Department of Energy
Washington, DC 20585

March 24, 2020

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Deputy Director
Mail Stop T8-F5
Washington, DC 20555-0001

Subject: U.S. Department of Energy, Office of Legacy Management Draft *2018 Annual Performance Report April 2017 Through March 2018 for the Shiprock, New Mexico, UMTRCA Title I Disposal Site* (NRC Docket No. WM-0058)

To Whom It May Concern:

Enclosed for Nuclear Regulatory Commission (NRC) review is the *2018 Annual Performance Report April 2017 Through March 2018 for the Shiprock, New Mexico, UMTRCA Title I Disposal Site* for the Shiprock, New Mexico, site. This annual report evaluates the performance of the groundwater remediation system at the Shiprock site for the period April 2017 through March 2018.

Please contact me at (970) 248-6018 or Mark.Kautsky@lm.doe.gov, if you have any questions. Please address any correspondence to:

U.S. Department of Energy
Office of Legacy Management
2597 Legacy Way
Grand Junction, CO 81503

Sincerely,

Digitally signed by MARK KAUTSKY
Date: 2020.03.24 14:08:34 -06'00'

Mark Kautsky
UMTRCA Program Manager

Enclosure

cc w/enclosure:
D. Orlando, NRC
S. Austin, NN EPA
J. Tallbull, NN AML/UMTRA
M. Yazzie, NN AML/UMTRA
D. Miller, Navarro (e)
K. Whysner, Navarro (e)
DOE Read File
File: SHP 3500-04

NMSS01
NMSS

LMS/SHP/S20604

Annual Performance Report April 2017 Through March 2018 for the Shiprock, New Mexico, Disposal Site

September 2019

U.S. DEPARTMENT OF ENERGY | Legacy Management

This page intentionally left blank

Contents

Figures

Tables

Appendixes

Plate

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

Abbreviations

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

This page intentionally left blank

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 2017 through March 2018. 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

This report differs from previous annual performance reports because there is little "performance"—that is, groundwater extraction and associated contaminant mass removal—to report. In the last several years, LM has observed that the evaporation pond liner is deteriorating to the point that LM must either replace the liner or decommission the pond entirely. The deteriorated liner has caused LM to temporarily cease pumping of groundwater from most locations at the site. Pumping was suspended at all Shiprock site treatment system locations except Bob Lee Wash on April 21, 2017. Between that time and April 1, 2018 (the end of this reporting period), there were only a few brief intermittent periods of groundwater extraction. As such, while the format of previous annual performance reports is largely maintained, another objective of this report is to evaluate whether suspending pumping for the bulk of the reporting period had any short-term adverse impacts.

Compliance Strategy and Remediation Goals

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

Semiannual Sampling Results

During the September 2017 and March 2018 sampling events, 114 monitoring wells were sampled (59 on the floodplain and 55 on the terrace). Fifteen surface water locations, including nine San Juan River sampling points and various seeps, were also sampled. Contaminant distributions of nitrate, sulfate, and uranium (the primary COCs at the site) continue to be generally the same as those observed in previous years. In general, relative to baseline (2000–2003) conditions, marked reductions in concentrations of uranium, sulfate, and (especially) nitrate are apparent in many floodplain wells, most notably in the vicinity of the three remediation areas (Trench 1, Trench 2, and pumping wells 1089 and 1104). These reductions have been attributed to pumping but could also reflect natural attenuation.

Because pumping on the floodplain was suspended for all but 3 weeks of this reporting period, it was important to evaluate whether this change had any impact on contaminant concentrations or the floodplain plume configuration. Apart from some increases in COC concentrations in wells installed near the trench areas, there were no notable changes in contaminant levels in most of the wells throughout the floodplain. Most of these increases were slight and within the range of historical observations. Consistent with historical observations, uranium and nitrate concentrations in samples collected from the San Juan River have been below established benchmarks and comparable to upstream (background) locations.

Summary of Remediation Performance and Site Evaluation Progress

During the first 3 weeks of this reporting period (April 1–21, 2017), groundwater in the floodplain system was extracted from two wells (wells 1089 and 1104) adjacent to the San Juan River north of the disposal cell, two collection trenches, and a seep collection sump. Pumping was then suspended, and later resumed only briefly in September 2017 and March 2018. As a result, only about 1.25 million gallons of groundwater were extracted from the floodplain aquifer system during this reporting period, in contrast to 15.7 million gallons extracted in 2016–2017. Approximately 150.3 million gallons have been extracted from the floodplain since DOE began active remediation in March 2003.

Pumping of the nine extraction wells on the terrace also ceased in late April 2017. However, groundwater extraction from the Bob Lee Wash collection drain trench continued, to meet the risk-based performance objective. From April 2017 through March 2018, approximately 1.7 million gallons of groundwater were extracted from the terrace system; the bulk of this (1.5 million gallons) was from Bob Lee Wash. The total cumulative volume extracted from the terrace system is approximately 49.6 million gallons. The cumulative volume removed from both the terrace and the floodplain combined (as of April 1, 2018) is nearly 200 million gallons. Estimated masses of nitrate, sulfate, and uranium removed from the floodplain and terrace well fields during this performance period were approximately 6937 pounds; 147,872 pounds; and 10.2 pounds, respectively.

1.0 Introduction

This report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal Site for the period April 2017 through March 2018. 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).

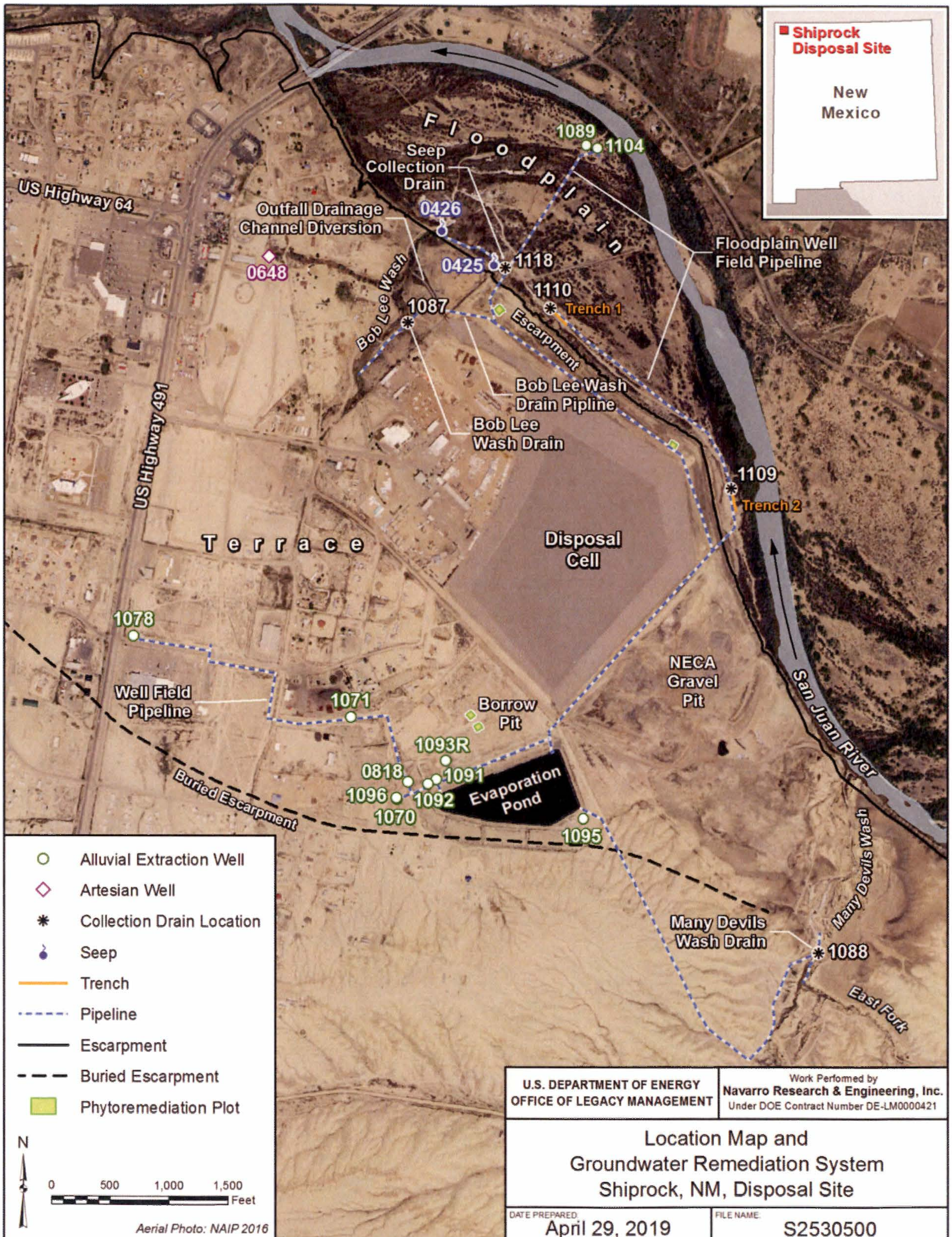
The Shiprock mill operated from 1954 to 1968; mill tailings were stabilized in an engineered disposal cell in 1986. As a result of milling operations, groundwater in the mill site area was contaminated with uranium, nitrate, sulfate, and associated constituents. In March 2003, DOE initiated active remediation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

1.1 Current Site Status

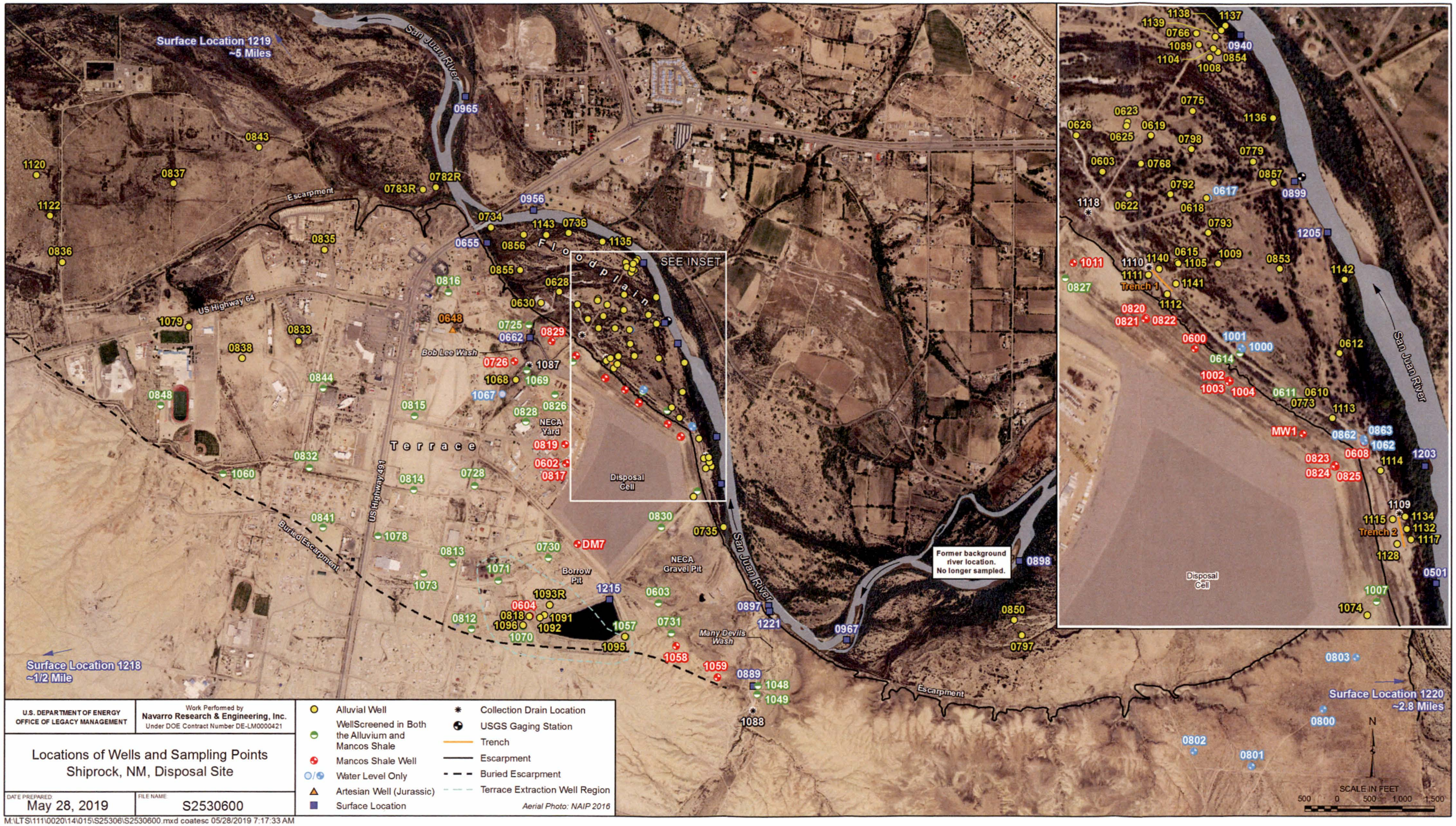
This report differs somewhat from previous annual performance reports because there is little "performance"—that is, groundwater extraction and associated contaminant mass removal—to report. In the last several years, LM has observed that the evaporation pond liner is deteriorating to the point that LM must either replace the liner or decommission the pond entirely (and continue with natural flushing). The deteriorated liner has caused LM to temporarily cease pumping of groundwater from most locations at the site. Pumping was suspended at all Shiprock site treatment system locations except Bob Lee Wash on April 21, 2017. Between that time and April 1, 2018 (the end of this reporting period), there were only temporary intermittent periods of resumed pumping. As such, while the format of previous annual performance reports (e.g., DOE 2018a) is largely maintained, an additional objective of this report is to evaluate whether the wide-scale suspension of pumping has resulted in an increase in contaminant concentrations or any adverse human health or environmental impacts.



M:\LTS\111\0020\14\015\S25305\S2530500.mxd coatesc 04/29/2019 12:31:04 PM

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



Note: 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.

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

This page intentionally left blank

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. Specific performance standards or metrics established for the Shiprock floodplain groundwater remediation system in the Baseline Performance Report (DOE 2003) are:

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

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

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

The performance standards summarized above are based on the active remediation aspects of the compliance strategies documented in the GCAP (DOE 2002). The site conceptual model on which the GCAP was based is documented in the Site Observational Work Plan (SOWP) (DOE 2000). Based on subsequent evaluations and investigations (e.g., DOE 2005; DOE 2009; DOE 2011a; DOE 2011d; and DOE 2013), LM has recently initiated an update of the site conceptual model. These evaluations indicate that some of the performance metrics listed above may no longer be appropriate.

For example, Many Devils Wash is no longer a focus (pumping of the 1088 collection drain was terminated in 2014) because the groundwater discharging to the wash is naturally contaminated, contradicting the original assumption of a mill site origin. As found for other desert arroyos in the area that are not impacted by uranium milling, the contamination in Many Devils Wash is the result of the natural interaction of water with the Mancos Shale and is not related to the mill site (DOE 2011b; DOE 2011c; Morrison et al. 2012; Robertson et al. 2016). Based on this information, LM has terminated remediation efforts in Many Devils Wash; the structures that were emplaced are slated for decommissioning.

LM is currently reevaluating all aspects of the site compliance strategy to ensure that performance standards are consistent with updated characterizations of site hydrogeology and the nature and extent of site-related contamination. With regard to the pumping suspension that characterized most of this reporting period, the GCAP states that "operation of any particular extraction well may be discontinued at any time if it is determined that continued extraction of contaminated water in its vicinity is no longer practical" (DOE 2002). The latter option to discontinue pumping does not apply to Bob Lee Wash, however, as it continues to be a potential point of exposure.

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* Part 192 (40 CFR Part 192), which apply to UMTRCA sites. The remediation goals listed in this table apply to the floodplain only because the current compliance strategy for the terrace is to decrease groundwater elevations and flow rates at seeps.

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

Contaminant	40 CFR Part 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 the EPA Safe Drinking Water Act maximum contaminant level. 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.

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

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

As listed in Table 1, the 40 CFR Part 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 Part 192 standard of 0.01 mg/L for this constituent can be met. Therefore, an alternate concentration limit for selenium of 0.05 mg/L was proposed for the floodplain in the GCAP (DOE 2002), which is the maximum contaminant level for drinking water established under the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act. This alternate level may still be too conservative, given the potential influence from natural sources addressed in several DOE evaluations (DOE 2011b, 2011c) and a report recently issued by the U.S. Geological Survey (Robertson et al. 2016).

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

Regulatory standards are also not available for strontium, a constituent typically not associated with uranium-milling sites. Strontium was selected as a COC in the Baseline Risk Assessment (DOE 1994) primarily because of concentrations measured in sediment (rather than groundwater) and a conservatively modeled agricultural uptake scenario. The form present at the Shiprock site is stable (nonradioactive) strontium, a naturally occurring element, and is distinguished from the radioactive and much more toxic isotope strontium-90, a nuclear fission product (ATSDR 2004). EPA's Regional Screening Level for stable strontium in drinking (tap) water is 12 mg/L, assuming a target hazard quotient of 1.0 (Table 1).

Historically, sulfate concentrations have been elevated in groundwater entering the floodplain from flowing artesian well 0648, where levels have ranged from 1810 to 2340 mg/L. Because of these elevated levels from a natural source, the GCAP proposed a cleanup goal of 2000 mg/L for sulfate in floodplain wells. This alternate goal is conservative, as sulfate concentrations in floodplain background wells have exceeded 2000 mg/L in the majority of samples from well 0797 (with levels as high as 5200 mg/L) and nearly one-third of those from well 0850.

1.4 Hydrogeological Setting

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

1.4.1 Floodplain Alluvial Aquifer

The thick Mancos Shale of Cretaceous age forms the bedrock underlying the entire site. A floodplain alluvial aquifer occurs in unconsolidated medium- to coarse-grained sand, gravel, and cobbles that were deposited in former channels of the San Juan River above the Mancos Shale.

The floodplain aquifer is hydraulically connected to the San Juan River; the river is a source of groundwater recharge to the floodplain aquifer in some areas, and it receives groundwater discharge in other areas. In addition, the floodplain aquifer receives some inflow from groundwater in the terrace area. The floodplain alluvium is up to 20 feet (ft) thick and overlies Mancos Shale, which is typically soft and weathered for the first several feet below the alluvium.

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

1.4.2 Terrace Groundwater System

The terrace groundwater system occurs partly in unconsolidated alluvium in the form of medium- to coarse-grained sand, gravel, and cobbles deposited in the floodplain of the ancestral San Juan River. Terrace alluvial material is Quaternary in age; it varies from 0 to 20 ft in thickness and caps the Mancos Shale. Although not as well mapped, some terrace groundwater also occurs in weathered Mancos Shale underlying the alluvium. The Mancos Shale is exposed in the escarpment adjacent to the San Juan River floodplain.

The terrace groundwater system is bounded on its south side by an east-west-trending buried bedrock (Mancos Shale) escarpment, about 1500 ft south of the southernmost tip of the disposal cell (Figure 1). The terrace system extends more than a mile west and northwestward, to more than 4000 ft west of Highway 491. Terrace alluvial material is exposed at ground surface in the vicinity of the terrace-floodplain escarpment; south and southwest of the former mill, the terrace alluvium is covered by eolian silt (deposited by wind), or loess, which increases in thickness with proximity to the buried bedrock escarpment. Up to 40 ft of loess overlies the alluvium along the base of the buried escarpment. Terrace alluvium consists of coarse-grained ancestral San Juan River deposits, primarily in the form of coarse sands and gravels.

Mancos Shale underlying the alluvium in the terrace area is soft and weathered. The weathered Mancos Shale is typically 2–10 ft thick, but some characteristics of weathering below the shale-alluvium contact occur as deep as 30 ft in places (DOE 2000). Groundwater 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 2017–2018 reporting period.

2.1 Floodplain Remediation System

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

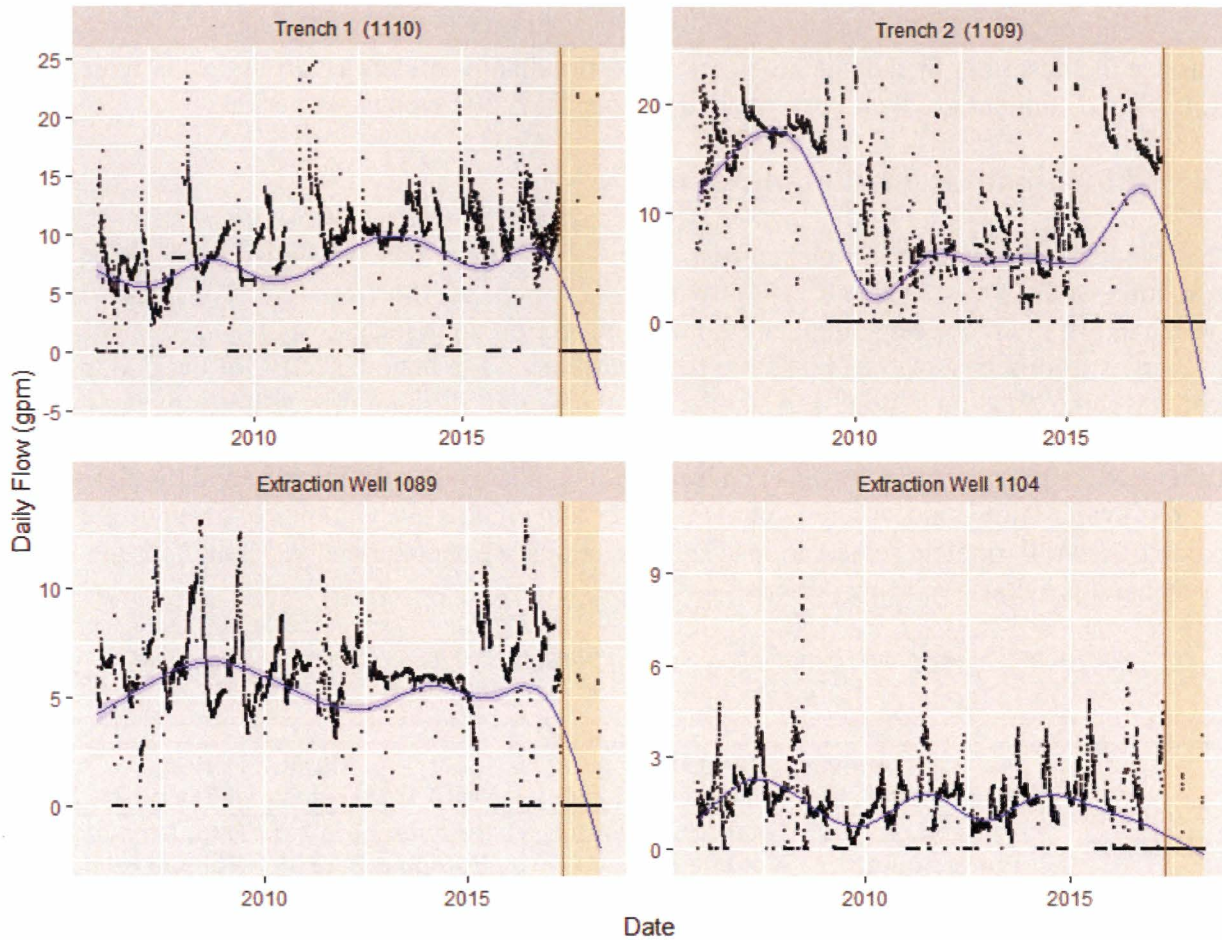
Table 2. Floodplain Remediation System Locations: Average Pumping Rates and Total Groundwater Volume Removed

Floodplain Location	Previous Period (April 1, 2016, through March 31, 2017)		Current Period (April 1, 2017, through March 31, 2018)	
	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
1089	5.95	3,129,716	0.39	204,973
1104	1.11	584,097	0.12	61,647
Trench 1 (1110)	9.84	5,172,146	1.0	524,556
Trench 2 (1109)	12.7	6,676,601	0.83	433,650
Seep (1118)	0.27	143,248	0.04	23,249
Total	**29.9** (cum. avg.)	**15,705,808**	**2.4**	**1,248,074**

Note: Pumping was suspended at all floodplain treatment system locations on April 21, 2017.

2.1.1 Extraction Well Performance

The floodplain extraction well system consists of wells 1089 and 1104 (Figure 1). These wells were constructed using slotted culverts placed in trenches excavated to bedrock. Because pumping was suspended on the floodplain just 3 weeks after the start of the current reporting period, corresponding pumping rates and volumes are markedly lower than those recorded in 2016–2017. From April 2017 through March 2018, approximately 267,000 gallons of water were removed from the two floodplain extraction wells (1089 and 1104), in contrast to the 3.7 million gallons extracted previously (Table 2). Average annual pumping rates were only 0.4 and 0.1 gpm (wells 1089 and 1104, respectively), resulting in just a small increment in cumulative flows. During the period since the start of operations in March 2003 through the end of March 2018, totals of approximately 39.6 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.



Notes:
Data plotted are since the inception of the System Operation and Analysis at Remote Sites (SOARS) system in late 2005.
y-axis scales are unique for each well, so plots are not directly comparable.
Pumping resumed temporarily in late September 2017 and late March 2018.

Figure 3. Historical Pumping Rates in Floodplain Trenches and Extraction Wells: 2005–2018

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 2017 through March 2018, about 524,560 and 433,650 gallons of water were removed from Trench 1 and Trench 2, respectively (Table 2). The total volume extracted from both drains, about 958,200 gallons, is 8% of the combined volume extracted in 2016–2017 (11.8 million gallons). Average pumping rates were ≤1 gpm in 2017–2018, in contrast to previous pumping rates of approximately 10–13 gpm in 2016–2017. During the period since the trenches were installed in 2006, totals of approximately

44.6 and 53.7 million gallons of water have been removed from Trench 1 and Trench 2, respectively (totaling 98 million gallons).

2.1.3 Floodplain Seep Sump Performance

In August 2006, seeps 0425 and 0426 were incorporated into the remediation system. Groundwater discharge from these two seeps is piped into a collection sump (location 1118) and then pumped to the evaporation pond. From April 2017 through March 2018, the average discharge rate from the seep collection drain was only 0.04 gpm (Table 2). Approximately 23,250 gallons were pumped from the seeps during this period (vs. 143,250 gallons in 2016–2017), yielding a total cumulative volume pumped of about 3 million gallons 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 that potential exposure pathways at seeps and at Bob Lee Wash are eventually eliminated and the flow of groundwater from the terrace to the floodplain is reduced. The terrace remediation system currently consists of four major components shown in Figure 1: the extraction wells, the evaporation pond, the terrace drain at Bob Lee Wash, and the terrace outfall drainage channel diversion.

2.2.1 Extraction Well Performance

During the current period, the terrace remediation well field consisted of wells 0818, 1070, 1071, 1078, 1091, 1092, 1093R, 1095, and 1096. Table 3 compares the average pumping rate and total groundwater volume removed from each terrace extraction well and drain location for the current (2017–2018) and previous (2016–2017) reporting periods. Figure 4 plots historical daily flows (pumping rates) for the nine terrace extraction wells.

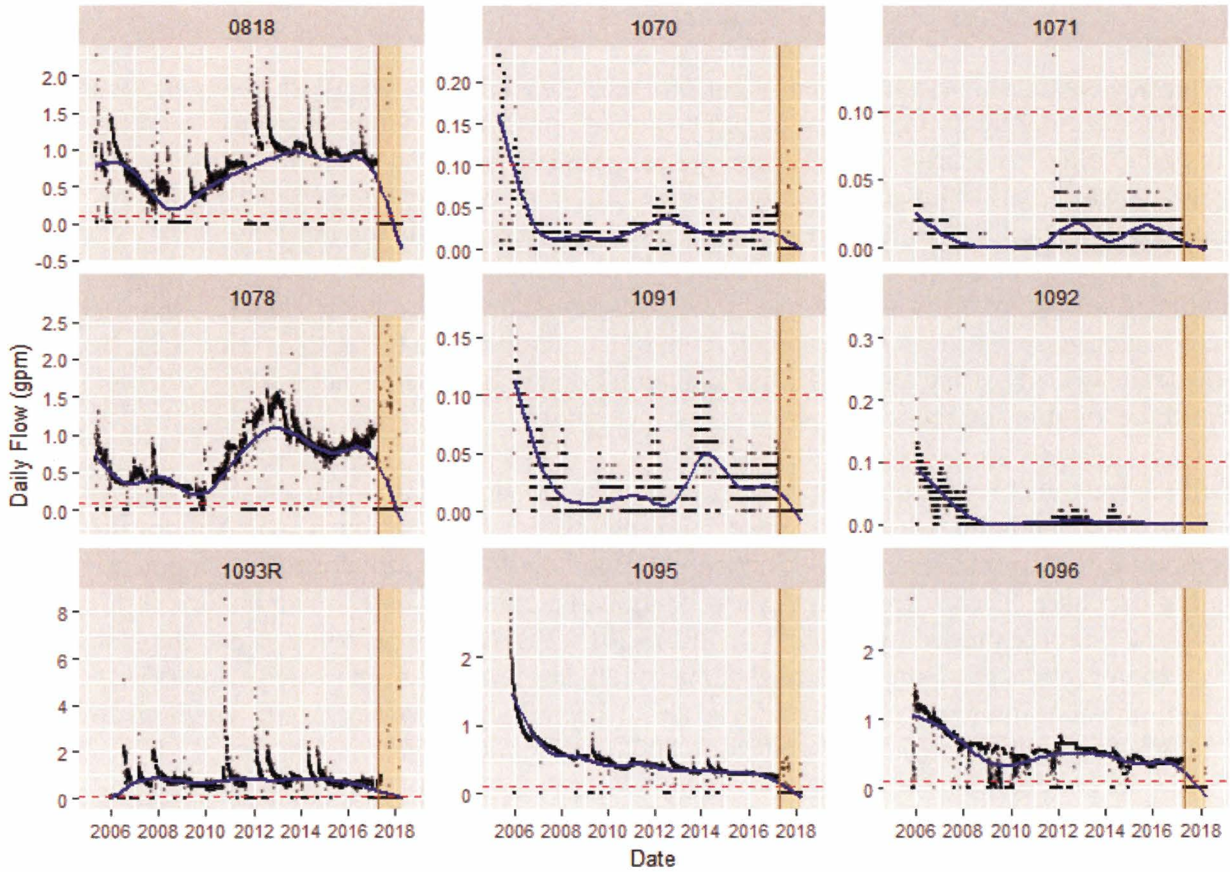
As has been the case since shortly after pumping began (Figure 4), average pumping rates from wells 1070, 1071, 1091, and 1092 continue to be less than 0.1 gpm, the minimum (150 gallons per day) yield required to be considered an aquifer under 40 CFR Part 192. Because pumping was suspended for the bulk of this reporting period, average pumping rates at all terrace extraction wells were low, ranging from 0 to 0.21 gpm (with the maximum at well 1093R). The total volume removed from pumping the terrace extraction wells in 2017–2018 was about 267,600 gallons. This volume corresponds to 18% of the volume extracted during the previous reporting period (1.5 million 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. As concluded in the last several annual reports, despite these enhancements, and even with continued maintenance of the pumping system, the 8 gpm objective has not been achieved. Historically, the combined pumping rate from terrace extraction wells has ranged from about 2 to 4 gpm.

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

Terrace Well or Drain	Previous Period (April 1, 2016, through March 31, 2017)		Current Period (April 1, 2017, through March 31, 2018)	
	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818	0.9	471,185	0.063	33,188
1070	0.024	12,802	0.005	2,509
1071	0.011	5,540	0.0004	201
1078	0.82	433,733	0.168	88,311
1091	0.023	12,349	0.003	1,758
1092	0	0	0	0
1093R	0.47	245,548	0.21	108,088
1095	0.26	137,908	0.031	16,035
1096	0.38	200,778	0.033	17,482
Extraction Well Subtotal	**2.9** (cum. avg.)	**1,519,843**	**0.51**	**267,572**
Bob Lee Wash (1087)	2.8	1,456,339	2.8	1,456,665
Many Devils Wash (1088)	0	0	0	0
Total	**5.66** (cum. avg.)	**2,976,181**	**3.3**	**1,724,237**

Notes:
Minor discrepancies in subtotal and total values versus manual addition of location-specific entries are due to rounding.
Many Devils Wash has not been pumped since 2014 because of the need for repairs and the presence of naturally occurring contamination.



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

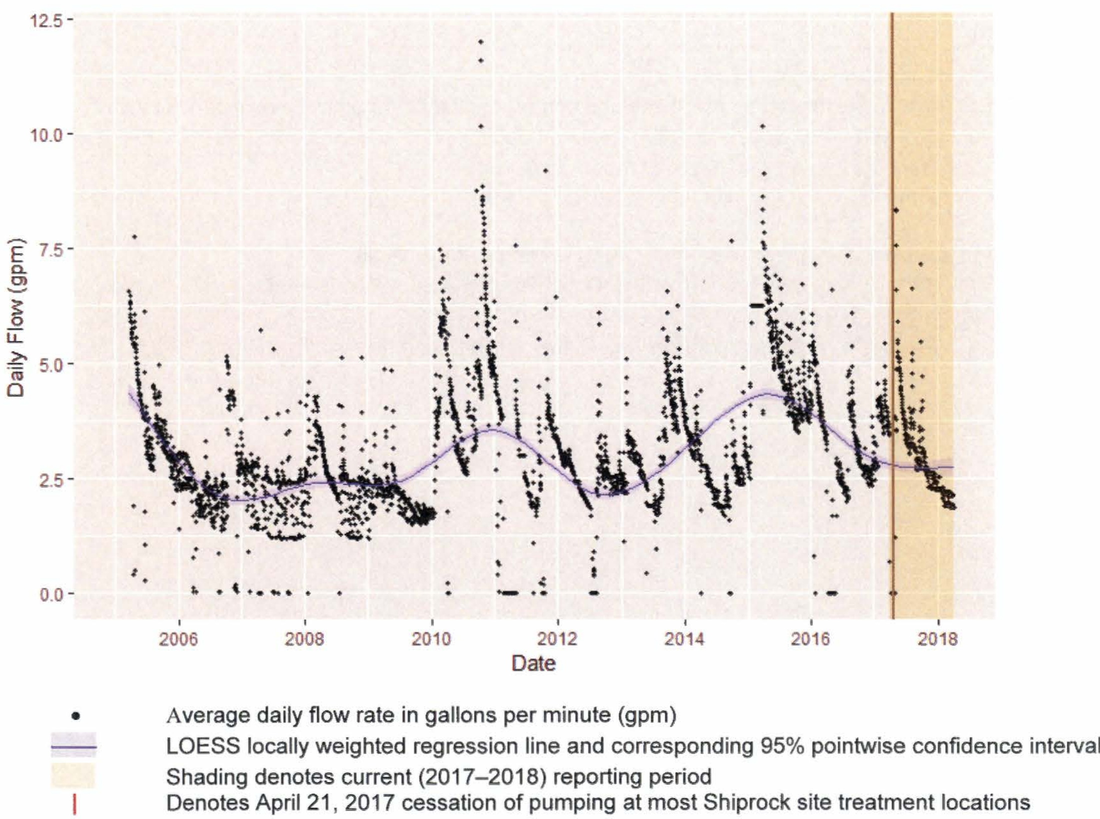
Notes:
Data plotted are since the inception of the SOARS system in 2005–2006.
y-axis scales are unique for each well so plots are not directly comparable.

Figure 4. Historical Pumping Rates in Terrace Extraction Wells: 2005–2018

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 for two reasons: (1) the need for extensive repairs of the system and (2) the groundwater in the wash was determined to be of a nonmill origin (refer to Section 1.2). Because of these factors, in particular the fact that contamination in the wash is naturally occurring, LM plans to decommission the interceptor drain system in this region.

Of all the treatment locations at the site, including the floodplain, Bob Lee Wash is the only location where pumping was not suspended during this reporting period. The reason for this exception is that, from a health risk perspective, Bob Lee Wash is still considered a potential point of exposure. Therefore, pumping was continued at rates consistent with historical flows; daily flow rates are plotted in Figure 5. In 2017–2018, the average pumping rate at the Bob Lee Wash drain was 2.8 gpm, the same as that measured during the last reporting period (Table 3). The groundwater interceptor drain removed about 1.5 million gallons of water, yielding a total cumulative volume (since pumping began in 2003) of 24 million gallons.

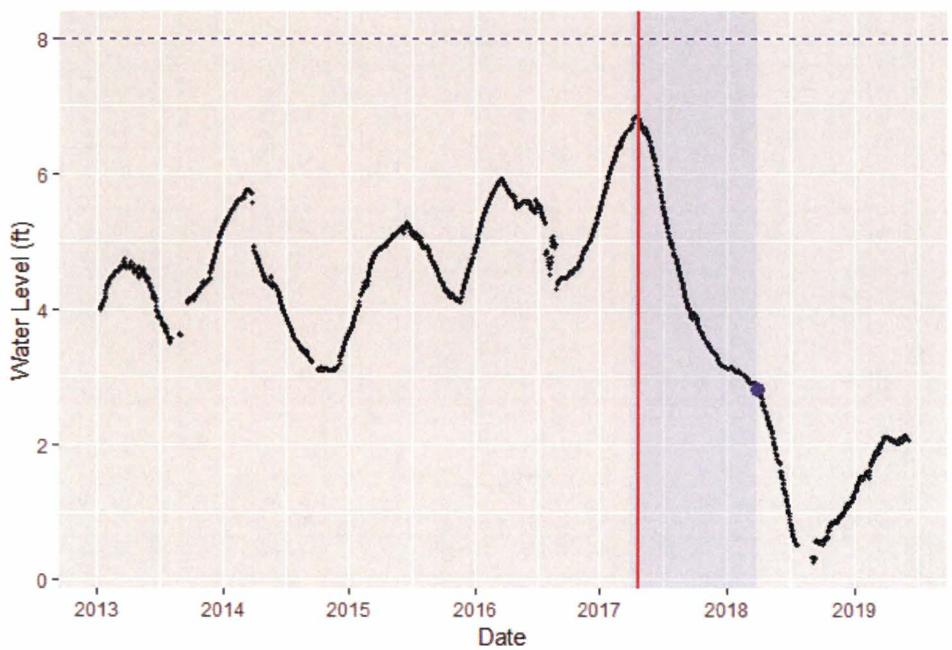


Note:
Data plotted are since the inception of the SOARS system in 2005.

Figure 5. Historical Flow Rates in Bob Lee Wash (1087): 2005–2018

2.2.3 Evaporation Pond

The selected method for handling groundwater from the interceptor drains and extraction wells is solar evaporation. Contaminated groundwater is pumped to an 11-acre lined evaporation pond in the south part of the radon-cover borrow pit area (Figure 1). At the close of this reporting period (March 31, 2018), the average water level in the evaporation pond was just 2.8 ft, measured as the distance above transducers. This low level relative to previous years is the result of the pumping suspension, which began just 3 weeks into the 2017–2018 reporting period (Figure 6).



- Pond water level (ft)
- Pond water level (2.8 ft) at end of reporting period, 2.8 ft

---- Pond capacity, 8 ft

Shading denotes current (2017–2018) reporting period

| Denotes April 21, 2017 cessation of pumping at most treatment system locations

Notes:

Water level data plotted are since the pond was instrumented with a SOARS transducer in early 2013. More recent pond water levels (beyond the current 2017–2018 reporting period) are also shown, primarily to illustrate the duration of the nonpumping period.

Figure 6. Water Levels in Evaporation Pond, 2013–June 2019

From April 2017 through March 2018, about 2.97 million gallons of extracted groundwater were pumped to the evaporation pond, in contrast to about 18.7 million gallons extracted the previous (2016–2017) reporting period. About one-half (1.5 million gallons, or 49%) of the influent liquids entering the pond during the current reporting period were from Bob Lee Wash, the only treatment system location where pumping was sustained through the reporting period (Table 4, Figure 5). As shown in Figure 7, at the end of the 2017–2018 reporting period, about 49.5 million gallons have been extracted from the terrace and 150.3 million gallons have been extracted from the floodplain since DOE began active remediation in March 2003. This yields a total cumulative extracted volume of nearly 200 million gallons of water pumped to the evaporation pond from all sources. Total cumulative contributions are 25% from the terrace and 75% from the floodplain.

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 Total Cum. Volume Pumped (%)	Nitrate as N Average Concentration, 2017–2018 (mg/L)	Nitrate Mass Removed, 2017–2018 (lb)[b]	Cumulative Mass of Nitrate Removed (lb)[c]	Sulfate Average Concentration, 2017–2018 (mg/L)	Sulfate Mass Removed, 2017–2018 (lb)[b]	Cumulative Mass of Sulfate Removed (lb)[c]	Uranium Average Concentration, 2017–2018 (mg/L)	Uranium Mass Removed, 2017–2018 (lb)[b]	Cumulative Mass of Uranium Removed (lb)[c]
Terrace												
0818	33,188	5,753,476	1.1	725	201	55,934	14,500	4,016	617,123	0.17	0.047	6.0
1070	2509	545,087	0.08	640	13.4	3870	14,500	304	75,901	0.095	0.002	0.55
1071	201	121,644	0.01	620	1.0	1799	13,500	23	7,468	0.145	0.0002	0.15
1078	88,311	4,738,156	3.0	395	291	23,086	13,000	9,581	543,667	0.105	0.077	5.18
1091	1	261,675	0.06	720	10.6	3079	13,500	198	27,428	0.115	0.002	0.25
1092	0	224,883	0	590	0	2875	14,500	0	24,820	0.092	0	0.22
1093R[c]	108,088	4,468,130	3.6	1850	1669	78,545	7,100	6,404	216,470	0.165	0.15	3.97
1094 (2003–2004)[d]		15,628	–	–	–	524	–	0	312	–	–	0.01
1095	16,035	2,815,247	0.54	2250	301	37,584	4,350	582	141,383	0.0535	0.007	1.37
1096	17,482	3,116,817	0.59	670	97.7	16,142	15,000	2,188	373,048	0.0855	0.012	2.66
1087 (BLW)	1,456,665	24,082,846	49.0	285	3465	60,776	6,150	74,762	1,424,038	0.435	5.29	109.6
1088 (MDW)	0	3,406,532	0	Not Sampled	0	18,654	Not Sampled	0	535,882	Not Sampled	0	5.00
Floodplain												
1077 (2003–2005)[d]	–	812,449	–	–	–	1214	–	–	116,410	–	–	16.8
1089	204,973	39,608,182	6.9	0.865	1.5	5632	4,050	6928	2,367,158	0.13	0.22	223.5
1104	61,647	8,562,167	2.1	0.64	0.33	2972	4,500	2315	615,250	0.21	0.11	69.3
Trench 1 (1110)	524,556	44,605,807	17.6	55.5	243	37,285	6,600	28,892	2,611,702	0.625	2.74	296.5
Trench 2 (1109)	433,650	53,693,053	14.6	175	633	32,924	2,900	10,495	665,604	0.40	1.45	96.5
Seep sump (1118)	23,249	3,013,883	0.78	52.5	10.2	1264	6,100	1184	150,977	0.395	0.077	12.0
Total terrace[d]	1,724,237	49,550,121	58.0	–	6049	302,867	–	98,058	3,987,540	–	5.6	134.9
Total floodplain[d]	1,248,074	150,295,540	42.0	–	888	81,292	–	49,814	6,527,101	–	4.6	714.7
Total to pond[d]	2,972,311	199,845,661	–	–	6937	384,159	–	147,872	10,514,641	–	10.2	849.6

Notes:

[a] Annual cumulative volumes are for this reporting period: April 1, 2017, through March 31, 2018. Total cumulative volumes are totals since 2003.

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

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

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

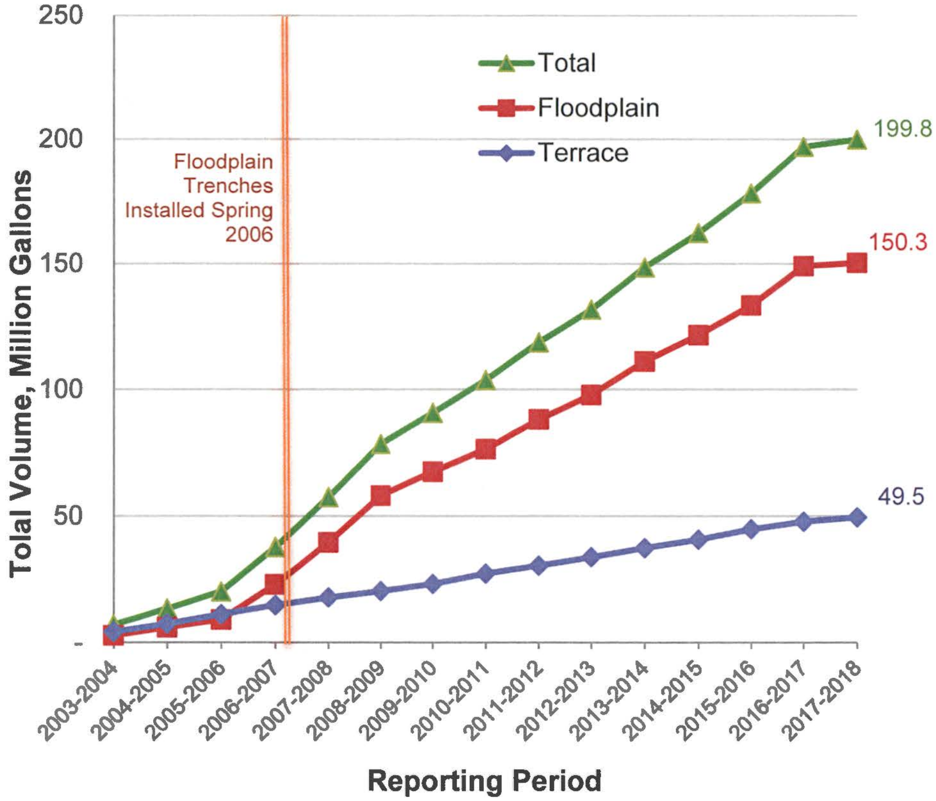


Figure 7. Total Groundwater Volume Pumped to the Evaporation Pond

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 2017–2018 performance period were approximately 6937 pounds nitrate (as N); 147,872 pounds sulfate; and 10.2 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.

This page intentionally left blank

3.0 Current Conditions

This section summarizes water quality and hydraulic characteristics of the floodplain and terrace groundwater systems for the April 2017 through March 2018 reporting period. During the March 2018 sampling event, 114 monitoring wells were sampled (59 on the floodplain and 55 on the terrace). Fifteen surface water locations, including nine San Juan River sampling points and various seeps, were also sampled.

3.1 Floodplain Contaminant Distributions and Temporal Trends

This discussion and the supporting figures presented in this section focus on nitrate, sulfate, and uranium because these contaminants are most widespread on the floodplain and are used to gauge the effectiveness of the remediation system at the Shiprock site. For these COCs, the alluvial plume maps (Figure 8 through Figure 10) compare baseline and current conditions using all alluvial wells that were sampled during both periods.[1] Because interpolations of COC concentrations at unsampled areas (i.e., between well locations) are based on measurements made at the closest surrounding sites, it is important to acknowledge the differing well density between the two periods. For example, additional wells were completed in 2006 after installation of the two trenches, and new near-river monitoring locations were also established. Corresponding time-concentration graphs for the primary COCs are provided in Appendix A using the spatial groupings shown in Figure 11 (see Figures A-1 through A-9).

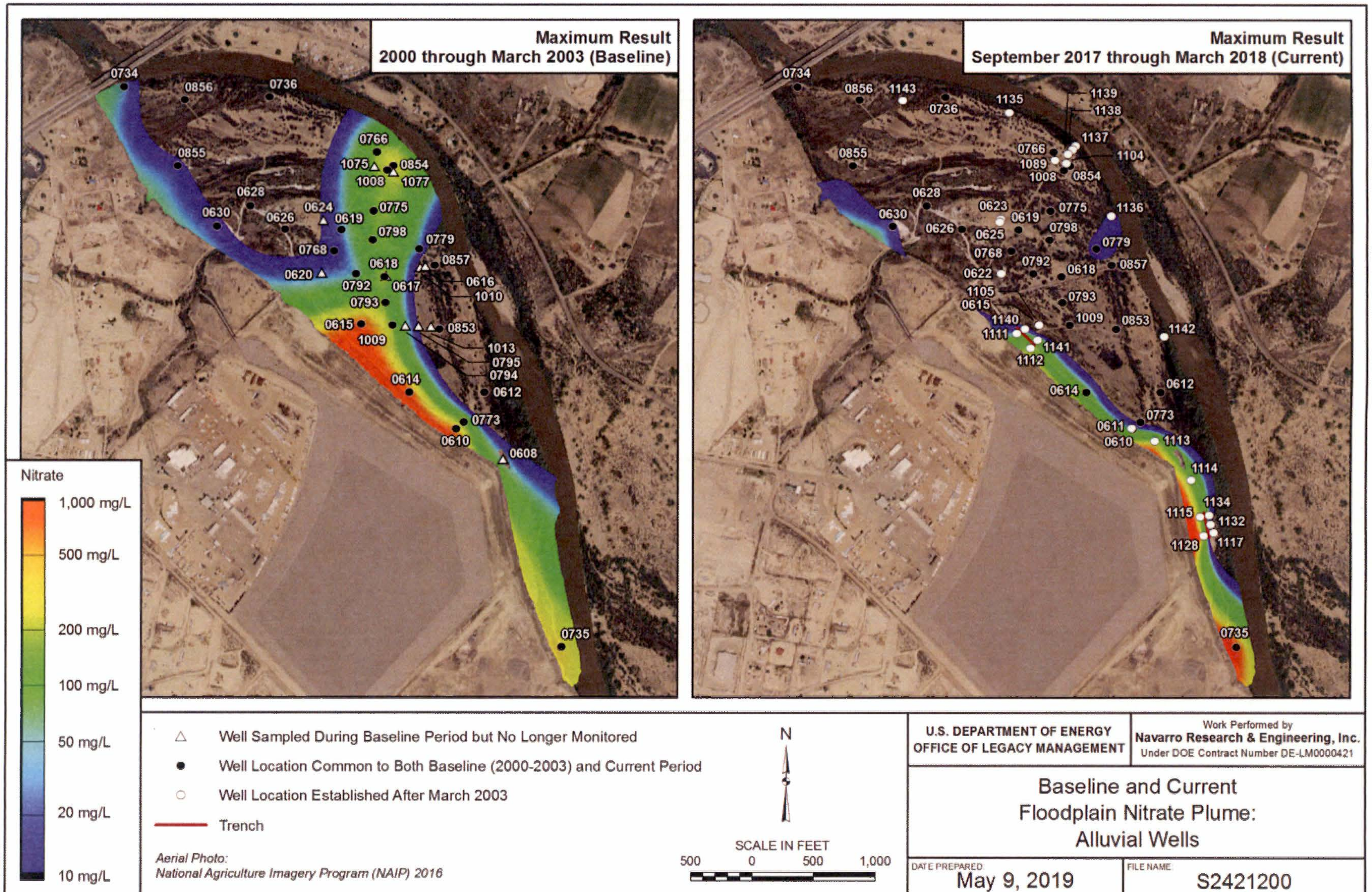
3.1.1 Current Conditions and Global Trends

Figure 8 through Figure 10 illustrate the marked reductions in contaminant concentrations since the baseline (2000–2003) period. This is particularly evident for nitrate (Figure 8); the extent of the plume, defined by regions exceeding the 10 mg/L MCL, is much smaller and generally limited to the base of the escarpment. Although the extent of the sulfate plume is about the same as that in 2000–2003, sulfate magnitudes are now notably lower (Figure 9; Appendix A). The sulfate plume is currently defined by regions exceeding the 2000 mg/L cleanup goal (Table 1), a level far lower than naturally occurring levels measured in Many Devils Wash and other desert arroyos (DOE 2012), which generally range from about 10,000 to 20,000 mg/L. Interpretations of changes in the uranium plume configuration (Figure 10) are similar. Concentrations have reduced relative to baseline (Appendix A) but still exceed the 0.044 mg/L MCL through much of the floodplain. However, the blue-shaded contours in Figure 10, corresponding to most of the western floodplain for the current period, are comparable to naturally occurring uranium levels (0.1-0.2 mg/L) measured in groundwater samples from Many Devils Wash (DOE 2012).

Because pumping on the floodplain was suspended for all but about 3 weeks of this reporting period, it is important to evaluate whether this change had any impact on contaminant concentrations or the plume configuration. Preliminary observations are discussed below.

---

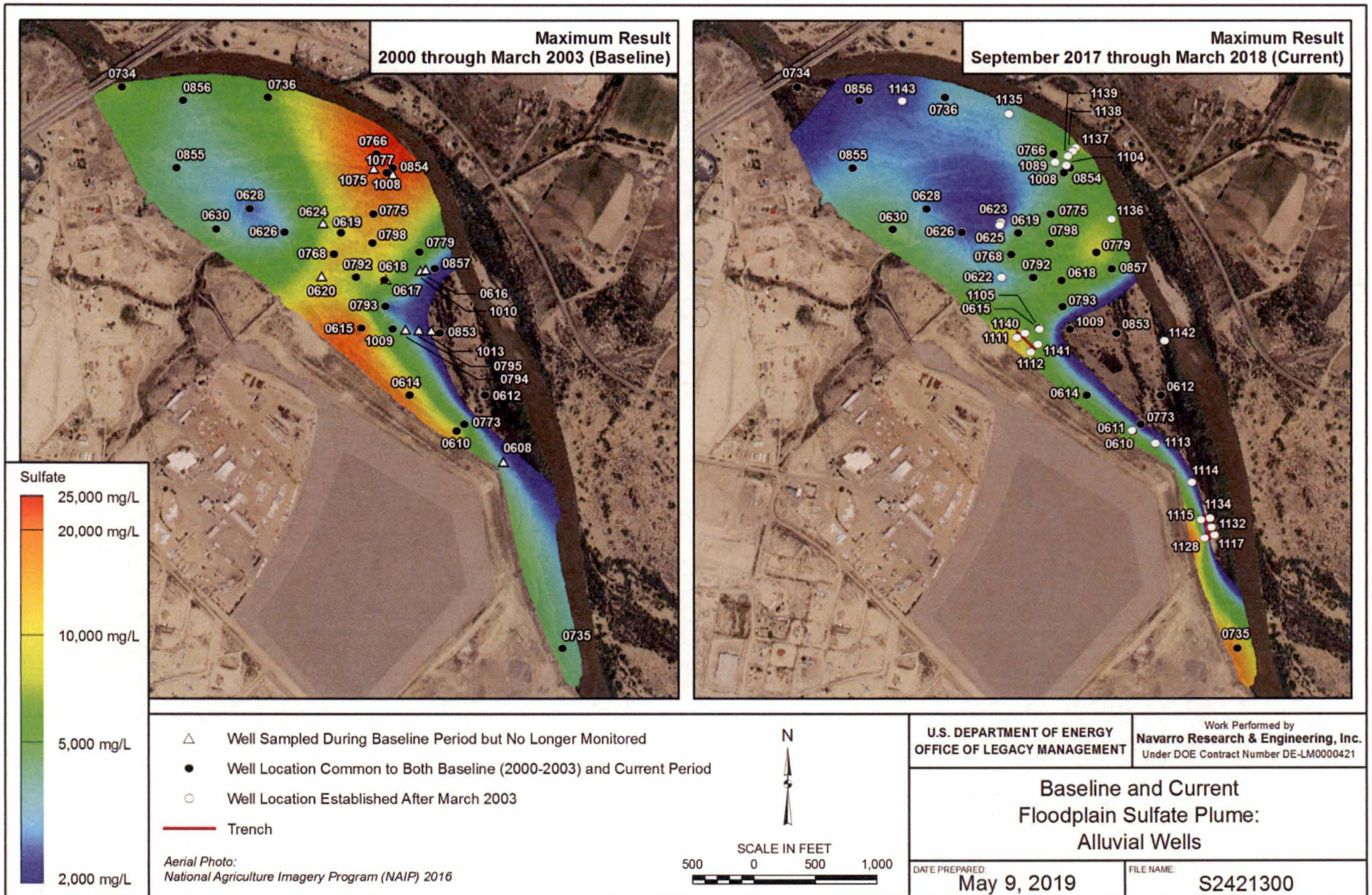
[1] The plume maps in Figure 8 through Figure 10 differ from those presented in previous annual reports (e.g., DOE 2018a). For example, the previous report included two versions of each (baseline vs. current) plume comparison figure for each of the primary COCs. The first set of contours was based on the range of the data (yielding greater color resolution) and the second was scaled relative to the corresponding remediation goal. In this report, color contours are only shown for regions with interpolated COC concentrations exceeding remediation goals. Plume maps were developed using Environmental Visualization System (EVS) software version 2019.2.0 (kriging estimation; simple anisotropy mode; spherical model; finite difference grid type).



M:\LTS\111\0020\14\014\S24212\S2421200.mxd coatesc 05/09/2019 9:55:25 AM

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

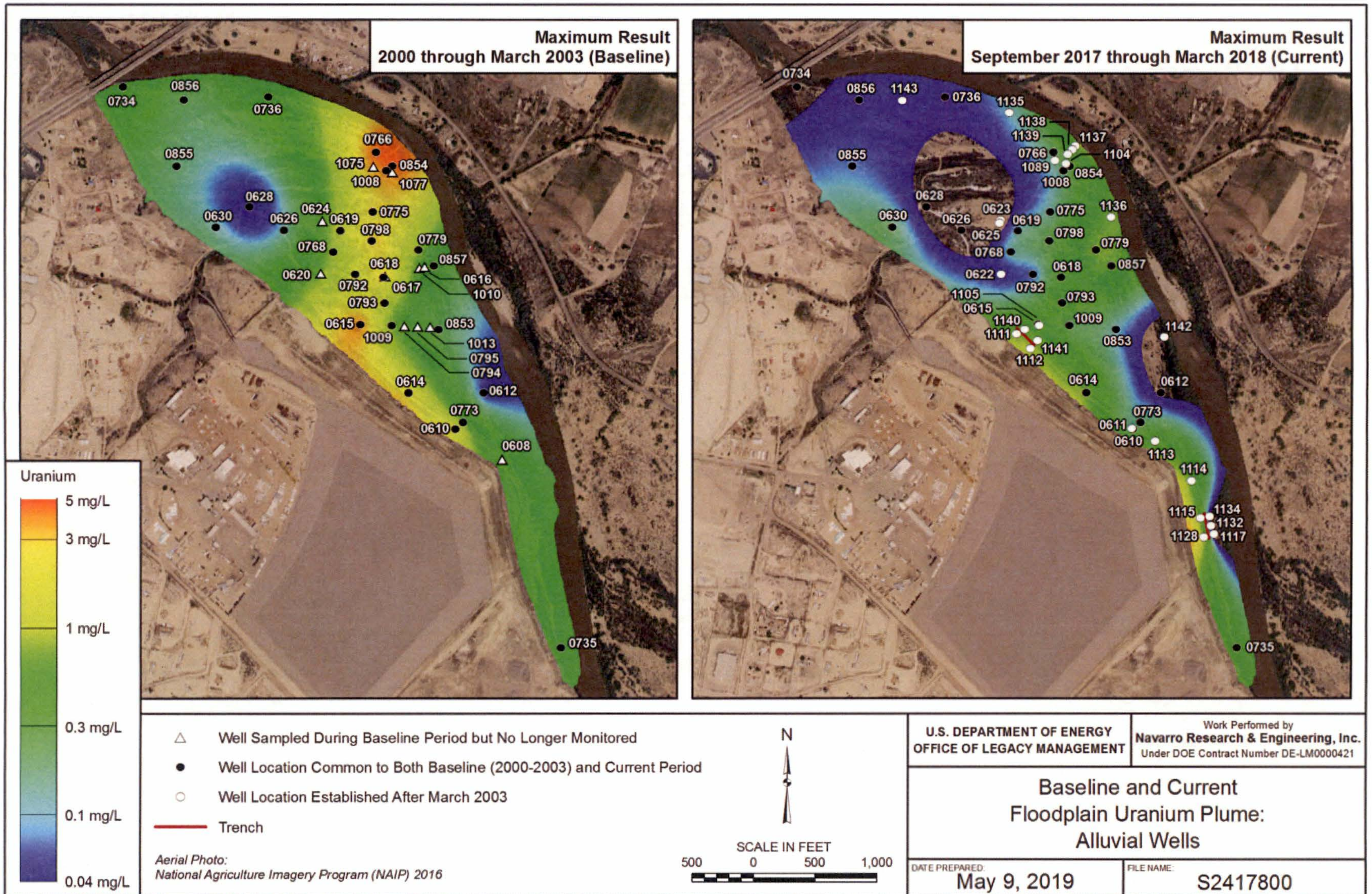
Figure 8. Baseline (2000–2003) and September 2017 Through March 2018 Shiprock Site Floodplain Nitrate Plumes



M:\LTS\111\0020\14\014\S24213\S2421300.mxd coatesc 05/09/2019 9:58:34 AM

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

Figure 9. Baseline (2000–2003) and September 2017 Through March 2018 Shiprock Site Floodplain Sulfate Plumes



M:\LTS\111\0020\14\014\S24178\S2417800.mxd coatesc 05/09/2019 9:57:59 AM

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

Figure 10. Baseline (2000–2003) and September 2017 Through March 2018 Shiprock Site Floodplain Uranium Plumes

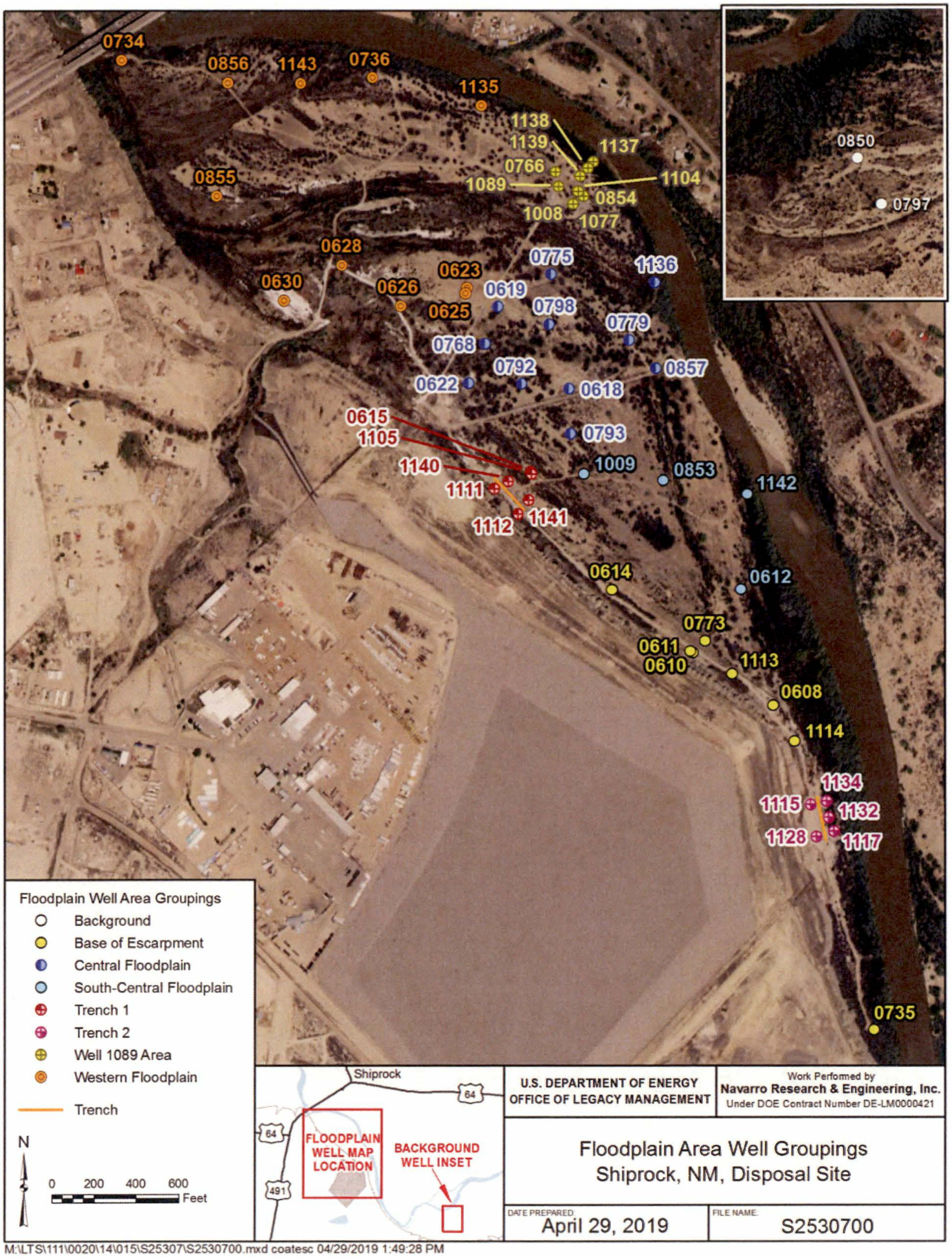


Figure 11. Shiprock Site Floodplain Area Well Groupings

Pumping of the floodplain trenches and extraction wells was suspended on April 21, 2017. Between that time and April 1, 2018 (the end of this reporting period), there were only a few brief intermittent periods of groundwater extraction. About 1.25 million gallons of groundwater were extracted from the trenches and extraction wells, corresponding to 8% of the volume extracted in 2016–2017 (15.7 million gallons). As such, the compliance strategy implemented on the floodplain for the bulk of this reporting period was natural flushing.

To help assess potential impacts of the pumping suspension, Figure 12 plots uranium concentrations in 48 alluvial wells on the contiguous floodplain for the period 2010–2018. 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. Because nitrate concentrations have markedly reduced in most floodplain wells (Figure 8), it receives less focus here. The time frame represented in Figure 12 is shorter and more recent than that shown in corresponding Appendix A graphs. The reason for this is that 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.

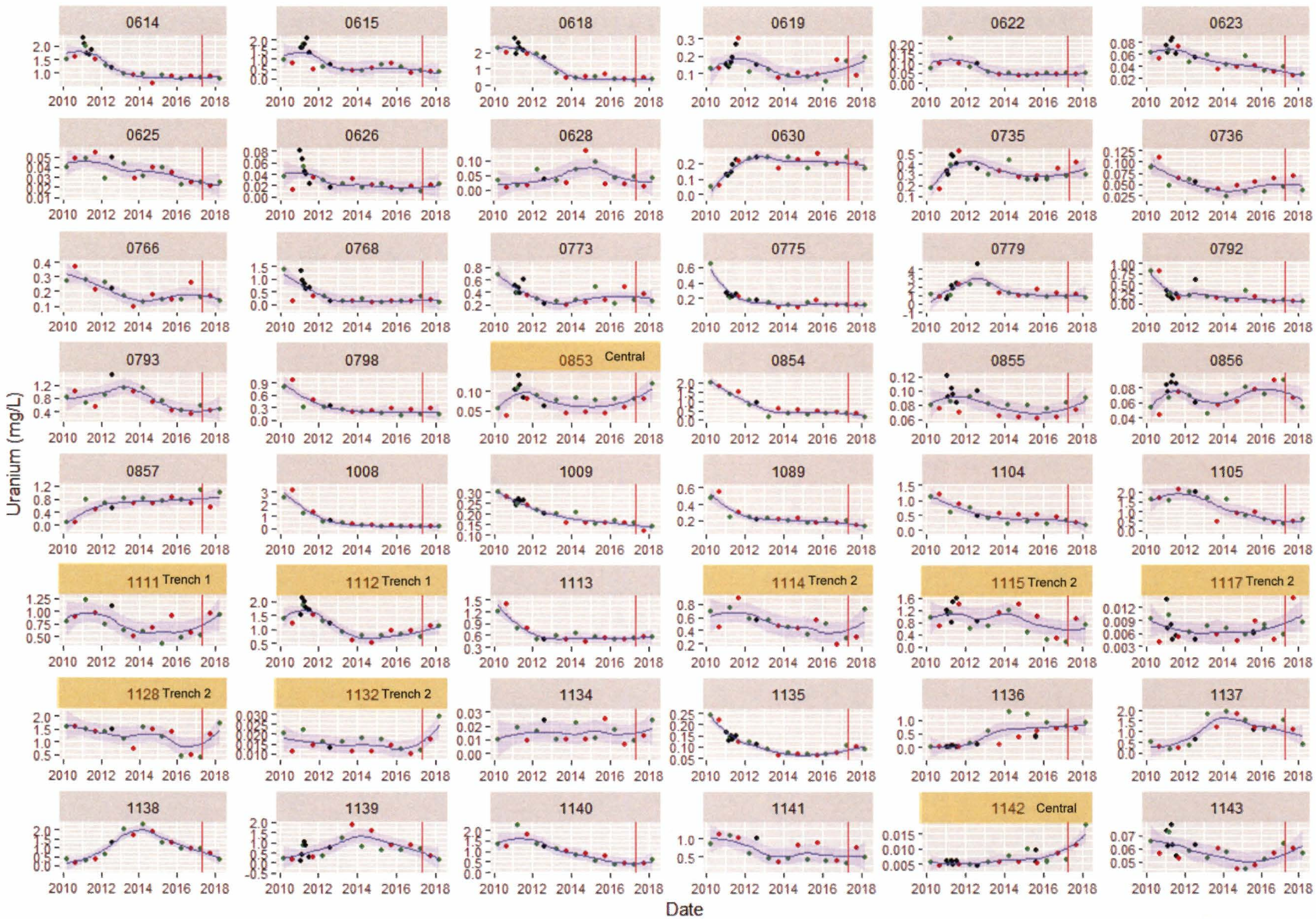
At the outset, given the limited data since pumping was suspended, only qualitative interpretations can be made regarding potential impacts of the nonpumping scenario. Two data points (the September 2017 and March 2018 sampling results) are not sufficient to characterize any subsequent trends.[2] Furthermore, other variables such as groundwater elevations and changing river flows and vegetation patterns also influence contaminant concentrations in the floodplain alluvial aquifer. For all of these potentially influential variables, time lags in responses to changes in processes are not easily quantified. Therefore, the main objective of the following discussion and accompanying exhibits is to ensure that no unusual or marked increases in contaminant concentrations has occurred in response to the pumping suspension.

As shown in Figure 12, uranium concentrations measured in this (2017–2018) reporting period were similar to previous results in the majority of floodplain wells. However, increases in uranium concentrations are apparent in about eight wells when compared to more recent (2016–2017) results. Six of the 8 wells are installed near the two trenches: Trench 1 wells 1111 and 1112 (escarpment side); Trench 2 wells 1114, 1115, and 1128 (escarpment side); and Trench 2 wells 1117 and 1132 (river side). These findings are not unexpected, as the two trenches account for about 65% of the cumulative volume extracted from the floodplain (Table 4). The two remaining wells, 0853 and 1142, are in the central floodplain (Figure 11). Although historical maximum uranium concentrations were measured in three of the wells (1128, 1132, and 1142), most of the increases are slight and within the range of historical observations. This finding is more evident in Figure 13, which plots corresponding sulfate and nitrate results, along with those for uranium, for the nine-well subset.

Again, due to the limited monitoring time since pumping was suspended, it is premature to draw any conclusions regarding potential impacts to the groundwater system. However, apart from the aforementioned increases in some wells installed near the trenches, there were no notable changes in contaminant concentrations in most of the wells throughout the floodplain.

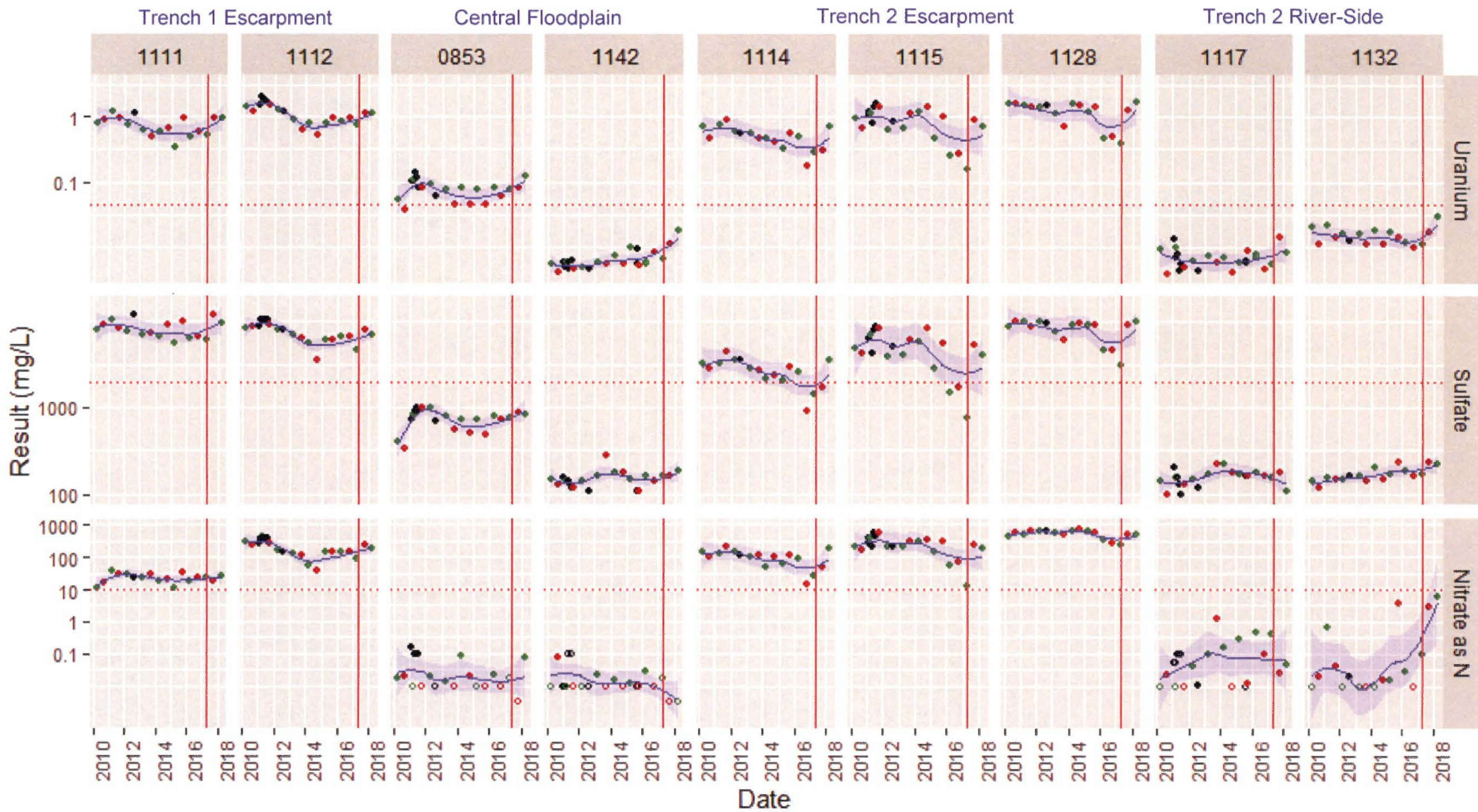
---

[2] The next (2018–2019) annual report will extend this evaluation to account for September 2018 and March 2019 sampling results and the full duration of the nonpumping period illustrated in Figure 6.



• September semiannual sampling event; • March semiannual sampling event; • Other sampling event. | denotes April 21, 2017, pumping suspension.
Recent increases in uranium concentrations observed in shaded wells; corresponding general locations on floodplain are also noted.

Figure 12. Uranium Time-Concentration Trends in Shiprock Site Floodplain Wells, 2010–March 2018



• September semiannual sampling event; • March semiannual sampling event; • Other sampling event

○ Hollow symbol denotes result below detection limit

| denotes April 21, 2017 pumping suspension.

··· Red dotted line denotes the 40 CFR Part 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate.

Note:

Because of the wide range in COC concentrations across the wells shown, data are plotted using a semilogarithmic (log 10) scale.

Figure 13. COC Trends in Selected Trench 1, Trench 2, and Central Floodplain Wells
Wells selected are those with apparent recent increases in COC concentrations (highlighted in Figure 12).

3.1.2 Analyte-Specific Trends

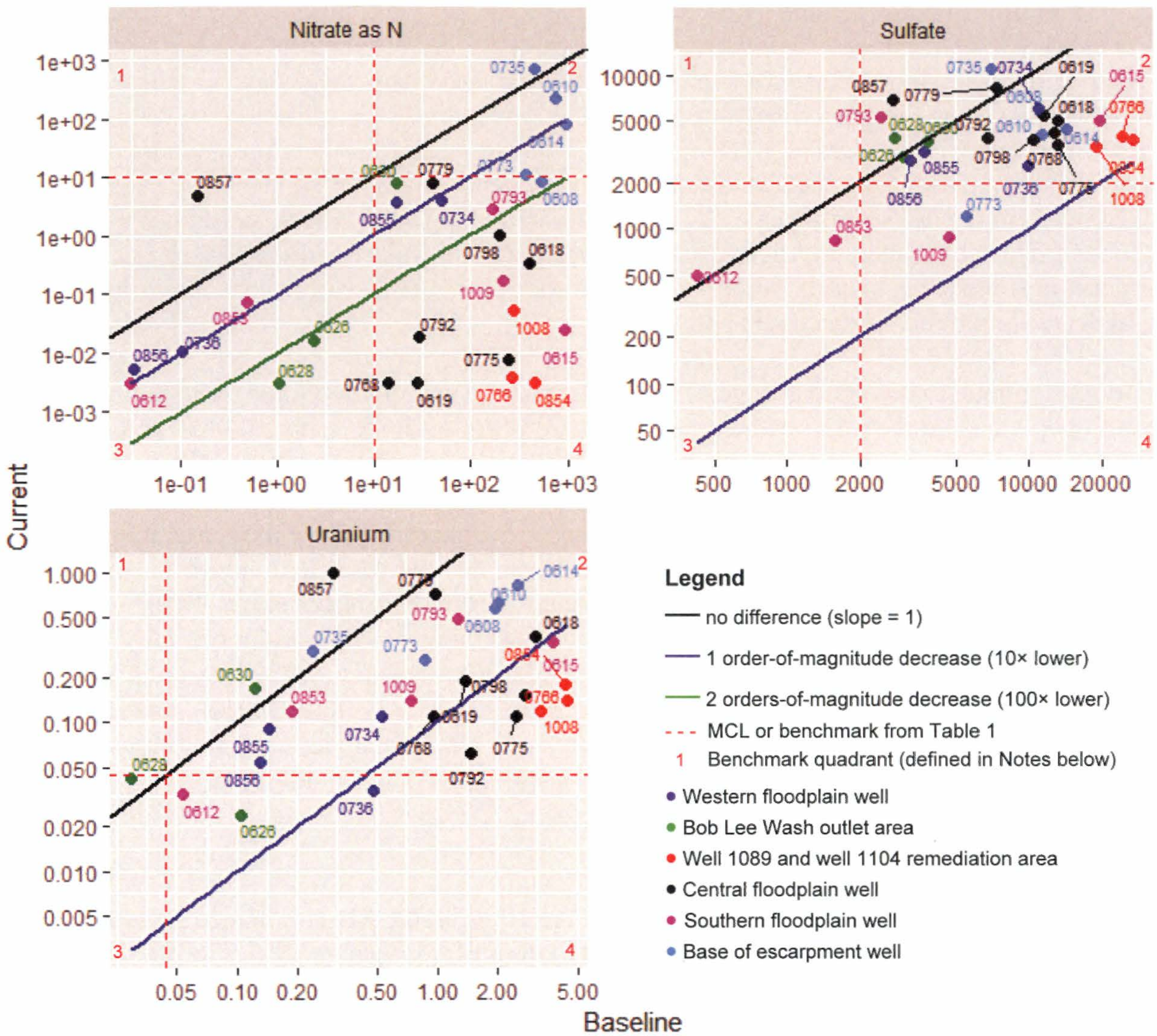
The remaining discussion evaluates contaminant trends in floodplain wells since baseline (2000–2003) based on the time-concentration plots in Appendix A. This discussion is similar to that presented in previous years (e.g., DOE 2018a) because, except for the aforementioned changes and seasonal fluctuations, COC concentrations trends in floodplain wells have not changed much in the last several years. 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. There are just a few exceptions to this general decreasing trend, as discussed below.

Exceptions continue to be found at several locations: near-river wells 0857 and 1136 in the central floodplain (Figure A-5); southernmost well 0735 (Figure A-7); and well 0630 at the base of Bob Lee Wash (Figure A-8). At most of these locations, contaminant concentrations, in particular sulfate and uranium, have increased since about 2010. Although these increasing trends have stabilized somewhat, COC concentrations are higher than those measured initially. Relative to observations in previous years, when fairly marked increases in uranium and sulfate levels in near-river wells 1137, 1138, and 1139 were noted, contaminant concentrations in these wells, although still elevated, have stabilized or declined (Figure A-3). For example, after pumping was suspended in late April 2017, no shifts in COC concentrations are apparent in extraction wells 1089 and 1104 or adjacent near-river wells (1137, 1138, and 1139) potentially influenced by changes in pumping (Figure 12; Figure A-3). The remainder of this discussion evaluates contaminant trends by analyte.

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. In Trench 1 well 1141, nitrate concentrations increased from 2.4 mg/L (March 2017 measurement) to 250 mg/L (September 2017 measurement), but this increase was not sustained (Figure A-2). The March 2018 result was 19 mg/L, just slightly above the 10 mg/L standard. A similar increase was found for sulfate, discussed below.

Declines in nitrate concentrations are also evident in Figure 14, which summarizes the progress of active remediation by comparing baseline (2000–2003) COC concentrations in floodplain monitoring wells to those measured during the current (2017–2018) reporting period. For each contaminant, the diagonal black line represents 1:1 concentration ratios indicating no change between the respective measurement dates (slope of 1). The blue diagonal line represents a 1 order-of-magnitude decline relative to baseline concentrations. The green diagonal line (which applies only to nitrate) represents a 2 orders-of-magnitude decline. The dashed red lines (horizontal and vertical) denote the corresponding benchmarks from Table 1. As shown in this figure, nitrate concentrations in many floodplain wells have declined by more than 2 orders of magnitude since the baseline period.



Note:
This figure only includes data for wells sampled during both baseline (2000–2003) and current (March 2018) periods. As such, most wells in the region of Trenches 1 and 2 are not represented, nor are recently installed 1100-series near-river wells. Because of this, the color-coded spatial groups defined above are different from those shown in Figure 11. For western floodplain near-river location 0734, the most recent (September 2014) measurement is plotted because this well has been dry since 2015. Data for background wells 0797 and 0850 are excluded.
Benchmark quadrants are defined as follows:

1 baseline < benchmark; current > benchmark
2 baseline & current > benchmark
3 baseline & current < benchmark
4 baseline > benchmark; current < benchmark

Figure 14. Baseline vs. Current Concentrations of Major COCs in Shiprock Site Floodplain Wells

3.1.2.2 Sulfate

Reductions in sulfate concentrations since the baseline period are evident in many floodplain wells (Appendix A), particularly in the Trench 1 and 1089/1104 remediation areas (Figure 9; Appendix A, Figures A-2 and A-3). Despite these declines, sulfate levels still exceed the 2000 mg/L GCAP-established benchmark over much of the floodplain (Figure 9; Figure 14). At the same time, this benchmark also has been exceeded in floodplain background wells 0797 and 0850 (Appendix A, Figure A-9). In well 0797, sulfate concentrations have exceeded the 2000 mg/L benchmark since about 2005, generally ranging from 3000 to 5000 mg/L.

Sulfate concentrations in central floodplain near-river wells 0857 and 1136 have approximately doubled since 2010, but levels have stabilized the last several years. The relationship between sulfate (and other COC) concentrations in these wells and groundwater elevations, San Juan River elevations, and other variables has not been examined in detail. Although beyond the scope of this annual performance report, these trends will be further evaluated as part of LM's recently initiated update to the site conceptual model. Sulfate levels in wells 1137–1139 have declined since their peak in about 2014 (Figure A-3). Concentrations in well 0630 at the base of Bob Lee Wash (Figure A-8) have stabilized somewhat, relative to marked increases observed between about 2010 and 2012.

Sulfate levels in many floodplain wells tend to be strongly correlated with uranium concentrations (DOE 2018b). This observation is also true for the small subset of wells where uranium concentrations increased after pumping on the floodplain was suspended. However, as shown in Appendix A (Figures A-2 and A-4), sulfate levels recently measured in Trench 1 and Trench 2 wells, although slightly elevated relative to previous measurements, are generally within the range of historical observations. The only exception is Trench 1 well 1141 where, similar to shifts in nitrate levels, sulfate concentrations increased from 1920 mg/L to 6900 mg/L between March and September 2017, but later declined. These trends will be further evaluated in the next annual report.

3.1.2.3 Uranium

As observed for sulfate, decreases in uranium concentrations in wells across a large portion of the floodplain are evident based on the baseline and current plume maps (Figure 10) and the time-concentration plots in Appendix A. These declines are also evident in Figure 14, which shows that uranium levels have decreased by 1 order of magnitude or more in some wells. Despite these reductions, uranium concentrations in most floodplain wells still exceed the 0.044 mg/L MCL (Figure 10). However, uranium levels also exceed this benchmark in background well 0850, ranging from 0.034 to 0.073 mg/L since 2014 (all but two of these results exceed the standard).

Uranium concentrations have decreased markedly in Trench 1 area wells since installation of the trench in 2006 (Appendix A, Figure A-2). Decreases of a similar magnitude are also apparent in the 1089/1104 remediation area (Figure A-3). However, similar to the trends found for sulfate, uranium levels have increased in near-river wells 0857 and 1136. Increases since baseline are also apparent in wells 0628, 0630, and 0735 but levels have stabilized in the last several years. The evaluation of apparent responses to the suspension of pumping addressed previously in this section is not repeated here.

3.1.2.4 Other COCs

Ammonia, manganese, selenium, and strontium are no longer discussed in detail in this annual report because these constituents are not as prevalent or as elevated at the site as the primary COCs (uranium, nitrate, and sulfate). The following brief summary is based largely on previous characterizations and reports. These characterizations will be updated in the forthcoming revised GCAP, which LM plans to issue in 2021.

Ammonia concentrations continue to be elevated in Trench 2 area wells on the floodplain. This spatial distribution has not changed significantly over the years and, apart from seasonal or pumping-related periodic variation, temporal trends have been fairly stable in most wells.

Most manganese concentrations have been within the 0.001–7.2 mg/L background range listed in Table 1. During this (2017–2018) reporting period, manganese concentrations on the floodplain ranged from 0.05 to 6.6 mg/L.

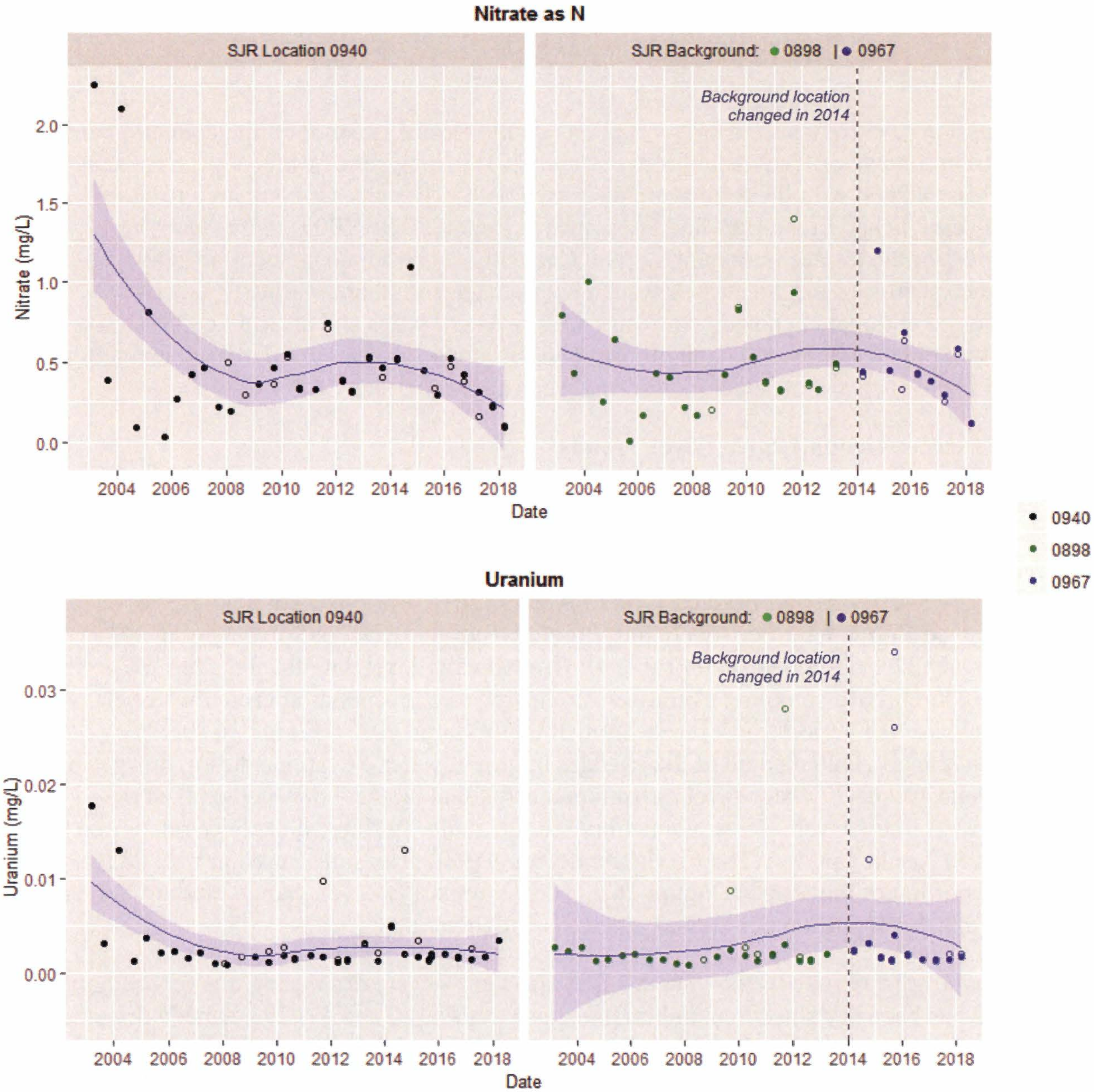
Selenium is no longer addressed in the annual reports because evidence suggests that the Mancos Shale is a likely source of this constituent in some areas of the site and in general (Morrison et al. 2012; Robertson et al. 2016). Historically, selenium concentrations have been highest in Many Devils Wash, where contamination has been demonstrated to be naturally occurring (Robertson et al. 2016); in wells along the terrace buried escarpment; and in only a few floodplain wells at the base of the escarpment (well 0614 and Trench 1 well 1112). Except for wells 0779, 0857, and 1136, selenium concentrations in floodplain wells near the river have been below the 0.05 mg/L GCAP compliance standard.

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

3.2 San Juan River Monitoring

DOE regularly monitors eight San Juan River locations, including one upgradient background location. Sampling point 0940, located just north of pumping wells 1089 and 1104, was identified as a point of exposure in the GCAP because of its location in an area where contamination in the alluvial aquifer was most likely to discharge to the river (DOE 2002). 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, historical uranium and nitrate trends in 0940 river samples are comparable to those at the upstream 0898 (or 0967) background locations. The long-term monitoring of the point of exposure (San Juan River location 0940) indicates that the Shiprock site poses no adverse risk to human health or environment, provided that the Navajo Water Code continues to restrict the use of shallow groundwater near the site.



• Filtered sample result (dissolved fraction)
○ Unfiltered result (total fraction)

Notes:

1. Since 2008, both filtered (•) and unfiltered (o) samples have been collected at each San Juan River (SJR) 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.
2. 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

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 2018. 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.

3.3.2 Terrace Groundwater Level Trends

Because pumping was suspended for the bulk of the 2017–2018 reporting period, only about 267,600 gallons of groundwater were pumped from the nine terrace extraction wells between April 2017 and March 2018, in contrast to more than 1.5 million gallons pumped in the preceding 2016–2017 period (Table 3). As of April 1, 2018, the cumulative volume of water removed from the terrace (excluding Bob Lee and Many Devils washes) was approximately 22.1 million gallons (Table 4). Groundwater level data from the terrace collected during the March 2018 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). Figure 16 shows a quantitative map view of some of the changes in groundwater elevations during this period for alluvial wells. Of the 27 water-level measurements (excluding the 7 dry wells) taken in March 2018 at terrace wells screened in alluvium, the majority showed declines relative to the (2000–2003) baseline period. The maximum decrease (9.0 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 this reporting period was a decrease of about 2.0 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 (see Appendix B hydrographs). Appendix C figures depict well construction and bedrock contacts along with current water levels. Figure 17 through Figure 19 are presented to further illustrate the declining water levels across the terrace. As shown in Figure 17, many seeps on the west terrace are dry; some have been dry since 2008. In fact, LM stopped monitoring nine terrace surface locations because they were historically dry.

Figure 18 plots groundwater elevations in terrace alluvial wells, showing contours for both baseline (March 2003) and current (March 2018) periods. Figure 19 depicts groundwater saturated thickness in the terrace alluvium using automated contours for both baseline (February 2000) and current (March 2018) periods. Table 5 includes an estimate of liquid volume for both dates based on these depictions, indicating a volumetric reduction of about 42% in the vicinity of the south terrace extraction wells. The volumetric reduction approximated with this method (approximately 12.5 million gallons) is a little over one-half the total cumulative volume (22.1 million gallons) extracted from the terrace swale alluvium pumping wells. These exhibits demonstrate that groundwater elevations have declined across much of the terrace groundwater system.

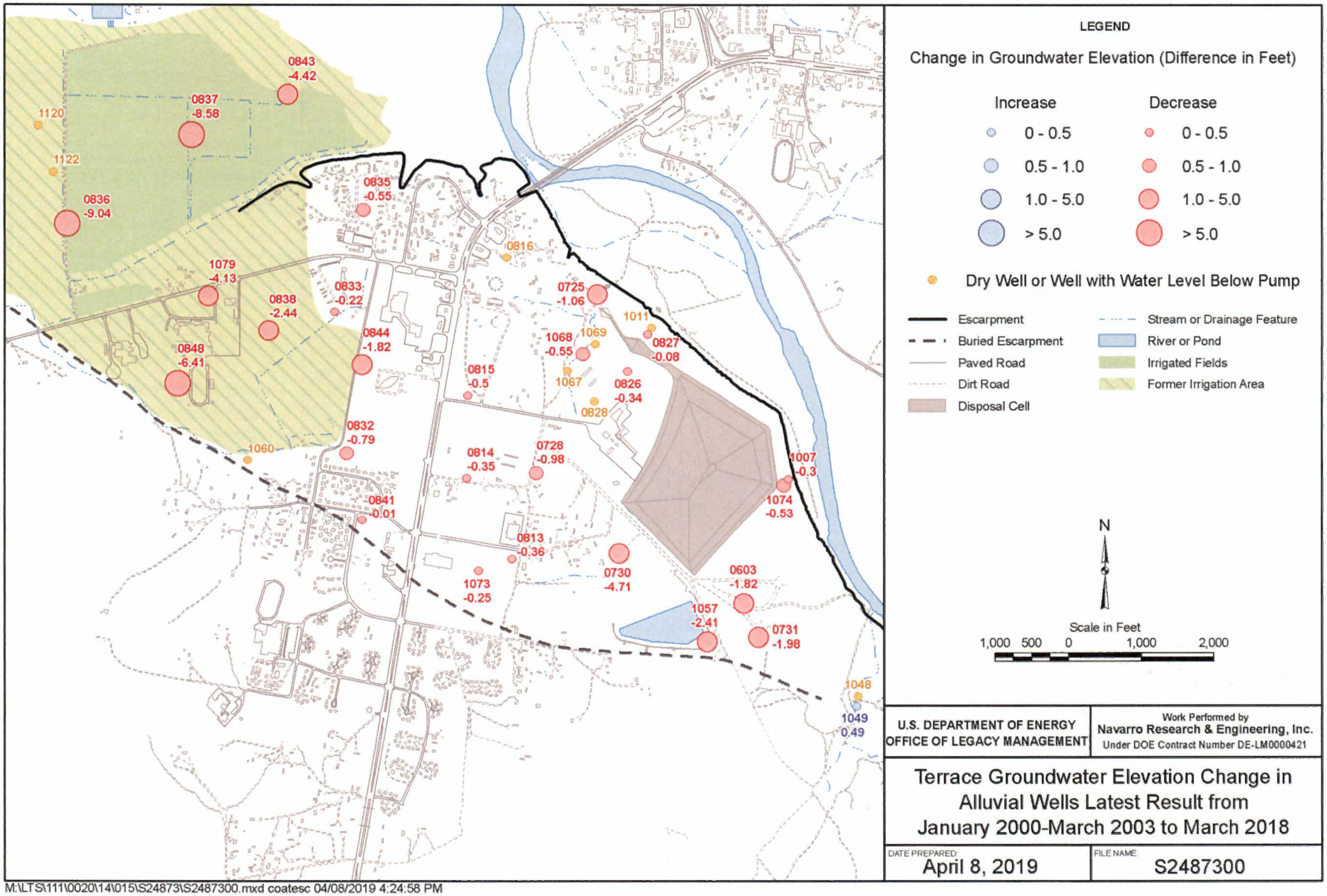
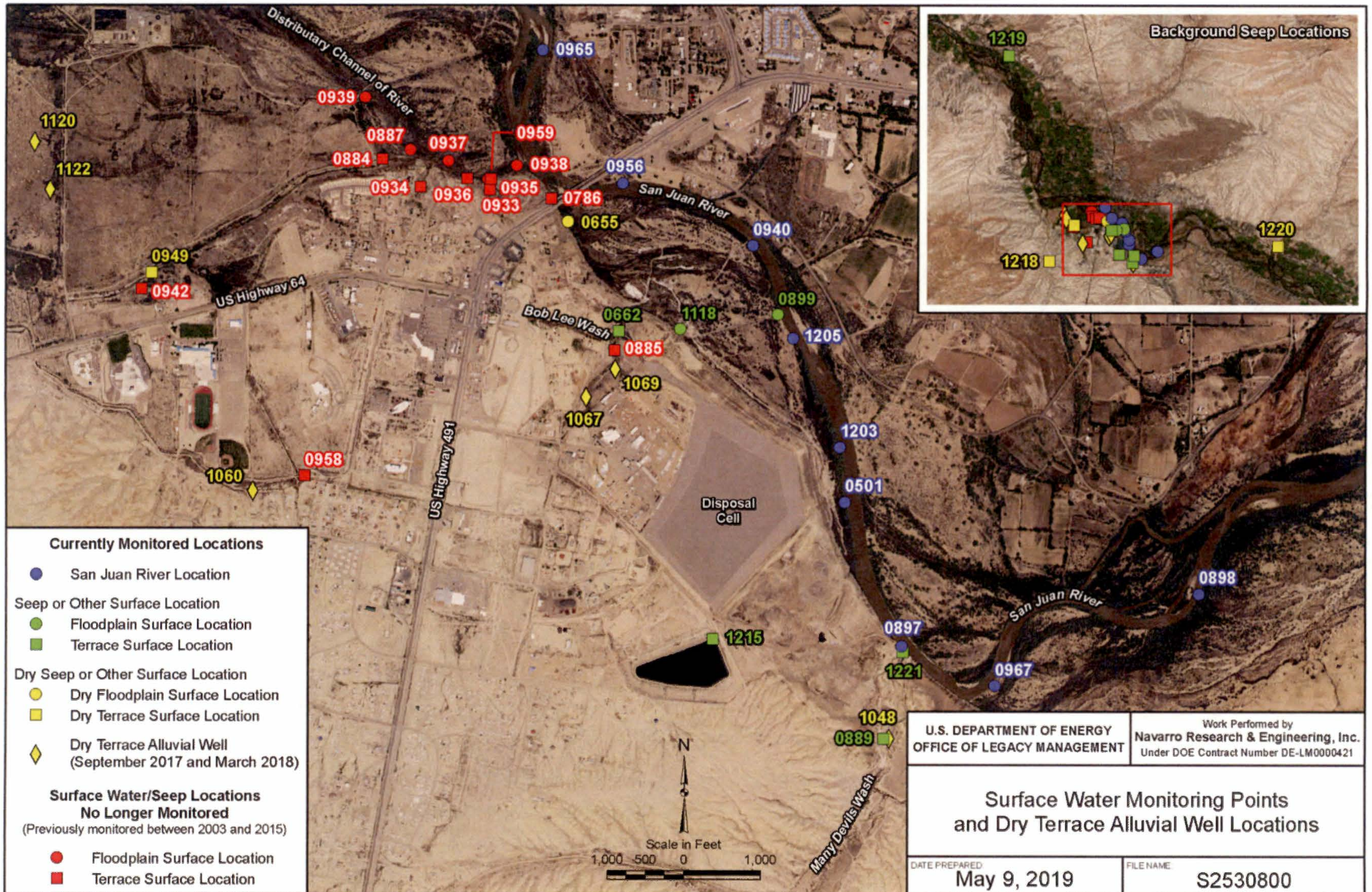


Figure 16. Shiprock Site Terrace Groundwater Elevation Changes from Baseline (2000–2003) to Current (March 2018) Conditions



M:\LTS\111\0020\14\015\S25308\S2530800.mxd coatesc 05/09/2019 7:13:49 AM

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)

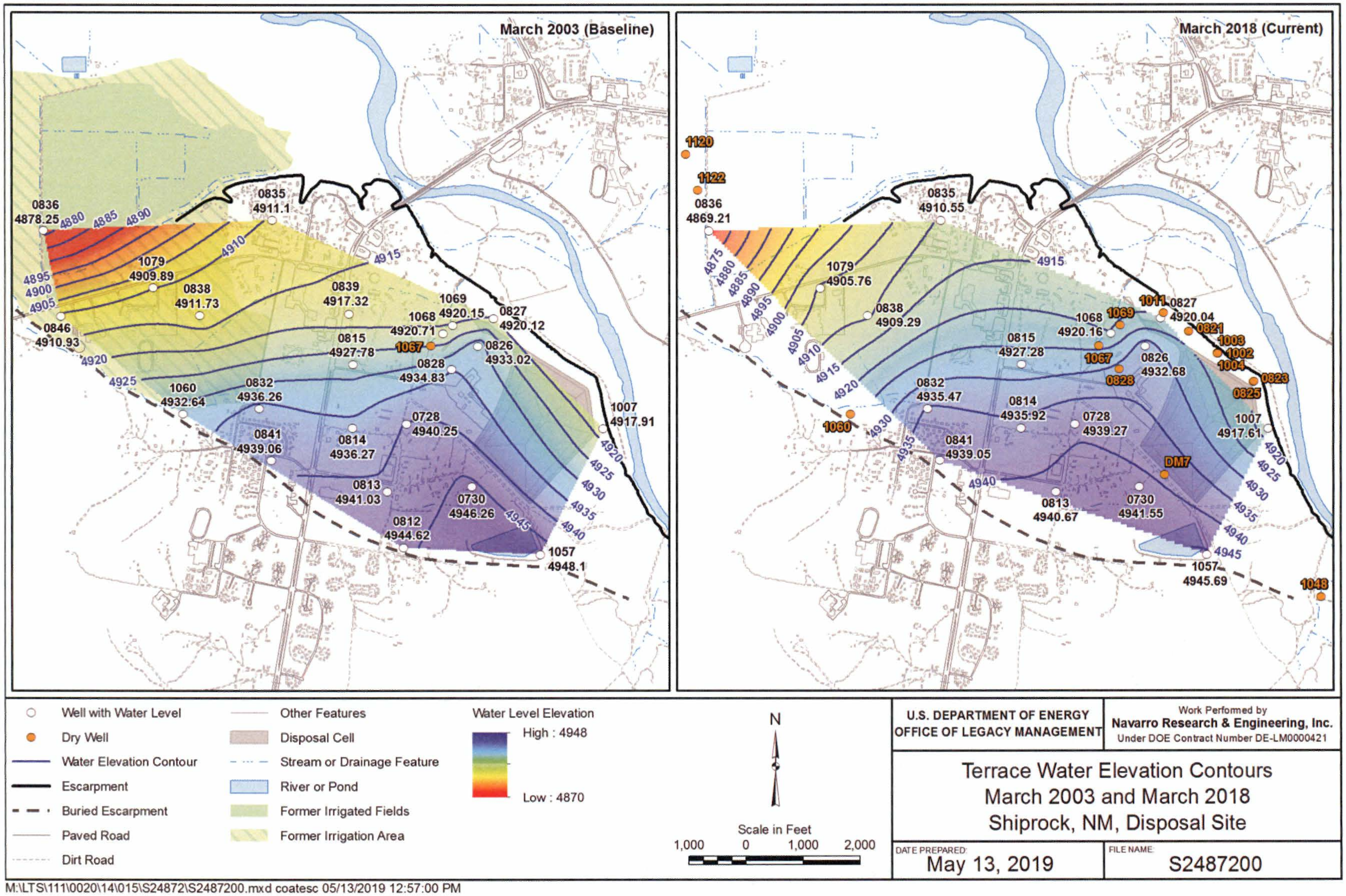
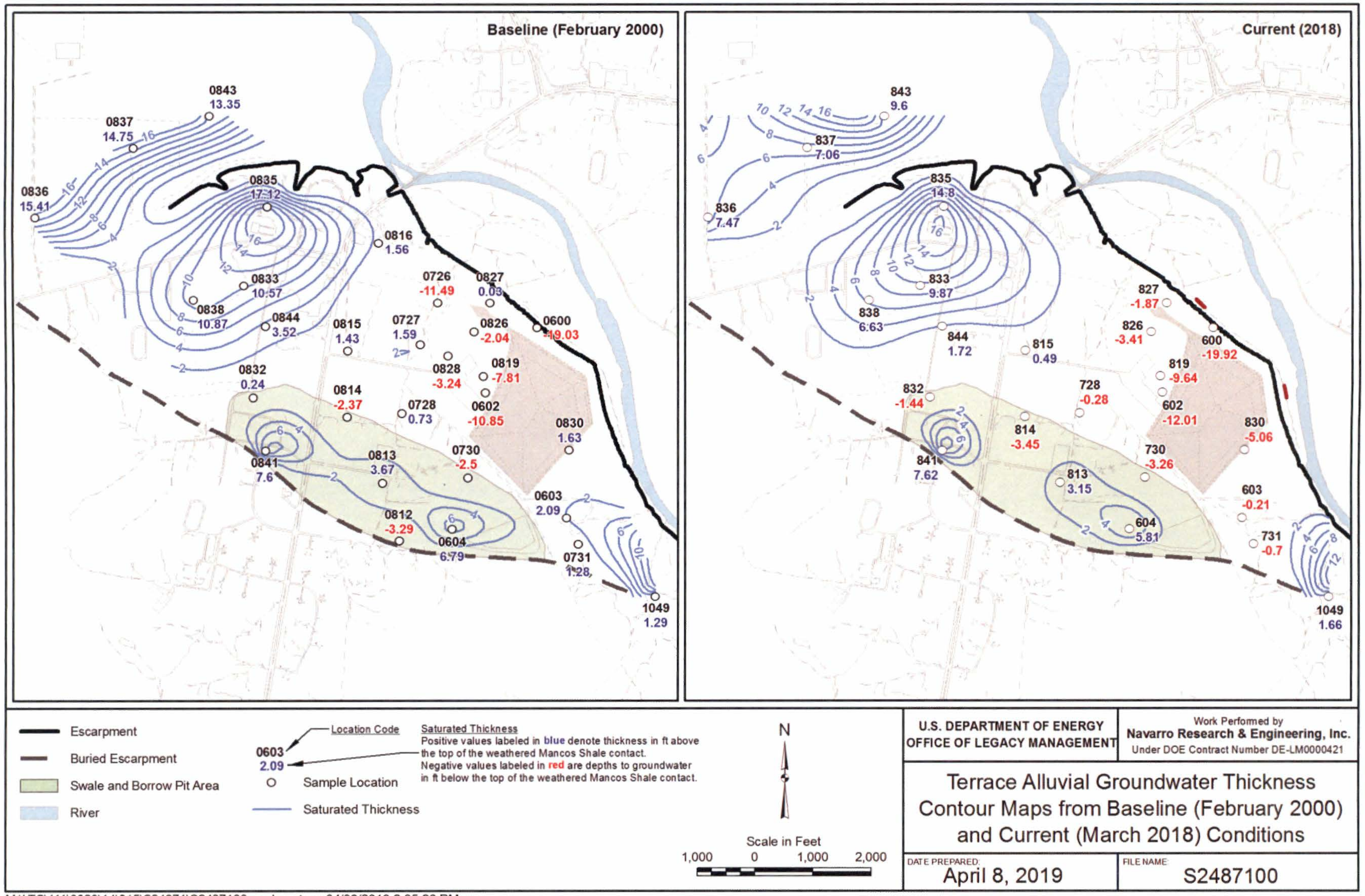


Figure 18. Terrace Water Elevation Contours: March 2003 (Baseline) and Current (March 2018)



M:\LTS\111\0020\14\015\S24871\S2487100.mxd coatesc 04/08/2019 2:35:20 PM

Figure 19. Terrace Alluvial Groundwater Thickness Contour Maps from Baseline (February 2000) and Current (March 2018) Conditions

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

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 (%)
February 2000 baseline depiction	13,465,399	30	4,039,620	30,218,452	–
March 2018 current depiction	7,875,014	30	2,362,504	17,672,758	42

Note:
Only the south terrace swale and borrow pit areas (shaded in Figure 19) were used in these calculations based on the integrated volumes within this extent. The 42% reduction cited above is less than that estimated in the previous annual report (55%). This discrepancy is due to improvements in contouring and estimation methods applied to the baseline estimates, which were previously based on those derived in the SOWP [DOE 2000]).

Abbreviation:
ft^3 = cubic feet

Only the terrace alluvium was considered in developing Figure 19 and 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.

This page intentionally left blank

4.0 Performance Summary

This section summarizes the findings of the most recent (April 2017 through March 2018) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the 15th year of active groundwater remediation. This report differs somewhat from previous annual performance reports because there is little "performance"—that is, groundwater extraction and associated contaminant mass removal—to report. 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. Between that time and April 1, 2018 (the end of this reporting period), there were only temporary intermittent periods of resumed pumping. As such, the compliance strategy implemented on the floodplain for the bulk of this reporting period was natural flushing.

From April 2017 through March 2018, nearly 3 million gallons of extracted groundwater were pumped to the evaporation pond, in contrast to about 18.7 million gallons extracted the previous (2016–2017) reporting period. About half of this volume (1.5 million gallons) was pumped from Bob Lee Wash, the only treatment system location where pumping was sustained through the reporting period. Since DOE began active remediation in March 2003, about 49.5 million gallons have been extracted from the terrace and 150.3 million gallons have been extracted from the floodplain, yielding a total cumulative volume of nearly 200 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 6937; 147,872; and 10.2 pounds, respectively.

Because pumping on the floodplain was suspended for all but 3 weeks of this reporting period, it was important to evaluate whether this change had any impact on contaminant concentrations or the floodplain plume configuration. Due to the limited monitoring time following the suspension, any conclusions regarding potential impacts to the groundwater system would be premature. However, based on an initial evaluation, apart from some increases in COC concentrations in wells installed near the trench areas (mainly escarpment sides), there were no notable changes in contaminant levels in most of the wells throughout the floodplain. Most of these increases were slight and within the range of historical observations.

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

Terrace-wide, groundwater levels in the majority of alluvial wells sampled during this performance period declined relative to the baseline period (2000–2003); average and maximum decreases were 2.0 and 9.0 ft, respectively. As has been the case for several years, five alluvial west terrace wells were dry during this reporting period. Several seeps on the west terrace have been dry since 2008.

This page intentionally left blank

5.0 References

ATSDR (Agency for Toxic Substances and Disease Registry), 2004. *Toxicological Profile for Strontium*, U.S. Department of Health and Human Services, Public Health Service, April.

DOE (U.S. Department of Energy), 1994. *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site at Shiprock, New Mexico*, DOE/AL/62350-48F, Rev. 1, Albuquerque Operations Office, Albuquerque, New Mexico, April.

DOE (U.S. Department of Energy), 2000. *Final Site Observational Work Plan for the Shiprock, New Mexico, UMTRA Project Site*, GJO-2000-169-TAR, Rev. 2, Grand Junction, Colorado, November.

DOE (U.S. Department of Energy), 2002. *Final Groundwater Compliance Action Plan for Remediation at the Shiprock, New Mexico, UMTRA Project Site*, GJO-2001-297-TAR, Grand Junction, Colorado, July.

DOE (U.S. Department of Energy), 2003. *Baseline Performance Report for the Shiprock, New Mexico, UMTRA Project Site*, GJO-2003-431-TAC, Grand Junction, Colorado, September.

DOE (U.S. Department of Energy), 2005. *Refinement of Conceptual Model and Recommendations for Improving Remediation Efficiency at the Shiprock, New Mexico, Site*, GJO-2004-579-TAC, Office of Legacy Management, Grand Junction, Colorado, July.

DOE (U.S. Department of Energy), 2009. *Evaluation of the Trench 2 Groundwater Remediation System at the Shiprock, New Mexico, Legacy Management Site*, LMS/SHP/S05037, Office of Legacy Management, Grand Junction, Colorado, March.

DOE (U.S. Department of Energy), 2011a. *2010 Review and Evaluation of the Shiprock Remediation Strategy,* LMS/SHP/S05030, Office of Legacy Management, Grand Junction, Colorado, January.

DOE (U.S. Department of Energy), 2011b. *Geology and Groundwater Investigation, Many Devils Wash, Shiprock Site, New Mexico*, LMS/SHP/S06662, ESL-RPT-2011-02, Office of Legacy Management, Grand Junction, Colorado, April.

DOE (U.S. Department of Energy), 2011c. *Natural Contamination from the Mancos Shale*, LMS/S07480, ESL-RPT-2011-01, Office of Legacy Management, Grand Junction, Colorado, April.

DOE (U.S. Department of Energy), 2011d. *Preliminary Evaluation of the Trench 1 Collection Drain Floodplain Area of the Shiprock, New Mexico, Site*, LMS/SHP/S07374, ESL-RPT-2011-03, Office of Legacy Management, Grand Junction, Colorado, June.

DOE (U.S. Department of Energy), 2012. *Multivariate Statistical Analysis of Water Chemistry in Evaluating the Origin of Contamination in Many Devils Wash, Shiprock, New Mexico* LMS/SHP/S09257, ESL-RPT-2012-03, Office of Legacy Management, Grand Junction, Colorado, December.

DOE (U.S. Department of Energy), 2013. *Optimization of Sampling at the Shiprock, New Mexico, Site*, LMS/SHP/S08223, Office of Legacy Management, Grand Junction, Colorado, March.

DOE (U.S. Department of Energy), 2018a. *Annual Performance Report, April 2016 Through March 2017 for the Shiprock, New Mexico, Site*, LMS/SHP/S16428, Office of Legacy Management, December.

DOE (U.S. Department of Energy), 2018b. *Variation in Groundwater Aquifers: Results of Phase II Field Investigations and Final Summary Report*, LMS/ESL/S16662, Office of Legacy Management, June.

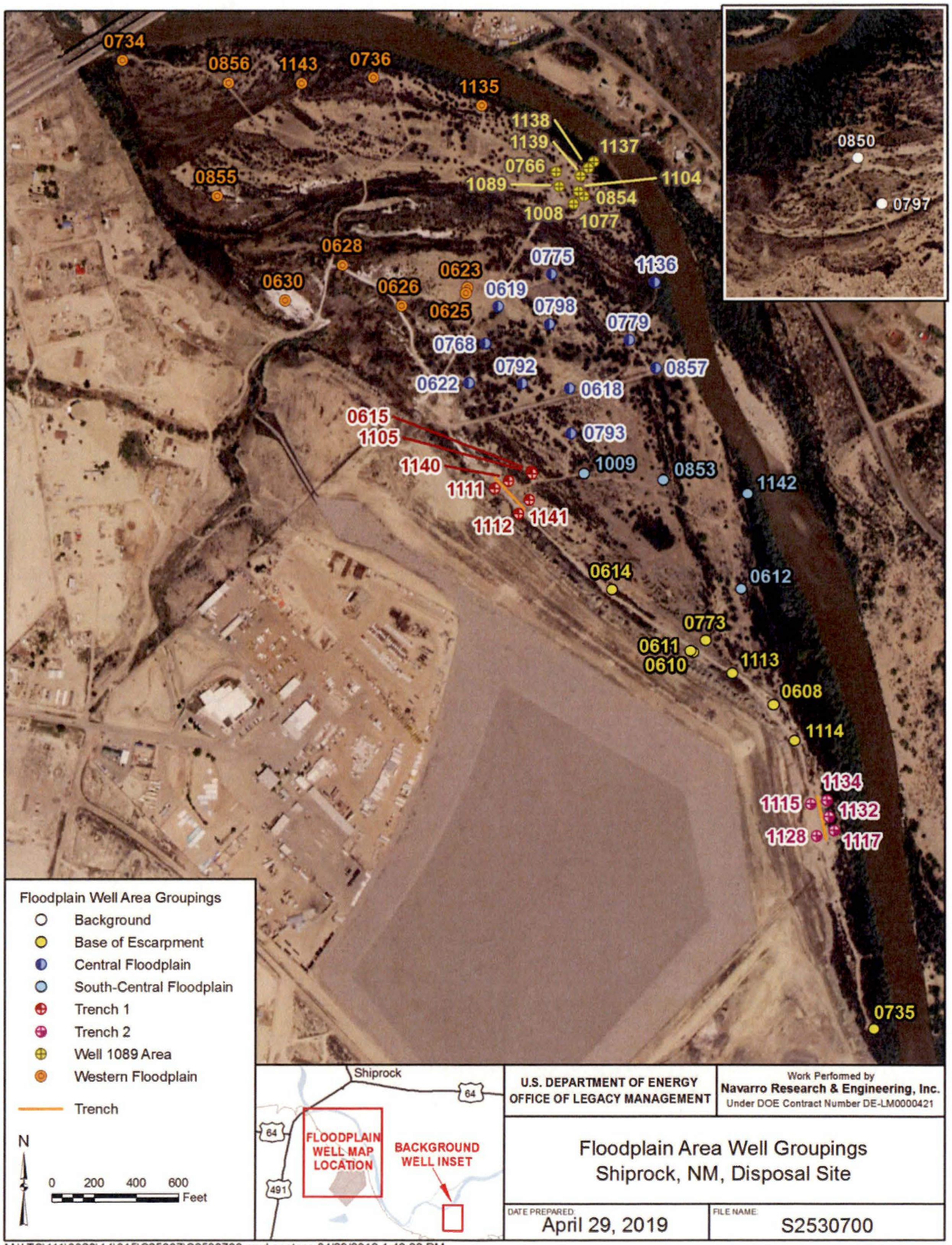
Morrison, S.J., C.S. Goodknight, A.D. Tigar, R.P Bush, and A. Gil, 2012. "Naturally occurring contamination in the Mancos Shale," *Environmental Science & Technology* 46(3):1379–1387.

Robertson, A.J., A.J. Ranalli, S.A. Austin, and B.R. Lawlis, 2016. *The Source of Groundwater and Solutes to Many Devils Wash at a Former Uranium Mill Site in Shiprock, New Mexico,* U.S. Geological Survey Scientific Investigations Report 2016-5031, Reston, Virginia, prepared in cooperation with the Navajo Nation Environmental Protection Agency.

Appendix A

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

This page intentionally left blank

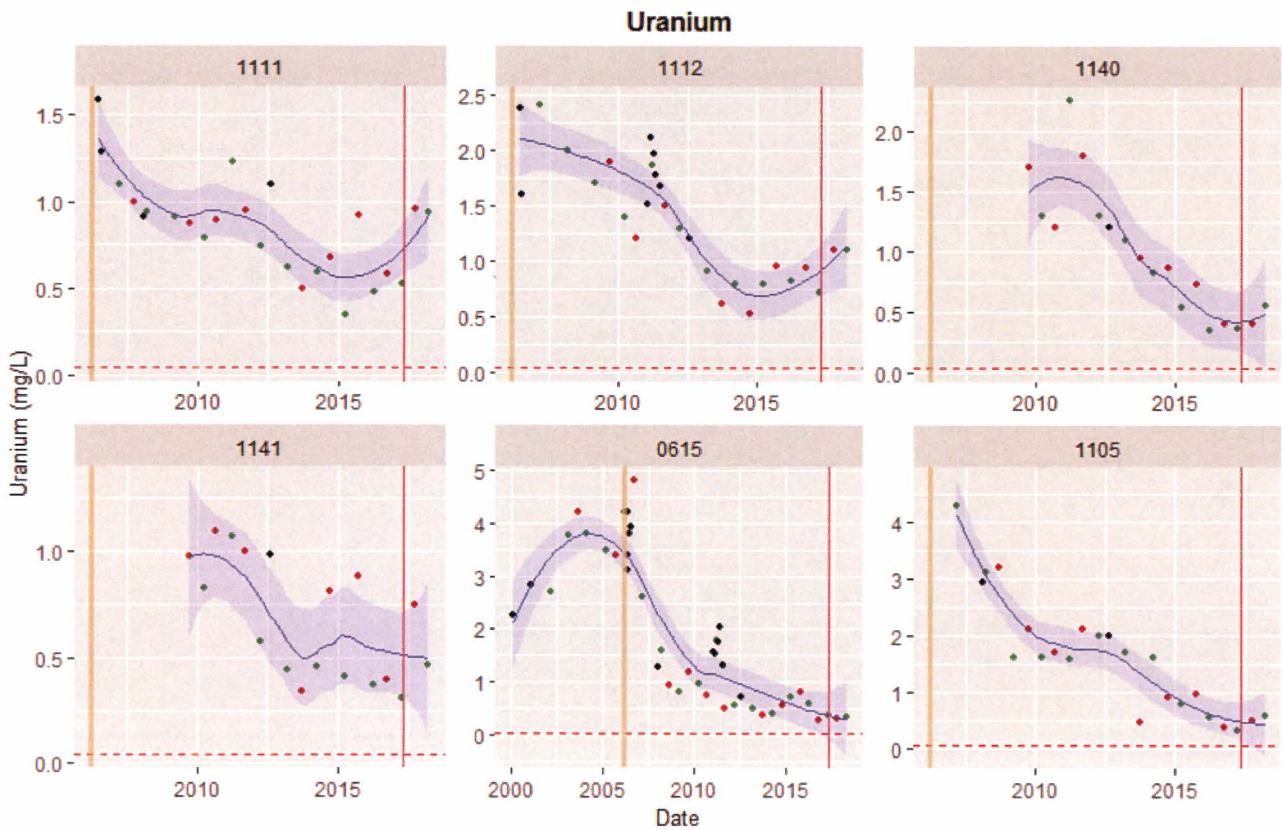


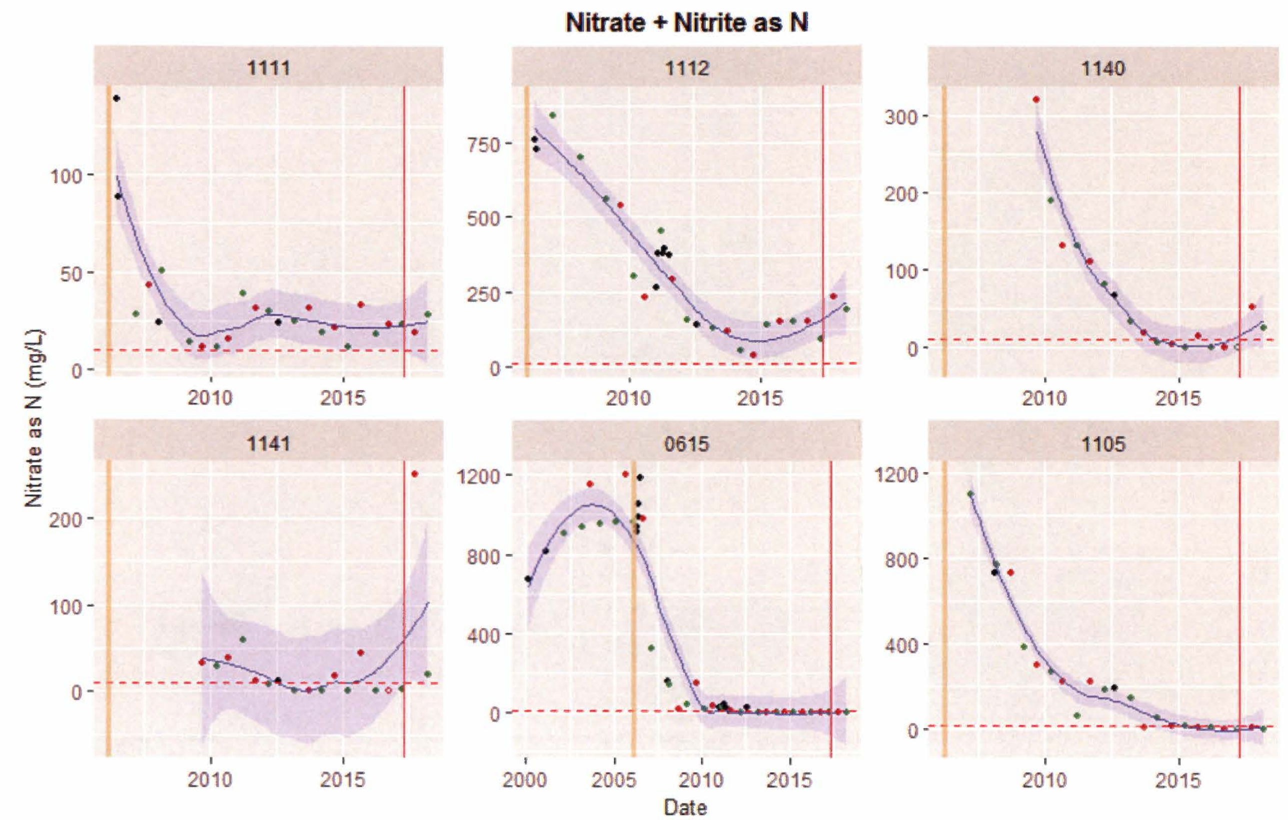
M:\LTS\111\0020\14\015\S25307\S2530700.mxd coatesc 04/29/2019 1:49:28 PM

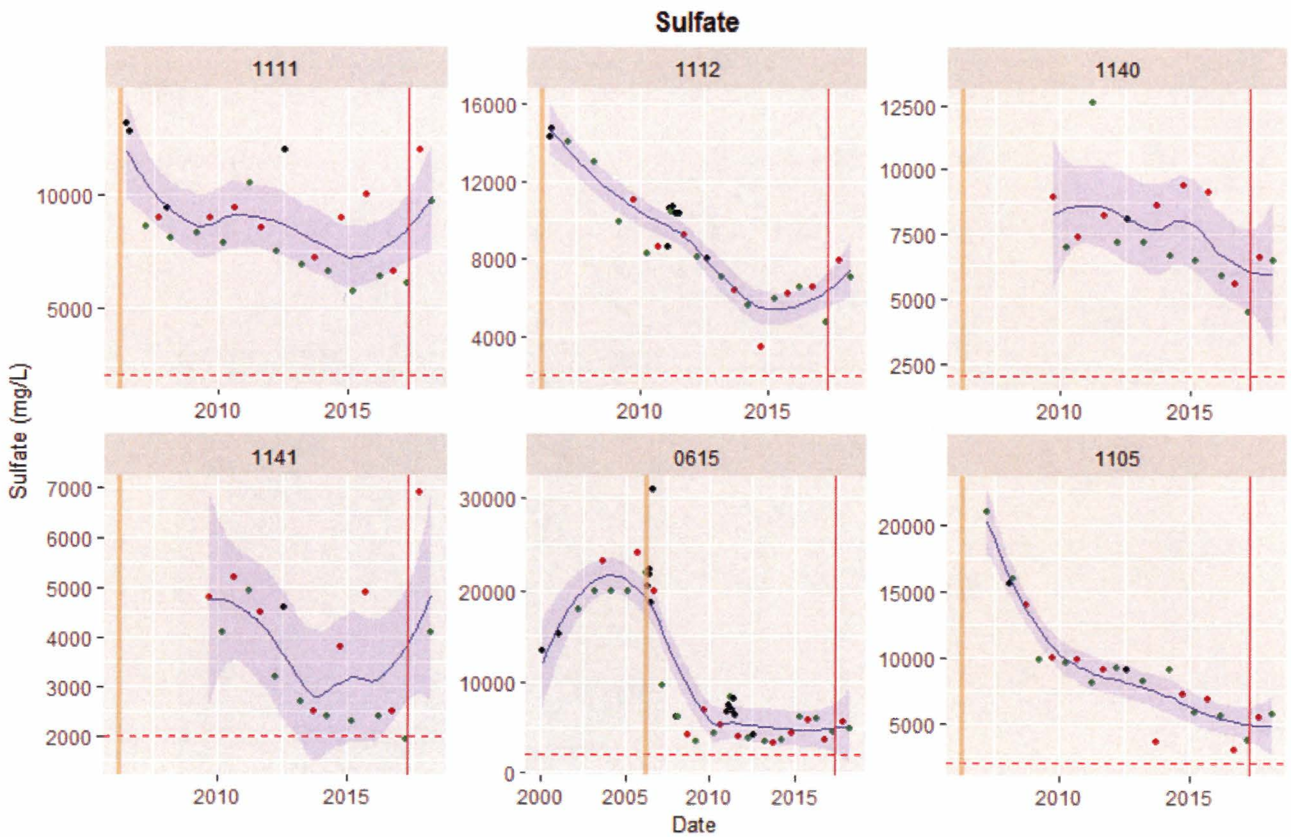
Figure A-1. Shiprock Site Floodplain Well Groupings

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

This page intentionally left blank







Time–Trend Plot Explanation.

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

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

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

• September semiannual sampling event; • March semiannual sampling event; • Other sampling event

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

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

Second vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3).

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

and

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

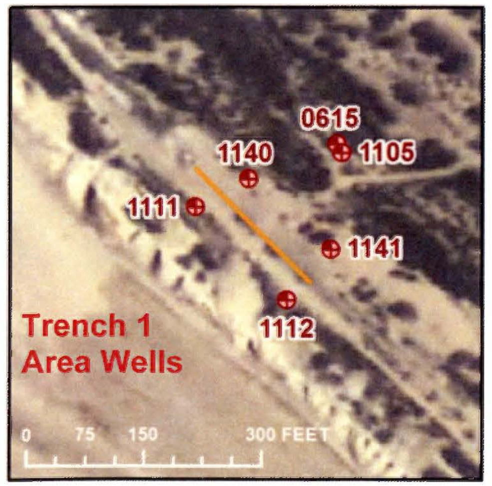
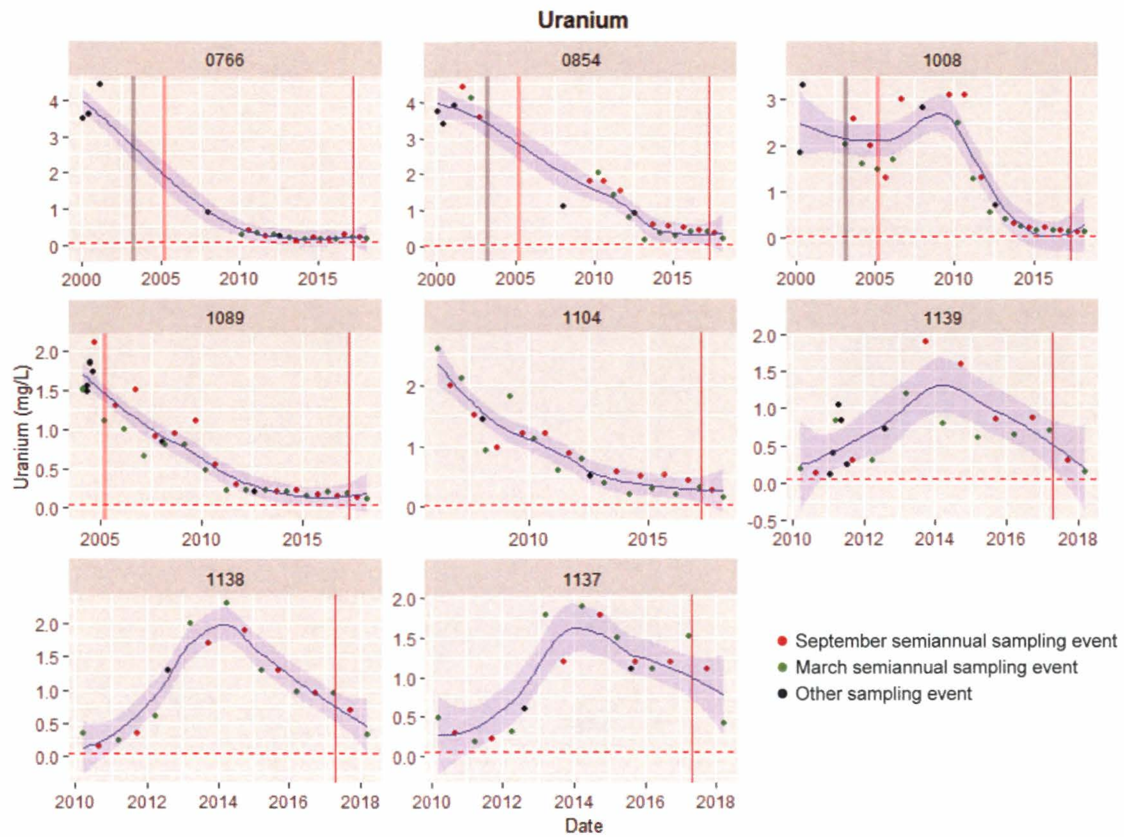
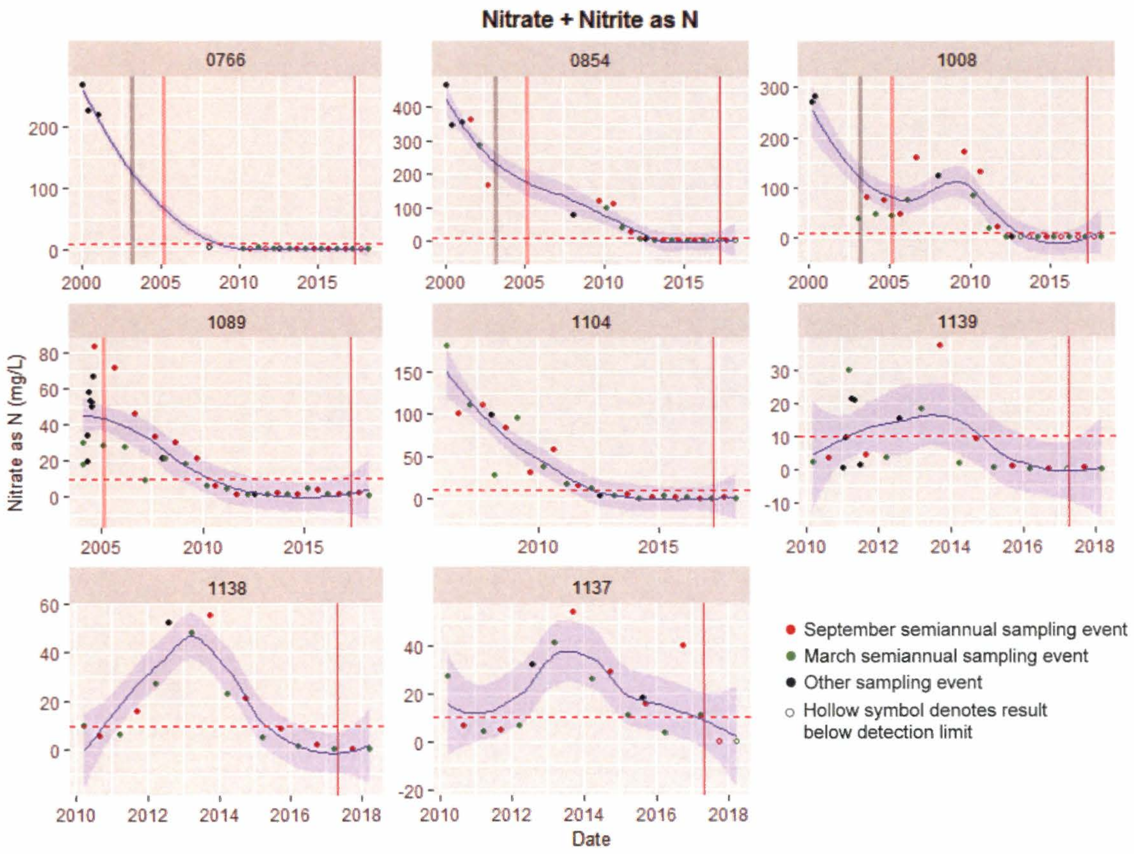


Figure A-2. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 1 Area Wells: 2000–March 2018





Time–Trend Plot Explanation.

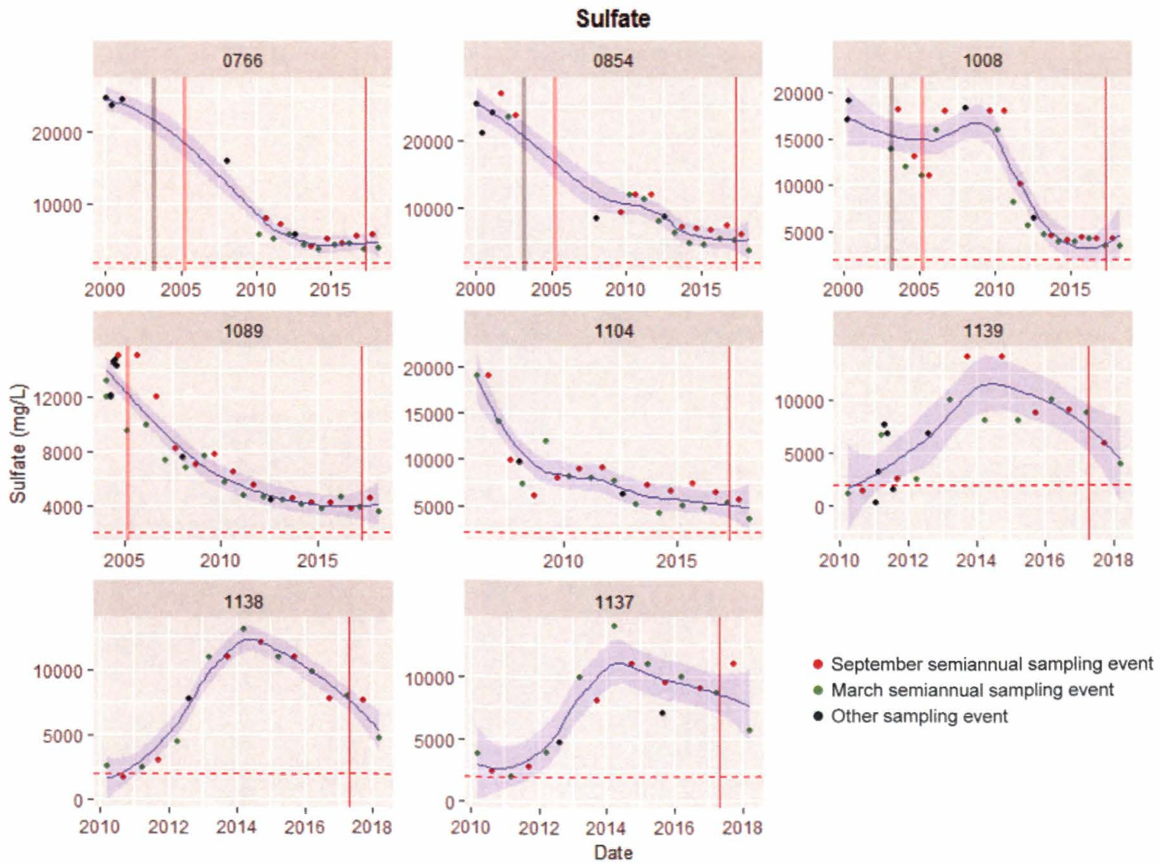
In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (date) and *y*-axis scales are unique for each well (refer to Figure A-2 explanation). In each plot, near-river wells 1137, 1138, and 1139 are listed in order of increasing distance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

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

- - - - denotes the 40 CFR Part 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).



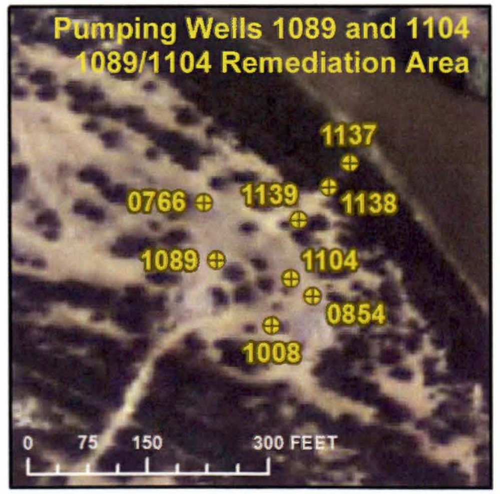
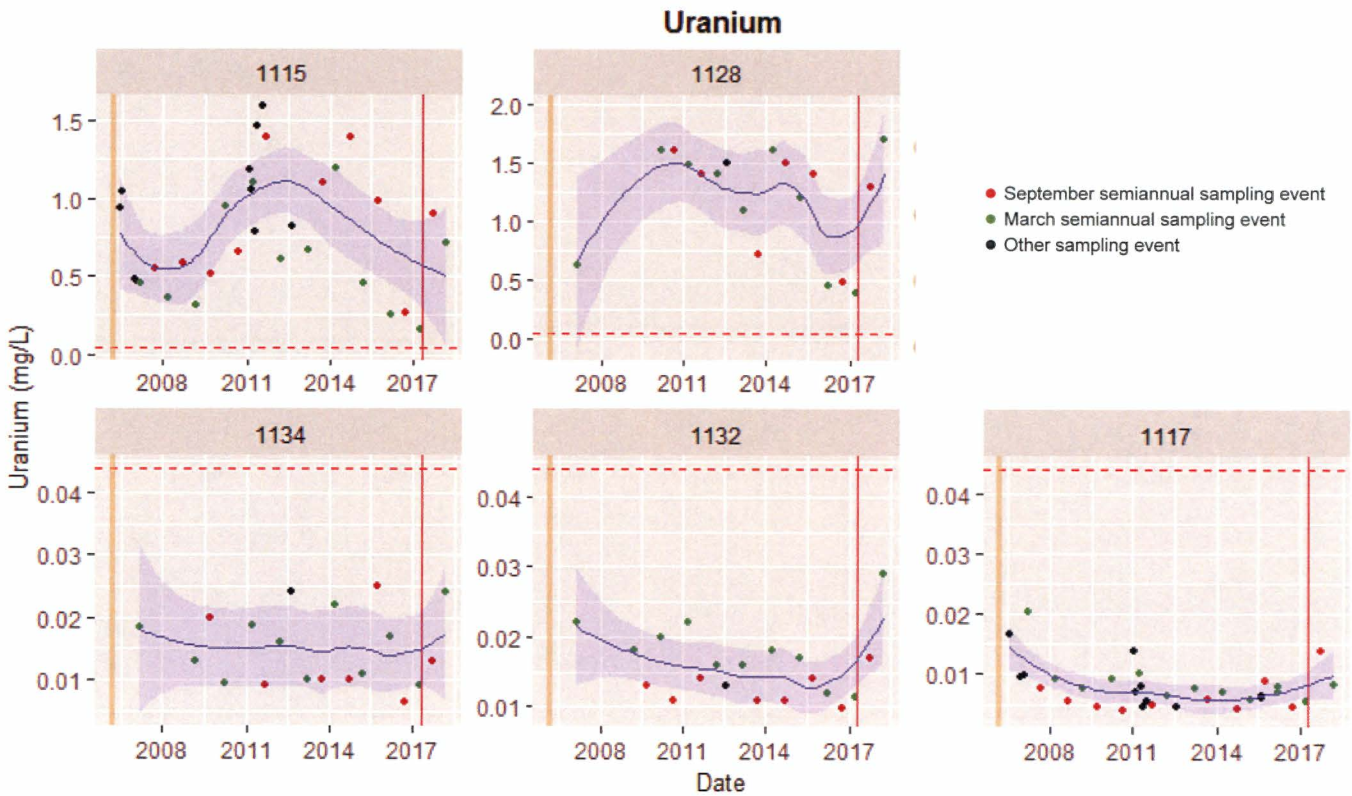
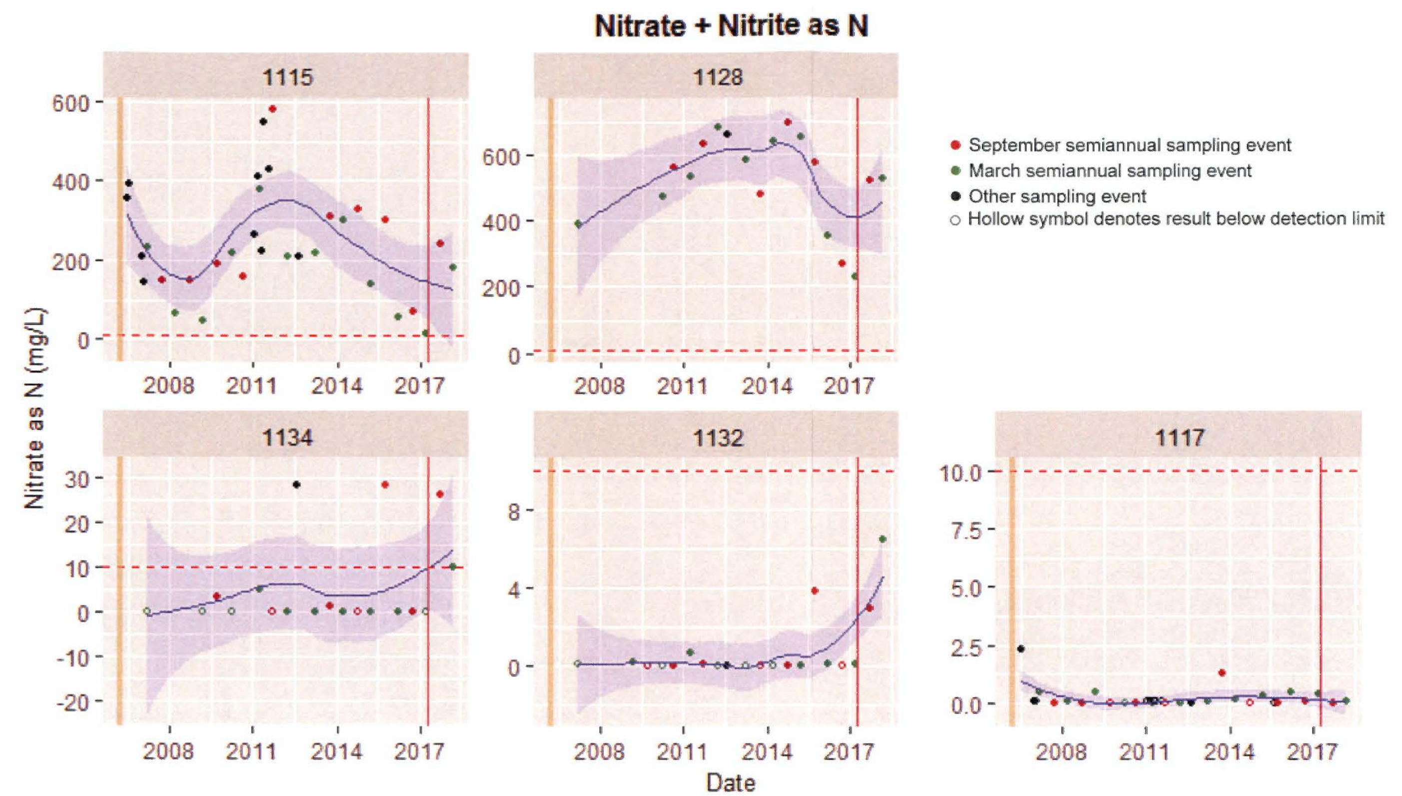
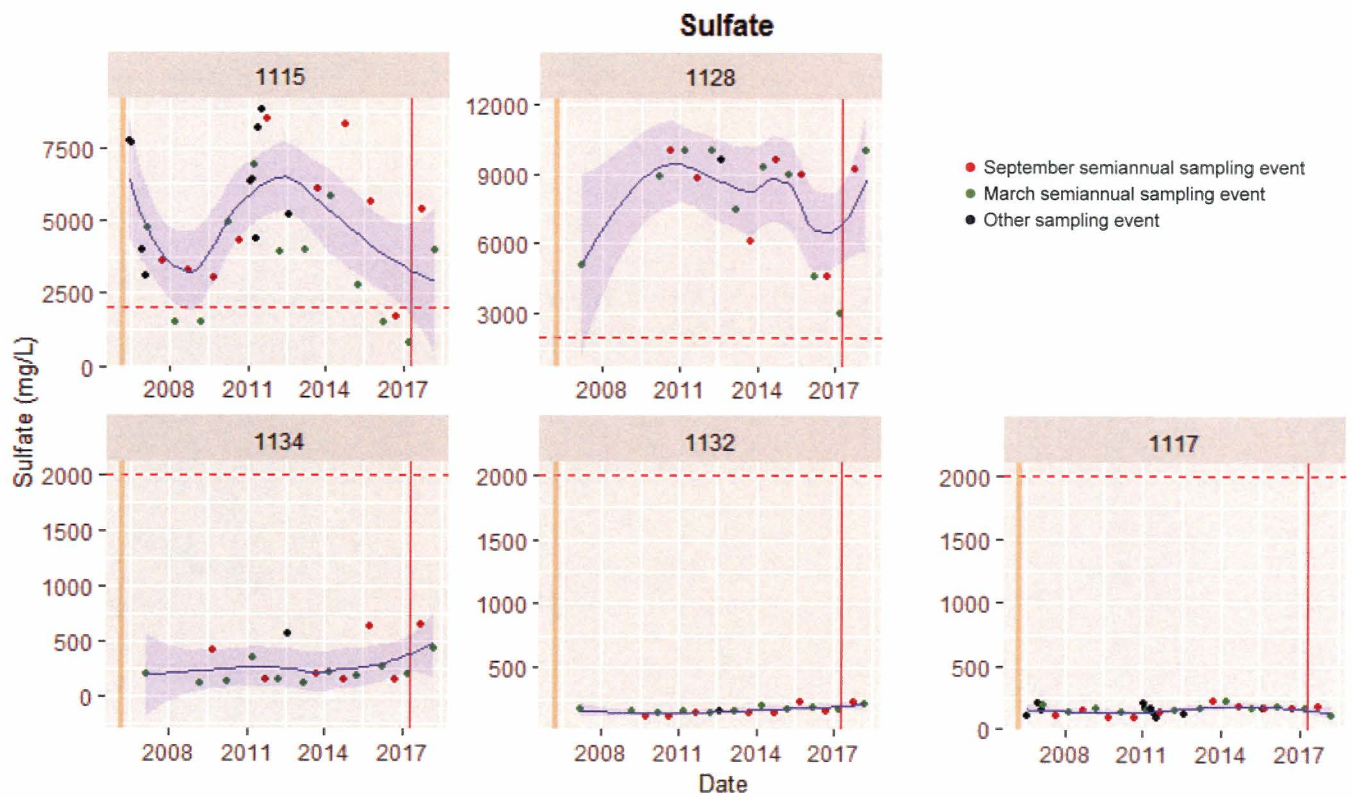


Figure A-3. Uranium, Nitrate, and Sulfate Concentration Trends in the 1089/1104 Remediation Area: 2000–March 2018







Time–Trend Plot Explanation.

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

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

- - - - denotes the 40 CFR Part 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).

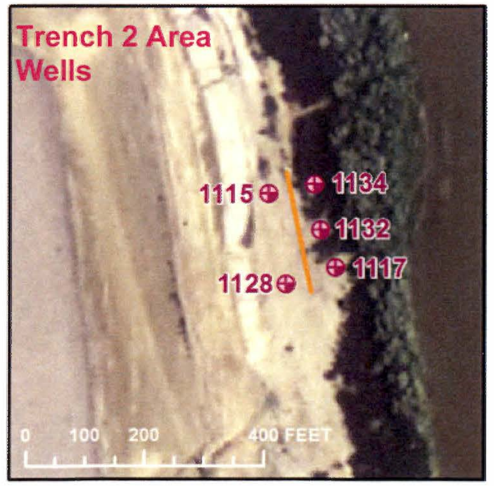
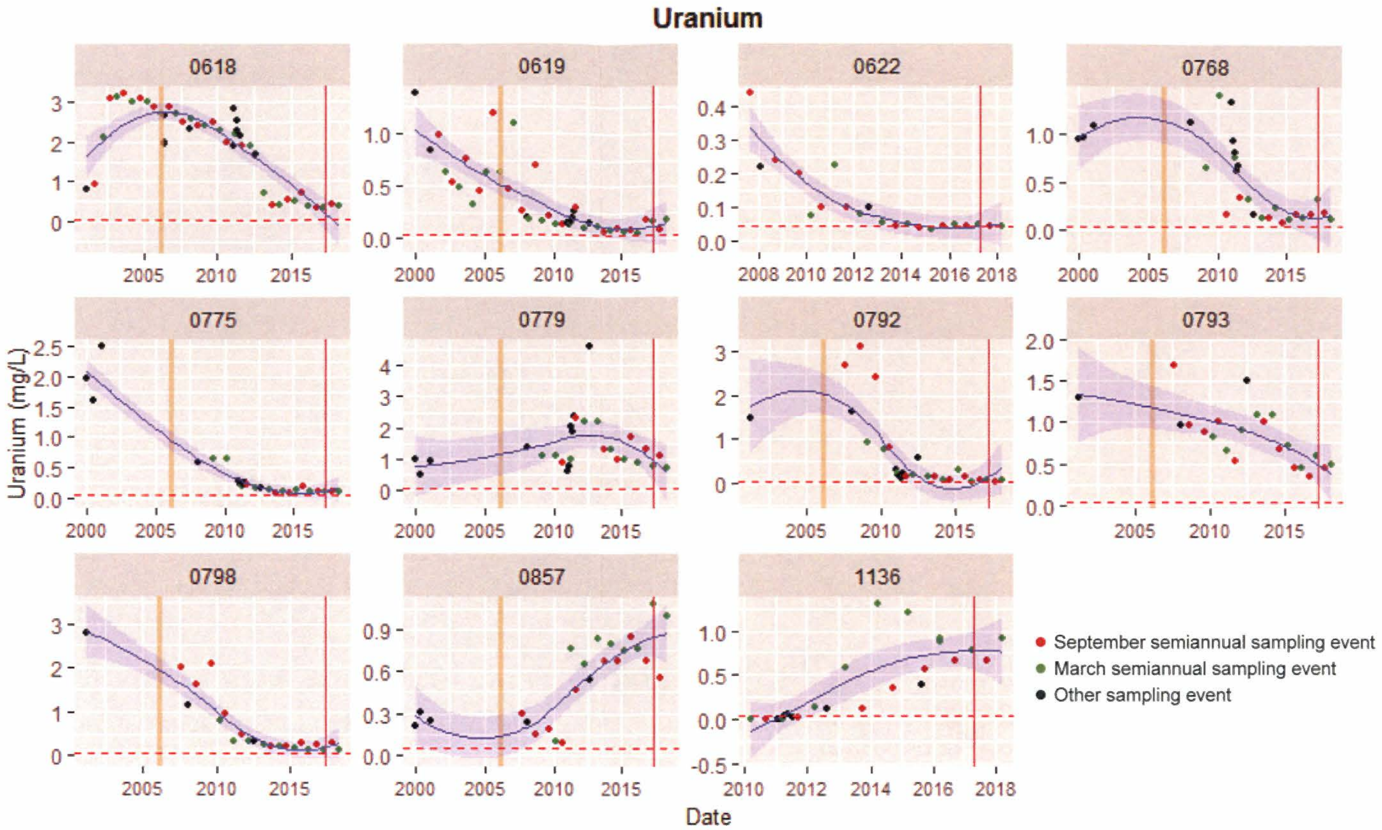
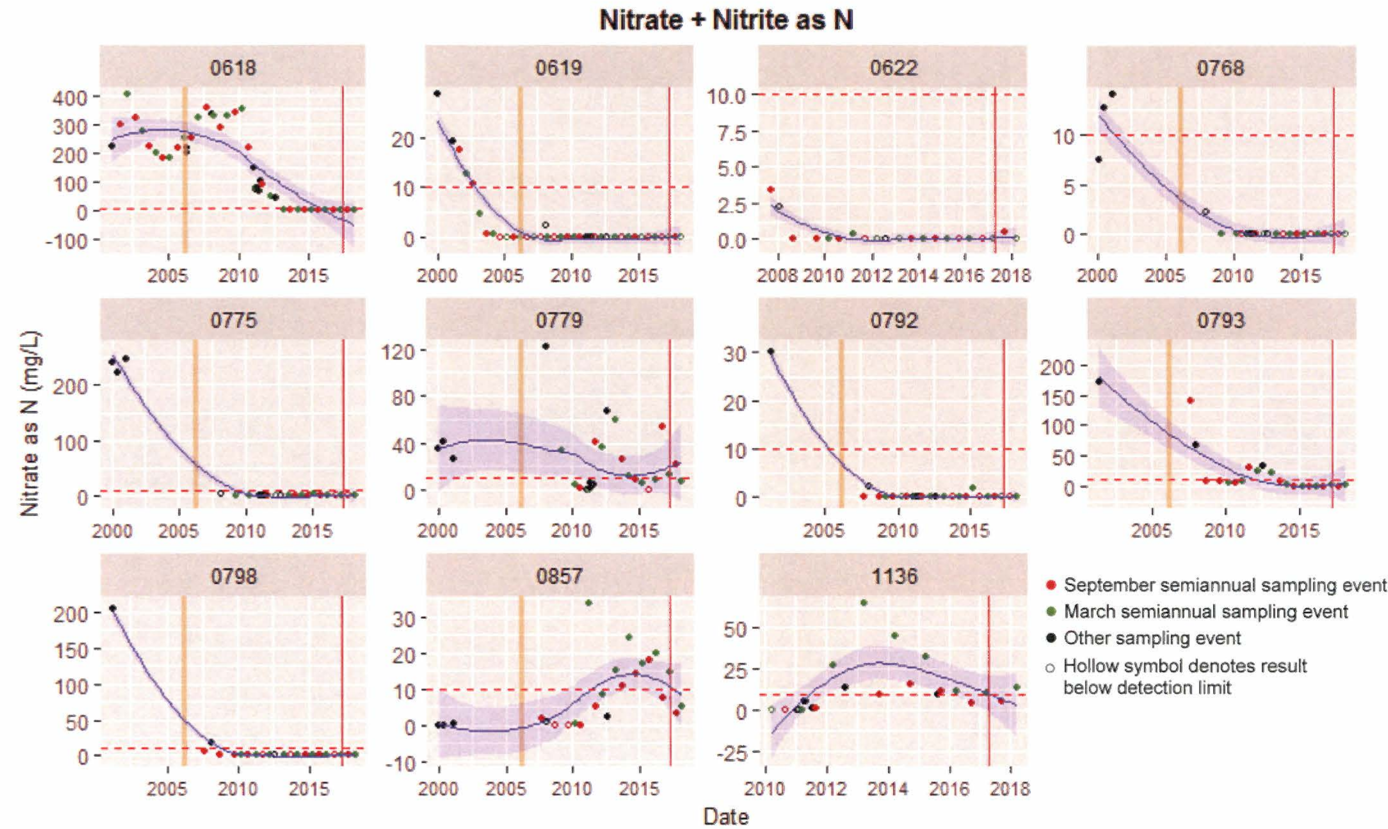


Figure A-4. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 2 Area Wells: 2006–March 2018





Time–Trend Plot Explanation.

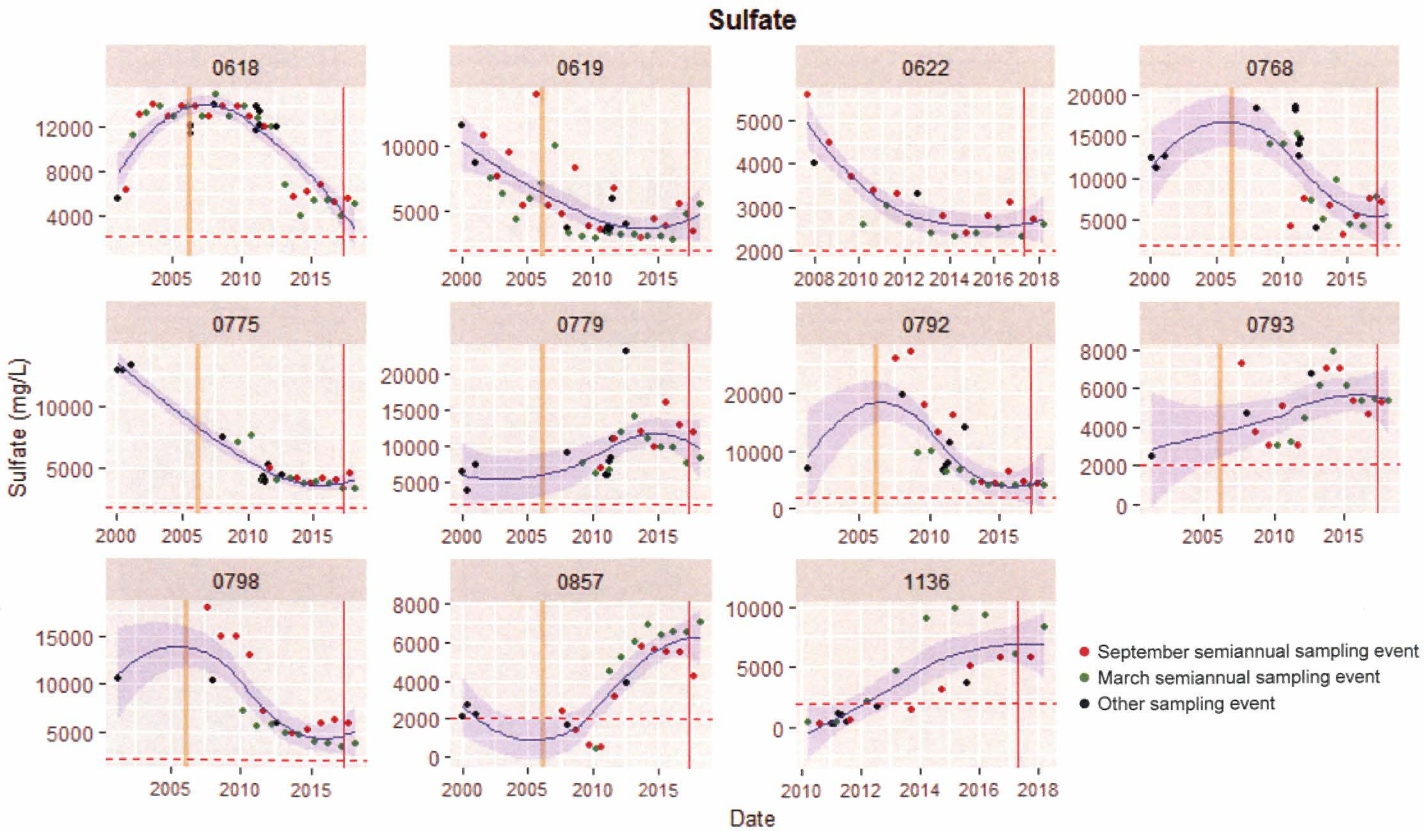
In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (date) and *y*-axis scales are unique for each well (refer to Figure A-2 explanation). For each constituent, wells are listed in order of well number.

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

- - - - denotes the 40 CFR Part 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).



Central Floodplain Wells

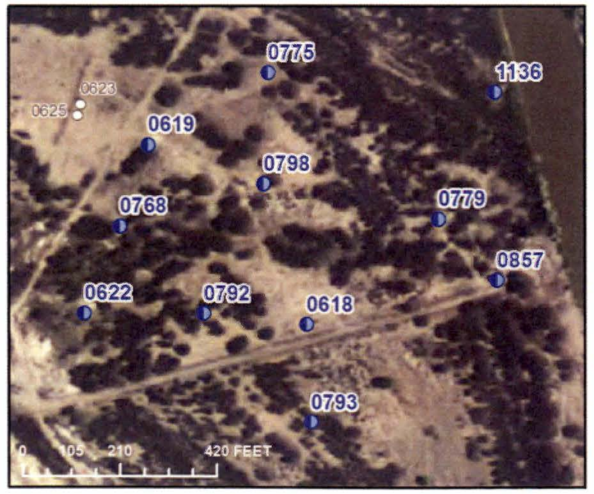
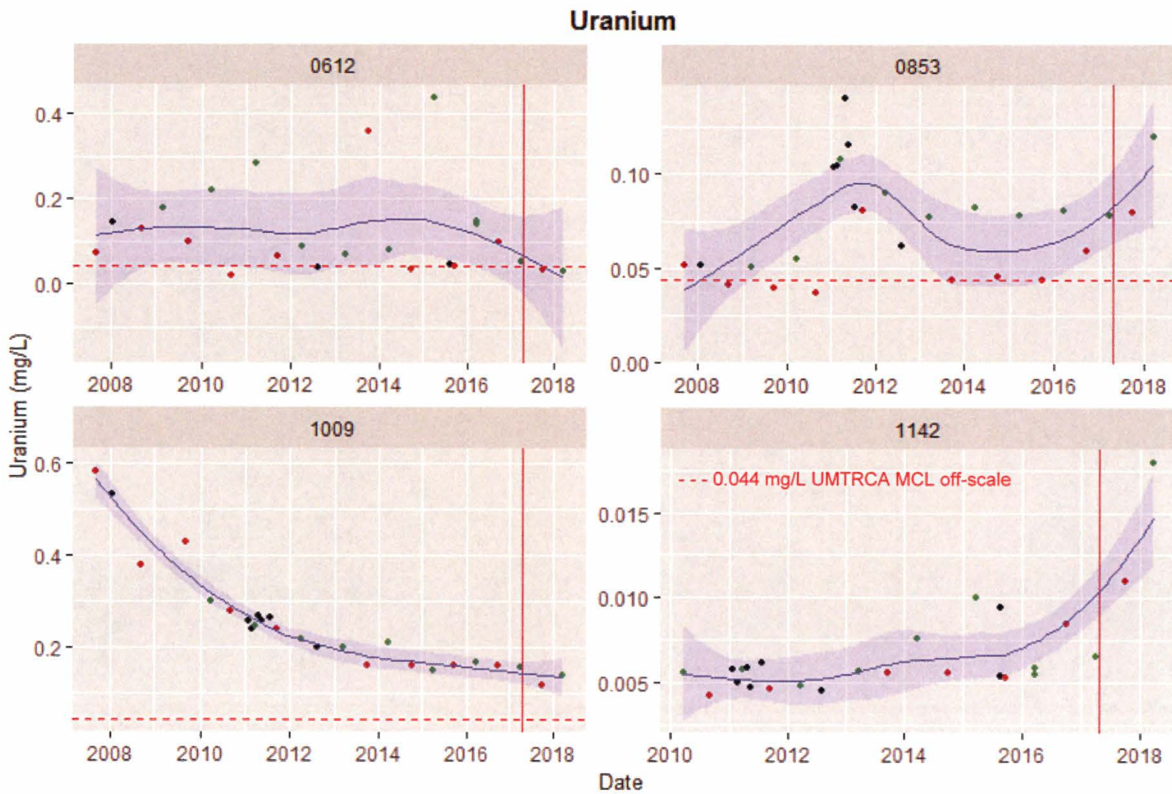
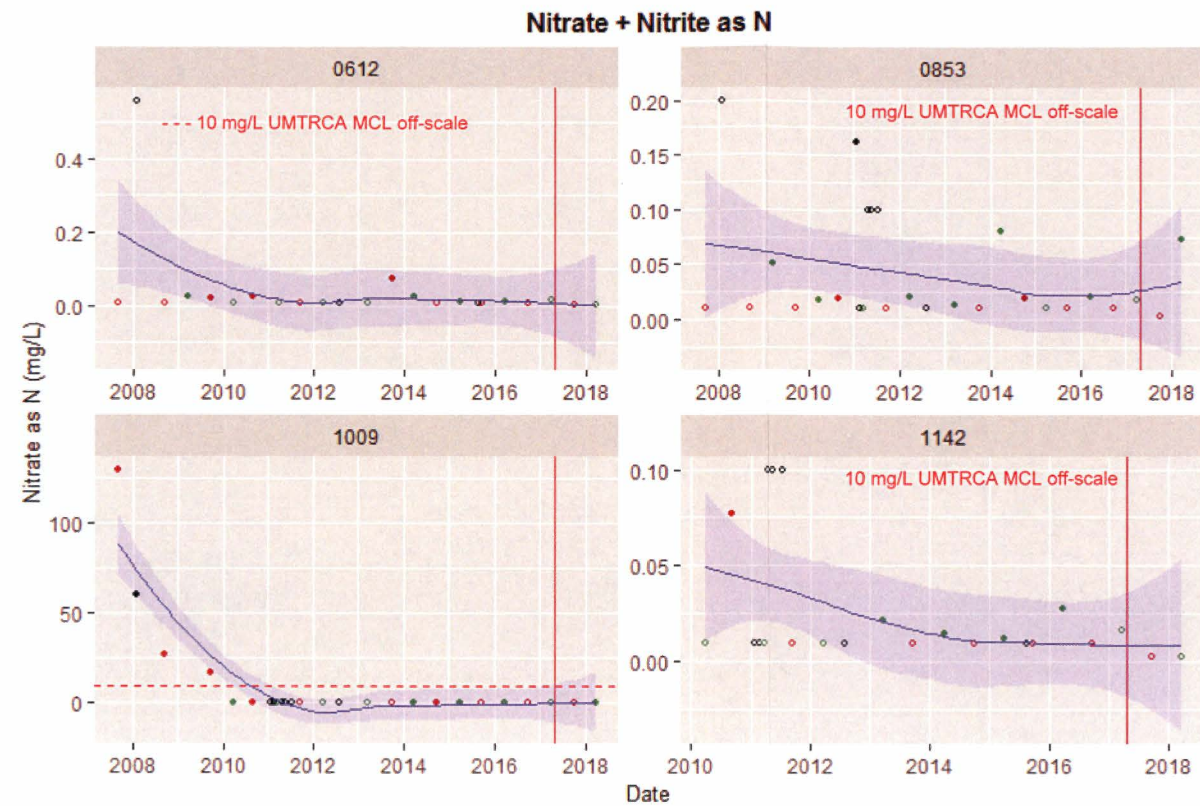
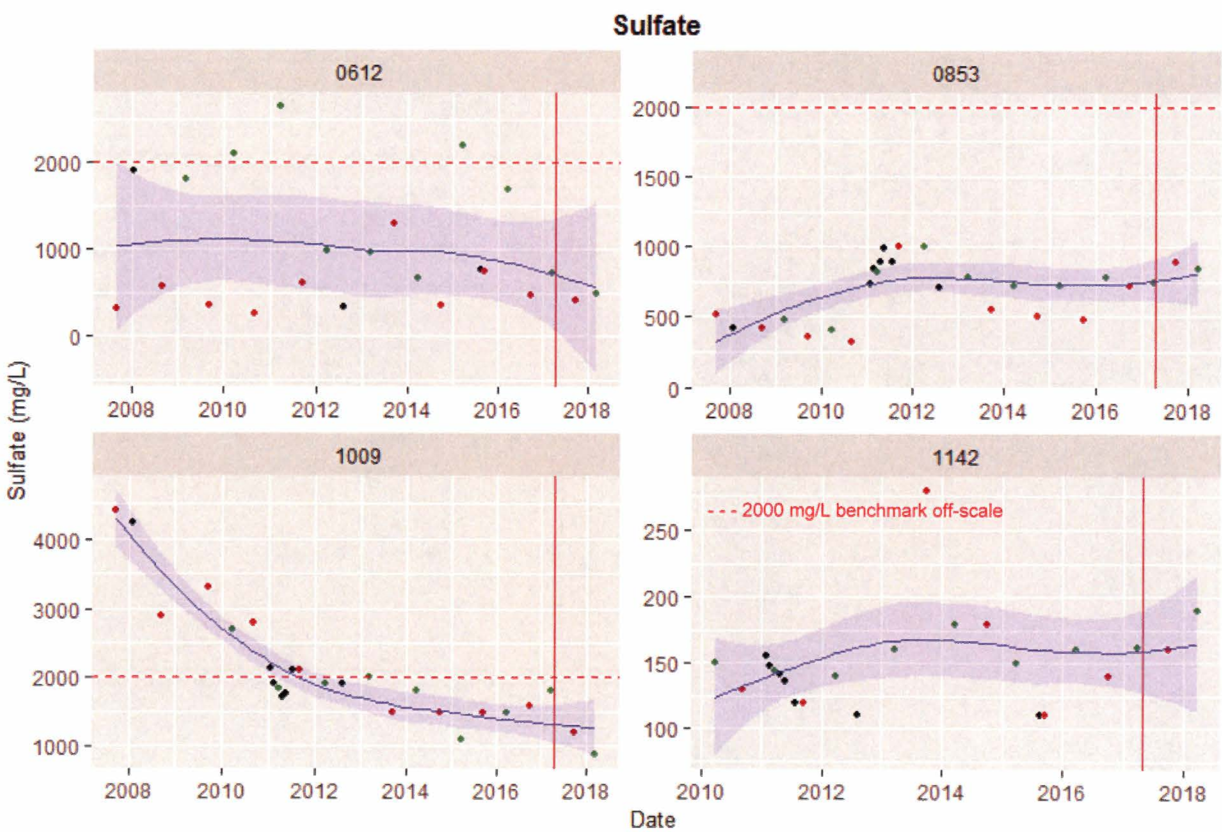


Figure A-5. Uranium, Nitrate, and Sulfate Concentration Trends in Central Floodplain Wells: 2000–March 2018







Time–Trend Plot Explanation.

In this figure, data for each well are plotted separately to facilitate understanding of well-specific trends; both *x*-axis (date) and *y*-axis scales are unique for each well. Unlike preceding figures, this figure includes data for only the period 2007–2018 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 Part 192 MCL or cleanup goal: 0.044 mg/L uranium; 10 mg/L nitrate as N; 2000 mg/L sulfate
This benchmark is not included in plots for those wells with very low or nondetect contaminant concentrations.

• 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).

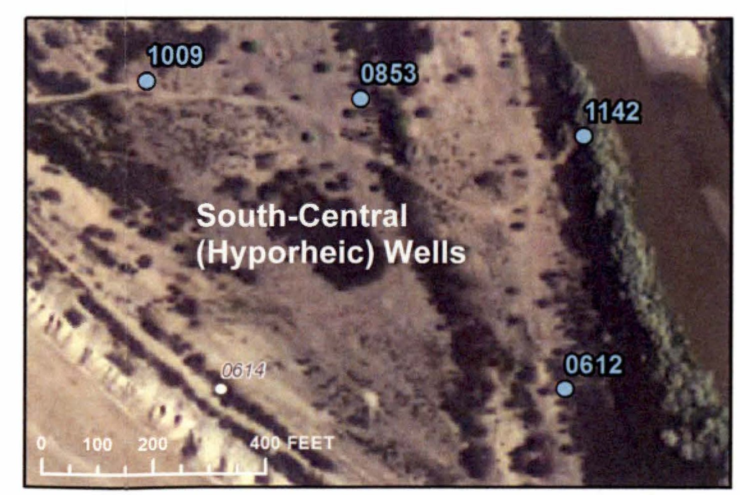
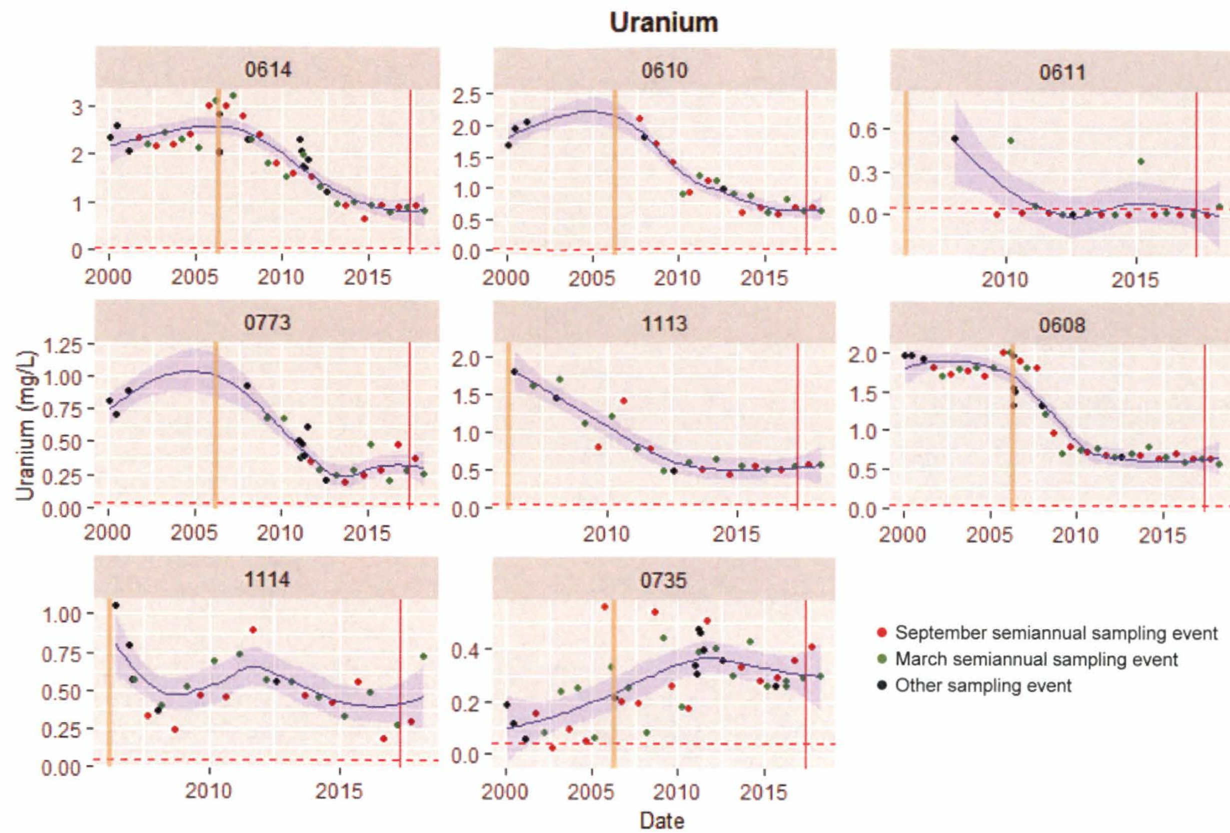
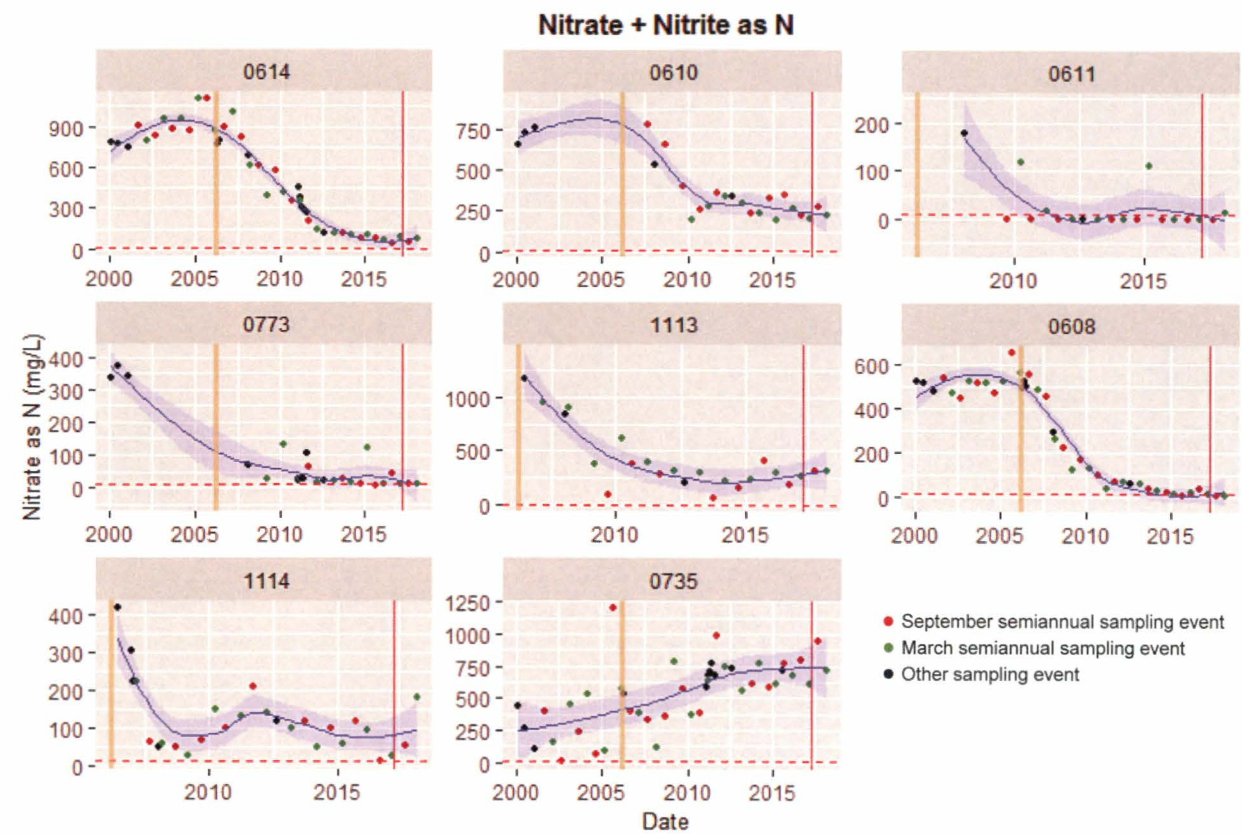
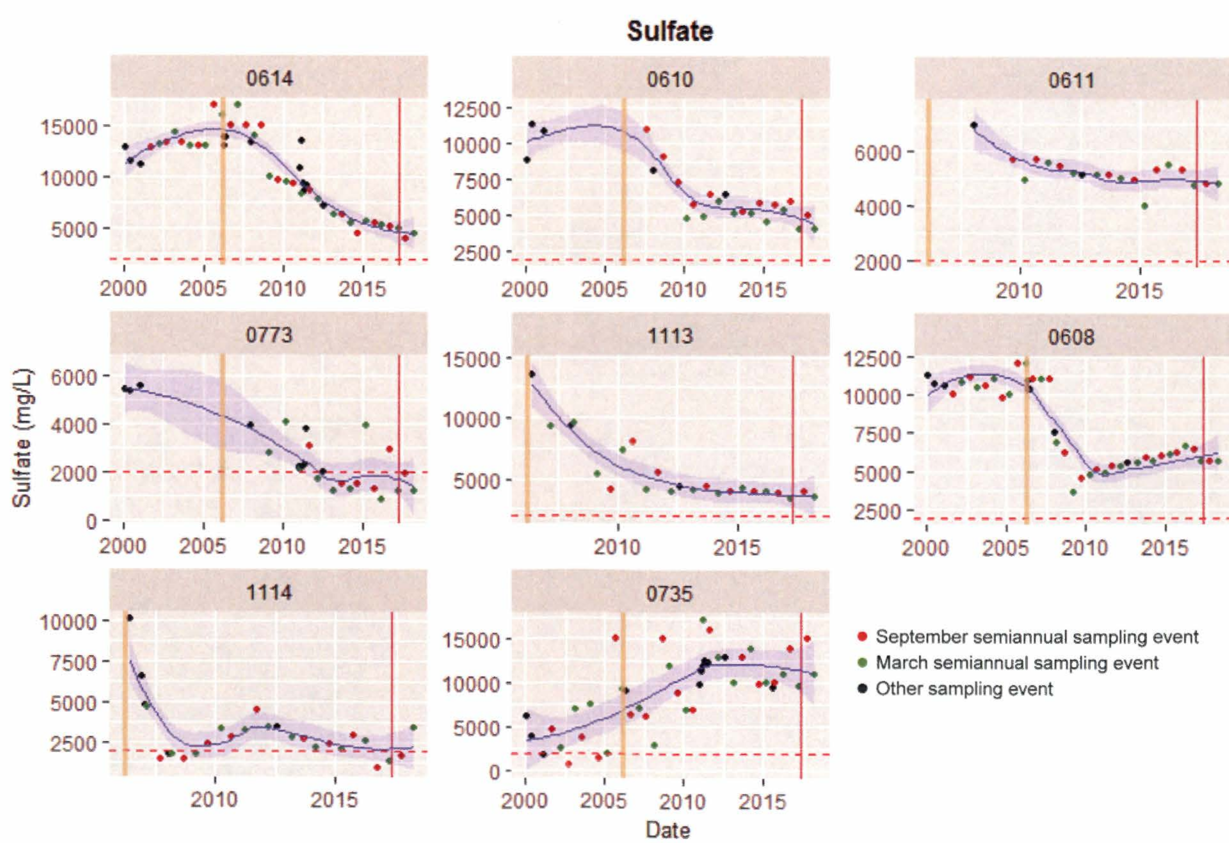
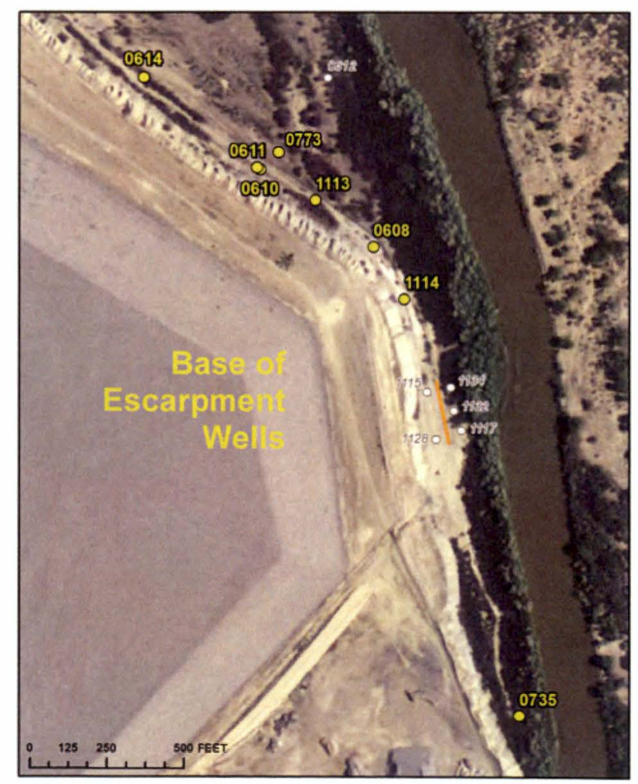


Figure A-6. Uranium, Nitrate, and Sulfate Concentration Trends in South-Central Floodplain Wells: 2007–March 2018









Time–Trend Plot Explanation.

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

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

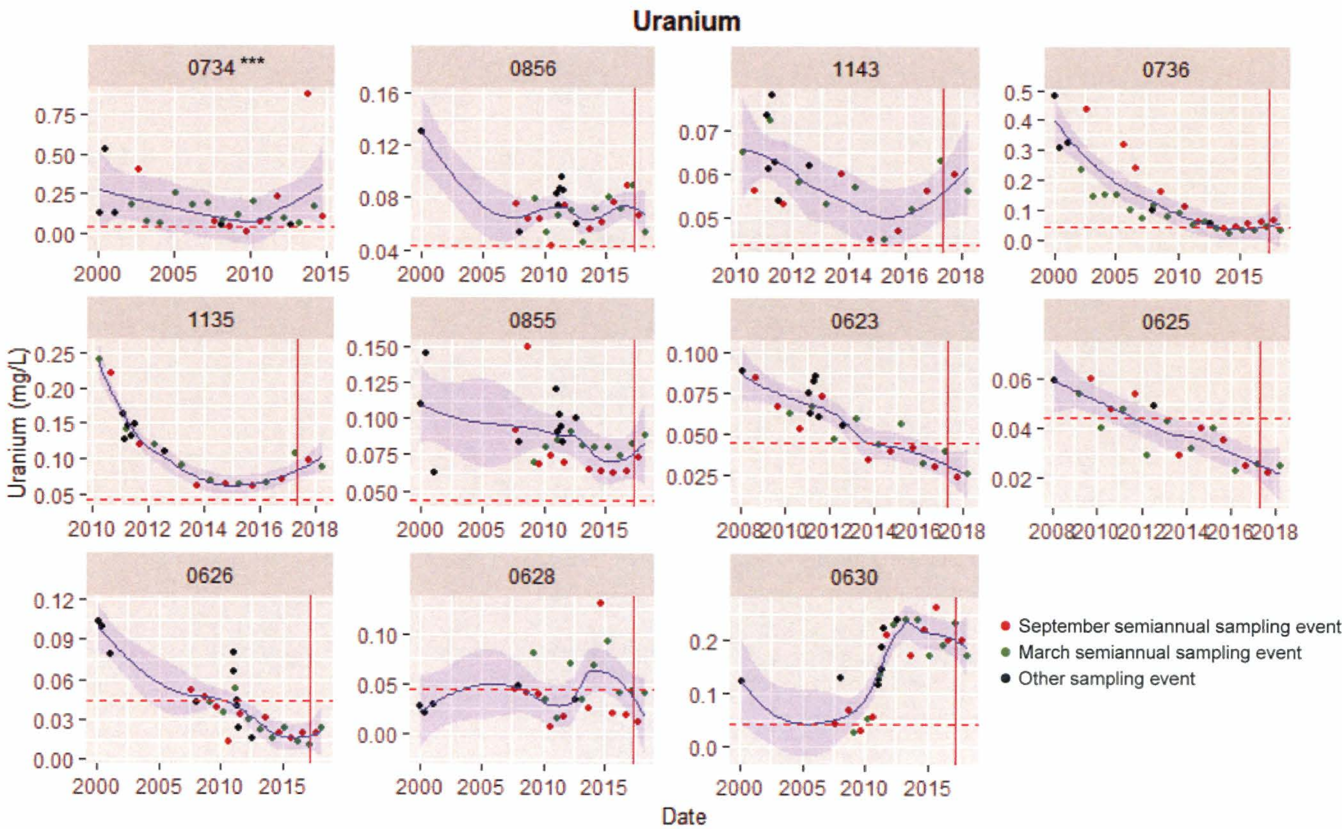
- - - - denotes the 40 CFR Part 192 MCL or cleanup goal:

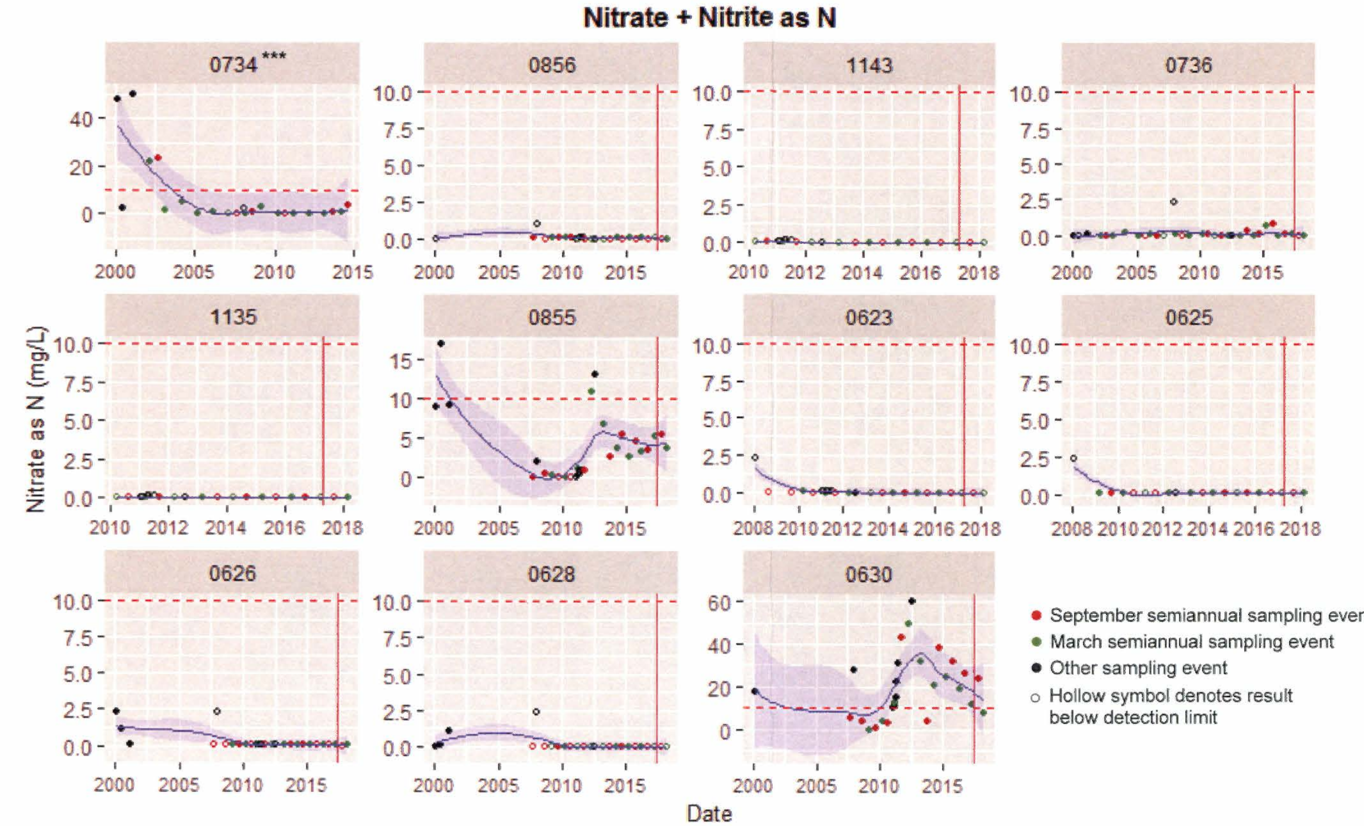
- 0.044 mg/L uranium
- 10 mg/L nitrate as N
- 2000 mg/L sulfate

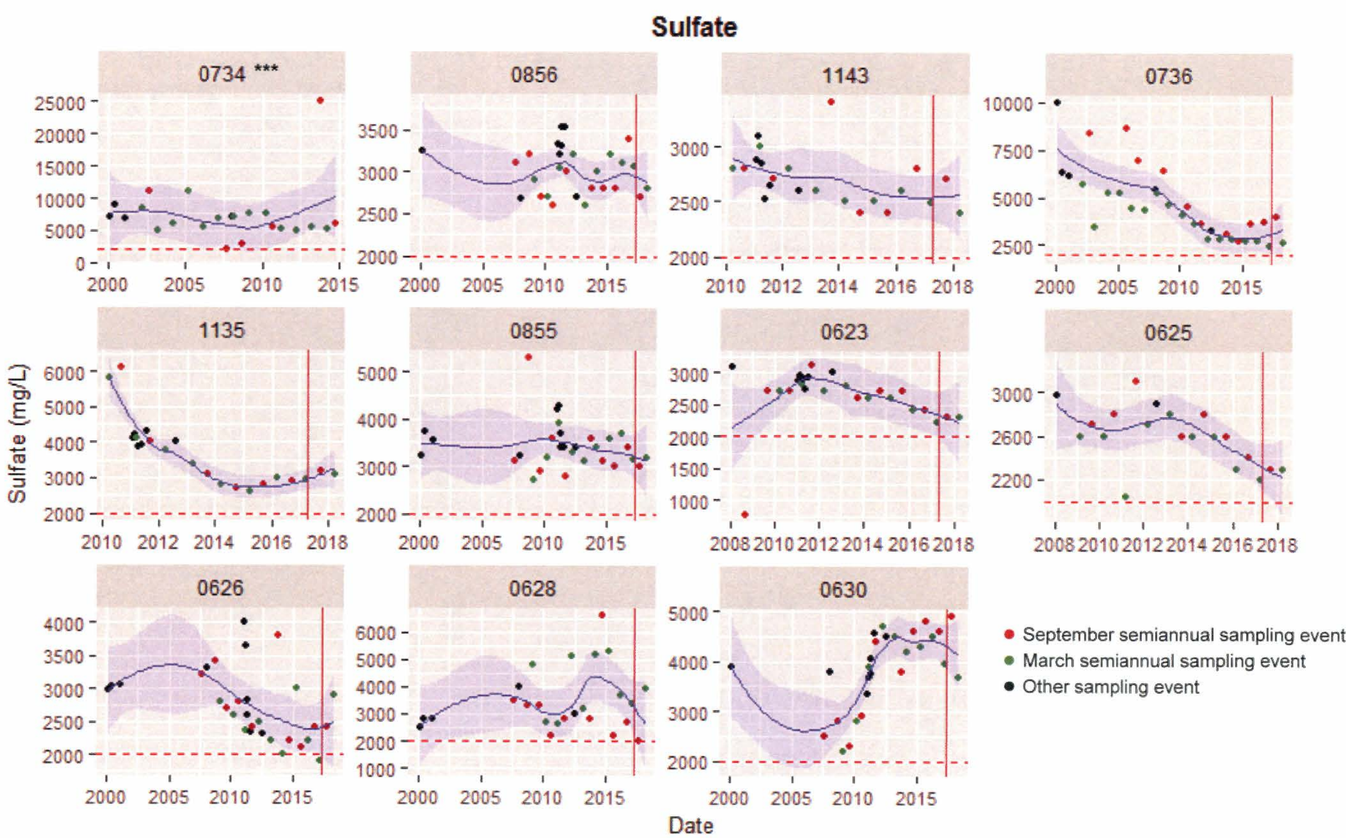
Vertical line | denotes time when Trench 1 and Trench 2 were installed (in spring 2006).

Second vertical line | denotes when pumping on the floodplain was suspended, on April 21, 2017 (Figure 3).

Figure A-7. Uranium, Nitrate, and Sulfate Concentration Trends in Base of Escarpment Floodplain Wells: 2000–March 2018







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

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

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

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

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

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

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

Western Floodplain Wells

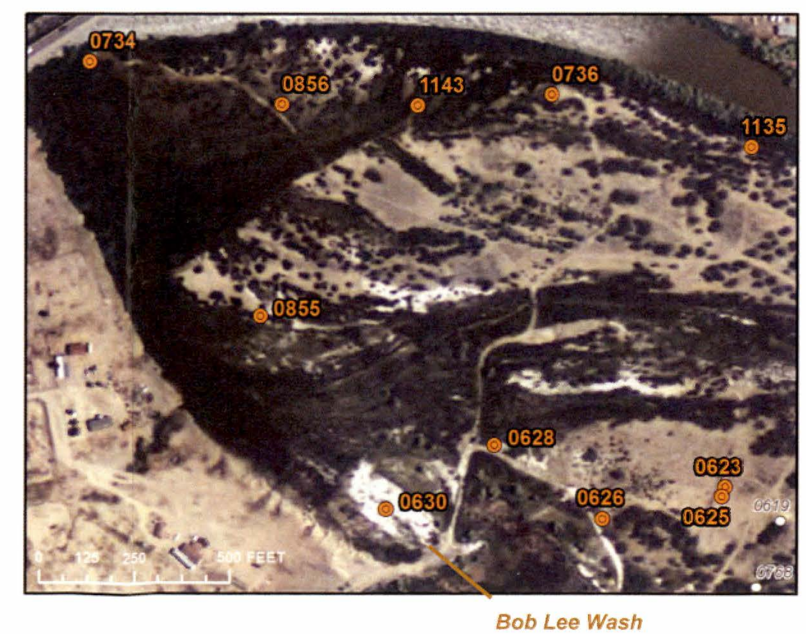
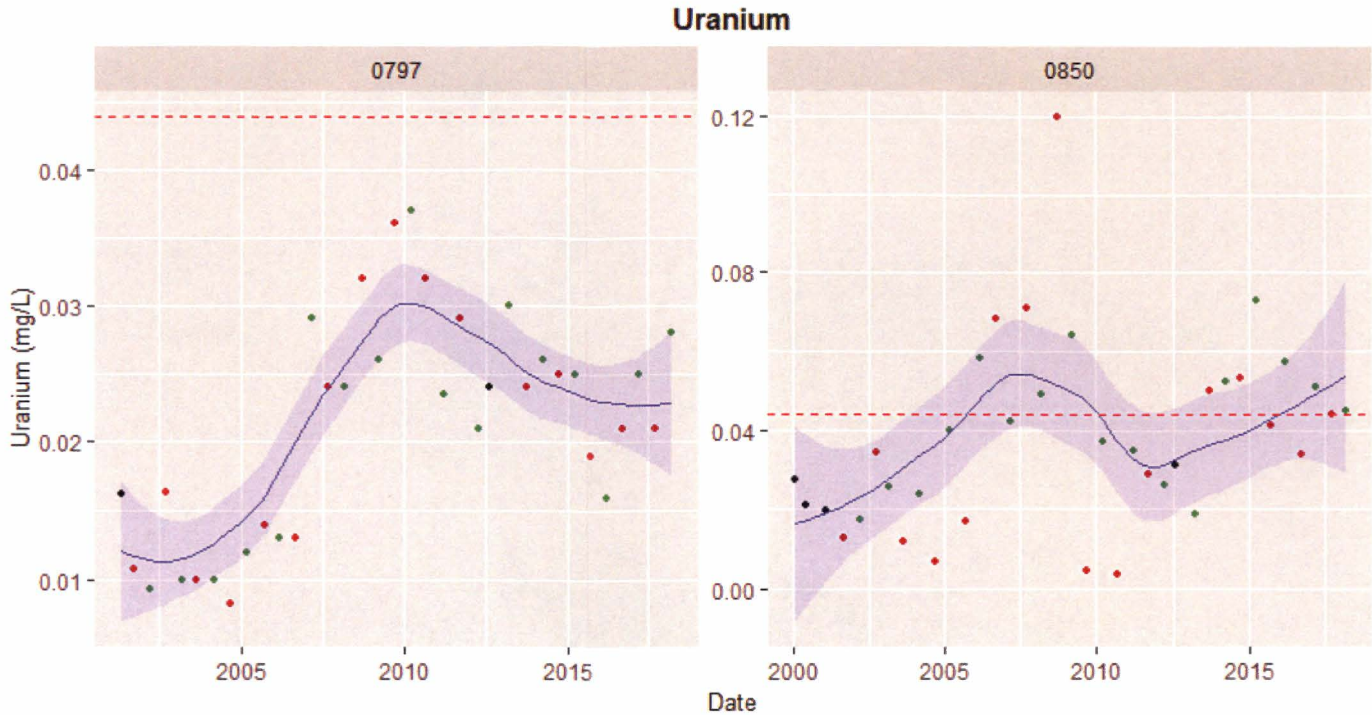
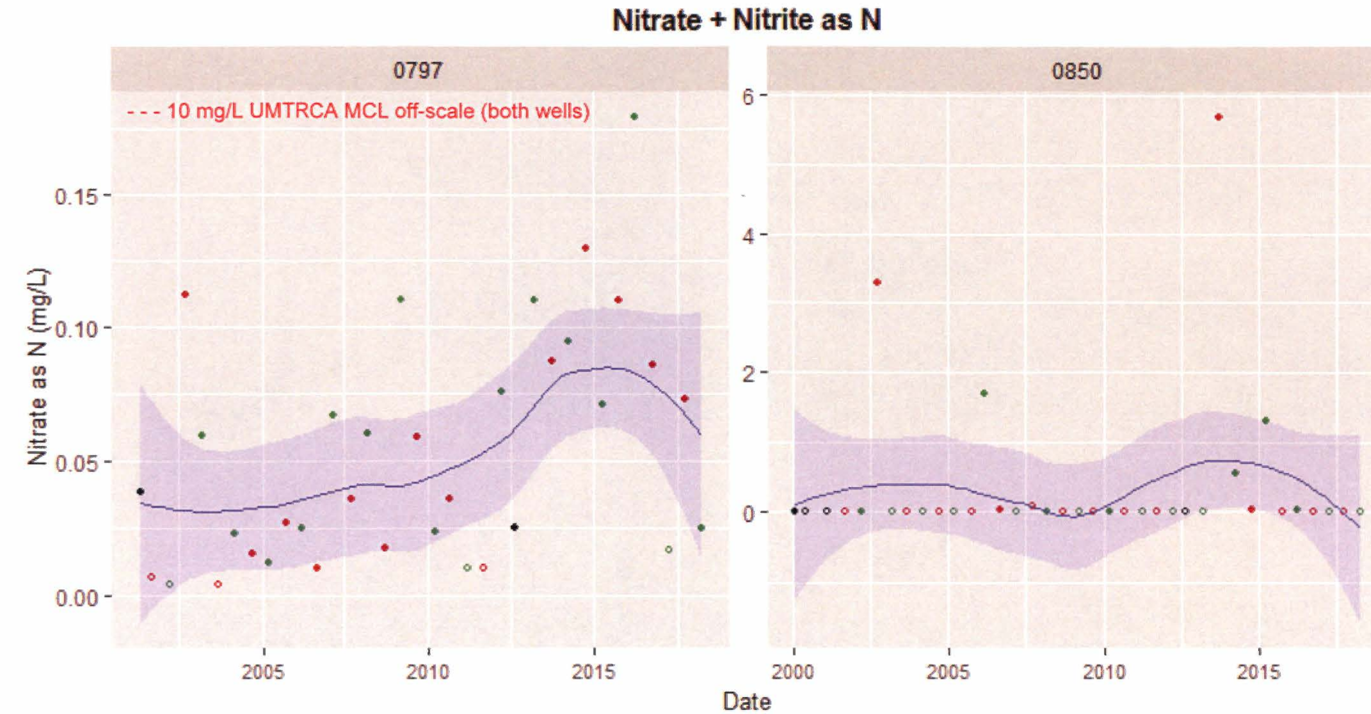
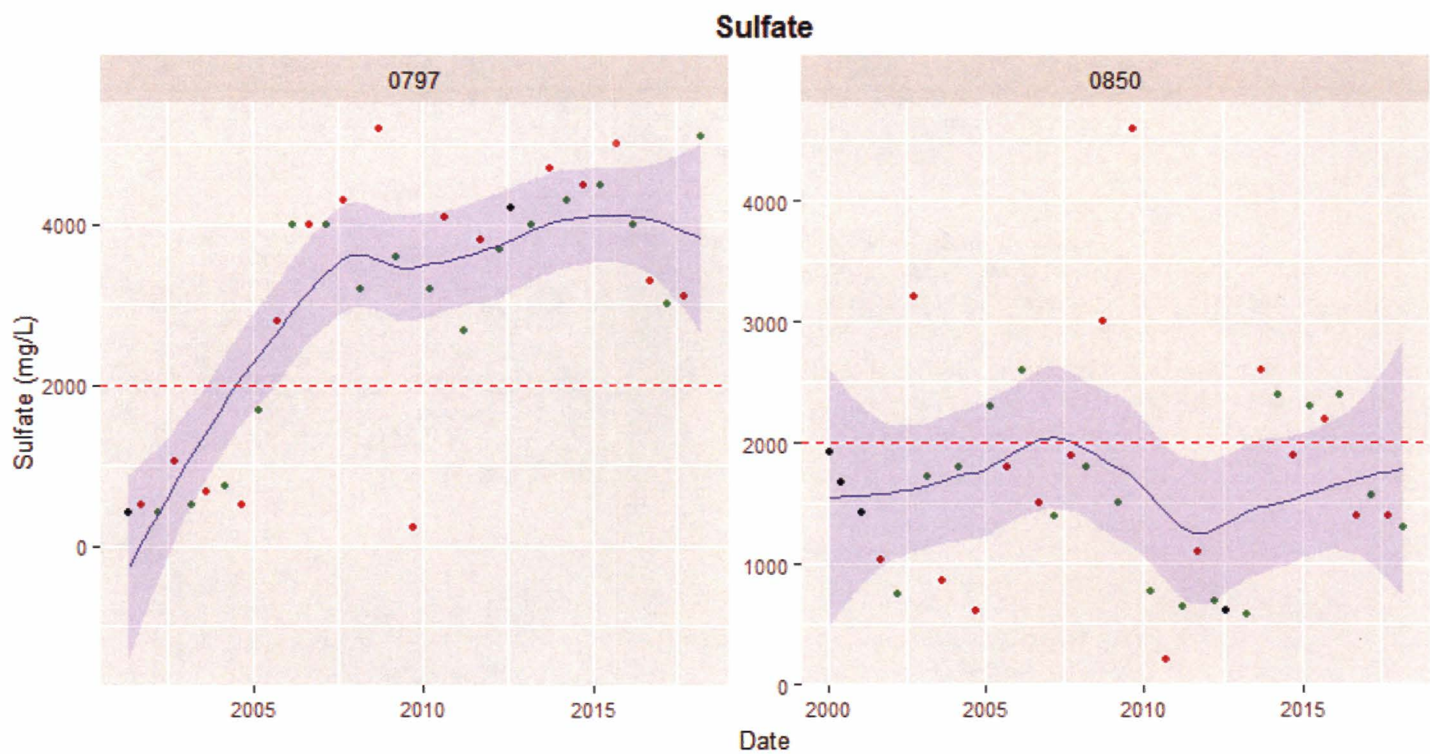


Figure A-8. Uranium, Nitrate, and Sulfate Concentration Trends in Western Floodplain Wells: 2000–March 2018







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

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

shaded area is the corresponding 95% pointwise confidence interval

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

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

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

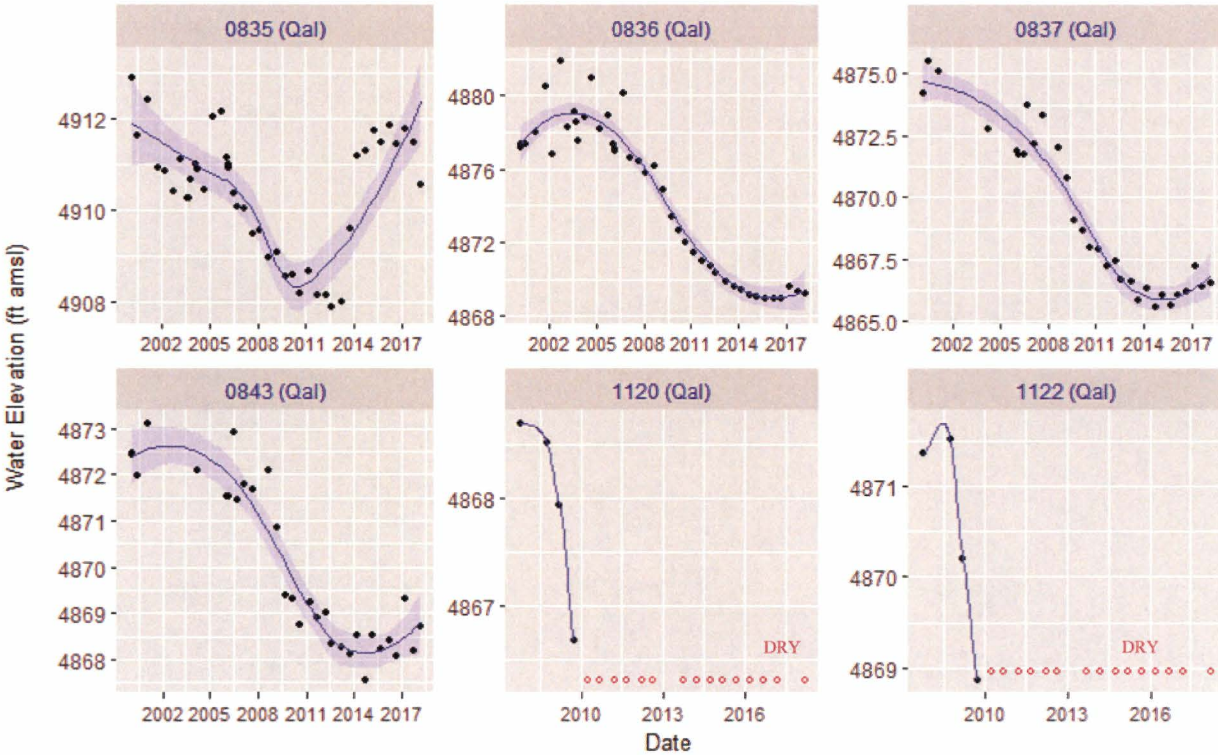
- September semiannual sampling event
- March semiannual sampling event
- Other sampling event
- ○ Denotes result below the detection limit

Figure A-9. Uranium, Nitrate, and Sulfate Concentration Trends in Background Floodplain Wells: 2000–March 2018

Appendix B

Hydrographs for Terrace Alluvial Wells

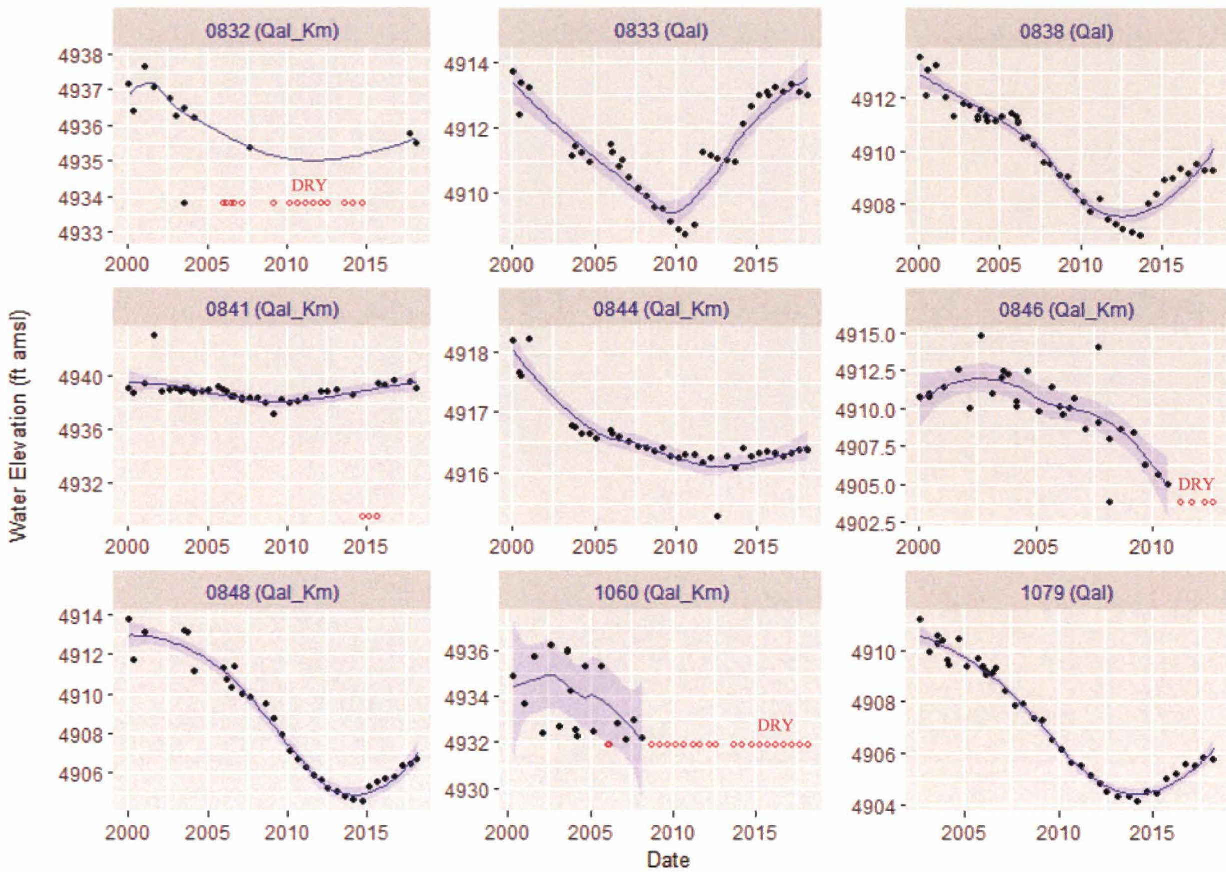
This page intentionally left blank



Notes:
In this and subsequent figures in this appendix, water-level data are plotted separately for each well.
In each of these plots, both *x*-axis (date) and *y*-axis scales are unique for each well. Refer to the detailed explanation in Appendix A, Figure A-2.
All wells shown here are screened solely in the alluvium (Qal); refer to well construction schematic in Figure C-1.

—	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)
ft amsl	feet above mean sea level

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

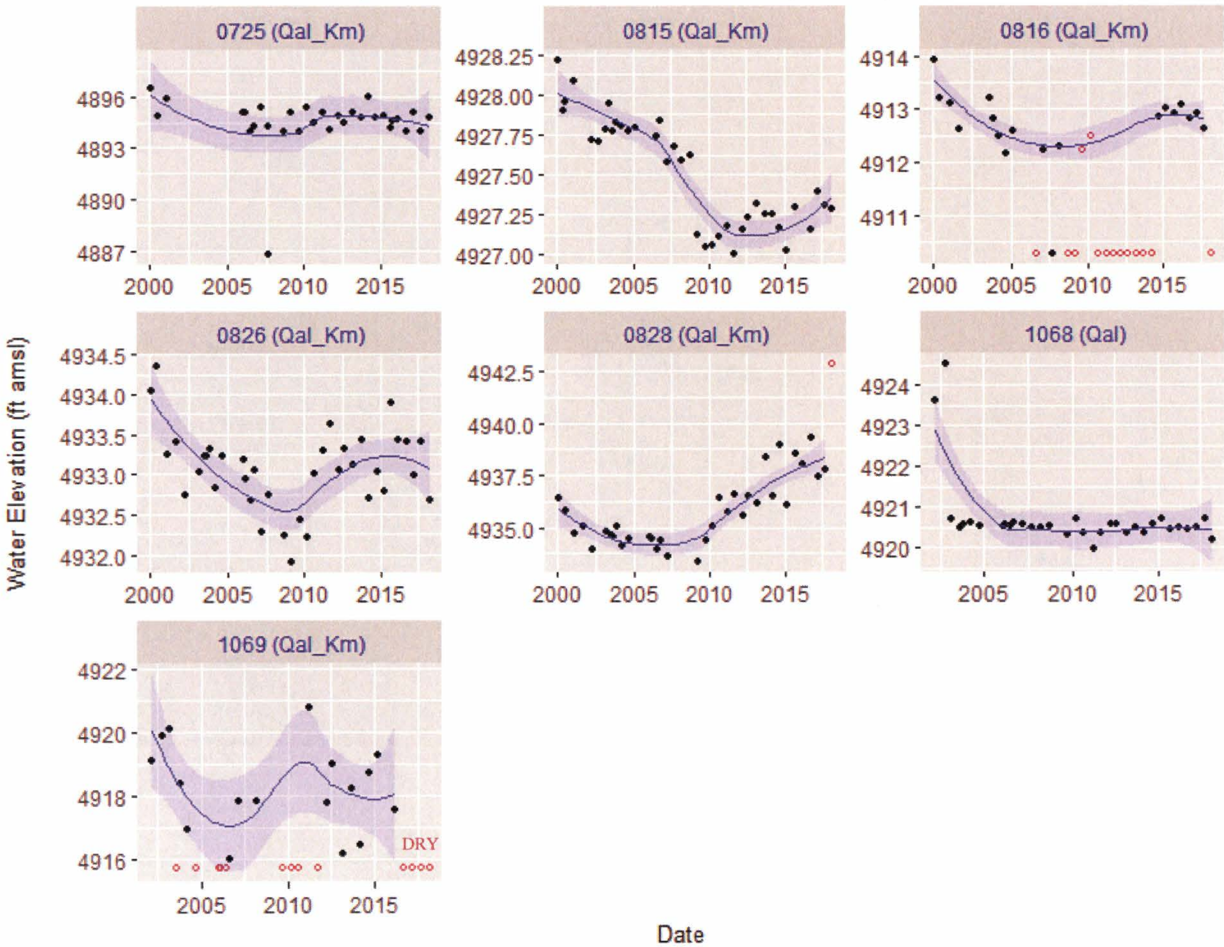


Notes:

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

—	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)
Qal	denotes wells screened solely in the alluvium
Qal_Km	denotes wells screened in both the alluvium and the Mancos Shale (see Figure C-2)
ft amsl	feet above mean sea level

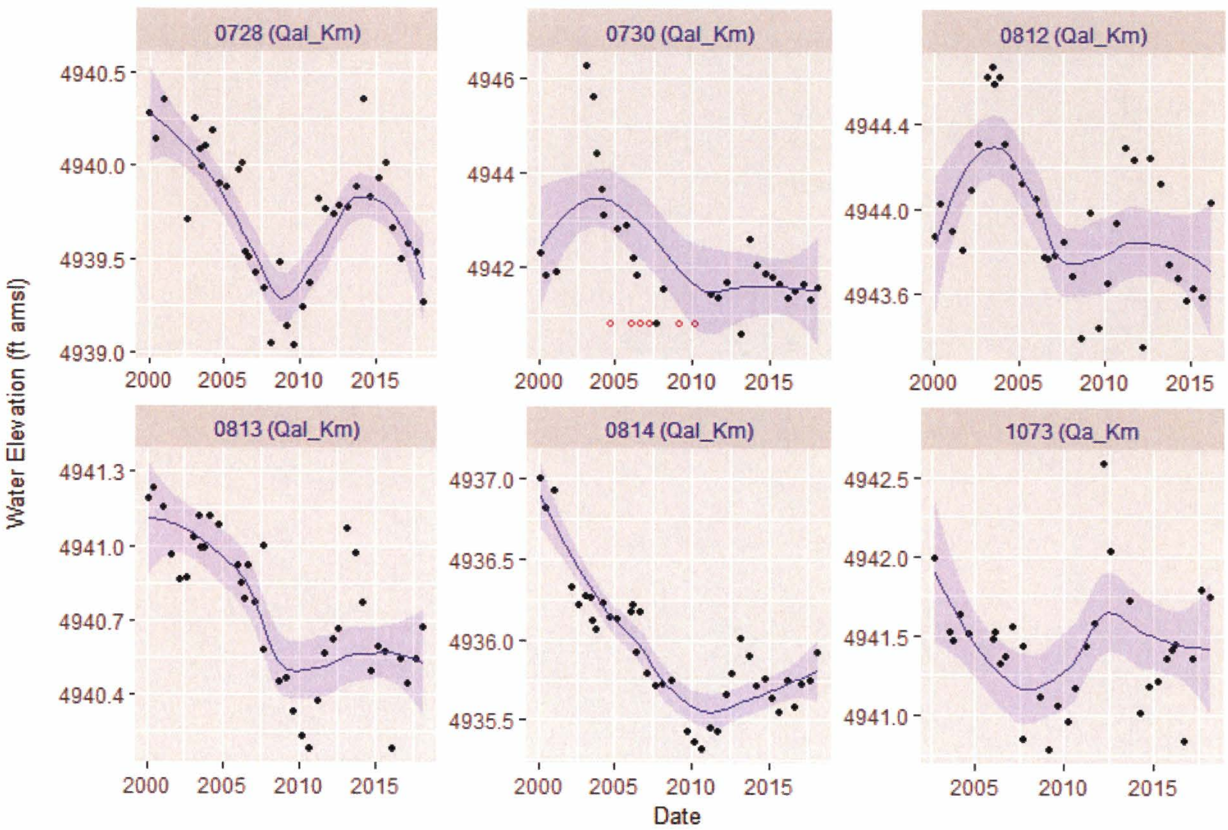
Figure B-2. Hydrographs for Southwest Alluvial Wells South of Highway 64 and West of Highway 491



Notes:

(blue line with shaded band)	blue line is the LOESS local regression line and corresponding 95% pointwise confidence interval
○	denotes that the well was dry or had insufficient water to sample at the time of that monitoring event (assigned values equal to the bottom screen elevation)
Qal	well screened solely in the alluvium (Figure C-1)
Qal_Km	well screened in the alluvium and the Mancos Shale (Figure C-2)
ft amsl	feet above mean sea level

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



Notes:

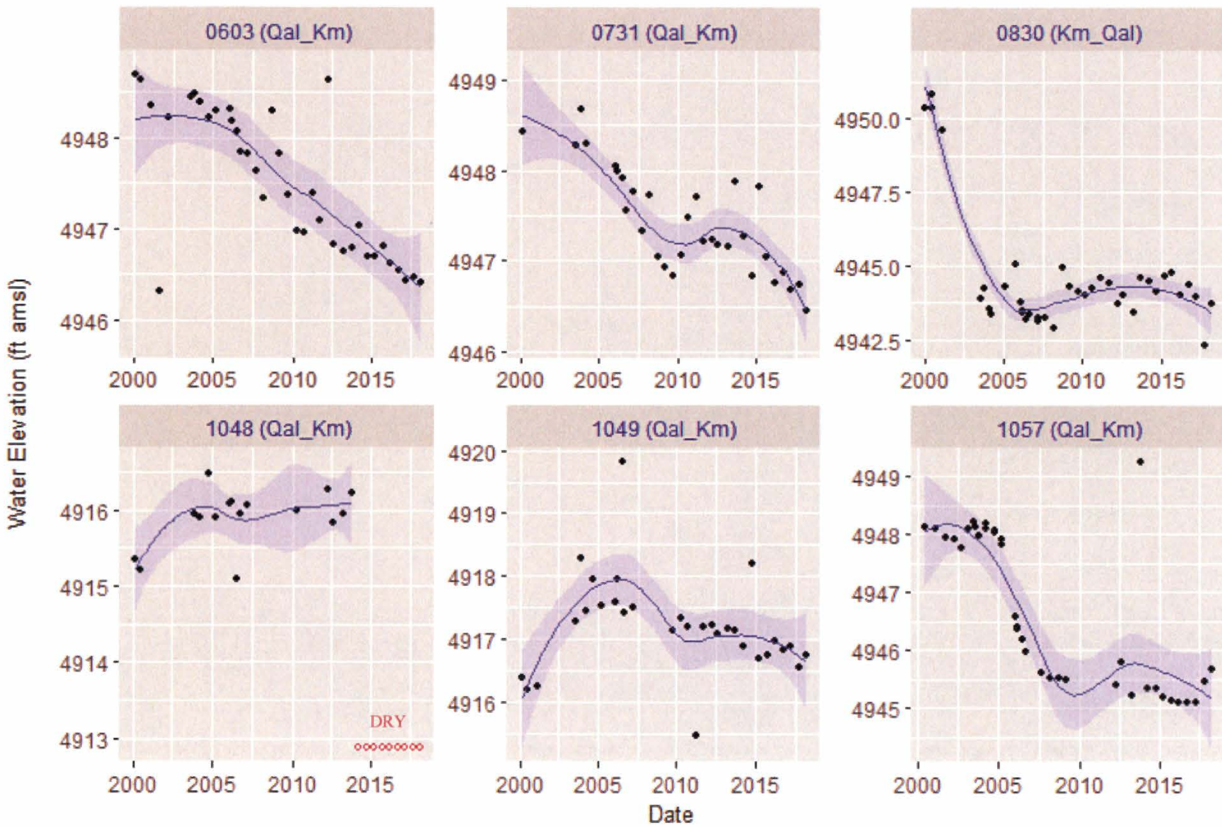
blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval

○ 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)

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

ft amsl feet above mean sea level

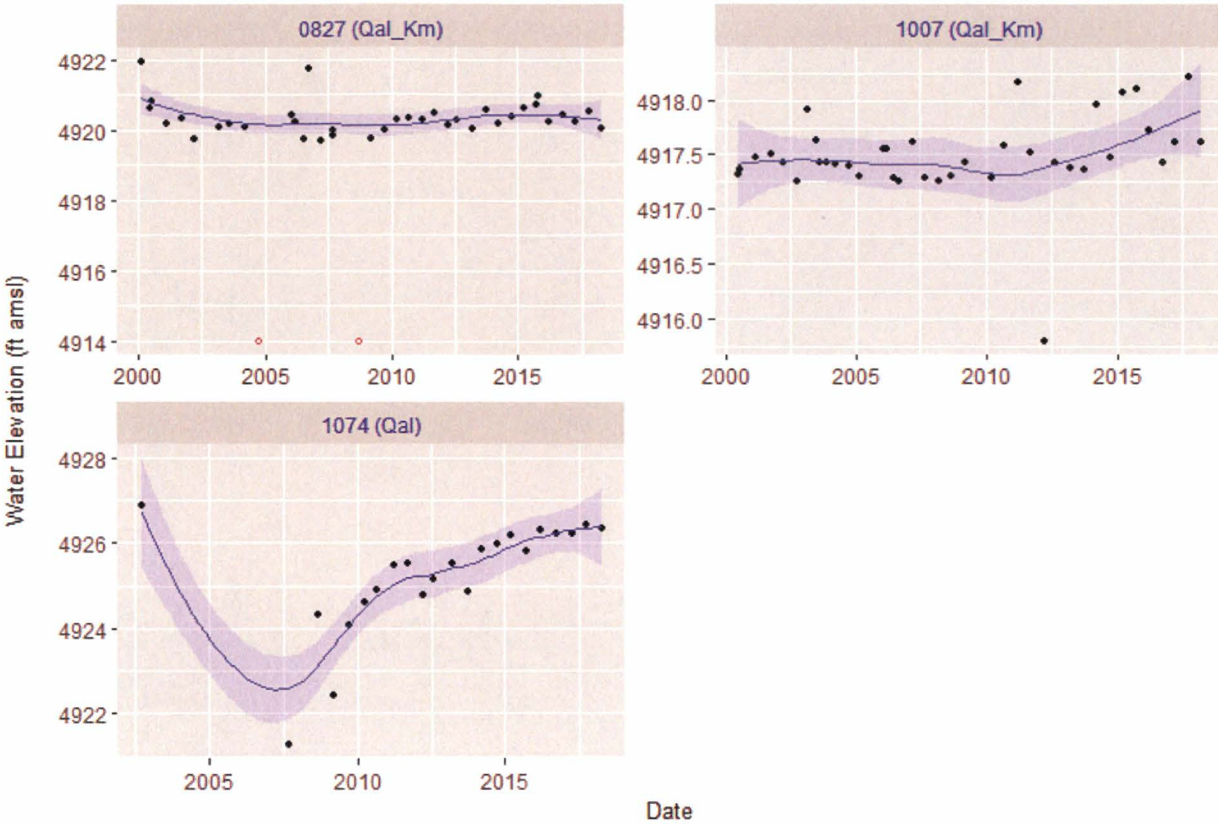
Figure B-4. Hydrographs for Terrace Alluvial Wells in Borrow Pit and Swale Area



Notes:

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

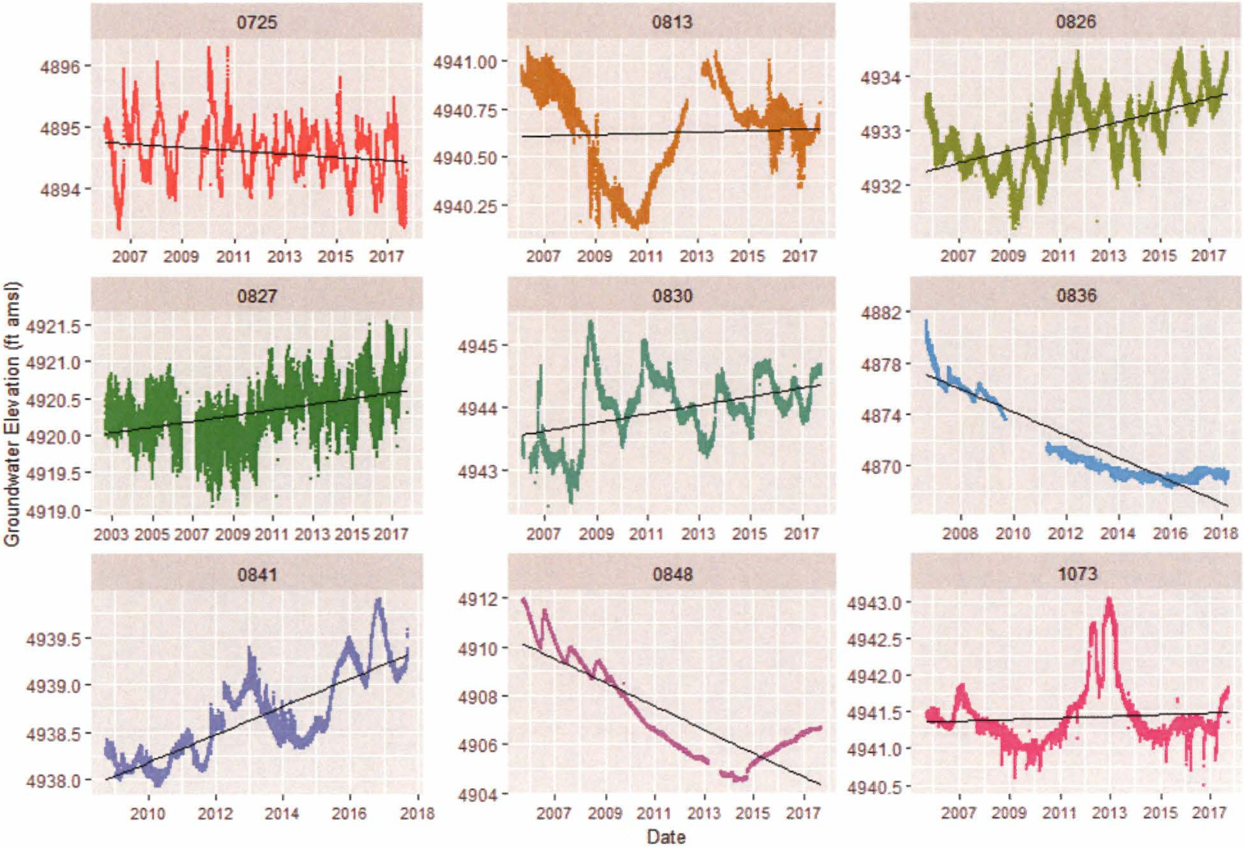
Figure B-5. Hydrographs for Terrace Wells East of the Disposal Cell and Evaporation Pond



Notes:

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

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



Note:
In each plot, line (—) is linear trend line on datalogger measurements (color-coded by well)

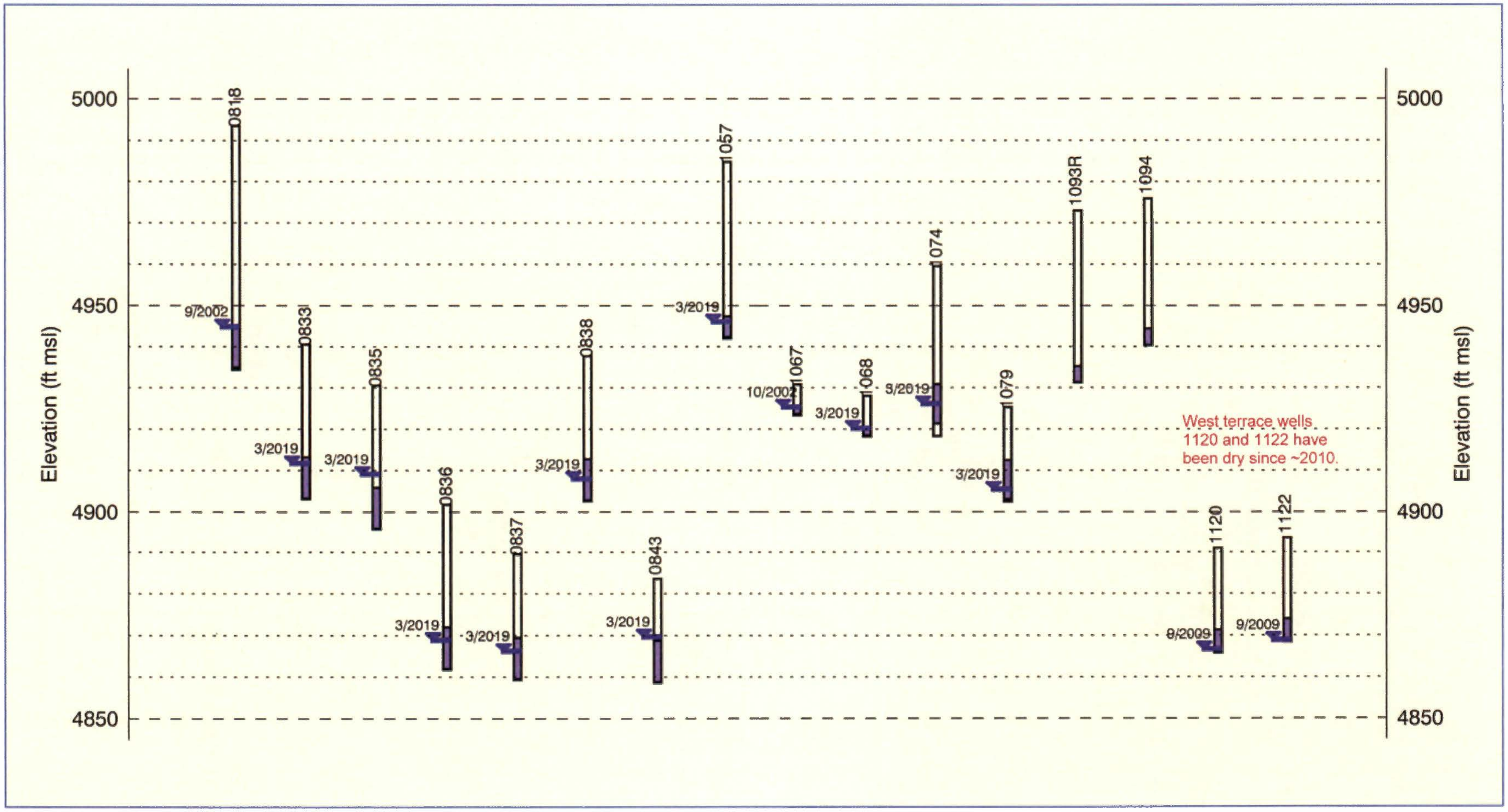
Figure B-7. Datalogger Measurements from Terrace Alluvial Wells: 2010–2018

This page intentionally left blank

Appendix C

Supplemental Well Construction Information

This page intentionally left blank

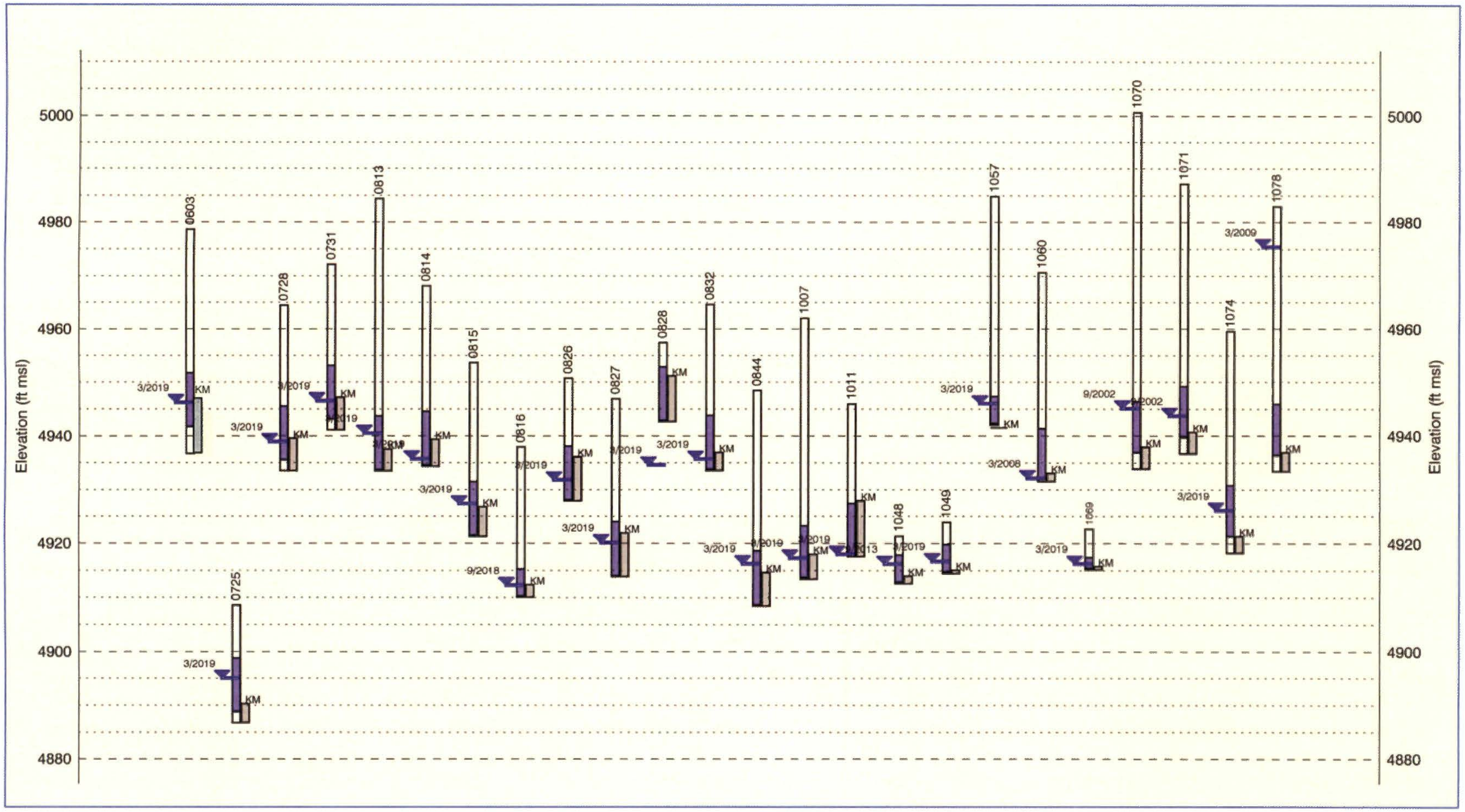


Notes:

1. Inverted blue triangles show the latest measured groundwater elevations. As shown above, some dates post-date the performance period addressed in this report (plot created in June 2019). Groundwater elevations are typically not measured in extraction wells 0818, 1093R, and 1094.
2. Black rectangles show the well casings; well screens are shaded blue.
3. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

Abbreviation:
ft amsl = feet above mean sea level

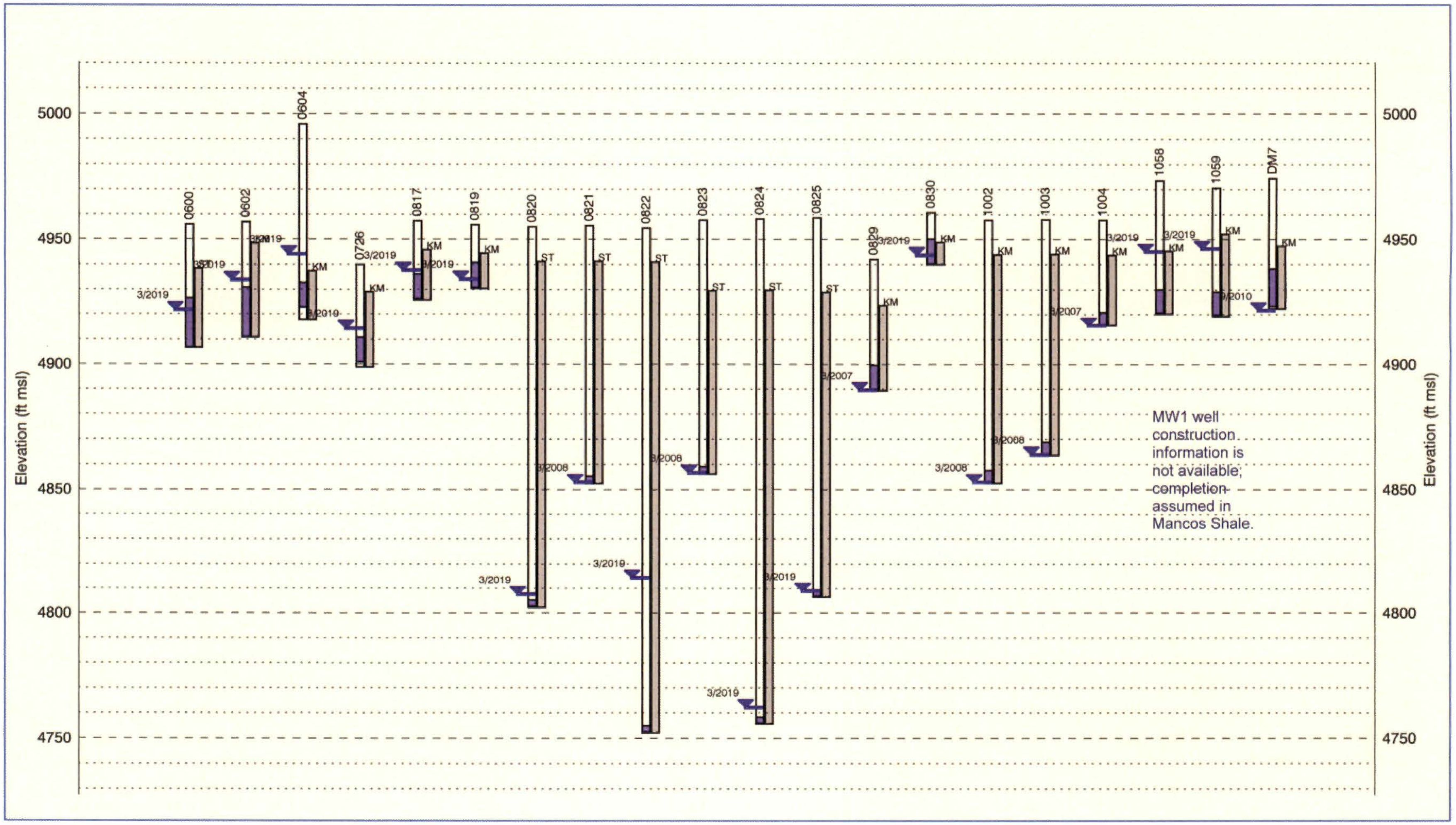
Figure C-1. Well Construction Information for Terrace Wells Screened Solely in the Alluvium



Notes:

1. Inverted blue triangles show the latest measured groundwater elevations. Some post-date the performance period addressed in this report (plot created in June 2019).
2. Black rectangles show the well casings; well screens are shaded blue.
3. Mancos Shale Formation (KM) is shown to the right of well screen (the alluvium overlies the Mancos Shale). For some wells, the overlap between the screened interval and the Mancos Shale formation is barely discernible in this figure because it is very slight (0.2 and 0.35 ft respectively). Well 0848 is not shown because lithology and well construction details are unknown.
4. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

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

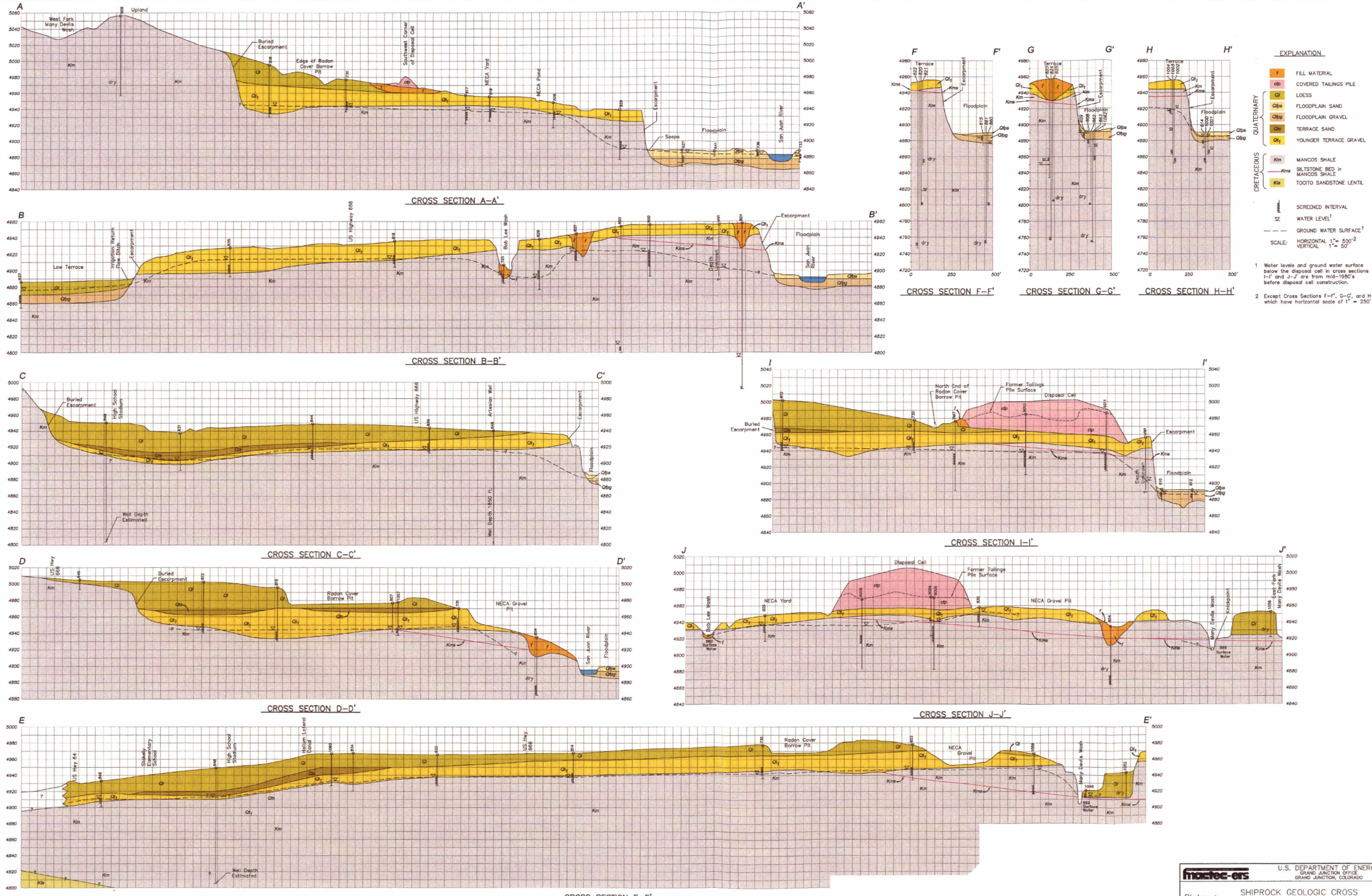


Notes:

1. Inverted blue triangles show the latest measured groundwater elevations. Some post-date the performance period addressed in this report (plot created in June 2019).
2. Black rectangles show the well casings; well screens are shaded blue.
3. Mancos Shale Formation (KM) is shown to the right of well screen.
4. Wells are plotted in order of well ID and, therefore, do not reflect horizontal location.

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

This page intentionally left blank



mactec-ers

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

Plate: 4

SHIPROCK GEOLOGIC CROSS SECTIONS

DATE PREPARED: SEPTEMBER 7, 2000

FILENAME: U0096400

This page intentionally left blank