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Geochemical Analysis of Surface and Ground Waters Around Cle Elum, WA; Implications for the Proposed Exempt Well Moratorium

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Abstract

The Yakima River drainage is one of the most heavily irrigated regions in the state, and water use has been much contested and litigated. Due to this water demand and the increase in drilling of domestic wells, a moratorium on exempt well drilling was proposed in 2007. In this study geochemical data is used to evaluate the surface-groundwater interaction in the area around Cle Elum, WA. The hydrogeology of this area is poorly understood due to the complex stratigraphy where the valley floor meets the bedrock of the Cascade Range. It is important to understand the relationship between groundwater and surface water because more than the available surface water in the Yakima drainage is appropriated and many water rights holders depend on this water for their livelihood. This study began as a class project for an Environmental Geochemistry class at Central Washington University. Students collected samples from over 30 domestic wells and nearby surface water sources in the Cle Elum/Roslyn area. Trace element and major ion data are presented for these samples and are used along with geochemical analysis to draw conclusions regarding the different sub-surface water bearing units as well as the relationship between the surface and ground waters. This report concludes that exempt wells need monitoring and suggests the current policy of over-appropriation be reviewed.

INTRODUCTION:

This report is the culmination of an Environmental Geochemistry class project at Central Washington University. The study consisted of collecting samples in the upper watershed of the Yakima River in WA State. Geochemical analyses of these samples were performed to determine trace and major ion concentrations, alkalinity, and pH. Also, inferences regarding the aquifer material and surface-ground water connections are explored.

The Yakima basin watershed encompasses 15,940 km and the main stem of the river flows a total 350 kilometers. Beginning on the east slopes of the Cascade Range at an elevation of 920 meters, the Yakima river flows generally south-east until its confluence with the Columbia River at 104 meters elevation. The mean annual precipitation at the headwaters exceeds 305 cm but it is only 18 cm at the confluence with the Columbia (Kent, 2004). The Yakima River flows through the "breadbasket" of Washington, where much of the state's agricultural products such as apples, pears, wheat, hops, hay and corn are grown. The sampling sites were located in and around the town of Cle Elum, 50 kilometers east of the cascade crest, and receive an average annual precipitation of 70 cm.

Surface water in the Yakima Basin is "over-appropriated," meaning that more water has been legally allocated than is naturally available. The exact amount of available surface water is unknown; however, it is known that the current amount of available surface water is insufficient to supply the increase in demand for domestic and agricultural uses as well as to maintain fish populations. Therefore, "these demands must be met by ground-water withdrawals and (or) by changes in the way water resources are allocated and used" (Vaccaro, 2007). Due to the increase in use of groundwater a moratorium on the drilling of exempt wells was proposed in 2007. The moratorium called for the cessation of developing new wells until the interaction between the groundwater and surface water in the basin is better understood. This study attempts to draw conclusions regarding this relationship by analyzing geochemical data in hopes of determining distinct chemical facies that reflect primarily the different water bearing units and influent/effluent locations.

METHODS:

The first step in this process is determining sample locations for groundwater and surface water (see Figure 1). In the case of a well, owner permission is first obtained and the Unique Well Number (UWN) recorded. The well is flushed until a minimum of 2 liters are taken to expel any pipe corrosion. Next, two samples are collected, one 60 mL bottle filtered, and another 125 mL bottle unfiltered. A 60 mL syringe and Whatman brand 0.45 micrometer filter are used to filter the water, and each sample bottle is rinsed with source water prior to collection. A conductivity meter is used to determine conductivity and temperature of source water. The conductivity meter is calibrated in the field immediately before sample collection. The samples are labeled according to a pre-determined system, where the location is recorded (SCE, NCE, TEA and ROS) followed by an integer corresponding to the order in which the sample is collected (NCE 1 being the first sample collected within the North Cle Elum study area). All samples were collected during the months of October and November 2008.
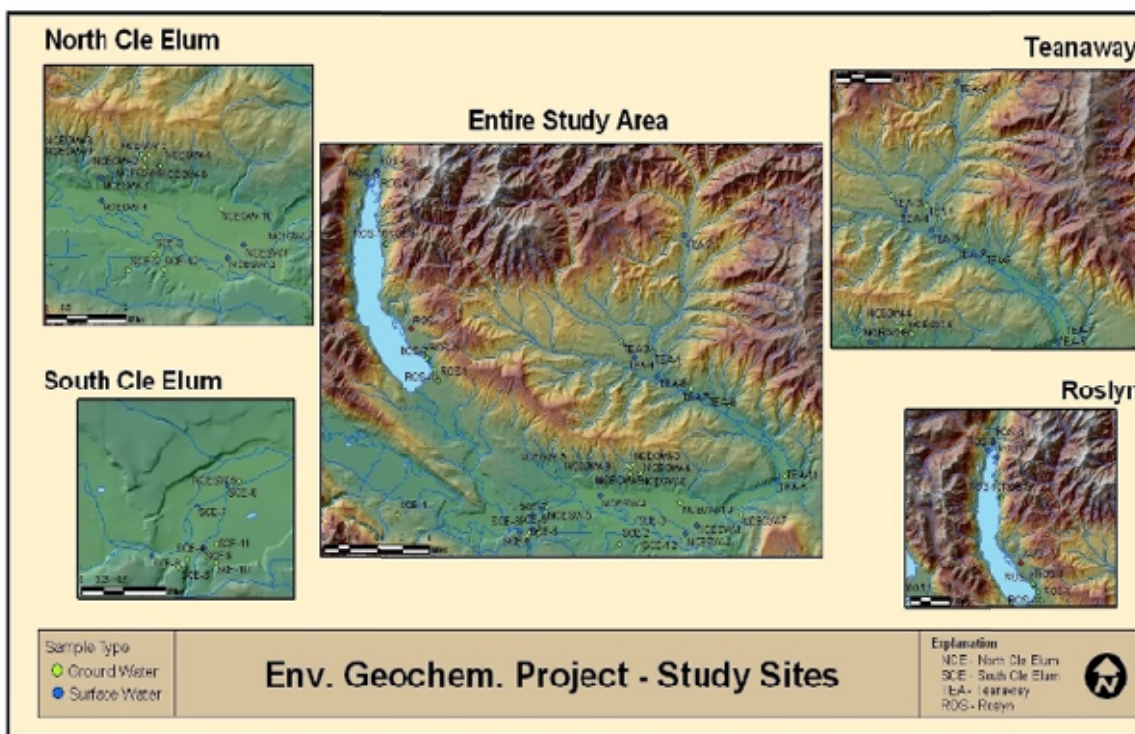
Figure 1: Map of study sites around Cle Elum, WA.

Alkalinity is determined by titration with 0.01N HCl. First, the pH meter is calibrated using pH 7.0 and pH 4.0 buffer solutions and an aliquot of 25 mL or 50 mL is measured with a graduated cylinder and poured into a beaker. An auto-pipette is used to add the HCl in increments of 0.5 ml or 1.0 ml, and a pH meter used to determine the initial pH and pH subsequent to each addition of HCl. The titration continues until the sample reaches a pH at or below 2.5. This information is used to create a titration curve (ml of HCl vs. pH), and from the titration curve, a Gran Plot is created (ml of HCl vs. $(V+v)(10^{-pH})(10^{-4})$), where V is the initial volume of sample, and v the volume of acid added (Drever, 1997). The laboratory procedures are carried out within 1 week of sample collection. In order to determine trace element and major ion concentrations a 60 ml bottle of filtered water is acidified to 2% using ultra-pure HNO_3^- and then analyzed using a Thermo Elemental X-series Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). The ICP-MS is used to analyze the ions: Na, Mg, Al, K, Ca, V, Mn, Fe, Ni, Cu, Zn, As, Se, Rb, Sr, Ba, Ce, Nd, Sm, Eu, Pb, U. The ICP-MS is calibrated using standards of increasing concentration in order to create a calibration curve. Also, a standard is run every five samples as an unknown as a way to ensure quality control.

ANALYSIS:
The data obtained from the ICP-MS runs are filtered to be sure that the information is below 10% standard deviation and that the values are above detection limits. After this, ions of particular interest are examined using x-y plots comparing concentration.

Furthermore, a map is created showing each sample location (see Figure 1) using GIS programming. Two maps were used to infer the underlying geologic units that wells were drawing water from (Tabor 2000, Vaccaro 2007).

RESULTS:

Pertinent results are presented here. The ions of interest have been reduced to only 13 of the original 22; Na, Ca, Mg, Al, and K were examined because these are commonly dominant constituents of igneous minerals. Fe, Mn, Cu, and Zn were examined to see if pipe corrosion might be a factor influencing the results. As and Pb were examined because of their importance as a threat to health in humans. And Ba, Sr and Zn were used because for each sample run on the ICP-MS these ions were always above detection limits and had standard deviations of less than 10 percent.

Table 1:
Sample Descriptions of Groundwaters Showing Rock Type and Depth to Water

GROUNDWATERS					
Sample #	Well Depth	Unique Well #	Depth to Water	Rock Type	Notes
ROS-1	NA	NA	148-195'	Al, Ti	Al-Alluvium, Ti-Till
ROS-2	128 ft	ACX678	128'	RF under Al, Ti	RF-Roslyn Formation, Arkose (Ca)
ROS-3	NA	NA	103'	Al, Ti	
ROS-9	NA	NA	170-211'	SF	SF-Swauk Formation, Arkose (Ca)
ROS-10	NA	ALF645	114-658'	6 Water bearing units	Very Heterogeneous
ROS-11	580 ft	NA	439-459', 519-579'	SF	Arkose (Ca)
SCE-1	643 ft, water at 25 ft	BAP327	23-403'	Ti, Dp	Dp-Darrington phyllite (meta slate), Chlorite (Cl), quartz (Si)
SCE-2	Owner said 188 ft	NA	188'	RF, Qa	Shallow Qa overlaying RF, close proximity to Grande Ronde Basalt (GRB)
SCE-3	Owner said 175 ft, water at 75 ft	NA	75-175'	"	"
SCE-4	Owner said about 62 ft	NA	62'	TB	TB-Teanaway Basalt
SCE-5	Owner said 16 ft, from spring	NA	16'	TB	
SCE-10	Well Log: 300 ft, water at 180 ft	AKL799	180'	TB (0-50'), MF (50'-on)	MF-Manastash Formation Feldspathic sandstone, quartz, coal (Na, Ca, Si, Cl, S)
SCE-11	Owner said 50 ft	ABL081	0-50'	TB	

SCE-12	NA	NA		RF, Qa	Shallow Qa overlaying RF, close proximity to Grande Ronde Basalt (GRB)
TEA-1	580 ft	AKW643	480-580'	RF	
TEA-3	284 ft	AKL748	200-284'	RF	
TEA-7	140 ft	ACL107	0-140'	RF	Numerous water bearing units, No perforations
TEA-8	300ft	NA	0-300'	RF	No perforations
TEA-9	117ft	NA	97-117"	RF overlain by stream Al	
TEA-10	338 ft	17FE358	220-338'	"	
TEA-11	460 ft	APG066	380-445'	RF	
NCEGW1	420-460 ft	BAF981	138-159'	RF	Arkose (Ca), coal bearing
NCEGW2	> 300 ft	AFH667	340-380'	RF	(Ca), coal bearing
NCEGW3	197 ft	ACL721		"	"
NCEGW4	720 ft	ALE102		"	"
NCEGW5	351 ft	ACL939		"	"
NCEGW6	465 ft	ACL940	260-420'	"	"
NCEGW7		AFO879		Igneous Flow under shallow landslide deposit	Landslide from RF?
NCEGW8	580 ft.	ALF420	360-560'	RF	(Ca)
NCEGW9	705 ft.	AKW793	500-600'	RF	Arkose (Ca), coal bearing
NCEGW10	305 ft.	AFH654	250-285'	RF	Arkose (Ca)
NCEGW11	440 ft.	AFH689	280-300', 400-440'	RF	"

Table 2: *Sample Descriptions of Surface Waters Showing Rock Type and Notes*

Surface Water		
Sample #	**Comments**	**Rock Type**
ROS-5	Water was moving quickly; not stagnant	Several lithology types: Kes (shuksan Greenschist), metavolcanics, siliceous, chlorite, qtz, albite, carbonate, and Swauk formation.
ROS-6	Sample taken from pool of water that the spring feeds into	Swauk formation sandstone, feldspathic, micacious and gabbro dikes, diabase and basalt
ROS-7	Somewhat stagnant	Teanaway formation at the south end; Small portion of the Silver Pass volcanic member dacite and andesite flows and pyroclastic rocks; Roslyn frm;.
ROS-8	Water was moving quickly; not stagnant	Large drainage with portions in the Swauk SS, Ingalls tectonic cmpx. - serpentinite, metaperidotite, horneblende; rocks of mt. daniel.
ROS-14		Teanaway frm. And quaternary alpine glacial deposits.
SCE-6		Running over alluvium here
SCE-7	Dan tasted chlorine in sample	Drains various quaternary alluvial deposits.
SCE-8	Stagnant	Drains various quaternary alluvial deposits.
SCE-9	Large pond	Lies in quaternary alluvial deposits.
TEA-2	NA	Swauk formation and a bend of Teanaway Basalt
TEA-4	NA	Drains a large section of lower and middle Roslyn frm.
TEA-5	NA	Lower Roslyn and teanaway frm.
TEA-6	NA	Drains a large section of lower and middle Roslyn frm.
NCESW1	N/A	Running over alluvium here
NCESW2	N/A	Running over alluvium here
NCESW3	lots of leaves	Drains Upper and Middle RF
NCESW4	N/A	Drains Upper and Middle RF
NCESW5	N/A	Upstream of Cle Elum River confluence near Crystal Creek confluence
NCESW5	N/A	

DISCUSSION:

In this section data is compared in various ways to determine distinctly different chemical facies within the waters of the upper Yakima Watershed. Each sample site is compared against the others in hopes of finding similarities in chemical composition, geologic unit, and location relative to other sites.

First the ground waters are examined. Selected graphs from the data analysis are presented, the X-Y plots of Na vs. Mg (see Figure 2), Na vs. Ca (see Figure 3), Mg vs. Ca (see Figure 4), Al vs. K (see Figure 5), Ca vs. Sr (see Figure 6), and Zn vs. Ba (see Figure 7). The sites selected for comparison come from Table 3.

Table 3: *Groundwaters that Show Similar Chemistry. Derived from X-Y Plots.*

| Comparison Analysis			
X-Y Plots	**Rock Type**	**Map Location**	**Depth to water**
Group 1			
NCE 1	RF (coal)	On cle elum ridge	138-159'
NCE 4	RF	Cle elum ridge (within 1/4 mi of NCE 1)	340-380'
TEA 7 (?)	RF	In teanaway valley, N. of Cle elum ridge	0-140'
Group 2			
SCE 2	RF, Qa	In town, very near SCE 3	188'
SCE 3	RF, Qa	In town, very near SCE 2	75-175'
SCE 10	TB, MF	E. of SCE 2,3 about 1/2-3/4 mi	180'
Group 3			
NCE 2	RF	Nearby NCE 5, 6 about 1/4 mi	340-380'
NCE 5	RF	Sam property as NCE 6	351 ft
NCE 6	RF	Same property as NCE 5	260-420'
NCE 9	RF	E of others, 1/2 mi, higher elevation	500-600'
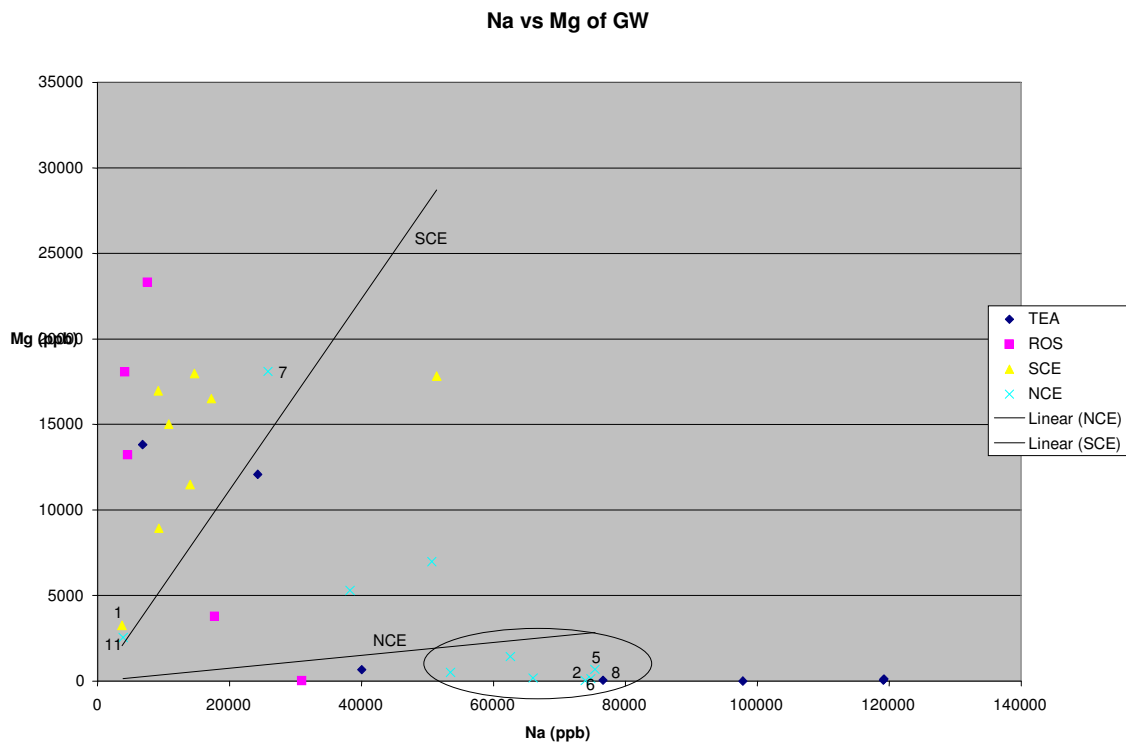
Figure 2: Graph of ion concentrations Na (ppb) and Mg (ppb). Trendlines are best-fit of SCE and NCE points indicating general trend.
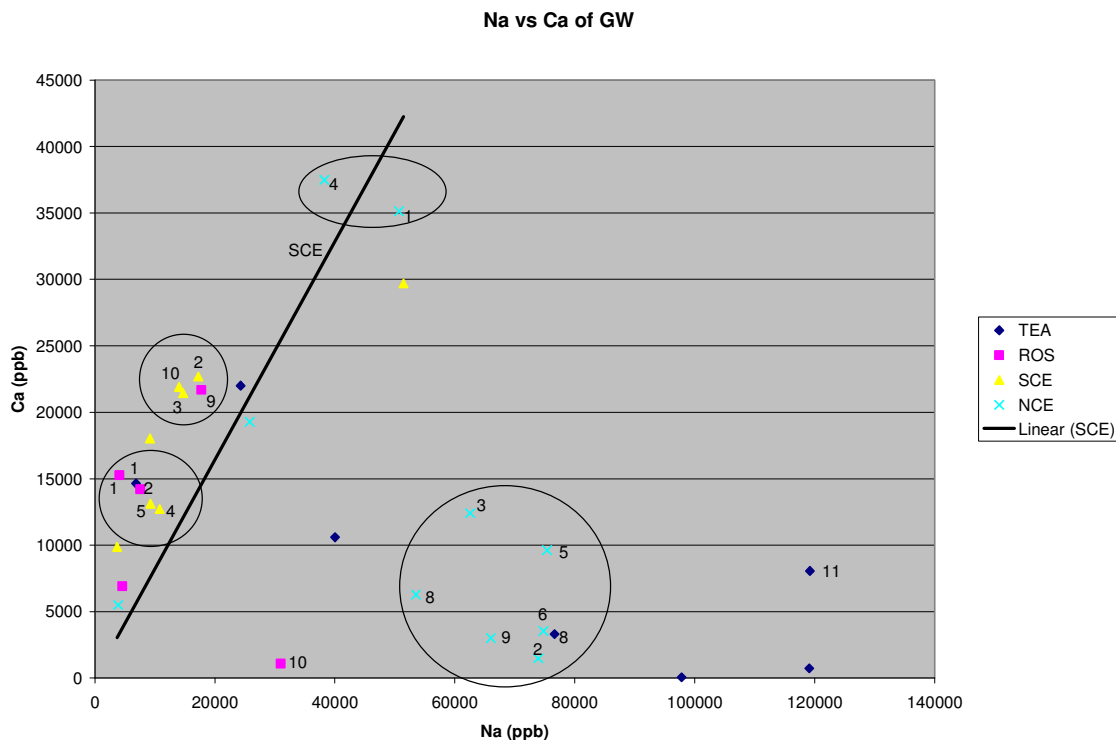
Figure 3: Graph of ion concentrations of Na (ppb) and Ca (ppb), note the circled areas indicating similar chemical composition. Trendline shows best-fit of SCE points.

The first sites to compare are NCE 1 and NCE 4 (see Table 3), both of these samples lie within the Roslyn Formation, also the two sites are within one half kilometer of each other. These two sites have very similar chemical signatures for all of the ions examined except for Cu and Zn (Appendix A). One can see in Figures 3, 4, and 6 that these two sites plot outside of the average concentrations of Na, Ca, Mg, and Sr. It is quite possible that these two samples were taken from the same aquifer body and that different well piping or age of piping would contribute to the differences in Cu and Zn concentrations (see Figure 7).

Next are SCE 2, 3, and 10 (see Table 3), these samples plot very close to one another on the graphs of Na vs. Ca (see Figure 3), and Ca vs. Sr (see Figure 6), also SCE 2 and 3 plot together on Figure 5 (Al vs. K). The three wells are all located on the valley floor

(see Figure 1) and water is found at very similar depths; within 5 meters of one another. In Figure 1 it can be seen that SCE 2 and 3 are right next to each other, while SCE 10 is about 3 kilometers west of SCE 2 and 3. Also, SCE 2 and 3 are within the Roslyn Formation which is arkosic sandstone with coal seams, but SCE 10 mapped within the Teanaway Basalt formation overlying the Manastash Formation which is composed primarily of arkosic sandstone. Since the locations have similar chemistry in Mg, Ca and Na which are the dominant ions in precipitation and also since the water level is relatively shallow maybe all three of these waters were taken from an unconfined aquifer which receive recharge from precipitation or surface waters. The similarities of SCE 2, 3 and 10 in Figure 6 (Ca vs. Sr) could be accounted for by ion exchange occurring in the soil, or chemical exchange within rocks.
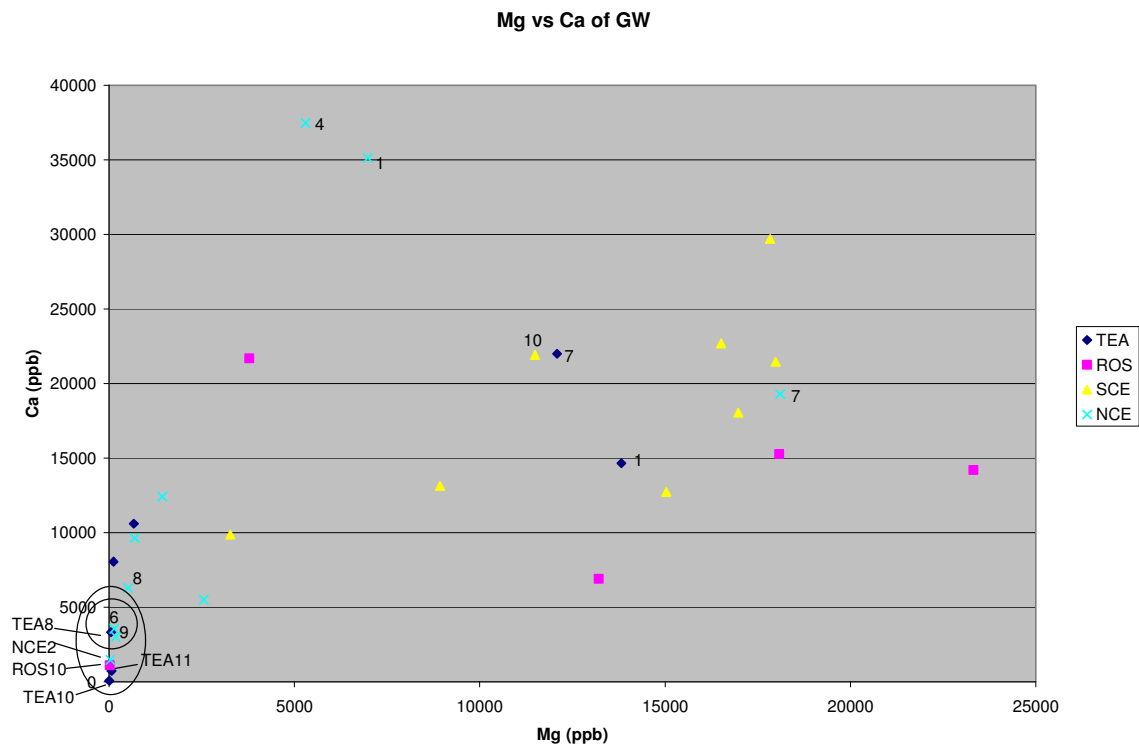
Figure 4: of ion concentrations, Mg (ppb) and Ca (ppb)

These points also fall on the best fit line set by all SCE ground waters found in Figures 3 and 6. These trendlines shows that the proportions of Ca to Sr are similar for all SCE ground waters (see Figure 6) and a parallel relationship between Ca and Na (see Figure 3). This indicates that these sites are being recharged by the same water but have different residence times; with longer residence times having higher concentrations of Na and Ca but the ratio staying the same.

The next comparison is between SCE 5, 8, 9 and TEA 4; these sites are mixed both surface and ground waters (Appendix A). SCE 8, 9 and TEA 4 are surface waters while SCE 5 is a very shallow well (5 meters). The three SCE samples all lie within close proximity to one another (see Figure 1). SCE 8 and 9 lie slightly west, and upstream of SCE 5, TEA 4 is not in close proximity to any of these sites. Furthermore it is highly unlikely that the SCE waters

could have mixed with the TEA water and vice-versa because they are separated by a ridge which would obstruct groundwater flow pathways. Also, the Teanaway surface water joins the trunk stream downstream of all of the SCE sample locations meaning that TEA could not be mixing with the SCE samples at those locations. One thing that all of these surface water sites have in common is that they all flow through the Roslyn Formation. It seems very likely that the similarities for the SCE sites can be attributed to the surface waters receiving effluent from groundwater. This is illuminated because SCE 5 plots along other SCE groundwaters; therefore, the surface waters are not affecting SCE 5 but rather the surface waters are in an effluent system where the river receives water from the water table. SCE 5 illustrates that the surface waters and ground waters are mixing.
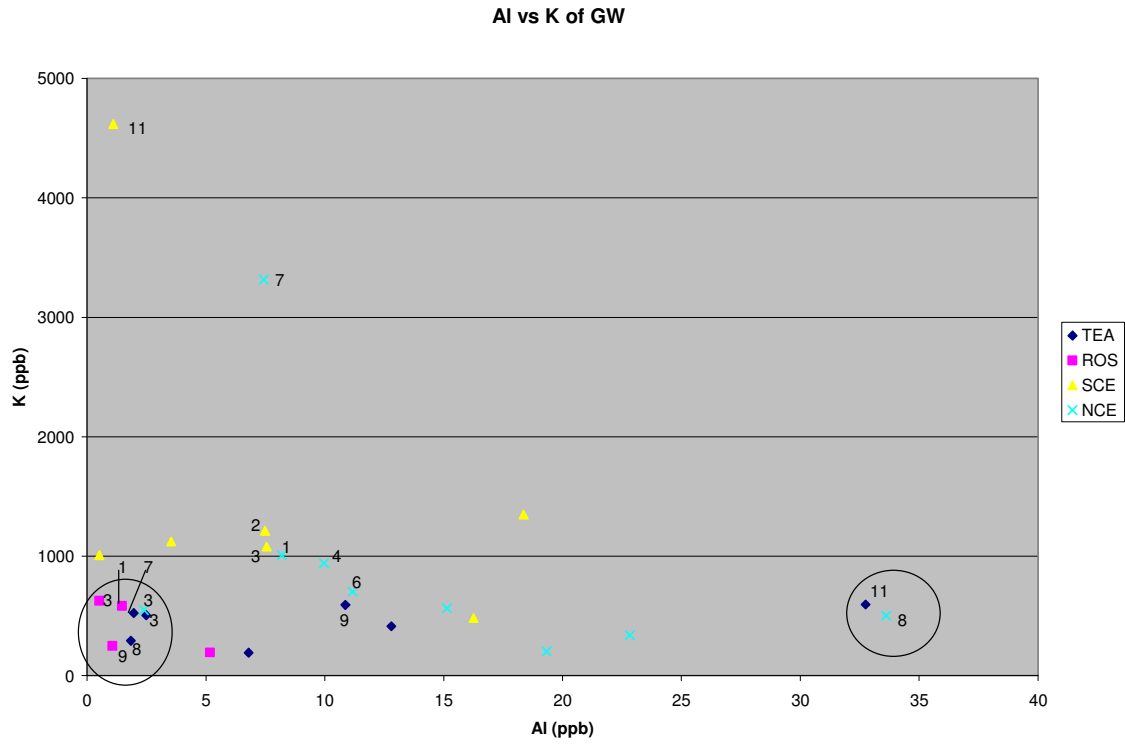
Al vs K of GW

Figure 5: Ion concentrations Al (ppb) and K (ppb).
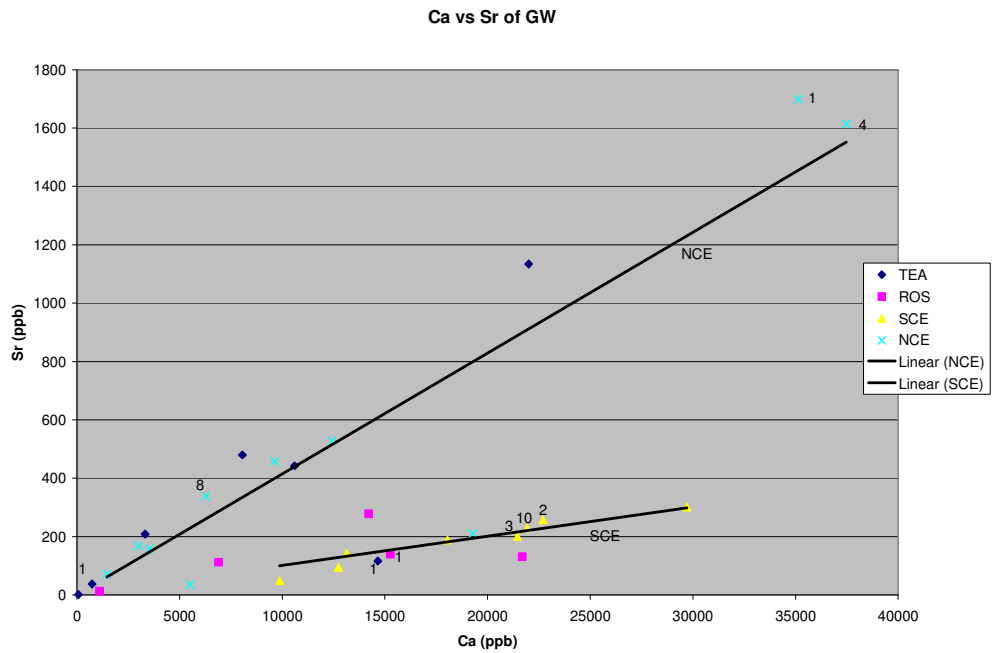
Ca vs Sr of GW

Figure 6: Ion concentrations of Ca (ppb) and Sr (ppb). Trendlines show best-fit for NCE, TEA and SCE, ROS points.
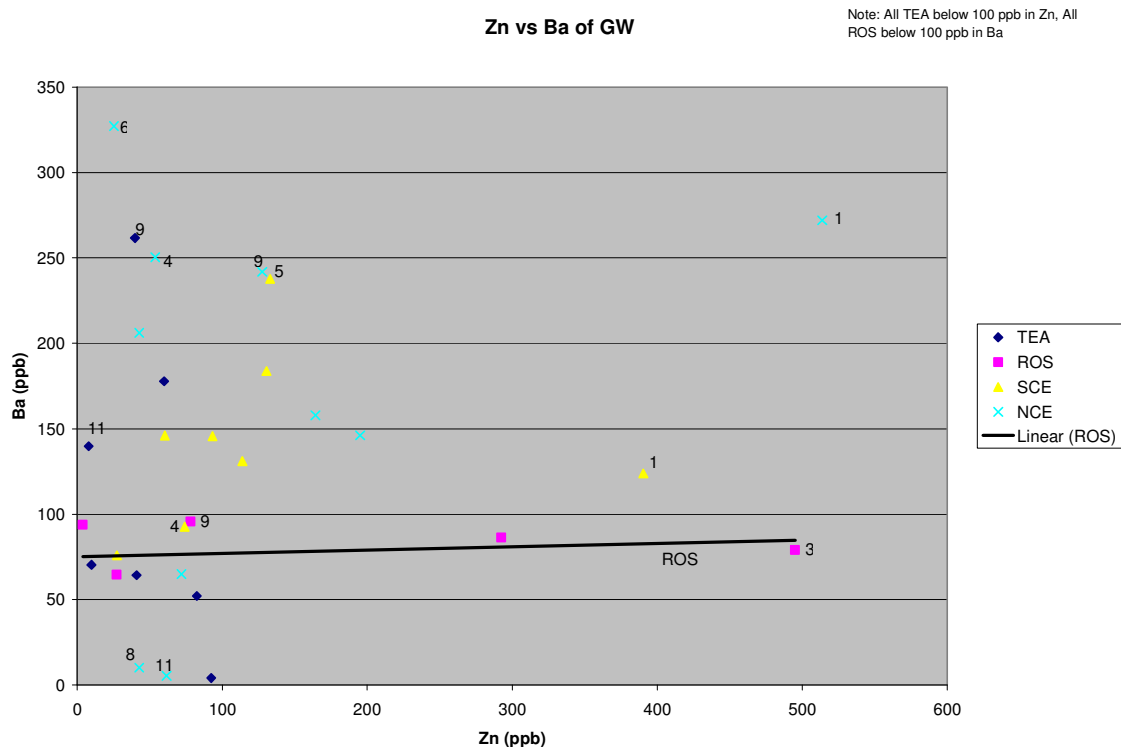
Figure 7: Ion concentrations of Zn (ppb) and Ba (ppb). Trendline shows best-fit of all ROS points.

It is interesting to note that Figure 6 (Ca vs. Sr) shows two distinct trendlines. There is one trendline defined by the best fit of NCE and TEA groups, and another trendline set by the best fit of SCE and ROS groups. This is interesting because the two different lines suggest that the majority of groundwaters are undergoing one of two chemical reaction pathways.

SUMMARY:

The comparison of SCE 5, 8, and 9 shows that surface waters and ground waters can mix. It is also found that samples that lie on a best-fit line could represent waters within the same aquifer, but have different residence times as in the case of SCE 2, 3 and 10. Also, something that seems insignificant such as the type and age of piping used in a well could be a factor affecting the concentration of trace elements.

Understanding the relationship between the chemistries of different waters can be a very difficult task. Many factors can influence what ions are present. Other actions that can be done to help characterize each location are determining where the water table lies relative to sea level instead of depth to water from the surface; this value would take elevation into account and make it possible to visualize where the subsurface bodies lie spatially relative to one another. Also characterizing the precipitation chemistry and trying to factor that contribution out in some way would make it more possible to see what water-rock interactions are taking place to influence the water chemistry. Using statistical software to do factor analysis and determine co-variance would be helpful as well. In short, there was so much information that most of the time was spent compiling data rather than analyzing it. Future studies should focus on spending

more time breaking the data down into a reasonable size; doing a few Piper diagrams would be helpful since concentrations are taken out so as to be able to compare both surface and ground waters on the same chart. Another benefit of a Piper diagram is that one can view the contribution of six ions within a single graph. Future studies should choose their sample site carefully by reading well logs thoroughly to determine what material the water most likely lies in. In this way, one could try to characterize the different ground waters based off of the aquifer material. Further work on this study should involve Ion Chromatography to get a wider spectrum of ions in the data, particularly sulfates and nitrates.

In light of the current moratorium policy and the legislation that will ensue, exempt wells should be monitored to get a better picture of where the water in the Yakima watershed is going. More importantly, the current system of "over-appropriations" must be disbanded so that a balance between ecosystem needs and the needs of people can be reached.

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Appendix A

Abridged Data Table Showing 13 Ions Analyzed

Run	Source Type (surface/ground)	23Na ppb	24Mg ppb	27Al ppb	39K ppb	44Ca ppb	55Mn ppb	56Fe ppb	65Cu ppb	66Zn ppb	75As ppb	88Sr ppb	137Ba ppb	208Pb ppb	Total ppb
High															
Low															
Groundwaters															
TEA-1	ground	6835	13820	12.8	415.3	14650.0	2.6	149.2	256.4	92.4	0.0	116.6	4.1	6.2	36360.3
TEA-3	ground	40030	666.1	2.5	506.4	10600.0	25.6	13.7	2.6	82.5	3.0	442.3	52.2	0.0	52427.0
TEA-7	ground	24290	12080	2.0	523.7	22000.0	59.9	54.1	16.7	59.9	1.6	1134.0	177.8	0.0	60399.1
TEA-8	ground	76620	52.2	1.8	293.3	3316.0	2.1	49.8	5.1	9.8	0.0	208.5	70.4	0.0	80628.9
TEA-9	ground	119200	118.9	10.9	592.6	8056.0	6.0	0.0	0.0	39.8	0.7	480.0	261.6	0.0	128767.3
TEA-10	ground	97820	3.7	6.8	193.3	68.4	0.0	20.6	43.3	40.9	1.3	1.5	64.3	0.0	98263.9
TEA-11	ground	119100	62.8	32.7	596.2	734.6	1.2	13.4	7.4	7.8	2.9	37.1	139.8	0.6	120736.5
ROS-1	ground	4114	18080	1.5	585.9	15270.0	0.0	0.0	14.0	27.2	6.5	139.1	64.7	0.0	38303.7
ROS-2	ground	7548	23320	0	539.5	14210.0	20.4	191.5	5.9	292.4	0.6	277.2	86.4	0.0	46491.3
ROS-3	ground	4574	13210	0	627.2	6898.0	145.7	9.7	0.0	495.1	0.0	111.5	79.0	0.0	26151.5
ROS-9	ground	17730	3781	1.1	250.0	21690.0	0.0	6.0	16.2	78.2	0.8	131.3	95.7	0.0	43780.3
ROS-10	ground	30980	22.9	5.2	194.1	1100.0	0.0	2.0	4.1	3.8	1.7	12.8	93.7	4.2	32424.4
SCE-1	ground	3695	3267	16.3	484.3	9872.0	1.4	38.1	11.8	60.4	3.2	48.7	146.1	1.0	17645.1
SCE-2	ground	17240	16510	7.5	1214.0	22690.0	339.5	19.9	17.6	130.5	2.4	257.3	183.8	0.0	58612.4
SCE-3	ground	14700	17980	7.6	1082.0	21460.0	4.0	53.0	5.8	113.8	1.3	200.4	131.1	0.0	55739.1
SCE-4	ground	10790	15030	3.5	1124.0	12730.0	1.1	18.1	42.4	74.2	0.6	94.3	92.8	0.0	40001.2
SCE-5	ground	9288	8926	18.4	1348.0	13130.0	2.2	6.9	73.1	133.0	1.8	142.2	237.7	3.8	33311.1
SCE-10	ground	14020	11490	0.0	1010.0	21920.0	6.0	102.3	4.8	27.4	1.4	229.3	75.9	0.0	48887.6
SCE-11	ground	9187	16970	1.1	4620.0	18040.0	720.0	623.6	11.0	390.4	1.1	188.1	123.9	0.0	50876.2
SCE-12	ground	51420	17830	2.0	12890.0	29700.0	44.2	3.3	35.8	93.2	2.4	302.0	145.7	0.0	112468.6
NCEcitywater	ground	3868	2554	22.8	338.3	5505.0	1.3	26.8	2.5	61.5	0.0	35.6	5.4	0.0	12420.5
NCEGW-1	ground	50680	6981	8.2	1008.0	35130.0	60.4	46.6	11.3	513.8	2.2	1699.0	272.0	1.6	96414.1
NCEGW-2	ground	73920	30.86	19.3	203.7	1469.0	1.6	10.8	1.7	42.7	2.3	71.0	10.2	0.0	75783.8
NCEGW-3	ground	62550	1433	2.4	550.7	12410.0	6.8	0.0	12.3	71.9	1.2	527.6	64.9	0.0	77630.6
NCEGW-4	ground	38260	5298	10.0	940.4	37480.0	40.8	67.5	56.0	53.7	0.8	1614.0	250.4	1.6	84073.2
NCEGW-5	ground	75390	693.6	15.1	564.4	9632.0	21.7	25.4	3.6	195.0	2.7	458.0	146.2	0.0	87148.3
NCEGW-6	ground	74770	139	11.2	703.7	3545.0	2.9	0.0	15.9	25.3	1.6	158.1	327.2	0.0	79696.4
NCEGW-7	ground	25810	18100	7.4	3317.0	19290.0	3.9	341.4	6.8	164.2	0.0	210.2	157.9	0.0	67408.7
NCEGW-8	ground	53510	513.4	33.6	501.9	6275.0	1.1	18.3	10.7	42.7	0.0	338.2	206.2	2.9	61454.5
NCEGW-9	ground	66020	182.4	89.0	559.4	3005.0	3.0	139.1	9.0	127.6	6.3	168.2	241.9	1.2	70552.0
	Average	40132.0	7638.2	11.8	1259.2	13395.9	50.8	68.4	23.5	118.4	1.7	327.8	133.6	0.8	63161.9
Surface Water															
TEA-2	surface	1763	9578	1.5	230.8	8678.0	0.8	0.0	9.0	6.9	0.0	46.3	4.0	0.0	20314.3
TEA-4	surface	2809	3131	1.0	311.3	9999.0	5.5	7.5	53.6	39.4	0.0	57.8	71.4	0.0	16487.0
TEA-5	surface	6772	7493	18.5	3211.0	9974.0	1.0	0.0	46.1	141.6	0.0	70.9	204.7	0.0	27931.0
TEA-6	surface	2939	9661	1.2	737.0	9070.0	0.0	0.0	5.2	45.7	0.0	58.5	90.7	0.0	22603.4
ROS-5	surface	2551	1733	2.7	339.4	9436.0	0.0	0.0	1.8	48.2	1.1	72.9	12.3	0.0	14199.7
ROS-6	surface	1744	3193	2.5	99.8	17510.0	0.0	8.4	2.2	37.4	0.0	55.6	0.7	0.0	22653.9
ROS-7	surface	1025	2711	5.9	203.9	3390.0	1.1	0.0	0.0	62.6	0.7	23.6	3.0	0.0	7426.5
ROS-8	surface	1017	2608	2.5	438.6	2823.0	0.0	0.0	1.3	43.0	0.0	20.2	2.5	0.0	6957.8
SCE-6	surface	2869	2264	9.3	292.2	4574.0	0.9	14.5	1.8	26.4	0.6	29.2	78.3	0.0	10159.9
SCE-7	surface	3870	2164	6.8	306.7	5810.0	0.0	35.7	110.1	39.9	0.0	34.2	72.5	2.2	12452.9
SCE-8	surface	10840	8383	19.3	962.6	10550.0	40.0	642.2	7.5	103.4	0.8	81.5	170.3	0.0	31800.4
SCE-9	surface	5241	5451	194.1	2347.0	9016.0	7.7	237.7	13.0	86.1	2.6	95.4	131.4	0.0	22823.3
NCESW-1	surface	3730	7835	11.7	272.2	10710.0	0.0	0.0	8.3	34.0	0.7	69.9	149.9	0.0	22823.0
NCESW-2	surface	3460	2312	10.6	243.5	4370.0	0.0	7.2	6.9	35.0	0.7	30.5	140.2	0.0	10617.0
NCESW-3	surface	10360	11840	13.4	974.1	25740.0	2.7	49.0	11.5	43.6	0.6	579.2	221.7	0.0	49836.1
NCESW-4	surface	47240	7952	55.4	2734.0	15810.0	9.8	104.7	2.1	78.8	2.1	545.5	222.9	0.0	74757.5
NCESW-5	surface	3307	2364	12.4	233.1	4452.0	1.6	17.9	0.0	23.9	0.0	28.9	116.1	0.0	10558.0
	Average	6561	5333.7	21.7	819.9	9524.2	4.2	66.2	16.5	52.7	0.6	111.8	99.6	0.1	22611.9

Note: Values in blue are particularly low concentrations; values in red are particularly high concentrations as compared with the rest of the data.

Appendix B

Table showing data collected in the field and alkalinity

Sample #	Conductivity (µS/cm)	Temperature (°C)	Normalized Conductivity (25°C)	pH	Alkalinity (meq/L)	well or surface
TEA-1	432	14.3	524.4	7.44	0.49	well
TEA-2	270	14.1	328.9	7.9	0.30	surface
TEA-3	463	14.3	562.1	8.17	0.47	well
TEA-4	212	14.3	257.4	7.69	0.27	surface
TEA-5	280	14.2	340.5	7.35	0.28	surface
TEA-6	430	14	524.6	7.75	0.28	surface
TEA-7	865	13.6	1062.2	8.08	0.64	well
TEA-8	866	22	918.0	8.28	0.60	well
TEA-9	1396	22	1479.8	8.27	0.95	well
TEA-10	1075	22	1139.5	8.09	0.67	well
TEA-11	1246	22	1320.8	9.32	0.77	well
SCE-1	73.1	11.1	93.4	7.03	0.24	well
SCE-2	261	12.8	324.7	6.89	0.74	well
SCE-3	224	10.9	287.2	7.7	0.90	well
SCE-4	181	13.3	223.4	7.2	1.29	well
SCE-5	143	12.1	179.9	7.45	0.43	well
SCE-6	62	24.2	63.0	7.54	0.09	surface
SCE-7	74.7	22.8	78.0	7.55	0.09	surface
SCE-8	176.2	22.8	184.0	7.31	0.37	surface
SCE-9	126.3	23	131.4	7.43	0.25	surface
SCE-10	278	23.8	284.7	8.09	0.63	well
SCE-11	291	23.8	298.0	7.52	0.68	well
SCE-12	549	23.9	561.1	8.24	1.22	well
ROS-1	242	22.3	255.1	8.04	0.25	well
ROS-2	292	21.9	310.1	7.2	0.31	well
ROS-3	160.9	22.1	170.2	6.95	0.17	well
ROS-4	76.1	-	-	7.46	0.02	surface
ROS-5	111.7	21.9	118.6	7.98	0.10	surface
ROS-6	981	22.9	1022.2	8.09	0.15	surface
ROS-7	1018	22.8	1062.8	7.68	0.04	survace
ROS-8	47.9	22.3	50.5	7.69	0.04	surface
ROS-9	243	22.8	253.7	7.57	0.24	well
ROS-10	146	22.8	152.4	10.13	0.12	well
ROS-11	256	22.5	268.8	9.2	0.23	well
NCEGW1	493	14.3	598.5	8.07	1.02	well
NCEGW2	332	10.8	426.3	8.71	0.30	well
NCEGW3	364	12.4	455.7	8.24	0.76	well
NCEGW4	460	13.5	565.8	8.04	0.93	well
NCEGW5	394	15	472.8	8.31	0.60	well
NCEGW6	345	14.9	414.7	8.54	0.52	well
NCEGW7	370	12.9	459.5	6.92	0.62	well
NCEGW8	268	13.5	329.6	8.38	0.42	well
NCEGW9	304	13.8	372.1	8.72	0.61	well
NCEGW10	-	-	-	-	-	well
NCEGW11	-	-	-	-	-	well
NCESW1	145	10	188.5	8.37	0.30	surface
NCESW2	66	11.3	84.1	7.69	0.10	surface
NCESW3	304	10.1	394.6	7.89	0.64	surface
NCESW4	368	21.8	391.6	7.41	0.51	surface
NCESW5	70.6	21.6	75.4	7.25	0.05	surface