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Environmental Management - Grand Junction Office

UMTRA Project

Moab UMTRA Project
Well Field Optimization Plan

June 2009

U.S. Department of Energy

Office of Environmental Management

Prepared by the Technical Assistance Contractor under contract number DE-AC30-07CC60012
for the U.S. Department of Energy Office of Environmental Management, Grand Junction, Colorado.

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Revision 0

Review and Approval

6/17/09

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6/17/09

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Acronyms and Abbreviations

bgs	below ground surface
cfs	cubic feet per second
CF	Configuration
ft	feet
gpm/ft	gallons per minute per foot
IA	interim action
kg	kilograms
kg/gal	kilograms per gallon
µs/cm	microsiemens per centimeter
mg/L	milligrams per liter
RAC	Remedial Action Contractor
SOWP	Site Observational Work Plan
TDS	total dissolved solids
UMTRA	Uranium Mill Tailings Remedial Action

Executive Summary

The interim action (IA) well field at the Moab Uranium Mill Tailings Remedial Action (UMTRA) site was designed to mitigate potential environmental effects of contaminated ground water discharging into the Colorado River. This system, installed starting in 2003, extracts ground water downgradient (southeast) from the tailings pile and transports it to an evaporation pond located on top of the tailings pile. The extracted ground water is then distributed through a sprinkler system (also located on top of the tailings pile) equipped with spray evaporation equipment.

Removal and transport of the tailings to the Crescent Junction disposal cell is scheduled to begin in spring 2009. As the tailings are systematically removed, the capacity of the sprinkler system to evaporate the extracted ground water will diminish. In order to continue extracting ground water using the current treatment system, it was necessary to provide well field pumping schedule alternatives that will optimize the well field's ability to protect adjacent Colorado River habitat areas and/or maximize ammonia and uranium mass removal.

These well field pumping alternatives presented in this document are based on ground water chemistry and elevation data collected primarily over the respective lifespan (through January 2009) of extraction well PW02, Configuration (CF) 1 extraction wells, CF3 remediation wells, and CF4 remediation wells. In addition, pumping schedules were modified based on a ground water/surface water interaction investigation completed in 2008 that monitored water chemistry changes as freshwater migrated into the well field subsurface during the 2008 spring runoff.

While a freshwater lens developed in both the Baseline Area and CF1 areas of the well field, the water chemistry changed significantly only in the vicinity of CF1. This suggests that protection of riparian habitat during periods of the presence of the freshwater lens is not necessary, and cessation of pumping when this condition occurs in specific areas of the well field would save evaporation pond capacity.

1.0 Introduction

The IA well field (Figure 1) at the Moab UMTRA site was installed to mitigate potential environmental effects from contaminated ground water in the alluvium discharging to the nearby Colorado River. This system first became operational in 2003 and currently consists of CF1, CF2, CF3, CF4, the Baseline Area, and the Infiltration Trench (DOE 2003a). CF1 consists of 10 ground water extraction wells installed in 2003, and CF2, CF3, and CF4 were installed in 2004, 2005, and 2006, respectively. Each of these CFs, or groups of wells, consist of 10 remediation wells that are capable of both ground water extraction and freshwater injection. The Infiltration Trench was installed in 2006 and injects freshwater from the Colorado River.

All extracted ground water is pumped to the evaporation pond located on the top of the tailings pile (Figure 2). The water is then distributed by a sprinkler system that covers 38 acres of the pile and is equipped with spray heads that enhance evaporation of the water. The distribution of the water provides dust suppression on the top of the pile.

Performance assessments have been completed each year since the first phase of the well field was installed in 2003 (DOE 2004, DOE 2005a, DOE 2005b, DOE 2005c, DOE 2006a, DOE 2007, DOE 2008). These documents provide details regarding the performance of the IA system based on water level and chemical data collected from both extraction and observation wells. Volume of ground water extracted, average pumping rates, ammonia and uranium mass removed, and specific capacity estimates among other details are included in this report.

The various types of data were collected from 2003 through January 2009 and were analyzed to determine which wells have been efficient at ground water extraction and under what river stage they remove the most contaminant mass. This information was compiled and summarized to generate this document.

2.0 Purpose and Scope

The purpose of this Well Field Optimization Plan is to fine-tune the well field operations in order to maximize mass removal and offer maximum protection of any habitat areas located adjacent to any of the CF wells or the Infiltration Trench. More efficient ground water pumping strategies and schedules are necessary as the tailings are transported off site and the sprinkler system capacity becomes increasingly reduced and eventually removed, along with the evaporation pond.

Results from a ground water/surface water interaction investigation completed in 2008 are presented in Section 3. The investigation was designed to determine the extent of inland influx of freshwater from the Colorado River under spring runoff conditions. Historical fluctuations of ammonia and uranium (contaminant) concentrations, contaminant mass removal, mass removal rates, and specific capacities for CF1, well SMI-PW02 (PW02), and CF3 and CF4 are presented in Section 4. Proposed pumping schedules for various scenarios for optimal mass removal and habitat protection are presented in Section 5.

In addition, updated plume maps and water table contour maps are presented in Sections 6 and 7, respectively. The plume maps represent sampling from a number of site-wide locations that in some cases have not been sampled since 2002.

3.0 Ground Water/Surface Water Interaction Investigation

A ground water/surface water investigation was initiated March 2008 to determine the extent of freshwater migration from the Colorado River into the well field during the peak spring runoff or comparable localized storm events in which the river stage remains elevated for a prolonged period of time. The information obtained from this study was used to optimize contaminant mass removal by ground water extraction wells on a yearly basis and provide optimal habitat protection during the spring months. CF1 and the Baseline Area in the IA well field were studied in this investigation because each one represents different site conditions. CF1 is located on the southern end of the well field and is adjacent to a main backwater channel that flows until the Colorado River flow decreases to approximately 2,500 cubic feet per second (cfs). The Baseline Area is located on the north end of the well field and is approximately 150 feet (ft) from the main river channel. A backwater channel flows through the baseline area when the Colorado River flow is approximately 11,000 cfs.

Levels of salinity in ground water can be described with respect to total dissolved solids (TDS) concentrations in units of milligrams per liter (mg/L). Ground water is typically characterized as being mildly saline (TDS = 1,000 to 3,000 mg/L), moderately saline (TDS = 3,000 to 10,000 mg/L), very saline (TDS = 10,000 to 35,000 mg/L), or briny (TDS > 35,000 mg/L). These TDS concentrations are larger than the TDS levels commonly reported for the Colorado River in the vicinity of Moab (250 to 1,000 mg/L), which is referred to as freshwater in this report (DOE 2006a).

Appendix A provides the details of this investigation. In general, flow associated with the Colorado River spring runoff impacted the two study areas differently because of their proximity to actively flowing side channels and the different elevation of the underlying brine interface. The lens of freshwater that flowed from the river into the well field subsurface during the prolonged high river stage lowered concentrations of contaminants and TDS in the vicinity of CF1 more than in the Baseline Area.

Figures 3 and 4 are water chemistry cross sections through CF1 based on the March and June 2008 sampling events. In addition to the posted TDS data, Stiff Diagrams provide additional water chemistry data collected during this investigation. The March 2008 data (Figure 3) represents the Colorado River base-flow conditions prior to the river transition from gaining to losing river conditions typically associated with sustained increased flows during the spring runoff. Based on the ground water samples collected in March 2008, only very saline or briny water types were present; however, by June 2008 a significant lens of water ranging from moderately saline to freshwater types had developed. Comparisons of the Stiff Diagrams suggest the overall ground water chemistry was significantly altered by the influx of the surface water.

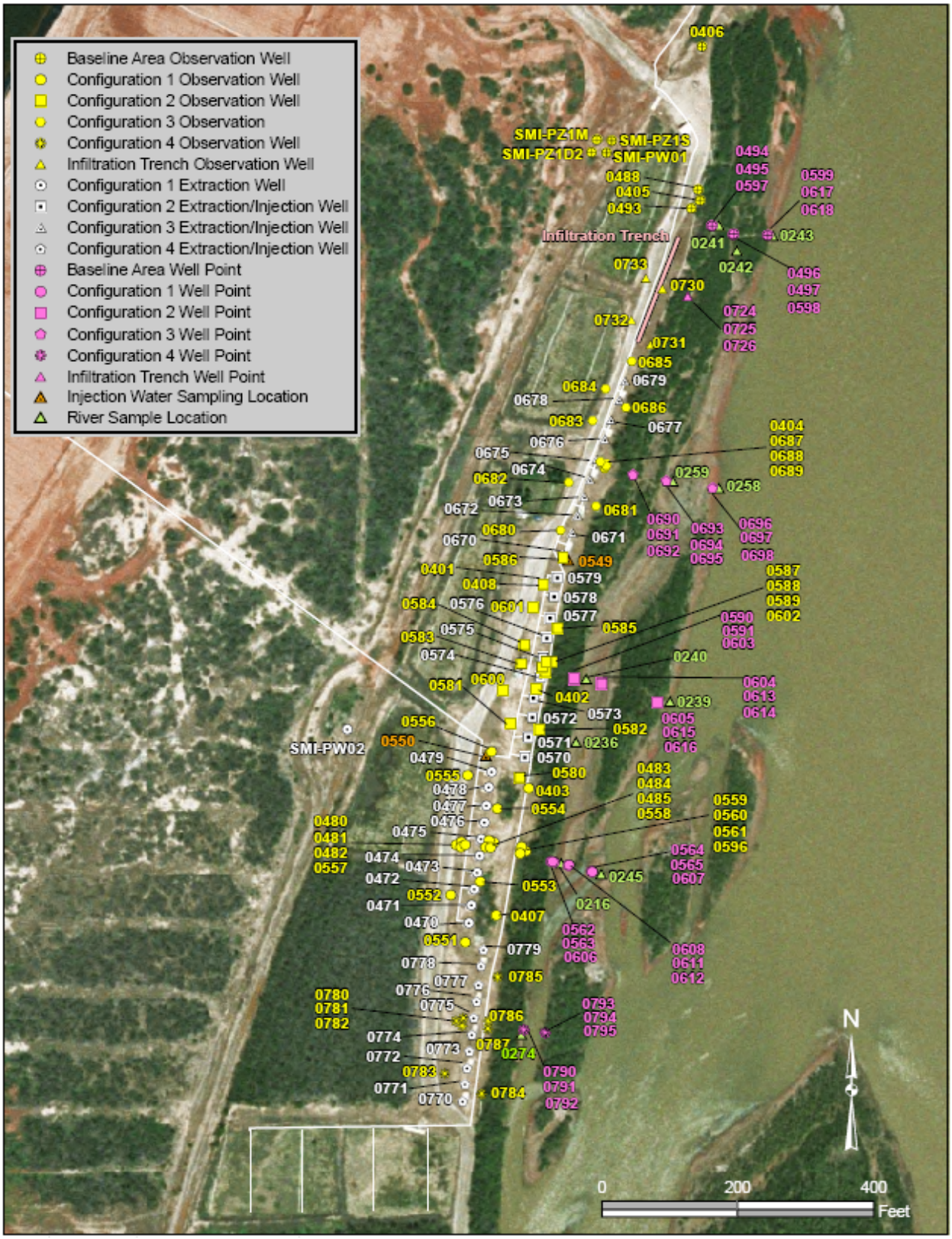

Figure 1. Interim Action Well Field and Baseline Area Location Map

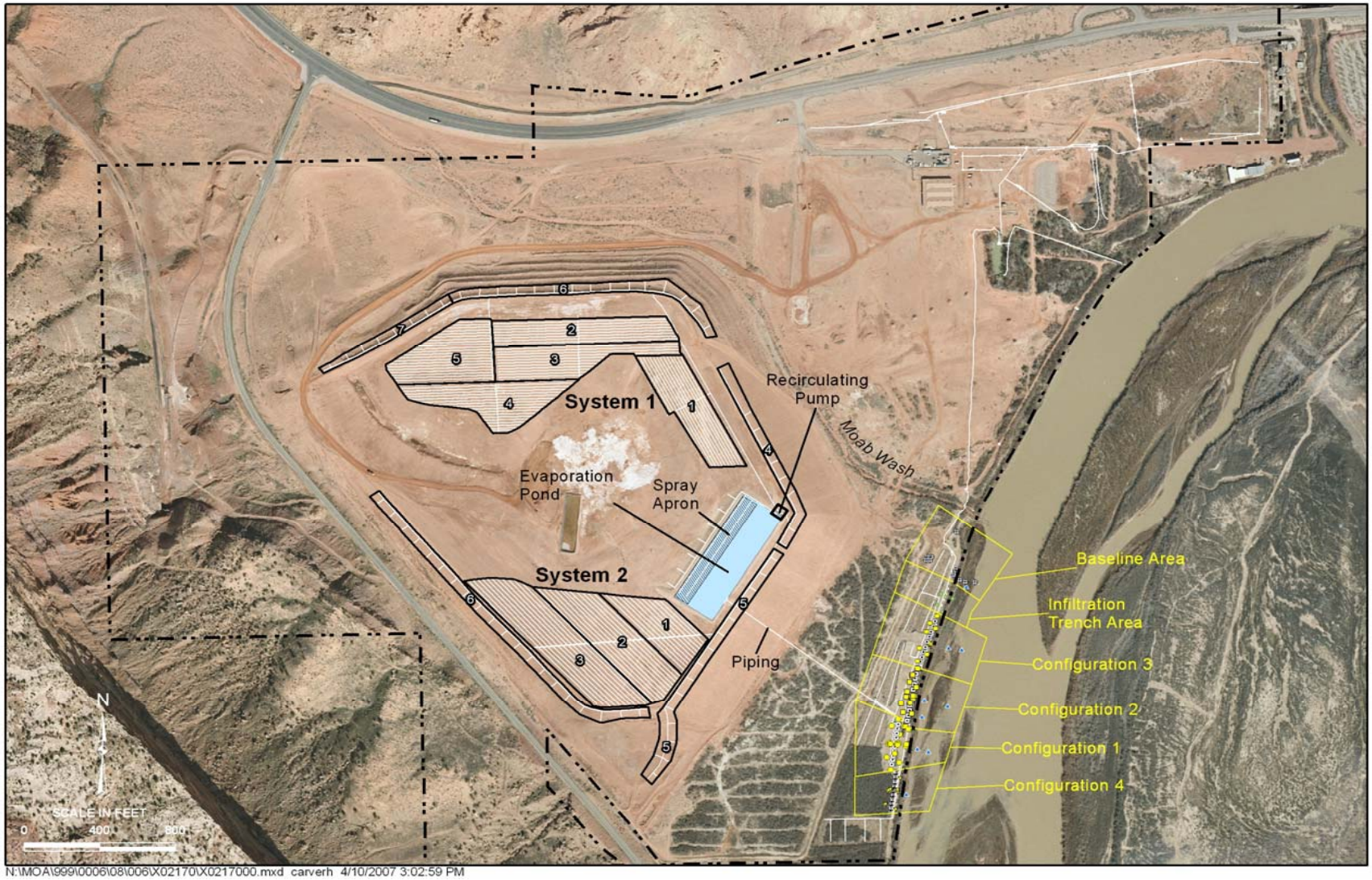

Figure 2. Treatment System Components

Comparable cross sections were developed for the Baseline Area and were also based on the March and June 2008 sampling events (Figures 5 and 6, respectively). As these cross sections show, ground water containing less than 10,000 mg/L was present during the river base-flow conditions (March 2008) and extended further into the well field by June 2008. While a freshwater lens was present in both the Baseline Area and CF1, the CF1 water chemistry changed significantly as evidenced by the accompanying Stiff Diagrams. This suggests that protection of riparian habitat during periods of the presence of the freshwater lens is not necessary. Cessation of pumping when this condition occurs in specific well field CFs would save evaporation pond capacity.

Figures A-27 through A-31 are a complete set of cross sections through CF1 in March, April, June, July, and September 2008, respectively, from the ground water/surface water interaction investigation. Baseline Area cross sections are shown as Figures A-32 through A-36. Each set of figures sequentially displays the development of the saline lens through June 2008 and subsequent rebound of the system back to near prerunoff conditions by September 2008.

4.0 Summary of Previous Ground Water Extraction

This section presents a brief synopsis of well operation, the ammonia and uranium concentrations measured during ground water extraction, the mass of ammonia and uranium removed over the respective life span of each well, and a summary of the specific capacity measured in CF1 extraction wells, CF3 remediation wells, CF4 remediation wells, and well PW02.

CF2 wells cannot be optimized and will not be discussed further in this section except for the following. For the first year after they were installed, CF2 wells were injected with freshwater. However, the freshwater pond was over utilized; the same water source was being used for injection and irrigation purposes. This caused fine sediment from the bottom of the pond to be transported and subsequently injected into the well screens and gravel packs, causing more clogging. A combination of this and the under design of the well screen slot size and gravel pack for the subsurface has resulted in an extremely low specific capacity of these wells. It is apparent that the CF2 wells are now ineffective for ground water extraction, and attempts at redevelopment of CF2 wells have not been successful.

4.1 CF1 Operation

CF1 ground water extraction wells were installed in the summer of 2003 and started actively extracting ground water in September 2003. In order to avoid damage to this system from freezing temperatures during the winter months, CF1 was not operated from December 2003 through June 2004, December 2004 through February 2005, December 2005 through March 2006, and December 2006 through February 2007. However, it operated continuously since the end of February 2007 through January 2009. An explanation for the change to year round operation is provided in Section 4.1.4. Between 2003 and 2008, the 10 CF1 wells extracted 41.2 million gallons of ground water and in doing so removed approximately 61,000 kilograms (kg) of ammonia and 330 kg of uranium.

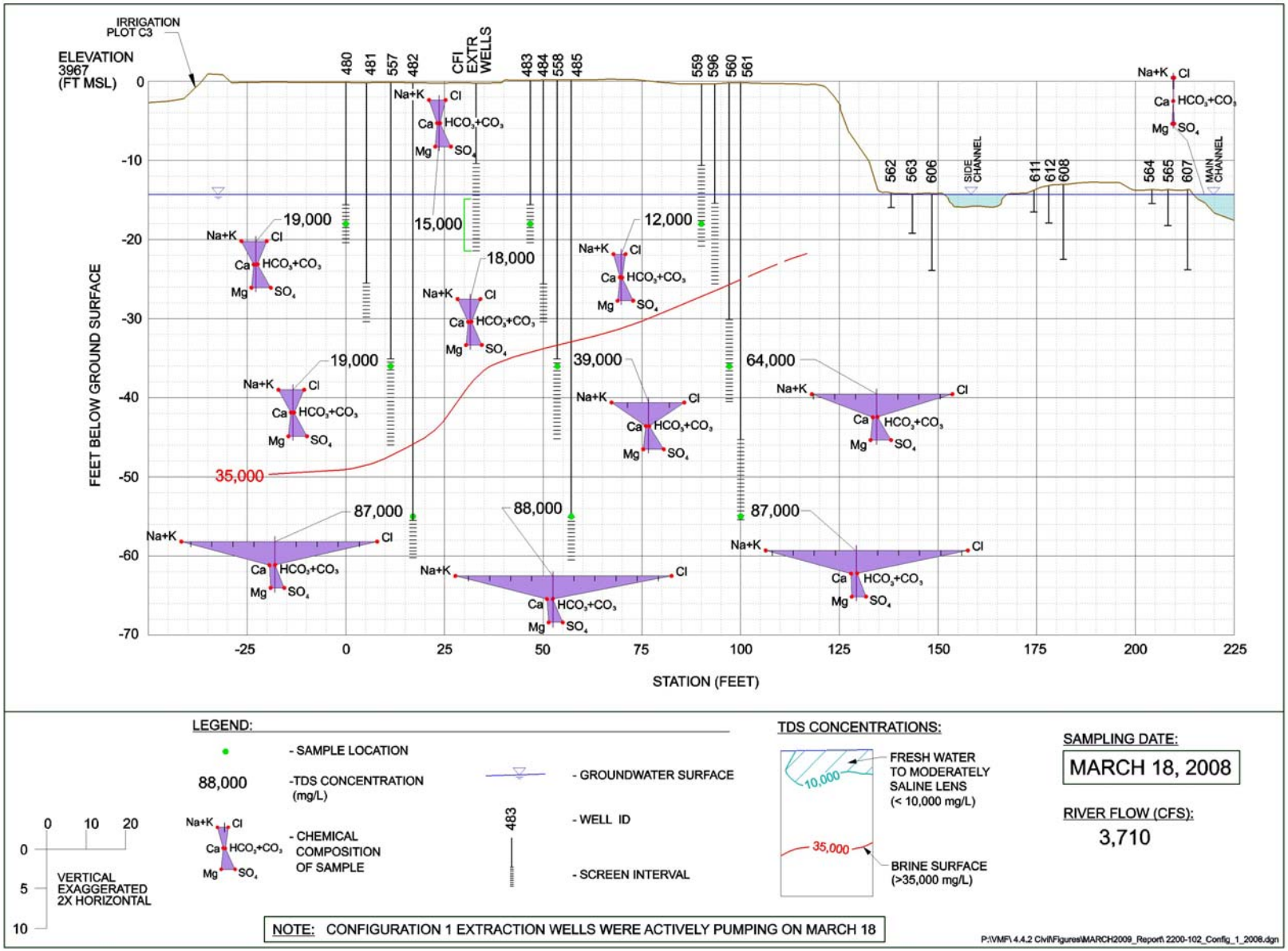

Figure 3. CF1 March 2008 Water Chemistry Cross Section

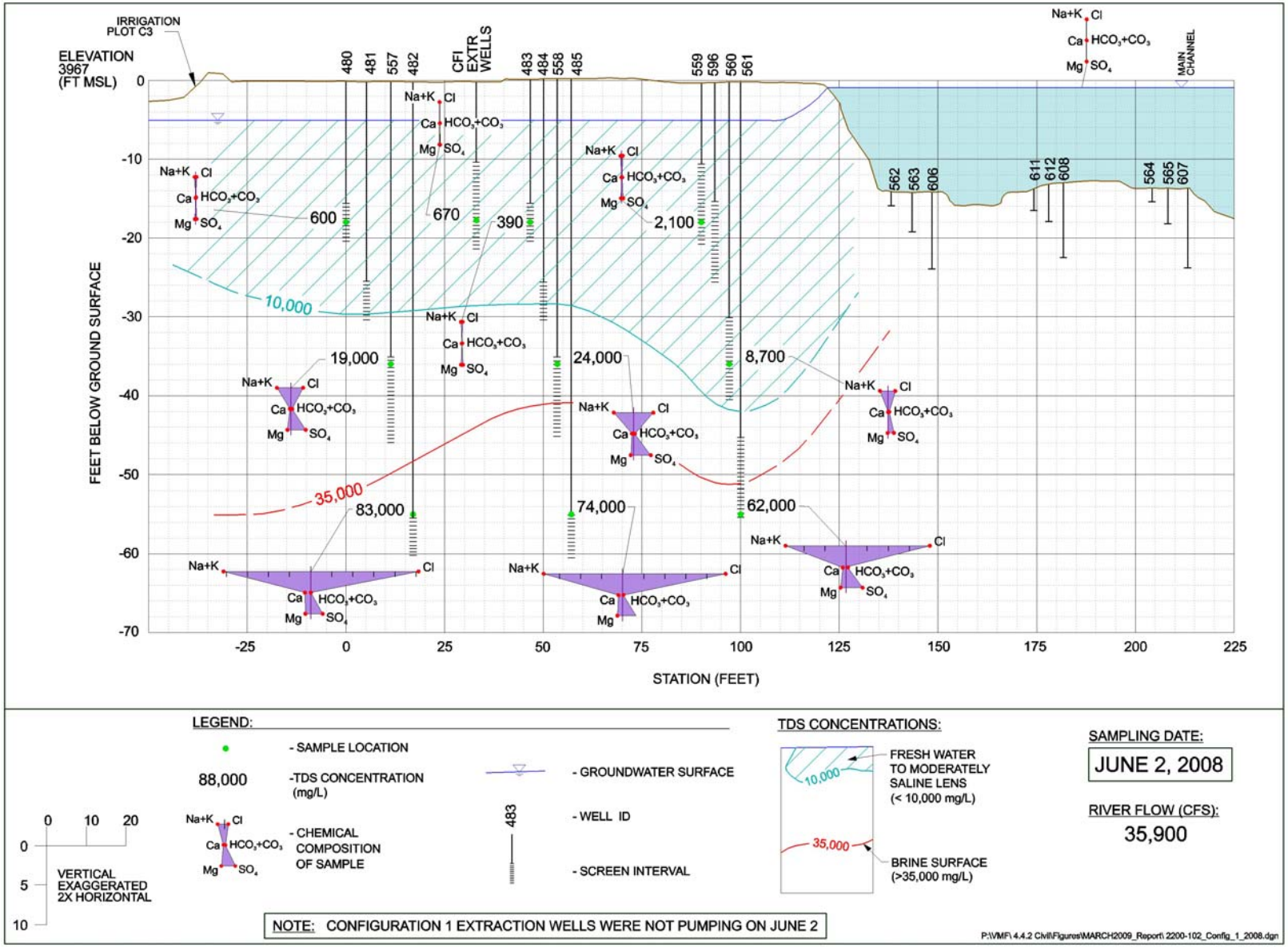

Figure 4. CF1 June 2008 Water Chemistry Cross Section

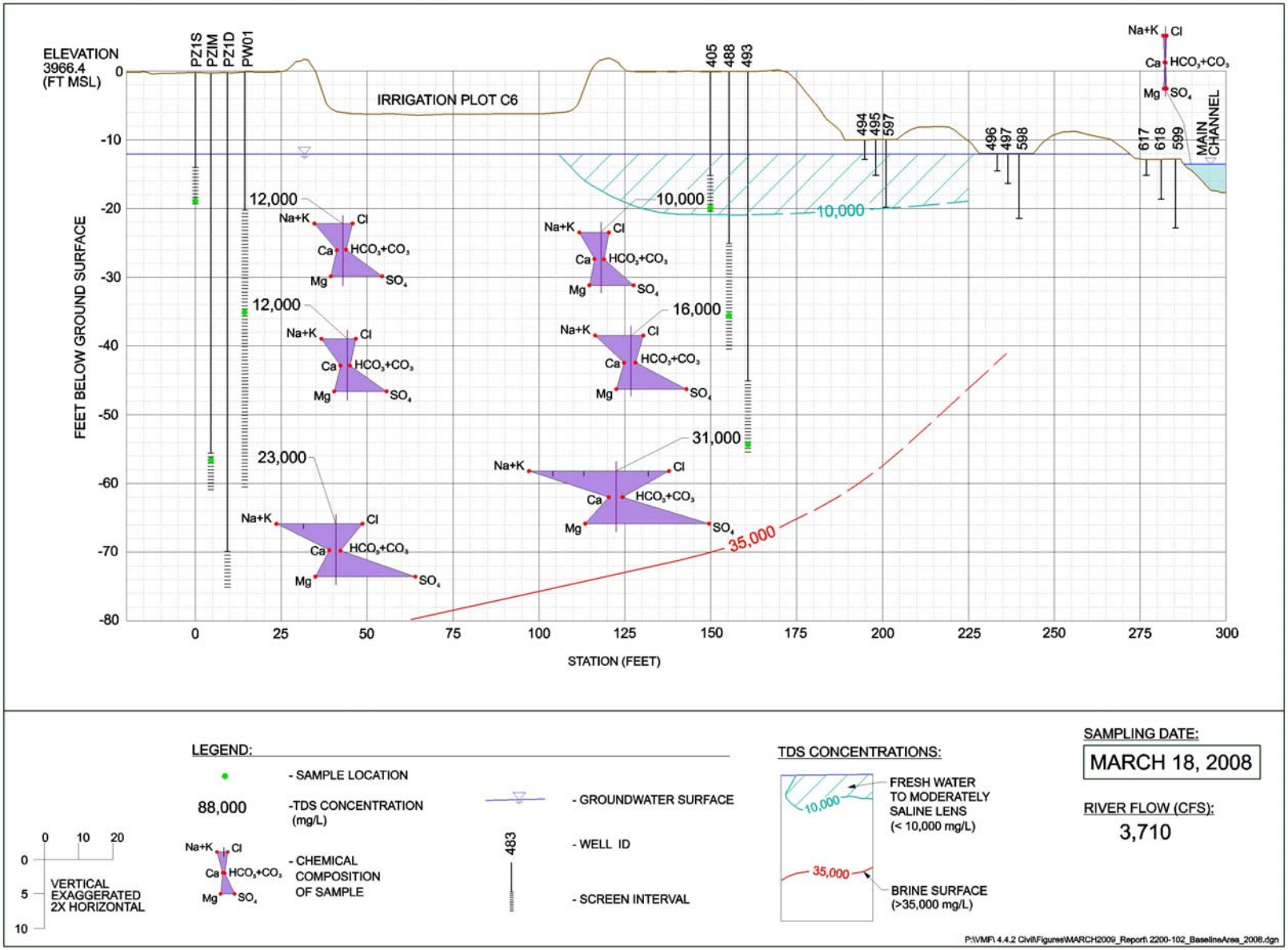

Figure 5. Baseline Area March 2008 Water Chemistry Cross Section

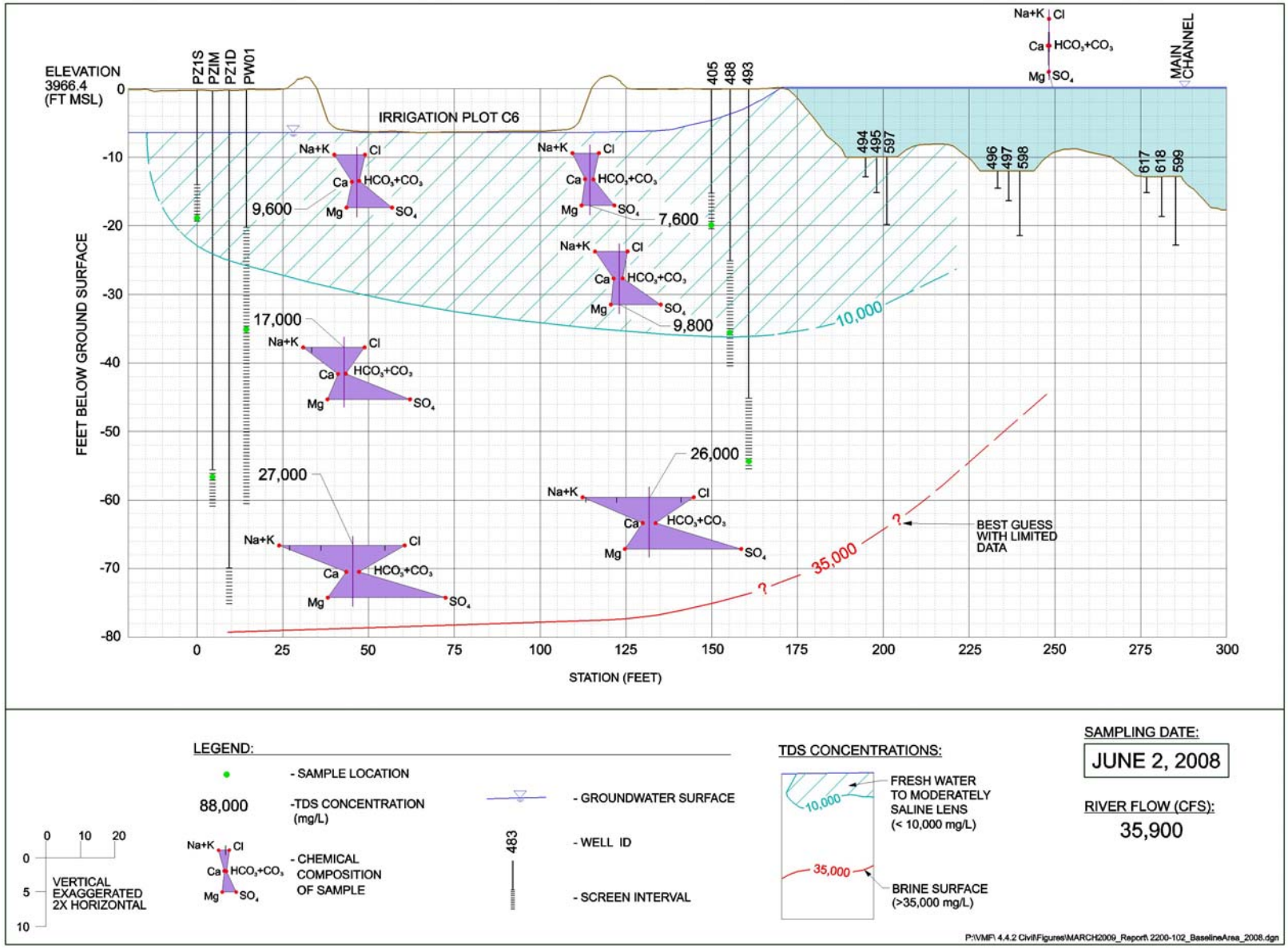

Figure 6. Baseline Area June 2008 Water Chemistry Cross Section

4.1.1 CF1 – Ammonia Concentrations and Mass Removal

Ammonia concentrations measured in CF1 wells during 2004 and prior to the spring runoff peak in 2005 ranged from 500 to 1000 mg/L. After mid-2005 the concentrations decreased and leveled off, generally ranging from approximately 250 to 500 mg/L (see Figure B-1 in Appendix B). Early in 2008, the ammonia concentrations significantly increased, especially in the northern half of the well field, and then decreased as the stage decreased.

As the time concentration plots show, CF1 extraction well concentrations decrease during spring runoff time periods. This is a direct result of the CF1 well field location and the configuration of the adjacent riparian river channel. During high river flows, the riparian channel directly off the bank fills with river water, causing losing stream conditions and promoting the migration of freshwater into the river bank sediments adjacent to the CF1 wells. Further information on interpretation of these conditions is presented as part of the results from the ground water/surface water interaction investigation contained in Appendix A.

The overall average ammonia concentration (based on all samples collected from all 10 extraction wells) through 2008 is 423 mg/L. A breakdown of the concentrations measured from each well is presented in Table 1.

Table 1. CF1 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2003 Through 2008

CF1	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0470	2003	418,836	992[a]	1,571	2.9[a]	4.6
	2004	1,174,174	833	3,725	2.7	11.7
	2005	1,450,680	400	2,016	1.8	9.4
	2006	1,288,344	337	1,632	1.8	9.7
	2007	652,212	353	893	1.9	4.7
	2008	511,638	485	693	1.9	3.2
	Total/Avg.	**5,495,884**	**491**	**10,529**	**2.1**	**43.2**
Well 0471	2003	265,182	1030[a]	1,032	2.9[a]	2.9
	2004	897,111	921	3,169	2.5	8.6
	2005	1,118,823	516	2,150	2.0	8.2
	2006	1,001,722	425	1,582	2.0	7.9
	2007	929,795	407	1,363	1.9	5.8
	2008	823,975	367	1,114	1.5	4.8
	Total/Avg.	**5,036,608**	**555**	**10,411**	**2.0**	**38.2**
Well 0472	2003	293,019	849[a]	932	3.1[a]	3.4
	2004	925,388	841	3,001	2.6	9.3
	2005	849,811	432	1,343	2.0	6.4
	2006	857,620	266	885	1.5	5.5
	2007	677,907	318	826	1.7	4.0
	2008	609,673	430	735	1.8	3.2
	Total/Avg.	**4,213,418**	**463**	**7,721**	**2.0**	**31.9**

Table 1. CF1 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2003 Through 2008 (continued)

CF1	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0473	2003	198,043	796[a]	596	2.8[a]	2.1
	2004	532,396	799	1,604	2.8	5.6
	2005	679,673	323	852	2.1	6.3
	2006	748,397	230	608	1.6	5.0
	2007	787,285	252	733	1.5	3.8
	2008	708,521	399	909	1.6	3.8
	Total/Avg.	**3,654,315**	**412**	**5,302**	**2.0**	**26.6**
Well 0474	2003	248,785	767[a]	721	3.0[a]	2.8
	2004	580,984	836	1,809	2.9	6.3
	2005	237,467	349	318	2.3	2.5
	2006	396,668	227	332	1.5	2.5
	2007	468,957	329	575	2.0	3.0
	2008	830,799	305	940	1.4	4.6
	Total/Avg.	**2,763,660**	**403**	**4,695**	**2.0**	**21.7**
Well 0475	2003	241,072	822[a]	804	2.9[a]	2.6
	2004	723,285	723	1,993	2.6	7.3
	2005	855,327	287	878	2.1	7.3
	2006	940,652	247	841	1.7	6.6
	2007	904,863	330	1,116	2.1	6.8
	2008	892,807	240	1,137	1.4	6.0
	Total/Avg.	**4,558,006**	**378**	**6,768**	**2.1**	**36.7**
Well 0476	2003	146,338	810[a]	448	2.9[a]	1.6
	2004	434,458	700	1,134	2.6	4.3
	2005	795,882	237	648	1.9	6.3
	2006	769,628	179	545	1.5	4.9
	2007	663,173	280	684	2.3	5.6
	2008	812,074	305	797	2.2	5.0
	Total/Avg.	**3,621,553**	**343**	**4,256**	**2.1**	**27.8**
Well 0477	2003	255,205	756[a]	729	2.8[a]	2.7
	2004	593,597	644	1,425	2.5	5.7
	2005	740,357	235	673	2.1	5.8
	2006	558,928	185	425	2.0	4.4
	2007	548,264	333	657	2.7	5.4
	2008	1,007,007	260	947	1.9	6.6
	Total/Avg.	**3,703,358**	**335**	**4,856**	**2.2**	**30.6**

Table 1. CF1 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2003 Through 2008 (continued)

CF1	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0478	2003	210,069	748[a]	594	2.8[a]	2.2
	2004	573,954	833	1,781	2.5	5.4
	2005	1,373,559	347	1,688	2.0	10.5
	2006	1,123,219	304	1,345	2.3	10.3
	2007	502,764	453	749	2.7	5.2
	2008	988,741	345	1,024	2.4	7.2
	Total/Avg.	**4,772,306**	**454**	**7,180**	**2.4**	**40.8**
Well 0479	2003	223,783	738[a]	624	2.8[a]	2.4
	2004	662,747	710	1,792	2.3	5.9
	2005	627,031	291	697	1.6	4.1
	2006	619,038	270	718	3.2	7.7
	2007	705,449	408	937	2.7	7.0
	2008	578,665	298	598	2.5	5.3
	Total/Avg.	**3,416,713**	**402**	**5,366**	**2.4**	**32.4**

Avg. Conc. = average concentration
[a]only one sample collected during base flow

Plots were generated to determine how ammonia concentrations compared to TDS concentrations (Figure B-2, Appendix B). This information is useful as monitoring the TDS concentration in the field is easily accomplished by measuring the specific conductance and converting this concentration into a TDS concentration by the following equation (based on Figure B-3): Specific conductance (microsiemens per centimeter [µs/cm]) = 1.32 x TDS (mg/L).

As these plots demonstrate, the ammonia concentrations increase with TDS concentration up to approximately 35,000 mg/L. Above this concentration, which represents the point where the brine/freshwater interface is located, one sample collected from well 0478 suggested the ammonia concentration drops significantly.

The average mass removal rate for all CF1 wells was 0.0016 kg of ammonia removed per gallon of ground water extracted. This average rate is comparable to CF3 and CF4. Table 2 provides a breakdown of the removal rates for each CF1 well, listed from the most efficient to least efficient wells with the highest mass removal and higher influent concentrations and extracted a larger volume of water.

Table 2. CF1 Ammonia Mass Removal Rates

Location	Total Ammonia Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Ammonia Removal Rate (kg/gal)
0471	10,411	5,036,608	0.0021
0470	10,529	5,495,884	0.0019
0472	7,721	4,213,418	0.0018
0474	4,695	2,763,660	0.0017

Table 2. CF1 Ammonia Mass Removal Rates (continued)

Location	Total Ammonia Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Ammonia Removal Rate (kg/gal)
0479	5,366	3,416,713	0.0016
0478	7,180	4,772,306	0.0015
0475	6,768	4,558,006	0.0015
0473	5,302	3,654,315	0.0015
0477	4,856	3,703,358	0.0013
0476	4,256	3,621,553	0.0012
		Avg.	**0.0016**

4.1.2 CF1 – Uranium Concentrations and Mass Removal

Uranium concentrations in samples collected from the CF1 extraction wells typically ranged from 2 to 4 mg/L during Colorado River base-flow time periods. Typically, uranium concentrations also decreased when the river stage increased, as exhibited in the time concentration plots for CF1 (Figure B-4). The average uranium concentration for all the samples collected from actively pumping CF1 extraction wells was 2.1 mg/L (Table 1).

Plots of uranium concentrations and TDS concentrations are provided as Figure B-5. In general, the TDS concentration increase with uranium concentrations. The exceptions to this generalization come from the samples collected from wells 0478 and 0479, which were installed 5 ft deeper compared to wells 0470 and 0477. Once the TDS concentration reaches above 25,000 mg/L, the uranium concentrations decrease significantly in these wells.

The average uranium mass removal rate is 0.000008 kilograms per gallon (kg/gal). Table 3 provides the individual well breakdown by well (listed from highest to lowest).

4.1.3 CF1 – Specific Capacity

Specific capacities for the IA well field have been measured annually, and the results have been presented in previous documents (DOE 2005a, DOE 2006a, DOE 2007, and DOE 2008). The specific capacity measures a well's performance relative to the formation (over which the well is screened) characteristics. Possible reasons for a well's low specific capacity in an alluvial formation with high transmissivity, such as the aquifer underlying the Moab well field, are either that the well is too shallow, has improper screen slot size and sand pack, or is underdeveloped, silted in, or encrusted.

Specific capacities are estimated by comparing the background ground water fluctuations (measured from an observation well located in the Baseline Area) to the water level measurements during pumping at each extraction well. The differences in the water levels are considered to be the drawdown caused by pumping. Water levels are also measured from these wells during time periods when the well is not pumping to confirm these drawdowns are representative. The pumping rate measured from the well during the time this drawdown was measured was used to determine the specific capacity. The results are provided in gallons per minute per foot (gpm/ft). As Table 4 demonstrates, the specific capacity of the CF1 wells has not significantly changed since 2004, with an overall average of 1.1 gpm/ft. This is lower than the average measured in CF3 and CF4. The lower specific capacity is due to lower conductivity materials in the screened zone.

Table 3. CF1 Uranium Mass Removal Rates

Location	Total Uranium Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Uranium Removal Rate (kg/gal)
0479	32.4	3,416,713	9.5×10^{-6}
0478	40.8	4,772,306	8.5×10^{-6}
0477	30.6	3,703,358	8.3×10^{-6}
0475	36.7	4,558,006	8.1×10^{-6}
0470	43.2	5,495,884	7.9×10^{-6}
0474	21.7	2,763,660	7.9×10^{-6}
0476	27.8	3,621,553	7.7×10^{-6}
0471	38.2	5,036,608	7.6×10^{-6}
0472	31.9	4,213,418	7.6×10^{-6}
0473	26.6	3,654,315	7.3×10^{-6}
		Avg.	8.0×10^{-6}

Table 4. CF1 Specific Capacity Measurements, 2004 Through 2008

	Well	Average Specific Capacity (gpm/ft)					Overall Average
		2004	2005	2006	2007	2008	
CF1	**0470**	1.4	1.8	1.7	1.8	1.2	**1.6**
	0471	0.9	1.3	1.5		1.6	**1.3**
	0472	0.8	1.5	1.4		1.7	**1.3**
	0473	0.6	0.7	1.1		1.9	**1.1**
	0474	0.8	0.6	1.0		2.8	**1.3**
	0475	0.7	1.0	1.0		1.1	**0.9**
	0476	0.5	1.7	0.9		1.3	**1.1**
	0477	0.6	0.9	0.9		1.3	**0.9**
	0478	0.6	0.6	0.5	0.7	1.1	**0.7**
	0479	0.5	0.9	0.8		1.1	**0.8**
	Avg.	**0.7**	**1.1**	**1.1**			**1.1**

4.1.4 CF1 Year Round Ground Water Extraction, 2007 Through 2009

From the time the first phases of the well field were installed, the system was shut down over the winter months (typically between the end of November through February). Chemical data collected from wells 0403 and 0407 (located on the river bank between the extraction wells and the Colorado River) suggests that this area did not respond because of pumping over the winter. Figure 7 displays the ammonia and uranium concentrations measured in samples collected from wells 0403 (located off the northern end of CF1) and 0407 (located off the southern end) along with corresponding CF1 total ground water extraction rates from 2004 through 2008.

As the plot shows, prior to the startup of the system in 2004, the ammonia concentrations ranged from 400 to 700 mg/L. By December 2004, the concentrations were less than 100 mg/L. In the winter of 2004-2005 when the system was shut down, the ammonia concentrations rebounded (especially in well 0407). Once the system was restarted in 2005, the concentrations decreased significantly. Of particular note is the gradual increase of ammonia concentrations in samples collected from 0403, starting in June 2006 through March 2008, from 32 to 380 mg/L. Ammonia concentrations in samples collected from 0407 also increased from 14 to 160 mg/L from

December 2007 through March 2008. These increases occurred while the system was actively extracting ground water (except for a three-week time period in December 2007) over the winter months.

It is difficult to determine the reason for these ammonia concentration increases. Similar general trends were observed regarding the uranium concentrations, with the exception of the significant increase detected in mid-2006. This may have been the result of the introduction of oxygenated water (potentially from the irrigation of plot C3 upgradient of location 0403) which increases uranium mobility in ground water and increases the concentration.

In addition to ground water extraction impacting contaminant concentrations in the winter, the Colorado River flow (especially during the annual spring runoff) also has an effect on the concentrations measured in samples collected from these locations. Figure 8 presents the same ammonia and uranium concentration data plotted along with the corresponding Colorado River flow measured from the Cisco U.S. Geological Survey gaging station.

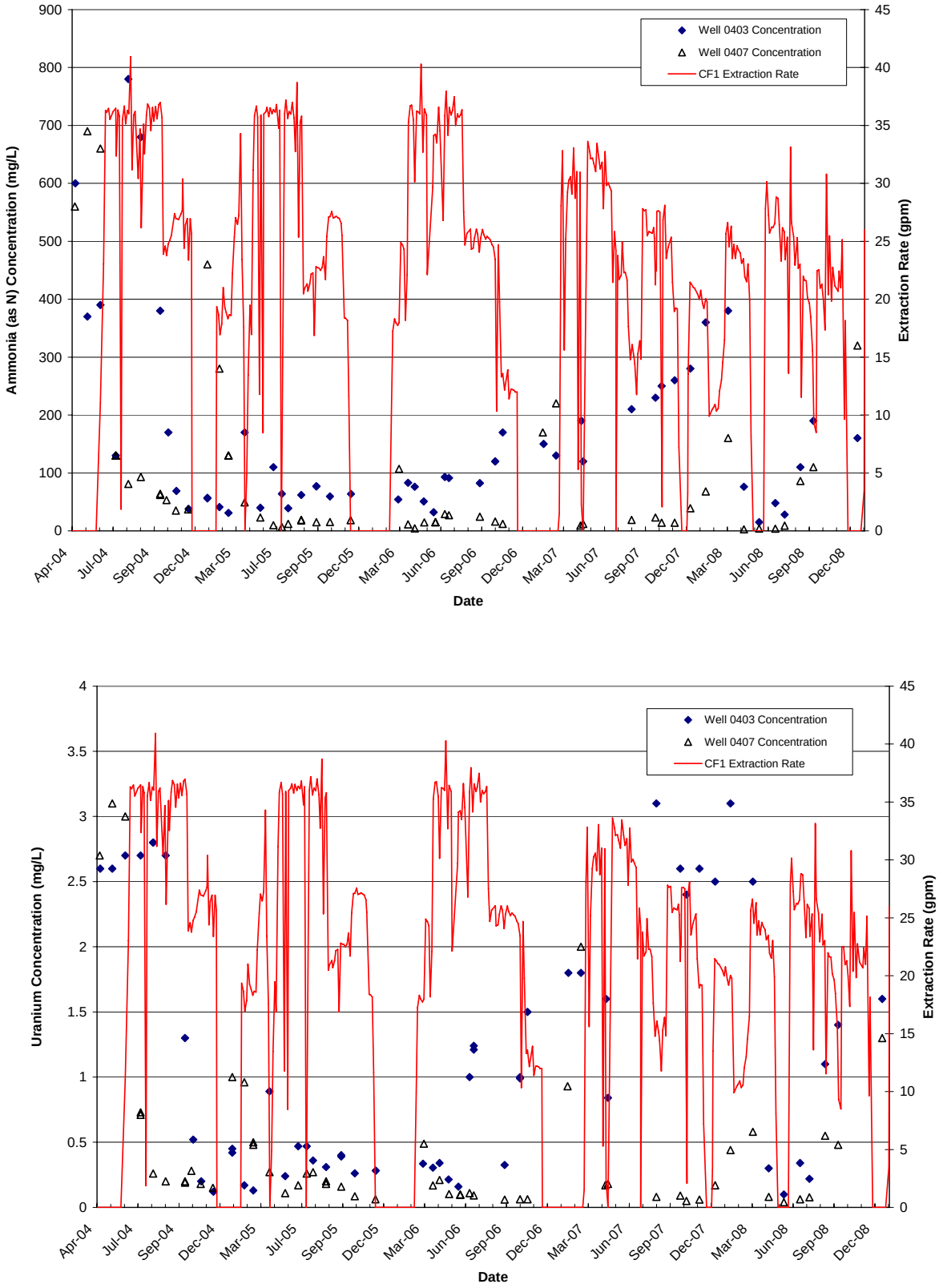

Figure 7. Ammonia (top) and Uranium (bottom) Concentrations Measured from Wells 0403 and 0407 Plotted With Corresponding CF1 Ground Water Extraction Rate

As Figure 8 exhibits, ammonia and uranium concentrations significantly decrease during high flows, particularly during peaks flows above 20,000 cfs. These data suggest that in the vicinity of the well field, CF1 ground water extraction from May through July during average or above average spring runoff flows is marginally effective at reducing concentrations in ambient ground water. Infiltration of river water is the primary reason for the decline in concentrations.

4.2 Well PW02 Operation

Well PW02 was installed as part of the Moab site characterization effort in November 2000. Early in 2005, a need for additional water for the sprinkler system was identified, and a submersible pump was installed into PW02 at a depth of approximately 55 ft below ground surface (bgs). Ground water extraction started from this location in April 2005, and through 2007 (equipment and power source technical difficulties limited the operation of PW02 in 2008), a total of 13.7 million gallons of ground water has been extracted along with the removal of approximately 471,600 kg of ammonia and 122 kg of uranium.

4.2.1 Well PW02 – Ammonia Concentrations and Mass Removal

Ammonia concentrations in ground water removed from this location has ranged from 500 to 1,400 mg/L, as shown in Figure C-1 in Appendix C. Due to the fact that this well is located Approximately 300 ft from the Colorado River bank, as exhibited by this time concentration plot, concentrations are independent of the Colorado River flows. The overall average ammonia concentration is 902 mg/L, which is the highest for the IA well field (Table 5). Total ammonia mass removal is 47,637 kg.

During a 2002 (DOE 2002) sampling event, discrete ground water samples were collected from various depths and greater than 3,000 mg/L ammonia was detected in a samples collected deeper than 50 ft bgs. However, during active pumping the majority of the samples contained approximately 1,000 mg/L with a TDS concentration of 50,000 mg/L (Figure C-2). Setting this pump 5 ft deeper in the well may increase the ammonia mass removal from this location. The ammonia mass removal rate for PW02 is 0.0035 kg/gal, which suggests this well is twice as effective at removing ammonia mass compared to CF1, CF3, and CF4. The TDS to specific conductance conversion for PW02 (based on Figure C-3) is: Specific conductance (µs/cm) = 1.48 x TDS (mg/L).

4.2.2 Well PW02 – Uranium Concentrations and Mass Removal

Uranium concentrations measured in discharge water samples ranged from approximately 2 to 3 mg/L, with an overall average of 2.4 mg/L (Table 5). The uranium time concentration plot (Figure C-4) also suggests concentrations are independent of river flows.

Figure C-5 displays the uranium concentrations compared to associated TDS concentrations. This plot suggests uranium concentrations drop off when the TDS concentration is greater than 40,000 mg/L. The average uranium mass removal rate for PW02 is 9.0×10^{-6} kg/gal. Total uranium mass removal is 122 kg.

4.2.3 Well PW02 – Specific Capacity

Background water level data are limited for this area of the site, making drawdown estimates difficult. However, this well is considered to be more efficient, and the estimated specific capacity is thought to range from 10 to 20 gpm/ft.

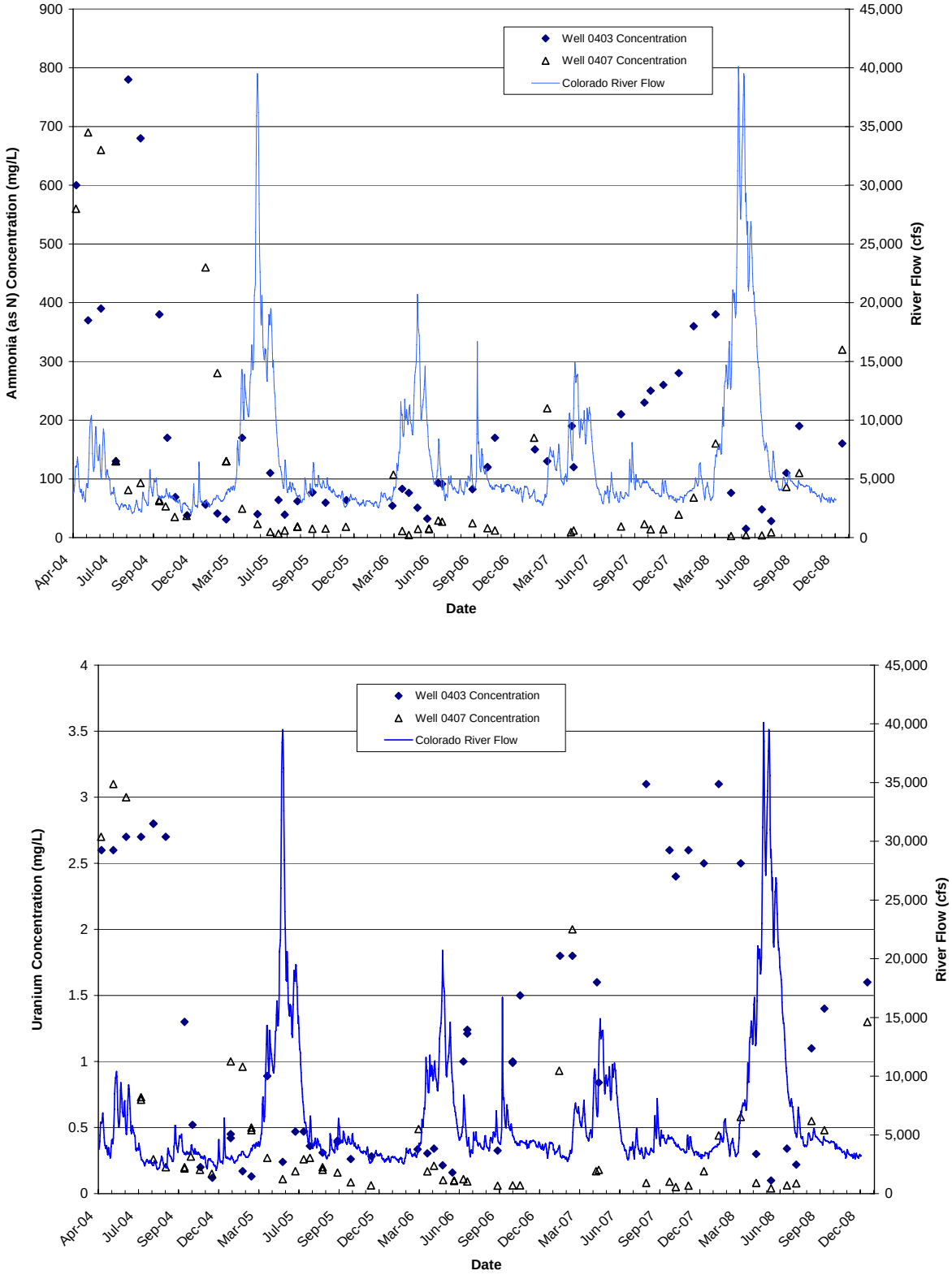

Figure 8. Ammonia (top) and Uranium (bottom) Concentrations Measured from Wells 0403 and 0407 Plotted With Corresponding Colorado River Flow

Table 5. Well PW02 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2005 through 2007

Location	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well PW02	2005	6,046,099	1051	24,271	2.2	48.4
	2006	6,181,885	816	18,626	2.5	58.5
	2007	1,543,177	697	4,730	2.6	15.3
	Total/Avg.	**13,771,161**	**902**	**47,627**	**2.4**	**122.2**

Avg. Conc. = average concentration

4.3 CF3 Operation

CF3 remediation wells were installed in June and July 2005 and were added to the IA system in September 2005. In general, these wells have operated in the extraction mode between March and November, and are shut down over the winter months. Through 2008, CF3 has extracted 32.2 million gallons of ground water and removed approximately 58,000 kg of ammonia and 309 kg of uranium in the process.

4.3.1 CF3 – Ammonia Concentrations and Mass Removal

Ammonia concentrations measured in discharge samples from CF3 have ranged from 250 to 750 mg/L (Figure D-1). Low ammonia concentrations measured in wells 0670 and 0671 in fall 2005 are the result of freshwater injection (diverted Colorado River water) activities in CF2 at that time. As exhibited by the time concentration plot, ammonia concentrations are not impacted by the Colorado River flows. CF3 lies adjacent to a portion of the Colorado River that has silted over the past three years (the configuration of the channel changed dramatically as a result of the 2005 spring runoff), and is comparable to the Baseline Area when it comes to potential impacts from the freshwater migration into the well field during the spring runoff (Appendix A). The overall average for all discharge samples collected from CF3 wells is 477 mg/L, and Table 6 provides a breakdown for the individual remediation wells.

Table 6. CF3 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2005 Through 2008

CF3	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0670	2005	462,761	293	532	1.6	2.8
	2006	1,613,491	453	2,762	2.8	17.0
	2007	303,928	385	497	2.0	2.4
	2008	385,154	420	633	2.1	2.9
	Total/Avg.	**2,765,334**	**396**	**4,424**	**2.2**	**25.1**
Well 0671	2005	532,442	475	1,008	2.3	4.9
	2006	1,148,628	493	2,132	2.8	12.0
	2007	1,085,352	380	1,632	1.6	8.0
	2008	773,931	425	1,252	2.2	5.9
	Total/Avg.	**3,540,353**	**449**	**6,023**	**2.3**	**30.8**

Table 6. CF3 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2005 Through 2008 (continued)

CF3	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0672	2005	517,485	628	1,296	2.3	4.5
	2006	1,227,016	583	2,761	2.5	11.7
	2007	194,134	410	310	2.2	2.2
	2008	84,121	no data	164	no data	0.7
	Total/Avg.	**2,022,756**	**534**	**4,531**	**2.3**	**19.1**
Well 0673	2005	554,786	680	1,458	2.5	5.1
	2006	1,249,738	625	3,038	2.6	12.5
	2007	541,222	448	872	1.8	4.1
	2008	892,726	503	1,670	2.2	7.4
	Total/Avg.	**3,238,472**	**583**	**7,038**	**2.4**	**29.1**
Well 0674	2005	336,820	623	785	2.7	3.4
	2006	1,243,409	560	2,688	3.0	14.3
	2007	333,073	373	462	2.1	3.0
	2008	1,005,800	440	1,845	2.3	8.5
	Total/Avg.	**2,919,102**	**509**	**5,781**	**2.6**	**29.2**
Well 0675	2005	507,822	508	947	3.1	5.2
	2006	1,126,376	498	2,112	3.1	13.1
	2007	467,017	376	781	1.8	3.9
	2008	499,413	455	905	2.2	4.1
	Total/Avg.	**2,600,628**	**466**	**4,745**	**2.6**	**26.3**
Well 0676	2005	436,259	422	700	3.0	5.3
	2006	1,514,830	445	2,553	2.9	16.8
	2007	948,404	348	1,283	2.0	7.3
	2008	887,894	425	1,562	2.1	7.2
	Total/Avg.	**3,787,387**	**410**	**6,098**	**2.6**	**36.6**
Well 0677	2005	426,582	655	1,051	3.2	5.2
	2006	1,324,212	570	2,963	3.3	17.0
	2007	433,933	372	674	1.6	3.1
	2008	1,018,010	540	1,894	2.3	8.4
	Total/Avg.	**3,202,737**	**538**	**6,583**	**2.7**	**33.6**
Well 0678	2005	522,959	613	1,214	3.4	6.6
	2006	1,599,466	421	2,910	2.9	19.9
	2007	1,001,913	442	1,373	1.9	6.6
	2008	1,663,505	565	2,575	2.1	12.4
	Total/Avg.	**4,787,843**	**474**	**8,073**	**2.6**	**45.6**
Well 0679	2005	483,792	523	950	4.3	8.0
	2006	1,014,394	479	1,984	3.8	14.6
	2007	827,592	301	986	1.4	4.4
	2008	990,966	480	1,478	1.8	6.7
	Total/Avg.	**3,316,744**	**443**	**5,398**	**3.0**	**33.6**

Avg. Conc. = average concentration

Similar to the previous CF1 and PW02 discussions, plots were generated to determine how ammonia concentrations compared to TDS concentrations (Figure D-2, Appendix D). In general, higher ammonia concentrations are associated with higher TDS concentrations. The TDS to specific conductance conversion (based on Figure D-3) for the CF3 wells is: Specific conductance (µs/cm) = 1.27 x TDS (mg/L).

As shown in Table 7, the overall average ammonia mass removal is 0.0018 kg/gal, which is comparable to CF1 and CF4. Table 7 lists the individual removal rates for CF3, listed from highest to lowest.

Table 7. CF3 Ammonia Mass Removal Rates

Location	Total Ammonia Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Ammonia Removal Rate (kg/gal)
0672	4,531	2,022,756	0.0022
0673	7,038	3,238,472	0.0022
0677	6,583	3,202,737	0.0021
0674	5,781	2,919,102	0.0020
0675	4,745	2,600,628	0.0018
0671	6,023	3,540,353	0.0017
0678	8,073	4,787,843	0.0017
0679	5,398	3,316,744	0.0016
0676	6,098	3,787,387	0.0016
0670	4,424	2,765,334	0.0016
		Avg.	0.0018

4.3.2 CF3 – Uranium Concentrations and Mass Removal

Uranium concentrations are higher in the northern end of the well field compared to the southern end, which may be the result of the irrigation of plot C5 and the tree area. As discussed in previous documents (DOE 2006a), the introduction of oxygenated freshwater into the aquifer promotes the mobility of uranium in ground water and increases the uranium concentration. As shown in Figure 1, wells 0676 through 0679 are located less than 30 ft from plot C5. The impacts of irrigating this plot were also evident in wells 0674 and 0675. Wells 0670 through 0673 had average uranium concentrations ranging from 2.3 to 2.4 mg/L, while wells 0674 through 0679 had a range of 2.6 to 3.0 mg/L (Table 6 and Figure D-4). Similar to the trend discussed previously regarding the ammonia concentrations, the freshwater injection appears to have impacted uranium concentrations in well 0670. The overall uranium average for discharge samples collected from the CF3 remediation wells is 2.5 mg/L, which is the highest average for the well field.

Along the southern end of CF3, once the TDS concentration reaches 15,000 to 30,000 mg/L, the uranium concentrations stabilize. This general rule does not apply to the northern half of the wells, where the higher the TDS concentrations correlate with higher uranium concentration (Figure D-5).

As shown in Table 8, the overall average uranium mass removal is 0.00001 kg/gal, which is the highest removal rate compared to PW02 and CF1 and CF3. Table 7 lists the individual removal rates for CF3, listed from highest to lowest.

Table 8. CF3 Uranium Mass Removal Rates

Location	Total Uranium Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Uranium Removal Rate (kg/gal)
0677	33.6	3,202,737	1.1×10^{-5}
0679	33.6	3,316,744	1.0×10^{-5}
0675	26.3	2,600,628	1.0×10^{-5}
0674	29.2	2,919,102	1.0×10^{-5}
0676	36.6	3,787,387	9.7×10^{-6}
0678	45.6	4,787,843	9.5×10^{-6}
0672	19.1	2,022,756	9.4×10^{-6}
0670	25.1	2,765,334	9.1×10^{-6}
0673	29.1	3,238,472	9.0×10^{-6}
0671	30.8	3,540,353	8.7×10^{-6}
		Avg.	1.0×10^{-5}

4.3.3 CF3 – Specific Capacity

The specific capacity of the CF3 wells has not significantly changed since 2005; in some cases, the specific capacity increased with an increase in the pumping rate in 2008. As shown in Table 9, the overall average specific capacity for the CF3 wells is 3.1 gpm/ft.

Table 9. CF3 Specific Capacity Measurements, 2005 Through 2008

		Average Specific Capacity (gpm/ft)				
	Well	**2005**	**2006**	**2007**	**2008**	**Overall Average**
CF3	**0670**	6.1	2.6		4.8	**4.5**
	0671	3.2	2.0		4.9	**3.4**
	0672	1.9	1.8			**1.9**
	0673	1.8	1.9		2.9	**2.2**
	0674	1.6	1.7	1.5	2.7	**1.9**
	0675	1.4	2.5		2.3	**2.1**
	0676	1.8	3.1		4.6	**3.2**
	0677	2.0	3.1		3.9	**3.0**
	0678	1.8	4.9	7.0	6.2	**5.0**
	0679	2.4	3.3		3.8	**3.2**
	Avg.	**2.4**	**2.7**		**4.0**	**3.1**

4.4 CF4 Operation

CF4 ground water remediation wells were installed to the south of CF1 in the summer of 2006 and have been extracting ground water since September 2006. Through 2008, CF4 remediation wells have extracted 19.4 million gallons along with approximately 31,000 kg of ammonia and 107 kg of uranium.

4.4.1 CF4 – Ammonia Concentrations and Mass Removal

Ammonia concentrations generally range from 250 to 750 mg/L and have been as high as 1,900 mg/L (measured in spring 2007 from well 0776). As shown in Figure E-1, similar to CF1, concentrations are impacted by Colorado River flows. This response is expected because the CF4 wells are located adjacent to a well-developed side channel that enhances the migration of freshwater into the river bank sediments during spring runoff (Appendix A).

The overall average ammonia concentration (based on all samples collected from all 10 remediation wells) through 2008 was 503 mg/L. A breakdown of the concentrations measured from each well is presented in Table 10.

Figure E-2 was generated to display how ammonia concentrations compare to associated TDS concentrations. Generally, in the southern half of CF4 ammonia concentrations drop off significantly when the TDS is greater than 40,000 mg/L. In the northern half, ammonia concentrations increase with increasing TDS concentrations up to 70,000 mg/L, then decrease significantly based on samples collected from 0775 and 0777. The TDS to specific conductance conversion (based on Figure E-3) is: Specific conductance (µs/cm) = 1.39 x TDS (mg/L).

Table 10. CF4 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2006 Through 2008

CF4	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0770	2006	461,303	615	1,050	2.0	3.1
	2007	1,004,669	455	1,462	1.3	4.4
	2008	0	130[b]	0	0.5[b]	0.0
	Total/Avg.	**1,465,972**	**484**	**2,512**	**1.5**	**7.5**
Well 0771	2006	272,949	500[a]	517	1.6[a]	1.7
	2007	1,782,270	318	2,077	1.0	7.3
	2008	827,909	377	1,003	1.5	4.1
	Total/Avg.	**2,883,128**	**360**	**3,597**	**1.2**	**13.1**
Well 0772	2006	400,644	444	605	1.9	2.6
	2007	592,265	252	618	1.1	2.4
	2008	684,929	310	596	1.0	2.0
	Total/Avg.	**1,677,838**	**331**	**1,818**	**1.3**	**7.0**
Well 0773	2006	257,723	450[a]	439	1.9[a]	1.9
	2007	2,930,397	353	3,653	1.3	17.2
	2008	966,035	340[a]	1,232	2.0[a]	5.5
	Total/Avg.	**4,154,155**	**367**	**5,324**	**1.5**	**24.6**
Well 0774	2006	343,615	533	651	2.2	2.8
	2007	1,074,462	453	1,817	1.7	7.3
	2008	1,279,207	299	1,856	1.3	7.4
	Total/Avg.	**2,697,284**	**432**	**4,324**	**1.7**	**17.4**
Well 0775	2006	26,683	670[a]	68	2.0[a]	0.2
	2007	1,132,344	706	2,450	2.3	8.3
	2008	167,371	740[a]	330	3.0[a]	1.3
	Total/Avg.	**1,326,398**	**706**	**2,847**	**2.3**	**9.8**
Well 0776	2006	667,648	573	1,344	1.8	4.2
	2007	718,910	700	1,421	1.1	3.3
	2008	263,575	438	515	0.9	1.1
	Total/Avg.	**1,650,133**	**580**	**3,280**	**1.2**	**8.5**

Table 10. CF4 Volume of Extracted Ground Water, Average Ammonia and Uranium Concentrations, and Ammonia and Uranium Mass Removed, 2006 Through 2008 (continued)

CF4	Year	Volume (gallons)	Ammonia		Uranium	
			Avg. Conc. (mg/L)	Mass Removed (kg)	Avg. Conc. (mg/L)	Mass Removed (kg)
Well 0777	2006	0	520[a]	0	1.9[a]	0.0
	2007	1,096,626	474	1,776	1.2	4.7
	2008	481,539	435	733	1.7	2.6
	Total/Avg.	**1,578,165**	**470**	**2,509**	**1.4**	**7.3**
Well 0778	2006	276,255	596	605	1.5	1.4
	2007	506,483	660	1,060	1.5	2.4
	2008	43,461	*160*[b]	26	*0.5*[b]	0.1
	Total/Avg.	**826,199**	**592**	**1,691**	**1.4**	**3.9**
Well 0779	2006	154,529	680[a]	398	1.3[a]	0.8
	2007	577,684	973	1,523	1.2	4.9
	2008	475,711	757	1,216	1.4	2.2
	Total/Avg.	**1,207,924**	**855**	**3,137**	**1.3**	**7.9**

Avg. Conc. = average concentration
[a]only one sample collected during runoff flow
[b]only one sample collected during base flow

The average mass removal rate for all CoF4 wells was 0.0017 kg of ammonia removed per gallon of ground water extracted, which is comparable to CF1 and CF3. Table 11 provides a breakdown of the removal rates for each CF4 well, listed from the highest to lowest.

Table 11. CF4 Ammonia Mass Removal Rates

Location	Total Ammonia Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Ammonia Removal Rate (kg/gal)
0779	3,137	1,207,924	0.0026
0775	2,847	1,326,398	0.0021
0778	1,691	826,199	0.0020
0776	3,280	1,650,133	0.0020
0770	2,512	1,465,972	0.0017
0774	4,324	2,697,284	0.0016
0777	2,509	1,578,165	0.0016
0773	5,324	4,154,155	0.0013
0771	3,597	2,883,128	0.0012
0772	1,818	1,677,838	0.0011
		Avg.	0.0017

4.4.2 CF4 – Uranium Concentrations and Mass Removal

Uranium concentrations typically ranged from 1 to 3 mg/L during Colorado River base-flow time periods. Typically, uranium concentrations decreased when the river stage increased, as exhibited in the time concentration plots for CF4 (Figure E-4). Taking into consideration all the uranium samples collected from CF4 extraction wells while actively pumping, the average concentration is 1.5 mg/L, which is the lowest average concentration measured in the well field (Table 10).

A comparable plot to demonstrate how uranium concentrations compare to TDS concentrations is provided as Figure E-5. As shown, once the TDS concentration reaches greater than 35,000 mg/L, uranium concentrations decrease significantly.

The average uranium mass removal rate is 6.0 x 10^{-6} kg/gal, as expected the lowest uranium mass removal rate of the well field. Table 12 provides the individual well break down (listed highest to lowest).

4.4.3 CF4 – Specific Capacity

While CF4 has only average ammonia mass removal capabilities and the lowest uranium mass removal capabilities, it does have the highest average specific capacity of the well field compared to CF1 and CF3. In other words, CF4 can supply most efficiently the highest volume of extracted ground water should the need arise for more water in the evaporation pond. As Table 13 demonstrates, the specific capacity of the CF4 wells has not significantly changed since 2006, with an overall average of 6.9 gpm/ft.

Table 12. CF4 Uranium Mass Removal Rates

Location	Total Uranium Mass Removed (kg)	Ground Water Volume Extracted (gallons)	Uranium Removal Rate (kg/gal)
0775	9.8	1,326,398	7.4 x 10^{-6}
0779	7.9	1,207,924	6.5 x 10^{-6}
0774	17.4	2,697,284	6.5 x 10^{-6}
0773	24.6	4,154,155	5.9 x 10^{-6}
0776	8.5	1,650,133	5.2 x 10^{-6}
0770	7.5	1,465,972	5.1 x 10^{-6}
0778	3.9	826,199	4.8 x 10^{-6}
0777	7.3	1,578,165	4.6 x 10^{-6}
0771	13.1	2,883,128	4.5 x 10^{-6}
0772	7.0	1,677,838	4.2 x 10^{-6}
		Avg.	5.5 x 10^{-6}

Table 13. CF4 Specific Capacity Measurements, 2006 Through 2008

	Well	Average Specific Capacity (gpm/ft)			
		2006	**2007**	**2008**	**Overall Average**
CF4	**0770**	4.9	5.6		**5.3**
	0771	4.1		13.2	**8.6**
	0772	2.8		4.5	**3.7**
	0773	2.1		12.2	**7.1**
	0774	3.8		17.0	**10.4**
	0775	3.2		15.0	**9.1**
	0776	4.0		14.8	**9.4**
	0777			8.4	**8.4**
	0778	1.6	1.6		**1.6**
	0779	3.8		9.0	**6.4**
	Avg	**3.4**		**11.8**	**6.9**

4.5 Section 4.0 Summary

Figure 9 provides a summary of the average ammonia mass removal, average uranium mass removal, and average specific capacity data for CF1, CF3, CF4, and PW02. As shown, PW02 has the highest average specific capacity and uranium mass removal rate, and the ammonia mass removal rate is comparable to CF1, CF3, and CF4.

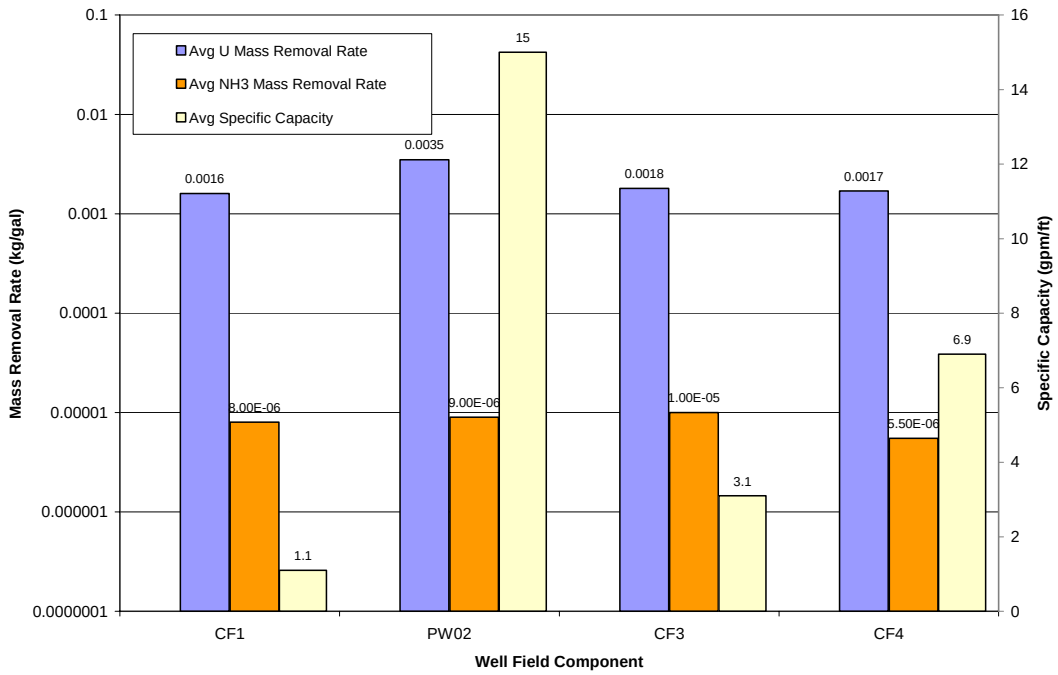

Figure 9. Comparison of Ammonia and Uranium Mass Removal and Specific Capacity Among CF1, CF3, CF4, and PW02

5.0 Ground Water Extraction Optimization

There are a number of potential pumping scenarios to optimize the well field. Optimization is defined as increasing the mass of contaminants removed per volume pumped, hydraulic control, and extraction of contaminants to protect riparian habitat areas in channels along the Colorado River. The Optimization Plan also considers that, as the tailings are removed, the evaporative capacity is expected to be reduced as portions of the sprinkler system are eliminated. Changes to the sprinkler system may take place as soon as 2009.

This section looks at five different pumping scenarios, all of which have a different focus. Each will be discussed separately in this section, and includes the following:

- Optimal maximum ground water volume extracted.
- Optimal ammonia mass removal.
- Optimal uranium mass removal.
- Optimal total mass removal.
- Habitat protection downgradient of CF1 and CF4.

- Habitat protection downgradient of CF2.
- Habitat Protection downgradient of CF3 and the Infiltration Trench.

All suggested optimal pumping scenarios developed in this section are based on the historical data collected in the well field through 2008. As a result of the temporal nature of the historical data and potential impacts of the spring runoff on the well field, the guidelines presented for each scenario are divided into three time periods, February (or startup of the well field) through April, May through July, and August through November (or winter shutdown of the well field). Separating the discussion into these time periods also allows for a combination of scenarios to be addressed. For example, should the focus early in the year be habitat protection and then switch to mass removal, the adjustments to the pumping schedule could be made using the information provided.

In general, CF1 wells average 2.5 gpm, CF3 and CF4 wells average approximately 5 gpm, and PW02 typically operates at an extraction rate of approximately 20 gpm.

5.1 Optimal Maximum Ground Water Volume Extraction

The specific capacity, used to monitor the efficiency of the extraction/remediation wells to remove ground water, is based on the drawdown measured while pumping at a specific rate. While this is not a rigorous method of calculating specific capacity because it does not account for well interference, it provides a qualitative evaluation of the relative performance of each configuration.

Table 14 provides the average specific capacity measured over the timeframe each CF has been actively extracting ground water.

Table 14. Well Field Average Specific Capacities

Well Field Component	Overall Average Specific Capacity (gpm/ft)
1	1.1
3	3.1
4	6.9
PW02	10 to 20[a]

[a]estimated value

Startup through April
Based on the data provided in Table 14, on average well PW02 is the most efficient at extracting ground water, followed by CF4 remediation wells, CF3 remediation wells, and CF1 extraction wells. This hierarchy should be followed when the priority is to provide the largest volume of water possible to the evaporation pond in the most efficient manner.

May through July
Pumping from well PW02 followed by CF4, CF3, and CF1 would efficiently provide the largest volume of water to the evaporation pond. However, as described in Appendix A, during this time frame the ground water extracted from CF1 and CF4 may (depending on the river stage) consist primarily of ground water diluted by river water. In order to avoid the pumping of this water

type, pumping from PW02 and CF3 exclusively at higher flow rates to make up the difference in the flow rate is recommended.

August through Shut-Down

Pumping from the well field during this time should be identical to the proposed schedule provided for the startup of the system through April.

5.2 Optimal Ammonia Mass Removal

Table 15 lists the wells with associated ammonia mass removal rates, ranked from the highest to lowest. Increasing pumping from wells with higher removal rates will optimize the well field's ability to remove ammonia.

Table 15. Extraction Well Ammonia Mass Removal Rate and Operating Priority

Location	Ammonia Mass Removal Rate (kg/gal)	Operating Priority
PW02	0.0035	Highest
Well 0779	0.0026	
Well 0672	0.0022	
Well 0673	0.0022	
Well 0775	0.0021	
Well 0471	0.0021	
Well 0677	0.0021	
Well 0778	0.0020	
Well 0776	0.0020	
Well 0674	0.0020	
Well 0470	0.0019	
Well 0472	0.0018	
Well 0675	0.0018	
Well 0770	0.0017	
Well 0671	0.0017	
Well 0474	0.0017	
Well 0678	0.0017	
Well 0679	0.0016	
Well 0676	0.0016	
Well 0774	0.0016	
Well 0670	0.0016	
Well 0777	0.0016	
Well 0479	0.0016	
Well 0478	0.0015	
Well 0475	0.0015	
Well 0473	0.0015	
Well 0477	0.0013	
Well 0773	0.0013	
Well 0771	0.0012	
Well 0476	0.0012	
Well 0772	0.0011	Lowest

There are a few important guidelines to follow in order to maximize ammonia mass removal for CF1 and CF4 wells as delineated below.

CF1 Wells

- Discharge water TDS concentrations should remain below 35,000 mg/L (which is equivalent to a specific conductance less than 46,200 µs/cm).

CF4 Wells

- Wells 0770 through 0774 should be operating when the discharge water TDS concentration is below 40,000 mg/L (or specific conductance below 55,600 µs/cm).
- Discharge water from wells 0775 through 0779 should be operating when TDS concentration is less than 70,000 mg/L (specific conductance of 97,300 µs/cm).

In order to operate within these guidelines it will be necessary to monitor the discharge field parameters a minimum of twice a month. Should the TDS concentrations from CF1 wells reach above 35,000 mg/L (which typically does not occur), the pumping rates will have to be adjusted lower. It may also be necessary to adjust the pumping rates of the CF4 wells, and if the problem persists, the elevations of the submersible pump's intake may have to be adjusted higher.

Startup through April

Startup should begin with PW02, and successive wells listed in Table 14 should be added until the desired total pumping rate is reached as recommended. When CF1 has been operating throughout the winter and the evaporation pond is near capacity, it may be necessary to wait for the sprinkler system to be restarted before a significant number of wells can be restarted.

May through July

All CF1 (0470 through 0479) and 4 (0770 through 0779) wells should be shut down during the years when the projected runoff is above 10,000 cfs. Well PW02 should continue running during this time period. CF3 should remain actively extracting ground water to provide sufficient volume to the evaporation pond, but is only operated for mass removal.

August through Shutdown

Well PW02 should continue extracting ground water. Wells shut down in the beginning of May should be restarted, again using Table 15 for the priority. The well field should typically be shut down by November; however, it may be necessary to shut wells down starting in October in order reduce the total well field extraction rate (and increase the storage capacity of the evaporation pond) if CF1 is to operate throughout the upcoming winter.

5.3 Optimal Uranium Mass Removal

Comparable to Table 15, Table 16 lists the wells and associated uranium mass removal rates, ranked from highest to lowest.

Table 16. Extraction Well Uranium Mass Removal Rate and Operating Priority

Location	Uranium Mass Removal Rate (kg/gal)	Operating Priority
Well 0677	0.0000105	Highest
Well 0679	0.0000101	
Well 0675	0.0000101	
Well 0674	0.0000100	
Well 0676	0.0000097	
Well 0678	0.0000095	
Well 0479	0.0000095	
Well 0672	0.0000094	
Well 0670	0.0000091	
Well 0673	0.0000090	
PW02	0.0000089	
Well 0671	0.0000087	
Well 0478	0.0000085	
Well 0477	0.0000083	
Well 0475	0.0000081	
Well 0470	0.0000079	
Well 0474	0.0000079	
Well 0476	0.0000077	
Well 0471	0.0000076	
Well 0472	0.0000076	
Well 0775	0.0000074	
Well 0473	0.0000073	
Well 0779	0.0000065	
Well 0774	0.0000065	
Well 0773	0.0000059	
Well 0776	0.0000052	
Well 0778	0.0000048	
Well 0777	0.0000046	
Well 0771	0.0000045	
Well 0772	0.0000042	Lowest

There are a few important guidelines to follow in order to maximize uranium mass removal for CF1, CF3, and CF4 wells as delineated below. However, uranium mass removal is subordinate to ammonia mass removal.

CF1 Wells

- Discharge water TDS concentrations should remain below 25,000 mg/L (which is equivalent to a specific conductance less than 33,000 µs/cm) for wells 0478 and 0479 (the 13th and 7th ranked wells listed in Table 15).

CF3 Wells

- Wells 0670 through 0673 (located in the southern half of CF3) remove the maximum uranium mass when the TDS concentration of the discharge water ranges from 15,000 to 35,000 mg/L (specific conductance range of 19, 050 to 44,450 µs/cm).

CF4 Wells

- Once the discharge water TDS concentration is above approximately 40,000 mg/L (or a specific conductance of 55,600 µs/cm), the uranium mass removal significantly decreases.

Again, in order to operate within these guidelines it will be necessary to monitor the discharge field parameters a minimum of twice a month. Should the TDS concentrations from CF1 wells 0478 and 0479 reach above 25,000 mg/L, the pumping rates will have to be adjusted lower. It may also be necessary to adjust the pumping rates of the CF3 and CF4 wells, and if the problem persists, the elevations of the submersible pump's intake may have to be adjusted higher.

Startup through April

Startup should begin with wells 0674 through 0679, and successive wells listed in Table 16 should be added until the desired pumping rate is obtained. When CF1 has been operating throughout the winter and the evaporation pond is near capacity, it may be necessary to wait for the sprinkler system to be restarted before a significant number of wells can be restarted.

May through July

The optimal uranium mass removal scenario is similar to the optimal ammonia mass removal scenario, where all CF1 (0470 through 0479) and CF4 (0770 through 0779) wells should be shut down when the projected runoff is above 10,000 cfs. Well PW02 should continue running during this time period, and all CF3 wells should be left running (and flow rates increased) in order to provide a sufficient volume of water to the evaporation pond (as potentially dictated by the Remedial Action Contractor [RAC]).

August through Shutdown

Well PW02 should continue extracting ground water. Wells shut down in the beginning of May should be restarted, again using Table 16 for the priority. The well field should typically be shut down by November; however, it may be necessary to shut wells down starting in October in order reduce the total well field extraction rate (and increase the storage capacity of the evaporation pond) if CF1 is to operate throughout the upcoming winter.

5.4 Optimal Total Mass Removal

The priority of which wells to use for optimal total mass removal (both ammonia and uranium) was generated by taking into account an individual well's ability to remove both uranium and ammonia. Similar to Tables 15 and 16, the wells are listed in Table 17 from highest to lowest priority for operation.

Table 17. Extraction Well Operating Priority for Overall Mass Removal

Location	Ammonia Removal Ranking	Uranium Removal Ranking	Overall Ranking	Operating Priority
Well 0677	7	1	1	Highest
Well 0672	3	8	2	
PW02	1	11	3	
Well 0673	4	10	4	
Well 0674	10	4	5	
Well 0675	13	3	6	
Well 0679	18	2	7	
Well 0678	17	6	8	
Well 0676	19	5	9	
Well 0471	6	19	10	
Well 0779	2	23	11	
Well 0775	5	21	12	
Well 0470	11	16	13	
Well 0671	15	12	14	
Well 0479	23	7	15	
Well 0670	21	9	16	
Well 0472	12	20	17	
Well 0474	16	17	18	
Well 0776	9	26	19	
Well 0778	8	28	20	
Well 0478	24	13	21	
Well 0475	25	15	22	
Well 0477	27	14	23	
Well 0770	14	27	24	
Well 0774	20	24	25	
Well 0473	26	22	26	
Well 0476	30	18	27	
Well 0777	22	29	28	
Well 0773	28	25	29	
Well 0771	29	30	30	
Well 0772	31	31	31	Lowest

The guidelines presented in Sections 5.2 and 5.3 in the optimal ammonia and uranium mass removal scenarios obviously still apply. While there may be some overlap in these guidelines, the general rules to follow in order to remove the highest mass include:

CF1 Wells

Discharge water TDS concentrations should remain below 30,000 mg/L (which is equivalent to a specific conductance less than 39,600 µs/cm).

CF3 Wells

Wells 0670 through 0673 (located in the southern half of CF3) remove the maximum uranium mass when the TDS concentration of the discharge water ranges from 15,000 to 35,000 mg/L (specific conductance range of 19,050 to 44,450 µs/cm).

CF4 Wells
Wells should operate when the discharge water TDS concentration is below 40,000 mg/L (or the specific conductance is below 55,600 µs/cm).

Monitoring the discharge water field parameters a minimum of twice a month and adjusting the discharge rate and/or pump intake elevations as necessary (as previously described) are recommended.

Startup through April
In general, PW02 and CF3 wells 0672 through 0679 should be brought online, and then successive wells listed in Table 17 should be added until obtaining the desired volume. When CF1 has been operating throughout the winter and the evaporation pond is near capacity, it may be necessary to wait for the sprinkler system to be restarted before a significant number of wells can be restarted.

May through July
Comparable to the previous scenarios, all CF1 (0470 through 0479) and CF4 (0770 through 0779) wells should be shut down when the projected runoff is above 10,000 cfs. Well PW02 should continue running during this time period, and all CF3 wells should be left running (and flow rates increased) in order to provide a sufficient volume of water to the evaporation pond (as potentially dictated by the RAC).

August through Shutdown
Well PW02 should continue to operate. Wells shut down in the beginning of May should be restarted, again using Table 16 for the priority. The well field should typically be shut down by November; however, it may be necessary to shut wells down starting in October in order reduce the total well field extraction rate (and increase the storage capacity of the evaporation pond) if CF1 is to operate throughout the upcoming winter.

5.5 Habitat Protection Downgradient of CF1 and CF4

As of spring 2009, the most developed habitat areas in the vicinity of the well field are located adjacent to CF1 and CF4 (along the southern end of the well field). Interpretation of chemical data indicates extracting ground water from CF1 (see Section 4.1.4) and CF4 offers riparian habitat protection during periods of lower river stage. Under this condition, ground water contamination from the site would discharge to the riparian habitat if it were not intercepted by the well field.

Startup through April
Operation of CF1 and CF4 wells would provide the best protection to these habitat areas during this period. Well PW02 should also be operating during this time period as it is located upgradient of these current habitat areas. Restarting CF3 wells would provide additional volume to the evaporation pond if required. As previously mentioned, when CF1 has been operating throughout the winter and the evaporation pond is near capacity, it may be necessary to wait for the sprinkler system to be restarted before a significant number of wells can be restarted.

May through July
Once the spring runoff starts, the side channels adjacent to CF1 and CF4 fill with a significant volume of Colorado River water when flows exceed 10,000 cfs. If the peak flow does not exceed 10,000 cfs, the CF1 and CF4 wells should continue pumping without interruption.

High flows in the Colorado River typically occur above 10,000 cfs from 4 to 6 weeks and reach a peak of approximately 20,000 cfs, flows have historically remained above 10,000 cfs. Under these circumstances, pumping from CF1 and CF4 may be temporarily interrupted once flows reach 10,000 cfs until the river has peaked. However, after the peak flow has been reached, the CF1 and CF4 wells should be restarted as flows subside below 10,000 cfs.

For years in which the flows are expected to exceed 30,000 cfs, the same approach as described above is suggested; however, the number of weeks in which the wells are shut down may be extended (due to the longer time frame that the flows exceed 10,000 cfs).

Well PW02 should continue running during this time period regardless of the peak flow.

August through Shutdown
Well PW02 should continue to operate, and pumping from CF1 and CF4 should continue. Again, the well field should typically be shut down by November; however, it may be necessary to shut wells down starting in October in order reduce the total well field extraction rate (and increase the storage capacity of the evaporation pond) if CF1 is to operate throughout the upcoming winter.

5.6 Habitat Protection Downgradient of CF2

It is not practical to extract from CF2 due to poor well efficiency; however, these wells are designed to both extract ground water and inject freshwater. As a result, should the side channel downgradient of CF2 redevelop into a habitat area (as of spring 2009 this portion of the river bed had silted in after the 2008 runoff and was no longer designated as a habitat area), CF2 may be used for injection. Previous investigations have documented the impacts of freshwater injection downgradient of CF2 (DOE 2005b, DOE 2005c).

Startup through April
Operation of CF2 wells in the injection mode should be initiated as soon as possible in the spring. In order to avoid ground water contaminant migration around the ends of CF2, the northern end of CF1 (wells 0476 through 0479 at a minimum) and the southern end of CF3 (wells 0670 through 0674 at a minimum) should be operational. PW02 should also be pumping during this time period, as it is located upgradient of this portion of the well field.

Remaining CF1 and CF3 wells and should be added as needed for increased volume to the pond. CF4 wells may also provide supplemental volume to the pond.

May through July
If the spring runoff peak flow does not exceed 10,000 cfs, the CF2 injection should proceed uninterrupted. CF1 wells 470 through 475 and all CF4 wells should be shut down during this time period if the river flows are projected to be above 10,000 cfs. Once the river has reached

base-flow conditions, these wells can be restarted. Well PW02 should continue running during this time period regardless of the peak flow.

August through Shutdown
Well PW02 should continue to operate, and injection into CF2 and extraction from the previously designated CF1 and CF3 wells located adjacent to CF2 should continue. Again, CF4 extraction may be necessary for added volume to the evaporation pond. The well field should typically be shut down by November; however, it may be necessary to shut wells down starting in October in order reduce the total well field extraction rate (and increase the storage capacity of the evaporation pond) if CF1 is to operate throughout the upcoming winter.

5.7 Habitat Protection Downgradient of CF3 and the Infiltration Trench

Prior to 2005, the river bed adjacent to CF3 had been considered a habitat area. High river flows associated with the spring runoff in 2005 significantly changed the configuration of this area and resulted in the area being silted in. The above average spring runoff in 2008 further added sediment to this area, and as of spring 2009, this portion of the river bed was no longer considered to be a habitat area. Should the configuration of the channel off CF3 change again and develop into a habitat area, then the following pumping scenario is recommended.

Startup through April
All CF3 wells should be restarted in the spring, along with well PW02, which will provide additional mass removal and add significant volume to the evaporation pond. CF1 and CF4 wells should be added to the extraction based on the evaporation pond volume requirements. Should any identified river bed habitat areas extend to the north of CF3, then freshwater injection into the Infiltration Trench is also recommended.

May through July
Regardless of the Colorado River spring runoff flows, CF3 ground water extraction should proceed uninterrupted. Any CF1 and CF4 wells should be shut down during this time period if the river flows are projected to be above 10,000 cfs. In addition, the Infiltration Trench freshwater injection needs to be suspended and restarted once the river flows have peaked.

Once the river has reached base flow conditions, the CF1 and CF4 wells can be restarted. Well PW02 needs to continue running during this time period regardless of the peak flow.

August through Shutdown
Well PW02 should continue to operate, and extraction from all CF3 wells should continue. Continue freshwater injection into the Infiltration Trench if dictated by the conditions, and extract from CF1 and CF4 as needed for added volume to the evaporation pond. The well field should typically be shut down by November; however, it may be necessary to shut wells down starting in October in order reduce the total well field extraction rate (and increase the storage capacity of the evaporation pond) if CF1 is to operate throughout the upcoming winter.

5.8 Section 5.0 Summary

The best overall well field pumping scheme would be to extract ground water from well PW02 year round to optimize ammonia and uranium mass removal. Assuming the habitat areas remain

in the southern half of the well field, pumping from PW02 will be augmented with ground water extraction from CF1 and CF4 from the well field startup through April. Under circumstances that there is an average (20,000 cfs) or above average spring runoff, in April CF1 and CF4 will be shut down, and CF3 will supplement the PW02 pumping. Once the runoff has subsided, pumping will continue from CF1 and CF4, and CF3 will continue extracting ground water only should the site activities dictate.

6.0 Contaminant Plume Maps

Plume maps were generated for ammonia and uranium based on ground water sampling events completed in August 2008 and January 2009. The August 2008 event was designed to update the sampling associated with the uranium plume just north of Moab Wash, in the area previously referred to as the Wood Chip Area, while in January 2009 the sampling focus was shifted away from the well field towards a number of the site-wide locations.

6.1 August 2008 Wood Chip Area Sampling

This section presents the results of the August 2008 sampling in the Wood Chip Area. Formally, in the vicinity of the site, miscellaneous debris, primarily in the form of wood chips saturated with tailings raffinate, were placed in an unlined disposal area. Elevated concentrations may be the result of uranium leaching from this debris into ground water in the alluvium (SMI 2001). The majority of these wells in the area had not been sampled since 2002.

In keeping with previous plume maps of the area (DOE 2003b), and taking into account the stratification of concentrations with depth, a series of plume maps were generated. Data collected in September 2008 were used to supplement the August 2008 data and provide more complete plume maps. Figure 10 presents the uranium concentrations near the ground water surface. A comparable map was presented in the Site Observational Work Plan (SOWP) as Figure 4-39 (uranium concentrations interpolated at the upper surface of the ground water).

Table 18 provides a comparison of the uranium results from the 2008 sampling event and previous sampling event (primarily December 2002) associated with the Wood Chip Area. As shown, the majority of concentrations measured in August 2008 were lower compared to 2002. There has been no active remediation system installed in this area of the site; therefore, any decreases in concentrations may be the result of natural attenuation or other naturally occurring processes.

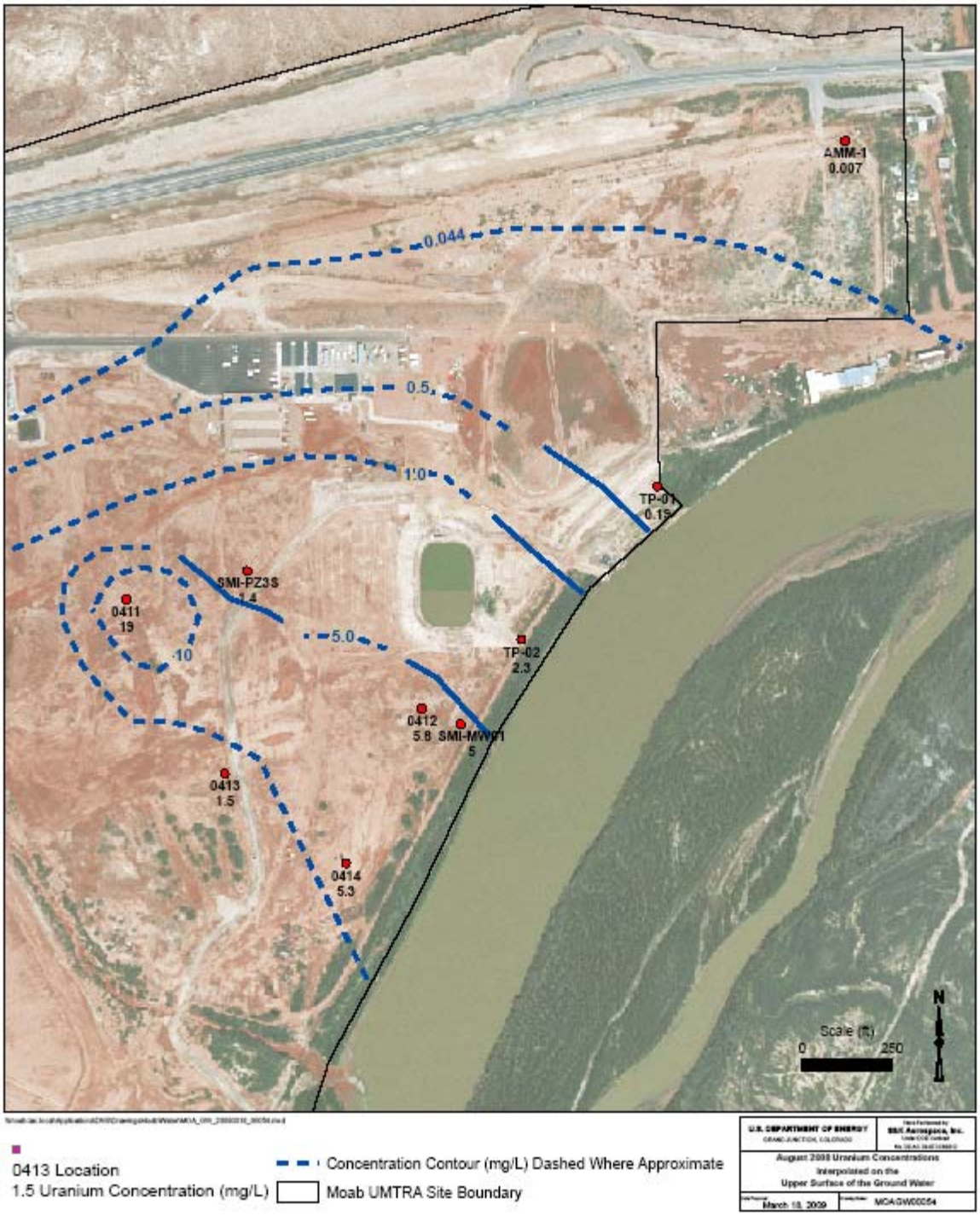

Figure 10. Uranium Concentrations at the Ground Water Surface in the Wood Chip Area, August 2008

Table 18. Comparison of Sampling Results from the 2008 Wood Chip Area Event

	Uranium Concentrations (mg/L)	
Location	**August 2008**	**December 2002**
0411	19	no data
0412	5.8	12.2
0413	1.5	1.73[a]
0414	5.3	3.18
AMM-1	0.007	0.01
SMI-MW01	5	13.2[b]
SMI-PZ3S	1.4	3.24
TP-01	0.19	0.23
TP-02	2.3	13.0
TP-20	0.027	0.001

[a]Result from sample collected September 2002
[b]Result from sample collected November 2000

6.2 January 2009 Site-Wide Sampling Event

Figures 11, 12, and 13 are the ammonia concentration plume maps interpolated for the ground water surface, 50 ft below the ground water surface, and 150 ft below the ground water surface (respectively) based on a site-wide sampling event that was started in December 2008 and completed in January 2009.

Figures 14, 15, and 16 provide comparable uranium concentration plume maps. These maps were generated to compare to the maps presented in the SOWP that were based on 2002 data. However, it was not possible to exactly update these maps because access was restricted to some of the 2002 sampling locations. For example, the data collected from underneath the tailings pile below the ground water surface in 2002 were based on grab samples collected while wells 0437, 0438, and 0439 were installed. The boring for well 0437 was drilled to a depth of 250 ft before it was completed as a well 100 ft deep. The same is true for well 0439 that was completed as a 120 ft deep well after backfilling a 300 ft boring. Only samples from the wells with well screens much shallower than the total boring depth are currently available.

In addition, well 0442, which was located along the southwestern boundary of the site (near State Route 279) was destroyed during a flash flood in July 2006. This sampling location was critical for the plume delineation in this vicinity of the site.

While the ammonia plume map from 2002 generated from data collected 150 ft below the ground water surface delineates the legacy ammonia plume underlying the tailings pile, the map generated based on the 2009 data does not show this plume (due to the lack of sampling locations currently available). Most likely this legacy plume is still present below the pile, but its existence could not be confirmed.

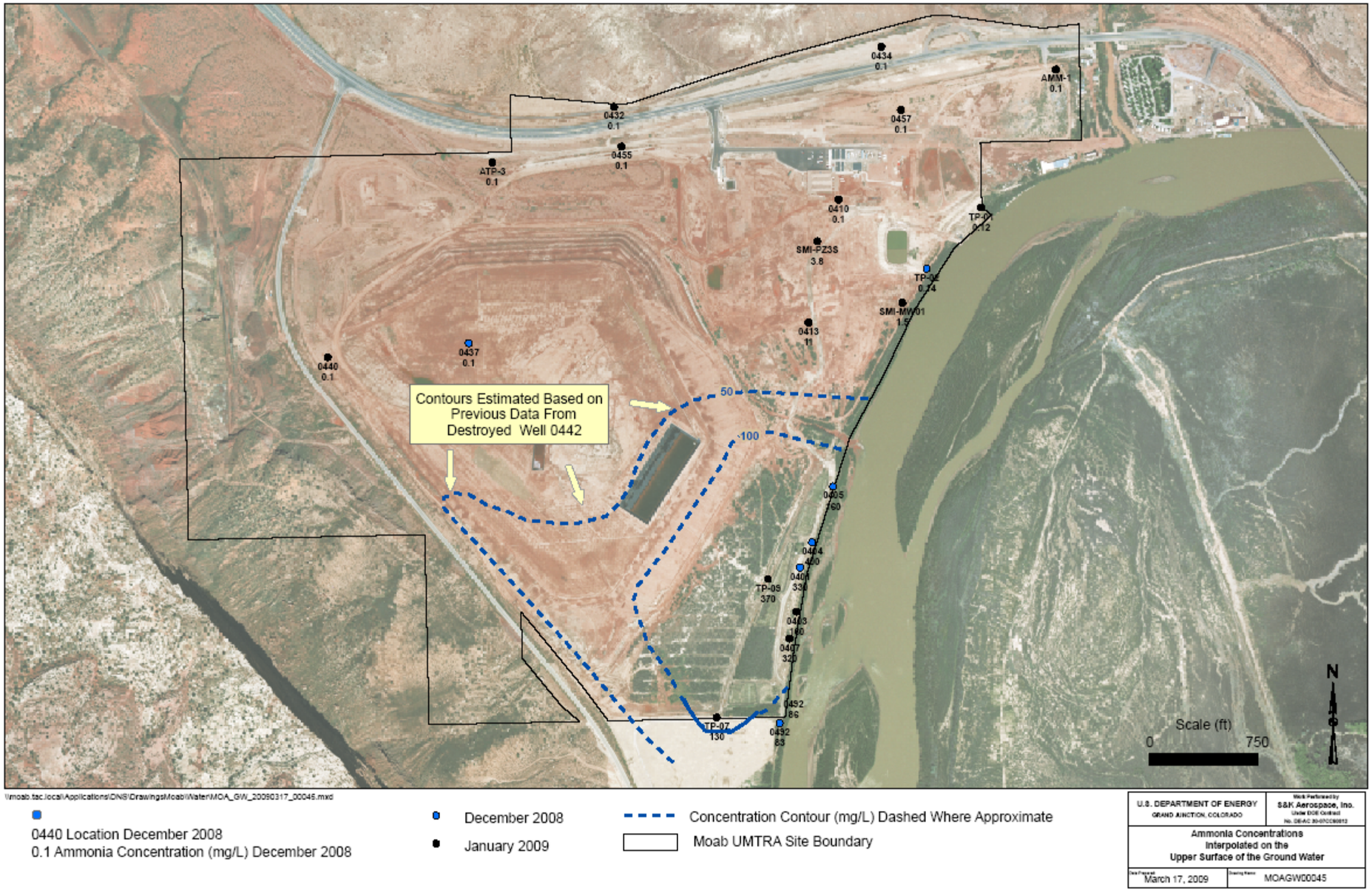

Figure 11. Site-Wide Ammonia Concentrations at the Ground Water Surface, January 2009

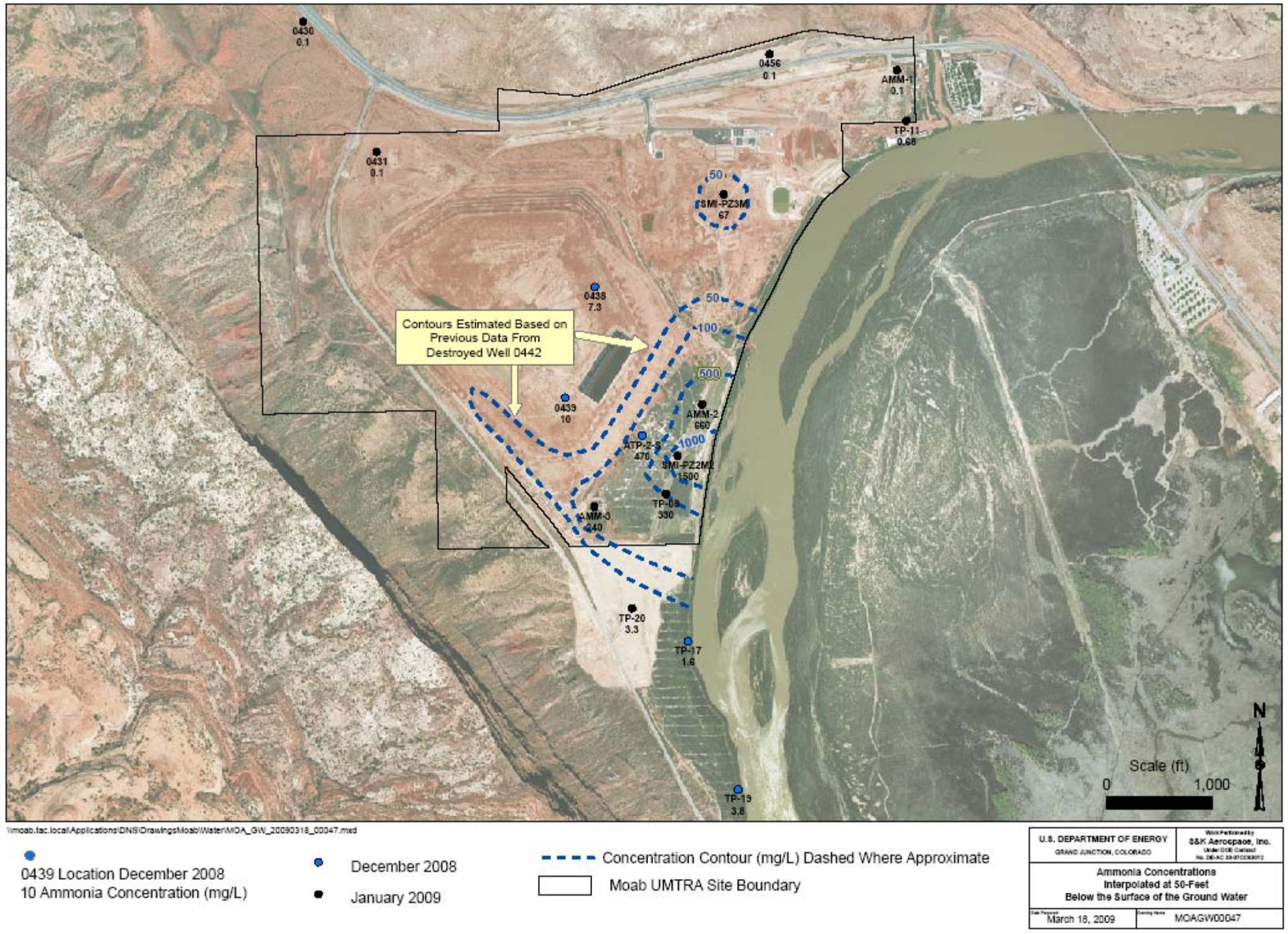

Figure 12. Site-Wide Ammonia Concentrations 50 Ft Below the Ground Water Surface, January 2009

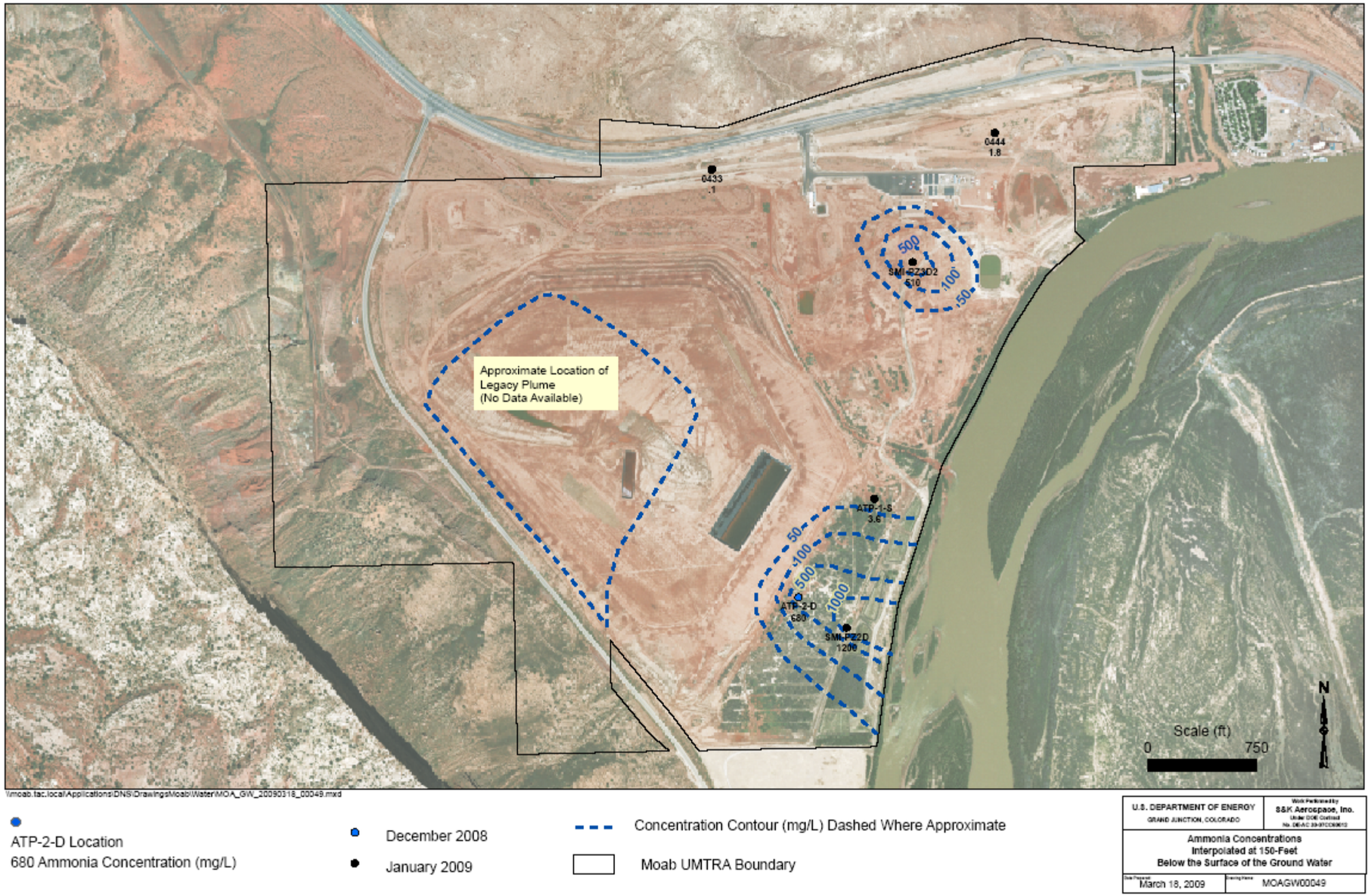

Figure 13. Site-Wide Ammonia Concentrations 150 Ft Below the Ground Water Surface, January 2009

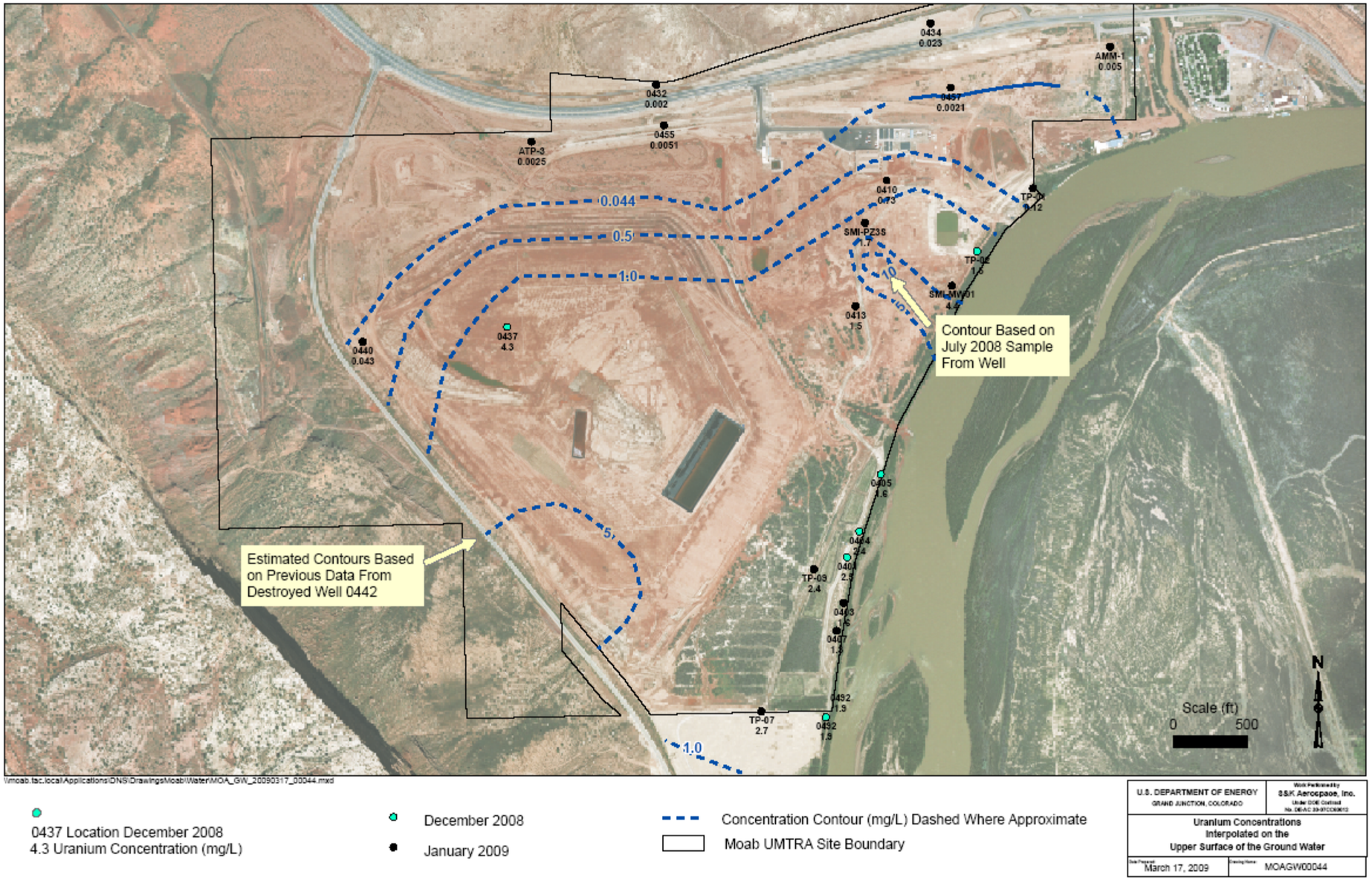

Figure 14. Site-Wide Uranium Concentrations at the Ground Water Surface, January 2009

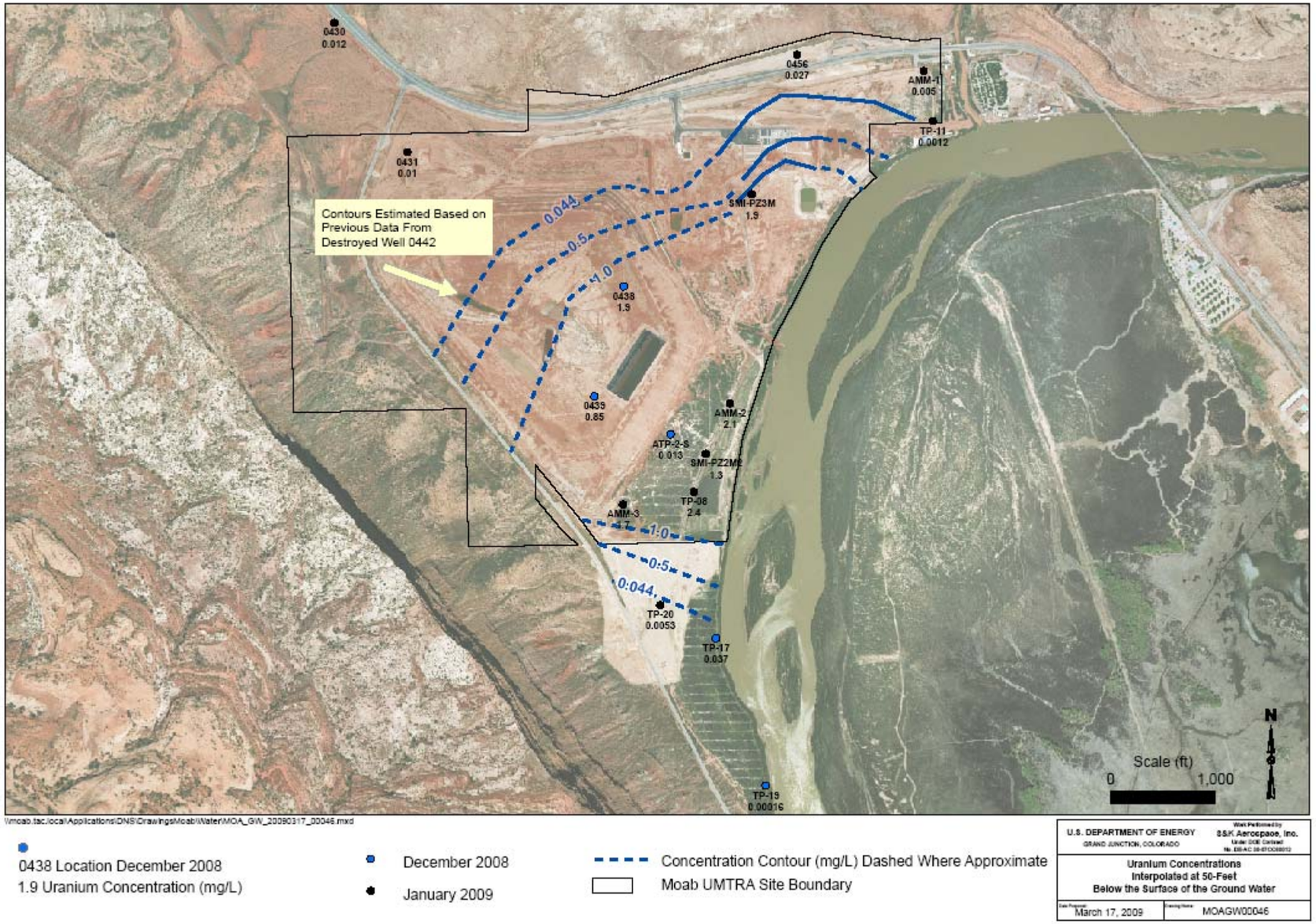

Figure 15. Site-Wide Uranium Concentrations 50 Ft. Below the Ground Water Surface, January 2009

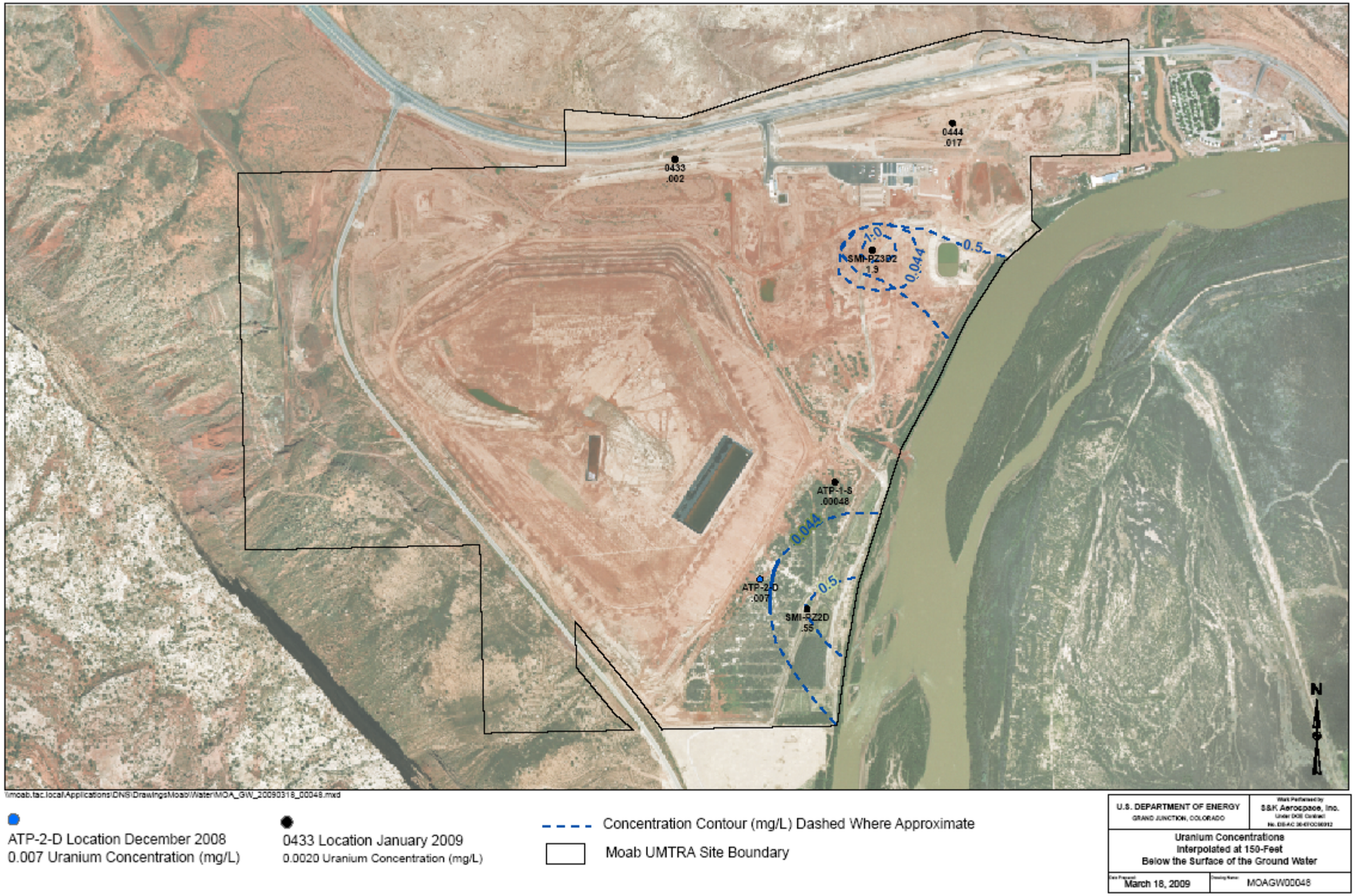

Figure 16. Site-Wide Uranium Concentrations 150 Ft. Below the Ground Water Surface, January 2009

Comparable to Table 18, Table 19 provides a comparison between the 2009 site-wide sampling event and the previous event (primarily samples were last collected in 2002).

Table 19. Comparison of Sampling Results from the 2009 Site-Wide Sampling Event

	Ammonia Data (mg/L)		Uranium Data (mg/L)	
Location	**Jan 09/Dec 08**	**Dec 02**	**Jan 09/Dec 08**	**Dec 02**
401	330	730[a]	2.5	2.39[a]
404	400	490[a]	2.4	2.35[a]
405	160	560[a]	1.6	1.51[a]
410	0.1	0.03[b]	0.73	0.53[b]
413	11	8.85[b]	1.5	1.73[b]
430	0.1	0.003	0.012	0.011
431	0.1	0.03	0.01	0.009
432	0.1	0.003	0.002	0.002
433	0.1	0.003	0.002	0.002
434	0.1	0.09	0.023	0.015
435	2	2.76	0.022	0.02
436	3.4	3.84	0.007	0
437	0.1	1.2	4.3	3.15
438	7.3	24.8	1.9	1.48
439	10	15.5	0.85	0.87
440	0.1	0.05	0.043	0.03
442[g]		1374		10.8
443	0.1	0.003	0.012	0.01
444	1.8	2.38	0.017	0
455	0.1	0.003	0.005	0
456	0.1	0.003	0.027	0.02
457	0.1	0.01	0.002	0
492	86	70[c]	1.9	5.50[c]
AMM-1	0.1 (15') 0.1 (53')	0.003	0.005 (15') 0.005 (53')	0.01
AMM-2	660	939	2.1	1.95
AMM-3	240	109	1.7	1.92
ATP-1-S	3.6	3.63	0.001	0
ATP-2-D	680	602	0.007	0.1
ATP-2-S	470	425	0.013	2.72
ATP-3	0.1	0.03	0.003	0.01
SMI-MW01	1.5	2.30[d]	4.4	13.20[d]
SMI-PW03	35	53[e]	0.6	1.51[e]
SMI-PZ2D	1200	1150[e]	0.55	0.60[e]
SMI-PZ2M2	1500	4600[e]	1.3	1.81[e]
SMI-PZ3D2	510	455	1.9	2.37

Table 19. Comparison of Sampling Results from the 2009 Site-Wide Sampling Event (continued)

	Ammonia Data (mg/L)	Uranium Data (mg/L)	1.9	0.67
Location	**Jan 09 / Dec 08**	**Dec 02**	**Jan 09 / Dec 08**	**Dec 02**
TP-01	0.12	0.003	0.12	0.23
TP-02	0.14	1.09	1.5	13
TP-07	130	68.4	2.7	2.63
TP-08	330	367[f]	2.4	2.58[f]
TP-09	370	947[f]	2.4	3.75[f]

[a]Result from sample collected December 2001
[b]Result from sample collected September 2002
[c]Result from sample collected May 2004
[d]Result from sample collected November 2000
[e]Result from sample collected February 2002
[f]Result from sample collected August 2002
[g]Location destroyed in July 2006; could not be resampled in 2009

6.3 Well Field Plume Maps – July and October 2008

In addition to the plume maps generated for the Wood Chip Area and the site, plume maps were also generated for the well field during high Colorado River flow and base flow conditions. The sampling events completed in July 2008 and October 2008 provided the most complete ground water chemistry data set available.

6.3.1 July 2008 Well Field Plume Maps

The July 2008 plume maps were generated from ground water chemistry data collected between June 30 and July 21, 2008, during which time the Colorado River flows steadily decreased from approximately 19,000 to 7,700 cfs. Prior to this sampling event the flows remained above 20,000 cfs (the approximate annual average peak flow) for 40 consecutive days, with surface water discharging into the sediments adjacent to the river.

Figure 17 is an ammonia concentration plume map for the ground water surface, while Figure 18 represents the ammonia plume map generated from samples collected from approximately 40 ft below the ground water surface. As shown in the ground water surface plume map, all samples collected near the river bank have decreased concentrations due to infiltration of surface water into the well field subsurface. Table 20 provides the ammonia concentrations along a transect moving inland from the river bank measured from locations 0559, 0483, and 0480 in July 2008. As exhibited in Figure 13 and Table 20, the concentrations were more heavily impacted near the bank compared to further inland away from the bank.

Table 20. Ammonia Concentrations Measured Across Wells 0559, 0483, and 0480, July 2008

Location	Distance from the Colorado River Bank (ft)	Ammonia Concentration (mg/L)
0559	0	18
0483	50	52
0480	90	510

The ammonia concentration measured from well 0480 during early June 2008 was only 50 mg/L, and by July the concentration rebounded to pre-runoff levels.

Figure 17. Well Field Ammonia Plume Map for the Ground Water Surface, July 2008

Figure 18. Well Field Ammonia Plume Map for 40 ft Below the Ground Water Surface, July 2008

The concentrations measured at the same distances from the bank from a depth of approximately 50 ft below the ground water surface are presented in Table 21 (and Figure 18).

Table 21. Ammonia Concentrations Measured Across Wells 0561, 0485, and 0482, July 2008

Location	Distance from the Colorado River Bank (ft)	Ammonia Concentration (mg/L)
0561	0	980
0485	50	1300
0482	90	1200

While the concentration measured from the sample collected from 0561 is less compared to the concentrations measured in 0485 and 0482, it is still close to the average concentration measured from this location.

Figures 19 and 20 are the well field uranium plume maps generated from water chemistry data collected from the ground water surface and 40 ft below the ground water surface, respectively. Similar changes to the uranium concentrations were detected compared to the previously discussed ammonia concentrations, both at the ground water surface and 40 ft below the surface.

In summary, the ammonia concentrations in shallow ground water were impacted by the migration of surface water into the subsurface between 50 and 90 ft inland from the bank, while at a depth of 40 ft below the ground water surface the water chemistry does not appear to be impacted.

6.3.2 October 2008 Well Field Plume Maps

By the time the October 2008 sampling event occurred, the Colorado River flows had returned to river base flow levels, and had been consistently below 5,000 cfs for approximately 60 days. While this sampling event represents the most complete data set post peak runoff, there were only limited data available for ammonia and uranium concentrations below the ground water surface at any depth. As a result, it was only practical to generate ammonia and uranium plume maps for the ground water surface exclusively (Figures 21 and 22, respectively).

As shown in both maps, the ammonia and uranium concentrations do not reflect any residual impacts from the 2008 runoff flows, and have returned to average concentrations that are consistent with river base flow conditions.

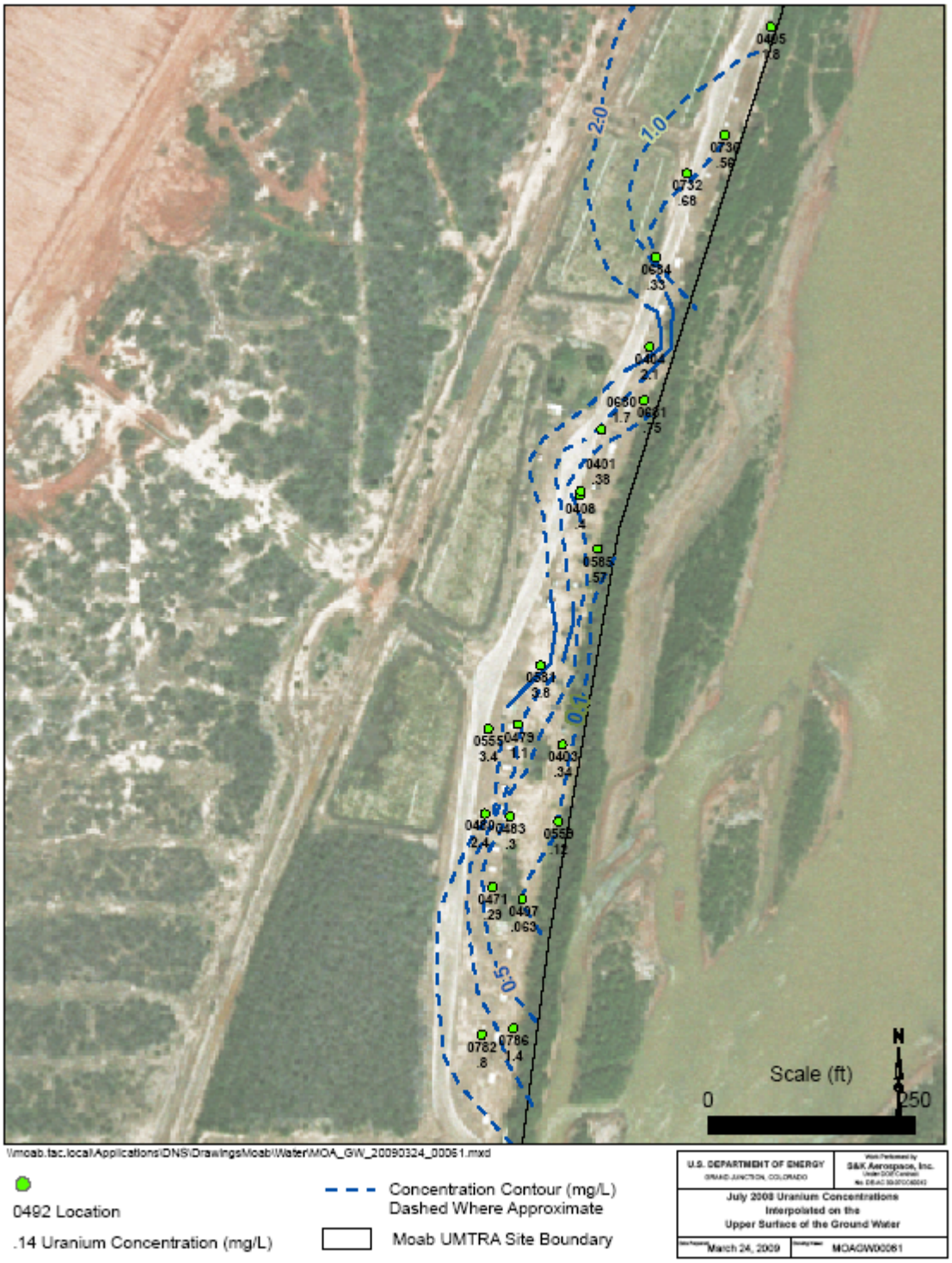

Figure 19. Well Field Uranium Plume Map for the Ground Water Surface, July 2008

Figure 20. Well Field Uranium Plume Map for 40 ft Below the Ground Water Surface, July 2008

Figure 21. Well Field Ammonia Plume Map for the Ground Water Surface, October, 2008

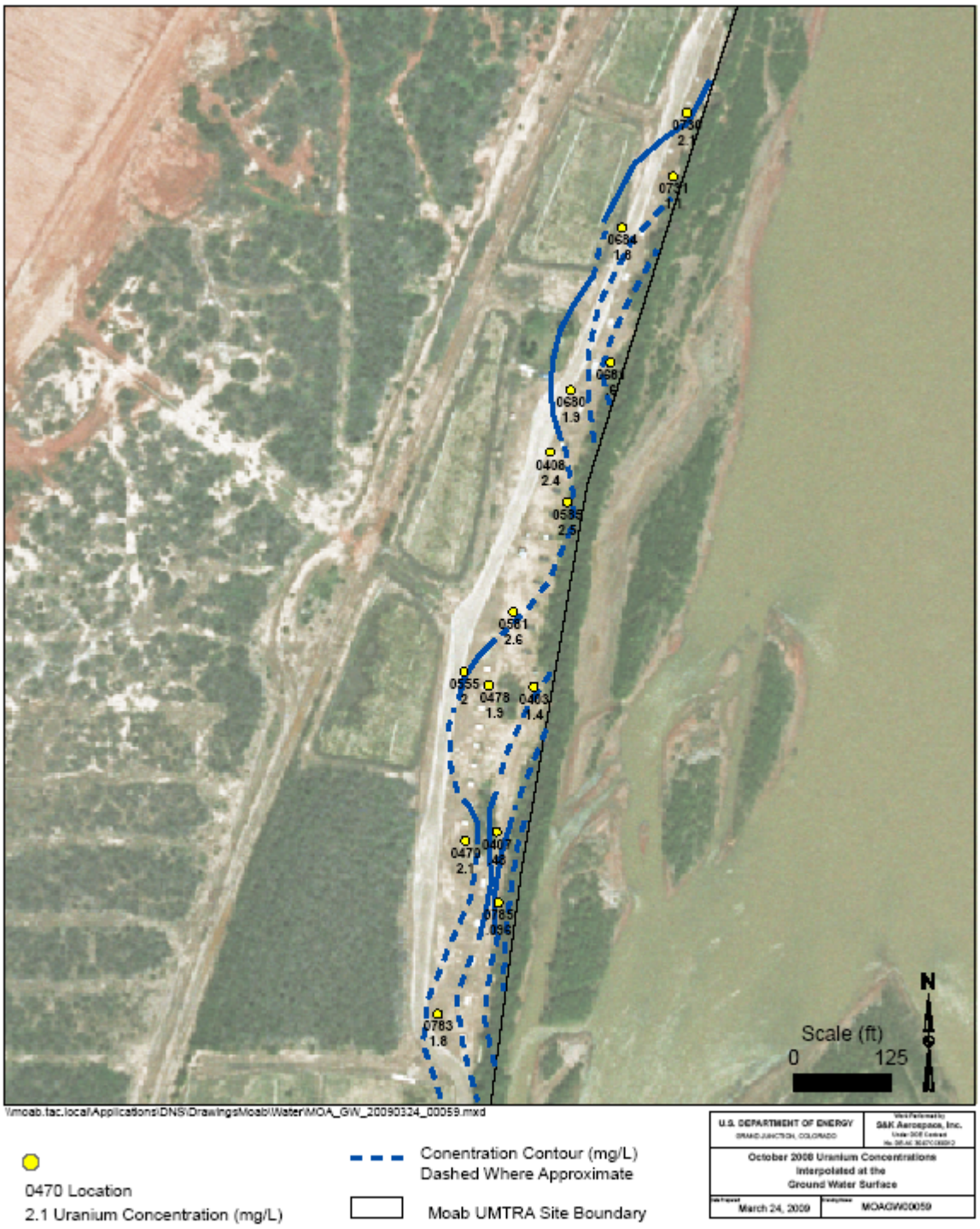

Figure 22. Well Field Uranium Plume Map for the Ground Water Surface, October, 2008

7.0 Ground Water Surface Contour Maps

Ground water elevation contour maps were generated for the June 2008 and January 2009 timeframes (Figures 23 and 24, respectively). Only water level data collected from wells screened over the ground water surface in areas not impacted by the underlying brine were used to complete these maps.

During June 2008, the ground water surface elevation reached near historical maximum levels due to the significantly higher than average peak runoff experienced in 2008. Not only was the peak flow nearly twice the average, but the flow remained above 10,000 cfs for 90 consecutive days. Flows during June 2008 ranged from 18,900 to 39,500 cfs and developed a freshwater mound in the vicinity of the well field that locally reversed the ground water flow gradient.

The ground water surface contour map generated based on the January 2009 data (Figure 24) was also collected from wells screened within the ground water surface in areas not influenced by the underlying brine. This contour map represents base river flow conditions for the site (flows of approximately 3,500 cfs). The ground water mound present in the June 2008 map has diminished by January 2009.

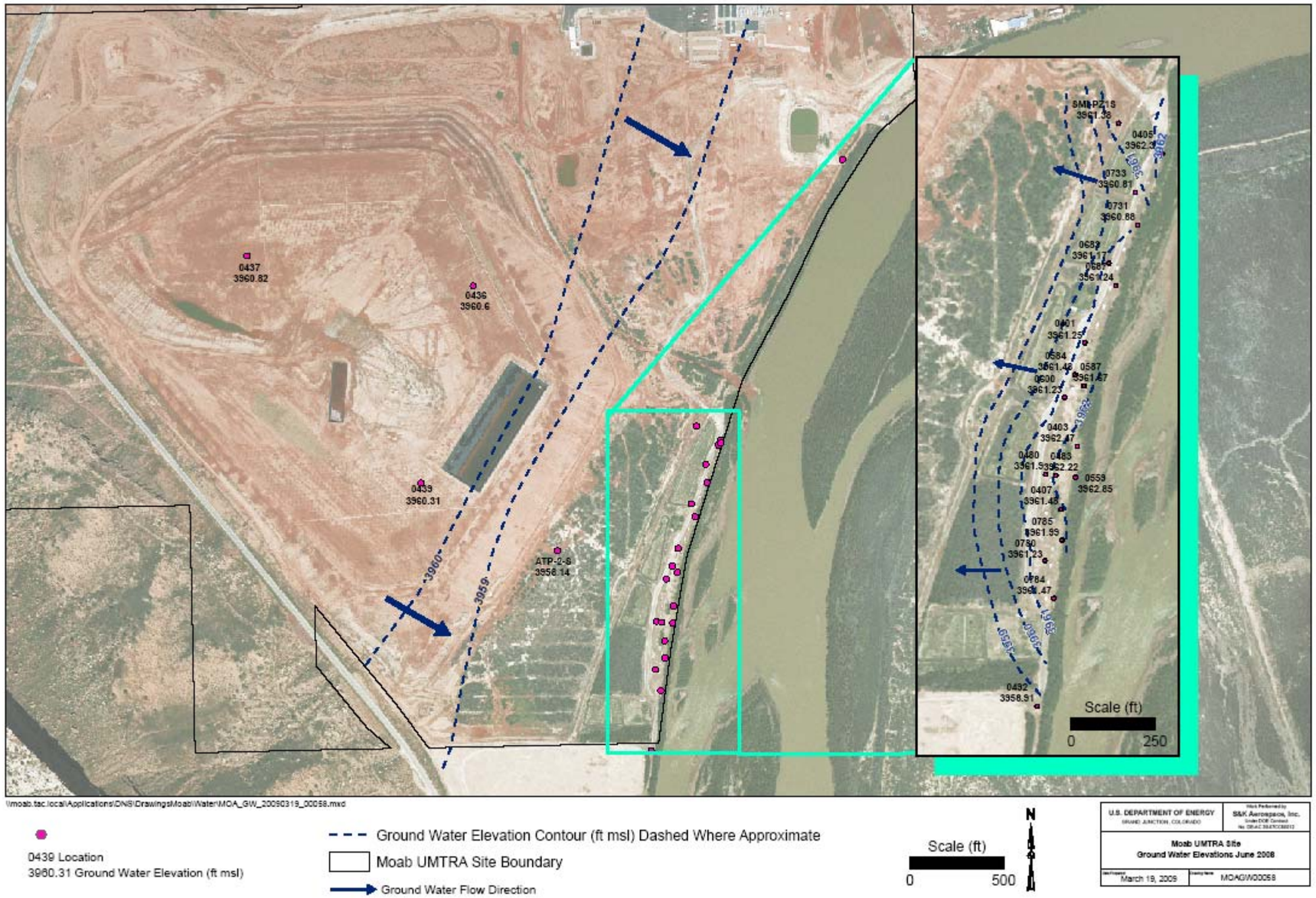

Figure 23. Ground Water Surface Elevation Contour Map, June 2008

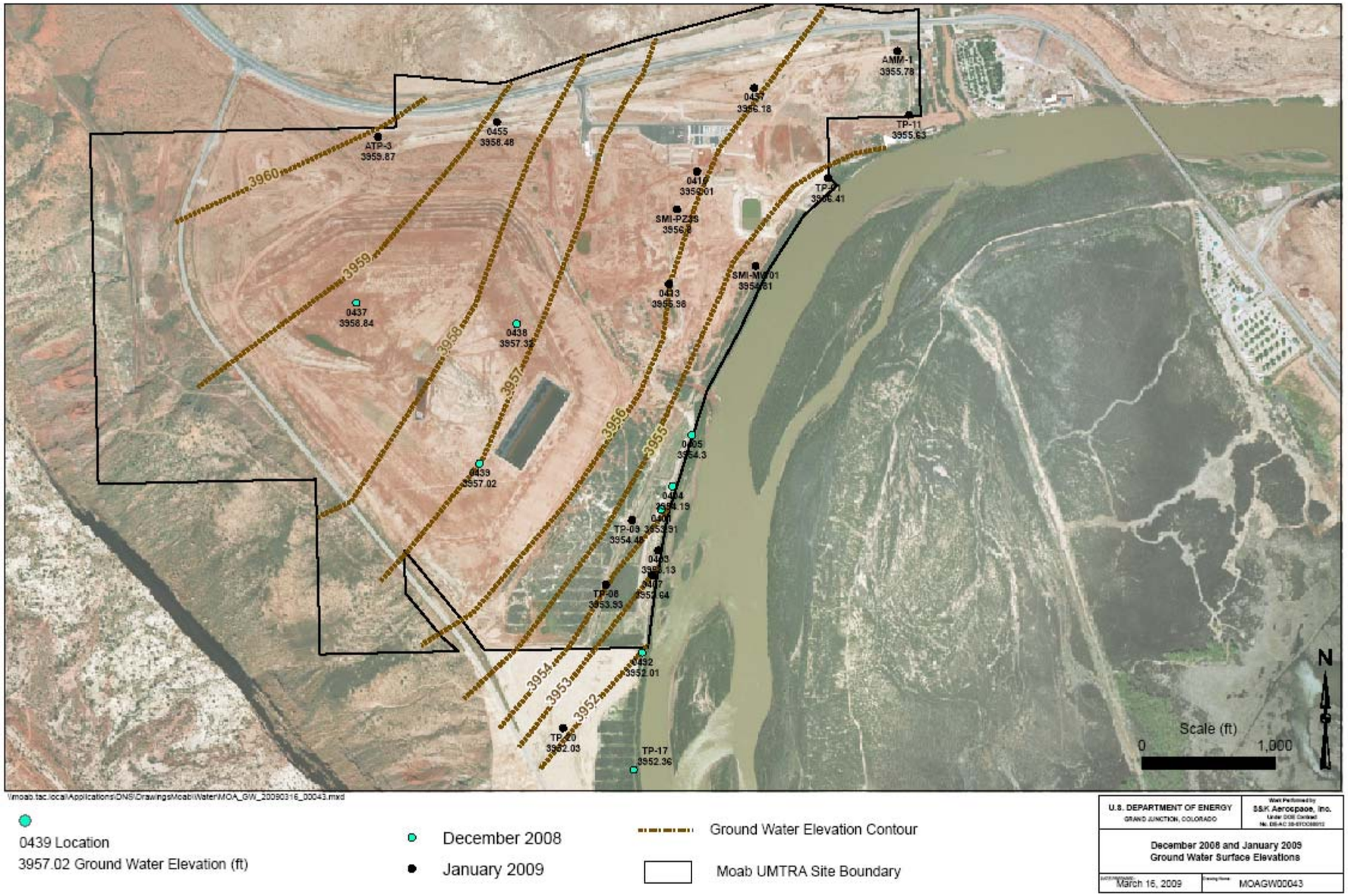

Figure 24. Ground Water Surface Elevation Contour Map, January 2009

8.0 References

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Appendix A
Ground Water/Surface Water Interaction Investigation

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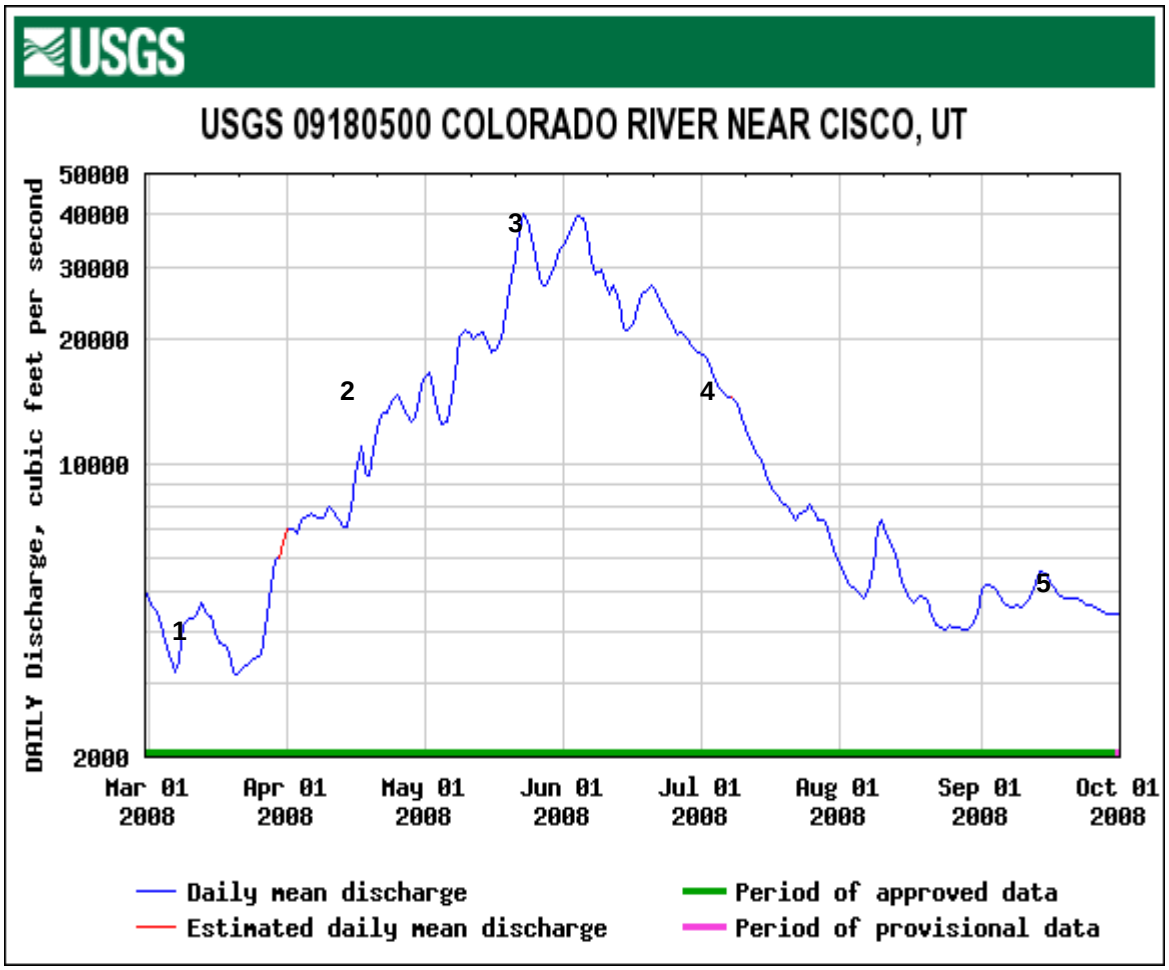
A ground water/surface water investigation was initiated March 2008 to determine the extent of infiltration of surface water from the Colorado River into the alluvium in the vicinity of the well field during the peak spring runoff. It is important to understand the extent of infiltration into the well field because the information obtained from this study will be used to optimize our contaminant mass removal during the spring months. Two specific areas of the IA well field were sampled in this investigation; CF1 and Baseline. CF1 is located on the southern end of the well field and is adjacent to a riparian backwater channel that flows until the Colorado River flow decreases to approximately 2,500 cfs. The Baseline Area is located on the north end of the well field and is approximately 150 ft from the main river channel. the backwater channel flows through the Baseline Area when the Colorado River flow is approximately 10,000 cfs. All sampling was completed in accordance with the *Moab Sampling and Analysis Plan* (DOE 2006c)

A series of shallow (18 ft bgs), intermediate (36 ft bgs), and deep (55 ft bgs) observation wells were sampled in Baseline and CF1 at varying distances from the Colorado River, and surface water samples were collected on the river bank adjacent to the observation wells (Table A-1). The observation wells and surface water locations were sampled for alkalinity, calcium, magnesium, sulfate, chloride, sodium, and potassium during various stages of Colorado River Flow. The analytical data was plotted on both Piper (trilinear) diagrams and Stiff Diagrams to show how the ionic composition of the ground water changed over space and/or time during various Colorado River flow values (Figure A-1).

Table A-1. Ground Water/Surface Water Investigation Sample Locations

Location in Well Field	Location Number	Location Type	Sample Depth	Approximate Distance from River Bank (ft)
Baseline Area	0242	SW	N/A	0
	0243	SW	N/A	0
	0405	OW	18	150
	0488	OW	36	150
	0493	OW	55	150
	SMI-PW01	OW	36	300
	SMI-PZ1S	OW	18	300
	SMI-PZ1M	OW	55	300
CF1	0216	SW	N/A	0
	0474	EW	18	160
	0480	OW	18	200
	0482	OW	55	200
	0483	OW	18	150
	0485	OW	55	150
	0557	OW	36	200
	0558	OW	36	150
	0559	OW	18	100
	0560	OW	36	100
	0561	OW	55	100

SW= Surface Water Location, OW= Observation Well Location, EW= Extraction Well Location



Numbers represent sampling events: 1= March 18 to 20, 2= April 28 to 30, 3= June 2 to 4, 4= July 8 to 10, 5= September 29 to 30

Figure A-1. Colorado River Cisco Gage Hydrograph during the Ground Water/Surface Water Investigation Sampling Events

As discussed in Section 3.0, levels of salinity in ground water in this document are described with respect to TDS concentrations in units of mg/L. Ground water is typically characterized as being mildly saline (TDS = 1,000 to 3,000 mg/L), moderately saline (TDS = 3,000 to 10,000 mg/L), very saline (TDS = 10,000 to 35,000 mg/L), or briny (TDS > 35,000 mg/L). These TDS concentrations are larger than the TDS levels commonly reported for river (250 to 1,000 mg/L), which is referred to as freshwater (DOE 2006a).

Baseline Area Hydrogeochemistry

The hydrogeology of the Baseline Area differs from CF1 because: (1) the elevation of the brine interface is deeper in elevation on the north end of the well field; (2) the observation wells extend up to 300 ft from the river bank; and (3) the main river channel is 150 ft from the first cluster of observation wells, and there is not a prominent backwater channel adjacent to this section of the well field. The CF1 well field is approximately 90 ft from the riparian backwater channel.

Throughout March and April, the ground water in the Baseline observation wells was classified as sodium-sulfate, and the surface water was a mixed calcium-sodium-chloride type classification (Figures A-2 through A-5). In April, the surface water displayed more of a calcium-bicarbonate hydrochemical signature, while the observation wells maintained a sodium-sulfate signature (Figures A-4 and A-5). The surface water increased in calcium and bicarbonate in June and July (Figures A-6 through A-9), while the observation wells still maintained a sodium-sulfate signature. In September, the surface water returned to classification as a mixed calcium-sodium chloride signature. The shift in the surface water chemistry in June and July is due to the introduction of melt water from the Upper Colorado Basin. Throughout the varying Colorado River flow, the observation wells in the Baseline Area showed little variation in water quality type. However, there was a decrease in TDS indicating the presence of a moderately saline lens.

The chemical analyses plotted on the trilinear plots and the Stiff Diagrams (Hem 1985) do not indicate that the infiltration of surface water had an impact on the Baseline Area ground water chemistry. This is likely due to the fact that the wells are 150 ft from the main river channel. It was noted on July 21, when the river flow was 7,400 cfs, that the backwater area adjacent to Baseline was nearly dry. In comparison, the backwater area adjacent to CF1 is dry around 2,000 cfs.

CF1 Hydrogeochemistry

The ground water/surface water investigation began March 18 when the river flow was 3,610 cfs (Figure A-1). The CF1 surface water locations and monitoring wells were sampled in order to establish low flow conditions for water quality type before the spring runoff. During this time, the shallow wells (and intermediate well 0557) had a sodium-potassium-sulfate signature, while the remaining intermediate wells and the deep wells had a sodium-potassium -hloride signature (Figures A-12 and A-13). The surface water was classified as a mixed calcium-sodium-chloride chemistry.

By April 28, the river flow had increased to 12,300 cfs, and the surface water chemistry showed an increase in carbonate-bicarbonate (Figures A-1, A-14, and A-15). In addition, shallow monitor well 0559 also showed an increase in carbonate-bicarbonate. This well is located approximately 50 ft from the main river channel and was likely impacted by the introduction of surface water infiltrating into the river bank. The chemical signature of shallow wells 0474 and 0483 also reflected an influence of freshwater infiltration from the river, indicating that a mildly to moderately saline lens propagated at least 165 ft into the well field. The chemical signature of the intermediate and deep observation wells suggests that this lens did not extend vertically past approximately 18 ft bgs.

On June 2, the river flow had increased to 34,900 cfs, which was well above the daily average of 23,300 cfs (Figure A-1). The surface water location and shallow observation wells showed an increase in carbonate-bicarbonate, and all of the shallow observation wells showed a chemical signature more similar to that of the surface water (calcium-bicarbonate type) (Figures A-16 and A-17). This indicates that a lens of fresh to moderately saline water migrated over 200 ft into the well field from the river. The chemistry of intermediate observation well 0560 (50 ft from river) was also impacted, suggesting that this lens propagated at least 100 ft into the well field at a depth of 36 ft bgs. There is evidence of ground water/surface water mixing at 36 ft bgs up to

200 ft into the well field (observation well 0557). The chemistry of the deep observation wells did not change.

By July, the river flow had decreased to 12,200 cfs, and some of the shallow observation wells, such as 0480 (200 ft from river bank), were less influenced by the surface water influx (Figures A-1, A-18, and A-19). This indicates that the freshwater to moderately saline lens was dissipating. Shallow wells 0474 and 0483, located approximately 150 to 160 ft from the river bank, were still impacted by this lens. Shallow well 0559, located approximately 50 ft from the river bank, still maintained the chemical signature (calcium-bicarbonate) similar to the river water in June, suggesting no additional dilution by river infiltration was occurring. The intermediate wells 0560 and 0558 had begun to rebound to the March chemical signature, but were still affected to some degree by the surface water influx. This indicates that there may have been a zone of mixing up to 36 ft bgs for up to 150 ft into the well field. The chemical signature of the deep observation wells remained unaffected by infiltration of river water.

On September 29, the river flow was 4,260 cfs, and ground water samples collected from shallow observation wells 0474, 0483, and 0559 indicated the presence of a moderately saline lens (Figures A-1, A-20, and A-21). Intermediate well 0560 still showed signs of mixing with this lens. Observation wells 0480, 0557, and 0482 (200 ft from river bank) had rebounded back to their original baseline March chemical signature (sodium-potassium-sulfate). At this time, the moderately saline lens had dissipated to approximately 18 ft bgs and 160 ft into the well field, with mixing present up to 36 ft bgs 150 ft into the well field.

Conclusions

While time concentration plots developed for both ammonia and uranium concentrations measured at the Baseline Area (Figures A-22 and A-23) and CF1 (Figures A-24 through A-26) suggest changes in the water chemistry, further data were necessary to provide a more complete understanding of the river stage influence on ground water chemistry in the vicinity of the well field.

Chemical data plotted on cross sections with Stiff Diagrams for the Baseline Area are provided as Figures A-27 through A-31. Chemical ground water and surface water data from the Baseline Area suggest infiltration of river water has a minor effect on the water quality type but produces a decrease in TDS in the northern end of the well field. The water quality type doesn’t change in the Baseline Area because the brine elevation is lower in the northern end of the well field and a prominent backwater channel does not exist adjacent to the Baseline Area. The main river channel is much farther from the monitoring points in the Baseline Area.

Comparable cross sections provided for CF1 (Figures A-27 through A-31) suggest that infiltration of fresh river water has a great impact on the groundwater chemistry at CF1 prior to and after peak runoff events.

A summary of the river flow values and the horizontal and vertical influence of river water infiltration is presented in Table A-2.

Table A-2. Summary of River Infiltration into the Well Field

Month	River Flow (cfs)	Horizontal Influence of River Infiltration (ft)	Vertical Influence of River Infiltration (ft bgs)
March	3,610	No impact	No impact
April	12,300	150	18
June	34,900	200	18
		100	36
		200	36 (mixing)
July	12,200	160	18
		150	36 (mixing)
September	4,260	160	18
		150	36 (mixing)

The results of the ground water/surface water investigation indicate that infiltration of freshwater occurs in the southern area of the well field when the Colorado River flow is at 12,300 cfs, or possibly as low as 10,000 cfs. A freshwater to moderately saline lens can propagate up to 200 ft into the well field when the river flow increases to 34,900 cfs. While the influx of surface water into the well field occurred rather quickly, it appears that in 2008 the impacts on the ground water system lasted for at least three months following the peak flow.

This data will be used to maximize the contaminant mass removal in the IA well field by adjusting the pump schedule. As a result of these studies, the southern end of the well field (CF1 and CF3) will not be operated during periods of high river stage to provide additional capacity in a pond for evaporation of pumped ground water. This will allow increased pumping during low river stage conditions when the well field is most effective at removing ammonia.

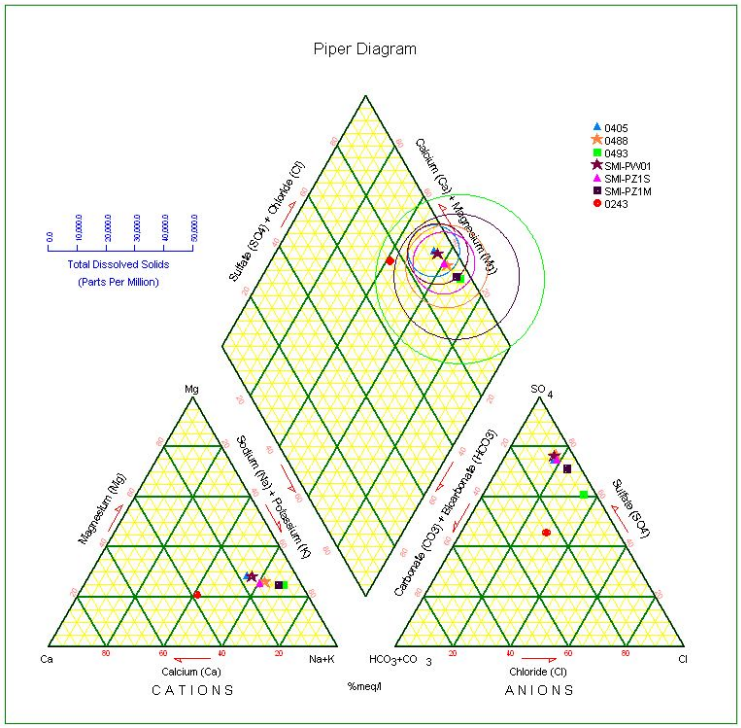


Figure A-2. March Baseline Trilinear Diagram

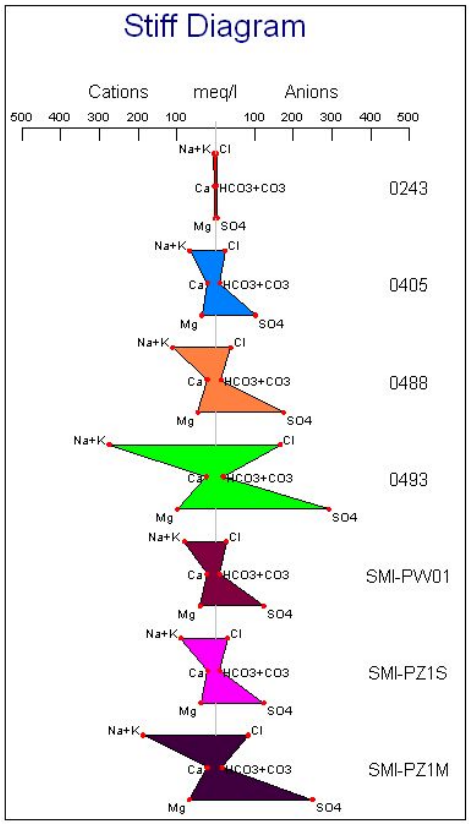


Figure A-3. March Baseline Stiff Diagram

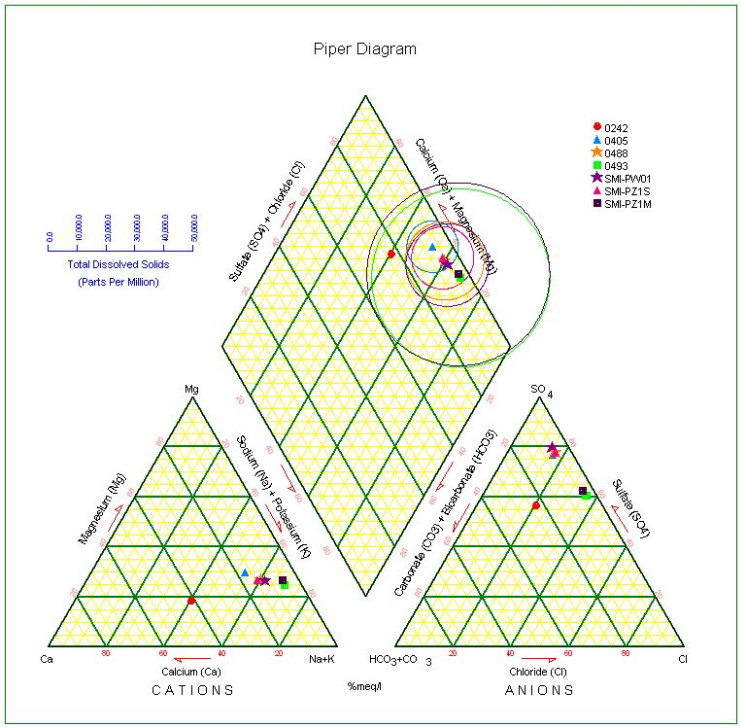


Figure A-4. April Baseline Trilinear Diagram

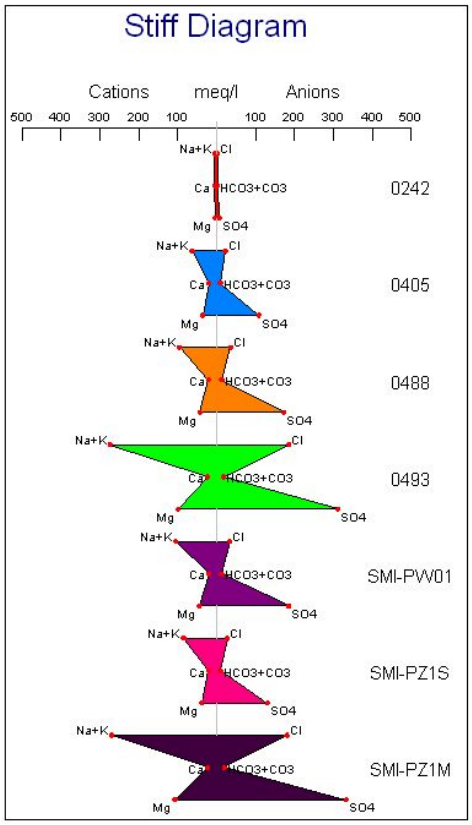


Figure A-5. April Baseline Stiff Diagram

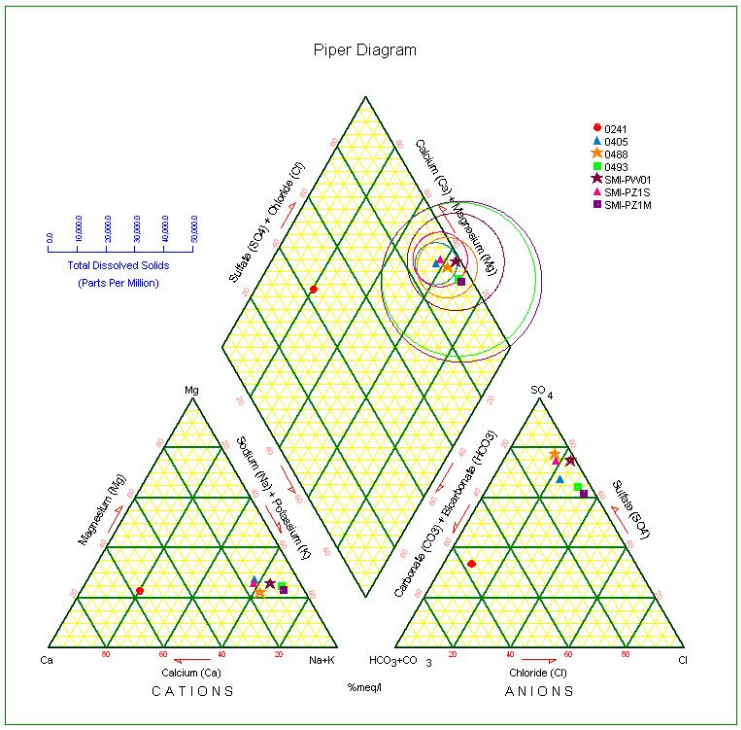


Figure A-6. June Baseline Trilinear Diagram

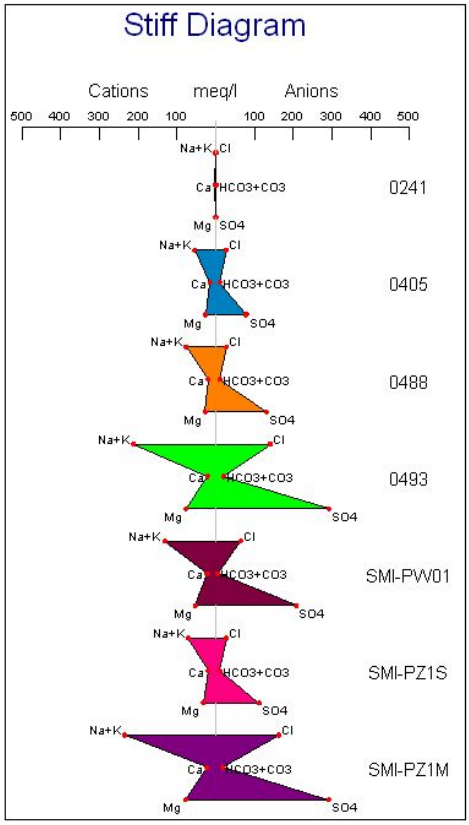


Figure A-7. June Baseline Stiff Diagram

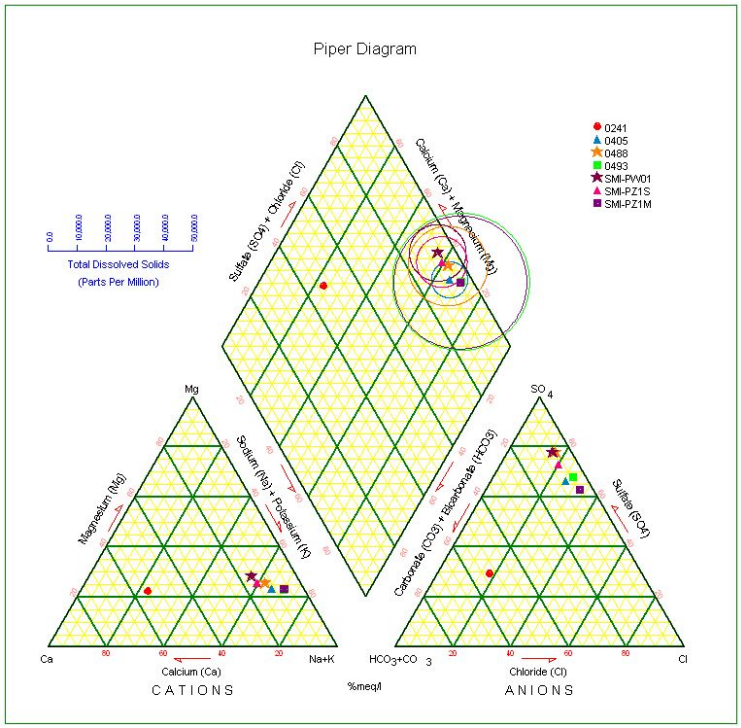


Figure A-8. July Baseline Trilinear Diagram

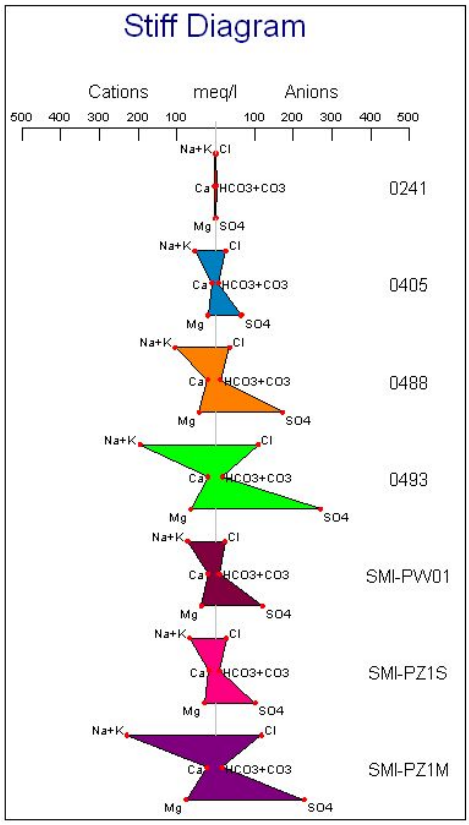


Figure A-9. July Baseline Stiff Diagram

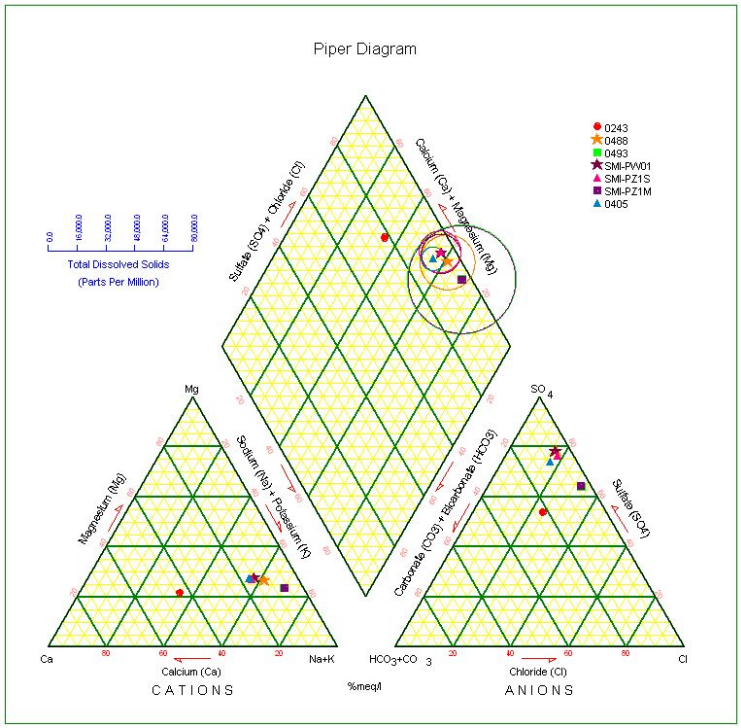


Figure A-10. September Baseline Trilinear Diagram

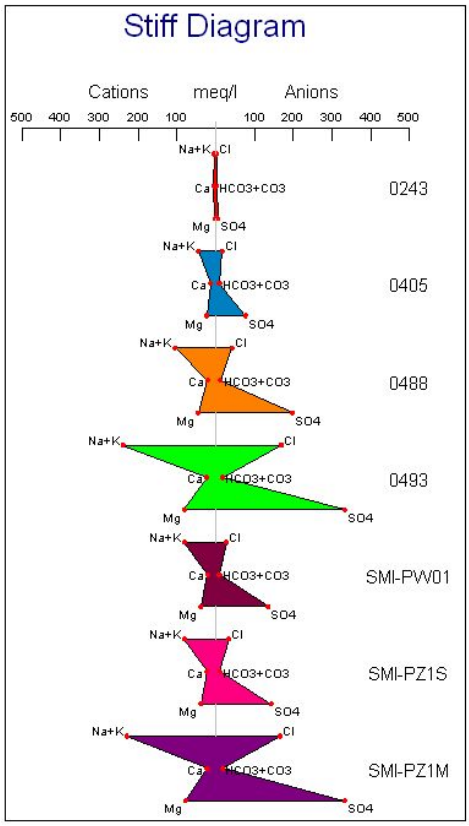


Figure A-11. September Baseline Stiff Diagram

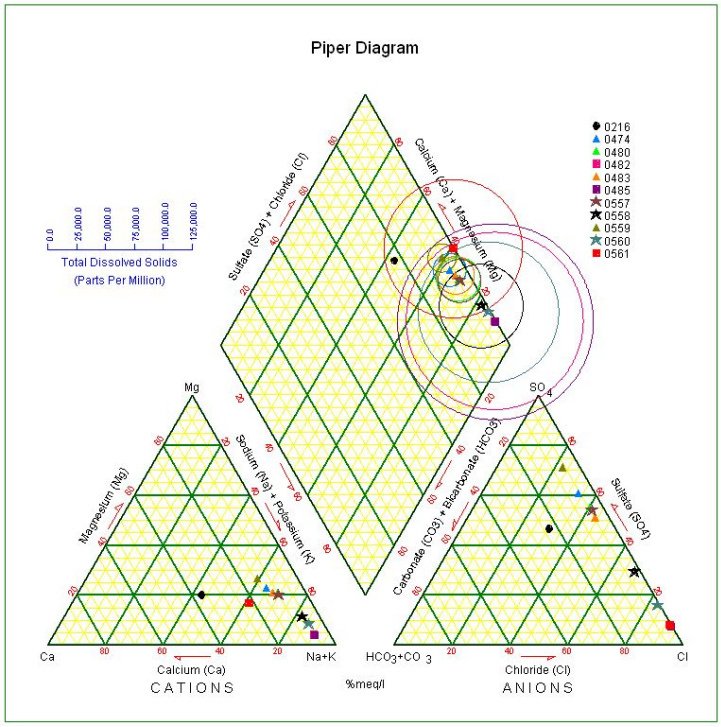


Figure A-12. March CF1 Trilinear Diagram

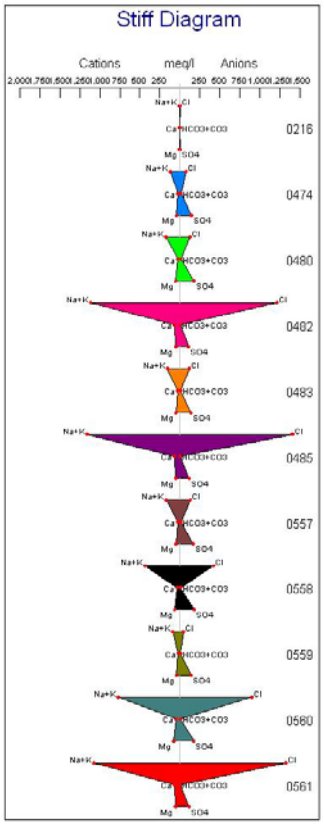


Figure A-13. March CF1 Stiff Diagram

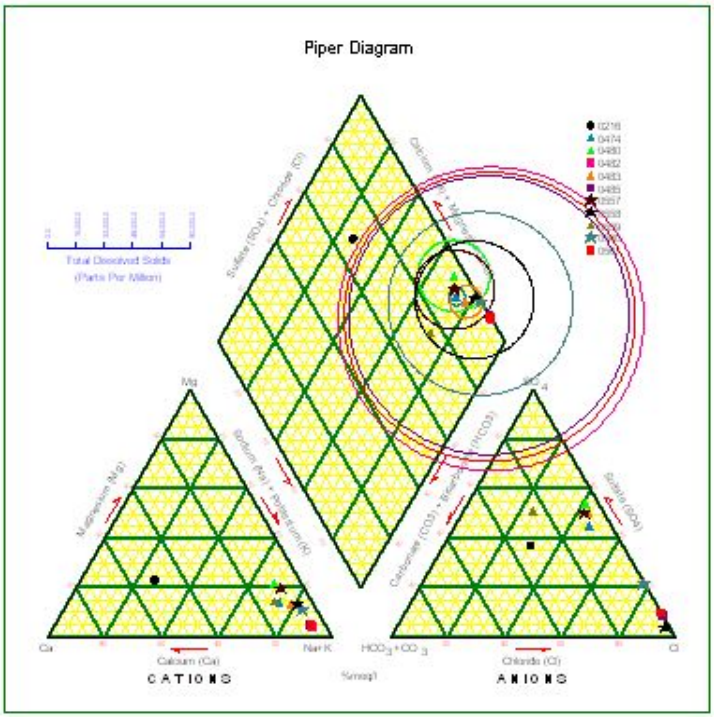


Figure A-14. April CF1 Trilinear Diagram

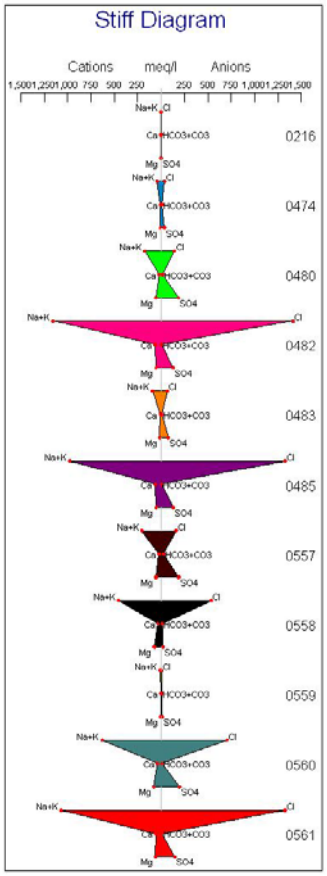


Figure A-15. April CF1 Stiff Diagram

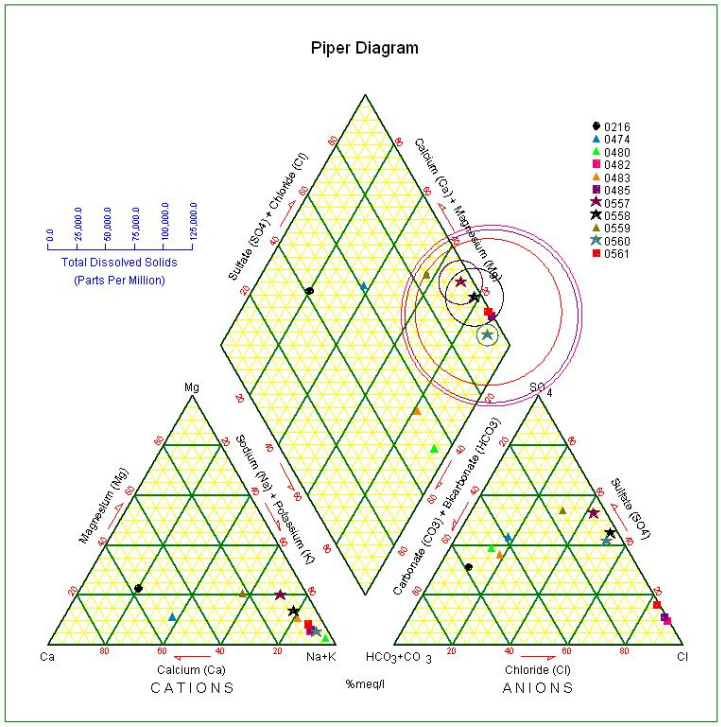


Figure A-16. June CF1 Trilinear Diagram

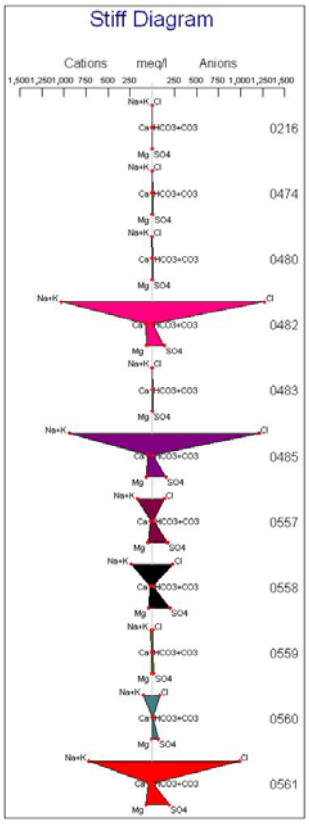


Figure A-17. June CF1 Stiff Diagram

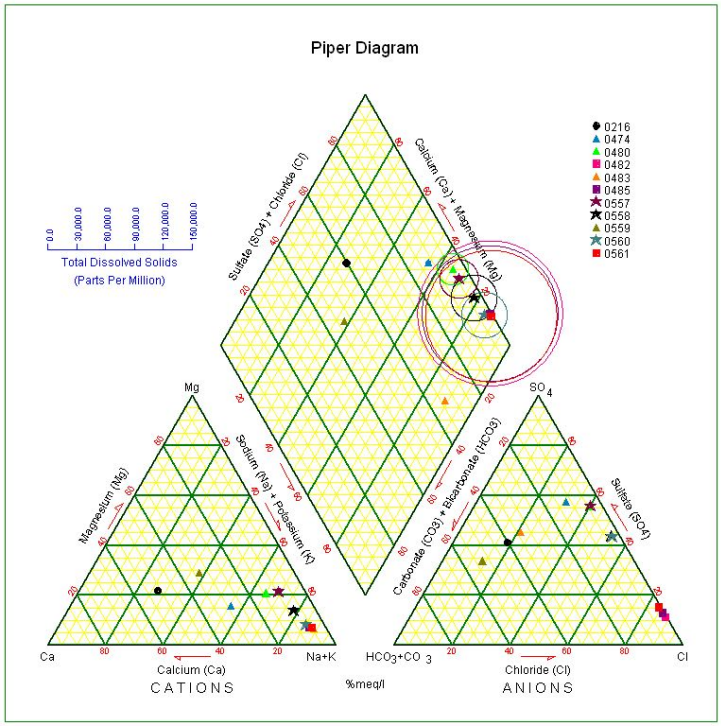


Figure A-18. July CF1 Trilinear Diagram

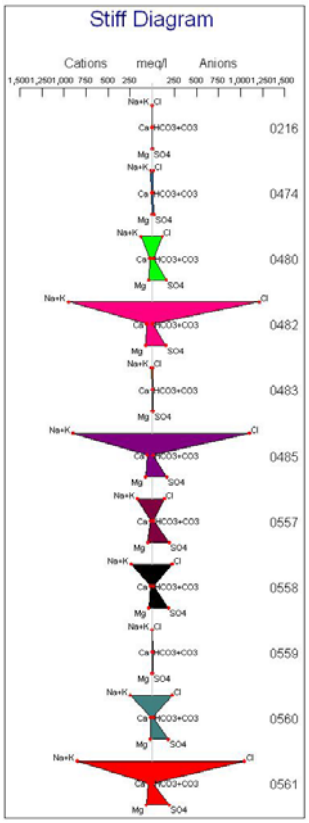


Figure A-19. July CF1 Stiff Diagram

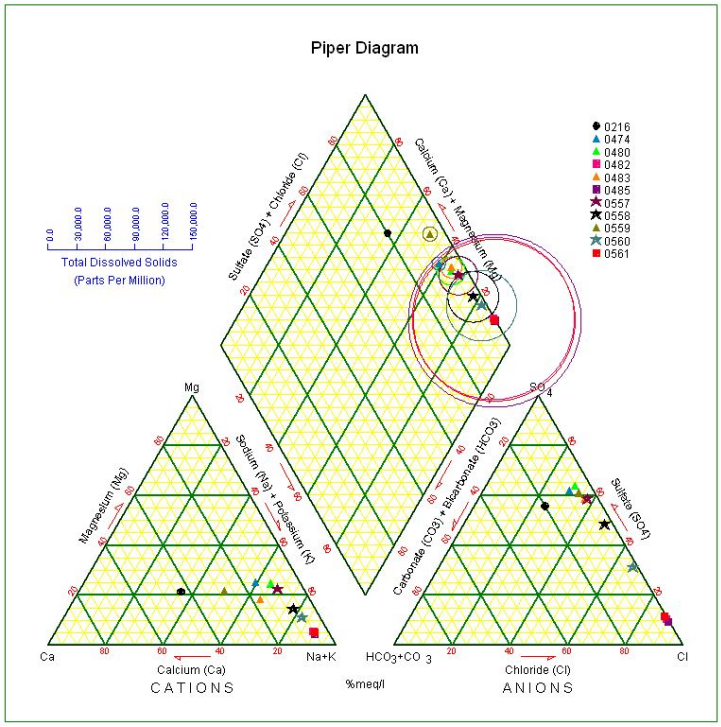


Figure A-20. September CF1 Trilinear Diagram

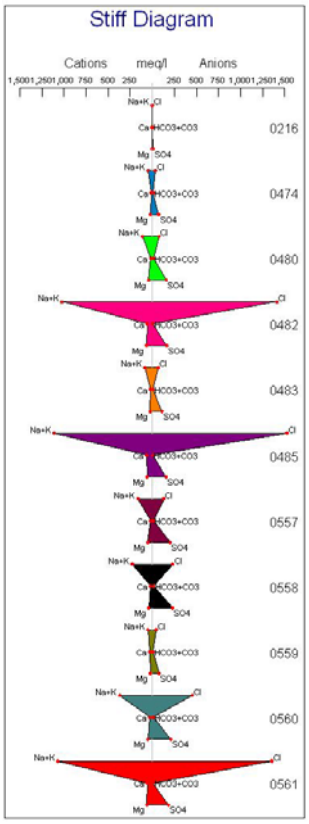


Figure A-21. September Cf1 Stiff Diagram

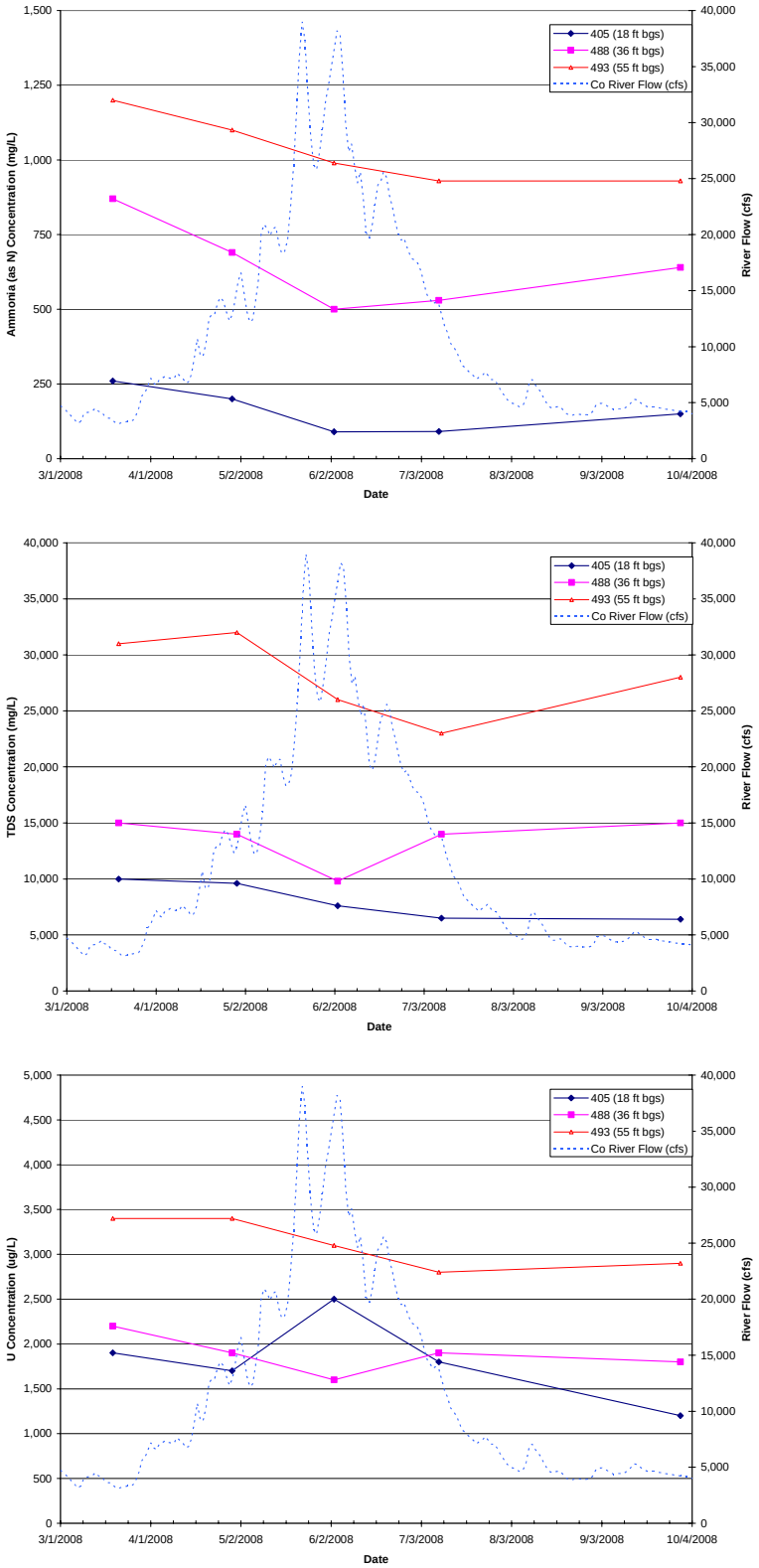


Figure A-22. Baseline Area Ammonia, TDS, and Uranium Concentrations Measured in Downgradient Wells

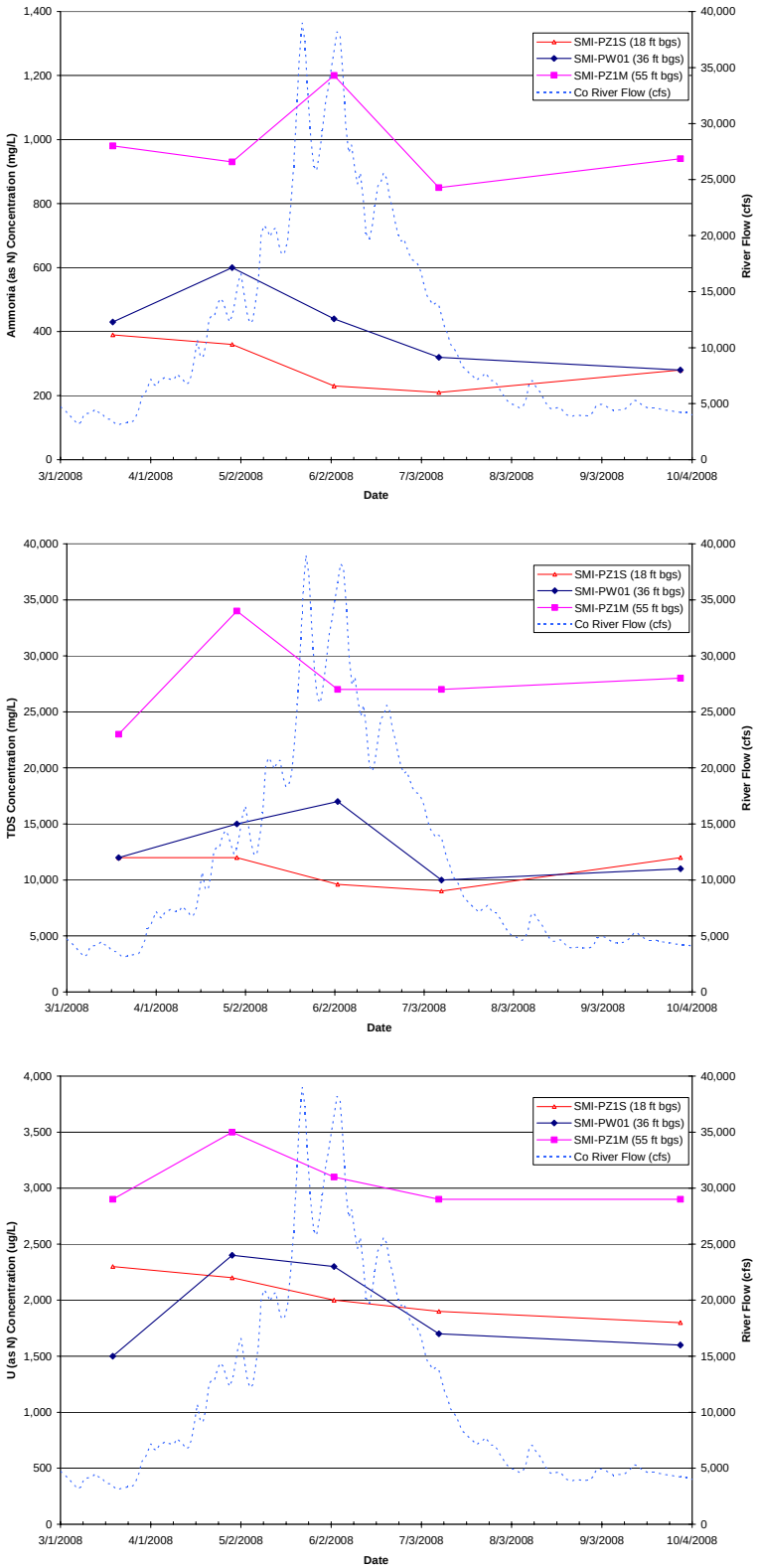


Figure A-23. Baseline Area Ammonia, TDS, and Uranium Concentrations Measured in Upgradient Wells

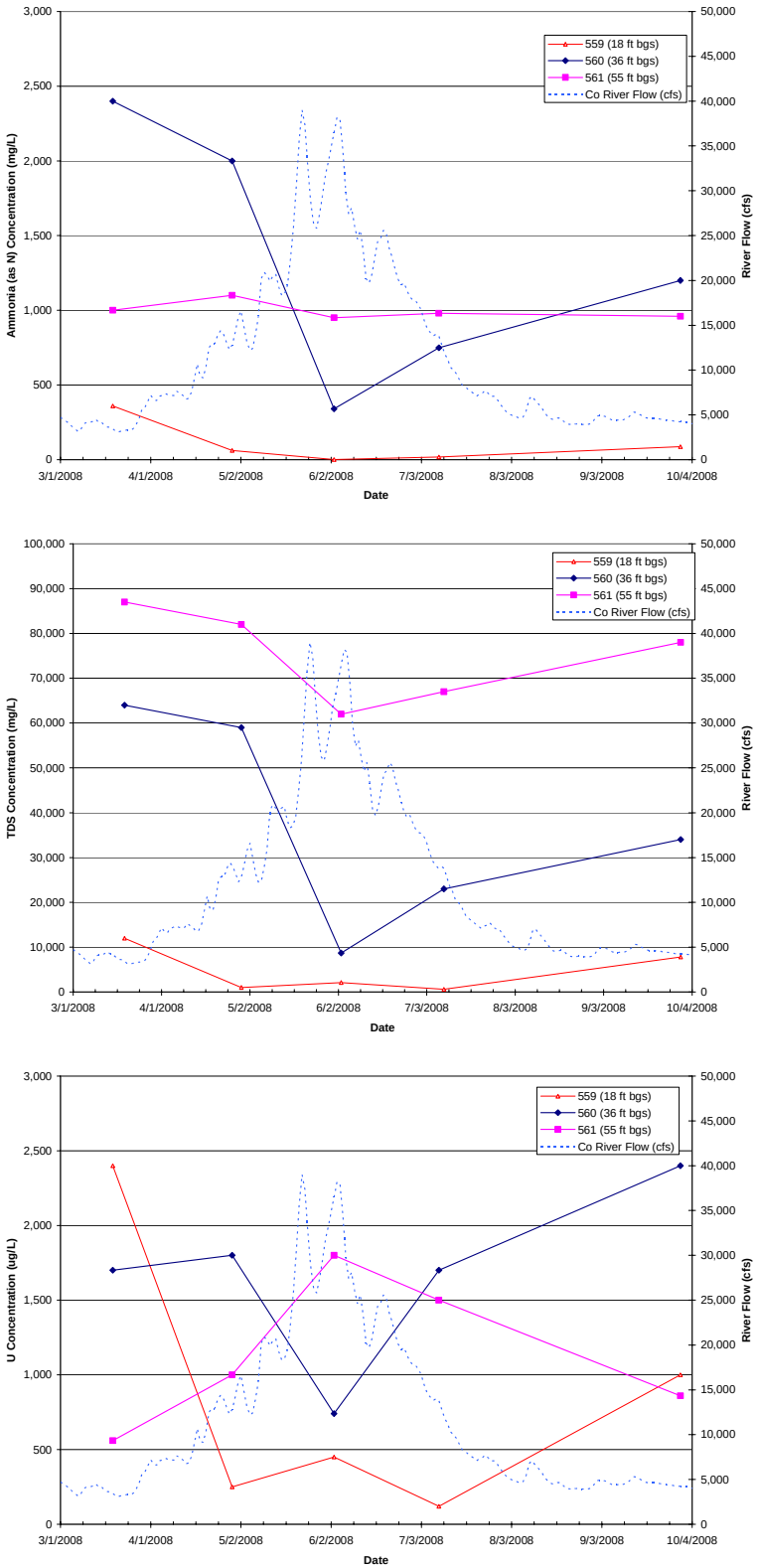


Figure A-24. CF1 Ammonia, TDS, and Uranium Concentrations Measured in Downgradient Wells

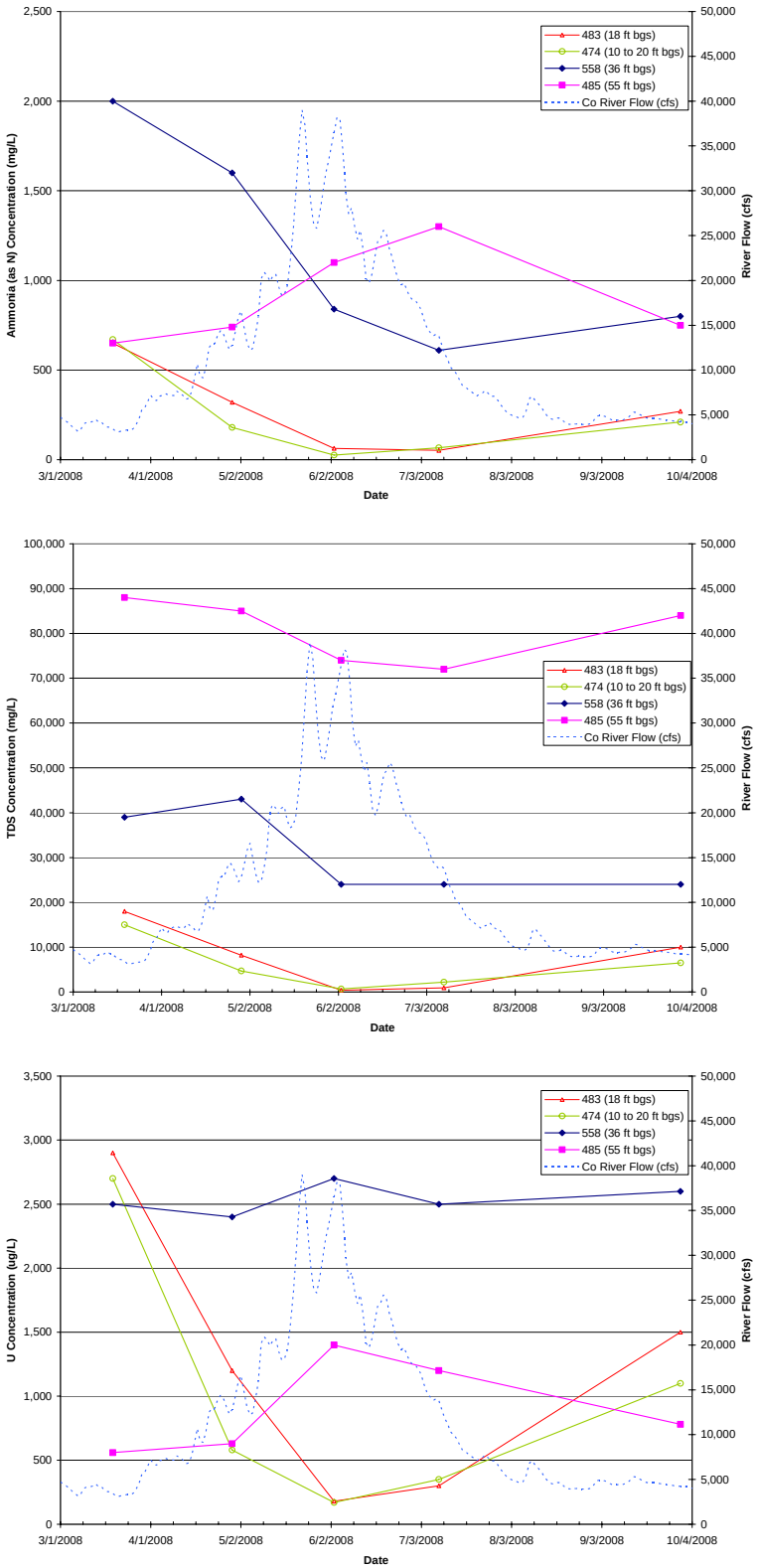


Figure A-25. CF1 Ammonia, TDS, and Uranium Concentrations Measured in Off-Axis Wells

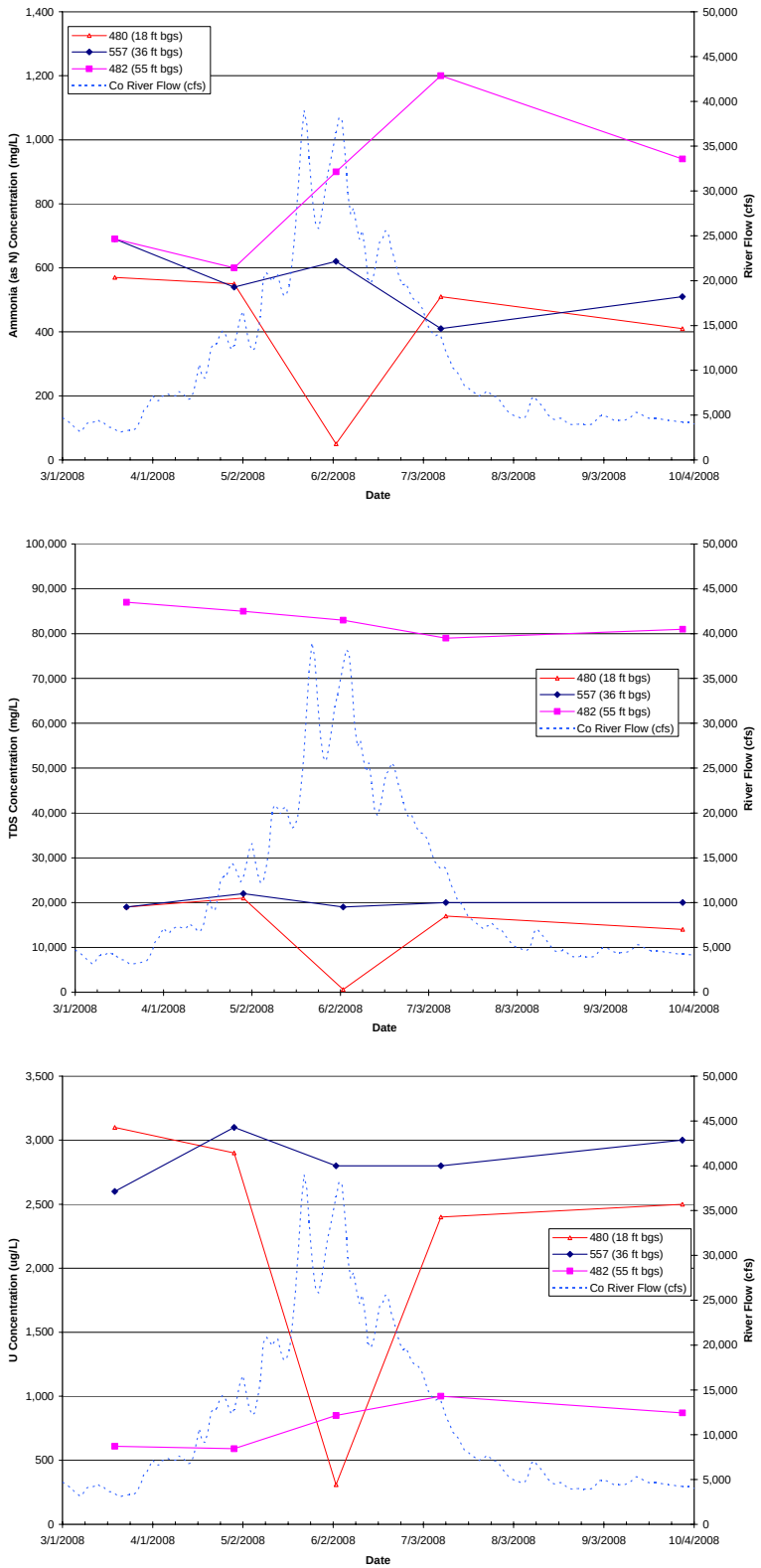


Figure A-26. CF1 Ammonia, TDS, and Uranium Concentrations Measured in Upgradient Wells

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

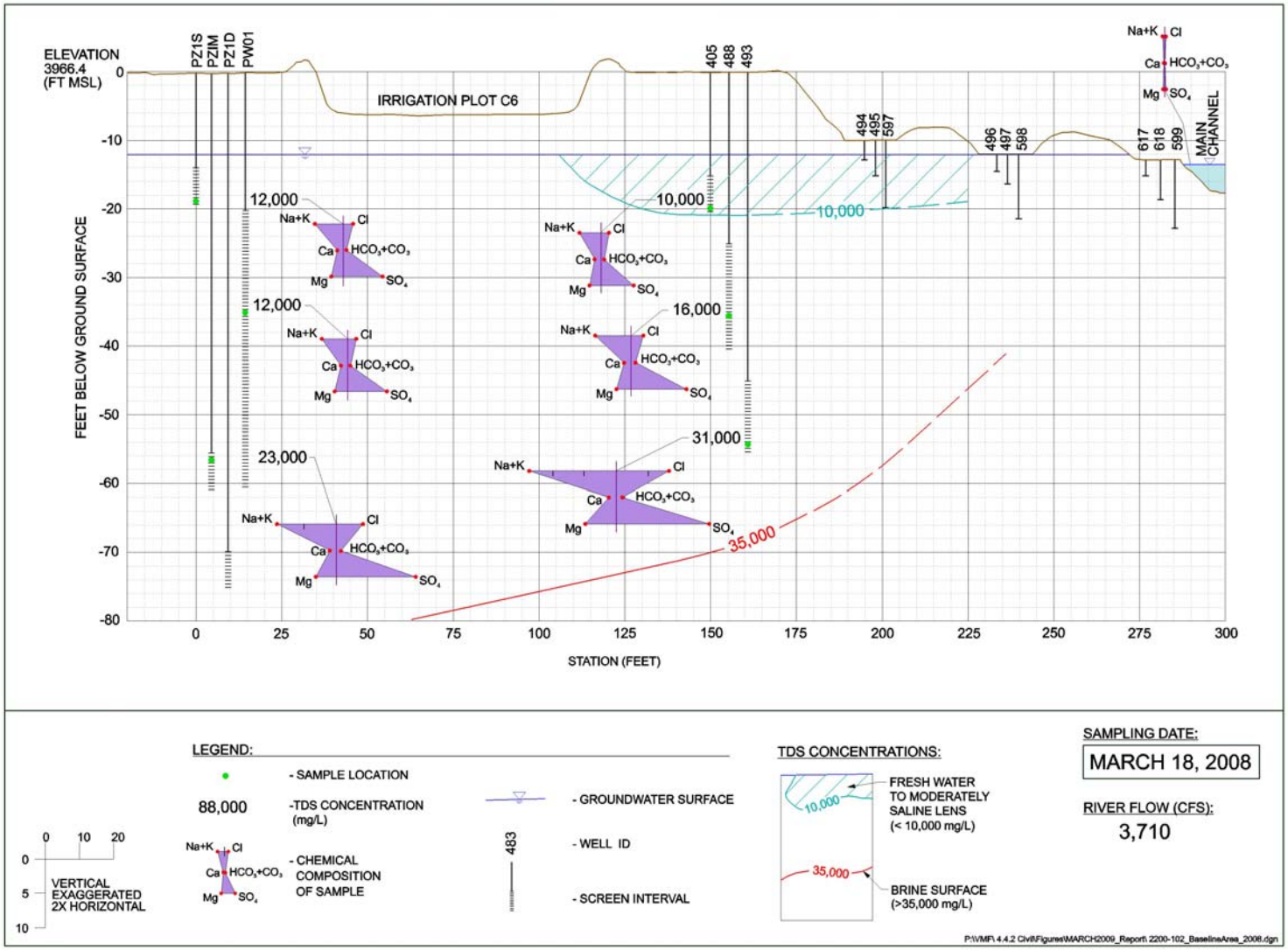


Figure A-27. Baseline Area Cross Section and Water Chemistry, March 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

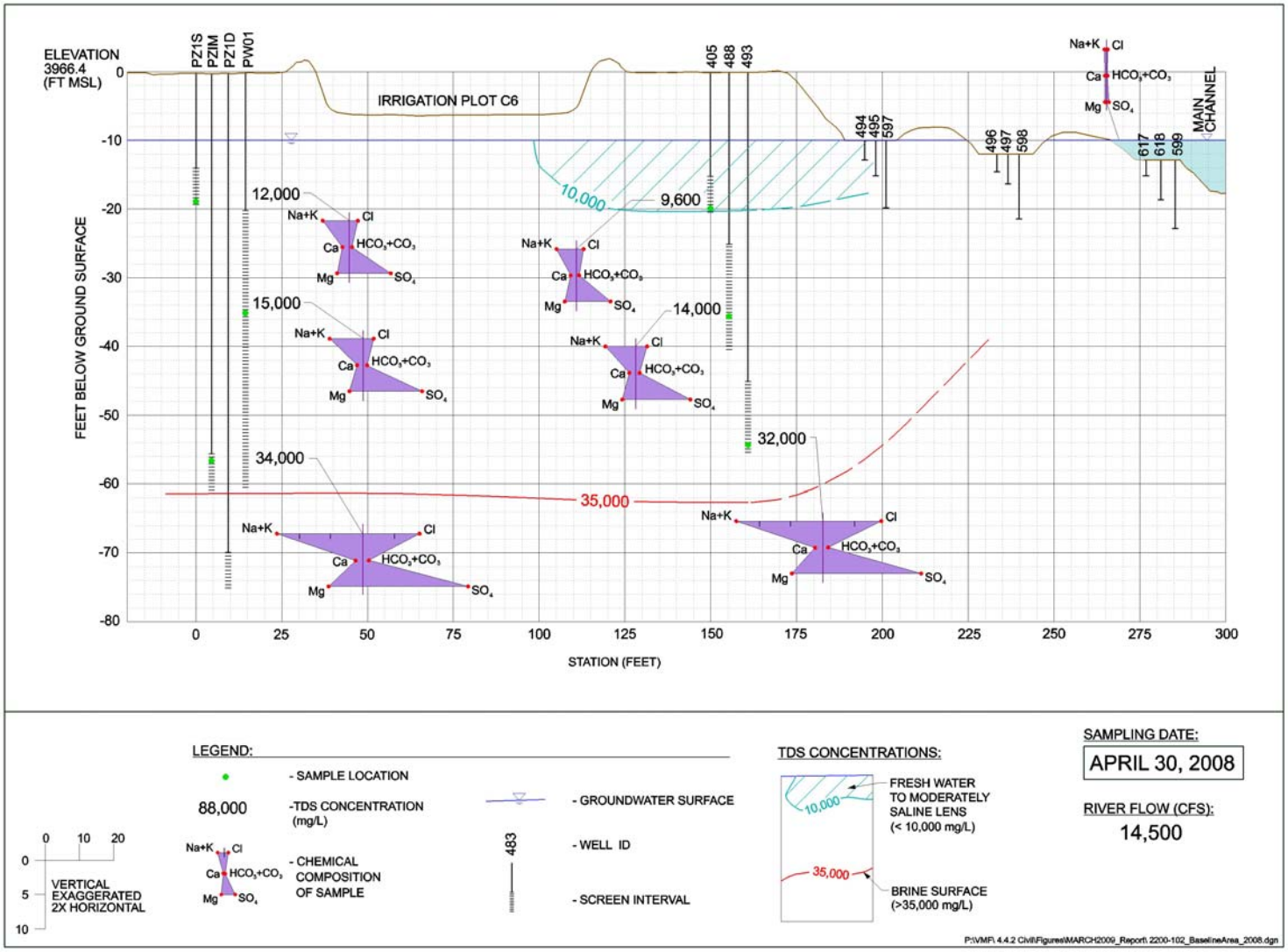


Figure A-28. Baseline Area Cross Section and Water Chemistry, April 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

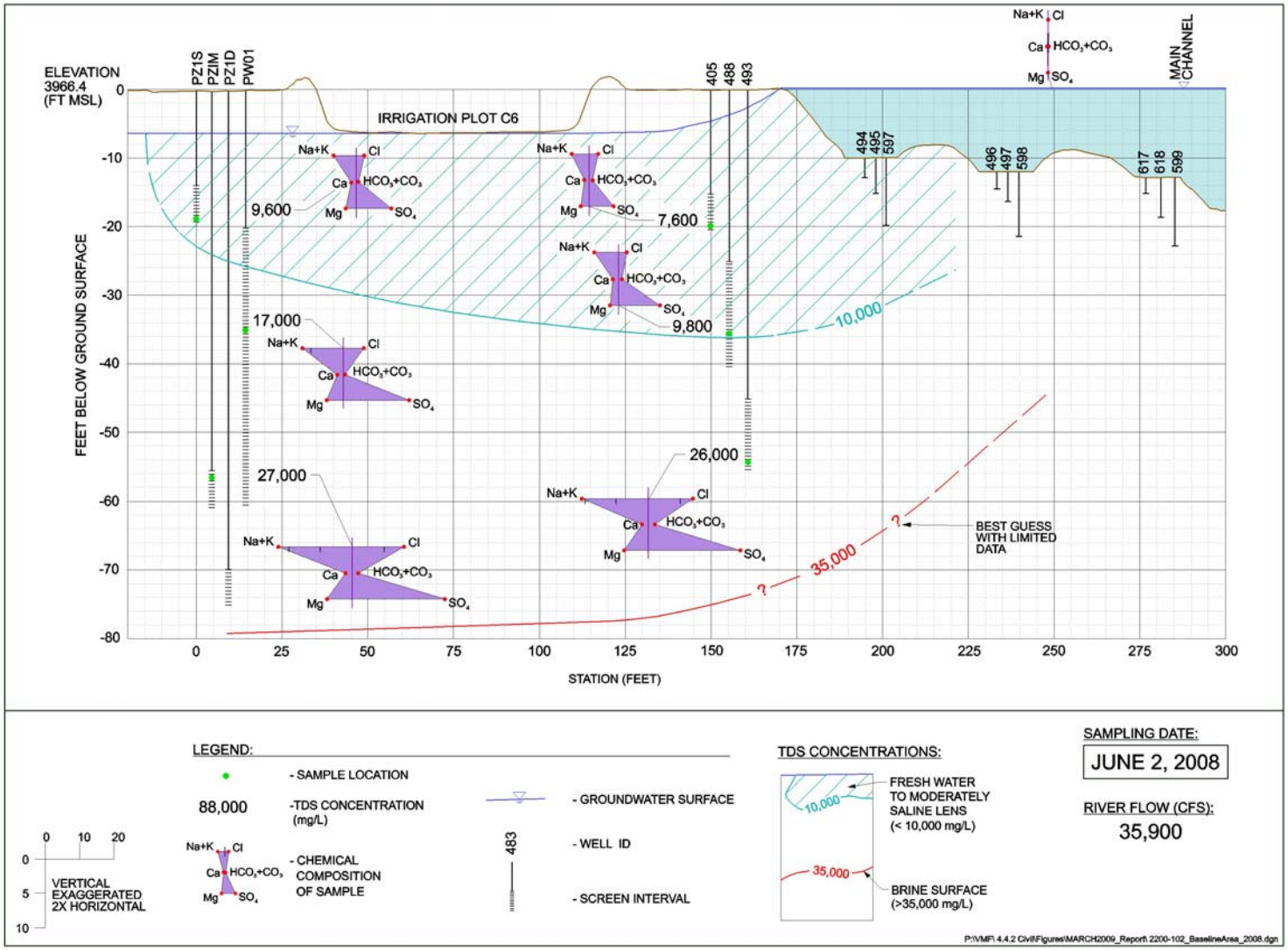


Figure A-29. Baseline Area Cross Section and Water Chemistry, June 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

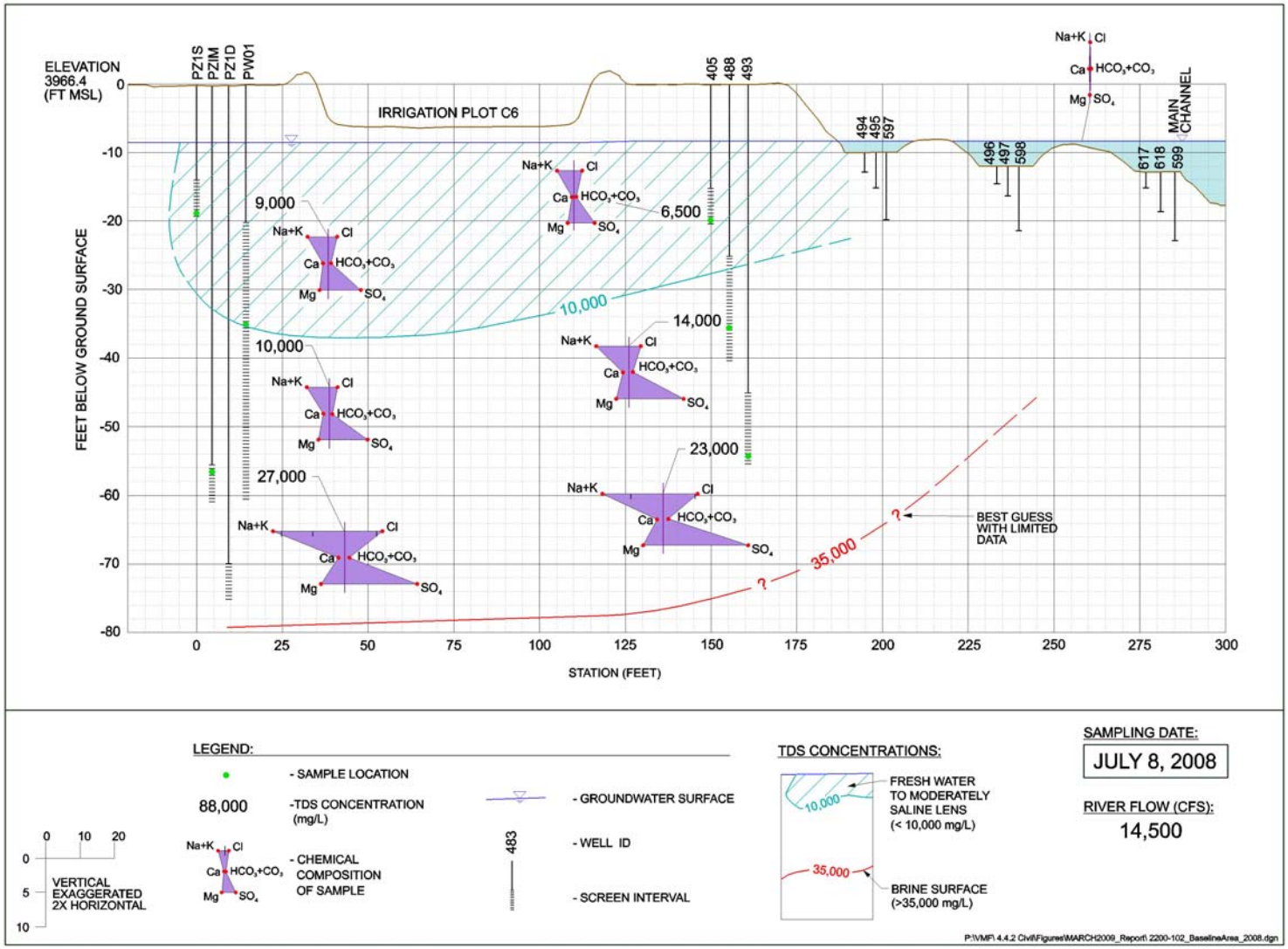


Figure A-30. Baseline Area Cross Section and Water Chemistry, July 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

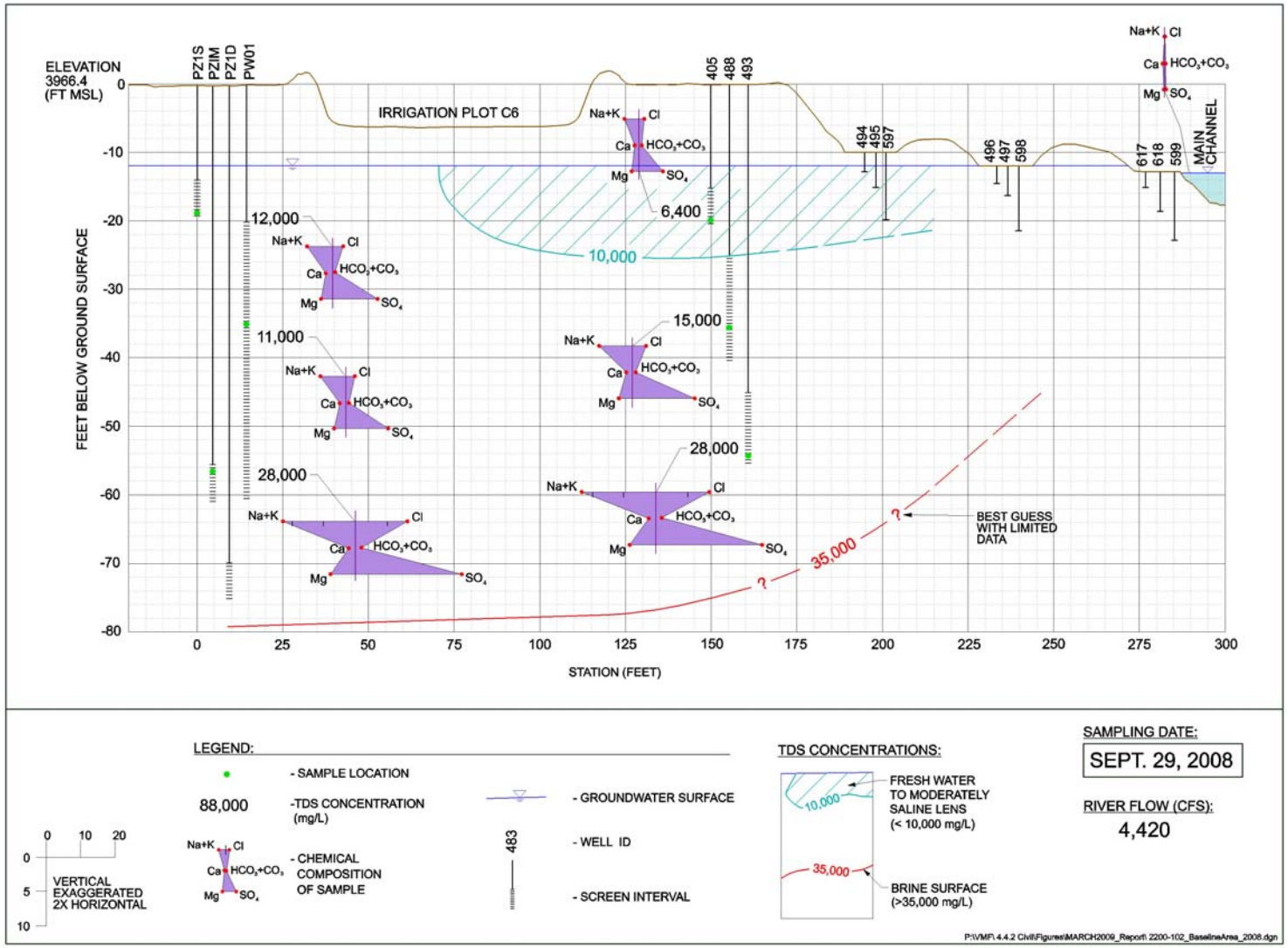


Figure A-31. Baseline Area Cross Section and Water Chemistry, September 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

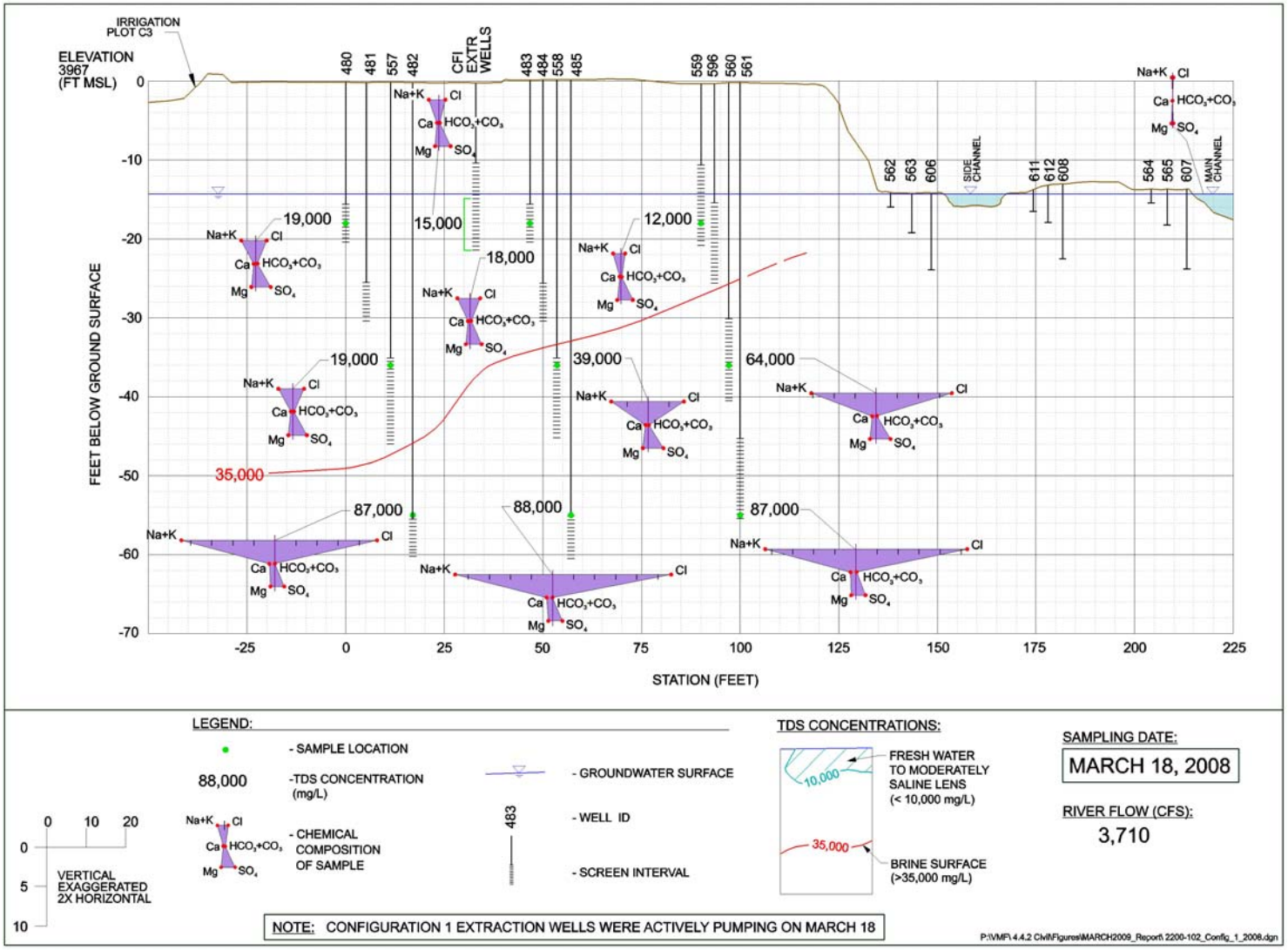


Figure A-32. CF1 Cross Section and Water Chemistry, March 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

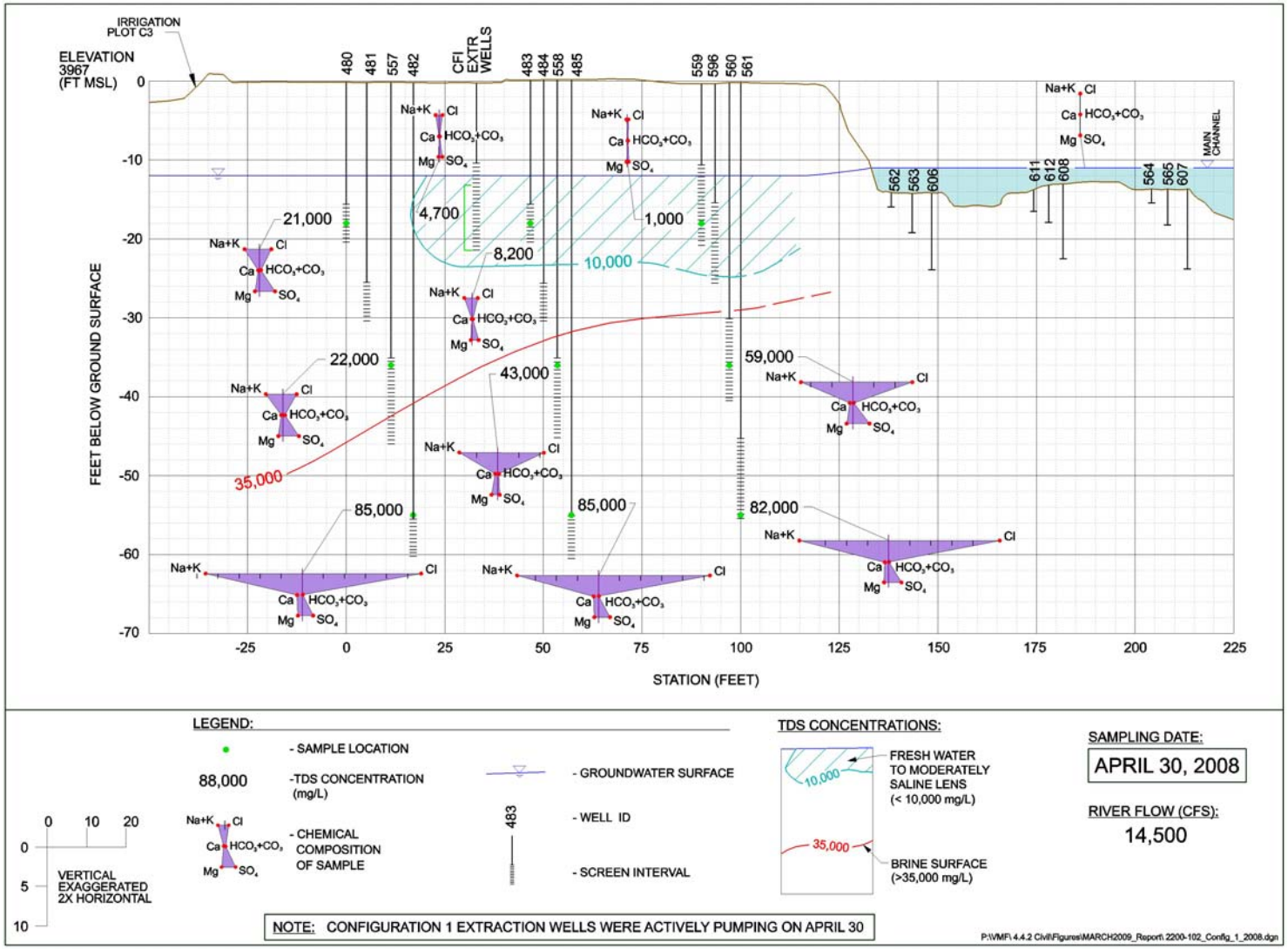


Figure A-33. CF1 Cross Section and Water Chemistry, April 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

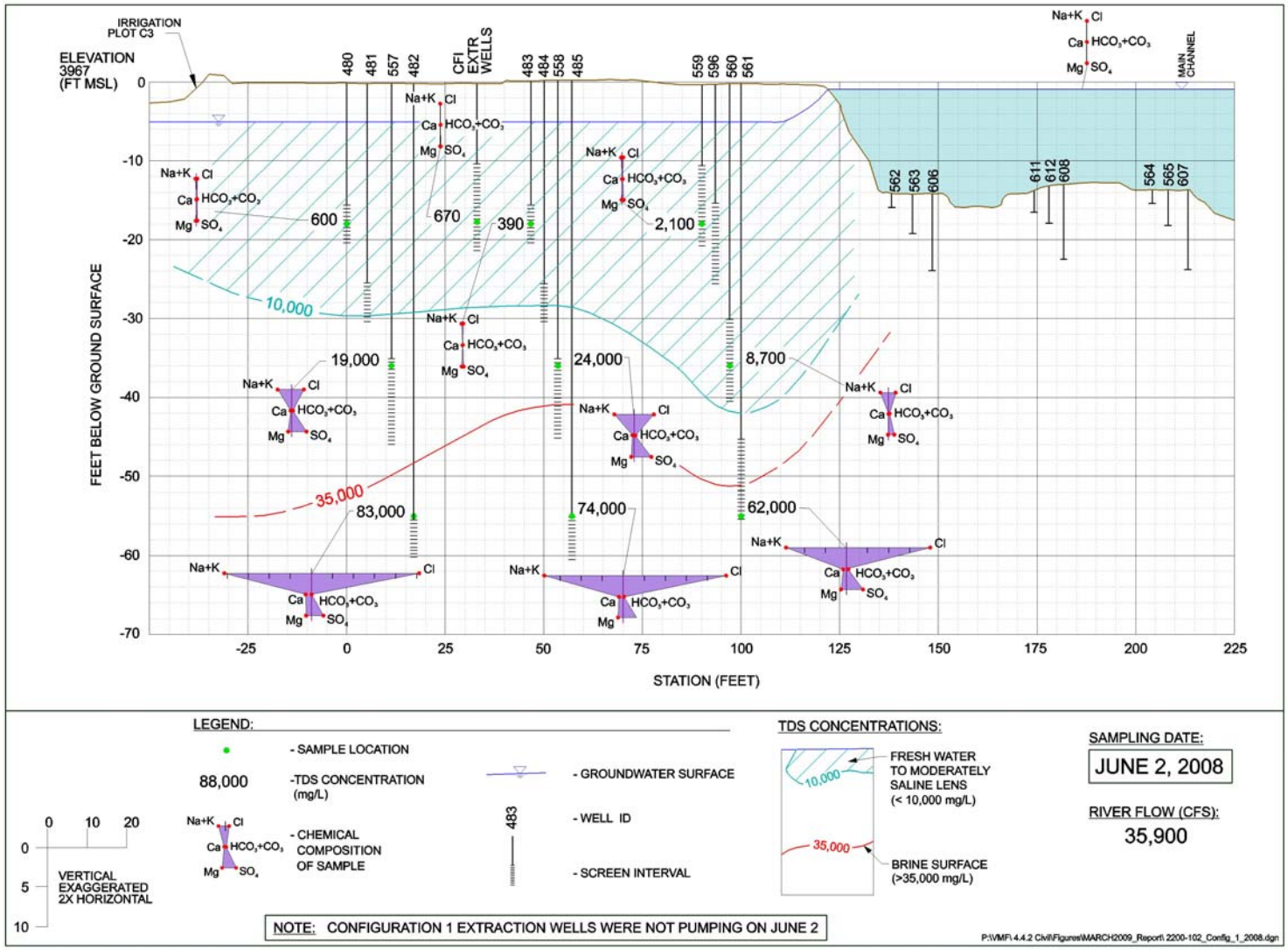


Figure A-34. CF1 Cross Section and Water Chemistry, June 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

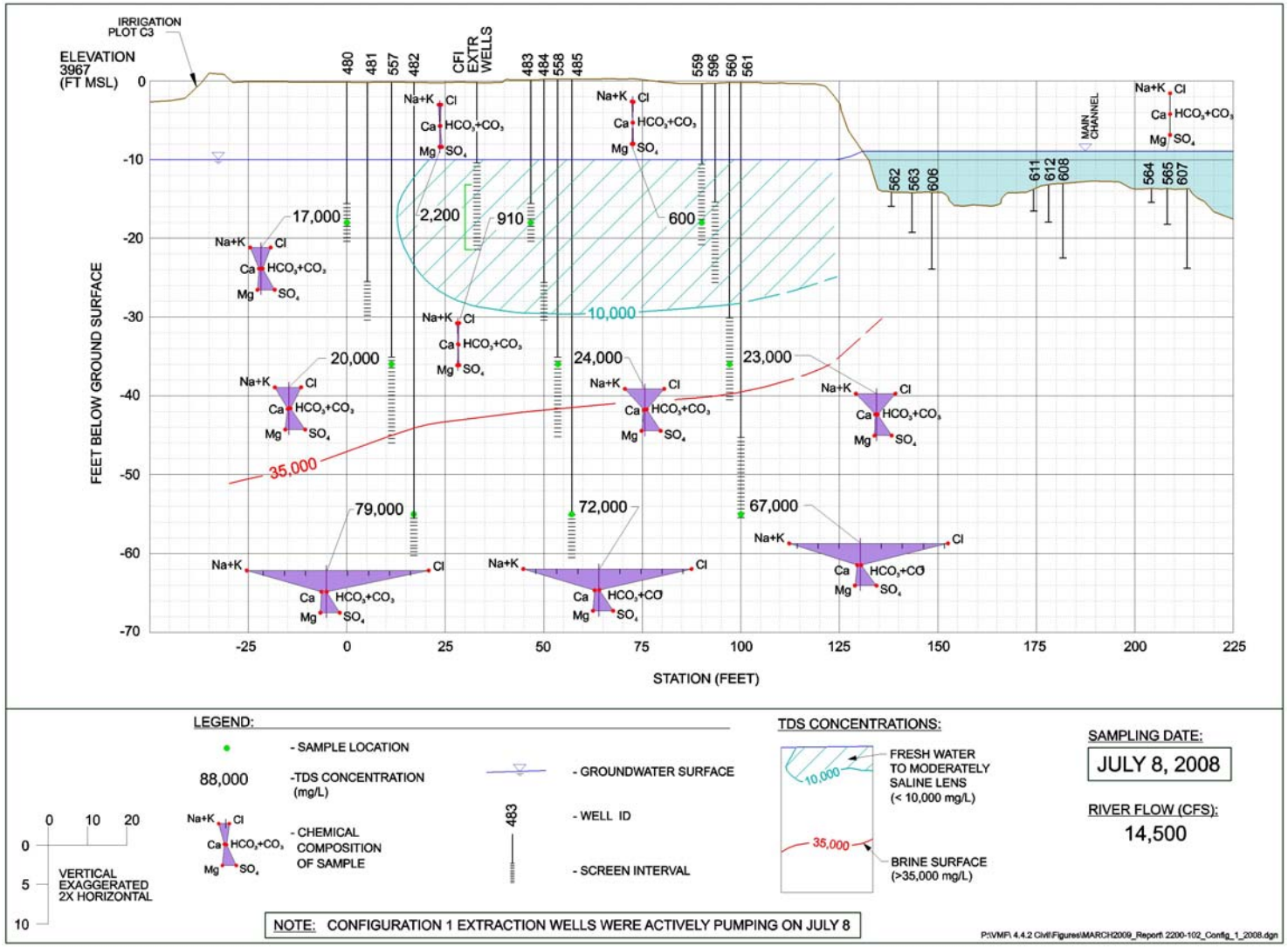


Figure A-35. CF1 Cross Section and Water Chemistry, July 2008

Appendix A
Ground Water/Surface Water Interaction Investigation (continued)

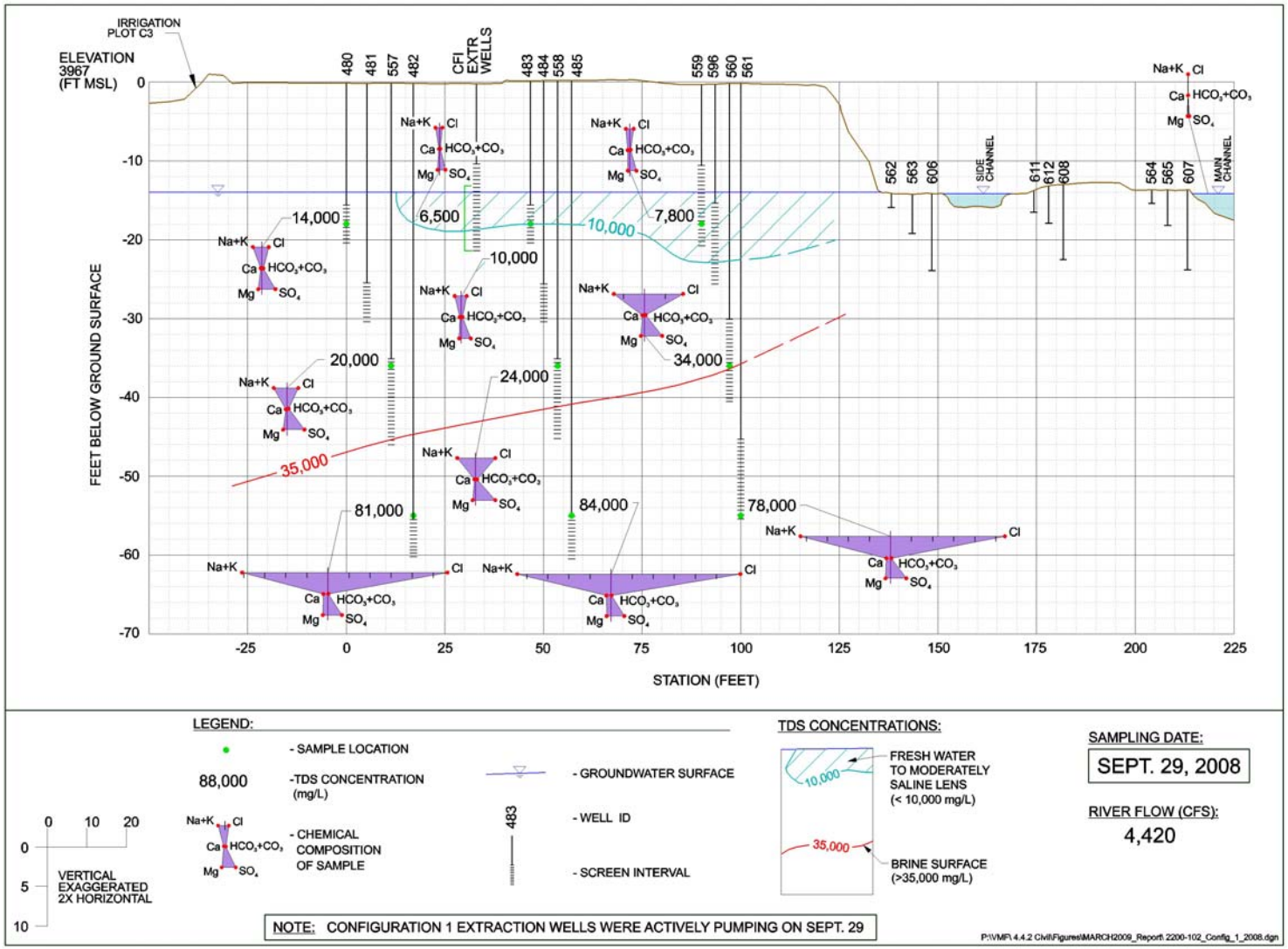
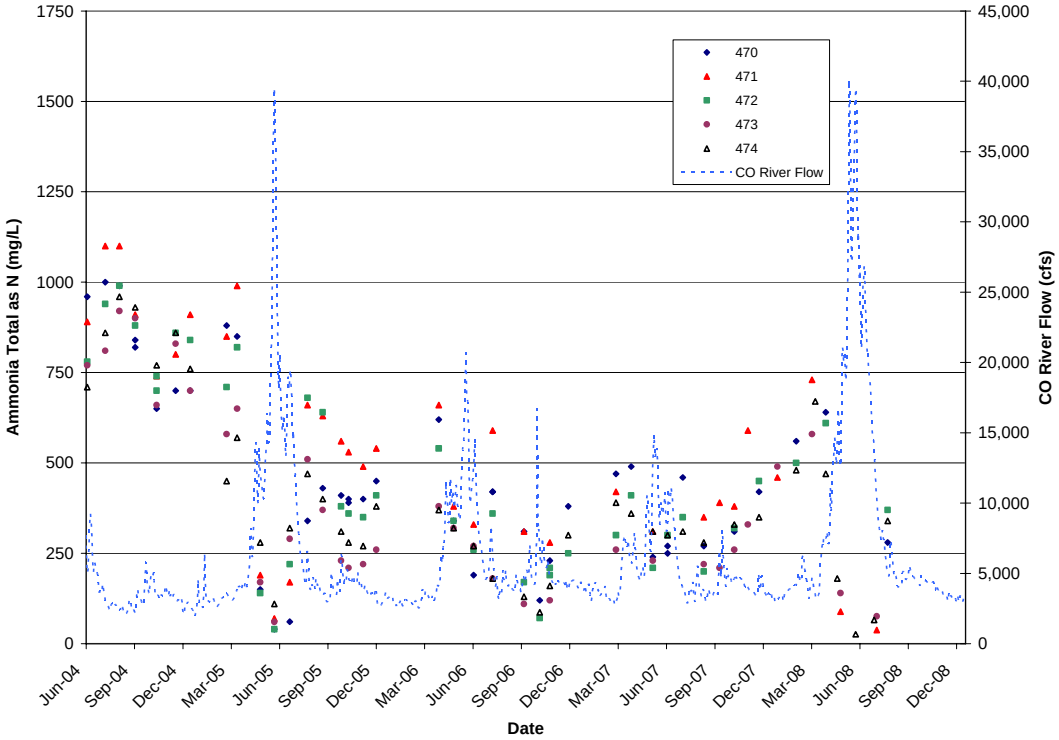


Figure A-36. CF1 Cross Section and Water Chemistry, September 2008

Appendix B
CF1 Ammonia and Uranium Concentration Plots

Appendix B
CF1 Ammonia and Uranium Concentration Plots



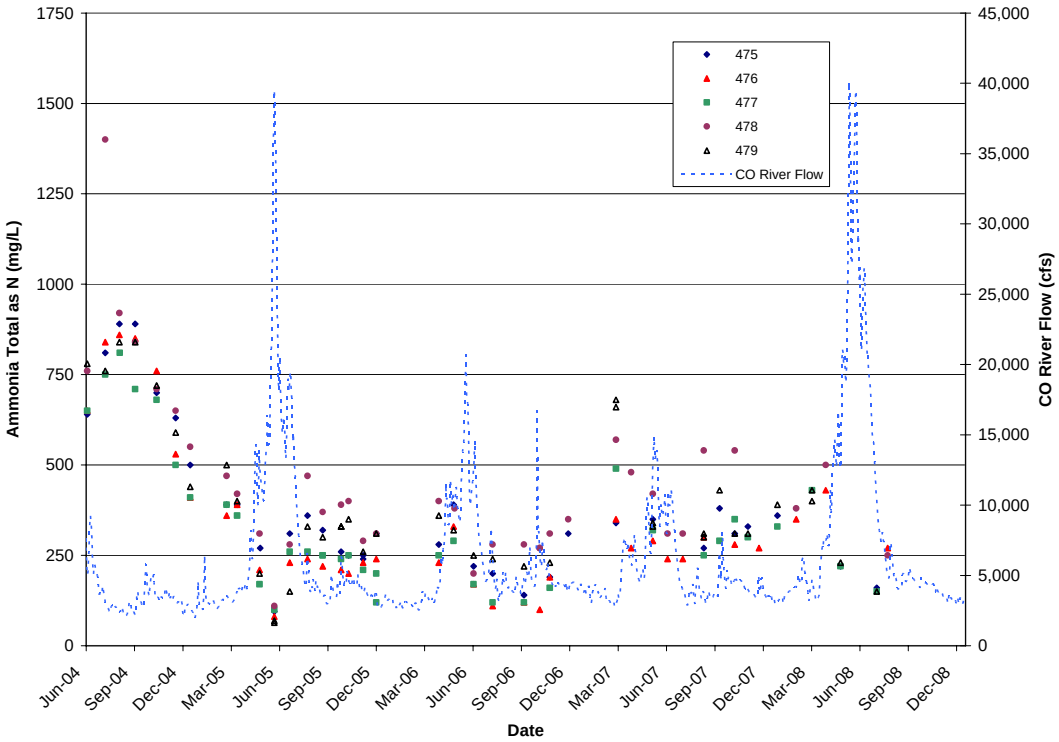
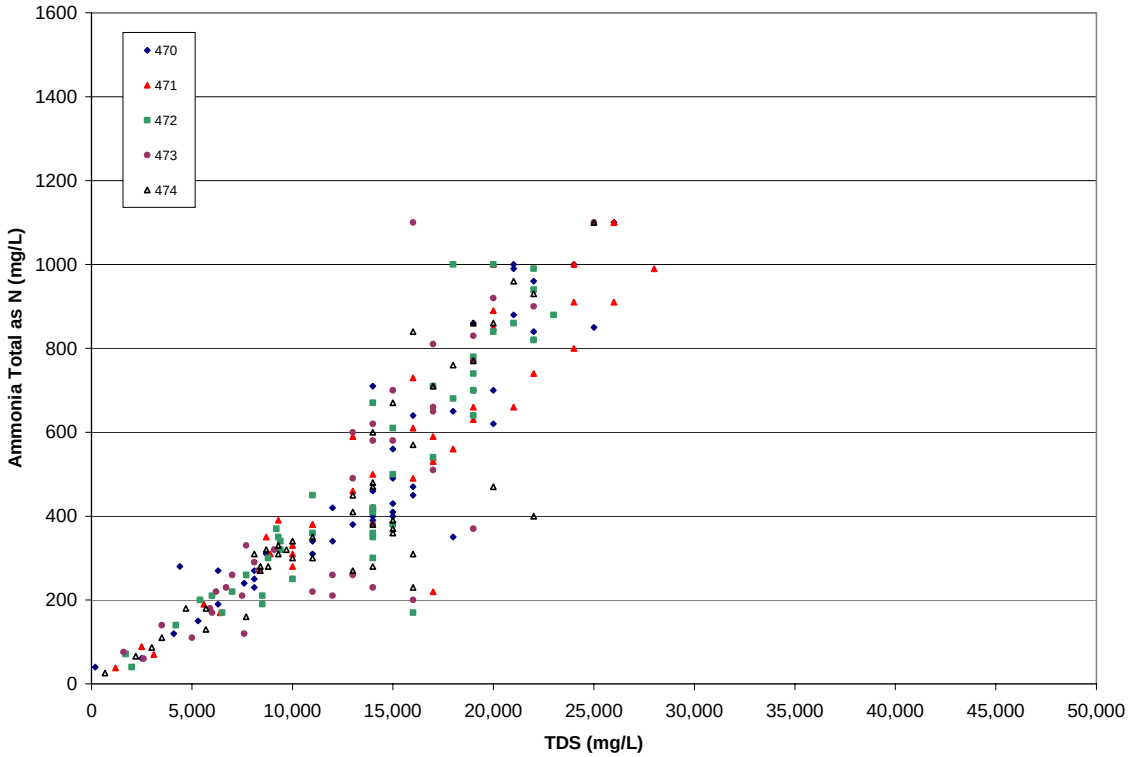


Figure B-1. CF1 Extraction Wells 0470 through 0474 (top) and 0475 through 0479 (bottom) Ammonia Concentrations, 2004 through 2008

Appendix B
CF1 Ammonia and Uranium Concentration Plots (continued)



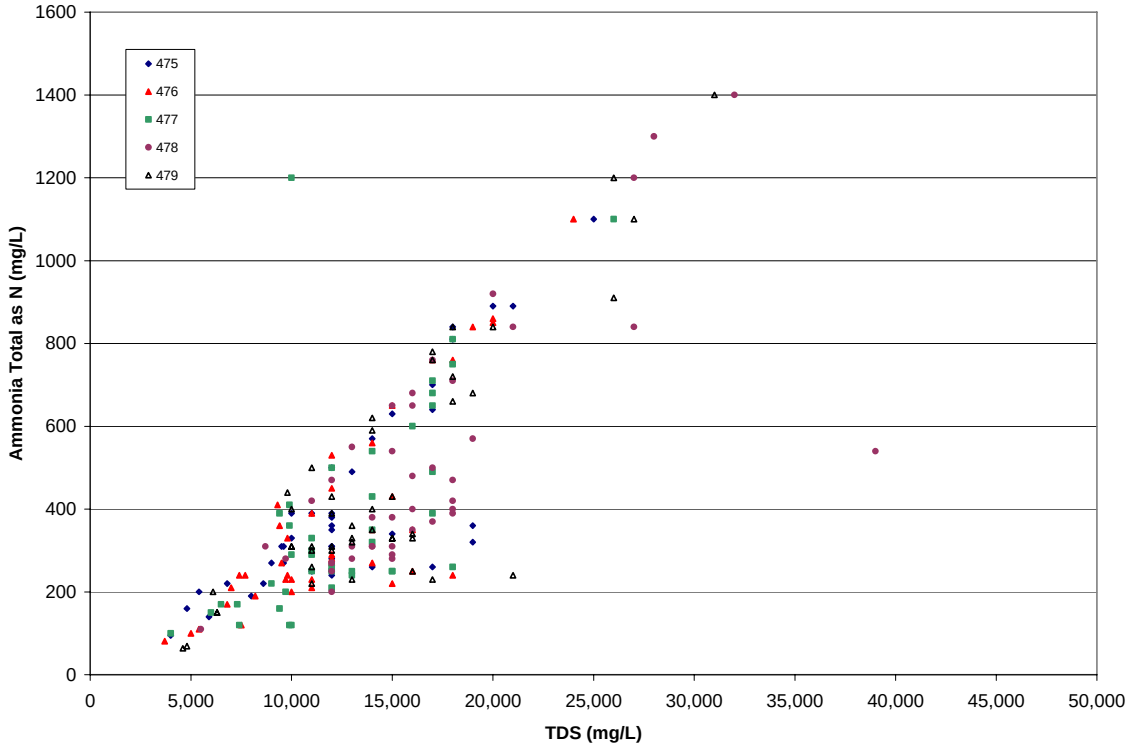


Figure B-2. CF1 Extraction Wells 0470 through 0474 (top) and 0475 through 0479 (bottom) Ammonia Concentrations Versus TDS Concentrations, 2004 through 2008

Appendix B
CF1 Ammonia and Uranium Concentration Plots (continued)

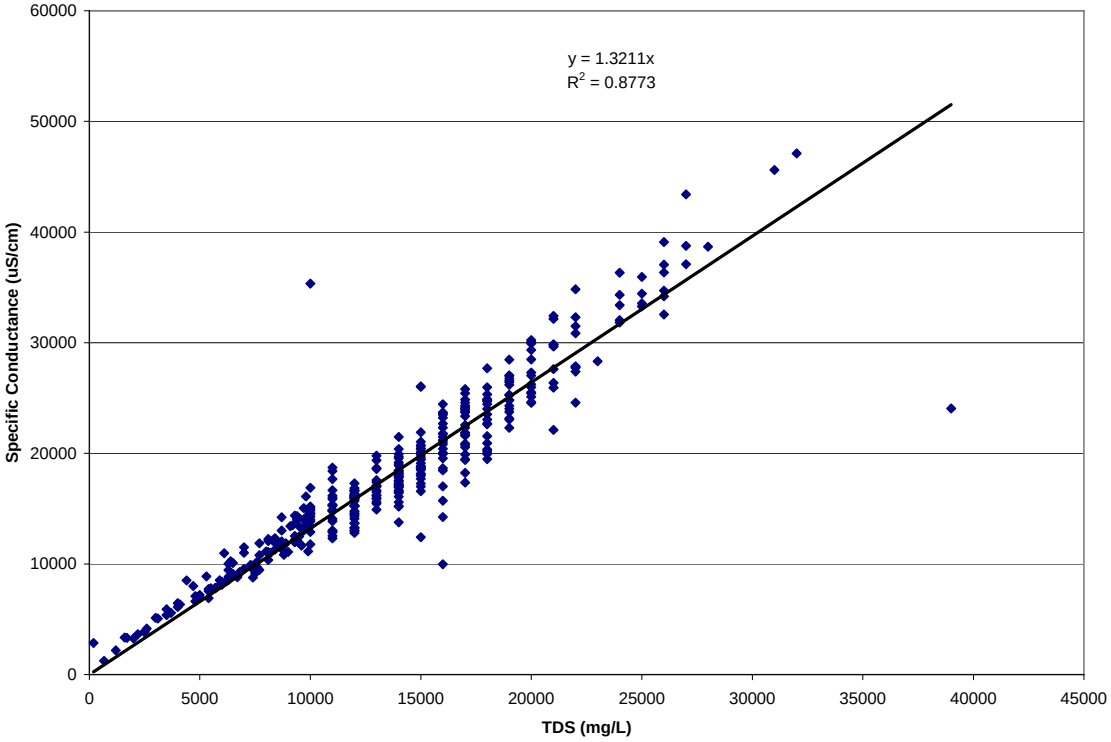
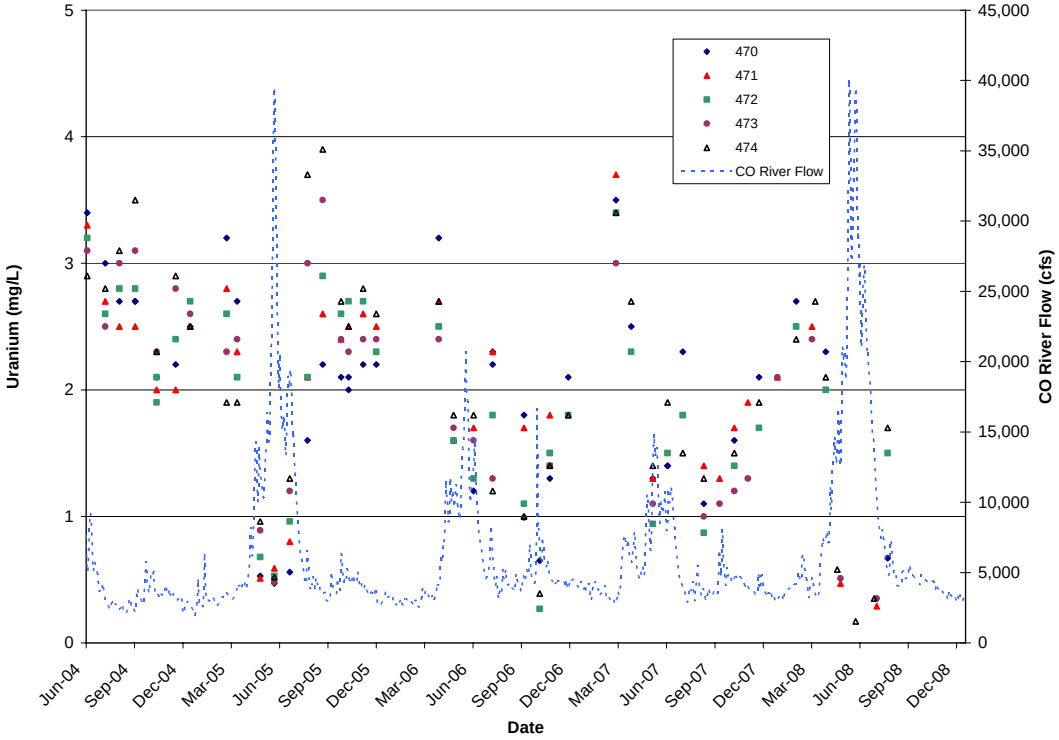


Figure B-3. CF1 TDS Concentration Versus Specific Conductance

Appendix B
CF1 Ammonia and Uranium Concentration Plots (continued)



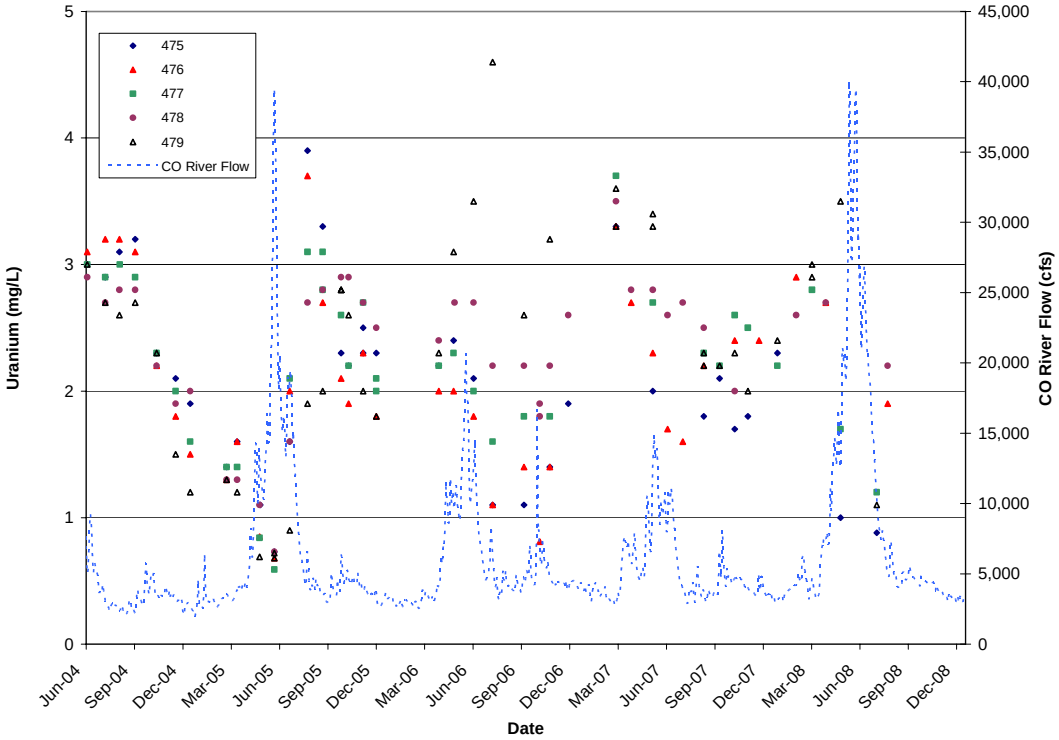
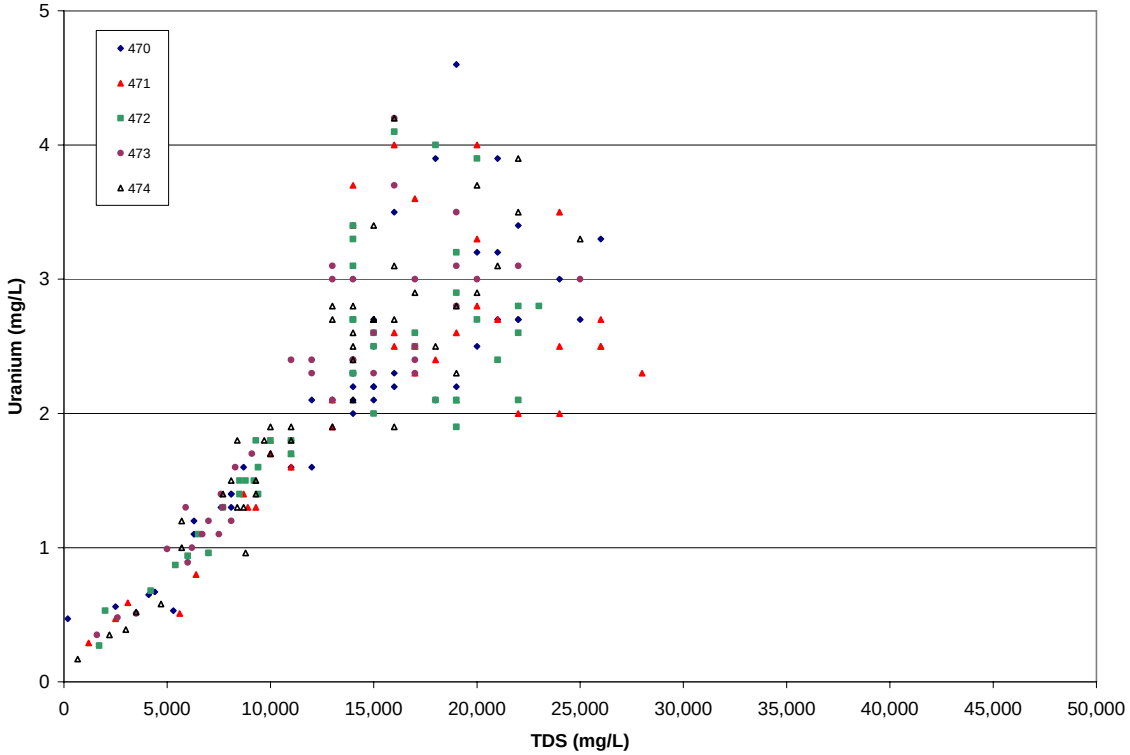


Figure B-4. CF1 Extraction Wells 0470 through 0474 (top) and 0475 through 0479 (bottom) Uranium Concentrations, 2004 through 2008

Appendix B
CF1 Ammonia and Uranium Concentration Plots (continued)



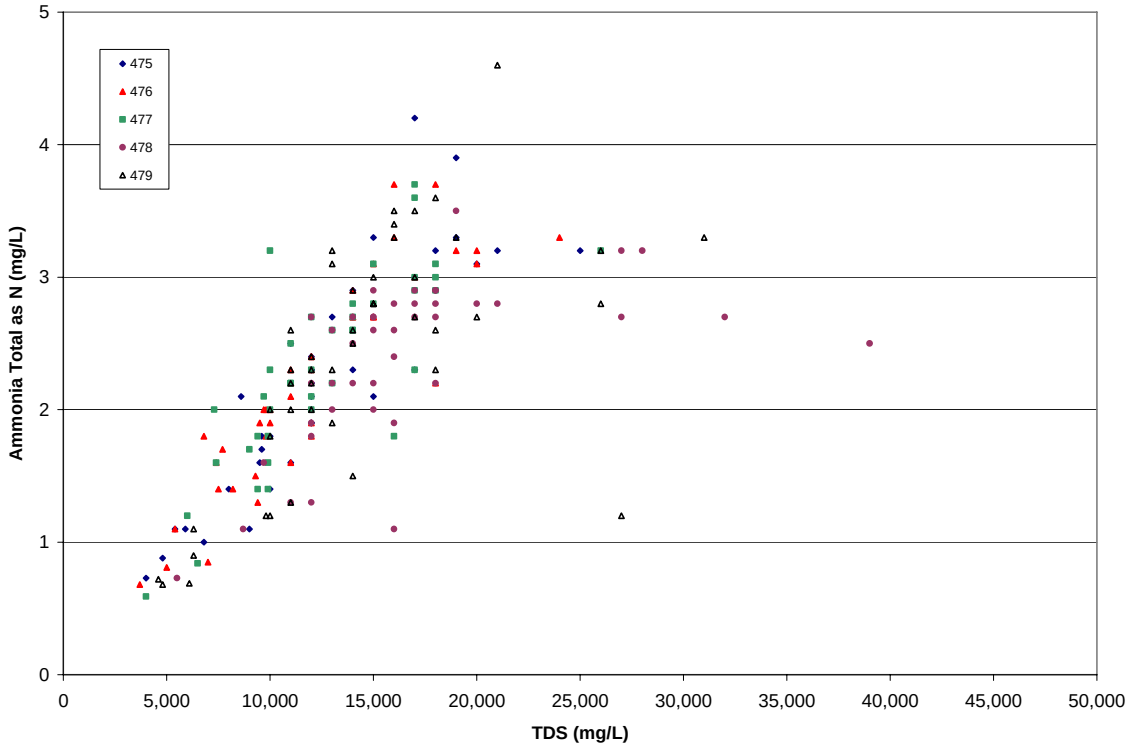


Figure B-5. CF1 Extraction Wells 0470 through 0474 (top) and 0475 through 0479 (bottom) Uranium Concentrations Versus TDS Concentrations, 2004 through 2008

Appendix C
Well PW02 Ammonia and Uranium Concentration Plots

Appendix C
Well PW02 Ammonia and Uranium Concentration Plots

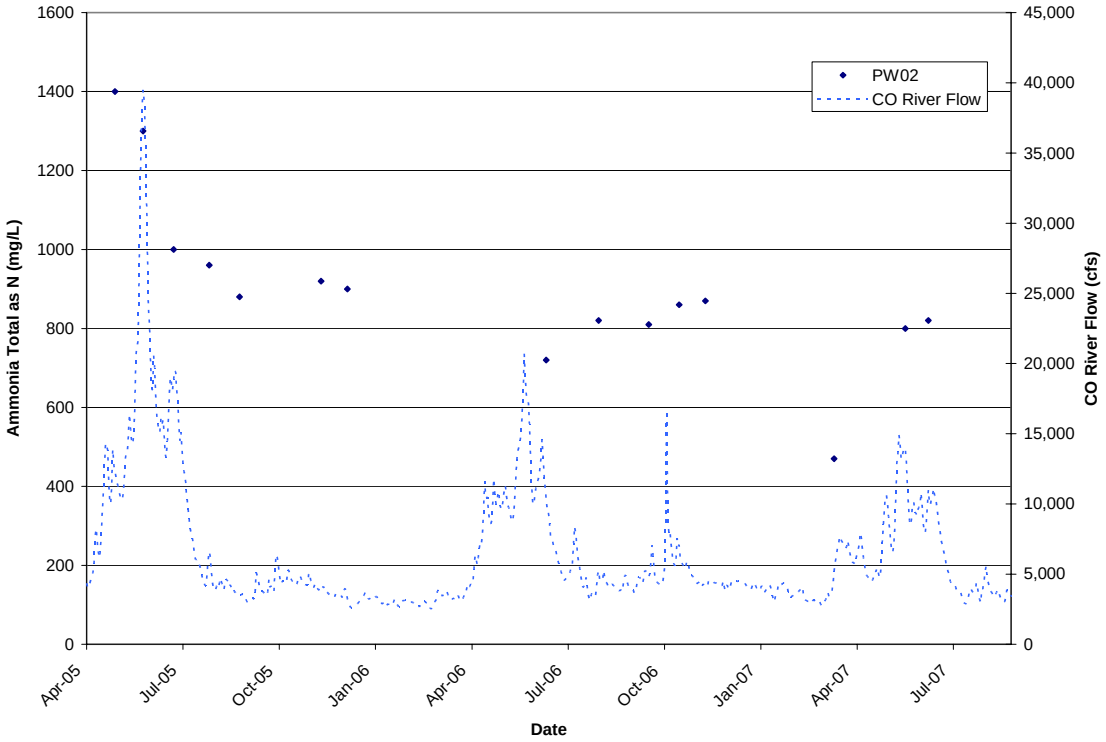


Figure C-1. Well PW02 Ammonia Concentrations, 2005 through 2007

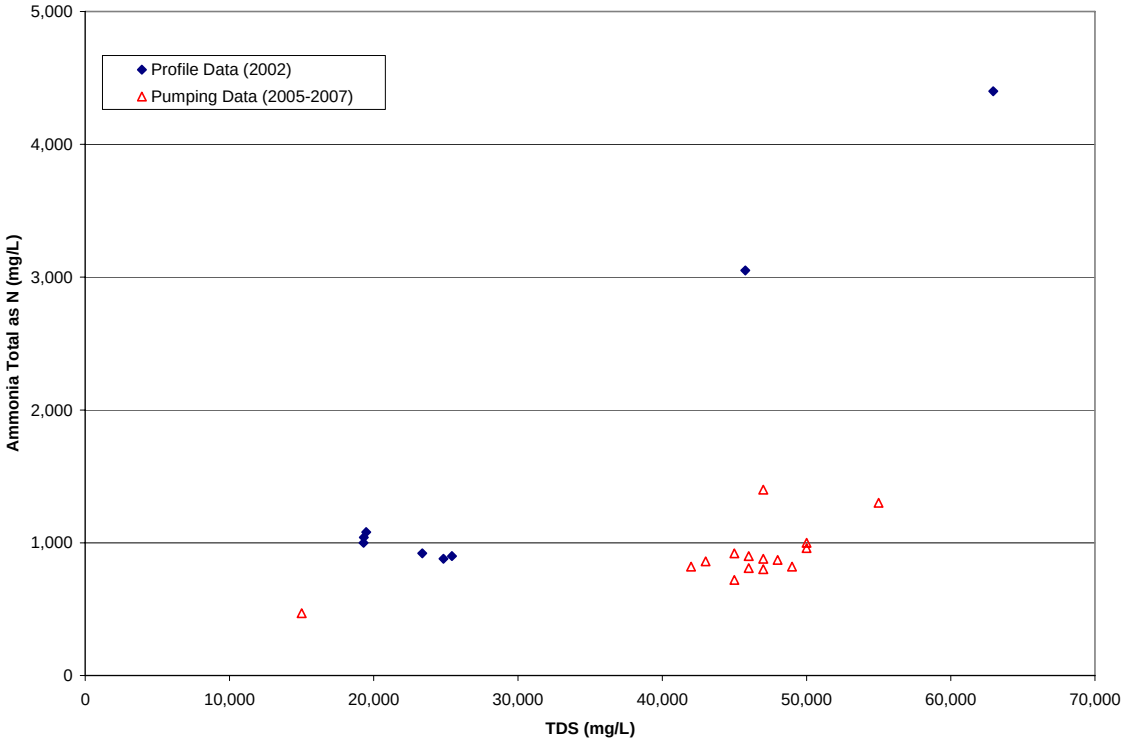


Figure C-2. Well PW02 Ammonia Concentrations Versus TDS Concentrations

Appendix C
Well PW02 Ammonia and Uranium Concentration Plots (continued)

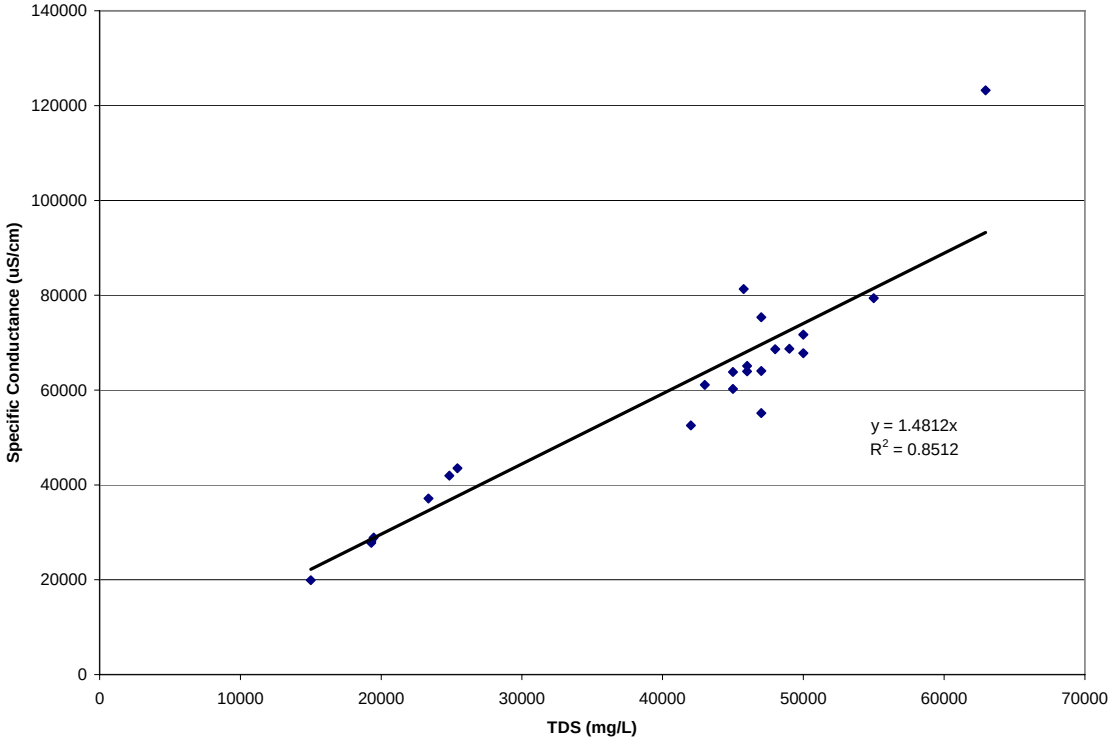


Figure C-3. PW02 TDS Concentration Versus Specific Conductance

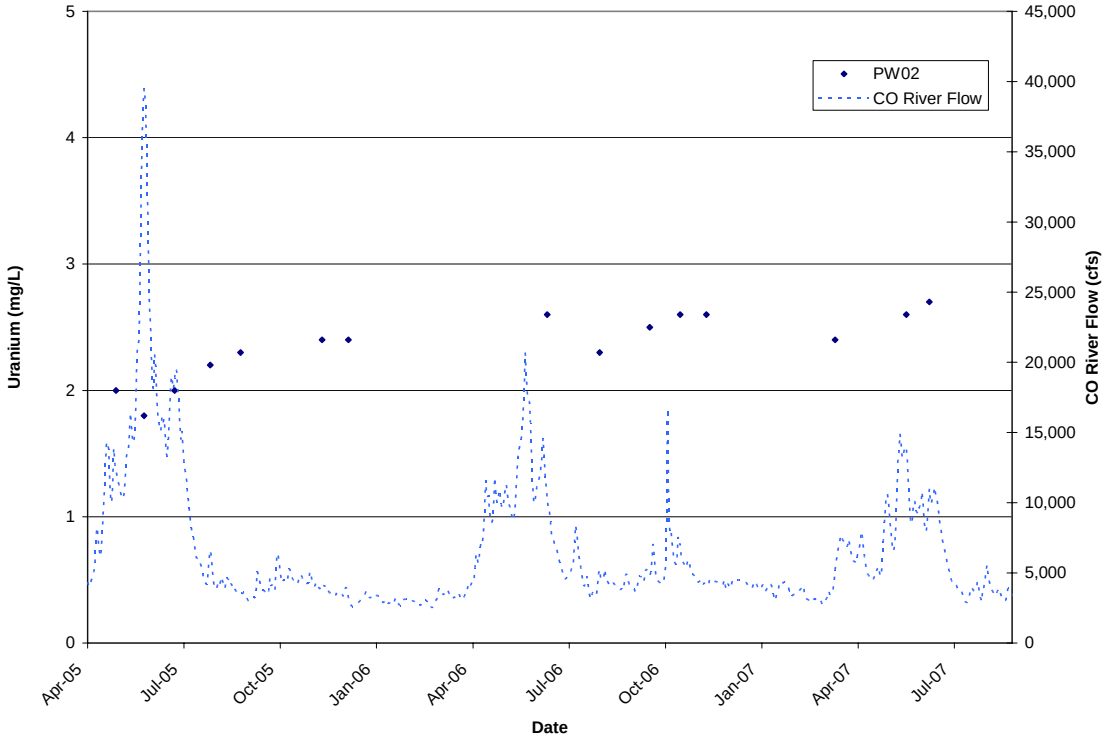


Figure C-4. Well PW02 Uranium Concentrations, 2005 through 2007

Appendix C
Well PW02 Ammonia and Uranium Concentration Plots (continued)

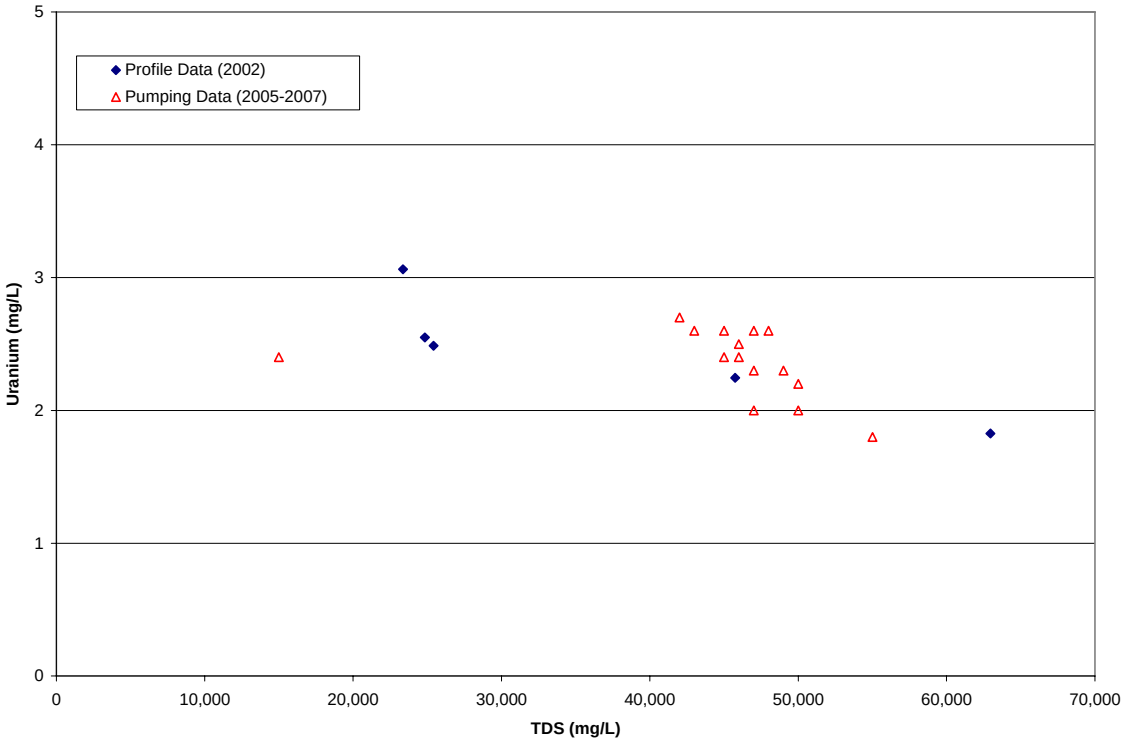
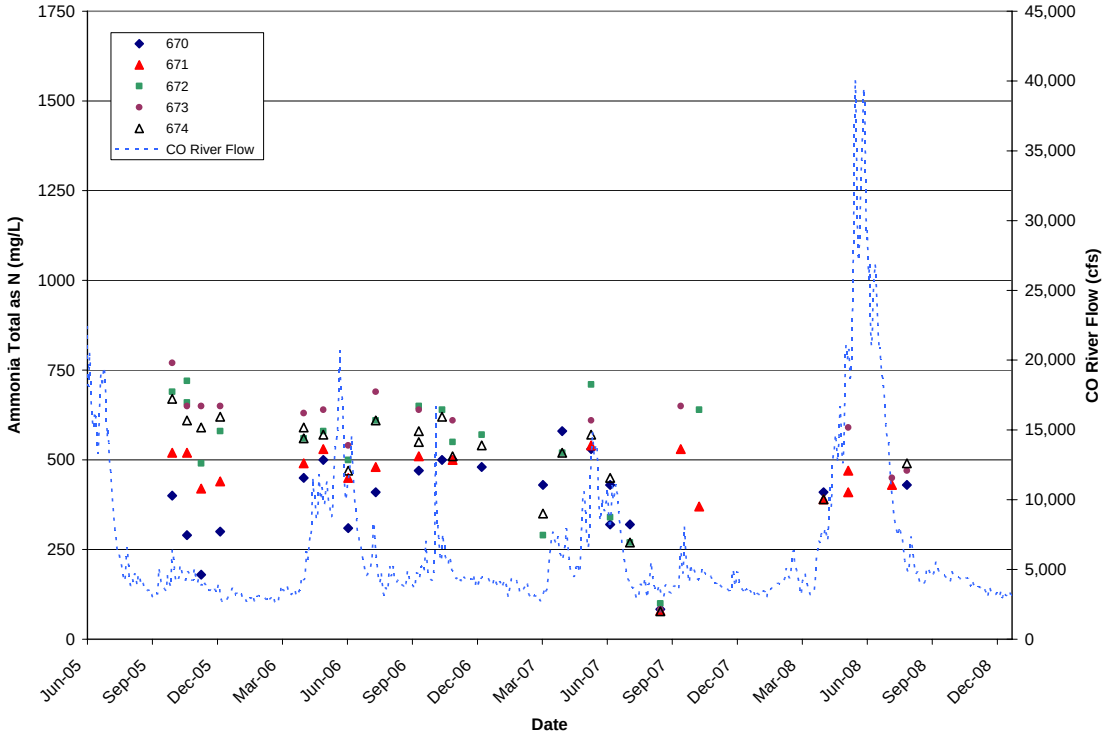


Figure C-5. Well PW02 Uranium Concentrations Versus TDS Concentrations

Appendix D
CF3 Ammonia and Uranium Concentration Plots

Appendix D
CF3 Ammonia and Uranium Concentration Plots



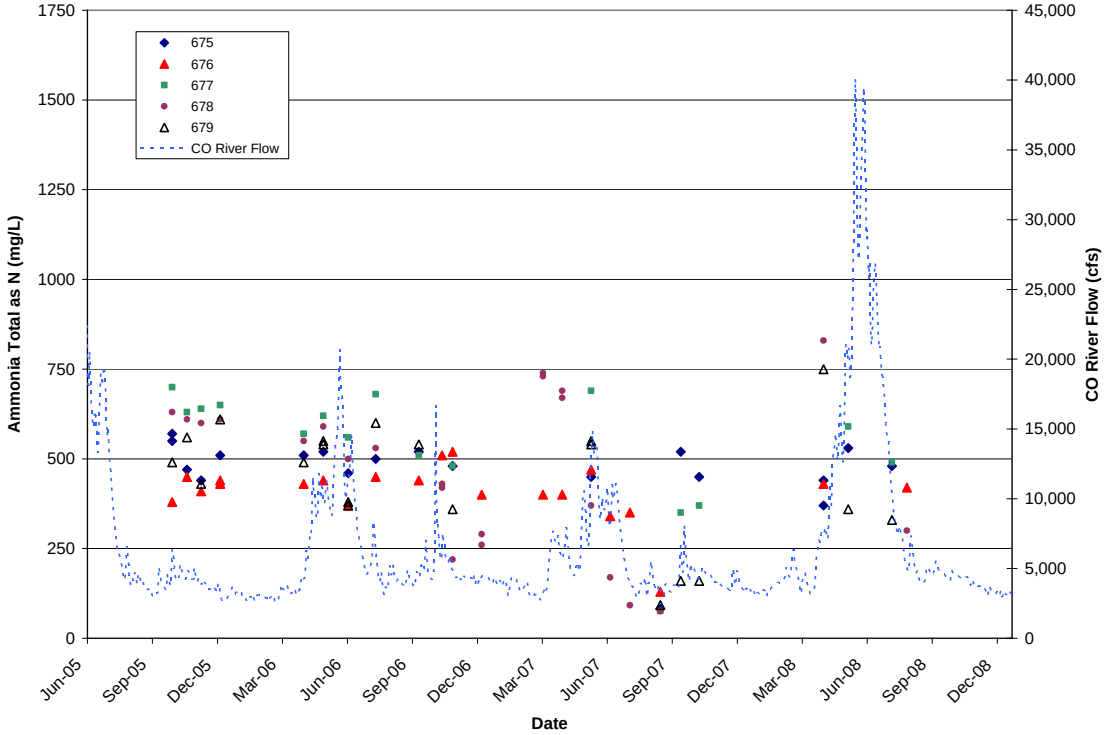
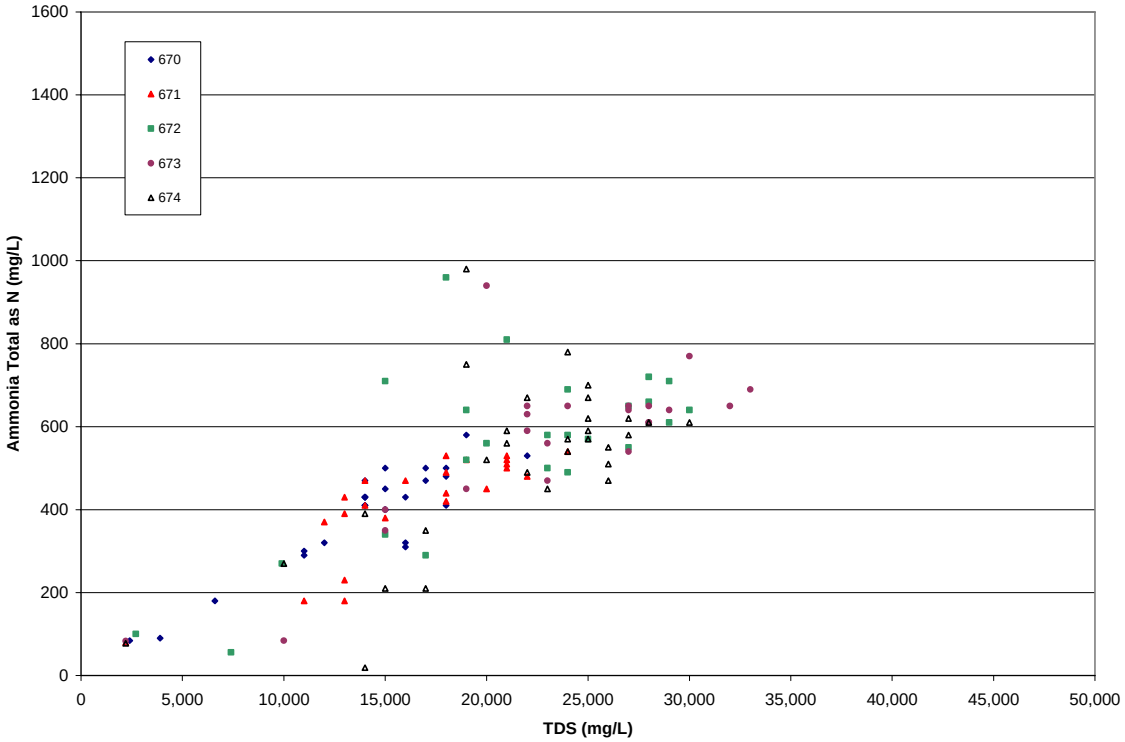


Figure D-1. CF3 Extraction Wells 0670 through 0674 (top) and 0675 through 0679 (bottom) Ammonia Concentrations, 2005 through 2008

Appendix D
CF3 Ammonia and Uranium Concentration Plots (continued)



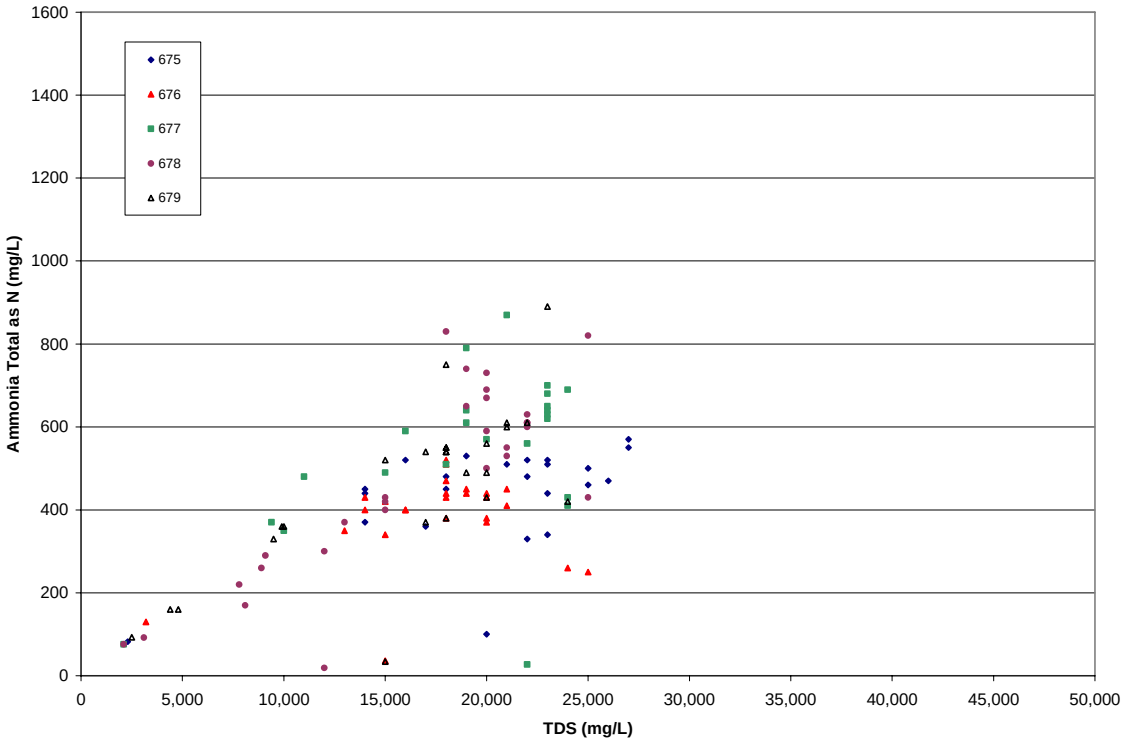


Figure D-2. CF3 Extraction Wells 0670 through 0674 (top) and 0675 through 0679 (bottom) Ammonia Concentrations Versus TDS Concentrations, 2005 through 2008

Appendix D
CF3 Ammonia and Uranium Concentration Plots (continued)

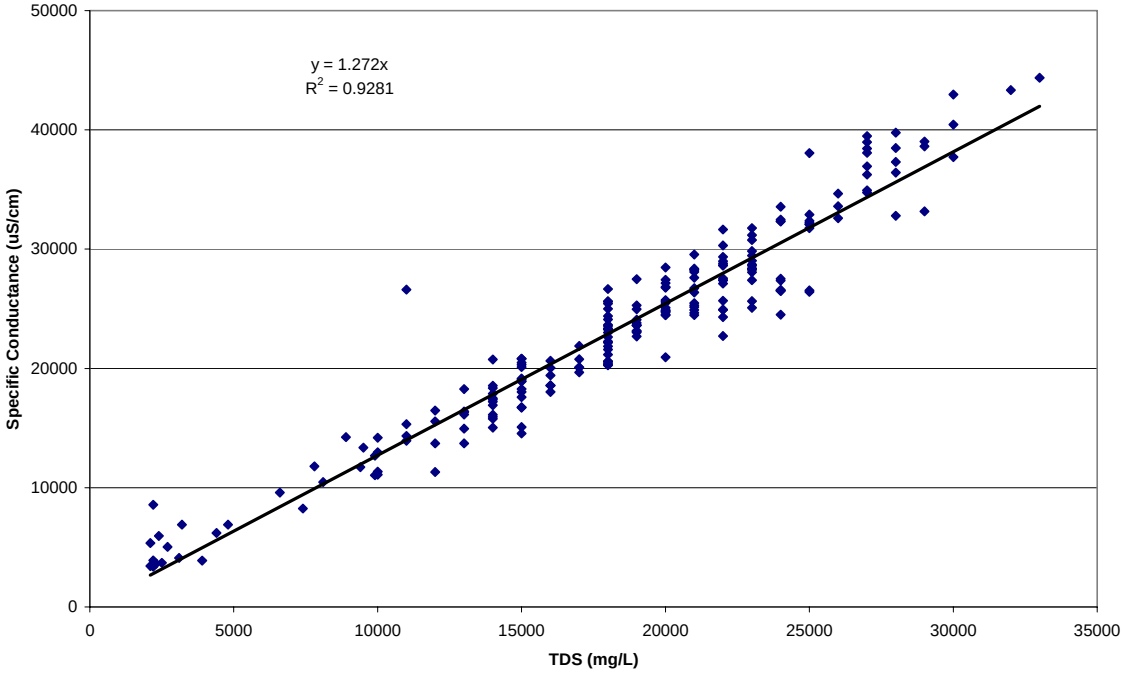
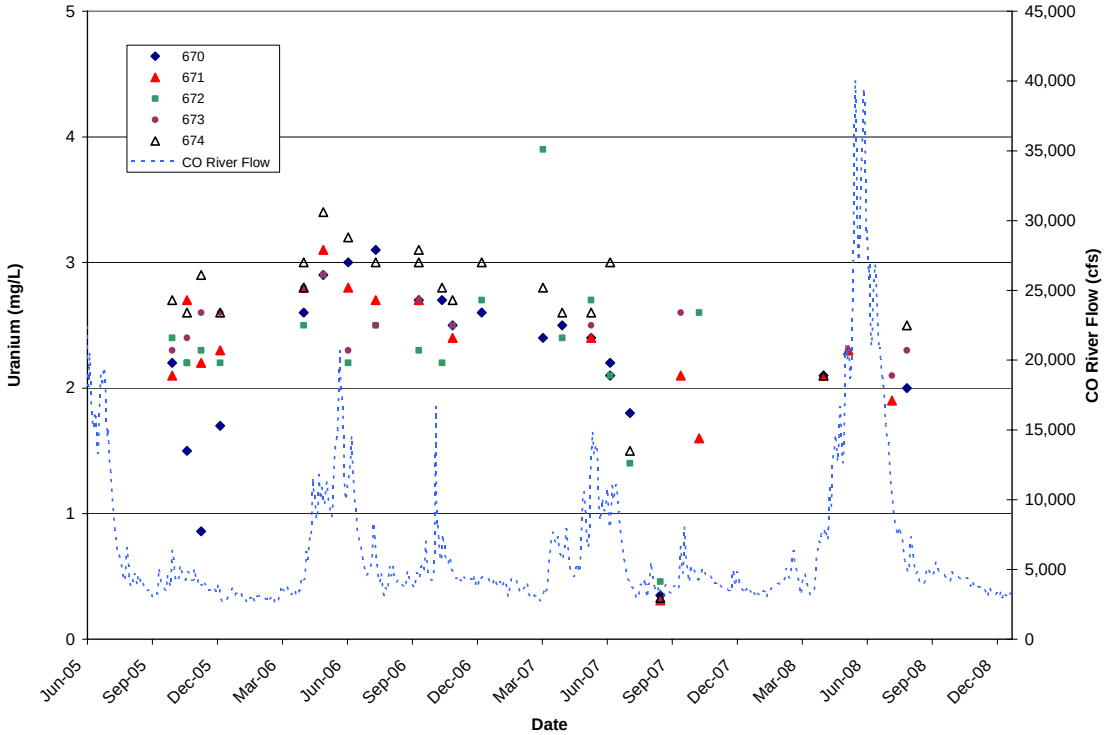


Figure D-3. CF3 TDS Concentration Versus Specific Conductance

Appendix D
CF3 Ammonia and Uranium Concentration Plots (continued)



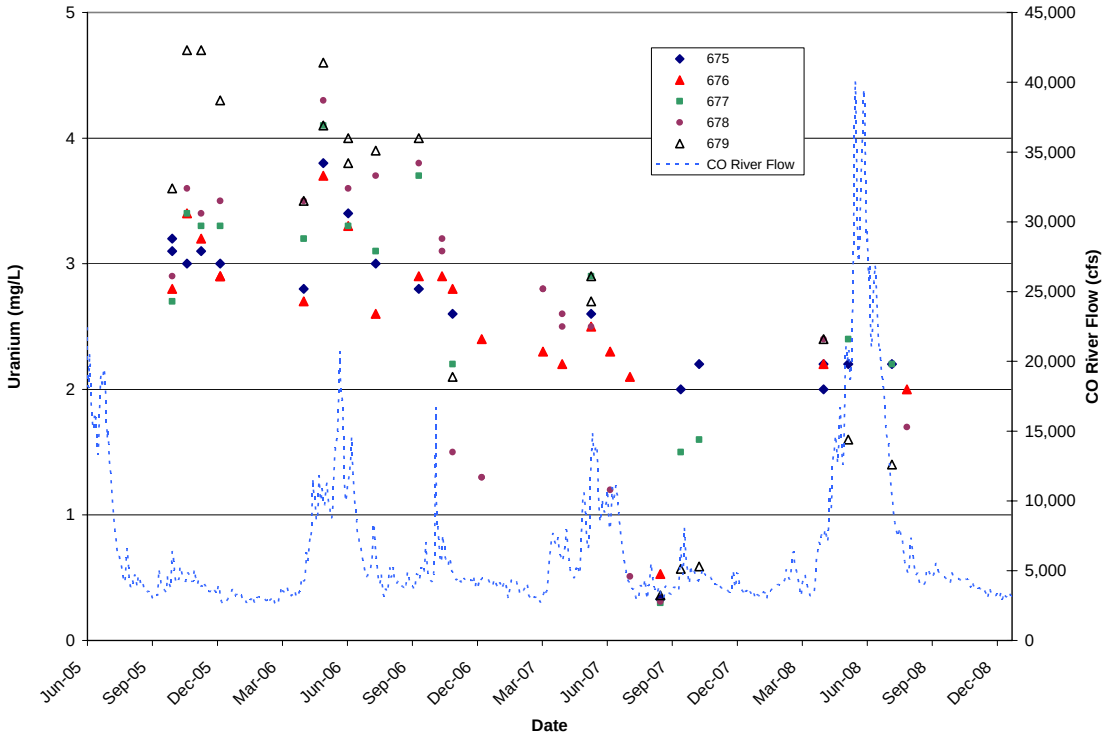
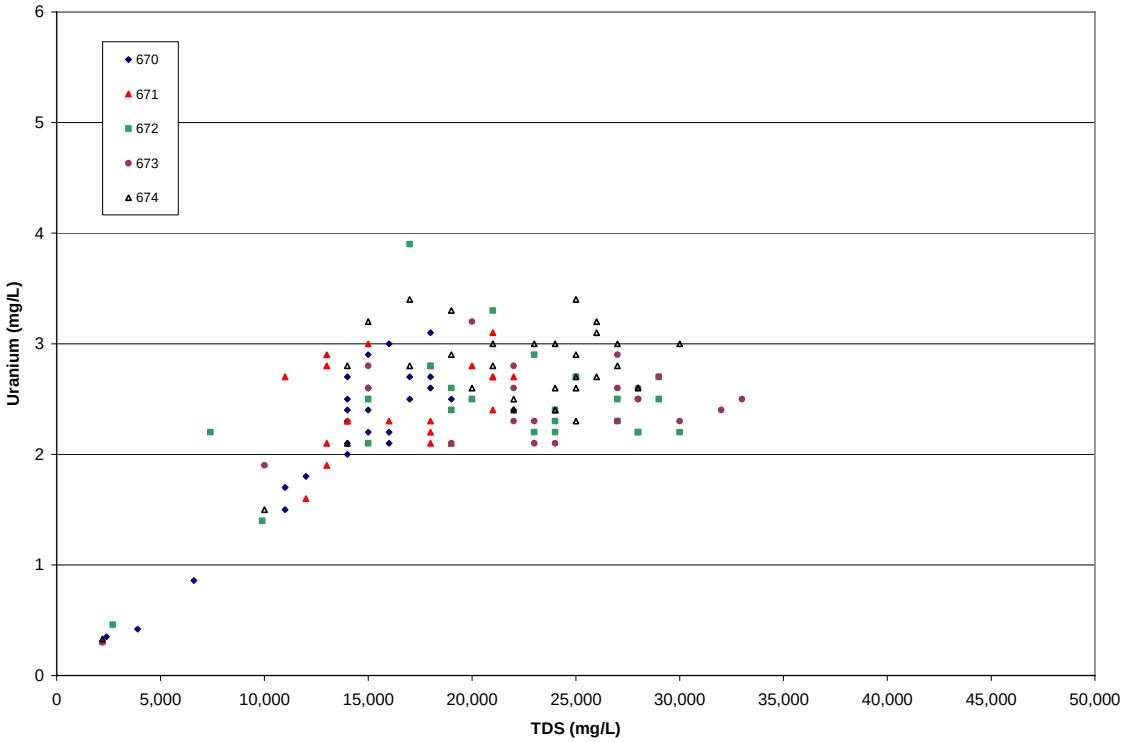


Figure D-4. CF3 Extraction Wells 0670 through 0674 (top) and 0675 through 0679 (bottom) Uranium Concentrations, 2005 through 2008

Appendix D
CF3 Ammonia and Uranium Concentration Plots (continued)



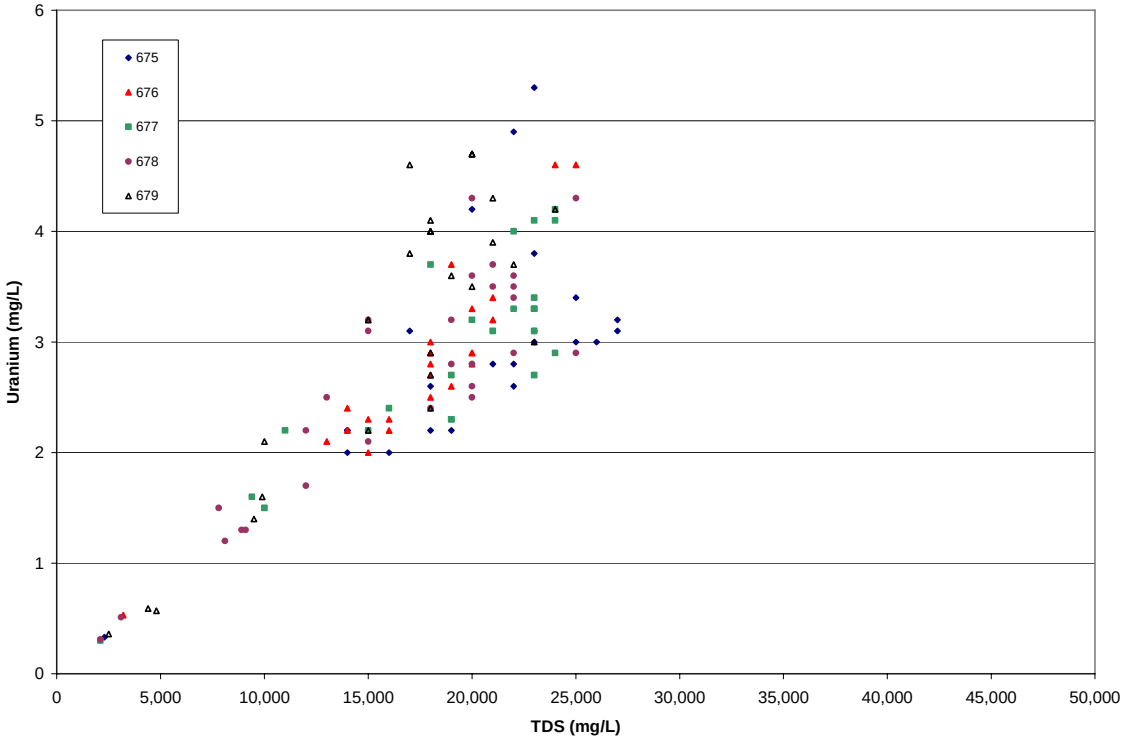
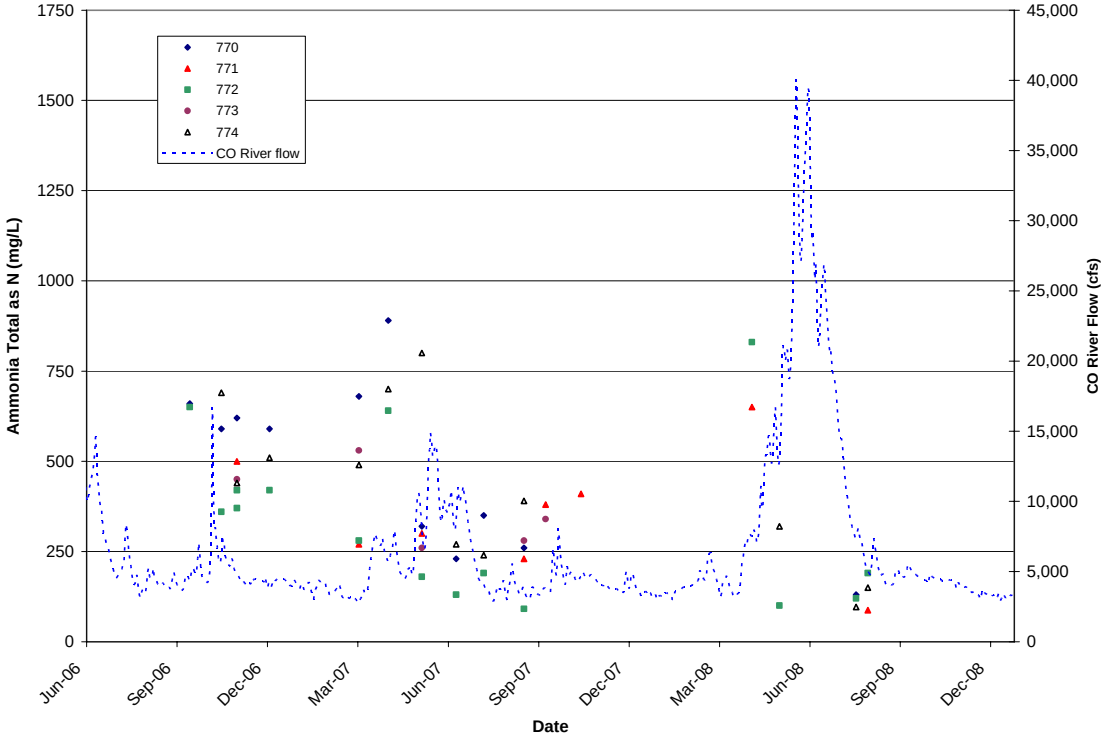


Figure D-5. CF3 Extraction Wells 0670 through 0674 (top) and 0675 through 0679 (bottom) Uranium Concentrations Versus TDS Concentrations, 2005 through 2008

Appendix E
CF4 Ammonia and Uranium Concentration Plots

Appendix E
CF4 Ammonia and Uranium Concentration Plots



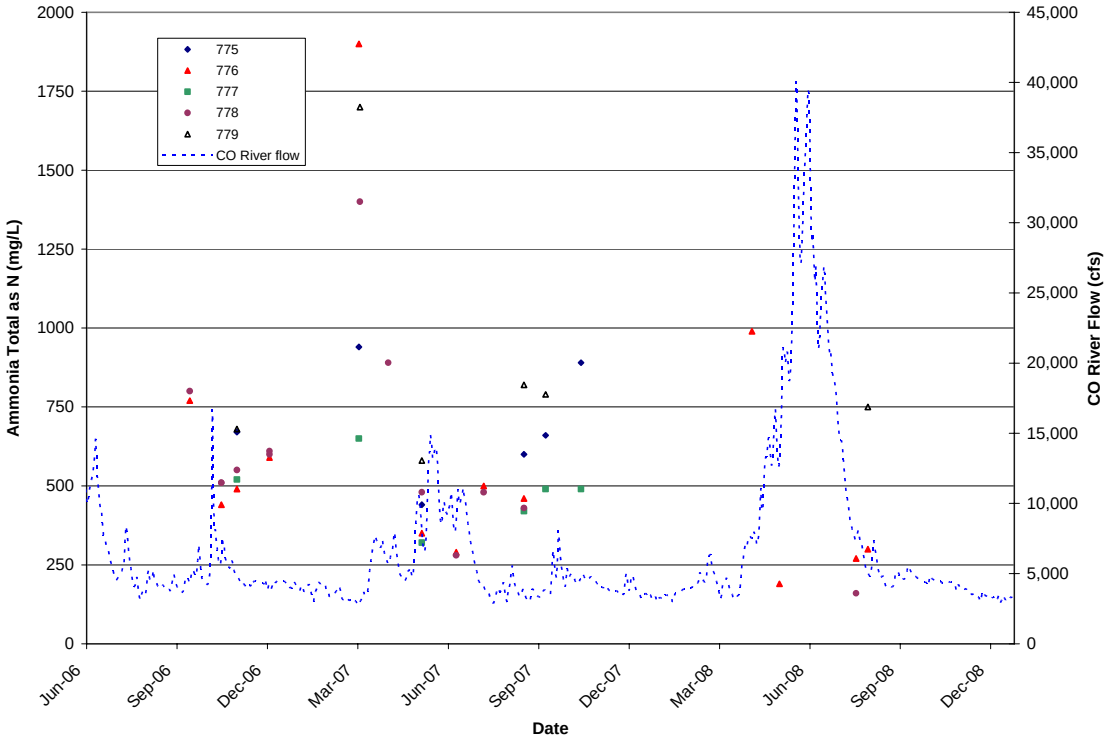
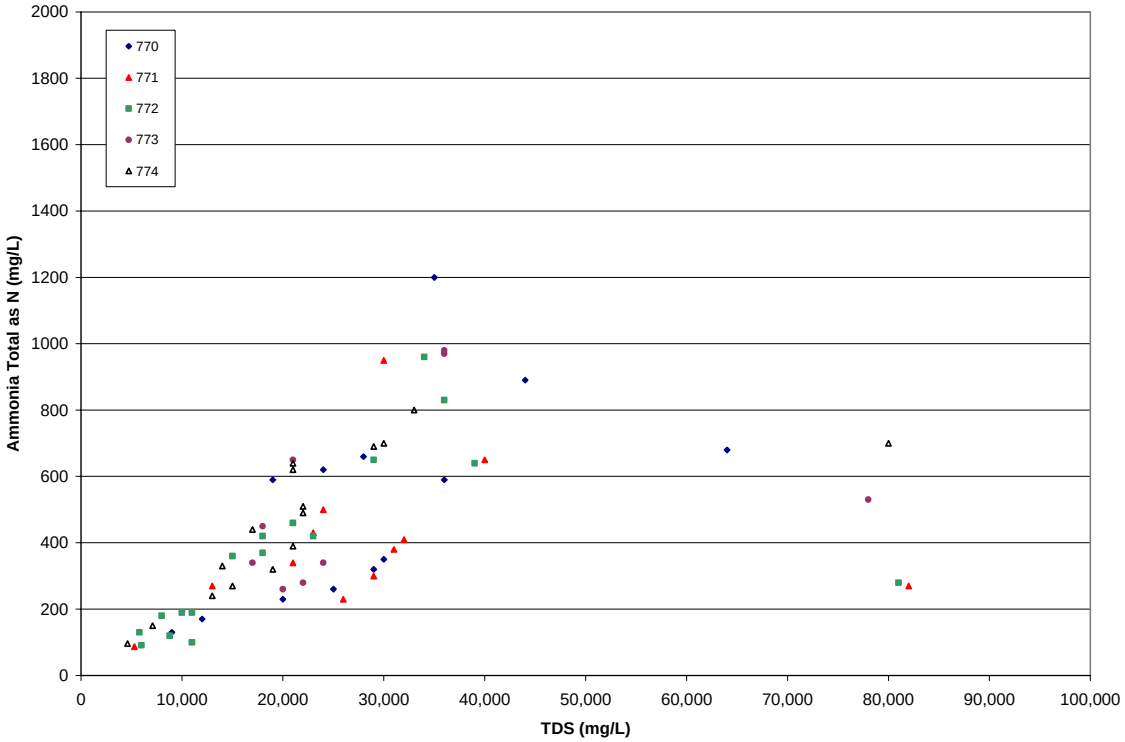


Figure E-1. CF4 Extraction Wells 0770 through 0774 (top) and 0775 through 0779 (bottom) Ammonia Concentrations, 2006 through 2008

Appendix E
CF4 Ammonia and Uranium Concentration Plots (continued)



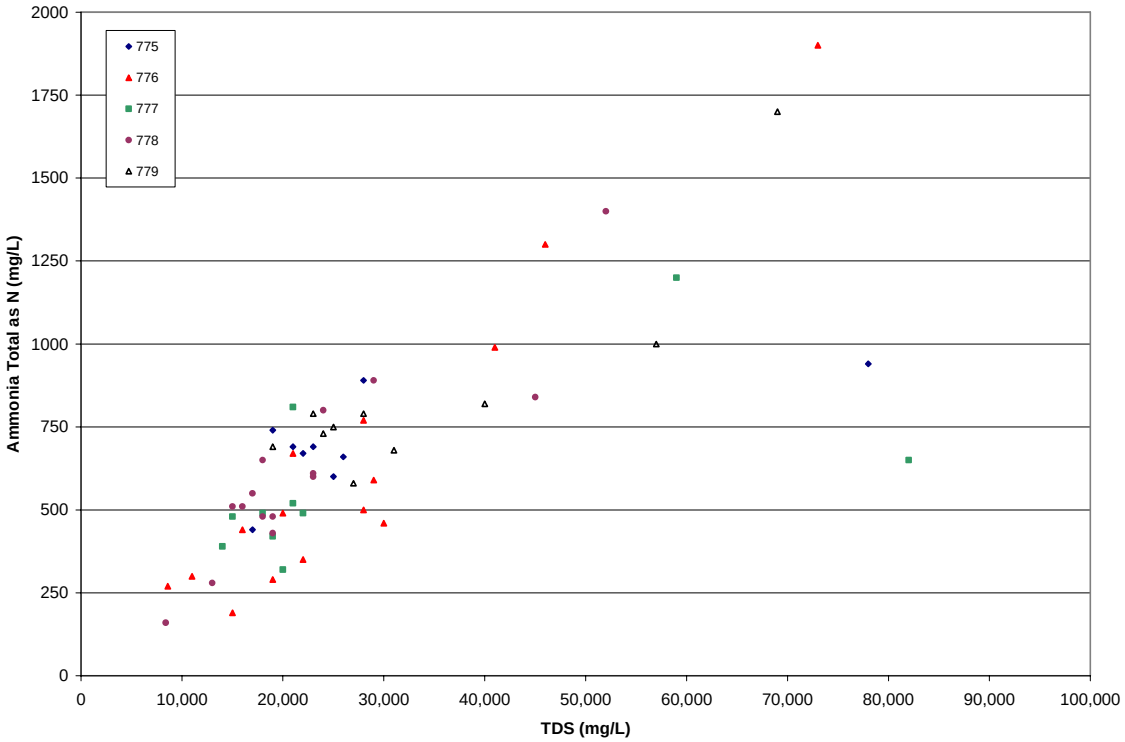


Figure E-2. CF4 Extraction Wells 0770 through 0774 (top) and 0775 through 0779 (bottom) Ammonia Concentrations Versus TDS Concentrations, 2006 through 2008

Appendix E
CF4 Ammonia and Uranium Concentration Plots (continued)

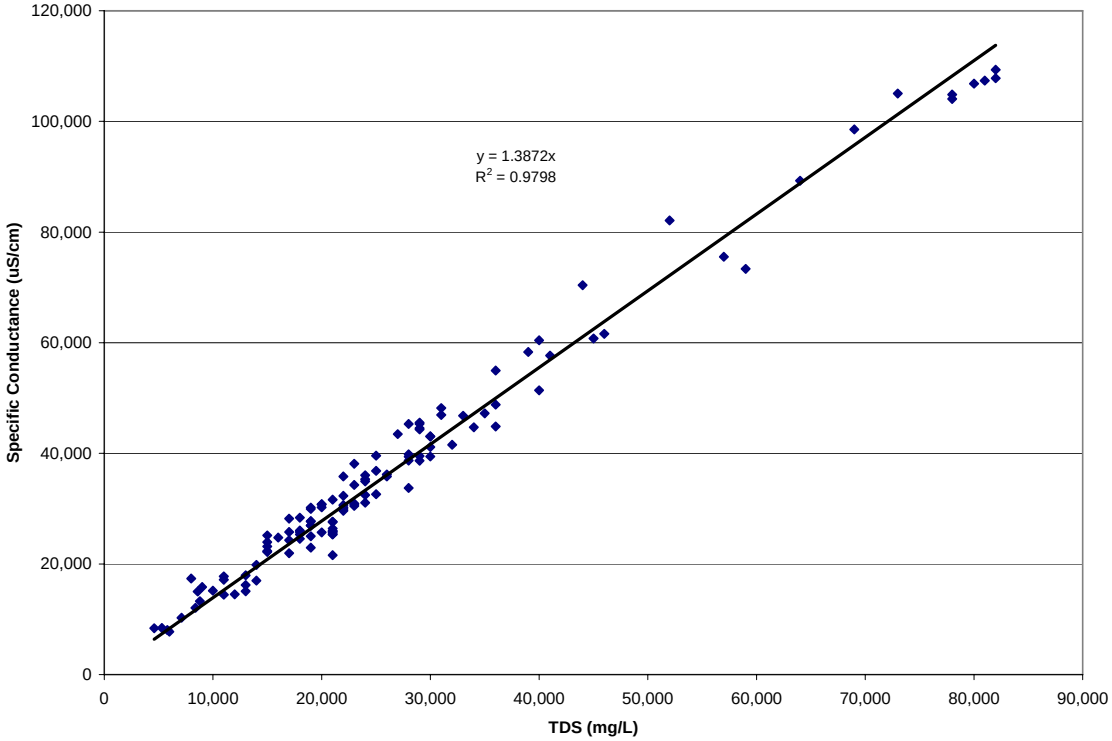


Figure E-3. CF4 TDS Concentration Versus Specific Conductance

Appendix E
CF4 Ammonia and Uranium Concentration Plots (continued)

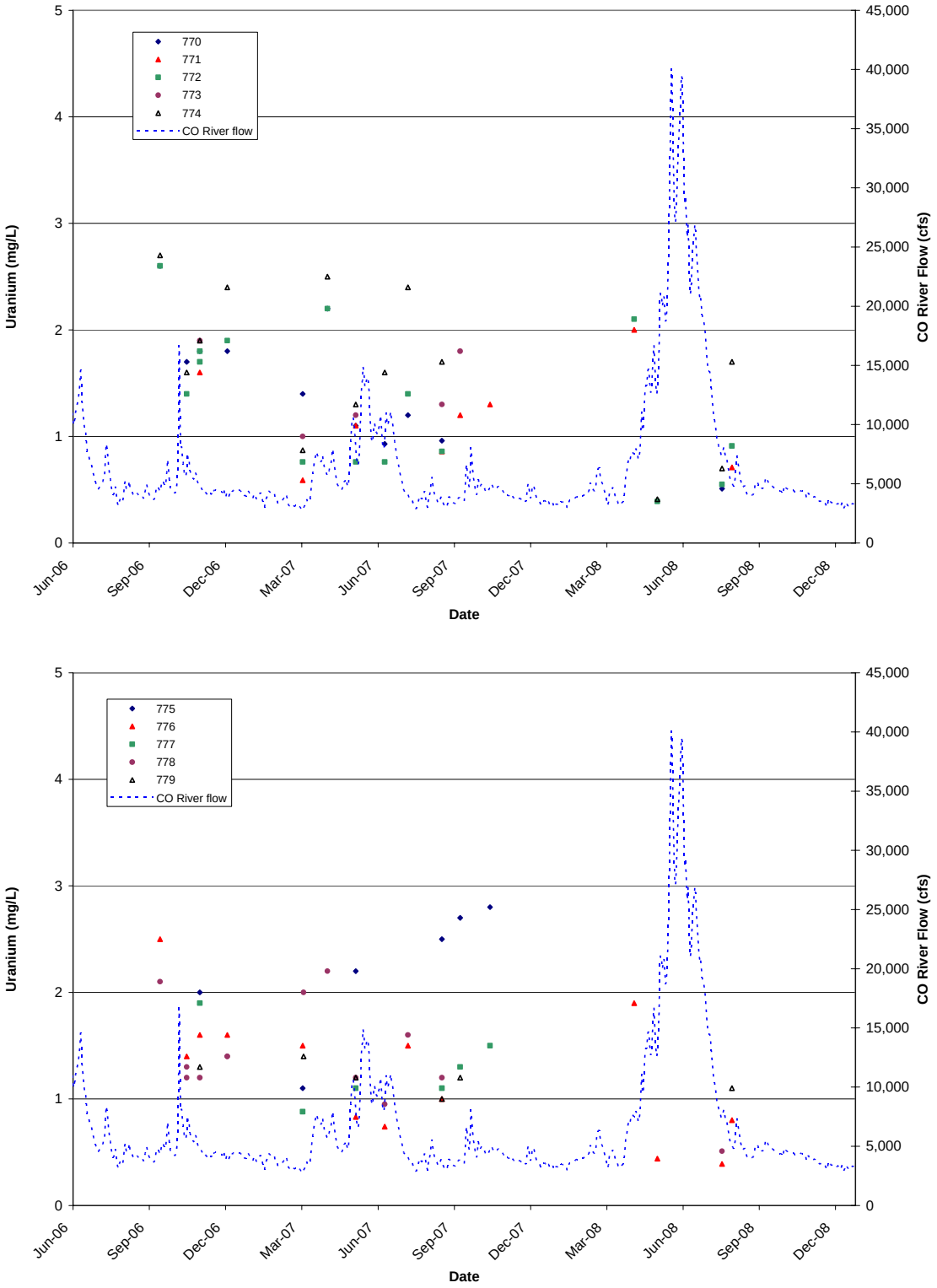


Figure E-4. CF4 Extraction Wells 0770 through 0774 (top) and 0775 through 0779 (bottom) Uranium Concentrations, 2006 through 2008

Appendix E
CF4 Ammonia and Uranium Concentration Plots (continued)

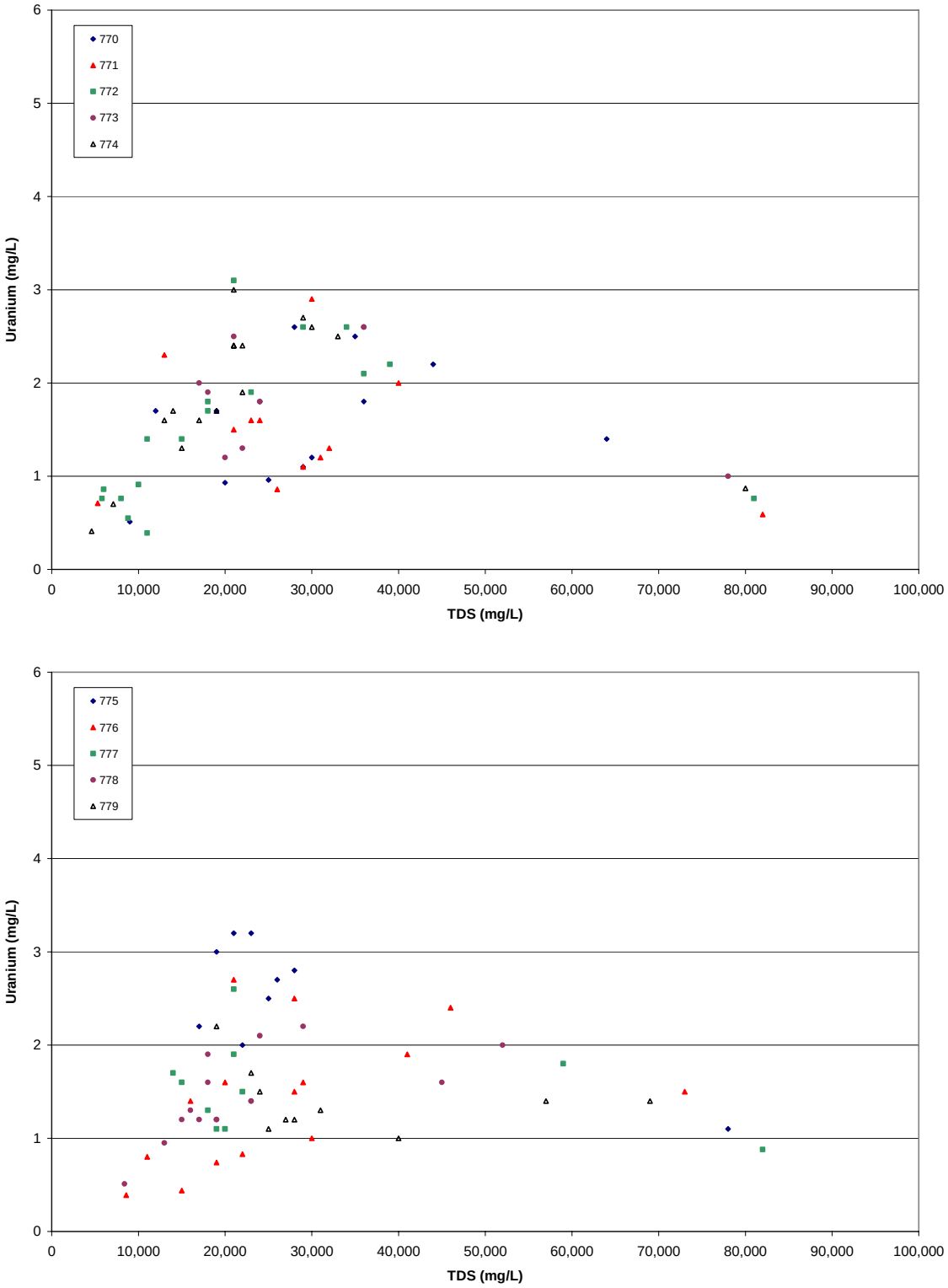


Figure E-5. CF4 Extraction Wells 0770 through 0774 (top) and 0775 through 0779 (bottom) Uranium Concentrations Versus TDS Concentrations, 2006 through 2008