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Annual Performance Report April 2015 Through March 2016 for the Shiprock, New Mexico, Disposal Site

October 2016

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Annual Performance Report
April 2015 Through March 2016
for the Shiprock, New Mexico, Disposal Site

The U.S. Department of Energy (DOE) has prepared the *Annual Performance Report, April 2015 Through March 2016 for the Shiprock, New Mexico, Disposal Site*. **At your request, you are receiving a hard copy of the report.**

The report is also available for your review on the Internet on the DOE Office of Legacy Management (LM) website — http://energy.gov/lm. From the LM website home page, select the LM SITES MAP. Then select Shiprock Site from the LM SITES list in the right column. The report will be available on the Shiprock Disposal Site page under Site Documents and Links.

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*Duplicated from Plate 4 of the 2000 *Final Site Observational Work Plan* (DOE 2000)

Abbreviations

CFR	*Code of Federal Regulations*
COC	contaminant of concern
DOE	U.S. Department of Energy
DVP	Data Validation Package (report)
EPA	U.S. Environmental Protection Agency
ft	feet
GCAP	Groundwater Compliance Action Plan
gpm	gallons per minute
lb	pounds
LOESS	a nonparametric, locally weighted statistical regression method
MCL	maximum concentration limit
mg/L	milligram(s) per liter
N	nitrogen
SOARS	System Operation and Analysis at Remote Sites
SOWP	Site Observational Work Plan
UMTRA	Uranium Mill Tailings Remedial Action (Project)
UMTRCA	Uranium Mill Tailings Radiation Control Act

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Executive Summary

This annual report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal Site (Shiprock site) for the period April 2015 through March 2016. The Shiprock site, a former uranium-ore processing facility remediated under the Uranium Mill Tailings Radiation Control Act, is managed by the U.S. Department of Energy (DOE) Office of Legacy Management. This annual report is based on an analysis of groundwater quality and groundwater level data obtained from site monitoring wells and the groundwater flow rates associated with the extraction wells, drains, and seeps.

Background

The Shiprock mill operated from 1954 to 1968 on property leased from the Navajo Nation. Remediation of surface contamination, including stabilization of mill tailings in an engineered disposal cell, was completed in 1986. During mill operation, nitrate, sulfate, uranium, and other milling-related constituents leached into underlying sediments and contaminated groundwater in the area of the mill site. In March 2003, DOE initiated active remediation of groundwater at the site using extraction wells and interceptor drains. At that time, DOE developed a baseline performance report that established specific performance standards for the Shiprock site groundwater remediation system.

The Shiprock site is divided into two distinct areas: the floodplain and the terrace. The floodplain remediation system consists of two groundwater extraction wells, a seep collection drain, and two collection trenches (Trench 1 and Trench 2). The terrace remediation system consists of nine groundwater extraction wells, two collection drains (Bob Lee Wash and Many Devils Wash), and a terrace drainage channel diversion structure. All extracted groundwater is pumped into a lined evaporation pond on the terrace.

Compliance Strategy and Remediation Goals

As documented in the Groundwater Compliance Action Plan, the U.S. Nuclear Regulatory Commission–approved compliance strategy for the floodplain is natural flushing supplemented by active remediation. The contaminants of concern (COCs) at the site are ammonia (total as nitrogen), manganese, nitrate (nitrate + nitrite as nitrogen), selenium, strontium, sulfate, and uranium. The compliance standards for nitrate, selenium, and uranium are listed in Title 40 *Code of Federal Regulations* Part 192. Regulatory standards are not available for ammonia, manganese, and sulfate; remediation goals for these constituents are either risk-based alternate cleanup standards or background levels. These standards and background levels apply only to the compliance strategy for the floodplain. The compliance strategy for the terrace is to eliminate exposure pathways at the washes and seeps and to apply supplemental standards in the western section.

Semiannual Sampling Results

For this reporting period, 112 monitoring wells (56 on the floodplain and 56 on the terrace) and 17 surface water locations (8 from the San Juan River) were sampled. Contaminant distributions of nitrate, sulfate, and uranium (the primary COCs at the site) are generally the same as those observed in previous years. Contaminant concentrations have decreased in several floodplain

wells in response to pumping—most notably in the Trench 1 area. COC concentrations in the easternmost Trench 2 area wells (closest to the San Juan River) are still lower than those nearer the escarpment, demonstrating the effectiveness of the Trench 2 system. Decreases in COC concentrations in the well 1089 area since remediation pumping began in 2003 are also evident.

Although concentrations of uranium, sulfate, and nitrate have decreased in most floodplain wells, especially in areas near the pumping regions, exceptions are found at several locations, most notably near-river wells 0857 and 1136 in the central floodplain, and well 0630 at the base of Bob Lee Wash. No measurable impacts to the San Juan River have resulted from these increases. Relative to observations in previous years, when marked increases in uranium and sulfate levels in near-river wells 1137, 1138, and 1139 were noted, contaminant concentrations in these wells, although still elevated, have stabilized or declined. In general, COC concentrations in samples collected from the San Juan River have been below established benchmarks and/or comparable to upstream (background) locations.

Summary of Remediation Performance and Site Evaluation Progress

Groundwater in the floodplain system is currently being extracted from two wells (wells 1089 and 1104) adjacent to the San Juan River north of the disposal cell, two collection trenches, and a seep collection sump. Approximately 11.8 million gallons of groundwater were extracted from the floodplain aquifer system during this performance period. Slightly over 133 million gallons have been extracted from the floodplain since DOE began active remediation in March 2003.

Groundwater in the terrace system is currently being extracted from a drainage trench (Bob Lee Wash) and nine extraction wells. During this reporting period, no groundwater was pumped from a second drainage trench in Many Devil Wash, due to the need for extensive repairs of the interceptor drain. From April 2015 through March 2016, approximately 4.1 million gallons of groundwater were extracted from the terrace system; the total cumulative volume extracted is approximately 44.8 million gallons. The cumulative volume removed from both the terrace and the floodplain combined (as of April 1, 2016) is about 178 million gallons. Estimated masses of sulfate, nitrate, and uranium removed from the floodplain and terrace well fields during this performance period were (rounded) 743,130 pounds; 28,230 pounds; and 51.8 pounds, respectively.

1.0 Introduction

This report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal Site for the period April 2015 through March 2016. The Shiprock site, a former uranium-ore processing facility remediated under the Uranium Mill Tailings Radiation Control Act (UMTRCA), is managed by the U.S. Department of Energy (DOE) Office of Legacy Management.

The Shiprock mill operated from 1954 to 1968; mill tailings were stabilized in an engineered disposal cell in 1986. As a result of milling operations, groundwater in the mill site area was contaminated with uranium, nitrate, sulfate, and associated constituents. In March 2003, DOE initiated active remediation of the groundwater using extraction wells and interceptor drains. At that time, DOE developed a baseline performance report (DOE 2003) that established specific performance standards for the Shiprock groundwater remediation system and documented the site conditions that form the basis for comparisons drawn herein.

The Shiprock site is divided into two distinct areas: the floodplain and the terrace. An escarpment forms the boundary between these two areas. The floodplain remediation system consists of two groundwater extraction wells, a seep collection drain, and two collection trenches (Trench 1 and Trench 2). The terrace remediation system consists of nine groundwater extraction wells, two collection drains (Bob Lee Wash and Many Devils Wash), and a terrace drainage channel diversion structure. All extracted groundwater is pumped into a lined evaporation pond on the terrace. Figure 1 shows the site layout and the major components of the floodplain and terrace groundwater remediation systems. Figure 2 shows all monitoring locations at the site, including groundwater monitoring wells, surface water sampling locations, and treatment system sample locations.

The Site Observational Work Plan (SOWP; DOE 2000) presents a detailed description of Shiprock site conditions, and the Groundwater Compliance Action Plan (GCAP; DOE 2002) documents the compliance strategy. Since these initial reports were developed, DOE has undertaken additional evaluations, including the *Refinement of Conceptual Model and Recommendations for Improving Remediation Efficiency at the Shiprock, New Mexico, Site* (DOE 2005), evaluations of the Trench 1 and Trench 2 groundwater remediation systems (DOE 2009, DOE 2011d), a midterm evaluation of the site remediation strategy (DOE 2011a), and the *Optimization of Sampling at the Shiprock, New Mexico, Site* (DOE 2013b).

1.1 Remediation System Performance Standards

This performance assessment is based on an analysis of groundwater quality and water-level data obtained from site monitoring wells and groundwater flow rates measured at the extraction wells, drains, and seeps. Specific performance standards or metrics established for the Shiprock floodplain groundwater remediation system in the Baseline Performance Report (DOE 2003) are:

- Groundwater flow directions in the vicinity of the extraction wells should be toward the extraction wells to maximize the zones of capture.
- Groundwater contaminant concentrations should be monitored and compared to the baseline concentrations to provide an indication as to whether the floodplain extraction system is effective and contaminant levels are decreasing.

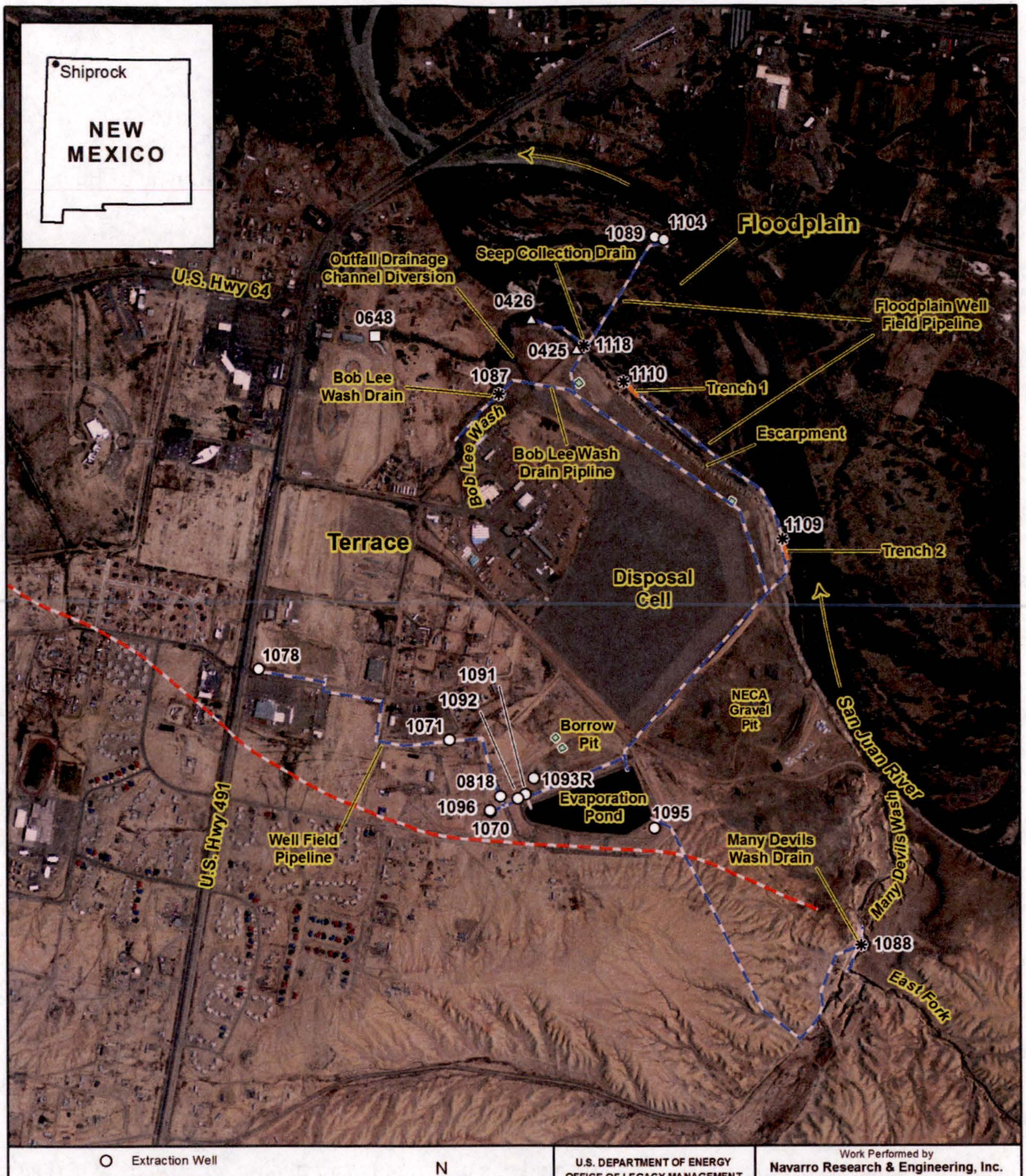

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Figure 1. Location Map and Groundwater Remediation System

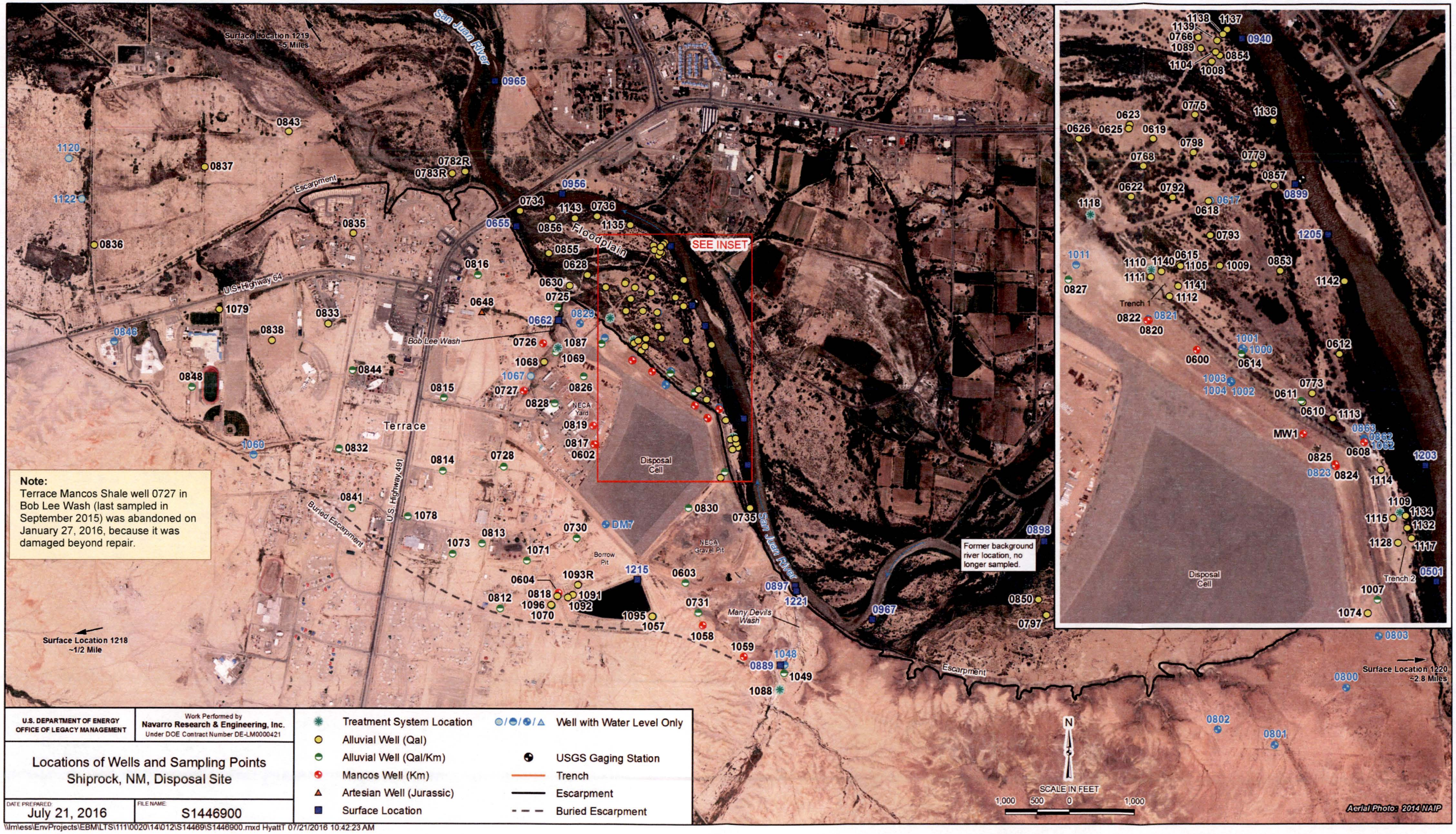

Figure 2. Locations of Wells and Sampling Points at the Shiprock Site

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Specific performance standards established for the terrace groundwater remediation system in the Baseline Performance Report (DOE 2003) are:

- Terrace groundwater elevations should decrease as water is removed from the terrace system.
- The volume of water discharging to the interceptor drains located in Bob Lee Wash and Many Devils Wash should decrease over time as groundwater levels on the terrace decline.
- The flow rates of seeps located at the base of the escarpment face (locations 0425 and 0426, represented by measurements from seep collection drain 1118) should decrease over time as groundwater levels on the terrace decline.

The performance standards summarized above are based on the active remediation aspects of the compliance strategies documented in the GCAP (DOE 2002).

1.2 Contaminants of Concern and Remediation Goals

The contaminants of concern (COCs) for both the floodplain and the terrace, defined in the GCAP, are ammonia (total as nitrogen), manganese, nitrate (nitrate + nitrite as nitrogen), selenium, strontium, sulfate, and uranium. These constituents are listed in Table 1 along with corresponding floodplain background data and maximum concentration limits (MCLs) established in Title 40 *Code of Federal Regulations* Part 192 (40 CFR 192), which apply to UMTRCA sites.

Table 1. Groundwater COCs for the Shiprock Site

Contaminant	40 CFR 192 MCL (mg/L)	Cleanup Goal (mg/L)	Historical Range in Floodplain Background Wells[a] (mg/L)	Comments
Ammonia as N	–	–	<0.074–0.20	Most (94% of) ammonia results for floodplain background wells have been nondetects (<0.1 mg/L).
Manganese	–	2.74	0.016–7.2	2.74 mg/L cleanup goal was the maximum background concentration at the time the GCAP was developed (DOE 2002, Table 3-2).
Nitrate as N	10	–	0.004–5.7	
Selenium	0.01	0.05	0.0001–0.02	The 0.05 mg/L cleanup goal is the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act maximum contaminant level.
Strontium	–	–	0.18–10	EPA's Regional Screening Level (RSL) for tap water is 12 mg/L (EPA 2016).
Sulfate	–	2000	210–5200	Because of elevated sulfate levels in artesian well 0648 (1810–2340 mg/L), a cleanup goal of 2000 mg/L was proposed (DOE 2002).
Uranium	0.044	–	0.004–0.12	Uranium levels measured in background well 0850 have varied widely and have exceeded the MCL at times—e.g., in five of the last six samples collected (0.05–0.07 mg/L).

Note:
[a] Data are from floodplain background wells 0797 and 0850 (locations shown in Figure 2).

Abbreviations:
– = not applicable (contaminant does not have an MCL in 40 CFR 192 or the alternate cleanup goal is not relevant)
mg/L = milligrams per liter

As listed in Table 1, the compliance standards for nitrate, uranium, and selenium are the respective 40 CFR 192 standards of 10 milligrams per liter (mg/L), 0.044 mg/L, and 0.01 mg/L. If the relatively high selenium concentrations in floodplain groundwater originate on the terrace, it may be unlikely that the 40 CFR 192 standard of 0.01 mg/L for this constituent can be met. Therefore, an alternate concentration limit for selenium of 0.05 mg/L was proposed for the floodplain in the GCAP (DOE 2002), which is the maximum contaminant level for drinking water established under the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act. This alternate level may still be too conservative, given the potential influence from natural sources addressed in a report recently issued by the U.S. Geological Survey (Robertson et al. 2016) and in several DOE evaluations (DOE 2011b, 2011c).

Regulatory standards have not been established for ammonia and manganese (Table 1). For the Shiprock site, an alternate cleanup goal was not developed for ammonia because (1) EPA has not developed any toxicity values upon which to base an associated risk-based standard, and (2) levels measured in floodplain background wells have been very low and most below detection limits (<0.1 mg/L in 47/50 background samples). For manganese, the 2.74 mg/L cleanup goal specified in the GCAP was based on the maximum background concentration at that time (DOE 2002). Since then, levels in background wells have ranged as high as 7.2 mg/L (Table 1).

Regulatory standards are also not available for strontium, a constituent typically not associated with uranium-milling sites. Strontium was selected as a COC in the Baseline Risk Assessment (DOE 1994) primarily because of concentrations measured in sediment (rather than groundwater) and a conservatively modeled agricultural uptake scenario. The form present at the Shiprock site is stable (nonradioactive) strontium, a naturally occurring element, and is distinguished from the radioactive and much more toxic isotope strontium-90, a nuclear fission product (ATSDR 2004). EPA's Regional Screening Level (RSL) for drinking (tap) water is 12 mg/L (EPA 2016).

Historically, sulfate concentrations have been elevated in groundwater entering the floodplain from flowing artesian well 0648, where levels have ranged from 1810 to 2340 mg/L (average of 2019 mg/L). Because of these elevated levels from a natural source, the GCAP proposed a cleanup goal for sulfate of 2000 mg/L for the floodplain. This alternate goal is conservative, as levels in floodplain background wells have exceeded 2000 mg/L in nearly half (46%) of the 68 samples collected. For example, in background well 0797, sulfate levels have ranged from 2690 to 5000 mg/L since 2010.

1.3 Hydrogeological Setting

This section presents a brief summary of the floodplain and terrace groundwater systems. More detailed descriptions are provided in the SOWP (DOE 2000), the refinement of the site conceptual model (DOE 2005), and the Trench 1 and Trench 2 floodplain remediation system evaluations (DOE 2011d, DOE 2009). Cross sections of the terrace and floodplain, developed for the SOWP (DOE 2000), are provided in Plate 1.

1.3.1 Floodplain Alluvial Aquifer

The thick Mancos Shale of Cretaceous age forms the bedrock underlying the entire site. A floodplain alluvial aquifer occurs in unconsolidated medium- to coarse-grained sand, gravel, and cobbles that were deposited in former channels of the San Juan River above the Mancos Shale. The floodplain aquifer is hydraulically connected to the San Juan River; the river is a source of groundwater recharge to the floodplain aquifer in some areas, and it receives groundwater discharge in other areas. In addition, the floodplain aquifer receives some inflow from groundwater in the terrace area. The floodplain alluvium is up to 20 feet (ft) thick and overlies Mancos Shale, which is typically soft and weathered for the first several feet below the alluvium.

Most groundwater contamination in the floodplain lies close to the escarpment east and north of the disposal cell. Contaminant distributions in the alluvial aquifer are best characterized by elevated concentrations of sulfate and uranium. Lower levels of contamination occur along the escarpment base in the northwest part of the floodplain because relatively uncontaminated surface water from Bob Lee Wash discharges to the floodplain at the wash's mouth. Surface water in Bob Lee Wash originates primarily as deep groundwater from the Morrison Formation that flows to the land surface via artesian well 0648. Well 0648 flows at approximately 65 gallons per minute (gpm) and drains eastward into lower Bob Lee Wash. Historically, background groundwater quality in the floodplain aquifer has been defined by the water chemistry observed at monitoring wells 0797 and 0850, installed in the floodplain approximately 1 mile upriver from the site (Figure 2).

1.3.2 Terrace Groundwater System

The terrace groundwater system occurs partly in unconsolidated alluvium in the form of medium- to coarse-grained sand, gravel, and cobbles deposited in the floodplain of the ancestral San Juan River. Terrace alluvial material is Quaternary in age; it varies from 0 to 20 ft in thickness and caps the Mancos Shale. Although less well mapped, some terrace groundwater also occurs in weathered Mancos Shale underlying the alluvium. The Mancos Shale is exposed in the escarpment adjacent to the San Juan River floodplain.

The terrace groundwater system is bounded on its south side by an east-west-trending buried bedrock (Mancos Shale) escarpment, about 1500 ft south of the southernmost tip of the disposal cell. The terrace system extends more than a mile west and northwestward, to more than 4000 ft west of Highway 491. Terrace alluvial material is exposed at ground surface in the vicinity of the terrace–floodplain escarpment; south and southwest of the former mill, the terrace alluvium is covered by eolian silt (deposited by wind), or loess, which increases in thickness with proximity to the buried bedrock escarpment. Up to 40 ft of loess overlies the alluvium along the base of the buried escarpment. Terrace alluvium consists of coarse-grained ancestral San Juan River deposits, primarily in the form of coarse sands and gravels.

Mancos Shale underlying the alluvium in the terrace area is soft and weathered. The weathered Mancos Shale is typically 2–10 ft thick, but some characteristics of weathering below the shale–alluvium contact occur as deep as 30 ft in places (DOE 2000). Groundwater is known to occur in the weathered shale and, in some areas, possibly flows through deeper portions of the shale, within fractures and along bedding surfaces.

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2.0 Remediation System Performance

This section describes the key components of the floodplain and terrace groundwater remediation systems and summarizes their performance for the 2015–2016 reporting period.

2.1 Floodplain Remediation System

The floodplain remediation system consists of three major components shown in Figure 1: two extraction wells (wells 1089 and 1104); two drainage trenches (horizontal wells), Trench 1 and Trench 2, installed in spring 2006; and a sump (collection drain location 1118) used to collect discharges from seeps 0425 and 0426 on the escarpment. The main objective of the floodplain groundwater extraction system is to supplement the natural flushing process by reducing the contaminant mass and volume within the floodplain alluvial aquifer. All groundwater collected from the floodplain extraction wells and trenches is piped south to the terrace and discharged into the evaporation pond. Average pumping rates and cumulative volumes of groundwater extracted from floodplain remediation system locations are summarized in Table 2 for the current and previous reporting periods.

Table 2. Floodplain Remediation System Locations: Average Pumping Rates and Total Groundwater Volume Removed

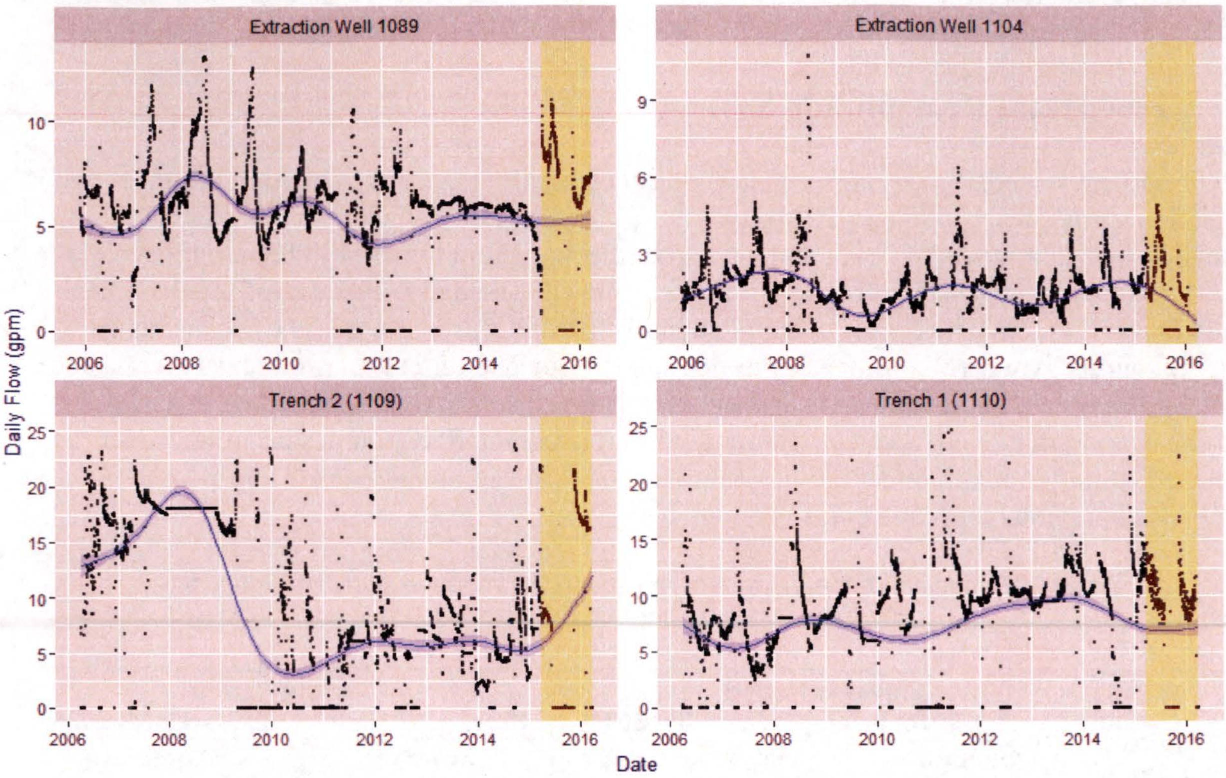
Floodplain Location	Previous Period (April 1, 2014, through March 31, 2015)		Current Period (April 1, 2015, through March 31, 2016)	
	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
1089	4.6	2,438,740	5.5	2,896,999
1104	1.5	785,166	1.2	648,179
Trench 1	6.94	3,647,202	7.23	3,799,444
Trench 2	6.3	3,322,335	7.8	4,087,242
Seep (1118)	0.53	278,735	0.65	342,501
Total	**19.9** (cum. avg.)	**10,472,178**	**22.4** (cum. avg.)	**11,774,365**

Note:
Since mid-2015, an extensive effort has been undertaken to verify and correct all pumping and flow data obtained through SOARS (System Operation and Analysis at Remote Sites), the telemetry system used to record all active treatment 5-minute and daily flow data. Examples of corrections made include accounting for when pumping was operating but the flow meter was not. As a result, some historical flow data have changed since last year's report was issued (corrected values for the period 2014–2015 are reported above). In most cases, cumulative flows have changed by only a small fraction.

2.1.1 Extraction Well Performance

The floodplain extraction well system consists of wells 1089 and 1104 (Figure 1). These wells were constructed using slotted culverts placed in trenches excavated to bedrock. From April 2015 through March 2016, approximately 2.9 million gallons of water were removed from well 1089 at an average pumping rate of about 5.5 gpm (Table 2). Pumping rates at well 1104 averaged about 1.2 gpm; the cumulative extracted volume was about 648,200 gallons. During the period since the start of operations in March 2003 through the end of March 2016, totals of approximately 36.3 and 7.9 million gallons of water have been removed from wells 1089

and 1104, respectively. Figure 3 plots historical daily flows (pumping rates) for extraction wells 1089 and 1104 and the two trenches.



Notes:
- Average daily flow rate in gallons per minute (gpm); shading denotes current (2015–2016) reporting period

—— LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval
Data plotted are since the inception of the SOARS system in 2006. (LOESS is a nonparametric regression method)

Figure 3. Historical Pumping Rates in Floodplain Trenches and Extraction Wells: 2006–2016

2.1.2 Floodplain Drain System Performance

In spring 2006, two drainage trenches—Trench 1 (1110) and Trench 2 (1109)—were installed in the floodplain just below the escarpment to enhance the extraction of groundwater from the alluvial system. Pumping began in April 2006. From April 2015 through March 2016, approximately 3.8 million gallons of water were removed from Trench 1 at an average pumping rate of 7.2 gpm. In 2015–2016, approximately 4.1 million gallons of water were removed from Trench 2 at an average pumping rate of 7.8 gpm (Table 2). As has been the case for several years, during this reporting period, pumping from floodplain locations was shut down periodically for maintenance and repairs and to increase evaporation pond capacity and maintain pond water levels.

2.1.3 Floodplain Seep Sump Performance

In August 2006, seeps 0425 and 0426 were incorporated into the remediation system. Groundwater discharge from these two seeps is piped into a collection drain (location 1118) and then pumped to the evaporation pond. From April 2015 through March 2016, the average discharge rate from the seep collection drain was 0.65 gpm, similar to the average rates reported in the last several years. Approximately 342,500 gallons were pumped from the seeps during this period (Table 2), yielding a total cumulative volume of about 2.8 million gallons.

2.2 Terrace Remediation System

The objective of the terrace remediation system is to remove groundwater from the southern portion of the terrace area so that potential exposure pathways at seeps and at Bob Lee Wash and Many Devils Wash are eventually eliminated and the flow of groundwater from the terrace to the floodplain is reduced. The terrace remediation system consists of four major components shown in Figure 1: the extraction wells, the evaporation pond, the terrace drains (Bob Lee Wash and Many Devils Wash), and the terrace outfall drainage channel diversion.

2.2.1 Extraction Well Performance

During the current period, the terrace remediation well field consisted of wells 0818, 1070, 1071, 1078, 1091, 1092, 1093R, 1095, and 1096. Table 3 compares the average pumping rate and total groundwater volume removed from each terrace extraction well and drain location for the current (2015–2016) and previous (2014–2015) reporting periods. The production rate from wells 1070, 1071, 1091, and 1092 (all less than 0.03 gpm this reporting period) was less than 0.1 gpm, the minimum production required to be considered an aquifer under 40 CFR 192. As shown in Table 3, the current-period average pumping rates for terrace extraction wells ranged from <0.0001 gpm to 0.93 gpm (well 0818). The total groundwater volume removed from each well during this period ranged from 2.5 to 486,654 gallons. The cumulative total volume removed from pumping the terrace extraction wells (about 1.62 million gallons) is comparable to the volume extracted during the 2014–2015 reporting period (Table 3).

Table 3. Terrace Extraction Wells and Drains: Average Pumping Rates and Total Groundwater Volume Removed

Terrace Well or Drain	Previous Period (April 1, 2014, through March 31, 2015)		Current Period (April 1, 2015, through March 31, 2016)	
	Average Pumping Rate (gpm)[c]	Total Groundwater Volume Removed (gallons)[c]	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818[a]	0.77	408,132	0.93	486,654
1070	0.020	10,419	0.018	9237
1071	0.007	3690	0.016	8,662
1078	0.74	386,606	0.79	413,612
1091	0.036	19,019	0.022	11,468
1092	0.002	1223	<0.0001	2.5
1093R	0.93	489,648	0.63	330,613
1095	0.31	160,660	0.30	156,104
1096	0.34	180,016	0.38	200,850
Subtotal	**3.2** (cum. avg.)	**1,659,413**	**3.1** (cum. avg.)	**1,617,202**
1087[b]	3.18	1,669,371	4.75	2,494,536
1088[b]	0	0	0	0
Total	**6.34** (cum. avg.)	**3,328,784**	**7.82** (cum. avg.)	**4,111,738**

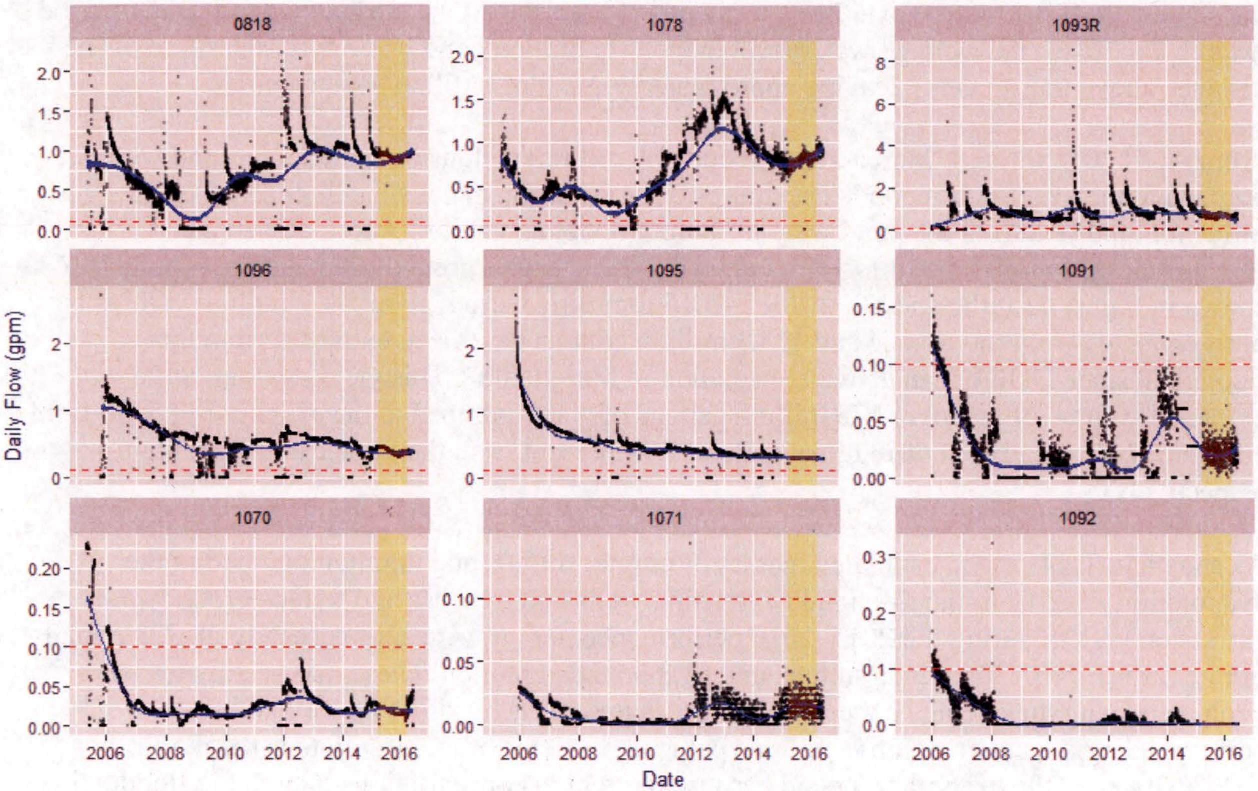
Notes:

[a] Well 0818 was identified in the GCAP as a performance assessment well.

[b] Locations 1087 and 1088 are Bob Lee Wash and Many Devils Wash drains, respectively.

[c] Since mid-2015, an extensive effort has been undertaken to verify and correct all pumping and flow data obtained through SOARS and to account for manual entries before the SOARS system was implemented. Because of these ongoing corrections, some historical flow results have changed, affecting the volumes and flow rates reported here for the preceding (2014–2015) period. In most cases, annual and cumulative extraction volumes changed by just a small fraction. An exception is well 1091, for which the annual flows documented in the previous annual report (DOE 2015) were under-reported for the 2014–2015 period: 2323 gallons vs. corrected value of 19,019 gallons (listed above).

One of the initial objectives for the terrace remediation system was the attainment of a cumulative 8 gpm extraction rate, a goal based on groundwater modeling conducted for the SOWP (DOE 2000). To meet this objective, two wells (1095 and 1096) were installed near the evaporation pond in March 2005. In September 2007, DOE installed a new large-diameter well (1093R) to increase groundwater extraction yields. Despite these enhancements, and continued maintenance of the pumping system, the 8 gpm objective has not been achieved. Historically, the combined pumping rate from terrace extraction wells has ranged from about 2 to 4 gpm. Figure 4 plots historical daily flows (pumping rates) for the nine terrace extraction wells.



Notes:
• Average daily flow rate in gallons per minute (gpm); shading denotes current reporting period.
—— LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval.
Wells are ordered by descending average pumping rate for the 2015–2016 reporting period.
- - - Denotes 0.1 gpm (150 gallons per day) low-yield definition for limited-use aquifer (40 CFR 192, Section 11(e)).

Figure 4. Historical Pumping Rates in Terrace Extraction Wells: 2006–2016

2.2.2 Terrace Drain System Performance

The terrace extraction system collects seepage from Bob Lee Wash and Many Devils Wash using subsurface interceptor drains. These drains, which consist of perforated pipe surrounded by drain rock and lined with geotextile filter fabric, are offset from the centerline of each wash to minimize the infiltration of surface water. All water collected by these drains is pumped through a pipeline to the evaporation pond. In 2015−2016, the average pumping rate from Bob Lee Wash was 4.8 gpm (vs. 3.2 gpm in 2014−2015), and the groundwater interceptor drain removed about 2.5 million gallons of water (Table 3). As was the case last year (DOE 2015), no water was pumped from the Many Devils Wash groundwater interceptor drain during this reporting period, because of the need for extensive repairs of the system. These repairs have not yet been addressed because the origins of the groundwater in Many Devils Wash are being explored (e.g., Robertson et al. 2016); these study findings may form the basis for decommissioning the interceptor drain system.

2.2.3 Evaporation Pond

The selected method for handling groundwater from the interceptor drains and extraction wells is solar evaporation. Contaminated groundwater is pumped to an 11-acre lined evaporation pond in

the south part of the radon-cover borrow pit area (Figure 1). At the close of this reporting period (March 31, 2016), the average water level in the evaporation pond was 5.8 ft (measured as the distance above transducers), leaving approximately 2.2 ft of unfilled pond capacity.

From April 2015 through March 2016, about 15.9 million gallons of extracted groundwater were pumped to the evaporation pond. The majority (11.8 million gallons, or 74 percent) of the influent liquids entering the pond were from the floodplain aquifer. About 26 percent (4.1 million gallons) of the inflow originated from the terrace groundwater system (Table 4). As shown in Figure 5, at the end of the 2015–2016 reporting period, about 44.9 million gallons have been extracted from the terrace and 133.3 million gallons have been extracted from the floodplain since DOE began active remediation in March 2003. This yields a cumulative extracted volume of just over 178 million gallons of water pumped to the evaporation pond from all sources (cumulative contributions of 25 and 75 percent from the terrace and floodplain, respectively).

As shown in Table 4, the estimated masses of nitrate, sulfate, and uranium pumped to the evaporation pond from the floodplain extraction wells and trenches and terrace groundwater extraction system during the 2015–2016 performance period were approximately 28,228 pounds nitrate (as N); 743,130 pounds sulfate; and 51.8 pounds uranium. These mass estimates were computed using the average concentrations measured in each extraction well and the corresponding annual cumulative volume pumped. In terms of mass, sulfate is the dominant COC that enters the evaporation pond because of its high concentrations in both the floodplain and terrace groundwater systems.

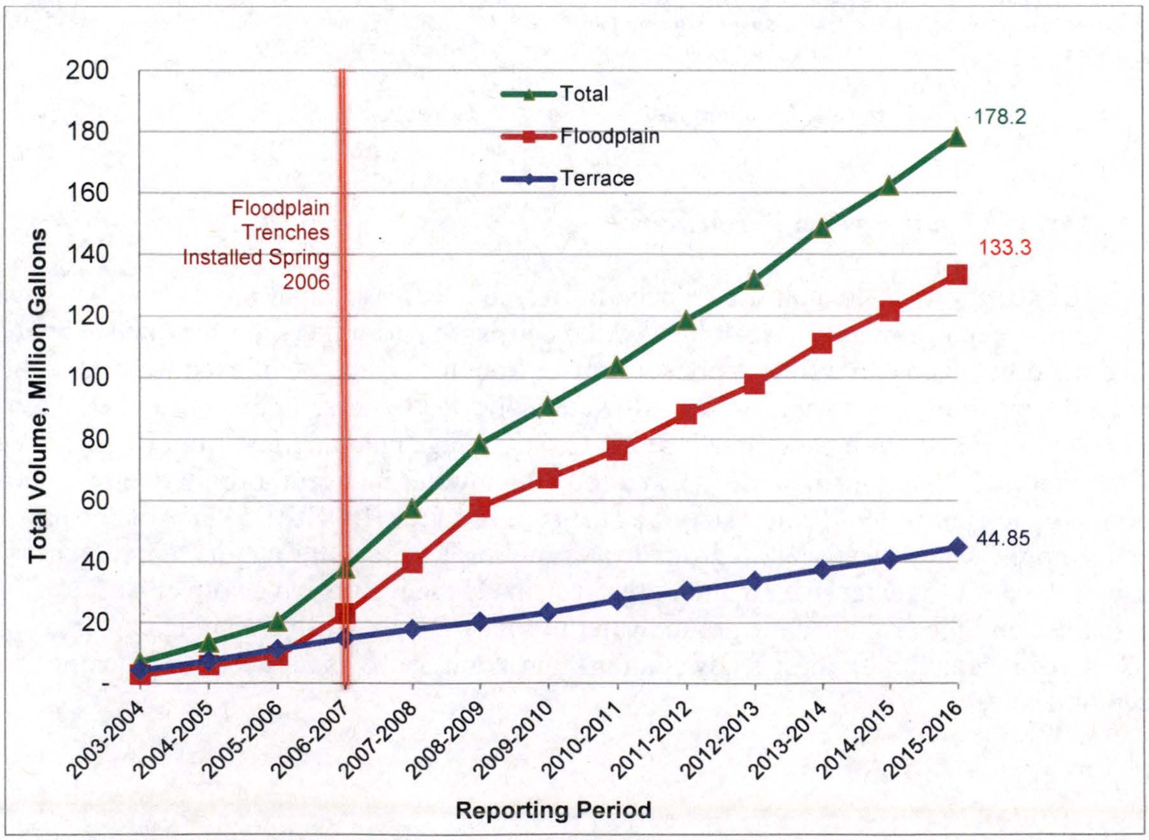


Figure 5. Total Groundwater Volume Pumped to the Evaporation Pond

Table 4. Estimated Total Mass of Selected Constituents Pumped from Terrace and Floodplain

Location	Annual Cumulative Volume (gal)[a]	Total Cumulative Volume (gal)[a]	Percent of Total Cum. Volume Pumped (%)	Nitrate as N Average Concentration, 2015–2016 (mg/L)	Nitrate Mass Removed, 2015–2016 (lb)[b]	Cumulative Mass of Nitrate Removed (lb)[c]	Sulfate Average Concentration, 2015–2016 (mg/L)	Sulfate Mass Removed, 2015–2016 (lb)[b]	Cumulative Mass of Sulfate Removed (lb)[c]	Uranium Average Concentration, 2015–2016 (mg/L)	Uranium Mass Removed, 2015–2016 (lb)[b]	Cumulative Mass of Uranium Removed (lb)[c]
Terrace												
0818	486,654	5,249,103	3.06	665	2701	53,629	14,000	56,858	557,663	0.12	0.487	5.47
1070	9237	529,776	0.06	565	43.6	3857	16,500	1272	73,979	0.08	0.006	0.537
1071	8662	115,904	0.05	525	38.0	1775	15,000	1084	6786	0.14	0.010	0.147
1078	413,612	4,216,112	2.6	420	1450	21,425	14,500	50,050	488,116	0.115	0.397	4.66
1091 (see Note)	11,468	247,568	0.07	690	66.0	3008	16,500	1579	25,715	0.105	0.010	0.24
1092	2.5	224,883	<0.001	475	0.01	2875	16,500	0.34	24,820	0.08	<0.0001	0.22
1093R[c]	330,613	4,114,494	2.08	2101	5794	74,048	7300	20,141	192,279	0.11	0.3035	3.587
1095	156,104	2,661,741	0.98	1701	2215	35,774	5750	7491	135,527	0.048	0.063	1.305
1096	200,850	2,898,557	1.26	505	846	15,218	16,000	26,819	345,810	0.083	0.139	2.487
1087 (BLW)	2,494,536	21,169,843	15.7	215	4476	55,530	5150	107,212	1,287,353	0.36	7.494	95.54
1088 (MDW)	0	3,406,532	0	Not Sampled	0	18,654	Not Sampled	0	535,882	Not Sampled	0	5.0
Floodplain												
1089	2,896,999	36,273,493	18.24	1.915	46.3	5614	4400	106,377	2,260,065	0.19	4.6	218.7
1104	648,179	7,916,423	4.08	1.135	6.14	2969	5950	32,185	584,590	0.36	1.95	67.37
Trench 1 (1110)	3,799,444	38,909,105	23.92	16.0	507	36,019	5400	171,222	2,381,236	0.42	13.32	277.65
Trench 2 (1109)	4,087,242	46,582,803	25.73	290	9892	30,433	4200	143,260	609,392	0.64	21.83	89.17
Seep sump (1118)	342,501	2,847,386	2.16	51.5	147.2	1206	6150	17,579	143,828	0.405	1.16	11.5
				Total Masses:	**28,228**	362,034		**743,130**	9,653,041		**51.8**	**783.6**
Total terrace[d]	4,111,738	44,850,142	25.9	–	17,630	286,289	–	272,507	3,674,241	–	8.9	123
Total floodplain[d]	11,774,365	133,341,659	74.1	–	10,599	77,455	–	470,623	6,095,521	–	42.9	681
Total to pond[d]	15,886,103	178,191,801	–	–	28,228	363,744	–	743,130	9,769,762	–	51.8	804

Notes:

[a] Annual cumulative volumes are for this reporting period: April 1, 2015, through March 31, 2016.

[b] Mass in pounds (lb) removed = annual volume (gal) × average concentration (mg/L) × (3.7854 L/gal) × (453,592.37 mg/lb)$^{-1}$.

[c] Cumulative volumes and masses are totals since March 2003. Cumulative volumes and masses listed for well 1093R combine flow and sampling data for former smaller-diameter well 1093 (2003–2007) with those for well 1093R (2008–present).

[d] Total cumulative volumes and masses include data from former terrace pumping well 1094 (15,628 gal, 2003–2004) and floodplain well 1077 (812,449 gal, 2003–2005). Because of ongoing corrections to the SOARS historical database, historical cumulative volumes for some wells have changed, in most cases by just a small fraction; refer to notes following Table 2 and Table 3.

Abbreviations: BLW = Bob Lee Wash; gal = gallon(s); lb = pound(s); MDW = Many Devils Wash. The MDW interceptor drain has not operated for several years.

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3.0 Current Conditions

This section summarizes water quality and hydraulic characteristics of the floodplain and terrace groundwater systems for the April 2015 through March 2016 reporting period. During this time frame, 112 monitoring wells were sampled (56 on the floodplain and 56 on the terrace). Seventeen surface water locations, including 8 San Juan River sampling points and various seeps, were also sampled. In the last several years, 13 surface/seep locations were eliminated because the locations had been historically dry.

Detailed information, including time–concentration graphs for both terrace and floodplain monitoring locations for all COCs, along with supporting quality assurance documentation, is provided in the corresponding Data Validation Package (DVP) reports (DOE 2016a, 2016b).

3.1 Floodplain Contaminant Distributions and Temporal Trends

This discussion and supporting figures presented in this section focus on nitrate, sulfate, and uranium because these contaminants are most widespread on the floodplain and are used to gauge the effectiveness of the remediation system at the Shiprock site. For these COCs, the alluvial plume maps in (Figure 6 through Figure 8) compare baseline and current conditions using all alluvial wells that were sampled during both periods. Because interpolations of COC concentrations at unsampled areas (i.e., between well locations) are based on measurements made at the closest surrounding sites, it is important to acknowledge the differing well density between the two periods. For example, additional wells were completed in 2006 after installation of the two trenches, and new near-river monitoring locations were also established.

For each major contaminant, two versions of each (baseline vs. current) plume map are provided. Figures with an "a" suffix plot contaminant concentrations based on the range of the data, allowing greater resolution of the spatial distribution. Companion figures (with a "b" suffix) plot the same data, but the color scale for the plume maps is determined based on the corresponding compliance standard or cleanup goal established in the GCAP (listed in Table 1). In these "b" series figures, the break between blue/green and yellow/red is set at this value.

Corresponding time–concentration graphs for the primary COCs are provided in Appendix A using the spatial groupings shown in Figure 9 (see Figures A-1 through A-9). As demonstrated in this appendix, concentrations of uranium, sulfate, and nitrate have decreased in most floodplain wells (relative to baseline conditions), especially in areas near the pumping regions. Exceptions are found at several locations: wells 1137, 1138, 1139 in the well 1089|1104 remediation area (Figure A-3), Trench 2 base-of-escarpment wells 1115 and 1128 (Figure A-4), wells 0857 and 1136 in the central floodplain (Figure A-5), southernmost well 0735 (Figure A-7), and well 0630 at the base of Bob Lee Wash. At most of these locations, contaminant concentrations, in particular sulfate and uranium, appear to be increasing. Relative to observations in previous years (DOE 2013a, DOE 2015), when fairly marked increases in uranium and sulfate levels in near-river wells 1137, 1138, and 1139 were noted, contaminant concentrations in these wells, although still elevated, have stabilized or declined (Figure A-3). The reasons for this shift in trends are not known at this time. For example, there is no apparent relationship between COC concentrations in these wells and regional pumping volumes or San Juan River elevations. Although water elevations in the wells have increased slightly (about 0.5 ft) since 2014, it is not clear whether these changes account for the recent declines.

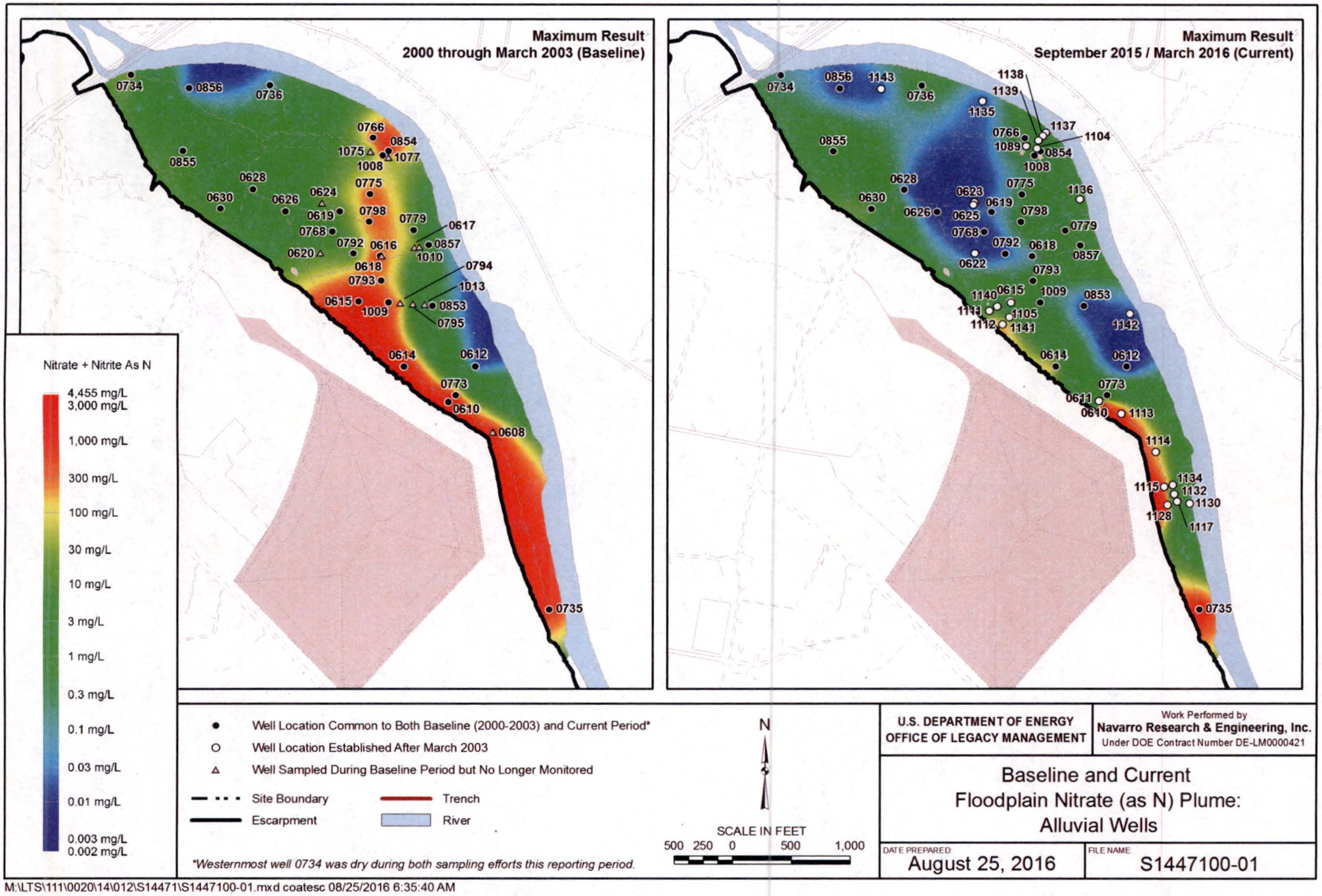

Figure 6a. Baseline (2000–2003) and September 2015 Through March 2016 Floodplain Nitrate Plumes Scale Based on Range of Data

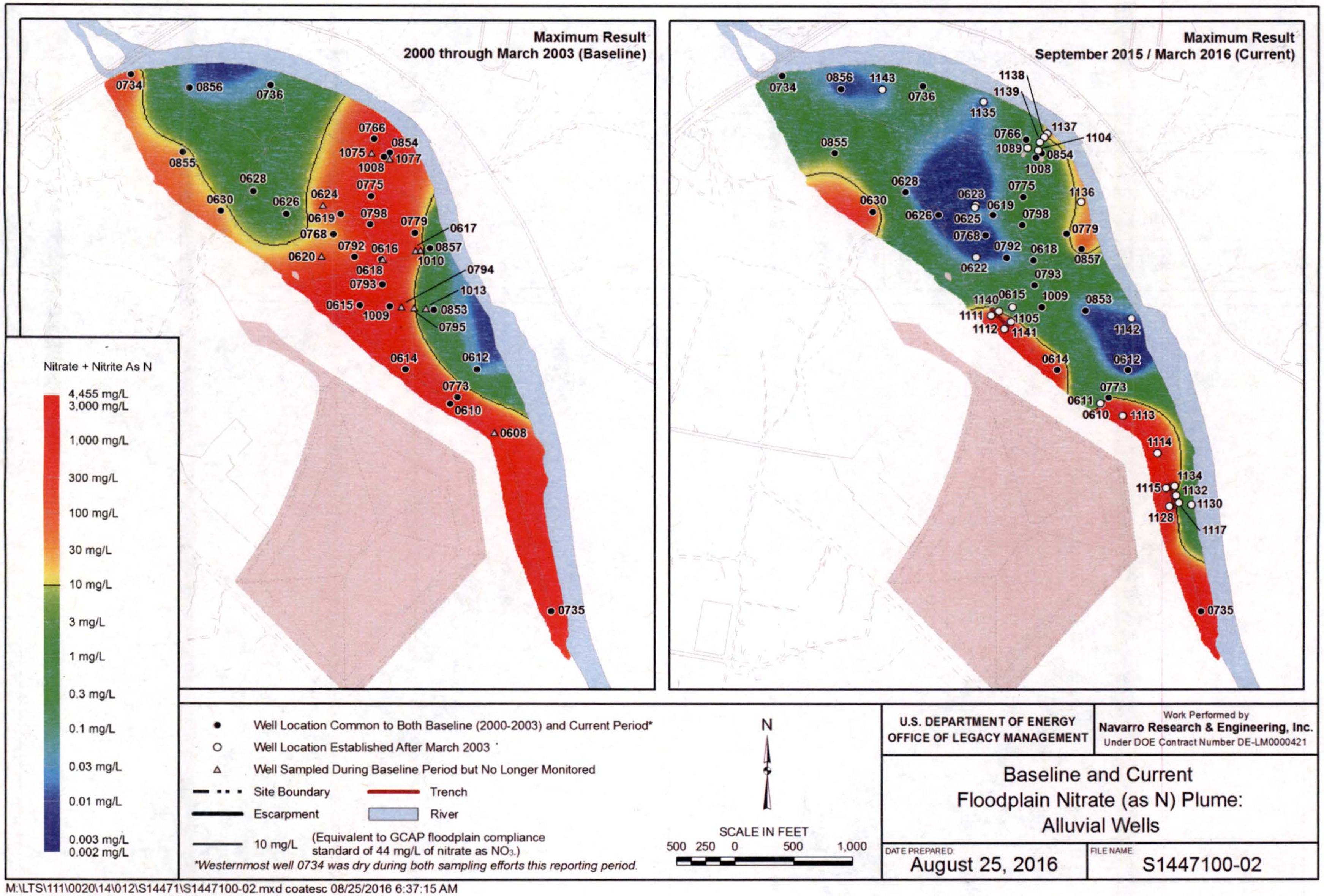

Figure 6b. Baseline (2000–2003) and September 2015 Through March 2016 Floodplain Nitrate Plumes Scale Based on 10 mg/L UMTRCA MCL

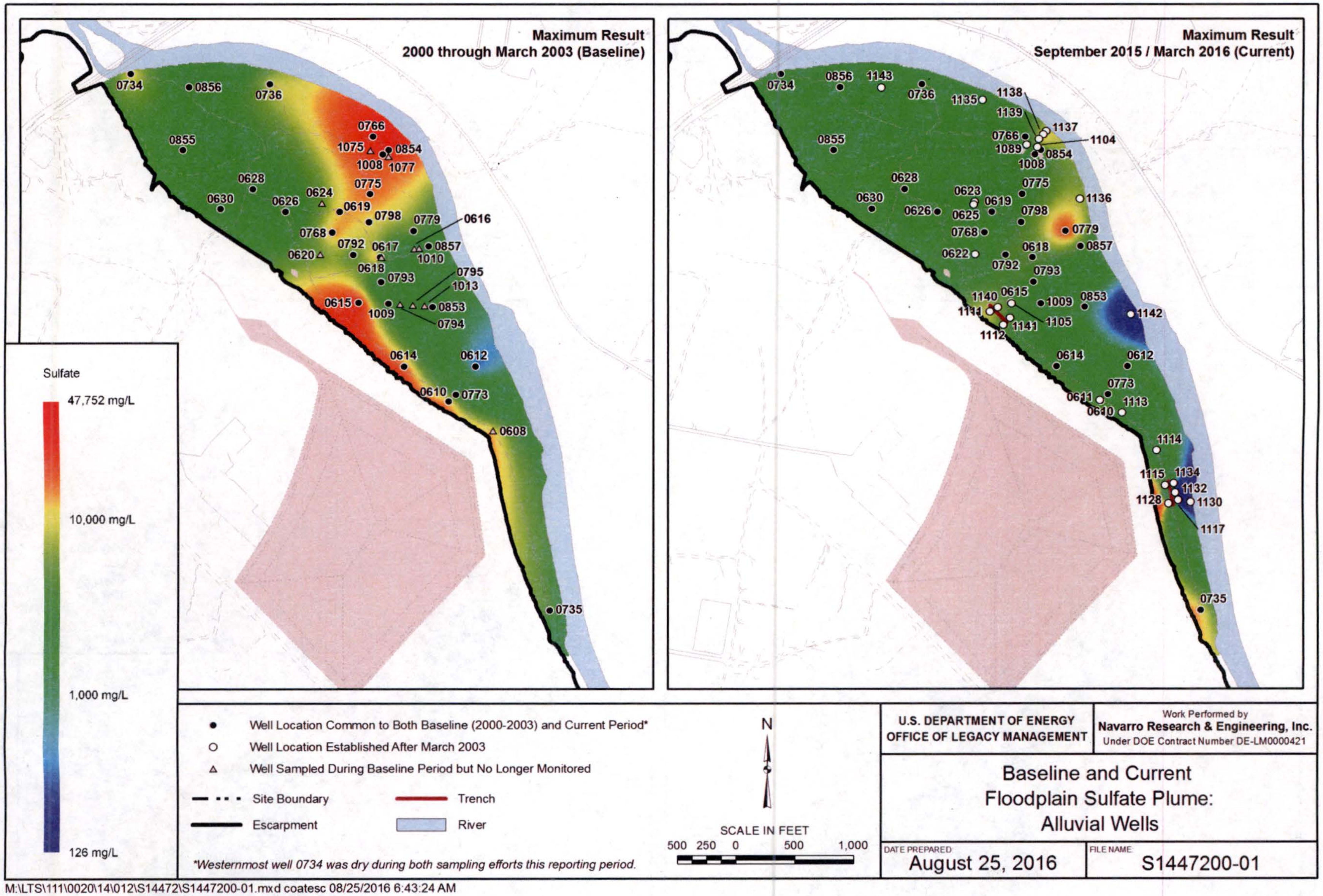

Figure 7a. Baseline (2000–2003) and September 2015 Through March 2016 Floodplain Sulfate Plumes
Scale Based on Range of Data

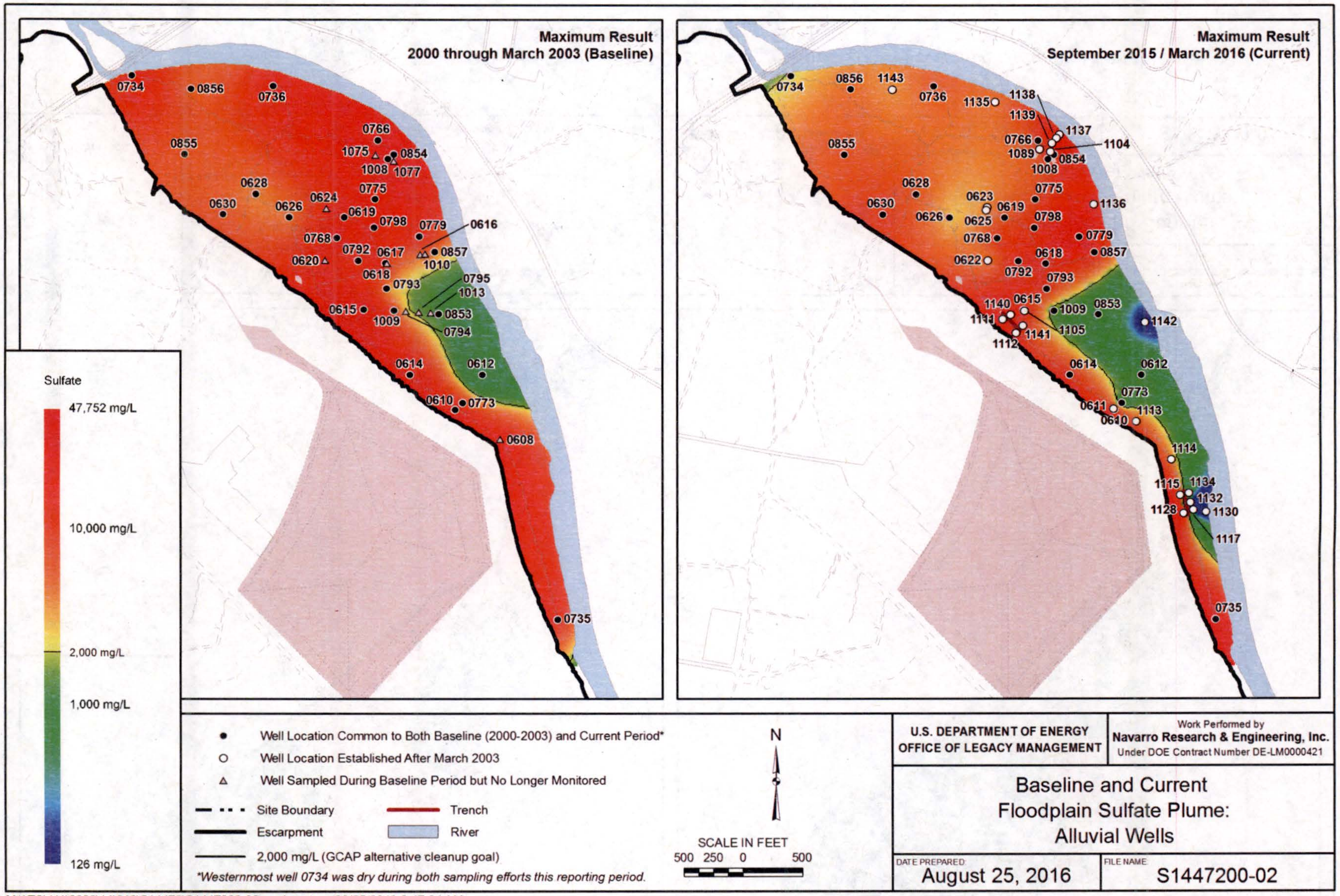

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Figure 7b. Baseline (2000–2003) and September 2015 Through March 2016 Floodplain Sulfate Plumes
Scale Based on 2000 mg/L Benchmark

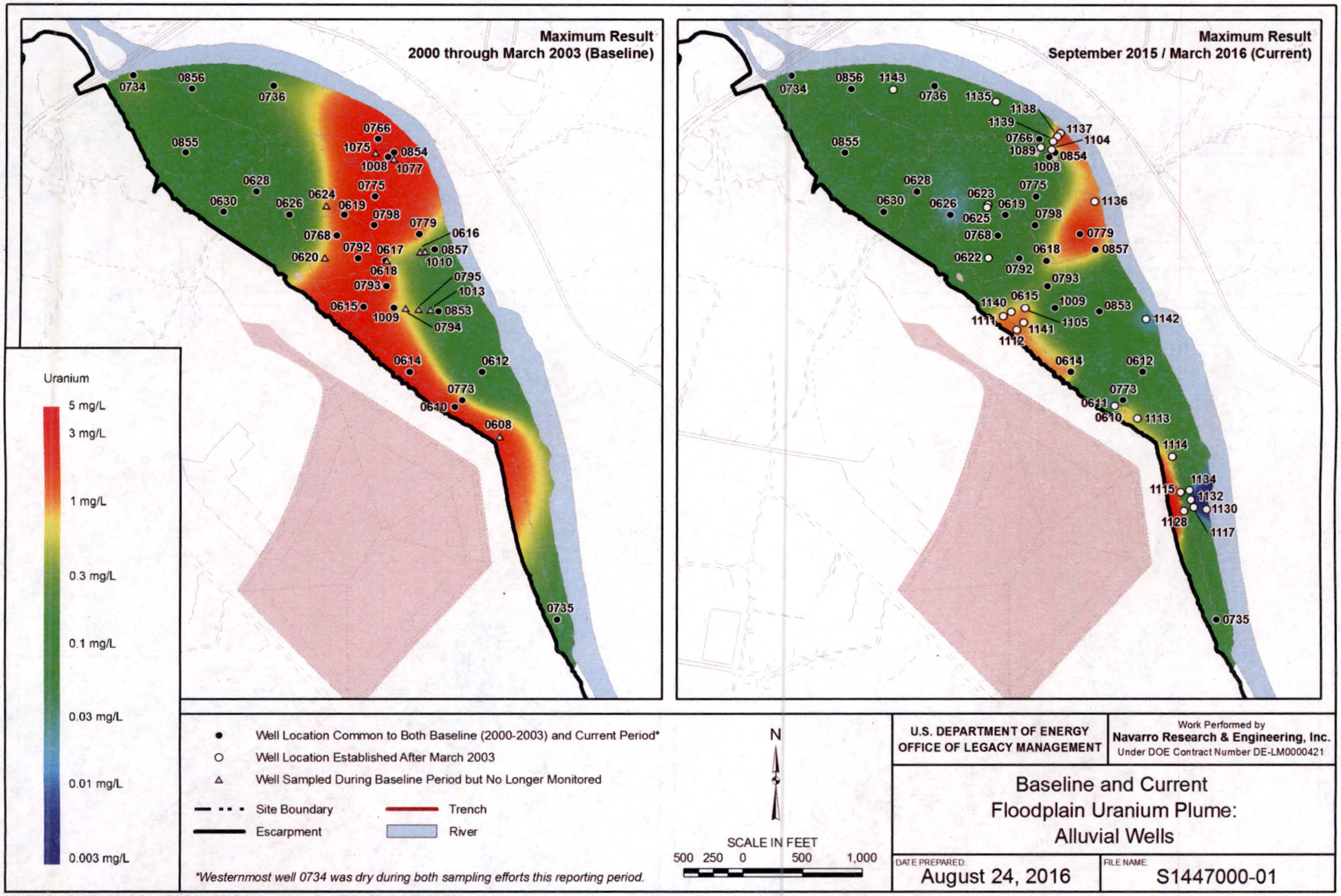

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Figure 8a. Baseline (2000–2003) and September 2015 Through March 2016 Floodplain Uranium Plumes
Scale Based on Range of Data

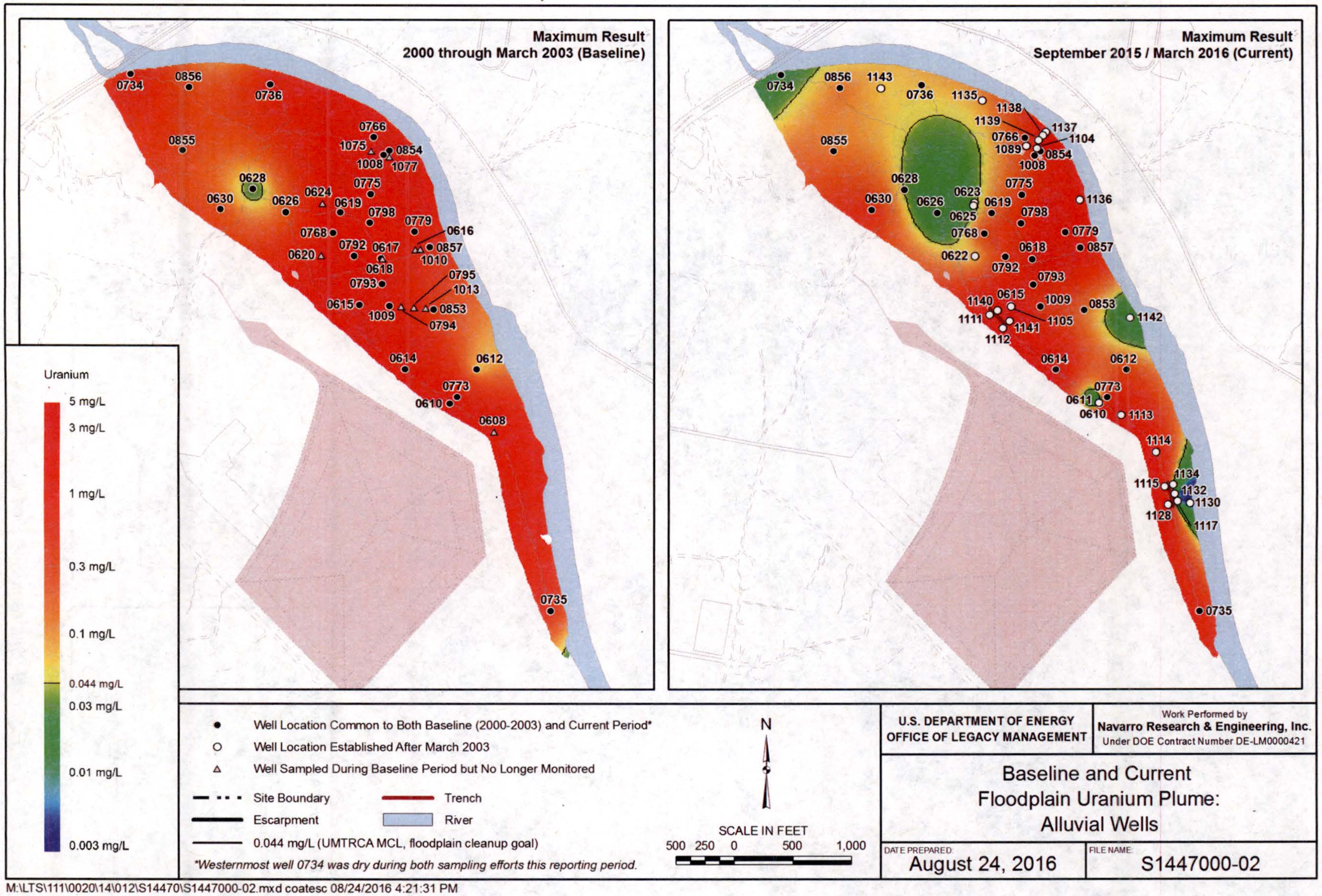


Figure 8b. Baseline (2000–2003) and September 2015 Through March 2016 Floodplain Uranium Plumes
Scale Based on 0.044 mg/L UMTRCA MCL

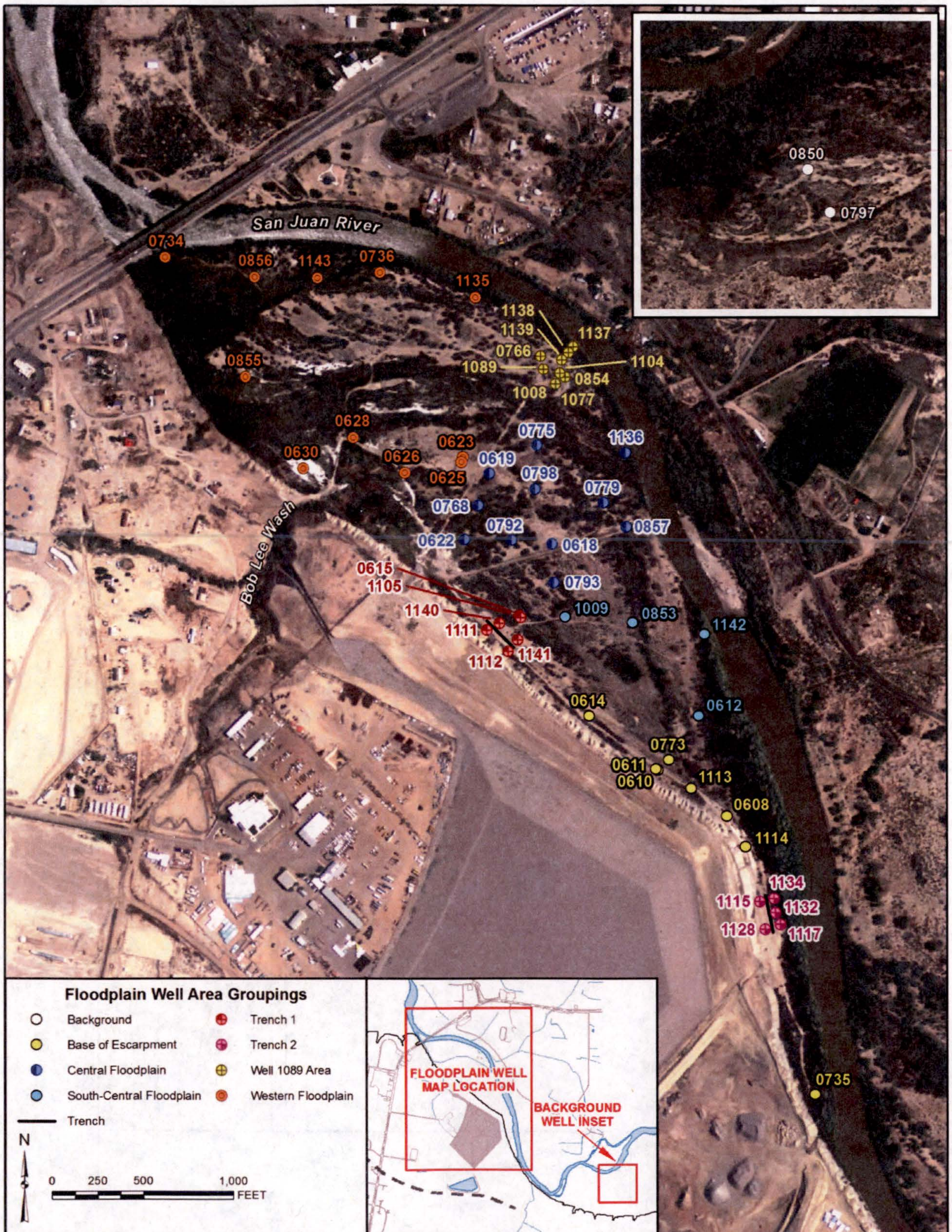


Figure 9. Shiprock Site Floodplain Area Well Groupings

Nitrate (as N)

Although still elevated on the floodplain relative to the 10 mg/L GCAP compliance standard, nitrate concentrations are much lower since the installation of trenches in 2006. The plume maps (Figure 6a) and time–concentration plots (Appendix A) show demonstrable progress on the floodplain (reductions in nitrate concentrations) when comparing baseline to current results. These declines are most evident in the central plume region, extending from the current Trench 1 area to the well 1089|1104 remediation areas near the San Juan River. Nitrate concentrations in most areas of the floodplain are now below the 10 mg/L cleanup goal (Figure 6b).

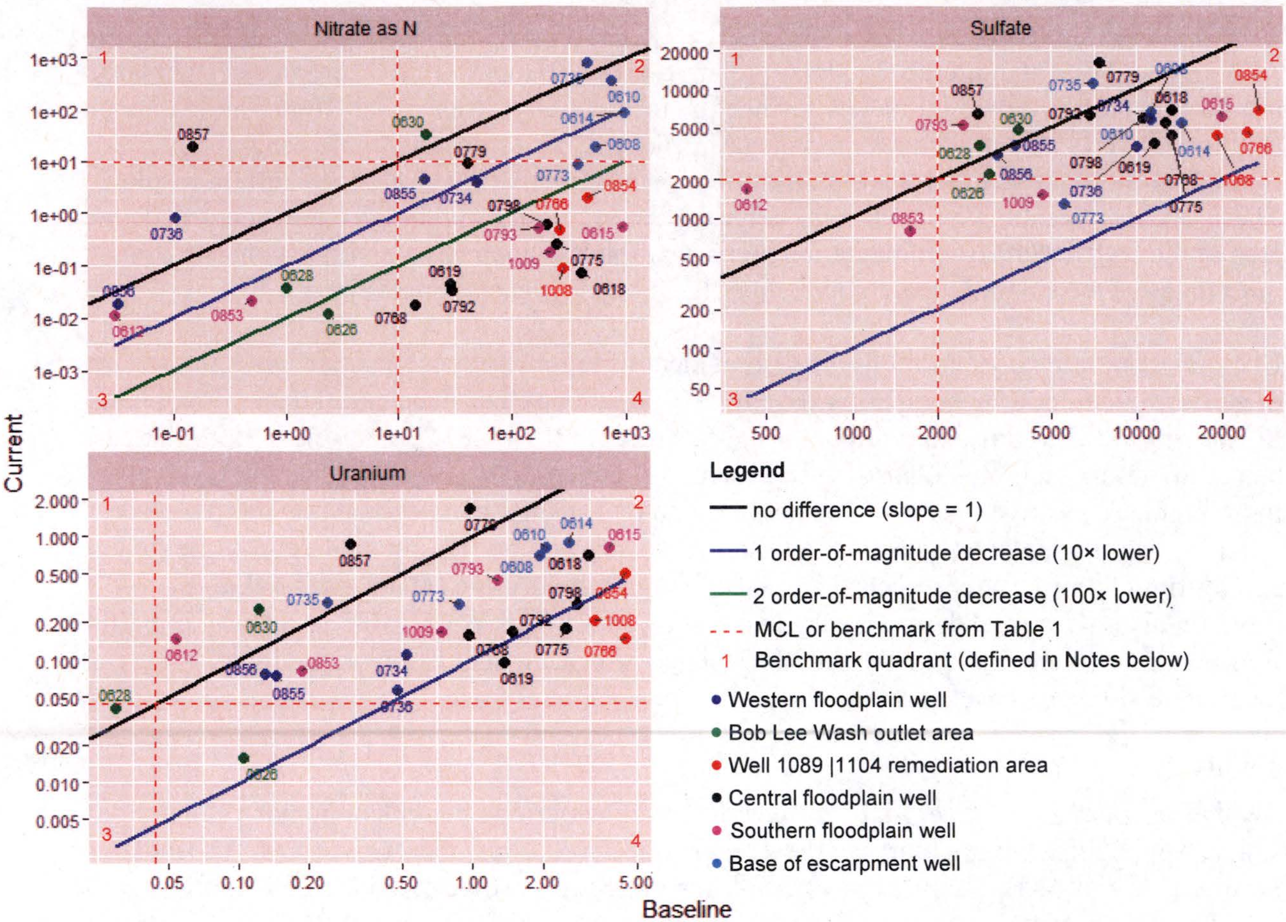
Declines in nitrate concentrations are also evident in Figure 10, which summarizes the progress of active remediation by comparing baseline (2000–2003) COC concentrations in floodplain monitoring wells to those measured during the current (2015–2016) reporting period. For each contaminant, the diagonal black line represents 1:1 concentration ratios indicating no change between the respective measurement dates (slope of 1). The blue diagonal line represents a 1 order of magnitude decline relative to baseline concentrations. The green diagonal line (which applies only to nitrate) represents a 2 order of magnitude decline. The dashed red lines (horizontal and vertical) denote the corresponding benchmark from Table 1. As shown in this figure, nitrate concentrations in many floodplain wells have declined by more than 2 orders of magnitude since the baseline period.

Sulfate

Reductions in sulfate concentrations since the baseline period are evident in many floodplain wells (Appendix A), particularly in the Trench 1 and well 1089 areas (Figure 7a, Appendix A Figures A-2 and A-3). Despite these declines, sulfate levels still exceed the 2000 mg/L GCAP-established benchmark over much of the floodplain (Figure 7b, Figure 10). At the same time, this benchmark is also exceeded in floodplain background wells 0797 and 0850 (Appendix A, Figure A-9). In well 0797, sulfate concentrations have exceeded this benchmark since 2006. In the last 3 years (since 2013), sulfate levels in this well have ranged from 4000 to 5000 mg/L, well above the benchmark. Sulfate concentrations in central floodplain near-river wells 0857 and 1136 have increased in the past few years as shown in Appendix A, Figure A-5. Sulfate levels in wells 1137–1139 (Figure A-3), southernmost well 0735 (Figure A-7), and well 0630 at the base of Bob Lee Wash (Figure A-8) have stabilized somewhat, relative to marked increases observed between about 2010 and 2012.

Uranium

As observed for sulfate, reductions in uranium concentrations in some portions of the floodplain are evident in a comparison of the baseline to current plume maps (Figure 8a) and the time–concentration plots in Appendix A. These declines are also evident in Figure 10, which shows that uranium levels have decreased by 1 order of magnitude or more in some wells. Despite these reductions, uranium concentrations in most floodplain wells still exceed the 0.044 mg/L MCL (Figure 8b). However, uranium levels have also recently exceeded this benchmark in background well 0850 (Appendix A, Figure A-9). Uranium concentrations have decreased in Trench 1 area wells since installation of the trench in 2006; decreases are also apparent in the well 1089 area (Appendix A, Figures A-2 and A-3). However, similar to the trends found for sulfate, uranium levels have increased in near-river wells 0857 and 1136 (Appendix A, Figure A-5). Previous increases observed in wells 1137–1139 (Figure A-3), 0735 (Figure A-7), and 0628 and 0630 (Figure A-8) appear to have stabilized.



Note:
This figure only includes data for wells sampled during both baseline (2000–2003) and current (2015–2016) periods. As such, most wells in the region of Trenches 1 and 2 are not represented, nor are recently installed 1100-series near-river wells. Because of this, the color-coded spatial groups defined above are different from those shown in Figure 9. For western floodplain near-river location 0734, the most recent (September 2014) measurement is plotted because this well has been dry since 2015. Data for background wells 0797 and 0850 are excluded.
Benchmark quadrants are defined as follows:

1 baseline < benchmark; current > benchmark

2 baseline & current > benchmark

3 baseline & current < benchmark

4 baseline > benchmark; current < benchmark

Figure 10. Baseline vs. Current Concentrations of Major COCs in Floodplain Wells

Other COCs

Previous annual reports (e.g., DOE 2013a) provide a more comprehensive discussion of the spatial distribution of remaining COCs. Ammonia, manganese, selenium, and strontium are no longer discussed in detail in this report; these constituents are not as prevalent or elevated at the site or (except for ammonia) as indicative of mill-related contamination as the primary COCs (uranium, nitrate, and sulfate). The following summary is based largely on previous characterizations and on recent data presented in the DVP reports (DOE 2016a, 2016b).

Ammonia concentrations continue to be elevated in Trench 2 area wells on the floodplain. This spatial distribution has not changed significantly over the years, and apart from seasonal or pumping-related periodic variation, temporal trends have been fairly stable in most wells. Most manganese concentrations have been within the 0–7.2 mg/L background range listed in Table 1. During the most recent (March 2016) sampling effort, manganese concentrations on the floodplain ranged from 0.022 to 5 mg/L.

In regard to selenium, the evidence suggests that the Mancos Shale is a likely source of this constituent in some areas of the site and in general (Morrison et al. 2012; Robertson et al. 2016). Historically, selenium concentrations have been highest in Many Devils Wash, where contamination has been demonstrated to be naturally occurring (Robertson et al. 2016), in wells along the terrace buried escarpment, and in only a few floodplain wells at the base of the escarpment (0614 and Trench 1 well 1112). With few exceptions, selenium concentrations in floodplain wells near the river have been below the 0.05 mg/L GCAP compliance standard.

Strontium is not typically associated with uranium milling sites but was selected as a COC based on a conservative ecological risk assessment (DOE 2000). Its spatial distribution at the site suggests a naturally occurring constituent rather than a mill-related contaminant. Historically, apart from seasonal variation, strontium concentrations have been fairly stable in floodplain wells (most less than 10 mg/L).

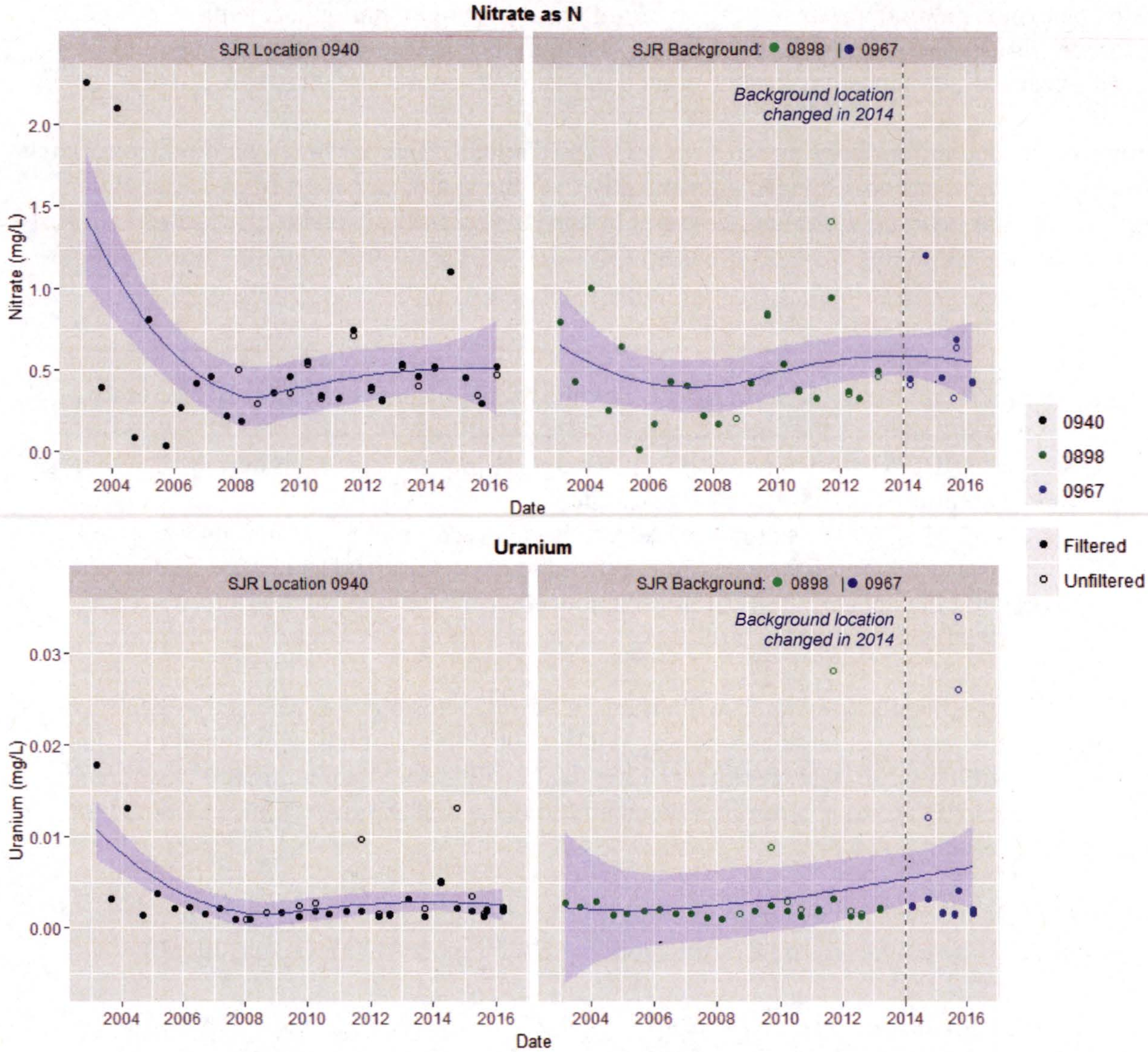
Updated time–concentration trend plots of all COCs—including ammonia, manganese, selenium, and strontium—are contained in the corresponding DVP reports (DOE 2016a, 2016b).

3.2 San Juan River Monitoring

DOE regularly monitors eight San Juan River locations, including one upgradient background location. Between 2003 and March 2013, surface 0898 (farther upgradient) was the representative upgradient location (Figure 2). Since 2014, surface location 0967 has been sampled instead because of difficulty in accessing location 0898. Location 0967 is now considered the representative upgradient San Juan River monitoring location.

Figure 11 plots concentrations of nitrate and uranium for location 0940 along with corresponding background (0898 and 0967) results. Sampling point 0940, located just north of pumping wells 1089 and 1104, was identified as a point of exposure in the GCAP because of its location in an area where contamination in the alluvial aquifer was most likely to discharge to the river (DOE 2002).

As shown in Figure 11, historical uranium and nitrate trends in 0940 river samples are comparable to those at the upstream 0898 (or 0967) background locations. During this reporting period, uranium concentrations from unfiltered background samples exceeded those measured in samples from downstream location 0940.



Note:
Since 2008, both filtered (•) and unfiltered (o) samples have been collected at each San Juan River location. At times, filtered results have been comparable to or equal to the unfiltered results. In these cases, the unfiltered (o) result is obscured by the filtered result in this figure.

Figure 11. Uranium and Nitrate Concentrations in Samples from San Juan River Location 0940 and Background Locations

3.3 Terrace System Subsurface Conditions

The discussion of current subsurface conditions on the terrace is based on the collection and analysis of groundwater level data through March 2016. Analyses of water-level trends and drain flow rates associated with the terrace are discussed below. Results are compared to baseline conditions established in the Baseline Performance Report (DOE 2003) to evaluate the effectiveness of the terrace treatment system.

Currently, there are no concentration-driven performance standards for the terrace system because the compliance strategy is active remediation to eliminate exposure pathways at escarpment seeps and at Bob Lee and Many Devils Washes. As a best management practice, however, contaminant concentrations are measured at each extraction well, drain, and seep and at select monitoring wells across the site.

3.3.1 Terrace Groundwater Level Trends

Approximately 1.6 million gallons of groundwater were pumped from the nine terrace extraction wells between April 2015 and March 2016 (Table 3). As of April 1, 2016, the cumulative volume of water removed from the terrace (excluding Bob Lee and Many Devils washes) is approximately 19 million gallons (Table 4). Groundwater level data from the terrace collected during the March 2016 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). Figure 12 shows a quantitative map view of some of the changes in groundwater elevations during this period for both alluvial and Mancos Shale wells. Of the 31 water-level measurements taken in September 2015 or March 2016 at terrace wells screened in alluvium, the majority showed declines relative to the baseline period of March 2003. Differences ranged from a maximum decrease of 8.23 ft to a maximum increase of 1.58 ft in terrace wells 0836 and 0828, respectively. The average change in terrace alluvial wells was about 2 ft.

Three alluvial west terrace wells—1060, 1120, and 1122—were dry during both the September (2015) and March (2016) sampling events. These wells have been dry for at least 7 years (see Appendix B hydrographs).

To support the observation of declining water levels across the terrace, Figure 13, Figure 14, and Figure 15 are also presented. Figure 13 shows that many seeps on the west terrace have been dry since 2008 alongside dry terrace wells. Figure 14 plots groundwater elevations in terrace alluvial wells (only), showing contours for both baseline (March 2003) and current (March 2016) periods. Figure 15 depicts groundwater saturated thickness in terrace alluvium, using (automated) contours for both (February 2000 and current March 2016) periods. Table 5 includes an estimate of liquid volume for both dates based on these depictions and a volumetric reduction of about 81 percent in the south terrace vicinity with active remediation. The volumetric reduction approximated with this method (approximately 21.7 million gallons) was relatively close to the 19 million gallons (cumulative) measured entering the evaporation pond from terrace alluvium pumping. These figures, table, and findings demonstrate that groundwater elevations have declined across much of the terrace groundwater system.

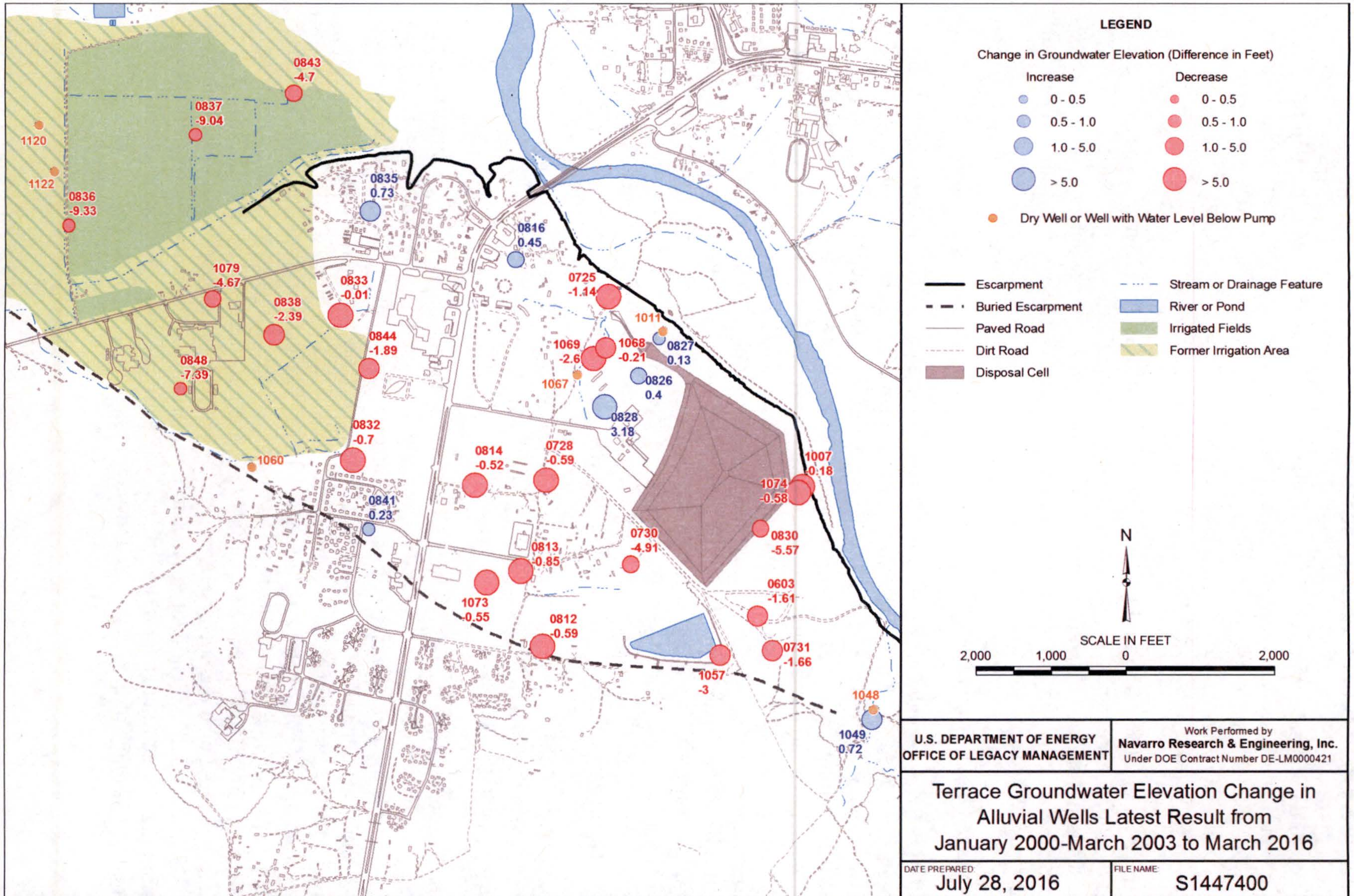


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Figure 12. Terrace Groundwater Elevation Changes from Baseline (2000–2003) to Current (March 2016) Conditions

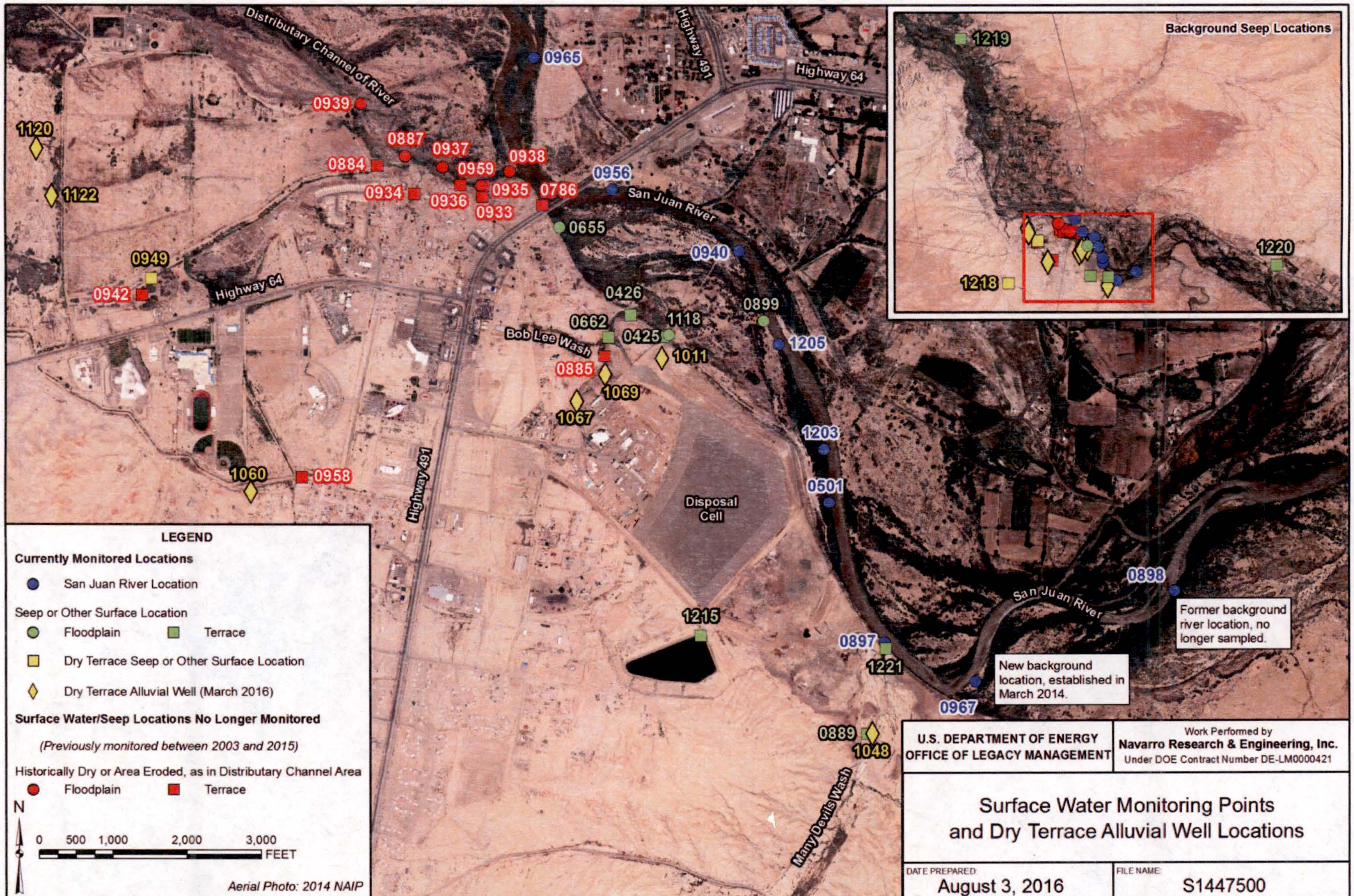

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Figure 13. Current and Previous Surface Water Monitoring Locations at the Shiprock Site
Locations of Current Dry Wells Also Shown To Allow Comparison with Dry Seep Locations

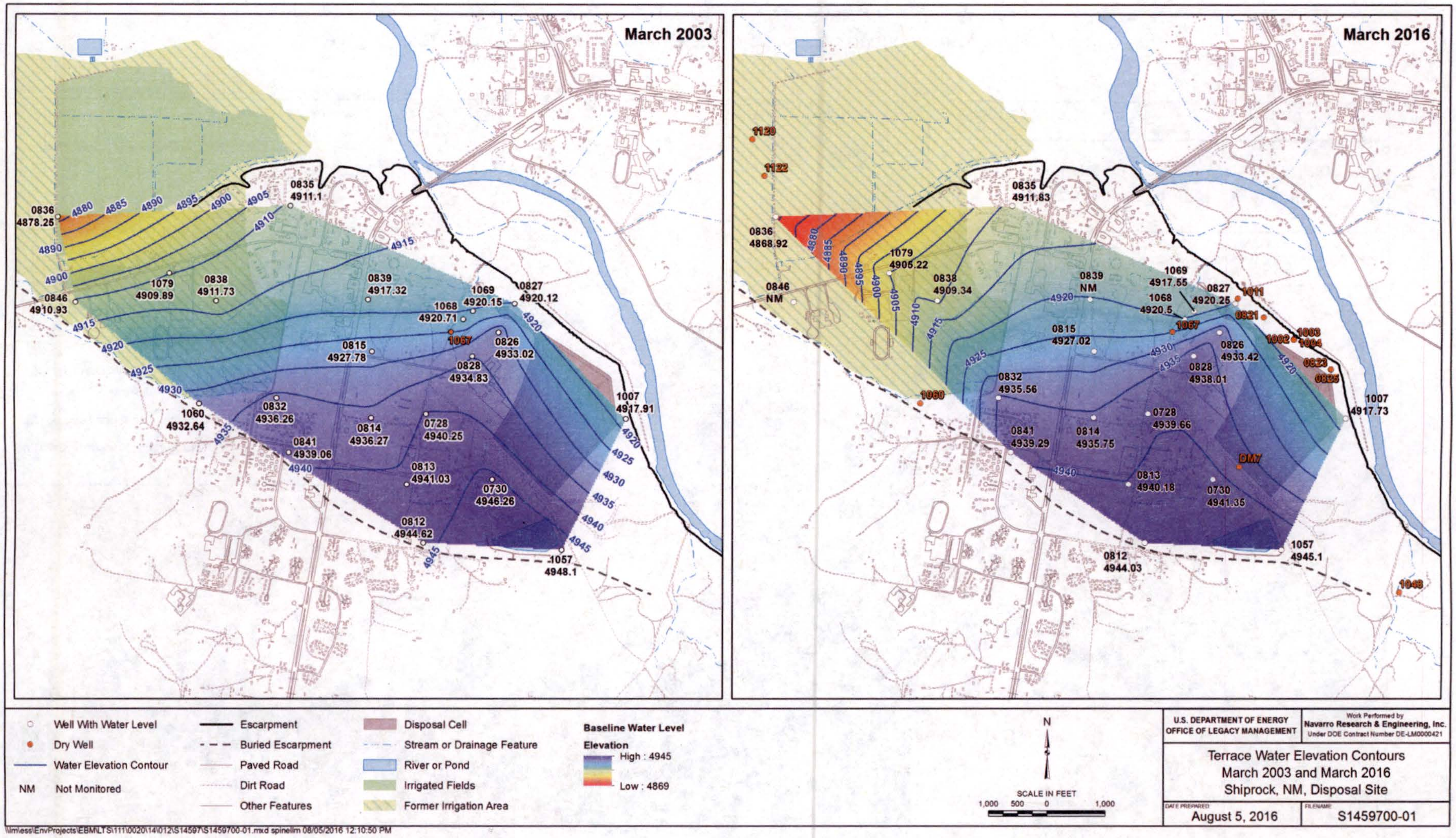

Figure 14. Terrace Water Elevation Contours: March 2003 (Baseline) and Current (March 2016)

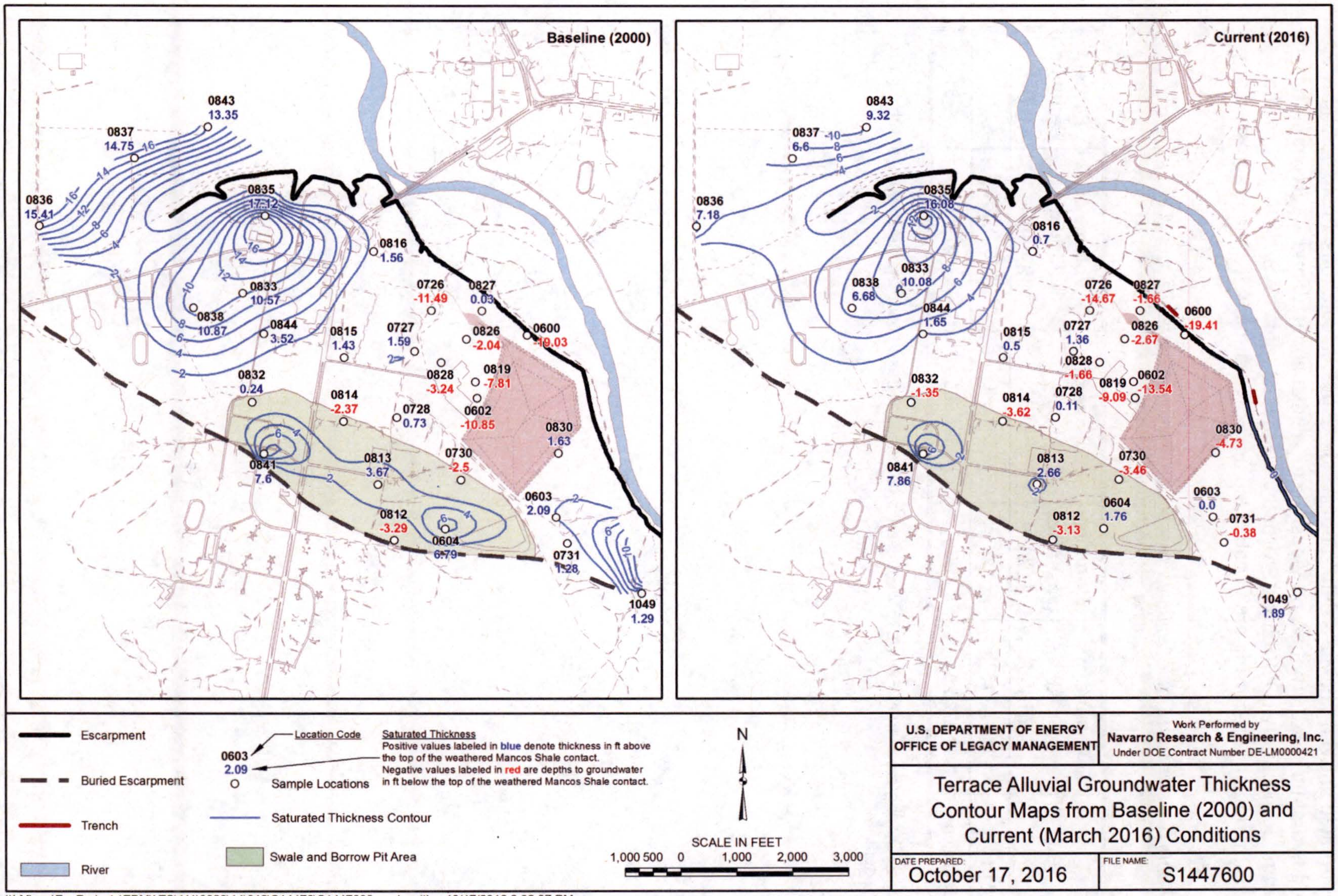

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Figure 15. Terrace Alluvial Groundwater Thickness Contour Maps from Baseline (2000) and Current (March 2016) Conditions

Note: Positive (blue) values represent the thickness of the saturated alluvium above the top of the weathered Mancos Shale (bedrock) contact. For wells in which water levels are below this contact, negative (red) values represent the depth of the water table below bedrock.

Groundwater contamination does exist in the weathered Mancos Shale; however it was not included in saturated alluvial thickness delineations and volume calculations due to much lower porosities and hydraulic conductivities, previously estimated at about 20 and 2 percent of the terrace alluvium, respectively (DOE 2000). Also, the weathered Mancos Shale thickness and degrees of weathering and fracturing are variable and unknown at many locations across the terrace.

Table 5. Estimated Liquid Volume Present and Removed in the Terrace Alluvium Active Remediation Vicinity

	Volume of Solid (ft^3)	Porosity (assumed) (%)	Volume of Liquid (ft^3)	Volume of Liquid (gallons)	Percent Reduction (%)
February 2000 Depiction	11,975,132	30	3,592,540	26,874,061	
March 2016 Depiction	2,273,284	30	681,985	5,101,603	81

Note:
Only south terrace shaded areas from Figure 15 were used in calculations based on integrated volumes within the 2-foot contour extent.

Abbreviation:
ft^3 = cubic feet

4.0 Performance Summary

This section summarizes the findings of the most recent (April 2015 through March 2016) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the 13th year of active groundwater remediation.

- Groundwater in the floodplain system is currently being extracted from two wells (wells 1089 and 1104) adjacent to the San Juan River north of the disposal cell, two collection trenches (Trenches 1 and 2), and a seep collection sump. Approximately 11.8 million gallons of groundwater were extracted from the floodplain aquifer system during this performance period, yielding a cumulative total of about 133 million gallons extracted from the floodplain since March 2003.
- Groundwater in the terrace system is currently being extracted from a drainage trench (Bob Lee Wash) and nine extraction wells. From April 2015 through March 2016, approximately 4.1 million gallons of groundwater were extracted from the terrace system, yielding a total cumulative volume (extracted since March 2003) of about 44.8 million gallons. The cumulative volume removed from both terrace and floodplain combined (as of April 1, 2016) is about 178 million gallons.
- During this reporting period, no groundwater was pumped from Many Devil Wash, given the need for extensive repairs of the interceptor drain.
- Terrace-wide, groundwater levels in the majority of alluvial wells sampled during this performance period declined relative to the baseline period (2000–2003); average and maximum decreases were 2.0 and 8.2 ft, respectively. Four alluvial west terrace wells were dry during this reporting period, and several seeps on the west terrace have been dry since 2008.
- The remediation system is effectively removing contaminant mass from the floodplain alluvial aquifer and accelerating the natural flushing process. This contaminated groundwater is pumped to the evaporation pond on the terrace just south of the disposal cell. The estimated masses of sulfate, nitrate, and uranium removed from the floodplain and terrace well fields during this performance period were 743,130 pounds, 28,228 pounds, and 51.8 pounds, respectively.

As observed for the last several years, decreases in contaminant concentrations are evident in selected floodplain wells—most notably in the Trench 1 area. Since Trench 1 was installed in 2006, reductions in concentrations of the primary COCs (nitrate, sulfate, and uranium) are apparent in surrounding wells, especially those on the river side of the trench. Trench 2, when pumped, appears to be lowering COC concentrations near the base of the escarpment. Decreases in COC concentrations in the well 1089 area since remediation pumping began in 2003 are also evident. Exceptions to this general decreasing trend are found at several locations, most notably in near-river wells 0857 and 1136 in the central floodplain, and well 0630 at the base of Bob Lee Wash. No measurable impacts to the San Juan River have resulted from these increases. Relative to observations in previous years, when fairly marked increases in uranium and sulfate levels in near-river wells 1137, 1138, and 1139 were noted, contaminant concentrations in these wells, although still elevated, have stabilized or declined. In general, COC concentrations in samples collected from the San Juan River have been below established benchmarks and/or comparable to upstream (background) locations.

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Appendix A

Time–Concentration Graphs for Nitrate, Sulfate, and Uranium in Floodplain Monitoring Wells

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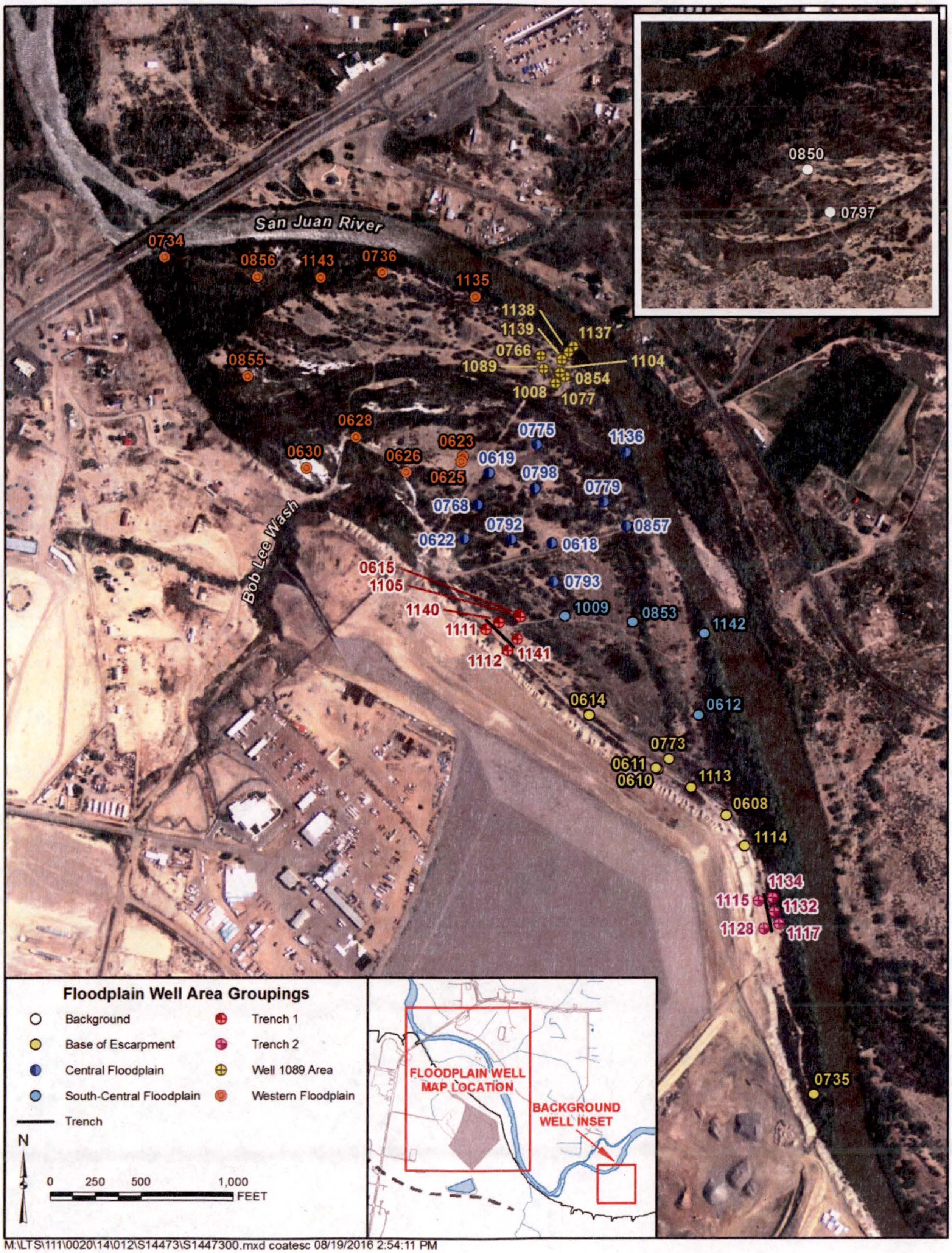

Figure A-1. Shiprock Site Floodplain Well Groupings

Figure repeated from Figure 9 of main report. The groups shown here are used as the basis for subsequent time–concentration plots.

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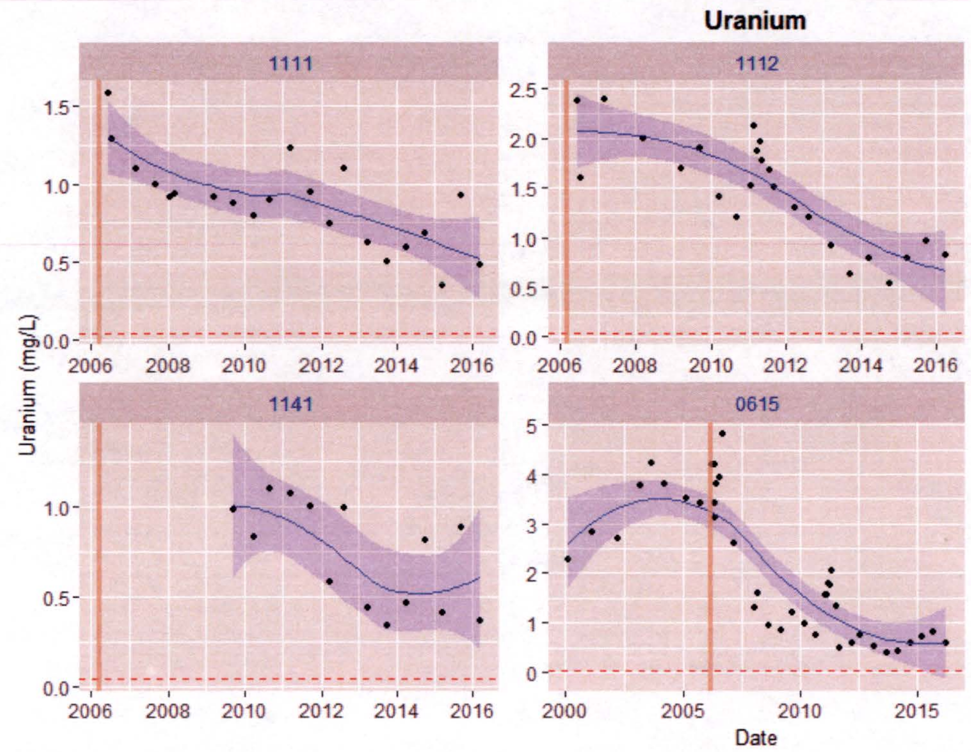
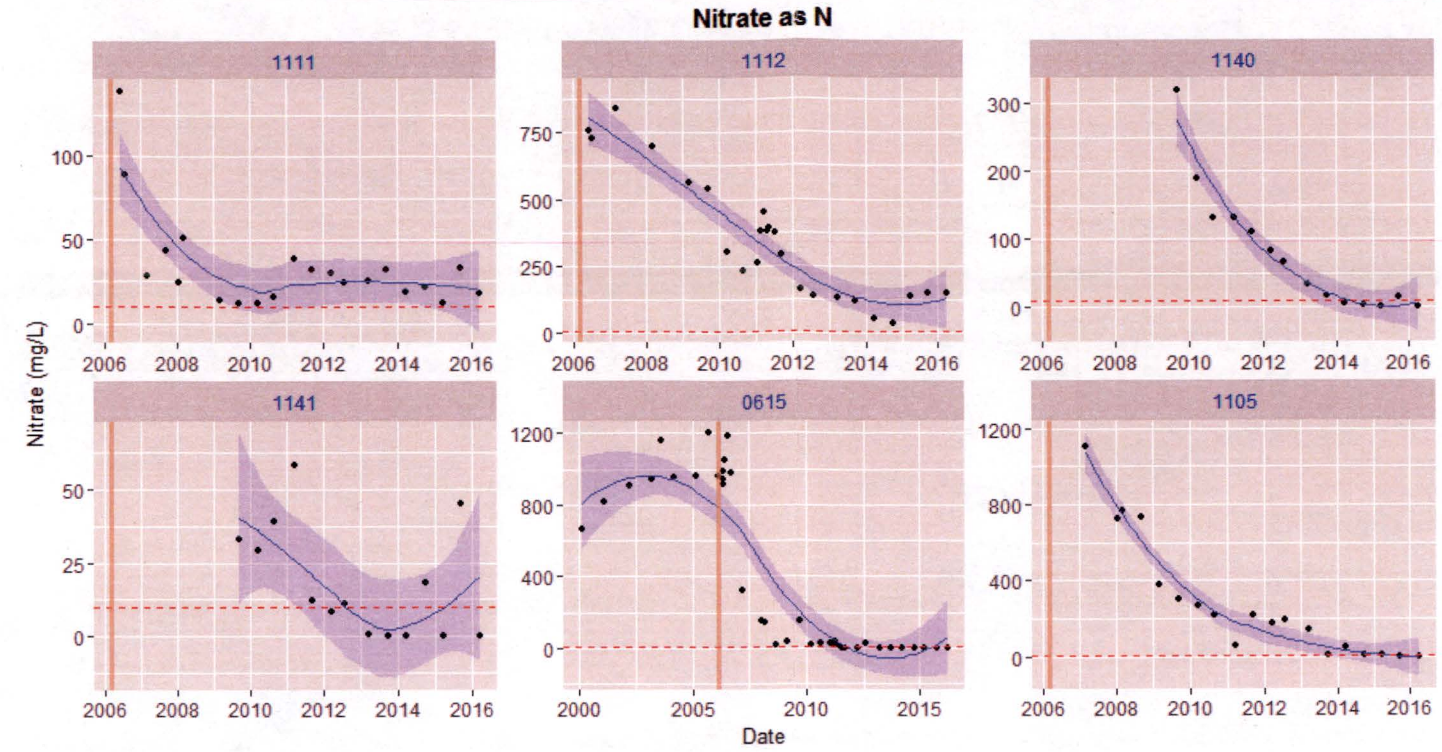
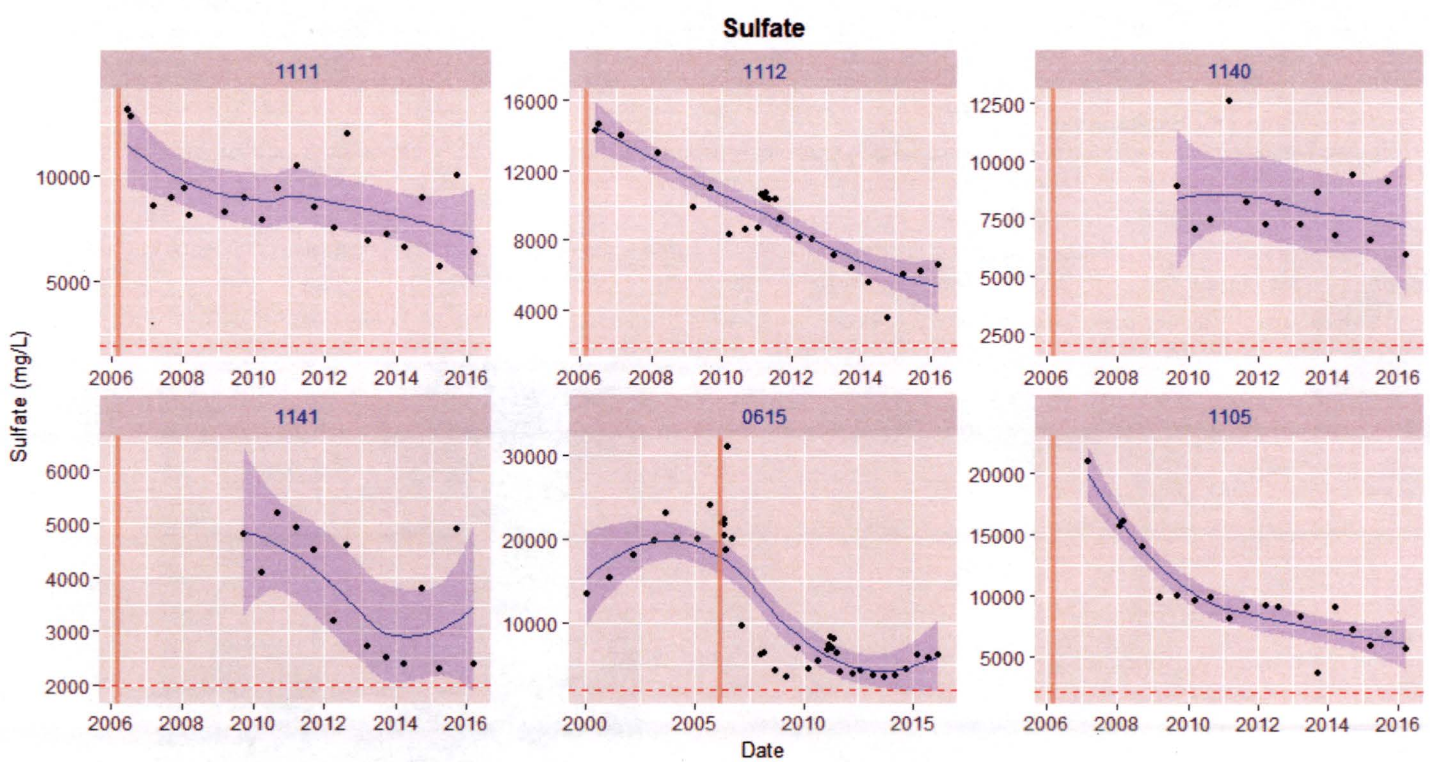






Time–Trend Plot Explanation.

In contrast with the traditional grouped line plots provided in previous annual reports (before 2015), data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*- (date) and *y*-axis scales are unique for each well. In this and subsequent figures, a nonparametric smoothing method or locally weighted regression— LOESS (not to be confused with the geologic term)—is used.† With this approach, overall trends in the data are more apparent and not obscured by "noise." In each plot, wells are listed in order of increasing distance from the escarpment, shown in the inset below.

——— blue line is a LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval

- - - - denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate

Vertical line | denotes time when Trench 1 was installed, in spring 2006.

† See: https://stat.ethz.ch/R-manual/R-devel/library/stats/html/loess.html
http://docs.ggplot2.org/0.9.3.1/stat_smooth.html

and

W.S. Cleveland, E. Grosse, and W. M. Shyu. 1992. Local regression models. Chapter 8 of *Statistical Models in S*, eds. J.M. Chambers and T.J. Hastie, Wadsworth & Brooks/Cole.

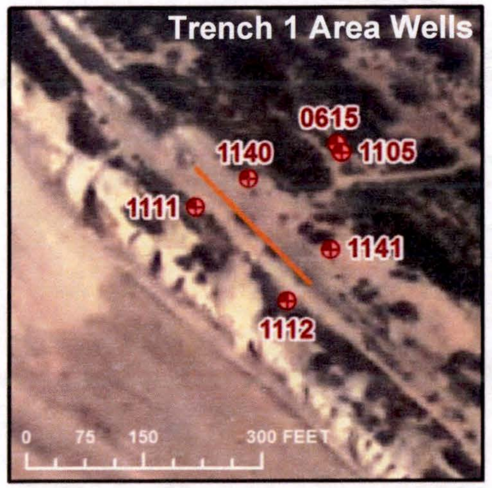
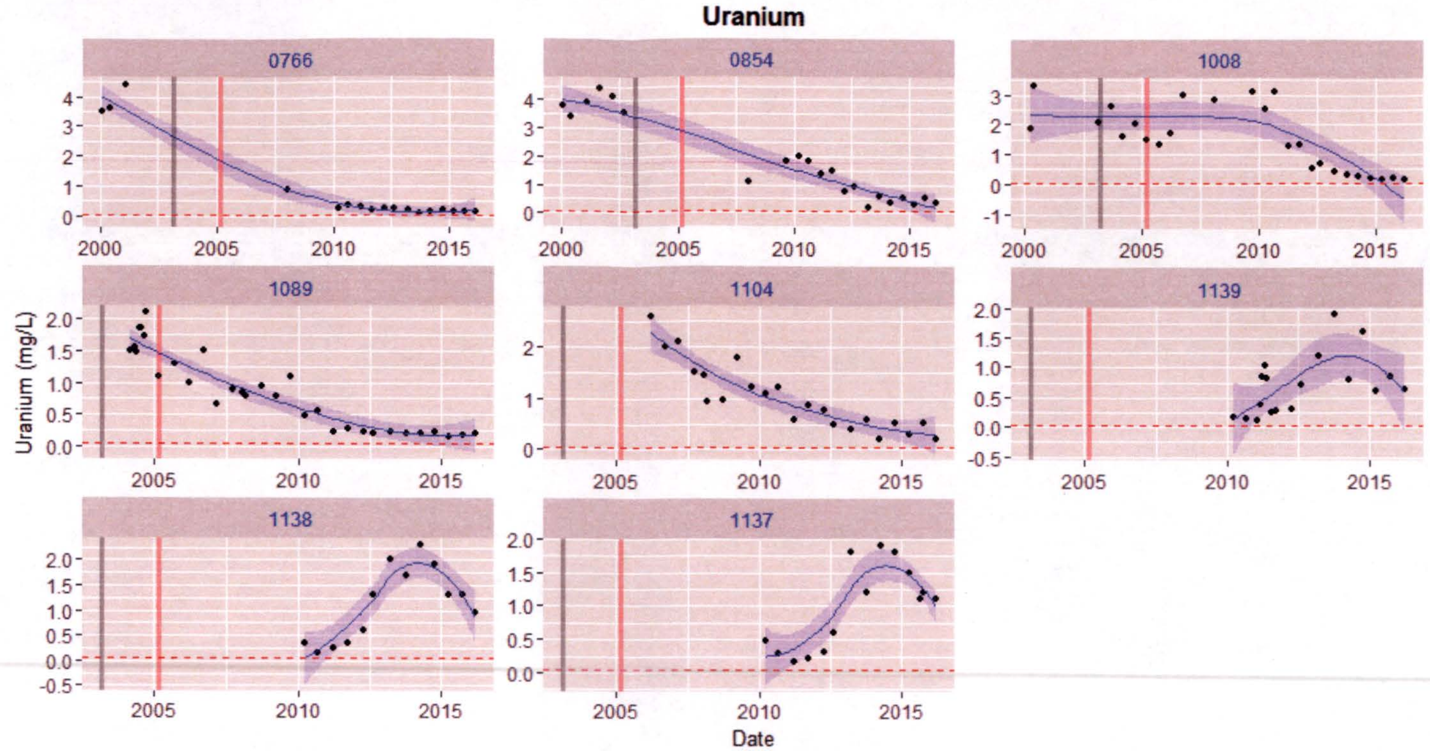
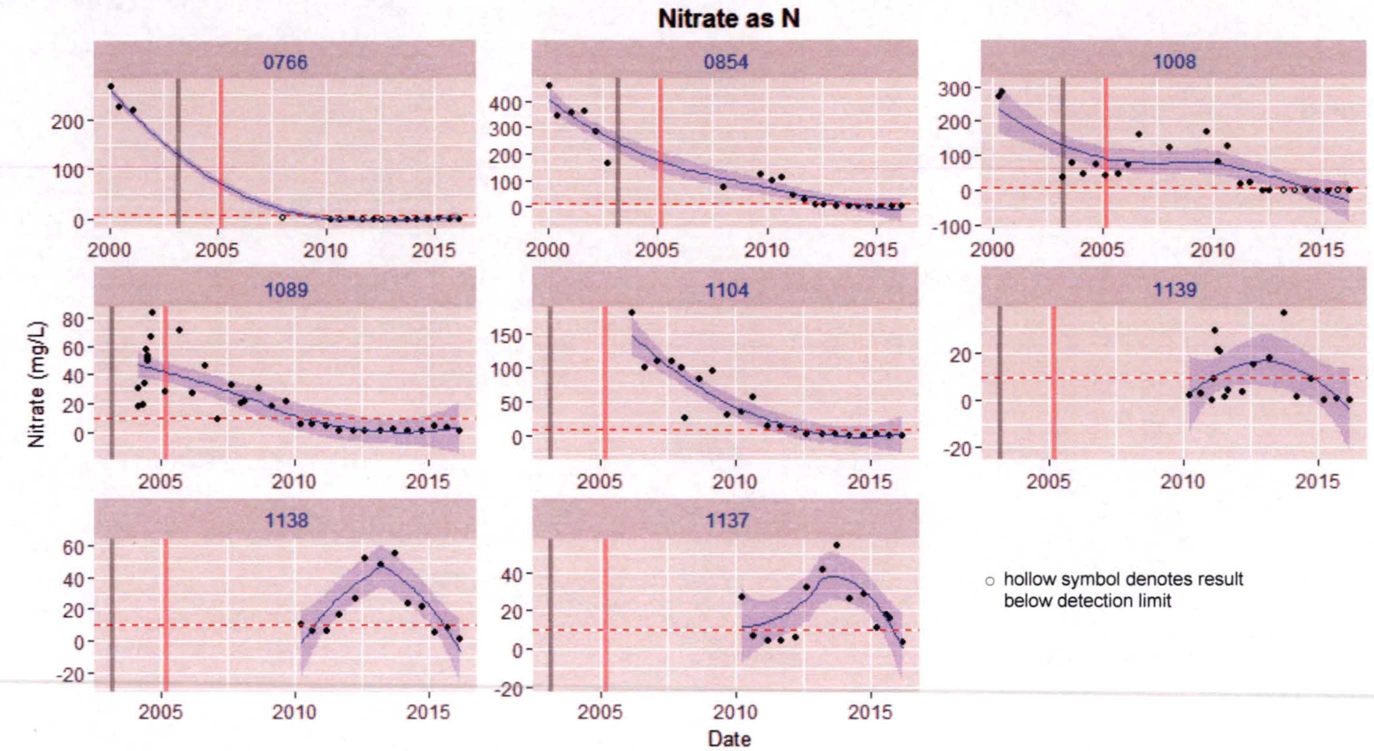
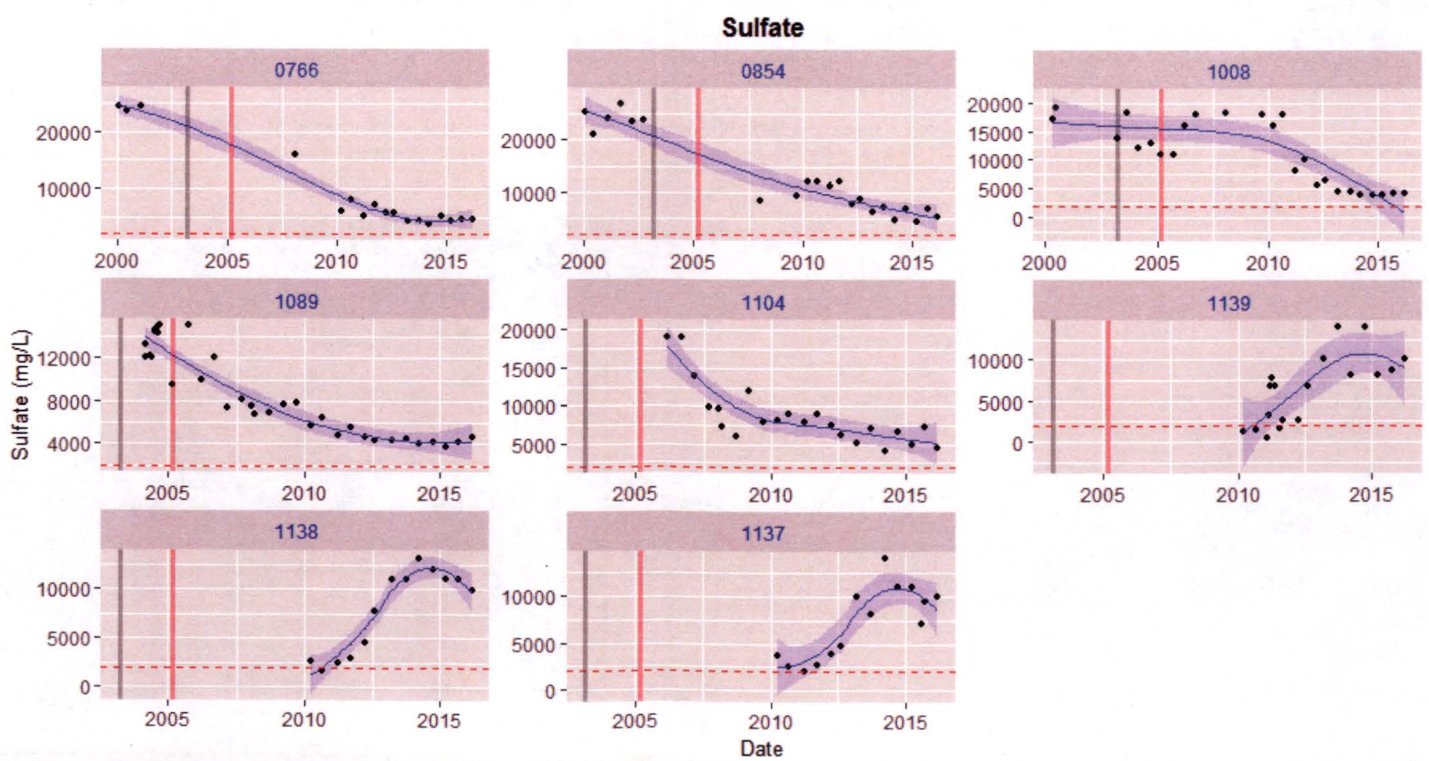


Figure A-2. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 1 Area Wells: 2000–March 2016







Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*- (date) and *y*-axis scales are unique for each well (refer to Figure A-2 explanation). In each plot, near-river wells 1137, 1138, and 1139 are listed in order of increasing distance from the remediation area (see inset).

—— blue line is a LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval

- - - - denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate

Vertical lines | | denote periods corresponding to installation of well 1089 (spring 2003) and well 1104 (spring 2005).

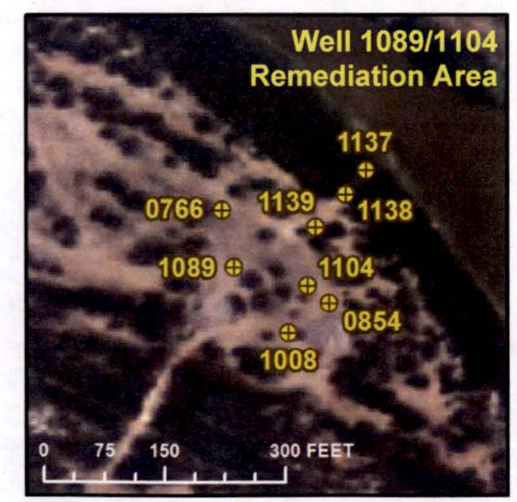
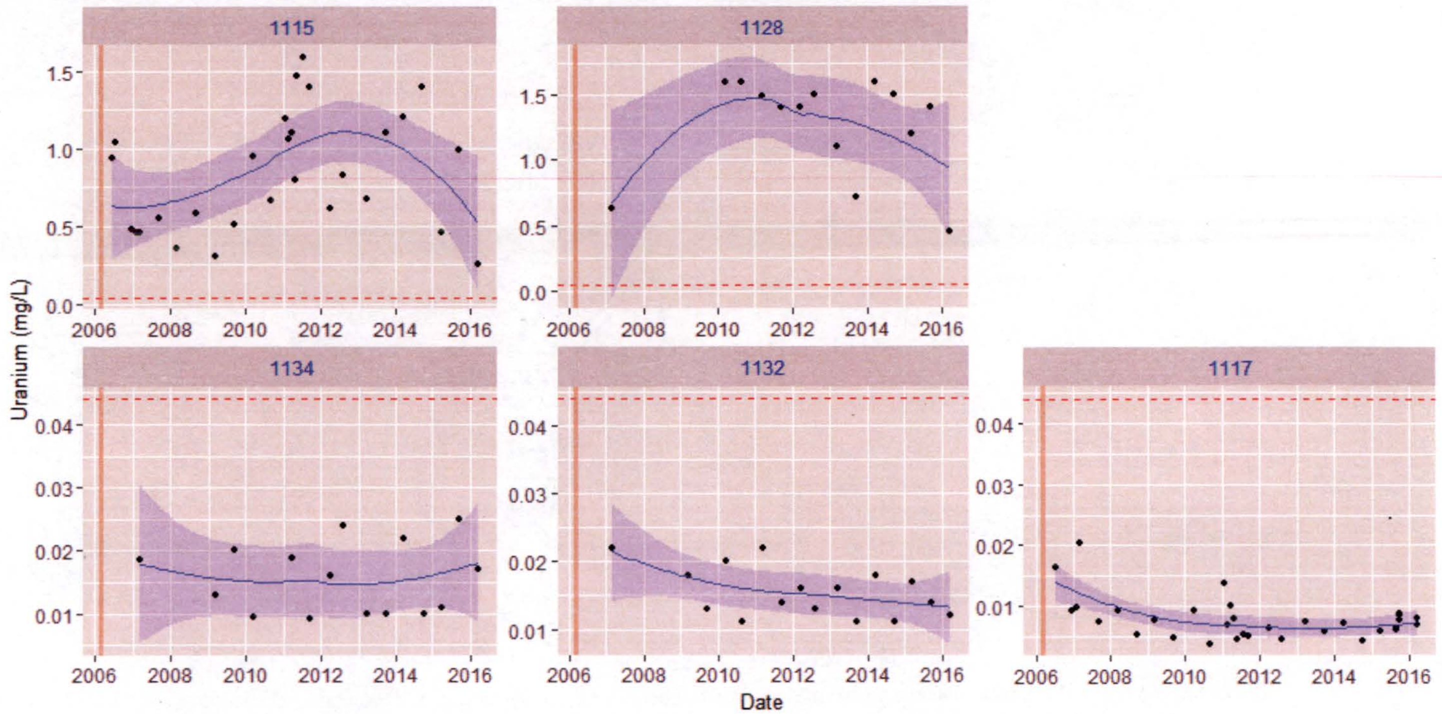


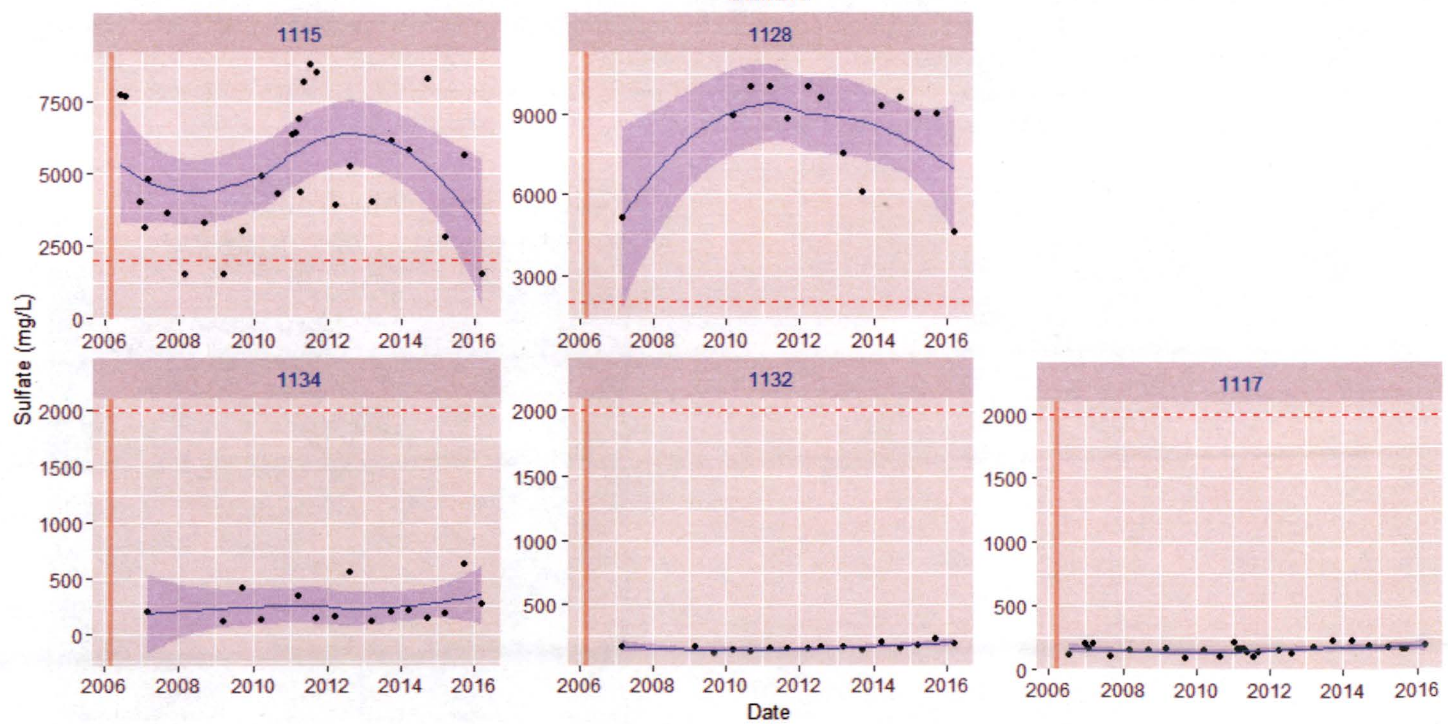
Figure A-3. Uranium, Nitrate, and Sulfate Concentration Trends in the Well 1089/1104 Remediation Area: 2000–March 2016

Uranium



Nitrate as N

Sulfate



Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*- (date) and *y*-axis scales are unique for each well (refer to Figure A-2 explanation). Wells on the escarpment side of the trench, with the highest contaminant concentrations, are plotted first (in the upper portion of the figure). Wells on the river side of the trench, with markedly lower concentrations, are shown in the bottom portion of each plot (locations shown in inset below).

—— blue line is a LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval

- - - - denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate

Vertical line | denotes time when Trench 2 was installed, in spring 2006. Trench 2 wells were installed between June 2006 and February 2007.

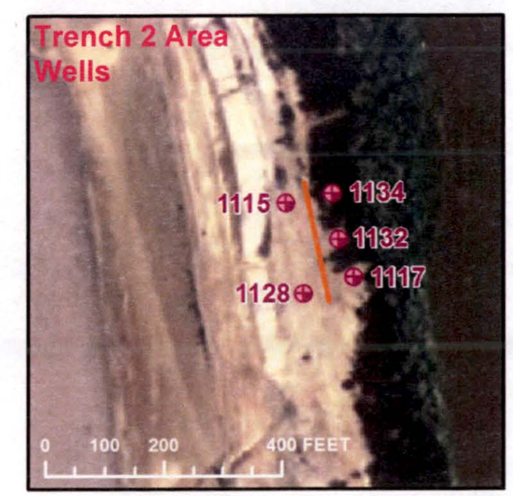
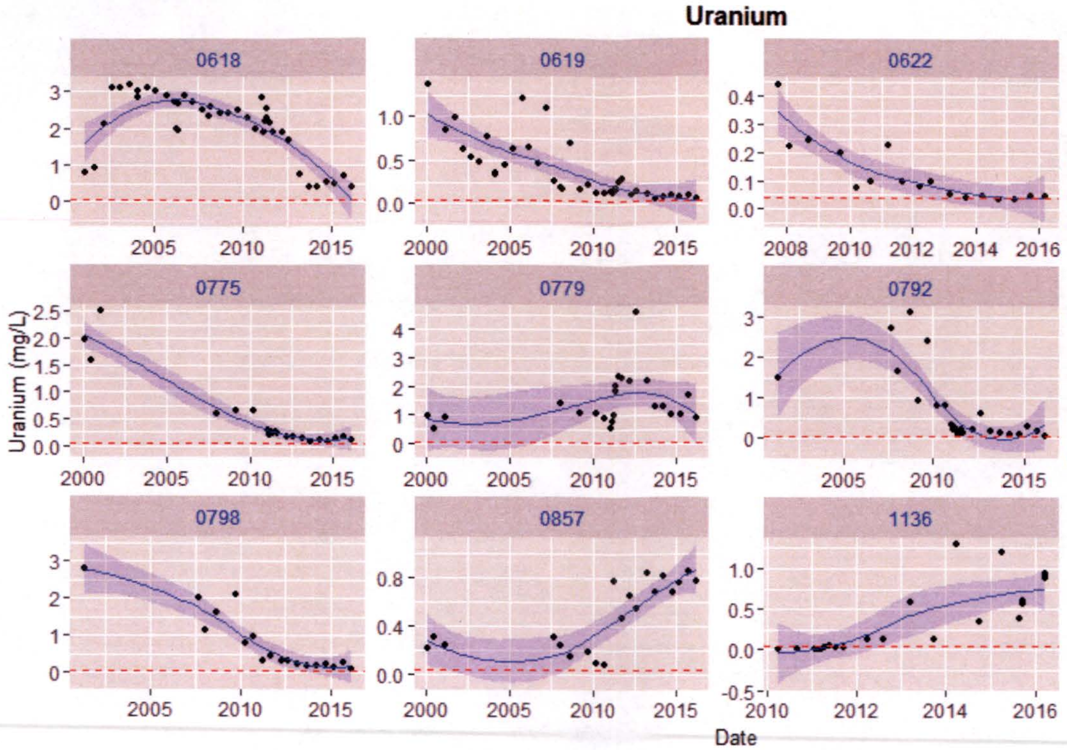
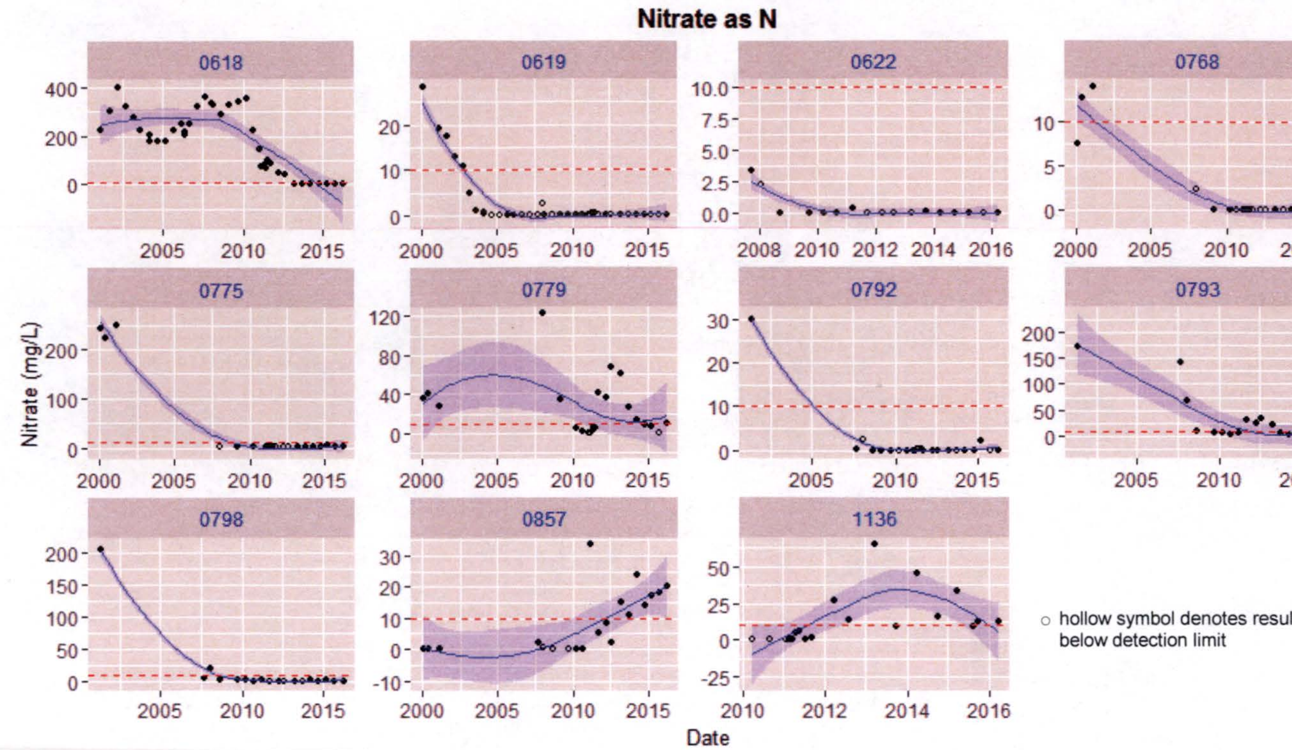
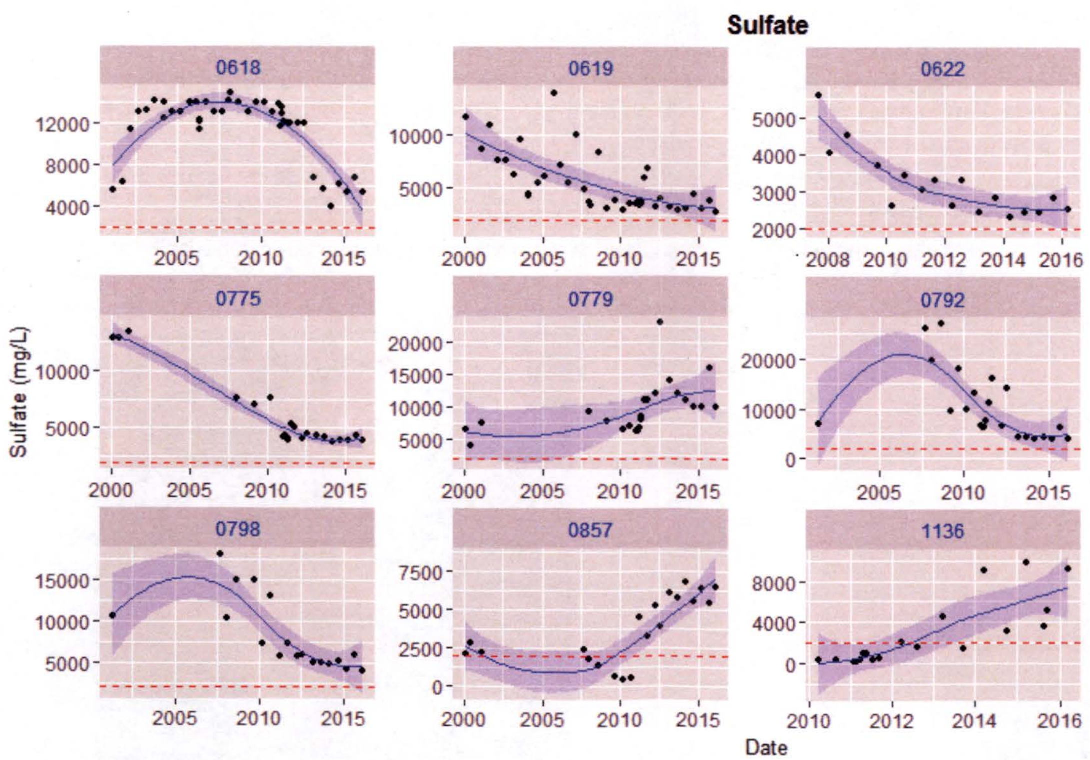


Figure A-4. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 2 Area Wells: 2006–March 2016







Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*- (date) and *y*-axis scales are unique for each well (refer to Figure A-2 explanation).

——— blue line is a LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval

- - - - denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate

Central Floodplain Wells

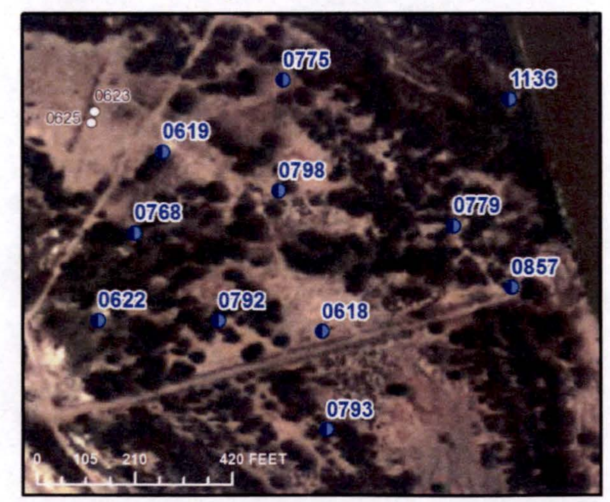
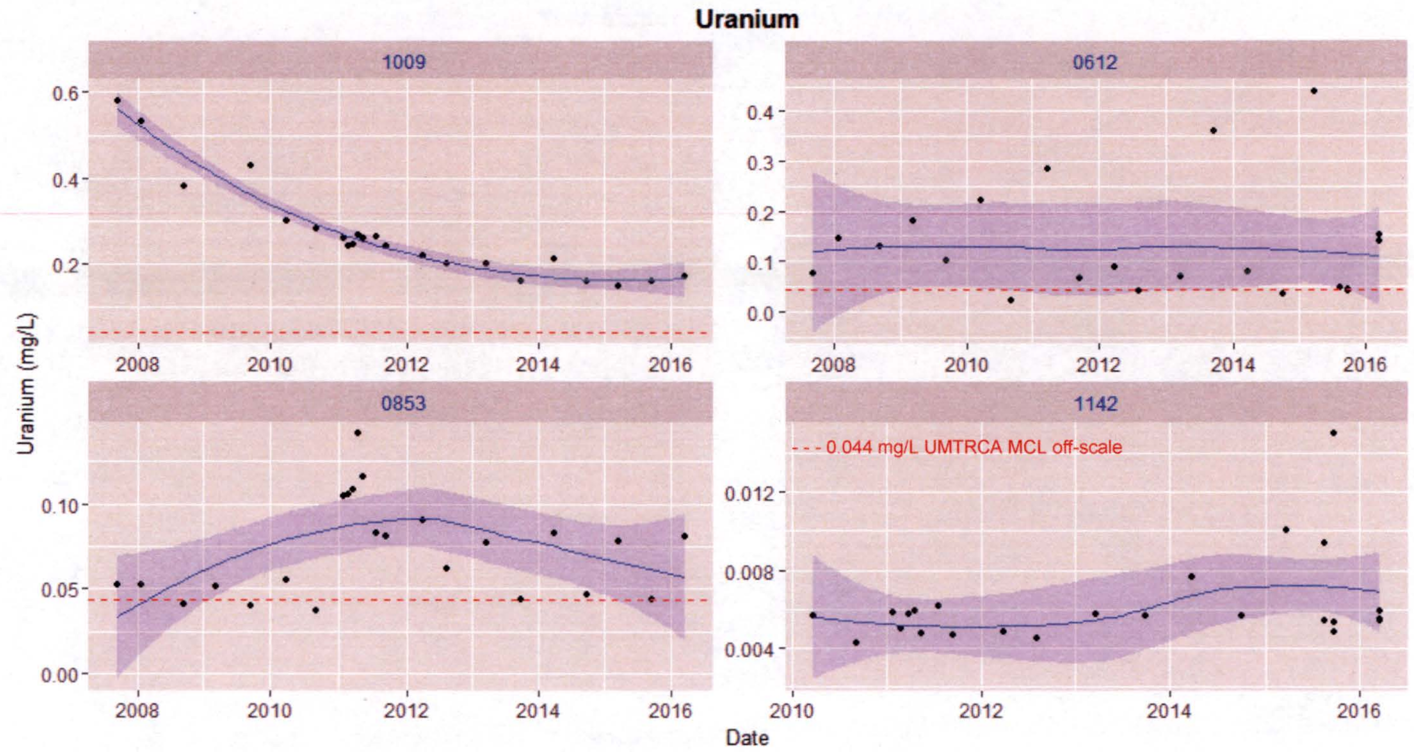
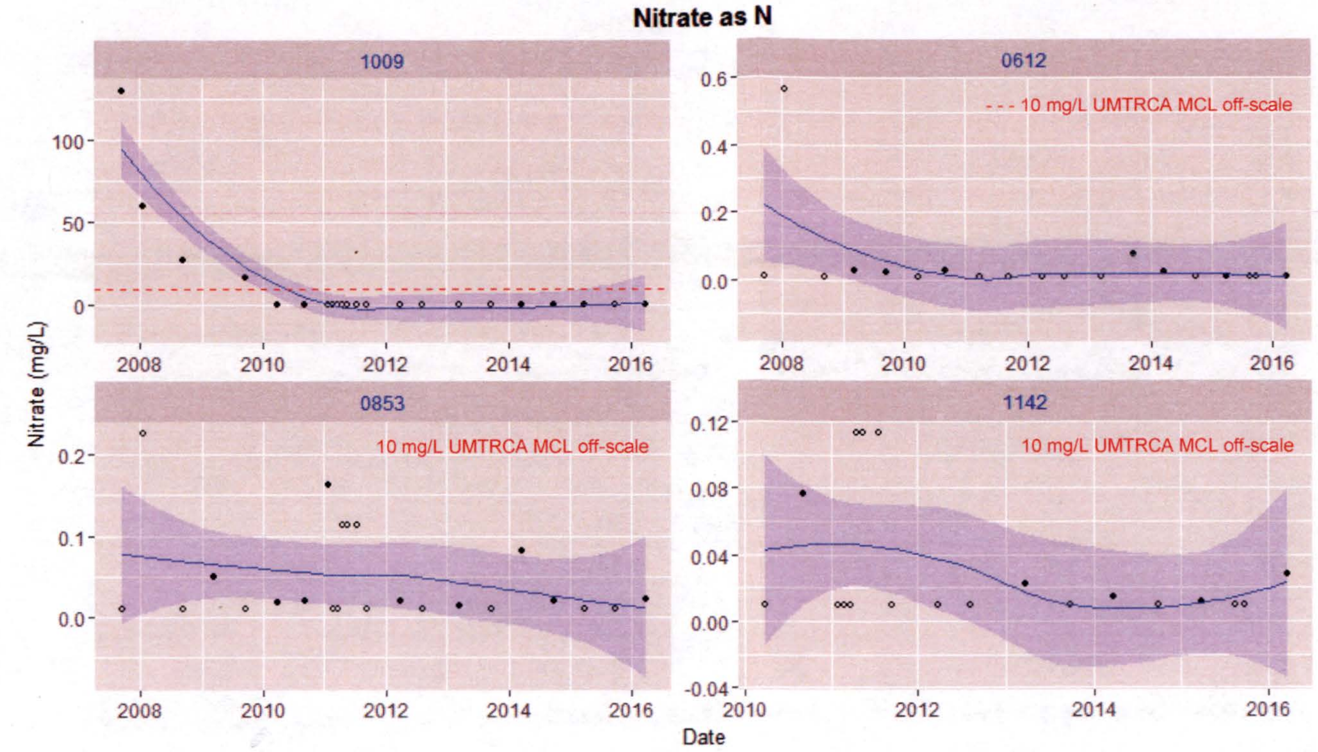
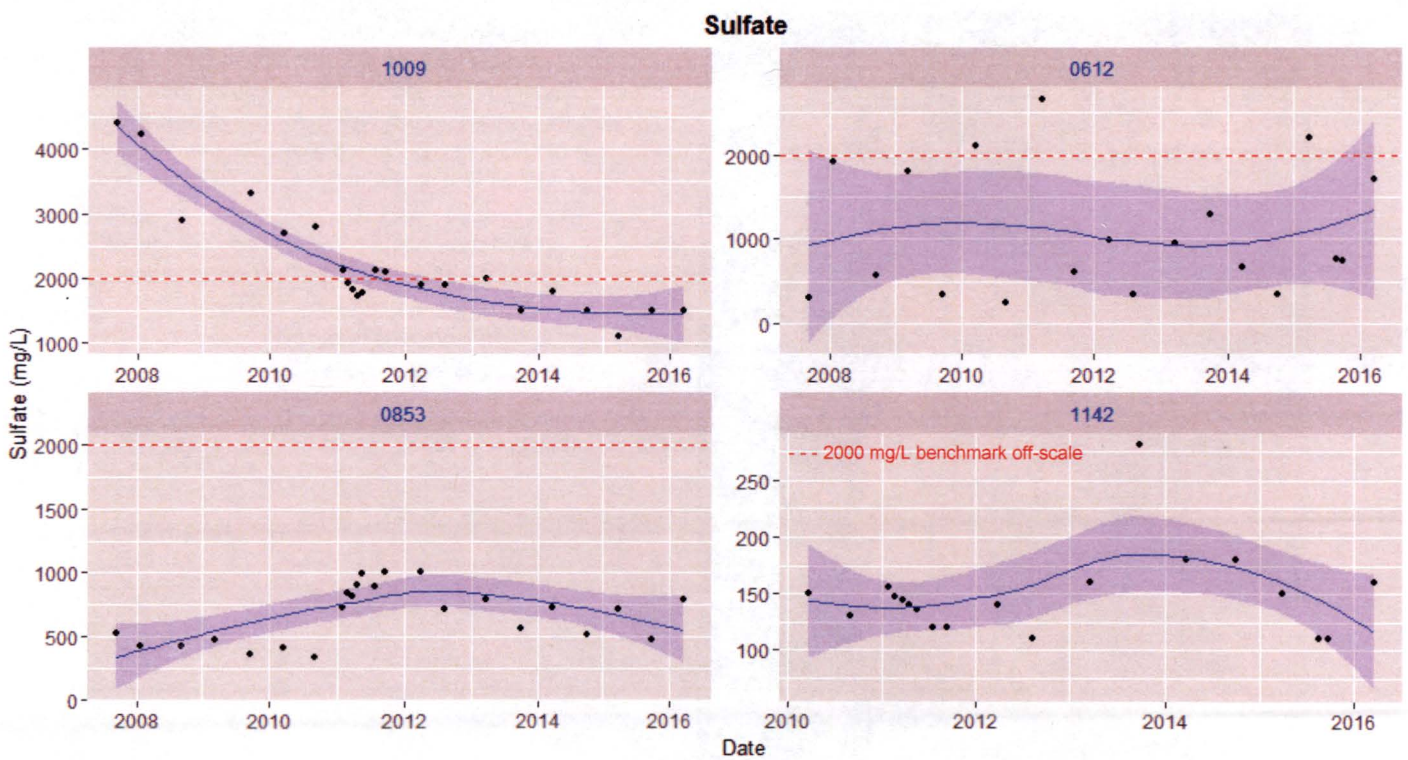


Figure A-5. Uranium, Nitrate, and Sulfate Concentration Trends in Central Floodplain Wells: 2000–March 2016







Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*- (date) and *y*-axis scales are unique for each well. Unlike preceding figures, this figure only includes data for the period 2007–2016 because of the large gap in sampling between 2000–2001 and 2007 for wells 0612, 0853, and 1009. (Well 1142 was installed in January 2010.)

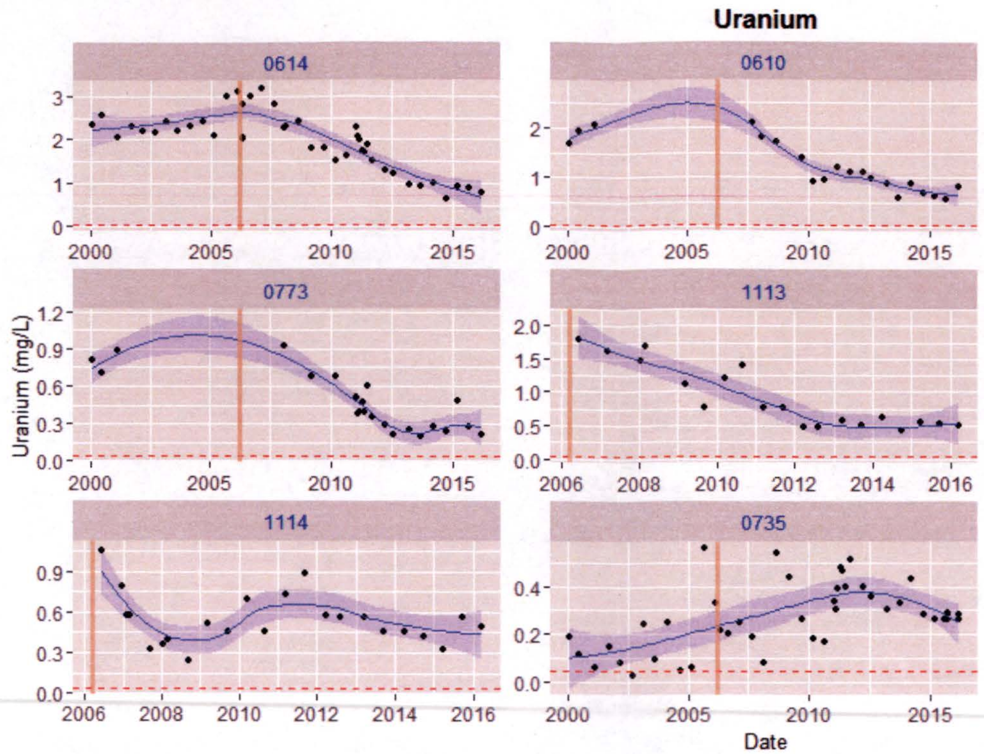
——— blue line is a LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval

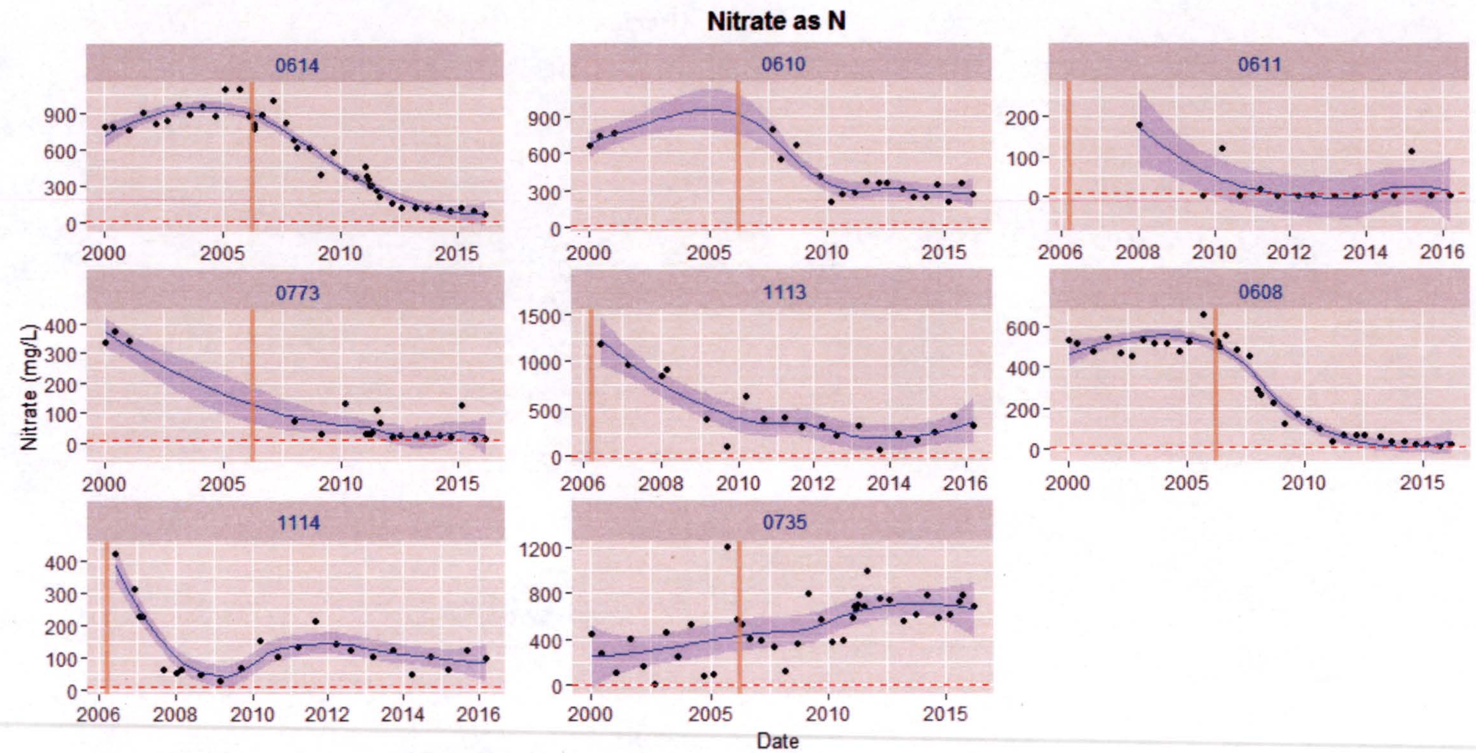
- - - - - denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate
This benchmark is not included in plots for those wells with very low or nondetect contaminant concentrations.

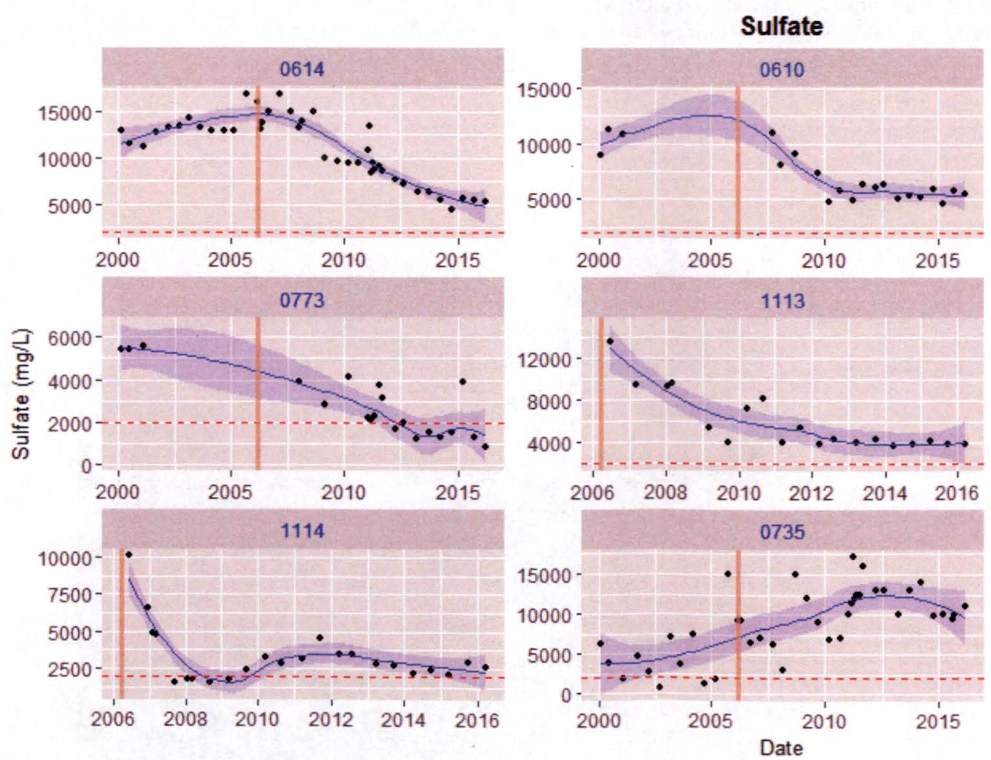
○ denotes result below the detection limit

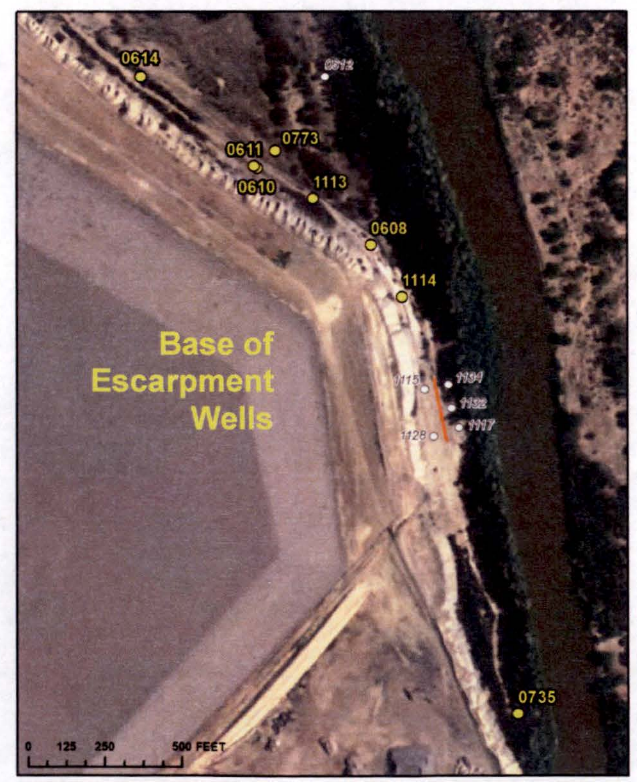
South-Central (Hyporheic) Wells

Figure A-6. Uranium, Nitrate, and Sulfate Concentration Trends in South-Central Floodplain Wells: 2007–March 2016









Time–Trend Plot Explanation.
In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*- (date) and *y*-axis scales are unique for each well (refer to Figure A-2 explanation). In each of the three COC group plots, wells are listed in general order of northwest to southeast direction (see inset to the left).

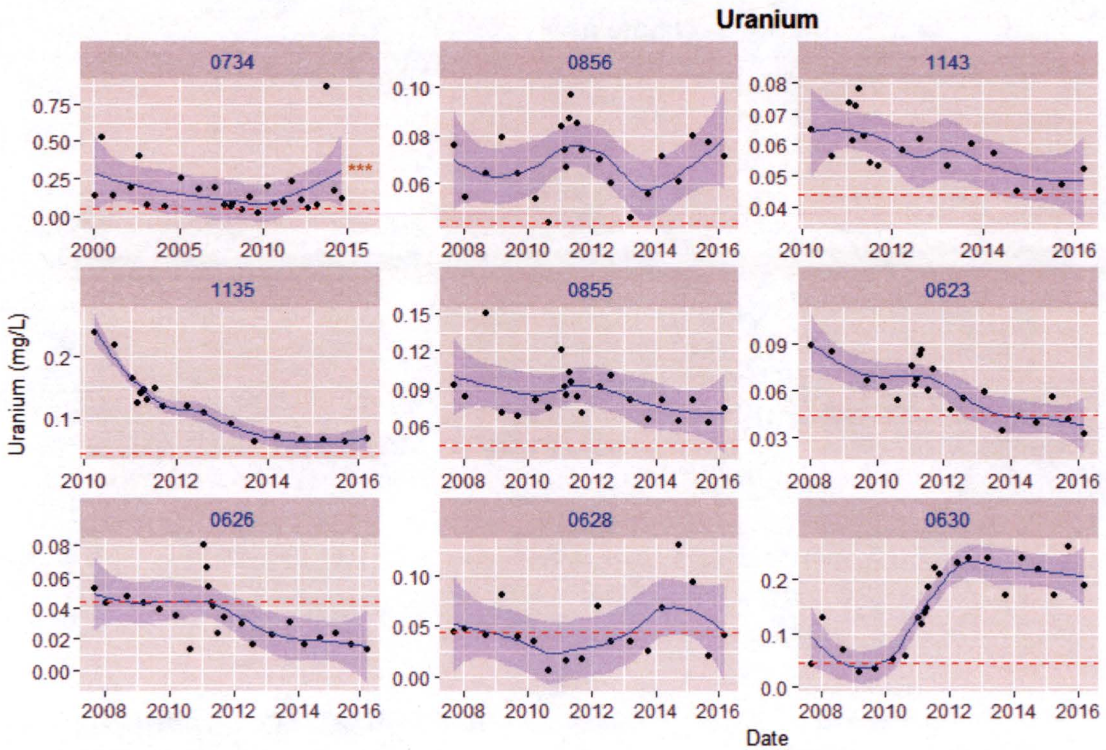
——— blue line is a LOESS local regression line; shaded area is the corresponding 95% pointwise confidence interval

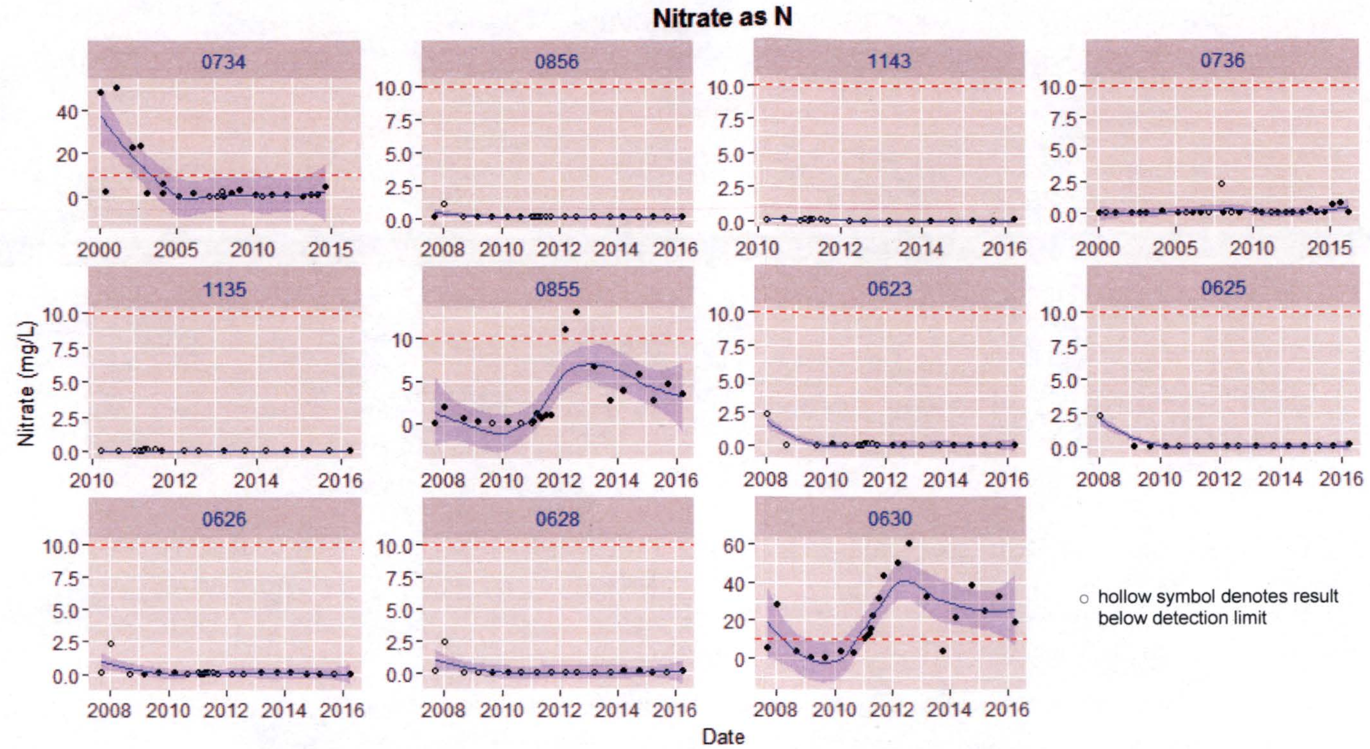
- - - - denotes the 40 CFR 192 MCL or cleanup goal:

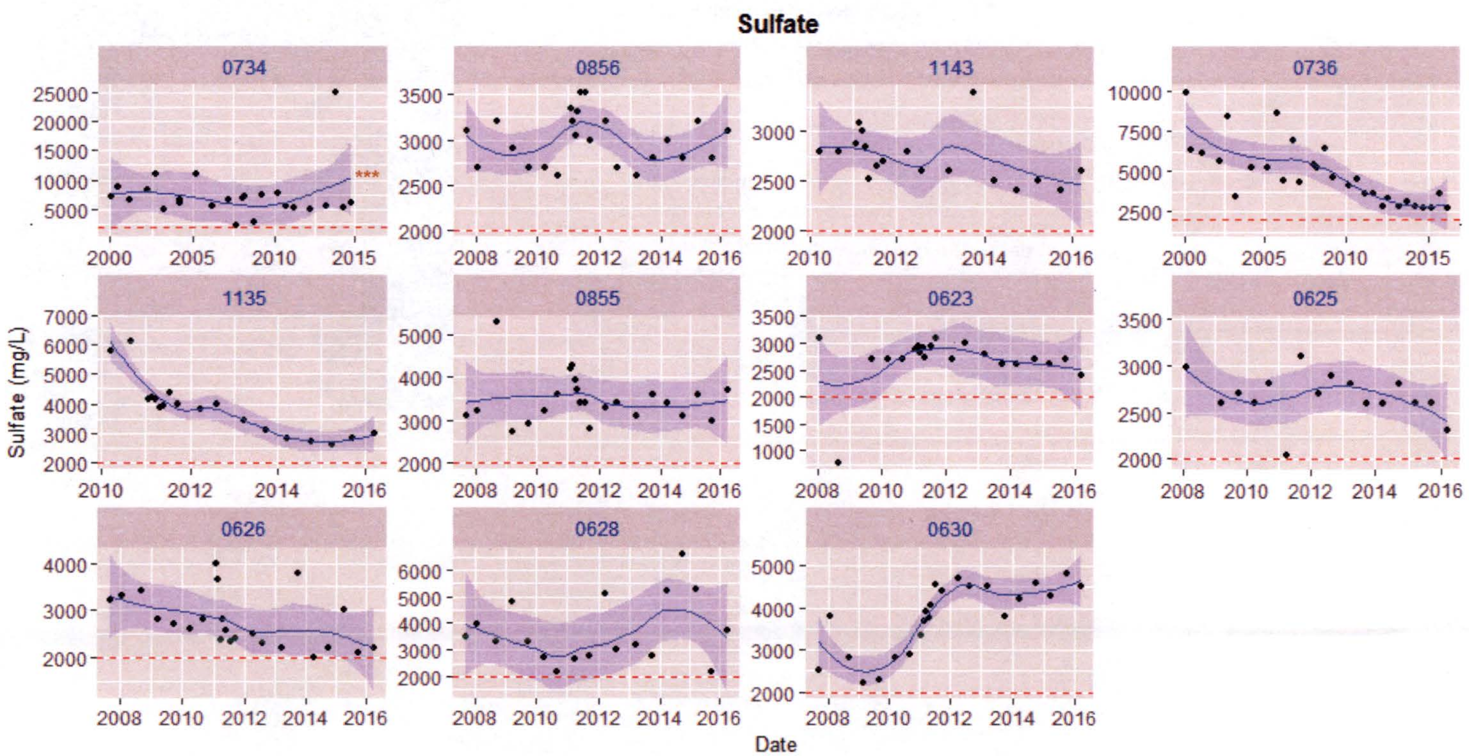
- 0.044 mg/L uranium
- 10 mg/L nitrate as N
- 2000 mg/L sulfate

Vertical line | denotes time when Trench 1 and Trench 2 were installed (in spring 2006).

Figure A-7. Uranium, Nitrate, and Sulfate Concentration Trends in Base of Escarpment Floodplain Wells: 2000–March 2016







Time–Trend Plot Explanation.

For each contaminant, western floodplain wells nearest the river are listed first (west to east direction), followed by well 0855. Remaining wells to the south (near the base of Bob Lee Wash) are listed in numeric order.

Because of the large gap in sampling between 2000–2001 and 2007 for wells 0626, 0628, 0630, 0855, and 0856 (causing a balloonlike appearance of the LOESS smoothing line), early (baseline) results for these wells are not plotted here.

—— blue line is a LOESS local regression line; shaded area is the corresponding 95% pointwise confidence interval

- - - - denotes the 40 CFR 192 MCL or cleanup goal:

- 0.044 mg/L uranium
- 10 mg/L nitrate as N
- 2000 mg/L sulfate

*** At the time of the last three semiannual monitoring events, well 0734 was dry or had insufficient water to sample.

Western Floodplain Wells

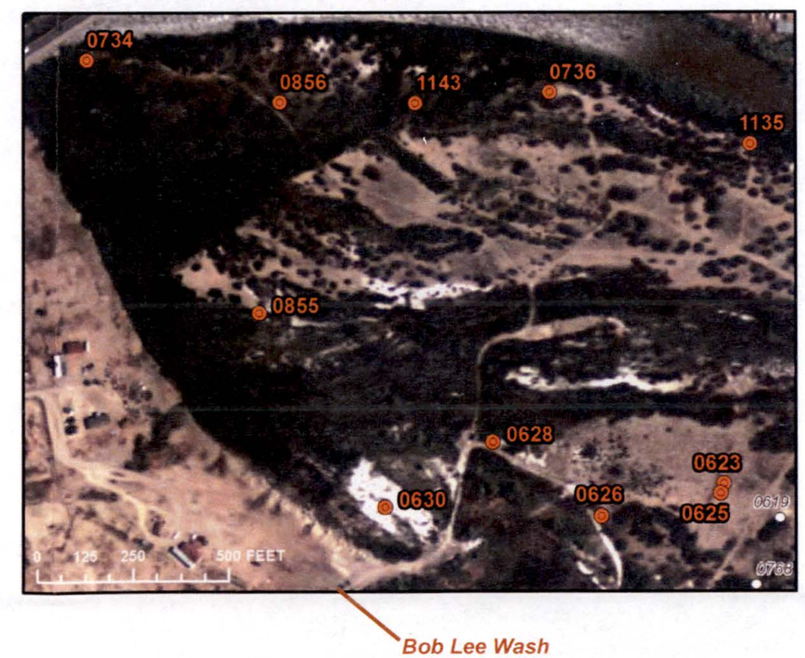
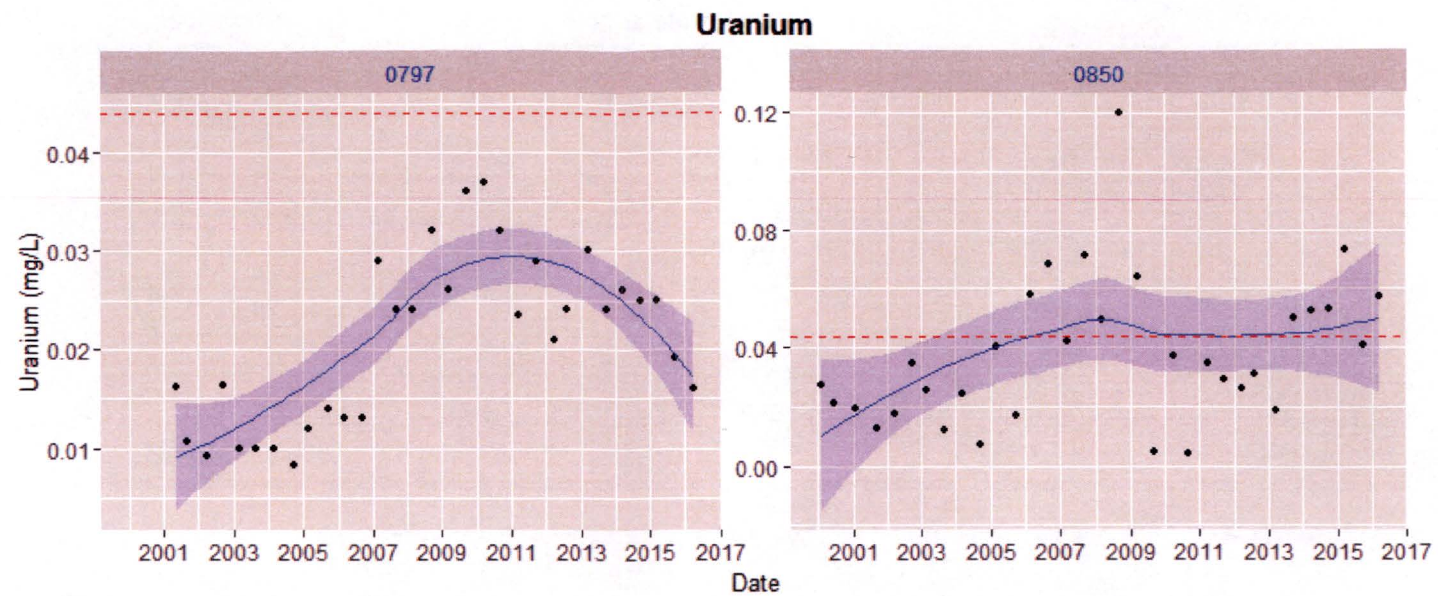
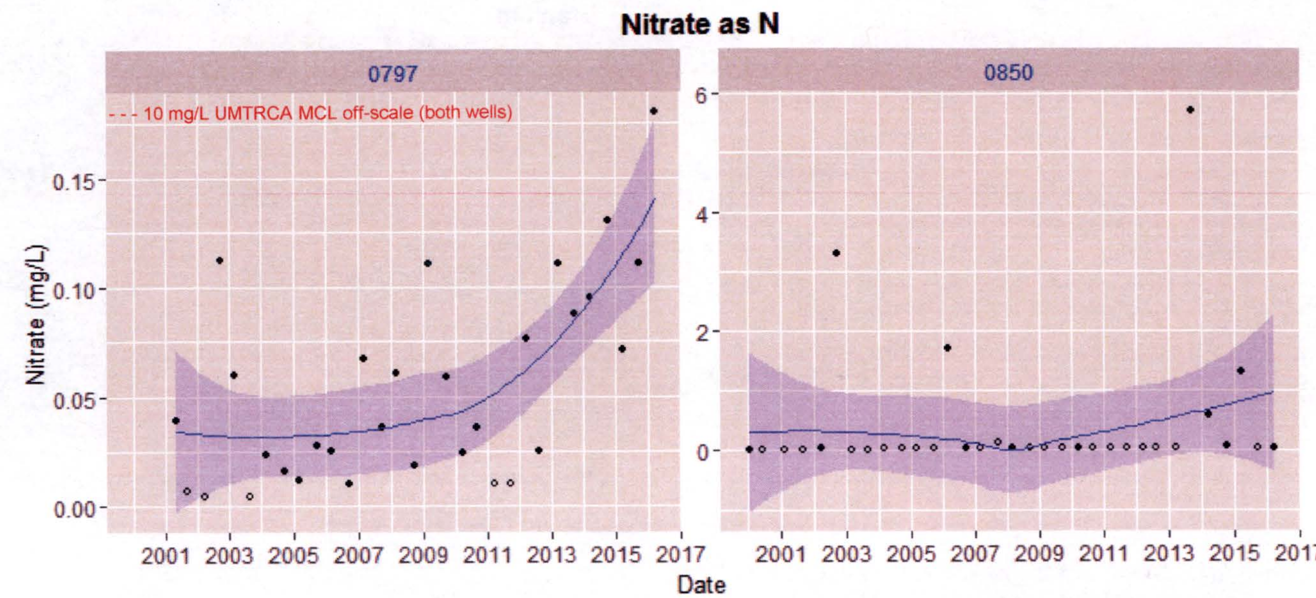
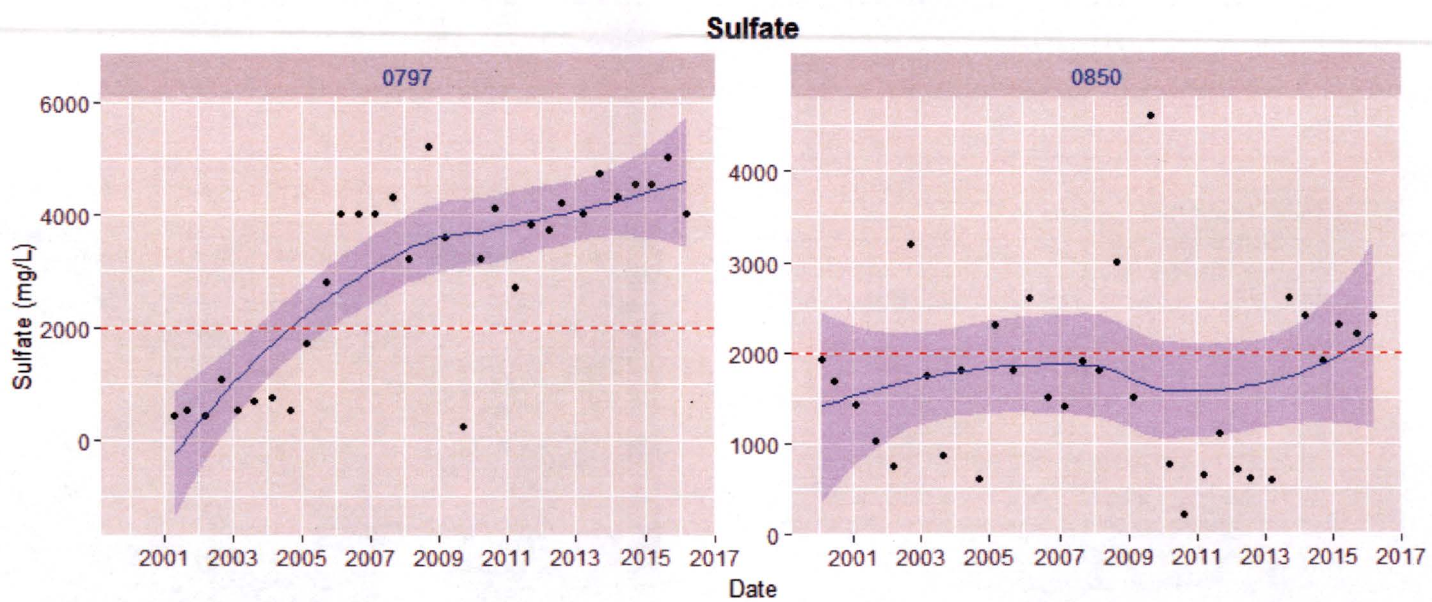


Figure A-8. Uranium, Nitrate, and Sulfate Concentration Trends in Western Floodplain Wells: 2000–March 2016







Time–Trend Plot Explanation.
In this figure, data for each of the two background wells are plotted separately to facilitate understanding of well-specific trends; *y*-axis scales are unique for each well (refer to Figure A-2 explanation).

——— blue line is a LOESS locally weighted regression line;

shaded area is the corresponding 95% pointwise confidence interval

- - - - - denotes the 40 CFR 192 MCL or cleanup goal:

- 0.044 mg/L uranium
- 2000 mg/L sulfate

10 mg/L UMTRCA MCL for nitrate as N is not shown in this figure because background results have been well below this benchmark

○ denotes result below the detection limit

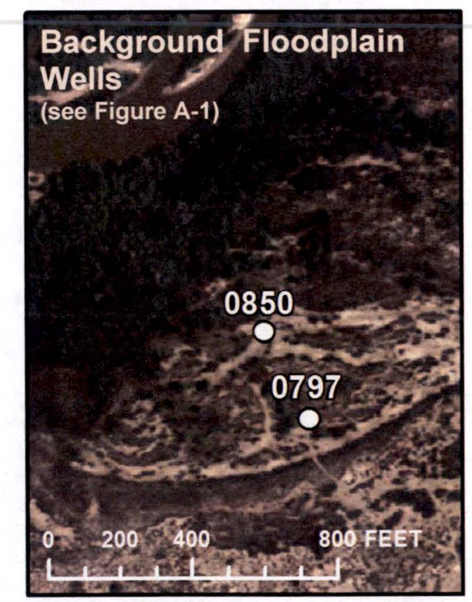


Figure A-9. Uranium, Nitrate, and Sulfate Concentration Trends in Background Floodplain Wells: 2000–March 2016

Appendix B

Hydrographs for Terrace Alluvial Wells

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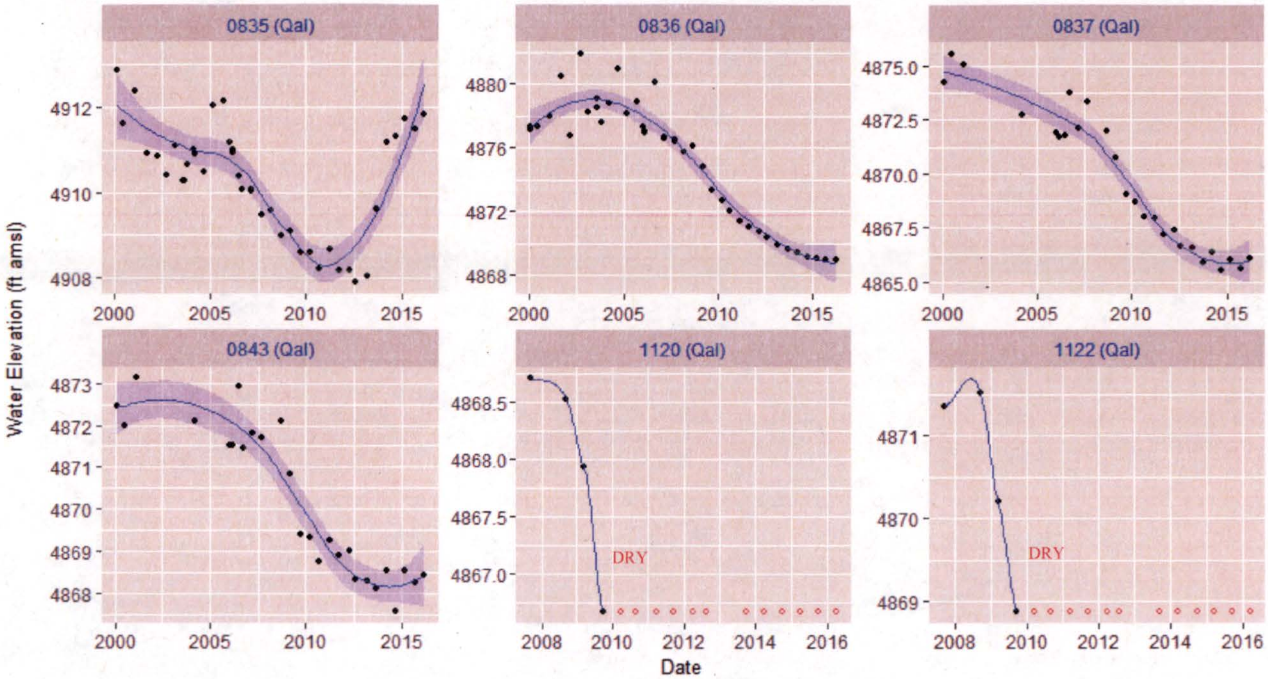


Notes:

In this and subsequent figures in this appendix, water-level data are plotted separately for each well. In each of these plots, both *x*- (date) and *y*-axis scales are unique for each well (refer to detailed explanation in Appendix A, Figure A-2).

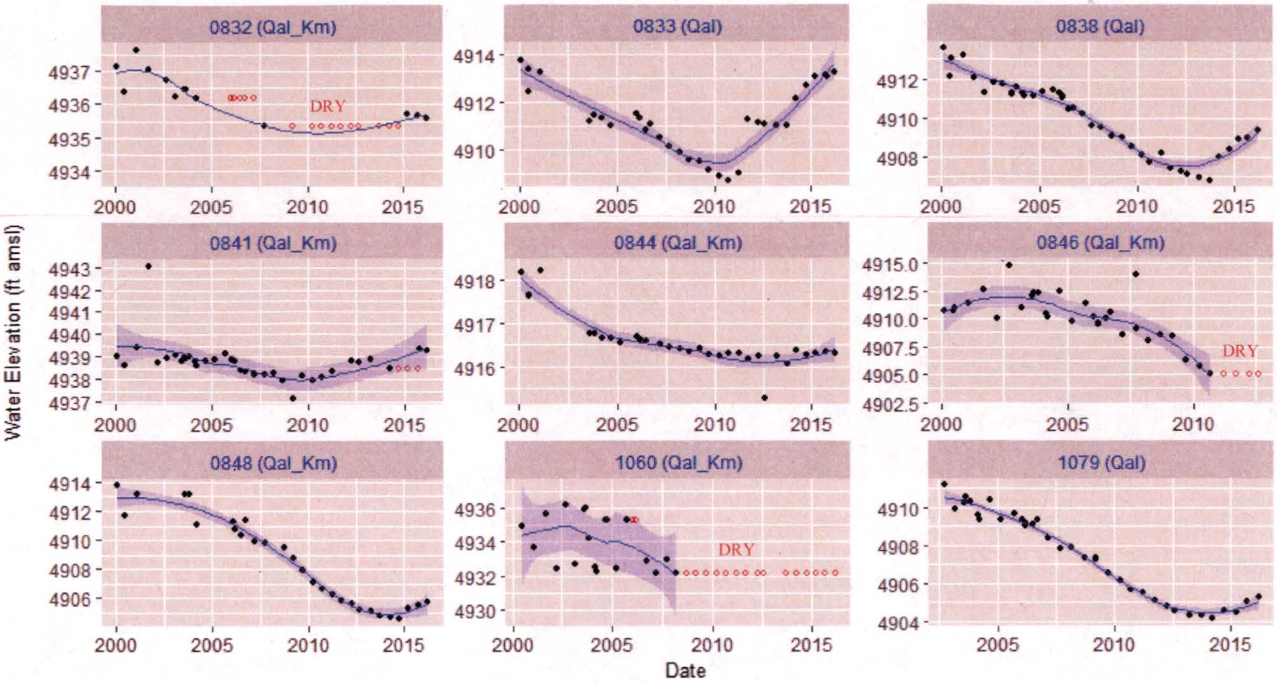
All wells shown here are screened solely in the alluvium (Qal); refer to well construction schematic in Figure C-1.

—— blue line is a LOESS local regression line; shaded area is the corresponding 95% pointwise confidence interval

○ denotes that the well was dry or had insufficient water to sample at the time of that monitoring event

ft amsl feet above mean sea level

Figure B-1. Hydrographs for Northwest Terrace Alluvial Wells North of Highway 64



Notes:

Water-level data are plotted separately for each well; both *x*- (date) and *y*-axis scales are unique to each location.

—— blue line is a LOESS local regression line; shaded area is the corresponding 95% pointwise confidence interval

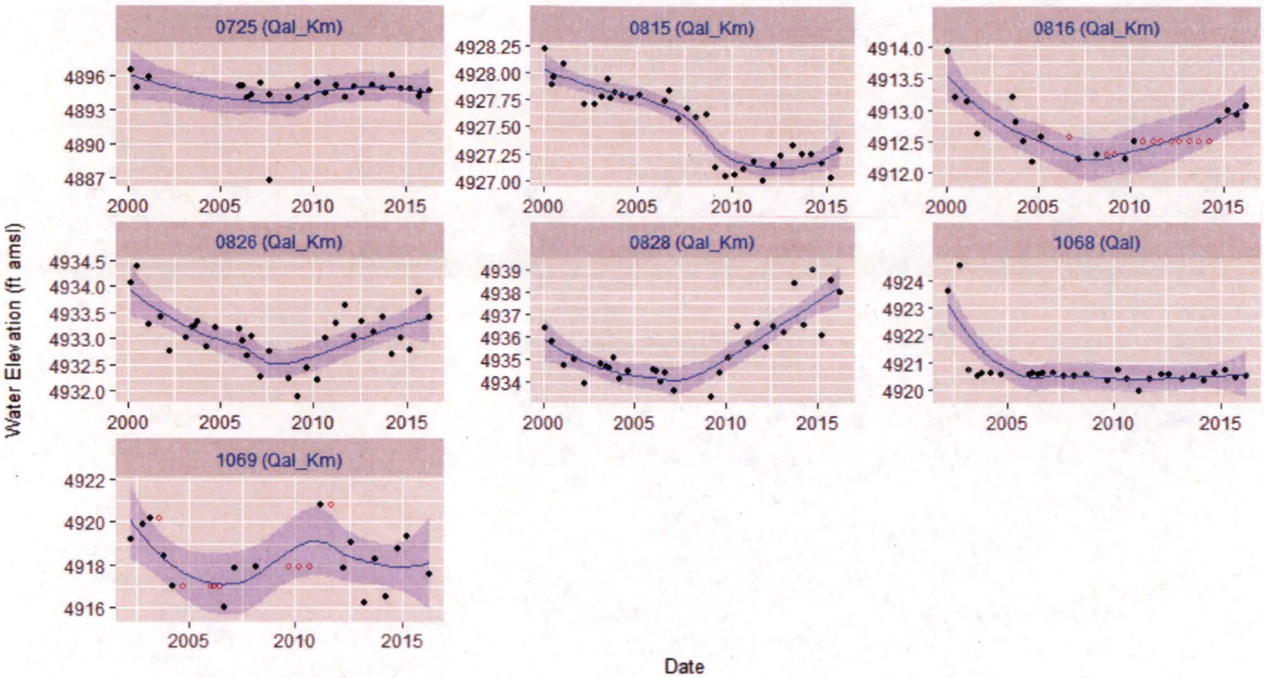
○ denotes that the well was dry or had insufficient water to sample at the time of that monitoring event; these points are assigned values equivalent to the last measured water elevation.

Qal denotes wells screened solely in the alluvium

Qal_Km denotes wells screened in both the alluvium and the Mancos Shale (see Figure C-2)

ft amsl feet above mean sea level

Figure B-2. Hydrographs for Southwest Alluvial Wells South of Highway 64 and West of Highway 491



Notes:

—— blue line is a LOESS local regression line

shaded area is corresponding 95% pointwise confidence interval

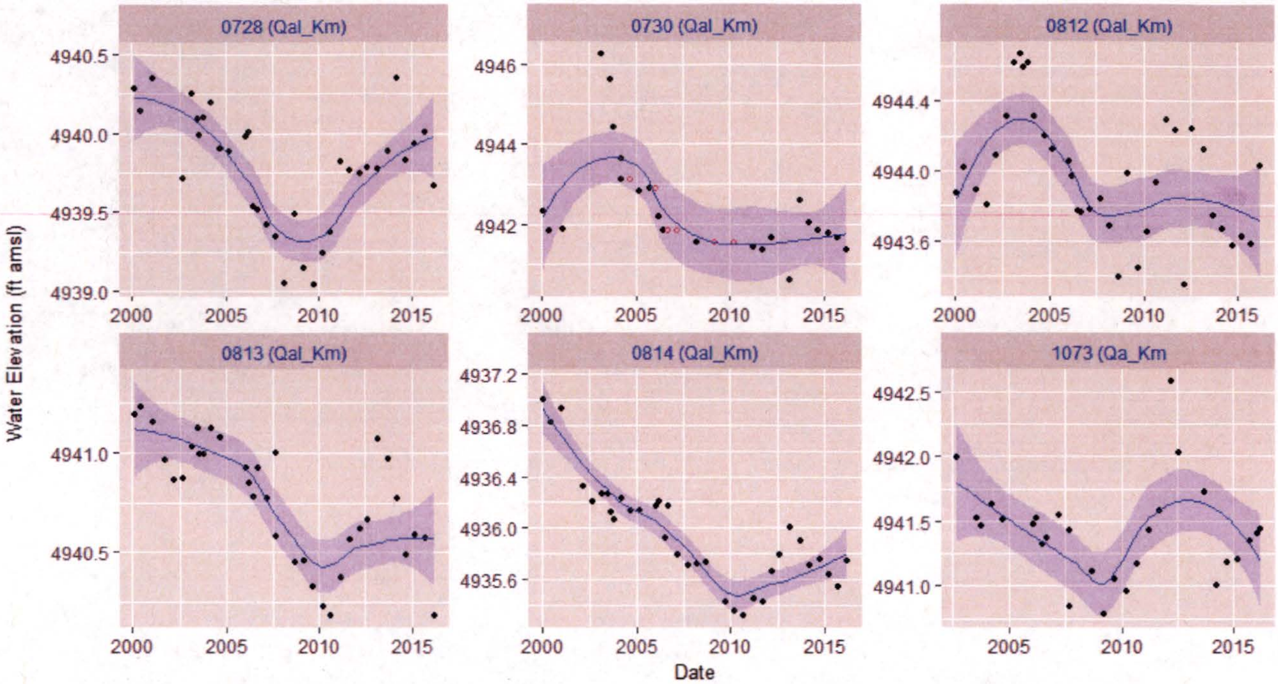
○ denotes that the well was dry or had insufficient water to sample (assigned values = to the last measured datum)

Qal well screened solely in the alluvium (Figure C-1)

Qal_Km well screened in the alluvium and the Mancos Shale (Figure C-2)

ft amsl feet above mean sea level

Figure B-3. Hydrographs for Terrace Alluvial Wells West of the Disposal Cell



Notes:

—— blue line is a LOESS local regression line

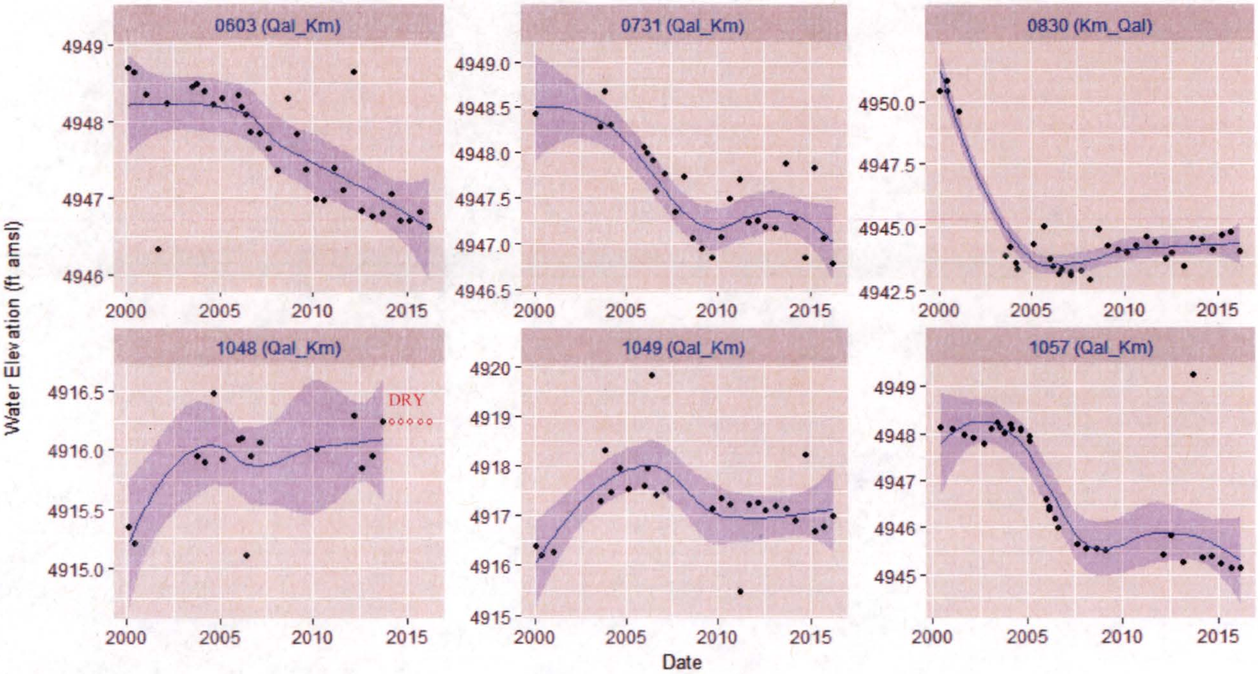
shaded area is corresponding 95% pointwise confidence interval

○ denotes that the well was dry or had insufficient water to sample (assigned values = to the last measured datum)

Qal_Km well screened in the alluvium and the Mancos Shale (well construction information shown in Figure C-2)

ft amsl feet above mean sea level

Figure B-4. Hydrographs for Terrace Alluvial Wells in Borrow Pit and Swale Area



Notes:

—— blue line is a LOESS local regression line

shaded area is corresponding 95% pointwise confidence interval

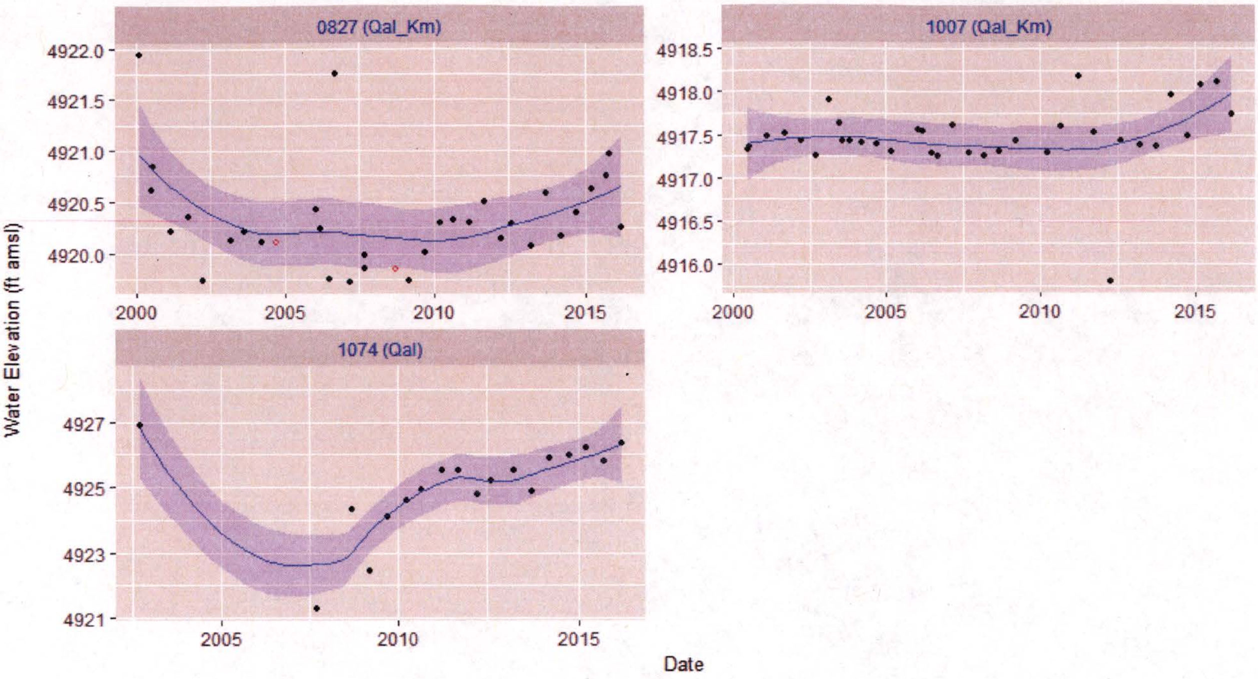
○ denotes that the well was dry or had insufficient water to sample (assigned values = to the last measured datum)

Qal_Km well screened in the alluvium and the Mancos Shale (well construction information shown in Figure C-2)

Km_Qal denotes well screened partially in alluvium but mostly in Mancos Shale (Figure C-2)

ft amsl = feet above mean sea level

Figure B-5. Hydrographs for Terrace Wells East of the Disposal Cell and Evaporation Pond



Notes:

—— blue line is a LOESS local regression line

shaded area is corresponding 95% pointwise confidence interval

○ denotes that the well was dry or had insufficient water to sample (assigned values = to the last measured datum)

Qal well screened solely in the alluvium (Figure C-1)

Qal_Km well screened in the alluvium and the Mancos Shale (Figure C-2)

ft amsl = feet above mean sea level

Figure B-6. Hydrographs for Terrace Alluvial Wells North of the Disposal Cell (Top of Escarpment)

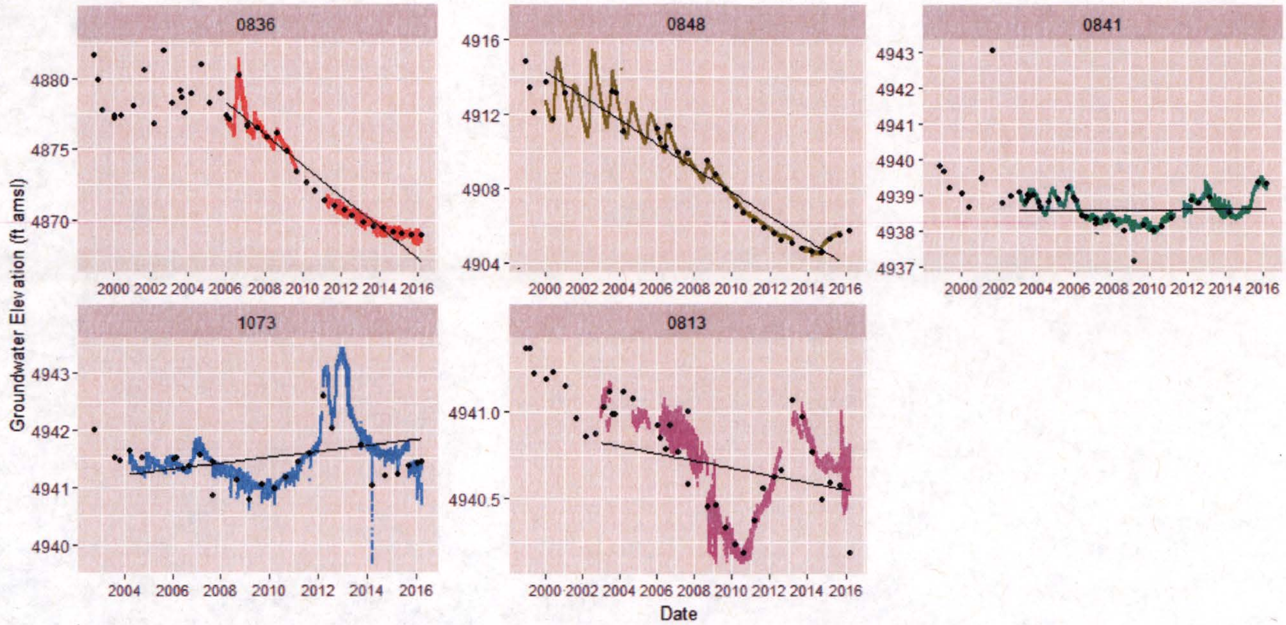


Figure B-7. Terrace Datalogger Measurements: West Terrace and Swale Area Alluvial Wells

In each plot, line (—) is linear trend line on datalogger measurements; • denotes manual measurement.

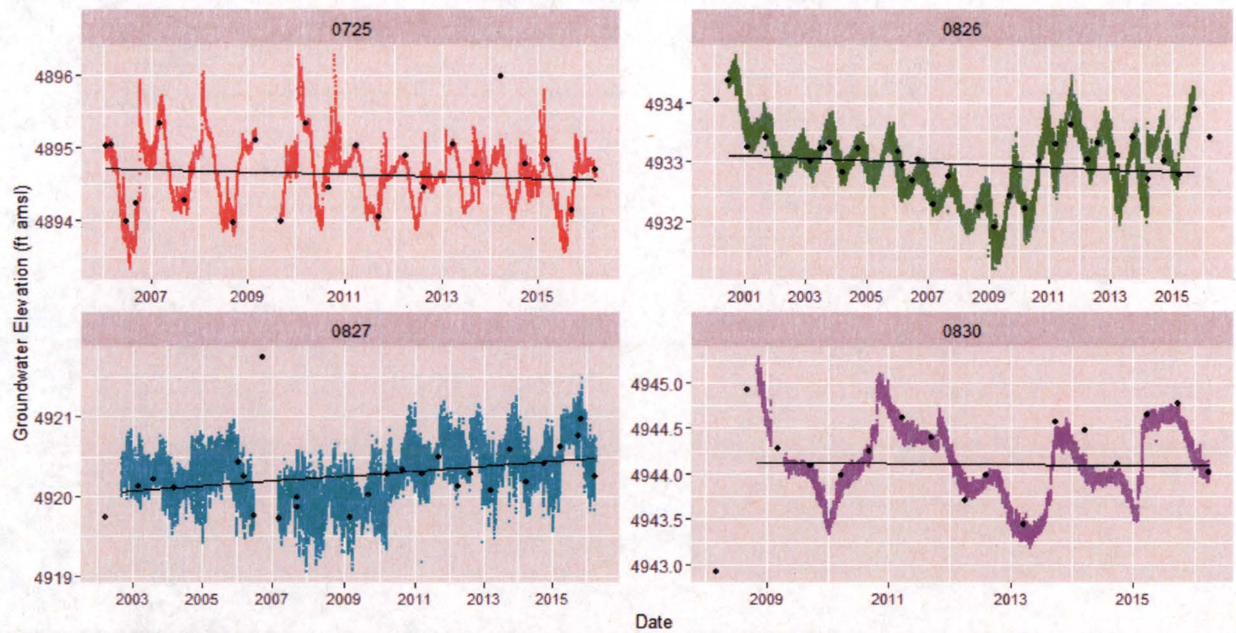


Figure B-8. Terrace Datalogger Measurements: Alluvial Wells East of Highway 64

In each plot, line (—) is linear trend line on datalogger measurements; • denotes manual measurement.

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Appendix C

Supplemental Well Construction Information

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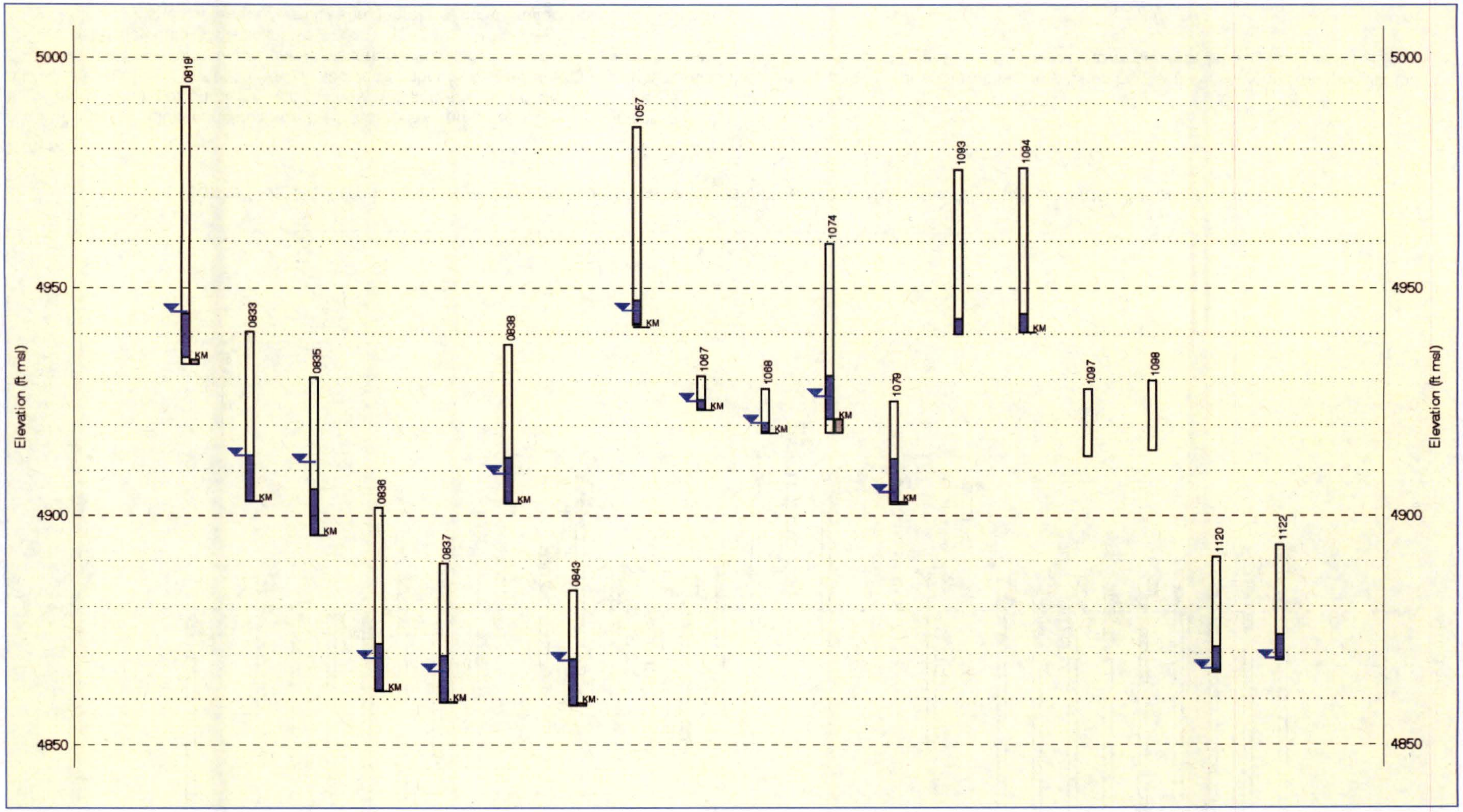

Figure C-1. Well Construction Information for Terrace Wells Screened Solely in the Alluvium

Notes:

1. Inverted blue triangles show the latest measured groundwater elevations.
2. Black rectangles show the well casings; well screens are shaded blue.
3. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

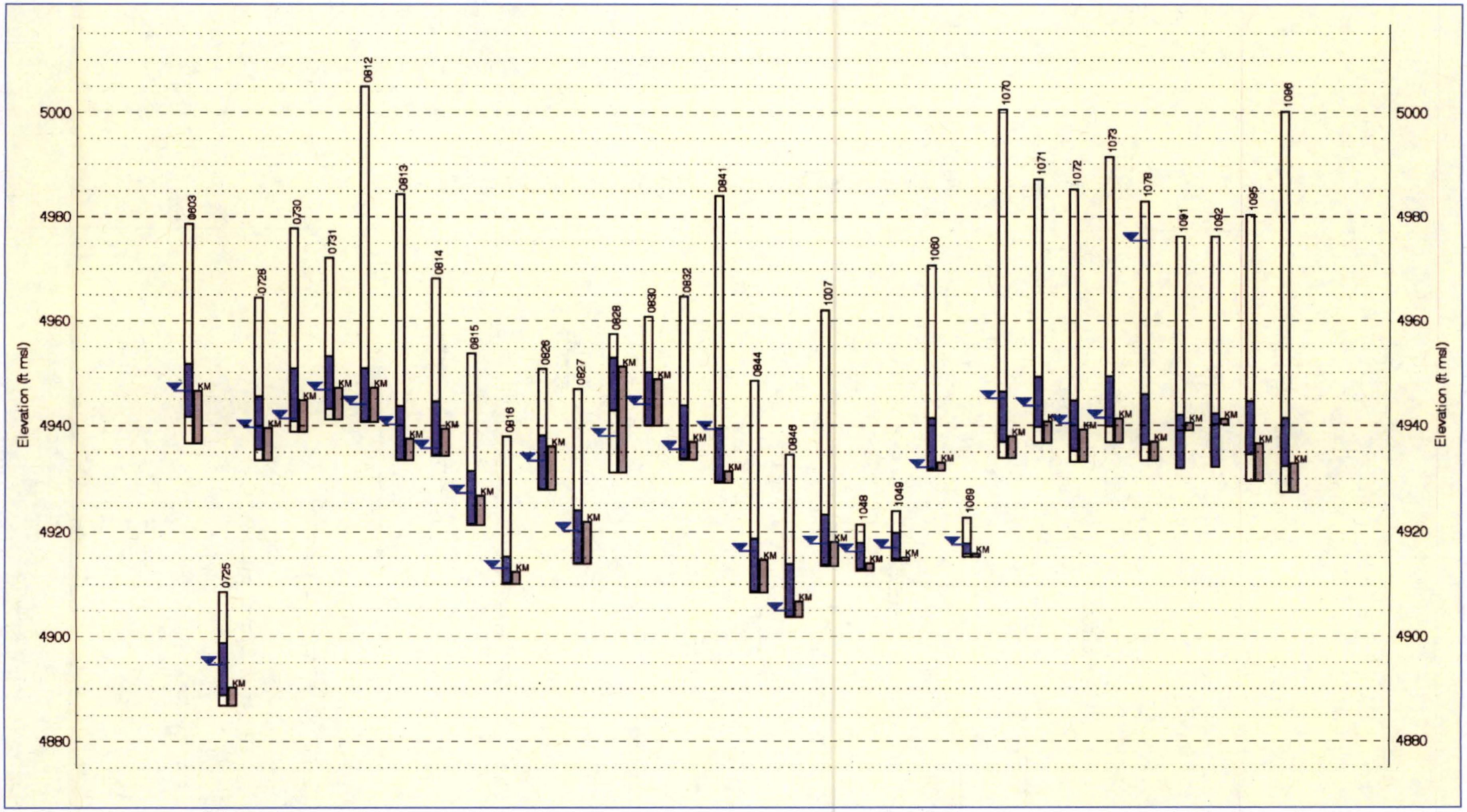

Figure C-2. Well Construction Information for Terrace Wells Screened in Both the Alluvium and the Mancos Shale

Notes:

1. Inverted blue triangles show the latest measured groundwater elevations.
2. Black rectangles show the well casings; well screens are shaded blue.
3. Mancos Shale Formation (KM) is shown to right of well screen (the alluvium overlies the Mancos Shale). For some wells, the overlap between the screened interval and the Mancos Shale formation is barely discernible in this figure because it is very slight (0.2 and 0.35 ft respectively).Well 0848 is not shown because lithology and well construction details are unknown.
4. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

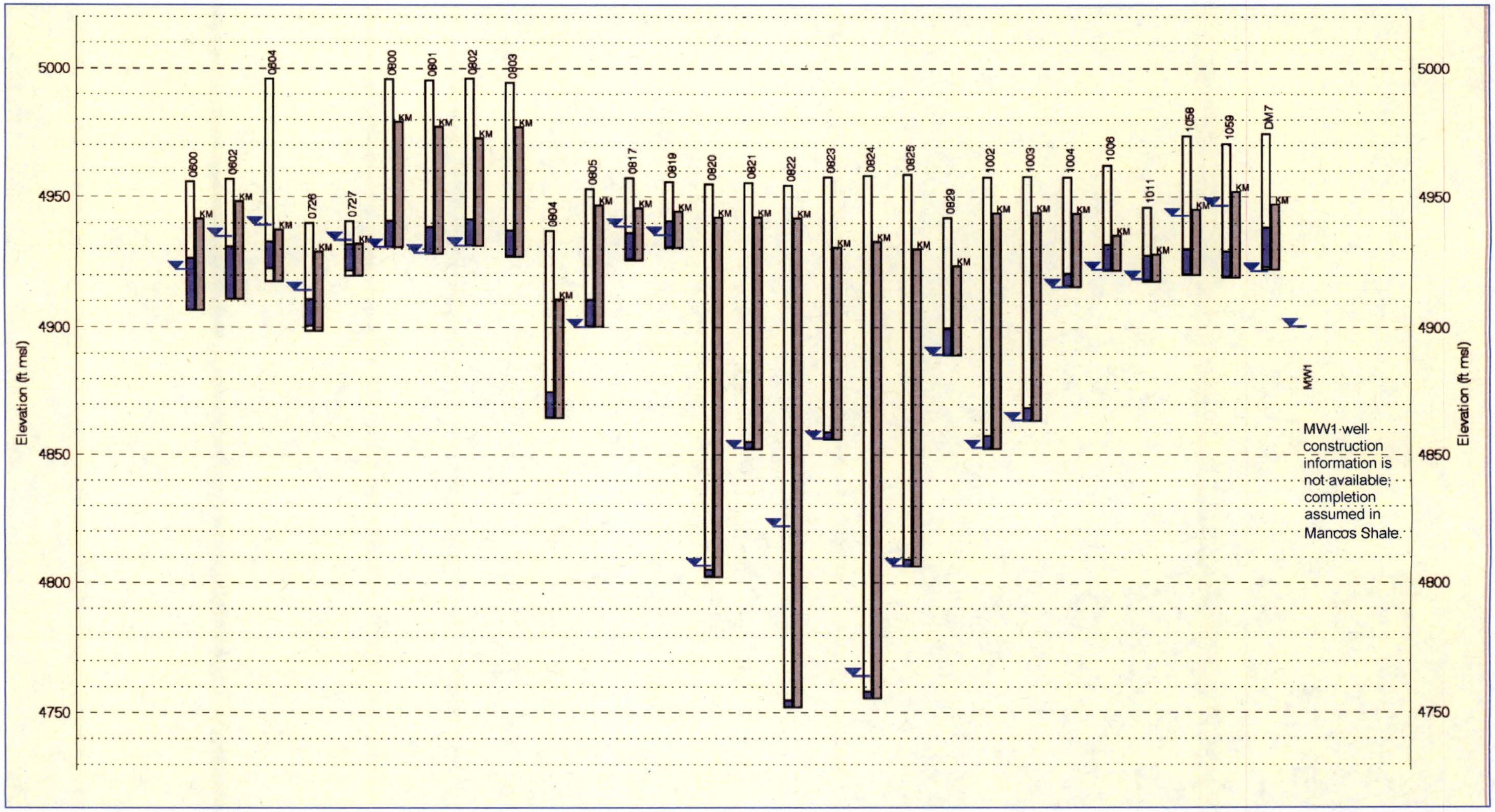

Figure C-3. Well Construction Information for Terrace Wells Screened Solely in the Mancos Shale

Notes:

1. Inverted blue triangles show the latest measured groundwater elevations.
2. Black rectangles show the well casings; well screens are shaded blue.
3. Mancos Shale Formation (KM) is shown to the right of well screen.
4. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

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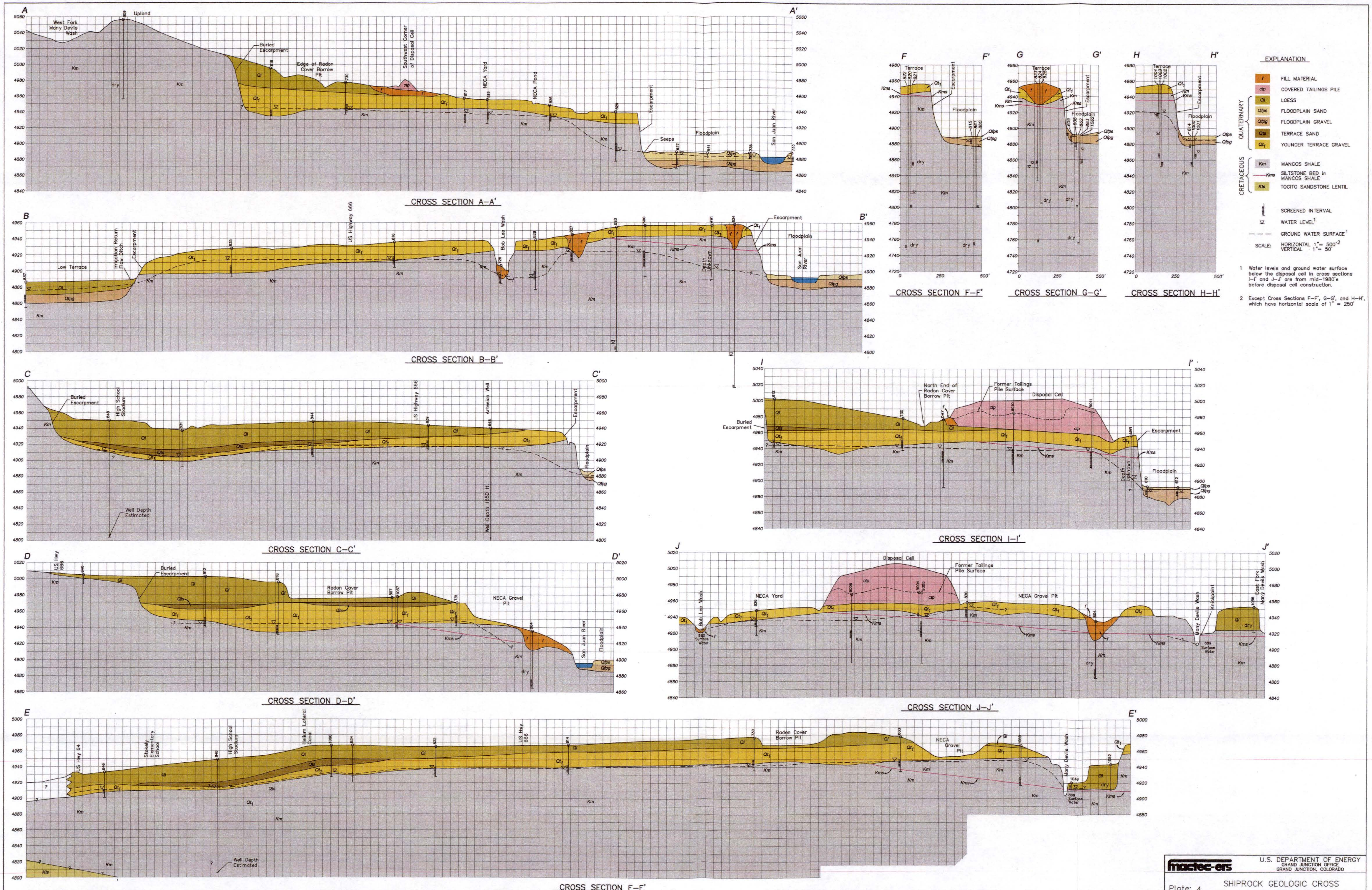

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U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE
GRAND JUNCTION, COLORADO

Plate: 4

SHIPROCK GEOLOGIC CROSS SECTIONS

DATE PREPARED: SEPTEMBER 7, 2000

FILENAME: U0096400