Spokane Valley Rathdrum Prairie Aquifer
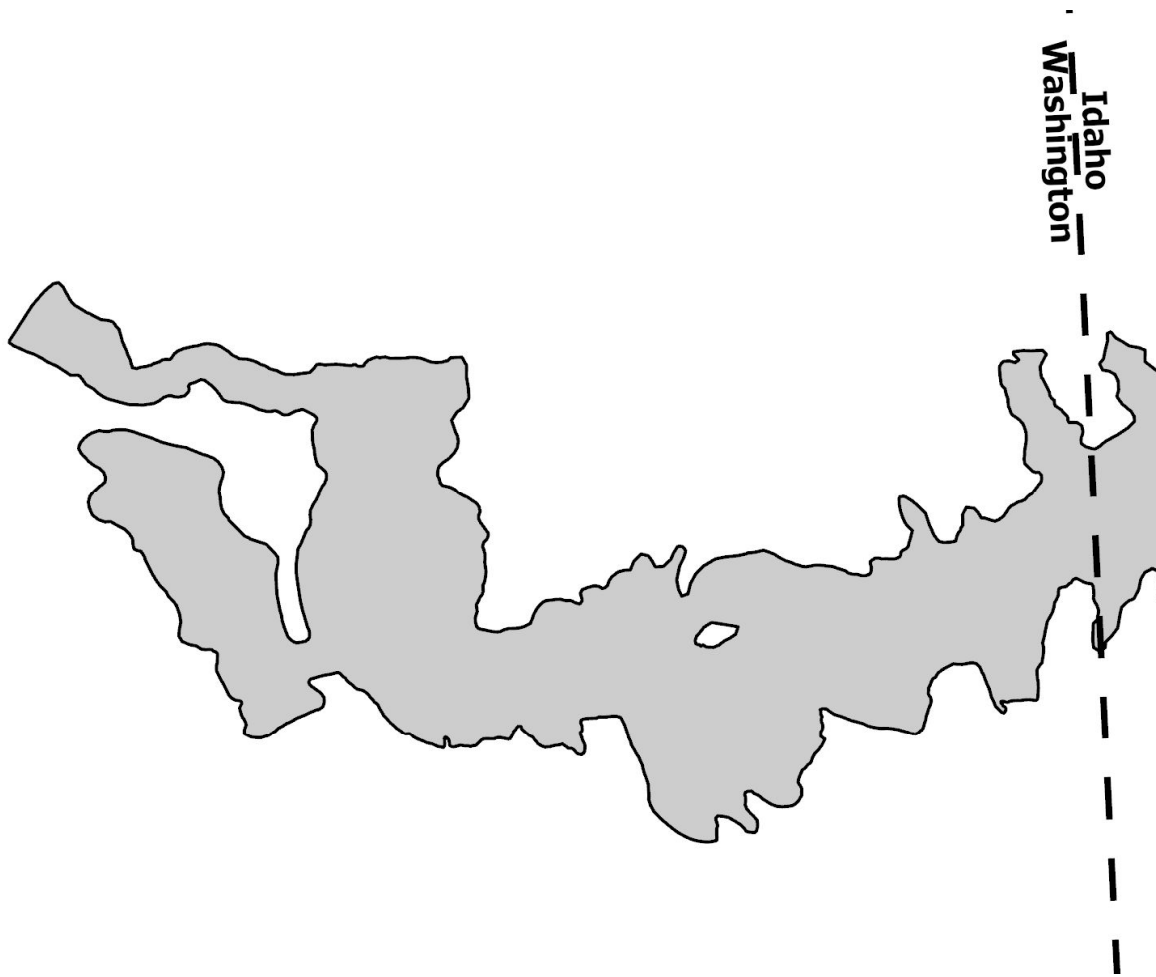# Spokane County, WA
Long-term Monitoring Program
20-Year Analysis (1999—2019)

Idaho
Washington

Spokane County Public Works
Water Resources
December 2023

Spokane Valley Rathdrum Prairie Aquifer
Long-term Monitoring Program
20-Year Analysis (1999—2019)

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Executive Summary

Spokane County conducted a comprehensive analysis of data collected as part of its Spokane Valley Rathdrum Prairie (SVRP) Aquifer Long Term Water Quality Monitoring Program during the 20-year period from 1999 to 2019. This assessment included data on groundwater temperature, conductivity, pH, dissolved oxygen, major ions, nutrients, and trace metals from 51 monitoring locations. The following summarizes the findings of this 20-year assessment.

- The SVRP Aquifer generally has good water quality:
  - Water sample results were below Maximum Contaminant Levels (MCLs) set to protect public health during the 20-year period except for lead, but these were limited to four one-time exceedances at different locations, none of which occurred in the last decade
  - Trace metals except arsenic are generally not detectable in the aquifer

- Groundwater levels throughout the SVRP aquifer were generally stable over the 20-year period

- Physical characteristics of the aquifer and natural processes are major influences on groundwater quality:
  - The amount of groundwater, represented by aquifer thickness, influences concentrations of major ions through dilution;
  - Dissolved oxygen (DO) and pH affect groundwater nutrient and metal concentrations through natural geochemical processes, and three combinations of conditions exist in the aquifer:
    - Groundwater in the aquifer is generally oxic (DO>0.5 mg/L) and alkaline (pH>7);
    - Groundwater influenced in some areas by the Spokane River has oxic, acidic (pH<7) conditions;
    - Groundwater in the confined aquifer at Plantes Ferry has anoxic (DO<0.5 mg/L), acidic conditions
  - Confining layers in some portions of the aquifer offer protection from surficial contamination
  - The presence of arsenic in the aquifer appears to be primarily from geologic sources

- Human activities have positively and negatively impacted the SVRP Aquifer over the 20-year period:
  - The County's Septic Tank Elimination Program (STEP) decreased or stabilized groundwater nitrate levels in most of its sewer service area but nitrate transported from upgradient unsewered areas are affecting certain sewered areas in Spokane Valley;
  - Chloride concentrations are generally increasing throughout the aquifer, likely from a combination of human activities;
  - Localized high levels of arsenic appear to be from releases at known contaminated sites but levels in the vicinity of these sites are decreasing;
  - Mining activities upstream of Coeur d'Alene Lake are a source of metals (Zn) to the Spokane River, which transports these metals into the near-river aquifer along the losing reach at Barker Road

Companion materials for this report (e.g. interactive ArcGIS StoryMap and Tableau Database) are available online at: https://www.spokanecounty.org/1285/Groundwater-Monitoring

Contents

Appendices

Abbreviations, Acronyms, and Units of Measurements

APA	Aquifer Protection Area		Q3	Third Quartile
C	Celsius		QA/QC	Quality Assurance/Quality Control
CFR	Code of Federal Regulations		QAPP	Quality Assurance Project Plan
CFS	Cubic Feet per Second		RM	River Mile
CID	Consolidated Irrigation District		RPWRF	Riverside Park Water Reclamation Facility
Cl/Br	Chloride to Bromide		SCC	Spokane Community College
DO	Dissolved Oxygen		SCRWRF	Spokane County Regional Water Reclamation Facility
EPA	US Environmental Protection Agency			
EIM	Environmental Information Management		SCWD	Spokane County Water District
EQN	Equation		SOC	Synthetic Organic Compounds
EVHS	East Valley High School		SRHD	Spokane Regional Health District
FERC	Federal Energy Regulatory Commission		SRP	Soluble Reactive Phosphorus
FT	Feet		STEP	Septic Tank Elimination Program
ID	Idaho		SVRP	Spokane Valley Rathdrum Prairie
LLSWD	Liberty Lake Sewer and Water District		TDS	Total Dissolved Solids
MCL	Maximum Contaminant Level		USGS	United States Geological Survey
mg/L	Milligrams/Liter		VOC	Volatile Organic Compounds
n	Number		WA	Washington
PCA	Principal Component Analysis		WAC	Washington Administrative Code
PCB	Polychlorinated Biphenyl		WSE	Water Surface Elevations
PDO	Pacific Decadal Oscillation		µs/cm	Microsiemens per Centimeter
Q1	Lower Quartile			

1. Introduction

Spokane County in cooperation with the Spokane Regional Health District (SRHD) has conducted an aquifer quality monitoring program since 1977. This began as an intensive one-year sampling effort during the 1977 water year to provide a baseline of water quality for the region's ground water quality and determine if surface "recharge" is occurring to carry ground surface pollutants to the aquifer (Esvelt, 1978). The same year this intensive sampling was wrapping up, the Environmental Protection Agency (EPA) designated the Spokane Valley Rathdrum Prairie (SVRP) aquifer as a "Sole Source Aquifer" under Section 1424(e) of the Safe Drinking Water Act.

The 1978 baseline study concluded that domestic, municipal, commercial, agricultural, and industrial activities on the ground surface above the SVRP aquifer impact aquifer water quality. This conclusion and the Sole Source Aquifer designation led to the development of an aquifer protection strategy, the *Spokane Aquifer Water Quality Management Plan* (Spokane County Engineers, 1979). Ongoing aquifer monitoring was one of the key recommendations of the plan. Monitoring provides information on the overall quality of the groundwater resource. In addition, the collection of long-term data allows water quality trends to be analyzed and used as an indicator of the effectiveness of aquifer protection measures. Therefore, in 1980, an ongoing voluntary monitoring program began for the Spokane County portion of the aquifer.

In 1985, the voters of Spokane County approved the formation of the Spokane Valley Rathdrum Prairie Aquifer Protection Area (APA) and authorized a fee on property owners to finance protection, preservation, and rehabilitation activities. The APA was reauthorized by Spokane County voters in 2004. The APA fee funds the monitoring program as well as other aquifer protection activities such as sewer and stormwater infrastructure, comprehensive planning, and water resource education.

While the aquifer monitoring program changed over time, changes were intended to effectively meet the program's objectives while not duplicating the various other monitoring efforts tracking the groundwater quality of the SVRP aquifer. Other monitoring efforts include on-going regulatory programs (e.g., compliance sampling required by the Washington State Department of Health for water systems) as well as focused investigations by other organizations and agencies (e.g., Spokane River Regional Toxics Task Force sampling for polychlorinated biphenyls). This allowed for monitoring efforts to be complimentary, providing comprehensive information on the condition of the aquifer. However, to date, the County's monitoring data has not been analyzed in detail, nor has there been a concerted effort to consolidate information from the various monitoring efforts.

This Program Review is intended to be a comprehensive analysis of the data collected by the County as part of the SVRP Aquifer Long Term Water Quality Monitoring Program (Monitoring Program) during the 20-year period from 1999 to 2019. The County's monitoring program and the production of this report was funded by the Aquifer Protection Area.

1.1. Program Goal and Objectives

Goal: In accordance with Spokane County Code 11.17 (Spokane—Rathdrum Aquifer Protection Area), monitor the quality and quantity of subterranean water within the Spokane Valley-Rathdrum Prairie Aquifer.

Objectives:
1. Continue to collect a comprehensive water quality data set for the SVRP.
2. Monitor the impact of onsite wastewater disposal on the SVRP.
   a. Effectiveness of Septic Tank Elimination Program.
   b. Continued impacts from areas not planned for sewer.
3. Monitor the influence of urbanization over the SVRP.
   a. Legacy contaminants from products no longer in use – *PCBs, pesticides/herbicides*
   b. Releases to environment – *spills, leaking underground storage tanks (LUSTs)*
   c. Potential contaminants from products currently in use – *PDBEs, pharmaceuticals*, fertilizer, herbicides, road deicers.
4. Monitor the influence of urbanized tributary basins on SVRP.
5. Monitor the impacts of Spokane River/SVRP interaction.

1.2. Report Organization

This report is divided into several sections to specifically address monitoring program objectives:

- Section 1 – Introduction: This section provides basic information on the monitoring program and the data analyses conducted for this report.
- Section 2 – Summary of Findings: This section provides a synopsis of the findings of this report in more detail than presented in the Executive Summary.
- Section 3 – Overall Water Quality: This section summarizes data and trends (where enough data are available) for each parameter.
- Section 4 – Groundwater Depth and Confining Layers: This section discusses the effects of depth and confining layers on groundwater quality by comparing data from wells completed in the same location at different depths (nested wells) and wells completed above and below confining layers in the aquifer.
- Section 5 – Spokane River – SVRP Aquifer Interactions: This section discusses groundwater-surface water interactions and their effect on groundwater quality by examining data from monitoring locations along a losing and two gaining reaches of the Spokane River.
- Section 6 – SVRP Aquifer Inputs into the Little Spokane River downstream of the Dartford gage.
- Section 7 – On-site Wastewater and Septic Tank Elimination Program: This section discusses the effects of on-site wastewater disposal on groundwater quality by examining data in relation to the sewer service areas.
- Section 8 – Releases to the Environment: This section discusses the effects of urbanization on groundwater quality by examining data in relation to known releases to the environment.
- Section 9 – Holistic Analysis: This section discusses the results of the multivariate statistical techniques used to identify relationships in the data to determine the main influences on groundwater quality in the SVRP Aquifer.

1.3. Study Area and Hydrogeologic Setting

The Spokane Valley Rathdrum Prairie (SVRP) aquifer underlies about 370 square miles of relatively flat, alluvial valley that spans across Washington and Idaho. The SVRP aquifer boundary used in this study is based on the extent described by the U.S. Geological Survey (USGS) in 2005 based on hydrogeologic information. This does not represent the SVRP aquifer boundary adopted by the U.S. Environmental

Protection Agency (EPA) under the Sole Source Aquifer program. This study focuses on the portion of the SVRP aquifer within Spokane County, Washington (Figure 1). There are discrete geographic regions of the SVRP aquifer mentioned in this report: the Stateline, Spokane Valley, Hillyard Trough, Little Spokane Arm, Trinity Trough, and the Western Arm (Figure 1).
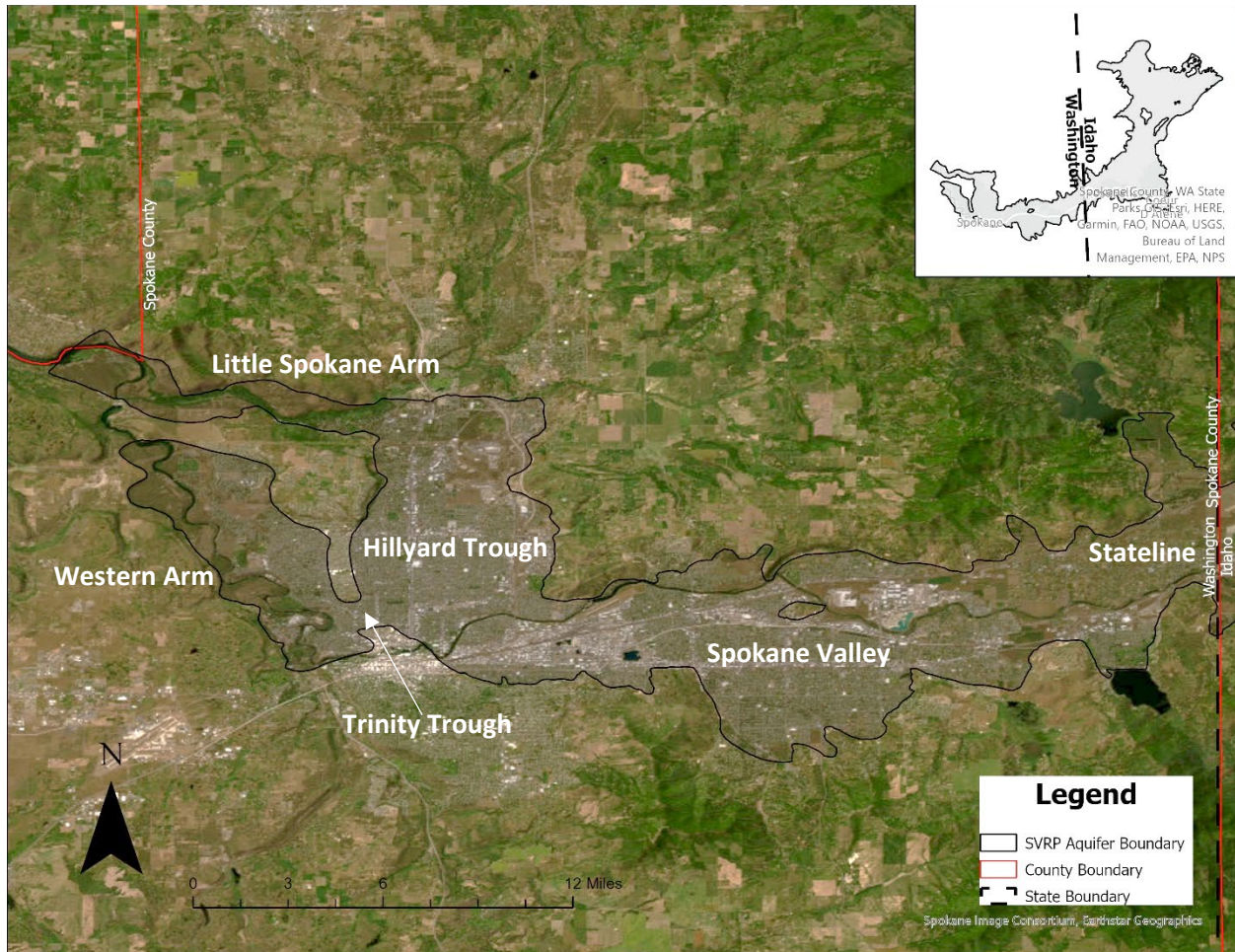
Figure 1. Aerial view of the Spokane Valley Rathdrum Prairie aquifer boundary within Spokane County, Washington with geographic regions identified.

The SVRP aquifer is divided between two of the U.S. principal aquifer systems: the Columbia Plateau aquifer system on the Washington side and the Northern Rocky Mountains Intermontane Basins aquifer system on the Idaho side. The SVRP aquifer is classified as an unconsolidated sand and gravel aquifer, or basin fill aquifer. The aquifer consists primarily of coarse-grained sediments including sand, gravels, cobbles, and boulders and is surrounded by metamorphic and igneous bedrock highlands.

While isolated fine-grained deposits occur locally, there is generally a greater percentage of finer material near the margins of the aquifer (Kahle et al, 2005). In the northwest portion of the aquifer, referred to as the Hillyard Trough, the deposits are finer grained and the aquifer consists of sand with some gravel, silt, and boulders. There is also an extensive fine-grained layer that extends through the Hillyard Trough and

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

along the Little Spokane Arm to Long Lake that divides the aquifer into an upper, unconfined unit and a lower confined unit.

The aquifer is highly productive, yielding as much as several thousand gallons per minute with relatively little drawdown. The hydraulic conductivity of the aquifer sediments is at the upper end of values measured in the natural environment (Kahle et al, 2005).

1.4. Data Collection and Quality

The County's monitoring program is a voluntary program that "monitor[s] the quality and quantity of subterranean water within the Spokane Valley-Rathdrum Prairie Aquifer." The County's current monitoring network is comprised of 51 monitoring locations including 29 dedicated monitoring wells, 17 public supply wells, and 5 natural springs. Figure 2 shows the current sampling locations. Characteristics of each monitoring location are provided in Appendix A.
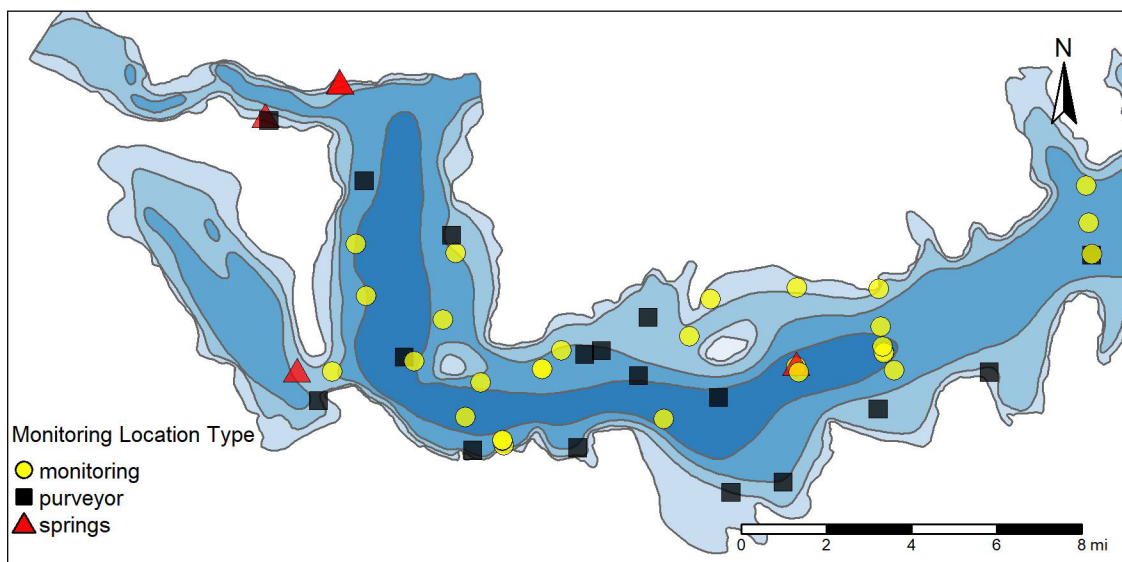
Figure 2. Current monitoring locations by type used in the Spokane County's Long-term Monitoring Program. Aquifer thickness is modeled from Kahle and Bartolino (2007).

The County's monitoring network is spatially distributed to provide information on general water quality throughout the aquifer, while also providing specific data for the objectives identified in Section 1.1.

Four monitoring locations at the Washington – Idaho stateline provide a baseline to which water quality data from downgradient wells can be compared. Approximately 5.25 miles west of stateline, along Barker Road, four monitoring locations provide data to evaluate the water quality in the vicinity of a losing reach of the Spokane River. Two miles west of Barker Road, at Sullivan Road, three monitoring locations provide data to evaluate water quality in the vicinity of a gaining reach of the Spokane River. Elsewhere, two sets of nested wells provide data at the same location but different depths. There are also three pairs of City of Spokane water supply with dedicated sentinel monitoring wells. Additionally, two locations provide information on separate confined aquifers. Finally, four natural spring locations provide information on aquifer water that enters the Spokane and Little Spokane Rivers.

The County's monitoring program focuses on inorganic chemicals including major ions, nutrients, and total metals. The County also collects field measurements for depth to water, water temperature, pH, dissolved oxygen, and specific conductance. In general, sampling occurred on a quarterly basis. However, changes in sampling frequency included monthly sampling at select locations in 1999 and between 2008 and 2010, and a permanent shift to either biannual (spring and summer) and annual (summer) sampling at select locations in 2011. A sampling matrix summarizing the sampling history for each monitoring location is provided in Appendix B. The County's monitoring procedures are described in the *Spokane County Water Resources Groundwater Monitoring Program Quality Assurance Project Plan* (QAPP) (2007).

Analytical services since 2008 were provided by SVL Analytical in Kellogg, Idaho and IEH Aquatic Research in Seattle, Washington using the analytical methods listed in Table 1.

Table 1. Analytical methods used since 2008.		
Lab	**Parameter/Analyte**	**Method**
SVL Analytical	Chloride, Fluoride	EPA 300.0
	Nitrate+Nitrite	EPA 353.2
	Mercury	EPA 245.1
	Metals	EPA 200.7 and 200.8
IEH Aquatic Research	Total Phosphorus	SM 4500PF
	Soluble Reactive Phosphorus (SRP)	SM 4500PF

However, the analytical laboratories, methodologies, and reporting limits have changed over time to improve the quality of data (Appendix C).

All analytical results were validated by County staff to ensure data quality objectives including precision, accuracy, representativeness, and completeness as outlined in the QAPP were met. Data qualified with an "R" (Rejected) for not meeting data quality objectives during the Quality Assurance/Quality Control (QA/QC) process were not used in the assessments presented in this report.

Some external data was utilized in this report. In Section 3.5, weather data, the Pacific Decadal Oscillation (PDO) Index data, and groundwater level from a long-term U.S. Geological Survey (USGS) monitoring well near Liberty Lake were used to help explain trends in SVRP groundwater levels. The Spokane area weather data was compiled from the National Weather Service NOWData online database. The PDO Index data was downloaded from the National Oceanic and Atmospheric Administration (NOAA) Physical Sciences Laboratory. The USGS groundwater level data was downloaded using the dataRetrieval package in R.

In Sections 5 and 6, data for the Spokane and Little Spokane Rivers respectively were used to assess river-groundwater interactions. Data for both rivers was compiled from the Washington Department of Ecology (Ecology) Environmental Information Management System (EIM). The Ecology EIM database houses environmental monitoring data collected by Ecology staff and various entities. The supplemental data from the EIM used in this report are described in the section in which it was utilized and the site and study information from the EIM is provided in the Works Cited section of this report.

Data from these sources is assumed to be of sufficient quality for use in this 20-year analysis.

1.5. Data Reporting and Analysis

Water quality data in this report are described through a variety of means. Descriptive statistics presented in this report include the number of samples, the minimum value, lower quartile (Q1), mean (average), median, upper quartile (Q3), the maximum value, standard deviation, and the number or percentage of non-detectable data. Data reported as non-detect (below the analytical method reporting level) were treated as "zero" in calculating the descriptive statistics. Data are visualized through boxplots (statistical data), scatter plots (time-series data), and maps (occurrence). Boxplots and the descriptive statistics visualized by this graph are described in Figure 3. Boxplots are not provided for data where a high proportion of non-detects results in the descriptive statistics as having values of zero and all detectable levels as high outliers. Descriptive statistics and data visualization were completed using R programming language (R Core Team, 2022). ArcGIS Pro and the tmap package (Tennekes, 2018) in R were used for mapping.
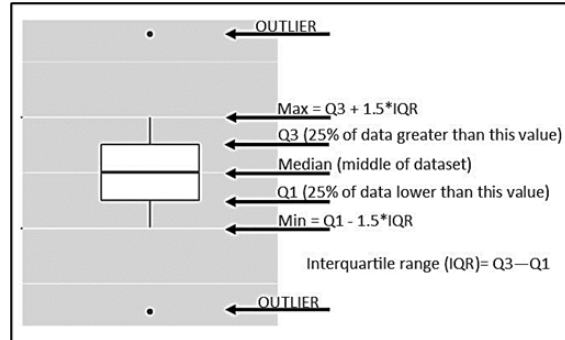

Figure 3. Statistics shown in a boxplot, also known as a box-and-whisker plot. The upper quartile (Q3) is the top of the box, and the lower quartile (Q1) is the bottom of the box. The interquartile range (IQR) is the difference between the Q3 and Q1 values, represented by the side of the box. The median is the middle of the dataset shown by the line dividing the box. The maximum and minimum are at the tips of the "whiskers," and are calculated from the IQR, the Q3, and Q1 values s shown. Outliers are data points lower or higher than the calculated min and max values, respectively.

Where applicable, data are reported in relation to the U.S. Environmental Protection Agency (EPA) drinking water standards, including the Maximum Contaminant Levels (MCL) and secondary drinking water standards defined in 40 CFR Chapter 1 Part 141, as well as applicable State of Washington trigger and reporting levels (WAC 246-290-310). MCLs are standards set for the protection of human health. Secondary Drinking Water Regulations (secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The EPA recommends secondary standards to water systems but does not require systems to comply. The State of Washington identifies trigger levels for some contaminants, which are concentrations that prompt additional sampling requirements for public water purveyors. For parameters considered here, the State's trigger levels are either equal to or one-half the MCL. The State also has reporting levels that are the minimum concentration above which the results must be reported to the Department of Health (DOH).

In regulation, these standards apply to source sampling performed by public water purveyors as prescribed in federal and state drinking water regulations. The County is not a public water purveyor and the SVRP Monitoring Program is not considered source sampling. These standards are referenced to provide context for the SVRP Monitoring Program results. While exceedances of these standards are noted in this report, such exceedances do not constitute a basis for regulatory action, as this is a non-regulatory monitoring program. Drinking water standards are provided in Appendix D.

1.6. Statistical Methods

A variety of statistical methods were used in the analysis of data. All statistical methods were implemented using R programming language (R Core Team, 2022). Data reported as non-detect (below the analytical method reporting level) were treated as "zero" in all statistical analyses.

The Mann-Kendall trend test was used to identify statistically significant trends in data sets by site and parameter. This test identifies simple monotonic (one-direction) trends over time. The Mann-Kendall test was chosen because it does not assume a data distribution (non-parametric), allows for missing data, allows for non-detect data, and is not affected by gross data errors and outliers. A 95-percent (p= 0.05) confidence level was used to identify statistically significant results.

The Seasonal Mann-Kendall test (a modification of the Mann-Kendall test) is more robust in detecting trends in data with seasonality. However, its use is only appropriate if the data exhibits seasonality and there are no opposing trends among seasons. These conditions were tested for using the Kruskal-Wallis test and the van Belle and Hughes heterogeneity test, respectively. For the purposes of these tests, data for each monitoring location and parameter was organized by quarter to represent each season as follows: quarter 1, winter; quarter 2, spring; quarter 3, summer; and quarter 4, fall. If the two conditions were not met for the Seasonal Mann-Kendall test, the non-modified Mann-Kendall test was used.

The Kruskall-Wallis test was implemented using the standard stats package in R. Seasonality was identified only in water surface elevation (WSE) data. Therefore, the details and results of the Kruskal-Wallis and the heterogeneity tests for the WSE data are discussed further in Section 3.5. Since seasonality was not identified in other data, the non-modified Mann-Kendall test was applied to all other data sets (e.g. major ions, nutrients, and total metals) and the results are shown in Sections 3.1 through 3.4. Both the Mann-Kendall and Seasonal Mann-Kendall were implemented using the EnvStats package in R (Millard 2013). The Seasonal Mann-Kendall test results include the results of the heterogeneity test.

There are some limitations with the Mann-Kendall trend test. The Mann-Kendall test loses sensitivity when applied to data sets with small sample size (n < 10) or with large proportions (>50 percent) of non-detect data. This is because the test is based on trends related to the median value and, therefore, has reasonable sensitivity when the median is based on detectable data. Given this, the test was only applied to data sets with sufficient sample size and 50 percent or fewer non-detects.

For data sets meeting these criteria, the non-detects must be appropriately treated prior to applying the test. Over the course of the 20-year period, some analytes had varying detection limits due to changes in labs and/or analytical methods (see Appendix C). In these cases, the standard practices of using the detection limit or one-half the detection limit could skew the results of the trend analysis since relative rankings of the non-detect results would not be based on true concentrations. Procedures for non-detects recommended by the EPA is to consider non-detect data "tied" in the test by setting the non-detects to the same value. Substituting the non-detect data with a value of zero does this efficiently across all data sets.

The Sen's slope estimation method was utilized to determine the magnitude of significant trends identified from the Mann-Kendall trend test. The Sen's slope is provided in the Mann-Kendall test results (both seasonal and non-seasonal). Note that the Mann-Kendall test and Sen's slope identifies trends within the given data. The identified trend and slope may not necessarily extend to periods outside that

7

considered and may change with the data utilized. For example, in Section 7, the Mann-Kendall trend test is used to assess trends in nitrate concentrations for the periods before and after sewer installation to see if a change occurred due to sewering. Section 7 also utilizes the test to assess nitrate trends over long periods of time where the data is available. These trends may differ from those reported for the 20-year period from 1999 to 2019.

The Wilcoxon Signed-Rank Test for Paired Samples is used to identify statistically significant differences between paired samples, or samples collected on the same day. This test was used to assess differences in water quality from nested wells (Section 4.1.1) and from wells completed in the confined and unconfined aquifer in the same location (Section 4.2). A 95-percent (p= 0.05) two-tailed confidence level was used to identify statistically significant results.

The Mann-Whitney (aka Wilcoxon-Mann-Whitney rank sum test or Wilcoxon rank sum test) is used to identify statistically significant differences between two independent groups of data. This test was used to compare all other sets of data where the paired samples test was not appropriate, such as comparing purveyor wells with their associated sentinel monitoring wells (Section 4.1.2) and comparing monitoring locations by type (Section 4.1.3). A 95-percent (p= 0.05) two-tailed confidence level was used to identify statistically significant results.

Both the Wilcoxon Signed-Rank Test for Paired Samples and the Mann-Whitney tests were implemented using the standard statistical package in R.

Hierarchical classification and Principal Component Analysis (PCA) are multivariate statistical techniques used in combination to identify relationships between various water quality parameters and the potential sources and processes contributing to water quality. These techniques were used to look at the County's data holistically to determine the main influences on water quality in the SVRP Aquifer (Section 9). The hierarchical classification was implemented using the standard stats package in R and the PCA was implemented using the FactoMineR package (Le, Josse, and Husson 2008). Visualization of the classification dendrogram was created using the factoextra package (Kassambara and Mundt, 2020)

2. Summary of Findings

2.1. Drinking Water Quality

The County is not a water purveyor; therefore, samples collected as part of this voluntary monitoring program are not required to meet the U.S. Environmental Protection Agency (EPA) drinking water standards or the Washington State trigger levels. Yet, these standards were used to provide context for the County's data since the Spokane Valley Rathdrum Prairie (SVRP) Aquifer is an important source of drinking water. This Program Review indicates the groundwater quality of the Spokane Valley Rathdrum Prairie (SVRP) aquifer is of overall excellent quality for drinking water. Most of the contaminants monitored by the County do not pose an on-going health risk at the levels found in the SVRP aquifer. Drinking water standards and the total number of exceedances are summarized in Appendix D. Site- and parameter-specific exceedances are provided in Appendix E.

Over the course of the 20-year period (1999 – 2019), the EPA's Maximum Contaminant Levels (MCLs) set to protect public health were met for most parameters assessed as part of the County's monitoring program. There were five, one-time MCL exceedances at different locations: four one-time exceedances of the MCL for lead (0.015 mg/L) (Section 3.4.6) and one sample with a concentration at the arsenic MCL level (0.010 mg/L) (Section 3.4.1). No other MCL exceedances occurred. Other metals with MCLs (cadmium, chromium, fluoride, and mercury) are generally not detectable throughout the aquifer.

For parameters with State trigger levels, most of these are equivalent to the MCL. This includes arsenic, cadmium, chromium, and mercury. Except for arsenic, these were not exceeded. Nitrate and fluoride are the only parameters with a more stringent State trigger level, which is equivalent to one-half of their respective MCLs. There were 33 exceedances of the State trigger level for nitrate (5 mg/L) from four locations. Most of these exceedances (n=26) occurred in samples collected from the East Valley High School monitoring well where nitrate levels are declining because of sewering (Section 3.3.1 ad 7.1.3). Therefore, exceedances are expected to decline. There were no exceedances of the fluoride State trigger level (2 mg/L) (Section 3.2.3).

Of the secondary standards, only those for iron (0.3 mg/L) and manganese (0.05 mg/L) were exceeded. Iron and manganese are not considered health risks in drinking water and, therefore, do not have MCLs. The EPA's secondary standards are set for these two metals as aesthetic contaminants, meaning they affect the appearance or usage of water above this concentration. There were 188 exceedances of the secondary standard for iron across 34 locations (Section 3.4.5). There were 40 exceedances of the secondary standard for manganese across 8 locations (Section 3.4.7).

The State reporting levels are minimum levels for reporting results to DOH and are not tied to a health criterion. This helps with monitoring levels for potentially increasing trends that could lead to reaching the State trigger levels or drinking water standards. Typical concentrations of arsenic, nitrate, chloride, and sulfate within the aquifer are above their respective State reporting levels. These parameters are likely to be reported and monitored by the purveyor. Cadmium, chromium, fluoride, mercury, copper, lead, iron, and manganese are typically well below their respective Sate reporting levels. Groundwater at most monitoring locations frequently has undetectable concentrations of these parameters (>70% non-detects).

2.2. Natural Processes and Human Activities Affecting Water Quality

The physical and chemical composition of the SVRP aquifer's subsurface material provides the foundation for how natural processes that affect its groundwater quality in four ways:

1. It makes the aquifer vulnerable to surface contaminants, except where confining layers offer some protection;
2. It allows for concentration or dilution of contaminants depending on location within the aquifer;
3. It maintains generally oxic, alkaline conditions throughout the aquifer; and
4. It allows the Spokane River and aquifer to interact.

Coarse-grained sediments have larger spaces through which water can easily move, both vertically and horizontally. This makes the aquifer vulnerable to contamination from surface activities. A well-known example of this is the presence of nitrates in the aquifer due to the use of onsite wastewater treatment, or septic systems. Background nitrate levels in groundwater without human activities are less than 1 mg/L (Harter, 2003). Nitrate levels in the SVRP aquifer were nearing the MCL (10 mg/L) in some locations by the early 1980s. Health concerns over increasing nitrate levels was the impetus for the County's Septic Tank Elimination Program (STEP), which addressed nitrate contamination at the source by expanding the sewer system into Spokane Valley and northern Spokane. Data suggests that the STEP was successful in reducing nitrates in sewered areas (Section 7), but that upgradient non-sewered areas continue to be a source of nitrates.

Chloride is another well-known indicator of human activities. While chloride is naturally abundant in rocks and soil, chloride also has sources from human activities that could impact groundwater. These activities include but are not limited to deicing salts, septic system discharge, drinking water and wastewater treatment, leachate from landfills, and fertilizers. Chloride is conservative (non-reactive) in the environment, which means little is lost when it is released from these various sources. Aquifers across the U.S. have seen increasing trends in chloride levels, particularly under urbanized areas (Mullaney et al, 2009). The SVRP aquifer is no exception. Chloride is the only parameter with increasing levels at nearly every monitoring location (Section 3.2.2).

Parameters typically indicative of surface activities such as chloride and nitrate are expected to become less concentrated through dilution, or mixing with groundwater, as they move through the aquifer. Both chloride and nitrate had statistically significant lower concentrations deeper in the aquifer based on analysis of nested wells (see Section 4.1). However, this amounted to only about a 0.2 mg/L difference in these contaminants between nested wells. Confining layers, which inhibit vertical movement of groundwater, offer the confined aquifer below them protection from surface contaminants. For example, the Hillyard Trough confined aquifer had significantly lower levels of chloride and nitrate than the above unconfined aquifer. This amounted to a greater difference, with the confined aquifer having nearly half the concentration of these contaminants. In addition, though chloride levels are increasing in the nearby unconfined aquifer, they were stable in the confined aquifer (see Section 4.2).

The horizontal movement of contaminants also promotes dilution because the aquifer's thickness changes. Aquifer thickness indicates how much groundwater can be held within the sediments. The margins of the aquifer cannot hold as much water because the sediments are thinner and contain more fine-grained sediments. This slows mixing, allowing contaminants to concentrate at the margins. Once

groundwater moves to the thicker main body of the aquifer, dilution occurs because more groundwater is available for mixing. Distribution mapping shows the relationship between chloride, other major ions, and nitrate concentrations and the aquifer thickness (see Section 3.2 and 3.3). This dilution process is one of the main driving factors in the aquifer's water quality (see Section 9).

The aquifer's physical and chemical composition promotes oxic, alkaline conditions and limits the development of anoxic and acidic conditions. Table 2 summarizes the conditions at the SVRP monitoring locations based on median values of dissolved oxygen and pH.

Table 2. Conditions at monitoring locations that drive geochemical processes in groundwater. Categorization is based on 20-year median values of dissolved oxygen (DO) and pH.

	pH <7 (Acidic)	pH >7 (Alkaline)
DO <0.5 (Anoxic)	1	None
DO >0.5 (Oxic)	3	47

The SVRP aquifer's coarse-grained material allows for groundwater recharge and flow that maintains mostly oxic conditions (dissolved oxygen levels >0.5 mg/L). Median dissolved oxygen concentrations for most monitoring locations (n = 50) falls between 5.8 to 10.5 milligrams per liter (mg/L) (Section 3.1.2). Anoxic conditions (dissolved oxygen <0.5 mg/L) generally develop in aquifers with a high proportion of fine-grained, organic matter. Organic matter consumes dissolved oxygen during decomposition and introduction of dissolved oxygen is limited because groundwater recharge and flow is relatively slow in fine-grained material.

The aquifer is comprised of calcium-magnesium-bicarbonate type groundwater due to the dissolution of these minerals from the sediments and rocks in contact with the groundwater. This chemical composition is responsible for the aquifer having hard (associated with high concentrations of calcium and magnesium) and slightly alkaline (pH > 7) water. Median pH for most monitoring locations (n = 47) is greater than pH 7. Acidic conditions are defined as groundwater having pH of less than 7.

There are four monitoring locations where natural influences have produced exceptions from the primarily oxic, alkaline conditions found throughout much of the aquifer.

Groundwater sampled from the Plantes Ferry monitoring well tends to be anoxic and slightly acidic. This well is completed beneath a confining layer of fine sediments, which impedes recharge and mixing with the upper aquifer. The groundwater at this location may occasionally increase to near-neutral pH and slightly oxic conditions, but these fluctuations do not appear to be seasonal. The acidic, anoxic conditions resulting from the confining layer are responsible for the unique groundwater chemistry at this location, as discussed in more detail in Section 4.2.

Three wells adjacent to Spokane River at Barker Road tend to have oxic, acidic groundwater. However, groundwater at these locations may increase to just above neutral pH and can temporarily have anoxic conditions. The fluctuations in pH and dissolved oxygen in groundwater at these locations are seasonal, with pH and dissolved oxygen generally the lowest in summer and highest in winter. This is due to the influence of the Spokane River on the aquifer at these locations, which is discussed in more detail in Section 5.1.

Outside of these four exceptions, no other natural or human-induced conditions appear to alter the generally oxic, alkaline conditions within the aquifer. It is important to note that quarterly sampling only

provides a snapshot of conditions at the exact moment sampling occurs and any drops to anoxic or acidic levels that may occur between sampling events could have been missed.

The combination of dissolved oxygen and pH levels influence the presence and transport of various contaminants including nutrients (nitrate and phosphorus) and trace metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, and zinc). This is because dissolved oxygen and pH control various natural geochemical processes that regulate these contaminants in groundwater. These processes are other major drivers in the aquifer's water quality (see Section 9).

Although the STEP controlled nitrates at the source, once in the aquifer nitrate mobility is controlled by dissolved oxygen levels. In groundwater with oxic conditions, nitrate can persist for decades. This is because denitrification, the process by which nitrate is naturally transformed into nitrogen gas, occurs only under anoxic conditions (Figure 4). In the SVRP aquifer, oxic conditions allow nitrate transported from upgradient unsewered areas to continue impacting some sewered areas (see Section 7). Conditions supporting denitrification only occur in the confined aquifer at Plantes Ferry, producing generally undetectable nitrate levels (Section 4.2).
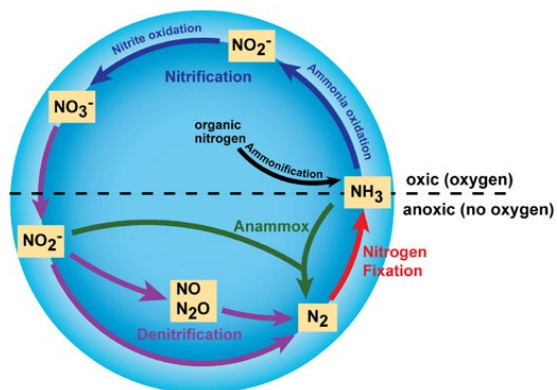

Figure 4. The Nitrogen Cycle processes separated by those occurring in oxic and anoxic conditions. Nitrate [NO_3^-] can persist in oxic conditions because denitrification occurs in anoxic conditions. This process reduces nitrate to nitrite [NO_2^-] and eventually to nitrogen gas (N_2).
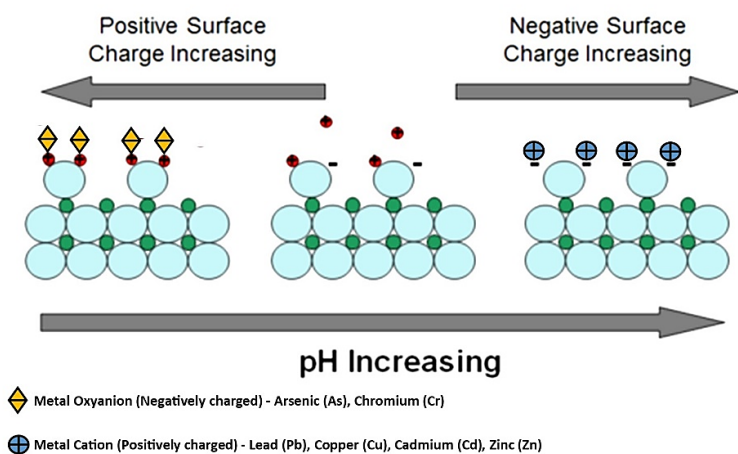

Figure 5. A model demonstrating how the adsorption of trace metals is affected by changes in pH levels. Metals that exist as oxyanions (e.g. arsenic, chromium) adsorb to aquifer sediments at lower pH as the surface charge becomes positive. Metals that exist at cations (e.g. cadmium, copper, lead, and zinc) adsorb to aquifer sediments at higher pH as the surface charge becomes more negative. Modified from ITRC (2010).

The mobility of phosphate and trace metals is linked with both dissolved oxygen and pH levels via two processes: adsorption and dissolution. Phosphate is of concern due to its contribution to eutrophication and low dissolved oxygen levels in both the Spokane River and Lake Spokane (Moore and Ross, 2010). Groundwater can be a source of phosphate to these surface waters (Section 5). Trace metals such as arsenic, cadmium, chromium, copper, iron, lead, and zinc are a concern because these can be toxic at certain concentrations.

12

Aquifer sediments are coated with metal oxides (usually iron or manganese oxides) that provide a surface onto which other elements can adsorb or attach. This process works like a magnet: when the coatings are negatively charged, they attract positively charged elements and vice versa. A simplified model demonstrating the sorption process is shown in Figure 5. When elements adsorb to the metal oxides, they are removed from the groundwater. The metal oxides can also release attached elements into the groundwater, either when the surface charge changes with pH or because the metal oxide itself dissolves.

The oxic conditions within the SVRP aquifer maintain the stability of the metal oxide coatings, which tend to dissolve under anoxic conditions. Therefore, the pH-driven adsorption processes have a greater influence on water quality throughout most of the aquifer.

Under alkaline conditions within much of the SVRP aquifer, the metal oxide coatings are more negatively charged. Therefore, elements that commonly exist as positively charged ions such as cadmium, copper, lead, and zinc will adsorb to aquifer sediments in these conditions. This explains the generally low concentrations and prevalence of non-detectable levels of these elements in the SVRP aquifer. Alkaline conditions have the opposite effect on phosphate, arsenic, chromium. These commonly exist as negatively charged oxyanions and, therefore, do not adsorb on the metal oxides as pH increases (Deverel et al 2012; McLean and Bledsoe, 1992; Smith 2007). This explains why phosphate and arsenic are generally detectable throughout the aquifer (Section 3.3.2 and 3.4.1).

Although arsenic within the aquifer is largely the result of geologic sources and natural conditions within the aquifer (e.g., pH and dissolved oxygen levels), the data indicate human activities may have localized influences on groundwater arsenic levels. For example, the Upriver Dam/Donkey Island and the Holcim Inc cleanup sites resulted in arsenic levels in sediments that exceeded state standards, and these sites are in the vicinity of elevated groundwater concentrations. Cleanup activities at the Upriver Dam/Donkey Island site were completed in 2006 and 2007, and in 2016 at the Holcim site. Though it may not be related, samples from wells in the vicinity of the Upriver Dam/Donkey Island site show decreasing levels of arsenic. Groundwater arsenic levels in samples from wells near the Holcim site were stable. Since clean-up activities at Holcim occurred relatively recently, the data may not yet reflect a response to these activities.

The Spokane River has a distinguishable effect on groundwater by influencing natural processes and providing a source for some metals in the river-influenced groundwater (Section 5.1). The generally acidic river-influenced groundwater causes arsenic to adsorb to sediments but prevents adsorption of cadmium, copper, lead, and zinc. Although cadmium, copper, lead, and zinc are transported into the groundwater from the river, these metals are not transported very far into the aquifer because the pH levels increase and promote their adsorption.

The confined aquifer at Plantes Ferry also has a unique groundwater chemistry because of the anoxic, acidic conditions (Section 4.2). The anoxic conditions promote dissolution of the metal oxides in aquifer and the mobility of phosphorus. This results in the Plantes Ferry confined aquifer having the highest iron, manganese, and phosphorus levels in the aquifer. The anoxia also promotes denitrification, resulting in generally non-detectable levels of nitrate. The acidic conditions promote adsorption of arsenic, also resulting in non-detectable levels of the metal.

3. Groundwater Quality Summaries

This section summarizes raw data for each water quality parameter for the 20-year period from 1999 through 2019. The parameters are discussed in alphabetical order by analyte group: field parameters, major ions, nutrients, and total metals.

3.1. Field Parameters

3.1.1. Conductivity

Conductivity measures water's ability to conduct electrical current and is directly related to the concentration of ions (charged particles) in the water. Conductivity is important for identifying where the Spokane River influences groundwater quality, as proximity to the river is not necessarily indicative of river influence (see Section 5).

Conductivity data are summarized in Appendix E. Levels in the aquifer range from 72 to 481 uS/cm with an overall median of 275 uS/cm (Figure 6). The spatial distribution of conductivity in relation to aquifer thickness is shown in Figure 7. Median conductivity at individual monitoring locations ranges from 53.50 to 537.40 uS/cm. The lowest conductivity occurs in groundwater at monitoring locations influenced by the Spokane River, which are along Barker Road adjacent to a losing reach of the river.

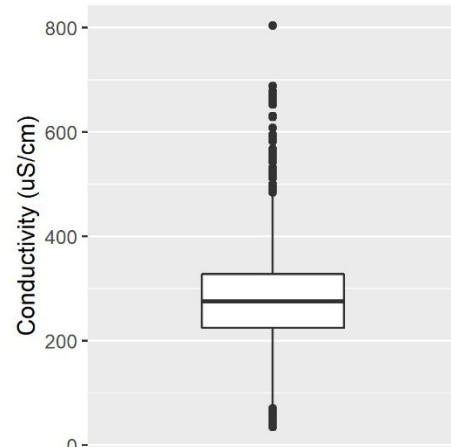Figure 6. Boxplot showing the statistical distribution of 3,183 conductivity measurements collected at 51 monitoring locations between 1999 and 2019.
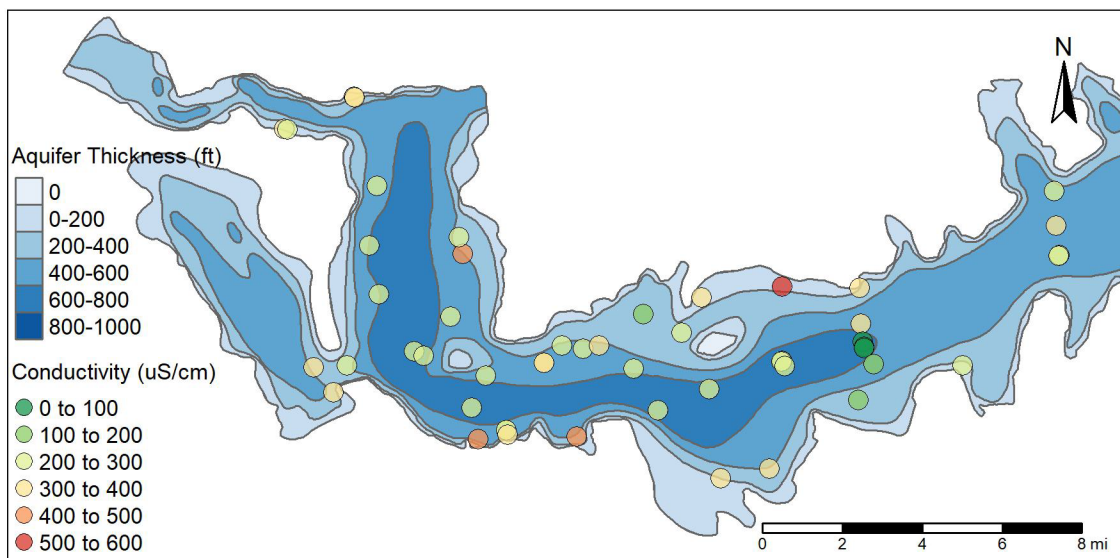

Figure 7. Spatial distribution of median conductivity (uS/cm) within the Spokane Valley Rathdrum Prairie aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007).

Outside of the river-influenced wells, conductivity is generally higher along the margins of the aquifer and lower in the main body of the aquifer, except in a few locations. This demonstrates conductivity is generally related to the amount of groundwater, which influences the concentrations of major ions through dilution.

3.1.2. Dissolved Oxygen

Dissolved oxygen (DO) is important for identifying oxic (DO >0.5mg/L) and anoxic (DO <0.5mg/L) conditions, which affect groundwater quality. DO data are summarized in Appendix E. Levels within the aquifer range from 4.41 to 12.54 mg/L with an overall median of 8.53 mg/L (Figure 8).

The spatial distribution of DO levels is shown in Figure 9. Groundwater sampled from the Plantes Ferry monitoring well has persistent anoxic conditions (median is 0.29 mg/L) due to a confining layer (see Section 4.2). Otherwise, groundwater in the aquifer has oxic conditions, with median DO ranging from 5.81 to 10.51 mg/L at other sites. Of these, the lowest DO concentrations occur in the Hillyard Trough/North Spokane, the river-influenced wells on Barker Road, and locations between the Stateline/Idaho Road and Barker Road (median concentrations <8.0 mg/L). The natural springs locations have some of the highest DO levels, likely due to exchange with the air.

Figure 8. Boxplot showing the statistical distribution of 1,288 dissolved oxygen measurements collected at 51 monitoring locations between 1999 and 2019.
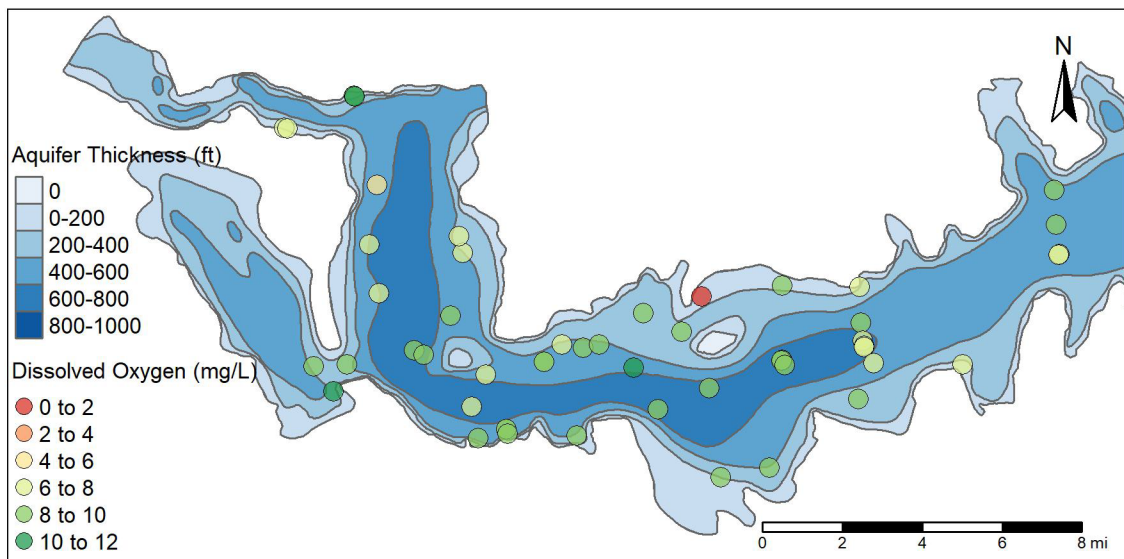
Figure 9. Spatial distribution of median dissolved oxygen (mg/L) within the Spokane Valley Rathdrum Prairie aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

3.1.3. pH

pH is important because acidic (pH<7) and alkaline (pH>7) conditions influence groundwater quality. The pH data are summarized in Appendix E. Levels within the aquifer range from 6.74 to 8.60 with an overall median of 7.72 (Figure 10).

The spatial distribution of pH levels is shown in Figure 11. Median pH at individual monitoring locations ranges from 6.84 to 8.27.

Slightly acidic conditions exist in the groundwater sampled from the confined aquifer at Plantes Ferry (median 6.84) and the three river-influenced monitoring wells at Barker Road (medians between 6.84 and 6.97). All other monitoring locations have alkaline conditions. Of these, the lowest pH occurs at the margins of the aquifer where median pH is near neutral.
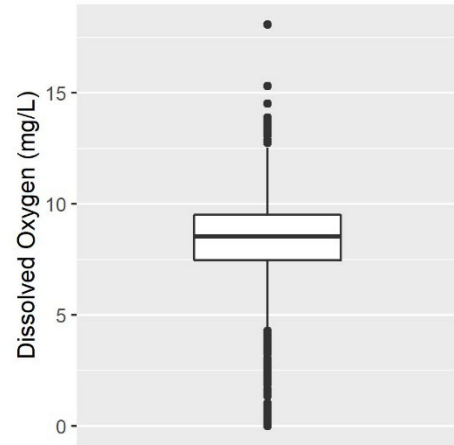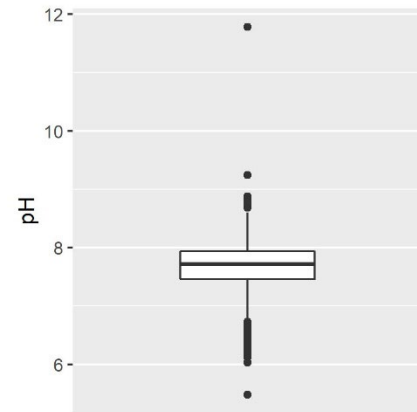

Figure 10. Boxplot showing the statistical distribution of 3,037 pH measurements collected at 51 monitoring locations between 1999 and 2019.
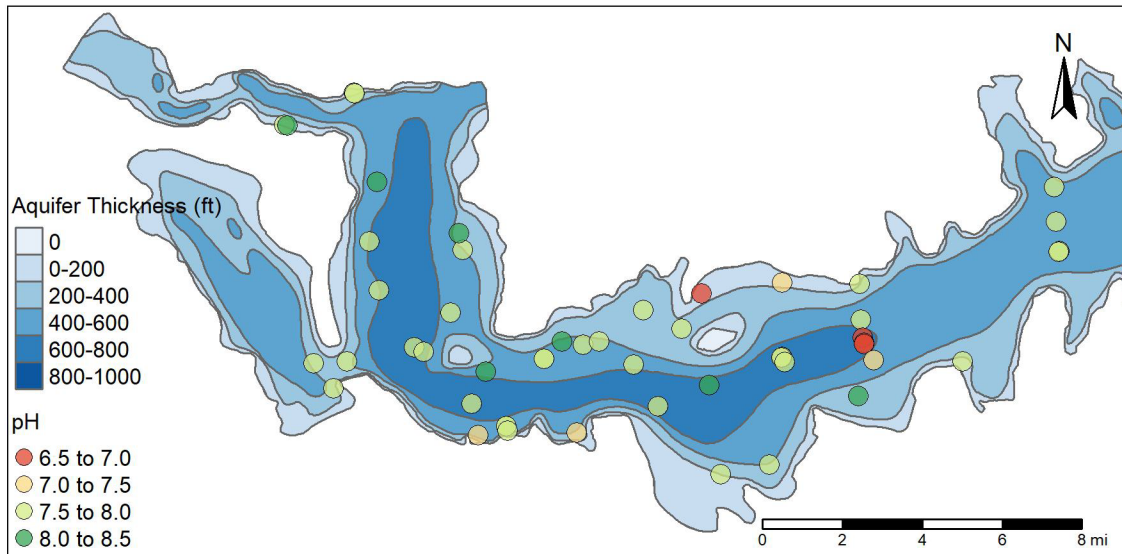
Figure 11. Spatial distribution of median pH within the Spokane Valley Rathdrum Prairie aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

3.1.4. Temperature

Groundwater temperature influences other parameters such as dissolved oxygen and pH. Groundwater temperature data is summarized in Appendix E. Temperatures within the aquifer range from 7.37 to 16.80 Celsius (C) with an overall median of 12 C (Figure 12).

The spatial distribution of groundwater temperature in relation to aquifer thickness is shown in Figure 13. Median groundwater temperature at individual monitoring locations ranges from 10.50 C to 13.8 C.

Spatial patterns in groundwater temperature are not easily apparent. However, the river-influenced locations on Barker Road are generally warmer and, outside of a few locations, groundwater generally warms from east to west.
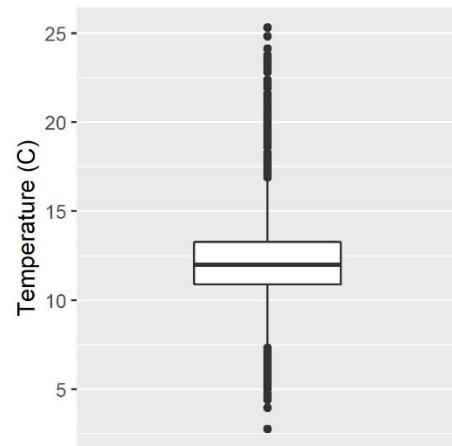

Figure 12. Boxplot showing the statistical distribution of 3,205 groundwater temperature measurements collected at 51 monitoring locations between 1999 and 2019.
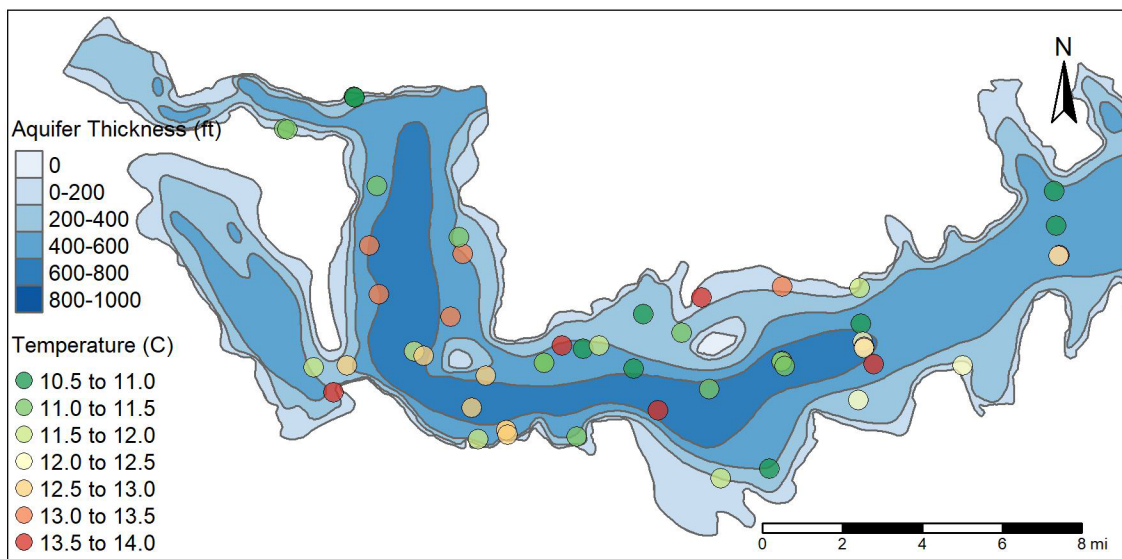
Figure 13. Spatial distribution of median groundwater temperature (Celsius) within the Spokane Valley Rathdrum Prairie aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

3.2. Major and Minor Ions

3.2.1. Calcium

Calcium data are summarized in Appendix E. Levels within the aquifer range from 9.89 to 54.5 mg/L with an overall median of 32.4 mg/L (Figure 14). All samples had detectable levels of calcium.

Spatial distribution of calcium levels within the aquifer are shown in Figure 15A. Median concentrations at each monitoring location range from 5.87 to 65.4 mg/L. The lowest concentrations occur in groundwater from river-influenced wells along Barker Road. The highest concentrations occur in groundwater from the East Valley High School (EVHS) monitoring well and other locations along the margins of the aquife


Figure 14. Boxplot showing the statistical distribution of calcium concentrations (mg/L) of 2,445 samples collected at 51 monitoring locations between 1999 and 2019.

Figure 15. (A) Spatial distribution of median calcium concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in calcium concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

During the 20-year period, calcium levels at most locations were either stable or decreasing (Figure 15B). Decreasing trends occurred in the western portion of the aquifer underlaying the City of Spokane. Levels were stable in the eastern portion from the Spokane Valley to the Stateline. Only Waikiki Springs (6306P01s) had increasing levels. Three sites did not have enough data for a trend analysis.

18

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Calcium in groundwater does not pose a health hazard and does not have applicable drinking water quality standards. However, calcium and magnesium contribute to water hardness.

3.2.2. Chloride

Chloride data are summarized in Appendix E. Levels within the aquifer range from non-detect (below the reporting limit of 0.2 mg/L) to 13.9 mg/L with an overall median of 4.09 mg/L (Figure 16). Less than 1 percent of all samples were non-detect.

The spatial distribution of chloride levels within the aquifer is shown in Figure 17A. Median concentrations at each monitoring location range from 1.26 to 17.55 mg/L. The lowest concentrations occur in groundwater from the river-influenced wells along Barker Road. The highest concentrations occur along the margins of the aquifer.
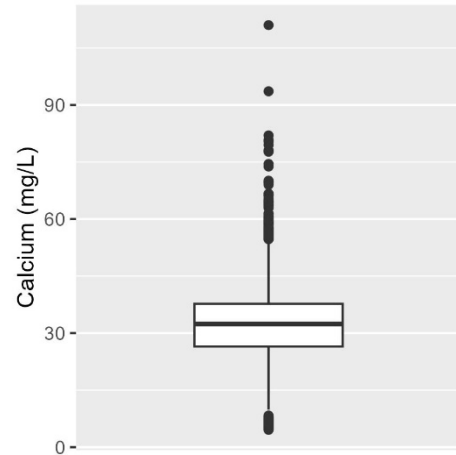
Figure 16. Boxplot showing the statistical distribution of chloride concentrations (mg/L) of 3,038 samples collected at 51 monitoring locations between 1999 and 2019.

Trend analysis indicates chloride levels increased at most locations (n = 46) over the 20-year period and were stable at five locations (Figure 17B). Two of the locations with stable concentrations are the North Spokane Irrigation District well and the Plantes Ferry monitoring well, which represent conditions in separate confined aquifers (see Section 4.2). The remaining three stable locations have smaller datasets.

Chloride does not pose a health hazard and does not have an MCL. As an aesthetic contaminant, chloride has a secondary standard of 250 mg/L to maintain palatability and use. However, chloride levels across the aquifer are well below 250 mg/L. There is no State trigger level for chloride.
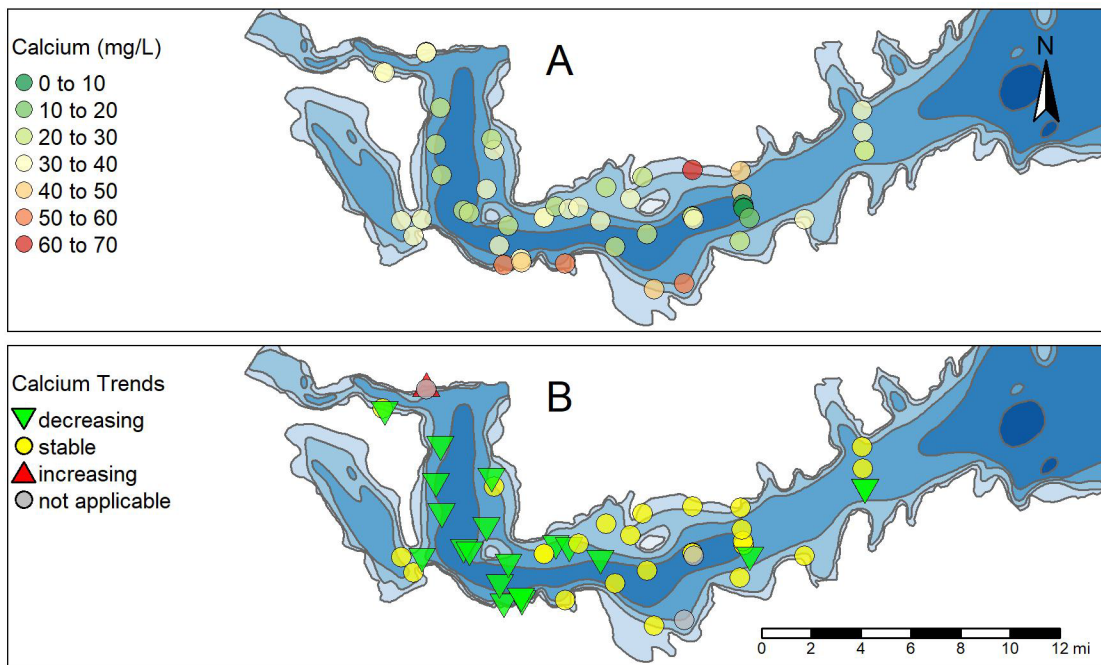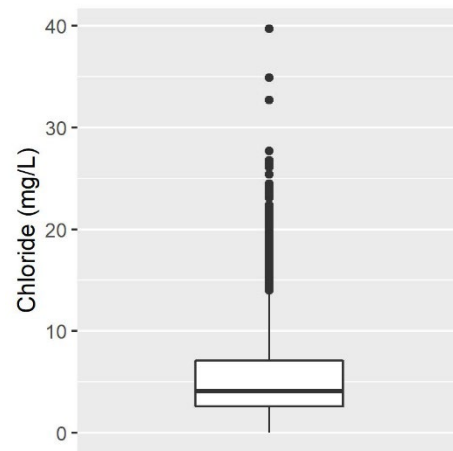
Figure 17. (A) Spatial distribution of median chloride concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in chloride concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

3.2.3. Fluoride

Fluoride data are summarized in Appendix E. Most samples (88 percent) were non-detect. Given this, the statistical distribution of fluoride data is not shown. Fluoride is generally not at detectable levels in the aquifer, except at three locations: the monitoring wells at EVHS (6306N01) and Plantes Ferry (5404A01), and the Vera Water and Power well (5426L03) (Figure 18A). The groundwater at the EVHS and Vera wells has median concentrations near 0.1 mg/L. Samples from the Plantes Ferry had a median concentration of 0.296 mg/L, nearly three times the other two locations. However, this represents unique conditions in a confined aquifer (see Section 4.2). Only the Plantes Ferry monitoring well had enough data to complete a trend analysis, which indicated stable fluoride concentrations over the 20-year period (Figure 18B).

Fluoride has a MCL of 4 mg/L. The secondary standard and State trigger level are both set at 2 mg/L. These levels were never exceeded during the 20-year period. The U.S. Department of Health and Human Services (HHS) recommends fluoride at 0.7 mg/L in drinking water as optimal for dental health, as fluoride helps prevent tooth decay. However, fluoride levels are generally below the HHS recommended levels.
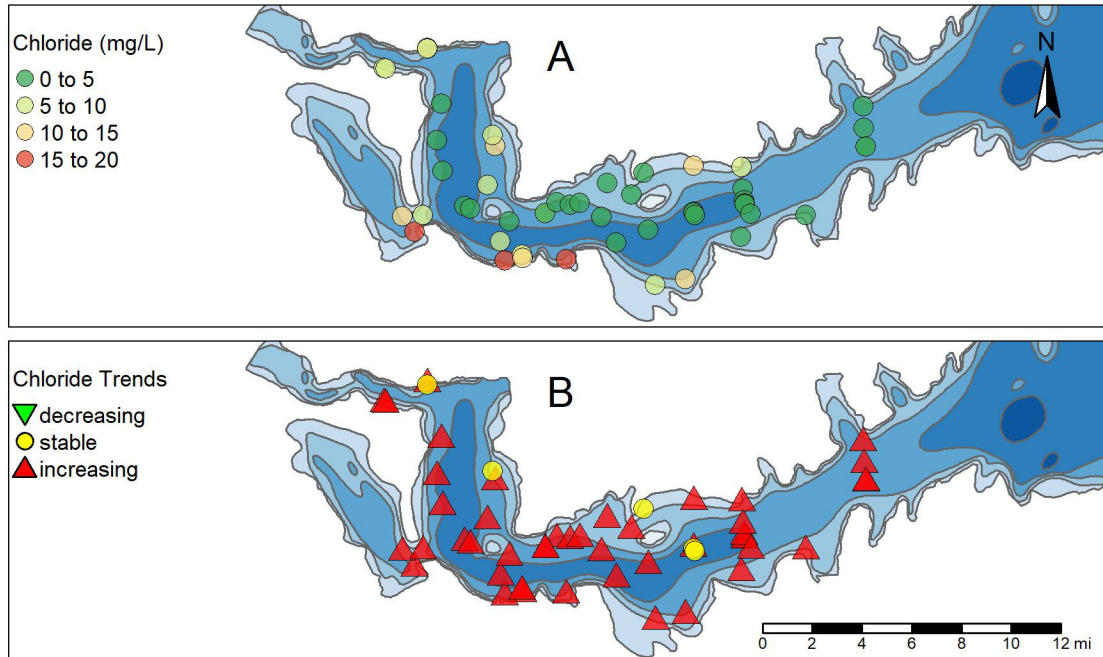
Figure 18. (A) Spatial distribution of median fluoride concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness data layer is modeled from Kahle and Bartolino (2007). (B) Trends in fluoride concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

3.2.4. Magnesium

Magnesium data are summarized in Appendix E. Levels within the aquifer range from 1.35 to 25.55 mg/L with an overall median of 13.20 mg/L (Figure 19). All samples had detectable levels of magnesium.

The spatial distribution of magnesium levels throughout the aquifer is shown in Figure 20A. Median concentrations at each monitoring location ranged from 1.71 to 28.9 mg/L. The lowest concentrations occur in groundwater from the river-influenced wells on Barker Road. The highest concentrations are found along the margin of the aquifer.

During the 20-year period, magnesium levels across the aquifer were primarily stable (n = 21) or decreasing (n = 26). Only Waikiki Springs (6306P01s) had increasing levels. Three locations did not have enough data for a trend analysis (Figure 20B).

Figure 19. Boxplot showing the statistical distribution of magnesium concentrations (mg/L) of 2,445 samples collected at 51 monitoring locations between 1999 and 2019.

Magnesium in groundwater does not pose a health hazard and does not have applicable drinking water quality standards. However, magnesium in groundwater contributes to water hardness.
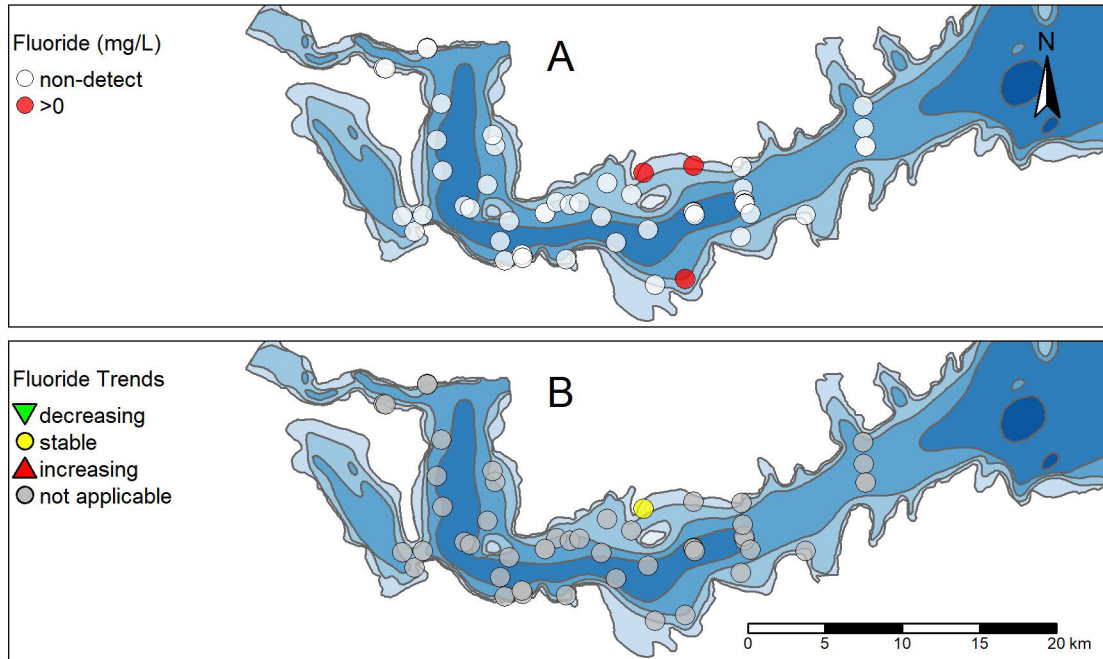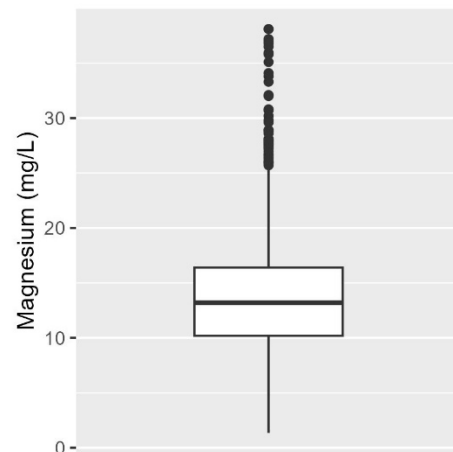
Figure 20. (A) Spatial distribution of median magnesium concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in magnesium concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

3.2.5. Potassium

Potassium data are summarized in Appendix E. Levels within the aquifer range from 0.89 to 3.16 mg/L with an overall median of 2.01 mg/L (Figure 21). Less than 1 percent of all samples were non-detect (below the reporting limit of 0.5 mg/L).

The spatial distribution of potassium levels within the aquifer is shown in Figure 22A. Median concentrations at each monitoring location ranged from 0.84 to 5.34 mg/L. The lowest levels occur in groundwater from the river-influenced wells on Barker Road. The highest concentrations are along the margin of the aquifer.

Trend analysis indicates potassium levels at most monitoring locations (n = 31) were stable over the 20-year period. Of the remaining locations, fourteen had decreasing levels and three had increasing levels. Trend analysis was not conducted for three locations due to small sample size (Figure 22B).
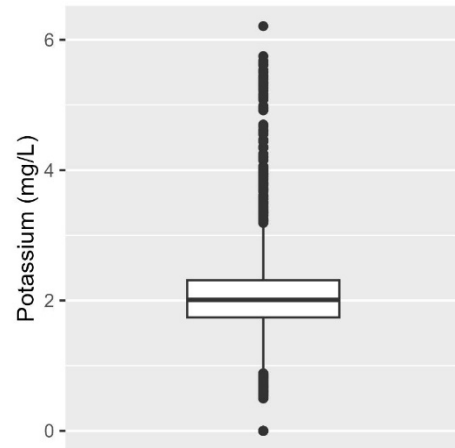
Figure 21. Boxplot showing the statistical distribution of potassium concentrations (mg/L) of 2,403 samples collected at 51 monitoring locations between 1999 and 2019.

Potassium in groundwater does not pose a health hazard and does not have applicable drinking water quality standards.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
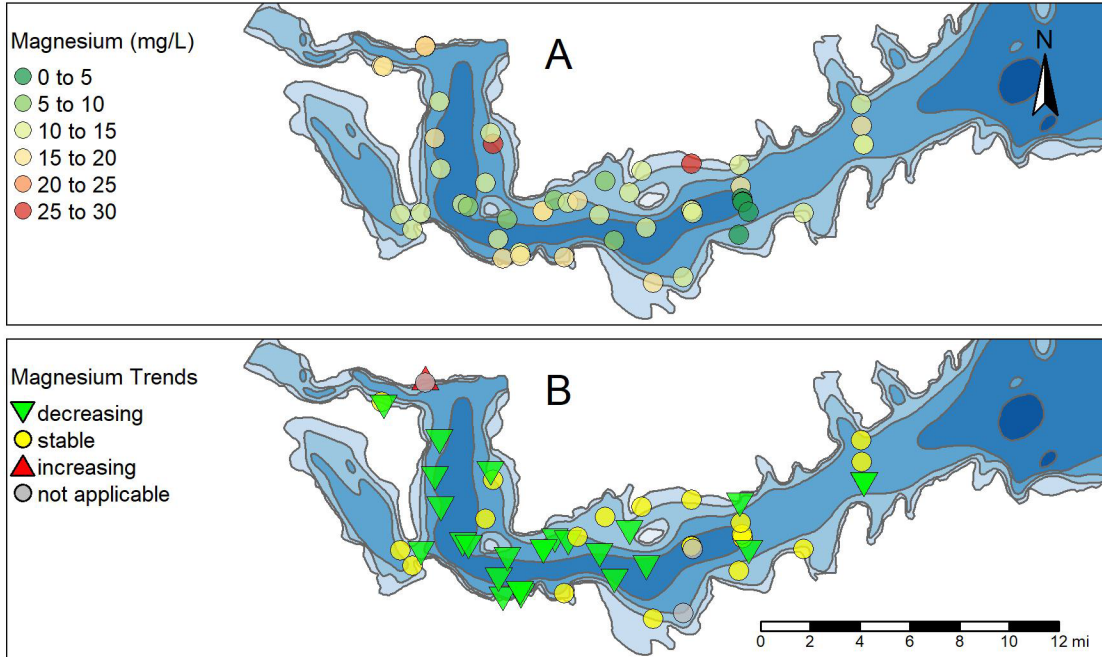Spokane County Water Resources, Dec. 2023

Figure 22. (A) Spatial distribution of median potassium concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in potassium concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

3.2.6. Sodium

Sodium data are summarized in Appendix E. Levels across all samples range from non-detect (below the analytical reporting limit of 0.5 mg/L) to 8.54 mg/L with an overall median of 3.72 mg/L (Figure 23). Less than 1 percent of the samples were non-detect.

The spatial distribution of sodium levels within the aquifer is shown in Figure 24A. Median concentrations at each monitoring location range from 1.87 to 11.80 mg/L. The lowest concentrations occur in groundwater from the river-influenced wells on Barker Road. The highest concentrations are along the margin of the aquifer.

Trend analysis indicates sodium levels were stable at most monitoring locations (n = 30) over the 20-year period. Of the remaining locations, 16 had decreasing levels and two had increasing levels. Trend analysis was not conducted for three locations due to small sample size (Figure 24B).

Sodium in groundwater does not pose a health hazard and does not have applicable drinking water quality standards.

Figure 23. Boxplot showing the statistical distribution of sodium concentrations (mg/L) of 2,447 samples collected at 51 monitoring locations between 1999 and 2019.

23

SVRP Aquifer Long-Term Monitoring Program
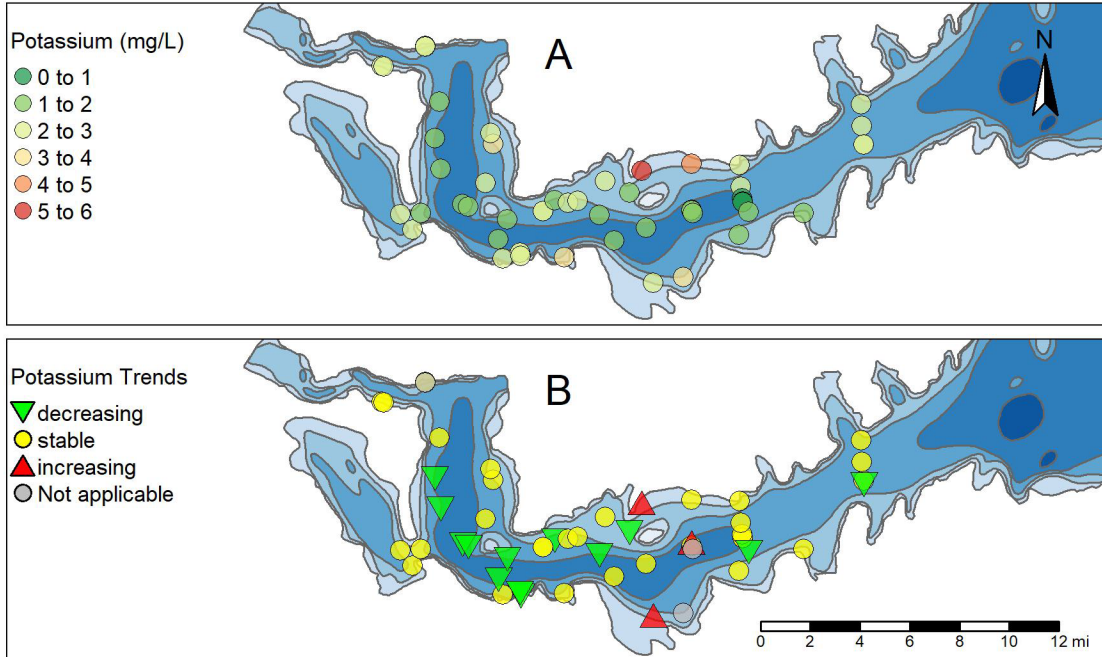20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Figure 24. (A) Spatial distribution of median sodium concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness data layer is modeled from Kahle and Bartolino (2007). (B) Trends in sodium concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

3.2.7. Sulfate

Sodium data are summarized in Appendix E. Sulfate analysis was discontinued after February 2011. Three locations do not have sulfate data as they were added to the monitoring network after the analysis was discontinued.

Sulfate levels within the aquifer range from 1.73 to 23 mg/L with an overall median of 11.70 mg/L (Figure 25). Less than 1 percent of the samples (n = 1) were non-detect (below the analytical reporting limit of 0.3 mg/L).

The spatial distribution of sulfate levels throughout the aquifer is shown in Figure 26A. Median concentrations at each monitoring location range from 4.13 to 21.40 mg/L. The lowest concentrations occur in samples collected from the river-influenced wells along Barker Road. The highest median concentration occurred at the Plante's Ferry monitoring well, which represents unique conditions in a confined aquifer (see Section 4.2).
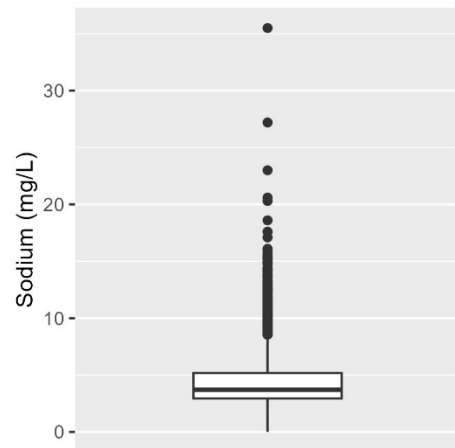

Figure 25. Boxplot showing the statistical distribution of sulfate concentrations (mg/L) of 1,979 samples collected at 51 monitoring locations between 1999 and 2011.

Trend analysis indicates sulfate levels were largely stable (n=23) or decreasing (n=21) over the 20-year period. Only three locations exhibited increasing levels. Four sites did not have enough data to complete a trend analysis (Figure 26B).

Sulfate does not pose a health hazard; it is an aesthetic contaminant with a secondary standard of 250 mg/L to maintain palatability and use. Sulfate levels across the aquifer are well below these levels. There is no State trigger level for sulfate.
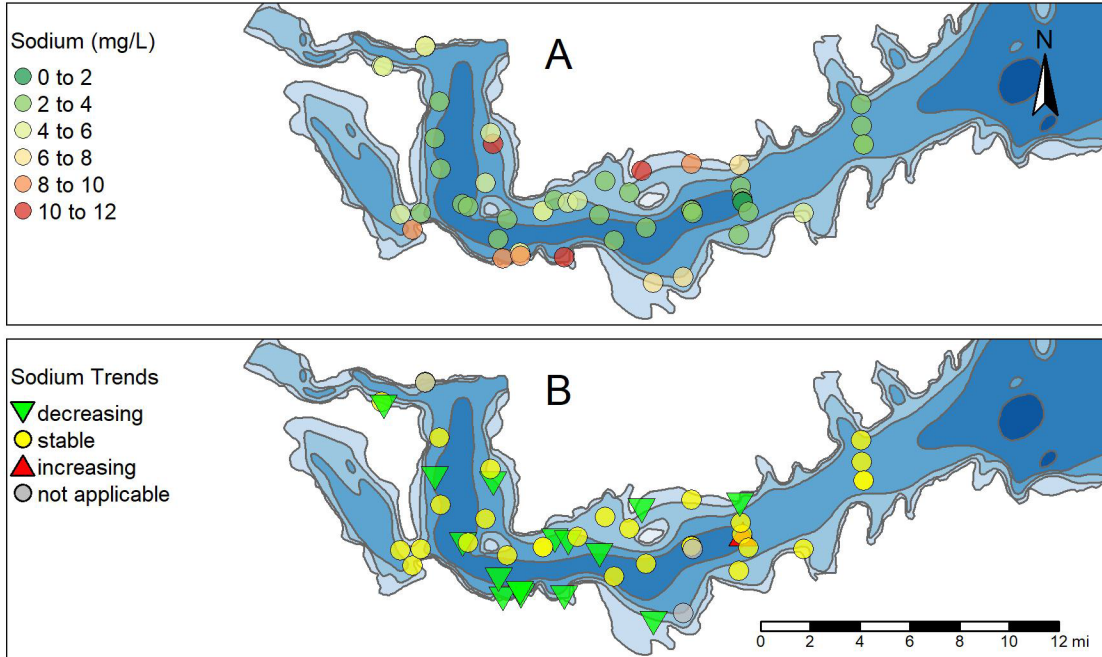

Figure 26. (A) Spatial distribution of median sulfate concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in sulfate concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

3.3. Nutrients

3.3.1. Nitrate

Nitrate data are summarized in Appendix E. Levels across all samples ranged from non-detectable levels (below the reporting limit 0.05 mg/L) to 3.77 mg/L with an overall median of 1.49 mg/L (Figure 27). Less than 1 percent of all samples were non-detect. Most non-detect samples were from the Plantes Ferry monitoring well, which represents conditions in a confined aquifer. These non-detects constitute 70 percent of samples from this location (see Appendix E).

The spatial distribution of nitrate levels within the aquifer is shown in Figure 28A. Median concentrations at each monitoring location range from non-detectable levels to 4.94 mg/L. The highest concentrations occurred in samples from the EVHS monitoring well. Other areas of elevated nitrate levels occur along the margin of the aquifer. The lowest levels are found in river-influenced groundwater along Barker Road.
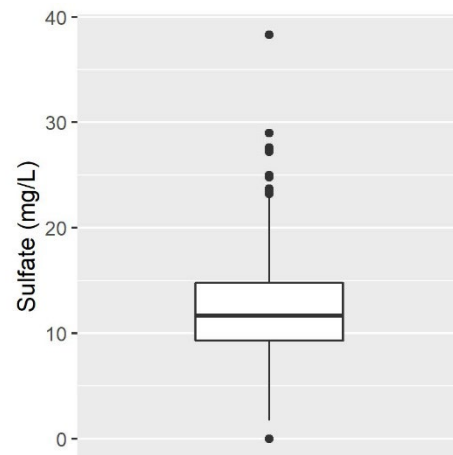

Figure 27. Boxplot showing the statistical distribution of nitrate concentrations (mg/L) of 3,083 samples collected at 51 monitoring locations between 1999 and 2019.

Trend analysis indicates nitrate levels increased at 13 monitoring locations, decreased at 23 locations, and were stable at 14 locations over the 20-year period (Figure 28B). Locations where nitrate concentrations increased included the 8 locations outside of a sewer service area and 6 locations influenced by nitrate transport from upgradient, non-sewered areas (see Section 7). The Plantes Ferry monitoring well did not have enough data to perform a trend analysis.

Nitrate has a MCL of 10 mg/L and a State reporting level of 5 mg/L. Over the 20-year period, the MCL was never exceeded. However, 33 samples from four monitoring locations had concentrations at or above the State reporting level (Figure 28C). Most of these exceedances (n=26) occurred in samples collected from the EVHS monitoring well. Three of the four sites have not had an exceedance in the last 10 years.
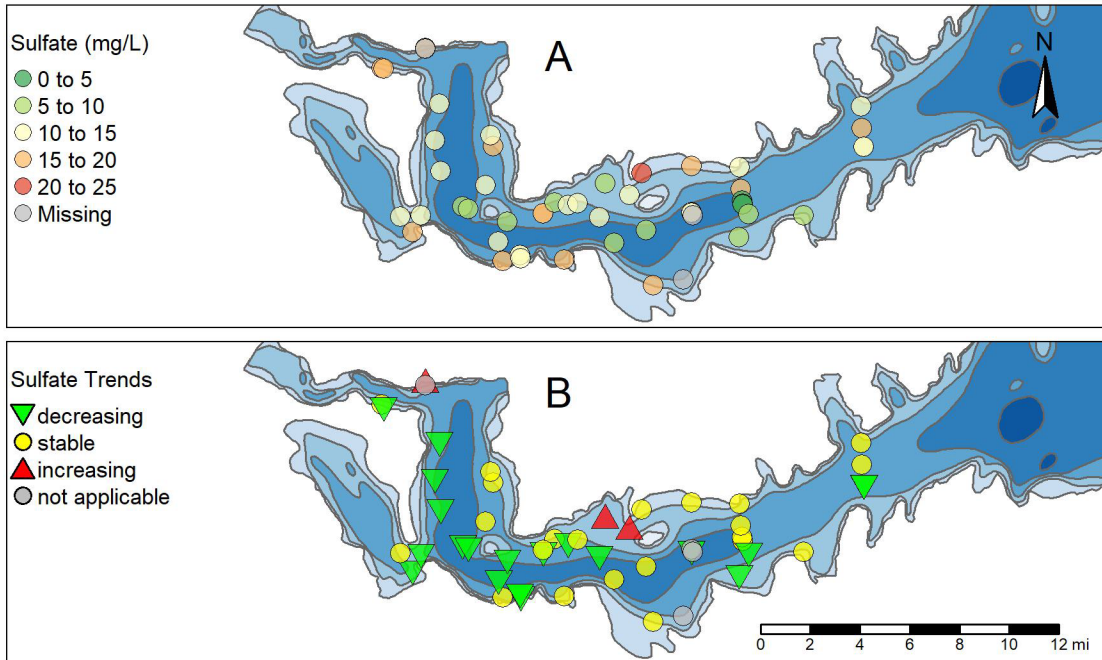
Figure 28. (A) Spatial distribution of median nitrate concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in nitrate concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019. (C) Number of exceedances of the State reporting level for nitrate (5 mg/L) over the 20-year period between 1999 and 2019.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

3.3.2. Phosphorus

Total phosphorus data are summarized in Appendix E. Levels within the aquifer range from non-detectable levels (below the reporting limit) to 0.0228 mg/L with an overall median of 0.0060 mg/L (Figure 29). Approximately 9 percent samples were non-detect. Reporting limits changed over the years (Appendix C).

The spatial distribution of phosphorus levels throughout the aquifer is shown in Figure 30A. Groundwater from the Plantes Ferry well, which represents unique conditions in a confined aquifer, has the highest median phosphorus concentration at 0.231 mg/L. This is well above the other locations, which have median concentrations ranging from 0.0025 to 0.05 mg/L.

Trend analysis indicates most locations (n = 33) had stable phosphorus levels over the 20-year period. Of the remaining locations, 16 exhibited decreasing levels and 2 exhibited increasing levels (Figure 30B). There are no drinking water quality standards for total phosphorus.
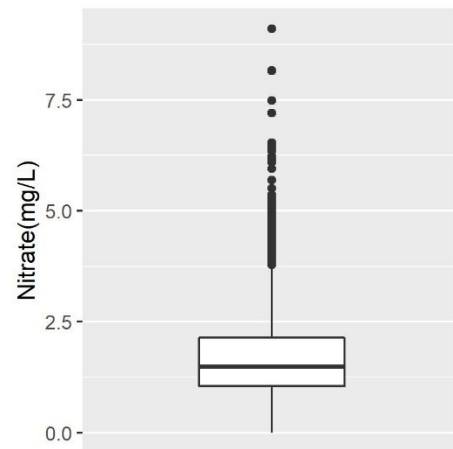

Figure 29. Boxplot showing the statistical distribution of total phosphorus concentrations (mg/L) of 2,465 samples collected at 51 monitoring locations between 1999 and 2019.

Figure 30. (A) Spatial distribution of median total phosphorus concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in total phosphorus concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

3.3.3. Soluble Reactive Phosphorus

Soluble Reactive Phosphorus (SRP) data are summarized in Appendix E. SRP is that portion of total phosphorus that is available for plant growth. Levels across all samples ranged from non-detectable levels to 0.0184 mg/L (Figure 31). Approximately 6 percent of samples were non-detect.

The spatial distribution of SRP concentrations throughout the aquifer is shown in Figure 32A, and it largely mirrors the spatial distribution of total phosphorus (Figure 30A). Median concentrations at individual monitoring locations range from 0.00165 to 0.0589 mg/L. The similarities in spatial patterns and concentrations in SRP and total phosphorus suggests that most of the phosphorus within aquifer is available for plant growth.

However, groundwater in the confined aquifer at Plantes Ferry has a median SRP concentration (0.0589 mg/L) that is about 15 percent of the median total phosphorus concentration (0.28 mg/L).

Figure 31. Boxplot showing the statistical distribution of soluble reactive phosphorus (SRP) concentrations (mg/L) of 2,987 samples collected at 51 monitoring locations between 1999 and 2019.

Figure 32. (A) Spatial distribution of median soluble reactive phosphorus (SRP) concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in SRP concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Trend analysis indicates SRP was either stable (n = 38) or decreasing (n = 23) over 20-year period (Figure 32B). There are no drinking water quality standards for SRP.

3.4. Metals

3.4.1. Arsenic

Arsenic data are summarized in Appendix E. Levels within the aquifer range from non-detect (below the reporting limit of 0.001 mg/L) to 0.0060 mg/L with an overall median is 0.0026 mg/L (Figure 33). About 12 percent of all samples were non-detect.

The spatial distribution of arsenic levels throughout the aquifer is shown in Figure 34A. Median concentrations at each monitoring location range from non-detect to 0.0067 mg/L. Samples from the Plantes Ferry monitoring well and the three river-influenced monitoring wells generally have non-detectable levels of arsenic. The highest concentrations are found in the vicinity of Felts Field in northwest Spokane Valley.
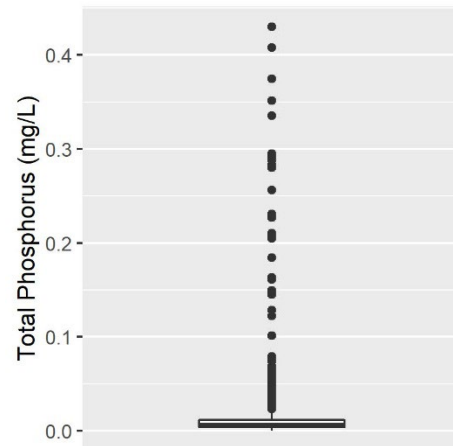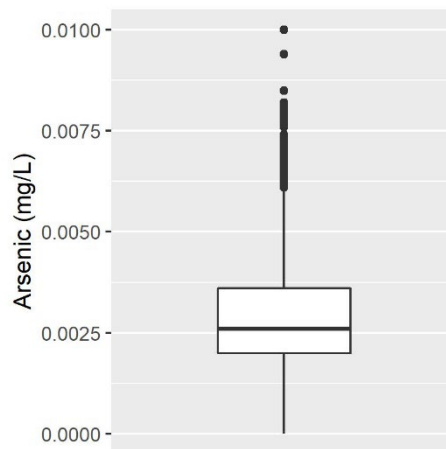

Figure 33. Boxplot showing the statistical distribution of arsenic concentrations (mg/L) of 2,276 samples collected at 51 monitoring locations between 1999 and 2019.

Trend analysis indicates arsenic levels at most locations (n = 30) were stable over the 20-year period. Of the remaining locations, nine locations exhibited decreasing levels and five exhibited increasing levels. Seven locations did not have enough data to perform a trend analysis due to a high proportion of non-detects or small sample size (Figure 34B, Appendix E).

Note that while the trend analysis indicated a decreasing trend for the Mission and Barker monitoring well (5517D05), the Sen slope calculated for this site indicates no change over time. This site has close to the threshold of 50 percent non-detectable data that would have excluded it from the trend test; the high percentage of non-detects is because of river influence on arsenic concentrations at this site (see Section 5.1). Therefore, it is likely that a trend does not exist at this location, as with other river-influenced locations.

Arsenic has a MCL of 0.010 mg/L, which is also the State trigger level. Over the 20-year period, this level was reached in one sample collected from the East Spokane Water District well (5324G01) in July 2001 (Figure 34C).

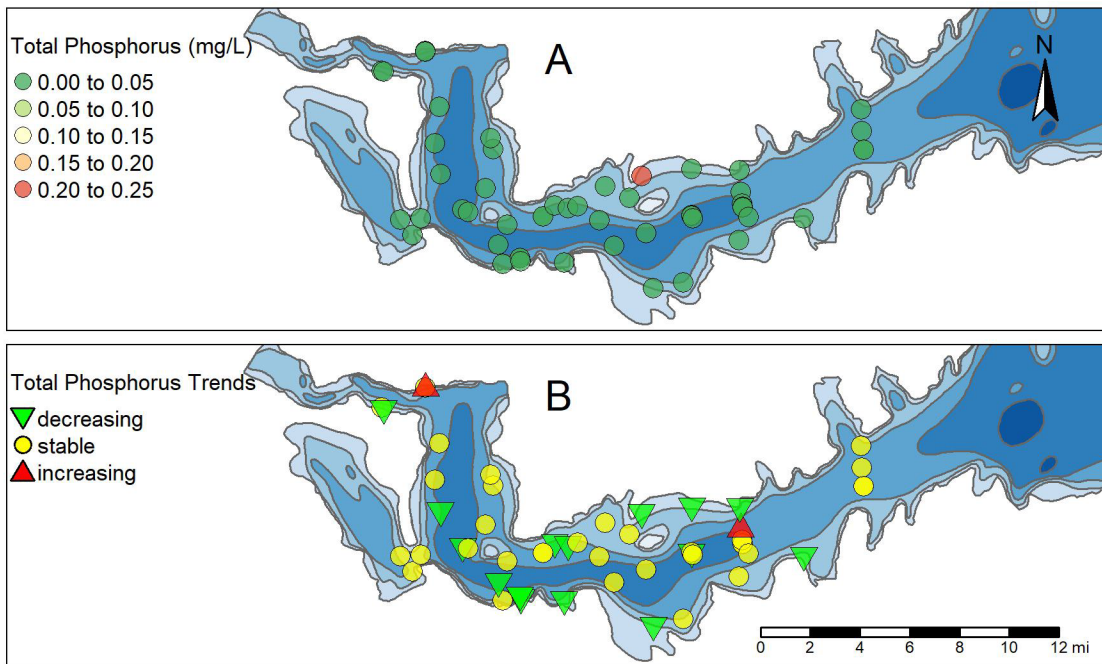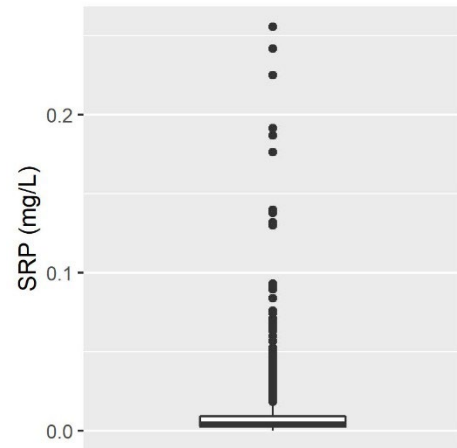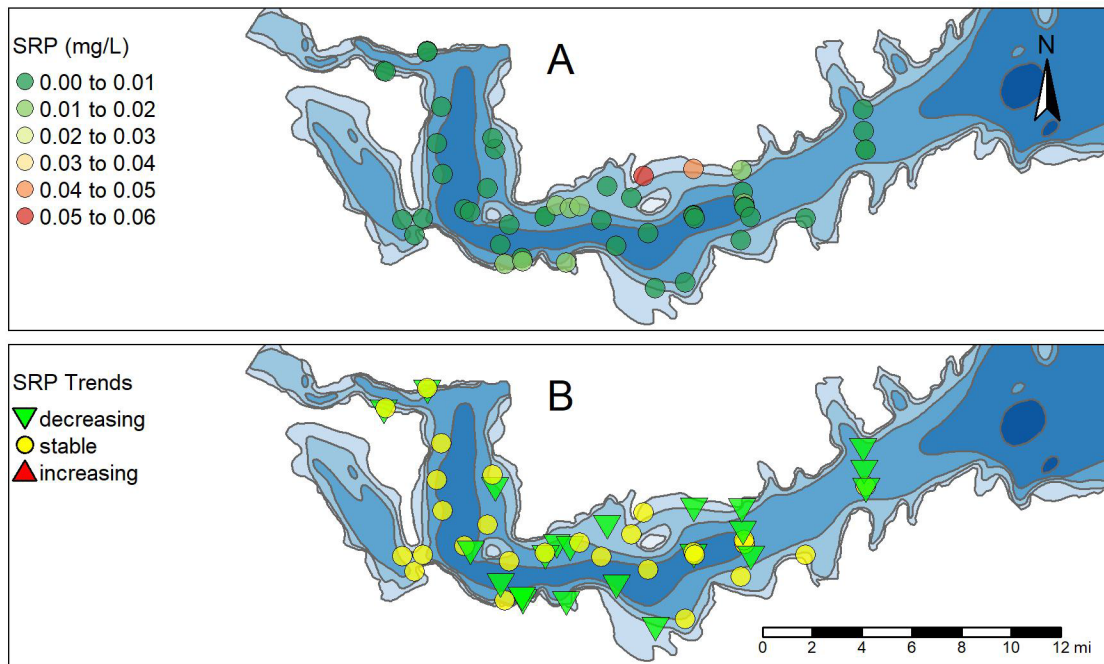Figure 34. (A) Spatial distribution of median arsenic concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in arsenic concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019. (C) Number of exceedances of the MCL for arsenic (0.01 mg/L) over the 20-year period between 1999 and 2019.

3.4.2. Cadmium

Cadmium data are summarized in Appendix E. Most samples (98 percent) were non-detect for cadmium. Cadmium is generally not detectable at any of the monitoring locations (median = 0 mg/L due to high proportion of non-detects). Given this, statistical and spatial distributions of cadmium data are not shown, and trend analysis was not conducted. Over the 20-year period, reporting limits for cadmium were lowered from 0.001 to 0.0002 mg/L, but this did not affect the ability to detect cadmium. Cadmium has a primary MCL of 0.005 mg/L, which is also the State trigger level. This level was never exceeded.

3.4.3. Chromium

Chromium data are summarized in Appendix E. Most samples (85 percent) were non-detect. Reporting limits for chromium analysis changed over time (Appendix C). Given the prevalence of non-detects, the statistical distribution is not shown.

Figure 35. (A) Spatial distribution of median chromium concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in chromium concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

Chromium is generally detectable at two locations: the monitoring wells at Franklin Park (6331J01) and the Northeast Community Center (5304G01) (Figure 35A). Both have median concentrations of 0.0011 mg/L, which is within the analytical reporting limits used over the course of the 20-year period.

Trend analysis of data from these two locations indicate decreasing concentrations at Franklin Park and stable levels at the Northeast Community Center (Figure 35B). Chromium has a MCL of 0.1 mg/L, which is also the State's trigger level. This level was never exceeded during the 20-year period.

3.4.4. Copper

Copper data are summarized in Appendix E. Levels within the aquifer ranged from non-detect (below the reporting limit of 0.001 mg/L) to 0.0027 mg/L. Most samples (69 percent) were non-detect. Given this, the Q1 and median concentrations are zero, but the Q3 concentration is 0.0011 mg/L (Figure 36).

The spatial distribution of copper levels throughout the aquifer is shown in Figure 37A. Most monitoring locations (n = 41) had non-detectable levels for 50 percent or more of their samples, resulting in median copper concentration of zero. The remaining 11 monitoring locations have median copper levels ranging from 0.00045 to 0.00230 mg/L. It is worth noting that 10 of these monitoring locations are purveyor wells.

These 11 monitoring locations had enough detectable data to perform a trend analysis. Over the 20-year period copper levels were stable at six locations, decreasing at four locations, and increasing at one location (Figure 37B). The location with the increasing trend is the I.E. Cold Storage well (5213B01).
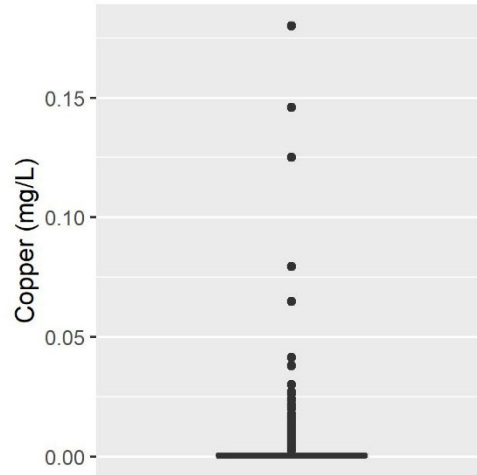
Figure 36. Boxplot showing the statistical distribution of copper concentrations (mg/L) of 2,445 samples collected at 51 monitoring locations between 1999 and 2019.
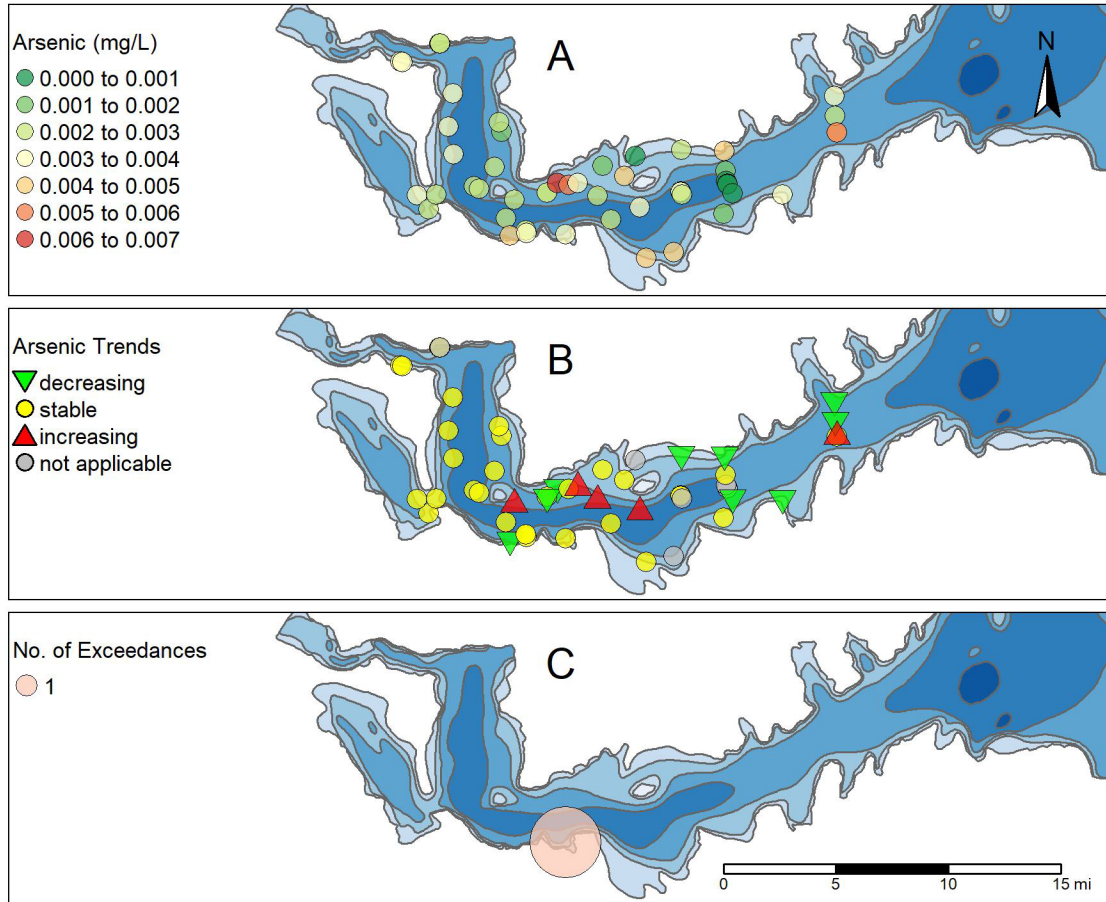

Figure 37. (A) Spatial distribution of median copper concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in copper concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Copper has an action level (equivalent to an MCL) of 1.3 mg/L and a secondary standard of 1.0 mg/L. Over the 20-year period, these were never exceeded.

3.4.5. Iron

Iron data are summarized in Appendix E. Levels within the aquifer range from non-detect (or below the reporting limit) to 0.0451 mg/L. About 72.2 percent of all samples were non-detect. Given the prevalence of non-detects, the Q1 and median concentrations are zero but the Q3 concentration is 0.0181 mg/L (Figure 38). Reporting limits for iron ranged from 0.01 to 0.15 mg/L (Appendix C), which affected the statistical distribution (e.g., the Q3 is within these levels).

The spatial distribution of iron levels throughout the aquifer is shown in Figure 39A. Three locations do not have data for iron as they were added to the monitoring network after iron analysis was discontinued following the February 2011 sampling event. Most monitoring locations (n = 42) have median iron concentrations at zero due to 50 percent or more of samples collected having non-detectable levels.

Figure 38. Boxplots showing the statistical distribution of iron concentrations (mg/L) of 1,995 samples collected at 51 monitoring locations between 1999 and 2011.

The remaining six monitoring locations have median concentrations above zero (Figure 39A). Five of these locations represent conditions in the upper, unconfined aquifer. These have median iron concentrations ranging from 0.0173 to 0.2385 mg/L. The Plantes Ferry monitoring well (5404A01), which represents unique conditions in a confined aquifer, has a median iron concentration at 6.14 mg/L. This is 25 times higher than the concentrations found in the unconfined aquifer. The unique conditions of this confined aquifer are discussed in Section 4.2.

These six locations had enough data for trend analysis. During the 20-year period, iron levels at half of these locations were stable (SCC, East Spokane, Frederick and Bowdish) and were decreasing at the other half (EVHS, Plantes Ferry, and Barker Rd. North of River) (Figure 39B).

Iron is not a health hazard in drinking water and, therefore, no MCL is established. Iron is an aesthetic contaminant with a secondary water quality standard of 0.3 mg/L. Over the 20-year period, a total of 188 samples from 34 monitoring locations exceeded the secondary standard (Figure 39C).
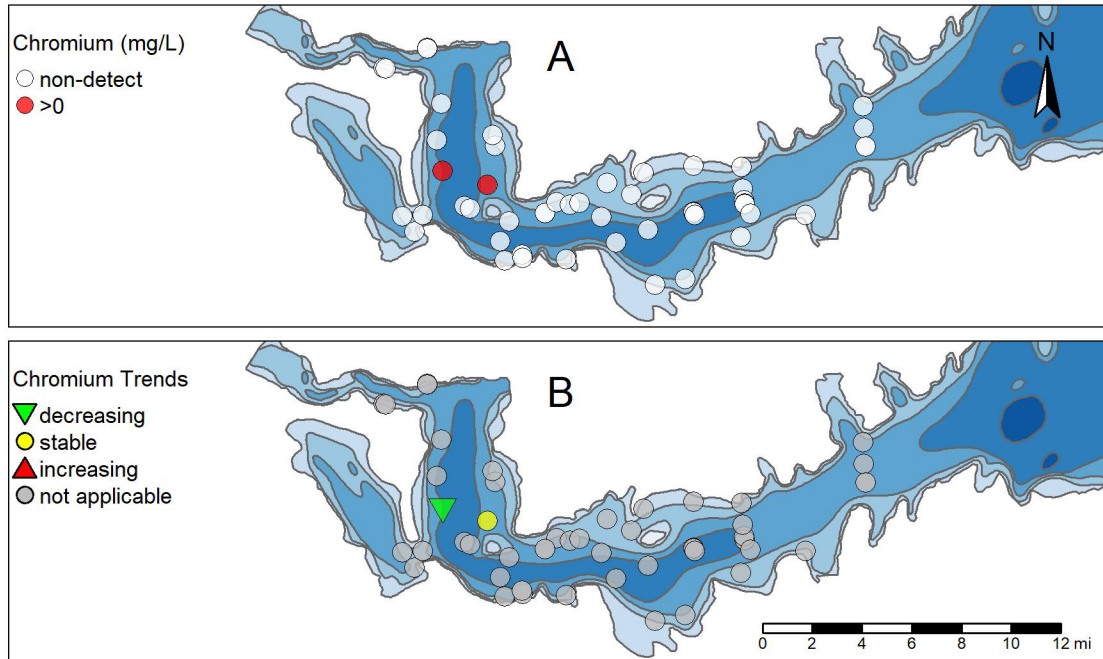
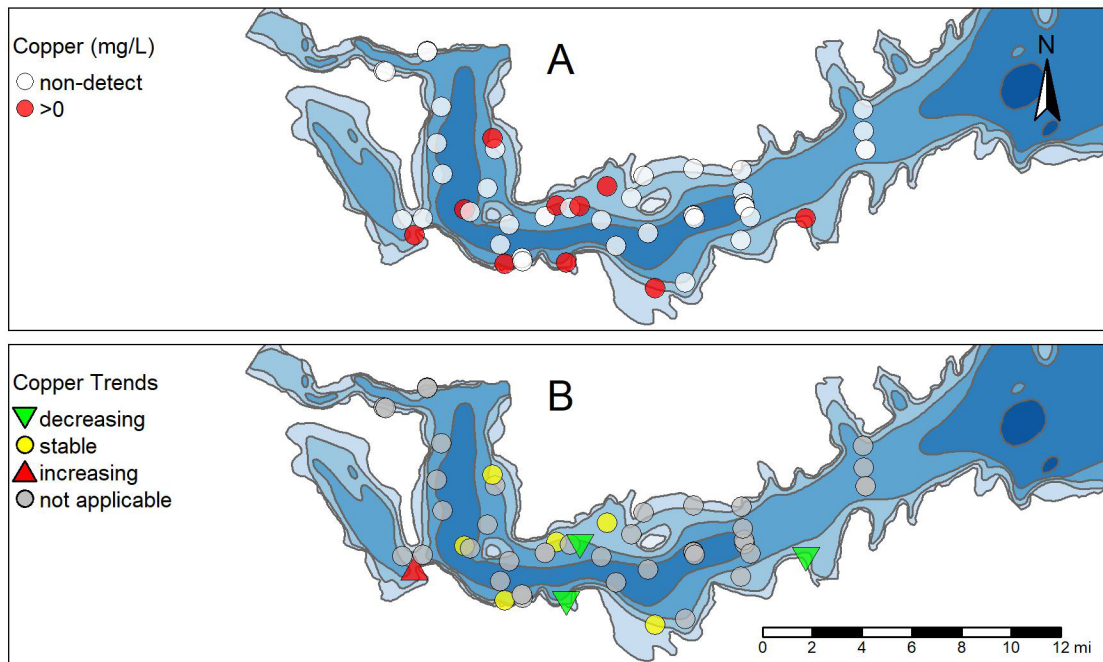Figure 39. (A) Spatial distribution of median iron concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness data layer is modeled from Kahle and Bartolino (2007). (B) Trends in iron concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019. (C) Number of exceedances of the secondary standard for iron (0.3 mg/L) over the 20-year period between 1999 and 2019.

3.4.6. Lead

Lead data are summarized in Appendix E. Approximately 94 percent of the samples were non-detect. All monitoring locations have median concentrations at zero due to 50 percent or more of the samples collected having non-detectable levels. Given this, the statistical and spatial distribution of lead data is not shown. There is not enough detectable data for site-specific trend analysis. Lead has an action level (equivalent to an MCL) of 0.015 mg/L. Over the 20-year period, there have been four exceedances of the action level, resulting from one-time exceedances at four different monitoring locations (Figure 40). None of these exceedances happened within the last 10 years.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023
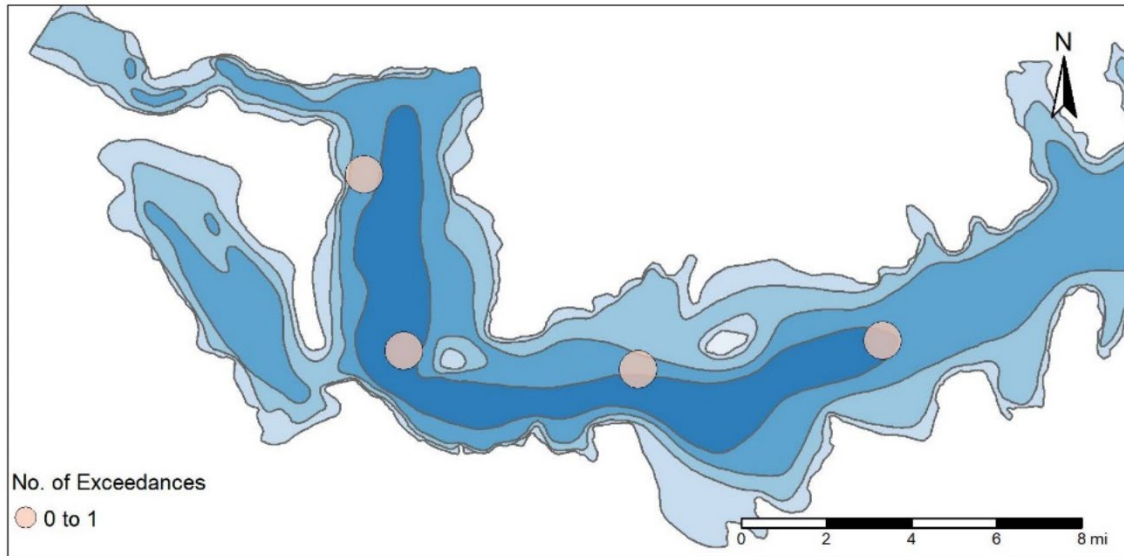
Figure 40. Number of exceedances of the Maximum Contaminant Limit (MCL) for lead (0.015 mg/L) over the 20-year period between 1999 and 2019.

3.4.7. Manganese

Manganese data are summarized in Appendix E. Approximately 88 percent of all samples were non-detect. Given this, the statistical distribution of manganese data is not shown. The spatial distribution of manganese concentrations throughout the aquifer is shown in Figure 41A. Most monitoring locations (n = 47) have median manganese concentrations at zero. Four locations have median concentrations above zero. Three of these locations are in the upper, unconfined aquifer: the monitoring wells at SCC (5310Q01), Frederick and Bowdish (5409C02), and EVHS (6436N01). Their median manganese concentrations range from 0.0019 to 0.01 mg/L. The Plantes Ferry monitoring well (5404A01) represents conditions in a confined aquifer with a median manganese concentration of 0.3590 mg/L. This is over 30 times higher than the other locations.

Site-specific trend analysis at these four locations indicates that over the 20-year period, the manganese levels in groundwater at EVHS were stable, were decreasing at Plantes Ferry, and were increasing at the SCC and Frederick and Bowdish monitoring wells (Figure 41B).

Manganese is not a health hazard in drinking water and, therefore, no MCL is established. Manganese is an aesthetic contaminant with a secondary water quality standard of 0.05 mg/L. The State reporting level is 0.01 mg/L. During the 20-year period, the secondary standard was exceeded in 40 samples from eight sites. Most of these exceedances (70 percent) occurred at the Plantes Ferry monitoring well. The other seven locations had five or less exceedances (Figure 41C). The State reporting level was exceeded in 128 samples from 25 sites. The Plants Ferry confined aquifer accounted for a large portion (22 percent) of these exceedances followed by the Frederick and Bowdish well (18 percent).
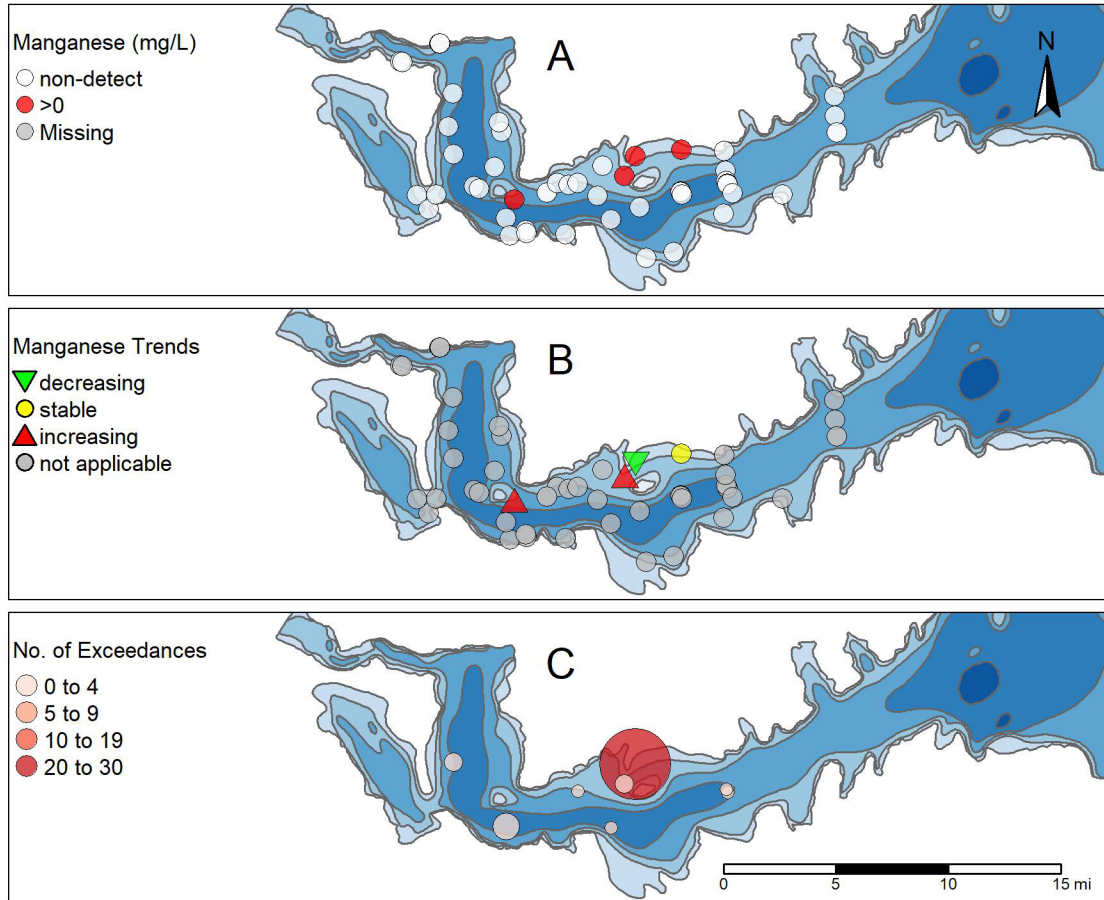
Figure 41. (A) Spatial distribution of median manganese concentrations (mg/L) within the Spokane Valley Rathdrum Prairie aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness data layer is modeled from Kahle and Bartolino (2007). (B) Trends in manganese concentrations (mg/L) within the Spokane Valley Rathdrum Prairie aquifer over the 20-year period between 1999 and 2019. (C) Number of exceedances of the secondary standard for manganese (0.05 mg/L) over the 20-year period between 1999 and 2019.

3.4.8. Mercury

Mercury data are summarized in Appendix E. Most samples (90 percent) were non-detect. Mercury is generally not detectable at any of the monitoring locations (median = 0 mg/L due to high proportion of non-detects). Given this, statistical and spatial distributions of mercury data are not shown, and trend analysis was not conducted. Mercury has a MCL of 0.002 mg/L, which is also the State's trigger level. During the 20-year period, this level was never exceeded.

3.4.9. Zinc

Zinc data are summarized in Appendix E. Most samples (77.5 percent) were non-detect. Given this, the statistical distribution of zinc data is not shown. The spatial distribution of zinc levels throughout the aquifer is shown in Figure 42A. Zinc is generally not detected at most monitoring locations (n = 44). Seven monitoring locations have median concentrations ranging from 0.0097 to 0.031 mg/L. These seven locations are all within the upper, unconfined aquifer. Three of these represent river-influenced groundwater along Barker Road (5508M01, 5508M02, and 5507H01).
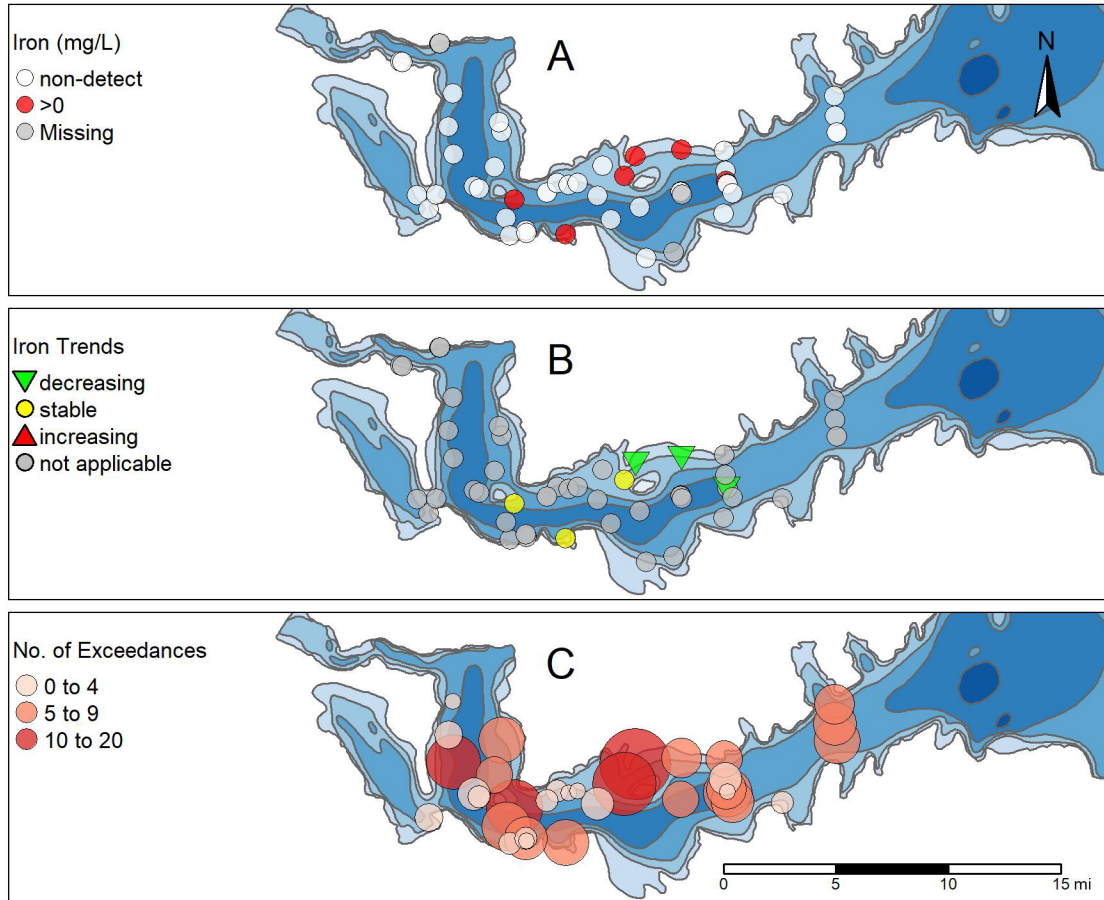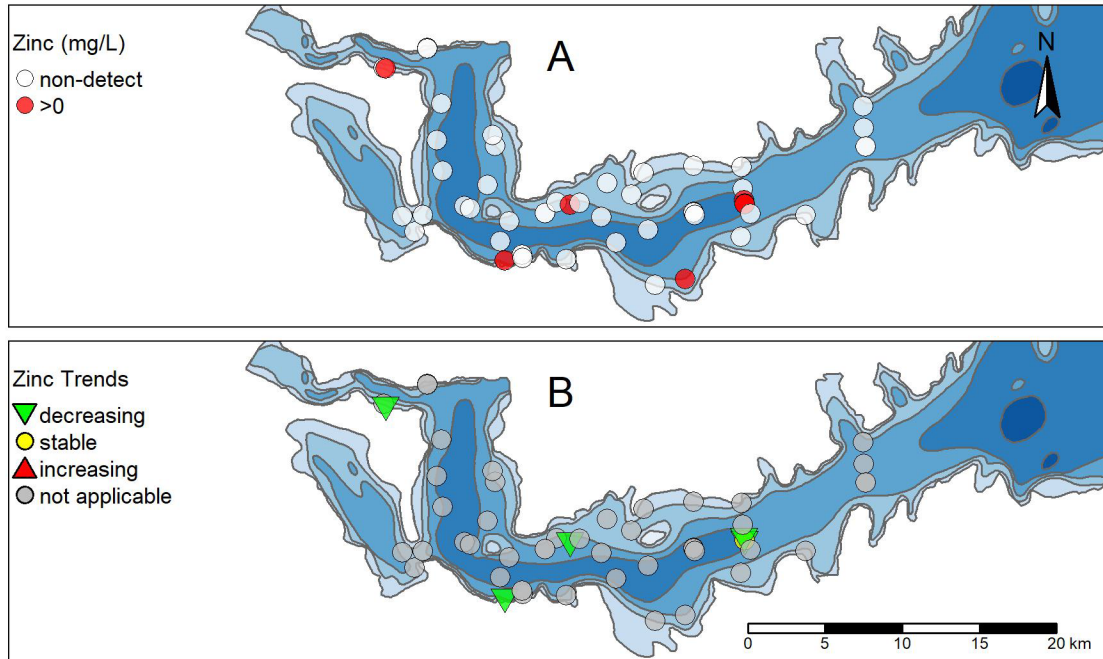
Figure 42. (A) Spatial distribution of median zinc concentrations (mg/L) within the Spokane Valley Rathdrum Prairie (SVRP) aquifer in relation to aquifer thickness (feet), an indicator of the amount of groundwater. Aquifer thickness is modeled from Kahle and Bartolino (2007). (B) Trends in zinc concentrations (mg/L) within the SVRP aquifer over the 20-year period between 1999 and 2019.

Trend analysis was conducted for the seven monitoring locations with detectable data. Zinc concentrations decreased over the 20-year period at five of these locations (6211K01, 5322F01, 6312H01, 5507H01, and 5508M01) and were stable at two of the locations (5508M02 and 5426L01) (Figure 42B).

Zinc does not have an MCL. It has a secondary standard of 5 mg/L and a State reporting level of 0.2 mg/L. The secondary standard was never exceeded. The State reporting level was exceeded three times.

3.5. Water Levels

Groundwater levels are monitored by the County only at the 29 monitoring wells. The static water level is measured in monitoring wells prior to sampling. Due to the infrastructure at purveyor wells, manual water level measurements were not collected at these locations.

Groundwater elevation contours, which indicate direction of groundwater flow from the highest elevation at the Stateline to the lowest at the tips of the Western and Little Spokane Arms, were produced in a previous study (Hsieh et al 2007). Median groundwater surface elevations measured at the monitoring wells fit within values of these groundwater elevation contours (Figure 43).
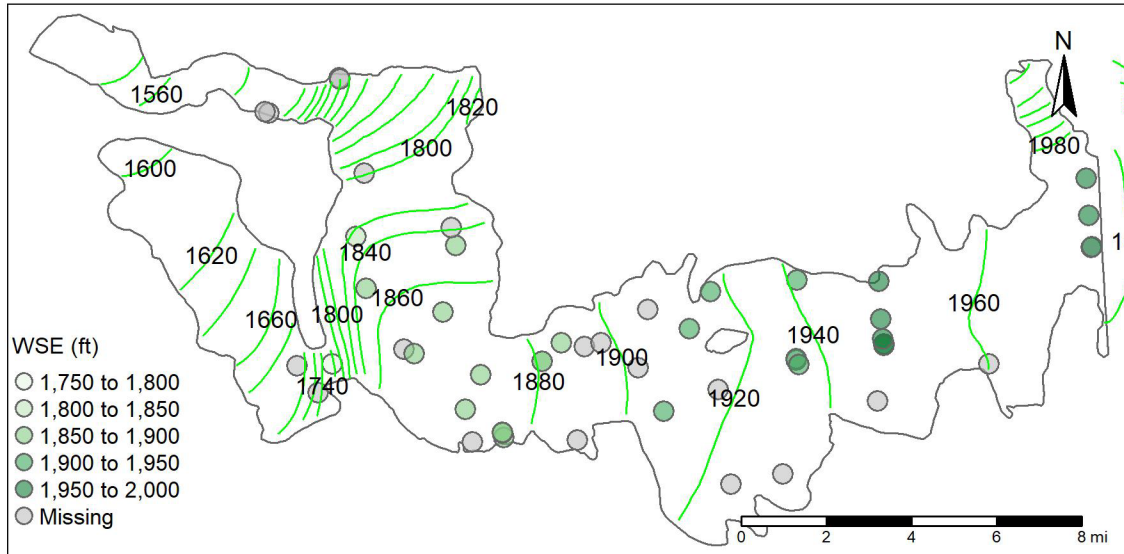
Figure 43. The 20-year (1999 – 2019) median groundwater surface elevations (WSEs) measured in feet at monitoring wells in relation to the groundwater elevation contours (in 20-foot increments) modeled after Hsieh et al (2007). WSEs are not measured at purveyor wells or springs (indicated as "missing").

The groundwater surface elevations measured at each site over time are shown in Figure 44 and WSE data are summarized in Appendix E. This shows the seasonal fluctuation of groundwater levels, which vary between two and six feet depending on the location.

Figure 44. Groundwater surface elevations (WSEs) measured at 28 monitoring wells over the 20-year period between 1999 and 2019.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023
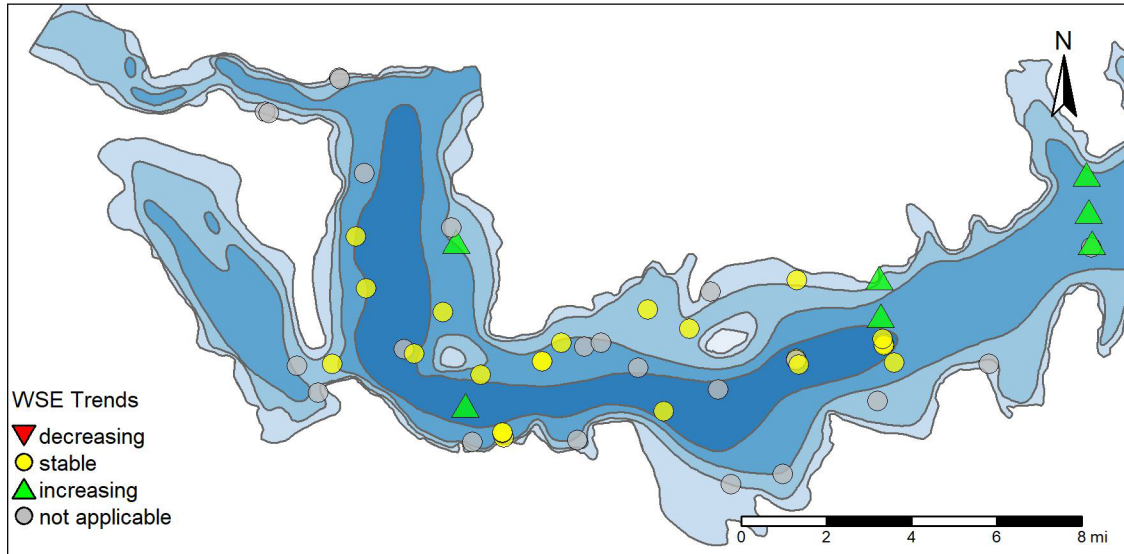
Figure 45. Trends in groundwater surface elevations (WSEs) measured at 28 monitoring wells over the 20-year period between 1999 and 2019. Groundwater surface elevations are not applicable for purveyor wells and natural springs, which are shown in gray.

Trends in WSE data were determined using either the Mann-Kendall or the Seasonal Mann-Kendall test based on seasonality and heterogeneity in the data (see Section 1.6). The Kruskal-Wallis test indicated all but two monitoring wells (6524R01 and 5411R06) exhibited seasonality in groundwater elevations. The van Belle and Hughes (1984) heterogeneity test found evidence of heterogeneity (opposing trends) for one site (5308H01). Therefore, the Mann-Kendall trend test was performed on those three sites, and the Seasonal Mann-Kendall test was performed on the remaining 26 sites.

Groundwater levels were stable at most monitoring wells (n = 21). Seven locations exhibited increasing trends in water levels (Figure 45). Three of these are on Idaho Road, including a monitoring well (6631M07) located adjacent to the CID East Farms well field. The increase was calculated at approximately 0.3 foot per year. The similarities in water level patterns at the Idaho Road wells suggest these locations are influenced by pumping at the CID East Farms well field. However, decreased water usage from the purveyor well field is not necessarily the reason for the increased water levels.

Two monitoring wells located north of the river at the Barker Road intersections with Trent and Euclid Avenues (5505D01 and 5507A04 respectively) also had increasing water levels. Since the Idaho Road locations are upgradient, the increase occurring there may be influencing the two Barker Road locations as more water is moving through the aquifer. However, the rate of increase at these locations was a little less than half that at Idaho Road, between 0.12 and 0.14 foot per year.

The remaining two monitoring wells with increasing trends include one located at the intersection of Olive and Fiske (5315L01) in an industrial/commercial area and another at the fire station on Houston and Regal in North Spokane (6327N04). The increase at these locations happened at a much lower rate than those at Idaho and Barker Roads, at 0.04 foot per year. Other monitoring wells located throughout the Hillyard Trough display similar patterns in water levels, but their data does not indicate any trends.

Spokane area weather data was compiled from the National Weather Service for the same 20-year period. The weather data included the monthly mean air temperature and the monthly mean and monthly total precipitation and snow fall amount. This data was assessed for trends on an annual and monthly basis. The results of this analysis did not account for the increases in groundwater levels. No trends were identified in precipitation or snowfall levels. There was a significant increase in annual temperatures over the 20-year period. However, this weather data is localized while the SVRP Aquifer is a regional aquifer system and, therefore, requires consideration of weather data at a larger spatial scale.

Rather than compiling and analyzing individual weather stations throughout Washington and Idaho to determine correlations, the Pacific Decadal Oscillation (PDO) Index was used as a regional climatic indicator. The PDO is a climatic pattern driven by sea surface temperatures in the North Pacific Ocean. The PDO Index classifies associated climatic patterns into warm (positive index values) or cool (negative index values) phases. In the Pacific Northwest, the PDO's warm phase is associated with warmer, drier winters and the cool phase is associated with cooler, wetter winters. These phases have historically occurred in irregular decadal cycles of 15 to 30 years though, more recently, the cycles have become shorter.

The groundwater levels from four monitoring wells were plotted in relation to the PDO phases over time (Figure 46). From this graphical analysis, the groundwater levels at these locations appear to be influenced by the PDO. Groundwater levels generally decreased from 1999 through 2007 following a 23-year warm phase. The short, 3-year cool phase (1999 to 2002) that occurred during this period was likely not long enough to counter the effects of the longer warm phases that preceded and followed it. Groundwater levels began to rise with the 7-year cool phase starting in 2007, peaking towards the end of this phase before decreasing with the most recent warm phase starting in 2014.
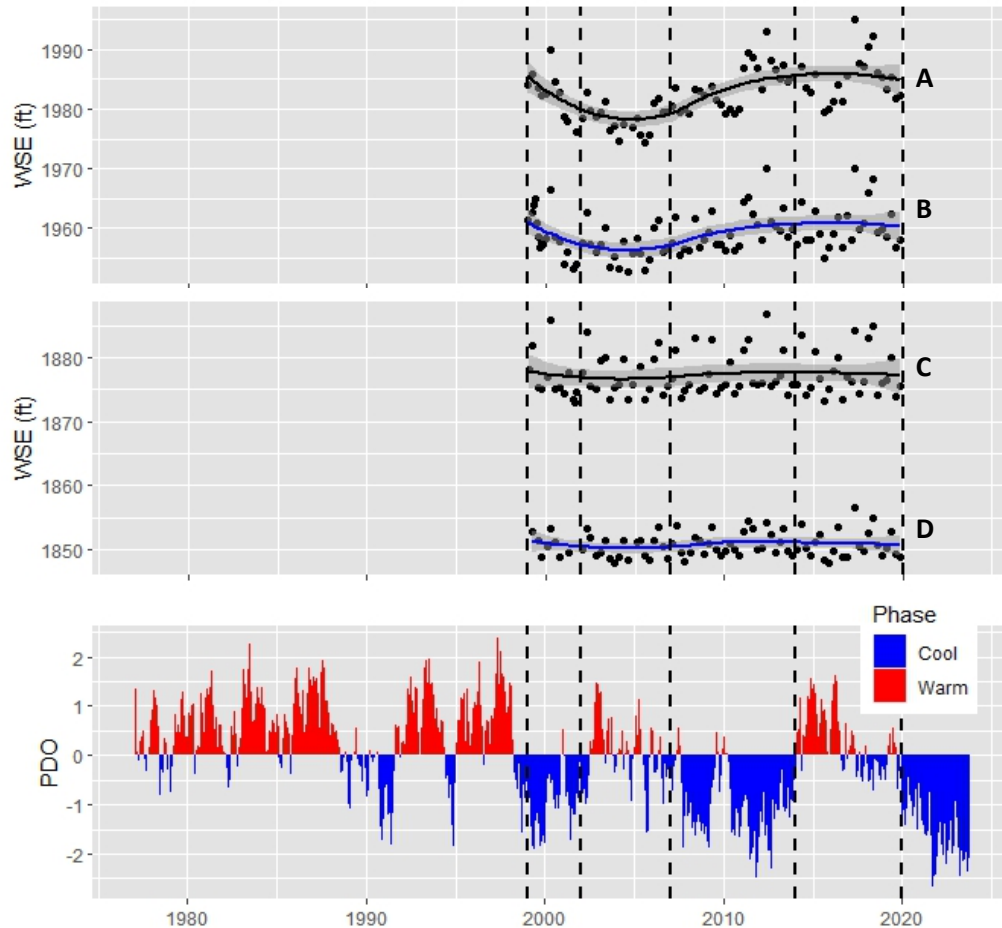
Figure 46. Plot of water surface elevations (WSE) (in feet) measured at four monitoring wells from January 1999 to December 2019 in relation to the Pacific Decadal Oscillation (PDO) Index by phase for the period January 1975 to October 2023. The four monitoring wells are: A) Idaho Road 1000 feet South of Trent (6524R01); B) Trent and Barker (5505D01); C) Olive and Fiske (5315L01); and D) Fire Station at Houston and Regal (6327N04). The dashed lines delineate the generally accepted periods of "warm" and "cool" phases. PDO Index is based on Huang et al 2017 and was downloaded from the NOAA Physical Sciences Laboratory (PSL).

While the graphical analysis shows a relationship between the PDO phase and groundwater levels, an advanced statistical analysis called Singular Spectrum Analysis is needed to confirm that the groundwater level fluctuations are correlated with the PDO. While this analysis is beyond the scope of this report, another study (Velasco et al 2017) utilized Singular Spectrum Analysis on long-term groundwater level data from a USGS monitoring well near Liberty Lake (USGS Site Number 474011117072901). A plot of the long-term data from the USGS well in relation to the PDO Index is shown in Figure 47 for reference. This demonstrates that groundwater levels from the USGS Liberty Lake well generally track with the PDO overtime with relatively lower levels during warm phases and higher levels during cool phases.
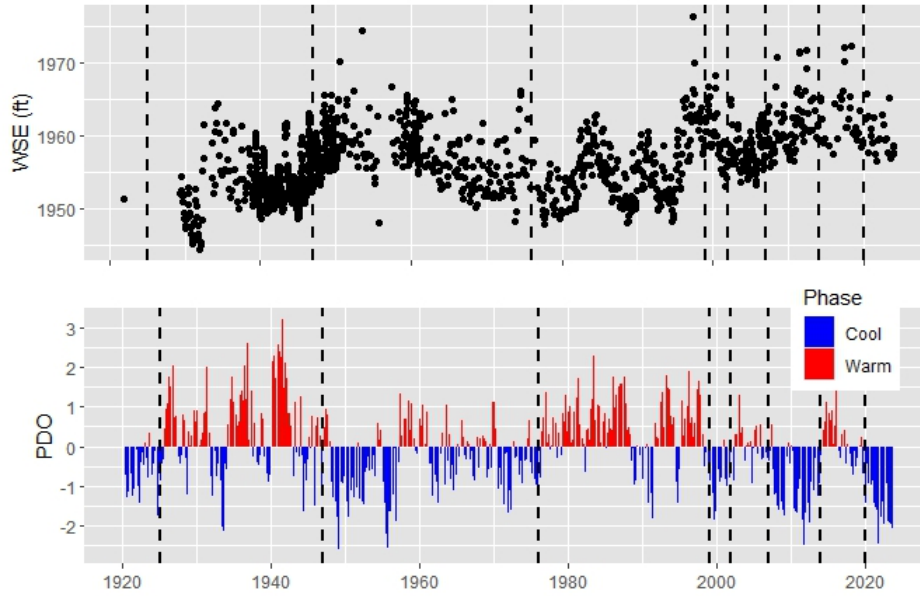
Figure 47. Plot of water surface elevations (WSE) (in feet) measured at a long-term U.S. Geologic Survey (USGS) monitoring well near Liberty Lake, Washington (USGS Site Number 474011117072901 in relation to the Pacific Decadal Oscillation (PDO) Index by phase for the period January 1920 to October 2023. The dashed lines delineate the generally accepted periods of "warm" and "cool" phases. Groundwater data was downloaded from the USGS National Water Information System (NWIS). The PDO Index is based on Huang et al 2017 and was downloaded from the NOAA Physical Sciences Laboratory (PSL).

However, Velasco et al (2017) indicated that the Atlantic Multidecadal Oscillation (AMO), another cyclic climatic pattern, had greater influence over the groundwater levels measured at the USGS Liberty Lake well than the PDO. The AMO is driven by sea surface temperatures in the North Atlantic Ocean and has much longer cycles (50 to 80 years). In the Pacific Northwest, the AMO index's positive phases are associated with increased precipitation and the negative phase with decreased precipitation (note that this is reversed from the PDO index). Due to its longer cycles, assessing correlations with the AMO requires a much longer water level record. The wells in the County's monitoring network do not have sufficient water level records for such an assessment.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

4. Effects of Groundwater Depth and Confining Layers on Water Quality

Groundwater movement occurs both horizontally and vertically. As groundwater percolates deeper into the aquifer, its chemical composition can change. For example, shallow groundwater is more vulnerable to human-made contaminants applied at or near the land surface, such as septic system discharge, fertilizer, and pesticides. Deeper groundwater is more likely to be affected by geological sources. Confining layers can limit vertical groundwater movement and protect the lower, confined portion of the aquifer from surface contaminants. This section looks at how groundwater depth, confining layers, and associated confounding factors may affect water quality in the SVRP aquifer.

4.1. Groundwater Depth

The depth to water in the SVRP aquifer study area ranges from less than 20 feet at locations near the Spokane River to around 300 feet in North Spokane (Figure 48). The wells used in this study range from 55 feet to 286 feet deep (Appendix A). There are several methods to assess the effect of groundwater depth on groundwater quality, which are discussed in this section.
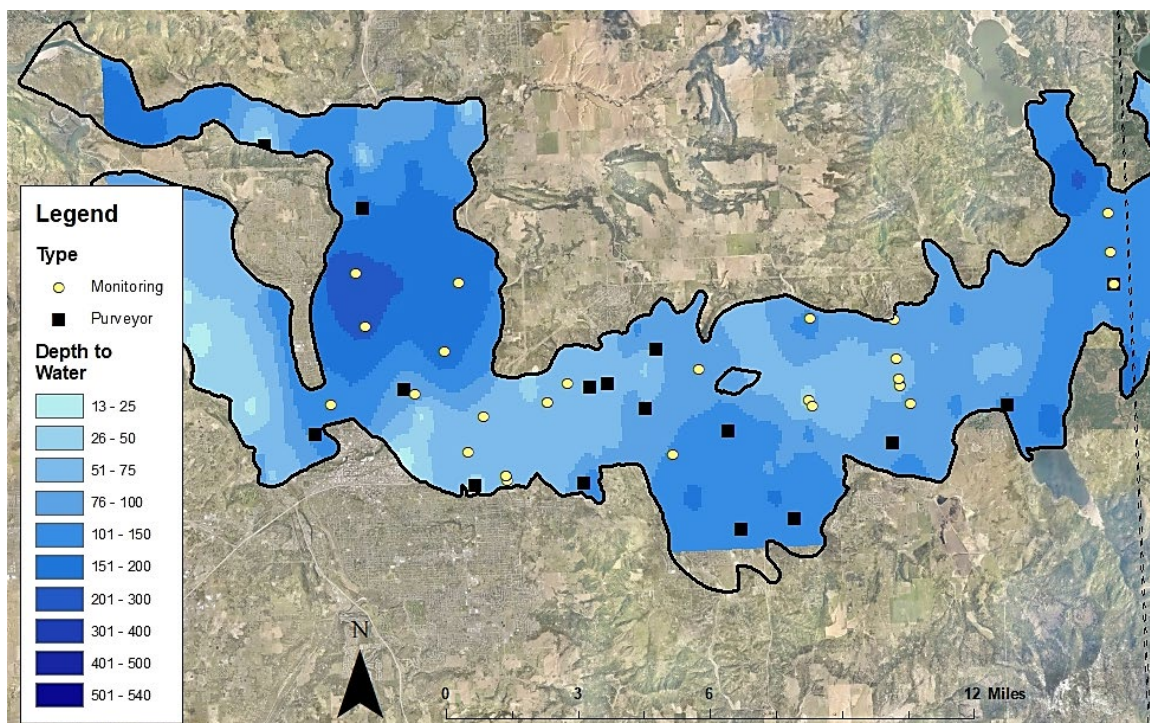
Figure 48. Depth to groundwater throughout the Spokane Valley Rathdrum Prairie aquifer in September 2004. This layer was derived from data presented in USGS Scientific Investigations Report 2007-5044 (Hsieh et al, 2007). Depth to water data not available for purveyor wells.

4.1.1. Nested Wells

Nested wells are monitoring wells at the same location completed at different depths. When sampled on the same day, a paired statistical analysis of the data can be used to determine if there is a significant difference between the shallow and deeper groundwater (see Section 1.6). The County's monitoring network includes two sets of nested monitoring wells that are sampled the same day: Hale's Ale (5311J05 and 5311J07) and 3rd and Havana (5322A01 and 5322A03).

There are also monitoring wells, called sentinel wells, associated with purveyor wells that are completed at a different (often shallower) depth in the aquifer, making these pairs useful in comparing groundwater quality by depth. Although three of these sentinel – purveyor well pairs are included in the County's monitoring program, only the set at the CID East Farms well field can be treated and analyzed similarly to the nested wells, as they are within proximity to each other and are sampled on the same day. The remaining sentinel – purveyor well pairs are discussed in Section 4.1.3.

The location of the nested wells and the CID East Farms wells are shown in Figure 49 and the results of the statistical analysis are summarized in Table 3.
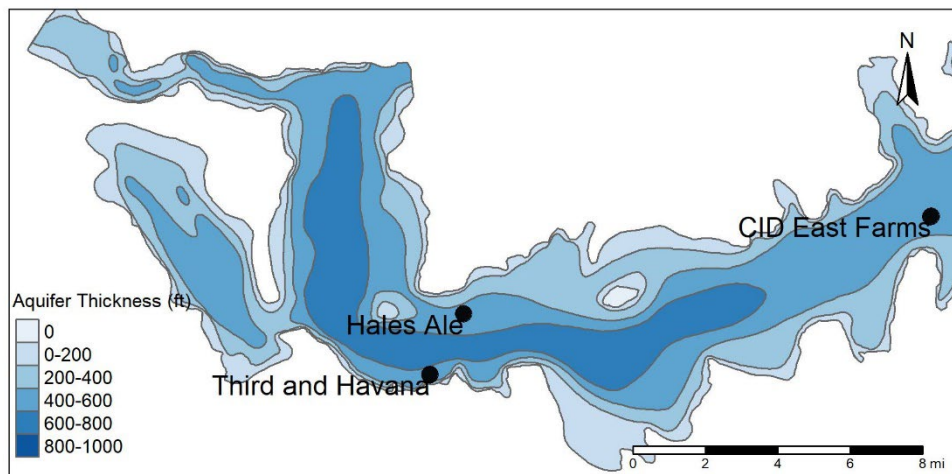
Figure 49. Location of wells considered in the paired well analysis. The nested monitoring wells are at Hales Ale and Third and Havana. A sentinel well and associated purveyor well at Consolidated Irrigation District (CID) East Farms are treated as a nested wells in the analysis.

The analysis suggests that groundwater depth affects water quality, although the effects are not necessarily consistent among the three locations. Data from all three sets of wells indicate depth of groundwater does not significantly affect dissolved oxygen, total phosphorus, fluoride, and most of the trace metals. All other parameters exhibited statistically significant differences between shallow and deeper groundwater in at least one set of wells.

Based on agreement in the results from at least two of the three sets of wells, this analysis suggests that deeper groundwater is generally:

- Cooler and more alkaline;
- Lower in calcium, chloride, sodium, nitrate, and SRP; and
- Higher in magnesium and arsenic.

However, it is important to recognize that the findings are inconsistent among the three sets of wells. Most of the inconsistencies occur between the two sets of nested monitoring wells, Hale's Ale and 3rd and Havana. These nested wells have only 43 feet difference between the shallow and deeper wells. However, the 3rd and Havana nested wells are closer to the margin of the aquifer and the Hale's Ale nested wells are closer to the middle of the aquifer (Figure 49). This positioning may explain the inconsistencies.

For example, parameters typically indicative of surface contamination like chloride, sodium, and nitrate are expected to be at lower levels deeper in the aquifer, as shown in the Hale's Ale nested wells. However, this is not the case for the 3rd and Havana nested wells, in which these parameters are significantly higher in the deeper well. Their location at the margin of the aquifer may allow these contaminants to concentrate deeper in the aquifer due to less groundwater capacity and slower flows.

Table 3. Comparison of nested wells at Hale's Ale and 3rd and Havana and the purveyor-sentinel monitoring well pair at the Consolidated Irrigation District (CID) East Farms complex. For each parameter, the median value for each well is shown. Median values are based on data from sampling events where both wells in each pair were sampled on the same day; therefore, values reported here may differ from those reported elsewhere in this report. Values in red for the deeper well in each pair indicate a statistically significant difference (p<0.05) between the wells. Well types include monitoring wells (M) and purveyor wells (P). Fluoride, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc are not shown as median values are zero for all locations and there is no significant difference between the paired sites.

	Hales Ale		3rd & Havana		CID East Farms	
Well Characteristics	5311J05 East	5311J07 Mid	5322A01 East	5322A03 Mid	6631M04	6331M07
Depth (ft.)	75.9	118.2	60.2	103.1	225	147
Difference in Depth (ft.)	42.3		42.9		78	
Well Type	M	M	M	M	P	M
Parameter						
Temperature (C)	11.295	11.00	12.9	12.7	12.62	13.7
pH	7.79	7.785	7.81	7.89	7.86	7.74
Dissolved Oxygen (mg/L)	9.09	9.07	8.89	8.88	7.14	6.47
Conductivity (uS/cm)	320	320	274	278.5	244	274
TDS (mg/L)	183	187	165	168.5	140	161
Calcium (mg/L)	38.1	37.4	34.8	34.85	28.4	32.05
Chloride (mg/L)	4.425	4.26	6.4	6.44	3.22	3.41
Magnesium (mg/L)	17.15	17.35	11.6	11.8	12.85	14.25
Potassium (mg/L)	2.145	2.135	2.04	2.02	2.035	2.25
Sodium (mg/L)	4.26	4.17	5.02	5.105	2.81	2.8875
Sulfate (mg/L)	15.3	15.4	10.45	10.7	10.6	11.4
Nitrate (mg/L)	1.62	1.56	1.69	1.725	1.365	1.67
Total Phosphorus (mg/L)	0.004728	0.004074	0.0111	0.0108	0.00513	0.005
SRP (mg/L)	0.004	0.003111	0.00795	0.0072	0.004	0.00392
Arsenic (mg/L)	0.002815	0.002785	0.00253	0.00262	0.00525	0.0043

The CID wells have significant differences in more parameters than the two sets of nested wells. This may be due to several compounding factors. Notably, the deeper groundwater is collected from a purveyor well, which can also affect groundwater quality (see Section 4.1.3). Further, the CID wells are completed within the main body of the aquifer at greater depths than the other sets of wells, with a larger difference in depth between the wells.

These inconsistencies indicate that groundwater depth does not affect groundwater quality the same way across the aquifer due to local conditions. It may also be that significant differences in groundwater related to depth are more likely to be detected under certain conditions such as when the difference in depth between wells is greater than 43 feet. Given the limited number of nested well sites and, thus, the limited range of depths analyzed, it is difficult to confirm.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

4.1.2. Sentinel Wells

Sentinel wells are monitoring wells located upgradient of a purveyor well and are intended to provide an early warning of potential contamination. The County has three sentinel – purveyor well pairs within its current monitoring network. One pair, located at the CID East Farms well field, was previously discussed (Section 4.1.2). The other two sets include the City of Spokane Nevada well (5308A02) and the Denver and Marietta sentinel well (5308H01) and the City of Spokane Ray Street well and the 3rd and Havana wells (5322A01 and 5322A03). Since the 3rd and Havana site are nested wells, both are used. These monitoring locations are shown in Figure 50.
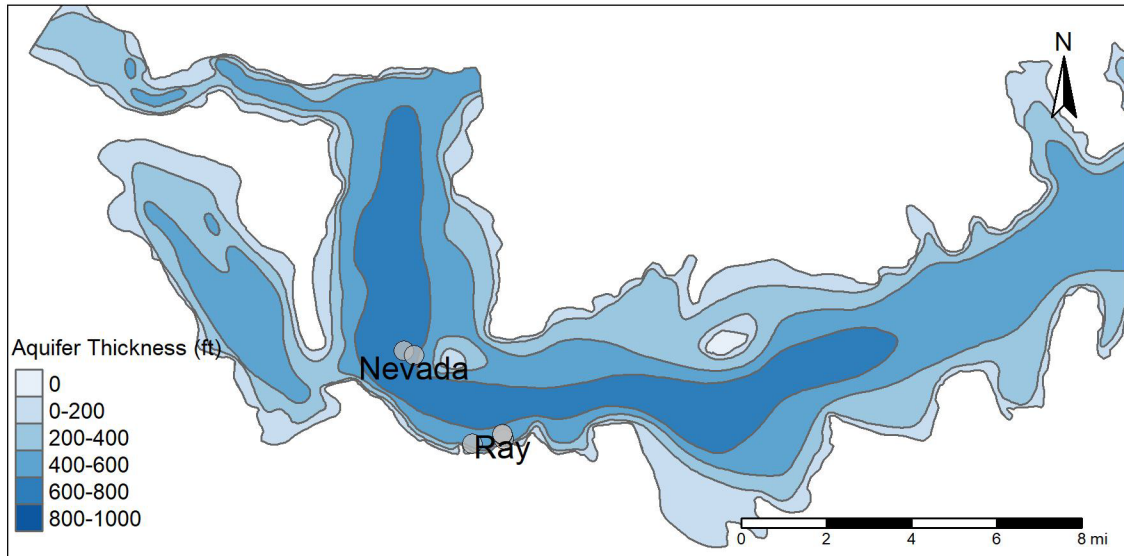
Figure 50. Location of the sentinel well and associated purveyor well for the City of Spokane's Nevada and Ray wells.

Unlike the CID East Farms wells, these sentinel – purveyor wells pairs have smaller differences in depth and the sentinel wells are over 1,000 feet upgradient from the purveyor well rather than being in proximity (Figure 50 and Table 4). In addition, these sentinel – purveyor well pairs are not sampled on the same day. Therefore, a different statistical test was used to compare these sets of wells (see Section 1.6), the results of which are shown in Table 4.

The groundwater sampled from the City of Spokane Nevada well and its sentinel well have statistically the same water quality for most parameters. Statistically significate differences occur in a few parameters: temperature, pH, conductivity, calcium, magnesium, SRP, and copper (Table 4). Most of these differences follow the pattern expected based on the nested well analysis: the deeper purveyor well is significantly cooler, more alkaline, and has higher magnesium and lower SRP concentrations. However, the result for calcium is the opposite of what is expected, with the deeper purveyor well having significantly higher concentrations of calcium.

Table 4. Comparison of sentinel wells and associated purveyor wells. For each parameter, the median value for each well is shown. Values in red indicate parameters for which the sentinel well is significantly different (p<0.05) from the purveyor well. Well types include monitoring wells (M) and purveyor wells (P). Fluoride, cadmium, chromium, iron, lead, manganese, and mercury are not shown as median values are zero for all locations and there is no significant difference between the paired sites.

Well Characteristics	City of Spokane Nevada	Denver & Marietta	City of Spokane Ray	3rd & Havana East	3rd & Havana Mid	6th & Havana
	5308A02	5308H01	5322F01	5322A01	5322A03	5323E01
Depth (ft)	126	99	77	60.2	103.1	79.5
Difference in Depth (ft)	27			16.8	26.1	2.5
Upgradient Distance (ft)	1,329			3,850	3,850	3,880
Well Type	P	M	P	M	M	M
Parameter						
Temperature (C)	11.6	12.9	11.8	12.8	12.7	12.65
pH	7.79	7.57	7.42	7.72	7.89	7.63
Dissolved Oxygen (mg/L)	8.62	8.01	9.38	8.89	8.88	8.91
Conductivity (uS/cm)	223.5	215	427	273	278.5	384.5
TDS (mg/L)	132	131.5	240	167	168.5	225.5
Calcium (mg/L)	29.4	26.9	51.90	34.85	34.85	47.45
Chloride (mg/L)	4.15	4.14	15.00	6.76	6.44	11.6
Magnesium (mg/L)	10.1	9.47	17.05	11.6	11.8	16.55
Potassium (mg/L)	1.68	1.69	2.89	2.01	2.02	2.72
Sodium (mg/L)	3.14	3.12	9.38	4.99	5.11	8.14
Sulfate (mg/L)	9.58	9.41	15.8	10.50	10.70	14.2
Nitrate (mg/L)	1.11	1.09	3.61	1.63	1.73	2.91
Total Phosphorus (mg/L)	0.00416	0.00417	0.0214	0.0099	0.0108	0.0125
SRP (mg/L)	0.0026	0.0031	0.0197	0.0080	0.0072	0.0117
Arsenic (mg/L)	0.00212	0.00219	0.00403	0.00253	0.00262	0.00354
Copper (mg/L)	0.0013	0.0	0.00121	0.0	0.0	0.0
Zinc (mg/L)	0.0	0.0	0.0132	0.0	0.0	0.0

The groundwater sampled at the City of Spokane Ray Street well and its sentinel well at 3rd and Havana have statistically significant differences for most water quality parameters. Compared to the 3rd and Havana wells, the Ray Street well has significantly higher concentrations of all the major parameters for which the groundwater is tested (Table 4). The County's Annual Water Quality Report (2001) suggests the 6th and Havana monitoring well might be better suited as a comparison for the Ray Street well. For this reason, the County also assessed the 6th and Havana well data as shown in Table 4. While groundwater sampled from this location also has significantly different water quality from the Ray Street well, the results are in much more in agreement.

The water quality of the Ray Street well and its upgradient sentinel wells do not follow the pattern expected patterns based on the nested well analysis. Depth does not appear to be a factor in water quality when comparing these wells since the shallower 3rd and Havana well and the deeper monitoring wells have similarities when compared to the City's Ray Street well. For example, the three monitoring wells are warmer and more alkaline, and have lower concentrations of major ions, nutrients, and metals than the Ray Street well. Perhaps this may be because the difference in depth is not that great between the wells.

There are several potential explanations for the differences in water quality between the Ray Street well and the upgradient monitoring wells. One potential reason is that different hillside tributary basins at the boundary of the aquifer contribute to the groundwater differences at these three locations (Spokane County 2001). Another potential reason explored here is that the type of monitoring location (e.g., monitoring well vs. purveyor well) can influence groundwater quality.

4.1.3. Type of Monitoring Location

The County's monitoring network includes purveyor wells, monitoring wells, and natural springs. As a group, purveyor wells are significantly deeper than monitoring wells (Figure 51), and the natural springs are sampled at the surface. Although the depth of groundwater for each type of monitoring location is different, this may not necessarily explain all differences among the types of monitoring locations.

Purveyor wells have large pumps, larger diameter wells, and longer screened intervals to draw the volumes necessary for drinking water supply. This creates large capture zones that may be affected by distant contaminant sources. Monitoring wells are intended to assess water quality near the water table where contaminants from the land surface first appear. These have smaller diameter wells with shorter screened intervals and do not have regularly running pumps, resulting in more localized capture zones. Natural springs are going to be the most vulnerable to contaminants in stormwater run-off since they are exposed (Figure 52). For these reasons, it is expected that the type of monitoring location affects groundwater quality.
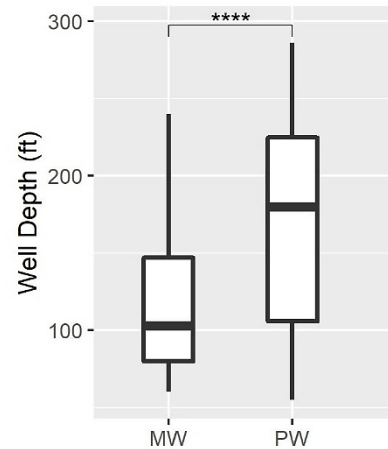
Figure 51. Boxplot showing the statistical distribution of well depths (feet) of monitoring wells (MW) versus purveyor wells (PW). Statistical significance between these group is noted as follows: **** = significant, p<0.0001

Figure 52. Pictures showing a purveyor well (left), monitoring well (middle), and a natural spring (right). Purveyor wells have infrastructure to pump and convey large volumes of water. Monitoring wells require a portable pump as shown in the photo. Natural springs can be sampled at the surface like a stream.

Data was grouped and compared by type of monitoring location for each parameter to identify statistically significant differences. Due to unique conditions, the Plantes Ferry monitoring well data was excluded in this assessment. Significant differences among the three types of monitoring locations occur for most parameters (Figures 53 – 55).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

The deeper purveyor wells compared to the monitoring wells:

- Are significantly cooler and more alkaline;
- Have significantly higher:
    - dissolved oxygen (DO);
    - conductivity and concentrations of all the major ions and nutrients;
    - concentrations of arsenic and zinc

While this is mostly what is expected given the nested well analysis (Section 4.1.1), the inconsistencies are that the deeper purveyor wells are significantly higher in dissolved oxygen as well as parameters typically indicative of surface contamination like calcium, chloride, sodium, and nitrate. This is potentially attributed to other circumstances than groundwater depth. The regular pumping and potential mixing of larger volumes of water at purveyor wells could be introducing oxygen. Further, most of the purveyor wells are in the relatively thinner margins of the aquifer compared to the monitoring wells. Therefore, dilution could also be contributing to the differences.

Compared to both types of wells, the natural springs:

- Are significantly cooler and more alkaline;
- Have significantly higher conductivity and concentrations of all the major ions and nitrate;
- Have significantly lower phosphorus and SRP

It is expected that deeper groundwater would have some of these characteristics. However, the springs are significantly cooler and more alkaline than both sets of wells (Figure 53). The warmer temperatures in the shallow monitoring wells are likely from recent recharge by water warmed at the surface in addition to being closer to surficial heating. The springs are cooler due to weather influences, particularly during the fall and winter, which likely influenced the median temperature.
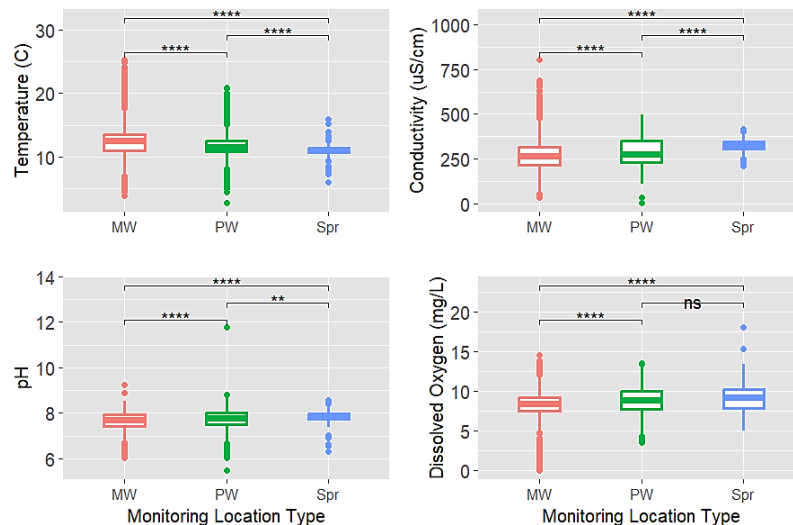
Figure 53. Boxplots showing the statistical distribution of temperature (C), pH, conductivity (uS/cm), and dissolved oxygen (mg/L) by monitoring location type. The types of monitoring locations include monitoring wells (MW), purveyor wells (PW), and natural springs (Spr). Statistical significance between each group is noted as follows: ns = not significant, $p>0.05$; * = significant, $p<0.05$; ** = significant, $p<0.01$; *** = significant, $p<0.001$; **** = significant, $p<0.0001$.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

The higher levels of dissolved oxygen at the purveyor wells and springs are likely attributed to a combination of factors. For both types of monitoring locations, their cooler water temperatures allow the groundwater to hold more dissolved oxygen. For the purveyor wells, the pumping and potential mixing of groundwater could be introducing oxygen. The springs have the advantage of exchanging oxygen with air at the surface.

The purveyor wells have significantly higher concentrations of all the major ions and nutrients than the monitoring wells (Figure 54). This is likely attributed to the volume of water being pumped at the purveyor wells. The springs have significantly higher concentrations of all the major ions and nitrates than both sets of wells. Most of the purveyor wells and springs are in the relatively thinner margins of the aquifer compared to the monitoring wells. Therefore, dilution could be contributing to the differences.

However, the springs have significantly lower levels of total phosphorus and soluble reactive phosphorus (SRP) than both sets of wells.

Figure 54. Boxplots showing the statistical distribution of major ions and nutrient concentrations (mg/L) by monitoring location type. The types of monitoring locations include monitoring wells (MW), purveyor wells (PW), and natural springs (Spr). Statistical significance between each group is noted as follows: ns = not significant, p>0.05; * = significant, p<0.05; ** = significant, p<0.01; *** = significant, p<0.001; **** = significant, p<0.0001.

Arsenic is the only trace metal with median concentrations at detectable levels for each of the monitoring location groups. Arsenic concentrations of each group are significantly different from each other with purveyor wells having the highest levels of arsenic (median = 0.0031 mg/L) and monitoring wells having the lowest levels (median = 0.0026 mg/L). Purveyor wells are the only type of monitoring location with a

51

median copper concentration at a detectable level (0.0011 mg/L). This makes sense given 10 of the 11 sites with median copper concentrations at detectable levels were purveyor wells (see Section 3.4.4). Fluoride is generally not detectable among the location types (medians at zero). However, as a group, the springs have enough detectable data that the Q3 value is 0.1 mg/L though the only three sites that had median concentrations of fluoride at detectable levels were not springs (see Section 3.4.5).

Cadmium, chromium, iron, lead, manganese, and mercury are generally not detectable among the monitoring location groups outside of outliers; therefore, a statistical comparison of these parameters is not shown in Figure 55.
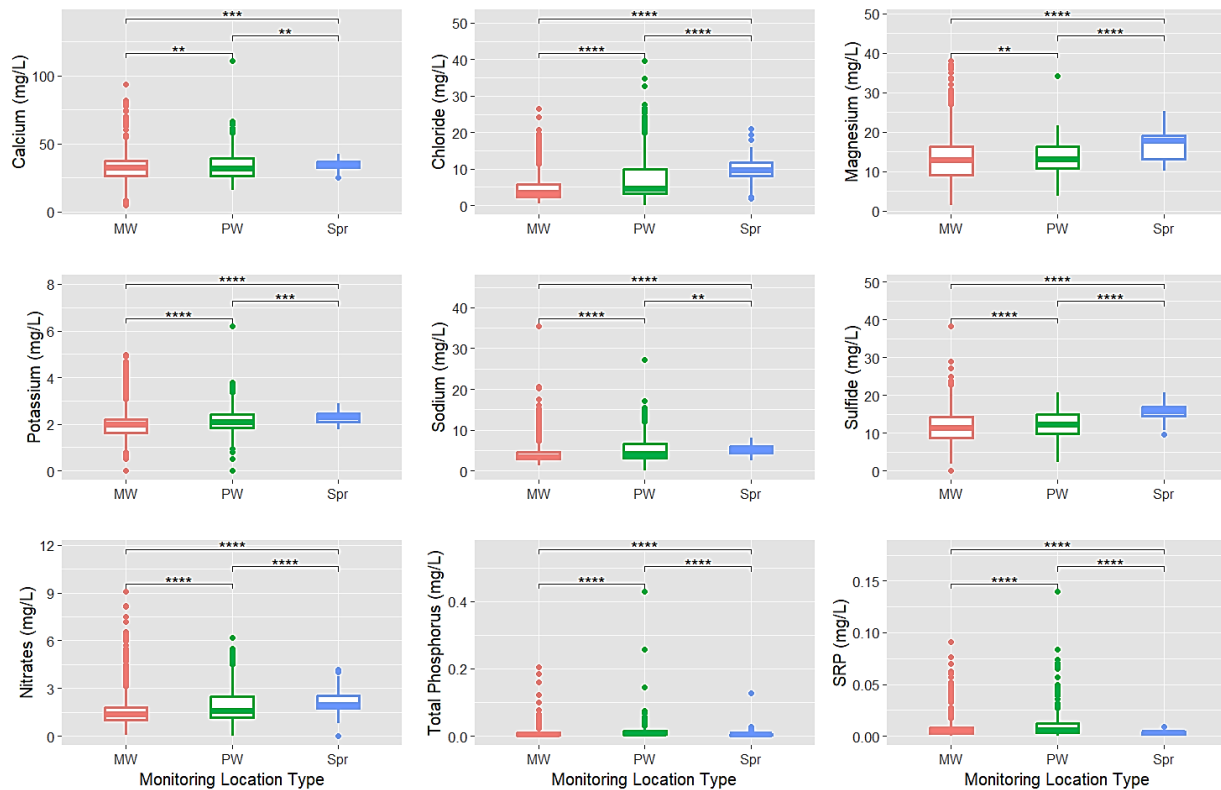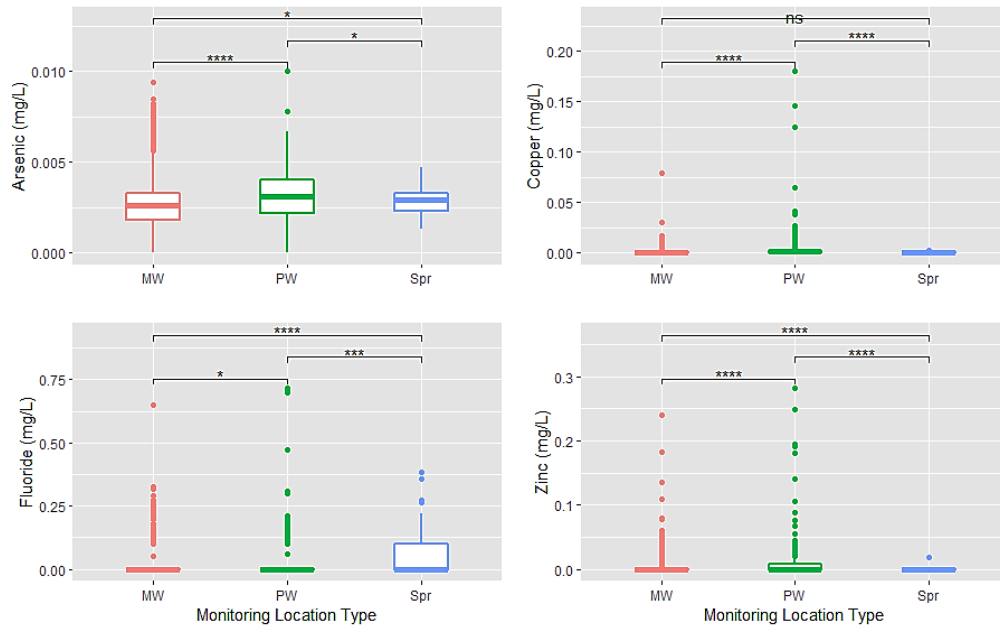

Figure 55. Boxplots showing the statistical distribution of certain trace metal concentrations (mg/L) by monitoring location type. The types of monitoring locations include monitoring wells (MW), purveyor wells (PW), and natural springs (Spr). Statistical significance between each group is noted as follows: ns = not significant, p>0.05; * = significant, p<0.05; ** = significant, p<0.01; *** = significant, p<0.001; **** = significant, p<0.0001.

4.2. Confining Layers

In some locations, the SVRP aquifer consists of an upper unconfined aquifer and a lower confined aquifer. An unconfined aquifer is bound at its top by the water table. A confined aquifer is bound at its top by a layer of fine material such as silt or clay through which water cannot easily flow (Figure 56). Studies have shown that the risk of contamination from the land surface is greater for unconfined aquifers than for confined aquifers due to the protection that the confining layer provides against contaminants within percolating water from the surface.

The Hillyard Trough and the Little Spokane Arm are the only locations where a continuous clay layer divides the aquifer into an upper unconfined unit and a lower confined unit (Figure 56). In other locations throughout the SVRP, there are localized discontinuous confining layers that create semi-confined aquifers.

Two sets of wells are used to assess differences in groundwater quality within different lower confined aquifers (Figure 57, Table 5). One set is in North Spokane within the Hillyard Trough and includes the Fire Station at Houston and Regal monitoring well (6306N04) and the North Spokane Irrigation District Site 4 well (6328H01). The Fire Station monitoring well is completed in the upper unconfined unit, while the North Spokane Irrigation District well is completed in the lower confined unit.
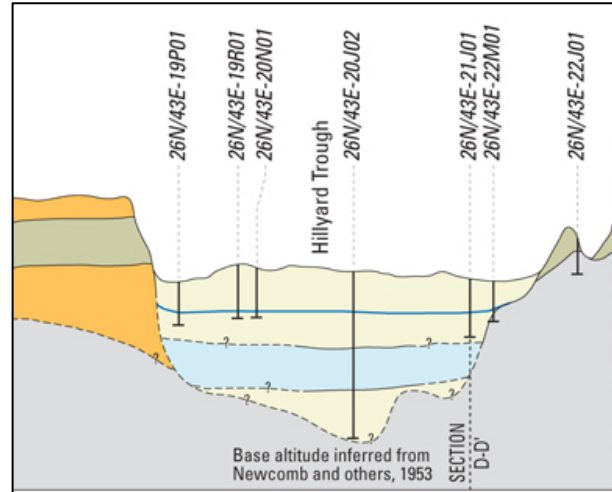
Figure 56. A cross section of the Hillyard Trough showing the unconfined and confined aquifer. Tan is Spokane Valley-Rathdrum Prairie Aquifer sediments, blue is the fine-grained confining layer, orange is basalt, green denotes fine grained material, and gray is bedrock. This figure is modified from Kahle and Bartolino, 2007.

The other set of wells is in Spokane Valley and includes the EVHS monitoring well (6436N01) and the Plantes Ferry Park monitoring well (5404A01). The Plantes Ferry Park monitoring well is completed under a localized, discontinuous layer of silty clay that is approximately 65 feet thick according to the well log. The EVHS well, though slightly deeper, is not located under a confining layer.
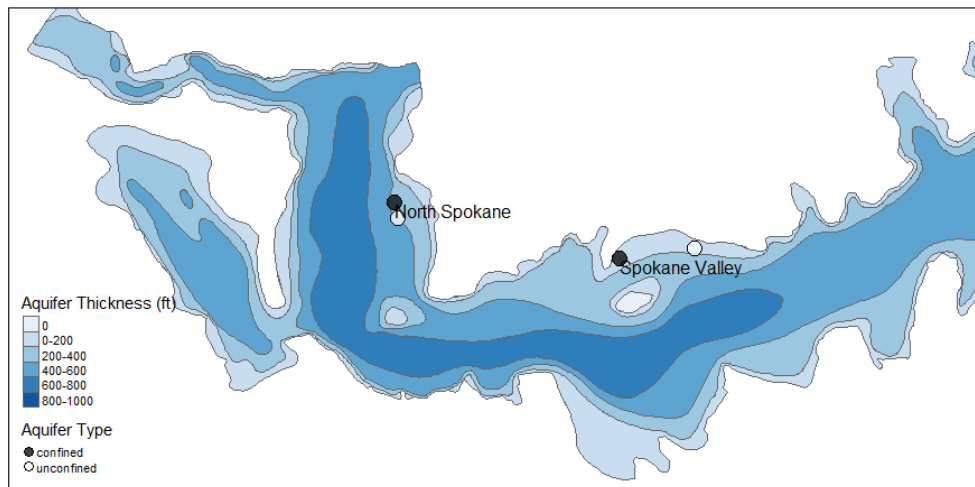
Figure 57. Monitoring locations used to compare groundwater in the confined and unconfined aquifers in the Hillyard Trough in North Spokane and in the Spokane Valley near Plantes Ferry.

The unconfined and confined wells in each location were compared using a statistical test as described in Section 1.6. The results are shown in Table 5.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Table 5. Comparison of wells completed in the unconfined (U) and confined (C) aquifer in North Spokane and Spokane Valley. For each parameter, the median value for each well is shown. Median values are based on data from sampling events where both wells in each pair were sampled on the same day; therefore, values reported here may differ from those reported elsewhere in this report. Values in red indicate parameters for which the confined aquifer is significantly different from the unconfined aquifer. Well types include monitoring wells (M) and purveyor wells (P). Cadmium, chromium, lead, mercury, and zinc are not shown as median values are zero for all locations and there is no significant difference between the paired sites.

	North Spokane		Spokane Valley	
	Fire Station	Irrigation District	East Valley HS	Plantes Ferry
Well Characteristics	6327N04	6328H01	6436N01	5404A01
Aquifer Type	U	C	U	C
Well Type	M	P	M	M
Depth (ft)	219	274	125	119.5
Difference in Depth (ft)	55		5.5	
Parameter				
Temperature (C)	13.2	11.4	13.5	13.5
pH	7.72	8.12	7.38	6.84
Dissolved Oxygen (mg/L)	7.57	6.55	9.11	0.29
Conductivity (uS/cm)	415.0	233.5	561.3	311.5
TDS (mg/L)	231.5	138.0	350.0	219.0
Calcium (mg/L)	36.6	26.0	65.8	26.2
Chloride (mg/L)	11.1	5.87	8.30	2.16
Magnesium (mg/L)	25.45	11.45	28.9	13.28
Potassium (mg/L)	3.77	2.16	4.01	5.34
Sodium (mg/L)	11.8	4.92	9.34	10.95
Sulfate (mg/L)	19.6	11.8	18.3	21.4
Nitrate (mg/L)	2.98	1.12	5.69	0.00
Total Phosphorus (mg/L)	0.00248	0.00371	0.05188	0.23100
SRP (mg/L)	0.00177	0.00345	0.05029	0.13171
Fluoride (mg/L)	0.0	0.0	0.296	0.103
Arsenic (mg/L)	0.00164	0.00299	0.00246	0.0
Copper (mg/L)	0.0	0.00104	0.0	0.0
Iron (mg/L)	0.0	0.0	0.094	12.46
Manganese (mg/L)	0.0	0.0	0.00164	0.718

Analysis of the North Spokane set of wells found the groundwater below the confining layer to be significantly:

- Cooler and more alkaline;
- Lower in conductivity and TDS;
- Lower in major ions and nitrogen; and
- Higher in total phosphorus, SRP, arsenic, and copper.

These results indicate the confining layer in the Hillyard Trough has much the same effect on groundwater quality as groundwater depth with some differences. The results also closely mirror the effects of purveyor wells on groundwater quality, which makes sense given the confined aquifer is also represented by a purveyor well. Therefore, these characteristics confound this analysis, making it difficult to attribute any effects solely to the confining layer.

However, trend analyses (Section 3.0) demonstrate that the North Spokane confining layer provides more stable groundwater conditions and is protective of confined groundwater. The confined aquifer had stable concentrations over time for most parameters. Indicators of surficial contaminants (e.g. chloride and nitrate), which were stable in the confined aquifer samples from the North Spokane Irrigation District well while increasing in samples from the unconfined aquifer at the Fire Station monitoring well.

Analysis of the Spokane Valley set of wells found the groundwater below the confining layer in the vicinity of Plantes Ferry to be significantly:

- More acidic;
- Lower in dissolved oxygen, most major ions, nitrate, and arsenic; and
- Higher in sodium, sulfate, total phosphorus, SRP, iron, and manganese.

It is easier to attribute these conditions to the confining layer since variables regarding depth and type of monitoring location (both are monitoring wells) are minimized.

The confining layer in the vicinity of Plantes Ferry creates unique conditions in the lower confined aquifer. Unlike groundwater in the unconfined aquifer, the groundwater here is acidic (median pH<7) and anoxic (median DO <0.5 mg/L). These conditions can generally explain the other results.

The confined aquifer at Plantes Ferry has persistent anoxic conditions that promote denitrification, explaining the high proportion (71 percent) of non-detect nitrate data. Anoxic conditions also mobilize iron, manganese, and phosphorus explaining the much higher levels of these parameters in the Plantes Ferry confined aquifer compared to other monitoring locations.

5. Spokane River – SVRP Aquifer Interaction

Water is exchanged between the Spokane River and the SVRP Aquifer for much of the river's length. The Spokane River is the largest source of recharge to the aquifer. There are several reaches where the Spokane River discharges to the aquifer: 1) Coeur d'Alene Lake to Flora Road; 2) Plantes Ferry to Upriver Dam; and 3) Green Street to Monroe Street (Figure 58). These reaches are considered losing reaches (Figure 59). It is estimated that the Spokane River loses 718 cubic feet per second (cfs) of water to the aquifer, representing 49 percent of the aquifer's total mean annual inflow of 1,417 cfs.
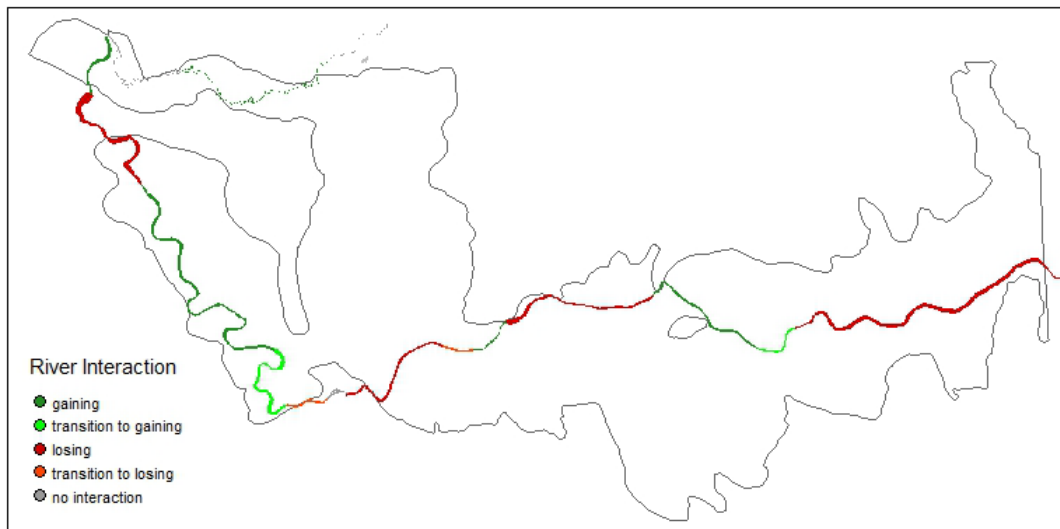
Figure 58. The gaining and losing reaches of the Spokane River and the groundwater source of each well. Groundwater source was determined by using total dissolved solids (TDS) and conductivity as an indicator of groundwater interaction with the Spokane River.

There are also two distinct river reaches where the Spokane River receives water from the aquifer: 1) Flora Road to Trent Road; and 2) The Spokane Gage to Nine Mile Dam. These reaches are considered gaining reaches (Figures 58 and 59). The Spokane River receives an estimated 861 cfs from the aquifer, representing 59 percent of the aquifer's total mean annual outflow of 1,468 cfs (Hsieh, et al 2007).

This section discusses the groundwater – surface water interactions in a losing reach and two gaining reaches of the Spokane River.
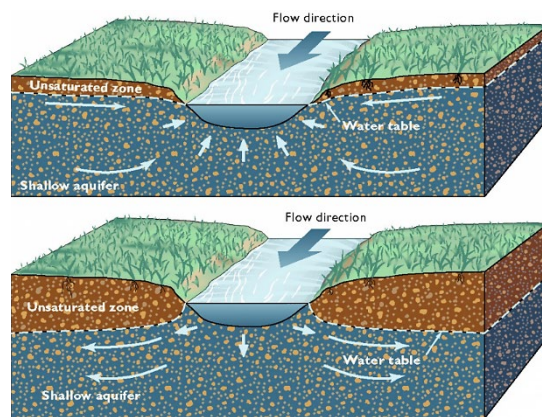
Figure 59. Diagram showing the groundwater-surface water interaction in a gaining reach (top) and losing reach (bottom).

5.1. Losing Reach: Barker Road Cross-Section

At a losing reach, the aquifer's water quality can be influenced by the river's water quality. The Spokane River's influence on groundwater was assessed by examining seven monitoring locations along Barker Road that provide a cross-section of a losing reach of the Spokane River. These sites span from the Trent and Barker Road monitoring well (5505D01) to the CID Site 2A purveyor well (5518R01) (Figure 60) and have been previously used to study the Spokane River – SVRP Aquifer interaction by both Ecology (Marti and Garrigues 2001) and the USGS (Caldwell and Bowers 2003).

Where available, data from Ecology's EIM database for the Spokane River at Barker Road for the same 20-year period was used for comparison with groundwater quality along the cross section. Due to the limited Spokane River data available, all available data was used and not limited to a certain season.
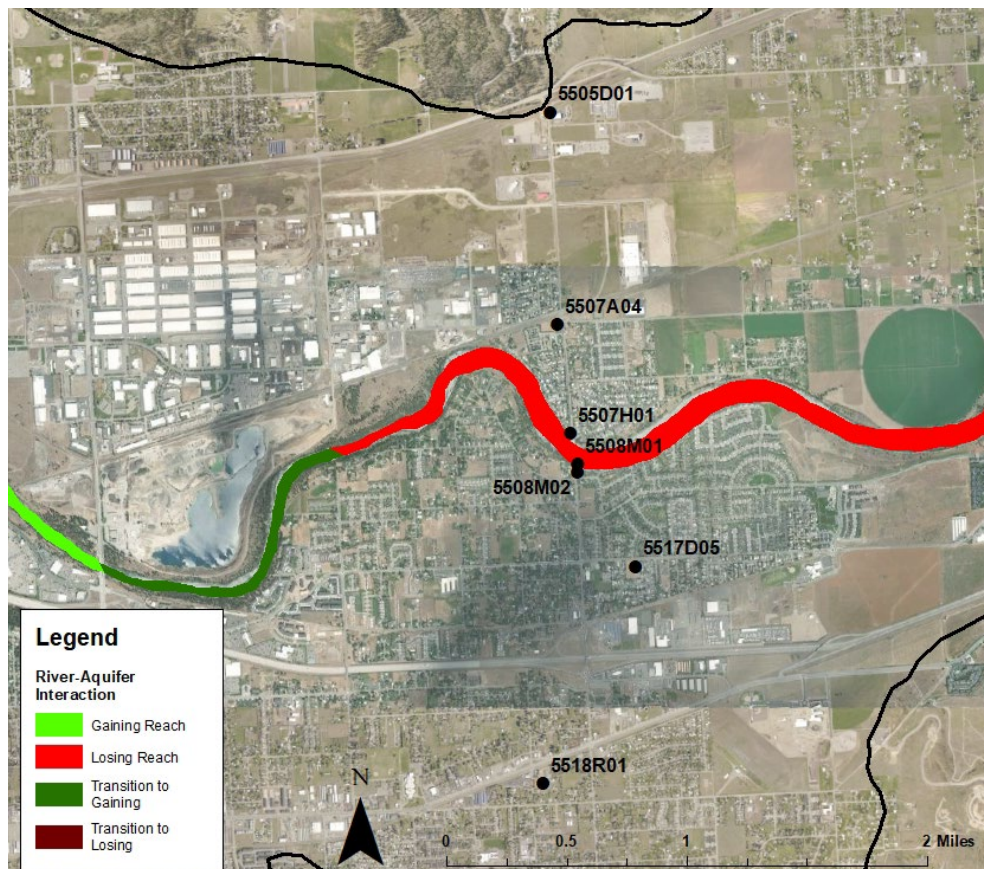
Figure 60. An aerial view of the lower portion of the losing reach of the Spokane River from the stateline to Flora Road, including the seven monitoring locations along Barker Road used to provide a cross-section of groundwater conditions.

This assessment confirms findings presented by Ecology (Marti and Garrigues 2001) and the USGS (Caldwell and Bowers 2003). The groundwater levels along the cross-section range from 10 to 20 feet below the river's bottom elevation at ~1980 feet, indicating the river recharges the groundwater at Barker Road. However, the groundwater gradient along the cross-section suggests the water tends to flow in a southwesterly direction. Therefore, the river provides more recharge and mixing with groundwater to the south. The groundwater from the northern-most wells (5505D01 and 5507A01) is not influenced by the river (Figure 61).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

This is confirmed by the water quality data. Groundwater temperature, conductivity, and major ion concentrations are useful indicators of the extent of the Spokane River's influence on the aquifer. Groundwater from the northern-most wells (5505D01 and 5507A01) has relatively stable, cooler temperatures with high conductivity and major ion concentrations indicative of the regional groundwater system. The groundwater immediately adjacent to the river (5507H01, 5508M01 and 5508M02) has highly variable, but generally warmer temperatures with lower conductivity and major ion concentrations like the river.
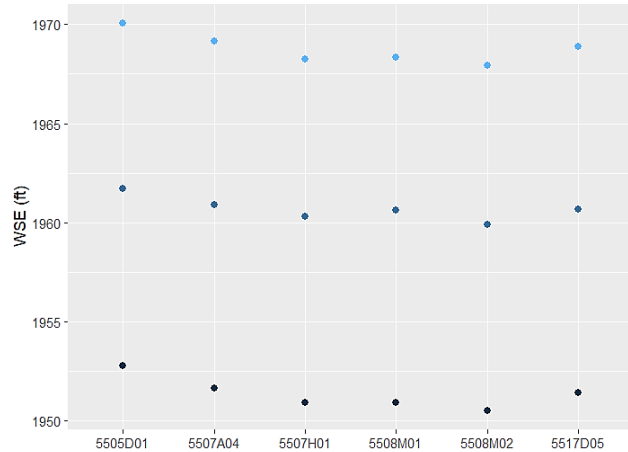
Figure 61. Water surface elevations (WSE, in feet) at six groundwater sites along Barker Road representing a cross-section at a losing reach of the Spokane River. Each set of WSEs were measured during three separate monitoring events occuring at high, medium, and lower groundwater levels. Groundwater moves in the direction from high to low elevations.
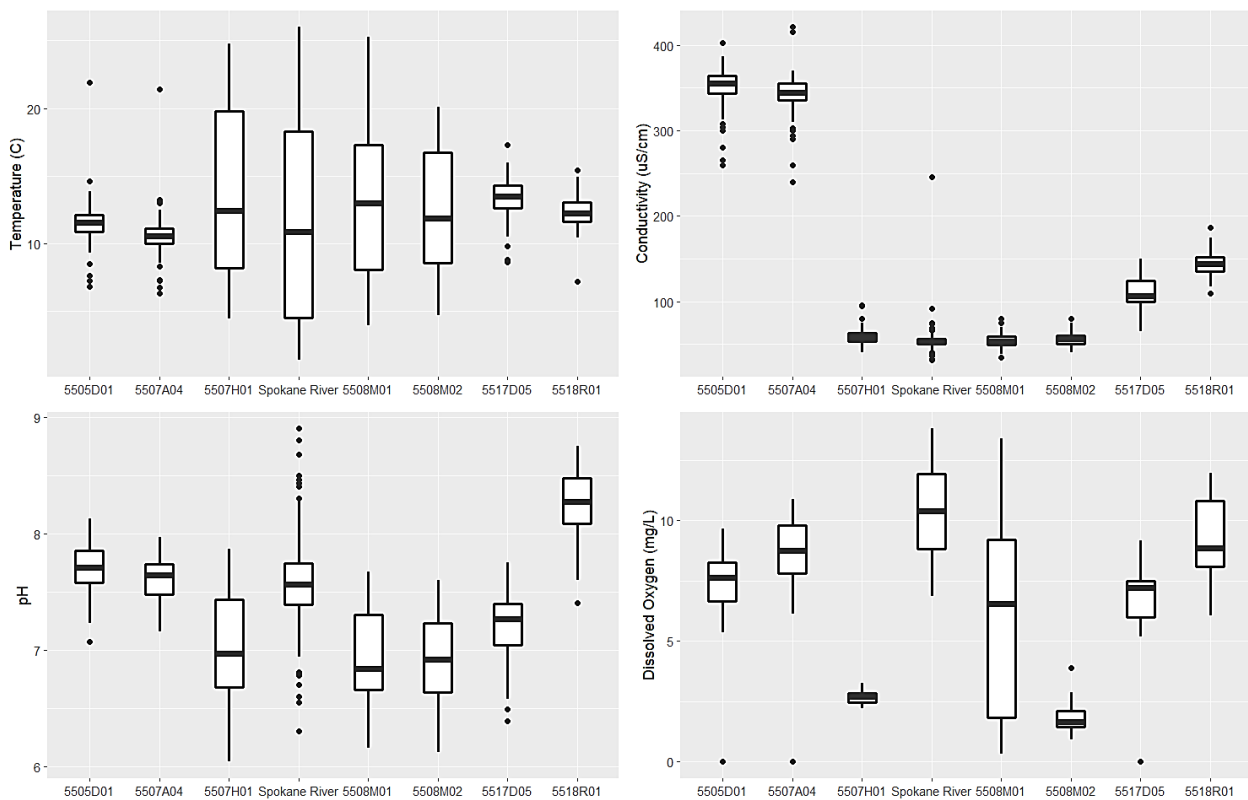
Figure 62. Boxplots comparing temperature (in Celsius), pH, conductivity (in uS/cm), and dissolved oxygen (in mg/L) measurements collected between 1999 and 2019 at seven wells along Barker Road and the Spokane River at Barker Road representing a cross-section at a losing reach of the river. From left to right, the sites are arranged from the northern most site at Trent and Barker monintoring well (5505D01) to the southern most site at the Consolidated Irrigation District Site 2A purveyor well (5518R01). Data for the Spokane River at Barker Road was compiled from Ecology's Environmental Information Management (EIM) database.

58

Groundwater from the southern-most locations (5517D05 and 5508R01) has slightly higher temperatures, conductivity, and major ion concentrations indicating a potential mixing of river water and groundwater (Figures 62 and 63).

The USGS categorized groundwater into three source water groups based on median total dissolved solids (TDS) concentration (Table 6). According to this scheme, a median TDS less than 50 mg/L indicates that groundwater primarily originates from the Spokane River, a median TDS greater than 100 mg/L indicates that groundwater originates from the regional groundwater system, and a median TDS between 50 and 100 mg/L indicates the groundwater is likely a mixing from the river and the regional system. Median conductivity levels at each location fit the USGS groundwater source classification scheme, given that conductivity can be converted to TDS using equation (EQN) 2:

EQN 2. Conductivity (us/cm) x 0.64 = TDS (mg/L)

Table 6. Groundwater source classification for the losing reach monitoring locations using total dissolved solids (TDS) and conductivity as an indicator of groundwater interaction with the Spokane River based on USGS.			
Groundwater Source	**TDS (mg/L) Range**	**Conductivity (uS/cm) Range**	**Monitoring Locations**
River	<50	<78	5507H01, 5508M01 and 5508M02
Transitional	50 – 100	78 – 156.25	5517D05 and 5508R01
Regional	>100	>156.25	5505D01 and 5507A01

Figure 63. Boxplots comparing major ion concentrations (in mg/L) measured in samples collected between 1999 and 2019 at seven wells along Barker Road and the Spokane River at Barker Road representing a cross-section at a losing reach of the river. From left to right, the sites are arranged from the northern most site at Trent and Barker monintoring well (5505D01) to the southern most site at the Consolidated Irrigation District Site 2A purveyor well (5518R01). Major ions are calcium (Ca), chloride (Cl), potassium (K), magnesium (Mg), sodium (Na), and sulfate. Data for the Spokane River at Barker Road was compiled from Ecology's Environmental Information Management (EIM) database.

Groundwater from the river influenced wells 5507H01 and 5508M02 have lower levels of dissolved oxygen (median DO<3 mg/L) and slightly acidic conditions (median pH<7). While this differs from the river's conditions, the USGS noted that the river transports fine-grained materials that settle into the spaces between the aquifer sediments, reducing permeability. This could be affecting dissolved oxygen and pH levels in the river-influenced aquifer. The difference in the DO and pH levels at each site helps explain differences in nutrient and trace metal concentrations along the cross-section.

Nitrate data reflect a similar pattern displayed in conductivity and major ion concentrations (Figure 64). The lower concentrations of nitrate in the Spokane River with groundwater concentrations increasing with distance from the river suggests a dilution effect from the river. Periodic anoxic conditions occurring in the near river aquifer may promote denitrification (the reduction of nitrate to nitrogen gas), which could also contribute to lower nitrate in the near-river aquifer.

Total phosphorus and SRP data along the losing reach demonstrate that the Spokane River may be contributing phosphorus into the near-river aquifer (Figure 64). This is evidenced by higher median concentrations in samples from wells in proximity to the river and concentrations generally decreasing with distance from the river. While there may be some direct transport, the slightly acidic and periodic anoxic conditions in the near-river aquifer may promote mobilization of phosphate anions, which could contribute to the higher concentrations.
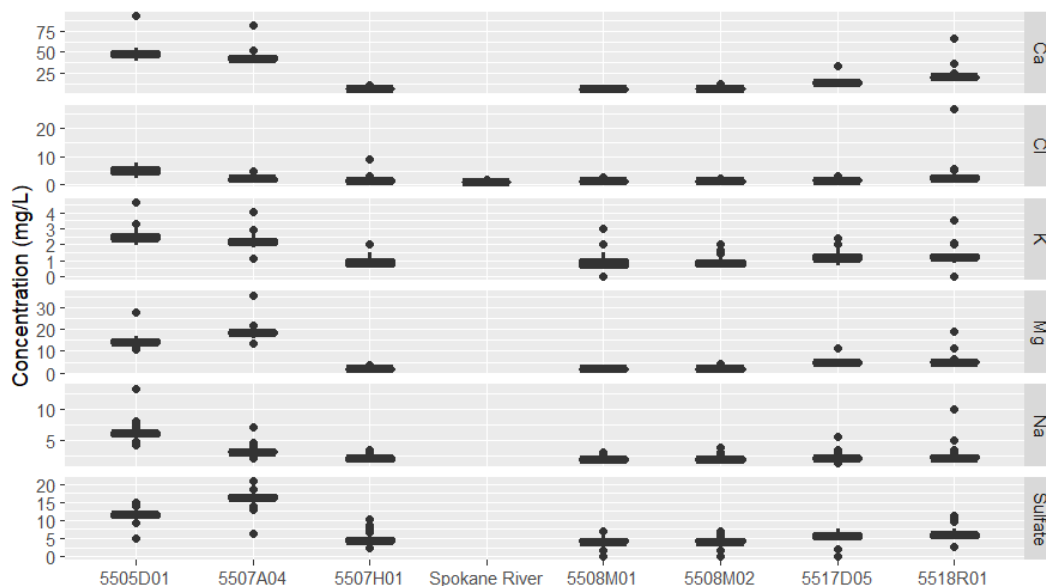

Figure 64. Boxplots comparing nutrient concentrations (in mg/L) measured in samples collected between 1999 and 2019 at seven wells along Barker Road and the Spokane River at Barker Road representing a cross-section at a losing reach of the river. From left to right, the sites are arranged from the northern most site at the Trent and Barker monintoring well (5505D01) to the southern most site at the Consolidated Irrigation District Site 2A purveyor well (5518R01). Nutrients are nitrate, soluble reactive phosphorus (SRP), and total phoshorus (TP). 5518R01 has a TP outlier of 0.43 mg/L not shown here. Data for the Spokane River at Barker Road was compiled from Ecology's Environmental Information Management (EIM) database.

Previous studies indicated the Spokane River is a likely source of cadmium, copper, lead, and zinc in the aquifer, but that these metals are not transported far in the aquifer. Data presented here mostly confirms this. The Spokane River has higher concentrations of these metals than groundwater and they are generally not detectable outside of the river-influenced aquifer (represented by 5507H01, 5508M01 and 5508M02) due to pH-influenced sorption processes (Figure 65). These metals commonly exist as positively charged ions and will sorb onto aquifer sediments as they move further from the river into the more alkaline (pH>7) conditions.

Even so, the metals transported from the Spokane River to the SVRP Aquifer have low detection rates in the river-influenced aquifer. Detection rates for the well immediately north of the river (5507H01) are as follows: cadmium, 20 percent; copper, 40 percent; and lead, 25 percent. For the well immediately south of the river (5508M01), lead is generally not detectable, and cadmium and copper are detectable 30 and 11 percent of the time, respectively.
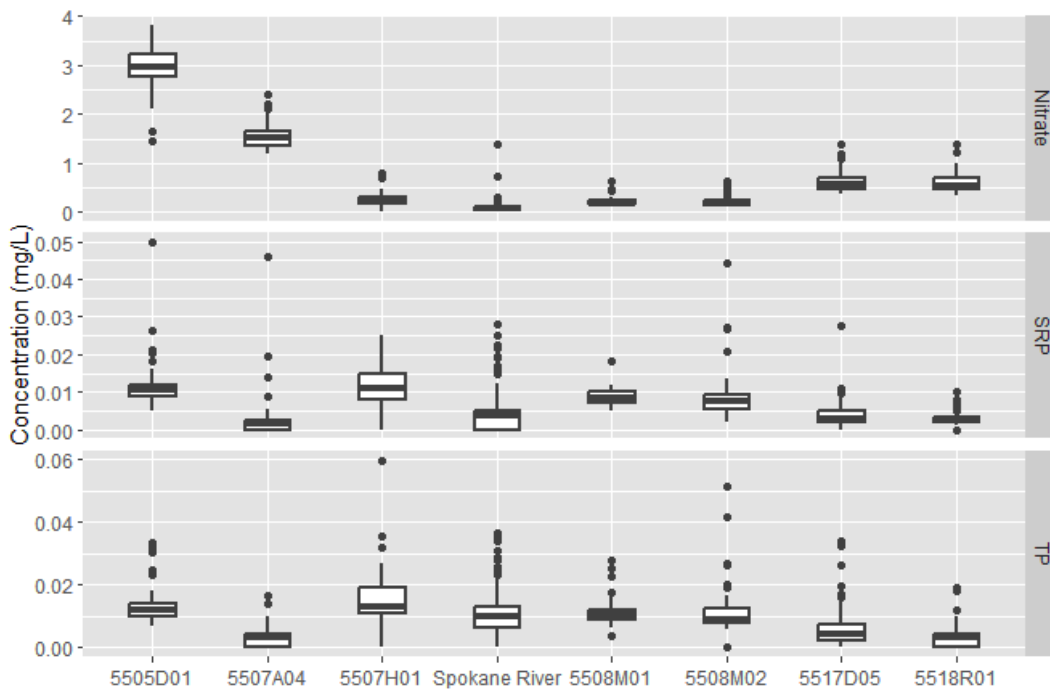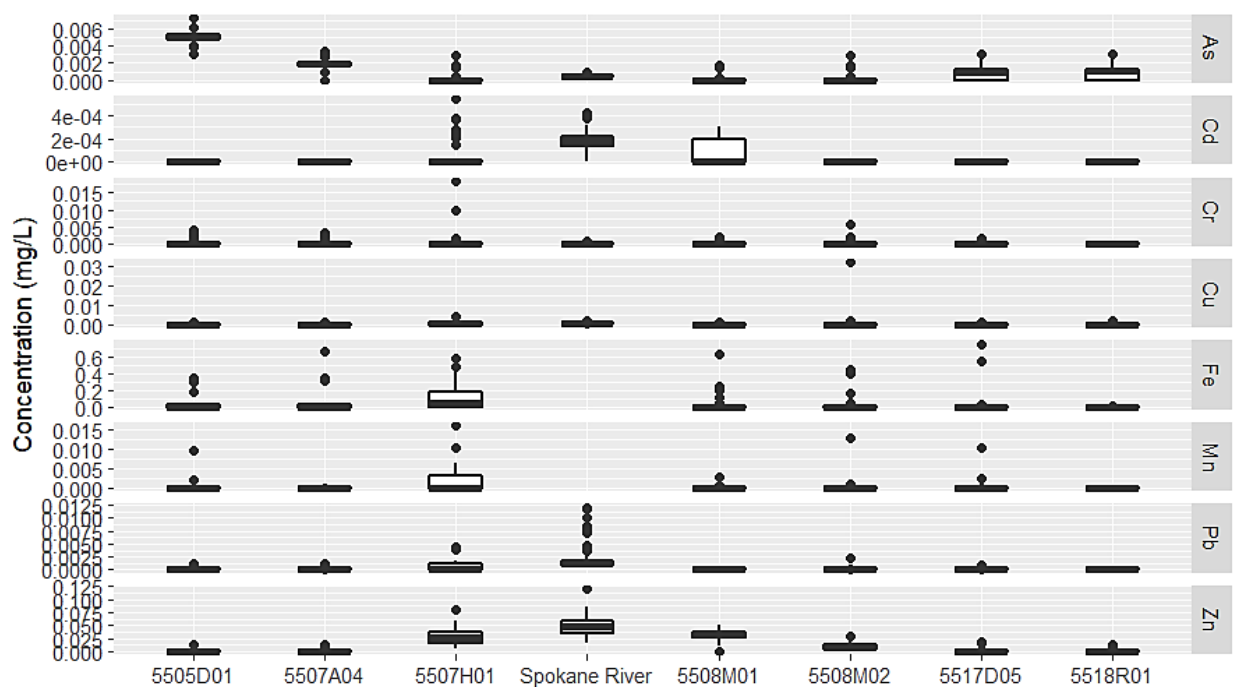

Figure 65. Boxplots comparing concentrations of trace metals (in mg/L) measured in samples collected between 1999 and 2019 at seven wells along Barker Road and the Spokane River at Barker Road representing a cross-section at a losing reach of the river. From left to right, the sites are arranged from the northern most site at Trent and Barker monintoring well (5505D01) to the southern most site at the Consolidated Irrigation District Site 2A purveyor well (5518R01), which is the general direction of groundwater flow (shown by arrow). Trace metals are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), lead (Pb), and zinc (Zn). Data for the Spokane River at Barker Road was compiled from Ecology's Environmental Information Management (EIM) database.

Zinc, however, is generally detectable in the river-influenced aquifer. The median groundwater concentration is about 0.03 mg/L immediately north (5507H01) and south (5508M01) of the river, slightly lower than the median river concentration of 0.0383 mg/L. The median groundwater concentration drops to 0.01 mg/L at 5508M02. Zinc is generally non-detectable in groundwater collected from outside of the river-influenced aquifer.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Of the other metals assessed, iron and manganese are detected about half the time in samples collected just north of the river (5507H01) but are generally not detectable at remaining groundwater locations along the cross-section. Due to lack of river data for these parameters, it is unclear if the Spokane River is a potential source, or if the iron and manganese levels are a result of more localized conditions. Chromium is generally not detectable in the Spokane River or the SVRP aquifer along the losing reach.

Arsenic is detectable in the regional and transitional groundwater. Median concentrations at these sites are between 0.002 and 0.005 mg/L. However, arsenic drops to undetectable levels in the river-influenced aquifer where groundwater becomes more acidic. This promotes adsorption of arsenic to the aquifer sediments, reducing the concentration in the river-influenced groundwater.

5.2. Gaining Reach: Sullivan Road to Trent Avenue

A gaining reach is where the aquifer discharges groundwater into the river (Figure 59). Along such reaches, groundwater mixes with river water influencing the river's water chemistry. To look at how the Spokane River's chemistry changes along the gaining reach in response to groundwater inputs, data from the Ecology EIM database was compiled for surface water monitoring locations along the gaining reach that spans from Sullivan Road to Plantes Ferry (Figure 66). For the same 20-year period (1999 – 2019), the EIM Spokane River dataset is limited to temperature, pH, conductivity, chloride, and nutrient (nitrate, phosphorus, and SRP) data for three locations along the gaining reach: Sullivan Road (RM87.8), Trent Street (RM85.3), and Plantes Ferry (RM84). The Spokane River at Barker Road (RM90.4) location is also provided to show river conditions just upstream of the gaining reach. Due to the limited Spokane River data available, all available data was used and not limited to low-flow summer conditions when groundwater influence is the strongest.

This was compared to the County's data for groundwater monitoring locations along the gaining reach. To better relate groundwater data to the Spokane River data, data from monitoring locations were combined to show conditions at each of the river locations (Table 7).

Table 7. Combined data from groundwater monitoring locations representing groundwater conditions at each river location.

River Locations	Groundwater Locations
Barker Rd.	*Groundwater data not used for analysis
Sullivan Rd.	5411R05s, 5411R03, 5411R06
Trent St.	6436N01
Plantes Ferry	(Plantes Ferry/5404A01 not used)

For example, data from the three groundwater monitoring locations at Sullivan Road (5411R05s, 5411R03, 5411R06) were combined to show overall groundwater conditions at Sullivan Road. Data from the East Valley High School monitoring well is used to represent groundwater entering the river in the vicinity of Trent based on flow paths from purveyor well capture zones (CH2M Hill 1998). The groundwater from the Plantes Ferry monitoring well (5404A01) represents a unique condition associated with its proximity to the edge of the aquifer boundary and a confining layer, and it is not used in this assessment since the data suggests that either the confined aquifer is not interacting with the river or the groundwater input from the confined aquifer is low enough to be extremely diluted.
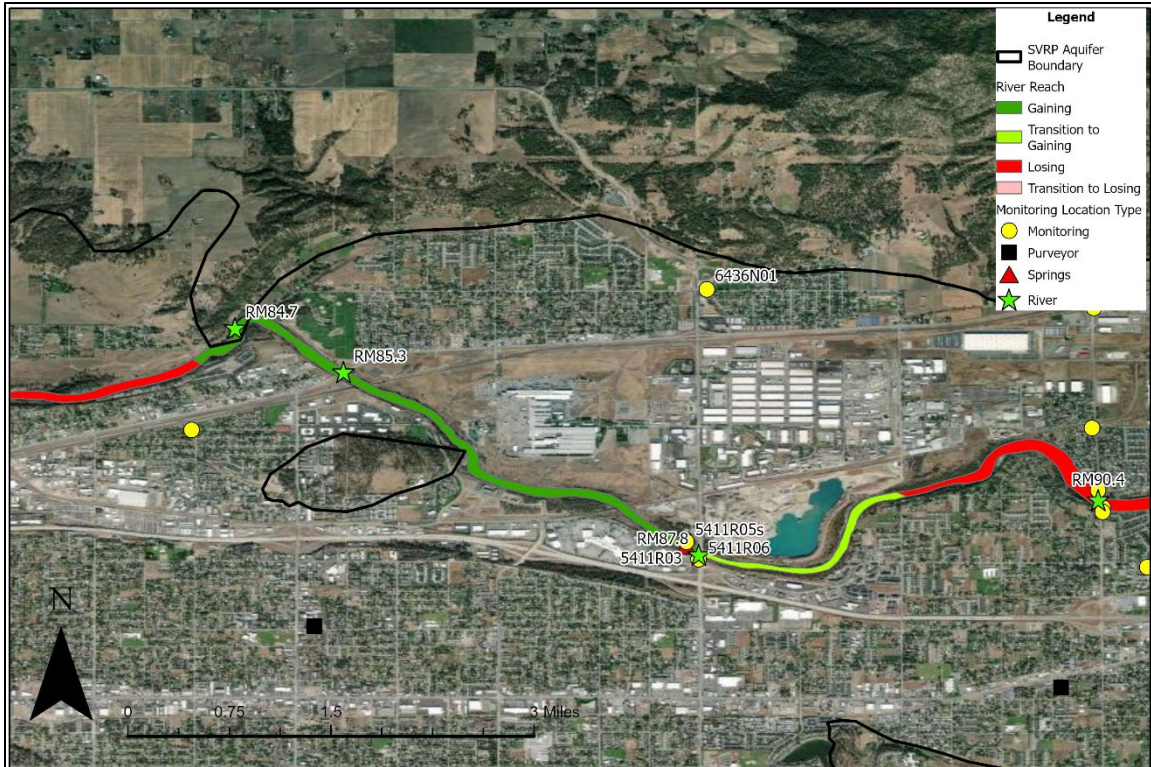
Figure 66. An aerial view highlighting the gaining reach of the Spokane River spanning from Sullivan Road at river mile (RM) 87.8 to Plantes Ferry at RM 84.7. The other monitoring locations used to assess surface water and groundwater conditions along the gaining reach include two monitoring wells at Sullivan Road (5411R03 and 5411R06), the Sullivan Park springs (5411R05s), the East Valley High School monitoring well (6436N01), and the Spokane River at Trent (RM85.3). Groundwater data from several wells were combined to provide groundwater conditions at each of the river locations as indicated in Table 7.

River temperature and conductivity data provide insight to groundwater contributions along a gaining reach. Groundwater influence is usually represented by a decrease in river temperatures and an increase in river conductivity. This generalization is for low-flow summer conditions when groundwater inputs are providing much of the river flow within a gaining reach. Though the data is not limited to low-flow conditions, this pattern can still be seen in the data.

While median river temperature increases from Barker to Trent, the max temperature decreases from 26 to 16 degrees Celsius. This demonstrates the cooling effect of the groundwater inputs along this reach. Median river conductivity increases from Barker (median 53 uS/cm) to Trent (median 205 uS/cm) in response to groundwater as expected (Figure 67).

63
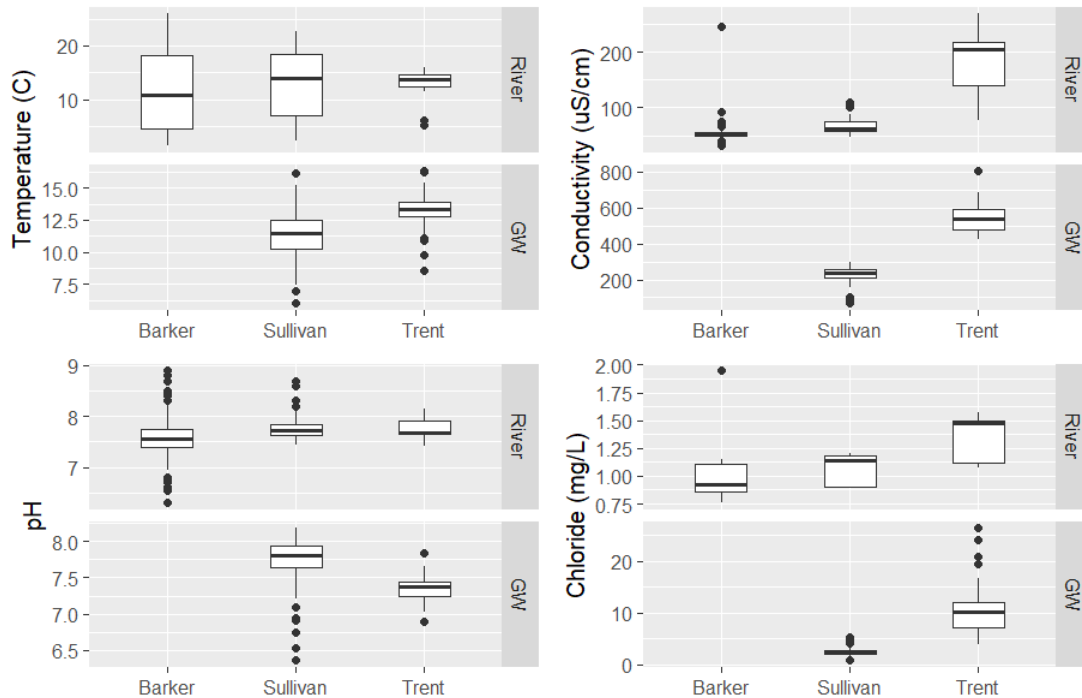
Figure 67. Boxplots comparing river and groundwater (GW) temperature (in Celsius), pH, conductivity (in uS/cm), and chloride concentrations (in mg/L) at locations along a gaining reach of the Spokane River. From left to right, the sites are arranged from east to west, from Barker Road to Trent Avenue, which is the direction of the Spokane River's flow. Spokane River data is from Ecology's Environmental Information Management (EIM) database.

The data suggests that the aquifer may be contributing chloride and nutrients to the river. The groundwater locations generally have higher concentrations of these constituents than their river counterparts, leading to an overall increase in river concentrations in the gaining reach (Figures 67 and 68). Between Barker and Trent, median river levels increase from 0.93 to 1.48 mg/L for chloride, 0.06 to 0.67 mg/L for nitrate, 0.0097 to 0.014 mg/L for total phosphorus, and 0.0036 to 0.005 mg/L for SRP.

In all cases, groundwater entering the river near Trent appears to have the largest impact on river water quality along the gaining reach. The groundwater entering the river at Trent has much higher concentrations of chloride and nutrients than that entering at Sullivan. This may be in part due to the groundwater from Trent traveling along the margins of the aquifer to the north of the river, where chloride and nutrients tend to concentrate. In addition, there may be some influence from non-sewered areas along this flow path (see Section 7.1.9)
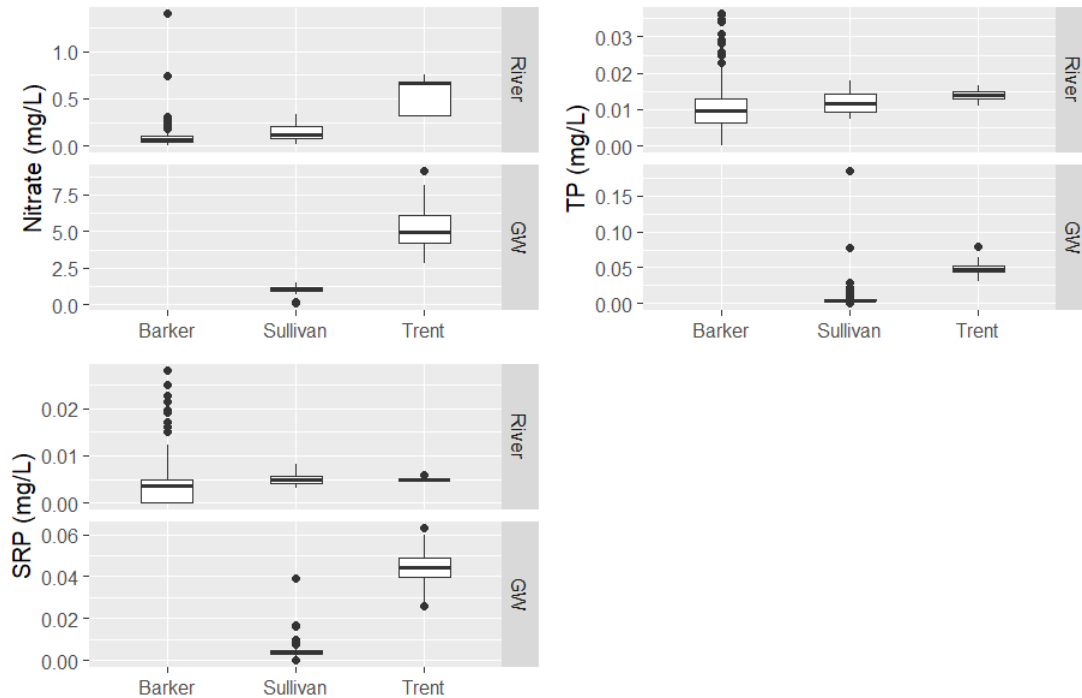
Figure 68. Boxplots comparing river and groundwater (GW) nitrate, soluable reactive phosphorus (SRP), and total phosphorus concentrations (in mg/L) at three locations along a gaining reach of the Spokane River. From left to right, the sites are arranged from east to west, from Barker Road to Trent Avenue, which is the direction of the Spokane River's flow. Spokane River data is compiled from Ecology's Environmental Information Management (EIM) database.

5.3. Three Springs/Western Arm Gaining Reach

Three Springs is a natural spring that enters the Spokane River just upstream of the T.J. Meenach bridge at the start of the gaining reach overlaying the Western Arm of the SVRP aquifer (Figure 69). Three Springs is a relatively small input to the Spokane River. A single flow comparison for the spring and the Spokane River below the T.J. Meenach bridge measured the spring at 1.88 cubic feet per second (cfs) and the river at 1030 cfs in September 2004 (Kimbrough et al, 2005). Three Springs, therefore, is unlikely to significantly influence the chemistry of the Spokane River itself. However, for the purpose of this analysis, Three Springs is considered to represent the general quality of groundwater moving through the Trinity Trough and discharging to the Spokane River at the start of the gaining reach overlaying the Western Arm of the SVRP aquifer.

To examine the possible influence of groundwater on the Spokane River, data from the Ecology EIM database was compiled for the same 20-year period (1999 – 2019) for two surface water monitoring locations up- and down-stream of Three Springs at the Sandifer (RM72.5) and T.J Meenach bridges (RM 69.8), respectfully (Figure 69). The EIM data for these locations are limited to temperature, dissolved oxygen, pH, conductivity, and nutrients (nitrate, phosphorus, and SRP). The County has monitored the water quality at the Three Springs location on a quarterly basis since October 2007.

Figure 69. Aerial and close-up view of Three Springs monitoring location (5212F01s) located on a gaining reach of the Spokane River overlaying the Western Arm of the Spokane Valley Rathdrum Prairie (SVRP) Aquifer between the Sandifer Bridge at River Mile 72.5 (RM72.5) and the T.J. Meenach Bridge (RM69.8).

There are two important items of note regarding this analysis. First, Latah Creek enters the Spokane River just downstream of the Sandifer Bridge (Figure 69). However, since August/September represent low flow conditions when Latah Creek's influence on the Spokane River is small compared to groundwater, the creek's influence is considered negligible. For example, Latah Creek's discharge in September 2004 at 7.43 cfs, which is about 8 percent of the total estimated inflow to the Spokane River along this reach during low flow. Groundwater, including the springs, accounted for the other 91 percent. Second, available data collected between June and September were used to assess groundwater influence since this is when groundwater accounts for most of the inflows.

Groundwater influence along a gaining reach is usually represented by decrease in river temperatures and an increase in river conductivity. The Spokane River between the Sandifer and TJ Meenach bridges, the groundwater (represented by Three Springs) appears to slightly cool the river and increase the conductivity as expected. The river's median temperature decreases from 14.45 to 14.20 degrees Celsius and the river's median conductivity increases from 150 to 313 uS/cm in response to groundwater inputs (Figure 70). Along this reach, the river's median pH and dissolved oxygen levels slightly increase. The pH goes from 8.11 to 8.17 and dissolved oxygen goes from 9.27 to 9.5 mg/L. However, this does not appear to be from groundwater influence.
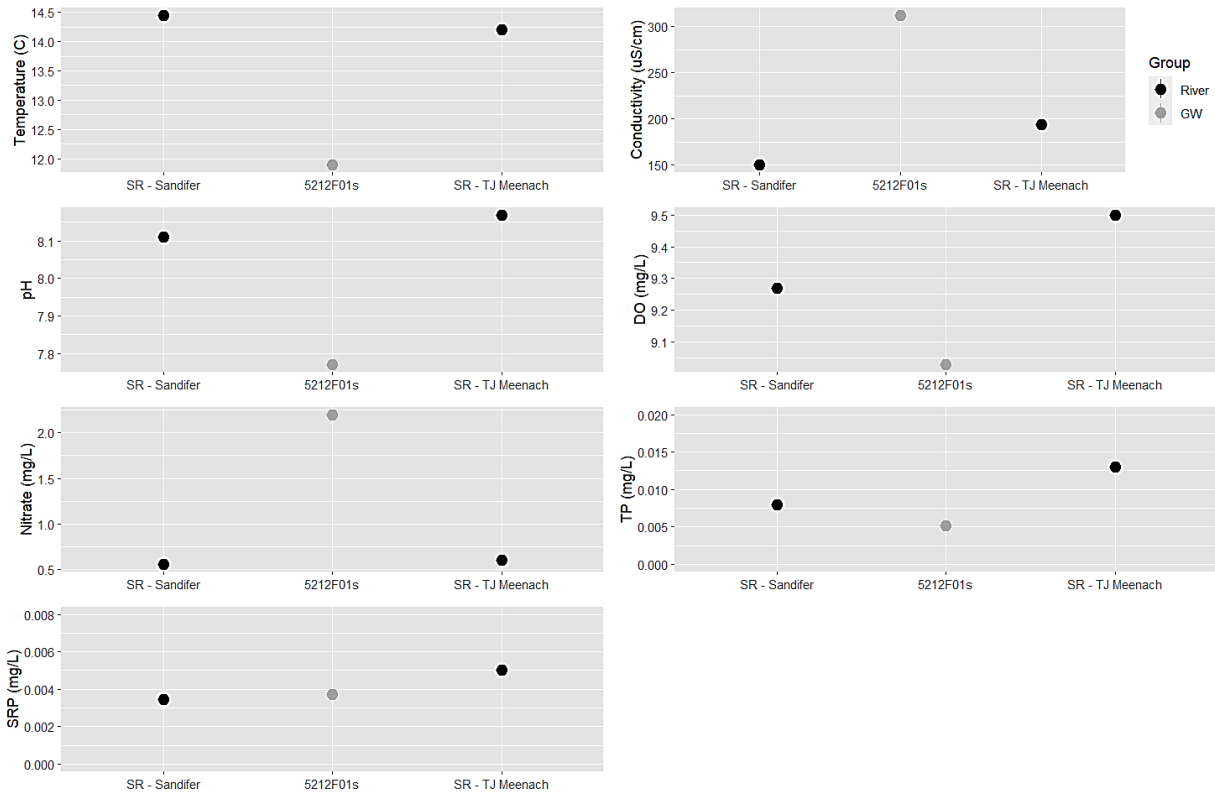
Figure 70. Plots comparing river and groundwater (GW) median temperature (in Celsius), conductivity (in uS/cm), pH, and dissolved oxygen (DO), nitrate, soluable reactive phosphorus (SRP), and total phosphorus (TP) concentrations (in mg/L) along a gaining reach of the Spokane River between the Sandifer and the TJ Meenach bridges in the direction of the Spokane River's flow. Three Springs (5212F01s) enters the river between these two river locations. Data for the Spokane River locations was compiled from Ecology's Environmental Information Management (EIM) database.

Concentrations of nitrate, SRP, and total phosphorus measured in Three Springs compared to the Spokane River at the Sandifer and TJ Meenach bridges are provided in Figure 70. Three Springs has higher median nitrate levels than the Spokane River (median = 2.06). The groundwater input raises the river nitrate levels between the Sandifer Bridge (median = 0.31 mg/L) and the TJ Meenach bridge (median = 0.56 mg/L). Groundwater total phosphorus levels are lower than those in the river upstream at Sandifer Bridge, but the groundwater SRP levels are near that in the river. The median river total phosphorus at Sandifer is 0.0073 mg/L and 0.0043 mg/L in the springs. The median SRP in the river at Sandifer and the springs is 0.0035 and 0.0038 mg/L, respectively. Therefore, the groundwater inputs are likely not a major contribution to the increased levels of total phosphorus and SRP measured in the river at TJ Meenach bridge, where median total phosphorus is 0.014 mg/L and SRP is 0.005 mg/L.

6. SVRP Aquifer Inputs into the Little Spokane River

The Little Spokane River is a tributary to the Spokane River, entering the Spokane River at river mile 56.3 just downstream of Nine Mile Dam. The lower Little Spokane River overlays the Little Spokane River Arm of the SVRP aquifer (Figure 71). In the 7-mile stretch between the USGS Dartford gage (12431000) and the USGS near Dartford gage (12431500), the Little Spokane River gains flow from the SVRP aquifer. Estimates of groundwater inflows range from 244 cfs to 254 cfs between July and October (USGS). It is thought groundwater inflows below the USGS near Dartford gage to the mouth of the Little Spokane is minimal.

Four groundwater monitoring locations representing two locations of groundwater discharge to the Little Spokane River: Waikiki Springs (6306P01s and 6306P01s2) and Griffith Springs at the Spokane Hatchery (6211J01s and 6211K01). No flow measurements exist for Waikiki or Griffith Springs, though the springs themselves are likely a relatively small input to the Little Spokane River. For this study, they are considered representative of the groundwater quality entering the Little Spokane River.
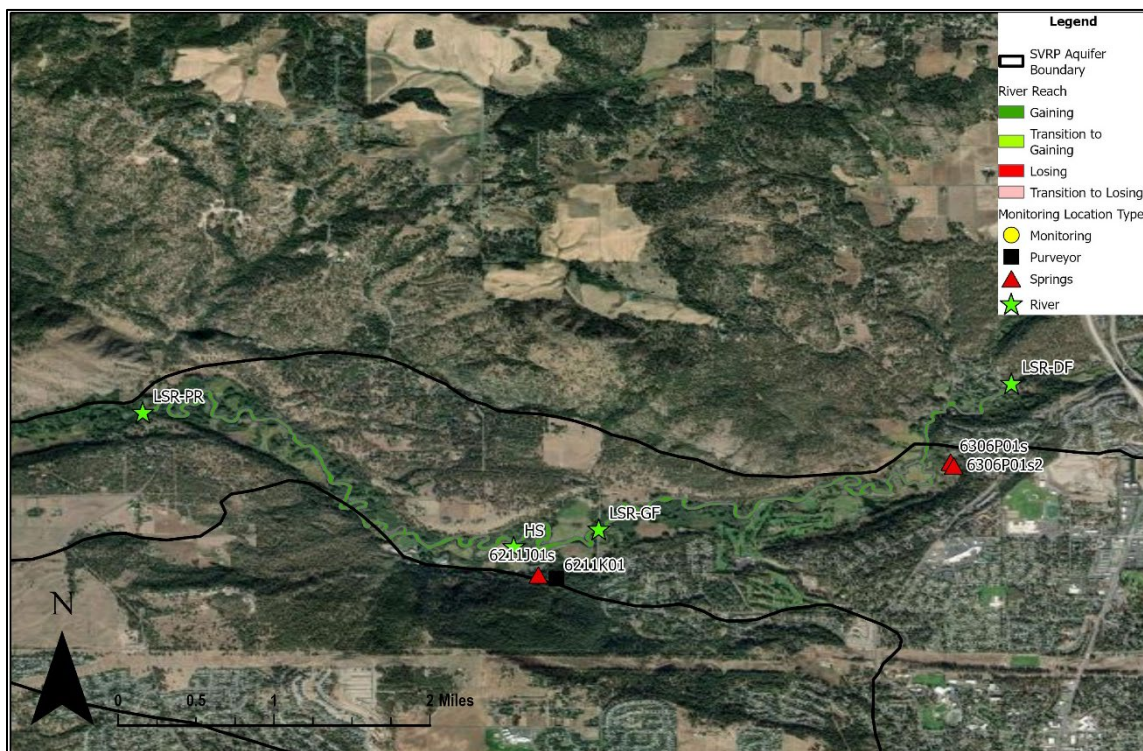
Figure 71. Aerial view of the Little Spokane Arm of the SVRP aquifer including both groundwater and surface monitoring locations. Groundwater monitoring locations include Waikiki Springs (6306P01s and 6306P01s2), Griffith Springs (6211J01s), and the Spokane Hatchery well (6211K01) and Little Spokane River (LSR) monitoring locations include the LSR at Dartford (LSR-DF), LSR near Griffith Springs (LSR-NGS), the Hatchery Slough (HS) and LSR at Painted Rocks (LSR-PF).

To determine groundwater influence from the SVRP aquifer on the Little Spokane River, EIM data for the Little Spokane River was used from three locations: Little Spokane at Dartford (LSR-DF), Little Spokane near Griffith Springs (LSR-NG), and Little Spokane at Painted Rocks/Rutter Parkway (LSR-PR) (Figure 71). The Dartford and Painted Rocks locations are adjacent to the USGS Dartford and near Dartford gages, respectively. Therefore, the river locations cover the length of the gaining reach and provide locations upstream, in between, and downstream of the groundwater monitoring locations. In addition, the EIM

68

data for the Hatchery Slough (HS) tributary near its confluence with the Little Spokane River was used due to the County's Griffith Springs monitoring location being upstream of this point (Figure 71). The Hatchery Slough is where water from Griffith Springs combines with the outflow from the hatchery before discharging into the Little Spokane River.

Data available for both groundwater and surface water monitoring locations for the 20-year period include temperature, pH, conductivity, dissolved oxygen, chloride, nitrogen, total phosphorus, and SRP. It should be noted that only data from June through September was used for two reasons: 1) data for the Little Spokane near Griffith Springs is limited to these months; and 2) this is when the groundwater is expected to primarily influence the river and, therefore, the contribution of the tributary, Dartford Creek, can be disregarded. Though Dartford Creek enters the Little Spokane River just below the Dartford gage, it's influence during low flow periods is expected to be minimal compared to groundwater. For example, the discharge of Dartford Creek at 2.37 cfs, which is 1 percent of the inflows occurring. Groundwater contributes 188 cfs to the Little Spokane River at the Dartford gage (Kimbrough et al, 2005).

Further, some unusual phosphorus data in EIM was excluded. The EIM database records for Little Spokane at Dartford include total phosphorus levels ranging from 24 to 103 mg/L measured from January 1999 to September 1999. These data were recorded for Site LS6, one of the two EIM sites at the Dartford location and conflicted with data recorded for the second site, 55B082, from the same dates. For example, the phosphorus level on January 11 at LS6 was 76 mg/L and for 55B082 it was 0.087 mg/L. It is possible the reported units for the Site LS6 data were intended to be in micrograms per liter (ug/L) rather than milligrams per liter (mg/L) as indicated. This would make the apparently high values more like those reported for Site 55B082 and other river locations. Even so, since these data appeared unusual and values could not be confirmed, they were not used in this analysis.

Groundwater influence along a gaining reach is usually represented by decrease in river temperatures and an increase in river conductivity. Median river temperatures go from 15.5 C at Dartford to 13.8 C at Near Griffith and 13.2 C at Painted Rocks (Figure 72). The smaller decrease in temperature between the Near Griffith and the Painted Rocks locations may be partly due to the Hatchery Slough discharge, which is warmer (median = 12.9 C) than the cooler groundwater at Griffith Springs. Median river conductivity increases between Dartford and Near Griffith (218 to 287 uS/cm) due to groundwater as expected. However, conductivity decreases between Near Griffith and Painted Rocks (median = 264 uS/cm), though the conductivity at Hatchery Slough is just as high as the contributing groundwater.

Temperature and conductivity data along the Little Spokane River between Dartford and Painted Rocks demonstrate the trends of a gaining reach but suggests that groundwater influence may not be as strong in the lower half. This corresponds with information from GeoEngineers (2009) indicating 68 percent of the groundwater inputs occur between the Dartford and the Near Griffith locations and 32 percent occur between Near Griffith and Painted Rocks locations.
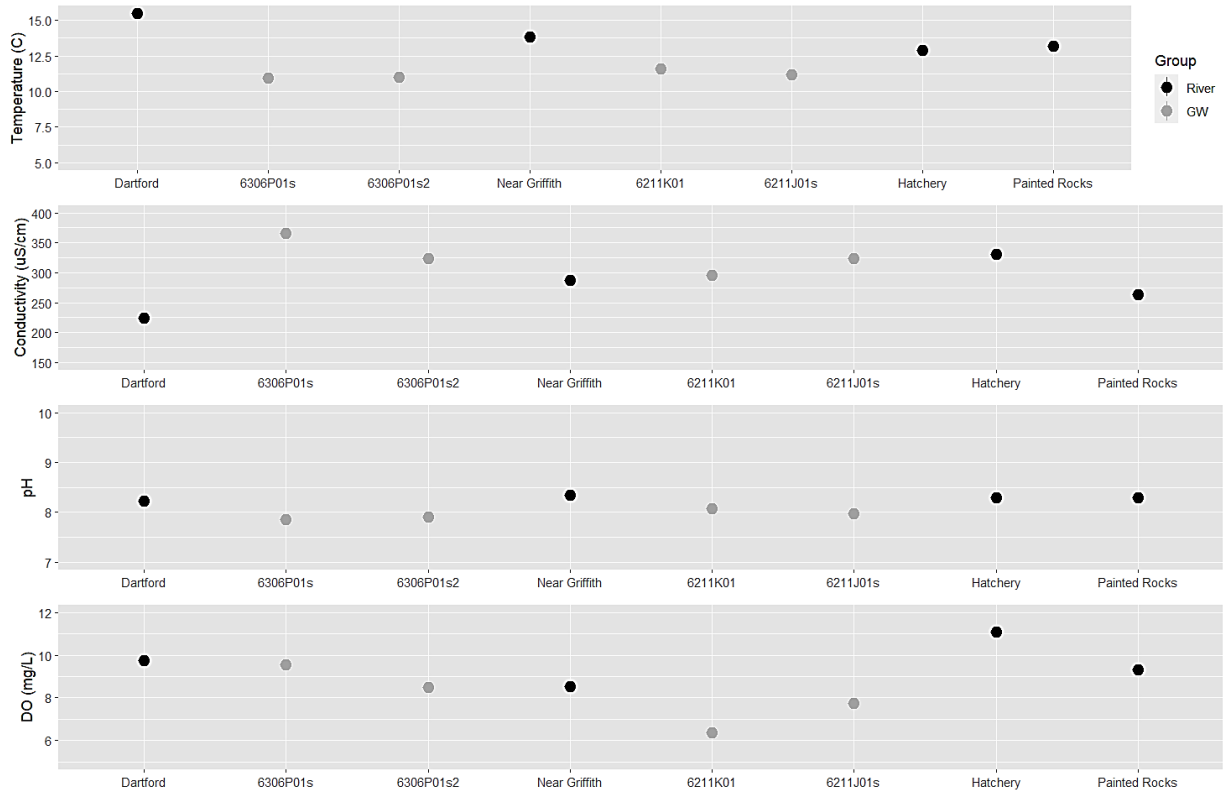
Figure 72. Median temperature, conductivity, pH, and dissolved oxygen (DO) concentrations at four groundwater (GW) and four surface water monitoring locations on the Little Spokane River (LSR). River locations are arranged, left to right, in the direction of flow from the Dartford gage to Painted Rocks, with Waikiki Springs (6306P01s and 6306P01s2) entering the river upstream of the Near Griffith Springs location and the groundwater from the Spokane Hatchery well (6211K01) and Griffith Springs (6211J01s) entering the Hatchery Slough tributary.

The Little Spokane River's pH and dissolved oxygen (DO) levels are not as affected by the groundwater inputs. The river's pH is generally around 8.3 at each location, and groundwater is around 7.8 at Waikiki Springs and 8.0 at Griffith Springs. The river's DO levels are generally between 8.5 and 9.5 mg/L though groundwater is slightly lower. The outflow from the hatchery appears to introduce DO in the Hatchery Slough, given the slough has higher levels than measured at Griffith Springs (Figure 72).

Data suggests groundwater is a source of chloride and nitrates in the Little Spokane River, given that groundwater levels are generally higher than the river. However, the river's median chloride and nitrate concentrations are similar at each location (~5 and 1 mg/L, respectively) suggesting some mechanism for diluting the groundwater chloride and nitrate inputs along this section. The outflow from the hatchery does not appear to greatly increase chloride or nitrate levels in the Hatchery Slough above the inputs from Griffith Springs (Figure 73).
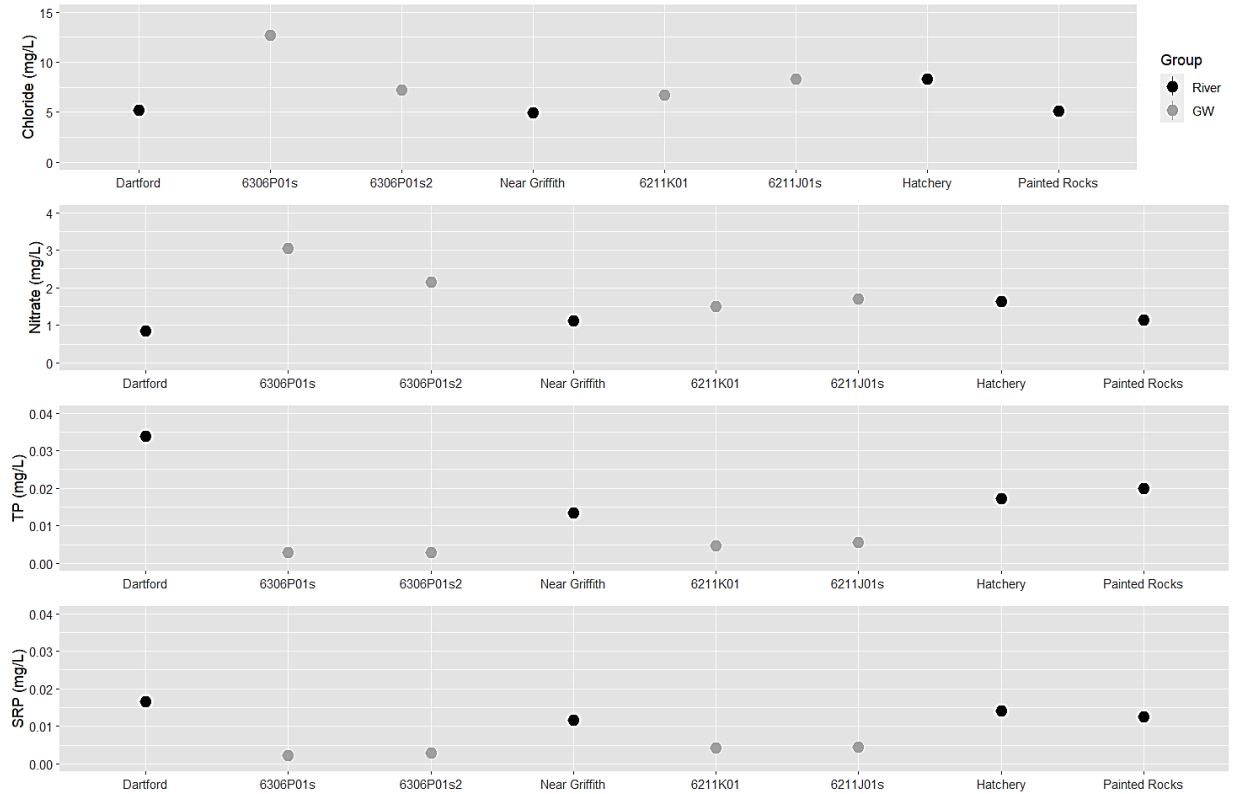
Figure 73. Median nitrate and total phosphorus at four groundwater (GW) and four surface water monitoring locations on the Little Spokane River (LSR). River locations are arranged, left to right, in the direction of flow from the Dartford gage to Painted Rocks, with Waikiki Springs (6306P01s and 6306P01s2) entering the river upstream of the Near Griffith Springs location and the groundwater from the Spokane Hatchery well (6211K01) and Griffith Springs (6211J01s) entering the Hatchery Slough tributary.

Groundwater levels of total phosphorus and SRP are generally lower than the river along this section of the Little Spokane River, suggesting groundwater serves to dilute river phosphorus levels contributed from other sources. The total phosphorus levels decrease from 0.04 mg/L at the Dartford gage to 0.02 mg/L at Painted Rocks, and SRP levels decrease from 0.02 to 0.01 mg/L (Figure 73). The median total phosphorus and SRP concentration at the Hatchery Slough (0.0193 and 0.0149 mg/L, respectively) is about three times the median concentrations at Griffith Springs (0.0057 and 0.0045 mg/L), indicating the hatchery outflow is likely the source of phosphorus in the slough.

7. On-Site Wastewater and the Septic Tank Elimination Program

There are several sewer service areas overlying the SVRP aquifer within Spokane County. The major ones include the City of Spokane's sewer service area, served by the Riverside Park Water Reclamation Facility (RPWRF); Spokane County's Spokane Valley sewer service area, served by the Spokane County Regional Water Reclamation Facility (SCRWRF) and RPWRF; Spokane County's North Spokane sewer service area, which is connected to the RPWRF; and the Liberty Lake Sewer and Water District (LLSWD) service area, served by the LLSWD's Water Reclamation Facility (Figure 74). Locations outside of these sewer service areas utilize septic systems to provide on-site wastewater treatment.

Figure 74. Sewer service areas overlying the Spokane Valley Rathdrum Prairie (SVRP) Aquifer. This shows the extent of sewer service as of 2023; future service areas are not shown. Spokane County's sewer service area is divided between its North Spokane sewer service area (north of the City of Spokane's service area) and its Spokane Valley sewer service area (east of the City of Spokane's service area).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Septic system leachate can degrade groundwater quality. While there is no local data regarding typical concentrations of contaminants in septic tank effluent, data from the U.S. EPA (2002) is presented in Table 8. Indicators of septic leachate impacting groundwater primarily includes elevated levels of nitrate, phosphate, and SRP. Elevated levels of chloride, sulfate, sodium, calcium, and potassium have also been linked to septic leachate. Groundwater below septic systems may also experience lower dissolved oxygen and pH (Katz et al 2011). Volatile organic compounds (VOCs) and synthetic organic compounds (SOCs) in septic tank effluent are

Table 8. Water quality characteristics of typical domestic septic tank effluent. Summarized from USEPA 2002.

Parameter	Typical Range
Temperature (C)	0 – 23
pH	6.4 – 7.8
TDS (mg/L)	354 – 610
Chloride (mg/L)	37 – 110
Total Nitrogen (mg/L)	40 – 100
Total Phosphorus (mg/L)	5 – 17
VOCs	0 – Trace
SOCs	0 – Trace
Heavy Metals	0 – Trace

likely to be removed in subsoils through gaseous diffusion, volatilization, or biodegradation before reaching groundwater. However, there have been instances of toxic organic contamination from septic infiltration fields.

Spokane County implemented the Septic Tank Elimination Program (STEP) to address concerns identified in the 1978 Spokane Aquifer Cause and Effect Report (Esvelt 1978), which determined that on-site sewage systems were contributing to water quality degradation in the SVRP aquifer. As a result, the 1979 Spokane Aquifer Water Quality Management Plan included the following:

> *The recommendations for handling sanitary wastewater and mitigation of its pollution to the groundwater include the collection of all sewage from urbanized areas and treatment for discharge in such manner that the pollutants cannot enter the aquifer. Central sewer planning within the aquifer sensitive area should result in sewering of areas that have been urbanized or are to be urbanized.*

The update to the Spokane Aquifer Cause and Effect Report (Esvelt and Miller 1983) found increasing trends in nitrate concentrations within the aquifer confirming the need to address on-site sewage disposal. Through the STEP, approximately 75 percent of existing septic systems draining to the SVRP aquifer in Spokane County were converted to sewer. This was done in phases over the course of several decades with much of the sewer installation completed by December 2011 when the SCRWRF came online (Figure 75).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

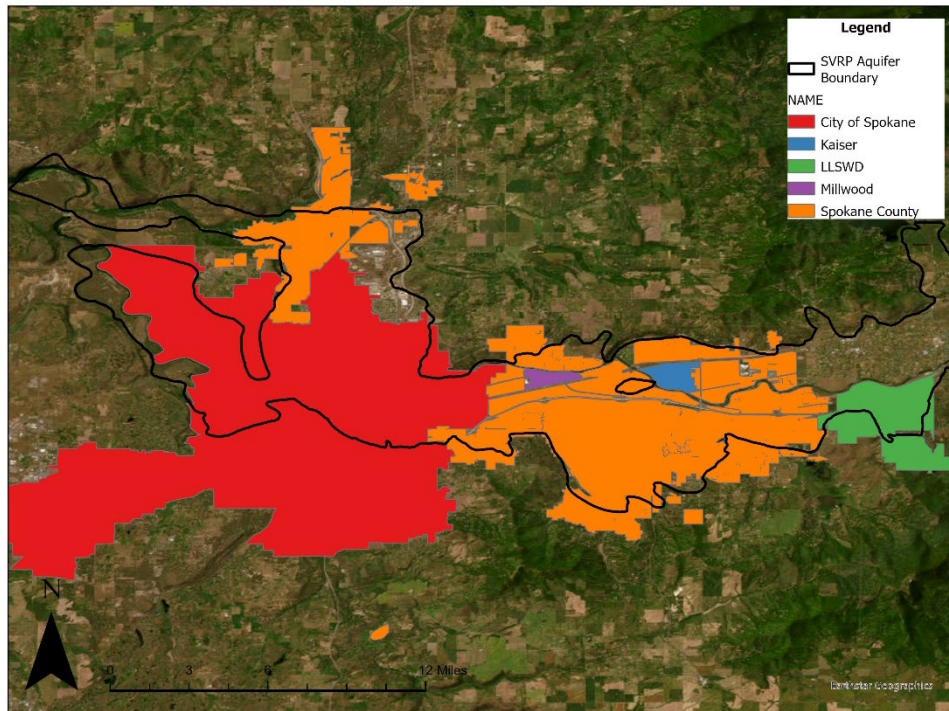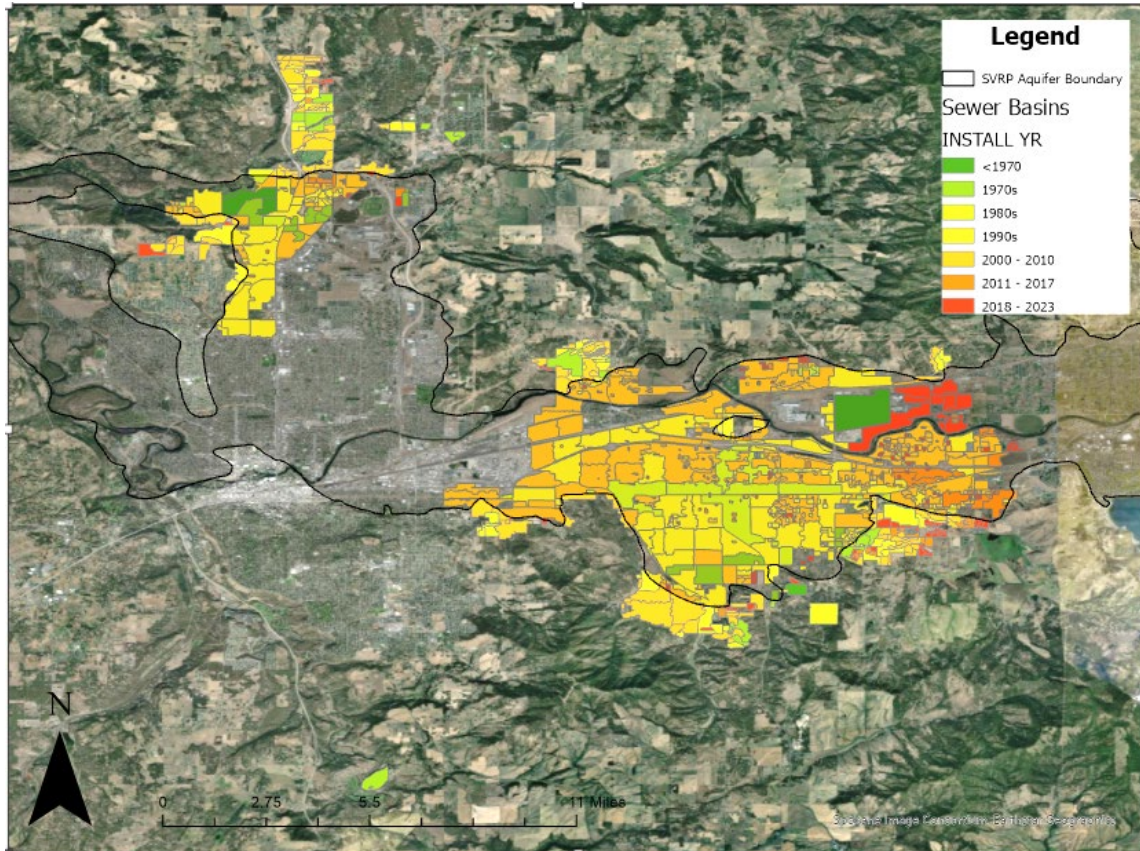Figure 75. Sewer basins in Spokane County's sewer service area by year installed. Sewer basins are shown overlying the Spokane Valley Rathdrum Prairie (SVRP) Aquifer. This shows the extent of sewer service as of 2023; future service areas are not shown.

This section evaluates the effect of onsite wastewater treatment on groundwater quality and provides an evaluation of the STEP in reducing nitrate concentrations in the aquifer. Because nitrate is a potential health concern and can persist for decades in groundwater with oxic conditions (dissolved oxygen levels >0.5 mg/L), it is important to determine whether the County's STEP has been effective at reducing nitrate levels in the aquifer.

The County's two separate sewer service areas were analyzed individually. Due to the potential persistence of nitrate within the aquifer, and the staggered manner and timespan in which sewer installation occurred, this analysis utilizes data outside of the twenty-year period that is the focus of this study, where available.

Several methods were used to assess the STEP program:

1) Overall trends: Looking at the 20-year (or longer, where data is available) trend in nitrates within the sewer service areas compared to the upgradient, non-sewered wells. Trends can differ depending on the data considered, so data outside the 20-year period may be insightful where available.
2) Before/After analysis: Comparing data from wells within the sewer service areas prior to and after installation of the sewer system. A change in trend provides more evidence that the trend is linked to sewer installation.

74

7.1. Spokane Valley Sewer Service Area

There are 21 monitoring locations within the County's Spokane Valley sewer service area and seven monitoring locations outside of sewer service along Barker and Idaho Roads that serve as a comparison. Areas along Barker Road north of the river were sewered beginning in 2018 (Figure 75) and, therefore, were not considered as sewered for the purposes of this study. Three monitoring locations on Barker Road (two within the service area and one outside of the service area) are river-influenced wells, which affects the nitrate levels. These monitoring locations are discussed in groups by location and sewer service connection date.

7.1.1. Non-Sewered Area

Seven wells along Idaho and Barker Roads north of the Spokane River are outside of the County's Spokane Valley sewer service area (Figure 76). Nitrate levels measured at the four monitoring locations along Idaho Road are considered the "background" groundwater nitrate levels.
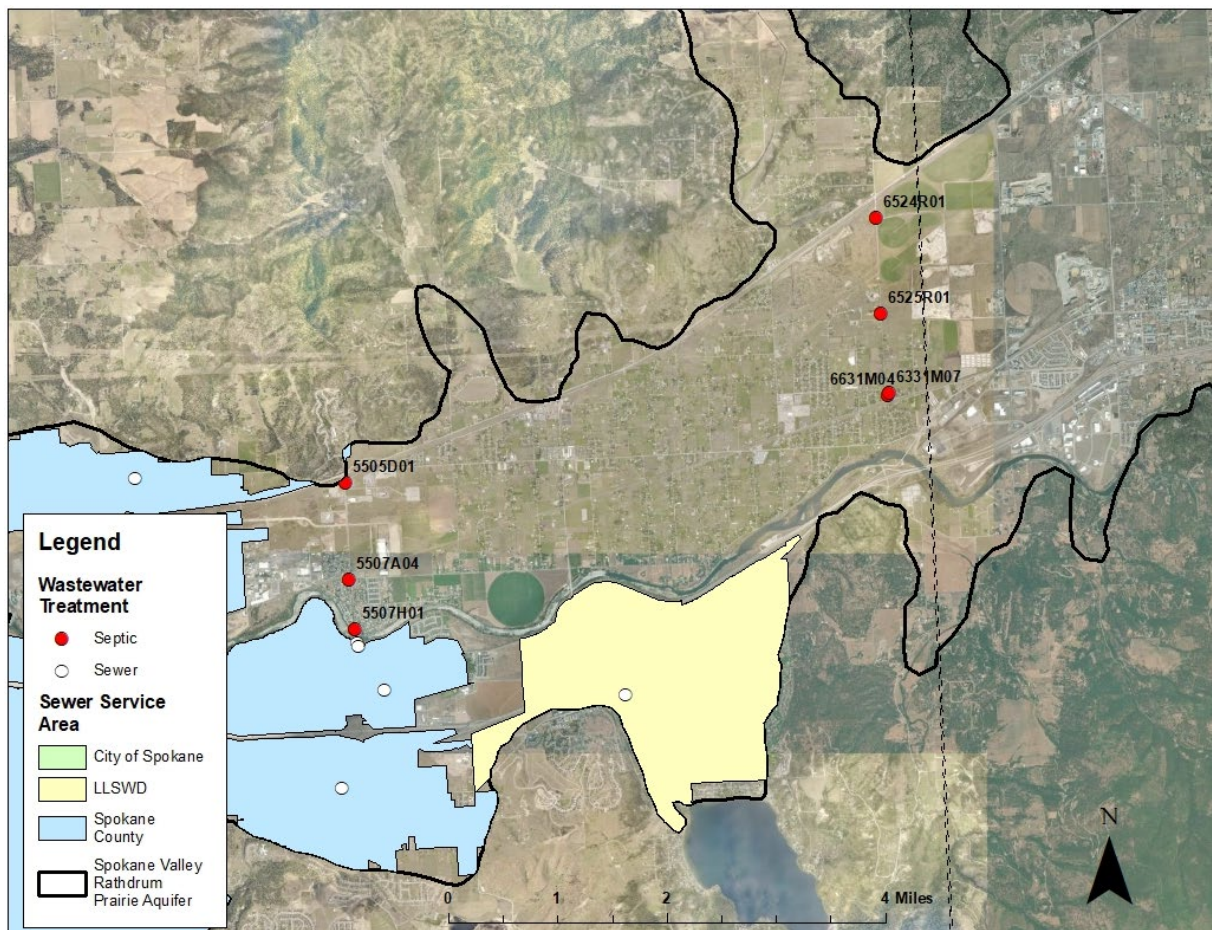
Figure 76. Seven monitoring wells on Idaho and Barker Roads outside of the Spokane County's Spokane Valley sewer service area as of 2017. The seven monitoring locations are 6624R01, 6625R01, 6331M04, 6331M07, 5505D01, 5507A04, and 5507H01.

A plot of nitrate concentrations over time for these seven locations is shown in Figure 77. The monitoring well 6525R01 has the lowest median nitrate levels of the Idaho Road locations at 1.02 mg/L. The

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

monitoring well to the north, 6524R01, has the highest nitrate concentrations at 2.26 mg/L. The data from these two locations exhibited increasing nitrate concentrations over the 20-year period (Appendix E).

The two southern-most monitoring locations on Idaho Road, the CID East Farms purveyor well (6631M04) and the associated monitoring well (6631M07), have median nitrate concentrations of 1.38 and 1.67 mg/L respectively (Figure 77). The data at these two locations exhibit decreasing nitrate concentrations over the 20-year period. These are the only locations outside of the sewer service area exhibiting a decreasing trend (Appendix E). The County has data dating back to the 1970s for the CID purveyor well (6631M04), and a trend analysis including this additional data indicates stable nitrate levels (z = -0.76, p>0.05).
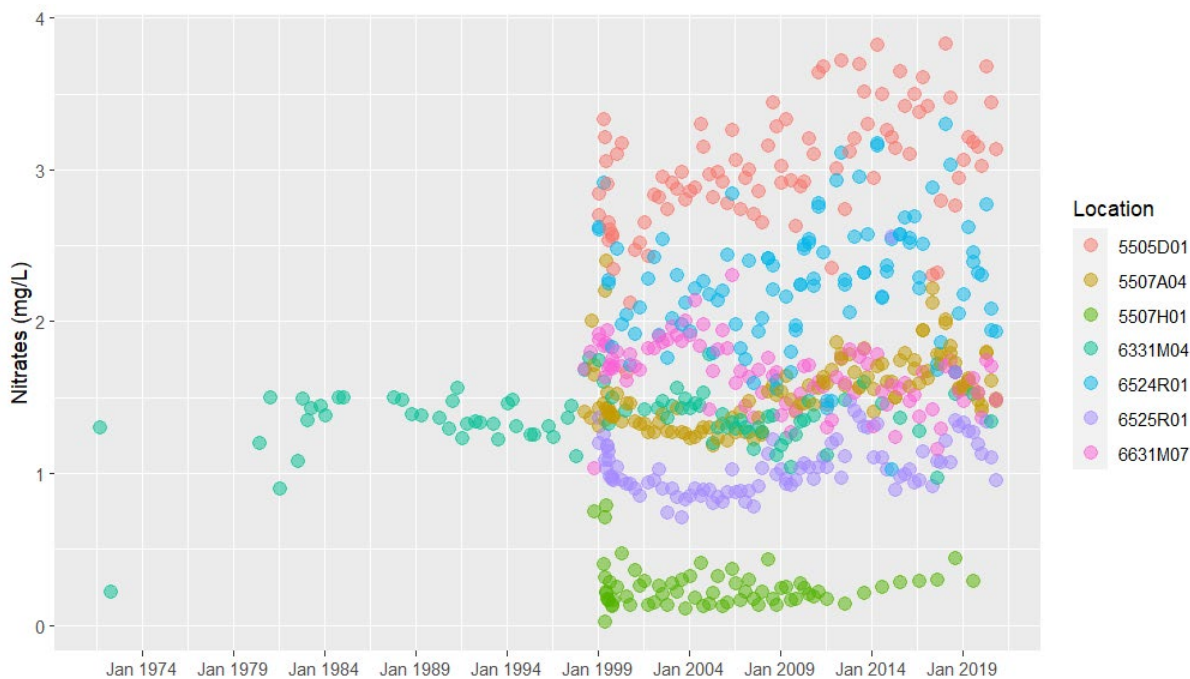
Figure 77. Plot of nitrate concentrations measured over time in samples collected at the seven monitoring locations outside of the sewer service areas along Barker and Idaho Roads.

Of the Barker Road monitoring locations outside of the sewer service area, groundwater from the Trent and Barker well (5505D01) has the highest nitrate levels (median = 2.97 mg/L). The Barker Road North of River well (5507H01) represents river-influenced groundwater and has the lowest nitrate levels (mean = 0.25 mg/L) of the seven monitoring locations outside of the sewer service area. The lower levels are likely due to river dilution (Section 5.1). Trend analysis indicates nitrate levels in samples collected from the Trent and Barker and the Euclid and Barker (5507A04) wells are increasing, while the groundwater sampled at the Barker Road North of River (5507H01) well exhibited stable nitrate levels over the 20-year period (Appendix M).

7.1.2. Barker Road South of River

Neighborhoods along Barker Road south of the river are sewered. There are four monitoring wells along Barker Road in sewered basins: two at the Barker Road Centennial Trail trailhead (5508M01 and

), one at Mission and Barker Road (5517D05), and the CID Site 2A (5518R01) (Figure 78). A plot of nitrate concentrations over time for these locations is shown in Figure 79.
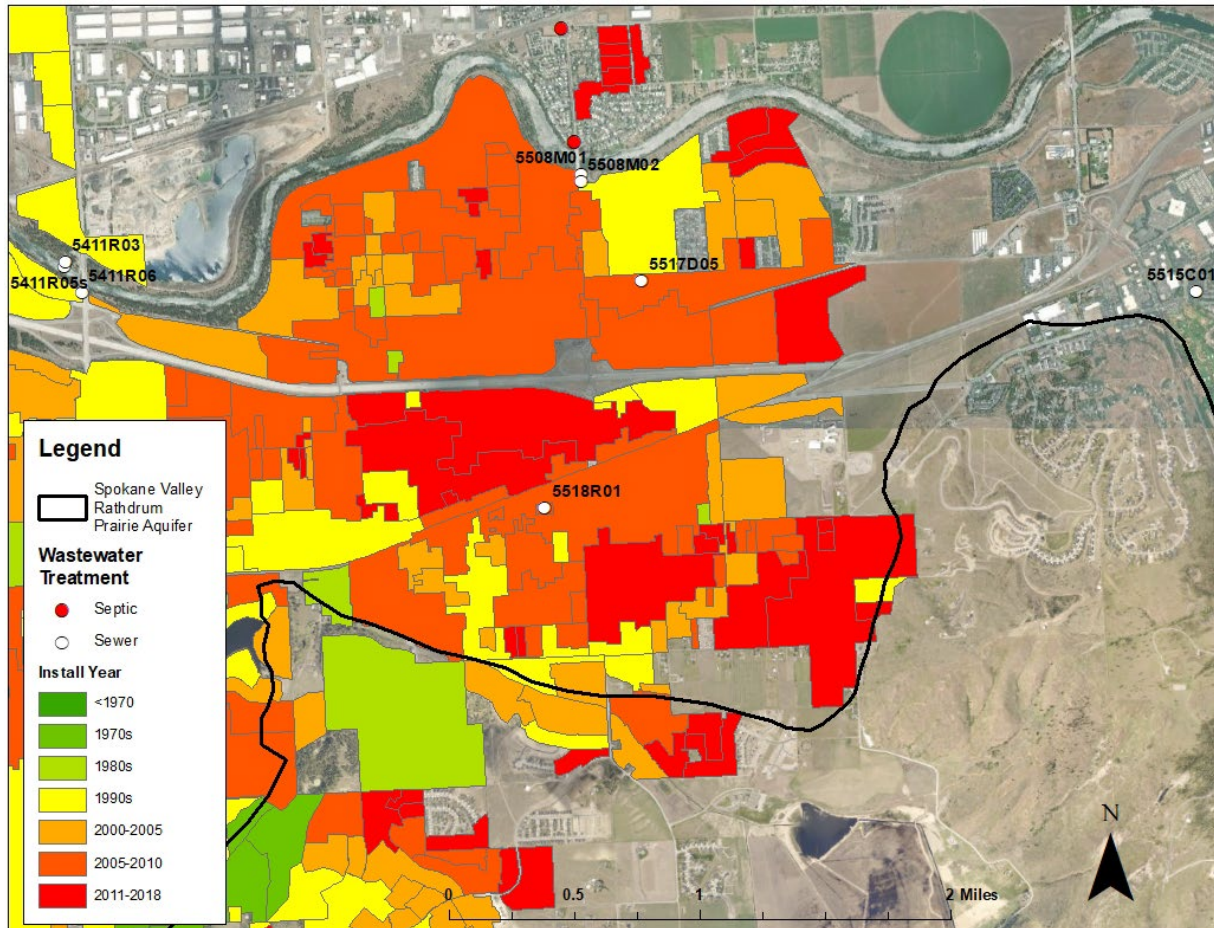
Figure 78. Four monitoring wells located along Barker Roads south of the river within Spokane County's Spokane Valley sewer service area. Sewer basins are colored according to the year installed with basins sewered after 2018 not shown. The four locations are the monitoring wells at the Centennial Trailhead (5508M01 and 5580M02), Mission and Barker Rd. (5517D05), and Consolidated Irrigation District Site 2A (5518R01).

The two monitoring wells at the Centennial Trailhead (5508M01 and 5508M02) are in a neighborhood sewered in 1995 (Figure 78). These also represent river-influenced groundwater, which dilutes nitrate concentrations (see Section 5.1). Periodic low dissolved oxygen (DO<0.5mg/L) at these locations potentially promotes denitrification. The 20-year trend analysis indicates nitrate levels at both wells significantly increased (Appendix E).

Since sampling began in late 1998 for these two wells, this additional data was considered. Trend analysis with this additional data indicates stable levels at both wells (Table 9. Therefore, it is likely that the nitrate levels in these river-influenced wells stabilized since sewer installation. The record does not include data prior to sewering for these locations, so a before-after comparison could not be completed (Table 9).

The other two locations, the Mission and Barker Road monitoring well (5517D05) and the CID Site 2A (5518R01) are further south in neighborhoods that were sewered in 2010 (Figure 78). The 20-year trend analysis indicates nitrate levels decreased at these locations. Though the County has additional data for both sites, including this data in a trend analysis did not change the results; nitrate levels decreased at both locations (Table 9).

A before and after trend analysis using all available data was completed for the Mission and Barker Road monitoring well (5517D05) and the CID Site 2A (5518R01). This shows decreasing nitrate levels prior to sewer installation with nitrate levels stabilizing afterwards at both locations (Table 9, Figure 79). The decreasing trend prior to sewer installation is likely the result of upgradient sewering in the 1990s and early 2000s. This is shown in Figure 79 where nitrate levels recorded at 5518R01 appear to be generally higher before 1995 than afterwards. Any additional reductions following more localized sewer installation may not yet be shown in the data given the recent installation.

Table 9. Results of trend analyses of nitrate concentrations measured in samples collected at monitoring locations in East Spokane. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering. The period covered by the data available is shown.

Well ID	Before	After	All data
5508M01			1998-2019
	---	---	Z= 1.79 p>0.05
			Not Trending
5508M02			1998-2019
	---	---	Z= -0.42 p>0.05
			Not Trending
5517D05	2010		
	Z= -4.23 p<0.05	Z= -1.41 P>0.05	Z= -5.47 p<0.05
	Decreasing	Not Trending	Decreasing
5518R01	2010		
	Z= -4.39 p<0.05	Z= -0.23 p>0.05	Z= -3.48 p<0.05
	Decreasing	Not Trending	Decreasing
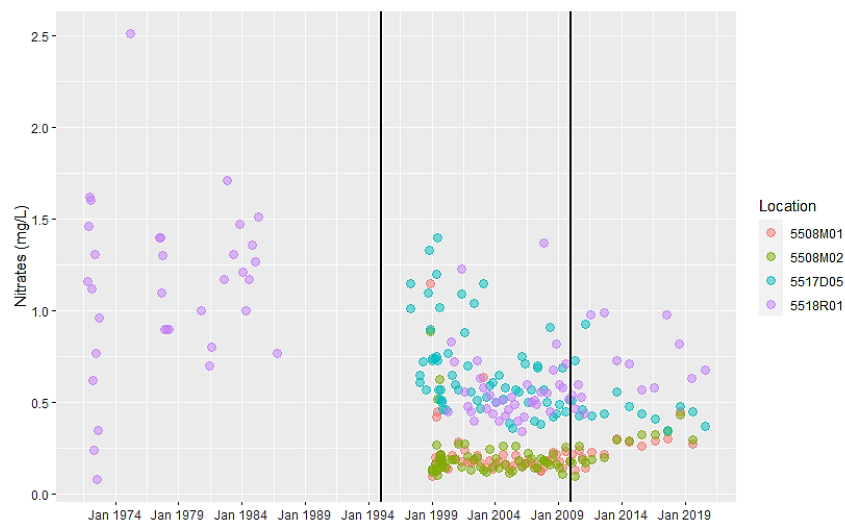
Figure 79. Plot of nitrate concentrations measured in samples collected at four monitoring locations along Barker Road south of the river over time. The four locations are the monitoring wells at the Centennial Trailhead (5508M01 and 5580M02), Mission and Barker Rd. (5517D05), and Consolidated Irrigation District Site 2A (5518R01). The solid lines indicate the date of sewer installation in 1995 (for 5508M01 and 5508M02) and 2010 (for 5517D05 and 5518R01), respectively.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

7.1.3. Northern Sullivan Road

Neighborhoods along the northern Sullivan Road corridor to the intersection with Indiana Avenue are sewered. These neighborhoods were generally sewered in the 1990s, with those closer to the Indiana intersection sewered earlier than those near the northern terminus. Four monitoring locations are used to monitor groundwater conditions along the northern Sullivan Road corridor. The northern-most location is a monitoring well at the East Valley High School (EVHS) (6436N01). The remaining locations are at the opposite end of the corridor. These include a well and a natural spring at Sullivan Park (5411R03 and 5411R05s, respectively) just north of the Spokane River and a monitoring well just south of the Spokane River (5411R06) closer to the intersection with Indiana Avenue (Figure 80). A plot of nitrate concentrations over time for these locations is shown in Figure 81.
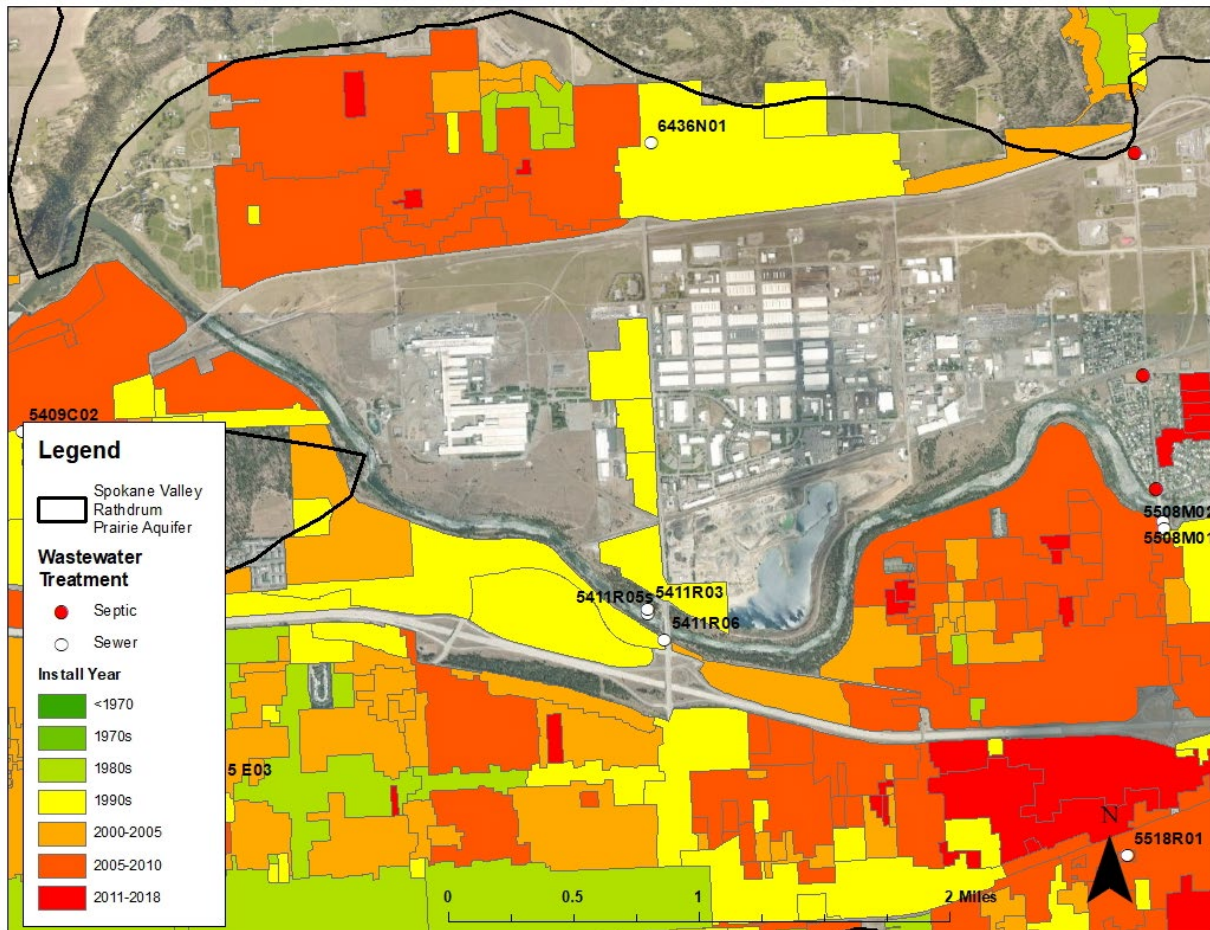
Figure 80. Monitoring wells located along Sullivan Road from its northern terminus to the Indiana Avenue intersection within County's Spokane Valley sewer service area. Sewer basins are colored according to the year installed with basins sewered after 2018 not shown. The four locations are the monitoring well at East Valley High School, (6436N01), a monitoring well and a natural spring at Sullivan Park (5411R03 and 5411R05s, respectively) just north of the Spokane River, and a monitoring well just south of the Spokane River at the intersection with Indiana Avenue (5411R06).

The neighborhood in the vicinity of the monitoring well at the EVHS was sewered in 1999, but sampling began at this location in 2006. Therefore, trends can only be assessed since that time. Nitrate levels in the EVHS monitoring well samples significantly decreased over the 13-year period (Table __, Figure _).
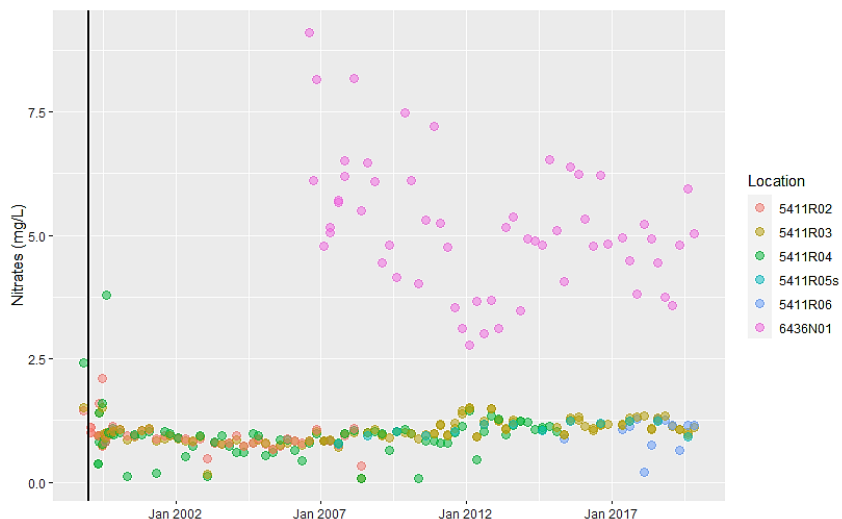
Figure 81. Plot of nitrate concentrations measured in samples collected over time at six monitoring locations along the northern Sullivan Road corridor. The six locations are the monitoring well at East Valley High School (6436N01), Sullivan Park South (5411R03), the natural springs at Sullivan Park (5411R05s), and the Sullivan Rd. Centennial Trail/Krispy Kreme (5411R04/6). The solid line indicates the date of sewer installation in 1999 (for 6436N01). The sewer installation in 1993 for the other locations is not shown since this predates the data record by 5 years.

The 20-year trend analysis indicates nitrate levels at the Sullivan Park monitoring well (5411R03) and the springs (5411R05s) increased. The neighborhoods in the vicinity of Sullivan Park were sewered in 1993. Data for these monitoring locations begins in 1998. A trend analysis including this additional data was completed, but this did not change the results. These locations still exhibited increasing nitrate levels (Table 10). A before and after analysis was not possible given available data.

The original 20-year trend analysis did not detect a trend in samples from the Sullivan Road well (5411R06), but data from this location only dates to May 2015. However, this monitoring well was a replacement for a former well at this location (5411R04), which was abandoned during construction at the Sullivan bridge in 2015. Data from the former well was used to supplement the data from the existing well so that nitrate trends could be determined for a longer period. The supplemental data resulted in an increasing trend in nitrate levels at this location (Table 10). A before and after analysis was not possible given available data.

The differences in both levels and trends in nitrates at the EVHS monitoring well and the other Sullivan Road locations suggest different sources of nitrates. The locations at Sullivan Park and the Indiana Avenue intersection may be impacted by upgradient locations (see Section 7.1.9).

Table 10. Results of trend analyses of nitrate concentrations measured in samples collected over time at four monitoring locations along Sullivan Road. Trends were assessed using all available nitrate data. The period covered by the data available is shown.

Well ID	All data
6436N01	2006 – 2019
	Z= -2.28
	p<0.05
	Decreasing
5411R03	1998 – 2019
	Z= 5.54
	P<0.05
	Increasing
5411R04/06	1998 – 2019
	Z= 3.02
	p<0.05
	Increasing
5411R05s	1998 – 2019
	Z= 2.59
	p<0.05
	Increasing

7.1.4. Northern Spokane Valley

For this analysis, northern Spokane Valley is defined as those neighborhoods north of Sprague and south of I-90. Outside of the Sprague and Pines Road corridors, which were sewered in the 1980s, most of the neighborhoods in northern Spokane Valley were sewered in the early 2000s (Figure 82).
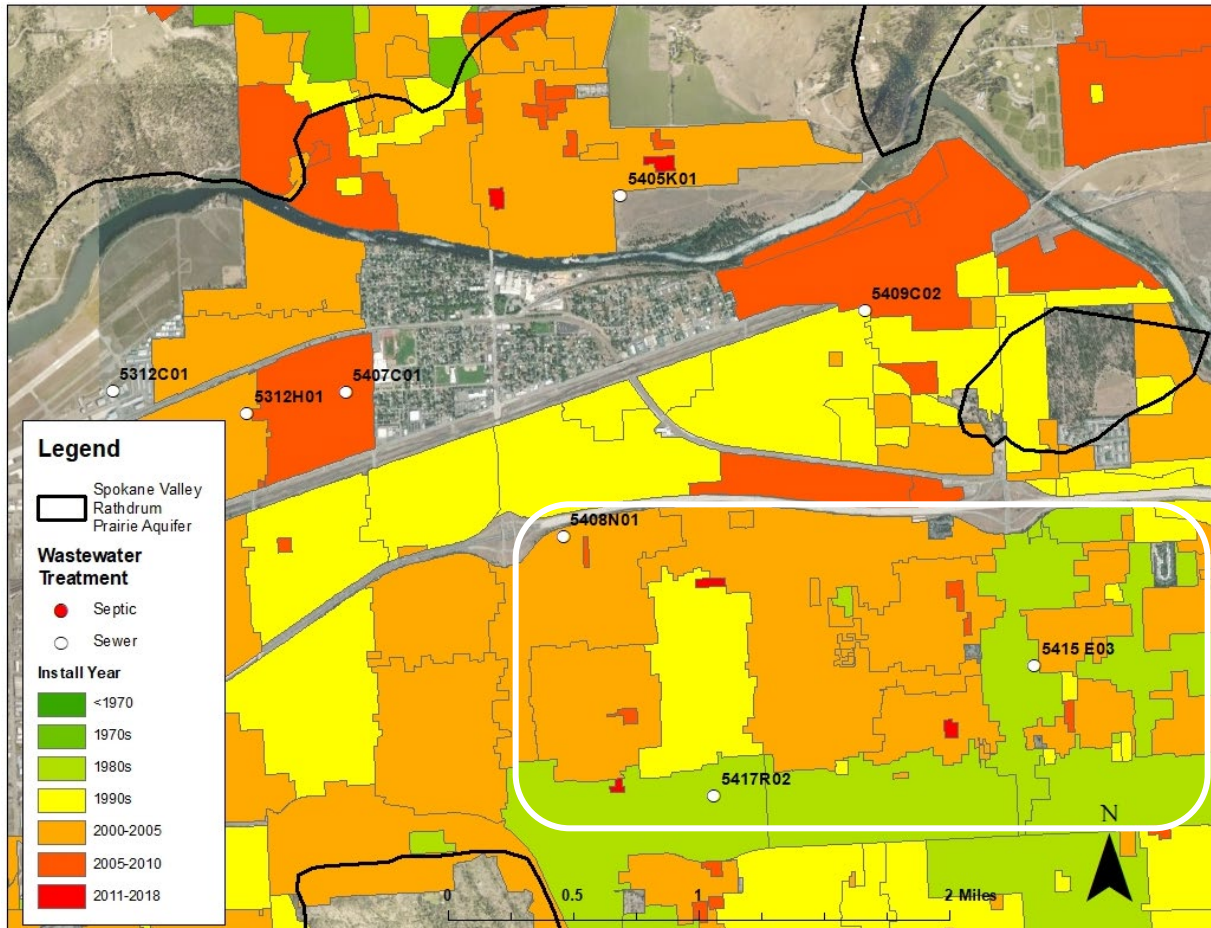
Figure 82. Monitoring wells located within the northern Spokane Valley. Sewer basins are colored according to the year installed with basins sewered after 2018 not shown. The three locations are the Balfour Park monitoring well (5417R02) and the Modern Electric wells at Site 6 and Site 11 (5408N01 and 5415E03, respectively).

There are three monitoring wells in northern Spokane Valley: the Modern Electric wells at Site 6 and Site 11 (5408N01 and 5415E02, respectively), and the Balfour Park monitoring well (5417R02) (Figure 82). A plot of nitrate concentrations over time for these locations is shown in Figure 83.

The 20-year trend analysis indicates nitrate levels in samples from the Balfour Park monitoring well (5417R02) and the Modern Electric Site 6 (5408N01) well decreased, but the nitrate levels in samples from the Modern Electric Site 11 (5415E03) well were not trending.
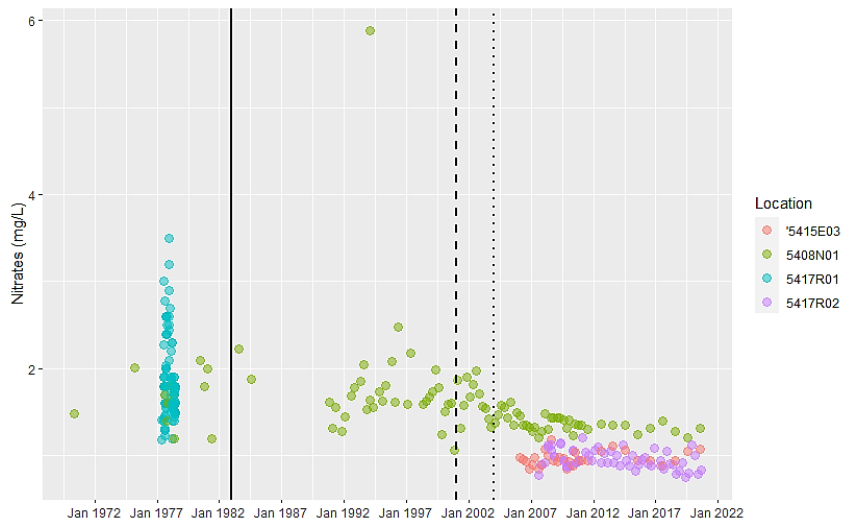
Figure 83. Plot of nitrate concentrations measured in samples collected over time at three monitoring locations within northern Spokane Valley. The three locations are the Balfour Park monitoring well (5417R01 and 5417R02) and the Modern Electric Site 6 and Site 11 wells (5408N01 and 5415E02, respectively). The lines indicate the year of sewer installation for each location as follows: 1983 (solid) for 5417R01/02, 2001 (dashed) for 5408N01, and 2004 (dotted) for 5415E03.

The two Modern Electric wells are in neighborhoods sewered in the early 2000s. The County's record of nitrate data for the Modern Electric Site 11 well (5415E02) begins in 2006, so additional analysis is not possible. The record for the Modern Electric Site 6 well (5408N01) begins in 1970, allowing for trend analysis over a longer period as well as before and after sewer installation. Nitrate levels significantly decreased since the 1970s, which does not differ from the 20-year trend. The before and after trend analysis shows no trend in nitrate levels prior to sewer installation, but a decreasing trend following installation (Table 11).

Table 11. Results of trend analyses of nitrate concentrations measured in samples collected over time at monitoring locations in northern Spokane Valley. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering. Year of sewer installation and the period covered by the data assessed is shown for each location.

| Well ID	Before	After	All data
5408N01	2001		1970 – 2019
	z= -0.28 p>0.05	Z= -4.91 p<0.05	Z= -6.32 p<0.05
	Not Trending	Decreasing	Decreasing
5415E02	2004		2006 – 2019
	---	---	Z= 0.97 p>0.05
	---	---	Not Trending
5417R01/R02	1983		1977 – 2019
	Z= -0.95 p>0.05	Z= -2.82 p<0.05	Z= -9.99 p<0.05
	Not Trending	Decreasing	Decreasing

The Balfour Park well is within a neighborhood in the Sprague corridor sewered in 1983. The Balfour Park monitoring well (5417R02) replaced a former well (5417R01) at this location. Data from the former well dates from 1977 to 1978. Using this data to supplement data from the existing well allows the long-term trend in nitrate levels to be assessed as well as a before and after analysis. With the additional data, nitrate levels at this location decreased and the decrease followed sewer installation (Table 11). This mirrors the results of the Modern Electric Site 6 well, demonstrating that the groundwater in the vicinity of the northern Spokane Valley responded similarly to sewering.

7.1.5. Southern Spokane Valley

For this analysis, southern Spokane Valley is defined as those neighborhoods south of Sprague, east of the Dishman-Mica Road and west of Sullivan Road. Two purveyor wells (5426L03 and 5427L01) are in southern Spokane Valley. While these wells are in neighborhoods that were sewered in 1991, most neighborhoods in southern Spokane Valley generally had sewer installed from the 1980s through the 1990s (Figure 84). A plot of nitrate concentrations over time for these locations is shown in Figure 85.
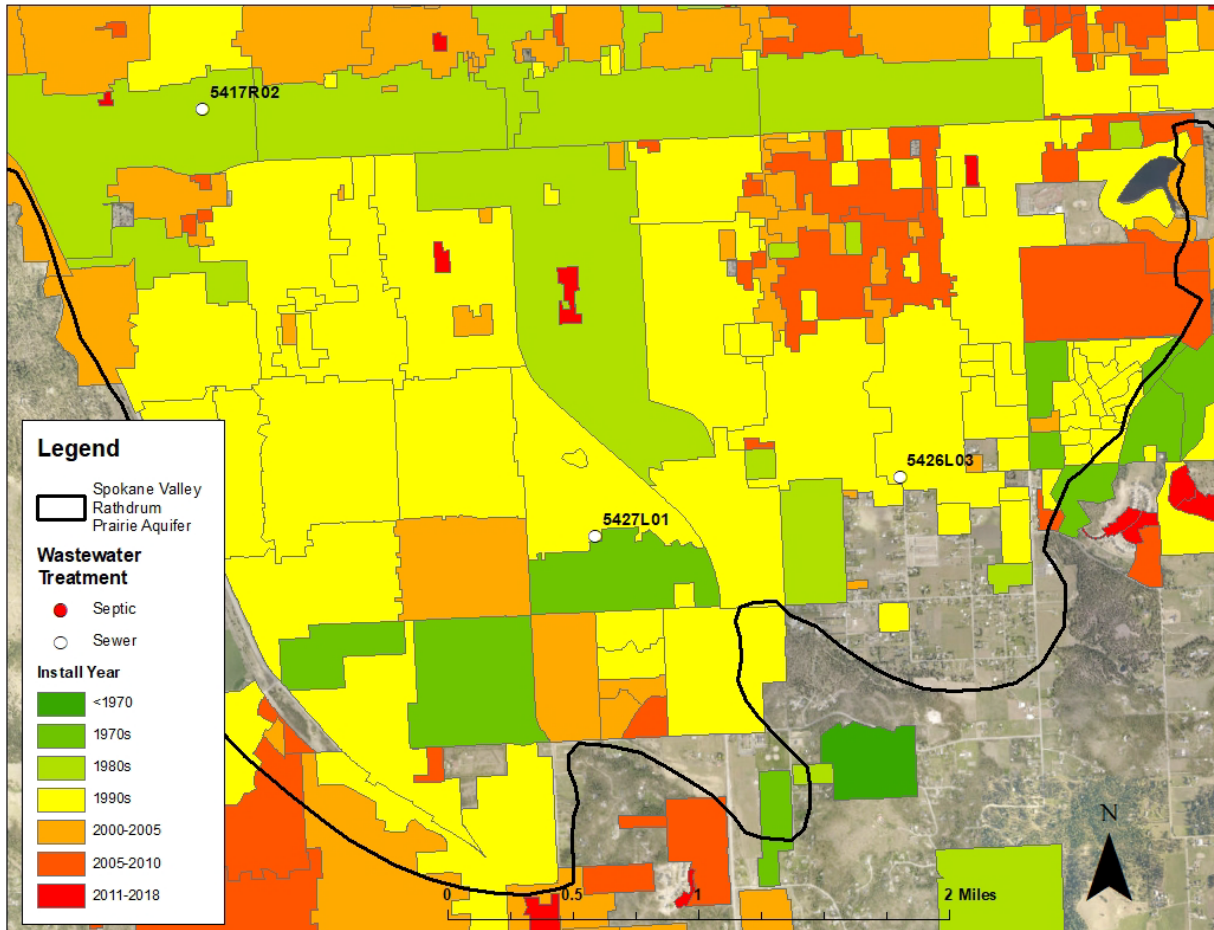
Figure 84. Monitoring wells located within the southern Spokane Valley. Sewer basins are colored according to the year installed with basins sewered after 2018 not shown. The two locations are the Spokane County Water District #3 well at 26th and Vercler (5427L01) and the Vera Water and Power well #4 (5426L03).

The 20-year trend analysis indicates nitrate levels in the Spokane County Water District (SCWD) #3 well (5427L01) were stable while the nitrate levels in the Vera Water and Power well (5426L03) decreased. For the Vera Water and Power well, the County's record starts in 2013, so additional analysis is not possible.

The County has a longer record for the SCWD #3 well (5427L01), including data prior to sewer installation in 1991. This data indicates a different outcome than the 20-year trend.

Analysis of all available data for the SCWD #3 well indicates nitrate levels decreased since 1980. A before and after analysis shows no trend in nitrate levels prior to sewer installation, but a decreasing trend following installation (Table 12). Overall, this suggests nitrate levels in southern Spokane Valley decreased throughout the 1990s during sewer installation but stabilized in the 2000s when sewer installation had finished in most neighborhoods.

Table 12. Results of trend analyses of nitrate concentrations measured in samples collected over time at monitoring locations in southern Spokane Valley. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering. Year of sewer installation and the period covered by the data assessed is shown for each location.

Well ID	Before	After	All data
5426L03	1991		2013 – 2019
	---	---	Z= -2.18 p<0.05
	---	---	Decreasing
5427L01	1991		1980 – 2019
	Z= 0.65 p>0.05	Z= -6.21 p<0.05	Z= -7.12 p<0.05
	Not Trending	Decreasing	Decreasing

Figure 85. Plot of nitrate concentrations measured in samples collected over time at two monitoring locations within southern Spokane Valley. The two locations are the Spokane County Water District #3 well at 26th and Vercler (5427L01) and the Vera Water and Power well (5426L03). The line indicates the year of sewer installation, 1991, for both wells.

7.1.6. Pasadena Park

Pasadena Park is located north of Millwood and the Spokane River within the Pasadena Park Irrigation District service area. Only the southernmost portion of Pasadena Park overlays the SVRP aquifer and includes a mix of neighborhoods with and without sewer. Sewer was generally installed in the early 2000s (Figure 86). The Irrigation District's well at Site 2 (5405K01) is used to monitor groundwater conditions. A plot of nitrate concentrations over time for this location is shown in Figure 87.
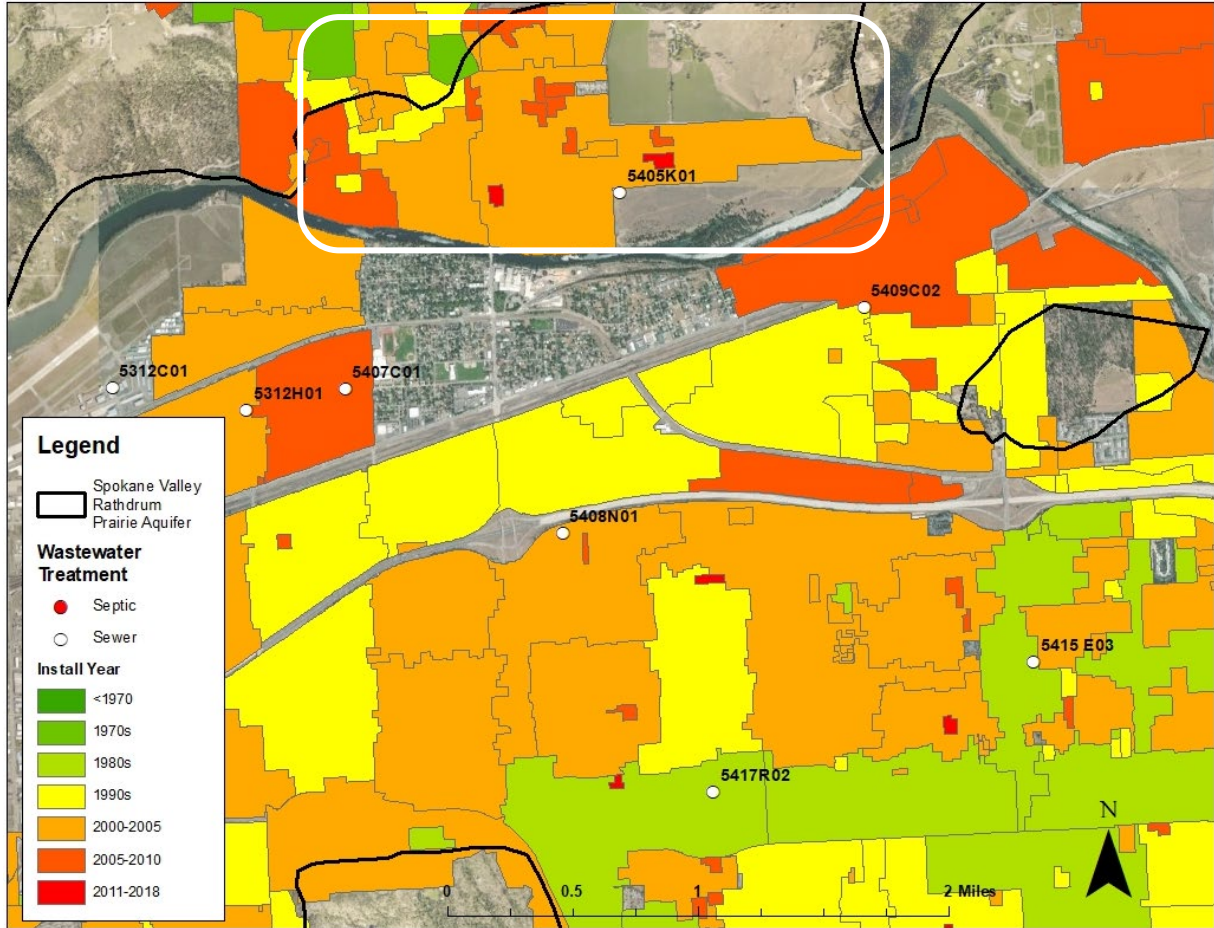
Figure 86. Monitoring location within Pasadena Park in sewered neighborhoods. This is the Pasadena Park Irrigation District Site 2 well (5405K01). Sewer basins are colored according to the year installed with basins sewered after 2018 not shown.

The trend analysis indicates nitrate levels were stable at this location. The County's nitrate data for the Site 2 (5405K01) well dates to 2001, so this is only an 18-year trend. The neighborhood in the vicinity of the well was sewered in 2002, only a year after the start of sampling. Therefore, a trend might not yet be detectable in the data.
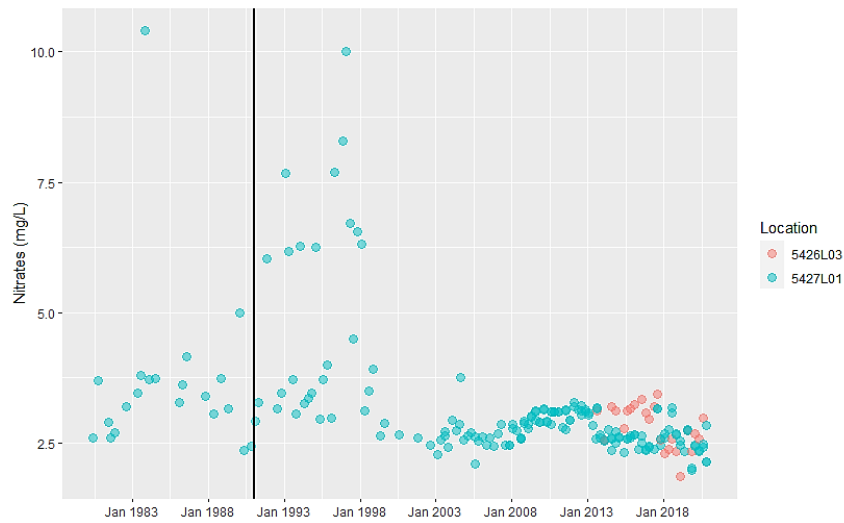
Figure 87. Plot of nitrate concentrations measured in samples collected over time at two monitoring locations within Pasadena Park. The two locations are the Pasadena Irrigation District Site 2 (5405K01) and Site 4 (5406A02). The lines indicate the year of sewer installation for each site as follows: 2002 (solid) for 5405K01 and 2003 (dashed) for 5406A02.

The County sampled other Pasadena Park Irrigation District wells in the past and has a few early records from the 1980s for the currently used well. Of the other wells, the well at Site 4 (5406A02) has the most consistent record with data spanning from 1983 to 2012. The available data appears to be comparable to the data for Site 2 (5405K01) well (Figure 87). In addition, the neighborhood represented by the Site 4 well had sewer installed a year after the Site 2 well in 2003. Therefore, the response to sewering should be comparable. Given this, Site 4 is assumed to be an appropriate surrogate to help assess long term trends within the area.

Table 13. Results of trend analyses of nitrate concentrations measured in samples collected over time at monitoring locations in Pasadena Park. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering.

Well ID	Before	After	All data
5405K01	2002		1980 – 2019
	z= -1.86 p>0.05	Z= -2.01 p<0.05	Z= -2.48 p<0.05
	Not Trending	Decreasing	Decreasing
5406A02	2003		1983 – 2012
	Z= -1.82 p>0.05	Z= 0.25 p>0.05	Z= -3.22 p<0.05
	Not Trending	Not Trending	Decreasing
Combined	2003		1983 – 2019
	Z= -4.12 p<0.05	Z= -2.01 p<0.05	Z= -8.17 p<0.05
	Decreasing	Decreasing	Decreasing

A trend analysis was conducted for each site separately using all available data, as well as for their combined data (Table 13). The results of this differed from the original assessment for the Site 2 well (5405K01). In each case, the data exhibited an overall decreasing trend when considering all data. However, the results of the before and after analysis did not agree. It is important to note that Site 2 had minimal data to consider in its "before" period and Site 4 had minimal data to consider for its "after" period. However, taken together with the plotted data, it appears that declines in nitrate levels occurred before and after localized sewer installation.

7.1.7. Orchard Avenue

Orchard Avenue is located immediately west of Millwood and is bound by the Spokane River to the north and Trent Avenue to the south. The neighborhoods within Orchard Avenue were sewered in 2006. This area's drinking water is provided by the Orchard Avenue Irrigation District. The Irrigation District wells at Site 1 and Site 2 (5312H01 and 5407C01, respectively) are used to monitor groundwater quality in this area. An upgradient monitoring well at Frederick and Bowdish (5409C02) is within a neighborhood sewered in 2007, a year following the Orchard Avenue neighborhoods (Figure 88). A plot of nitrate concentrations over time for these locations is shown in Figure 89.

The 20-year trend analysis indicates nitrate levels at the Site 1 well (5312H01) and the upgradient monitoring well (5409C02) increased but levels were stable at the Site 2 well (5407C01) (Appendix E).
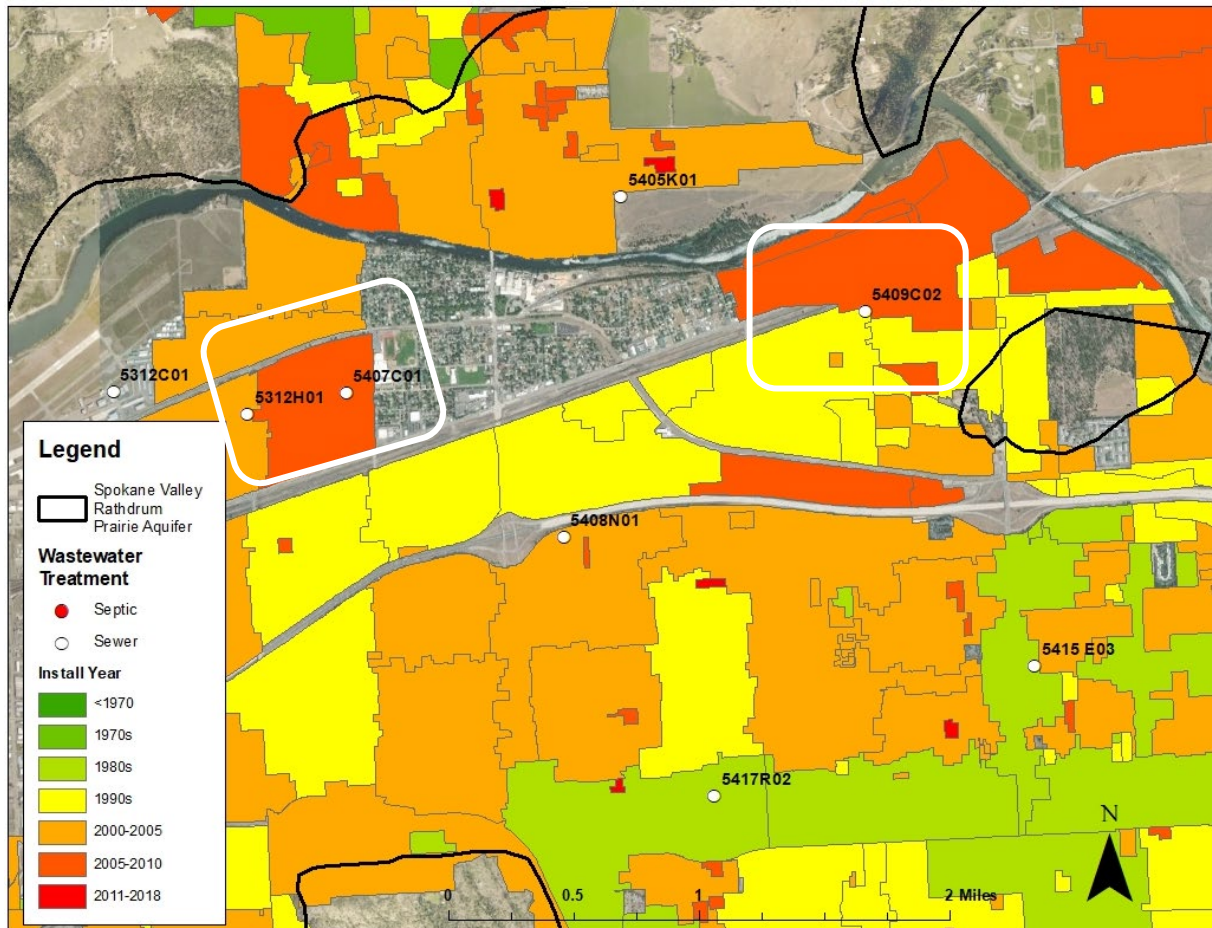
Figure 88. Monitoring locations within Orchard Avenue Irrigation District's service area. This includes Orchard Avenue Irrigation District Site 1 and Site 2 wells (5312H01 and 5407C01, respectively) and an upgradient monitoring well at Frederick and Bowdish (5409C02). Sewer basins are colored according to the year installed with basins sewered after 2018 not shown.

The County has data for the Orchard Avenue Irrigation District wells prior to the 20-year period, allowing for a trend analysis over a longer period as well as a before and after analysis. The Site 1 well (5312H01) has a relatively consistent record dating back to 1970. The Site 2 well (5407C01) has records dating back to 1973, but with a large gap in the record from 1982 to 2000. The upgradient monitoring well at Frederick

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

and Bowdish (5409C02) only has 17 years of data starting in 2002. While this does not allow for analysis of trends beyond this period, it does allow for a before and after analysis.
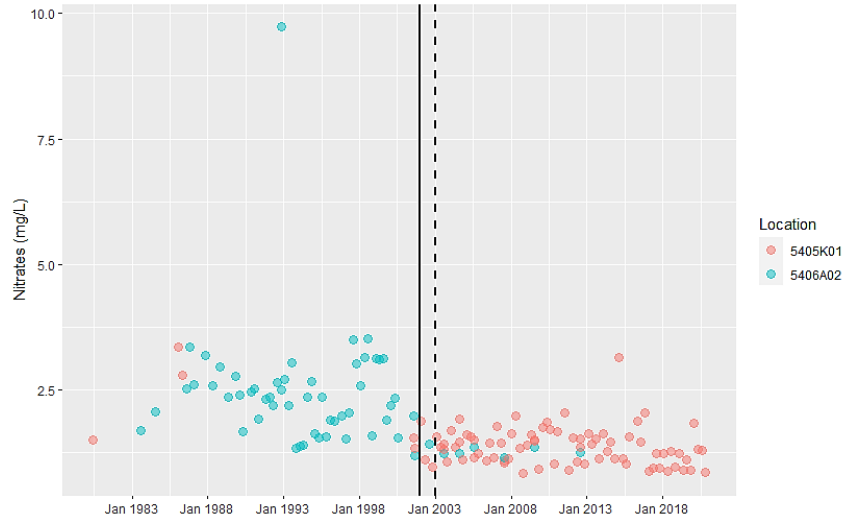

Figure 89. Plot of nitrate concentrations measured in samples collected over time at two monitoring locations within the Orchard Avenue Irrigation District service area. This includes the Irrigation District Site 1 (5312H01) and Site 2 (5407C01) wells, and an upgradient monitoring well at Frederick and Bowdish (5409C02). The lines indicate the year of sewer installation for each site as follows: 2006 (solid) for 5312H01 and 5407C01, and 2007 (dashed) for 5409C02.

The trend analysis of all available data for the three sites indicates nitrate levels increased over time (Table 14). However, the results of the before and after analysis differ among the three sites. This is likely due to the difference in available data. Since Site 1 (5312H01) has the most consistent long-term record, its results are likely more reliable, indicating nitrate levels increased and then stabilized after sewer installation. The lack of a trend after sewering could either be because there is not enough post-sewer data to detect a trend or because any decrease from sewer installation is potentially compromised by nitrate inputs occurring further upgradient (see Section 7.1.9).

Table 14. Results of trend analyses of nitrate concentrations measured in samples collected at monitoring locations in the North Spokane sewer service area. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering.

Well ID	Before	After	All data
5312H01	2006		1970 – 2019
	z= 6.84, p<0.05	z= -1.13 p>0.05	z= 6.85 p<0.05
	Increasing	Not Trending	Increasing
5407C01	2006		1973 – 2019
	z= 2.33 p<0.05	z= 2.35 p<0.05	z= 5.41 P<0.05
	Increasing	Increasing	Increasing
5409C02	2007		2002 – 2019
	z= -0.52 p>0.05	z= 1.95 p>0.05	z= 2.80 p<0.05
	Not Trending	Not Trending	Increasing

7.1.8. East Spokane

East Spokane is defined as the neighborhoods on the westside of Dishman Hills and south of Sprague Avenue (Figure 90). Most neighborhoods in this area were sewered in the early 2000s. There are four wells in East Spokane: the East Spokane Irrigation District Site 1 well (5324G01), the two nested monitoring wells at 3rd and Havana (5322A01 and 5322A03), and the 6th and Havana monitoring well

88

(5323E01). A plot of nitrate concentrations over time for these locations is shown in Figure . The 20-year trend analysis indicates that the nitrate levels at all four wells decreased (Appendix E).
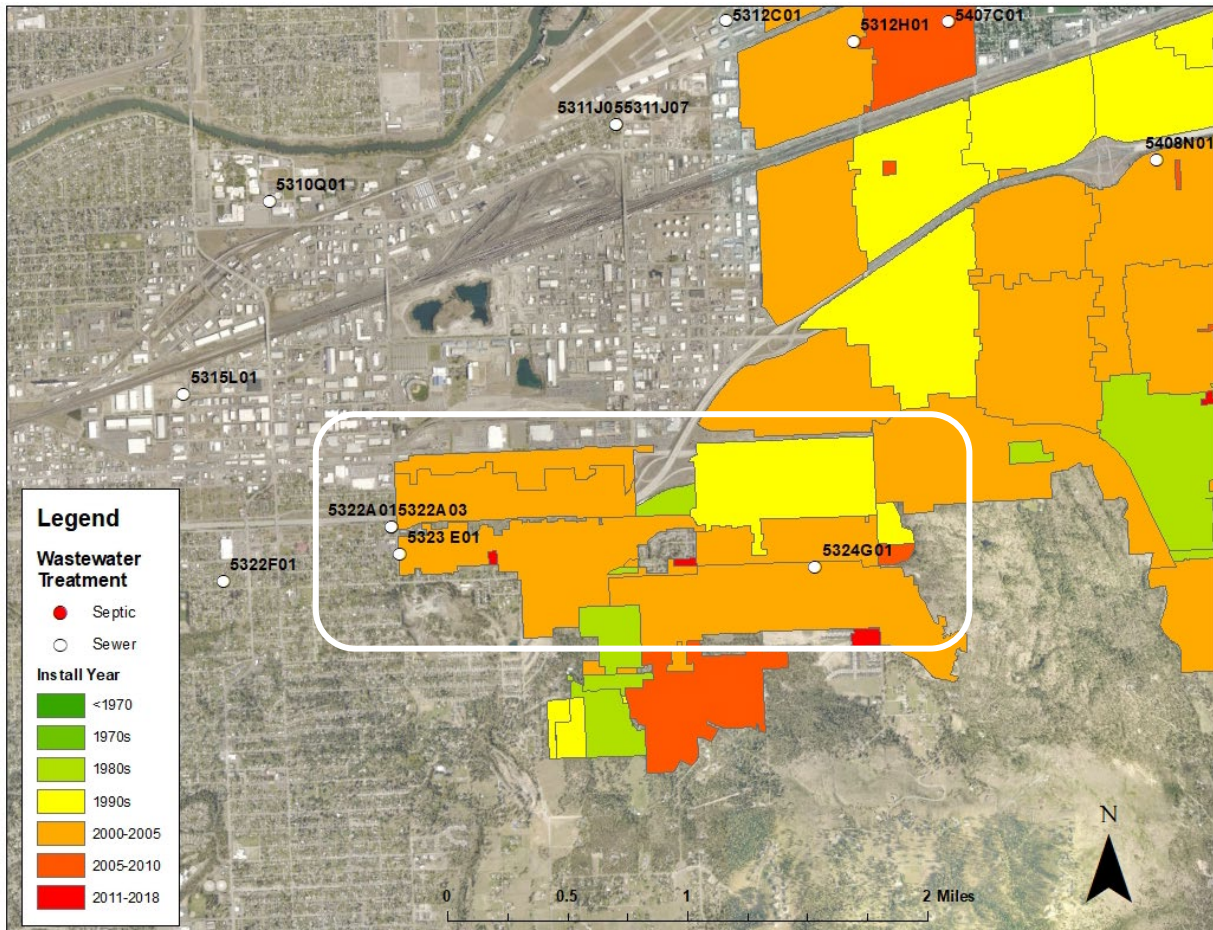
Figure 90. Monitoring locations within east Spokane in sewered neighborhoods. This includes East Spokane Irrigation District Site 1 (5342G01), the nested wells at 3rd and Havana (5322A01 and A03), and the 6th and Havana monitoring well (5323E01). Sewer basins are colored according to the year installed with basins sewered after 2018 not shown.

The neighborhoods in the vicinity of the East Spokane Irrigation District Site 1 well (5324G01) and the Third and Havana nested wells (5322A01 and A03) were sewered in 2002. The County has data dating back to 1970 for the East Spokane Irrigation District well. For the nested wells at 3rd and Havana, the County has data dating to 1995. This allows for a trend analysis over a longer period, as well as a before and after analysis. The trend analysis using all available data indicates nitrate levels decreased over time at all three wells. The before and after trend analysis indicates nitrate levels were stable prior to sewer installation in 2002, but that nitrate levels decreased following sewer installation (Table15).
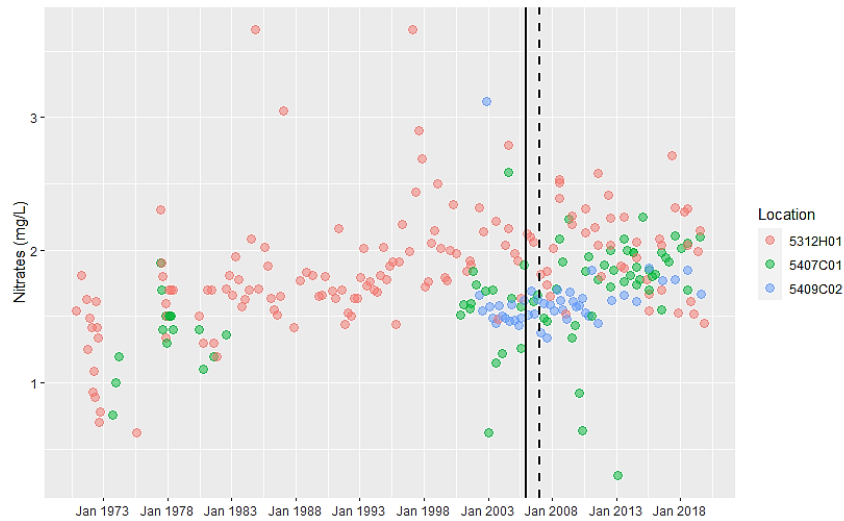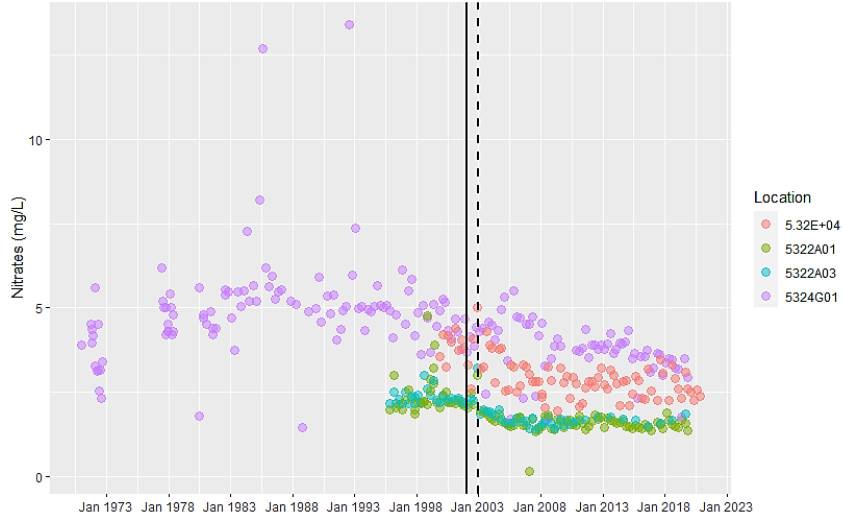
Figure 91. Plot of nitrate concentrations measured in samples collected over time at four monitoring locations within east Spokane Valley. This includes the East Spokane Irrigation District Site 1 (5324G01), the nested monitoring wells at 3rd and Havana (5322A01 and 5322A03), and the 6th and Havana monitoring well (5323E01). The lines indicate the year of sewer installation for each site as follows: 2002 (solid) for 5324G01, 5322A01, and 5322A03; and 2003 (dashed) for 5323E01.

For the 6th and Havana well, the County does not have data prior to the 20-year period considered here. Therefore, a trend analysis over a longer period is not possible. However, since the neighborhood in the vicinity of this well was sewered in 2003, a before and after analysis is possible. The results of this analysis mirror the results of the other wells, with nitrate levels appearing stable prior to sewer installation and then decreasing following installation.

Table 15. Results of trend analyses of nitrate concentrations measured in samples collected at monitoring locations in east Spokane. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering.

Well ID	Before	After	All data
5324G01	2002		1970 – 2019
	z= 0.83 p>0.05	Z= -4.54 p<0.05	Z= -6.59 p<0.05
	Not Trending	Decreasing	Decreasing
5322A01	2002		1995 – 2019
	Z= 0.72 p>0.05	Z= -2.68 p<0.05	Z= -8.04 p<0.05
	Not Trending	Decreasing	Decreasing
5322A03	2002		1995 – 2019
	Z= 0.25 p>0.05	Z= -1.72 p>0.05	Z= -6.86 p<0.05
	Not Trending	Not Trending	Decreasing
5323E01	2003		1999 – 2019
	Z= -0.25 p>0.05	Z= -2.22 p<0.05	Z= -5.08 p<0.05
	Not Trending	Decreasing	Decreasing

7.1.9. Impacts from Unsewered Areas

Increasing nitrate levels at several locations within the Spokane Valley sewer service area is a concern because sewering is intended to prevent nitrates from entering groundwater. An assessment of purveyor well capture zones developed by CH2M Hill (1998) demonstrates these locations may be influenced by nitrate inputs occurring further upgradient in unsewered areas. A capture zone defines the area where groundwater flows toward a well within a specified period. The locations where nitrates increased are within the 5-year and 10-year capture zones of the City of Spokane's Electric and Parkwater wells. The 5-year capture zone extends out to Harvard Road and the 10-year capture zone extends beyond the stateline (Figure 92). Given the persistence of nitrates in oxic conditions, it is feasible that nitrate inputs from septic system use outside of the sewer service area is being transported along these capture zones. (5409C02, 5407C01, and 5312H01, see Section 6.1.7).
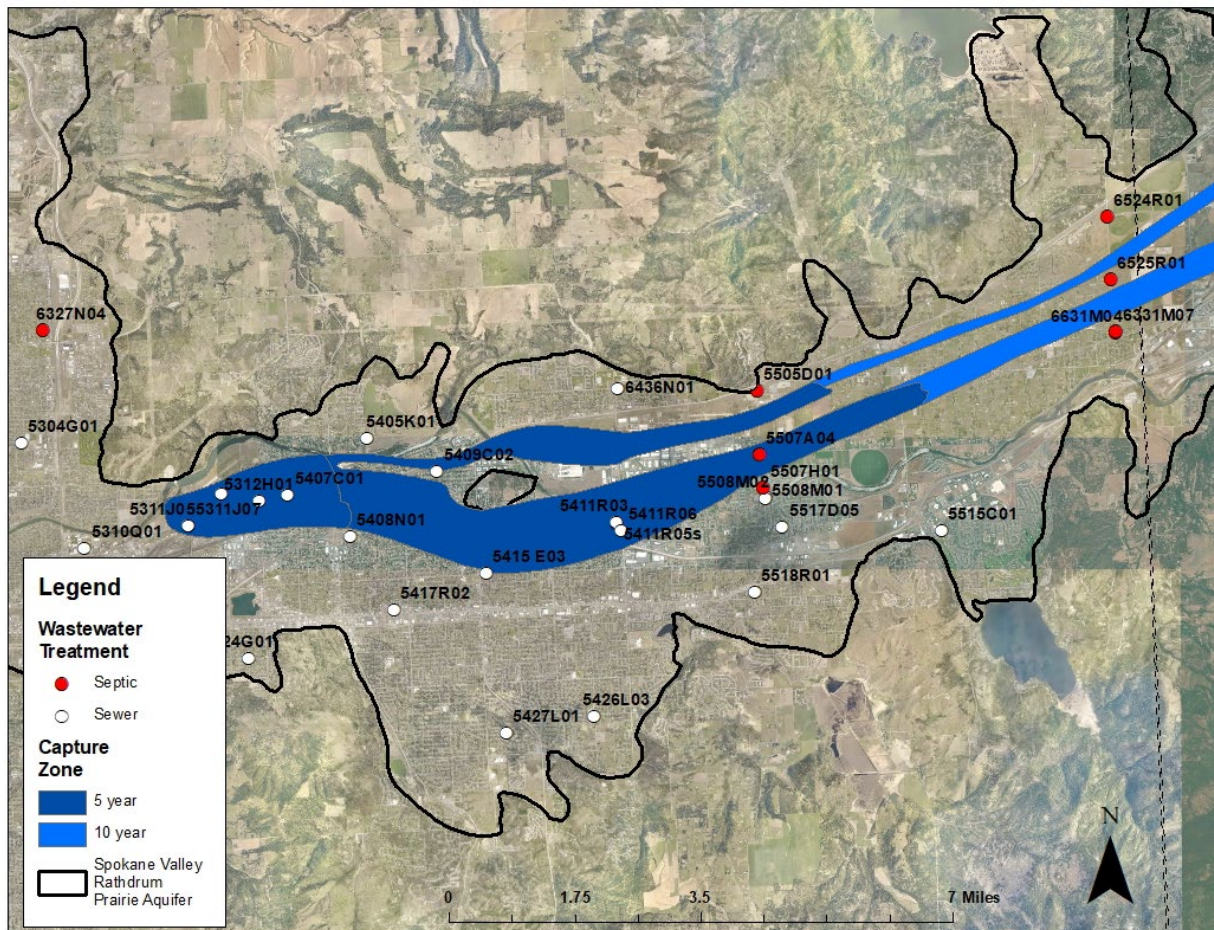
Figure 92. The five and ten-year capture zones for the City of Spokane Electric and Parkwater wells, which potentially convey nitrates from unsewered areas to areas with sewer. Four monitoring locations with increasing 20-year trends in nitrate levels (5311J05, 5409C02, 5407C01, 5411R05s) within the County's sewer service area are along this flow path. The capture zones were developed by CH2M Hill (1998) as part of wellhead protection planning.

7.2. North Spokane Sewer Service Area

There are eight County monitoring locations in North Spokane. Six of these locations are within a sewered neighborhood or influenced by adjacent sewered neighborhoods. Two of these locations are completely outside of the influence of sewer service and are in areas where septic systems are used to treat wastewater. These are discussed in groups by location and sewer service connection date as shown in Figure 93.
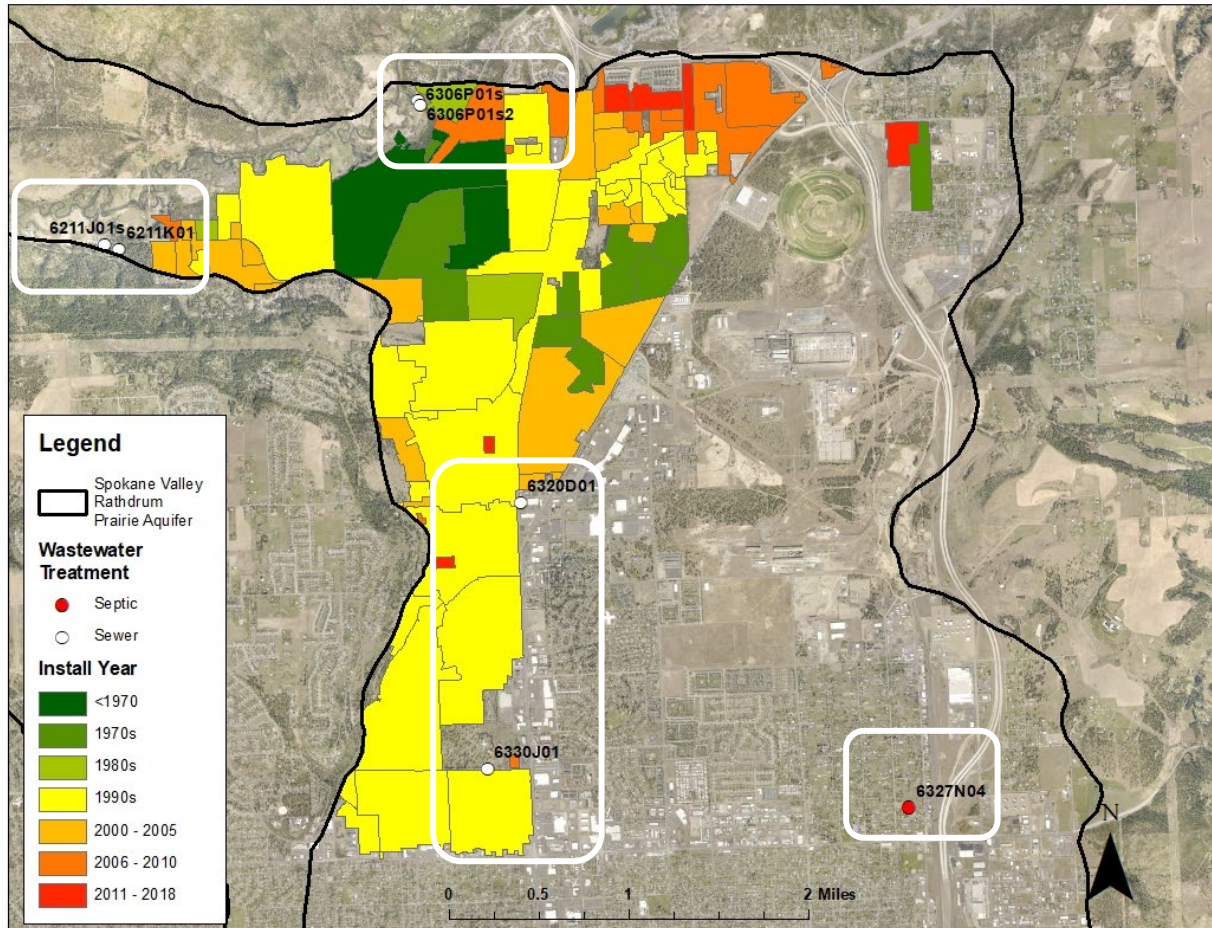
Figure 93. Sewer basins and monitoring locations within the North Spokane sewer service area. Sewer basins are colored according to the year installed with basins sewered after 2018 not shown.

7.2.1. Non-Sewered Area

The North Spokane Irrigation District well (6328H01) and the Fire Station at Houston and Regal well (6327N04) are within the non-sewered area of North Spokane and are outside the influence of the County's and City of Spokane's sewer system (Figure 93). A plot of nitrate concentrations over time for these locations is shown in Figure 94. It should be noted that the North Spokane Irrigation District well is completed in the confined aquifer in the Hillyard Trough, which influences groundwater chemistry at this location (see Section 4.2).

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Figure 94. Plot of nitrate concentrations measured in samples collected over time at two monitoring locations in North Spokane outside of sewer service. This includes the North Spokane Irrigation District well (6328H01), which is completed beneath a confining layer, and the monitoring well at the Fire Station at Houston and Regal (6327N04).

The 20-year trend analysis indicates that nitrate concentrations in groundwater samples from the and the Fire Station well (6327N04) were increasing. There is no additional data for this location to conduct further analysis. Nitrate levels from the North Spokane Irrigation District (6328H01) were stable (i.e. not trending) over the 20-year assessment. Including the County's additional data for the North Spokane Irrigation District well (6328H01) did not change the results, indicating nitrate levels in groundwater sampled from this location have been stable since 1980. This is likely the result of the protective qualities of the confining layer.

7.2.2. Whitworth

Neighborhoods in North Spokane in the vicinity of Town and Country, Country Homes, and Whitworth University were connected to sewer between 1998 and 2000. However, these are intermingled with non-sewered neighborhoods. There are two wells in this area: the Whitworth Water District Well 2A (6320D01) and the Holy Cross, Rhoades and Washington monitoring well (6330J01) (Figure 93).

The Whitworth Water District well (6320D01) is near the border between the County's North Spokane sewer service area and the City of Spokane's sewer service area. This well has some data collected prior to sewer installation, but there is a gap from the early 1980s through 1999 during the transition to sewer.

The Holy Cross monitoring well (6330J01) is in an unsewered neighborhood, but near a sewered neighborhood, Spokane Terrace, which was sewered in 1998. All the County's data for the Holy Cross well post-dates sewering in the bordering neighborhood, as monitoring of this location started in 1999.

Given the two monitoring locations do not have data that adequately covers pre- and post-sewering, the County's database was assessed for a past monitoring location that is wholly within a sewered neighborhood in the vicinity and has enough data to help assess trends. The Spokane County Water District (SCWD) Lyons & Normandie Well (6330R02) was identified as an appropriate comparison well. It

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

is located within the upgradient sewered neighborhood of Spokane Terrace and has data that spans a timeframe (1970s to 2014) prior to and after sewer installation.

A plot of nitrate concentrations over time for these locations is shown in Figure 95. The data from these three wells demonstrates that the two current monitoring locations (6330J01 and 6320D01) have nitrate levels comparable to the upgradient SCWD well (6330R02), so they are likely representing similar conditions as predicted.
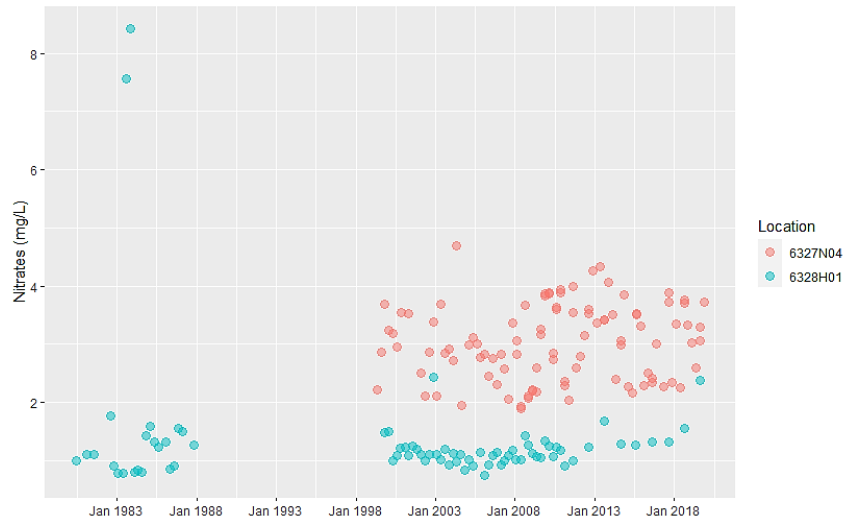

Figure 95. Plot of nitrate concentrations measured in samples collected over time at three monitoring locations within North Spokane sewer service area. This includes the Whitworth Water District well (6320D01), Holy Cross monitoring well (6330J01), and the Spokane County Water District (SCWD) Lyons & Normandie Well (ID 6330R02). The line indicates the year of sewer installation (1998) for these wells.

Trends were assessed before and after 1998, as well as over the entire dataset, for each location (Table 16). Nitrate levels measured in the SCWD well (6330R02) and the Whitworth Water District well (6320D01) did not have a significant trend prior to sewer installation. Following installation, levels significantly decreased at both locations. The Holy Cross well (6330J01), which only has post-1998 data, was also found to have a significant decreasing trend in nitrate concentrations. The general decrease in nitrate concentrations after 1998 indicates that the sewer connection influenced this downward trend at all locations. This demonstrates that the two downgradient wells are influenced by the adjacent, upgradient sewered neighborhoods.

Table 16. Results of trend analyses of nitrate concentrations measured in samples collected at monitoring locations in the North Spokane sewer service area. Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation to determine the effects of sewering.

Well ID	Before 1998	After 1998	All data
6330R02	z = 0.19, p>0.05	z = -1.76 p>0.05	1964 – 2014
			Z= -2.77 P<0.05
	Not Trending	Not Trending	Decreasing
6330J01	---	z = -5.06 p<0.05	1999 – 2019
			-5.06 P<0.05
	---	Decreasing	Decreasing
6320D01	-1.64 p>0.05	z = -3.99 p<0.05	1971 – 2019
			-5.75 P<0.05
	Not Trending	Decreasing	Decreasing

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

7.2.3. Spokane Hatchery – Griffith Springs

While the Griffith Springs monitoring location is outside of the North Spokane sewer service area, GIS data suggests the headwaters of Griffith Springs surface within the adjacent sewered neighborhoods to the east (Figure 93). Given direction of groundwater flow, the groundwater sampled at the Spokane Hatchery well may also be influenced by these adjacent sewered neighborhoods. These neighborhoods were connected to sewer between 2000 and 2009.

A plot of nitrate concentrations over time for the Spokane Fish Hatchery well (6211K01) and Griffith Springs (6211J01s) is shown in Figure 96. Unfortunately, Griffith Springs lacks data for the period of sewer installation. However, given that nitrate concentrations are comparable to the nearby Hatchery well, it is assumed the groundwater sampled at these two locations would have responded similarly to sewer installation.
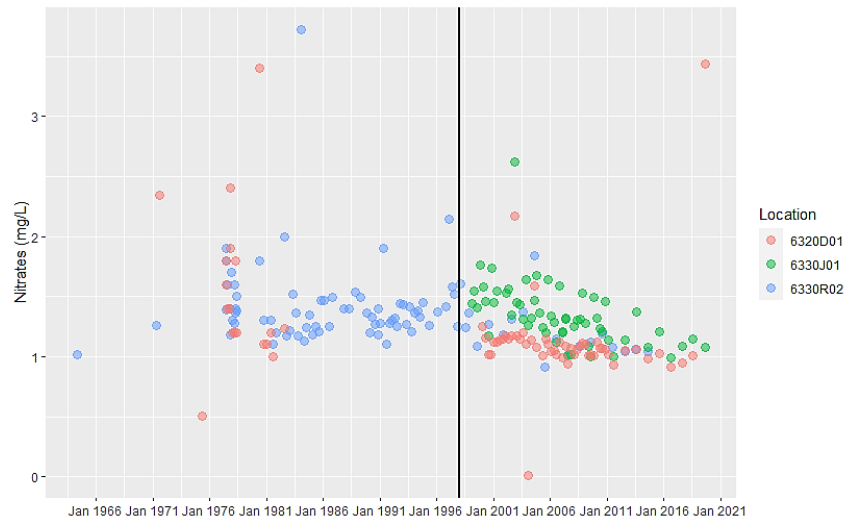

Figure 96. Plot of nitrate concentrations measured in samples collected over time at two monitoring locations near the Spokane Fish Hatchery. This includes Griffith Springs (6211J01s) and the Spokane Hatchery well (6211K01). The lines indicate the years 2000 and 2009, between which sewer installation occurred upgradient of the monitoring locations.

Figure 96 shows that the groundwater at the Hatchery well had a decline in nitrate concentrations during the period when sewer was being connected in adjacent neighborhoods. Although data is missing for Griffith Springs during this period, the available data also suggests a decline in nitrate concentrations from the levels present in the 1990s.

Table 17. Results of trend analyses of nitrate concentrations measured in samples collected at the Spokane Hatchery Well (6211K01) and Griffith Springs (6211J01s). Trends were assessed using all available nitrate data, and nitrate data before and after sewer installation in 2000 and 2009 to determine the effects of sewering.

Well ID	Before	After	Before	After	All data
	2000		**2009**		**1996 – 2019**
6211K01	z=-1.86, p>0.05	Z=-5.10, p<0.05	-6.30, p<0.05	Z = 0, p>0.05	Z= -7.07, P<0.05
	Not Trending	Decreasing	Decreasing	Not Trending	Decreasing
	2000		**2009**		**1972 – 2019**
6211J01s	-0.90, p>0.05	-0.01, p>0.05	-3.57, p<0.05	-0.15, p>0.05	Z= -6.97 P<0.05
	Not Trending	Not Trending	Decreasing	Not Trending	Decreasing

Trend analysis was conducted before and after the years 2000 and 2009, as well as over the entire dataset for each location (Table 17). A downward trend in nitrate levels at the Hatchery well occurred after 2000

95

and before 2009. This suggests that the start of sewer connections in 2000 initiated the downward trend and that nitrate levels stabilized by the last sewer connections in 2009. The analysis for Griffith Springs is influenced by the data gaps between 1978 and 1989, and in 1996 and 2007. It is possible that the post-2000 trend was missed, and nitrate concentrations had relatively stabilized by the time monitoring resumed. However, the before and after 2009 analysis for the springs mirrors that for the well.

7.2.4. Waikiki Springs

Waikiki Springs is on the northern border of the Little Spokane Arm of the SVRP aquifer. The neighborhood upgradient of the Waikiki Springs monitoring locations was sewered in 1987 (Figure 93), although County records indicate this basin was not connected to sewer until 2017. Internal discussions during review of this report confirmed that the area was sewered closer to 1987. Monitoring started at the original Waikiki Springs location (6306P01s) in 2007 and the second location (6306P01s2) in 2016.

A plot of nitrate over time for the two Waikiki Springs monitoring locations is shown in Figure 97. Given the data, it appears nitrate concentrations were affected after 2017 but is unlikely attributable to sewer although coincident with the year the area was thought to be connected. The first monitoring location at Waikiki Springs (6306P01s) has data spanning pre- and post-2017. The second location (6306P01s2) only has a few data points that pre-date 2017.
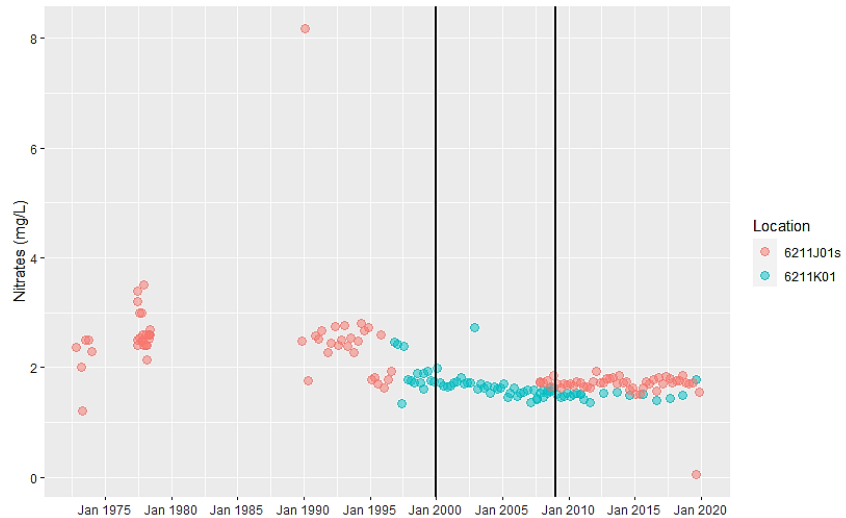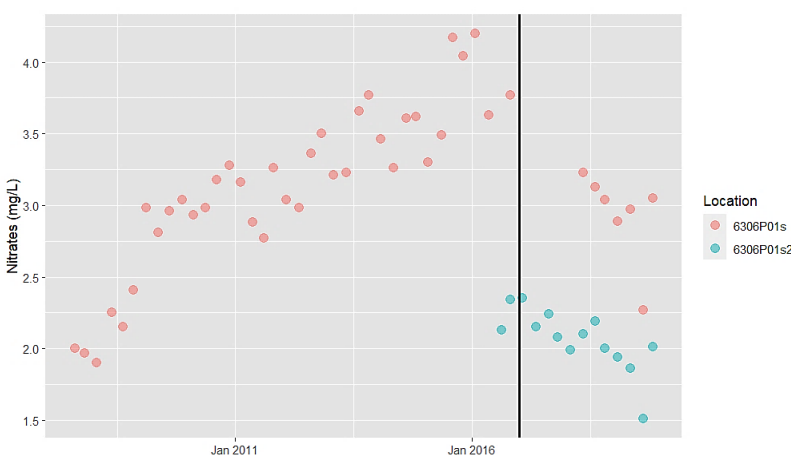

Figure 97. Plot of nitrate concentrations measured in samples collected over time at two monitoring locations at Waikiki Springs. The line indicates the year 2017.

Though nitrate concentrations at 6306P01s appear to increase prior to 2017 and decrease following (Figure 97), the analysis indicates there is no trend post-2017 (Table 18). The overall increasing trend at this location appears to be driven by the increase in concentrations prior to 2017.

Figure 97 shows that nitrate concentrations at the second monitoring location, 6306P01s2, also appears to be decreasing. The second location has a downward trend overall, but when the data is separated into pre- and post-sewer, no trends are detected. It is unclear what drove the nitrate trends in this basin given sewer occurred prior to any data collected.

Table 18. Results of trend analyses of nitrate concentrations measured in samples collected at Waikiki Springs monitoring locations. Trends were assessed using all available nitrate data, and nitrate data before and after 2017.

Well ID	Before 2017	After 2017	All data
6303P01s	z=6.45, p<0.05	Z=6.65, p>0.05	Z= 4.11, P<0.05
	Increasing	Not Trending	Increasing
6303P01s2	-0.38, p>0.05	-1.11, p>0.05	Z=-2.85 P<0.05
	Not Trending	Not Trending	Decreasing

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

8. Releases to the Environment

Releases of contaminants to the environment include spills, leaks, and other discharges or disposals that occur during human activities. The Washington Department of Ecology Toxics Cleanup Program (TCP) has identified 582 cleanup sites overlaying the SVRP aquifer (Figure 98). Cleanup sites are those where the release of one or more toxic substances is a risk to humans and the environment. The majority occur in the vicinity of downtown Spokane, along the Trent and Sprague corridors leading east to Spokane Valley, and along the Division Street/U.S. Route 2 and Market Street corridors going north, indicating this is largely an urban problem.
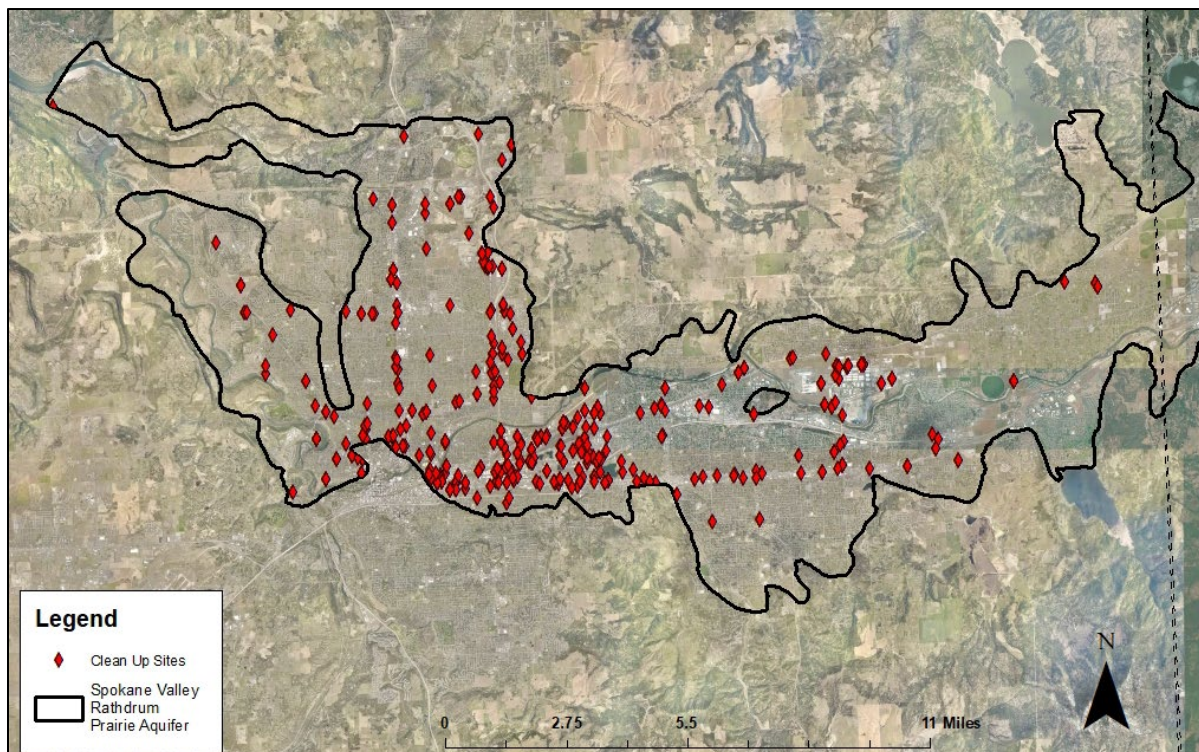
Figure 98. Washington Department of Ecology Toxics Cleanup Program (TCP) identified cleanup sites located over the Spokane Valley Rathdrum Prairie (SVRP) Aquifer in Spokane County.

The TCP identifies the contaminant(s) associated with each clean-up site, but most are grouped in broad categories with only a few contaminants identified individually. Only the County's metals data correspond with TCP contaminant categories. Arsenic, lead, and mercury are individually identified by the TCP. These three metals are also included in a category for "priority pollutants" along with cadmium, chromium, copper, zinc, and other metals not tested for by the County.

While the SVRP aquifer is susceptible to contamination from direct releases, much of the metals data does not indicate high levels of contamination from direct releases. Most metals categorized as priority pollutants (cadmium, chromium, copper, lead, mercury, and zinc) are largely not detectable throughout the SVRP aquifer (Section 3.4) though there are 63 clean-up sites associated with priority pollutant metals. These 63 sites are difficult to correlate with detectable levels of individual metals because this group

includes several metals and detections are infrequent. Therefore, this analysis will focus on the three metals that are identified individually: lead, mercury, and arsenic.

For lead and mercury, the clean-up sites associated with these metals do not appear to be spatially or temporally correlated with the drinking water exceedances of these metals. For lead, exceedances occurred down-gradient from sites, but these are not correlated temporarlly with any exceedances (Figure 99). Mecury exceedances all occurred up-gradient of known contaminated sites (Figure 100).
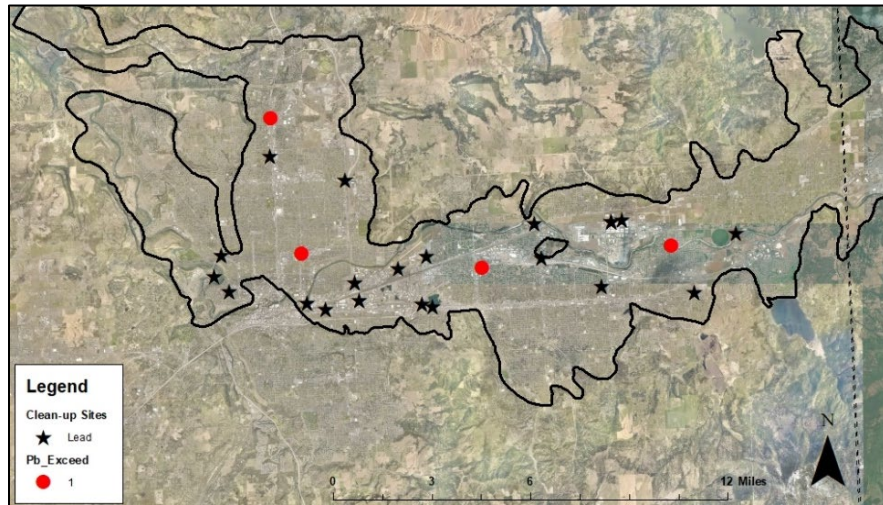
Figure 99. Locations of exceedances of the lead Drinking Water Standards in relation to Washington Department of Ecology Toxics Cleanup Program (TCP) cleanup sites associated with discharges of lead located over the Spokane Valley Rathdrum Prairie (SVRP) Aquifer in Spokane County.
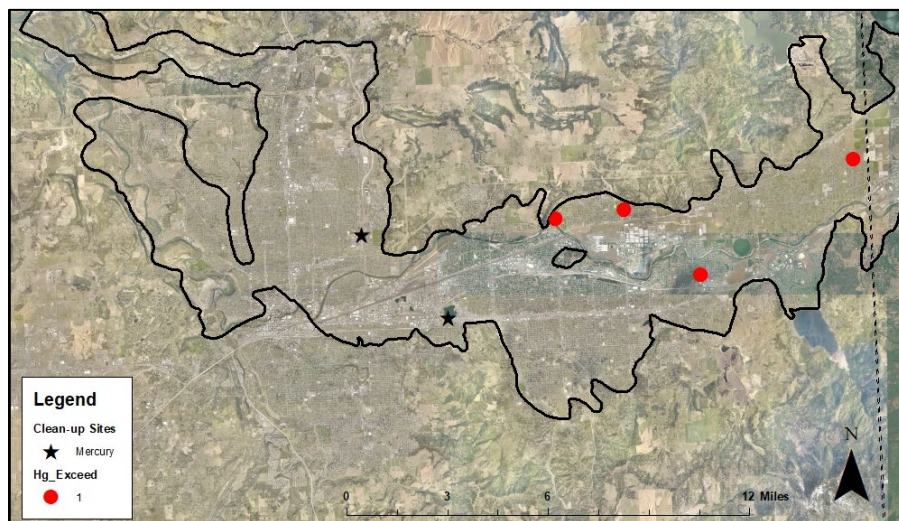
Figure 100. Locations of exceedances of the mercury Drinking Water Standards in relation to Washington Department of Ecology Toxics Cleanup Program (TCP) cleanup sites associated with discharges of mercury located over the Spokane Valley Rathdrum Prairie (SVRP) Aquifer in Spokane County.

There are 16 cleanup sites that are associated with the release of arsenic. While there are clean-up sites located in areas of high arsenic concentrations, there are also sites in areas with lower concentrations

(Figure 101). Two sites appear to be in the vicinity of elevated groundwater arsenic levels: the Spokane River Upriver Dam and Donkey Island and the HOLCIM cleanup sites.
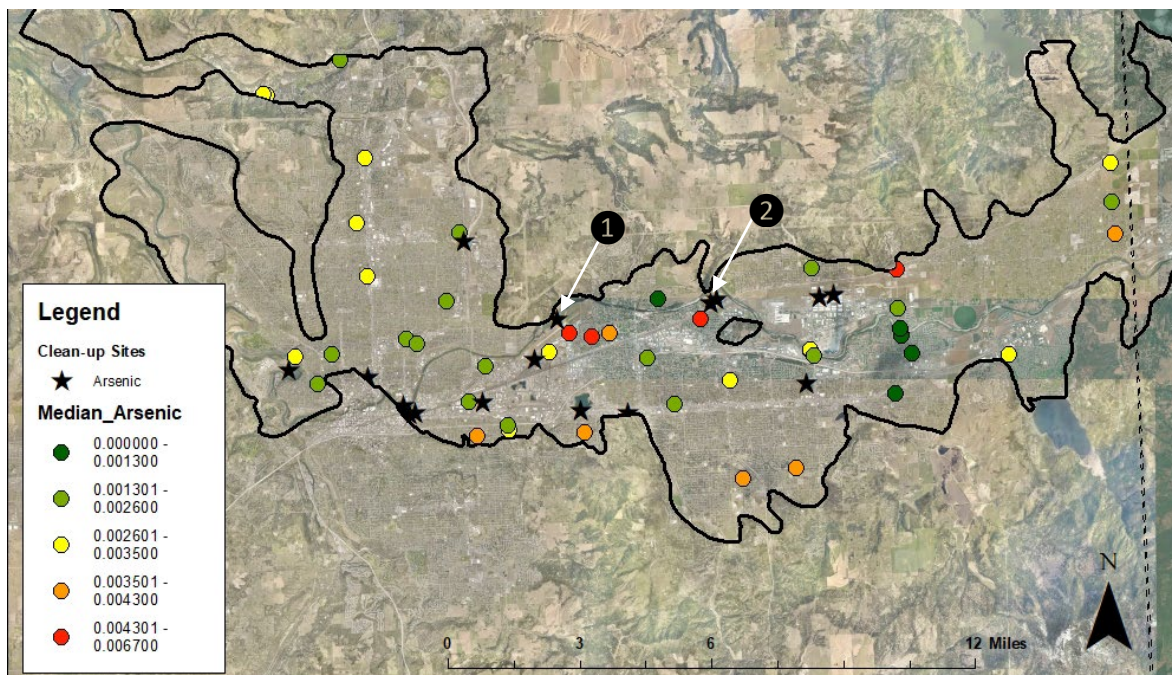
Figure 101. Median arsenic concentrations at monitoring locations in relation to Washington Department of Ecology Toxics Cleanup Program (TCP) cleanup sites associated with discharges of arsenic located over the Spokane Valley Rathdrum Prairie (SVRP) Aquifer in Spokane County. The Spokane River Upriver Dam and Donkey Island site and the HOLCIM site are noted by arrows 1 and 2, respectively.

The Upriver Dam and Donkey Island site is primarily known as a source of polychlorinated biphenyl (PCB) contamination in the Spokane River, but arsenic levels in river sediments were also found above clean-up limits. Clean-up activities at the site were completed in 2006 and 2007, which included capping contaminated sediments to prevent leaching of contaminants. The Spokane River at Upriver Dam is known as a losing reach and samples from nearby wells at Felts Field (5312C01) and Hales Ale (5311J05 and 5311J07) have higher median arsenic levels than other nearby locations (Figure 101).

Based on the 20-year trend analysis, the groundwater at these three locations shows decreasing levels of arsenic (Figure 102, Appendix E). However, the trend does not appear to be directly tied to clean-up activities at the site.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Data from the Felts Field well (5312C01) exhibited a declining trend in arsenic levels prior to 2007 ($z = -2.63$, $p<0.05$) but no significant trend after ($z = -0.73$, $p>0.05$). The shallower Hales Ale nested well (5311J05) had similar results with a decline in arsenic levels prior to 2007 ($z = -2.18$, $p<0.05$), but no trend afterwards ($z = 1.91$, $p>0.05$). The deeper Hales Ale nested well (5311J07) did not have a trend in arsenic level before ($z = -1.50$, $p>0.05$) or after ($z = 0.11$, $p>0.05$) clean-up activities in 2007.
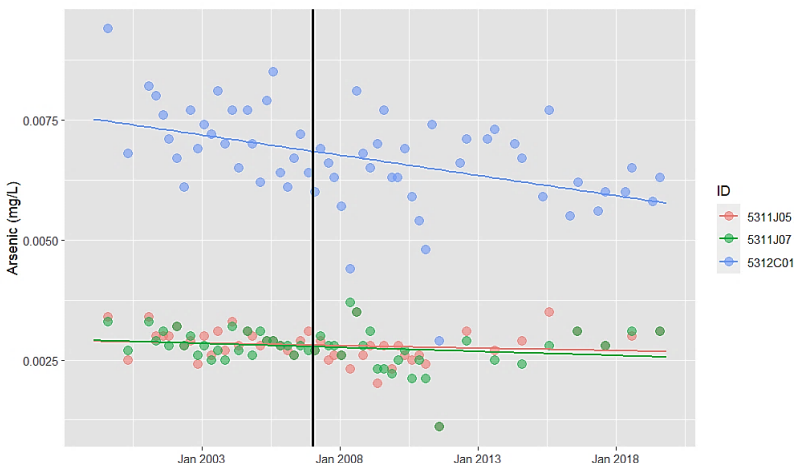
Figure 102. Plot of arsenic concentrations measured in samples collected over time at Felts Field monitoring well (5312C01) and the Hales Ale nested wells (5311J05 and 5311J07). The lines indicate the year 2007, which represents the date clean-up activities were finalized at the Upriver Dam and Donkey Island Site.

The HOLCIM site resulted in metal contamination in soils and groundwater including arsenic, cadmium, and lead resulting from cement kiln dust disposed at the site from operations between 1910 and 1967. Cleanup activities at the site were completed in 2016, including excavation of contaminated soils, use of clean back-fill, and capping the site. The monitoring well at Frederick and Bowdish (5409C02) is about 0.6 mile from the HOLCIM site. Arsenic levels at this well were stable over the 20-year period. There is not enough post clean-up data to determine if these activities had any impact on arsenic concentrations.

Although not covered under the TCP, the increase of chloride across the SVRP aquifer (Section 3.2.2) has concerned the County. It was suspected that this increase in chloride may be associated with the use of deicers [e.g. sodium chloride (NaCl), or magnesium chloride (MgCl)] in treating roads surfaces during the winter. In 2020, the County conducted a special investigation where samples were analyzed for bromide in to utilize chloride to bromide ratios to identify sources of chloride.

Chloride source identification is possible with the chloride to bromide (Cl/Br) ratio because these elements have different abundances in various substances and both are conserved in groundwater, meaning they are less affected by physical and chemical processes such as adsorption and oxidation-reduction reactions. This allows the use of simple binary mixing curves to describe how chloride and bromide concentrations in dilute groundwater would change with increasing influence from another source. The methodology is explained in more detail in the 2020 Annual Water Quality Monitoring Report (Spokane County Water Resources).

During this investigation, almost all samples (98 percent) were non-detect for bromide. Therefore, the Cl/Br ratios could not be accurately calculated for most of the samples. The two samples with detectable concentrations of bromide were collected from the monitoring well located at the Fire Station on Houston and Regal in North Spokane (Well ID 6327N04). These two samples had Cl/Br ratios of 332.98 and 456.95 with chloride concentrations of 19.5 and 22.3 mg/L respectively (Figure 103). These are at the low end of the range given for groundwater influenced by septic tank leachate, which has Cl/Br ratios between 400

and 1,100 with chloride concentrations between 20 and 100 mg/L (Katz et al 2011). The Fire Station well is located outside of the sewered area, so septic tank leachate makes sense as a possible source of chloride.

The prevalence of non-detects of bromide seemingly confounds the overall analysis. However, if the reporting limit of 0.1 mg/L is used, or even one-half the reporting limit, to substitute for the non-detect bromide data, the data would fall within the range of dilute groundwater just below the mixing line for septic tank effluent. Chloride concentrations in samples collected during the special investigation ranged from 7.45 to 32 mg/L and Cl/Br rations fell between 36 and 640 using one-half the reporting limit and between 18 and 320 using the reporting limit for bromide.
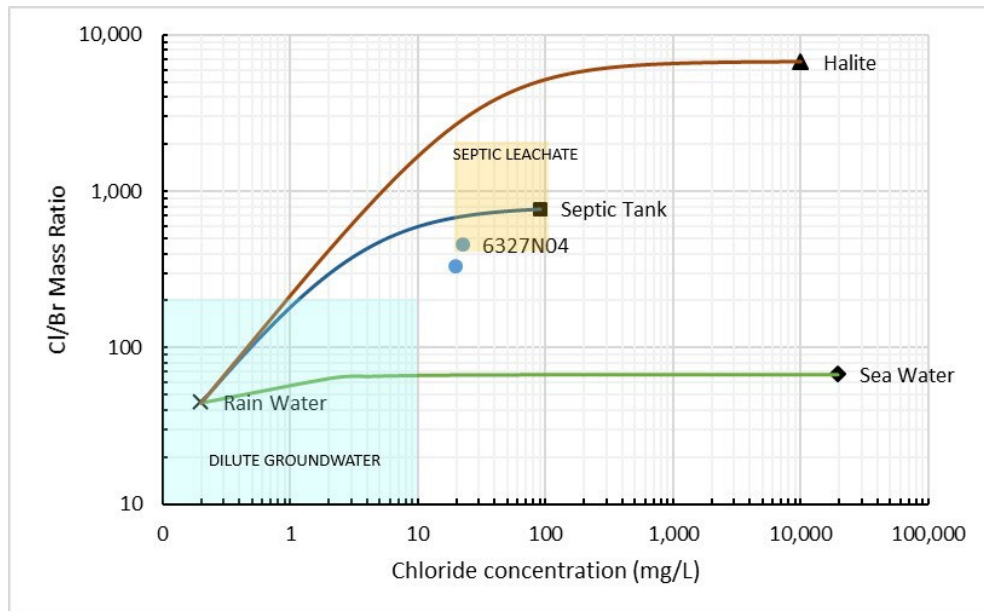
Figure 103. Plot of chloride to bromide (Cl/Br) ratios versus chloride concentrations in groundwater samples from Well ID 6327N04 in relation to the rain water, sea water, septic tank leachate, and halite (road rock salt) end members (Katz et al 2011) and the binary mixing lines between rain water and halite, septic tank leachate, and seawater. The range for dilute groundwater and septic tank leachate is also shown.

If runoff from road salt (halite) was the primary source of chloride as suspected, the data would result in higher Cl/Br ratios and higher chloride concentrations. For example, studies found that groundwater dominated by halite sources would have Cl/Br ratios of at least 1,000 with chloride concentrations of at least 100 mg/L and usually come from wells in usually within 100 feet of roads (Katz et al, 2011; Jagucki and Darner 2001; and Mullaney et al 2009). Even though most SVRP aquifer monitoring locations are within 100 feet of a road or parking lot, the data from this investigation is still not indicative of road deicing as the primary source of chloride. Given this, it is likely that chloride increase in the aquifer is the result of a combination of surface activities and not attributable to one main source.

9. Holistic Analysis

Multivariate statistical techniques can be used to identify relationships between various water quality parameters and the potential sources and processes contributing to the water quality. A common combination of multivariate statistical techniques includes use of hierarchical classification with Principal Component Analysis (PCA). Hierarchical classification is used to group monitoring sites based on similarity in water quality. PCA identifies relationships between water quality parameters and uses these relationships to isolate factors or components that describe processes or sources that control water quality. The combination of the two techniques allows for understanding of spatial variations in water quality, processes, and pollution sources, providing a more holistic assessment of the data.

9.1.1. Hierarchical Classification

The hierarchal classification algorithm was based on the 20-year median concentrations of the measured water quality parameters (e.g. major ions, nutrients, and trace elements) of each site. Data on aquifer thickness and water surface elevation were excluded to reduce the influence of site location in the algorithm, since it is assumed that groundwater chemistry is inherently spatially correlated. This could help identify other potential patterns in groundwater chemistry not necessarily dependent on spatial distribution.

The classification algorithm separated the 51 monitoring locations into four groups as shown in Figure 104. The spatial distribution of the monitoring locations within each group is shown in Figure 105 and a summary of characteristics and water quality for each group is listed in Table 19.

A review of the results provides a quick check that the hierarchal classification worked as expected. Note that each set of nested wells at Hales Ale and 3rd and Havana are grouped together, indicating they are more like each other than other sites. In addition, other sets of adjacent sites are also grouped together, such as Sullivan Road and the springs at Sullivan Park, the two Orchard Avenue Irrigation District wells, and Waikiki Springs and the Spokane Fish Hatchery well.

However, sites that are not close to each other have also been grouped together because their water quality is similar without being in proximity, such as the monitoring wells at the Northeast Community Center and Frederick and Bowdish, the Sullivan Park monitoring well and the North Spokane Irrigation District well, and the monitoring well at the Fire Station on Houston and Regal with the City of Spokane Ray Street well.

The resultant classification scheme demonstrates the influence of source water, aquifer thickness (amount of groundwater), sewering, and confining layers on water quality.

Group 2 contains only the river and transitional monitoring sites. Therefore, all sites in Group 2 have some degree of influence from the Spokane River. As a group, these monitoring locations have the lowest concentrations of major ions and nitrates. This makes sense given the Spokane River has generally low concentrations of these constituents and that Group 2 does not include any sites that are currently influenced by septic systems. However, the influence of the Spokane River causes the groundwater to have higher temperatures and lower pH and dissolved oxygen.
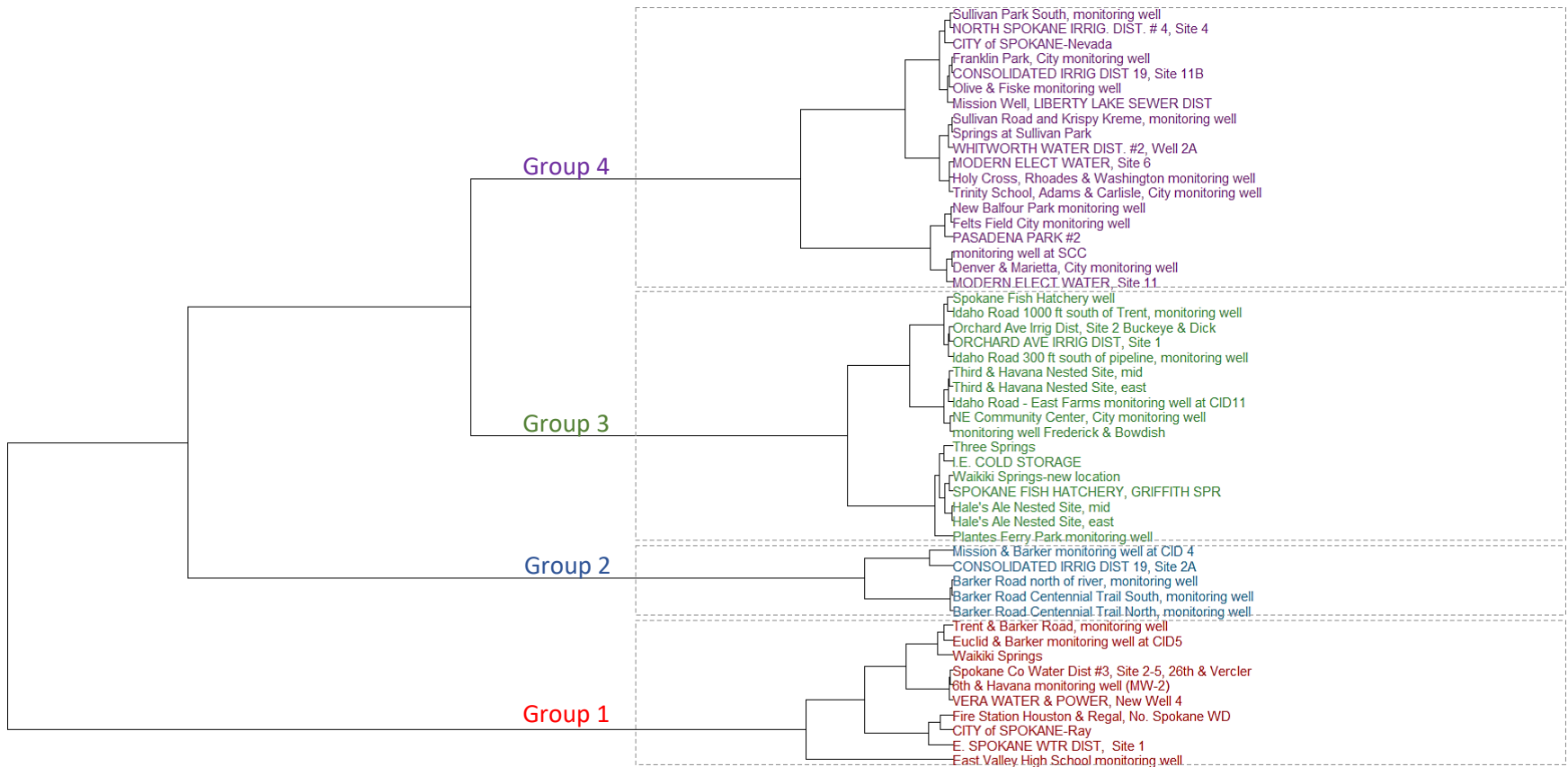
Figure 104. Cluster dendrogram grouping the Spokane Valley Rathdrum Prairie (SVRP) Aquifer monitoring locations by water quality characteristics.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023
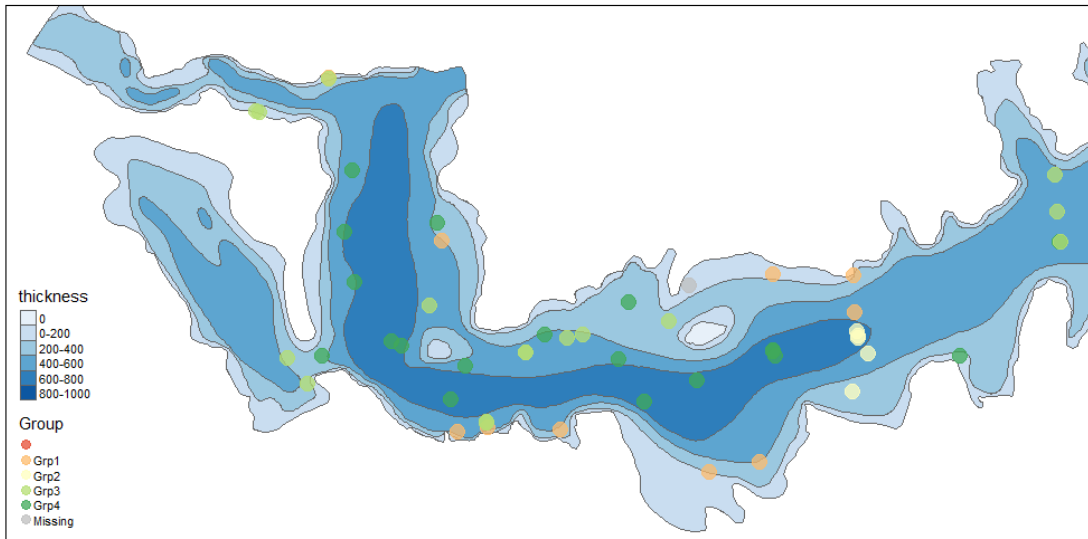
Figure 105. Spatial distribution of the Spokane Valley Rathdrum Prairie (SVRP) Aquifer monitoring locations by the group in which they were classified in the cluster dendrogram (Figure 104).

Groups 1, 3, and 4 contain all regional monitoring locations, which lack any influence from the Spokane River. These three groups generally have higher concentrations of major ions, nitrates, and arsenic. However, the concentrations of these constituents are the greatest in Group 1, followed by Group 3 and then Group 4 due to the influence of aquifer thickness, sewer installation, and presence of confining layers.

Group 1 contains regional monitoring locations at or near the margin of the aquifer where the aquifer is thinnest (Figure 105). This group also includes three non-sewered monitoring locations: two along Barker Road and one in North Spokane. This indicates groundwater at sewered sites where less groundwater is available to provide for dilution has similar chemistry as sites in non-sewered areas.

Group 3 contains monitoring locations closer to the main body of the aquifer than those in Group 1. This group also contains the four locations on Idaho Road outside of the sewer service areas. The Idaho Road sites are the furthest upgradient and within the main body of the aquifer, which allows them to be considered "background" for the other monitoring sites. For this reason, it makes sense that these sites are grouped with sites that do not have the highest concentrations of constituents even though they are located outside of the sewer service area.

Group 4 contains monitoring locations within or near the main body (or thickest part) of the aquifer. The only non-sewered location included in Group 4 is the North Spokane Irrigation District Site 4 well, which is completed beneath a confining layer. This indicates the confining layer is protective of groundwater quality such that the groundwater in the confined aquifer underlaying a non-sewered area has similar chemical composition as sewered sites where large amounts of groundwater can provide for dilution of chemical constituents.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

Table 19. Summary of the characteristics of each grouping of the Spokane Valley Rathdrum Prairie (SVRP) Aquifer monitoring locations resulting from the hierarchical classification analysis based physical and water quality attributes. Aquifer thickness, depth to water, well depth, and all water quality parameter values are the median measurements calculated by group.

	Group 1	Group 2	Group 3	Group 4
Number of sites	10	5	17	19
% of sites	19.61	9.80	33.33	37.26
Characteristics				
Source water	Regional	River/ Transitional	Regional	Regional
Aquifer thickness (ft)	255.08	576.34	433.94	490.18
Depth to water* (ft)				
Well depth* (ft)	125.0	97.0	118.2	148.2
# Purveyor wells	4	1	4	8
# Monitoring wells	5	4	10	10
# Springs	1	0	3	1
# Non-sewered sites	3	0	4	1
based on monitoring wells only				
Water Quality				
Temperature (C)	11.55	12.46	11.33	12.10
pH	7.64	6.97	7.79	7.91
Dissolved Oxygen (mg/L)	9.01	7.55	8.89	7.96
Conductivity (uS/cm)	387.05	58.00	302.00	240.00
Calcium (mg/L)	48.55	6.13	34.85	27.90
Chloride (mg/L)	10.98	1.47	5.24	3.31
Magnesium (mg/L)	18.02	1.86	14.50	11.45
Potassium (mg/L)	2.81	0.90	2.14	1.85
Sodium (mg/L)	7.96	2.07	4.45	3.11
Sulfate (mg/L)	16.10	4.24	14.20	10.70
Nitrate (mg/L)	2.97	0.22	1.63	1.12
Total Phosphorus (mg/L)	0.01	0.01	0.005	0.005
SRP (mg/L)	0.0085	0.008	0.004	0.003
Arsenic (mg/L)	0.0036	0.0	0.0028	0.0028
Zinc (mg/L)	0	0.0104	0	0

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

9.1.2. Principal Component Analysis

The PCA identified five Principal Components that explain ~85 percent of the data's variability. Each component represents different aquifer characteristics, hydrogeochemical processes, and/or pollution sources influencing groundwater quality as summarized in Table 20.

Principal Component	% of variance	Cumulative % of variance	Loadings	Groundwater Influences
Table 20. Principal Components (PC) in order of the percent (%) of the groundwater data variance explained, including the loadings of the major contributing parameters and the interpretation of groundwater influences driving each PC.				
PC1 Conductance factor	36.00	---	Conductivity (0.84), K (0.98), Na (0.90), Sulfate (0.85), Ca (0.73), Mg (0.73)	Groundwater conductivity and ion concentrations modified by accumulation/dilution
PC2 Geochemical/ Sewer Factor	28.41	64.41	DO (0.79), NO3 (0.66), Ca (0.60), pH (0.56), As (0.56); Mn (-0.79), Fe (-0.78), Total P (-0.75)	Redox and sorption processes, and their influence on water quality; specifically, elements sensitive to these processes such as nitrate (NO3), arsenic (As), manganese (Mn), iron (Fe), and total phosphorus. Septic system discharge is a secondary influence for the nitrate loading.
PC3 Zinc Factor	8.92	73.33	Zn (0.68), pH (-0.68)	Sources of zinc (Zn); Spokane River influence; sorption processes influencing zinc transport/fate
PC4 Temperature Factor	6.09	79.42	Temp (0.77)	Influences leading to warmer groundwater, e.g. Spokane River, urban areas, longer residence time
PC5 Copper Factor	5.45	84.87	Cu (0.80)	Sources of copper (Cu), e.g. purveyor wells, wells with steel casing, and the Spokane River

The first principal component (PC1) consists of positive loadings for conductivity and most of the major ions. Groundwater naturally dissolves minerals from the subsurface materials, some of which disassociate in water as ions (charged particles). The major ions (calcium, chloride, magnesium, potassium, sodium, and sulfate) come from minerals and salts abundant within soil and rocks. The concentration of ions in the groundwater directly affects its conductivity: the greater the ion concentration, the greater the conductivity. PC1 recognizes this relationship, since all the loadings are positive. For this reason, PC1 is considered the conductance factor.

The second principal component (PC2) includes positive loadings of dissolved oxygen, nitrate, calcium, pH, and arsenic and negative loadings of manganese, iron, total phosphorus, and fluoride. PC2 can be primarily interpreted as the influence of redox reactions and adsorption processes on water quality in the aquifer. Redox reactions are driven by dissolved oxygen levels and adsorption is driven by pH levels. The positive loading of both dissolved oxygen and pH suggests oxic-alkaline conditions are the prevailing

geochemical controls. Given the other loadings, PC2 recognizes how these redox-sorption conditions control various other parameters. Secondarily, PC2 accounts for the influence of septic system discharge since nitrates have a large positive loading and these do not have a natural source in the aquifer.

The third principal component (PC3) is characterized by a positive loading for zinc and a negative loading for pH. Therefore, PC3 is driven by inputs of zinc into the aquifer. The mobility of zinc in groundwater is controlled by adsorption processes regulated by pH levels. As a cation, zinc is more mobile in acidic conditions and tends to adsorb to aquifer sediments at more alkaline pH levels. PC3 recognizes this inverse relationship between zinc and pH and is considered the zinc factor.

The fourth principal component (PC4) is dominated by groundwater temperature. The locations with positive PC4 scores generally have higher groundwater temperatures (median >12C) and are primarily located in the western half of the SVRP (Figure 108). Therefore, it is likely that PC4 is temperature driven with chromium. (e.g. basalt) (e.g. industry).

The fifth principal component (PC5) is dominated by copper. Though copper can be controlled by adsorption processes like other metals, the loadings do not indicate an influence from pH. In fact, copper tends to have complete absorption at pH levels typical in the aquifer, which reduces its presence in groundwater. This suggests PC5 is driven by a source(s) of copper that may not be affected by adsorption. Many of the locations with positive PC5 scores are purveyor wells. It is possible that the copper is being introduced via the piping/infrastructure of the purveyor wells.

9.1.3. Drivers of Water Quality

The PCA combined with the hierarchical classification provides insight regarding the influences on water quality. Plots of the monitoring sites based on their scores for the first three principal components is a way to assess similarities or differences among individual sites and among their assigned groups from the hierarchal classification. A three-dimensional and several two-dimensional plots are provided for visualization. The first three principal components are used because they account for most of the variation in the site data (Table 20).

Figure 106. Three-dimensional plot of the 51 monitoring locations along the first three principal components colored by their groups assigned in the hierarchical classification (Figure 104). Dimension (Dim.) is equivalent to Principal Component (PC) (e.g., Dim.1 is PC1).

Figure 107. Two-dimensional plots of the 51 monitoring locations along the first three principal components colored by their groups assigned in the hierarchical classification (Figure 104), including a 95 percent confidence level. Dimension (Dim.) is equivalent to Principal Component (PC) (e.g., Dim.1 is PC1).

108

All the regional groups (Groups 1, 3 and 4) have some overlap in the PCA plots, indicating that these groups are generally influenced by the same processes but to a slightly different degree. Sites in Group 2 (river-influenced groundwater) are separated from the other groups in the PCA plots (Figures 106 and 107). This confirms the Spokane River has a distinguishable effect on groundwater quality along the losing reach at Barker Road.

River-influenced groundwater (Group 2) is generally defined by negative scores for PC1 and PC2 with positive scores PC3 (Figure 107). The negative scores for PC1 (conductance factor) are indicative of the low conductivity and ion concentrations measured at these sites. The spread along PC1 among sites within Group 2 accounts for the river-influenced groundwater (5507H01, 5508M01, and 5508M02) having lower conductivity and major ion concentrations than the transitional sites (5507D01 and 5518R01).

PC2 and PC3 generate more spread among the sites within Group 2 than PC1, indicating these factors are responsible for more of the variation within the group (Figure 107). The gradient along both PC2 and PC3 is due to the shift from acidic conditions in river-influenced groundwater (5507H01, 5508M01, and 5508M02) to the alkaline conditions at the transitional sites (5507D01 and 5518R01) and regional sites, along with the associated responses in the affected parameters. For example, under PC2 arsenic is not found in the river-influenced groundwater due to adsorption under acidic conditions. Under PC3, zinc is detectable in the river-influenced groundwater but not in the transitional sites due to adsorption under alkaline conditions. The gradient along PC2 is also impacted by septic influence. The river-influenced groundwater has lower levels of nitrates due to earlier sewer installation than the transitional sites.

The regional groups have a greater spread across PC1 (conductance factor), indicating this is responsible for most of the variance within and between the three groups (Figure 107). The conductance factor has the strongest influence on Group 1 (all sites have positive PC1 scores), some influence on Group 3 (mix of positive and negative PC1 scores) and the least influence on Group 4 (all sites have negative PC1 scores). This gradient is primarily based on conductivity and ion concentrations, which are regulated by the amount and flow of groundwater.

Sites in Group 1 and Group 3 with positive scores along PC1 are located more on the edge of the aquifer where major ions that increase conductance tend to accumulate (Figure 108). At the margins of the aquifer, the aquifer sediments are thinner and groundwater moves slower. This allows ions to accumulate in these locations, resulting in higher conductivity. In the main body of the aquifer, where the aquifer is thicker and groundwater moves faster, ion concentrations are diluted by the larger volume of groundwater.

PC2 accounts for less variation within the regional groups than it did for the river-influenced group (Figure 107). This is because sites within the regional groups do not vary in geochemical conditions; all regional sites have oxic, alkaline groundwater. Therefore, the septic discharge aspect of PC2 plays a larger role in regional groundwater quality. Most sites in Groups 1 and 3 have positive scores in PC2 (Figure 108). These two groups include the majority of the non-sewered sites and sites that have higher nitrate levels, including those impacted by upgradient inputs (Table 19). Most sites in Group 4 have negative PC2 scores and generally have lower nitrate levels. The only non-sewered site included in this group is the confined aquifer sampled at the North Spokane Irrigation District well (Table 19).

The regional groups have even less variation across PC3 (Figure 107). Zinc is generally not detectable in the aquifer because it is more mobile under acidic conditions. Most sites in Group 1 have positive PC3 scores, and most sites in Groups 3 and 4 have negative PC3 scores. Of the regional sites that have positive scores, only three have median concentrations of zinc at detectable levels. The other regional sites with positive PC3 scores generally have a pH below 8.0, which is the pH level above which zinc has complete adsorption. Therefore, a positive PC3 score appears to recognize groundwater locations that might be sensitive to contamination from zinc.

One site, the monitoring well at Plantes Ferry (5404A01), plots far outside of the 95 percent confidence limits of its group and is separate from any other site on the plot. This indicates the water quality of the confined aquifer sampled from the Plantes Ferry well is unique. It is the only location defined by a positive PC1 scores and negative PC2 and PC3 scores. The negative PC2 score is due to the confined aquifer's anoxic, acidic conditions and non-detectable levels of nitrates. The anoxic groundwater promotes denitrification in addition to the confining layer likely providing some protection from nitrogen transport from septic system discharge. In addition, the anoxic, acidic conditions also allow for the high levels of manganese, iron and phosphorus accounted for in PC2.
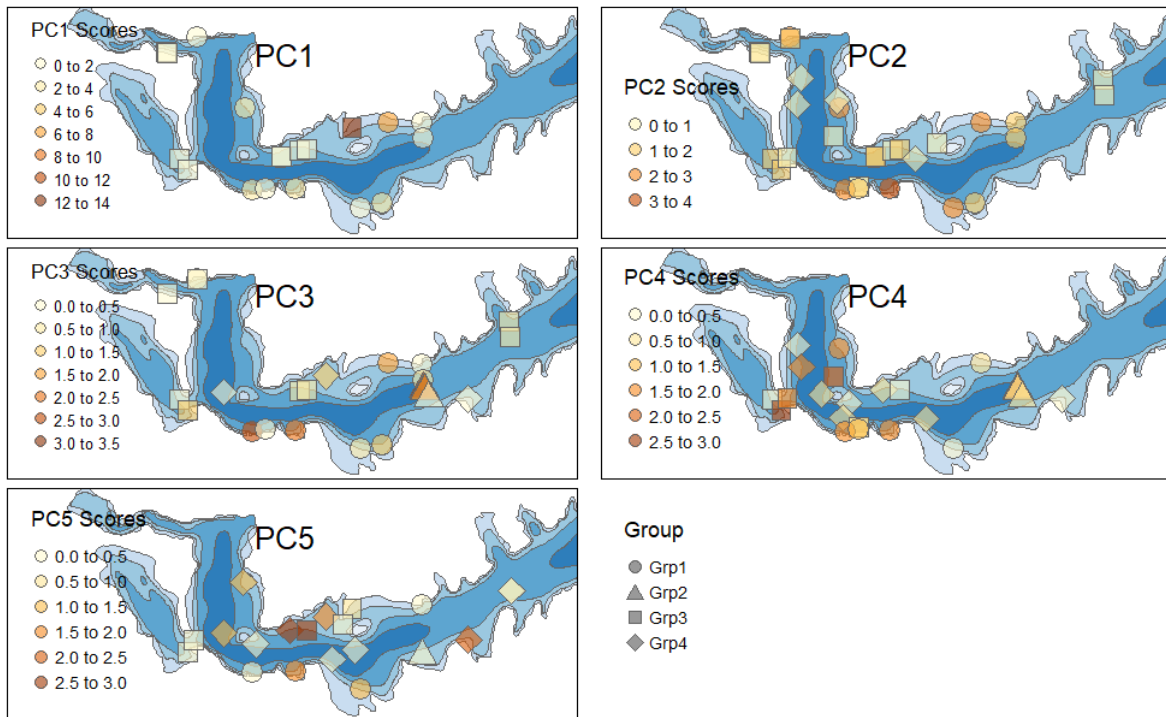

Figure 108. Spatial distribution of sites with positive scores for each of the principal components by group.

SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023

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SVRP Aquifer Long-Term Monitoring Program
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River	Location	EIM Site IDs	EIM Study IDs	Date Range
Spokane	Barker Road	57A148	AMS001E	10/2006 – 12/2008
		SPK90.4	BCUS0005	8/1999 – 9/2000
		SRRTTF-9	SRRTTF-2014 SRRTTF-2015 SRRTTF-2016 SRRTTF-2018	8/2014 – 8/2018
	Sullivan Road	57A146	AMS001 AMS001E	10/2008 – 12/2010
		SPK87.8	BCUS0005	8/1999 – 9/2000
	Trent Avenue	RM 85.3	BCUS0005 GPEL0004	7/1992 – 9/2000
	Sandifer Bridge	57A123	AMS001 AMS001E	10/2008 – 12/2010
		SPK72.5	BCUS0005	8/2000 – 9/2000
	TJ Meenach Bridge	54A130	AMS001 AMS001E	10/2008 – 12/2010
		SPK69.8	BCUS0005	8/1999, 8 – 9/2000
River	**Location**	**EIM Site IDs**	**EIM Study IDs**	**Date Range**
Little Spokane	Dartford	55B082	AMS001D Jjoy0007	1/1999 – 9/1999 7/2010 – 8/2010
		LS6	G9900036	1/1999 – 9/1999
	Near Griffith	55B080	Jjoy0007	7/2010 – 8/2010
		WAM06600	WHM_WAM0	9/2019
	Hatchery Slough	55GRI-00.0	Jjoy0007	7/2010 – 8/2010
			Jros0003	2/2009 – 9/2009
			Jjoy0009	3/2007 – 4/2007
	Painted Rocks	55B075	Jjoy0007	7/2010 – 8/2010
			AMS001D	1/1999 – 9/1999
		LSRTMDL-21	C0500017	12/2004 – 4/2006

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SVRP Aquifer Long-Term Monitoring Program
20-Year Analysis (1999 – 2019)
Spokane County Water Resources, Dec. 2023