Big Sky Nutrient Monitoring Project
2018 – 2023 Monitoring Well Data Analysis Report


Cover photo: Spotted Elk (GWIC #257677), a sample location in Big Sky, MT

Prepared by:
Meggie Olson
Water Quality Specialist/Hydrogeologist
Gallatin Local Water Quality Department

Revised in 2024 by:
Xiang Fan
Water Quality Specialist/Hydrogeologist
Gallatin Local Water Quality Department

Contact Person:
Nick Banish nick.banish@gallatin.mt.gov
Gallatin Local Water Quality Department

Prepared for:
Local Water Quality Department Board of Directors and the Gallatin County Commission

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1.0 Introduction

Big Sky is a ski resort community located in southwest Montana close to Yellowstone National Park and the Gallatin River. The Big Sky 2022 Economic Profile reports a total population of 3,054 as of 2020, and states the population doubled since 2010 (Haines, 2022). The Meadow Village area is a part of the unincorporated Big Sky area and includes residential and commercial development. There is a town center, an 18-hole golf course, horseback riding operations and hiking and biking trails. Much of the development is connected to the Big Sky County Water and Sewer District No. 363 (BSCWSD) system whose principal source of drinking water for residents is the shallow, alluvial aquifer that underlies Meadow Village. The treated wastewater from the district is stored in retention ponds and reused for irrigating the turf grass golf course, a practice applied since the 1970's. While the BSCWSD provides treatment to the unincorporated census-designated place (CDP); there are residential units with on-site subsurface wastewater treatment systems. The historical land-use practices and the ever-growing human activity combined with water quality data of local streams and the aquifer below the Meadow Village area has generated communal concern for water resource degradation. For example, For the past few years, nuisance *Cladophora* algal blooms have occurred along the Upper W. Gallatin River near Big Sky.

1.1. Background

The Gallatin River Task Force (GRTF), a watershed group based in Big Sky, has been monitoring the water quality of local streams since 2000. With the help of the GRTF, in 2010 the Montana Department of Environmental Quality identified three streams as impaired using the Total Maximum Daily Load water quality assessment framework. The Middle Fork West Fork Gallatin River (MF), South Fork West Fork Gallatin River and the West Fork of the Gallatin

River are listed as impaired due to their loads of Nitrate + Nitrite and sediment. The GRTF has identified other areas of concern. The MF and the West Fork of the Gallatin River have elevated concentrations of total nitrogen and chloride. These impaired streams have recurring algal growth.

In 2018, the Big Sky Area Sustainable Watershed Stewardship Plan was published. This was a collaboration effort between stakeholders, including the Gallatin Local Water Quality District (GLWQD) to address water resource concerns and devise solutions. Among the various action items determined, several projects were developed to address or supplement priority action items related to water quality including the Big Sky Nutrient Monitoring project, the focus of this report.

1.2. Objective of Study

The Big Sky Nutrient Monitoring Project is a ten-year cooperative agreement between the GLWQD, the Montana Bureau of Mines and Geology (MBMG), and the BSCWSD. The goals of the project are to conduct groundwater sampling on a regular basis, review data, and generate a summary report. Since starting the project in 2018, seven to nine monitoring sites have been sampled regularly for the wastewater indicators nitrate + nitrite as nitrogen (NO_3-N) and chloride (Cl^-). This report describes the GLWQD's findings from the analysis of 2018 – 2023 dataset.

1.3. Previous Investigations

Baldwin (1997) study evaluated aquifer vulnerability and provided baseline water quality data. The Meadow Village Aquifer (MVA) was ranked as most vulnerable due to soil media, depth to groundwater and vadose zone media. Three wells were sampled in September of 1995 from the quaternary alluvium that comprises the MVA just north of the golf course, and results suggested nitrate levels below 2 *mg/L* (Baldwin, 1997). Gardner et al (2011) work characterized potential sources of nitrogen in Big Sky. More recently, WGM Group (2020) assessed primary contributions of anthropogenic nitrogen to the West Fork, ranking them from largest to smallest. WGM concluded that the greatest contributions are from wastewater irrigation and onsite wastewater treatment systems with estimated annual loads of 12,000 and 4,400 pounds of nitrogen, respectively. MBMG studies (Waren et al., 2021; Rose and Waren, 2022) illustrated the connection of the aquifer to the nearby stream environments, underscoring the need to further characterize hydrochemical conditions within the aquifer over varying spatiotemporal scales. However, to date no studies have examined longer term patterns of wastewater indicators and nutrients in the study area.

2.0 Materials and Methods

2.1. Study Area and Site Characteristics

There are nine groundwater monitoring sites within the Meadow Village study area (Fig. 1).

Site locations were selected for proximity to potential sources of concern, recharge and discharge zones, and saturated thickness of the MVA. Most of the selected monitoring sites existed from previous studies. The MVA is an alluvial, unconfined aquifer composed of modern alluvium and quaternary glacial outwash. The saturated thickness of the MVA thins to the South, varying from 30 to 60 feet and is highly transmissive (Waren et al., 2021). The Cretaceous-age Frontier Formation underlies the MVA. It is a water-bearing sandstone interbedded with low permeable shale layers. Waren et al.et al. (2021) report theorizes that a portion of the MVA fills a northeast-southwest trending shale trough that is theorized to be an ancestral river channel cut into the Frontier Formation in the western part of the aquifer (i.e., See MBMG Groundwater Information Center (GWIC) Log # 281359). Groundwater generally flows from west to east and has a strong connectivity to the West Fork of the Gallatin River (Fig. 2), as suggested by potentiometric surface map, the general streamflow and hydrograph patterns that is, further supported by modelling (Waren et al. 2021).

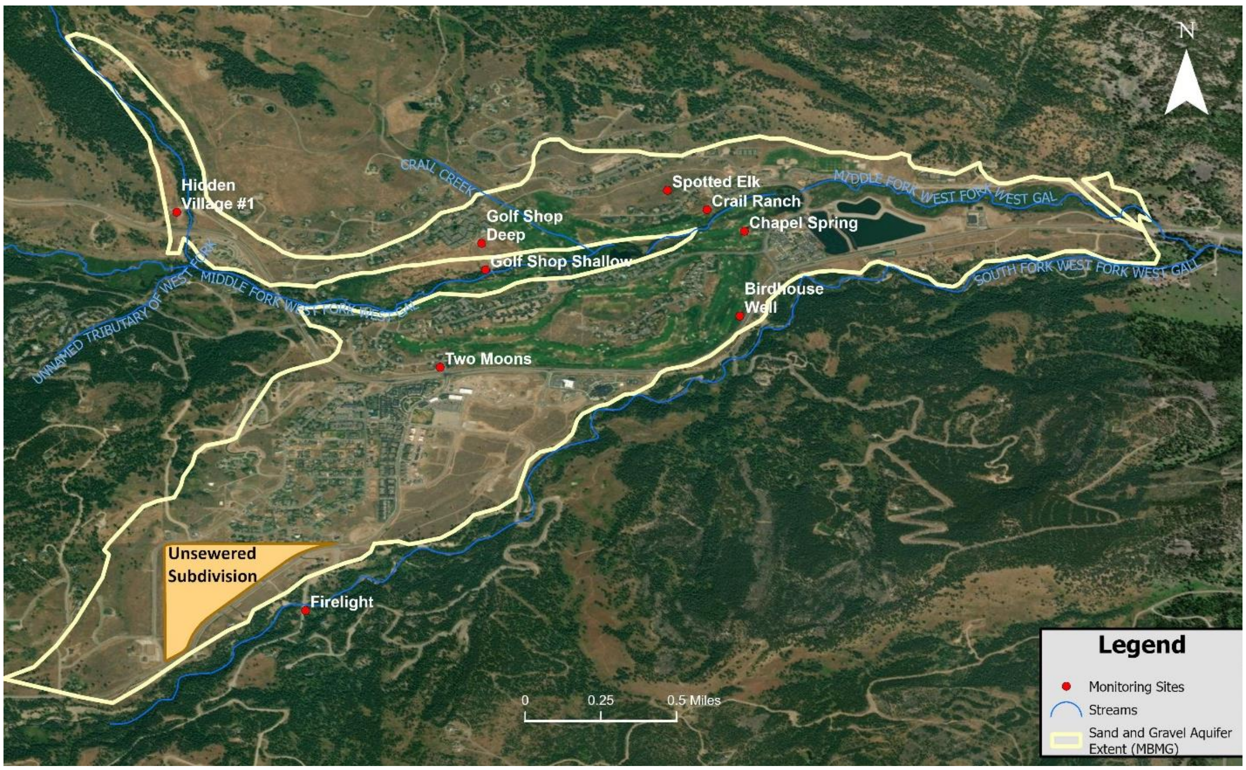

Fig. 1 ESRI® aerial imagery showing location of nine monitoring sites, two principal tributaries of the Gallatin River, 18-hole golf course, and an unsewered subdivision within Meadow Village, Big Sky, Montana.

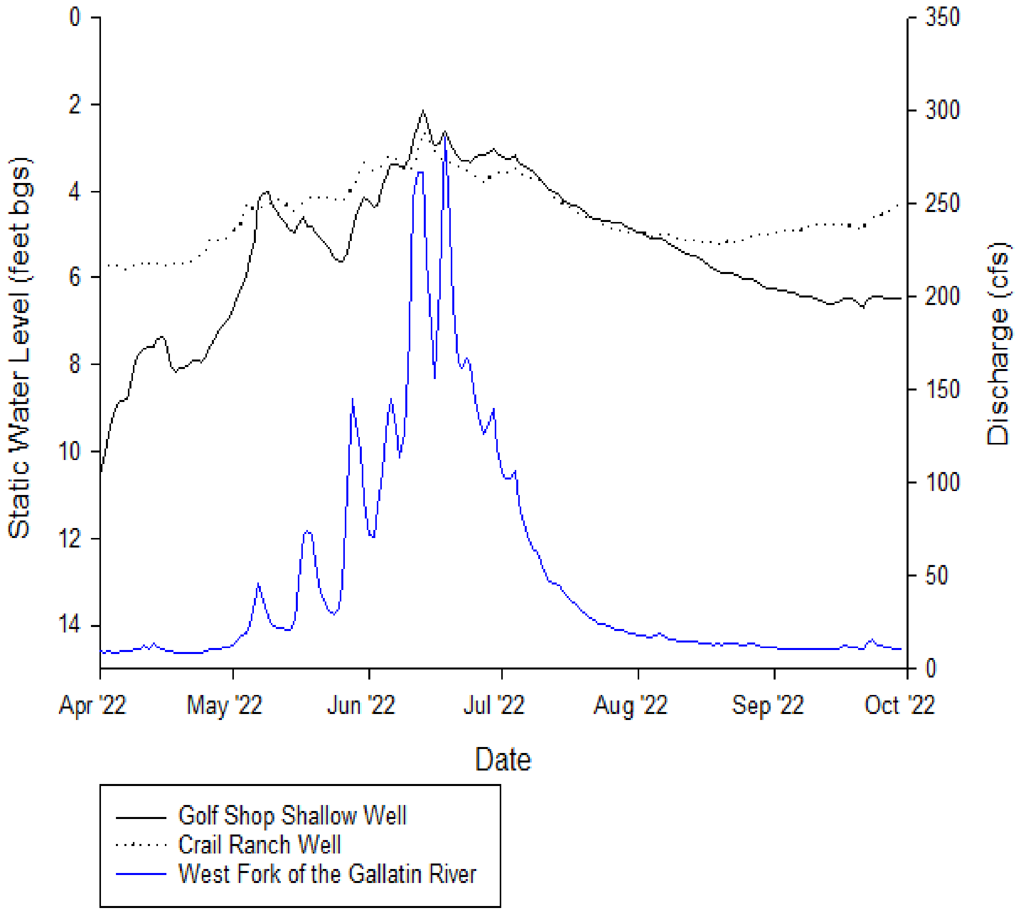

Fig. 2 Continuous levellogger data from April – October 2022 illustrating the relationship between shallow, near stream monitoring sites (black solid and dotted lines) and streamflow (blue line). Data shown are static water level in feet below ground surface (bgs) and West Fork of the Gallatin River discharge in cubic feet per second (*cfs*). Water level data downloaded from MBMG's Groundwater and Information Center. Streamflow data collected and shared by GRTF.

There are eight monitoring wells and one spring (Table 1). Seven monitoring wells have standard construction (see corresponding MBMG GWIC well logs). The Birdhouse Well is a two-inch, screened PVC pipe drilled to 17.7 feet below ground surface (bgs) and is located within a berm of the golf course that parallels Lone Mountain Trail. Chapel Spring is on the Chapel Spring (Fig. 3) is on the of the golf course and serves as a groundwater drain, appears to drain several golf courses holes (i.e., see GWIC log # 255834). Average annual flows for the spring are 20-23 gallons per minute (~0.05 ft^3/s, Table 1).

Table 1. Monitoring site characteristics

Site Name	Static Water Level Range (*ft* bgs)	Total Depth (*ft* bgs)	Depth Interval of Screen (*ft*)	Ground Surface Altitude (*ft*)	GWIC ID
Hidden Village #1	6 - 12	45	34 - 44	6430	103499
Firelight	0 - 14	26.5	11.5 - 26.5	6300.18	185435
Two Moons	24 - 47	45	20 - 45	6308.34	281359
Golf Shop Shallow	-1 - 16	15	10 - 15	6259.73	281362
Golf Shop	1 - 24	58	38 - 48	6262.19	257678
Spotted Elk	3 - 28	49	35 - 45	6211.52	257677
Crail Ranch	0 - 14	15	10 - 15	6193.28	281368
Birdhouse Well	2 - 15	17.7	7 - 17.7	6228.58	165685
Chapel Spring*	-	-	-	6195.31	255834

Fig. 3 Chapel Spring serves as a groundwater drain. Discharging pipe in dashed red circle connects to subdivision upgradient. Blue arrow represents flow direction. Grab samples taken at culvert. The drain is located at the eastern edge of the golf course (see Fig. 2). Photos were taken in 2019 (left) and 2022 (right) prior to the W. Fork Wetland Enhancement Project.

2.2. Static Water Level Measurement: Sample Collection

Groundwater samples were measured with a handheld groundwater levels electronic tape (Geotech, Denver, CO.) by GLWQD or MBMG personnel, or derived from continuous logger (Solinst Ltd., Canada). Prior to sample collection, a calibrated handheld YSI meter was configured with a flow- through cell to measure groundwater physicochemical conditions, including temperature, pH, dissolved oxygen (DO) concentration and saturation, and specific conductivity (SC) was sampled. Well water was collected after three well volumes were purged and to ensure that 'formation water' was sampled, well water was collected after three well volumes were purged; field parameters were recorded after values reached relative stabilization.

Groundwater was purged using a decontaminated submersible pump (Geosub 2, Geotech, Denver, CO.) or dedicated Teflon™ bailers. If well water was pumped, water quality parameters were measured using the flow-through cell configuration. If well water was bailed, water quality parameters were measured with the a handheld meter (YSI Incorporated, Yellow Springs, OH)+ placed in a 5-gallon bucket while bailer was emptied into the bucket. Samples were collected in triple rinsed, lab-grade containers supplied by Energy Laboratories, Inc. (Billings, Montana). Following collection, samples were placed on ice, shipped to the lab, and analyzed following standard methods (APHA, 2022).

2.3. Water Quality Parameters Measured

Water temperature can be indicative of the chemical and biological processes taking place within a body of water, especially with respect to dissolved oxygen. Many other water quality indicators are directly influenced by temperature.

The potential of hydrogen, or pH, is the activity of hydrogen ions in solution. Average groundwater systems fall between a pH of 6 and 8.5. pH determines the solubility and bioavailability of the chemical constituents sampled in this study.

Dissolved oxygen (DO) is present in groundwater due to the direct contact with the atmosphere. In unconfined, shallow aquifers such as the MVA, we expect groundwater to contain more DO. Dissolved oxygen influences many chemical and biological processes and can have a significant influence on groundwater quality. The amount of oxygen in a system controls redox potential which like pH, influence to the solubility and bioavailability of many elements. The concentration of DO is reported in *mg/L* and percent saturation. Percent saturation is calculated as the percentage of DO concentration relative to complete saturation at the groundwater temperature of that measured at the sample depth.

Specific Conductivity (SC) measures the groundwater's ability to conduct electricity based on the presence of ions. Higher values of specific conductivity indicate higher ionic concentrations which can be interpreted as more dissolved solids in solution. Typical values in natural groundwater in Gallatin County range from 200 to 500 $\mu S/cm$ (GLWQD, unpublished data).

Nitrate (nitrate + nitrite as NO_3-N) is a common form of plant-available dissolved inorganic nitrogen that is taken up by biota, including algae. It is the predominant form of nitrogen on the landscape. Sources of nitrate may include atmospheric deposition, naturally occurring soil organic matter, fertilizer, livestock waste and wastewater. Under the Safe Drinking Water Act the US Environmental Protection Agency (EPA) has established the maximum concentration level (MCL) for public drinking water supplies of 10 *mg/L* nitrate. At nitrate concentrations above the 10 *mg/L* MCL there is a risk of methemoglobinemia (aka blue-baby syndrome) for infants.

Orthophosphate, or soluble reactive phosphorus (SRP), is the predominant form of dissolved inorganic plant-available phosphorus that is taken up by biota. Low concentration can be associated with local lithology and soils. Anthropogenic sources of phosphorus may include phosphorus fertilizers, industrial wastes, sewage, and detergents.

Chloride (Cl^-) is a naturally occurring ionic form of inorganic chlorine. It commonly occurs in low concentrations in pristine watersheds (< 20 parts per million, or *mg/L*). It is not a plant nutrient but can be used as a wastewater indicator and when found in high concentrations may suggest human impact on water resources. In our work, we use it as a "conservative tracer", a chemical marker non affected by biota and used to identify contamination. Potential sources of chloride in watersheds may include dissolution of evaporite and marine shale deposits, thermal and mineral springs in volcanic areas, water softeners, domestic sewage, and road salt.

Static Water Level (SWL), is the elevation of the water table above the sea level. It can be acquired by subtracting a depth to water table measurement from the ground surface elevation. Groundwater level data in this report is displayed in feet below ground surface (bgs). Level data was collected by MBMG staff using continuous levelloggers (Solinst, Canada) and downloaded from the GWIC database.

2.4. Data Analysis

The GLWQD compiled all sampling data during for the period of 2018 to 2023. Statistical data analysis was specific to $NO_3\text{-}N$ and Cl^-. This dataset includes 177 paired observations of nitrate and chloride and 79 observations of SRP. Analysis of the dataset included generating descriptive statistics (e.g., means, ranges), characterize and assess groundwater quality in the

MVA. Standard error of the means (SEM) were calculated ($\sigma/\sqrt{n}$, σ is the standard deviation) to show variation about the mean. To illustrate spatiotemporal variation of solutes, concentrations of common wastewater indicators nitrate and chloride were plotted against time, and the association between these analytes were assessed using Spearman Correlation analysis. Due to the non-normal distribution of the data, the nonparametric Mann-Whitney U Test (Rank Sum Test) was used to compare concentrations in 2022 and 2023 to those observed in 2018.

3.0 Results

3.1. Whole Dataset Overview

Fig. 4 shows the distribution of all paired observations of *N* and Cl^- (n =177) and P (n = 79). The nitrate frequency histogram (Fig. 4a) shows a bimodal distribution with nearly 50% of observed values above 2.1 *mg/L*. For all observations, nitrate concentrations ranged from 0.03 to 10.40 *mg/L* with the most frequently observed values below 0.6 *mg/L*. Chloride concentrations ranged from 2 to 129 *mg/L* (Fig. 4b). Roughly 65% of samples are above 20 *mg/L* but most chloride observations fall within the lower ranges. SRP values (Fig. 4c) ranged from below detection to 0.032 *mg/L*. More 50% of observed SRP values are non-detections or slightly above the reporting limit (RL) of 0.005 *mg/L*.

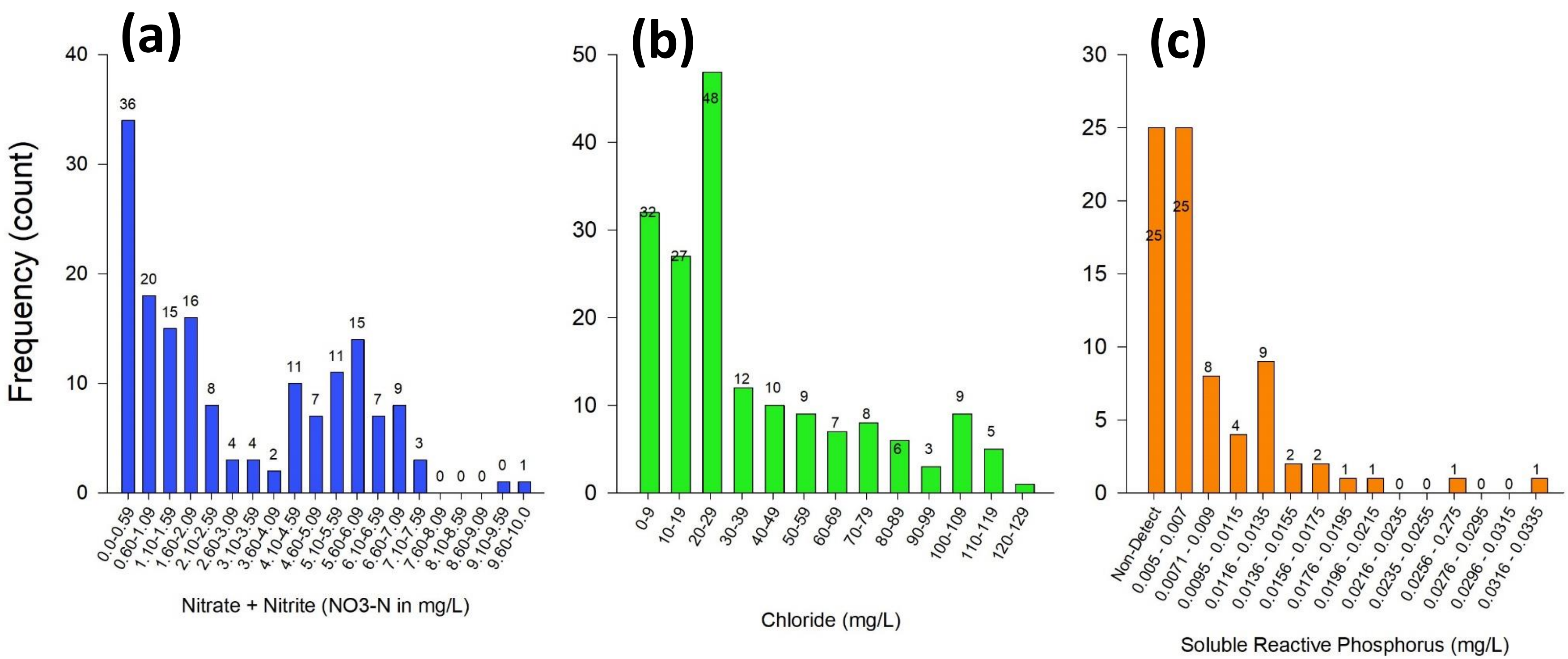

Fig. 4 Frequency histogram displays distributions of concentrations for **a)** Nitrate + Nitrite (*NO_3-N* in *mg/L*), **b)** Chloride (*mg/L*), and **c)** Soluble Reactive Phosphorus (*mg/L*). Data shown are all observations from 2018 to 2023.

Table 2. Field measured water quality/purge parameters for MVA monitoring sites. Data shows means ± standard error of the means. All site means determined by averaging all data from all sites and dates.

Site	Temperature (°C)	pH	Dissolved Oxygen (*mg/L*)	Dissolved Oxygen (% saturation)	Specific Conductivity (µS/cm)
Hidden Village #1	6.38 ± 0.11	7.76 ± 0.08	5.74 ± 0.58	54.19 ± 4.48	350.15 ± 12.19
Firelight*	6.79 ± 0.59	7.13 ± 0.05	3.38 ± 0.65	29.46 ± 5.99	491.73 ± 18.70
Two Moons*	7.98 ± 0.25	7.37 ± 0.05	8.44 ± 0.15	78.51 ± 2.34	716.89 ± 13.89
Golf Shop Shallow	6.66 ± 0.94	7.52 ± 0.09	7.05 ± 0.51	59.74 ± 3.43	234.84 ± 12.28
Golf Shop Deep*	6.73 ± 0.19	7.46 ± 0.05	5.69 ± 0.17	52.17 ± 1.48	478.07 ± 10.01
Spotted Elk*	7.03 ± 0.14	7.38 ± 0.05	7.15 ± 0.16	65.94 ± 1.61	547.61 ± 12.78
Crail Ranch	6.52 ± 0.43	7.37 ± 0.03	5.24 ± 0.27	46.46 ± 2.34	516.41 ± 4.91
Birdhouse Well	6.67 ± 0.54	7.23 ± 0.04	6.79 ± 0.48	63.46 ± 4.49	985.43 ± 20.32
Chapel Spring	7.34 ± 0.57	7.30 ± 0.06	8.14 ± 0.33	75.00 ± 2.91	764.95 ± 7.33
All Sites	**6.96 ± 0.16**	**7.39 ± 0.02**	**6.63 ± 0.16**	**60.51 ± 1.46**	**588.92 ± 15.62**

*Parameters measured with flow-through cell configuration.

The results of field measured water quality parameter measurements in the MVA study area are summarized in Table 2.

For across all observations, the temperature ranged from 0.4 to 12.1 °C (mean = 6.96 ± 0.16°C). The lowest temperature was observed at the Golf Shop Shallow site, while the highest was observed at the Chapel Spring site. Groundwater pH ranged from 6.4 to 8.4 (mean = 7.39 ± 0.02). The lowest pH was observed at the Chapel Spring site, while the highest was observed at both Golf Shop Shallow and the Hidden Village #1 sites. For all observations, the DO concentrations ranged from 0.89 to 14.55 *mg/L* (mean = 6.63 ± 0.16 *mg/L*). The lowest DO concentration was observed at the Firelight site, while the highest was observed at the Chapel Spring site. Similarly, the DO percent saturation ranged from 7.10% to 117.50% (mean = 60.51 ± 1.46%). The lowest DO % Saturation was observed at the Firelight site, while the highest was observed at the Chapel Spring site. Across all observations, the SC values ranged from 156.80 to 1320 µS/cm (mean = 588.92 ± 15.62 µS/cm). The lowest conductivity was observed at the Golf Shop Shallow site.

3.2. Site-Specific Analysis

3.2.1. Wastewater Indicators

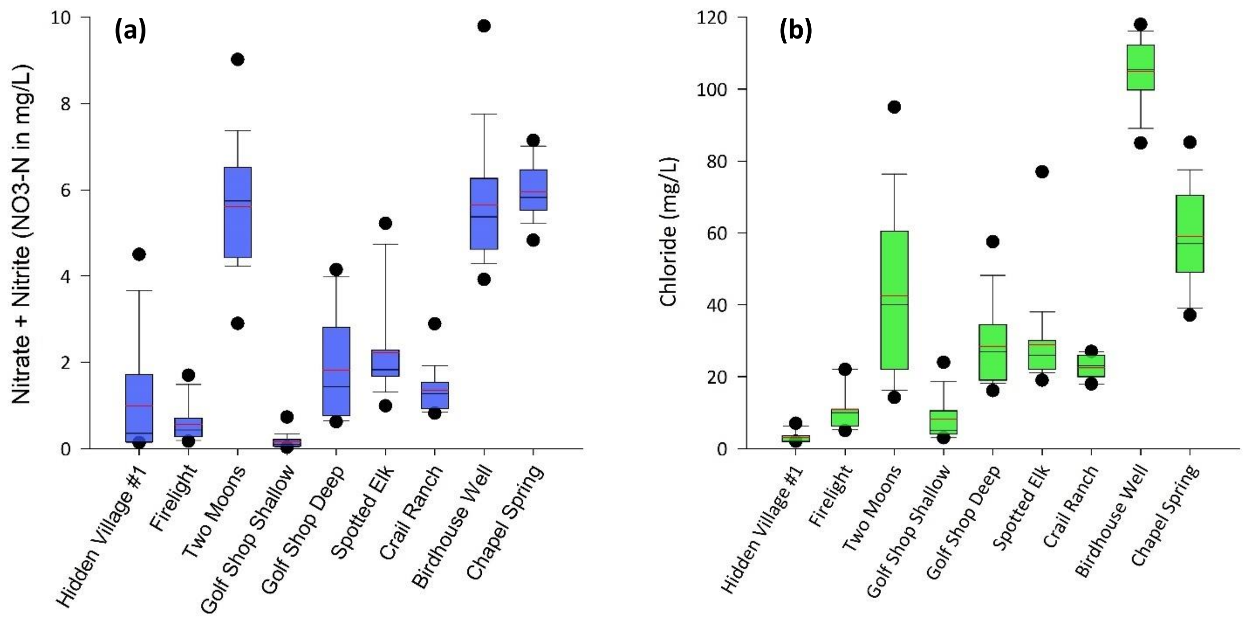

Fig. 5 Box plots showing site-specific **a)** Nitrate + Nitrite (*NO_3-N* in *mg/L*) and **b)** Chloride (*mg/L*) data for all observations. Box plot symbols show medians (black line), means (red line), and 5th/95th percentile outliers as black circles.

Box plots for each site elucidate the spatial patterns of nitrate and chloride (Fig. 5).

There are three sites (Two Moons, Birdhouse Well, and Chapel Spring) displaying the highest concentrations of nitrate and chloride in the study. These are denoted as high-level sites and have averages approximately 6 *mg/L* nitrate and approximately 70 *mg/L* chloride. The remaining sites are denoted as low-level sites with average concentrations nearing 1.5 *mg/L* nitrate and 20 *mg/L* chloride. Nonetheless, Hidden Village #1 exhibits significant seasonal variation. Specifically, the concentration levels during the snowmelt pulse period are approximately tenfold higher than those observed under static conditions (Fig. 6). Two Moons displays the greatest range of chloride (14 - 97 *mg/L*) and Birdhouse Well has the greatest values of chloride (85 - 118 *mg/L*). Minimal nitrate concentrations are associated with Golf Shop Shallow (0.03 *mg/L*) while Hidden Village #1 shows minimal chloride values (2 *mg/L*).

Site-specific nitrate and chloride relationships (Spearman Correlations) are shown in Table 3. Golf Shop Deep displays a very strong (r = 0.88) and statistically significant ($p < 0.05$) association between N and Cl^-. Hidden Village #1, Firelight, and Spotted Elk also show strong and statistically significant associations. Birdhouse Well and Chapel Spring show a negative, statistically insignificant, and weak association between variables.

Table 3. Spearman Correlation results of nitrate concentrations versus chloride concentrations for each site. Data shown are correlation coefficients (*r*), p-values (*p*), and number of observations (*n*) for all monitoring sites.

Site name / **Statistical Indicator**	Hidden Village #1	Firelight	Two Moons	Golf Shop Shallow	Golf Shop Deep	Spotted Elk	Crail Ranch	Birdhouse Well	Chapel Spring
Correlation Coefficients (*r*)	0.71*	0.77*	0.25	0.37	0.88*	0.7*	0.3	-0.24	-0.13
P-Value (*p*) < 0.05?	Y	Y	N	N	Y	Y	N	N	N
Number of Observations (*n*)	13	12	21	18	20	19	19	18	21

*Indicates strong to very strong correlations ($r > 0.6$)

Nitrate and chloride concentrations vary through time; however, seasonal highs and lows differ between sites. Two Moons chloride concentrations dip during the winter and early spring and rebound during early summer months (Fig. 7c). Hidden Village #1 peak nitrate values occur during June and July. At Firelight (Fig. 7b) and Golf Shop Deep (Fig. 7e) nitrate and chloride simultaneously rise and fall while the three high level sites (Fig. 7c, h and i) show different

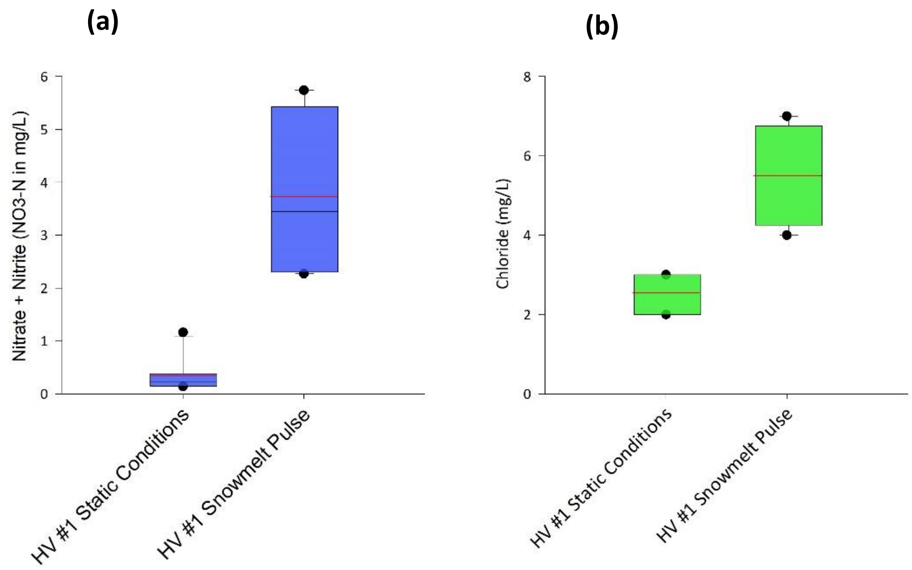

Fig. 6 Box plots showing Hidden Village #1 **a)** Nitrate + Nitrite (*NO_3-N* in *mg/L*) and **b)** Chloride (*mg/L*) data in snowmelt pulse period and static conditions. Box plot symbols show medians (black line), means (red line), and 5th/95th percentile outliers as black circles.

timing of peak concentrations and more variability compared to other sites. Conversely, Golf Shop Shallow summer and winter values of nitrate are relatively invariant.

Spearman correlation analysis using SWL and wastewater indicators (*N* and Cl^-) highlight strong relationships at specific sites. The groundwater altitude and chloride concentrations at Two Moons display a positive and statistically significant relationship (Table 4). This relationship is apparent in Fig. 7c. Although not as strong (r = 0.54), groundwater altitude and chloride concentrations display a statistically significant relationship at Golf Shop Deep.

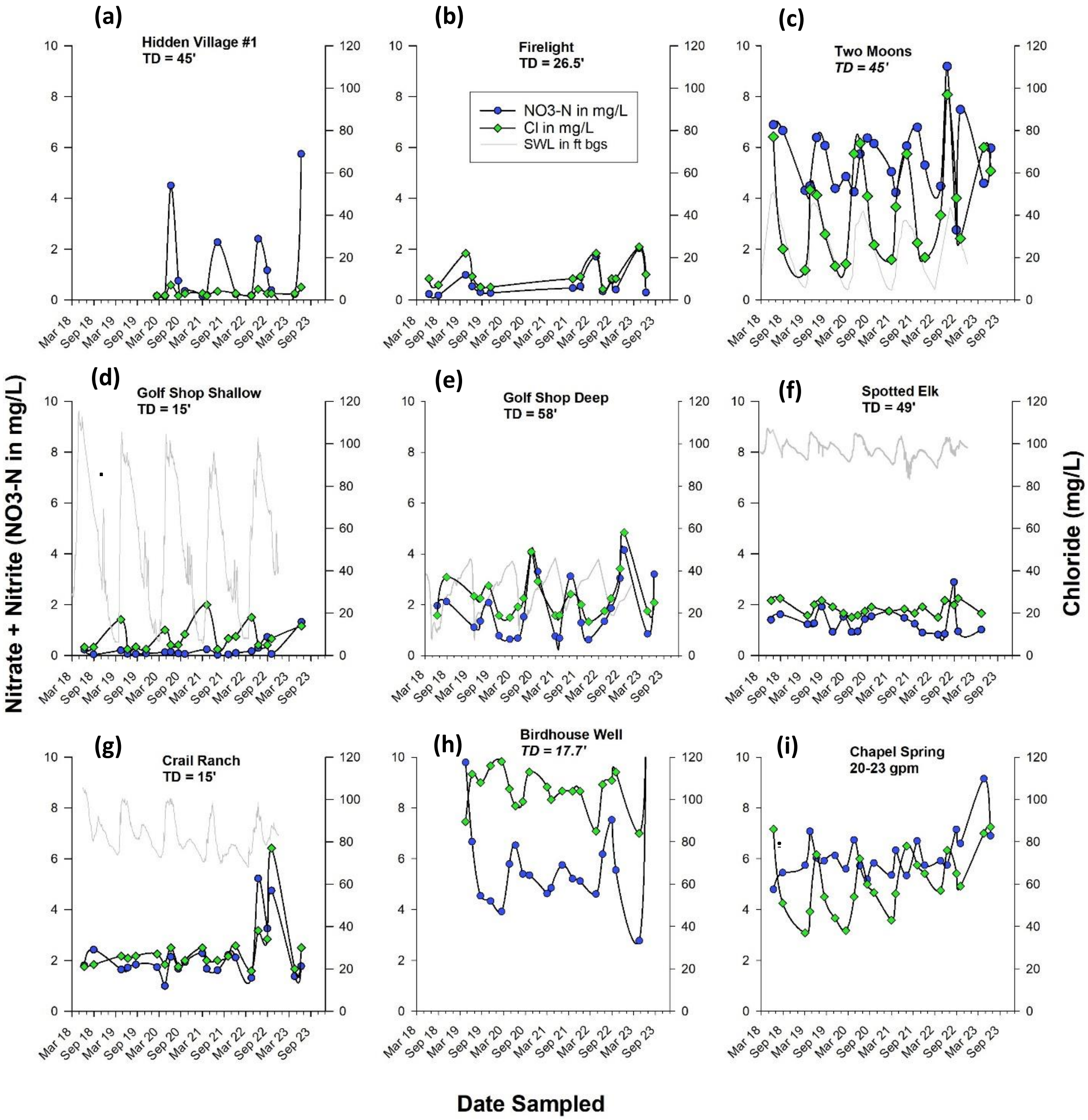

Fig. 7 Line plot displaying Nitrate (blue circles) and Chloride (green diamonds) concentrations from 2018 through 2023 at each site. Figs. **c – g** show continuous water level data in feet below ground surface. Water levels are scaled from total depth (TD) to ground surface (Note: No y-axis for water level data).

Table 4. Spearman Correlation results of groundwater altitude versus nitrate and chloride concentrations. Data shown are correlation coefficients (*r*), p-values (*p*), and number of samples (*n*) for all monitoring wells.

Statistical Indicator	**Site name**							
	Hidden Village #1	Firelight	Two Moons	Golf Shop Shallow	Golf Shop Deep	Spotted Elk	Crail Ranch	Birdhouse Well
Groundwater Elevation versus Nitrate (NO_3)								
Correlation Coefficients (*r*)	*0.60	0.17	*0.52	0.3	*0.60	0.21	-0.32	0.38
P-Value (*p*) < 0.05?	Y	N	Y	N	Y	N	N	N
Number of Observations (*n*)	13	12	21	18	20	19	19	18
Groundwater Elevation versus Chloride (Cl^-)								
Correlation Coefficients (*r*)	0.35	0.1	†0.8	-0.43	*0.54	0.16	0.31	-0.33
P-Value (*p*) < 0.05?	N	N	Y	N	Y	N	N	N
Number of Observations (*n*)	13	12	21	18	20	19	19	18

†Indicates very strong correlation (*r* >= 0.80)

*Indicates moderate to strong correlation (0.5 to 0.79)

3.2.2. Orthophosphate (SRP) and Inorganics

Orthophosphate was measured at each sampling event at the start of the project (2018 and 2019) and again in June and August of 2022. The highest mean soluble reactive phosphorus (SRP) concentrations (data not shown) were found in three near-stream, shallow wells: Firelight, Golf Shop Shallow, and Crail Ranch (see Fig. 1). The maximum SRP concentration (0.032 *mg/L*) was observed in the Golf Shop Shallow well in November of 2019. The maximum values at Crail Ranch (0.02 *mg/L*) and Firelight (0.015 *mg/L*) were detected in June 2019. Of the sites located away from stream environments, Birdhouse Well has the highest mean SRP (data not shown).

Select inorganic analytes including major ions and trace metals were sampled for in June and August of 2018 and 2022. Major ion chemistry is presented in Table A-1 (Appendix A). With the exception of magnesium, maximum concentrations of all major ions were from the Birdhouse Well. For all observations (n = 34), calcium concentrations ranged from 28 to 150 *mg/L* (mean = 83.1 ± 5.7 *mg/L*). The lowest calcium concentration was observed at the Golf Shop Shallow site, while the highest was observed at the Birdhouse Well site. For all observations, magnesium concentrations ranged from 6 to 33 *mg/L* (mean = 18.3 ± 1.3 *mg/L*). The lowest magnesium concentration was observed at the Golf Shop Shallow site, while the highest was observed at the Two Moons site. For all observations, sodium concentrations ranged from 3 to 40 *mg/L* (mean = 17.9 ± 1.7 *mg/L*). The lowest sodium concentration was observed at Hidden Village #1, while the highest was observed at the Birdhouse Well site. Overall, the dominant positive charge is from calcium while the dominant negative charge is from bicarbonate.

3.3. Whole Dataset Analysis

177 paired observations of nitrate and chloride collected between 2018 – 2023 suggest a moderately strong, statistically significant correlation (Fig. 8, $r = 0.82$; $p < 0.05$). The Spearman Correlation between nitrate and chloride show a tight association when values of chloride are low (2-30 *mg/L*), but this relationship weakens as chloride concentrations increase (Fig. 8). A linear regression shows 56% of nitrate variation can be explained by chloride concentration (data not shown).

3.3.1. Temporal Variations in Wastewater Indicators

Fig. 9 presents the quarterly fluctuations in Nitrate + Nitrite and Chloride concentrations from the second quarter of 2018 through the second quarter of 2023 (excludes the first quarter of 2018 and the third and fourth quarters of 2023 due to unavailability of data). Figs. a – d correspond to the Nitrate + Nitrite (NO_3-N in *mg/L*) concentrations in the first through fourth quarters, respectively, while Figs. e – h correspond to the Chloride (*mg/L*) concentrations in the first through fourth quarters, respectively. The mean and median concentrations of Nitrate (N) and Chloride (Cl^-) between 2018 and 2022 does not reveal significant changes, indicating stable solute levels over the observed period. However, relying solely on mean and median data to assess changes in concentration levels may not provide a comprehensive understanding. A more robust statistical method is necessary to accurately evaluate the significance of these changes. In this context, we have utilized the non-parametric Mann-Whitney U Test, which is better suited for analyzing the significance level of changes in our dataset, particularly given its non-normal distribution (see Fig. 4).

3.3.2. Evaluating the Statistical Significance of Changes from 2018 to 2022

The Mann-Whitney test offers a method for comparing two groups by avoiding the presumption of a specific distribution pattern. This approach is particularly applicable under circumstances where the data may not follow a normal distribution, in cases of small sample sizes, or when dealing with variances that are not homogenous (Leon, 1998). The results of the Mann-Whitney test are detailed in Appendix B, Tables B-1 and B-2. The results indicate that for both nitrogen (N) and chloride (Cl^-), the significance level is below 5%. This suggests that there is no significant difference in the distribution between the datasets from 2018 and those from 2022.

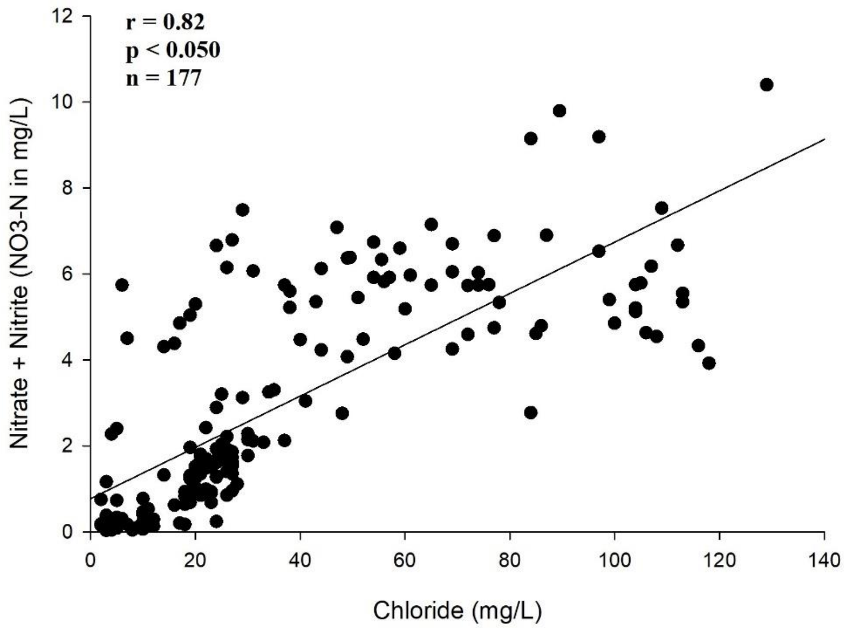

Fig. 8 Whole dataset correlation plot shows positive ($r = 0.82$) and statistically significant ($p < 0.05$) relationship between chloride and nitrate concentrations.

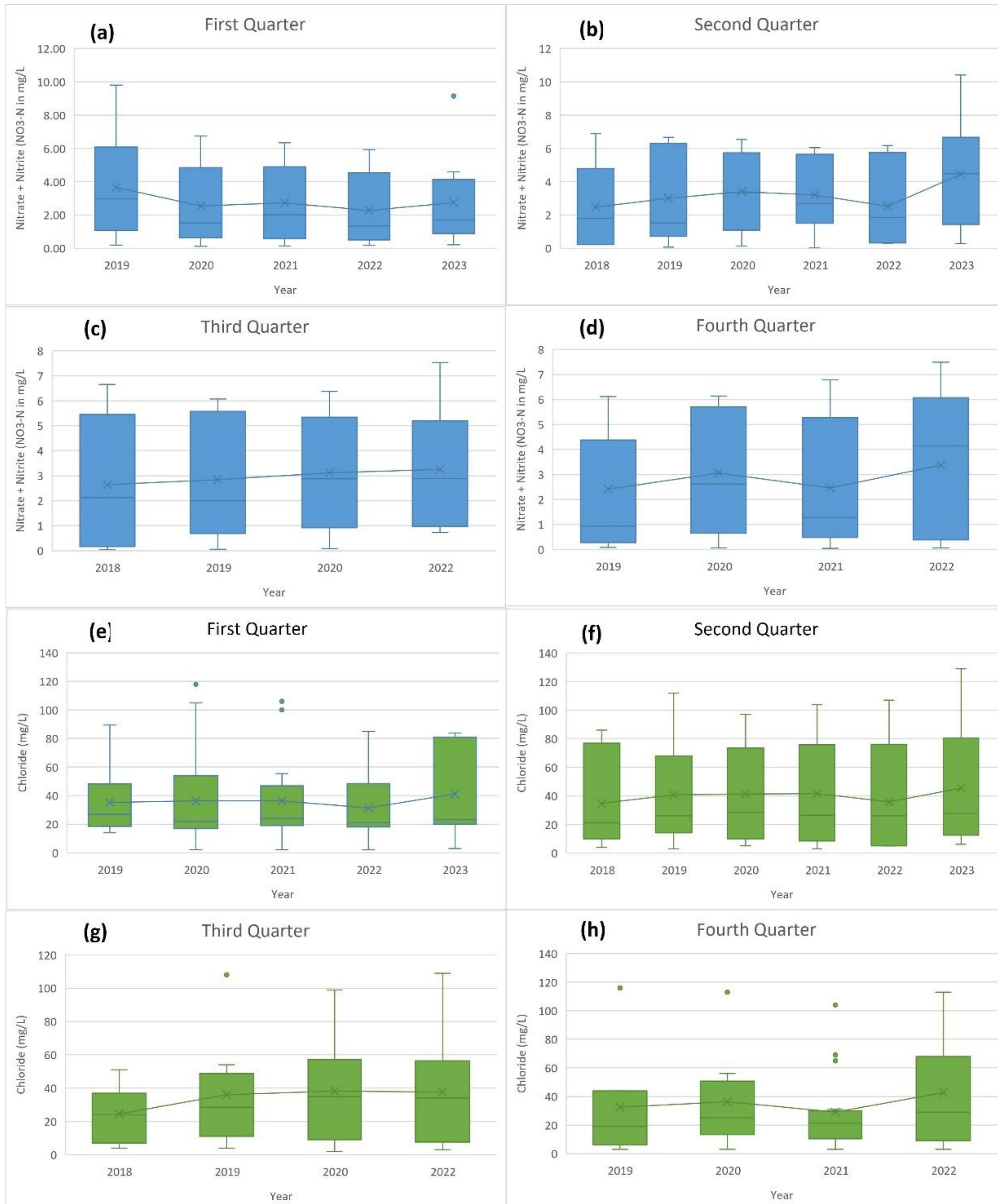

Fig. 9 Box plots illustrate the quarterly variation in concentrations from 2018 to 2023 for **a – d)** Nitrate + Nitrite (*NO_3-N* in *mg/L*) and **e – h)** Chloride (*mg/L*). Figs. a to d correspond to the first through fourth quarters, respectively, for Nitrate + Nitrite concentrations, while Figs. e – h correspond to the first through fourth quarters, respectively, for Chloride concentrations. The markers "X" indicate mean values; lines connecting these markers represent the mean trend across each quarter. The solid line within each box denotes the median value, and dots illustrate outliers at the 5th/95th percentiles.

3.3.3. Evaluating the Statistical Significance of Changes from 2022 to 2023

The initial purpose of this report focused on assessing the changes in wastewater indicators between 2018 and 2022. As the project progressed, additional data from the first two quarters of 2023 became available, prompting a subsequent analysis. Utilizing the Mann-Whitney test, we examined whether there were significant changes in wastewater indicators during the early half of 2023. The results presented in Appendix B, Tables B-3 and B-4, reveal that the significance levels for both nitrogen (*N*) and chloride (Cl^-) still remain below 5%. This result suggests that there were no significant changes in wastewater indicators during the first two quarters of 2023.

3.3.4. Comparison with Reference Conditions

Paired observations ($n = 44$) of nitrate and chloride from six monitoring wells were used for comparison. These "reference" sites are drilled within a relatively unimpacted area of similar geologic formation per MBMG map (study area and reference wells drilled into Qgr (MBMG)) to the MVA (Fig. 10), and well water samples were collected by MBMG staff during the summer months of 2020 and 2021.

Results are tabulated in Table 5. Nitrate values at the reference sites are often non-detectable, the highest detection being 1.43 *mg/L* at the UG 6 site. Treating non-detects as half the reporting limit (0.005 *mg/L*), the mean nitrate value for all reference site samples (n = 44) is 0.37 ± 0.07 *mg/L*, whereas the MVA high-level sites have a mean nitrate concentration of 5.83 ± 0.26 *mg/L*, low-level sites mean is 1.33 ± 0.21 *mg/L*. The reference area has a mean chloride concentration of 8.83 ± 1.22 *mg/L* compared to mean chloride concentrations of high-level study sites, of 67.63 ± 3.13 *mg/L* and low-level study sites, 18.70 ± 1.56 *mg/L*.

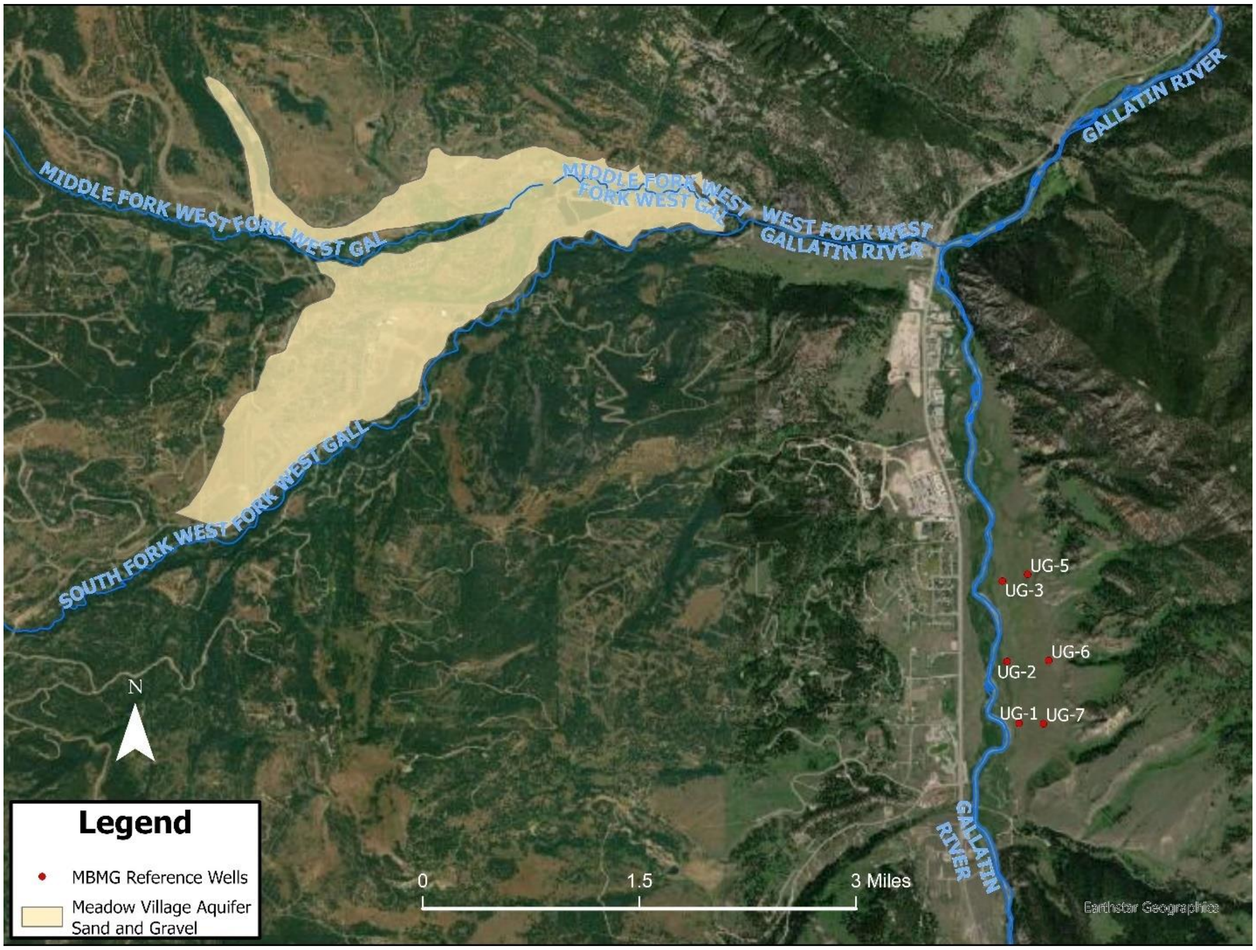

Fig. 10 ESRI® aerial imagery showing location of six reference wells relative to the Meadow Village aquifer.

Table 5. Summary of Nitrate and Chloride concentrations at each Meadow Village study site and each reference area site, and comparing data across sites. Data shown are number of samples (*n*), minimum, maximum, and mean plus or minus the standard error of the mean (SEM). Non-detections (ND) treated as half the reporting limit (0.005 *mg/L*) in statistical analysis. Study site nitrate reported as nitrate + nitrite as *N* and reference site nitrate reported as nitrate as *N*.

				NO_3-N in mg/L			**Cl^- in mg/L**		
	GWIC ID	**Name**	***n***	**Min**	**Max**	**Mean ± SEM**	**Min**	**Max**	**Mean ± SEM**
High-Level Sites	281359	Two Moons	23	2.75	9.19	5.56 ± 0.27	14	97	43.52 ± 4.61
	165685	Birdhouse Well	20	2.77	10.4	5.93 ± 0.40	84	129	104.41 ± 2.28
	255834	Chapel Spring	23	4.79	9.15	6.02 ± 0.14	37	87	59.75 ± 2.52
Low-Level Sites	103499	Hidden Village #1	15	0.14	5.74	1.25 ± 0.44	2	7	3.33 ± 0.38
	185435	Firelight	14	0.17	2.03	0.64 ± 0.15	5.00	25.00	11.93 ± 1.65
	281362	Golf Shop Shallow	19	0.03	1.32	0.21 ± 0.07	3.00	24.00	8.47 ± 1.34
	257678	Golf Shop Deep	22	0.62	4.15	1.73 ± 0.20	16.00	58.00	27.19 ± 1.93
	257677	Spotted Elk	21	0.99	7.89	2.44 ± 0.30	19.00	77.00	31.08 ± 3.02
	281368	Crail Ranch	20	0.82	2.89	1.33 ± 0.11	18.00	27.00	22.35 ± 0.65
		All Study Sites	**177**	**0.03**	**10.4**	**3.16 ± 0.18**	**2**	**129**	**38.39 ± 2.25**
Reference Sites	308526	FWP-UG 1	*8*	ND	ND	ND	1.62	1.86	1.72 ± 0.03
	308527	FWP-UG 2	*8*	ND	ND	ND	1.86	2.04	1.95 ± 0.02
	308528	FWP-UG 3	*8*	ND	ND	ND	2.82	3.22	2.98 ± 0.04
	308532	FWP-UG 5	*8*	0.44	0.71	0.61 ± 0.03	15.07	18.32	16.72 ± 0.41
	308545	FWP-UG 6	*8*	1.12	1.43	1.27 ± 0.03	20.82	22.71	21.48 ± 0.31
	308558	FWP-UG 7	*4*	ND	0.38	0.29 ± 0.04	6.26	8.19	7.47 ± 0.43
		All Reference Sites	***44***	**ND**	**1.43**	**0.37 ± 0.07**	**1.62**	**22.71**	**8.83 ± 1.22**

4.0 Discussion

In this study we monitored sites at a greater frequency than had been done in the past by collecting samples on a semi-routine basis for the same chemical constituents, providing detail into seasonal and annual changes in groundwater quality conditions. Overall, results of our work suggest that groundwater underlying the Meadow Village area is moderately affected by elevated levels of nitrate and chloride in some areas of the aquifer, and most likely linked to human activities on the landscape.

Our study presents the first long-term assessment of groundwater quality in the Big Sky area. While some studies have examined the aquifer chemical conditions, to date, no studies have examined seasonal and long-term changes in groundwater quality in the area. This study will provide a baseline dataset from which to compare future conditions. The main purpose of this study was to establish seasonal "snapshots" of groundwater quality conditions through time as local land use activities change in effort to assess impacts to water quality from these changes. The shallow groundwater below the Meadow Village is the principal source of drinking water in the Big Sky Community and is highly connected to local streams. Identification of impacted aquifer areas by analyzing the compiled chemical dataset will facilitate greater understanding of the scale of aquifer degradation, the potential contributing sources, and how aquifer water quality and contributing nutrient/indicator sources change over time.

4.1. High-Level Site Conditions

Among the nine monitoring sites we studied, three (Two Moons, Birdhouse Well, and Chapel Spring) showed elevated levels of specific conductivity (table 2), major ions (table A-1), nitrate, and chloride (table 5). We propose three potential activities or processes that may be influencing conditions at these sites.

Wastewater Sources – There are multiple potential sources of wastewater in the study area. Here we discuss how the application of treated effluent, community and private onsite wastewater treatment systems may likely contribute to overall water quality observed at the three high-level sites. One major wastewater source in Meadow Village is the application of BSCWSD treated effluent to the golf course during the late spring and summer (DOWL HKM, 2012), a practice likely to have been occurring since the 1970s (Rose and Waren, 2022). According to the 2012 Nutrient Management Plan, about 108 pounds of nitrogen/acre/year can be applied to the golf course via reclaimed wastewater irrigation. The application of treated wastewater to the landscape can contaminate groundwater and negatively impacts soils (Mora et al., 2022). Shallow groundwater beneath a wastewater irrigated golf course in Spain was found to have increased calcium and magnesium content in addition to elevated nitrate concentrations (Candela et al., 2006). The Birdhouse Well and Chapel Spring sites are shallow, within the irrigated area of the golf course and have the highest observed concentrations of wastewater indicators, N and Cl^- (Fig. 5). Therefore, our data shows that the application of treated effluent is likely influencing groundwater quality at these sites.

Based on preliminary nitrogen isotope data it is likely that the nitrate in Hidden Village #1 well is sourced from septic system effluent and/or animal waste. Given the lack of septic systems in this area, and the presence of the horse corrals; at least some of the nitrate is likely sourced from this animal waste.

Another potential influence on groundwater quality is wastewater input from a community wastewater treatment system (Firelight Meadows Subdivision) associated with a major subdivision, located upgradient of the Two Moons site. It has been reported that this system exceeded the permitted nitrate discharge from 2016-2020 (Rose and Waren, 2022). Septic system failures are often linked to groundwater degradation and elevated concentrations of N, Cl^-, etc. (DeBorde et al., 1998; Drake and Bauder, 2005; Withers et al., 2013). The three high-level sites show similar quantities of wastewater indicators and values for physicochemical parameters as observed in other studies. Data in our study agree with those observation by Deborde et al. (1998) who examined potential impacts from nearby subsurface wastewater treatment systems on groundwater quality (Deborde et al., 1998).

Road Salt – High values of conductivity (Table 2) and solute concentrations (Table A-1) observed at the Two Moons and Birdhouse Well may be influenced by road salt application. The Montana Department of Transportation (MDOT) applies various preventative substances to roadways to reduce dangerous driving conditions. These chemicals lower the freezing temperature of water and consist of magnesium chloride ($MgCl_2$) or sodium chloride ($NaCl$), and have been found to increase salinity of groundwater near roadways (Cooper et al., 2014). In addition, impervious surfaces including roads, parking lots, and neighborhoods near the Chapel Spring site may contribute deicer and other surface contaminants from stormwater runoff. Due to the proximity and connectivity of these wells to streams, in addition to aquifer conditions, road salt has also been found to negatively influence surface water quality (Kaushal et al., 2005).

Influence of Geology – Within the study area, water-rock interactions may contribute dissolved constituents to the aquifer. Water-rock interaction can dissolve ionic solids causing higher concentrations of chloride and other ions like Na+ and Ca2+ (Berner and Berner, 1996). A portion of the Meadow Village Aquifer overlays the Upper Cretaceous Frontier Formation that is thought to contain an eroded shale layer (Rose and Waren, 2022) that may contribute higher concentrations of dissolved minerals than other formations.

In the MVA, the Two Moons well is completed at the aforementioned shale contact, and the Birdhouse Well is drilled within shale-derived detrital sediments. Other monitoring wells are drilled and screened just above the shale layer. This could explain the higher ionic concentrations seen at these sites (Table A-1, 5).

Within the study area, local lithologies are known to contribute dissolved *N* to streams. For example, Montross and others (2013) found that mineral dissolution of several lithologies in sub-watersheds of the Big Sky area are a source of stream water nitrogen. Therefore, similar lithology beneath the MVA may be contributing small amounts of nitrogen to groundwater given the process of mineral dissolution. However, their concentration is most likely negligible compared to those derived from human sources. The GLWQD is currently investigating sources of nitrogen through isotopic analysis and these results will be included in the next monitoring report.

4.2. Seasonal Variation

Nitrate and chloride concentrations vary seasonally, and this seasonal variation differs between monitoring sites. In this study we observed seasonal pulses of solutes that seemed to be associated with snowmelt pulse signatures at some sites. High concentrations of wastewater indicators were observed to coincide with peaks in well hydrographs (see Fig. 7c, e), influenced by spring recharge from snowmelt and rainfall. However, this pattern was not uniform across all sites, nor was it consistent for each solute. Seasonal variation of *N* and Cl^- between sites is likely due to various factors such as land-use activities, subsurface properties, and screen interval depth. The movement of water through the MVA can largely be attributed to recharge events (Waren et al., 2021), that govern much of the seasonal variation of dissolved constituents like nitrate and chloride.

Land use activities can also have impacts on the seasonal variation of solute concentrations. Site variation of *N* and Cl^- concentration may depend on spatial relationships to land use activities. Diffuse pollution through septic loading, fertilization, livestock waste, and wastewater disposal can accumulate over time in groundwater systems (Lerner and Harris, 2009; Lee et al., 2021). In their study in the Big Sky area, Gardner and McGlynn (2009) found stream nitrate concentrations to be two to three-fold higher in developed areas versus pristine areas. In addition to land use, site-specific *N* and Cl^- behavior is likely influenced by well screen depth (Table 1), groundwater altitude (Table 4), hydraulic conductivity, and gradient (Warren and Breitmeyer, 2021).

A Spearman Correlation of our data shows that chloride concentrations are not reliable predictors of nitrate concentrations. At low-level sites chloride concentrations were tightly correlated with nitrate concentrations, however the relationship between *N* and Cl^- at high-level sites are weakly associated. Determining the differing *N* and Cl^- correlation between sites is outside the scope of this study but may be attributed to disparate sources of nitrogen and nitrogenous processing within the study area. This may be due to differing sources of chloride other than wastewater, such as road salting.

4.3. Orthophosphate (SRP)

Our data show higher concentrations of SRP at shallow, near-stream sites compared to other study sites. One would expect this result given the local groundwater-surface water interactions, stream water chemical conditions. As mentioned above, the MVA is highly connected to the Middle Fork (MF) of the West Fork. Previous studies describe the stream recharging the aquifer as the MF reaches Meadow Village, but further downstream the MVA loses water to the MF (Waren and Breitmeyer, 2021). Data from GRTF in 2022 show SRP concentrations of the MF (above the golf course) to be of similar concentrations found in Golf Shop Shallow (GRTF, unpublished). However, results from Crail Ranch are greater than detected stream water levels. Favorable biogeochemical conditions that mobilize SRP such as low presence of iron and aluminum oxides, high concentrations of sulfate and silica, and/or low concentrations of dissolved oxygen (Tesoriero et al, 2009), may explain higher concentrations of SRP. It is likely that some of these conditions are influencing the observed SRP levels at Firelight (Table 2).

5.0 Conclusion

Big Sky's Meadow Village is experiencing rapid expansion to accommodate current residents, workers, tourists, and commerce. This growth and increased activity are occurring above the principal source of drinking water, the MVA. This aquifer has a very shallow depth to water and permeable soils, which make it very susceptible to contamination from surface sources, such as septic systems, waste water irrigation, animal manure, and fertilizer application. Comparison of nitrate and other nutrient concentrations in upgradient reference wells with wells in the MVA study area shows that human activities in the Meadow Village study area are significantly increasing nitrate and other nutrient concentrations in the MVA aquifer.

Concerns about degradation of the aquifer and its potential hydraulic connection to nearby stream health prompted creation of the Big Sky Nutrient Monitoring project in 2018. Water quality samples from eight wells and one spring were collected seasonally and analyzed following standard methods. The compiled 2018 – 2023 dataset was analyzed for spatiotemporal trends and patterns of nitrate-nitrogen, chloride, and soluble reactive phosphorous. Analysis included descriptive statistics, Spearman Correlations, and the nonparametric Mann-Whitney test. Spatial patterns highlight elevated nitrate and chloride at three sites near transportation infrastructure, domestic sewage discharge, and treated wastewater irrigation. Additionally, we suggest the underlying shale bedrock may be imparting some quantity of nitrogen and chloride to groundwater. Temporal analysis revealed seasonal variation of *N* and Cl^{-} that seems to be dictated largely by spring snowmelt and heavy rainfall. In general, as water levels rise there tends to be higher solute concentrations. However, observed seasonal variation seems to be site specific, likely influenced by various factors such as nearby land-use activities, subsurface properties, and well-screen depth. Overall, our results indicate a potential hydraulic connection between streams and the aquifer, and that the MVA experiences areas of moderate nitrate and chloride contamination, likely due to human land-use practices.

6.0 Recommendations and Future Work

As the Big Sky Nutrient Monitoring Project continues to evolve along with the development of the resort community, the LWQD Board of Directors and Gallatin County Commission should:

- Continue to sample the wells but only test for nitrate and chloride to reduce lab testing costs. Reduce the nutrient concentrations in the effluent from all new septic systems by requiring secondary treatment for all new systems. Where feasible all new developments should be sewered to reduce the number of new septic systems.
- Conduct a site-specific study of wastewater irrigation in the MVA area to determine how much nutrients in the wastewater are affecting groundwater; then modify the irrigation application rate to prevent groundwater contamination.
- Review relevant subdivision proposals, communications, and newsletters to stay apprised of developments that could potentially further degrade groundwater quality or improve wastewater treatment infrastructure. Generate informed comments on proposed

development that draw on technically-based findings from the GLWQD and the scientific literature.

- Manage the animal wastes near the Hidden Village #1 well to isolate them and prevent leaching nutrients to groundwater. Enhanced best management practices are recommended, such as lining the manure pit with an impermeable HDPE liner.

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Appendix A

Table A-1. Major ion concentration data for site-specific major ions sampled in June and August during 2018 and 2022

Site	Sample Date	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}
		mg/L						
Hidden Village #1	6/13/2022	58	13	4	2	223	8	5
	8/30/2022	55	13	3	2	231	7	3
Firelight	6/13/2018	67	13	32	3	311	11	10
	8/30/2018	59	11	26	3	270	17	7
	6/15/2022	40	8	17	2	185	9	5
	8/30/2022	58	12	26	3	277	22	10
Two Moons	6/13/2018	104	29	31	2	357	15	77
	8/30/2018	88	24	22	2	350	17	24
	6/14/2022	117	33	26	2	392	15	97
	8/29/2022	85	24	27	1	328	16	48
Golf Shop Shallow	6/13/2018	50	10	7	2	203	7	4
	8/29/2018	28	6	6	1	115	7	4
	6/15/2022	29	6	5	1	116	6	5
	8/29/2022	28	6	5	2	115	8	5
Golf Shop Deep	6/12/2018	68	15	9	2	250	9	19
	8/29/2018	73	16	13	3	259	11	37
	6/15/2022	66	15	10	2	234	13	27
	8/29/2022	72	16	12	3	251	14	41
Spotted Elk	6/12/2018	79	16	11	2	289	9	21
	8/30/2018	84	17	12	3	312	10	22
	6/14/2022	83	18	13	2	288	13	38
	8/30/2022	87	19	12	3	304	12	34
Crail Ranch	6/13/2018	81	17	14	2	284	14	26
	8/29/2018	81	17	15	2	299	15	27
	6/14/2022	79	16	15	1	291	19	26
	8/29/2022	70	14	13	2	279	15	24
Birdhouse Well	6/10/2019	143	29	36	3	394	34	112
	8/20/2019	141	29	29	4	397	28	108
	6/13/2022	150	31	40	3	434	26	107
	8/30/2022	148	32	31	4	445	22	109
Chapel Spring	6/13/2018	125	26	21	2	362	20	86
	8/29/2018	114	23	20	2	376	19	51
	6/13/2022	106	22	22	2	341	17	76
	8/30/2022	110	26	22	2	373	19	65

Appendix B

Table B-1. Mann Whitney Rank Sum process for nitrate concentrations of 2018 and 2022

2018's Data			2022's Data		
Sample Date	Concentration (mg/L)	Rank	Sample Date	Concentration (mg/L)	Rank
6/13/2018	0.23	3.5	6/15/2022	0.33	6
8/30/2018	0.17	2	8/30/2022	0.77	8
6/13/18	6.89	25	8/29/22	2.75	17
8/30/18	6.66	24	6/15/22	0.3	5
6/13/2018	0.23	3.5	8/29/2022	0.73	7
8/29/2018	0.04	1	6/15/2022	1.86	13
6/12/2018	1.96	14	8/29/2022	3.04	19
8/29/2018	2.12	15	8/30/2022	3.12	20
6/12/2018	1.8	12	6/14/2022	0.85	9
8/30/2018	2.42	16	8/29/2022	2.89	18
6/13/2018	1.4	10	6/13/2022	5.75	23
8/29/2018	1.62	11	8/30/2022	7.15	26
6/13/2018	4.79	21			
8/29/2018	5.45	22			
Sum of Ranks		180	Sum of Ranks		171

n_1	14	When $n_1 = 14$, $n_2 = 12$, U^* for 5% significance level is 45. Our calculated $U = 75 > U^*$, so it fails to reject the null hypothesis (H_0), indicating that there is not enough evidence to suggest a difference in the distributions.
n_2	12	
R_1	180	
R_2	171	
U_1	93	
U_2†	75	

†The obtained U value

.

Table B-2. Mann Whitney Rank Sum process for chloride concentrations of 2018 and 2022

2018's Data			2022's Data		
Sample Date	Concentration (mg/L)	Rank	Sample Date	Concentration (mg/L)	Rank
6/13/2018	10	7.5	6/15/2022	5	4
8/30/2018	7	6	8/30/2022	10	7.5
6/13/18	77	25	8/29/22	48	21
8/30/18	24	12.5	6/15/22	5	4
6/13/2018	4	1.5	8/29/2022	5	4
8/29/2018	4	1.5	6/15/2022	27	16.5
6/12/2018	19	9	8/29/2022	41	20
8/29/2018	37	19	8/30/2022	3.12	18
6/12/2018	21	10	6/14/2022	26	14.5
8/30/2018	22	11	8/29/2022	24	12.5
6/13/2018	26	14.5	6/13/2022	76	24
8/29/2018	27	16.5	8/30/2022	65	23
6/13/2018	86	26			
8/29/2018	51	22			
Sum of Ranks		182	Sum of Ranks		169

n_1	14
n_2	12
R_1	182
R_2	169
U_1	91
U_2†	77

When $n_1 = 14$, $n_2 = 12$, U^* for 5% significance level is 45. Our calculated $U = 77 > U^*$, so it fails to reject the null hypothesis (H_0), indicating that there is not enough evidence to suggest a difference in the distributions.

†The obtained U value

Table B-3. Mann Whitney Rank Sum process for nitrate concentrations of 2022 and 2023

2022's Data			2023's Data		
Sample Date	Concentration (mg/L)	Rank	Sample Date	Concentration (mg/L)	Rank
4/18/2022	0.17	1.5	4/17/2023	0.22	3
6/13/2022	2.4	19	6/12/2023	5.74	25
4/20/22	1.7	15	4/18/23	2.03	18
6/15/22	0.33	6	6/13/23	0.29	4
4/20/2022	4.47	22	4/17/2023	4.59	23
4/20/2022	0.17	1.5	6/15/2023	5.97	28
6/15/2022	0.3	5	6/13/2023	1.32	12
4/20/2022	1.345	13	4/18/2023	0.85	8.5
6/15/2022	1.86	17	6/13/2023	3.2	21
4/18/2022	1.31	11	4/17/2023	1.37	14
4/18/2022	0.82	7	6/12/2023	1.77	16
6/14/2022	0.85	8.5	4/17/2023	1.02	10
4/18/2022	4.61	24	4/18/2023	2.77	20
6/13/2022	6.18	29	6/13/2023	10.4	32
4/18/2022	5.92	27	4/18/2023	9.15	31
6/13/2022	5.75	26	6/13/2023	6.9	30
Sum of Ranks		232.5	Sum of Ranks		295.5
n_1	16	When n_1 = 16, n_2 = 16, U^* for 5% significance level is 75. Our calculated U = 96.5 > U^*, so it fails to reject the null hypothesis (H_0), indicating that there is not enough evidence to suggest a difference in the distributions.			
n_2	16				
R_1	232.5				
R_2	295.5				
U_1	159.5				
U_2†	96.5				

†The obtained U value

Table B-4. Mann Whitney Rank Sum process for chloride concentrations of 2022 and 2023

2022's Data			2023's Data		
Sample Date	Concentration (mg/L)	Rank	Sample Date	Concentration (mg/L)	Rank
4/18/2022	2	1	4/17/2023	3	2
6/13/2022	5	4	6/12/2023	6	6
4/20/22	22	16	4/18/23	25	17.5
6/15/22	5	4	6/13/23	12	7
4/20/2022	40	22	4/17/2023	72	25
4/20/2022	18	9.5	6/15/2023	61	24
6/15/2022	5	4	6/13/2023	14	8
4/20/2022	21	14.5	4/18/2023	21	14.5
6/15/2022	27	20	6/13/2023	25	17.5
4/18/2022	19	11	4/17/2023	20	12.5
4/18/2022	18	9.5	6/12/2023	30	21
6/14/2022	26	19	4/17/2023	20	12.5
4/18/2022	85	29	4/18/2023	84	27.5
6/13/2022	107	31	6/13/2023	129	32
4/18/2022	57	23	4/18/2023	84	27.5
6/13/2022	76	26	6/13/2023	87	30
Sum of Ranks		243.5	Sum of Ranks		284.5

n_1	16
n_2	16
R_1	243.5
R_2	284.5
U_1	148.5
U_2†	107.5

When $n_1 = 16$, $n_2 = 16$, U^* for 5% significance level is 75. Our calculated $U = 107.5 > U^*$, so it fails to reject the null hypothesis (H_0), indicating that there is not enough evidence to suggest a difference in the distributions.

†The obtained U value

Appendix C

List of Acronyms and Abbreviations Defined

APHA: American Public Health Association

BSCWSD: Big Sky County Water and Sewer District

bgs: Below Ground Surface

CDP: Census-designated place

DO: dissolved oxygen

EPA: Environmental Protection Agency

ft^3/s: cubic feet per second

GLWQD: Gallatin Local Water Quality District

GRTF: Gallatin River Task Force

GWIC: Groundwater Information Center @ MBMG

MBMG: Montana Bureau of Mines and Geology

µS/cm: microsiemens per centimeter

MCL = Maximum Contaminant Level

MF: Middle Fork of the W. Fork of the Gallatin

mg/L: milligrams per liter

MVA: Meadow Village Aquifer

NO_3-N: Nitrate-N; refers to Nitrate + Nitrite as Nitrogen

PVC = polyvinyl chloride

SC: Specific conductivity

SWL: Static Water Level

YSI: Xylem, Inc. brand of handheld meter