2016 Horseshoe Lake Emergency Pumping–Groundwater Monitoring

October 2016

King County

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2016 Horseshoe Lake Emergency Pumping–Groundwater Monitoring

Prepared for:

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Citation

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EXECUTIVE SUMMARY

In water year 2016, the water levels of Horseshoe Lake increased to near-flood levels after one of the wettest October through March periods on record, raising the groundwater levels that control the lake level in the winter. Pumping of the lake water to an infiltration site was performed intermittently from February 5 to March 18, 2016. Four pumping events occurred during this time period ranging from two to six days of continuous pumping at variable rates. A total of 90 acre-ft was pumped from Horseshoe Lake.

This report summarizes water quality monitoring activities related to the 2016 Horseshoe Lake emergency pumping to assess the water quality of groundwater before and after the emergency pumping events. Groundwater data were collected from seven existing monitoring wells between February 1 and April 1, 2016. Two types of data were collected:

- Water level data – this task was completed by Golder Associates staff
- Water quality data – this task was completed by King County WLRD staff

Groundwater levels rose at all sites during the monitoring period due to the groundwater recharge associated with wet season rainfall. March is the typical time period for the groundwater high level to occur for wells in the area. At the two wells nearest the infiltration site (MW-29 and MW-30), the water level data also showed short-term mounding responses to the infiltration during the emergency pumping events. During periods of pumping the water levels rose in both wells, with MW-30 recording a greater magnitude of change for the pumping periods than MW-29. When the pump was turned off, the water levels in these wells receded to background levels. Data from the other five wells (MW-10, MW-12, MW-13, MW-27 and MW-28) did not show any apparent responses from the pumping events, instead showing gradual increases in water levels associated with winter rainfall followed by gradual decreases as rainfall amounts decreased during the monitoring period.

All seven monitoring wells were sampled for water quality between February 16 and March 10, 2016. Every site had initial high turbidity (>100 NTU or more) that was unacceptable for testing water quality. Continued pumping dropped turbidity to acceptable levels (<15 NTUs) for sampling to occur in six of our seven wells. Well MW-29 was sampled after 3.5 hours of pumping with a turbidity level of 38. No wells had results above the primary drinking water standards. Although these wells are not intended for potable use, groundwater water quality results are typically compared to drinking water standards. The results of two parameters, total iron and pH, had values above the secondary drinking water standards – guidelines for aesthetic considerations, such as taste, color, corrosion, and odor. Wells MW-10, MW-13, MW-29 and MW-30 had total iron concentrations greater than the standard of 300 µg/L. Well MW-29 had the greatest concentration of total iron at 5,470 µg/L. This well also had a pH value (6.1) below the secondary standard of 6.5. All other wells had pH values between 6.5 and 8.5.

Well MW-10 is the deepest well sampled and differed from the other wells in regard to the following parameters: higher pH, conductivity, hardness, total alkalinity and lower dissolved oxygen. These differences infer a deeper, longer groundwater flow path at this site when compared to the other sites sampled.

Well MW-29 is the only well that was sampled for water quality during active pumping of Horseshoe Lake. With only one sample, it is unknown if the infiltration affected the water chemistry of this site. Some parameters at this well were lower than at other sites, such as low pH, conductivity, hardness, total alkalinity and sulfate.

Groundwater water quality had not been monitored in the Horseshoe Lake area prior to this study. This report summarizes water quality monitoring activities related to the 2016 Horseshoe Lake emergency pumping. Additional sampling is necessary to confirm the background water quality of the groundwater in the area.

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1.0 INTRODUCTION

Horseshoe Lake is a closed depression in southeast King County located west of the city of Black Diamond, Washington. The lake water surface elevation rises and falls seasonally in response to groundwater pressure and surface runoff. Prolonged wet weather increases these inflows and the lake level sometimes rises to a level that may impact surrounding homes and roads with flooding. King County has responded to these episodes by pumping water from the lake to nearby water bodies that have the capacity to drain the water away from the area.

King County has previously pumped down the lake level in 1991, 1996, 1997, 2007, 2009, 2011, and 2014. During these pumping events, County staff monitored various environmental factors in the area to determine impacts, if any, from the pumping events. Monitoring of levels in the lake and receiving water is part of these activities. Groundwater water quality had not been previously monitored.

In water year 2016, the water levels of Horseshoe Lake increased to near-flood levels after one of the wettest October through March periods on record[1], raising the groundwater levels that control the lake level in the winter, Figure 1. This report summarizes King County activities related to groundwater water quality monitoring.

1.1 2016 Emergency Pumping

King County Water and Land Resources (WLRD) made a decision to conduct emergency pumping of the lake due to a rapid steady rise in lake levels during January 2016, Figure 1. Water was pumped from the lake to the location of a proposed Regional Stormwater facility in the middle of property owned by Yarrow Bay Holdings, located to the south of the lake, Figure 2. An infiltration test facility has been constructed at this location. Ongoing monitoring and analysis by the company's subcontractor, Golder Associates, indicated that water pumped to the infiltration test facility would infiltrate with little or no resulting increase in surface flows in nearby creeks or rivers.

Representatives from the Muckleshoot Indian Tribe expressed concern about the new infiltration facility because of the sensitivity of their hatchery operation located downstream of the facility. King County WLRD science staff carried out water quality monitoring similar to that completed in 2014 (King County, 2014a & 2014b). In 2016, water quality monitoring included groundwater sites in addition to surface water sites.

[1] Record rain amounts as measured at SeaTac, the area reference point for precipitation: http://green2.kingcounty.gov/streamsdata/Precip.aspx

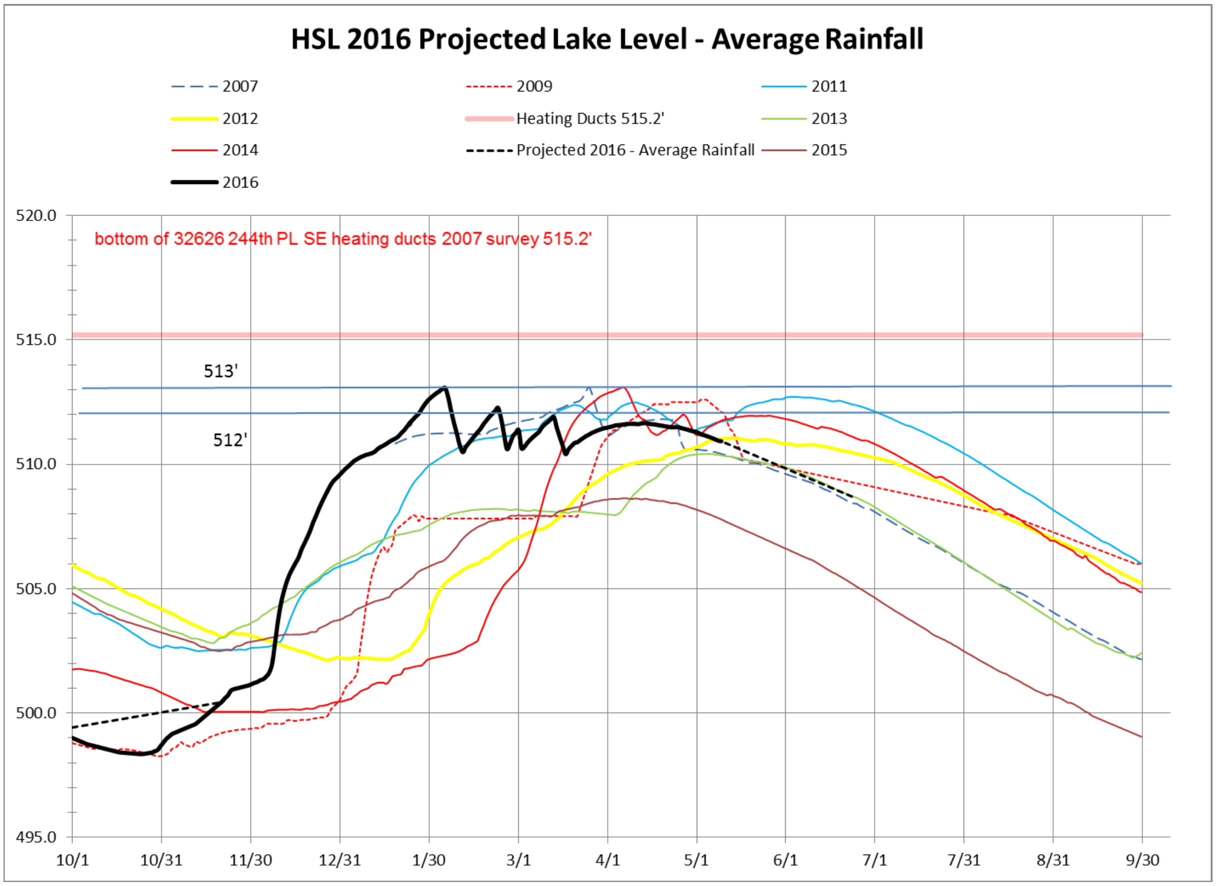

Figure 1. Horseshoe Lake Levels – 2007, 2009, 2011-16. This chart shows the elevation of the lake level for various years of monitoring; most recent monitoring year – 2016 shown as the black line.

Pumping was performed from February 5 to March 18, 2016. Four pumping events occurred during this time period ranging from 2 to 6 days of continuous pumping at variable rates. A total of 90 acre-ft was pumped from Horseshoe Lake into the infiltration facility (King County, 2016b).

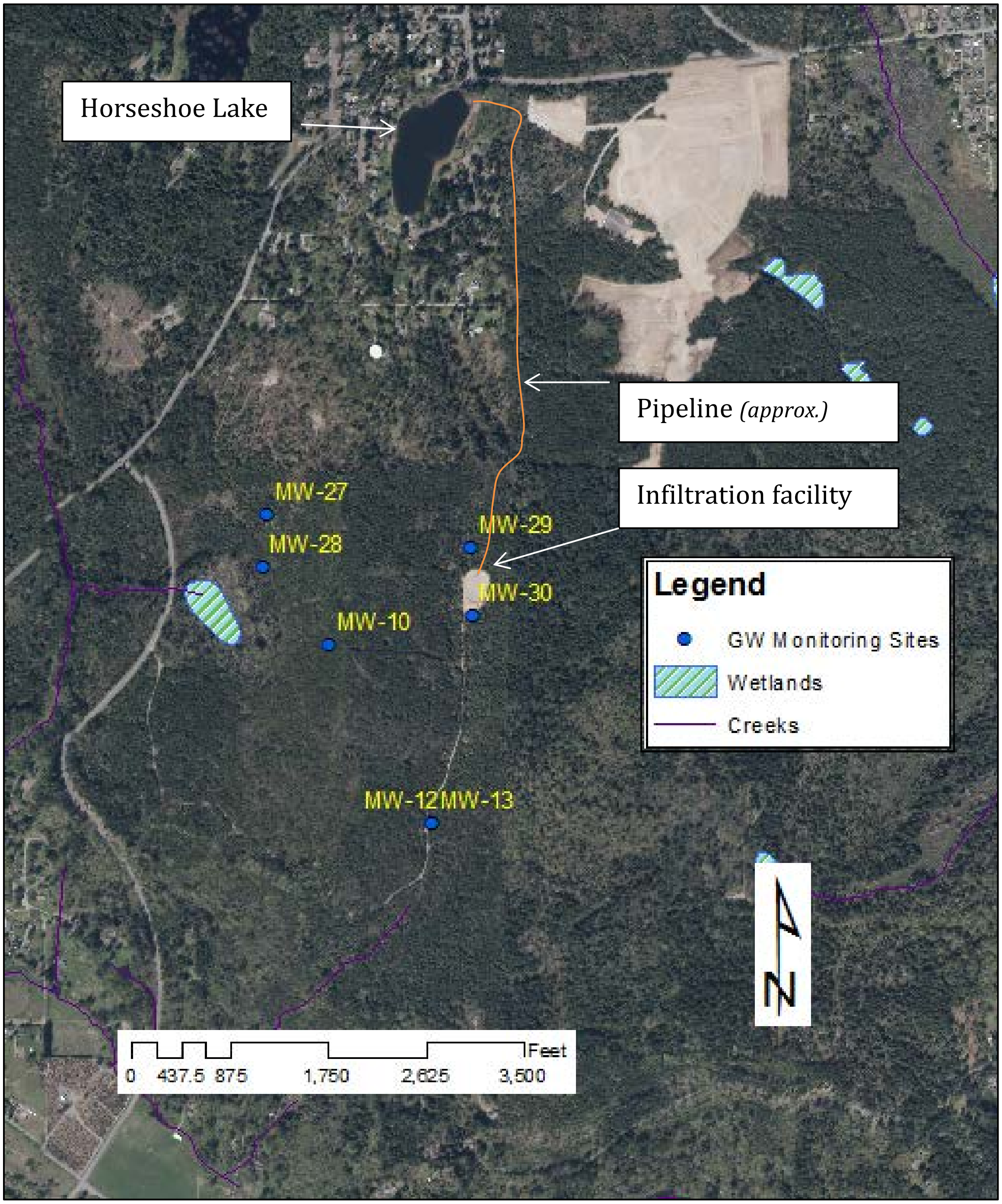

Figure 2. Horseshoe Lake Groundwater Monitoring Site Map. Seven monitoring wells in the vicinity of the infiltration facility were monitored for water level changes and water quality during this emergency pumping.

2.0 METHODS

Groundwater data were collected from seven existing monitoring wells, Figure 2 and Table 1. Permission to sample at these locations was obtained from Golder Associates and Yarrow Bay Holdings.

Two types of data were collected as part of the groundwater monitoring related to the emergency pumping of Horseshoe Lake:

- Water level data – this task was completed by Golder Associates staff
- Water quality data – this task was completed by King County WLRD staff

Table 1. Monitoring Well Information

Well id	Elevation	Well depth	Well diameter	Geo unit	X coord	Y coord	Source	KC locator
MW-10	581.7	173.0	6	Qpog1c	1339796	110665	Golder	SEKC_mw-10
MW-12	532.9	78.5	6	Qpog1c	1340714	109074	Golder	SEKC_mw-12
MW-13	532.9	48.9	6	Qpog1s/Qvr	1340715	109071	Golder	SEKC_mw-13
MW-27	526.8	55.0	2	Qpog1c	1339244	111842	Golder	SEKC_mw-27
MW-28	510.2	40.0	2	Qpog1c	1339198	111371	Golder	SEKC_mw-28
MW-29	556.8	70.0	2	Qpog1s	1341069	111533	Golder	SEKC_mw-29
MW-30	553.6	69.0	2	Qpog1s	1341076	110931	Golder	SEKC_mw-30

Units for elevation and well depth are feet and well diameter is inches – data provided by Golder, 2016.
Coordinates are shown as State Plane Feet – North
Geo unit refers to geologic unit assigned to the screen zone in previous reports (Golder 2013).

2.1 Water Level Data Collection

Data loggers were deployed by Golder Associates in all wells except for MW-12. Golder staff collected manual depth to water level measurements at the time of downloading data loggers.

King County staff took manual depth to water level measurements at each well before and after sampling. At well sites with two-inch diameter casing (MW-27- 30), the data loggers were removed from the well before sampling began and after depth to water level measurements were recorded. The data loggers were replaced in the wells post-pumping.

A. 

B. 

Figure 3. Monitoring Well Wellhead Configurations.
A. Monitoring well MW-12 – 6" well; This configuration applies to wells MW-10, 12 and 13.
B. Monitoring well MW-27 – 2" well; This configuration applies to wells MW-27 through 30.

2.2 Water Quality Data Collection

Water quality samples were collected by King County WLRD staff. Monitoring wells were purged and sampled for all parameters using low-flow purging methods (see King County, 2014c for details of this method).

2.2.1 Sample Collection

The wells were purged by pumping a small volume of water to ensure sampled water represented aquifer conditions. The volume pumped was determined in the field based on stabilization of field parameters (King County, 2014c). Wells were purged slowly with a Grundfos pump set at a depth corresponding to roughly the top of the screen zone, securing the tubing to prevent vertical movement and then pumping at a rate not to exceed water levels dropping into the pump zone (a rate of about two gallons per minute or less).

The water quality parameters collected were the same as measured during the surface water sample collection effort (King County, 2016 – in press). The list of parameters included field parameters, nutrients, selected metals (dissolved and total) and conventionals, see Table 2.

Table 2. List of Parameters Collected for the Monitoring of the 2016 Emergency Pumping at Horseshoe Lake.

Parameters	
Sample Temperature, Field	Aluminum, Dissolved, ICP-MS
Dissolved Oxygen, Field	Arsenic, Dissolved, ICP-MS
Conductivity, Field	Beryllium, Dissolved, ICP-MS
pH, Field	Cadmium, Dissolved, ICP-MS
Turbidity, Field	Calcium, Dissolved, ICP-MS
Orthophosphate Phosphorus	Chromium, Dissolved, ICP-MS
Total Phosphorus	Copper, Dissolved, ICP-MS
Ammonia Nitrogen	Iron, Dissolved, ICP-MS
Nitrite + Nitrate Nitrogen	Lead, Dissolved, ICP-MS
Total Nitrogen	Magnesium, Dissolved, ICP-MS
Sulfate	Manganese, Dissolved, ICP-MS
Total Alkalinity	Nickel, Dissolved, ICP-MS
Total Suspended Solids	Selenium, Dissolved, ICP-MS
Calcium, Total, ICP-MS	Silver, Dissolved, ICP-MS
Magnesium, Total, ICP-MS	Thallium, Dissolved, ICP-MS
Iron, Total, ICP-MS	Zinc, Dissolved, ICP-MS
Hardness, Calc	

3.0 RESULTS AND DISCUSSION

Groundwater water quality sample collection began on February 16th and was completed on March 10th. The following sites were pumped and/or sampled on these dates:

- MW – 12 – sampled on 2/16/16
- MW – 13 – sampled on 2/16/16
- MW – 10 – sampled on 2/17/16
- MW – 27 – sampled on 3/02/16
- MW – 28 – sampled on 3/02/16
- MW – 29 – sampled on 3/03/16
- MW – 30 – pumped on 2/16/16; 2/17/16; and 3/03/16
- MW – 30 – sampled on 3/10/16

3.1 Groundwater Levels

Groundwater levels in monitored wells rose at all sites during the emergency pumping period (2/1 – 4/1) due to the groundwater recharge. March is the typical time period for high groundwater levels to occur for wells in the area (Golder, 2013). The water levels at these sites have been shown to vary up to seven feet or more during previous monitoring events (Golder, 2013).

The rain gauge at Black Diamond (King County gauge: BDIA) measured 11.4 inches of precipitation from 2/1 to 4/1 with a water year to date (4/1) cumulative amount of 46.1 inches, Figure 4. The median annual water-year rainfall for the BDIA gauge is 51.2 inches (WY2001-2016). Based on data from Sea-Tac, the regional precipitation station for the National Weather Service, water year 2016 has been one of the wettest October to March periods[2].

At wells MW-29 and MW-30, the two wells closest to the infiltration pond, data-logger water level data show a mounding response to the infiltration during the emergency pumping, Figure 5. During periods of pumping, the water levels rose in both wells, with MW-30 recording a greater magnitude of change for the pumping periods, Figure 5. When the pump was turned off, the water levels in MW-29 and MW-30 slowly recovered to background levels, Figure 5. Data from sites MW-10 and MW-13 show a gradual increase then decrease over the pumping period with no apparent response(s) from the pumping events, Figure 6. Sites MW-10, MW-13, and MW-30 were recording data hourly and site MW-29 was recording data every four hours. Data from MW-27 and MW-28 was not

[2] see graphic: http://www.kingcounty.gov/services/environment/watersheds/hic/SeaTacPrecipitation.aspx

currently available for review at the time of report writing. MW-12 did not have a data logger.

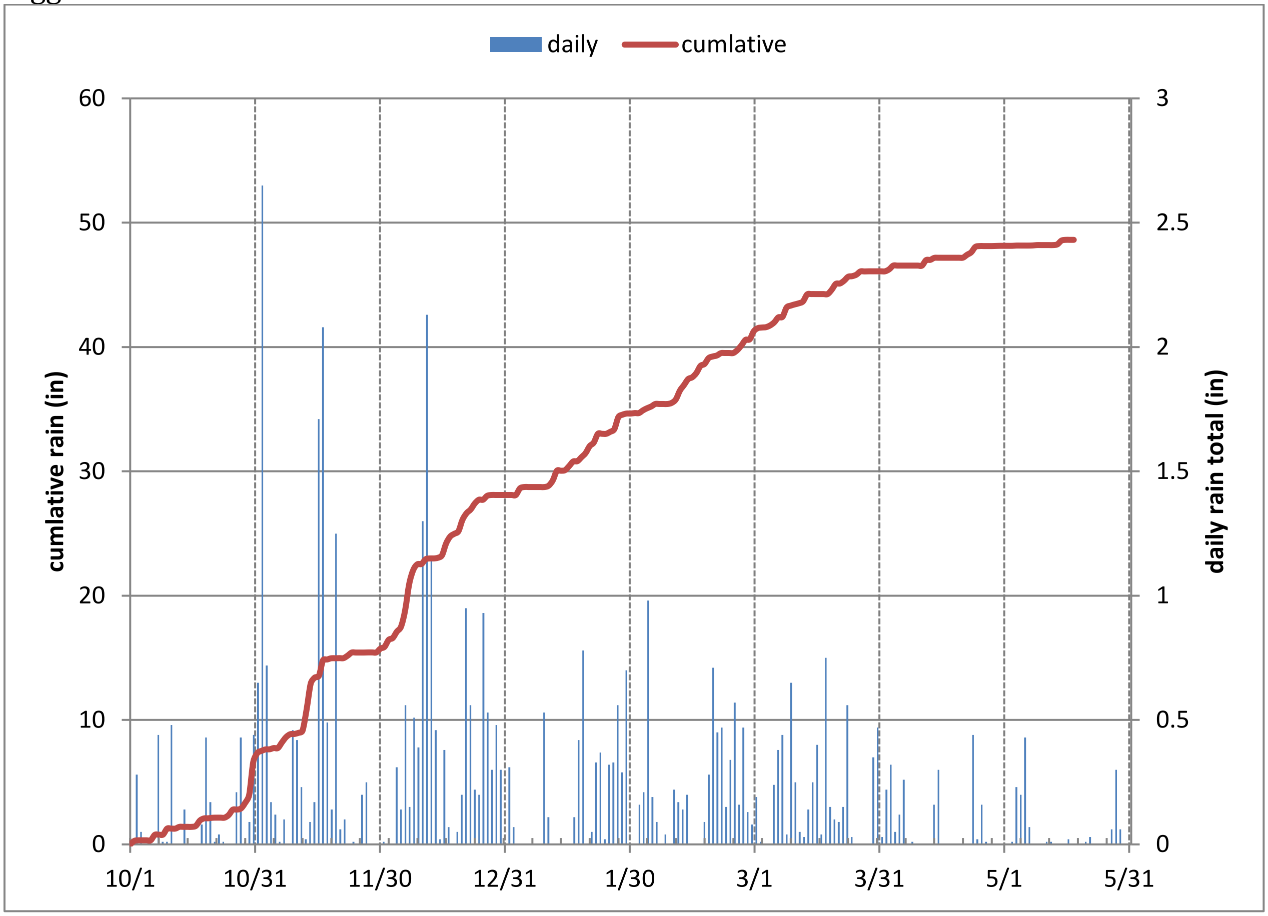

Figure 4. Rainfall Data – cumulative and daily totals for the Black Diamond rain gauge during water year 2016. Data presented through 5/18/2016 while the water year continues until September 30.

Depth to water (DTW) level measurements collected during routine site visits confirm the changes seen in the data logger data, Figure 7. Most DTW data was collected and shared by Golder Associates, Appendix A.

3.2 Groundwater Water Quality

As noted earlier, water quality samples were collected at all monitoring sites. All sites had initial high turbidity (>100 NTU or more). With continued pumping, the turbidity levels dropped to acceptable levels (<15 NTUs) for sampling to occur with the exception of two wells – MW-29 and MW-30. At MW-29, turbidity levels lowered from the initial level (240 NTU) but did not drop below 38 NTUs. After 3 ½ hours of pumping, a sample was taken with a turbidity value of 38.1 NTU.

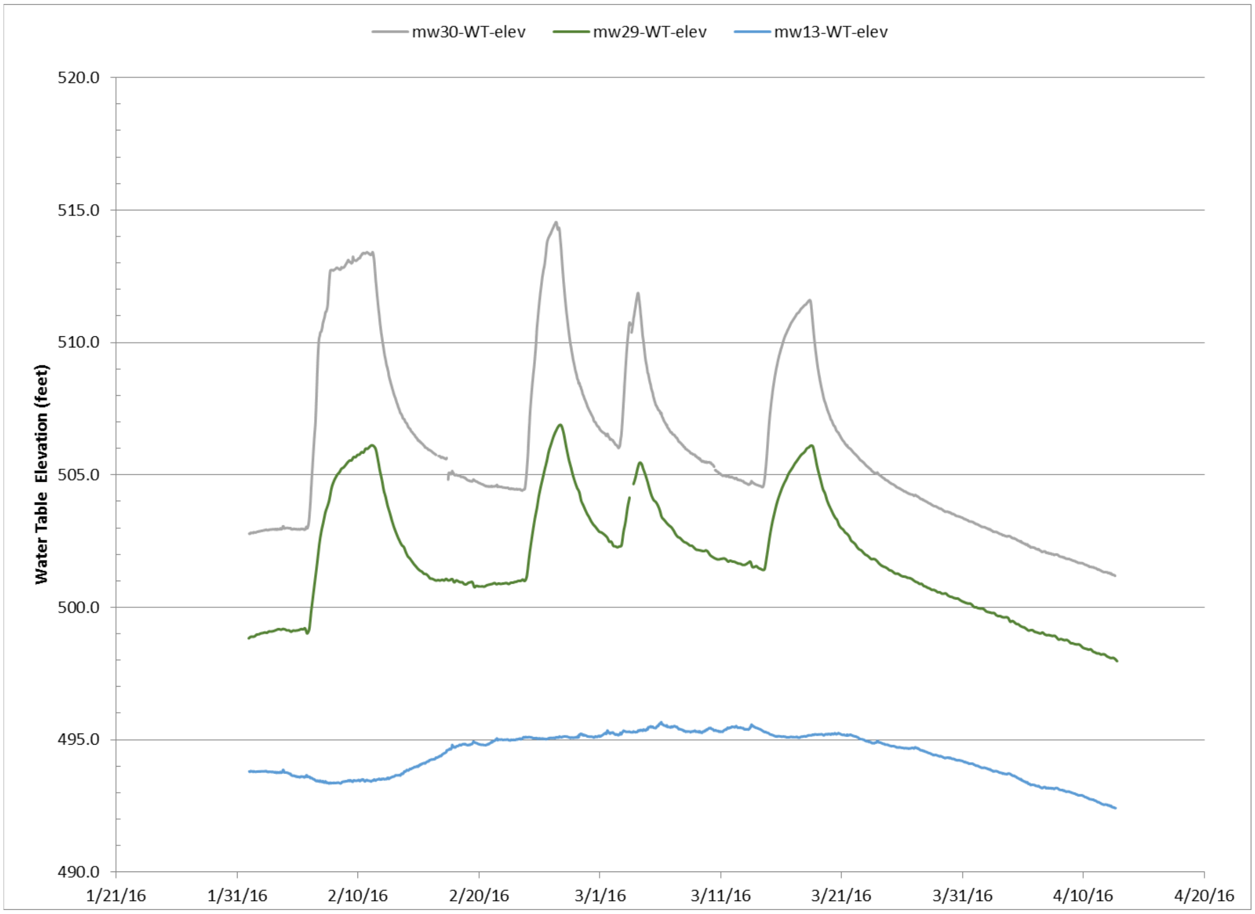

Figure 5. Groundwater Levels for MW-13, MW-29 and MW-30. Data presented are from 2/1 to 4/12/2016. Sites MW-13 and MW-30 were recording data hourly and site MW-29 was recording data every 4 hours. Sites MW-29 and MW-30 show a mounding response (higher water table elevation) to the infiltration of water while site MW-13 does not. Gaps in records are periods where the logger was removed from the well during pumping/sample collection.

Well MW-30 also had turbidity issues that took four separate pumping events to resolve. This site was pumped on 2/16, 2/17, 3/3 and 3/10, with a sample collected on 3/10. Turbidity on this date was measured at 11.9 NTU, a dramatic improvement from the 1000+ NTU values from the earlier dates. MW-30 also had flow issues; low flow (<0.5 GPM) with lowering water levels. Balancing the pumping rate, lowering water levels and lift capacity was challenging to achieve at MW-30 while trying to lower the high turbidity levels.

Table 3 contains the primary and secondary drinking water standards for inorganic parameters. Groundwater water quality results are typically compared to drinking water standards even though these sites are not for potable use. Results for water quality sampling are presented in Table 4.

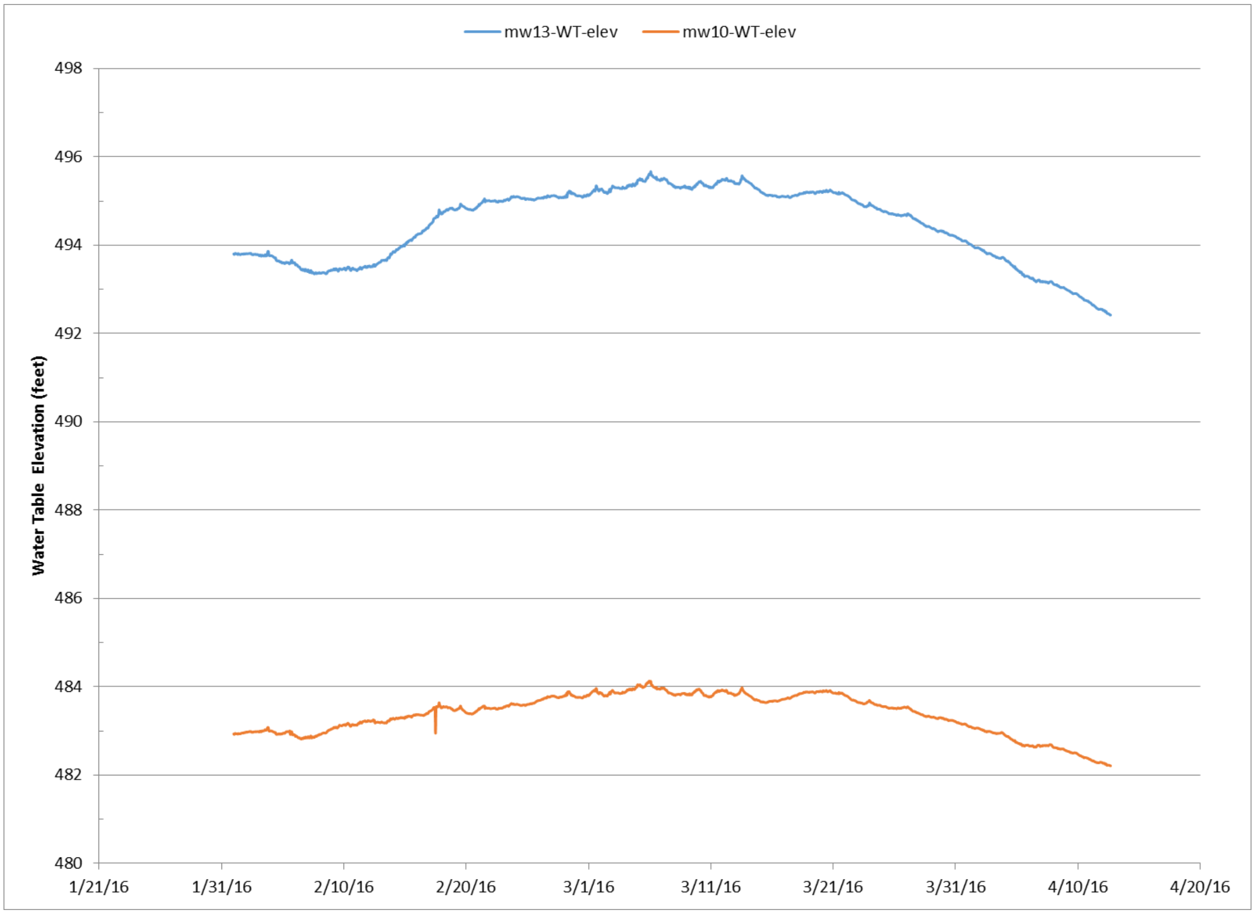

Figure 6. Groundwater Levels for MW-10 and MW-13. Data presented are from 2/1 to 4/12/2016. Data was recorded hourly. The downward spike (only seen in MW-10) occurred during pumping/sample collection.

No sites had results above the primary drinking water standards, Table 3 and Table 4. Two parameters, total iron and pH, did have results beyond the secondary drinking water standards, Table 3 and Table 4. Wells MW-10, 13, 29 and 30 had total iron concentrations greater than the standard of 300 µg/L. Well MW-29 had the greatest concentration of total iron at 5,470 µg/L. Water from this well also had a pH value (6.1) below the secondary standard of 6.5. All other wells had pH values between 6.5 and 8.5.

3.2.1 Water Quality Comparison

In the previous monitoring of emergency pumping of Horseshoe Lake (King County, 2014b) several parameters– total iron, dissolved aluminum, sulfate, and hardness - were discussed as parameter of interest due to the proximity of the hatchery. Total iron results are discussed above with four of the seven wells having higher total iron concentrations. These four wells also had higher turbidity values (5 – 38.1 NTUs) and several had higher total suspended solids (TSS) values that infer the total iron concentrations are likely associated with suspended sediments, Table 4. Higher levels of iron and manganese are common in

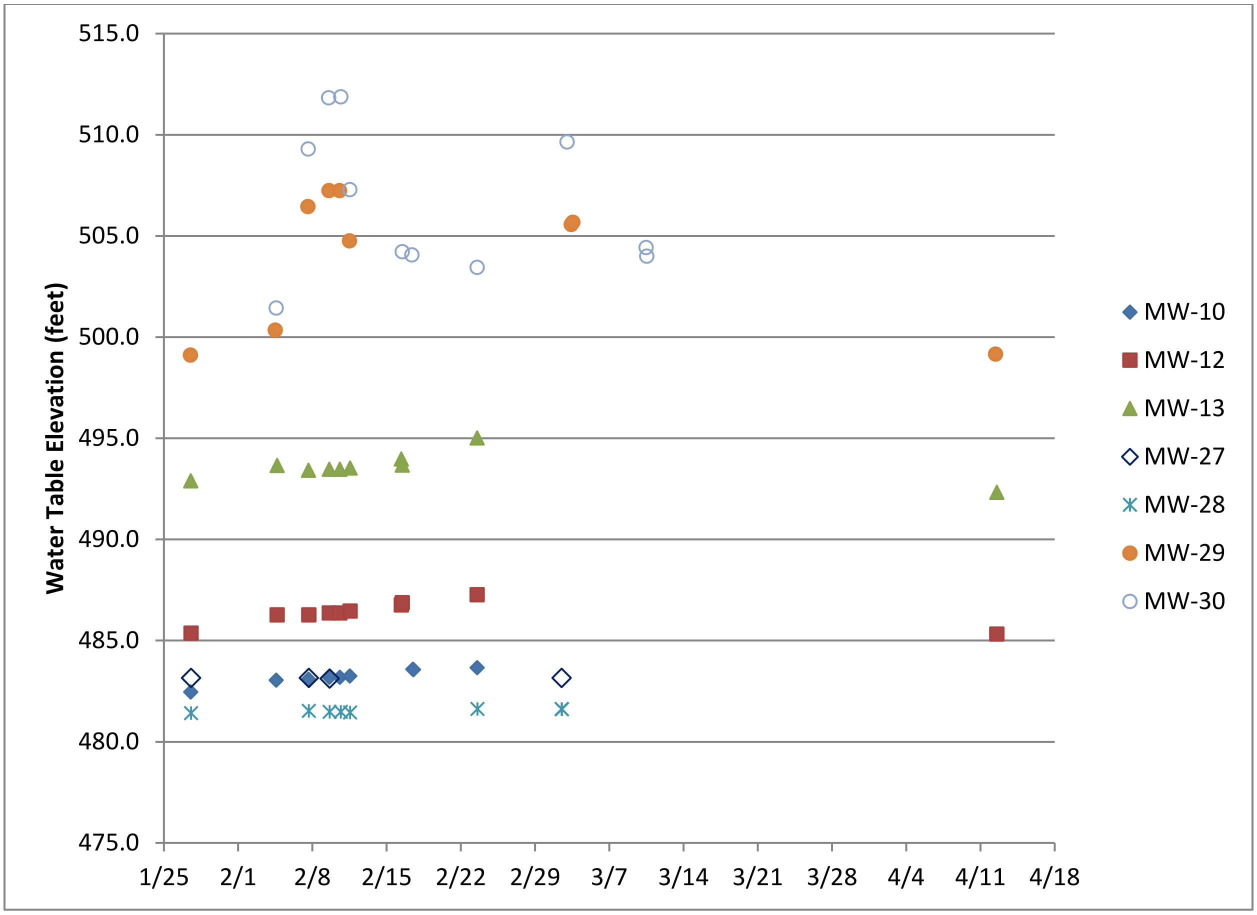

Figure 7. Water Level Elevations in Wells near Infiltration Facility Data presented are from 1/27 to 4/12/2016. Data was collected by Golder Assocaites except for days when the site was pumped/sampled. Data table presented in Appendix A.

glacial sediments associated with older geologic units such as Qpog which is the geologic unit many of these wells are screened in. (Golder, 2013 and King County, 2004). Dissolved aluminum concentrations were below the detection limit of 2 µg/L for all wells. The sulfate results ranged from 1.8 to 3.7 mg/L for 5 in seven wells, Table 4. Wells MW-10 and MW-28 had results greater than 6 mg/L – 6.1 and 6.9, respectively.

Horseshoe Lake is within a closed basin that gets its water from surface water runoff and groundwater inflow. There are differences in water quality results of the samples from groundwater wells and surface water monitoring sites. Samples from the groundwater wells typically had low/lower nutrient values, except for wells MW-27through MW-30, which have higher total nitrogen (ranging from 1.9 to 2.9 mg/L) and nitrate+nitrite (ranging from 1.8 to 2.8 mg/L) values than the surface water sites, Table 4. Sulfate was present in both surface and groundwater samples. Most of the sulfate values in groundwater samples were on the lower range of surface water results, except for wells

Table 3. Primary and Secondary Drinking Water Standards for Inorganic Parameters. Parameters that are italicized were not sampled as part of this effort.

A. Primary Drinking Water Standards;

Inorganic parameters	MCL*	units	MCL (µg/L)
Antimony	0.006	mg/L	6
Arsenic	0.01	mg/L	10
Barium	2.0	mg/L	2,000
Beryllium	0.004	mg/L	4
Cadmium	0.005	mg/L	5
Chromium	0.10	mg/L	10
Copper	1.3	mg/L	1,300
Cyanide	0.2	mg/L	200
Fluoride	4.0	mg/L	4,000
Lead	0.015	mg/L	15
Mercury	0.002	mg/L	2
Nitrate as N	10.0	mg/L	10,000
Nitrite as N	1.0	mg/L	1,000
Selenium	0.05	mg/L	50
Sodium	20	mg/L	20,000
Thallium	0.002	mg/L	2

B. Secondary Drinking Water Standards.

Inorganic parameters	MCL*	units	MCL (µg/L)
Aluminum	0.05 to 0.2	mg/L	50 to 200
Chloride	250	mg/L	250,000
Color	15	color unit	-
Copper	1	mg/L	1,000
Corrosivity	noncorrosive	-	-
Fluoride	2	mg/L	2,000
Foaming Agents	0.5	mg/L	500
Iron	0.3	mg/L	300
Manganese	0.05	mg/L	50
Odor	3 threshold	odor number	-
pH	6.5-8.5	pH units	-
Silver	0.1	mg/L	100
Sulfate	250	mg/L	250,000
Total Dissolved Solids	500	mg/L	500,000
Zinc	5	mg/L	5,000

"MCL" = refers to Maximum Contamination Level;

Units: mg/L = milligrams per liter; µg/L = micrograms per liter;

Table 4. Groundwater Water Quality Results. Results displayed in bold red and shaded cell text are above secondary drinking water standards shown in Table 3. This result table with surface water data presented in Appendix B.

LOCATOR	SEKC_MW-10		SEKC_MW-12		SEKC_MW-13		SEKC_MW-27		SEKC_MW-28		SEKC_MW-29		SEKC_MW-30				
COLLECTDATE	2/17/2016 12:35		2/16/2016 11:25		2/16/2016 10:10		3/2/2016 11:35		3/2/2016 12:55		3/3/2016 13:25		3/10/2016 12:20				
Parameters	Qualifier	Result	Qualifier	Result	Qualifier	Result	Qualifier	Result	Qualifier	Result	Qualifier	Result	Qualifier	Result	Units	MDL	RDL
Sample Temperature, Field		10.7		9.5		9.5		10.1		10.1		10.5		10.9	deg C		
Dissolved Oxygen, Field		5.1		10.4		11.6		10.3		8.3		11.4		8.5	mg/L	0.5	1
Conductivity, Field		169		77.1		71.1		99.8		144		62.8		83.9	umhos/cm	0.5	10
pH, Field		7.0		6.6		6.6		6.5		6.7		**6.1**		6.5	pH		
Turbidity, Field		5		9.6	<RDL	0.74		2.1		3.7		38.1		11.9	NTU	0.5	2
Aluminum, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	2	10
Ammonia Nitrogen	<MDL		<MDL		<MDL		<MDL			0.013		0.0113	<MDL		mg/L	0.002	0.01
Arsenic, Dissolved	<RDL	0.41	<RDL	0.22	<RDL	0.12	<RDL	0.23	<RDL	0.33	<MDL		<RDL	0.16	µg/L	0.1	0.5
Beryllium, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	0.1	0.5
Cadmium, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	0.05	0.25
Calcium, Dissolved		21700		7030		6400		9140		16900		5750		6130	µg/L	50	50
Calcium, Total		21900		7030		6620		8870		16100		6860		6180	µg/L	50	50
Chromium, Dissolved	<RDL	0.4	<RDL	0.22	<RDL	0.2	<RDL	0.24	<RDL	0.4	<RDL	0.39	<RDL	0.5	µg/L	0.2	1
Copper, Dissolved	<MDL		<MDL		<MDL		<RDL	0.24	<MDL		<MDL		<RDL	0.25	µg/L	0.2	2
Hardness, Calc		79.7		31.8		30.9		37.3		61		28.8		31.6	mg CaCO3/L	0.331	0.331
Iron, Dissolved		115		97.1	<MDL		<MDL		<MDL		<MDL		<RDL	41	µg/L	10	50
Iron, Total		**822**		**1490**	<RDL	16		93.2		239		**5470**		**598**	µg/L	10	50
Lead, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	0.1	0.5
Magnesium, Dissolved		5050		2960		2910		3280		4250		1510		3580	µg/L	50	50
Magnesium, Total		6050		3470		3500		3680		5080		2840		3930	µg/L	50	50
Manganese, Dissolved		5.23		13.5	<RDL	0.15		2.93	<MDL			0.937		20.9	µg/L	0.1	0.5
Nickel, Dissolved	<RDL	0.39	<RDL	0.2	<RDL	0.14	<RDL	0.27	<RDL	0.21	<RDL	0.24		2.08	µg/L	0.1	0.5
Nitrite + Nitrate Nitrogen		0.839		0.839		0.469		2.22		1.84		2.66		2.82	mg/L	0.01	0.04
Orthophosphate Phosphorus		0.0089		0.0146		0.0144		0.00683		0.00743		0.00601		0.00322	mg/L	0.0005	0.002
Selenium, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	0.5	1
Silver, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	0.04	0.2
Sulfate		6.85		2.63		2.58		3.71		6.07		1.77		3.4	mg/L	0.1	0.2
Thallium, Dissolved	<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		<MDL		µg/L	0.1	0.2
Total Alkalinity		71.3		29.7		28.9		34.6		54.7		15.2		23.7	mg CaCO3/L	1	5
Total Nitrogen		0.834		0.801		0.462		2.27		1.9		2.66		2.88	mg/L	0.05	0.1
Total Phosphorus		0.0115		0.0193		0.0136		0.0115		0.0146		0.092		0.0216	mg/L	0.005	0.01
Total Suspended Solids	<RDL	0.5		2.3	<MDL		<MDL			1.8		178		27.8	mg/L	1	2
Zinc, Dissolved	<MDL		<RDL	0.56	<RDL	1.4	<RDL	0.68	<MDL		<MDL		<RDL	0.54	µg/L	0.5	2.5

"RDL" = refers to Reporting Detection Limit;

"MDL" = refers to Method Detection Limit;

Units: mg/L = milligrams per liter; µg/L = micrograms per liter; umhos/cm = micro-ohms per centimeter; deg C – degrees Celsius; NTU = nephalitic turbidity units; pH = pH units; mg CaCO3/L = milligrams of calcium carbonate per liter.

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MW-28 and MW-10, which are higher as noted above. The metal concentrations are similar in groundwater and surface water samples, except for the following; groundwater wells had lower concentrations of dissolved aluminum, copper, and zinc than surface water sites. Groundwater typically has greater concentrations of calcium, magnesium, chromium, and total iron. Overall, the hardness in the groundwater wells is within the range of surface water sites except for wells MW-28 and MW-10, which have values of 61.0 and 79.8 mg/L respectively, Table 3.

The following is a brief assessment of individual wells that have slightly different results:

Site MW-10 is the deepest well sampled and has slight differences in the following parameters: higher pH, conductivity, hardness, total alkalinity, and lower dissolved oxygen. These differences infer a deeper, longer groundwater flow path at this site when compared to the other sites sampled.

Site MW-29 is the only well that was sampled during active pumping of Horseshoe Lake. With only one sample, it is unknown if the infiltration affected the water chemistry of this site. The high turbidity (38.1 NTU) and high total suspended solids (178 mg/L) are a result of no development of the well than a result of infiltration. Golder Associates informed King County (personal communication, 2016) that wells MW-27through MW-30 were not developed after completion. Some parameters are lower than other sites, such as low pH, conductivity, hardness, total alkalinity and sulfate, Table 3. Additional sampling events are necessary to confirm the range of results to determine the background water quality of the groundwater in this area.

4.0 SUMMARY

Groundwater water quality had not been previously monitored by any activity in this area. This work summarizes water quality monitoring activities related to the 2016 Horseshoe Lake emergency pumping. All seven monitoring wells were sampled for water quality between 2/16 and 3/10/2016. No wells had results above the primary drinking water standards, Table 3 and Table 4. Although these wells are not intended for potable use, groundwater water quality results are typically compared to drinking water standards. The results for two parameters, total iron and pH, did have values beyond the secondary drinking water standards, Table 3 and Table 4. Wells MW-10, 13, 29 and 30 have total iron concentrations greater than the standard of 300 µg/L. Well MW-29 had the greatest concentration of total iron at 5,470 µg/L. This well also had a pH value (6.1) below the secondary standard of 6.5. All other wells had pH values between 6.5 and 8.5.

Well MW-10 is the deepest well sampled and has slight differences in the following parameters: higher pH, conductivity, hardness, total alkalinity, and lower dissolved oxygen. These differences infer a deeper, longer groundwater flow path at this site when compared to the other sites sampled.

Well MW-29 is the only well that was sampled during active pumping of Horseshoe Lake. With only one sample, it is unknown if the infiltration affected the water chemistry of this site. Some parameters are lower than at other wells, such as low pH, conductivity, hardness, total alkalinity, and sulfate. Additional sampling events are necessary to confirm the background water quality of the groundwater in this area.

Groundwater levels rose in all wells during the emergency pumping period (2/1 – 4/1) due to the groundwater recharge associated with winter rainfall. March is the typical time period for the groundwater high level to occur in wells in this area (Golder, 2013). At wells MW-29 and MW-30, the data-logger data shows a mounding response to the infiltration during the emergency pumping, Figure 5. During periods of pumping, the water levels rose in both wells with MW-30 recording a greater magnitude of change for the pumping periods. When the pump was turned off, the water levels in MW-29 and MW-30 slowly returned to background. Data from wells MW-10, MW-12, MW-13, MW-27, and MW-28 shows a gradual increase then decrease over the emergency pumping period with no apparent response(s) from the pumping events.

5.0 REFERENCES

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Appendix A: Water Level Data

As noted in the report, Golder Associates was tasked with hydrologic portion of the groundwater monitoring. Golder Associates already had data loggers deployed in six of the seven wells monitored (no device in MW-12).

Data shared by Michael Klisch at Golder Associates post pumping in late April.

No data was available for MW-27 and MW-28 at the time of report writing.

Table A-1 Depth to Water (manual water level) Measurements. Elevations based on data presented in Table 1. Data provided by Golder, 2016 except as noted.

Well id	Date time	Depth to water*	Horseshoe Lake pumping	Staff	Water Level Elevation
MW-10	1/27/16 12:40	99.28	No	Golder/KC	482.5
	2/4/16 14:24	98.70	No	Golder	483.0
	2/7/16 15:05	98.65	Yes	Golder	483.1
	2/9/16 14:05	98.55	Yes	Golder	483.2
	2/10/16 14:05	98.55	Yes	Golder	483.2
	2/11/16 12:40	98.49	No	Golder	483.3
	2/17/16 11:07	98.15	No	King County	483.6
	2/17/16 12:40	98.18	No	King County	483.6
	2/23/16 12:40	98.08	No	King County	483.7
MW-12	1/27/16 13:10	47.57	No	Golder/KC	485.4
	2/4/16 16:02	46.67	No	Golder	486.3
	2/7/16 15:33	46.67	Yes	Golder	486.3
	2/9/16 14:27	46.57	Yes	Golder	486.4
	2/10/16 14:27	46.57	Yes	Golder	486.4
	2/11/16 13:05	46.48	No	Golder	486.5
	2/16/16 9:15	46.18*	No	King County	486.8
	2/16/16 11:30	46.06	No	King County	486.9
	2/23/16 13:03	45.68	No	King County	487.3
	4/12/16 13:00	47.61	No	Golder	485.3
MW-13	1/27/16 13:00	39.99	No	Golder/KC	492.9
	2/4/16 16:06	39.23	No	Golder	493.7
	2/7/16 15:30	39.46	Yes	Golder	493.4
	2/9/16 14:25	39.41	Yes	Golder	493.5
	2/10/16 14:25	39.41	Yes	Golder	493.5
	2/11/16 13:00	39.35	No	Golder	493.5
	2/16/16 9:10	38.91	No	King County	494.0
	2/16/16 11:25	39.20	No	King County	493.7
	2/23/16 13:05	37.86	No	King County	495.0
	4/12/16 13:05	40.55	No	Golder	492.3
MW-27	1/27/16 13:45	unable	No	Golder/KC	
	2/7/16 16:05	43.61	Yes	Golder	483.2
	2/9/16 15:09	43.62	Yes	Golder	483.2
	2/10/16 15:09	43.62	Yes	Golder	483.2
	2/11/16 13:40	43.64	No	Golder	483.1
	2/23/16 14:00	43.31	No	King County	483.5
	3/2/16 10:55	43.26	No	King County	483.5
	3/2/16 11:40	43.28	No	King County	483.5

Well id	Date time	Depth to water*	Horseshoe Lake pumping	Staff	Water Level Elevation
MW-28	1/27/16 13:40	28.82	No	Golder/KC	481.4
	2/7/16 15:52	28.70	Yes	Golder	481.5
	2/9/16 14:58	28.75	Yes	Golder	481.5
	2/10/16 15:58	28.75	Yes	Golder	481.5
	2/11/16 13:25	28.78	No	Golder	481.5
	2/23/16 13:50	28.61	No	King County	481.6
	3/2/16 11:55	28.61	No	King County	481.6
	3/2/16 12:55	28.62	No	King County	481.6
MW-29	1/27/16 11:50	57.65	No	Golder/KC	499.1
	2/4/16 11:35	56.42	No	Golder	500.3
	2/7/16 13:55	50.31	Yes	Golder	506.5
	2/9/16 13:15	49.51	Yes	Golder	507.3
	2/10/16 13:15	49.51	Yes	Golder	507.3
	2/11/16 11:48	52.00	No	Golder	504.8
	2/23/16 0:00	not taken	No	King County	
	3/3/16 9:55	51.19	Yes	King County	505.6
	3/3/16 13:30	51.09	Yes	King County	505.7
	4/12/16 10:00	57.60	No	Golder	499.2
MW-30	1/27/16 12:10	unable	No	Golder/KC	
	2/4/16 14:04	52.14	No	Golder	501.4
	2/7/16 14:45	44.28	Yes	Golder	509.3
	2/9/16 12:30	41.75	Yes	Golder	511.8
	2/10/16 15:58	41.71	Yes	Golder	511.9
	2/11/16 12:25	46.29	No	Golder	507.3
	2/16/16 11:40	49.36	No	King County	504.2
	2/17/16 8:45	49.51	No	King County	504.1
	2/23/16 12:52	50.14	No	King County	503.4
	3/3/16 0:00	43.93	Yes	King County	509.7
	3/10/16 11:05	49.16	No	King County	504.4
	3/10/16 12:30	49.58	No	King County	504.0

* = depth to water level measurement taken from measuring point; typically top of casing.

Unit for depth to water and elevation are feet.

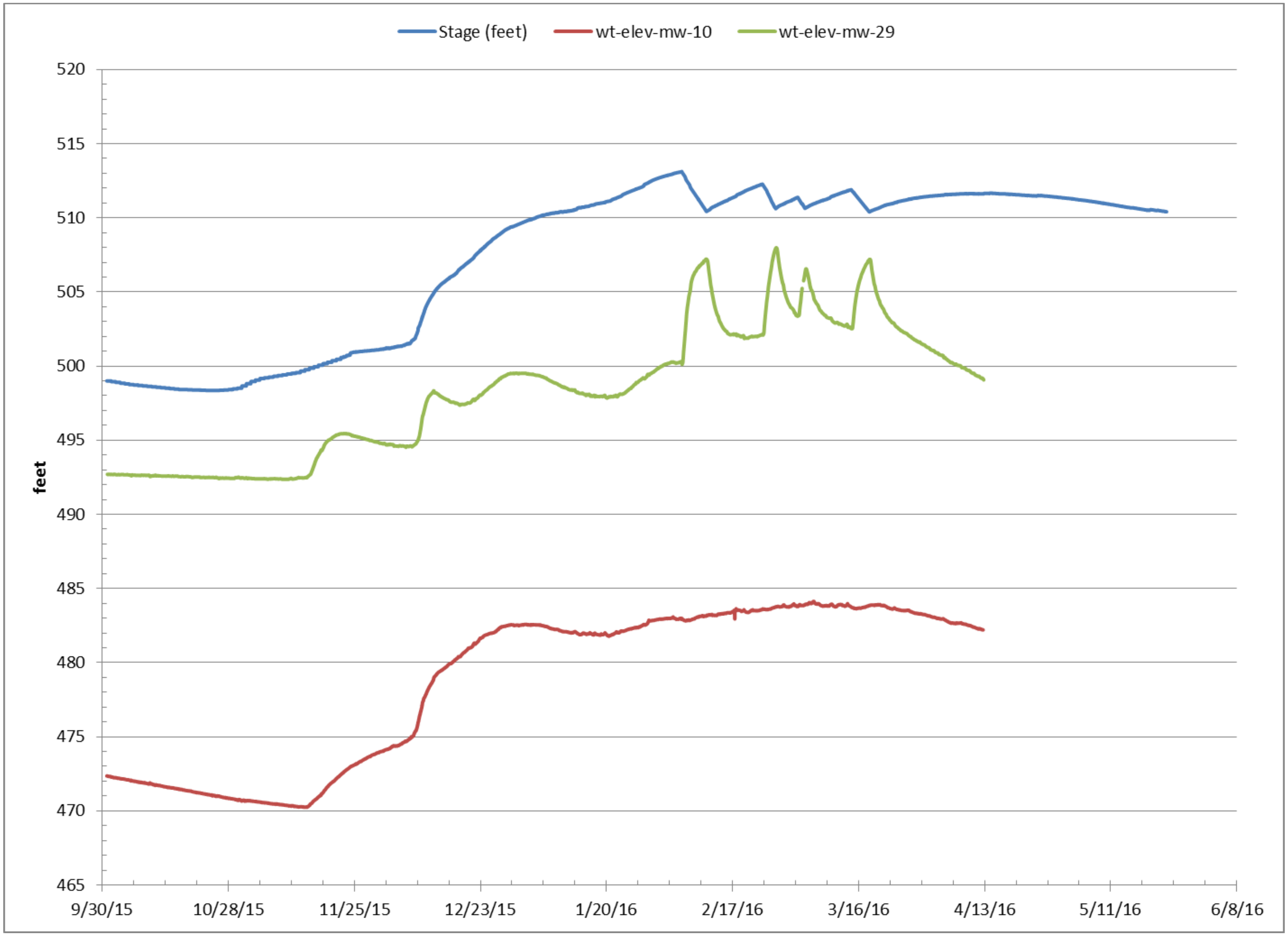

Figure A-1 Comparison of Horseshoe Lake Surface Elevation and Water Table Elevations of well MW-10 and well MW-29 for Water Year 2016.

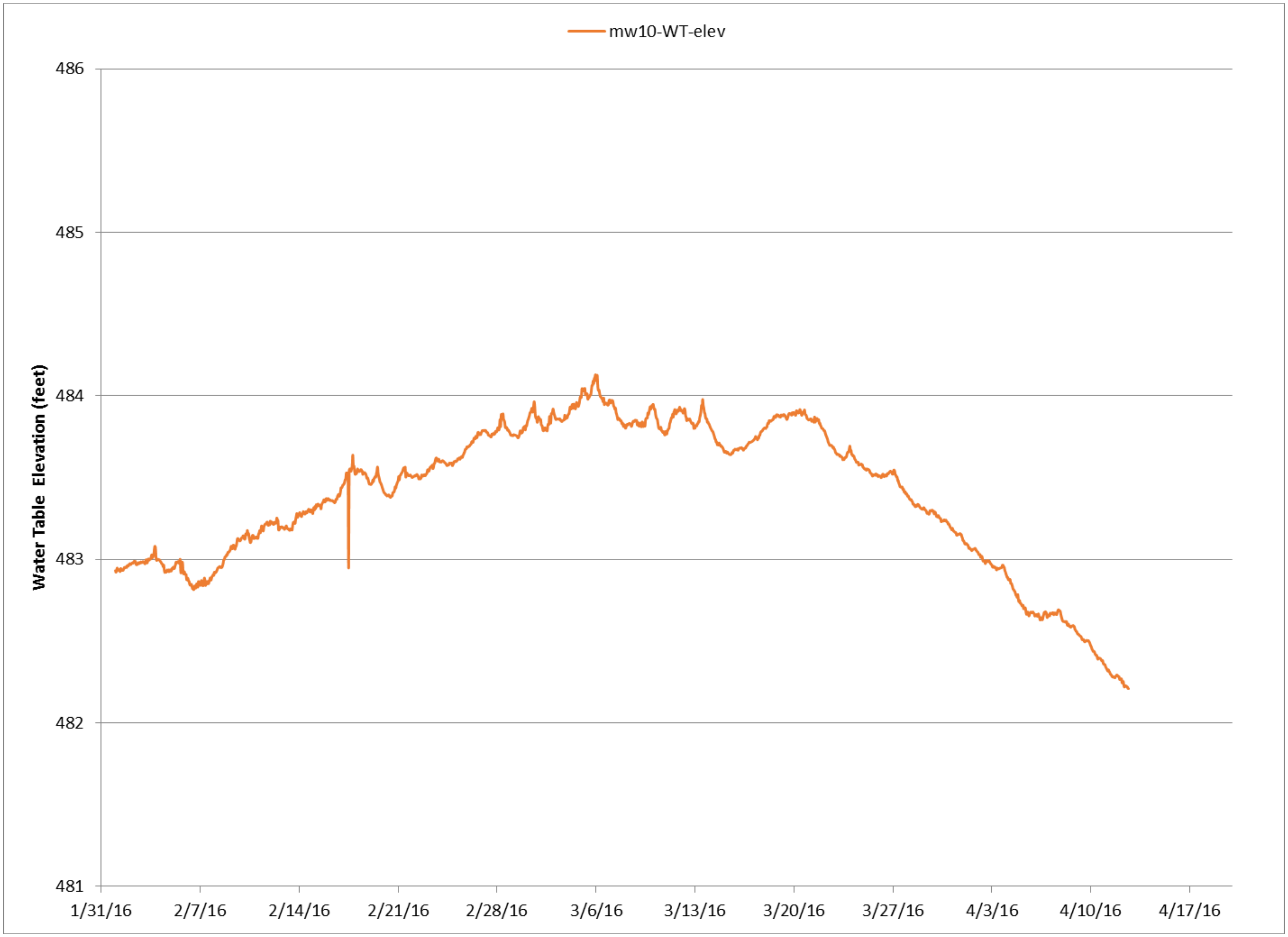

Figure A-2 Water Table Elevation chart for well MW-10.

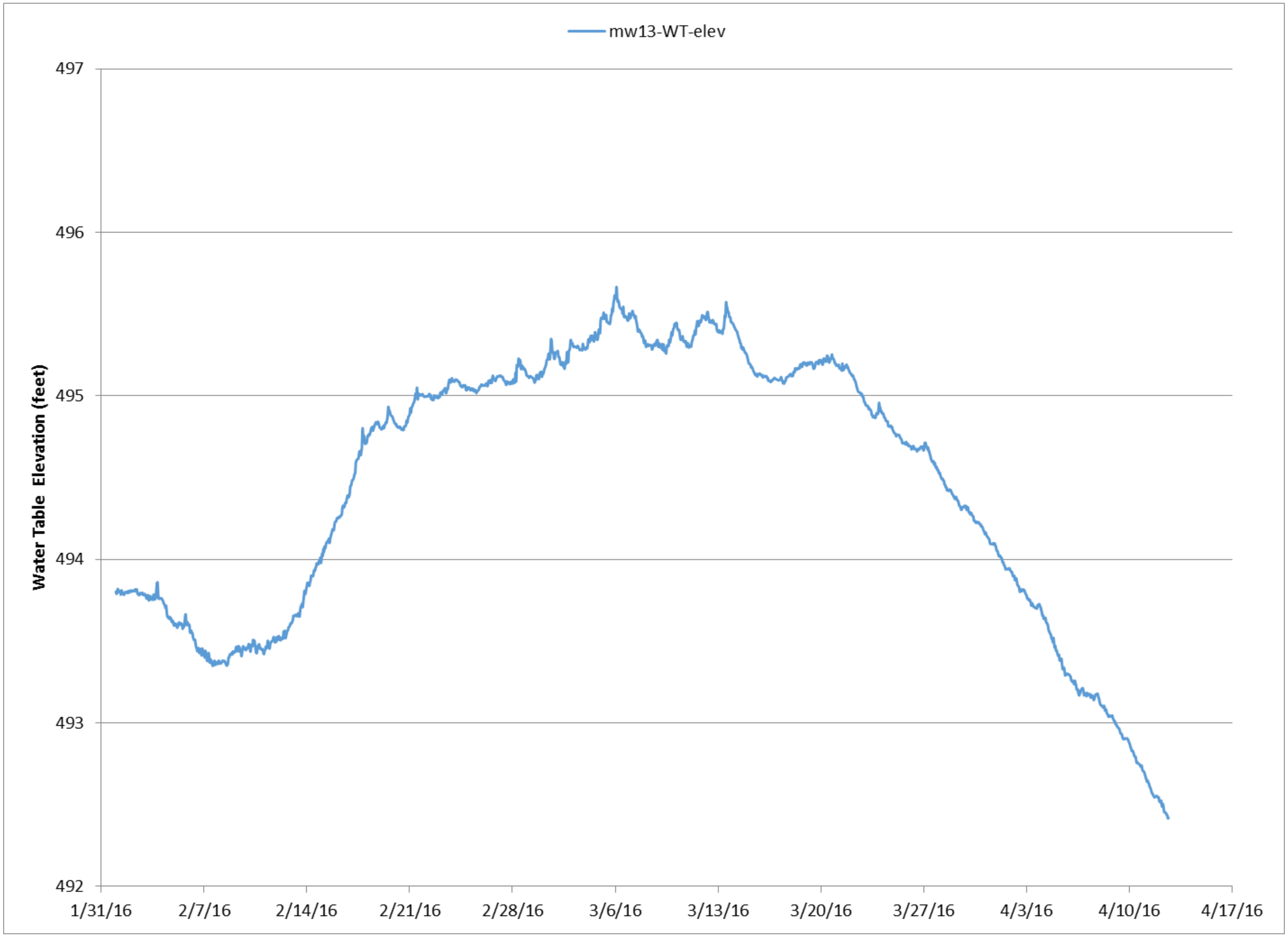

Figure A-3 Water Table Elevation chart for well MW-13.

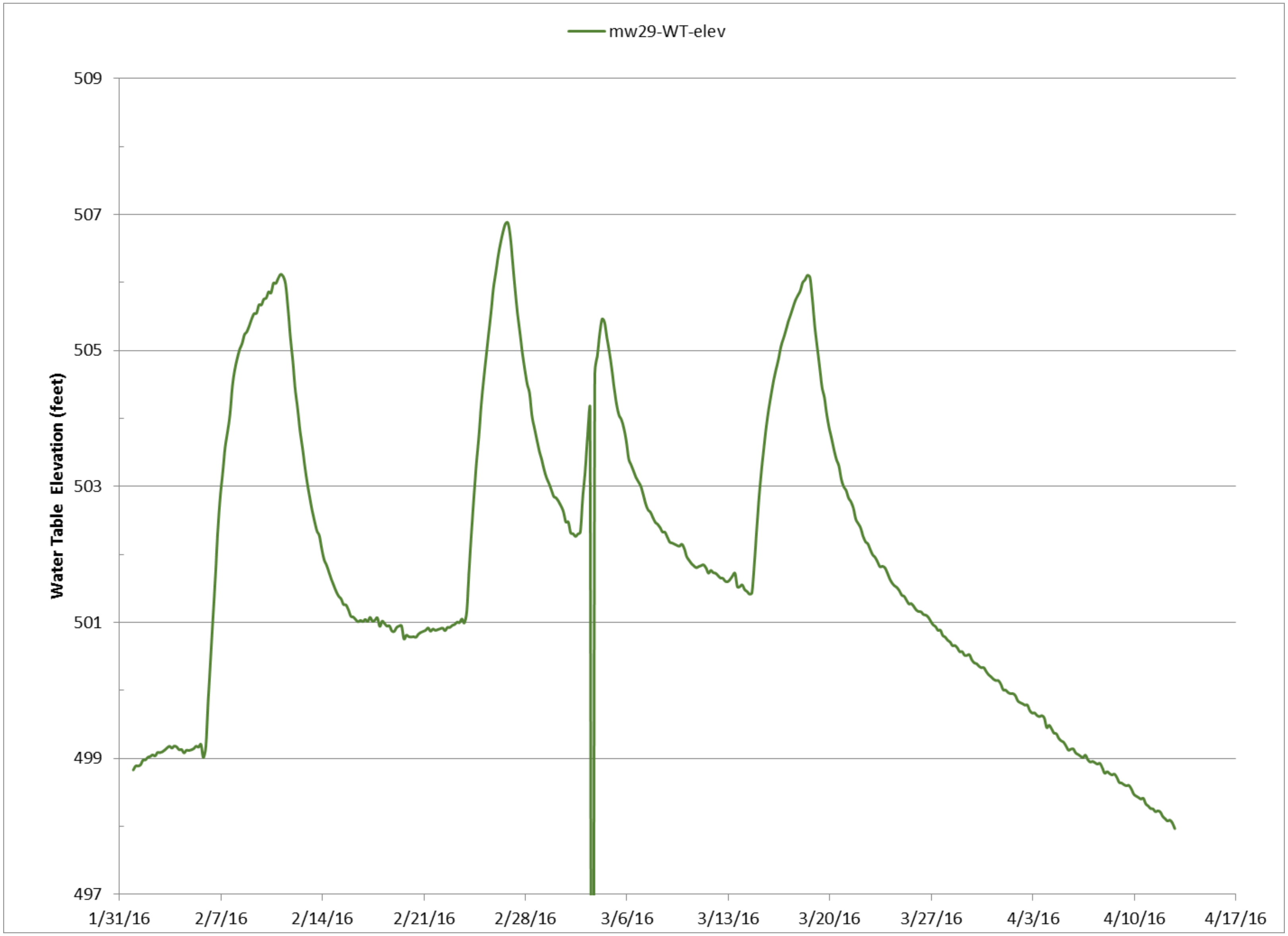

Figure A-4 Water Table Elevation chart for well MW-29.

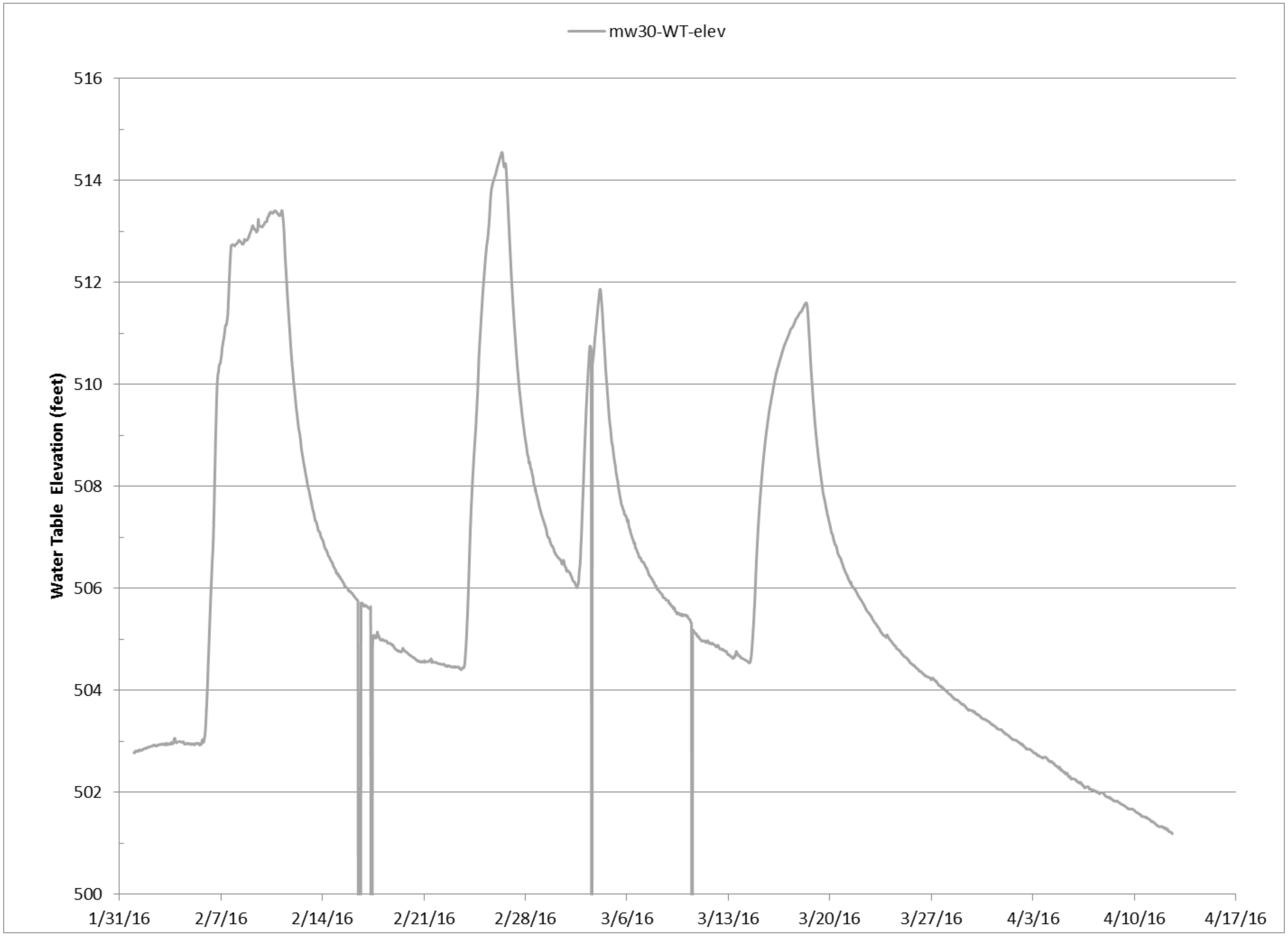

Figure A-5 Water Table Elevation chart for well MW-30.

Appendix B: GW-SW Water Quality Data

Surface water monitoring for the 2016 Emergency Pumping is summarized in another report – King County (in-press, 2016)

The following table is compilation of surface water sampling and groundwater data into one table – organized by sample date.

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Table B-1 Water Quality Data for Surface and Groundwater Monitoring Sites through 3/10/2016. Organized by sample date.

	1/7/2016	1/27/2016			2/10/2016				2/16/2016 11:25	2/16/2016 10:10	2/17/2016 12:35	2/18/2016				
	Lake	Lake	Wetland	Crisp Crk	Lake	Wetland	Crisp Crk	Infilt	SEKC_MW-12	SEKC_MW-13	SEKC_MW-10	Lake	Wetland	Crisp Crk	Infilt	
Temperature	3.302	8.859	9.768	9.291	7.307	8.717	8.721	7.059	9.5	9.5	10.7	8.329	9.292	9.054	No Flow	°C
Dissolved Oxygen	9.14	6.99	7.03	11.59	7.54	6.28	11.87	8.64	10.4	11.6	5.1	5.19	6.74	11.29		mg/L
Conductivity	71.3	42.5	87.5	86.9	79.5	95.8	102.6	79.3	77.1	71.1	169	36.7	94	90.8		µS/cm
pH	6.52	6.4	6.41	7.66	6.29	6.37	7.74	6.47	6.58	6.6	7.04	6.18	6.34	7.63		pH units
Aluminum, Dissolved, ICP-MS	24.8	32.8	5.3	32.3	62.4	3	12.5	20.8	<MDL	<MDL	<MDL	58.6	7.9	26.8		ug/L
Ammonia Nitrogen	0.007	0.0056	0.0096	0.0029	0.216	0.0099	0.0037	0.0981	<MDL	<MDL	<MDL	0.0073	0.0124	0.0035		mg/L
Arsenic, Dissolved, ICP-MS	0.846	0.34	0.23	0.39	0.885	0.21	0.39	0.892	0.22	0.12	0.41	0.651	0.24	0.4		ug/L
Beryllium, Dissolved, ICP-MS	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL		ug/L
Cadmium, Dissolved, ICP-MS	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL		ug/L
Calcium, Dissolved, ICP-MS	5350	3310	8910	8970	6740	8780	10300	6500	7030	6400	21700	3950	9170	9610		ug/L
Calcium, Total, ICP-MS	5140	3320	8380	8950	6930	8930	10500	6570	7030	6620	21900	4150	9200	9800		ug/L
Chromium, Dissolved, ICP-MS	<MDL	<MDL	<MDL	0.22	0.29	<MDL	<MDL	<MDL	0.22	0.2	0.4	0.35	<MDL	<MDL		ug/L
Copper, Dissolved, ICP-MS	1.1	2.58	0.31	1.1	3.15	<MDL	<MDL	0.78	<MDL	<MDL	<MDL	2.93	0.24	0.27		ug/L
Hardness, Calc	20.4	15	30.3	33.3	26.2	32.3	38.6	24.7	31.8	30.9	79.7	15.6	32.8	35.7		mg CaCO3/L
Iron, Dissolved, ICP-MS	267	40	12	27	298	<MDL	11	315	97.1	<MDL	115	231	22	24		ug/L
Iron, Total, ICP-MS	327	158	21	379	383	12	80.3	429	1490	16	822	289	42	73.8		ug/L
Lead, Dissolved, ICP-MS	<MDL	<MDL	<MDL	<MDL	0.17	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.15	<MDL	<MDL		ug/L
Magnesium, Dissolved, ICP-MS	1930	1560	2360	2540	2050	2310	2890	1950	2960	2910	5050	1230	2410	2720		ug/L
Magnesium, Total, ICP-MS	1840	1620	2280	2660	2150	2420	3020	2020	3470	3500	6050	1280	2400	2730		ug/L
Manganese, Dissolved, ICP-MS	14.3	24.3	3.09	0.91	42.2	1.97	0.43	58.5	13.5	0.15	5.23	11.2	3.6	0.754		ug/L
Nickel, Dissolved, ICP-MS	0.42	0.38	<MDL	0.36	0.706	<MDL	<MDL	0.35	0.2	0.14	0.39	0.936	<MDL	<MDL		ug/L
Nitrite + Nitrate Nitrogen	0.346	<MDL	0.666	0.885	0.341	0.689	0.836	0.68	0.839	0.469	0.839	<MDL	0.653	0.872		mg/L
Orthophosphate Phosphorus	0.00227	0.0137	0.0057	0.00982	0.00894	0.00522	0.00921	0.0014	0.0146	0.0144	0.0089	0.0103	0.00589	0.00905		mg/L
Selenium, Dissolved, ICP-MS	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL		ug/L
Silver, Dissolved, ICP-MS	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL		ug/L
Sulfate	6.61	4.11	3.53	3.78	5.8	3.49	4.35	6.1	2.63	2.58	6.85	3.38	3.23	3.68		mg/L
Thallium, Dissolved, ICP-MS	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL		ug/L
Total Alkalinity	17	12.4	32.3	33	22.5	33.4	40	22.5	29.7	28.9	71.3	12	32.5	34.6		mg CaCO3/L
Total Nitrogen	0.67	0.542	0.745	1.04	1.21	0.763	0.909	1.03	0.801	0.462	0.834	1.02	0.735	0.979		mg/L
Total Phosphorus	0.0317	0.0554	0.0115	0.0298	0.038	0.01	0.0172	0.023	0.0193	0.0136	0.0115	0.082	0.0174	0.0202		mg/L
Total Suspended Solids	10.3	8.16	0.65	6.6	2.4	<MDL	4.47	1.53	2.3	0.0136	0.5	13.8	1.4	2.6		mg/L
Zinc, Dissolved, ICP-MS	6.35	9.1	0.68	<MDL	8.59	0.7	1.3	5.21	0.56	1.4	<MDL	11.8	1.5	0.97		ug/L

(***See table 4 for abbreviations***)

Table B-1 continued:

	2/24/2016				3/2/2016 11:35	3/2/2016 12:55	3/3/2016 1:25	3/10/2016 12:20	3/17/2016				3/29/2016			4/14/2016			
	Lake	**Wetland**	**Crisp Crk**	**Infilt**	SEKC_MW-27	SEKC_MW-28	SEKC_MW-29	SEKC_MW-30	**Lake**	**Wetland**	**Crisp Crk**	**Infilt**	**Lake**	**Wetland**	**Crisp Crk**	**Lake**	**Wetland**	**Crisp Crk**	Units
Sample Temperature, Field	7.477	8.833	8.297	8.244	10.1	10.1	10.5	10.9	5.0	8.0	8.0	9.2	6.1	8.4	8.7	12.3	9.6	9.9	deg C
Dissolved Oxygen, Field	6.34	7.7	12.01	9.21	10.3	8.3	11.4	8.5	7.8	7.6	12.0	9.7	6.3	7.1	11.7	8.7	6.9	11.4	mg/L
Conductivity, Field	67.7	94.5	97.9	78.6	99.8	144	62.8	83.9	72.2	93.3	98.7	81.5	72.2	92.3	102.8	78.8	97.7	106.3	umhos/cm
pH, Field	6.45	6.46	7.71	6.69	6.48	6.67	6.05	6.46	6.21	6.4	7.47	6.64	6.71	6.6	7.7	7.05	6.57	7.55	pH
Turbidity, Field	51.8	3.3	16.9	22.8	<MDL	<MDL	<MDL	<MDL	26.2	2.8	17.1	19.3	24.9	3.0	13.9	15.0	4.9	13.3	ug/L
Aluminum, Dissolved	0.0048	0.0086	0.0026	0.105	<MDL	0.013	0.0113	<MDL	0.012	0.005	0.003	0.100	0.008	0.006	0.002	0.007	0.007	0.003	mg/L
Ammonia Nitrogen	0.5	0.22	0.4	0.784	0.23	0.33	<MDL	0.16	0.714	0.21	0.4	0.885	0.577	0.22	0.41	0.632	0.22	0.47	ug/L
Arsenic, Dissolved	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	ug/L
Beryllium, Dissolved	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	ug/L
Cadmium, Dissolved	5220	9550	10400	6940	9140	16900	5750	6130	6920	9500	10600	7220	5820	9370	10700	6820	10000	11400	ug/L
Calcium, Dissolved	5640	9480	11000	7350	8870	16100	6860	6180	7080	10500	12600	9870	6380	9870	10900	7470	10900	11300	ug/L
Calcium, Total	0.23	<MDL	<MDL	<MDL	0.24	0.4	0.39	0.5	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.22	<MDL	<MDL	0.21	ug/L
Chromium, Dissolved	2.07	<MDL	0.33	0.79	0.24	<MDL	<MDL	0.25	2.0	<MDL	<MDL	0.7	2.3	0.2	0.2	1.1	<MDL	0.3	ug/L
Copper, Dissolved	21.9	33.7	40	27.1	37.3	61	28.8	31.6	27	38	47	37	24	36	41	29	39	41	mg CaCO3/L
Hardness, Calc	157	<MDL	14	356	<MDL	<MDL	<MDL	<MDL	307	<MDL	17	438	281	12	16	267	24	16	ug/L
Iron, Dissolved	386	31	60.1	529	93.2	239	5470	598	385	37	55	928	437	42	62	1140	90	50	ug/L
Iron, Total	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.1	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	ug/L
Lead, Dissolved	1820	2520	2960	2070	3280	4250	1510	3580	2140	2580	3130	2200	1980	2600	3190	1950	2610	3180	ug/L
Magnesium, Dissolved	1910	2440	3040	2140	3680	5080	2840	3930	2160	2930	3740	3090	2050	2720	3210	2460	2840	3150	ug/L
Magnesium, Total	6	1.79	0.588	50.3	2.93	<MDL	0.937	20.9	21.9	1.3	0.7	50.8	12.0	1.5	0.6	8.0	2.6	0.6	ug/L
Manganese, Dissolved	0.46	<MDL	0.11	0.34	0.27	0.21	0.24	2.08	0.5	<MDL	<MDL	0.35	0.5	<MDL	<MDL	0.36	<MDL	<MDL	ug/L
Nickel, Dissolved	0.132	0.7	0.877	0.726	2.22	1.84	2.66	2.82	0.26	0.58	0.75	0.64	0.23	0.55	0.71	0.32	0.53	0.69	mg/L
Nitrite + Nitrate Nitrogen	0.00341	0.00576	0.0084	0.0019	0.00683	0.00743	0.00601	0.00322	0.0026	0.0048	0.0085	0.0023	0.0085	0.0021	0.0077	0.0022	0.0015	0.0077	mg/L
Orthophosphate Phosphorus	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	ug/L
Selenium, Dissolved	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	ug/L
Silver, Dissolved	4.24	3.53	4.23	5.81	3.71	6.07	1.77	3.4	5.2	3.6	4.2	5.4	4.8	3.8	4.3	5.1	4.3	4.7	mg/L
Sulfate	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	ug/L
Thallium, Dissolved	19.8	33.6	37.5	22.9	34.6	54.7	15.2	23.7	24.5	34.4	39.3	25.4	22.7	35.5	40.9	24.9	38.9	42.8	mg CaCO3/L
Total Alkalinity	0.644	0.752	0.94	1.07	2.27	1.9	2.66	2.88	0.93	0.65	0.84	1.01	0.70	0.59	0.77	0.95	0.66	0.78	mg/L
Total Nitrogen	0.0363	0.0148	0.0173	0.0224	0.0115	0.0146	0.092	0.0216	0.04	0.01	0.01	0.02	0.03	0.01	0.01	0.04	0.01	0.01	mg/L
Total Phosphorus	8.19	2.32	1.54	1.1	<MDL	1.8	178	27.8	9.3	11.2	1.4	3.1	10.6	1.9	1.6	43.9	45.1	1.2	mg/L
Total Suspended Solids	5.95	0.51	1.2	6.69	0.68	<MDL	<MDL	0.54	3.61	0.83	1.10	7.51	5.61	<MDL	0.84	2.84	0.61	0.95	ug/L

(***See table 4 for abbreviations***)