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Annual Performance Report April 2019 Through March 2020 for the Shiprock, New Mexico, Disposal Site

August 2021

U.S. DEPARTMENT OF ENERGY | Legacy Management

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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
MCL	maximum concentration limit
mg/L	milligrams per liter
N	nitrogen
NECA	Navajo Engineering and Construction Authority
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 2019 through March 2020. 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 aging to the point that an assessment is warranted of the need to either replace the liner or decommission the pond entirely. On April 21, 2017, LM suspended pumping of groundwater from most of the Shiprock site treatment system locations when water filled the evaporation pond to its maximum capacity. That suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches, primarily in support of ongoing evaluations regarding the pond liner. Several terrace extraction wells were pumped intermittently but the volume of groundwater extracted was negligible relative to the sump and trenches. Pumping of Bob Lee Wash has continued without interruption because the wash is a potential point of exposure. Groundwater extraction resumed at the floodplain trenches in July 2018 to prevent desiccation of pond sediments and continued through most of this reporting period. Pumping was halted for 3 months following a late spring flood but resumed in early September 2019.

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 2019 sampling event, 113 monitoring wells were sampled (59 on the floodplain and 54 on the terrace). Twelve surface water locations, including nine San Juan River sampling points and various seeps, were also sampled. Due to the COVID-19 pandemic and pursuant to general directives in Navajo Nation Public Health Emergency Order No. 2020-007, sampling did not take place in March 2020.

Contaminant distributions in the floodplain alluvial aquifer are characterized by elevated concentrations of sulfate and uranium, present adjacent to the escarpment north and east of the disposal cell and in a zone traversing the floodplain in a line trending north toward the San Juan River. Lower levels of sulfate and uranium, albeit still elevated relative to site remediation goals, are present in the northwest part of the floodplain where relatively uncontaminated surface water from Bob Lee Wash discharges to the floodplain. Nitrate contamination is presently limited to the base of the escarpment.

Because of the changes in the floodplain pumping regime over the last 3 years, LM continues to evaluate whether the reduced groundwater extraction volume has resulted in an increase in contaminant concentrations in the floodplain alluvial aquifer or any adverse changes in plume geometry. With only a few exceptions, no increases in COC concentrations were identified based on the September 2019 sampling results. In general, uranium, sulfate, and nitrate concentrations measured this reporting period were similar to previous (pre-pumping-suspension) results in the majority of floodplain wells. Relative to baseline (2000–2003) conditions, significant reductions in all contaminant concentrations are still apparent despite the reduced pumping volumes in the last 3 years. This is most 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. Mann-Kendall trend analysis results support these observations, indicating significant decreasing trends in the majority of alluvial wells on the contiguous floodplain. 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. Uranium and nitrate concentrations in samples collected from the San Juan River continue to be below established benchmarks and comparable to upstream (background) locations.

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. Groundwater levels in the majority of terrace alluvial wells remain low relative to those measured during the baseline period (average decrease of 1.6 ft). Six alluvial west terrace wells were dry during this reporting period, as were several seeps that have been dry since 2008.

Summary of Remediation Performance and Site Evaluation Progress

From April 2019 through March 2020, about 10.2 million gallons of extracted groundwater were pumped to the evaporation pond, slightly greater than the volume extracted during the previous reporting period (8.4 million gallons in 2018–2019). The bulk of this total volume (8.8 million gallons, or 86.2%) of the influent liquids entering the pond during the current reporting period was from the floodplain trenches. Since DOE began active remediation in March 2003, about 53.7 million gallons have been extracted from the terrace and 166.3 million gallons have been extracted from the floodplain, yielding a total cumulative volume of about 220 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 (rounded) 10,700; 415,000; and 33.5 pounds, respectively.

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1.0 Introduction

This report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal Site for the period April 2019 through March 2020. 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.

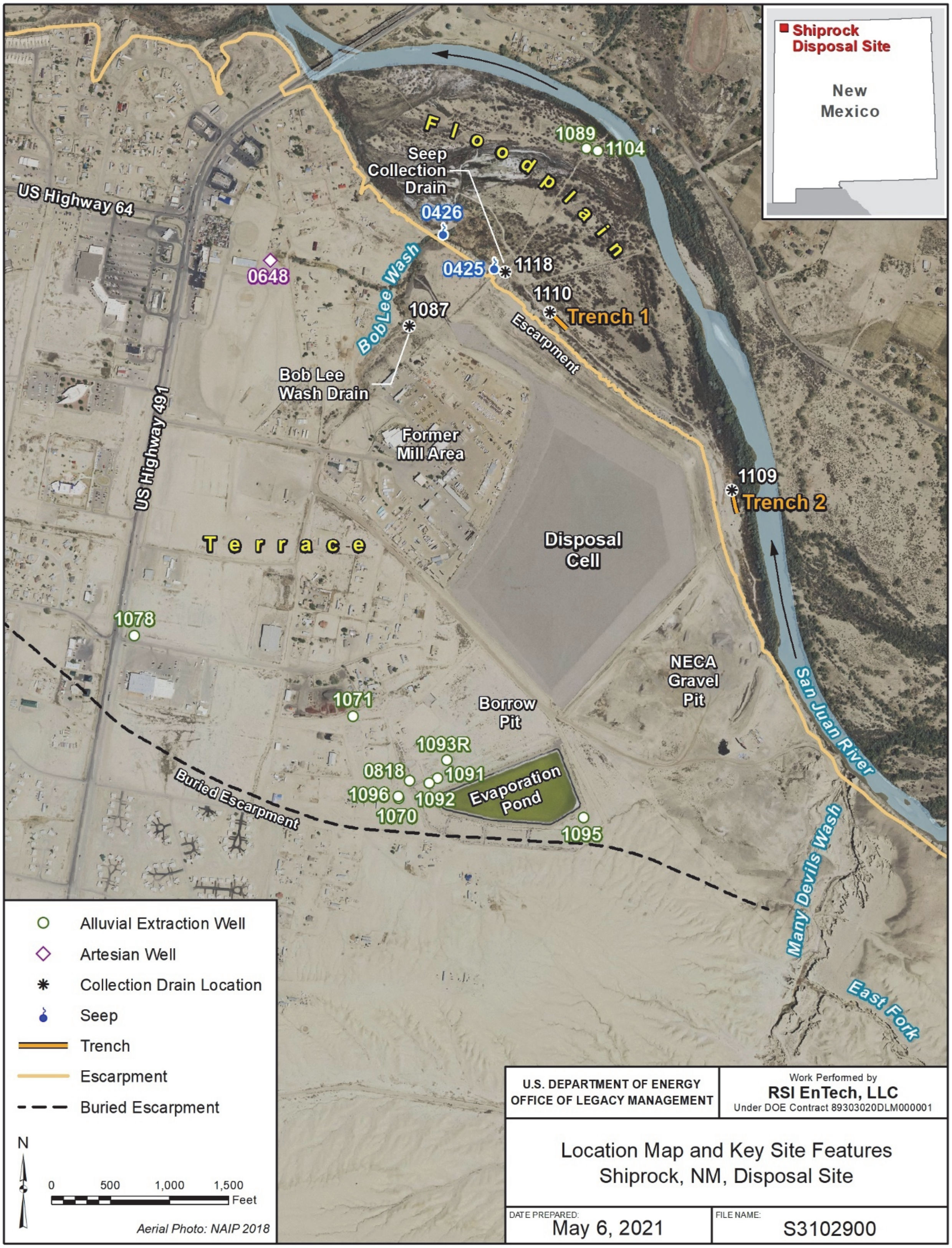
The Shiprock site is divided into two distinct areas: the floodplain and the terrace. An escarpment forms the boundary between these two areas. The floodplain remediation system consists of two groundwater extraction wells, a seep collection drain, and two collection trenches (Trench 1 and Trench 2). 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

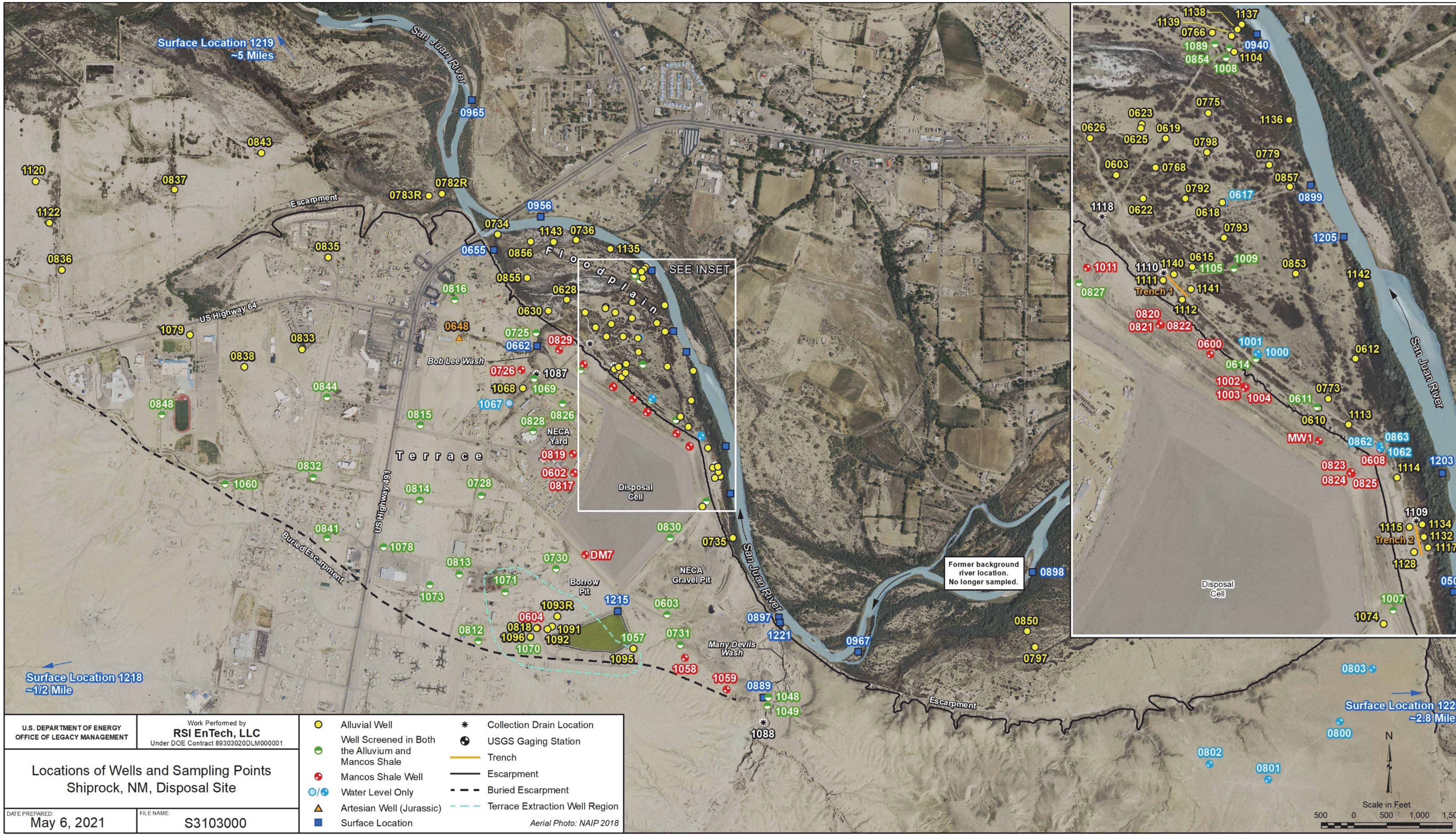
In the last several years, LM has observed that the evaporation pond liner is aging to the point that an assessment is warranted of the need to either replace the liner or decommission the pond entirely. On April 21, 2017, LM suspended pumping of groundwater from most of the Shiprock site treatment system locations when water filled the evaporation pond to its maximum capacity. That suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches, primarily in support of ongoing evaluations regarding the pond liner. Groundwater extraction resumed at the floodplain trenches in July 2018 to prevent desiccation of pond sediments and continued through most of this reporting period. Pumping was discontinued for 3 months following a late spring flood but resumed in early September 2019.

LM's current approach is to maintain a balance of pumping enough water to ensure that the evaporation pond sediments remain covered while remediating as much as possible in accordance with the compliance strategy.



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 and 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 described 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 2011b; 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 (DOE 2020b).

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 in 2022–2023. 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 2011a; Morrison et al. 2012; Robertson et al. 2016).

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.

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 2020) result for well 0850 was 0.021 mg/L.

Notes:

[a] Data are from floodplain background wells 0797 and 0850 (locations shown in Figure 2). LM is currently reevaluating the representativeness of these wells as background locations for floodplain alluvial groundwater (DOE forthcoming).

[b] https://www.env.nm.gov/gwqb/gw-regulations/ (accessed March 2020).

[c] https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables/ (accessed March 2020).

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

The remediation goals listed Table 1 apply to the floodplain only because the compliance strategy for the terrace is to decrease groundwater elevations and flow rates at seeps. As listed in this table, 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 benchmark is the maximum contaminant level for drinking water established under the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act.

Unlike for uranium and nitrate, regulatory standards have not been developed for sulfate, the other primary COC monitored at the Shiprock site. 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.

In addition to sulfate (a primary COC), regulatory standards have also not been established for ammonia, manganese, and strontium (Table 1). Along with selenium, these COCs have received less focus in LM's annual reporting. While levels of these constituents in site wells have at times clearly exceeded background, this occurs to a more limited degree relative to the magnitude and extent of the primary COCs (uranium, nitrate, and sulfate). Two constituents, manganese and strontium, have never been definitively associated with former processing activities and as such have not been useful indicators of tailings-derived waters. LM is currently reevaluating whether ammonia, manganese, selenium, and strontium still warrant designation as COCs and, if so, to what degree or monitoring extent (DOE forthcoming).

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 2011b; DOE 2009).

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). LM is currently reevaluating background conditions for the floodplain. Preliminary findings of this analysis suggest that wells 0782R and 0783R may be more representative background locations for floodplain wells geochemically influenced by the San Juan River.

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 2019–2020 reporting period.

2.1 Floodplain Remediation System

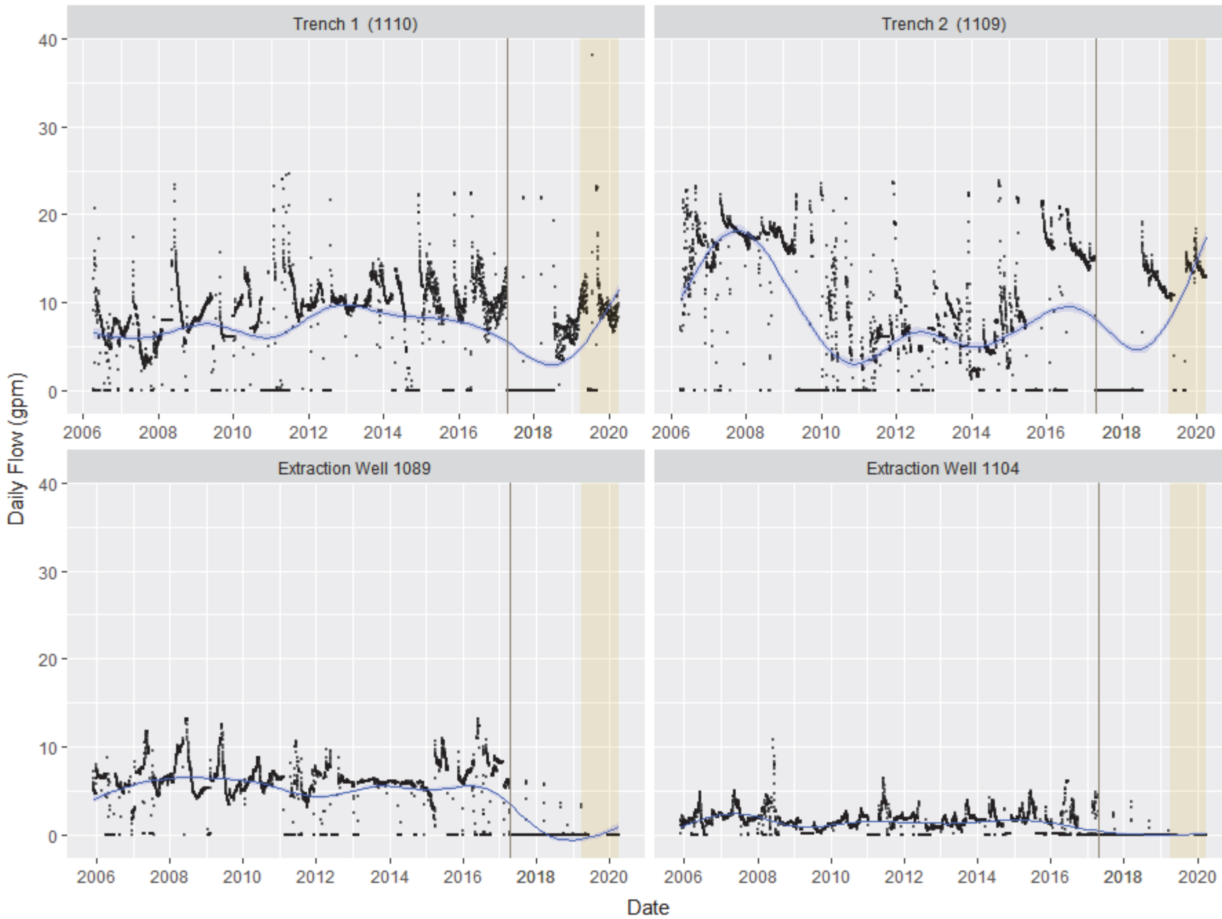
The floodplain remediation system consists of three major components shown in Figure 1: two extraction wells (wells 1089 and 1104); two drainage trenches (horizontal wells), Trench 1 and Trench 2; and a sump (collection drain location 1118) used to collect discharges from seeps 0425 and 0426 on the escarpment. 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. 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 (2019–2020) reporting period. At the trenches, pumping resumed on July 19, 2018, to prevent desiccation of evaporation pond sediments.

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

Floodplain Location	Previous Period (April 1, 2018, through March 31, 2019)		Current Period (April 1, 2019, through March 31, 2020)	
	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
1089	0.04	20,797	Nil	44.7
1104	0.01	3772	0	0
Trench 1 (1110)	4.67	2,456,135	7.6	4,017,639
Trench 2 (1109)	8.99	4,723,318	9.1	4,783,420
Seep (1118)	0	0	Nil	2.0
Total	**13.7**	**7,204,022**	**16.7**	**8,801,106**

2.1.1 Extraction Well Performance

The floodplain extraction well system consists of wells 1089 and 1104 (Figure 1), installed in late June 2003 using slotted culverts placed in trenches excavated to bedrock. As indicated above and in Table 2, there is no recent performance to report for these wells because the pumping suspension that began in April 2017 continued through the current (2019–2020) period. Since the start of operations in 2003 through the end of March 2020, totals of approximately 39.6 million and 8.6 million gallons of water have been removed from wells 1089 and 1104, respectively. Figure 3 plots historical daily flows (pumping rates) for extraction wells 1089 and 1104 and the two trenches.



- Average daily flow rate (gpm)
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- Shading denotes current (2019–2020) 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.
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: 2005–2020

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 2019 through March 2020, 4.0 million and 4.8 million gallons of water were removed from Trench 1 and Trench 2, respectively (Table 2); average pumping rates were 8–9 gpm. Since the trenches were installed in 2006, totals of approximately 51.1 million and 63.2 million gallons of water have been removed from Trench 1 and Trench 2, respectively (totaling 114.3 million gallons).

2.1.3 Floodplain Seep Sump Performance

Seeps 0425 and 0426 were incorporated into the remediation system in August 2006. Groundwater discharge from these two seeps is piped into a collection sump (location 1118) and then pumped to the evaporation pond. The pumping suspension initiated in April 2017 continued through this (2019–2020) reporting period. As such, no water has been pumped from the collection sump for the last 2 years (Table 2). Consistent with LM's last annual report (DOE 2020), 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. As noted in the last annual report (DOE 2020a), 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. Except for brief intermittent pumping at a few locations (e.g., 1093R), this suspension continued into the current (2019–2020) reporting period.

2.2.1 Extraction Well Performance

During the current period, the terrace remediation well field consisted of wells 0818, 1070, 1071, 1078, 1091, 1093R, 1095, and 1096. (Well 1092 was removed from the network in late March 2019). Table 3 compares the average pumping rate and total groundwater volume removed from each terrace extraction well and drain location for the current (2019–2020) and previous (2018–2019) 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 0.33 gpm (with the maximum at well 1093R). The total volume removed from pumping the terrace extraction wells in 2019–2020 was about 237,000 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 (between approximately 2008 and 2017), the 8 gpm objective was not achieved. Instead, 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. As noted previously, LM is currently reevaluating the terrace compliance strategy (DOE 2020b).

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

Terrace Well or Drain	Previous Period (April 1, 2018, through March 31, 2019)		Current Period (April 1, 2019, through March 31, 2020)	
	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Annual Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818	0.023	11,919	0.008	4269
1070	Nil	11	Nil	8.5
1071	Nil	68	Nil	25.5
1078	0.037	19,504	0.07	36,802
1091	0.001	593	Nil	756
1092[a]	0	0	–	–
1093R	0.078	41,090	0.33	175,468
1095	0.031	16,145	0.037	19,381
1096	0.008	4320	0.001	301
Extraction Well Subtotal[b]	**0.18**	**93,649**	**0.45**	**237,010**
Bob Lee Wash (1087)	3.5	1,858,747[c]	2.2	1,172,593
Many Devils Wash (1088)[d]	0	0	0	0
Total[b]	**3.7**	**1,952,396**	**2.7**	**1,409,604**

Notes:

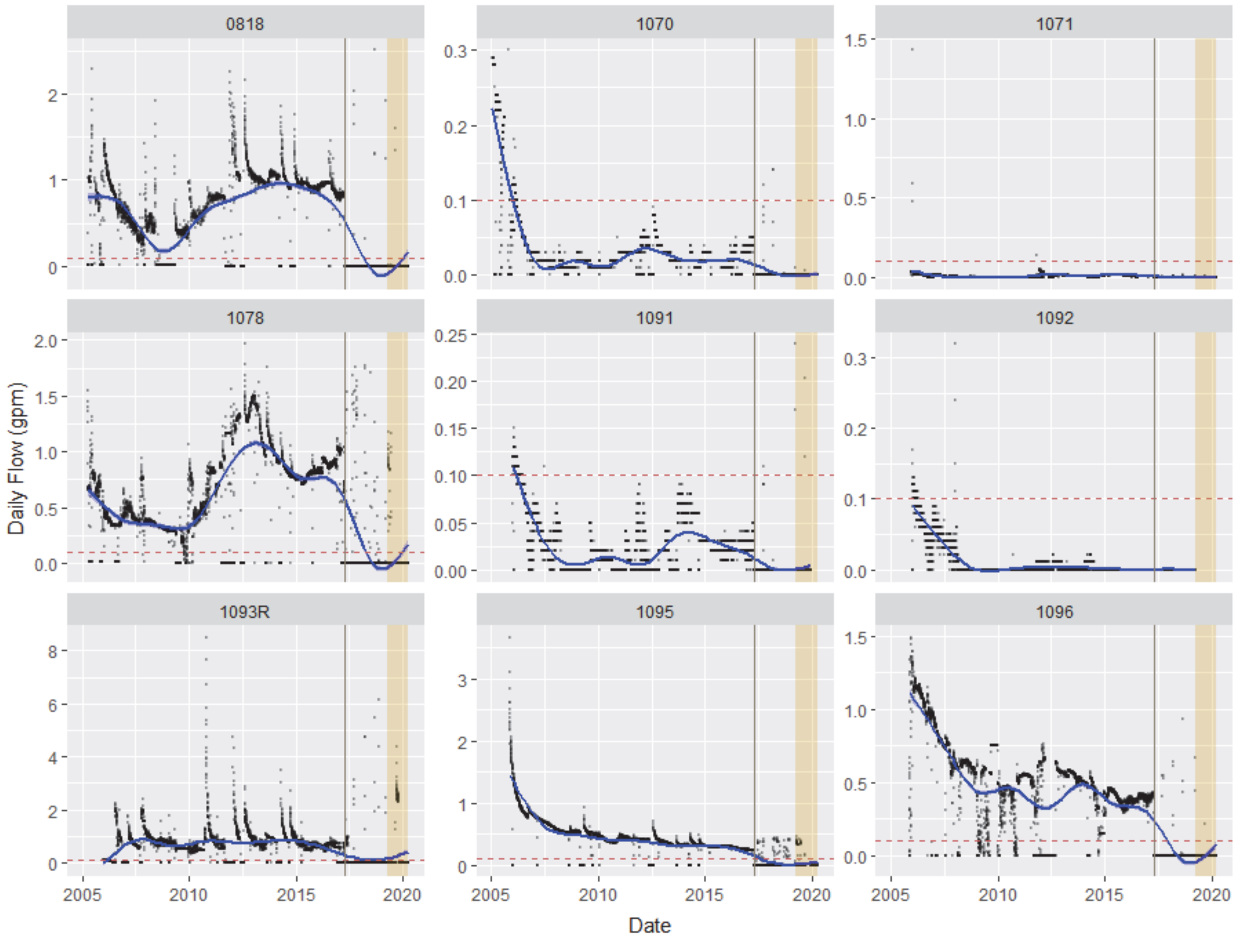
[a] Extraction well 1092 was offline the entire 2019–2020 reporting period. It is no longer a viable extraction well (or groundwater monitoring location) because the well is dry.

[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 bulk of the previous (2018–2019) reporting period. This location was being pumped, however, as evidenced by line pressures and water elevations measured during that period. To estimate extraction volumes, zero values were substituted with a surrogate value of 3.5 gpm based on professional judgment. The 2018–2019 total annual flow reported here (1.9 million gallons) differs from that provided in the previous annual performance report (1,140,161 gallons; Table 3 of DOE 2020a) because of the updated corrections to the dataset.

[d] Many Devils Wash has not been pumped since 2014 because of the need for repairs and the presence of naturally occurring contamination. Decommissioning of associated infrastructure is scheduled for 2022–2023.

Abbreviation:
– = Not applicable (no data)



- Average daily flow rate (gpm)
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- 0.1 gpm (150 gallons per day) low-yield definition for limited-use aquifer (40 CFR 192.11[e])
- Shading denotes current (2019–2020) reporting period
- April 21, 2017, pumping suspension

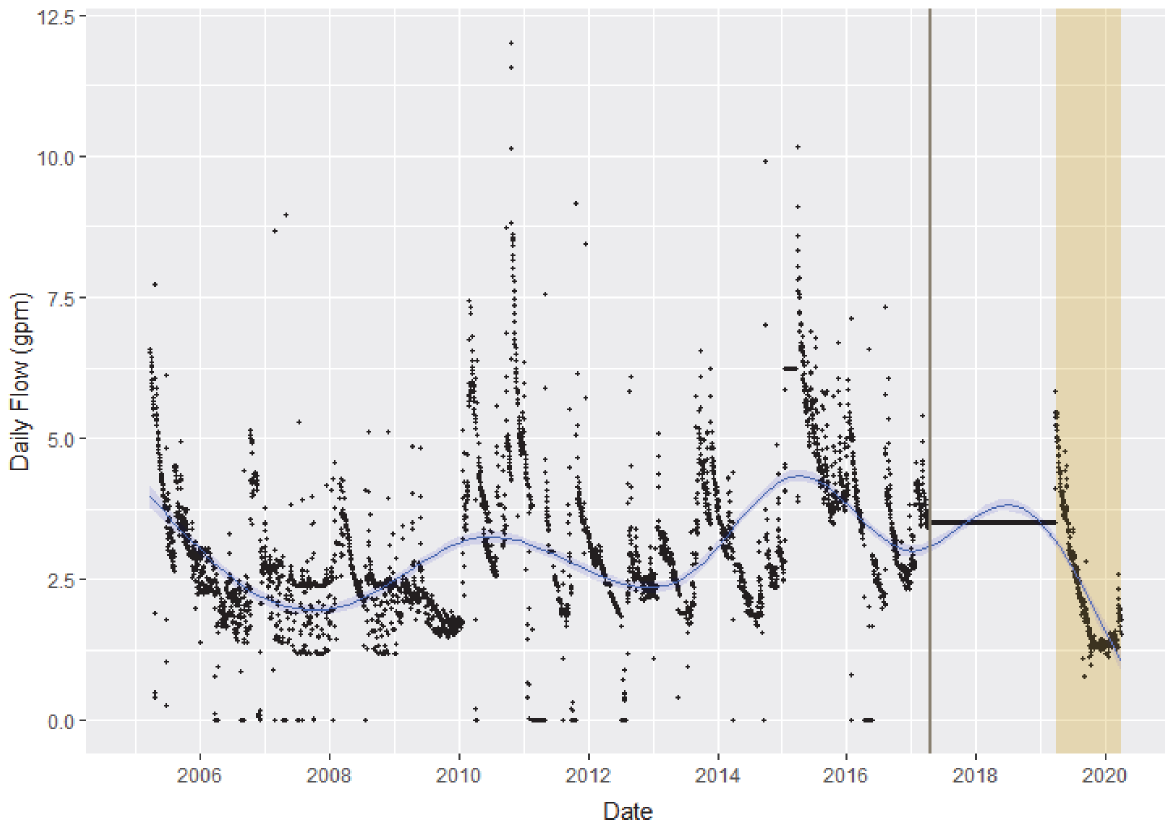
Notes: Data plotted are since the inception of the System Operation and Analysis at Remote Sites (SOARS) system in 2005–2006. *y*-axis scales are unique for each well to allow better resolution of the recent low values. As such, the plots are not directly comparable.

Figure 4. Historical Pumping Rates in Terrace Extraction Wells: 2005–2020

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. Decommissioning of associated infrastructure is scheduled for 2022–2023.

Pumping continued at Bob Lee Wash throughout the entire (2019–2020) reporting period because the wash is considered a potential point of exposure; daily flow rates are plotted in Figure 5. In 2019−2020, the groundwater interceptor drain removed close to 1.2 million gallons of water; the average pumping rate was 2.2 gpm (Table 3). The cumulative volume extracted since pumping began in 2003 is 27.9 million gallons. However, this cumulative volume is uncertain because the flow meter was not functioning for an extended period between 2017 and early 2019.



- Average daily flow rate in gallons per minute (gpm). A surrogate value of 3.5 gpm was applied for the extended period of flowmeter malfunction between April 2017 and early 2019 (refer to Note c of Table 3)
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- Shading denotes current (2019–2020) reporting period
- Denotes April 21, 2017, cessation of pumping at most Shiprock site treatment locations

Note: Data plotted are since the inception of the System Operation and Analysis at Remote Sites (SOARS) system in 2005.

Figure 5. Historical Flow Rates in Bob Lee Wash (1087): 2005–2020

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 since September 2006. At the close of this reporting period (March 31, 2020), the water level in the evaporation pond was 1.96 ft, measured as the distance above transducers. The average water level during the reporting period was 1.4 ft. These low pond water levels relative to those measured in previous years are the result of the pumping suspension that began in April 2017.[1] This suspension continued into 2020 for most treatment system locations except Bob Lee Wash and the floodplain trenches. The first marked water level decline shown in Figure 6 followed the April 2017 pumping suspension. To prevent desiccation of pond sediments, pumping was resumed at the trenches in mid-July 2018. The subsequent decline in pond water levels was due to the mid-June 2019 San Juan River flood, which necessitated the shutdown of all System Operation and Analysis at Remote Sites (SOARS) equipment on the floodplain and subsequent repairs. Pumping of the trenches resumed on September 8, 2019.

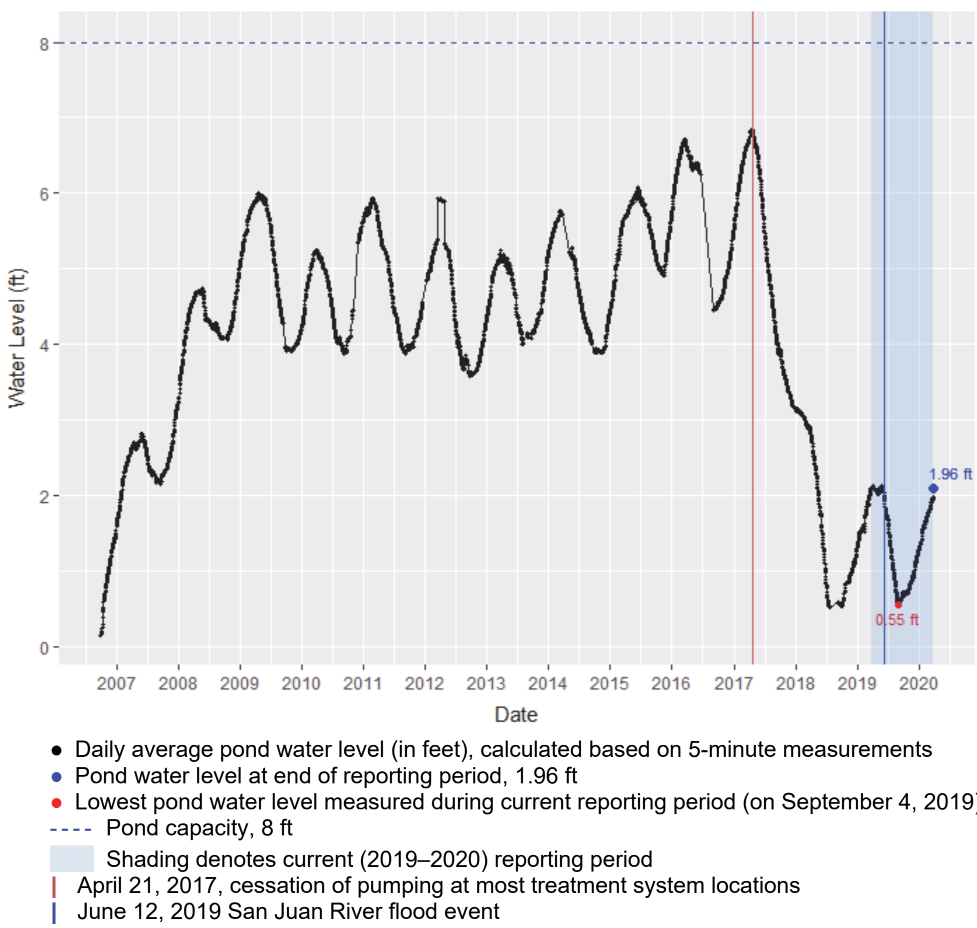


Figure 6. Water Levels in Evaporation Pond, 2006–March 2020

[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.)

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, 2019–2020 (mg/L)	Nitrate Mass Removed, 2019–2020 (lb)[b]	Cumulative Mass of Nitrate Removed (lb)[a,b]	Sulfate Average Concentration, 2019–2020 (mg/L)	Sulfate Mass Removed, 2019–2020 (lb)[b]	Cumulative Mass of Sulfate Removed (lb)[a,b]	Uranium Average Concentration, 2019–2020 (mg/L)	Uranium Mass Removed, 2019–2020 (lb)[b]	Cumulative Mass of Uranium Removed (lb)[a,b]
Terrace												
0818	4269	5,769,663	0.04	640	22.8	56,174	17,000	606	619,542	0.11	0.004	6.0
1070	8.5	545,106	<0.01	550	0.04	4232	16,000	1.1	81,779	0.11	<0.0001	0.59
1071	25	121,737	<0.01	560	0.12	1866	15,000	3.2	7568	0.12	<0.0001	0.16
1078	36,802	4,794,462	0.36	330	101	23,404	13,000	3993	552,762	0.11	0.034	5.3
1091	756	263,024	<0.01	620	3.9	3082	16,000	101	27,575	0.096	0.0006	0.25
1092	–	224,883	0	–	0	2866	–	0	24,714	–	0	0.22
1093R[c]	175,468	4,684,688	1.7	920	1347	80,612	9867	14,449	233,884	0.165	0.24	4.3
1094 (2003–2004)[d]	–	15,628	–	–	–	524	–	–	312	–	–	0.01
1095	19,381	2,850,773	0.19	1700	275	38,512	4200	679	134,696	0.04	0.0065	1.3
1096	301	3,121,438	<0.01	500	1.3	15,256	17,000	43	365,457	0.10	0.0003	2.5
1087 (BLW)	1,172,593	27,915,282	11.5	200	1957	68,323	6100	59,693	1,642,837	0.36	3.5	124
1088 (MDW)	–	3,406,532	–	–	0	18,761	–	0	538,436	–	0	5.0
Floodplain												
1077 (2003–2005)[d]	–	812,449	–	–	–	1214	–	–	116,410	–	–	16.8
1089	44.7	39,629,023	<0.01	0.005	0.005	5632	5100	1.9	2,361,762	0.10	0.0	224
1104	0	8,565,939	0.0	0.0	0.0	2972	5500	0	612,076	0.12	–	68.8
Trench 1 (1110)	4,017,639	51,138,861	39.4	140	4694	42,671	8500	284,994	3,020,368	0.71	23.8	331
Trench 2 (1109)[e]	4,783,420	63,204,843	46.8	57.5[e]	2295	37,696	1255[e]	50,099	767,814	0.148[e]	5.91	109
Seep sump (1118)	2	3,013,885	0	36.0	0.001	1259	6500	0.11	150,641	0.41	0	11.9
Totals												
Total terrace[d]	1,409,604	53,713,216	13.8	–	3709	313,612	–	79,567	4,229,562	–	3.8	150
Total floodplain[d]	8,801,106	166,300,669	86.2	–	6989	91,389	–	335,095	7,029,072	–	29.7	761
Total to pond[d]	10,210,710	220,013,886	–	–	10,698	405,001	–	414,662	11,258,634	–	33.5	911

Notes:
[a] Annual cumulative volumes are for this reporting period: April 1, 2019, through March 31, 2020. 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] Trench 2 (1109) could not be sampled in September 2019 because the pump was damaged. COC concentrations from the last reporting period were used to estimate masses.
Abbreviations: – = Not applicable or not sampled; BLW = Bob Lee Wash; lb = pounds; MDW = Many Devils Wash (the MDW interceptor drain has not operated since 2014)

From April 2019 through March 2020, about 10.2 million gallons of extracted groundwater were pumped to the evaporation pond, slightly more than the volume extracted during the previous reporting period (8.44 million gallons in 2018–2019). The bulk of this total volume (8.8 million gallons, or 86.2%) of the influent liquids entering the pond during the current reporting period was from the floodplain trenches. Pumping of Bob Lee Wash (1.2 million gallons, 11.5% of total volume) accounted for most of the remaining extraction volume.[2] As shown in Figure 7, at the end of the 2019–2020 reporting period, about 53.7 million gallons have been extracted from the terrace, and 166.3 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 220 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.

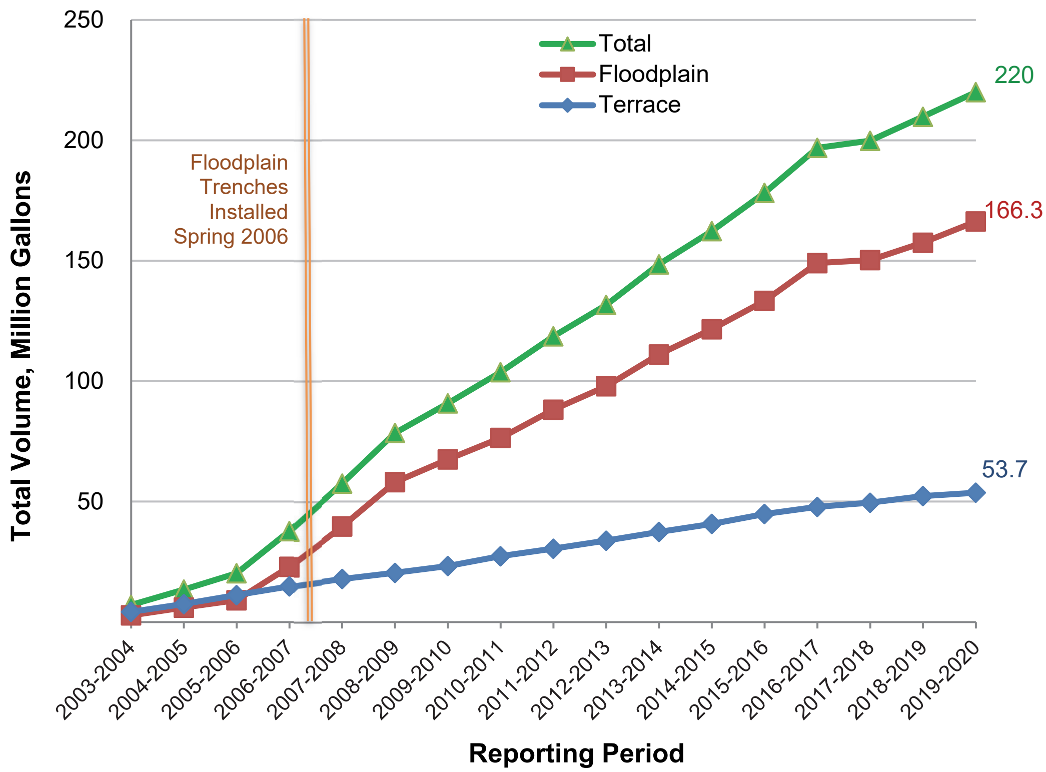


Figure 7. Total Groundwater Volume Pumped to the Evaporation Pond

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 2019–2020 performance period were approximately 10,698 pounds nitrate (as N); 414,662 pounds sulfate; and 33.5 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 extended period, corresponding cumulative extraction volumes 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 2019 through March 2020 reporting period. Due to the COVID-19 pandemic and pursuant to general directives in Navajo Nation Public Health Emergency Order No. 2020-007, sampling did not take place in March 2020. During the September 2019 sampling event, 113 monitoring wells were sampled (59 on the floodplain and 54 on the terrace). Twelve surface water locations, including nine San Juan River sampling points and various seeps, were also sampled.

3.1 Floodplain Contaminant Distributions and Temporal Trends

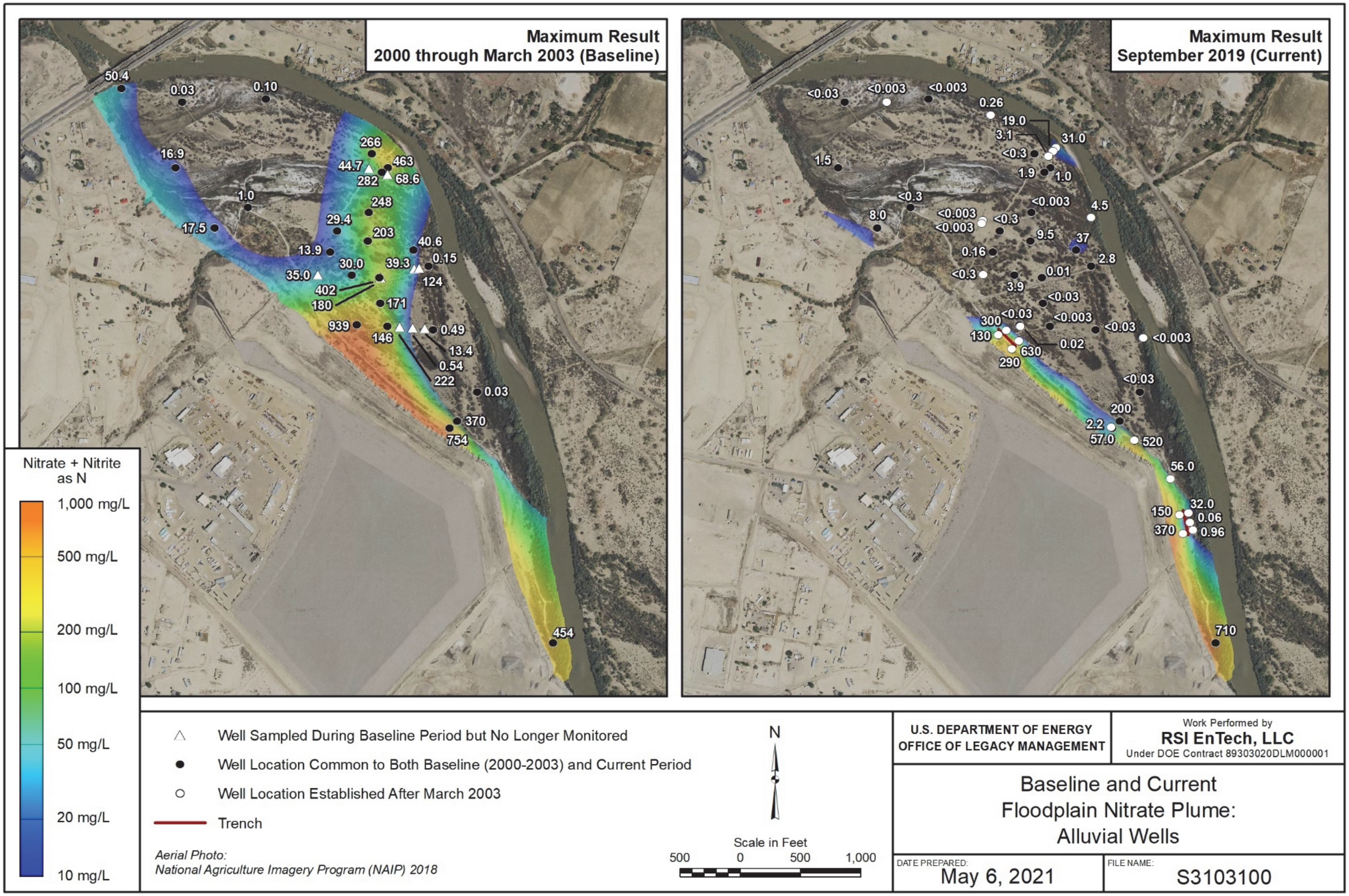
This discussion and the supporting figures presented in this section focus on nitrate, sulfate, and uranium because these contaminants are most widespread on the floodplain and are used to gauge the effectiveness of the remediation system at the Shiprock site. For these COCs, the alluvial plume maps (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. 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). Appendix B documents the corresponding Mann-Kendall trend analysis results.

3.1.1 Current Conditions and Global Trends

Figure 8 through Figure 10 illustrate the marked reductions in contaminant concentrations in floodplain groundwater since the baseline (2000–2003) period. This reduction is most evident for nitrate (Figure 8). The extent of the current nitrate plume, defined by regions exceeding the 10 mg/L MCL, is much smaller than that shown for baseline conditions. Elevated concentrations are currently generally limited to the base of the escarpment. Two exceptions (19–31 mg/L) in the extraction well region near the river exceed the 10 mg/L standard. 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 (Figure 9). Sulfate concentrations in most regions of the floodplain alluvium are at or lower than 4000–5000 mg/L, a range consistent with levels measured in background well 0797. In September 2019, higher concentrations (7300–20,000 mg/L) were measured in Trench 1 area wells, Trench 2 well 1128 (8000 mg/L), southernmost well 0735 (15,000 mg/L), central well 0779 (8900 mg/L), and near-river wells 1136 and 1137 (11,000 mg/L and 9200 mg/L, respectively).

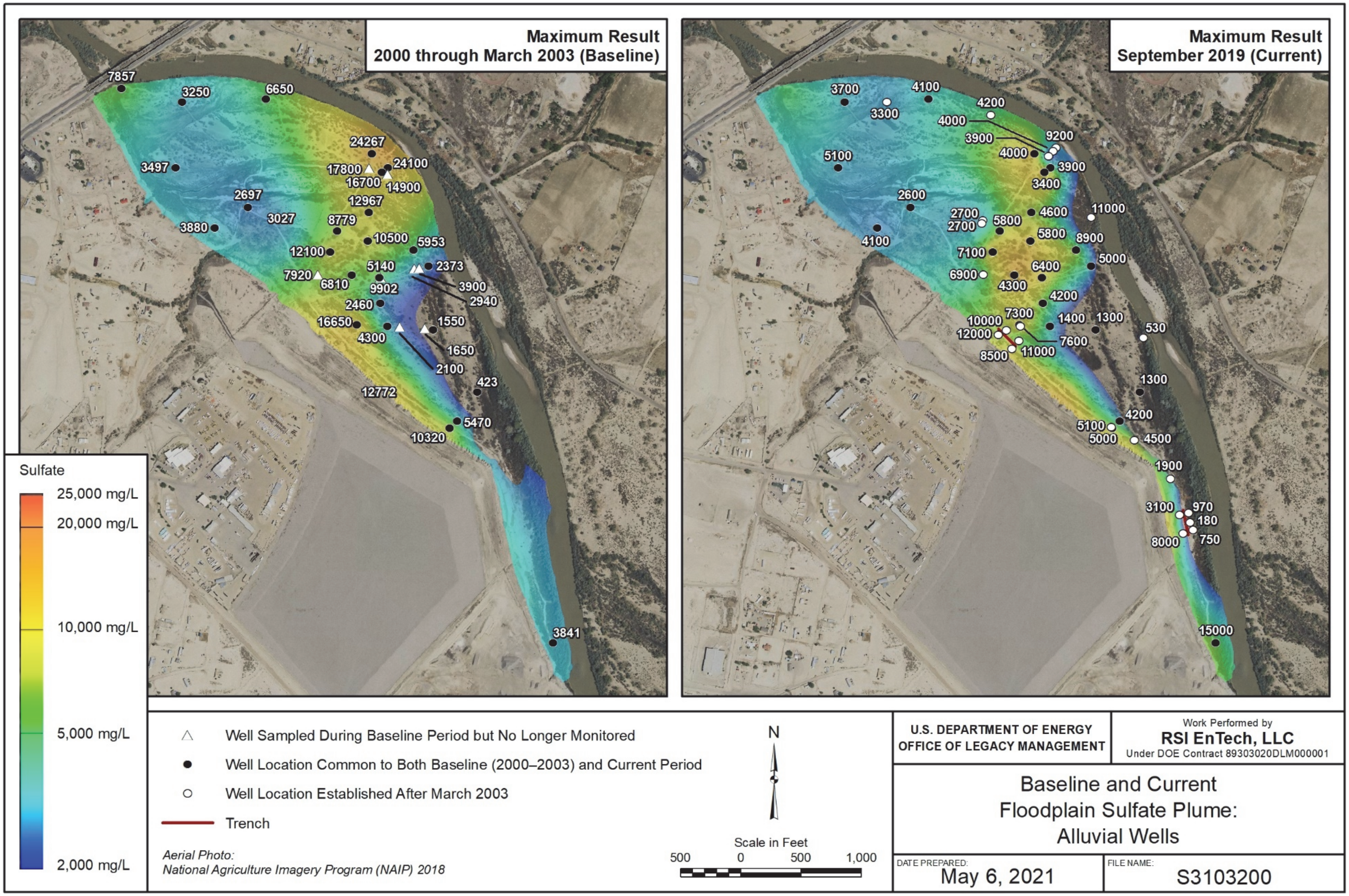
Interpretations of changes in the uranium plume configuration (Figure 10) are generally consistent with the conclusions drawn in previous annual reports (e.g., DOE 2020a). Although uranium concentrations have declined relative to baseline conditions (Appendix A), in most floodplain wells, levels still exceed the 0.044 mg/L MCL.

[3] The plume maps in Figures 8 through 10 were developed using Environmental Visualization System software version 2019.2.0 (kriging estimation; simple anisotropy mode; spherical model; finite difference grid type).



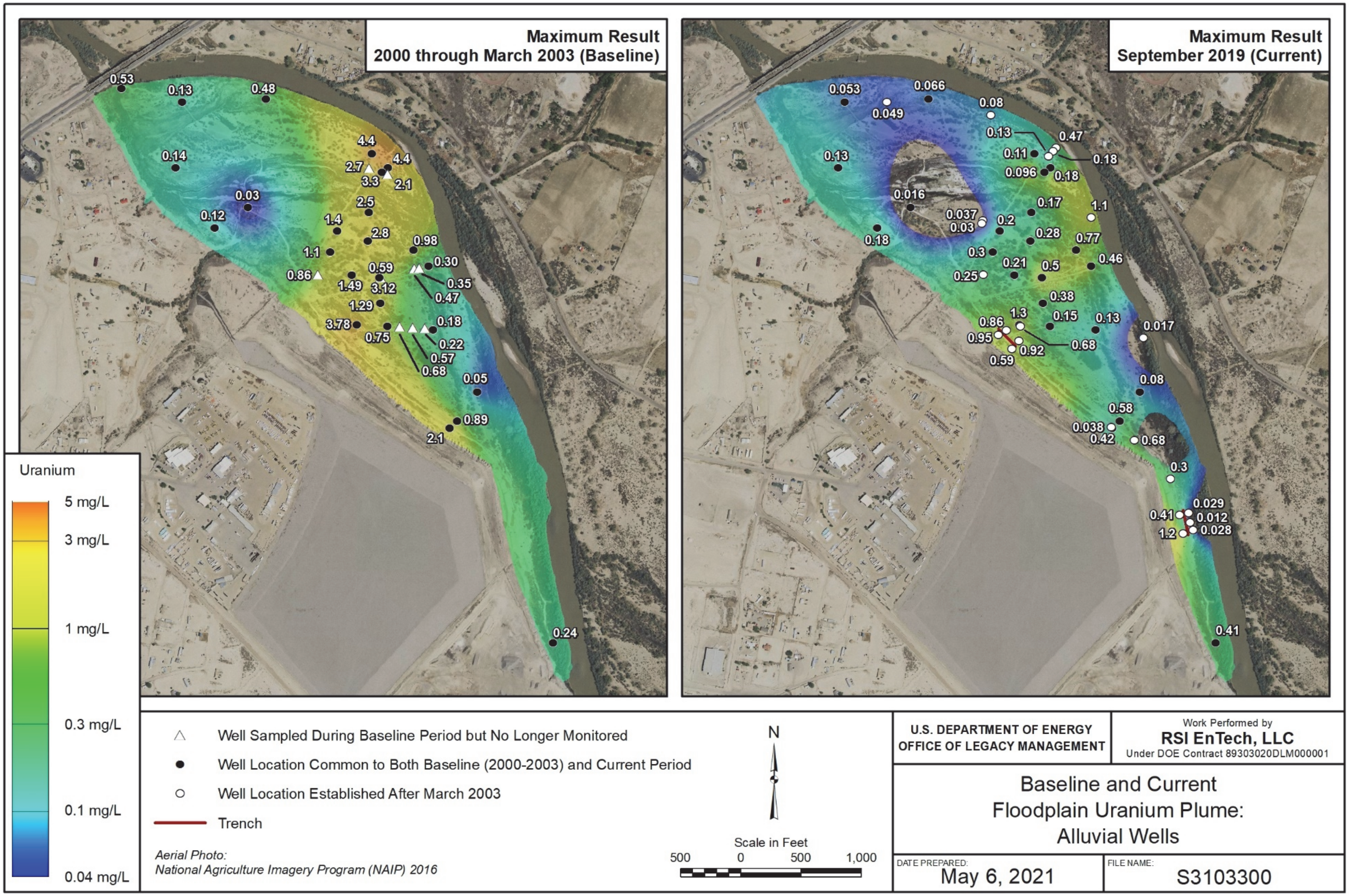
Note: Hollow or uncontoured portions of both plume maps denote regions with nitrate concentrations below the 10 mg/L MCL. Only results are labeled due to the density of floodplain monitoring locations; Figure 11 provides a cross-reference to the specific well identifiers.

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



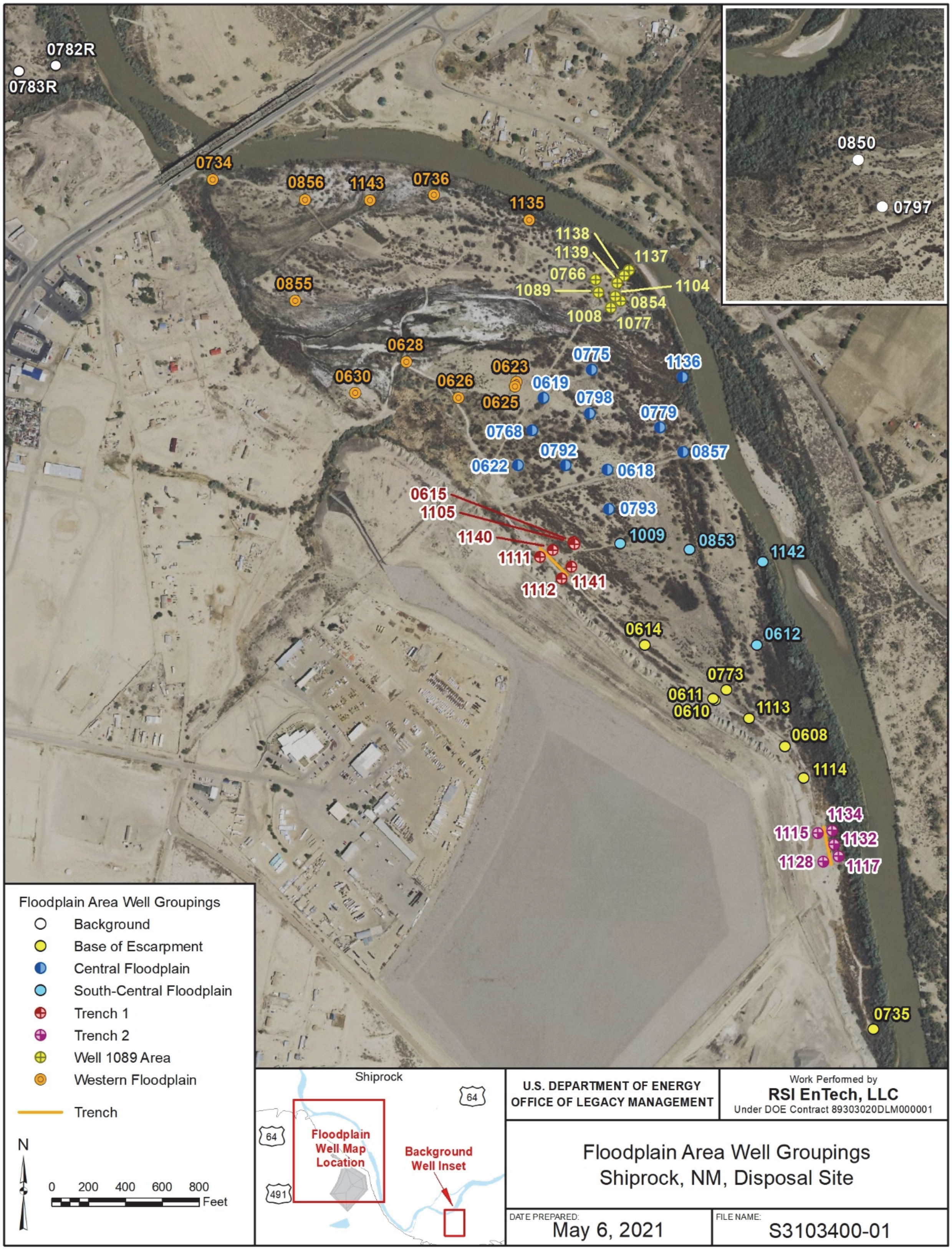
Note: Hollow or uncontoured portions of both plume maps denote regions with sulfate concentrations below the 2000 mg/L remediation goal. Only results are labeled due to the density of floodplain monitoring locations; Figure 11 provides a cross-reference to the specific well identifiers.

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



Note: Hollow or uncontoured portions of both plume maps denote regions with uranium concentrations below the 0.044 mg/L standard. Only results are labeled due to the density of floodplain monitoring locations; Figure 11 provides a cross-reference to the specific well identifiers.

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



Note: Based on LM's ongoing reevaluation of the site conceptual model, wells 0782R and 0783R are candidate background locations for floodplain wells geochemically influenced by the San Juan River. Although not identified as such in the GCAP (wells 0797 and 0850 have been historically used as background wells [DOE 2002]), these wells are categorized as background locations here.

Figure 11. Shiprock Site Floodplain Area Well Groupings

As a supplement to the detailed plots in Appendix A, Figure 12 plots uranium concentrations in 52 alluvial wells on the contiguous floodplain between 2010 and September 2019 (the last sampling event). Figure 13 plots the same data, but with a common semilog (versus unique 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.

It is not possible to quantitatively evaluate potential impacts of the periodic pumping suspensions because there is insufficient data to do so. While pumping was halted at the extraction wells (1089 and 1104) during this period, it resumed at the trenches in mid-July 2018. Other variables such as groundwater elevations and changing river flows (e.g., the early June 2019 flood) 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.

As shown in Figure 12 and Figure 13, uranium concentrations measured in the last several years are generally similar to previous (pre-pumping-suspension) results in the majority of floodplain wells. To facilitate review, the plot order in these figures is based 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. Although slight increases in uranium concentrations in a few Trench 1 and 2 wells are apparent in the last several years, levels are within the historical range. Despite the sustained pumping suspension in the region of the extraction wells, uranium levels in this region remain low relative to baseline conditions. Elevated levels of uranium (along with sulfate) measured in near-river wells 1137, 1138, and 1139 circa 2012–2015 have since declined. Since the last reporting period, uranium levels increased markedly in two wells: central floodplain well 0622 and western floodplain well 0855. Mann-Kendall trend analysis of data collected between 2006 and September 2019 (Appendix B) indicates significant increasing trends for the following well/COC combinations:[4]

- Well 0630 (mouth of Bob Lee Wash): sulfate and uranium
- Southernmost base of escarpment well 0735: nitrate and sulfate
- Near-river central floodplain well 0857: sulfate and uranium
- Near-river well 1136: nitrate, sulfate, and uranium (and remaining COCs)
- Hyporheic well 0853: sulfate
- Western floodplain well 0855: nitrate
- Trench 2 well 1132: sulfate

Levels of nitrate, sulfate, and uranium in most remaining wells have significantly decreased as documented in Appendix B.

[4] A start date of 2006 was used because it coincides with the initiation of pumping at the two trenches.

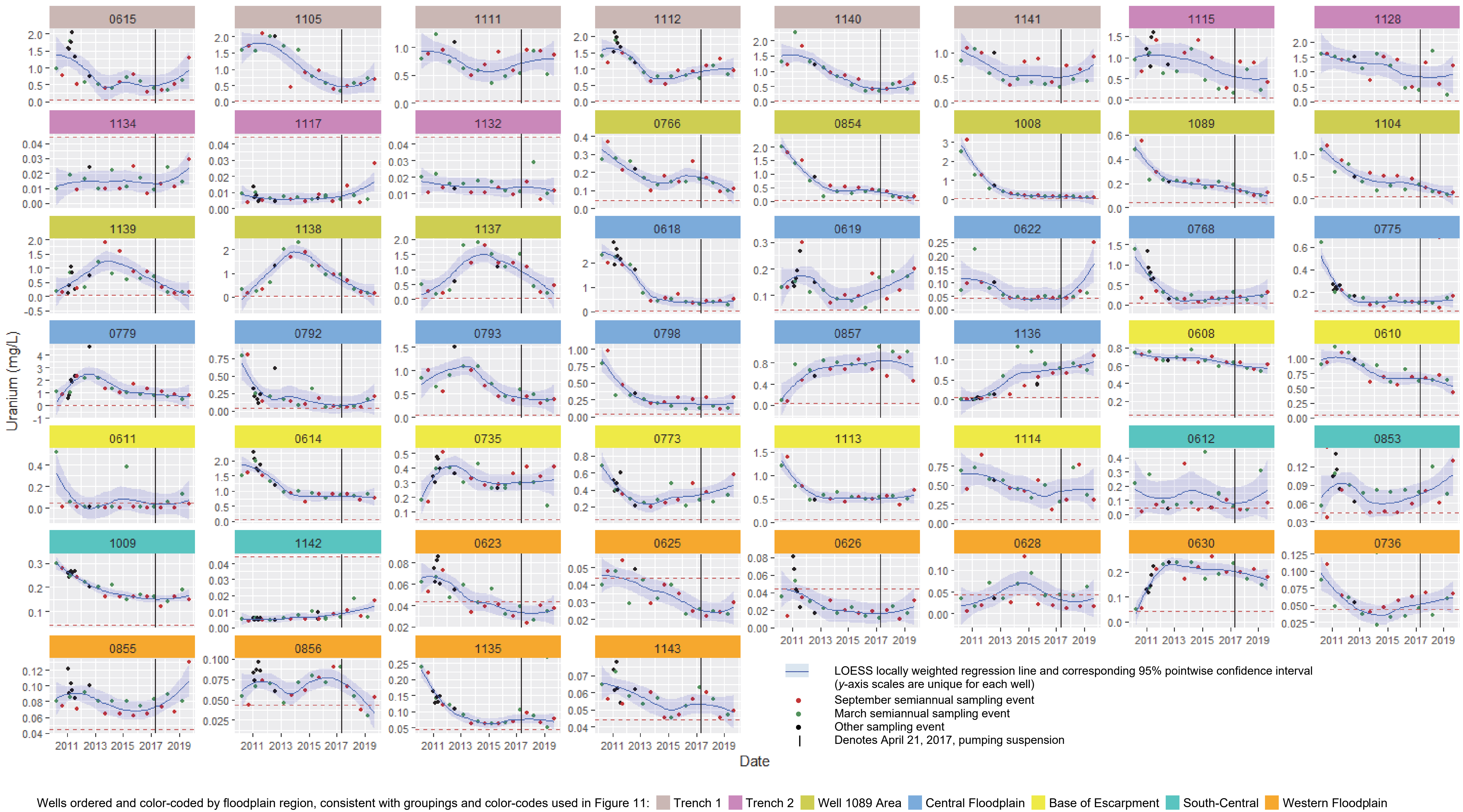


Figure 12. Uranium Time–Concentration Trends in Shiprock Site Floodplain Wells, 2010–2020: Linear Scale

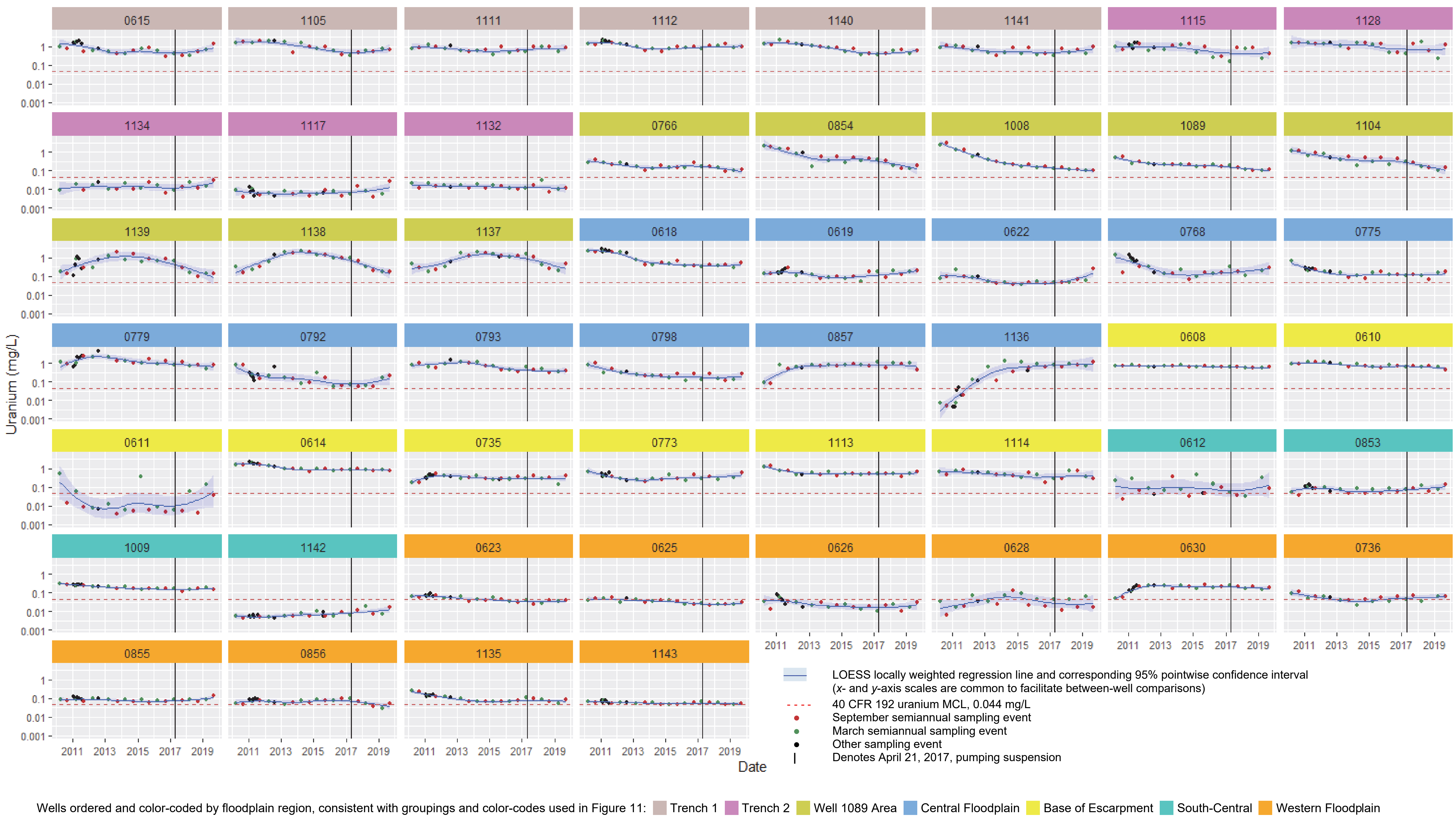


Figure 13. Uranium Time–Concentration Trends in Shiprock Site Floodplain Wells, 2010–2019: Semilog Scale

3.1.2 Analyte-Specific Trends

The remaining discussion evaluates contaminant trends in floodplain alluvial wells since baseline (2000–2003) based on the time–concentration plots in Appendix A. 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. Mann-Kendall trend analysis indicates significant decreasing concentrations for all primary COCs in about 60% of floodplain wells. 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 significantly in the last decade. Although these increasing trends appear to have stabilized, COC concentrations are higher than those measured initially.

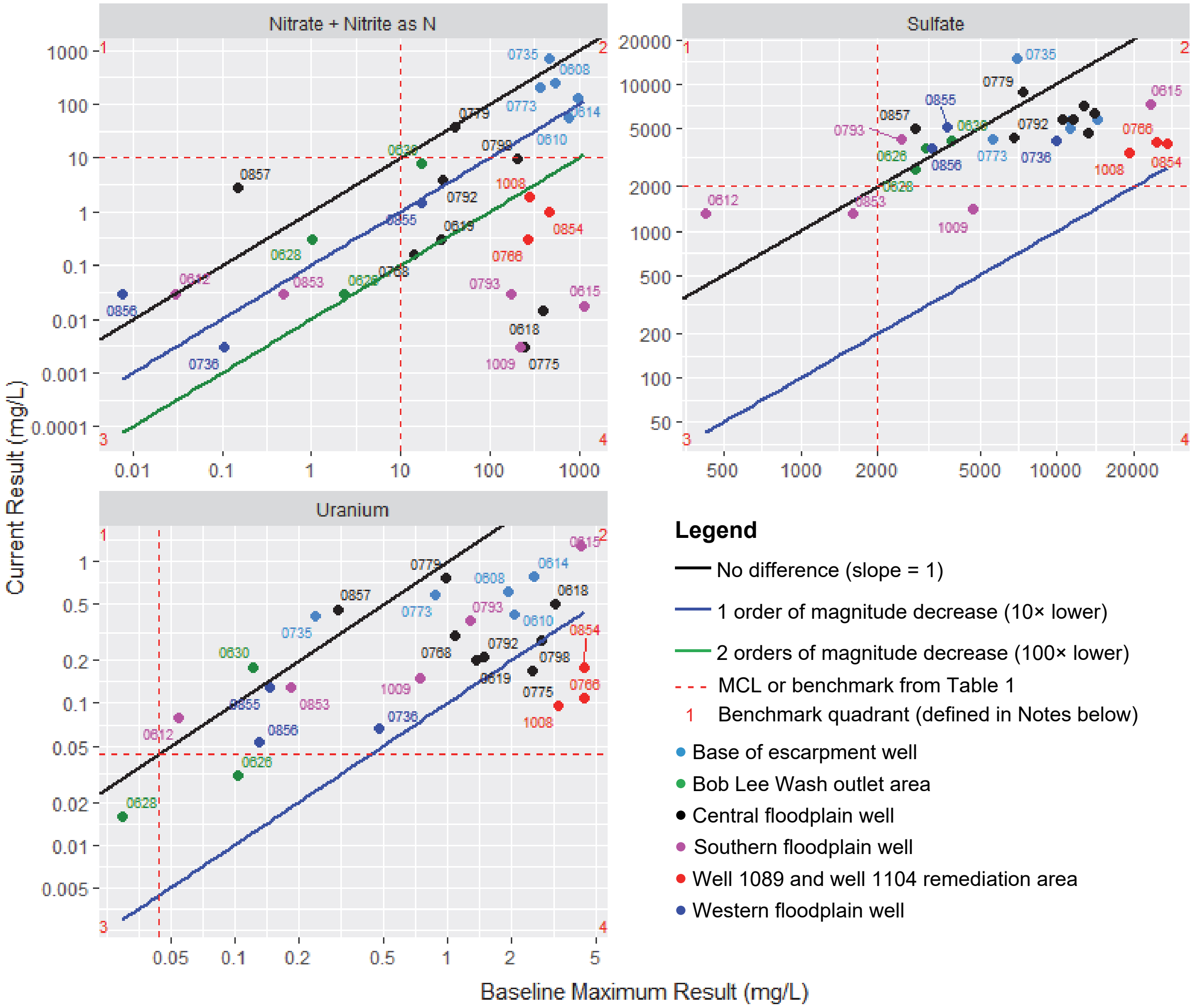
Figure 14 summarizes the progress of active remediation by comparing baseline (2000–2003) COC concentrations in floodplain monitoring wells to those measured in September 2019. For each contaminant, the diagonal black line represents 1:1 concentration ratios indicating no change between the respective 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 decrease of 2 orders of magnitude. The dashed red lines (horizontal and vertical) denote the corresponding benchmarks from Table 1.

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. For those wells with a longer monitoring history, nitrate concentrations have declined by more than 2 orders of magnitude since the baseline period (Figure 14).

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). Sulfate concentrations in central floodplain near-river wells 0857 and 1136 have more than doubled since 2010, and increasing trends are still apparent as noted previously. 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 4100 mg/L since then.



Notes: This figure only includes data for nonbackground wells sampled during both baseline (2000–2003) and current (2019–2020) 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.
There was only one sampling event this reporting period, so the current result is the September 2019 measurement.
Nondetect results for nitrate are assigned the detection limit value (0.003–0.03 mg/L).
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

3.1.2.3 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, the time–concentration plots in Appendix A, and the Mann-Kendall trend analyses documented in Appendix B. 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, despite the suspension of pumping in this region (Figure 14). Despite these reductions, uranium concentrations in most floodplain wells still exceed the 0.044 mg/L MCL (Figure 10).

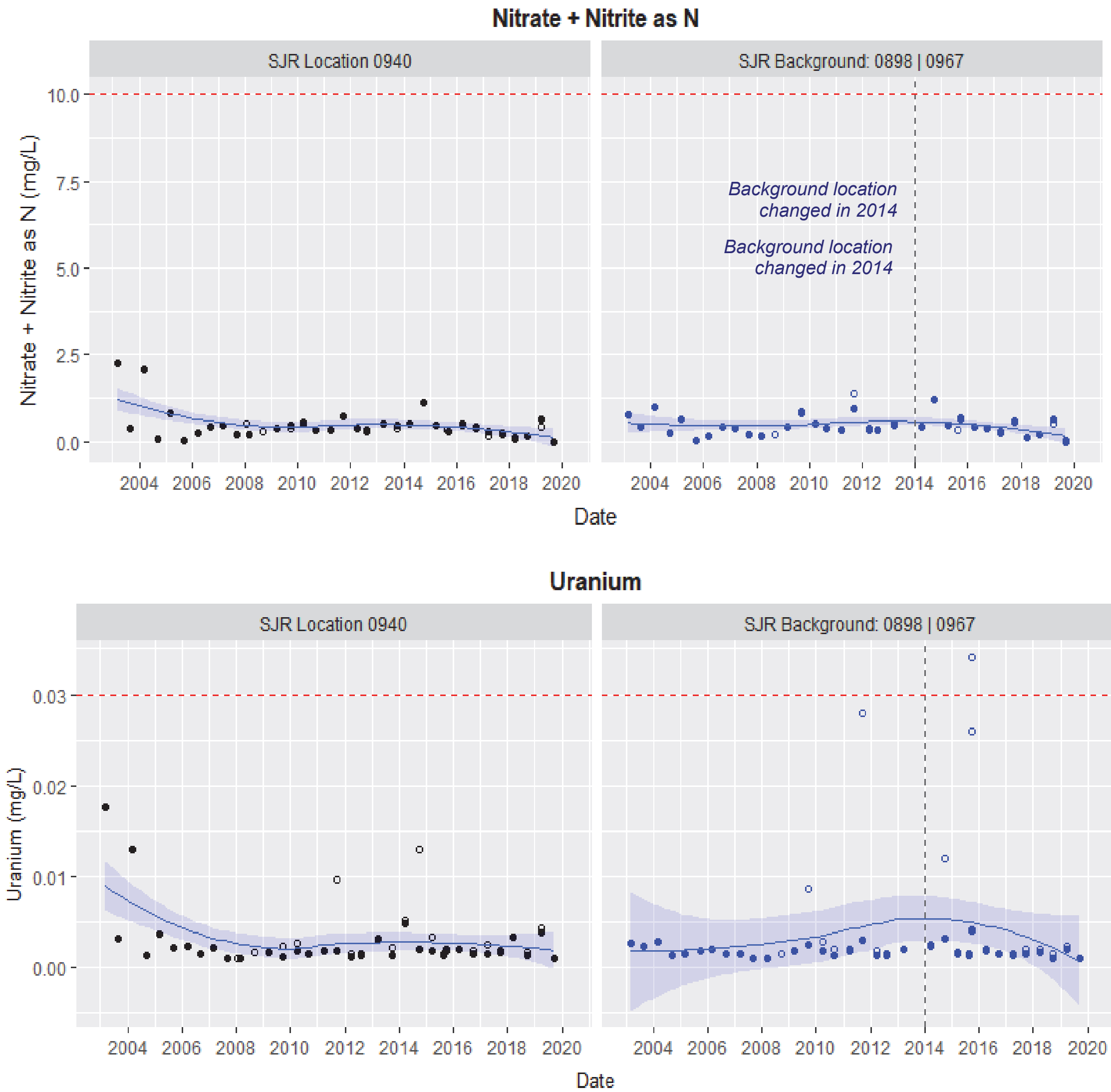
3.1.2.4 Other COCs

Ammonia, manganese, selenium, and strontium are no longer discussed in detail in annual reports because these constituents are not as prevalent or as elevated at the site as the primary COCs (uranium, nitrate, and sulfate). As indicated in Section 1.3, LM is currently reevaluating whether these analytes still warrant designation as COCs and, if so, to what degree or monitoring extent. A comprehensive analysis of their distributions in both floodplain and terrace alluvial groundwater relative to background conditions is being developed concurrent with this annual report.

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[5]
• 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

[5] 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 2020 (or in some cases through September 2019 where data was limited). 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.

Nonmill-related sources to terrace groundwater appear to have influenced water quality, levels, and flow (DOE 2019). 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 and Construction Authority (NECA) yard. Groundwater mounding in the residential area near well 0835 and within the NECA 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 indicate that groundwater is locally mixed with either Animas River or San Juan River water (DOE 2019). 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 may 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 2019–2020 reporting period, only about 237,000 gallons of groundwater were pumped from the nine terrace extraction wells between April 2019 and March 2020 (Table 3). This volume is about 2.5 times greater than the volume pumped (93,650 gallons) during the preceding (2018–2019) inactive pumping period (Table 3) and corresponds to approximately 15% of the volume pumped during prior active sustained pumping periods. As of April 1, 2020, the cumulative volume of water removed from the terrace (excluding Bob Lee Wash and Many Devils Wash) was approximately 22.4 million gallons (Table 4). Groundwater-level data from the terrace collected during the September 2019 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). March 2020 water levels were not collected due to COVID-19-related access restrictions and closures on the Navajo Nation. Figure 16 shows a quantitative map view of some of the changes in groundwater elevations during this period for terrace monitoring wells. Of the 27 water-level measurements (excluding the one damaged and seven dry wells) taken in September 2019 at terrace wells, the majority showed declines relative to the (2000–2003) baseline period. The maximum decrease (4.3 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 1.6 ft.

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 (refer to hydrographs in Appendix C). Figure 17 through Figure 19 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.

Figure 18 plots groundwater elevations in terrace wells, showing automated contours for both baseline (March 2003) and current (September 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 31% in the vicinity of the south terrace extraction wells. The volumetric reduction approximated with this method (approximately 19.5 million gallons) is about 87% of the total cumulative volume (22.2 million gallons) extracted from the terrace swale alluvium pumping wells (from Table 4).

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	25,252,164	30	7,575,649	56,669,788	–
September 2019 current depiction	17,458,106	30	5,237,432	39,178,708	31

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 31% reduction cited above is slightly less than estimated in the previous annual report (34%) using the same methods. To ensure consistency in the future, a calculation package was prepared that documents the development of the surfaces, method of analysis, observations used in the interpolation, and assumptions.

Abbreviation:
ft^3 = cubic feet

Only the terrace alluvium was considered in developing Figure 19, and only the terrace remediation vicinity (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.

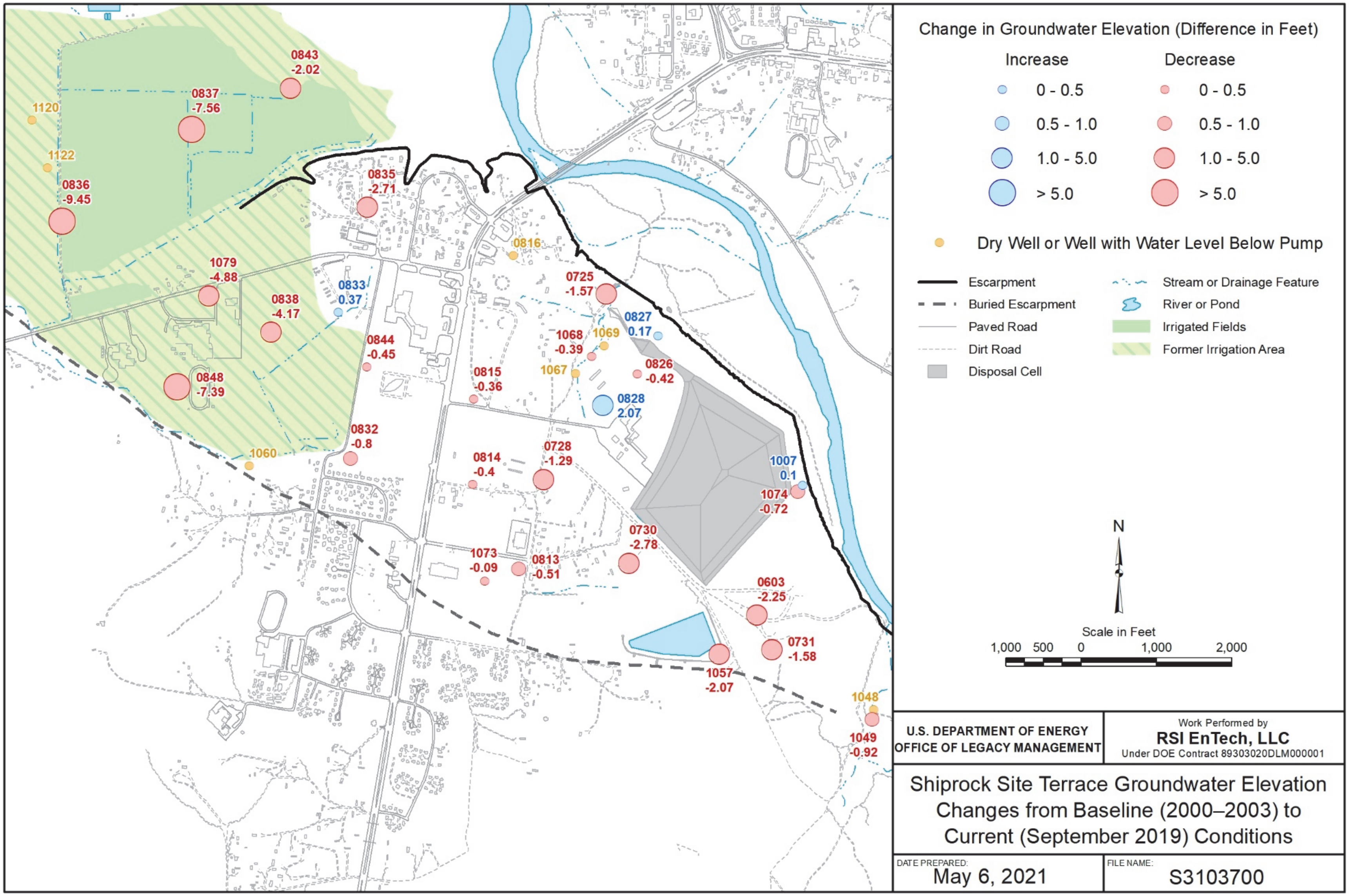
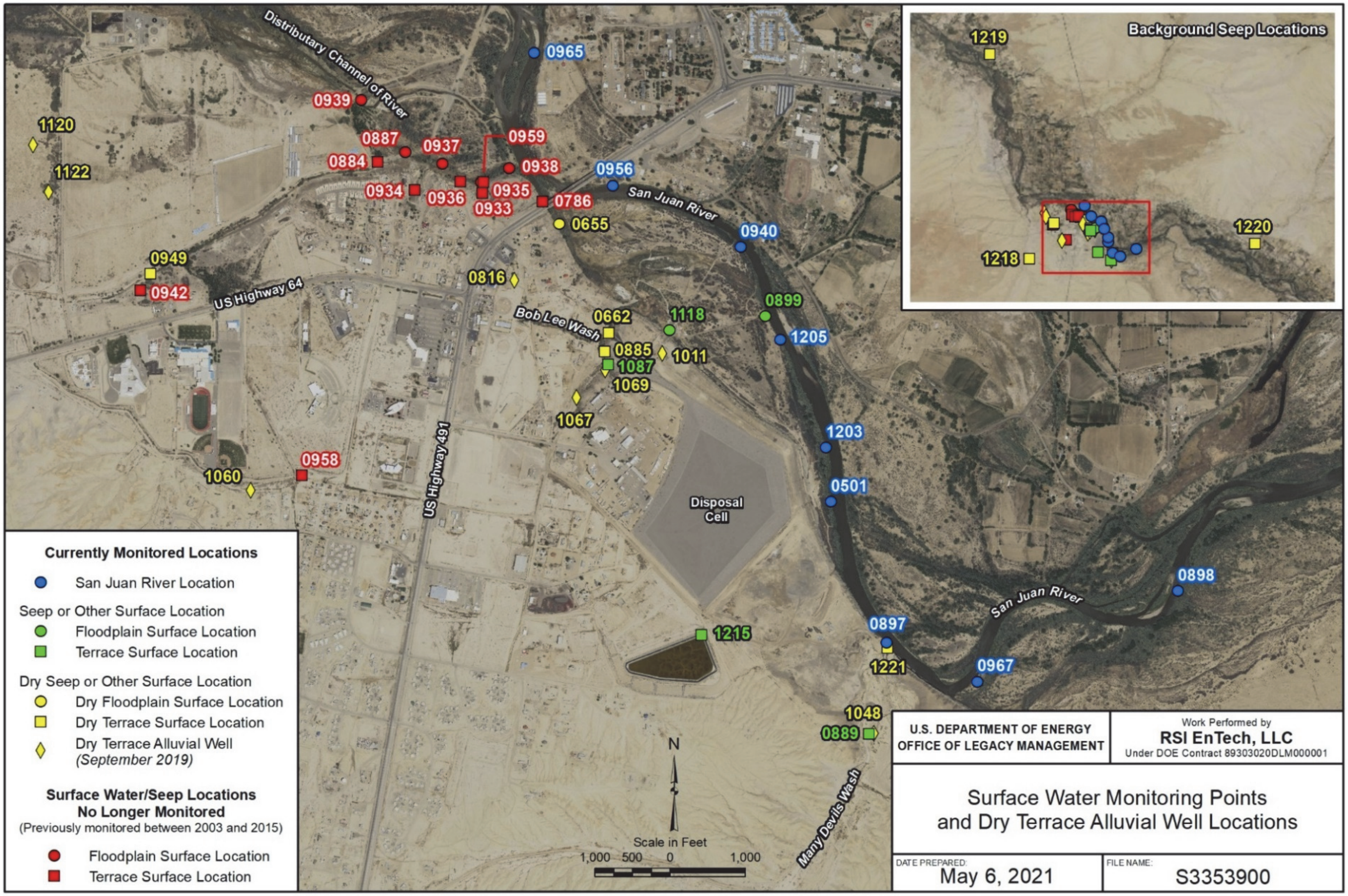


Figure 16. Shiprock Site Terrace Groundwater Elevation Changes: Baseline (2000–2003) Versus Current (September 2019) Conditions



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)

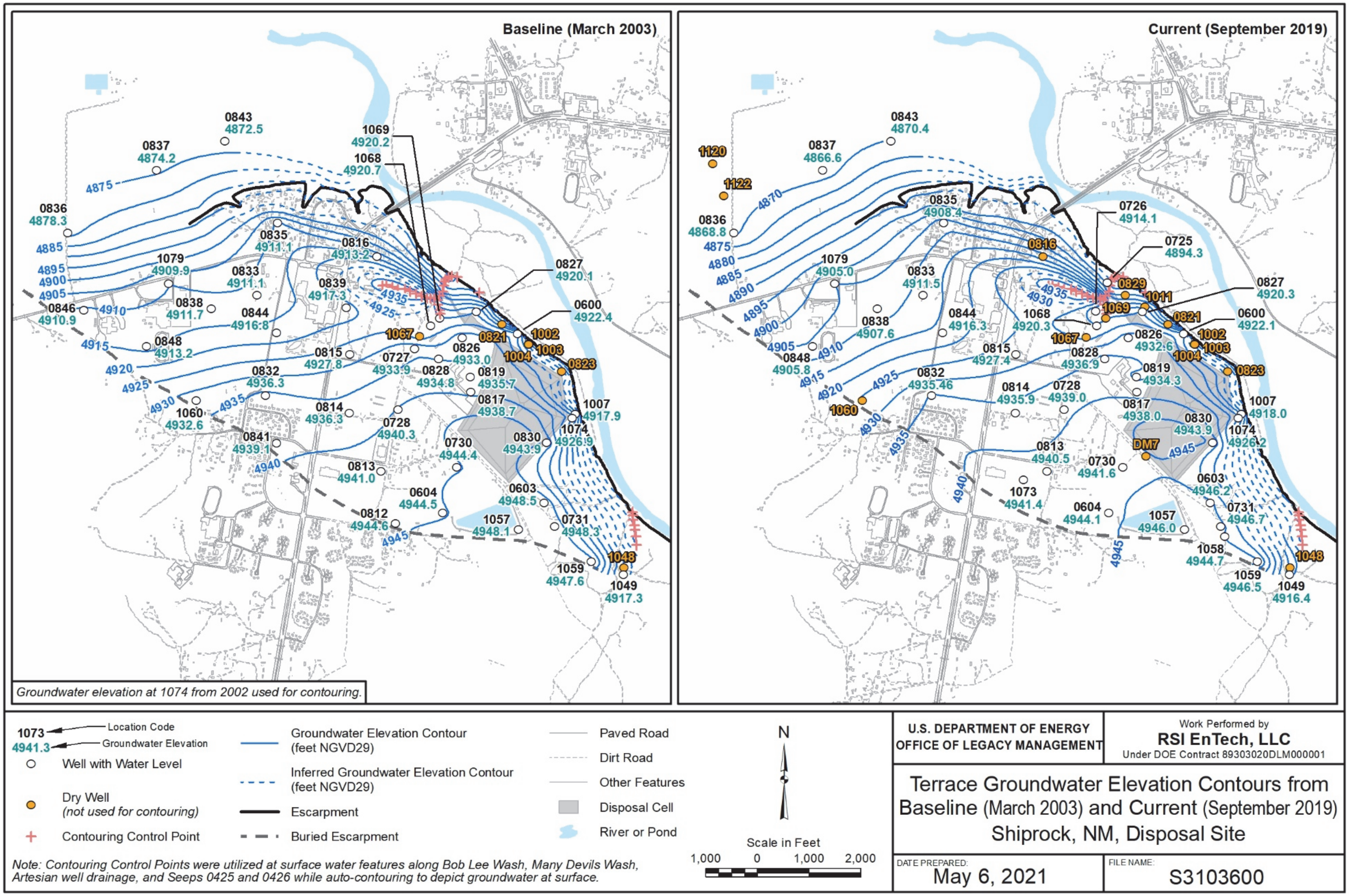
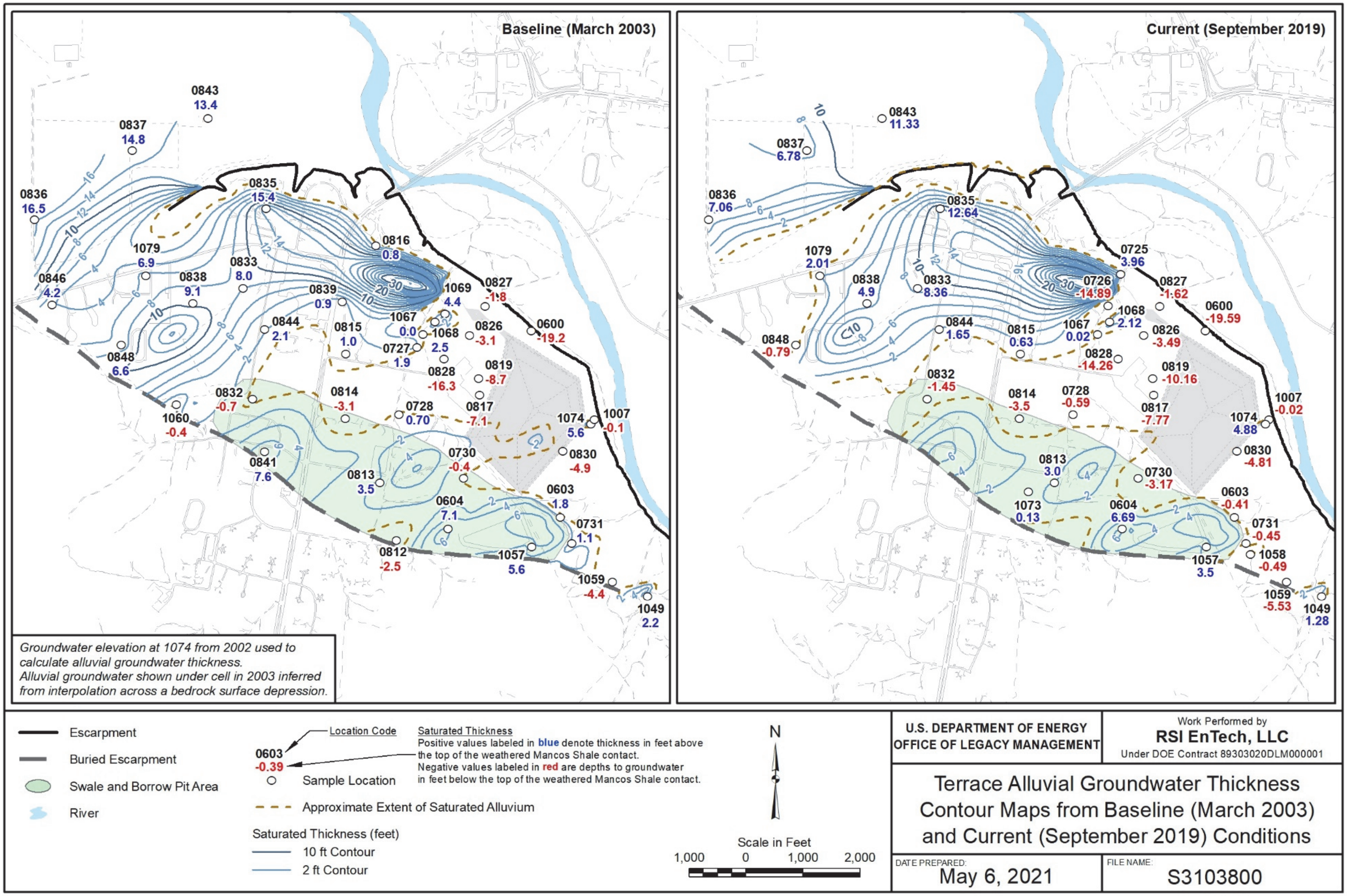


Figure 18. Terrace Water Elevation Contours: March 2003 (Baseline) and Current (September 2019)



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

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

4.0 Performance Summary

This section summarizes the findings of the most recent (April 2019 through March 2020) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the 17th 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. The (now 3-year) suspension continued into this reporting period for all treatment system locations except Bob Lee Wash and the floodplain trenches. A few additional terrace wells were pumped intermittently (e.g., associated with sampling events), with only relatively small volumes extracted. Pumping of Bob Lee Wash has continued without interruption. Pumping of the floodplain trenches was suspended for an approximate 3-month period because of damage caused by the mid-June San Juan River flood.

From April 2019 through March 2020, about 10.2 million gallons of extracted groundwater were pumped to the evaporation pond, slightly greater than the volume extracted during the previous reporting period (8.4 million gallons in 2018–2019). The bulk of this total volume (8.8 million gallons, or 86.2%) of the influent liquids entering the pond during the current reporting period was from the floodplain trenches. Since DOE began active remediation in March 2003, about 53.7 million gallons have been extracted from the terrace and 166.3 million gallons have been extracted from the floodplain, yielding a total cumulative volume of about 220 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 (rounded) 10,700; 415,000; and 33.5 pounds, respectively.

In general, uranium, sulfate, and nitrate concentrations measured this reporting period were similar to previous (pre-pumping-suspension) results in the majority of floodplain wells. Relative to baseline conditions, significant reductions in all contaminant concentrations are still apparent despite the reduced pumping volumes in the last 3 years. This is most 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. Uranium and nitrate concentrations in samples collected from the San Juan River continue to be below established benchmarks and comparable to upstream (background) locations.

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. Groundwater levels in the majority of terrace alluvial wells remain low relative to those measured during the baseline period (average decrease of 1.6 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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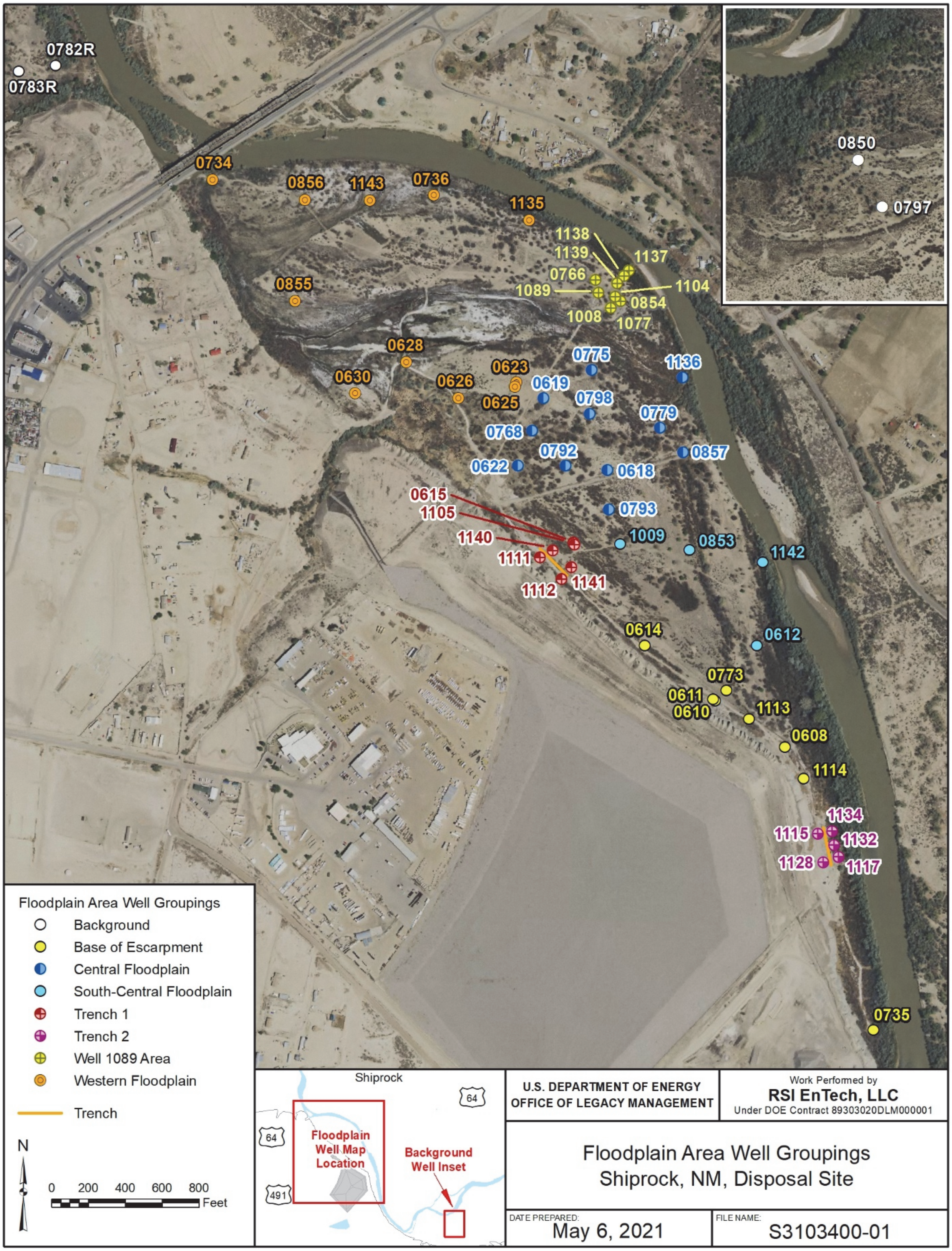

Figure A-1. Shiprock Site Floodplain Well Groupings

(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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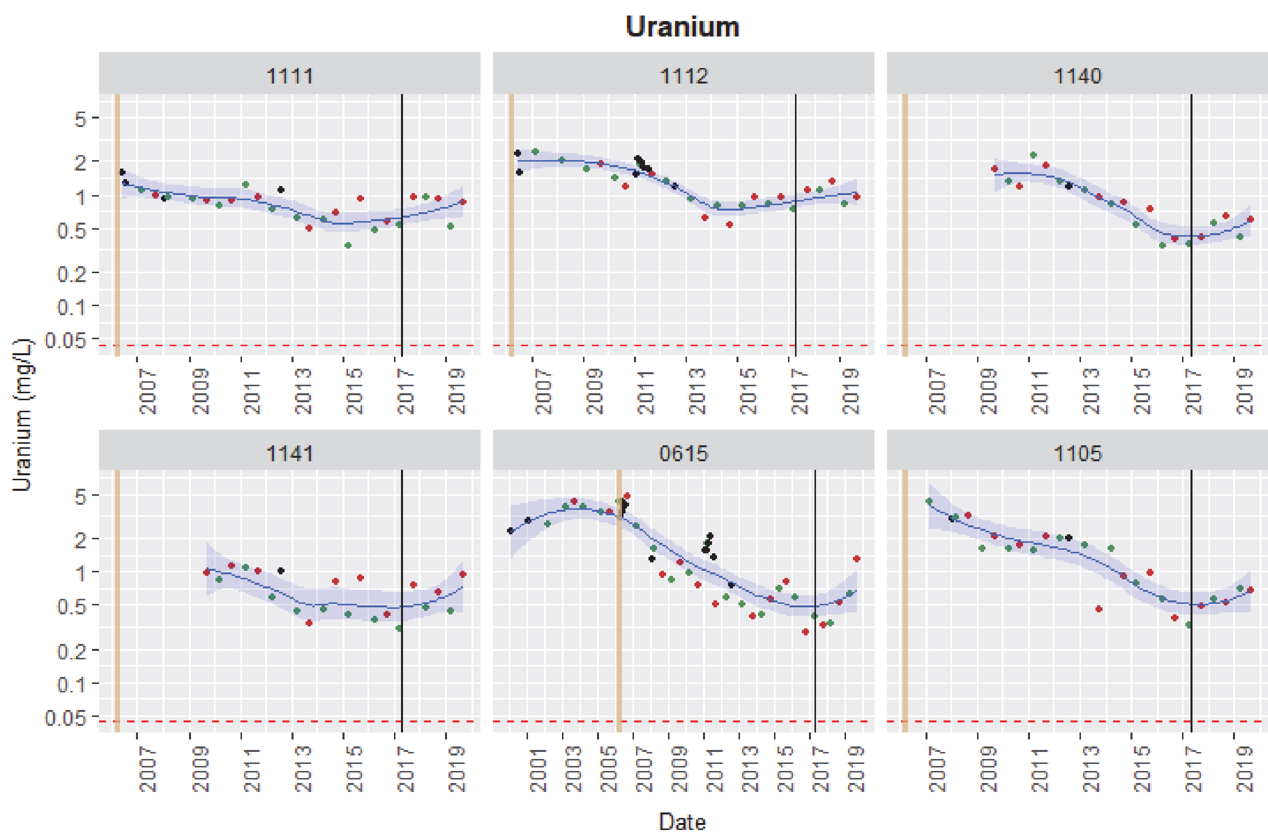
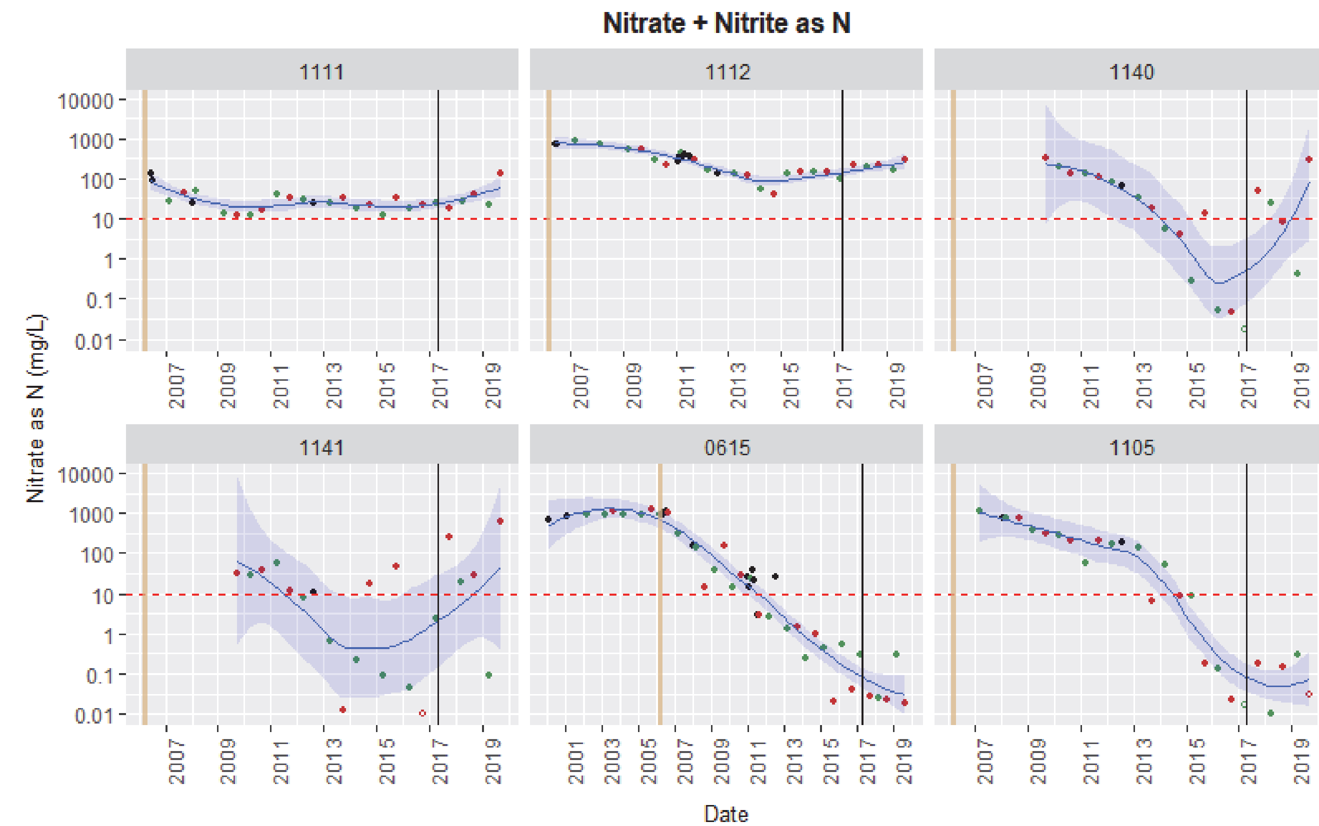
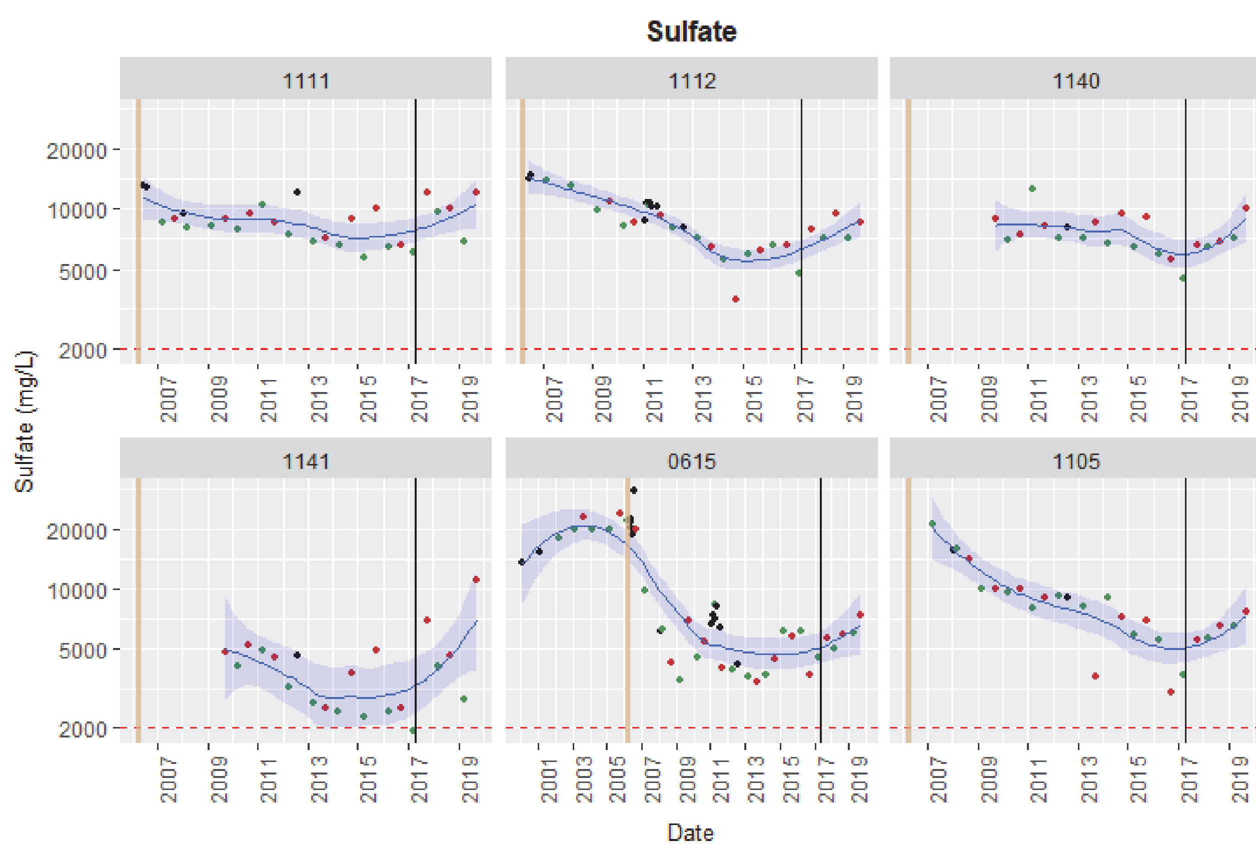






Explanation/Legend

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 only to a few recent nitrate results)

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 most of this reporting period.

Trench 1 Area Wells

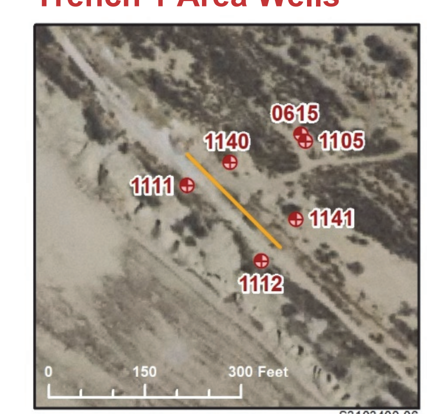
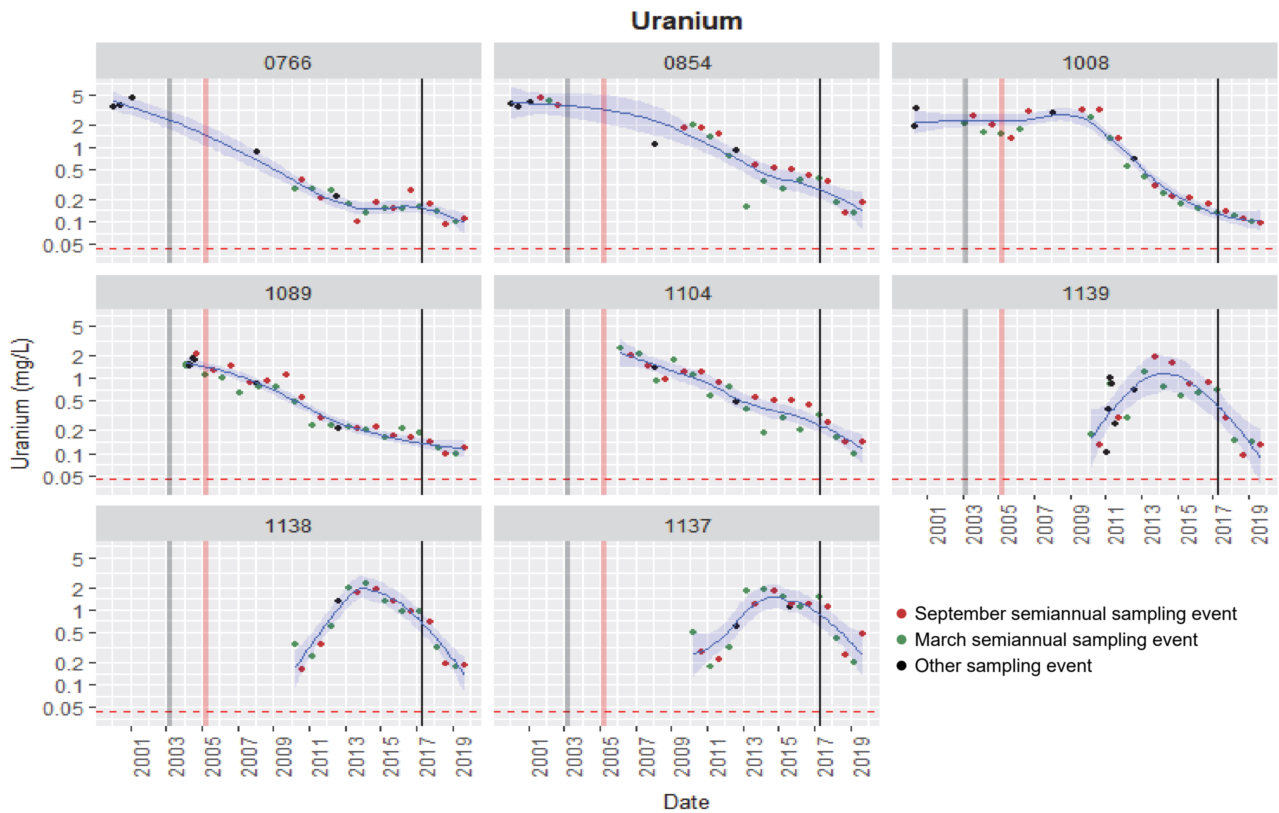
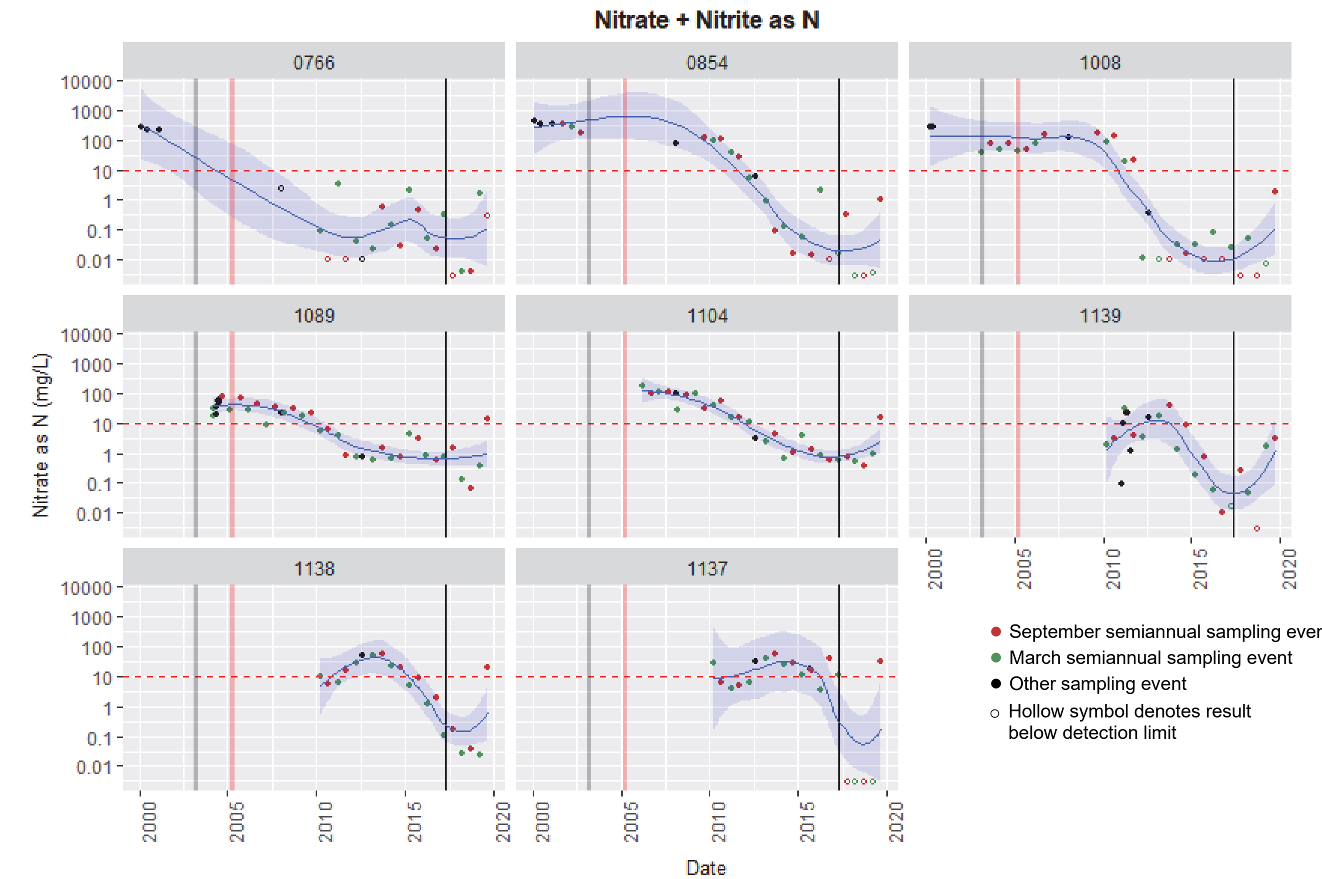
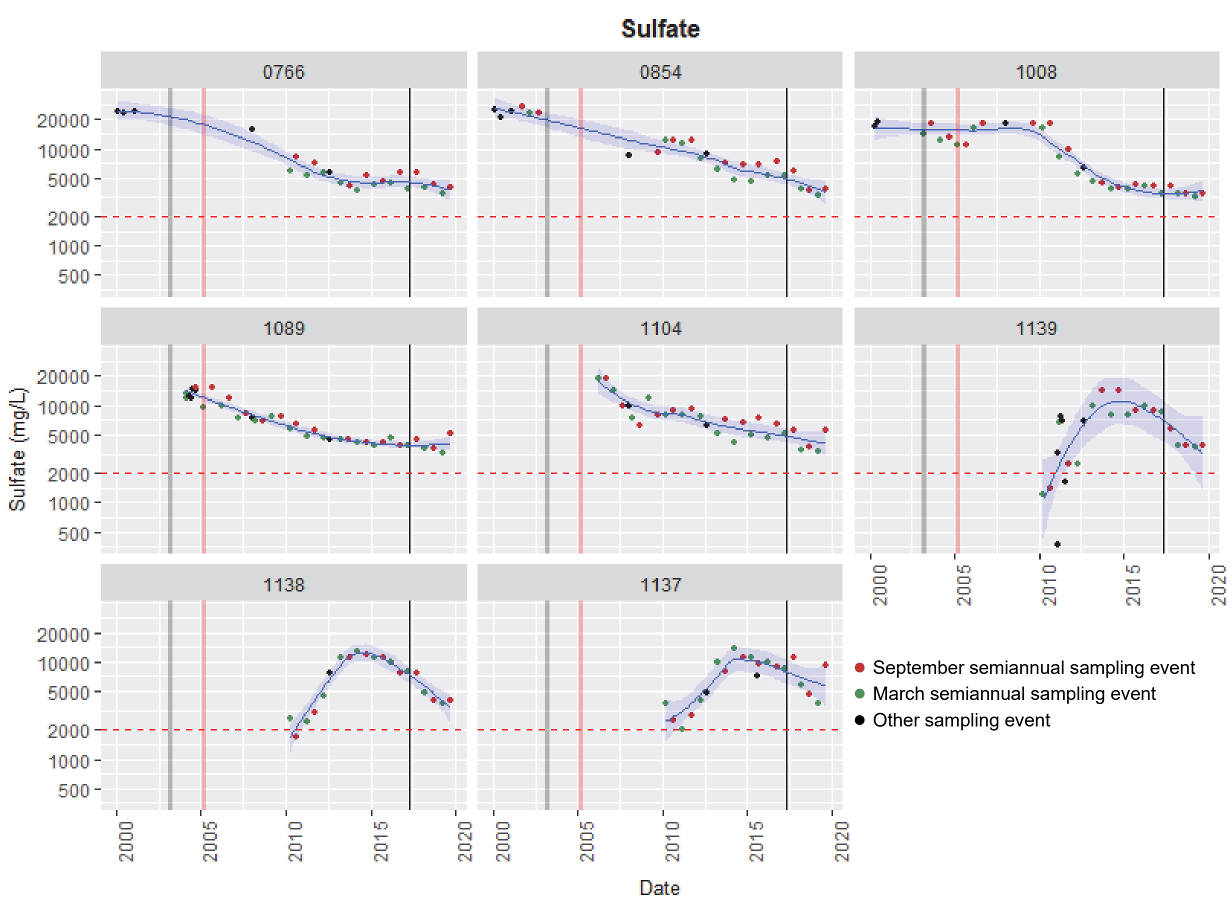


Figure A-2. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 1 Area Wells: 2000–September 2019







Explanation/Legend

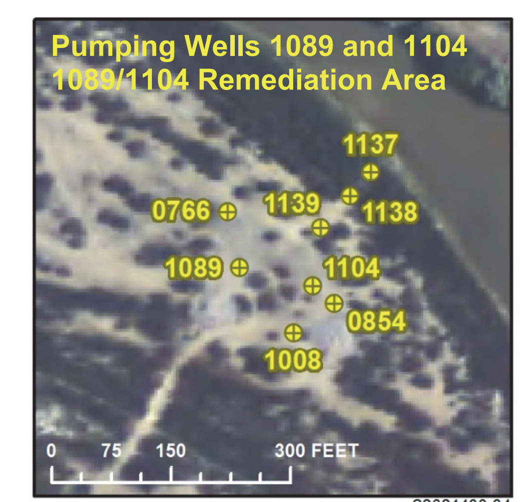
In each plot, near-river wells 1137, 1138, and 1139 are listed in order of increasing distance from the remediation area (see inset).

——— 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

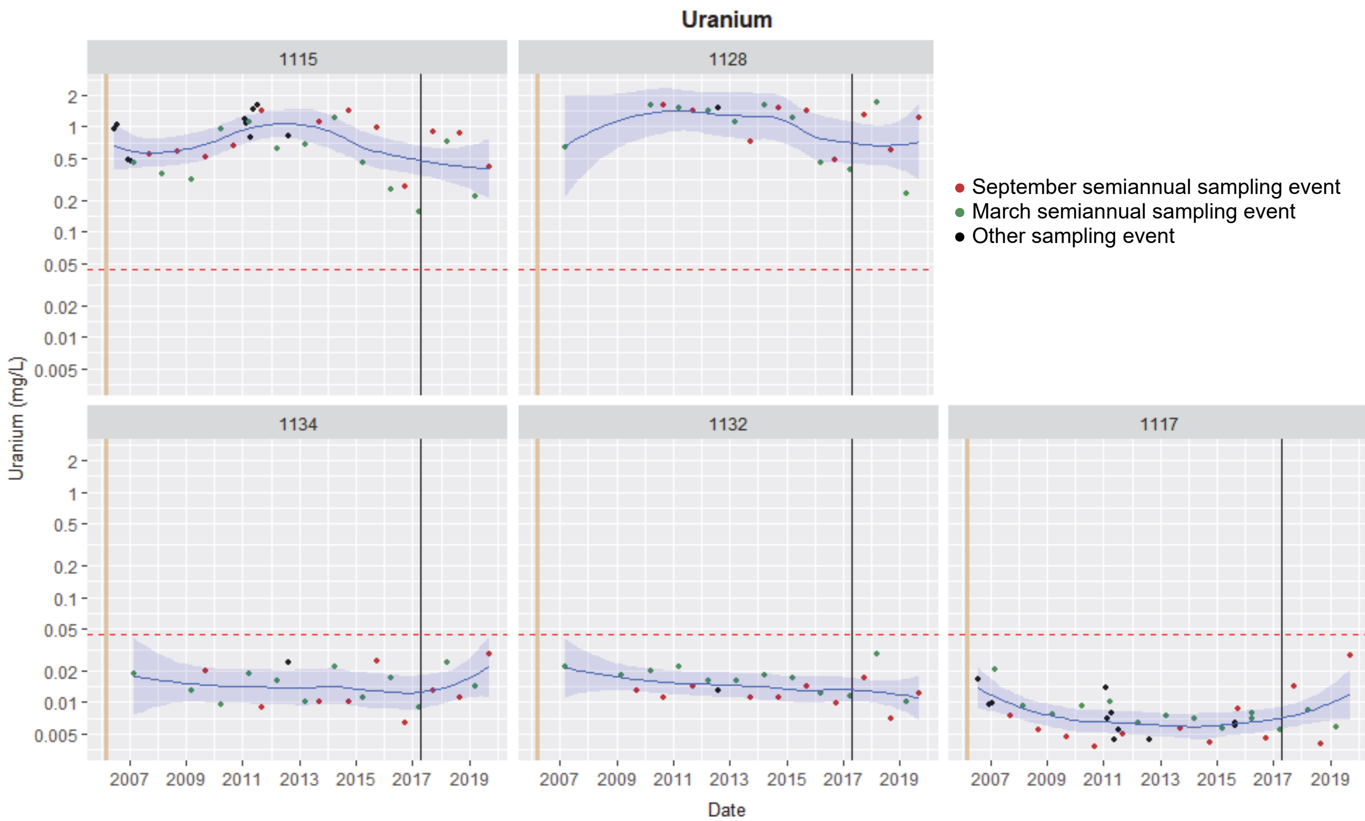
Vertical lines | | denote periods corresponding to installation of well 1089 (spring 2003) and well 1104 (spring 2005).

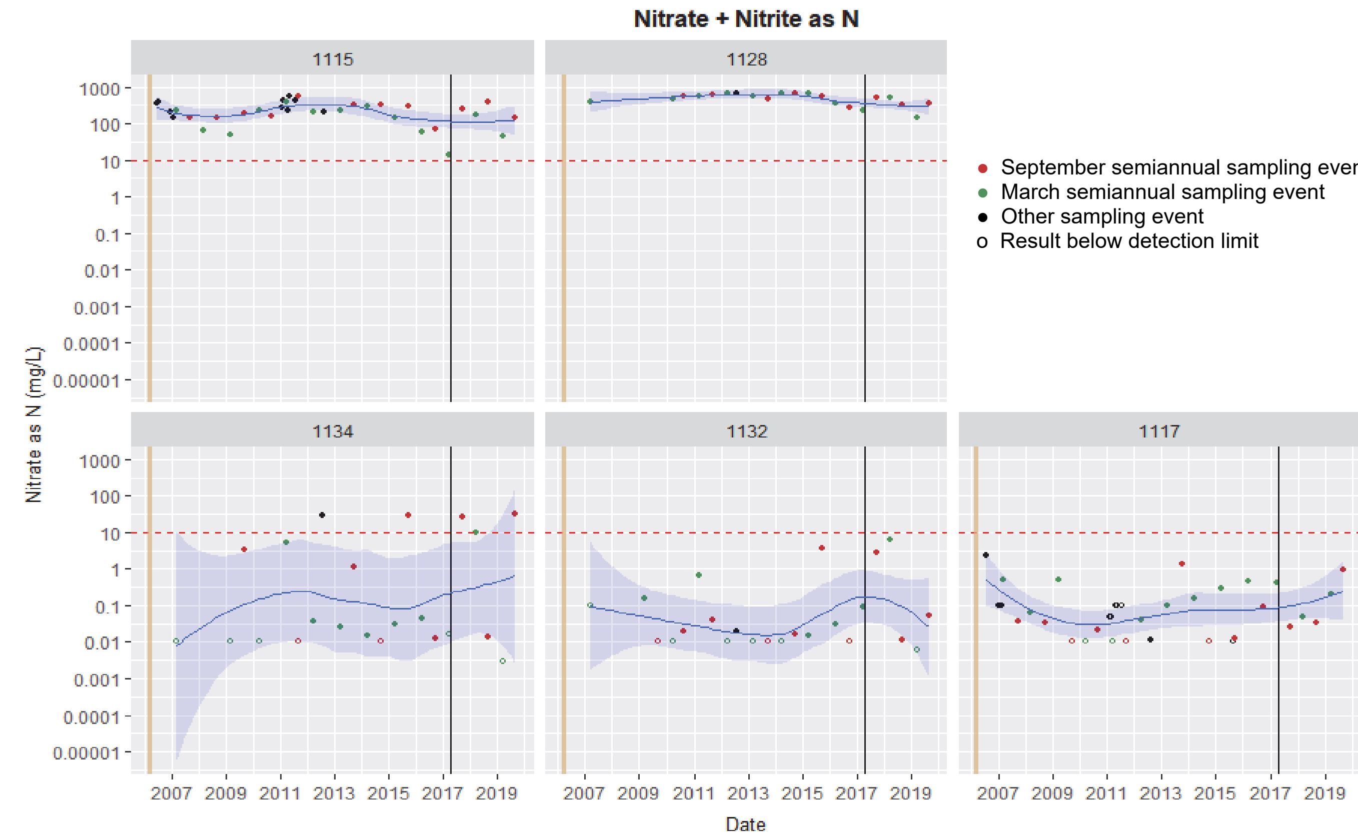
Third vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3).
This suspension was sustained through the 2019–2020 reporting period at extraction wells 1089 and 1104 (Table 2).

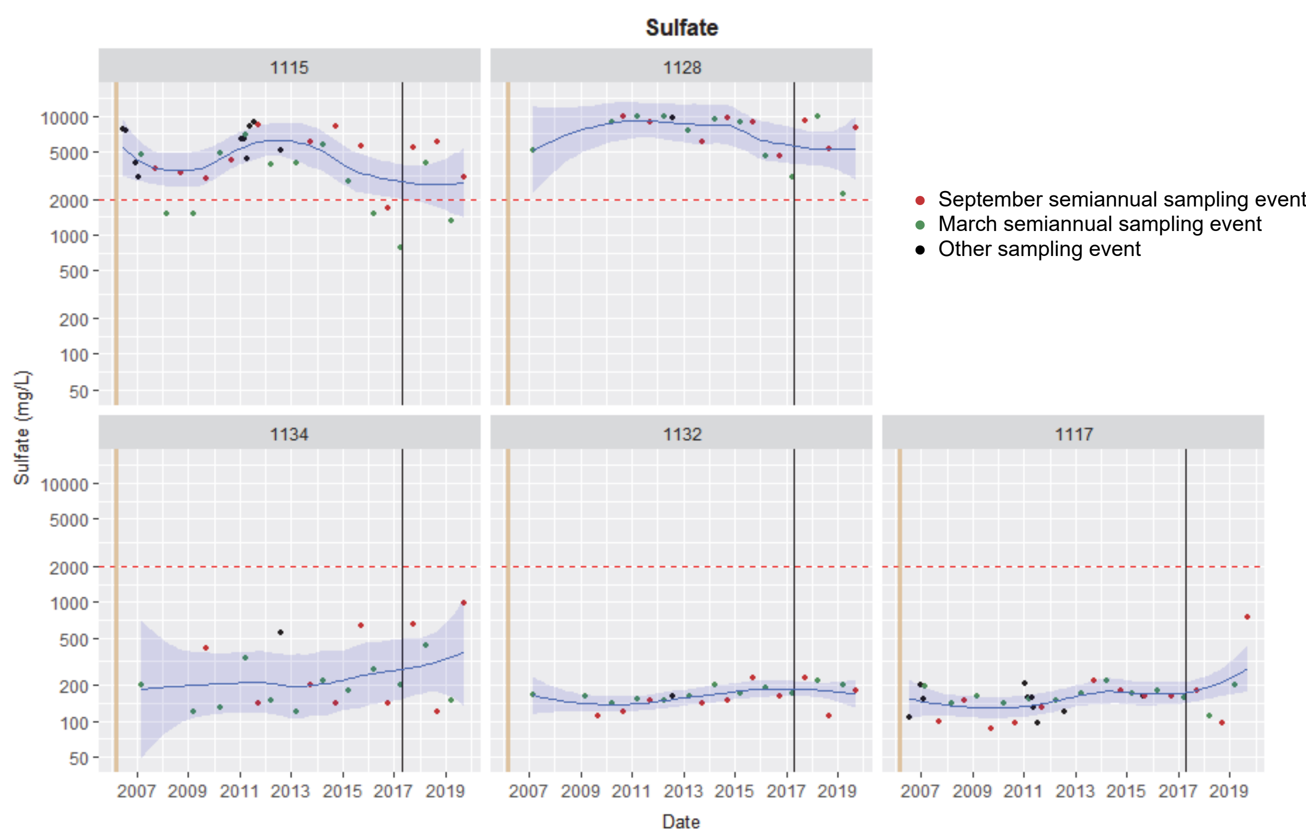


S2624400-04

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







Explanation/Legend

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).

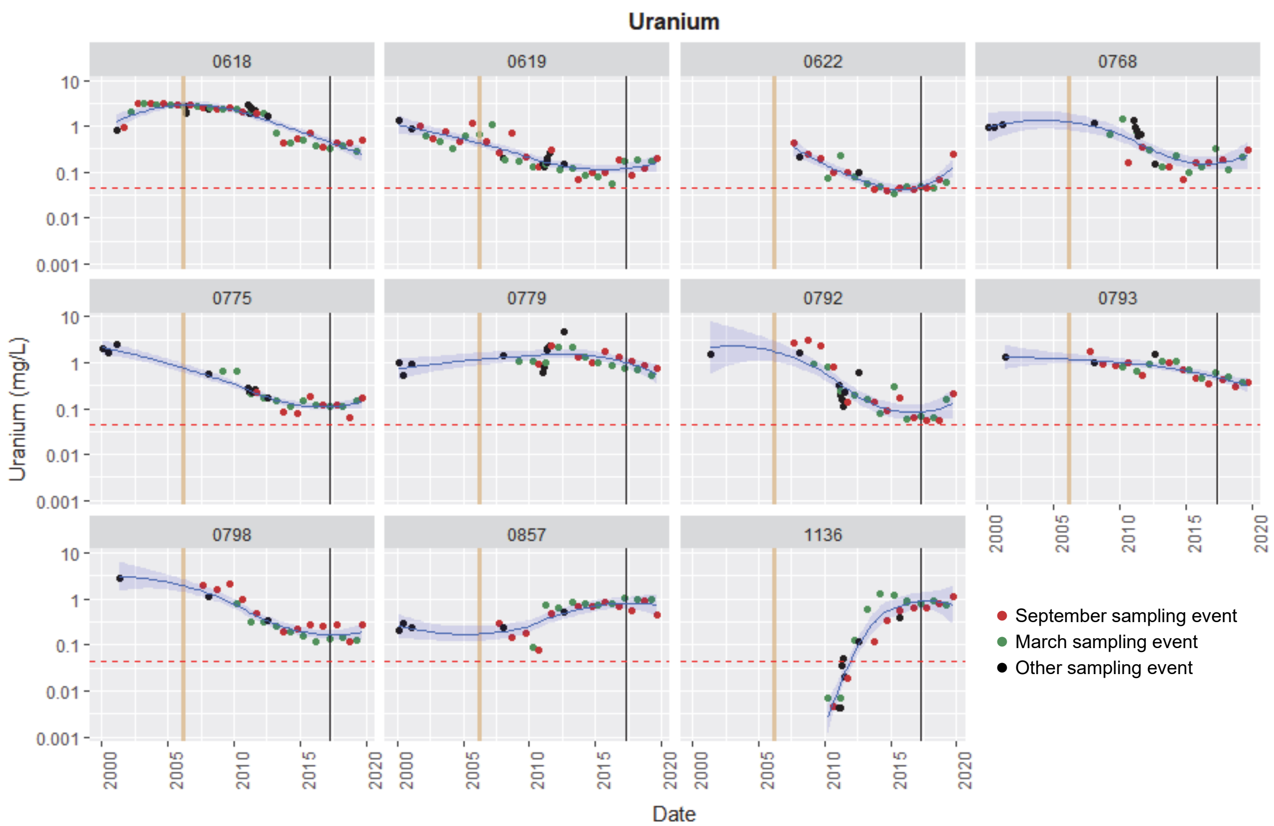
Blue line is a LOESS locally weighted regression line; shaded area is the corresponding 95% pointwise confidence interval

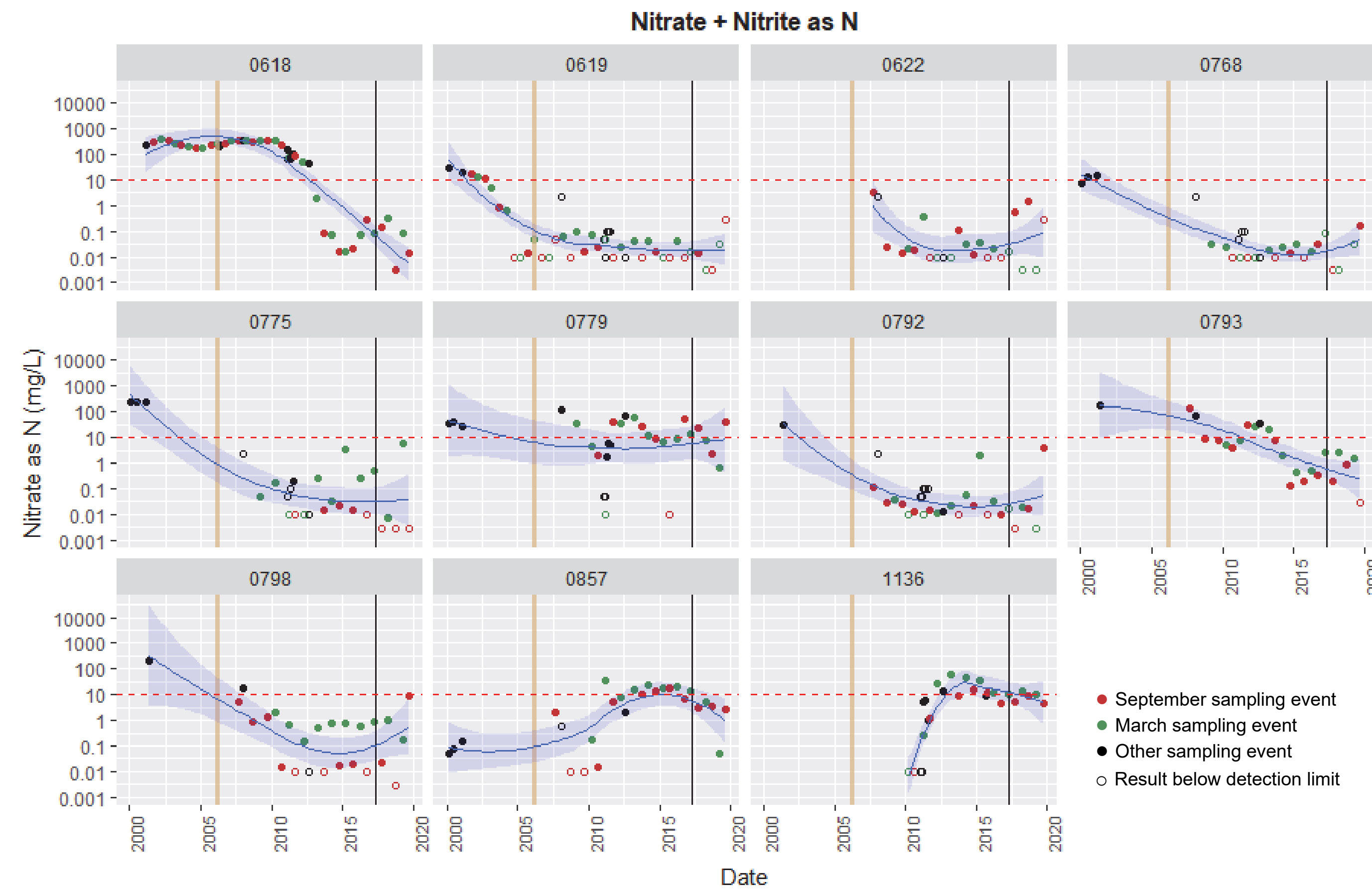
Denotes the 40 CFR 192 MCL or cleanup goal: 0.044 mg/L uranium, 10 mg/L nitrate as N, 2000 mg/L sulfate

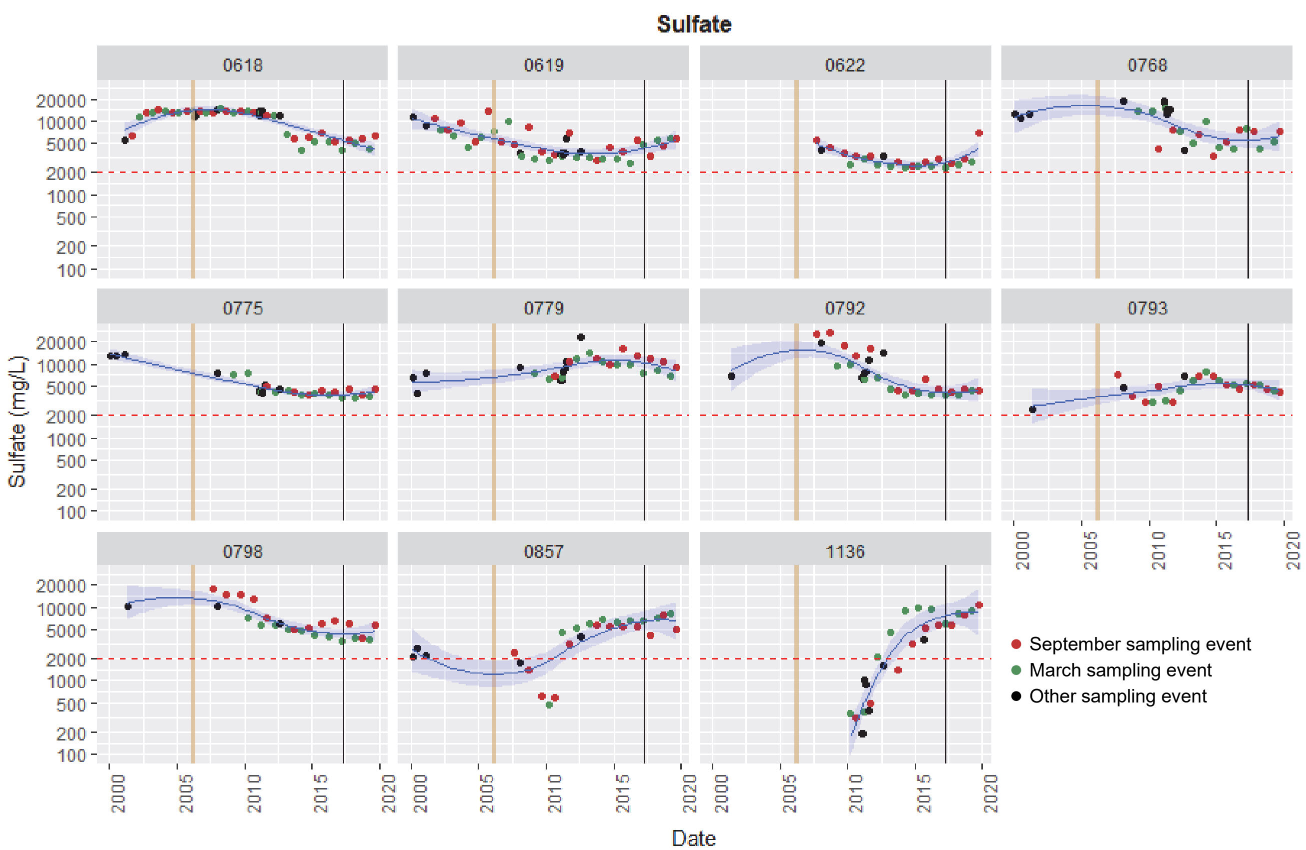
Vertical line | denotes time when Trench 2 was installed, in spring 2006. Trench 2 wells were installed between June 2006 and February 2007. Second vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3). Pumping resumed at Trench 2 on July 19, 2018, and continued through most of the 2019–2020 reporting period.

S2624400-08

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







Explanation/Legend

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 most of the 2019–2020 reporting period (Figure 3). Suspension of pumping at the well 1089/1104 complex was maintained.

Central Floodplain Wells

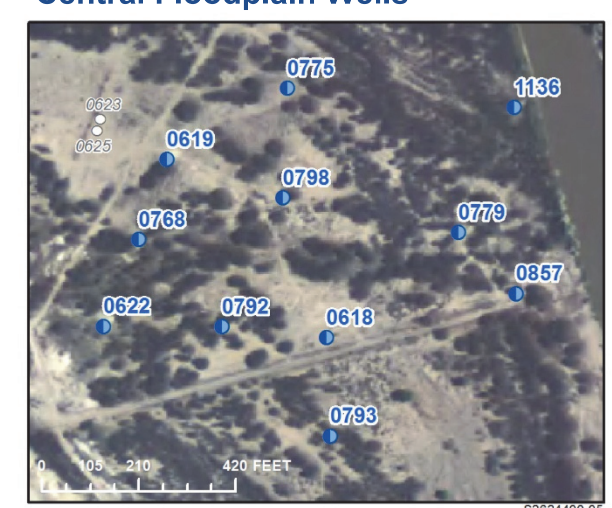
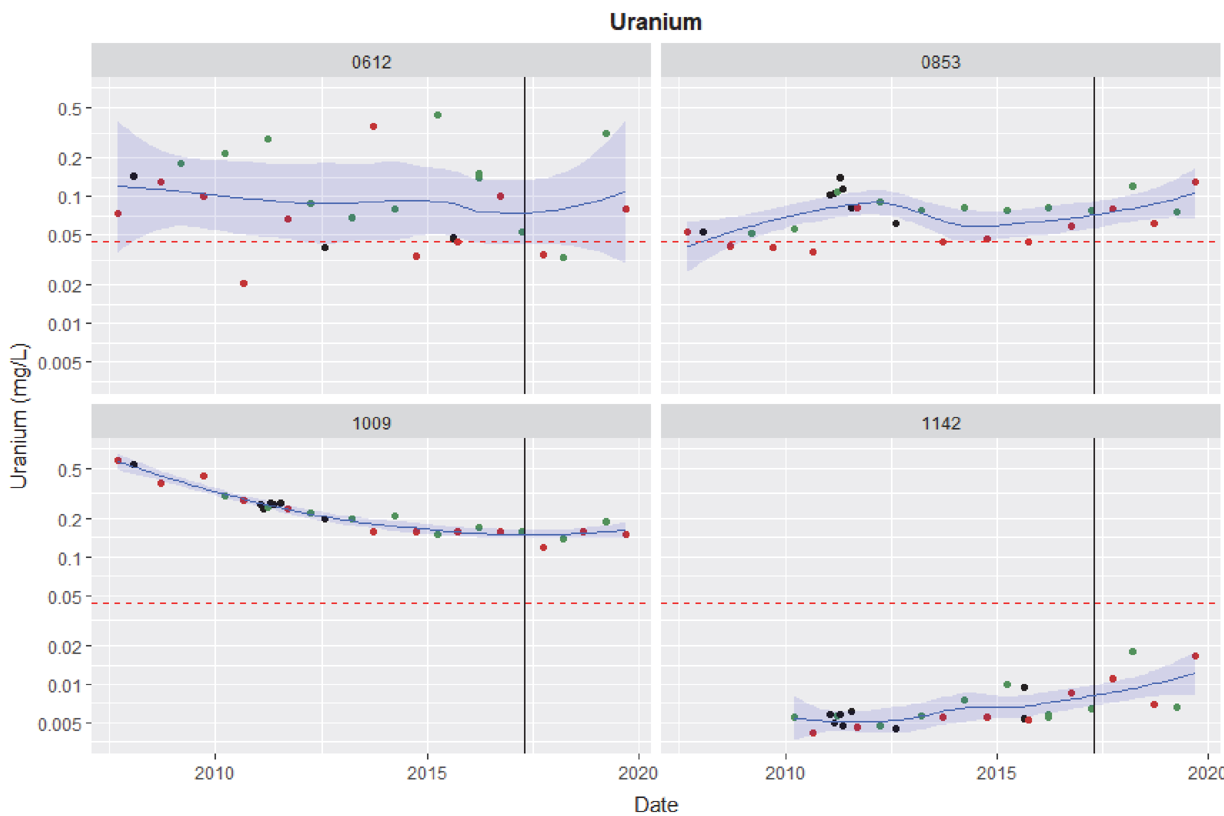
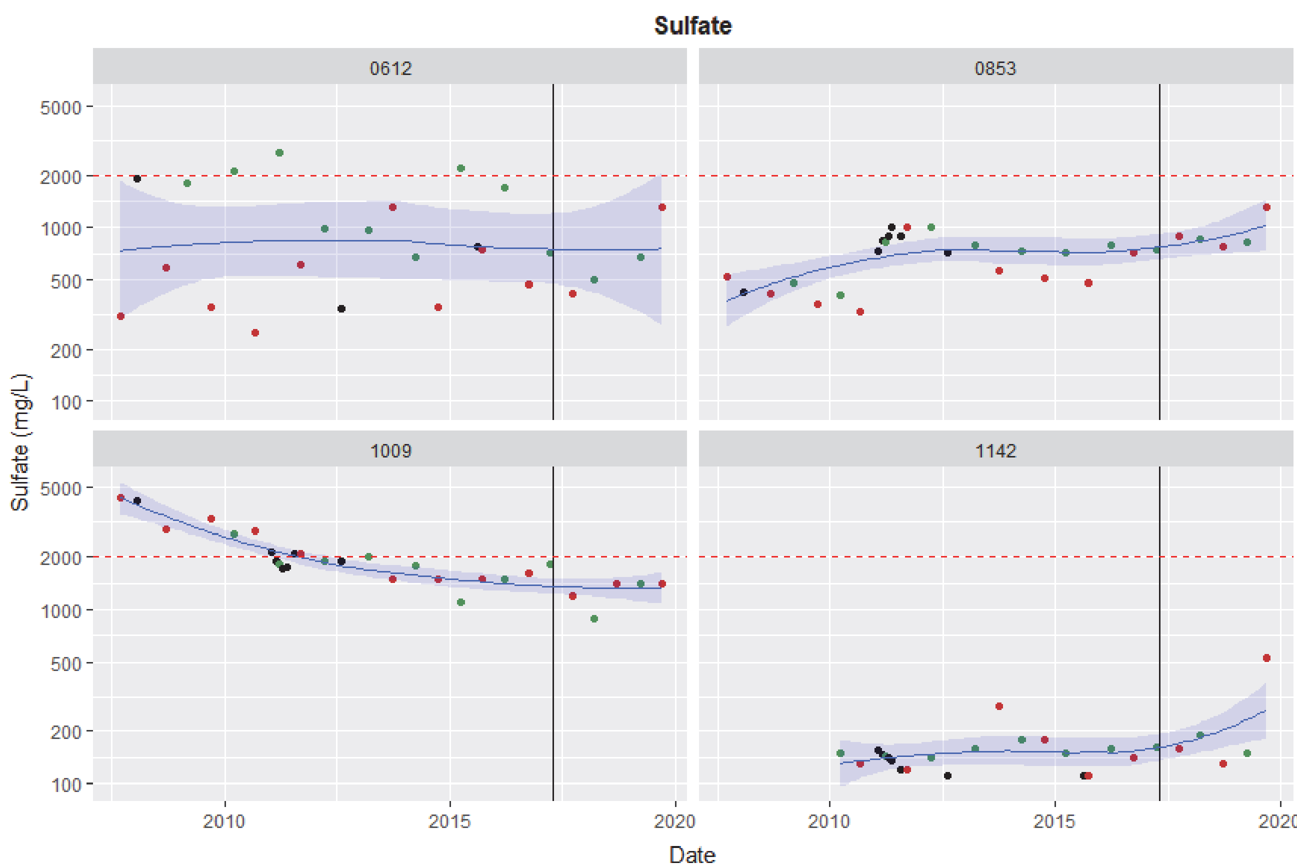
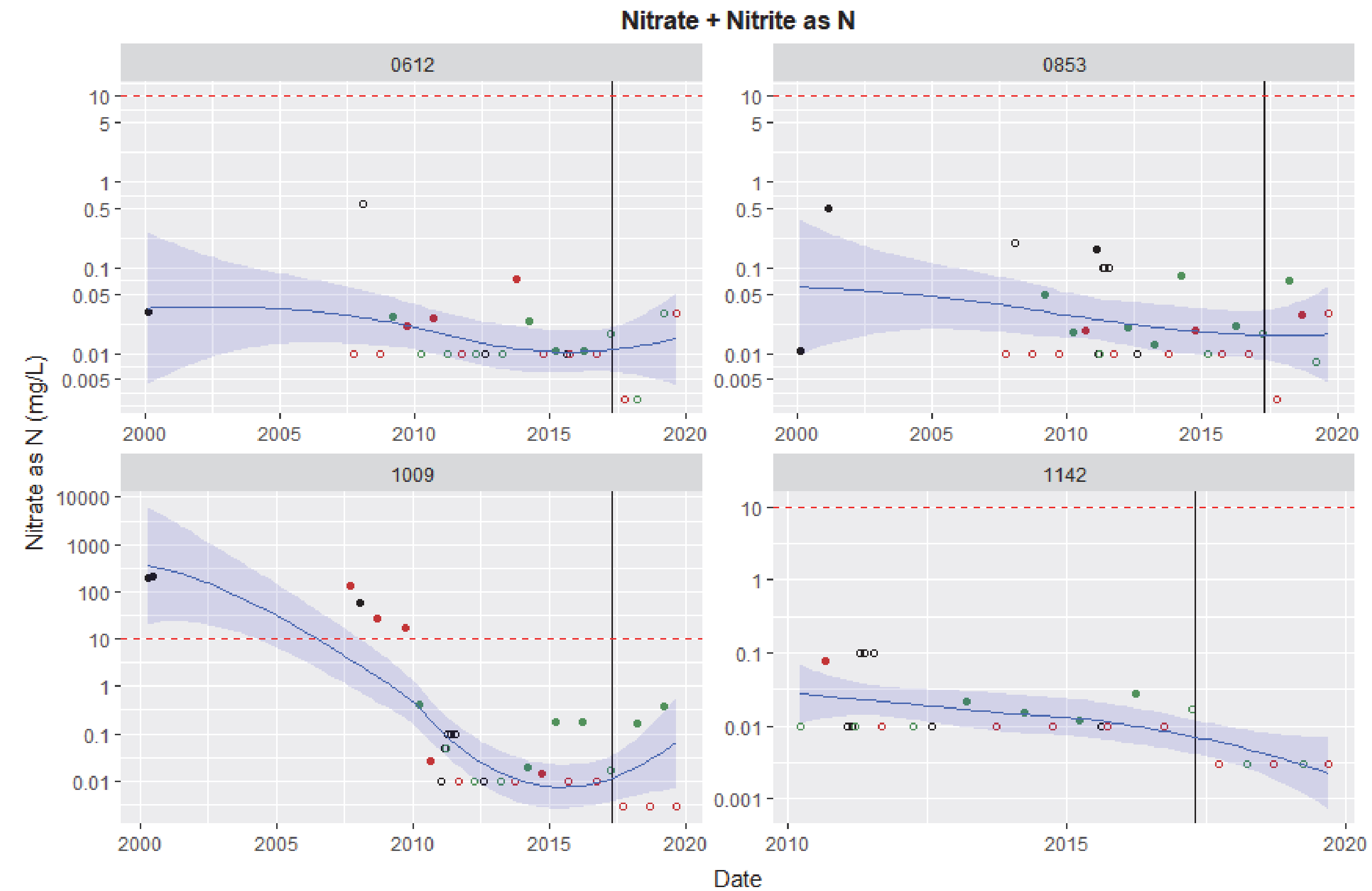


Figure A-5. Uranium, Nitrate, and Sulfate Concentration Trends in Central Floodplain Wells: 2000–September 2019







Explanation/Legend

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 most of this reporting period. Note, however, that wells 0612, 0853, and 1142 are outside the capture zone.

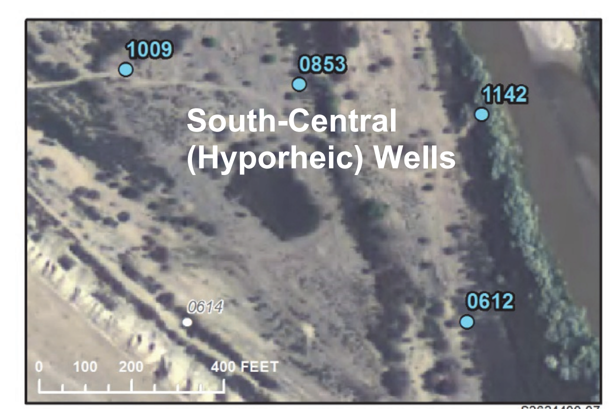
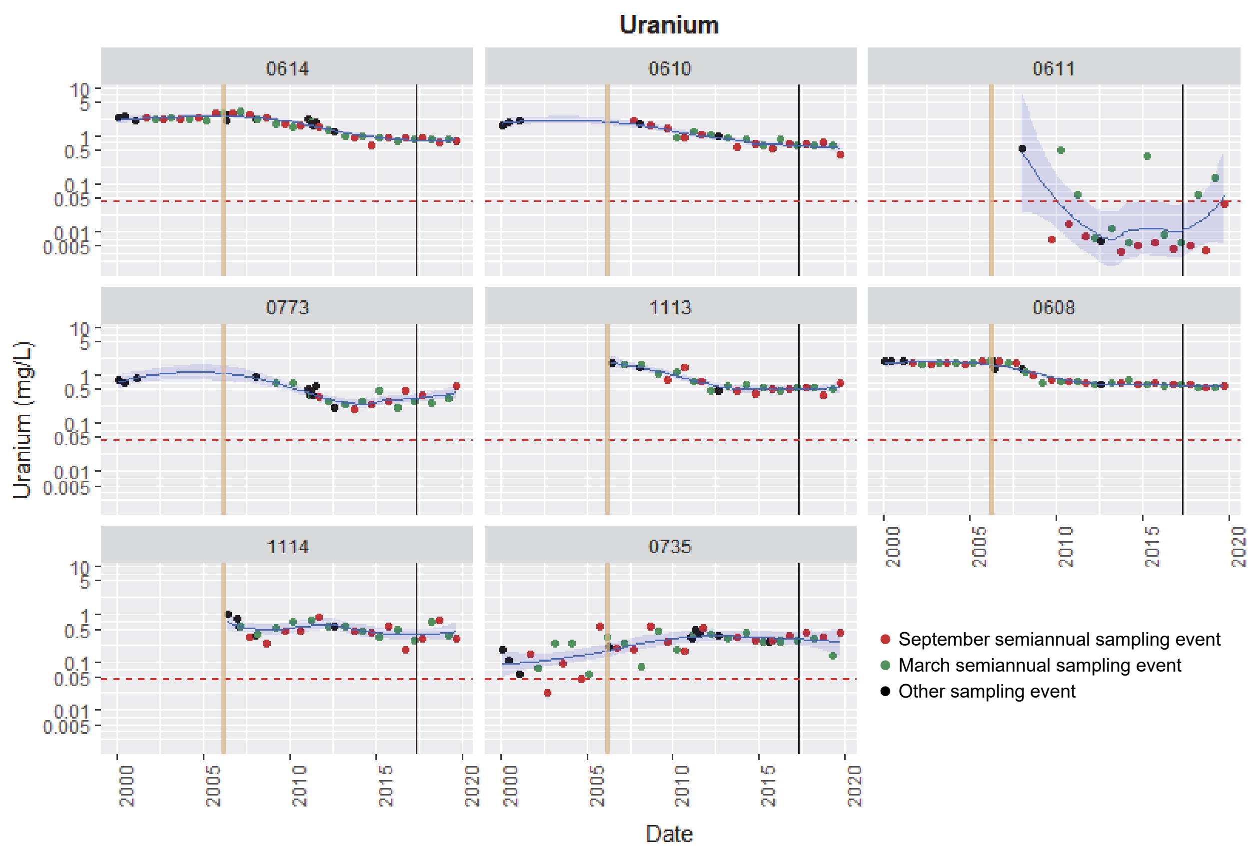
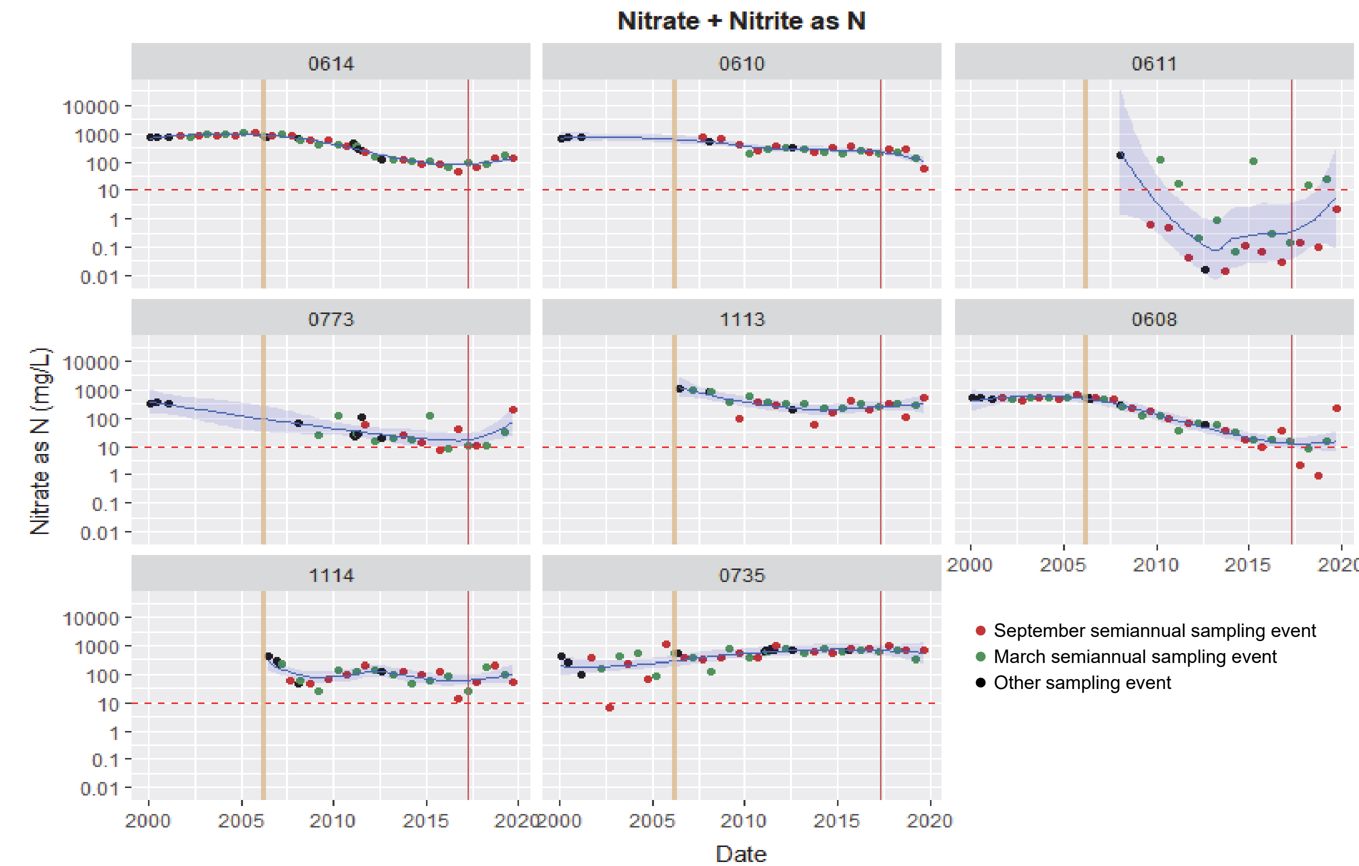
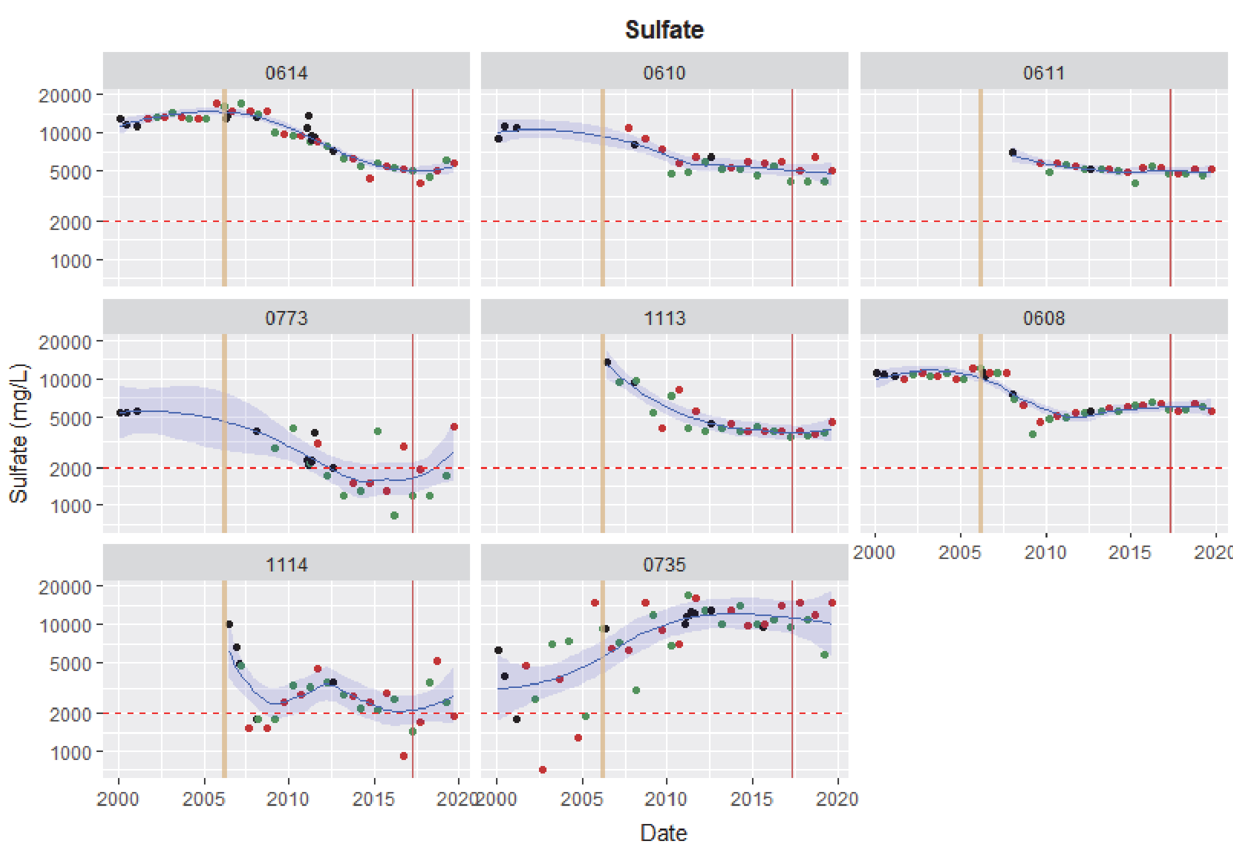
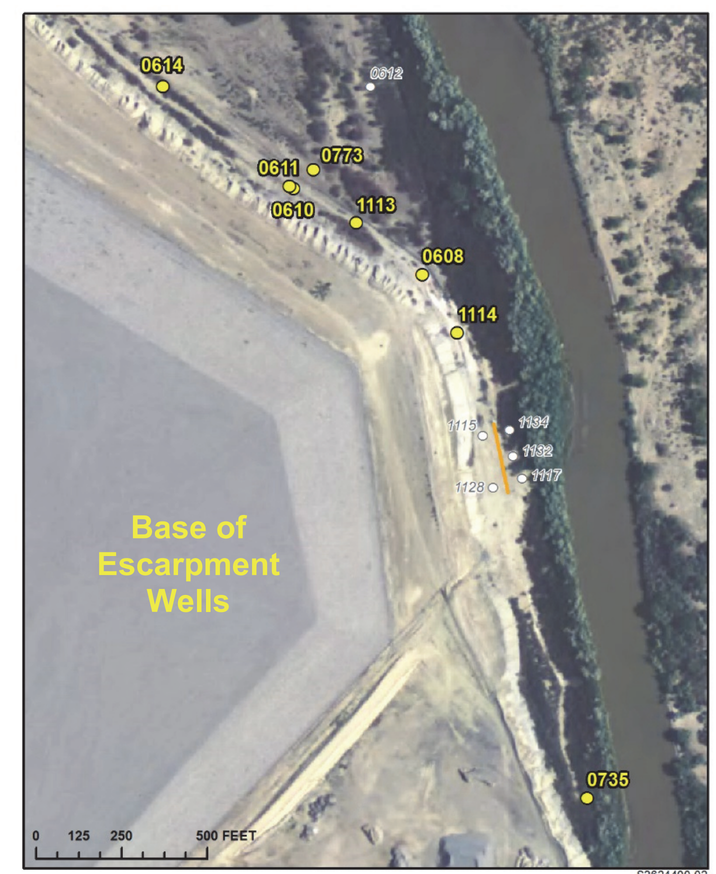


Figure A-6. Uranium, Nitrate, and Sulfate Concentration Trends in South-Central Floodplain Wells: 2007–September 2019









Explanation/Legend

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

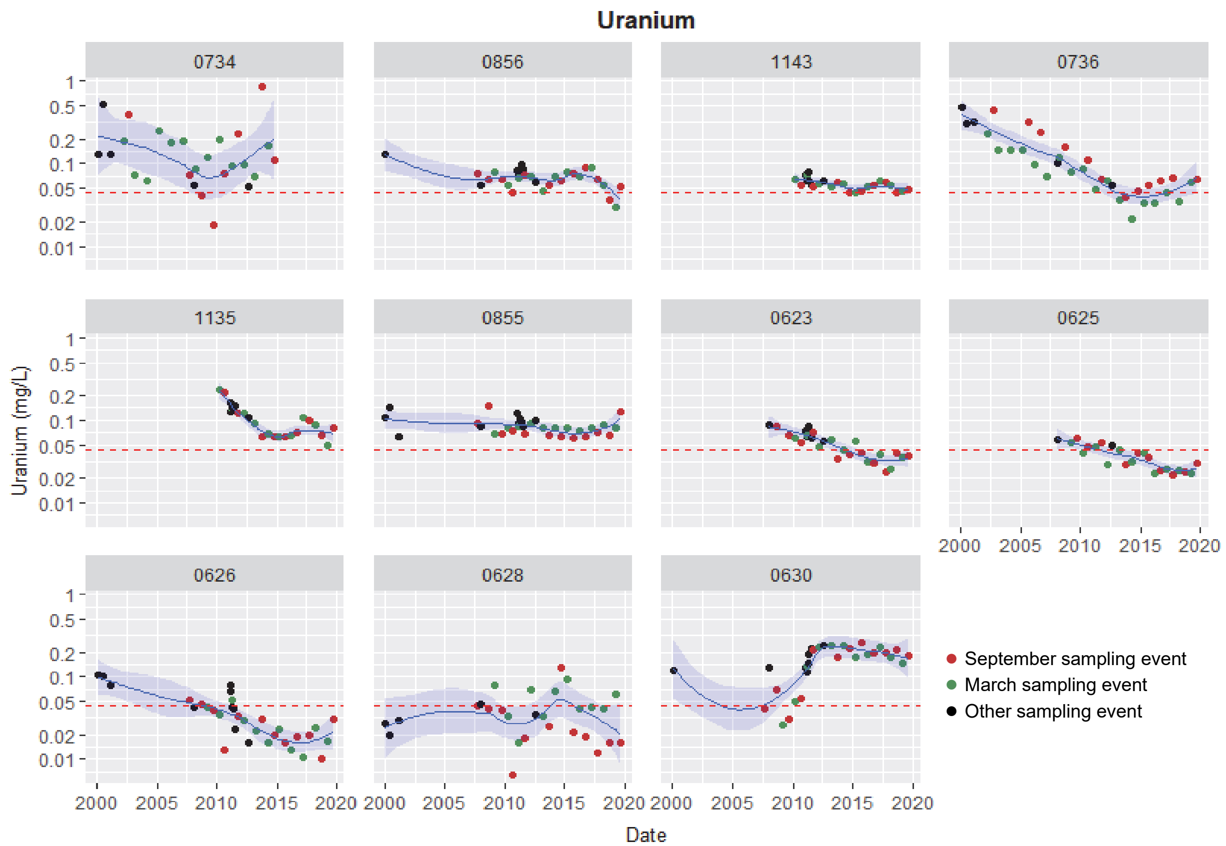
- - - - Denotes the 40 CFR 192 MCL or cleanup goal:

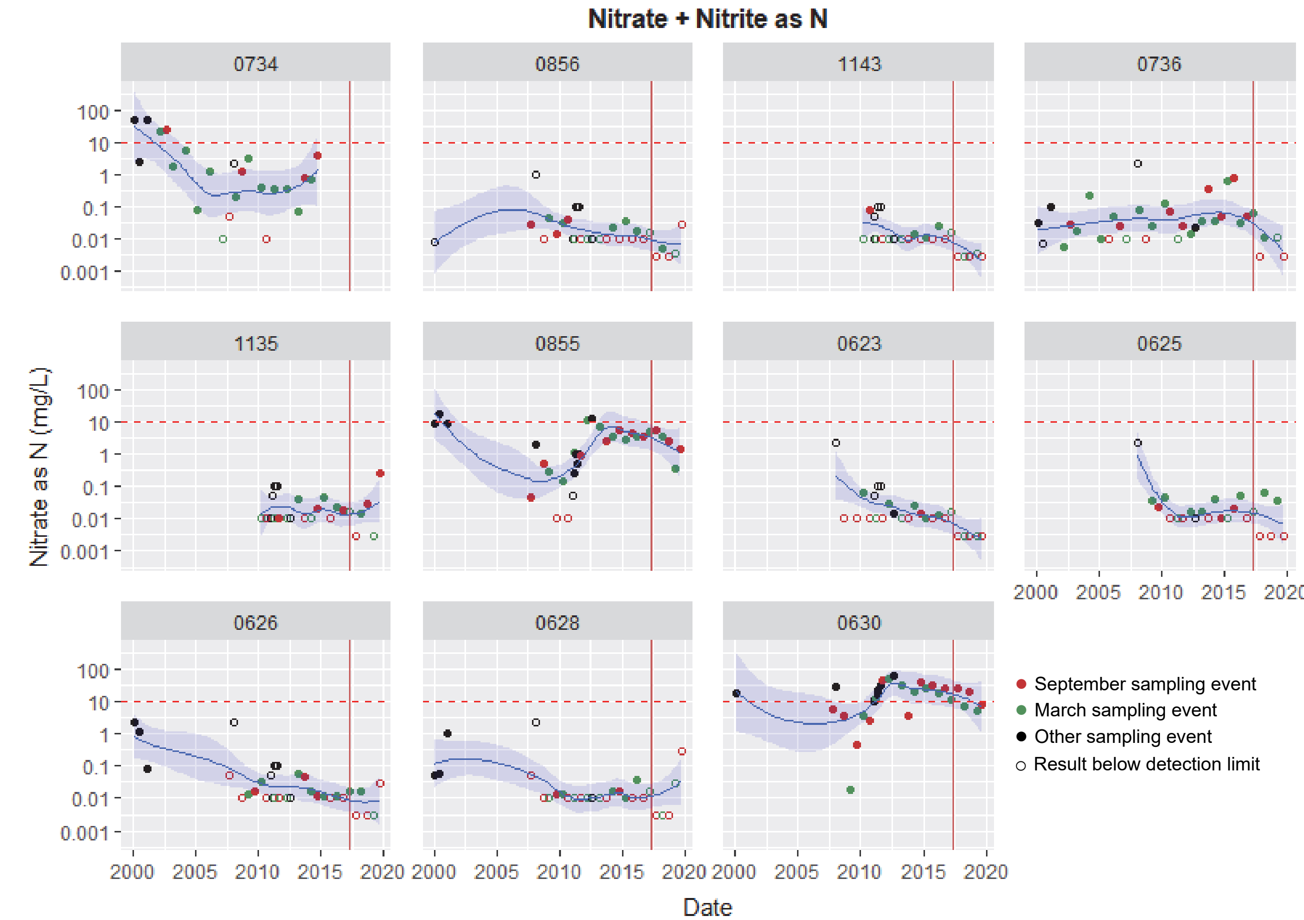
- 0.044 mg/L uranium
- 10 mg/L nitrate as N
- 2000 mg/L sulfate

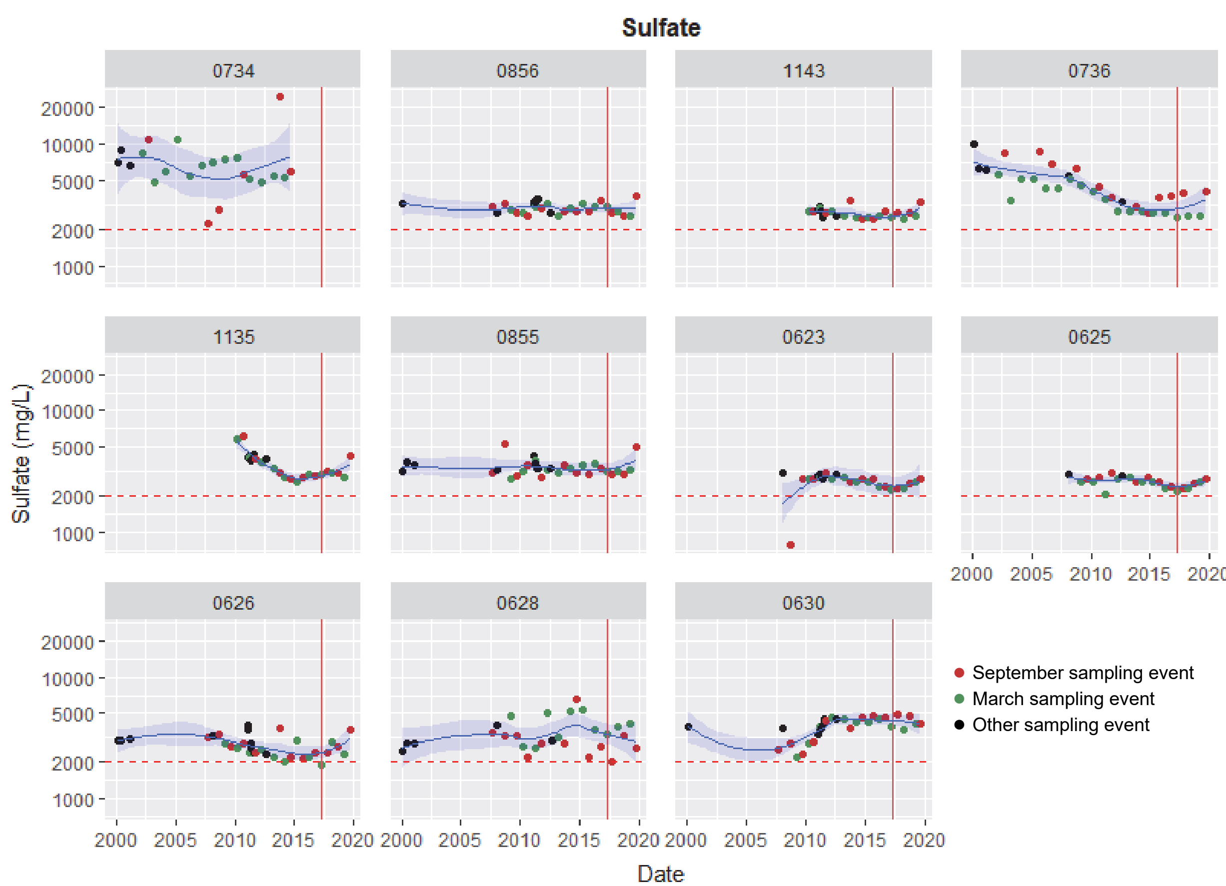
Vertical line | denotes time when Trench 1 and Trench 2 were installed (in spring 2006).

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 most of this reporting period.

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







Explanation/Legend

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

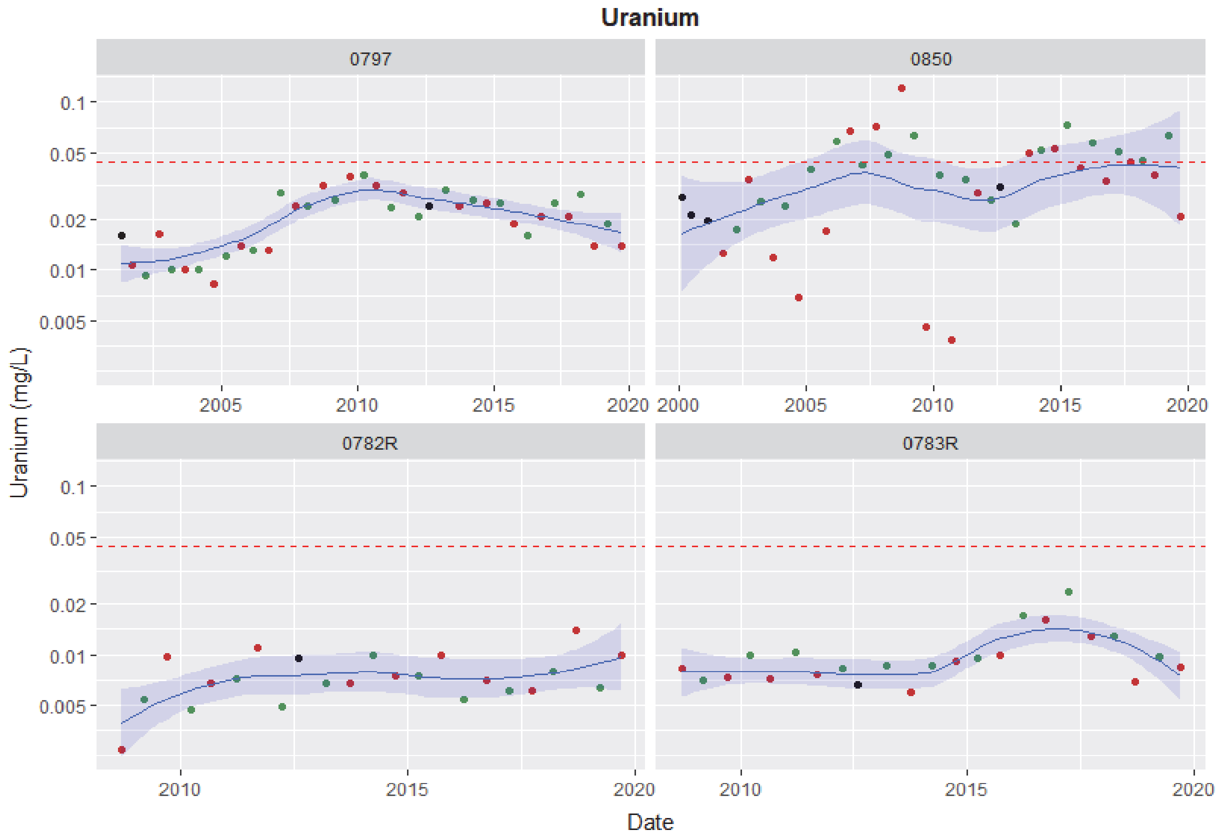
- - - - Denotes the 40 CFR 192 MCL or cleanup goal:

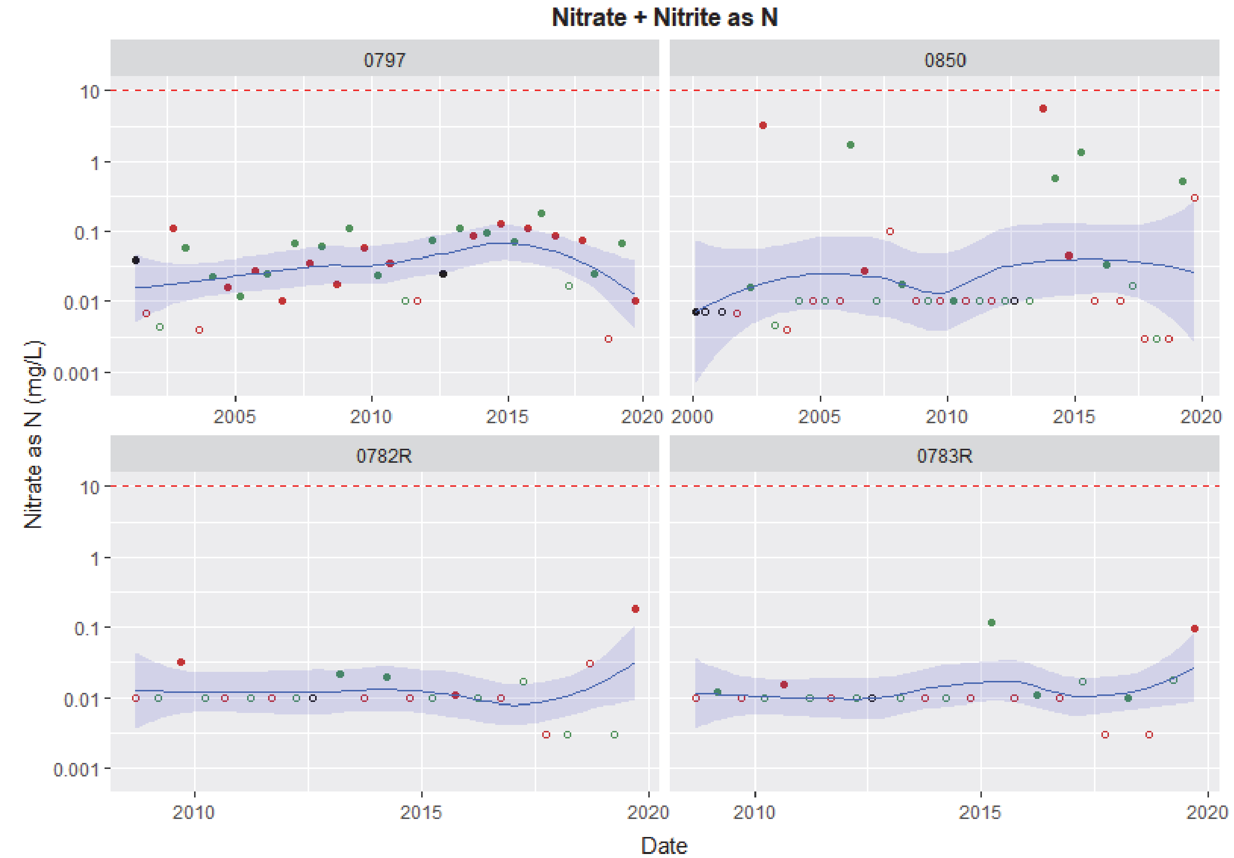
- 0.044 mg/L uranium
- 10 mg/L nitrate as N
- 2000 mg/L sulfate

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

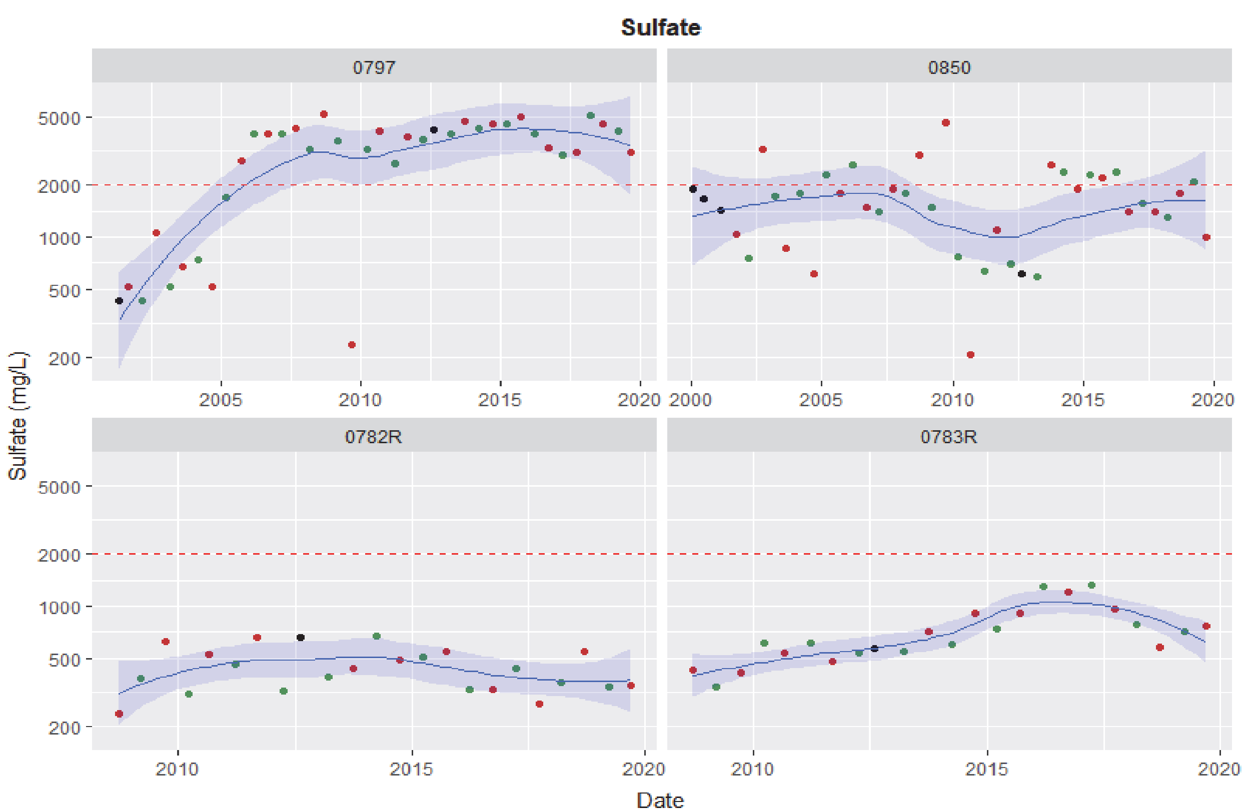
Western Floodplain Wells

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





f



Explanation/Legend

Well locations shown in Figure 11 and in Figure A-1.

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
- Denotes result below the detection limit

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

Appendix B

Mann-Kendall Trend Analysis Results for Floodplain Wells

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Table B-1. Mann-Kendall Trend Test Results, Nitrate + Nitrite as N in Floodplain Wells: 2006–2019

Well	Area	Initial Date	Final Date	Number of Samples	Most Recent Result (mg/L)	Trend	Tau Value
0610	BOE Well	9/11/2007	9/12/2019	25	57.0	Decreasing	-0.50
0611	BOE Well	1/22/2008	9/12/2019	23	2.2	None	-0.07
0612	South-Central (Hyporheic)	9/11/2007	9/12/2019	27	0.03	None	-0.01
0614	BOE Well	3/9/2006	9/12/2019	38	130.00	Decreasing	-0.79
0615	Trench 1	3/9/2006	9/12/2019	38	0.018	Decreasing	-0.81
0618	Central Floodplain	3/8/2006	9/9/2019	39	0.014	Decreasing	-0.66
0619	Central Floodplain	3/8/2006	9/11/2019	35	0.30	None	-0.20
0622	Central Floodplain	9/12/2007	9/12/2019	25	0.30	None	-0.13
0623	Western Floodplain	1/24/2008	9/12/2019	28	0.003	Decreasing	-0.46
0625	Western Floodplain	1/24/2008	9/12/2019	23	0.003	None	-0.23
0626	Western Floodplain	9/13/2007	9/12/2019	31	0.03	None	-0.23
0628	Western Floodplain	9/13/2007	9/12/2019	27	0.30	None	-0.02
0630	Western Floodplain	9/13/2007	9/12/2019	31	8.0	None	0.20
0734	Western Floodplain	3/15/2006	9/30/2014	15	4.0	None	0.16
0735	BOE Well	3/9/2006	9/12/2019	36	710	Increasing	0.31
0736	Western Floodplain	3/10/2006	9/11/2019	26	0.003	None	-0.08
0766	Well 1089/1104 Area	1/23/2008	9/11/2019	21	0.30	None	-0.11
0768	Central Floodplain	1/24/2008	9/12/2019	26	0.16	None	-0.13
0773	BOE Well	1/22/2008	9/12/2019	25	200	None	-0.24
0775	Central Floodplain	1/24/2008	9/12/2019	26	0.003	None	-0.21
0779	Central Floodplain	1/23/2008	9/12/2019	27	37.00	None	0.05
0792	Central Floodplain	9/12/2007	9/9/2019	31	3.90	None	-0.17
0793	Central Floodplain	9/12/2007	9/13/2019	24	0.03	Decreasing	-0.54
0797	Background	9/16/2008	9/13/2019	23	0.01	None	-0.01
0798	Central Floodplain	9/12/2007	9/11/2019	24	9.50	None	-0.18
0850	Background	9/17/2008	9/13/2019	23	0.30	None	0.07
0853	South-Central (Hyporheic)	9/12/2007	9/12/2019	30	0.03	None	-0.13
0854	Well 1089/1104 Area	1/23/2008	9/11/2019	22	1.00	Decreasing	-0.67
0855	Western Floodplain	9/13/2007	9/10/2019	30	1.50	Increasing	0.40
0856	Western Floodplain	9/13/2007	9/11/2019	30	0.03	Decreasing	-0.36
0857	Central Floodplain	9/12/2007	9/9/2019	27	2.80	None	0.16
1008	Well 1089/1104 Area	3/10/2006	9/11/2019	25	1.90	Decreasing	-0.52
1009	South-Central (Hyporheic)	9/12/2007	9/12/2019	30	0.003	Decreasing	-0.37
1089	Well 1089/1104 Area	3/14/2006	9/11/2019	29	14.00	Decreasing	-0.60
1104	Well 1089/1104 Area	3/14/2006	9/11/2019	29	15.00	Decreasing	-0.77
1105	Trench 1	3/6/2007	9/12/2019	28	0.03	Decreasing	-0.83
1111	Trench 1	6/13/2006	9/11/2019	29	130	None	-0.09
1112	Trench 1	6/13/2006	9/12/2019	31	290	Decreasing	-0.52
1113	BOE Well	6/13/2006	9/12/2019	26	520	Decreasing	-0.33
1114	BOE Well	6/13/2006	9/11/2019	30	56.0	None	-0.23
1115	Trench 2	6/13/2006	9/11/2019	37	160	None	-0.07
1117	Trench 2	7/18/2006	9/11/2019	35	0.96	None	0.02
1128	Trench 2	3/6/2007	9/11/2019	21	369.99	None	-0.30
1132	Trench 2	3/6/2007	9/11/2019	23	0.05	None	0.07
1134	Trench 2	3/6/2007	9/11/2019	23	36.0	None	0.15
1135	Western Floodplain	3/25/2010	9/11/2019	26	0.26	None	0.04
1136	Central Floodplain	3/25/2010	9/10/2019	30	4.50	Increasing	0.32
1137	Well 1089/1104 Area	3/25/2010	9/11/2019	25	31.0	None	-0.26
1138	Well 1089/1104 Area	3/25/2010	9/11/2019	23	19.0	Decreasing	-0.45
1139	Well 1089/1104 Area	3/25/2010	9/11/2019	28	3.1	Decreasing	-0.38
1140	Trench 1	9/16/2009	9/12/2019	21	300.0	Decreasing	-0.52
1141	Trench 1	9/16/2009	9/12/2019	22	630.0	None	-0.09
1142	South-Central (Hyporheic)	3/24/2010	9/12/2019	26	0.003	Decreasing	-0.39
1143	Western Floodplain	3/26/2010	9/10/2019	26	0.003	Decreasing	-0.36
0782R	Background	3/7/2006	9/10/2019	28	0.18	None	0.08
0783R	Background	3/7/2006	9/10/2019	28	0.09	None	-0.10

Notes:
Area groupings are consistent with those shown in Figure 11 and Figure A-1. The term "BOE" refers to base of escarpment wells. Mann-Kendall trend analyses were conducted at the 0.05 significance (or alpha) level. The test statistic, Kendall's tau, is a measure of the strength of the association between two variables, with values always falling between −1 and +1. An initial date of 2006 was used for most wells because that time frame corresponds to the installation of the floodplain trenches.

2.2 Most recent result less than the 10 mg/L 40 CFR 192 MCL (Table 1).

Significant decreasing trend based on Mann-Kendall test. Significant increasing trend based on Mann-Kendall test.

Table B-2. Mann-Kendall Trend Test Results, Sulfate in Floodplain Wells: 2006–September 2019

Well	Area	Initial Date	Final Date	Number of Samples	Most Recent Result (mg/L)	Trend	Tau Value
0610	BOE Well	9/11/2007	9/12/2019	24	5,000	Decreasing	-0.44
0611	BOE Well	1/22/2008	9/12/2019	22	5,100	Decreasing	-0.48
0612	South-Central (Hyporheic)	9/11/2007	9/12/2019	25	1,300	None	-0.01
0614	BOE Well	3/9/2006	9/12/2019	37	5,800	Decreasing	-0.78
0615	Trench 1	3/9/2006	9/12/2019	38	7,300	Decreasing	-0.38
0618	Central Floodplain	3/8/2006	9/9/2019	37	6,400	Decreasing	-0.61
0619	Central Floodplain	3/8/2006	9/11/2019	34	5,800	None	-0.04
0622	Central Floodplain	9/12/2007	9/12/2019	24	6,900	Decreasing	-0.30
0623	Western Floodplain	1/24/2008	9/12/2019	28	2,700	Decreasing	-0.51
0625	Western Floodplain	1/24/2008	9/12/2019	23	2,700	None	-0.30
0626	Western Floodplain	9/13/2007	9/12/2019	30	3,700	Decreasing	-0.30
0628	Western Floodplain	9/13/2007	9/12/2019	25	2,600	None	-0.04
0630	Western Floodplain	9/13/2007	9/12/2019	30	4,100	Increasing	0.53
0734	Western Floodplain	3/15/2006	9/30/2014	15	6,000	None	0.10
0735	BOE Well	3/9/2006	9/12/2019	35	15,000	Increasing	0.26
0736	Western Floodplain	3/10/2006	9/11/2019	26	4,100	Decreasing	-0.56
0766	Well 1089/1104 Area	1/23/2008	9/11/2019	21	4,000	Decreasing	-0.53
0768	Central Floodplain	1/24/2008	9/12/2019	26	7,100	Decreasing	-0.45
0773	BOE Well	1/22/2008	9/12/2019	25	4,200	Decreasing	-0.33
0775	Central Floodplain	1/24/2008	9/12/2019	26	4,600	Decreasing	-0.43
0779	Central Floodplain	1/23/2008	9/12/2019	27	8,900	None	0.23
0792	Central Floodplain	9/12/2007	9/9/2019	30	4,300	Decreasing	-0.62
0793	Central Floodplain	9/12/2007	9/13/2019	24	4,200	None	0.01
0797	Background	3/7/2006	9/10/2019	28	3,100	None	0.09
0798	Central Floodplain	9/12/2007	9/11/2019	24	5,800	Decreasing	-0.61
0850	Background	3/7/2006	9/10/2019	28	1,000	None	-0.07
0853	South-Central (Hyporheic)	9/12/2007	9/12/2019	30	1,300	Increasing	0.31
0854	Well 1089/1104 Area	1/23/2008	9/11/2019	22	3,900	Decreasing	-0.68
0855	Western Floodplain	9/13/2007	9/10/2019	30	5,100	None	-0.06
0856	Western Floodplain	9/13/2007	9/11/2019	30	3,700	None	-0.05
0857	Central Floodplain	9/12/2007	9/9/2019	24	5,000	Increasing	0.57
1008	Well 1089/1104 Area	3/10/2006	9/11/2019	24	3,400	Decreasing	-0.78
1009	South-Central (Hyporheic)	9/12/2007	9/12/2019	29	1,400	Decreasing	-0.74
1089	Well 1089/1104 Area	3/14/2006	9/11/2019	29	5,100	Decreasing	-0.73
1104	Well 1089/1104 Area	3/14/2006	9/11/2019	29	5,500	Decreasing	-0.68
1105	Trench 1	3/6/2007	9/12/2019	26	7,600	Decreasing	-0.68
1111	Trench 1	6/13/2006	9/11/2019	28	12,000	None	-0.18
1112	Trench 1	6/13/2006	9/12/2019	31	8,500	Decreasing	-0.55
1113	BOE Well	6/13/2006	9/12/2019	26	4,500	Decreasing	-0.64
1114	BOE Well	6/13/2006	9/11/2019	30	1,900	None	-0.19
1115	Trench 2	6/13/2006	9/11/2019	35	3,100	None	-0.08
1117	Trench 2	7/18/2006	9/11/2019	35	750	None	0.20
1128	Trench 2	3/6/2007	9/11/2019	21	8,000	None	-0.29
1132	Trench 2	3/6/2007	9/11/2019	23	180	Increasing	0.39
1134	Trench 2	3/6/2007	9/11/2019	22	970	None	0.18
1135	Western Floodplain	3/25/2010	9/11/2019	25	4,200	Decreasing	-0.48
1136	Central Floodplain	3/25/2010	9/10/2019	26	11,000	Increasing	0.73
1137	Well 1089/1104 Area	3/25/2010	9/11/2019	21	9,200	None	0.23
1138	Well 1089/1104 Area	3/25/2010	9/11/2019	20	4,000	None	0.03
1139	Well 1089/1104 Area	3/25/2010	9/11/2019	25	3,900	None	0.27
1140	Trench 1	9/16/2009	9/12/2019	21	10,000	Decreasing	-0.33
1141	Trench 1	9/16/2009	9/12/2019	21	11,000	None	-0.13
1142	South-Central (Hyporheic)	3/24/2010	9/12/2019	26	530	None	0.18
1143	Western Floodplain	3/26/2010	9/10/2019	25	3,300	None	-0.29
0782R	Background	9/16/2008	9/13/2019	23	350	None	-0.06
0783R	Background	9/17/2008	9/13/2019	23	770	Increasing	0.56

Notes:

Area groupings are consistent with those shown in Figure 11 and Figure A-1. The term "BOE" refers to base of escarpment wells. Mann-Kendall trend analyses were conducted at the 0.05 significance (or alpha) level. The test statistic, Kendall's tau, is a measure of the strength of the association between two variables, with values always falling between −1 and +1. An initial date of 2006 was used for most wells because that time frame corresponds to the installation of the floodplain trenches.

1300 Most recent result less than the 2000 mg/L remediation goal (Table 1).

Significant decreasing trend based on Mann-Kendall test. Significant increasing trend based on Mann-Kendall test.

Table B-3. Mann-Kendall Trend Test Results, Uranium in Floodplain Wells: 2006–September 2019

Well	Area	Initial Date	Final Date	Number of Samples	Most Recent Result (mg/L)	Trend	Tau Value
0610	BOE Well	9/11/2007	9/12/2019	24	0.42	Decreasing	-0.68
0611	BOE Well	1/22/2008	9/12/2019	22	0.04	None	-0.24
0612	South-Central (Hyporheic)	9/11/2007	9/12/2019	25	0.08	None	-0.14
0614	BOE Well	3/9/2006	9/12/2019	37	0.78	Decreasing	-0.78
0615	Trench 1	3/9/2006	9/12/2019	38	1.30	Decreasing	-0.60
0618	Central Floodplain	3/8/2006	9/9/2019	37	0.50	Decreasing	-0.71
0619	Central Floodplain	3/8/2006	9/11/2019	34	0.20	Decreasing	-0.35
0622	Central Floodplain	9/12/2007	9/12/2019	24	0.25	Decreasing	-0.39
0623	Western Floodplain	1/24/2008	9/12/2019	28	0.04	Decreasing	-0.65
0625	Western Floodplain	1/24/2008	9/12/2019	23	0.03	Decreasing	-0.66
0626	Western Floodplain	9/13/2007	9/12/2019	30	0.03	Decreasing	-0.53
0628	Western Floodplain	9/13/2007	9/12/2019	25	0.016	None	-0.14
0630	Western Floodplain	9/13/2007	9/12/2019	30	0.18	Increasing	0.46
0734	Western Floodplain	3/15/2006	9/30/2014	18	0.17	None	0.11
0735	BOE Well	3/9/2006	9/12/2019	35	0.41	None	0.10
0736	Western Floodplain	3/10/2006	9/11/2019	26	0.066	Decreasing	-0.44
0766	Well 1089/1104 Area	1/23/2008	9/11/2019	21	0.11	Decreasing	-0.60
0768	Central Floodplain	1/24/2008	9/12/2019	26	0.30	Decreasing	-0.48
0773	BOE Well	1/22/2008	9/12/2019	25	0.58	Decreasing	-0.33
0775	Central Floodplain	1/24/2008	9/12/2019	26	0.17	Decreasing	-0.62
0779	Central Floodplain	1/23/2008	9/12/2019	27	0.77	None	-0.27
0792	Central Floodplain	9/12/2007	9/9/2019	30	0.21	Decreasing	-0.63
0793	Central Floodplain	9/12/2007	9/13/2019	24	0.38	Decreasing	-0.56
0797	Background	3/7/2006	9/10/2019	28	0.014	None	-0.24
0798	Central Floodplain	9/12/2007	9/11/2019	24	0.28	Decreasing	-0.65
0850	Background	3/7/2006	9/10/2019	28	0.021	None	-0.09
0853	South-Central (Hyporheic)	9/12/2007	9/12/2019	30	0.13	None	0.15
0854	Well 1089/1104 Area	1/23/2008	9/11/2019	22	0.18	Decreasing	-0.70
0855	Western Floodplain	9/13/2007	9/10/2019	30	0.13	None	-0.19
0856	Western Floodplain	9/13/2007	9/11/2019	30	0.05	None	-0.12
0857	Central Floodplain	9/12/2007	9/9/2019	24	0.46	Increasing	0.52
1008	Well 1089/1104 Area	3/10/2006	9/11/2019	24	0.10	Decreasing	-0.89
1009	South-Central (Hyporheic)	9/12/2007	9/12/2019	29	0.15	Decreasing	-0.78
1089	Well 1089/1104 Area	3/14/2006	9/11/2019	30	0.12	Decreasing	-0.80
1104	Well 1089/1104 Area	3/14/2006	9/11/2019	30	0.14	Decreasing	-0.81
1105	Trench 1	3/6/2007	9/12/2019	26	0.68	Decreasing	-0.65
1111	Trench 1	6/13/2006	9/11/2019	28	0.86	Decreasing	-0.41
1112	Trench 1	6/13/2006	9/12/2019	31	0.95	Decreasing	-0.54
1113	BOE Well	6/13/2006	9/12/2019	26	0.68	Decreasing	-0.52
1114	BOE Well	6/13/2006	9/11/2019	30	0.30	None	-0.23
1115	Trench 2	6/13/2006	9/11/2019	35	0.41	None	-0.03
1117	Trench 2	7/18/2006	9/11/2019	35	0.03	None	-0.18
1128	Trench 2	3/6/2007	9/11/2019	21	1.20	Decreasing	-0.35
1132	Trench 2	3/6/2007	9/11/2019	23	0.012	Decreasing	-0.31
1134	Trench 2	3/6/2007	9/11/2019	22	0.029	None	0.07
1135	Western Floodplain	3/25/2010	9/11/2019	25	0.08	Decreasing	-0.61
1136	Central Floodplain	3/25/2010	9/10/2019	26	1.10	Increasing	0.69
1137	Well 1089/1104 Area	3/25/2010	9/11/2019	21	0.47	None	0.00
1138	Well 1089/1104 Area	3/25/2010	9/11/2019	20	0.18	None	-0.19
1139	Well 1089/1104 Area	3/25/2010	9/11/2019	25	0.13	None	-0.05
1140	Trench 1	9/16/2009	9/12/2019	21	0.59	Decreasing	-0.66
1141	Trench 1	9/16/2009	9/12/2019	21	0.92	Decreasing	-0.33
1142	South-Central (Hyporheic)	3/24/2010	9/12/2019	26	0.017	Increasing	0.45
1143	Western Floodplain	3/26/2010	9/10/2019	25	0.049	Decreasing	-0.42
0782R	Background	9/16/2008	9/13/2019	23	0.010	None	0.24
0783R	Background	9/17/2008	9/13/2019	23	0.008	Increasing	0.33

Notes:
Area groupings are consistent with those shown in Figure 11 and Figure A-1. The term "BOE" refers to base of escarpment wells. Mann-Kendall trend analyses were conducted at the 0.05 significance (or alpha) level. The test statistic, Kendall's tau, is a measure of the strength of the association between two variables, with values always falling between −1 and +1. An initial date of 2006 was used for most wells because that time frame corresponds to the installation of the floodplain trenches.

2.2 Most recent result less than the 10 mg/L 40 CFR 192 MCL (Table 1).

Significant decreasing trend based on Mann-Kendall test. Significant increasing trend based on Mann-Kendall test.

Table B-4. Summary of Mann-Kendall Trend Test Results for Nitrate, Sulfate, and Uranium in Floodplain Wells: 2006–September 2019

Well	Area	Initial Date	Final Date	Mann-Kendall Trend		
				Nitrate	Sulfate	Uranium
0610	BOE Well	9/11/2007	9/12/2019	Decreasing	Decreasing	Decreasing
0611	BOE Well	1/22/2008	9/12/2019	None	Decreasing	None
0612	South-Central (Hyporheic)	9/11/2007	9/12/2019	None	None	None
0614	BOE Well	3/9/2006	9/12/2019	Decreasing	Decreasing	Decreasing
0615	Trench 1	3/9/2006	9/12/2019	Decreasing	Decreasing	Decreasing
0618	Central Floodplain	3/8/2006	9/9/2019	Decreasing	Decreasing	Decreasing
0619	Central Floodplain	3/8/2006	9/11/2019	None	None	Decreasing
0622	Central Floodplain	9/12/2007	9/12/2019	None	Decreasing	Decreasing
0623	Western Floodplain	1/24/2008	9/12/2019	Decreasing	Decreasing	Decreasing
0625	Western Floodplain	1/24/2008	9/12/2019	None	None	Decreasing
0626	Western Floodplain	9/13/2007	9/12/2019	None	Decreasing	Decreasing
0628	Western Floodplain	9/13/2007	9/12/2019	None	None	None
0630	Western Floodplain	9/13/2007	9/12/2019	None	Increasing	Increasing
0734	Western Floodplain	3/15/2006	9/30/2014	None	None	None
0735	BOE Well	3/9/2006	9/12/2019	Increasing	Increasing	None
0736	Western Floodplain	3/10/2006	9/11/2019	None	Decreasing	Decreasing
0766	Well 1089/1104 Area	1/23/2008	9/11/2019	None	Decreasing	Decreasing
0768	Central Floodplain	1/24/2008	9/12/2019	None	Decreasing	Decreasing
0773	BOE Well	1/22/2008	9/12/2019	None	Decreasing	Decreasing
0775	Central Floodplain	1/24/2008	9/12/2019	None	Decreasing	Decreasing
0779	Central Floodplain	1/23/2008	9/12/2019	None	None	None
0792	Central Floodplain	9/12/2007	9/9/2019	None	Decreasing	Decreasing
0793	Central Floodplain	9/12/2007	9/13/2019	Decreasing	None	Decreasing
0798	Central Floodplain	9/12/2007	9/11/2019	None	Decreasing	Decreasing
0853	South-Central (Hyporheic)	9/12/2007	9/12/2019	None	Increasing	None
0854	Well 1089/1104 Area	1/23/2008	9/11/2019	Decreasing	Decreasing	Decreasing
0855	Western Floodplain	9/13/2007	9/10/2019	Increasing	None	None
0856	Western Floodplain	9/13/2007	9/11/2019	Decreasing	None	None
0857	Central Floodplain	9/12/2007	9/9/2019	None	Increasing	Increasing
1008	Well 1089/1104 Area	3/10/2006	9/11/2019	Decreasing	Decreasing	Decreasing
1009	South-Central (Hyporheic)	9/12/2007	9/12/2019	Decreasing	Decreasing	Decreasing
1089	Well 1089/1104 Area	3/14/2006	9/11/2019	Decreasing	Decreasing	Decreasing
1104	Well 1089/1104 Area	3/14/2006	9/11/2019	Decreasing	Decreasing	Decreasing
1105	Trench 1	3/6/2007	9/12/2019	Decreasing	Decreasing	Decreasing
1111	Trench 1	6/13/2006	9/11/2019	None	None	Decreasing
1112	Trench 1	6/13/2006	9/12/2019	Decreasing	Decreasing	Decreasing
1113	BOE Well	6/13/2006	9/12/2019	Decreasing	Decreasing	Decreasing
1114	BOE Well	6/13/2006	9/11/2019	None	None	None
1115	Trench 2	6/13/2006	9/11/2019	None	None	None
1117	Trench 2	7/18/2006	9/11/2019	None	None	None
1128	Trench 2	3/6/2007	9/11/2019	None	None	Decreasing
1132	Trench 2	3/6/2007	9/11/2019	None	Increasing	Decreasing
1134	Trench 2	3/6/2007	9/11/2019	None	None	None
1135	Western Floodplain	3/25/2010	9/11/2019	None	Decreasing	Decreasing
1136	Central Floodplain	3/25/2010	9/10/2019	Increasing	Increasing	Increasing
1137	Well 1089/1104 Area	3/25/2010	9/11/2019	None	None	None
1138	Well 1089/1104 Area	3/25/2010	9/11/2019	Decreasing	None	None
1139	Well 1089/1104 Area	3/25/2010	9/11/2019	Decreasing	None	None
1140	Trench 1	9/16/2009	9/12/2019	Decreasing	Decreasing	Decreasing
1141	Trench 1	9/16/2009	9/12/2019	None	None	Decreasing
1142	South-Central (Hyporheic)	3/24/2010	9/12/2019	Decreasing	None	Increasing
1143	Western Floodplain	3/26/2010	9/10/2019	Decreasing	None	Decreasing

Notes:
This table summarizes the trend analysis results based on more detailed information presented in Tables B-1 through B-3.
Area groupings are consistent with those shown in Figure 11 and Figure A-1. The term “BOE” refers to base of escarpment wells.
Only wells on the contiguous floodplain are listed; background wells 0797, 0850, 0783R, and 0783R are excluded.
Significant decreasing trend based on Mann-Kendall test. Significant increasing trend based on Mann-Kendall test.

Appendix C

Hydrographs for Terrace Alluvial Wells

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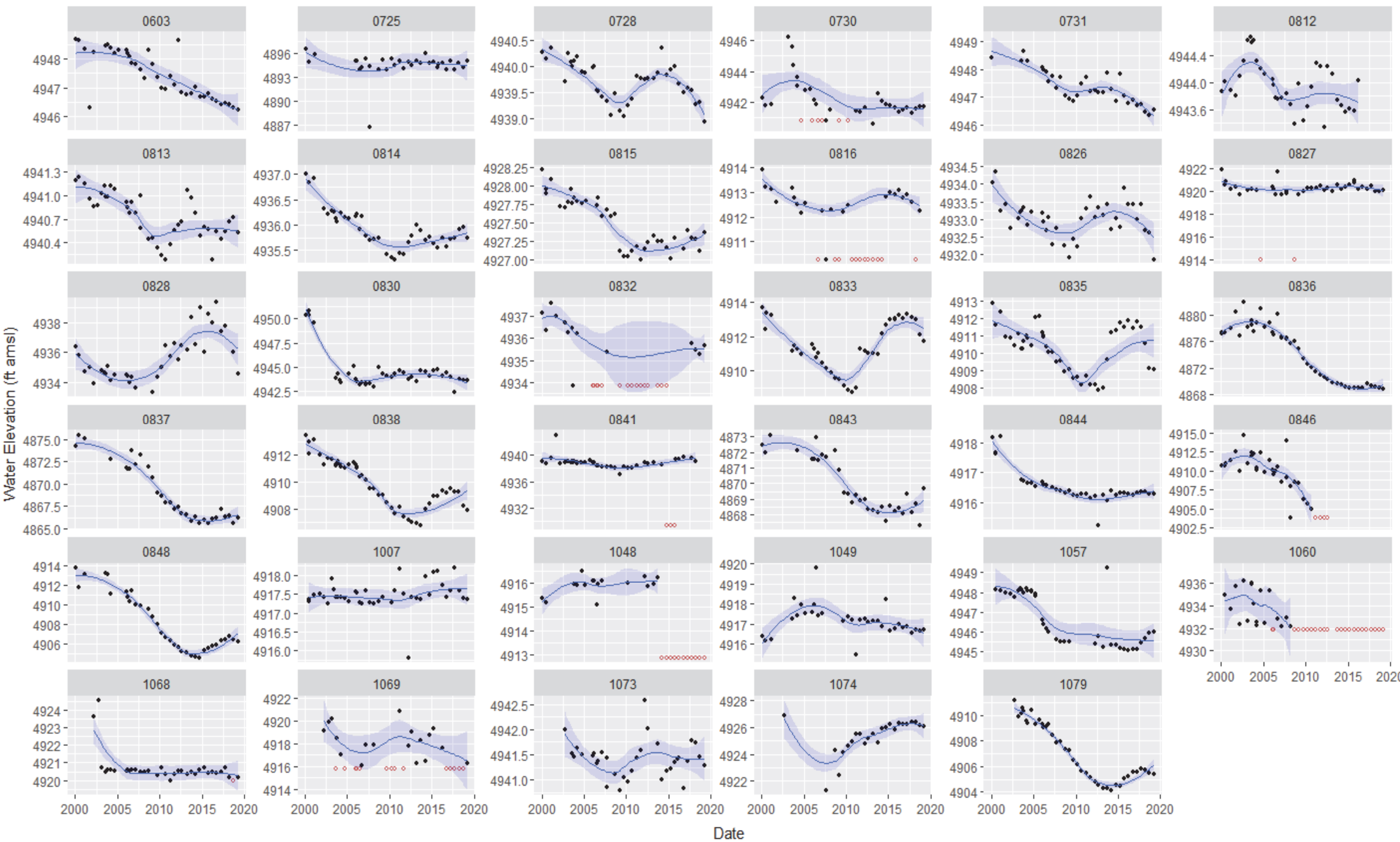

Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ 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)

Note: Water level data for terrace wells 1120 and 1122 are not shown because these wells have been dry since March 2010.

Abbreviation: ft amsl = feet above mean sea level

Figure C-1. Hydrographs for Shiprock Disposal Site Terrace Alluvial Wells, 2000–September 2019

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