LMS/SHP/44889

Annual Performance Report April 2022 Through March 2023 for the Shiprock, New Mexico, Disposal Site

August 2024

Shiprock Disposal Cell, 1987

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

CFR	*Code of Federal Regulations*
COC	contaminant of concern
DOE	U.S. Department of Energy
EVS	Earth Volumetric Studio
ft	feet
GCAP	Groundwater Compliance Action Plan
gpm	gallons per minute
lb	pounds
LM	Office of Legacy Management
LOESS	locally estimated scatterplot smoothing
MCL	maximum concentration limit
mg/L	milligrams per liter
N	nitrogen
NECA	Navajo Engineering and Construction Authority
NRC	U.S. Nuclear Regulatory Commission
SOARS	System Operation and Analysis at Remote Sites
SOWP	Site Observational Work Plan
UMTRCA	Uranium Mill Tailings Radiation Control Act

Executive Summary

This annual report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal Site (Shiprock site) from April 2022 through March 2023. The Shiprock site, a former uranium-ore processing facility remediated under the Uranium Mill Tailings Radiation Control Act (UMTRCA) Title I program, is managed by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) and is regulated by the U.S. Nuclear Regulatory Commission (NRC). This performance summary includes an analysis of groundwater quality and groundwater-level data obtained from site monitoring wells and the groundwater flow rates associated with the extraction wells, drains, and seeps.

Background

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

Hydrologically, the Shiprock site is divided into two distinct areas: the floodplain and the terrace. The terrace is separated from the floodplain below it by a steep 50–60-foot-high escarpment. For purposes of assessing compliance, the terrace is further divided into the east and west terrace. The floodplain remediation system consists of two groundwater extraction wells, two collection trenches installed in 2006 (Trench 1 and Trench 2), and a seep collection drain. The terrace east remediation system currently consists of eight groundwater extraction wells, a collection drain (Bob Lee Wash), a terrace drainage channel diversion structure, and an 11-acre lined evaporation pond, into which all extracted groundwater is pumped.

Compliance Strategy and Remediation Goals

As documented in the 2002 Groundwater Compliance Action Plan, the NRC-approved compliance strategy for the floodplain is natural flushing supplemented by active remediation. The compliance strategy for the east terrace is active remediation to dewater the alluvium via pumping and in turn eliminate exposure pathways at washes and seeps, reduce the flow of groundwater from the terrace to the floodplain, and cut off any hydrologic connection to the west terrace. Because groundwater on the west terrace qualifies as limited use, the compliance strategy for that region is supplemental standards and monitoring (with no active remediation). The contaminants of concern (COCs) at the site are ammonia, manganese, nitrate, selenium, strontium, sulfate, and uranium. The compliance standards for nitrate, selenium, and uranium are listed in Title 40 *Code of Federal Regulations* Section 192; remaining COCs are not regulated under UMTRCA. Because of the nature of the compliance strategy for the terrace (essentially eliminating exposure), these aforementioned remediation standards apply only to the floodplain. This performance evaluation focuses only on the primary milling-related constituents most prevalent in terms of magnitude and extent: uranium, nitrate, and sulfate.

Current Site Status

Since active groundwater treatment began in 2003, several factors have impacted LM's management and operations of the Shiprock remediation system. In April 2017, LM suspended pumping groundwater at all locations except Bob Lee Wash when water filled the evaporation pond to its maximum capacity. Groundwater extraction at floodplain locations resumed in July 2018 to prevent desiccation of evaporation pond sediments. Since then, LM's approach has been to maintain a balance of pumping enough water to keep pond sediments submerged but only extracting from targeted locations with the greatest yields to optimize contaminant mass removed.

Another factor that has impacted remediation operations is the condition of the evaporation pond liner. An inspection in 2017 revealed that the liner has reached the end of its design life. The management of the pond liner condition will continue to impact remediation efforts until a new treatment technology is implemented. LM recently prepared an Environmental Assessment under the National Environmental Policy Act to evaluate steps to decommission and dispose of the current evaporation pond. To continue groundwater treatment and remain in compliance with the Groundwater Compliance Action Plan (GCAP), a new water treatment unit and associated infrastructure will be installed before the pond is removed.

During this 2022–2023 reporting period, 109 monitoring wells were sampled in accordance with the routine semiannual sampling schedule: 58 on the floodplain and 51 on the terrace. In addition to sampling of the two floodplain trenches, 14 surface water locations, including 9 San Juan River sampling points and various seeps, were also sampled.

Summary of Remediation Performance

From April 2022 through March 2023, about 11.2 million gallons of extracted groundwater were pumped to the evaporation pond. Consistent with previous years, the bulk of this total volume (10.2 million gallons, or 91.5%) was from the floodplain, most notably the trenches. Pumping of terrace extraction wells 0818 and 1095 and the Bob Lee Wash drain (approximately 945,000 gallons) accounted for most of the remaining extraction volume. Since DOE began active remediation in March 2003, about 56.2 million gallons have been extracted from the terrace and 191.2 million gallons have been extracted from the floodplain, yielding a total cumulative volume of approximately 247.5 million gallons of groundwater pumped to the evaporation pond from all sources. Total cumulative groundwater contributions are 23% from the terrace and 77% from the floodplain.

The estimated masses of the primary COCs pumped to the evaporation pond from the floodplain and terrace during the 2022–2023 performance period were approximately: 18.4 pounds (lb) uranium; 5868 lb nitrate (as nitrogen [N]); and 320,209 lb sulfate. Corresponding cumulative masses, representing the COC masses removed since the onset of remediation, are (rounded) 954 lb uranium; 419,000 lb nitrate (as N); and 12.2 million lb of sulfate.

Currently, there are no concentration-driven performance standards for the terrace system because the east terrace compliance strategy is active remediation to eliminate exposure pathways at escarpment seeps and at Bob Lee Wash, and the west terrace compliance strategy is supplemental standards. As a best management practice, however, contaminant concentrations

are measured at each extraction well, drain, and seep and at select monitoring wells across the site. Groundwater levels in the majority of terrace alluvial wells remain low relative to those measured during the baseline period (average decrease of 3.1 feet). Eleven alluvial terrace wells were dry during this reporting period, as were several seeps that have been dry since 2008.

Summary of Floodplain Restoration Progress

With respect to contaminant distributions and trending, site conditions have not changed much in approximately the last decade. Contaminant distributions in the floodplain alluvial aquifer are similar to those in recent years and are characterized by elevated concentrations of sulfate and uranium, present adjacent to the escarpment north and east of the disposal cell and in a zone traversing the floodplain in a line trending north toward the San Juan River. Lower levels of sulfate and uranium, albeit still elevated relative to site remediation goals, are present in the northwest portion of the floodplain as a result of relatively uncontaminated surface water from Bob Lee Wash (sourced from artesian well 0648) discharging to the floodplain in the wetland area. Nitrate contamination is presently limited to the base of the escarpment. Relative to baseline (2000–2003) conditions, marked reductions in concentrations of uranium, sulfate, and especially nitrate are apparent in most floodplain wells, most notably those within the remediation capture zones. Mann-Kendall trend analysis results support these observations, indicating significant decreasing trends of the primary COCs (uranium, nitrate, and sulfate) in the majority of alluvial wells on the contiguous floodplain.

Despite these observations, after 20 years of groundwater extraction from a combination of wells and infiltration galleries (Trenches 1 and 2), the compliance goal of achieving regulatory standards within 100 years (most notably for uranium) is not expected to be met with the existing system. Analysis of temporal data indicate that remediation progress on the floodplain has slowed since approximately 2015, as indicated by stable (flat) concentration trends.

1.0 Introduction

This report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal Site from April 2022 through March 2023. 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).

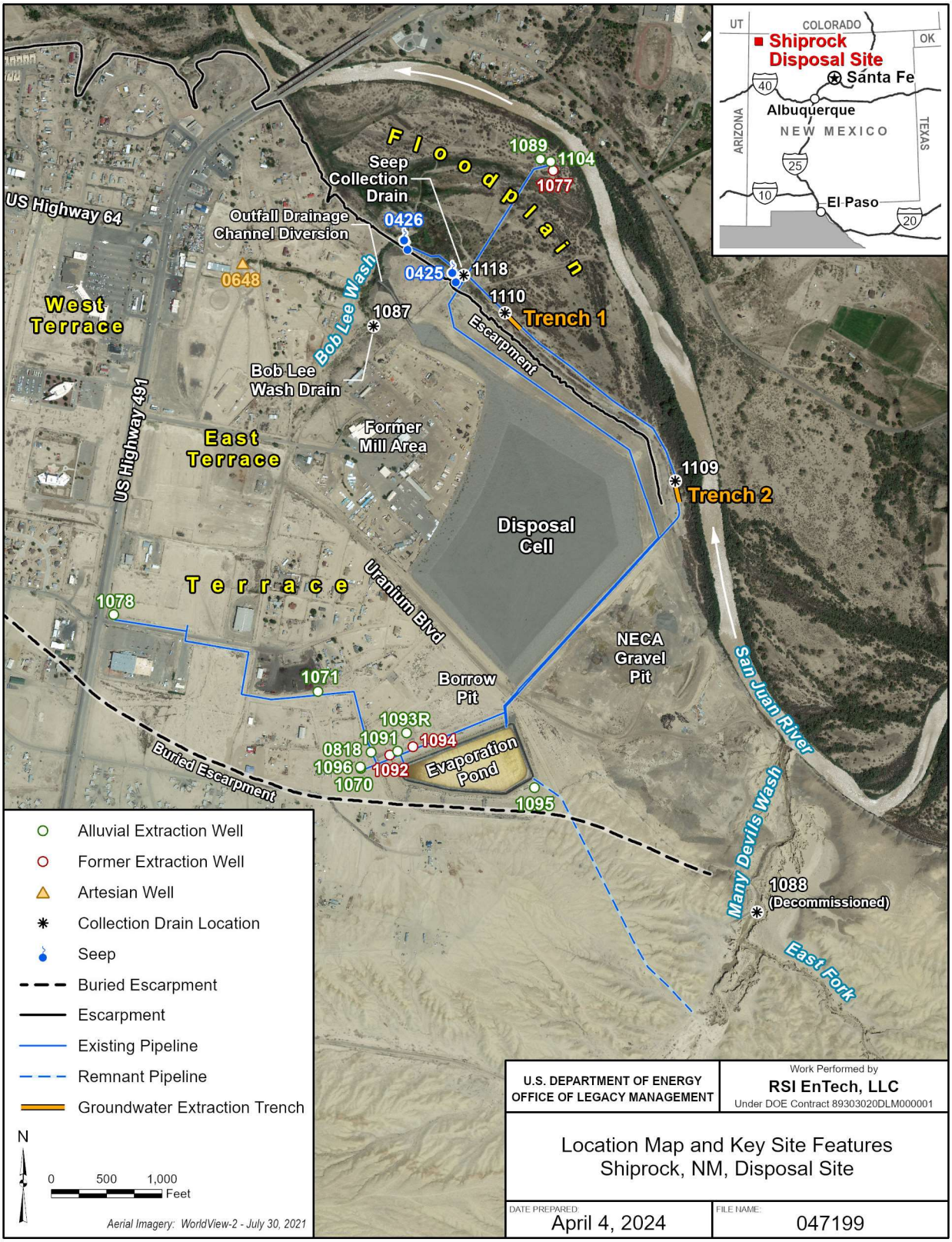
The site is a former uranium- and vanadium-ore processing facility in the northwest corner of New Mexico (Figure 1), near the town of Shiprock and within the Navajo Nation. The Shiprock mill operated from 1954 to 1968 on property leased from the Navajo Nation. Remediation of surface contamination, including the stabilization of mill tailings in an engineered disposal cell, was completed in 1986. As a result of milling operations, groundwater in the mill site area was contaminated with uranium, nitrate, sulfate, the primary milling-related contaminants of concern (COCs), as well as other constituents, including ammonia and selenium. The 77-acre disposal cell is situated on an alluvial terrace above the floodplain of the San Juan River. Hydrologically, the site is divided into these two distinct areas: the floodplain and the terrace. The terrace is separated from the floodplain below it by a steep 50–60-foot (ft)-high escarpment. The terrace is further divided into the east and west terrace; the boundary that separates them is defined as a line just east of and roughly parallel to U.S. Highway 491 (DOE 2002) (Figure 1).

1.1 Groundwater Compliance Strategy and Remediation Approach

In accordance with the U.S. Nuclear Regulatory Commission (NRC)-approved Groundwater Compliance Action Plan (DOE 2002), also called the GCAP, a combination of compliance strategies was implemented to address the three unique hydrological environments at the site: the floodplain, the east terrace, and the west terrace (Figure 1).

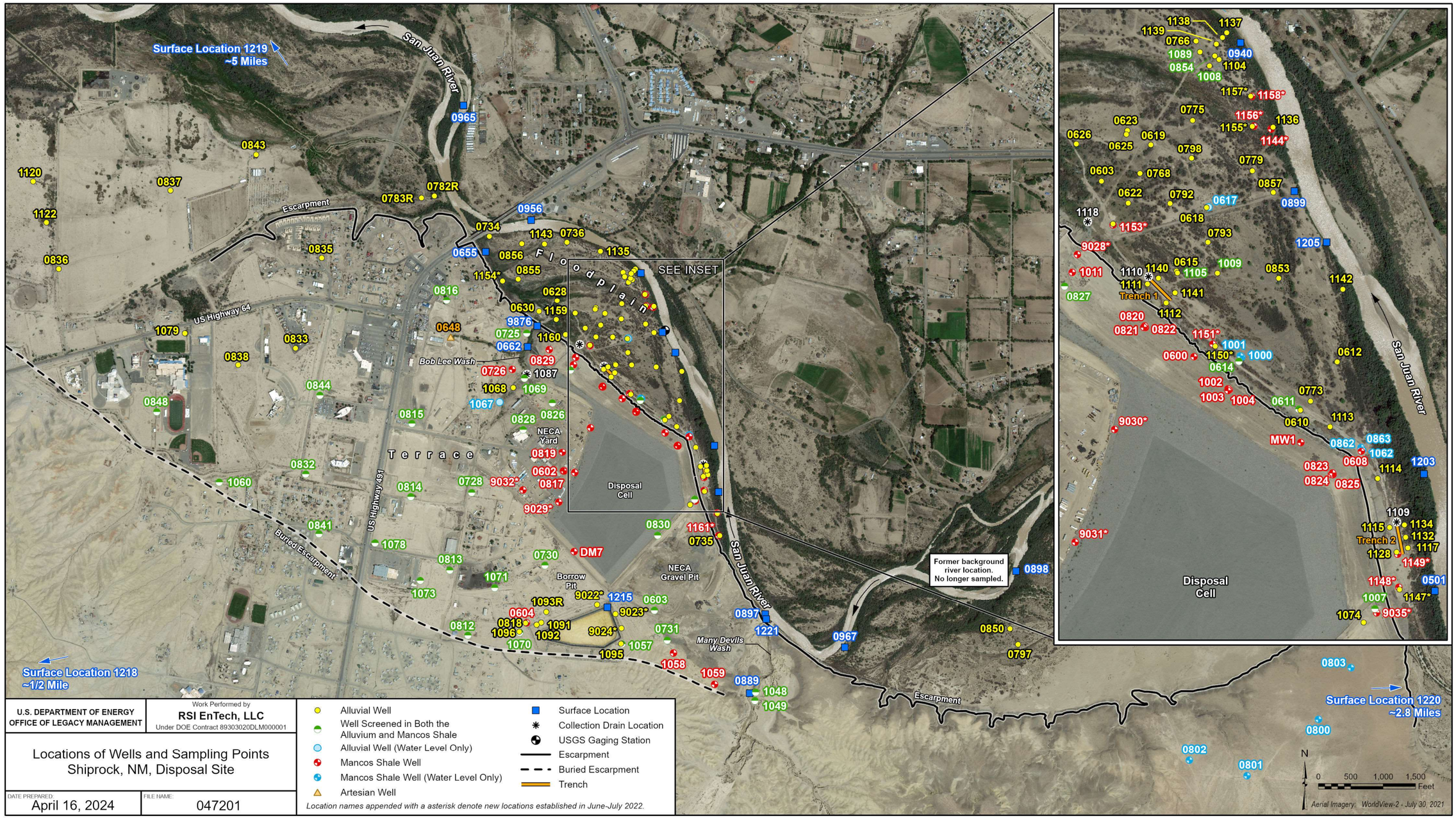
The compliance strategy for the floodplain is natural flushing supplemented by active remediation. The strategy for the east terrace is active remediation using a system of extraction wells and interceptor drains in the bounding washes to dewater the alluvium and in turn eliminate exposure pathways at washes and seeps, reduce groundwater flow to the floodplain, and cut off any hydrologic connection to the west terrace (DOE 2002). Because of significant background contamination in groundwater on the west terrace (qualifying as limited use), the compliance strategy for that region is supplemental standards and monitoring (no active remediation). For all three areas, the compliance strategy also includes institutional controls prohibiting site access, consumptive groundwater use, and grazing.

DOE initiated active groundwater remediation at the Shiprock site in March 2003. The current groundwater treatment program entails extracting groundwater from 14 extraction locations and treating the water, via evaporation, in an 11-acre lined evaporation pond constructed in 2002. The floodplain remediation system consists of two extraction wells, two collection trenches (Trench 1 and Trench 2), and a seep collection drain. The terrace remediation system currently consists of eight extraction wells, a collection drain (Bob Lee Wash), and a terrace drainage channel diversion structure. 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.



Note: The Many Devils Wash collection drain (former location 1088) and associated infrastructure was decommissioned in November 2022 (DOE 2024). Well 1092 was removed from the terrace treatment system well network in March 2019 because it was routinely dry.

Figure 1. Location Map and Groundwater Remediation System



U.S. DEPARTMENT OF ENERGY OFFICE OF LEGACY MANAGEMENT	Work Performed by **RSI EnTech, LLC** Under DOE Contract 89303020DLM000001
Locations of Wells and Sampling Points Shiprock, NM, Disposal Site	
DATE PREPARED: April 16, 2024	FILE NAME: 047201

- Alluvial Well
- Well Screened in Both the Alluvium and Mancos Shale
- Alluvial Well (Water Level Only)
- Mancos Shale Well
- Mancos Shale Well (Water Level Only)
- Artesian Well
- Surface Location
- Collection Drain Location
- USGS Gaging Station
- Escarpment
- Buried Escarpment
- Trench

Location names appended with a asterisk denote new locations established in June-July 2022.

Note: Information related to the September 2022 and March 2023 sampling events, including a summary of samples planned but ultimately not collected, is provided in Appendix A.
Abbreviations: ~ = approximately, NECA = Navajo Engineering and Construction Authority, USGS = U.S. Geological Survey

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

1.2 Current Site Status

Since active groundwater treatment began in 2003, several factors have impacted LM's management and operation of the Shiprock remediation system. This section summarizes current site conditions and highlights events or decisions that are most pertinent to the implementation of the current NRC-approved compliance strategy. Table 1 summarizes the key site activities, events, and evaluations germane to this performance evaluation.

1.2.1 Key Factors Impacting the Site Compliance Strategy

In April 2017, LM suspended pumping groundwater at all locations except Bob Lee Wash when water filled the evaporation pond to its maximum capacity (DOE 2018b). Groundwater extraction at floodplain locations resumed in July 2018 to prevent desiccation of evaporation pond sediments. Since then, LM's approach has been to maintain a balance of pumping enough water to keep pond sediments submerged but only extracting from targeted locations with the greatest yields to optimize contaminant mass removed. For the last several years, the majority of extracted water has been from four extraction locations on the floodplain and the terrace Bob Lee Wash drain.

Another factor that has impacted remediation operations is the condition of the evaporation pond liner. An inspection in 2017 revealed that the liner has reached the end of its design life (TRI 2021). The management of the pond liner condition will continue to impact remediation efforts until a new treatment technology is implemented. LM recently prepared an Environmental Assessment under the National Environmental Policy Act to evaluate steps to decommission and dispose of the current evaporation pond (DOE 2023c). To continue groundwater treatment and remain in compliance with the GCAP, a new water treatment unit and associated infrastructure will be installed before the pond is removed (DOE 2023b).

The recognition that the evaporation pond liner has reached the end of its useful life has provided an opportunity for LM to reexamine the effectiveness of the 2002 GCAP objectives. As documented in the *Revised Groundwater Compliance Action Plan (GCAP) Work Plan, Shiprock, New Mexico, Disposal Site* (Draft) (DOE 2022c), also called the GCAP Work Plan, LM is pursuing a GCAP revision to better understand, and more effectively manage, the COCs on site. Until a revised GCAP is completed, this report will continue to be used to assess the effectiveness of the current compliance strategy.

1.2.2 Water Quality Monitoring

During this 2022–2023 reporting period, 109 monitoring wells were sampled in accordance with the routine semiannual sampling schedule: 58 on the floodplain and 51 on the terrace (locations shown in Figure 2). In addition to sampling of the two floodplain trenches, 14 surface water locations, including 9 San Juan River sampling points and various seeps, were also sampled. Following recommendations set forth in the GCAP Work Plan (DOE 2022c), in June and July of 2022, 27 new wells were installed at the site—18 on the floodplain and 9 on the terrace. These wells were sampled for the standard suite of COCs and data were used to buttress LM's understanding of the current contaminant plume extents and configuration. Supplementary information related to the September 2022 and March 2023 sampling events, including a summary of samples planned but ultimately not collected, is provided in Appendix A.

Table 1. Summary of Key Site Activities, Events, and Evaluations

Activity or Evaluation	Date or Time Frame	Description or Major Findings
Mill operation	1954–1968	Mill operated by Kerr-McGee (1954–1963) and Vanadium Corporation of America (1963–1968).
Surface remediation	1986	Mill tailings and all associated materials encapsulated in newly constructed disposal cell.
Long-Term Surveillance Plan (LTSP)	1994	An LTSP was prepared for the disposal site in 1994 (DOE 1994).
NRC license	September 1996	License issued to DOE for long-term care of the site.
Site characterization	1998–2001	Site characterization efforts culminating in the Site Observational Work Plan (SOWP), a report documenting the site conceptual model on which the compliance strategy was based (DOE 2000).
GCAP issued	2002	GCAP issued. LM completed construction of the active groundwater remediation system (DOE 2002).
NRC approval of GCAP Active groundwater remediation begins	2003	Active remediation begins on the terrace and the floodplain, pumping to an 11-acre pond on the terrace. DOE developed a Baseline Performance Report establishing specific performance standards for the Shiprock site groundwater remediation system (DOE 2003).
Interim refinement of conceptual site model (CSM)	2005	Report evaluated the previous CSM presented in the SOWP and proposed refinements to the remedial strategy (DOE 2005).
Trenches installed on floodplain	Spring 2006	Two groundwater withdrawal systems consisting of horizontal wells in excavated trenches (Trench 1 and Trench 2) were installed in the floodplain alluvial aquifer near the base of the escarpment.
Trench 2 evaluation	2009	LM issued a report demonstrating that Trench 2, in the southernmost trench, successfully intercepts contamination discharging across the escarpment (DOE 2009).
Trench 1 evaluation	2011	This study demonstrated that pumping at Trench 1 and at extraction wells 1089 and 1104 creates a groundwater flow divide in the floodplain aquifer (DOE 2011b).
Many Devils Wash investigations	2010–2012	Studies performed by LM and later confirmed by U.S. Geological Survey (Robertson et al. 2016) revealed that the contamination in the wash is the result of the natural interaction of water with the Mancos Shale and not related to the mill site (DOE 2011a; DOE 2012a; DOE 2012b; Morrison et al. 2012).
Many Devils Wash remediation efforts terminated	March 2014	Rationale for decommissioning cited above.
2017 pumping cessation	April 21, 2017	Active groundwater extraction at all locations except Bob Lee Wash when the evaporation pond reaches the maximum fill capacity.
Flow Processes Report	2018	Comprehensive investigation of the seasonal variations controlling groundwater flow on the floodplain (DOE 2018a).
Pumping resumption on floodplain	July 19, 2018	Pumping of the trenches resumed on July 19, 2018, to maintain a minimum water level in the evaporation pond.
LM and DOE National Laboratory Network (NLN) Collaborative Initiative (DOE 2020)	2020	LM and representatives from the DOE NLN met regularly to identify state-of-the-art approaches to inform the development of stable and effective groundwater compliance strategies for the Shiprock site.
Aerial survey	January 2022	Small, unmanned aircraft system used to monitor topographical information and collect high-resolution orthoimagery at the site.
Interim repairs of evaporation pond	March 2022	LM completed interim repairs of the evaporation pond to enable continued groundwater treatment until a revised remedy is developed and implemented.
Activities During This 2022–2023 Reporting Period		
New well installation on floodplain and terrace	June–July 2022	In accordance with study objectives outlined in the GCAP Work Plan (DOE 2022c), LM installed 27 new monitoring wells at the site.
LM issues *Revised Groundwater Compliance Action Plan (GCAP) Work Plan, Shiprock, New Mexico, Disposal Site* (Draft) (DOE 2022c)	November 2022	The work plan documents the approach that provides the basis for the development of a revised GCAP in accordance with recommendations stemming from the LM and DOE NLN collaboration noted above (DOE 2020). Supporting evaluations include DOE 2022a and DOE 2022b.

Table 1. Summary of Key Site Activities, Events, and Evaluations (continued)

Activity or Evaluation	Date or Time Frame	Description or Major Findings
Many Devils Wash drain decommissioned	November 2022	Many Devils Wash infrastructure decommissioning completed. LM constructed a 250 ft low-flow channel in the wash and regraded and revegetated the area (DOE 2024).
Recent (Postevaluation Period) Activities and Ongoing Work		
Environmental Assessment	October 2023	LM published an Environmental Assessment and Finding of No Significant Impact regarding the decommissioning of the existing 11-acre evaporation pond, defining the environmental impact of the material removal and transfer to a facility licensed to receive the waste (DOE 2023c).
Draft Interim Treatment Plan (ITP) development	2023–2024	LM drafted a document outlining the steps and timeline to transition from the treatment of groundwater via evaporation to a new water treatment unit through which treated effluent will be discharged into the environment. The document details how LM will monitor the performance of the water treatment unit to defined standards of operation.
Ongoing work supporting GCAP revision and CSM updates	2019–present	Ongoing work to better understand the sources of contamination at the site and the concentrations, quantities, distributions, solubilities, and mobilities of the site-specific COCs.

Note:
A detailed summary of the investigations cited above is provided in Section 1.3 of the GCAP Work Plan (DOE 2022c). Some activities following the April 2022–March 2023 evaluation period are also noted.

1.3 Remediation System Performance Standards

Until LM completes the evaluations supporting a GCAP revision, the requirements set forth in the NRC-approved GCAP (DOE 2002) must still be met. Therefore, this performance assessment continues to be 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. Performance standards or metrics established for the Shiprock site remediation system are documented in the *Baseline Performance Report for the Shiprock, New Mexico, UMTRA Project Site* (DOE 2003).

Specific performance standards established for the floodplain groundwater remediation system are as follows:

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

Specific performance standards established for the terrace groundwater remediation system are as follows:

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

The performance standards summarized above are based on the active remediation aspects of the compliance strategies described in the GCAP (DOE 2002). The site conceptual model on which the GCAP was based is documented in the Site Observational Work Plan (SOWP) (DOE 2000).

LM terminated remediation efforts in Many Devils Wash in March 2014 because the groundwater discharging to the wash was found to contain naturally elevated concentrations of several site COCs (uranium, nitrate, selenium, and sulfate), contradicting the original assumption of a mill site origin (Robertson et al. 2016; DOE 2011a; DOE 2012a; DOE 2012b). The Many Devils Wash collection drain (1088) and associated infrastructure was decommissioned in November 2022 (DOE 2024).

1.4 Contaminants of Concern and Remediation Goals

The 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 2 along with corresponding floodplain background data and maximum concentration limits (MCLs) established in Title 40 *Code of Federal Regulations* Section 192 (40 CFR 192), which apply to UMTRCA sites. The remediation goals listed in Table 2 apply only to the floodplain because the current compliance strategy for the terrace is to reduce groundwater elevations via pumping and to eliminate exposure pathways.

In the last decade, evaluation of site remediation progress has focused largely on uranium, sulfate, and nitrate. Uranium is the primary COC in terms of potential risk, magnitude, and spatial distribution. Nitrate and sulfate have also been important indicators of milling-related contamination. The four remaining COCs—ammonia (total as N), manganese, selenium, and strontium—have received less focus given their more limited magnitude and extent relative to the primary COCs or lack of associated regulatory standards. While levels of these constituents in site wells have at times exceeded background (DOE 2022b), this occurs to a more limited degree relative to the magnitude and extent of the primary COCs. Given these findings and consistent with previous annual reports, with respect to contaminant mass removed, this performance evaluation addresses only uranium, nitrate, and sulfate.

As listed in Table 2, the 40 CFR 192 compliance standards for nitrate and uranium are 10 and 0.044 milligrams per liter (mg/L), respectively. Regulatory standards have not been developed for sulfate, which has been historically elevated in groundwater entering the floodplain from flowing artesian well 0648. Because of these elevated concentrations from a natural source (1810–2340 mg/L), the GCAP proposed a cleanup goal of 2000 mg/L for sulfate in floodplain alluvial wells.

Table 2. Groundwater COCs for the Shiprock Site and Floodplain Remediation Goals

Contaminant	40 CFR 192 MCL (mg/L)	Floodplain Remediation Goal[a] (mg/L)	Historical Range in Floodplain Background Wells[b] (mg/L)	Comments
Ammonia as N[c]	–	–	<0.003–0.36	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 is the maximum concentration measured in floodplain background well 0850 at the time the GCAP was developed.
Nitrate as N[c]	10	–	<0.003–5.7	As demonstrated later in this report, the nitrate contaminant plume on the floodplain has reduced markedly relative to baseline (2000–2003) conditions.
Selenium	0.01	0.05	<0.0001–0.02	The 0.05 mg/L floodplain cleanup goal is based on the EPA Safe Drinking Water Act maximum contaminant level (DOE 2002). This goal is the same as the State of New Mexico Environment Department groundwater standard.[d]
Strontium	–	–	0.18–10	EPA's Regional Screening Level for tap water is 12 mg/L, assuming a target hazard quotient of 1.0.[e]
Sulfate	–	2000	210–5200	Because of elevated sulfate levels in terrace artesian well 0648 (1810–2340 mg/L), the GCAP proposed a cleanup goal of 2000 mg/L (DOE 2002). Water sourced from well 0648 enters the northern portion of the floodplain in the region of the Bob Lee Wash outlet.
Uranium	0.044	–	0.004–0.12	Uranium levels measured in background well 0850 have varied widely and have exceeded the MCL in 14 of the 31 samples collected since 2006.

Primary mill-related COC and indicator of plume metrics, the focus of this report.

Notes:

[a] From Table 3-2 of the GCAP (DOE 2002). Remediation goals were established only for the floodplain and only for those constituents retained as COCs based on human health risk endpoints.

[b] Data are from wells 0797 and 0850 (locations shown in Figure 2), identified as floodplain background wells in the GCAP (DOE 2002). Background range determined for the period 2000 through March 2023; minimum values preceded by "<" correspond to the detection limit. LM recently issued a report reevaluating background conditions for the floodplain and the terrace (DOE 2022b). Although the findings are preliminary, that analysis suggests that westernmost wells 0782R and 0783R may be more representative background locations for floodplain wells geochemically influenced by the San Juan River.

[c] To determine background ranges, earlier (total NH4+) results were converted to NH3-N equivalents by applying a multiplier of 0.776. Early results for nitrate as NO_3 were converted to nitrate as N by applying a multiplier of 0.2259.

[d] https://www.env.nm.gov/gwqb/gw-regulations/.

[e] https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables/ (November 2023 update).

Abbreviations:

– = not applicable (contaminant does not have an MCL in 40 CFR 192, or the alternate cleanup goal is not relevant)
EPA = U.S. Environmental Protection Agency

1.5 Hydrogeological Setting

This section presents a brief summary of the floodplain and terrace groundwater systems. More recent supporting information is provided in the GCAP Work Plan (DOE 2022c).

1.5.1 Floodplain Alluvial Aquifer

The approximately 20 ft thick floodplain alluvial aquifer is underlain by Mancos Shale and is bounded to the east by the San Juan River and separated from the terrace to the west by a 60 ft vertical escarpment (Figure 1). The alluvial aquifer consists of a heterogeneous mix of permeable coarse-grained sands, gravels, and cobbles with a bulk hydraulic conductivity of approximately 80 ft per day (DOE 2018a). The underlying Mancos Shale is relatively impermeable with hydraulic conductivity decreasing with depth (DOE 2000).

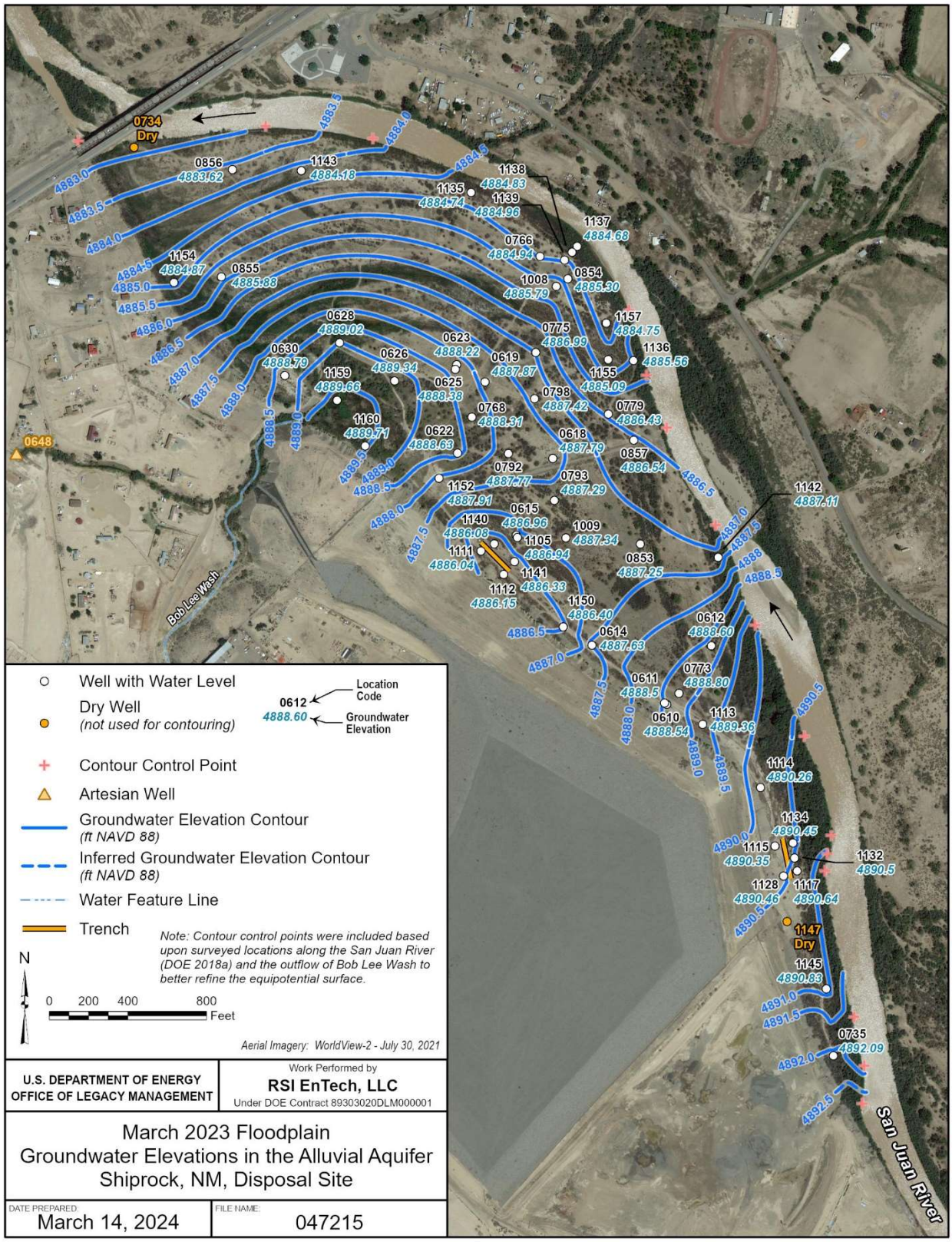
Precipitation infiltration, surface water inflow from the San Juan River, groundwater inflow from the terrace, and discharge from terrace artesian well 0648, which enters the floodplain via Bob Lee Wash, recharge the floodplain aquifer. Discharge to the river, evapotranspiration, and pumping from extraction wells and trenches remove groundwater from the floodplain aquifer. Flow through the floodplain aquifer is approximately 60 gallons per minute (gpm), with the majority of recharge and discharge associated with artesian well 0648 flow and evapotranspiration, respectively (DOE 2018a). The terrace and floodplain groundwater systems are hydraulically connected below the escarpment via the weathering Mancos Shale, allowing terrace groundwater to discharge to the floodplain alluvial aquifer.

A water table map constructed using March 2023 groundwater levels shows a groundwater mound resulting from artesian well 0648 waters entering the floodplain at the mouth of Bob Lee Wash (Figure 3). East of the disposal cell at the base of the escarpment, the water table elevation contours indicate that river water is recharging the floodplain aquifer. Groundwater primarily discharges to the San Juan River along the remainder of the shoreline via hyporheic flow.

1.5.2 Terrace Groundwater System

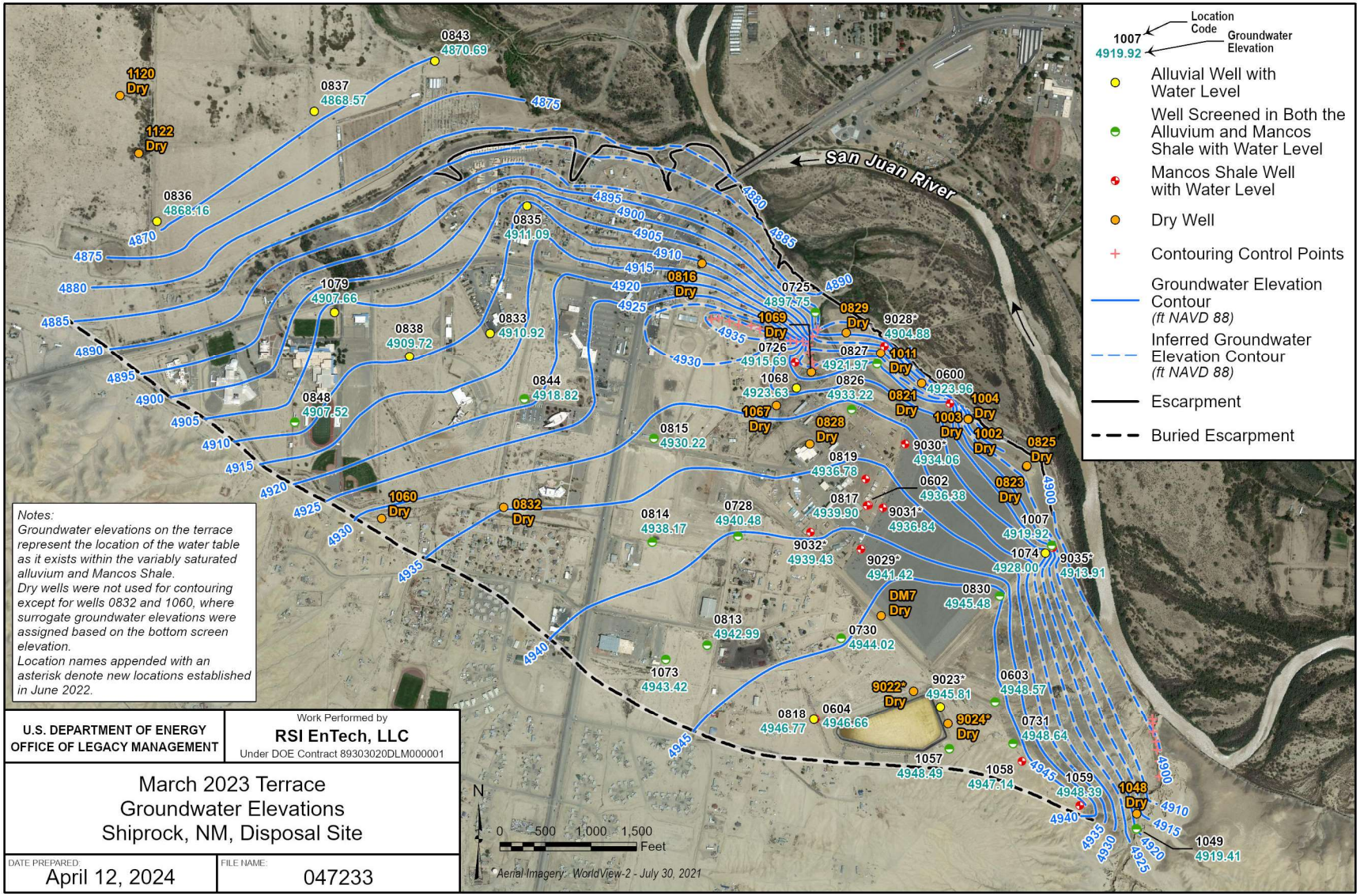
The terrace groundwater system, located at a higher elevation than the floodplain, is underlain by Mancos shale and is bounded to the south by an east-west-trending buried bedrock (Mancos Shale) escarpment, to the west by the 60 ft vertical escarpment, and to the south by Many Devils Wash (Figure 1). Eolian silt (loess), exposed at ground surface, overlies coarse sand and gravel alluvium resting on weathered Mancos Shale (DOE 2000). Mancos Shale underlying the alluvium in the terrace area is soft and weathered. The weathered Mancos Shale is typically 2 to 10 ft thick. Precipitation and anthropogenic (leaky water lines and septic tank) infiltration recharge the terrace groundwater flow system. Groundwater is removed from the terrace flow system via the following mechanisms: discharge to Bob Lee Wash and Many Devils Wash, seeps present on the escarpment, and extraction wells and groundwater flow from the terrace to the floodplain across the escarpment where the two systems are in contact.

A water table, extending through both the alluvium and the weathered shale constructed using March 2023 groundwater levels, shows a groundwater mound extending southward from the disposal cell to the buried escarpment (Figure 4). Based on contour orientation, groundwater flows from the mound eastward to the escarpment, northward to Bob Lee Wash and the escarpment, and westward to the escarpment.



Abbreviation: NAVD 88 = North American Vertical Datum of 1988

Figure 3. March 2023 Groundwater Elevations in Shiprock Site Floodplain Alluvial Wells



Note: Current water elevations are compared to baseline conditions in Section 4.0 (Figure 22).

Figure 4. March 2023 Terrace Groundwater Elevations in Shiprock Site Terrace Monitoring Wells

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 2022–2023 reporting period. Consistent with LM's reporting since 2018, the bulk of the pumping has been from the floodplain, while groundwater volumes extracted from most terrace treatment systems have been relatively negligible. As an introductory overview, Figure 5 plots daily average pumping rates for all site remediation system locations since 2005. As shown in this figure, the highest groundwater extraction volumes have been from the floodplain trenches and extraction wells and the terrace drain at Bob Lee Wash. With few exceptions, pumping rates and corresponding groundwater volumes at most terrace extraction well locations have been negligible in comparison.

All flow rate data presented in this section are from LM's System Operation and Analysis at Remote Sites (SOARS) telemetry program, which began in late 2005. Environmental and operational data are collected by dataloggers at each Shiprock site treatment system location and transmitted and stored real time into LM's AQUARIUS database. Although cumulative data are presented, this section focuses on remediation system performance for the current reporting period. A detailed summary of historical annual extraction volumes and contaminant masses removed is provided in Appendix B.[1]

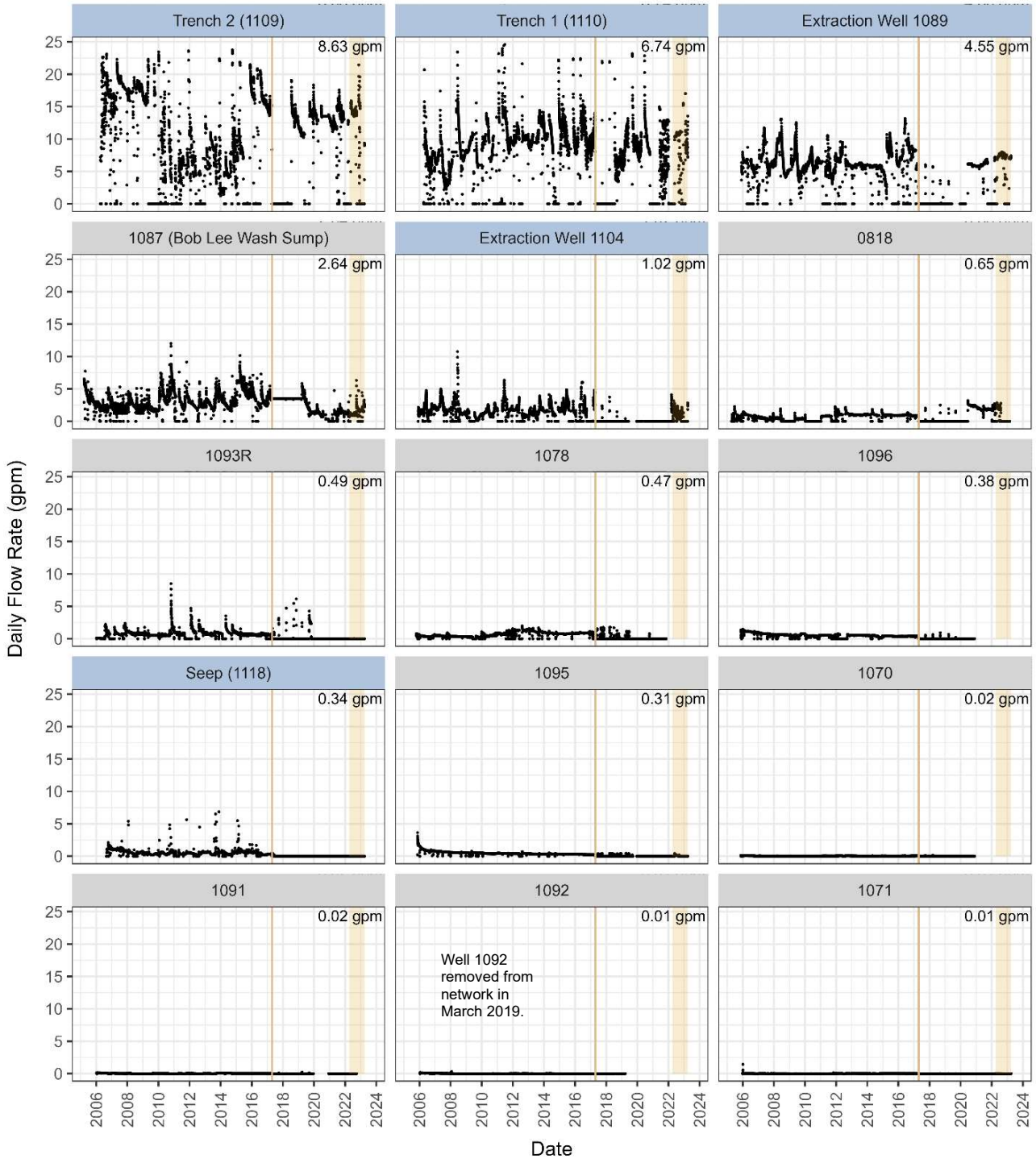
2.1 Floodplain Remediation System

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. The floodplain remediation system consists of three major components: two extraction wells (wells 1089 and 1104); two extraction trenches, Trench 1 and Trench 2; and a sump (collection drain location 1118) used to collect discharges from seeps 0425 and 0426 on the escarpment (Figure 1). Extraction wells 1089 and 1104 were installed in late June 2003 within about 250 ft of the San Juan River (DOE 2018a). In spring 2006, Trench 1 and Trench 2 were installed near the base of the escarpment to enhance the extraction of groundwater from the alluvial system (DOE 2018a). All groundwater collected from the floodplain extraction wells and trenches is piped south to the terrace and discharged into the evaporation pond.

During this performance period, approximately 10.2 million gallons of groundwater were extracted from the floodplain treatment system locations. Annual volumes extracted and corresponding average pumping rates are detailed in Table 3 and summarized as follows for the current (2022–2023) reporting period:

- 3.2 million and 3.6 million gallons of water were removed from Trench 1 and Trench 2, respectively (average pumping rates of 6.1 and 6.8 gpm [Table 3]).
- 3 million and 457,000 gallons of water were removed from extraction wells 1089 and 1104, respectively (average pumping rates of 5.6 and 0.9 gpm).
- Consistent with LM's reporting since the April 2017 pumping suspension (DOE 2023a), no groundwater was extracted from interceptor drain 1118.

[1] All temporal data plots provided in this section and in the remainder of the report were developed using R, version 4.3.2 (R Core Team 2023) and the ggplot2 package (version 3.5.0) (Wickham 2016).



Panel colors: Floodplain Terrace

- Average daily flow rate (average flow rate for 2005–2023 period shown in upper right plot corner)

| Denotes April 21, 2017, cessation of pumping (see Notes)

Notes:
Treatment system locations are shown in order of descending daily average flow rates calculated since March 2005 (onset of SOARS). Treatment locations not pumped in the last 10 years are not shown: former extraction wells 1077 and 1094 (floodplain and terrace, respectively) and former Many Devils Wash Drain (location 1088).

Figure 5. Average Daily Flow Rates at Shiprock Site Remediation System Locations, March 2005 Through March 2023

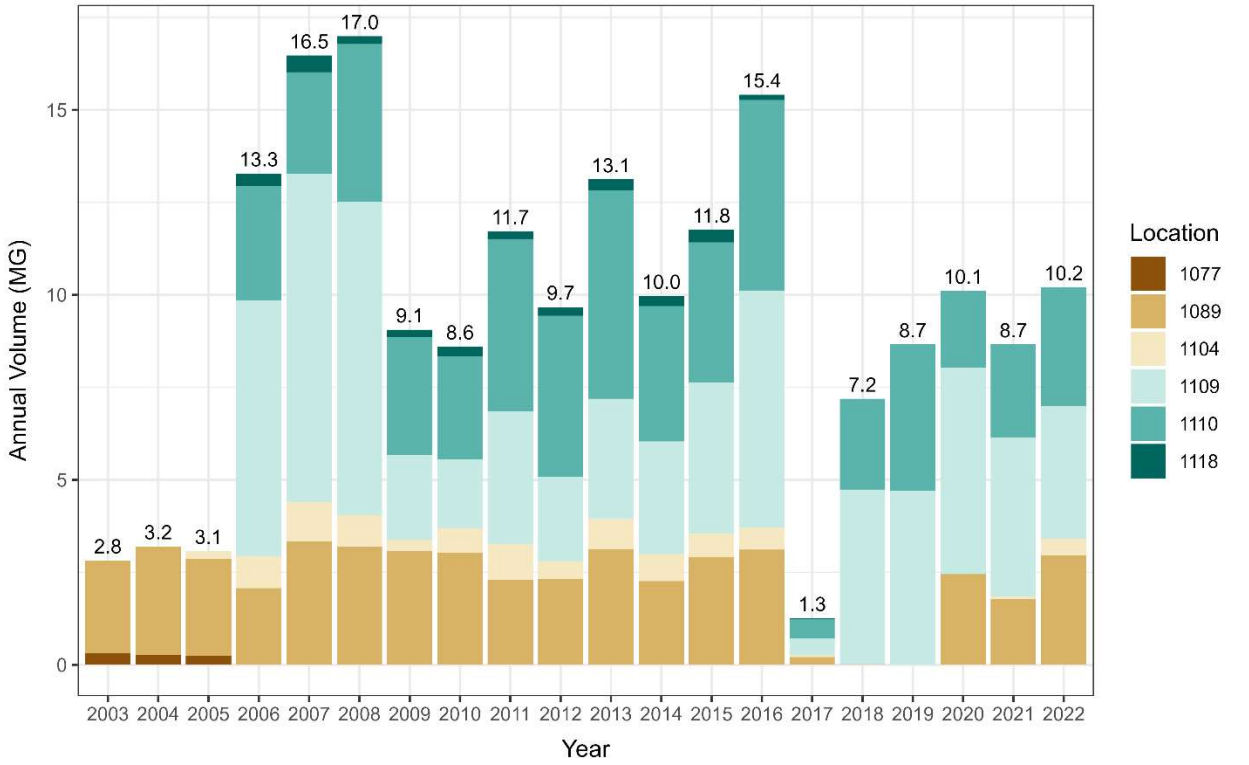
Table 3. Floodplain Remediation System Locations: Annual Pumping Rates and Total Groundwater Volume Removed

Location	Groundwater Volume Removed (gallons)[a]		Days Pumping[c]	2022–2023 Annual Pumping Rates (gpm)[d]		
	Annual Volume (2022–2023)	Cumulative Volume[b]		Average	Maximum	Average, Pumping Only
Trench 1 (1110)	3,210,211	58,083,914	229	6.1	17.0	9.7
Trench 2 (1109)	3,589,743	74,441,894	181	6.8	21.4	13.8
Extraction Well 1089	2,953,695	46,151,666	285	5.6	8.0	7.2
Extraction Well 1104	457,123	8,789,984	233	0.9	3.2	1.4
Seep (1118)	0	2,948,030	0	–	–	–
1077 (former location)[e]	–	812,449				
Total	10,210,772	191,227,937				

Notes:
[a] Because all volumes are rounded to the nearest integer, total annual or cumulative volumes may differ slightly from the sum of preceding rows.
[b] Corresponding historical annual extraction volumes are provided in Appendix B, Table B-1. Accounting for the most recent (2022–2023) volumes, cumulative volumes reported here may differ somewhat from previous annual reports because of retroactive corrections to data retrieved from the SOARS/AQUARIUS database.
[c] Days pumping determined by filtering on all records with daily average flow rates ≥ 0.0007 gpm, corresponding to 1 gallon per day.
[d] Pumping rates rounded to one decimal point.
[e] Former extraction well 1077 was pumped between 2003 and 2005 (Appendix B, Table B-1).
– = Not applicable (e.g., no pumping).

Based on the data from Table 3 and Appendix B, Figure 6 plots the volumes extracted from the floodplain by year and location, illustrating that the bulk of the volume continues to be from the floodplain trenches. At interceptor drain 1118, the pumping suspension initiated in April 2017 continued through this reporting period. No water has been pumped from the collection sump for the last 5 years (Figure 5; Appendix B, Table B-1).

Since DOE began active remediation in March 2003, approximately 191.2 million gallons have been extracted from the floodplain.



Notes: In this figure, "Year" denotes the beginning of the reporting year. For example, "2022" corresponds to the current April 1, 2022, through March 31, 2023, performance period. Supporting data are provided in Appendix B, Table B-1. Locations 1110 and 1109 correspond to Trench 1 and Trench 2, respectively.

Abbreviation: MG = million gallons

Figure 6. Shiprock Site Floodplain Groundwater Extraction Volumes by Year and Location

2.2 Terrace Remediation System

The objective of the terrace remediation system is to remove groundwater from the southern portion of the terrace area so potential exposure pathways at seeps and at Bob Lee Wash are eventually eliminated and the flow of groundwater from the terrace to the floodplain is reduced (DOE 2002; DOE 2003). The terrace remediation system currently consists of four major components shown in Figure 1: the terrace drain at Bob Lee Wash (location 1087), the terrace outfall drainage channel diversion, eight extraction wells, and the evaporation pond. The terrace outfall drainage channel conveys runoff from the disposal cell to Bob Lee Wash. All groundwater extracted from the east terrace is piped to the evaporation pond. Along with average pumping rates for this period, Table 4 summarizes annual and cumulative volumes of groundwater extracted from the terrace remediation system locations.

During this reporting period, about 945,000 gallons of groundwater were extracted from the terrace extraction wells and the Bob Lee Wash Drain. Since DOE began active remediation in March 2003, approximately 56.2 million gallons have been extracted from the terrace (Table 4). Figure 7 plots the volumes extracted from the terrace by year and location, illustrating that the bulk of the recent volumes have been from extraction well 0818 and Bob Lee Wash.

Table 4. Terrace Extraction Wells and Drains: Average Pumping Rates and Total Groundwater Volume Removed

Location	Groundwater Volume Removed (gallons)[a]		Days Pumping[b]	2022–2023 Annual Pumping Rates (gpm)[b]		
	Annual Volume (2022–2023)	Cumulative Volume[c]		Average	Maximum	Average, Pumping Only
0818	283,225	7,377,638	97	0.59	2.87	2.03
1070	0	517,622				
1071	556	125,212	152	0.001	0.005	0.003
1078	0	4,587,986				
1091	0	260,851				
1092[d]	0	223,804				
1093R[e]	152	4,657,330	6	0.0003	0.024	0.018
1094[f]	0	15,628				
1095	25,575	2,806,079	125	0.049	0.42	0.14
1096	0	3,000,492				
Extraction Well Subtotal	**309,508**	**23,572,643**				
1087 (Bob Lee Wash)[g]	635,402	29,281,801	288	1.2	6.32	1.53
1088 (Many Devils Wash)[h]	0	3,388,155				
Total Terrace	**944,910**	**56,242,598**				

Shaded rows denote locations that are no longer operational.

Notes:

[a] Because all volumes are rounded to the nearest integer, total annual or cumulative volumes may differ slightly from the sum of preceding rows.

[b] Average pumping rates are not calculated for annual extraction volumes ≤ 1 gpm (table cells left blank). Days pumping determined by filtering on records with daily average flow rates ≥ 0.0007 gpm, corresponding to 1 gallon per day.

[c] Corresponding historical annual extraction volumes are provided in Appendix B, Table B-2. Accounting for the most recent (2022–2023) volumes, cumulative volumes reported here may differ somewhat from previous annual reports because of retroactive corrections to data retrieved from the SOARS/AQUARIUS database.

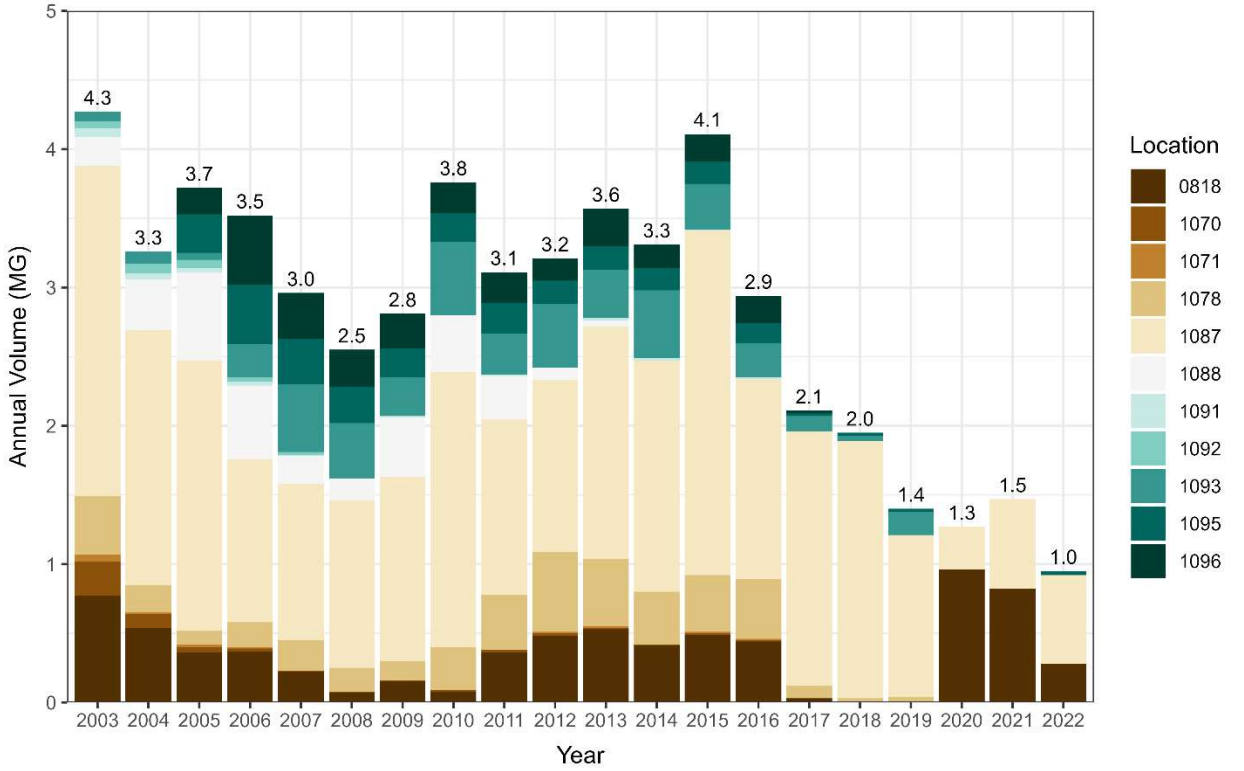
[d] Extraction well 1092 is no longer a viable extraction well (or groundwater monitoring location) because the well is dry. This well was removed from the terrace treatment system well network in March 2019. Prior to that, most average pumping rates were <0.005 gpm.

[e] Cumulative volumes for well 1093R combine data from former smaller-diameter well 1093 (2003–2007) with data from larger-diameter well 1093R (2008–present).

[f] Former extraction well 1094 was pumped only in 2003 and 2004 (Appendix B, Table B-2).

[g] Corresponding flows and groundwater extraction volumes reported for Bob Lee Wash are at times uncertain because of periodic flow meter malfunctions. In these cases, surrogate values corresponding to estimated average flow rates for the preceding period are applied based on an analysis of battery voltage, line pressure, and water levels.

[h] Pumping of the Many Devils Wash drain (location 1088) was terminated in March 2014; the drain was decommissioned in November 2022.



Notes: In this figure, "Year" denotes the beginning of the reporting year. For example, "2022" corresponds to the April 1, 2022, through March 31, 2023, performance period. Data for former extraction well 1094, pumped only in 2003 and 2004 (10,819 and 4809 gallons, respectively) are not shown. Supporting data are provided in Appendix B, Table B-2.

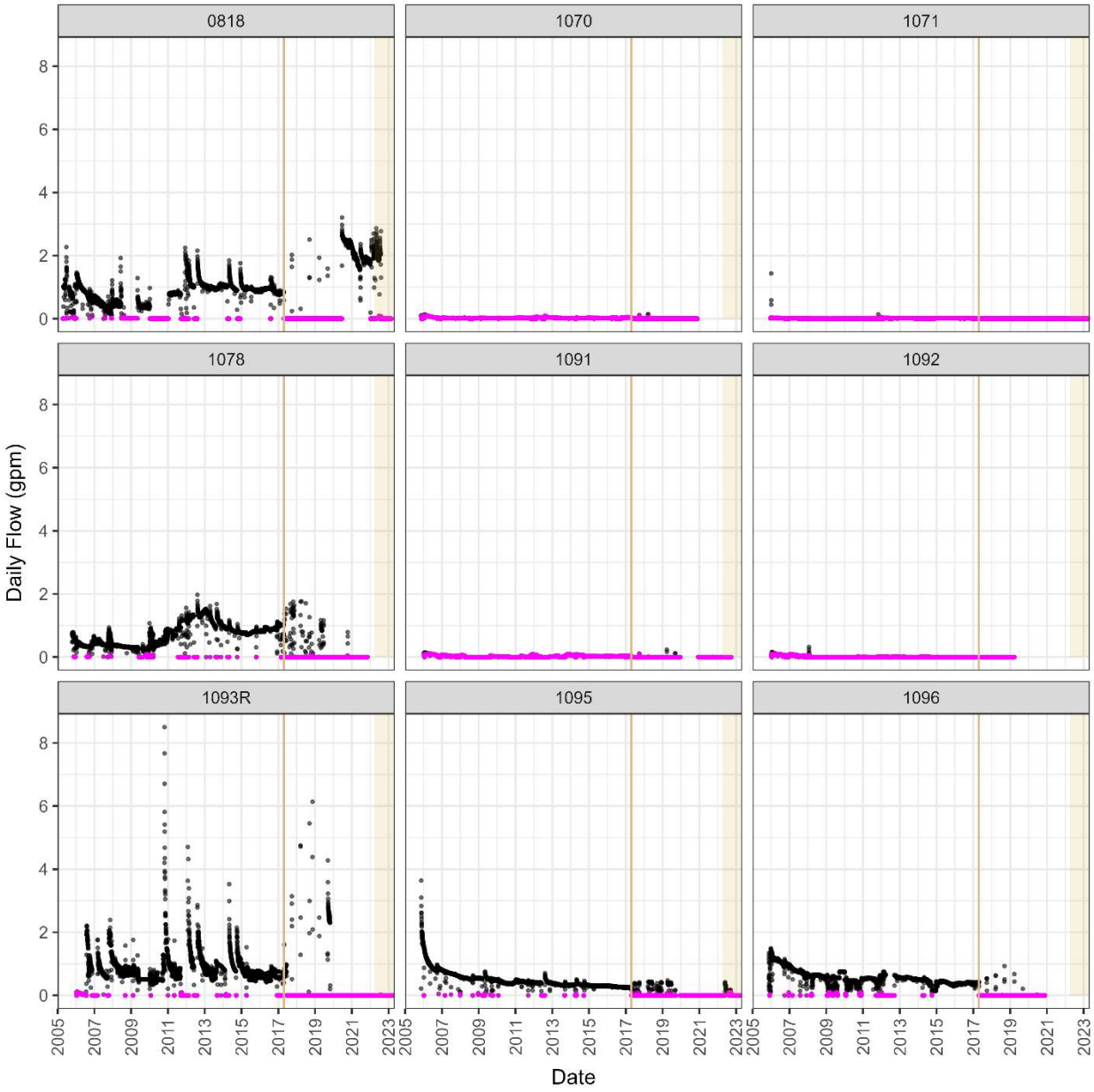
Abbreviation: MG = million gallons

Figure 7. Shiprock Site Terrace Groundwater Extraction Volumes by Year and Location

2.2.1 Extraction Well Performance

The terrace remediation well field currently consists of eight wells: 0818, 1070, 1071, 1078, 1091, 1093R, 1095, and 1096 (Figure 1). Well 1092 was removed from the network in late March 2019. To minimize inputs to the evaporation pond in support of LM's ongoing evaluation of the pond liner, the pumping suspension initiated in April 2017 continued into this (2022–2023) reporting period at most terrace extraction well locations. As shown in Table 4 and in Figure 8, extraction volumes were nominal at all extraction wells except well 0818 and 1095.

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). Even though new wells were installed to meet this objective (wells 1095 and 1096 in 2005 and well 1093R in 2007), except for periodic higher yields at well 1093R, terrace pumping rates have been at best 2–4 gpm, and expected extraction performance is not being met. Figure 8 illustrates the nominal volumes pumped at most terrace extraction wells since 2005. Daily average pumping rates in half of the wells (1070, 1071, 1091, and 1092) have usually been less than 0.1 gpm, the minimum (150 gallons per day) yield required to be considered an aquifer as defined in 40 CFR 192.11[e].



- Average daily flow rate (gpm) ≥ 0.1 gpm
- Average daily flow rate (gpm) < 0.1 gpm (150 gallons per day), low-yield definition for limited-use aquifer (40 CFR 192.11[e])

Shading denotes current (2022–2023) reporting period

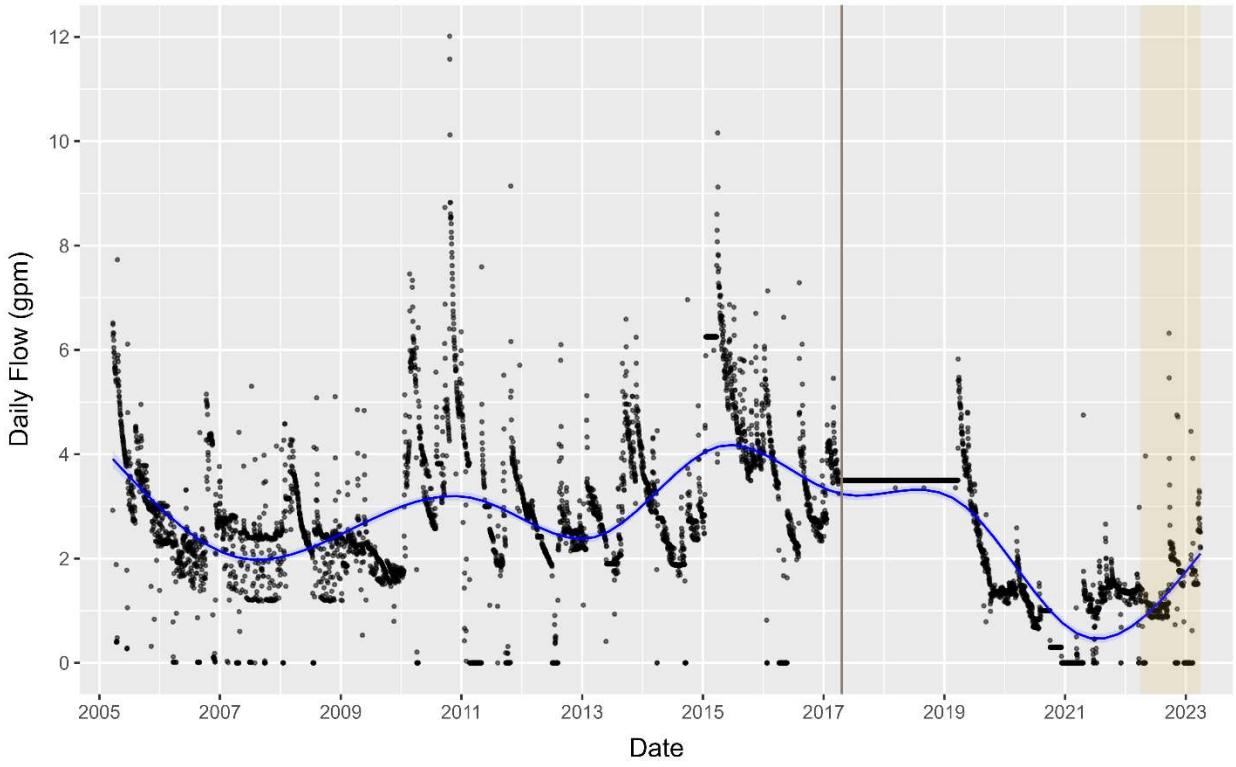
April 21, 2017, pumping suspension

Notes: Data plotted are since the inception of the SOARS system in 2005–2006. A linear scale is used to best illustrate comparative trends. Applying a semilogarithmic scale yielded errors because of the prevalence of zero values. The plot for well 1093R includes data from former well 1093 (see Note "e" in Table 4).

Figure 8. Historical Pumping Rates in Shiprock Site Terrace Extraction Wells, 2005–2023

2.2.2 Bob Lee Wash Drain System Performance

The terrace extraction system 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. Pumping continued at Bob Lee Wash location 1087 throughout most of this (2022–2023) reporting period because the wash is considered a potential point of exposure; daily flow rates are plotted in Figure 9. In 2022−2023, the groundwater interceptor drain removed approximately 635,400 gallons of water; the average pumping rate was 1.2 gpm (Table 4). The cumulative volume extracted since pumping began in 2003 is 29.3 million gallons. As noted in previous annual reports (e.g., DOE 2023a), this cumulative volume is uncertain because of periodic flow meter malfunctions (refer to Note "g" in Table 4).



- Average daily flow rate in gpm
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval (Due to the volume of data, the confidence interval is small, as illustrated above.)
- Shading denotes current (2022–2023) reporting period

Notes: Data plotted are since the inception of the SOARS system in 2005. During periods of flow meter malfunctions, surrogate values are applied based on analysis of voltage, line pressure, water levels, and preceding daily flow rates. For example, a surrogate value of 3.5 gpm was applied between April 4, 2017, and March 25, 2019.

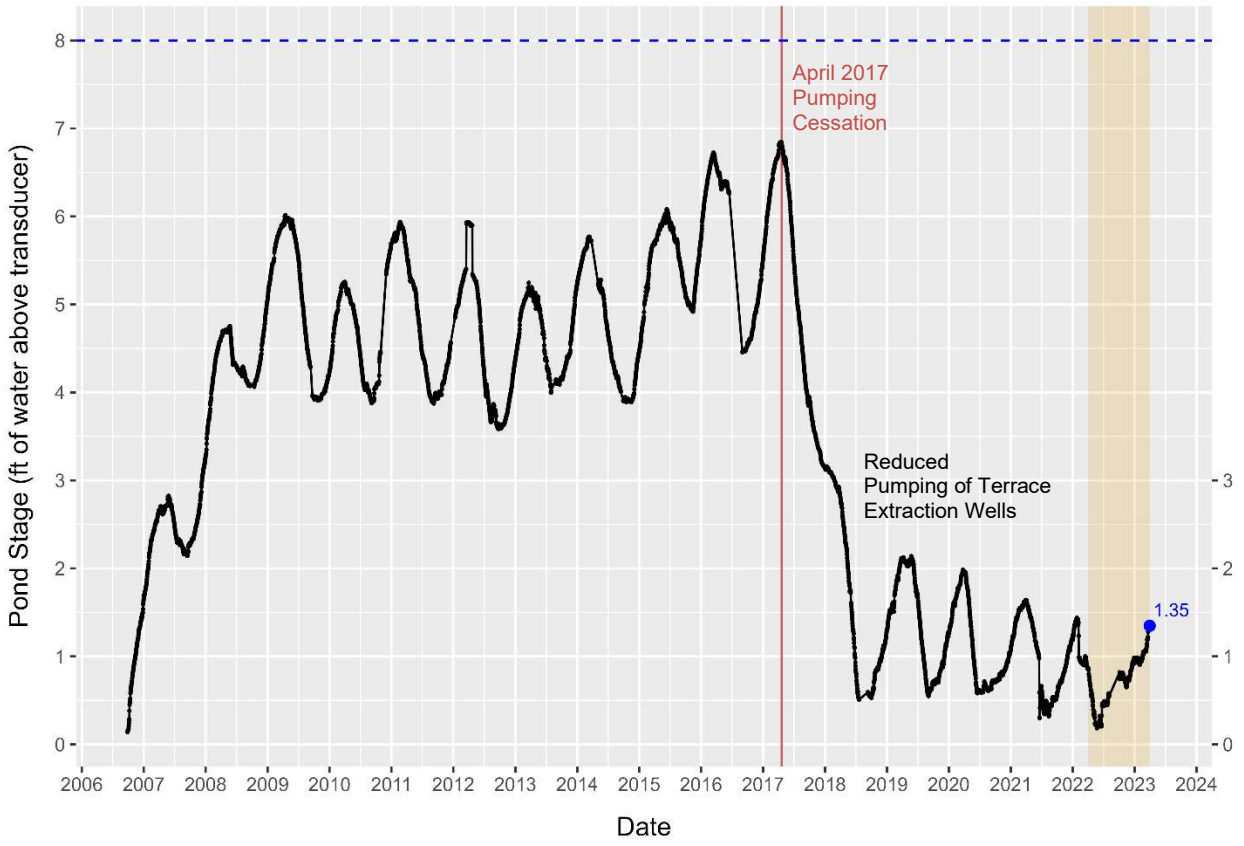
Abbreviation: LOESS = locally estimated scatterplot smoothing[2]

Figure 9. Historical Flow Rates in Bob Lee Wash (1087): 2005–2023

[2] In this and subsequent similar temporal plots, a nonparametric smoothing method or locally weighted regression—LOESS (not to be confused with the geologic term referred to in Section 1.5.2)—is used. With this approach, overall trends in the data are more apparent.

2.2.3 Evaporation Pond

Until the interim treatment plan is implemented (DOE 2023b) and pond decommissioning is initiated, the method for handling groundwater from the interceptor drains and extraction wells continues to be solar evaporation in the 11-acre lined evaporation pond (Figure 1). Figure 10 plots daily average pond water levels measured as a stage height above the transducer since September 2006. As discussed in the previous sections, LM suspended pumping of groundwater from most treatment system locations in April 2017. Since then, LM's approach has been to maintain a balance of pumping enough water to ensure that the evaporation pond sediments remain covered while remediating as much as possible in accordance with the site compliance strategy. During this reporting period, the pond stage ranged from 0.18–1.35 ft above the transducer with an average stage of 0.71 ft. At the close of this reporting period (March 31, 2023), the water level in the evaporation pond was 1.35 ft above the transducer (the highest level measured during this period).



- Daily average evaporation pond stage (ft of water), calculated based on 5-minute measurements
- Evaporation pond stage at end of reporting period, 1.35 ft of water above the transducer (*y*-axis labels are duplicated on the lower portion of the secondary (right) *y*-axis to facilitate review)
- ---- Pond capacity, 8 ft of water above the transducer
- | April 21, 2017, cessation of pumping at most treatment system locations
- Shading denotes current (2022–2023) reporting period

Figure 10. Shiprock Site Evaporation Pond Stage, 2006 Through March 2023

2.3 Summary

From April 2022 through March 2023, about 11.2 million gallons of extracted groundwater were pumped to the evaporation pond. The bulk of this total volume (10.2 million gallons, or 91.5%) of the influent liquids entering the pond was from the floodplain, most notably the trenches (Table 5). Pumping of terrace extraction wells 0818 and 1095 and the Bob Lee Wash drain (approximately 945,000 gallons) accounted for most of the remaining extraction volume. Since DOE began active remediation in March 2003, about 56.2 million gallons have been extracted from the terrace and 191.2 million gallons have been extracted from the floodplain. This yields a total cumulative volume of approximately 247.5 million gallons of groundwater pumped to the evaporation pond from all sources (Table 5; Figure 11). Total cumulative groundwater contributions are 23% from the terrace and 77% from the floodplain.

The estimated masses of nitrate, sulfate, and uranium pumped to the evaporation pond from the floodplain and terrace during the 2022–2023 performance period were approximately 18.4 pounds (lb) uranium; 5868 lb nitrate (as N); and 320,209 lb sulfate (Table 5). 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. Corresponding cumulative masses, representing the COC masses removed since the onset of remediation, are (rounded) 954 lb uranium; 419,000 lb nitrate (as N); and 12.2 million lb of sulfate (Table 5).

Table 5. Estimated Total Mass of Selected Constituents Pumped from Shiprock Site Terrace and Floodplain

Location	Annual Volume (gallons)[a]	Percent of Annual Volume	Total Cumulative Volume (MG)[a]	Mass Removed, 2022–2023 (lb)[b]			Cumulative Mass Removed (lb)[b]			Average Concentration, 2022–2023 (mg/L)		
				Nitrate as N	Sulfate	Uranium	Nitrate as N	Sulfate	Uranium	Nitrate as N	Sulfate	Uranium
Terrace												
0818	283,225	2.5	7.4	2036	39,000	0.326	63,471	836,045	7.58	861.5	16,500	0.138
1070	0		0.52				3734	72,229	0.52	607.5	13,400	0.124
1071	556	0.005	0.125	12.7	18.0	nil	1876	7,547	0.16	2730	3795	0.080
1078	0		4.6				22,069	525,593	5.0	403	13,050	0.107
1091	0		0.26				3065	27,366	0.25	498.5	15,050	0.056
1092*	0		0.22				2865	24,700	0.22	0.124	10,390	0.058
1093R	152	0.001	4.7	3.4	7.0	nil	78,704	237,932	4.5	2680	5180	0.112
1094	0		0.016				525	312	0.006			
1095	25,575	0.2	2.8	422.6	963	0.011	38,982	133,976	1.3	1980	4510	0.053
1096	0		3.0				15,214	364,165	2.5	672.5	15,350	0.103
1087 (BLW)	635,402	5.7	29.3	1978	40,804	2.87	72,569	1,737,475	130.1	373	7695	0.542
1088 (MDW)*	0		3.4				18,548	532,678	4.97			
Floodplain												
1077*	–		0.812				1214	116,410	16.8			
1089	2,953,695	26.5	46.2	2.7	74,072	2.42	5839	2,561,953	227.9	0.111	3005	0.098
1104	457,123	4.1	8.8	1.3	12,818	0.53	2783	606,398	66.6	0.347	3360	0.139
Trench 1 (1110)	3,210,211	28.8	58.1	632	133,416	10.2	45,374	3,375,300	356.6	23.6	4980	0.380
Trench 2 (1109)	3,589,743	32.2	74.4	779	19,113	2.09	41,171	848,086	117.3	26.0	638	0.070
Seep (1118)			2.95				1238	147,970	11.7	25.0	9095	0.651
Totals												
Total terrace	944,910	8.5	56.2	4453	80,790	3.2	321,622	4,500,019	157.1	675.4	13,131	0.15
Total floodplain	10,210,772	91.5	191.2	1415	239,419	15.2	97,619	7,656,117	796.9	15.8	3937	0.24
Total to pond	11,155,682	–	247.5	5868	320,209	18.4	419,241	12,156,136	953.9			

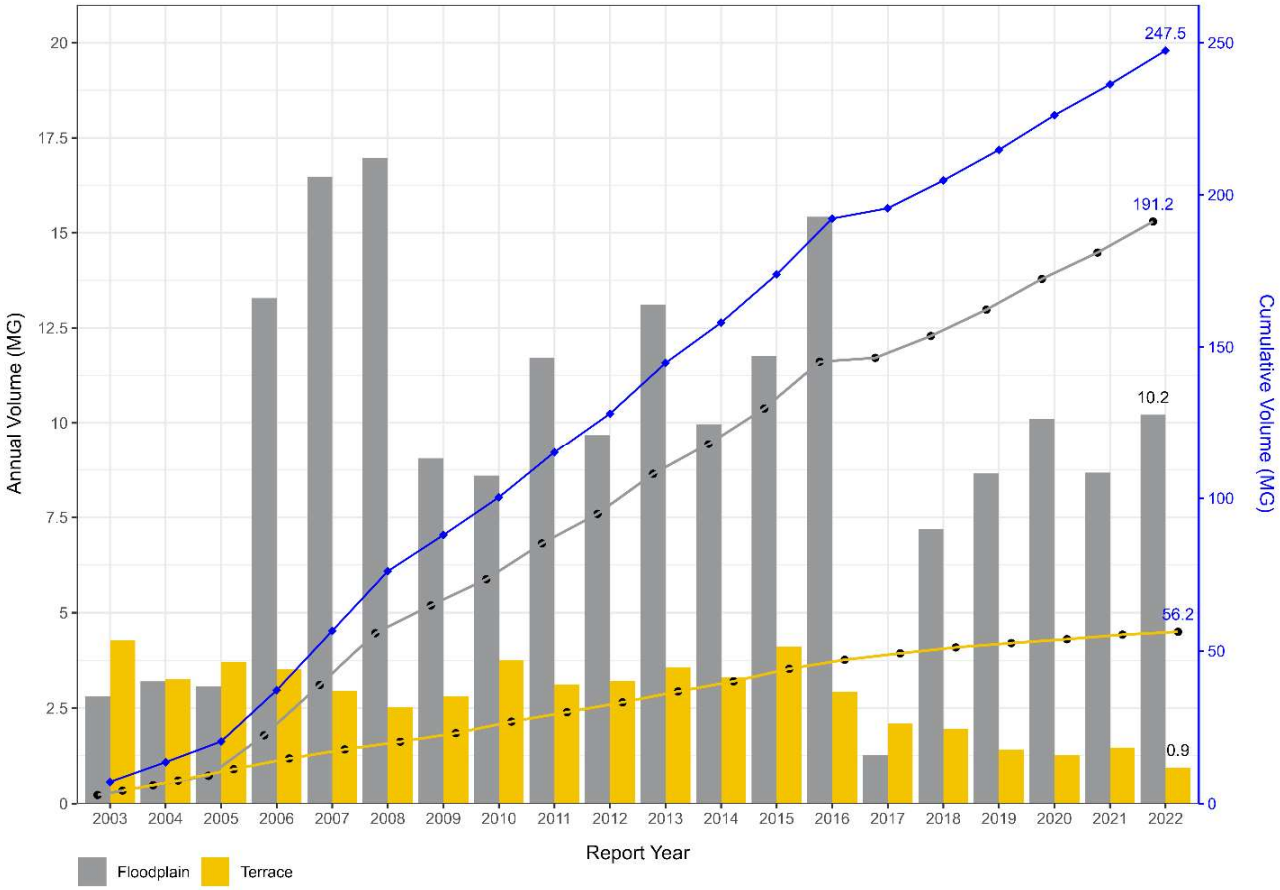
***** Asterisk denotes treatment system location no longer operational.

Notes:

[a] Annual cumulative volumes are for this reporting period: April 1, 2022, through March 31, 2023. Cumulative volumes are since 2003 and listed in units of million gallons. Because cumulative volumes (in MG) are rounded, total cumulative volumes may differ slightly from the sum of preceding rows. Detailed historical volumes and masses are provided in Appendix B. Additional supporting information is provided in the detailed location-specific notes in Table 3 and Table 4. Blank shaded cells correspond to locations that were not pumped during this reporting period (thus no volume or contaminant mass extracted).

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

Abbreviations: – = not pumped or not applicable; BLW = Bob Lee Wash; MDW = Many Devils Wash; MG = million gallons



Notes: Years denote the beginning of the reporting year; for example, 2022 corresponds to the April 1, 2022, through March 31, 2023, reporting period. Cumulative volumes (shown as points in line plots) are reflected on the right *y*-axis. The most recent cumulative volumes shown in blue font.

Abbreviation: MG = million gallons

Figure 11. Total Groundwater Volume Pumped to the Shiprock Site Evaporation Pond

3.0 Floodplain Restoration Progress

The current groundwater compliance strategy for the Shiprock site floodplain alluvial aquifer is natural flushing supplemented by active remediation. Uranium, nitrate, and sulfate are most widespread on the floodplain and therefore are used to gauge the effectiveness of this strategy. First, maps showing the current (March 2023) configurations of these primary COCs were created and compared to baseline (2000–2003) conditions to evaluate changes in plume geometry over time. To assess corresponding temporal trends for individual wells, Mann-Kendall trend analyses were then performed. To assess the collective contaminant plume trend, bulk plume metrics were calculated and compared to 2006 conditions, coinciding with the installation of the trenches, when a consistent monitoring well network was established. Section 3.1 briefly discusses the technical approaches used in this assessment. Detailed supporting information is provided in Appendix C.

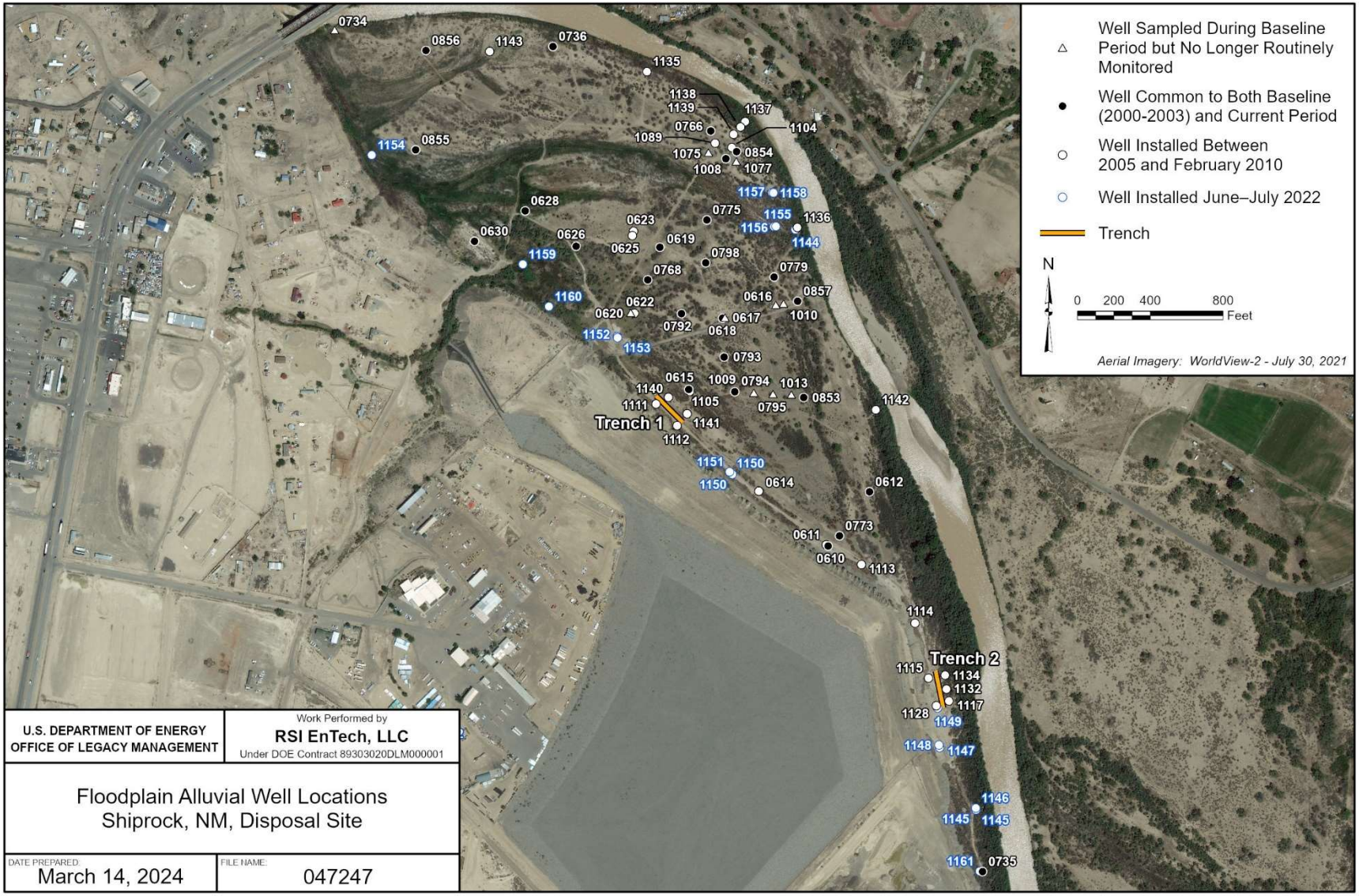
3.1 Technical Approach

3.1.1 Evaluation of Spatial Distributions

Consistent with previous annual reports, the alluvial plume maps presented in Section 3.2 through Section 3.4 compare baseline (2000–2003) and current conditions using all alluvial wells that were sampled during both periods. These figures were created using Earth Volumetric Studio (EVS) software version 2019.2.0 (kriging estimation, simple anisotropy mode, spherical model, finite difference grid). 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 additional near-river monitoring locations were also established. More recently, in accordance with recommendations in the GCAP Work Plan (DOE 2022c), LM installed 18 additional wells on the floodplain, 9 of which were screened in the alluvium. Sample locations used in the baseline versus current plume map comparisons for the alluvial aquifer are shown in Figure 12.

3.1.2 Evaluation of Concentration Trends

Time-concentration plots are provided in Appendix C for each primary COC for the period 2000 through March 2023. Corresponding Mann-Kendall trend analysis and linear regression trends for uranium, nitrate, and sulfate in floodplain wells are provided in Appendix C (Tables C-1 through C-3). For these analyses, an initial date of 2006 was used because it corresponds to the installation of the floodplain trenches. To facilitate comparison of trend analysis results by well and parameter, a summary matrix of these results is provided in Table 6 for the 2006–2023 time frame. This table only includes wells on the contiguous floodplain because COC trends in background wells are not germane to the evaluation of remediation system performance. Following the 2017 pumping cessation, NRC expressed concern that the reduction in groundwater extraction might result in increases in COC concentrations on the floodplain (Orlando 2020). To address these concerns, Mann-Kendall trend analysis was also conducted for the more recent (2017–2023) time frame (Table 7). Overall, these results indicate no significant increases in COC concentrations resulting from the 2017–2018 pumping cessation.



Note: This figure is intended as a cross-reference for subsequent figures depicting interpolated concentrations of COCs on the floodplain.

Figure 12. Sample Locations Used in Baseline Versus Current Plume Comparisons

Table 6. Mann-Kendall Trend Analysis Summary for 2006–2023 Time Frame

Uranium			
Location	tau	p	Trend
0608	−0.84	<0.001	Decreasing
0610	−0.49	<0.001	Decreasing
0611	−0.15	0.29	None
0612	−0.25	0.07	None
0614	−0.84	<0.001	Decreasing
0615	−0.44	<0.001	Decreasing
0618	−0.78	<0.001	Decreasing
0619	−0.42	<0.001	Decreasing
0622	−0.53	<0.001	Decreasing
0623	−0.72	<0.001	Decreasing
0625	−0.74	<0.001	Decreasing
0626	−0.43	<0.001	Decreasing
0628	0.02	0.91	None
0630	0.24	0.07	None
0735	−0.12	0.32	None
0736	−0.51	<0.001	Decreasing
0766	−0.56	<0.001	Decreasing
0768	−0.42	0.003	Decreasing
0773	−0.34	0.026	Decreasing
0775	−0.59	<0.001	Decreasing
0779	−0.47	<0.001	Decreasing
0792	−0.47	<0.001	Decreasing
0793	−0.49	<0.001	Decreasing
0798	−0.63	<0.001	Decreasing
0853	0.11	0.41	None
0854	−0.7	<0.001	Decreasing
0855	−0.28	0.033	Decreasing
0856	−0.33	0.012	Decreasing
0857	0.40	0.004	Increasing
1008	−0.86	<0.001	Decreasing
1009	−0.61	<0.001	Decreasing
1089	−0.82	<0.001	Decreasing
1104	−0.8	<0.001	Decreasing
1105	−0.53	<0.001	Decreasing
1111	−0.42	0.002	Decreasing
1112	−0.51	<0.001	Decreasing
1113	−0.41	0.003	Decreasing
1114	−0.32	0.018	Decreasing
1115	−0.2	0.11	None
1117	−0.22	0.074	None
1128	−0.53	<0.001	Decreasing
1132	−0.46	<0.001	Decreasing
1134	−0.2	0.18	None
1135	−0.68	<0.001	Decreasing
1136	0.53	<0.001	Increasing
1137	−0.15	0.33	None
1138	−0.25	0.09	None
1139	−0.15	0.29	None
1140	−0.62	<0.001	Decreasing
1141	−0.34	0.018	Decreasing
1142	0.52	<0.001	Increasing
1143	−0.55	<0.001	Decreasing

Nitrate as N			
Location	tau	p	Trend
0608	−0.52	<0.001	Decreasing
0610	−0.35	0.011	Decreasing
0611	−0.09	0.53	None
0612	−0.12	0.34	None
0614	−0.59	<0.001	Decreasing
0615	−0.81	<0.001	Decreasing
0618	−0.55	<0.001	Decreasing
0619	−0.14	0.22	None
0622	−0.21	0.12	None
0623	−0.04	0.74	None
0625	−0.03	0.82	None
0626	−0.08	0.55	None
0628	−0.02	0.88	None
0630	0.05	0.72	None
0735	0.07	0.56	None
0736	−0.16	0.24	None
0766	−0.07	0.67	None
0768	0.03	0.83	None
0773	−0.34	0.025	Decreasing
0775	0.02	0.90	None
0779	−0.19	0.16	None
0792	−0.07	0.57	None
0793	−0.54	<0.001	Decreasing
0798	−0.21	0.12	None
0853	0.05	0.69	None
0854	−0.59	<0.001	Decreasing
0855	0.24	0.06	None
0856	−0.22	0.06	None
0857	−0.1	0.48	None
1008	−0.49	<0.001	Decreasing
1009	−0.05	0.68	None
1089	−0.67	<0.001	Decreasing
1104	−0.78	<0.001	Decreasing
1105	−0.8	<0.001	Decreasing
1111	−0.12	0.39	None
1112	−0.34	0.008	Decreasing
1113	−0.33	0.016	Decreasing
1114	−0.26	0.05	None
1115	−0.15	0.26	None
1117	0.06	0.62	None
1128	−0.49	<0.001	Decreasing
1132	0.14	0.30	None
1134	−0.04	0.79	None
1135	0	0.42	None
1136	0.00	1.0	None
1137	−0.36	0.011	Decreasing
1138	−0.53	<0.001	Decreasing
1139	−0.47	<0.001	Decreasing
1140	−0.59	<0.001	Decreasing
1141	−0.24	0.09	None
1142	−0.09	0.50	None
1143	−0.06	0.64	None

Sulfate			
Location	tau	p	Trend
0608	−0.08	0.53	None
0610	−0.3	0.033	Decreasing
0611	−0.47	0.001	Decreasing
0612	−0.21	0.12	None
0614	−0.8	<0.001	Decreasing
0615	−0.08	0.51	None
0618	−0.73	<0.001	Decreasing
0619	0.00	0.99	None
0622	−0.3	0.031	Decreasing
0623	−0.36	0.010	Decreasing
0625	−0.26	0.08	None
0626	−0.17	0.19	None
0628	0.07	0.63	None
0630	0.44	0.001	Increasing
0735	0.00	1.00	None
0736	−0.59	<0.001	Decreasing
0766	−0.6	<0.001	Decreasing
0768	−0.44	0.002	Decreasing
0773	−0.4	0.008	Decreasing
0775	−0.52	<0.001	Decreasing
0779	−0.12	0.42	None
0792	−0.59	<0.001	Decreasing
0793	−0.01	0.98	None
0798	−0.6	<0.001	Decreasing
0853	0.19	0.153	None
0854	−0.73	<0.001	Decreasing
0855	−0.14	0.28	None
0856	−0.3	0.026	Decreasing
0857	0.56	<0.001	Increasing
1008	−0.83	<0.001	Decreasing
1009	−0.47	0.001	Decreasing
1089	−0.78	<0.001	Decreasing
1104	−0.7	<0.001	Decreasing
1105	−0.58	<0.001	Decreasing
1111	−0.13	0.34	None
1112	−0.49	<0.001	Decreasing
1113	−0.67	<0.001	Decreasing
1114	−0.22	0.10	None
1115	−0.18	0.16	None
1117	0.25	0.053	None
1128	−0.5	0.001	Decreasing
1132	0.33	0.021	Increasing
1134	0.06	0.67	None
1135	−0.59	<0.001	Decreasing
1136	0.61	<0.001	Increasing
1137	0.06	0.71	None
1138	−0.1	0.53	None
1139	0.07	0.64	None
1140	−0.38	0.009	Decreasing
1141	−0.22	0.13	None
1142	0.14	0.31	None
1143	−0.34	0.0175	Decreasing

Note: Details provided in Appendix C. Statistically significant increasing and decreasing trends are highlighted to faciliate review. Results for floodplain background locations 0797, 0850, 0782R, and 0783R are excluded.

Table 7. Mann-Kendall Trend Analysis Results for 2017–2023 Time Frame

Uranium				Nitrate as N				Sulfate			
Location	tau	p	Trend	Location	tau	p	Trend	Location	tau	p	Trend
0608	−0.87	<0.001	Decreasing	0608	0.33	0.21	None	0608	−0.34	0.21	None
0610	0.11	0.72	None	0610	−0.07	0.86	None	0610	−0.02	1.00	None
0611	0.02	1	None	0611	−0.29	0.28	None	0611	−0.11	0.72	None
0612	−0.28	0.35	None	0612	0	1.0	None	0612	−0.37	0.21	None
0614	−0.67	0.009	Decreasing	0614	0.45	0.09	None	0614	−0.16	0.59	None
0615	0.51	0.049	Increasing	0615	−0.49	0.053	None	0615	0.31	0.24	None
0618	−0.07	0.86	None	0618	0.38	0.15	None	0618	−0.2	0.47	None
0619	−0.18	0.53	None	0619	0.11	0.67	None	0619	−0.09	0.79	None
0622	−0.42	0.11	None	0622	−0.2	0.40	None	0622	0.02	1.0	None
0623	−0.54	0.039	Decreasing	0623	0.20	0.35	None	0623	0.27	0.32	None
0625	−0.64	0.012	Decreasing	0625		0.84	None	0625	0.45	0.09	None
0626	−0.02	1	None	0626	−0.18	0.45	None	0626	0.13	0.65	None
0628	0.31	0.24	None	0628	0	1.0	None	0628	0.13	0.65	None
0630	−0.42	0.11	None	0630	−0.51	0.049	Decreasing	0630	0.02	1.0	None
0735	−0.45	0.09	None	0735	−0.6	0.020	Decreasing	0735	−0.45	0.09	None
0736	−0.5	0.08	None	0736	−0.22	0.38	None	0736	−0.08	0.83	None
0766	−0.33	0.25	None	0766	0.11	0.74	None	0766	−0.54	0.06	None
0768	−0.56	0.048	Decreasing	0768	0.11	0.72	None	0768	−0.7	0.012	Decreasing
0773	−0.33	0.37	None	0773	0	1.0	None	0773	−0.29	0.45	None
0775	−0.2	0.53	None	0775	−0.06	0.91	None	0775	−0.25	0.40	None
0779	−0.69	0.007	Decreasing	0779	−0.67	0.009	Decreasing	0779	−0.6	0.020	Decreasing
0792	0.42	0.11	None	0792	0.00	1.0	None	0792	0.09	0.79	None
0793	0.16	0.59	None	0793	−0.4	0.13	None	0793	−0.2	0.47	None
0798	−0.13	0.65	None	0798	−0.31	0.23	None	0798	0.00	1.0	None
0853	−0.38	0.15	None	0853	0.11	0.70	None	0853	−0.51	0.049	Decreasing
0854	−0.3	0.28	None	0854	0.11	0.70	None	0854	−0.4	0.13	None
0855	−0.33	0.21	None	0855	−0.42	0.11	None	0855	−0.05	0.93	None
0856	−0.6	0.020	Decreasing	0856	−0.02	1.0	None	0856	−0.6	0.023	Decreasing
0857	−0.4	0.13	None	0857	−0.6	0.018	Decreasing	0857	0.04	0.93	None
1008	−0.4	0.13	None	1008	−0.18	0.48	None	1008	−0.69	0.008	Decreasing
1009	0.51	0.049	Increasing	1009	0.42	0.09	None	1009	0.63	0.018	Increasing
1089	−0.54	0.039	Decreasing	1089	−0.36	0.18	None	1089	−0.63	0.015	Decreasing
1104	−0.48	0.09	None	1104	−0.28	0.35	None	1104	−0.4	0.17	None
1105	0.72	0.005	Increasing	1105	−0.07	0.85	None	1105	0.45	0.09	None
1111	−0.56	0.03	Decreasing	1111	−0.29	0.28	None	1111	−0.18	0.53	None
1112	−0.36	0.18	None	1112	−0.02	1.00	None	1112	−0.27	0.32	None
1113	−0.13	0.65	None	1113	−0.45	0.09	None	1113	−0.38	0.15	None
1114	−0.4	0.13	None	1114	−0.42	0.11	None	1114	−0.38	0.15	None
1115	−0.24	0.37	None	1115	−0.16	0.59	None	1115	−0.24	0.37	None
1117	−0.47	0.07	None	1117	−0.36	0.17	None	1117	0.11	0.72	None
1128	−0.38	0.15	None	1128	−0.33	0.21	None	1128	−0.38	0.15	None
1132	−0.56	0.032	Decreasing	1132	−0.18	0.52	None	1132	−0.2	0.47	None
1134	−0.33	0.21	None	1134	−0.13	0.63	None	1134	−0.24	0.37	None
1135	−0.87	0.001	Decreasing	1135	0	1.0	None	1135	−0.58	0.025	Decreasing
1136	−0.16	0.59	None	1136	−0.6	0.020	Decreasing	1136	0.13	0.65	None
1137	−0.42	0.11	None	1137	−0.13	0.61	None	1137	−0.42	0.11	None
1138	−0.24	0.37	None	1138	−0.18	0.52	None	1138	−0.51	0.049	Decreasing
1139	−0.16	0.59	None	1139	−0.16	0.56	None	1139	−0.49	0.06	None
1140	0.07	0.86	None	1140	−0.31	0.24	None	1140	−0.02	1.0	None
1141	−0.07	0.86	None	1141	−0.33	0.21	None	1141	−0.29	0.28	None
1142	0.11	0.72	None	1142	0	1.0	None	1142	−0.16	0.59	None
1143	−0.73	0.004	Decreasing	1143	0	1.0	None	1143	−0.16	0.6	None

Note: Trend tests were run for the period January 1, 2017 (preceding the April 2017 pumping pause), through March 31, 2023 (7 to 10 results depending on location). Statistically significant increasing and decreasing trends are highlighted to faciliate review. Results for floodplain background locations are excluded.

3.1.3 Bulk Plume Metrics

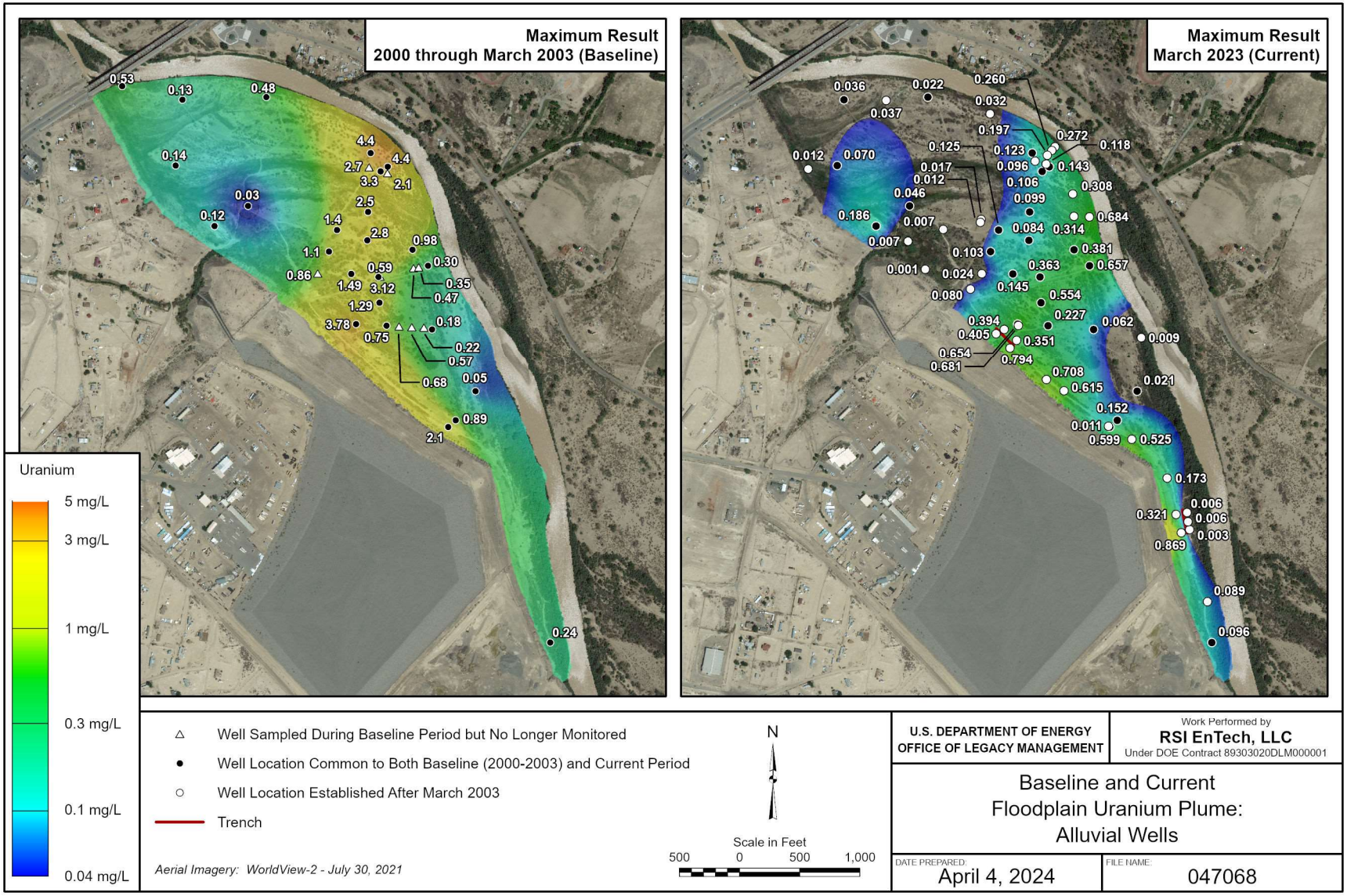
The bulk plume metrics presented in this section were evaluated by three-dimensional interpolation of temporal dissolved COC concentration data from March 2006 through March 2023. Consistent with the trend evaluation discussed above, a start date of 2006 was used for the bulk plume metrics because it coincides with the installation of the floodplain trenches and is the date after which a consistent set of wells was sampled annually. The interpolated plume volume was bounded on the bottom by the top of the bedrock surface and on the top by the water table (interpolated from groundwater elevation measurements for each sampling event). A porosity of 0.25 was assumed for pore volume and plume mass calculations. Between the bedrock and the water table, the plume extents were defined by the MCLs for uranium and nitrate (0.044 mg/L and 10 mg/L [as N], respectively) and the 2000 mg/L cleanup goal for sulfate. The resulting three-dimensional representations of the plumes for uranium, nitrate, and sulfate provide estimates of the plume footprint area, volume, average contaminant concentrations, and corresponding dissolved plume mass, allowing a more comprehensive assessment of groundwater restoration progress on the Shiprock site floodplain.

3.2 Uranium

Decreases in uranium concentrations in wells across a large portion of the floodplain are evident (Figure 13, Table 6, Table 7, and Appendix C). Despite these reductions in relative to baseline conditions, uranium concentrations in groundwater continue to exceed the MCL in most floodplain wells (Figure 13). Exceptions include the northwest portion of the floodplain, where COC concentrations are likely diluted from the discharge of artesian well 0648 groundwater onto the floodplain. Low concentrations in groundwater also occur in the east and southeast part of the floodplain, resulting from mixing with San Juan River water through hyporheic exchange (DOE 2018a). The highest concentrations of uranium in the floodplain alluvium (typically 0.8–0.9 mg/L) currently occur along the base of the escarpment just north of the disposal cell and in a zone traversing the floodplain in a line trending northward from the disposal cell.

For the 2006–2023 time frame, Mann-Kendall trend analysis indicates statistically significant decreasing trends in uranium concentrations for the majority of floodplain wells (Table 6). Three wells, near-river wells 0857 and 1136 and hyporheic well 1142, have a statistically significant increasing trend. Since 2017, uranium concentrations in most floodplain wells have been stable, with no trend (Table 7). Although statistically significant increasing trends were found for three wells in the Trench 1 region (0615, 1009, and 1105), these increases are slight, and recent concentrations are well within historical ranges (Appendix C, Figure C-2).

Figure 14 shows the results of the bulk plume metric analysis for uranium in the floodplain alluvium for average concentrations (plot a), plume volume (plot b), dissolved plume mass (plot c), and the plume footprint (plot d). The average uranium concentration has decreased from approximately 0.5 mg/L in 2006 to 0.2 mg/L in 2023. However, paralleling the stabilization of concentration trends in many wells evident in Appendix C, Figure C-2, the average bulk plume metric uranium concentration has remained relatively constant at approximately 0.2 mg/L since 2014 (Figure 14a). The corresponding uranium plume volume has decreased from approximately 125 million gallons in 2006 to about 50 million gallons in 2023 (Figure 14b). Since 2006, the dissolved uranium plume mass has decreased from 500 to approximately 100 lb (Figure 14c). The uranium plume footprint has reduced about 50%, from 120 acres in 2006 to 60 acres in 2023 (Figure 14d).



Notes: Hollow or uncontoured portions of both plume maps denote regions with uranium concentrations below the 0.044 mg/L standard. Only results are shown due to the density of floodplain monitoring locations. Figure 12 provides a cross-reference to the specific well identifiers.

Figure 13. Baseline (2000–2003) and March 2023 Shiprock Site Floodplain Uranium Plumes

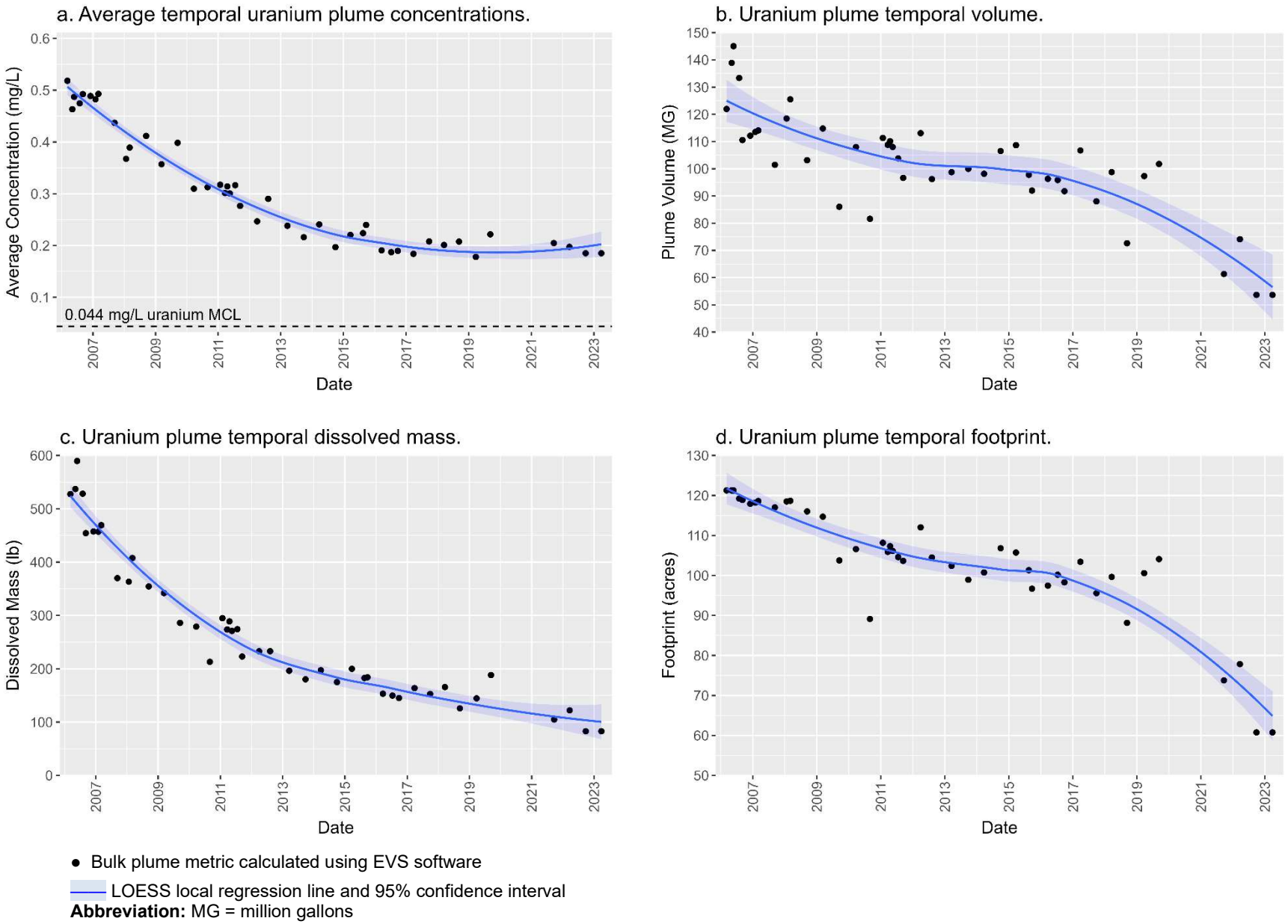


Figure 14. Shiprock Site Floodplain Alluvium Bulk Plume Metrics for Uranium, 2006–2023

These findings indicate that the current compliance strategy for the floodplain has been successful in decreasing the mass of the uranium plume. However, given fairly consistent average uranium concentrations and corresponding dissolved plume mass since 2015, it is unlikely that the uranium plume will sufficiently attenuate to reach the 0.044 mg/L uranium MCL within the 100-year performance period.

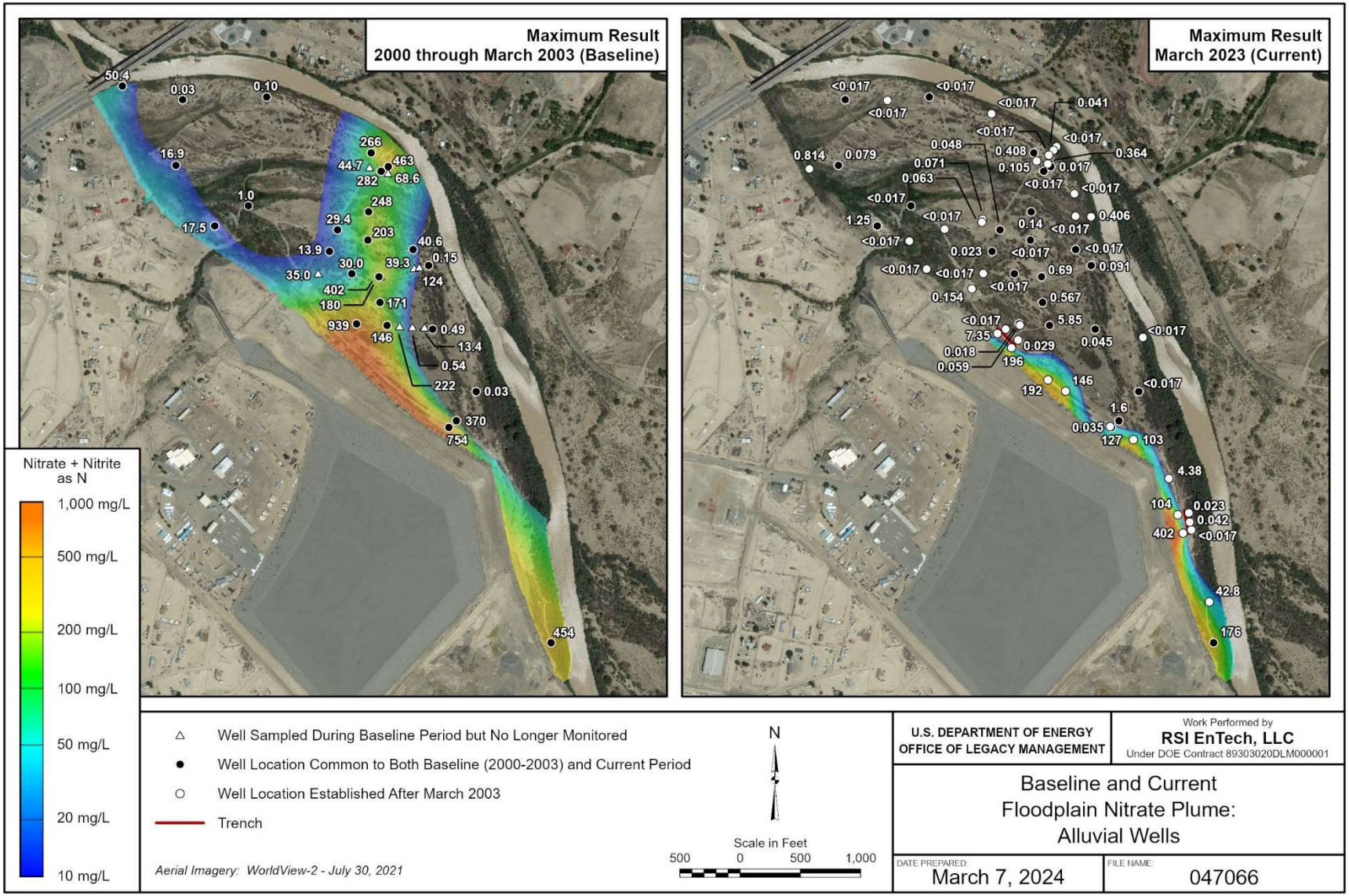
3.3 Nitrate (as N)

Consistent with previous annual reports (DOE 2023a), the extent of the current nitrate plume, defined by regions exceeding the 10 mg/L MCL, is much smaller than that shown for baseline conditions (Figure 15). In March 2023, elevated nitrate concentrations were limited to the base of the escarpment. The nitrate plume maps and time-concentration plots show demonstrable progress on the floodplain (reductions in nitrate concentrations) relative to baseline conditions. In many wells, nitrate concentrations have declined by more than 2 orders of magnitude since installation of the trenches in 2006, as well as since the (2000–2003) baseline period (Appendix C). These declines are most evident in the central plume region, extending from Trench 1 to pumping wells 1089 and 1104 near the San Juan River.

For the 2006–2023 time frame, Mann-Kendall trend analysis indicates statistically significant decreasing trends for about one-third of floodplain wells and no significant trend for the remainder (Table 6). No statistically significant increasing nitrate concentration trends were identified for either the 2006–2023 (Table 6) or the more recent (2017–2023) time frames (Table 7). Analysis of the bulk plume metrics for the floodplain alluvial aquifer (Figure 16) shows a decrease in average plume concentration, plume mass, plume volume, and plume footprint. Since the installation of the trenches in 2006, the average nitrate plume concentration has halved, from approximately 200 mg/L in 2006 to about 100 mg/L in 2023 (Figure 16a). Although not directly comparable, the latter plume concentration is generally consistent with current nitrate concentrations (about 100 mg/L) measured in wells at the base of the escarpment.

Remaining bulk plume metrics for nitrate shown in Figure 16 indicate the following:

- A nearly sevenfold decrease in the nitrate plume volume, from 35 million gallons in 2006 to 5 million gallons in 2023 (Figure 16b)
- A twelvefold decrease in the dissolved nitrate mass, from approximately 60,000 lb to 5000 lb (Figure 16c)
- A fourfold decrease in the nitrate plume footprint, from about 43 acres in 2006 to 10 acres in 2023 (Figure 16d)



Notes: Hollow or uncontoured portions of both plume maps denote regions with nitrate concentrations below the 10 mg/L (as N) MCL. Only results are shown due to the density of floodplain monitoring locations; Figure 12 provides a cross-reference to the specific well identifiers.

Figure 15. Baseline (2000–2003) and March 2023 Shiprock Site Floodplain Nitrate Plumes

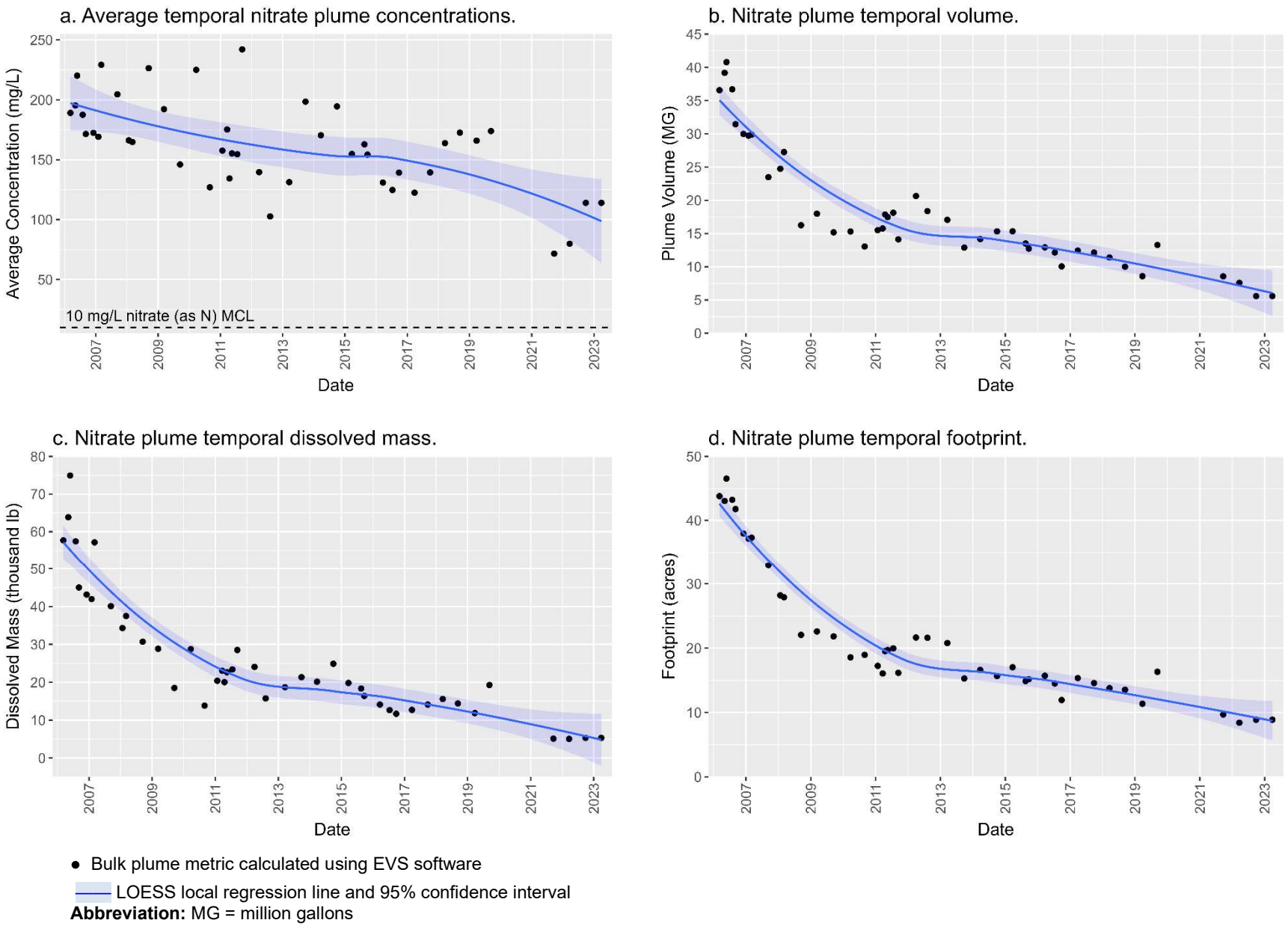


Figure 16. Shiprock Site Floodplain Alluvium Bulk Plume Metrics for Nitrate: 2006–2023

3.4 Sulfate

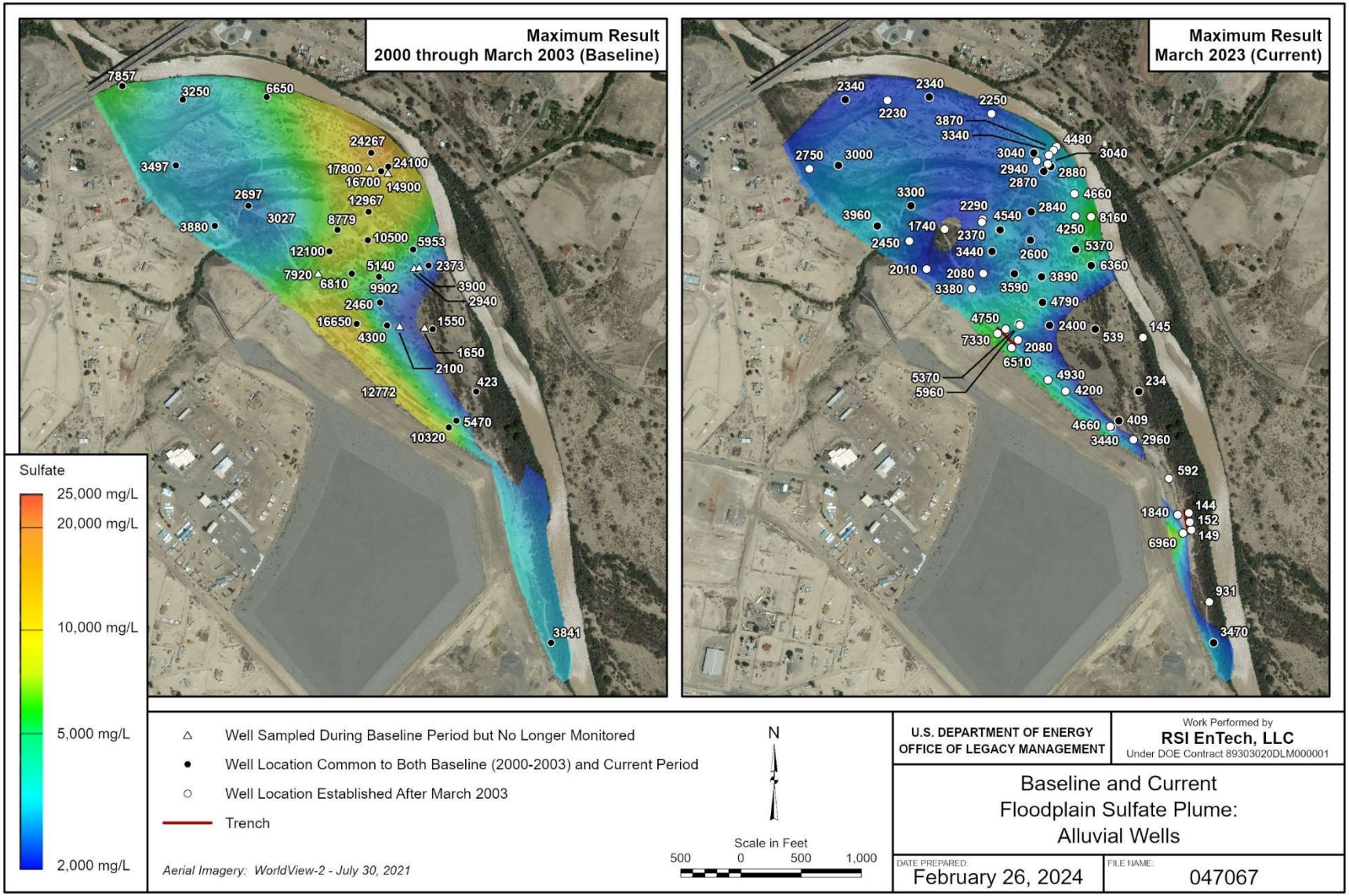
Except for where the San Juan River recharges the alluvial aquifer, the extent of the sulfate plume, as defined by regions exceeding the 2000 mg/L cleanup goal, is about the same as that in 2000–2003 (Figure 17). During the baseline period, sulfate concentrations in groundwater exceeded the proposed cleanup goal throughout the floodplain. In floodplain groundwater, higher concentrations of sulfate are at the base of this escarpment, indicating a groundwater flow connection along the escarpment from the terrace to the floodplain (DOE 2018a). Since pumping began in 2006, sulfate concentrations within the treatment system's interpreted capture zone (DOE 2018a) have decreased considerably but are still elevated relative to those within the rest of the floodplain aquifer.

Reductions in sulfate concentrations since the baseline period are evident in many floodplain wells, particularly in the Trench 1 and wells 1089 and 1104 remediation areas. However, as noted above, sulfate levels still exceed the 2000 mg/L GCAP-established benchmark in the majority of wells. Sulfate concentrations in the western floodplain (2000–3000 mg/L) are fairly consistent with those measured in artesian well 0648, which were used to establish the 2000 mg/L cleanup goal (DOE 2000; DOE 2002). As discussed in Section 1.5.1, most of the recharge onto the northern portion of the floodplain is sourced from terrace artesian well 0648 at the head of Bob Lee Wash, while recharge in the remainder (southern portion) of the floodplain is primarily sourced from the San Juan River in the form of hyporheic flow.

Although Mann-Kendall trend analysis identified statistically significant decreasing trends for the majority of wells for the 2006–2023 time frame (Table 6), concentrations have stabilized as shown in Table 7. Consistent with last year's reporting (DOE 2023a), for the 2006–2023 period, a significant increasing trend was found for only five wells: 0630, 0857, 1132, 1136, and background well 0783R (Table 6; Appendix C, Table C-3). Mann-Kendall trend analysis conducted for the recent 2017–2023 time frame identified a significant increasing trend only in well 1009, northeast of Trench 1 (Table 7).

Since installation of the floodplain trenches in 2006, the sulfate bulk plume metrics for the floodplain alluvium (Figure 18) indicate:

- A decrease in the average plume concentration from 6200 mg/L to 3500 mg/L (Figure 18a)
- A decrease in plume volume from 110 million gallons to 90 million gallons (Figure 18b)
- A decrease in the dissolved plume mass from about 5.8 million lb to 2.5 million lb (Figure 18c)
- Consistent with the baseline versus current plume comparison (Figure 17), only a slight reduction in the plume footprint, from about 102 acres to 87 acres (Figure 18d)



Notes: Hollow or uncontoured portions of both plume maps denote regions with sulfate concentrations below the 2000 mg/L remediation goal. Only results are labeled due to the density of floodplain monitoring locations; Figure 12 provides a cross-reference to the specific well identifiers.

Figure 17. Baseline (2000–2003) and March 2023 Shiprock Site Floodplain Sulfate Plumes

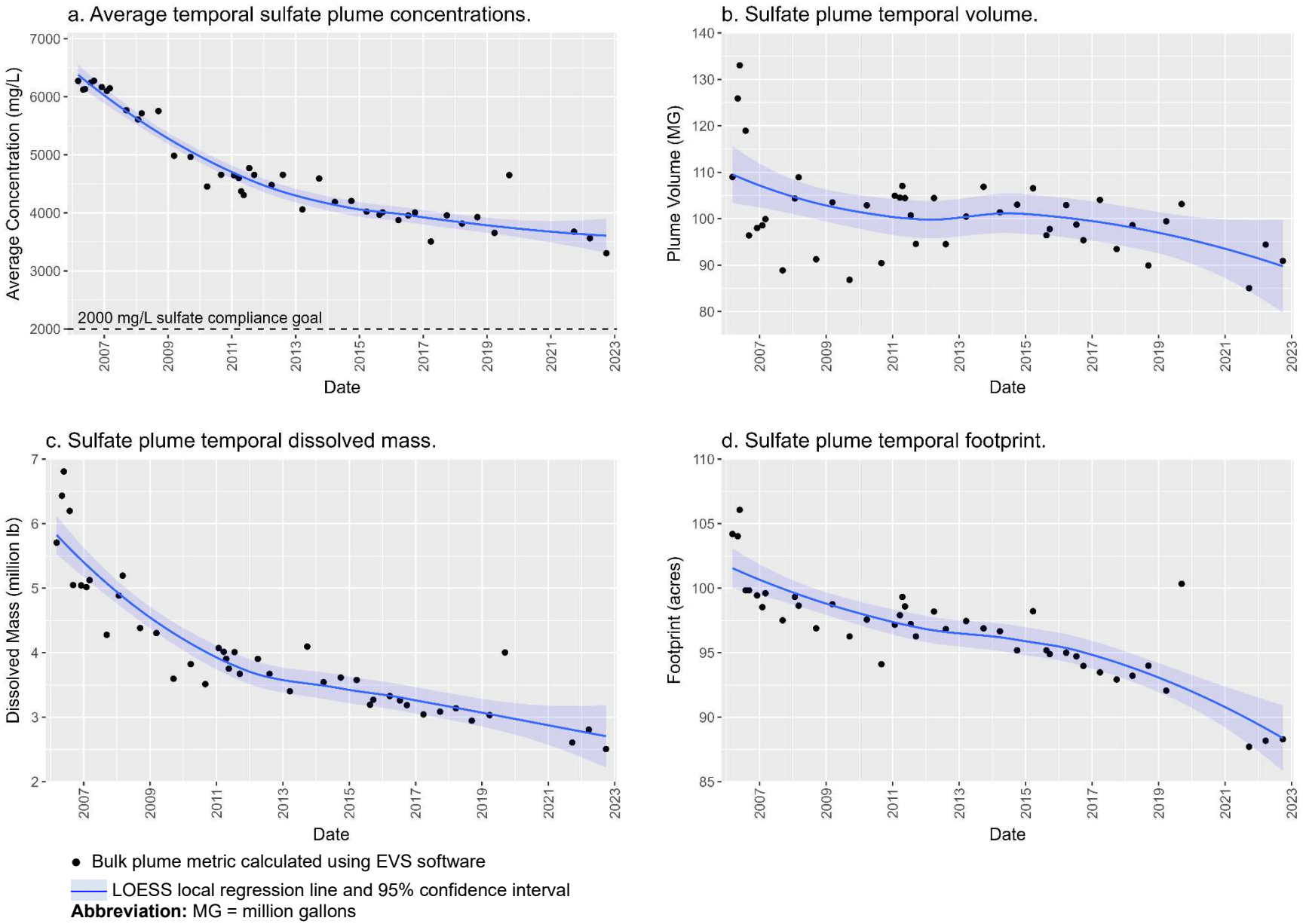


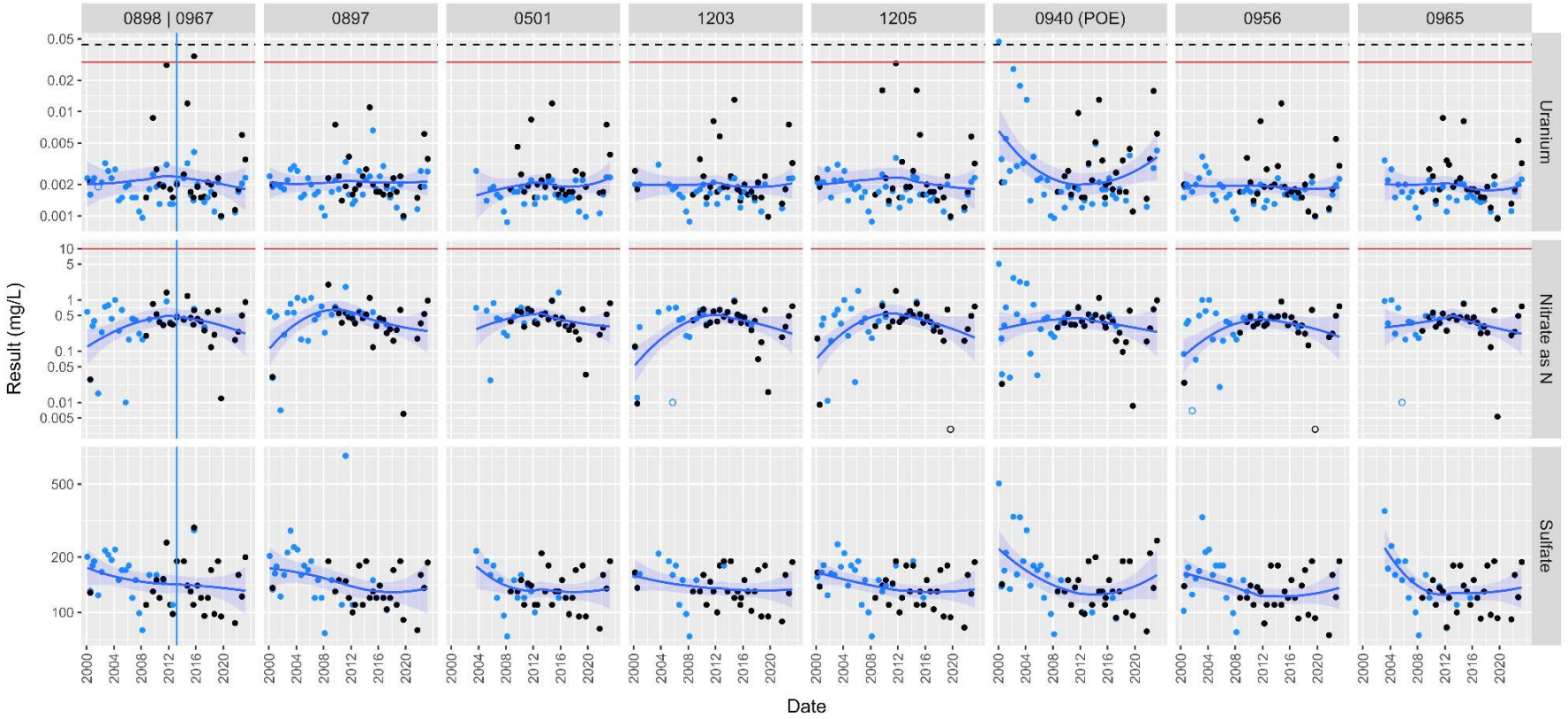
Figure 18. Shiprock Site Floodplain Alluvium Bulk Plume Metrics for Sulfate, 2006–2023

3.5 San Juan River Monitoring

In terms of the number of locations and evaluation of remediation progress, the focus of LM's monitoring is on groundwater (the focus of this annual report). However, potential impacts to the San Juan River are also monitored because the river is a point of exposure for both human and ecological receptors. DOE regularly monitors eight San Juan River locations, including one upgradient background location (Figure 2; Figure 19.). Sampling point 0940, just north of pumping wells 1089 and 1104, was identified as a point of exposure in the GCAP because of early exceedances of the Navajo Nation surface water standard and its location in an area where contamination in the alluvial aquifer was most likely to discharge to the river (DOE 2002).

Figure 19. plots concentrations of uranium, nitrate, and sulfate measured since 2000 at all eight San Juan River monitoring locations. In this figure, data are ordered from farthest upstream to farthest downstream from the site. Apart from the early (1999–2000) exceptions for uranium noted above, concentrations of the primary COCs in San Juan River samples remain consistent with those measured at the corresponding upstream background location. The spikes in COC concentrations in 2015, most evident at the upstream location, are likely attributable to impacts from the August 5, 2015, Gold King Mine spill (DOE 2017).

Long-term monitoring of the San Juan River adjacent to the floodplain continues to indicate that the Shiprock site poses no adverse risk to human health or the environment, provided that the Navajo Nation Water Code continues to restrict the use of shallow groundwater near the site.



- Total (unfiltered) • Dissolved (filtered)
- Analytical result below the detection limit
- LOESS locally weighted regression line and corresponding 95% pointwise confidence interval
- - - UMTRCA standard (not necessarily appropriate for application to surface water)
- Navajo Nation Surface Water Quality Standard (standard for nitrate is the same as the UMTRCA standard)
  https://www.epa.gov/sites/production/files/2014-12/documents/navajo-tribe.pdf
- November 2014 change in upstream San Juan River sample location

Notes: Plots are ordered from farthest upstream (left) to farthest downstream (right) from the site (locations shown in Figure 2 and Figure 21). The vertical line in the first (0898 | 0967) plot denotes the change in the upstream (background) sample location in 2014; sampling at location 0898 (Figure 2) was discontinued because it was difficult to access.
Location 0940 was identified as a point of exposure in the GCAP because of early (1999–2000) exceedances of the UMTRCA and Navajo Nation water quality standards for uranium. LM also monitors a stilling well (0899). Results are not shown here because this location has only been sampled since 2009 and results have been consistent with those measured at upgradient location 1205.
Abbreviation: POE = point of exposure

Figure 19. Uranium, Nitrate (as N), and Sulfate Concentrations in Samples from San Juan River Monitoring Locations, 2000–2023

4.0 Terrace System Subsurface Conditions

4.1 Overview

The discussion of current subsurface conditions on the terrace is based on the collection and analysis of groundwater-level data through March 2023. Analyses of water-level trends (detailed plots in Appendix D) 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 the terrace monitoring wells shown in Figure 2.

In recent years, LM has observed that nonmill-related sources to terrace groundwater appear to have influenced water quality, levels, and flow (DOE 2022a). Potential sources include (1) infiltration of surface runoff; (2) domestic water use, including leaking utilities; (3) infiltration of water discharged from artesian well 0648; and (4) leach fields from residential properties and the Navajo Engineering and Construction Authority (NECA) yard. Groundwater mounding in the residential area near well 0835 (note water level changes in Appendix D) along with continued discharges into Bob Lee Wash (well 1067) and seeps 0425 and 0426 are apparent. Geochemical analysis of samples collected from wells 0835, 0828 (dry in 2023), and others on the terrace indicate that groundwater is locally mixed with either Animas River or San Juan River water (DOE 2022a). These findings will be investigated further as part of current efforts to revise the GCAP (DOE 2022c).

4.2 Terrace Groundwater Elevation Trends

Approximately 945,000 gallons of groundwater were pumped from the terrace extraction wells during this reporting period (April 2022 through March 2023; Table 4). As of April 1, 2023, the cumulative volume of water removed from the terrace (excluding Bob Lee Wash and Many Devils Wash) was about 23.6 million gallons (Table 4). Groundwater elevation data from the terrace collected during the March 2023 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). Changes in groundwater elevations for terrace monitoring wells screened solely or partially in the alluvium are shown in Figure 20. Of the 27 terrace alluvium water-level measurements collected in both March 2023 and the baseline period (2000–2003), all but two (wells 1049 and 1068) showed declining levels. The maximum decrease (9.8 ft) was measured in well 0836, in the northwest portion of the terrace (Figure 20). The average water-level change measured in terrace alluvial wells through this reporting period was a decrease of about 3.1 ft.

Eleven alluvial west terrace wells (0816, 0828, 0832, 1048, 1060, 1067, 1069, 1120, 1122, and recently installed wells 9022 and 9024) were dry during the March 2023 sampling event. Most of these wells have been consistently dry for at least a decade as shown in the hydrographs provided in Appendix D. As shown in Figure 21, many seeps on the west terrace continue to be dry; some have been dry since 2008. Figure 22 plots groundwater elevations in terrace wells, showing contours for both baseline (March 2003) and current (March 2023) periods.

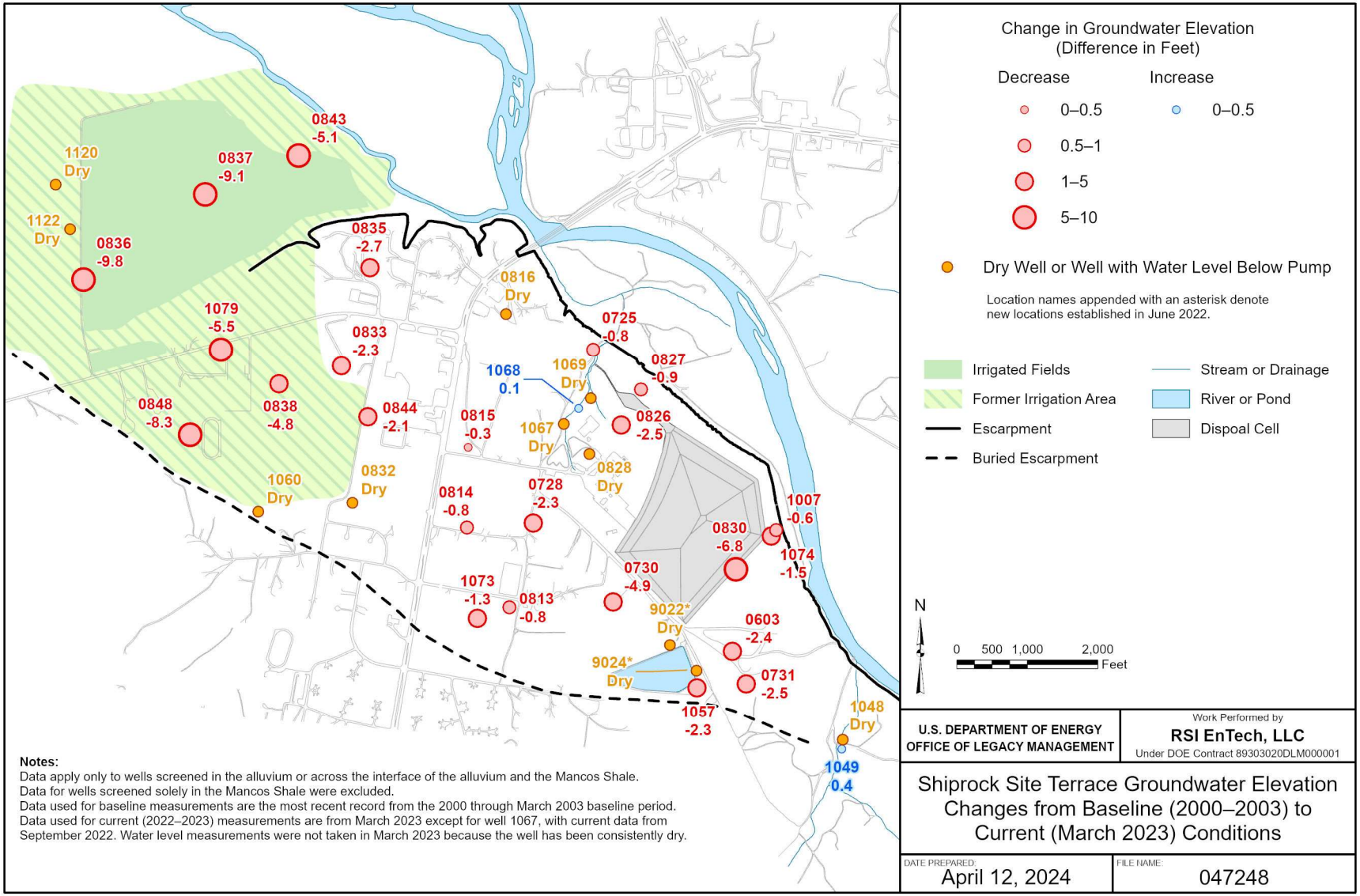
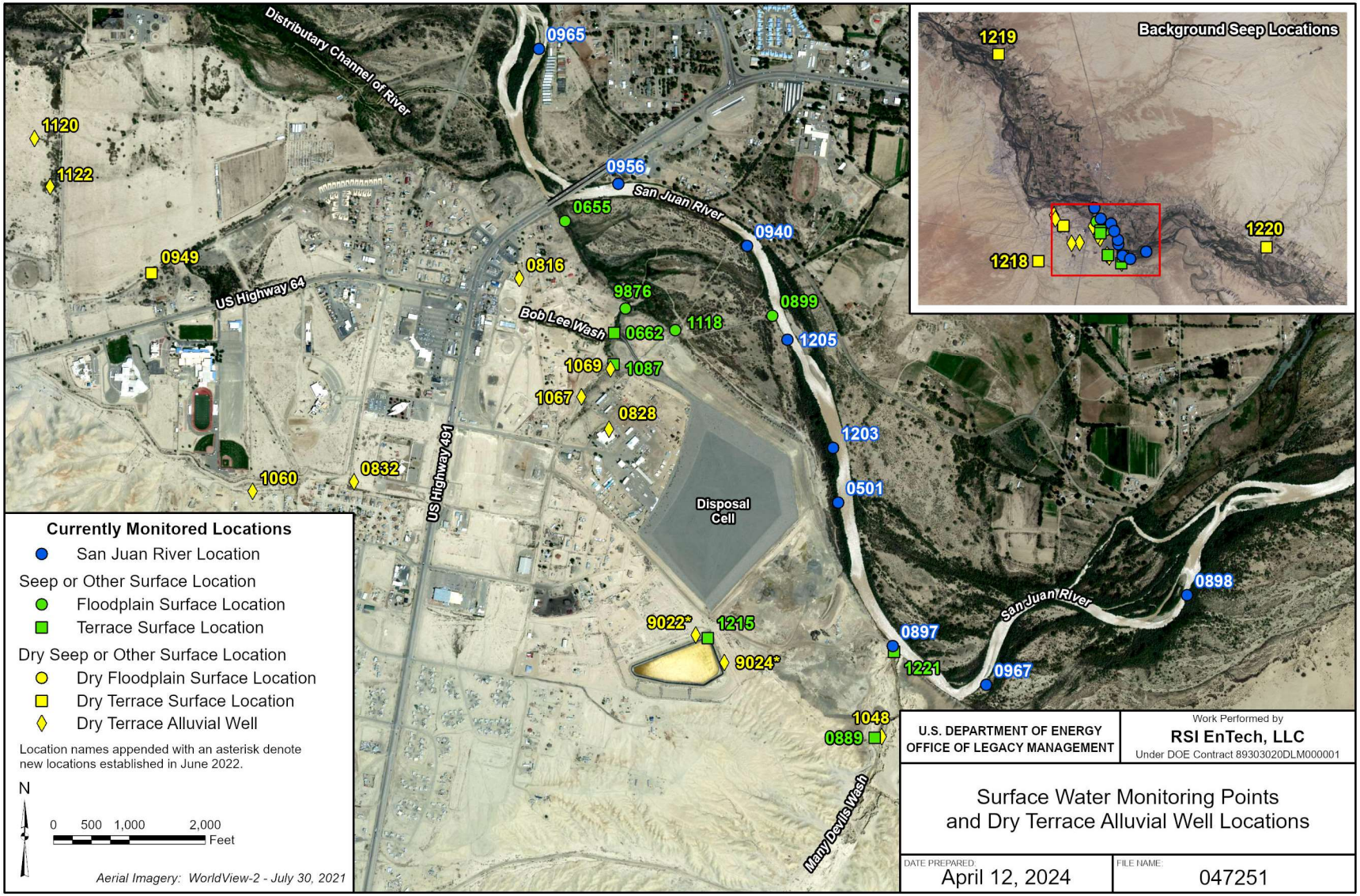
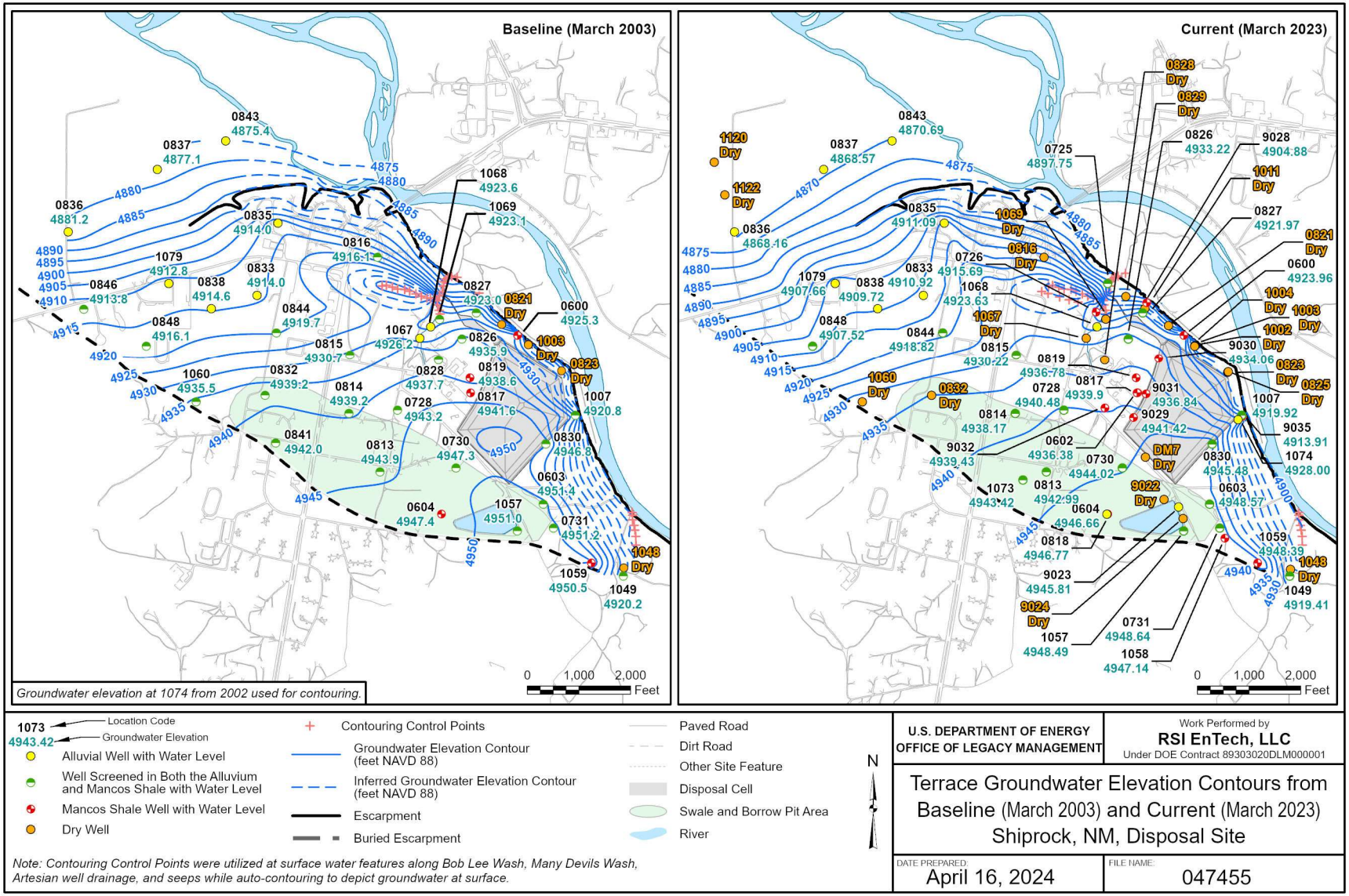


Figure 20. Shiprock Site Terrace Groundwater Elevation Changes: Baseline (2000–2003) Versus Current (March 2023) Conditions



Notes: Surface location 0898 (farthest upgradient San Juan River location) is no longer sampled because it was difficult to access. It was replaced by location 0967 in 2014. In this figure, references to dry surface water or alluvial well locations correspond only to this (2022–2023) reporting period.

Figure 21. Current Surface Water Monitoring Locations at the Shiprock Site
(Locations of Current Terrace Alluvial Dry Wells Also Shown to Allow Comparison with Dry Seep Locations)



Notes: Previous annual reports included an analysis of changes in saturation thickness (e.g., Figure 28 in DOE 2023a). This analysis was discontinued in this report because the previous evaluations only addressed the overlying alluvium and did not account for the weathered Mancos Shale. Also, that analysis, while an important component of LM's ongoing GCAP investigations (DOE 2022c), is not necessarily germane to this performance evaluation.

Figure 22. Terrace Water Elevation Contours: March 2003 (Baseline) and Current (March 2023)

5.0 Performance Summary

This section summarizes the findings of the most recent (April 2022 through March 2023) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the 20th year of active groundwater remediation. Since April 2017, when LM temporarily suspended pumping at most Shiprock site treatment system locations because of the deteriorating evaporation pond liner, LM's approach has been to maintain a balance of pumping enough water to ensure that the evaporation pond sediments remain covered while remediating as much as possible in accordance with the compliance strategy.

From April 2022 through March 2023, approximately 11.2 million gallons of extracted groundwater were pumped to the evaporation pond. The bulk of this total volume (10.2 million gallons, or 91.5%) of the influent liquids entering the pond during the current reporting period was from the floodplain. Pumping of terrace extraction wells 0818 and 1095 and the Bob Lee Wash drain (945,000 gallons) accounted for most of the remaining extraction volume. Since DOE began active remediation in March 2003, about 56.2 million gallons have been extracted from the terrace and 191.2 million gallons have been extracted from the floodplain, yielding a total cumulative volume of approximately 247.5 million gallons of groundwater pumped to the evaporation pond from all sources. Total cumulative groundwater contributions are 23% from the terrace and 77% from the floodplain.

The estimated masses of the primary COCs removed from the floodplain and terrace during this performance period were: 18.4 lb uranium; 5868 lb nitrate (as N); and 320,209 lb sulfate. 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. Corresponding cumulative masses, representing the COC masses removed since the onset of remediation, are (rounded) 954 lb uranium; 419,000 lb nitrate (as N); and 12.2 million lb of sulfate.

In terms of spatial extent and temporal trends of COCs, results from the 2022–2023 semiannual sampling are consistent with LM's reporting in the last decade. In general, uranium, sulfate, and nitrate concentrations measured in floodplain alluvial wells this reporting period are similar to previous results. Relative to baseline conditions, statistically significant decreases in contaminant concentrations are apparent in most wells for all the primary COCs. This is most evident for nitrate, as the extent of the plume is much smaller and currently generally limited to the base of the escarpment. Despite the measurable reduction in concentrations relative to baseline conditions, many wells now have asymptotic uranium concentration trends. Consistent with previous annual reports, COC concentrations in samples collected from the San Juan River continue to be below established benchmarks and comparable to upstream locations.

Currently, there are no concentration-driven performance standards for the terrace system because the compliance strategy is active remediation to eliminate exposure pathways at escarpment seeps and at Bob Lee Wash. However, as a best management practice, contaminant concentrations are measured at each extraction well, drain, and seep and at select monitoring wells across the site. Groundwater levels in the majority of terrace alluvial wells remain low relative to those measured during the baseline period (average decrease of 3.1 ft). Eleven alluvial terrace wells were dry during this reporting period, as were several seeps that have been dry since 2008.

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Appendix A

2022–2023 Semiannual Sampling Event Summary

Preface

This appendix summarizes information documented in trip reports prepared following the September 2022 and March 2023 sampling events. Sample locations are shown in Figure 2 in the main body of this report.

Table A.1. Planned Versus Sampled Location Summary

Area	Sample Type	September 26–29, 2022, Sampling Event		March 27–31, 2023, Sampling Event[a]	
		Planned Locations	Sampled Locations	Planned Locations	Sampled Locations
Floodplain	Monitoring and extraction wells	59	57	59	58
	Newly installed monitoring wells[a]	18	15	18	17
	Surface water[a]	12	11	12	12
Terrace	Monitoring and extraction wells	66	51	65	46
	Newly installed monitoring wells[a]	9	7	11	8
	Surface water	8	4	8	4
Totals:		**172**	**145**	**173**	**145**

Note:
[a] In June and July of 2022, 27 new wells were installed at the site following recommendations documented in the GCAP Work Plan (DOE 2022c); detailed rationales are provided in Appendix B of that plan. A new surface location, 9876, was also established at the base of Bob Lee Wash on the floodplain.

General observations regarding wells no longer sampled:

- 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.
- Because it is damaged, well 0841—west of U.S. Highway 491 adjacent to the buried escarpment—is scheduled for abandonment.

Table A-2. Locations Not Sampled in September 2022 or March 2023 and Reason

Area	Location Type	Location	Zone of Completion	September 2022	March 2023	Reason
Floodplain	Monitoring Well	0734	AL	X	X	Dry or insufficient water
		0773	AL	X		
		1144*	KM	X		
		1147*	AL	X	X	
		1158*	KM	X		
	Surface Location	0655	–	X		Dry
Terrace	Monitoring Well	0730	AL-KM	X	X	Dry or insufficient water
		0819	KM		X	
		0821	KM	X	X	
		0823	KM	X	X	
		0825	KM		X	
		0826	AL-KM		X	
		0829	KM	X	X	
		0832	AL-KM	X	X	
		1002	KM	X	X	
		1003	KM	X	X	
		1004	KM	X	X	
		1011	KM	X	X	
		1048	AL-KM	X	X	
		1060	AL-KM	X	X	
		1069	AL-KM	X	X	
		1120	AL	X	X	
		1122	AL	X	X	
		9022*	AL	X	X	
		9024*	AL	X	X	
		DM7	KM	X	X	
	Extraction Well	1095	AL		X	Pump non-operational; inaccessible with bailer
	Surface Location	0949	–	X	X	Dry
		1218	–	X	X	
		1219	–	X	X	
		1220	–	X	X	

* Location names appended with an asterisk denote new locations established in June–July 2022.

Abbreviations:

– = not applicable

AL-KM = well screened in both the alluvium and the Mancos Shale

KM = Mancos Shale

X = planned but not sampled

Appendix B

Historical Groundwater Extraction Volumes and Contaminant Masses Removed

Preface

This appendix documents the historical annual volumes and contaminant masses (uranium, nitrate, and sulfate) extracted from each floodplain and terrace treatment location, supplementing the information provided in Section 2.0 of the main report.

Except for the very early phases of remediation (2003–2004), all extraction volumes documented in this appendix are from LM's SOARS remote monitoring program. Environmental and operational data are collected by dataloggers at each Shiprock site treatment system location and transmitted and warehoused real-time into LM's AQUARIUS database. Along with flow rates (used to calculate extraction volumes), water levels, temperature, and (at some locations) specific conductivity are also measured.

Corrections to this database—for example, to account for field-related interferences or instrument (e.g., flowmeter) malfunctions—are made regularly and at times are applied retroactively. Cumulative volumes and masses presented in this appendix are since 2003, the onset of active remediation. Some early volumes are based on manual records from 2003–2005, prior to the inception of the SOARS system. In the following tables, "Year" denotes the beginning of the reporting year, which for the Shiprock site begins April 1 and ends March 31 of the following year. For example, Year 2022 corresponds to the April 1, 2022, through March 31, 2023, performance period.

Table B-1. Floodplain Treatment System Extraction Volumes, 2003 Through March 2023

Year	1077	1089	1104	1109	1110	1118	Total	Total (MG)
2003	305,131	2,512,391	0	0	0	0	2,817,522	2.8
2004	268,588	2,927,742	0	0	0	0	3,196,330	3.2
2005	238,730	2,620,878	212,124	0	0	0	3,071,732	3.1
2006	0	2,065,692	874,837	6,912,407	3,100,590	333,958	13,287,484	13.3
2007	0	3,330,061	1,079,221	8,857,038	2,749,047	451,732	16,467,099	16.5
2008	0	3,192,686	847,650	8,475,174	4,262,356	206,509	16,984,376	17
2009	0	3,069,562	297,693	2,296,565	3,201,841	188,568	9,054,231	9.1
2010	0	3,028,407	651,324	1,880,885	2,774,643	265,820	8,601,079	8.6
2011	0	2,285,358	967,344	3,587,402	4,661,069	211,989	11,713,162	11.7
2012	0	2,323,967	480,661	2,285,837	4,355,000	226,890	9,672,354	9.7
2013	0	3,115,035	818,811	3,245,549	5,641,409	290,519	13,111,323	13.1
2014	0	2,261,875	731,229	3,047,738	3,659,725	265,722	9,966,289	10
2015	0	2,901,442	646,893	4,080,293	3,792,394	341,694	11,762,715	11.8
2016	0	3,111,526	586,732	6,424,954	5,153,563	142,845	15,419,621	15.4
2017	0	208,592	64,175	442,749	530,126	21,781	1,267,422	1.3
2018	0	20,797	3,772	4,715,158	2,448,377	0	7,188,103	7.2
2019	0	45	0	4,708,866	3,946,062	2	8,654,974	8.7
2020	0	2,447,090	0	5,583,428	2,083,524	0	10,114,043	10.1
2021	0	1,774,824	70,394	4,308,107	2,513,979	0	8,667,305	8.7
2022	0	2,953,695	457,123	3,589,743	3,210,211	0	10,210,772	10.2
Total	812,449	46,151,665	8,789,983	74,441,893	58,083,916	2,948,029	191,227,936	191.2

Notes:
"Year" denotes the beginning of the reporting year. For example, Year 2023 corresponds to the April 1, 2022, through March 31, 2023, performance period. The extraction volumes listed above support summaries provided in Table 5 of the main report. In this and subsequent Appendix B tables, total volumes (and masses) may differ slightly from the sum of preceding rows because of rounding.

Abbreviation: MG = million gallons

Table B-2.Terrace Treatment System Extraction Volumes, 2003 Through March 2023

Year	0818	1070	1071	1078	1091	1092	1093	1094	1095	1096	1087	1088	Total	Total (MG)
2003	770,697	246,641	50,074	423,626	57,467	46,144	72,591	10,819	0	0	2,386,022	207,674	4,271,755	4.3
2004	544,334	102,799	12,054	196,277	39,092	67,179	93,945	4809	0	0	1,835,174	365,594	3,261,257	3.3
2005	364,856	36,576	15,914	96,402	30,234	58,092	49,013	0	277,009	187,618	1,951,118	640,244	3,707,075	3.7
2006	373,387	20,315	6872	184,530	31,306	29,394	237,754	0	428,200	502,721	1,175,676	532,838	3,522,992	3.5
2007	215,115	8733	3284	221,937	14,476	17,030	485,209	0	329,028	329,719	1,134,630	202,653	2,961,814	3.0
2008	71,100	6885	948	169,004	189	13	396,466	0	260,163	266,534	1,207,919	155,169	2,534,391	2.5
2009	145,560	7627	325	136,059	6518	10	281,556	0	213,296	245,385	1,334,903	431,384	2,802,623	2.8
2010	79,417	9474	432	307,069	2886	322	533,724	0	213,738	217,101	1,985,662	413,384	3,763,208	3.8
2011	357,337	15,139	4181	400,007	9682	1602	301,575	0	218,031	222,719	1,265,372	311,677	3,107,321	3.1
2012	480,343	18,352	6952	582,965	4832	2,173	464,013	0	172,512	160,314	1,241,113	89,105	3,222,674	3.2
2013	526,953	10,050	5280	490,390	19,263	625	351,528	0	166,226	273,718	1,683,265	38,373	3,565,669	3.6
2014	405,861	10,413	3839	384,740	18,403	1217	492,404	0	157,175	170,711	1,667,581	0	3,312,343	3.3
2015	486,165	9240	8736	414,362	11,476	2	330,970	0	156,056	200,720	2,492,014	0	4,109,740	4.1
2016	436,692	12,825	5421	432,839	12,317	0	245,105	0	137,842	200,794	1,454,290	19	2,938,144	2.9
2017	33,493	2535	205	88,696	1775	0	108,498	0	16,183	17,712	1,839,249	41	2,108,387	2.1
2018	11,919	11	68	19,504	593	0	39,570	0	15,664	4318	1,856,913	0	1,948,560	1.9
2019	4269	8	25	36,802	336	0	173,257	0	19,381	301	1,174,945	0	1,409,325	1.4
2020	962,173	0	0	2778	0	0	0	0	1	106	312,239	0	1,277,297	1.3
2021	824,744	0	47	0	7	0	0	0	1	0	648,314	0	1,473,113	1.5
2022	283,225	0	556	0	0	0	152	0	25,575	0	635,402	0	944,910	0.9
Total	7,377,640	517,623	125,213	4,587,987	260,852	223,803	4,657,330	15,628	2,806,081	3,000,491	29,281,801	3,388,155	56,242,598	56.2

Notes:
"Year" denotes the beginning of the reporting year. For example, Year 2022 corresponds to the April 1, 2022, through March 31, 2023, performance period. The data in this table support summaries provided in Table 4 and Table 5 of the main report.

Abbreviation: MG = million gallons

Table B-3a. Floodplain Treatment System Uranium Masses Removed, 2003 Through March 2023

Year	1077	1089	1104	1109	1110	1118	Total
2003	5.27	31.5	0	0	0	0	36.8
2004	5.78	40.7	0	0	0	0	46.5
2005	5.78	25.2	4.6	0	0	0	35.5
2006	0	18.5	14.97	19.51	46.57	0.92	100.5
2007	0	23.3	11.59	8.87	34.44	1.52	79.8
2008	0	23.1	9.8	9.9	44.29	0.8	87.8
2009	0	20.2	2.86	4.98	29.26	1.03	58.4
2010	0	9.88	4.88	2.62	14.82	1.49	33.7
2011	0	4.96	6.62	3.74	37.34	1.16	53.8
2012	0	4.17	1.75	4.29	20.72	0.86	31.8
2013	0	5.33	2.6	6.57	19.07	1.18	34.7
2014	0	3.59	2.47	3.94	10.38	1.13	21.5
2015	0	4.6	1.94	21.79	13.29	1.16	42.8
2016	0	5.91	1.81	7.43	16.84	0.42	32.4
2017	0	0.23	0.11	1.48	2.77	0.07	4.65
2018	0	0.02	0	5.82	11.95	0	17.8
2019	0	0	0	5.82	23.38	0	29.2
2020	0	2.45	0	6.9	12.35	0	21.7
2021	0	1.75	0.11	1.53	8.96	0	12.4
2022	0	2.42	0.53	2.09	10.17	0	15.2
Total	**16.8**	**227.9**	**66.6**	**117.3**	**356.6**	**11.7**	**796.9**

Table B-3b. Floodplain Treatment System Nitrate (as N) Masses Removed, 2003 Through March 2023

Year	1077	1089	1104	1109	1110	1118	Total
2003	219	629	0	0	0	0	848
2004	457.3	1356	0	0	0	0	1813
2005	537.9	1071.7	318.6	0	0	0	1928
2006	0	473.2	766.6	4932.2	9056.5	139.3	15,368
2007	0	750.3	621.4	2624	5161.9	141.4	9299
2008	0	639.5	633.1	2617	6900.8	56.9	10,847
2009	0	338.1	84.5	1734.5	3072.9	53.5	5284
2010	0	121.9	199.2	999.1	1017.7	142.5	2481
2011	0	15.4	104.9	1392.1	3850.9	115	5478
2012	0	12.9	10.8	1831.3	1,762.7	102.2	3720
2013	0	29.4	17.6	1841.8	1459.5	142.2	3490
2014	0	45.5	15.6	1678.7	2137.9	140.8	4019
2015	0	46.4	6.1	9,875	506.4	146.9	10,581
2016	0	17.3	3	2461.1	1138.3	47.9	3668
2017	0	1.5	0.3	646.6	245.5	9.5	903.5
2018	0	0	0	2262.6	817.3	0	3080
2019	0	0	0	2259.6	4610.4	0	6870
2020	0	285.9	0	2679.3	2434.3	0	5400
2021	0	1.7	0.1	557.3	568.6	0	1128
2022	0	2.7	1.3	778.9	632.3	0	1415
Total	**1214.2**	**5838.6**	**2783.3**	**41,171**	**45,374**	**1238**	**97,619**

Table B-3c. Floodplain Treatment System Sulfate Masses Removed, 2003 Through March 2023

Year	1077	1089	1104	1109	1110	1118	Total
2003	36,604	263,910	0	0	0	0	300,514
2004	35,976	325,837	0	0	0	0	361,813
2005	43,830	273,403	33,635	0	0	0	350,868
2006	0	167,218	120,464	145,027	395,612	11,984	840,305
2007	0	208,745	81,140	52,480	252,452	19,024	613,841
2008	0	195,835	64,019	64,717	350,374	9,910	684,855
2009	0	172,912	19,875	30,665	200,404	10,858	434,714
2010	0	142,288	45,849	19,754	141,132	16,405	365,428
2011	0	96,314	67,408	25,448	282,013	13,268	484,452
2012	0	85,335	22,664	30,331	203,527	11,361	353,218
2013	0	111,783	38,266	45,097	221,275	15,153	431,575
2014	0	75,505	35,089	31,793	105,369	15,412	263,168
2015	0	106,540	32,122	143,017	170,904	17,537	470,120
2016	0	99,583	28,473	56,139	205,580	5949	395,723
2017	0	7050	2410	10,715	29,199	1109	50,483
2018	0	590	110	49,384	134,855	0	184,939
2019	0	2	0	49,318	279,917	0	329,237
2020	0	104,152	0	58,478	147,796	0	310,426
2021	0	50,878	2056	16,610	121,475	0	191,019
2022	0	74,072	12,818	19,113	133,416	0	239,419
Total	**116,410**	**2,561,953**	**606,398**	**848,086**	**3,375,300**	**147,970**	**7,656,117**

Table B-4a. Terrace Treatment System Uranium Masses Removed, 2003 Through March 2023

Year	0818	1070	1071	1078	1087	1088	1091	1092	1093	1094	1095	1096	Total
2003	0.804	0.279	0.079	0.467	13.401	0.285	0.054	0.043	0.072	0.004	0	0	15.488
2004	0.524	0.103	0.012	0.216	9.211	0.484	0.037	0.062	0.093	0.002	0	0	10.744
2005	0.426	0.037	0.013	0.109	9.607	0.988	0.03	0.058	0.049	0	0.123	0.157	11.597
2006	0.421	0.02	0.007	0.231	7.162	0.711	0.033	0.033	0.236	0	0.248	0.503	9.605
2007	0.215	0.008	0.002	0.278	7.054	0.271	0.015	0.017	0.445	0	0.176	0.316	8.797
2008	0.08	0.005	0.001	0.19	6.452	0.246	0	0	0.364	0	0.136	0.227	7.701
2009	0.117	0.006	0	0.17	6.851	0.72	0.007	0	0.317	0	0.087	0.225	8.5
2010	0.075	0.008	0	0.345	8.948	0.642	0.003	0	0.457	0	0.092	0.19	10.76
2011	0.403	0.011	0.005	0.434	5.702	0.429	0.009	0.001	0.289	0	0.091	0.162	7.536
2012	0.541	0.012	0.008	0.657	5.438	0.138	0.004	0.002	0.484	0	0.075	0.116	7.475
2013	0.572	0.007	0.006	0.532	6.251	0.056	0.018	0.001	0.199	0	0.071	0.203	7.916
2014	0.406	0.007	0.005	0.401	6.819	0	0.017	0.001	0.493	0	0.071	0.123	8.343
2015	0.487	0.006	0.01	0.398	7.487	0	0.01	0	0.304	0	0.063	0.139	8.904
2016	0.454	0.01	0.007	0.435	4.751	0	0.011	0	0.229	0	0.064	0.156	6.117
2017	0.048	0.002	0	0.078	6.677	0	0.002	0	0.149	0	0.007	0.013	6.976
2018	0.013	0	0	0.018	7.981	0	0.001	0	0.063	0	0.004	0.004	8.084
2019	0.004	0	0	0.034	3.53	0	0	0	0.239	0	0.006	0	3.813
2020	0.883	0	0	0.003	0.938	0	0	0	0	0	0	0	1.824
2021	0.778	0	0	0	2.976	0	0	0	0	0	0	0	3.754
2022	0.326	0	0	0	2.874	0	0	0	0	0	0.011	0	3.211
Total	**7.577**	**0.521**	**0.155**	**4.996**	**130.11**	**4.97**	**0.251**	**0.218**	**4.482**	**0.006**	**1.325**	**2.534**	**157.145**

Table B-4b. Terrace Treatment System Nitrate (as N) Masses Removed, 2003 Through March 2023

Year	0818	1070	1071	1078	1087	1088	1091	1092	1093	1094	1095	1096	Total
2003	12,220	2038	1045	2581	7168	1196	767	616	1551	497	0	0	29,679
2004	8177	712	171	1261	3905	2014	538	869	2007	28	0	0	19,682
2005	4872	253	312	579	6106	3820	416	824	1047	0	4577	783	23,591
2006	5142	115	48	1024	4023	2512	536	343	5079	0	5539	2853	27,214
2007	2603	59	82	1528	3930	956	181	177	10,123	0	3611	1816	25,066
2008	576	50	16	1051	4335	1017	3	0	9595	0	3908	1412	21,963
2009	1039	47	3	715	3509	2520	57	0	5874	0	2937	1300	18,002
2010	576	55	4	1531	5990	2265	26	3	9933	0	3059	1140	24,581
2011	2281	83	22	1886	3221	1600	97	10	4908	0	2911	1069	18,088
2012	3187	106	45	2895	2952	524	42	12	8906	0	2663	809	22,141
2013	4398	53	33	2026	3442	125	147	6	660	0	2289	1462	14,640
2014	2388	51	19	1718	2992	0	114	5	6712	0	2230	776	17,005
2015	2698	44	38	1452	4471	0	66	0	5800	0	2214	846	17,630
2016	1950	54	22	1367	1778	0	60	0	2823	0	1800	825	10,680
2017	203	14	1	292	4375	0	11	0	1675	0	304	99	6973
2018	59	0	0	53	3564	0	3	0	677	0	242	21	4620
2019	23	0	0	101	1961	0	2	0	1330	0	275	1	3694
2020	5139	0	0	8	521	0	0	0	0	0	0	0	5668
2021	3906	0	0	0	2348	0	0	0	0	0	0	0	6254
2022	2036	0	12.7	0	1978	0	0	0	3.4	0	422.6	0	4453
Total	**63,471**	**3,734**	**1,876**	**22,069**	**72,569**	**18,548**	**3,065**	**2,865**	**78,704**	**525**	**38,982**	**15,214**	**321,622**

Table B-4c. Terrace Treatment System Sulfate Masses Removed, 2003 Through March 2023

Year	0818	1070	1071	1078	1087	1088	1091	1092	1093	1094	1095	1096	Total
2003	72,473	32,840	1,573	49,645	162,394	29,057	5,897	5,299	3,108	190	0	0	362,476
2004	54,482	13,680	532	23,413	116,949	52,925	4,035	7,528	4,022	122	0	0	277,687
2005	39,583	4,867	491	11,263	127,820	104,190	3,028	6,302	2,098	0	10,426	26,618	336,687
2006	34,277	6,612	659	20,020	87,813	73,371	2,443	3,189	10,179	0	26,265	60,833	325,660
2007	21,543	1,093	103	25,930	85,220	30,442	1,450	1,691	23,486	0	18,946	37,147	247,051
2008	8,307	948	95	21,156	91,229	25,899	17	1	17,701	0	13,787	32,253	211,393
2009	14,577	1,018	17	16,464	88,008	82,801	762	1	14,686	0	9,790	28,670	256,794
2010	9,676	1,206	38	36,261	102,492	65,202	324	29	26,591	0	8,901	25,909	276,628
2011	37,276	1,895	471	45,066	78,672	49,420	1,050	174	14,471	0	8,552	25,092	262,140
2012	54,117	2,221	754	63,246	75,092	13,757	544	263	19,362	0	6,766	18,730	254,853
2013	61,567	1,342	617	59,341	89,904	5,604	2,331	81	5,574	0	7,214	34,264	267,838
2014	44,032	1,303	400	41,740	86,283	0	2,073	142	35,888	0	6,690	19,945	238,497
2015	56,801	1,272	1,094	50,141	107,104	0	1,580	0	20,163	0	7,488	26,801	272,446
2016	51,386	1,621	645	45,875	61,836	3	1,511	0	17,755	0	6,476	25,052	212,160
2017	4,053	307	23	9,623	94,398	7	200	0	6,429	0	587	2,217	117,843
2018	1,492	1	8	2,116	114,675	0	74	0	2,146	0	444	577	121,534
2019	606	1	3	3,993	59,813	0	45	0	14,267	0	679	43	79,449
2020	136,505	0	0	301	15,895	0	0	0	0	0	0	15	152,717
2021	94,294	0	6	0	51,074	0	1	0	0	0	0	0	145,376
2022	39,000	0	18.0	0	40,804	0	0	0	7	0	963	0	80,790
Total	**836,045**	**72,229**	**7,547**	**525,593**	**1,737,475**	**532,678**	**27,366**	**24,700**	**237,932**	**312**	**133,976**	**364,165**	**4,500,019**

Appendix C

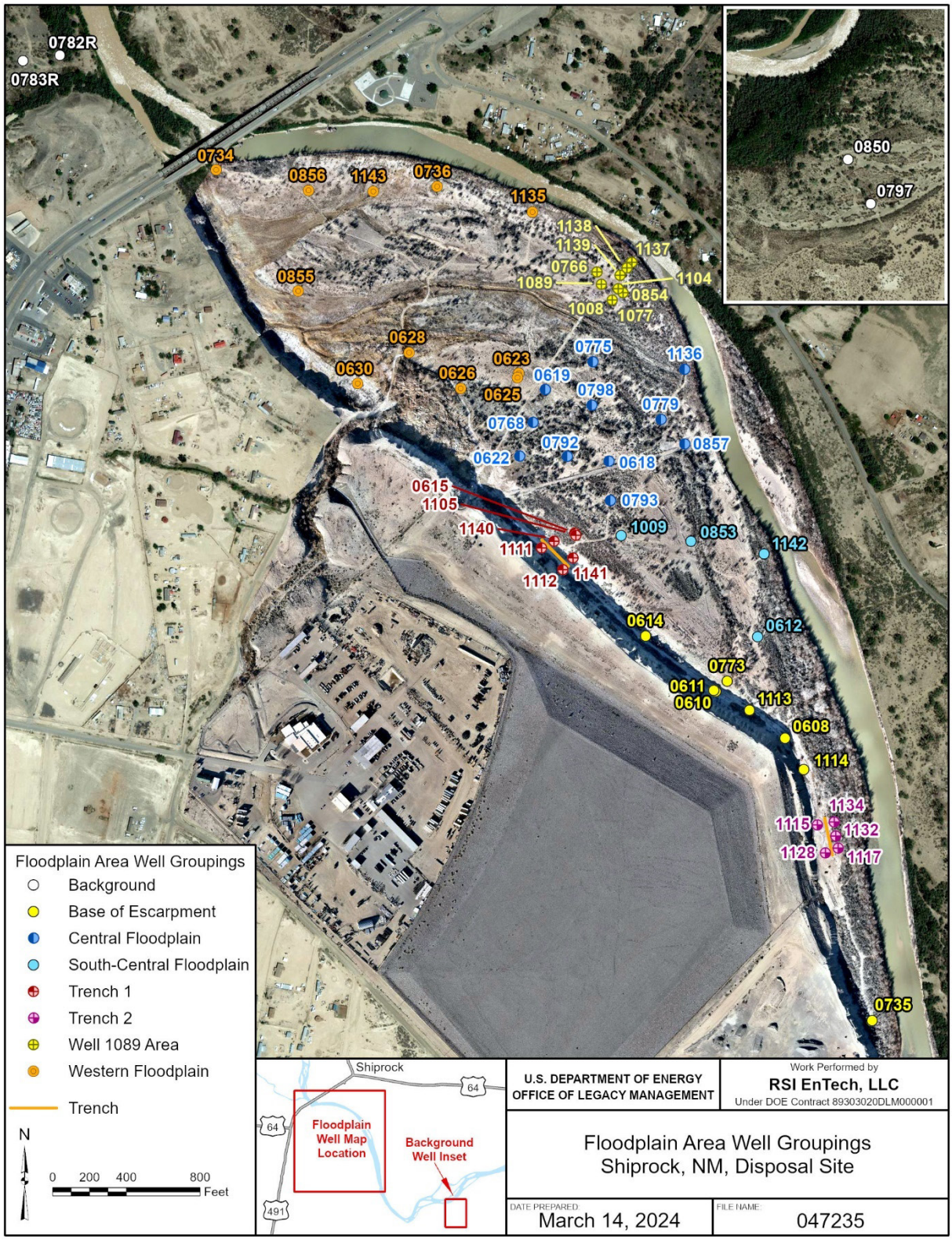
Mann-Kendall Trend Analysis Results and Corresponding Time-Concentration Graphs for Floodplain Alluvial Wells

Preface

This appendix documents the results of Mann-Kendall trend analyses performed to determine whether concentration trends for the primary COCs in floodplain alluvial monitoring wells are upward, stable (no trend), or declining. To facilitate comparison with the corresponding Mann-Kendall trend results, for each COC, corresponding time-concentration plots follow each table. In each of these figures, wells are listed in alphabetical order and individual plot labels denote the general region of the floodplain using the groupings shown in Figure C-1.[1] In each plot, both the average and most recent concentration are identified in the upper-left and -right margins of the plot, respectively. To address concerns about increases in COC concentrations potentially resulting from the April 2017 to July 2018 pumping cessation, these plots also show the linear trend line for the 2017–2023 period.

For wells with concentrations above the corresponding remedial goal (Table 2 of main report) and identified as having declining trends, linear regression of the log-transformed concentration data was performed to determine when that concentration is expected to decline below the standard. Some caution is warranted in interpreting these predictions because of the recent stabilization of contaminant concentrations evident in many wells. For example, although the uranium concentration in well 1008 was predicted to reach the 0.044 mg/L MCL by 2023 (this reporting period), it is clear from the trends shown in the corresponding time-concentration plot figure (Figure C-2) that this prediction is not likely to be borne out.

[1] Monitoring well 0608 is installed north of Trench 2, centrally located between wells 1113 and 1114 along the base of the escarpment (Figure C-1). Although screened in the Mancos Shale, well 0608 is included in time-concentration plots because of its shallow depth (screened 10–15 ft below ground surface) and elevated concentrations relative to other floodplain wells screened in the Mancos Shale. Data from this well were not used to establish contours of COC concentrations in the main report. Well 0608 is routinely sampled, unlike colocated well 0609, which is partially screened in the alluvial aquifer at about the same location. A previous comparison of water-level measurements at wells 0608 and 0609 indicated that, although differing at times by as much as 0.5 ft, they generally tracked each other and were typically about the same value (DOE 2011b).



Notes: The spatial groups shown here are used as the basis for subsequent time-concentration plots. Although not identified as such in the GCAP (wells 0797 and 0850 have been historically used as background wells [DOE 2002]), wells 0782R and 0783R are now considered candidate background locations for floodplain wells geochemically influenced by the San Juan River (DOE 2022b).

Figure C-1. Shiprock Site Floodplain Well Groupings

Table C-1. Uranium Concentration Trends in Floodplain Monitoring Wells and MCL Attainment Predictions: 2006–2023 (page 1 of 2)

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Most Recent Uranium Concentration (mg/L)	Mann-Kendall Trend Analysis Results		Linear Regression Results					
							Half-Life (years)			Year Remedial Goal of 0.044 mg/L Reached		
					Trend	Tau Value	Trend Line	Lower 95% CI	Upper 95% CI	Trend Line	Lower 95% CI	Upper 95% CI
0608	3/9/2006	3/29/2023	32	0.447	Decreasing	−0.84	10.42	8.33	13.90	2056	2048	2070
0610	9/11/2007	3/29/2023	27	0.599	Decreasing	−0.49	13.46	8.84	28.13	2072	2053	2134
0611	9/15/2009	3/29/2023	25	0.011	None	−0.15	Not applicable, concentration less than remediation goal					
0612	9/11/2007	3/30/2023	28	0.0211	None	−0.25	Not applicable, concentration less than remediation goal					
0614	3/9/2006	3/30/2023	34	0.615	Decreasing	−0.84	7.05	6.10	8.34	2047	2043	2054
0615	3/9/2006	3/30/2023	33	0.654	Decreasing	−0.44	7.57	5.27	13.44	2045	2036	2070
0618	3/8/2006	3/28/2023	34	0.363	Decreasing	−0.79	4.24	3.60	5.14	2032	2029	2036
0619	3/8/2006	3/30/2023	34	0.125	Decreasing	−0.42	7.60	5.25	13.73	2027	2023	2038
0622	9/12/2007	3/30/2023	27	0.0243	Decreasing	−0.53	Not applicable, concentration less than remediation goal					
0623	9/10/2008	3/29/2023	28	0.0165	Decreasing	−0.72	Not applicable, concentration less than remediation goal					
0625	3/12/2009	3/29/2023	26	0.0117	Decreasing	−0.74	Not applicable, concentration less than remediation goal					
0626	9/13/2007	3/30/2023	30	0.00674	Decreasing	−0.43	Not applicable, concentration less than remediation goal					
0628	9/13/2007	3/30/2023	28	0.0463	None	0.02	Not applicable, no trend					
0630	9/13/2007	3/30/2023	30	0.186	None	0.24	Not applicable, no trend					
0734	3/15/2006	9/30/2014	17	0.11	None	0.09	Not applicable, no trend					
0735	3/9/2006	3/28/2023	35	0.0955	None	−0.12	Not applicable, no trend					
0736	3/10/2006	3/29/2023	29	0.0224	Decreasing	−0.51	Not applicable, concentration less than remediation goal					
0766	3/25/2010	3/28/2023	23	0.123	Decreasing	−0.56	8.87	6.17	15.82	2032	2027	2045
0768	3/12/2009	3/30/2023	26	0.103	Decreasing	−0.42	5.18	3.39	10.98	2027	2023	2040
0773	3/10/2009	3/29/2023	23	0.152	Decreasing	−0.34	13.26	7.21	82.31	2053	2035	2250
0775	3/11/2009	3/30/2023	25	0.0989	Decreasing	−0.59	7.21	4.94	13.33	2028	2024	2039
0779	3/11/2009	3/30/2023	27	0.381	Decreasing	−0.47	8.25	5.35	17.96	2052	2039	2095
0782R*	9/16/2008	3/28/2023	27	0.0083	Increasing	0.28	Not applicable, concentration less than remediation goal					
0783R*	9/17/2008	3/28/2023	27	0.0106	None	0.17	Not applicable, concentration less than remediation goal					
0792	9/12/2007	3/30/2023	30	0.145	Decreasing	−0.47	4.62	2.99	10.15	2026	2022	2039
0793	9/12/2007	3/30/2023	27	0.554	Decreasing	−0.49	9.40	6.67	15.91	2051	2041	2077
0797*	3/7/2006	3/29/2023	32	0.011	Decreasing	−0.38	Not applicable, concentration less than remediation goal					
0798	9/12/2007	3/30/2023	27	0.0836	Decreasing	−0.63	4.41	3.37	6.36	2027	2024	2032
0850*	3/7/2006	3/29/2023	32	0.0306	None	−0.17	Not applicable, concentration less than remediation goal					
0853	9/12/2007	3/30/2023	30	0.0618	None	0.11	Not applicable, no trend					
0854	9/17/2009	3/27/2023	25	0.143	Decreasing	−0.70	3.73	2.94	5.10	2028	2025	2032
0855	9/13/2007	3/29/2023	30	0.0696	Decreasing	−0.28	41.96					
0856	9/13/2007	3/29/2023	30	0.0356	Decreasing	−0.33	Not applicable, concentration less than remediation goal					
0857	9/12/2007	3/28/2023	27	0.657	Increasing	0.40	Not applicable, increasing trend					
1008	3/10/2006	3/27/2023	27	0.106	Decreasing	0.86	2.92	2.43	3.67	2023	2022	2025
1009	9/12/2007	3/30/2023	29	0.227	Decreasing	–0.61	11.83	8.56	19.13	2041	2034	2057
1089	3/14/2006	3/30/2023	33	0.0964	Decreasing	–0.82	4.51	3.89	5.38	2025	2024	2028
1104	3/14/2006	3/30/2023	32	0.118	Decreasing	–0.80	3.84	3.34	4.51	2027	2025	2029
1105	3/6/2007	3/30/2023	29	0.681	Decreasing	–0.53	6.06	4.57	8.98	2042	2035	2056
1111	3/7/2007	3/30/2023	29	0.405	Decreasing	–0.42	16.80	10.73	38.72	2082	2058	2170
1112	3/7/2007	3/30/2023	30	0.794	Decreasing	–0.51	11.76	8.34	19.97	2069	2053	2107
1113	3/6/2008	3/29/2023	27	0.525	Decreasing	–0.41	11.29	7.88	19.88	2058	2045	2090
1114	9/10/2007	3/29/2023	29	0.173	Decreasing	0.32	8.87	5.72	19.65	2042	2032	2074

Table C-1. Uranium Concentration Trends in Floodplain Monitoring Wells and MCL Attainment Predictions: 2006–2023
(page 2 of 2)

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Most Recent Uranium Concentration (mg/L)	Mann-Kendall Trend Analysis Results		Linear Regression Results					
							Half-Life (years)			Year Remedial Goal of 0.044 mg/L Reached		
					Trend	Tau Value	Trend Line	Lower 95% CI	Upper 95% CI	Trend Line	Lower 95% CI	Upper 95% CI
1115	9/10/2007	3/28/2023	31	0.321	None	−0.20	Not applicable, no trend					
1117	9/10/2007	3/28/2023	32	0.00334	None	−0.22	Not applicable, concentration less than remediation goal					
1128	3/23/2010	3/28/2023	24	0.869	Decreasing	−0.53	4.17	2.89	7.48	2033	2028	2046
1132	3/10/2009	3/28/2023	26	0.00564	Decreasing	−0.46	Not applicable, concentration less than remediation goal					
1134	3/10/2009	3/28/2023	25	0.00588	None	−0.20	Not applicable, concentration less than remediation goal					
1135	3/25/2010	3/29/2023	26	0.032	Decreasing	−0.68	Not applicable, concentration less than remediation goal					
1136	3/25/2010	3/30/2023	27	0.684	Increasing	0.53	Not applicable, increasing trend					
1137	3/25/2010	3/27/2023	25	0.272	None	−0.15	Not applicable, no trend					
1138	3/25/2010	3/27/2023	24	0.26	None	−0.25	Not applicable, no trend					
1139	3/25/2010	3/27/2023	26	0.197	None	−0.15	Not applicable, no trend					
1140	9/16/2009	3/30/2023	25	0.394	Decreasing	−0.62	6.43	4.86	9.52	2042	2035	2054
1141	9/16/2009	3/30/2023	25	0.351	Decreasing	−0.34	15.69	8.23	166.25	2075	2047	2642
1142	3/24/2010	3/30/2023	27	0.00883	Increasing	0.52	Not applicable, concentration less than MCL and increasing trend					
1143	3/26/2010	3/29/2023	26	0.0371	Decreasing	−0.55	Not applicable, concentration less than remediation goal.					

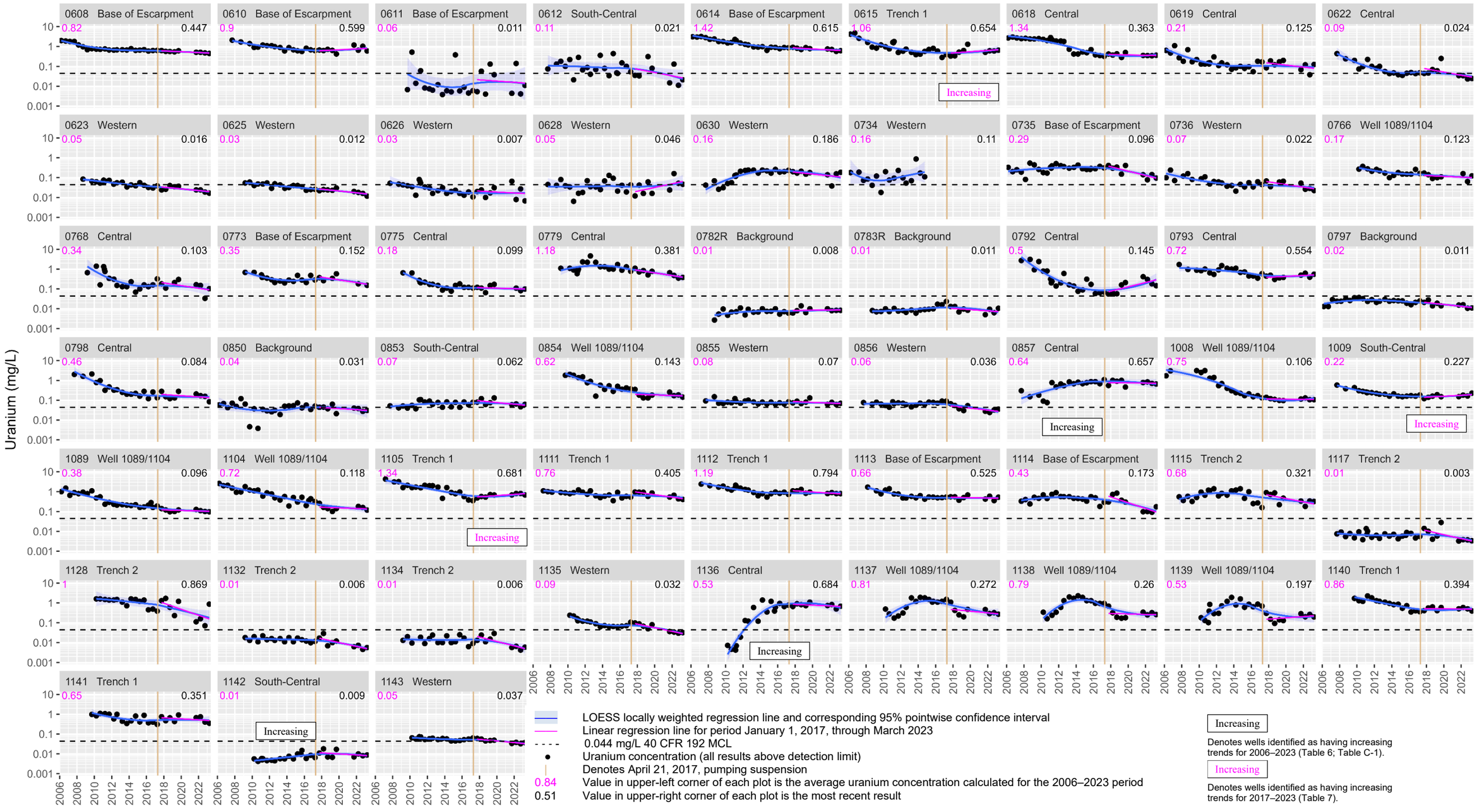
* Asterisk following well ID denotes current or proposed floodplain background locations.

Notes:

1. Both Mann-Kendall and linear regression trend analyses were run for all floodplain wells that are routinely monitored. An initial date of 2006 was used for most wells because that time frame corresponds to the installation of the floodplain trenches; only validated data were used in the analysis. Linear regression and half-life predictions were applied only to wells with significant decreasing concentration trends and with uranium concentrations exceeding the 0.044 mg/L standard.
2. Trend analyses were conducted at the 0.05 significance (or alpha) level using a two-sided test. The test statistic, Kendall's tau, is a measure of the strength of the association between two variables, with values always falling between −1 and +1. For wells identified as having statistically significant increasing concentration trends, results are shown in red font.
3. Detection frequencies for uranium in floodplain alluvial wells have been 100%.

Abbreviation:

CI = confidence interval



Note: In each plot label, the general area of the sample location is also identified, using the groupings shown in Figure C-1.

Figure C-2. Uranium Concentration Trends in Shiprock Site Floodplain Wells, 2006–2023

Table C-2. Nitrate (as N) Concentration Trends in Floodplain Monitoring Wells and MCL Attainment Predictions: 2006–2023 (page 1 of 2)

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Number of Nondetects	Most Recent Nitrate Concentration (mg/L)	Mann-Kendall Trend Analysis Results		Linear Regression Results					
								Half-Life (years)			Year Remedial Goal of 10 mg/L Reached		
						Trend	Tau Value	Trend Line	Lower 95% CI	Upper 95% CI	Trend Line	Lower 95% CI	Upper 95% CI
0608	3/9/2006	3/29/2023	32	0	101	Decreasing	−0.52	4.60	2.76	13.82	2025	2021	2048
0610	9/11/2007	3/29/2023	27	0	127	Decreasing	−0.35	12.82	6.84	102.30	2076	2047	2498
0611	9/15/2009	3/29/2023	25	0	0.035	None	−0.09	Not applicable, concentration less than remediation goal					
0612	9/11/2007	3/30/2023	28	21	<0.017	None	−0.12	Not applicable, concentration less than remediation goal					
0614	3/9/2006	3/30/2023	34	0	146	Decreasing	−0.59	4.96	3.84	6.99	2035	2030	2044
0615	3/9/2006	3/30/2023	33	2	0.018	Decreasing	−0.81	Not applicable, concentration less than remediation goal					
0618	3/8/2006	3/28/2023	34	0	0.69	Decreasing	−0.55	Not applicable, concentration less than remediation goal					
0619	3/8/2006	3/30/2023	34	21	0.048	None	−0.14	Not applicable, concentration less than remediation goal					
0622	9/12/2007	3/30/2023	27	14	<0.017	None	−0.21	Not applicable, concentration less than remediation goal					
0623	9/10/2008	3/29/2023	28	20	0.0708	None	−0.04	Not applicable, concentration less than remediation goal					
0625	3/12/2009	3/29/2023	26	14	0.0632	None	−0.03	Not applicable, concentration less than remediation goal					
0626	9/13/2007	3/30/2023	30	19	<0.017	None	−0.08	Not applicable, concentration less than remediation goal					
0628	9/13/2007	3/30/2023	28	22	<0.017	None	−0.02	Not applicable, concentration less than remediation goal					
0630	9/13/2007	3/30/2023	30	0	1.25	None	0.05	Not applicable, concentration less than remediation goal					
0734	3/15/2006	9/30/2014	14	3	4.0	None	0.23	Not applicable, concentration less than remediation goal					
0735	3/9/2006	3/28/2023	35	0	186	None	0.07	Not applicable, no trend					
0736	3/10/2006	3/29/2023	29	10	<0.017	None	−0.16	Not applicable, concentration less than remediation goal					
0766	3/25/2010	3/28/2023	23	7	0.41	None	−0.07	Not applicable, concentration less than remediation goal					
0768	3/12/2009	3/30/2023	26	16	0.023	None	0.03	Not applicable, concentration less than remediation goal					
0773	3/10/2009	3/29/2023	23	0	1.6	Decreasing	−0.34	Not applicable, concentration less than remediation goal					
0775	3/11/2009	3/30/2023	25	12	0.14	None	0.02	Not applicable, concentration less than remediation goal					
0779	3/11/2009	3/30/2023	27	6	<0.017	None	−0.19	Not applicable, concentration less than remediation goal					
0782R*	9/16/2008	3/28/2023	27	22	<0.017	None	−0.01	Not applicable, concentration less than remediation goal					
0783R*	9/17/2008	3/28/2023	27	21	<0.017	None	0.04	Not applicable, concentration less than remediation goal					
0792	9/12/2007	3/30/2023	30	12	<0.017	None	−0.07	Not applicable, concentration less than remediation goal					
0793	9/12/2007	3/30/2023	27	2	0.57	Decreasing	−0.54	Not applicable, concentration less than remediation goal					
0797*	3/7/2006	3/29/2023	32	7	<0.017	None	−0.01	Not applicable, concentration less than remediation goal					
0798	9/12/2007	3/30/2023	27	8	<0.017	None	−0.21	Not applicable, concentration less than remediation goal					
0850*	3/7/2006	3/29/2023	32	21	<0.017	None	−0.03	Not applicable, concentration less than remediation goal					
0853	9/12/2007	3/30/2023	30	17	0.045	None	0.05	Not applicable, concentration less than remediation goal					
0854	9/17/2009	3/27/2023	25	7	0.017	Decreasing	−0.59	Not applicable, concentration less than remediation goal					
0855	9/13/2007	3/29/2023	30	3	0.079	None	0.24	Not applicable, concentration less than remediation goal					
0856	9/13/2007	3/29/2023	30	21	<0.017	None	−0.22	Not applicable, concentration less than remediation goal					
0857	9/12/2007	3/28/2023	27	5	0.091	None	−0.10	Not applicable, concentration less than remediation goal					
1008	3/10/2006	3/27/2023	27	11	<0.017	Decreasing	−0.49	Not applicable, concentration less than remediation goal					
1009	9/12/2007	3/30/2023	29	15	5.85	None	−0.05	Not applicable, concentration less than remediation goal					
1089	3/14/2006	3/30/2023	32	0	0.11	Decreasing	−0.67	Not applicable, concentration less than remediation goal					
1104	3/14/2006	3/30/2023	31	0	0.36	Decreasing	−0.78	Not applicable, concentration less than remediation goal					
1105	3/6/2007	3/30/2023	29	4	0.06	Decreasing	−0.80	Not applicable, concentration less than remediation goal					
1111	3/7/2007	3/30/2023	29	0	7.35	None	−0.12	Not applicable, concentration less than remediation goal					
1112	3/7/2007	3/30/2023	30	0	196	Decreasing	−0.34	9.50	5.57	32.02	2056	2039	2153
1113	3/6/2008	3/29/2023	27	0	103	Decreasing	−0.33	8.89	5.23	29.71	2055	2039	2149
1114	9/10/2007	3/29/2023	29	0	4.38	None	−0.26	Not applicable, concentration less than remediation goal					

Table C-2. Nitrate (as N) Concentration Trends in Floodplain Monitoring Wells and MCL Attainment Predictions: 2006–2023 (page 2 of 2)

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Number of Nondetects	Most Recent Nitrate Concentration (mg/L)	Mann-Kendall Trend Analysis Results		Linear Regression Results					
									Half-Life (years)			Year Remedial Goal of 10 mg/L Reached	
						Trend	Tau Value	Trend Line	Lower 95% CI	Upper 95% CI	Trend Line	Lower 95% CI	Upper 95% CI
1115	9/10/2007	3/28/2023	31	0	104	None	−0.145	Not applicable, no trend					
1117	9/10/2007	3/28/2023	32	11	<0.017	None	0.063	Not applicable, concentration less than remediation goal					
1128	3/23/2010	3/28/2023	24	0	427	Decreasing	−0.486	4.22	2.94	7.47	2037	2031	2054
1132	3/10/2009	3/28/2023	26	9	0.042	None	0.145	Not applicable, concentration less than remediation goal					
1134	3/10/2009	3/28/2023	25	9	0.023	None	−0.040	Not applicable, concentration less than remediation goal					
1135	3/25/2010	3/29/2023	26	17	<0.017	None	0.108	Not applicable, concentration less than remediation goal					
1136	3/25/2010	3/30/2023	27	4	0.41	None	−0.003	Not applicable, concentration less than remediation goal					
1137	3/25/2010	3/27/2023	25	7	<0.017	Decreasing	−0.363	Not applicable, concentration less than remediation goal					
1138	3/25/2010	3/27/2023	24	2	0.041	Decreasing	−0.533	Not applicable, concentration less than remediation goal					
1139	3/25/2010	3/27/2023	26	6	<0.017	Decreasing	−0.474	Not applicable, concentration less than remediation goal					
1140	9/16/2009	3/30/2023	25	3	<0.017	Decreasing	−0.590	Not applicable, concentration less than remediation goal					
1141	9/16/2009	3/30/2023	25	2	0.029	None	−0.243	Not applicable, concentration less than remediation goal					
1142	3/24/2010	3/30/2023	27	22	<0.017	None	−0.085	Not applicable, concentration less than remediation goal					
1143	3/26/2010	3/29/2023	26	22	<0.017	None	−0.062	Not applicable, concentration less than remediation goal					

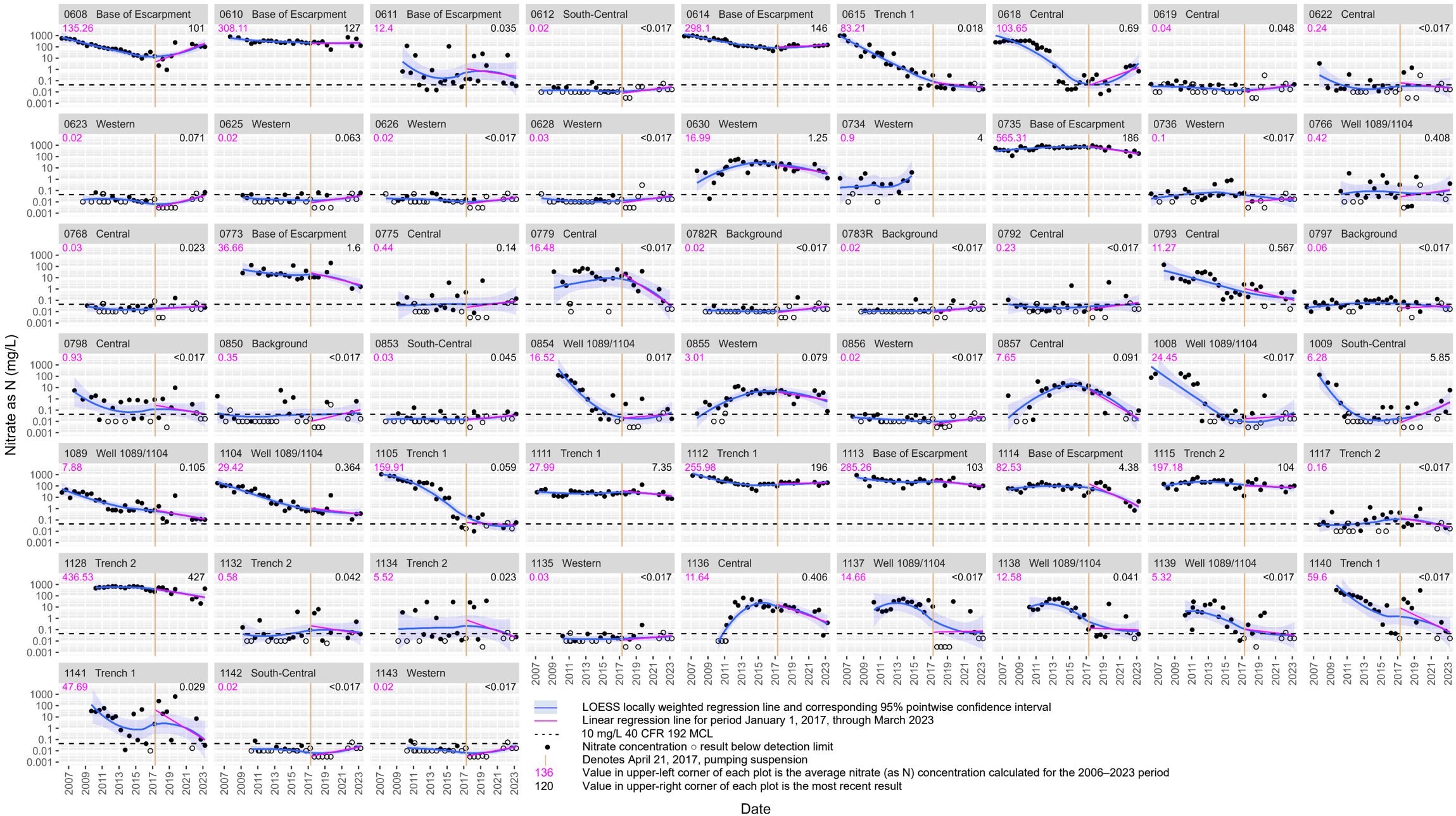
* Asterisk following well ID denotes current or proposed floodplain background locations.

Notes:

1. Mann-Kendall and linear regression trend analyses were run for all floodplain wells that are routinely monitored. An initial date of 2006 was used for most wells because that time frame corresponds to the installation of the floodplain trenches; only validated data were used in the analysis. Linear regression and half-life predictions were applied only to wells with significant decreasing concentration trends and with nitrate concentrations exceeding the 10 mg/L standard.
2. Trend analyses were conducted at the 0.05 significance (or alpha) level using a two-sided test. The test statistic, Kendall's tau, is a measure of the strength of the association between two variables, with values always falling between −1 and +1.
3. For wells with nondetects, trend tests were performed using the "NADA: Nondetects and Data Analysis for Environmental Data" package in R, version 1.6-1.1 (Lee 2020). The NADA trend test is similar to the traditional Mann-Kendall trend test except that it accounts for the presence of nondetects at multiple detection limits.

Abbreviation:

CI = confidence interval



Notes: In each plot label, the general area of the sample location is also identified, using the groupings shown in Figure C-1. The linear regression line for the recent (2017–2023) period was not applied to wells with average nitrate concentrations <1 mg/L or a high proportion of recent nondetects. As shown in Table 6 and Table 7, no statistically significant increasing trends were found for nitrate (as N) for either the full (2006–2023) or recent (2017–2023) time frames.

Figure C-2. Nitrate (as N) Concentration Trends in Shiprock Site Floodplain Wells, 2006–2023

Table C-3. Sulfate Concentration Trends in Floodplain Monitoring Wells and Remedial Goal Attainment Predictions: 2006–2023 (page 1 of 2)

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Most Recent Sulfate Concentration (mg/L)	Mann-Kendall Trend Analysis Results		Linear Regression Results					
							Half-Life (years)			Year Remedial Goal of 2000 mg/L Reached		
					Trend	Tau Value	Trend Line	Lower 95% CI	Upper 95% CI	Trend Line	Lower 95% CI	Upper 95% CI
0608	3/9/2006	3/29/2023	32	5160	None	−0.08	Not applicable, no trend					
0610	9/11/2007	3/29/2023	27	3440	Decreasing	−0.30	22.320	12.301	120.321	2048	2033	2197
0611	9/15/2009	3/29/2023	25	4660	Decreasing	−0.47	36.840	23.605	83.862	2064	2046	2127
0612	9/11/2007	3/30/2023	28	234	None	−0.21	Not applicable, concentration less than remediation goal					
0614	3/9/2006	3/30/2023	34	4200	Decreasing	−0.80	7.818	6.811	9.176	2028	2026	2031
0615	3/9/2006	3/30/2023	33	5370	None	−0.08	Not applicable, no trend					
0618	3/8/2006	3/28/2023	34	3890	Decreasing	−0.73	7.827	6.555	9.712	2029	2026	2033
0619	3/8/2006	3/30/2023	34	4540	None	0.00	Not applicable, no trend					
0622	9/12/2007	3/30/2023	27	2080	Decreasing	−0.30	Not applicable, no linear trend					
0623	9/10/2008	3/29/2023	28	2290	Decreasing	−0.36	Not applicable, no linear trend					
0625	3/12/2009	3/29/2023	26	2370	None	−0.26	Not applicable, no trend					
0626	9/13/2007	3/30/2023	30	1740	None	−0.17	Not applicable, no trend					
0628	9/13/2007	3/30/2023	28	3300	None	0.07	Not applicable, no trend					
0630	9/13/2007	3/30/2023	30	3960	Increasing	0.44	Not applicable, increasing trend					
0734	3/15/2006	9/30/2014	14	6000	None	0.11	Not applicable, no trend					
0735	3/9/2006	3/28/2023	35	3560	None	0.00	Not applicable, no trend					
0736	3/10/2006	3/29/2023	29	2940	Decreasing	−0.59	15.708	11.170	26.457	2026	2022	2035
0766	3/25/2010	3/28/2023	23	3040	Decreasing	−0.60	9.919	6.928	17.454	2028	2024	2038
0768	3/12/2009	3/30/2023	26	3440	Decreasing	−0.44	7.575	5.079	14.898	2028	2024	2043
0773	3/10/2009	3/29/2023	23	409	Decreasing	−0.40	Not applicable, concentration less than remediation goal					
0775	3/11/2009	3/30/2023	25	2840	Decreasing	−0.52	17.470	11.923	32.672	2034	2027	2051
0779	3/11/2009	3/30/2023	27	5370	None	−0.12	Not applicable, no trend					
0782R*	9/16/2008	3/28/2023	27	277	None	−0.17	Not applicable, concentration less than remediation goal					
0783R*	9/17/2008	3/28/2023	27	540	Increasing	0.27	Not applicable, concentration less than remediation goal					
0792	9/12/2007	3/30/2023	30	3590	Decreasing	−0.59	6.158	4.627	9.204	2025	2022	2030
0793	9/12/2007	3/30/2023	27	4790	None	−0.01	Not applicable, no trend					
0797*	3/7/2006	3/29/2023	32	2160	None	−0.08	Not applicable, no trend					
0798	9/12/2007	3/30/2023	27	2600	Decreasing	−0.60	7.672	5.781	11.401	2026	2023	2032
0850*	3/7/2006	3/29/2023	32	1440	None	0.00	Not applicable, no trend					
0853	9/12/2007	3/30/2023	30	539	None	0.19	Not applicable, concentration less than remediation goal					
0854	9/17/2009	3/27/2023	25	2880	Decreasing	−0.73	7.219	5.792	9.581	2026	2024	2030
0855	9/13/2007	3/29/2023	30	3000	None	−0.14	Not applicable, no trend					
0856	9/13/2007	3/29/2023	30	2340	Decreasing	−0.30	Not applicable, no trend					
0857	9/12/2007	3/28/2023	27	6360	Increasing	0.56	Not applicable, increasing trend					
1008	3/10/2006	3/27/2023	27	2870	Decreasing	−0.83	5.220	4.281	6.689	2022	2021	2024
1009	9/12/2007	3/30/2023	29	2400	Decreasing	−0.47	11.118	7.980	18.321			
1089	3/14/2006	3/30/2023	32	2940	Decreasing	−0.78	10.544	8.767	13.225	2027	2025	2031
1104	3/14/2006	3/30/2023	31	3040	Decreasing	−0.70	7.931	6.386	10.462	2027	2024	2031
1105	3/6/2007	3/30/2023	29	5960	Decreasing	−0.58	9.299	6.708	15.150	2032	2027	2043
1111	3/7/2007	3/30/2023	29	7330	None	−0.13	Not applicable, no trend					
1112	3/7/2007	3/30/2023	30	6510	Decreasing	−0.49	13.519	9.685	22.378	2041	2033	2059
1113	3/6/2008	3/29/2023	27	2960	Decreasing	−0.67	10.029	7.682	14.442	2026	2023	2032
1114	9/10/2007	3/29/2023	29	592	None	−0.22	Not applicable, concentration less than remediation goal					

Table C-3. Sulfate Concentration Trends in Floodplain Monitoring Wells and Remedial Goal Attainment Predictions: 2006–2023 (page 2 of 2)

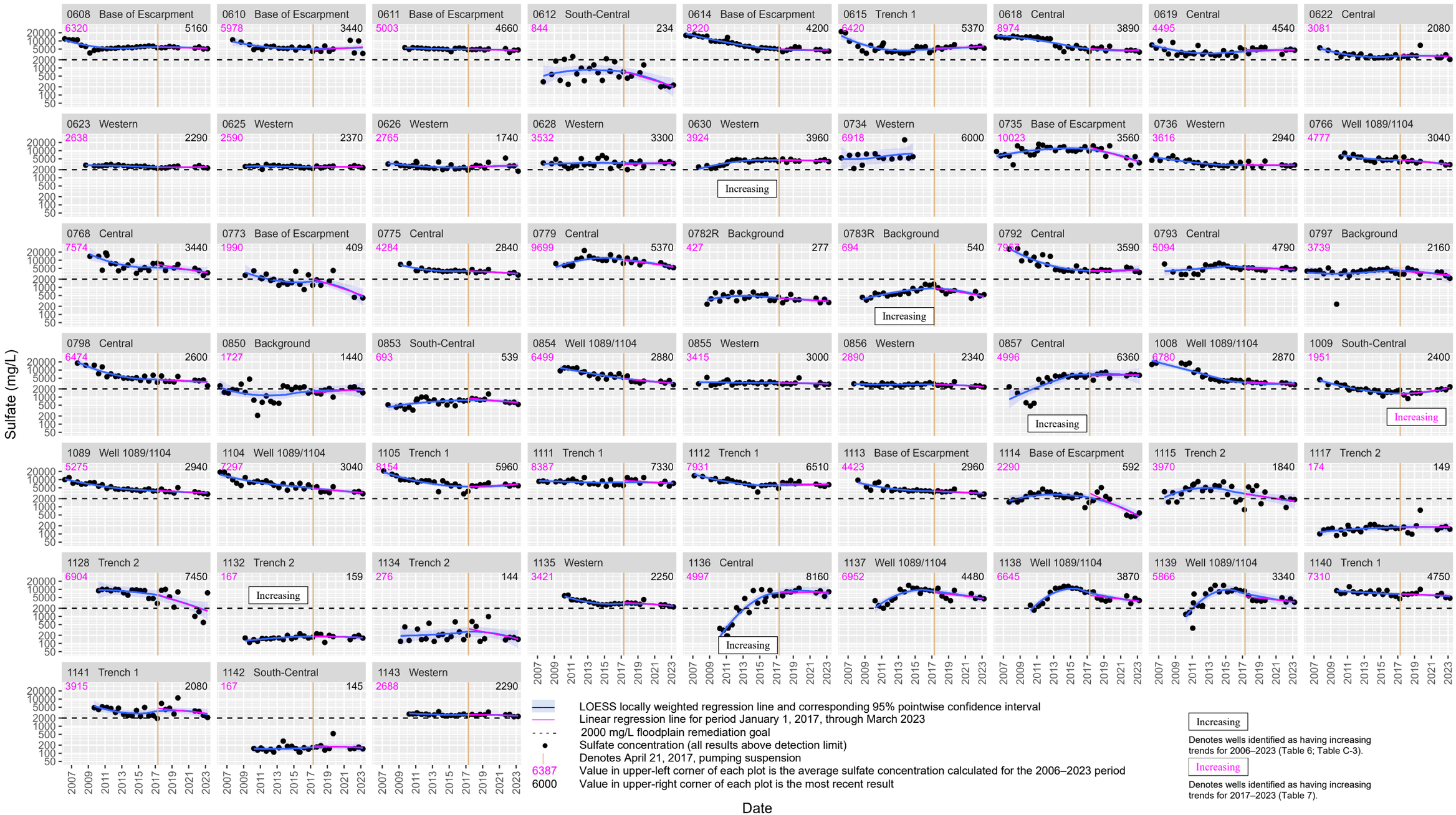
Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Most Recent Sulfate Concentration (mg/L)	Mann-Kendall Trend Analysis Results		Linear Regression Results					
							Year Remedial Goal of 2000 mg/L Reached			Year Remedial Goal of 2000 mg/L Reached		
					Trend	Tau Value	Trend Line	Lower 95% CI	Upper 95% CI	Trend Line	Lower 95% CI	Upper 95% CI
1115	9/10/2007	3/28/2023	31	1840	None	−0.18	Not applicable, concentration less than remediation goal					
1117	9/10/2007	3/28/2023	32	149	None	0.25	Not applicable, concentration less than remediation goal					
1128	3/23/2010	3/28/2023	24	7450	Decreasing	−0.50	4.94	3.38	9.18	2023	2021	2029
1132	3/10/2009	3/28/2023	26	159	Increasing	0.33	Not applicable, concentration less than remediation goal					
1134	3/10/2009	3/28/2023	25	144	None	0.06	Not applicable, concentration less than remediation goal					
1135	3/25/2010	3/29/2023	26	2250	Decreasing	−0.59	14.99	10.85	24.2	2026	2023	2033
1136	3/25/2010	3/30/2023	27	8160	Increasing	0.61	Not applicable, increasing trend					
1137	3/25/2010	3/27/2023	25	4480	None	0.06	Not applicable, no trend					
1138	3/25/2010	3/27/2023	24	3870	None	−0.10	Not applicable, no trend					
1139	3/25/2010	3/27/2023	26	3340	None	0.07	Not applicable, no trend					
1140	9/16/2009	3/30/2023	25	4750	Decreasing	−0.38	22.15	13.16	70.01	2056	2040	2143
1141	9/16/2009	3/30/2023	25	2080	None	−0.22	Not applicable, no trend					
1142	3/24/2010	3/30/2023	27	145	None	0.14	Not applicable, concentration less than remediation goal					
1143	3/26/2010	3/29/2023	26	2290	Decreasing	−0.34	61.75	33.0	480.25	2041	2029	2215

* Asterisk following well ID denotes current or proposed floodplain background locations.

Notes:

1. Both Mann-Kendall and linear regression trend analyses were run for all floodplain wells that are routinely monitored. An initial date of 2006 was used for most wells because that time frame corresponds to the installation of the floodplain trenches; only validated data were used in the analysis. Linear regression and half-life predictions were applied only to wells with significant decreasing concentration trends and with sulfate concentrations exceeding the 2000 mg/L remedial goal.
2. Trend analyses were conducted at the 0.05 significance (or alpha) level using a two-sided test. The test statistic, Kendall's tau, is a measure of the strength of the association between two variables, with values always falling between −1 and +1. For wells identified as having statistically significant increasing concentration trends, results are shown in red font.
3. Detection frequencies for sulfate in floodplain alluvial wells have been 100%.

Abbreviation:
CI = confidence interval

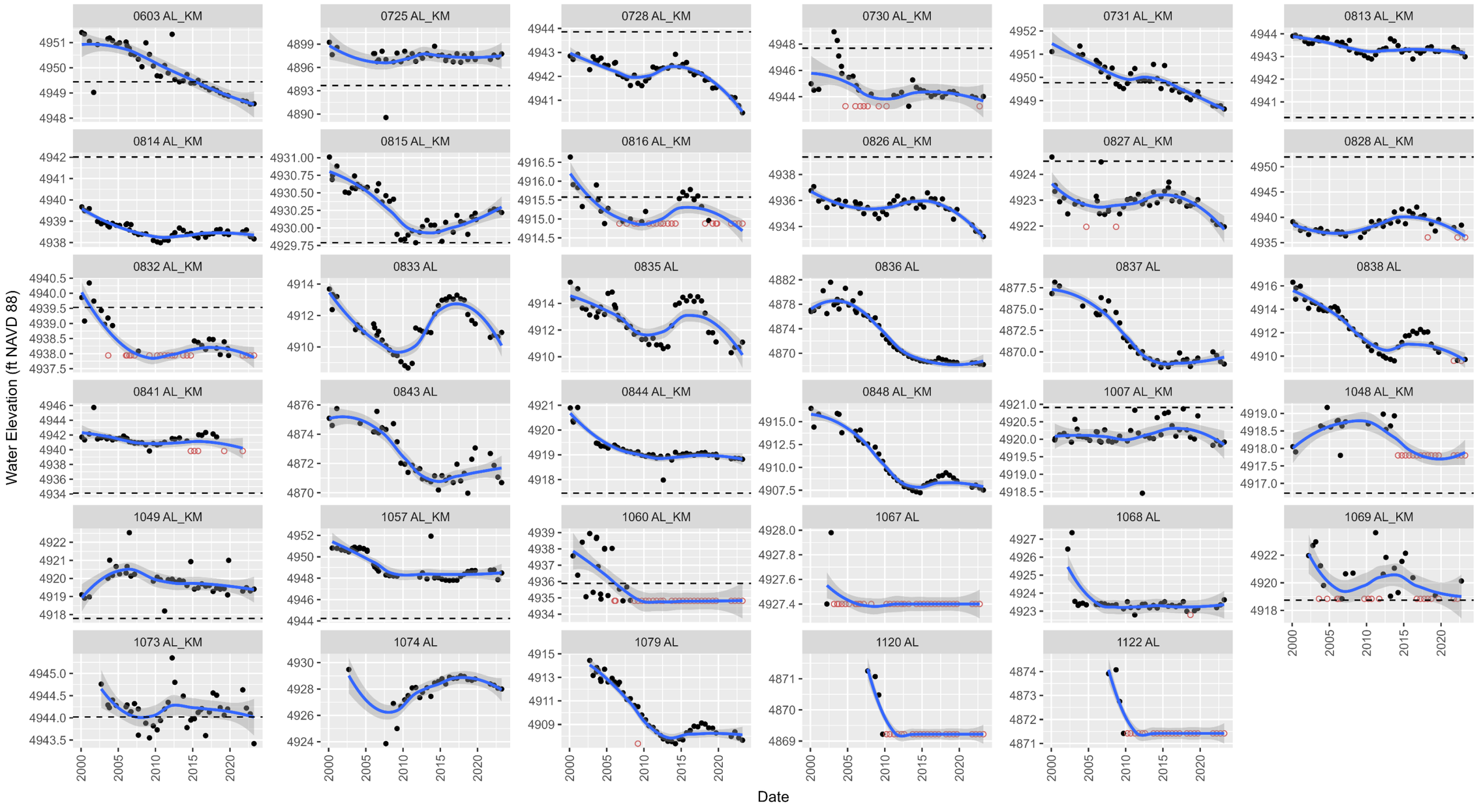


Note: In each plot label, the general area of the sample location is also identified, consistent with the groupings used in Figure C-1.

Figure C-3.Sulfate Concentration Trends in Shiprock Site Floodplain Wells, 2006–2023

Appendix D

Hydrographs for Terrace Alluvial Wells



Blue shaded line is the LOESS local regression line and corresponding 95% pointwise confidence interval
For wells screened in both the alluvium and the Mancos Shale (assigned AL_KM), dashed line denotes the top of bedrock
Denotes that the well was dry or had insufficient water to sample; assigned values equal to the minimum recorded elevation
Note: Scales are unique for each well given differences in elevations across the terrace.
Abbreviations: AL = alluvium; KM = Mancos Shale; NAVD 88 = North American Vertical Datum of 1988

Figure D-1. Hydrographs for Shiprock Disposal Site Terrace Wells Screened in the Alluvium, 2000–March 2023