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Monitored Natural Attenuation Demonstration Report Operable Unit III, Monticello Mill Tailings Site, Monticello, Utah

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U.S. DEPARTMENT OF ENERGY | Legacy Management

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Contents

Figures

Tables

Appendix

Abbreviations

ACL	alternate concentration limit
AOA	Area of Attainment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESD	Explanation of Significant Difference
ET	evapotranspiration
ft	feet
ft/day	feet per day
Geosyntec	Geosyntec Consultants Inc.
GRO	groundwater remedy optimization
IC	institutional control
lb	pounds
LM	Office of Legacy Management
LMS	Legacy Management Support
LTS&M	long-term surveillance and maintenance
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
µg/L	micrograms per liter
MMTS	Monticello Mill Tailings Site
MNA	monitored natural attenuation
NPL	National Priorities List
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
PMP	Performance Monitoring Plan
PRB	permeable reactive barrier
ROD	Record of Decision
TI	technical impracticability
UDEQ	Utah Department of Environmental Quality
UO_2^{2+}	uranyl ion

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Executive Summary

On behalf of the U.S. Department of Energy (DOE), this report evaluates and requests monitored natural attenuation (MNA) with institutional controls (ICs) and contingencies as the final remedy for Operable Unit (OU) III (contaminated surface water and groundwater) at the Monticello Mill Tailings Site (MMTS). The MMTS is regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and uranium is the site's primary contaminant of concern. Specifically, this report evaluates MNA in accordance with the requirements of the U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) directive on the MNA of inorganics (2015 OSWER Directive), which applies to uranium. This evaluation was informed by results of significant recent site characterization and modeling activities.

The 2015 OSWER Directive provides general requirements that a site should satisfy prior to implementing a remedy based on MNA. This report evaluates these requirements and demonstrates how each requirement is satisfied at MMTS OU III. The general requirements include the following:

- Protectiveness of human health and the environment
- Identification of the contaminant source
- Site characterization
- Sufficiency of the conceptual site model
- Geochemical evidence of attenuation
- ICs
- Reasonable time frame

The most recent CERCLA Five-Year Review in 2017 concluded that the MMTS OU III remedy remains protective of human health and the environment and that ICs are effective in preventing exposure to contaminated groundwater. ICs operable at MMTS OU III prevent the domestic use of MMTS OU III groundwater and restrict land use within the floodplain of Montezuma Creek, where sediments with uranium are present. Additionally, there are land use restrictions for the former mill site property, which was transferred from DOE to the City of Monticello and is used as a public park. Tailings remediation activities in MMTS OU I and OU II removed the primary uranium source to groundwater and surface water in MMTS OU III. Multiple passive and active remedial technologies have been applied for uranium at MMTS OU III, including the current contingency pump-and-treat system, known as the groundwater remedy optimization (GRO) system. Other general requirements are also met for MMTS OU III, as described herein.

The 2015 OSWER Directive also recommends a Tiered Analysis Approach in which successively more detailed information is collected and analyzed to evaluate the suitability of MNA. This report presents how each of the four phases of the Tiered Analysis Approach is satisfied at MMTS OU III, summarized as follows:

1. **Demonstration of plume stability.** Evaluation of uranium concentration trends at individual groundwater monitoring wells and plumewide metrics show that the uranium plume at MMTS OU III is stable or shrinking.

2. **Mechanism and rate of attenuation.** Sorption of uranium has been identified as the primary geochemical attenuation mechanism at MMTS OU III, and flow and transport modeling shows that attenuation rates are sufficient to achieve remediation goals in a reasonable time frame compared to that of other active groundwater remedies. The overall remediation time frame for MNA at the MMTS OU III is on the order of hundreds to thousands of years, and continuing active remediation (i.e., operation of the GRO system and the permeable reactive barrier [PRB]) does not affect the remediation time frame.

3. **System capacity and stability of attenuation.** A combination of field measurements, laboratory testing, and computational modeling provides independent lines of evidence that (1) the aquifer has sufficient capacity to achieve the remediation goal; and (2) attenuated uranium is sufficiently stable against remobilization. Decreasing trends in mass and average concentration of the dissolved uranium plume and the transport model simulations indicate that MMTS OU III has capacity to support continued natural attenuation until the remediation goals are achieved. The stability of attenuated uranium is supported by selective extractions of soil and a sensitivity analysis of a numerical reactive transport model.

4. **MNA performance monitoring program and contingency remedies.** Monitoring is ongoing at MMTS OU III, and contingencies are described in the site regulatory documents. A forthcoming Performance Monitoring Plan will provide the specific performance monitoring program for the proposed MNA remedy and further describe contingency remedies.

The 2004 Record of Decision (ROD)-defined goals for MMTS OU III consist of protection of human health and environment and water quality restoration to existing water quality standards for surface water and groundwater. As shown in this report, MNA with ongoing ICs and contingencies can achieve the ROD-defined goals of protectiveness and restoration to water quality standards in a time frame that is reasonable compared to that of other active groundwater remedies; implementation of this remedy is therefore requested.

DOE is requesting EPA and Utah Department of Environmental Quality review and approval of the proposed approach, contingent upon the submittal and approval of the following documents:

- GRO Termination Memorandum, which will outline the technical basis for the cessation of GRO system operation
- MNA Performance Monitoring Plan, which will outline performance monitoring to evaluate the ongoing effectiveness of MNA and criteria for implementing contingencies if needed

The ROD prescribed MNA with comprehensive monitoring, implementation and enforcement of ICs, and removal of the PRB. A 2009 Explanation of Significant Difference (ESD) formalized the pump-and-treat system upgradient of the PRB as a remedy component and identified the PRB as a hydraulic barrier. To revert to the MNA-focused remedy and discontinue the GRO system, a regulatory document (an ESD or ROD Amendment) would likely be required.

1.0 Introduction

This report presents an evaluation of monitored natural attenuation (MNA) as the basis for a remedy for Operable Unit (OU) III of the Monticello Mill Tailings Site (MMTS). The MMTS is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site near Monticello, Utah. The MMTS is at and near the Monticello, Utah, Disposal and Processing Sites that are operated by the U.S. Department of Energy (DOE) Office of Legacy Management (LM). This report was prepared by Geosyntec Consultants Inc. (Geosyntec) and the Legacy Management Support (LMS) contractor on behalf of LM.

At the request of LM, the LMS contractor and Geosyntec evaluated potential closure strategies for MMTS OU III that provide for termination of active groundwater remediation within the existing regulatory framework while protecting human health and the environment. The preferred strategy recommended in the *OU III Closure Strategy for the Monticello Mill Tailings Site, Monticello, Utah* (also called the Closure Strategy Report) was evaluation of a transition to a remedy consisting of MNA, institutional controls (ICs), and contingencies, with no active remediation (DOE 2018). To address data gaps identified in the Closure Strategy Report, a geochemical conceptual site model (CSM) (DOE 2020a) and a reactive transport model (DOE 2021) were developed to evaluate the feasibility of transitioning the remedy to MNA. The objective of this report is to evaluate whether an MNA remedy is suitable at MMTS OU III; in other words, whether an MNA remedy can be protective of human health and the environment and achieve the long-term goal of site closure.

2.0 Context for Evaluating MNA

This section presents context for the evaluation of MNA for MMTS OU III, including the key regulations applicable to the site and historical site activities, including regulatory framework, site history and usage, remedial activities, and long-term site strategies.

2.1 Regulatory Context

The MMTS is regulated under CERCLA. As stated in the Federal Facility Agreement for the Monticello site (DOE 1988), DOE serves as the lead federal agency in planning, implementing, and directing response actions. The U.S. Environmental Protection Agency (EPA) and State of Utah share responsibility for the oversight of Monticello site activities; EPA has ultimate responsibility and oversight. At the state level, oversight of MMTS OU III remediation actions, decisions, and documents is provided by the Utah Department of Environmental Quality (UDEQ). UDEQ will continue to provide input and oversee MMTS OU III remedial decisions and future changes in site status to achieve site completion.

2.2 Site History and Usage

The MMTS is in southeast Utah, near the city of Monticello (Figure 1). The Vanadium Corporation of America and the U.S. Atomic Energy Commission operated a uranium- and vanadium-ore processing mill at the MMTS from 1941 to 1960 (DOE 2017). The mill produced tailings that contained radioactive and inorganic contaminants.

Contaminated tailings were impounded onsite and repurposed as construction materials at nearby properties. Process water from mill operations, leachate from tailing impoundments, and wind-deposited tailings contaminated groundwater beneath the MMTS and surface water in Montezuma Creek, a waterway that runs through the former mill site.

In 1989, the MMTS was listed on the CERCLA National Priorities List (NPL). The MMTS is composed of three OUs. OU I consists of the former mill site property and the permanent repository for contaminated materials, OU II consists of peripheral properties that were contaminated by the former mill site, and OU III consists of land areas with contaminated surface water and groundwater that resulted from the former mill site operations and is the focus of this report.

Land within MMTS OU III is owned by several entities, including DOE, the City of Monticello, and private owners. Land use at the former mill site is restricted to recreational usage (i.e., day-use park areas). The remainder of MMTS OU III is sparse residential, agricultural, or undeveloped private property. The alluvial aquifer is not currently or historically used for domestic purposes due to poor yields, and alternate sources of domestic water are readily available throughout MMTS OU III (DOE 2017). ICs provide additional restrictions and are discussed below in Section 4.1.6.

2.3 Remedial Activities

The selected remedy for OU I and OU II was soil excavation and containment in a permanent, capped, onsite repository (DOE 1990). Remediation of OU I and OU II began in 1992 and was completed in 1999. The repository was capped in 2000, and 2.54 million cubic yards of contaminated material was sealed in the repository. Tailings remediation activities in OU I and OU II removed the primary uranium source to groundwater and surface water in OU III.

While the feasibility study for MMTS OU III was ongoing, interim remedies were put in place. In 1999, a permeable reactive barrier (PRB) was installed as a treatability study pilot demonstration. ICs to restrict the use of land and groundwater were adopted over the course of the remedial action and preparation of the MMTS OU III Record of Decision (ROD). In 2004, the OU III ROD was issued (DOE 2004), which documented MNA for groundwater and continued maintenance of ICs as the selected remedy for OU III. MNA was selected as the remedy for MMTS OU III based on documented source removal, demonstration of natural attenuation processes, and mitigation of the potential for human exposure and risk through implementation of ICs (DOE 2004). Based on information at the time, the remedial time frame of MNA for uranium was estimated to be 42 years, and it was assumed that remedial objectives for other contaminants of concern would be met within that period. The ROD defined groundwater remedial action objectives that consisted of protecting human health and the environment and restoring water quality to remediation goals (existing water quality standards) for surface water and groundwater. The groundwater remediation goal for uranium is 30 micrograms per liter (µg/L).

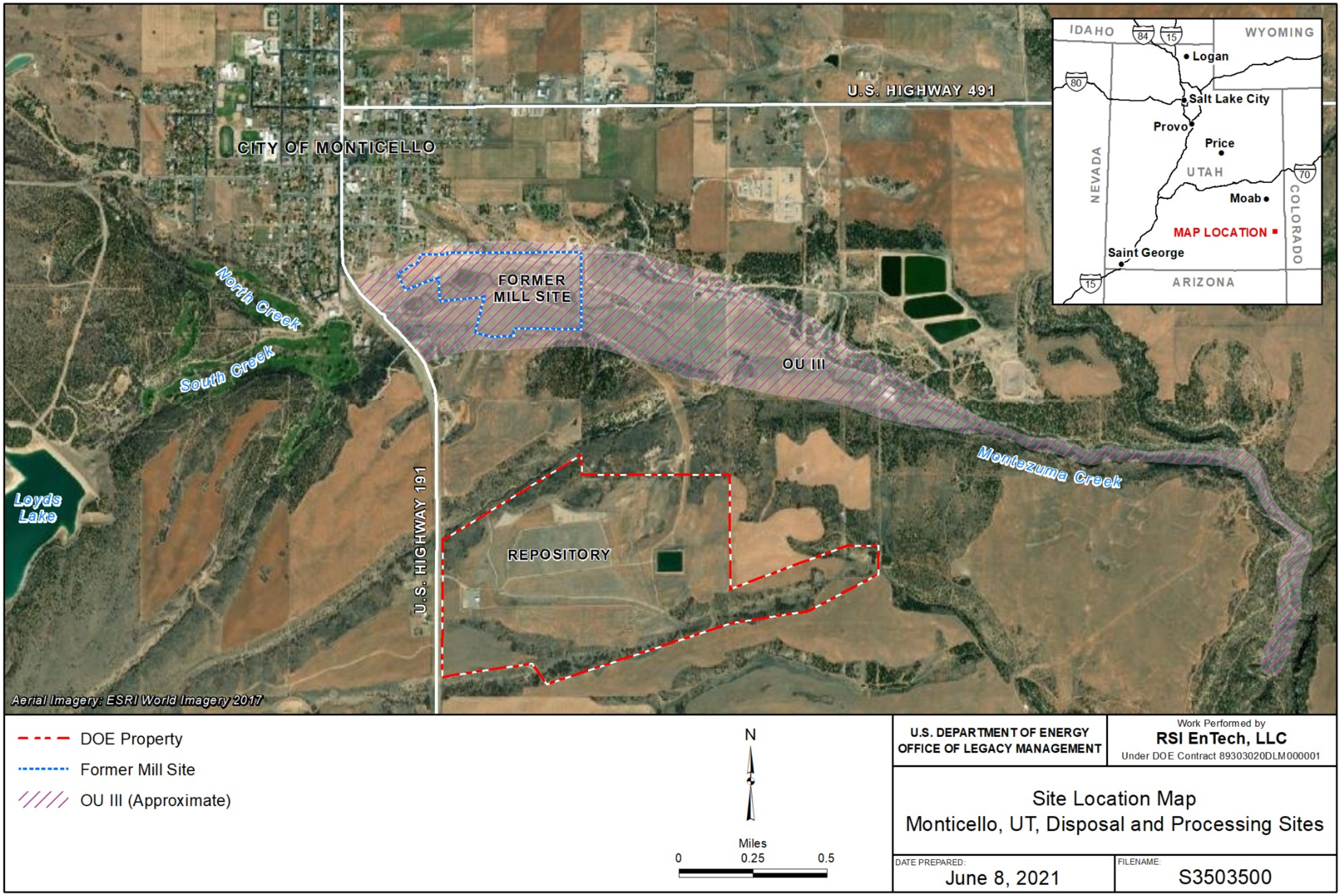

Figure 1. MMTS OU III Location Map

Over time, the PRB, which was not part of the ROD-specified remedy, experienced a decline in permeability due to mineralization, resulting in upgradient groundwater mounding (DOE 2017). To reduce groundwater mounding, DOE installed a pump-and-treat system in 2005 with one extraction well upgradient of the PRB. By 2007, it was determined that the MNA remedy would not achieve the remedial time frame of 42 years that was specified in the 2004 ROD (DOE 2007). As a result, DOE implemented a contingency remedy through an Explanation of Significant Difference (ESD) in 2009 that formalized the ex situ pump-and-treat system upgradient of the PRB as a remedy component and identified the PRB as a hydraulic barrier (DOE 2009). In 2014, the contingency remedy was enhanced with the groundwater remedy optimization (GRO) system (DOE 2014), which consisted of eight extraction wells installed in the area with the highest uranium concentrations in groundwater, known as the Area of Attainment (AOA), upgradient of the PRB. Groundwater extracted by the GRO system is pumped to a solar evaporation pond on the neighboring DOE property and managed under OU I. The ex situ pump-and-treat system was deactivated upon completion of the GRO system.

Currently, the compliance remedy at MMTS OU III is MNA and active remediation (GRO system) with ICs that restrict alluvial aquifer groundwater use in an area that roughly corresponds to the footprint of the uranium plume. The active remediation component of the compliance remedy focuses on the AOA.

2.4 Evaluation of Long-Term Strategies

The Closure Strategy Report (DOE 2018) considered three closure strategies for MMTS OU III: (1) restoring natural attenuation conditions and conducting MNA; (2) applying alternate concentration limits (ACLs); and (3) waiving the uranium remediation goal within a designated area based on technical impracticability (TI) of achieving water quality restoration by active remediation technologies (TI waiver). MNA and TI waivers were determined to be feasible closure strategies for MMTS OU III. A closure strategy involving ACLs was determined to not be viable for MMTS OU III because the groundwater discharge does not meet the CERCLA definition of an acceptable ACL.

The preferred closure strategy recommended for MMTS OU III in the Closure Strategy Report was to transition to a remedy based on MNA, ICs, and contingencies, with no active remediation (DOE 2018). The proposed remedy is consistent with the remedy established in the 2004 ROD (DOE 2004), before active remediation was added to the remedy by the 2009 ESD (DOE 2009). The new proposed strategy includes establishing criteria for MNA acceptance, GRO system termination, evaluation of TI waivers if needed, long-term monitoring, and eventual site delisting, as well as feedback loops to revisit and improve the basis for making key decisions if needed. If MNA is deemed not acceptable and asymptotic uranium concentration behavior is observed (indicating a decline in GRO system performance), it is recommended that a TI waiver be evaluated for MMTS OU III.

3.0 Conceptual Site Model

The Closure Strategy Report reviewed the CSM for MMTS OU III and identified data gaps (DOE 2018). Additional geochemical evaluation (DOE 2020a) and numerical modeling (DOE 2019; DOE 2021) were subsequently performed to address data gaps in the CSM; initial results of these evaluations are presented within the corresponding reports. This section presents an updated comprehensive CSM for MMTS OU III based on recent data analysis and modeling efforts.

3.1 Geology and Hydrogeology

3.1.1 Hydrostratigraphy

MMTS OU III occupies the valley of Montezuma Creek, a small stream that forms at the confluence of North and South Creeks about 0.5 mile west of the former mill site and flows eastward through MMTS OU III. The valley of Montezuma Creek is underlain by a shallow, thin, unconfined to semiconfined alluvial aquifer composed of 10–15 feet (ft) of unconsolidated silt, sand, and gravel.

The Dakota Sandstone Formation forms an aquitard (Dakota Aquitard) beneath the alluvial aquifer until about 0.6 mile downgradient of the former mill site. There, the formation is absent due to erosion in the creek valley. This exposes the regionally extensive Burro Canyon sandstone, a local drinking water source, as the upper bedrock formation. The Burro Canyon sandstone is underlain by low-permeability mudstones of the Morrison Formation. The bedrock formations are regionally extensive.

3.1.2 Horizontal and Vertical Extent of Groundwater Flow System

The areal extent of the alluvial aquifer is shown in Figure 2. The depth to groundwater and the saturated thickness of the alluvial aquifer along the axis of the alluvial valley are generally not more than 10 ft. Groundwater flow in the alluvial aquifer is west to east following the slope of the valley and varies seasonally depending on precipitation events and irrigation returns. During summer months, it is common for extended portions of Montezuma Creek to be dry, and portions of the creek that remain wet in summer months are due to groundwater discharge to the creek.

A geologic cross section of the MMTS OU III is shown in Figure 3. The alluvial aquifer is narrow (up to several hundreds of feet wide), being constrained by the bedrock formations that form the valley margins. The Dakota Sandstone Formation is approximately 65 ft thick in the AOA, and the Burro Canyon sandstone is approximately 100 ft thick at its maximum but is removed by erosion in the creek valley approximately 1.3 miles east of the former mill site. The Morrison Formation reaches up to 800 ft thick and locally is not water bearing.

3.1.3 Recharge and Discharge

Potential sources of recharge to the alluvial aquifer in MMTS OU III include (1) precipitation; (2) irrigation water in some areas of MMTS OU III; (3) upward groundwater discharge from the Burro Canyon aquifer where the Dakota Sandstone aquitard is absent; (4) underflow at the western, northern, and southern boundaries of the former mill site; and (5) Montezuma Creek, following big snow years when creek levels are high.

Potential losses of groundwater from the alluvial aquifer include (1) discharge to Montezuma Creek in some reaches; (2) evapotranspiration, particularly in the riparian zone of Montezuma Creek; and (3) groundwater extraction in the AOA. Montezuma Creek is the primary discharge location for the alluvial aquifer.

3.2 Aquifer Hydraulic Properties

The 2019 *Monticello Mill Tailings Site Operable Unit III Groundwater Flow Conceptual Site Model Update* report describes the hydraulic properties of the MMTS OU III alluvial aquifer (DOE 2019). The alluvial aquifer has a saturated thickness of typically 3 to 4 ft. Hydraulic conductivity of alluvial aquifer sediments has been determined from field tests and laboratory analyses conducted during multiple site investigations throughout the history of the MMTS (DOE 2019). Recent estimates of hydraulic conductivity in the AOA derived from short-term aquifer tests ranged from approximately 4 to 444 feet per day (ft/day) with a mean value of approximately 100 ft/day (DOE 2019).

Hydraulic gradients in MMTS OUIII vary spatially and temporally. A typical horizontal hydraulic gradient in the alluvial aquifer is 0.02. At the upgradient end of the site, the alluvial aquifer and Burro Canyon aquifer are separated by the Dakota Sandstone, and the average vertical hydraulic gradient calculated between Burro Canyon and alluvial aquifer well pairs in this area is 0.9 (downward). The average vertical hydraulic gradient decreases in the downgradient direction to –0.3 (upward), where the Burro Canyon Formation directly underlies the alluvial aquifer (DOE 2019).

Groundwater generally flows in the direction of the canyon formation, from west to east. Alluvial aquifer groundwater velocity ranges from 0.3 to 36 ft/day, and the median estimated groundwater flow rate across the mill site is approximately 140 gallons per minute (DOE 2019).

3.3 Uranium Distribution

3.3.1 Historical Uranium Source Areas

The historical source areas for contamination of MMTS OU III groundwater and surface water were the four mill tailings impoundments (or tailings piles) located on the mill site. Drainage of process water and leaching by meteoric water transported contaminants from the tailings in dissolved form to the underlying alluvial aquifer. The impounded tailings were present since 1941, when milling started, through 2000, when surface remedial actions were completed and radiologically contaminated material was relocated to the DOE repository. The tailings piles had been covered with earthen caps in 1964 to stabilize and prevent direct exposure to the wastes.

3.3.2 Dissolved Uranium Plume

The total mass of dissolved uranium in MMTS OU III is estimated to be approximately 40 pounds (lb) (DOE 2020b), which represents <1% of the total uranium mass in MMTS OU III (DOE 2021). Dissolved-phase uranium at concentrations that exceed the remediation goal (30 µg/L) extends from the central portion of the former mill site to approximately 1 mile downgradient (east) of its eastern boundary. At the downgradient plume boundary, discharge from the Burro Canyon aquifer displaces and dilutes uranium-bearing groundwater, and the diluted groundwater discharges to Montezuma Creek. The primary mechanism by which uranium mass exits the groundwater system is discharge to Montezuma Creek. The areal extent of the uranium plume is depicted in Figure 2, and isoconcentration contours of dissolved uranium concentration in 2020 are presented in Figure 4. The average dissolved uranium plume concentration is approximately 160 µg/L (DOE 2020b). Maximum dissolved uranium concentrations in the AOA were approximately 880 µg/L in May 2020 (DOE 2020b).

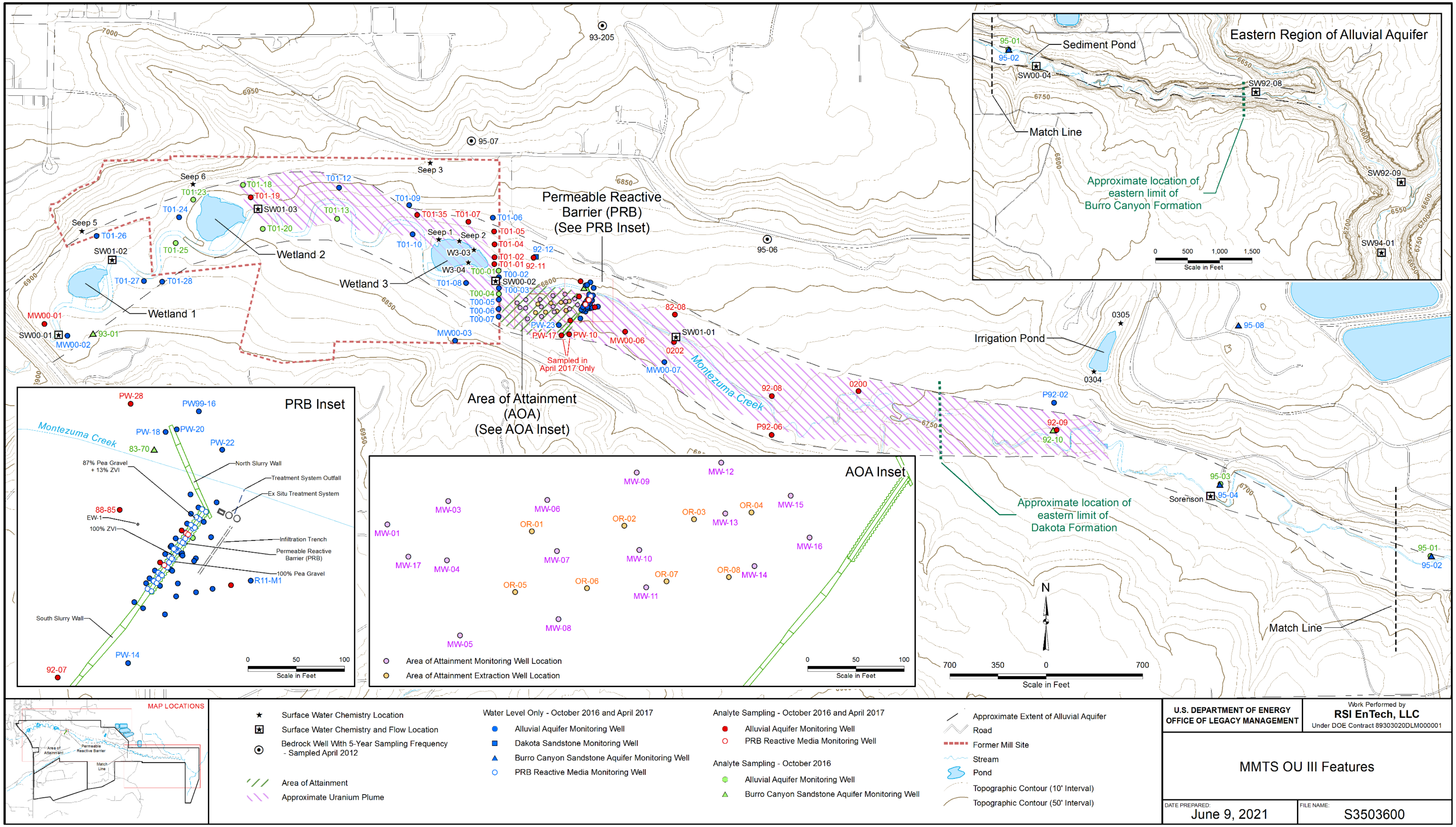

Figure 2. MMTS OU III Aquifer Extent

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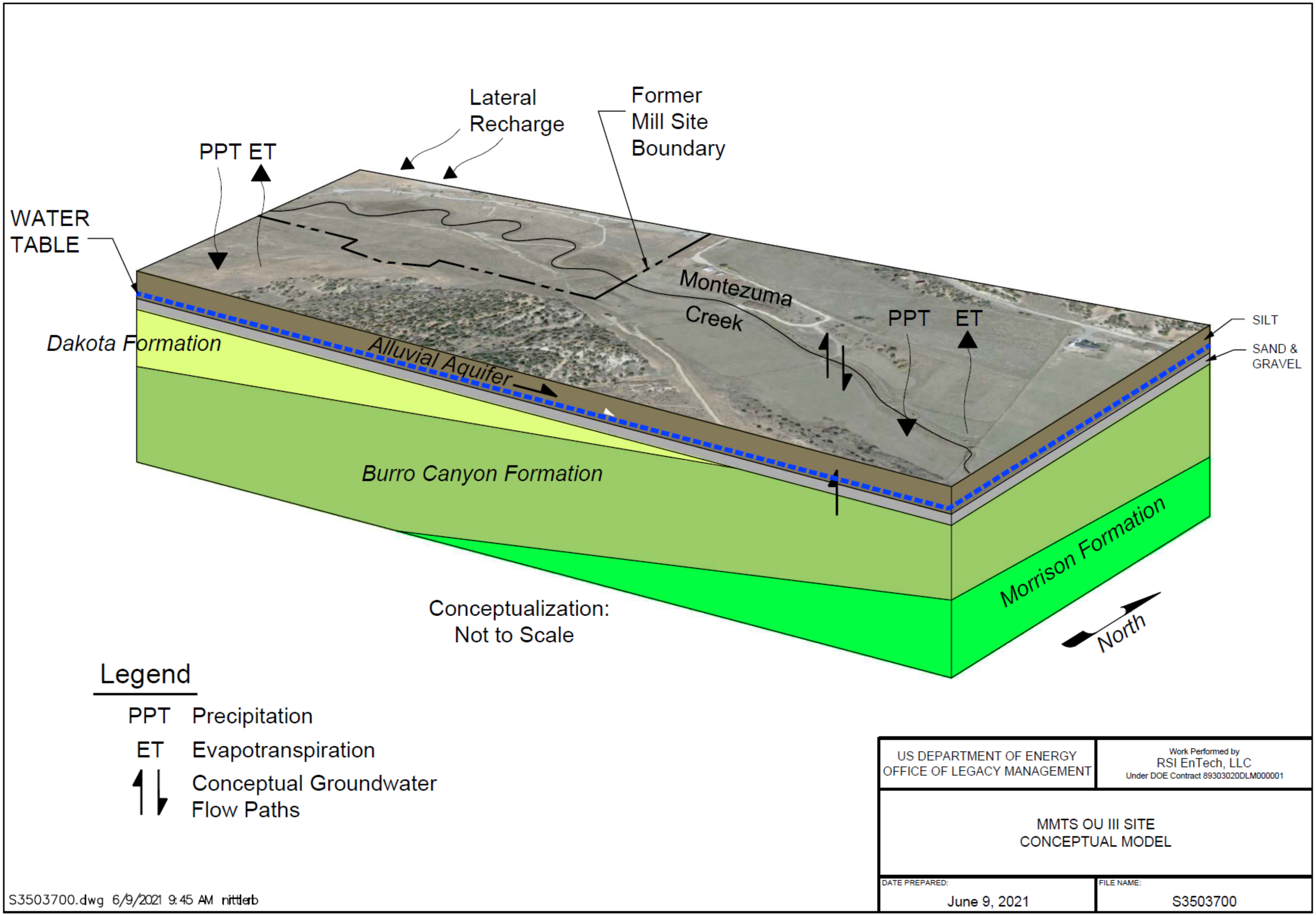

Figure 3. MMTS OU III Flow Conceptual Site Model

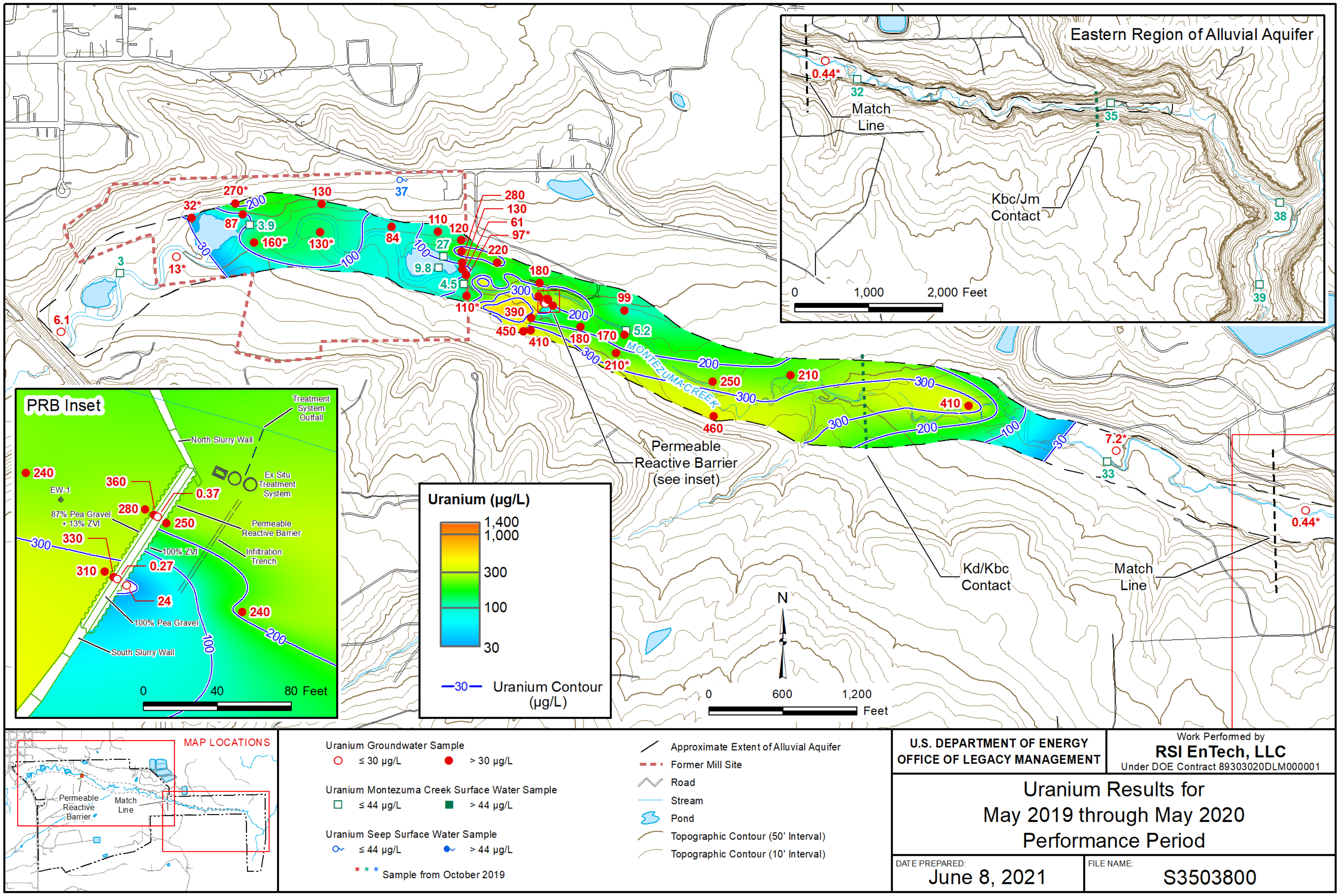

Figure 4. MMTS OU III Uranium Plume Map

3.3.3 Solid-Phase Uranium Distribution

Sorbed and/or precipitated uranium in or on solid phases within the saturated and vadose zones of the aquifer is regarded as a secondary source of uranium contamination to groundwater. More than 99% of uranium in MMTS OU III is associated with the solid phase, and the total mass of solid-phase uranium in MMTS OU III is estimated at 33,600 lb (DOE 2021). Table 1 presents the average concentration and distribution of solid-phase uranium across areas of the site, which are shown on Figure 5.

Table 1. Solid-Phase Uranium Mass Estimates

Area	Average Uranium Concentration (mg/kg)[a]	Total Digestion Uranium Mass (lb)[a]	Carbonate Extraction Uranium Mass (lb)[a,b]	5% Nitric Acid Extraction Uranium Mass (lb)[a,c]
Saturated Zone[d]	5.1 (4.4–6.1)	11,400 (9,900–13,600)	6400 (5600–7600)	8200 (7200–9800)
Mill Site Vadose Zone[d]	5.1 (3.4–7.6)	13,500 (8,900–20,000)	7500 (5000–11,200)	9700 (6400–14,400)
Downgradient Vadose Zone[d]	4.9 (3.4–8.1)	6600 (4500–10,900)	3700 (2500–6100)	4700 (3200–7800)
Creek Supplemental Standards[e]	15.6 (7.7–24.5)	800 (400–1300)	400 (200–700)	600 (300–900)
South Supplemental Standards[e]	15.6 (7.7–24.5)	1300 (700–2100)	700 (400–1200)	900 (500–1500)
Total Solid-Phase Mass	--	33,600 (24,400–47,800)	18,800 (13,700–26,700)	24,200 (17,600–34,400)

Notes:

[a] The mean estimate is presented outside parentheses, and the 95% confidence interval of the mean is presented inside parentheses.

[b] Calculated as 56% of the total digestion uranium mass based on the carbonate extraction results.

[c] Calculated as 72% of the total digestion uranium mass based on the 5% nitric acid extraction results.

[d] Estimated by sequential Gaussian simulation.

[e] Estimated by bootstrapping.

Abbreviations:

mg/kg = milligrams per kilogram

lb = pounds

Solid-phase uranium is distributed throughout MMTS OU III, and the largest fraction of solid-phase uranium mass is associated with the mill site vadose zone (Table 1, Figure 5). According to extensive solid-phase sampling in 2018 and geospatial statistical modeling, approximately 60% of solid-phase uranium is in the vadose zone, 35% is in the saturated zone, and the remaining fraction is in the supplemental standards areas (DOE 2021). According to solid-phase selective extraction tests, approximately 55% of solid-phase uranium in MMTS OU III is adsorbed to soil (approximated by carbonate extraction), whereas approximately 30% of solid-associated uranium is immobile (recalcitrant fraction after 5% nitric acid extraction) (DOE 2021). The immobile fraction may include uranium that is coprecipitated with solid phases not extracted by 5% nitric acid and that is therefore unlikely to be mobilized via natural processes.

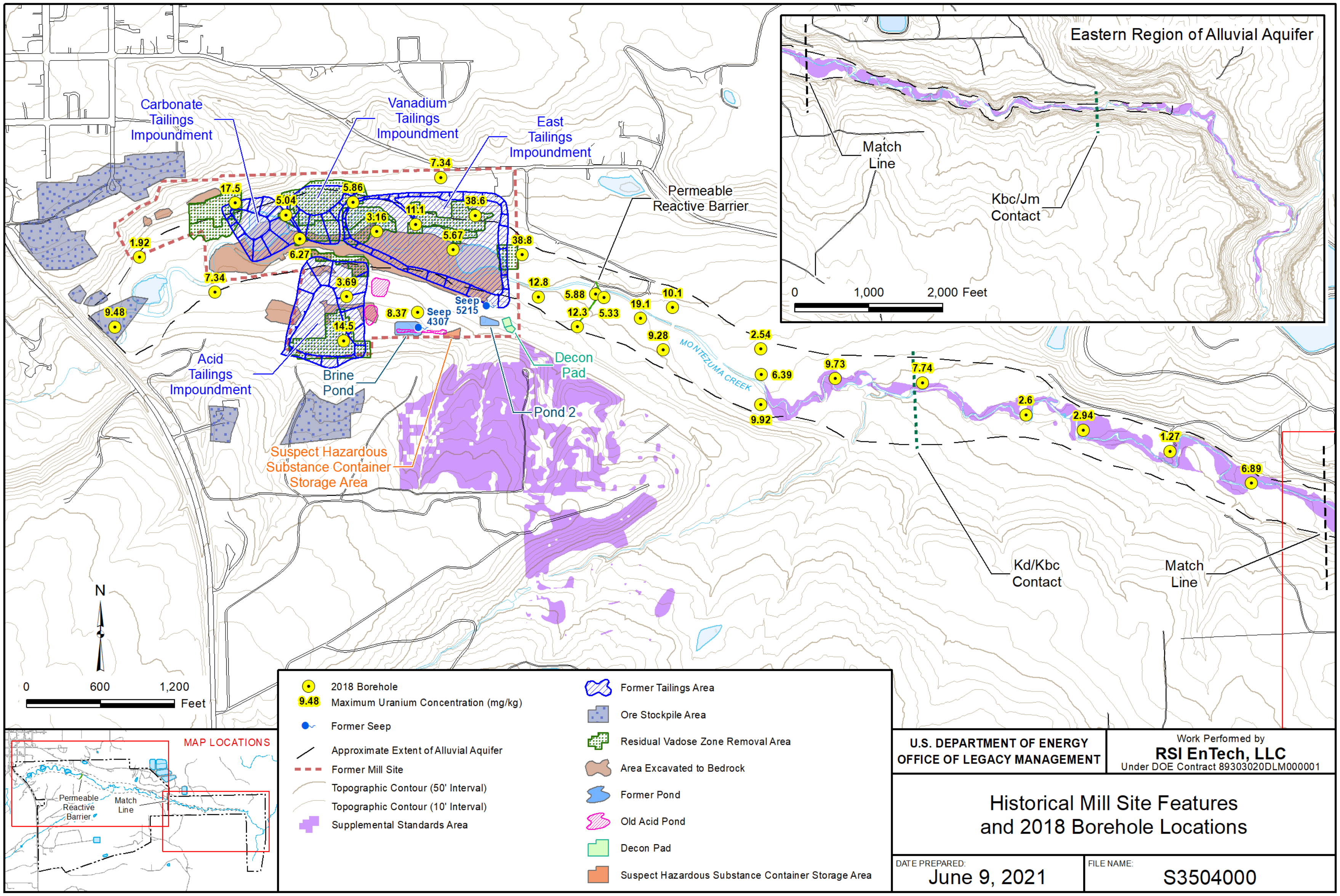

Figure 5. Historical Mill Site Features and 2018 Borehole Locations

3.4 Geochemical Processes Affecting Groundwater Quality

Sorption of uranium to aquifer solids within the saturated and vadose zones is the primary geochemical process affecting the distribution and transport of uranium in groundwater at MMTS OU III. Uranium readily sorbs to iron and manganese oxyhydroxides, phosphates, layered silicates, and solid humic phases (DOE 2004). Sorption of uranium can be represented by Equations 1 and 2, whereby the uranyl ion (UO_2^{2+}) binds with strong (SOH) and superstrong (SSOH) sorption sites:

$$SSOH + UO_2^{2+} = SSOUO_2^{+} + H^{+} \quad (1)$$
$$SOH + UO_2^{2+} = SOUO_2^{+} + H^{+} \quad (2)$$

Sorption of uranium to solid phases is affected by solid-phase mineralogy, pH, and groundwater composition (EPA 2010). Natural sediment and precipitated iron and manganese oxyhydroxide minerals are the primary sorbents of uranium in MMTS OU III (DOE 2020a). Uranium sorption is greatest around circumneutral pH; shifts in groundwater pH may remobilize sorbed uranium. Likewise, the presence of complexing ligands, such as carbonate and calcium, decreases sorption of uranium to iron and manganese oxyhydroxides, and changes in groundwater composition may remobilize sorbed uranium.

The large percentage of uranium in MMTS OU III associated with solid phases (>99%) (DOE 2021) demonstrates the strong affinity of uranium for the alluvial matrix.

3.5 Long-Term Uranium Fate and Transport

Residual uranium loading from the vadose zone is the primary cause of persistent uranium concentrations in the aquifer. As background groundwater flows through MMTS OU III, uranium desorbs from aquifer solids, is transported in the direction of groundwater flow, and resorbs at available sorption sites on downgradient solids, depending on concentration gradients and geochemical conditions. Uranium loading from the vadose zone is enhanced during periods of greater precipitation, leading to seasonal variations in groundwater uranium concentrations. Laboratory column experiments demonstrated a sustained uranium release from soils even after more than 10 pore volumes of flushing (DOE 2001; DOE 2020a). More-mobile phases of uranium may release rapidly early in the flushing process, while the less-mobile phases provide a persistent long-term source.

In the present CSM, geometrical aspects of Montezuma Creek, recharge zones, evapotranspiration (ET) zones, aquifer thickness, and boundary conditions are assumed to be fixed; however, over hundreds or thousands of years, the geometry of these features is likely to change. For example, climate change might result in shifts in the plant community that would change the geometry of ET zones; erosional processes might cause Montezuma Creek to shift its course; or land development outside the former mill site might reconfigure recharge zones. Additionally, over long remedial time frames, physical transport mechanisms (e.g., sediment erosion caused by high flow rates in Montezuma Creek) could impact contaminant distribution by rapidly transporting contaminated sediment away from the site. While the model does not simulate surface runoff processes, the potential resulting uranium release and transport mechanisms (e.g., increase in water levels and release from the vadose zone) are similar to model-simulated processes. Hence, attempting to explicitly simulate surface runoff processes is not expected to significantly change the model predictions. The effects of these processes on long-term uranium fate and transport are discussed in detail in the 2021 *Monticello Mill Tailings Site Operable Unit III Groundwater Flow and Contaminant Transport Model Report* (DOE 2021).

4.0 MNA Evaluation

MNA relies on natural processes to attenuate contamination and monitoring to verify that these processes are working to meet site objectives. The EPA policy for MNA is documented in the Office of Solid Waste and Emergency Response (OSWER) Directive 9200.4-17P (EPA 1999). In 2007 and 2010, EPA released a three-volume set of technical reports addressing the technical basis and requirements for assessing MNA of inorganics (EPA 2007; EPA 2010). In 2015, EPA released OSWER Directive 9283.1-36, *Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites,* referred to herein as the 2015 OSWER Directive (EPA 2015). The 2015 OSWER Directive provides formal guidance on the MNA of inorganics, which applies to uranium.

The 2015 OSWER Directive provides general requirements that a site should satisfy prior to implementing a remedy based on MNA. Section 4.1 evaluates these requirements and demonstrates how each requirement is satisfied at MMTS OU III. Additionally, the 2015 OSWER Directive recommends a Tiered Analysis Approach in which successively more detailed information is collected and analyzed to evaluate the suitability of MNA. Section 4.2 presents how each of the four phases of the Tiered Analysis Approach is satisfied at MMTS OU III.

4.1 General Requirements

This section presents an evaluation of how the general requirements for MNA detailed in the 2015 OSWER Directive are satisfied at MMTS OU III.

4.1.1 Protectiveness of Human Health and the Environment

The 2015 OSWER Directive states that “MNA should not be used where such an approach would result in… impacts to environmental resources that would be unacceptable to the overseeing regulatory authority” (EPA 2015). Since MMTS OU III is regulated under CERCLA, a primary objective of the current MMTS OU III remedy (i.e., MNA with ICs and active remediation) is maintaining the protectiveness of human health and the environment. CERCLA mandates a Five-Year Review process to ensure protectiveness of human health and the environment at sites where levels of contamination remaining onsite prevent unlimited use and unrestricted exposure, which includes MMTS OU III.

In the latest Five-Year Review for the MMTS (DOE 2017), published in June 2017, DOE, UDEQ, and EPA concluded that:

1. The MMTS OU III remedy is “functioning as intended to prevent risk of exposure to contaminated groundwater through the use of ICs.”

2. Current exposure assumptions, toxicity data, cleanup levels, and remedial action objectives at MMTS OU III are valid.
3. The remedy for MMTS OU III is protective of human health and the environment.

LM conducts long-term surveillance and maintenance (LTS&M) activities to ensure that the current remedy is working as intended, to ensure that ICs remain relevant and effective in preventing exposure to contamination, and to identify any changing site conditions that may compromise remedy protectiveness. LTS&M activities, including annual site inspection, semiannual groundwater monitoring, and annual groundwater reporting, are described in the *Long-Term Surveillance and Maintenance Plan for the Monticello NPL Sites* (LMS/MNT/S00387), referred to herein as the Monticello LTS&M Plan.

Transitioning to a remedy based on MNA and ICs and contingencies, with no active remediation, will maintain protectiveness of human health and the environment because the ICs, which have been deemed effective by UDEQ and EPA, will remain in effect. LTS&M activities and the Five-Year Review process will continue to ensure the remedy is achieving the intended goals.

4.1.2 Identification of Contaminant Source

The 2015 OSWER Directive states that "control of source materials is the most effective means of ensuring the timely attainment of remediation objectives. EPA, therefore, expects that source control measures will be evaluated for all contaminated sites and that source control measures will be taken at most sites where practicable" (EPA 2015). Source control measures at MMTS OU III began in 1997 and were completed in 1999 (DOE 2004).

The primary sources of uranium in OU III groundwater were four mill tailings impoundments on the former mill site and contaminated soil, sediment, and debris that resulted from leaching of the tailings impoundments. As described in Section 2.3, 2.54 million cubic yards of radiologically contaminated material, including the tailings piles and impacted soil and sediment, were excavated to or near bedrock, removed from the site, and consolidated within a permanent repository 1 mile south of the MMTS. It is estimated that approximately 2,000,000 lb of uranium were removed from the site during this phase of remediation (DOE 2021). Cleanup of source material was established by field radiological surveys and confirmed by laboratory analysis of soil samples. Removal of contaminated material was completed in 1999, and the repository was sealed in 2000. These remediation activities removed the primary source of uranium to OU III groundwater and surface water, and the MMTS OU III satisfies the 2015 OSWER Directive requirement for source control measures.

Sorbed or precipitated uranium in or on solid phases within the saturated and vadose zones of the aquifer is regarded as a secondary source of uranium, which currently contributes to contamination of MMTS OU III groundwater. The current total mass of solid-phase uranium in MMTS OU III is estimated at 33,600 lb (Table 1), which represents less than 2% of the original source mass (approximately 2,000,000 lb). The distribution of uranium on soil and sediments throughout MMTS OU III was investigated in November 2018 when samples were collected from boreholes at 32 locations across the site (DOE 2020a). Results of this investigation relative to potential source areas are presented in Figure 5. Although samples were collected from multiple depths through the unsaturated and saturated zones at each borehole location, only the maximum result for each location is displayed in the figure. Background solid-phase uranium concentrations at the MMTS are generally less than 2 milligrams per kilogram (mg/kg) (DOE 2020a). As illustrated in Figure 5, concentrations exceeding background levels of uranium are dispersed throughout the former mill site and the alluvial aquifer. Even in portions of the former mill site where the excavation extended to bedrock, uranium transport through the saturated zone has resulted in contamination of the backfill material.

The effect of targeted removal of secondary source mass on the remedial time frame was investigated using a transport model (DOE 2021). Removal of the residual mill site vadose zone source decreased the remedial time frame significantly; however, the residual uranium mass in the mill site vadose zone (13,500 lb) is diffused over a large volume of soil (1.2 million cubic yards), representing less than 1% of the original source mass while occupying approximately 50% of the volume of the originally excavated material. Because remediation of a diffuse vadose zone source is not expected to be efficient, more targeted removal of a portion of the residual source mass was considered as well. Even with targeted remediation of the south mill site source (280,000 cubic yards), the remediation time frame is predicted to be on the order of hundreds of years to over 1000 years (DOE 2021). Additionally, the simulated benefits of this scenario are considered optimistic because 100% removal efficiency is not likely to be achieved and because supplemental standards areas south of the former mill site are also suspected to contribute to the south mill site source loading. Due to the diffuse nature of the secondary source mass, the benefits of targeted removal of contaminated soil are uncertain.

4.1.3 Site Characterization

The 2015 OSWER Directive provides guidance on the level of site characterization needed to support the use of MNA as a remedy. Site characterization should provide "a quantitative understanding of source mass; groundwater flow (including preferential pathways); contaminant phase distribution and partitioning between soil, groundwater, and soil gas; rates of biological and non-biological transformation; and an understanding of how all of these factors are likely to vary with time" (EPA 2015). Numerous geochemical and hydrogeological investigations have been performed over the past 30 years that provide a level of quantitative understanding suitable to evaluate the transition of the MMTS OU III remedy back to MNA.

The source mass and distribution of uranium in MMTS OU III soil and groundwater is well-characterized. Environmental investigations have been conducted at or near MMTS OU III since the early 1950s, and DOE conducted annual environmental monitoring inspections and prepared annual reports from the early 1960s until the mid-1990s (DOE 2004). In addition to significant historical studies, recently, 194 soil samples were collected from 32 borings to delineate solid-phase uranium distribution at the site. Uranium source mass, phase distribution, and partitioning between soil and groundwater are documented in the 2020 *Monticello Mill Tailings Site Operable Unit III Geochemical Conceptual Site Model Update* (DOE 2020a) and 2021 *Monticello Mill Tailings Site Operable Unit III Groundwater Flow and Contaminant Transport Model Report* (DOE 2021).

Groundwater flow and the hydrogeology of MMTS OU III have been characterized extensively using soil borings, aquifer tests, and groundwater monitoring wells. The 2019 Groundwater Flow Conceptual Site Model Update (DOE 2019) synthesizes historical groundwater monitoring datasets with precipitation records, irrigation volumes, satellite imagery, surface water flow, and groundwater extraction rates to present a sitewide groundwater flow CSM for MMTS OU III

(DOE 2019). Groundwater at MMTS OU III is monitored semiannually using a network of 77 groundwater monitoring wells. The most recent groundwater monitoring results are presented in the 2020 Annual Groundwater Report (DOE 2020b).

Rates of geochemical, nonbiological processes controlling uranium transport in groundwater have been quantified using laboratory column testing and geochemical modeling. Twenty-four column tests were performed with MMTS OU III soil and groundwater to quantify the rates of uranium release (i.e., desorption from soil and dissolution of uranium-bearing minerals) from soil (DOE 2020a). Uranium distribution coefficients (K_d) were refined using geochemical modeling for incorporation into a sitewide uranium transport model (DOE 2021). Additionally, a range of uranium sorption parameters that vary with groundwater geochemistry was derived for use in a reactive transport model (DOE 2021). The 2021 *Monticello Mill Tailings Site Operable Unit III Groundwater Flow and Contaminant Transport Model Report* describes how the geochemistry and hydrogeology of MMTS OU III are expected to evolve over the remedial time frame of MNA. Because most of the groundwater at the Monticello site appears to be oxidizing (DOE 2020a), biological reduction of uranium, which occurs under strongly reducing conditions, is not expected to be significant.

Consideration of MNA as a remedy at MMTS OU III has been documented in the administrative record since the earliest site investigations, including the 1998 Remedial Investigation (DOE 1998), 2004 ROD (DOE 2004), and 2009 ESD (DOE 2009). Recently, historical and modern site characterization data have been synthesized in the Closure Strategy Report (DOE 2018), Geochemical Conceptual Site Model Update (DOE 2020a), Groundwater Flow Conceptual Site Model Update (DOE 2019), and Groundwater Flow and Contaminant Transport Model Report (DOE 2021). Together, these documents demonstrate a comprehensive understanding of the site suitable to evaluate the transition to MNA.

4.1.4 Sufficiency of Conceptual Site Model

The 2015 OSWER Directive specifies the use of a CSM to assess the suitability of MNA as a remedy for sites with inorganic contaminants. The MMTS OU III has been extensively characterized over the past 30 years, and the CSM for OU III has been continually refined to incorporate the most up-to-date site characterization data and understanding of uranium geochemistry.

The Closure Strategy Report reviewed the CSM, including descriptions of site hydrostratigraphy, hydrology, contaminant distribution, and contaminant fate and transport, and identified data gaps (DOE 2018). The Closure Strategy Report recommended the following tasks to address data gaps in the MMTS OU III CSM:

- Update lines of evidence for MNA, including conducting a time-series analysis of existing and newly collected water quality data and considering other data on existing natural processes, data from geochemical studies, and the implications of numerical modeling results
- Conduct updated numerical modeling of flow and transport to guide expectations of uranium concentration trends and plume behavior and to estimate remediation times
- Conduct bench-scale laboratory studies to evaluate geochemical behavior of uranium, generating data that can be used to improve the CSM and basis for numerical modeling

- Make other improvements to the CSM and underlying basis of the numerical model, including refinement of groundwater flow in the AOA, seepage from the alluvial aquifer to the Mancos/Dakota Formation aquitard, surface water–groundwater interaction, and recharge and evapotranspiration processes in the alluvial aquifer

To address these data gaps, additional work was completed between 2018 and 2021. Site characterization (194 soil samples from 32 new boreholes, 56 nonroutine groundwater samples), laboratory studies (24 column tests using site soil and groundwater), data evaluation, and numerical modeling were performed. Results from these field, laboratory, and numerical modeling investigations were used to refine the MMTS OU III CSM, including identifying the primary geochemical controls of uranium transport in MMTS OU III groundwater (DOE 2020a) and developing updated groundwater flow and transport models (DOE 2021) capable of predicting remedial performance and time frames under different scenarios. Additionally, evaluations of groundwater uranium concentration trends and bulk uranium plume metrics have been performed annually since 2018 to assess the OU III remedy progress and validate the CSM (e.g., DOE 2020b).

Data gaps related to site characterization and contaminant fate and transport have been identified and addressed. The CSM is sufficient to assess the suitability of MNA at the MMTS OU III.

4.1.5 Geochemical Evidence of Attenuation

The 2015 OSWER Directive highlights the distinction between organic contaminants, which can be degraded, and inorganic contaminants, which cannot be degraded but can be immobilized on aquifer solids. Therefore, the Directive requires knowledge of the specific mechanism of attenuation (type of sorption or redox reaction) and demonstration that attenuation is occurring. Knowledge of the mechanism and rate of attenuation are also a requirement of Phase II of the Tiered Analysis Approach for evaluating the suitability of MNA and are therefore addressed in detail in Section 4.2.2.

4.1.6 Institutional Controls

The 2015 OSWER Directive recommends the implementation of ICs "in the event of long duration MNA remediation timeframes…to help ensure protectiveness of human health as a short-term tool to supplement MNA" (EPA 2015). The 2004 ROD instated ICs to prevent the domestic use of MMTS OU III groundwater and restrict land use within the floodplain of Montezuma Creek where sediments with uranium are present (DOE 2004). Additionally, there are land use restrictions for the former mill site property, which was transferred from DOE to the City of Monticello and is used as a public park. ICs in place at MMTS OU III are described in detail in Section 2.2 of the Monticello LTS&M Plan, which is presented as Appendix A.

LTS&M activities at MMTS OU III include monitoring compliance with the ICs of the 2004 ROD. As described in the Monticello LTS&M Plan, various mechanisms are used to maintain ICs, including visual surveillance of properties for evidence of disturbance; confirmation that administrative mechanisms (e.g., zoning) remain in place; contacts with City and UDOT personnel regarding planned excavation activities on affected properties; and contact with the State Engineer regarding proposed drilling in or near the groundwater restricted area. All ICs are confirmed during the annual site inspections. ICs on some non-DOE-owned properties are monitored more frequently.

The 2017 Five-Year Review for the Monticello site concluded that administration of the current ICs successfully eliminates potential exposure pathways relevant to MMTS OU III (DOE 2017). The ICs will continue to be administered throughout the duration of the MNA remedy, and the efficacy of the ICs will be reviewed on a 5-year basis to ensure the remedy is protective of human health.

The ICs currently in place at MMTS OU III are sufficient to ensure protectiveness of human health.

4.1.7 Reasonable Time Frame

MNA may be an appropriate remedy for a site if the remediation time frame is deemed reasonable. The 2015 OSWER Directive provides considerations for determining if the remediation time frame of MNA is reasonable, including "contaminant properties, exposure risk, classification of the protected resource (for example, a source of drinking water), the potential for plume stability, and the relative timeframe for active remediation methods" (EPA 2015). ICs are administered at MMTS OU III to ensure that exposure risk is minimized and acceptable and, as described below, the plume is stable.

A transport model was used to evaluate the remedial time frame of MNA at MMTS OU III. The calibrated model estimate for the remedial time frame for MNA without active remediation is on the order of hundreds to thousands of years (DOE 2021). Estimates of the remedial time frame based on mass balance of uranium loading to and discharge from groundwater support the model results. Thirty years of operation of the GRO system in the model prior to a transition to MNA did not decrease the estimated remedial time frame. Likewise, removal of the PRB did not affect the estimated remedial time frame. Results of the transport modeling demonstrate that the remedial time frame of MNA without active remediation is on the order of hundreds to thousands of years and is reasonable compared to the time frame for groundwater remediation using active remedies (DOE 2021).

The 2015 OSWER Directive states that "longer timeframes for inorganic plumes may be reasonable if the source term has already been addressed, the plume is stable or shrinking, the exposure risks for the source term and daughter products are acceptable, and when active measures have similar time frames." Additional considerations include whether "source control or removal is complete, there is high confidence in the attenuation mechanisms, rates, and capacity identified; and contingency plans are included for both the monitoring program and containment or treatment approaches" (EPA 2015).

As discussed herein, the contaminant source at MMTS OU III has been identified and addressed (Section 4.1.2); the contaminant plume is stable or shrinking (Section 4.2.1); and ICs are administered to ensure exposure risks are appropriate (Section 4.1.6). Results of the transport model demonstrate that the remediation time frame for MNA is comparable to that of active remedies (i.e., hundreds to thousands of years). Extensive geochemical characterization and laboratory testing has been performed to ensure high confidence in the attenuation mechanisms, rates, and capacity (Section 4.2; DOE 2020a). Additionally, sensitivity testing of a sitewide reactive transport model demonstrates that reasonable fluctuations in geochemical conditions at MMTS OU III do not significantly affect the estimated remedial time frame (DOE 2021). Finally, contingency remedies are in place and will be reevaluated if a transition to MNA is approved (Section 4.2.4).

Multiple lines of evidence demonstrate that the remedial time frame of MNA at MMTS OU III satisfies the 2015 OSWER Directive standard of reasonableness.

4.2 Tiered Analysis Approach

This section presents an evaluation of how each phase of the Tiered Analysis Approach described in the 2015 OSWER Directive is satisfied at MMTS OU III.

4.2.1 Phase I: Demonstration of Plume Stability

The objective of Phase I is to evaluate whether MNA should be eliminated from further consideration because the plume is not stable or is continuing to expand. The 2015 OSWER Directive recommends focusing the evaluation on delineation of areal and vertical plume boundaries and demonstrating plume stability using hydrogeological and geochemical datasets.

MMTS OU III hydrogeology and aquifer geometry has been characterized extensively. Recently, a three-dimensional model of MMTS lithology was constructed based on 185 lithologic logs, topographic survey data, and geologic mapping of bedrock outcrop locations (DOE 2019). Areal boundaries of the alluvial aquifer are shown in Figure 2. The alluvial aquifer of MMTS OU III has a saturated thickness of typically 3 to 4 ft and is bounded to the north and south by the bedrock canyon walls. The aquifer extends east and west of the MMTS along the canyon.

Groundwater monitoring at MMTSOU III is performed semiannually and reported annually. The areal extent of the uranium groundwater plume during the most recent groundwater monitoring event is shown in Figure 4. The plume extends across the entire alluvial aquifer in the north-south direction, bounded by the canyon walls, and extends east from the former mill site approximately 1 mile in the downgradient direction along the canyon. The downgradient extent of the uranium plume has not expanded since 1995 due to the upward flow from the Burro Canyon Formation and subsequent discharge into Montezuma Creek (DOE 2020a).

To evaluate plume stability, a Mann-Kendall trend analysis was performed of MMTS OU III groundwater uranium concentration data collected at 56 monitoring wells between 2001 and 2020 (Figure 6). Thirty-one monitoring wells (55%) were identified with decreasing uranium concentration trends, 1 monitoring well (2%) was identified with an increasing uranium concentration trend, and 24 monitoring wells (43%) were identified as having no statistically significant trend (DOE 2020b). Uranium concentrations are below the remediation goal at the one location with an increasing trend (R4-M6), which is within the PRB and therefore is not representative of alluvial groundwater.

Plumewide metrics have also been analyzed to evaluate plume stability. The volume, dissolved mass, and average concentration of the uranium plume are affected by seasonal changes in water table elevation and heavy precipitation events that can mobilize uranium from the vadose zone to the alluvial aquifer. Dissolved plume mass and average plume concentration have a decreasing trend from 2008 to present (Figure 7 and Figure 8), whereas plume volume has remained relatively constant over the same period (DOE 2020b) (Figure 9).

Discharge of the plume to Montezuma Creek likely contributes to stability of the plume. Routine surface water monitoring and biomonitoring prescribed in the 2004 ROD confirmed that discharge to Montezuma Creek does not pose a threat to potential human or ecological receptors (DOE 2012). Biomonitoring performed between 2005 and 2012 included selenium sampling of surface water and macroinvertebrates and avian surveys. In 2012, EPA, in consultation with UDEQ, concluded that the criteria established in the 2004 ROD for discontinuing biomonitoring at MMTS OU III were met (EPA 2012). Groundwater and surface water sampling near the alluvial aquifer discharge location in Montezuma Creek is performed semiannually and reported annually (DOE 2020b). Five-Year Reviews continue to verify that the MMTS OU III remedy remains protective of human health and the environment, and the Five-Year Review process includes processes for updating standards to assess protectiveness, as necessary.

Taken together, evaluation of uranium concentration trends at individual groundwater monitoring wells and plumewide metrics indicates that the MMTS OU III satisfies the Phase I requirement of a stable or shrinking plume.

4.2.2 Phase II: Mechanism and Rate of Attenuation

The objective of Phase II is to "(1) evaluate the mechanism and rate of the attenuation process or processes, and (2) evaluate whether MNA should be eliminated from further consideration… for sites where further analysis shows that attenuation rates are insufficient for attaining site cleanup objectives within a timeframe that is reasonable compared with other remedial alternatives" (EPA 2015).

The 2015 OSWER Directive recommends data collection and analyses to evaluate the mechanism of attenuation; Table 2 shows how each of these recommendations was addressed for MMTS OU III.

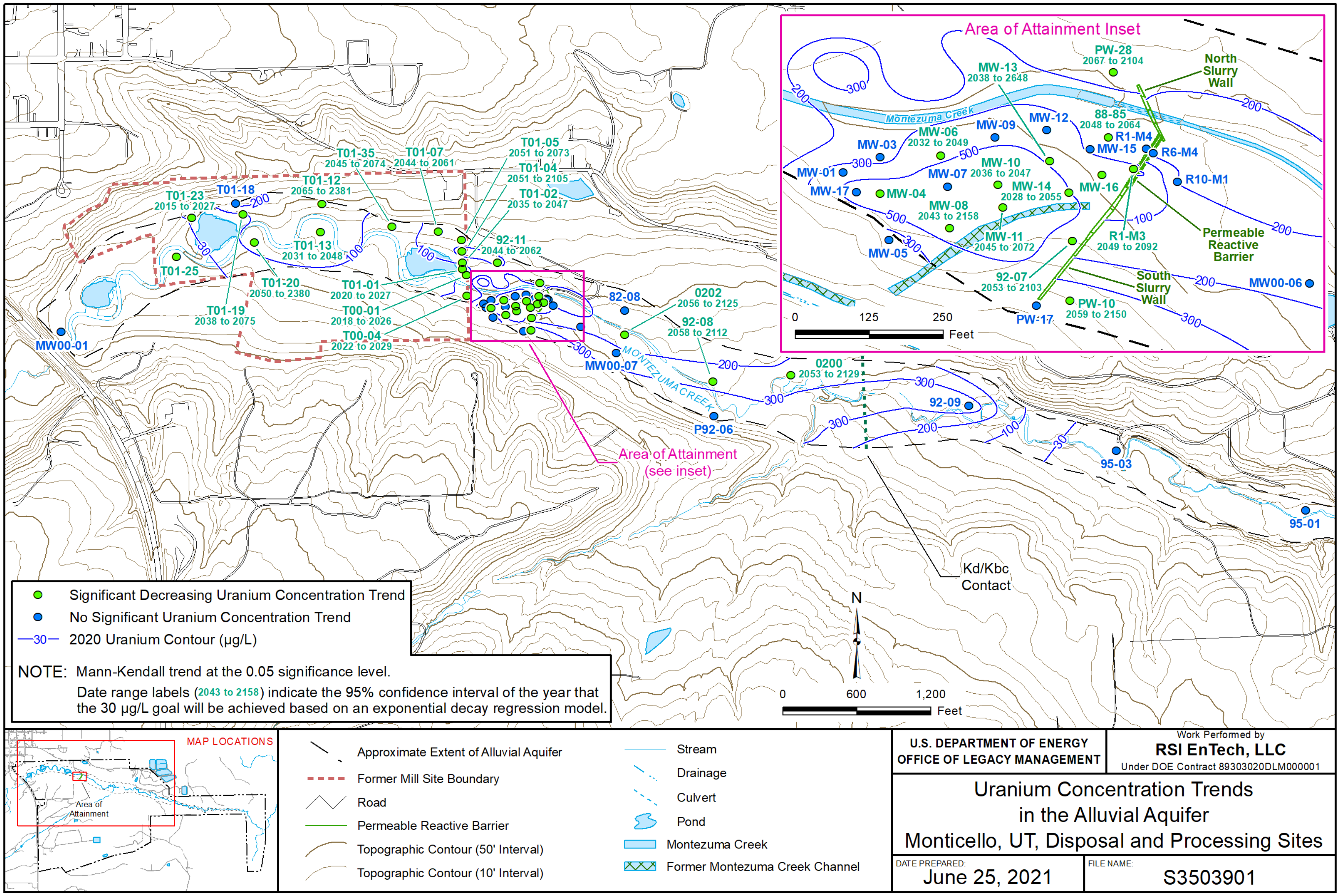

Figure 6. Alluvial Aquifer Uranium Concentration Trends

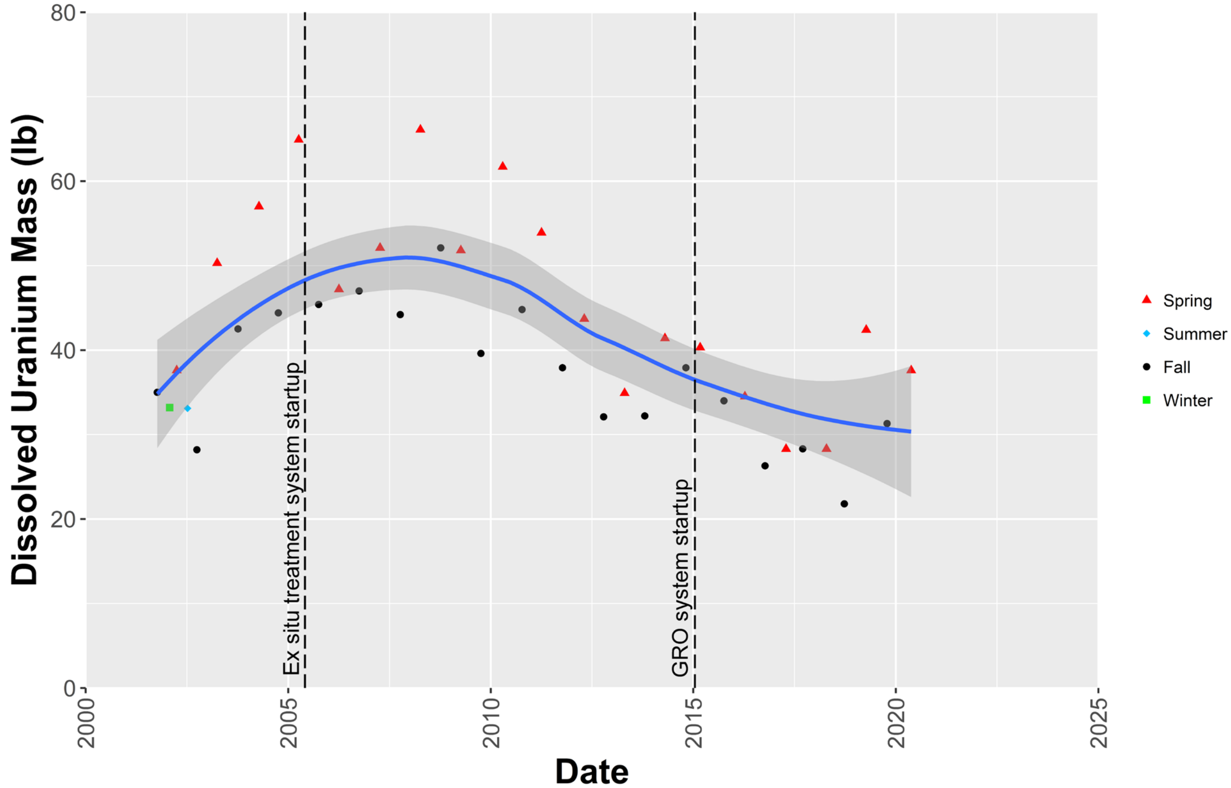

Figure 7. OU III Uranium Mass vs. Time

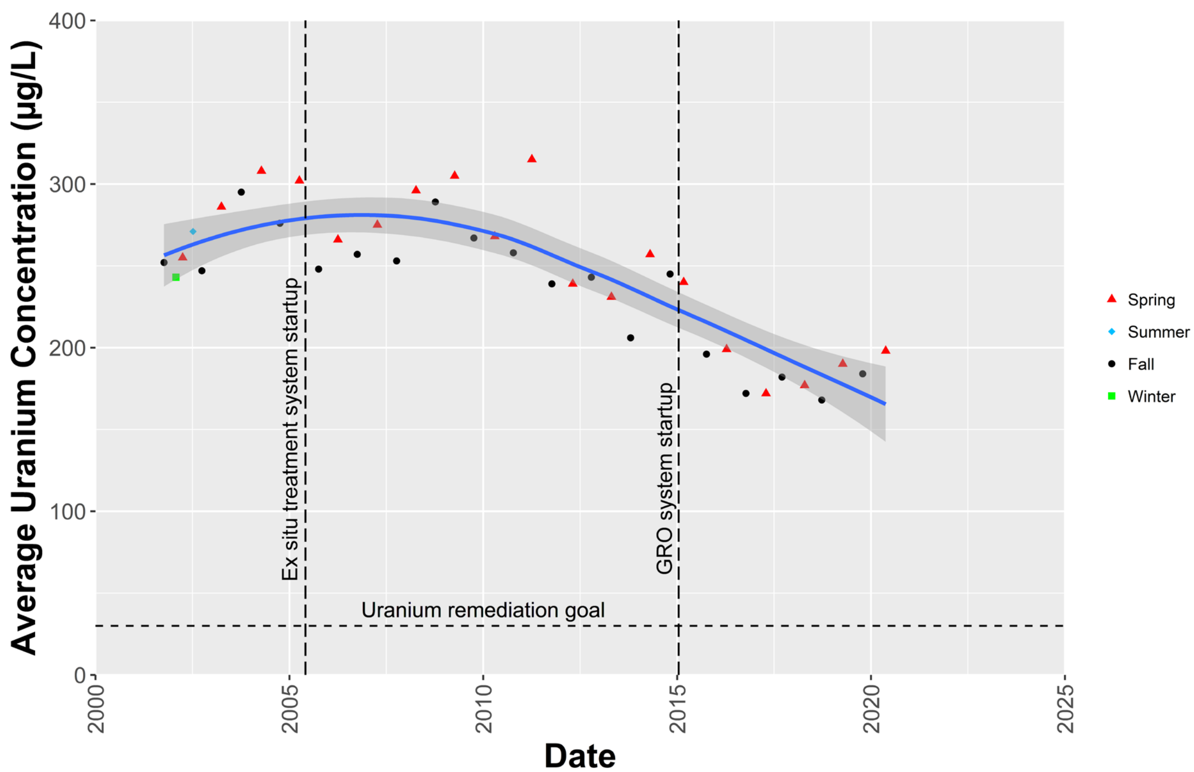

Figure 8. OU III Average Uranium Concentration vs. Time

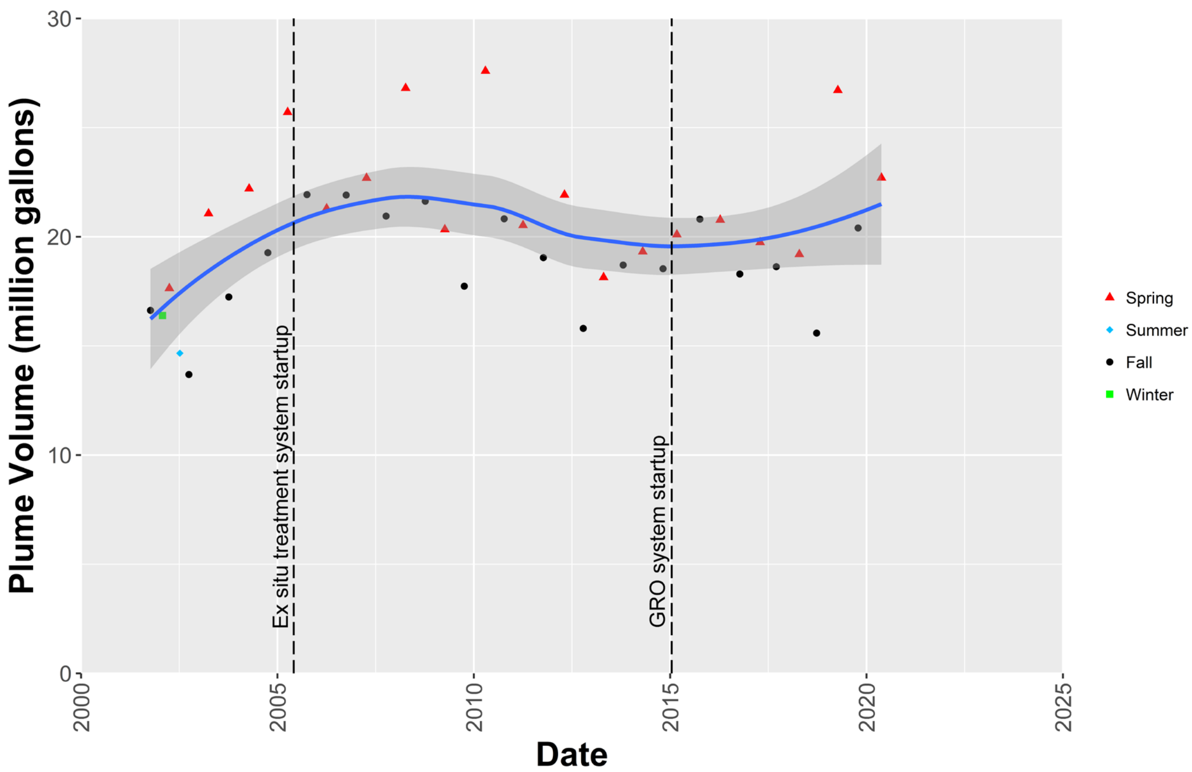

Figure 9. OU III Uranium Plume Volume vs. Time

Table 2. OU III Data Collection and Analysis Addressing the Mechanism and Rate of Attenuation

OSWER Recommendation	OU III Data Collection and Analysis
Detailed characterization of system hydrology (spatial and temporal heterogeneity; flow model development)	A groundwater flow model was developed using historical and recent hydrogeological site data (DOE 2019; DOE 2021).
Detailed characterization of groundwater chemistry	Historical and recent groundwater monitoring data, including uranium concentration and relevant geochemical parameters, have been and are measured semiannually and reported annually (e.g., DOE 2020b).
Subsurface mineralogy and microbiology	Historical and recent soil data and geochemical equilibrium modeling with recent groundwater data were used to evaluate the subsurface mineralogy of MMTS OU III (DOE 2020a).
Contaminant speciation (groundwater and aquifer solids)	Selective extractions were performed on MMTS OU III soil samples to quantify the speciation of solid-phase uranium (DOE 2021). Uranium distribution coefficients across MMTS OU III were determined through direct laboratory measurements and through column data combined with modeling (DOE 2021).
Reaction mechanism (site data, laboratory testing, chemical reaction modelling)	Site soil and groundwater were used in laboratory studies to evaluate the geochemical behavior of uranium at MMTS OU III (DOE 2021). A groundwater flow model, a transport model, and a reactive transport model were developed using MMTS OU III field measurements to further support the understanding of uranium mobility at MMTS OU III (DOE 2021).

Sorption of uranium to solid phases is the primary geochemical attenuation mechanism for uranium at MMTS OU III. Natural sediment and precipitated iron and manganese oxyhydroxide minerals are the primary sorbents of uranium in MMTS OU III (DOE 2020a). The 2004 ROD identified uranium sorption and dispersion as the primary natural attenuation mechanisms (DOE 2004), and recent investigations and analyses demonstrate that these attenuation mechanisms remain operative (DOE 2020a; DOE 2021). Sorption of uranium to solid phases (Equations 1 and 2) is a well-documented and widely accepted uranium attenuation mechanism (EPA 2010).

Uranium transport through MMTS OU III is dynamic and consists of an influx of uranium originating from the mill site, uranium flow through the alluvial aquifer, and discharge of uranium to Montezuma Creek. Over time, as uranium in groundwater has flowed through the alluvial aquifer, a stationary, equilibrated mass of solid-associated uranium has formed. While the annual uranium mass flow rate is estimated to be of the same order of magnitude, or larger, than the mass associated with the dissolved phase (DOE 2021), the equilibrated solid-associated mass is driven by the uranium concentration in groundwater and not by the mass flow rate.

Based on comprehensive soil sampling conducted in 2018, >99% of uranium in the saturated zone (approximately 11,400 lb) is associated with the solid phase (Table 1), whereas <1% of uranium in the saturated zone (approximately 40 lb in May 2020) is dissolved in groundwater (DOE 2021; DOE 2020b), demonstrating the affinity of uranium for OU III soils.

Solid-phase selective extractions on OU III soil samples were performed to quantify the fraction of solid-associated uranium adsorbed (approximated by carbonate extraction), potentially mobile (represented maximally with 5% nitric acid extraction), and immobile (remaining fraction after total acid digestion) (DOE 2021) (Figure 10). Approximately 55% of solid-associated uranium in OU III is adsorbed to soil, whereas approximately 30% of solid-associated uranium in OU III is immobile (DOE 2021). The immobile fraction may include uranium that is coprecipitated with solid phases that are not extracted by 5% nitric acid and are, therefore, unlikely to be mobilized via natural processes.

A transport model for MMTS OU III was developed to evaluate the rate of uranium attenuation and the remedial time frame under different scenarios (DOE 2021). The transport model includes geochemical attenuation processes (i.e., uranium sorption to solid phases) as well as physical attenuation processes (e.g., dispersion and discharge to Montezuma Creek) and was calibrated using OU III field measurements. The results of the fate and transport model support the following conclusions:

- The overall remediation time frame for MNA at the MMTS OU III is on the order of hundreds to thousands of years.
- Thirty additional years of GRO system operation does not affect the remediation time frame.
- Removal of the PRB does not affect the remediation time frame.

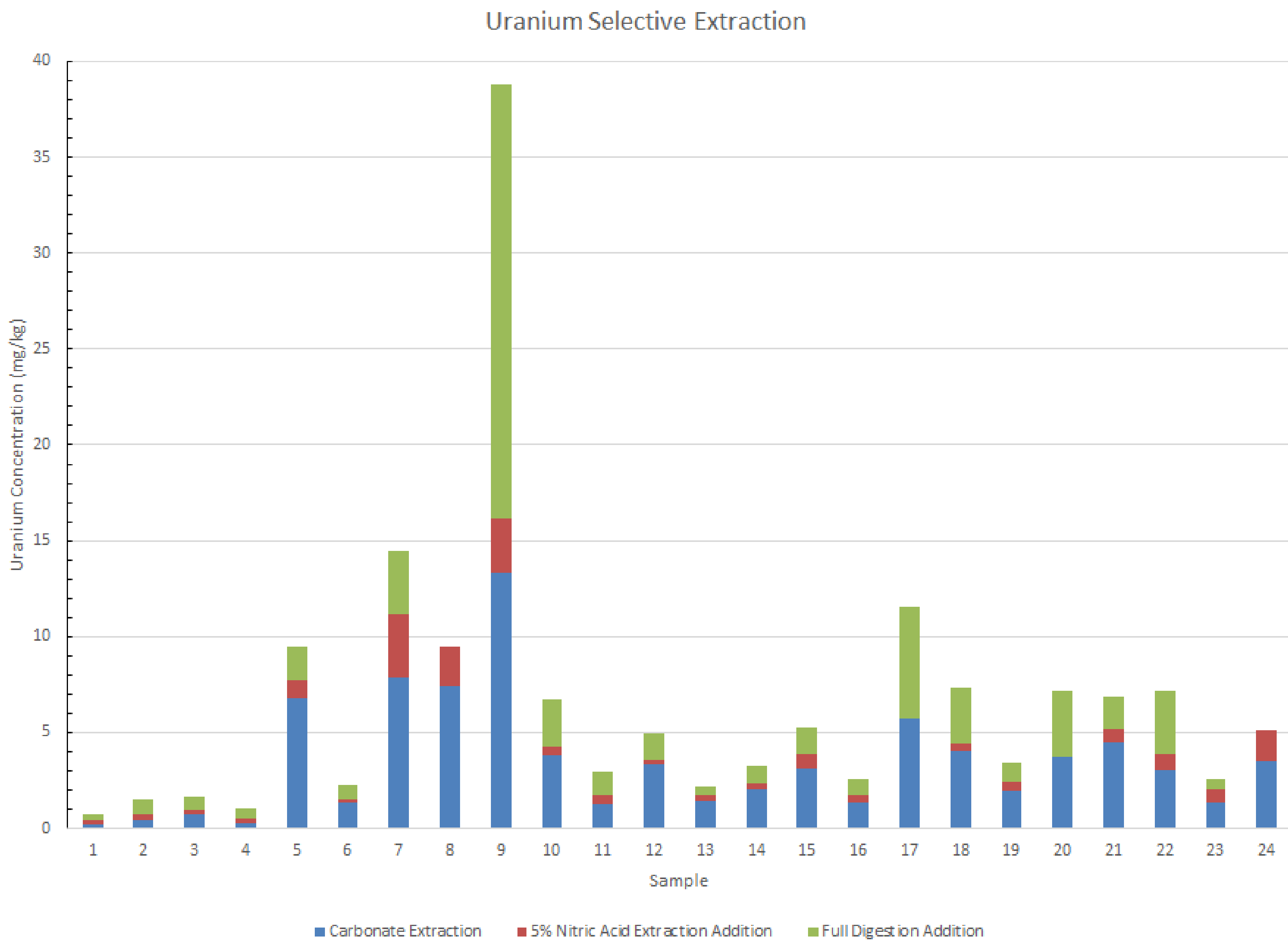

Figure 10. MMTS OU III Selective Extraction Results

Because active remediation (i.e., operation of the GRO system and PRB) does not decrease the remediation time frame, the remediation time frame for MNA with no active remediation is deemed reasonable.

Taken together, sorption is identified as the primary geochemical attenuation mechanism and attenuation rates are sufficient to achieve remediation goals in a reasonable time frame compared to that of other active groundwater remedies (i.e., hundreds to thousands of years, based on the results of the transport model). Thus, MMTS OU III satisfies the requirements of Phase II.

4.2.3 Phase III: System Capacity and Stability of Attenuation

The objective of Phase III is to "obtain data and information that can be used to evaluate whether MNA should be eliminated from further consideration for sites where there is insufficient capacity in the aquifer to attenuate contaminant mass to groundwater cleanup levels" (EPA 2015). Additionally, the 2015 OSWER Directive recommends evaluating whether the stability of the immobilized contaminant is sufficient to prevent remobilization in the future.

Metrics for the OU III dissolved uranium plume have been tracked since 2001 and provide one line of evidence that the OU III aquifer has capacity to achieve the remediation goals. The OU III dissolved uranium plume mass was 35 lb in 2001 and increased to a maximum of 52 lb in 2008, with an increase in water levels (DOE 2020b). Since 2008, the dissolved uranium plume mass has steadily decreased to a minimum of approximately 30 lb in 2019 (DOE 2020b). Simultaneously, the average dissolved uranium plume concentration decreased from 275 µg/L in 2008 to 160 µg/L in 2019 (DOE 2020b).

Uranium sorption testing was performed using MMTS OU III soil and artificial groundwater to evaluate the sorption capacity of MMTS OU III soils. Sorption isotherms were linear throughout the uranium concentration range tested (up to 4.5 milligrams per liter [mg/L] dissolved uranium) indicating that the maximum sorption capacity of MMTS OU III soils is achieved at dissolved uranium concentrations greater than 4.5 mg/L. The highest uranium concentration measured during the most recent groundwater monitoring event was approximately 1 mg/L, and groundwater uranium concentrations are expected to decrease over the remedial time frame. Thus, the maximum sorption capacity is not expected to be reached before the groundwater uranium source is depleted, and the system has sufficient capacity to achieve the remedial goals.

As an additional line of evidence, the transport model developed for MMTS OU III predicts that the mass and average concentration of the dissolved uranium plume will decrease further until remediation goals are achieved as uranium is removed from groundwater via sorption to soils and discharged to Montezuma Creek (DOE 2021). Taken together, the decreasing trends in mass and average concentration of the MMTS OU III dissolved uranium plume and the transport model simulations indicate that MMTS OU III has the capacity to support continued natural attenuation until the remediation goals are achieved.

The degree to which uranium sorbs to solid phases is primarily a function of solid-phase mineralogy, pH, and groundwater composition (EPA 2010). Uranium sorption is generally greatest in circumneutral pH groundwater with low concentrations of complexing ligands, such as carbonate and calcium. Sorbed uranium may be remobilized by shifts in groundwater pH, changes in groundwater composition (e.g., dissolution/precipitation of calcium carbonate), or dissolution of the sorbent mineral (e.g., dissolution of iron oxyhydroxides under reducing conditions).

The stability of attenuated uranium in OU III was evaluated using selective extractions of MMTS OU III soil and sensitivity analysis of a reactive transport model. Selective extractions indicate that approximately 30% of uranium is considered immobile and unlikely to be remobilized via natural processes, such as changing geochemical conditions (DOE 2021). Sorbed uranium accounts for approximately 55% of solid-phase uranium, which may be potentially remobilized due to changes in pH, redox conditions, or groundwater composition (e.g., dissolved inorganic carbon, calcium) (DOE 2021).

To evaluate the effect of potential changes in subsurface geochemistry on the stability of attenuated uranium in OU III groundwater, a reactive transport model was developed for OU III and a sensitivity analysis was performed on model parameters that impact uranium sorption. Reasonable variations in sorption parameters and saturation indexes of carbon dioxide (representing changes in dissolved inorganic carbon concentration) and calcite (representing changes in dissolved calcium concentration) had the potential to shift the remediation time frame on the order of ±150 years, which is expected to remain approximately the same regardless of the model scenarios (DOE 2021). The effects of changes in subsurface geochemistry on the remediation time frame are relatively small compared to the approximate time frame predicted by the transport model (hundreds to thousands of years). A combination of field measurements, laboratory testing, and computational modeling provides independent lines of evidence that (1) the MMTS OU III aquifer has sufficient capacity to achieve the remediation goal; and (2) attenuated uranium is sufficiently stable against remobilization. Thus, MMTS OU III satisfies the requirements of Phase III.

4.2.4 Phase IV: MNA Performance Monitoring Program and Contingency Remedies

The objective of Phase IV is to "develop a performance monitoring program to assess long-term performance of MNA and to identify alternative remedies that could be implemented in case MNA fails" (EPA 2015).

The 2015 OSWER Directive recommends the performance monitoring program be able to achieve the following:

1. Adequate spatial coverage to verify that the groundwater plume is stable or shrinking.
2. Verification of continued contaminant removal from groundwater and monitoring geochemical conditions that affect the attenuation mechanism.
3. Assessment of groundwater flow patterns to inform adjustments to the monitoring well network.

The Monticello LTS&M Plan developed by DOE includes monitoring for MMTS OU III. A Performance Monitoring Plan (PMP) will be prepared specifically for MNA and will include performance metrics to satisfy the MNA performance monitoring requirements of Phase IV. The PMP will be submitted to EPA and UDEQ under separate cover following approval of the transition to MNA and may be subsequently appended to the LTS&M. EPA will consult with UDEQ on the transition to MNA, and UDEQ's concurrence will be needed prior to the transition.

Phase IV also recommends (1) identifying contingencies that would serve as alternate remedies to MNA in the event of declining MNA performance and (2) including the contingencies in the MNA decision document. Additionally, Phase IV recommends the establishment of decision criteria to determine when a contingency would be implemented.

As stated in the 2004 ROD, “EPA guidance recommends that contingency plans should be flexible enough to allow for incorporation of new information about site risks and technologies. DOE, EPA, and UDEQ will jointly determine the need for and the appropriate contingency action based on an analysis of monitoring results” (DOE 2004).

The 2004 ROD includes the following contingency remedies for MMTS OU III:

- Enhancement of the existing PRB via pump-and-treat or in situ techniques
- Relocation and construction of a PRB at a location downgradient of the existing PRB
- Treatment of high uranium concentration groundwater hot spots with small-scale pump-and-treat and evaporative treatment using an existing pond at the DOE repository site
- Pumping of contaminated groundwater downgradient of the PRB, followed by evaporative treatment

Additionally, the 2009 ESD stipulates that DOE, EPA, and UDEQ may petition for applicable or relevant and appropriate requirement waivers based on technical impracticability if meeting remedial action goals is deemed infeasible (DOE 2009).

Contingency plans described in the 2004 ROD and 2009 ESD form the basis of the contingency requirement of Phase IV. If the remedy for MMTS OU III is transitioned to MNA and ICs and contingencies, an evaluation of contingency remedies will be included in the PMP. Contingencies included in the PMP will focus on the types of technologies that could be used at MMTS OU III, rather than a detailed evaluation of how the contingencies could be implemented. The contingency evaluation will leave open the possibility of new technologies that could be developed in the future.

5.0 Recommendations and Next Steps

The ROD-defined goals for MMTS OU III are protection of human health and environment and water quality restoration to remediation targets (existing water quality standards) for surface water and groundwater. The most recent CERCLA Five-Year Review (DOE 2017) concluded that the MMTS OU III remedy remains protective of human health and the environment and that ICs are effective in preventing exposure to contaminated groundwater. Remediation activities on the former mill site and adjacent properties removed the primary sources of groundwater contamination (mill tailings and contaminated soil, sediment, and debris) by 2000. Subsequent groundwater remediation efforts were implemented over the following decades, including the implementation of both passive and active treatment systems. As shown in this report, MNA with ongoing ICs and contingencies can now achieve the ROD-defined goals of protectiveness and restoration to water quality standards in a time frame that is reasonable compared to that of other active groundwater remedies (i.e., hundreds to thousands of years); implementation of an MNA-based remedy is therefore requested.

The 2004 ROD prescribed MNA with comprehensive monitoring, implementation and enforcement of ICs, and removal of the PRB (DOE 2004). A 2009 ESD formalized the pump-and-treat system upgradient of the PRB as a remedy component and identified the PRB as a hydraulic barrier (DOE 2009). A regulatory document (an ESD or ROD Amendment) would likely be required to revert to the MNA-focused remedy (with ICs and contingencies), including discontinuing the GRO system and decommissioning and removing the PRB.

DOE is requesting that EPA and UDEQ review and approve the proposed approach, contingent upon the submittal and approval of the following documents:

- A 2021 *Monticello Mill Tailings Site Operable Unit III Groundwater Flow and Contaminant Transport Model Report*, which presents results of recent numerical modeling, including evaluation of the remedial time frame of MNA at MMTS OU III
- A GRO Termination Memorandum, which will outline the technical basis for the cessation of GRO system operation
- An MNA PMP, which will outline performance monitoring to evaluate the ongoing effectiveness of MNA, evaluate contingencies to MNA, and present criteria for implementing contingencies if needed

6.0 References

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Long-Term Surveillance and Maintenance Plan for the Monticello National Priorities List (NPL) Sites, LMS/MNT/S00387, continually updated, prepared by the LMS contractor for the U.S. Department of Energy Office of Legacy Management.

Appendix A

Long-Term Surveillance and Maintenance Plan for Monticello National Priorities List (NPL) Sites, Section 2.2

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Appendix A: Long-Term Surveillance and Maintenance Plan for Monticello National Priorities List (NPL) Sites, Section 2.2

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2.2 Institutional Controls

Each property identified in Table 1 is affected by one or more ICs that restrict land or groundwater use, as summarized in the table. Figure 1 shows the locations of the different properties listed in Table 1. DOE will conduct specific LTS&M activities to ensure that these ICs remain effective in protecting human health and the environment. Details of the ICs and necessary restrictions are summarized below.

Table 1. Summary of Current MMTS and MVP Institutional Controls

DOE Property ID	Type of Property					Institutional Control					IC Confirmation[e]
	Transferred from DOE to City of Monticello (quitclaim deed)	Contains Supplemental Standards Areas	Within Montezuma Creek Restrictive Easement	Within Groundwater Restricted Area (established by Utah State Engineer)	DOE-Owned Property	Restrictions on Construction of Habitable Structures	Recreational Day Use Only (no overnight camping)	No Soil Removal from Supplemental Standards or Easement Areas	Groundwater Use Restrictions for Domestic Purposes on Shallow Alluvial Aquifer	Special Zoning Restrictions Related to Building Structures	
MMTS OU I											
MS-00893[a]	X			X		X	X		X		1,2,3
MP-01040 (south portion)[b]					X						1
MP-01080[b]					X						1
MMTS OU II											
MP-00179				X					X		2
MP-00181	X			X		X	X		X		1,2,3
MP-00211				X					X	X[d]	1,2,4
MP-00391	X	X				X	X	X	X		1,3
MP-00947				X					X		2
MP-00951		X	X	X		X		X	X		1,2,3
MP-00990		X	X	X		X		X	X		1,2,3
MG-01026		X	X			X		X			1,3
MG-01027		X	X			X		X			1,3
MG-01029		X	X			X		X			1,3
MG-01030		X	X			X		X			1,3
MG-01033		X	X	X		X		X	X		1,2,3

DOE Property ID	Type of Property					Institutional Control					IC Confirmation[e]
	Transferred from DOE to City of Monticello (quitclaim deed)	Contains Supplemental Standards Areas	Within Montezuma Creek Restrictive Easement	Within Groundwater Restricted Area (established by Utah State Engineer)	DOE-Owned Property	Restrictions on Construction of Habitable Structures	Recreational Day Use Only (no overnight camping)	No Soil Removal from Supplemental Standards or Easement Areas	Groundwater Use Restrictions for Domestic Purposes on Shallow Alluvial Aquifer	Special Zoning Restrictions Related to Building Structures	
MP-01040[g] (north portion)	X					X	X				1,3
MP-01041	X	X				X	X	X			1,3
MP-01042[g]	X					X	X				1,3
MP-01077	X	X				X	X	X	X		1,3
MP-01081[c] (south portion)					X						1
MP-01081 (north portion)				X					X		1,2
MP-01084		X	X	X		X		X	X		1,2,3
MVP											
MS-00176		X						X[f]		X[d]	1,4
City Streets and Utilities		X						X[f]			1,4
Highways 191 and 491		X						X[f]			1,4

Notes:

[a] Former mill site property.
[b] DOE repository property.
[c] DOE retained this area as a perpetual wildlife corridor; disturbances are prohibited.
[d] Properties MP-00211 and MS-00176 are included in City of Monticello Overlay Zone OL-1, which was created through City of Monticello zoning ordinances 2002-04 and 2003-02.
[e] 1=Routine, and/or annual LTS&M inspections.
2=Contact State of Utah, Division of Water Rights regarding water appropriation applications.
3=Review property deeds during annual LTS&M inspection; verify that annotations transfer with deeds.
4=Radiological control performed on excavations.
[f] Any soil removal from a supplemental standards area on this property must be done as described in Sections 2.2.2 and 2.2.3 and in accordance with the applicable procedures in Appendix E.
[g] Property meets UU/UE criteria with respect to residual contamination. ICs were imposed as a condition of land transfer from the federal government.

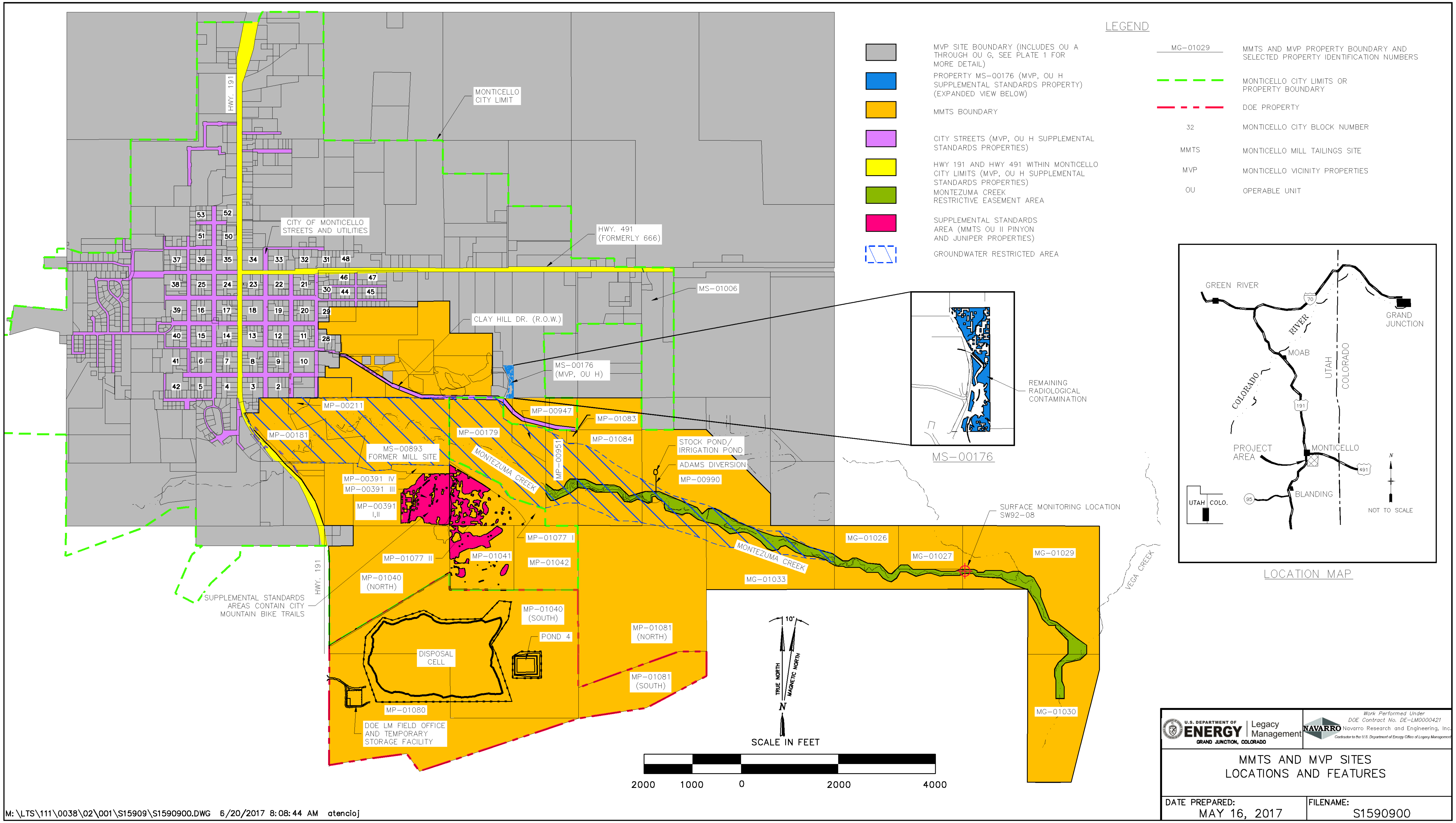

Figure 1. Monticello MMTS and MVP Sites Locations and Features

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2.2.1 ICs on Properties Transferred from DOE to the City of Monticello

The transfer of approximately 383 acres from DOE to the City of Monticello was completed in 2000 through the federal Lands-to-Parks program administered by the National Park Service (DOE 2000). This program allows the transfer of federal holdings to state or local government provided the lands remain open to the public for parks and recreation in perpetuity. Consistent with the conditions of the transfer, the former mill site was restored to a park setting, including reintroduction of native plants, establishing riparian and wetland habitat for wildlife along Montezuma Creek, and providing picnic areas and walking paths for public use.

To protect public health, DOE placed deed restrictions with ICs (in the form of restrictive easements) on the transferred properties where the underlying groundwater was contaminated or soil was remediated to supplemental standards (DOE 1999a). The easement generally prohibits overnight camping, nighttime use, and construction of a habitable structure; as indicated in Table 1, removal of soil and use of the shallow aquifer for domestic purposes is prohibited on specific parcels. Table 1 identifies the properties transferred from DOE to the City of Monticello and their respective ICs; Figure 1 shows the locations of those properties.

2.2.2 ICs on Public Roads and Utilities

Public roads and utilities, which are properties historically known as city streets and utilities (DOE 1999c) and Highways 191 and 491 rights-of-way (DOE 1999e), are supplemental standards properties that are managed by controlling radioactive material encountered during City or UDOT excavations within Monticello city limits. Under the cooperative agreement with the City of Monticello (DOE 1999g), DOE provided the City with heavy equipment for use in removing and transferring radiologically contaminated material from City and UDOT excavations within Monticello city limits to the TSF. These properties are shown on Figure 1.

ICs affecting these properties include DOE-conducted scans for radioactive material in UDOT highways, city streets, and utility corridor excavations within Monticello city limits. Radiologically contaminated material (>5 pCi/g ^{226}Ra above background) encountered in a city street or utility excavation is removed and transferred to the TSF or is stockpiled temporarily at City-owned property MS-01006 or MP-00181 (see Figure 1 for locations). At the option of UDOT, through a memorandum of understanding between DOE and UDOT (DOE 1999h), radiologically contaminated material may be returned to a UDOT Highway 191 or 491 rights-of-way excavation as fill, transferred directly to the TSF by City workers and equipment, or transferred to either properties MS-01006 or MP-00181 for temporary stockpiling and later transfer to the TSF by the City.

2.2.3 ICs as Zoning Restrictions

Private property MS-00176 (Figure 1) is a supplemental standards property (DOE 1999d) and was assigned a special zoning designation, Overlay Zone OL-1, as an IC through Zoning Ordinances 2002-04 and 2003-02. In accordance with the ordinances, the City of Monticello will not issue a building permit until the excavated foundation of any new permanent, habitable structure on property MS-00176 meets cleanup levels specified in 40 CFR Part 192.12, as determined by the contractor operations lead. Any radiological contamination found in an excavation would be removed to the TSF in accordance with applicable procedures in Appendix E and Appendix G. The property deed for MS-00176 was annotated to identify the supplemental standards used to remediate the property and the location of remaining radiological contamination.

Property MP-00211 is City property adjoining the northern boundary of the former mill site (Figure 1). This property is not a supplemental standards property; however, at one location on the property (MP-00211 Phase I), uranium in soil exceeds the EPA Region III risk-based standard for residential use. The current zoning for the property is recreational and, based on the completion report for this property (DOE 1999f), future land use is assumed to be industrial. Conditions are suitable for either use. The current zoning for the property is recreational. Through Zoning Ordinances 2002-04 and 2003-2, the City assigned a special zoning designation (Overlay Zone OL-1) as an IC for this property in case it should be zoned for residential use in the future. The ordinances require DOE to complete a radiological survey in the footprint of any future habitable structure. If a habitable structure is proposed in the future, DOE will evaluate the suitability of the property for this use (see Appendix E, Section E8.0). Pending the results of this evaluation, a building permit may be issued.

2.2.4 ICs on Private Properties Within the Montezuma Creek Restrictive Easement Area

Eight private properties traversed by Montezuma Creek that were remediated to supplemental standards (DOE 1999b) are affected by ICs (in the form of restrictive easements). The ICs, negotiated by the U.S. Army Corps of Engineers, were applied to the portion of those properties where contaminated soil and sediments were left in place, generally within the 50 to 100 ft wide floodplain of Montezuma Creek. Construction of habitable structures within, and soil removal from, designated easement areas is prohibited. Authorized representatives of DOE, EPA, and UDEQ are granted right of entry to and across the easement areas for purposes of inspection. The private properties, identified in Table 1 and Figure 1, are sometimes referred to as Upper, Middle, and Lower Montezuma Creek, the Montezuma Creek Soil and Sediment Properties, or the Montezuma Creek restrictive easement properties. The affected properties are collectively referred to as the “Montezuma Creek restrictive easement area” for the remainder of this plan.

2.2.5 ICs in the Groundwater Restricted Area

The use of contaminated water within OU III is prohibited through a groundwater management policy (State of Utah 1999) issued and administered by the State Engineer’s Office. The policy states that applications to appropriate water from the shallow alluvial aquifer in the groundwater restricted area (GWRA) (see Figure 1) for domestic purposes will not be approved; construction of a suitable well into the deeper bedrock aquifer may be approved. The restricted area encompasses all property underlain by groundwater contamination, including properties transferred from DOE to the City of Monticello where a water use restriction was applied as a condition of the land transfer (Section 4.1.1). Table 1 identifies properties within the GWRA.

2.2.6 DOE-Owned Property

Although there are no formal ICs placed on the DOE-owned properties, federal ownership of these properties ensures that appropriate restrictions are maintained. Procedures in place require regular inspections and reporting (see Section 4.1).Table 1 identifies DOE-owned properties; Figure 1) shows the locations of those properties.

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