Groundwater Quality of the Raft River Basin

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Introduction

The Raft River Basin, located in southeastern Idaho, is a tributary basin to the eastern Snake River Plain. The primary uses of land are agriculture and rangeland. The area is home to multiple unique features including a geothermal plant and City of Rocks National Reserve. Groundwater is an important resource used locally for domestic and irrigation purposes. Declining groundwater levels in the aquifer led to the establishment of the Raft River Critical Ground Water Area in 1963. Investigations of water quality in the area are limited.

The Idaho Department of Water Resources (IDWR) was awarded a Supplemental Environmental Project (SEP) grant from the U.S. Department of Energy (DOE) to conduct the Raft River Basin Hydrogeologic Investigation Project. As part of this project, 11 monitoring wells were drilled, constructed, and outfitted with submersible pumps across the Raft River Basin in the spring of 2022 (McVay, 2024). Water samples were collected in November 2023 and in April 2024. Samples were analyzed for major ions, metals, nutrients, pesticides, stable isotopes, radiochemistry, and per- and polyfluoroalkyl substances (PFAS).

Study Area

The Raft River Basin is located at the southern border of Idaho and has its headwaters in Utah (Figure 1). The basin covers 967,150 total acres, of which 788,881 acres are located within Idaho. Rangeland, shrubland, and forests account for the majority of land use, at 73 percent. Sixteen percent is grass, pasture, or hayland. Eleven percent is cropland, and the remainder is water, wetlands, or barren (NRCS, 2008). Few perennial streams exist, as most flow is ephemeral or intermittent. The most prominent hydrologic features include the Raft River, Cassia Creek, and Sublett Creek.

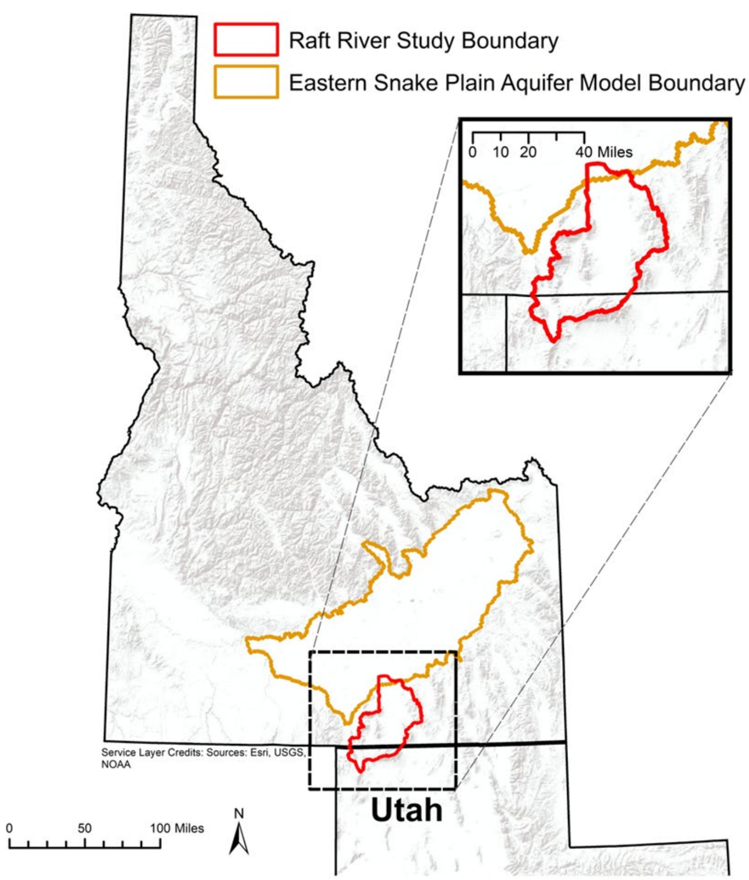

Figure 1: Overview of study boundary.

Monitoring wells drilled utilizing SEP funding are located throughout the basin. Locations and depths were determined by geologists and hydrogeologists from Idaho Geological Survey (IGS) and IDWR to provide lithologic information for the hydrogeologic investigation project and to provide dedicated water level and water quality monitoring locations in areas with little groundwater information (Figure 2).

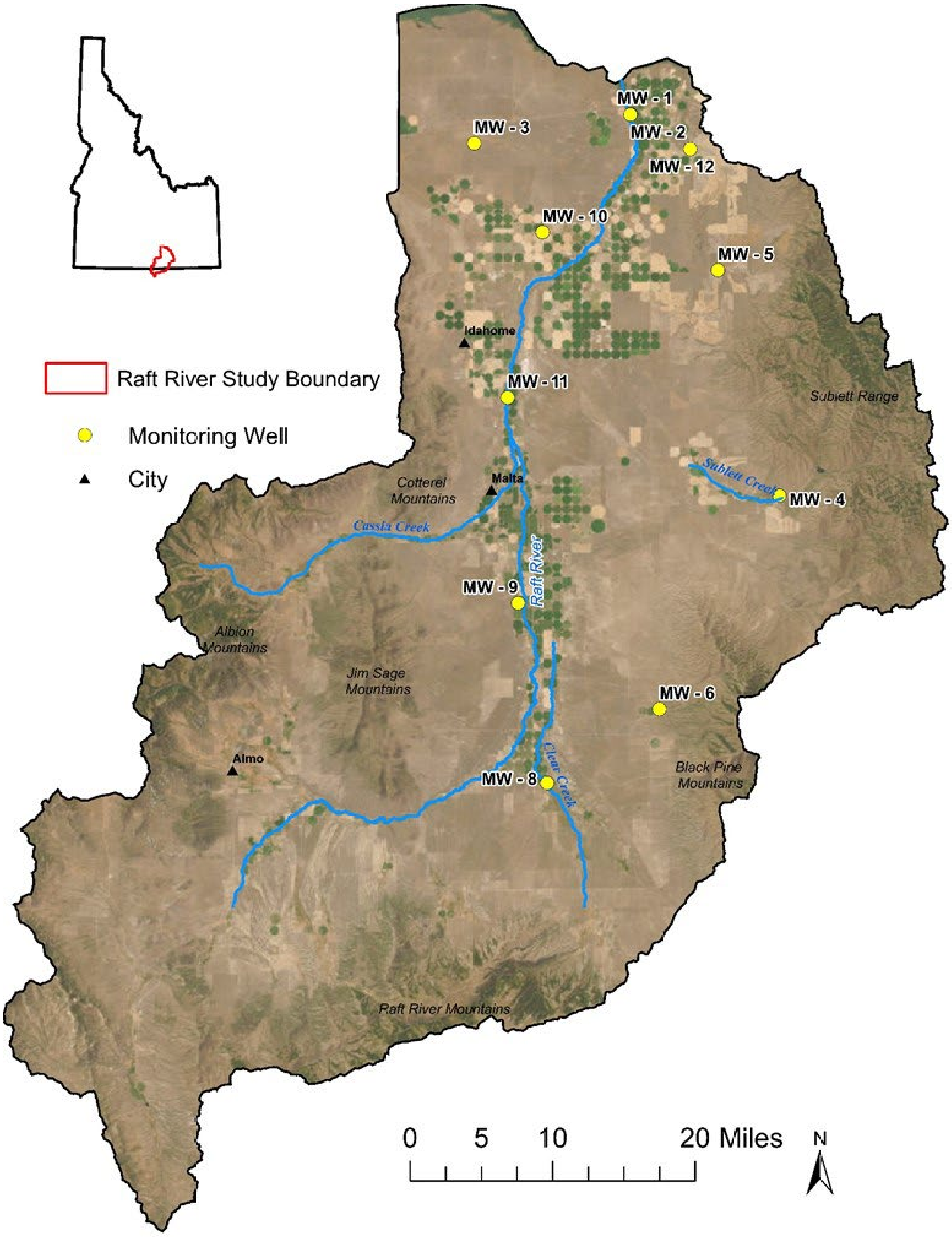

Figure 2: Locations of monitoring wells drilled in the Raft River Basin where water quality samples were collected.

Basin Characterization

One of the main goals of the Raft River Basin Hydrogeologic Investigation Project is to develop a hydrogeologic framework for the basin. The following descriptions summarize findings developed as part of that project. More detailed descriptions of the basin hydrogeology can be found in the final project report (Clark, 2024).

Geology

Basin development has spanned Pre-Cambrian to recent times. Mountain ranges, reflecting different tectonic histories, complex folding and faulting, and variable geologic conditions, form the eastern, southern, and western boundaries of the Raft River Basin (Figure 2). Sedimentary deposits of limestone and sandstone, metamorphosed in places, comprise the Sublett Range and Black Pine Mountains on the eastern side of the basin (Smith, 1983). Metamorphic core complexes form the Raft River Mountains in the southern part of the basin (Hintze and others, 2000). Granitic intrusions and metamorphic rocks comprise the Albion Mountains along the western side of the basin (Armstrong, 1968). The Jim Sage and Cotterel mountains in the central and northern parts of the basin are comprised of rhyolite flows of the Salt Lake Formation (Williams and others, 1982; Konstantinou and others, 2012). Mountain building was followed by periods of upland erosion and deposition of basin-fill sediments and intervening periods of volcanism. More recent alluvial and alluvial-fan deposition and basalt flows, associated with the Snake River Group, comprise the surficial geology throughout much of the valley (Figure 3) (Lewis and others, 2012).

Hydrogeology

The shallow aquifer is composed of unconsolidated, fluvial sediments (clay, silt, sand, gravel, and cobbles) and varying degrees of indurated sedimentary deposits at depth, separated by and interfingered with layers of volcaniclastic material (McVay 2024; Utah Division of Water Rights, 2023). In general, coarser-grained deposits tend to occur in the southern part of the valley, with finer-grained deposits in the northern part of the valley (Figure 3) (Walker and others, 1970). The uppermost 700 feet of the aquifer acts as a single, generally unconfined, aquifer. Deeper wells may intercept semi-confined parts of the aquifer (Walker and others, 1970). Groundwater flow is from higher to lower elevations and overall from south to north. Recharge to the aquifer is from precipitation, primarily as natural infiltration (areal recharge), incidental recharge from surface water irrigation, stream seepage, and tributary canyon underflow to the aquifer. Discharge from the aquifer is mostly from groundwater pumping for irrigation. Long-term groundwater withdrawal for crop irrigation has resulted in large declines in groundwater levels. Although the total aquifer thickness is unknown, most wells are completed to depths between 100 feet to 500 feet, with some wells completed to depths of over 1,000 feet (IDWR, 2024).

Geothermal

A deeper confined aquifer, separate from the shallow aquifer, hosts a geothermal resource in the southern part of the basin. Geothermal wells intercept the metasediments at depths between 5,000 feet and 6,000 feet below ground surface and produce water at approximately 280°F (Plummer and others, 2016; Ayling and Moore, 2013). The Raft River area was designated as a Known Geothermal Resources Area in 1971 and the aquifer supplies Idaho's only commercially operated geothermal power plant.

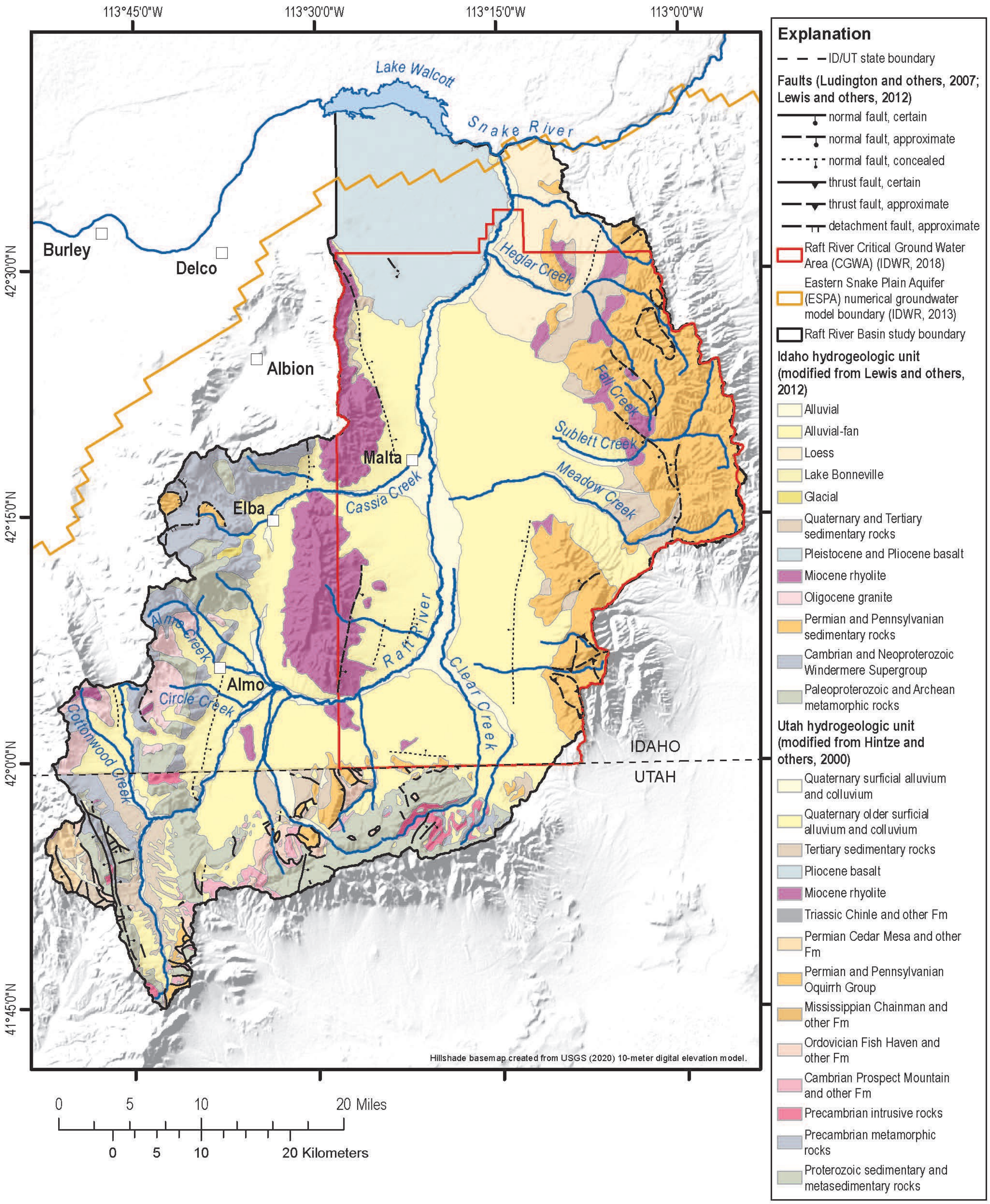

Figure 3: Hydrogeologic units of the Raft River Basin (Clark, 2024).

Methods

Groundwater Quality Sample Collection

Two sampling events occurred, one in November 2023 (fall) and another in April 2024 (spring). Groundwater samples were collected at 11 sites (Table 1) after a minimum of three well-casing volumes were pumped from the well.

Table 1: Information for groundwater sampling sites in the Raft River Basin.

Well Name	Fall Sample Date	Spring Sample Date	Latitude	Longitude	Altitude (ft)	Total Well Depth (ft)
MW 1	11/14/2023	4/23/2024	42.5909	-113.2350	4212.98	358
MW 2	11/14/2023	4/23/2024	42.5906	-113.2353	4210.84	768
MW 3	11/14/2023	4/22/2024	42.5692	-113.3937	4418.55	940
MW 4	11/14/2023	4/23/2024	42.3055	-113.0842	5188.59	510
MW 5	11/14/2023	4/23/2024	42.4744	-113.1466	4725.28	720
MW 6	11/14/2023	4/23/2024	42.1449	-113.2059	5490.54	753
MW 8	11/14/2023	4/23/2024	42.0894	-113.3196	4811.28	495
MW 9	11/14/2023	4/23/2024	42.2247	-113.3491	4597.73	300
MW 10*	--	4/24/2024	42.5028	-113.3243	4394.18	1007
MW 11	11/14/2023	4/22/2024	42.3789	-113.3598	4416.43	500
MW 12	11/14/2023	4/22/2024	42.5649	-113.1746	4402.07	1010

**MW 10 was unable to be sampled in the fall sampling period and the spring sample was not indicative of aquifer conditions due to inadequate purging capabilities. Results have been excluded from analysis but are available for review in the appendices.*

Field parameters (dissolved oxygen, pH, specific conductance, and temperature) were recorded leading up to and at the time of sample collection using an OrionStar A329 multimeter probe. Field parameters were used to confirm adequate well purging prior to sample collection.

Alkalinity was measured on-site after sample collection using a HACH AL-AP titration test kit.

Laboratory Analysis

The Idaho Bureau of Laboratories performed analyses for major ions, metals, nutrients, pesticides, and semi-volatile organic compounds using EPA Methods 200.7, 200.8, 245.1, 300.0, 350.1, 353.2, 365.1, 515.4, and 525.2. Stable isotopes were analyzed using cavity ringdown spectroscopy at Boise State University in their Stable Isotope Laboratory. Fall 2023 samples were analyzed for gross alpha and gross beta activity by Analytical Laboratories using EPA Method 9310. Spring 2024 samples were analyzed for PFAS by Anatek Laboratories using EPA Method 533.

Quality Assurance and Quality Control

Quality assurance/quality control samples were collected to determine the integrity of sample handling by field staff and laboratories, cleanliness of sample bottles, and accuracy of laboratory methods. Replicate samples and field blank samples were collected for major ions, metals, nutrients, pesticides, semi-volatile organic compounds, and stable isotopes. Replicate samples for radiochemistry were collected in fall 2023. Field blanks for PFAS were collected at each site in spring 2024 and were to be analyzed in the event of a detection. Field multimeter probes were calibrated in the field at the beginning of each day against known standards.

Water Quality Results and Discussion

Physical Parameters

Physical water quality parameters were collected at each sampling location; Table 2 and Figure 4 present summary statistics of these results. A full table of results can be found in Appendix A, Table A.1.

Major Ions and Metals

All samples were analyzed for major cations, anions, and metals. Major cations included calcium, magnesium, potassium, and sodium. Major anions included chloride, fluoride, and sulfate. Metals included arsenic, cadmium, copper, iron, manganese, potassium, selenium, and uranium. Additionally, samples from the spring sampling period were analyzed for antimony, beryllium, cobalt, molybdenum, nickel, and thallium. Summary statistics of these results are presented in Table 2 and Figure 4. A full table of results can be found in Appendix A, Table A.1.

No EPA maximum contaminant level (MCL) exceedances for major ions or metals were found in any study samples. However, multiple wells exceeded EPA secondary maximum contaminant levels (SMCLs, U.S. EPA, 2024) for at least one of the sampling events. These EPA SMCL exceedances included the following:

- Six manganese exceedances (>0.5 mg/L) at four wells in the fall (MW 2, 3, 9, and 11) and two wells in the spring (MW 3 and 4).
- Three chloride exceedances (>250 mg/L) at two wells in the fall (MW 3 and 9) and one well in the spring (MW 3).
- Ten iron exceedances (>0.3 mg/L) at six wells in the fall (MW 1, 2, 3, 4, 9, and 11) and four wells in the spring (MW 3, 4, 6, and 9).
- Five total dissolved solids exceedances (>500 mg/L) at two wells in the fall (MW 3 and 9) and three wells in the spring (MW 3, 9, and 11).

Table 2: Summary statistics results of all study samples. "ND" indicates parameter was not detected.

Parameter type	Parameter	Fall Sampling Period				Spring Sampling Period			
		Min	Max	Mean[1]	Median	Min	Max	Mean[1]	Median
Physical Parameters	Alkalinity (mg/L)	5	160	87	100	15	180	92	100
	Dissolved Oxygen (mg/L)	<0.010	10.3	2.24	0.19	<0.010	7.39	1.67	0.14
	pH	7.20	9.92	8.58	8.67	7.51	9.46	8.54	8.65
	Specific Conductance (µS/cm)	101.8	1814	662.1	505.9	165.6	1864	710.0	463.3
	Total Dissolved Solids (mg/L)	63	1100	390	190	76	1100	400	230
	Water Temperature (°C)	11.3	18.3	14.4	14.3	11.1	18.6	14.9	14.5
Major Ions and Metals	Antimony (mg/L)	-	-	-	-	<0.0010	<0.0010	<0.0010	<0.0010
	Arsenic (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	4.0	0.70-2.3	<2.0
	Beryllium (mg/L)	-	-	-	-	<0.0010	<0.0010	<0.0010	<0.0010
	Cadmium (mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	Calcium (mg/L)	2.99	89.4	34.9	25.9	3.30	100	40.2	26.5
	Chloride (mg/L)	12.7	463	150	51.7	12.8	487	147	47.6
	Cobalt (mg/L)	-	-	-	-	<0.0010	0.0011	0.00011-0.0010	<0.0010
	Copper (µg/L)	<1.0	3.2	0.70-1.3	<1.0	<1.0	38	4.0-4.8	<1.0
	Fluoride (mg/L)	<0.20	1.7	0.70-0.80	0.60	<0.20	2.2	0.60-0.70	0.50
	Iron (mg/L)	<0.010	6.8	1.1	0.49	<0.010	3.2	0.68	0.28
	Magnesium (mg/L)	3.1	42	16	15	4.9	48	18	16
	Manganese (mg/L)	<0.0010	0.18	0.050-0.051	0.039	0.0011	0.14	0.039	0.025
	Molybdenum (mg/L)	-	-	-	-	<0.0010	0.0075	0.0018-0.0021	0.0012
	Nickel (mg/L)	-	-	-	-	<0.0010	<0.0010	<0.0010	<0.0010
	Potassium (mg/L)	3.7	20	9.4	8.5	4.0	22	9.9	8.8
	Selenium (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	3.6	0.36-2.2	<2.0
	Silica (mg/L)	<0.20	61	20	1.7	0.25	64	24	13
	Sodium (mg/L)	10.2	195	53.9	29.2	11.0	200	56.7	29.5
	Sulfate (mg/L)	<0.80	32	8.5-9.0	0.80	<0.80	30	8.3	2.9
	Thallium (µg/L)	-	-	-	-	<0.10	<0.10	<0.10	<0.10
	Uranium (µg/L)	<1.0	2.2	0.5-1.2	<1.0	<1.0	6.3	1.0-1.7	<1.0
Nutrients	Ammonia (mg/L)	<0.050	0.53	0.07-0.11	<0.050	<0.050	0.70	0.080-0.12	<0.050
	Nitrate (mg/L)	<0.010	1.2	0.13-0.14	<0.010	<0.010	0.89	0.11-0.12	0.010
	Total Phosphorus (mg/L)	<0.0050	0.019	0.055-0.056	0.010	<0.0050	0.070	0.019-0.020	0.014
Stable Isotopes	δ2H (‰)	-133.4	-127.7	-130.8	-131.3	-133.3	-128.7	-130.7	-130.1
	δ18O (‰)	-17.5	-16.9	-17.2	-17.1	-17.6	-16.9	-17.2	-17.1
Radiochemistry	Gross Alpha	ND	ND	ND	ND	-	-	-	-
	Gross Beta	<4.0	10	4.1-6.1	5.4	-	-	-	-
PFAS	25 PFAS analytes	-	-	-	-	ND	ND	ND	ND

[1]When results included values below a detection limit, a range for the mean was calculated by replacing the below-detection-limit results with a value of zero for the lower end of the range, and the value of the detection limit for the higher end of the range.

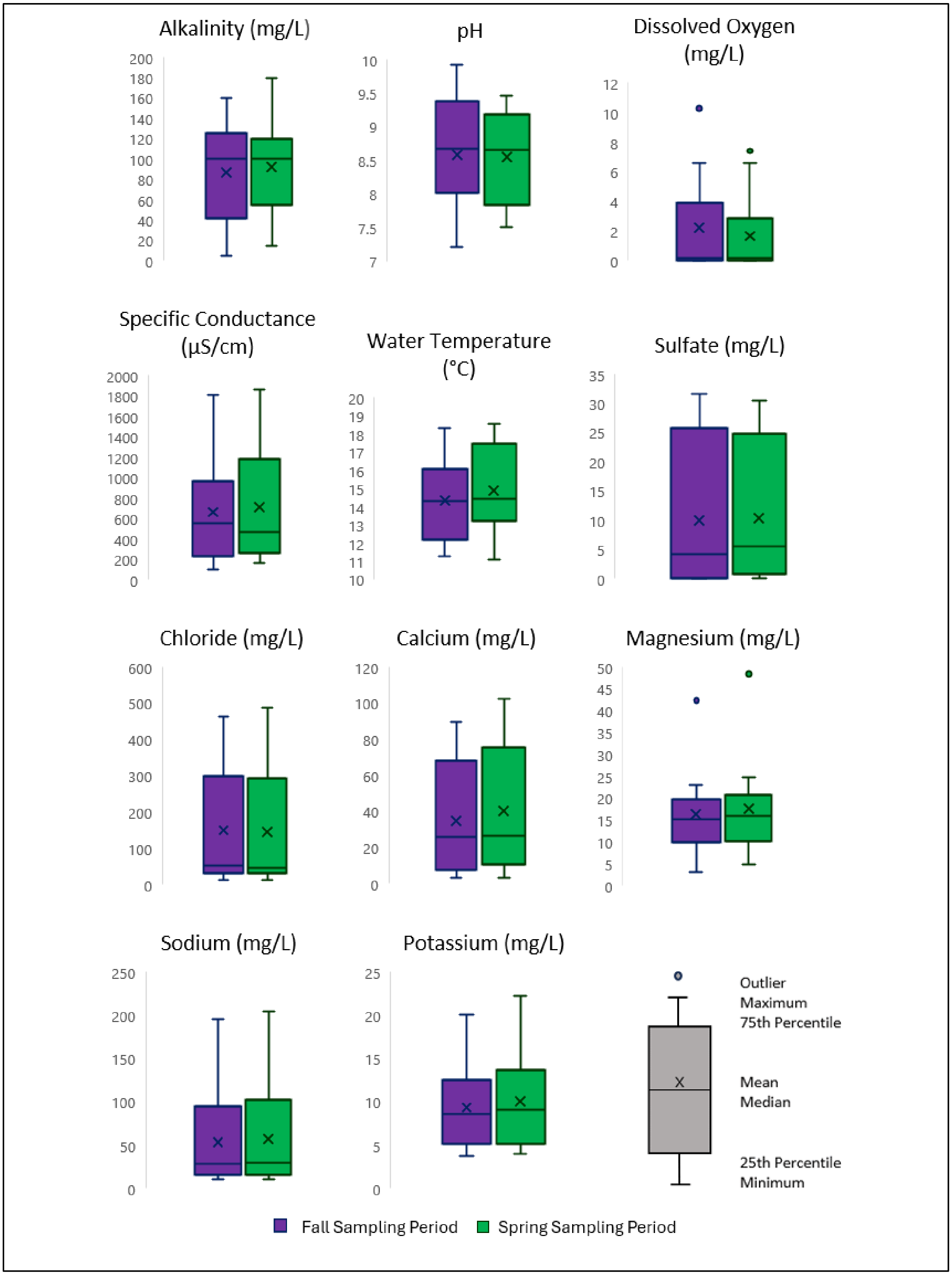

Figure 4: Box and whisker plots for selected physical parameters and analyte concentrations.

When plotted on a trilinear diagram, major ion concentrations can provide another measure of variability and determine if a dominant water type is present, as described by Piper (1944). No dominant water type was observed across study samples (Figure 5). Stacking of data points indicates there was little change from fall to spring for each unique monitoring well. A shift in data is observed for MW 5 due to change in chloride values from fall to spring sampling events, with values decreasing from 122 mg/L to 42.3 mg/L respectively. A full list of results can be found in Appendix A, Table A.1.

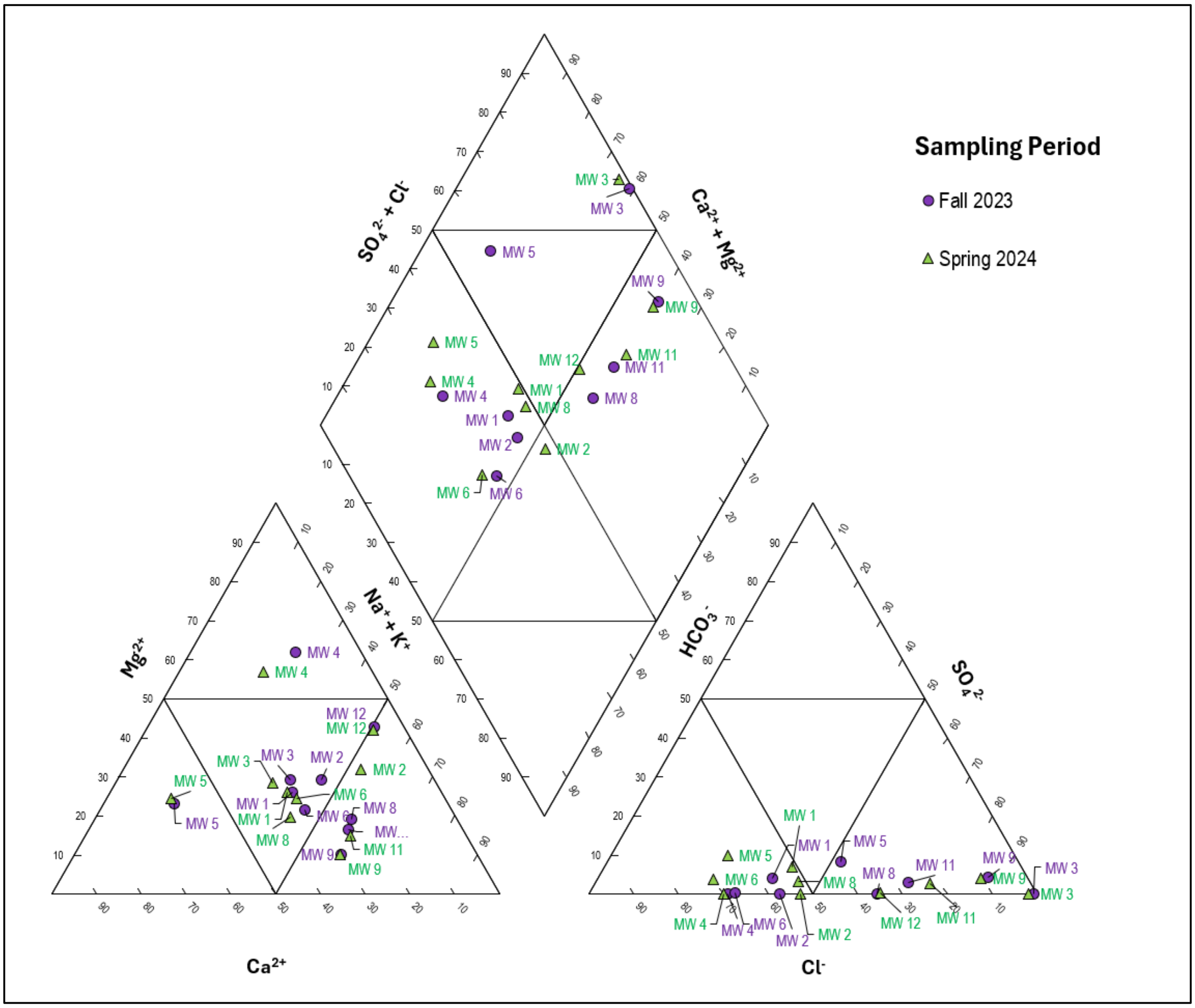

Figure 5: Trilinear diagram of major ion composition from all study samples.

Nutrients

All samples were analyzed for ammonia, nitrate, and total phosphorus. Summary statistics of these results can be found in Table 2. Aside from MW 5 and MW 9, all other nitrate concentrations were below the reporting detection limit. The highest nitrate concentration in the study was 1.2 mg/L at MW 5 during the fall sampling period. The highest ammonia concentration in the study was 0.70 mg/L at MW 12 during the spring sampling period. The highest total phosphorus concentration was 0.070 mg/L at MW 1 during the spring sampling period. A full list of results can be found in Appendix A, Table A.1.

Pesticides and Semi-Volatile Organic Compounds

Samples were analyzed for common herbicides, insecticides, and other semi-volatile organic compounds (SVOCs). A total of 118 analytes were analyzed during each sampling period. Only two analytes reported detections above the detection limit. MW 6 had one detection of herbicide 3,5-Dichlorobenzoic acid with a concentration of 1.19 µg/L during the spring sampling period. Seven wells had detections of bis(2-ethylhexyl)phthalate, with most detections occurring in the spring. The highest concentration was 18 µg/L in MW 6. Bis(2-ethylhexyl)phthalate is a plasticizer used in the construction of PVC and is a common distribution contaminant. For a complete list of SVOC analytes and detection results, see Appendix A, Table A.2, and Table A.3.

PFAS

PFAS are synthetic chemicals commonly associated with products that resist water, oil, and grease. These chemicals are widespread and resist breaking down in the environment. Spring 2024 samples were analyzed for 25 different PFAS analytes. No detections were found. For a full list of PFAS analytes included in this study, see Appendix A, Table A.2.

Quality Control Results

Six replicate samples (three in the fall and three in the spring) were collected and analyzed for major ions, metals, nutrients, pesticides, and SVOCs. Three replicate samples were collected and analyzed for radiochemistry in the fall. Seven replicates in the fall and eight replicates in the spring were collected and analyzed for stable isotopes.

A relative percent difference (RPD) analysis was used to determine the change between study samples and replicate samples. Any value over 20% was flagged, indicating a high percentage difference in study samples versus replicate samples. The majority of RPD's that exceeded 20% occurred where measured concentrations were small and near the detection limit, meaning slight differences in concentrations led to higher RPD values. The analysis revealed acceptable data quality for this study.

One blank sample was collected and analyzed for each sampling period for all sample types except PFAS and stable isotopes. The blank samples revealed no results above the reporting detection limit for all analytes. For a comparison of study, replicate, and blank samples, see Appendix B, Table B.1, Table B.2.

Conclusions

IDWR collected water samples from 11 SEP monitoring wells during fall 2023 and spring 2024 to characterize groundwater quality conditions of the Raft River Basin. Water samples were analyzed at a variety of laboratories and no EPA MCL exceedances were found. However, EPA SMCL exceedances were reported at multiple wells for at least one sampling event. These included SMCL exceedances for manganese, chloride, iron, and total dissolved solids. Few wells reported nutrient, pesticide, or SVOC detections above the detection limit.

Additional sampling is needed to help establish long-term groundwater quality trends in the Raft River Basin. The 11 monitoring wells installed for this SEP can facilitate continued sampling for other studies and help bring attention to water quality changes in the region.

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Appendix A – Water Quality Results

Groundwater data are also available on IDWR's Groundwater Data Portal at https://idwr-groundwater-data.idaho.gov

Table A.1 : Major ion, nutrient, and stable isotope results for all study samples. Unshaded rows indicate fall sampling period, shaded rows indicate spring sampling period.

Analyte	MW 1	MW 2	MW 3	MW 4	MW 5	MW 6	MW 8	MW 9	MW 10	MW 11	MW 12
Alkalinity[1]	140	120	5	120	160	45	30	80	–	120	50
(mg/L)	120	100	15	120	180	60	65	100	35	120	40
Aluminum	<0.0050	<0.0050	0.0051	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	–	<0.0050	<0.0050
(mg/L)	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Ammonia	<0.10	<0.050	<0.050	0.18	<0.050	<0.050	<0.050	<0.050	–	<0.050	0.53
(mg/L)	<0.050	<0.050	<0.050	0.060	<0.050	0.060	<0.050	<0.050	<0.050	<0.050	0.70
Antimony	–	–	–	–	–	–	–	–	–	–	–
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Arsenic	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	–	<0.0020	<0.0020
(mg/L)	0.0040	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	0.0026	<0.0020
Barium	0.18	0.28	0.13	0.0030	0.097	0.010	0.0040	0.20	–	0.031	0.0070
(mg/L)	0.19	0.11	0.20	0.014	0.097	0.0090	0.0080	0.22	0.014	0.038	0.0080
Beryllium	–	–	–	–	–	–	–	–	–	–	–
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Boron	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	–	0.30	<0.10
(mg/L)	<0.10	<0.10	<0.10	<0.10	0.70	0.10	<0.10	<0.10	0.40	0.20	<0.10
Cadmium	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	–	<0.0010	<0.0010
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Calcium	32	19	76	8.9	66	7.6	7.7	89	–	39	3.0
(mg/L)	35	10	100	18	68	11	16	96	4.6	45	3.3
Chloride	55.7	51.7	416	31.4	122	12.7	31.4	463	–	180	43.4
(mg/L)	56.9	52.0	487	30.0	42.3	12.8	32.9	478	103	231	43.2
Chromium	<0.0010	<0.0010	<0.0010	<0.0010	0.0024	<0.0010	<0.0010	<0.0010	–	<0.0010	<0.0010
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	0.0012	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Cobalt	–	–	–	–	–	–	–	–	–	–	–
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Copper	<1.0	<1.0	3.2	<1.0	<1.0	<1.0	<1.0	2.2	–	1.1	<1.0
(µg/L)	<1.0	<1.0	38	<1.0	<1.0	<1.0	<1.0	1.8	<1.0	<1.0	<1.0
Dissolved Oxygen[1]	0.05	0.19	<0.01	0.10	10.28	3.90	0.02	6.59	–	1.51	<0.01
(mg/L)	0.08	0.01	<0.01	0.01	7.39	0.19	0.72	6.60	1.41	1.64	0.01
Fluoride	0.91	0.52	1.7	0.68	0.20	0.33	<0.20	0.60	–	1.4	1.0
(mg/L)	0.80	0.44	2.2	<0.20	<0.20	0.82	0.33	0.56	0.56	1.1	<0.20
Iron	0.73	0.96	6.8	1.1	<0.01	0.080	0.060	0.53	–	0.45	0.060
(mg/L)	0.26	0.30	1.1	3.2	<0.01	1.1	0.22	0.31	<0.01	0.26	0.060
Lead	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	–	<0.0010	<0.0010
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Lithium	0.023	0.017	0.069	0.0061	0.0079	0.0087	0.0090	0.29	–	0.035	0.011
(mg/L)	0.024	0.018	0.074	0.0051	0.0073	0.013	0.0092	0.29	0.030	0.053	0.011
Magnesium	16	14	42	23	15	3.1	3.8	18	–	15	12
(mg/L)	16	13	48	25	17	4.9	5.2	19	5.9	16	12

[1]Parameter collected in the field at time of sample collection

Table A.1: (continued)

Analyte	MW 1	MW 2	MW 3	MW 4	MW 5	MW 6	MW 8	MW 9	MW 10	MW 11	MW 12
Manganese	0.038	0.051	0.18	0.040	<0.0010	0.015	0.015	0.096	–	0.058	0.017
(mg/L)	0.018	0.035	0.084	0.14	0.0010	0.023	0.021	0.026	0.0060	0.035	0.018
Mercury	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	–	<0.50	<0.50
(µg/L)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Molybdenum	–	–	–	–	–	–	–	–	–	–	–
(mg/L)	0.0029	0.0012	<0.0010	<0.0010	<0.0010	0.0012	0.0011	0.0018	0.0051	0.0022	0.0075
Nickel	–	–	–	–	–	–	–	–	–	–	–
(mg/L)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Nitrate	<0.010	<0.010	<0.010	<0.010	1.2	<0.010	<0.010	0.066	–	<0.010	<0.010
(mg/L)	0.073	<0.010	<0.010	0.014	0.89	0.024	<0.010	0.13	<0.010	<0.010	<0.010
pH[1]	8.37	8.83	8.79	8.67	7.20	9.37	9.75	7.30	–	8.01	9.92
	7.92	9.10	9.46	8.30	7.51	9.08	9.00	7.57	9.60	8.04	9.42
Potassium	12	10	20	6.7	4.9	3.7	5.2	14	–	11	5.3
(mg/L)	12	10	22	7.6	4.0	4.9	5.2	15	12	13	5.4
Selenium	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	–	<0.0020	<0.0020
(mg/L)	0.0036	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Silica	48	0.36	1.8	0.99	31	0.42	1.5	61	–	55	<0.20
(mg/L)	56	0.25	0.26	2.0	27	1.7	23	64	0.23	63	0.25
Sodium	39	34	95	13	17	10	19	200	–	94	24
(mg/L)	39	35	100	11	16	13	19	200	67	110	24
Specific Conductance[1]	558.6	453.2	1217	246.8	615.8	101.8	155.2	1814	–	961.0	224.4
(µS/cm)	542.1	381.2	1679	384.5	559.0	165.6	237.3	1864	490.0	1020	267.4
Strontium	0.38	0.24	0.49	0.01	0.24	0.09	0.07	0.57	–	0.46	0.08
(mg/L)	0.39	0.09	0.66	0.02	0.24	0.10	0.16	0.58	0.05	0.51	0.01
Sulfate	8.2	<0.80	<0.80	<0.80	26	<0.80	<0.80	32	–	11	<0.80
(mg/L)	13	<0.80	<0.80	<0.80	22	2.7	3.1	30	<0.80	11	<0.80
Thallium	–	–	–	–	–	–	–	–	–	–	–
(µg/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total Dissolved Solids	290	190	960	150	340	63	98	1100	–	500	120
(mg/L)	290	160	1100	150	300	76	120	1100	220	590	110
Total Phosphorus	0.013	<0.0050	0.011	0.0050	0.019	0.0090	0.0070	0.016	–	0.016	0.0070
(mg/L)	0.070	0.0090	0.0060	<0.0050	0.018	0.017	0.011	0.025	0.011	0.024	0.011
Uranium	1.5	<1.0	<1.0	<1.0	1.6	<1.0	<1.0	2.2	–	<1.0	<1.0
(µg/L)	6.3	<1.0	<1.0	<1.0	1.3	<1.0	<1.0	2.1	<1.0	<1.0	<1.0
Temperature[1]	13.0	13.2	16.1	11.6	18.3	11.3	12.2	16.8	–	14.3	15.8
(°C)	13.5	13.5	17.6	11.1	18.6	13.5	12.4	17.4	15.6	15.4	15.8
$\delta^{2}H$ (‰)	-132.0 [2.8]	-132.9 [0.70]	-129.5 [1.3]	-128.7 [1.4]	-131.7 [2.1]	-127.7 [1.0]	-129.2 [1.5]	-131.1 [1.9]	–	-133.4 [2.3]	-131.5 [1.0]
[1σ]	133.3 [2.1]	133.8 [1.4]	129.8 [1.2]	128.8 [1.4]	130.8 [1.6]	129.5 [0.40]	129.4 [2.2]	130.0 [1.1]	129.6 [1.2]	130.4 [1.2]	132.3 [1.1]
$\delta^{18}O$ (‰)	-17.4 [0.32]	-17.4 [0.21]	-16.9 [0.30]	-17.1 [0.25]	-17.0 [0.39]	-16.9 [0.11]	-17.1 [0.31]	-17.1 [0.21]	–	-17.5 [0.19]	-17.3 [0.17]
[1σ]	-17.4 [0.26]	-17.6 [0.28]	-17.2 [0.22]	-16.9 [0.22]	-16.9 [0.29]	-17.2 [0.27]	-17.1 [0.28]	-17.0 [0.31]	-16.9 [0.22]	-17.0 [0.25]	-17.3 [0.17]

[1]Parameter collected in the field at time of sample collection

Table A.2: Full list of all pesticides, semi-volatile organic compounds, and PFAS analytes included in this study.

EPA METHOD 525.2

- 2,2',3,3'4,4',6-Heptachlorobip
- 2,2',3,3'4,5',6,6'-Octachlorob
- 2,2',3'4,6-Pentachlorobiphenyl
- 2,2'4,4'5,6'Hexachlorobiphenyl
- 2,2'4,4'-Tetrachlorobiphenyl
- 2,3-Dichlorobiphenyl
- 2,4,5-Trichlorobiphenyl
- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- 2-Chlorobiphenyl
- 4,4'-DDD
- 4,4'-DDE
- 4,4'-DDT
- Acenaphthylene
- Alachlor
- Aldrin
- alpha-BHC
- alpha-Chlordane
- Ametryn
- Anthracene
- Atraton
- Atrazine
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(g,h,i)perylene
- Benzo(k)fluoranthene
- beta-BHC
- bis(2-ethylhexyl)phthalate
- Bromacil
- Butachlor
- Butylate
- Butylbenzylphthalate
- Chlorobenzilate
- Chloroneb
- Chloropyrifos (Dursban)
- Chlorothalonil
- Chlorpropham
- Chrysene
- Cyanazine
- Cycloate
- DCPA
- delta-BHC
- Di(2-ethylhexyl)adipate
- Diazinon
- Dibenz(a,h)anthracene
- Dichlorovos
- Dieldrin
- Diethylphthalate
- Dimethyl-phthalate
- Di-n-butylphthalate
- Diphenamid
- Endosulfan I
- Endosulfan II
- Endosulfan Sulfate
- Endrin
- Endrin aldehyde
- EPTC
- Ethoprop
- Etridiazole
- Fenarimaol
- Fluorene
- Fluridone
- gamma-BHC (Linda)
- gamma-Chlordane
- Heptachlor
- Heptachlor epoxi
- Hexachlorobenzene
- Hexachlorocyclopentadiene
- Hexazinone (Velpar)
- Indeno(1,2,3-cd)pyrene
- Isophorone
- Malathion
- Methoxychlor
- Methyl Paraoxon
- Metolachlor
- Metribuzin
- Mevinphos
- MGK-264-Total
- Molinate
- Napropamide(Devrinol)
- Norflurazon
- Pebulate
- Pentachlorophenol
- Permethrin
- Phenanthrene
- Prometon
- Prometryn
- Pronamide
- Propachlor
- Propazine
- Pyrene
- Simazine (Princep)
- Simetryn
- Tebuthiuron
- Terbacil
- Terbutryn
- Tetrachlorvinphos
- trans-Nonachlor-chlordane
- Triadimefon
- Tricyclazole (Beam)
- Trifluralin (Treflan)
- Vernolate

EPA METHOD 515.4

- 2,4,5-T
- 2,4,5-TP (Silvex)
- 2,4-D
- 2,4-DB
- 3,5-Dichlorobenzoic acid
- Acifluorfen
- Bentazon
- Chloramben
- Dalapon
- DCPA
- Dicamba
- Dichloroprop
- Dinoseb
- Pentachlorophenol
- Picloram

EPA METHOD 533

- 11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
- 9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid
- 4,8-Dioxa-3H-perfluorononanoic acid
- Hexafluoropropylene oxide dimer acid
- Nonafluoro-3,6-dioxaheptanoic acid
- Perfluorobutanoic acid
- Perfluorobutanesulfonic acid
- 1H,1H, 2H, 2H-Perfluorodecane sulfonic acid
- Perfluorodecanoic acid
- Perfluorododecanoic acid
- Perfluoro(2-ethoxyethane)sulfonic acid
- Perfluoroheptanesulfonic acid
- Perfluoroheptanoic acid
- 1H,1H, 2H, 2H-Perfluorohexane sulfonic acid
- Perfluorohexanesulfonic acid
- Perfluorohexanoic acid
- Perfluoro-3-methoxypropanoic acid
- Perfluoro-4-methoxybutanoic acid
- Perfluorononanoic acid
- 1H,1H, 2H, 2H-Perfluorooctane sulfonic acid
- Perfluorooctanesulfonic acid
- Perfluorooctanoic acid
- Perfluoropentanoic acid
- Perfluoropentanesulfonic acid
- Perfluoroundecanoic acid

Table A.3: Pesticide and SVOC detections.

Well Name	Sample Period	Analyte Detected	Concentration (µg/L)
MW 3	Fall	bis(2-ethylhexyl)phthalate	3.7
MW 6	Fall	bis(2-ethylhexyl)phthalate	4.2
MW 3	Spring	bis(2-ethylhexyl)phthalate	0.87
MW 4	Spring	bis(2-ethylhexyl)phthalate	0.56
MW 6	Spring	bis(2-ethylhexyl)phthalate	18
MW 8	Spring	bis(2-ethylhexyl)phthalate	7.0
MW 9	Spring	bis(2-ethylhexyl)phthalate	0.92
MW 10	Spring	bis(2-ethylhexyl)phthalate	1.6
MW 11	Spring	bis(2-ethylhexyl)phthalate	0.56
MW 6	Spring	3,5-Dichlorobenzoic acid	1.19

Appendix B – Replicate and Blank Results

Table B.1: Replicate and blank results. Relative percent difference (RPD) provides a measure of difference between study samples and their replicates. RPD's over 20% are highlighted.

Sample Name	Aluminum (mg/L)		Ammonia (mg/L)		Antimony (mg/L)		Arsenic (mg/L)		Barium (mg/L)		Beryllium (mg/L)		Boron (mg/L)		Cadmium (mg/L)	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
MW 1	<0.0050		<0.10				<0.0020		0.18				<0.10		0.003	
Replicate	<0.0050		<0.10				<0.0020		0.17				<0.10		<0.001	
RPD	0		0				0		5.7				0		100	
MW 3	0.0050		<0.050				<0.0020		0.13				<0.10		<0.0010	
Replicate	0.0056		<0.050				<0.0020		0.13				<0.10		<0.0010	
RPD	9.4		0				0		0				0		0	
MW 4	<0.0050		0.18				<0.0020		0.0033				<0.10		<0.0010	
Replicate	<0.0050		0.20				<0.0020		0.0033				<0.10		<0.0010	
RPD	0		11				0		0				0		0	
MW 6		<0.0050		0.060		<0.0010		<0.0020		0.0094		<0.0010		0.13		<0.0010
Replicate		<0.0050		0.067		<0.0010		<0.0020		0.0094		<0.0010		0.14		<0.0010
RPD		0		11		0		0		0		0		7.4		0
MW 8		<0.0050		<0.050		<0.0010		<0.0020		0.0083		<0.0010		<0.10		<0.0010
Replicate		<0.0050		<0.050		<0.0010		<0.0020		0.0085		<0.0010		<0.10		<0.0010
RPD		0		0		0		0		2.4		0		0		0
MW 12		<0.0050		0.7		<0.0010		<0.0020		0.0077		<0.0010		<0.10		<0.0010
Replicate		<0.0050		0.7		<0.0010		<0.0020		0.0080		<0.0010		<0.10		<0.0010
RPD		0		0		0		0		0		0		0		0
Blank Samples	<0.0050	<0.0050	<0.050	<0.050		<0.0010	<0.0020	<0.0020	<0.0010	<0.0010		<0.0010	<0.10	<0.10	<0.0010	<0.0010

Sample Name	Calcium (mg/L)		Chloride (mg/L)		Chromium (mg/L)		Cobalt (mg/L)		Copper (µg/L)		Fluoride (mg/L)		Iron (mg/L)		Lead (mg/L)	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
MW 1	32		55.7		<0.0010				<1.0		0.91		0.73		<0.0010	
Replicate	32		56.7		<0.0010				<1.0		0.92		0.74		<0.0010	
RPD	0		1.78		0				0		1.3		1.4		0	
MW 3	76		416		<0.0010				3.2		1.7		6.8		<0.0010	
Replicate	76		420		<0.0010				2.1		1.7		6.7		<0.0010	
RPD	0		0.96		0				42		0		1.5		0	
MW 4	8.9		31.4		<0.0010				<1.0		0.68		1.1		<0.0010	
Replicate	8.9		31.1		<0.0010				<1.0		0.49		1.1		<0.0010	
RPD	0		0.960		0				0		32		0		0	
MW 6		11		12.8		<0.0010		0.0011		<1.0		0.82		1.1		<0.0010
Replicate		11		12.8		<0.0010		<0.0010		<1.0		0.82		0.64		<0.0010
RPD		0		0		0		9.5		0		0		53		0
MW 8		16		32.9		<0.0010		<0.0010		<1.0		0.33		0.22		<0.0010
Replicate		16		32.9		<0.0010		<0.0010		<1.0		0.32		1.4		<0.0010
RPD		0		0		0		0		0		3.1		150		0
MW 12		3.3		43.2		<0.0010		<0.0010		<1.0		<0.20		0.064		<0.0010
Replicate		3.3		43.2		<0.0010		<0.0010		<1.0		<0.20		0.064		<0.0010
RPD		0		0		0		0		0		0		0		0
Blank Samples	<0.10	<0.10	<0.40	<0.40	<0.0010	<0.0010		<0.0010	<0.0010	<0.0010	<0.20	<0.20	<0.010	<0.010	<0.0010	<0.0010

Table B.1 (continued)

Sample Name	Lithium (mg/L)		Magnesium (mg/L)		Manganese (mg/L)		Mercury (µg/L)		Molybdenum (mg/L)		Nickel (mg/L)		Nitrate (mg/L)		Potassium (mg/L)	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
MW 1	0.023		16		0.038		<0.50						<0.010		12	
Replicate	0.023		15		0.038		<0.50						<0.010		12	
RPD	0		6.5		0		0						0		0	
MW 3	0.069		42		0.18		<0.50						<0.010		20	
Replicate	0.070		42		0.18		<0.50						<0.010		20	
RPD	1.4		0		0		0						0		0	
MW 4	0.0061		23		0.04		<0.50						<0.010		6.7	
Replicate	0.0060		23		0.04		<0.50						<0.010		6.7	
RPD	0		0		0		0						0		0	
MW 6		0.013		4.9		0.023		<0.50		0.0012		<0.0010		0.024		4.9
Replicate		0.013		4.9		0.020		<0.50		0.0023		<0.0010		0.025		4.9
RPD		0		0		14		<0.50		63		0		4.1		0
MW 8		0.0092		5.2		0.012		<0.50		0.0011		<0.0010		<0.010		5.2
Replicate		0.0094		5.3		0.026		<0.50		<0.0010		<0.0010		<0.010		5.2
RPD		2.2		1.9		74		0		9.5		0		0		0
MW 12		0.011		12		0.018		<0.50		0.0075		<0.0010		<0.010		5.4
Replicate		0.011		12		0.018		<0.50		0.0074		<0.0010		<0.010		5.5
RPD		0		0		0		0		1.3		0		0		1.8
Blank Samples	<0.0020	<0.0020	<0.1	<0.1	<0.0010	<0.0010	<0.50	<0.50		<0.0010		<0.0010	<0.010	<0.010	<0.10	<0.10

Sample Name	Selenium (mg/L)		Sodium (mg/L)		Strontium (mg/L)		Sulfate (mg/L)		Thallium (µg/L)		Total Dissolved Solids (mg/L)		Total Phosphorus (mg/L)		Uranium (µg/L)	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
MW 1	<0.0020		39		0.38		8.2				290		0.013		1.5	
Replicate	<0.0020		39		0.38		7.8				300		0.014		1.4	
RPD	0		0		0		5.0				3.4		7.4		6.9	
MW 3	<0.0020		95		0.49		<0.80				960		0.011		<1.0	
Replicate	<0.0020		94		0.48		<0.80				990		0.012		<1.0	
RPD	0		1.1		2.1		0				3.1		8.7		0	
MW 4	<0.0020		13		0.0054		<0.80				150		0.0052		<1.0	
Replicate	<0.0020		13		0.0055		<0.80				150		<0.0050		<1.0	
RPD	0		0		1.8		0				0		3.9		0	
MW 6		<0.0020		13		0.10		2.7		<0.10		76		0.017		<1.0
Replicate		<0.0020		13		0.10		2.6		<0.10		68		0.019		<1.0
RPD		0		0		0		3.7		0		11		11		0
MW 8		<0.0020		19		0.16		3.1		<0.10		120		0.011		<1.0
Replicate		<0.0020		19		0.17		3.2		<0.10		130		0.012		<1.0
RPD		0		0		6.1		3.2		0		8.0		8.7		0
MW 12		<0.0020		24		0.01		<0.80		<0.10		106		0.011		<1.0
Replicate		<0.0020		24		0.01		<0.80		<0.10		102		0.011		<1.0
RPD		0		0		0		0		0		3.85		0		0
Blank Samples	<0.0020	<0.0020	<0.10	<0.10	<0.0020	<0.0020	<0.80	<0.80		<0.10	<10	<10	<0.0050	<0.0050	<1.0	<1.0

Table B.2: Replicate results for stable isotope and radiochemistry samples.

Sample Name	δ^2H (‰) *Fall*	δ^2H (‰) *Spring*	$\delta^{18}O$ (‰) *Fall*	$\delta^{18}O$ (‰) *Spring*	Radiochemistry[1]	
					Gross Alpha	*Gross Beta*
MW 1	-132	-133	-17.4	-17.4	ND	7.0
Replicate	-130	-133	-17.2	-17.4	ND	6.9
RPD	1.53	0	1.16	0	0	1.4
MW 3	-130	-130	-16.9	-17.2	ND	10.0
Replicate	-129	-130	-17.1	-17.2	ND	9.9
RPD	0.77	0	1.18	0.0	0	1.0
MW 4	-129	-129	-17.1	-16.9	ND	ND
Replicate	-128	-128	-16.9	-16.9	ND	ND
RPD	0.77	0.77	1.2	0.0	0	0
MW 5	-132	-131	-17.0	-16.9		
Replicate	-132	-131	-17.4	-17.2		
RPD	0	0	2.33	1.8		
MW 6	-128	-130	-16.9	-17.2		
Replicate	-127	-129	-16.8	-17.4		
RPD	0.78	0.77	0.6	1.2		
MW 8	-129	-129	-17.1	-17.1		
Replicate	-128	-129	-17.1	-17.1		
RPD	0.79	0	0.0	0.0		
MW 9		-130		-17.0		
Replicate		-129		-17.1		
RPD		0.77		0.59		
MW 12	-132	-132	-17.3	-17.3		
Replicate	-131	-131	-17.1	-17.1		
RPD	0.76	0.76	1.16	1.16		

[1] "ND" indicates parameter was not detected.