Department of Energy
Washington, DC 20585

March 17, 2020

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

Subject: U.S. Department of Energy Office of Legacy Management draft document *Revised Groundwater Compliance Action Plan (GCAP) Work Plan* for the Shiprock, New Mexico, UMTRCA Title I Disposal Site (NRC Docket No. WM-0058)

To Whom it May Concern:

Enclosed for Nuclear Regulatory Commission (NRC) review is the draft document titled *Revised Groundwater Compliance Action Plan (GCAP) Work Plan, Shiprock, New Mexico, Disposal Site*. This work plan identifies the objectives, rationale, data collection and analysis activities, and quality assurance and quality control measures necessary to revise the Shiprock GCAP to address current site conditions and processes and to provide informed consideration of stakeholder concerns and expectations.

At the convenience of NRC and the Navajo Nation Abandoned Mine Land/Uranium Mill Tailings Remedial Action (AML/UMTRA) Program, we would like to schedule a briefing meeting with both organizations to discuss this document and address any questions or concerns.

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

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Sincerely,

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Enclosure

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File: SHP 3500-04

LMS/SHP/S28119

DRAFT
Revised Groundwater Compliance Action Plan (GCAP) Work Plan Shiprock, New Mexico, Disposal Site

March 2020

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Contents

Figures

Tables

Appendix

Abbreviations

3D	three dimensional
APE	area of potential effect
BIA	U.S. Bureau of Indian Affairs
BLRA	Baseline Risk Assessment
CFR	*Code of Federal Regulations*
COC	contaminant of concern
DOE	U.S. Department of Energy
DQO	data quality objective
EA	Environmental Assessment
EC	Environmental Compliance
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
EVS	Earth Volumetric Studio
ft	feet
FWS	U.S. Fish and Wildlife Service
GCAP	Groundwater Compliance Action Plan
gpm	gallons per minute
IC	institutional control
IDW	investigation-derived waste
JSA	job safety analysis
K_d	sorption partitioning coefficient
lidar	light detection and ranging
LM	Office of Legacy Management
LMS	Legacy Management Support
LOESS	locally weighted smoothing line
MCL	maximum concentration limit
mg/L	milligrams per liter
N	nitrogen
NECA	Navajo Engineering and Construction Authority
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act

NLN	National Laboratory Network
NNAML/UMTRA	Navajo Abandoned Mine Lands/Uranium Mill Tailings Remedial Action Program
NNEPA	Navajo Nation Environmental Protection Agency
NNFW	Navajo Nation Fish and Wildlife
NNH&HPD	Navajo Nation Heritage & Historic Preservation Department
NNWCA	Navajo Nation Water Code Administration
NRC	U.S. Nuclear Regulatory Commission
PEIS	Programmatic Environmental Impact Statement
PPE	personal protective equipment
RAP	Remedial Action Plan
RGB	red, green, and blue
SOWP	Site Observational Work Plan
TDS	total dissolved solids
THPO	tribal historic preservation officer
$^{234}U/^{238}U$	uranium-234/uranium-238 (activity ratio)
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey
VWP	vibrating wire piezometer

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Executive Summary

This work plan reflects a systematic and informed approach that provides the basis for the development of a revised Groundwater Compliance Action Plan (GCAP) for the Shiprock, New Mexico, Uranium Mill Tailings Radiation Control Act (UMTRCA) Title I Disposal Site (site). In accordance with UMTRCA, the U.S. Department of Energy Office of Legacy Management (LM) is responsible for developing a GCAP that identifies the strategy for complying with groundwater standards in Title 40 *Code of Federal Regulations* Section 192, and which addresses the U.S. Nuclear Regulatory Commission (NRC) *Standard Review Plan for the Review of DOE Plans for Achieving Regulatory Compliance at Sites with Contaminated Ground Water Under Title 1 of the Uranium Mill Tailings Radiation Control Act*, NUREG-1724. The Shiprock site has a GCAP that was approved by NRC in 2003; the site conceptual model that the groundwater compliance approach was based on requires significant updates for information gathered since 2003, including an indication that the approach is not expected to achieve the regulatory compliance goals set by the GCAP. Additionally, the evaporation pond that is part of the current groundwater compliance strategy is aging and the liner is in need of replacement or removal, and a decision to remove the pond would require a viable alternate strategy. The revised GCAP will evaluate whether an alternate strategy would address the site conditions more efficiently than the current system and what controls are needed in the future to ensure the protection of human health and the environment.

The approved Shiprock GCAP addresses three distinct areas at the site, each with different compliance strategies as described in the Programmatic Environmental Impact Statement for groundwater compliance at UMTRCA sites. The basis behind these strategies is explained in more detail in Section 2.0. Supplemental standards were chosen for the west terrace because the groundwater qualified as limited use based on the presence of widespread ambient contamination. Monitoring was required as part of the west terrace compliance strategy because the two terrace areas were thought to be hydrologically connected. Decreasing groundwater elevations from active remediation in the east terrace were hypothesized to induce decreasing groundwater elevations at seep occurrences in the west terrace. While irrigation activities in the area influence the status of the seeps and limit progress in the context of the GCAP, recent isotopic investigations in terrace groundwater have demonstrated that there are likely no mill-related impacts on the west terrace.

The east terrace compliance strategy detailed in the approved GCAP is active remediation, specifically described as a system of extraction wells on the terrace and interceptor drains in Many Devils Wash and Bob Lee Wash. This approach was intended to pump groundwater to dry the seeps and curtail surface expression of groundwater in Many Devils and Bob Lee Washes, as well as reduce the flow of groundwater from the terrace to the floodplain. Semiannual monitoring has shown that while groundwater elevations have seemed to decrease in the terrace area, the long-term effectiveness of this strategy will be marginal because of the complexity of anthropogenic contributions and natural recharge of water to the area, which continues to be a source of high concentrations of mill-related contaminants of concern (COCs). In addition, many of the terrace monitoring and extraction wells have failed to produce groundwater pumping rates that would continue to qualify the terrace alluvium as an aquifer. The projected and prescribed 7 gallons per minute (gpm) from the terrace wellfield has not been feasible; the wellfield there, constructed in the area with the greatest saturated thickness, provides less than 2 gpm on average. Many Devils Wash, an area included in the east terrace strategy, is now understood to contain widespread ambient contamination, and the terrace well field contains isotopic signatures that are indicative of widespread ambient contamination. A focused strategy to address the concerns of points of exposure and groundwater flux originating from contamination on the terrace will require additional characterization and quantification, especially in the areas underneath and immediately to the west and north of the disposal cell.

The third area described in the Shiprock GCAP is the floodplain, for which the strategy comprises natural flushing supplemented by the extraction of groundwater as a best management practice. After approximately 17 years of groundwater extraction from a combination of wells and infiltration galleries (trenches 1 and 2), concentrations of COCs on the floodplain have been reduced significantly; however, the compliance goal of achieving regulatory standards within 100 years is not expected to be met with the existing system. The rate of COC concentration reduction since 2003 projected for an additional 80 years is not likely to achieve Uranium Mill Tailings Remedial Action (UMTRA) groundwater standards, and background uranium concentrations at well 850 are often above UMTRA standards (sulfate concentrations at wells 0850 and 0797 are also elevated); even without contributions of mill-related mass from the source areas, widespread ambient contamination may keep concentrations in the floodplain above the standards set by the existing GCAP. LM has conducted various investigative efforts that have produced information about the extraction system efficiency, assistance in groundwater uptake that may be provided by floodplain vegetation, and the seasonal effects of recharge and flushing interaction with the San Juan River. Considering the revisions required to the terrace compliance strategies, a complementary revised approach for the floodplain will be evaluated to achieve appropriate regulatory standards that are protective of human health and the environment.

Five data quality objectives (DQOs) have been formulated to encompass the requirements of NUREG-1724 and the primary goals of the revised GCAP effort:

- O1: Define the source mass term and update the extent of mill-related uranium, nitrate, and sulfate contamination.
- O2: Characterize the hydraulic connection between the terrace and the floodplain.
- O3: Evaluate how the hydrology of the floodplain impacts natural contaminant flushing or groundwater treatment.
- O4: Determine whether remediation options other than groundwater extraction and evaporation are a viable alternative for groundwater compliance.
- O5: Define the range of appropriate institutional controls to be protective of human health and the environment.

Each of these objectives contains specific information inputs, geographic and temporal boundaries, parameters, analytical methods, and performance criteria that define their scope, and these details are presented in Section 4.0. Section 5.0 discusses the individual data collection tasks that are planned to achieve the objectives. Site characterization tasks to address DQOs O1, O2, and O3 will generally be performed first and will inform the evaluation of remediation options and regulatory logistical considerations included in DQOs O4 and O5.

This work plan has been prepared in parallel with an ongoing collaborative initiative between LM and the National Laboratory Network (NLN) to identify innovative and state-of-the-art approaches that inform the development of stable and effective groundwater compliance strategies for the Shiprock site. By proceeding in parallel, LM acknowledges that there is a potential that the activities identified in this work plan may be affected by the LM–NLN collaborative process. Depending on the results of the collaborative initiative, there may be a need to supplement or modify this plan accordingly to address proposed efforts and actions and associated time frames. LM is committed to engaging with tribal stakeholders and regulators and communicating any required modification to the work plan that may arise as a result of this process. Additionally, LM will identify an updated schedule for planning and execution of proposed field activities and work plan finalization that identifies opportunities for integration of input from the LM–NLN collaborative process.

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1.0 Introduction

This work plan reflects a systematic and informed approach that provides the basis for the development of a Groundwater Compliance Action Plan (GCAP) for the Shiprock, New Mexico, Uranium Mill Tailings Radiation Control Act (UMTRCA) Title I Disposal Site (site). In accordance with UMTRCA, the U.S. Department of Energy (DOE) Office of Legacy Management (LM) is responsible for developing a GCAP that identifies the strategy for complying with groundwater standards in Title 40 *Code of Federal Regulations* Section 192 (40 CFR 192) and which addresses the U.S. Nuclear Regulatory Commission (NRC) *Standard Review Plan for the Review of DOE Plans for Achieving Regulatory Compliance at Sites with Contaminated Ground Water Under Title 1 of the Uranium Mill Tailings Radiation Control Act*, NUREG-1724 (NRC 2000). The Shiprock site has a GCAP (drafted in 2002) that was approved by NRC in 2003; however, the site conceptual model that the groundwater compliance approach was based on requires significant updates from information gathered since 2003, including an indication that the approach is not expected to achieve the regulatory compliance goals set by the GCAP based on the rate of mass removal to date and the existence of widespread ambient contamination in both upgradient floodplain and terrace groundwater with regards to uranium and sulfate (DOE 2002).

A revision to the GCAP will incorporate necessary modifications and additions to the site conceptual model; in addition, the evaporation pond liner that was constructed to hold extracted site groundwater as part of the 2002 GCAP active remediation approach is aging and a decision regarding the fate of the pond is required. LM has begun an Environmental Assessment (EA) that addresses the possibility of removing the pond or replacing it, and the decision to modify the size of the pond or to take it out may require an evaluation of the viability of alternate approaches to active remediation at the site. The revised GCAP will address the technical considerations behind the groundwater compliance decisions and strategy that will drive remediation efforts as necessary at the site for the future.

Towards that end, this work plan identifies the data quality objectives (DQOs), rationale, and data collection and analysis activities planned to prepare a revised GCAP that addresses a matured understanding of site conditions and provides informed consideration of stakeholder concerns and expectations. This work plan has been prepared in parallel with an ongoing collaborative initiative between LM and the National Laboratory Network (NLN) to identify innovative and state-of-the-art approaches that inform the development of stable and effective groundwater compliance strategies for the Shiprock site. By proceeding in parallel, LM acknowledges that there is a potential that the activities identified in this work plan may be affected by the LM–NLN collaborative process. Depending on the results of the collaborative initiative, there may be a need to supplement or modify this plan accordingly to address proposed efforts and actions and associated time frames. LM is committed to engaging with tribal stakeholders and regulators and communicating any required modification to the work plan that may arise as a result of this process. Additionally, LM will identify an updated schedule for planning and execution of proposed field activities and work plan finalization that identifies opportunities for integration of input from the LM–NLN collaborative process. Upon stakeholder review and comment on this work plan, as well as review of the outcome of the LM–NLN collaborative initiative, required modifications will be incorporated into this work plan by revision, or by addendum.

1.1 Purpose and Scope

The purpose of this work plan is to identify data needs and data collection activities required to support the development of a GCAP for the Shiprock site. Following this introductory section, the work plan includes the following:

- A summary of general groundwater compliance considerations and strategic approach
- A summary of relevant data evaluations in the context of the 2002 GCAP
- The identification of outstanding data gaps related to NUREG-1724 guidelines
- Updated site groundwater plume metrics based on monitoring to date
- The DQOs that encompass the data gaps and the current understanding of the site GCAP considerations
- Details on the data collection strategy to address the DQOs
- Implementation considerations regarding data collection activities, including safety and health, quality assurance, data management, and environmental management

1.2 Site Background

The Shiprock disposal site contains one of the first UMTRCA surface remediation efforts. The disposal cell was built prior to the promulgation of the Uranium Mill Tailings Remedial Action (UMTRA) Ground Water Project, which now governs the remediation of groundwater at the Shiprock site. The following subsections include a brief history of the site and the current groundwater compliance strategy.

Site History

The Shiprock disposal site is in the Navajo Nation in the town of Shiprock, New Mexico, approximately 30 miles west of Farmington, New Mexico. A uranium-ore processing mill operated at the site from 1954 to 1968 on property leased from the Navajo Nation (Figure 1). The mill closed in 1968, and control of the site reverted to the Navajo Nation in 1973. During its operating lifetime, the mill processed approximately 1.5 million tons of ore. Tailings from the milling operation were stored in two tailings piles just east of the mill site. Raffinate from the solvent extraction process was composed mainly of acidic solvents, neutralizing ammonia, and San Juan River water pumped from an intake 0.6 mile upstream from the site. The raffinate was allowed to evaporate in up to 10 unlined raffinate ponds that covered an approximate total area of 20 acres south and southwest of the tailings piles.

The U.S. Environmental Protection Agency (EPA) conducted a radiation survey in 1974 and recommended decontaminating the site and stabilizing the tailings. Decontamination work under EPA guidance began in January 1975 and continued until 1980. Uranium Mill Tailings Radiation Control Act legislation passed in 1978 specified significant changes to remedial action criteria for former uranium mill sites compared to the completed decommissioning work criteria at the site. DOE performed a series of surface and groundwater characterization studies in the early 1980s for preparation of the Remedial Action Plan (RAP) in 1985 (DOE 1985).

Figure 1. Aerial View of Shiprock Mill Site, 1965

To comply with the RAP, in late 1985 and 1986 DOE removed windblown and water-transported contaminated soils from the area surrounding the mill site and tailings impoundments and placed this material in an engineered disposal cell on site. The disposal cell is generally located on the area that formerly contained the tailings impoundments, whereas the Navajo Engineering and Construction Authority (NECA) offices and yard stand upon some of the old mill site (Figure 2 and Figure 3).

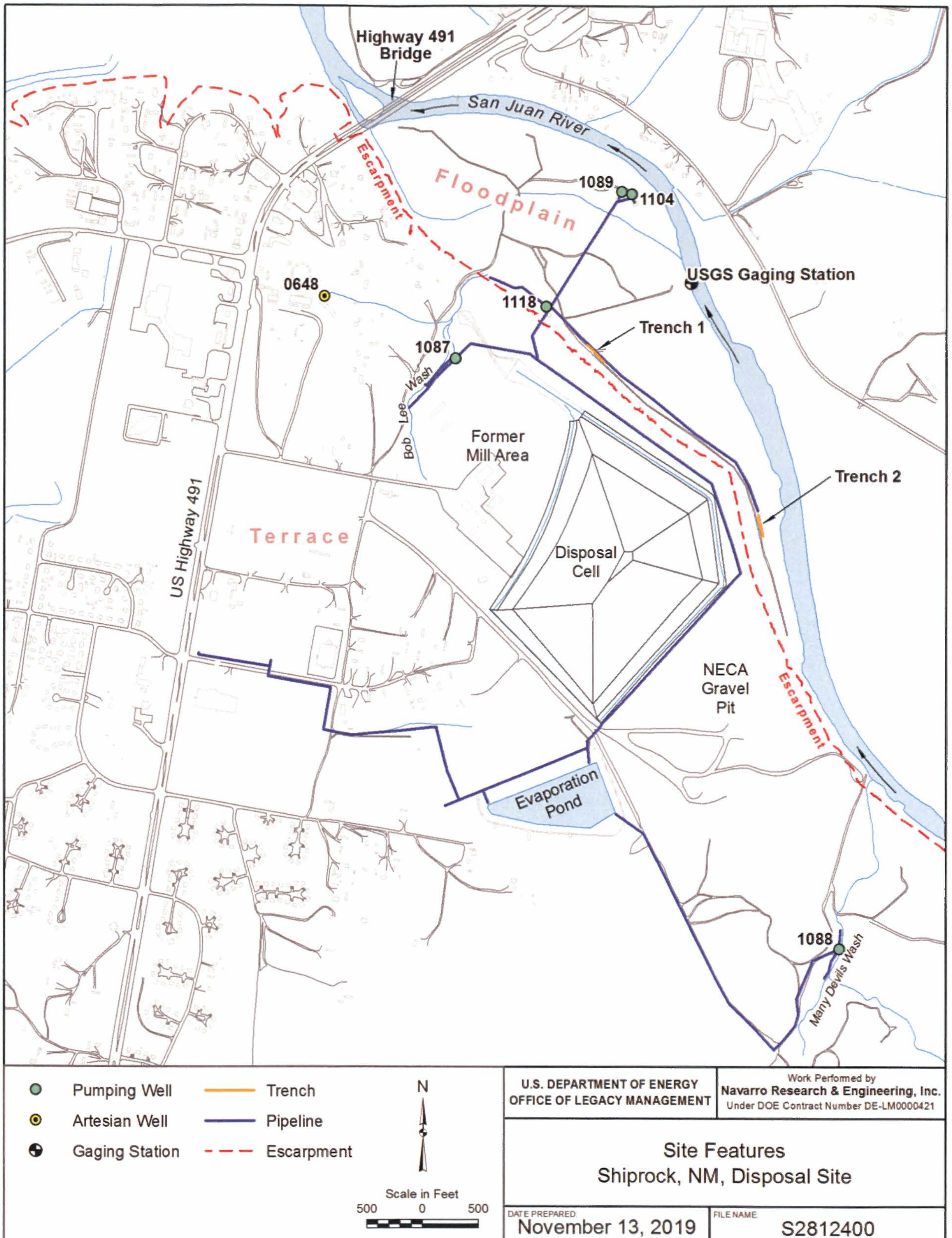

Figure 2. Shiprock Disposal Site Figure with Major Remediation Components

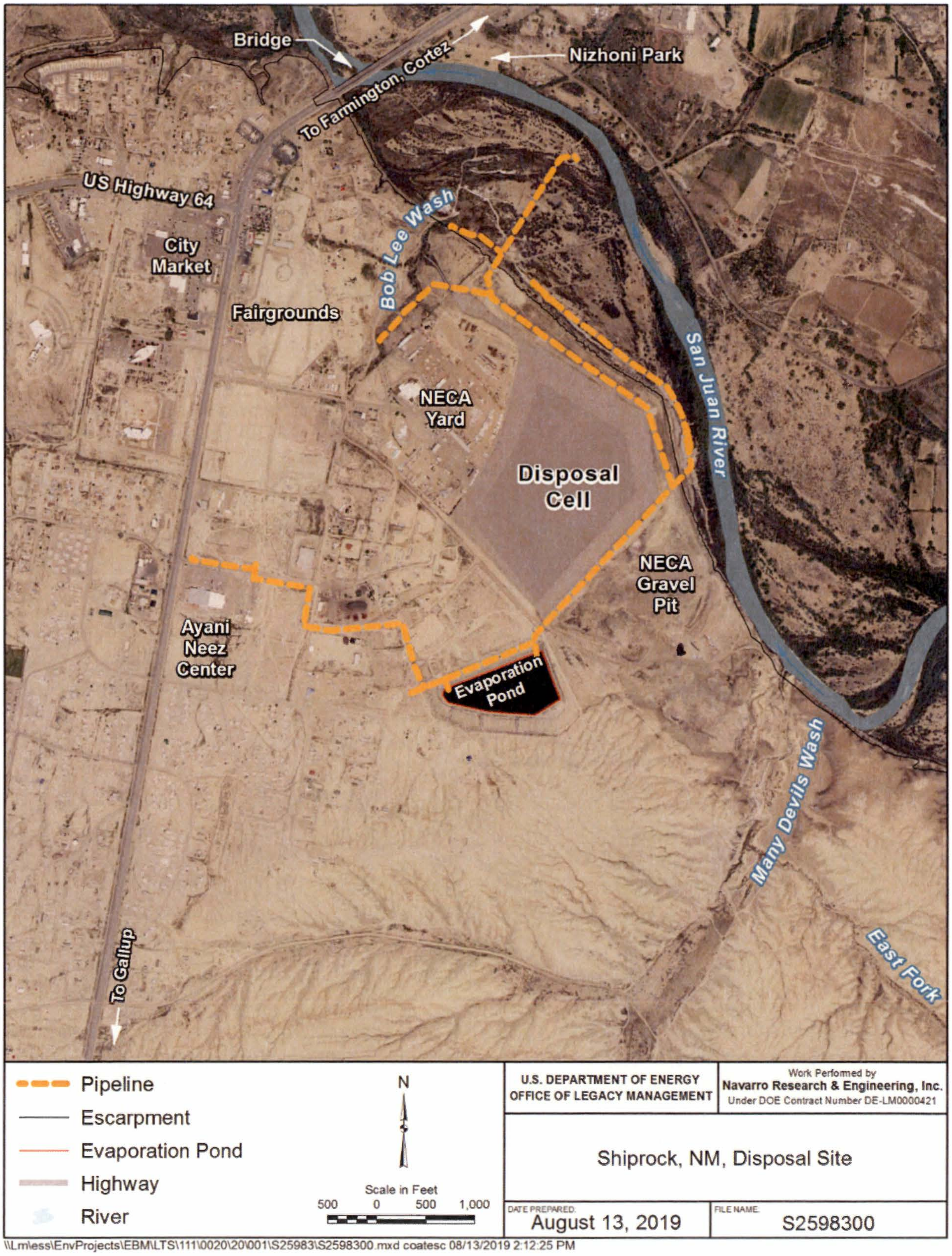

Figure 3. Shiprock Disposal Site with Community Landmarks

A long-term surveillance plan was prepared for the disposal site in 1994 (DOE 1994a). After this plan was approved, NRC issued a license in September 1996 to the DOE Grand Junction Office for the long-term care of the site. The license also deferred site groundwater cleanup to the UMTRA Ground Water Project.

Groundwater standards were defined in 1987 for the UMTRA Ground Water Project, and the final rule, published in 1995, requires DOE to comply with those standards. The 1996 Final Programmatic Environmental Impact Statement (PEIS) describes the regulatory requirements for adherence to the standards, as described in Section 2.0 (DOE 1996a). In support of the initial site-specific GCAP, site investigation work was conducted to address data gaps as they were understood prior to groundwater remediation implementation. The *Final Site Observational Work Plan for the Shiprock, New Mexico, UMTRA Project Site*, referred to as the SOWP, culminated these field investigations and modeling efforts (DOE 2000).

The 2002 GCAP (approved by NRC in 2003) was built upon the conceptual model presented in the SOWP. It defined the site-specific compliance strategy and the requirements for monitoring progress towards achievement of the groundwater standards set by the UMTRA Groundwater Project. A summary of the requirements of the 2002 GCAP is presented below, along with brief explanations of the aspects of the original GCAP strategy that require revision.

Existing Groundwater Compliance Strategy

The 2002 GCAP describes three distinct areas of the Shiprock disposal site: the west terrace, the east terrace, and the floodplain. Figures 2 and 3 show the location of the remediation components at the site. All three areas are prescribed a different groundwater compliance approach as follows.

1. **West Terrace, Supplemental Standards**

   The boundary between the east and west terrace groundwater systems was estimated by flow modeling reported in the SOWP and is just east of and roughly parallel to Highway 491, with the east terrace containing the disposal cell and the former mill site. The groundwater compliance strategy described in the 2002 GCAP sought to extract groundwater from terrace east and eliminate communication between terrace east and terrace west (DOE 2002). Contamination in the west terrace was concluded in the GCAP to originate from both anthropogenic groundwater related to milling activities and some leaching from irrigation water application to naturally contaminated Mancos Shale. Supplemental standards were applied to the west terrace, where the groundwater has significant background contamination and therefore qualifies as limited-use groundwater (DOE 2002). The seeps in the terrace west area have since gone dry, and further investigation detailed in the report titled *Investigation of Non-Mill-Related Water Inputs to the Terrace Alluvium at Shiprock, New Mexico* (DOE 2018a) has demonstrated that there is no mill influence to the groundwater west of Bob Lee Wash.

2. **East Terrace: Active Remediation**

   The east terrace is bound by Many Devils Wash to the southeast, a buried escarpment to the southwest, a hydrologic boundary roughly parallel to Highway 491 to the northwest, and an exposed escarpment to the northeast. The exposed escarpment is a naturally occurring, steep surface expression of carved Mancos Shale from the terrace to the floodplain. The escarpment is approximately 60 feet (ft) high, forming a sharp contrast between the floodplain and the terrace environments. The east terrace forms a plateau that drains north to Bob Lee Wash and southeast to Many Devils Wash. The east terrace compliance strategy included active remediation in the form of groundwater pumping, with the objective of pumping remaining relic water out of the terrace sediments to allow the groundwater system to revert to its original nature, which was assumed to be dry prior to milling activities (DOE 2002). The terrace pumping has resulted in a reduction in groundwater elevations overall (DOE 2019c); however, the continued success of this remediation strategy may be hindered by the contribution of non-mill anthropogenic water sources, which are now better understood. Pumping rates reported in Annual Performance Reports for the site have been lower than expected, often lower than the threshold to define an aquifer, 0.1 gallon per minute (gpm) per 40 CFR 192. In addition, isotopic mill signatures have demonstrated that the terrace well field itself pumps non-mill-influenced groundwater (DOE 2019a). Contaminant concentration reductions were not a part of the 2002 GCAP strategy for the east terrace; nonetheless, this understanding of the mill-related groundwater plume extent will be important as the site conceptual model is updated and the strategy is reevaluated.

3. **Floodplain: Natural Flushing Supplemented by Groundwater Extraction ("Enhanced Natural Flushing")**

The alluvial floodplain at the site pinches out to the southeast near the mouth of Many Devils Wash and to the northwest near the Highway 491 bridge over the San Juan River. Mancos Shale underlies the alluvial aquifer, which is composed mainly of basal gravels and cobbles to a depth of approximately 10–15 feet below ground surface. There is residual milling-related groundwater contamination present in the floodplain, and there may be a continued source contribution from the terrace or from solid-phase mass within the floodplain. Groundwater extraction, along with other remediation methods, was identified in the 2002 GCAP as means to help reduce risks of exposure and reduce contaminant mass in conjunction with natural flushing provided by some interaction with the San Juan River (DOE 2002). Groundwater pumping has resulted in substantial decreases in groundwater contaminants of concern (COCs) concentrations since 2002; however, it is not anticipated that the concentrations will decrease to achieve UMTRA groundwater standards in the timeline required by the PEIS (100 years) or the timeline stipulated in the approved GCAP (up to 60 years) using the existing system configuration (DOE 1996a, DOE 2019b). The evaporation pond liner, which helps holds groundwater extracted from both the terrace and floodplain wells, is in need of replacement or removal. A groundwater remediation strategy that does not involve an evaporation pond in the future may be preferable if a viable alternate technology is identified.

4. **Institutional Controls**

The institutional controls (ICs) described in the approved GCAP included a 7-year grazing restriction, DOE and Navajo Nation control of access to the floodplain, an agreement between DOE and Navajo Nation regarding prohibition of new well construction and groundwater use in the floodplain, and Navajo Nation Water Code Administration assurance that artesian well 648 will be allowed to continue to flow (DOE 2002). These institutional controls have been instituted in practice, although the range of these controls will be reexamined on a risk-related basis as required by the NUREG-1724 guidelines, to determine what level of controlled access and restricted use is warranted based on the fate and transport models and a human health and ecological risk assessment.

As described in the separate strategies above, the initial active remediation system included the pumping of groundwater from six extraction wells on the east terrace and from interceptor drains in Many Devils Wash and Bob Lee Wash. It also included the pumping of milling-related groundwater from two extraction wells in the contaminant plume close to the San Juan River as a best management practice. The GCAP included a conceptual approach for a second phase, which might include additional floodplain extraction wells, a flow barrier, and interceptor drain at the base of the escarpment. LM completed a detailed analysis of groundwater extraction efficiency from the wells and made the case for system improvements in the report, *Refinement of Conceptual Model and Recommendations for Improving Remediation Efficiency at the Shiprock, New Mexico, Site* (DOE 2005). In 2006, two infiltration galleries, referred to as Trench 1 and Trench 2, were added in the floodplain with sump areas to increase the amount of water and contaminant removal.

The remediation system operated at full capacity until 2017, when the evaporation pond water level reached its maximum allowable level, and liner degradation became an increasing concern. (Groundwater extraction from Many Devils Wash ceased in 2014, after the investigations demonstrated that the water was not mill-related, and because that part of the system needed significant repairs to continue operating). In April 2017, pumping was suspended from all locations except for Bob Lee Wash to allow the water level to drop. Bob Lee Wash pumping continued to prevent the potential surface expression of mill-related contamination, by controlling the water level in the sump. Pumping from the floodplain trenches was reinstated in July 2018 to keep the evaporation pond sediments covered with water, limiting potential dust migration.

The pumping regime in the floodplain has caused contaminant concentration decreases there, as mentioned. Based on the latest reporting period data of 2018–2019, uranium concentrations have decreased approximately fivefold since 2003, from approximately 5 milligrams per liter (mg/L) on average to just over 1 mg/L on average, as reported in recent Annual Performance Reports and summarized in Table 1. Sulfate and nitrate have also exhibited significant concentration reductions.

Table 1. Contaminant Maximum Concentrations in the Floodplain, 2000–2003 vs. 2018–2019

Contaminant	Baseline Maximum (2000–2003) (mg/L)	Most Recent Sampling Period Maximum (September 2018–March 2019) (mg/L)	UMTRA Standard for Shiprock Site (mg/L)
Uranium	4.44	1.3	0.044
Sulfate	24,266	12,000	2,000
Nitrate as nitrogen	957	660	10

That progress is significant; however, removal of COC concentrations to achieve regulatory standards within the 100-year time frame imposed by the PEIS is unlikely considering the rates of removal to date and some background concentrations of COCs above the UMTRA standards in wells 797 and 850. Concentrations of other COCs identified in the 2002 GCAP, including selenium, strontium, and manganese, have not been reduced to the same extent as those of uranium, sulfate, and nitrate; however, these other COCs are currently present in the groundwater at levels that are below background concentrations or below EPA referenced maximum concentration limits (MCLs) or regional screening levels in most locations. A separate report is in progress to describe the recommendations regarding monitoring these constituents moving forward, and as a part of the revised GCAP. Similarly, the east terrace wellfield and Many Devils Wash are now understood to contain non-mill-related groundwater; active remediation from those areas is expected to be discontinued as part of the revised groundwater compliance strategy.

In the years since the 2002 GCAP, additional studies have been performed to evaluate remediation system performance, phytoremediation, mill-related extent of groundwater contamination, floodplain hydrological processes, and others summarized in the following subsection. The aggregation of data and analyses presented in these studies, the 2000 SOWP, and the GCAP formulates the basis of the remaining data gaps and the DQOs presented herein.

1.3 Relevant Site Studies

LM continues to evaluate the groundwater compliance strategy with several areas of focus. The remedial system has been evaluated to date in the form of a refined site conceptual model, evaluations of the two floodplain trenches, and an evaluation of the overall remediation system operation (DOE 2005, DOE 2009, DOE 2011a, DOE 2011b). In addition to these discrete efforts, the Annual Performance Report is completed following each year of semiannual groundwater monitoring, which characterizes the performance of the system as it relates to the groundwater compliance objectives. In addition to the system evaluations, LM completed four large assessments that are relevant to groundwater compliance: (1) a study of phytoremediation and its potential to provide treatment at the Shiprock site, (2) isotopic fingerprinting and source identification in Many Devils Wash and the terrace, (3) an evaluation of the seasonal variations controlling flow on the floodplain, and (4) preliminary laboratory studies on polyphosphate injection potential to provide treatment in areas of high concentrations of uranium and nitrate. These site studies and their findings are described below.

Assessments of Remediation System Operations

1. Refinement of the Site Conceptual Model

   In 2005, after 3 years of remediation system operation, a revised site conceptual model report was completed, the *Refinement of Conceptual Model and Recommendations for Improving Remediation Efficiency at the Shiprock, New Mexico, Site* (DOE 2005). This revised site conceptual model detailed additional hydrologic features that had not been previously identified or accurately located, including the elevations and locations of the bedrock escarpment and the swale south of the disposal cell, as well as a previously unidentified bedrock ridge parallel to both features. The revised conceptual site model also attributed the difficulty of the extraction well network operation to the subsurface heterogeneity, well construction, well efficiency, and drilling methods used for well installation. It was reported that only 2 of 16 tested extraction and monitoring wells could pump at rates greater than 1 gpm. Contaminated groundwater was removed from the subsurface through eight extraction wells on the terrace, two extraction wells in the floodplain, and one interceptor drain each in Bob Lee Wash and Many Devils Wash. The extraction wells and interceptor drains were designed to produce approximately 20 gpm but were reported to produce approximately 13 gpm. Two wells on the floodplain accounted for approximately half of the production, one of which produces nearly 6 gpm. On the terrace, the remainder of the production was reported from two interceptor drains in Bob Lee Wash and Many Devils Wash totaling approximately 4 gpm, and eight extraction wells totaling approximately 3 gpm. The difference in overall extraction efficiency compared to the design has led to projections that the time required for natural flushing will be greater than anticipated.

2. Floodplain Trench Evaluations

   In 2009 and 2011, LM completed interim evaluations of Trench 2 and Trench 1, respectively. These two evaluation reports describe the effectiveness of the floodplain infiltration galleries. The Trench 2 evaluation titled *Evaluation of the Trench 2 Groundwater Remediation System at the Shiprock, New Mexico, Legacy Management Site* (DOE 2009) found that Trench 2 successfully intercepts contamination discharging across the Mancos Shale escarpment in the upstream floodplain and creates a zone of noncontaminated alluvial groundwater. The *Preliminary Evaluation of the Trench 1 Collection Drain Floodplain Area of the Shiprock, New Mexico, Site* (DOE 2011b) found that the combination of Trench 1 and the two extraction wells 1089 and 1104 creates a flow divide in the floodplain aquifer. It also found that Trench 1 was performing as designed, resulting in removal of uranium from the aquifer.

3. Remediation System Evaluation

   The *2010 Review and Evaluation of the Shiprock Remediation Strategy* (DOE 2011a) summarized the groundwater compliance strategy, modifications to the system in the years 2002–2010, evaporation pond investigations, disposal cell cover investigations, and investigations into the source of water in Many Devils Wash. The report described the shortcomings of the terrace wells, which extracted groundwater at a rate of 2 gpm rather than 8 gpm, and relative success in the floodplain. It outlined the path forward for investigation of background concentrations on the terrace, as well as ongoing evaluations of the remediation system in the floodplain.

4. Annual Performance Reports

   These reports for the Shiprock site discuss the performance of the remediation system as it relates to COC concentrations across the site. The semiannual groundwater sampling events that inform these data assessments, as well as the analysis provided in those documents, have been included in the formation of the DQOs communicated in this document.

Phytoremediation Studies

A phytoremediation experiment was conducted from 2006 to 2016 in three separate test plots at the site. Two of the plots were constructed along the terrace between the disposal cell and the escarpment. Another plot was constructed in the borrow area next to the evaporation pond. Results from the experiments are detailed in the report *Growing Desert Phreatophytes for Hydraulic Control of Groundwater at the Shiprock, New Mexico, Disposal Site* (DOE 2017a).

The main findings included the following:

1. Irrigated fourwing saltbush and black greasewood transplants were successfully established from native seed accessions. Saltbush plants grew larger than the greasewood plants, and all transplants grew larger in the terrace plots.
2. An evaluation of water isotope ratios indicated that, after irrigation ceased, the healthiest transplants growing in the river terrace plots were those primarily using shallow groundwater, and less healthy plants were using a combination of rainwater and residual irrigation water that may have mounded under the plots.
3. Uptake of contaminants by transplants did not exceed maximum tolerable levels for animals; therefore, phreatophytes rooted in shallow contaminated groundwater at the site are unlikely to create undue environmental exposure for grazing animals.
4. Preliminary calculations indicate that a large planting of fourwing saltbush and black greasewood could potentially remove a significant volume of shallow groundwater from the river terrace, possibly slowing or limiting groundwater flow to the San Juan River floodplain.

Investigations Related to Mill- and Non-Mill-Related Groundwater

The understanding of mill-related contamination at the Shiprock site has evolved significantly over the past several years. A series of papers regarding contamination in the Many Devils Wash details the revised understanding of the origin of contamination in that area. The paper *Application of Environmental Isotopes to the Evaluation of the Origin of Contamination in a Desert Arroyo: Many Devils Wash, Shiprock, New Mexico* (DOE 2012a), the subsequent *Multivariate Statistical Analysis of Water Chemistry in Evaluating the Origin of Contamination in Many Devils Wash, Shiprock, New Mexico* (DOE 2012b), and the U.S. Geologic Survey (USGS) report titled *The Source of Groundwater and Solutes to Many Devils Wash at a Former Uranium Mill Site in Shiprock, New Mexico* (Robertson et al. 2016) all set the stage for the final report of *Position Paper: Origin of Contamination in Many Devils Wash, Shiprock, New Mexico* (DOE 2017b). These reports develop the understanding that contamination in Many Devils Wash is naturally occurring, not related to the former mill site or disposal site.

The report *Investigation of Non-Mill-Related Water Inputs to the Terrace Alluvium at Shiprock, New Mexico* (DOE 2018a) expanded the understanding of mill- and non-mill-related contamination to include the terrace area. The evaluation demonstrated that the west terrace groundwater contains uranium that is naturally occurring, not related to milling activities. The east terrace was demonstrated through the same report to contain both mill- and non-mill-related areas of groundwater. The data included in the report demonstrate that the existing terrace remediation well network pumps non-mill-related groundwater and may not contribute to the overall GCAP objectives of containing and reducing the mill-related groundwater plume.

Flow Processes in the Floodplain Alluvial Aquifer

Advances have also been made in the understanding of the hydrology at the site. The report *Flow Processes in the Floodplain Alluvial Aquifer, Shiprock, New Mexico* (DOE 2018b) discusses flow regimes present in the floodplain aquifer as well as potential interactions with the San Juan River, which are important to set the stage for the hydrological work proposed in this GCAP work plan.

The major findings in the report include:

1. The floodplain groundwater system is dynamic and is influenced heavily by seasonal variations. Effective groundwater remediation in the floodplain is dependent on a thorough understanding of the complexity of the system, including groundwater–river interactions, evapotranspiration, and the influence of pumping on groundwater flow.
2. During winter and early spring, groundwater flow in the south half of the floodplain is parallel to the escarpment and receives inflow from the river as well as potential discharge from the terrace.
3. There are hyporheic areas in the floodplain that undergo mixing of fresh water from the river as water travels from one point in the river, through the floodplain alluvium, back to the river downstream.
4. In winter and early spring, the north half of the alluvial aquifer is recharged by surface water from Bob Lee Wash. This water mounds and diverts groundwater in the floodplain in a perpendicular fashion to the river, to the northeast.
5. In the late spring and early summer, flows in the San Juan River increase and water is lost from the river to the aquifer; after peak runoff this water returns to the river. Evapotranspiration in these months is also at its peak. The combination of these factors contributes to dilution of contaminant concentrations in the floodplain.
6. In mid-summer and early fall, flow patterns vary because of decreasing groundwater levels caused by continued evapotranspiration and decreasing river gage height.
7. Modeling simulations demonstrate that extraction from wells 1089 and 1104, combined with the two infiltration galleries (Trench 1 and Trench 2), is effective in capturing contaminated groundwater and limiting discharge to the river.
8. The current mounding caused by the artesian well input to Bob Lee Wash is necessary to prevent contaminants in the mid-floodplain area from migrating.
9. Additional groundwater extraction wells near Trench 1 may improve remediation efficiency.

Uranium Sequestration Experiments

DOE is in the process of conducting a series of column experiments to evaluate the potential of uranium sequestration at the Shiprock site. A draft Batch Test Report was completed in 2019, titled *Results of the Laboratory Batch Test of Phosphate Amendment Added to the Shiprock Sediment and Groundwater* (DOE 2019a), which detailed the treatment potential of polyphosphate to reduce uranium concentrations in Shiprock groundwater. Column tests are ongoing and generate data that will be used to provide insight into alternative groundwater treatment technologies and their potential uses at the site to achieve groundwater quality objectives. The insight from these experiments will include an assessment of geochemical treatment potential and is expected to include a discussion of considerations and limitations that may affect performance. Other experiments or pilot studies may be considered, pending the revised site characterization, as a part of the alternatives evaluation to select a remedial technology.

Context for GCAP Revision

The aggregated information from these relevant site studies provided the basis for the data gaps and the DQOs that are presented in Section 4.0. While significant information is available regarding the current system performance, the ability of the system to achieve regulatory standards is limited in its current capacity. The productivity of the groundwater extraction system wells in both the terrace and the floodplain is significantly less than what was projected in the GCAP and may not adequately address continued contributions of source material from the terrace or from secondary sources. The aging of the evaporation pond liner has further incentivized the evaluation of alternate strategies for groundwater remediation. The current compliance strategy and framework for the revised GCAP is presented in Section 2.0, followed by a summary of current plume metrics in Section 3.0. The DQOs and approach to address them in support of the site conceptual model update, and then the revision of the GCAP, are presented in Sections 4.0 and 5.0.

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2.0 Groundwater Compliance Considerations

This section describes the groundwater compliance considerations for groundwater contaminants that are attributable to milling activities, which are applicable across all of the UMTRCA sites. The PEIS compliance selection framework discussed previously is shown in Figure 4. This framework will guide revisions to groundwater compliance decisions for the Shiprock site, as it has governed compliance decisions to date. This compliance selection framework is documented in Section 2.0 of the PEIS (DOE 1996a) and is supported by the PEIS Record of Decision (62 FR 22913–22916). Human health and environmental risk, stakeholder input, and cost are all factors that contribute to the decision points within the framework.

2.1 Groundwater Compliance Strategies for UMTRCA Sites

If mill-related groundwater contamination is present in excess of MCLs or background concentrations, as it is at the Shiprock site, a step-by-step approach is followed until one or a combination of the following three available compliance strategies is selected. It is noted herein which of the strategies were selected as part of the approved Shiprock GCAP.

- **No remediation (supplemental standards or alternate concentration limits):** Compliance with EPA groundwater protection standards would be met without altering the groundwater or cleaning it up in any way. This strategy could be applied at the Shiprock site for contaminants of concern at or below EPA standards or background levels, or for contaminants of concern above EPA standards or background levels that qualify for supplemental standards or alternate concentration limits, or both. Supplemental standards were applied in the 2002 GCAP to the west terrace area, where groundwater was shown to be of limited use, due to flow rates and widespread ambient contamination (DOE 2002).
- **Natural flushing:** Allows natural groundwater movement and geochemical processes to decrease contaminant concentrations to regulatory limits within a period of 100 years. Natural flushing is part of the current compliance strategy in the floodplain at the Shiprock site (DOE 2002). It was applied under the assumption that groundwater compliance could be achieved within 100 years, if effective monitoring and institutional controls could be maintained, and assuming the groundwater was not projected to be a drinking water source. After 17 years of natural flushing, enhanced by active remediation in the form of groundwater extraction, it is apparent that concentrations are not expected to achieve the prescribed regulatory standards within the 100-year time frame, and therefore a different strategy may be evaluated.
- **Active groundwater remediation:** Requires the application of engineered groundwater remediation methods, such as gradient manipulation, groundwater extraction, treatment, land application, phytoremediation, or in situ groundwater treatment to achieve compliance with the standards. Active remediation is the current compliance strategy in the Shiprock east terrace, where groundwater pumping was conducted from 2002 until 2017 (DOE 2002, DOE 2019b). A better understanding of the terrace system has been obtained over the remediation period regarding the existence of non-mill recharge sources to the terrace, as well as an understanding that groundwater that was pumped from terrace wells as part of the active groundwater remediation strategy contains contamination that is not mill related (DOE 2018a). There are areas in the east terrace that do contain mill-related contamination; groundwater from those areas was not pumped as part of the active remediation system, and therefore an alternate strategy may be employed to better target the plume for which DOE is

responsible. Active remediation is also a part of the floodplain compliance strategy, where groundwater extraction wells and infiltration galleries are used to reduce risk of exposure and enhance the pace of concentration reduction in combination with natural flushing.

2.2 Groundwater Compliance Action Plan Strategic Approach

This work plan presents DQOs that will be used to support the development of a revised GCAP. Several activities will be conducted to address the DQOs; these activities incorporate task-based data collection, which is primarily rooted in hydrogeologic and geochemical field work, as well as ongoing data collection that involves collaboration with external entities and some potentially longer-duration investigation efforts. The process that encompasses these activities, and by which the Shiprock revised GCAP will be developed, is shown in Figure 4. A site-specific GCAP development flow chart is shown in Figure 5. Five DQOs are identified as part of this work plan, which are detailed in Section 4.0.

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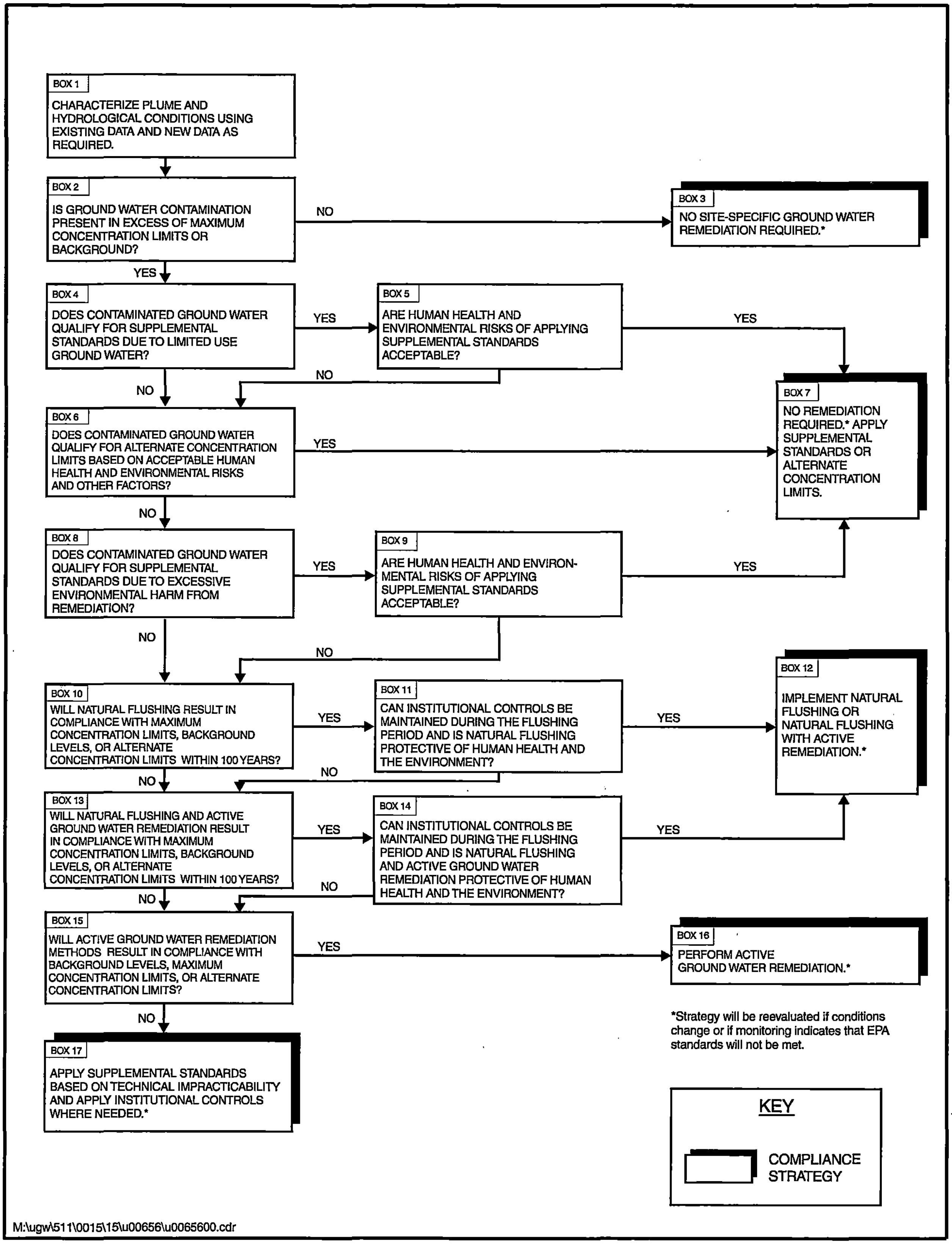

Figure 4. PEIS Compliance Selection Framework

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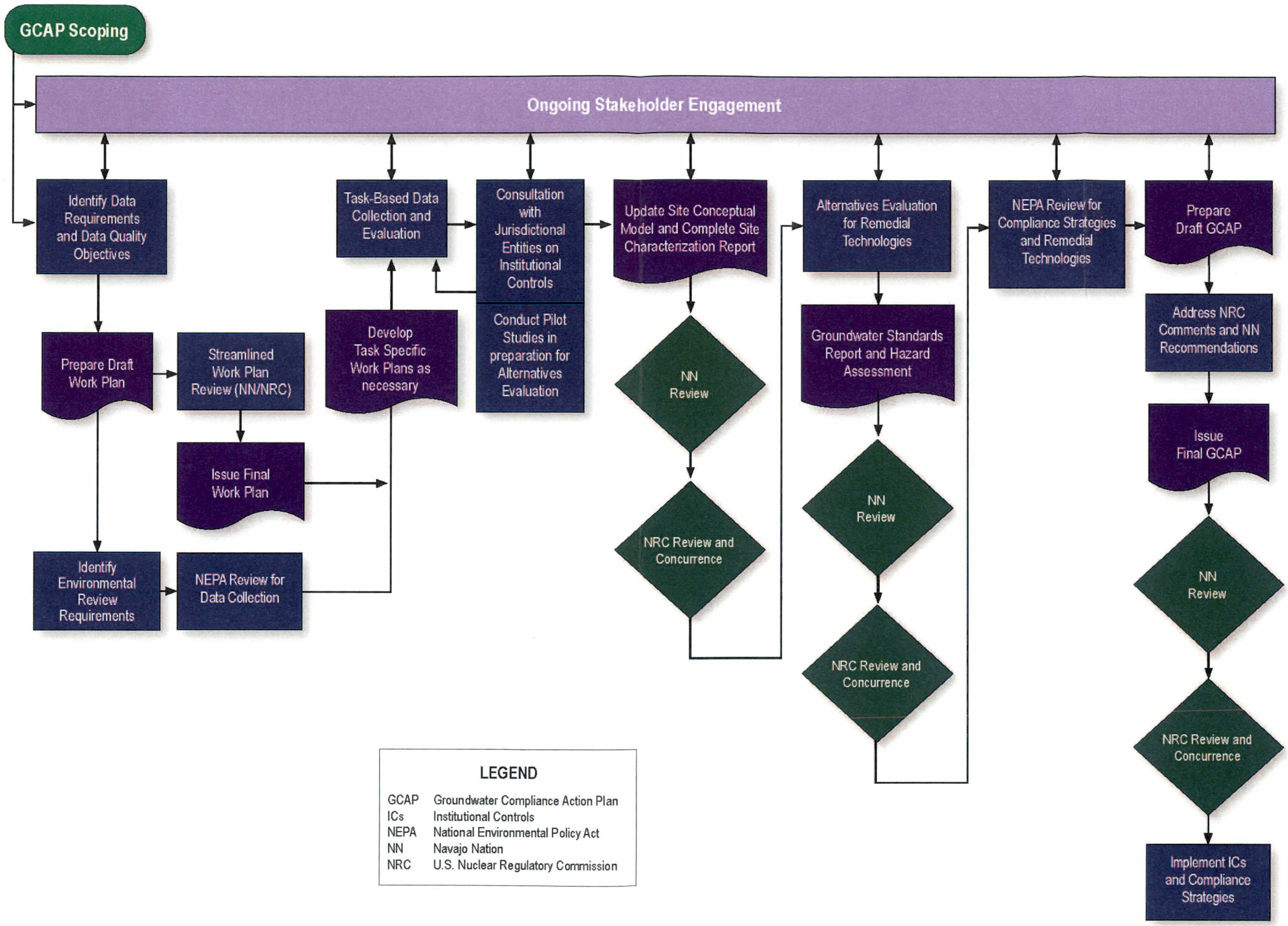

Figure 5. Shiprock Groundwater Compliance Flowchart

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3.0 Site Evaluations

The proposed field investigations discussed in this work plan, which are needed to support a revised GCAP for the site, were formulated based on a review of available data:

- Review and compilation of site geology and historical lithologic logs review and compilation into a three-dimensional (3D) lithologic model using the Earth Volumetric Studio (EVS) software.
- Evaluation and plotting of historical groundwater elevations.
- Review and evaluation of site investigations intended to characterize solid-phase contaminant mass.
- Review and evaluation of packer and pumping test results in the context of the boring logs at the site to determine field locations for further testing.
- Calculation of vertical gradients to evaluate what is known about potential connectivity between the terrace and floodplain Mancos Shale.
- Evaluation of uranium-234/uranium-238 ($^{234}U/^{238}U$) activity ratios and other indicating isotopic ratios to determine data gaps for understanding mill-related extent of contamination.
- Evaluation of historical concentration trends for nitrate, uranium, sulfate, and ammonium, as well as manganese, strontium, and selenium.
- Investigation of correlations between uranium and mill-related constituents.
- Application of the geochemical modeling program PHREEQC (Parkhurst and Appelo 2013) to perform limited geochemical evaluations, including determination of saturation indexes and calculation of retardation factors for uranium and nitrate transport.

The extent and duration of groundwater treatment required to achieve compliance standards will be determined using a 3D model that incorporates source mass, geochemical bulk plume metrics, and groundwater flow information. The most recent bulk plume metrics for the nitrate, sulfate, and uranium plumes have been updated using EVS software, and trend analysis was performed, as presented in Section 3.1. Major COCs (sulfate, nitrate, and uranium) are discussed first, followed by other constituents that are monitored as required by the approved GCAP, but are present at or below background concentrations and, therefore, evaluated for their relevance to mill-related groundwater compliance.

3.1 Analysis of Contaminant Occurrence and Distribution

The following section summarizes the current understanding of the dissolved COC plume metrics, developed through analysis of both semiannual groundwater sampling data and supplementary isotopic data collection (DOE 2012a, DOE 2012b, DOE 2017b, DOE 2018a). Bulk plume metrics presented herein were evaluated with 3D interpolation of temporal dissolved COC concentration data using EVS. Individual data points discussed in the text are approximate numbers derived from the data trends and do not necessarily represent exact data measurements in the field.

3.1.1 Sulfate

The background groundwater concentration of sulfate at the Shiprock site was reported in the 2002 GCAP to be 1432 mg/L from floodplain alluvium wells 0850, 0851, and 0852 between June 1999 and February 2000. The sulfate concentration of water from artesian well 0648 (screened within the Morrison Formation) was reported as high as 2340 mg/L (DOE 2002). Because of the continual discharge of artesian well 0648 to the floodplain aquifer through Bob Lee Wash, DOE proposed a cleanup goal of 2000 mg/L for the floodplain (DOE 2002). There are two potential sources of sulfate to groundwater at the Shiprock site. One source is naturally occurring and is related to the weathering of sulfate-bearing minerals within the Mancos Shale, which can potentially release high concentrations to groundwater. A second source of dissolved sulfate was related to the use of concentrated sulfuric acid during mill operation (Kamp and Morrison 2014). Mill-derived sulfate migrated to terrace groundwater by seepage from the tailings piles and raffinate ponds. Mill process fluids that infiltrated through the terrace alluvium and underlying Mancos Shale ultimately migrated with eastward-flowing groundwater across the escarpment and into the floodplain alluvial aquifer (DOE 2015). Contamination of the floodplain aquifer was also caused by direct surface discharge of mill effluent through unintended or accidental releases (DOE 2015).

3.1.1.1 Spatial Distribution of Sulfate

During the 2000 to 2003 baseline conditions prior to remediation, sulfate concentrations in groundwater exceeded the proposed cleanup goal throughout the floodplain and the terrace (Appendix A, Figures A-1 and A-2) (DOE 2016). In floodplain groundwater, higher concentrations of sulfate are located at the base of this escarpment, indicating a groundwater flow connection along the escarpment from the terrace to the floodplain (DOE 2018b). Since pumping began in 2006, sulfate concentrations within the treatment system's interpreted capture zone (DOE 2018b) have decreased considerably but are still elevated in comparison to those within the rest of the floodplain aquifer (Appendix A, Figure A-1).

Sulfate contamination in terrace groundwater is widespread. Most of the mass is within the non-mill-related area in the swale (Appendix A, Figure A-2). The $\delta^{34}S$ values less than –5‰ measured in several swale wells indicate that sulfate in the swale is naturally occurring. Within the mill-affected area, the alluvial wells are dry; therefore, there is a smaller dissolved sulfate plume. The highest concentrations of sulfate on the terrace occur adjacent to the disposal cell and in the swale where the mill's raffinate ponds were located (Appendix A, Figure A-2).

3.1.1.2 Sulfate Concentration Trends

Sulfate concentration trends in the Shiprock site floodplain and terrace groundwater vary. After 13 years of groundwater extraction from the floodplain, sulfate concentrations have generally decreased from the baseline period of 2000–2003 to 2018–2019 (Appendix A, Figures A-3–A-9). Wells within the interpreted floodplain treatment system capture zones (DOE 2018b) show a decrease in concentration over time. Most wells outside of the capture zones and at the mouth of Bob Lee Wash have no discernible trend or an increasing trend (Appendix A, Table A-1).

Mann-Kendall analysis indicated that 13 wells had a decreasing sulfate trend, 13 wells had no trend, and 14 wells had an increasing trend during the time period from 1999 to 2019 (Appendix A, Table A-2 and Figures A-10–A-14).

3.1.1.3 Sulfate Bulk Plume Metrics

Analysis of the sulfate bulk plume metrics for the floodplain alluvium shows a decrease in total plume mass from approximately 5 million pounds in 2007 to 4 million pounds in 2019 (Appendix A, Figure A-15). Average plume concentration decreased from 5500 to 4500 mg/L. Plume volume has slightly increased from 95 to 104 million gallons since pumping began in 2006 (Appendix A, Figures A-16 and A-17).

In contrast to that of the floodplain alluvium, the average sulfate plume concentration in the terrace alluvium has increased from approximately 5000 to 7500 mg/L (Appendix A, Figure A-18) from 1999 to 2019. Plume mass and plume volume initially increased but in 2004 began slowly decreasing (Appendix A, Figures A-19 and A-20).

3.1.2 Nitrate

The UMTRA-established MCL for nitrate at the site is 10 mg/L as nitrogen (N) or 44 mg/L as nitrate (NO_3^-). The two potential sources of nitrate in groundwater at the Shiprock site are related to the background concentration in the Mancos Shale and the mill-related contamination. During the milling processes, ammonium used to extract uranium from the ore body was discharged into the unlined raffinate ponds and converted to nitrate through contact with atmospheric or dissolved oxygen (DOE 2000).

3.1.2.1 Spatial Distribution of Nitrate

Nitrate concentrations in groundwater exceed the MCL in floodplain and terrace groundwater (Appendix A, Figures A-21 and A-22). Like with sulfate, the highest concentrations of nitrate in the floodplain are currently along the escarpment (Appendix A, Figure A-21). The nitrate plume within the floodplain remains along the southeastern edge of the escarpment, below the location of the former mill site on the escarpment, and at the mouth of Bob Lee Wash.

In terrace groundwater, most of the nitrate plume mass is within the non-mill-related area, with the highest concentrations below the former raffinate ponds (Appendix A, Figure A-22).

3.1.2.2 Nitrate Concentration Trends

Current nitrate concentrations throughout much of the floodplain are lower than they were in the 2000–2003 baseline period (Appendix A, Figures A-23–A-29). Most locations in the floodplain are already below the nitrate MCL. Concentrations in wells with nitrate concentrations above the MCL are decreasing, increasing, or have no discernible trend (Appendix A, Table A-3).

Nitrate concentrations exceed the MCL throughout the terrace (Appendix A, Figures A-30–A-34). Mann-Kendall analysis shows a decrease in concentration for most wells throughout the terrace. Of the 40 terrace wells evaluated, 15 are estimated to achieve the remedial goal of 10 mg/L by approximately year 2075 (Appendix A, Table A-4).

3.1.2.3 Nitrate Bulk Plume Metrics

Analysis of the bulk plume metrics for the floodplain alluvial aquifer shows a decrease in average plume concentration, plume mass, and plume volume. Since pumping began in 2006, average plume concentration has decreased from approximately 210 mg/L in 2007 to approximately 150 mg/L in 2019 (Appendix A, Figure A-35). During that period, mass decreased from approximately 40,000 to 15,000 pounds and plume volume has decreased from 22 million to approximately 12 million gallons (Appendix A, Figures A-36 and A-37).

The average plume nitrate concentration, estimated plume mass, and plume volume in the terrace alluvium aquifer have been variable between 1999 and 2019 (Appendix A, Figures A-38, A-39, and A-40). The updates to the site conceptual model will incorporate an evaluation of the significance of concentration variations and trends over time.

3.1.3 Uranium

Background concentrations for uranium in groundwater at the site can be distinguished from mill-related uranium by observing the $^{234}U/^{238}U$ activity ratio (Appendix A, Figure A-41). Background, or naturally occurring uranium, has a $^{234}U/^{238}U$ activity ratio greater than 2.0, whereas uranium that has been chemically purified during the milling process has a $^{234}U/^{238}U$ activity ratio of approximately 1.0. Background concentrations of uranium in groundwater at the site are a result of oxidative dissolution from the Mancos Shale. In contrast, mill-related uranium is sourced from the dissolution of uranium within the tailings piles and the infiltration of uranium from the raffinate ponds.

3.1.3.1 Spatial Distribution of Uranium

Uranium concentrations in groundwater exceed the MCL throughout the floodplain and most areas of the terrace (Appendix A, Figures A-42 and A-43). Relatively low uranium concentrations on the northwest portion of the floodplain are likely diluted from the discharge of Bob Lee Wash water onto the floodplain (DOE 2018b). 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 2018b). The highest concentrations of uranium on the floodplain consistently occur along the base of the escarpment and near the San Juan River at wells 0779 and 0857, within the interpreted treatment system capture zones (DOE 2011, 2018b).

The lowest concentrations of uranium in the terrace groundwater are in the non-mill-related, northern area (Appendix A, Figure A-43). The highest concentrations of uranium are within the mill-related area, adjacent to the disposal cell (Appendix A, Figure A-43). Uranium concentrations in groundwater are also above the MCL beneath the former raffinate ponds and within Bob Lee Wash where $^{234}U/^{238}U$ activity ratios are above 2.0, indicative of non-mill uranium (Appendix A, Figure A-41).

3.1.3.2 Uranium Concentration Trends

Despite the 13 years of groundwater extraction, current uranium concentrations remain as high as 1.3 mg/L within the floodplain and 2.3 mg/L within the terrace (Appendix A, Figures A-44–A-55). Overall, uranium concentrations throughout much of the floodplain have decreased (Appendix A, Figures A-44–A-50) whereas concentrations on the terrace remain nearly unchanged since 2006 (Appendix A, Figures A-51–A-55).

Mann-Kendall trend analysis shows that the current compliance strategy for the floodplain has been successful in decreasing the mass of the uranium plume (Appendix A, Table A-5). In general, neither an increasing nor decreasing trend in uranium concentration could be established for the majority of wells on the terrace (Appendix A, Table A-6).

3.1.3.3 Uranium Bulk Plume Metrics

Bulk plume metric analysis for the floodplain alluvium shows decreases in average concentration and plume mass. Compared to that of 2000–2003 baseline conditions (prior to remediation), average uranium concentration has decreased from 0.36 mg/L in 2007 to 0.22 mg/L in 2019 (Appendix A, Figure A-56); dissolved plume mass has decreased from 310 to 195 pounds (Appendix A, Figure A-57). Plume volume has fluctuated over time, staying around 100 million gallons (Appendix A, Figure A-58).

Within the Shiprock site terrace, the bulk uranium plume average concentration has slightly increased from 0.14 mg/L in 1999 to 0.17 mg/L in 2019 (Appendix A, Figure A-59). However, plume mass and volume have decreased since June of 1999. Plume mass has decreased from approximately 210 to 130 pounds (Appendix A, Figure A-60), and plume volume has decreased from approximately 175 million to 93 million gallons (Appendix A, Figure A-61).

3.1.4 Other Constituents

Selenium, manganese, ammonium, and strontium were listed in the 2002 GCAP as COCs (DOE 2002). These constituents are present at the Shiprock site above regulatory standards or background concentrations to a more limited degree than uranium, nitrate, and sulfate. A justification paper is in preparation for submittal to NRC in 2020 to recommend a reduction in the extent of monitoring of these constituents as site COCs.

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4.0 Data Quality Objectives

DQOs were developed for the revision of the Shiprock GCAP in general accordance with EPA guidance (EPA 2006). The DQOs encompass the data gaps that were identified through a review of the relevant site studies, available data, NUREG-1724 guidelines, and comments LM has received to date on Shiprock documents. The revision of the Shiprock GCAP will follow the DQO process, which is a systematic planning tool for developing scientifically sound and cost-effective data collection plans. Implementation of the DQO process for this work plan generally follows the seven major planning steps recommended by EPA:

[1] State the Problem
Define the problem that necessitates the study.

[2] Identify the Study Objectives
Develop study objectives and questions.

[3] Identify Information Inputs
Identify the data and information needed to address study questions and objectives.

[4] Define the Study Boundaries
Identify the spatial boundaries and temporal limits of the study.

[5] Develop the Analytic Approach
Identify parameters of interest and develop the logic for inference.

[6] Specify Performance and Acceptance Criteria
Develop performance criteria for new data being collected.

[7] Plan for Obtaining Data
Define the plan that meets performance criteria for obtaining the required data.

The DQO process elements for this work plan are described in detail in the following sections.

4.1 State the Problem

Evaluations of human health risks and ecological risks associated with contamination related to the Shiprock site are presented in the Baseline Risk Assessment (DOE 1994b) (BLRA) and the Supplement to the BLRA (1996b). The results of the BLRA human health risk assessment and the ecological risk assessment are summarized in the SOWP (DOE 2000). The summary states that unacceptable risks to humans would result only from the use of terrace or floodplain groundwater as a primary source of drinking water, and substantial human health risks are eliminated based on only agricultural irrigation and grazing uses. Ecological risks on the terrace were not identified to be significant, whereas nitrate, selenium, sulfate and uranium were identified as posing ecological risks within the Shiprock floodplain wetland with some potential uptake concerns in a few riparian plant species. Since the BLRA and SOWP were completed, COC groundwater concentrations in the Shiprock floodplain have declined, and the human health and ecological risks from seep water and consumption or other cultural use of vegetation need to be updated to reflect the current contamination levels in potential surface water expressions and the floodplain groundwater. Cultural uses of plants were not considered in the BLRA or BLRA supplement; this category of potential exposures should be considered as a part of enforcing institutional controls in the future.

The following problem statement was defined for this GCAP work plan:

> The groundwater compliance strategy outlined in the 2002 GCAP for the Shiprock site was based on the risk of mill-related contamination exposures as outlined in the BLRA and SOWP. The strategy consisted of the application of supplemental standards on the west terrace due to widespread ambient background contamination, natural flushing in the floodplain to reduce contaminant concentrations, and active remediation in the terrace to reduce groundwater elevations associated with the potential transport of contamination from the terrace to the floodplain. The active treatment system consisting of groundwater extraction and evaporation has operated for over 17 years, and the evaporation pond liner is aging, such that a decision is needed regarding its removal or replacement. Groundwater compliance has not been achieved over the treatment period and is not expected to be achieved within the regulatory time frames established in the 2002 GCAP. DOE is therefore undertaking an initiative to revise the GCAP, including a consideration of the range of currently available remedial technologies that could be implemented to achieve compliance and the range of institutional controls needed to protect human health and the environment based on a reassessment of current exposure risks.

4.2 Identify the Study Objectives

The following five study objectives (O1–O5) and associated study questions were developed for the GCAP work plan:

- O1: Define the source mass term and update the extent of mill-related uranium, nitrate, ammonium, and sulfate contamination.
  - — What is the extent of the mill-related uranium, nitrate, ammonium, and sulfate plumes?
  - — How do uranium, nitrate, ammonium, and sulfate concentrations in groundwater vary in the alluvium and the transmissive zone of the Mancos Shale?
  - — What is the total mass of COCs beneath the disposal cell, and what is the mass that is bound to saturated and unsaturated soils downgradient of the disposal cell that can serve as a persistent secondary source?
  - — What is the estimated loading rate and process for COCs from beneath the disposal cell and from identified persistent secondary sources to dissolve into groundwater?
  - — Is there a justification for removing selenium, strontium, or manganese from the COC list?
- O2: Characterize the hydraulic connection between the terrace and the floodplain.
  - — What are the vertical and horizontal hydraulic gradients in the terrace and the floodplain, and how do these hydraulic gradients vary temporally?
  - — What is the variability in thickness and permeability of the transmissive zone in the Mancos Shale, and how does the Mancos Shale control groundwater flow between the terrace and floodplain?
  - — Do existing surface water features including Bob Lee Wash and the terrace seeps discharge a significant amount of mill-related contaminant mass to the floodplain?

- O3: Evaluate how the hydrology of the floodplain impacts natural contaminant flushing or groundwater treatment.
  - — What is the variability in hydraulic conductivity and specific yield across the floodplain?
  - — Given the relatively high concentration of total dissolved solids (TDS) in groundwater, what is the impact of variable-density groundwater flow on COC transport in the floodplain?
  - — Are there preferential pathways of plume migration and locations of discharge to the point of exposure, the San Juan River?
  - — What are the seasonal and spatial variations in floodplain groundwater discharge to the San Juan River and recharge from the San Juan River?
  - — How does evapotranspiration vary across the floodplain, and does it significantly affect the flow of groundwater and transport of dissolved COC mass?
- O4: Determine whether remediation options other than groundwater extraction and evaporation are a viable alternative for groundwater compliance.

  The following questions are identified for the list of remedial alternatives that have been contemplated for the site thus far. This does not constitute a complete or final list and will be modified based on the initial literature review and compilation of the range of alternatives to be considered.
  - — What is the capacity of the existing groundwater extraction system to reduce contaminant concentrations, either through evaporation or through water treatment?
  - — What would be the capacity of an improved groundwater extraction network to reduce contaminant concentrations, either through evaporation or through water treatment?
  - — What is the expected site-specific attenuation capacity of the polyphosphate amendment to remove uranium from groundwater from the floodplain aquifer? Regarding potential injections of polyphosphate to precipitate uranium from groundwater, what are the anticipated changes in effective porosity, hydraulic conductivity, groundwater flow direction, and seepage velocity within and around the treatment zone?
  - — What are the limitations for applying polyphosphate at the site with respect to injectability, undesired changes in groundwater flow, long-term uranium sequestration, or potential adverse groundwater chemistry effects?
  - — What other amendments are potential alternatives for remediation if polyphosphate is not a viable option for the site?
  - — Are permeable or impermeable barrier technologies appropriate given the revised site conceptual model and fate and transport modeling for the site?
  - — Would groundwater extraction, treatment, and reinjection be viable and cost effective in the context of the revised fate and transport modeling and matured understanding of groundwater quality and hydrology at the site?

- — Can phreatophytes effectively remove COC mass from groundwater through transpiration such that (1) COC mass removed through transpiration cannot be released back into groundwater through recharge; and (2) phytoremediation could be successfully implemented as part of the overall remedial strategy?
- — What are the other viable remediation technologies that should be evaluated as feasible and appropriate alternatives to extraction and evaporation?

- O5: Define the range of appropriate institutional controls to be protective of human health and the environment.
  - — What is the risk-based need for grazing restrictions?
  - — What is the risk-based need for access restrictions associated with potential wildlife consumption or cultural use of plants?
  - — What is the ecological risk posed by concentrations at seeps and in groundwater?
  - — Can groundwater well permitting be structured to legally restrict any potable or irrigation wells from being drilled within the area of mill-related contaminated groundwater?
  - — What would be considered an appropriate point of compliance, or points of compliance, considering the source mass term, groundwater flow regime, COCs, background concentrations, and regulatory designations?
  - — What would be considered appropriate point(s) of exposure that would be monitored, given the known surface expressions of groundwater, potential surface expressions of mill contamination, and San Juan River–floodplain interaction?

4.3 Identify Information Inputs

The following information inputs were identified to meet each study objective. NRC responses to site-specific documents have been referenced in some instances to indicate where requests for additional information were made.

- **O1 Information Inputs:** Define the source mass term, and update the extent of mill-related uranium, nitrate, and sulfate contamination.
  - — Isotopic analysis and isotopic activity ratios from existing wells in Bob Lee Wash, the terrace, and the floodplain are needed to identify the geographic extent of mill-related groundwater (NRC 2019).
  - — Additional monitoring well or direct-push groundwater sampling locations are needed in the floodplain north of Bob Lee Wash to delineate the mill-related plume.
  - — Soil samples from the vadose and saturated zones are needed to derive the estimated location and mass of COCs in the subsurface (NRC 2003).
  - — Solid-phase and groundwater sampling in conjunction with new wells or a vibrating wire piezometer (VWP) installation near, within, or underneath the disposal cell is needed to estimate the mass flux from transient drainage or infiltration (NRC 2003).
  - — Concentrations of dissolved oxygen and ferrous and total iron are needed to simulate redox reactions that affect the fate and transport of COCs.

- **O2 Information Inputs:** Characterize the hydraulic connection between the terrace and the floodplain.
  - — Updated quantification of groundwater influx in seep areas between the terrace and the floodplain between Bob Lee Wash and Many Devils Wash is needed to estimate contaminant mass flux. Routine flow measurements from the 425/426 seep area should be collected, along with an evaluation of potential groundwater contribution from the infill areas on the terrace.
  - — Installation of a flume at the base of Bob Lee Wash to help quantify the amount of surface water contributed from the drainage. Bob Lee Wash is likely a combination of artesian water from well 0648 as well as potentially contaminated water generated upstream from the artesian well, and the relative contributions can be understood by monitoring flow from well 0648 as it enters Bob Lee Wash and where Bob Lee Wash enters the floodplain wetland (DOE 2018b). The site conceptual model can be updated to separate groundwater contributions from surface water contributions with this data.
  - — Evaluation of the flow regime within the Mancos Shale will address concern regarding groundwater flux from the terrace.
    - ➢ Installation of nested piezometers screened in the alluvium and the Mancos Shale along the escarpment and in the floodplain north of Bob Lee Wash, and potentially at the discharge point of the infill areas in the terrace, will determine the flow regime in the outlying area of the floodplain and along the potential flux areas from the terrace (NRC 2014, NRC 2015, NRC 2017).
    - ➢ Monitoring heads in existing and new wells screened exclusively in the Mancos Shale, near active alluvial pumping locations such as sumps 1109 and 1110 and extraction wells 1089 and 1104 are needed to establish hydraulic connectivity between the Mancos Shale and the alluvium (NRC 2014, NRC 2015, NRC 2017).
    - ➢ Packer testing and/or geophysical logging (caliper logs, heat pulse flow meter logs, and acoustic televiewer logs) of newly installed borings within the Mancos Shale to identify the distribution of transmissive fractures with depth and obtain estimates of their transmissivity (NRC 2014, NRC 2017).
- **O3 Information Inputs:** Evaluate how the hydrology of the floodplain impacts natural contaminant flushing or groundwater treatment.
  - — Review of temporal hydraulic head data across existing paired wells is needed to understand changes in vertical hydraulic gradient. Installation of VWPs in boreholes may be needed to compare heads from the upper, finer-grained alluvium with those of the lower gravel deposits.
  - — Pneumatic slug tests in various locations in the floodplain are needed to measure hydraulic conductivity at well screens or in profile with direct-push temporary piezometers (NRC 2017).
  - — Tabulation of water-level changes associated with the activation of wells 1089 and 0618 will provide hydraulic head data to calculate specific yield for these locations of the alluvial aquifer. Additional values are needed for comparison with the pumping test described in the SOWP, which is 1500 ft south of well 1089.

- — Calculation of equivalent freshwater heads from observed hydraulic head and TDS data is needed to assess potential variable-density transport of COCs.
- — Multispectral and red, green, and blue (RGB) imagery paired with San Juan River gauge data from USGS are needed to provide spatial estimates of evapotranspiration potential across the site, including on the terrace, in the washes, and in the floodplain.
- — Thermal imagery of the San Juan River during low-stage conditions in the winter to identify locations of potential groundwater discharge. A Trident probe survey is an alternative approach that collects point measurements of temperature and specific conductance between the San Juan River water and underlying San Juan River sediment pore water (NRC 2017).
- — Nested VWPs attached to dataloggers will be installed into the streambed to quantify and record hydraulic head and vertical hydraulic gradients in the potential groundwater discharge zones identified above (NRC 2017).
- — A limited seepage meter survey will be conducted at the VWP nest locations to collect specific discharge data over a period that is synchronous with the collected vertical hydraulic gradient data. A correlation will be developed from the synchronous specific discharge and vertical hydraulic gradient data. The correlation will allow for the continued estimation of specific discharge using the VWPs after the seepage meters are removed (NRC 2017, DOE 2018b).

- **O4 Information Inputs:** Determine whether remediation options other than groundwater extraction and evaporation are a viable alternative for groundwater compliance.

  The following inputs are identified for the list of remedial alternatives that have been contemplated for the site thus far. This does not constitute a complete or final list and will be modified based on the initial literature review and compilation of the range of alternatives to be considered for the site.

  - — A literature review and identification of a range of potentially reasonable alternatives for treatment must be performed.
  - — Column studies are needed to investigate the potential for polyphosphate or other amendments to attenuate uranium in groundwater. An understanding of application frequency, maximum groundwater velocity at application location, number of injections or surface applications required, application concentration, and potential for uranium remobilization is needed.
  - — The capacity for the floodplain alluvium and Mancos Shale to sorb COCs as a function of groundwater salinity needs to be characterized to understand the transport velocity of COCs through the floodplain alluvium and Mancos Shale. Distribution coefficients, K_d, will be quantified using site groundwater with high and low salinity and site soils without polyphosphate amendment.
  - — A thorough understanding of anticipated site-specific geochemical effects from injecting polyphosphate into Shiprock aquifer materials is needed.
  - — An understanding of potential changes in porosity and hydraulic conductivity is needed as a result of amendment injections into the floodplain alluvium. This will identify if precipitation or biofouling in the treatment area occurs, which might lead to undesired flow of groundwater and transport of uranium around the treatment area.

- Batch tests and/or column tests with alternate amendments may be needed to evaluate other remediation options, including bicarbonate application, treatment of extracted water, reinjection of treated water, and others. These may include active or passive water treatment systems such as ion exchange, membrane treatment, biological treatment (as in bioreactors or others), or a combination of processes.
- Hydrologic modeling and an understanding of source mass distribution are needed to determine whether a subsurface permeable or impermeable barrier wall would be effective in aiding groundwater treatment or hydraulic control of the site. Design parameters including basic geotechnical analysis and groundwater compatibility analysis are needed to qualify constructability and expected performance of any of these technologies.
- Water treatment process treatment requirements, waste generation, water storage or reinjection design, and hydraulic requirements need to be evaluated to determine applicability of treatment options.
- The applicability of phytoremediation as researched at the site needs to be evaluated within the context of the revised site conceptual model to determine its role as a part of the groundwater compliance strategy.
- Other inputs may be necessary after the full range of alternatives to be considered is identified.

- **O5 Information Inputs:** Define the range of appropriate institutional controls to be protective of human health and the environment.
  - Evaluation with the District 12 Grazing Committee, Navajo Land Department, and the U.S. Bureau of Indian Affairs (BIA) regarding the appropriate controls is recommended if grazing restriction is necessary to mitigate exposure risk.
  - Confirmation from the Navajo Nation Water Code Administration (NNWCA) is needed that groundwater wells for use other than monitoring or remediation will not be permitted within the areas of mill-related contamination, including the terrace and the floodplain.
  - Analysis is needed to determine which, if any, plants that grow on the floodplain are potentially utilized by the community for cultural or medicinal purposes.
  - An analysis of contaminant uptake in the plants on the floodplain and the terrace is needed to determine potential ecological or human exposures from cultural use, wildlife, or livestock consumption.
  - Analysis of COC concentration trends in terrace and floodplain wells relative to background concentrations will be utilized to assist in point of compliance location selection and determination of upper confidence limit for point of compliance determination.
  - Selection of background wells, points of compliance, and points of exposure will be predicated on findings in the Many Devils Wash reports (DOE 2012a, DOE 2012b, Robertson et al. 2016, DOE 2017b), the updated site conceptual model, and the horizontal and vertical delineation of mill-derived groundwater.

4.4 Define the Study Boundaries

The spatial boundaries of the study are different for each DQO. The horizontal study boundaries for objectives O1 through O3 will be determined in part by the establishment of the extent of mill-derived contamination in the floodplain. This will require an iterative approach; if wells and investigation points north of Bob Lee Wash in the floodplain demonstrate the presence of residual mill-related contamination, or that a groundwater flow divide is not fully controlled by Bob Lee Wash mounding, the extent of the O3 investigation will include that area. The boundaries of the investigation will include the following areas:

1. The terrace mill-related plume as demonstrated by the report titled *Investigation of Non-Mill-Related Water Inputs to the Terrace Alluvium at Shiprock, New Mexico*, including the escarpment between Many Devils Wash and Bob Lee Wash (DOE 2018a).
2. The floodplain area bounded by the San Juan River, the escarpment, and the two washes, or the area of the floodplain mill-related groundwater plume as it is defined by the new isotopic data.
3. Locations in the San Juan River between Many Devils Wash and the Highway 491 bridge, to address prior comments regarding the interactions between the floodplain and the River.

The vertical boundary for this study includes the alluvium in both the floodplain and the terrace mill-related plume extent, including the Mancos Shale and the hydraulically conductive unit at the top of the Mancos Shale, referred to as the "weathered Mancos." Interpretations from boring logs have indicated that the thickness of the "weathered," or transmissive zone, in the Mancos Shale typically varies between 5 and 10 ft above the top of the competent bedrock surface with some characteristics of weathering described as thick as 30 ft above the competent bedrock surface (DOE 2000).

Objective O4 boundaries will be defined by the extent of mill-related contamination and 3D-modeling efforts to demonstrate the predicted geographic extent of migration or plume changes for various remediation scenarios.

Objective O5 is bounded by the extent of mill-derived contamination and may include areas outside the mill-related plume as advised by community resources including NNWCA, Navajo Land Department, the District 12 Grazing Committee, and any local leaders that are engaged to address the DQOs presented.

4.5 Develop the Analytic Approach

This step of the DQO process includes defining the parameters of interest, determining appropriate parameter estimation methods, and developing decision rules. The EPA document titled *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA 2006) distinguishes between hypothesis testing and estimation approaches. The DQOs for this work plan primarily utilize estimation approaches rather than formal hypothesis testing. At the same time, the NRC guidance in *Standard Review Plan for the Review of DOE Plans for Achieving Regulatory Compliance at Sites with Contaminated Ground Water Under Title I of the Uranium Mill Tailings Radiation Control Act* (NRC 2000) informs some of the requirements for each specific groundwater compliance parameter. The following parameters of interest were defined for each objective.

- **O1 Parameters:** Define the source mass term, and update the extent of mill-related uranium, nitrate, and sulfate contamination.
  - The spatial distribution of uranium ($^{234}U/^{238}U$), sulfur ($^{34}S/^{32}S$), and oxygen ($^{18}O/^{16}O$) isotope concentrations at key locations within the understood groundwater plume to delineate mill-related contamination from background.
  - The spatial distribution of ($^{15}N/^{14}N$) and oxygen ($^{18}O/^{16}O$) isotopes to interpret the subsurface chemical reactions that could control plume movement.
  - Dissolved groundwater plume mass, center of mass, volume, and footprint concentration greater than 0.044 mg/L for uranium, 10 mg/L nitrate as nitrogen, and approximately 2000 mg/L for sulfate, relative to established background concentrations at the site.
  - Spatial distribution of uranium, nitrate, ammonium, and sulfate concentrations in soil and groundwater in various locations within floodplain.
  - Spatial distribution of uranium, nitrate, ammonium, and sulfate concentrations in soil and groundwater in terrace locations associated with the old milling footprint and disposal site.
  - Spatial distribution of dissolved oxygen and ferrous and total iron across the terrace and in the floodplain.
- **O2 Parameters:** Characterize the hydraulic connection between the terrace and the floodplain.
  - Seasonal flow rates at seep areas within the mill-related groundwater plume.
  - Mean daily flow rates at the mouth of Bob Lee Wash and Many Devils Wash.
  - Horizontal and vertical hydraulic gradients along the escarpment in the floodplain and terrace.
  - Hydraulic conductivity and transmissivity of identified zones of fracturing and weathering of the Mancos Shale.
  - The magnitude and direction of hydraulic gradients from measured groundwater elevations in the existing eight nested Mancos Shale wells in the floodplain, near the terrace.
  - Vertical hydraulic gradients between the Mancos Shale and floodplain alluvium across the study area.
  - Vertical hydraulic gradients between the terrace alluvium and collocated Mancos Shale wells.
- **O3 Parameters:** Evaluate how the hydrology of the floodplain impacts natural contaminant flushing or groundwater treatment.
  - Spatial and temporal variability in the orientation and magnitude of hydraulic gradients.
  - Variability in hydraulic conductivity both laterally and in profile in floodplain alluvium across the study area.

— Specific yield variability within floodplain alluvial aquifer.

— Equivalent freshwater heads within floodplain alluvial aquifer.

— Variability in evapotranspiration rates for all vegetated surfaces across the site.

— Spatial distribution of the potential locations of groundwater discharge into the San Juan River.

— Discharge and seepage rates through the San Juan River sediment.

- **O4 Parameters:** Determine whether remediation options other than groundwater extraction and evaporation are a viable alternative for groundwater compliance.

  The following parameters are identified for the list of remedial alternatives that have been contemplated for the site thus far. This does not constitute a complete or final list and will be modified based on the initial literature review and compilation of the range of alternatives to be considered for the site.

— Sequestration amendments:

  ➢ Optimal number, timing and concentration of amendments, effects on geochemistry at the site, attenuation capacity of amendments, and permanence of treatment.

  ➢ Changes in porosity, hydraulic gradient, groundwater velocity, and hydraulic conductivity associated with treatment.

  ➢ Cost-benefit analysis of treatment.

— Subsurface permeable or impermeable barriers:

  ➢ Hydrological effects of barrier placement.

  ➢ Groundwater chemistry effects on barrier composition, for either treatment purposes or groundwater flow impediment.

  ➢ Impacts to COC concentrations throughout the floodplain after installation of barrier.

  ➢ Permeable barrier amendment considerations, similar to chemical amendment considerations, including composition of backfill material, uranium treatment capacity, permanence of treatment, and hydraulic changes due to precipitation and other water quality effects.

  ➢ Geotechnical aspects of wall constructability and cap technology, if applicable.

  ➢ Cost-benefit analysis of installation and maintenance of the barrier wall.

— Water treatment and reinjection technologies:

  ➢ Optimal locations of groundwater extraction and reinjection.

  ➢ Breakthrough curves of treatment medium or process.

  ➢ Effective biological, chemical, or membrane treatment materials.

  ➢ Byproducts created as a waste stream from treatment process.

  ➢ Footprint and hydraulic design of potential treatment technology.

  ➢ Mass removed per unit of groundwater flow through treatment system.

  ➢ Cost-benefit analysis of treatment system.

— Phytoremediation:

- ➢ Comparing the spatial distribution of dissolved- and solid-phase COC concentrations with the spatial distribution of elevated evapotranspiration rates and seasonal horizontal hydraulic gradients.
- ➢ Consideration of grazing, cultural use, and overall vegetation management as evaluated through Objective 5.
- ➢ Cost-benefit analysis of phytoremediation.

The specific remediation technologies evaluated, along with the breadth and depth of their evaluation, may be subject to change pending results of site characterization studies and updated fate and transport modeling efforts. The remedial alternatives will be evaluated based on technical viability and compatibility with the site conceptual model, time to reach the groundwater compliance criteria, ability to reduce mobility and/or volume of the contamination, long and short-term effectiveness, and costs. Following the evaluation, viable alternatives will undergo detailed evaluations to identify the optimal alternative. Batch, pilot, field, or other tests may be required to further investigate options prior to the implementation of any remedial technology.

- **O5 Parameters:** Define the range of appropriate institutional controls that are protective of human health and the environment.

— Current and potential grazing and land use restrictions associated with areas with mill-related groundwater.

— Well permitting restrictions associated with areas with mill-related groundwater.

— Cultural plant usage of any plants encountered in areas with mill-related groundwater.

— Consumption of contaminants of concern present in water or plants consumed by wildlife or livestock in areas with mill-related groundwater.

— Background concentrations as statistically verified for each included COC.

Decision Rules

Some data collection activities will only be needed under certain circumstances. Decision rules must be developed to determine when those data collection activities are needed. The following decision rules apply:

DR1: If a higher spatial or vertical density of hydraulic conductivity data is required to implement a remedial technology than can be provided practicably through slug testing, additional methods of characterization will be considered for high-efficiency data collection.

DR2: If the acquired aerial thermal survey data cannot identify potential locations for groundwater to discharge into the San Juan River, a Trident probe survey will be conducted to identify potential groundwater discharge zones to guide the placement of seepage meters.

DR3: If a greater frequency of hydraulic head data is required during remedial alternative pilot testing, pressure transducers will be installed in relevant piezometers and wells.

DR4: If predictive simulations with a revised flow and transport model conclude that natural flushing will not achieve the remedial objectives within the allowable time frame, then a remedial alternatives evaluation will be performed.

Analytical Methods

O1: Spatial and temporal interpolation of the geochemical parameters will be the primary means of estimating primary source mass beneath the disposal cell, dissolved mass distribution, bulk plume metrics, and secondary sources of contamination on site soils beyond the limits of the disposal cell. Multivariate statistical methods (e.g., cluster analysis, principal components analysis), traditional geochemical techniques (e.g., Stiff and Piper diagrams), and geochemical modeling (e.g., PHREEQC) will be used to evaluate and interpret observed geochemical data.

O2/O3: Vendor-provided software will be used for borehole geophysical data derived from the hydrological investigation. Three-point estimation codes will be used to evaluate horizontal hydraulic gradient magnitudes and directions. Trident probe data, if generated, will be collected by the multiparameter meter directly. The remote-sensing methodology is described in Section 5.0 under Task 1.7. A pumping test analysis software (e.g., AQTESOLV or approved equivalent) will be used to estimate parameters from the pumping test and slug test results.

O4: Appropriate analytical methods will be highly dependent on the specific remedial options evaluated following site characterization and revision of the site conceptual model. Analytical methods may be extensive depending on the technology selected and will be defined at a later stage.

O5: Analytical methods regarding the institutional controls will not be necessary, except where they relate to risk assessment. Risk assessment methodology will be defined by the subject matter expert or institution that provides the assessment; those methods will be defined prior to the work and will be clearly stated in the relevant documentation. Institutional controls will be defined by the appropriate jurisdictional authorities, within the context of the risk assessment that DOE conducts regarding the anticipated levels of contamination.

4.6 Specify Performance and Acceptance Criteria

Performance and acceptance criteria are used to determine if the DQOs have been met. These criteria establish the acceptable range of error for parameter estimates.

O1: In general, contracted laboratory procedures will guide the acceptance criteria for data developed for both solid-phase and dissolved-phase contaminants. Laboratory quality assurance/quality control manuals develop protocols for acceptance or rejection of results and in some instances provide data that contain a qualifier. Where applicable, these qualifiers will be reviewed and metadata will be evaluated to determine whether specific data points should be deleted from a data set.

The determination of mill influence for groundwater and for soil will be made according to protocols developed for the Many Devils Wash data analysis, as well as those utilized in the recent terrace isotopic reporting (DOE 2018a).

Source mass estimates based on current empirical data from the field investigations and semiannual groundwater sampling will be compared with estimates of source mass derived from known site history, and processing information from the mill site, to confirm that the remaining source mass reflects reasonable site assumptions about the amount that would have been flushed or remediated thus far.

O2/O3: Work instructions and procedures will be developed for individual field programs by subject matter experts. Field geology will be observed and logged by a competent geologist, in accordance with established field procedures. Slug tests, pump tests, geophysical tests, and others will be performed through established procedures, work instructions, or industry-established methods if subcontracted. Hydrologic data will be compared with data obtained from prior field investigations. The new data will be analyzed by a qualified hydrogeologist who will ensure that new and existing data are incorporated and interpreted according to standard practice. Anomalous data or spurious results will be reviewed and eliminated, explained, or reduced as appropriate.

O4: Acceptance of viable remedial alternatives will be determined by the applicability of the alternatives to the site conditions, the time required to achieve the clean-up goals, the optimization of effectiveness, treatment permanence, implementability, and costs. The cost of a proposed remedial alternative will be compared with (1) the current and projected value of the pre-contaminated water resources, (2) the cost of continued monitoring, and (3) the risk of exposure associated with each remedial alternative.

O5: Determination of background concentrations, points of compliance, and points of exposure will be determined by the 95% upper confidence limit, upper tolerance level, or upper simultaneous limit of calculated existing concentrations and estimated future concentrations extrapolated from linear regression for scenarios covering the surveillance period.

4.7 Develop the Data Collection Plan

The data collection plan is presented in detail in Section 5.0. Data collection will occur as soon as is practicable. The order presented represents the proposed sequences, although some tasks may be rearranged for efficiency or logical reasons as the work progresses. As site data are compiled into a revised site conceptual model, study questions, associated data collection activities, and investigation locations may be subject to revision based on site conceptual model development.

- Task 1: Discrete field activities will be conducted to address site characterization updates:
  - Task 1.1: Groundwater isotopic analysis in floodplain and isolated locations in the terrace to establish full extent of mill-related contamination (applies to objective O1)
  - Task 1.2: Solid-phase geochemical sampling (applies to O1)
  - Task 1.3: Floodplain pumping tests with existing locations (applies to objective O3)
  - Task 1.4: Installation of piezometers in the floodplain (applies to objectives O2 and O3)

- — Task 1.5: Hydraulic conductivity testing and elevation confirmation in existing and new piezometer locations (applies to objectives O2 and O3)
- — Task 1.6: Baseline aerial survey including light detection and ranging (lidar), RGB, multispectral, and thermal technologies (applies to objective O3)
- — Task 1.7: Trident probe survey along floodplain with subcontractor (applies to objective O3)
- — Task 1.8: Seepage meter survey (applies to objective O3)
- — Task 1.9: Construction of flume in Bob Lee Wash and quantification of seeps (applies to objective O2)
- — Task 1.10: Disposal cell source mass investigation (applies to objective O1)

- Task 2: Additional activities will be conducted both during and after the discrete field investigations to prepare for selection of remedial technologies and appropriate institutional controls:
  - — Task 2.1: Coordination with external entities (applies to objective O5)
    - ➢ Administration of the GCAP with Navajo Abandoned Mine Lands/Uranium Mill Tailings Remedial Action (NNAML/UMTRA) Program
    - ➢ Consultation regarding grazing restrictions with District 12 Grazing Committee and BIA
    - ➢ Consultation on land use restrictions with Navajo Land Department, BIA, and Shiprock Planning Committee
    - ➢ Vegetation risk assessment with Argonne National Laboratory and local cultural leadership
    - ➢ Coordination with NNWCA on well permitting restrictions
    - ➢ Consultation regarding technical stakeholder concerns with the Navajo Nation Environmental Protection Agency (NNEPA)
  - — Task 2.2: Sequestration column studies (applies to objective O4)
  - — Task 2.3: Sorption studies (applies to objectives O3 and O4)
  - — Task 2.4: Remedial alternatives evaluation of viable remedial technologies to address groundwater compliance requirements (applies to objective O4)

Addenda will be added to this work plan to further detail locations and field methodologies selected for each of the tasks. If additional required tasks are identified to complete the site characterization, risk evaluation, and remedial alternative selection for the revision of the GCAP, a description of those tasks and objectives will also be added to this work plan.

Locations and methodologies selected may be revised as data are evaluated and as field programs progress. Minor adjustments to the tasks identified herein will be recorded and reported as part of the GCAP as applicable but may not require the completion of an addendum to the work plan. The locations and data presented herein are approximate and, therefore, may not constitute a complete list of those necessary for the revised GCAP document.

5.0 Data Collection

The data collection effort to address the DQOs will consist of various field efforts and methodologies. If possible, various methodologies will be combined in fewer field efforts if efficiencies and safe execution can be realized. The individual tasks that have been identified are described in this section.

5.1 Data Collection: Site Characterization Activities

The field investigation to support the DQOs consists of multiple tasks as described below. These tasks are listed for each category in anticipated schedule sequence, which is subject to change. As site data are compiled into a revised site conceptual model, study questions, associated data collection activities, and investigation locations may be subject to revision based on site conceptual model development.

5.1.1 Task 1.1: Groundwater Isotopic Analysis in Floodplain and Isolated Areas in the Terrace to Establish Full Extent of Mill-Related Contamination

Uranium, nitrogen, and sulfur isotopic analyses, along with associated water quality parameters, will be conducted on samples collected at select existing monitoring wells to help address study objective O1 (Section 4.2). Redox conditions will be determined in the field by analyzing ferrous iron via colorimeter and dissolved oxygen via low-flow sampling equipment. Groundwater chemistry and isotopic data from selected locations will delineate the lateral extent of the mill-related groundwater contamination at the site. Investigations have been completed in Many Devils Wash, as well as in some locations on the terrace, which have demonstrated that groundwater contamination is generated from widespread ambient background levels associated with natural subsurface materials, rather than from the mill activities or the disposal cell. Similar isotopic analysis has not been performed in the floodplain to date. A few locations in the terrace and in Bob Lee Wash have been identified along with the floodplain locations to address specific data gaps identified and inform fate and transport modeling. Those locations are presented in Figure 6.

The isotopic analyses will be conducted in the field (Fe^{2+}) or by an accredited laboratory by the methods identified in the following table:

Analyte	Method	Detection Limit
Nitrogen isotopes	Mass spectrometry	N/A
Fe^{2+}/total iron	Hach Ferrous Method 8146 – 1,10-Phenanthroline Method, EPA SW-846 6020.	Ferrous iron: 0.2 mg/L Total iron: 0.1 mg/L
Sulfur isotopes	Mass spectrometry	N/A
Uranium isotopes	Alpha spectrometry	0.1 pCi/L

Abbreviations:
Fe^{2+} = iron(II)
N/A = not applicable
pCi/L = picocuries per liter

Samples will be preserved, containerized, and shipped in accordance with the *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (SAP) (LMS/PRO/S04351).

Figure 6. Sampling Locations Identified for Isotopic Analysis

5.1.2 Task 1.2: Solid-Phase Geochemical Sampling

Solid-phase samples will be collected at various locations within the mill-related plume area to determine the existence and amount of residual contamination that may be bound to soil and bedrock above and below the water table. These samples will provide information regarding the potential for a secondary source of contamination that was not eliminated by capping of the tailings or by decommissioning of the former milling operations and raffinate ponds. Vadose zone and saturated zone samples will be taken at discrete intervals between the ground surface and the Mancos Shale interface. Samples will be evaluated for major cations, uranium, selenium, strontium, sulfate, manganese, iron, chloride, nitrate, and total organic and inorganic carbon. It is currently anticipated that samples will be obtained from boreholes completed as part of the field hydrological investigation (O2 and O3) that will progress until bedrock is encountered, or the onsite geologist confirms total depth of borehole necessary per location. Locations for solid-phase sampling are anticipated to be primarily collocated with slug testing locations in the floodplain. Terrace locations are anticipated to primarily be collocated with new well installation areas. Solid-phase and aqueous samples associated with investigations of the disposal cell area will be discussed as part of Task 2.5. Proposed locations are given in Figure 7 and Figure 8.

The analyses will be conducted by the methods identified in Table 2 and Table 3.

Table 2. Analytical Methods for Groundwater Geochemical Analytes

Analyte	Required Detection Limit (mg/L)	Analytical Method
Ammonia as N (NH_3–N)	0.1	EPA 350.1
Calcium	5	EPA SW-846 6010
Chloride	0.5	EPA SW-846 9056
Iron	0.1	EPA SW-846 6020
Magnesium	5	EPA SW-846 6010
Manganese	0.005	EPA SW-846 6010
Nitrogen isotopes	N/A	Mass spectrometry
Nitrate + nitrite as N (NO_3+NO_2)–N	0.05	EPA 353.1
Oxygen isotopes	N/A	Mass spectrometry
Potassium	1	EPA SW-846 6010
Selenium	0.0001	EPA SW-846 6020
Sodium	1	EPA SW-846 6010
Strontium	0.2	EPA SW-846 6010
Sulfate	0.5	EPA SW-846 9056
Sulfur isotopes	N/A	Mass spectrometry
Tritium	400 pCi/L	Liquid scintillation
Uranium isotopes	0.1 pCi/L	Alpha spectrometry
Uranium	0.0001	SW-846 6020

Abbreviations:
N/A = not applicable
pCi/L = picocuries per liter

Table 3. Analytical Methods of Solid-Phase Geochemical Analysis

Analyte	Required Detection Limit (mg/kg)	Analytical Method
Percent moisture	N/A	ASTMD2216MODFD
Iron	7.97	EPA SW-846 6010
Magnesium	8.47	EPA SW-846 6010
Manganese	0.199	EPA SW-846 6010
Sodium	6.97	EPA SW-846 6010
Calcium	7.97	EPA SW-846 6010
Uranium	0.0131	EPA SW-846 6020
Selenium	0.357	EPA SW-846 6020
Sulfate	1.29	EPA SW-846 9056
Chloride	0.697	EPA SW-846 9056
Nitrate as nitrogen	0.320	EPA SW-846 9056
Total organic carbon	200	EPA SW-846 9060
Total inorganic carbon	500	EPA SW-846 9060

Abbreviation:
N/A = not applicable

5.1.3 Task 1.3: Floodplain Pumping Test with Existing Locations

Pumping tests will be conducted using wells 1089 and 0618 as pumping wells. Combined with slug testing results and the previous pumping test at well 0858, the additional pumping test data will contribute comparative data toward understanding the variability of hydraulic conductivity across the floodplain and assessing the hydraulic communication between the alluvial aquifer and Mancos Shale.

All pumping tests will be conducted for approximately 1 week with water levels monitored in adjacent wells with pressure transducers. After approximately 1 week of continuous pumping—or until the measured drawdown in nearby monitoring wells has approached steady state—the pump will be shut off and groundwater level recovery will be monitored and recorded. Analysis of the drawdown and recovery phase will provide specific yield and transmissivity data in the vicinity of the observation wells around the pumping well. Locations proposed for pumping test extraction wells and monitoring locations are shown in Figure 7.

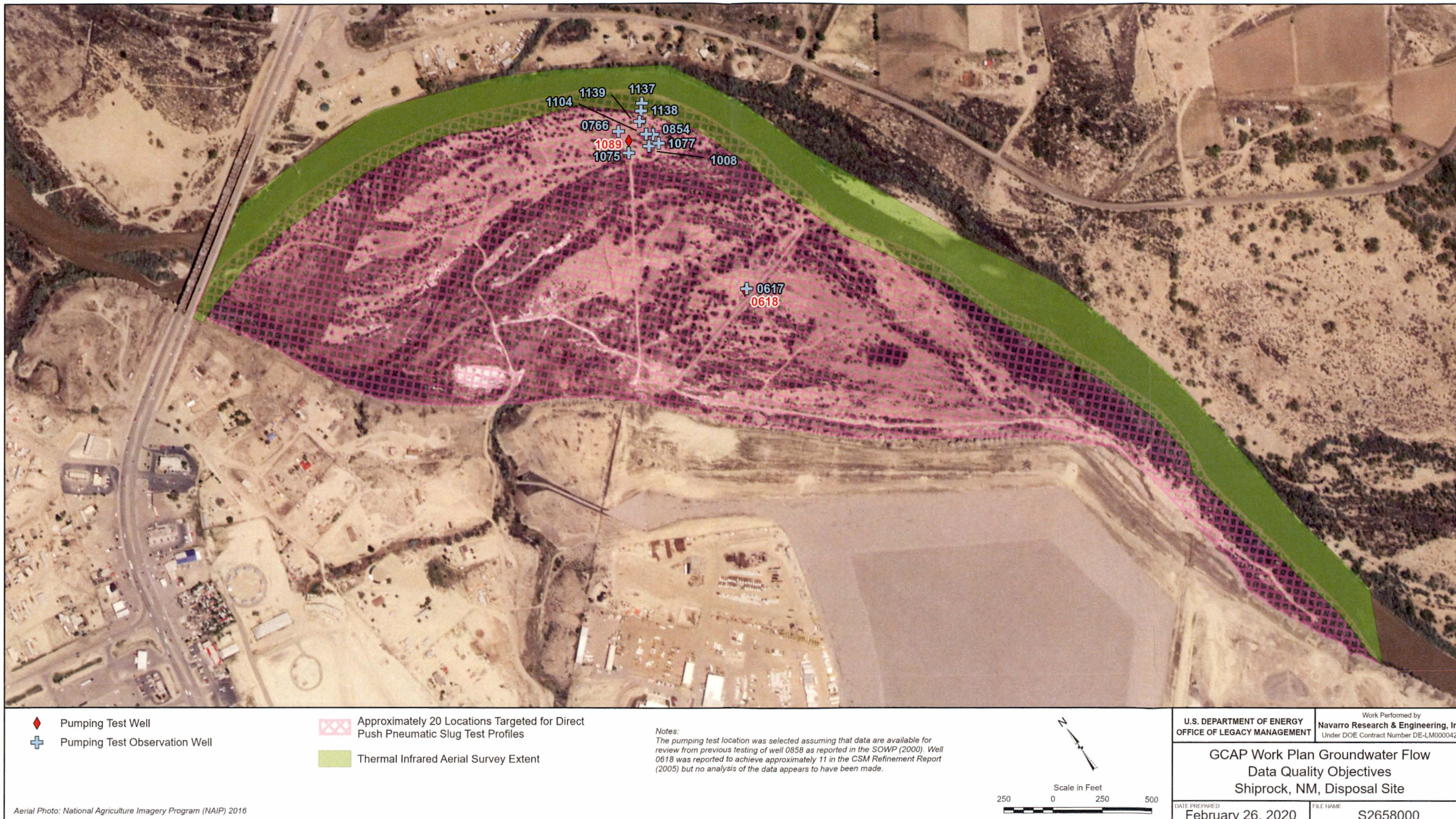

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Figure 7. Shiprock Site Extent of Hydraulic Conductivity Investigation with Candidate Locations

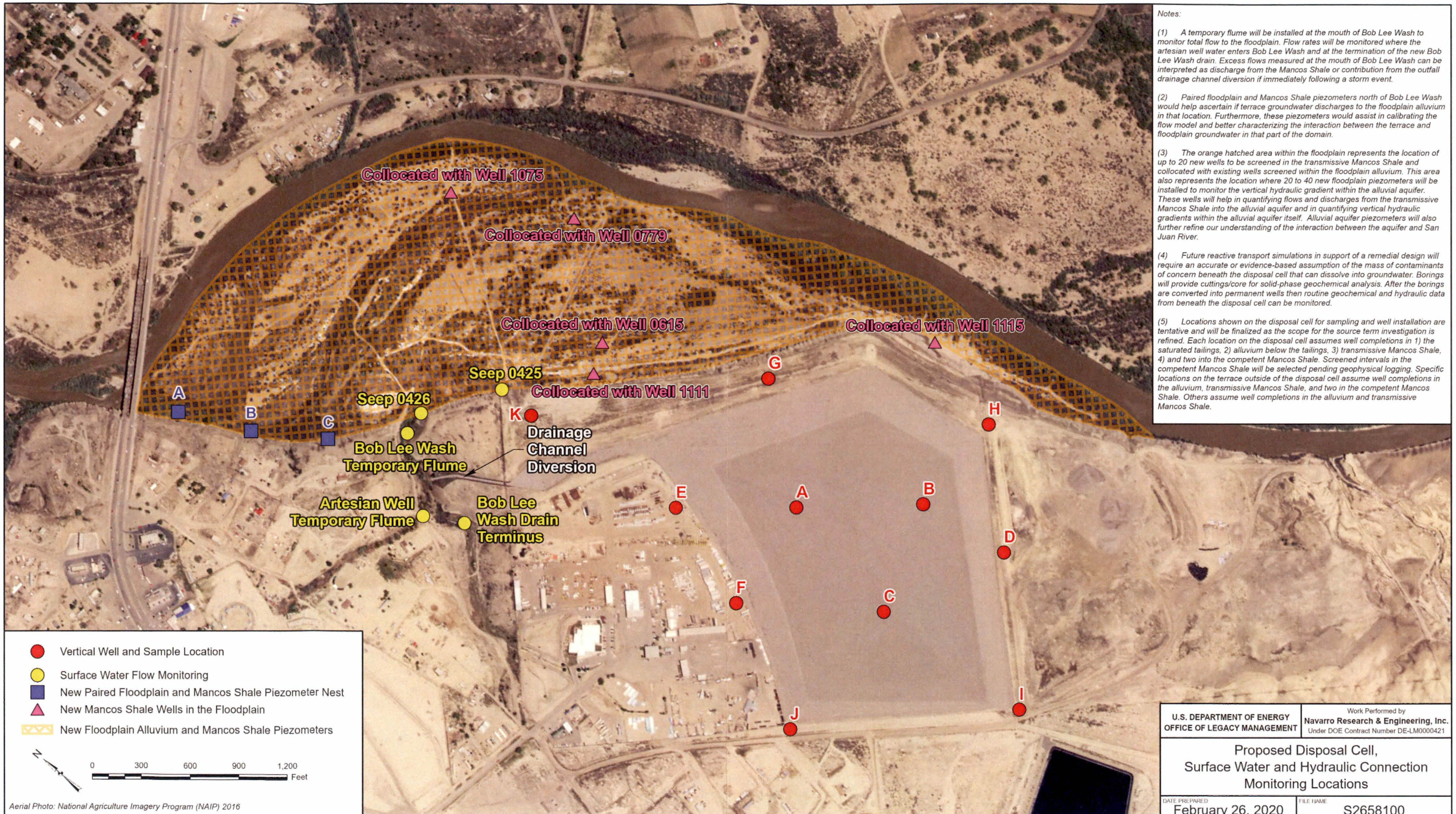

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Figure 8. Shiprock Site Terrace–Floodplain Connectivity and Disposal Cell Investigation Locations

5.1.4 Task 1.4: Installation of Piezometers in the Floodplain

Piezometers will be installed to achieve the following objectives:

1. Characterize the thickness, hydraulic conductivity, and both horizontal hydraulic gradients within and vertical hydraulic gradients across the transmissive zone in the Mancos Shale. Very limited data currently exist to evaluate the role of the Mancos Shale in the transport of COCs and interaction with the floodplain alluvium.
2. Augment the existing floodplain alluvium well network such that vertical hydraulic gradient data can be collected with well pairs that do not have overlapping screened intervals.
3. Collect hydraulic conductivity data in profile across the floodplain (See Task 1.5).

If there is insufficient vertical separation of screened intervals in paired existing floodplain alluvial wells to obtain reliable vertical hydraulic gradient data, then VWPs or screened piezometers with 2 ft screens will be installed to allow for a calculation of vertical hydraulic gradients at each location. Where sufficient vertical separation exists among existing well screens, pressure transducers can be deployed to obtain water-level data for hydraulic gradient calculation. It is anticipated that direct-push drilling (e.g., Geoprobe or approved equivalent rig) can install the proposed piezometers with screens that are sufficiently short (~2 ft) to prevent overlapping elevations in the relatively thin alluvium. Piezometers that cannot be installed using a direct-push rig may be installed through rotasonic or mud rotary drilling methods as necessary. The deepest piezometer will be installed at the depth of drilling refusal (or top of the Mancos Shale), and shallower piezometers will be installed up to approximately 10 ft above the deepest screen depth.

Information from the piezometers will be incorporated into the site conceptual model, including both data captured during installation and data that is monitored over the months following installation. If remote monitoring is required for remedial technology pilot testing or design, temporal variations in hydraulic gradients can be available via real-time pressure data communicated through Systems Operations at Remote Sites (SOARS) telemetry.

Nested piezometers with varying screen depth intervals in the floodplain area along the base of the escarpment will monitor heads and help establish hydraulic gradients where dissolved contaminants potentially discharge from the terrace to the floodplain. Nested piezometers adjacent to or within the river sediments will provide the same information regarding potential discharge of dissolved contaminants from the floodplain to the San Juan River. Three nests of alluvial and Mancos Shale piezometers exist in the floodplain near the escarpment immediately north and northeast of the disposal cell, which will be monitored with the new locations. A minimum of two new piezometer nests will be installed at the base of the escarpment with wells screened in the alluvium and Mancos Shale. One nest is proposed near surface sampling location 0655, approximately 1400 ft north of Bob Lee Wash. A second nest of piezometers is proposed within or around 500 ft northwest of where Bob Lee Wash enters the floodplain. A third piezometer nest is proposed between the two nests mentioned above, around the discharge point from the former artesian well channel (Figure 8). Alluvium wells will likely be screened at less than 20 ft depth as indicated by the observed contact with the Mancos Shale in floodplain boring logs. Up to 20 additional shallow Mancos Shale piezometers are proposed for installation into the floodplain and will be paired with existing alluvial wells to help characterize vertical hydraulic gradients away from the terrace (Figure 7). The screened interval of the Mancos Shale wells should be determined after geophysical logging of rock core and within the context of observations of likely transmissive fractures or the degree of weathering.

5.1.5 Task 1.5: Hydraulic Conductivity Testing and Elevation Confirmation in Existing and New Piezometer Locations

Limited packer and pump testing were conducted as part of the SOWP (DOE 2000), and this provided a basis for the hydraulic conductivity of the Mancos Shale and the alluvium but does not provide an estimate of variability. Slug testing new and existing wells will provide information regarding the variability of hydraulic conductivity across the site. Packer tests will be conducted at select locations to provide transmissivity data. Understanding the variability of hydraulic conductivity will inform calculations/simulations of COC fate and transport, evaluate remedial alternatives, and assess the performance of selected remedial actions recommended with the revised GCAP.

A combination of existing well locations and new piezometers will be slug tested to develop information regarding hydraulic conductivity or transmissivity at various depths. Any existing monitoring well locations utilized will need to be redeveloped prior to hydraulic conductivity testing. Establishing the variability of hydraulic conductivity with depth in the floodplain alluvium will also be accomplished with slug test profiling using temporary piezometers advanced with a direct-push rig. Slug test profiling will require the advancement of a temporary piezometer to the desired depth below the water table. The piezometer's screen is shielded during the advancement stage, and once the desired depth is reached, the shielding is retracted to expose the screen to the formation and the temporary piezometer is developed. Once developed, a pneumatic slug test manifold is attached to the drill rods and a slug test is conducted. The temporary well is then removed, and the hole is abandoned. The rig will offset a few feet and advance a collocated temporary well at a lower depth, and the slug test is repeated.

The number of pneumatic slug tests conducted for a single depth profile will depend upon the piezometer screen length, thickness of saturated alluvium, and depth of encountered refusal. A total of 20 nested profile locations are proposed for pneumatic slug testing with temporary wells. Data will be compiled from the slug testing results and statistically summarized for each hydrostratigraphic unit in accordance with NUREG-1724 guidelines (NRC 2000).

5.1.6 Task 1.6: Baseline Aerial Survey Including Lidar, RGB, Multispectral, and Thermal Sensors

Aerial survey data will accomplish four objectives:

1. Provide high-resolution surface elevation data using lidar for 3D geological and groundwater flow and transport models as well as providing a valuable input for future design work.
2. RGB imagery data will provide a high-resolution photograph of the area that will support future design, risk assessment, and provide context if questions arise regarding spatial extent of any site infrastructural or natural features.

3. Multispectral imagery collected by satellite will be used to provide evapotranspiration estimates across the site.

4. Thermal imagery along the San Juan River bank at the floodplain, as well as the base of the escarpment, will be used to identify potential groundwater discharge locations (seeps) along the escarpment in the floodplain and within the San Juan River.

Aerial Survey

The aerial survey shown in Figure 9 for the site will collect lidar data that will be used to generate an elevation point cloud across the site during the summer. RGB aerial survey data will be collected in the summer months during the peak growing season. The survey vendor will provide the data associated with the survey event after validation and postprocessing. RGB data will be used to provide a high-resolution photo for the site, as well as important data for estimating evapotranspiration (ET) following the methods described in Glenn et al. (2016), Groeneveld et al. (2007), Jarchow et al. (2017), or methods currently in development, which will be described in the reporting.

The evaluation area is shown in Figure 9 and encompasses Shiprock features including the disposal cell, the floodplain, Bob Lee Wash, the evaporation pond, and as an option, Many Devils Wash.

Evapotranspiration Modeling

A watershed-scale evapotranspiration evaluation will be performed to inform Objectives O2 and O3, as well as future remediation efforts. Evapotranspiration exhibits diurnal, seasonal, and long-term trends on groundwater elevations that locally affect groundwater flow and contaminant fate and transport.

Evapotranspiration and groundwater uptake potential were evaluated over several years in phytoremediation pilot study areas on the terrace, including plots immediately upstream of the escarpment and to the west of the evaporation pond in the radon barrier borrow pit (DOE 2017a). As part of a separate but related study, Unmanned Aerial System imagery collected by USGS in 2016 was used to delineate vegetation zones on the Shiprock floodplain. The delineated vegetation zones were used to extract 30-meter resolution, LANDSAT satellite-based evapotranspiration estimates of tamarisk plants across the Shiprock floodplain for years 2000–2018. To provide a more precise, spatially explicit estimate of evapotranspiration on the floodplain, high-resolution commercial satellite imagery (<2 meter) will be applied to an empirically calibrated evapotranspiration (ET) algorithm. The specific existing remote-sensing algorithm used to estimate evapotranspiration will be dictated by the multispectral satellite sensor used. The algorithm will be regionally appropriate and based on an empirical relationship between evapotranspiration of riparian phreatophytes, as measured by eddy covariance, Bowen ratio, or lysimetry, and a vegetation index (measure of greenness) derived from a multispectral satellite sensor.

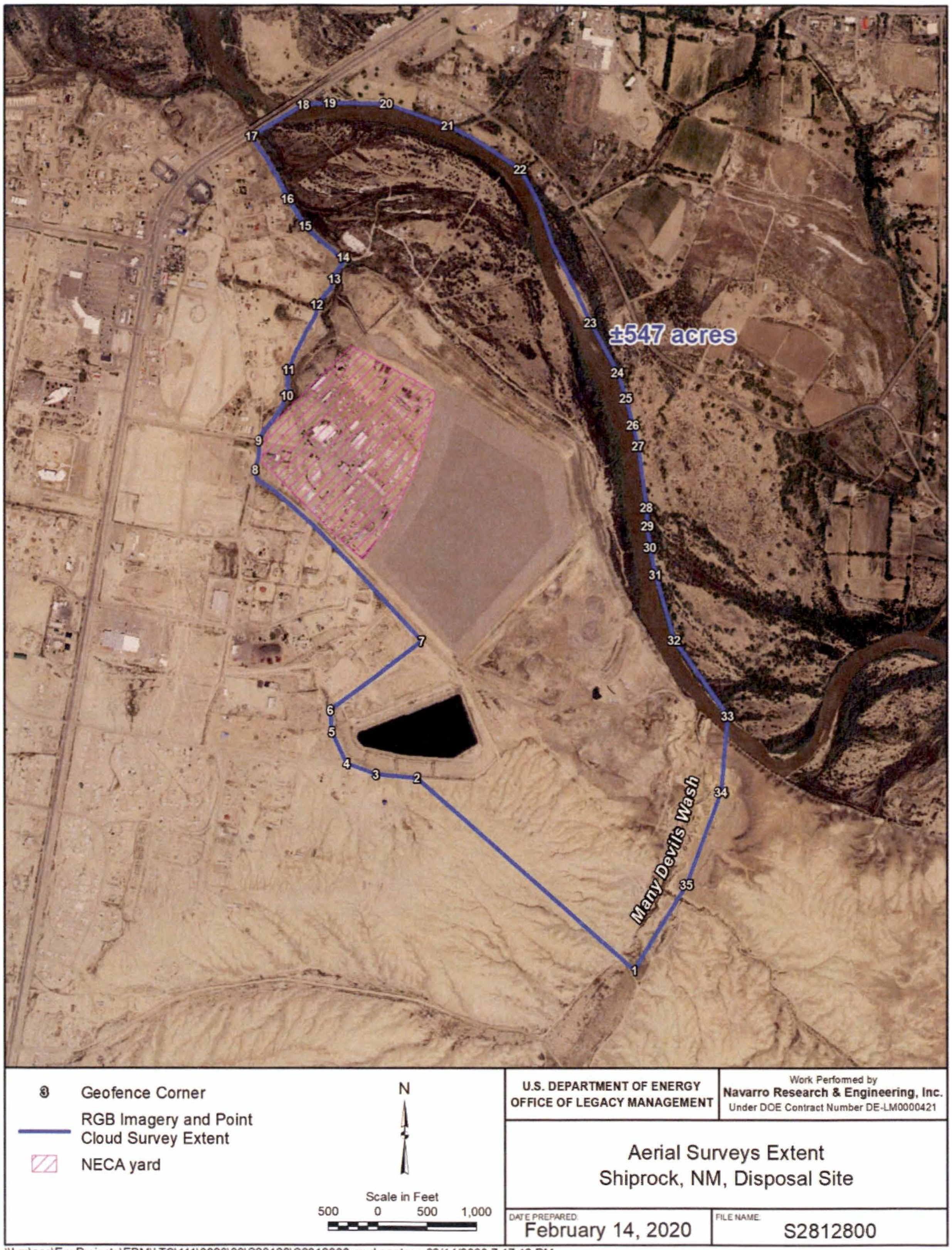

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Figure 9. Aerial Surveys Extent

The plant delineations derived from the tamarisk evaluation will be updated with the new high-resolution RGB imagery. The product will be a map of discrete functional vegetation zones. These functional zones will represent those plant species that are of direct interest in groundwater flow and transport modeling—species that directly use groundwater (phreatophytes) and those that extract water from the vadose zone (upland plants).

Aerial Infrared Survey

For identifying where groundwater may be preferentially discharging into the San Juan River, infrared (thermal) aerial survey data will be collected over the river and along the southern bank. This thermal data will be collected during the winter months (December to February) when the San Juan River stage reaches a seasonal low, the potential for groundwater discharge is high with upward hydraulic gradients, and the thermal contrast between the relatively warm groundwater and the relatively cold San Juan River water is greatest (Figure 10). The low flows in the San Juan River during the winter months should minimize the mixing with discharged groundwater to maximize the potential to observe thermal gradients in the aerial imagery. If a thermal gradient is observed, it will inform installation locations for seepage meters, along with nested VWPs. Targeted locations will be chosen based on the areas with the largest observed thermal gradients. Targeted locations may also include other areas where lower thermal gradients are observed if the groundwater temperature signal is believed to have been attenuated by enhanced mixing with surface water or riverbed depth.

Thermal survey is anticipated to also include an evaluation of the base of the escarpment, where any thermal gradients observed may indicate areas of flux from the terrace to the floodplain. Similar methodology and analysis will be conducted for the floodplain.

5.1.7 Task 1.7: Trident Probe Survey

If thermal imagery data cannot be collected or if the imagery data collected requires additional confirmation, a Trident probe survey will be conducted to further identify areas of potential groundwater discharge into the San Juan River. The Trident probe is a manually pushed, multisensor probe that simultaneously measures specific conductance and temperature from both shallow pore water and surface water samples collected using low-flow sampling protocols. Differences in observed conductivity and temperature indicate areas where groundwater discharge may be occurring. A boat will be deployed under low-stage conditions in the San Juan River when upward hydraulic gradients are expected and the thermal contrast between the shallow pore water and surface water is greatest. The locations selected will be within the extent identified by the thermal aerial imagery survey in Task 1.7, or wherever spatial data coverage needs dictate.

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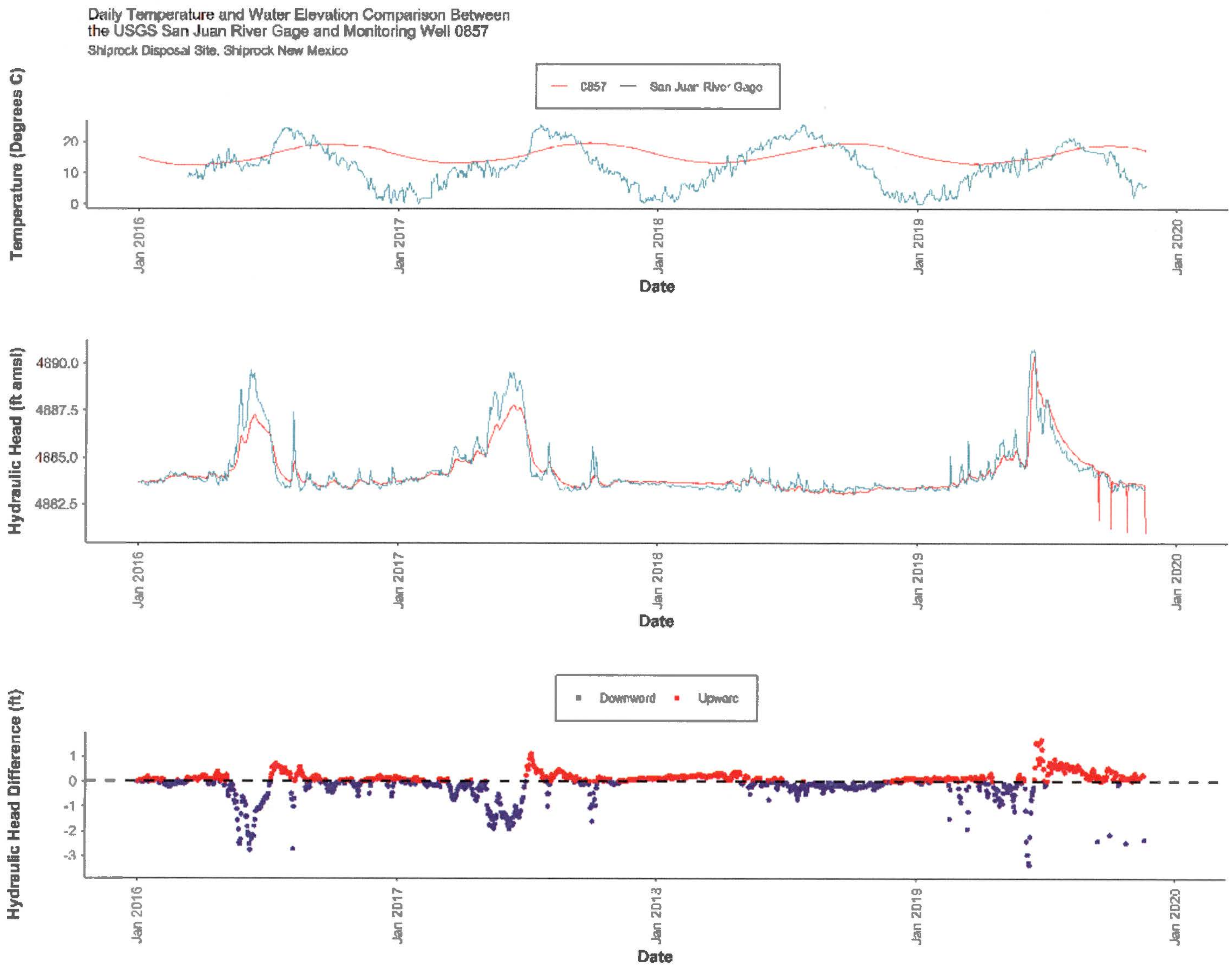

Figure 10. Daily Temperature and Water Elevation Comparison Between the USGS San Juan River Gage and Monitoring Well 0857

5.1.8 Task 1.8: Seepage Meter Survey

Aerial thermal survey or Trident probe results will identify potential areas where groundwater may be preferentially discharging to the San Juan River. Quantifying the exchange between the San Juan River and the shallow pore water will be done using ultrasonic seepage meters and nested VWPs. The ultrasonic seepage meter uses an ultrasonic flow sensor attached to a large funnel that is secured to the river bed. The ultrasonic flow sensor allows for the precise quantification of seepage rates (as specific discharge) at 15-minute intervals. The number of seepage meter locations will depend upon the results of Task 1.7 or Task 1.8, and the testing duration of each seepage meter location will be approximately 72 hours. The goal is (1) to provide robust estimates of total groundwater discharge along the San Juan River; and (2) directly observe and understand the temporal variations in groundwater–surface water interactions. Ahead of the seepage meter deployment, nested VWPs will be installed within the streambed that are collocated with the planned seepage meter locations. The VWPs would provide synchronous vertical hydraulic gradient data that can be directly correlated to the specific discharge data collected from the seepage meters. VWPs can continue to record heads and gradients after the seepage meters are removed to provide a correlated estimate of specific discharge.

5.1.9 Task 1.9: Construction of Flume in Bob Lee Wash and Quantification of Seeps

Flume Construction in Bob Lee Wash

Surface water flow into the floodplain from Bob Lee Wash is important to understand, as it (1) forms what has been characterized as a hydraulic barrier to groundwater flow northward in the floodplain and (2) serves as a potential point of exposure if flows are not controlled and redirected underground. Surface flow in Bob Lee Wash consists of four components: (1) water that originates upstream of the existing sump and is currently pumped from sump 1087 to the evaporation pond, (2) surface water flows that originate from the artesian well, (3) water from any seeps that enter the wash downstream of the sump, and (4) episodic discharges from the outfall drainage channel diversion. A flume constructed downstream of the sump near the wetland would estimate and monitor the current surface water flows from lower Bob Lee Wash onto the floodplain alluvium. Existing pumping data from the sump pump in Bob Lee Wash will constitute the upper Bob Lee Wash contribution. This, coupled with the isotopic geochemical analysis proposed as Task 1.1 and a review of the existing groundwater-level measurements in nearby wells, will achieve the data quality objective of determining if there are potential points of exposure along the wash that need to be controlled, as well as the flux input to the floodplain from the drainage. Additionally, assumed groundwater and surface water contributions from Bob Lee Wash can be separately quantified with this approach.

It is anticipated that lidar-derived elevation data will be sufficient to assign a groundwater sink boundary condition representing Many Devils Wash for the purposes of numerical flow and transport modeling. The 2017 report described non-mill contamination that occurs in Many Devils Wash and determined that there is no influence from the mill in water that flows in Many Devils Wash; however, flow rates of surface water from Many Devils Wash will bracket the hydrologic profile of the site between the two washes. The water balance of the site depends on the inputs from the two washes.

Quantification of Terrace Seep Flows

Seeps 0425 and 0426 were identified in previous site characterizations and are currently captured in sump 1118, which is pumped to the evaporation pond. Currently, a flowmeter is installed on the outlet pipe to the sump and measures flows including groundwater that infiltrates into the sump from the surrounding saturated area, as well as from seeps 0425 and 0426. The contribution to the floodplain from terrace seep areas close to 0425 and 0426, as well as upgradient of Trench 2, will be important to distinguish from groundwater flow regimes within the floodplain. These two seep areas have been historically identified as potential preferential pathways from the terrace that may transport contaminant mass. Any remedial option in the floodplain will need to address quantified potential contributions to floodplain groundwater from the terrace.

An additional well may be installed in the infill area on the terrace, upgradient from Trench 2 in the eastern portion of the floodplain within the Mancos Shale. This well will help identify the potential flows that are originating from that area towards the floodplain. To address the seep area around 0425 and 0426, manual flow measurements may be conducted in line on the discharge pipe to verify previous data points. Nested piezometers may be installed near the base of the seep infill area to evaluate the hydraulic head distribution, vertical gradients, and COC concentrations.

5.1.10 Task 1.10: Disposal Cell Investigation (further scoping required)

The Shiprock disposal cell tailings may contain a significant, continuing source of COC mass. The total potential mass can be roughly quantified by an evaluation of tailings assays from the milling era. There may also be a significant amount of mass residing underneath the cell, in the terrace alluvium and transmissive zones within the Mancos shale; this is evident from the high concentrations of uranium (approximately 10 mg/L) in groundwater that have been detected in wells within the NECA yard, adjacent to the disposal cell on the terrace. Because the former mill site and tailings piles were located in the footprint of the current NECA yard and the disposal cell, there is likely to be source mass from the milling era beneath the cell that has not been measured or delineated.

Furthermore, initial estimates indicated that very little infiltration was expected from transient drainage through the disposal cell (DOE 2001). Mobilization of the COCs found in the tailings can be caused either by the gradual, transient drainage of initially wet tailings materials in the impoundment or by precipitation that infiltrates through the cell cover material and tailings before recharging the underlying aquifer. A recent LM report estimated the contribution of water infiltration during historical phases at the Shiprock site and projected scenarios of volumes that might infiltrate over the 1000-year life of the cell (DOE 2019c). Those scenarios did not include estimates of mass flux, since source mass data are not available. A targeted investigation of the solid- and dissolved-phase COC mass beneath the disposal cell would satisfy a significant DQO. An investigation could include vertical borings through the cell to evaluate hydraulic heads and gradients and vertical profiles of COC mass. Borehole geophysics could be used to target screen intervals, especially within the Mancos Shale layer under the cell to identify areas of potentially higher hydraulic conductivity. In lieu of vertical borings, angled borings could be drilled to avoid disturbance of the cell. Proposed vertical boring locations are shown in Figure 8 as part of the vertical well and sampling location identification, points A–K. The investigation would seek to quantify the volume of water present, the distribution of dissolved- and solid-phase COC mass, and the hydraulic gradients for mass transport.

Additional scoping is required to quantify the mass flux contributions from the tailings within the disposal cell and the subsurface beneath the disposal cell for the site conceptual model. This specific investigation will be discussed as part of the DQO review process, and a detailed scope of work will be developed.

5.2 Data Collection: Remedial Technologies and Institutional Controls

As described below, a few data collection activities are ongoing and will continue coincident with field work identified in Section 5.1.

5.2.1 Task 2.1: Coordination and Consultation with External Entities

Coordination and consultation with local leadership and organizations will be needed to adequately assess the range of institutional controls that may be needed as a part of the revised GCAP. The framework for these controls needs to be understood, and then the applicability of each should be assessed based on risk and the requirements of each jurisdictional entity.

The institutional controls currently in question include access restrictions such as fencing and signage, water use and permitting restrictions, grazing and other land use restrictions, and land status. Specifically, input will be needed from the following entities: NNAML/UMTRA, District 12 Grazing Committee, BIA, NNWCA, NNEPA, and local leadership.

Administration of the GCAP: Navajo AML/UMTRA

DOE has an ongoing Cooperative Agreement with NNAML/UMTRA, in which NNAML/UMTRA is involved as a partner in the development of major changes to the groundwater compliance program. NNAML/UMTRA will be consulted as part of the GCAP development process and have the opportunity to provide comments on relevant documents prior to their finalization. NNEPA will be consulted as appropriate on technical issues related to the GCAP and site monitoring.

Vegetation Risk Assessment: Argonne National Laboratory and Local Cultural Leadership

Traditional ecological knowledge is an important aspect of the impacts of the Shiprock site to the local community. As such, coordination with local cultural leadership is planned to incorporate cultural information into decision making and risk assessment.

Currently, a vegetation sampling event is being coordinated by Argonne National Laboratory. The sampling event, in conjunction with cultural consultation, will support a risk assessment to evaluate the potential ecological and human exposures from plant use or consumption. This study will be located on the floodplain and will determine the potential exposure risks of use of the plants growing in areas with mill-related groundwater or impacts. A list of existing plant species will be compiled from past site inventories and surveys and will be cross referenced with a list of culturally important species and uses, as determined by Navajo cultural leadership and consultants. A sampling event will be conducted in the late spring or summer to collect tissue samples of culturally important plants, which will be evaluated by a third-party laboratory and incorporated into a risk assessment based on potential uses. Local cultural leadership may desire increased involvement through the completion of their own study, for which access will be accommodated. As mentioned, the risk assessment will include metrics on consumption of potential livestock and wildlife that might graze in impacted areas, if institutional controls such as fences and signs were not maintained. This information will help to define the appropriate access restrictions to protect human health and the environment.

Grazing Restrictions: District 12 Grazing Committee and Bureau of Indian Affairs

As a part of the GCAP risk assessment, the potential exposure to wildlife, livestock, and humans from consumption or other use of plants growing in areas influenced by mill-related contamination will be assessed as discussed. After the risk assessment is complete, if it is determined that there is an incurred risk to livestock from grazing in those areas, grazing restrictions may be needed. These restrictions will need to be codified with the District 12 Grazing Committee with the consultation of BIA. (District 12 is the grazing management unit that has jurisdiction over the Shiprock area.) The restrictions will necessitate legal surveys of the restricted areas, determination of any compensation required for the restriction, and compliance with the correct processes for codification over the time period that is necessary.

Land Use Restrictions: Navajo Land Department, Bureau of Indian Affairs, and Shiprock Chapter Planning Committee

Current land use and development planning will be important factors in the determination of which institutional controls may be necessary and what will be required after remediation of the site is determined to be complete. While planning remedial alternatives and evaluating viability, the footprint, land use, and local preferences for development opportunities will be incorporated into the evaluation. The Navajo Land Department and the Shiprock Chapter Planning Committee will both be consulted regarding land use plans, along with other entities.

BIA and the Navajo Land Department may be consulted with on other land use or access restrictions needed as determined by the risk assessment, after the site characterization is updated and regulatory standards are recommended.

Water Use Restrictions: Navajo Nation Water Code Administration

The 2002 GCAP recommended that the NNWCA produce and enforce restrictions on well permitting in areas of mill-related contamination. This has been done in practice, and the official restriction is in progress. The restriction would include wells for potable, livestock, or irrigation use. On the basis of the risk assessment provided as part of the GCAP, Navajo Nation Water Code will be consulted and restrictions will be coordinated to eliminate potential exposures as necessary. DOE has consulted with NNWCA regarding permitting restrictions, but no official restrictions have been codified.

Technical Stakeholder Concerns: Navajo EPA

Navajo EPA will be consulted as part of the GCAP development process and will have the opportunity to comment on the official draft documents as they are completed. Input from

Navajo EPA on technical aspects of the Shiprock site and groundwater compliance is valued and will be considered before documents are finalized.

5.2.2 Task 2.2: Sequestration Column Studies

LM conducted column studies to evaluate the potential of polyphosphate to sequester uranium in the subsurface. Subsurface floodplain soil samples were taken and packed into columns at the Grand Junction Environmental Sciences Laboratory. A control column was fed site groundwater from floodplain well 1111 through the column at a rate of 1 pore volume per day. Several experimental columns received incremental doses of polyphosphate amendment over 1-week or 1-month intervals, as shown in Table 4. Following the completion of the amendments, groundwater from floodplain well 1111 was fed through the column at 1 pore volume per day. Samples were taken at regular time intervals for a comprehensive suite of groundwater chemistry analytes. Control and experimental effluent concentrations were compared to bracket the potential success of polyphosphate amendment. The data generated include the number of pore volumes of COC removal provided per number of polyphosphate injections applied, effluent dissolved COC concentrations relative to UMTRA standards and bulk changes in soil minerology, the longevity of the effect of the amendment application, and others.

Table 4. Experimental Design and Column Descriptions for the Sequestration Column Study

	Control Column	Column 2	Column 3	Column 4	Column 5	Column 6
Dates sampled (2019)	May 23–Oct 15	May 30–Aug 13	Jun 6–Aug 13	Jun 13–Oct 17	Jul 11–Oct 25	Sep 5–present
Flow rate	10 mL/min	10 mL/min	10 mL/min	10 mL/min	5 mL/min	10 mL/min
Number of phosphate injections	0	1	2	3	4	3
Interval between injections	N/A	N/A	1 week	1 week	1 week	1 month

Abbreviations:
mL/min = milliliters per minute
N/A = not applicable

Column studies will continue to assess the applicability of polyphosphate to sequester dissolved uranium at the Shiprock site. If polyphosphate amendments warrant pilot testing in the field, additional laboratory experiments will be conducted to (1) evaluate any adverse changes in hydraulic conductivity from mineral precipitation/biomass accumulation; (2) optimize the amendment injection concentration relative to hydraulic effect; and (3) assess if the amendment is better delivered through surface irrigation or direct injection into the saturated zone.

If polyphosphate is determined to be inefficient or inapplicable to the Shiprock site due to high groundwater flows, high uranium concentrations, high variability in groundwater chemistry, and so on, another amendment may be evaluated or other alternatives will be tested.

5.2.3 Task 2.3: Sorption Studies

Batch tests will be conducted to evaluate the sorption capacity of soils at the site for uranium. The distribution coefficients (K_d) of the floodplain alluvium will be needed for the site conceptual model and for solute fate and transport modeling. Native floodplain alluvial and Mancos Shale material from a non-mill-related area will be collected and placed into batch reactors, after which contaminated floodplain groundwater will be added to the solid-phase material to determine the effect on uranium concentrations.

5.2.4 Task 2.4: Remedial Alternatives Evaluation of Viable Remedial Technologies

Revision of the site conceptual model will contain important information to inform the viability of remedial technologies for the Shiprock site, including:

- Distribution of the source mass in the solid and soluble phases.
- Preferential pathways between the terrace and floodplain for contaminant flux.
- Preferential pathways within the floodplain for contaminant flux.
- Areas of high and low hydraulic conductivity.

With this information, available technologies will be assessed by a thorough literature review and an evaluation of viability and past effectiveness. Frameworks for each theoretically viable technology will be developed to demonstrate technical feasibility and applicability, implementability, and effectiveness, as well as rough cost estimates for design, construction, maintenance, and operation of each technology relative to its treatment potential. A comprehensive analysis will be updated to provide qualitative assessments of each technology to incorporate community and agency concerns and other issues not related to the site conceptual model and the monetary evaluation.

For remedial technologies that have the greatest potential, laboratory or pilot studies will be conducted to gather site-specific performance data. The rough cost estimates will be refined, and recommendations will be provided for selecting a remedial technology or combination of technologies.

6.0 Safety and Health

This section describes the project safety and health requirements, which will be implemented for all field tasks associated with this work plan. All work shall be conducted in accordance with safety regulations promulgated by federal, state, and local agencies and DOE regulations that are contained in the Legacy Management Support (LMS) *Safety and Health Procedures Manual* (LMS/POL/S04337). Additional field work plans will be developed for each field program to provide detail on specific scope, data collection locations, roles and responsibilities, field procedures, analytical procedures, equipment, and other relevant information.

Workers are responsible for identifying safety concerns, potential hazards, or unsafe conditions and notifying management. Each worker has the right, responsibility, and authority to report unsafe or environmentally unsound conditions or practices and to pause or stop work activities without fear of reprisal. Unsafe workers, including workers who do not wear required personal protective equipment (PPE), will be required to leave the site.

6.1 Job Safety Analysis

All LMS team, subcontractors, and research group workers shall read, sign, and adhere to the hazard controls specified in the approved job safety analysis (JSA). Workers shall not perform work not covered by the JSA or for which the JSA does not provide adequate protection. Workers shall follow all requirements stated in the JSA, such as heat stress evaluation and monitoring. The designated LMS contractor line supervisor or Safety and Health representative can modify the JSA to reflect changed conditions or equipment as needed or as requested by a worker. Additional safety requirements will be assessed as specific work packages are prepared for internal teams, as well as subcontractors.

6.2 Safety Briefings

Workers are responsible for performing tasks in accordance with provided training and may not perform tasks for which they have not been adequately trained. Specific training requirements will reflect the individual tasks planned, as coordinated through field activity planning documents. Minimum training requirements include the following:

- **Initial Site Briefing:** All field personnel shall attend an initial site briefing conducted by the LMS project lead on the first day of work before conducting any fieldwork. The JSA and other field forms will be covered and signed at this time. If circumstances require the use of personnel who did not attend the initial site briefing, these personnel must receive individual briefings from the LMS project lead before they may begin fieldwork.
- **Tailgate Safety Meetings:** At the beginning of each day's work and before specific tasks with significant or modified safety considerations, the LMS team will conduct an operations safety and health meeting for all personnel. The scope of the upcoming day's operations and activities will be reviewed, and hazards associated with those activities will be identified along with the safety implications and procedures to mitigate the hazards. Relevant safety documentation associated with the upcoming work will be reviewed. In addition, issues or concerns noted from previous activities will be discussed. This briefing will be documented with a required sign-in sheet to identify the topics discussed and the personnel in attendance. A separate briefing with sign-in will be conducted for any worker(s) who requests to be on

site and cannot attend the daily meeting. All workers are required to participate and sign in, or they will not be allowed to participate in activities at the site.

6.3 Onsite Considerations

The LMS team will provide a person who is trained in first aid and CPR to be onsite at all times while work is being performed and will ensure that a first aid kit and automated external defibrillator (AED) unit are onsite at all times when workers are present.

The LMS team will provide a chemical toilet and hand-washing station at the worksite to ensure proper sanitation.

Bottled drinking water will be provided to the field crews, and proper hydration will be encouraged throughout the study.

7.0 Quality Assurance

Work will be performed in a manner consistent with the SAP and with field procedures defined in the specific field work plans for each effort. Quality assurance and quality control requirements, which are specified in the SAP, apply to all such efforts, but are specific to the type of data generated and the methods of collection and analysis. The requirements include procedures for sample collection, calibration and operational checks of field instrumentation, collection of quality control samples, documentation of sampling activities, decontamination of sampling equipment, training, use of approved laboratories and analytical methods, and data validation and qualification. Specific quality assurance and quality control requirements will be further defined with each field work plan.

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8.0 Environmental Management System

In accordance with LM's Environment, Safety and Health Policy, and Environmental Management System, all work performed shall follow safe and environmentally sound work practices. Work shall be conducted in a manner that protects workers and the public, complies with DOE directives, and complies with all applicable federal, state, local, and tribal regulatory requirements and agreements and permits under the LMS contract.

In addition, work will be conducted in a manner that prevents pollution, minimizes wastes, and conserves natural and cultural resources to the extent that such activities are technically and economically feasible. Contaminating additives (e.g., diesel fuel, oil, barite), hydrocarbon-based lubricants (e.g., grease or oil), and biocides (e.g., formaldehyde) shall not be used in boreholes or wells. Only nonhydrocarbon-based lubricants, such as silicon, Teflon, or vegetable oil, will be used on any downhole equipment or tools. Each worker has the right, responsibility, and authority to report unsafe or environmentally unsound conditions or practices and to pause or stop work activities without fear of reprisal.

8.1 National Environmental Policy Act

DOE-related National Environmental Policy Act (NEPA) regulations are contained in 10 CFR 1021, "National Environmental Policy Act Implementing Procedures." Pursuant to NEPA, in 1994 DOE drafted a PEIS for the UMTRA Ground Water Project. The PEIS document was made final in October 1996. The purpose of the NEPA document was to analyze the potential impacts of implementing four programmatic alternatives for groundwater compliance at the designated processing sites. The preferred alternative for the UMTRA Ground Water Project was published in a Record of Decision in 1997.

The proposed field activities will need to demonstrate compliance with NEPA and other regulations, as applicable. Compliance with key acts, such as Section 106 of the National Historic Preservation Act (NHPA) and Section 7 of the Endangered Species Act, would be documented in the NEPA document. Routine data collection and routine maintenance typically are anticipated to be conducted under a categorical exclusion evaluation. Major work, such as replacement or removal of the evaporation pond, would be expected to be the subject of an Environmental Assessment (EA). An EA is currently in process to evaluate the potential impacts of a decision regarding the fate of the evaporation pond, as it relates to the revision of the GCAP and the aging of the existing infrastructure.

8.2 Cultural Resources

Section 306108 of the NHPA (also known as Section 106) requires that the federal government consider the effects of its actions upon historic property prior to taking those actions through the Section 106 process, as defined at 36 CFR 800, "Protection of Historic Properties." The applicable state or tribal historic preservation officer (SHPO or THPO) is allowed an opportunity to review and comment on the proposed action and its anticipated effects prior to final approval of the proposed action(s) by the federal government. This project would take place within the boundaries of the Navajo Nation; thus, the applicable review agencies would be the Navajo

Nation Heritage & Historic Preservation Department (NNH&HPD), which hosts their THPO. The BIA provides NHPA oversight to the NNH&HPD as needed.

LM conducted a reassessment of archaeological sites in an approximately 903-acre area where future work could occur at the Shiprock disposal site. This area of potential effect (APE) had been subjected to archaeological surveys over time; however, most of the survey information was over 10 years old. A professionally qualified archaeological firm with a current permit to conduct fieldwork in the Navajo Nation was retained to review the existing information and revisit the previously identified sites within this future work area. They were also tasked with resurveying portions of the APE if required based on their professional opinion and experience. The resulting information was then presented to NNH&HPD along with the LM conclusion that there were no historic properties within the proposed APE. Previously identified archaeological sites were no longer present due to ongoing non-LM activity conducted primarily by local residents, or the sites were outside the APE boundary. NNH&HPD concurred with this determination in writing on January 8, 2019. BIA also concurred, on February 1, 2019. No further consultation is required for the APE for the work currently being evaluated. Per LM/LMS stop work protocol, work would stop in the unlikely event that an inadvertent discovery was made.

8.3 Migratory Bird Treaty Act

Personnel shall not pursue or harass birds or otherwise intentionally disturb nests or eggs. If active nests or eggs are discovered that could be unintentionally disturbed by the work, particularly if the work could cause birds to abandon the nest, personnel shall notify LMS Environmental Compliance (EC) for avoidance and mitigation measures to be taken before any work continues. The Migratory Bird Treaty Act (Title 16 *United States Code* Section 703–712) prohibits intentionally harassing, destroying, pursuing, or collecting birds, nests, or eggs. Most bird species in the United States are protected year-round by the Act. Also, in accordance with Executive Order 13186, *Responsibilities of Federal Agencies to Protect Migratory Birds*, DOE has a Memorandum of Understanding with the U.S. Fish and Wildlife Service (FWS) to use principles, standards, and practices that lessen the unintentional take of migratory birds.

8.4 Wetland Delineation

A wetland exists at the base of Bob Lee Wash. In 2019, a protocol wetland survey was conducted to delineate the boundary of jurisdictional wetland along the floodplain. Completion of the technical report is in progress. The regulatory compliance strategy to address the wetland will depend on the degree to which impacts to jurisdictional wetlands can be avoided or minimized. Any work conducted within the footprint of the wetland area identified during the survey will be reviewed with the EC subject matter expert to determine appropriate avoidance, minimization, and mitigation measures.

8.5 Endangered Species Act

Mesa Verde cactus (*Sclerocactus mesae*), a plant federally listed as endangered, could be present in the area east of the disposal cell and within Many Devils Wash. Invasive work and off-road vehicular traffic shall not proceed in the previously identified areas without notification of the EC lead and may require further consultation with FWS and Navajo Nation Fish and Wildlife

(NNFW). In association with planned work to decommission the groundwater remediation system infrastructure in Many Devils Wash (outside the scope of the Shiprock GCAP revision), a survey is planned for late April or May 2020. The survey will be performed by a qualified biologist licensed with NNFW to verify the locations of any Mesa Verde cactus in planned disturbance areas as part of that work. If GCAP investigation work is planned in the east terrace area or Many Devils Wash in areas identified as Mesa Verde cactus habitat, the EC subject matter expert will be consulted and additional field survey work may be required. Designated critical habitat does exist in the San Juan River for two listed species of fish; any work conducted in the San Juan River or work that would disturb the riverine habitat may require additional consultation with NNFW or FWS.

Many animal and plant species are also protected by Navajo Nation tribal law. Work that could affect tribally listed species requires EC to consult with NNFW prior to the start of work. The Navajo Nation requires a formal data request, and species surveys must be performed by a biologist licensed with the tribe. LMS is working to obtain the relevant tribal species lists while completing the inventory of species found onsite. This information will contribute to the incorporation of traditional ecological knowledge in the planning process and to the risk analysis.

8.6 Waste Management

Personnel shall properly manage all waste generated by project activities. Work will be performed in an environmentally responsible manner consistent with the LMS *Management Plan for Field-Generated Investigation-Derived Waste at UMTRCA Sites* (LMS/PLN/S04352). No hazardous or radioactive waste materials are expected to be generated during field activities. The site shall be kept clean and orderly, and personnel shall clean up debris and waste material from the site daily. Construction debris and nonhazardous waste materials are expected to be very minimal and shall be disposed of in approved receptacles. Although not anticipated, personnel shall immediately notify the line supervisor if any hazardous waste is suspected or generated outside the scope of the project and then follow EC's directions to manage the waste. The LMS line supervisor will be ultimately responsible for ensuring that all workers adhere to these waste management requirements.

Investigation-derived waste (IDW) includes purge water, equipment calibration waste, excess sample material (both water and soil), decontamination rinsate, and solid waste (tubing, soil sampling liners, disposable gloves, disposable pipettes, paper towels, Visqueen, etc.). Excess soil will be spread out evenly around the borehole. All excess liquid IDW will be dispersed broadly to the ground surface in the vicinity of the borehole. IDW may not be discharged to the ground surface in suspected wetland areas nor may it be discharged to places where it could be washed away, such as in dry washes (see discussion below). Solid waste will be collected and disposed of in a municipal landfill.

8.6.1 Waste Reduction and Recycling

Work will be performed in an environmentally responsible manner consistent with the LMS *Environmental Management System Sustainability Teams Manual* (LM-Manual-3-20.3-1.0, LMS/POL/S11374) waste reduction and recycling targets. In working toward these targets:

- All personnel are encouraged to minimize the waste generated and maximize the amount of material that is reused, salvaged, and recycled.
- All materials recycled and disposed of shall be tracked with total volumes or weights by the project lead, who will report the totals to EC.

8.7 Spills

If spills of any fluids from equipment operations or maintenance (e.g., fuel, hydraulic fluids, coolant, lubricants, cleaning solvents, used oil) occur, personnel shall immediately notify the line supervisor, site lead, Safety and Health, and EC and follow their directions to clean up the spill. All spills will be managed in accordance with the *Environmental Instructions Manual* (LMS/POL/S04338). Equipment leaks and other types of spills shall be diapered, contained, absorbed, or otherwise blocked to prevent ground surface contamination until the leak is repaired or the equipment is replaced. Personnel shall clean up and subsequently manage spilled materials and associated wastes (e.g., contaminated soils), including proper storage, until EC can arrange for offsite disposal of the material.

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Appendix A

Bulk Plume Metrics: Maps and Figures

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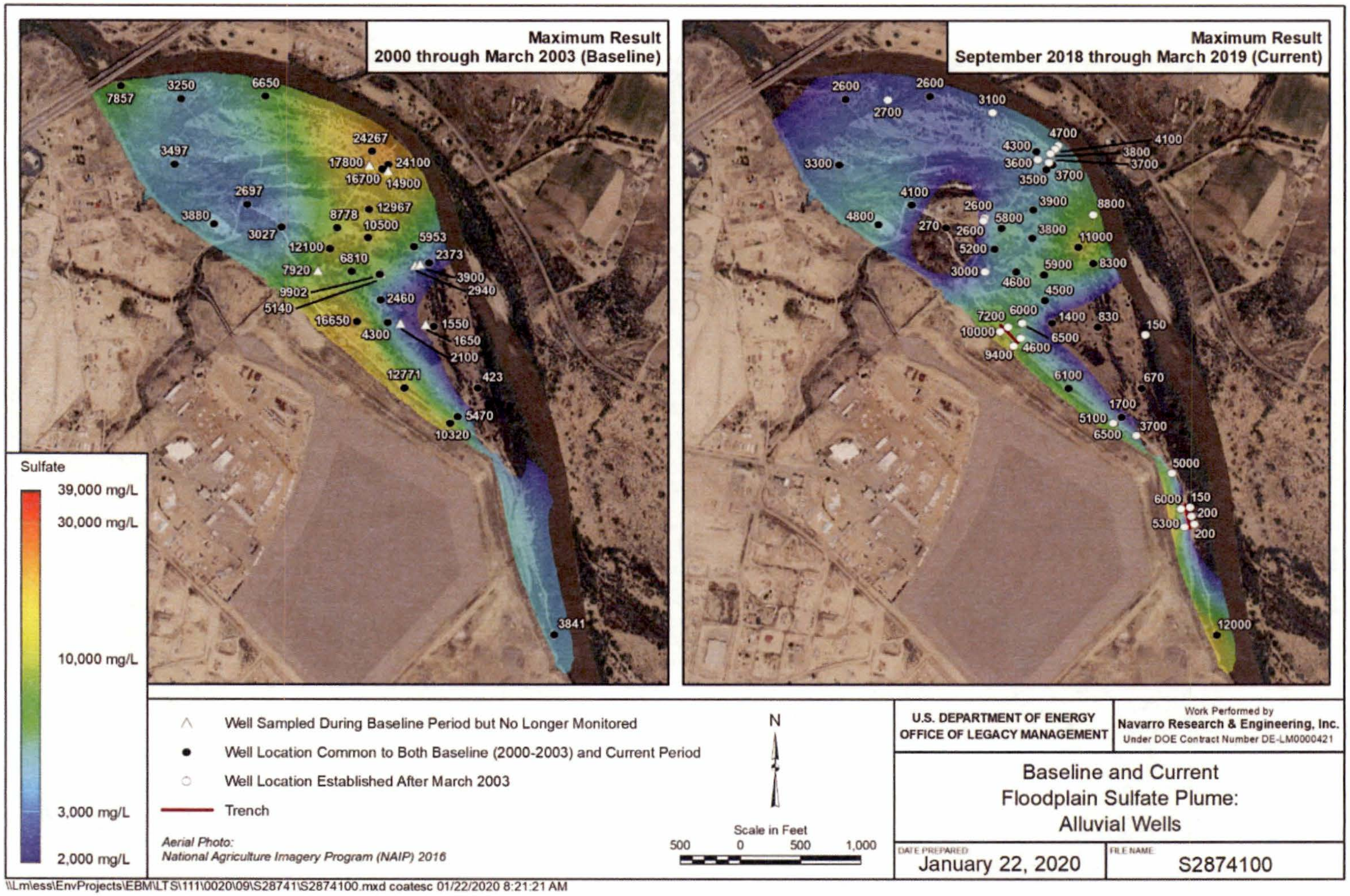

Figure A-1. Shiprock floodplain sulfate plume above the proposed cleanup goal of 2000 mg/L. The baseline condition is reflective of the maximum concentration at each well between 2000 and March 2003. The right side uses the maximum concentration of each sampled alluvial well for the most recent sampling period (September 2018 through March 2019). The sulfate plume footprint and concentration have decreased since the baseline period.

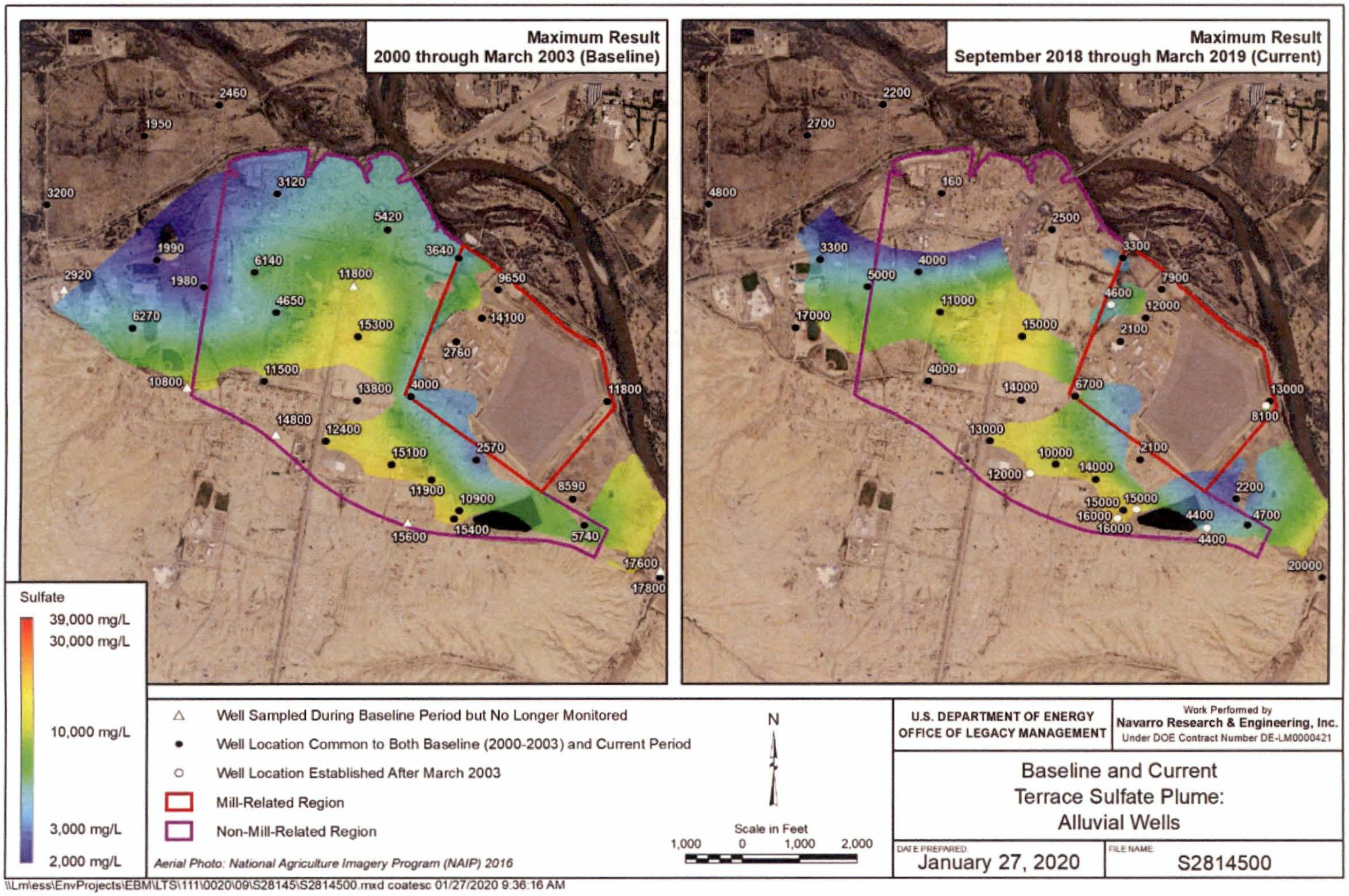

Figure A-2. Shiprock terrace sulfate plume above the proposed cleanup goal of 2000 mg/L. The baseline condition is reflective of the maximum concentration at each alluvial well between 2000 and March 2003. The right side uses the maximum concentration of each sampled alluvial well for the most recent sampling period (September 2018 through March 2019). The red and purple outlines represent the non-mill-related and mill-related plume areas, as determined by an isotopic study (DOE 2018a). The sulfate plume footprint has remained largely unchanged since the baseline period.

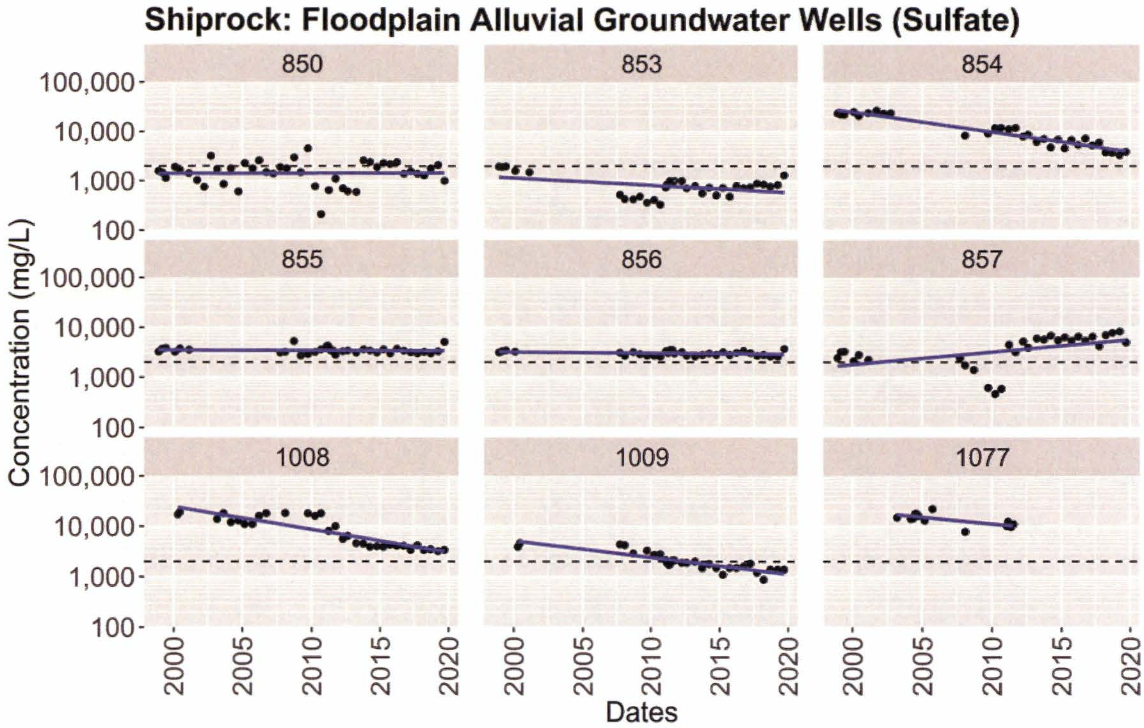

Figure A-3. Sulfate trends at individual alluvial wells on the Shiprock floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

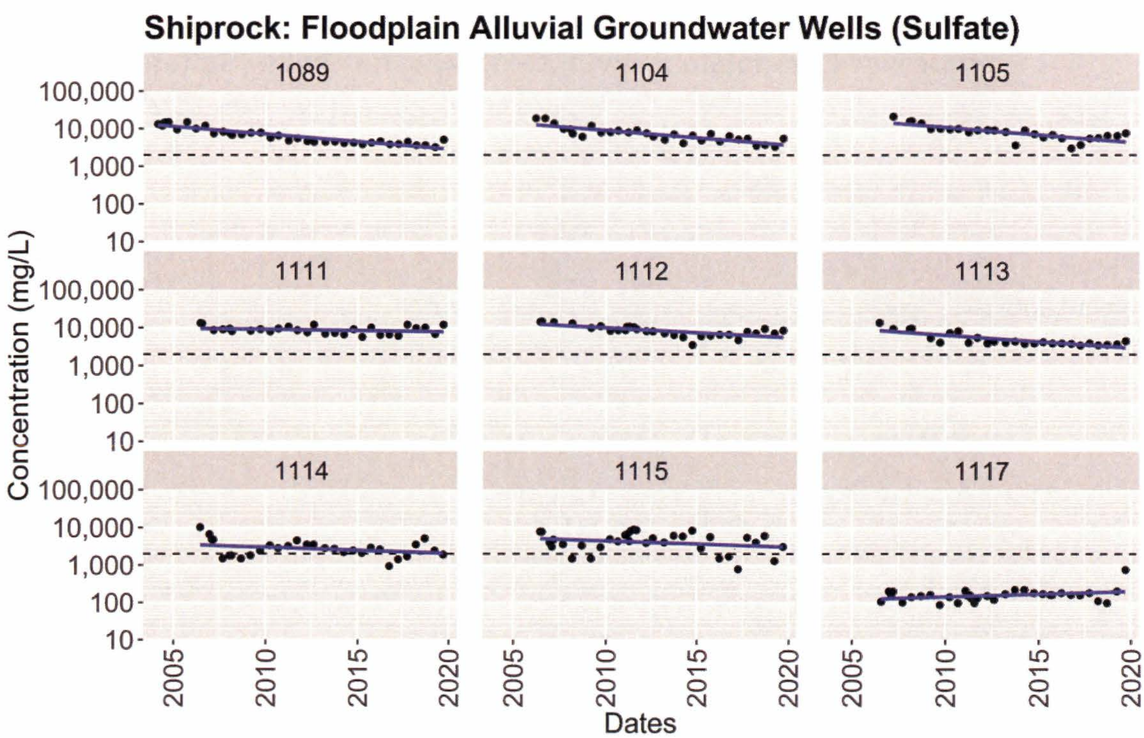

Figure A-4. Sulfate trends at individual alluvial wells on the Shiprock floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

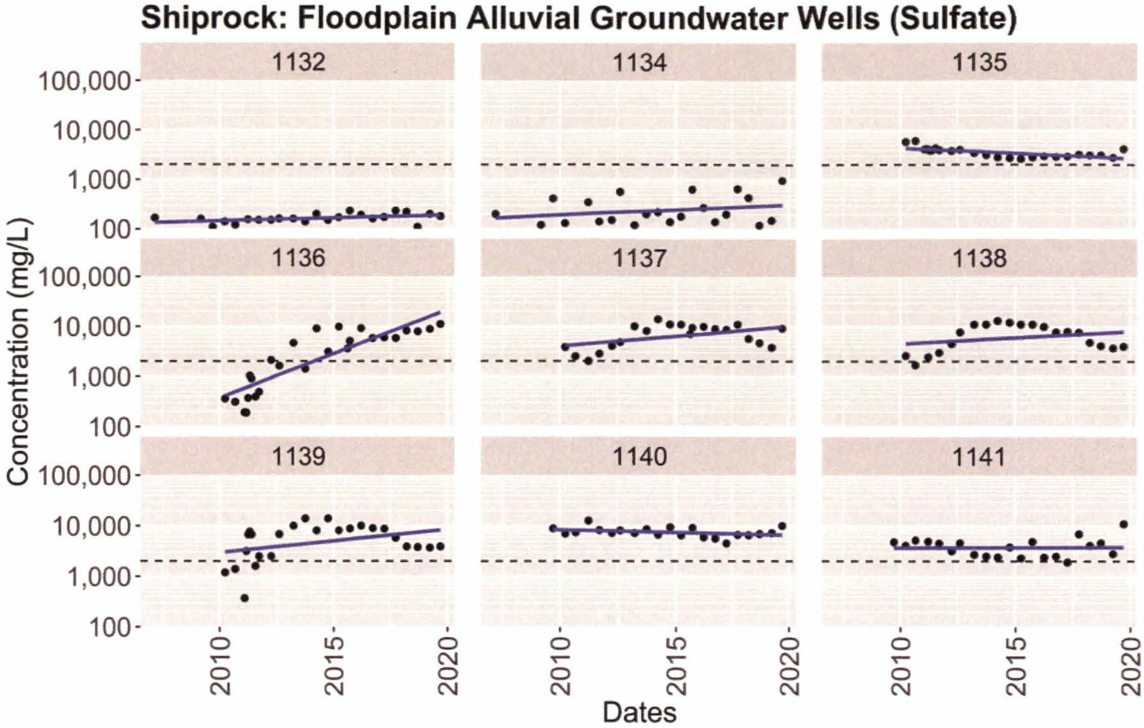

Figure A-5. Sulfate trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

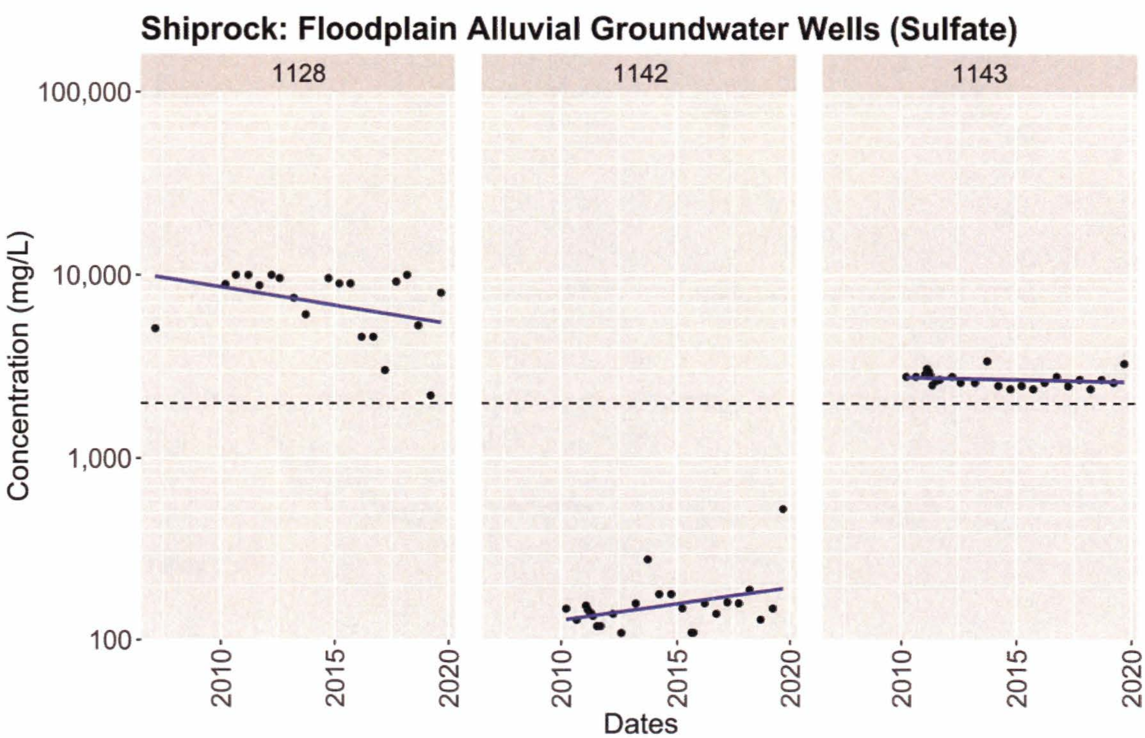

Figure A-6. Sulfate trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

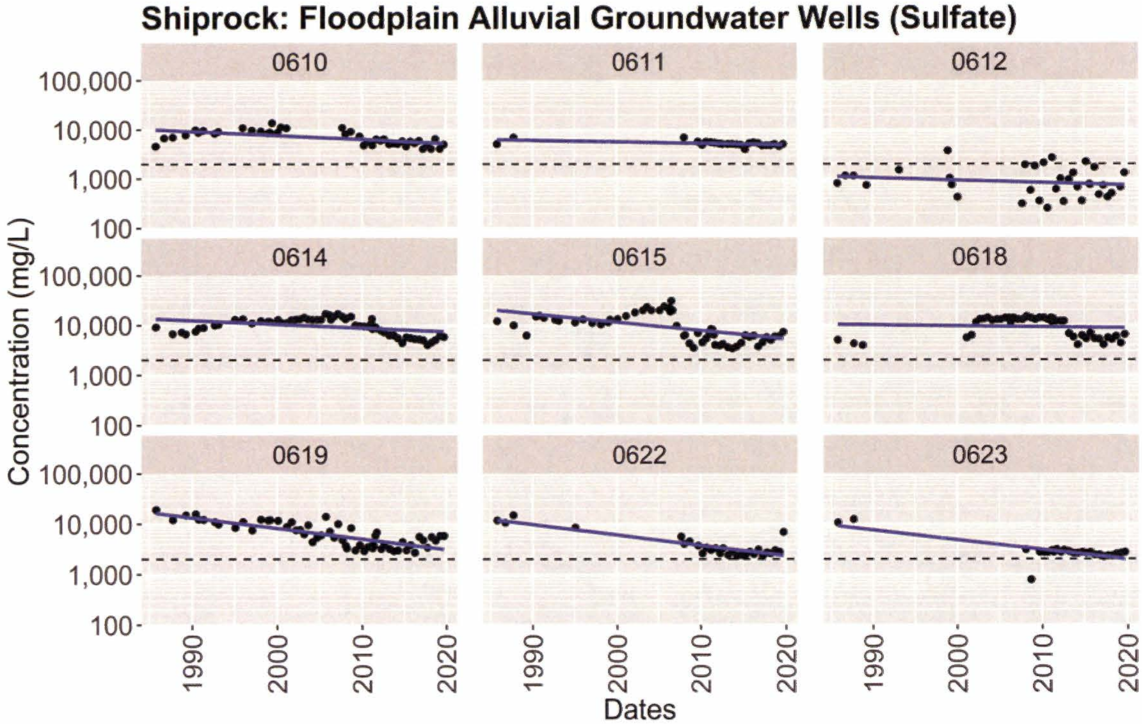

Figure A-7. Sulfate trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

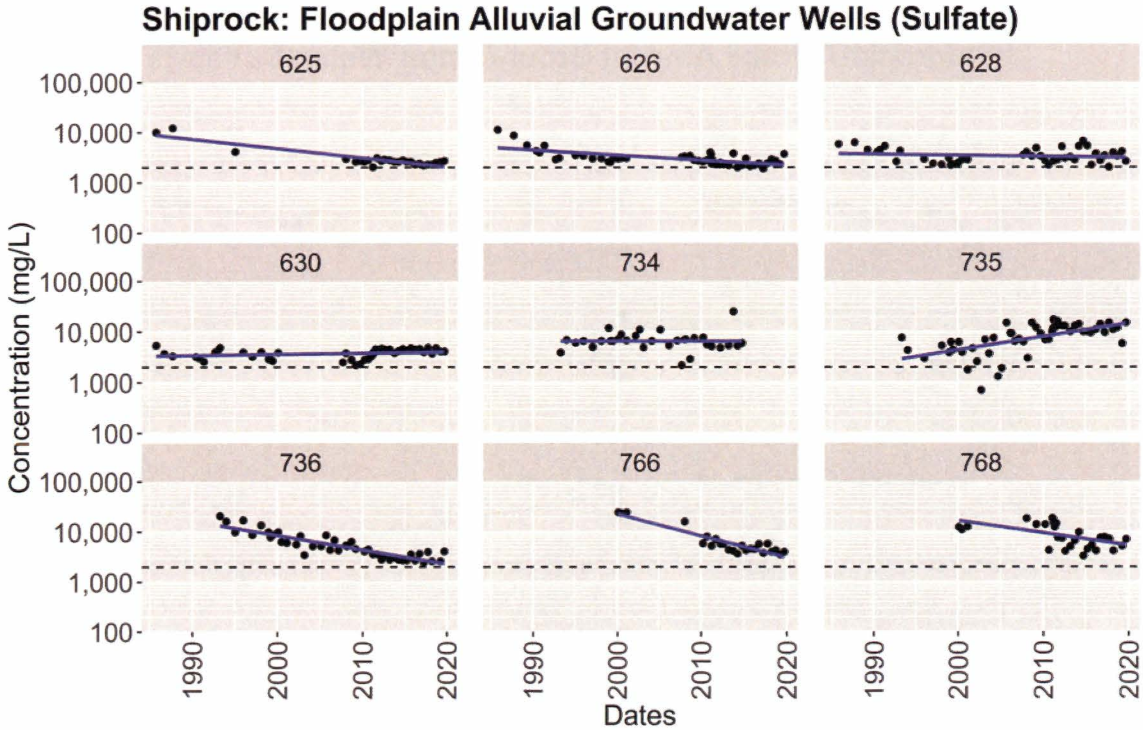

Figure A-8. Sulfate trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

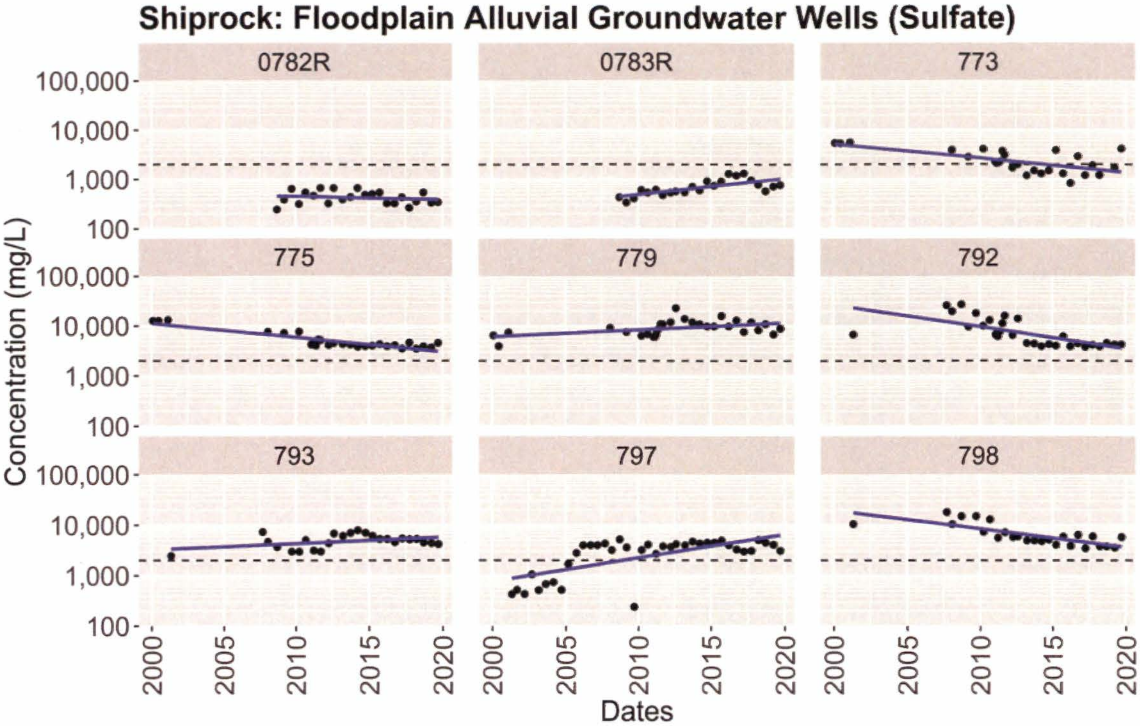

Figure A-9. Sulfate trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

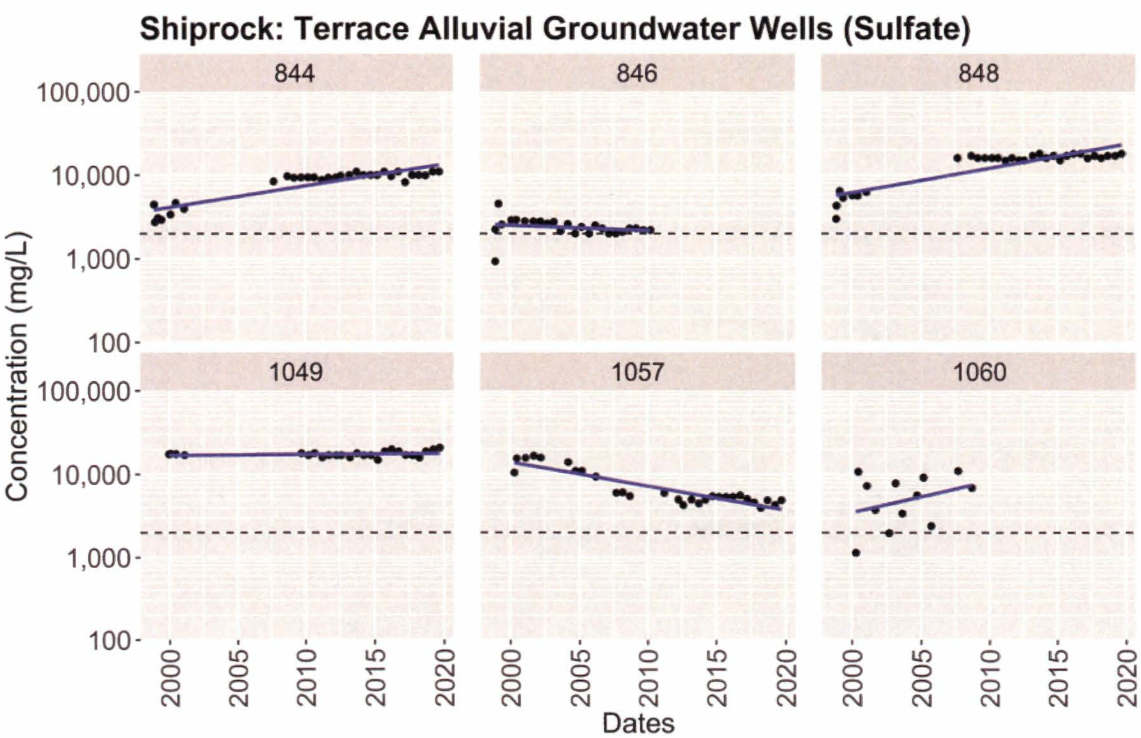

Figure A-10. Sulfate trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

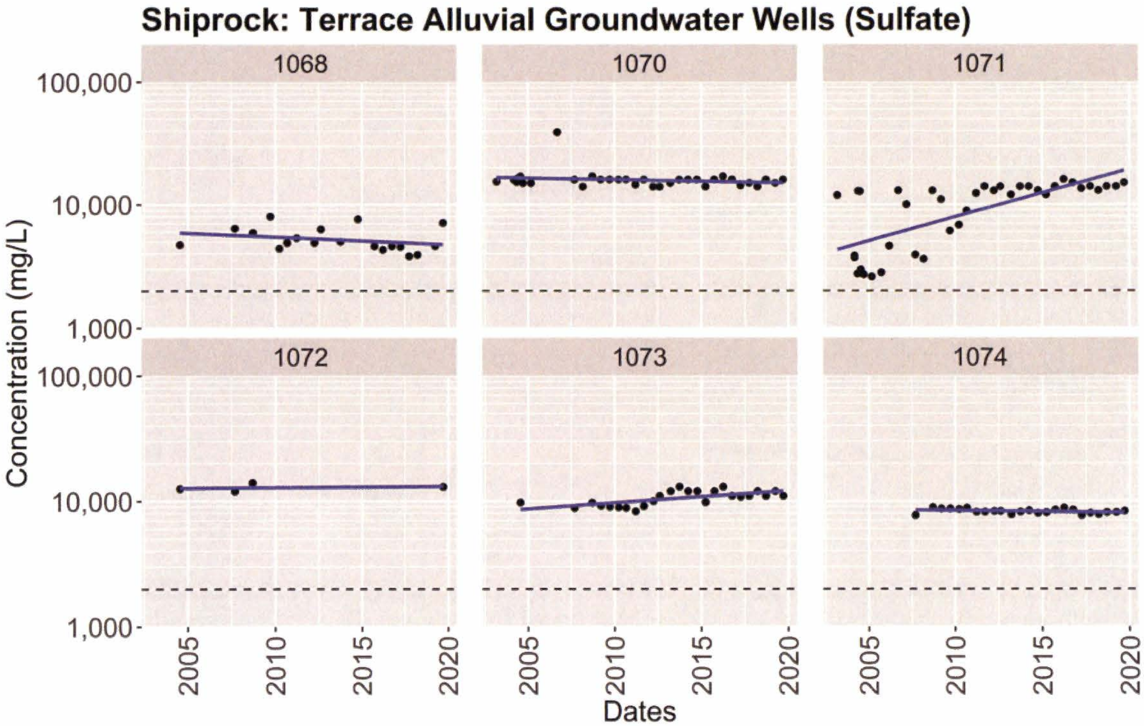

Figure A-11. Sulfate trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

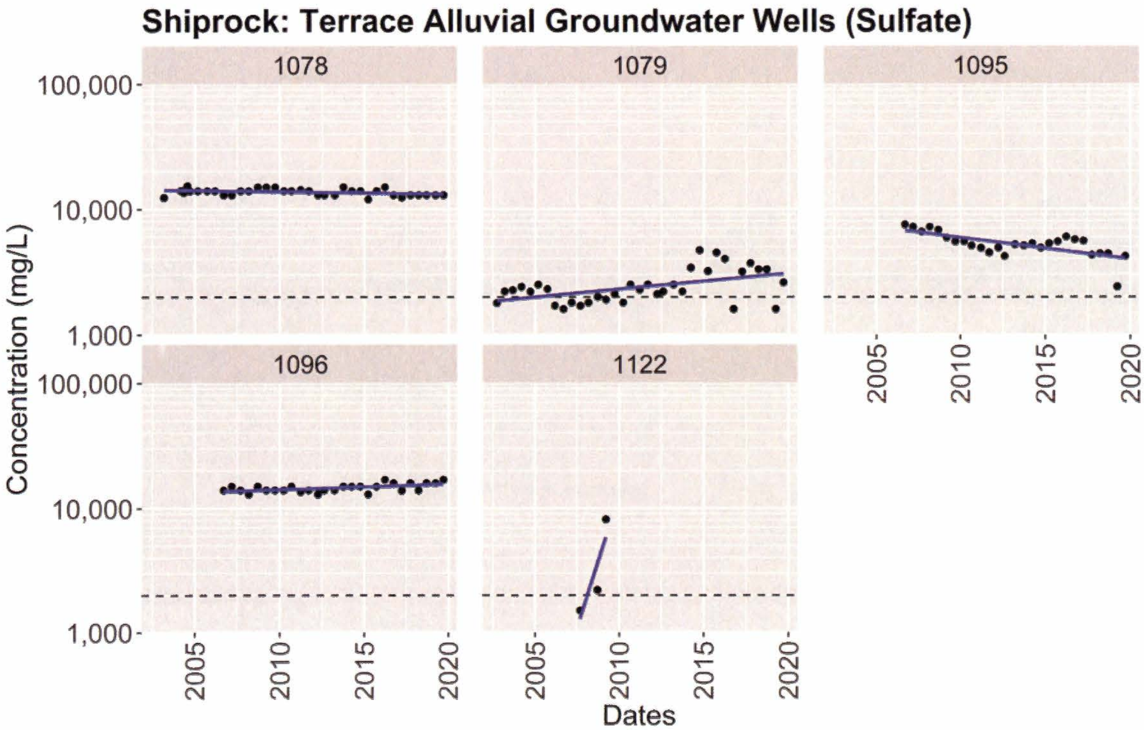

Figure A-12. Sulfate trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

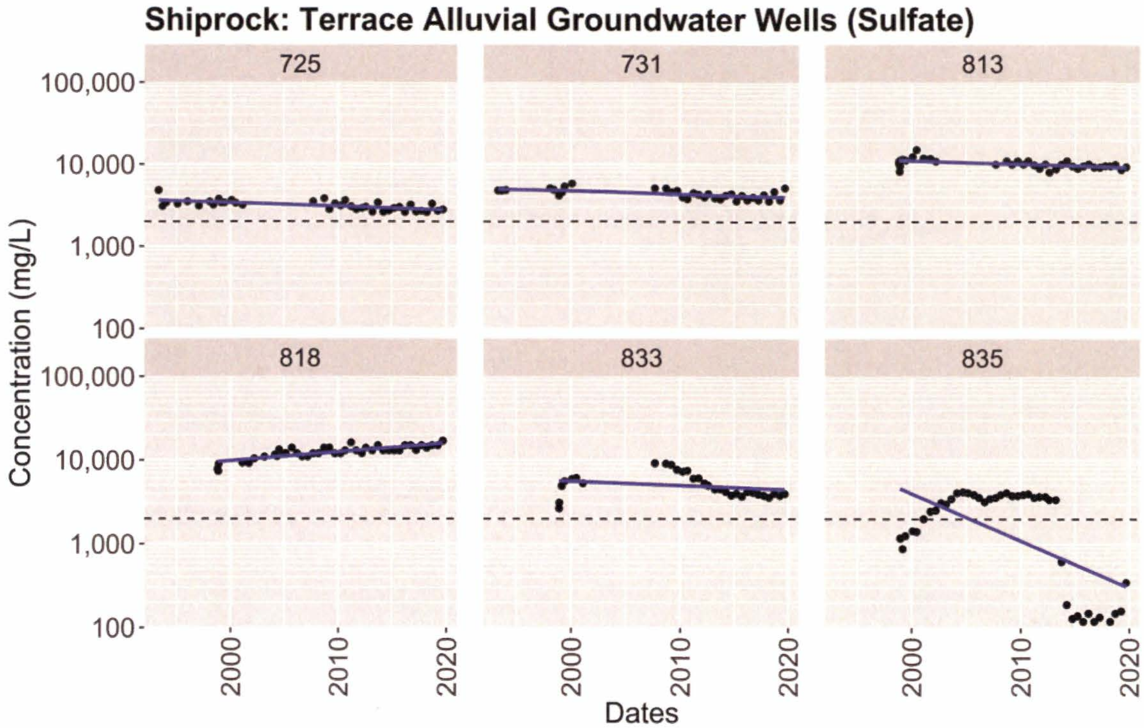

Figure A-13. Sulfate trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

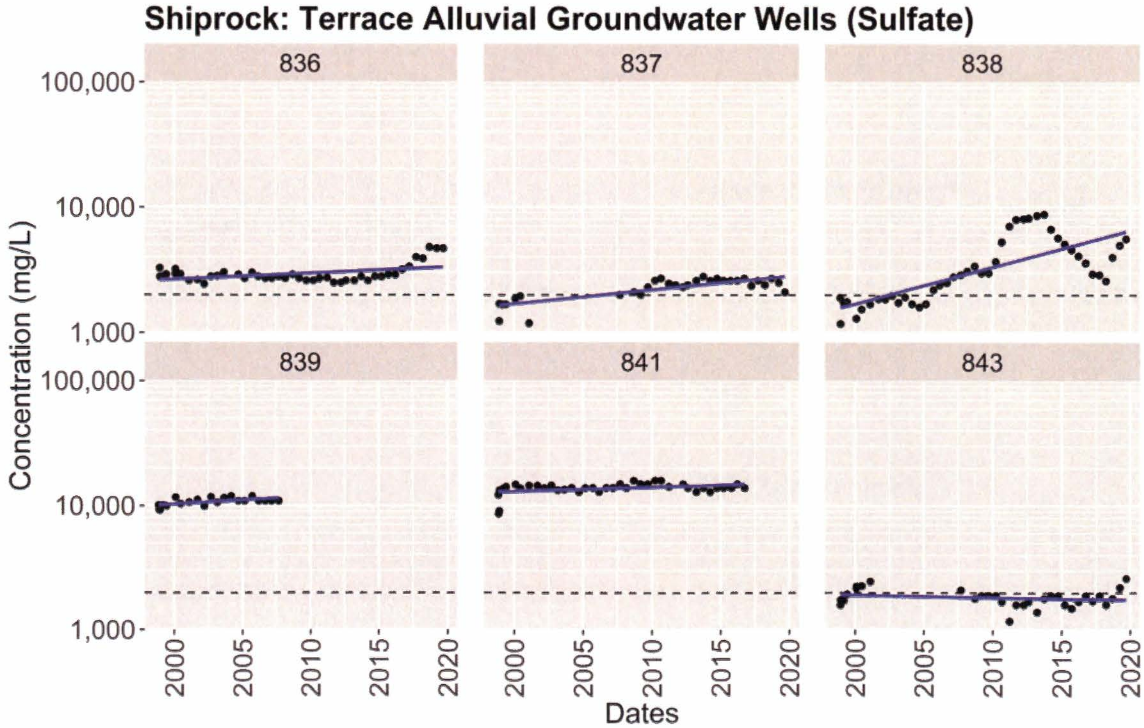

Figure A-14. Sulfate trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend. The black, dashed line represents the proposed cleanup goal of 2000 mg/L.

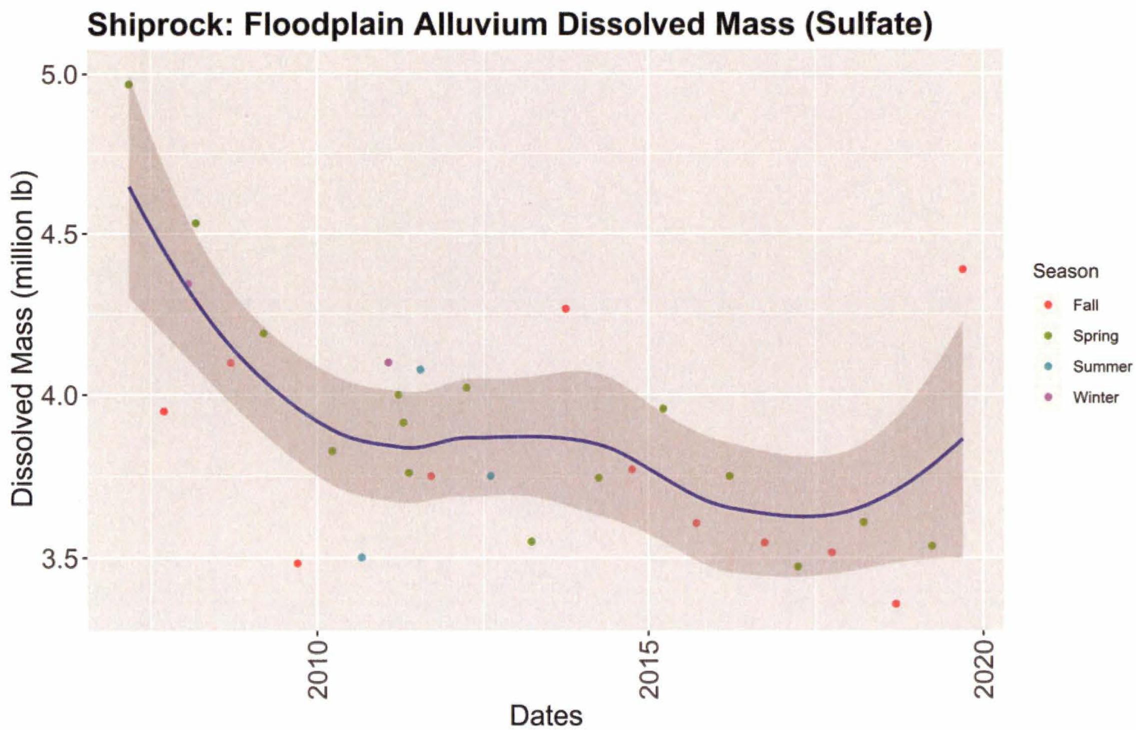

Figure A-15. Bulk sulfate plume mass on the Shiprock site floodplain. The blue line is a locally weighted smoothing line (LOESS), and the shaded region is the 95% confidence interval. Mass has decreased over time.

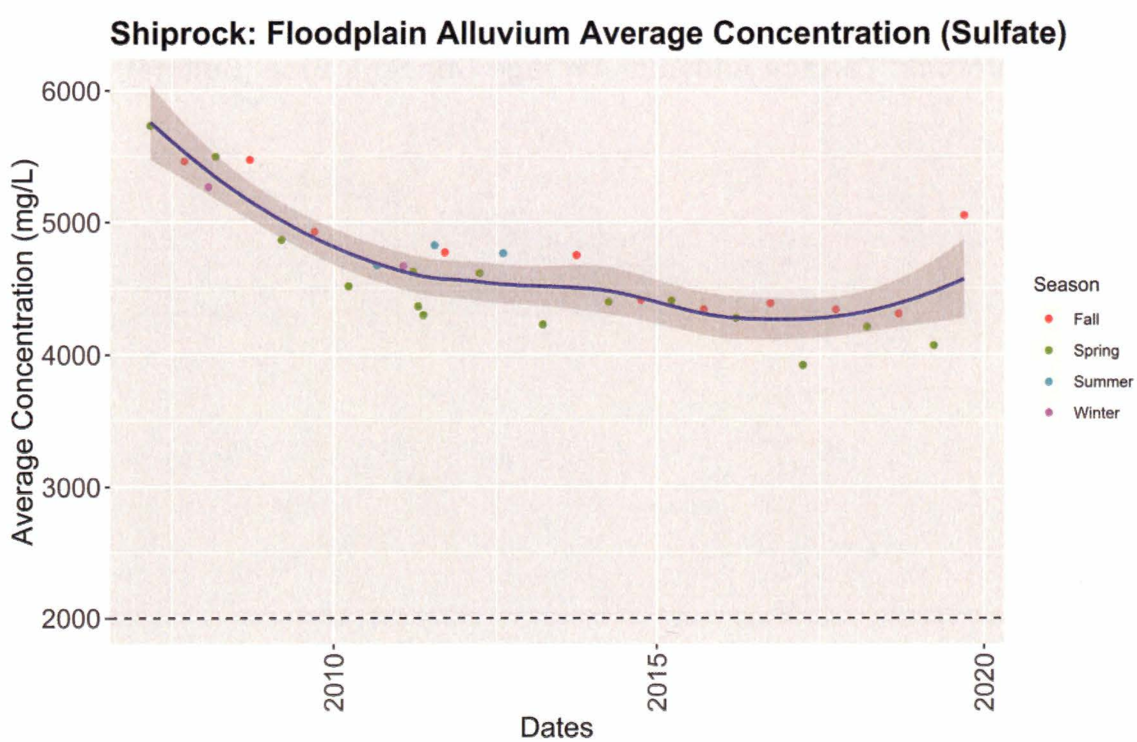

Figure A-16. Bulk sulfate plume average concentration on the Shiprock site floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Average concentration has decreased ver time but still remains over the proposed cleanup goal of 2000 mg/L.

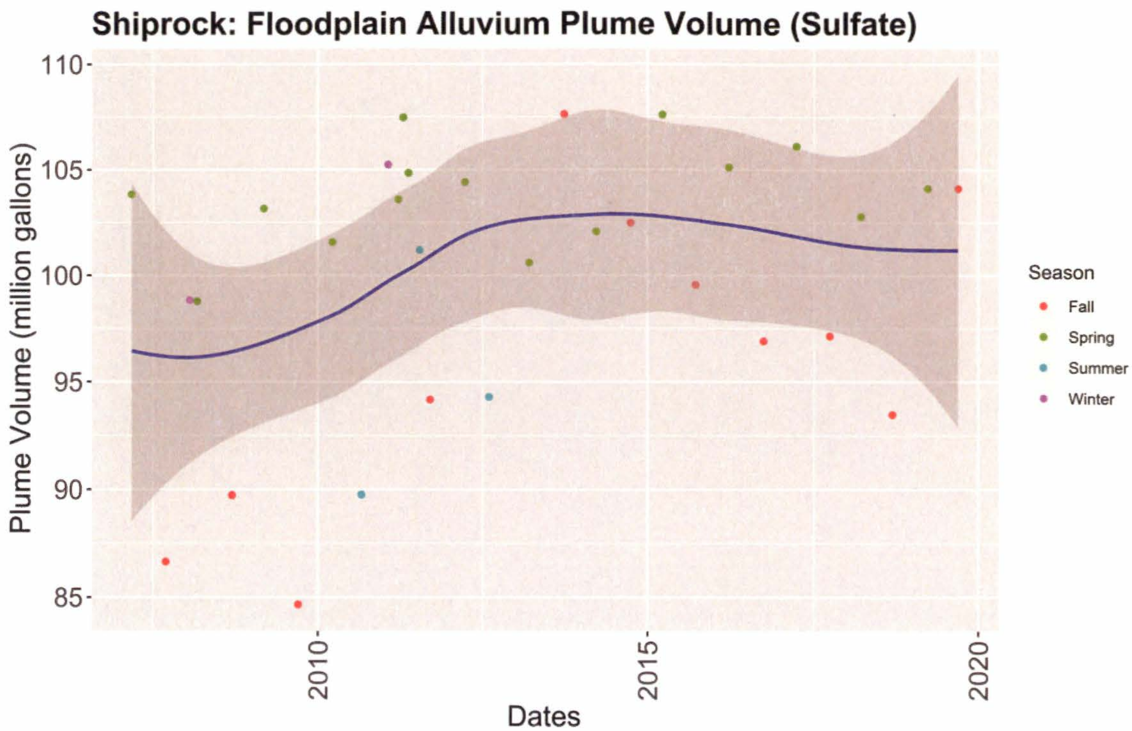

Figure A-17. Bulk sulfate plume volume on the Shiprock site floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume volume initially increased but has remained steady since 2012.

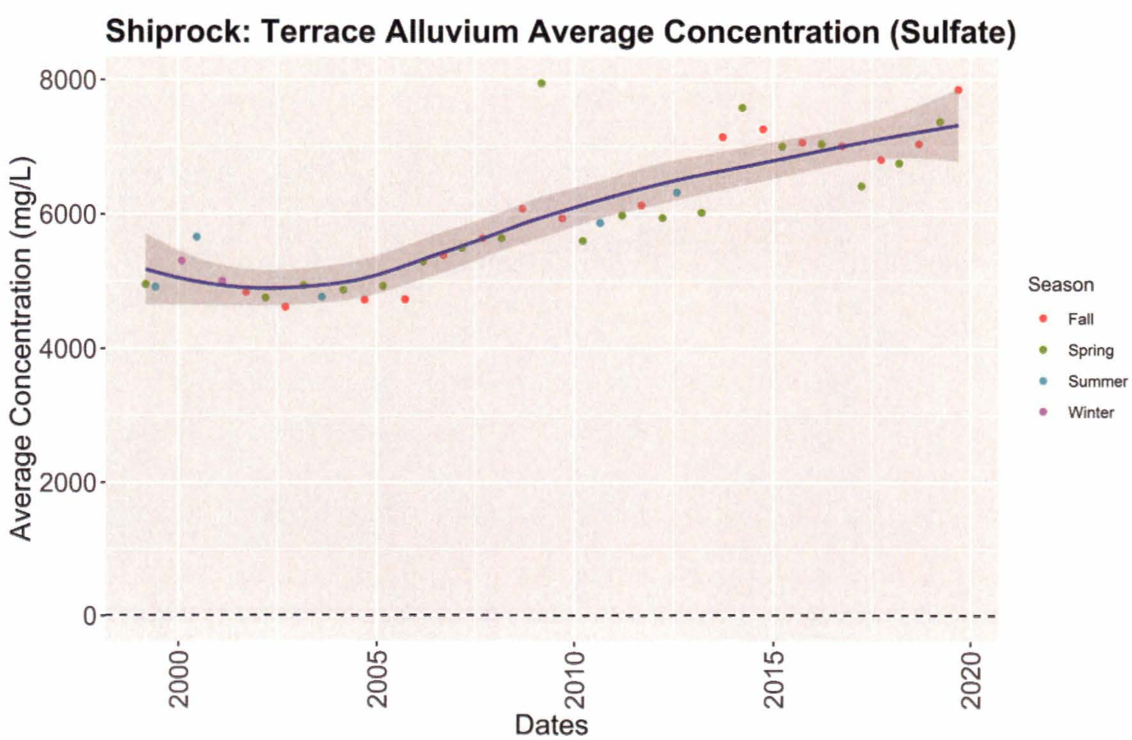

Figure A-18. Bulk sulfate plume average concentration on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Average plume concentration has increased over time.

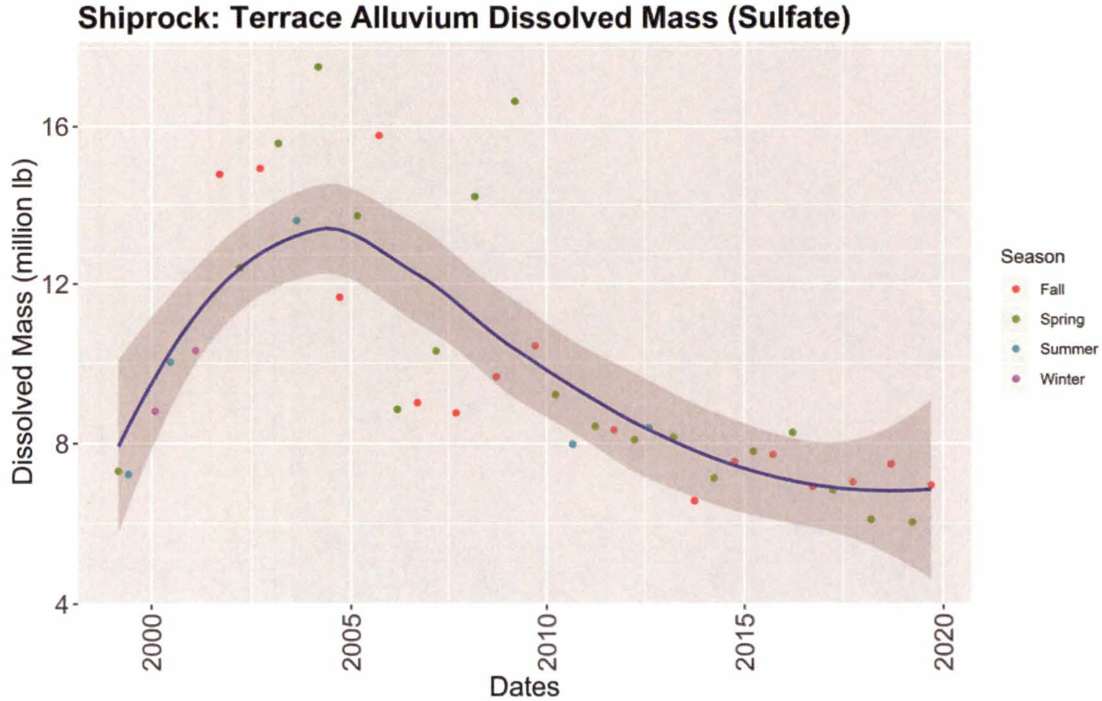

Figure A-19. Bulk sulfate plume mass on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. After an initial increase, plume mass has been decreasing since approximately 2004.

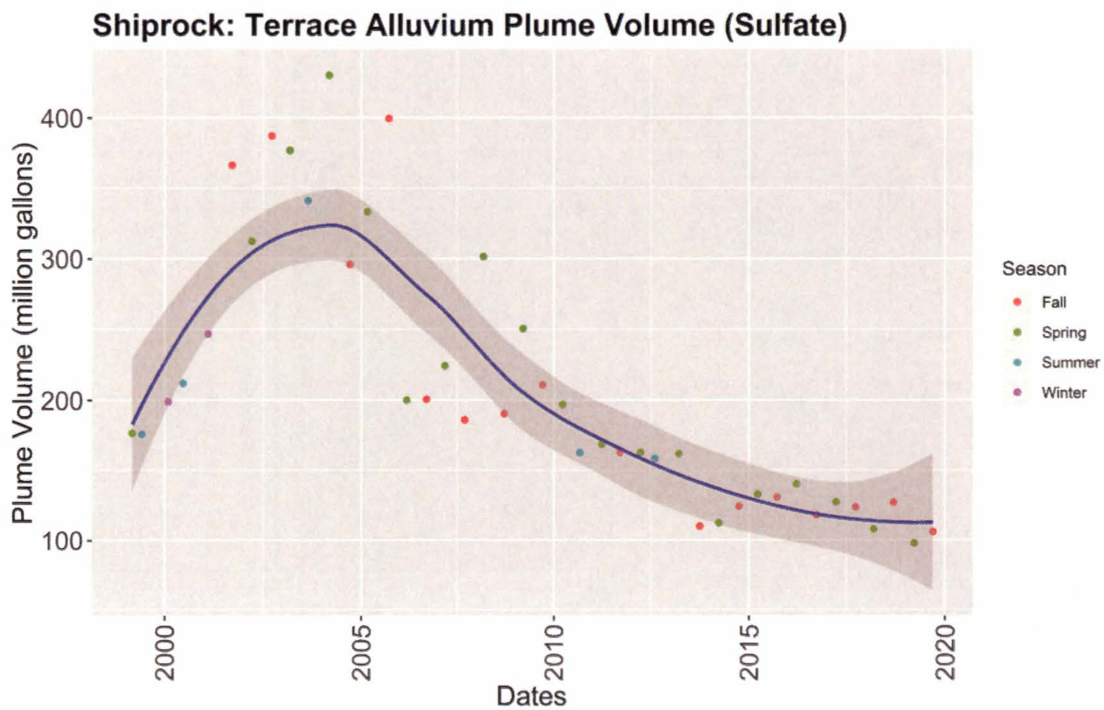

Figure A-20. Bulk sulfate plume volume on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume volume has been decreasing since 2004.

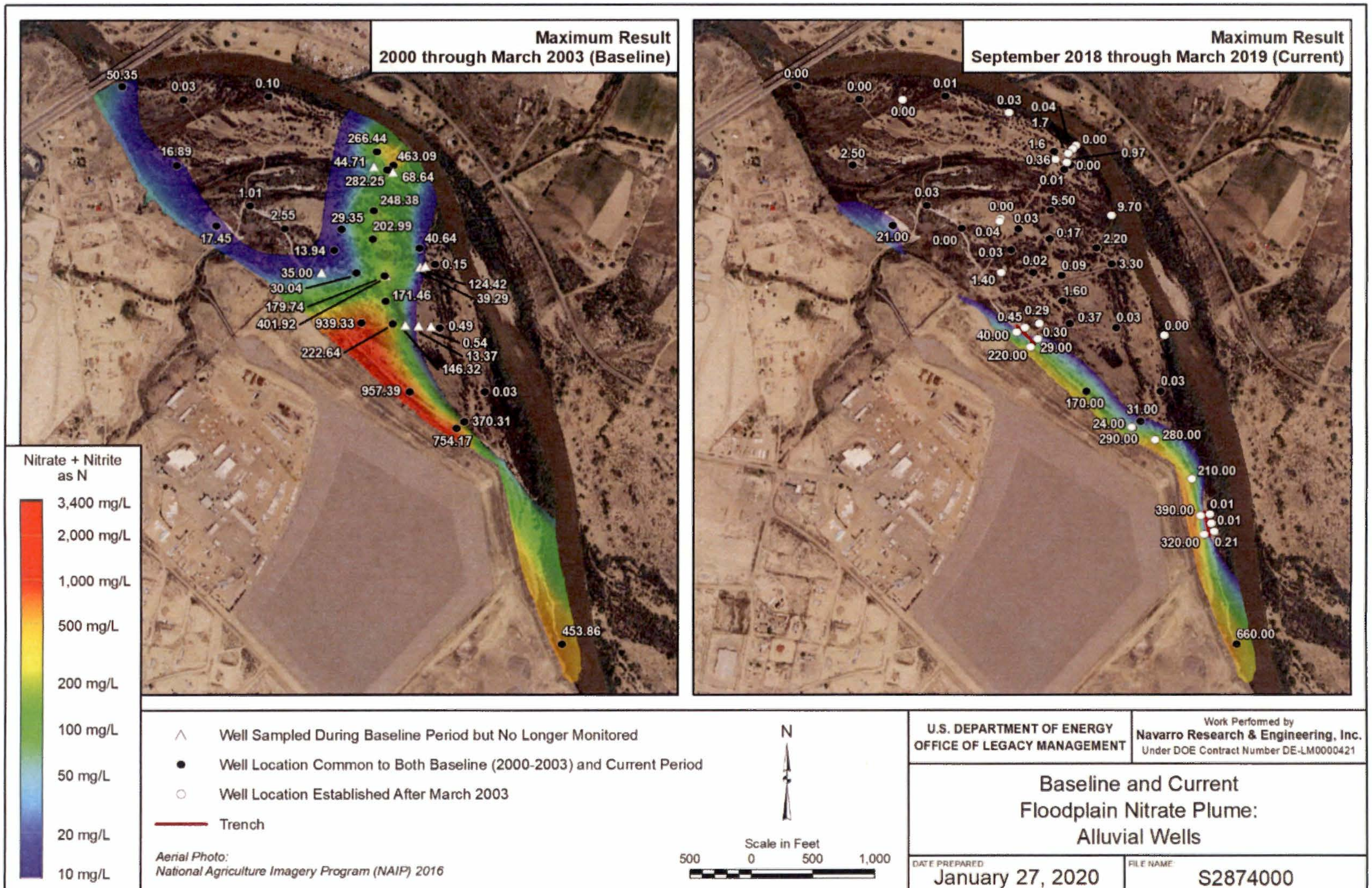

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Figure A-21. Shiprock site floodplain nitrate as nitrogen plume above the MCL of 10 mg/L. The baseline condition is reflective of the maximum concentration at each well between 2000 and March 2003. The right side uses the maximum concentration of each sampled alluvial well for the most recent sampling period (September 2018 through March 2019). The nitrate as nitrogen plume footprint has decreased since the baseline period.

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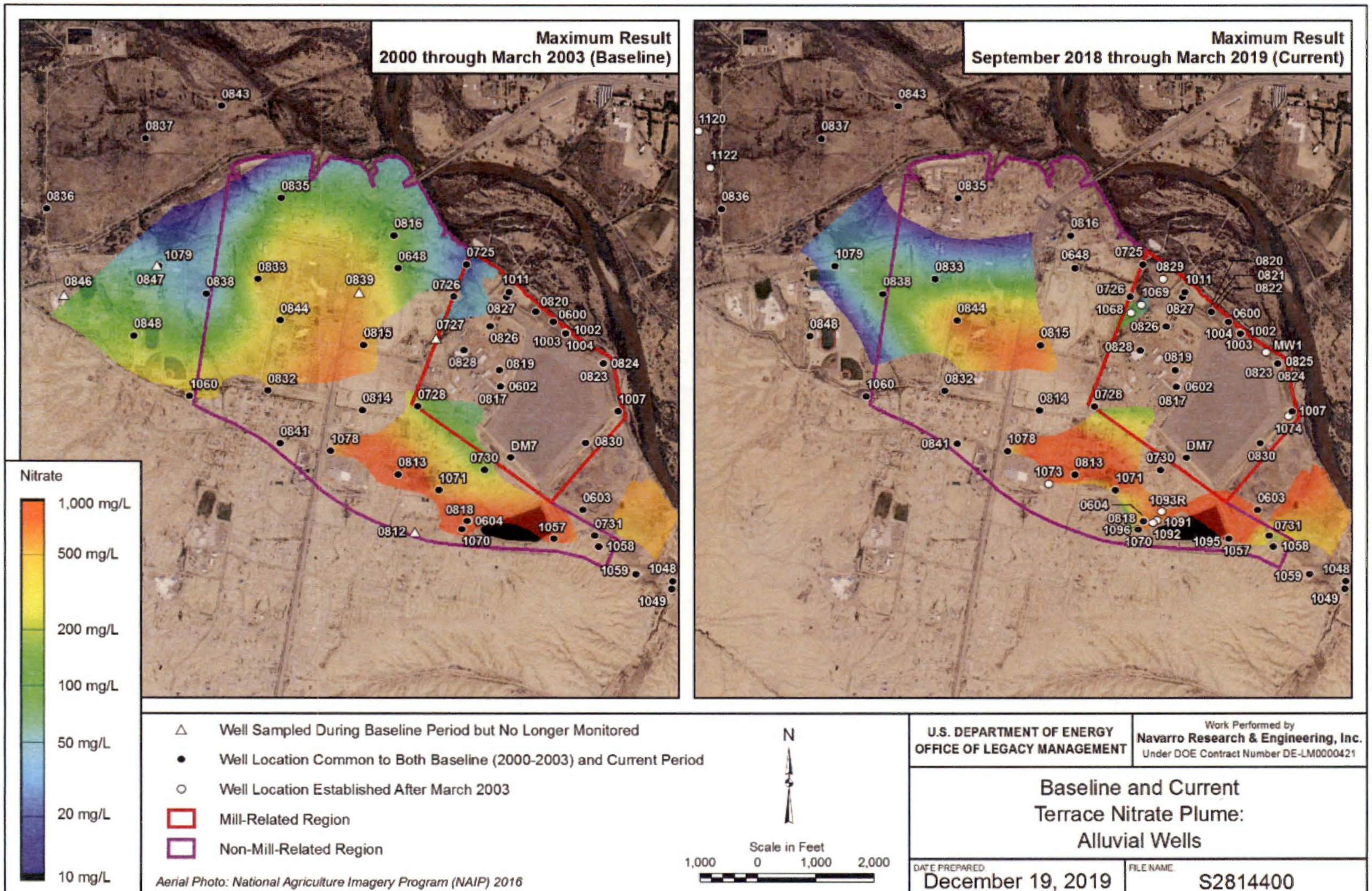

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Figure A-22. Shiprock site terrace nitrate as nitrogen plume above the MCL of 10 mg/L. The baseline condition is reflective of the maximum concentration at each well between 2000 and March 2003. The right side uses the maximum concentration of each sampled alluvial well for the most recent sampling period (September 2018 through March 2019). The red and purple outlines represent the non-mill-related and the mill-related plume areas, as determined by an isotopic study (DOE 2018a). The nitrate as nitrogen plume footprint has decreased since the baseline period.

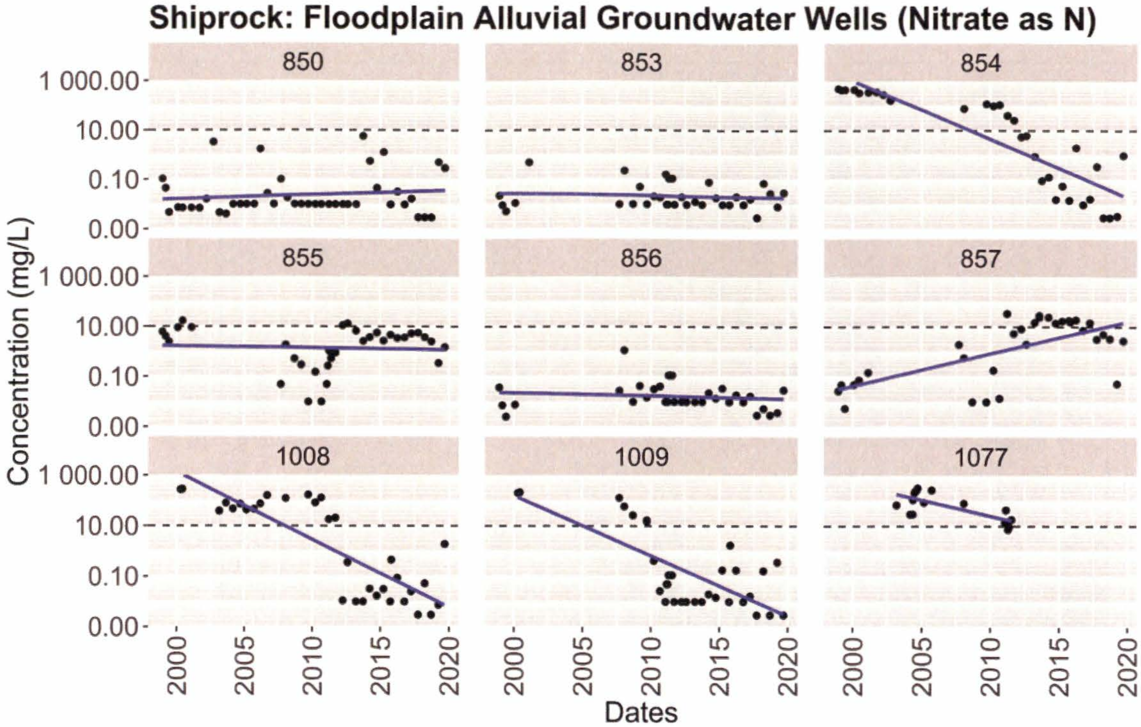

Figure A-23. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

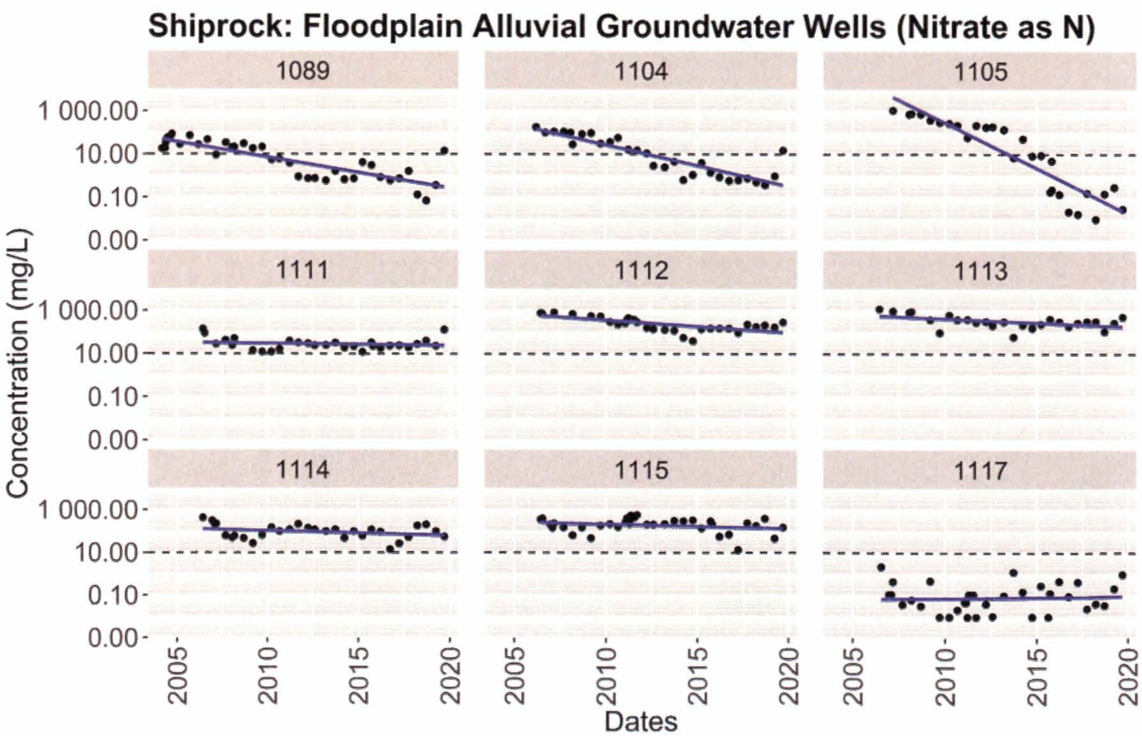

Figure A-24. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

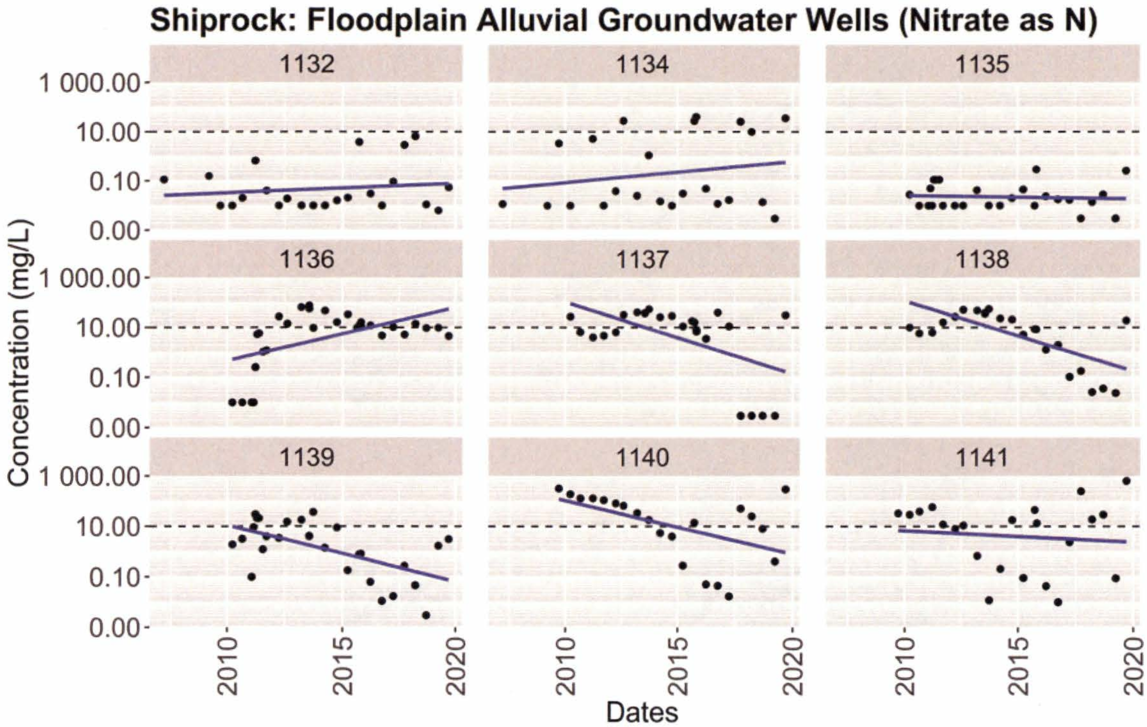

Figure A-25. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

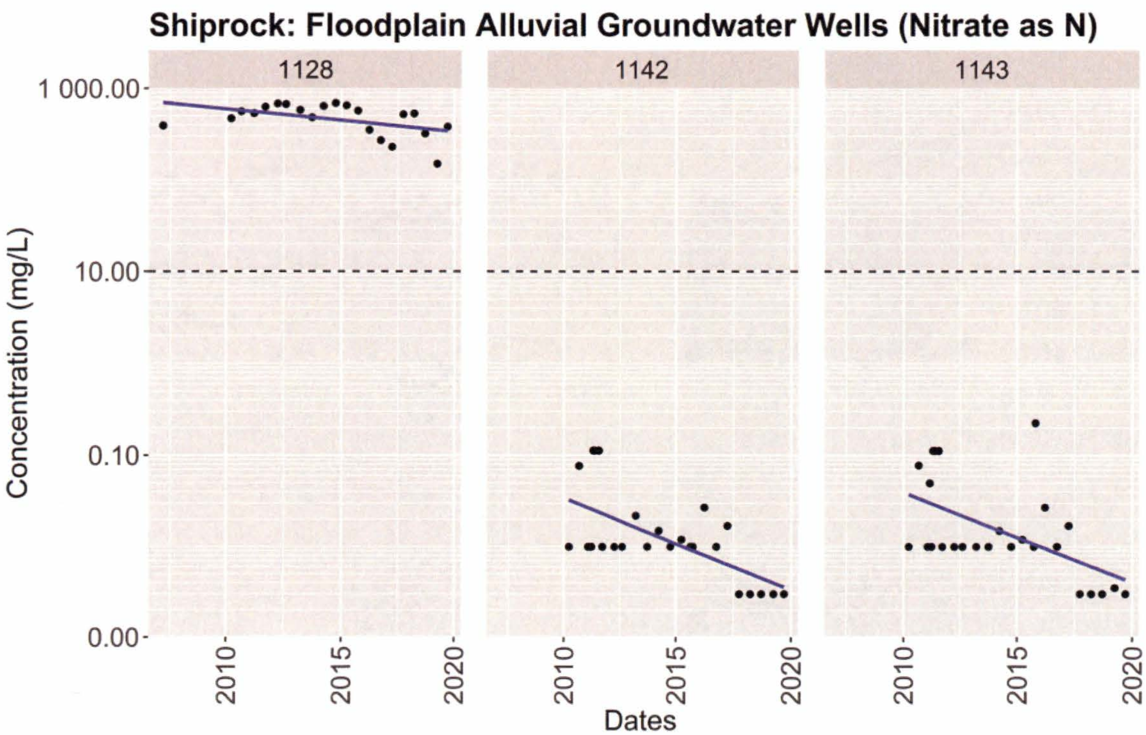

Figure A-26. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

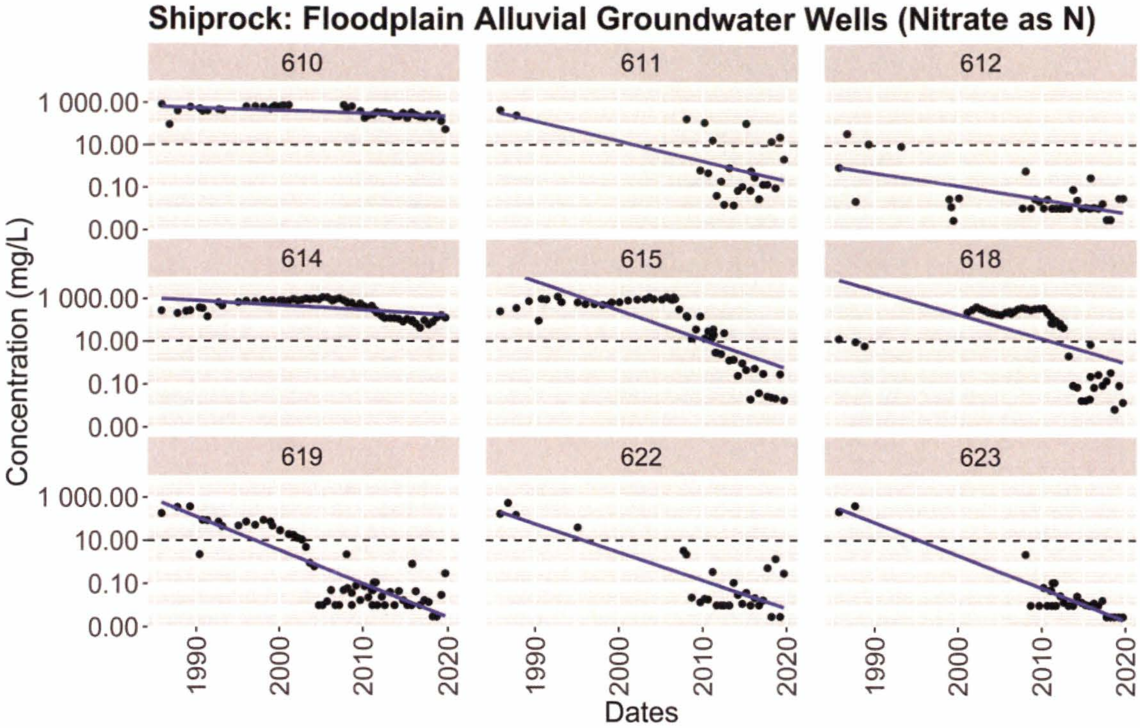

Figure A-27. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

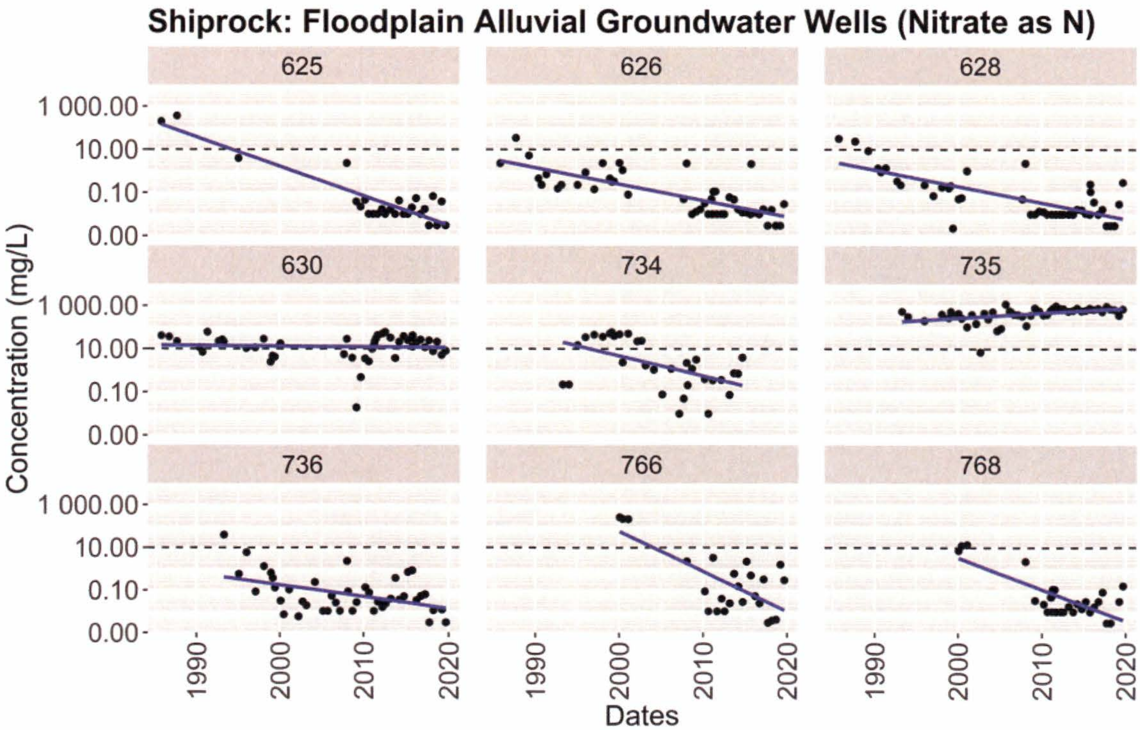

Figure A-28. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

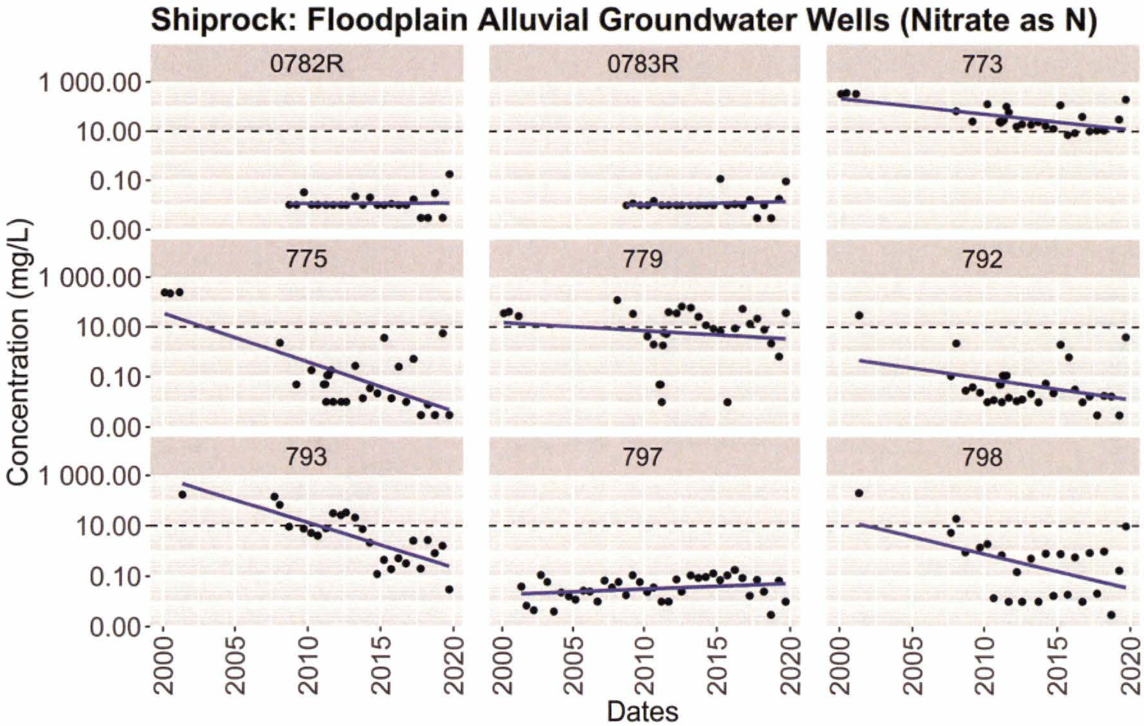

Figure A-29. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

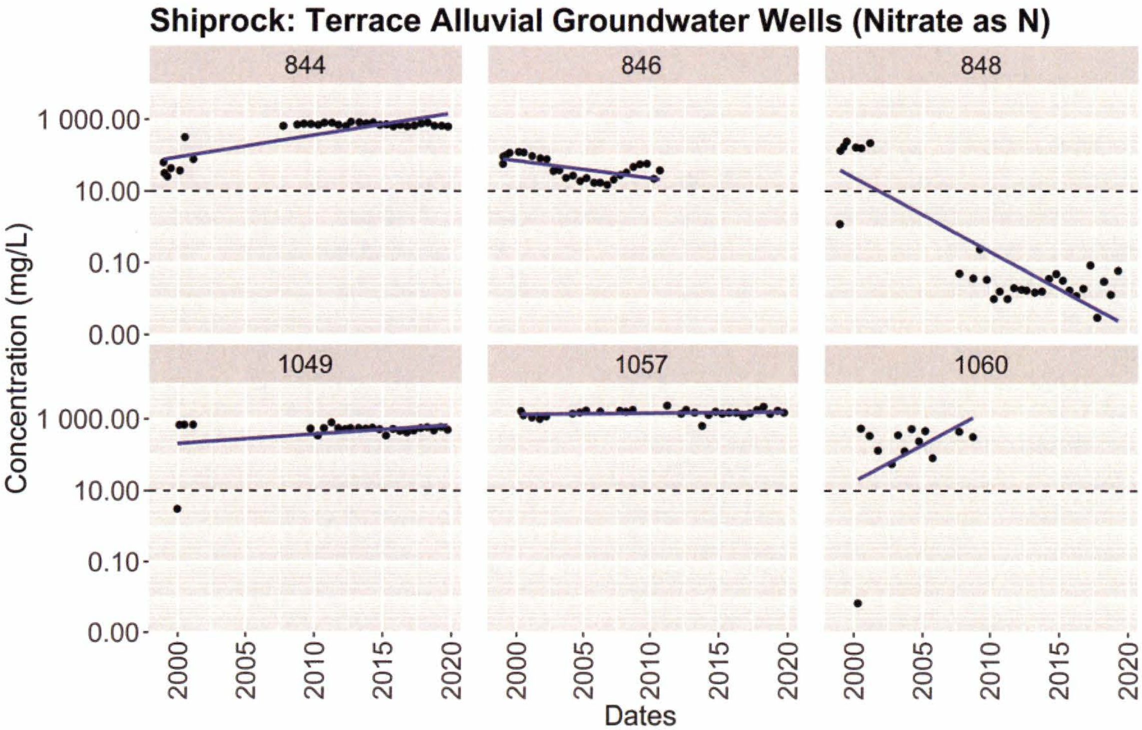

Figure A-30. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

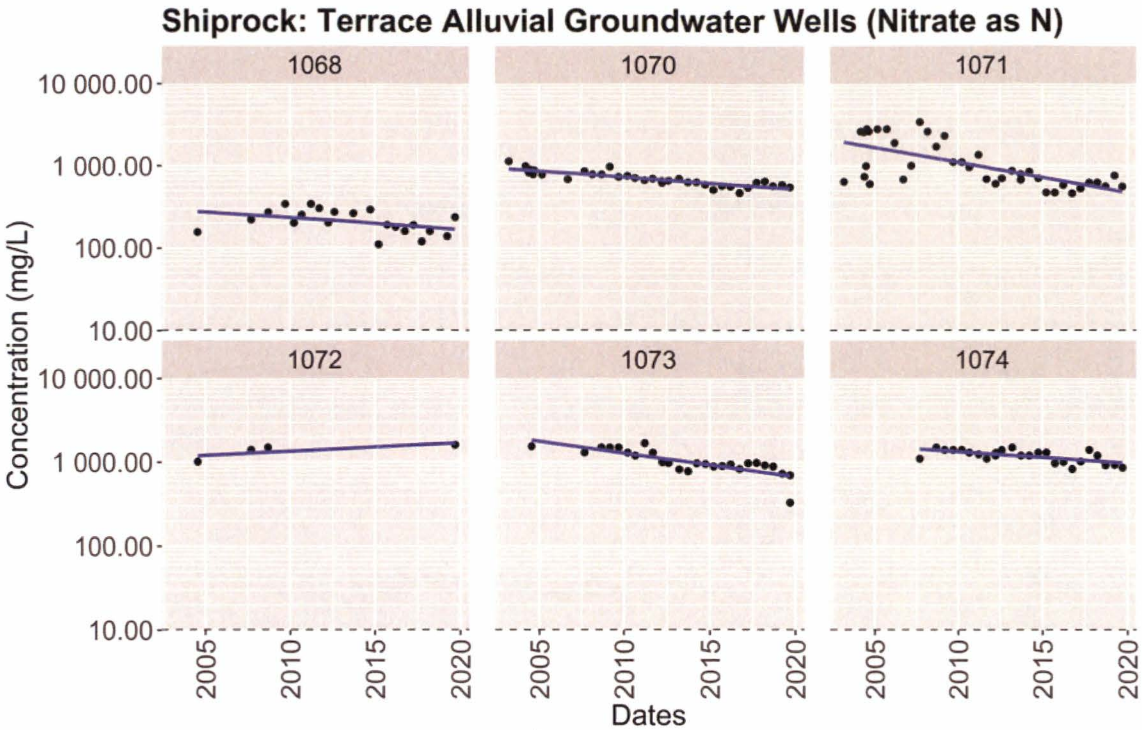

Figure A-31. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

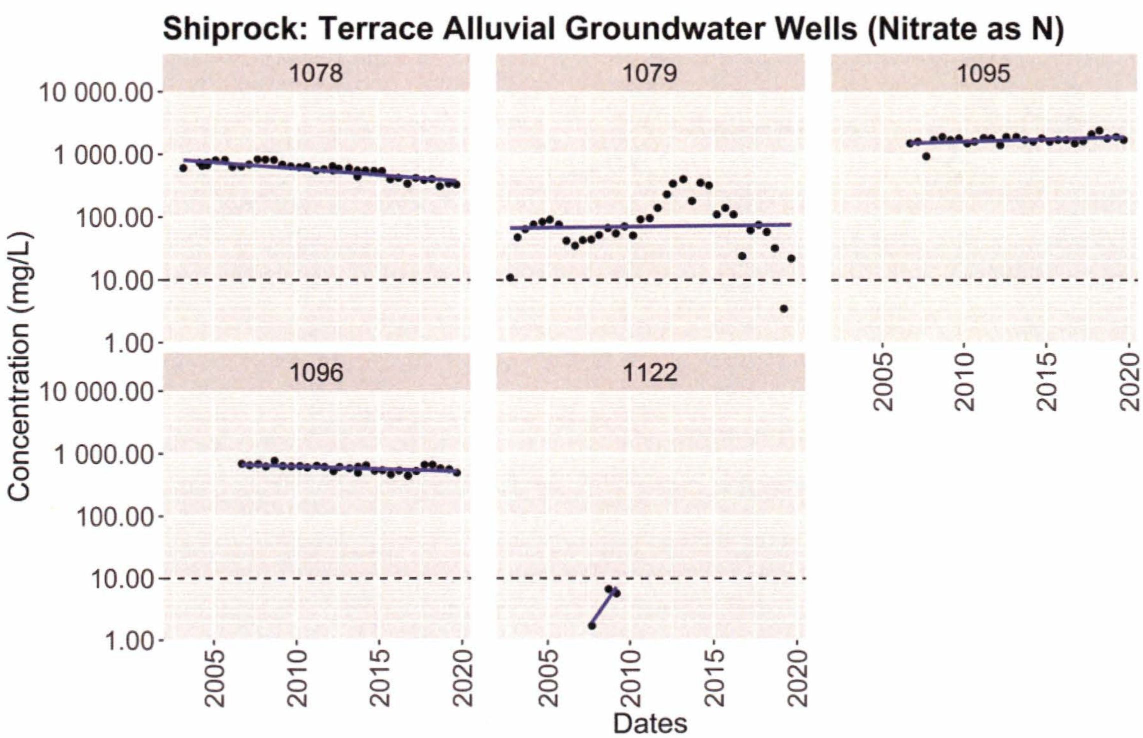

Figure A-32. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

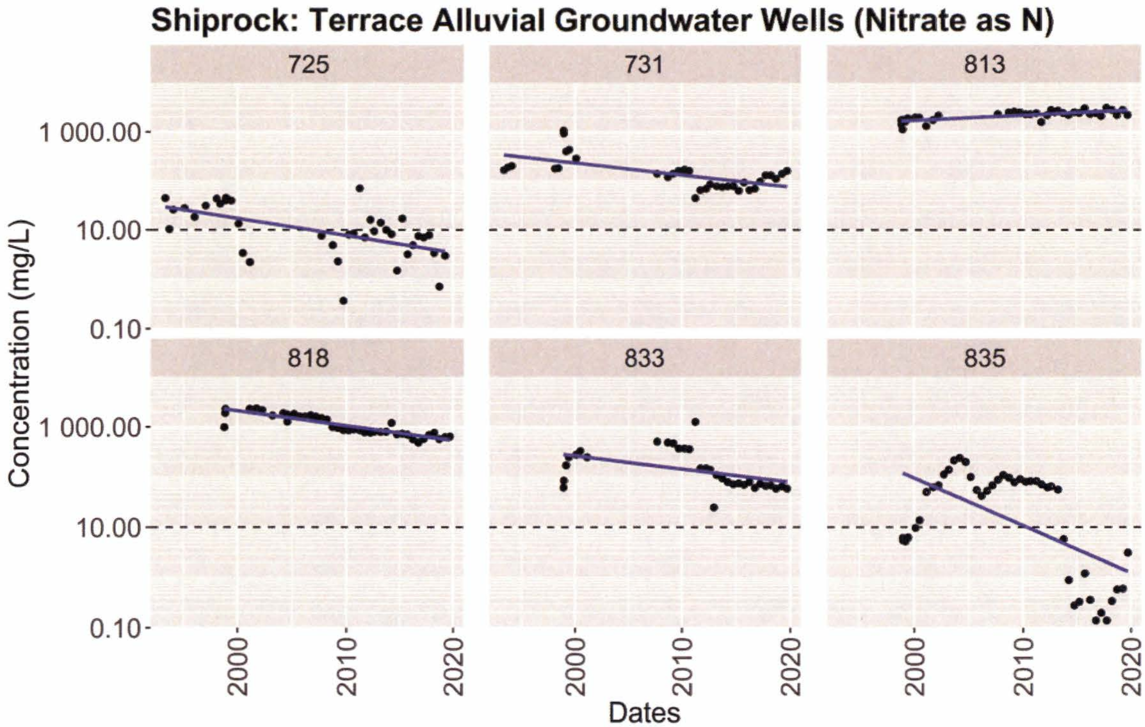

Figure A-33. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

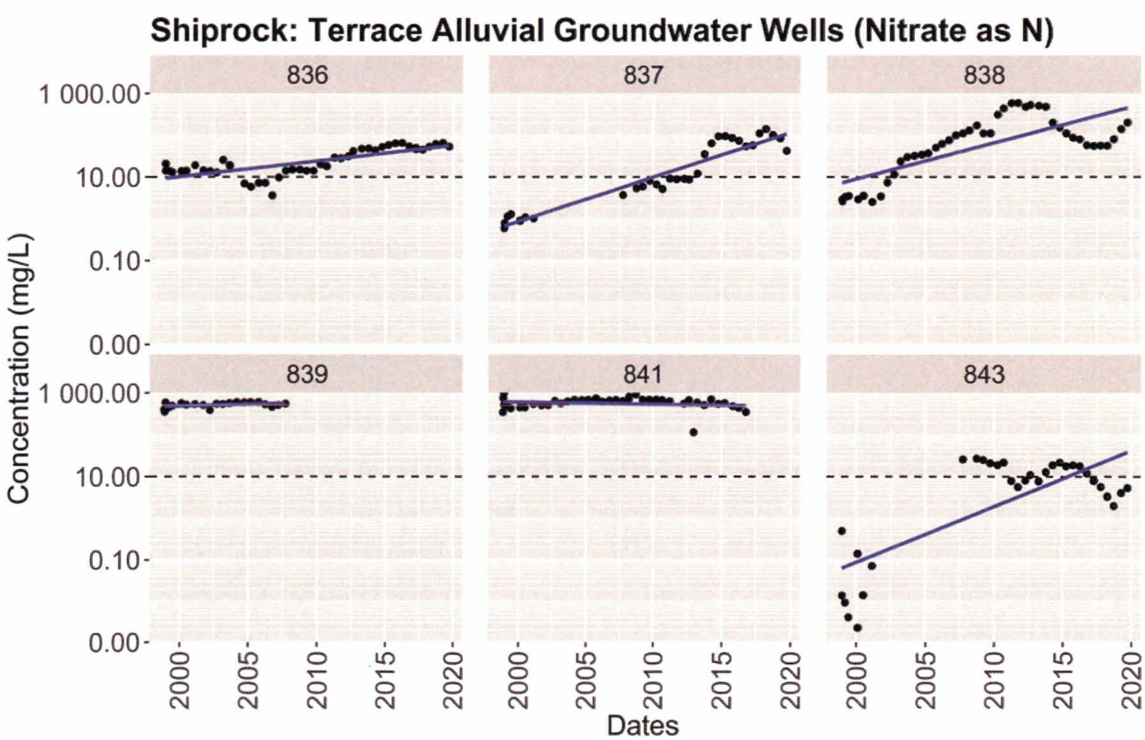

Figure A-34. Nitrate as nitrogen trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 10 mg/L.

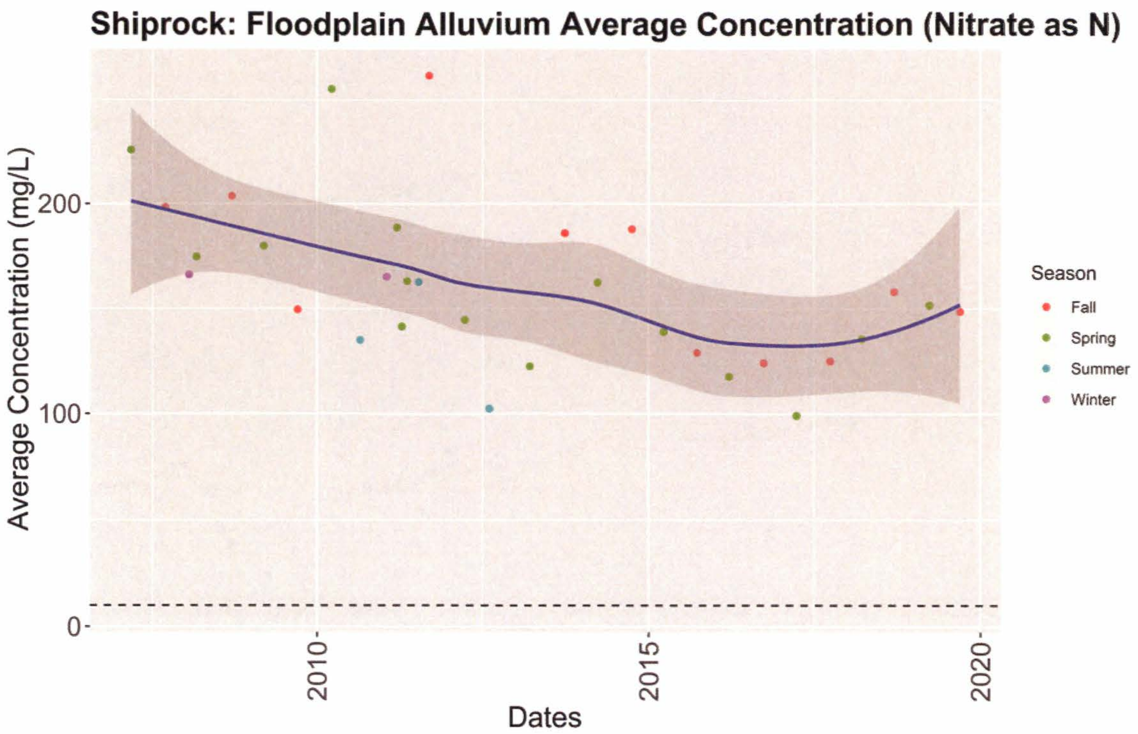

Figure A-35. Bulk nitrate as nitrogen average plume concentration on the Shiprock site floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Average plume concentration initially decreased but has been increasing since 2017.

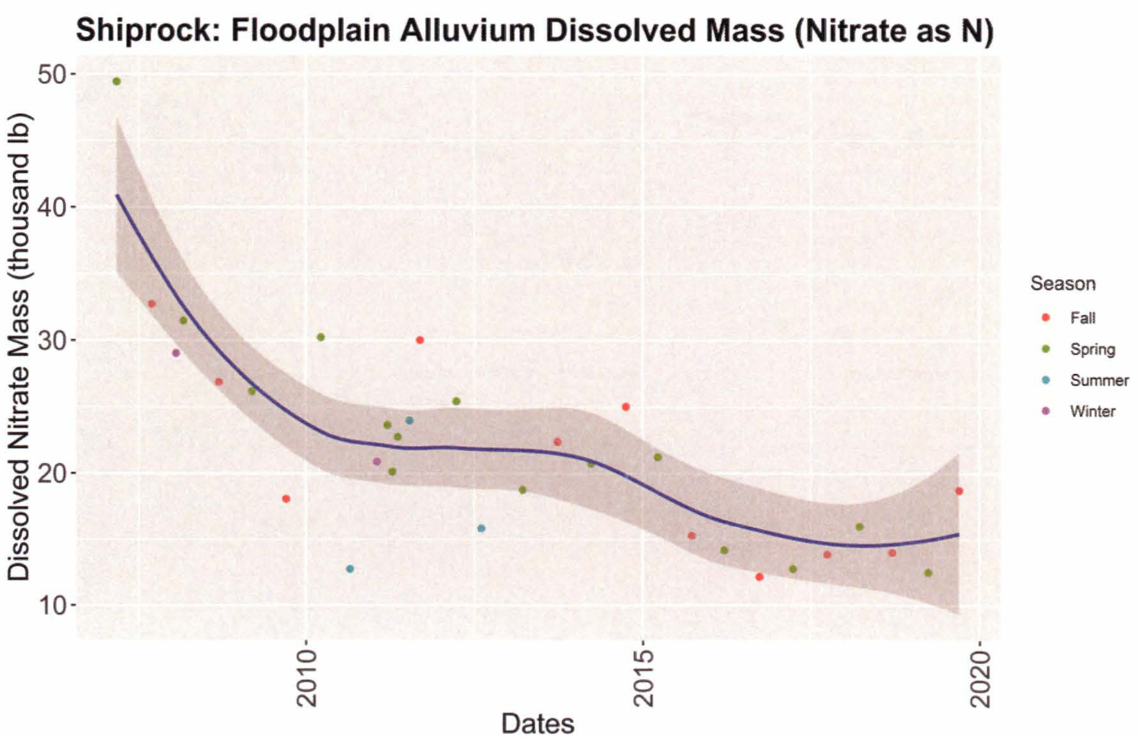

Figure A-36. Bulk nitrate as nitrogen plume mass on the Shiprock floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume mass has been decreasing over time.

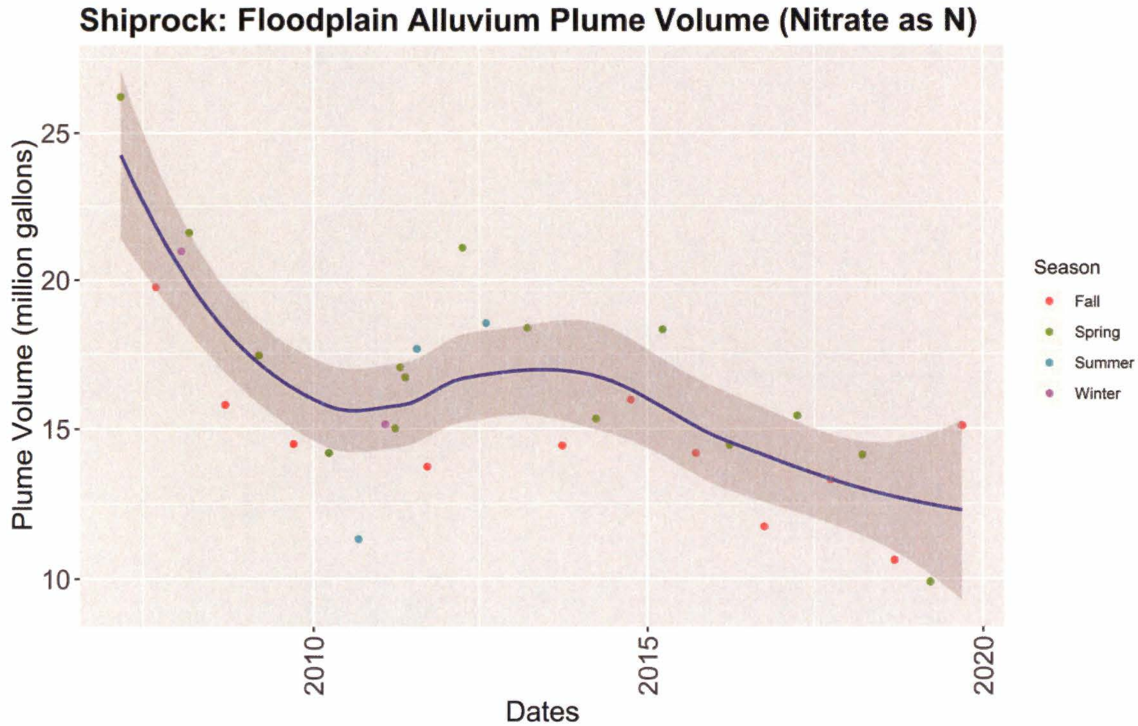

Figure A-37. Bulk nitrate as nitrogen plume volume on the Shiprock floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume volume has been decreasing over time.

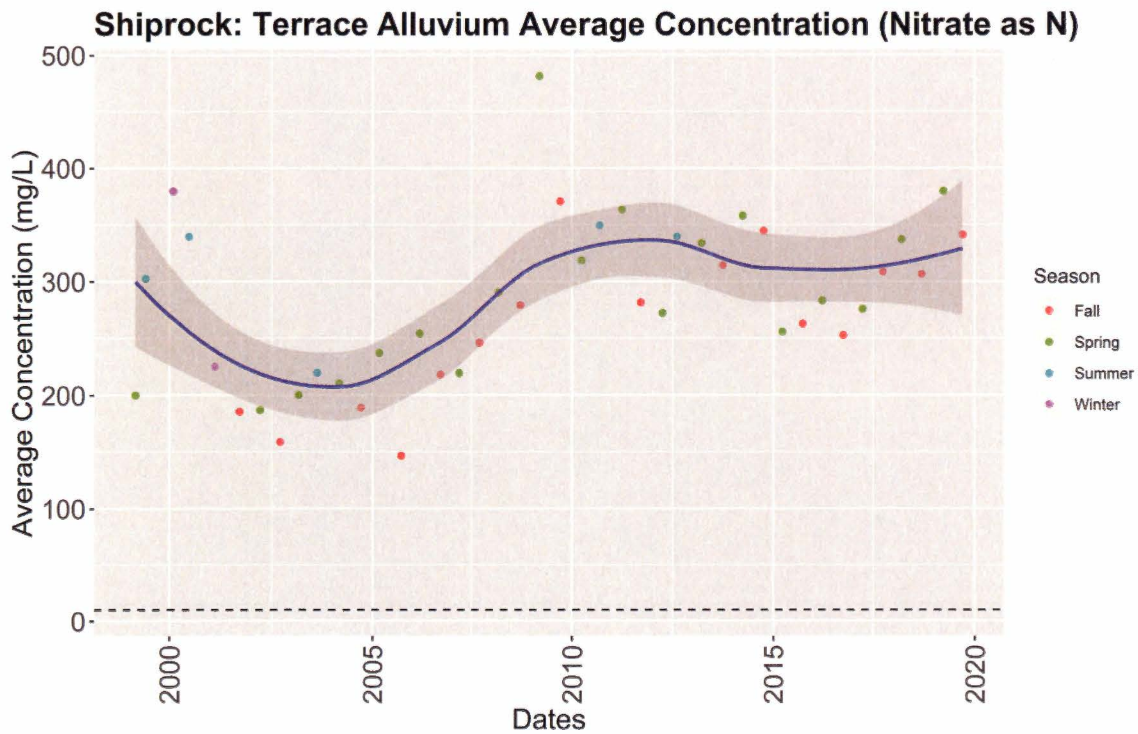

Figure A-38. Bulk nitrate as nitrogen average plume concentration on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Average concentration has fluctuated over time but has been increasing since 2005.

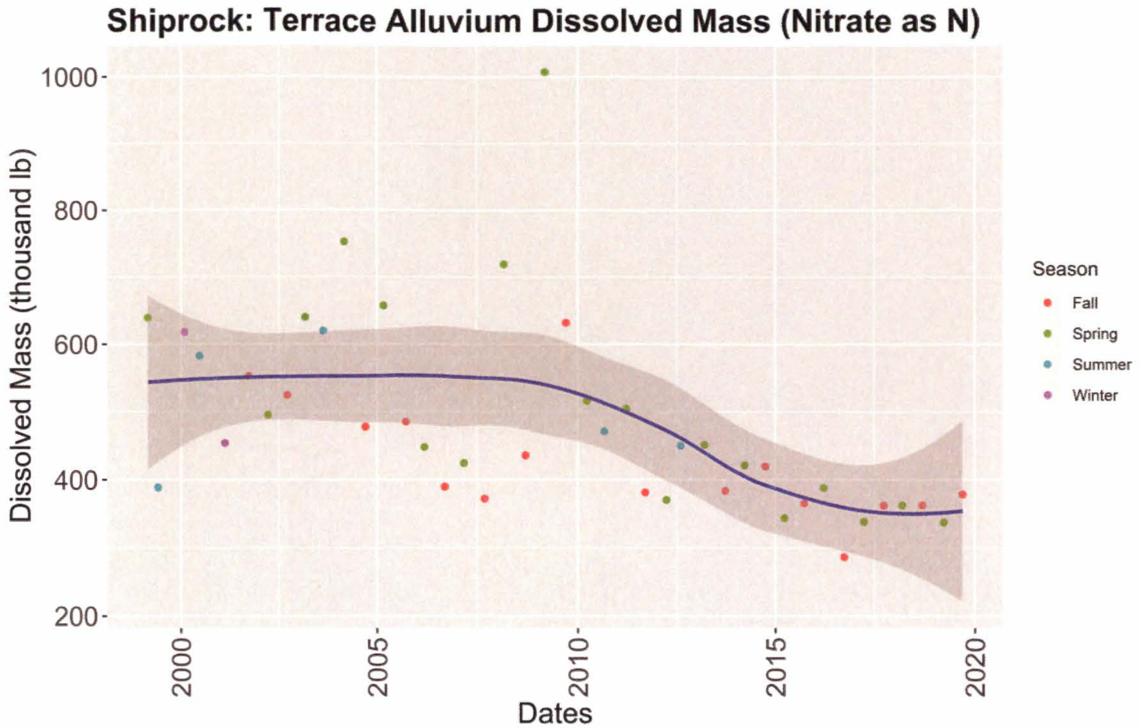

Figure A-39. Bulk nitrate as nitrogen plume mass on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume mass has been decreasing since 2010.

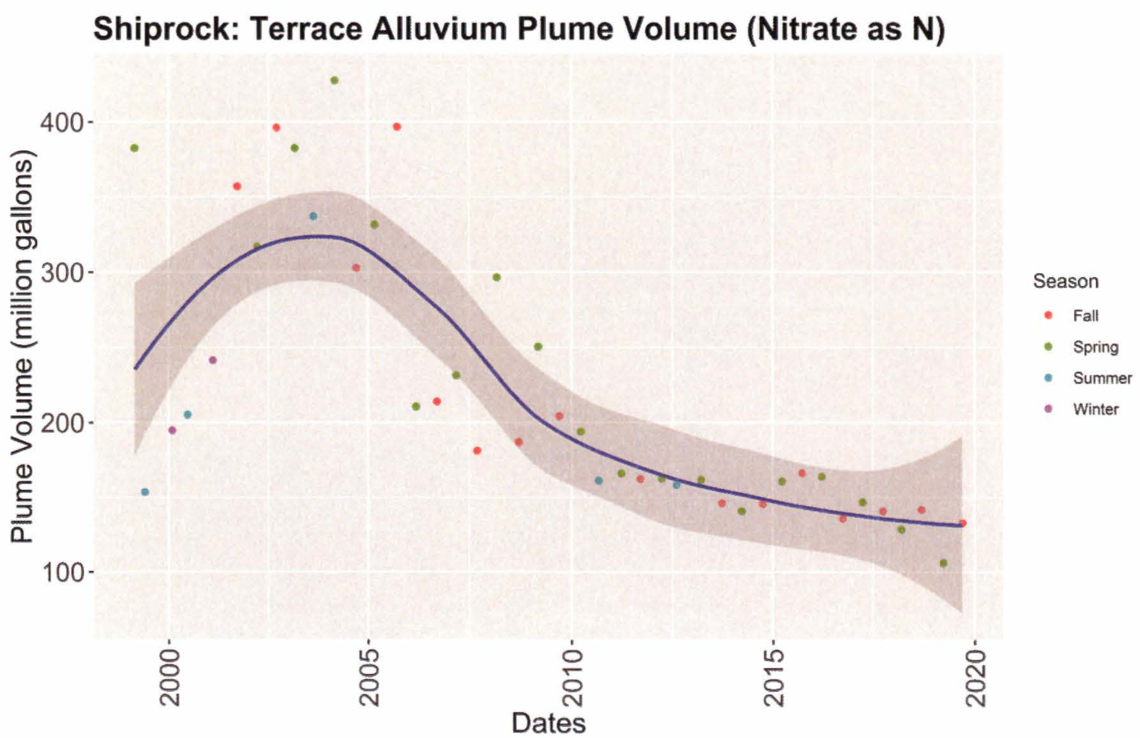

Figure A-40. Bulk nitrate as nitrogen plume volume on the Shiprock terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume volume has fluctuated over time but has been decreasing since 2005.

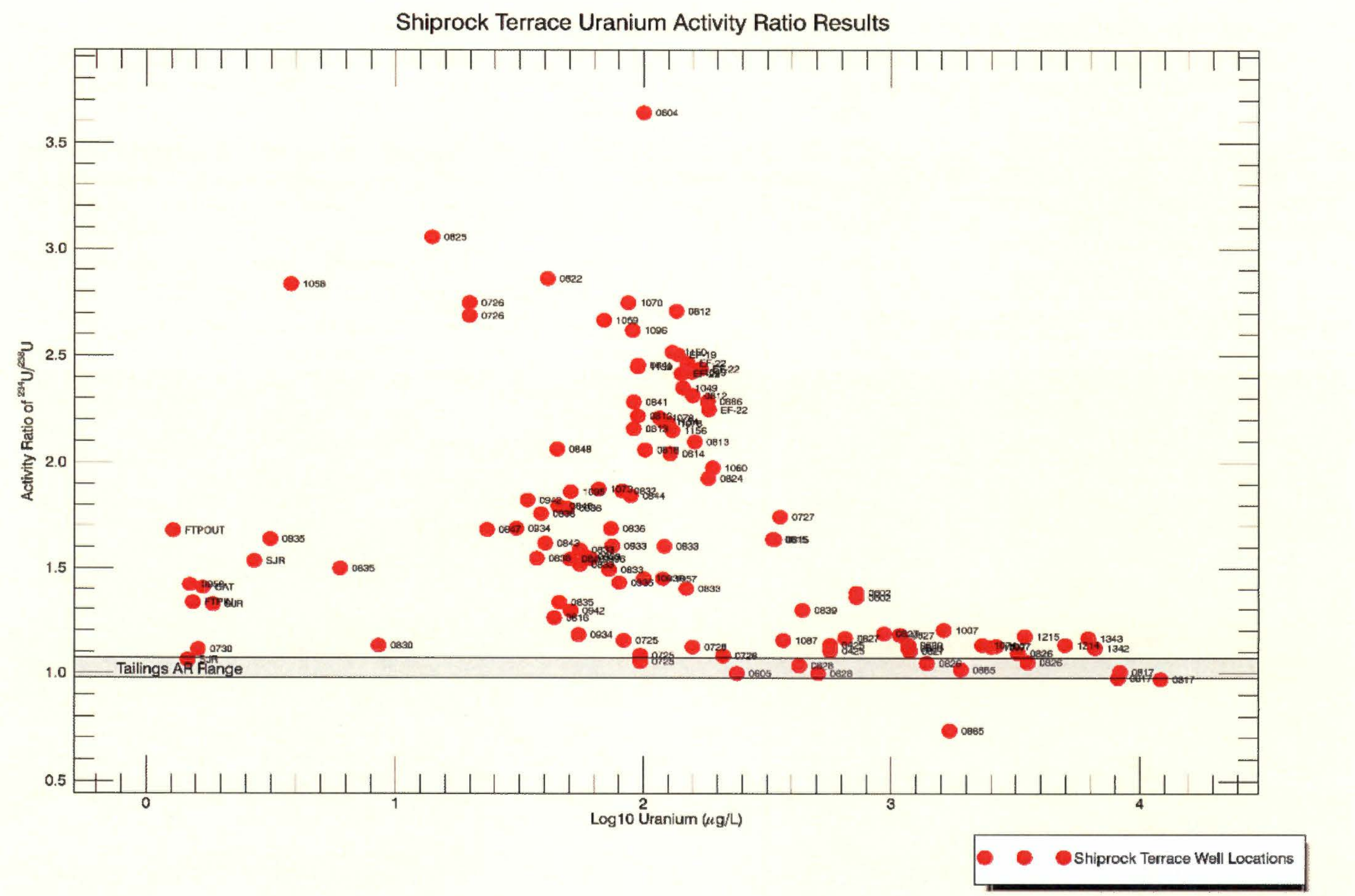

Figure A-41. Shiprock site terrace activity ratios for $^{234}U/^{238}U$ compared to uranium concentrations in µg/L, in log scale. Wells within and below the tailings activity ratio range can be considered mill related.

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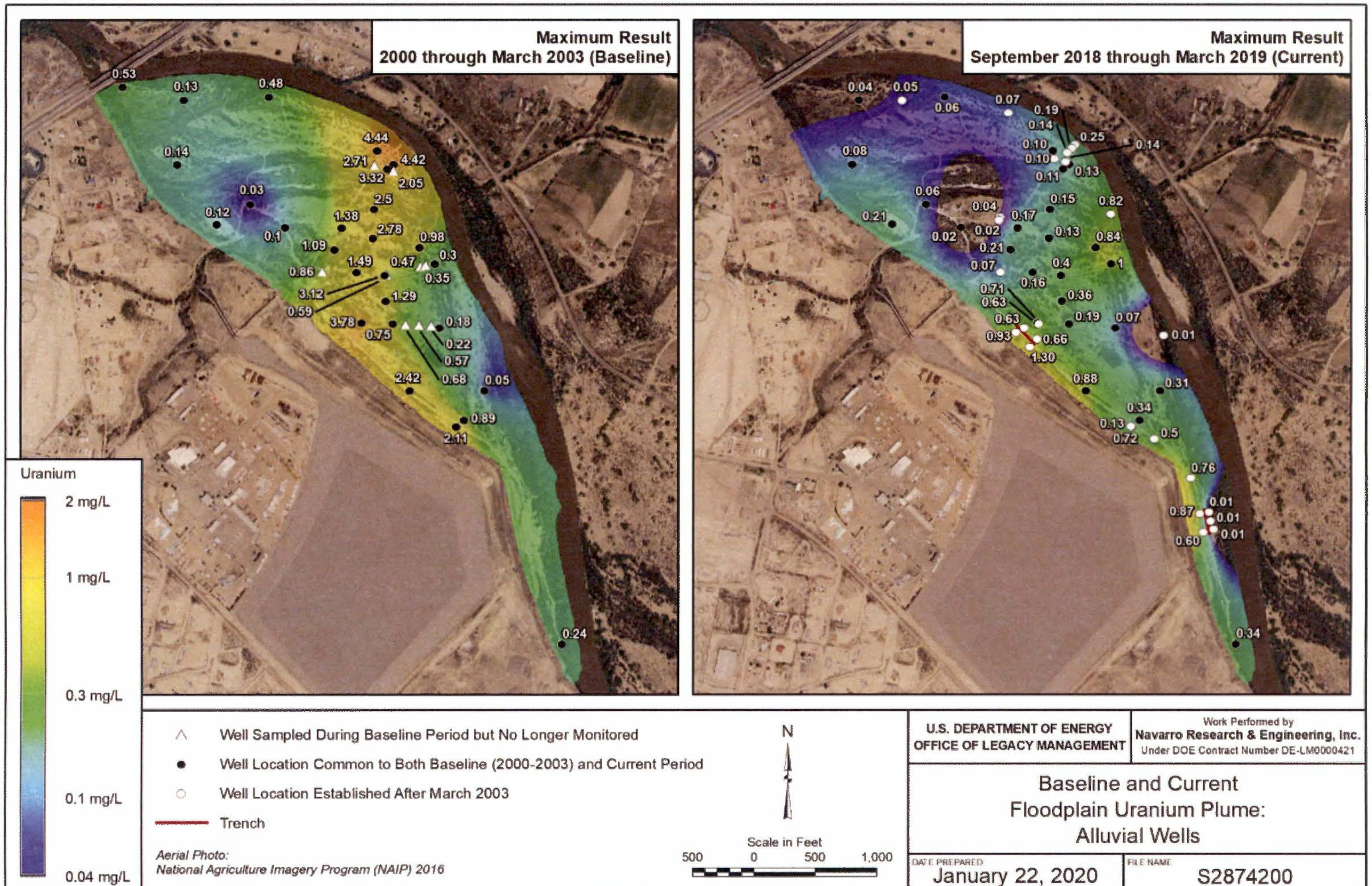

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Figure A-42. Shiprock site floodplain uranium plume above the MCL of 0.044 mg/L. The baseline was determined using the maximum concentration at each well between 2000 and March 2003. The right side uses the maximum concentration of each sampled alluvial well for the most recent sampling period (September 2018 through March 2019). The uranium plume footprint has decreased since the baseline period.

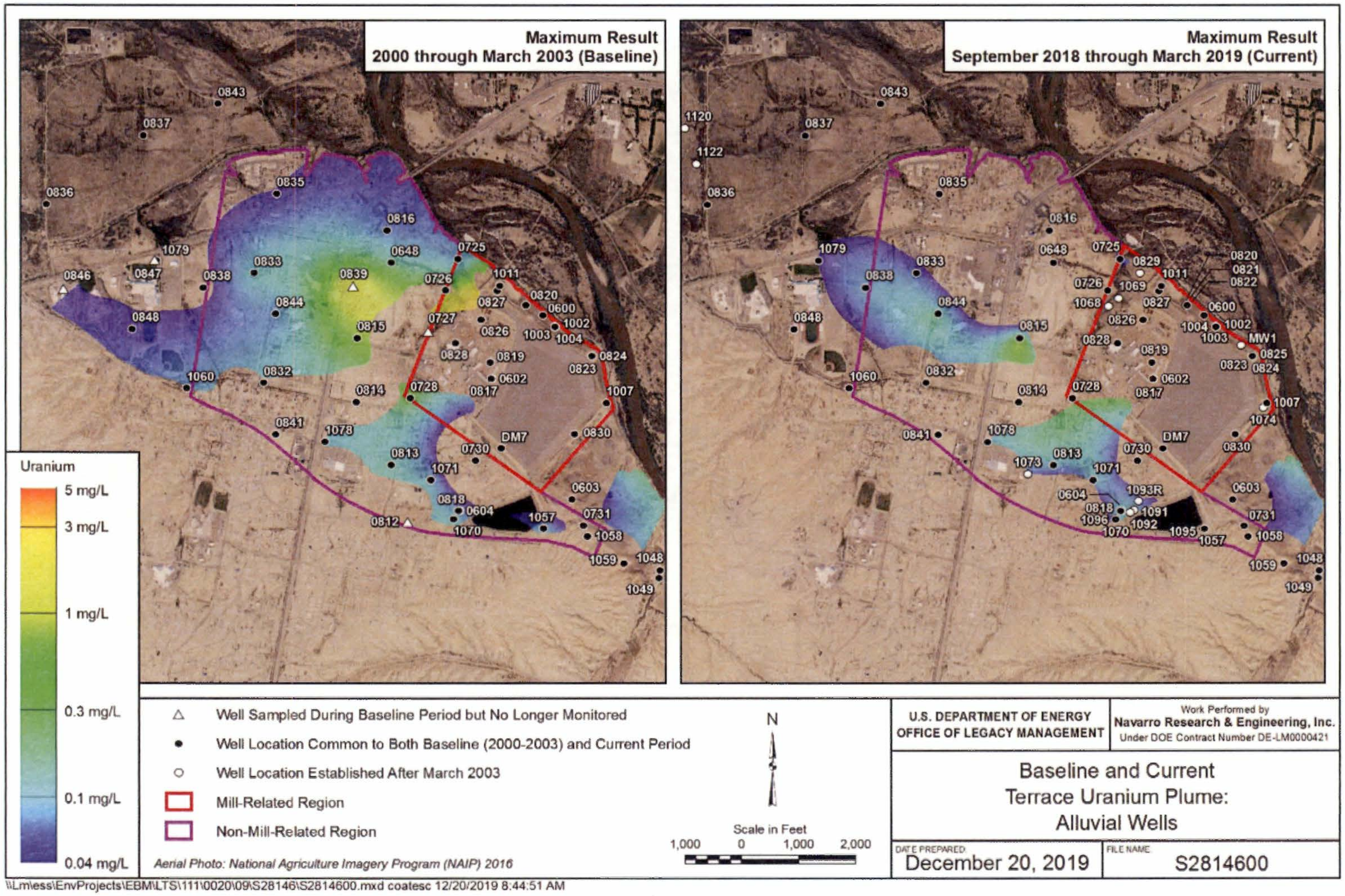

Figure A-43. Shiprock site terrace uranium plume above the MCL of 0.044 mg/L. The baseline was determined using the maximum concentration at each well between 2000 and March 2003. The right side uses the maximum concentration of each sampled alluvial well for the most recent sampling period (September 2018 through March 2019). The red and purple outlines represent the non-mill-related and the mill-related plume areas, as determined by an isotopic study (DOE 2018a). The uranium plume footprint has decreased in size since the baseline period.

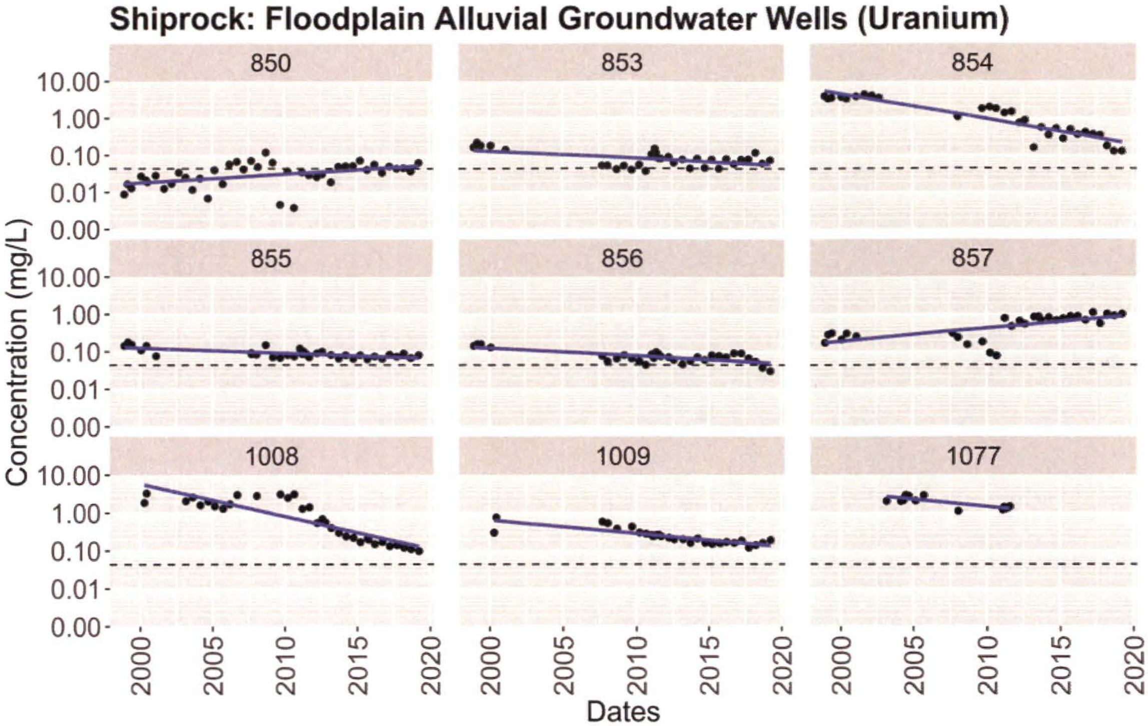

Figure A-44. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

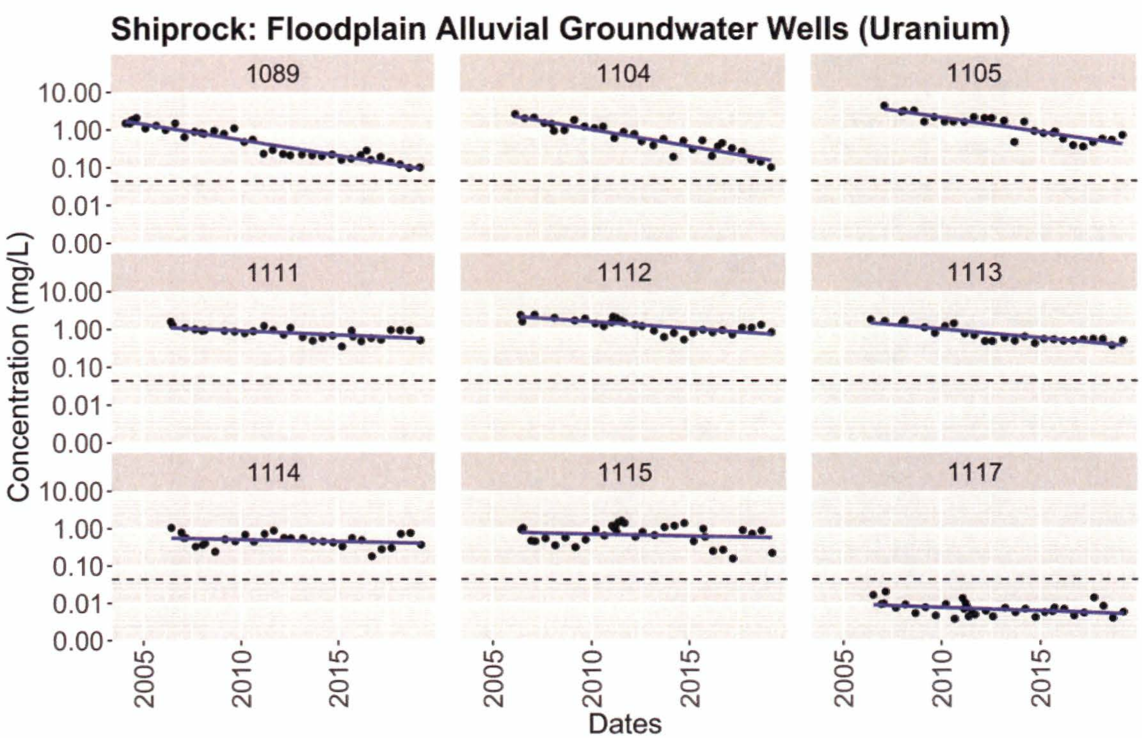

Figure A-45. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

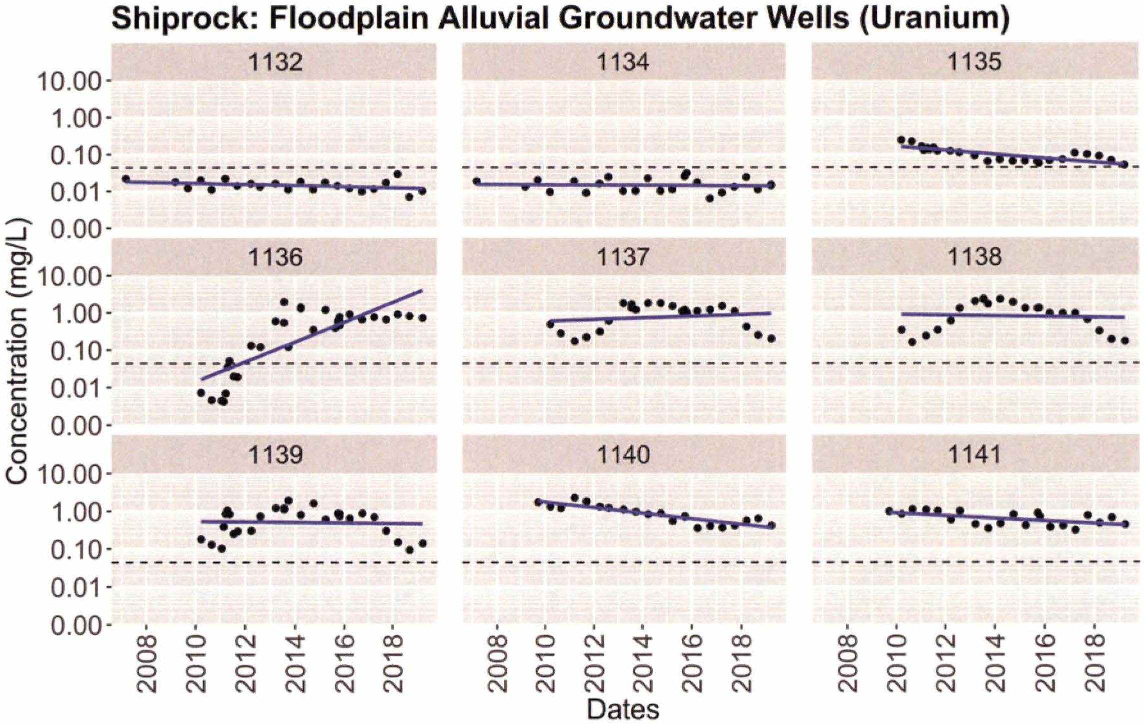

Figure A-46. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

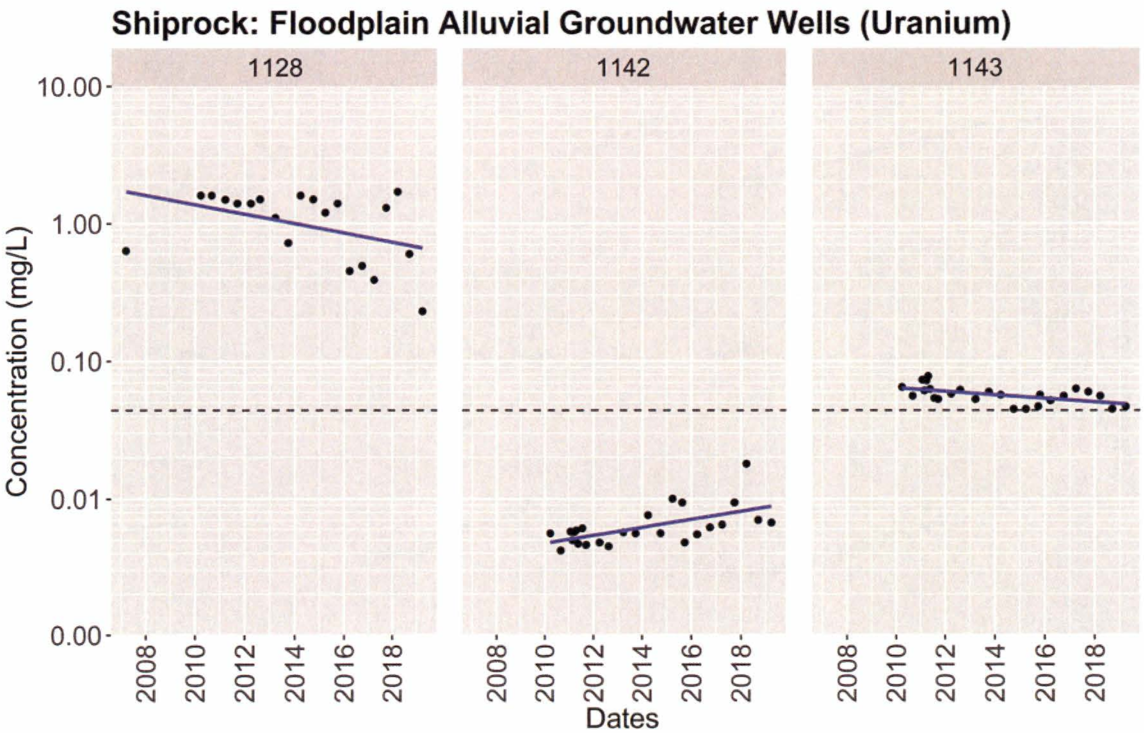

Figure A-47. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

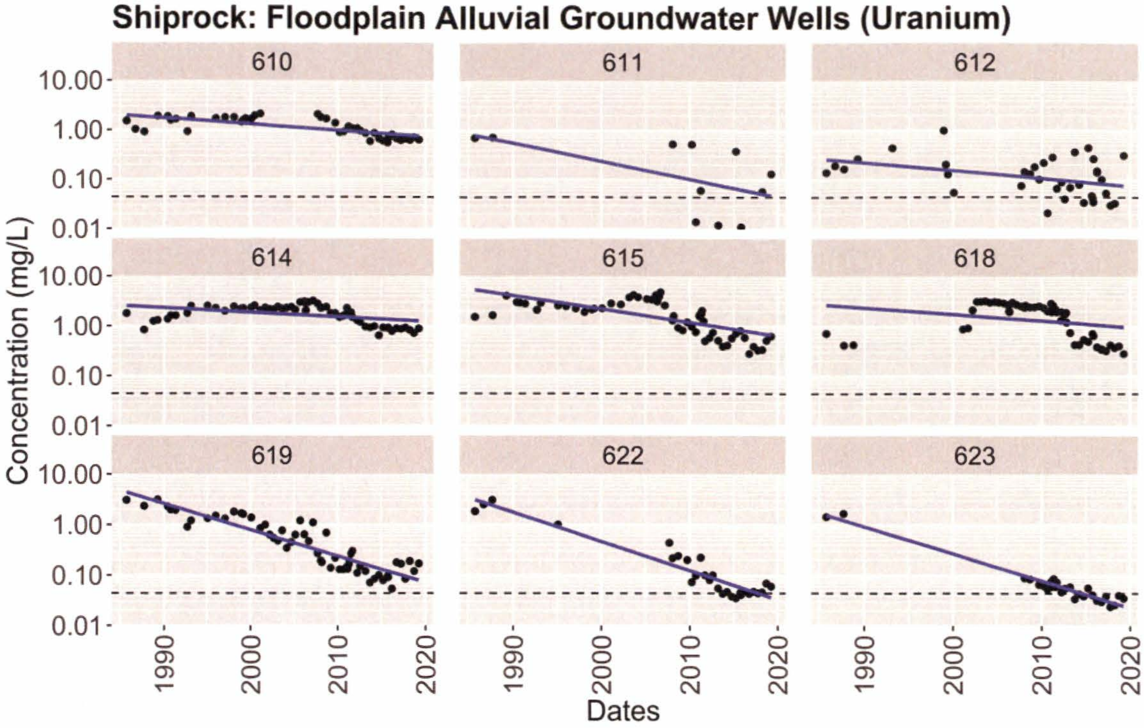

Figure A-48. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

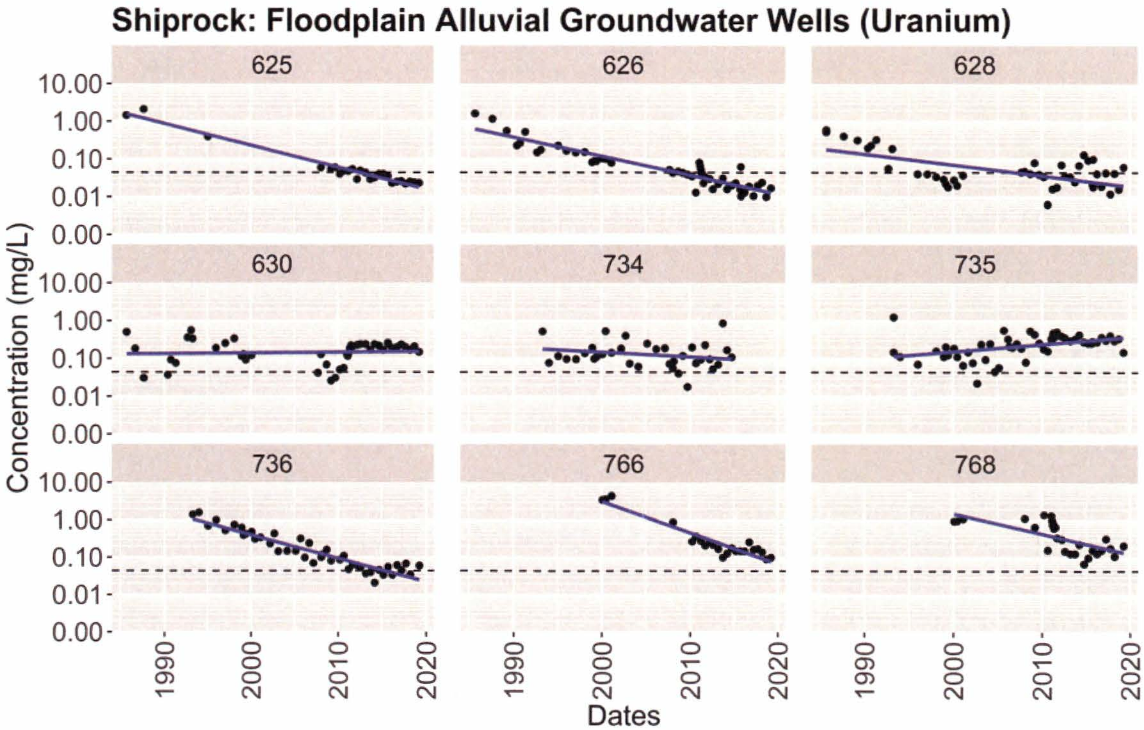

Figure A-49. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

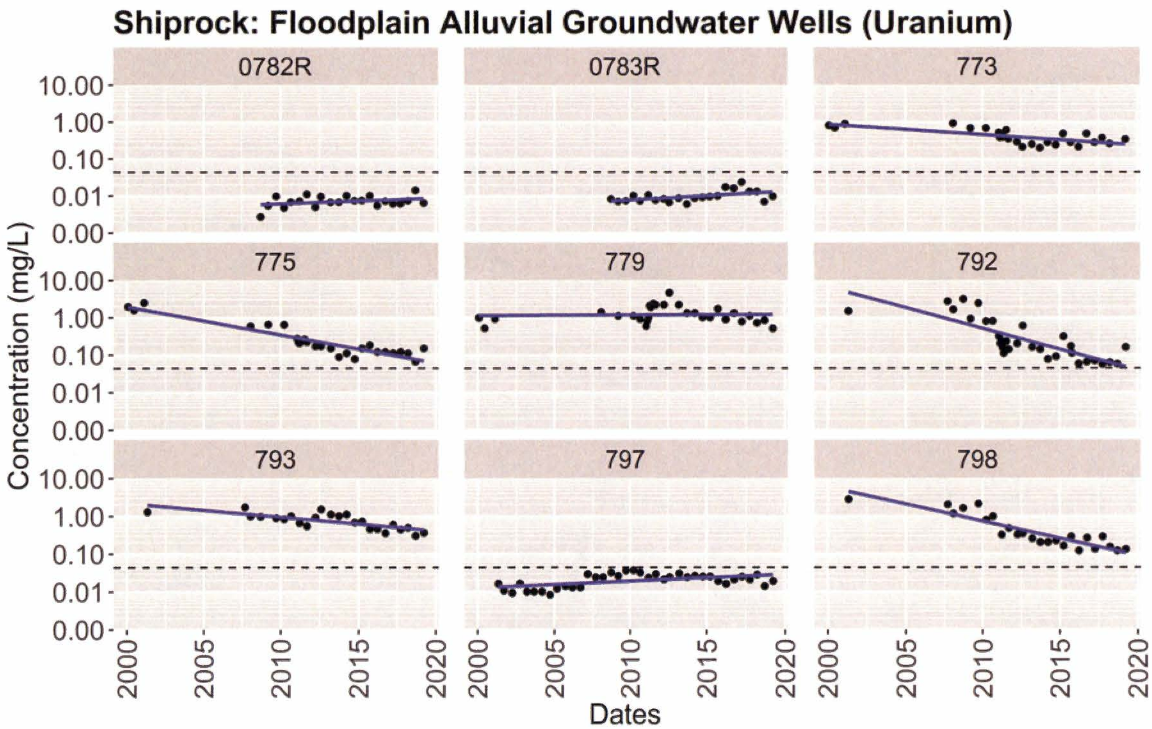

Figure A-50. Uranium trends at individual alluvial wells on the Shiprock site floodplain. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

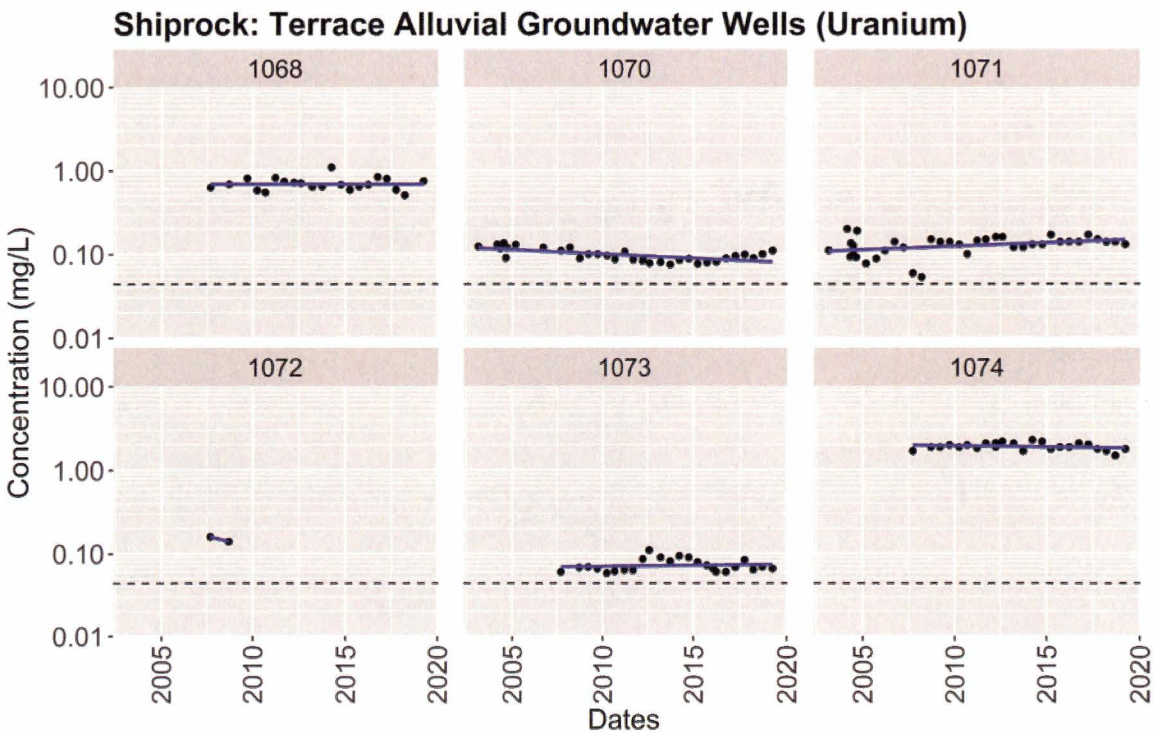

Figure A-51. Uranium trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

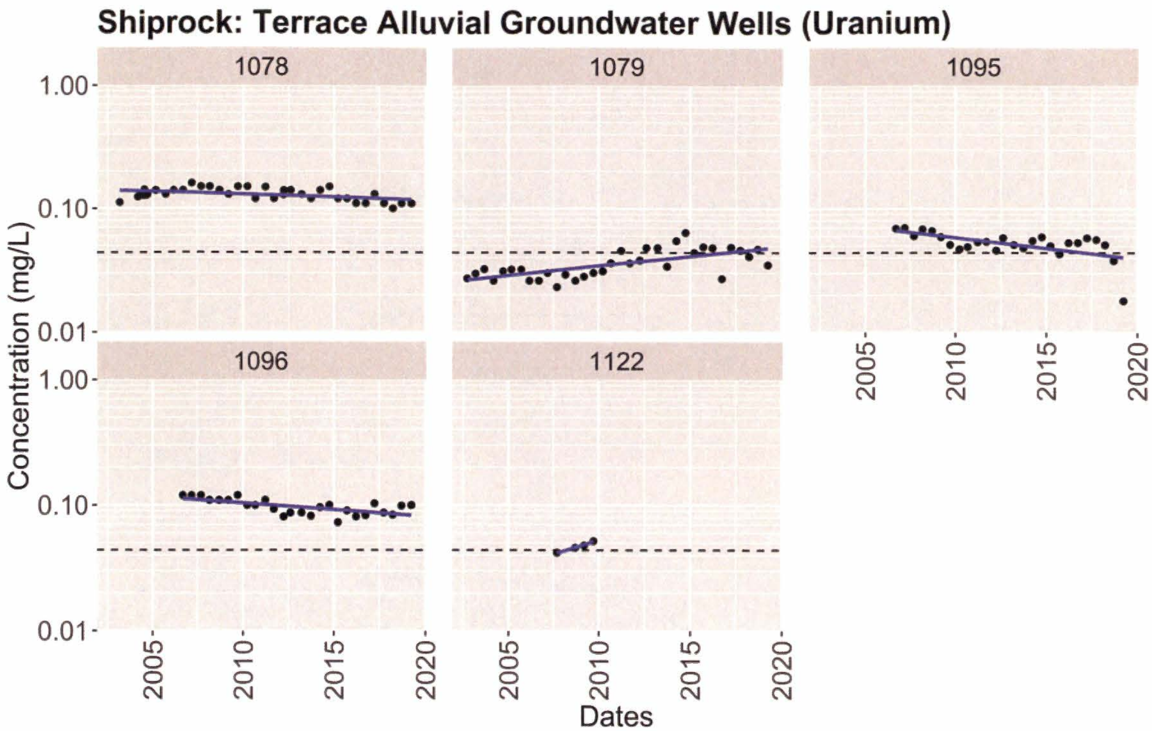

Figure A-52. Uranium trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

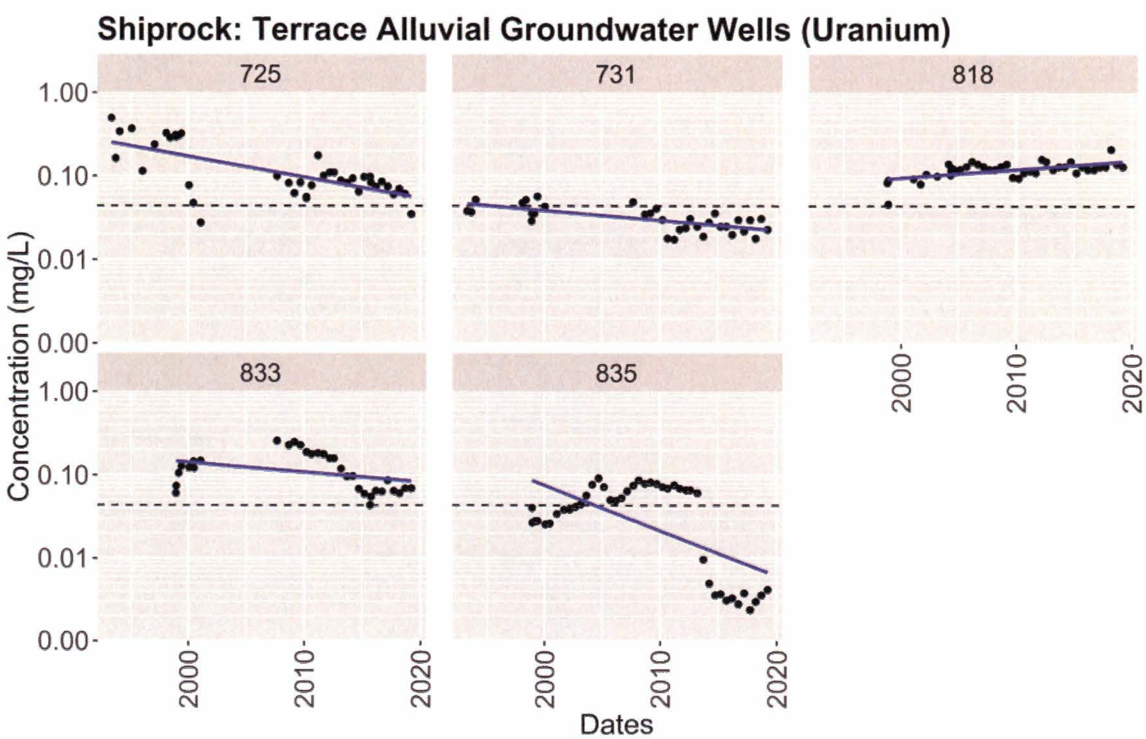

Figure A-53. Uranium trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

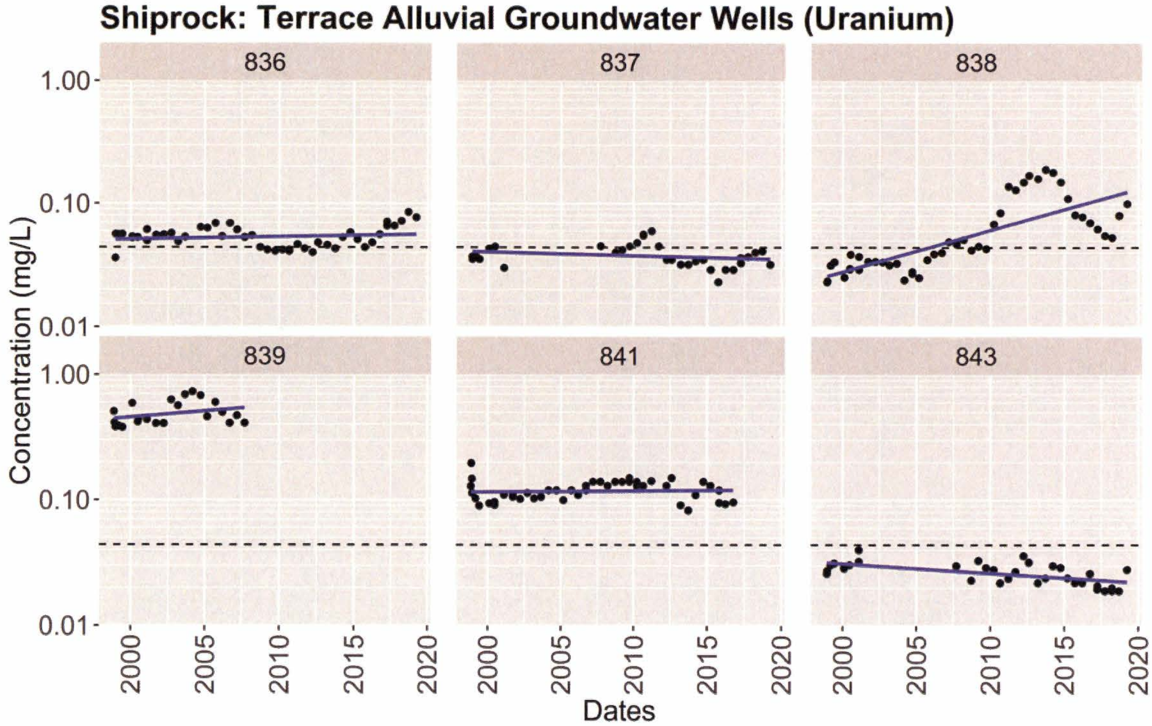

Figure A-54. Uranium trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

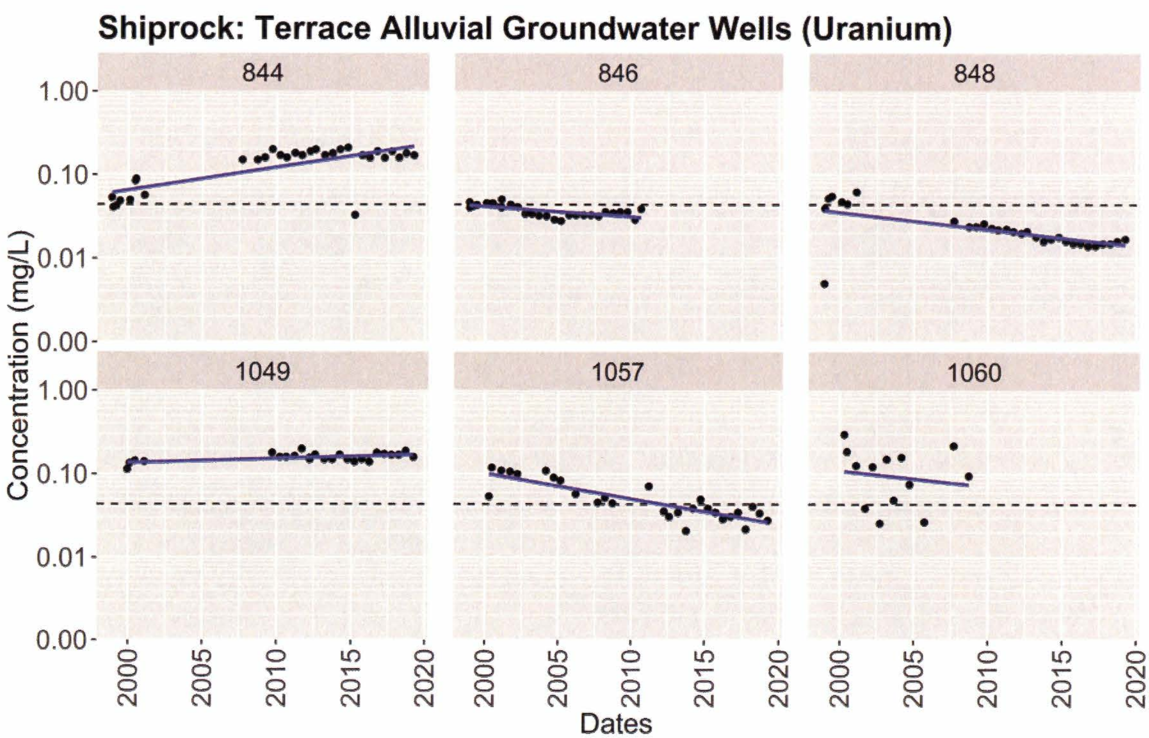

Figure A-55. Uranium trends at individual alluvial wells on the Shiprock site terrace. The blue line is a linear regression trend line. The dashed line represents the UMTRCA MCL of 0.044 mg/L.

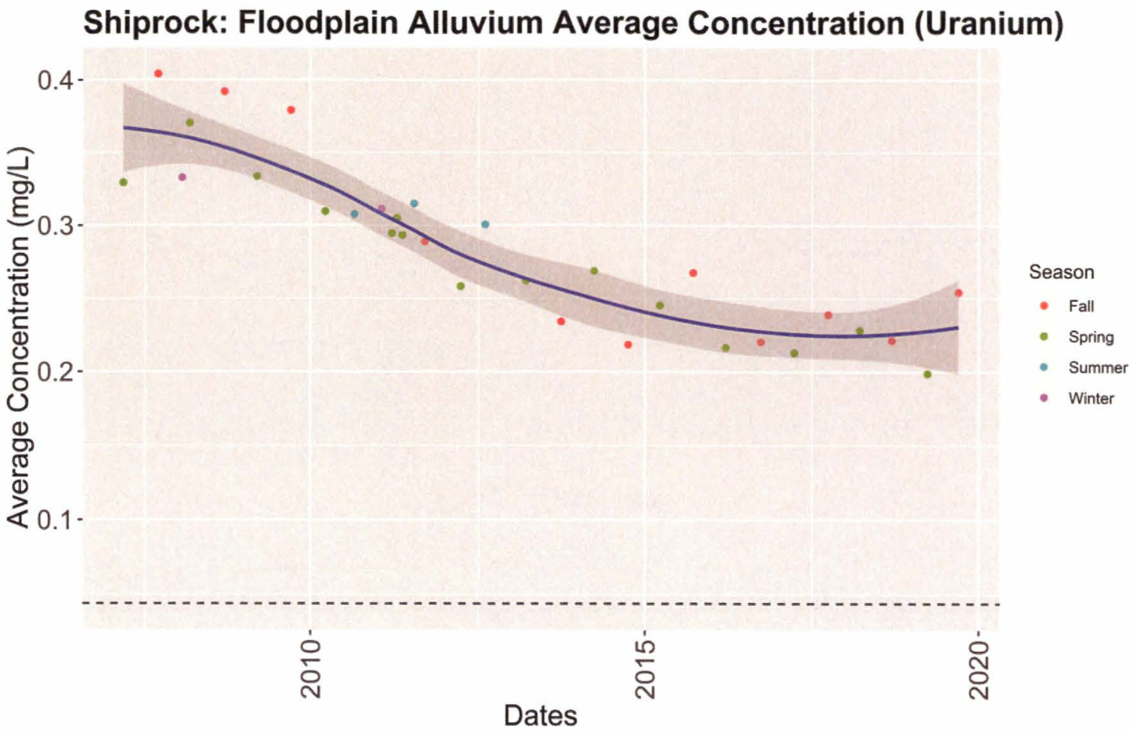

Figure A-56. Bulk uranium average plume concentration on the Shiprock site floodplain. The blue line is a LOESS line, and the shaded region is the 95% confidence interval. Plume concentration has been decreasing over time.

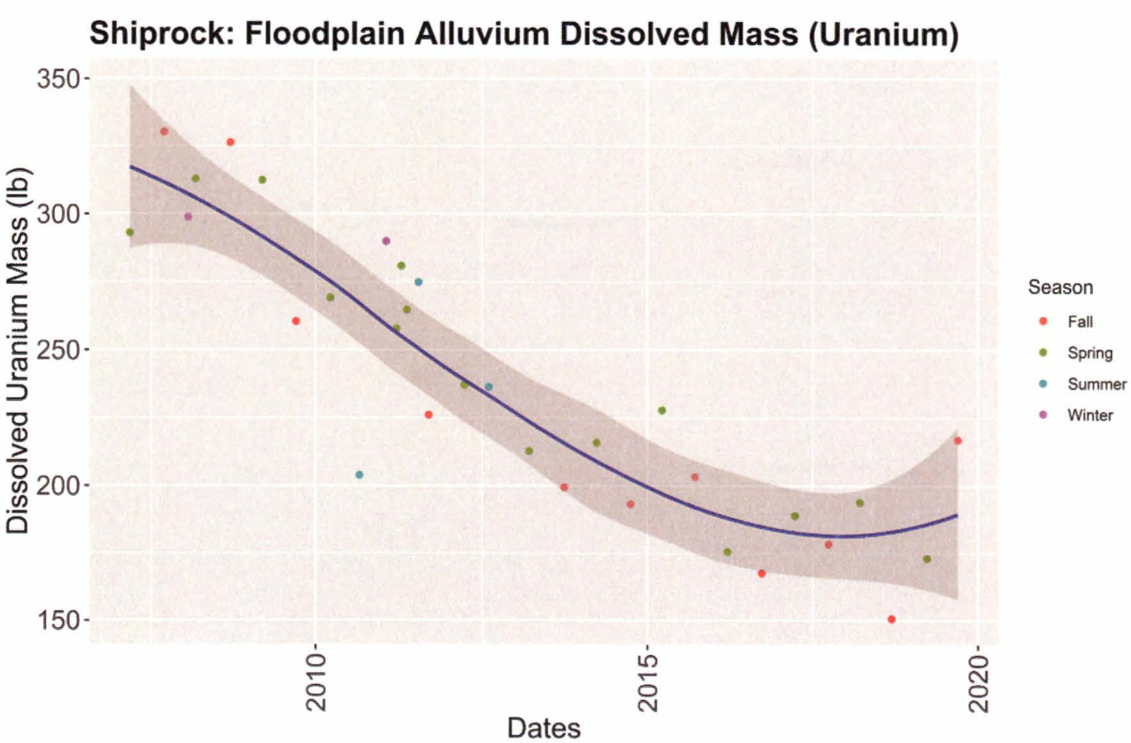

Figure A-57. Bulk uranium plume mass on the Shiprock site floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume mass has been decreasing over time.

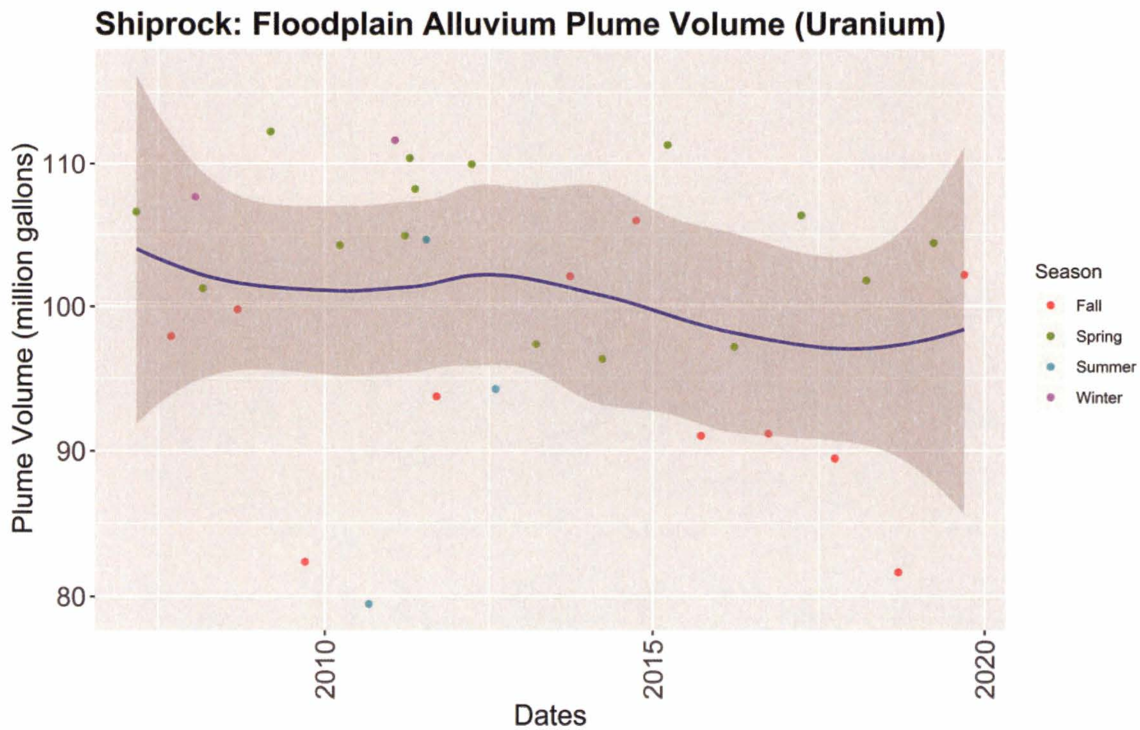

Figure A-58. Bulk uranium plume volume on the Shiprock site floodplain. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume volume has been decreasing over time.

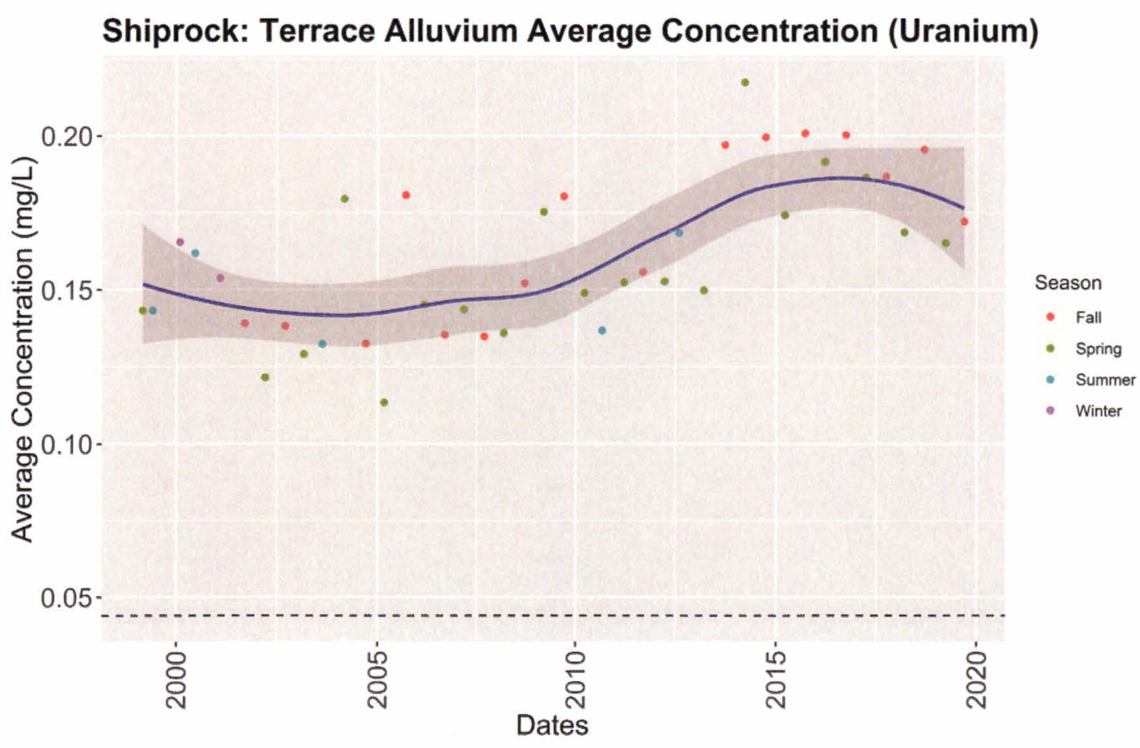

Figure A-59. Bulk uranium average plume concentration on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Average concentration has increased over time.

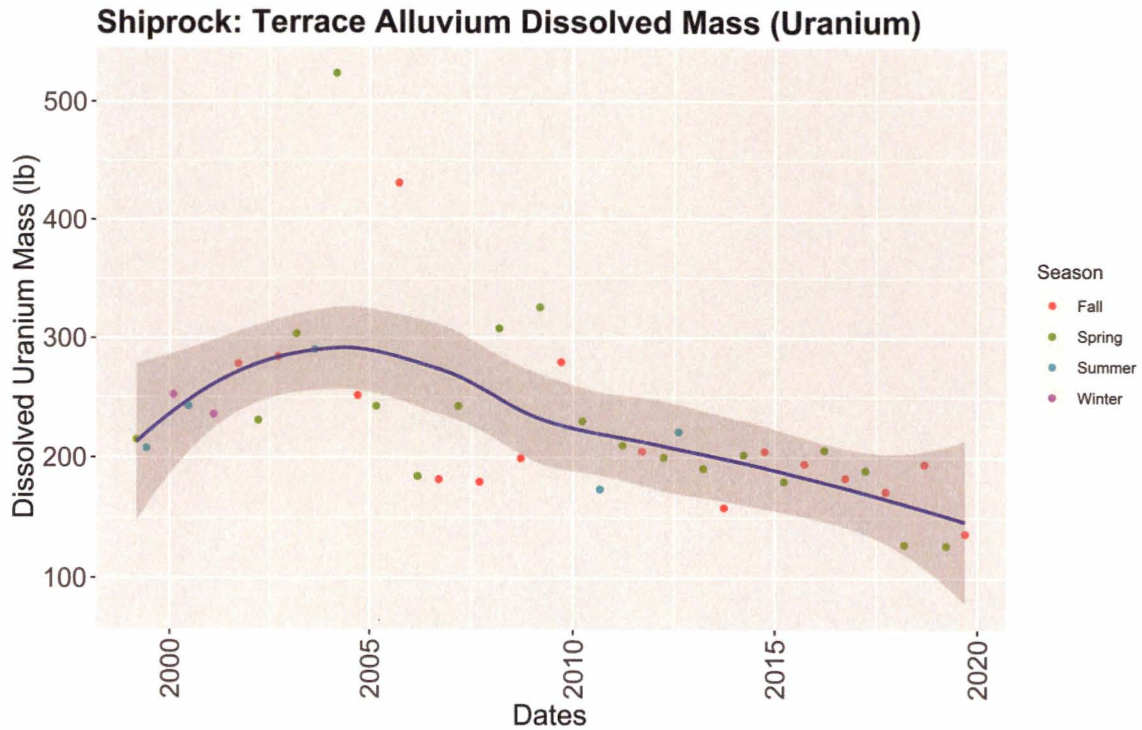

Figure A-60. Bulk uranium plume mass on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume mass has decreased over time.

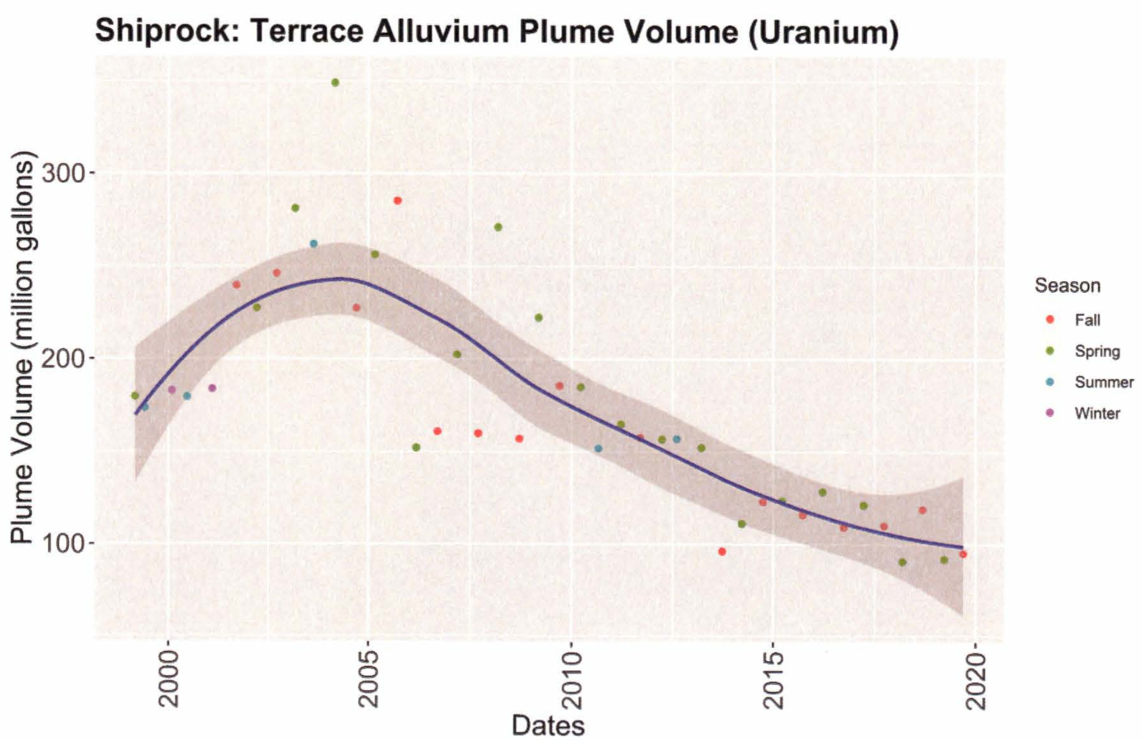

Figure A-61. Bulk uranium plume volume on the Shiprock site terrace. The blue line is a LOESS, and the shaded region is the 95% confidence interval. Plume volume has decreased over time.

Table A-1. Mann-Kendall trend analysis of sulfate on the Shiprock site floodplain. The interpreted capture zones for the combined treatment system elements in the floodplain alluvium are presented in DOE 2018b.

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Last Sulfate Concentration (mg/L) Sampled	Mann- Kendall		Half-Life, years			Year Remedial Goal of 2,000 mg/L		
					Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Shiprock Floodplain												
Wells within capture zones												
0610	9/11/2007	9/12/2019	24	5000	Decreasing	-0.44	15.11	10.31	28.26	2036	2029	2056
0611	1/22/2008	9/12/2019	22	5100	Decreasing	-0.48	38.05	23.20	105.77	2066	2046	2158
0614	3/9/2006	9/12/2019	37	5800	Decreasing	-0.78	7.07	6.19	8.25	2026	2024	2029
0615	3/9/2006	9/12/2019	38	7300	Decreasing	-0.38	7.65	5.34	13.48	2025	2021	2036
0618	3/8/2006	9/9/2019	37	6400	Decreasing	-0.61	7.39	6.09	9.40	2028	2025	2032
0619	3/8/2006	9/11/2019	34	5800	None	-0.04	Not applicable, no trend					
0622	9/12/2007	9/12/2019	24	6900	Decreasing	-0.30	30.83					
0623	1/24/2008	9/12/2019	28	2700	Decreasing	-0.51	35.65907	25.89257859	57.2553711	2028	2024	2038
0625	1/24/2008	9/12/2019	23	2700	None	-0.30	Not applicable, no trend					
0626	9/13/2007	9/12/2019	30	3700	Decreasing	-0.30	39.67					
0766	1/23/2008	9/11/2019	21	4000	Decreasing	-0.53	9.06	6.27	16.35	2027	2023	2036
0768	1/24/2008	9/12/2019	26	7100	Decreasing	-0.45	6.69	4.32	14.84	2027	2022	2043
0773	1/22/2008	9/12/2019	25	4200	Decreasing	-0.33	13.19					
0775	1/24/2008	9/12/2019	26	4600	Decreasing	-0.43	17.08	11.25	35.48	2033	2026	2054
0792	9/12/2007	9/9/2019	30	4300	Decreasing	-0.62	4.84	3.78	6.70	2022	2020	2025
0793	9/12/2007	9/13/2019	24	4200	None	0.01	Not applicable, no trend					
0854	1/23/2008	9/11/2019	22	3900	Decreasing	-0.68	6.79	5.27	9.54	2026	2023	2030
1008	3/10/2006	9/11/2019	24	3400	Decreasing	-0.78	4.54	3.77	5.70	2021	2019	2023
1009	9/12/2007	9/12/2019	29	1400	Decreasing	-0.74	7.68	6.16	10.22			
1089	3/14/2006	9/11/2019	29	5100	Decreasing	-0.73	9.68	7.98	12.29	2026	2024	2030
1104	3/14/2006	9/11/2019	29	5500	Decreasing	-0.68	7.72	6.13	10.43	2026	2023	2031
1105	3/6/2007	9/12/2019	26	7600	Decreasing	-0.68	7.52	5.57	11.55	2028	2024	2036
1111	6/13/2006	9/11/2019	28	12000	None	-0.18	Not applicable, no trend					
1112	6/13/2006	9/12/2019	31	8500	Decreasing	-0.55	11.78	8.39	19.76	2037	2030	2053
1113	6/13/2006	9/12/2019	26	4500	Decreasing	-0.64	8.89	6.76	12.99	2024	2022	2030
1114	6/13/2006	9/11/2019	30	1900	None	-0.19	Not applicable, no trend					
1135	3/25/2010	9/11/2019	25	4200	Decreasing	-0.48	14.09	9.44	27.77	2025	2022	2037
1137	3/25/2010	9/11/2019	21	9200	None	0.23	Not applicable, no trend					
1138	3/25/2010	9/11/2019	20	4000	None	0.03	Not applicable, no trend					
1139	3/25/2010	9/11/2019	25	3900	None	0.27	Not applicable, no trend					
1140	9/16/2009	9/12/2019	21	10000	Decreasing	-0.33	20.99					
1141	9/16/2009	9/12/2019	21	11000	None	-0.13	Not applicable, no trend					
Wells outside captured zones												
0612	9/11/2007	9/12/2019	25	1300	None	-0.01	Not applicable, concentration less than remediation goal					
0734	3/15/2006	9/30/2014	15	6000	None	0.10	Not applicable, no trend					
0735	3/9/2006	9/12/2019	35	15000	Increasing	0.26	Not applicable, increasing trend					
0736	3/10/2006	9/11/2019	26	4100	Decreasing	-0.56	13.75831	9.642978288	24.00135	2024	2021	2033
0779	1/23/2008	9/12/2019	27	8900	None	0.23	Not applicable, no trend					
0798	9/12/2007	9/11/2019	24	5800	Decreasing	-0.61	6.59067	4.966016959	9.79521317	2024	2022	2029
0853	9/12/2007	9/12/2019	30	1300	Increasing	0.31	Not applicable, concentration less than remediation goal					
0855	9/13/2007	9/10/2019	30	5100	None	-0.06	Not applicable, no trend					
0856	9/13/2007	9/11/2019	30	3700	None	-0.05	Not applicable, no trend					
0857	9/12/2007	9/9/2019	24	5000	Increasing	0.57	Not applicable, increasing trend					
1115	6/13/2006	9/11/2019	35	3100	None	-0.08	Not applicable, no trend					
1117	7/18/2006	9/11/2019	35	750	None	0.20	Not applicable, concentration less than remediation goal					
1128	3/6/2007	9/11/2019	21	8000	None	-0.29	Not applicable, no trend					
1132	3/6/2007	9/11/2019	23	180	Increasing	0.39	Not applicable, concentration less than remediation goal					
1134	3/6/2007	9/11/2019	22	970	None	0.18	Not applicable, concentration less than remediation goal					
1136	3/25/2010	9/10/2019	26	11000	Increasing	0.73						
1142	3/24/2010	9/12/2019	26	530	None	0.18	Not applicable, concentration less than remediation goal					
1143	3/26/2010	9/10/2019	25	3300	None	-0.29	Not applicable, no trend					
Wells at mouth of Bob Lee Wash												
0628	9/13/2007	9/12/2019	25	2600	None	-0.04	Not applicable, no trend					
0630	9/13/2007	9/12/2019	30	4100	Increasing	0.53	Not applicable, increasing trend					
Wells outside of the institutional controls boundary												
0782R	9/16/2008	9/13/2019	23	350	None	-0.06	Not applicable, concentration less than remediation goal					
0783R	9/17/2008	9/13/2019	23	770	Increasing	0.56	Not applicable, concentration less than remediation goal					
0797	3/7/2006	9/10/2019	28	3100	None	0.09	Not applicable, no trend					
0850	3/7/2006	9/10/2019	28	1000	None	-0.07	Not applicable, concentration less than remediation goal					

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Table A-2. Mann-Kendall trend analysis of sulfate on the Shiprock site terrace. Justification for delineating mill-influenced areas is presented in the report titled Investigation of Non-Mill-Related Water Inputs to the Terrace Alluvium at Shiprock, New Mexico (DOE 2018a).

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Last Sulfate Concentration (mg/L) Sampled	Mann- Kendall		Half-Life, years			Year Remedial Goal of 2,000 mg/L		
					Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Shiprock Terrace												
Wells within mill influenced areas												
0725	3/7/1999	9/13/2019	29	2800	Decreasing	-0.45	59.59	39.87	117.91	2047	2035	2081
0826	3/4/1999	9/10/2019	32	15000	Decreasing	-0.42	70.58	41.32	241.74	2199	2121	2655
0827	3/6/1999	9/12/2019	31	8000	None	0.15	Not applicable, no trend					
0828	3/4/1999	9/10/2019	30	1600	None	-0.21	Not applicable, concentration less than remediation goal					
1007	4/17/2000	9/12/2019	28	12000	None	0.15	Not applicable, no trend					
1068	7/15/2004	9/11/2019	19	7100	None	-0.30	Not applicable, no trend					
1074	9/10/2007	9/12/2019	24	8300	None	-0.27	Not applicable, no trend					
Wells outside of mill influenced areas												
0603	3/4/1999	9/12/2019	31	2200	Decreasing	-0.79	10.13	8.85	11.85			
0728	3/4/1999	9/11/2019	29	6400	Increasing	0.29	Not applicable, increasing trend					
0730	3/6/1999	9/11/2019	26	1900	Decreasing	-0.54	Not applicable, concentration less than remediation goal					
0731	3/5/1999	9/12/2019	27	5200	Decreasing	-0.40	52.09	32.75	127.14	2070	2048	2152
0812	3/8/1999	9/11/2019	25	20000	Increasing	0.38	Not applicable, increasing trend					
0813	3/4/1999	9/11/2019	31	9400	Decreasing	-0.55	47.24	35.50	70.59	2121	2094	2176
0814	3/4/1999	9/11/2019	27	15000	None	0.21	Not applicable, no trend					
0815	3/6/1999	9/10/2019	28	16000	None	0.10	Not applicable, no trend					
0816	3/9/1999	9/12/2019	31	1200	Decreasing	-0.32	Not applicable, concentration less than remediation goal					
0818	2/8/2001	9/10/2019	41	17000	Increasing	0.61	Not applicable, increasing trend					
0832	3/4/1999	9/9/2019	26	5200	None	-0.22	22.44	13.43	68.10	2050	2033	2134
0833	3/3/1999	9/10/2019	29	4000	Decreasing	-0.63	25.69	16.40	59.25	2046	2034	2091
0835	3/3/1999	9/9/2019	42	350	Decreasing	-0.23	Not applicable, concentration less than remediation goal					
0838	3/3/1999	9/9/2019	42	5600	Increasing	0.57	Not applicable, increasing trend					
0841	3/4/1999	9/29/2016	35	14000	None	0.10	Not applicable, no trend					
0844	3/3/1999	9/9/2019	29	11000	Increasing	0.66	Not applicable, increasing trend					
0848	3/8/1999	9/10/2019	29	18000	Increasing	0.52	Not applicable, increasing trend					
1057	4/17/2000	9/11/2019	29	4900	Decreasing	-0.66	10.46	8.79	12.93	2029	2026	2033
1070	3/3/2003	9/10/2019	37	16000	None	-0.22	Not applicable, no trend					
1071	3/3/2003	9/10/2019	39	15000	Increasing	0.58	Not applicable, increasing trend					
1073	7/16/2004	9/11/2019	26	11000	Increasing	0.48	Not applicable, increasing trend					
1078	3/3/2003	9/10/2019	39	13000	Decreasing	-0.25	152.97	85.11	754.76	2435	2247	4107
1079	9/18/2002	9/10/2019	35	2600	Increasing	0.37	Not applicable, increasing trend					
1091	3/3/2004	9/10/2019	38	16000	Increasing	0.50	Not applicable, increasing trend					
1092	3/3/2004	9/12/2018	36	15000	Increasing	0.25	Not applicable, increasing trend					
1093R	3/5/2008	9/10/2019	24	12000	Increasing	0.35	Not applicable, increasing trend					
1095	9/13/2006	9/10/2019	27	4200	Decreasing	-0.48	17.57	12.28	30.90	2037	2030	2055
1096	9/14/2006	9/10/2019	27	17000	Increasing	0.34	Not applicable, increasing trend					
Wells outside of the institutial controls boundary												
0836	3/3/1999	9/10/2019	42	4700	None	0.17	Not applicable, no trend					
0837	3/4/1999	9/10/2019	30	2100	Increasing	0.53	Not applicable, increasing trend					
0843	3/4/1999	9/10/2019	30	2600	None	-0.16	Not applicable, no trend					
0846	3/3/1999	3/25/2010	23	2200	Decreasing	-0.59	17.77	12.41	31.29			
1049	12/13/1999	9/11/2019	25	21000	None	0.15	Not applicable, no trend					

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Table A-3. Mann-Kendall trend analysis of nitrate as nitrogen on the Shiprock site floodplain. The interpreted capture zones for the combined treatment system elements in the floodplain alluvium are presented in DOE 2018b.

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Last Nitrate Concentration (mg/L) Sampled	Mann- Kendall		Half-Life, years			Year Remedial Goal of 10 mg/L		
					Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Shiprock Floodplain												
Wells within capture zones												
0610	9/11/2007	9/12/2019	25	57.00	Decreasing	-0.50	6.98	4.86	12.40	2047	2037	2073
0611	1/22/2008	9/12/2019	23	2.20	None	-0.07	Not applicable, concentration less than remediation goal					
0614	3/9/2006	9/12/2019	38	130.00	Decreasing	-0.79	3.38	2.91	4.04	2027	2025	2030
0615	3/9/2006	9/12/2019	38	0.02	Decreasing	-0.81	Not applicable, concentration less than remediation goal					
0618	3/8/2006	9/9/2019	39	0.01	Decreasing	-0.66	Not applicable, concentration less than remediation goal					
0619	3/8/2006	9/11/2019	35	0.30	None	-0.20	Not applicable, concentration less than remediation goal					
0622	9/12/2007	9/12/2019	25	0.30	None	-0.13	Not applicable, concentration less than remediation goal					
0623	1/24/2008	9/12/2019	28	0.00	Decreasing	-0.46	Not applicable, concentration less than remediation goal					
0625	1/24/2008	9/12/2019	23	0.00	None	-0.23	Not applicable, concentration less than remediation goal					
0626	9/13/2007	9/12/2019	31	0.03	None	-0.23	Not applicable, concentration less than remediation goal					
0766	1/23/2008	9/11/2019	21	0.30	None	-0.11	Not applicable, concentration less than remediation goal					
0768	1/24/2008	9/12/2019	26	0.16	None	-0.13	Not applicable, concentration less than remediation goal					
0773	1/22/2008	9/12/2019	25	200.00	None	-0.24	11.60					
0775	1/24/2008	9/12/2019	26	0.00	None	-0.21	Not applicable, concentration less than remediation goal					
0792	9/12/2007	9/9/2019	31	3.90	None	-0.17	Not applicable, concentration less than remediation goal					
0793	9/12/2007	9/13/2019	24	0.03	Decreasing	-0.54	Not applicable, concentration less than remediation goal					
0854	1/23/2008	9/11/2019	22	1.00	Decreasing	-0.67	Not applicable, concentration less than remediation goal					
1008	3/10/2006	9/11/2019	25	1.90	Decreasing	-0.52	Not applicable, concentration less than remediation goal					
1009	9/12/2007	9/12/2019	30	0.00	Decreasing	-0.37	Not applicable, concentration less than remediation goal					
1089	3/14/2006	9/11/2019	29	14.00	Decreasing	-0.60	2.12	1.58	3.20			
1104	3/14/2006	9/11/2019	29	15.00	Decreasing	-0.77	1.58	1.30	2.00			
1105	3/6/2007	9/12/2019	28	0.03	Decreasing	-0.83	Not applicable, concentration less than remediation goal					
1111	6/13/2006	9/11/2019	29	130.00	None	-0.09	Not applicable, no trend					
1112	6/13/2006	9/12/2019	31	289.99	Decreasing	-0.52	5.29	3.70	9.27	2037	2030	2055
1113	6/13/2006	9/12/2019	26	519.99	Decreasing	-0.33	8.28	4.65	38.10	2054	2036	2202
1114	6/13/2006	9/11/2019	30	56.00	None	-0.23	Not applicable, no trend					
1135	3/25/2010	9/11/2019	26	0.26	None	0.04	Not applicable, concentration less than remediation goal					
1137	3/25/2010	9/11/2019	25	31.00	None	-0.26	Not applicable, no trend					
1138	3/25/2010	9/11/2019	23	19.00	Decreasing	-0.45	1.13	0.75	2.26			
1139	3/25/2010	9/11/2019	28	3.10	Decreasing	-0.38	Not applicable, concentration less than remediation goal					
1140	9/16/2009	9/12/2019	21	299.99	Decreasing	-0.52	1.41	0.77	8.23			
1141	9/16/2009	9/12/2019	22	629.99	None	-0.09	Not applicable, no trend					
Wells outside captured zones												
0612	9/11/2007	9/12/2019	27	0.03	None	-0.01	Not applicable, concentration less than remediation goal					
0734	3/15/2006	9/30/2014	15	4.00	None	0.16	Not applicable, concentration less than remediation goal					
0735	3/9/2006	9/12/2019	36	709.99	Increasing	0.31	Not applicable, increasing trend					
0736	3/10/2006	9/11/2019	26	0.00	None	-0.08	Not applicable, concentration less than remediation goal					
0779	1/23/2008	9/12/2019	27	37.00	None	0.05	Not applicable, no trend					
0798	9/12/2007	9/11/2019	24	9.50	None	-0.18	Not applicable, concentration less than remediation goal					
0853	9/12/2007	9/12/2019	30	0.03	None	-0.13	Not applicable, concentration less than remediation goal					
0855	9/13/2007	9/10/2019	30	1.50	Increasing	0.40	Not applicable, increasing trend					
0856	9/13/2007	9/11/2019	30	0.03	Decreasing	-0.36	Not applicable, concentration less than remediation goal					
0857	9/12/2007	9/9/2019	27	2.80	None	0.16	Not applicable, concentration less than remediation goal					
1115	6/13/2006	9/11/2019	37	160.00	None	-0.07	Not applicable, no trend					
1117	7/18/2006	9/11/2019	35	0.96	None	0.02	Not applicable, concentration less than remediation goal					
1128	3/6/2007	9/11/2019	21	369.99	None	-0.30	12.01	6.41	94.96	2080	2049	2536
1132	3/6/2007	9/11/2019	23	0.05	None	0.07	Not applicable, concentration less than remediation goal					
1134	3/6/2007	9/11/2019	23	36.00	None	0.15	Not applicable, no trend					
1136	3/25/2010	9/10/2019	30	4.50	Increasing	0.32	Not applicable, increasing trend					
1142	3/24/2010	9/12/2019	26	0.00	Decreasing	-0.39	Not applicable, concentration less than remediation goal					
1143	3/26/2010	9/10/2019	26	0.00	Decreasing	-0.36	Not applicable, concentration less than remediation goal					
Wells at mouth of Bob Lee Wash												
0628	9/13/2007	9/12/2019	27	0.30	None	-0.02	Not applicable, concentration less than remediation goal					
0630	9/13/2007	9/12/2019	31	8.00	None	0.20	Not applicable, concentration less than remediation goal					
Wells outside of the institutional controls boundary												
0782R	3/7/2006	9/10/2019	28	0.18	None	0.08	Not applicable, concentration less than remediation goal					
0783R	3/7/2006	9/10/2019	28	0.09	None	-0.10	Not applicable, concentration less than remediation goal					
0797	9/16/2008	9/13/2019	23	0.01	None	-0.01	Not applicable, concentration less than remediation goal					
0850	9/17/2008	9/13/2019	23	0.30	None	0.07	Not applicable, concentration less than remediation goal					

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Table A-4. Mann-Kendall trend analysis of nitrate as nitrogen on the Shiprock site terrace. Justification for delineating mill-influenced areas is presented in the report titled Investigation of Non-Mill-Related Water Inputs to the Terrace Alluvium at Shiprock, New Mexico (DOE 2018a).

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Last Nitrate Concentration (mg/L) Sampled	Mann- Kendall		Half-Life, years			Year Remedial Goal of 10 mg/L		
					Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Shiprock Terrace												
Wells within mill influenced areas												
0725	3/7/1999	3/27/2019	28	3	None	-0.20	Not applicable, concentration less than remediation goal					
0826	3/4/1999	9/10/2019	33	8	Decreasing	-0.43	Not applicable, concentration less than remediation goal					
0827	3/6/1999	9/12/2019	31	49	None	-0.16	12.21	6.83	57.48	2031	2022	2106
0828	3/4/1999	9/10/2019	30	2	Decreasing	-0.36	Not applicable, concentration less than remediation goal					
1007	4/17/2000	9/12/2019	29	430	None	0.00	Not applicable, no trend					
1068	7/15/2004	9/11/2019	21	240	Decreasing	-0.35	21.93					
1074	9/10/2007	9/12/2019	25	860	Decreasing	-0.47	21.95	14.38	46.42	2164	2112	2333
Wells outside of mill influenced areas												
0603	3/4/1999	9/12/2019	32	2000	Increasing	0.59	Not applicable, increasing trend					
0728	3/4/1999	9/11/2019	29	110	Decreasing	-0.29	9.47					
0730	3/6/1999	9/11/2019	26	260	Increasing	0.37	Not applicable, increasing trend					
0731	3/5/1999	9/12/2019	27	160	None	-0.18	11.16	7.47	22.08	2051	2038	2089
0812	3/8/1999	9/11/2019	27	1100	None	-0.02	Not applicable, no trend					
0813	3/4/1999	9/11/2019	32	2200	Increasing	0.39	Not applicable, increasing trend					
0814	3/4/1999	9/11/2019	28	620	Decreasing	-0.33	86.66	49.08	369.75	2569	2327	4391
0815	3/6/1999	9/10/2019	29	15	None	-0.11	Not applicable, no trend					
0816	3/9/1999	9/12/2019	31	640	Decreasing	-0.73	5.54	4.76	6.61			
0818	2/8/2001	9/10/2019	41	610	Decreasing	-0.81	8.98	8.01	10.22	2070	2064	2079
0832	3/4/1999	9/9/2019	26	200	None	-0.18	4.47	3.29	7.00	2027	2022	2037
0833	3/3/1999	9/10/2019	30	59	Decreasing	-0.65	7.58	5.10	14.71	2040	2031	2067
0835	3/3/1999	9/9/2019	42	3	Decreasing	-0.37	Not applicable, concentration less than remediation goal					
0838	3/3/1999	9/9/2019	42	200	Increasing	0.50	Not applicable, increasing trend					
0841	3/4/1999	9/29/2016	36	350	None	0.04	Not applicable, no trend					
0844	3/3/1999	9/9/2019	29	630	None	0.18	Not applicable, no trend					
0848	3/8/1999	3/26/2019	28	1500	Decreasing	-0.36	1.38	1.12	1.81			
1057	4/17/2000	9/11/2019	29	550	None	0.12	Not applicable, no trend					
1070	3/3/2003	9/10/2019	38	560	Decreasing	-0.74	21.83	18.10	27.50	2145	2122	2179
1071	3/3/2003	9/10/2019	39	330	Decreasing	-0.50	8.21	6.02	12.90	2065	2051	2096
1073	7/16/2004	9/11/2019	26	700	Decreasing	-0.66	10.67	8.02	15.93	2084	2067	2119
1078	3/3/2003	9/10/2019	40	330	Decreasing	-0.65	15.34	12.85	19.02	2100	2085	2121
1079	9/18/2002	9/10/2019	35	22	None	0.11	Not applicable, no trend					
1091	3/3/2004	9/10/2019	38	620	Decreasing	-0.67	9.35	8.15	10.97	2074	2066	2085
1092	3/3/2004	9/12/2018	36	510	Decreasing	-0.53	7.00	5.54	9.50	2057	2047	2073
1093R	9/13/2006	9/10/2019	27	920	None	0.25	Not applicable, no trend					
1095	9/14/2006	9/10/2019	27	1700	Decreasing	-0.40	39.66	24.33	107.23	2247	2157	2647
1096	3/5/2008	9/10/2019	24	500	Decreasing	-0.51476	13.33					
Wells outside of the institutial controls boundary												
0836	3/3/1999	9/10/2019	42	53	Increasing	0.64	Not applicable, increasing trend					
0837	3/4/1999	9/10/2019	30	42	Increasing	0.75	Not applicable, increasing trend					
0843	3/4/1999	9/10/2019	30	5	None	0.00	Not applicable, concentration less than remediation goal					
0846	3/3/1999	8/31/2010	24	38	Decreasing	-0.38	6.04	3.77	15.22	2017	2012	2035
1049	12/13/1999	9/11/2019	26	500	None	-0.16	Not applicable, no trend					

Table A-5. Mann-Kendall trend analysis of uranium on the Shiprock site floodplain. The interpreted capture zones for the combined treatment system elements in the floodplain alluvium are presented in DOE 2018b.

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Last Uranium Concentration (mg/L) Sampled	Mann- Kendall		Half-Life, years			Year Remedial Goal of 0.044 mg/L		
					Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Shiprock Floodplain												
Wells within capture zones												
0610	9/11/2007	9/12/2019	24	0.420	Decreasing	-0.68	7.09	5.75	9.24	2044	2038	2053
0611	1/22/2008	9/12/2019	22	0.038	None	-0.24	Not applicable, concentration less than remediation goal					
0614	3/9/2006	9/12/2019	37	0.780	Decreasing	-0.78	6.38	5.56	7.50	2044	2040	2049
0615	3/9/2006	9/12/2019	38	1.300	Decreasing	-0.60	4.38	3.49	5.87	2032	2028	2038
0618	3/8/2006	9/9/2019	37	0.500	Decreasing	-0.71	3.77	3.21	4.58	2030	2027	2033
0619	3/8/2006	9/11/2019	34	0.200	Decreasing	-0.35	7.18	4.73	14.92	2026	2021	2041
0622	9/12/2007	9/12/2019	24	0.250	Decreasing	-0.39	5.70	3.60	13.70	2018	2017	2025
0623	1/24/2008	9/12/2019	28	0.037	Decreasing	-0.65	Not applicable, concentration less than remediation goal					
0625	1/24/2008	9/12/2019	23	0.030	Decreasing	-0.66	Not applicable, concentration less than remediation goal					
0626	9/13/2007	9/12/2019	30	0.031	Decreasing	-0.53	Not applicable, concentration less than remediation goal					
0766	1/23/2008	9/11/2019	21	0.110	Decreasing	-0.60	5.52	4.01	8.82	2026	2022	2032
0768	1/24/2008	9/12/2019	26	0.300	Decreasing	-0.48	3.90	2.59	7.93	2024	2020	2035
0773	1/22/2008	9/12/2019	25	0.580	Decreasing	-0.33	12.89	6.64	225.47	2053	2034	2705
0775	1/24/2008	9/12/2019	26	0.170	Decreasing	-0.62	5.11	3.73	8.10	2024	2021	2030
0792	9/12/2007	9/9/2019	30	0.210	Decreasing	-0.63	2.60	1.96	3.83	2019	2018	2022
0793	9/12/2007	9/13/2019	24	0.380	Decreasing	-0.56	6.75	5.01	10.34	2040	2033	2054
0854	1/23/2008	9/11/2019	22	0.180	Decreasing	-0.70	3.06	2.40	4.24	2025	2022	2029
1008	3/10/2006	9/11/2019	24	0.096	Decreasing	-0.89	2.26	1.94	2.70	2021	2020	2022
1009	9/12/2007	9/12/2019	29	0.150	Decreasing	-0.78	7.12	5.86	9.07	2030	2027	2034
1089	3/14/2006	9/11/2019	30	0.120	Decreasing	-0.80	3.79	3.29	4.48	2023	2022	2025
1104	3/14/2006	9/11/2019	30	0.140	Decreasing	-0.81	3.38	2.96	3.96	2025	2023	2027
1105	3/6/2007	9/12/2019	26	0.680	Decreasing	-0.65	4.12	3.34	5.38	2032	2029	2038
1111	6/13/2006	9/11/2019	28	0.860	Decreasing	-0.41	15.96	9.73	44.29	2079	2053	2198
1112	6/13/2006	9/12/2019	31	0.950	Decreasing	-0.54	8.88	6.51	13.96	2055	2044	2080
1113	6/13/2006	9/12/2019	26	0.680	Decreasing	-0.52	7.01	5.40	9.98	2041	2035	2053
1114	6/13/2006	9/11/2019	30	0.300	None	-0.23	Not applicable, no trend					
1135	3/25/2010	9/11/2019	25	0.080	Decreasing	-0.61	6.66	4.86	10.57	2022	2019	2026
1137	3/25/2010	9/11/2019	21	0.470	None	0.00	Not applicable, no trend					
1138	3/25/2010	9/11/2019	20	0.180	None	-0.19	Not applicable, no trend					
1139	3/25/2010	9/11/2019	25	0.130	None	-0.05	Not applicable, no trend					
1140	9/16/2009	9/12/2019	21	0.590	Decreasing	-0.66	4.45	3.46	6.26	2033	2029	2040
1141	9/16/2009	9/12/2019	21	0.920	Decreasing	-0.33	11.21	5.74	242.73	2057	2036	2939
Wells outside captured zones												
0612	9/11/2007	9/12/2019	25	0.080	None	-0.14	Not applicable, no trend					
0734	3/15/2006	9/30/2014	18	0.170	None	0.11	Not applicable, no trend					
0735	3/9/2006	9/12/2019	35	0.410	None	0.10	Not applicable, no trend					
0736	3/10/2006	9/11/2019	26	0.066	Decreasing	-0.44	8.30	5.49	16.98	2017	2015	2021
0779	1/23/2008	9/12/2019	27	0.770	None	-0.27	11.27	5.84	163.28	2067	2041	2794
0798	9/12/2007	9/11/2019	24	0.280	Decreasing	-0.65	3.32	2.61	4.57	2023	2021	2027
0853	9/12/2007	9/12/2019	30	0.130	None	0.15	Not applicable, no trend					
0855	9/13/2007	9/10/2019	30	0.130	None	-0.19	Not applicable, no trend					
0856	9/13/2007	9/11/2019	30	0.053	None	-0.12	Not applicable, no trend					
0857	9/12/2007	9/9/2019	24	0.460	Increasing	0.52	Not applicable, increasing trend					
1115	6/13/2006	9/11/2019	35	0.410	None	-0.03	Not applicable, no trend					
1117	7/18/2006	9/11/2019	35	0.028	None	-0.18	Not applicable, concentration less than remediation goal					
1128	3/6/2007	9/11/2019	21	1.200	Decreasing	-0.35	10.48					
1132	3/6/2007	9/11/2019	23	0.012	Decreasing	-0.31	Not applicable, concentration less than remediation goal					
1134	3/6/2007	9/11/2019	22	0.029	None	0.07	Not applicable, no trend					
1136	3/25/2010	9/10/2019	26	1.100	Increasing	0.69	Not applicable, increasing trend					
1142	3/24/2010	9/12/2019	26	0.017	Increasing	0.45	Not applicable, concentration less than remediation goal					
1143	3/26/2010	9/10/2019	25	0.049	Decreasing	-0.42	23.71	14.80	59.63	2022	2019	2035
Wells at mouth of Bob Lee Wash												
0628	9/13/2007	9/12/2019	25	0.016	None	-0.14	Not applicable, concentration less than remediation goal					
0630	9/13/2007	9/12/2019	30	0.180	Increasing	0.46	Not applicable, increasing trend					
Wells outside of the institutional controls boundary												
0782R	9/16/2008	9/13/2019	23	0.010	None	0.24	Not applicable, concentration less than remediation goal					
0783R	9/17/2008	9/13/2019	23	0.008	Increasing	0.33	Not applicable, concentration less than remediation goal					
0797	3/7/2006	9/10/2019	28	0.014	None	-0.24	Not applicable, concentration less than remediation goal					
0850	3/7/2006	9/10/2019	28	0.021	None	-0.09	Not applicable, concentration less than remediation goal					

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Table A-6. Mann-Kendall trend analysis of uranium on the Shiprock site terrace. Justification for delineating mill-influenced areas is presented in the report titled Investigation of Non-Mill-Related Water Inputs to the Terrace Alluvium at Shiprock, New Mexico (DOE 2018a).

Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Last Uranium Concentration (mg/L) Sampled	Mann- Kendall		Half-Life, years			Year Remedial Goal of 0.044 mg/L		
					Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Shiprock Terrace												
Wells within mill influenced areas												
0725	3/7/1999	9/13/2019	29	0.028	Decreasing	-0.30	Not applicable, concentration less than remediation goal					
0826	3/4/1999	9/10/2019	31	2.000	Decreasing	-0.52	13.73	10.1012718	21.4260519	2088	2068	2132
0827	3/6/1999	9/12/2019	32	0.940	Increasing	0.34	Not applicable, increasing trend					
0828	3/4/1999	9/10/2019	29	0.330	None	0.10	Not applicable, no trend					
1007	4/17/2000	9/12/2019	28	1.900	None	0.08	Not applicable, no trend					
1068	9/12/2007	9/11/2019	22	0.560	None	-0.09	Not applicable, no trend					
1074	9/10/2007	9/12/2019	24	1.800	None	-0.15	Not applicable, no trend					
Wells outside of mill influenced areas												
0603	3/4/1999	9/12/2019	31	0.005	Decreasing	-0.40	Not applicable, concentration less than remediation goal					
0728	3/4/1999	9/11/2019	29	0.220	None	-0.25	Not applicable, no trend					
0730	3/6/1999	9/11/2019	29	0.005	Increasing	0.64	Not applicable, increasing trend					
0731	3/5/1999	9/12/2019	27	0.034	Decreasing	-0.29	Not applicable, concentration less than remediation goal					
0812	3/8/1999	9/11/2019	24	0.130	None	0.28	Not applicable, no trend					
0813	3/4/1999	9/11/2019	31	0.094	Decreasing	-0.71	27.21	22.37	34.72	2047	2041	2057
0814	3/4/1999	9/11/2019	28	0.083	Decreasing	-0.47	29.17	22.90	40.17	2043	2036	2055
0815	3/6/1999	9/10/2019	28	0.320	None	-0.01	Not applicable, no trend					
0816	3/9/1999	9/12/2019	31	0.009	Decreasing	-0.72	Not applicable, concentration less than remediation goal					
0818	2/8/2001	9/10/2019	40	0.130	None	0.20	Not applicable, no trend					
0832	3/4/1999	9/9/2019	26	0.064	None	-0.22	14.47	9.31	32.48	2020	2016	2033
0833	3/3/1999	9/10/2019	29	0.065	Decreasing	-0.53	15.43	9.63	38.71	2032	2024	2063
0835	3/3/1999	9/9/2019	42	0.005	Decreasing	-0.24	Not applicable, concentration less than remediation goal					
0838	3/3/1999	9/9/2019	42	0.120	Increasing	0.58	Not applicable, increasing trend					
0841	3/4/1999	9/29/2016	35	0.096	Increasing	0.28	Not applicable, increasing trend					
0844	3/3/1999	9/9/2019	29	0.160	Increasing	0.34	Not applicable, increasing trend					
0848	3/8/1999	9/10/2019	29	0.017	Decreasing	-0.79	Not applicable, concentration less than remediation goal					
1057	4/17/2000	9/11/2019	29	0.035	Decreasing	-0.65	Not applicable, concentration less than remediation goal					
1070	3/3/2003	9/10/2019	35	0.110	Decreasing	-0.41	33.17	22.64	62.01	2049	2037	2083
1071	3/3/2003	9/10/2019	38	0.120	None	0.22	Not applicable, no trend					
1073	9/11/2007	9/11/2019	25	0.100	None	0.15	Not applicable, no trend					
1078	3/3/2003	9/10/2019	38	0.110	Decreasing	-0.33	48.19	32.20	95.78	2085	2060	2158
1079	9/18/2002	9/10/2019	35	0.040	Increasing	0.46	Not applicable, increasing trend					
1091	3/3/2004	9/10/2019	37	0.096	None	-0.17	Not applicable, no trend					
1092	3/3/2004	9/12/2018	35	0.110	None	-0.21	Not applicable, no trend					
1093R	3/5/2008	9/10/2019	24	0.140	None	0.26	Not applicable, no trend					
1095	9/13/2006	9/10/2019	27	0.040	Decreasing	-0.46	Not applicable, concentration less than remediation goal					
1096	9/14/2006	9/10/2019	27	0.100	Decreasing	-0.42	31.46	20.29	69.94	2048	2036	2091
Wells outside of the institutial controls boundary												
0836	3/3/1999	9/10/2019	42	0.068	None	0.06	Not applicable, no trend					
0837	3/4/1999	9/10/2019	30	0.029	Decreasing	-0.30	Not applicable, concentration less than remediation goal					
0843	3/4/1999	9/10/2019	30	0.029	Decreasing	-0.42	Not applicable, concentration less than remediation goal					
0846	3/3/1999	8/31/2010	24	0.039	Decreasing	-0.31	Not applicable, concentration less than remediation goal					
1049	12/13/1999	9/11/2019	25	0.180	Increasing	0.33	Not applicable, increasing trend					