, which calculates the number of days since the previous sample. Copy, PasteValues. The data were sorted by DateCheck, then Date. A value of 1 was entered into the Dup 1 field for samples with DateCheck = 0.
6. *Average Replicates* –The average of the Routine and Field Replicate sample values from the same well on the same day was calculated. On eight occasions, a routine sample and two field replicate samples were collected. On one occasion (UMA160 on 3/12/92), two regular samples were collected using different techniques. The result from the traditional method was used in this analysis.

   The Averaging procedure followed was:
   1. Copied Trimmed worksheet to Dup Check worksheet.
   2. Sort by Dup 1
   3. Cut Dup 1 records out and past into Replicates worksheet,
   4. Inserted a column called Average and calculated average of Routine and Field Replicates results from the same well on the same day. Copy, PasteValue
   5. Sort by Average. Copy and Paste rows with Average value to worksheet called Averages. Copy and paste values from Average column to Nitrate column. Delete Average column.
   6. Copy and paste contents of Averages worksheet to Reassemble worksheet.
   7. Copy and paste remaining records from DupCheck worksheet into Reassemble worksheet.

8. Sort by Monitoring Location Name, then Date. Delete the UMA160 sample on 3/12/1992 collected using low flow technique (0.211 mg/L) but keep the 0.262 mg/L result from traditional purge sample.

7. *<u>Prepare Data Set for Statistical Analysis</u>* – The following steps were taken to enable statistical analysis:
   a. Reassemble worksheet was saved as INPUT worksheet and then trimmed of excess fields *(Monitoring Location ID, Monitoring Location Latitude, Monitoring Station Longitude, Activity Type, Dup 1, DateCheck, Project ID1, Activity Comment, Result Qualifier 1, and Result Comment 1)*, sampling date was converted to decimal date, and Monitoring Location Name was parsed to just well ID (e.g., UMA029).
   b. Censored data (i.e., results reported as below detection limit) were parsed into a less than symbol and the detection limit. The variable BDL=1 and/or cen numberwas added to indicate when result was censored at the detection limit.
   c. Each well was designated as either tapping the Alluvial Aquifer or the Basalt Aquifer.
   d. *<u>Assign Quarter</u>* - In order to evaluate seasonality and trends, each result is assigned to a particular quarter of the year (i.e., Q1, Q2, Q3, or Q4). Samples collected in the target months of March, May, September, and November were assigned to Q1, Q2, Q3, and Q4 respectively. No sampling event occurred in 2020 or in May 2021 or September 2021. Eleven sampling events were not fully completed within the target month. Six events were completed within one or two days of the target month. Four events were conducted within four to eight days of the target month. One event was conducted within fifteen days of the target month. In addition to samples collected in the target months of March, May, September, and November the following seasonal assignments were made that affect 219 samples:
      i. The first sampling event occurred on 9/30/91 through 10/3/91 with one sample collected 10/10/91. These results were assigned to the Q3 1991.
      ii. *Complete sampling events were conducted in May, June, and July 1992. Results from the sampling event that occurred 6/22/92 to 6/25/92 were deleted.*
      iii. The March 1998 sampling event occurred on 3/30/98 through 4/1/98. These samples were assigned to Q1 1998.
      iv. The November 1999 sampling event occurred on 11/30/99 through 12/2/99. These samples were assigned to Q4 1999.
      v. The November 2005 sampling event occurred on 10/31/05 through 11/02/2005. These samples were assigned to Q4 2005.
      vi. The November 2007 sampling event occurred on 10/30/07 and 10/31/2007. These samples were assigned to Q4 2007.
      vii. The May 2014 event occurred on 6/3/14 and 6/4/14. These samples were assigned to Q2 2014.
      viii. The November 2014 sampling event occurred 10/27 through 10/28/14. These samples were assigned to Q4 2014.
      ix. The November 2015 sampling event occurred on 12/14/15 through 12/15/15. These samples were assigned to Q4 2015.
      x. The May 2017 event occurred on 5/31/17 and 6/1/17. These samples were assigned to Q2 2017.

xi. The November 2021 sampling event occurred on 10/25/21 through 10/27/21. These samples were assigned to Q4 2021.

xii. The May 2022 event occurred on 6/7/22 and 6/8/22. These samples were assigned to Q2 2022.

8. Each result was assigned a "QtrSeason" which is a combination of the well ID and quarter sampled (e.g., "UMA029_Q1". This is the seasonal term used in the Kruskal-Wallis test, Seasonal Kendall test, and Regional Kendall test. This worksheet ("INPUT" from AWQMS export.xlsx) was then saved as "INPUT" in "R Input.xlsx".
9. Variations on the full dataset (including resulting trend line coordinates) are saved in various worksheets of "R Input.xlsx".
10. Output from running the R functions censeaken and Kruskal.test is in "R output.xlsx" The spreadsheet also includes R results used to construct tables and figures in the report.
11. The 29 Long Term well data set from 1991 through 2023 was trimmed one year at a time (i.e., 1991 through 2022, 1991 through 2021, etc.) to allow evaluation of the change in trends over time. These data sets were saved in "29 LT Wells.xlsx". Results are stored in the "censeaken summary" worksheet of "R output.xlsx".
12. The analyses conducted utilized the NADA2 package for R (https://cran.r-project.org/package=NADA2) with the censeaken and kruskal.test functions with the following usage:
    - censeaken(DecDate,Nitrate,`BDL=1`,QtrSeason,LOG=FALSE,R=4999,nmin=4,seaplots=FALSE, printstat=TRUE)
    - kruskal.test(Nitrate,QtrSeason)
    - cfit(Nitrate,cen)

Monitoring Locations

- 16100-ORDEQ
- 16096-ORDEQ
- 16019-ORDEQ
- 16024-ORDEQ
- 16023-ORDEQ
- 16154-ORDEQ
- 16134-ORDEQ
- 16170-ORDEQ
- 16093-ORDEQ
- 16086-ORDEQ
- 16158-ORDEQ
- 16123-ORDEQ
- 16102-ORDEQ
- 16175-ORDEQ
- 16181-ORDEQ
- 16180-ORDEQ
- 16177-ORDEQ
- 16028-ORDEQ
- 16038-ORDEQ
- 16046-ORDEQ
- 16036-ORDEQ
- 16146-ORDEQ
- 16106-ORDEQ
- 16109-ORDEQ
- 16074-ORDEQ
- 16037-ORDEQ
- 16084-ORDEQ
- 16188-ORDEQ
- 16099-ORDEQ
- 16150-ORDEQ
- 16191-ORDEQ
- 36979-ORDEQ
- 36964-ORDEQ

Appendix B

Statistical Test Assumptions

Appendix B
Statistical Test Assumptions

Statistical Test	Assumption	Discussion
Seasonal Kendall test for linear trends	When no trend is present the observations are not serially correlated over time. In other words, they are independent and identically distributed.	Serial correlation within this data set was evaluated in a previous analysis of data from this network and shown to be inconsequential. Evaluation of serial correlation was not performed on this data set but is assumed to still be inconsequential. Evaluation of serial correlation will be considered in future analyses.
	The observations obtained over time are representative of the true conditions at sampling times.	The data used to evaluate groundwater nitrate trends was collected by the Oregon DEQ laboratory under a Sampling and Analysis Plan and Quality Assurance / Quality Control Plan developed using industry standards and designed to obtain samples that represent conditions in the aquifer. Therefore, observations are believed to be representative and unbiased.
	The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.	
	The null hypothesis is for each season, all observations are randomly ordered (i.e., no trend). The alternative hypothesis is there is a monotonic trend in one or more seasons. If one season shows a significant increasing trend and another shows a significant decreasing trend, these can cancel each other out so that there is no overall significant Seasonal Kendall Trend.	In general, violating the monotonicity assumption results in a loss of power to detect a trend. In this study, the assumption is violated at nine of the 33 wells evaluated. The loss of power to detect a trend due to violating the monotonicity assumption was minimal because the three wells exhibiting an overall statistically insignificant trend each had either three or four statistically insignificant seasonal trends. The other six wells exhibiting less than four monotonic seasonal trends exhibited statistically significant overall trends.
	The standard normal distribution may be used to evaluate if the computed SK test statistic indicates the existence of a monotonic trend over time.	
Regional Kendall test for linear trends	In addition to the assumptions of the Seasonal Kendall test, spatial dependence between locations should be evaluated and accounted for. The effect of spatial dependence is rejection of the null hypothesis (no trend) too frequently.	Spatial dependence was evaluated visually (by comparing time series plots of nearby wells) and statistically (by using ESRI's Global Moran's I tool in ArcGIS Pro). No spatial autocorrelation was observed using either method. Details are in Section 2.2.7.

E:\LUB\2024 Trend Analysis\LUBGWMA Network\Report\Appendices\B - Statistical Test Assumptions\[Statistical Tests and Assumptions.xlsx]Table

Appendix B
Statistical Test Assumptions

Statistical Test	Assumption	Discussion
Kruskal-Wallis test and Peto-Peto test for (1) evaluation of nitrate seasonality at individual wells and (2) for comparing DEQ and OHA data sets	All samples are random samples from their respective populations.	The data are random in the sense that groundwater sample volumes are assumed to be drawn more or less at random from the population of possible same-sized volumes comprising the underlying aquifer.
	All samples are independent.	The data are independent in the sense that there is no natural structure in the order of observations across groups (i.e., there are no pairings of data between observation 1 of group 1 and observation 1 of group 2). Independence roughly means that observing a given sample measurement does not allow a precise prediction of other sample measurements. For example, a volume of groundwater collected in one area is unique and different from groundwater collected in nearby wells or from one season to the next.
	The variables being analyzed must be either continuous or ordinal.	Groundwater nitrate concentration data are a continuous variable.
Kendall's tau for correlation of (1) well depth vs average nitrate, (2) well depth vs trend slope, and (3) depth to well open interval vs seasonal fluctuation	The variables being analyzed must be either continuous or ordinal.	Groundwater nitrate concentration data are a continuous variable.
	The two variables should have a monotonic relationship.	Kendall's tau-b determines whether there is a monotonic relationship between your two variables. As such, it is desirable if your data would appear to follow a monotonic relationship, so that formally testing for such an association makes sense, but it is not a strict assumption or one that you are often able to assess.
	The two variables are independent.	The data are independent in the sense that there is no natural structure in the order of observations across groups. Independence roughly means that observing a given sample measurement does not allow a precise prediction of other sample measurements. For example, a volume of groundwater collected in one area is unique and different from groundwater collected in nearby wells or from one season to the next.
	The data are random.	Nitrate data are random in the sense that groundwater sample volumes are assumed to be drawn more or less at random from the population of possible same-sized volumes comprising the underlying aquifer. Substantial similarities in well construction details in the 30-member data set (i.e., depths to top and bottom of the open interval) suggest well construction details may not be random. The more the samples vary from the randomness assumption, the less power the test has.
	No ties allowed in data unless adjustments are made and Kendall's tau-b is calculated.	The R function cor.test calculates Kendall's tau-b. Numerous ties in well construction details resulted in low correlation coefficient values and high p-values.

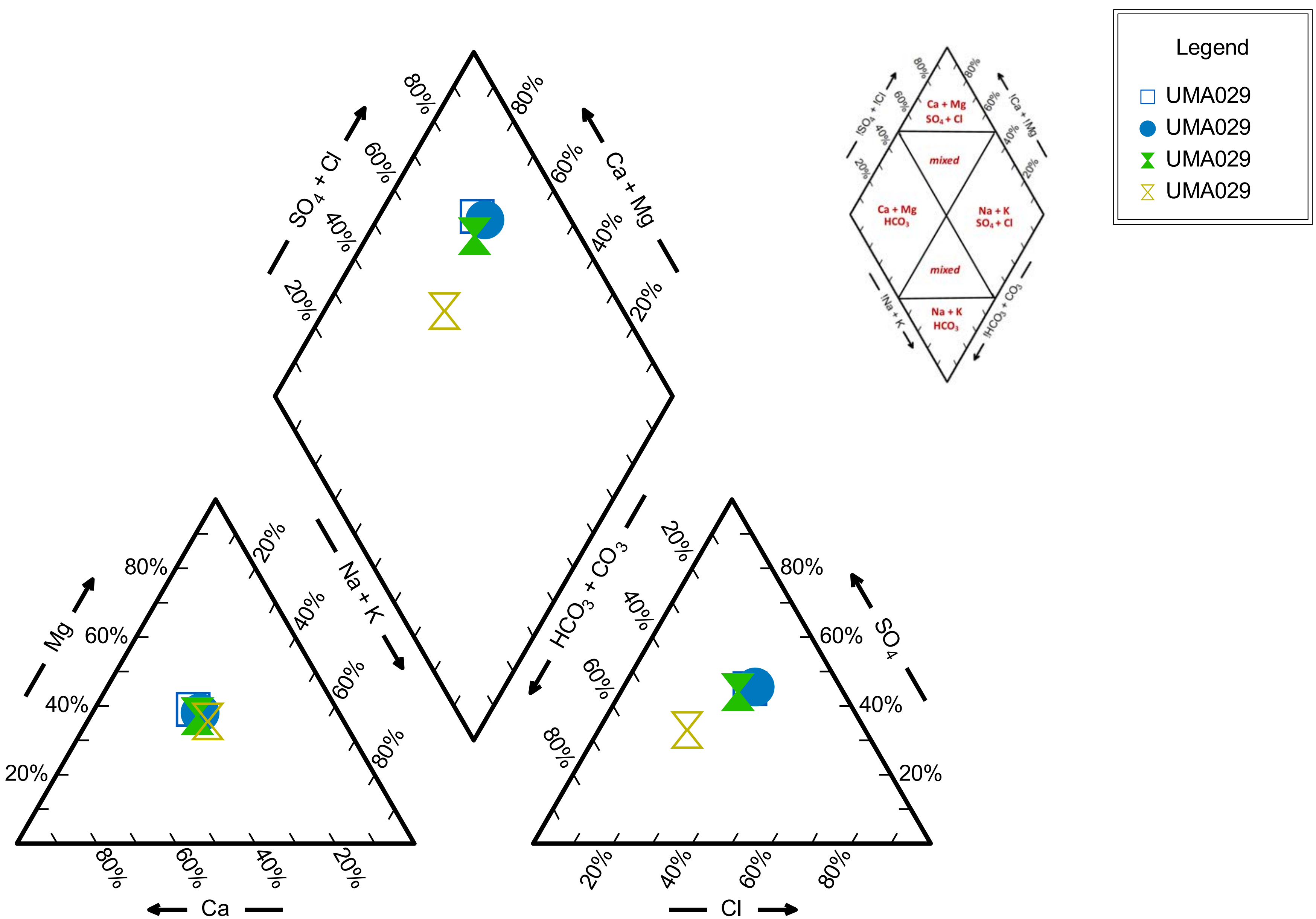
Appendix B
Statistical Test Assumptions

Statistical Test	Source Reference	Source Name	Source Link
Seasonal Kendall test	PNNL, 2024	Pacific Northwest National Laboratory's Visual Sample Plan training materials	https://vsp.pnnl.gov/help/Vsample/Design_Trend_Seasonal_Kendall.htm
	Hirsch and Slack, 1984	A Nonparametric Trend Test for Seasonal Data With Serial Dependence	https://pinellas.wateratlas.usf.edu/upload/documents/Hirsch_et_al-1984-Water_Resources_Research.pdf
	Helsel, 2019	Trend Analysis for Data with Nondetects training materials	https://www.practicalstats.com/resources/Webinar-pdfs/Trends-with-Nondetects.pdf
Regional Kendall test	Renard, et. al., 2008	Regional methods for trend detection: Assessing field significanceand regional consistency	https://agupubs.onlinelibrary.wiley.com/share/XY2JYDD7VQ4GXPSBMAAP?target=10.1029/2007WR006268
	Sprague and Lorenz, 2009	Regional Nutrient Trends in Streams and Rivers of the United States 1993-2003	https://slo-oregon-illiad-oclc-org.slo.idm.oclc.org/illiad/illiad.dll?Action=10&Form=75&Value=223932
	Frans and Helsel, 2005	Evaluating Regional Trends in Ground-Water Nitrate Concentrations of the Columbia Basin Groundwater Management Area, WA. USGS Scientific Investigations Report 2005-5078.	https://pubs.usgs.gov/sir/2005/5078/
	ESRI, 2024	ArcGIS Pro training materials	https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-how-spatial-
Kruskal-Wallis test	Helsel et al, 2020	Statistical Methods in Water Resources	https://pubs.usgs.gov/publication/tm4A3
	SPSS, 2024a	SPSS training materials	https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php#:~:text=Assumption%20%232:%20Your%20independent%20variable,e.g.%2C%20a%20Friedman%20test).
	EPA, 2009	Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance	https://archive.epa.gov/epawaste/hazard/web/pdf/unified-guid.pdf
Kendall's tau	SPSS, 2024b	SPSS training materials	https://statistics.laerd.com/spss-tutorials/kendalls-tau-b-using-spss-statistics.php
	Statstest, 2024	Statstest.com training materials	https://www.statstest.com/kendalls-tau/
	SPSS, 2024c	SPSS Training material	https://spssanalysis.com/kendalls-tau-correlation-in-spss/#:~:text=Assumption%20of%20Kendall's%20Tau%20Correlation,in%20the%20correlation%20coefficient%20calculation.
	Rdocumentation.org, 2024	Rdocumentation.org	https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/cor.test
	Wikipedia, 2024	Wikipedia	https://en.wikipedia.org/wiki/Kendall_rank_correlation_coefficient

Appendix C

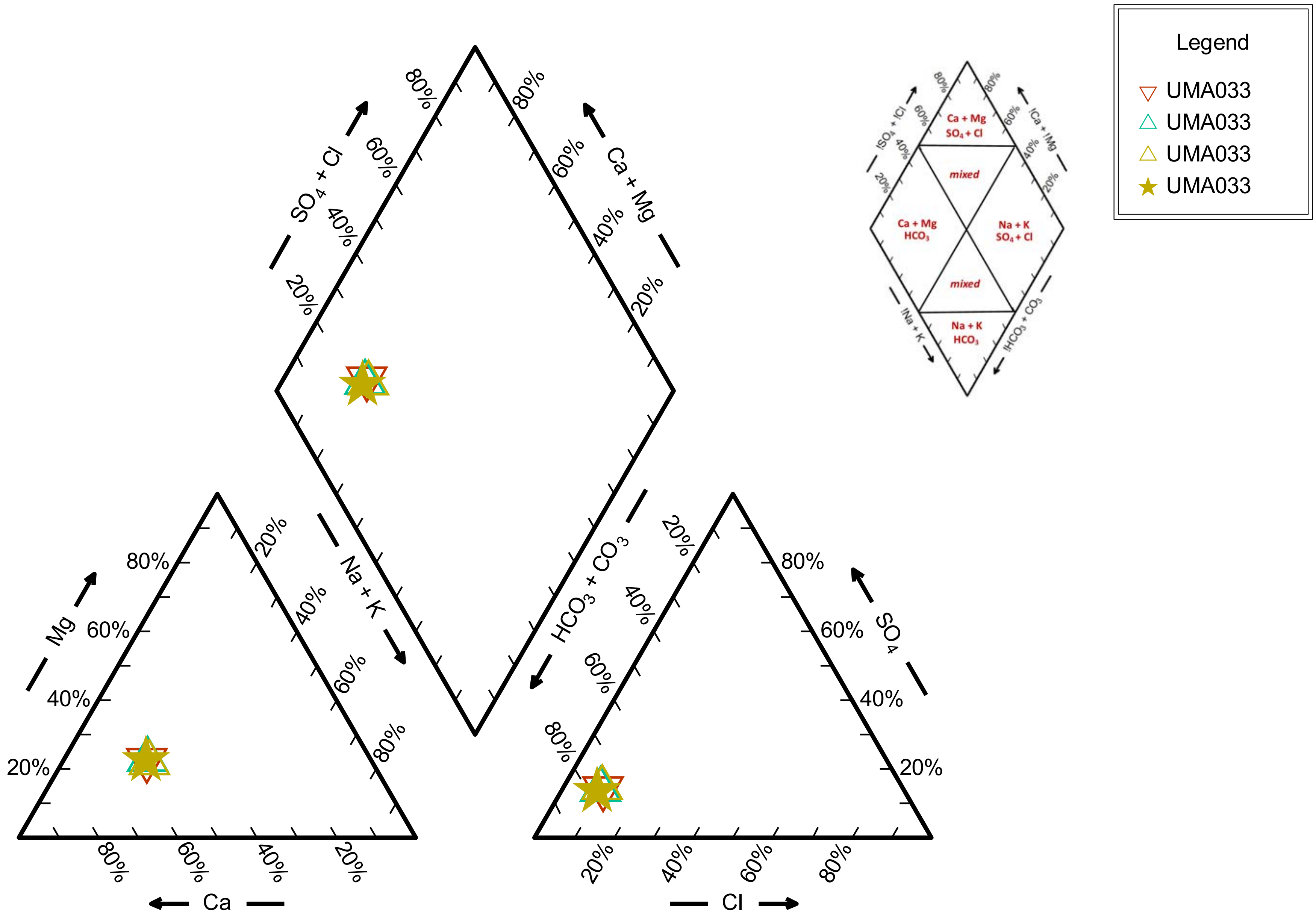
Piper Diagrams

Piper Diagram



This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



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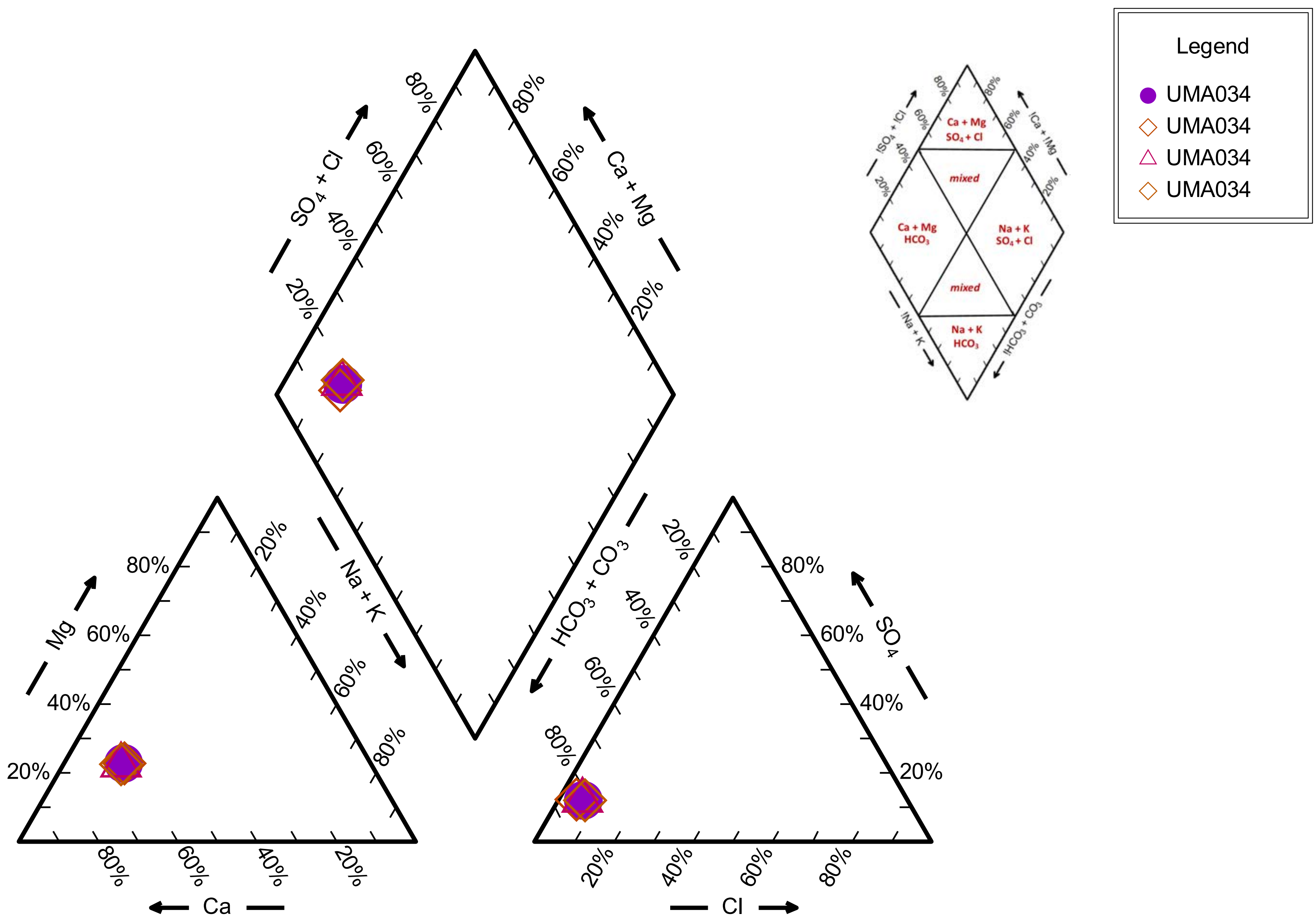
Piper Diagram



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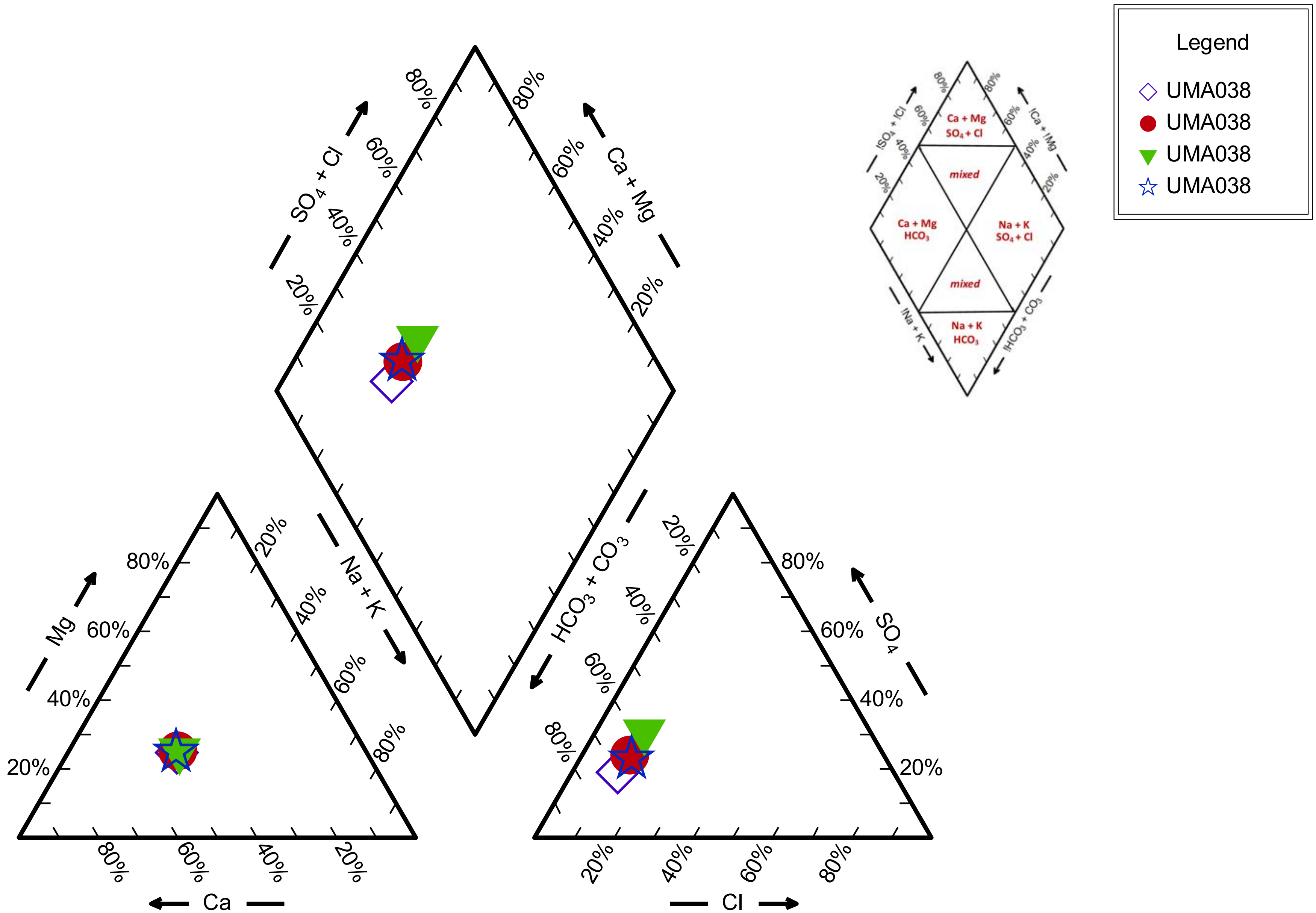
Piper Diagram



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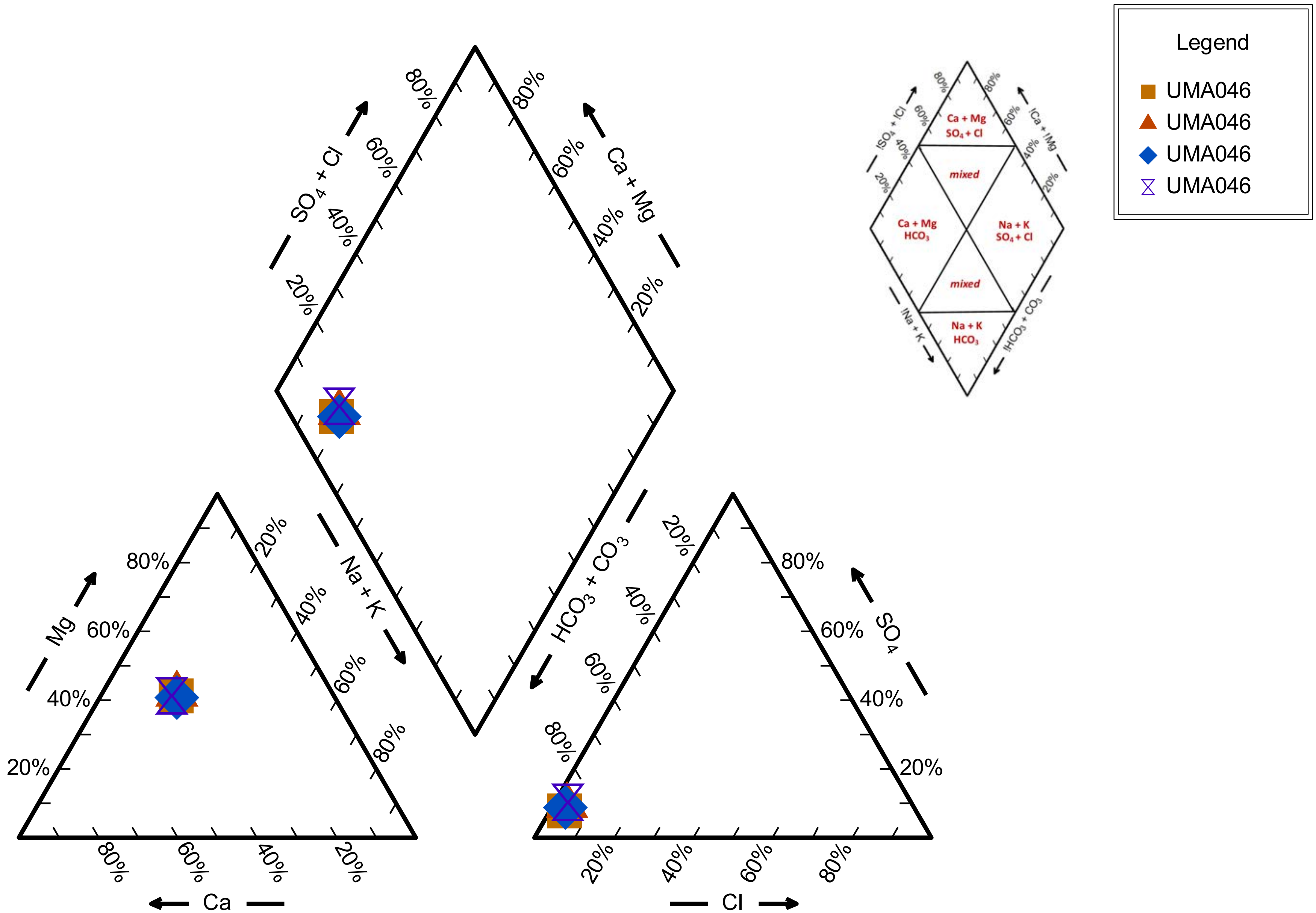
Piper Diagram



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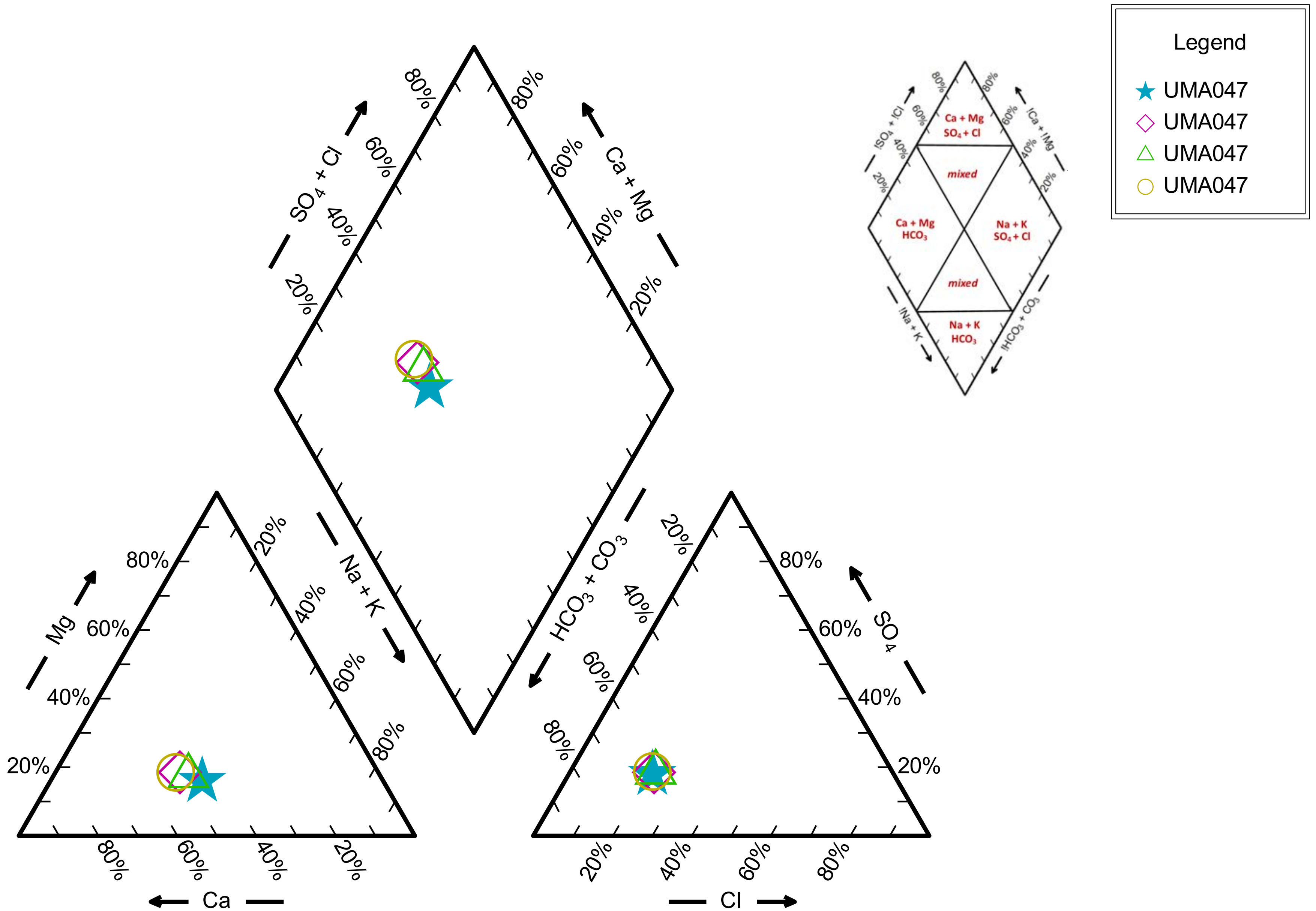

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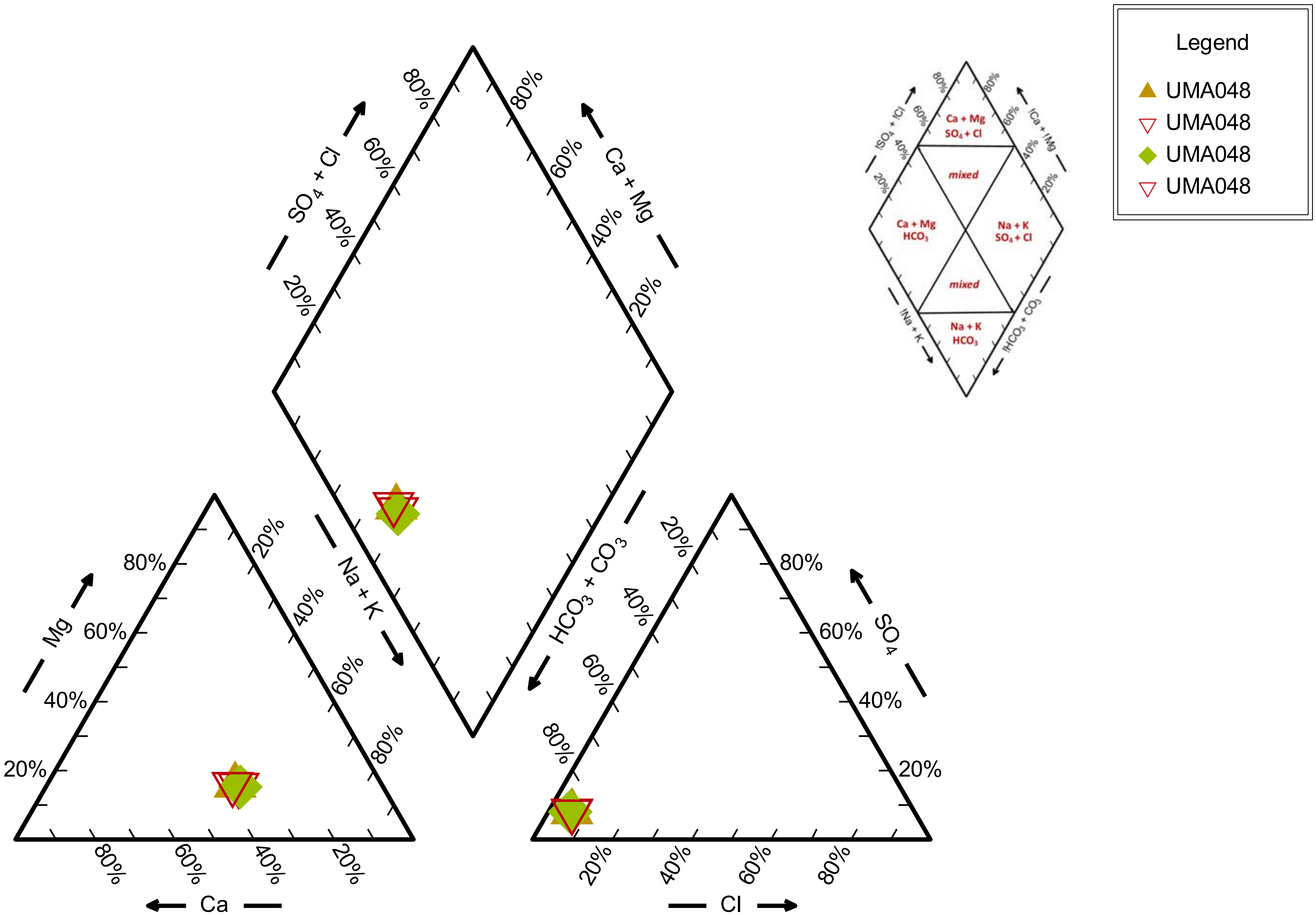
Piper Diagram



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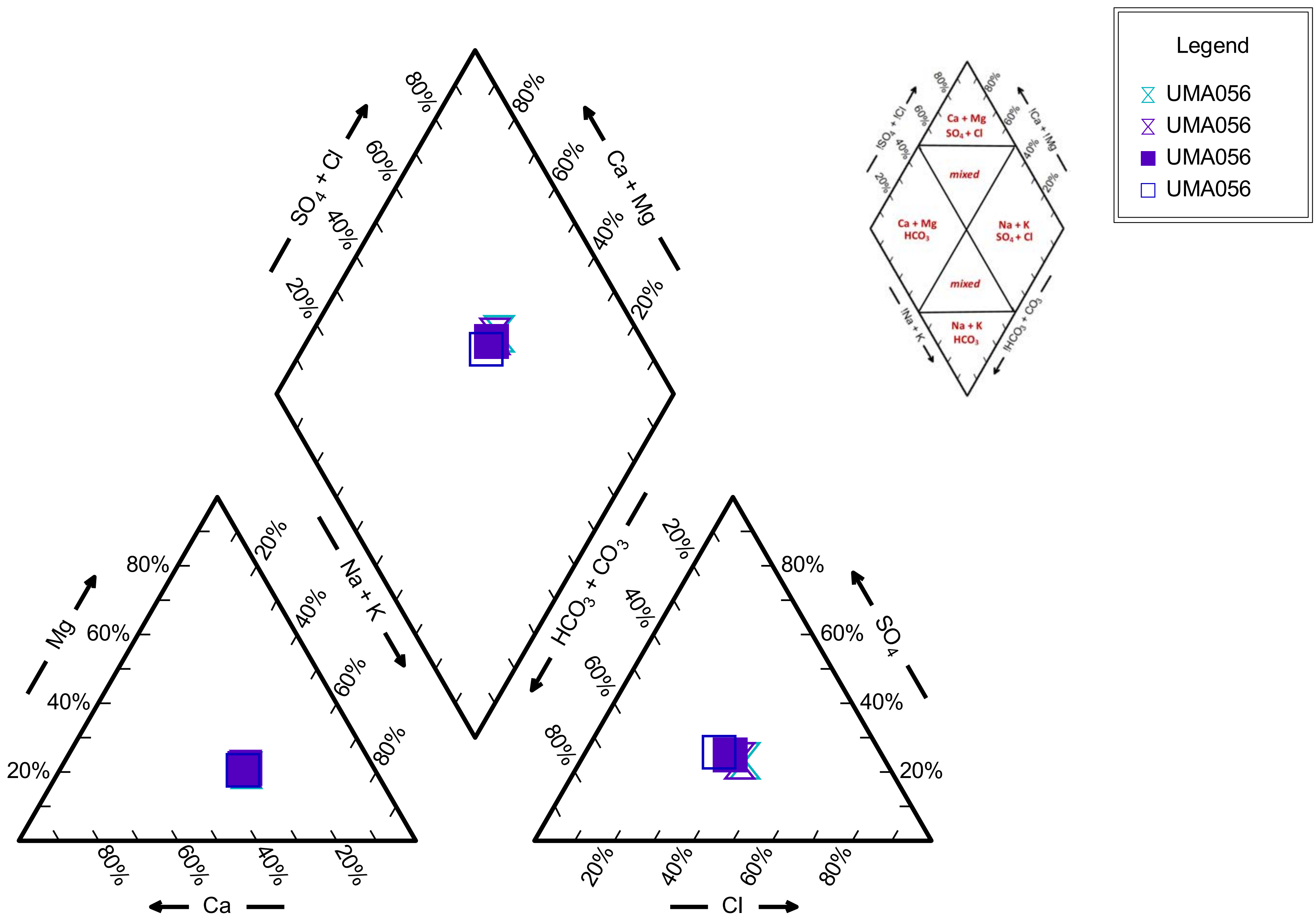
Piper Diagram



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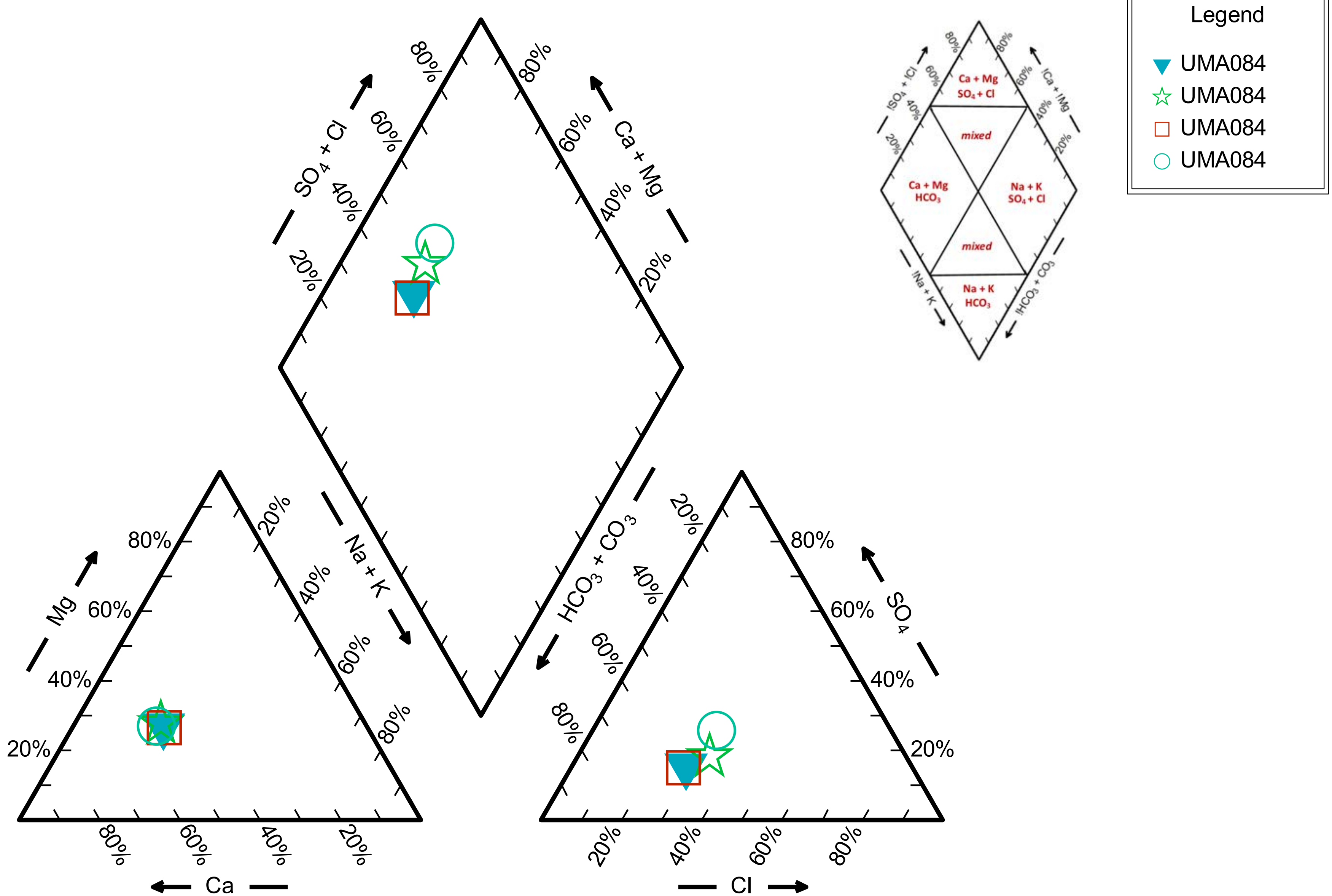
Piper Diagram



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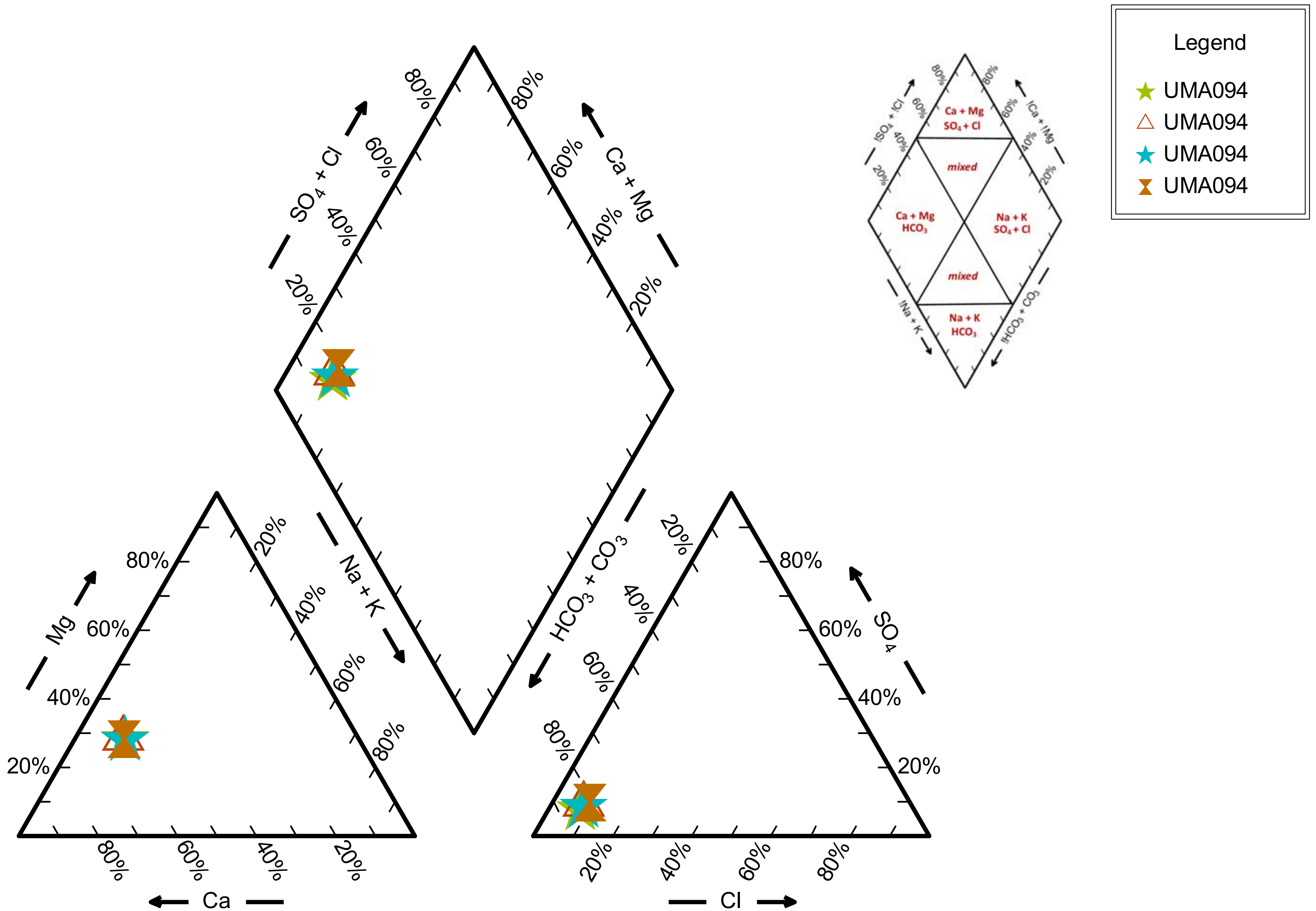
Piper Diagram



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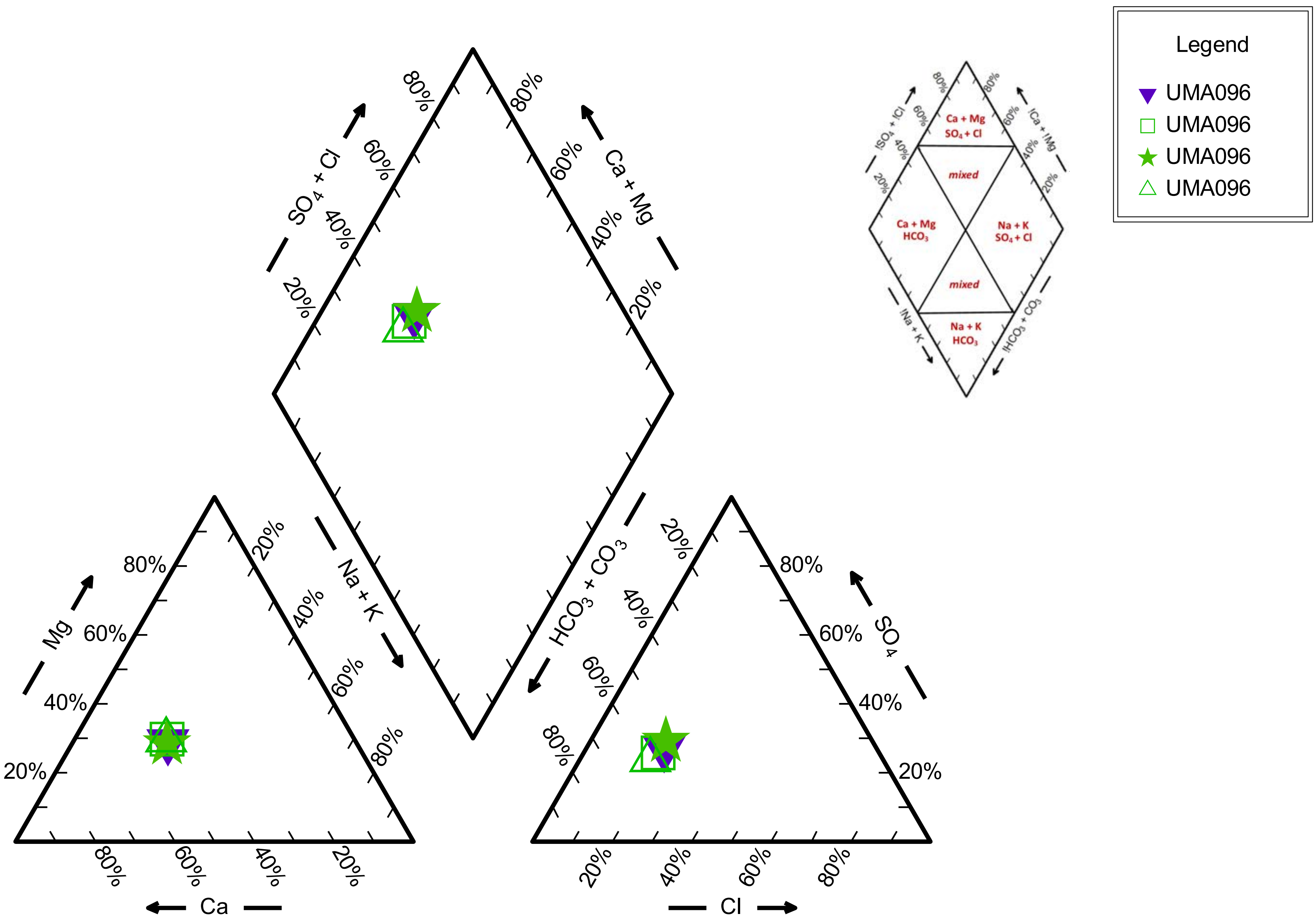

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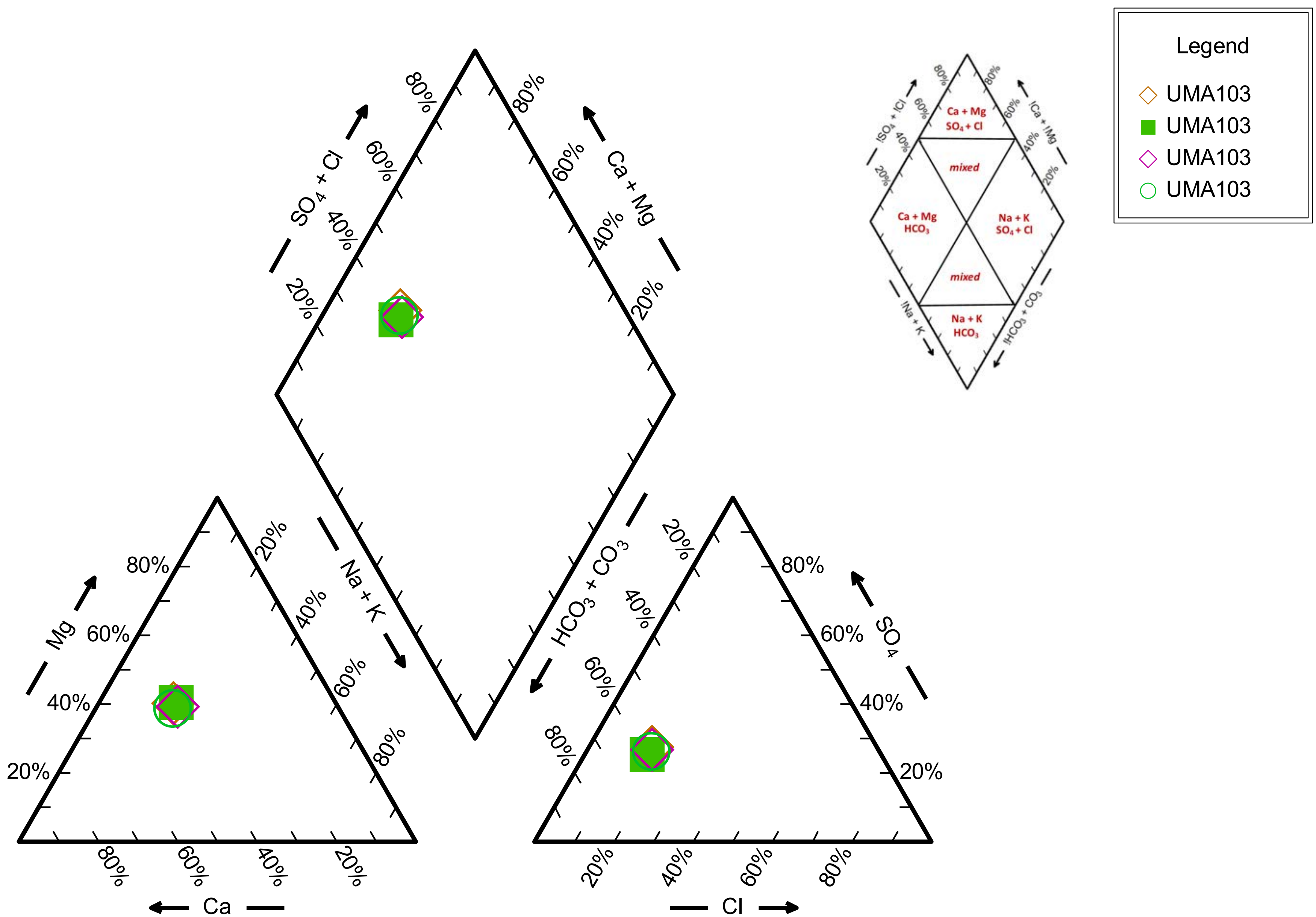

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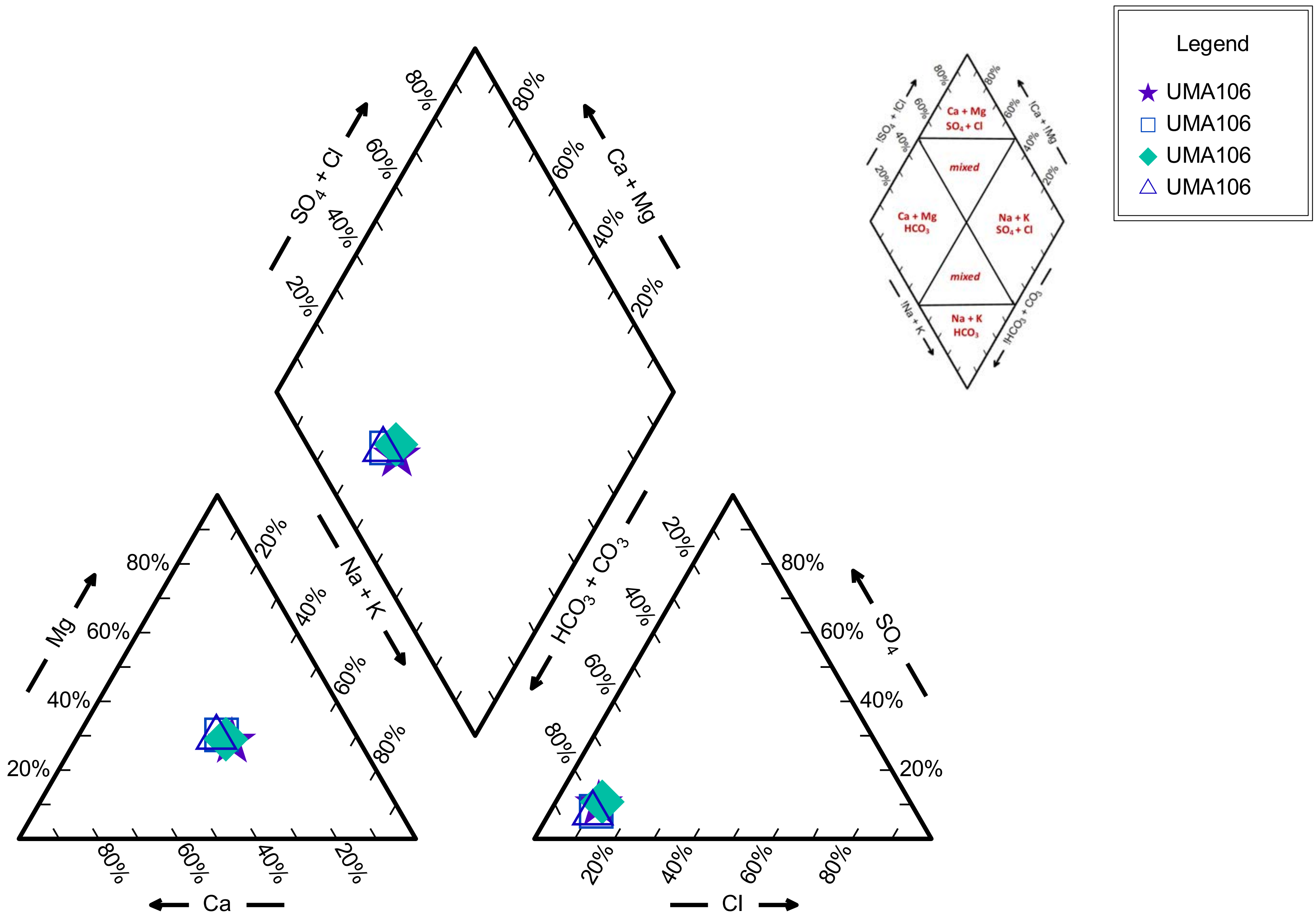

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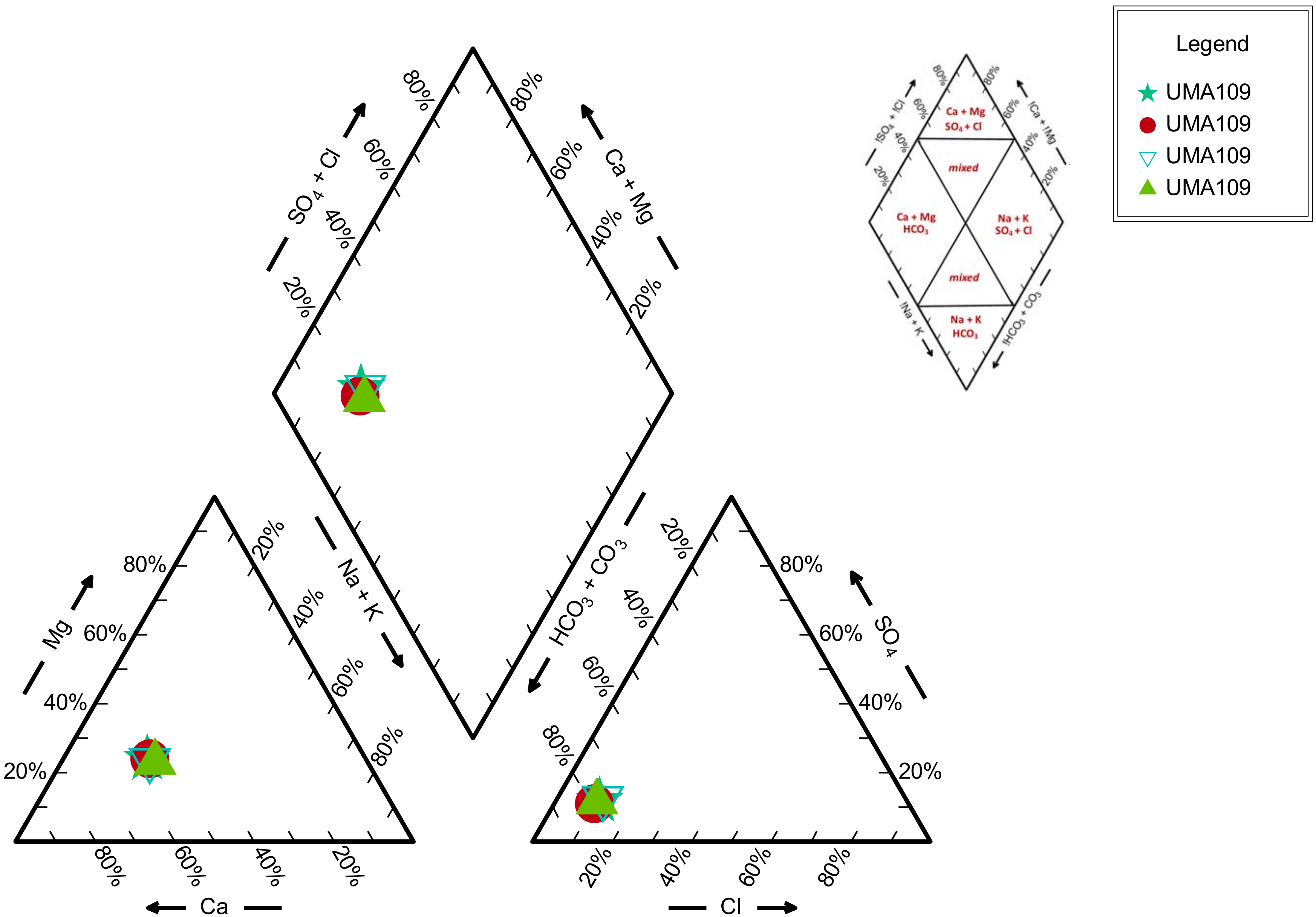

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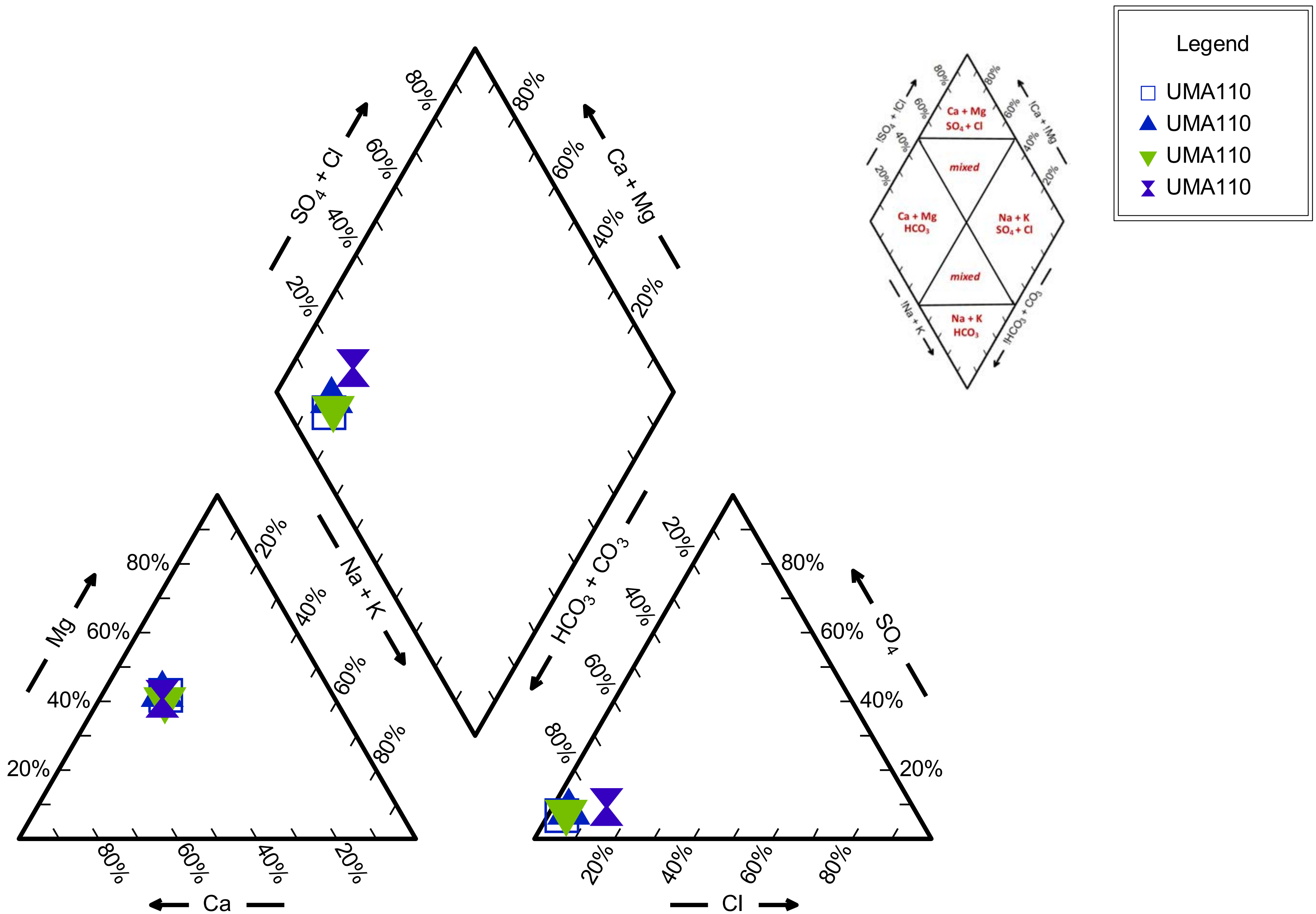
Piper Diagram



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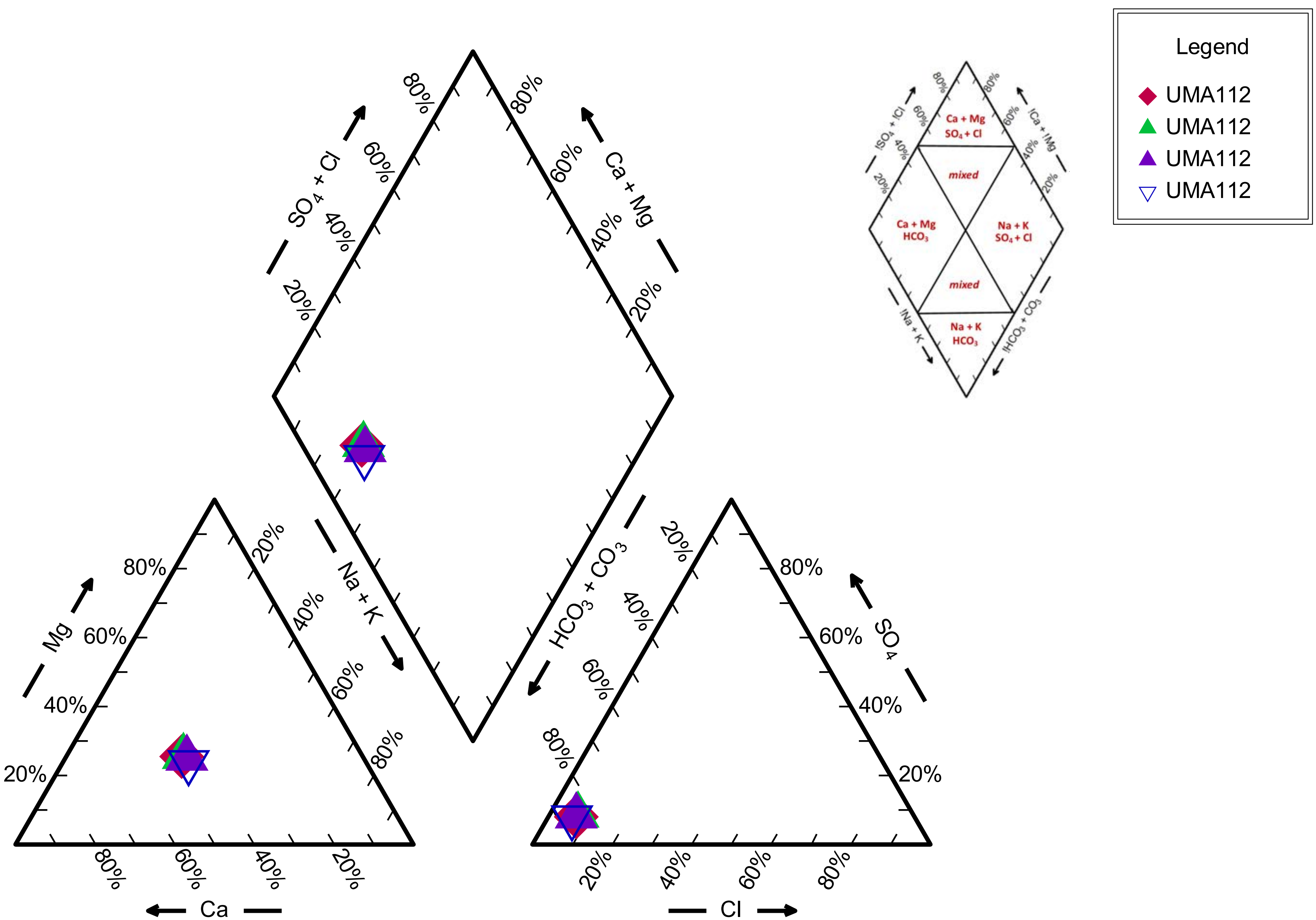

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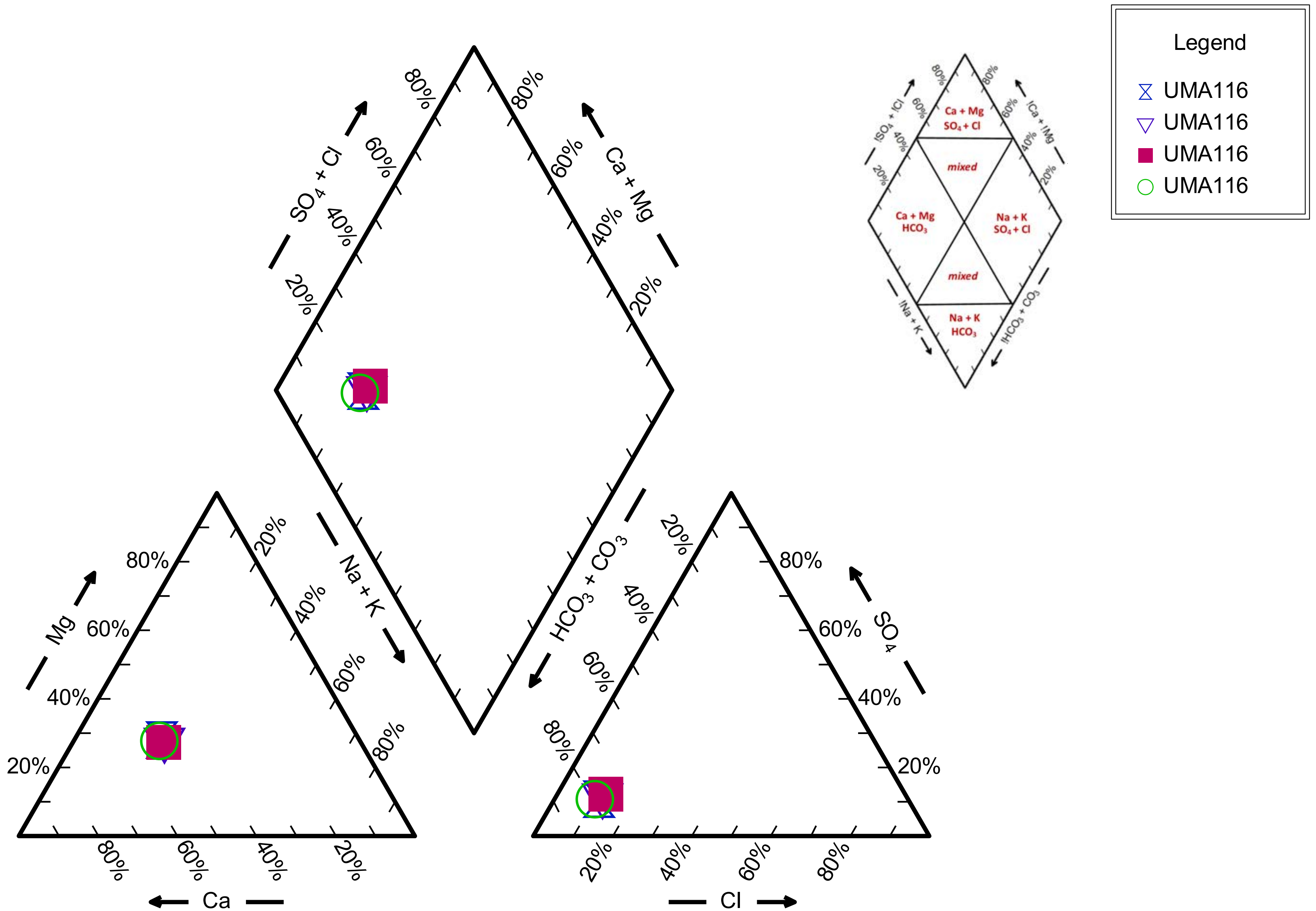
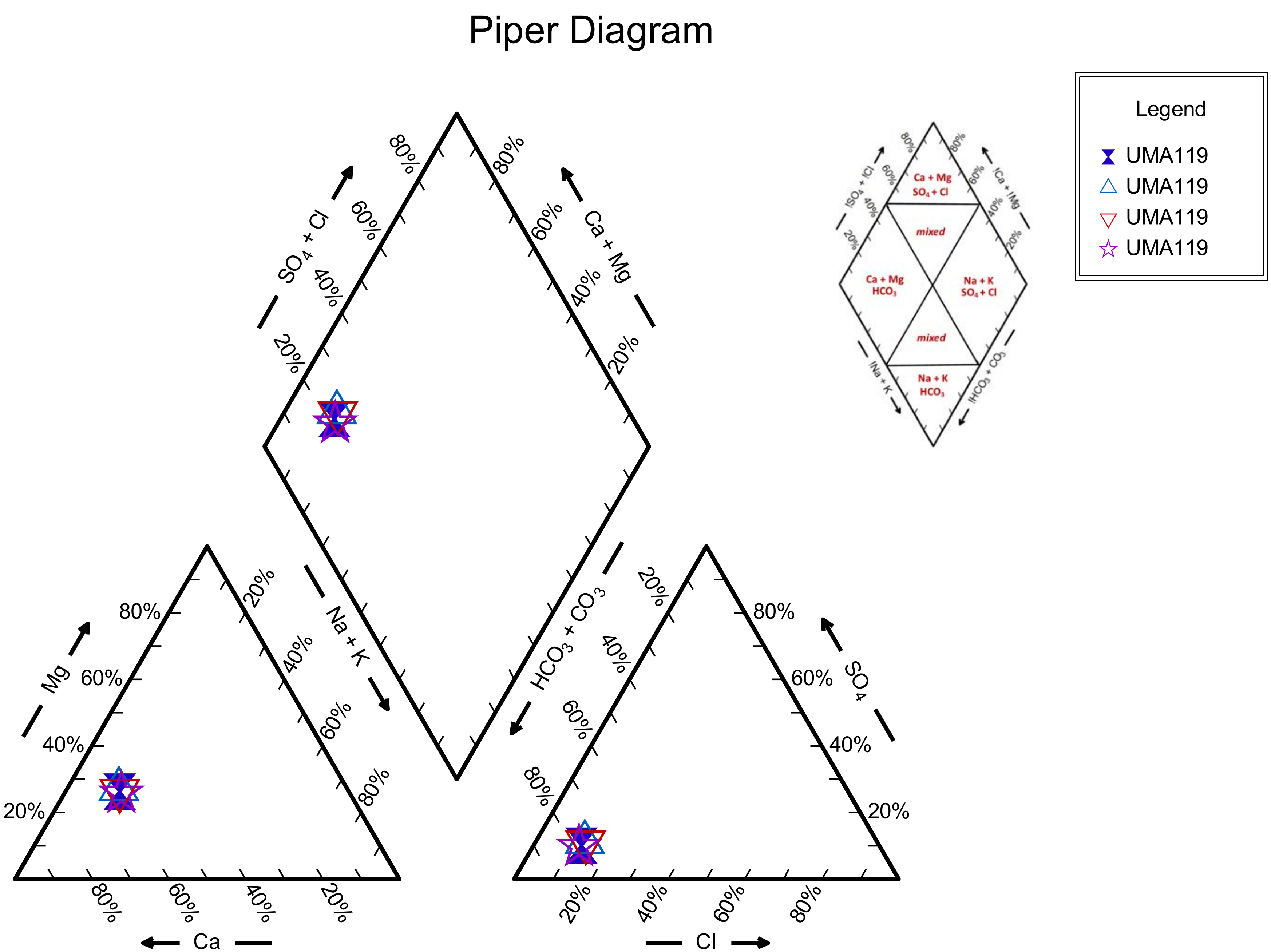


This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.



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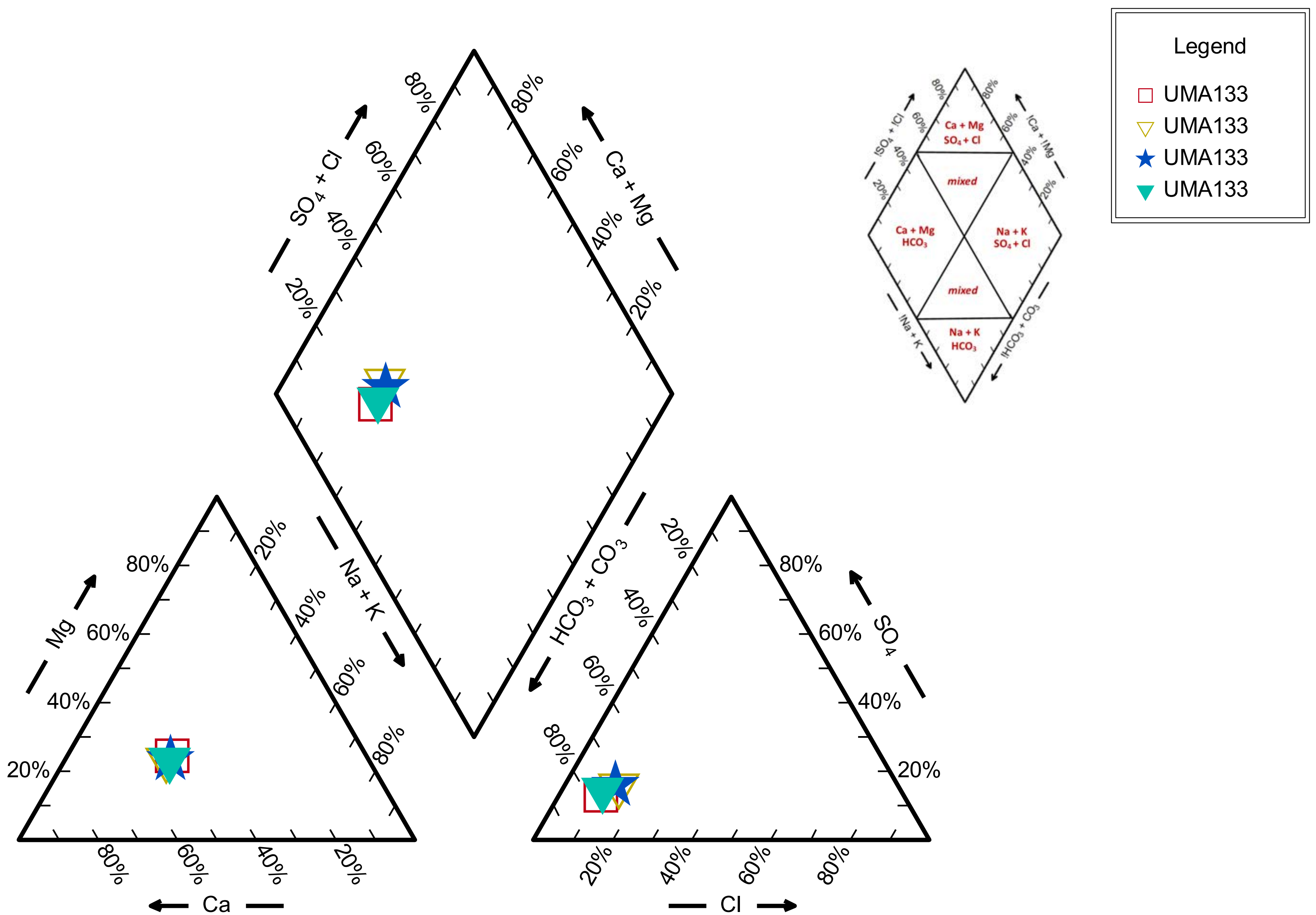
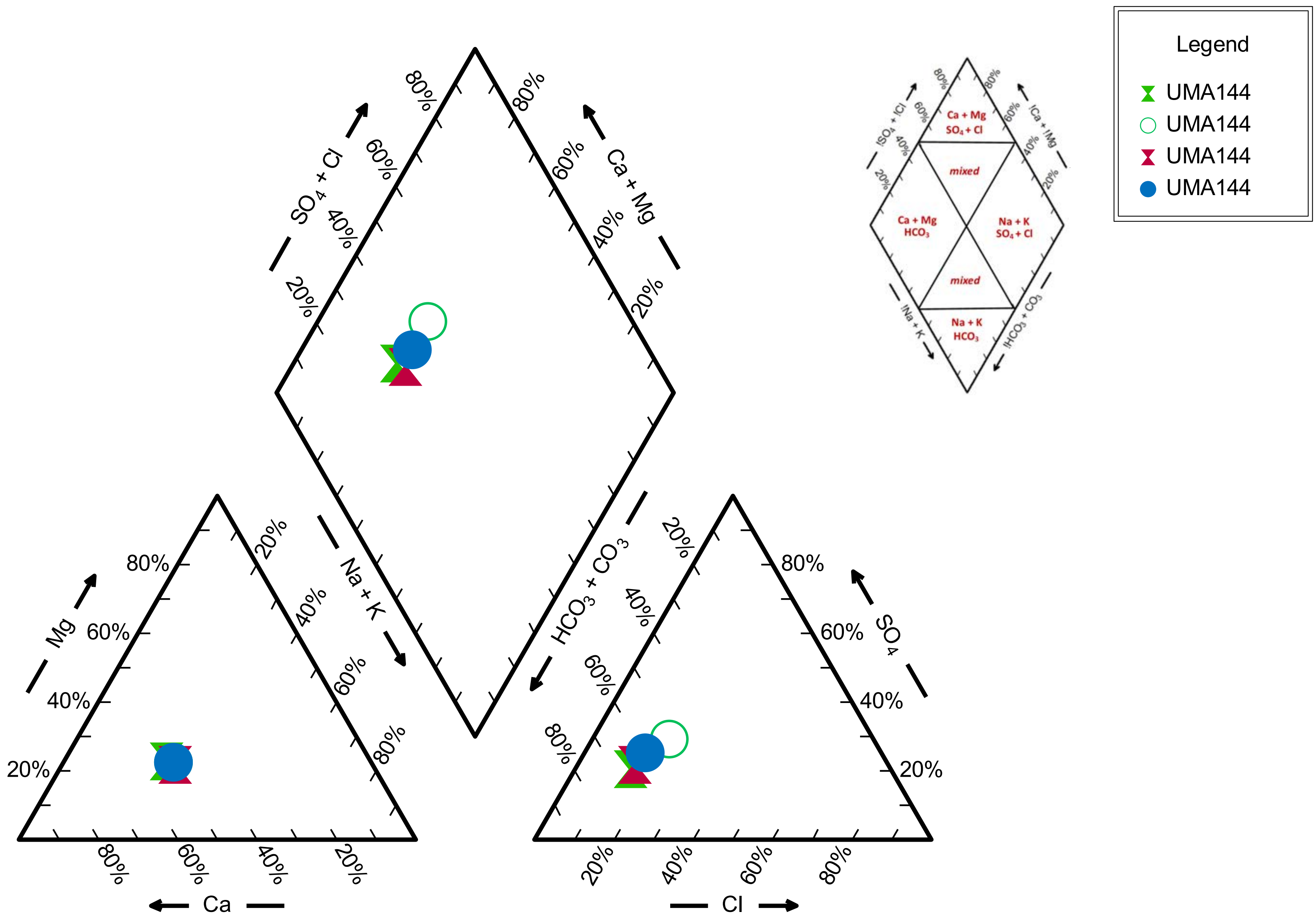
Piper Diagram



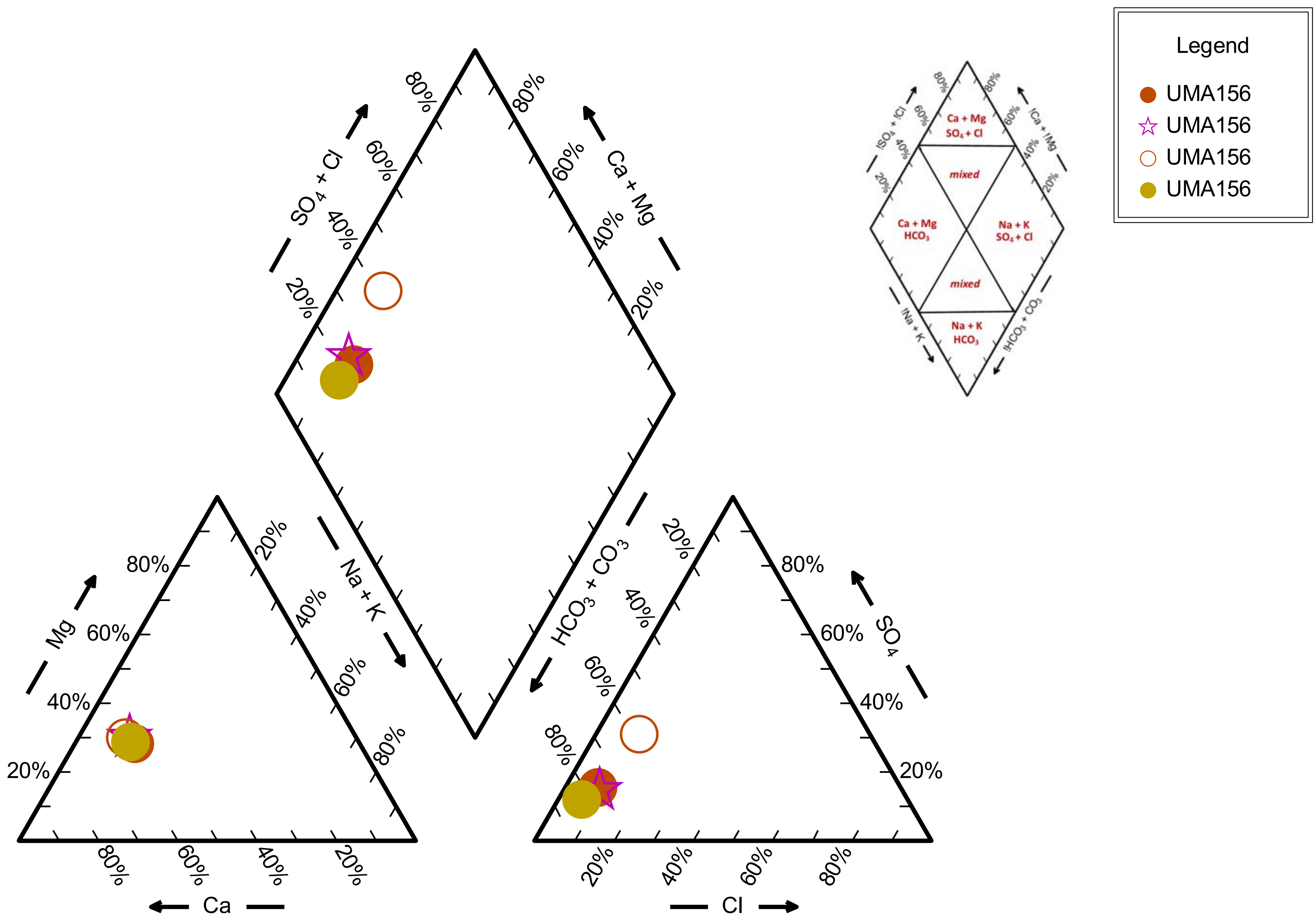
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



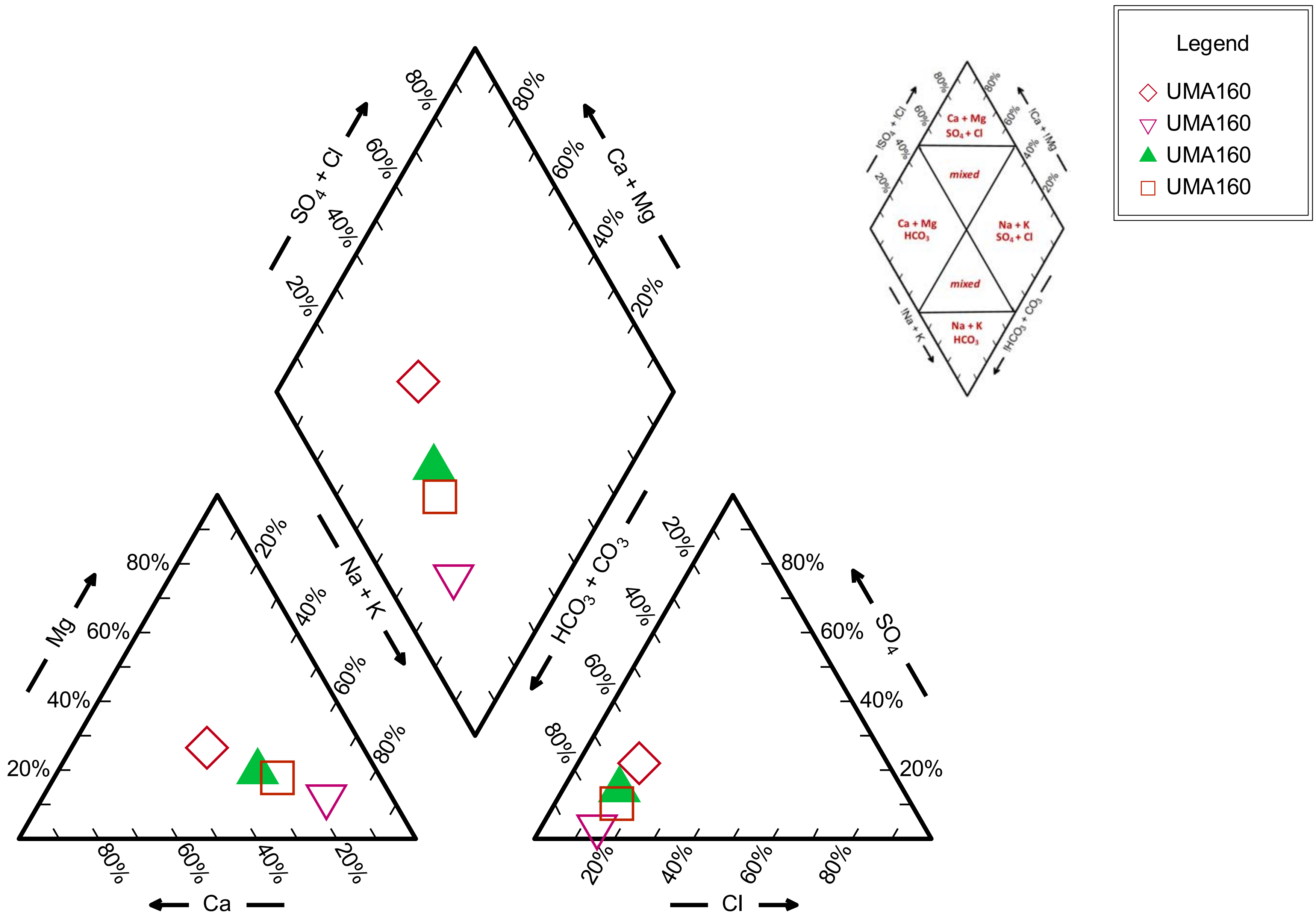
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



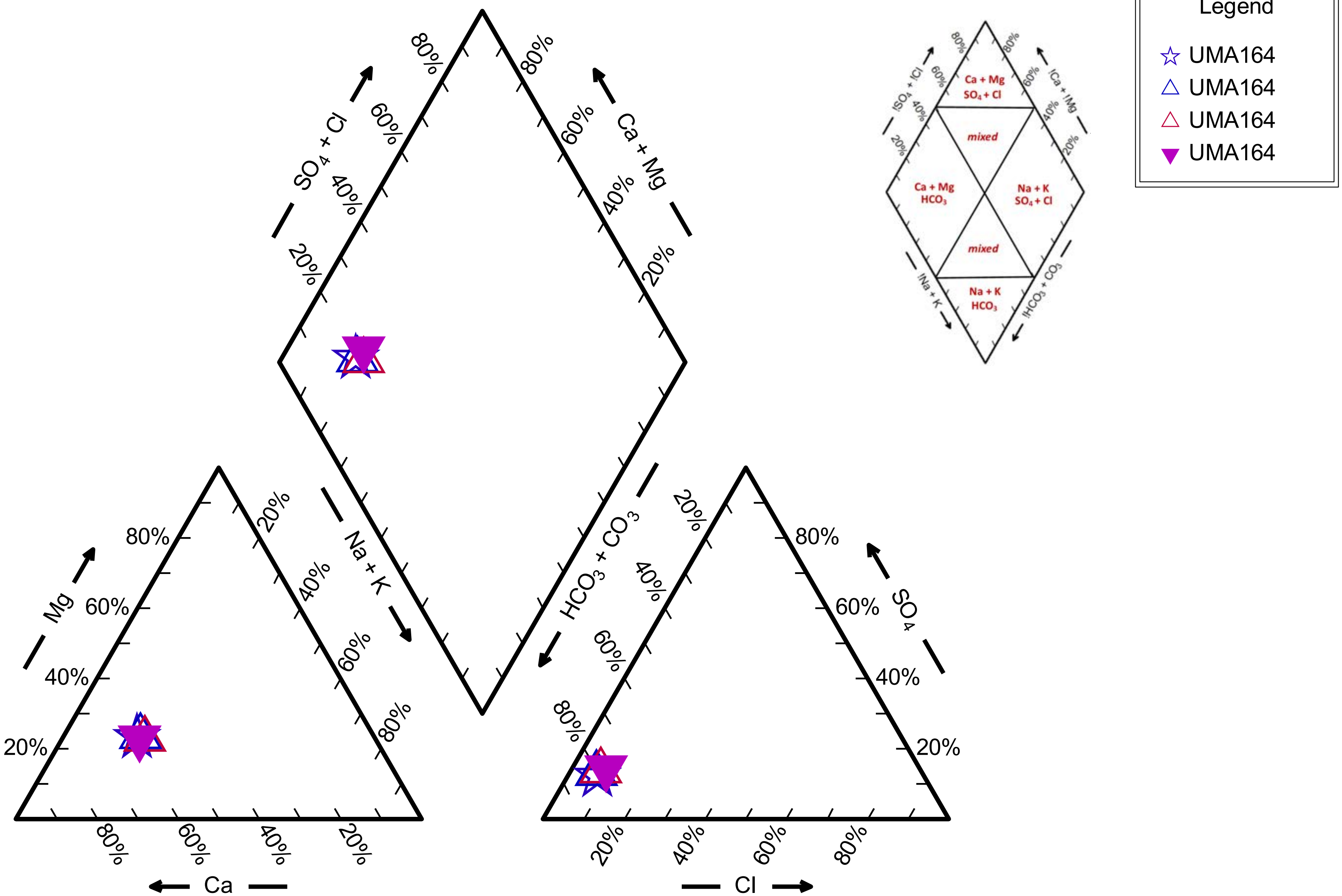
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



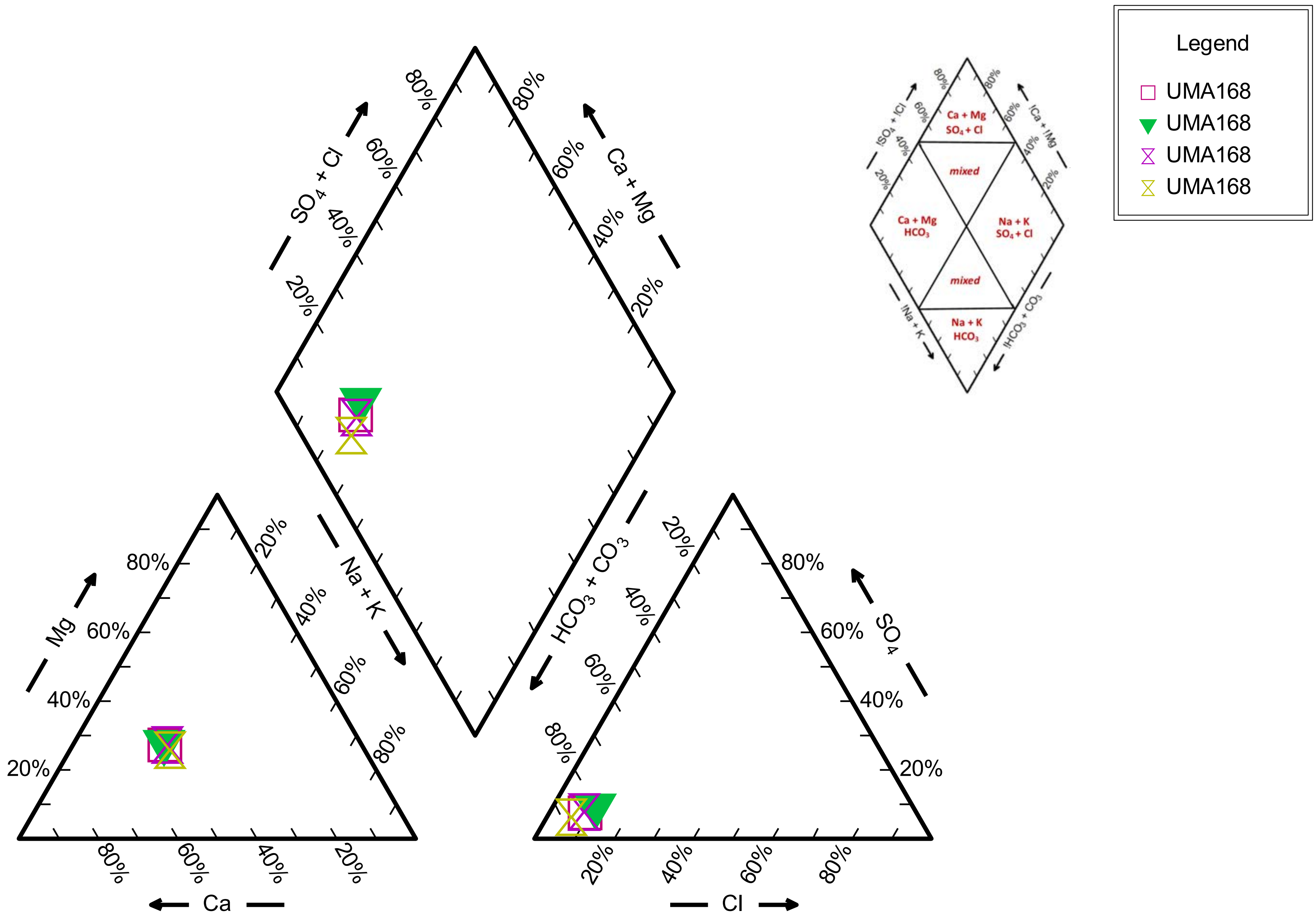
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



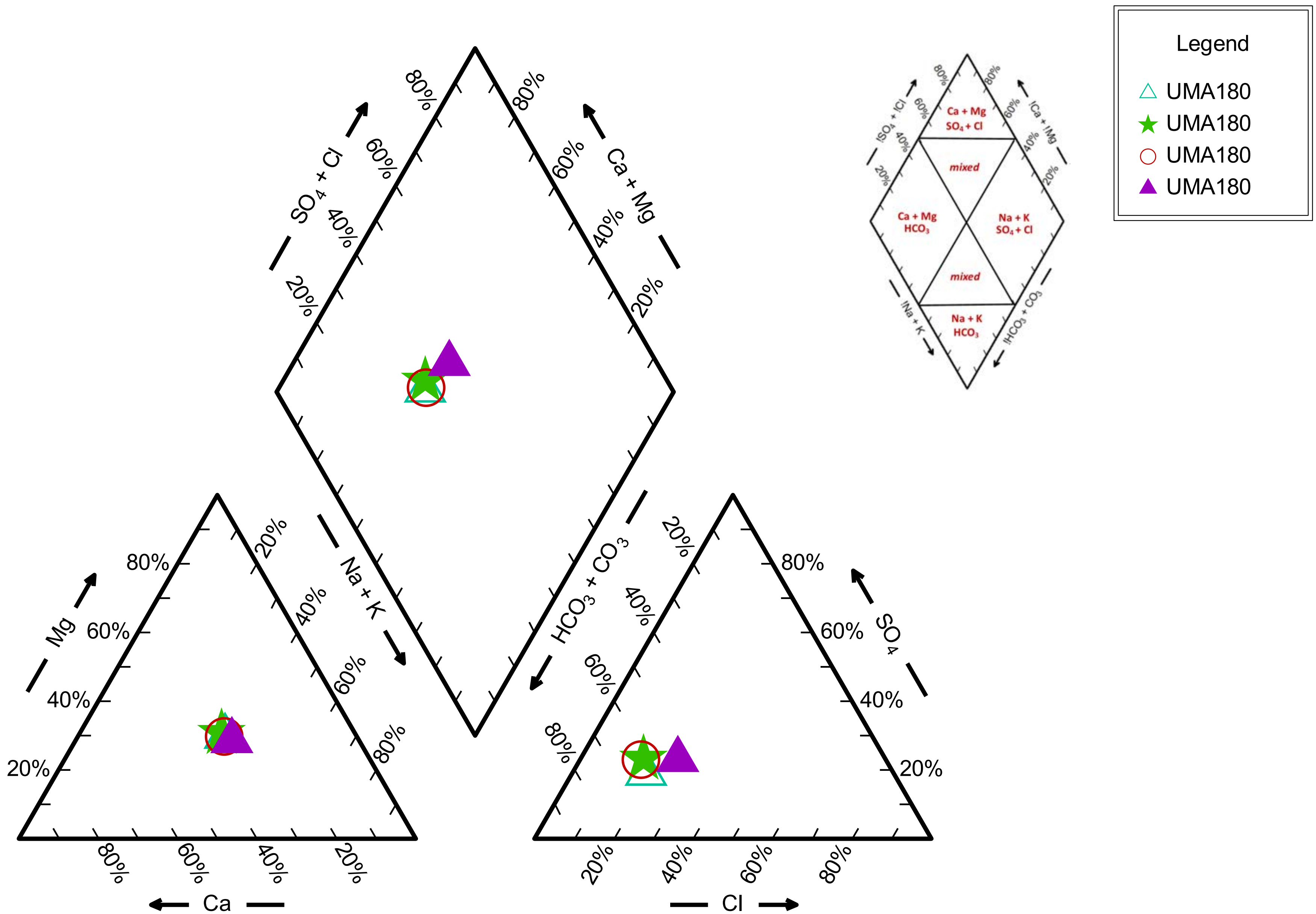
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



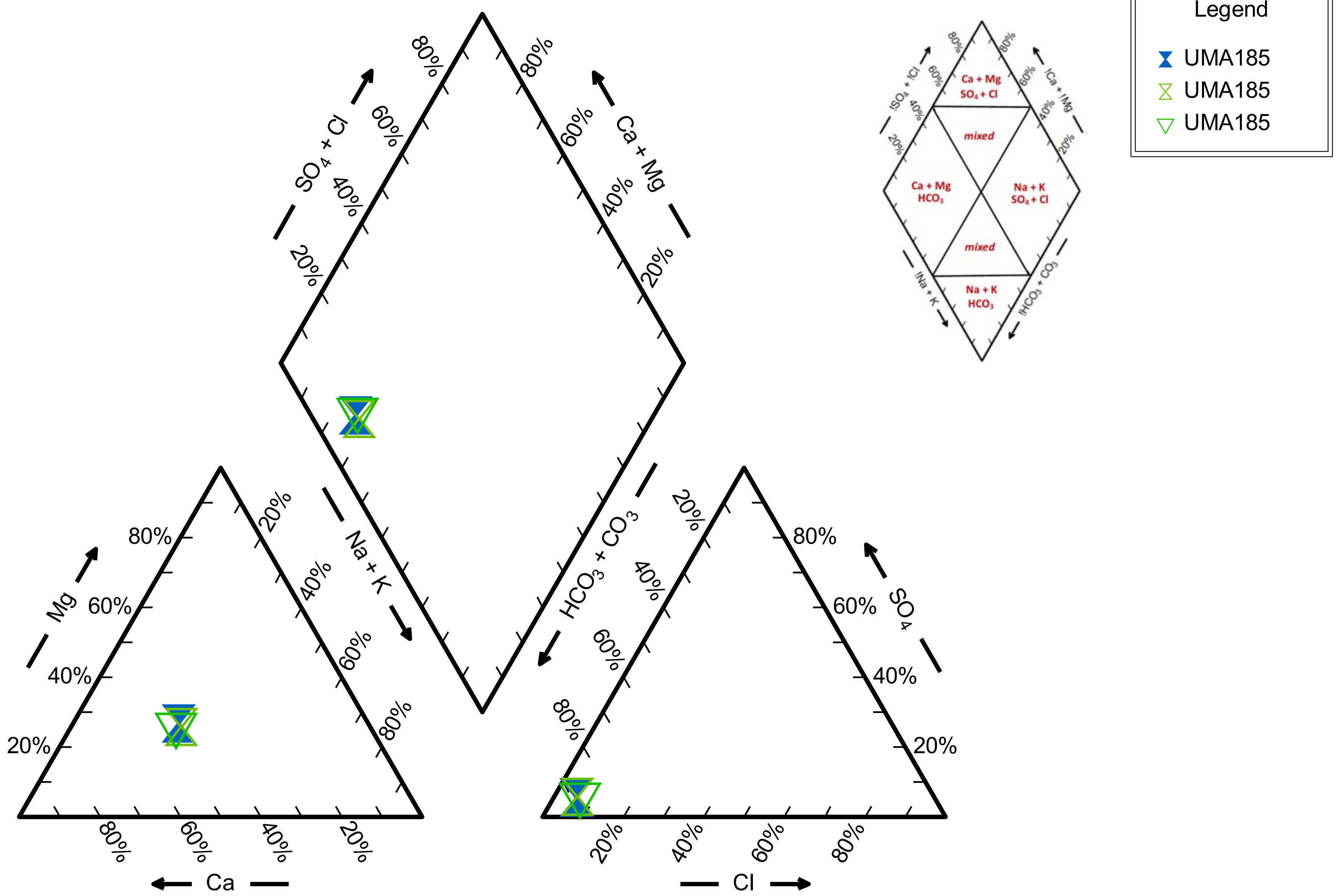
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



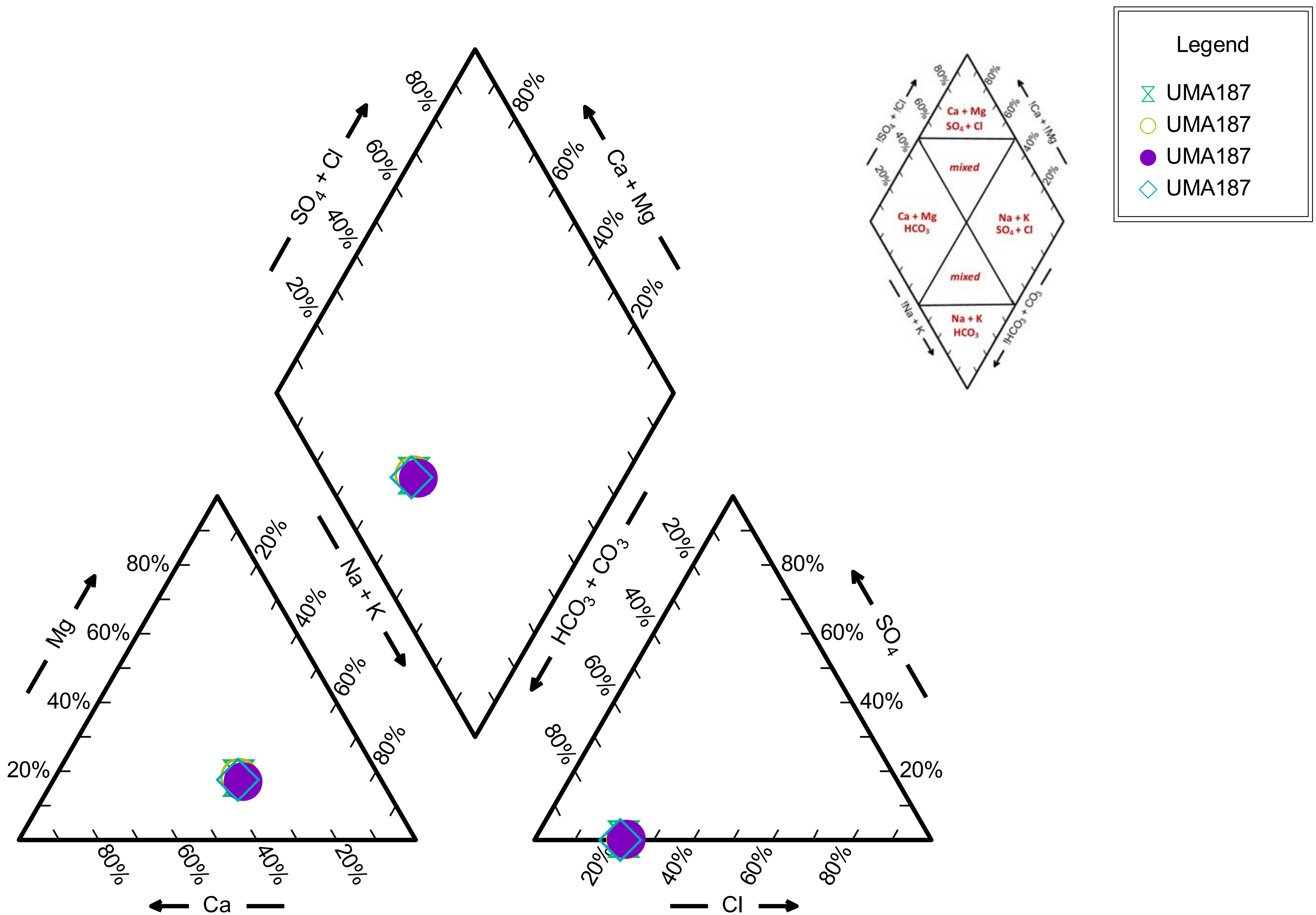
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



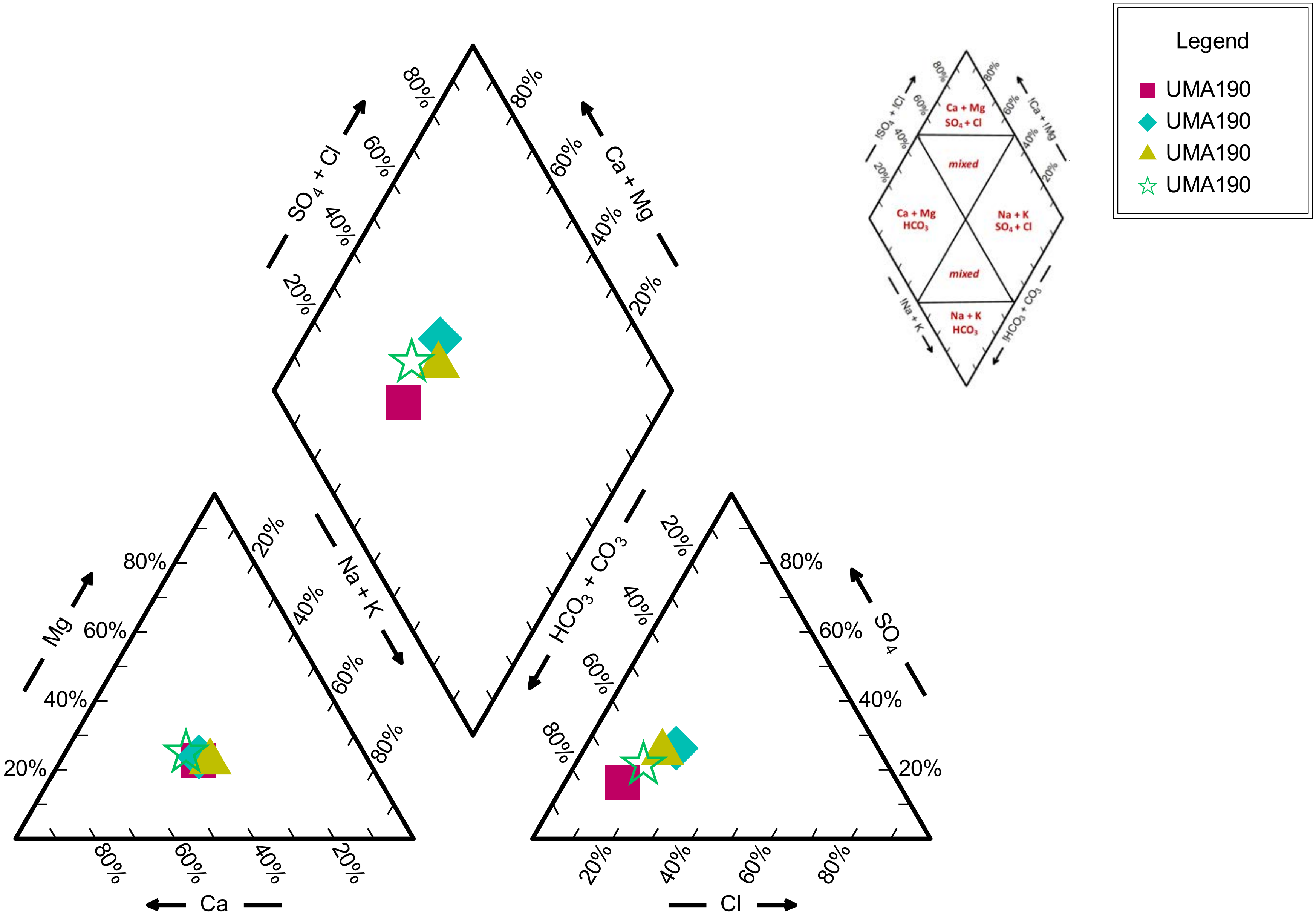
This diagram contains results from the July 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



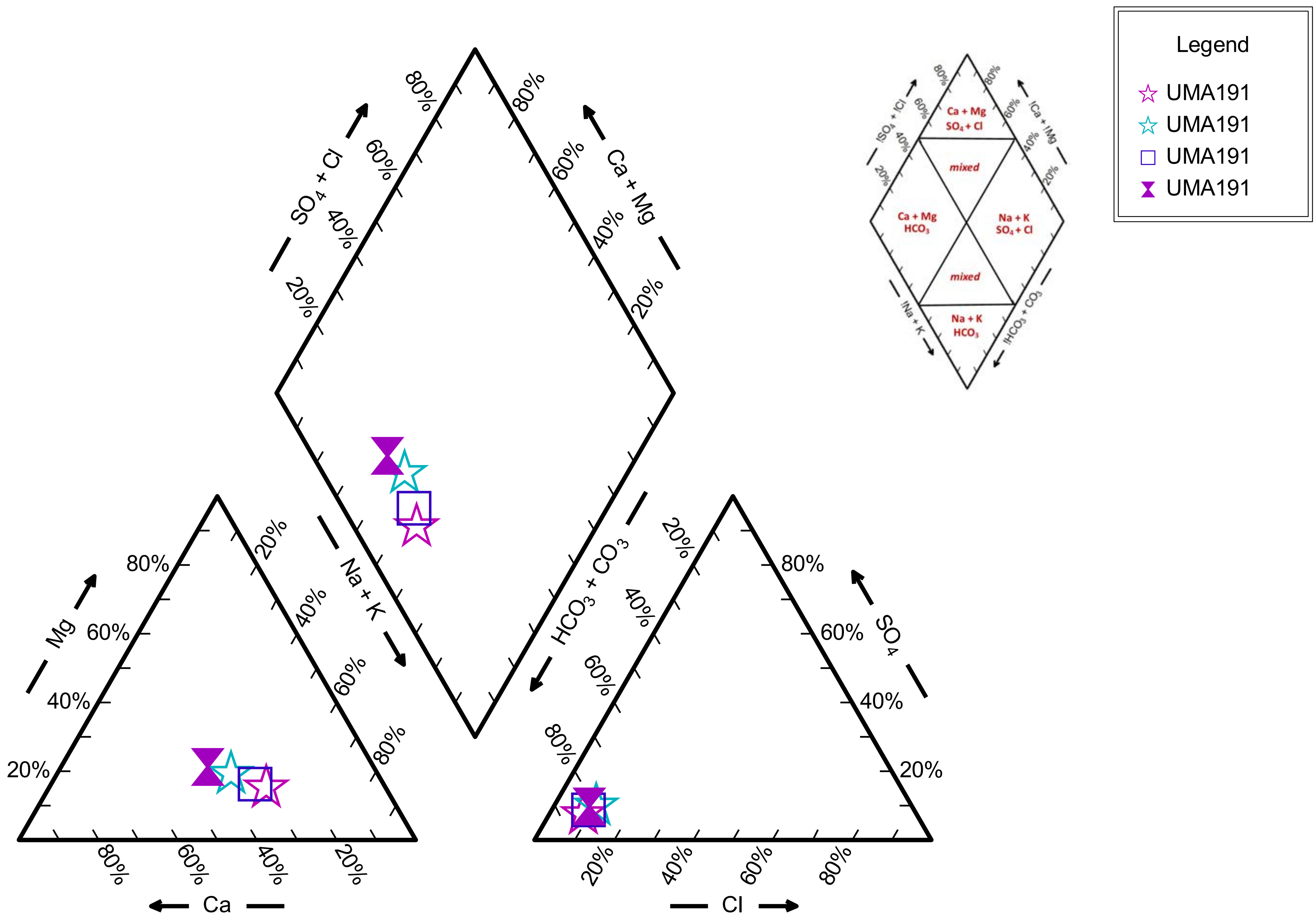
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



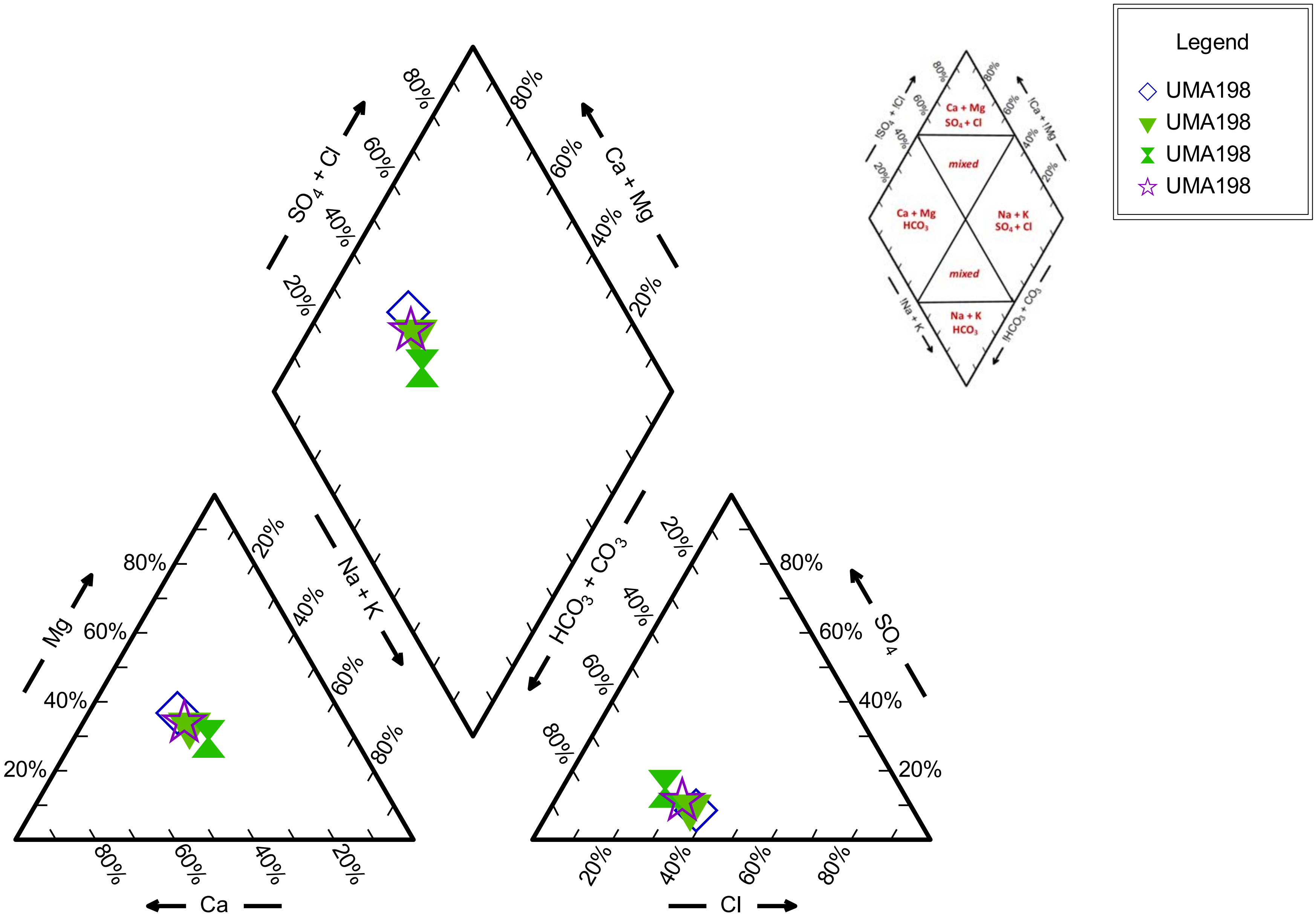
This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram

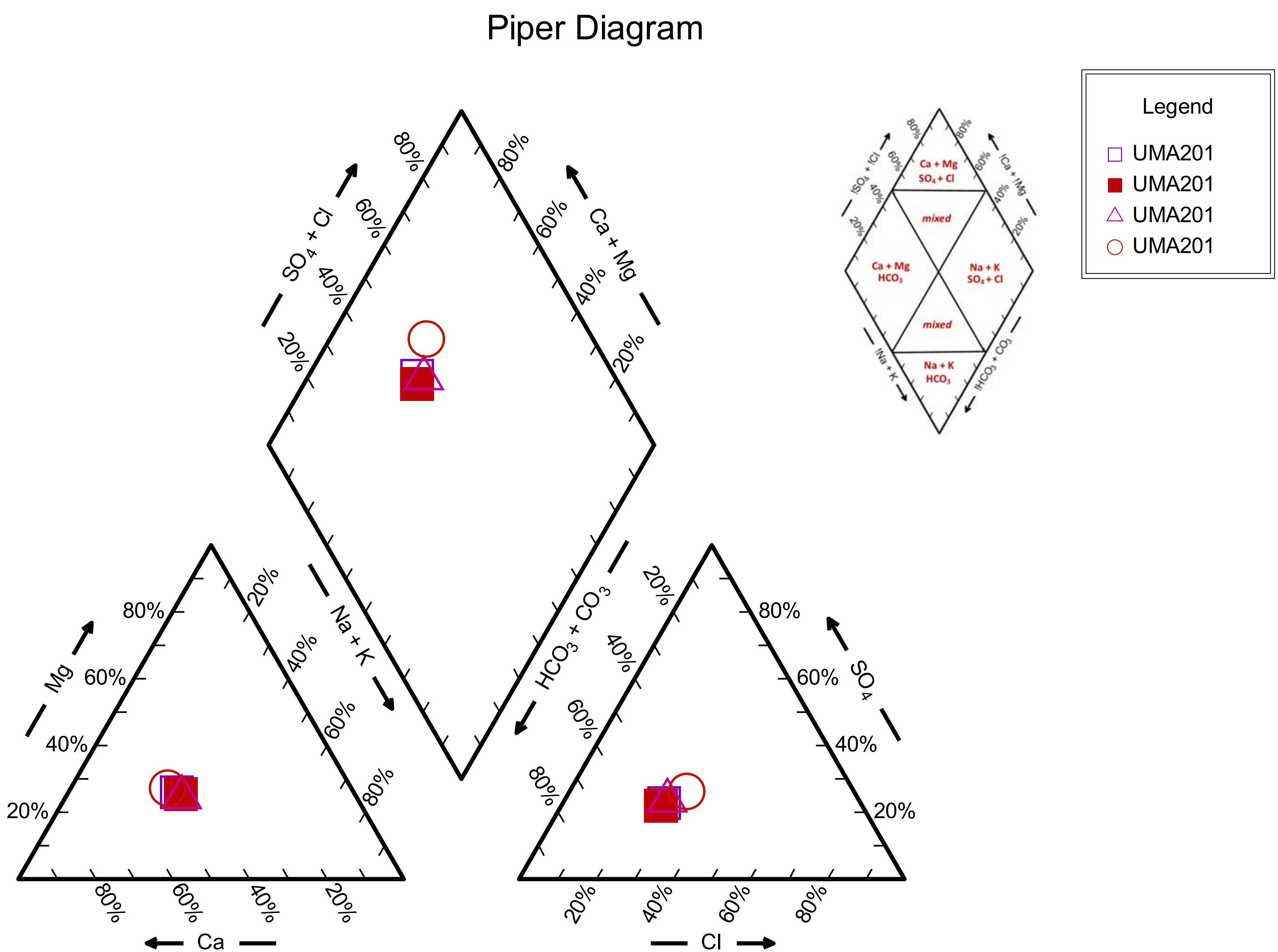


This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Piper Diagram



This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

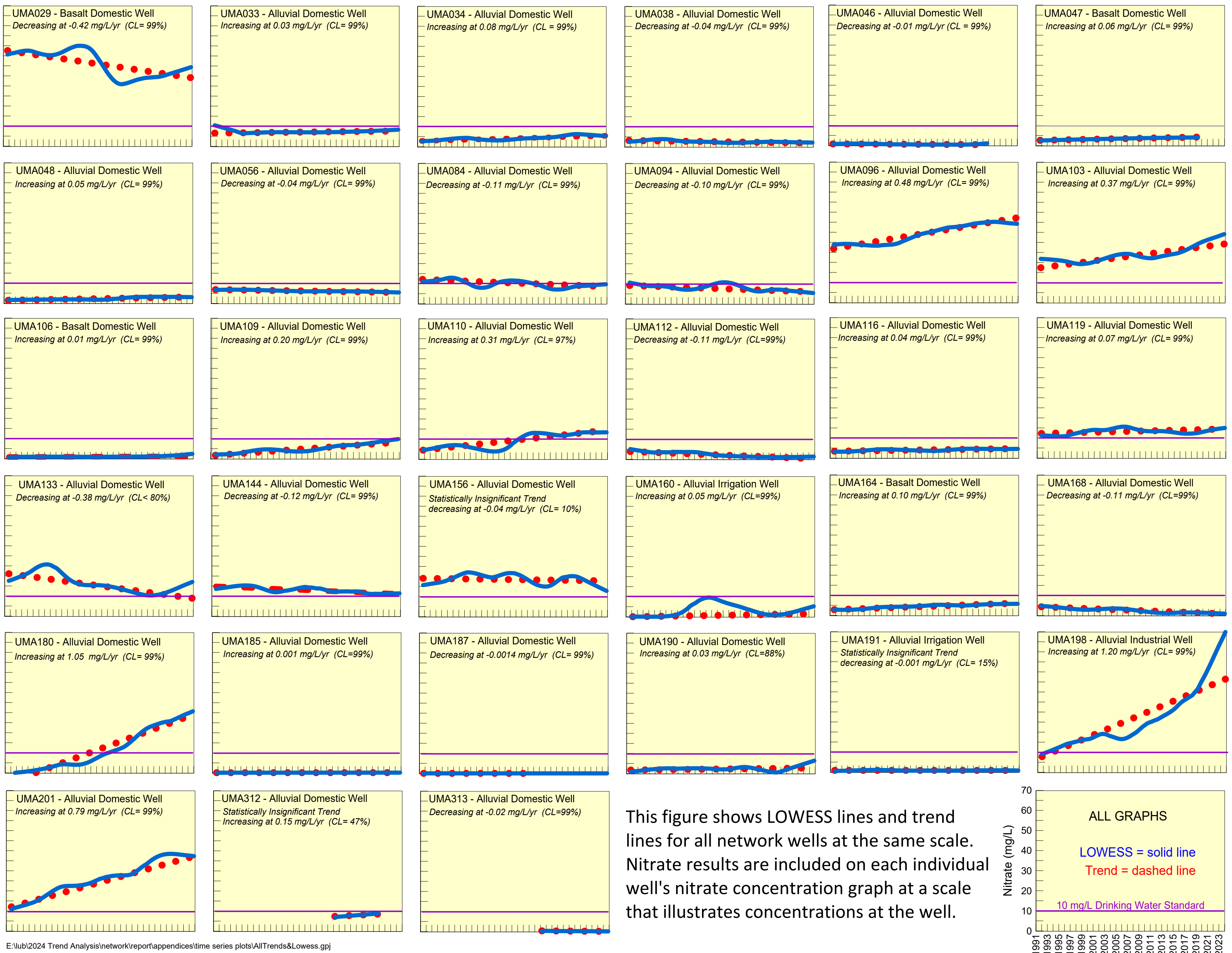


This diagram contains results from the July 2005, November 2005, March 2006, and September 2009 sampling events. Results are arranged chronologically in the legend.

Appendix D

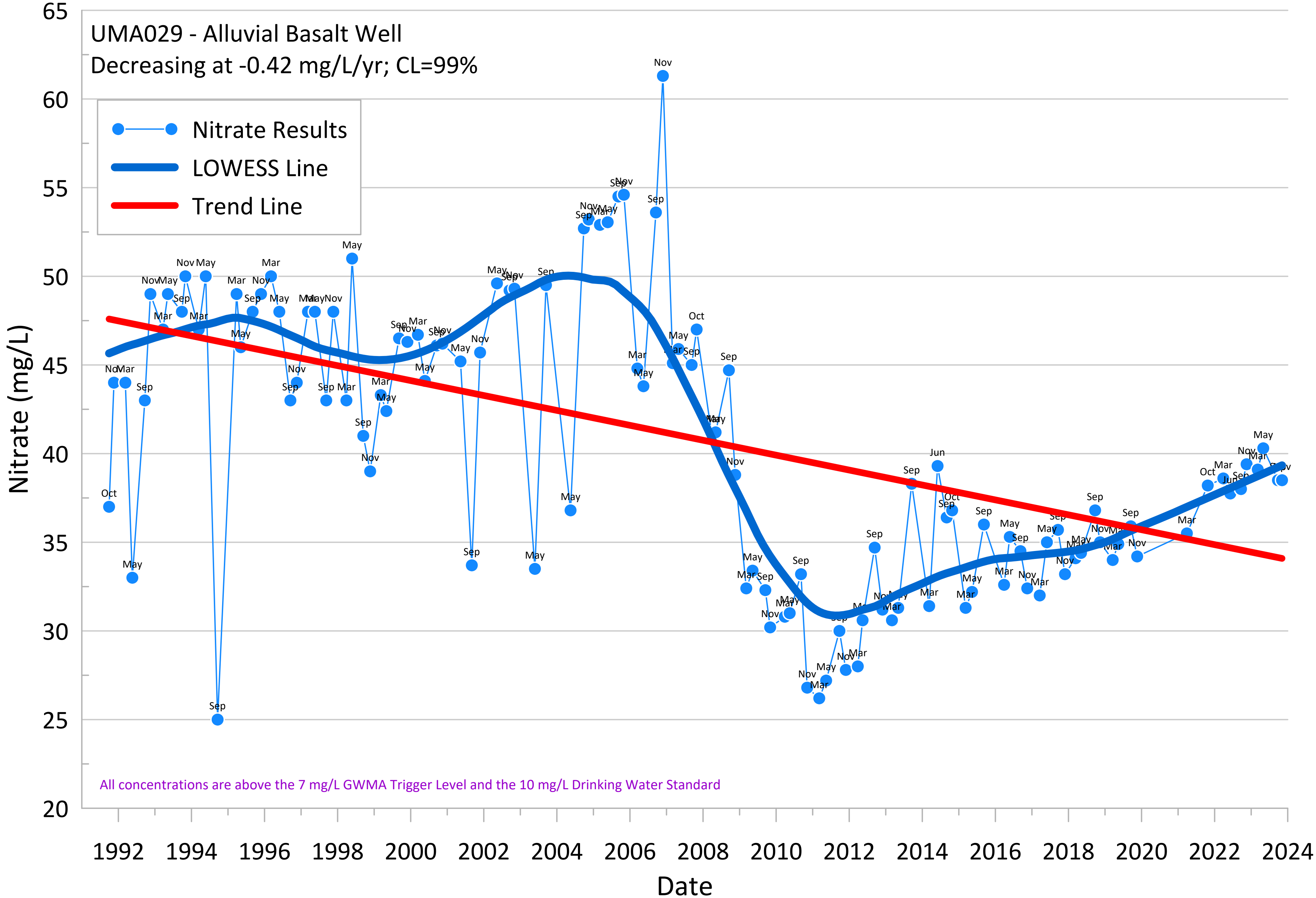
Nitrate Concentration Graphs

LOWESS Lines and Seasonal Kendall Trend Lines - LUBGWMA Network Wells

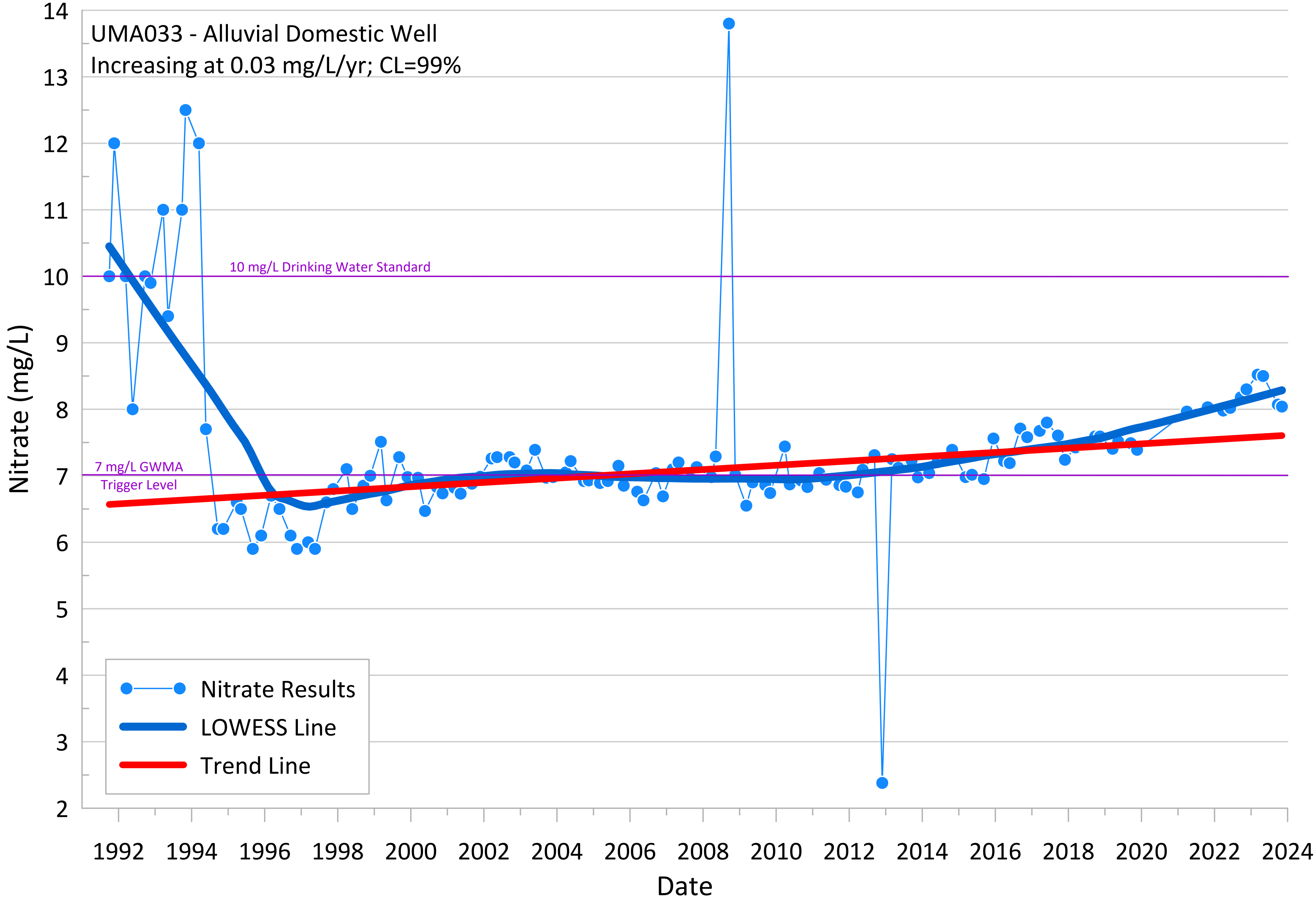


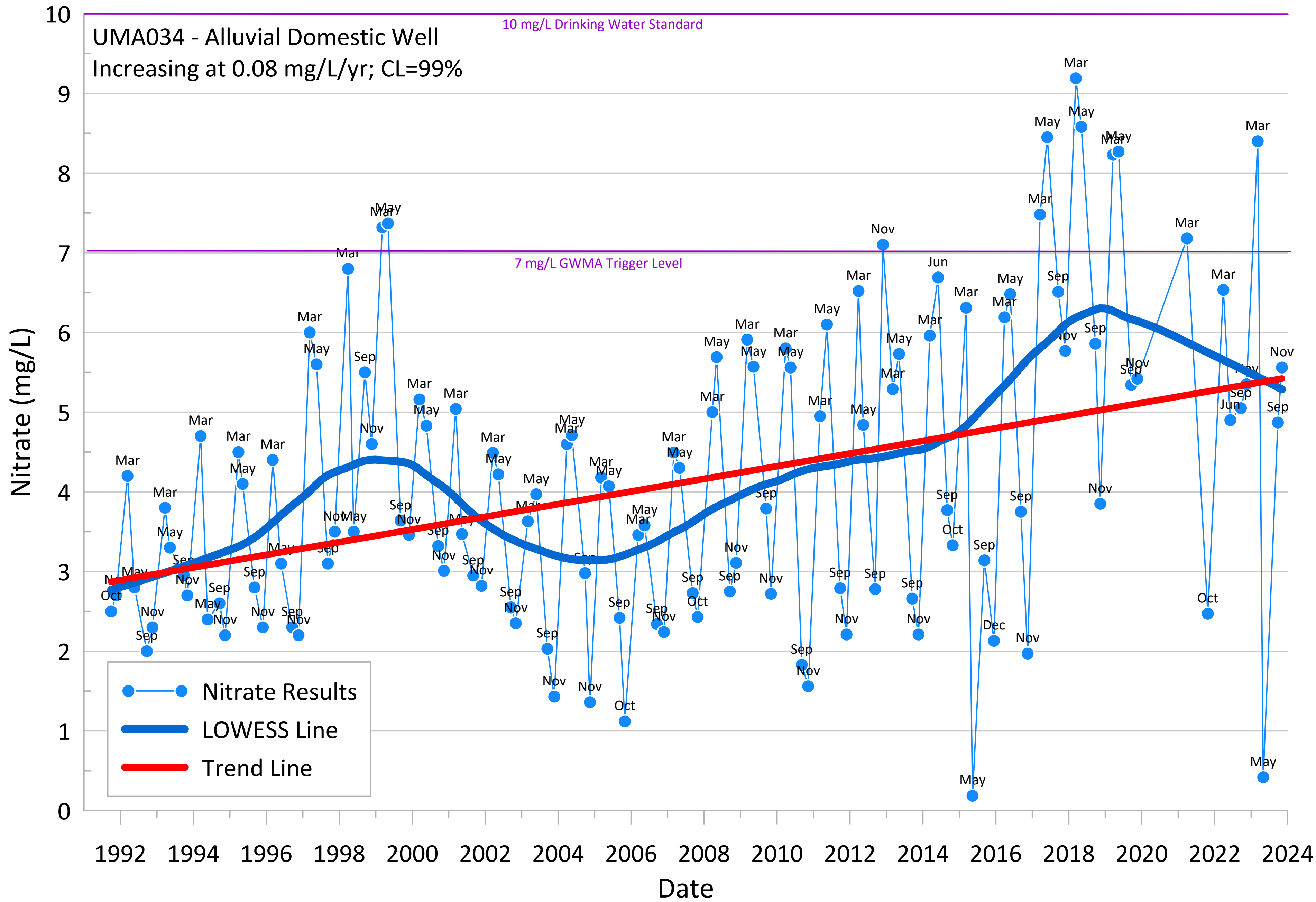
This figure shows LOWESS lines and trend lines for all network wells at the same scale. Nitrate results are included on each individual well's nitrate concentration graph at a scale that illustrates concentrations at the well.

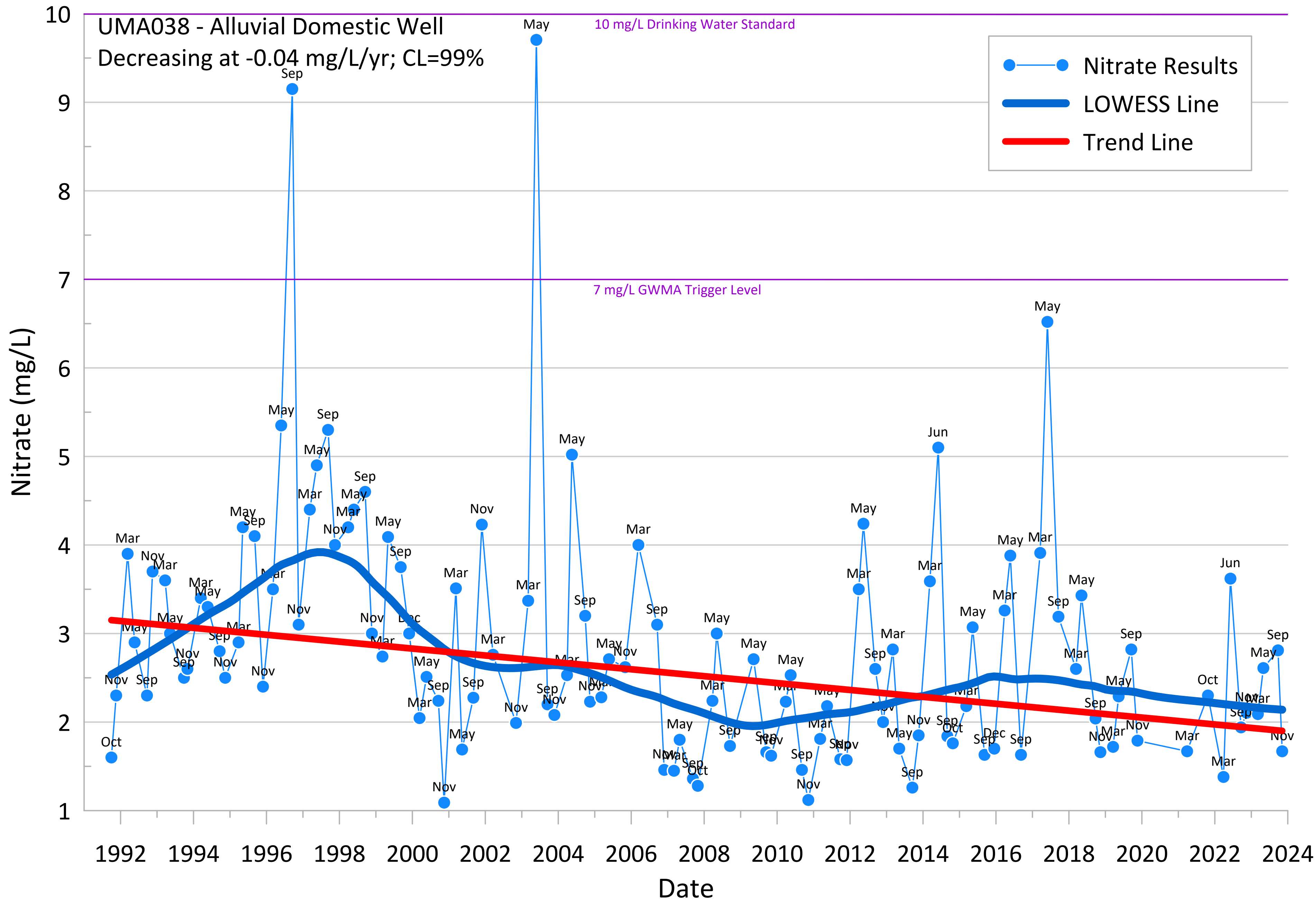
E:\lub\2024 Trend Analysis\network\report\appendices\time series plots\AllTrends&Lowess.gpj



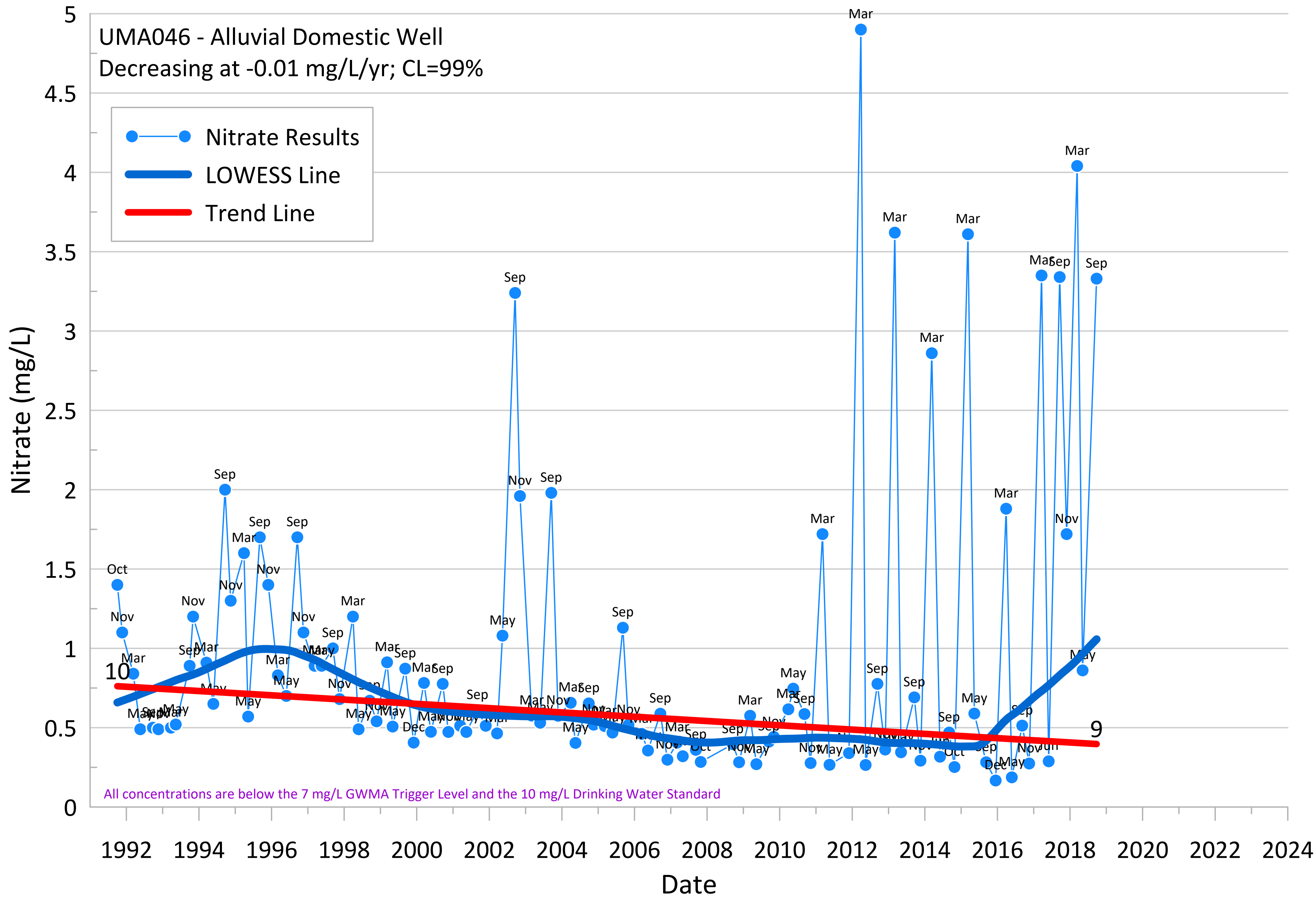
UMA029 - Alluvial Basalt Well
Decreasing at -0.42 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are above the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date
65
60
55
50
45
40
35
30
25
20
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA033 - Alluvial Domestic Well
Increasing at 0.03 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA
Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
14
13
12
11
10
9
8
7
6
5
4
3
2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

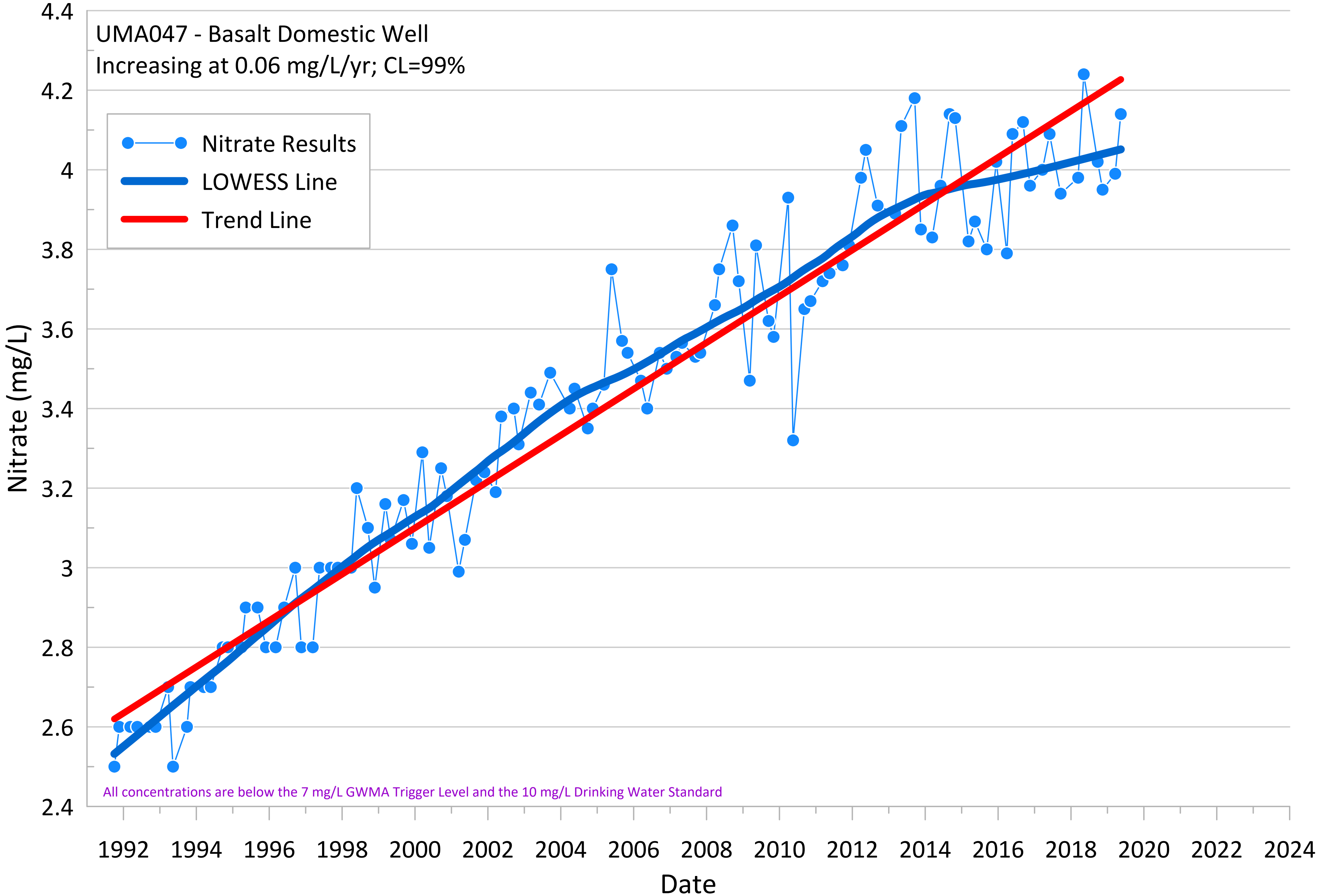

UMA034 - Alluvial Domestic Well
Increasing at 0.08 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
0
1
2
3
4
5
6
7
8
9
10
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

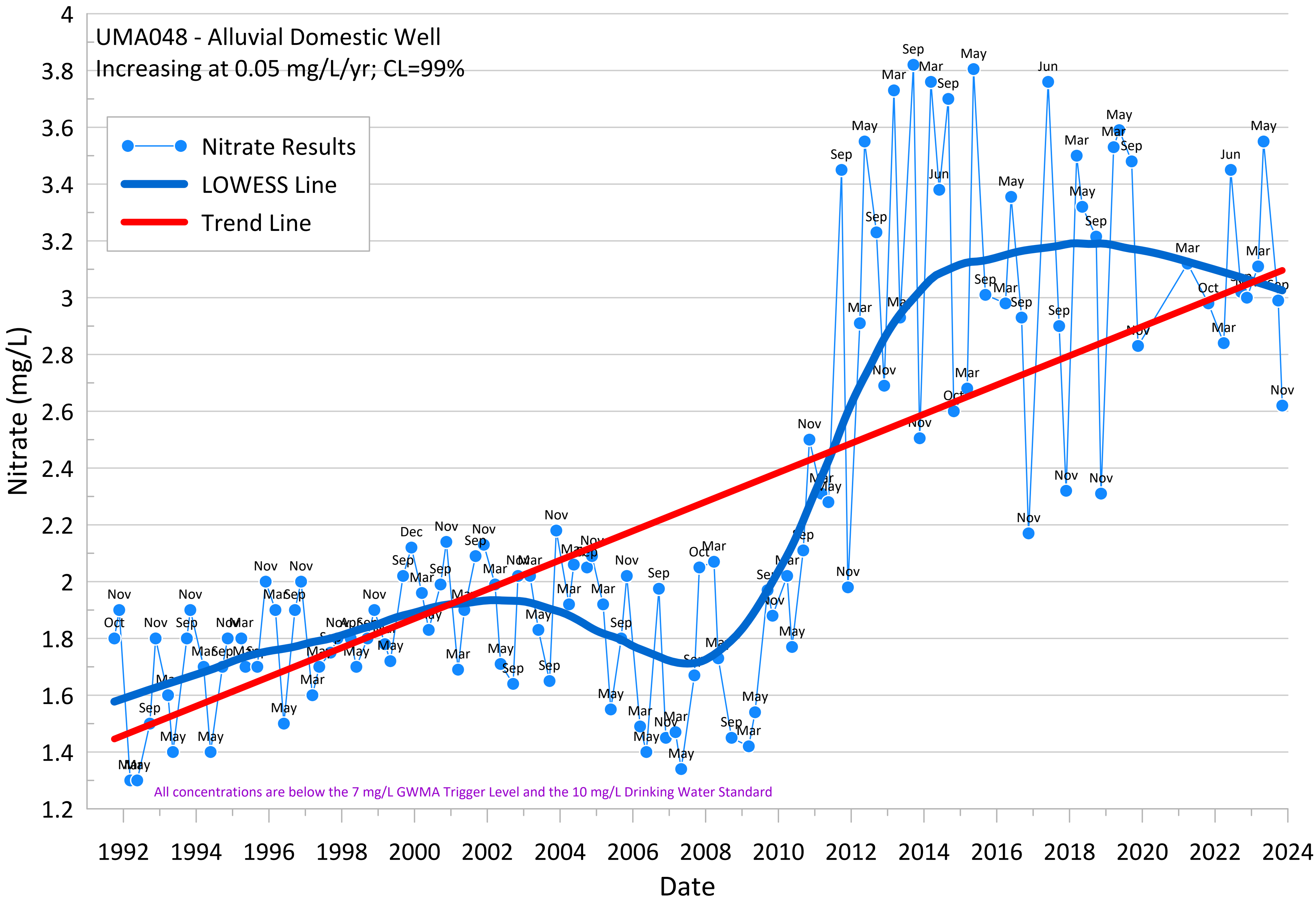


UMA038 - Alluvial Domestic Well
Decreasing at -0.04 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date

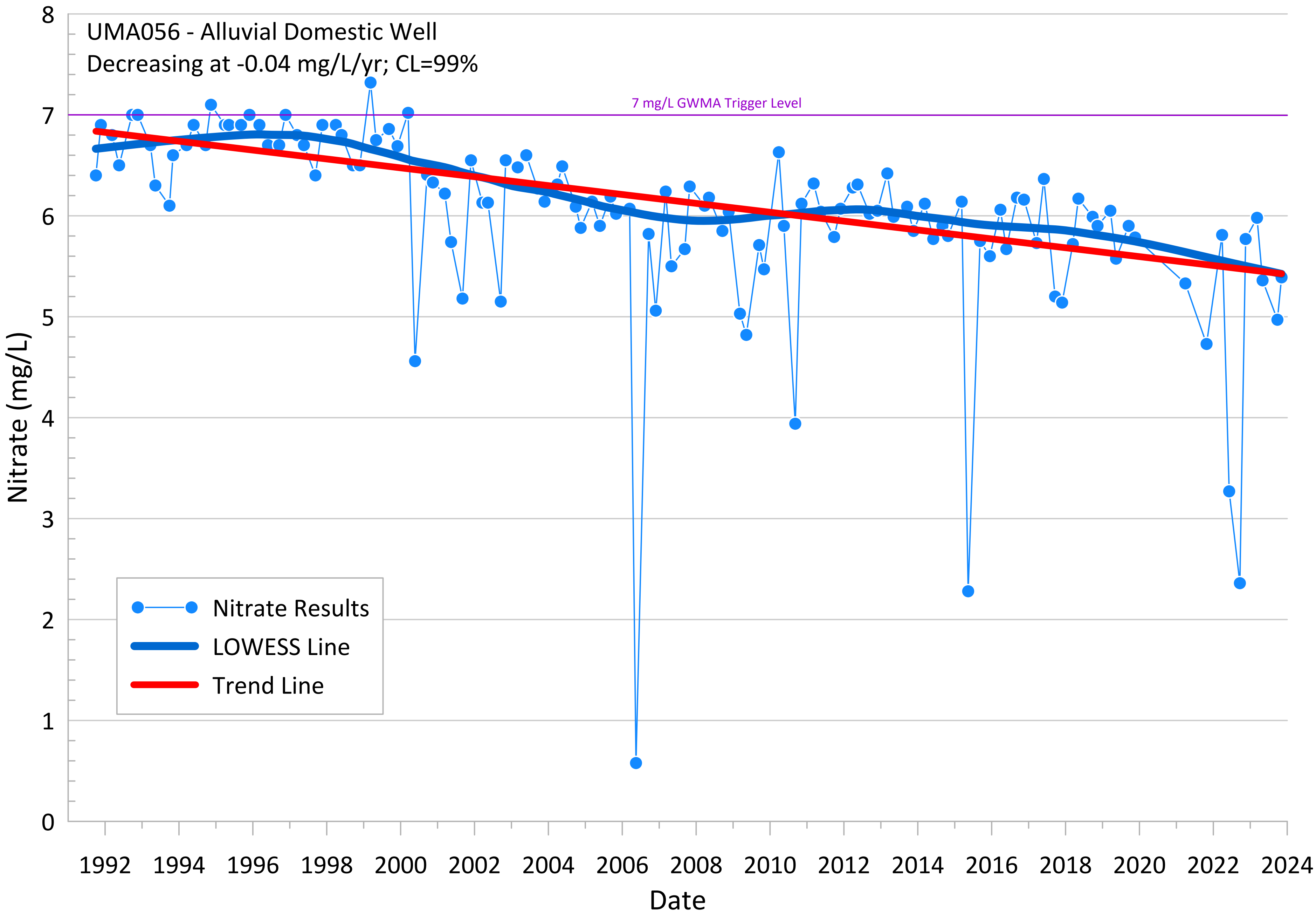


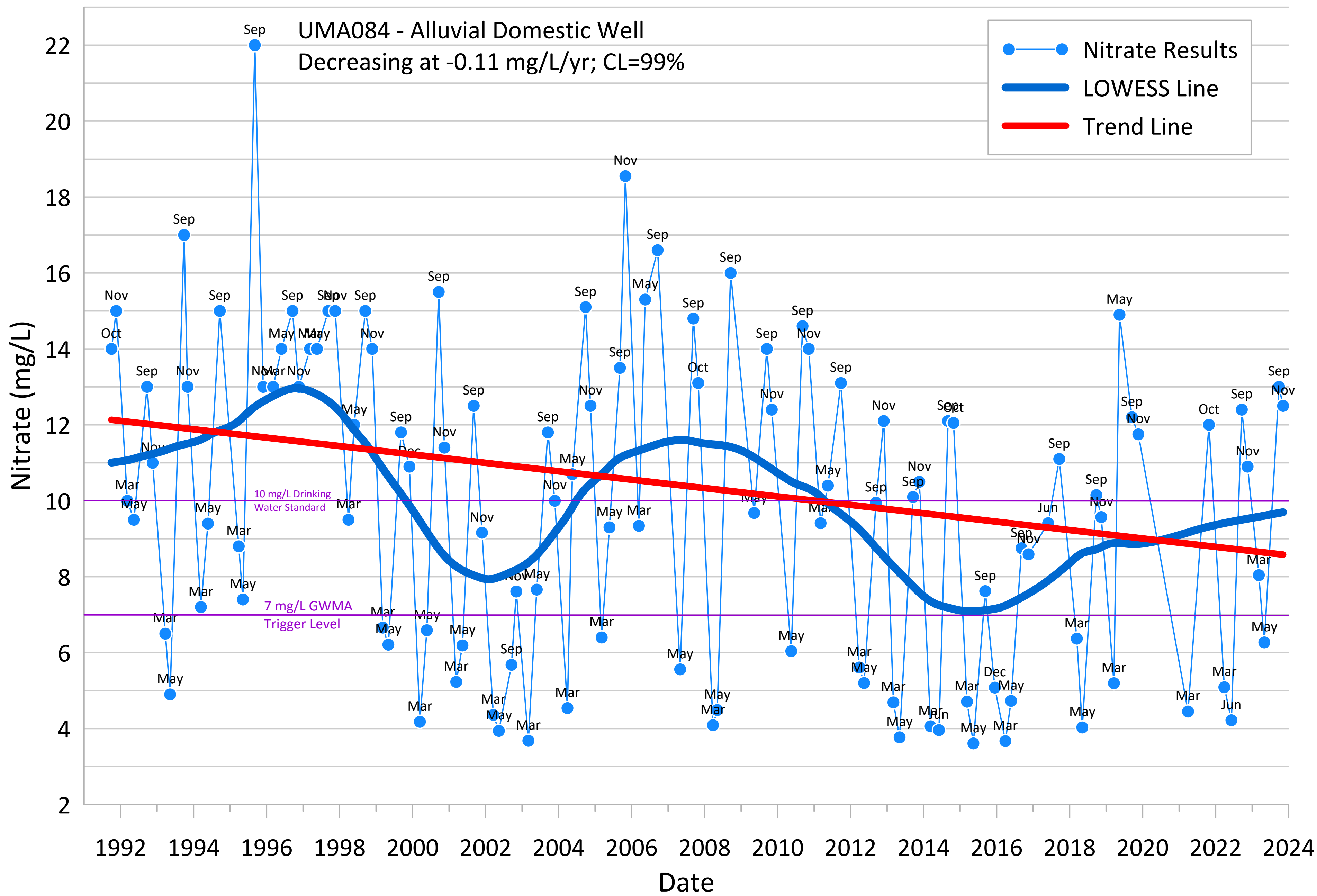
UMA046 - Alluvial Domestic Well
Decreasing at -0.01 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard


UMA047 - Basalt Domestic Well
Increasing at 0.06 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard

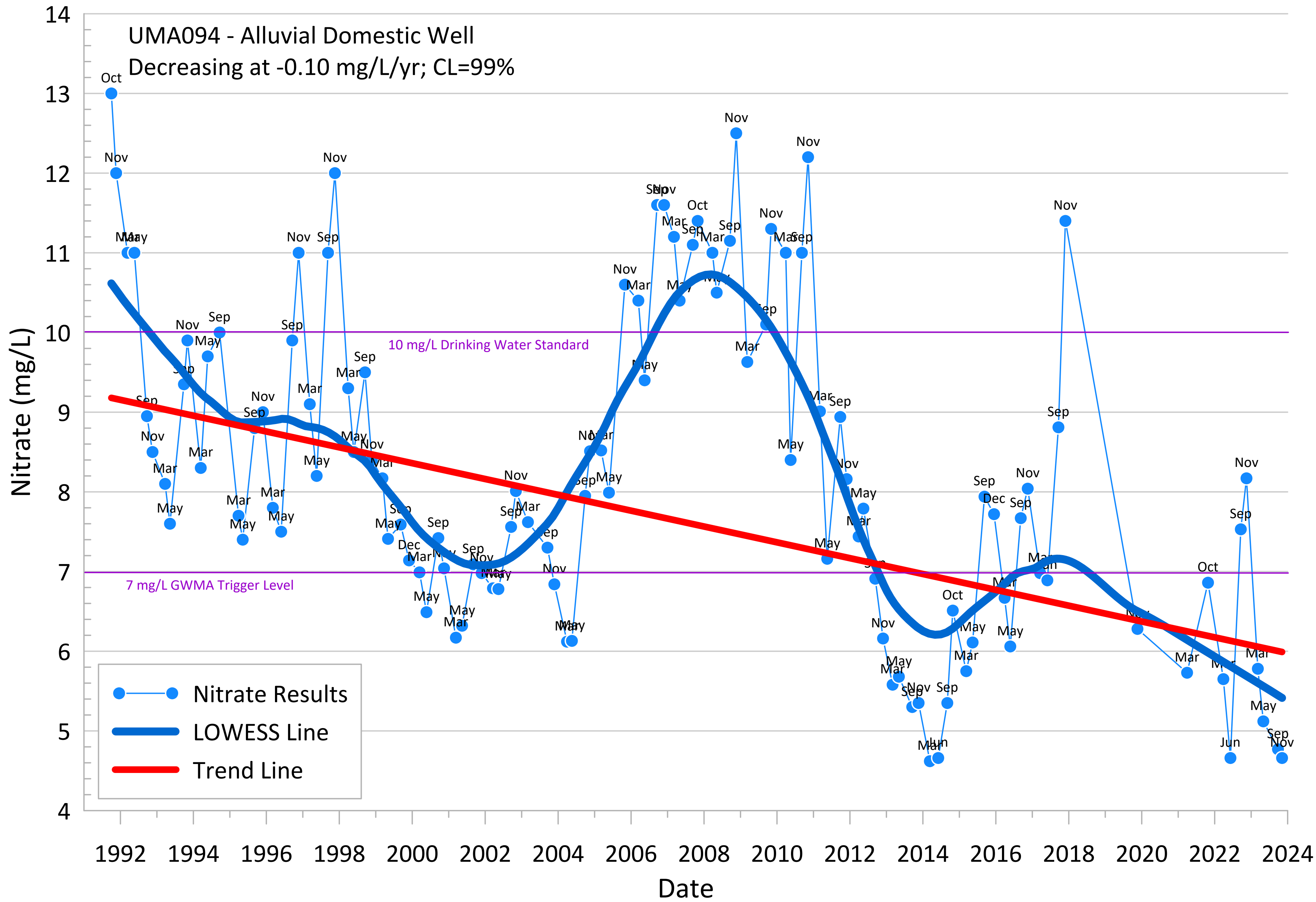


UMA048 - Alluvial Domestic Well
Increasing at 0.05 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date

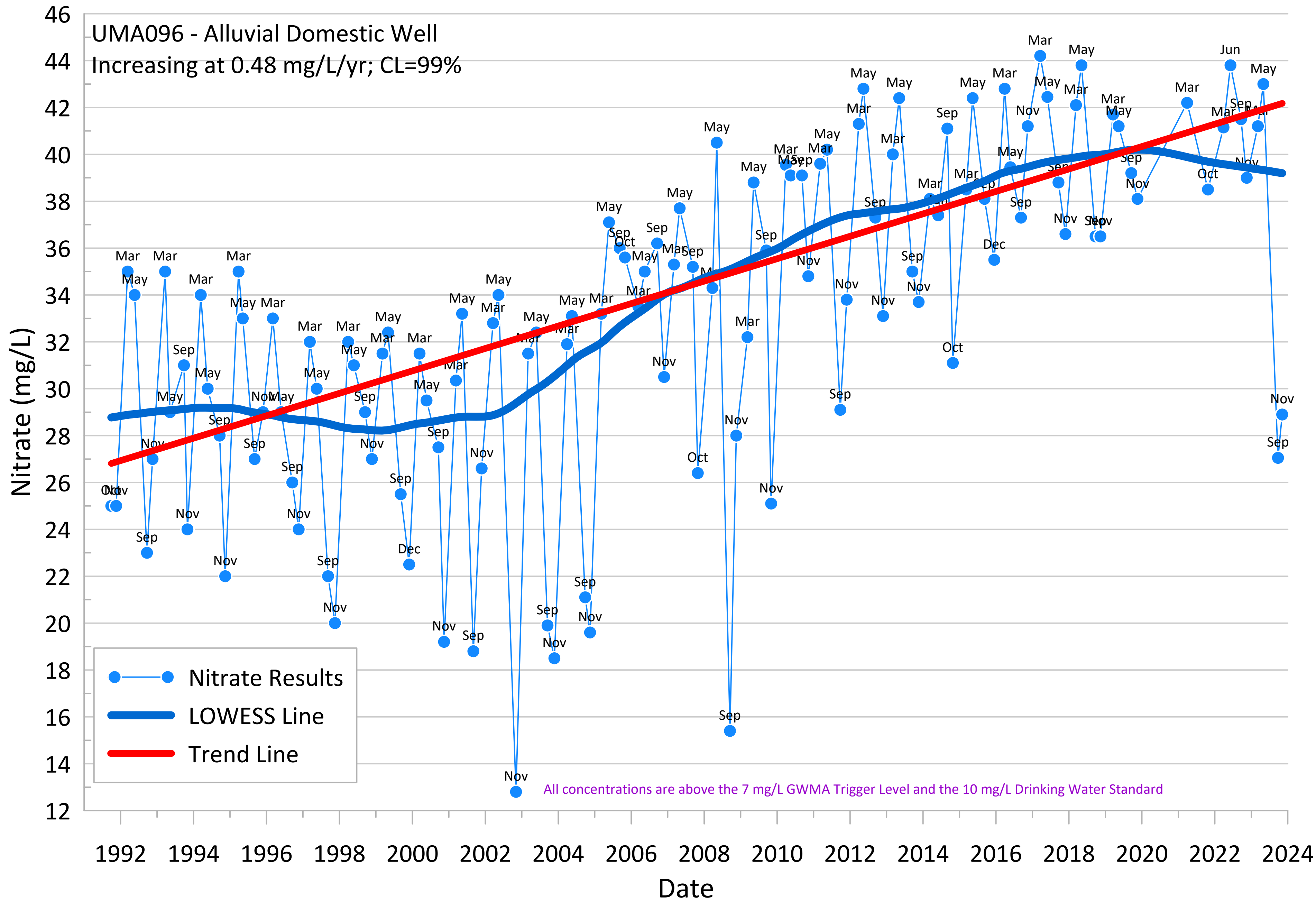

UMA056 - Alluvial Domestic Well
Decreasing at -0.04 mg/L/yr; CL=99%
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
0
1
2
3
4
5
6
7
8
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



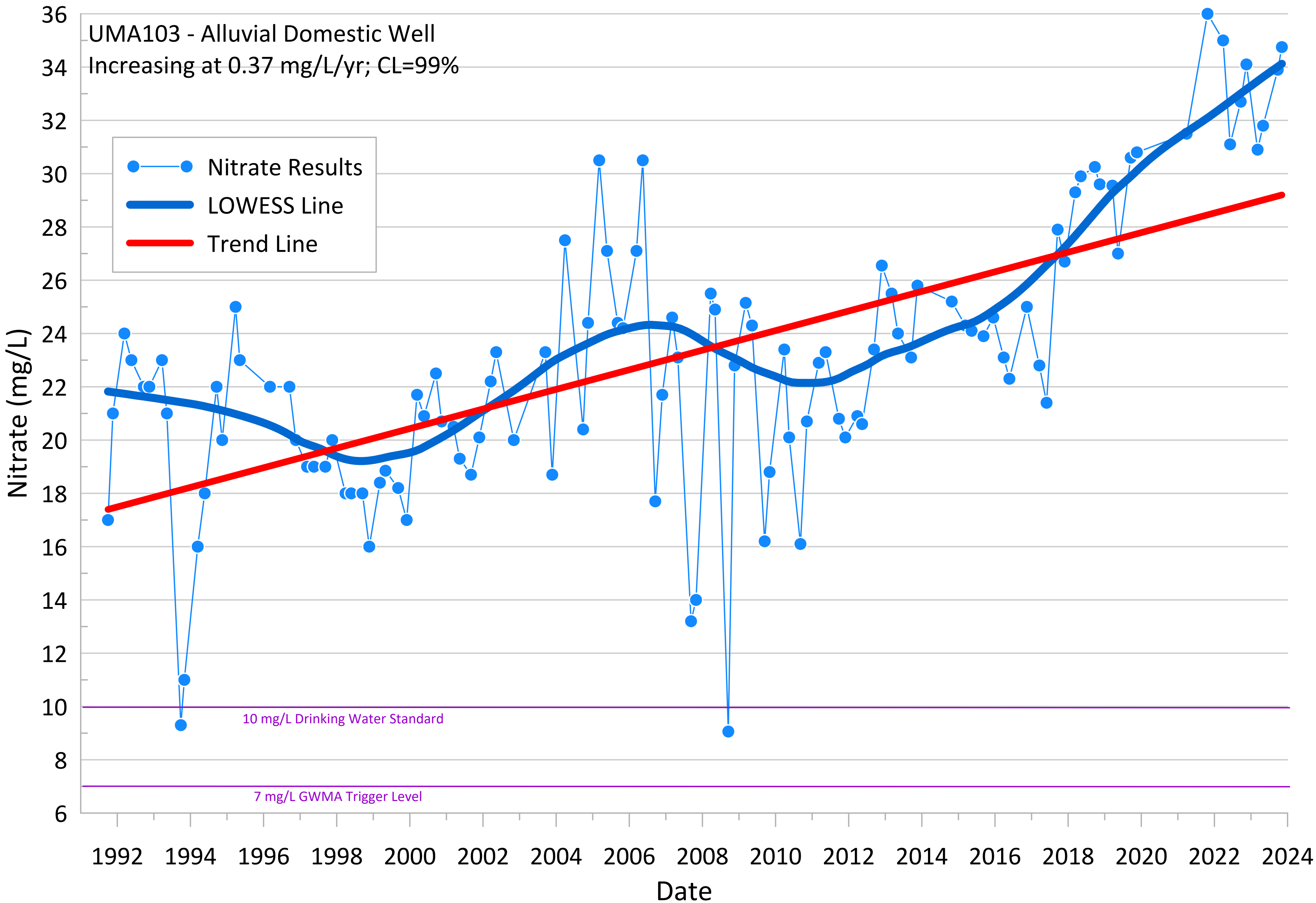
UMA084 - Alluvial Domestic Well
Decreasing at -0.11 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
2
4
6
8
10
12
14
16
18
20
22
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



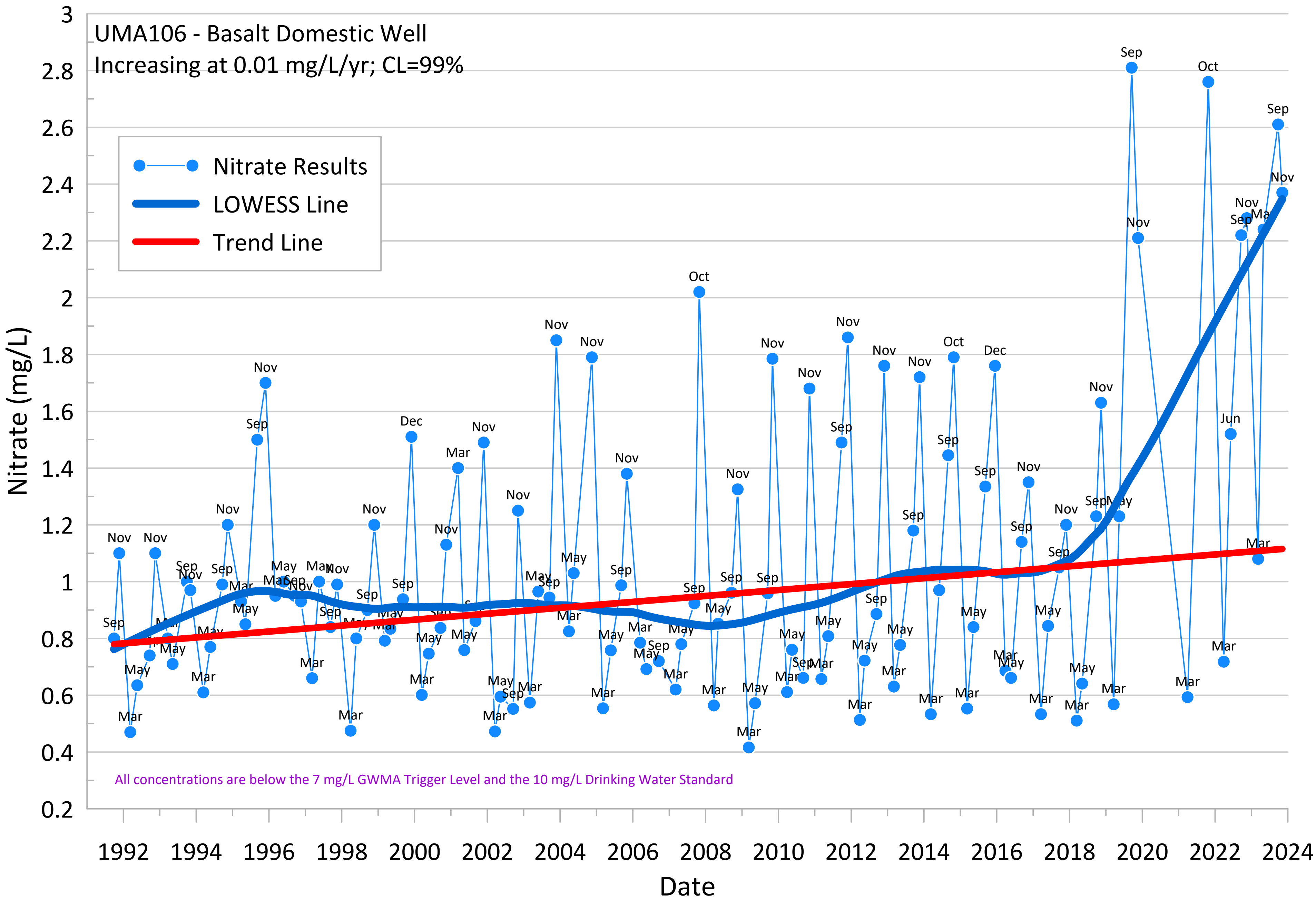
UMA094 - Alluvial Domestic Well
Decreasing at -0.10 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line



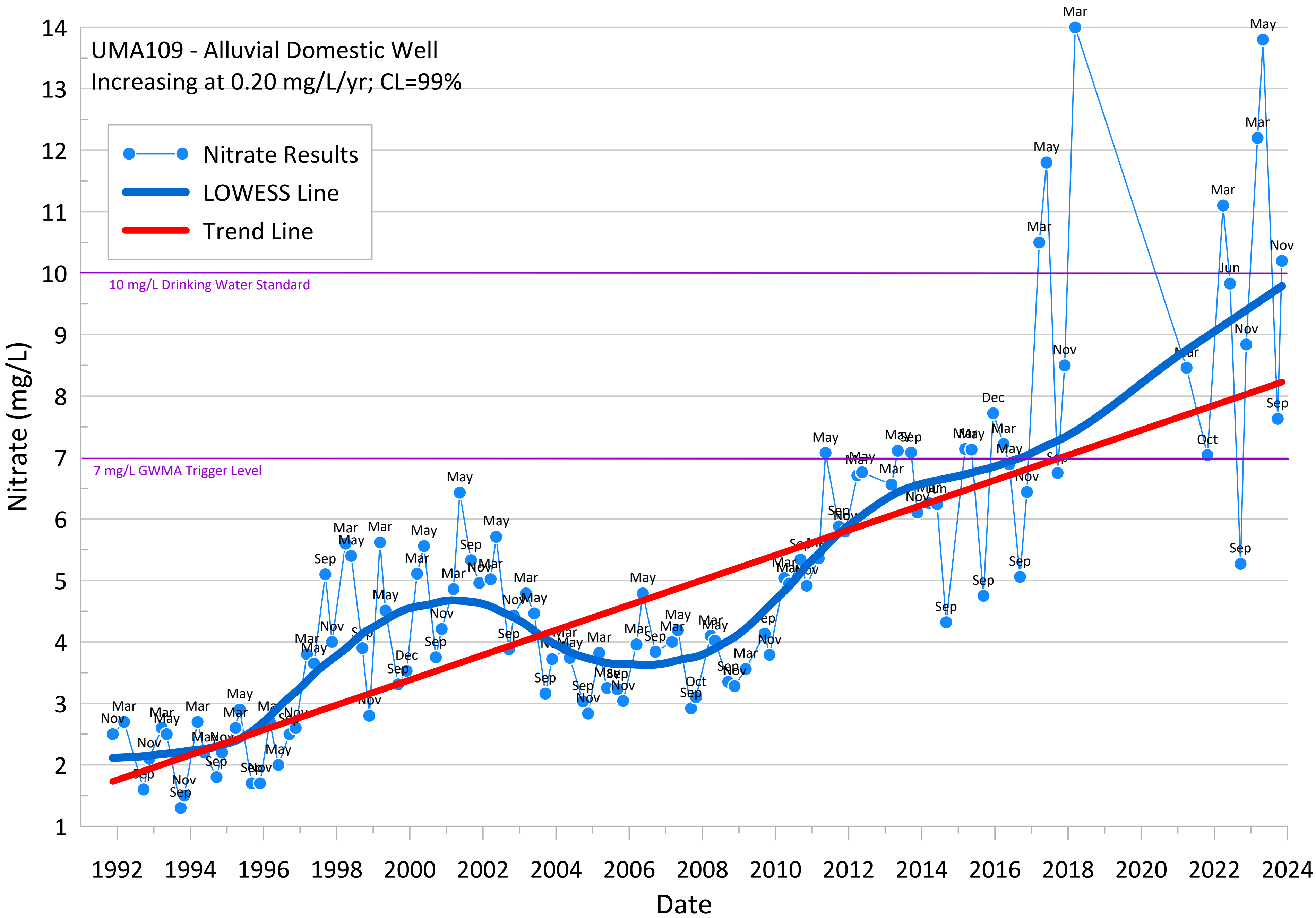
UMA096 - Alluvial Domestic Well
Increasing at 0.48 mg/L/yr; CL=99%
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
All concentrations are above the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard



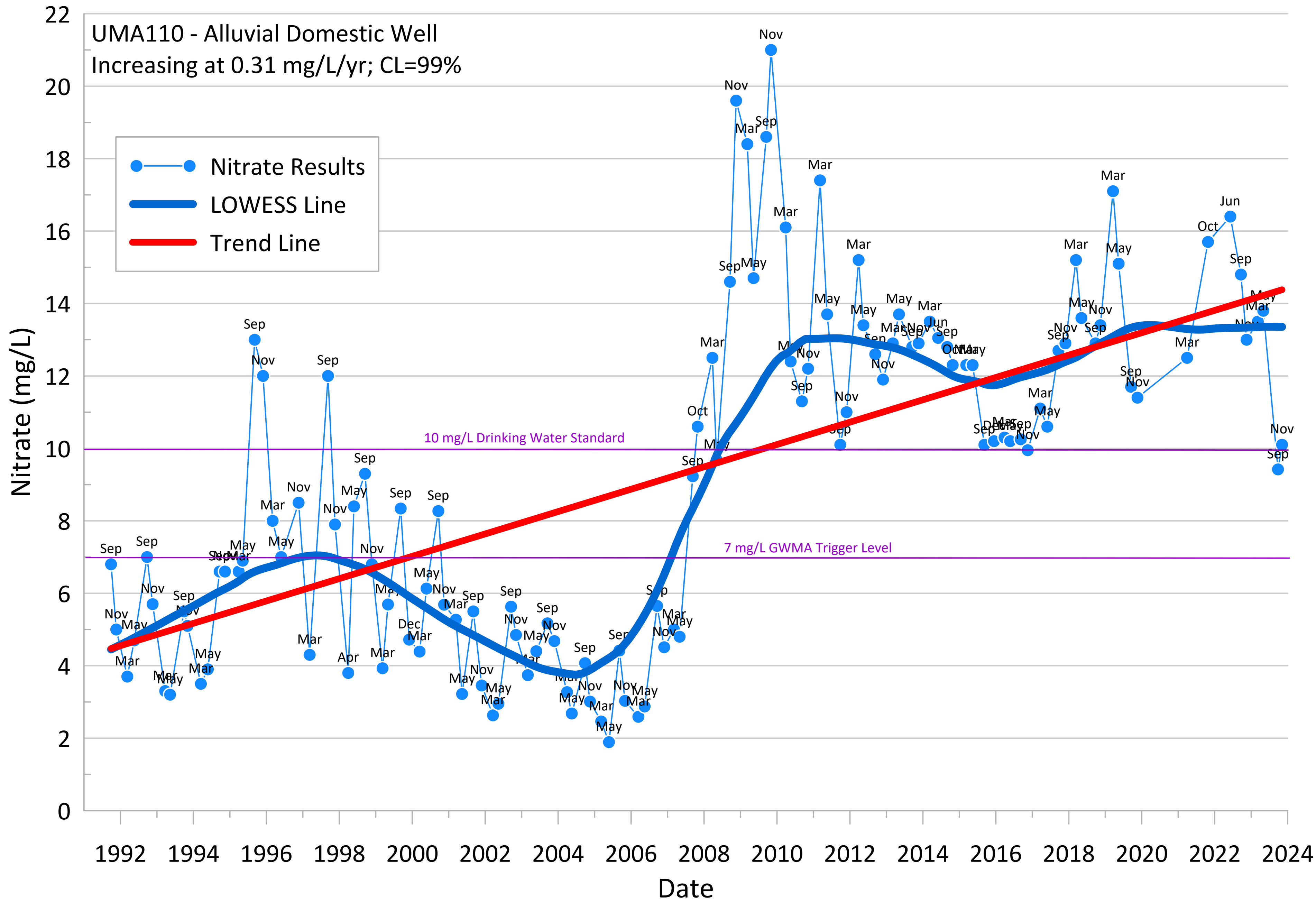
UMA103 - Alluvial Domestic Well
Increasing at 0.37 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



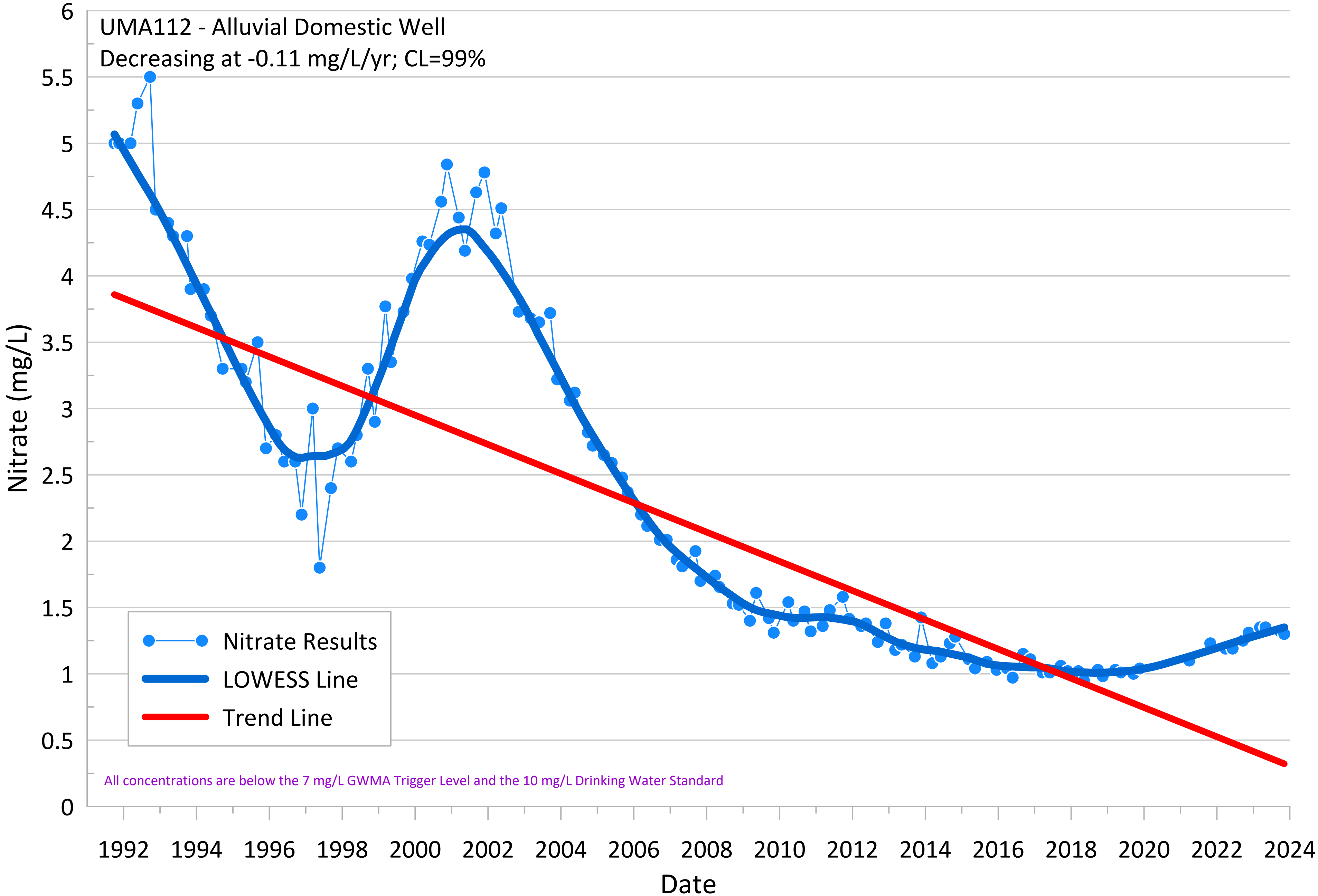
UMA106 - Basalt Domestic Well
Increasing at 0.01 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



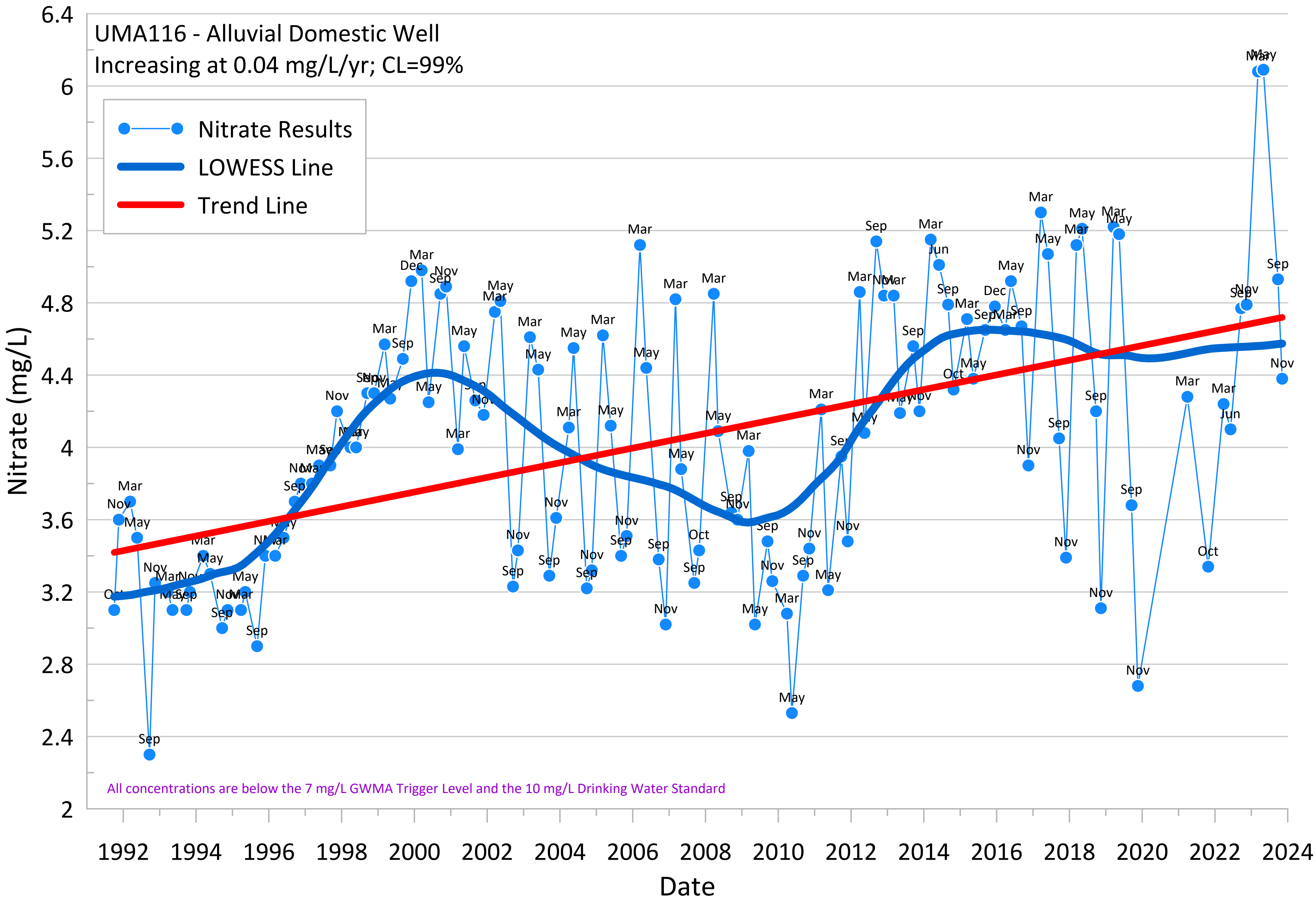
UMA109 - Alluvial Domestic Well
Increasing at 0.20 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date



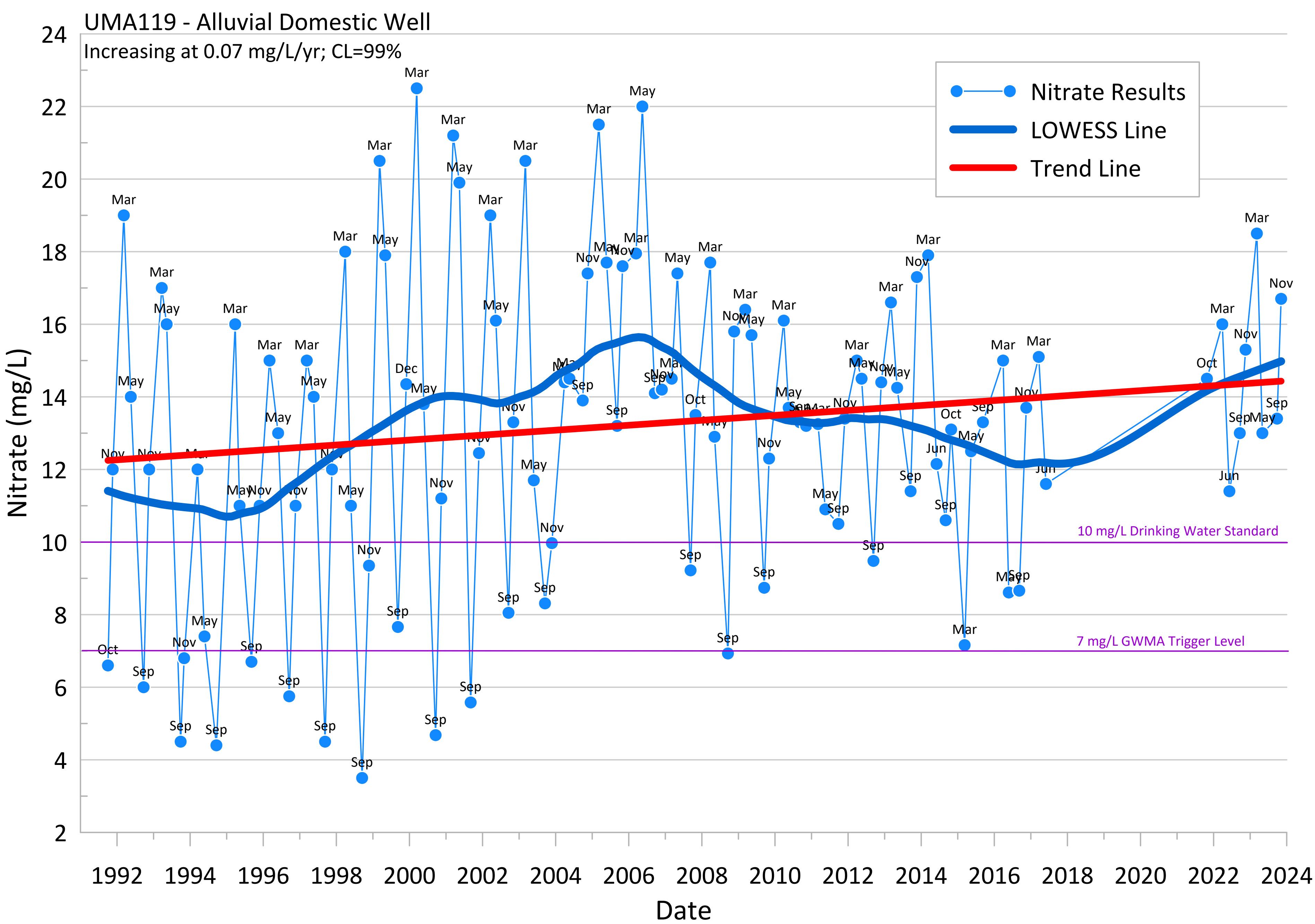
UMA110 - Alluvial Domestic Well
Increasing at 0.31 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date

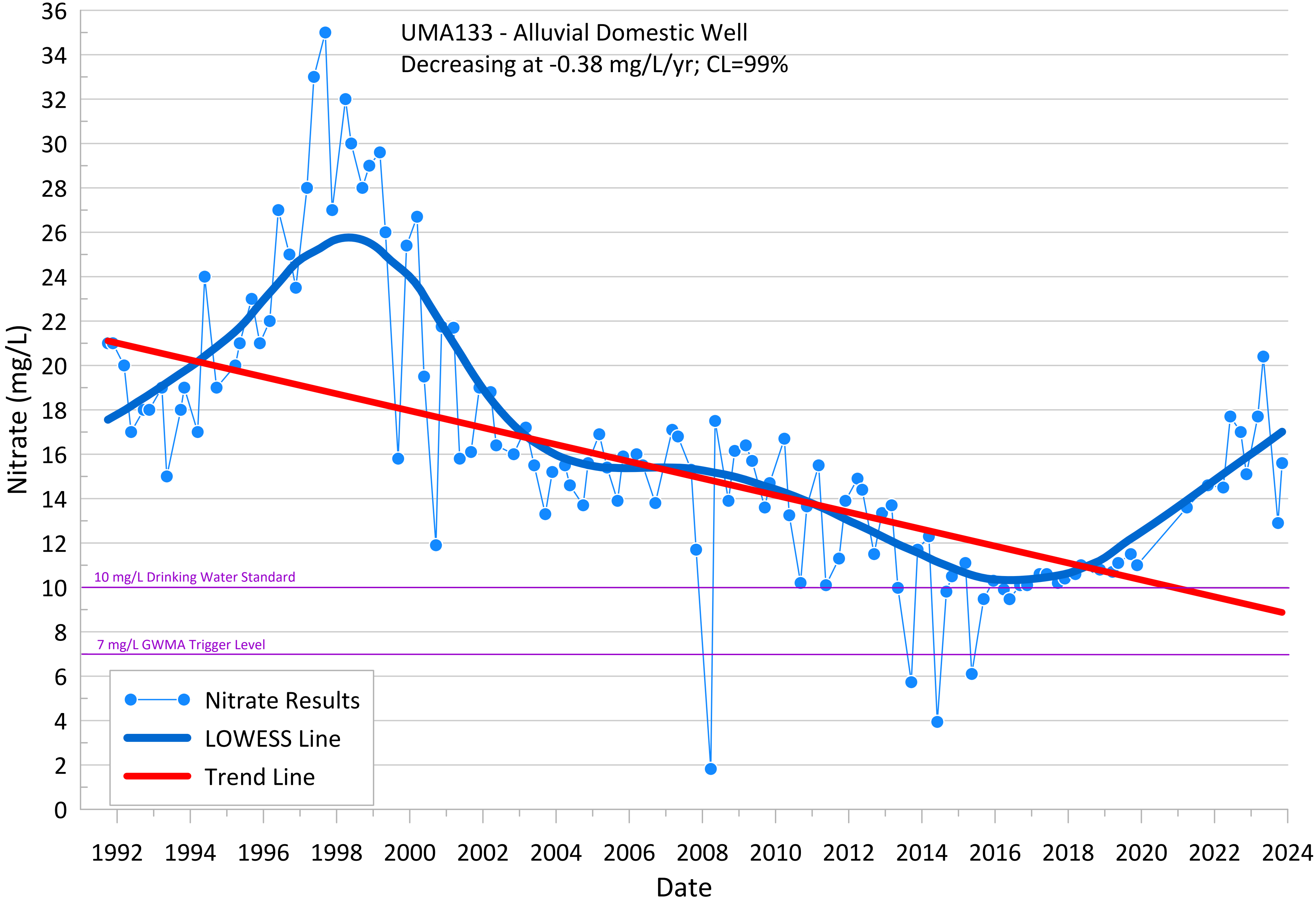


UMA112 - Alluvial Domestic Well
Decreasing at -0.11 mg/L/yr; CL=99%
Nitrate (mg/L)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard

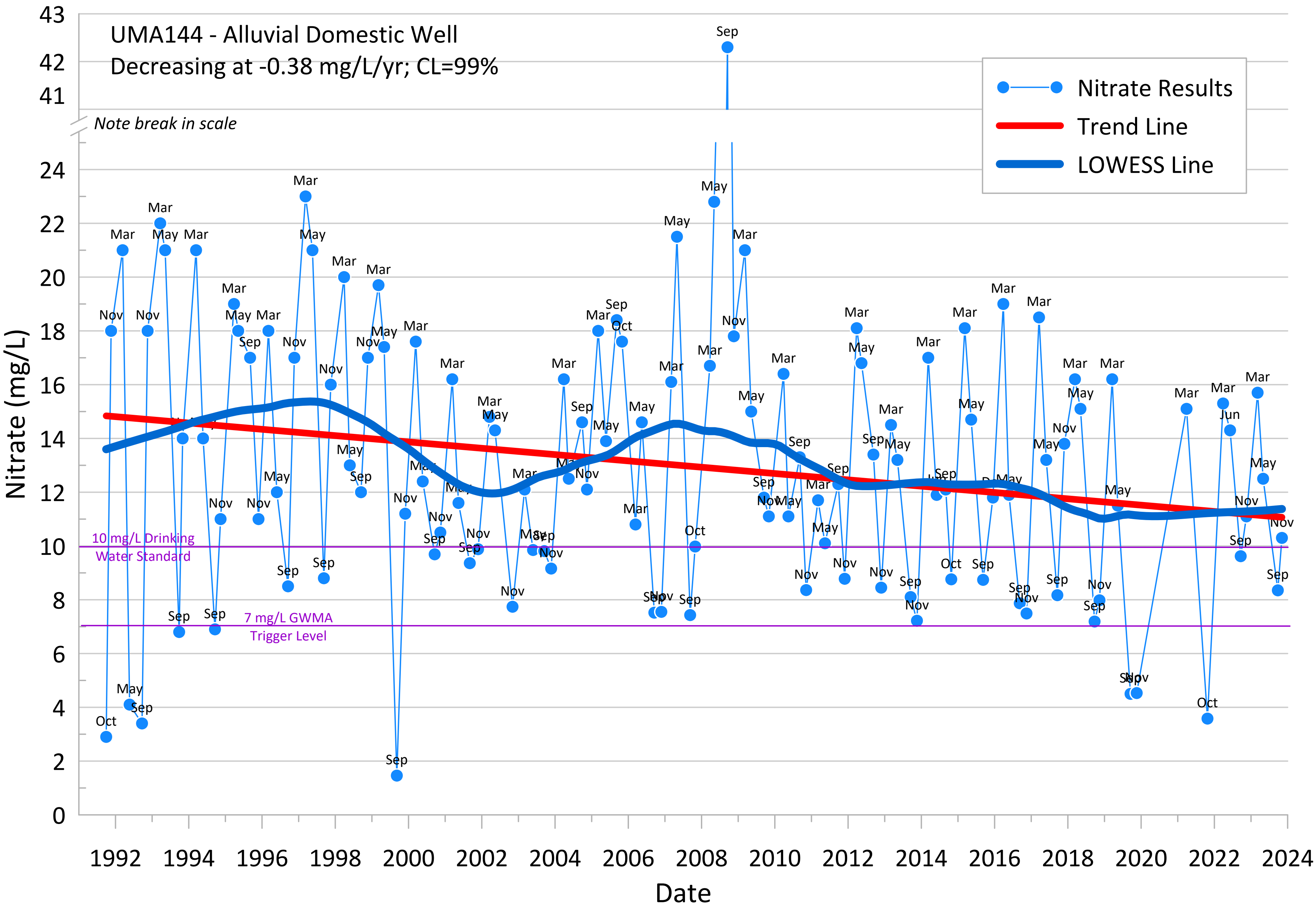


UMA116 - Alluvial Domestic Well
Increasing at 0.04 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date
2
2.4
2.8
3.2
3.6
4
4.4
4.8
5.2
5.6
6
6.4
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

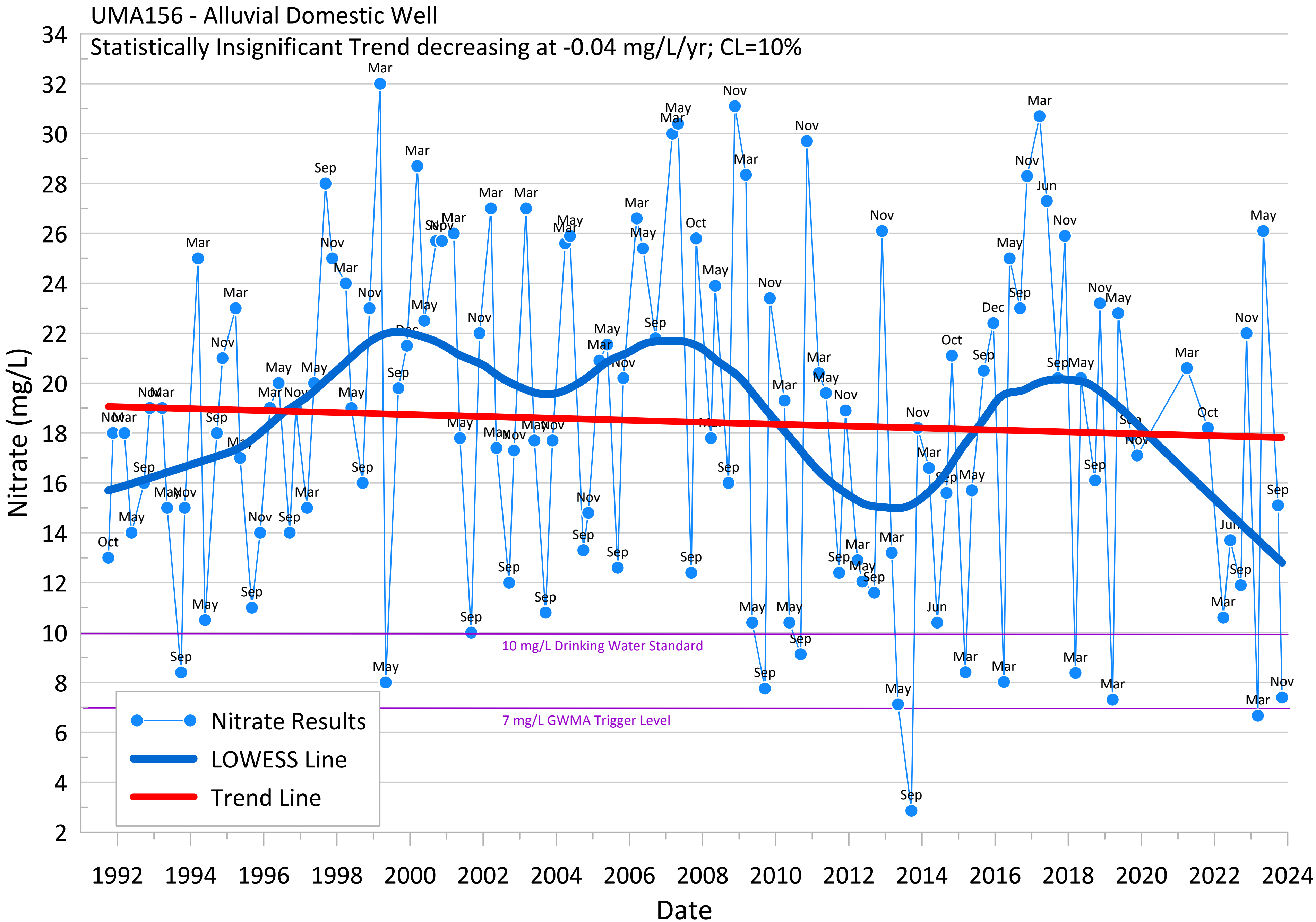

UMA119 - Alluvial Domestic Well
Increasing at 0.07 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
24
22
20
18
16
14
12
10
8
6
4
2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



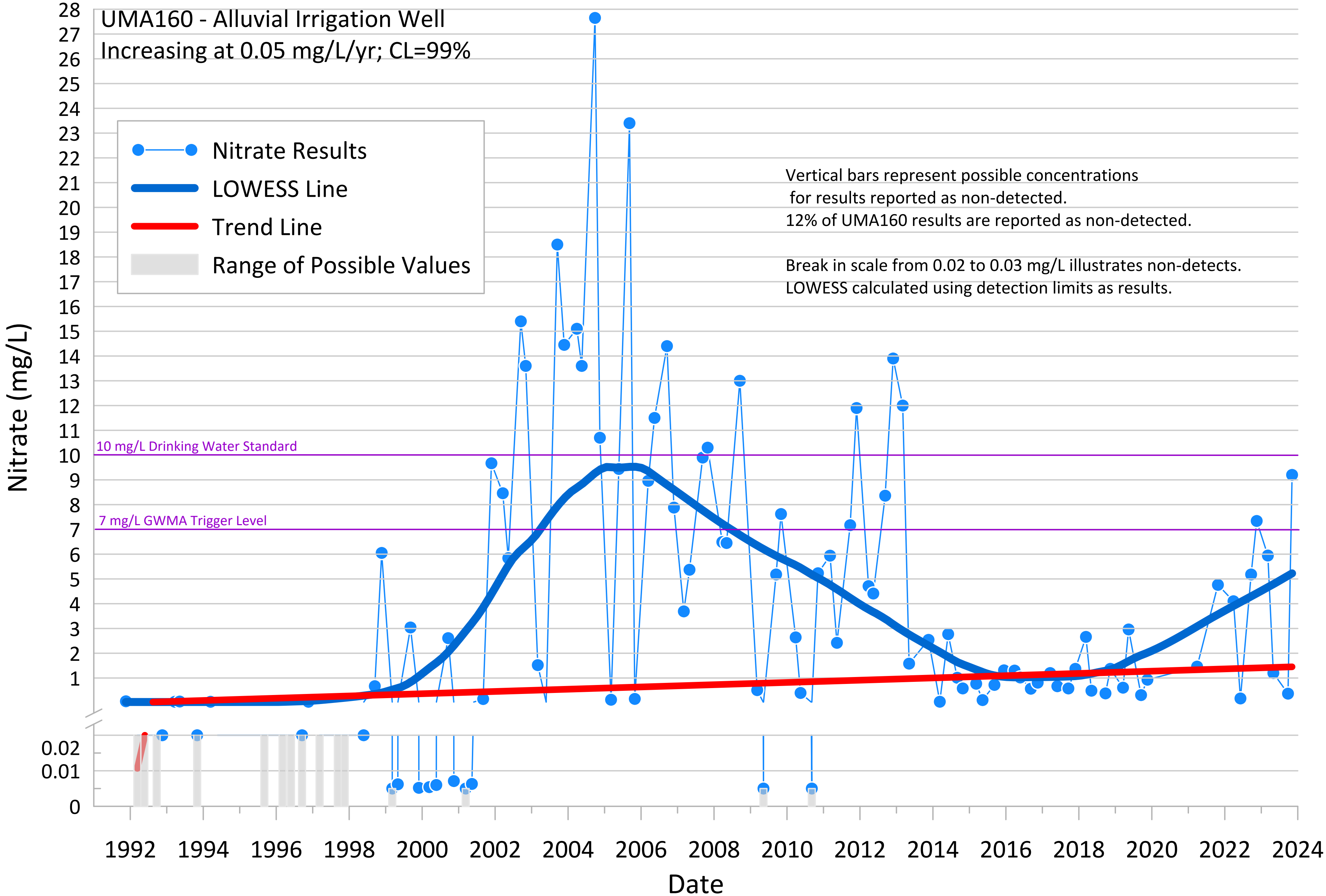
UMA133 - Alluvial Domestic Well
Decreasing at -0.38 mg/L/yr; CL=99%
Nitrate (mg/L)
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date



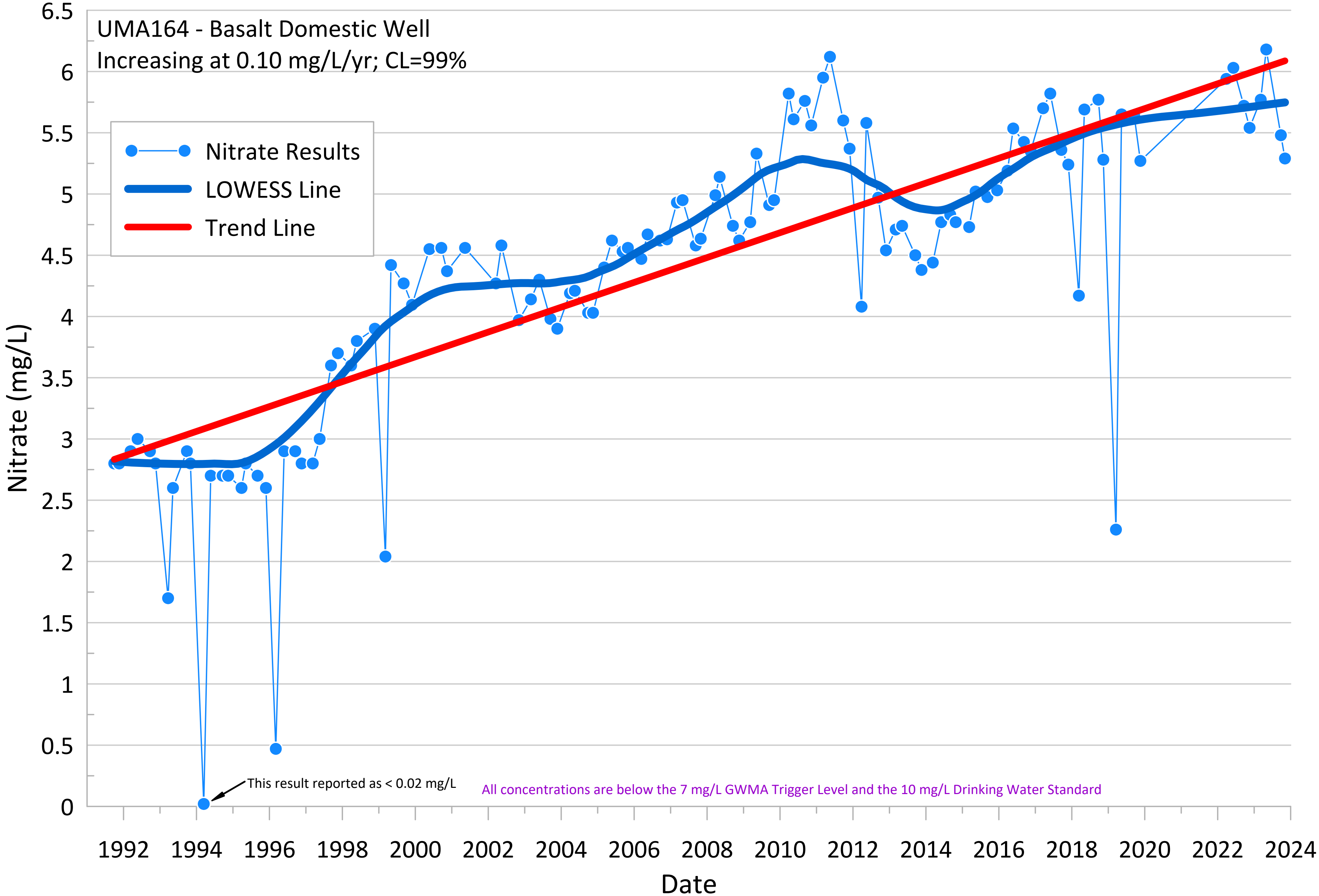
UMA144 - Alluvial Domestic Well
Decreasing at -0.38 mg/L/yr; CL=99%
Note break in scale
Nitrate Results
Trend Line
LOWESS Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date



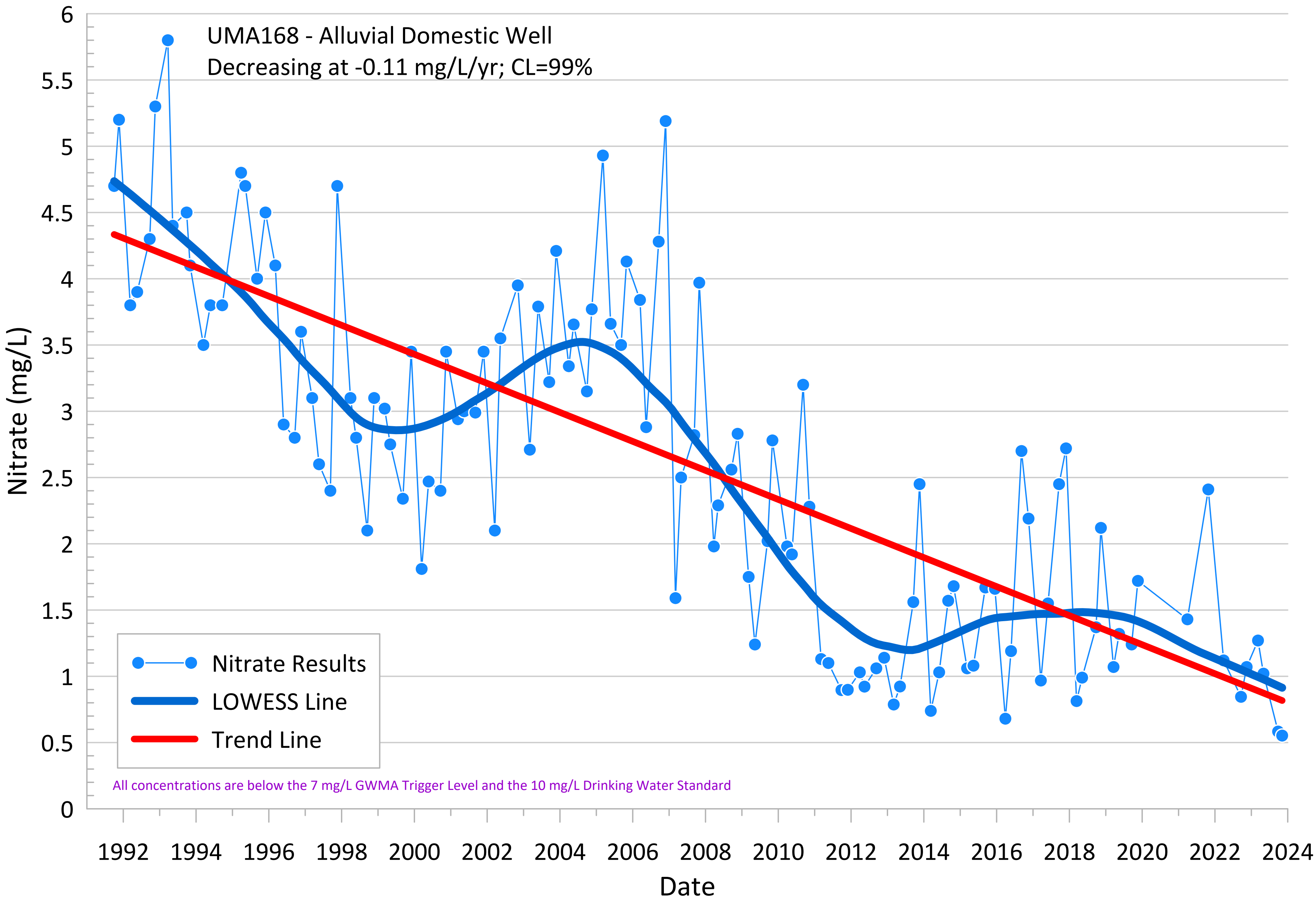
UMA156 - Alluvial Domestic Well
Statistically Insignificant Trend decreasing at -0.04 mg/L/yr; CL=10%
Nitrate (mg/L)
Date
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line

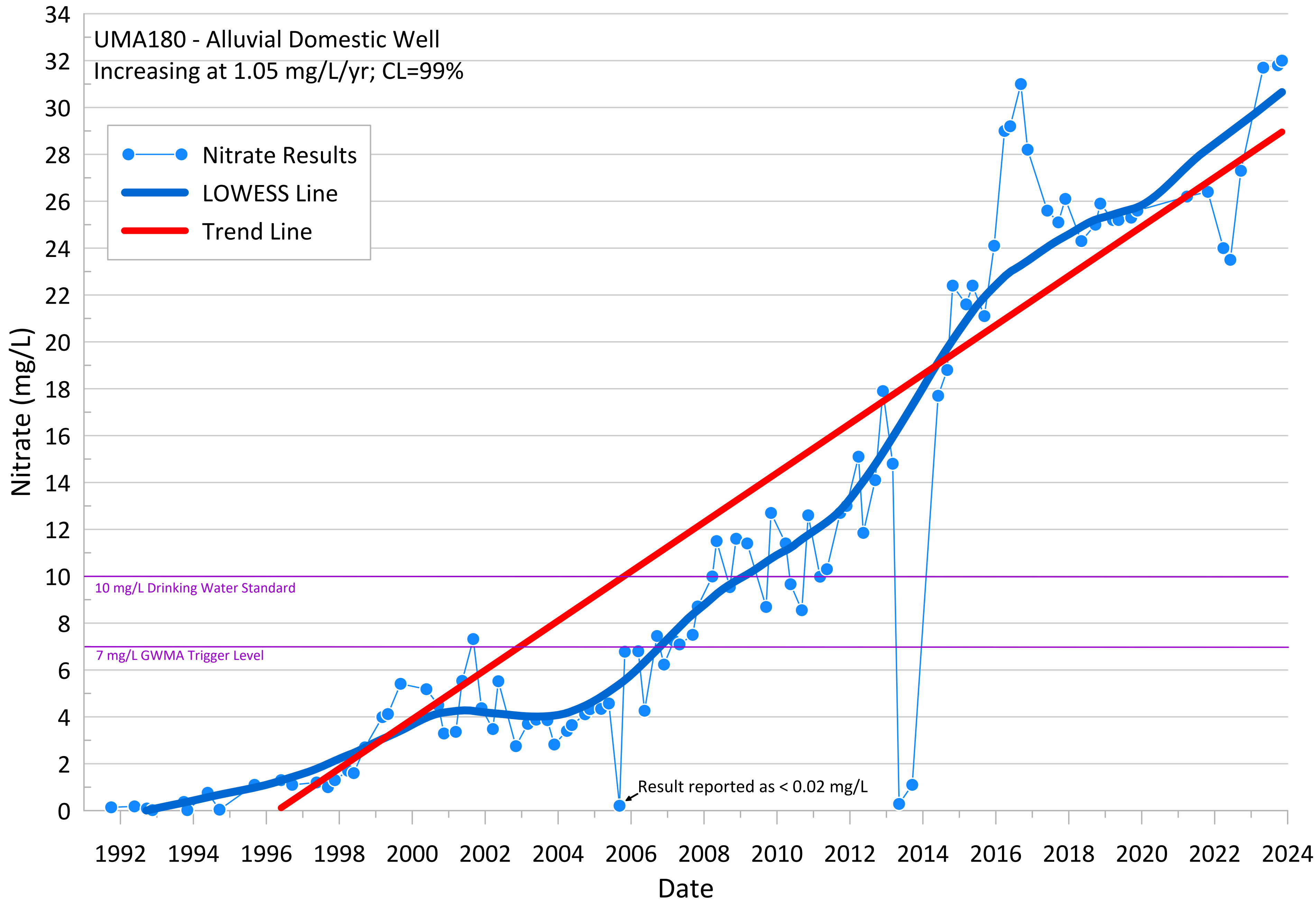


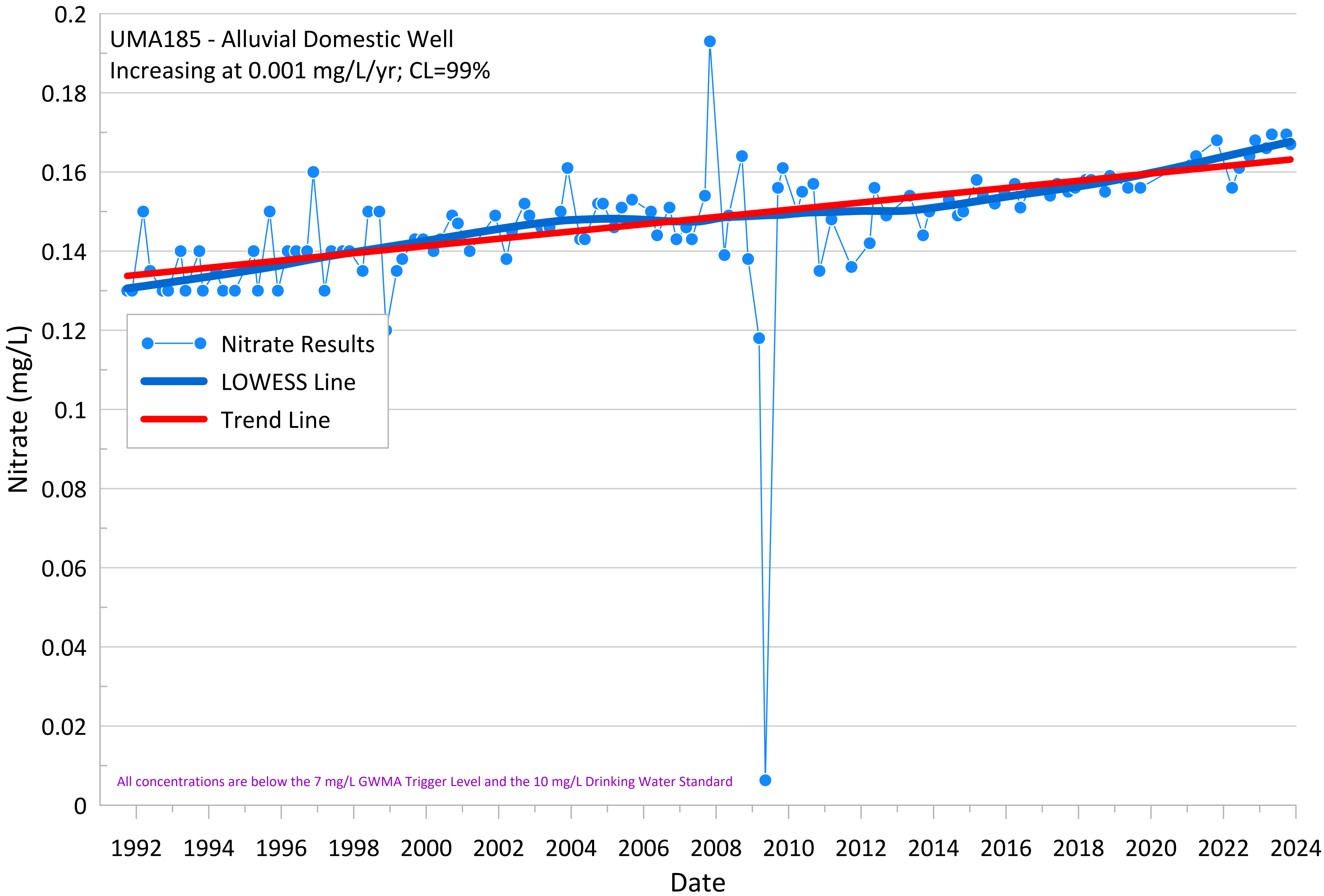
UMA160 - Alluvial Irrigation Well
Increasing at 0.05 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Range of Possible Values
Vertical bars represent possible concentrations for results reported as non-detected.
12% of UMA160 results are reported as non-detected.
Break in scale from 0.02 to 0.03 mg/L illustrates non-detects.
LOWESS calculated using detection limits as results.
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0.02
0.01
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

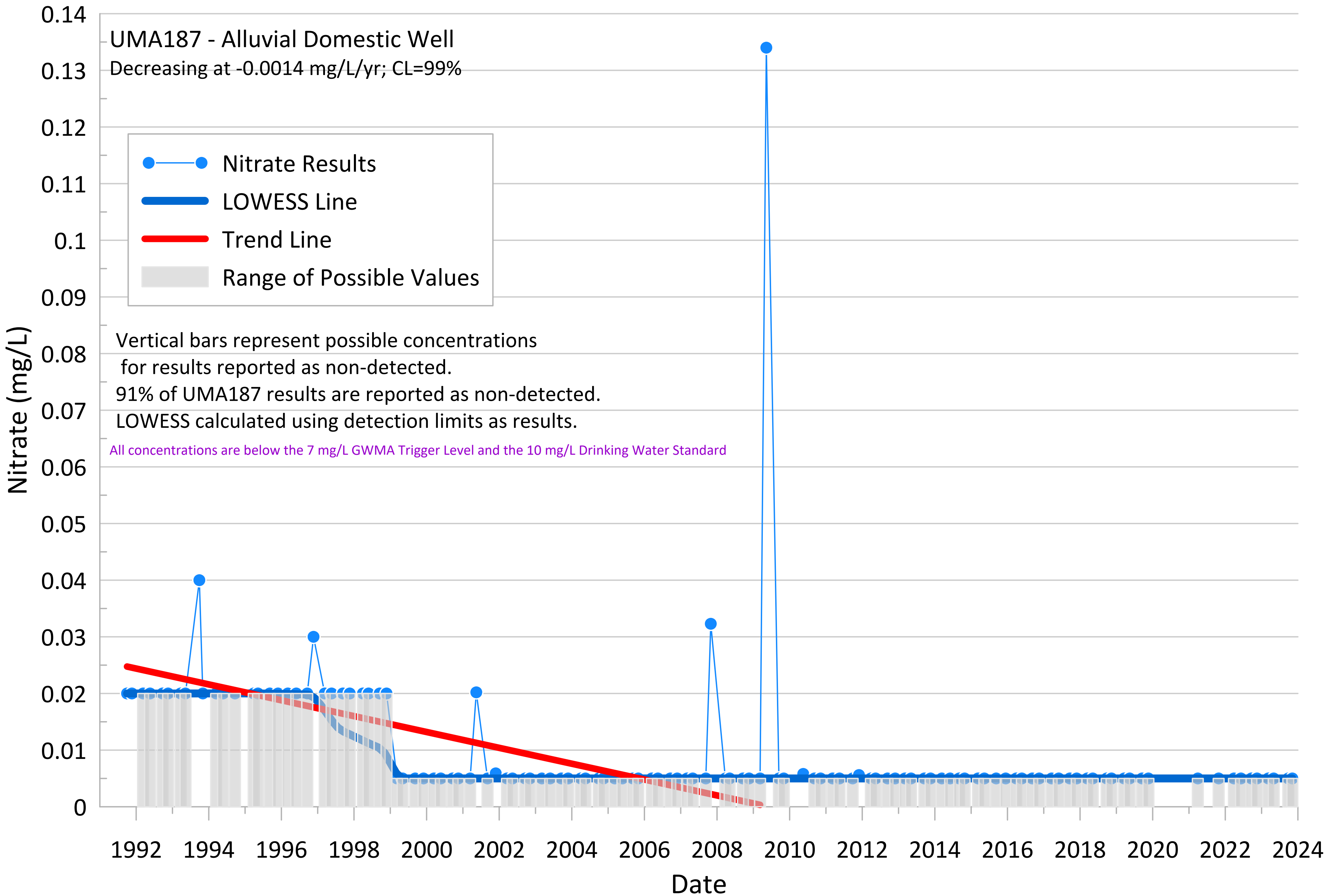


UMA164 - Basalt Domestic Well
Increasing at 0.10 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
This result reported as < 0.02 mg/L
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

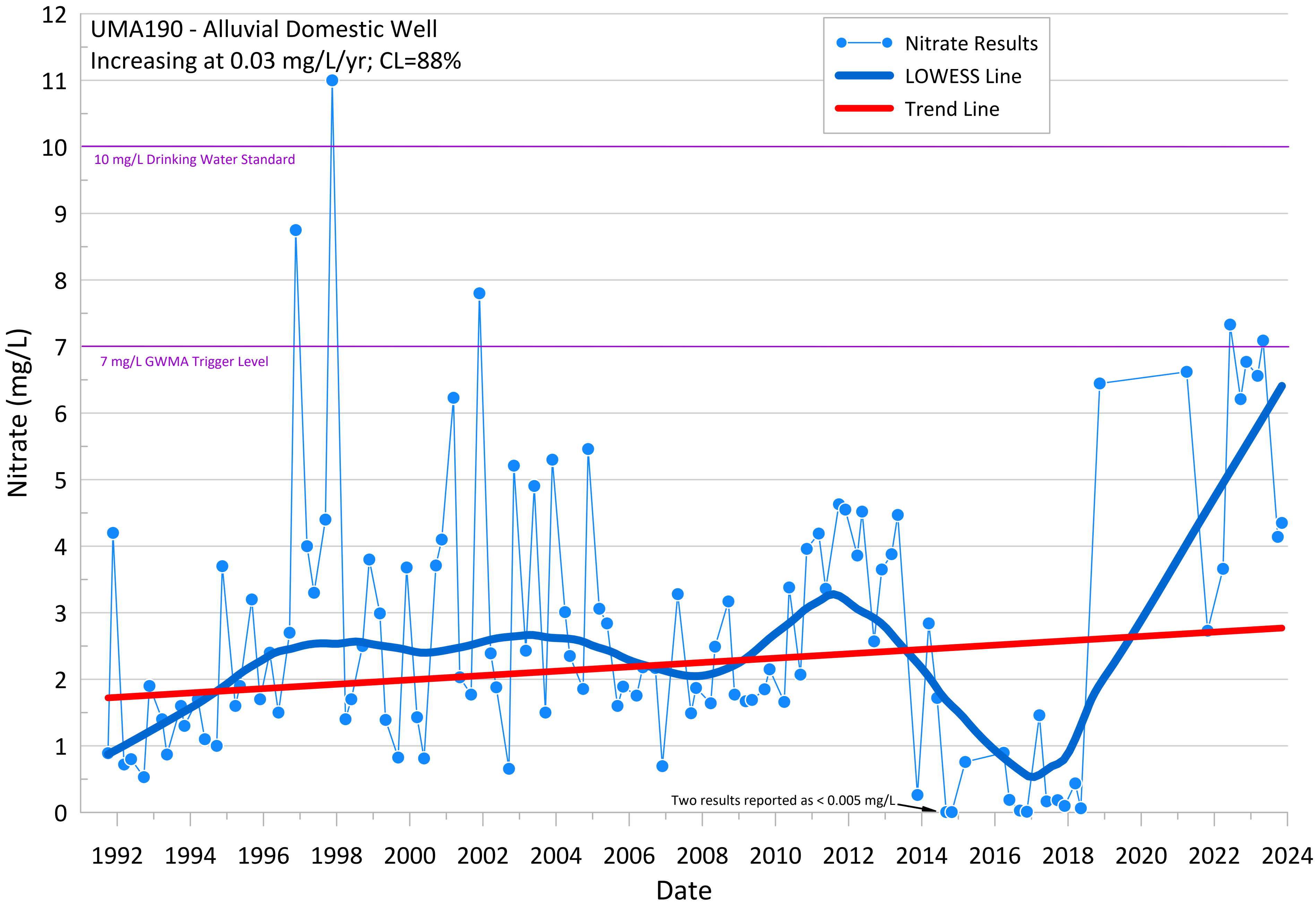

UMA168 - Alluvial Domestic Well
Decreasing at -0.11 mg/L/yr; CL=99%
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA180 - Alluvial Domestic Well
Increasing at 1.05 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Result reported as < 0.02 mg/L
Nitrate (mg/L)
Date
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

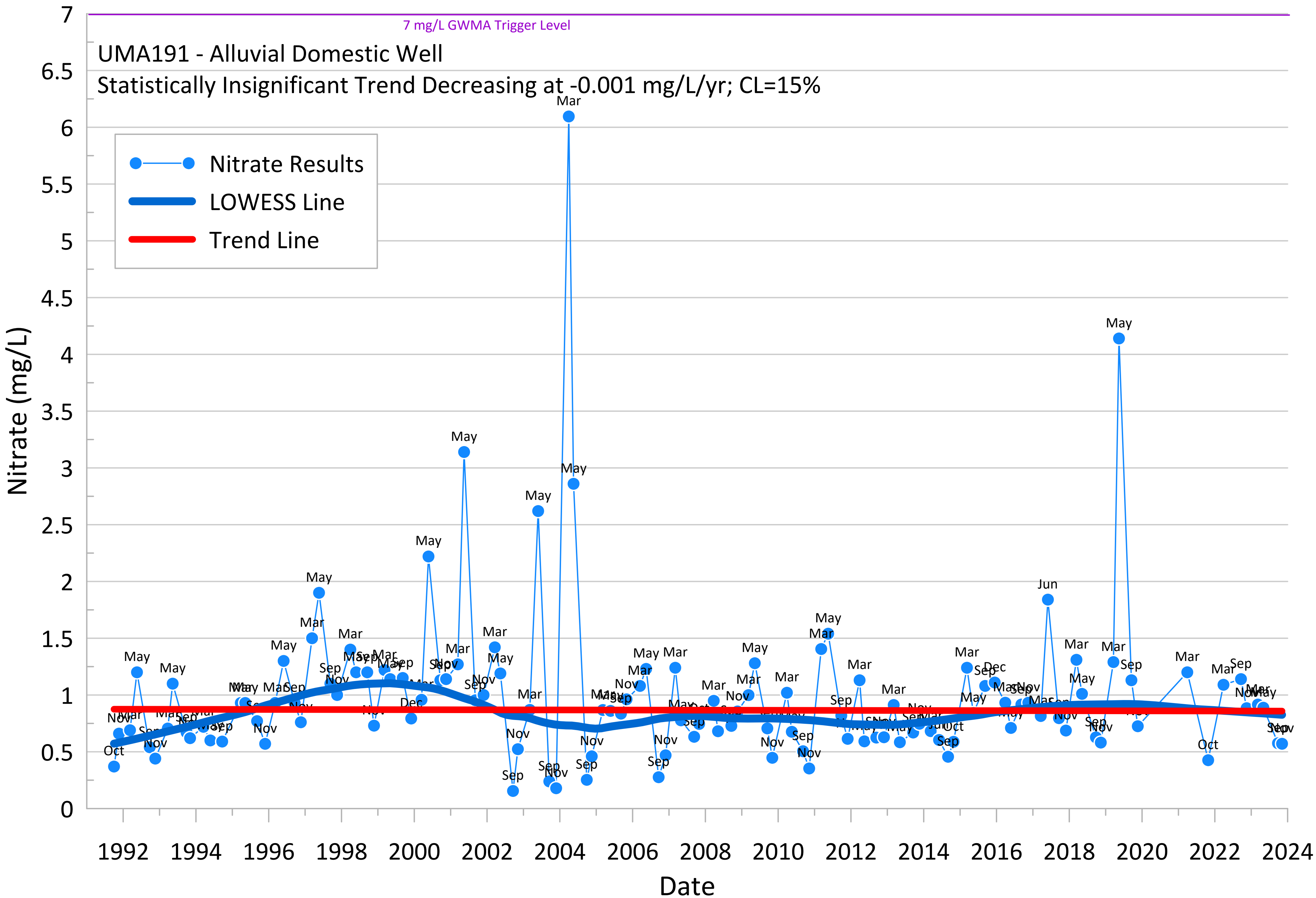

UMA185 - Alluvial Domestic Well
Increasing at 0.001 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

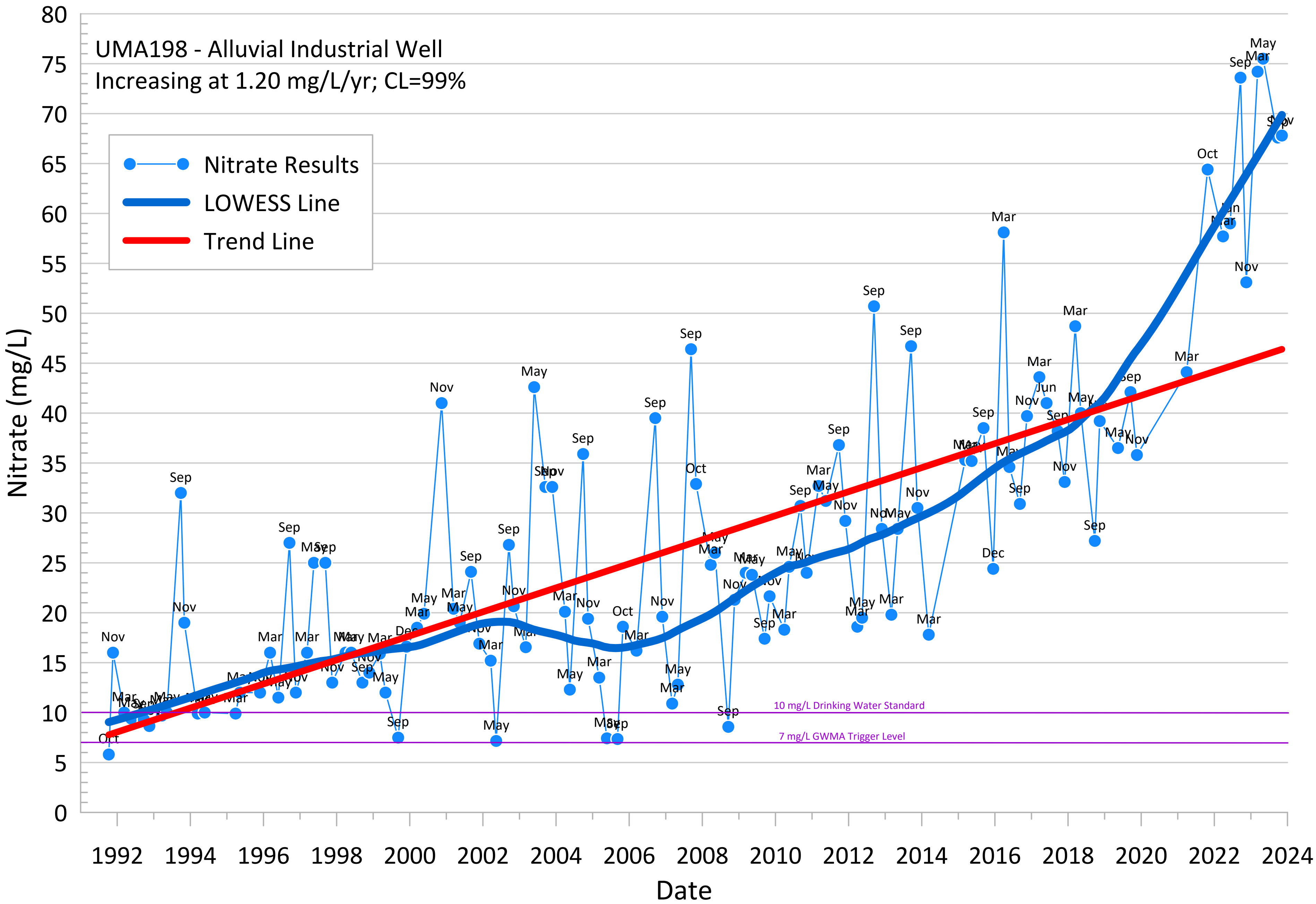


UMA187 - Alluvial Domestic Well
Decreasing at -0.0014 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Range of Possible Values
Vertical bars represent possible concentrations
for results reported as non-detected.
91% of UMA187 results are reported as non-detected.
LOWESS calculated using detection limits as results.
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

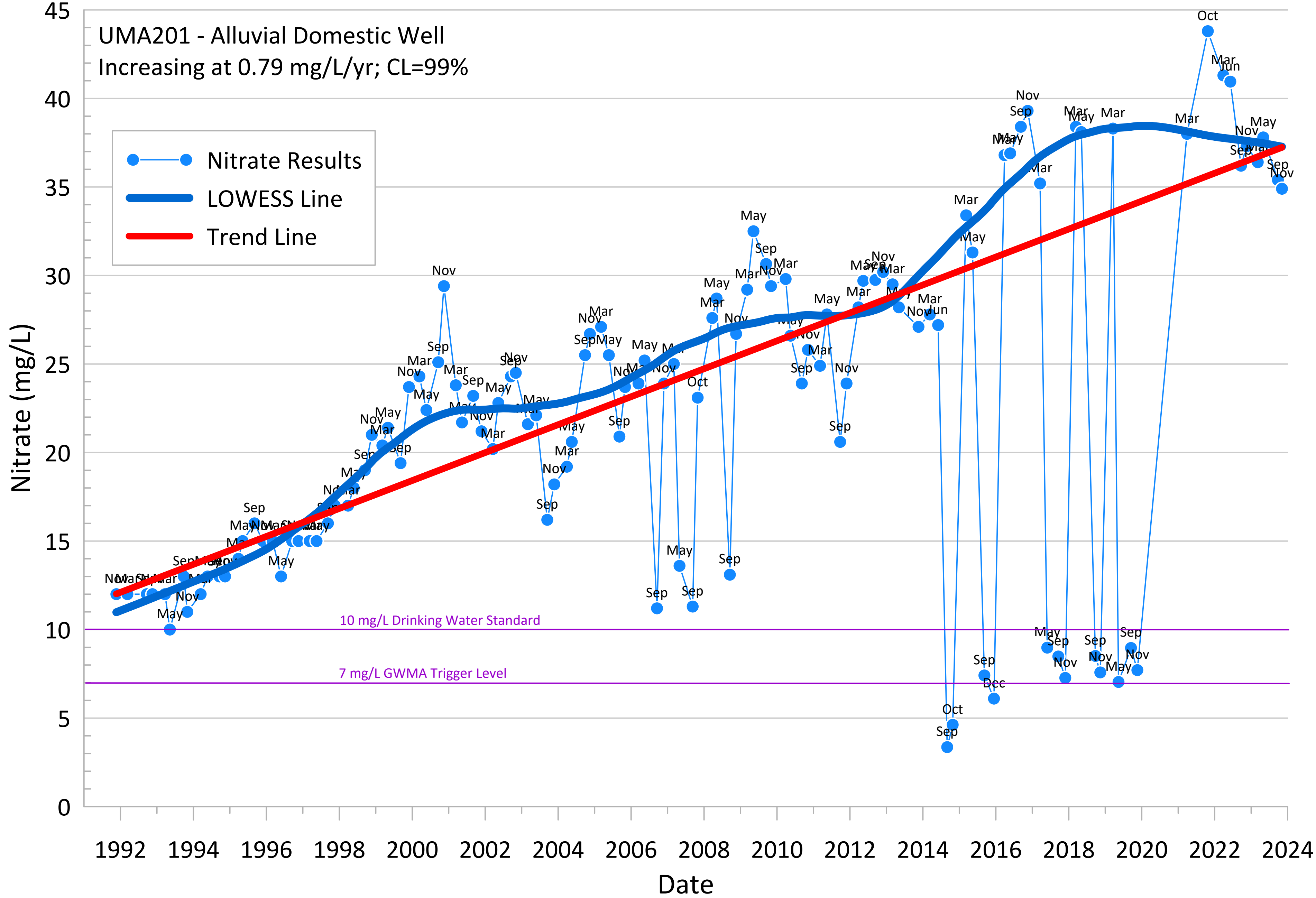


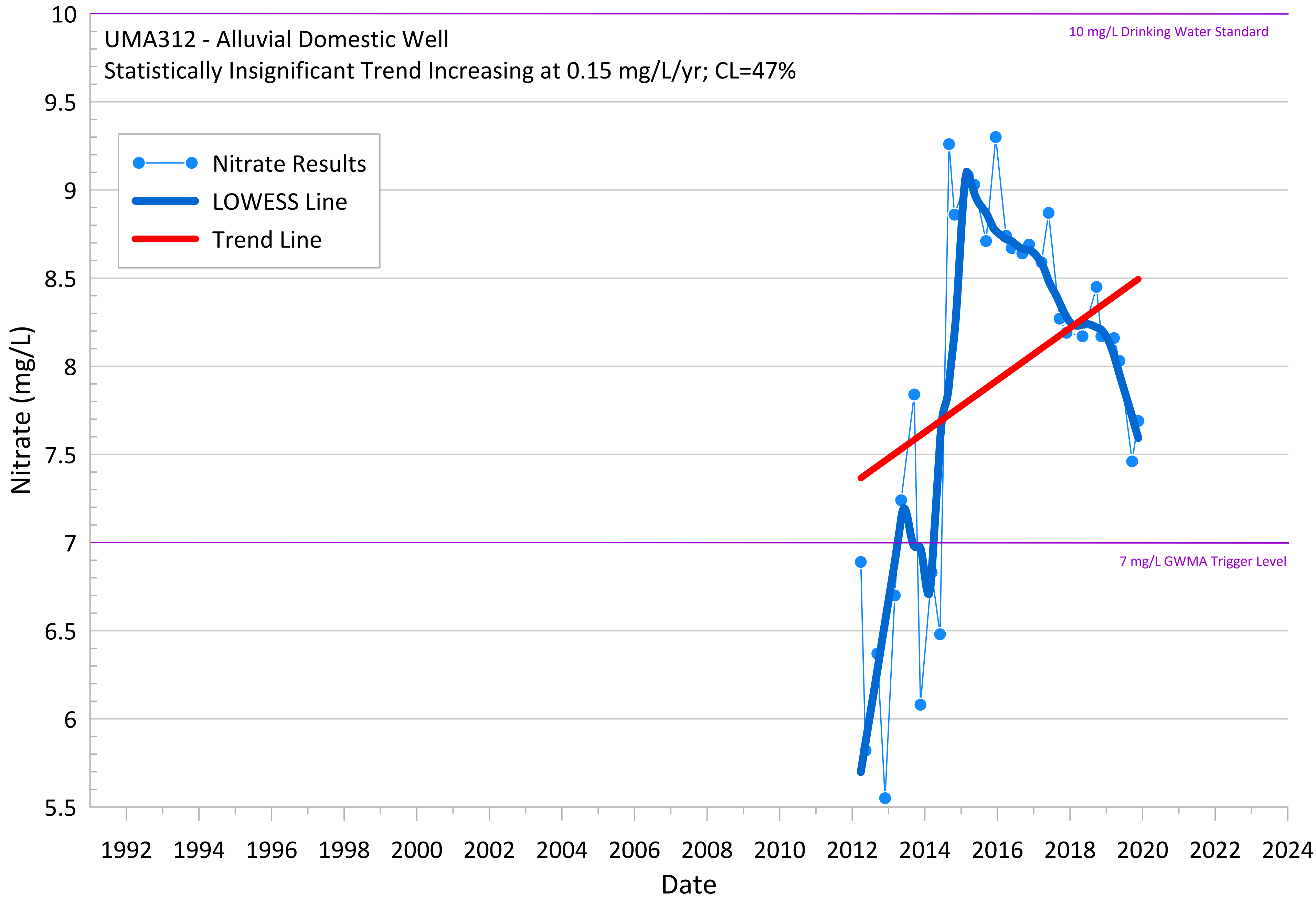
UMA190 - Alluvial Domestic Well
Increasing at 0.03 mg/L/yr; CL=88%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Two results reported as < 0.005 mg/L
Nitrate (mg/L)
Date
0
1
2
3
4
5
6
7
8
9
10
11
12
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


7 mg/L GWMA Trigger Level
UMA191 - Alluvial Domestic Well
Statistically Insignificant Trend Decreasing at -0.001 mg/L/yr; CL=15%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date

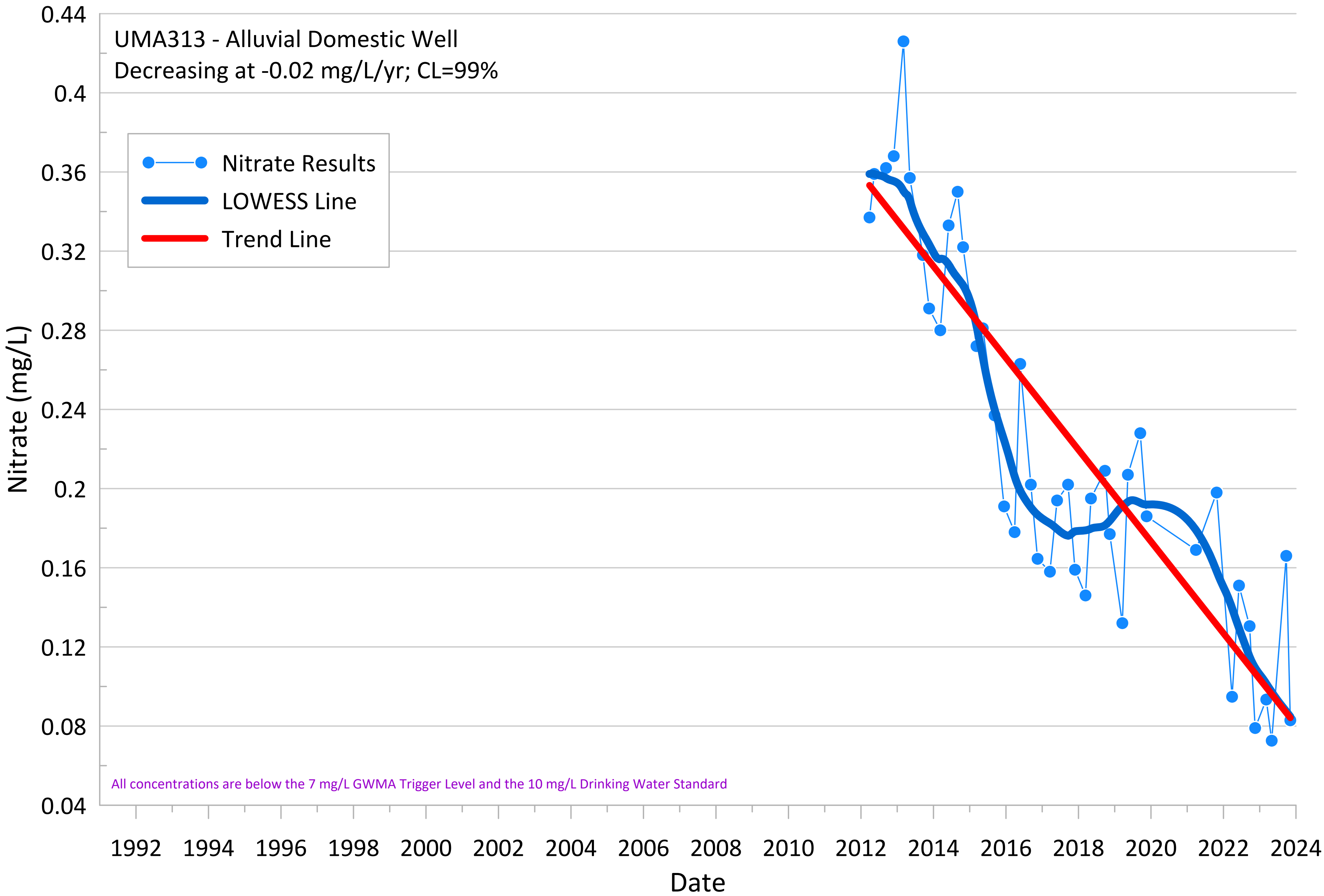


UMA198 - Alluvial Industrial Well
Increasing at 1.20 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA201 - Alluvial Domestic Well
Increasing at 0.79 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
0
5
10
15
20
25
30
35
40
45
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



UMA312 - Alluvial Domestic Well
Statistically Insignificant Trend Increasing at 0.15 mg/L/yr; CL=47%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

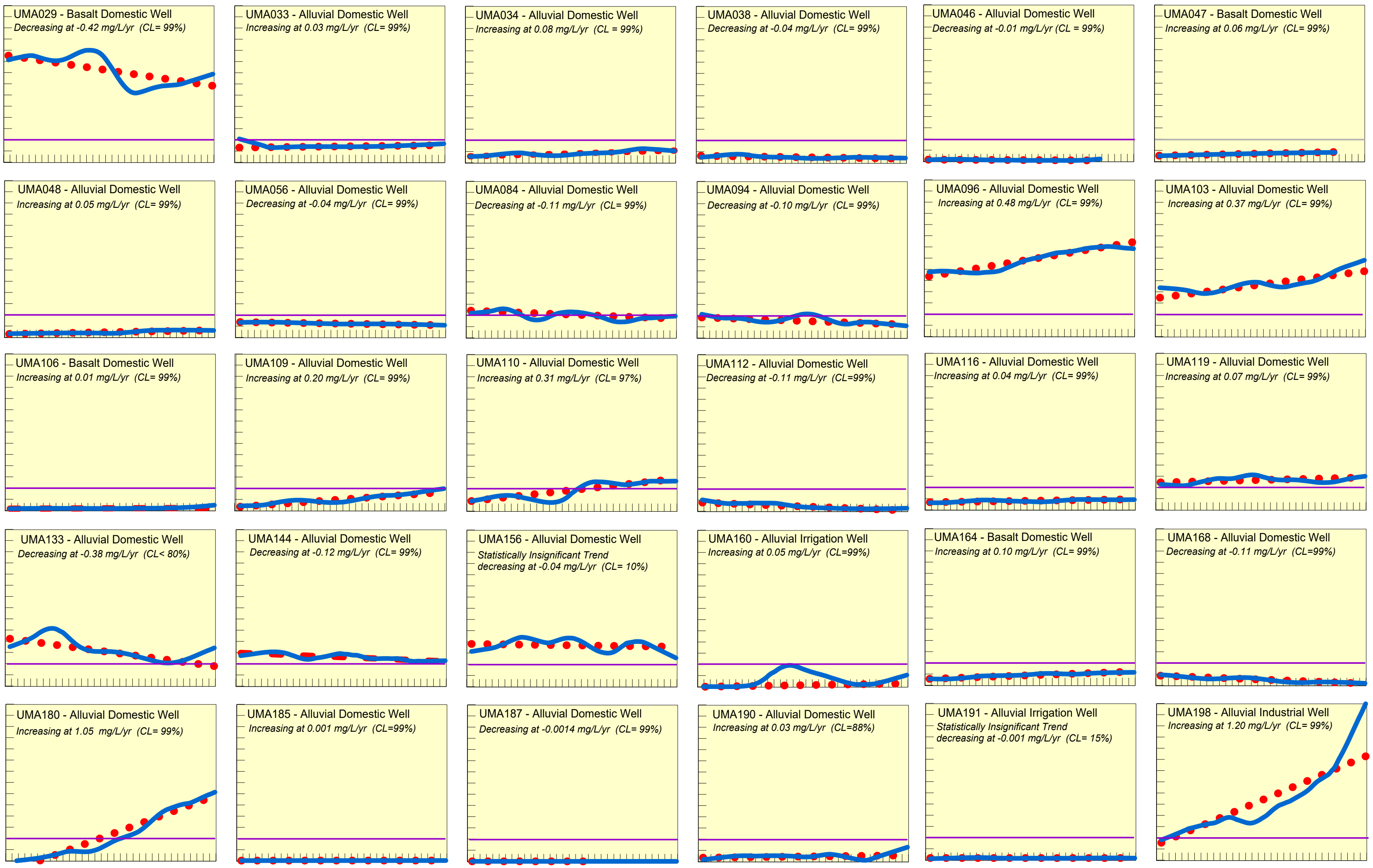


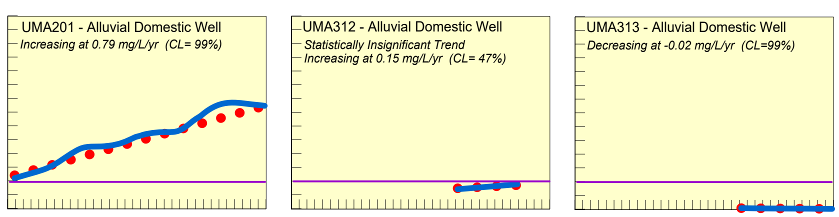
UMA313 - Alluvial Domestic Well
Decreasing at -0.02 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
0.44
0.4
0.36
0.32
0.28
0.24
0.2
0.16
0.12
0.08
0.04
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

Appendix D

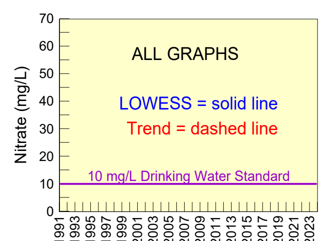
Nitrate Concentration Graphs

LOWESS Lines and Seasonal Kendall Trend Lines - LUBGWMA Network Wells

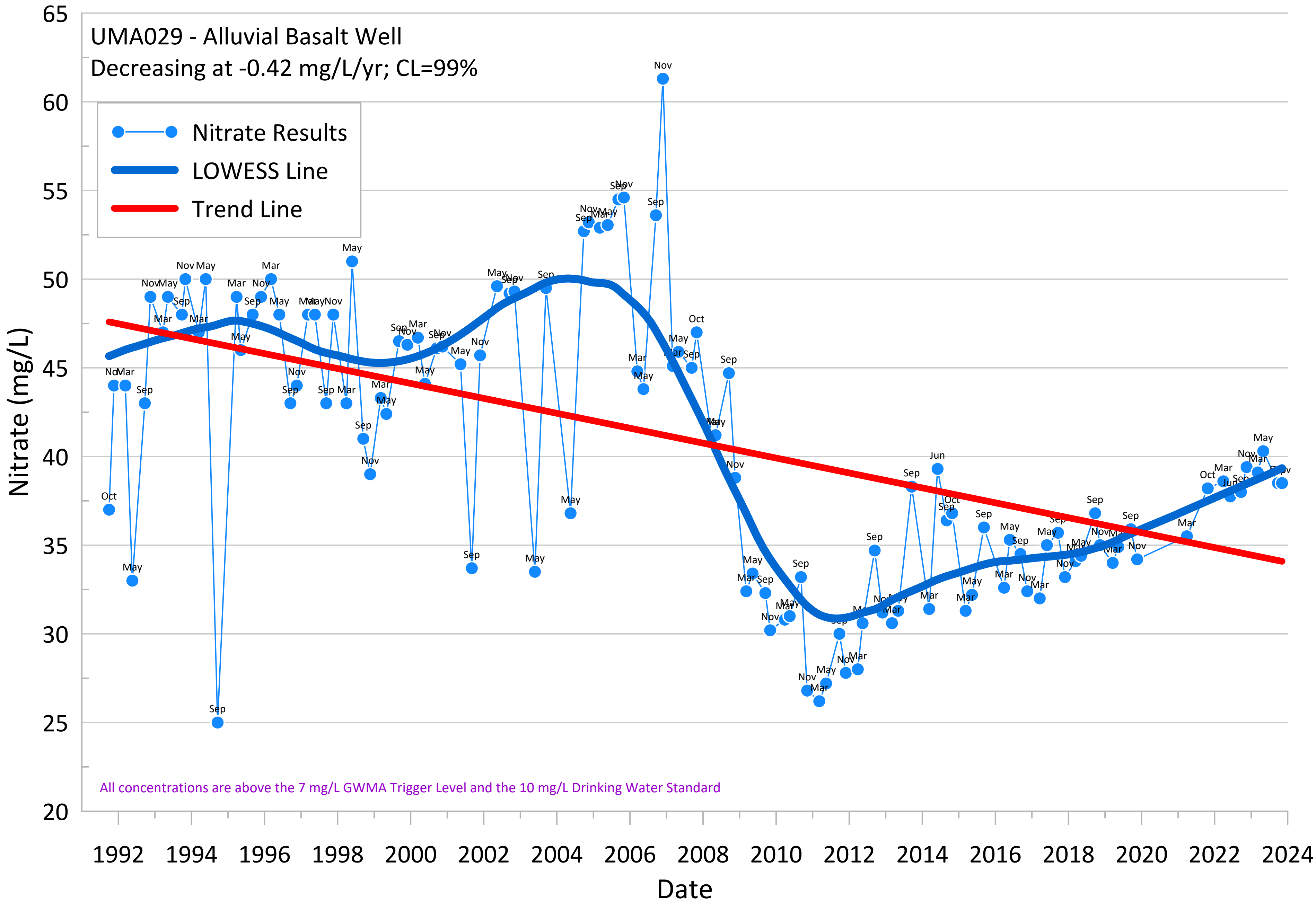


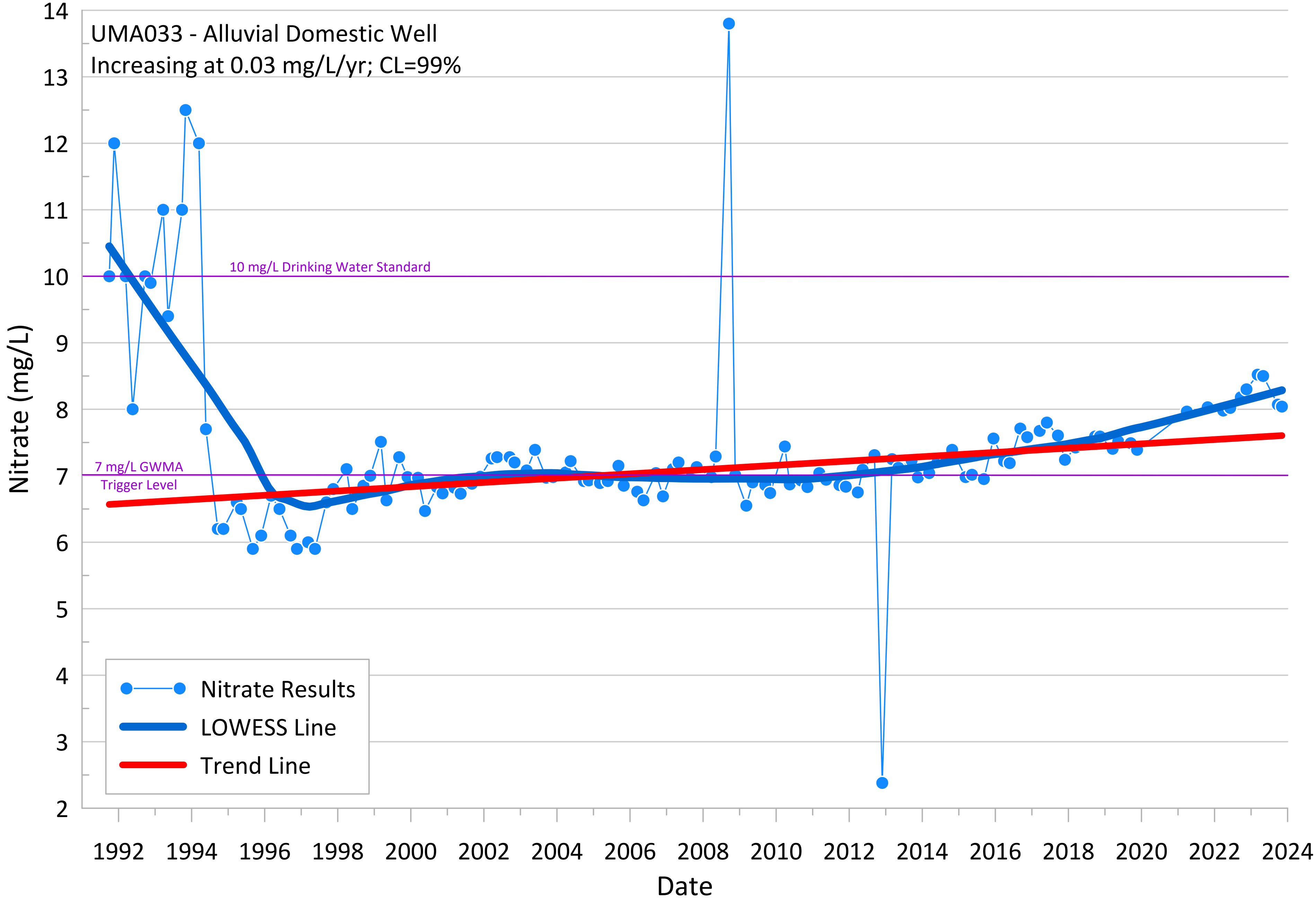


This figure shows LOWESS lines and trend lines for all network wells at the same scale. Nitrate results are included on each individual well's nitrate concentration graph at a scale that illustrates concentrations at the well.

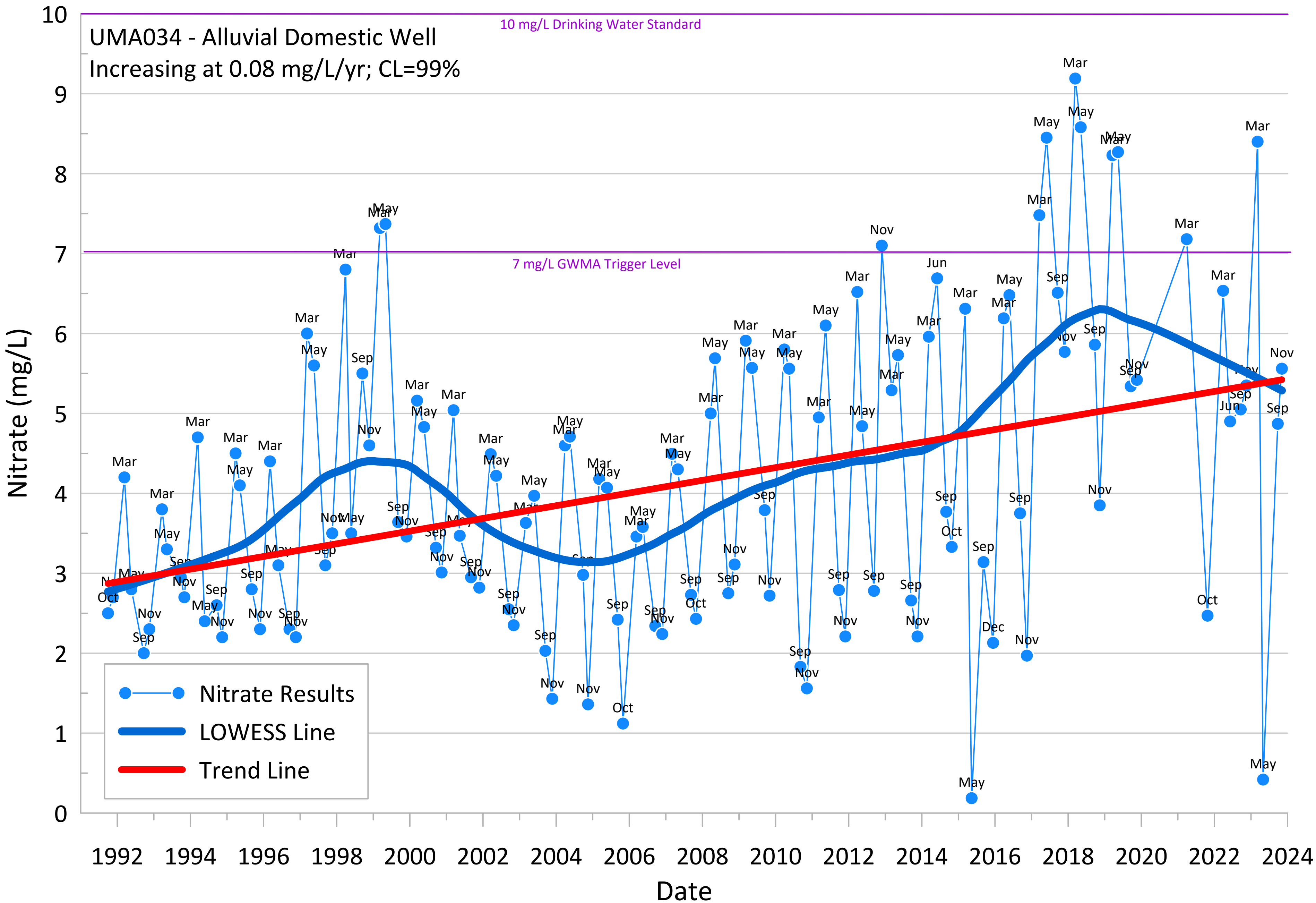


E:\lub\2024 Trend Analysis\network\report\appendices\time series plots\AllTrends&Lowess.gpj

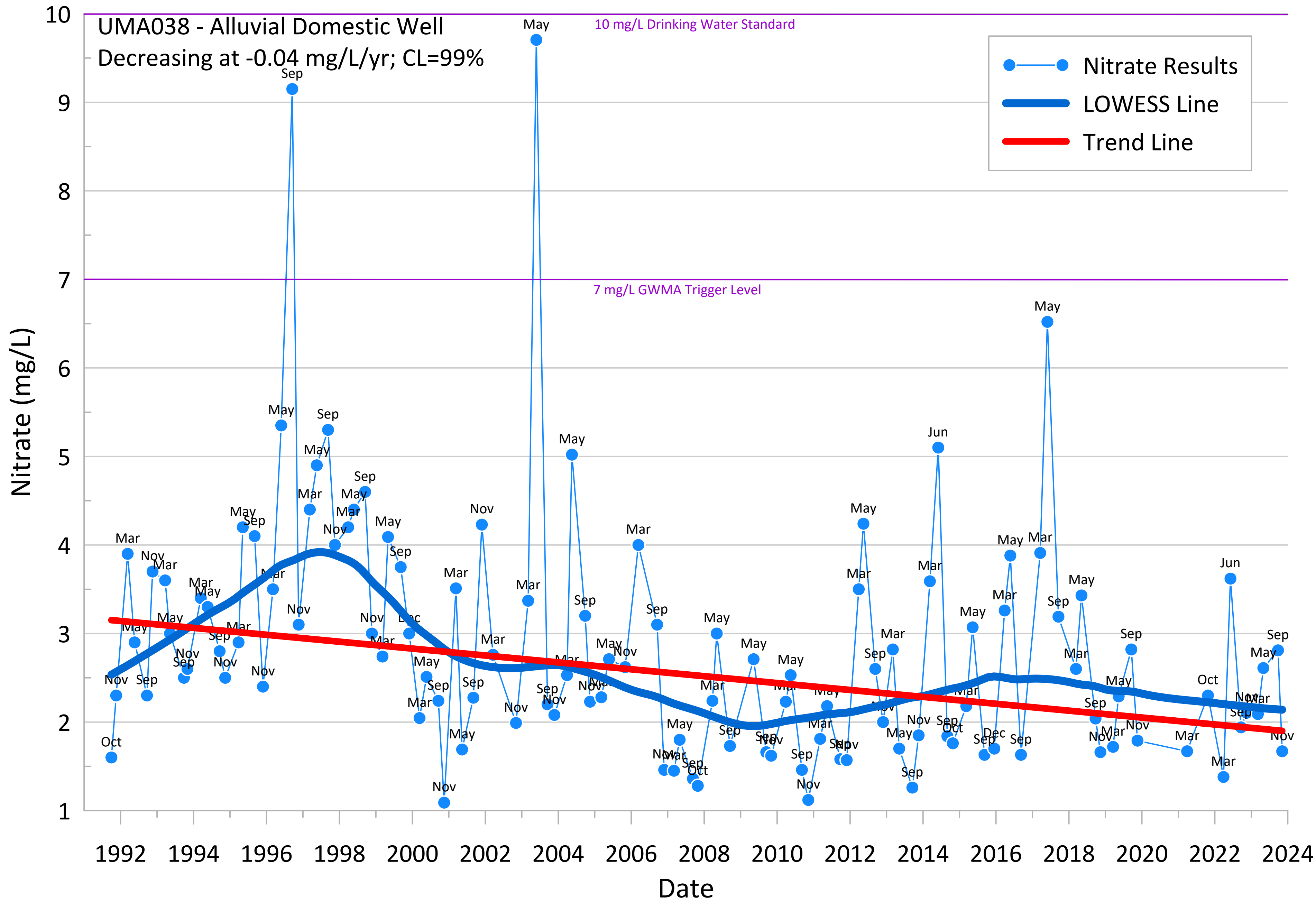

UMA029 - Alluvial Basalt Well
Decreasing at -0.42 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
All concentrations are above the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard



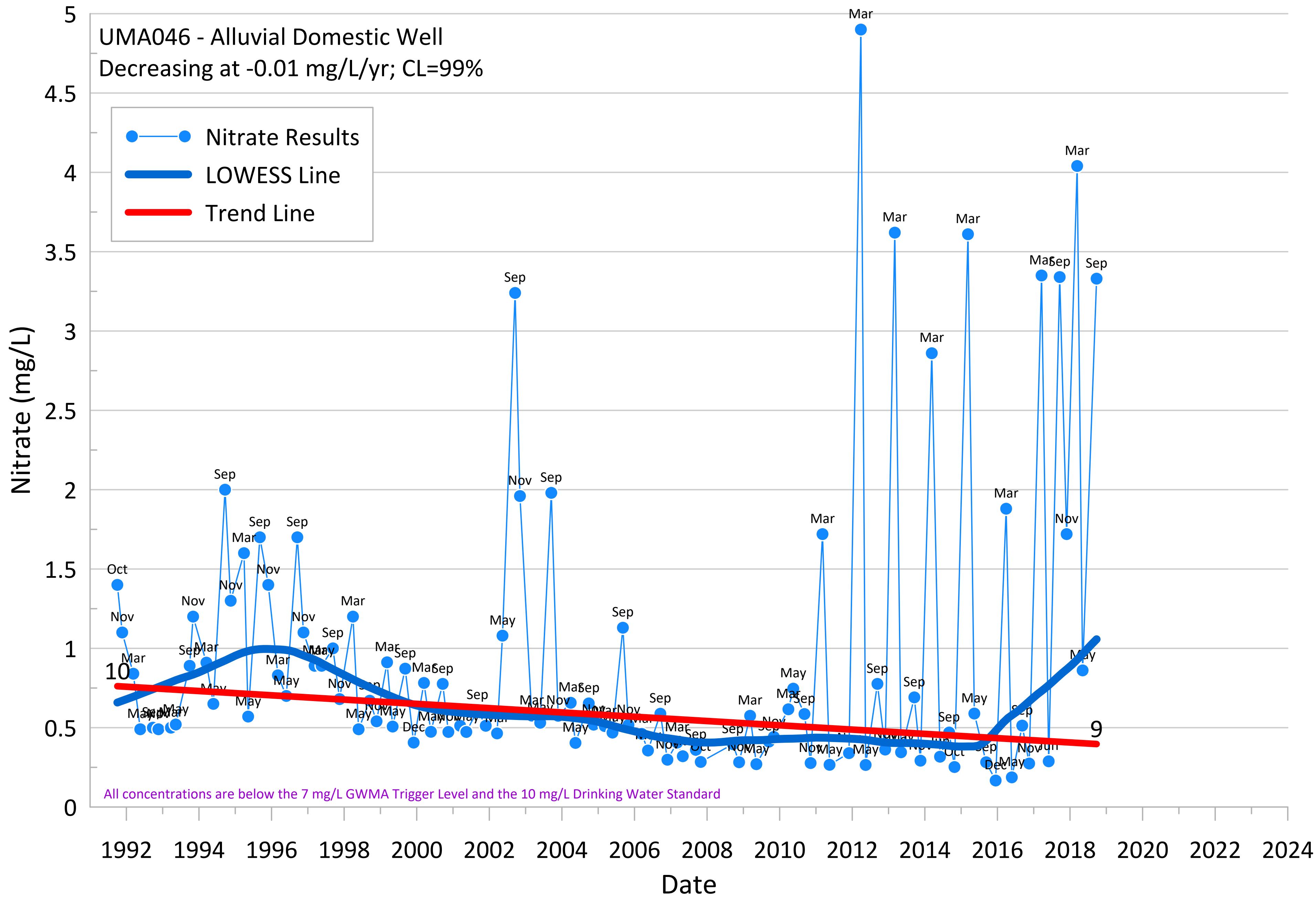
UMA033 - Alluvial Domestic Well
Increasing at 0.03 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA
Trigger Level
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
14
13
12
11
10
9
8
7
6
5
4
3
2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



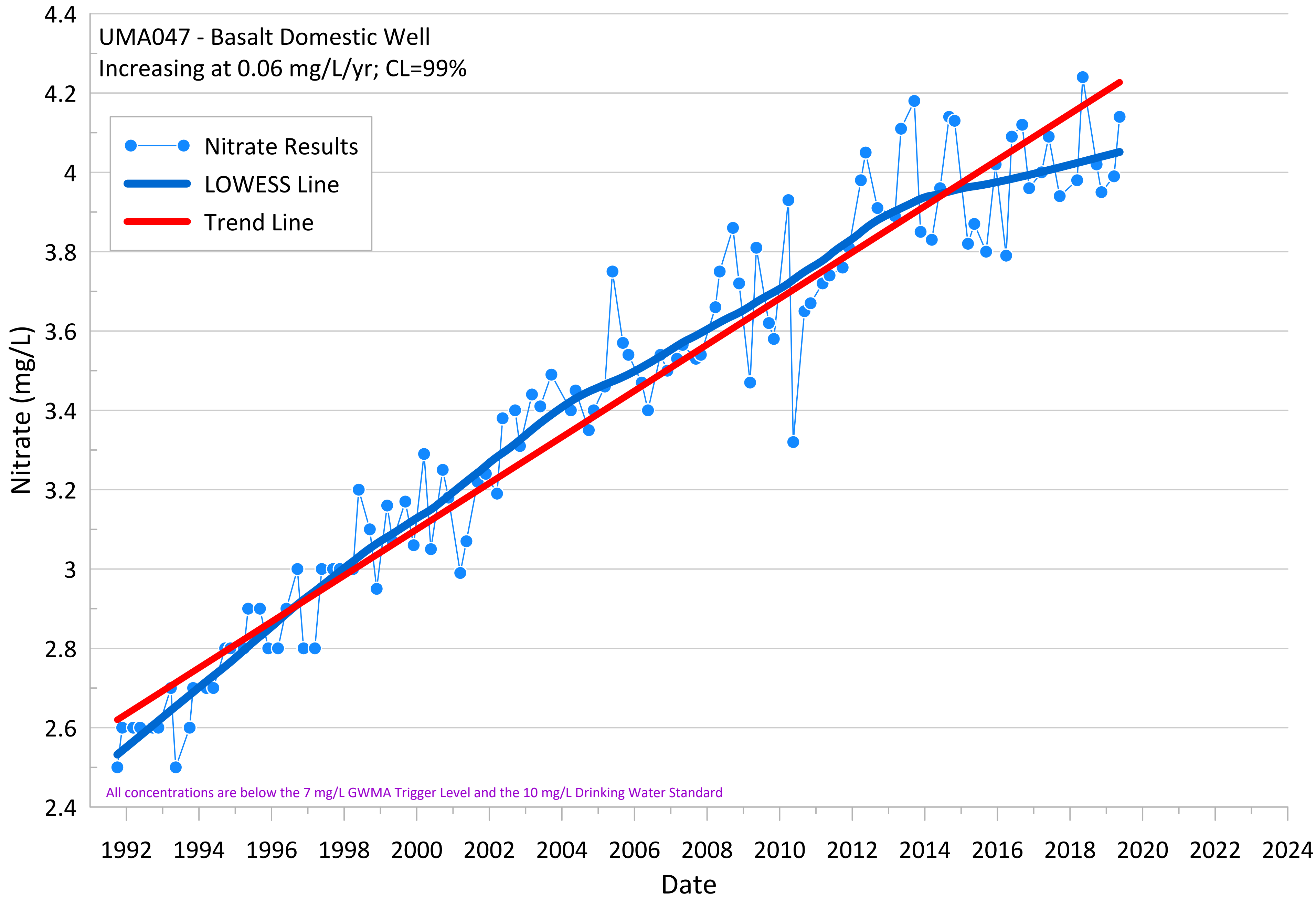
UMA034 - Alluvial Domestic Well
Increasing at 0.08 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
0
1
2
3
4
5
6
7
8
9
10
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



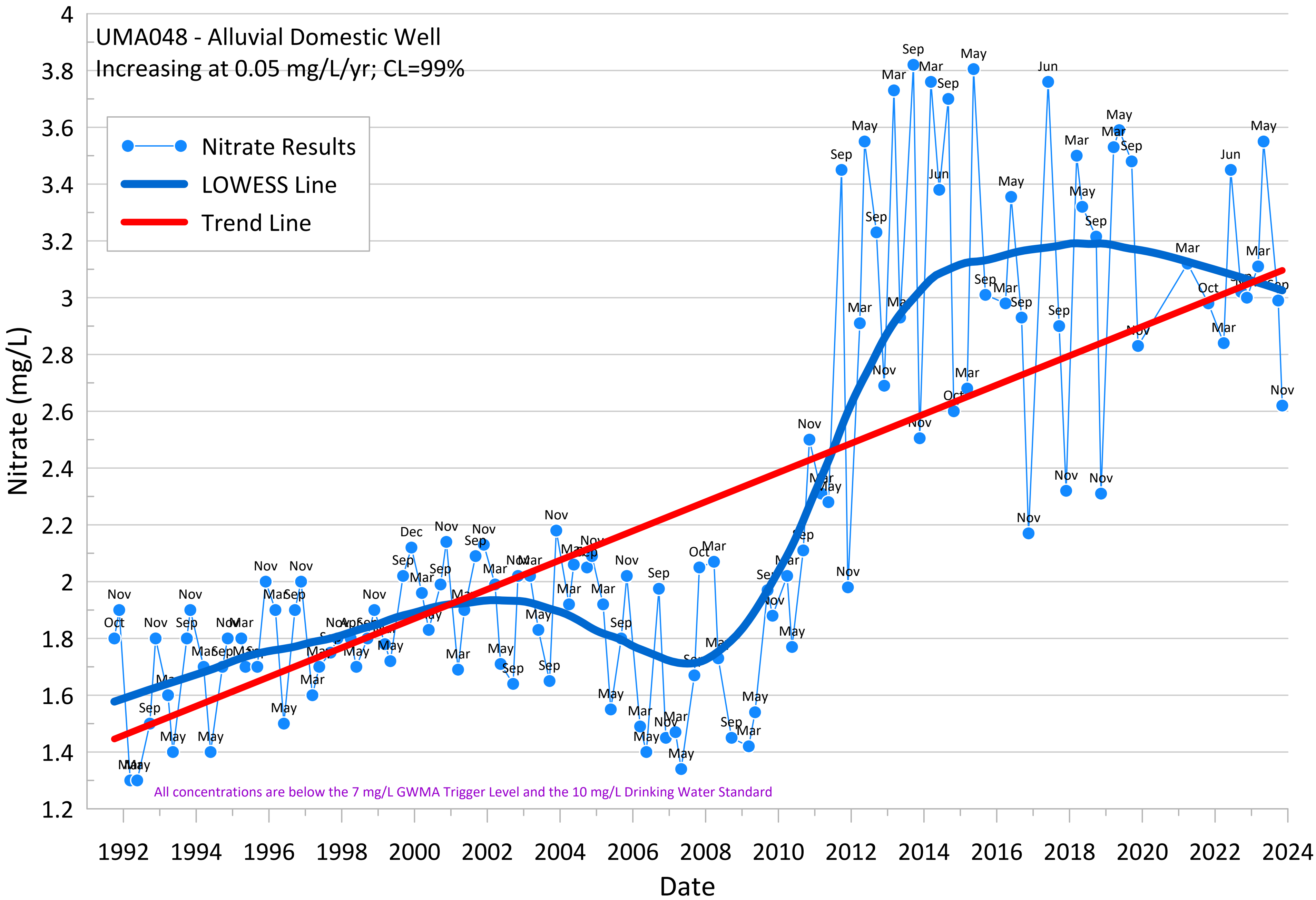
UMA038 - Alluvial Domestic Well
Decreasing at -0.04 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date



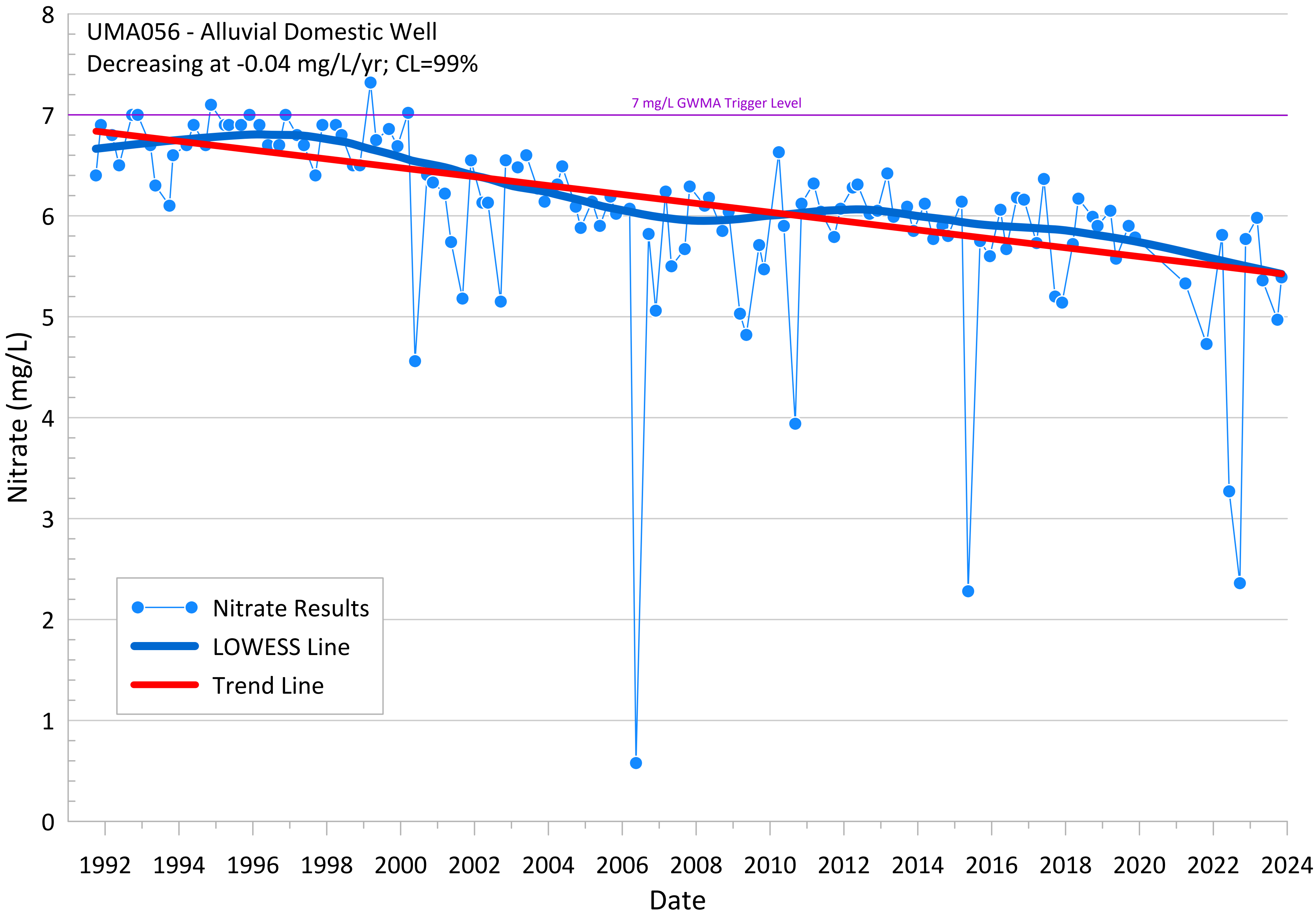
UMA046 - Alluvial Domestic Well
Decreasing at -0.01 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard



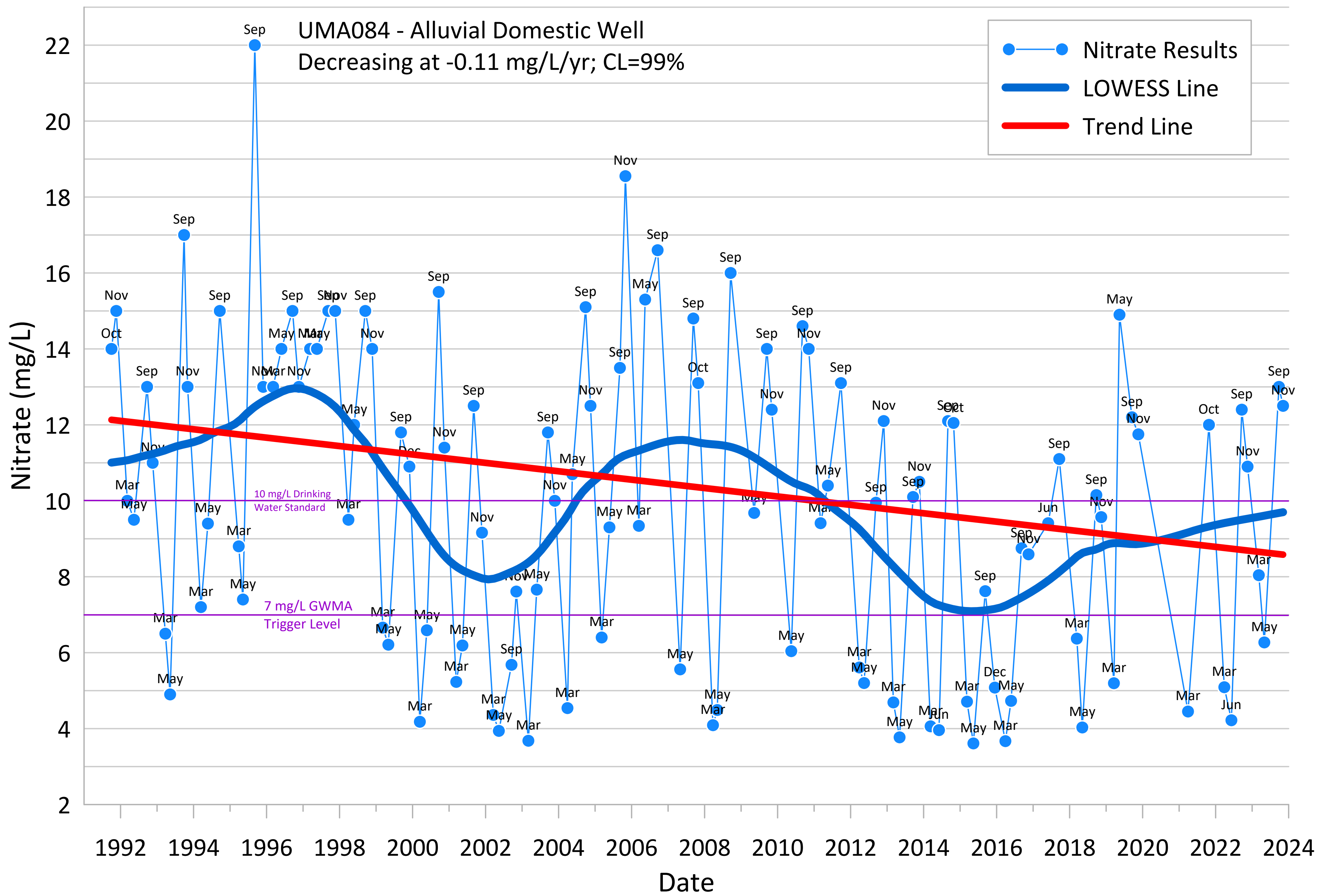
UMA047 - Basalt Domestic Well
Increasing at 0.06 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

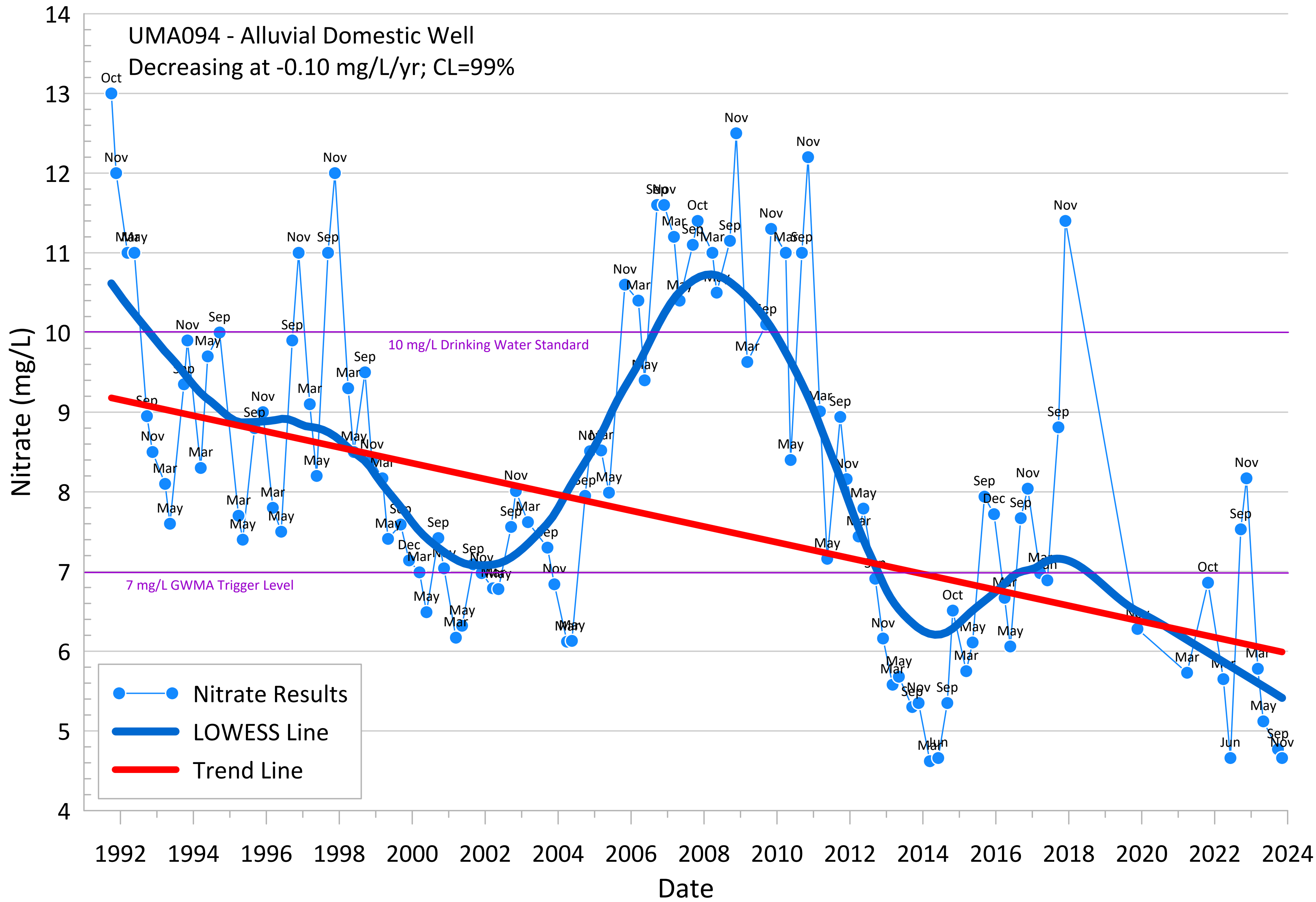


UMA048 - Alluvial Domestic Well
Increasing at 0.05 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date

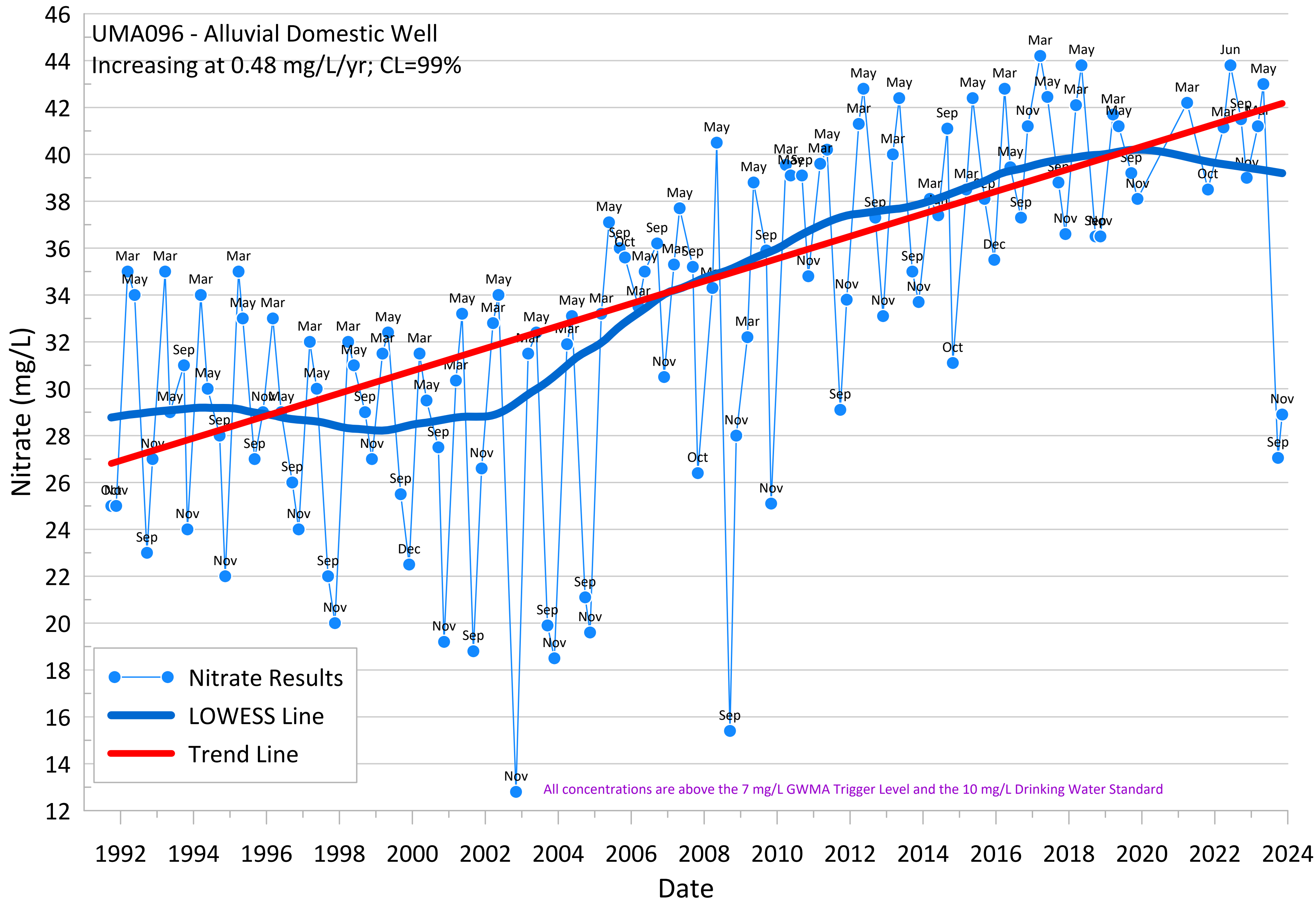


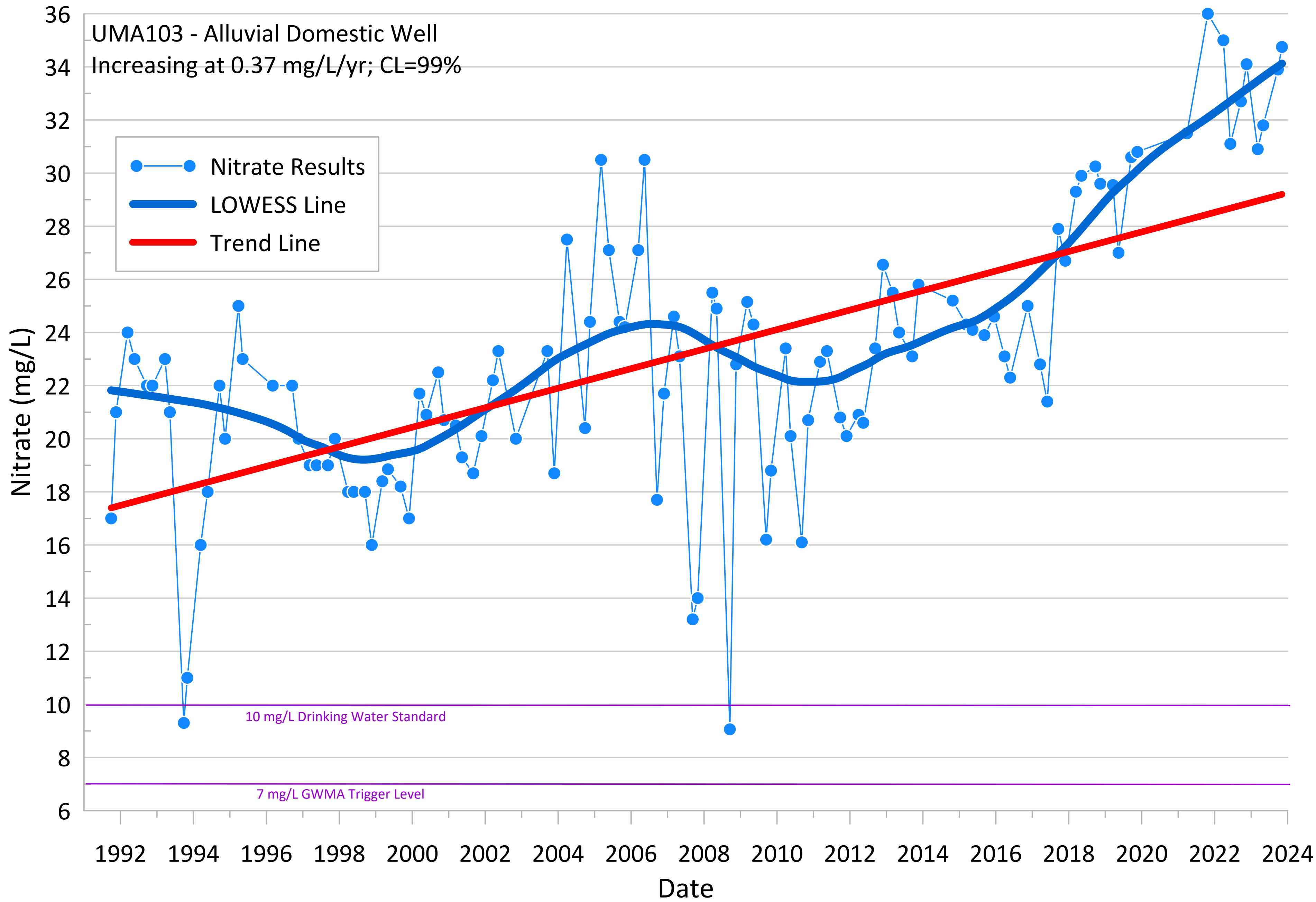
UMA056 - Alluvial Domestic Well
Decreasing at -0.04 mg/L/yr; CL=99%
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
0
1
2
3
4
5
6
7
8
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

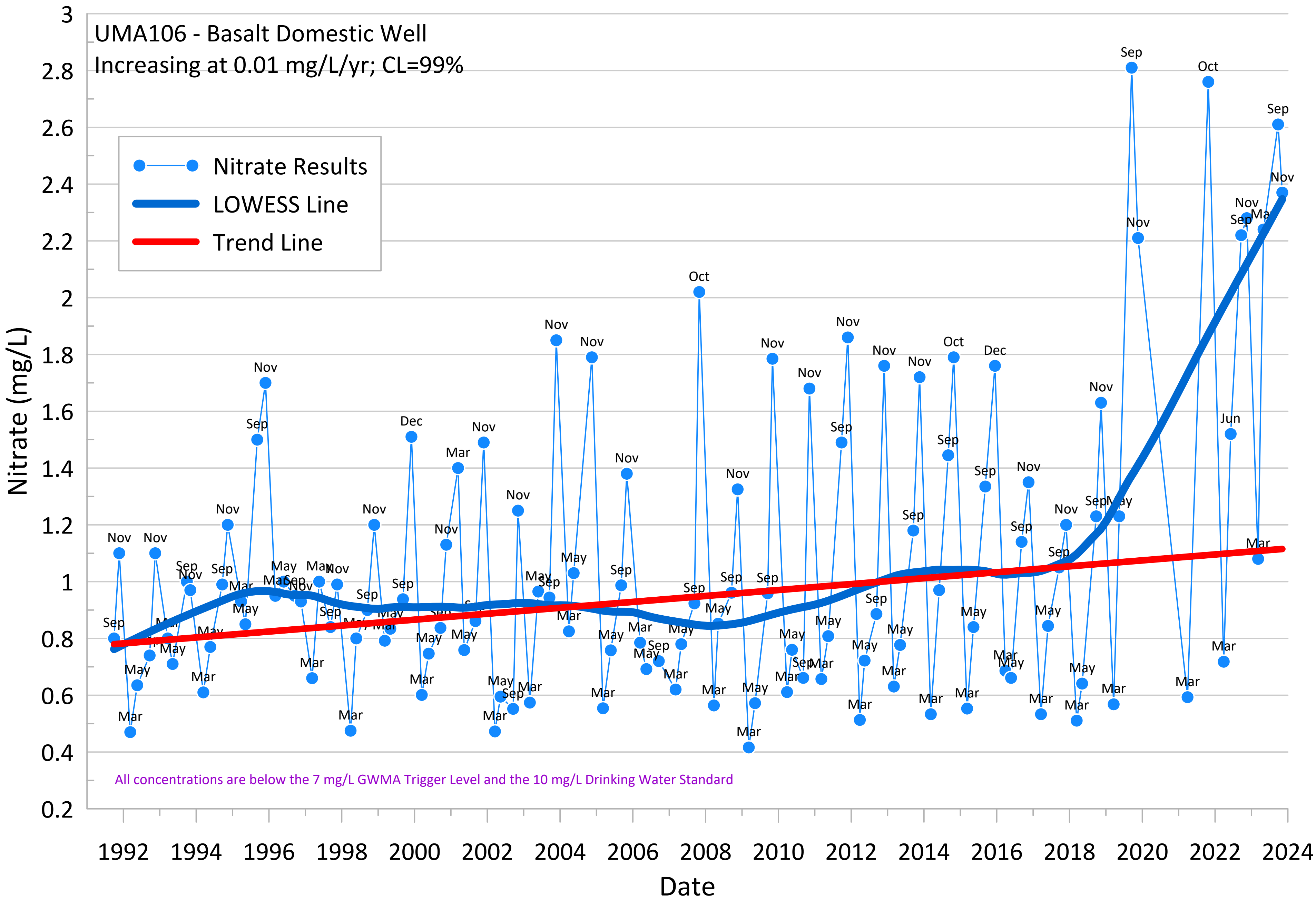

UMA084 - Alluvial Domestic Well
Decreasing at -0.11 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
22
20
18
16
14
12
10
8
6
4
2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

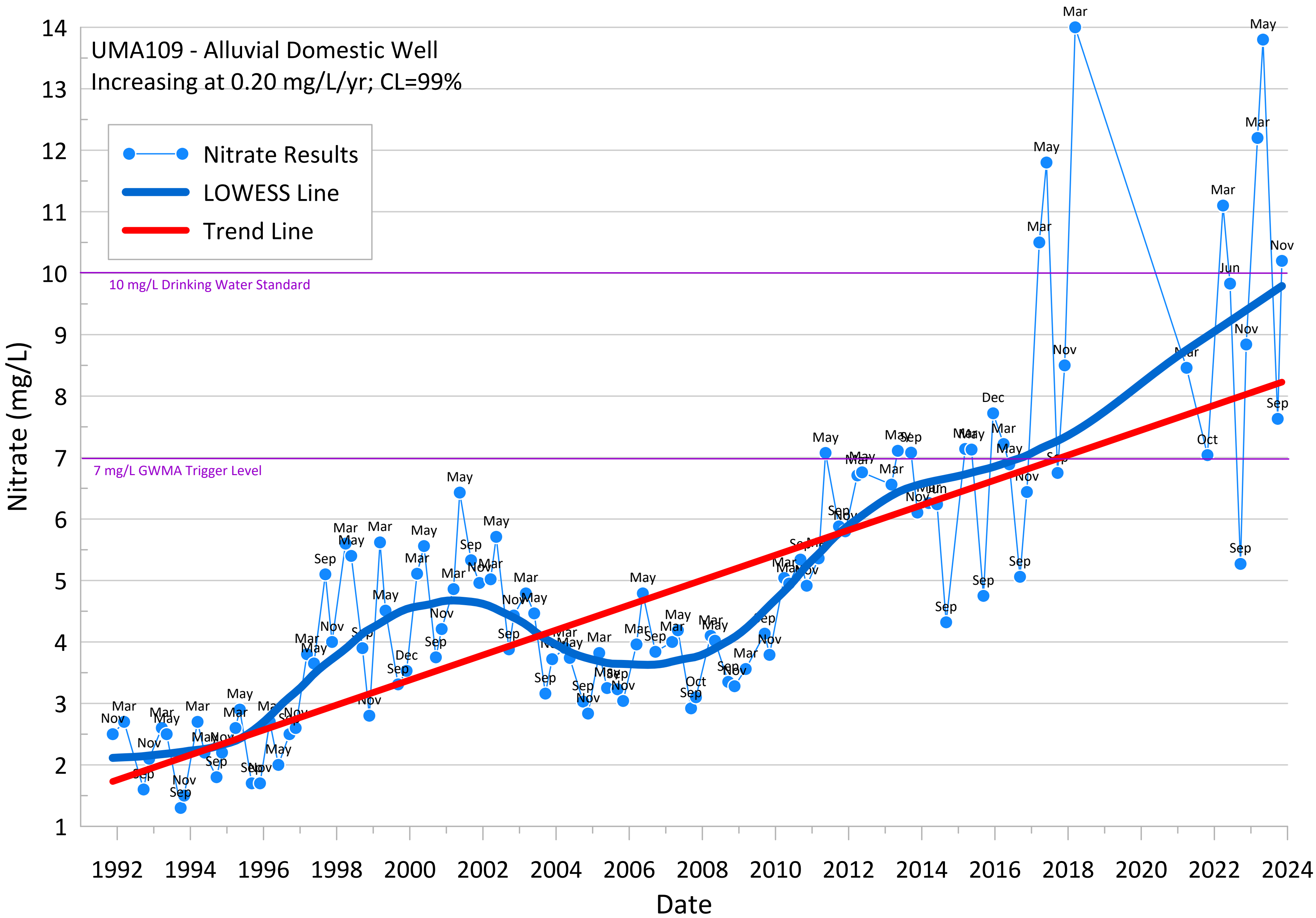


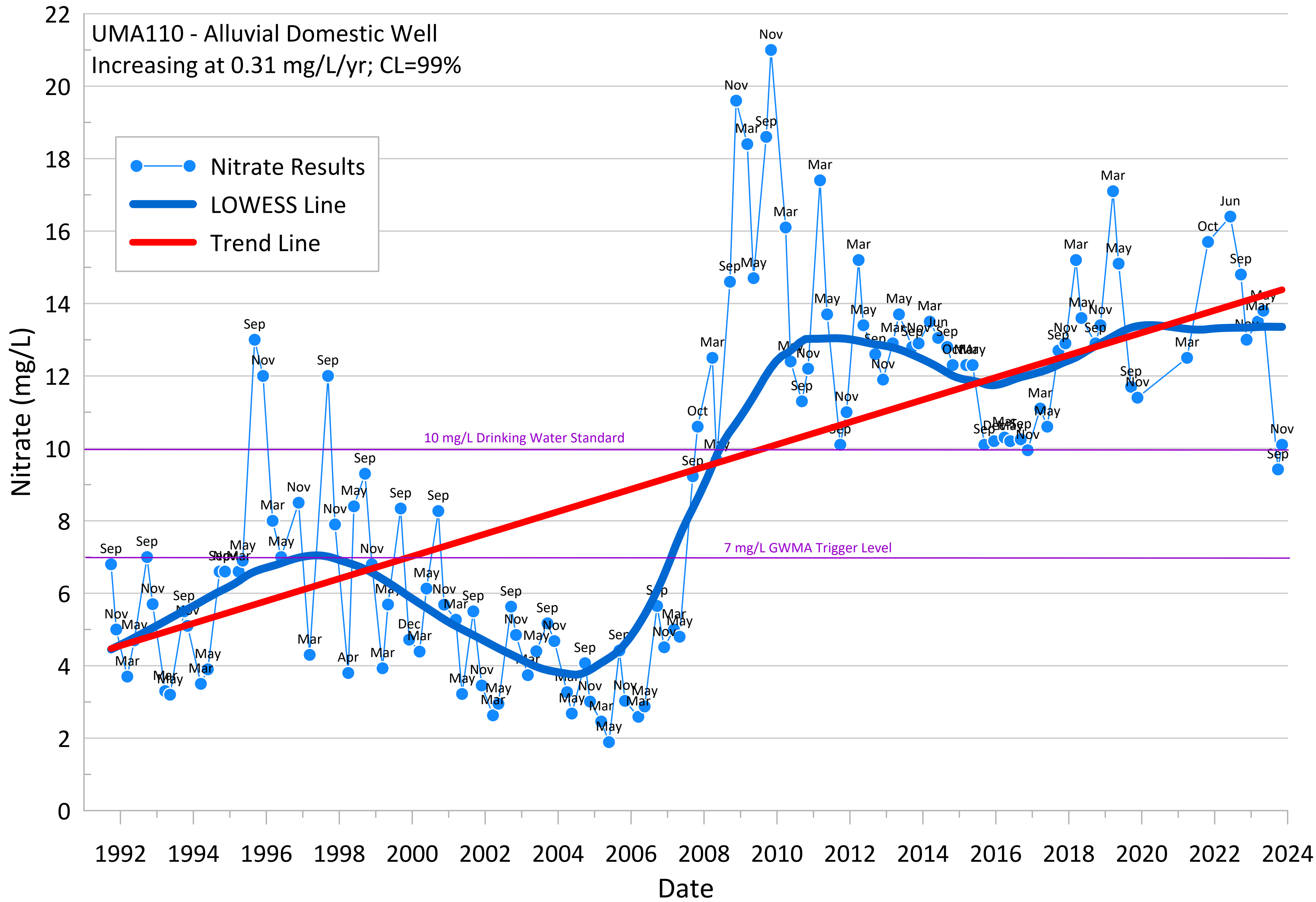
UMA094 - Alluvial Domestic Well
Decreasing at -0.10 mg/L/yr; CL=99%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line

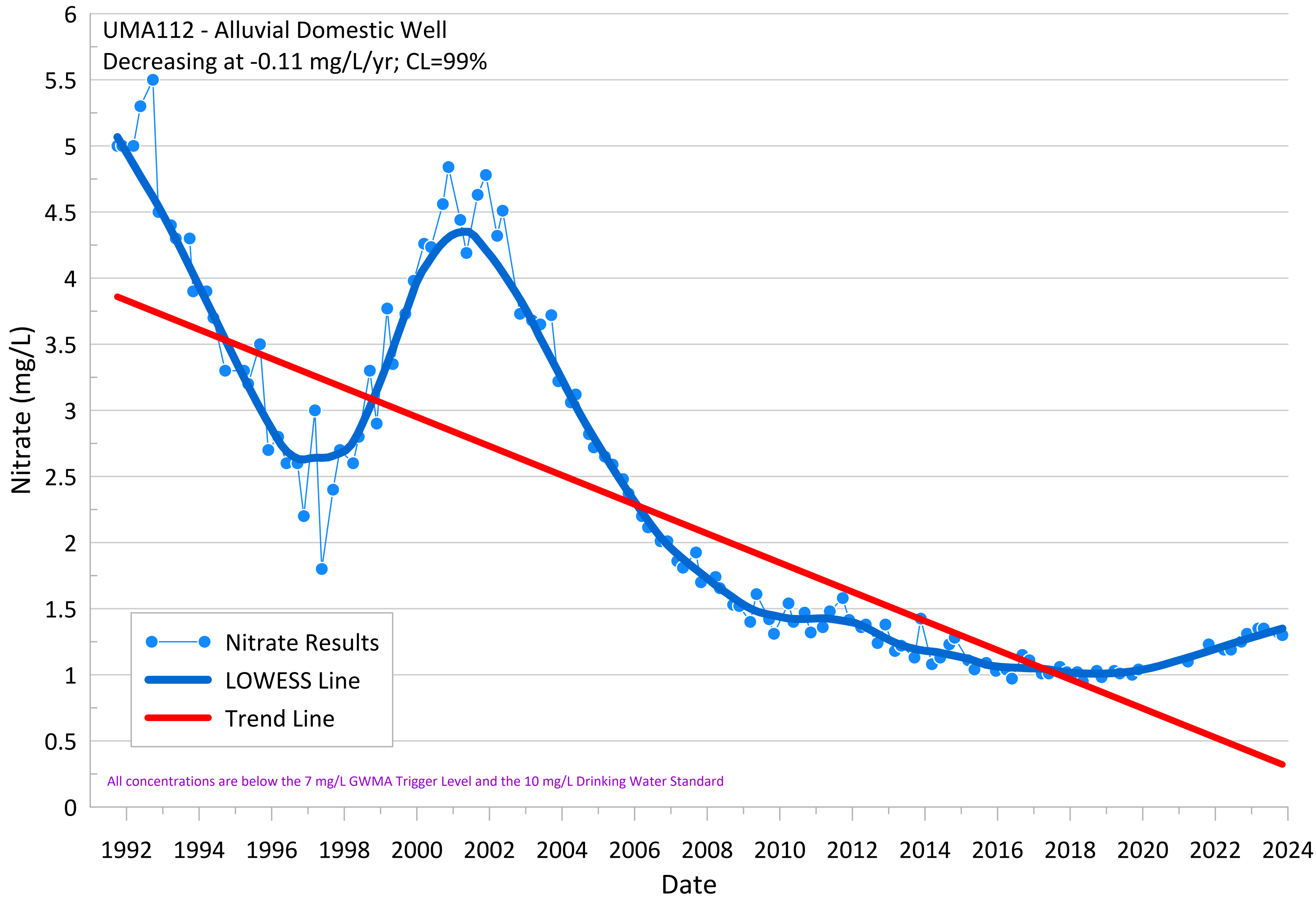

UMA096 - Alluvial Domestic Well
Increasing at 0.48 mg/L/yr; CL=99%
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
All concentrations are above the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard

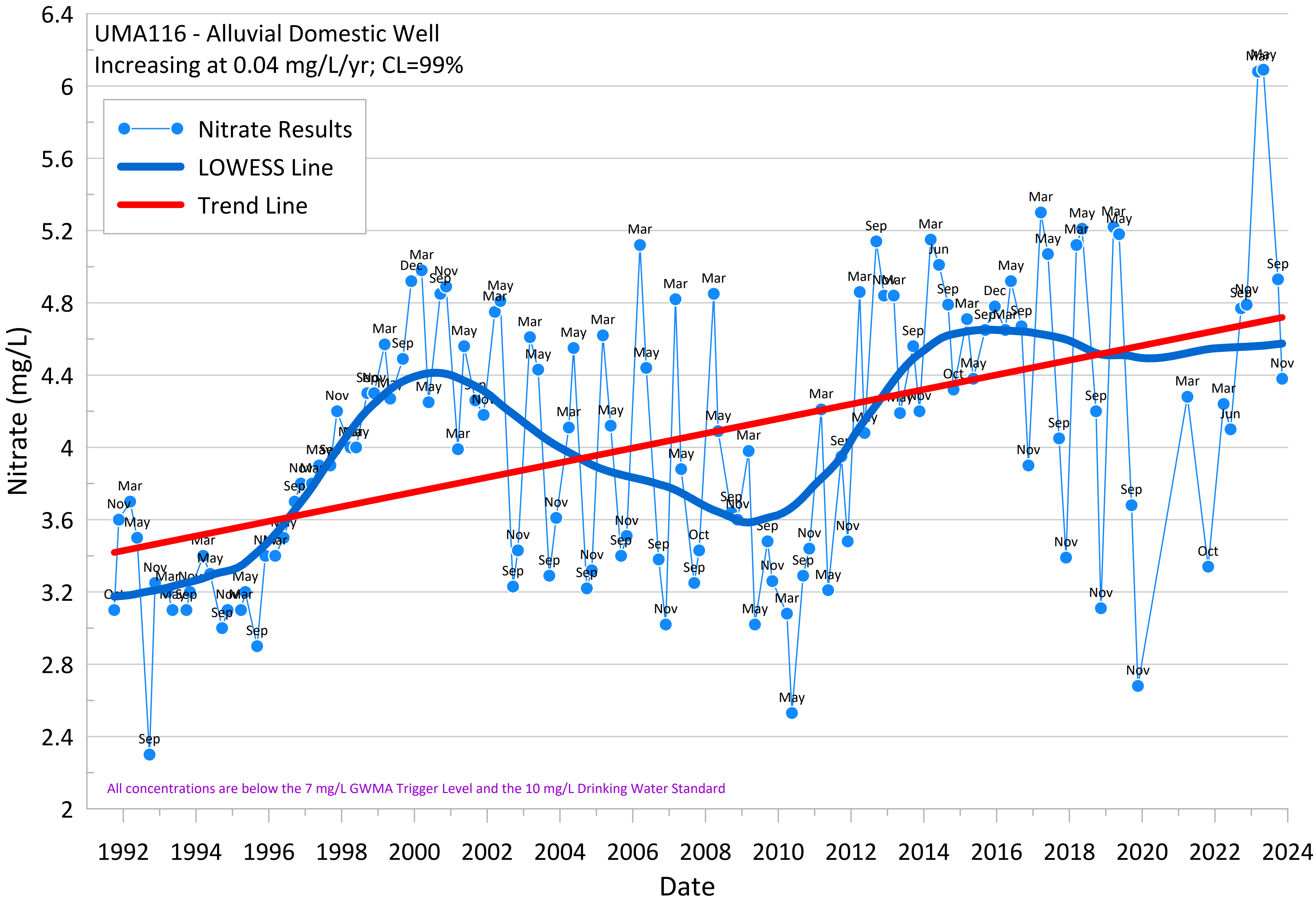

UMA103 - Alluvial Domestic Well
Increasing at 0.37 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

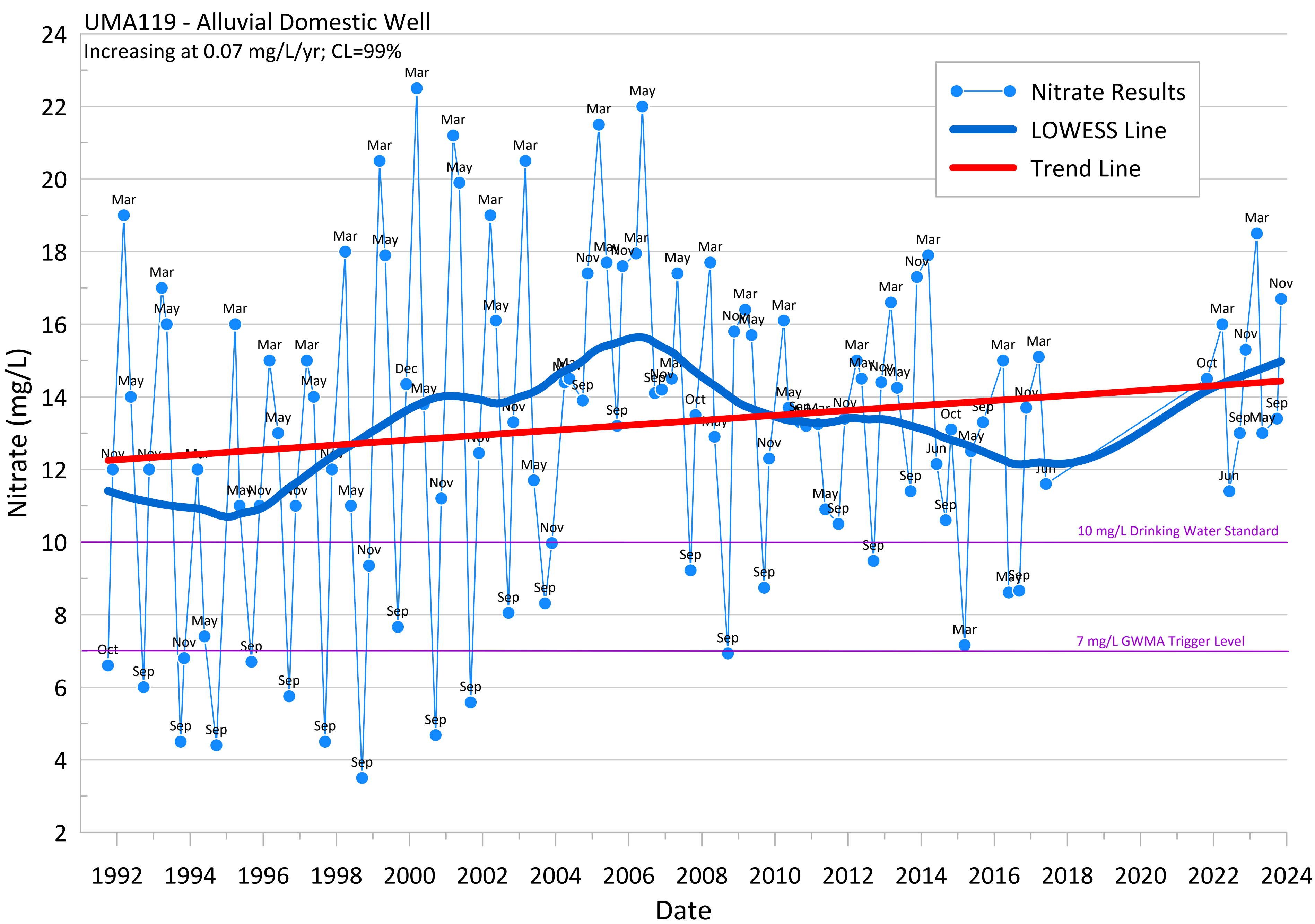

UMA106 - Basalt Domestic Well
Increasing at 0.01 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard


UMA109 - Alluvial Domestic Well
Increasing at 0.20 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

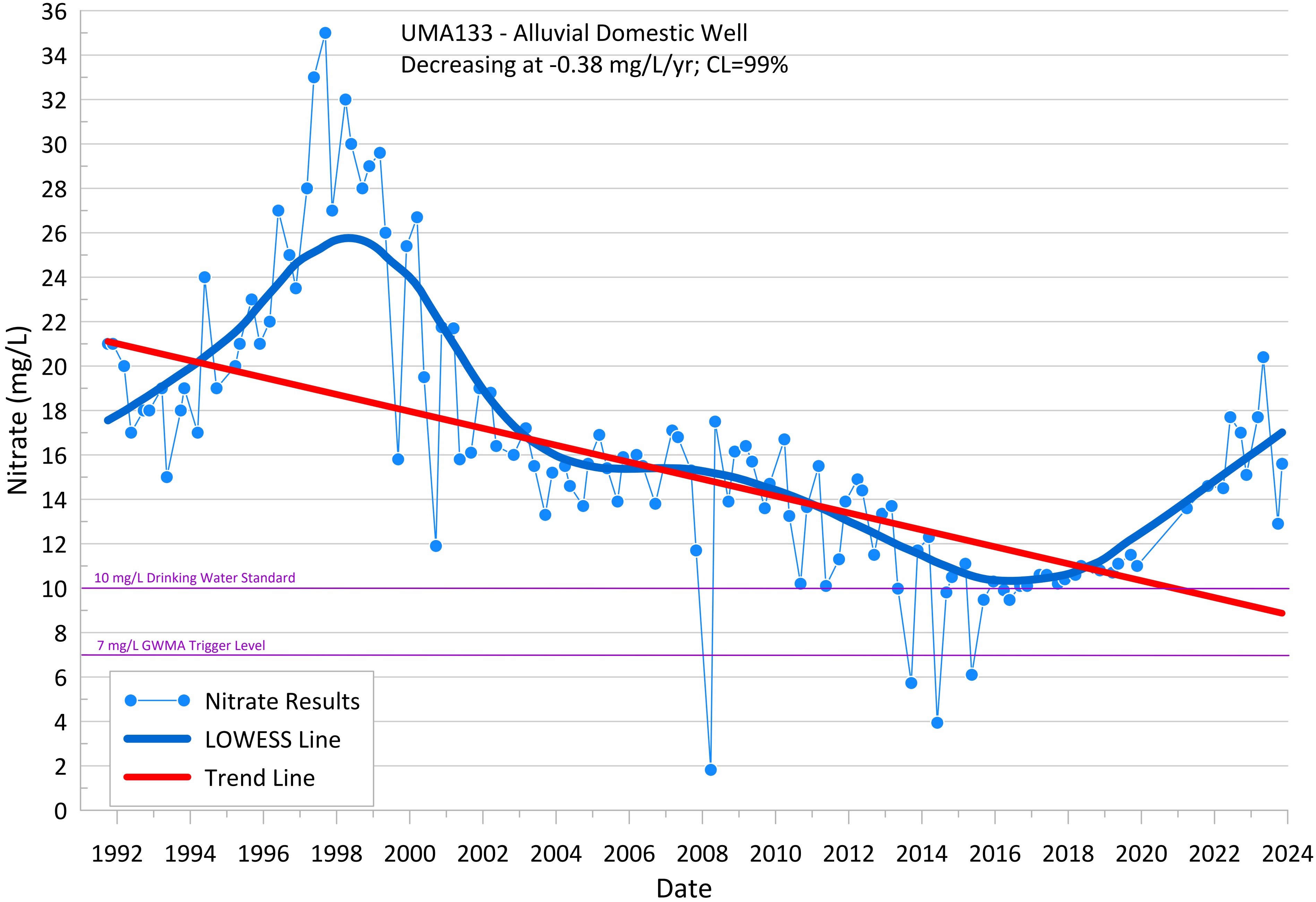

UMA110 - Alluvial Domestic Well
Increasing at 0.31 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
0
2
4
6
8
10
12
14
16
18
20
22
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

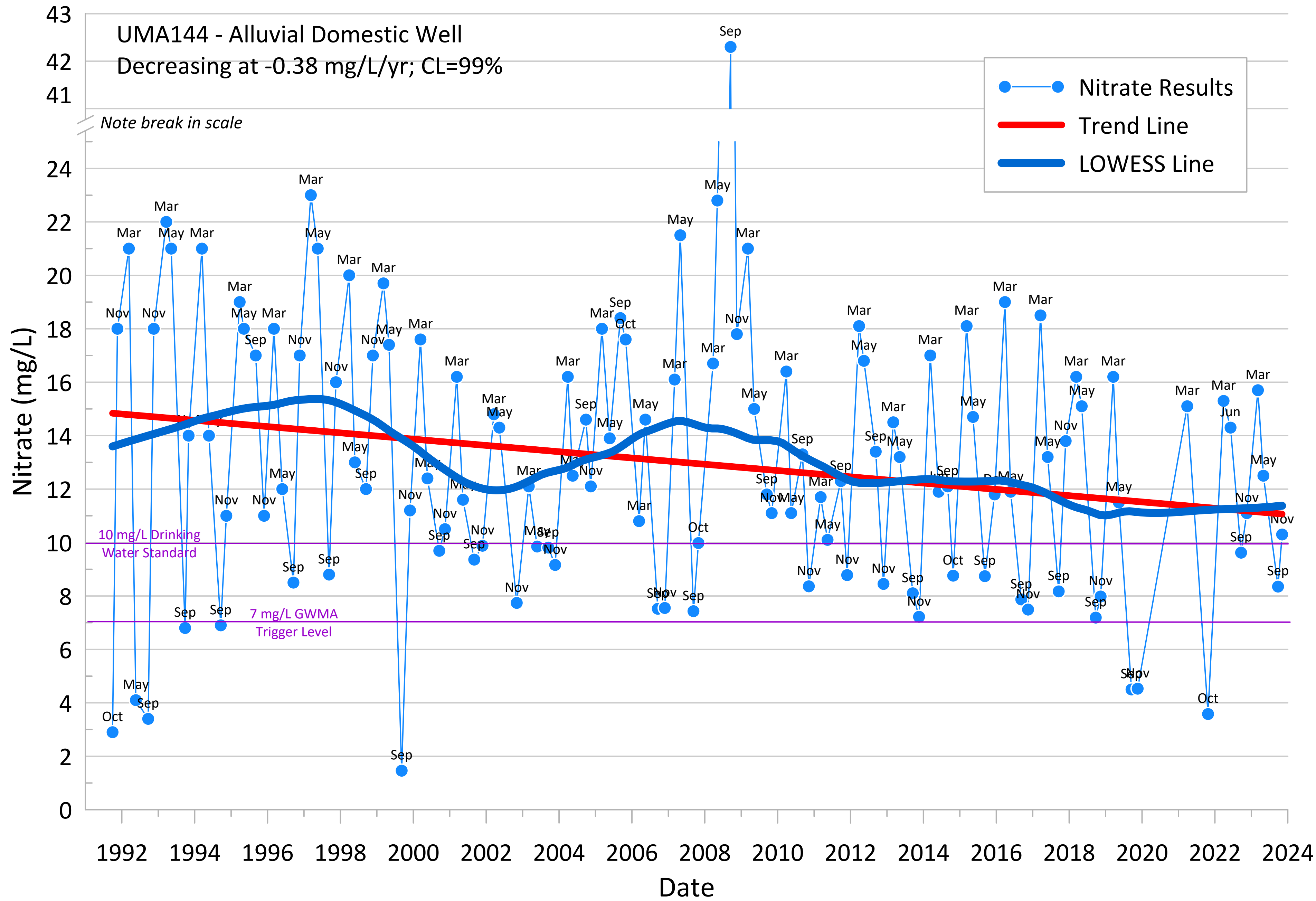

UMA112 - Alluvial Domestic Well
Decreasing at -0.11 mg/L/yr; CL=99%
Nitrate (mg/L)
Date
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA116 - Alluvial Domestic Well
Increasing at 0.04 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date
6.4
6
5.6
5.2
4.8
4.4
4
3.6
3.2
2.8
2.4
2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

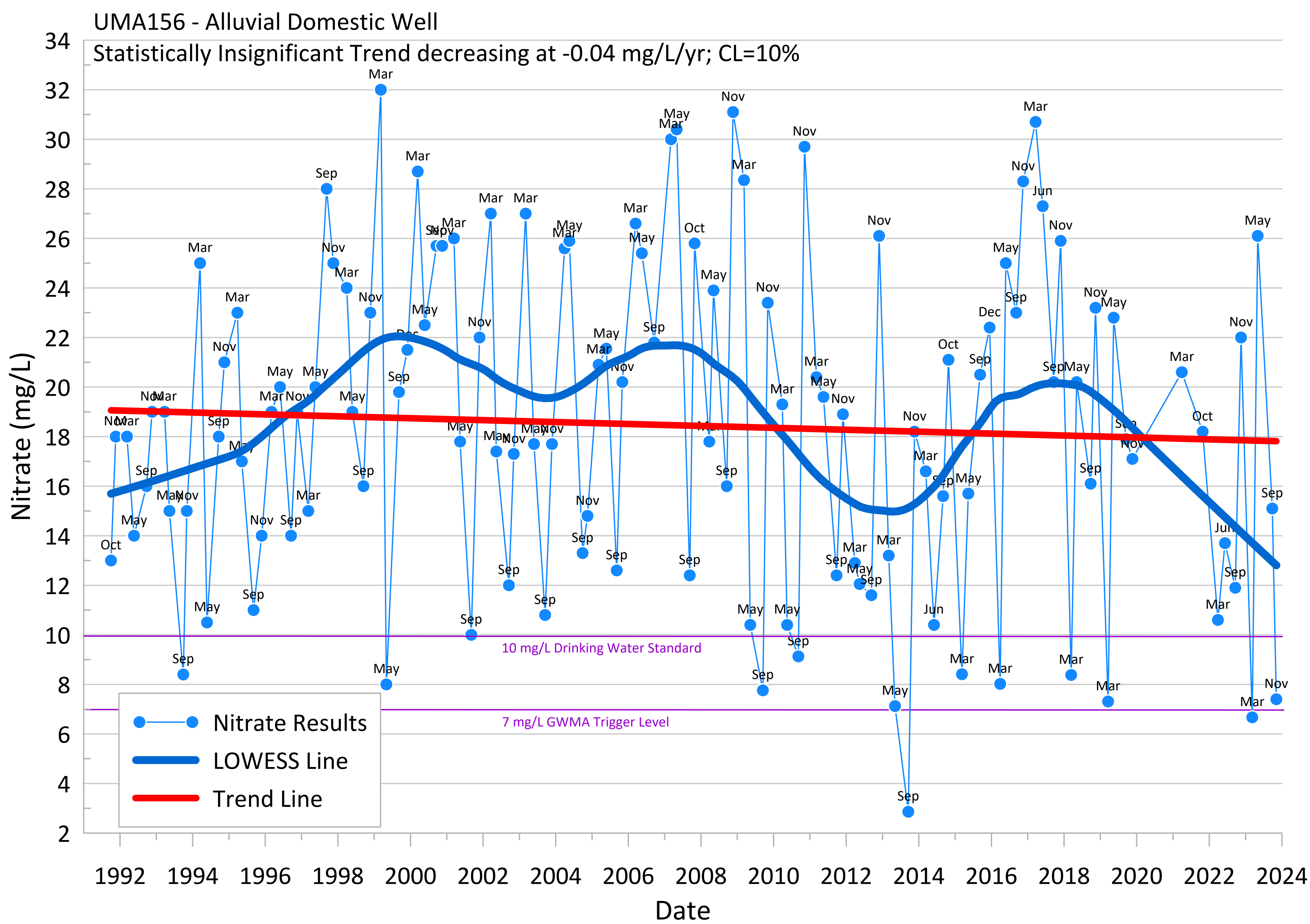


UMA119 - Alluvial Domestic Well
Increasing at 0.07 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
24
22
20
18
16
14
12
10
8
6
4
2
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

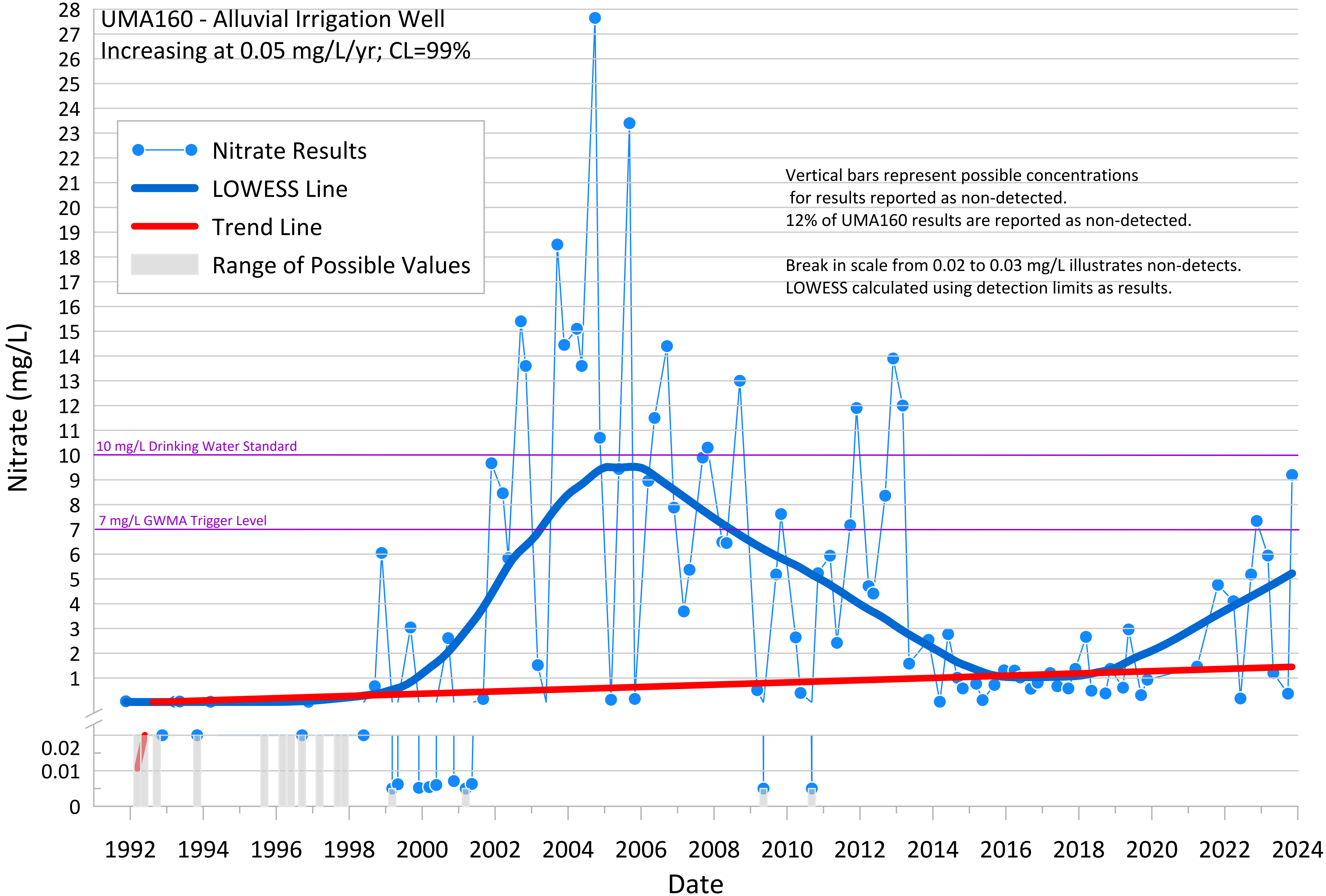

UMA133 - Alluvial Domestic Well
Decreasing at -0.38 mg/L/yr; CL=99%
Nitrate (mg/L)
Date
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

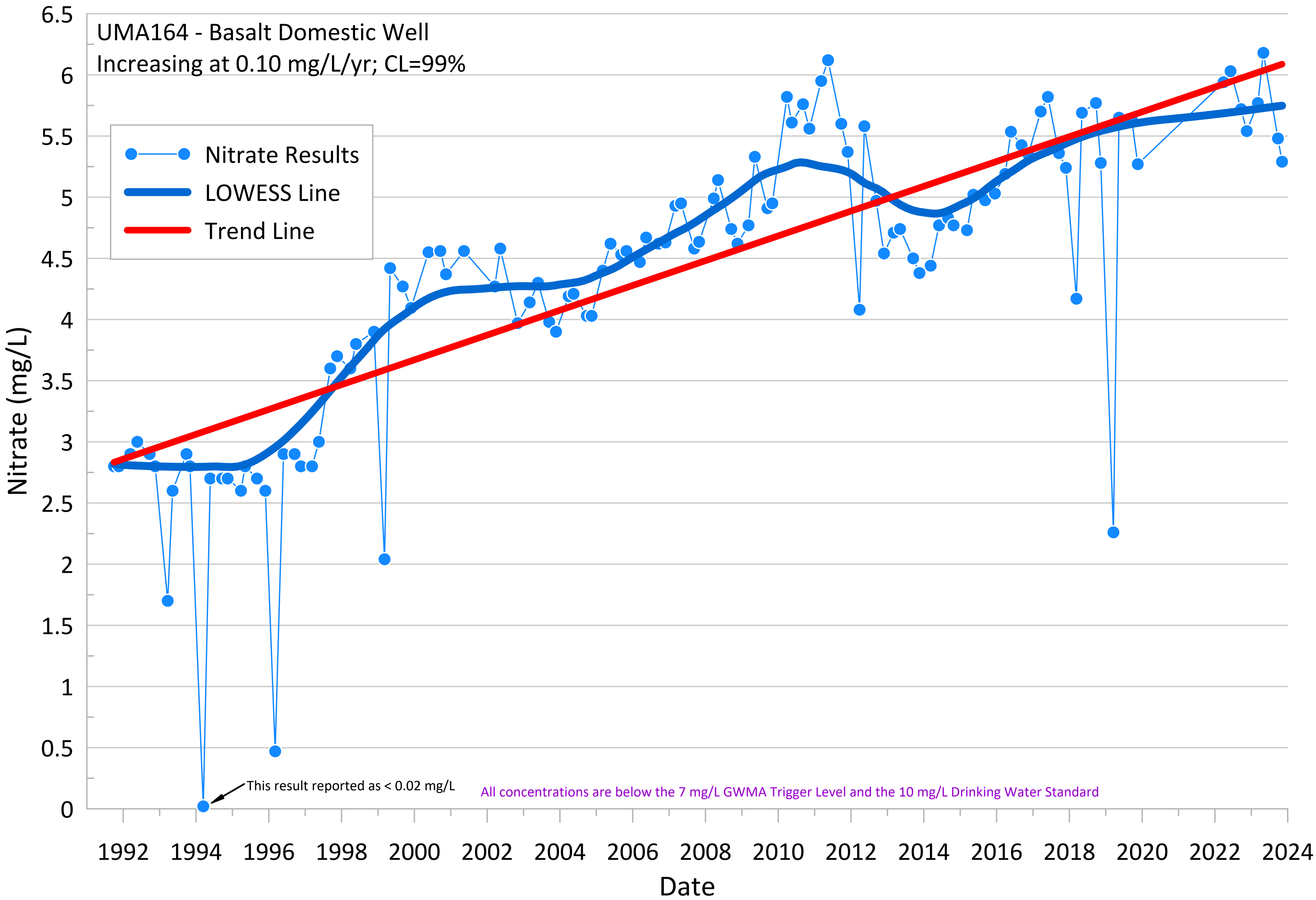


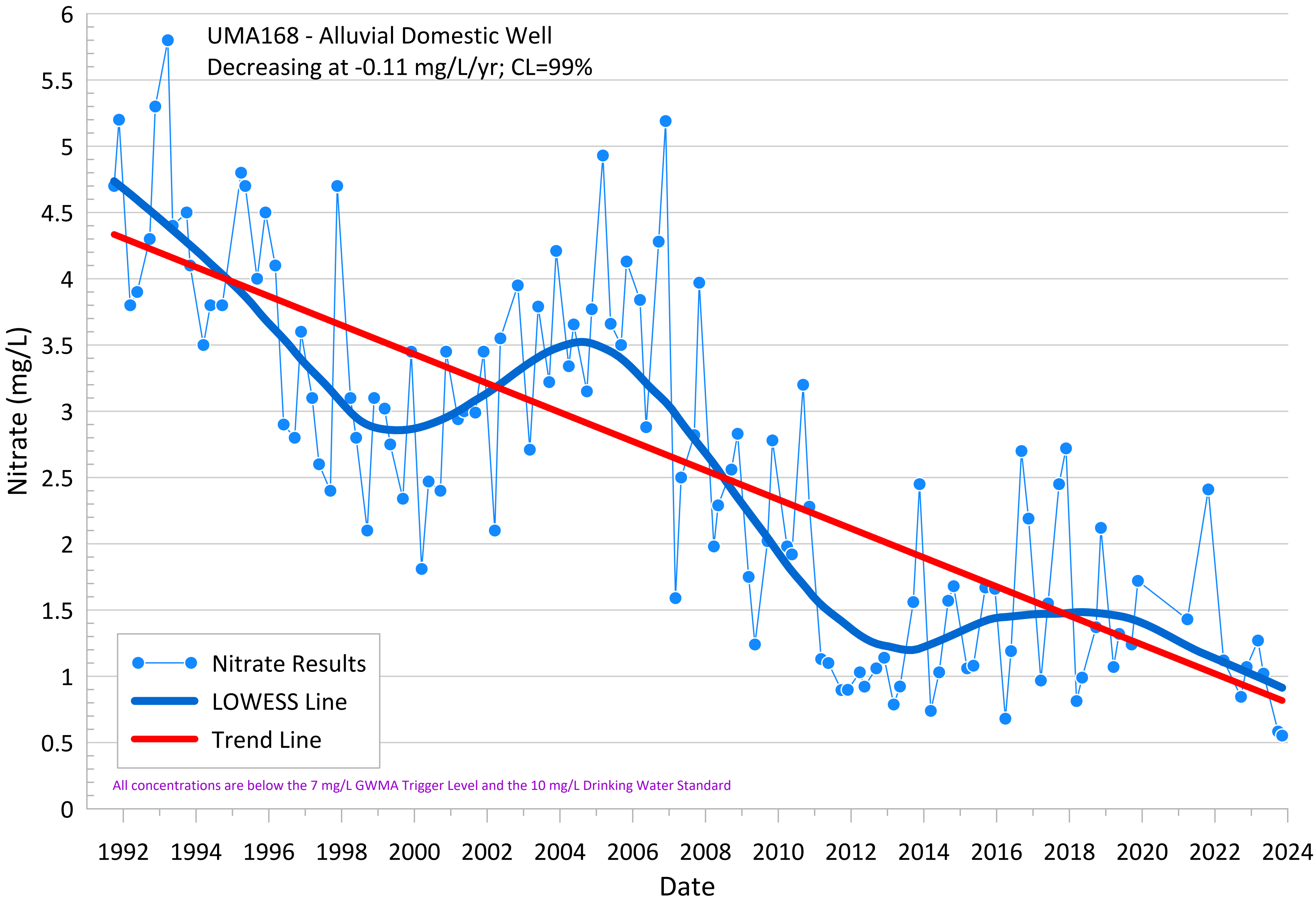
UMA144 - Alluvial Domestic Well
Decreasing at -0.38 mg/L/yr; CL=99%
Note break in scale
Nitrate Results
Trend Line
LOWESS Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date

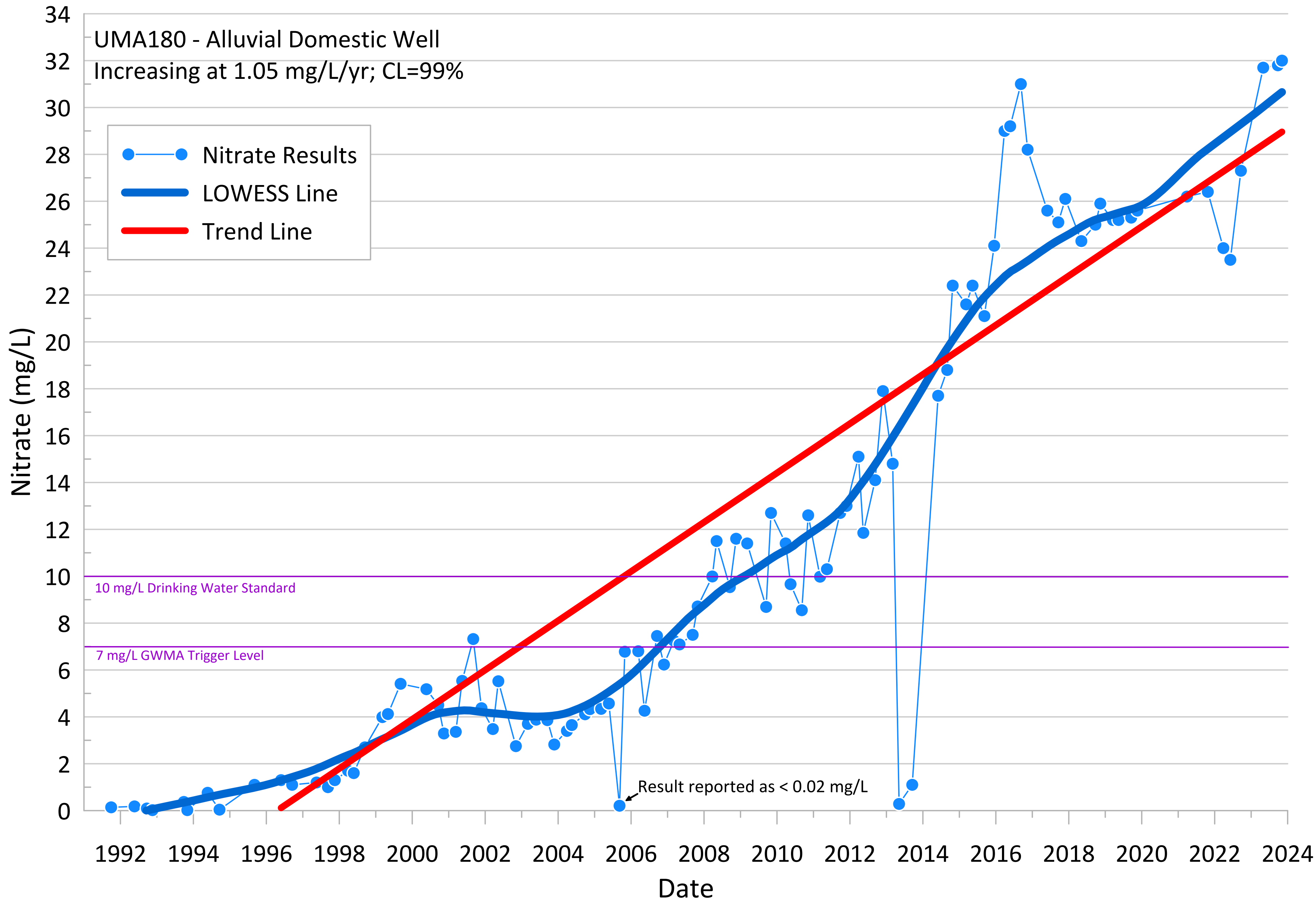


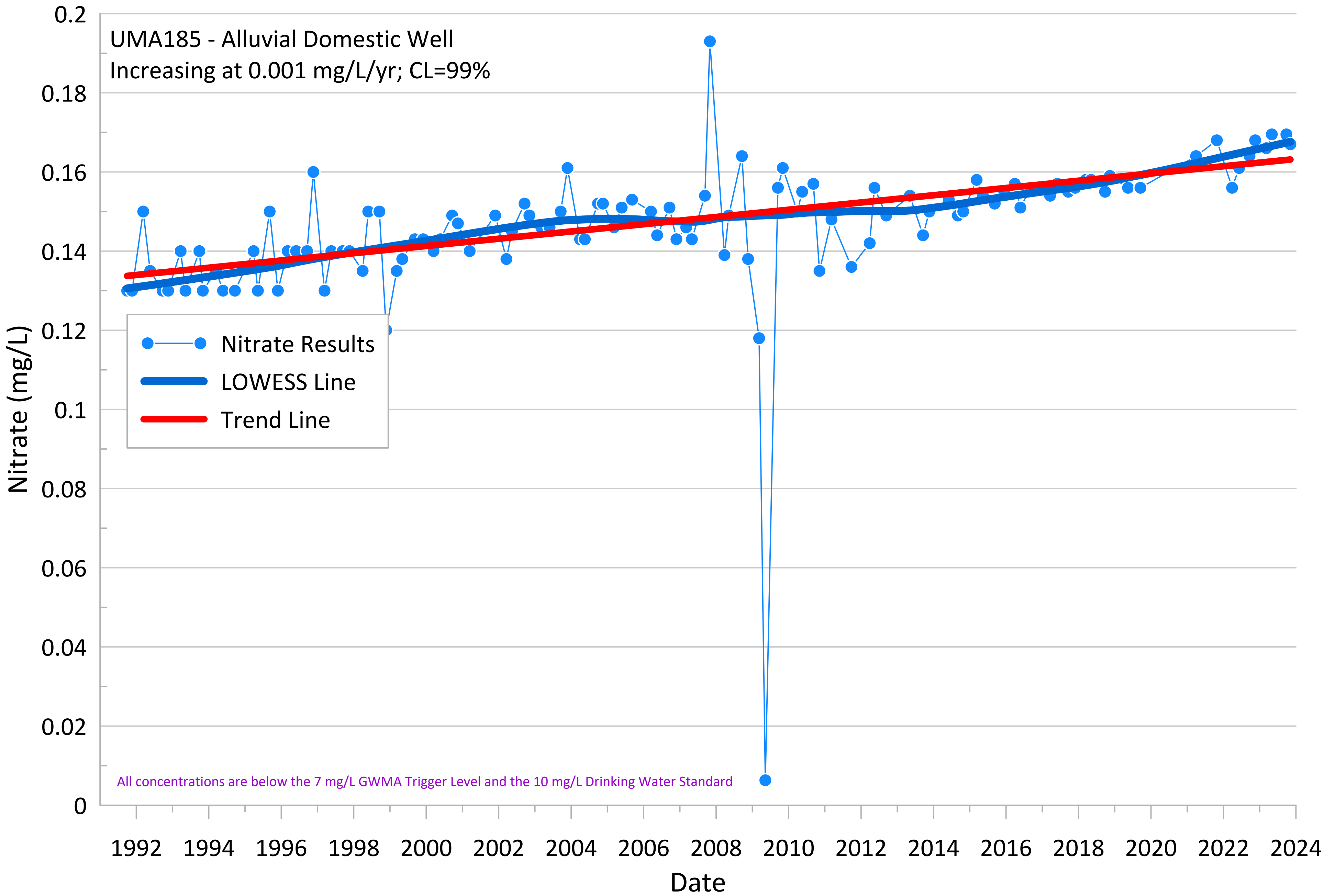
UMA156 - Alluvial Domestic Well
Statistically Insignificant Trend decreasing at -0.04 mg/L/yr; CL=10%
Nitrate (mg/L)
Date
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line


UMA160 - Alluvial Irrigation Well
Increasing at 0.05 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Range of Possible Values
Vertical bars represent possible concentrations
for results reported as non-detected.
12% of UMA160 results are reported as non-detected.
Break in scale from 0.02 to 0.03 mg/L illustrates non-detects.
LOWESS calculated using detection limits as results.
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0.02
0.01
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

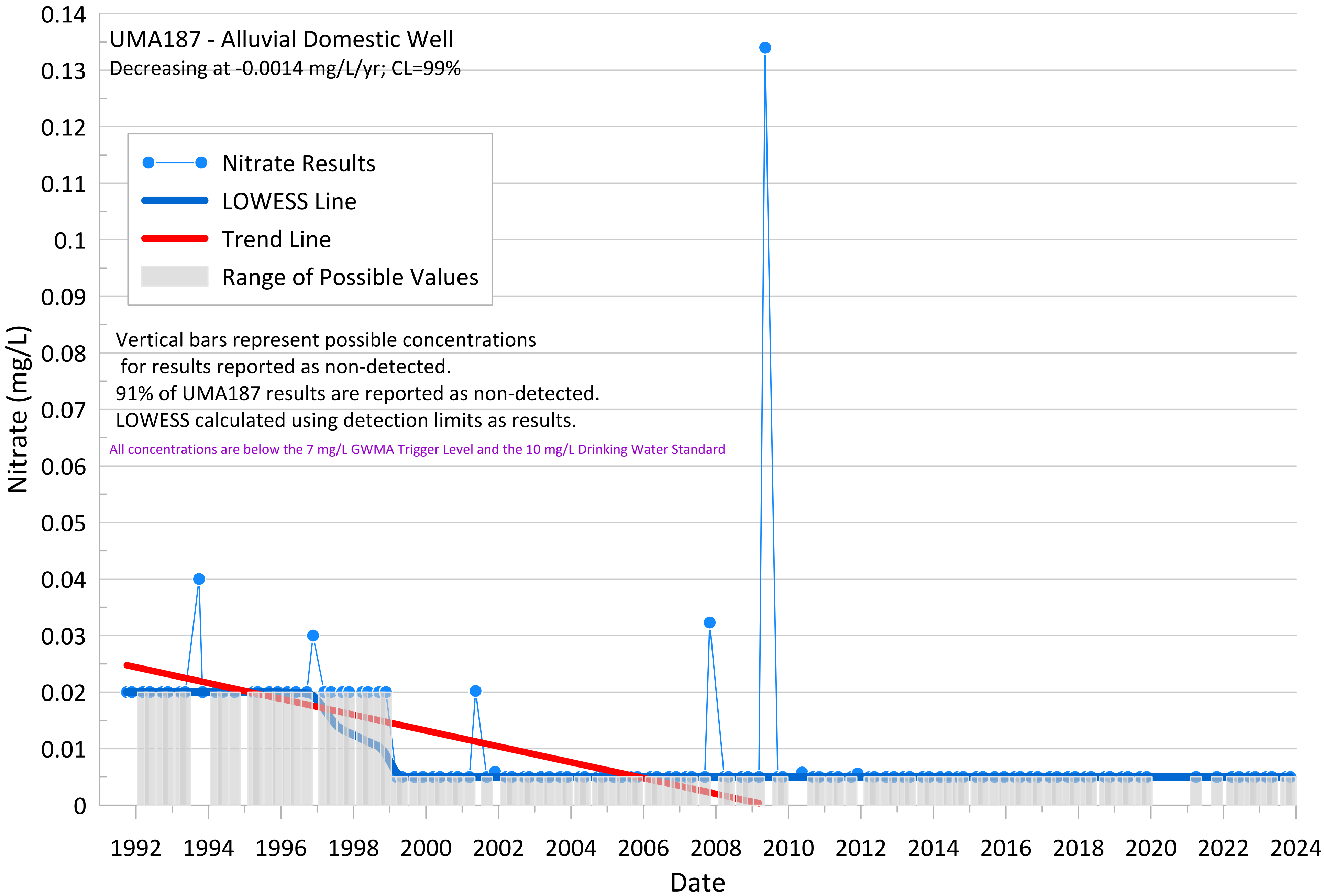

UMA164 - Basalt Domestic Well
Increasing at 0.10 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
This result reported as < 0.02 mg/L
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA168 - Alluvial Domestic Well
Decreasing at -0.11 mg/L/yr; CL=99%
Nitrate (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard

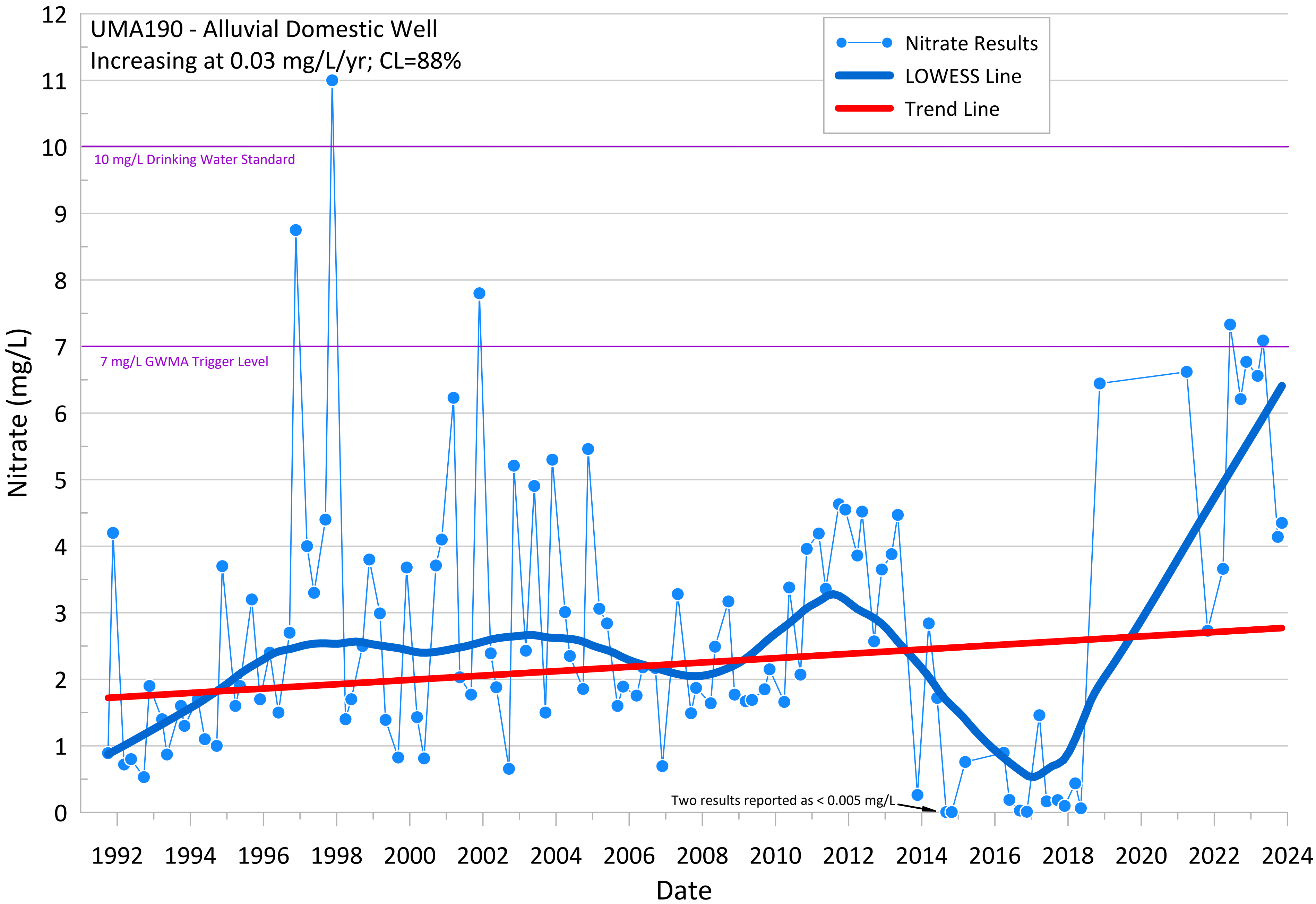

UMA180 - Alluvial Domestic Well
Increasing at 1.05 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Result reported as < 0.02 mg/L
Nitrate (mg/L)
Date
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024



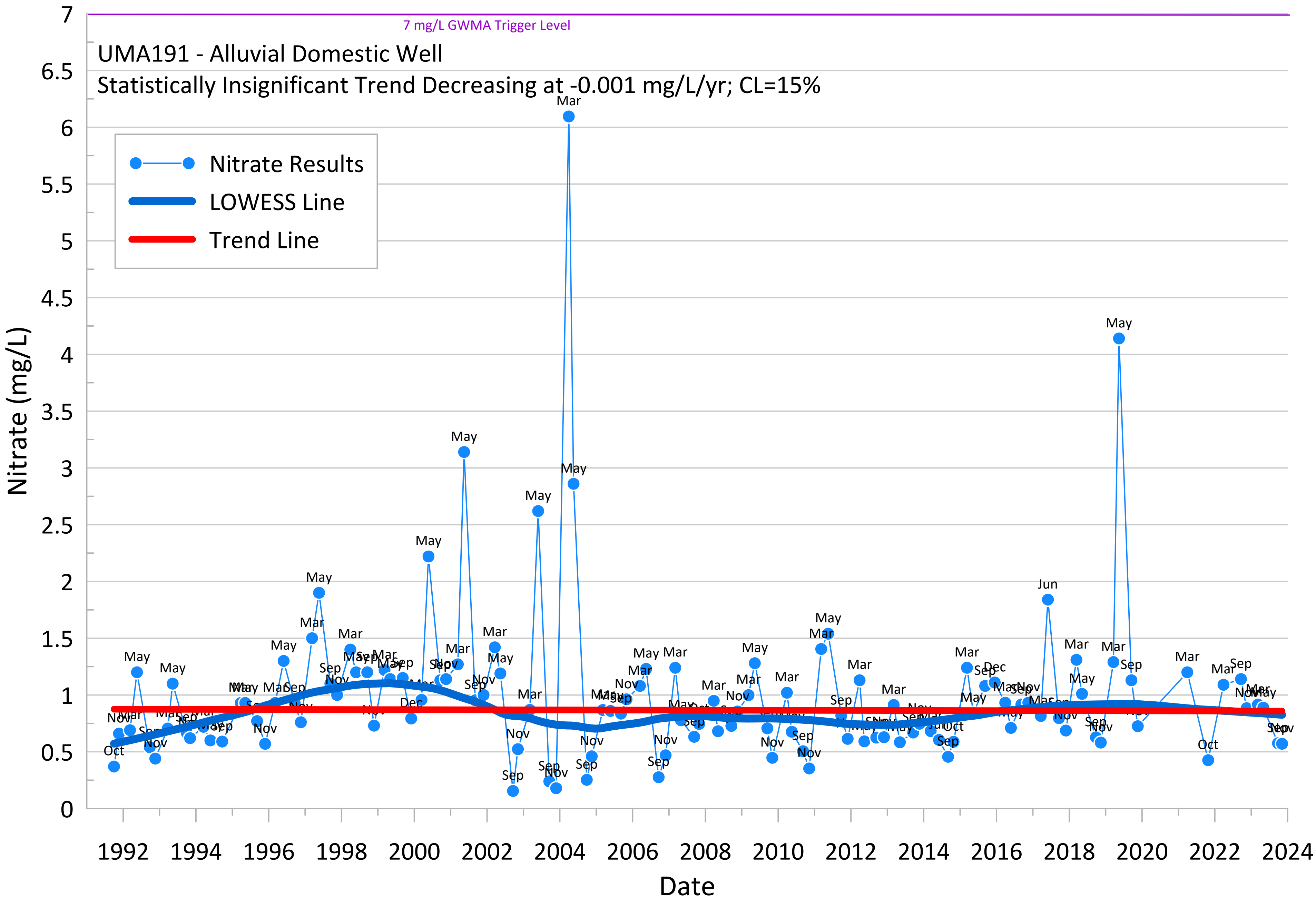
UMA185 - Alluvial Domestic Well
Increasing at 0.001 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

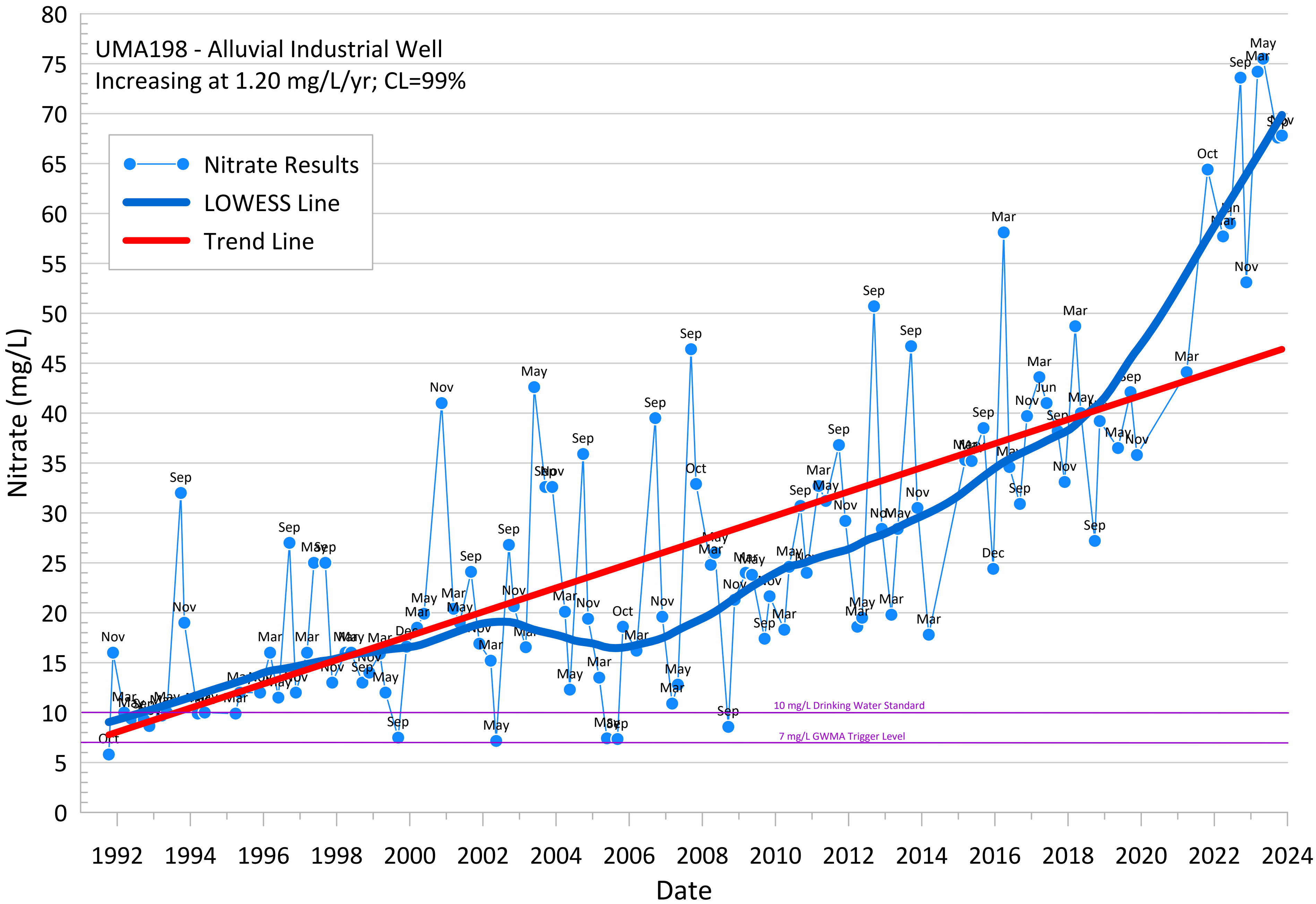


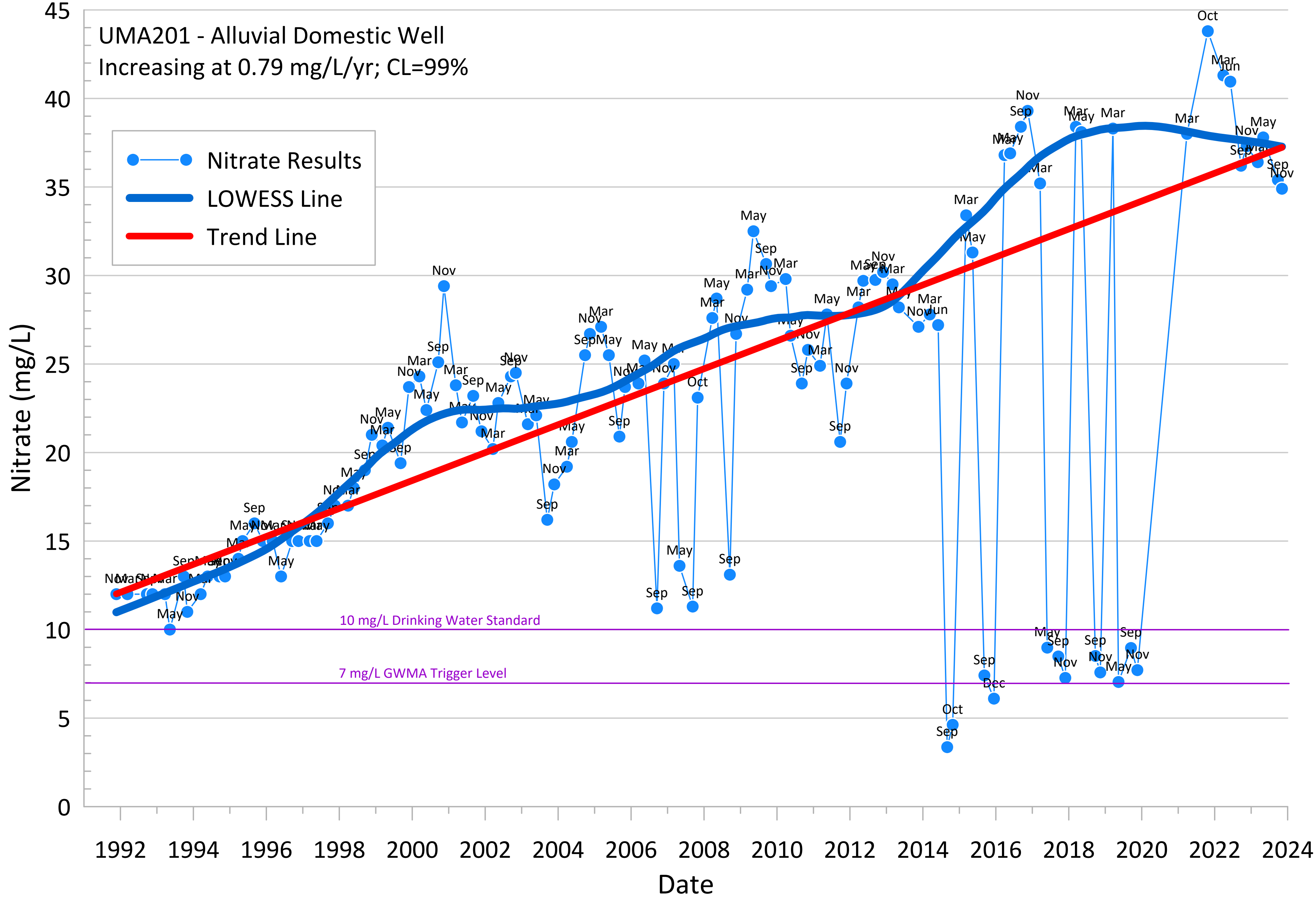
UMA187 - Alluvial Domestic Well
Decreasing at -0.0014 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
Range of Possible Values
Vertical bars represent possible concentrations
for results reported as non-detected.
91% of UMA187 results are reported as non-detected.
LOWESS calculated using detection limits as results.
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Date

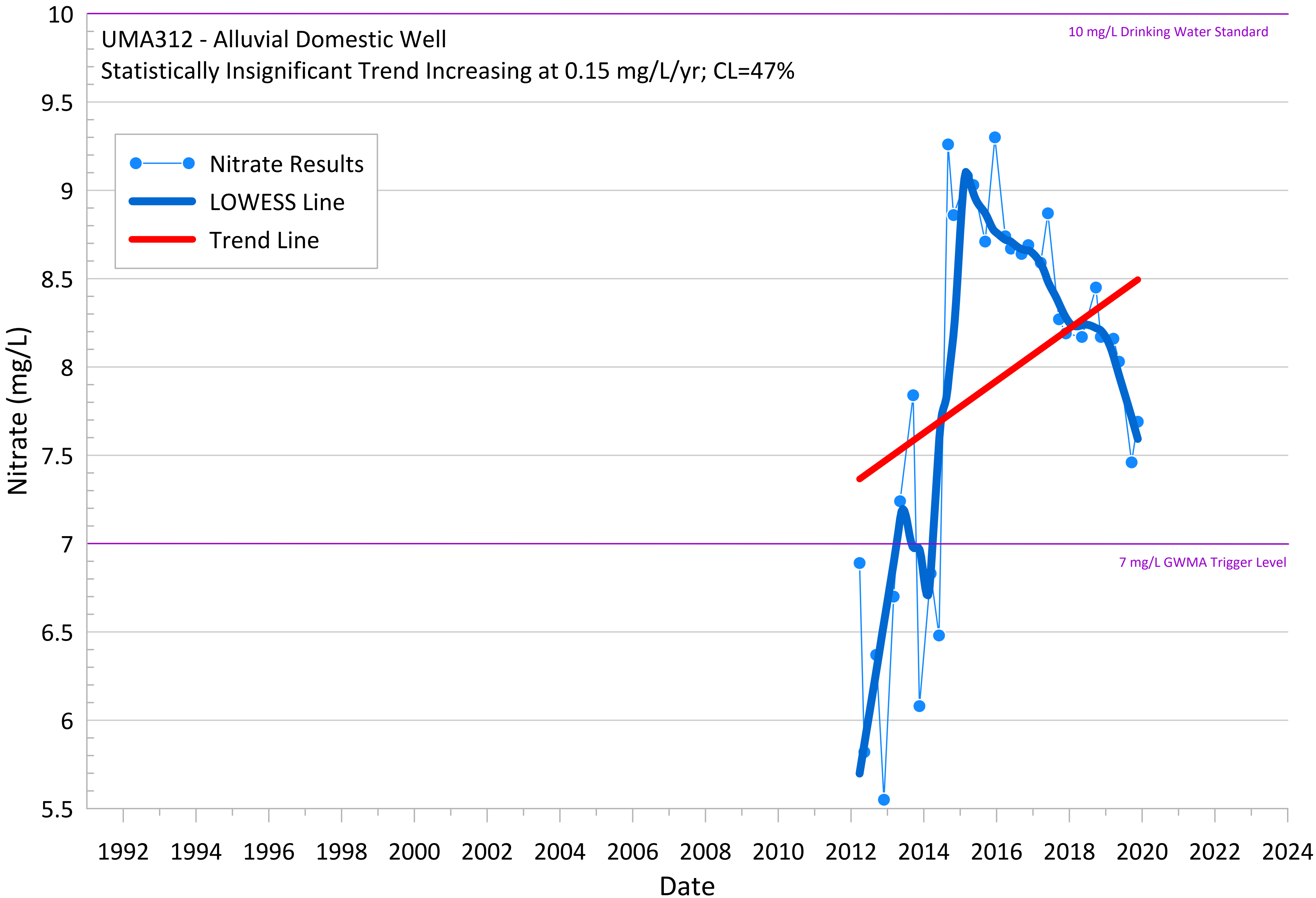


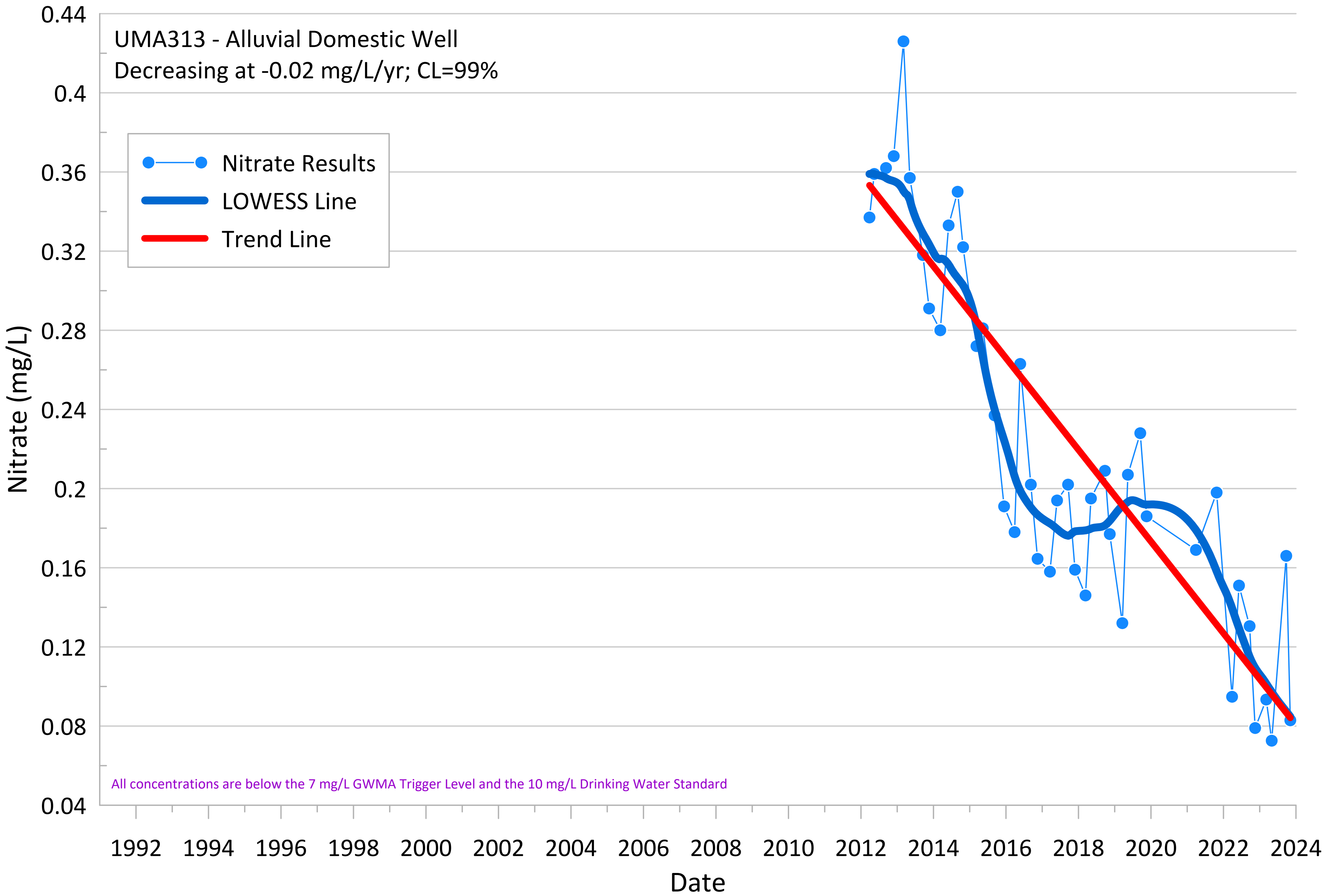
UMA190 - Alluvial Domestic Well
Increasing at 0.03 mg/L/yr; CL=88%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Two results reported as < 0.005 mg/L
Nitrate (mg/L)
Date
0
1
2
3
4
5
6
7
8
9
10
11
12
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


7 mg/L GWMA Trigger Level
UMA191 - Alluvial Domestic Well
Statistically Insignificant Trend Decreasing at -0.001 mg/L/yr; CL=15%
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date


UMA198 - Alluvial Industrial Well
Increasing at 1.20 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA201 - Alluvial Domestic Well
Increasing at 0.79 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate (mg/L)
Date
0
5
10
15
20
25
30
35
40
45
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA312 - Alluvial Domestic Well
Statistically Insignificant Trend Increasing at 0.15 mg/L/yr; CL=47%
10 mg/L Drinking Water Standard
7 mg/L GWMA Trigger Level
Nitrate Results
LOWESS Line
Trend Line
Nitrate (mg/L)
Date
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024


UMA313 - Alluvial Domestic Well
Decreasing at -0.02 mg/L/yr; CL=99%
Nitrate Results
LOWESS Line
Trend Line
All concentrations are below the 7 mg/L GWMA Trigger Level and the 10 mg/L Drinking Water Standard
Nitrate (mg/L)
Date
0.44
0.4
0.36
0.32
0.28
0.24
0.2
0.16
0.12
0.08
0.04
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024