

APPENDIX I

**WATER QUALITY: WELL NB-3, WELL TW-5, AND THE MIDDLE FORK
SNOQUALMIE RIVER**

1.0 WATER QUALITY

Water quality samples were taken in 2005 and 2006 during pump tests at Well TW-5 and Well NB-3. The water quality sampling at Well TW-5 included field parameter measurements in 2005 and 2006, a laboratory metals analysis in 2006, and a hydrogen and oxygen isotope analysis in 2006. Table I-1 summarizes the water quality sampling events and primary analytes.

Water quality samples taken during the 2006 Well TW-5 long-term pump test included groundwater from pumping well and surface water from the Middle Fork Snoqualmie River. The pumped ground water was sampled from the end of the discharge line. The river water was sampled approximately 100 feet above the point where the pumped discharge emptied into the river.

Field water quality parameters were monitored throughout the step and constant-rate pumping tests performed on Well NB-3. A comprehensive water quality sample was collected at the end of the constant-rate test and submitted to a certified laboratory for analysis. A summary of the results is provided below. See Appendix F for more detail concerning the Well TW-5 water quality results and Golder (2007a) for more detail concerning the Well NB-3 water quality results.

1.1 Field Water Quality Parameters

1.1.1 Well TW-5 Pump Tests

Field water quality parameters (temperature, pH, specific conductivity, dissolved oxygen and turbidity) were measured during the step pumping test and constant-rate pumping test in 2005, and again during the short and long-duration tests in 2006. The temperature of the pumped groundwater was between 8.2 and 8.7° C during December 2005 and between 9.8 and 11.7° C during August 2006. The temperature of the Middle Fork Snoqualmie River was approximately 3.1° C in December 2005 or about 5 degrees colder than the pumped discharge. However, this was reversed in summer 2006 when the Middle Fork Snoqualmie River temperature was approximately 12° C, or about 2 degrees warmer than the groundwater. During the Well TW-5 pump test, the water temperature of the river was cooler than the groundwater, but this will likely be reversed in the summer when the river temperatures warm.

The pH of the pumped groundwater ranged from 8.36 to 8.55 standard units (s.u.) in December 2005 and 6.69 to 8.40 s.u. in August 2006. The pH of the river water ranged from 7.91 to 8.38 s.u. in December 2006 and 6.69 to 8.00 s.u. in August 2006. This relatively wide range in the 2006 pH might be due in part to changes in water temperature. The pH was also measured in the laboratory analysis, and the laboratory results indicate that the river water pH was 0.2 to 0.5 s.u. higher than the groundwater.

The conductivity of the pumped discharge ranged from 157.8 to 158.8 micro Siemens per centimeter ($\mu\text{S}/\text{cm}$) in December 2005 and 69.6 to 168.3 $\mu\text{S}/\text{cm}$ in August 2006. The conductivity of the river water ranged from 110.0 to 149.3 $\mu\text{S}/\text{cm}$ in December 2005 and 40.5 to 150.9 in August 2006. The lower conductivity observed in the river water samples indicates that a component of the flow might be attributable to low ionic strength precipitation that is transported by the river. The higher conductivity observed during August indicates that less low ionic strength water enters the surface and groundwater systems, which is consistent with the temporal distribution of precipitation in the Snoqualmie basin.

The turbidity during the 2006 pump test ranged between 0.80 to 2.48 nephelometric turbidity unit (NTU). The river water was slightly more turbid in 2006 with values ranging from 1.54 to 2.75 NTU.

The laboratory samples indicate much lower turbidity of approximately 0.3 NTU at Well TW-5 and approximately 0.5 NTU in the Middle Fork Snoqualmie River. Higher turbidity in surface waters is expected because the open channel and sometimes turbulent flow, in the river tends to carry river sediments, particulate organic matter, and microbes.

1.1.2 Well NB-3 Pump Tests

Field water quality parameters (temperature, pH, specific conductivity, and turbidity) were measured during both the step-pumping test and 72-hour constant-rate-pumping test. Iron and manganese concentrations were also measured in the field using Hach field test kits. Both the field iron concentrations and field manganese concentrations were low (less than 0.2 milligrams per liter [mg/L] and 0.1 mg/L, respectively). The turbidity levels were slightly elevated during the step test, but by the end of the constant-rate test the turbidity was less than 1 NTU and the sand production was less than 0.5 parts per million [ppm].

1.2 **Laboratory Analyses**

1.2.1 Laboratory Metals Analysis – Well TW-5

The August 29, 2006 and September 13, 2006 water quality samples were taken to AMTEST Laboratories. The samples were analyzed for conventional parameters, minerals, nutrients, and metals. Changes in water quality over time were evaluated using stiff diagrams (Figures I-1 and I-2). Samples from Well TW-5 on August 29, 2006 and September 13, 2006 plot almost directly on top of each other, which indicates that metal concentrations from Well TW-5 were generally consistent between the two sample dates (Figure I-1). The surface water diagrams (Figure I-2) show that the latter sampling (September 13, 2006) solution is more dilute than the August 29, 2006 sampling event. This could have been caused by a modest rainfall event that occurred between the sampling dates.

Differences in groundwater composition and possible compositional trends were identified using piper plots. Piper plots are the cation and anion percentages (in milliequivalents) plotted in two base triangles. The data is then projected on to a center grid which shows total ion relationships. Figure I-3 shows the relative proportions of Calcium(Ca)-Magnesium(Mg)-Sodium(Na)-Chlorine(Cl)-Bicarbonate(HCO_3)-Sulfate(SO_4) in the groundwater and surface water. The surface water samples from the Middle Fork Snoqualmie River have a higher Cl to HCO_3 ratio than the groundwater samples for both sampling dates. The surface water sample taken on August 29, 2006 has a similar cation composition to the groundwater samples. The September 13, 2006 sampling date showed a higher Na to Ca ratio.

The consistency between the sample results at Well TW-5 indicates that there was no change in the source of the pumped groundwater during the sampling interval. The observed shift in the mineral and nutrient content in the Middle Fork Snoqualmie River was apparently caused by rainfall in early September. The groundwater samples were not affected by this rainfall.

1.2.2 Laboratory Water Quality Analysis – Well NB-3

A water quality sample was collected at the end of the 72-hour constant-rate pumping test and sent to AmTest Laboratories in Redmond, Washington, a Washington Department of Health (DOH) certified laboratory, for drinking water analysis, inorganic and organic regulated water quality parameters, bacteriological parameters, and selected unregulated parameters. Radionuclide analyses were completed by Energy Laboratories, Inc. in Casper, Wyoming, a DOH certified laboratory for

radiological parameters. All water quality results met the federal and state safe drinking water standards.

The water collected from Well NB-3 has conductivity values of 170 $\mu\text{S}/\text{cm}$ and turbidity of 0.10 NTU. The water quality sampling indicates that groundwater from Well NB-3 is slightly alkaline, moderately hard, balanced, and has a low dissolved solids content.

1.3 Isotope Analysis

1.3.1 Background

The chemical properties of stable isotopes make them useful in determining several characteristics of the water. Isotopic analyses are commonly used to distinguish rain water or surface water runoff from groundwater (Sklash and Farvolden, 1979). The general principle is that “new” rain water has a different isotopic composition than “old” groundwater. Natural and anthropogenic processes can modify the proportion of oxygen and hydrogen isotopes, leading to depletion or enrichment of Oxygen-18 (^{18}O) and Hydrogen-2 (^2H) relative to sea water. Although many factors affect the isotopic composition of water, evaporation is a key factor. During evaporation, lighter isotopes (Oxygen-16 and Hydrogen-1) are preferentially vaporized, which means that water that is subjected to evaporation becomes enriched in the heavier isotopes (Oxygen-17, -18 and Hydrogen-2). The change in proportion between isotopes of the same element and between $\delta^{18}\text{O}$ and $\delta^2\text{H}$ between samples is used to trace the pathway and history of surface and groundwater.

Hydrogen and oxygen isotope values are generally reported in terms of the percentage of Oxygen-18 ($\delta^{18}\text{O}$) and hydrogen-2 ($\delta^2\text{H}$) relative to the Standard Mean Ocean Water (SMOW) standard. Negative values indicate that a sample contains a higher percentage of the heavier elements than the standard, and positive values indicate that a sample contains a lower percentage of the heavier elements than the standard. Therefore, in broad terms, samples with negative values have likely been subjected to more evaporation than samples with less negative values.

Hydrogen and oxygen isotope data are commonly plotted against the “global meteoric water line”, or GWML. The GWML has been defined by Craig (1961), as

$$\delta^2\text{H} = 8 \delta^{18}\text{O} + 10\text{‰}.$$

Although the global meteoric water line (GWML) will vary regionally, essentially all freshwater open to atmospheric conditions will plot on or near this line. Deviations above or below the meteoric water line indicates the occurrence of some type of chemical or physical alteration. Alternatively, groundwater that has been stored for very long time periods might deviate from the GWML if the meteoric conditions during recharge were significantly different than present conditions.

1.3.2 Results

Three groundwater samples from Well TW-5 and three surface water samples from the Middle Fork Snoqualmie River were taken during the long-duration pumping tests. The samples were sent to Zymax Laboratories in San Luis Obispo, California, and analyzed for Oxygen-18 and Hydrogen-2. Samples were taken on August 29, September 13, and September 14, respectively. The August 23rd samples were taken during the start of the short-duration pumping tests, while the samples on September 13th and September 14th were taken at the end of the first cycle of the long-duration test.

Results of the analysis are shown on Figure I-4. In general, the samples fall above the GMWL. That could be due to differences in humidity in this region vs. the average humidity of the GMWL. Surface water and groundwater would be in a similar region of the graph if precipitation recharge reached groundwater immediately. However, the groundwater samples plot in a different region of the graph than the surface water samples. This indicates that the recharge water might take some time to reach the groundwater. Groundwater might plot further up slope on the GMWL line because of differences in altitude. Groundwater might be from a lower or coastal source whereas surface water could be from farther inland or from a high altitude environment.

There was little change in the isotopic composition of the three samples at Well TW-5, which plot in a cluster on Figure I-4. Little change in the Well TW-5 samples over time suggests that there is little vertical leakage through the streambed to the aquifer in the vicinity of Well TW-5. A strong hydraulic connection between Well TW-5 and the Middle Fork Snoqualmie River would cause the pumped groundwater to resemble more closely the composition of the river water over time.

1.4 Water Quality Modeling

An equilibrium speciation and mass-transfer model, PHREEQCI Version 2.12, developed by the United States Geological Survey (USGS) was used to model the geochemistry of groundwater and surface water samples taken from Well TW-5 and the Middle Fork Snoqualmie River during the 2005 and 2006 pump tests (Parkhurst and Appelo, 1999). This model can simulate many physical and geochemical processes that might affect iron behaviour, such as mixing of multiple solutions, precipitation/dissolution of selected solids, redox reactions, atmospheric interaction, and sorption. PHREEQC was chosen because it combines the thermodynamic and adsorption capabilities of MINTQA2 with the ability to conduct mixing and reaction path modeling. The reaction path portion of PHREEQC performs mass-balance calculations while keeping track of the total concentrations of each element in the solution and solid phases. The code has gained widespread use and acceptance by the regulatory and technical community both in North America and abroad.

Speciation modeling of the samples taken during the long-term Well TW-5 pump test is reported in Table I-2. Charge balance errors were calculated for the speciated surface water and groundwater samples using PHREEQC (Parkhurst and Appelo, 1999). Constituents reported below detectable limits were assumed equal to the detection limit. Charge balance errors were acceptable, ranging from -2.9 to 5.0 percent for all samples.

PHREEQCI was allowed to calculate the P_{CO_2} of the solutions and the precipitation of supersaturated credible mineral phases was simulated. The P_{CO_2} of the waters helps to identify the processes and reactions that might occur as surface waters and groundwater move through a catchment. Natural waters in equilibrium with the atmosphere have a P_{CO_2} equal to -3.5 bars. Water samples collected from the Middle Fork Snoqualmie River in August indicate that the P_{CO_2} is slightly higher at -3.2 bars. This might indicate that there is decomposition or dissolution of organic matter in the surface waters of the Snoqualmie River. Typically, groundwater samples are slightly enriched in P_{CO_2} because of organic matter decomposition in the unsaturated zone of soils, which adds carbon dioxide to the groundwater system. The water is in equilibrium with the atmosphere based on the water quality samples from Well TW-5. This indicates that the groundwater is most likely an open system where there is frequent and prevalent exchange between surface waters and groundwater's and relatively short residence times in the basin.

A limited number of water quality controlling mineral phases were identified (ferrihydrite $[Fe(OH)_3]$, manganite $[MnOOH]$, and calcite $[CaCO_3]$). These results demonstrate that both surface waters and

groundwaters in the upper Snoqualmie Basin are slightly supersaturated with respect to iron-bearing minerals (ferrihydrite). Additionally, when Well TW-5 is pumped, it appears that waters that are slightly enriched in calcite and manganite might be accessed during long-term pumping. This slight change in chemistry likely reflects the spatial variability of the aquifer materials and is not sufficiently large to indicate long-term issues related to well yield.

1.5 Water Quality Summary

The water quality results support the conceptual model of the stream-aquifer relationship in the vicinity of Well TW-5. The similarity between the ionic and isotopic water quality for Well TW-5 and the Middle Fork Snoqualmie River during the first sampling period (August 29th) suggests that during baseflow the surface water and groundwater is being recharged from a common source. The rainfall that diluted the river water on September 13th was not observed in groundwater. The water quality analysis for groundwater from Well NB-3 showed that all water quality results met the federal and state safe drinking water standards.

1.6 References

- Craig, H., 1961. Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. *Science* 133: 1833-1834.
- Golder, 2007a. Report on City of North Bend Production Well NB-3 Drilling and Aquifer Testing. Report. Submitted to Law Offices of Thomas Pors on behalf of City of North Bend on January 15, 2007.
- Parkhurst, D.L., and C.A.J. Appelo, 1999. User's Guide to PHREEQC (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations, U.S. Geological Survey Water-Resources Investigations Report 99-4259, Denver, CO.
- Sklash, M.G., and R.N. Farvolden, 1979. The role of groundwater in storm runoff. *Journal of Hydrology* 43: 45-65.

TABLES

TABLE I-1
Water Quality Sampling Events and Parameters

Parameter	Well NB-3	Well TW-5			
	4-Oct-06 and 5-Oct-06	1-Dec-05	29-Aug-06	13-Sep-06	1-Dec-05
Field Water Quality Data					
pH	X	X	X		X
Conductivity	X	X	X		X
Turbidity	X	X	X		X
Dissolved Oxygen		X	X		X
Temperature	X	X	X		X
Iron	X				
Manganese	X				
Laboratory Water Quality Data					
Major Anions	X		X	X	
Metals	X		X	X	
Stable Isotopes			X	X	
TDS	X		X	X	
Turbidity	X		X	X	

Notes

"X" indicates that the parameter was tested.

TABLE I-2
Speciation Modeling Results

Water Type:		Surface Water					Ground Water			
Sample:		MFS-1 (8-29-06)		MFS-2 (9-13-06)		TW-5 (8-29-06)		TW-5 (9-13-06)		
Analyte	Units	Laboratory Data	Geochemical Modeling Results	Laboratory Data	Geochemical Modeling Results	Laboratory Data	Geochemical Modeling Results	Laboratory Data	Geochemical Modeling Results	
pH	pH	s.u.	8.0	8.0	7.9	7.8	8.2	8.2	8.3	8.3
Charge Balance Error		%	-2.9	0	3.7	0	4.9	0	4.0	0
P _{CO2(g)}		bar	-3.2	-3.1	-3.5	-3.5	-3.4	-3.4	-3.5	-3.5
Alkalinity (CaCO ₃)	Alk	mg CaCO ₃ /L	58	58	18	18	74	74	72	72
Chloride	Cl	mg/l	7.2	7.2	2.6	3.9	1.9	7.9	2.1	6.8
Sulfate	SO ₄	mg/l	6.0	6.0	3.3	3.3	6.9	6.9	6.3	6.3
Silver	Ag	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Aluminum	Al	mg/l	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01
Arsenic	As	mg/l	0.01	0.01	0.01	0.01	0.04	0.04	0.01	0.01
Boron	B	mg/l	0.05	0.05	0.7	0.7	0.05	0.05	0.3	0.3
Barium	Ba	mg/l	0.006	0.006	0.005	0.005	0.006	0.006	0.006	0.006
Beryllium	Be	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Calcium	Ca	mg/l	18	18	5.5	5.5	25	25	24	24
Cadmium	Cd	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Cobalt	Co	mg/l	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Chromium	Cr	mg/l	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Copper	Cu	mg/l	0.001	0.001	0.001	0.001	0.004	0.004	0.003	0.003
Iron	Fe	mg/l	0.1	0.00005	0.09	0.00006	0.01	0.0001	0.02	0.0001
Mercury	Hg	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Potassium	K	mg/l	1.1	4.4	0.7	0.7	1.3	1.3	1.3	1.3
Magnesium	Mg	mg/l	2.5	2.5	0.8	0.8	3.0	3.0	3.0	3.0
Manganese	Mn	mg/l	0.04	0.04	0.008	0.008	0.05	0.05	0.04	0.04
Molybdenum	Mo	mg/l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Sodium	Na	mg/l	6.2	6.2	4.1	4.1	7.3	7.3	6.5	6.5
Nickel	Ni	mg/l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Phosphorus	P	mg/l	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2
Lead	Pb	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sulfur	S	mg/l	2.0	2.0	1.1	1.1	2.3	2.3	2.1	2.1
Selenium	Se	mg/l	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.01
Silicon	Si	mg/l	3.7	3.7	10	10.0	4.0	4.0	7.0	7.0
Strontium	Sr	mg/l	0.1	0.1	0.03	0.03	0.2	0.2	0.2	0.2
Thallium	Tl	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Vanadium	V	mg/l	0.01	0.01	0.005	0.005	0.008	0.008	0.008	0.008
Zinc	Zn	mg/l	0.01	0.01	0.01	0.01	0.008	0.008	0.01	0.01
Minerals that may precipitate:										
Ferrihydrite [Fe(OH)3]				X			X			X
Manganite [MnOOH]										X
Calcite [CaCO3]										X

Note:

"X" indicates the mineral may precipitate

= Detection limit was assumed for nondetect samples.

FIGURES

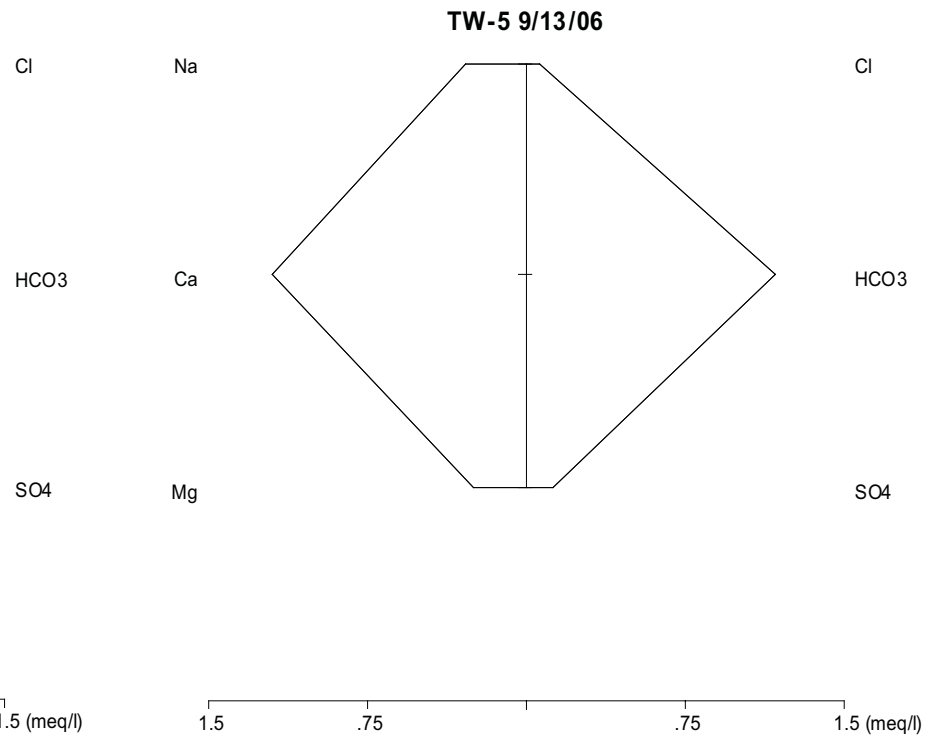
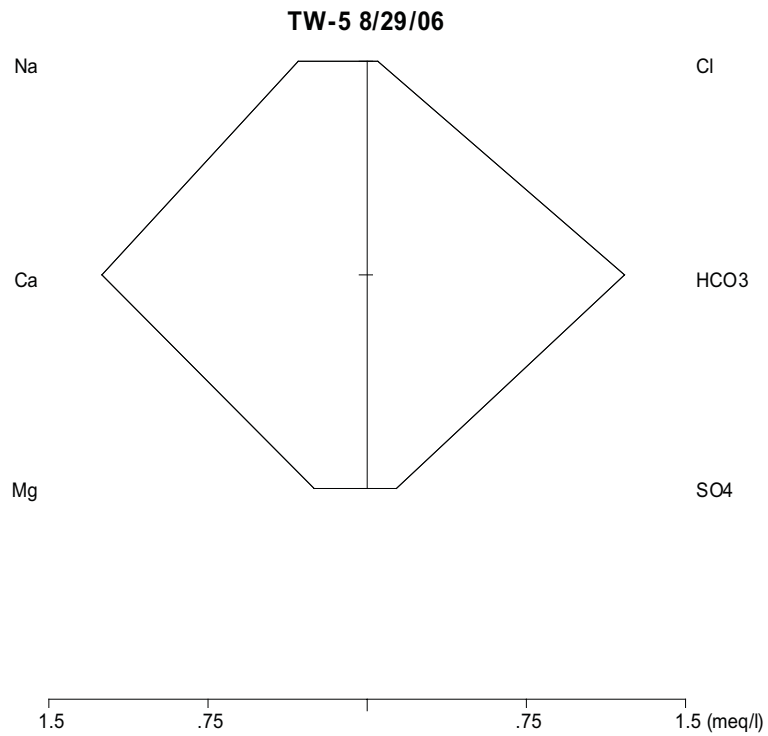


FIGURE **I-1**
STIFF DIAGRAMS - WELL TW-5
 EAST KING CO.RWA/AQUIFER ENHANCE/WA

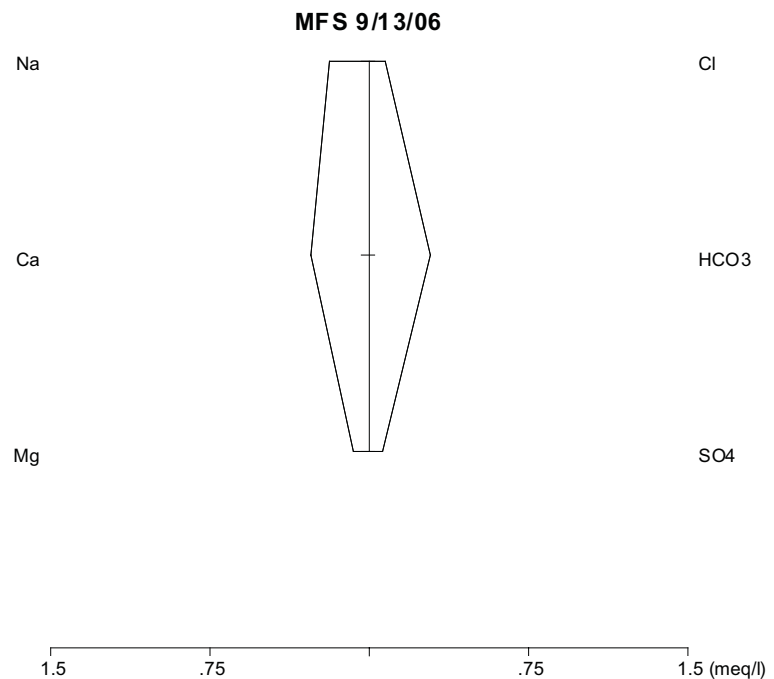
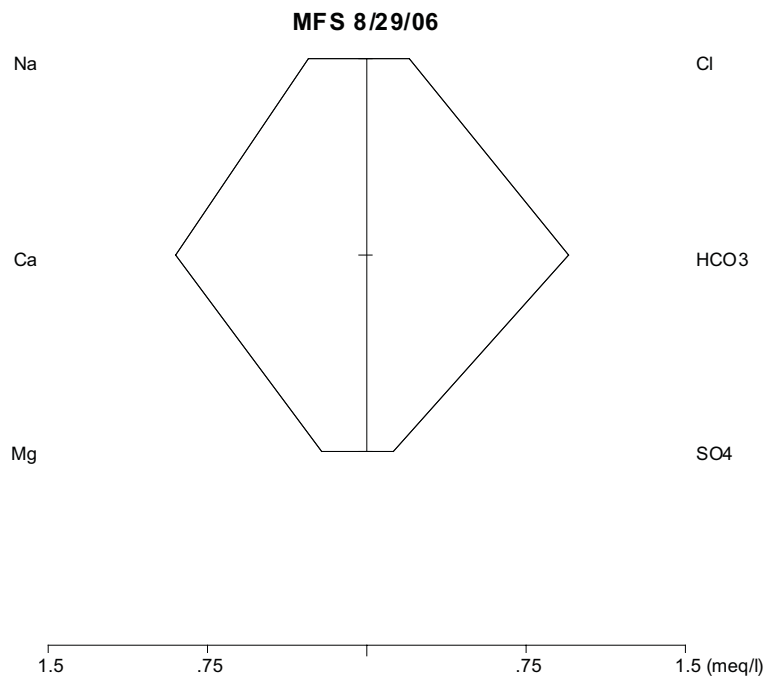


FIGURE **I-2**
STIFF DIAGRAMS - MIDDLE FORK SNOQUALMIE RIVER
 EAST KING CO. RWA/AQUIFER ENHANCE/WA

Legend :

- ▽ MFS 8/29/06
- ▲ MFS 9/13/06
- + TW-5 8/29/06
- * TW-5 9/13/06

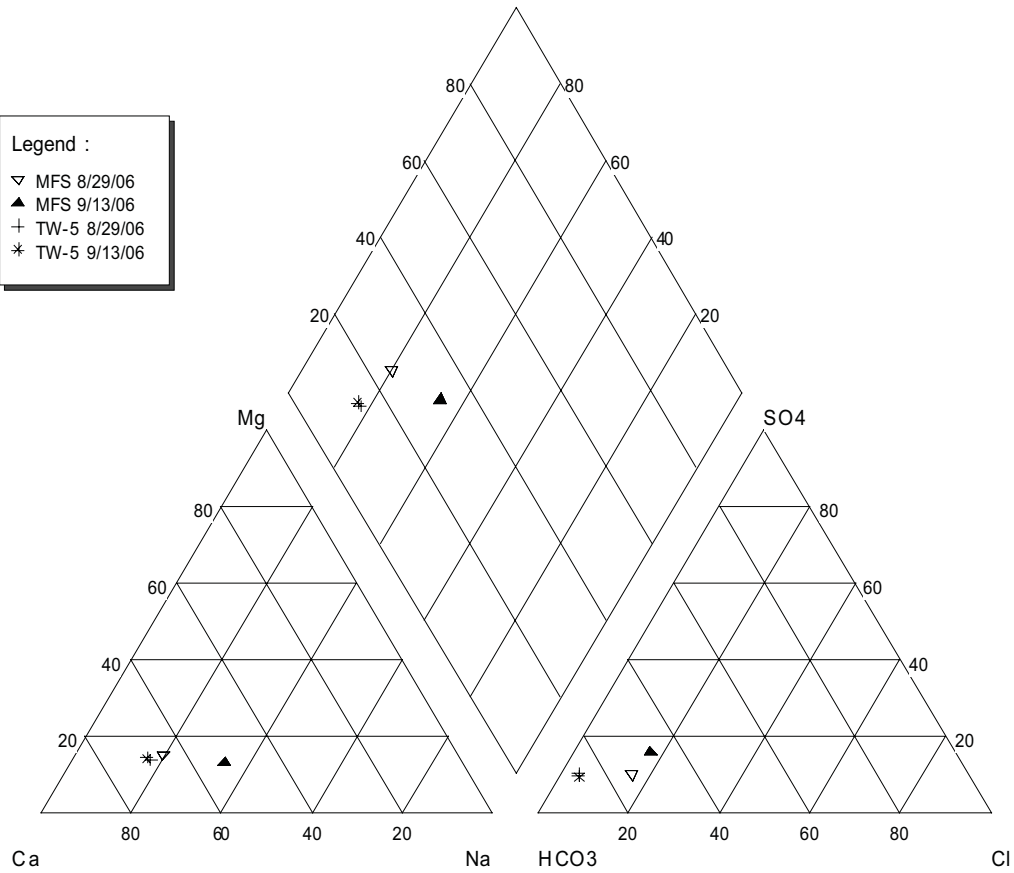


FIGURE I-3
PIPER DIAGRAMS - WELL TW-5 AND THE MIDDLE FORK SNOQUALMIE RIVER
 EAST KING CO.RWA/AQUIFER ENHANCE/WA