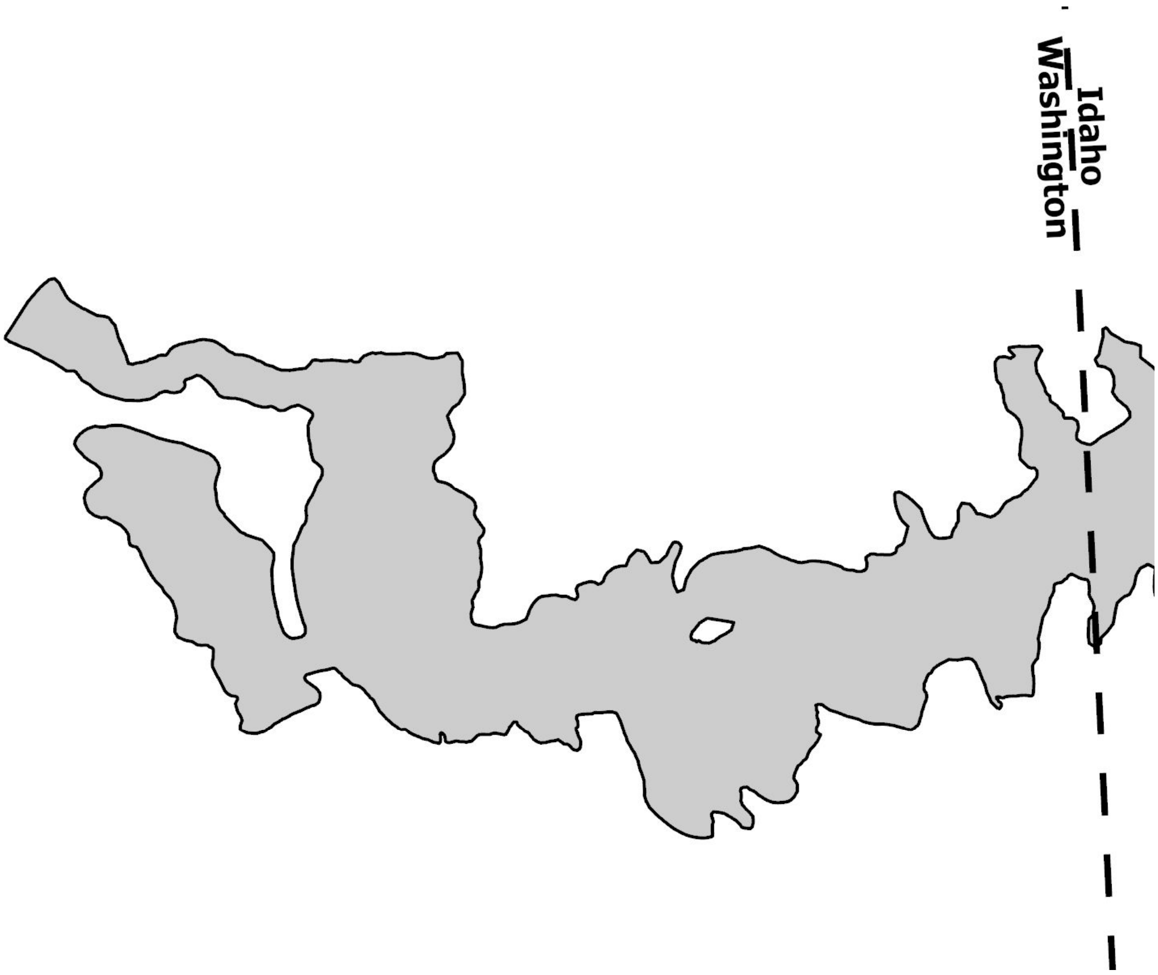
Spokane Valley Rathdrum Prairie Aquifer
Spokane County, WA
Long-term Monitoring Program
20-Year Analysis (1999—2019)



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

THE SVRP MONITORING PROGRAM AND THE PRODUCTION OF THIS REPORT WAS FUNDED BY THE VOTER APPROVED AQUIFER PROTECTION AREA (APA) FEE ASSESSED BY THE COUNTY. FOR MORE INFORMATION ON THE APA FEE VISIT [WWW.SPOKANECOUNTY.ORG/1530/AQUIFER-PROTECTION-AREA](https://www.spokanecounty.org/1530/aquifer-protection-area)

Contents

Appendices

Abbreviations, Acronyms, and Units of Measurements

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

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

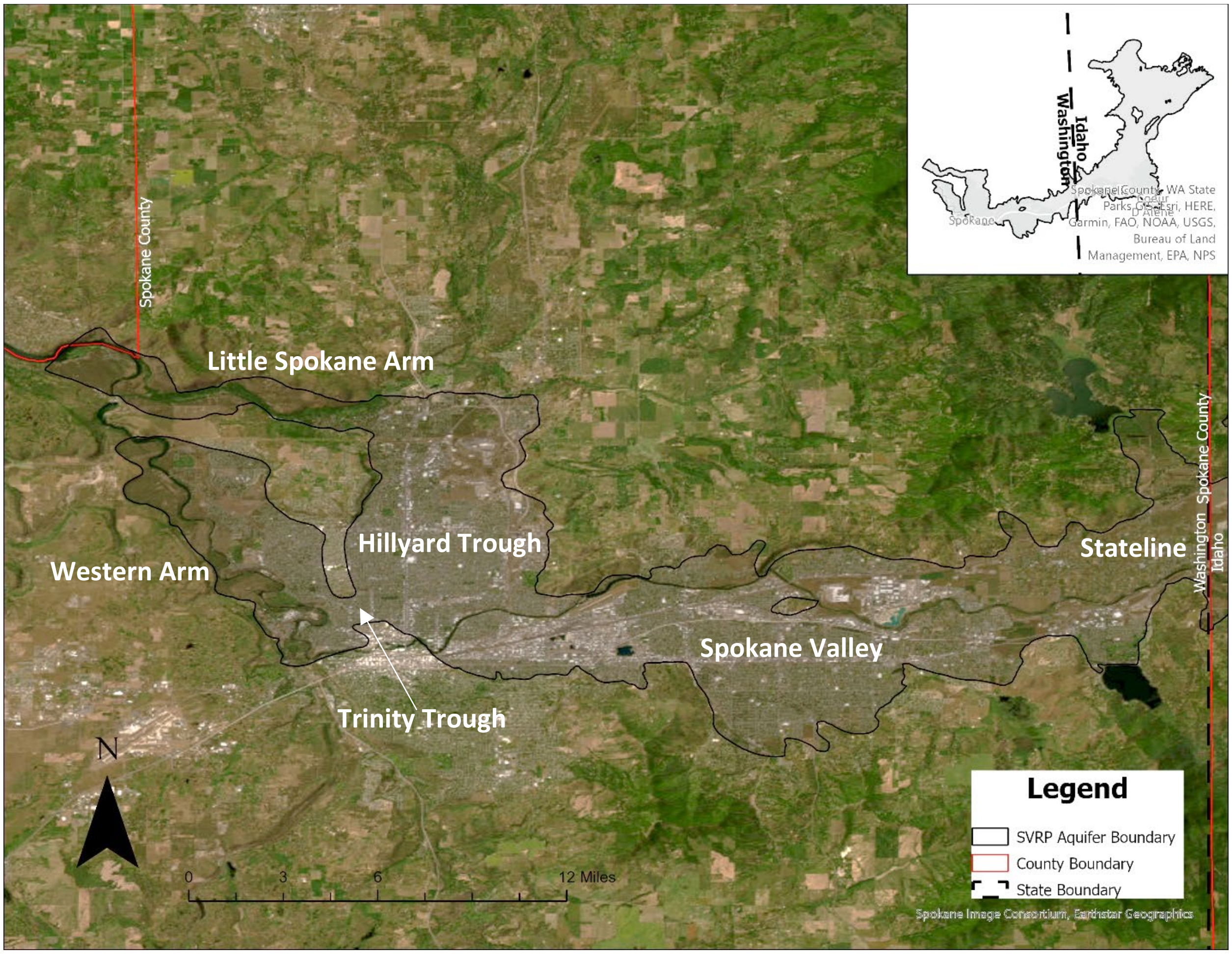
This report is divided into several sections to specifically address monitoring program objectives:

- 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).



Spokane County, WA State Parks, GIS, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

Spokane Image Consortium, Earthstar Geographics

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 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.

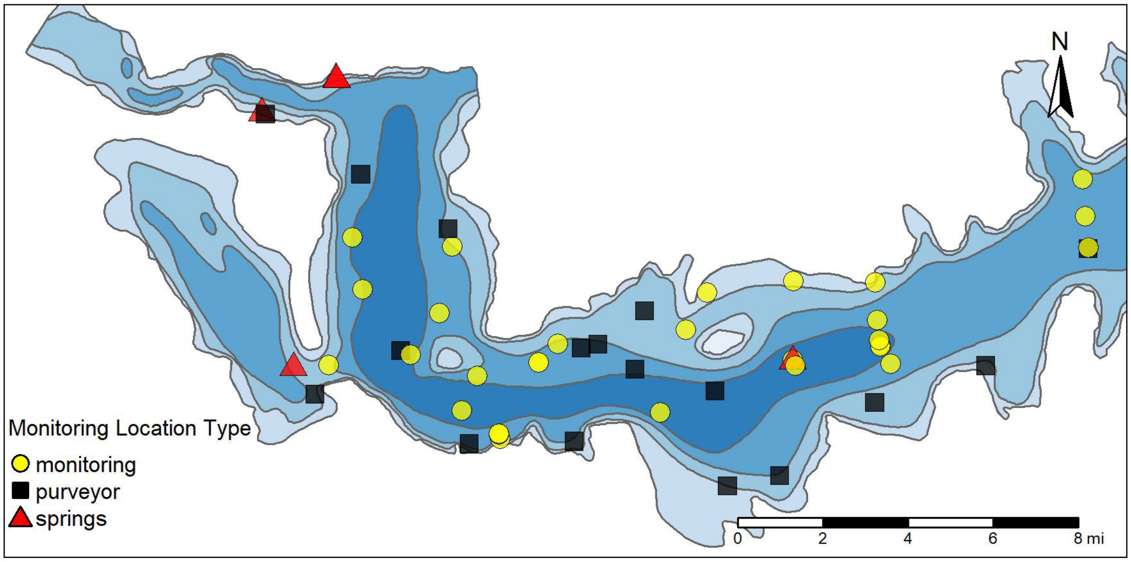


Figure 2. Current monitoring locations by type used in the Spokane County's Long-term Monitoring Program. Aquifer thickness is modeled from Kahle and Bartolino (2007).

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.

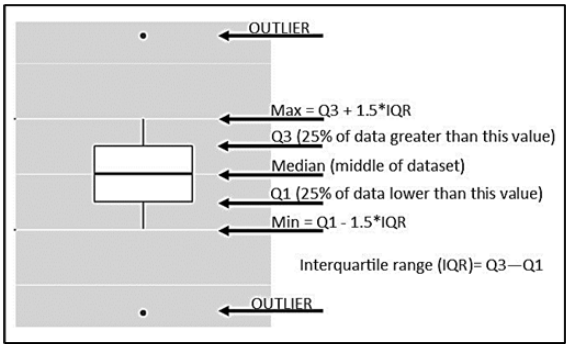


Figure 3. Statistics shown in a boxplot, also known as a box-and-whisker plot. The upper quartile (Q3) is the top of the box, and the lower quartile (Q1) is the bottom of the box. The interquartile range (IQR) is the difference between the Q3 and Q1 values, represented by the side of the box. The median 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 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).

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 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.

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).

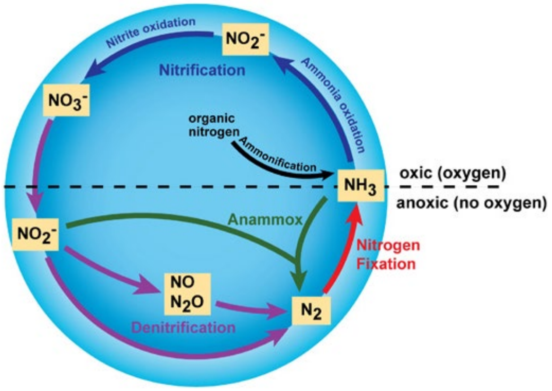


Figure 4. The Nitrogen Cycle processes separated by those occurring in oxic and anoxic conditions. Nitrate [NO_3-] can persist in oxic conditions because denitrification occurs in anoxic conditions. This process reduces nitrate to nitrite [NO_2-] and eventually to nitrogen gas (N_2).

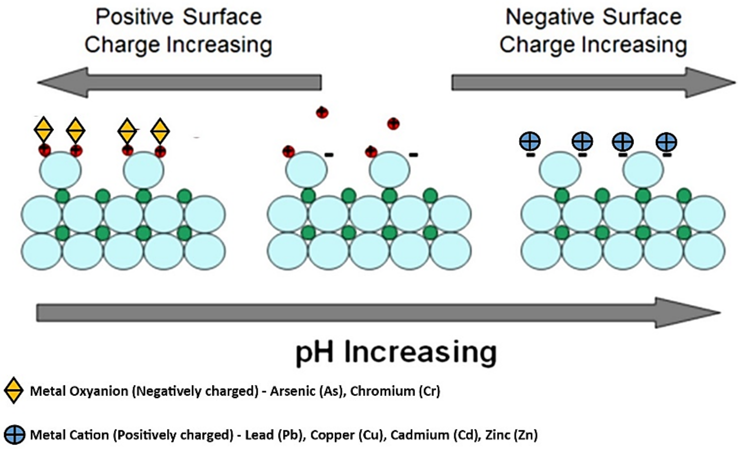


Figure 5. A model demonstrating how the adsorption of trace metals is affected by changes in pH levels. Metals that exist as oxyanions (e.g. arsenic, chromium) adsorb to aquifer sediments at lower pH as the surface charge becomes positive. Metals that exist at cations (e.g. cadmium, copper, lead, and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

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.