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

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

4.1. Groundwater Depth

The depth to water in the SVRP aquifer study area ranges from less than 20 feet at locations near the Spokane River to around 300 feet in North Spokane (Figure 48). The wells used in this study range from 55 feet to 286 feet deep (Appendix A). There are several methods to assess the effect of groundwater depth on groundwater quality, which are discussed in this section.

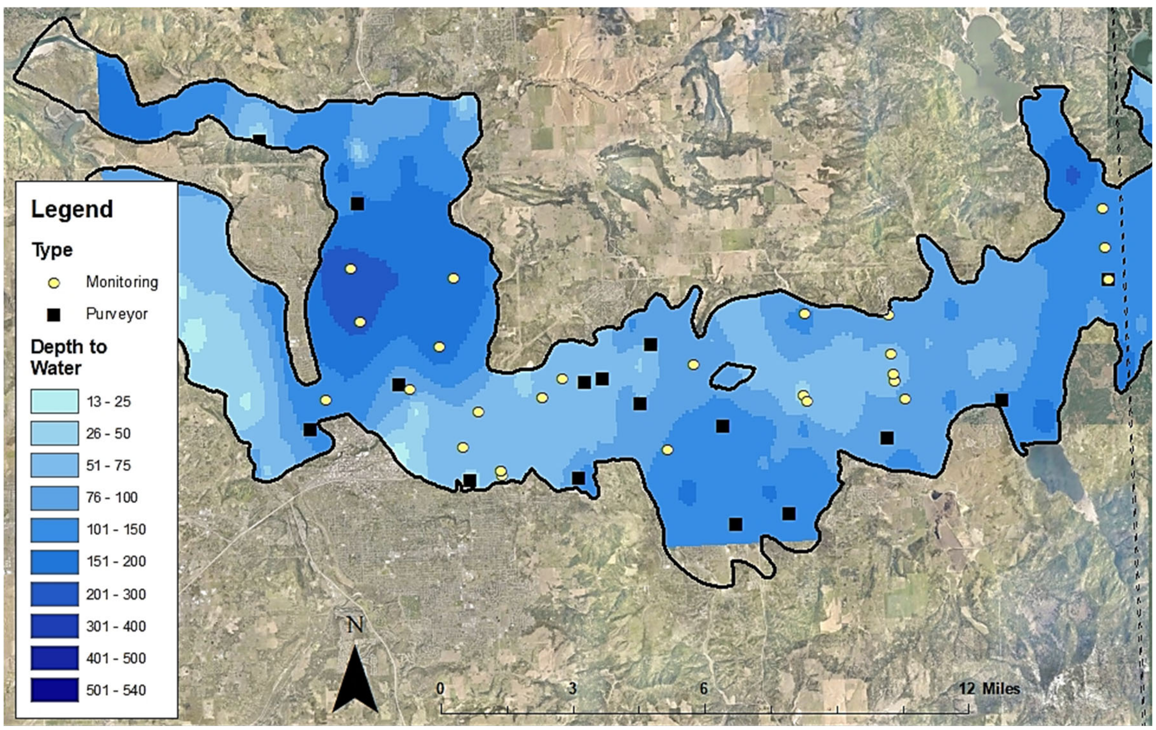

Figure 48. Depth to groundwater throughout the Spokane Valley Rathdrum Prairie aquifer in September 2004. This layer was derived from data presented in USGS Scientific Investigations Report 2007-5044 (Hsieh et al, 2007). Depth to water data not available for purveyor wells.

4.1.1. Nested Wells

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

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

The location of the nested wells and the CID East Farms wells are shown in Figure 49 and the results of the statistical analysis are summarized in Table 3.

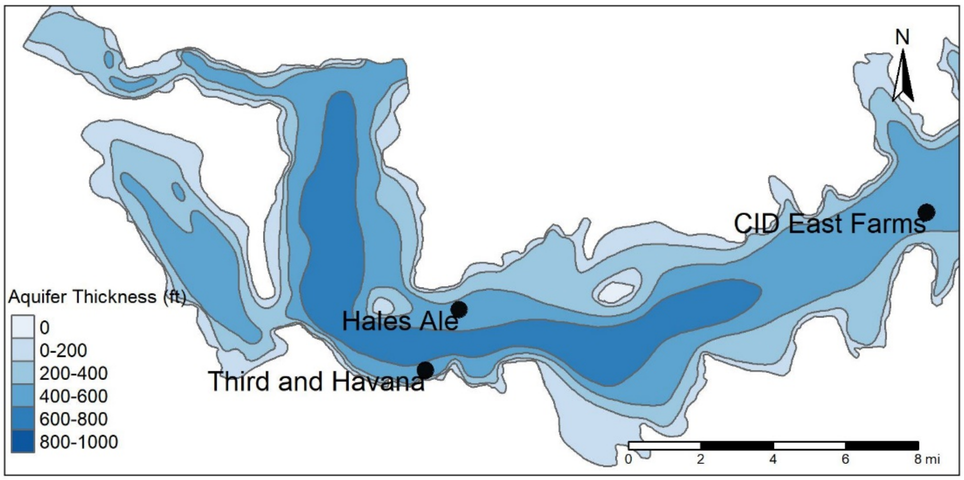

Figure 49. Location of wells considered in the paired well analysis. The nested monitoring wells are at Hales Ale and Third and Havana. A sentinel well and associated purveyor well at Consolidated Irrigation District (CID) East Farms are treated as a nested wells in the analysis.

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

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

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

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

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

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

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

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

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

4.1.2. Sentinel Wells

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

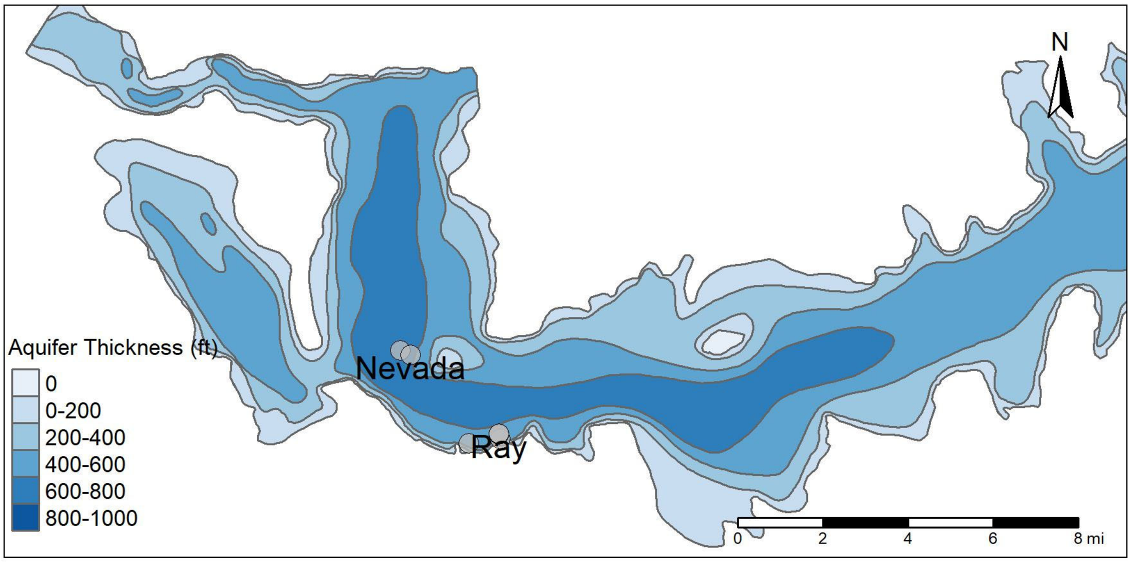

Figure 50. Location of the sentinel well and associated purveyor well for the City of Spokane's Nevada and Ray wells.

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

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

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

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

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

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

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

4.1.3. Type of Monitoring Location

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

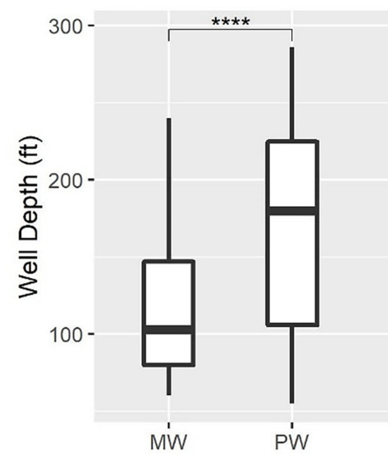

Figure 51. Boxplot showing the statistical distribution of well depths (feet) of monitoring wells (MW) versus purveyor wells (PW). Statistical significance between these group is noted as follows: **** = significant, p<0.0001

Purveyor wells have large pumps, larger diameter wells, and longer screened intervals to draw the volumes necessary for drinking water supply. This creates large capture zones that may be affected by distant contaminant sources. Monitoring wells are intended to assess water quality near the water table where contaminants from the land surface first appear. These have smaller diameter wells with shorter screened intervals and do not have regularly running pumps, resulting in more localized capture zones. Natural springs are going to be the most vulnerable to contaminants in stormwater run-off since they are exposed (Figure 52). For these reasons, it is expected that the type of monitoring location affects groundwater quality.


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

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

The deeper purveyor wells compared to the monitoring wells:

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

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

Compared to both types of wells, the natural springs:

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

It is expected that deeper groundwater would have some of these characteristics. However, the springs are significantly cooler and more alkaline than both sets of wells (Figure 53). The warmer temperatures in the shallow monitoring wells are likely from recent recharge by water warmed at the surface in addition to being closer to surficial heating. The springs are cooler due to weather influences, particularly during the fall and winter, which likely influenced the median temperature.

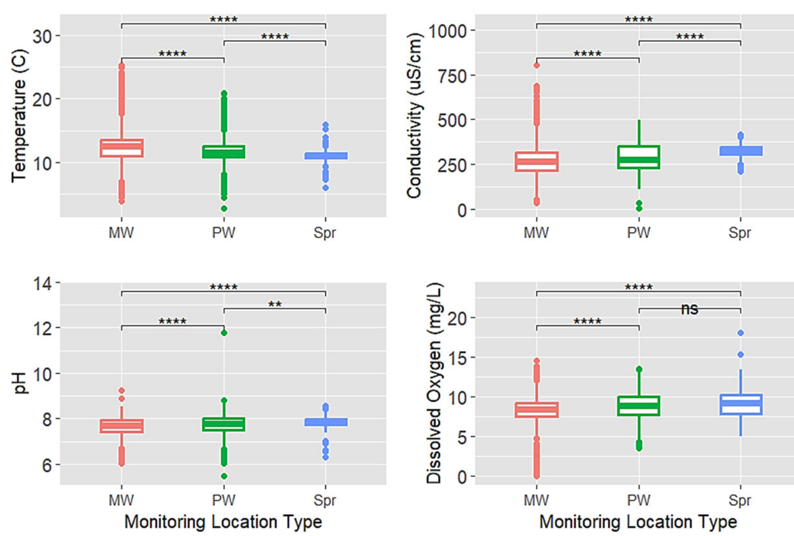

Figure 53. Boxplots showing the statistical distribution of temperature (C), pH, conductivity (uS/cm), and dissolved oxygen (mg/L) by monitoring location type. The types of monitoring locations include monitoring wells (MW), purveyor wells (PW), and natural springs (Spr). Statistical significance between each group is noted as follows: ns = not significant, p>0.05; * = significant, p<0.05; ** = significant, p<0.01; *** = significant, p<0.001; **** = significant, p<0.0001.

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

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

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

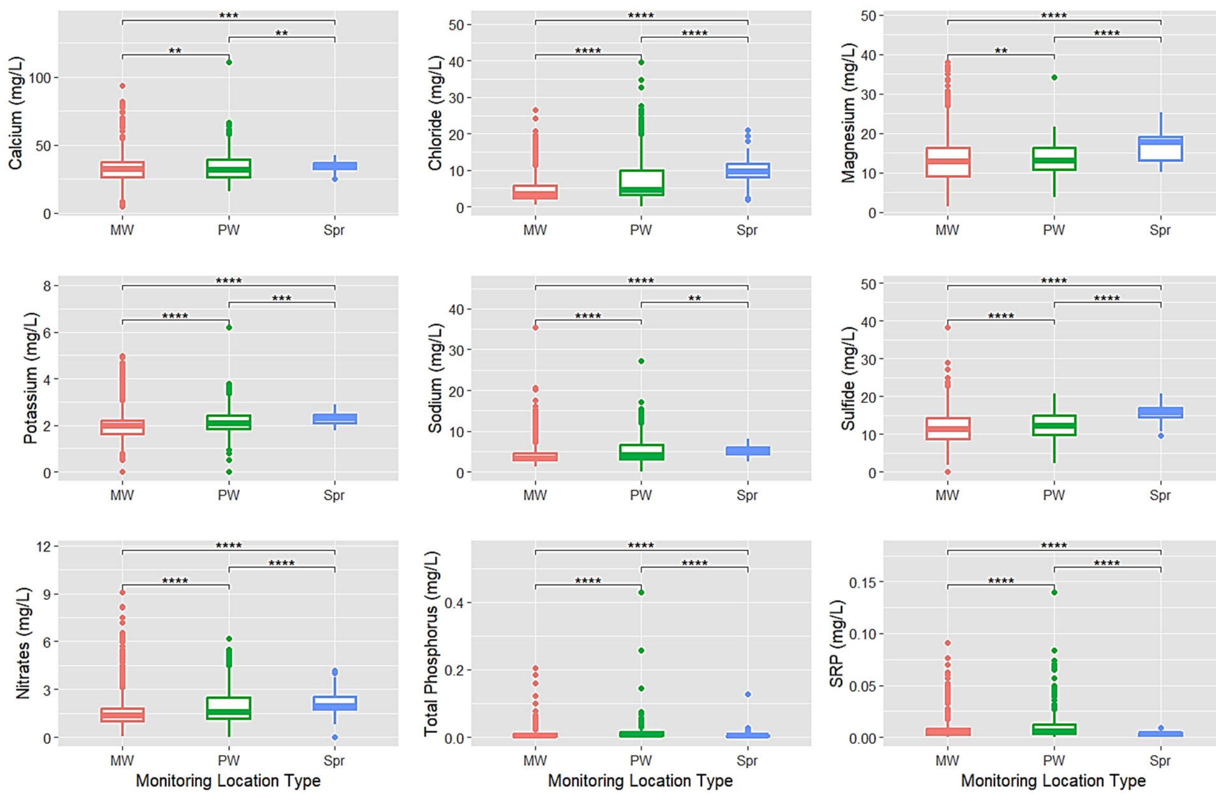

Figure 54. Boxplots showing the statistical distribution of major ions and nutrient concentrations (mg/L) by monitoring location type. The types of monitoring locations include monitoring wells (MW), purveyor wells (PW), and natural springs (Spr). Statistical significance between each group is noted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

Arsenic is the only trace metal with median concentrations at detectable levels for each of the monitoring location groups. Arsenic concentrations of each group are significantly different from each other with purveyor wells having the highest levels of arsenic (median = 0.0031 mg/L) and monitoring wells having the lowest levels (median = 0.0026 mg/L). Purveyor wells are the only type of monitoring location with a median copper concentration at a detectable level (0.0011 mg/L). This makes sense given 10 of the 11 sites with median copper concentrations at detectable levels were purveyor wells (see Section 3.4.4). Fluoride is generally not detectable among the location types (medians at zero). However, as a group, the springs have enough detectable data that the Q3 value is 0.1 mg/L though the only three sites that had median concentrations of fluoride at detectable levels were not springs (see Section 3.4.5).

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

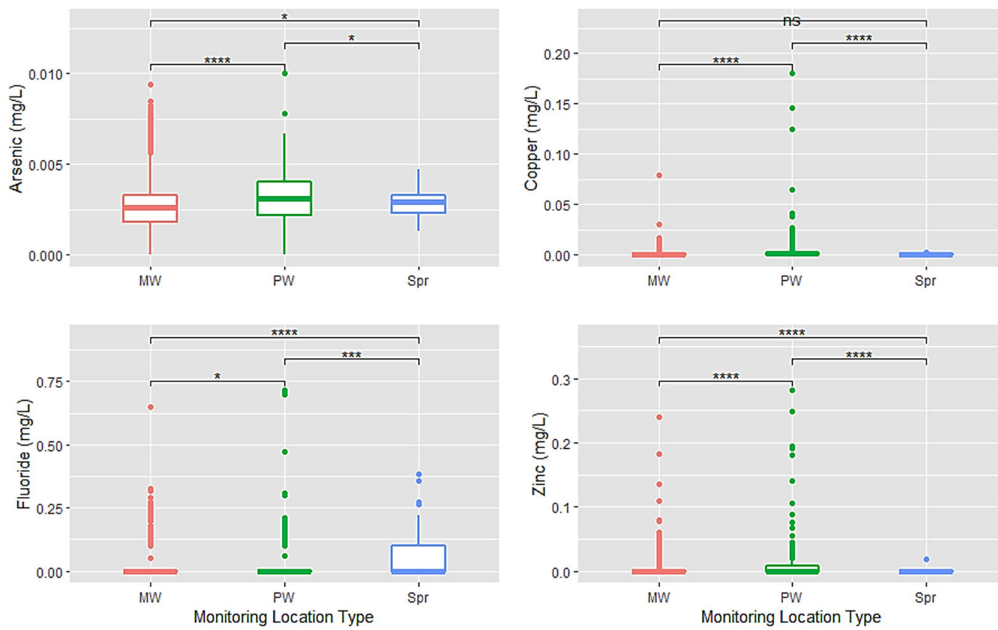

Figure 55. Boxplots showing the statistical distribution of certain trace metal concentrations (mg/L) by monitoring location type. The types of monitoring locations include monitoring wells (MW), purveyor wells (PW), and natural springs (Spr). Statistical significance between each group is noted as follows: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

4.2. Confining Layers

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

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

Two sets of wells are used to assess differences in groundwater quality within different lower confined aquifers (Figure 57, Table 5). One set is in North Spokane within the Hillyard Trough and includes the Fire Station at Houston and Regal monitoring well (6306N04) and the North Spokane Irrigation District Site 4 well (6328H01). The Fire Station monitoring well is completed in the upper unconfined unit, while the North Spokane Irrigation District well is completed in the lower confined unit.

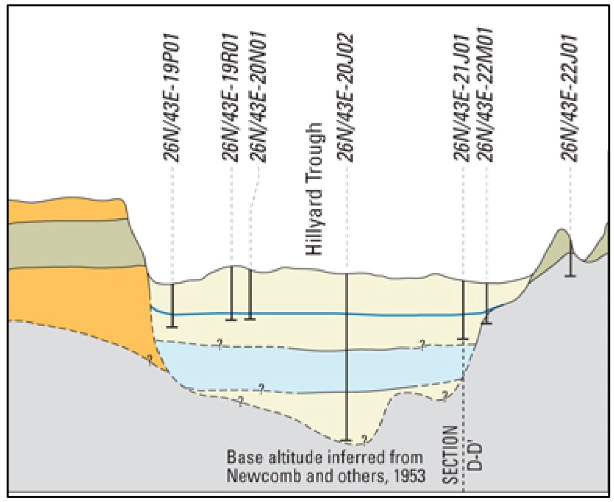

Figure 56. A cross section of the Hillyard Trough showing the unconfined and confined aquifer. Tan is Spokane Valley-Rathdrum Prairie Aquifer sediments, blue is the fine-grained confining layer, orange is basalt, green denotes fine grained material, and gray is bedrock. This figure is modified from Kahle and Bartolino, 2007.

The other set of wells is in Spokane Valley and includes the EVHS monitoring well (6436N01) and the Plantes Ferry Park monitoring well (5404A01). The Plantes Ferry Park monitoring well is completed under a localized, discontinuous layer of silty clay that is approximately 65 feet thick according to the well log. The EVHS well, though slightly deeper, is not located under a confining layer.

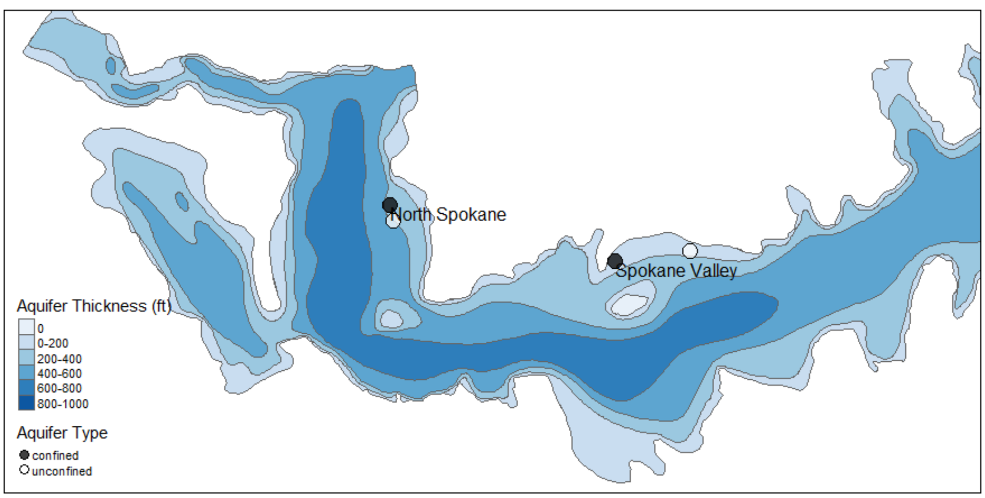

Figure 57. Monitoring locations used to compare groundwater in the confined and unconfined aquifers in the Hillyard Trough in North Spokane and in the Spokane Valley near Plantes Ferry.

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

Table 5. Comparison of wells completed in the unconfined (U) and confined (C) aquifer in North Spokane and Spokane Valley. For each parameter, the median value for each well is shown. Median values are based on data from sampling events where both wells in each pair were sampled on the same day; therefore, values reported here may differ from those reported elsewhere in this report. Values in red indicate parameters for which the confined aquifer is significantly different from the unconfined aquifer. Well types include monitoring wells (M) and purveyor wells (P). Cadmium, chromium, lead, mercury, and zinc are not shown as median values are zero for all locations and there is no significant difference between the paired sites.				
	North Spokane		**Spokane Valley**	
	Fire Station	Irrigation District	East Valley HS	Plantes Ferry
Well Characteristics	6327N04	6328H01	6436N01	5404A01
Aquifer Type	U	C	U	C
Well Type	M	P	M	M
Depth (ft)	219	274	125	119.5
Difference in Depth (ft)	55		5.5	
Parameter				
Temperature (C)	13.2	11.4	13.5	13.5
pH	7.72	8.12	7.38	6.84
Dissolved Oxygen (mg/L)	7.57	6.55	9.11	0.29
Conductivity (uS/cm)	415.0	233.5	561.3	311.5
TDS (mg/L)	231.5	138.0	350.0	219.0
Calcium (mg/L)	36.6	26.0	65.8	26.2
Chloride (mg/L)	11.1	5.87	8.30	2.16
Magnesium (mg/L)	25.45	11.45	28.9	13.28
Potassium (mg/L)	3.77	2.16	4.01	5.34
Sodium (mg/L)	11.8	4.92	9.34	10.95
Sulfate (mg/L)	19.6	11.8	18.3	21.4
Nitrate (mg/L)	2.98	1.12	5.69	0.00
Total Phosphorus (mg/L)	0.00248	0.00371	0.05188	0.23100
SRP (mg/L)	0.00177	0.00345	0.05029	0.13171
Fluoride (mg/L)	0.0	0.0	0.296	0.103
Arsenic (mg/L)	0.00164	0.00299	0.00246	0.0
Copper (mg/L)	0.0	0.00104	0.0	0.0
Iron (mg/L)	0.0	0.0	0.094	12.46
Manganese (mg/L)	0.0	0.0	0.00164	0.718

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

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

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

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

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

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

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

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

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