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Annual Performance Report April 2018 Through March 2019 for the Shiprock, New Mexico, Disposal Site

September 2020

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Contents

Figures

Tables

Appendixes

Plate

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

Abbreviations

CFR	*Code of Federal Regulations*
COC	contaminant of concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	feet
GCAP	Groundwater Compliance Action Plan
gpm	gallons per minute
LM	Office of Legacy Management
LOESS	a nonparametric, locally weighted statistical regression method
MCL	maximum concentration limit
mg/L	milligrams per liter
N	nitrogen
SOARS	System Operation and Analysis at Remote Sites
SOWP	Site Observational Work Plan
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 2018 through March 2019. 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 (LM). This annual report is based on an analysis of (1) groundwater quality and groundwater-level data obtained from site monitoring wells and (2) 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 installed in 2006 (Trench 1 and Trench 2). The terrace remediation system currently consists of nine groundwater extraction wells, a collection drain (Bob Lee Wash), and a terrace drainage channel diversion structure. All extracted groundwater is pumped into a lined evaporation pond on the terrace.

Current Site Status

In the last several years, LM has observed that the evaporation pond liner is deteriorating to the point that LM must either replace the liner or decommission the pond entirely. The deteriorated liner caused LM to suspend pumping of groundwater from most Shiprock site treatment system locations on April 21, 2017. That suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches. Pumping of Bob Lee Wash has continued without interruption because the wash is a potential point of exposure. Groundwater extraction was resumed at the floodplain trenches in mid-July 2018 to prevent desiccation of pond sediments (water levels in the pond were too low). Given these recent changes, another objective of this report is to evaluate whether the pumping suspension has had any short-term impacts on contaminant levels or the floodplain plume configuration.

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* Section 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 Bob Lee Wash and seeps and to reduce groundwater elevations.

Semiannual Sampling Results

During the September 2018 and March 2019 sampling events, 110 monitoring wells were sampled (58 on the floodplain and 52 on the terrace). Fifteen surface water locations, including nine San Juan River sampling points and various seeps, were also sampled. Contaminant distributions of nitrate, sulfate, and uranium (the primary COCs at the site) continue to be generally the same as those observed in previous years. In general, relative to baseline (2000–2003) conditions, marked reductions in concentrations of uranium, sulfate, and especially nitrate are apparent in many floodplain wells, most notably near the three remediation areas (Trench 1, Trench 2, and pumping wells 1089 and 1104).

Because of the recent changes in the floodplain pumping regime, it was important to evaluate whether the decrease in groundwater extraction volumes in the last 2 years has impacted contaminant concentrations or the plume configuration on the floodplain. Uranium, sulfate, and nitrate concentrations measured during this reporting period were similar to previous (before pumping suspension) results in the majority of floodplain wells. Apparent upticks noted in the previous annual report were not sustained. Apparent recent increases in uranium concentrations identified in a few wells were slight or within the range of historical observations. Uranium and nitrate concentrations in samples collected from the San Juan River continue to be below established benchmarks and comparable to upstream (background) locations.

Summary of Remediation Performance and Site Evaluation Progress

Because of the deteriorating evaporation pond liner, LM suspended pumping at all Shiprock site treatment system locations except Bob Lee Wash on April 21, 2017. That suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches.

From April 2018 through March 2019, about 8.44 million gallons of extracted groundwater were pumped to the evaporation pond, nearly 3 times greater than the volume extracted during the previous (2017–2018) reporting period (2.97 million gallons). The bulk of this total volume (7.2 million gallons, or 85.4%) of the influent liquids entering the pond during the current reporting period was from the floodplain trenches. The trenches, along with Bob Lee Wash, were the only treatment system locations where pumping was sustained through the reporting period. Since DOE began active remediation in March 2003, about 50.8 million gallons have been extracted from the terrace and 157.5 million gallons have been extracted from the floodplain, yielding a total cumulative volume of about 208.3 million gallons of water pumped to the evaporation pond from all sources. The estimated masses of nitrate, sulfate, and uranium removed from the floodplain and terrace well fields during this performance period were 6364; 262,819; and 22.9 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 2018 through March 2019. 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 (LM).

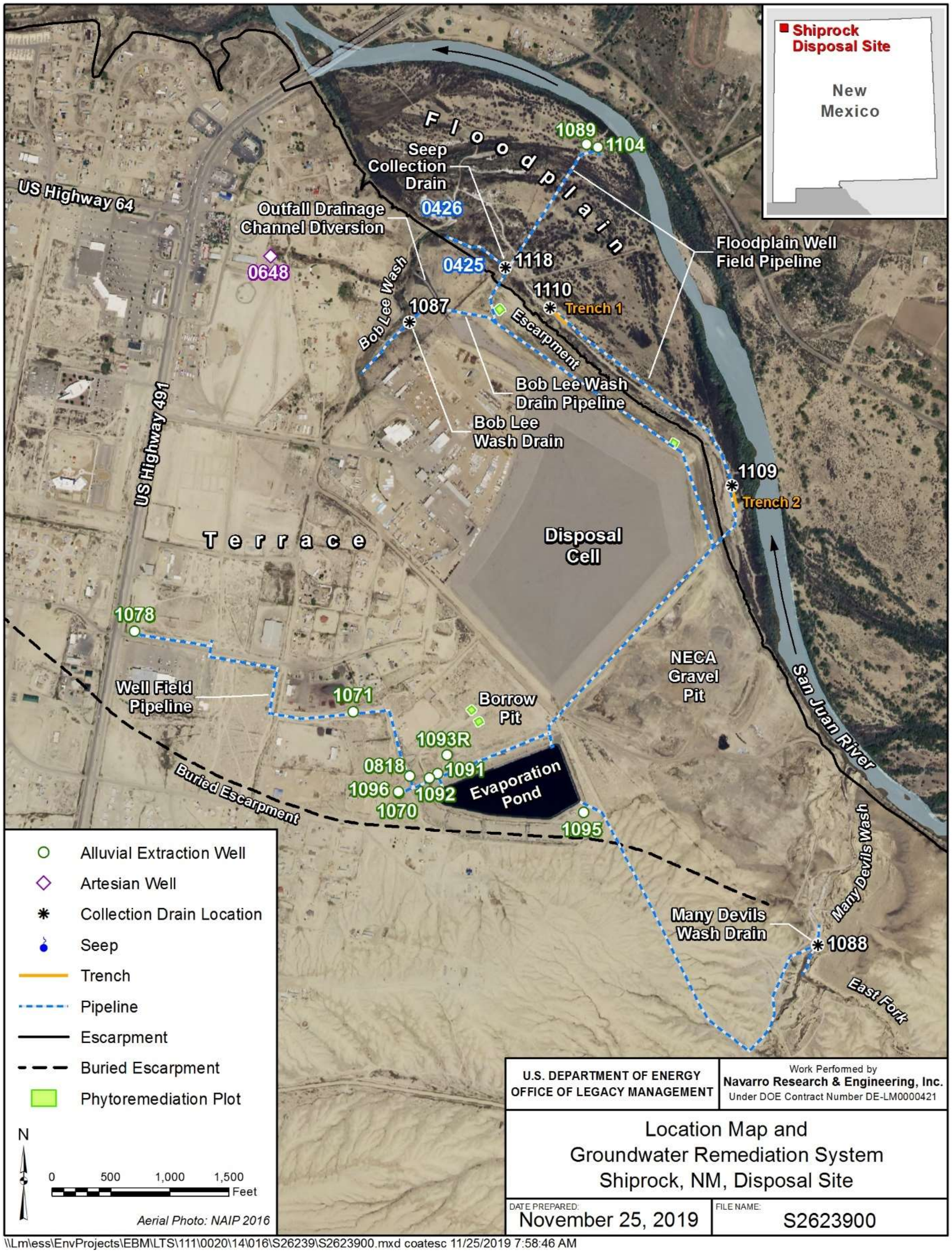
The Shiprock mill operated from 1954 to 1968; mill tailings were stabilized in an engineered disposal cell in 1986. As a result of milling operations, groundwater in the mill site area was contaminated with uranium, nitrate, sulfate, and associated constituents. In March 2003, DOE initiated active remediation 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.

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 currently consists of nine groundwater extraction wells, a collection drain (Bob Lee 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 locations.

The Groundwater Compliance Action Plan (GCAP) (DOE 2002) documents the site compliance strategy, the basis for the remediation approach, and performance standards addressed in this report. The U.S. Nuclear Regulatory Commission–approved compliance strategy for the floodplain is natural flushing supplemented by active remediation. The compliance strategy for the terrace is to eliminate exposure pathways at Bob Lee Wash and seeps and to reduce groundwater elevations.

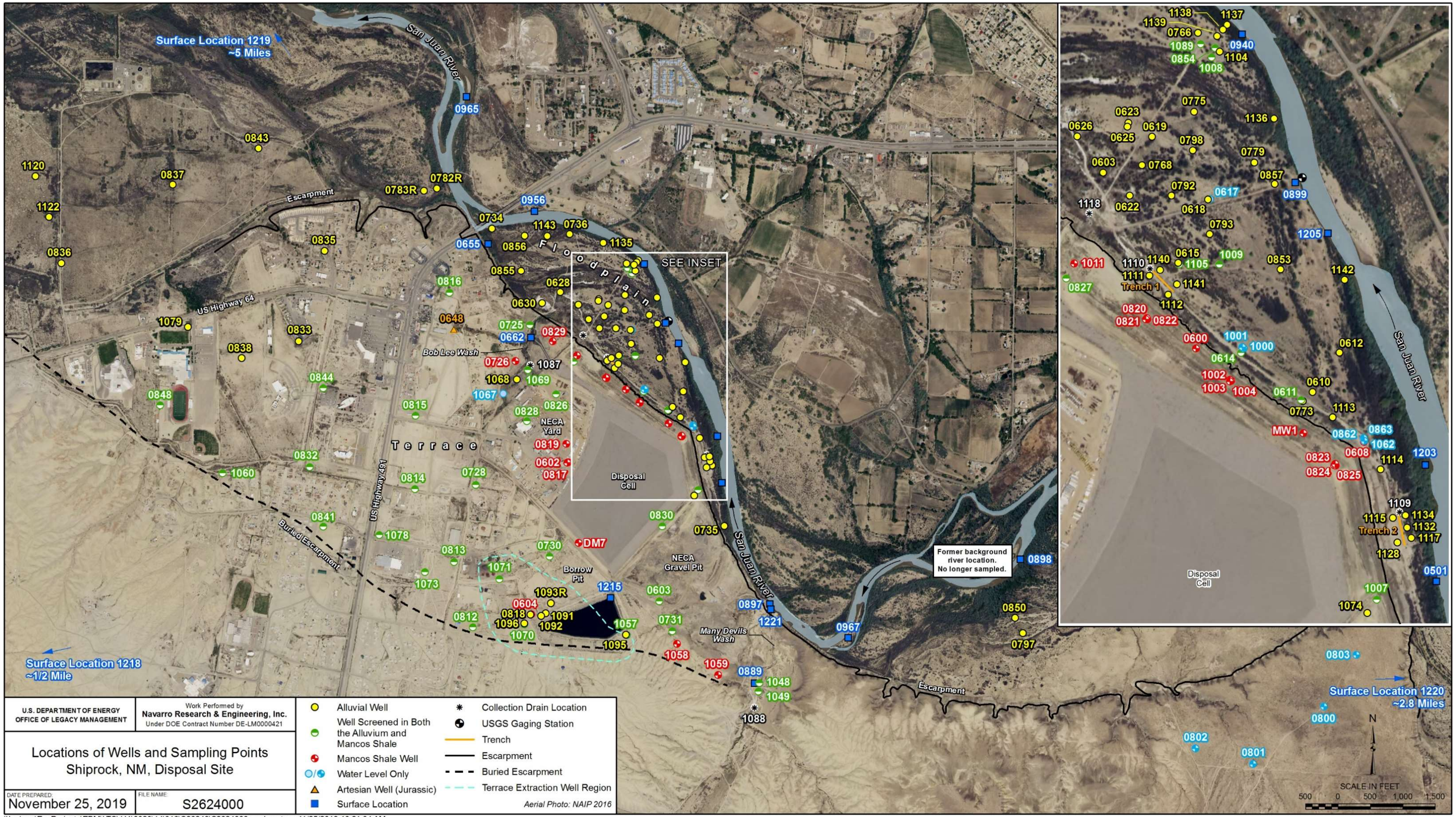
1.1 Current Site Status

In the last several years, LM has observed that the evaporation pond liner is deteriorating to the point that LM must either replace the liner or decommission the pond entirely and continue with natural flushing (DOE 2018a). The deteriorated liner caused LM to suspend pumping of groundwater from most Shiprock site treatment system locations on April 21, 2017. That suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches. Pumping of Bob Lee Wash has continued because the wash is a potential point of exposure. Groundwater extraction was resumed at the floodplain trenches in mid-July 2018 to prevent desiccation of pond sediments (water levels in the pond were too low). Given the wide-scale cessation of pumping, there continues to be little “performance”—that is, groundwater extraction and associated contaminant mass removal—to report. As such, an additional objective of this report is to evaluate whether the wide-scale suspension of pumping has resulted in a change in contaminant concentrations or changes in plume geometry.



Note: The Many Devils Wash collection drain (1088) has not been pumped since 2014 because of the need for repairs and the presence of naturally occurring contamination.

Figure 1. Location Map and Groundwater Remediation System



Notes: Floodplain well 0734, the westernmost well on the site floodplain, has not been sampled since September 2014 because water levels have been below the pump. Terrace well 0812 is damaged and has not been sampled since September 2015. Due to recent damage, well 0841—west of U.S. Highway 491 adjacent to the buried escarpment—could not be sampled this reporting period and is scheduled for abandonment pending approval by the Navajo Nation Water Code.
Abbreviations: NAIP = National Agriculture Imagery Program; NECA = Navajo Engineering & Construction Authority; USGS = U.S. Geological Survey

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

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1.2 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. The following specific performance standards or metrics were established for the Shiprock floodplain groundwater remediation system in the Baseline Performance Report (DOE 2003):

- 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 indicate whether the floodplain extraction system is effective and contaminant levels are decreasing.

The following specific performance standards were established for the terrace groundwater remediation system in the Baseline Performance Report (DOE 2003):

- Terrace groundwater elevations should decrease as water is removed from the terrace system.
- The volume of water discharging to the interceptor drains in Bob Lee Wash and Many Devils Wash should decrease over time as groundwater levels on the terrace decline.
- The flow rates of seeps 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). The site conceptual model on which the GCAP was based is documented in the Site Observational Work Plan (SOWP) (DOE 2000). Based on subsequent evaluations and investigations (e.g., DOE 2005; DOE 2009; DOE 2011a; DOE 2011d; and DOE 2013), LM has recently initiated an update of the site conceptual model and revision of the GCAP. Initial supporting evaluations indicate that some of the performance metrics listed above may no longer be appropriate.

For example, LM terminated remediation efforts in Many Devils Wash because the groundwater discharging to the wash was found to be naturally contaminated, contradicting the original assumption of a mill site origin. Pumping of the 1088 collection drain was terminated in 2014, and associated structures are slated for decommissioning. As found with other desert arroyos in the area that are not impacted by uranium milling, the contamination in Many Devils Wash is the result of the natural interaction of water with the Mancos Shale and is not related to the mill site (DOE 2011b; DOE 2011c; Morrison et al. 2012; Robertson et al. 2016).

LM continues to reevaluate all aspects of the site compliance strategy to ensure that performance standards are consistent with updated characterizations of site hydrogeology and the nature and extent of site-related contamination. The pumping suspension, initiated in April 2017, was sustained through most of the last two reporting periods for all treatment system locations except the floodplain trenches and Bob Lee Wash. LM is closely monitoring site data to ensure that these recent changes to the pumping regime do not result in sustained increases in contaminant concentrations or any adverse changes in plume geometry.

1.3 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 [N]), manganese, nitrate (nitrate + nitrite as N), 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* Section 192 (40 CFR 192), which apply to UMTRCA sites. The remediation goals listed in this table apply to the floodplain only because the current compliance strategy for the terrace is to decrease groundwater elevations and flow rates at seeps.

Table 1. Groundwater COCs for the Shiprock Site and Floodplain Remediation Goals

Contaminant	40 CFR 192 MCL (mg/L)	Floodplain Remediation Goal (mg/L)	Historical Range in Floodplain Background Wells[a] (mg/L)	Comments
Ammonia as N	–	–	<0.074–0.20	Most ammonia results for floodplain background wells have been nondetects (<0.1 mg/L).
Manganese	–	2.74	<0.001–7.2	The 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	The nitrate contaminant plume has reduced markedly relative to baseline (2000–2003) conditions.
Selenium	0.01	0.05	0.0001–0.02	The 0.05 mg/L cleanup goal is an ACL that uses the EPA Safe Drinking Water Act maximum contaminant level (DOE 2002). This goal is also consistent with the State of New Mexico Environment Department groundwater standard.[b]
Strontium	–	–	0.18–10	EPA's Regional Screening Level for tap water is 12 mg/L, assuming a target hazard quotient of 1.0.[c]
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. The most recent (March 2019) result for well 0850 was 0.063 mg/L.

Notes:
[a] Data are from floodplain background wells 0797 and 0850 (locations shown in Figure 2).
[b] https://www.env.nm.gov/gwqb/gw-regulations/ (accessed August 2019).
[c] https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables (accessed August 2019).

Abbreviations:
– = not applicable (contaminant does not have an MCL in 40 CFR 192, or the alternate cleanup goal is not relevant)
ACL = alternate concentration limit
EPA = U.S. Environmental Protection Agency
mg/L = milligrams per liter

As listed in Table 1, the 40 CFR 192 compliance standards for nitrate, uranium, and selenium are 10, 0.044, and 0.01 milligrams per liter (mg/L), respectively. 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); this 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 several DOE evaluations (DOE 2011b, 2011c) and a subsequent report issued by the U.S. Geological Survey (Robertson et al. 2016).

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 have been below detection limits (<0.1 mg/L). For manganese, the 2.74 mg/L cleanup goal (Table 1) 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.

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 for stable strontium in drinking (tap) water is 12 mg/L, assuming a target hazard quotient of 1.0 (Table 1).

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. Because of these elevated levels from a natural source, the GCAP proposed a cleanup goal of 2000 mg/L for sulfate in floodplain wells. This alternate goal is conservative, as sulfate concentrations in floodplain background wells (upstream of the former mill site) have exceeded 2000 mg/L in the majority of samples from well 0797 (with levels as high as 5200 mg/L) and nearly one-quarter of those from well 0850.

1.4 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.

1.4.1 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, which are installed in the floodplain approximately 1 mile upriver from the site (Figure 2).

1.4.2 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 not as 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 (Figure 1). The terrace system extends more than a mile west and northwestward, to more than 4000 ft west of U.S. Highway 491. Terrace alluvial material is exposed at ground surface near 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 in the Mancos Shale occurs in discrete discontinuous zones of limited lateral and vertical extent.

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 2018–2019 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; 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.

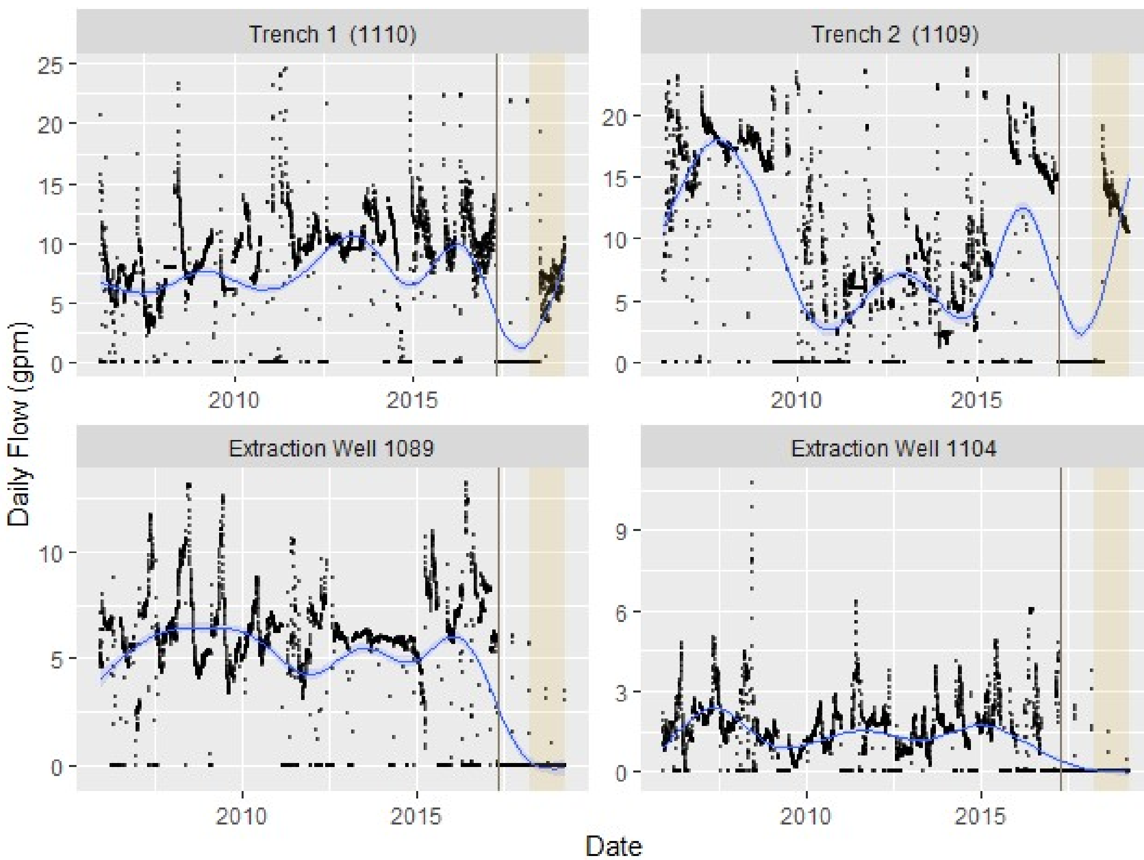
Table 2. Floodplain Remediation System Locations: Average Pumping Rates and Total Groundwater Volume Removed

Floodplain Location	Previous Period (April 1, 2017, through March 31, 2018)		Current Period (April 1, 2018, through March 31, 2019)	
	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
1089	0.39	204,973	0.04	20,797
1104	0.12	61,647	0.01	3,772
Trench 1 (1110)	1.0	524,556	4.67	2,456,135
Trench 2 (1109)	0.83	433,650	8.99	4,723,318
Seep (1118)	0.04	23,249	0	0
Total	**2.4**	**1,248,074**	**13.7**	**7,204,022**

Note:
Pumping was suspended at all floodplain treatment system locations on April 21, 2017. For extraction wells 1089 and 1104 and seep 1118, except for some intermittent periods of pumping, this suspension continued through this (2018–2019) reporting period. At the trenches, pumping resumed on July 19, 2018, to prevent desiccation of evaporation pond sediments.

2.1.1 Extraction Well Performance

The floodplain extraction well system consists of wells 1089 and 1104 (Figure 1), both installed in late June 2003. These wells were constructed using slotted culverts placed in trenches excavated to bedrock. The pumping suspension that began in the last (2017–2018) reporting period continued through this current period. From April 2018 through March 2019, approximately 24,600 gallons of water were removed from the two floodplain extraction wells (1089 and 1104), corresponding to roughly 10% of the 267,000 gallons extracted previously (Table 2). Average annual pumping rates were only 0.04 and 0.01 gpm (wells 1089 and 1104, respectively), resulting in a small increment in cumulative flows. During the period since the start of operations in 2003 through the end of March 2019, totals of approximately 39.6 million and 8.6 million gallons of water have been removed from wells 1089 and 1104, respectively. These (rounded) cumulative volumes are essentially equal to those reported last year (DOE 2019b). Figure 3 plots historical daily flows (pumping rates) for extraction wells 1089 and 1104 and the two trenches.



- Average daily flow rate (gpm)
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- Shading denotes current (2018–2019) reporting period
- Denotes April 21, 2017, cessation of pumping (see Notes)

Notes:
Data plotted are since the inception of the System Operation and Analysis at Remote Sites (SOARS) system in late 2005.
y-axis scales are unique for each well, so plots are not directly comparable.
For the trenches, the nonpumping period extended from April 21, 2017, until July 19, 2018, after which pumping resumed to maintain a minimum water level in the evaporation pond. Except for brief intermittent periods, pumping was not resumed at the two extraction wells.

Figure 3. Historical Pumping Rates in Floodplain Trenches and Extraction Wells: 2005–2019

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 2018 through March 2019, about 2.5 million and 4.7 million gallons of water were removed from Trench 1 and Trench 2, respectively (Table 2). The total volume extracted from both drains, about 7.2 million gallons, is about 7.5 times greater than the combined volume extracted in 2017–2018 (958,200 million gallons). This increase reflects the resumption of pumping at the trenches in mid-July 2018. Average pumping rates were 5–9 gpm in 2018–2019, in contrast to previous pumping rates of ≤1 gpm in 2017–2018. Since the trenches were installed in 2006, totals of approximately 47.1 million and 58.4 million gallons of water have been removed from Trench 1 and Trench 2, respectively (totaling 105.5 million gallons).

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 sump (location 1118) and then pumped to the evaporation pond. From April 2018 through March 2019, no water was pumped from the collection sump because of the continued pumping suspension (Table 2). Previously, in 2017–2018, only 23,250 gallons were pumped from this location, corresponding to an average discharge rate of 0.04 gpm. As reported last year (DOE 2019b), about 3 million gallons of water have been removed from the 1118 collection sump since the seeps were incorporated into the remediation system in 2006.

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 potential exposure pathways at seeps and at Bob Lee Wash are eventually eliminated and the flow of groundwater from the terrace to the floodplain is reduced. The terrace remediation system currently consists of four major components shown in Figure 1: the extraction wells, the evaporation pond, the terrace drain at Bob Lee 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 (2018–2019) and previous (2017–2018) reporting periods. Figure 4 plots historical daily flows (pumping rates) for the nine terrace extraction wells. Because of the continued pumping suspension, average pumping rates at all terrace extraction wells were again low, ranging from 0 to 0.08 gpm (with the maximum at well 1093R). The total volume removed from pumping the terrace extraction wells in 2018–2019 was about 93,650 gallons. This volume corresponds to 35% of the volume extracted during the previous reporting period (267,600 gallons).

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, even when the terrace pumping system was fully operational (approximately 2008–2017), the 8 gpm objective was not achieved. During this (2008–2017) period, the combined pumping rate from terrace extraction wells typically ranged from about 2 to 4 gpm. At that time, average pumping rates from wells 1070, 1071, 1091, and 1092 were often less than 0.1 gpm, the minimum (150 gallons per day) yield required to be considered an aquifer under 40 CFR 192.

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

Terrace Well or Drain[a]	Previous Period (April 1, 2017, through March 31, 2018)		Current Period (April 1, 2018, through March 31, 2019)	
	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818	0.063	33,188	0.023	11,919
1070	0.005	2,509	Nil	11
1071	0.0004	201	Nil	68
1078	0.168	88,311	0.037	19,504
1091	0.003	1,758	0.001	593
1092	0	0	0	0
1093R	0.21	108,088	0.078	41,090
1095	0.031	16,035	0.031	16,145
1096	0.033	17,482	0.008	4,320
Extraction Well Subtotal[b]	**0.5**	**267,572**	**0.18**	**93,649**
Bob Lee Wash (1087)	2.8	1,456,665	2.2	1,140,161[c]
Many Devils Wash (1088)[d]	0	0	0	0
Total[b]	**3.3**	**1,724,237**	**2.4**	**1,233,810**

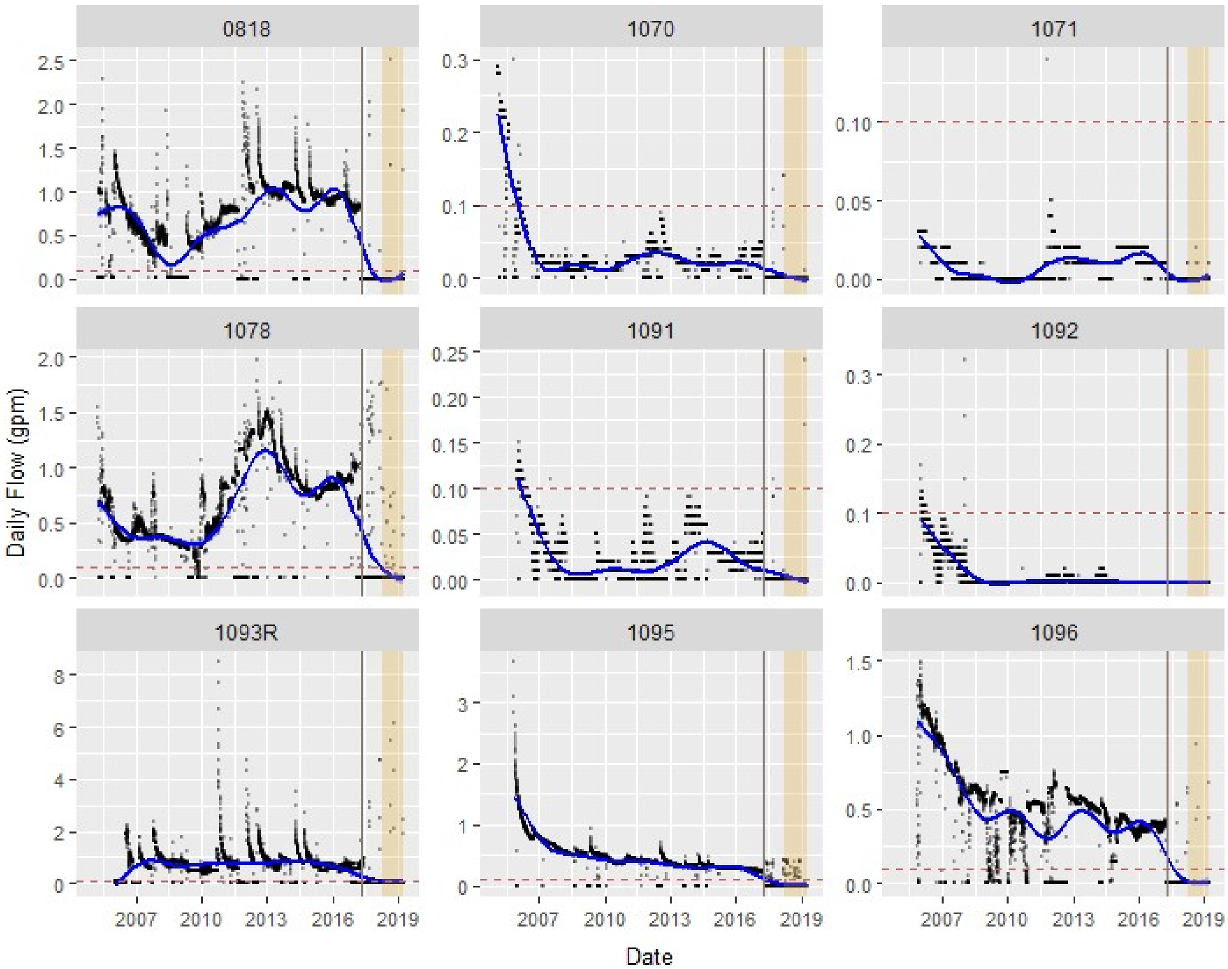
Notes:

[a] Because of evaporation pond liner maintenance and integrity issues, pumping was largely suspended at all terrace treatment locations except Bob Lee Wash (1087) on April 21, 2017. During this (2018–2019) reporting period, pumping was resumed at terrace extraction wells only for brief, intermittent periods.

[b] Minor discrepancies in subtotal and total values versus manual addition of location-specific entries are due to rounding. Subtotals for average annual pumping rates are cumulative averages.

[c] The flow meter installed at Bob Lee Wash location 1087 was not functioning properly during the second half of this reporting period, from 9/13/2018 through 3/24/2019. Because this location was being pumped, as evidenced by line pressures and water elevations measured during that period, zero values were substituted with a surrogate value of 2.5 gpm based on professional judgment. This surrogate value is slightly less than the 2.8 gpm average annual pumping rate corresponding to the previous (2017–2018) reporting period.

[d] Many Devils Wash has not been pumped since 2014 because of the need for repairs and the presence of naturally occurring contamination.



- Average daily flow rate (gpm)
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- ----- Denotes 0.1 gpm (150 gallons per day) low-yield definition for limited-use aquifer (40 CFR 192.11[e])
- Shading denotes current (2018–2019) reporting period
- | Denotes April 21, 2017, pumping suspension

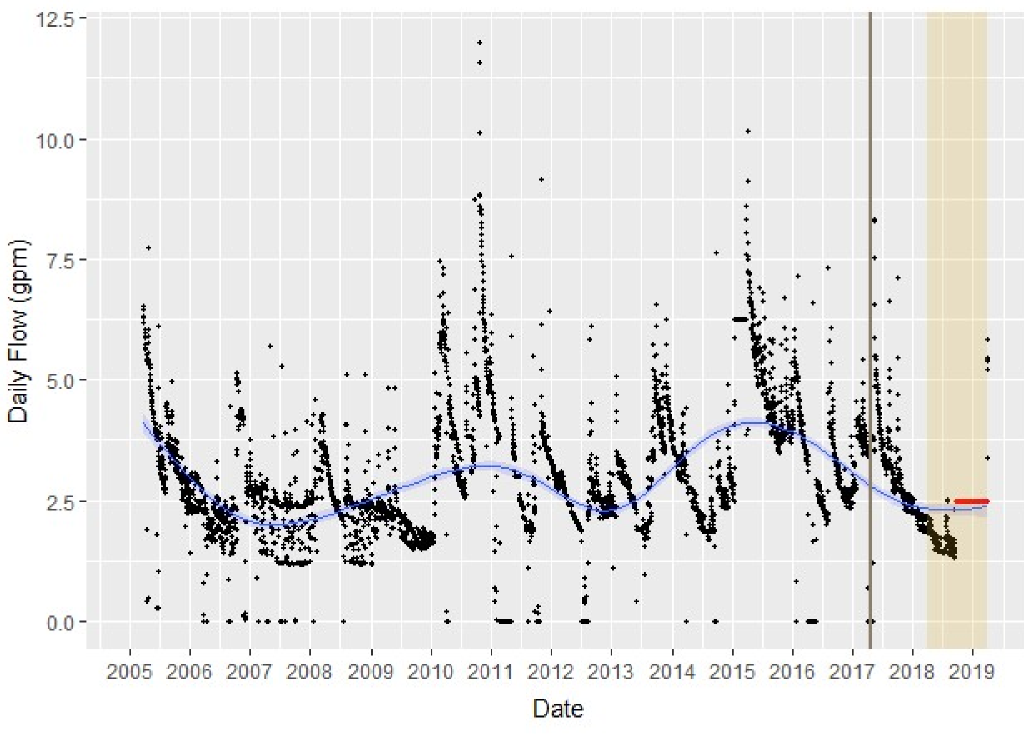
Notes:
Data plotted are since the inception of the SOARS system in 2005–2006.
y-axis scales are unique for each well so plots are not directly comparable.

Figure 4. Historical Pumping Rates in Terrace Extraction Wells: 2005–2019

2.2.2 Terrace Drain System Performance

The terrace extraction system currently collects seepage from Bob Lee Wash using a subsurface interceptor drain. The drain, consisting of perforated pipe surrounded by drain rock and lined with geotextile filter fabric, is offset from the centerline of the wash to minimize the infiltration of surface water. All water collected by the Bob Lee Wash drain is pumped through a pipeline to the evaporation pond. A similar groundwater interceptor drain installed in Many Devils Wash (Figure 1) has not been operating since March 2014. Pumping at Many Devils Wash was terminated at that time primarily because contamination in the wash was determined to be naturally occurring and also because the system needed extensive repairs.

Pumping continued at Bob Lee Wash throughout the entire (2018–2019) reporting period because the wash is considered a potential point of exposure; daily flow rates are plotted in Figure 5. In 2018−2019, the average pumping rate at the Bob Lee Wash drain was 2.2 gpm, slightly less than the 2.8 gpm measured during the last reporting period (Table 3). The groundwater interceptor drain removed about 1.14 million gallons of water, yielding a total cumulative volume (since pumping began in 2003) of 25.2 million gallons. Both the annual and cumulative volumes are uncertain because the flow meter was not functioning during the second half of this reporting period (see Table 3, Note c).



- Average daily flow rate in gallons per minute (gpm)
- Surrogate (2.5 gpm) value assigned for the period when the Bob Lee Wash flow meter was not functioning, from 9/13/2018 through 3/24/2019 (refer to Table 3, Note c)
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- Shading denotes current (2018–2019) reporting period
- Denotes April 21, 2017, cessation of pumping at most Shiprock site treatment locations

Note: Data plotted are since the inception of the SOARS system in 2005.

Figure 5. Historical Flow Rates in Bob Lee Wash (1087): 2005–2019

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). Figure 6 plots daily average pond water levels measured over the last 10 years (2009–2019). More recent pond water levels, beyond the end of the current reporting period, are also shown. At the close of this reporting period (March 31, 2019), the water level in the evaporation pond was 2.1 ft, measured as the distance above transducers. The average water level during the reporting period was 1.4 ft. These low levels relative to those measured in previous years are the result of the pumping suspension that began in April 2017 and, for all locations except Bob Lee Wash and the floodplain trenches, continued into 2019. As shown in Figure 6, pond water levels declined markedly from the start of the reporting period until early September 2018, reaching a low of 0.25 ft. To prevent desiccation of pond sediments, pumping was resumed at the trenches in mid-July 2018.[1]

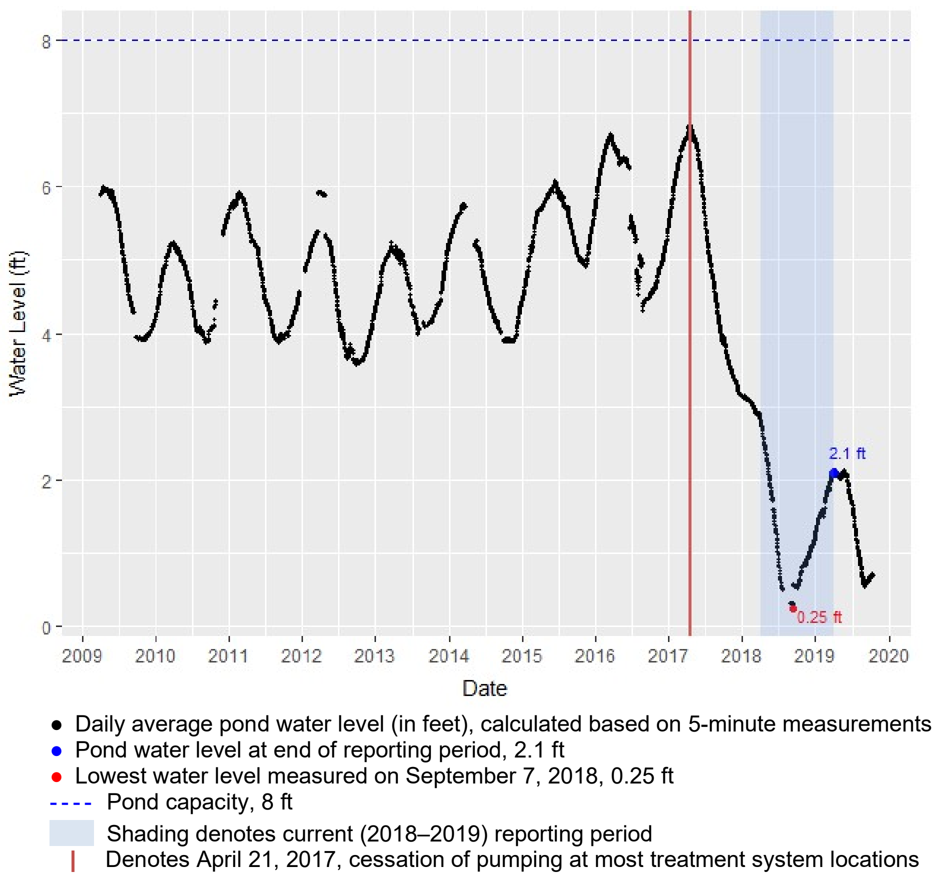


Figure 6. Water Levels in Evaporation Pond, 2009–October 2019

[1] Allowing pond water levels to decline to this low level was intentional, to inform LM's decisions regarding (1) the time required for complete evaporation and (2) whether or not enhanced evaporation would be needed prior to pond decommissioning. (Based on LM's observations, enhanced evaporation would not be necessary.) The second steep decline in pond water levels that followed this reporting period, shown in Figure 6, was due to the June 2019 San Juan River flood. This event necessitated the shutdown of all SOARS equipment on the floodplain and subsequent repairs.

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

Location	Annual Cumulative Volume (gallons)[a]	Total Cumulative Volume (gallons)[a]	Percent of Annual Cum. Volume Pumped (%)	Nitrate as N Average Concentration, 2018–2019 (mg/L)	Nitrate Mass Removed, 2018–2019 (lb)[b]	Cumulative Mass of Nitrate Removed (lb)[a,b]	Sulfate Average Concentration, 2018–2019 (mg/L)	Sulfate Mass Removed, 2018–2019 (lb)[b]	Cumulative Mass of Sulfate Removed (lb)[a,b]	Uranium Average Concentration, 2018–2019 (mg/L)	Uranium Mass Removed, 2018–2019 (lb)[b]	Cumulative Mass of Uranium Removed (lb)[a,b]
Terrace												
0818	11,919	5,765,395	0.14	595	59.2	55,993	15,000	1492	618,615	0.135	0.013	6.0
1070	11	545,098	<0.001	580	0.1	3,870	15,500	1.4	75,902	0.105	<0.001	0.55
1071	68	121,712	0.001	660	0.4	1,799	14,000	7.9	7,476	0.135	<0.001	0.15
1078	19,504	4,757,660	0.23	325	52.9	23,139	13,000	2116	545,783	0.110	0.018	5.2
1091	593	262,268	0.007	640	3.2	3,082	15,000	74.2	27,502	0.104	0.001	0.25
1092	0	224,883	0	510	0	2,875	15,000	0	24,820	0.110	0	0.22
1093R[c]	41,090	4,509,220	0.49	2050	703	79,248	6500	2229	218,699	0.190	0.065	4.04
1094 (2003–2004)[d]		15,628	–	–	–	524	–	–	312	–	–	0.01
1095	16,145	2,831,392	0.19	1850	249	37,833	3400	458	141,841	0.028	0.004	1.37
1096	4,320	3,121,137	0.05	580	20.9	16,163	16,000	577	373,625	0.10	0.004	2.66
1087 (BLW)[e]	1,140,161	25,223,007	13.5	230	2188	62,964	7400	70,412	1,494,450	0.515	4.9	114.5
1088 (MDW)	0	3,406,532	0	Not sampled	0	18,654	Not sampled	0	535,882	Not sampled	0	5.00
Floodplain												
1077 (2003–2005)[d]	–	812,449	–	–	–	1,214	–	–	116,410	–	–	16.8
1089	20,797	39,628,979	0.25	0.215	0.037	5,632	3400	590	2,367,748	0.10	0.017	223.5
1104	3,772	8,565,939	0.04	0.675	0.021	2,972	3500	110	615,360	0.12	0.004	69.3
Trench 1 (1110)	2,456,135	47,061,942	29.1	40.0	820	38,105	6600	135,283	2,746,985	0.585	12.0	308.5
Trench 2 (1109)	4,723,318	58,416,371	56.0	57.5	2267	35,191	1255	49,469	715,073	0.148	5.83	102.3
Seep sump (1118)	0	3,013,883	0	37.0	0	1,264	6300	0	150,977	0.405	0	12.0
Totals												
Total terrace[d]	1,233,810	50,783,931	14.6	–	3277	306,145	–	77,367	4,064,907	–	5.0	140
Total floodplain[d]	7,204,022	157,499,562	85.4	–	3086	84,377	–	185,452	6,712,553	–	17.8	732
Total to pond[d]	8,437,832	208,283,493	–	–	6364	390,523	–	262,819	10,777,460	–	22.9	872

Notes:

[a] Annual cumulative volumes are for this reporting period: April 1, 2018, through March 31, 2019. Cumulative volumes and masses are totals since 2003.
[b] Mass in pounds (lb) removed = annual volume (gallons) × average concentration (mg/L) × (3.7854 liters per gallon) × (1 lb per 453,592.37 milligrams).
[c] Cumulative volumes and masses listed for well 1093R combine data from former smaller-diameter well 1093 (2003–2007) with data from larger-diameter well 1093R (2008–present).
[d] Total cumulative volumes and masses in lower portion of table include data from former terrace pumping well 1094 (2003–2004) and former floodplain pumping well 1077 (2003–2005).
[e] The annual volume reported for Bob Lee Wash is uncertain because of an extended flow meter dysfunction; see Table 3, Note c.

Abbreviations: BLW = Bob Lee Wash; lb = pounds; MDW = Many Devils Wash (the MDW interceptor drain has not operated since 2014)

From April 2018 through March 2019, about 8.44 million gallons of extracted groundwater were pumped to the evaporation pond, nearly 3 times greater than the volume extracted the previous (2017–2018) reporting period (2.97 million gallons). The bulk of this total volume (7.2 million gallons, or 85.4%) of the influent liquids entering the pond during the current reporting period was from the floodplain trenches. The trenches, along with Bob Lee Wash,[2] were the only treatment system locations where pumping was sustained through the majority of the reporting period. As shown in Figure 7, at the end of the 2018–2019 reporting period, about 50.8 million gallons have been extracted from the terrace, and 157.5 million gallons have been extracted from the floodplain since DOE began active remediation in March 2003. This yields a total cumulative extracted volume of about 208.3 million gallons of water pumped to the evaporation pond from all sources. Total cumulative contributions are 24% from the terrace and 76% from the floodplain.

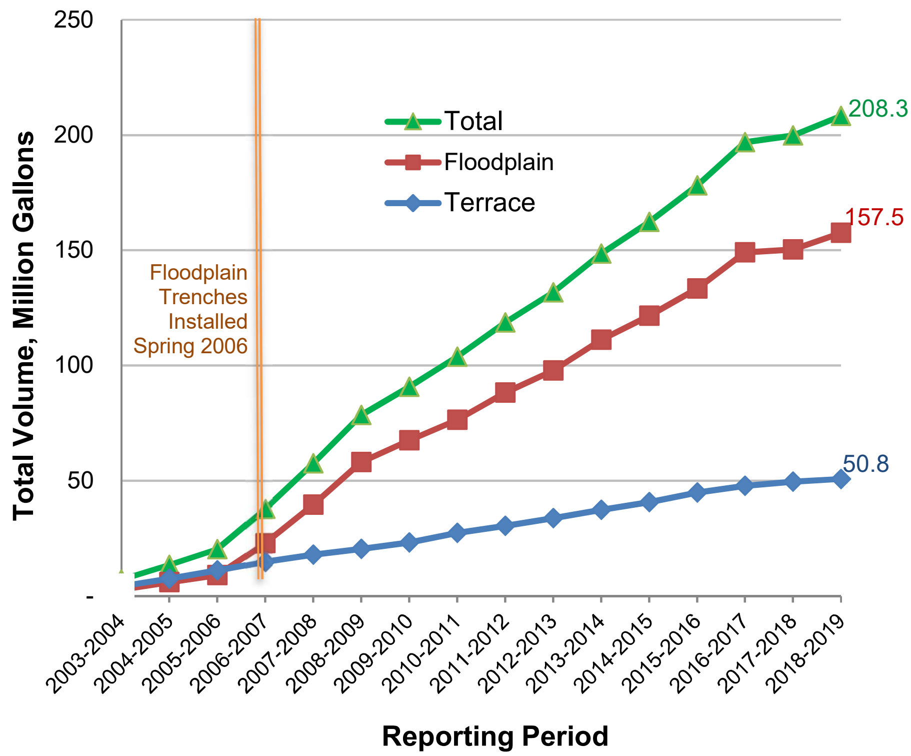


Figure 7. Total Groundwater Volume Pumped to the Evaporation Pond

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 2018–2019 performance period were approximately 6364 pounds nitrate (as N); 262,819 pounds sulfate; and 22.9 pounds uranium (Table 4). 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.

[2] Because the flow meter installed at Bob Lee Wash location 1087 was not functioning properly for an approximate 6-month period, corresponding cumulative volumes reported for 2018–2019 are uncertain (refer to Table 3).

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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 2018 through March 2019 reporting period. During the March 2019 sampling event, 110 monitoring wells were sampled (58 on the floodplain and 52 on the terrace). Fifteen surface water locations, including nine San Juan River sampling points and various seeps, were also sampled.

3.1 Floodplain Contaminant Distributions and Temporal Trends

This discussion and the 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 (Figure 8 through Figure 10) compare baseline and current conditions using all alluvial wells that were sampled during both periods.[3] 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. Corresponding time–concentration graphs for the primary COCs are provided in Appendix A using the spatial groupings shown in Figure 11 (see Figures A-1 through A-9).

3.1.1 Current Conditions and Global Trends

Figure 8 through Figure 10 illustrate the marked reductions in contaminant concentrations since the baseline (2000–2003) period. This is particularly evident for nitrate (Figure 8). The extent of the nitrate plume, defined by regions exceeding the 10 mg/L MCL, is much smaller and currently (for the first time since pumping began) limited to the base of the escarpment. Although the extent of the sulfate plume, defined by regions exceeding the 2000 mg/L cleanup goal (Table 1), is about the same as that in 2000–2003, sulfate magnitudes are now notably lower (Appendix A). As shown in Figure 9, sulfate concentrations in most regions of the floodplain alluvium are at or lower than 4000–5000 mg/L, a range consistent with that measured in background well 0797 in the last 6–7 years. Except for wells 0735 and 0779, sulfate concentrations measured during this reporting period were lower than naturally occurring levels (10,000–20,000 mg/L) reported for Many Devils Wash and other desert arroyos (DOE 2012).

Interpretations of changes in the uranium plume configuration (Figure 10) are similar and generally consistent with the conclusions drawn in previous annual reports (e.g., DOE 2019b). Although uranium concentrations have declined relative to baseline conditions (Appendix A), in most floodplain wells, levels still exceed the 0.044 mg/L MCL. However, the blue-shaded contours in Figure 10 for the current period, corresponding to the western floodplain and most wells near the San Juan River, are comparable to naturally occurring uranium levels (0.1–0.2 mg/L) measured in groundwater samples from Many Devils Wash (DOE 2012).

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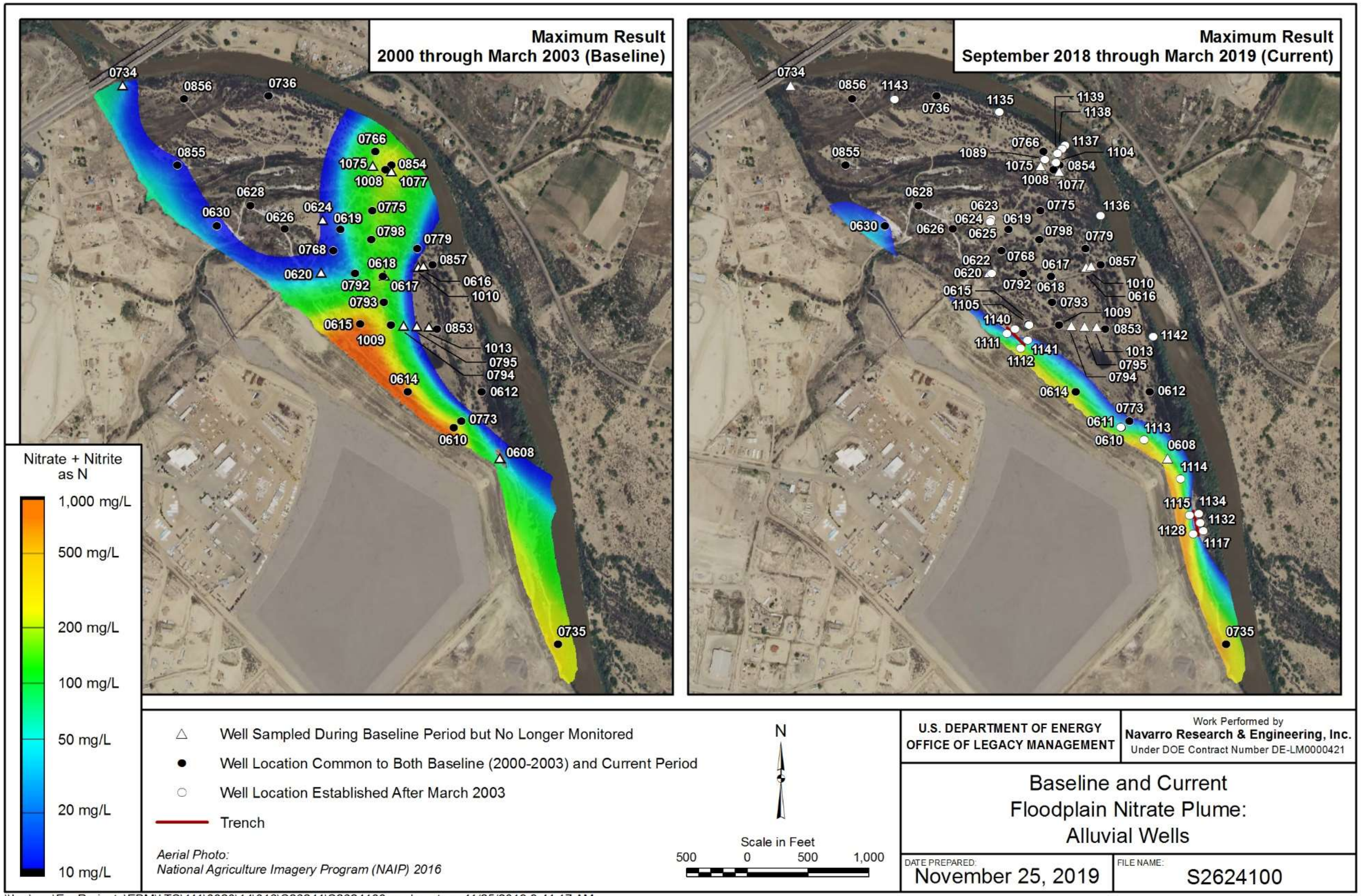
[3] The plume maps in Figure 8 through Figure 10 were developed using Environmental Visualization System software version 2019.2.0 (kriging estimation; simple anisotropy mode; spherical model; finite difference grid type). In these figures, color contours are only shown for regions with interpolated COC concentrations exceeding remediation goals.



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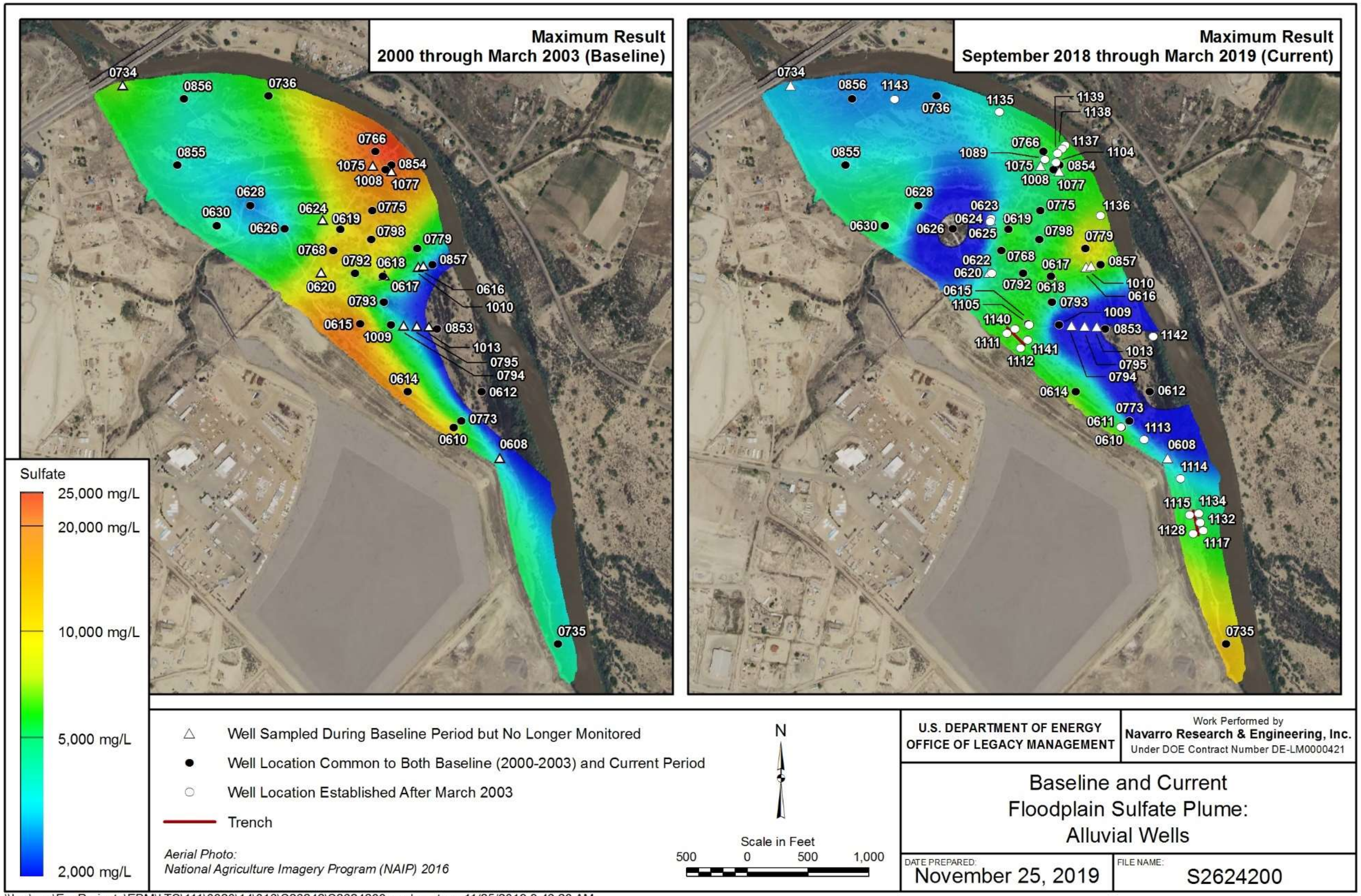
Note: Hollow or uncontoured portions of both plume maps denote regions with nitrate concentrations below the 10 mg/L MCL. In westernmost well 0734, there has been insufficient water to sample since September 2014. Before then (2004–2014), nitrate concentrations ranged from 0.01 to 5.5 mg/L, below the MCL.

Figure 8. Baseline (2000–2003) and September 2018 Through March 2019 Shiprock Site Floodplain Nitrate Plumes



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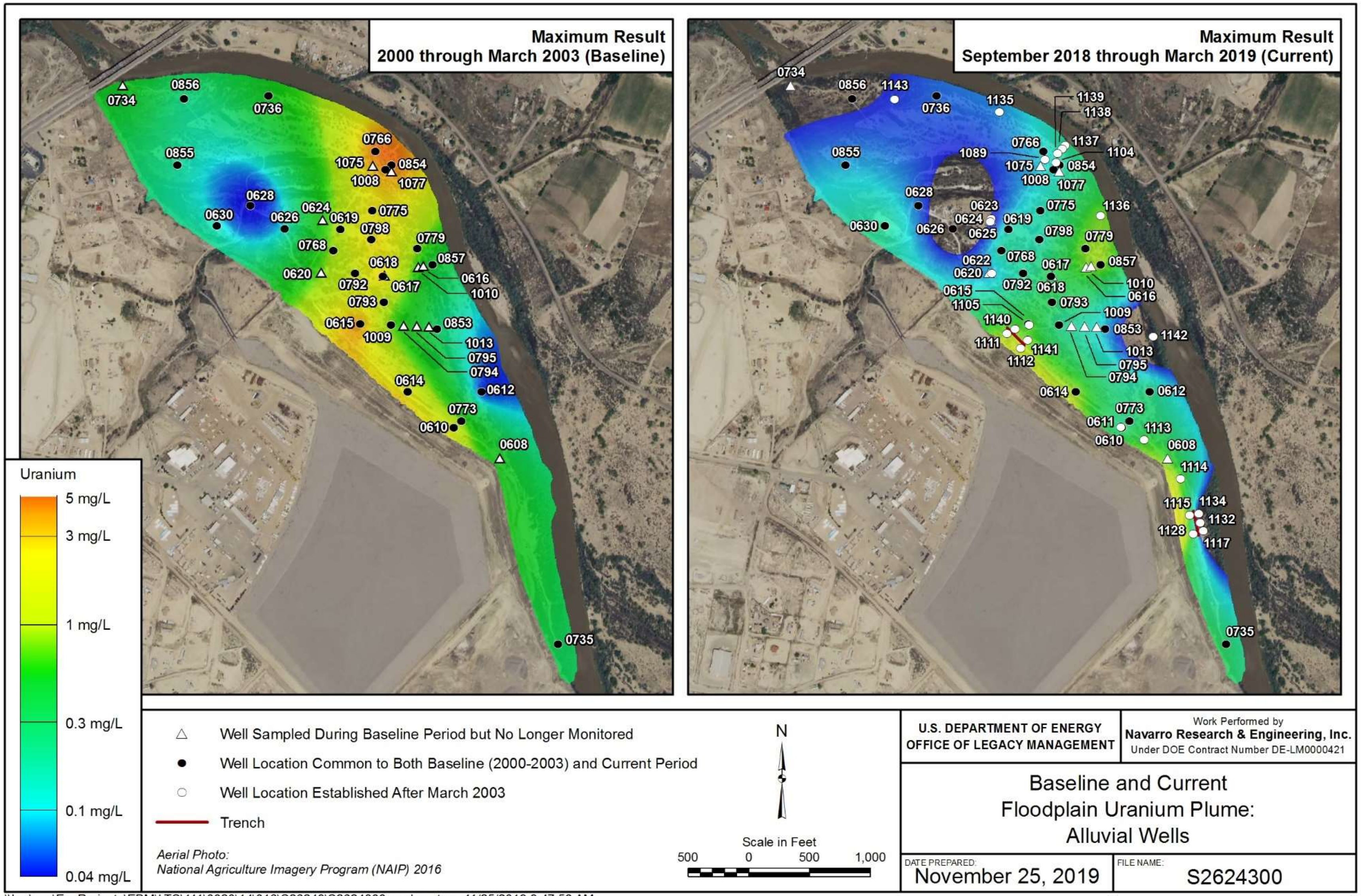
Note: Hollow or uncontoured portions of both plume maps denote regions with sulfate concentrations below the 2000 mg/L remediation goal. In westernmost well 0734, there has been insufficient water to sample since September 2014. Based on previous measurements (2004–2014), sulfate concentrations ranged from 2200 to 25,000 mg/L (10/2/2013 measurement), with all exceeding the 2000 mg/L goal. If these geochemical conditions prevail, the westernmost edge of the plume would likely extend to the river in the well 0734 region.

Figure 9. Baseline (2000–2003) and September 2018 Through March 2019 Shiprock Site Floodplain Sulfate Plumes



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Note: Hollow or uncontoured portions of both plume maps denote regions with uranium concentrations below the 0.044 mg/L standard. In westernmost well 0734, there has been insufficient water to sample since September 2014. Based on previous measurements (2004–2014), uranium concentrations ranged from 0.018 to 0.87 mg/L (10/2/2013 measurement), with most exceeding the 0.044 mg/L cleanup goal. If these geochemical conditions prevail, the westernmost edge of the plume would likely extend to the river in the well 0734 region.

Figure 10. Baseline (2000–2003) and September 2018 Through March 2019 Shiprock Site Floodplain Uranium Plumes

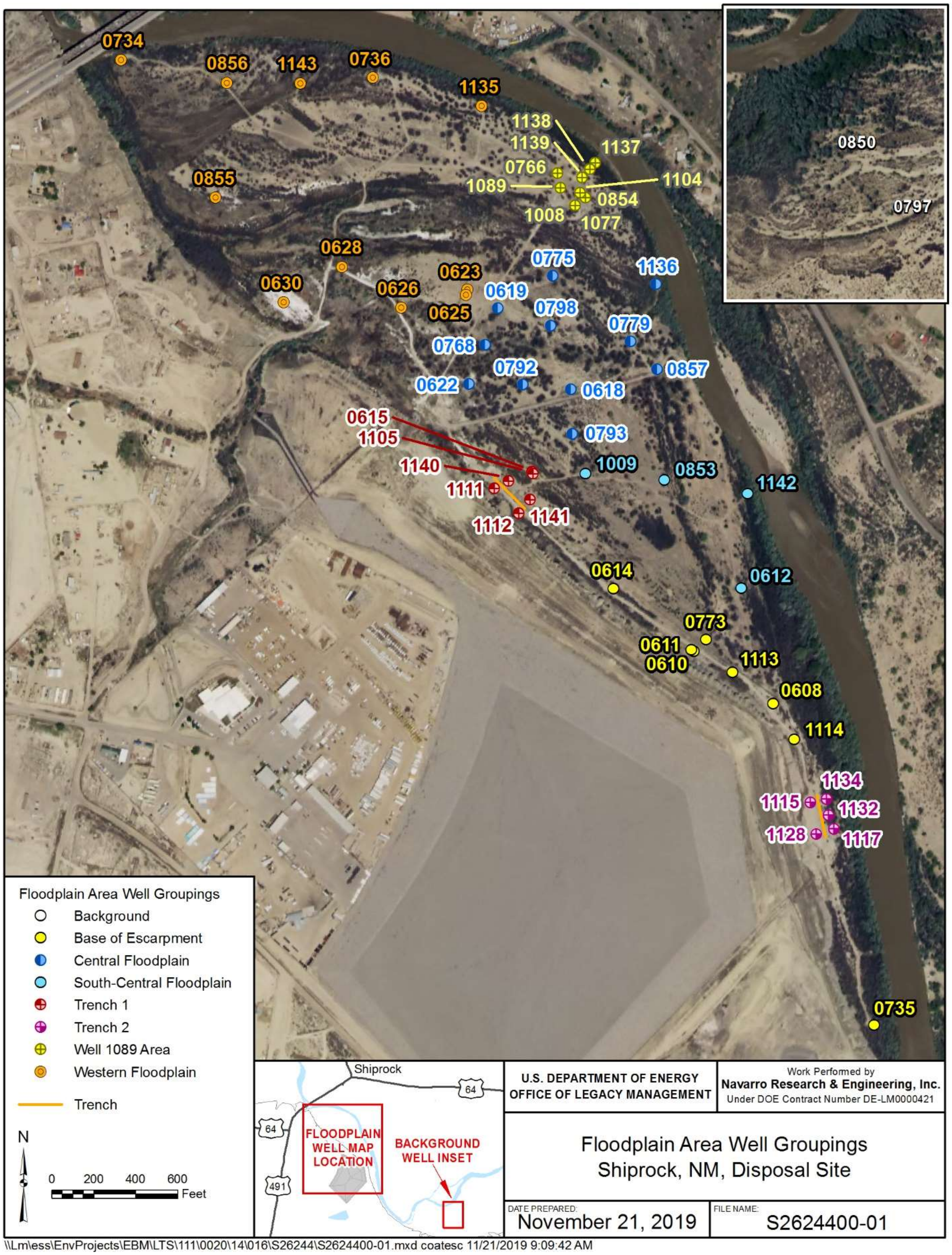


Figure 11. Shiprock Site Floodplain Area Well Groupings

Pumping on the floodplain (at all locations) was suspended for all but about 3 weeks of the previous (2017–2018) reporting period. At the well 1089/1104 pumping complex near the San Juan River, the pumping suspension continued through March 2019. This was not the case at the trenches, where pumping was resumed in mid-July 2018 to prevent desiccation of pond sediments. Because of these recent changes, it is important to evaluate whether the decrease in groundwater extraction volumes in the last 2 years has impacted contaminant concentrations or the plume configuration on the floodplain. The following discussion is a continuation of the preliminary observations noted in the previous annual report (DOE 2019b).

To help assess potential impacts of the pumping suspension, Figure 12 plots uranium concentrations in 52 alluvial wells on the contiguous floodplain for the period 2010–2019. Figure 13 plots the same data, but with a common semilog (versus linear) scale. Uranium was chosen as the representative COC because it is most important from a risk perspective. It is also strongly correlated with sulfate, as demonstrated in previous reports (e.g., DOE 2018b) and as illustrated in Appendix A, Figures A-1 through A-9. Because nitrate concentrations have markedly reduced in most floodplain wells (Figure 8), it receives less focus here. The time frame represented in Figure 12 and Figure 13 is shorter and more recent than that shown in corresponding Appendix A graphs. This is because the marked reductions in uranium concentrations since the baseline (2000–2003) period, or since the trenches were installed in 2006, might mask recent increases because of the vertical (*y*-axis) scale.

Given the limited data since pumping was suspended, only qualitative interpretations can be made regarding potential impacts of the nonpumping scenario. Four data points (corresponding to semiannual monitoring results for the last two reporting periods) are not sufficient to characterize any subsequent trends. Such an analysis is further complicated by the fact that pumping resumed at the trenches in mid-July 2019 and continued through the end of this reporting period. Other variables such as groundwater elevations and changing river flows and vegetation patterns also influence contaminant concentrations in the floodplain alluvial aquifer. For all of these potentially influential variables, time lags in responses to changes in processes are not easily quantified. Therefore, the main objective of the following interpretation is to analyze for any possible effects of the pumping suspension.

As shown in Figure 12 and Figure 13, uranium concentrations measured in this (2018–2019) reporting period were similar to previous (pre-pumping-suspension) results in the majority of floodplain wells. To facilitate review, the plot order in these figures is based first on the floodplain region. For example, wells in pumping areas (e.g., Trench 1 and Trench 2) are plotted first, whereas areas less susceptible to pumping influences (e.g., the western floodplain) are plotted last. The last annual report (DOE 2019b) identified apparent upticks in eight wells: Trench 1 wells 1111 and 1112 (escarpment side); Trench 2 wells 1114, 1115, and 1128 (escarpment side); Trench 2 wells 1117 and 1132 (river side); and central floodplain wells 0853 and 1142. On the basis of the updated plots (Figure 12, Figure 13), those apparent upticks were not sustained. Any recent increases in uranium concentrations (e.g., in south-central well 0612) are slight or within the range of historical observations. In summary, the previous (nearly yearlong) pumping suspension in 2017–2018, followed by the partial suspension this reporting period, has had no apparent impact on uranium concentrations in floodplain alluvial wells. As shown for uranium (Figure 12 and Figure 13), as well as for nitrate and sulfate (Appendix A, Figures A-1 through A-9), concentrations are similar to presuspension levels and continue to be markedly lower than baseline levels in many wells throughout the floodplain.

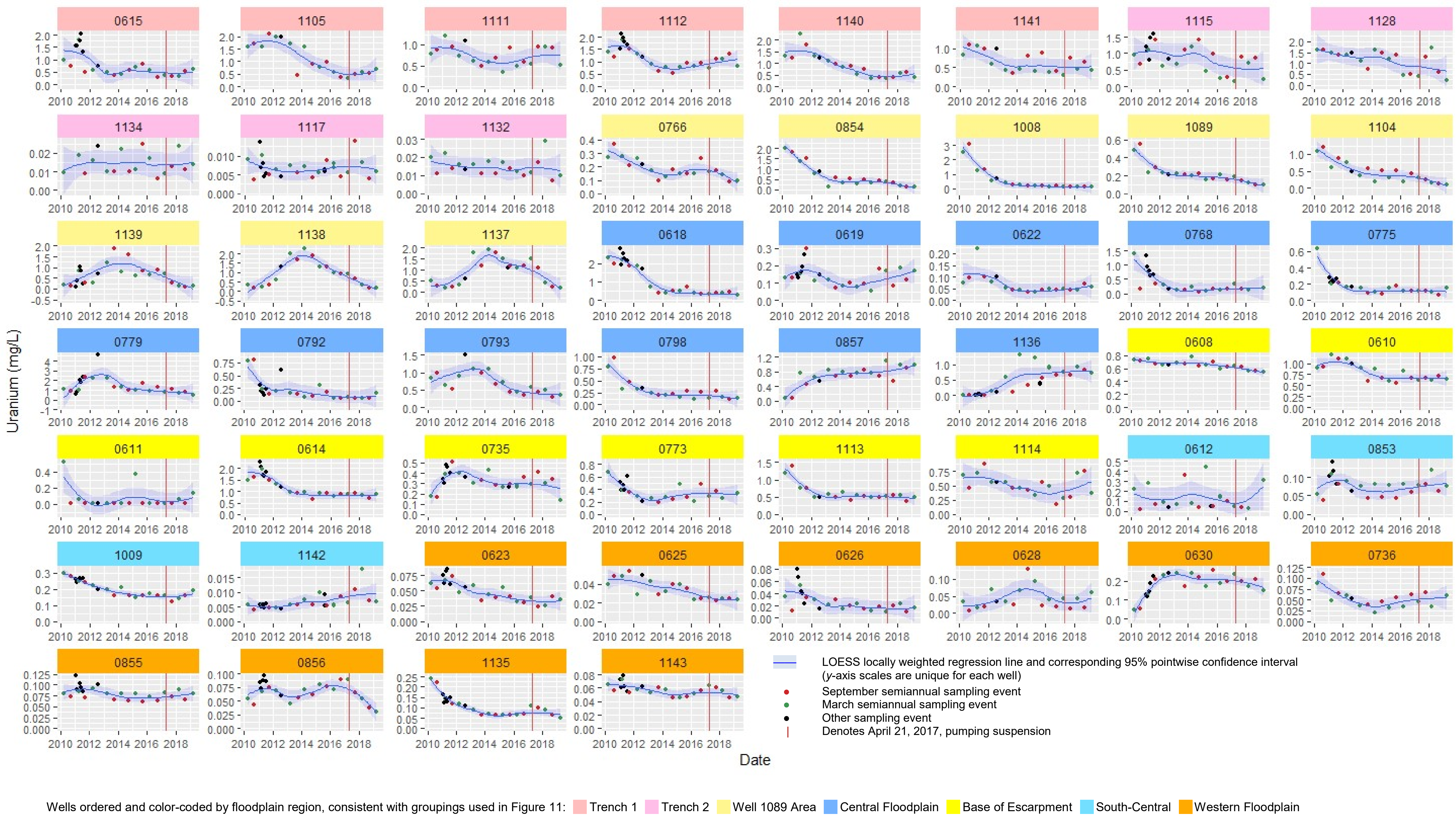


Figure 12. Uranium Time–Concentration Trends in Shiprock Site Floodplain Wells, 2010–2019: Linear Scale

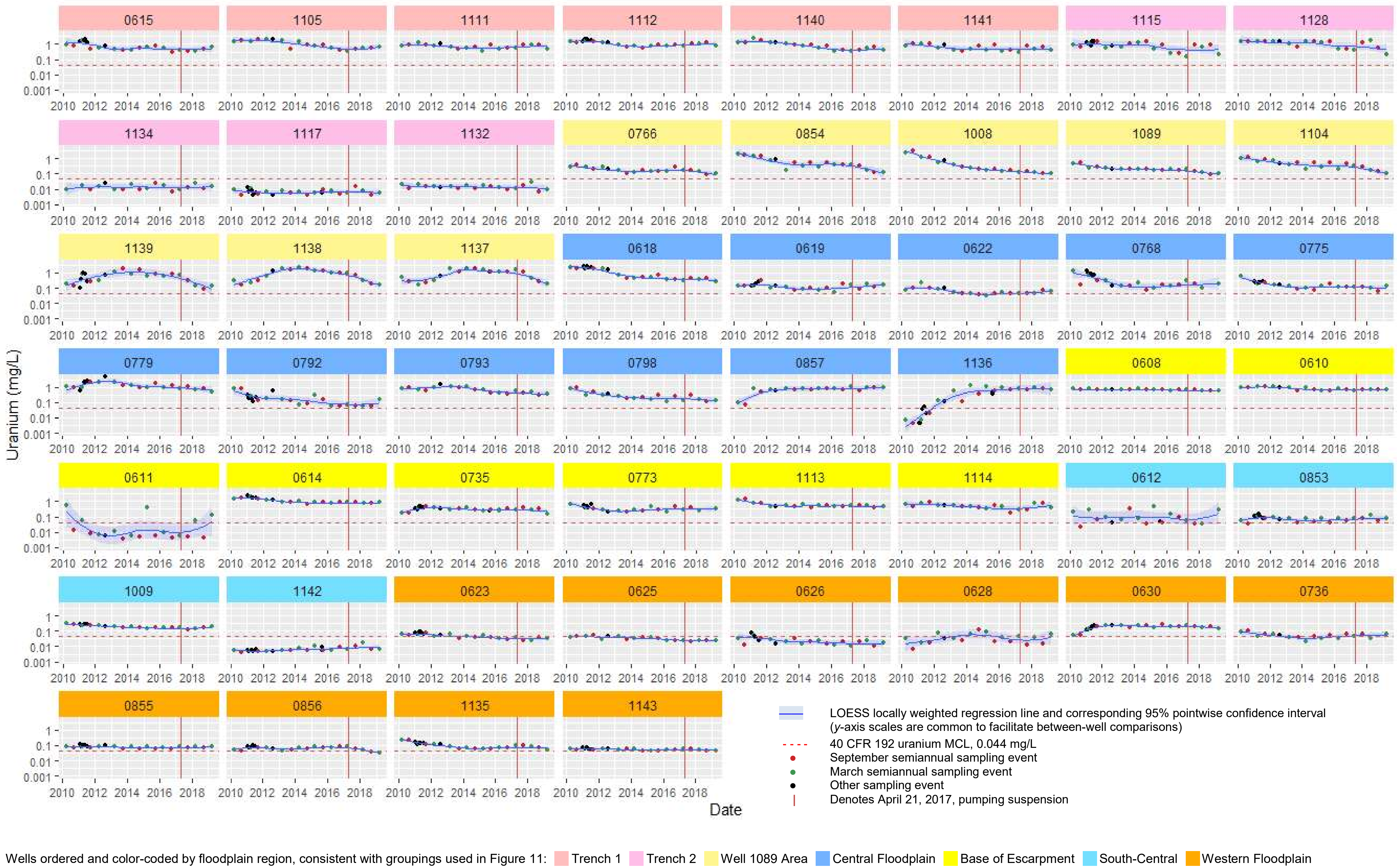


Figure 13. Uranium Time–Concentration Trends in Shiprock Site Floodplain Wells, 2010–2019: Semilog Scale

3.1.2 Analyte-Specific Trends

The remaining discussion evaluates contaminant trends in floodplain alluvial wells since baseline (2000–2003) using the time–concentration plots in Appendix A. Despite the recent marked reduction in floodplain groundwater extraction volumes, this discussion is similar to that presented in the last few years because, as indicated in Figure 12, little or no change in contaminant trends is apparent. As demonstrated in Appendix A, concentrations of uranium, sulfate, and nitrate have decreased in most floodplain wells relative to baseline conditions, in some cases by 1 to 2 orders of magnitude. Although there are a few exceptions to this general decreasing trend, overall, COC concentrations in floodplain wells have not changed much in the last several years.

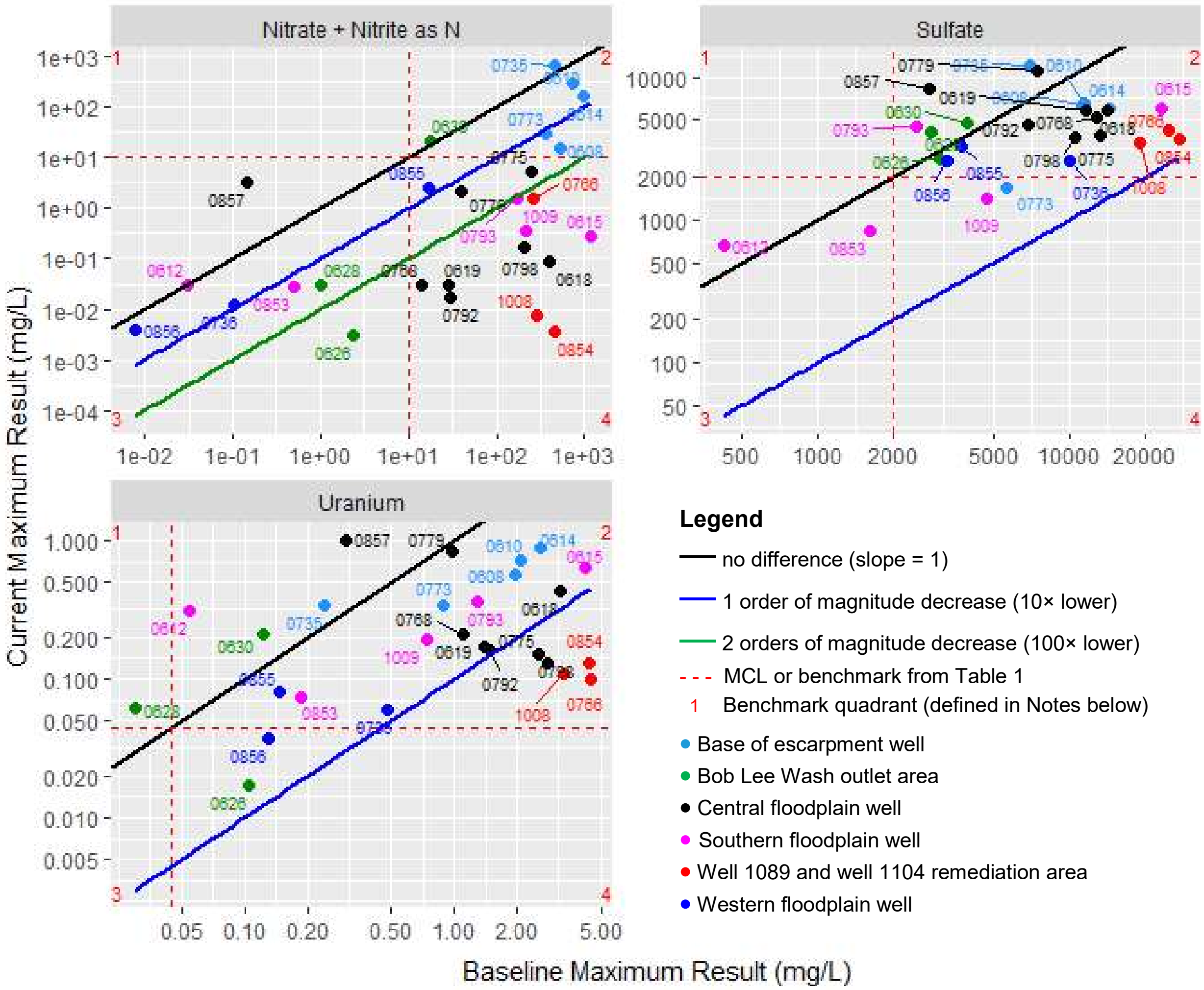
Exceptions continue to be found at several locations: near-river wells 0857 and 1136 in the central floodplain (Figure A-5); southernmost well 0735 (Figure A-7); and well 0630 at the base of Bob Lee Wash (Figure A-8). At most of these locations, contaminant concentrations, in particular sulfate and uranium, have increased since about 2010. Although these increasing trends appear to have stabilized, COC concentrations are higher than those measured initially. 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 (Figure A-3). For example, despite the pumping suspension in late April 2017, no shifts in COC concentrations are apparent in extraction wells 1089 and 1104, nor in adjacent near-river wells (1137, 1138, and 1139) potentially influenced by changes in pumping (Figure 12; Figure A-3).

The remainder of this discussion evaluates contaminant trends by analyte. For nitrate, sulfate, and uranium, the discussion is based on the plume maps shown in Figure 8 through Figure 10 and the time–concentration plots provided in Appendix A.

3.1.2.1 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 8) 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 Trench 1 to pumping wells 1089 and 1104 (the 1089/1104 remediation area) near the San Juan River. Nitrate concentrations in most areas of the floodplain are now below the 10 mg/L cleanup goal.

Declines in nitrate concentrations are also evident in Figure 14, which summarizes the progress of active remediation by comparing baseline (2000–2003) COC concentrations in floodplain monitoring wells to those measured during the current (2017–2018) 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 orders of magnitude decline. The dashed red lines (horizontal and vertical) denote the corresponding benchmarks 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.



Notes:
This figure only includes data for non-background wells sampled during both baseline (2000–2003) and current (2018–2019) periods. As such, most wells in the region of Trenches 1 and 2 are not represented, nor is western floodplain well 0734, which has been dry since 2015. Because of this, the color-coded spatial groups defined above are different from those shown in Figure 11. Consistent with the plume maps in Figure 8 through Figure 10, the maximum result for each period is plotted. 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 14. Baseline vs. Current Concentrations of Major COCs in Shiprock Site Floodplain Wells

3.1.2.2 Sulfate

Reductions in sulfate concentrations since the baseline period are evident in many floodplain wells, particularly in the Trench 1 and 1089/1104 remediation areas (Appendix A; Figure 9). However, sulfate levels still exceed the 2000 mg/L GCAP-established benchmark in most floodplain wells (Figure 9; Figure 14). At the same time, this benchmark also has been exceeded in floodplain background wells 0797 and 0850. In well 0797, sulfate concentrations have exceeded the 2000 mg/L benchmark since about 2005, generally ranging from 3000 to 5000 mg/L (Appendix A, Figure A-9). If the sulfate benchmark were redefined based on the most recent results for background well 0797 (4100–4500 mg/L), then the corresponding plume extent would be much smaller than that currently shown in Figure 9. That is, the 2000–4000 mg/L blue-colored scale ramp and plume contours would no longer apply.

Sulfate concentrations in central floodplain near-river wells 0857 and 1136 have more than doubled since 2010, and increasing trends are still apparent. Although beyond the scope of this annual performance report, these trends will be further evaluated as part of LM's recently initiated update to the site conceptual model. As part of this effort, the relationship between sulfate (and other COC) concentrations in these near-river wells and groundwater elevations, San Juan River elevations, and other variables will be examined in detail. Sulfate levels in wells 1137–1139 continue to decline since their peak in about 2014 (Figure A-3). Although sulfate concentrations in well 0630 at the base of Bob Lee Wash (Figure A-8) increased markedly between about 2010 and 2012, levels have remained stable at about 4500 mg/L (consistent with background) since then.

3.1.2.3 Uranium

As evident in Appendix A, uranium trends in many floodplain wells are similar to those found for sulfate. These correlations are expected, as a strong positive correlation between uranium and specific conductance was established based on previous vertical profiling of selected floodplain wells (DOE 2018b). Decreases in uranium concentrations in wells across a large portion of the floodplain are evident based on the plume maps in Figure 10, as well as the time–concentration plots in Appendix A. These decreases are most apparent in the well 1089/1104 remediation area and several central floodplain wells, where uranium levels have decreased by 1 order of magnitude or more (Figure 14). Despite these reductions, uranium concentrations in most floodplain wells still exceed the 0.044 mg/L MCL (Figure 10). However, in most samples collected since 2014, the MCL has also been exceeded in background well 0850; the most recent (March 2019) result was 0.063 mg/L.

Exceptions to the general decreasing trends noted above are found in a few wells. For example, recent upticks in uranium concentrations are apparent in Trench 1 area wells, central floodplain well 0619, base of escarpment well 1114, and a few hyporheic (south-central) wells (Figure 12). However, in all of these cases, the increases are slight or results are well within the range of historical observations. Although uranium concentrations in near-river wells 0857 and 1136 and well 0630 (base of Bob Lee Wash) are still notably higher than those measured in 2010, levels have stabilized in the last few years. In summary, in most floodplain wells, uranium concentrations are similar to pre-pumping-suspension levels and continue to be markedly lower than baseline levels.

3.1.2.4 Other COCs

Ammonia, manganese, selenium, and strontium are no longer discussed in detail in this annual report because these constituents are not as prevalent or as elevated at the site as the primary COCs (uranium, nitrate, and sulfate). The following characterizations, based largely on previous characterizations and reports, will be updated in the forthcoming revised GCAP.

Ammonia concentrations continue to be elevated (recent maximum of 120 mg/L) in Trench 2 area wells (escarpment side only). 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 0.001–7.2 mg/L background range listed in Table 1. During this reporting period, the maximum manganese concentration (5.1 mg/L) was measured in background well 0797 in September 2018.

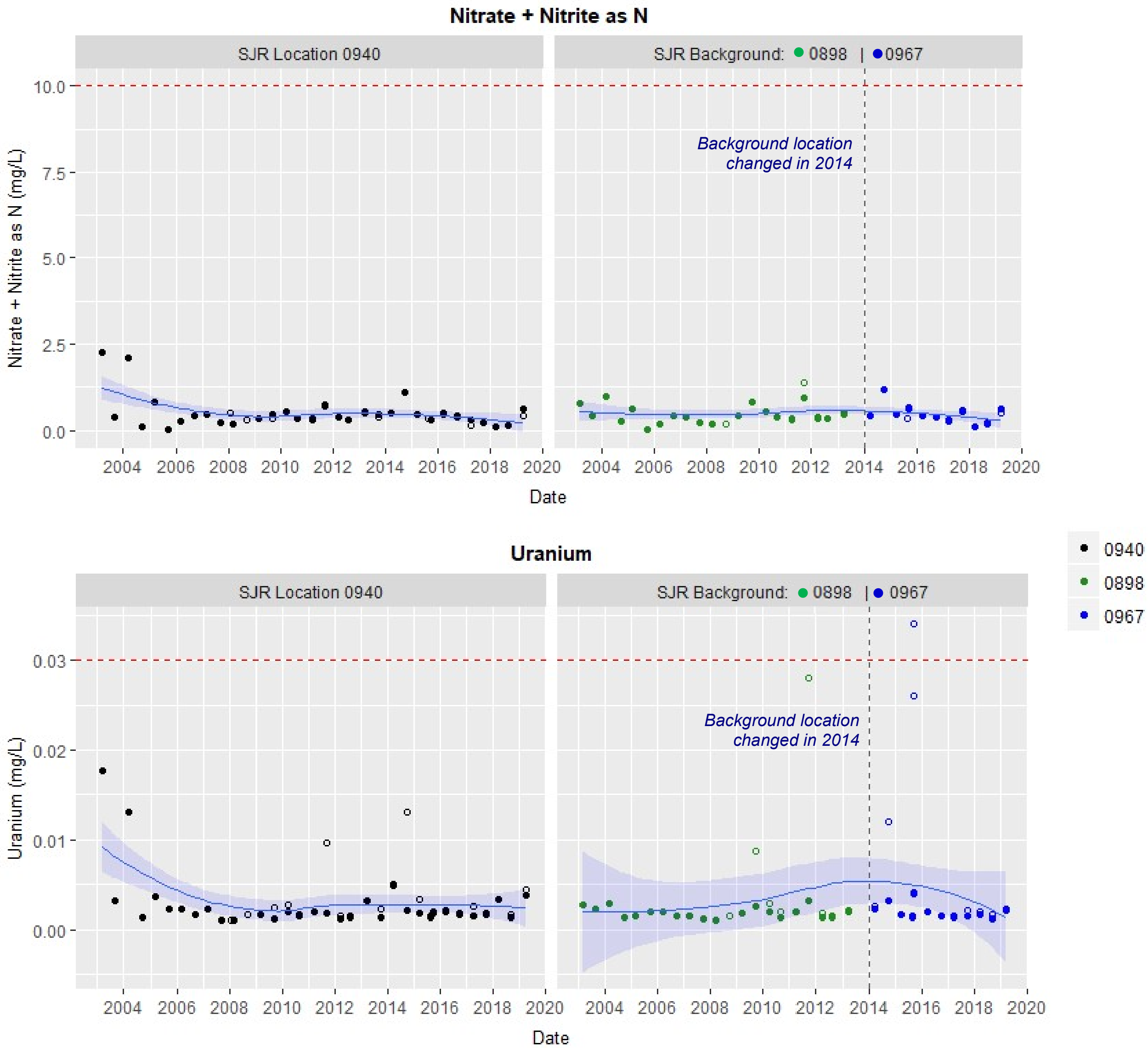
Selenium is no longer addressed in the annual reports because evidence suggests that the Mancos Shale is a likely source of this constituent in some areas of the site and in general (Morrison et al. 2012; Robertson et al. 2016). Historically, selenium concentrations have been highest in Many Devils Wash, where contamination has been demonstrated to be naturally occurring (Robertson et al. 2016); in swale area wells along the terrace buried escarpment; and in several floodplain wells situated along the base of the escarpment. Except for wells 0779, 0857, and 1136, 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 (levels are highest in the western floodplain) 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 and mostly below the risk-based standard of 12 mg/L (most less than 10 mg/L).

3.2 San Juan River Monitoring

DOE regularly monitors eight San Juan River locations, including one upgradient background location (Figure 2). Sampling point 0940, 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). Figure 15 plots concentrations of nitrate and uranium measured in sampling point 0940 surface water samples along with corresponding background results. The current background location (0967), situated where the river bends to the north just east of Many Devils Wash (Figure 2), has been sampled since March 2014. The former background location, 0898 (farther upgradient), was sampled between 1998 and March 2013.

As shown in Figure 15, nitrate and uranium concentrations in 0940 river samples remain consistent with those measured at the upstream background location. Long-term monitoring of the point of exposure (San Juan River location 0940) continues to indicate that the Shiprock site poses no adverse risk to human health or the environment, provided that the Navajo Water Code continues to restrict the use of shallow groundwater near the site.



LOESS locally weighted regression line and corresponding 95% pointwise confidence interval

- - - Navajo Nation Surface Water Quality Standard: 10 mg/L for nitrate as N; 0.03 mg/L for uranium[4]

• Filtered sample result (dissolved fraction)

○ Unfiltered result (total fraction)

Notes:

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

Since 2014, surface location 0967 has been sampled because of the difficulty in accessing former background location 0898 (Figure 2). Location 0967 is now considered the representative upgradient San Juan River monitoring location.

Abbreviation:

SJR = San Juan River

Figure 15. Uranium and Nitrate Concentrations in Samples from San Juan River Location 0940 and Background Locations

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[4] https://www.epa.gov/sites/production/files/2014-12/documents/navajo-tribe.pdf
The nitrate standard is the same as that listed in Table 2-2 of the GCAP (DOE 2002). The current standard for uranium, 0.03 mg/L, is lower than the 0.035 mg/L standard cited in the GCAP (DOE 2002).

3.3 Terrace System Subsurface Conditions

3.3.1 Overview

The discussion of current subsurface conditions on the terrace is based on the collection and analysis of groundwater-level data through March 2019. 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 Wash. 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.

Non-mill-related sources to terrace groundwater appear to have influenced water quality, levels, and flow (DOE 2019a). Potential sources include but are not limited to (1) infiltration of surface runoff, (2) domestic water use including leaking utilities, (3) infiltration of water discharged from artesian well 0648, and (4) leach fields from residential properties and the Navajo Engineering & Construction Authority yard. Groundwater mounding in the residential area near well 0835 and within the Navajo Engineering & Construction Authority yard near well 0828 along with continued discharges into Bob Lee Wash (well 1067) and seeps 0425 and 0426 are apparent. Geochemical analysis of samples collected from wells 0835, 0828, and others on the terrace indicates that groundwater is locally mixed with either Animas or San Juan River water (DOE 2019a). Application of San Juan River water for irrigation, or release of potable water (sourced from the Animas River by the Navajo Tribal Utility Authority) through intended application or utility losses, is likely occurring in those two areas and will be investigated further as part of current efforts to revise the GCAP.

3.3.2 Terrace Groundwater-Level Trends

Because pumping on the terrace was suspended for the bulk of the 2018–2019 reporting period, only about 93,650 gallons of groundwater were pumped from the nine terrace extraction wells between April 2018 and March 2019. This volume corresponds to about one-third of the volume pumped (267,570 gallons) during the preceding (2017–2018) inactive pumping period (Table 3), and about 1/20th of the volume pumped during prior active pumping periods. As of April 1, 2019, the cumulative volume of water removed from the terrace (excluding Bob Lee Wash and Many Devils Wash) was approximately 22.2 million gallons (Table 4).

Groundwater-level data from the terrace collected during the March 2019 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). Figure 16 shows a quantitative map view of some of the changes in groundwater elevations during this period for alluvial monitoring wells. Of the 28 water-level measurements (excluding the one damaged and 6 dry wells) taken in March 2019 at terrace wells screened in alluvium, the majority showed declines relative to the (2000–2003) baseline period. The maximum decrease (9.4 ft) was measured in well 0836, in the northwest portion of the terrace (Figure 16). The average water-level change measured in terrace alluvial wells through this reporting period was a decrease of about 2.3 ft.

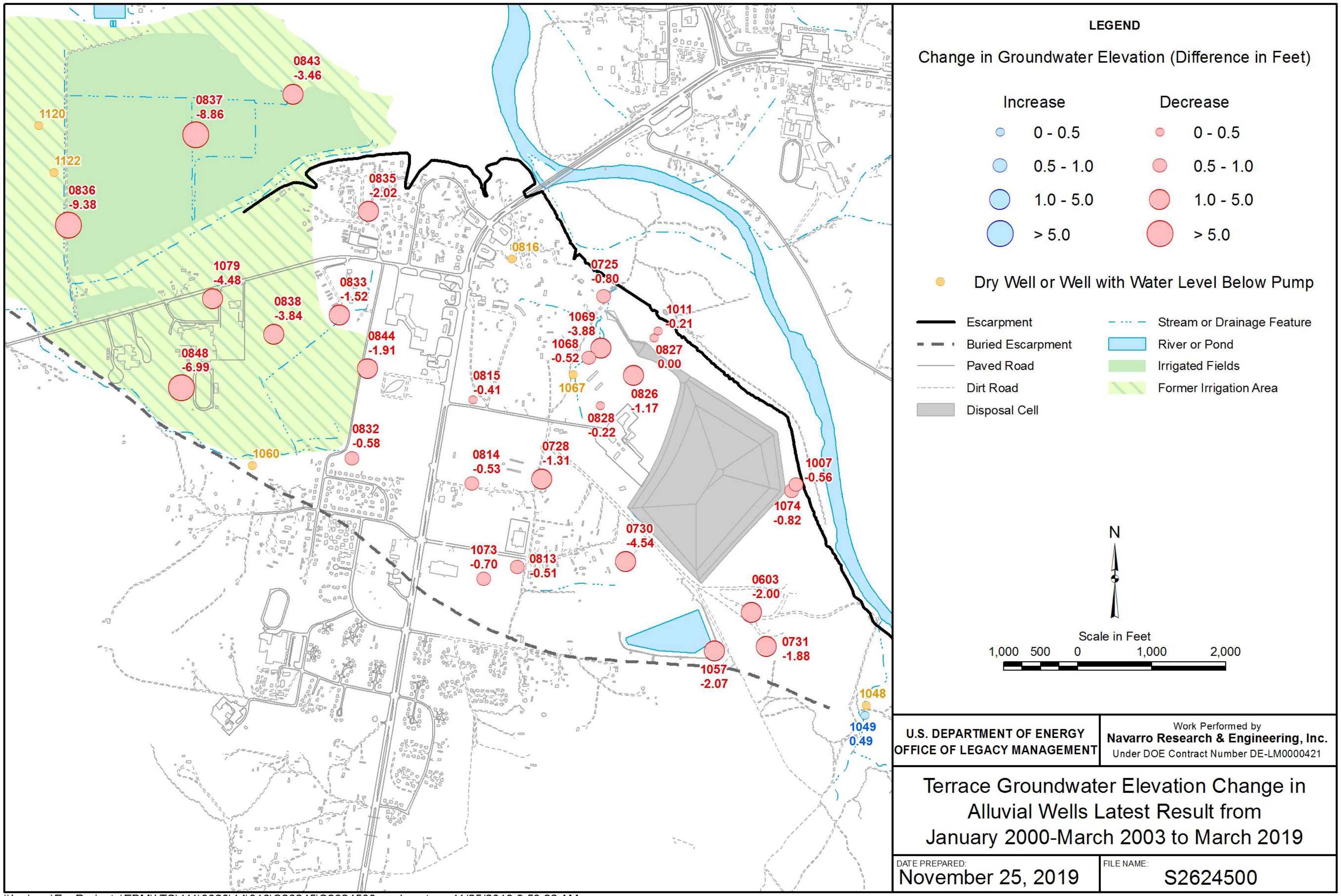

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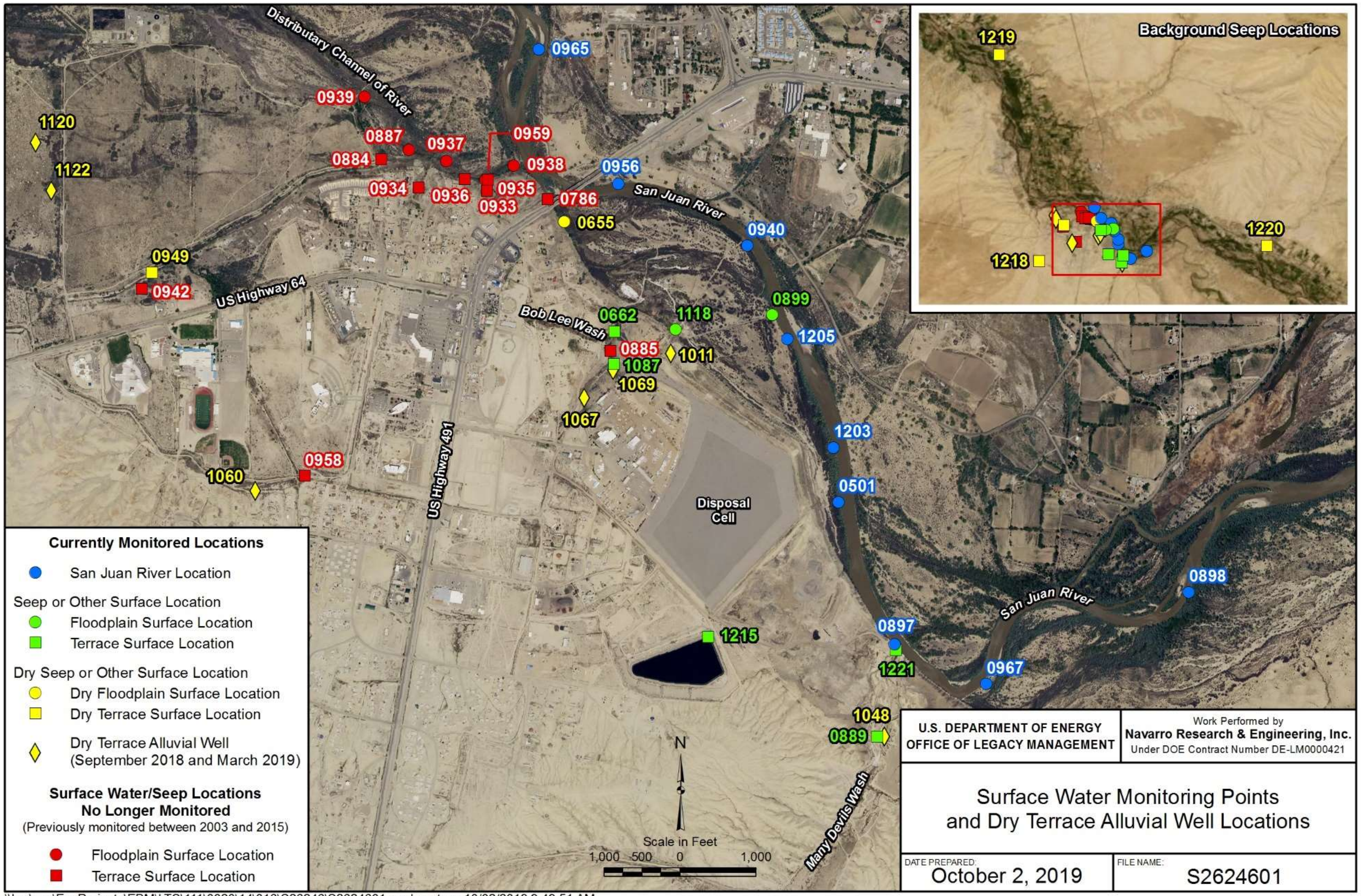
Figure 16. Shiprock Site Terrace Groundwater Elevation Changes from Baseline (2000–2003) to Current (March 2019) Conditions



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Note: Surface location 0898 (farthest upgradient San Juan River location) is no longer sampled because it was difficult to access. It was replaced by location 0967 in 2014.

Figure 17. 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)

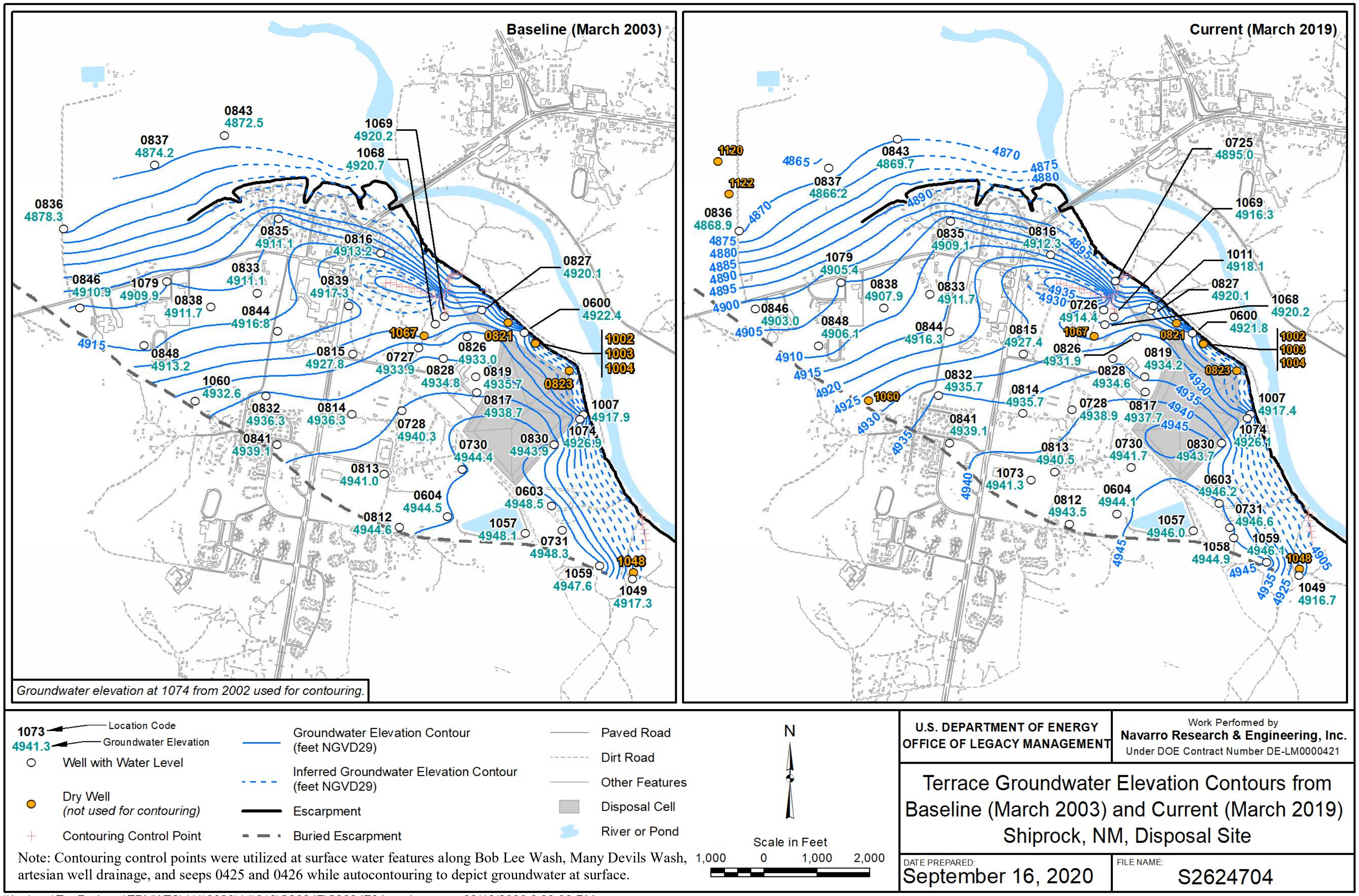

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Figure 18. Terrace Groundwater Elevation Contours from Baseline (March 2003) and Current (March 2019) Conditions

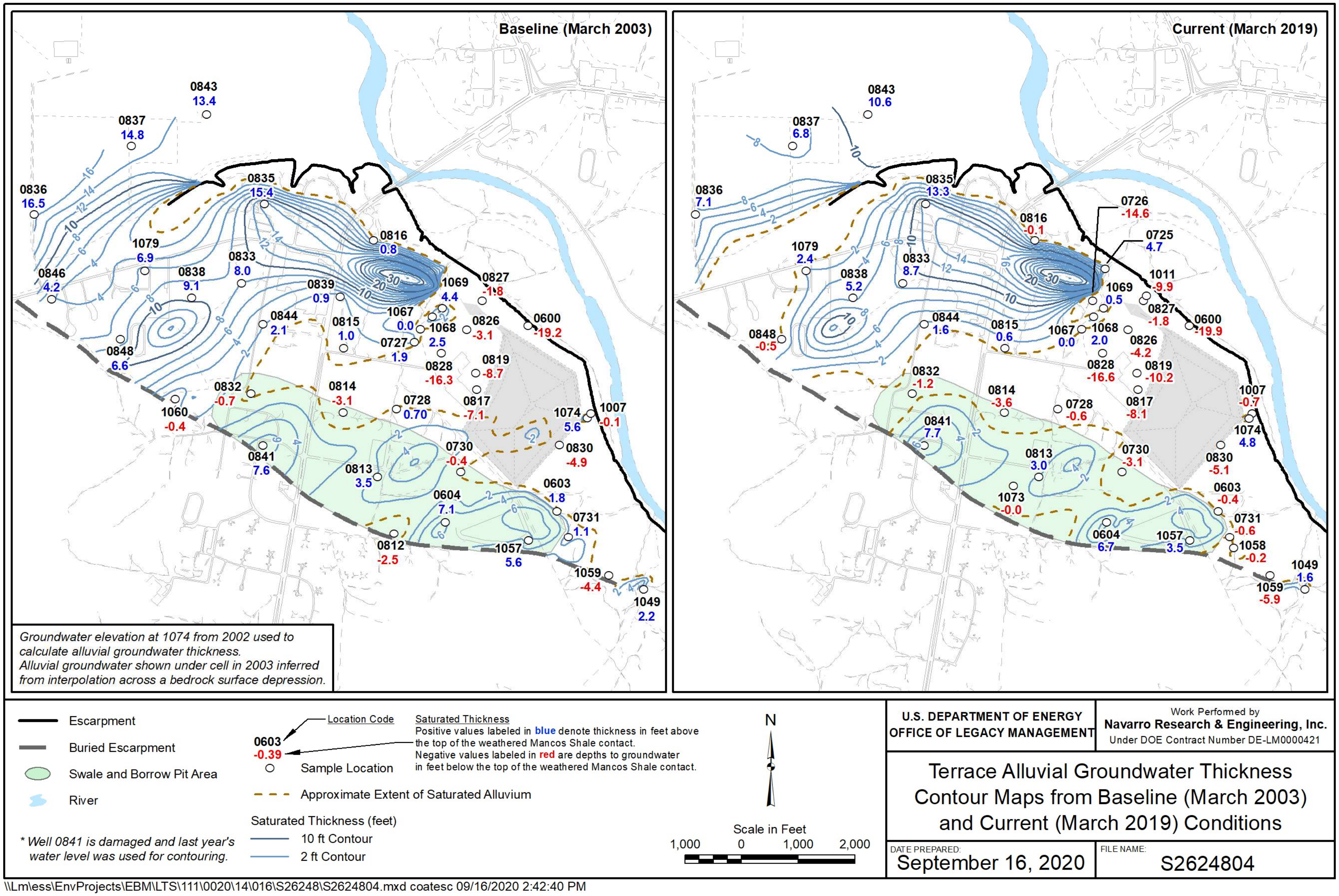

Figure 19. Terrace Alluvial Groundwater Thickness Contour Maps from Baseline (March 2003) and Current (March 2019) Conditions

Three alluvial west terrace wells—1060, 1120, and 1122—were dry during this reporting period. Well 1060 has been dry since September 2008, and wells 1120 and 1122 have been dry since March 2010 (see Appendix B hydrographs). Appendix C figures depict well construction and bedrock contacts along with current water levels. Figure 17 through Figure 19 are presented to further illustrate the declining water levels across the terrace. As shown in Figure 17, many seeps on the west terrace are dry; some have been dry since 2008. In fact, LM stopped monitoring nine terrace surface locations because they were historically dry.

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

	Volume of Saturated Alluvium (ft^3)	Porosity (assumed) (%)	Volume of Liquid (ft^3)	Volume of Liquid (gallons)	Percent Reduction (%)
March 2003 baseline depiction	25,252,163	30	7,575,649	56,669,788	–
March 2019 current depiction	16,578,201	30	4,973,460	37,204,064	34

Note:
Only the south terrace swale and borrow pit areas (shaded light green in Figure 19) were used in these calculations based on the integrated volumes between the interpreted bedrock and groundwater surface within this extent. The 34% reduction cited above is less than that estimated in the previous annual report (42%) as a result of modifying the estimation approach to honor additional site data and observations for both the current and baseline estimates. To ensure consistency in the future, a calculation package (S31463) was prepared that documents the development of the surfaces, method of analysis, observations used in the interpolation, and assumptions.

Abbreviation:
ft^3 = cubic feet

Figure 18 plots groundwater elevations in terrace wells, showing automated contours for both baseline (March 2003) and current (March 2019) periods. Figure 19 depicts groundwater saturated thickness in the terrace alluvium using automated groundwater elevation contours for both baseline and current periods and the bedrock surface. Table 5 includes an estimate of liquid volume for both dates based on these depictions, indicating a volumetric reduction of about 34% in the vicinity of the south terrace extraction wells. The volumetric reduction approximated with this method (approximately 19.5 million gallons) is about 88% the total cumulative volume (22.2 million gallons) extracted from the terrace swale alluvium pumping wells.

Only the terrace alluvium was considered in developing Figure 19, and only the active remediation vicinity area (shaded terrace swale and borrow pit areas) was considered in developing the volume estimates in Table 5. The Mancos Shale 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% of the terrace alluvium, respectively (DOE 2000). These Mancos Shale properties significantly limit yield and thus do not meet the definition of an aquifer. The weathered Mancos Shale contact with the underlying unweathered Mancos Shale and degrees of weathering and fracturing are variable and unknown at many locations across the terrace.

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4.0 Performance Summary

This section summarizes the findings of the most recent (April 2018 through March 2019) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the 16th year of active groundwater remediation. Because of the deteriorating evaporation pond liner, LM suspended pumping at all Shiprock site treatment system locations except Bob Lee Wash on April 21, 2017. That suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches. Pumping of Bob Lee Wash has continued without interruption, while groundwater extraction resumed at the floodplain trenches in mid-July 2018 to prevent desiccation of pond sediments. Pumping from floodplain wells 1089 and 1004, as well as the terrace extraction wells, occurred intermittently and did not significantly influence remediation system performance during the reporting period.

From April 2018 through March 2019, about 8.44 million gallons of extracted groundwater were pumped to the evaporation pond, a volume nearly 3 times greater than the volume extracted the previous (2017–2018) reporting period (2.97 million gallons). The bulk of this total volume (7.2 million gallons, or 85.4%) of the influent liquids entering the pond during the current reporting period was from the floodplain trenches. The trenches, along with Bob Lee Wash, were the only treatment system locations where pumping was sustained through the reporting period. Since DOE began active remediation in March 2003, about 50.8 million gallons have been extracted from the terrace, and 157.5 million gallons have been extracted from the floodplain, yielding a total cumulative volume of about 208.3 million gallons of water pumped to the evaporation pond from all sources. The estimated masses of nitrate, sulfate, and uranium removed from the floodplain and terrace well fields during this performance period were 6364; 262,819; and 22.9 pounds, respectively.

Because of the recent changes in the floodplain pumping regime, it was important to evaluate whether the decrease in groundwater extraction volumes in the last 2 years has impacted contaminant concentrations or the plume configuration on the floodplain. Uranium, sulfate, and nitrate concentrations measured this reporting period were similar to previous (pre-pumping-suspension) results in the majority of floodplain wells. Apparent upticks noted in the previous annual report were not sustained. Apparent recent increases in uranium concentrations identified in a few wells were slight or within the range of historical observations. Uranium and nitrate concentrations in samples collected from the San Juan River continue to be below established benchmarks and comparable to upstream (background) locations.

Relative to baseline conditions, marked reductions in all contaminant concentrations are still apparent. This is particularly evident for nitrate, as the extent of the plume is much smaller and currently generally limited to the base of the escarpment. Concentrations of all COCs have decreased in most floodplain wells relative to baseline conditions—in some cases by 1 to 2 orders of magnitude. Exceptions to this general decreasing trend continue to be found at several locations, most notably in near-river wells 0857 and 1136 in the central floodplain and at well 0630 at the base of Bob Lee Wash. No measurable impacts to the San Juan River have resulted from these increases.

Groundwater levels in the majority of terrace alluvial wells remain low relative to those measured during the baseline period (average decrease of 2.3 ft). Six alluvial west terrace wells were dry during this reporting period, as were several seeps that have been dry since 2008.

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5.0 References

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Appendix A

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

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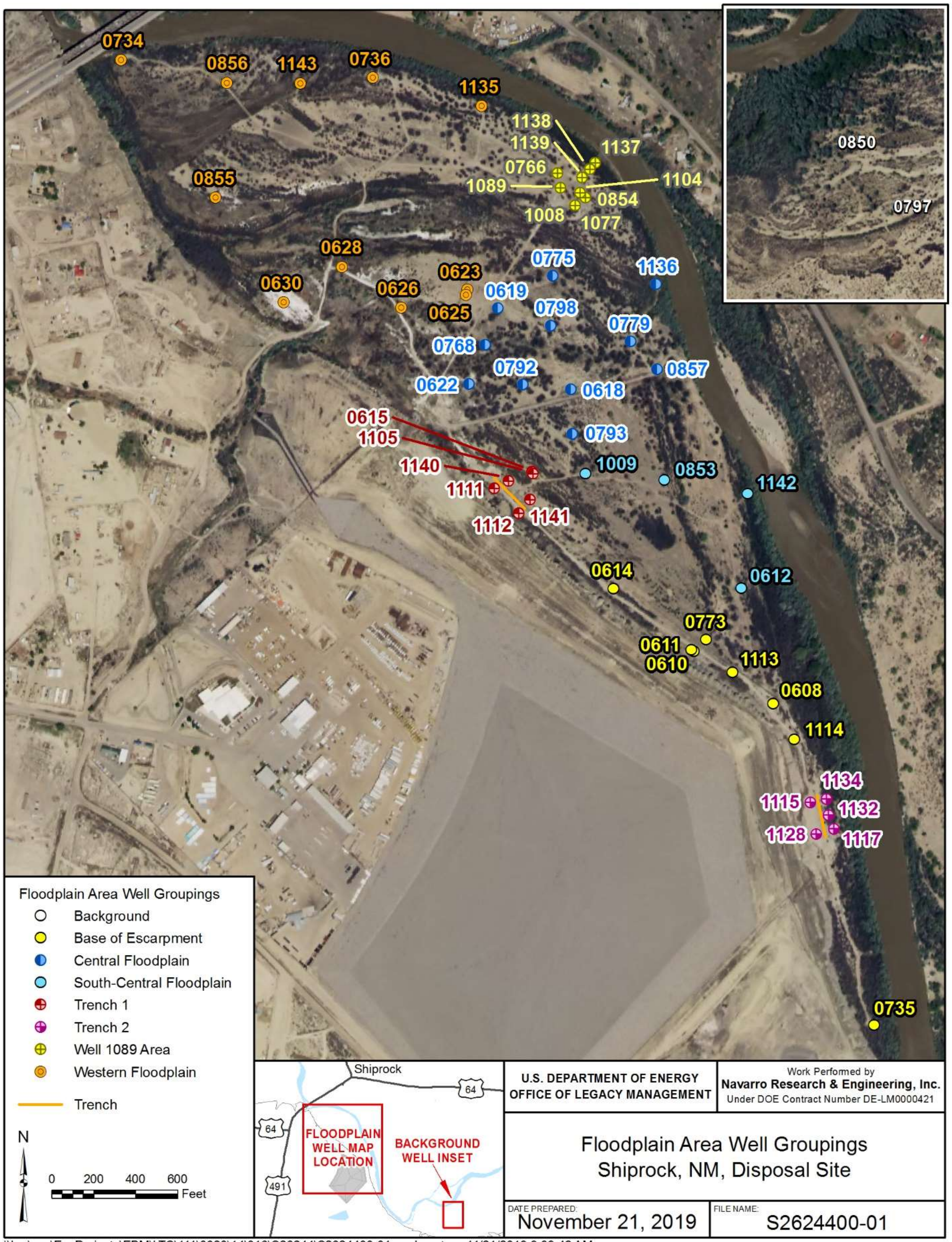

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Figure A-1. Shiprock Site Floodplain Well Groupings

(Figure repeated from Figure 11 of main report. The groups shown here are used as the basis for subsequent time–concentration plots.)

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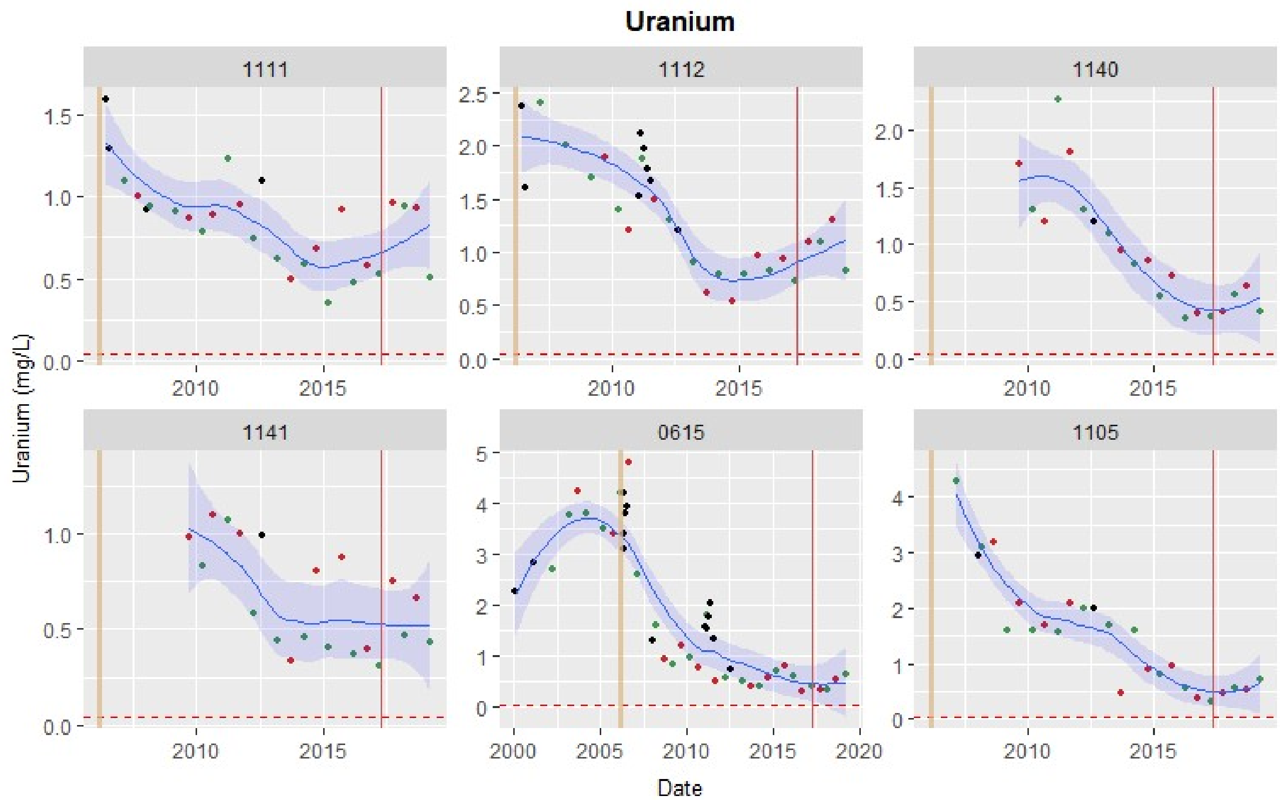
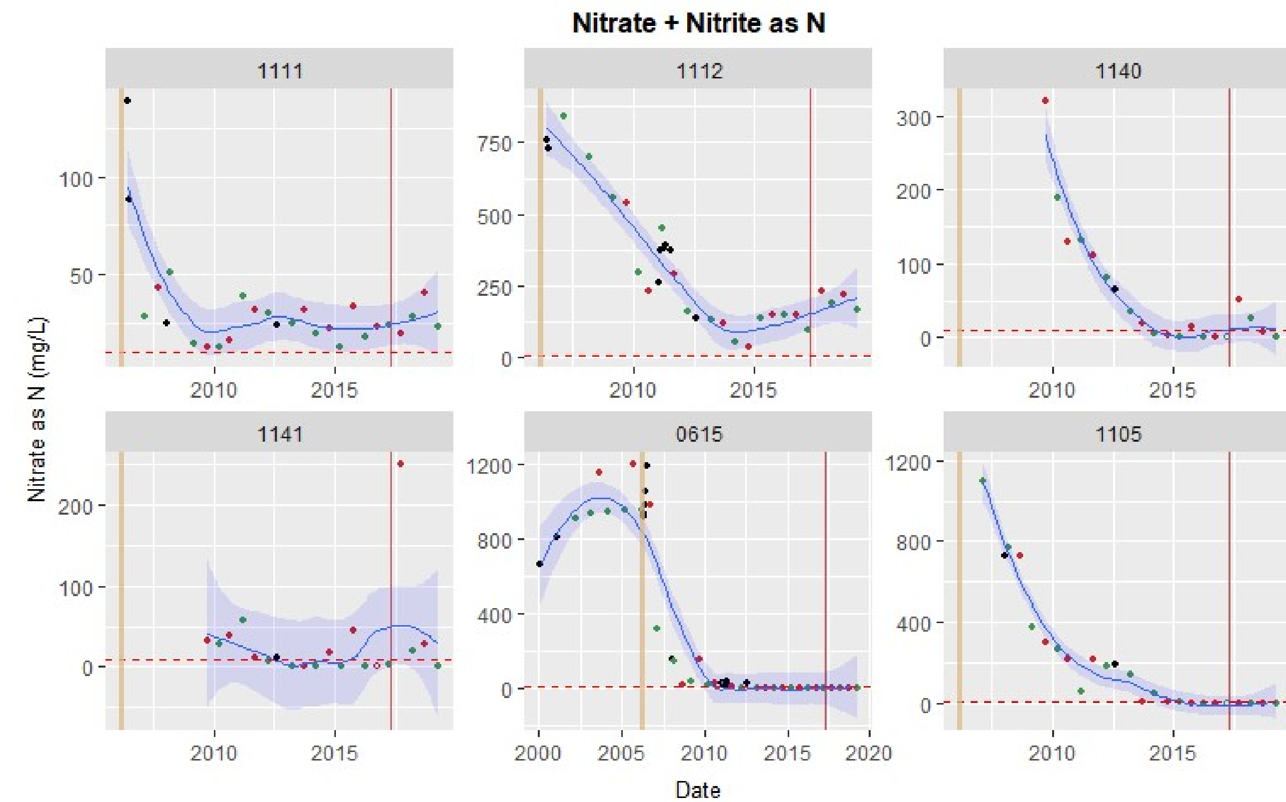
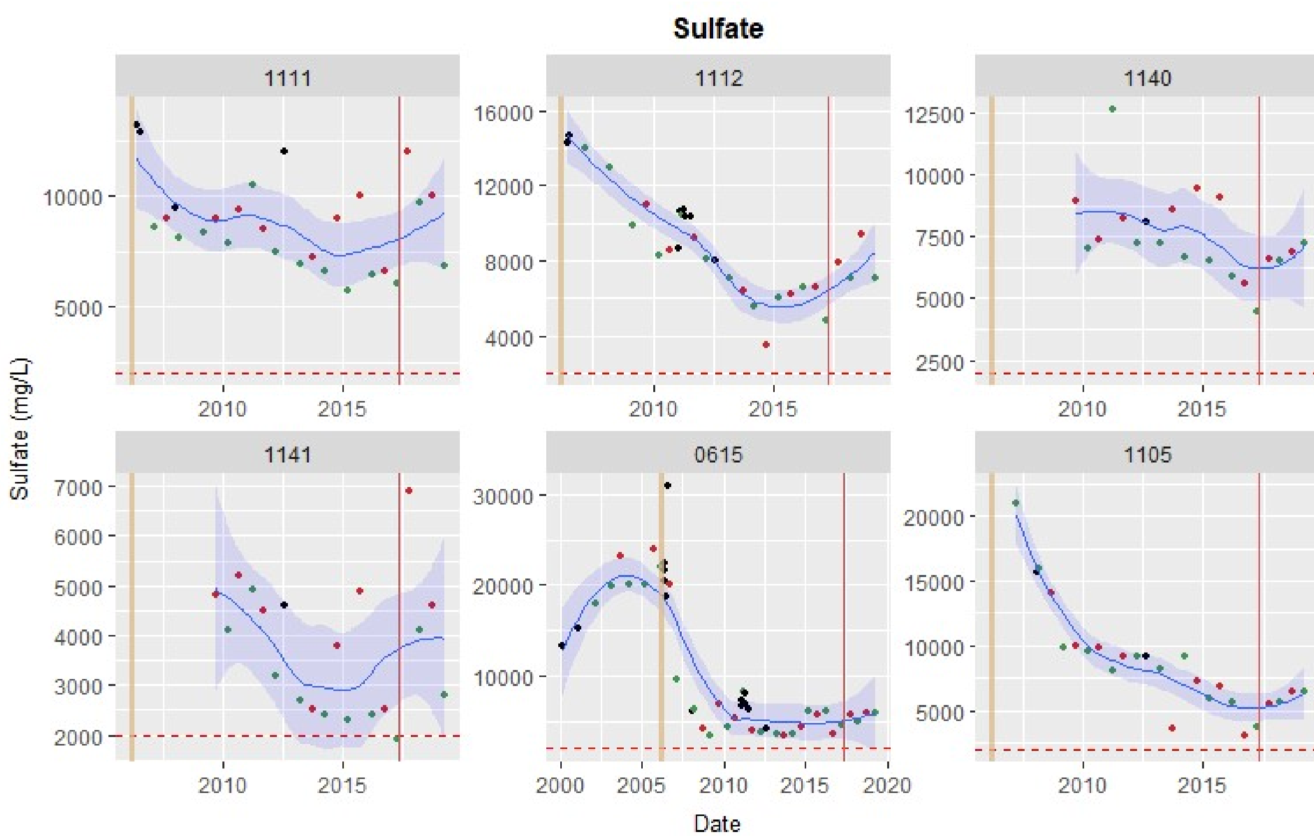






Time–Trend Plot Explanation.

In this and subsequent Appendix A figures, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (date) and *y*-axis scales are unique for each well. In each plot, a nonparametric smoothing method or locally weighted regression—known as 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." For each constituent, 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

● September semiannual sampling event ● March semiannual sampling event ● Other sampling event

○ Hollow symbol denotes result below detection limit (applies to recent nitrate results only)

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

Second vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). Pumping resumed at Trench 1 on July 19, 2018, and continued through March 2019.

† See:
https://stat.ethz.ch/R-manual/R-devel/library/stats/html/loess.html
http://ggplot2.tidyverse.org/reference/geom_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.

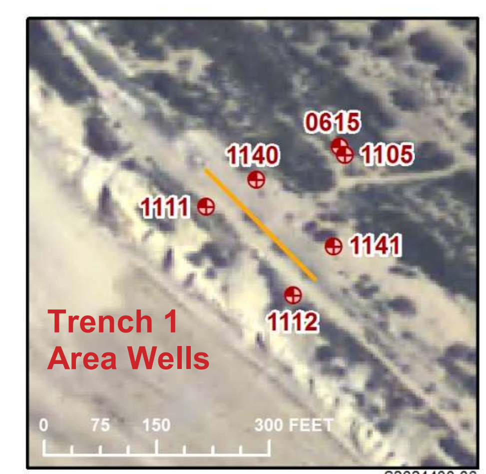
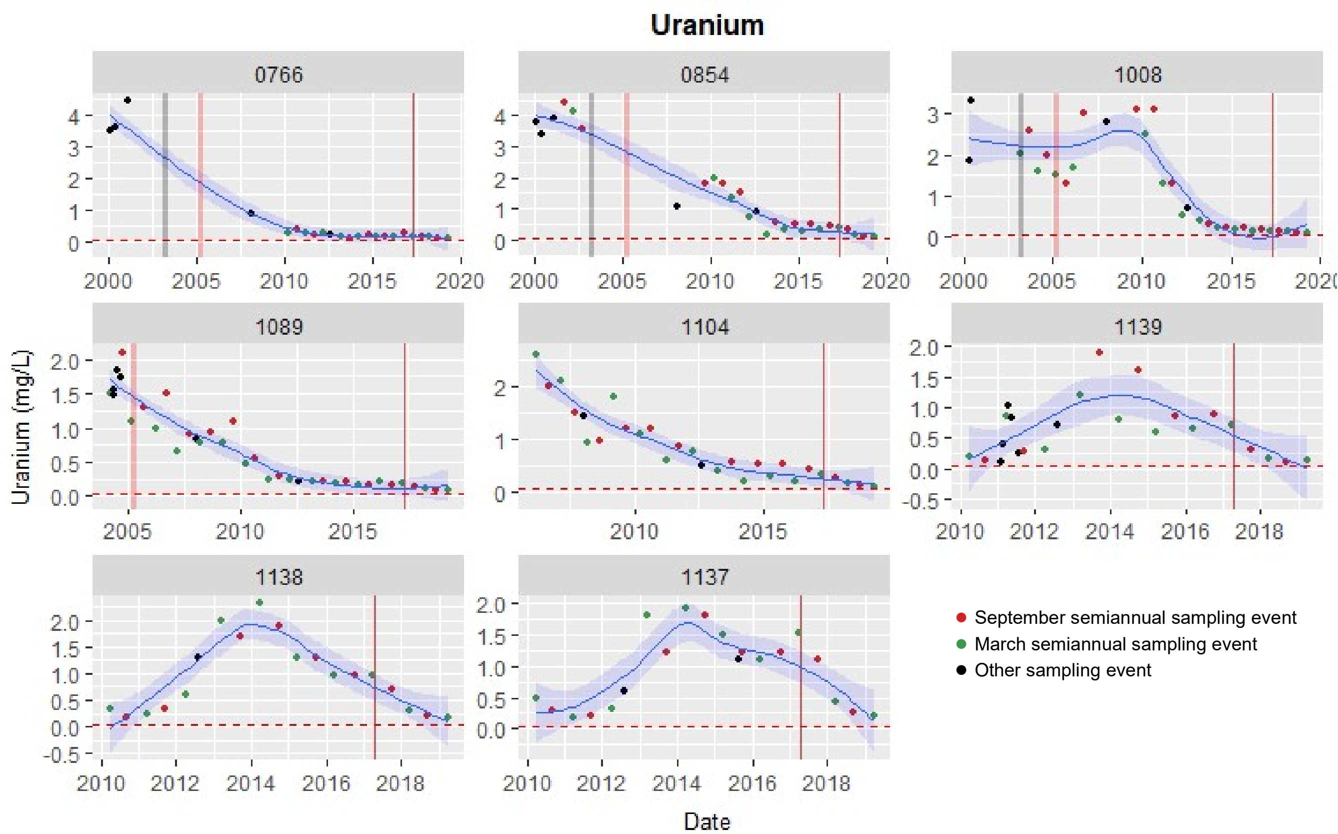
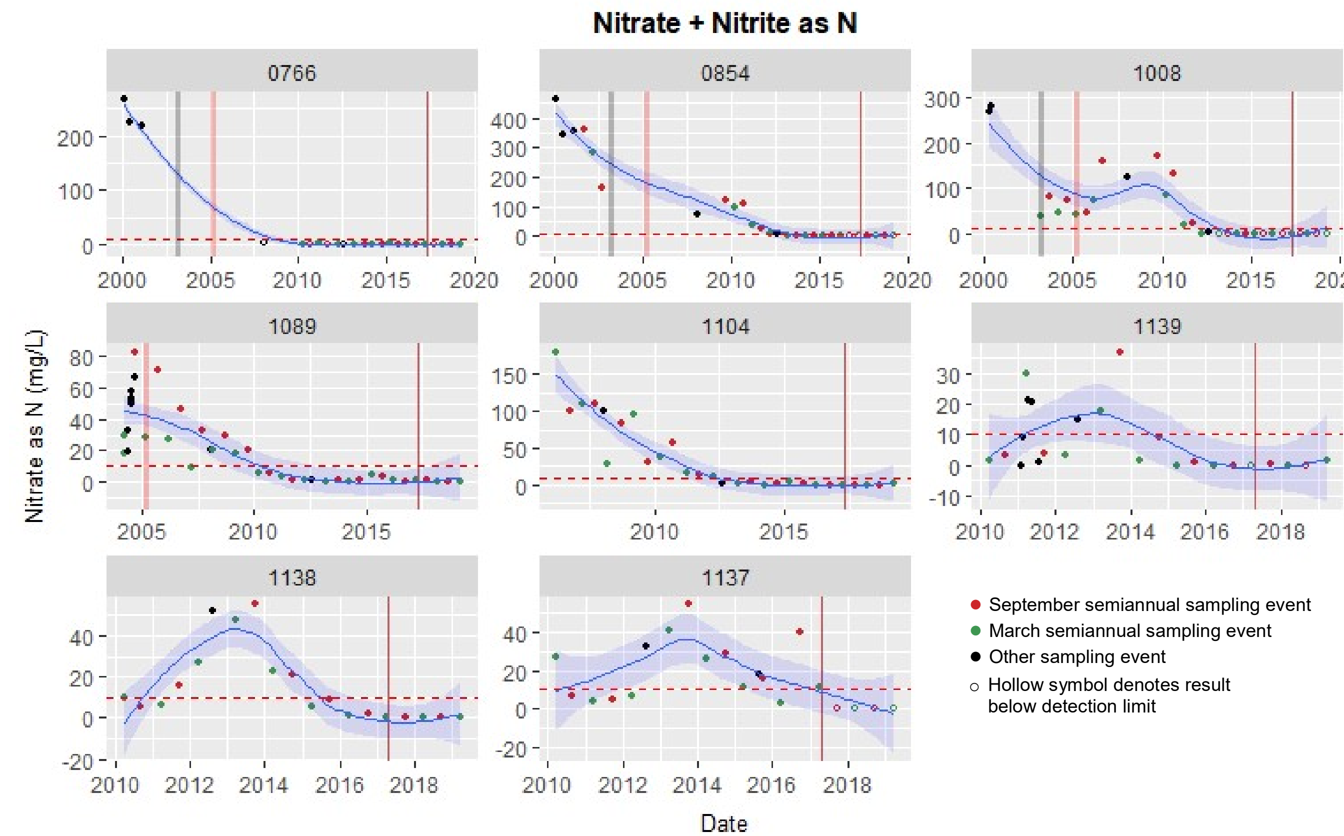
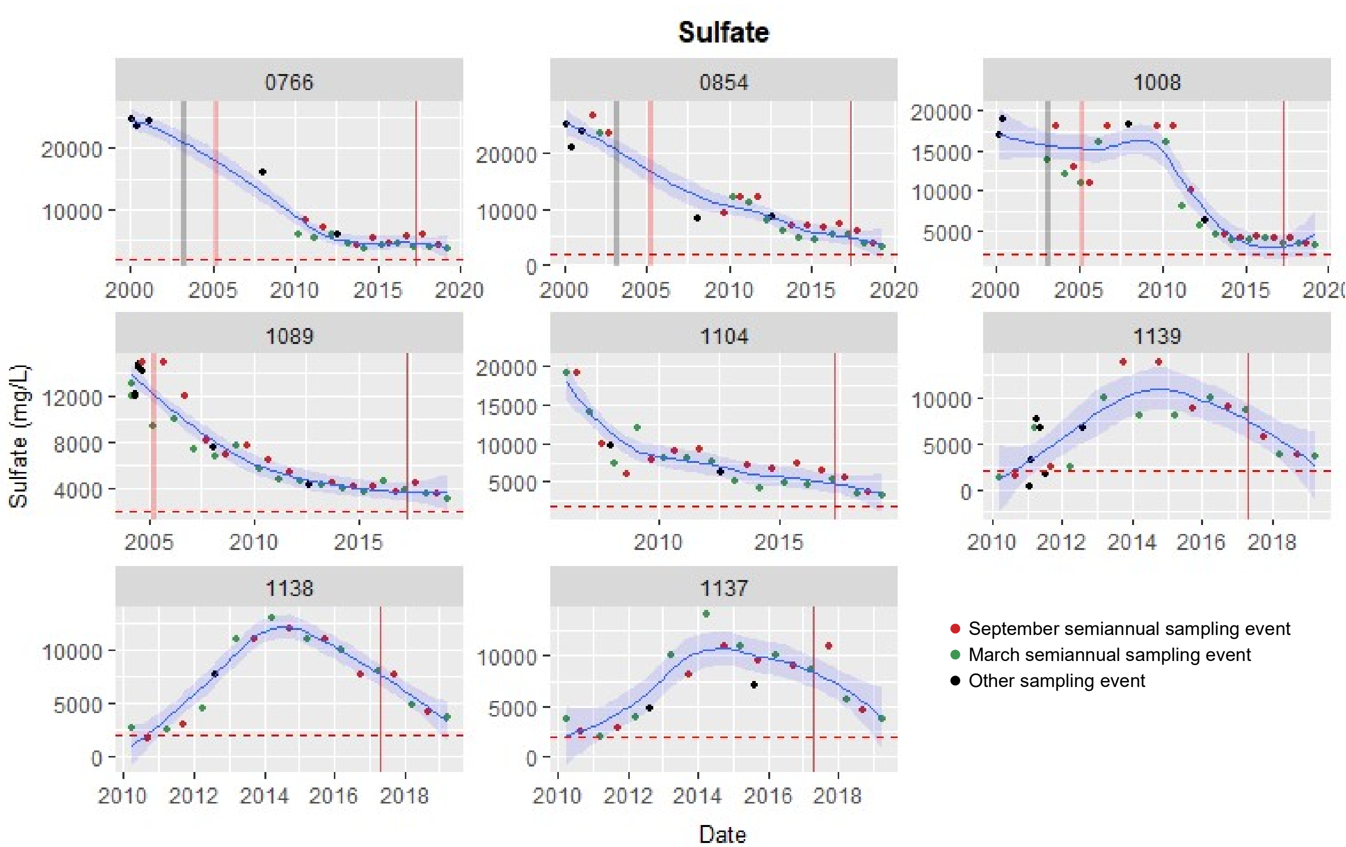


Figure A-2. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 1 Area Wells: 2000–March 2019







Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (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).

Third vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). This suspension was sustained through the entire 2018–2019 reporting period.

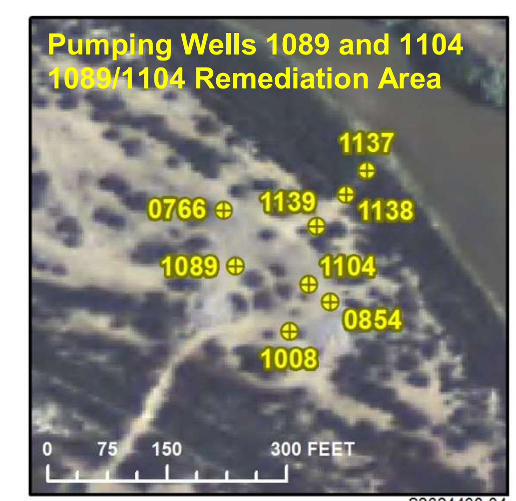
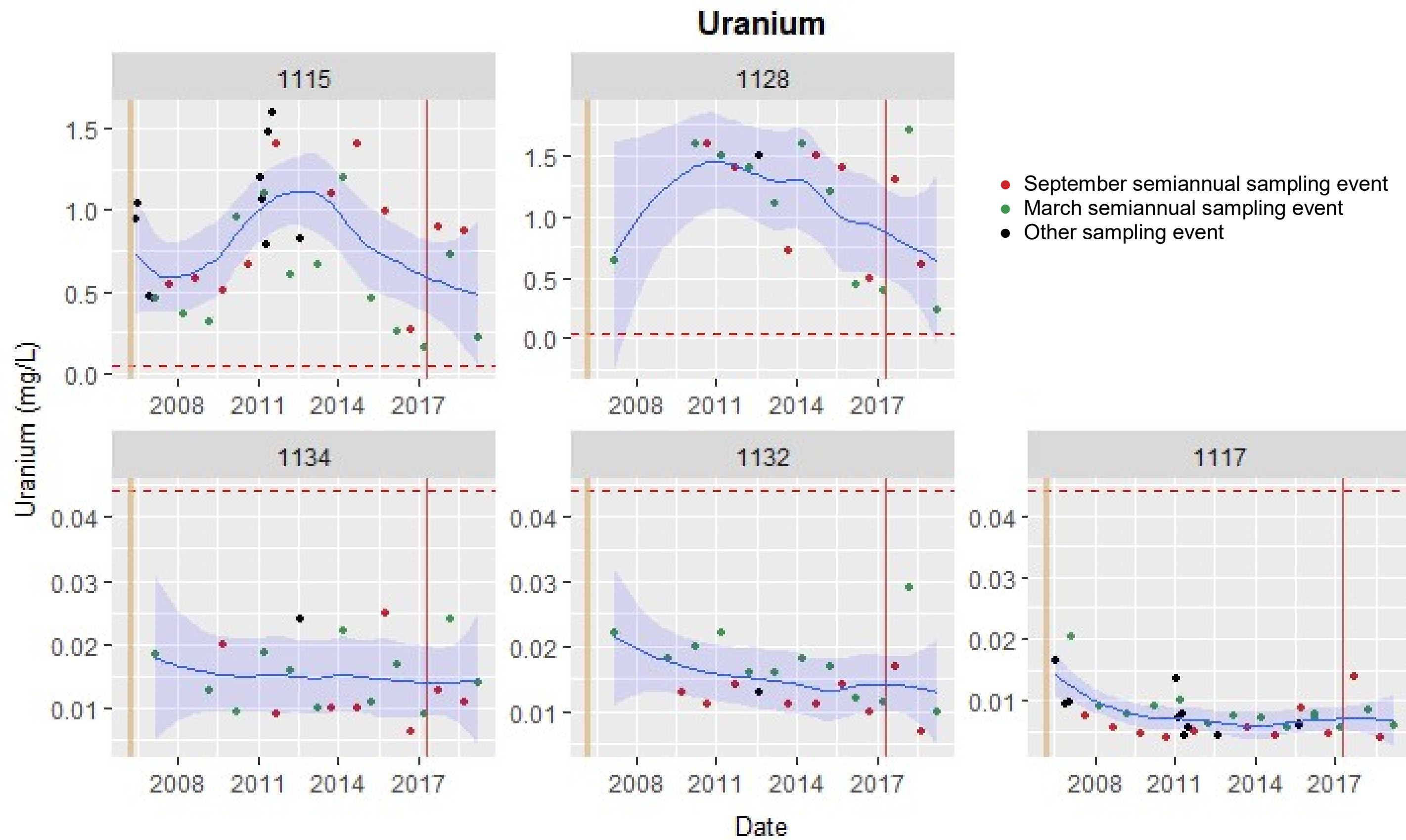
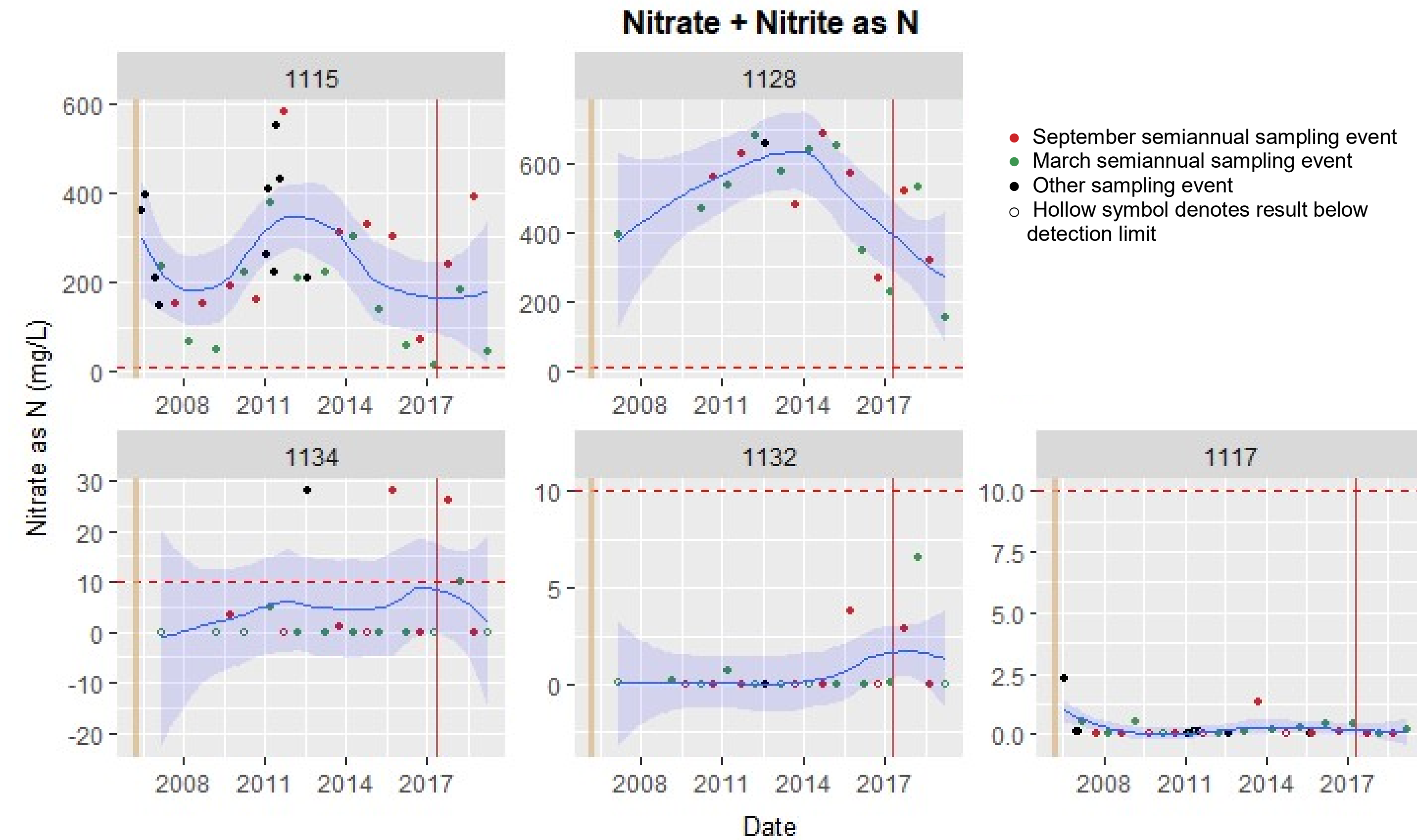


Figure A-3. Uranium, Nitrate, and Sulfate Concentration Trends in the 1089/1104 Remediation Area: 2000–March 2019





Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (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. Second vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). Pumping resumed at Trench 2 on July 19, 2018 and continued through March 2019.

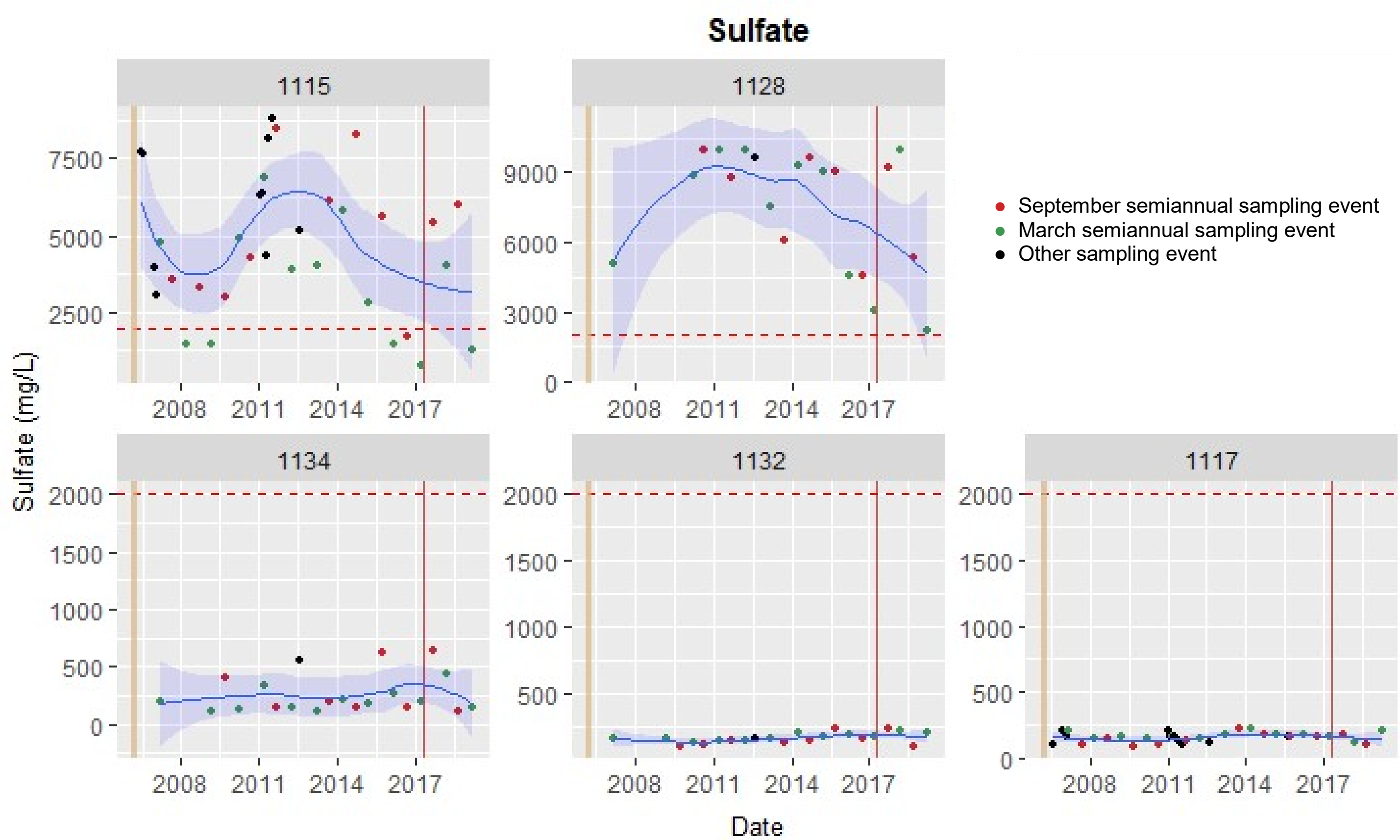
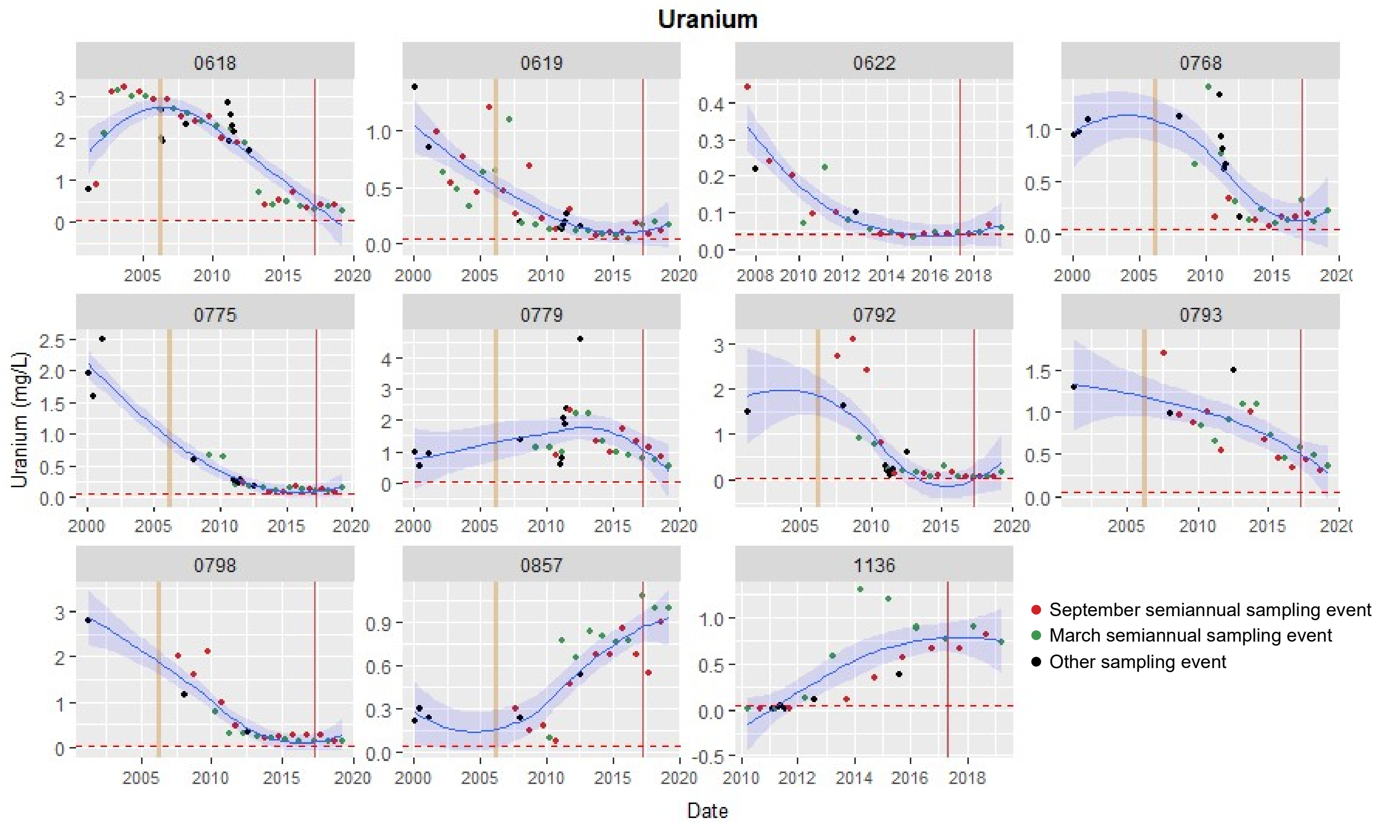
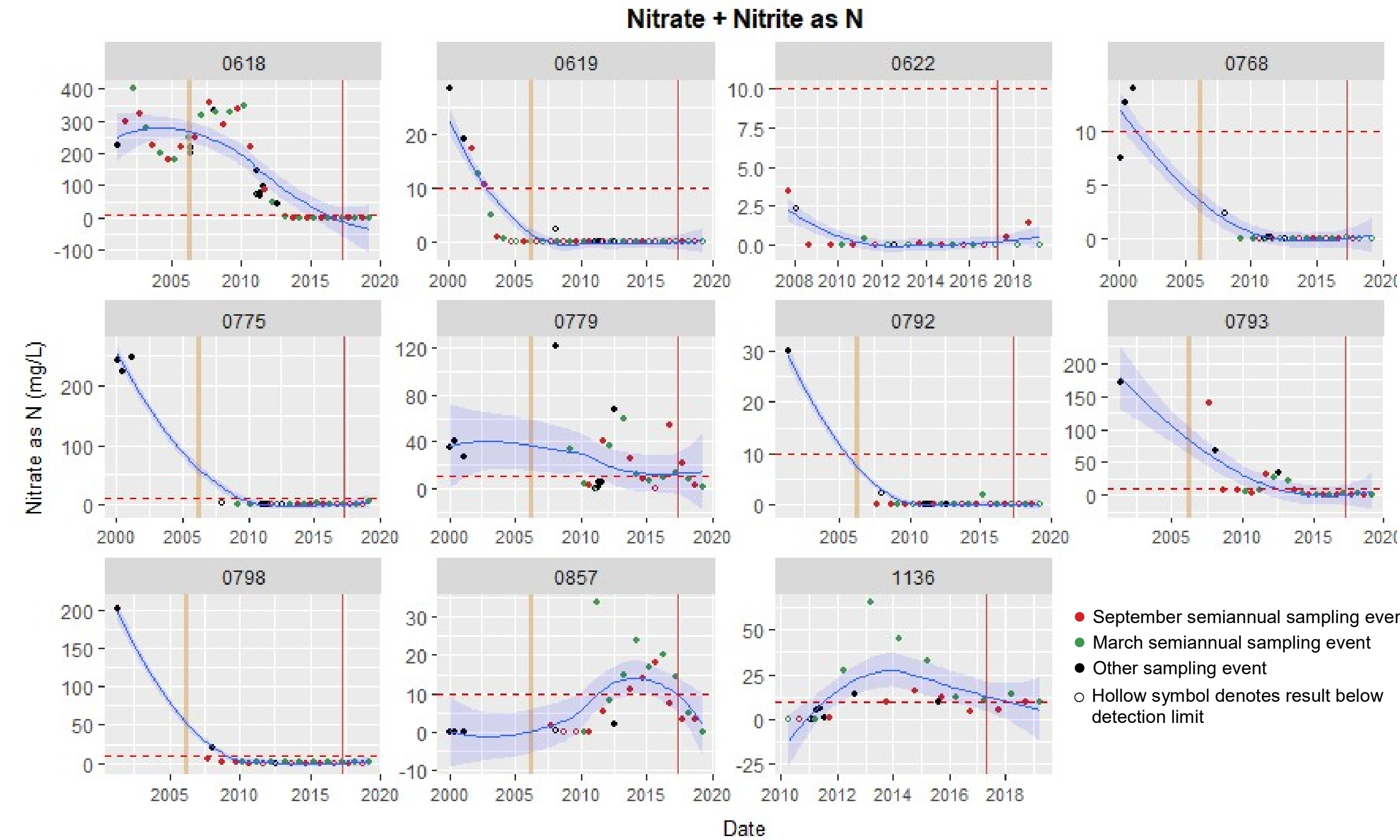
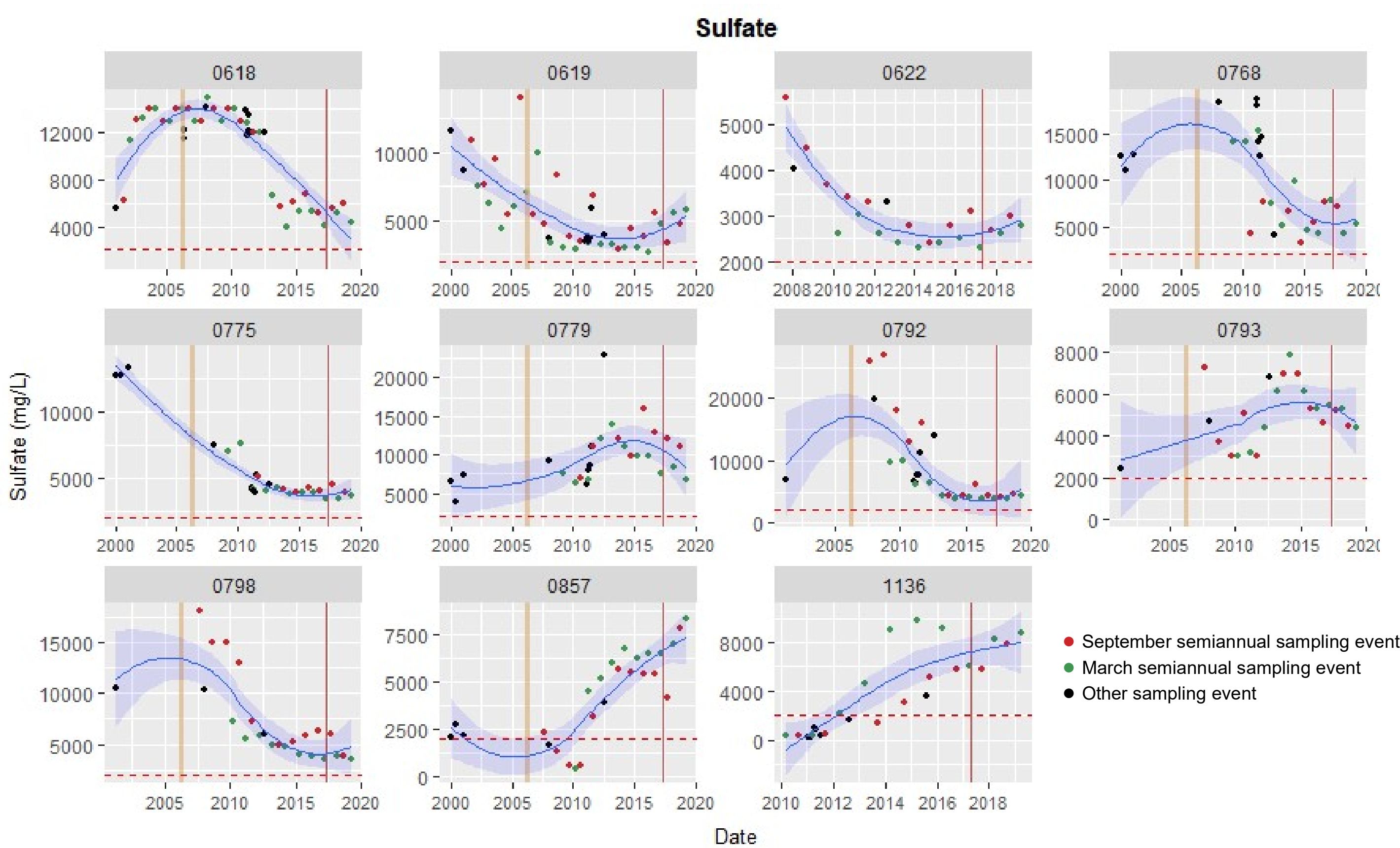


Figure A-4. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 2 Area Wells: 2006–March 2019







Time–Trend Plot Explanation.

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

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

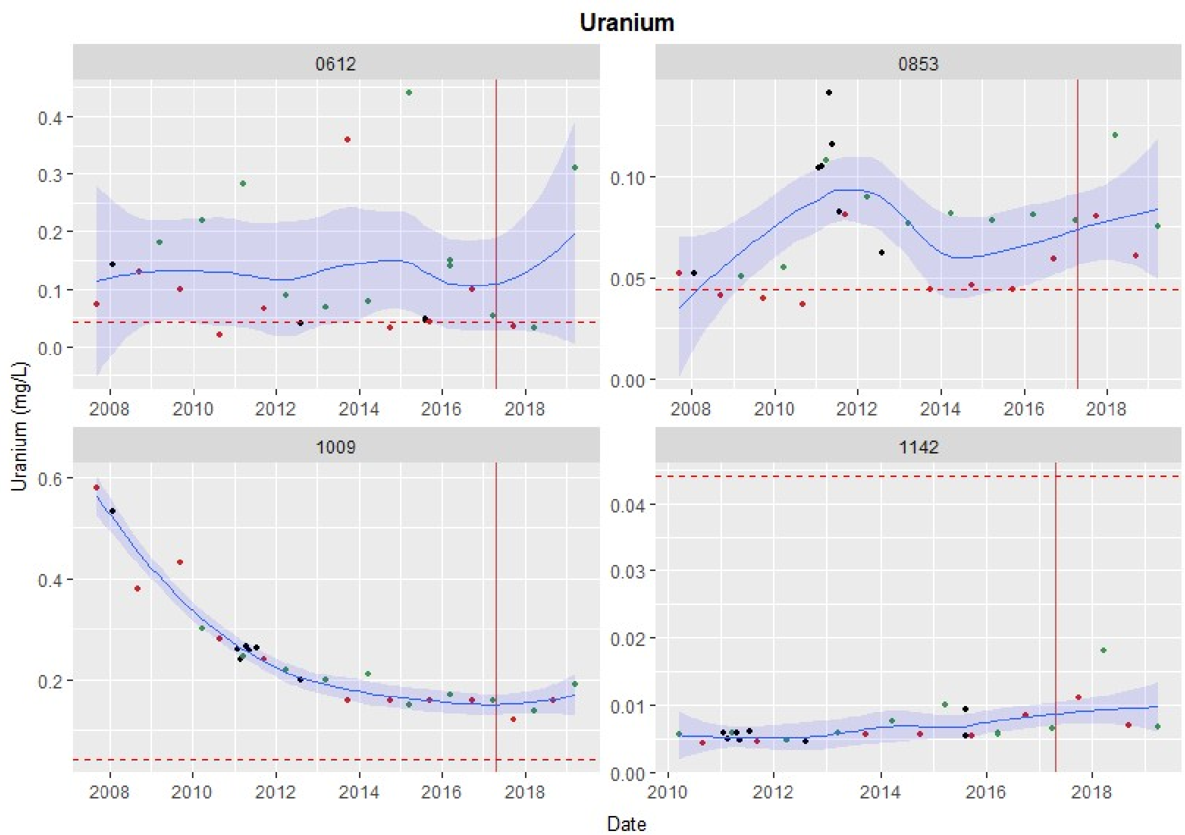
Denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium, 10 mg/L nitrate as N, 2000 mg/L sulfate

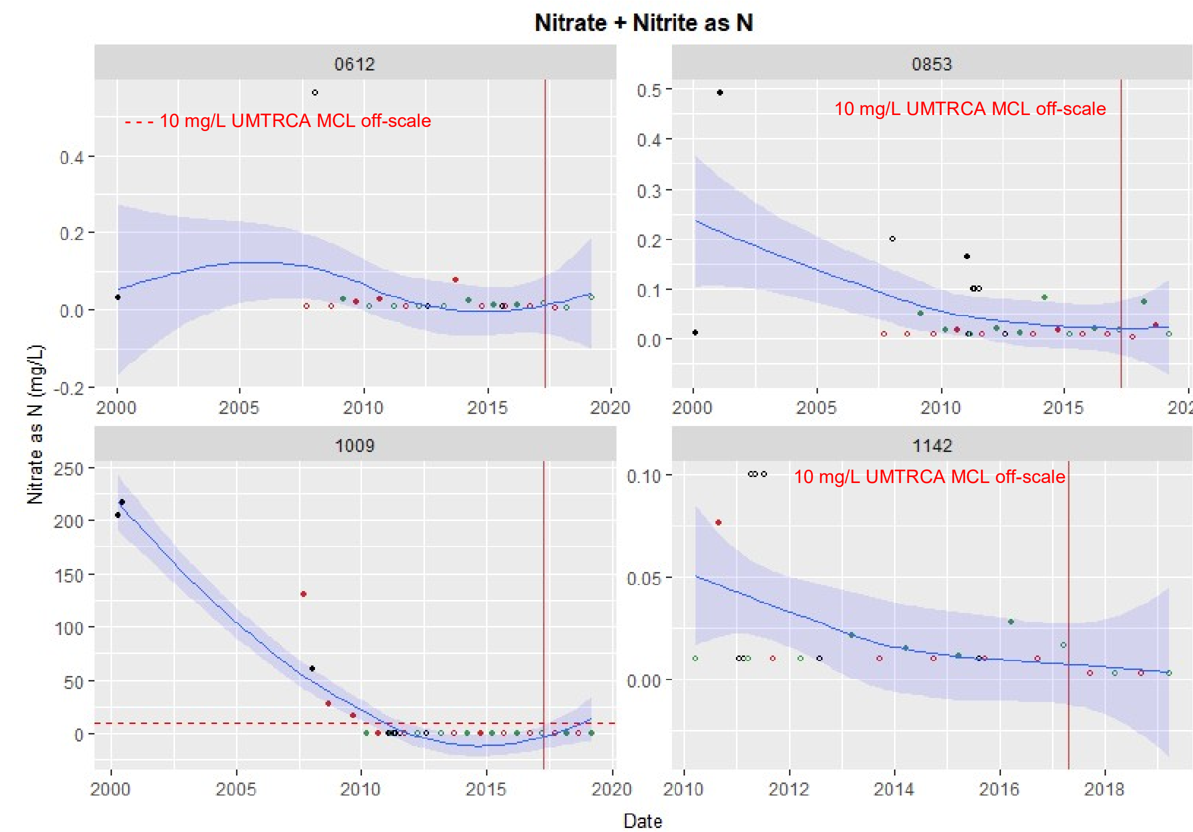
Vertical line denotes time when Trench 2 was installed, in spring 2006.

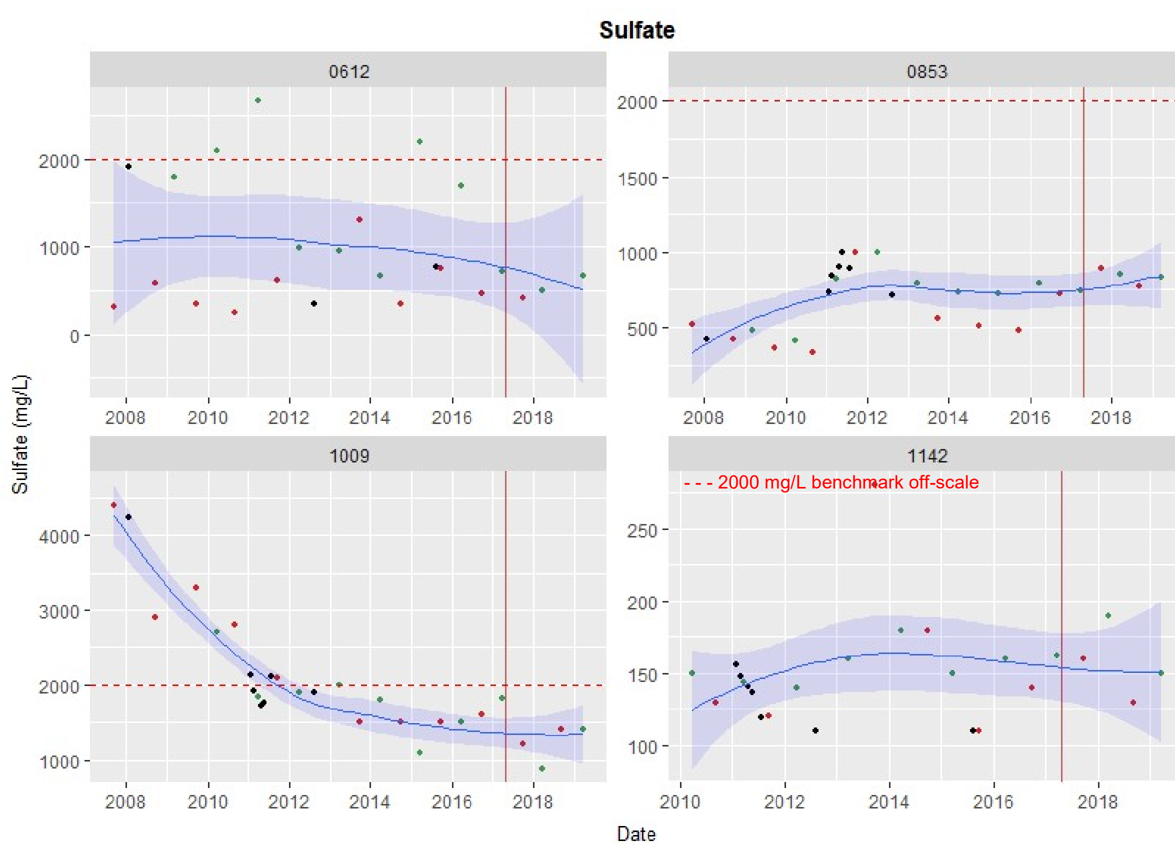
Second vertical line denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). Pumping resumed at the trenches on July 19, 2018 and continued through March 2019. Suspension at the well 1089/1104 complex was maintained.

Central Floodplain Wells

Figure A-5. Uranium, Nitrate, and Sulfate Concentration Trends in Central Floodplain Wells: 2000–March 2019







Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (date) and *y*-axis scales are unique for each well. Unlike preceding figures, this figure includes data for only the period 2007–2019 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 wells with very low or nondetect contaminant concentrations

● September semiannual sampling event ● March semiannual sampling event ● Other sampling event

○ Hollow symbol denotes result below detection limit (applies to nitrate results only)

Vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). Pumping resumed at the trenches on July 19, 2018, and continued through March 2019. Suspension at the well 1089/1104 complex was maintained.

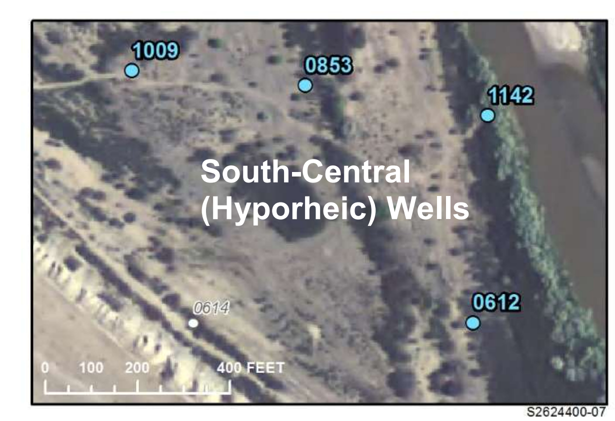
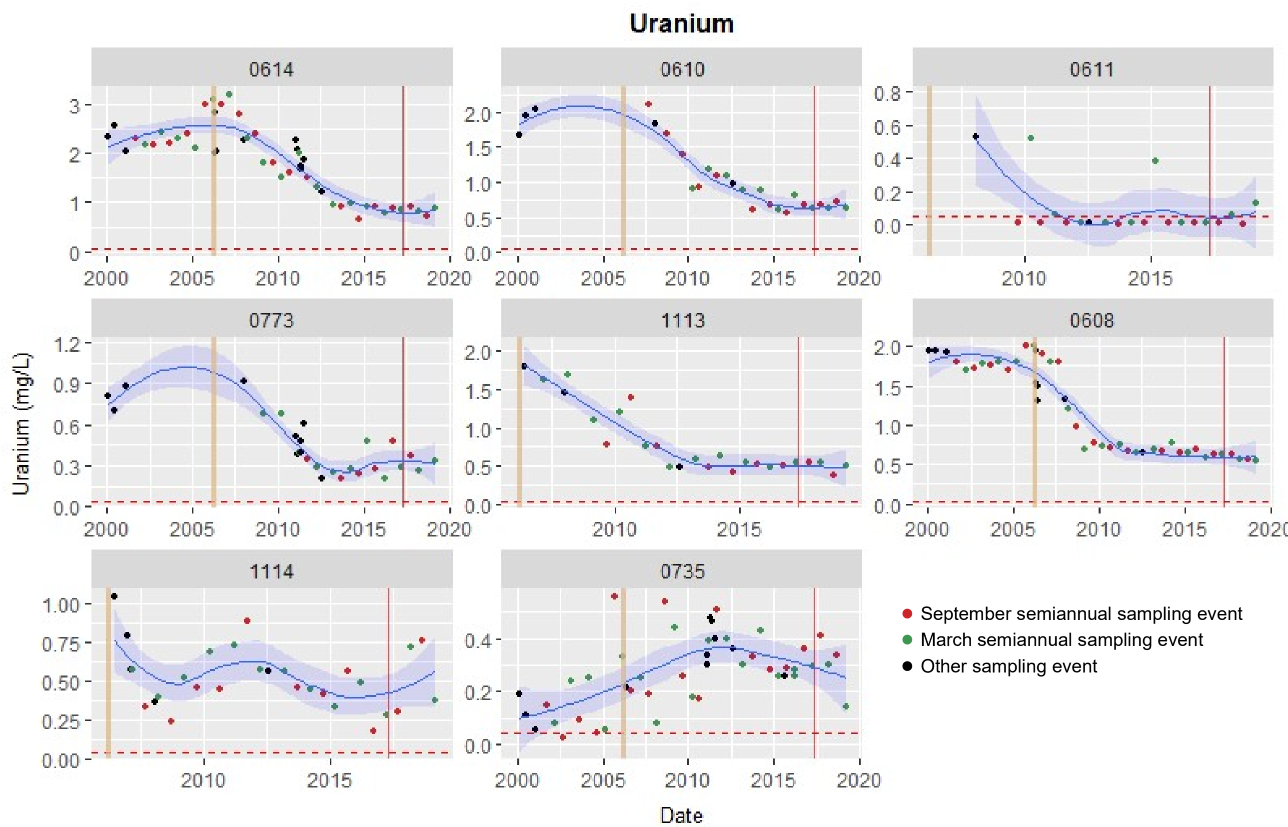
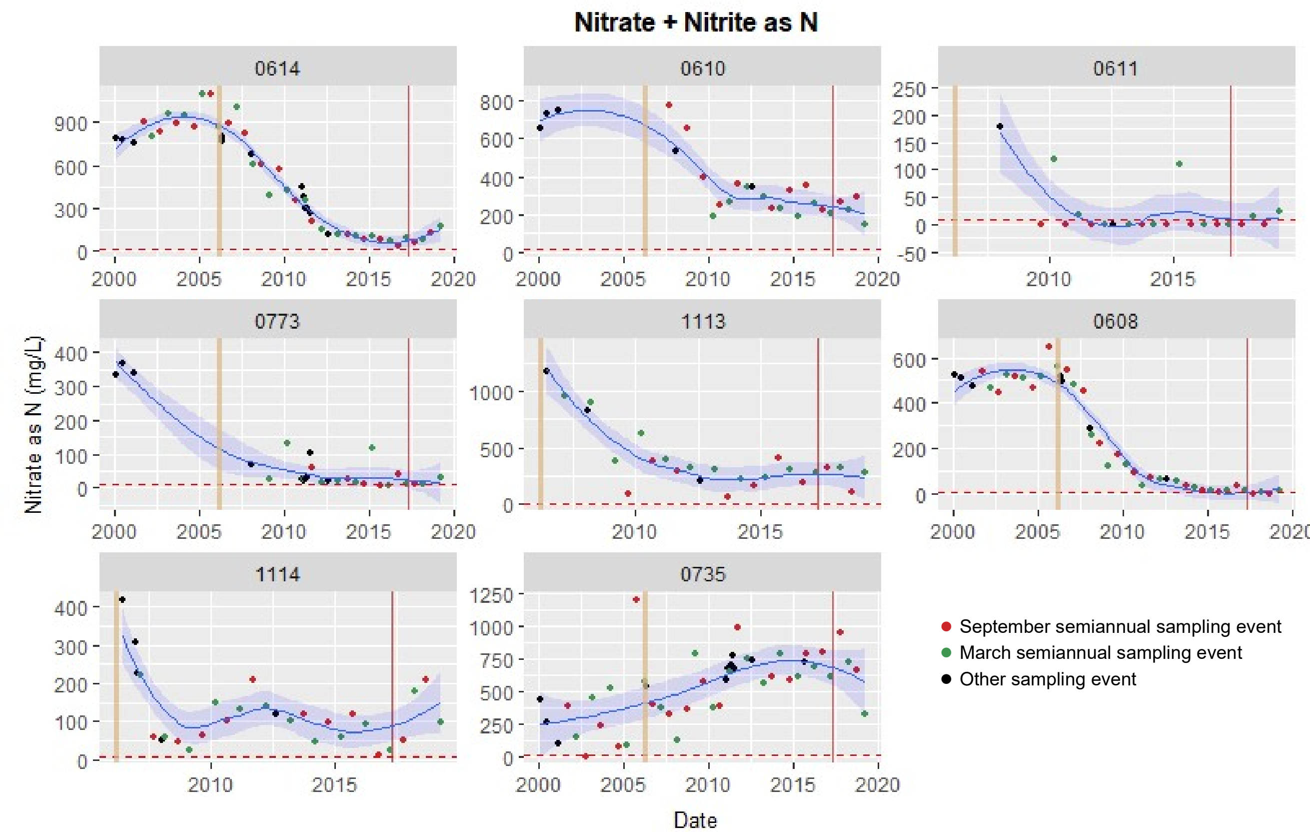
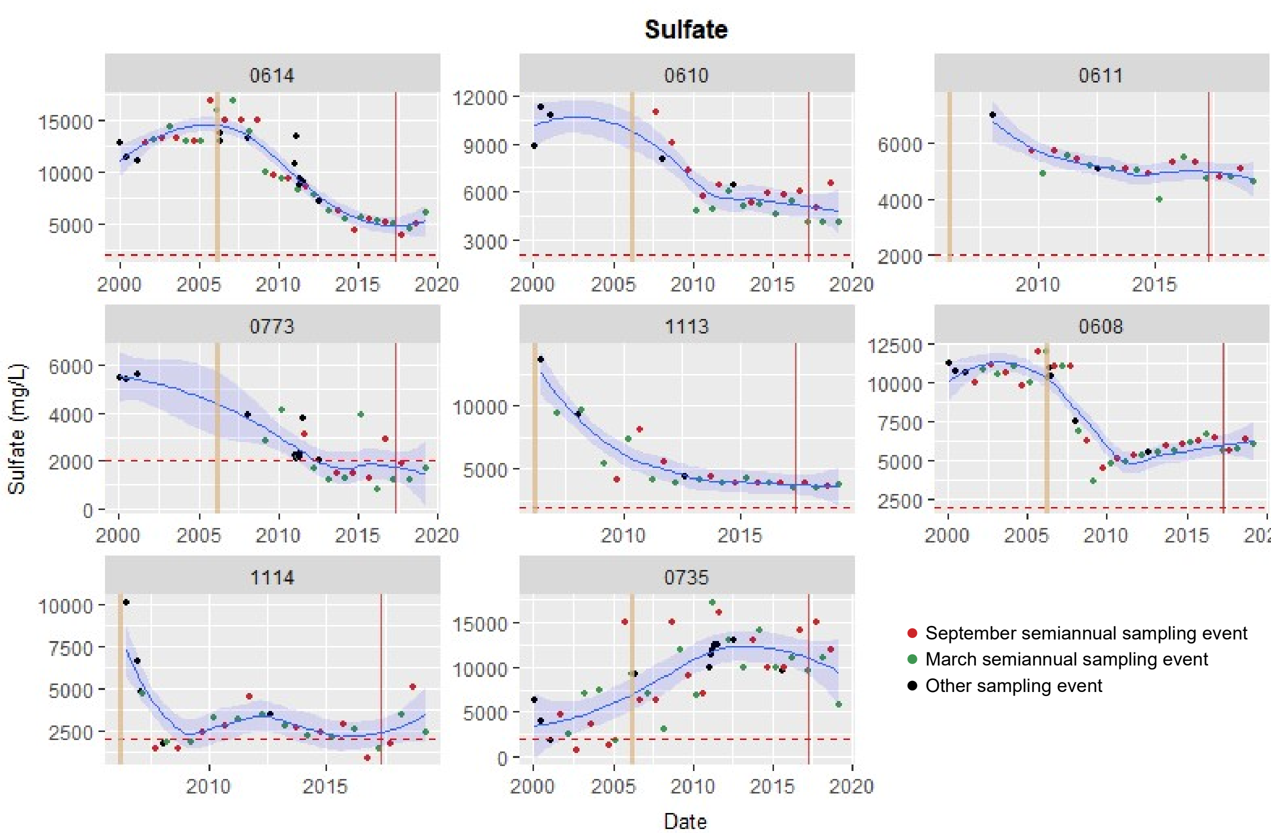


Figure A-6. Uranium, Nitrate, and Sulfate Concentration Trends in South-Central Floodplain Wells: 2007–March 2019







Time–Trend Plot Explanation.
In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (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

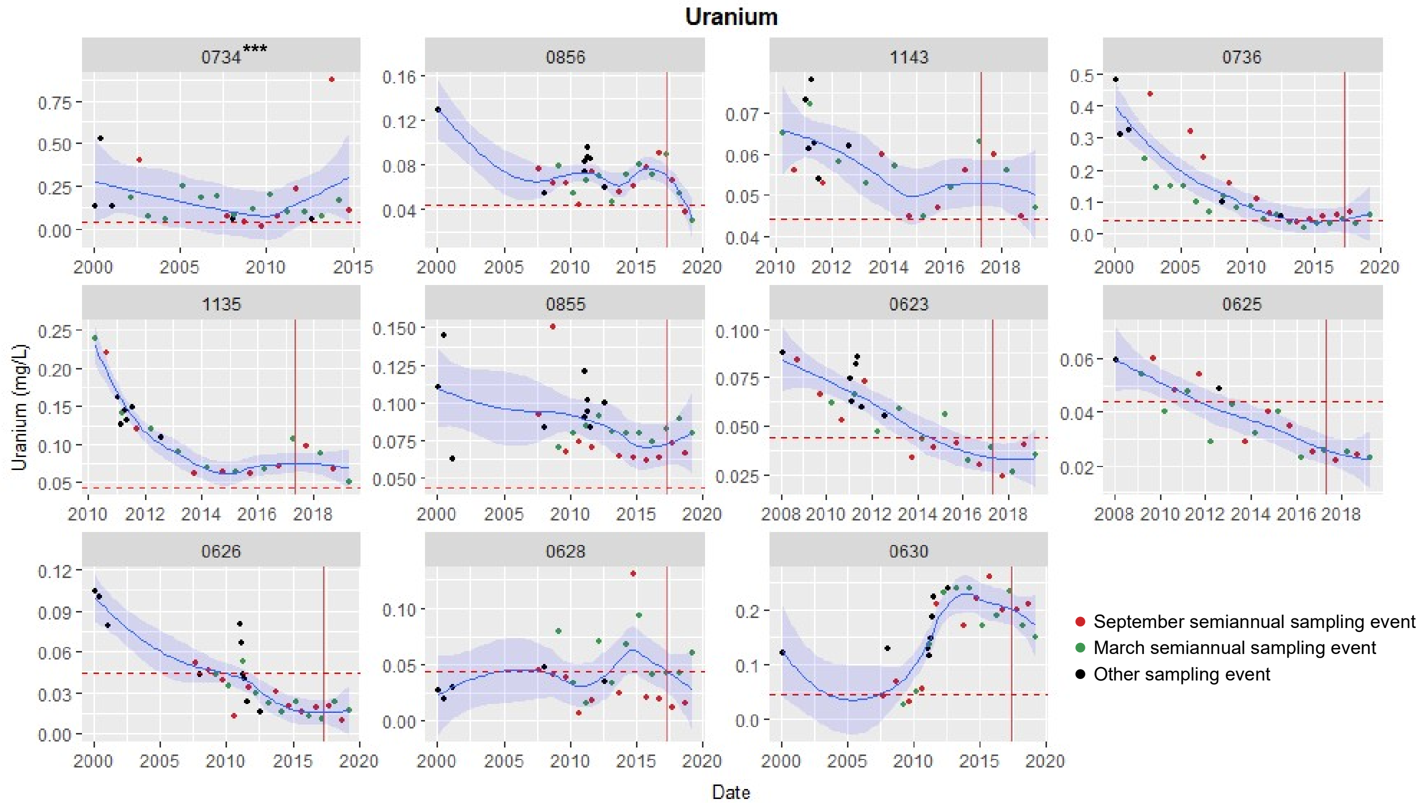
Denotes the 40 CFR 192 MCL or cleanup goal:

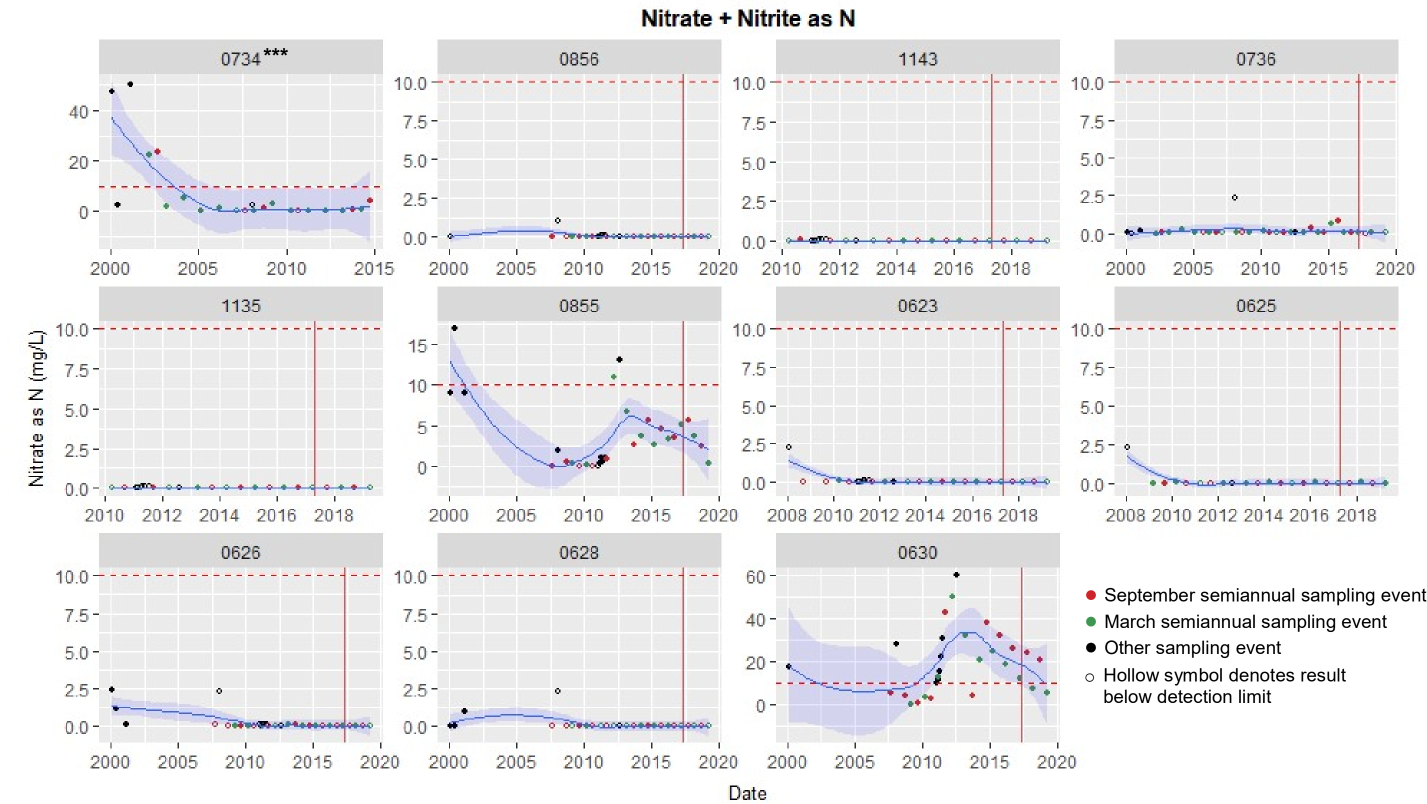
- 0.044 mg/L uranium
- 10 mg/L nitrate as N
- 2000 mg/L sulfate

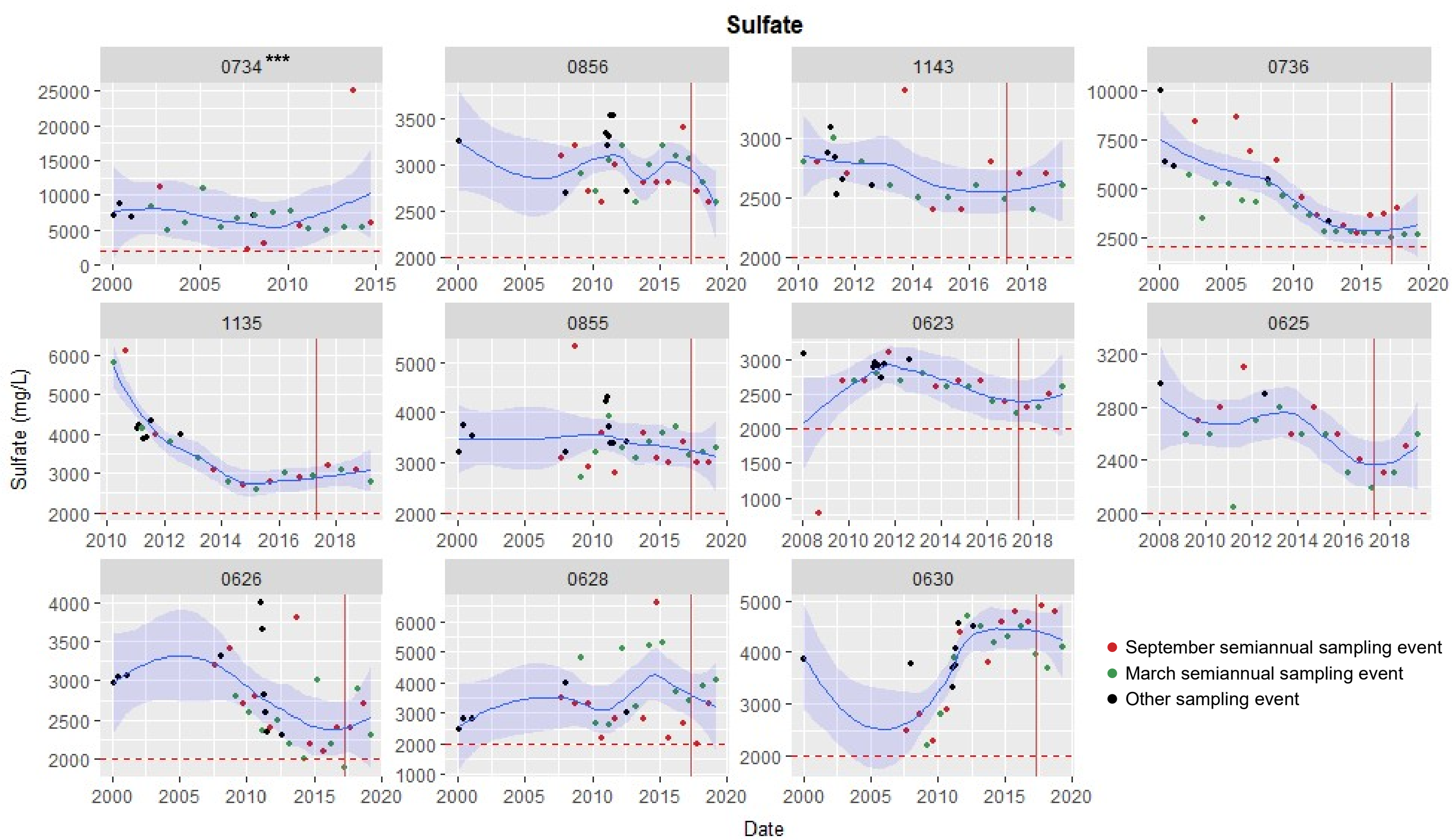
Vertical line denotes time when Trench 1 and Trench 2 were installed (in spring 2006).

Second vertical line denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). Pumping resumed at the trenches on July 19, 2018, and continued through March 2019.

Figure A-7. Uranium, Nitrate, and Sulfate Concentration Trends in Base of Escarpment Floodplain Wells: 2000–March 2019







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.

The large gap in sampling between 2000–2001 and 2007 for wells 0626, 0628, 0630, 0855, and 0856 causes a balloon-like appearance of the confidence band around the LOESS smoothing line.

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 when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3).

*** Since September 2014, well 0734 has been dry or had insufficient water to sample.

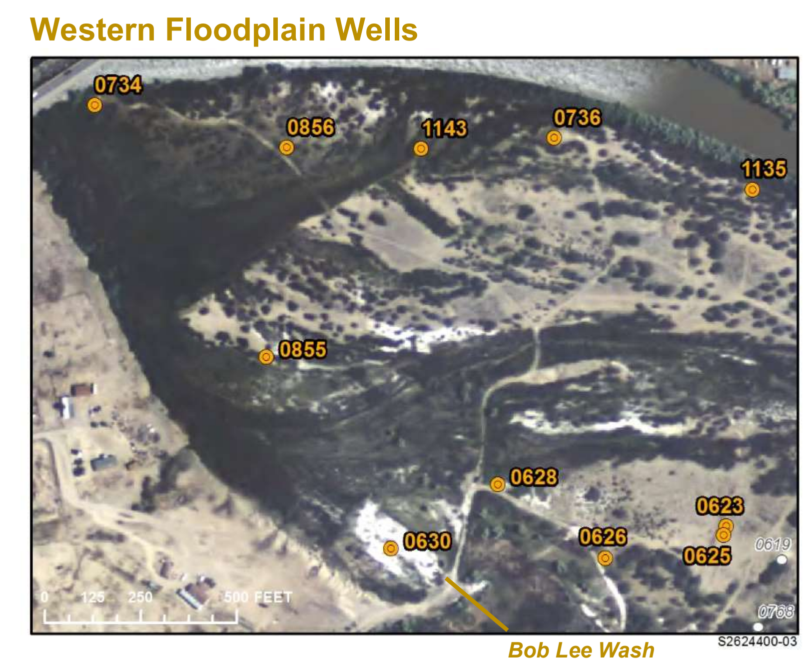
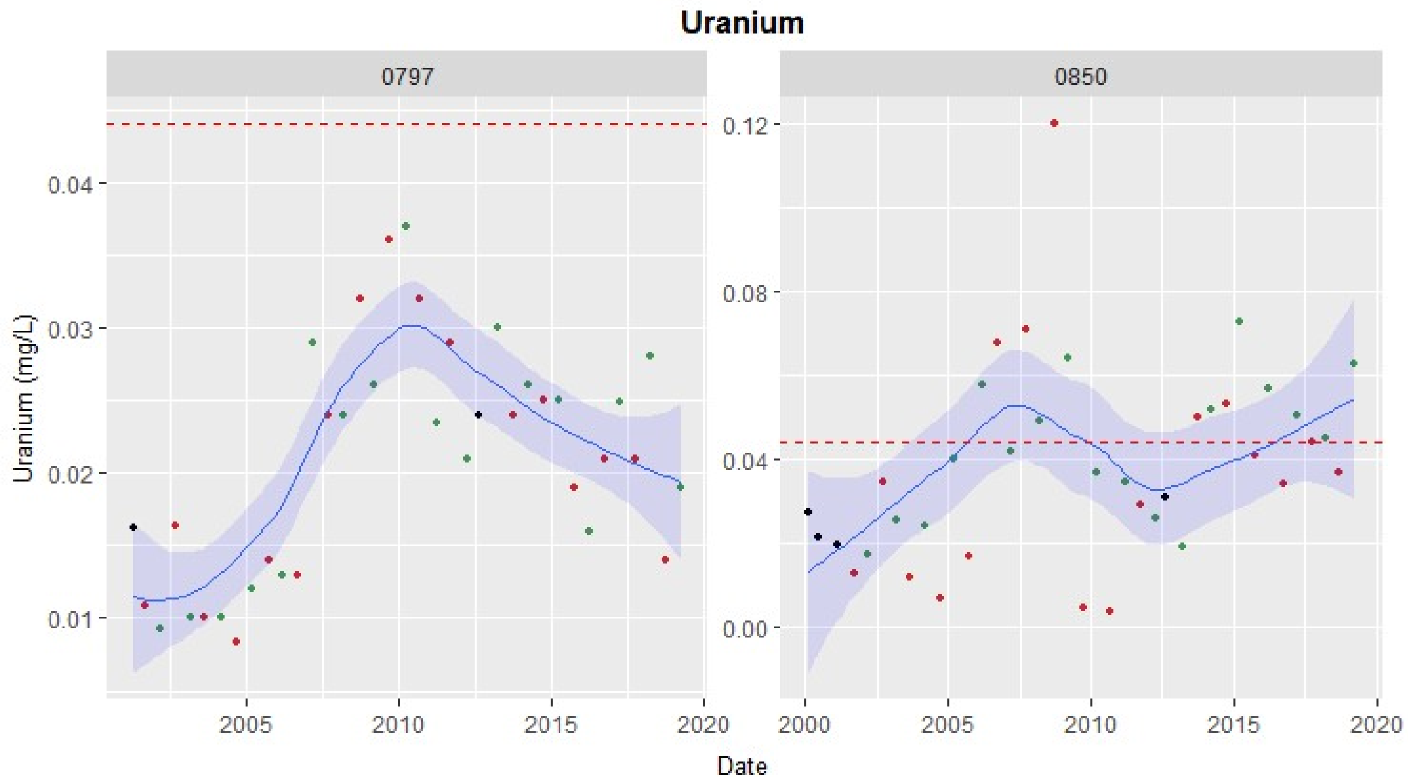
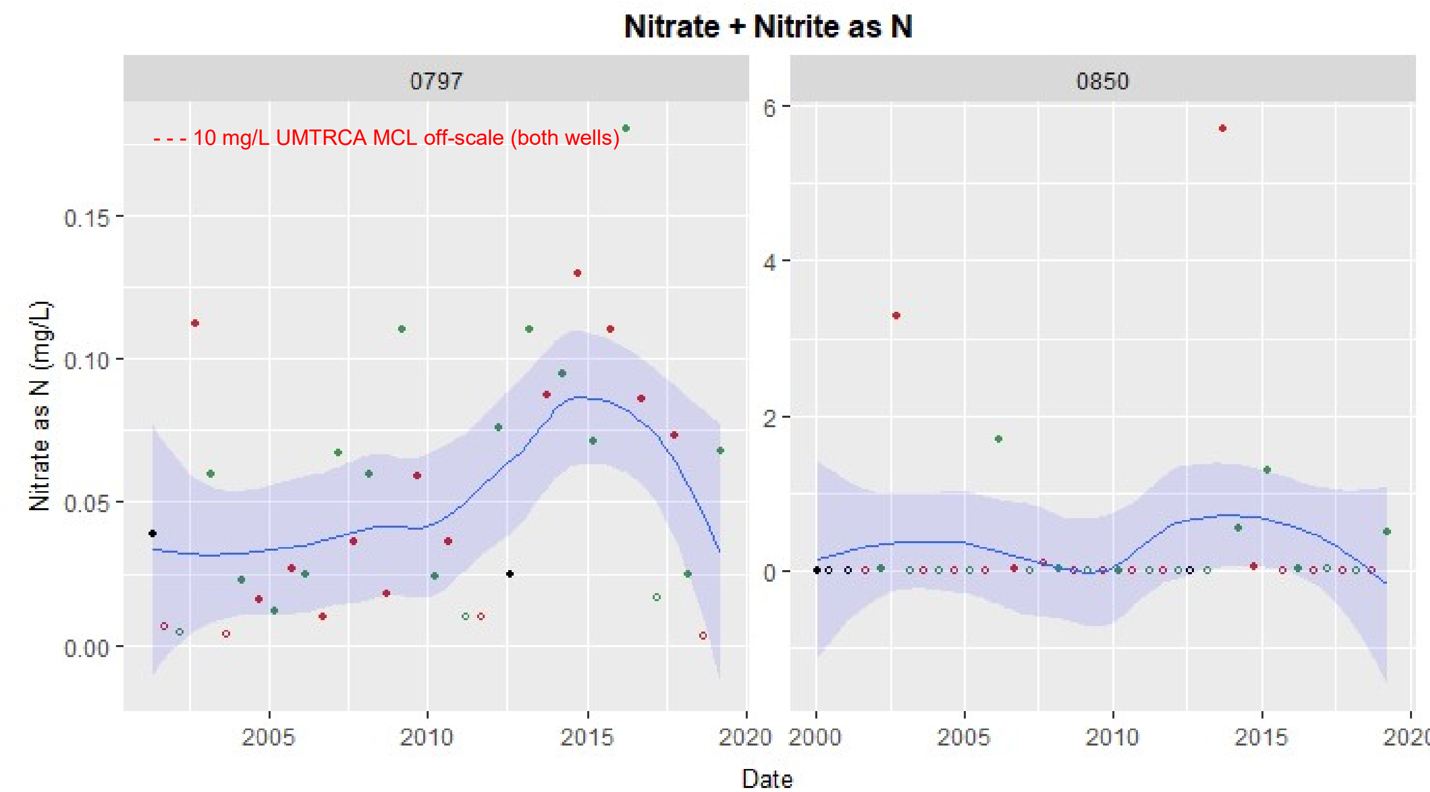
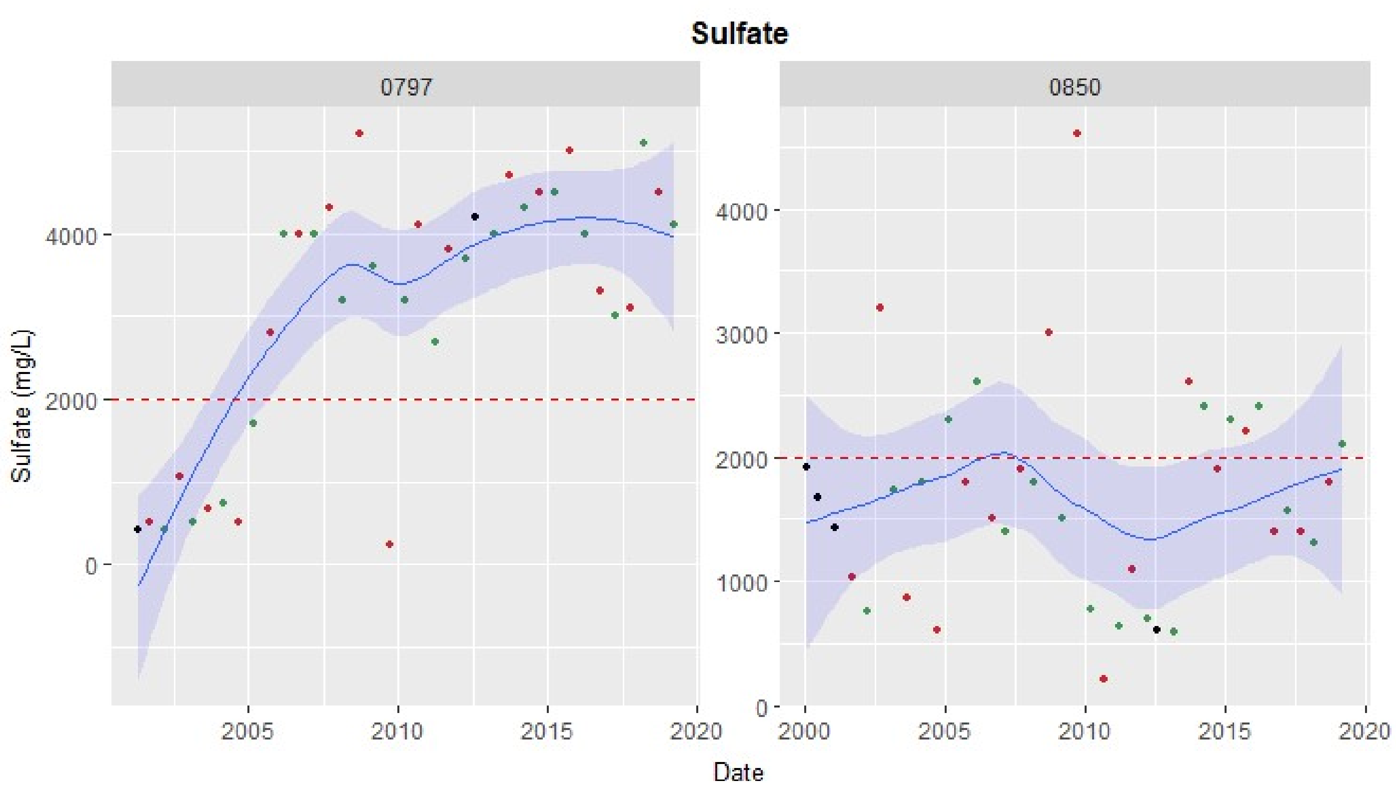


Figure A-8. Uranium, Nitrate, and Sulfate Concentration Trends in Western Floodplain Wells: 2000–March 2019







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.

- September semiannual sampling event
- March semiannual sampling event
- Other sampling event
- ○ Denotes result below the detection limit

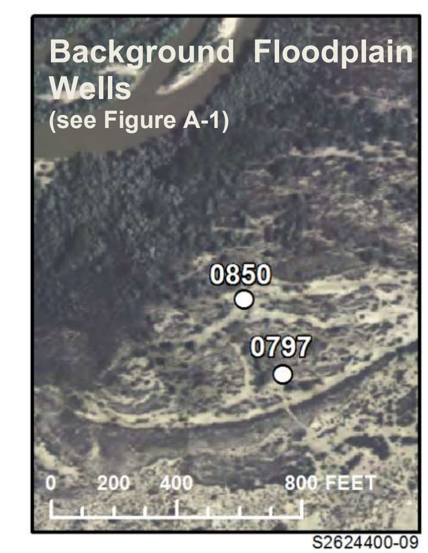


Figure A-9. Uranium, Nitrate, and Sulfate Concentration Trends in Background Floodplain Wells: 2000–March 2019

Appendix B

Hydrographs for Terrace Alluvial Wells

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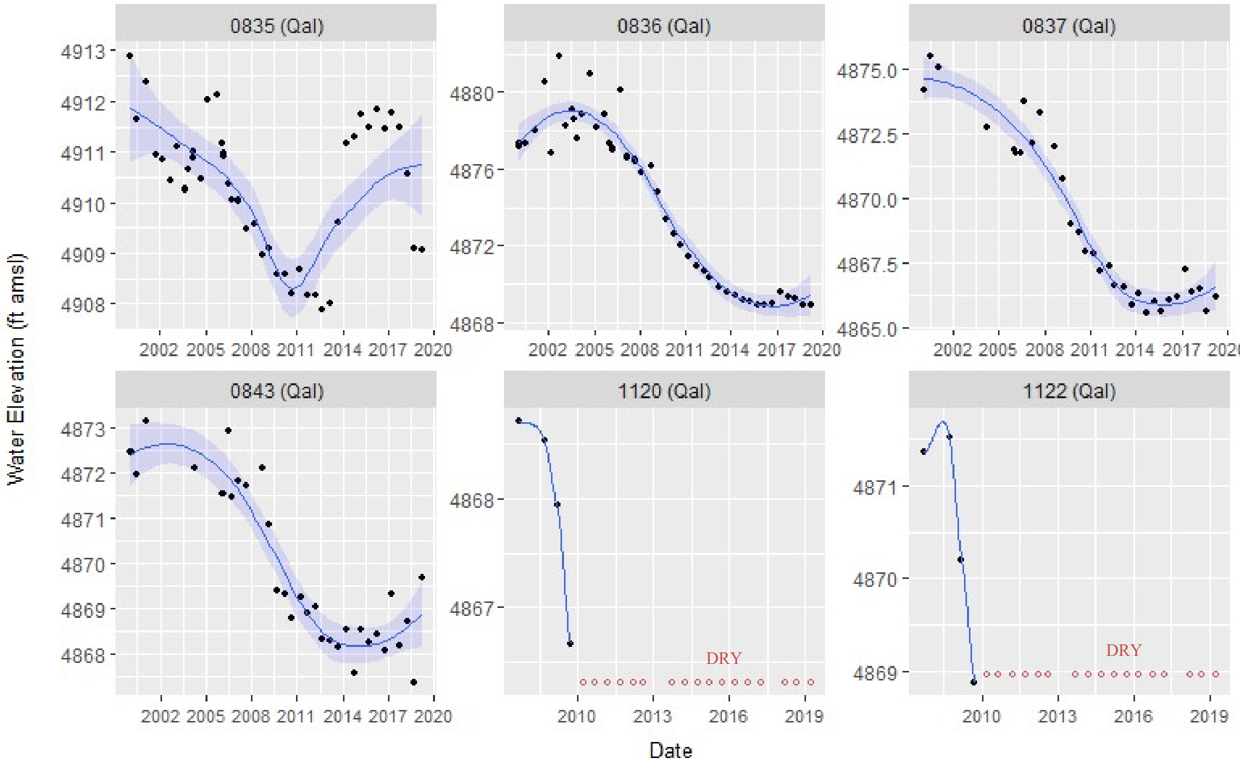


Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ Denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)

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*-axis (date) and *y*-axis scales are unique for each well. Refer to the detailed explanation in Appendix A, Figure A-2.

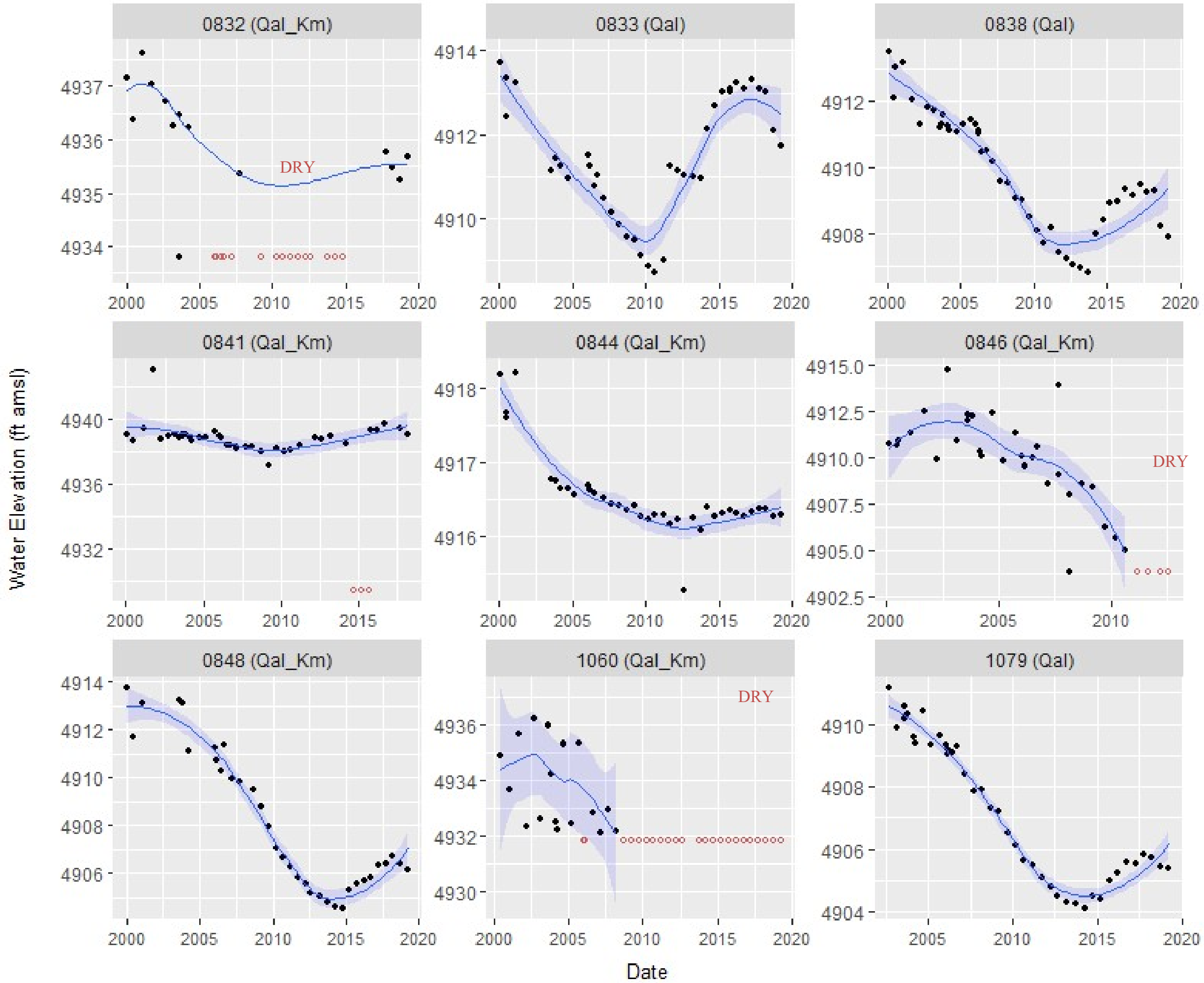
All wells shown here are screened solely in the alluvium (Qal); refer to well construction schematic in Figure C-1.

Abbreviations:

ft amsl feet above mean sea level

Qal denotes wells screened solely in the alluvium

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



Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ Denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)

Notes:

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

Well 0841 was recently damaged so no water level data were obtained.

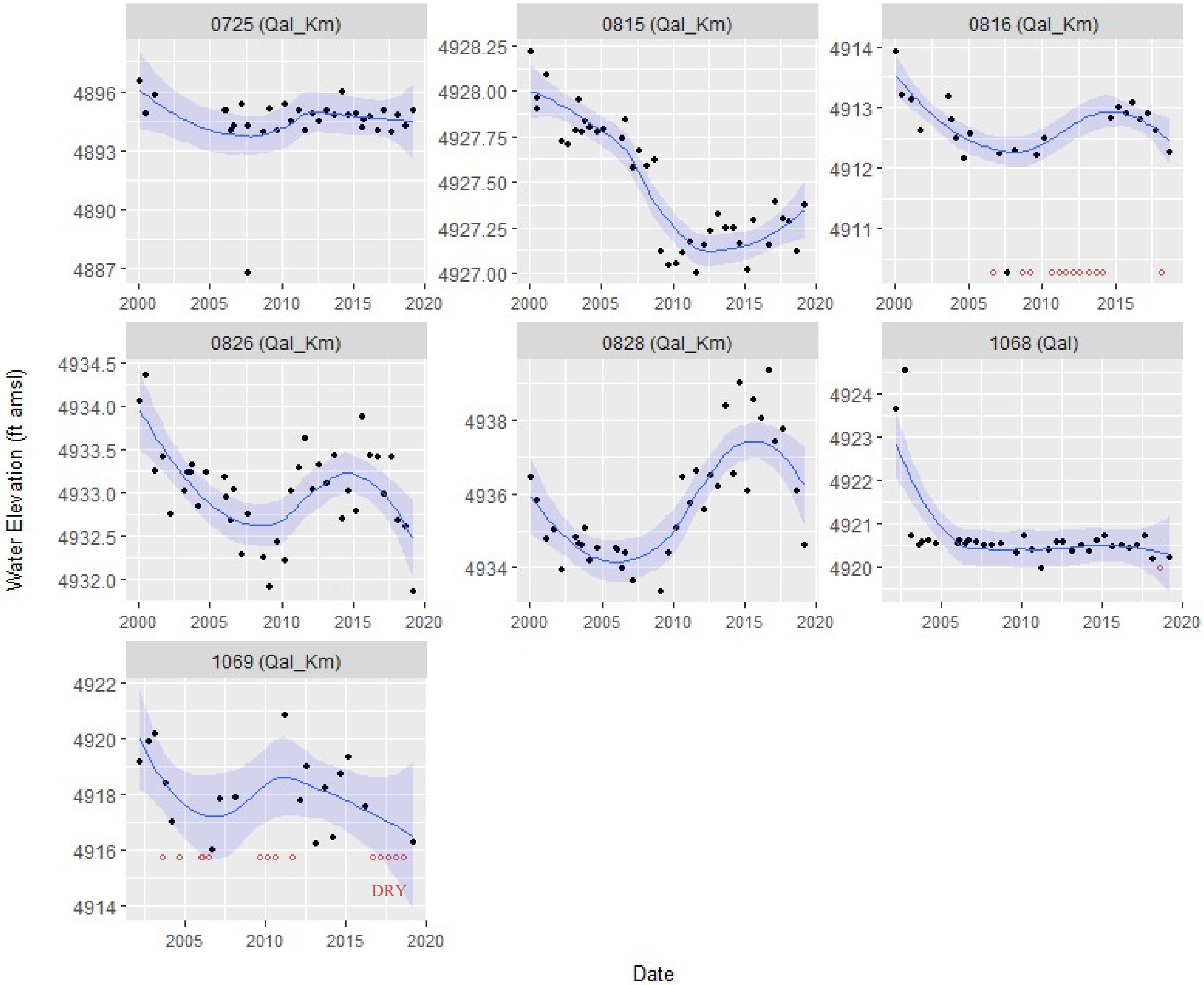
Abbreviations:

ft amsl feet above mean sea level

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)

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



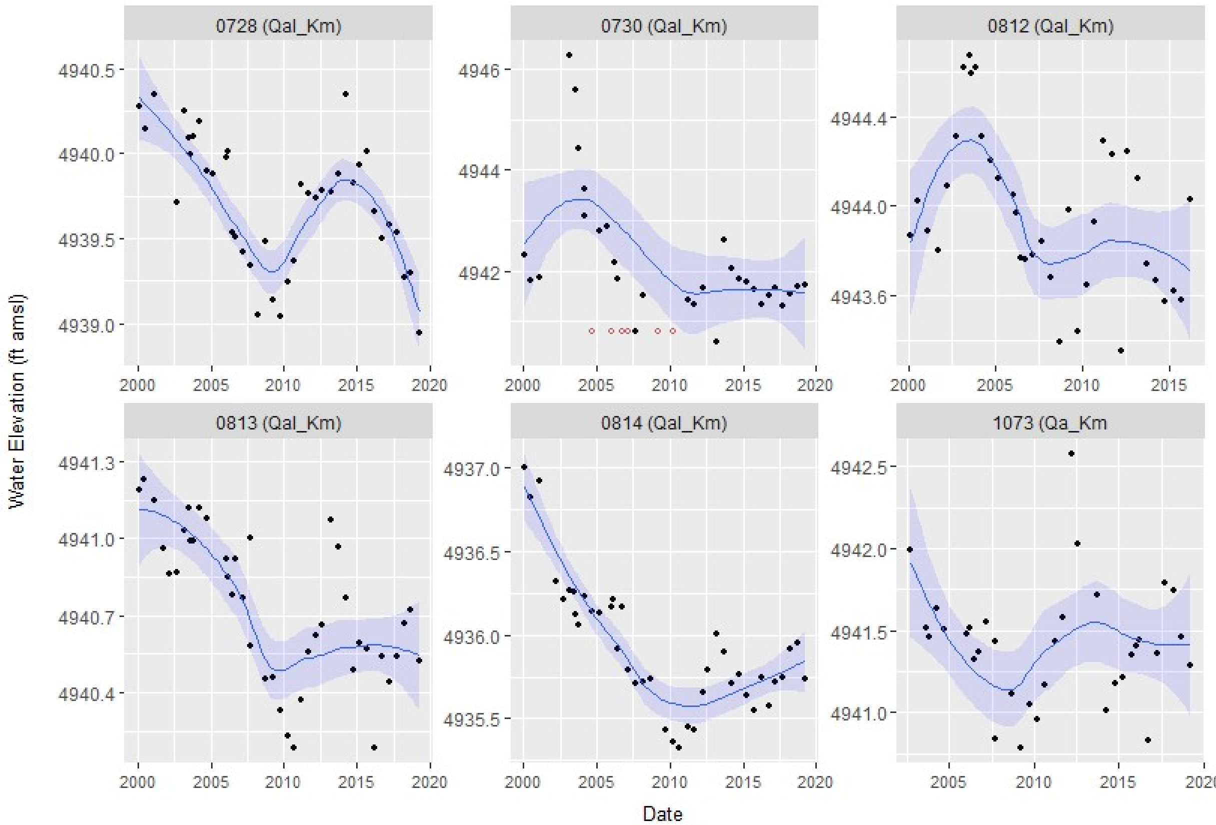
Blue line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ Denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)

Abbreviations:

ft amsl feet above mean sea level
Qal well screened solely in the alluvium (Figure C-1)
Qal_Km well screened in the alluvium and the Mancos Shale (Figure C-2)

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



Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

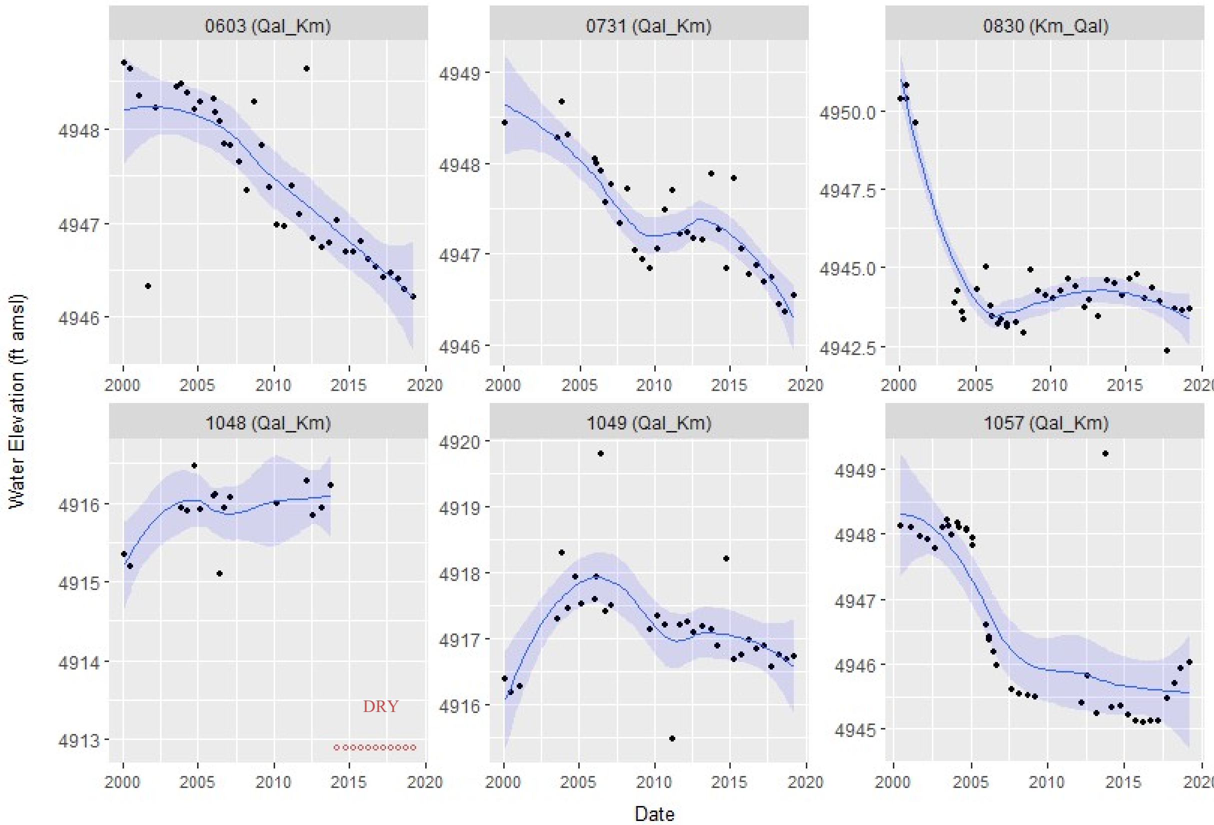
○ Denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)

Abbreviations:

ft amsl feet above mean sea level

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

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



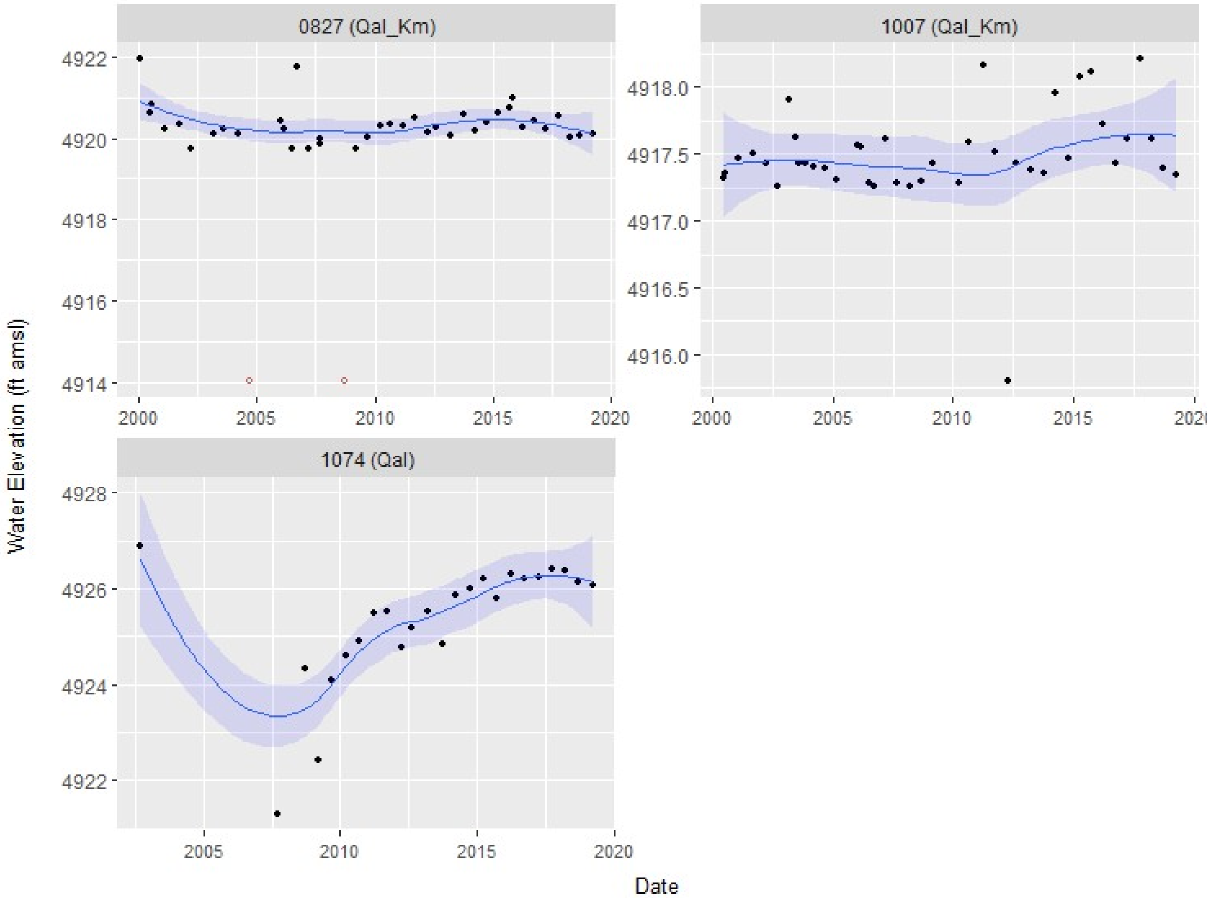
Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ Denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)

Abbreviations:

ft amsl feet above mean sea level
Qal_Km well screened in the alluvium and the Mancos Shale (well construction information shown in Figure C-2)
Km_Qal well screened partially in alluvium but mostly in Mancos Shale (Figure C-2)

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



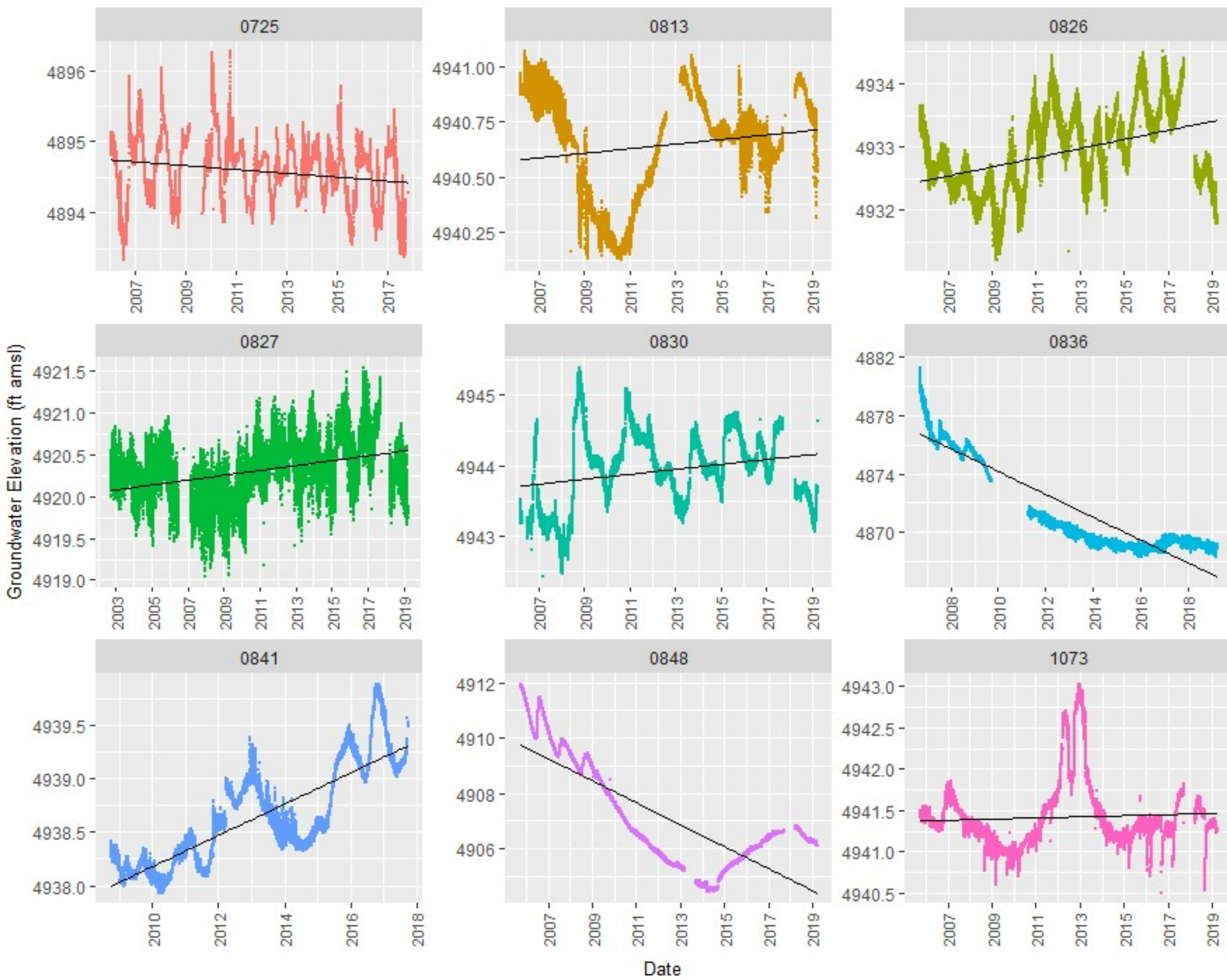
Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ Denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)

Abbreviations:

ft amsl feet above mean sea level
Qal well screened solely in the alluvium (Figure C-1)
Qal_Km well screened in the alluvium and the Mancos Shale (Figure C-2)

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



Notes:
In each plot, line (—) is linear trend line on datalogger measurements (color-coded by well).
Updated datalogger data, corresponding to the 2018–2019 reporting period, are not available for well 0725 and recently damaged well 0841.

Figure B-7. Datalogger Measurements from Terrace Alluvial Wells: 2010–2019

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Appendix C

Supplemental Well Construction Information

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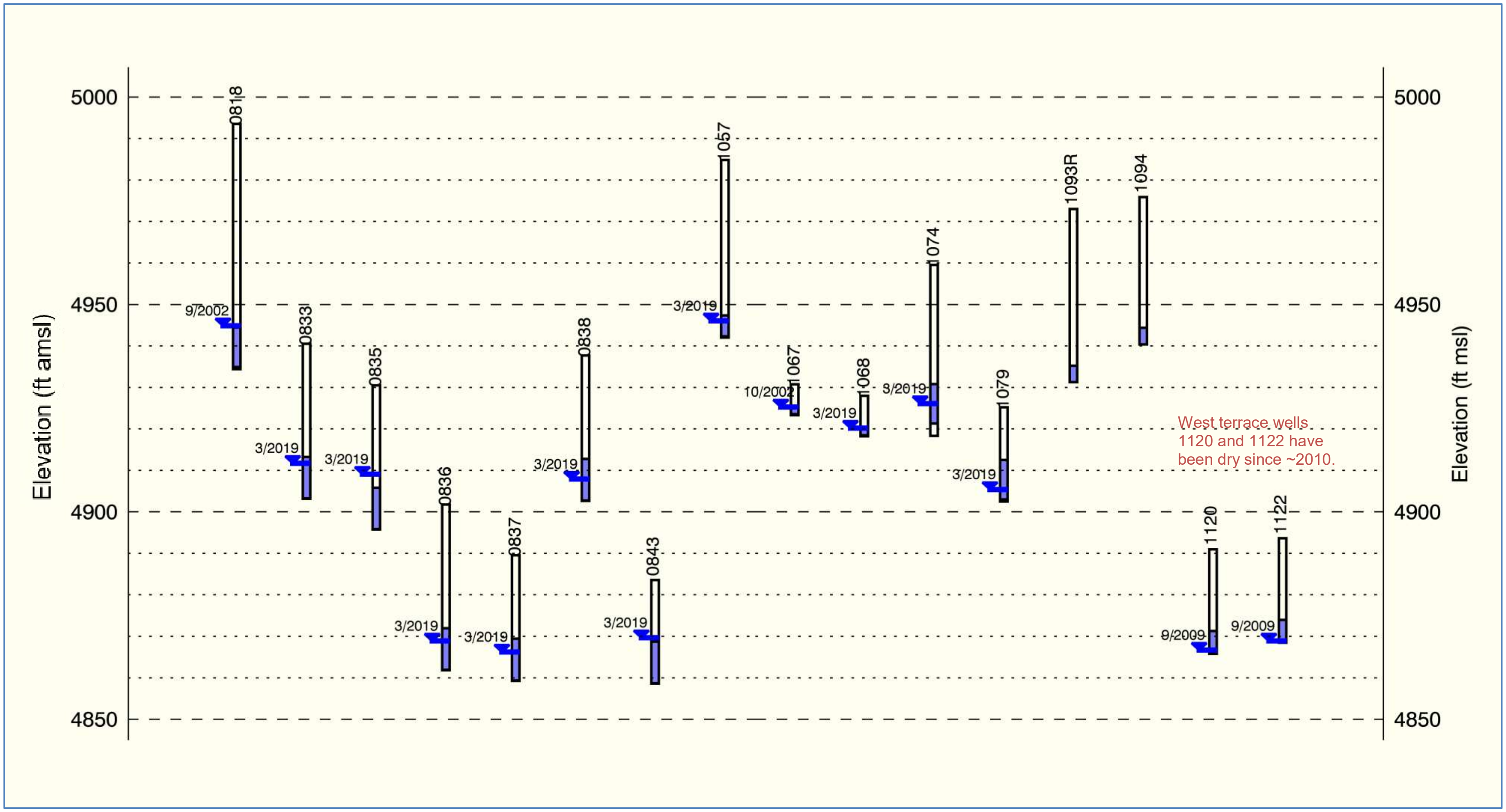


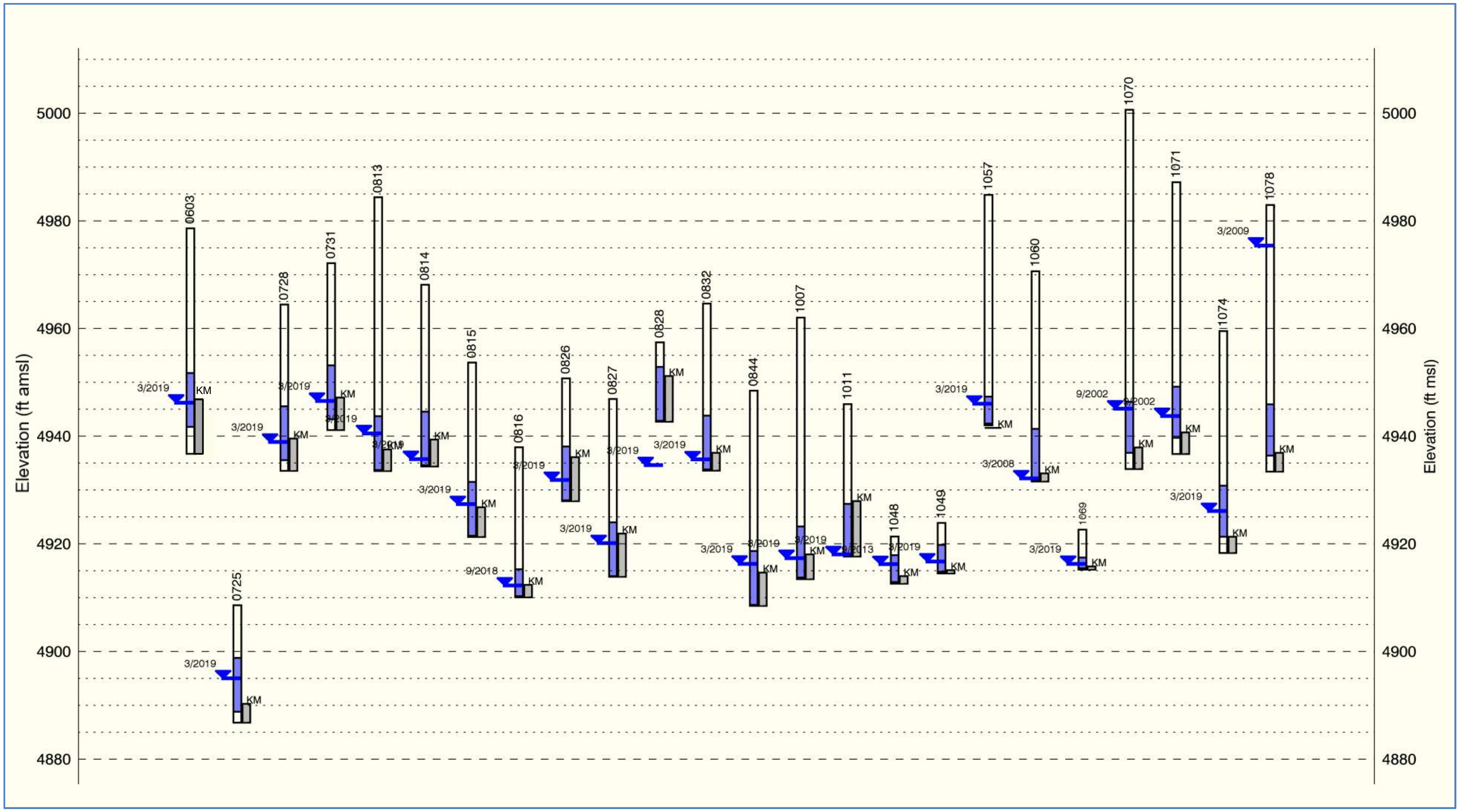
Notes:

1. Inverted blue triangles show the latest measured groundwater elevations. Groundwater elevations are typically not measured in extraction wells 0818, 1093R, and 1094.
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.

Abbreviation:

ft amsl = feet above mean sea level

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

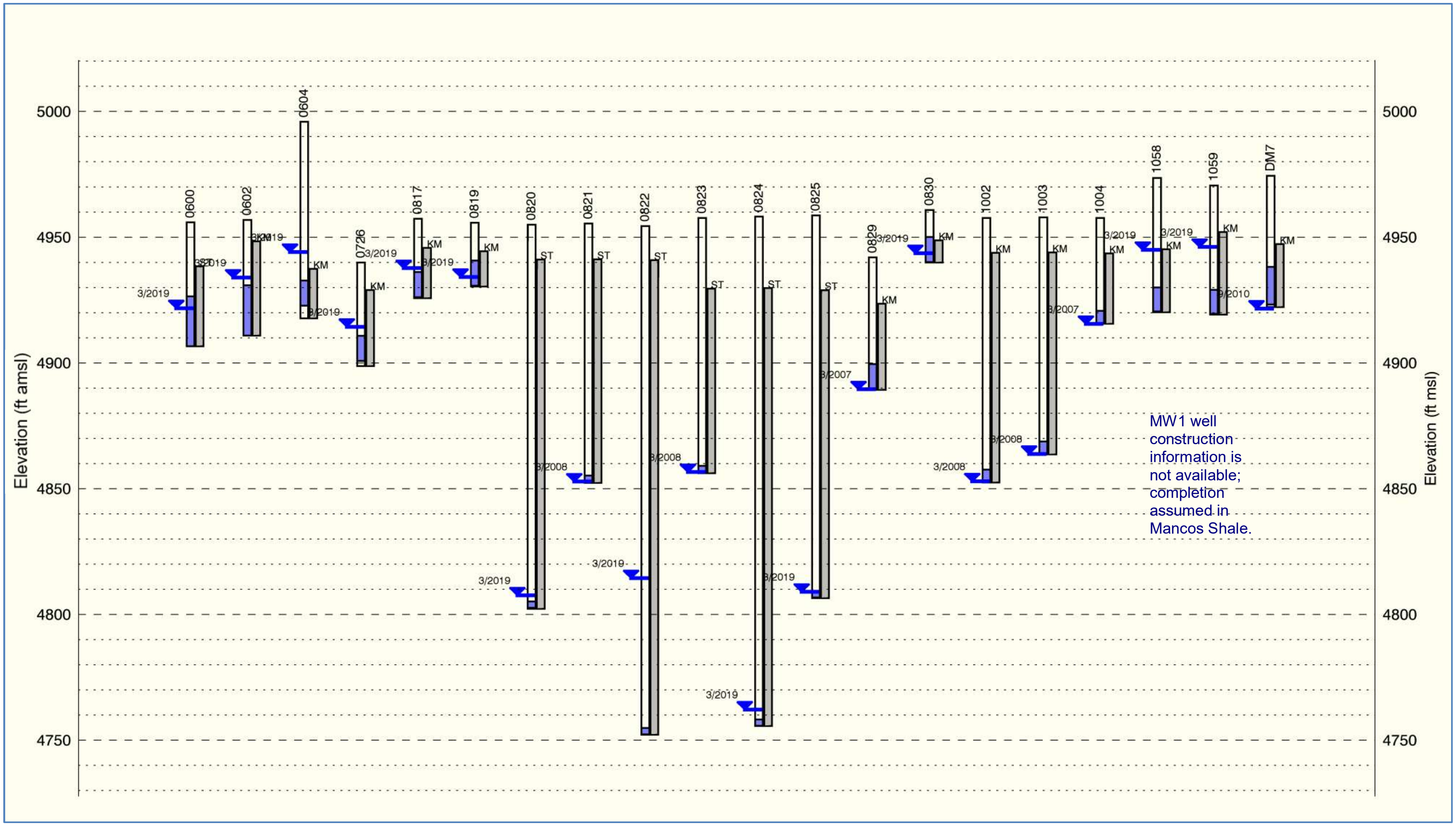


Notes:

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

Abbreviation:
KM = Mancos Shale

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 the right of well screen.
4. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

Abbreviation:
KM = Mancos Shale

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

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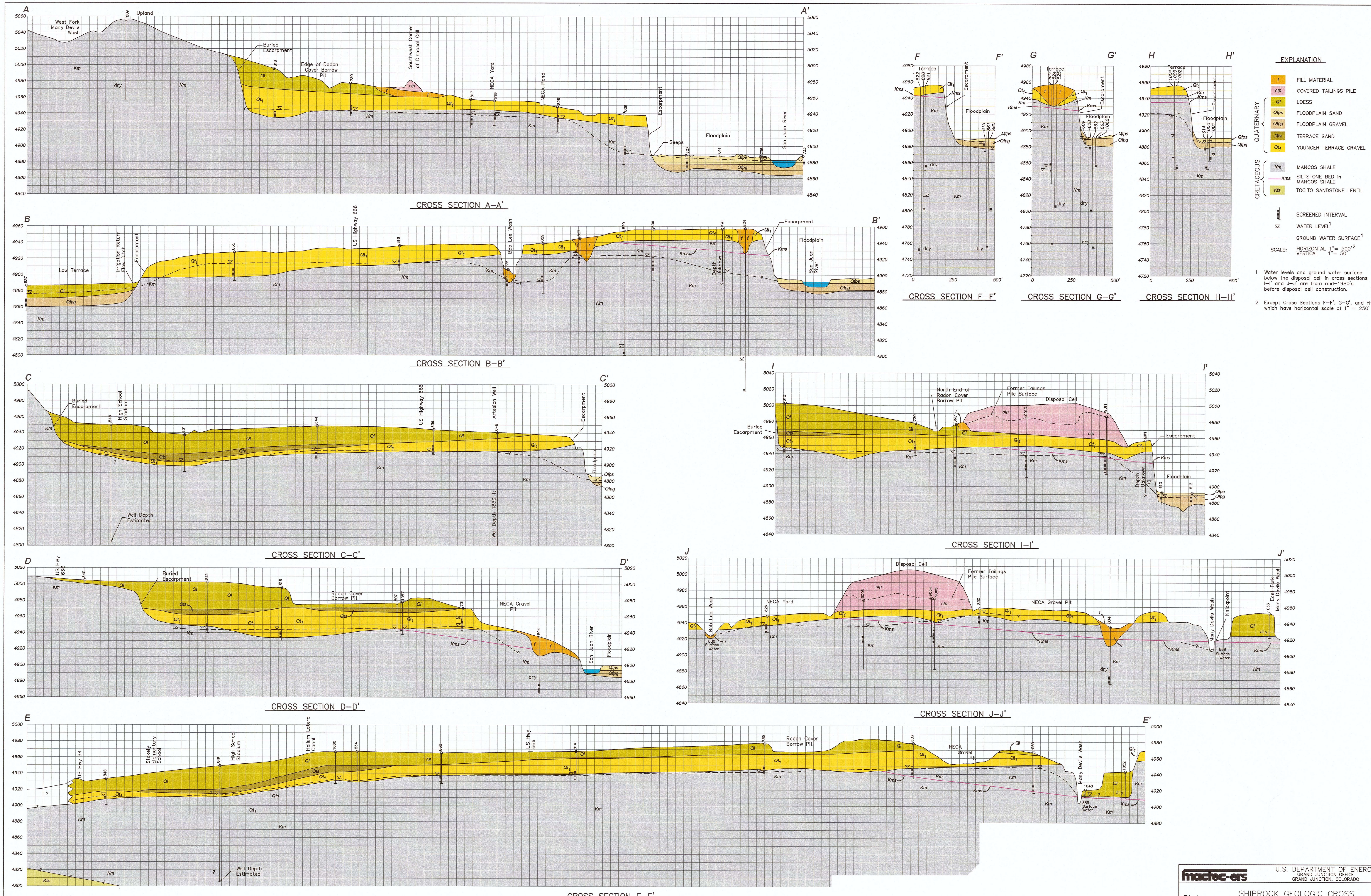

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U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE
GRAND JUNCTION, COLORADO

Plate: 4

SHIPROCK GEOLOGIC CROSS SECTIONS

DATE PREPARED:	FILENAME:
SEPTEMBER 7, 2000	U0096400

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