LMS/MNT/S30735

Monticello Mill Tailings Site Operable Unit III

Annual Groundwater Report May 2019–May 2020

December 2021

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

AOA	Area of Attainment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CI	confidence interval
cm	centimeters
COC	contaminant of concern
DOE	U.S. Department of Energy
ft	feet
gpm	gallons per minute
GRO	Groundwater Remedy Optimization
ICs	institutional controls
lb	pounds
LM	Office of Legacy Management
LOESS	locally estimated scatterplot smoothing
mg/kg	milligrams per kilogram
µg/L	micrograms per liter
mm	millimeters
MMTS	Monticello Mill Tailings Site
MNA	monitored natural attenuation
OU	Operable Unit
PRB	permeable reactive barrier
ZVI	zero-valent iron

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Executive Summary

The Monticello Mill Tailings Site (MMTS) Operable Unit (OU) III Annual Groundwater Report documents remedial system performance and alluvial aquifer restoration progress for the period of May 2019 through May 2020. The MMTS is at and near the Monticello, Utah, Disposal and Processing Sites operated by the U.S. Department of Energy Office of Legacy Management. The performance review period is a month longer than previous performance review periods due to a delay in groundwater sampling resulting from travel restrictions associated with the COVID-19 pandemic. The OU III compliance remedy is monitored natural attenuation and active remediation with institutional controls that restrict alluvial aquifer groundwater use in an area roughly corresponding to the footprint of the uranium plume. The active remediation component of the compliance remedy focuses on the Area of Attainment (AOA), a portion of the alluvial aquifer having the highest uranium groundwater concentrations.

Eight extraction wells, collectively referred to as the Groundwater Remedy Optimization (GRO) system, were installed in the AOA, and pumping commenced in 2015. Extracted water is piped to an evaporation pond for volume reduction. Because of a need to match extraction rates with pond evaporation rates, only a few of the extraction wells are operated at the same time. The cumulative pumping rate from the GRO system ranges between approximately 2 and 16 gallons per minute as a function of monthly pond evaporation rates. During this performance period the GRO system removed 1.9 million gallons of groundwater containing 9 pounds (lb) of uranium from the AOA. From May 2018 to April 2019, the GRO system removed approximately 3 million gallons of contaminated groundwater and 12 lb of uranium. Since system startup in 2015, the GRO system has removed 21.5 million gallons of groundwater and 115 lb of uranium from the AOA. For comparison, an estimated 1400 lb of dissolved and solid-phase uranium are calculated to be present in the AOA. AOA uranium groundwater concentrations have been reduced from a maximum of 1400 micrograms per liter (µg/L) at GRO startup (January 2015) to a maximum of 880 µg/L in May 2020. The decline in AOA uranium concentration is primarily attributable to operation of the GRO system.

While AOA uranium concentrations are expected to decline in response to pumping, the decline will be punctuated by periodic increases in uranium concentrations in response to rising water tables or recharge, caused primarily by snowmelt events. Rising water tables or recharge may dissolve solid-phase uranium stored in the vadose zone. Additionally, infiltrating snowmelt dissolves uranium from the margins of the former mill site and a supplemental standard area located outside the OU III plume footprint, and the uranium containing water flows on the top of bedrock and delivers uranium to the margins of the alluvial aquifer. Transport simulations suggest these and other solid-phase sources may continue to provide uranium to groundwater.

Bulk plume metrics including mass, volume, and average concentration were estimated locally for the AOA and for the OU III uranium plume as a whole. Comparison of 2008 and 2020 bulk uranium plume metrics shows continual improvement of OU III alluvial aquifer groundwater quality resulting primarily from natural attenuation. From 2008 to 2020, the OU III uranium plume mass decreased from 52 to 30 lb. Over the same period, the OU III uranium plume volume remained relatively constant between 20 and 22 million gallons, and the OU III uranium plume average concentration declined from 275 to 160 µg/L. Although GRO operation reduced AOA uranium groundwater concentrations, concentration reductions can be reversed as a function of changing meteorological conditions, From 2014 to 2019, AOA uranium plume mass decreased from 9.5 to 4.0 lb. Infiltration and corresponding rises in the water table resulting from two consecutive, higher than normal snow years in 2019 and 2020 resulted in average AOA uranium plume mass increasing from 4.0 to 6.3 lb.

May 2016 through May 2020 Burro Canyon Formation water quality results are all below the OU III groundwater remediation goals, with the exception of arsenic (84 µg/L in October 2016) in monitoring well 93-205. This well is on a 5-year sample frequency and is not scheduled to be sampled again until 2021. The 2016 measured arsenic concentration is consistent with historical concentrations.

All five seep locations within OU III have declining or stable uranium concentration trends.

1.0 Introduction

This report provides the annual analysis (May 2019–May 2020) of water quality restoration for Operable Unit (OU) III at the Monticello Mill Tailings Site (MMTS), which is at and near the Monticello, Utah, Disposal and Processing Sites operated by the U.S. Department of Energy (DOE) Office of Legacy Management (LM). This evaluation period is longer by one month than previous evaluation periods due to spring samples being collected in May rather than April in response to travel restrictions associated with the COVID-19 pandemic. The MMTS is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List site in and near the city of Monticello, San Juan County, Utah (Figure 1). Groundwater and surface water at the MMTS are designated as OU III, with water quality restoration managed by LM.

The focus of the Annual Performance Report is OU III water quality restoration. Recent study findings separate from Annual Report evaluations are reported when relevant. Information related to site history, compliance strategies, hydrogeology, and remedial activities is provided as summaries. Details related to OU III can be found in the documents referenced throughout the report.

In addition, the annual performance assessment focuses on alluvial aquifer uranium groundwater and surface water concentration trends within OU III. Uranium is the most widely distributed OU III groundwater contaminant, is confined to the alluvial aquifer, and is the primary contributor to potential risk to human health. Although other OU III alluvial aquifer contaminants of concern (COCs) were not extensively evaluated, trend graphs and summary tables for those constituents can be found in Appendix A.

Uranium and other COCs are largely absent from bedrock monitoring wells, and water quality results for these wells are not discussed in this report, which focuses on uranium within the alluvial aquifer. Appendix B presents bedrock monitoring well COC trend graphs. Appendix C contains surface water and seep COC (absent uranium, which is discussed in the report) trend graphs.

1.1 Site History

From 1942 through 1960, a uranium and vanadium mill operated at the MMTS. The majority of groundwater contamination occurred during that time, primarily from infiltration of tailings fluids through the bottom of four unlined tailings impoundments (DOE 1998a) (Figure 2). The mill closed in 1960, and the site remained idle until surface remediation began in 1990 in response to the MMTS being placed on the CERCLA National Priority List in 1989. Between 1990 and 1999, mill tailings and tailings-contaminated surface soils were collected from the MMTS (OU I) and peripheral properties (OU II) and encapsulated in an engineered disposal cell located on DOE property (Figure 2). OU III sediment, groundwater, and surface water were characterized concurrently with tailings removal. In 1999 a permeable reactive barrier (PRB) was installed to passively treat uranium and vanadium groundwater contamination (Figure 2) (DOE 1998b). A pump-and-treat program was implemented in 2005, and the system was expanded in 2015 (DOE 2008, DOE 2014). The original OU III compliance remedy (2004) was monitored natural attenuation (MNA) with institutional controls (ICs) prohibiting alluvial aquifer groundwater use within an area roughly corresponding to the footprint of the uranium plume, which is contained wholly within the OU III boundary and includes the Area of Attainment (AOA) (DOE 2004a). In 2009, to improve aquifer restoration progress, the compliance remedy was changed to MNA and active remediation combined with the same ICs (DOE 2009a). Section 1.3 provides additional details about OU III groundwater remedial activities and compliance remedies.

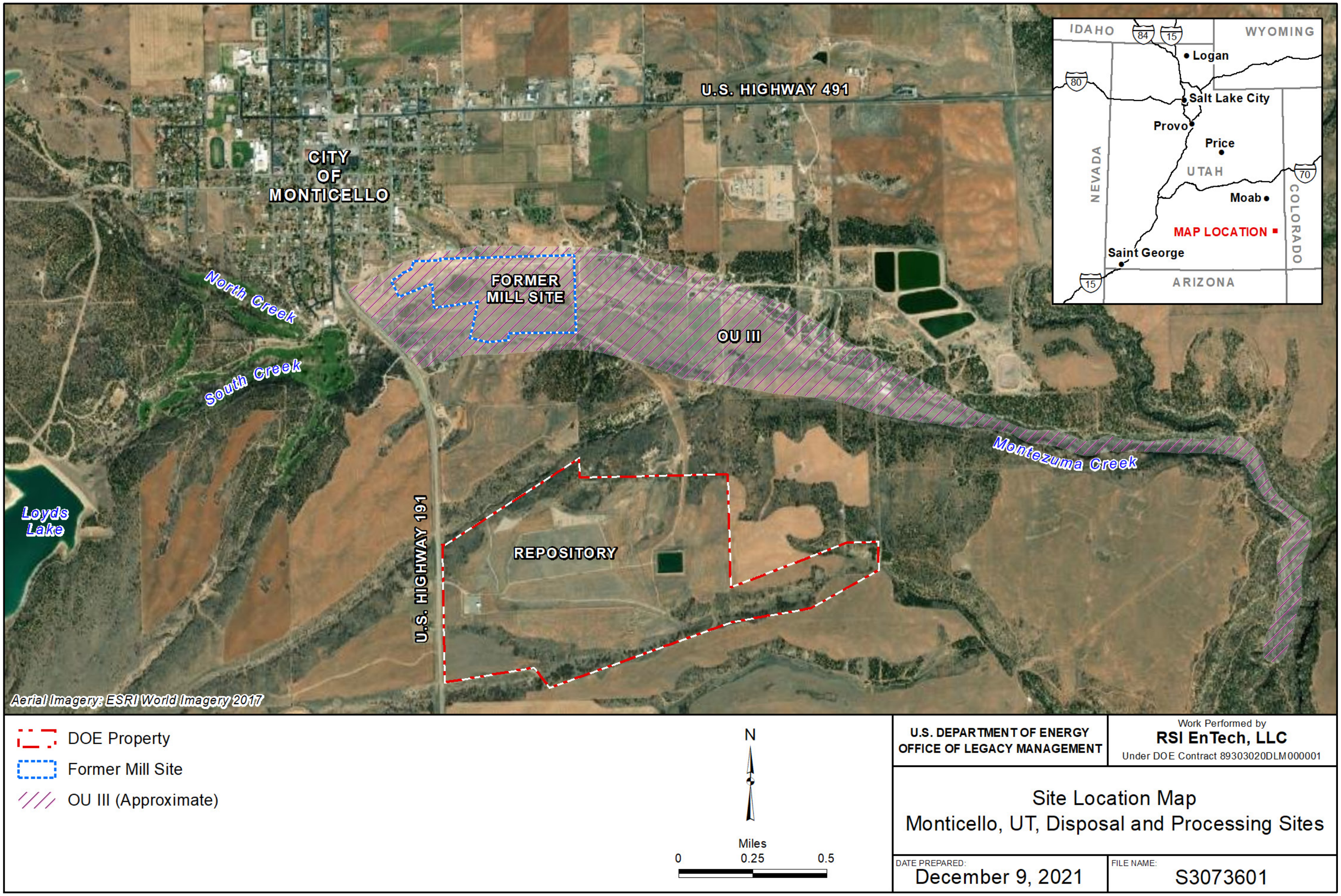

Figure 1. Location of the Monticello Mill Tailings Site

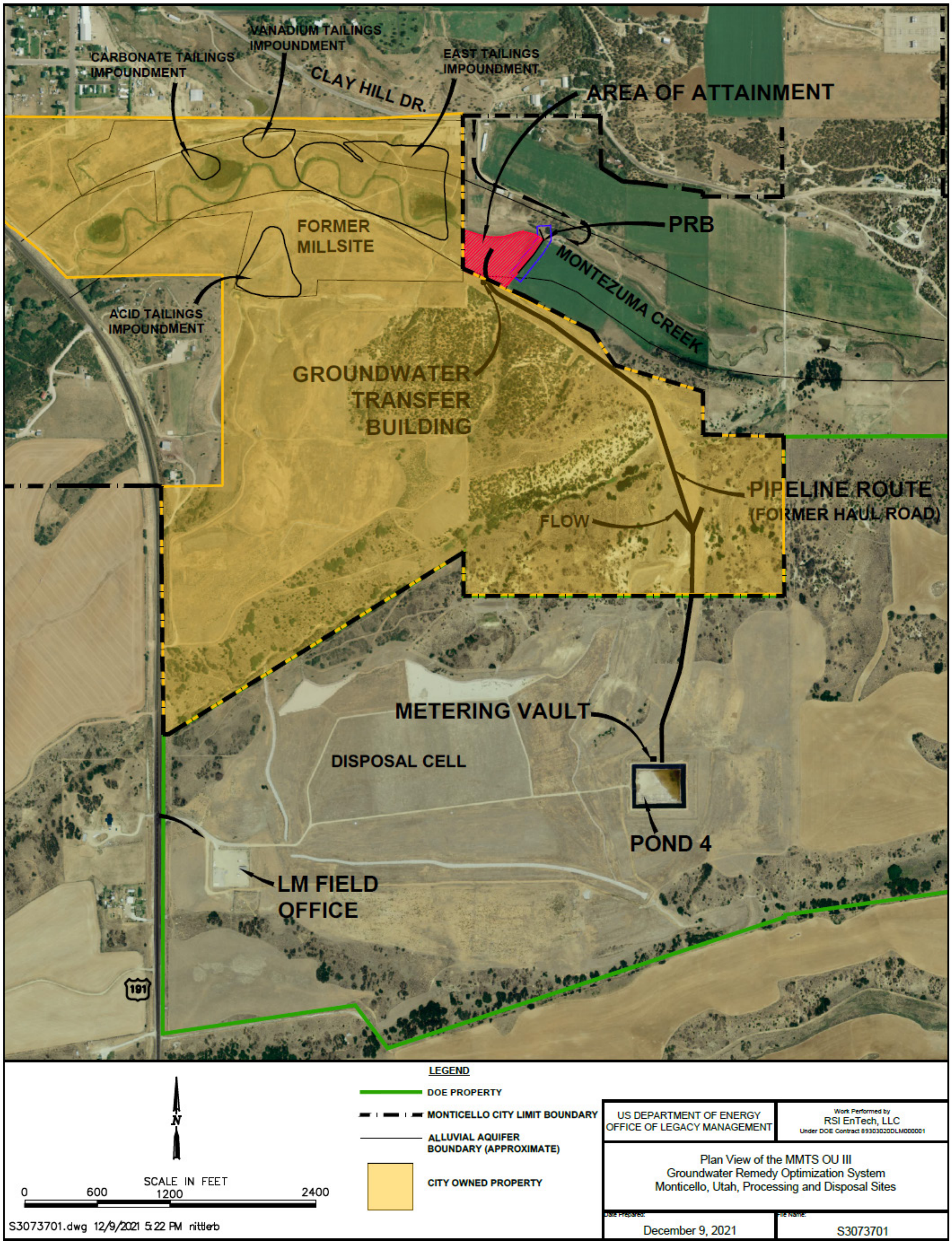

Figure 2. Monticello Mill Tailings Site Historical and Current Features

1.2 Hydrologic Setting

Because groundwater contamination is limited to the alluvial aquifer, the lateral extent of the MMTS hydrologic domain is based on the hydrologic extent of the alluvial aquifer and the distribution of mill-related groundwater contamination (Figure 3). The alluvial aquifer is bounded to the north and south by increasing bedrock elevations, which cause the unconsolidated silts, sands, and gravels composing the aquifer to pinch out. Because mill-related groundwater contamination is absent west of U.S. Highway 191, the western boundary of the MMTS terminates at the highway. To the east, the MMTS hydrologic domain terminates where the Morrison Formation subcrops, downgradient of the area where contaminated alluvial aquifer groundwater discharges to Montezuma Creek upon being displaced by clean Burro Canyon Formation groundwater.

The alluvial aquifer within the MMTS hydrologic domain comprises 10–15 feet (ft) of unconsolidated silts, sands, and gravels. In general, the alluvial aquifer consists of an average of 3–4 ft of sand and/or gravel overlain by silt extending to ground surface (Figure 3). AOA pumping test results indicate that the sand and/or gravel layer is semiconfined when groundwater levels extend above the sand or gravel and silt contact (DOE 2019a). Groundwater moves downward from the overlying silt into the underlying sand or gravel primarily during colder periods following recharge events and upward during the growing season in response to evapotranspiration. Within the sand or gravel, groundwater flow is mostly horizontal from west to east, mimicking declining surface topography.

The alluvial aquifer is underlain by the Mancos Shale, Dakota Sandstone, Burro Canyon, and Morrison Formations (Figure 3). The Mancos Shale is not shown in Figure 3 because it is completely eroded away below the aquifer within the valley except to the west of the former mill site. The Dakota Sandstone forms an 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 Montezuma Creek valley. This exposes the permeable Burro Canyon Formation, a regional water supply aquifer, allowing direct hydraulic communication with the alluvial aquifer. Burro Canyon sandstone is underlain by low-permeability mudstones of the Morrison Formation, which also due to erosion in the creek valley, subcrop approximately 2 miles east of the MMTS.

Due to the low hydraulic conductivity of the Dakota Sandstone, there is minimal hydraulic connection between the Dakota Sandstone and overlying alluvial aquifer. At some locations within the MMTS hydrologic domain, lithologic logs describe the Dakota Sandstone as being dry. An upward hydraulic gradient develops between the Burro Canyon Formation and the alluvial aquifer 500–2000 ft downgradient of the eastern limit of the Dakota Sandstone in the Montezuma Creek valley.

Montezuma Creek extends the entire length of the MMTS hydrologic domain (Figure 3). Flow in Montezuma Creek is highly variable depending on the season and irrigation returns. During summer months it is not unusual for the creek to be dry over extended lengths. Portions of Montezuma Creek that remain wet during summer months are locations where groundwater discharges to the creek. When creek levels rise in response to precipitation events or irrigation returns, the creek recharges the alluvial aquifer in the area of the former mill site (DOE 2004b).

In the spring following big snow years, creek levels rise enough to recharge the alluvial aquifer throughout OU III. Because the high creek levels temporarily prevent groundwater discharge to the creek, alluvial aquifer groundwater elevations rise everywhere within OU III, a condition, because of storage, that remains for months after creek levels decline.

Precipitation recharge occurs across the entire MMTS hydrologic domain (Figure 3). Infiltration of irrigation water on agricultural land east of the former mill site adds additional water to the MMTS hydrologic domain during the growing season. Lateral inflow associated with precipitation runoff from the surrounding higher elevations also contributes water to the MMTS hydrologic domain. Evapotranspiration removes water from the hydrologic domain, primarily during the summer growing season when plant activity is at a maximum. The water removed by evapotranspiration is a combination of groundwater and percolated precipitation and irrigation water that has yet to reach the water table.

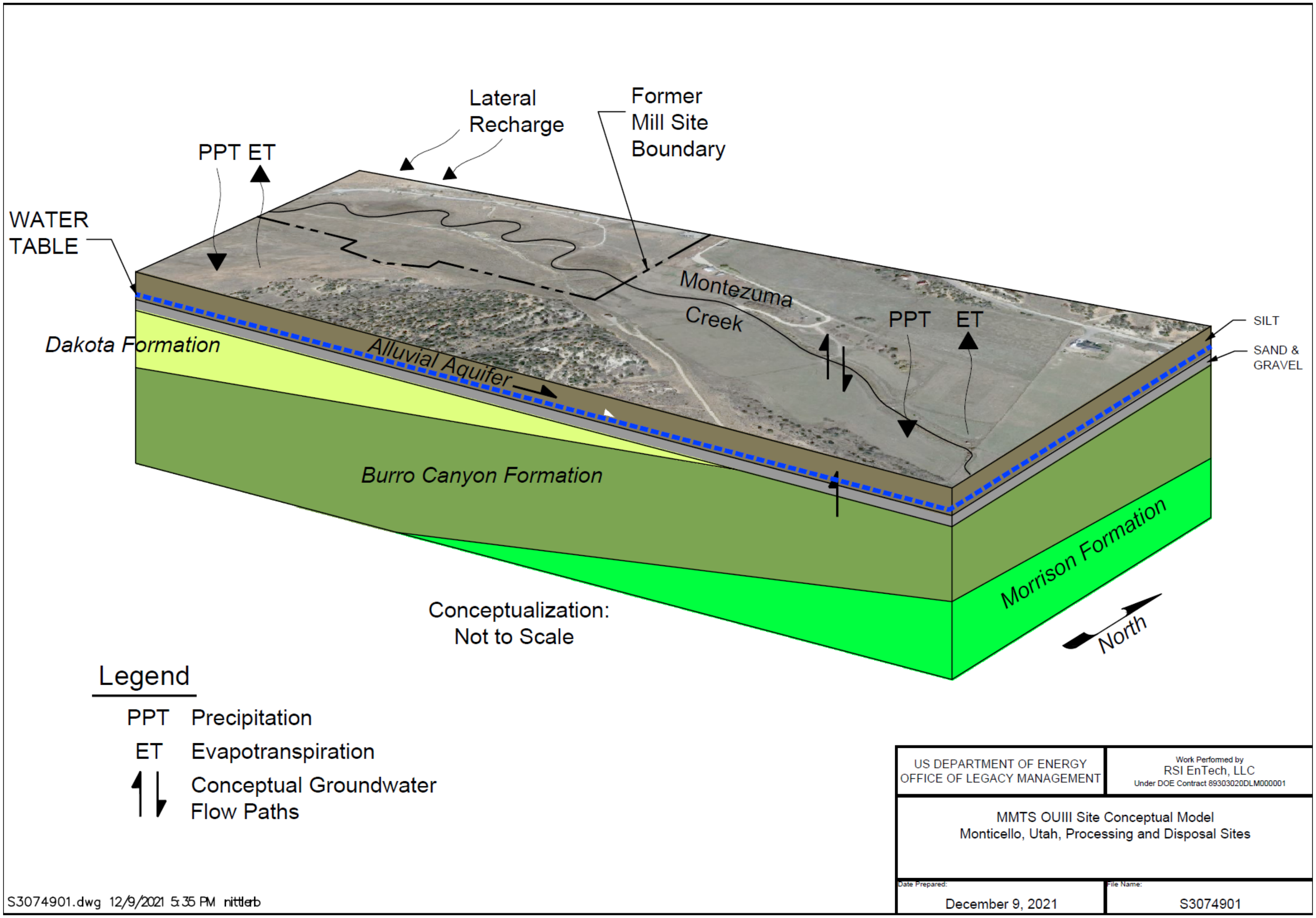

Figure 3. MMTS Hydrogeologic Site Conceptual Model

1.3 Site Remediation, Compliance Strategy, and Water Quality Monitoring

Groundwater and surface water quality characterization performed in the 1990s identified COCs at the MMTS. In 2004, based on evaluations of COC migration and attenuation potentials, groundwater remedial undertakings, risk assessment, groundwater flow and transport modeling, and COC trend evaluations, MNA with ICs prohibiting alluvial aquifer groundwater use within an area roughly corresponding to the uranium plume footprint was selected as the compliance remedy (DOE 2004a). In 2009, the compliance remedy was modified to include active remediation (DOE 2009a). Groundwater and surface water quality sampling is routinely performed to assess COC concentration trends and compliance remedy performance.

1.3.1 Contaminants of Concern and Remedial Goals

Surface water and groundwater sampling conducted during characterization activities identified arsenic, manganese, molybdenum, nitrate, selenium, uranium, vanadium, and gross alpha and gross beta activity as OU III COCs (DOE 2004a). Table 1 lists the remediation goals for these constituents in groundwater and surface water.

Table 1. OU III Contaminants of Concern and Groundwater and Surface Water Remediation Goals

COC[a]	OU III Groundwater Remediation Goals[a]	Surface Water Remediation Goals[a,b]
Arsenic	10 µg/L[c]	10 µg/L
Manganese	880 µg/L[d]	--
Molybdenum	100 µg/L[e]	--
Nitrate (as nitrogen)	10,000 µg/L[c]	4000 µg/L
Selenium	50 µg/L[c]	5 µg/L
Uranium—metal toxicity	30 µg/L[c]	--
Vanadium	330 µg/L[d]	--
Uranium-234 plus Uranium-238—radiological dose	30 pCi/L[e]	30 pCi/L[b]
Gross alpha activity	15 pCi/L[c,f]	15 pCi/L[g]

Notes:

[a] From DOE (2004a).
[b] State of Utah's standard for surface water; Utah's uranium standard postdates the OU III Record of Decision (DOE 2004a).
[c] U.S. Environmental Protection Agency's (EPA) maximum contaminant level in the Safe Drinking Water Act.
[d] Based on OU III human health risk assessment.
[e] EPA's maximum concentration limit established for the Uranium Mill Tailings Remedial Action Project.
[f] Excluding uranium and radon.
[g] Excluding uranium and radon for MMTS OU III.

Abbreviations:

µg/L = micrograms per liter
pCi/L = picocuries per liter

1.3.2 Timeline

Table 2 provides a timeline of MMTS remedial activities and when various compliance remedies were adopted. Note that neither the 1999 PRB installation nor the extraction well installed in 2005 was a requirement of the original MNA with ICs compliance remedy. OU III ICs prohibit alluvial aquifer groundwater use within an area roughly corresponding to the footprint of the uranium plume. The decision to change the compliance remedy from MNA with ICs to MNA and active remediation was based on a 2007 evaluation (DOE 2007) that showed COC concentrations were not declining within OU III at the rate predicted by modeling. To increase uranium mass removal, eight extraction wells were installed and pumped in an area within OU III having the highest alluvial aquifer uranium concentrations (DOE 2014). Additional details related to remediation and compliance remedies can be found in the references listed in Table 2.

Table 2. Summary of Site Remedial Activities and Compliance Remedies

Activity	Date	References
MMTS OU I and OU II remedial actions initiated.	1992	DOE 1990, DOE 2002a
Surface remediation of mill site started.	May 1997	DOE 2000, DOE 2001
Permeable reactive barrier treatability study started for OU III.	Jun 1999	DOE 1998b, DOE 2002b, DOE 2006a, DOE 2006b
Tailings removal completed from OU I and OU II.	Aug 1999	DOE 2002a, DOE 2004b
Mill site restoration completed (OU I).	Aug 2001	DOE 2004b
Record of Decision (ROD) for OU III signed. The ROD documented monitored natural attenuation and continued maintenance of institutional controls as the selected remedy for OU III.	May 2004	DOE 2004a
Ex situ groundwater treatment system installed as a treatability study for OU III.	2005	DOE 2008
Ex situ groundwater treatment system expanded.	2007	DOE 2008
Explanation of Significant Difference issued to implement a pump-and-treat contingency remedy for MMTS OU III.	Jan 2009	DOE 2009a
Groundwater remedy optimization system installed in the Area of Attainment.	2014	DOE 2014, DOE 2016

1.3.3 Area of Attainment Extraction Well Field, Monitoring Well Network, and Pumping Schedule

In 2014, eight extraction wells, collectively referred to as the Groundwater Remedy Optimization (GRO) system, were installed upgradient of the PRB (Figure 4) to improve uranium mass removal rates from groundwater in a portion of the alluvial aquifer having the highest uranium concentrations and the greatest saturated thickness (AOA) (Figure 2). The concept behind the GRO system was that focused pumping in the AOA would increase uranium mass removal rates relative to ambient mass removal rates and lessen the time required to reach the OU III uranium groundwater remediation goal of 30 micrograms per liter (µg/L).

In 2014, 16 monitoring wells (Figure 4) were installed in the AOA to monitor trends in groundwater levels and groundwater quality. Six additional monitoring wells were installed in 2017 north of Montezuma Creek (Figure 4) to assess uranium groundwater concentration and groundwater elevation trends in an area that may or may not be influenced by GRO system operation. During the summer months when Montezuma Creek is dry, it may be possible that groundwater in the area of the six monitoring wells flows under the creek and is captured by the GRO system.

When Montezuma Creek levels are sufficiently high, the creek recharges the alluvial aquifer, preventing groundwater from flowing under the creek to the GRO extraction wells.

Groundwater extracted by the GRO extraction wells is piped to Pond 4 (Figure 2), where the extracted volume is reduced by evaporation. Maintaining the Pond 4 level at a constant elevation requires matching the GRO system monthly cumulative extraction rates to mean monthly pond evaporation rates, which can be zero when the pond is frozen, but generally range between 2 gallons per minute (gpm) during cooler months and 16 gpm during warmer months (Figure 5). In 2017 an evaluation (ranking test) was undertaken to assess individual extraction well uranium mass removal rates at different pumping rates (DOE 2018a). The evaluation found that extraction well uranium effluent concentration was independent of the pumping rate, suggesting that individual extraction wells should be pumped at the highest rate possible. The evaluation also determined that to maximize uranium mass removal, priority should be given to pumping the extraction wells having the highest uranium effluent concentrations. Based on the evaluation results, a monthly pumping schedule was developed that maximizes AOA uranium mass removal while matching monthly pond evaporation rates (Table 3). Because the listed pumping schedule is based on mean monthly pond evaporation rates, and the actual monthly pond evaporation rates will differ from the mean values, the pumping schedule is adjusted each month to match actual pond evaporation rates, based on the concept that extraction wells having the highest effluent uranium concentrations should be preferentially operated over extraction wells having lower effluent concentrations. Thus, when pond levels drop below a prescribed elevation (approximately 50% capacity), GRO pumping is increased, and when pond levels rise above the prescribed pond elevation, GRO pumping is decreased.

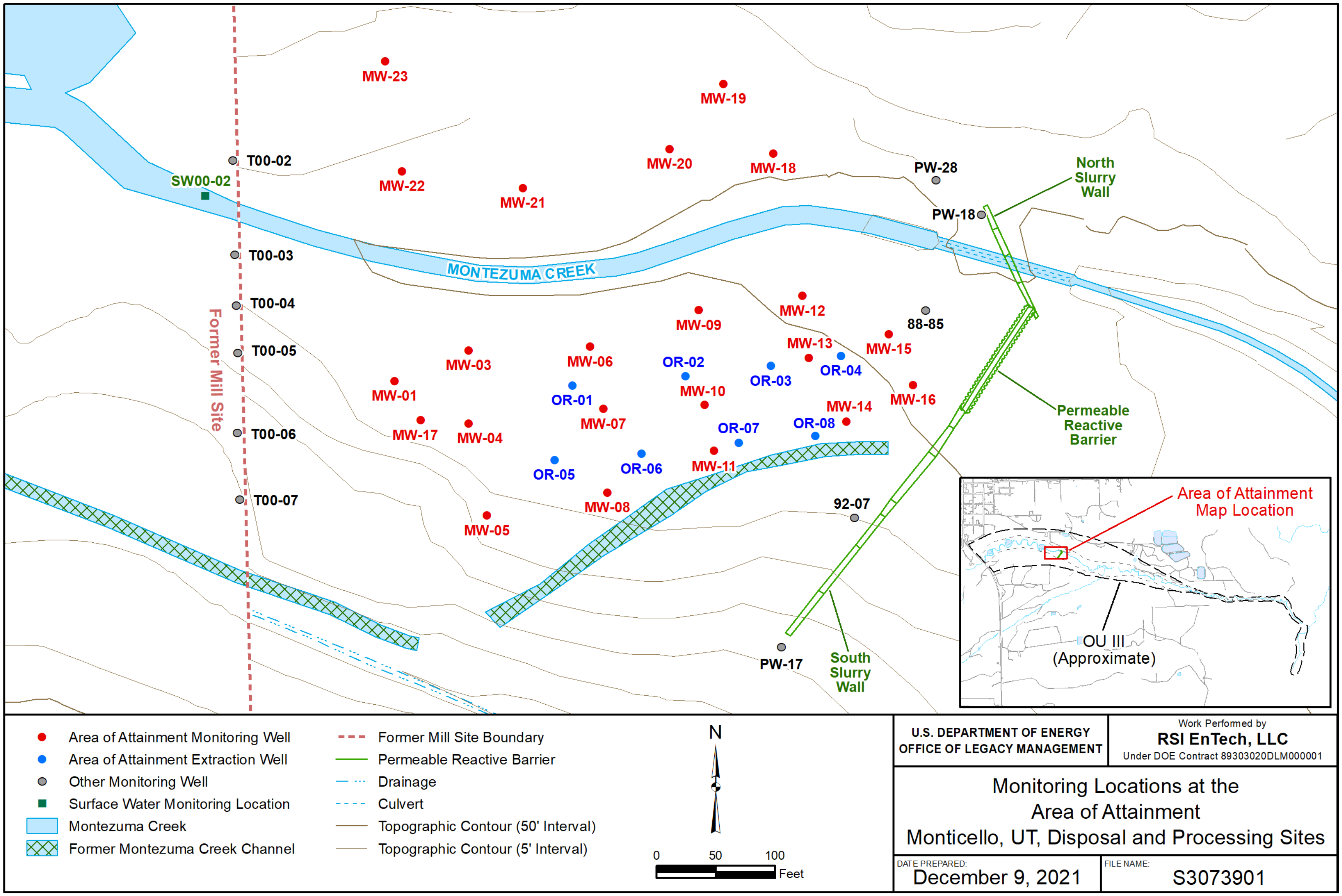

Figure 4. AOA Extraction and Monitoring Well Locations

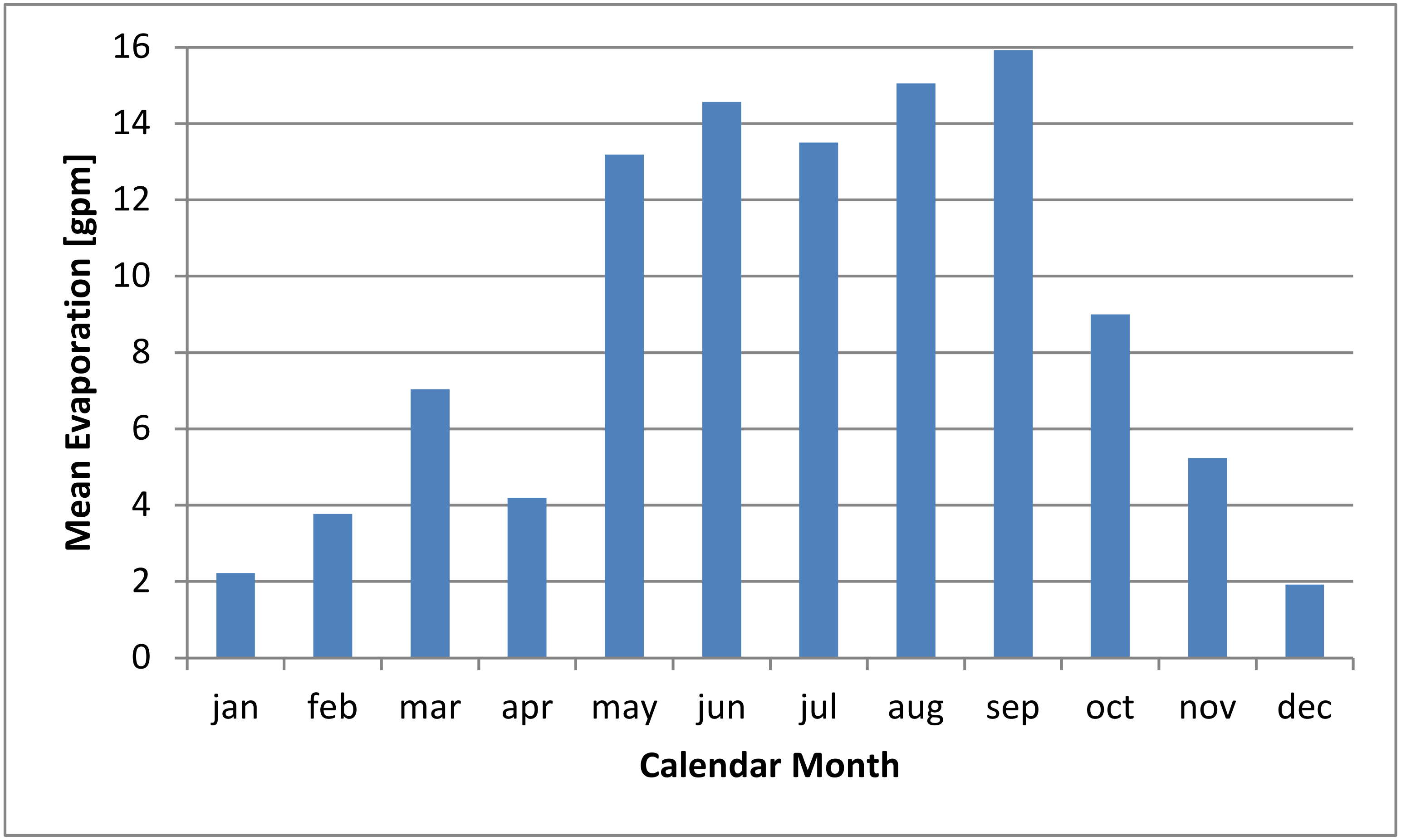

Figure 5. Pond 4 Monthly Average Evaporation Rates

Table 3. Monthly GRO Pumping Schedule

Month	Extraction Well			OR-2		OR-3		OR-5		OR-6		OR-7		OR-8	
	Uranium Concentration, µg/L			675		550		675		675		700		475	
	Average Pond Evaporation Rate, gpm	Total Extraction Rate, gpm	Total Mass Uranium Removed, lb	Extraction Rate, gpm	Mass Uranium Removed, lb	Extraction Rate, gpm	Mass Uranium Removed, lb	Extraction Rate, gpm	Mass Uranium Removed, lb	Extraction Rate, gpm	Mass Uranium Removed, lb	Extraction Rate, gpm	Mass Uranium Removed, lb	Extraction Rate, gpm	Mass Uranium Removed, lb
Jan	2.2	2.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.6	0.0	0.0
Feb	3.8	3.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.9	0.0	0.0
Mar	7.0	7.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.8	4.0	1.0	0.0	0.0
Apr	4.2	4.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	1.1	0.0	0.0
May	13.2	13.2	3.4	2.5	0.6	0.0	0.0	3.0	0.8	3.5	0.9	4.2	1.1	0.0	0.0
Jun	14.6	14.6	3.5	2.5	0.6	1.4	0.3	3.0	0.7	3.5	0.9	4.2	1.1	0.0	0.0
Jul	13.5	13.7	3.5	2.5	0.6	0.5	0.1	3.0	0.8	3.5	0.9	4.2	1.1	0.0	0.0
Aug	15.1	14.1	3.5	1.5	0.4	2.1	0.4	3.0	0.8	3.5	0.9	4.0	1.0	0.0	0.0
Sep	15.9	14.9	3.5	1.5	0.4	2.0	0.4	3.0	0.7	3.5	0.9	4.0	1.0	0.9	0.2
Oct	9.0	9.1	2.3	0.8	0.2	0.0	0.0	0.8	0.2	3.5	0.9	4.0	1.0	0.0	0.0
Nov	5.2	5.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.3	4.0	1.0	0.0	0.0
Dec	1.9	1.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.5	0.0	0.0

Abbreviation:
lb = pounds

1.3.4 Groundwater and Surface Water Monitoring Schedule and Locations

OU III groundwater and surface water samples were collected in October 2019 (fall) and May 2020 (spring), as listed in Table 4. In addition, a number of monitoring wells are sampled once every 5 years (Table 4). Figure 6 shows the OU III monitoring well locations and surface water sampling locations, and Figure 7 shows monitoring locations within and adjacent to the PRB.

Table 4. OU III Monitoring Well Sampling Schedule

Well	Aquifer/Formation Monitored	October 2019 (Fall)	May 2020 (Spring)	Every 5 Years, Last Sampled October 2016
0200	Alluvial	Yes	Yes	No
0202	Alluvial	Yes	Yes	No
82-08	Alluvial	Yes	Yes	No
83-70	Burro Canyon	Yes	No	No
88-85	Alluvial	Yes	Yes	No
92-07	Alluvial	Yes	Yes	No
92-08	Alluvial	Yes	Yes	No
92-09	Alluvial	Yes	Yes	No
92-10	Burro Canyon	Yes	No	No
92-11	Alluvial	Yes	Yes	No
93-01	Burro Canyon	Yes	No	No
95-01	Alluvial	Yes	No	No
95-03	Alluvial	Yes	No	No
MW00-01	Alluvial	Yes	Yes	No
MW00-06	Alluvial	Yes	Yes	No
MW00-07	Alluvial	Yes	No	No
MW-01	Alluvial	Yes	Yes	No
MW-03	Alluvial	Yes	Yes	No
MW-04	Alluvial	Yes	Yes	No
MW-05	Alluvial	Yes	Yes	No
MW-06	Alluvial	Yes	Yes	No
MW-07	Alluvial	Yes	Yes	No
MW-08	Alluvial	Yes	Yes	No
MW-09	Alluvial	Yes	Yes	No
MW-10	Alluvial	Yes	Yes	No
MW-11	Alluvial	Yes	Yes	No
MW-12	Alluvial	Yes	Yes	No
MW-13	Alluvial	Yes	Yes	No
MW-14	Alluvial	Yes	Yes	No
MW-15	Alluvial	Yes	Yes	No
MW-16	Alluvial	Yes	Yes	No
MW-17	Alluvial	Yes	Yes	No
MW-18	Alluvial	Yes	Yes	No
MW-19	Alluvial	Yes	Yes	No
MW-20	Alluvial	Yes	Yes	No
MW-21	Alluvial	Yes	Yes	No

Table 4. OU III Monitoring Well Sampling Schedule (continued)

Well	**Aquifer/Formation Monitored**	**October 2019 (Fall)**	**May 2020 (Spring)**	**Every 5 Years, Last Sampled October 2016**
MW-22	Alluvial	Yes	Yes	No
MW-23	Alluvial	Yes	Yes	No
OR-01	Alluvial	Yes	Yes	No
OR-02	Alluvial	Yes	Yes	No
OR-03	Alluvial	Yes	Yes	No
OR-04	Alluvial	Yes	Yes	No
OR-05	Alluvial	Yes	Yes	No
OR-06	Alluvial	Yes	Yes	No
OR-07	Alluvial	Yes	Yes	No
OR-08	Alluvial	Yes	Yes	No
P92-06	Alluvial	Yes	Yes	No
PW-10	Alluvial	Yes	Yes	No
PW-17	Alluvial	Yes	Yes	No
PW-28	Alluvial	Yes	Yes	No
R10-M1	Alluvial	Yes	Yes	No
R1-M3	Alluvial	Yes	Yes	No
R1-M4	Alluvial	Yes	Yes	No
R3-M2	Alluvial	Yes	Yes	No
R3-M3	Alluvial	Yes	Yes	No
R4-M3	Alluvial	Yes	No	No
R4-M6	Alluvial	Yes	Yes	No
R6-M4	Alluvial	Yes	No	No
R6-M4	Alluvial	Yes	No	No
T00-01	Alluvial	Yes	No	No
T00-04	Alluvial	Yes	No	No
T01-01	Alluvial	No	Yes	No
T01-02	Alluvial	Yes	Yes	No
T01-04	Alluvial	Yes	Yes	No
T01-05	Alluvial	Yes	Yes	No
T01-07	Alluvial	Yes	Yes	No
T01-12	Alluvial	Yes	Yes	No
T01-13	Alluvial	Yes	No	No
T01-18	Alluvial	Yes	No	No
T01-19	Alluvial	Yes	Yes	No
T01-20	Alluvial	Yes	No	No
T01-23	Alluvial	Yes	No	No
T01-25	Alluvial	Yes	No	No
T01-35	Alluvial	Yes	Yes	No
93-205	Burro Canyon	No	No	Yes
95-06	Burro Canyon	No	No	Yes
95-07	Burro Canyon	No	No	Yes

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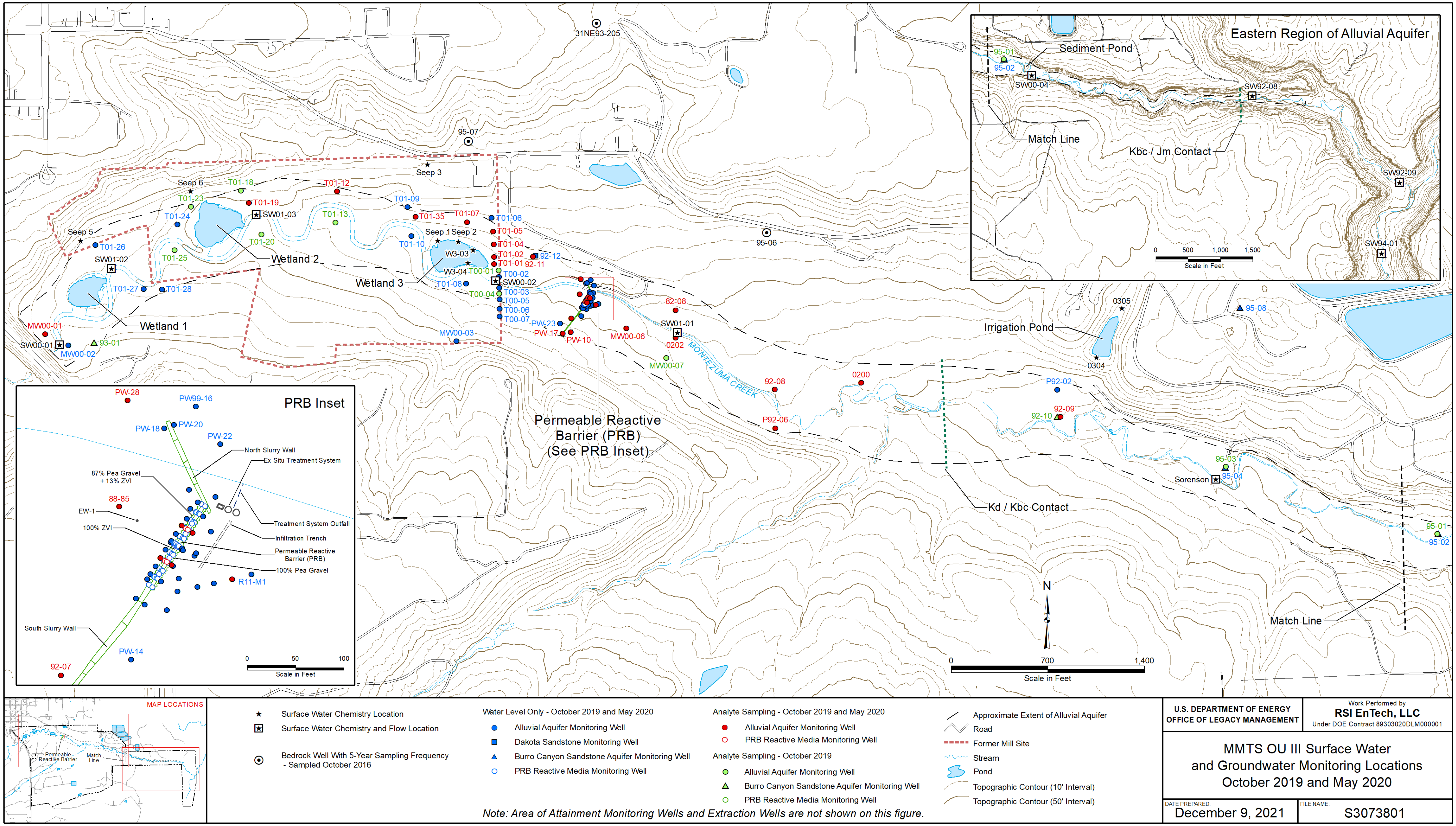

Figure 6. OU III Water Quality Monitoring Locations

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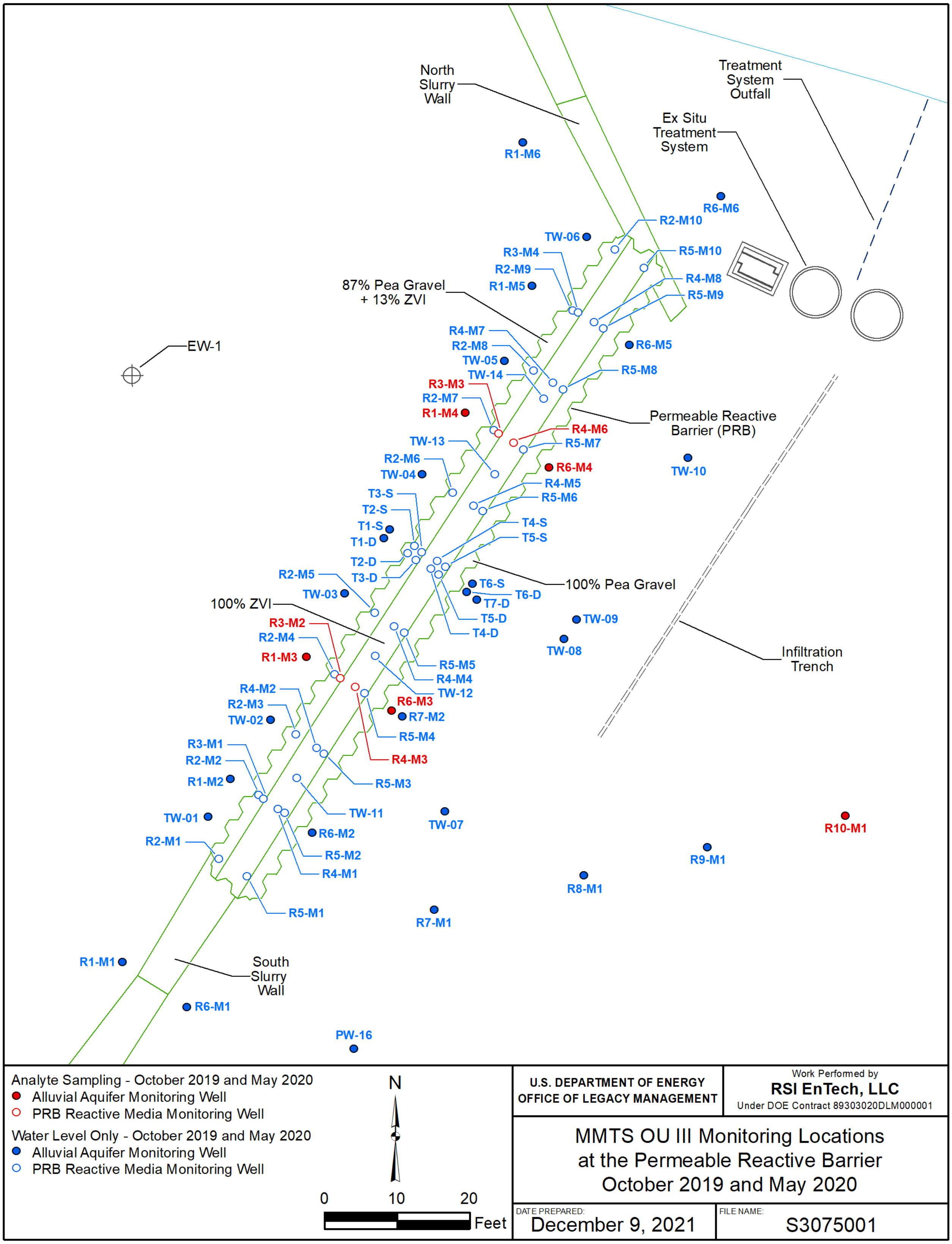


Analyte Sampling - October 2019 and May 2020
- ● Alluvial Aquifer Monitoring Well
- ○ PRB Reactive Media Monitoring Well

Water Level Only - October 2019 and May 2020
- ● Alluvial Aquifer Monitoring Well
- ○ PRB Reactive Media Monitoring Well

U.S. DEPARTMENT OF ENERGY
OFFICE OF LEGACY MANAGEMENT

Work Performed by
RSI EnTech, LLC
Under DOE Contract 89303020DLM000001

MMTS OU III Monitoring Locations
at the Permeable Reactive Barrier
October 2019 and May 2020

DATE PREPARED: December 9, 2021

FILE NAME: S3075001

Figure 7. Location of PRB Monitoring Wells

1.4 Source Area Geometry and Mass

The primary source of uranium and other contaminants to the alluvial aquifer was the four unlined tailings impoundments that were active during milling operations (1942 to 1960) (Figure 2). The tailings impoundments covered approximately 44 acres and were removed between 1990 and 1999 during surface remediation activities. Tailings and contaminated soils associated with the tailings impoundments were removed and encapsulated in the onsite disposal cell.

Soils beneath portions of the MMTS tailings impoundments were removed down to or near bedrock, thus removing a significant mass of solid-phase uranium (usually sorbed to precipitated iron), which is an ongoing source at other sites (DOE 2018b). During milling, tailings fluids were either very acidic (pH ~2) or very basic (pH ~11), depending on the milling process. Because of pH extremes, infiltrating fluids originating from the different tailings impoundments contained high concentrations of dissolved metals. Soils beneath and downgradient of the tailings impoundment buffered the tailings fluids to near neutral pH, potentially causing uranium to sorb to iron precipitating from solution onto the aquifer solids. Clean groundwater or precipitation infiltration flowing through the sorbed uranium can remobilize this uranium and continue to feed the uranium plume.

Because soils beneath portions of the former tailings impoundments were excavated to or near bedrock, uranium source mass associated with the former tailings impoundments was greatly reduced. However, for those portions of the former mill site that were not excavated to bedrock, uranium was left in place at concentrations up to 10–12 milligrams per kilogram (mg/kg) and these soils are continuing sources of uranium to OU III groundwater. On the hillsides of the former mill site, snowmelt dissolves uranium, and the infiltrated water, the volume being a function of snow depth, flows for a brief period in the spring along the bedrock surface to the margins of the alluvial aquifer. This flow path is incomplete for the rest of the year. There are supplemental standards areas south of the former mill site that may also contribute uranium by this mechanism. Section 1.5.1 provides a location map for the uranium source areas previously described and estimates of soluble, solid phase uranium present in each of the areas. Additionally, downgradient vadose zone uranium secondary sources associated with the precipitation and evapotranspiration cycle continue to store and release uranium to OU III groundwater as a function of snowmelt.

1.5 Evaluations Conducted This Performance Period

Two evaluations, a solid-phase geochemical study and transport modeling, were conducted this performance period to better understand solid- and dissolved-phase uranium mass and distribution, the factors controlling uranium mobility in groundwater, and expected durations to achieve uranium groundwater standards for different remedial scenarios. Results of both evaluations are presented in the Groundwater Flow and Contaminant Transport Model Report, which is currently undergoing regulatory review (DOE 2020).

1.5.1 Solid-Phase Geochemical Study

The solid-phase geochemical study, consisting of column studies, geochemical modeling, and mobile and immobile solid-phase uranium mass quantification, was conducted using the cores collected from 32 core holes (Figure 8) in November 2018 (DOE 2019a). The study found that 33,600 pounds (lb) of mill-derived uranium was present in the subsurface and that 24,200 lb is soluble and available to dissolve into OU III groundwater (DOE 2020) (Table 5). For comparison, according to the current dissolved mass assessment (Section 2.5), approximately 30–40 lb of uranium are present in the OU III plume. Within the OU III plume footprint, in the saturated zone, 8200 lb of soluble, solid-phase uranium is present (Table 5 and Figure 8). An additional 14,400 lb of soluble, solid-phase uranium are present in the mill site and downgradient area vadose zone. The supplemental standard areas contain 1500 lb of soluble, solid-phase uranium. All the soluble, solid-phase uranium will ultimately dissolve into groundwater, albeit very slowly.

Column experiments coupled with PHREEQC geochemical modeling identified adsorption (the partitioning of a constituent between solid and dissolved phases) as the dominant mechanism controlling uranium transport. The range of sorption parameters estimated by the geochemical studies was used to define input uranium sorption parameter distributions for transport modeling.

The remediation time frame for MNA was estimated from the geochemical study results using simple mass balance calculations (DOE 2020). A minimum time frame for MNA, based on the solid-phase uranium dissolving at a constant rate, of approximately 300 years was estimated. Based on a more realistic assumption that the solid-phase uranium sources dissolve exponentially rather than at a constant rate, the estimated time frame was 1300–1700 years. The evaluations predicting the 1300–1700-year time frame are currently undergoing regulatory review.

Table 5. MMTS OU III Solid-Phase Uranium Mass

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 (9900–13,600)	6400 (5600–7600)	8200 (7200–9800)
Mill site vadose zone[d]	5.1 (3.4–7.6)	13,500 (8900–20,000)	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.

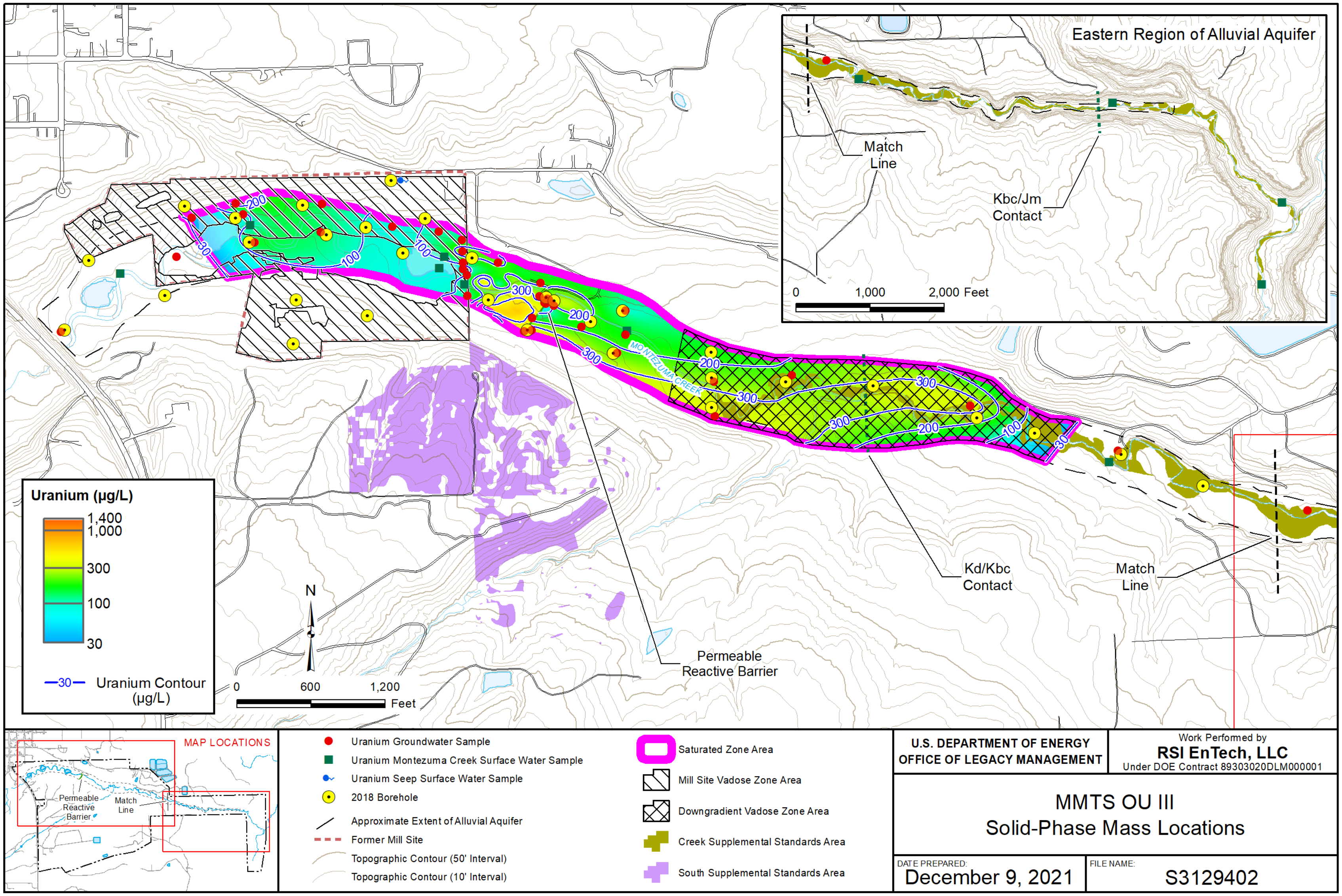


Figure 8. Solid-Phase Uranium Mass Distribution Locations

1.5.2 Transport Modeling

Three remediation scenarios were simulated with the transport model: (1) MNA with immediate termination of the GRO system and removal of the PRB, (2) MNA without pumping with the PRB left in place, and (3) 30 years of additional GRO system operation followed by MNA with the PRB left in place. The predicted durations to achieve groundwater standards within OU III for the three scenarios, which assume exponential decreasing source terms, are nearly the same and have an interquartile range of 1900–2600 years based on a probabilistic modeling analysis (DOE 2020). The similar durations result because most of the soluble, solid-phase uranium is within the vadose zone. Extraction well pumping and the PRB influence saturated zone groundwater flow patterns and as such do not alter vadose zone source dissolution rates.

Transport model simulation results that include the effects of vadose zone and supplemental standard area uranium loading to groundwater predict that after 30 years of continuous GRO extraction well field operation, AOA uranium concentrations will not reduce below the remediation goal. The same simulations show that AOA uranium concentrations will rebound to the same levels as the nonpumping model scenarios following the cessation of pumping.

2.0 Compliance Remedy Performance

The current OU III compliance remedy is MNA and active remediation with ICs. To assess the effectiveness of the OU III compliance remedy, current and historical trends of alluvial aquifer groundwater levels and flow directions, uranium plume geometry and concentrations, and uranium plume mass, volume, and average concentrations are compared to baseline conditions. OU III baseline conditions correspond to 2001 when the mill site reconstruction was completed and the current monitoring well network was first established. Although monitoring wells have been abandoned and installed since 2001, the overall coverage of the monitoring well network has remained relatively consistent, which allows 2001 conditions to be compared to subsequent years. AOA baseline conditions correspond to 2014, the year before the GRO system became operational. To complete the evaluation, current and historical surface water concentration trends are also compared to baseline conditions. In addition to comparison to baseline conditions, GRO system performance was evaluated by examining historical extraction volumes and uranium mass removal rates.

MNA is an in situ remediation technique that relies on natural processes in soil and groundwater to reduce, without active intervention, uranium mass in the subsurface. Because of a long radioactive half-life (245,500 years for uranium-234, 4.5 billion years for uranium-238), the only natural attenuation mechanisms available to reduce OU III subsurface uranium mass are discharge to Montezuma Creek, dispersion along the plume flow path, strong to irreversible adsorption, and mineral precipitation due to changing geochemical conditions. Active remediation at OU III is accomplished by pumping, which in theory improves MNA compliance remedy performance by reducing the distance subsurface uranium travels before exiting the aquifer relative to ambient flow paths. For maximum compliance remedy performance efficiency, the uranium plume needs to migrate at the same rate as OU III groundwater. Subsurface physical and chemical processes that retard uranium plume movement relative to corresponding OU III groundwater movement reduce the efficiency of the compliance remedy. This evaluation examines compliance remedy efficiency and the progress of alluvial aquifer water quality restoration.

2.1 GRO System Pumping Volumes and Uranium Mass Removal

Since 2015, the GRO system has removed 21.6 million gallons of contaminated groundwater and approximately 115 lb of uranium (Figure 9). Current estimates suggest that 1400 lb of uranium are present in the AOA as dissolved and solid-phase mass. From May 2019 to May 2020, the GRO system removed approximately 2 million gallons of contaminated groundwater and 9 lb of uranium. In comparison, from May 2018 to April 2019, the GRO system removed approximately 3 million gallons of contaminated groundwater and 12 lb of uranium. The decrease in the mass of uranium removed relative to that of the previous performance period can be attributed to a reduction in the annual extraction volume, which occurred because of less than favorable pond evaporation rates during the performance period resulting from lower spring and summer temperatures.

2.2 Alluvial Aquifer Groundwater Levels

The 2014 AOA water table is shown in Figure 10. Groundwater levels are higher upgradient than downgradient of the PRB, showing that the permeability of the PRB, installed in 1999, is reduced relative to design specification and has restricted groundwater movement through the treatment zone. The water table also shows that groundwater is migrating around the southern end of the PRB in response to higher groundwater levels caused by declining PRB permeability. In addition, reduced PRB permeability directs groundwater flow around the northern end of the PRB. Downgradient of the PRB the water table shows groundwater flowing to the east.

The 2020 AOA water table, developed from groundwater depth measurements collected from AOA monitoring wells during the May sampling event, is shown in Figure 11. Similar to the case in 2014 and following years, groundwater levels are higher upgradient relative to downgradient of the PRB. As before, the difference in upgradient and downgradient water levels results from reduced PRB permeability. GRO system pumping minimally lowers the water table in the vicinity of the only AOA extraction well (OR-07) operating during the measurement period. Operation of OR-7 results in groundwater capture from an extensive region surrounding the pumping well (Figure 10). Some groundwater still flows around the southern end of the PRB but at a reduced rate relative to 2014, due to pumping. Downgradient of the PRB, the water table shows groundwater flowing to the east.

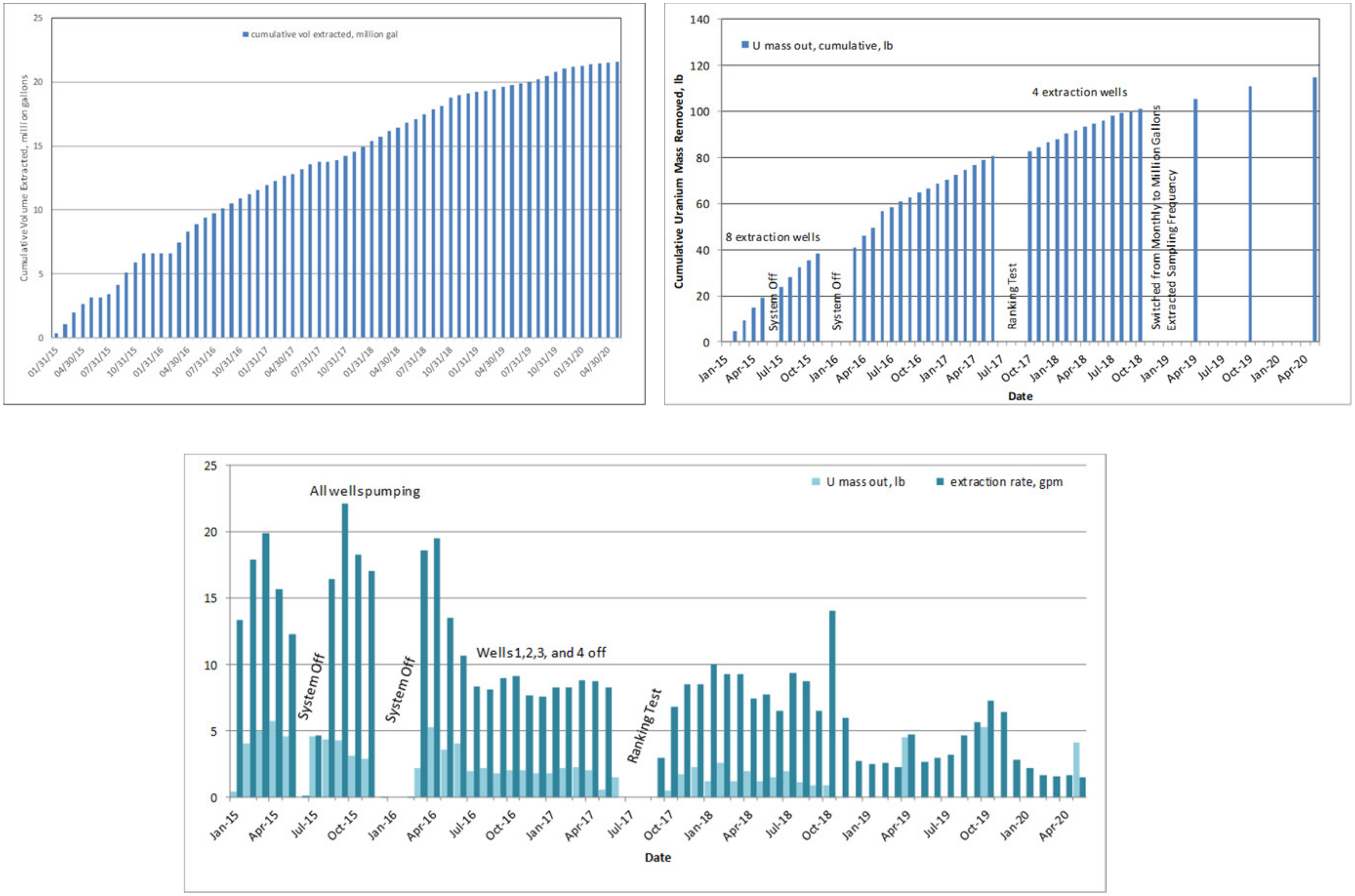


Figure 9. Cumulative Extraction Volumes, Uranium Mass Removed, and Monthly Pumping Performance

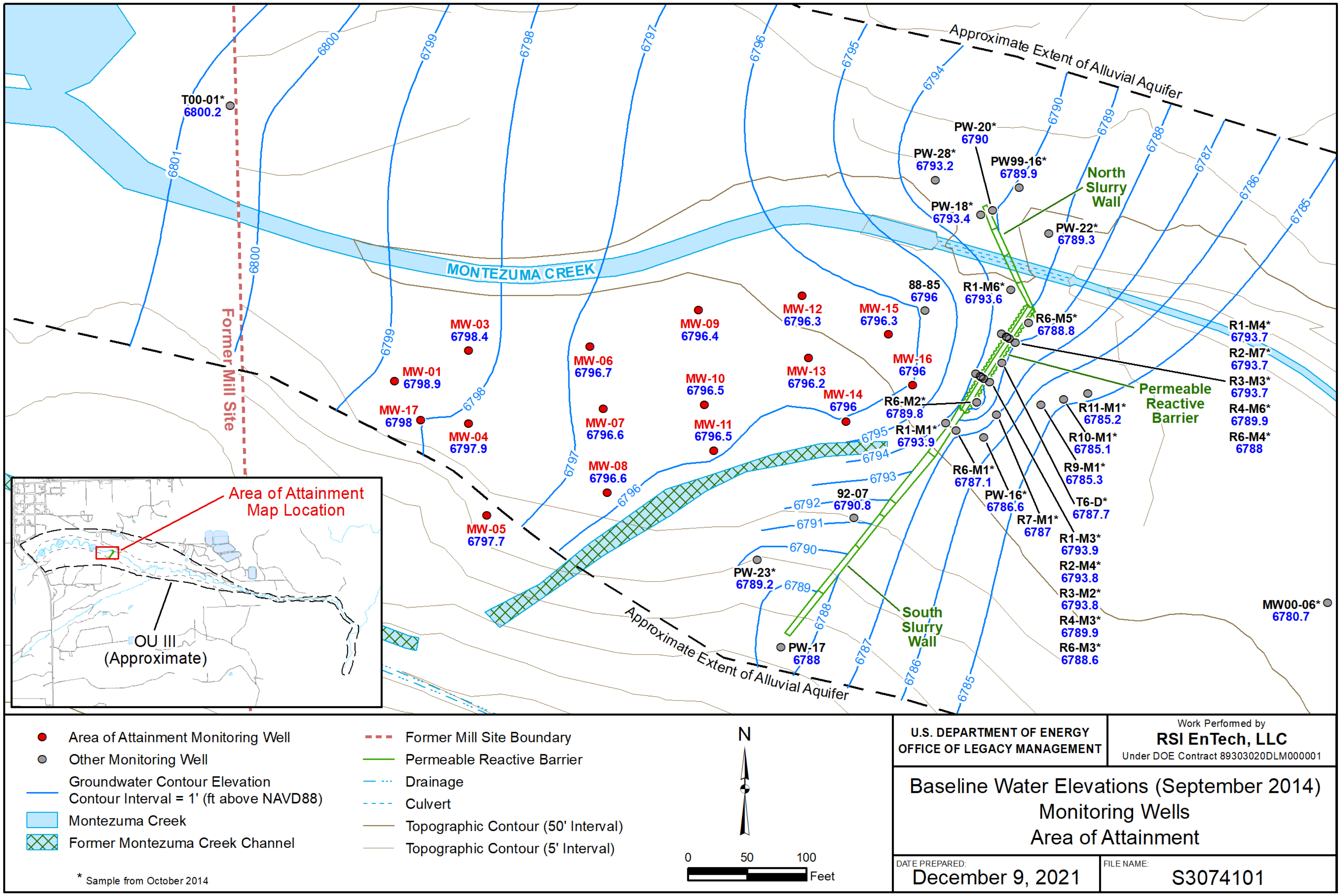


Figure 10. 2014 AOA Water Table

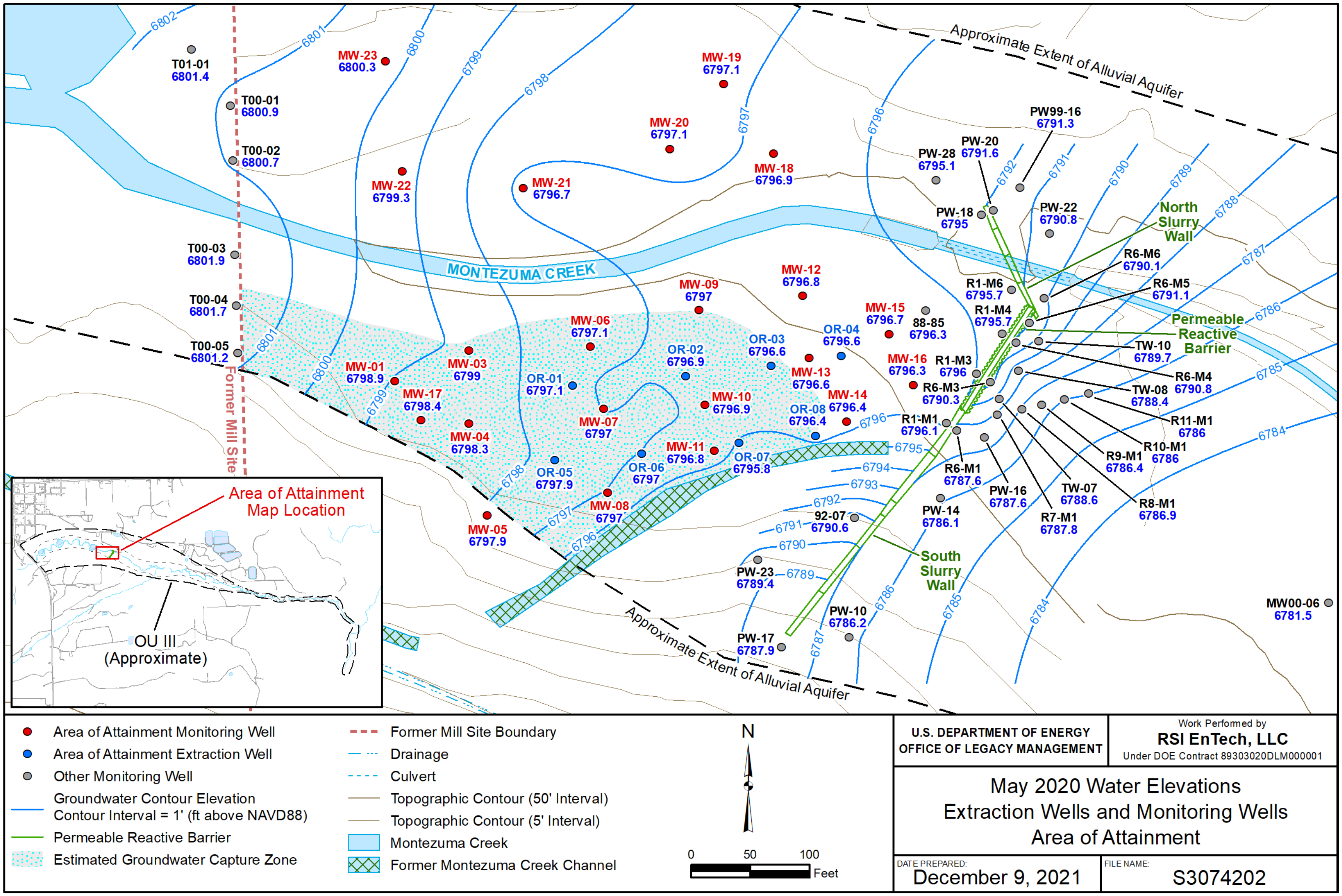


Figure 11. 2020 AOA Water Table

2.3 Alluvial Aquifer Monitoring Well Uranium Concentration Trends

Uranium groundwater concentration trends for the monitoring wells listed in Table 6 are shown in Figure 12 through Figure 16. Mann-Kendall trend analysis was performed to characterize whether uranium concentration trends were upwards, stable (no trend) or declining. For the wells identified as having declining trends, linear regression of the log-transformed concentration data was performed to determine when a well's uranium concentration was expected to decline below the groundwater standard. Both the Mann-Kendall trends and linear regression analysis predictions are representative of conditions spanning the duration of the measurements. While the linear regression predictions change with the addition of new concentration measurements, specifically, concentrations very different than the other data within the evaluation duration, Mann-Kendall trend analysis evaluates the trend for the evaluation duration and the trend designation will not change with the periodic occurrence of a few low or high concentration measurements. Changing the Mann-Kendall trend designation requires the continued occurrence of concentrations different than those previously observed. For example, if Mann-Kendall trend analysis of concentrations collected over 20 years shows a downward trend, approximately 20 years of continuously increasing concentrations are needed to change the upward trend to no or increasing trend.

For the statistical trend analyses, the number of samples used for each well was reduced to a bimonthly sample frequency as necessary to ensure statistical independence. Figure 17 shows the location of the wells, color codes identifying uranium concentration trends, and estimated range in years, for wells having declining trends, until the remediation goal of 30 µg/L is reached. Mann-Kendall trend analysis using a 0.05 significance level identified 13 of the 23 AOA monitoring wells as having decreasing uranium concentration trends (Figure 12 and Figure 13, Table 6). The remaining 10 monitoring wells were identified as having no significant statistical trends. While having trends that could not be identified statistically, the tau values (tau characterizes the relationship between a series of values) for 7 of 10 AOA monitoring wells are all negative, indicating decreasing tendencies. Although the trends may not be statistically identifiable, the fact that the tau values for 20 of 23 AOA monitoring wells are negative suggests that the uranium concentrations are decreasing everywhere within the AOA, likely in response to GRO system pumping.

In the upgradient portion of OU III, Mann-Kendall trend analysis results identified 14 of the 16 monitoring wells as having decreasing uranium concentration trends (Figure 14, Table 6). Monitoring well T01-18, identified as having no significant trend, shows uranium concentrations initially increasing followed by a decreasing trend. The current visually decreasing trend in this well suggests that uranium concentrations are decreasing everywhere in the upgradient portion of OU III. This is expected because clean water originating as upgradient groundwater or infiltrating creek water constantly flows through this area, replacing uranium-contaminated groundwater with "clean" groundwater, which results in decreasing uranium groundwater concentrations. The second monitoring well (MW00-01) identified as having no significant trend is a background monitoring well that has uranium concentrations below the 30 µg/L uranium standard.

The downgradient portion of OU III has variable uranium concentration trends (Figure 15, Table 6). Mann-Kendall trend analysis results for the downgradient portion of OU III identified 9 of 13 monitoring wells as having no significant trend, and 4 of 13 monitoring wells as having downward trends. Two monitoring wells (MW00-06 and MW00-07) previously had increasing concentration trends caused by higher AOA concentrations that migrated around the southern end of the PRB (Section 2.4). Currently, both monitoring wells visually have decreasing trends, although the Mann-Kendall results indicate no trend. Wells 95-01 and 95-03 are downgradient monitoring wells with uranium concentrations below the 30 µg/L uranium standard, and the stable trends at these wells indicate that the plume is not expanding. The four decreasing trends (wells 0200, 0202, 92-08 and PW-10) reflect uranium plume attenuation. The reasons why monitoring wells 82-08, 92-09, P92-06, and R10-M1 have stable trends have not been identified. Well R6-M4 is located immediately downgradient of the PRB and, given the minimal volume of water currently passing through the PRB, that well is expected to have stable concentrations.

Three out of four monitoring wells located within the PRB did not have significant uranium concentration trends (Figure 16, Table 6). Wells R3-M2 and R3-M3 located in the upgradient gravel/zero-valent iron (ZVI) portion of the PRB show stable uranium concentrations. Wells R4-M3 and R4-M6 are within the 100% ZVI portion of the PRB. Well R4-M6 shows an increasing uranium concentration trend, but there is not a significant trend at well R4-M3. Note that measurements taken prior to October 2009 were not used in the trend analysis for wells R4-M3 and R4-M6 because of the high number of results below the detection limit and a change in the analytical detection limit. The concentrations remain below the uranium standard at R4-M3 and R4-M6 (Figure 16).

For the 28 monitoring wells identified as having decreasing trends with concentrations above the remediation goal, linear regression of the log-transformed concentration data was performed to determine the uranium attenuation half-lives and associated upper and lower 95% confidence intervals (CI) (Table 6). Based on the attenuation half-lives and confidence intervals, the year that uranium levels in individual monitoring wells would decrease below the remediation goal of 30 µg/L was calculated (Table 6). The attenuation half-lives are applicable to current site conditions, and changing site conditions, such as removal of the PRB, termination of the GRO system, or variable temporal recharge rates, could change the half-lives. To account for uncertainty, upper and lower 95% confidence level predictions that bracket the year that the uranium remediation goal concentration would be reached were also calculated. Within the AOA, trend evaluation predicts that if current uranium concentration trends continued, the uranium remedial standard would be reached in the 13 monitoring wells having decreasing trends sometime between 2028 (MW-14, lower 95% CI) and 2648 (MW-13, upper 95% CI). In the upgradient portion of OU III, the uranium remedial standard is predicted to be reached in the 14 monitoring wells having decreasing trends sometime between 2015 (T01-23, lower 95% CI) and 2381 (T01-12, upper 95% CI). In the downgradient portion of OU III, the uranium remedial standard is predicted to be reached in the four monitoring wells having decreasing trends sometime between 2053 (0200, lower 95% CI) and 2150 (PW-10, upper 95% CI). The predicted years to reach uranium remedial standards and some of the wells defining the range of dates when cleanup will be achieved are different than those in the May 2018 through April 2019 performance period (DOE 2019b) This is because the duration estimates are based on best-fit lines whose slope changes as additional data points are added to the regression analysis.

The time to reach the uranium remediation goal concentration for the monitoring wells characterized as having no statistical trend is unknown but likely will be longer than that required for the monitoring wells having statistically identifiable downward concentration trends.

Table 6. *AOA and OU III Monitoring Well Uranium Concentration Trends and Year Remediation Goal Is Reached*

Monitoring Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Mann-Kendall		Half-Life (years)			Year Remedial Goal of 30 µg/L Reached		
				Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
AOA											
MW-01	3/31/2015	4/24/2019	10	None	0.00	Not applicable, no trend					
MW-03	3/31/2015	5/18/2020	22	None	0.21	Not applicable, no trend					
MW-04	3/31/2015	5/18/2020	20	Decreasing	−0.35	Decreasing trend according to Mann-Kendall analysis, but no trend by linear regression					
MW-05	3/31/2015	5/19/2020	14	None	−0.28	Not applicable, no trend					
MW-06	4/1/2015	5/18/2020	22	Decreasing	−0.60	4.9	3.6	7.6	2038	2032	2049
MW-07	4/1/2015	5/18/2020	22	None	−0.23	Not applicable, no trend					
MW-08	4/1/2015	5/19/2020	21	Decreasing	−0.40	9.6	5.7	30.9	2061	2043	2158
MW-09	4/1/2015	5/18/2020	21	None	−0.26	Not applicable, no trend					
MW-10	4/1/2015	5/18/2020	22	Decreasing	−0.80	4.9	4.0	6.3	2040	2036	2047
MW-11	4/1/2015	5/18/2020	22	Decreasing	−0.73	7.4	5.6	11.2	2054	2045	2072
MW-12	4/1/2015	5/18/2020	22	None	−0.12	Not applicable, no trend					
MW-13	4/1/2015	5/18/2020	22	Decreasing	−0.39	11.1	5.8	172.0	2058	2038	2648
MW-14	3/31/2015	5/19/2020	22	Decreasing	−0.58	4.2	2.7	9.7	2033	2028	2055
MW-15	3/31/2015	5/19/2020	22	None	−0.02	Not applicable, no trend					
MW-16	3/31/2015	5/19/2020	22	Decreasing	−0.39	Decreasing trend according to Mann-Kendall analysis, but no trend by linear regression					
MW-17	3/31/2015	5/18/2020	19	None	0.28	Not applicable, no trend					
88-85[a]	10/17/2001	5/19/2020	44	Decreasing	−0.73	14.6	12.5	17.5	2055	2048	2064
92-07[a]	10/16/2001	5/19/2020	44	Decreasing	−0.27	13.0	9.5	20.7	2069	2053	2103
92-11[a]	10/15/2001	5/20/2020	43	Decreasing	−0.62	14.5	12.0	18.3	2051	2044	2062
PW-17[a]	10/16/2001	5/19/2020	43	None	−0.15	Not applicable, no trend					
PW-28[a]	10/16/2001	5/18/2020	40	Decreasing	−0.63	26.3	21.1	34.8	2081	2067	2104
R1-M3	10/15/2001	5/20/2020	43	Decreasing	−0.33	13.9	10.3	21.6	2063	2049	2092
R1-M4	10/11/2001	5/20/2020	43	None	−0.18	Not applicable, no trend					

Table 6. AOA and OU III Monitoring Well Uranium Concentration Trends and Year Remediation Goal Is Reached (continued)

Monitoring Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Mann-Kendall		Half-Life (years)			Year Remedial Goal of 30 µg/L Reached		
				Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
PRB Wells											
R3-M2	9/30/2002	5/20/2020	37	None	−0.07	Not applicable, no trend					
R3-M3	9/30/2002	5/20/2020	37	None	0.05	Not applicable, no trend					
R4-M3	10/6/2009	5/20/2020	17	None	0.24	Not applicable, concentration less than remediation goal					
R4-M6	10/6/2009	5/20/2020	22	Increasing	0.43	Not applicable, concentration less than remediation goal					
OU III Upgradient, Former Mill Site											
MW00-01	10/8/2001	5/20/2020	0.0140054	None	−0.11	Not applicable, concentration less than remediation goal					
T00-01	10/9/2001	10/15/2019	−0.787979	Decreasing	−0.63	5.0	3.9	7.0	2021	2018	2026
T00-04	10/15/2001	10/15/2019	−0.818629	Decreasing	−0.76	4.5	3.8	5.7	2025	2022	2029
T01-01[a]	10/9/2001	5/19/2020	−0.640602	Decreasing	−0.62	6.6	5.2	9.2	2022	2020	2027
T01-02[a]	1/30/2002	5/19/2020	−0.473133	Decreasing	−0.71	11.8	9.9	14.5	2040	2035	2047
T01-04[a]	10/10/2001	5/19/2020	0.0199745	Decreasing	−0.54	23.3	16.6	38.8	2067	2051	2105
T01-05[a]	10/9/2001	5/19/2020	0.1653993	Decreasing	−0.69	21.8	18.1	27.5	2060	2051	2073
T01-07[a]	10/9/2001	5/20/2020	0.1084453	Decreasing	−0.69	17.3	14.4	21.8	2050	2044	2061
T01-12[a]	10/9/2001	5/20/2020	0.0513676	Decreasing	−0.31	39.9	23.0	152.4	2107	2065	2381
T01-13	1/31/2002	10/14/2019	−0.443518	Decreasing	−0.79	10.2	8.0	14.1	2037	2031	2048
T01-18	10/10/2001	10/15/2019	0.1004405	None	0.19	Not applicable, no trend					
T01-19[a]	10/10/2001	5/20/2020	−0.413455	Decreasing	−0.50	26.2	18.7	43.4	2049	2038	2075
T01-20	10/11/2001	10/14/2019	−0.467864	Decreasing	−0.32	22.9	12.7	116.1	2083	2050	2380
T01-23	10/8/2001	10/15/2019	−0.221481	Decreasing	−0.49	30.0	20.0	59.8	2018	2015	2027
T01-25	10/11/2001	10/14/2019	0.2312117	Decreasing	−0.62	Not applicable, concentration less than remediation goal					
T01-35[a]	10/23/2001	5/20/2020	0.0201466	Decreasing	−0.57	24.5	19.0	34.4	2055	2045	2074

Table 6. AOA and OU III Monitoring Well Uranium Concentration Trends and Year Remediation Goal Is Reached (continued)

Monitoring Well	Initial Trend Analysis Date	Final Trend Analysis Date	Number of Samples	Mann-Kendall		Half-Life (years)			Year Remedial Goal of 30 µg/L Reached		
				Concentration Trend	Tau Value	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Trend Line	Lower 95% Confidence Interval	Upper 95% Confidence Interval
OU III Downgradient of PRB											
0200	10/5/2004	5/20/2020	32	Decreasing	−0.46	19.3	13.0	37.5	2072	2053	2129
0202	10/5/2004	5/21/2020	32	Decreasing	−0.48	23.1	16.0	41.5	2075	2056	2125
82-08[a]	10/17/2001	5/21/2020	40	None	0.21	Not applicable, no trend					
92-08[a]	10/16/2001	5/21/2020	39	Decreasing	−0.49	20.2	14.7	31.9	2075	2058	2112
92-09[a]	10/16/2001	5/21/2020	38	None	0.04	Not applicable, no trend					
95-01	10/17/2001	10/16/2019	18	None	−0.09	Not applicable, concentration less than remediation goal					
95-03	10/11/2001	10/16/2019	19	None	0.19	Not applicable, concentration less than remediation goal					
MW00-06[a]	10/16/2001	5/21/2020	41	None	0.21	Not applicable, no trend					
MW00-07[a]	10/16/2001	10/16/2019	19	None	0.33	Not applicable, no trend					
P92-06[a]	10/16/2001	5/21/2020	40	None	0.04	Not applicable, no trend					
PW-10	10/16/2001	5/19/2020	32	Decreasing	−0.29	15.5	10.4	30.4	2082	2059	2150
R10-M1[a]	10/11/2001	5/20/2020	43	None	0.10	Not applicable, no trend					
R6-M4	10/11/2001	5/20/2020	40	None	0.18	Not applicable, no trend					

Note:

[a] Monitoring well identified for trend analysis in Appendix B of the 2004 Record of Decision.

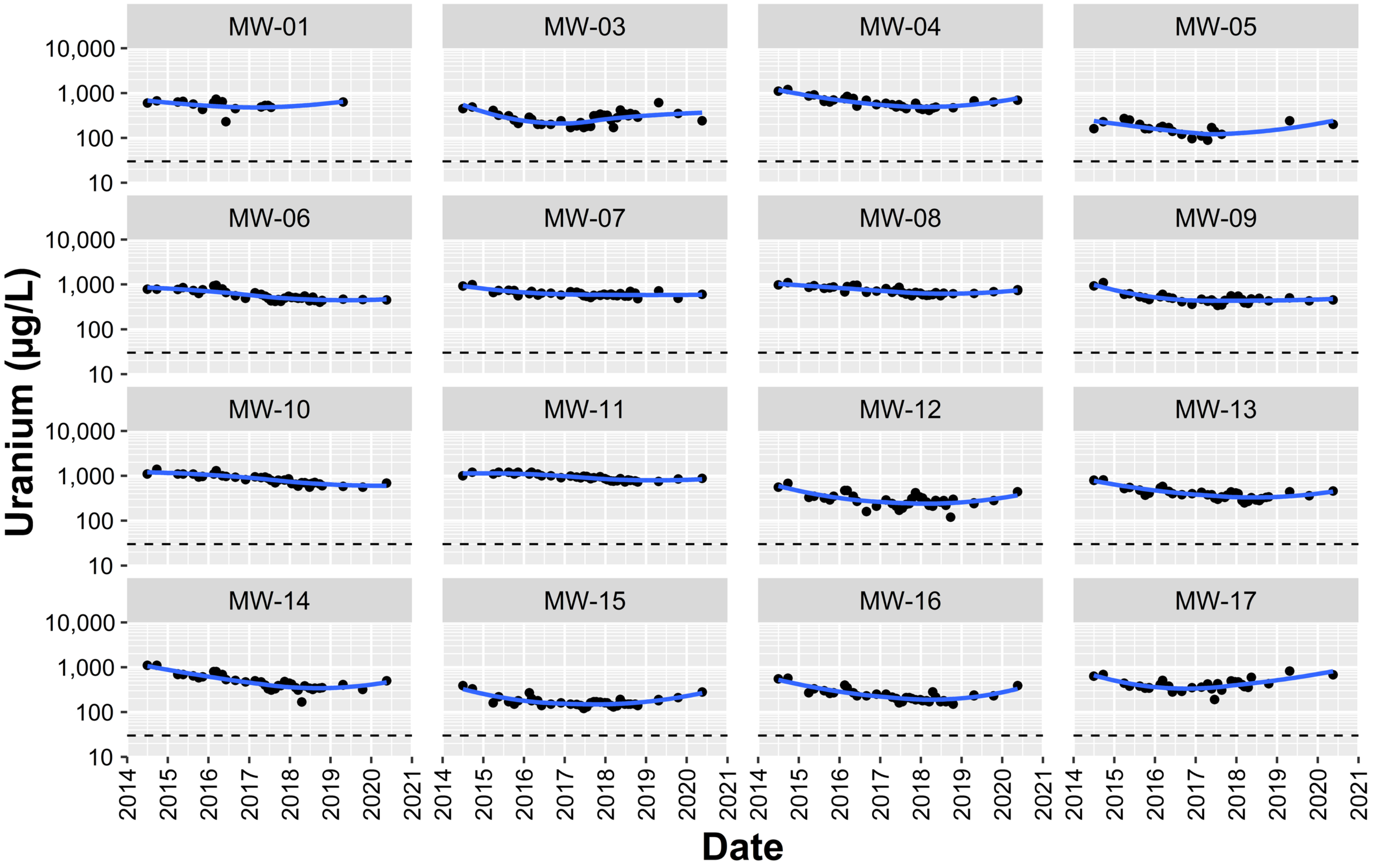
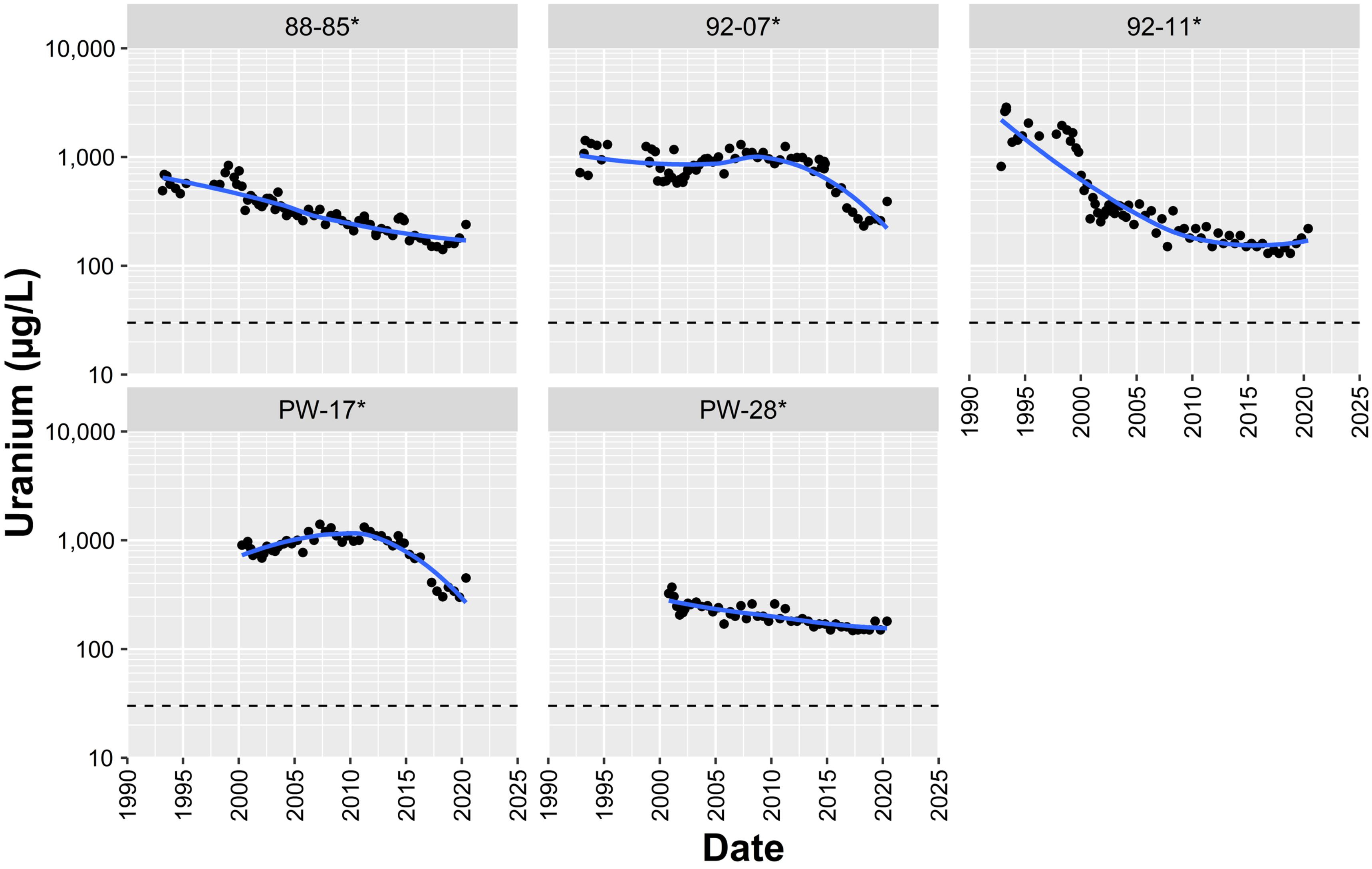
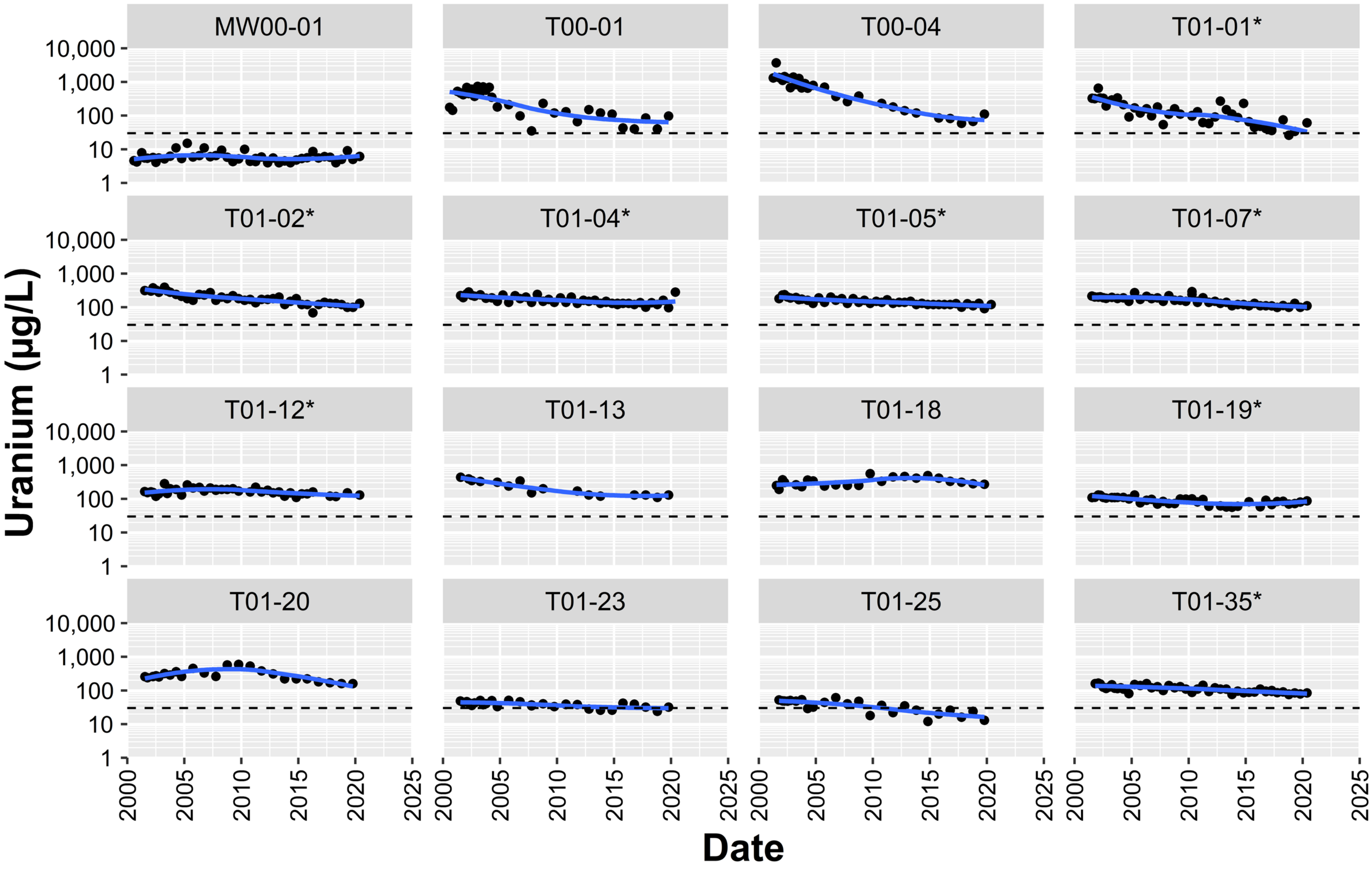


Figure 12. AOA Monitoring Well (Installed 2014) Uranium Concentration Trends



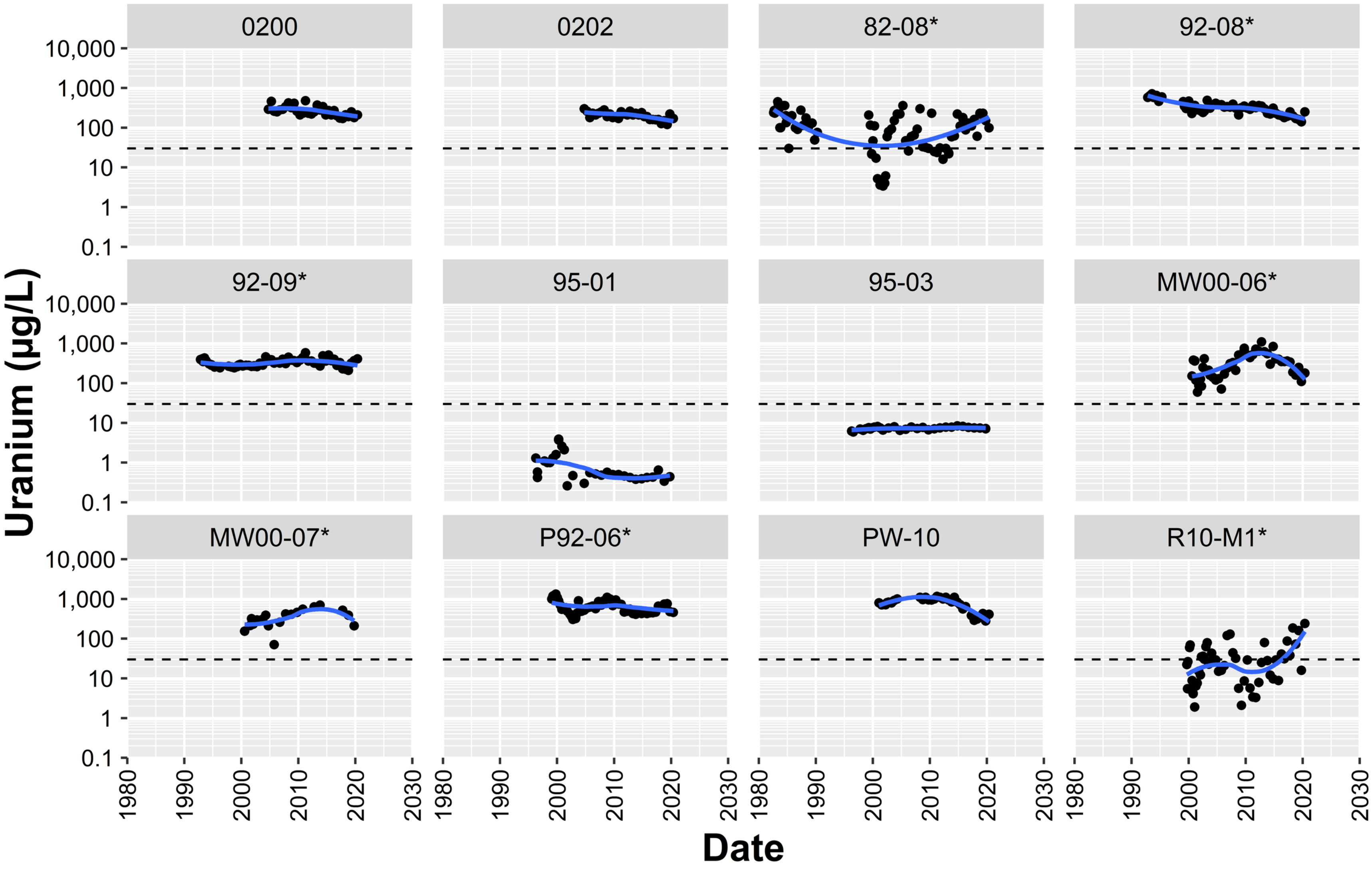
Note: * Monitoring well identified for trend analysis in Appendix B of the 2004 Record of Decision.

Figure 13. AOA Other Monitoring Well Uranium Concentration Trends



Note: * Monitoring well identified for trend analysis in Appendix B of the 2004 Record of Decision.

Figure 14. OU III Upgradient Monitoring Well Uranium Concentration Trends



Note: * Monitoring well identified for trend analysis in Appendix B of the 2004 Record of Decision.

Figure 15. OU III Downgradient Monitoring Well Uranium Concentration Trends

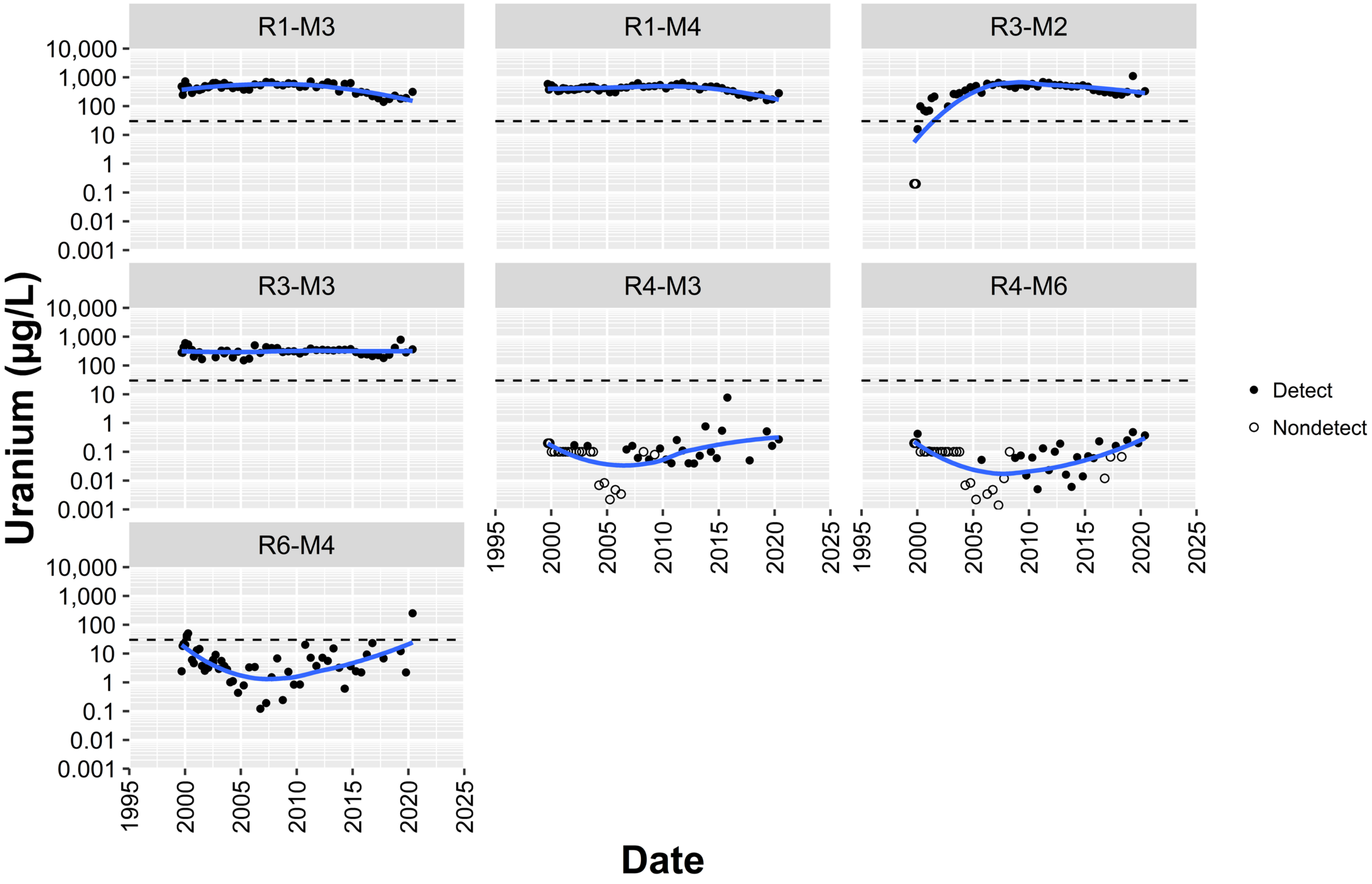


Figure 16. PRB Monitoring Well Uranium Concentration Trends

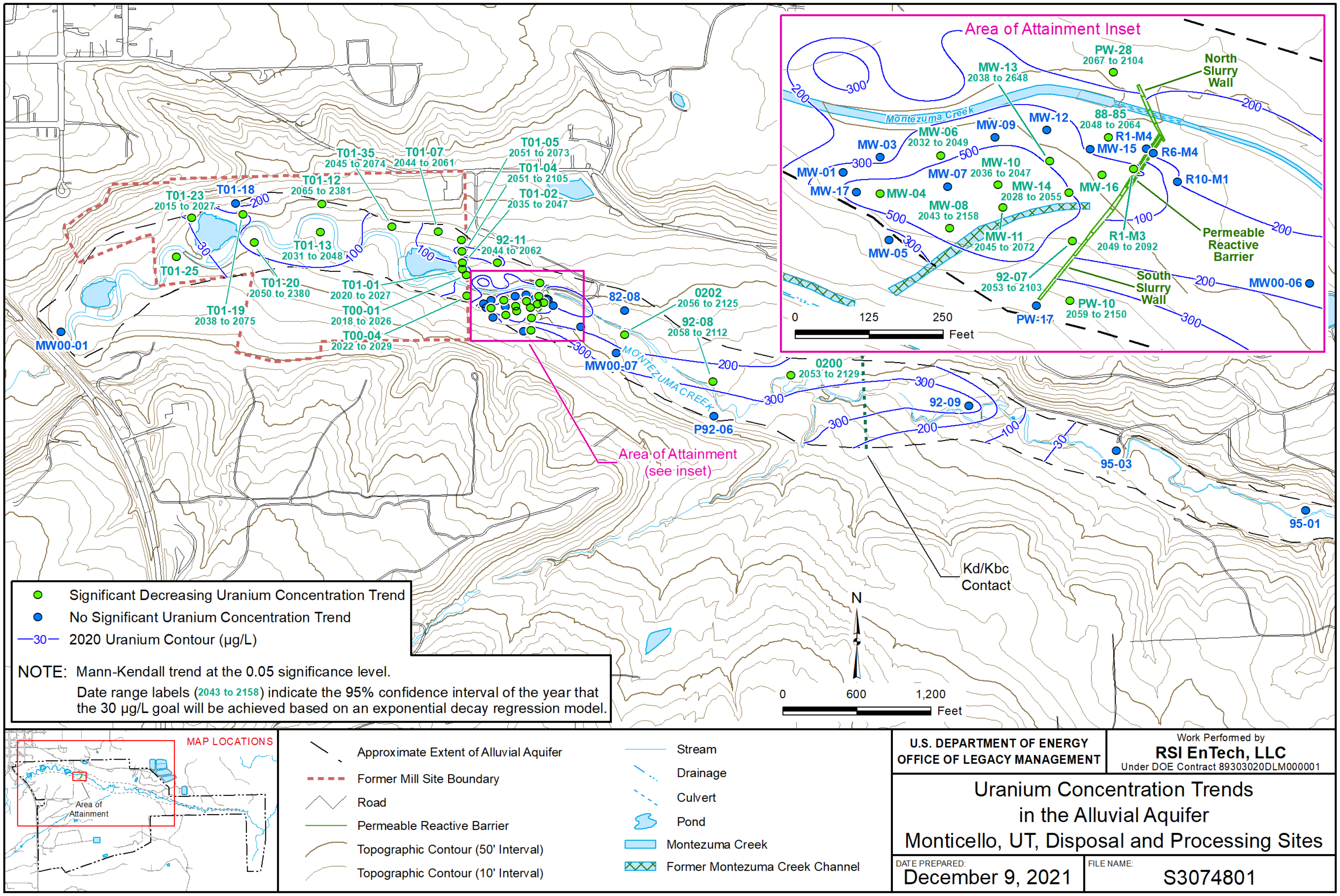


Figure 17. Uranium Concentration Trends in the Alluvial Aquifer and Estimated Time Frame the Uranium Remediation Goal Will Be Reached in the Alluvial Aquifer

2.4 Alluvial Aquifer Uranium Plume Geometry and Concentrations

In 2001, the highest alluvial aquifer uranium plume concentrations (1340 µg/L) were upgradient of the PRB in the AOA (Figure 18). Uranium groundwater concentrations approaching 500 µg/L were present downgradient of the PRB along the southern margins of the alluvial aquifer. In the western portion of the former mill site, uranium groundwater concentrations were 239 µg/L or less.

Nineteen years later, in 2020, uranium concentrations greater than 300 µg/L are still found upgradient of the PRB in the AOA (Figure 19). Uranium concentrations in downgradient monitoring wells MW00-06 and MW00-07 increased from 2001 to 2012 but since that time are generally trending downward. In general, in the western portion of the former mill site, uranium groundwater concentrations are lower than 2001 concentrations. An exception is monitoring well T01-18, where uranium concentrations increased from 191 to 270 µg/L between 2001 and 2019.

The installation of 15 new monitoring wells within the AOA well field in 2014 allowed for more detailed characterization of the spatial distribution of uranium contamination in groundwater relative to that of 2001. Data from the new monitoring wells showed that in 2014 a significant portion of the AOA had uranium groundwater concentrations above 500 µg/L, with a high concentration of 1400 µg/L (Figure 20). Six years later, in 2020, the area containing 500 µg/L uranium concentrations has contracted significantly relative to that of 2014, and the maximum concentration declined to 880 µg/L (Figure 21). The reduction in AOA uranium groundwater concentrations is a function of GRO operation. In both 2014 and 2020, an area of <30 µg/L is present downgradient of the PRB, suggesting that some groundwater is passing through the PRB and uranium is being sequestered despite the reduction in PRB permeability.

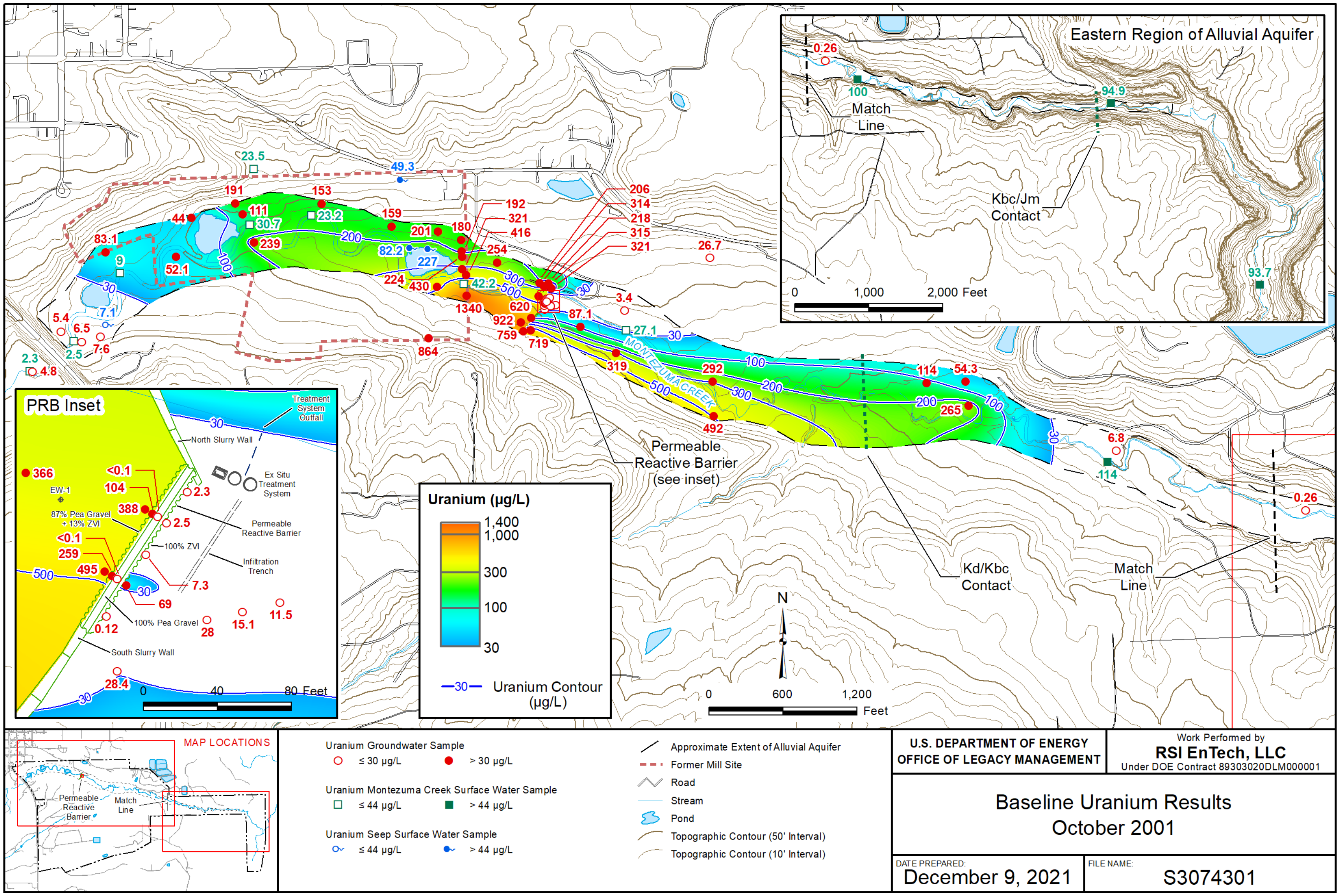


Figure 18. 2001 OU III Uranium Plume

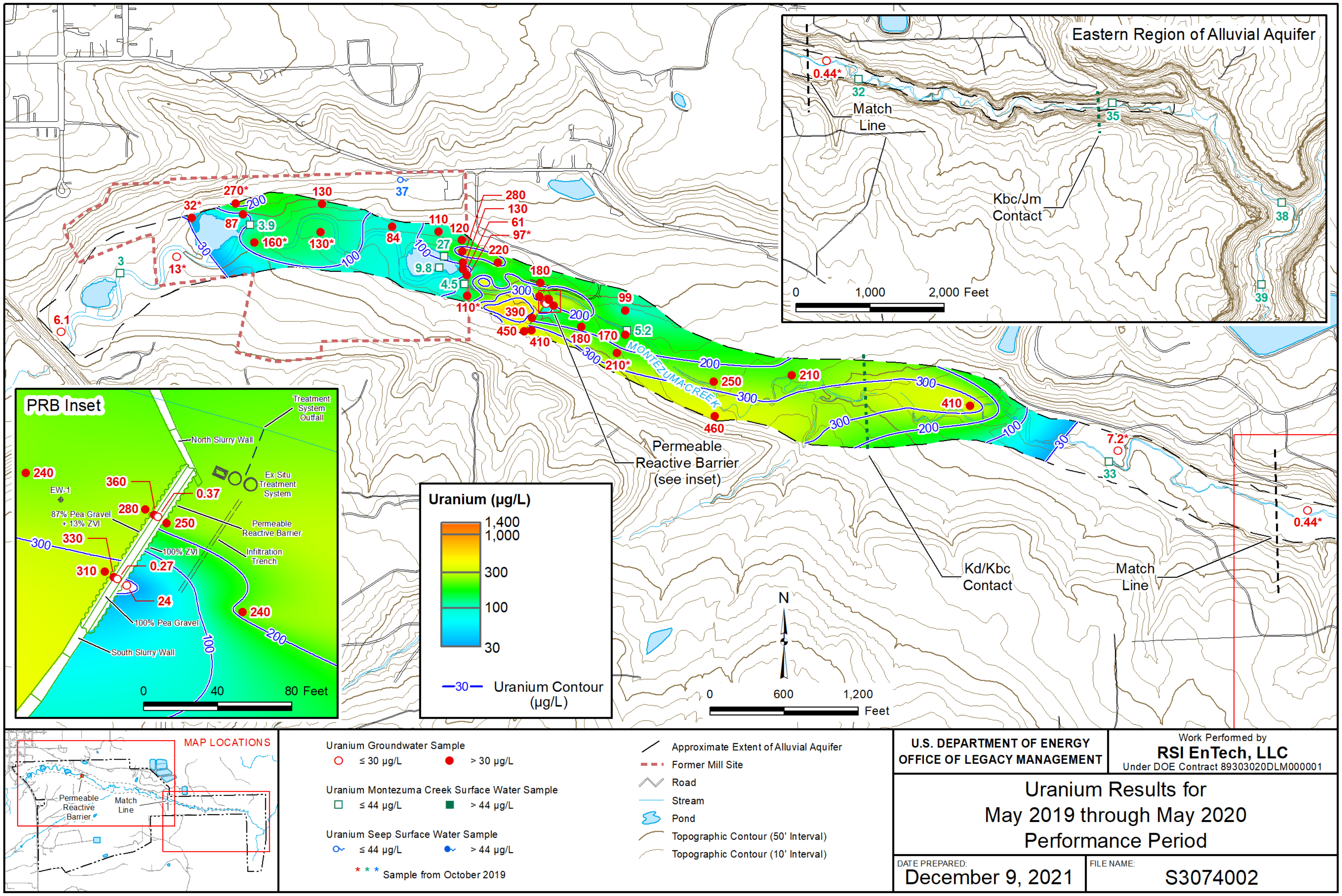


Figure 19. 2020 OU III Uranium Plume

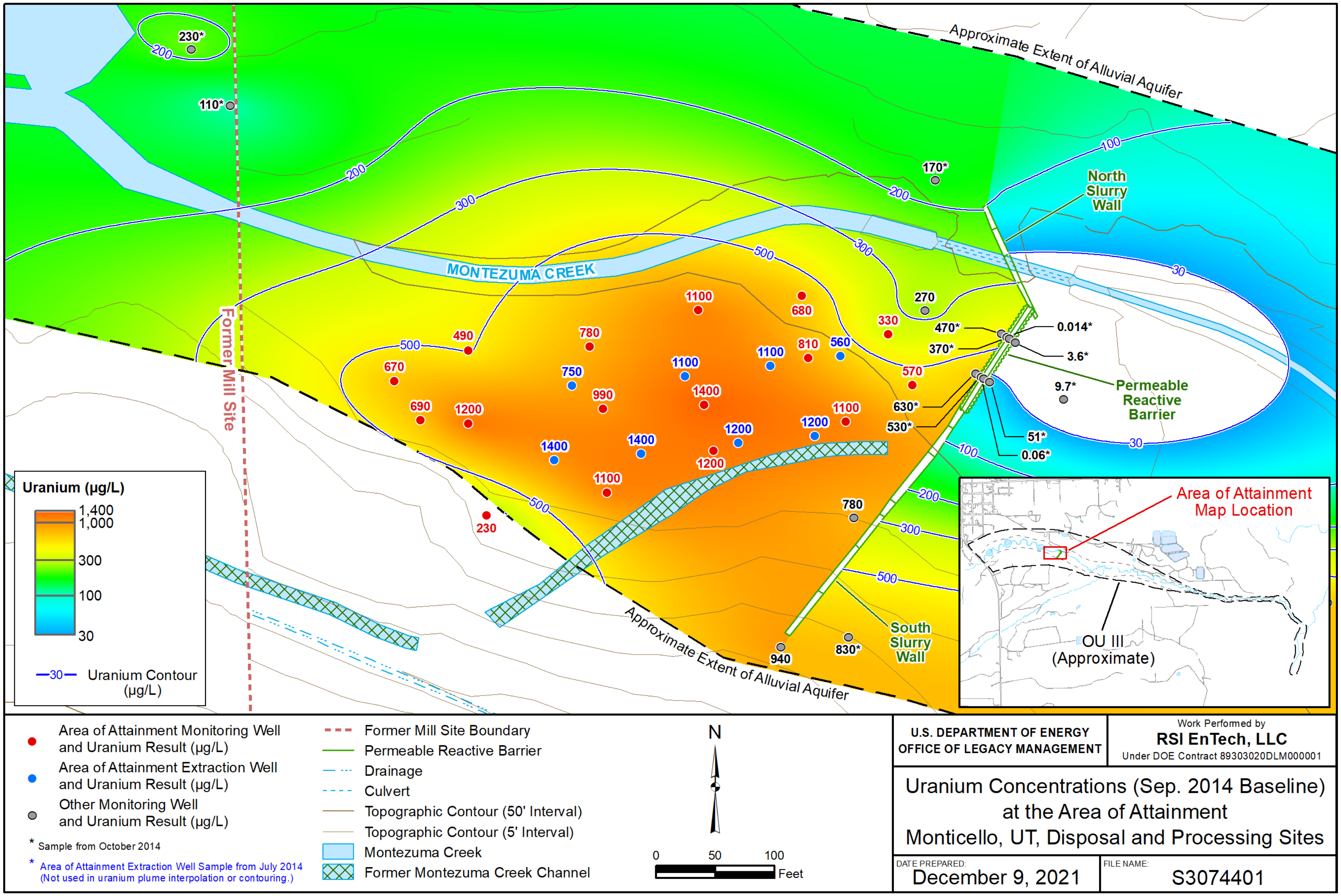
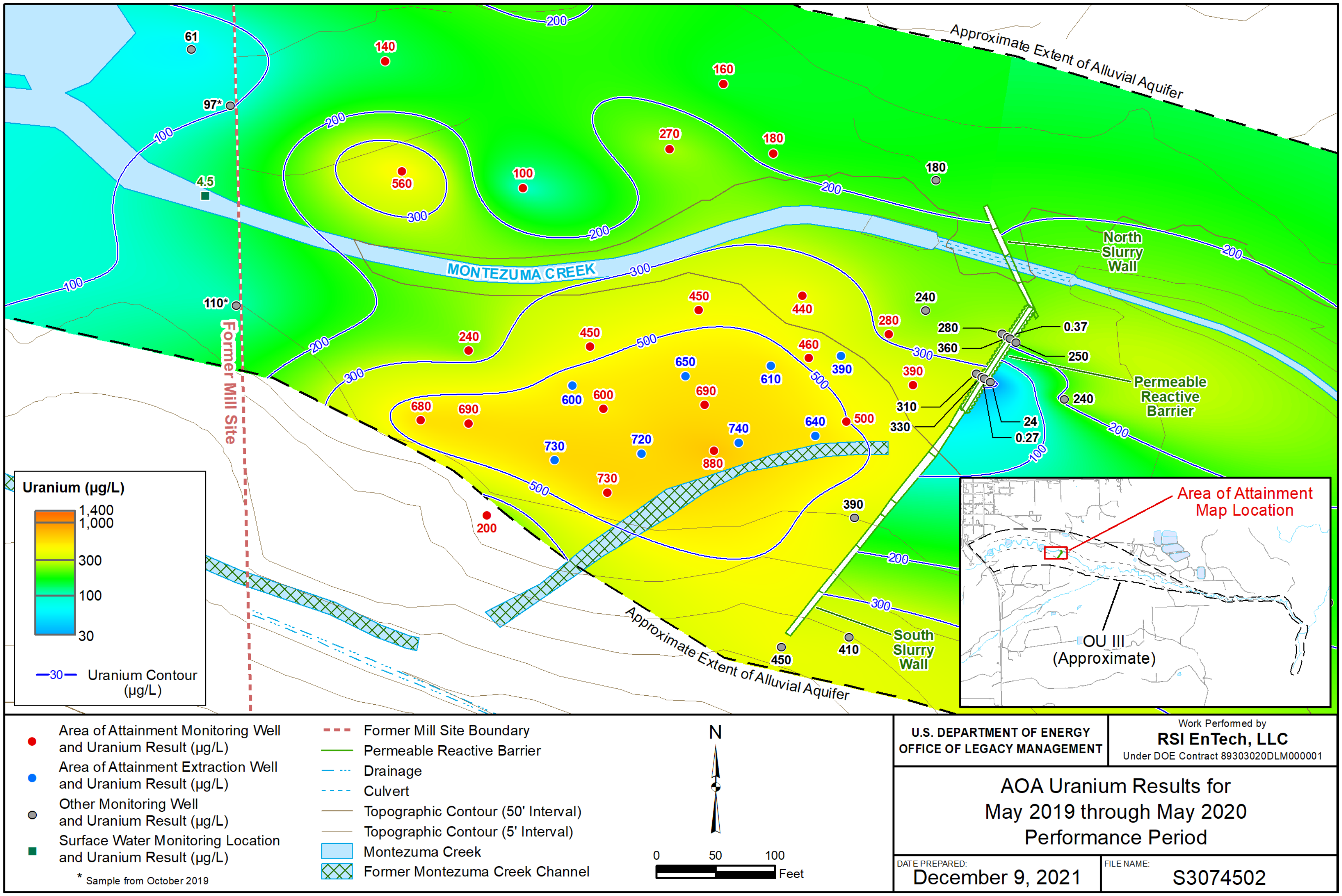


Figure 20. 2014 AOA Uranium Plume



● Area of Attainment Monitoring Well and Uranium Result (µg/L)
● Area of Attainment Extraction Well and Uranium Result (µg/L)
● Other Monitoring Well and Uranium Result (µg/L)
■ Surface Water Monitoring Location and Uranium Result (µg/L)
* Sample from October 2019

Former Mill Site Boundary
Permeable Reactive Barrier
Drainage
Culvert
Topographic Contour (50' Interval)
Topographic Contour (5' Interval)
Montezuma Creek
Former Montezuma Creek Channel

**U.S. DEPARTMENT OF ENERGY
OFFICE OF LEGACY MANAGEMENT**

Work Performed by
RSI EnTech, LLC
Under DOE Contract 89303020DLM000001

AOA Uranium Results for
May 2019 through May 2020
Performance Period

DATE PREPARED: December 9, 2021

FILE NAME: S3074502

Figure 21. 2020 AOA Uranium Plume

2.5 Bulk Uranium Plume Metrics

Bulk plume metrics were calculated using the Earth Volumetric Studio (EVS) software. The calculation was performed by three-dimensional interpolation of well concentration data using kriging for each recorded sampling event since October 2001. A 10:1 horizontal-to-vertical anisotropy was assumed. The interpolated plume volume was bounded on the bottom by the top of bedrock surface (interpolated from lithologic logs) and bounded on the top by the water table (interpolated from groundwater elevation measurements for each sampling event) or the top of the sand and/or gravel layer (interpolated from lithologic logs), whichever was at a lower elevation. A porosity of 0.25 was assumed for pore volume and plume mass calculations. Because this interpolation uses dynamic water table elevations and spatially variable top of bedrock and sand or gravel elevations when estimating plume volumes, the reported values will be different than those previously calculated using either a constant alluvial aquifer saturated thickness (pre-2016–2017) or an unconfined water table surface as the upper bound (2017–2018) (DOE 2018c).

Bulk plume metrics were calculated separately for the OU III uranium plume, including all contaminated groundwater in the alluvial aquifer and in the AOA uranium plume, including the limited area of contaminated groundwater from the eastern boundary of the former mill site to the PRB. Alluvial aquifer monitoring wells with an annual or semiannual sampling frequency (Figure 6) were used for the calculation of OU III bulk uranium plume metrics from October 2001 through May 2020. The GRO system monitoring wells (MW-01 and MW-03 through MW-17) were not used for the OU III uranium plume calculations because they were installed in 2014, and a consistent set of wells should be used for analyzing temporal trends in bulk plume metrics. In case a well was not sampled during a particular sampling event, linear interpolation was used to assign a uranium concentration to that well for that event. The GRO system wells (with the exception of MW-01 and MW-05 because they are frequently dry) along with a subset of wells within or near the AOA (92-07, 92-11, PW-17, PW-28, T01-01, T01-02, T01-04, and T01-05) were used for calculation of the AOA bulk plume metrics from April 2014 through May 2020. Because different sets of wells were used for calculation of bulk plume metrics of the OU III uranium plume versus the AOA uranium plume, the results are not directly comparable. The OU III uranium plume results are more representative of the overall plume attenuation subsequent to mill site restoration, whereas the AOA uranium plume results are more representative of the effects of GRO system operation.

Bulk plume metrics characterizing plume volume, dissolved plume mass, and average plume concentration provide an assessment of OU III groundwater restoration progress (Figure 22 through Figure 24). The blue line is the locally estimated scatterplot smoothing (LOESS) line; the surrounding gray area represents the 95% confidence intervals about the LOESS line. Unless noted, bulk plume trend discussions are reflective of the LOESS line. The three graphs all show an increasing trend from 2001 to 2008 and a decreasing trend from 2008 to present, with the exception of plume volume, which has been relatively constant at around 20 million gallons since 2012. The current hypothesis assumes that the observed LOESS line trends are a function of changing water table elevation. Because the plume footprint has remained relatively constant (Figure 18 and Figure 19), the relationship between increasing and decreasing uranium plume volume (Figure 22) is obvious; a rising water table results in greater saturated thickness (the sand or gravel layer is not saturated everywhere, temporally within OU III), which causes plume volume to increase; a dropping water table results in less saturated thickness and causes the plume volume to decrease. The relationship between dissolved uranium plume mass and uranium plume average concentration and water table elevation change is not obvious and is discussed later in this section.

Hydrographs from selected OU III monitoring wells show the same general increasing and decreasing or stable temporal trends (Figure 25) as those associated with plume volume, dissolved plume mass, and average plume concentration (Figure 22 through Figure 24). The fact that the water table elevation increases or decreases similarly throughout OU III indicates that temporal variability in precipitation infiltration (primarily snowmelt) is associated with increases and decreases in the water table elevation. Note that the volume of groundwater extracted represents a relatively small fraction of the overall water budget, so groundwater extraction has a minimal influence on plume volume (DOE 2019a).

The alluvial aquifer comprises 1–3 ft of sand and gravel overlain by 7–14 ft of silt. Typically, the water table extends into the silt. The literature reports that the capillary fringe for silt ranges between 9.8 ft (300 centimeters [cm]) and 24.6 ft (750 cm), with finer silt having a capillary fringe thickness greater relative to that of coarser silt (Fetter 2001). Given that the total thickness of OU III alluvial sediments is approximately 15 ft, the capillary fringe within the silt should be thick enough to make water readily available to plant roots. During the growing season, plants transpire groundwater from the capillary fringe. The effect of transpiration could be to concentrate uranium in the unsaturated zone; the plants use the water and leave uranium behind. Transpiration and associated uranium storage in the unsaturated zone occur during the growing season regardless of whether the water table elevation is increasing or decreasing. Increasing water table elevation may cause uranium stored in the unsaturated zone to become submerged and mix with groundwater, resulting in increased uranium plume concentrations, which would lead to increased dissolved uranium plume mass and increased uranium plume average concentration. When the water table elevation is declining, uranium may be removed from the plume by transpiration, which could result in decreasing uranium plume concentrations and decreasing dissolved uranium plume mass.

Infiltration of spring snowmelt and rainfall during periods of minimal transpiration (winter and early spring months) also causes increases in dissolved plume mass and the plume average concentration. During the growing season, transpiration results in groundwater moving upward from the water table toward land surface. Except for large precipitation events, transpiration generally prevents water that infiltrates land surface from reaching the water table. During the winter and spring months, water infiltrating land surface can reach the water table when transpiration is absent or minimal. If the infiltrating water remained clean as it migrated through the unsaturated zone, then uranium plume concentrations would decrease due to dilution, and the dissolved mass would remain constant; however, the opposite effect is observed. It is therefore inferred that as the water moves from land surface to the water table the water mixes with uranium stored in the unsaturated zone, causing increases in plume uranium concentrations, which results in increases in dissolved uranium plume mass and in uranium plume average concentration.

This phenomenon is illustrated in the temporal plots of average plume concentration (Figure 24). In spring 2011, the uranium plume average concentration was 315 µg/L but declined to less than 240 µg/L by the fall of that year. While not as dramatic, similar spring and fall trends were present in 2004, 2009, 2014, 2015, and 2019. Spring and fall increases and decreases in uranium plume average concentration and volume produce similar trends in the dissolved plume mass (Figure 23). A statistical analysis of the uranium plume volume, mass, and average concentration was performed to quantify the seasonal effects that are qualitatively apparent in Figure 22 through Figure 24. The regression residuals (i.e., the difference between each data point and the LOESS line) were calculated for each of the three metrics. A negative residual indicates a value that is less than the local average, and a positive residual indicates a value that is greater than the local average. If seasonal effects were present, then some seasons would be expected to have more positive residuals on average while other seasons would have more negative residuals on average. Wilcoxon rank sum tests were performed to determine if the spring residuals are statistically different than the fall residuals. The Wilcoxon rank sum test is a nonparametric form of the more familiar two sample *t* test, and it does not assume that the data follow a normal distribution. A statistical difference between the spring and fall residuals was identified for uranium plume volume, mass, and average concentration at the 0.05 significance level, which indicates that these three metrics are influenced by seasonal effects.

Confidence intervals were calculated for the average difference between spring and fall means by assuming the residuals follow a normal distribution. The normality assumption was tested using the Shapiro-Wilk normality test for each set of residuals, and the residuals did not significantly deviate from a normal distribution at the 0.05 significance level in the six cases tested. The results of the analysis indicate with 95% confidence that on average the plume volume is 1.4–4.3 million gallons greater in the spring than in the fall, the plume mass is 5–13 lb greater in the spring than in the fall, and the average plume concentration is 5–31 µg/L greater in the spring than in the fall.

In response to changes in precipitation recharge, the OU III uranium plume volume trend line increased between 2001 and 2008 from 16 to 22 million gallons and remained relatively constant between 2008 and 2020 at 20 to 22 million gallons (Figure 22).

In 2001, OU III dissolved uranium plume mass was 35 lb (Figure 23). From 2001 to 2008, the uranium plume mass LOESS line steadily increased to a high of 52 lb, reflecting the transfer of unsaturated zone uranium to groundwater, probably in response to recharge and increases in water table elevation (Figure 25). Note that from 2001 to 2008, dissolved uranium was also being removed from the alluvial aquifer by the PRB, extraction well pumping, and discharge to Montezuma Creek. The uranium plume mass LOESS line decreased from a high of 52 lb to approximately 30 lb in 2020. Increased water table elevation associated with a large 2019 snowmelt (125 inches of snow fell on Monticello during the winter of 2018/2019) resulted in an increase of dissolved uranium plume mass to approximately 42 lb in April 2019. A lesser snowfall, 55 inches, during the winter of 2019/2020 produced a smaller increase in spring plume mass (to 38 lb).

Between 2001 and 2008, the OU III uranium plume average concentration LOESS line increased from approximately 250 to 275 µg/L, in response to recharge and rising alluvial aquifer groundwater levels (Figure 24). As discussed in the previous paragraph, recharge and increasing water levels cause uranium stored in the unsaturated zone to mix with groundwater. The average OU III uranium plume concentration trend line declined from 275 to 160 µg/L between 2008 and 2020, potentially as a result of uranium being transferred from groundwater to the unsaturated zone in response to transpiration, extraction well pumping, and plume discharge to Montezuma Creek.

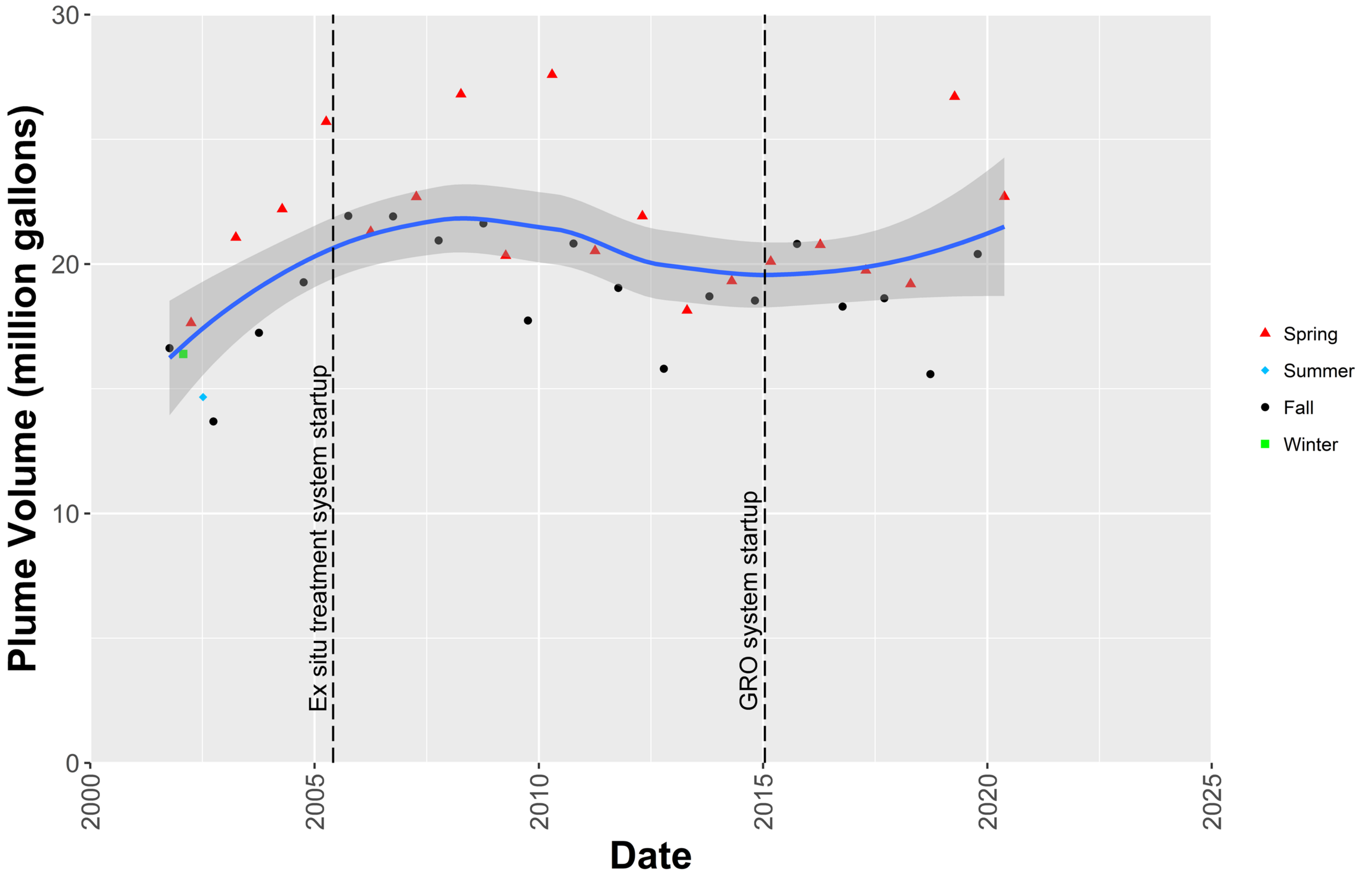


Figure 22. OU III Uranium Plume Volume Trend

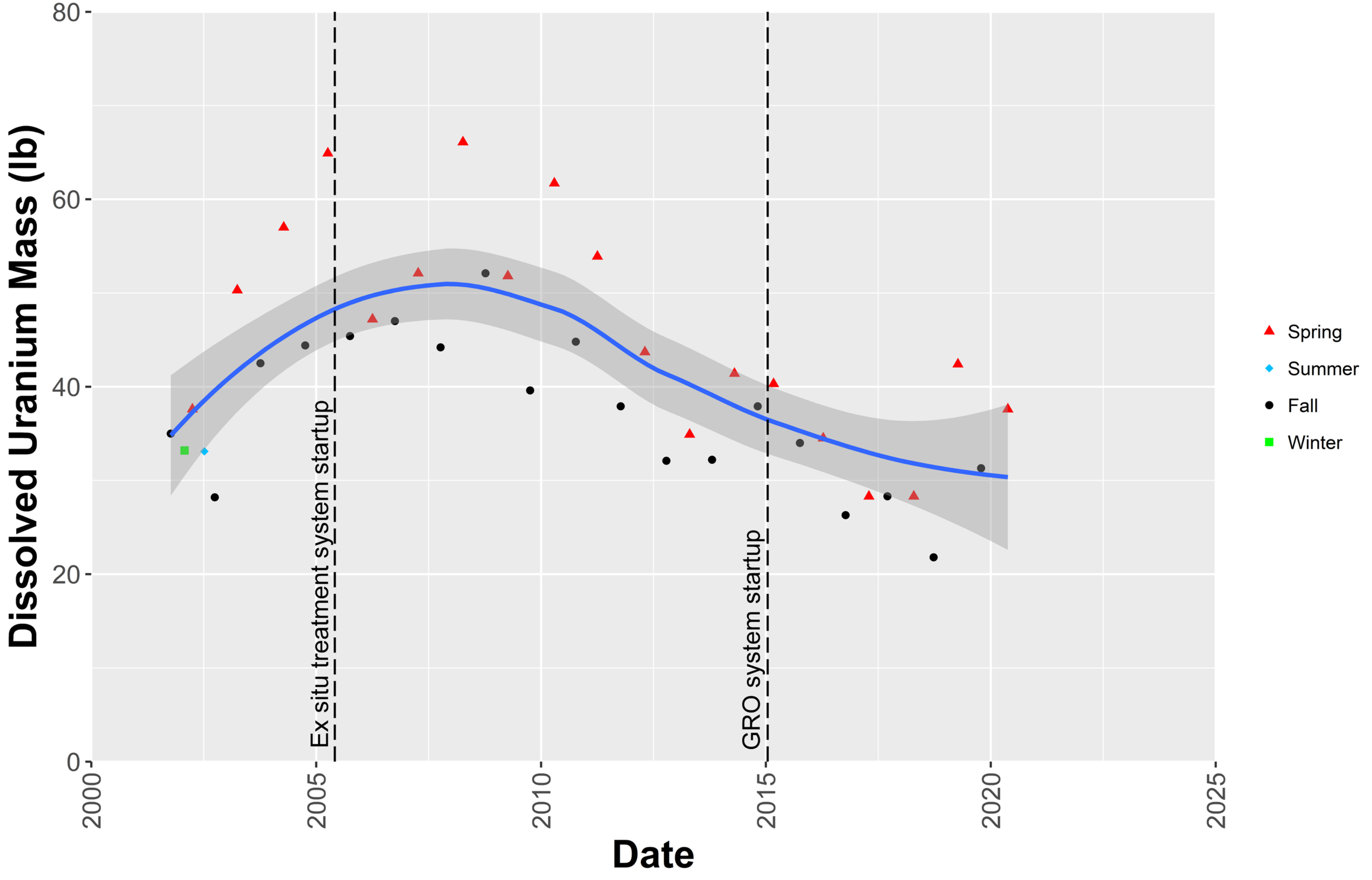


Figure 23. OU III Uranium Plume Mass Trend

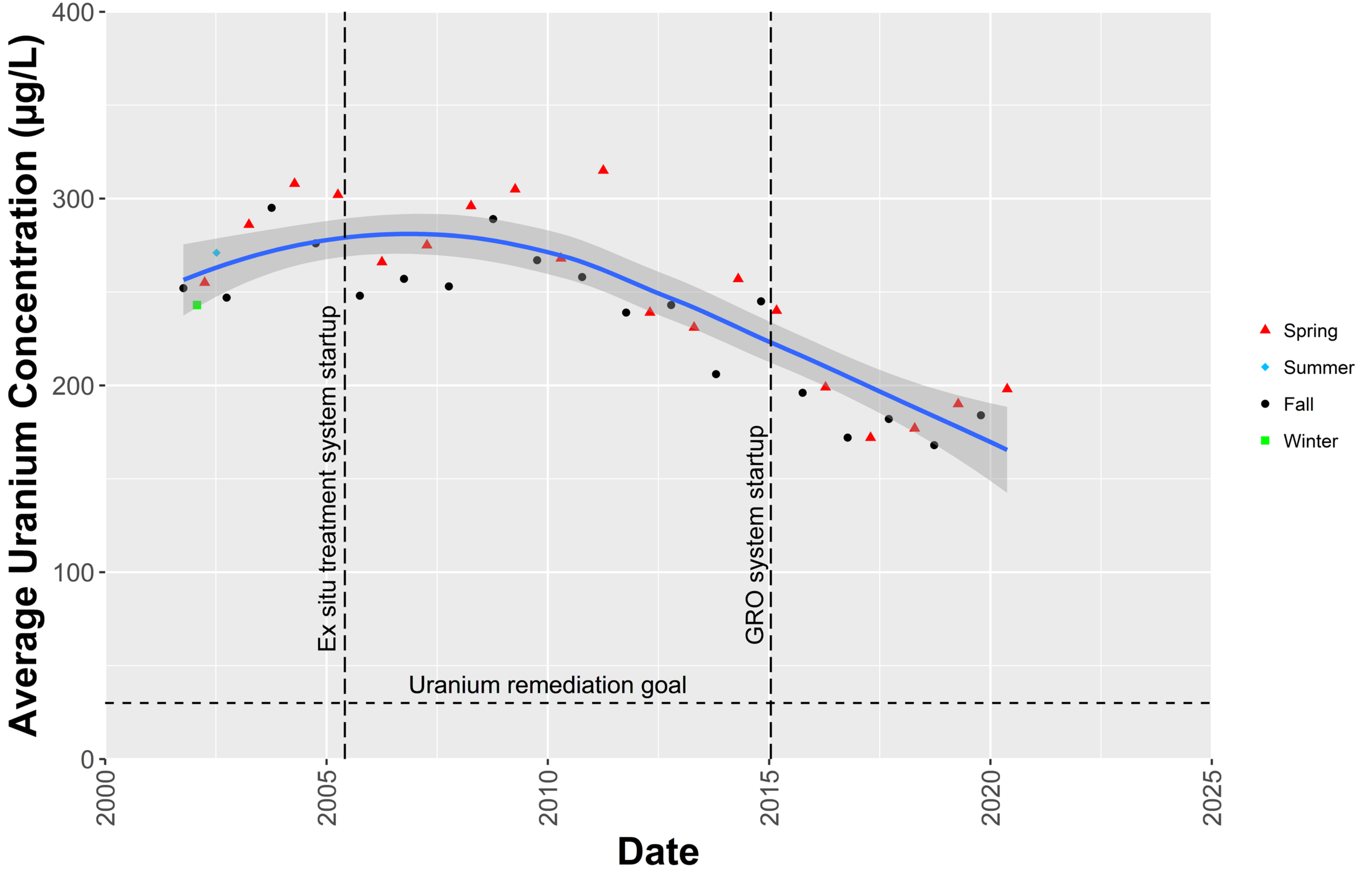


Figure 24. OU III Uranium Plume Average Concentration Trend

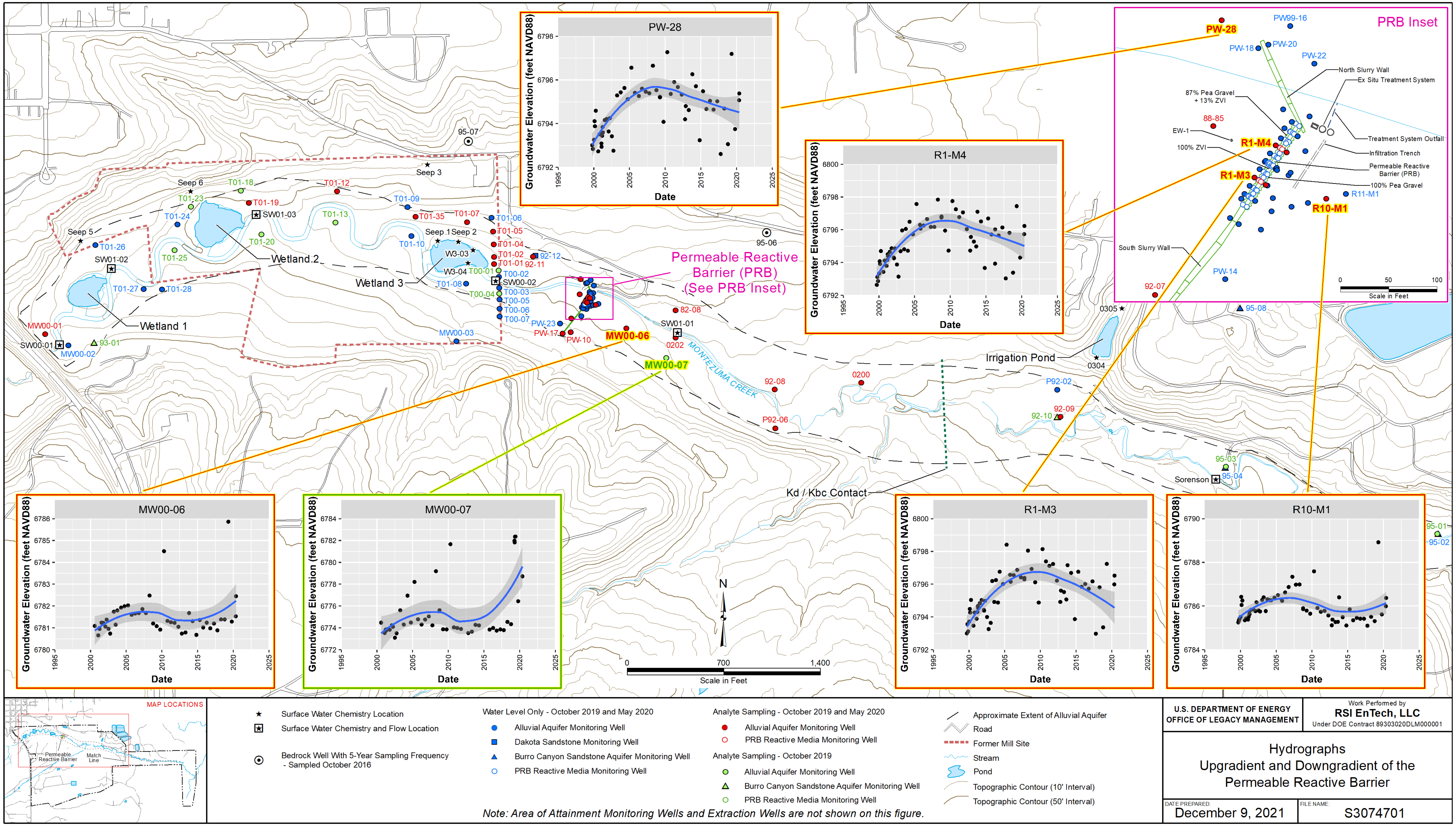


Figure 25. Water-Level Elevation Trends for Selected OU III Monitoring Wells

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AOA uranium plume volume, uranium plume mass, and uranium plume average concentration trends (Figure 26 through Figure 28) between 2014, just before GRO system installation, and 2020 were also evaluated to assess aquifer restoration progress. Between 2014 and 2016, the AOA uranium plume volume LOESS line increased from 2.3 to 2.6 million gallons despite the removal of 6 million gallons of water by the GRO system during that time. Groundwater levels in the AOA respond to both extraction well field pumping and precipitation recharge, making it impossible to separate the influence of one from the other. Monticello annual precipitation was 8.7 inches (222 millimeters [mm]) in 2014, 17.0 inches (433 mm) in 2015, and 15.6 inches (395 mm) in 2016, suggesting that the rise in the AOA water table elevation is in response to increased precipitation (DOE 2018c). Between 2016 and 2018, the AOA plume volume LOESS line decreased from 2.6 to 2.0 million gallons in response to AOA groundwater extraction and decreases in annual precipitation rates between 2016 (15.6 inches, 395 mm) and 2017 (10.4 inches, 264 mm). From 2018 to 2020, the AOA plume volume LOESS line increased from 2.0 to 2.4 million gallons in response to declining extraction rates and rising water tables. Short-term nonpumping periods appear to have minimal if any effect on uranium plume volume.

From 2014 to 2019, the AOA uranium plume mass LOESS line decreased from 9.5 to 4.0 lb (Figure 27). Since 2019, AOA uranium plume mass has increased from 4.0 to 6.3 lb in response to a rising water table, which dissolves solid-phase uranium in the vadose zone, and lateral inflow of dissolved uranium from the southern margin of the mill site. Short-term nonpumping periods appear to have minimal if any effect on uranium plume mass.

The AOA uranium plume average concentration LOESS line declined from 500 to 260 µg/L between 2014 and 2019 and has since risen to 310 µg/L (Figure 28). As with the uranium plume mass, the reduction in uranium plume average concentration is a function of both declining AOA groundwater levels and groundwater extraction. The increase in AOA uranium plume average concentration is associated with recharge and a rising water table. Short-term nonpumping periods appear to have minimal if any effect on uranium plume average concentration.

A statistical analysis of seasonal differences was not performed for the AOA uranium plume. An autocorrelation analysis indicates that the number of samples should be reduced to bimonthly sample frequency prior to statistical testing to ensure statistical independence. After reducing the AOA dataset to bimonthly sample frequency and classifying the data points by season, too few data points are available for each season to perform a meaningful statistical comparison. Data for five complete seasonal cycles are available since the GRO system began operation, and an estimated 17 seasons of data would be needed to estimate a difference similar in magnitude to that detected for the OU III uranium plume as a whole.

The temporal location of the center of plume mass is a bulk plume metric that characterizes the temporal distribution of contamination concentration within the plume. In the case of the OU III uranium plume, decreases in upgradient and AOA uranium concentrations in groundwater (Figure 12 through Figure 14) and mostly stable uranium concentrations in groundwater downgradient of the PRB (Figure 15) caused the center of mass (Figure 29) to move downgradient between 2001 and 2020.

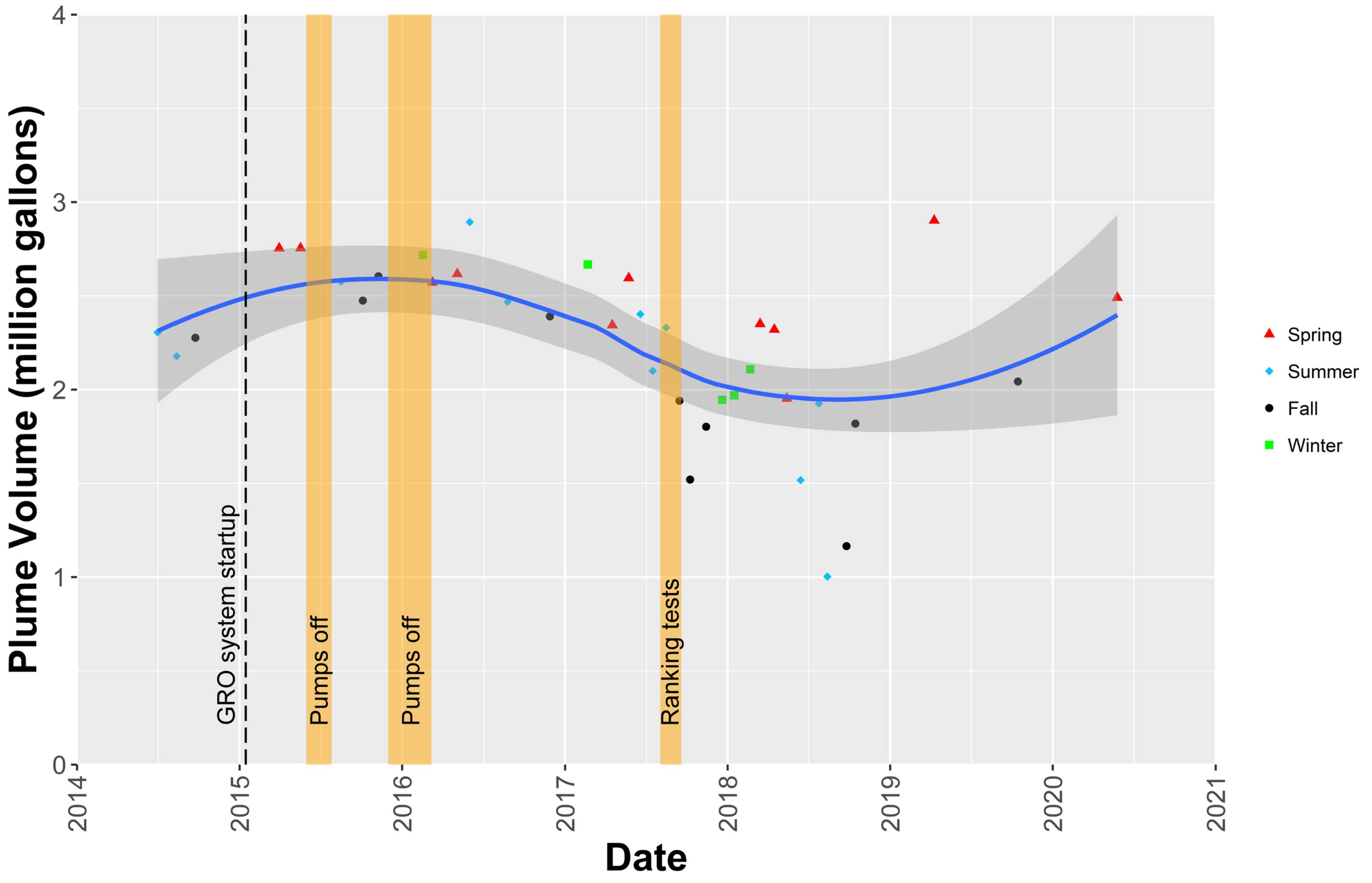

Figure 26. AOA Uranium Plume Volume Trend

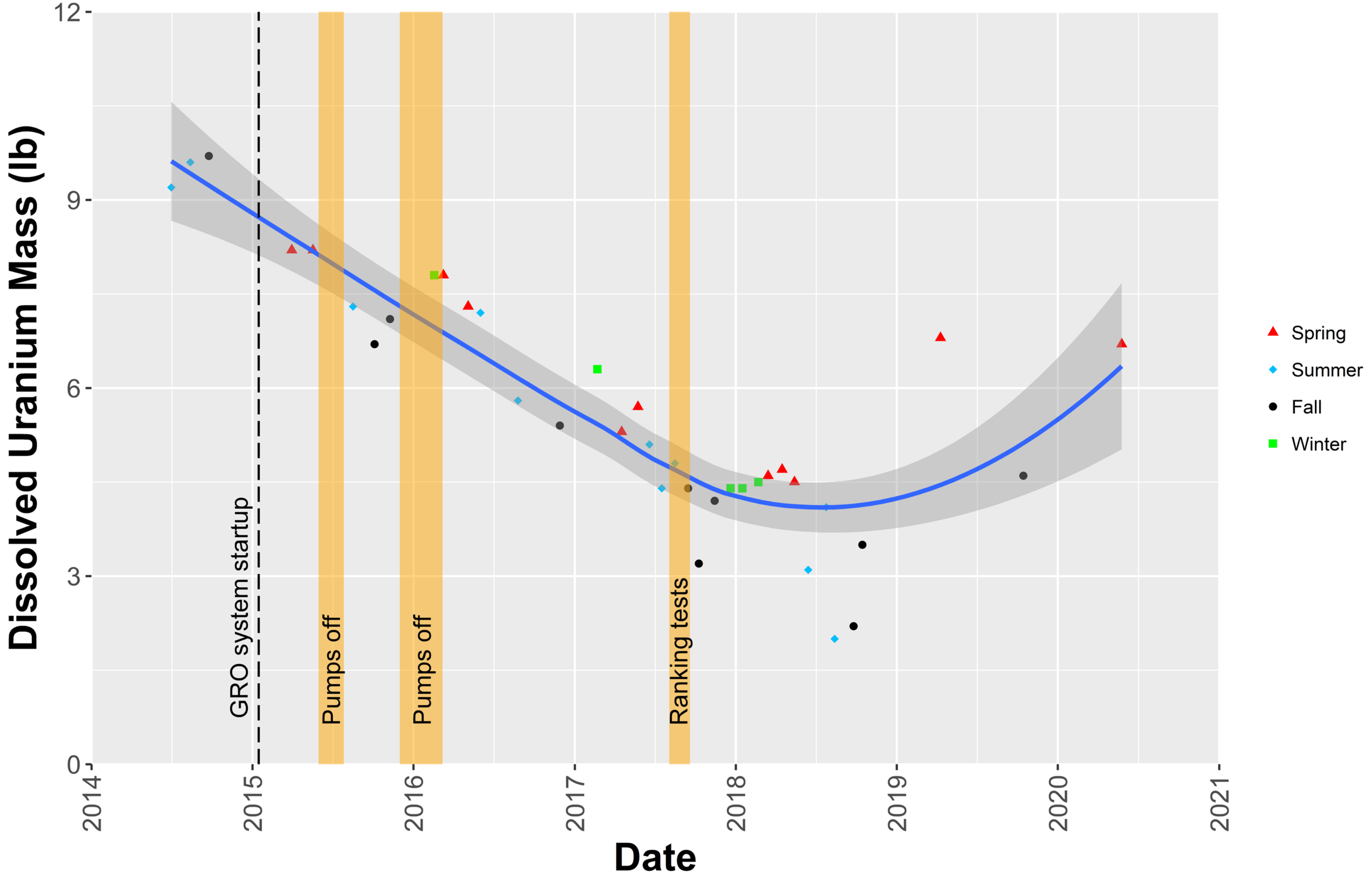

Figure 27. AOA Uranium Plume Mass Trend

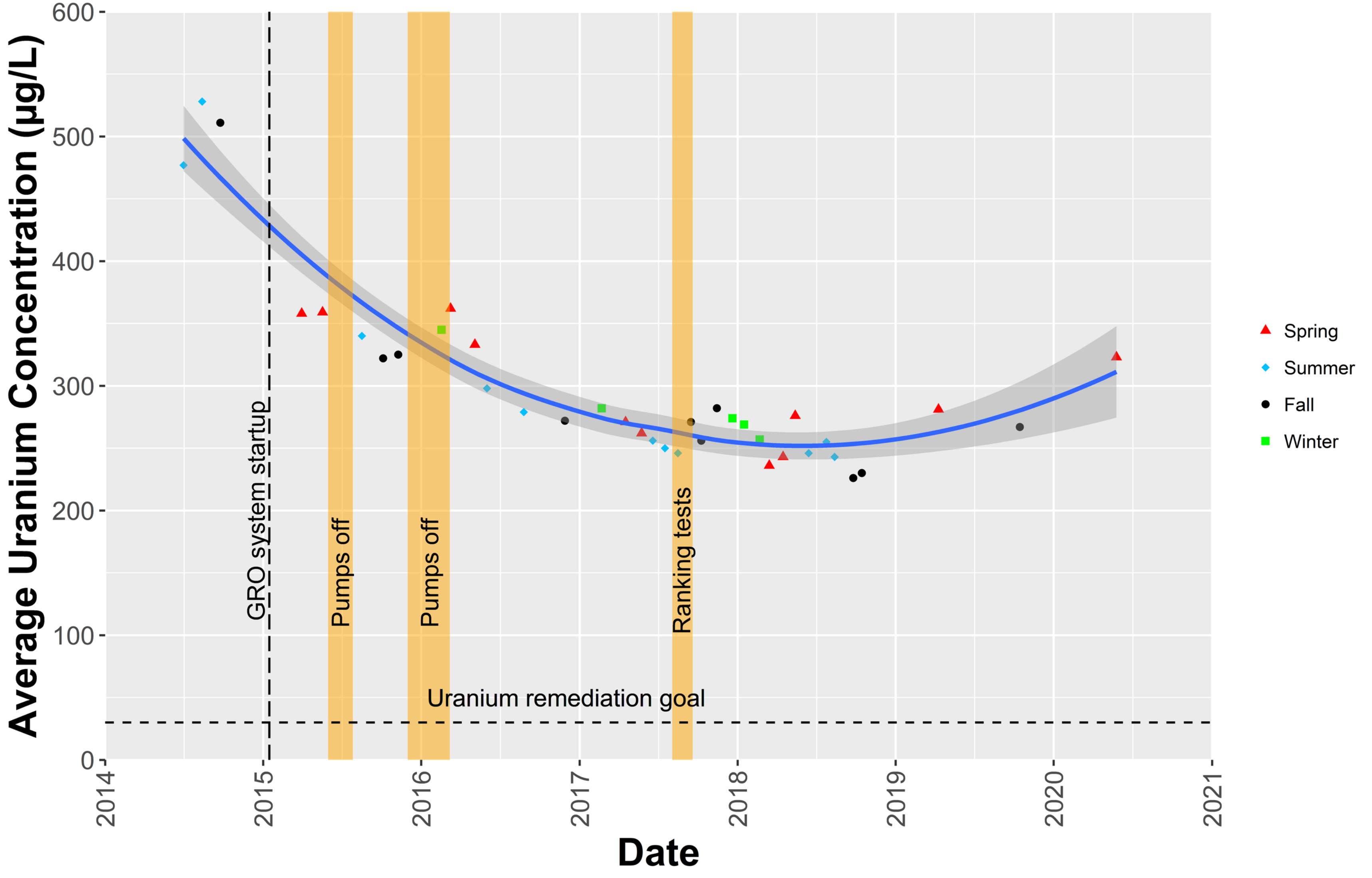

Figure 28. AOA Uranium Plume Average Concentration Trend

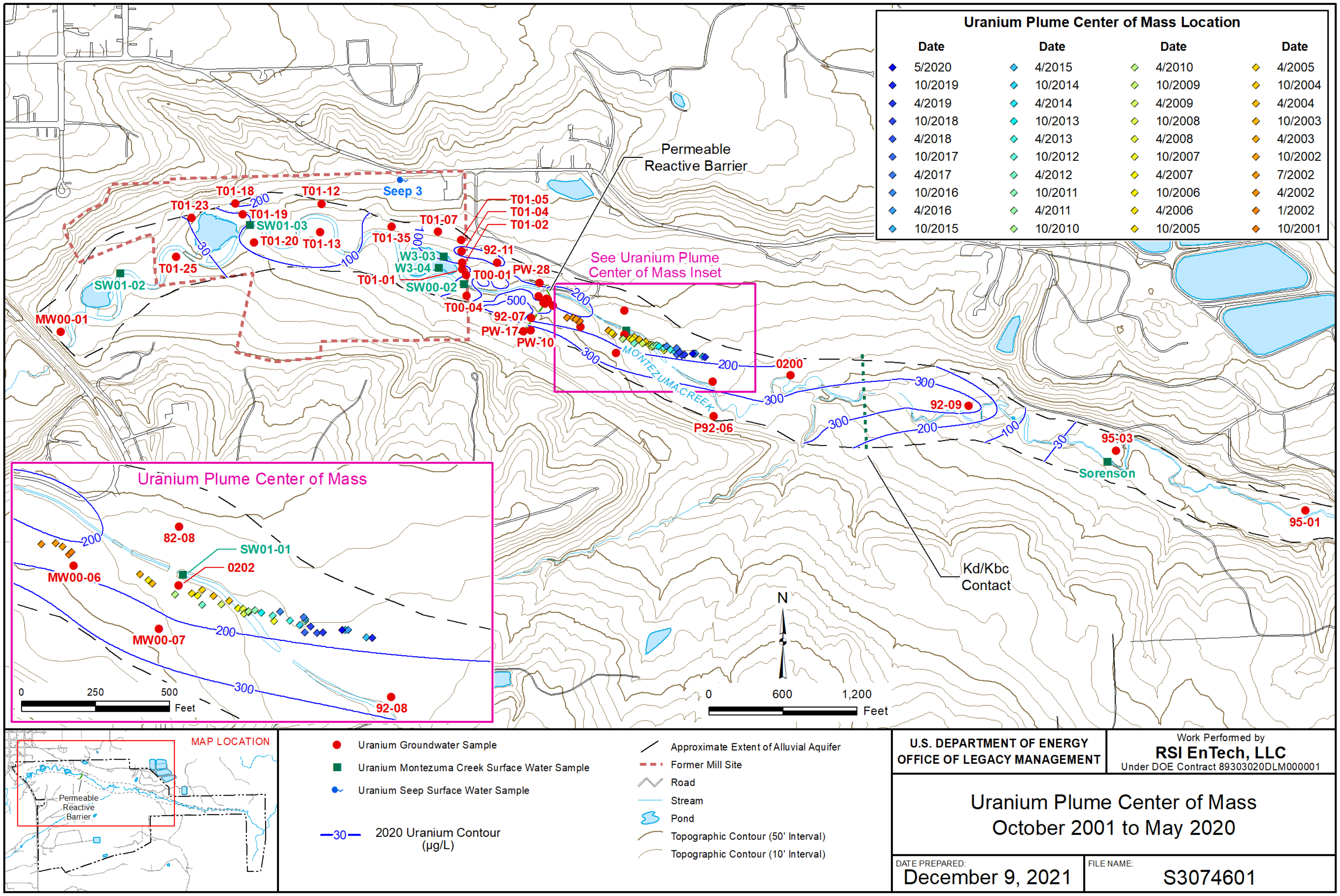

Figure 29. OU III Uranium Plume Center of Mass Temporal Locations

2.6 Surface Water Uranium Concentration Trends

Surface water samples were collected from 10 locations (Figure 6) within Montezuma Creek during the May 2019 to May 2020 sampling period. Figure 30 shows historical surface water uranium concentrations for those locations. The five most upgradient surface sample locations (SW00-01, SW01-02, SW01-03, SW00-02, and SW01-01) visually have declining uranium concentrations trends that have historically remained below the State of Utah surface water uranium standard of 44 µg/L. The trend graphs for the five sampling locations show that uranium surface water concentrations increase upstream to downstream. At the Sorenson sampling location (sample identification number 95-04), uranium concentrations are typically above the State of Utah surface water uranium standard of 44 µg/L. The May 2020 uranium concentration at this location was approximately 40 µg/L. Downstream, sample results from the next four sampling locations, similar to those of 2019, are at or near the State of Utah surface water uranium standard of 44 µg/L. The observed uranium concentration trend with distance along the creek is related to groundwater discharge. Upstream, where the Dakota Sandstone is present, contaminated groundwater discharge to the creek is minimal and as such uranium surface water concentrations are relatively low. Upgradient of the Sorenson surface water sampling location, the Dakota Sandstone pinches out, allowing the underlying Burro Canyon Formation to come into direct contact with the alluvial aquifer (Section 1.2). The addition of Burro Canyon Formation water to the alluvial aquifer causes the uranium plume to discharge to Montezuma Creek downgradient of the pinch-out location. The correlation between the area where the uranium plume ends and the occurrence of historically elevated uranium surface water concentrations suggests that plume discharge and not supplemental standard areas located adjacent to and within the creek bed is responsible for the increased uranium surface water concentrations. Supplemental standard areas are places where mill-contaminated soils were left in place adjacent to and within Montezuma Creek based on cost benefit and risk analyses. For example, contaminated soils were left in place when removal of those soils would compromise fish and wildlife habitat and the contaminated soils were determined to have minimal adverse effects on human health and the environment. Contaminated soils were also left in place if removal costs outweighed potential benefits.

Five OU III seep locations (1, 2, 3, 5, and 6) are included in the monitoring program (Figure 31). Seep 6 was not sampled in 2020 because it was dry. Seeps 1 and 2 have not been sampled since 2014 because they have been dry, and Seep 5 has been dry since 2013. Seeps 2, 3, and 5 visually have downward uranium concentration trends, with Seeps 3 and 5 having concentrations below the State of Utah surface water uranium standard of 44 µg/L (Figure 30). The uranium concentration trends at Seeps 1 and 6 appear stable at approximately 200 and 2000 µg/L, respectively. The source of the Seep 6 uranium is believed to be tailings-contaminated soil used in a municipal water utility corridor that contains sanitary sewer and secondary water lines (DOE 2009b).

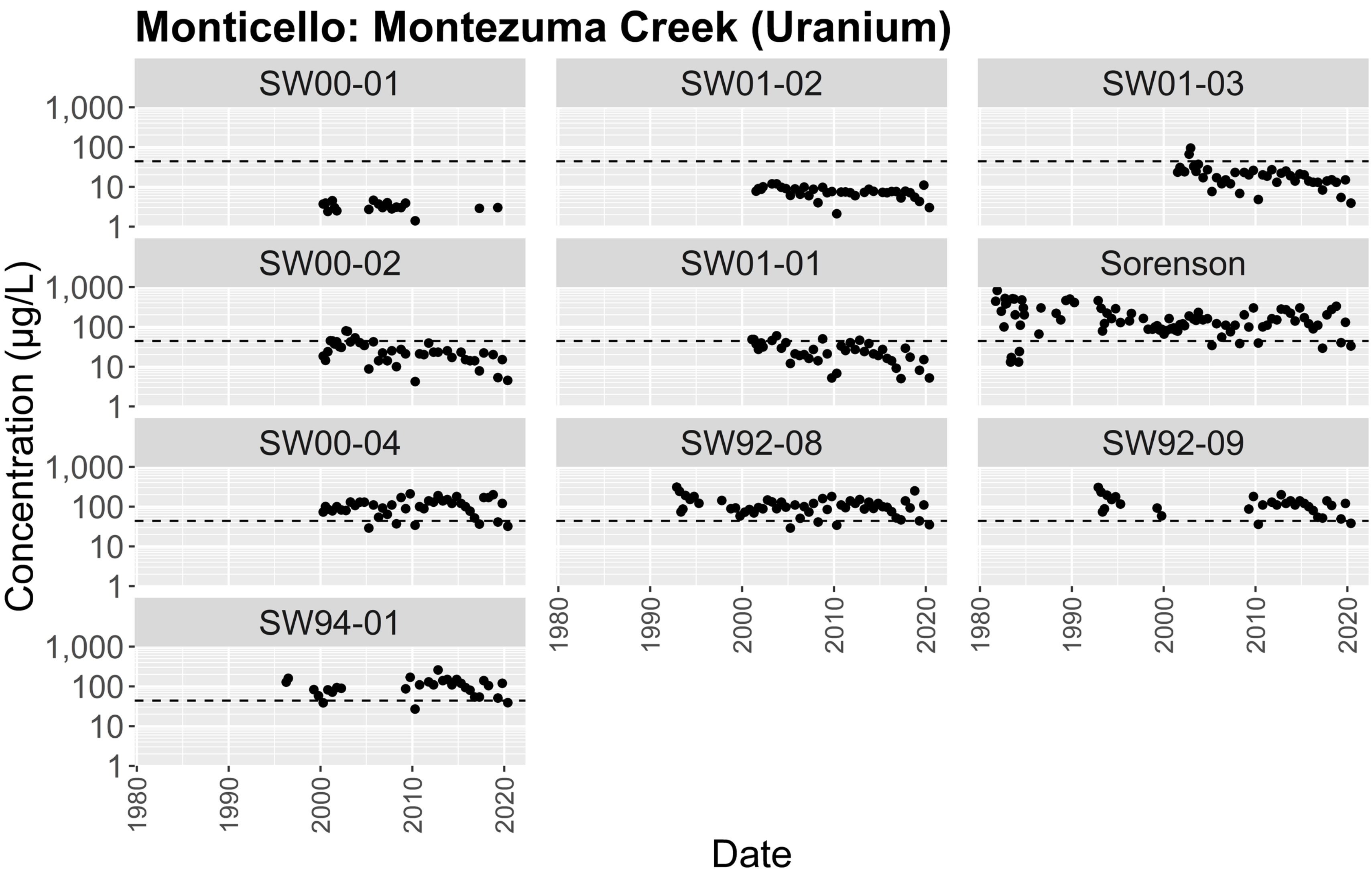

Figure 30. OU III Surface Water Uranium Concentration Trends

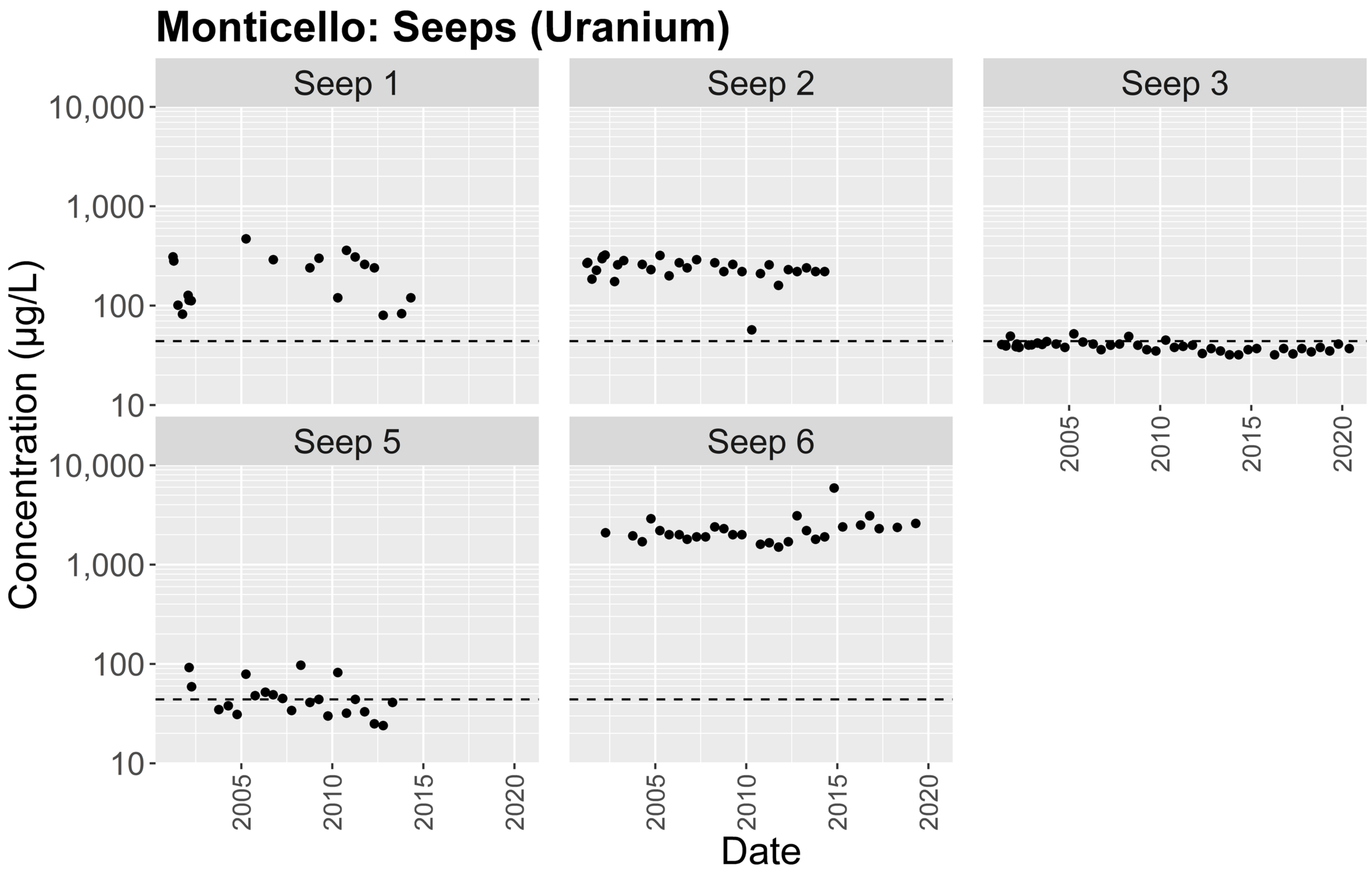

Figure 31. OU III Seep Uranium Concentration Trends

3.0 Compliance Remedy Performance Summary

The current OU III compliance remedy is MNA and active remediation with ICs. MNA relies on natural physical and chemical processes in soil and groundwater to reduce uranium mass in the subsurface. Because of a long radioactive half-life (245,500 years for uranium-234, 4.5 billion years for uranium-238), the only natural attenuation mechanisms available to reduce OU III subsurface uranium concentration are discharge to Montezuma Creek, dispersion along the plume flow path, strong to irreversible adsorption, and mineral precipitation due to changing geochemical conditions. This evaluation examined uranium groundwater concentrations and bulk plume metrics to characterize uranium attenuation progress (aquifer restoration) in OU III and the AOA and whether there are physical and chemical processes that may impede the compliance remedy efficiency. In addition, the annual extraction volumes and uranium mass removed by the GRO system were evaluated to characterize the system performance. Lastly, relevant findings from evaluations performed during this evaluation period are presented and implications to aquifer restoration progress are discussed.

With respect to OU III groundwater:

Trends for uranium plume volume, plume mass, and plume average concentration show increases from 2001 until approximately 2008. Plume mass and average concentration show downward trends from 2008 to 2020, whereas plume volume was relatively stable during this period (Figure 22 through Figure 24). The increasing and decreasing trends shown in the three graphs correlate to upward and downward movement of the water table (Figure 25). Transpiration by plants removes contaminated groundwater from the alluvial aquifer and leaves behind uranium in the unsaturated zone. The transpiration process occurs continuously during the growing season, independent of water table rise and fall. When the water table is declining, transpiration may remove uranium from groundwater and store it in the unsaturated zone, resulting in declining uranium plume mass and average concentration. When the water table rises, uranium stored in the portion of the unsaturated zone that becomes saturated mixes with groundwater, increasing uranium plume mass and increasing uranium plume average concentration.

Mixing of spring snowmelt and rainfall infiltration with uranium stored in the unsaturated zone can cause dissolved plume mass and average plume concentration to increase relative to fall conditions (Figure 23 and Figure 24). Springtime infiltration of snowmelt and precipitation that mixes with uranium stored in the unsaturated zone caused uranium plume mass to nearly double in 2005, 2008, and 2010. The rapid increase in uranium plume mass between fall and spring suggests how rapidly springtime infiltration mobilizes uranium stored in the unsaturated zone, and the rapid reduction in uranium plume mass between spring and fall indicates how effective discharge to Montezuma Creek and transpiration are at removing uranium from groundwater. Similar to sorption to soils, transpiration of uranium to the unsaturated zone retards uranium plume movement.

From 2008 to 2020, uranium plume mass, and average concentration have steadily declined, whereas plume volume was relatively stable during this period (Figure 22 through Figure 24). Over the 12-year period, OU III uranium plume mass declined from 52 to 30 lb. Similarly, the OU III uranium plume average concentration declined from 275 to 160 µg/L. The declining trends of the uranium plume mass and average concentration show that OU III alluvial aquifer water quality improved from 2008 to 2020 as a result of uranium being discharged to Montezuma Creek, extracted by pumping, and stored in the unsaturated zone due to capillary action and transpiration.

Two evaluations, a solid-phase geochemical study and transport modeling, were conducted this performance period. Results of both evaluations are presented in the Groundwater Flow and Contaminant Transport Model Report (DOE 2020), which is currently undergoing regulatory review. The solid-phase geochemical study found nearly 1000 times more uranium mass on the solid phase than in the dissolved phase, and the majority of the solid-phase mass is stored in the vadose zone. Transport modeling predicted MNA time frames on the order of 1000 years. The simulated remediation time frame was not reduced by PRB removal (~1000 years) or 30 additional years of GRO system operation (~1000 years).

With respect to the AOA groundwater and GRO performance:

Since becoming operational in 2015, the GRO system has removed approximately 21.5 million gallons of contaminated groundwater containing approximately 115 lb of uranium (Figure 9). The maximum AOA uranium plume pore volume was 2.9 million gallons. Based on the maximum plume volume and assuming all the groundwater extracted by the GRO system was plume water, the GRO system has removed 7 plume pore volumes since beginning operation in 2015. Based on the 2014 AOA uranium plume pore volume of 2.3 million gallons, the GRO has removed 9 pore volumes since 2015. Prior to GRO system startup in January 2015, the AOA plume contained approximately 9.5 lb of dissolved uranium. At the conclusion of this performance period, in May 2020, the average dissolved uranium mass in the AOA plume estimated by the LOESS method was 6.3 lb, a reduction of 3.2 lb relative to initial conditions. The discrepancy between the AOA uranium plume mass reduction (3.2 lb) and the mass of uranium removed by the GRO system (115 lb) since January 2015 results because there is significant (~1400 lb) solid-phase uranium present in the AOA that continues to feed the plume. In addition, the margins of the mill site vadose zone and a supplemental standard area source south of the AOA continue to provide uranium to groundwater at the margins of the aquifer following snowmelt events.

From 2014 to 2019, AOA uranium plume mass decreased from 9.5 to 4.0 lb (Figure 27). During this performance period, AOA uranium plume mass increased from 4.0 lb to 6.3 lb as a result of increased precipitation infiltration, primarily associated with snowmelt, over the past 2 years which causes the water table to rise and dissolve solid-phase uranium from the mill site vadose zone and a supplemental standard area located south of the AOA. From 2014 to 2020, based on the current AOA uranium plume mass, plume mass has decreased by a factor of 1.5 (9.5 lb/6.3 lb), which is slightly greater than the 1.3 factor (38 lb/30 lb) decrease of the OU III uranium plume mass. The AOA uranium plume volume decreased from a maximum of 2.9 to 2.4 million gallons, and the average AOA uranium plume concentration declined from 500 to 310 µg/L (Figure 26 and Figure 28). However, the increasing trends of the three bulk plume metrics during this performance period show that while AOA alluvial aquifer water quality has improved from 2015 to 2020, primarily as a result of GRO pumping, water quality improvement can rapidly reverse as a function of increasing precipitation infiltration.

Transport model simulation results that include the effects of vadose zone and supplemental standard area uranium loading to groundwater predict that after 30 years of continuous AOA extraction well field operation, AOA uranium concentrations will not reduce below the remediation goal. The same simulations show that AOA uranium concentrations will rebound to the same levels as the nonpumping model scenarios following the cessation of pumping.

Implications of transpiration and water table elevation variability on aquifer restoration:

Previous Annual Reports noted that while declining OU III and AOA bulk uranium plume metrics indicate improvement in OU III alluvial aquifer water quality over the past decade, the improvement period corresponds to a time when the OU III water table elevation was declining or stable in response to dry climatic conditions. It is possible that when wet climatic conditions prevail, the OU III water table elevation will increase, and gains made in alluvial aquifer water quality restoration will be reversed, similar to what was observed from 2001 to 2008, a period during which the water table elevation steadily increased (Figure 25). AOA bulk plume metrics all increased this performance period in response to a rising water table, supporting the hypothesis that alluvial water quality restoration progress can reverse as a result of wet climatic conditions.

With respect to the bedrock aquifer:

May 2016 through May 2020 Burro Canyon Formation water quality results are all below the OU III groundwater remediation goals with the exception of arsenic (84 µg/L in October 2016) in monitoring well 93-205 (Appendix B). The 2016 measured arsenic concentration is consistent with historical concentrations dating back to 1995.

With respect to OU III surface water:

Surface water uranium concentrations in the upper reaches of Montezuma Creek, above the Sorenson sampling location (Figure 6), where contaminated groundwater discharge to the creek is minimal relative to the downstream reaches, are declining and remain below the State of Utah surface water uranium standard of 44 µg/L (Figure 30). From the Sorenson sampling location and farther downstream, uranium surface water concentrations were approximately 40–50 µg/L in May 2020. Contaminated groundwater discharging to this portion of Montezuma Creek and not supplement standard areas located adjacent to and within the creek bed is responsible for the uranium measured at these surface water sampling locations. Montezuma Creek water quality will improve as OU III groundwater quality improves.

All five seep locations (Figure 6) visually have declining or stable uranium concentration trends (Figure 31). The source of the Seep 6 uranium is believed to be tailings-contaminated soil used in a municipal water utility corridor that contains sanitary sewer and secondary water lines (DOE 2009b).

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Appendix A

Alluvial Aquifer Concentration Trends
May 2019–May 2020

Arsenic, Manganese, Molybdenum, Nitrate, Selenium, Vanadium

Arsenic

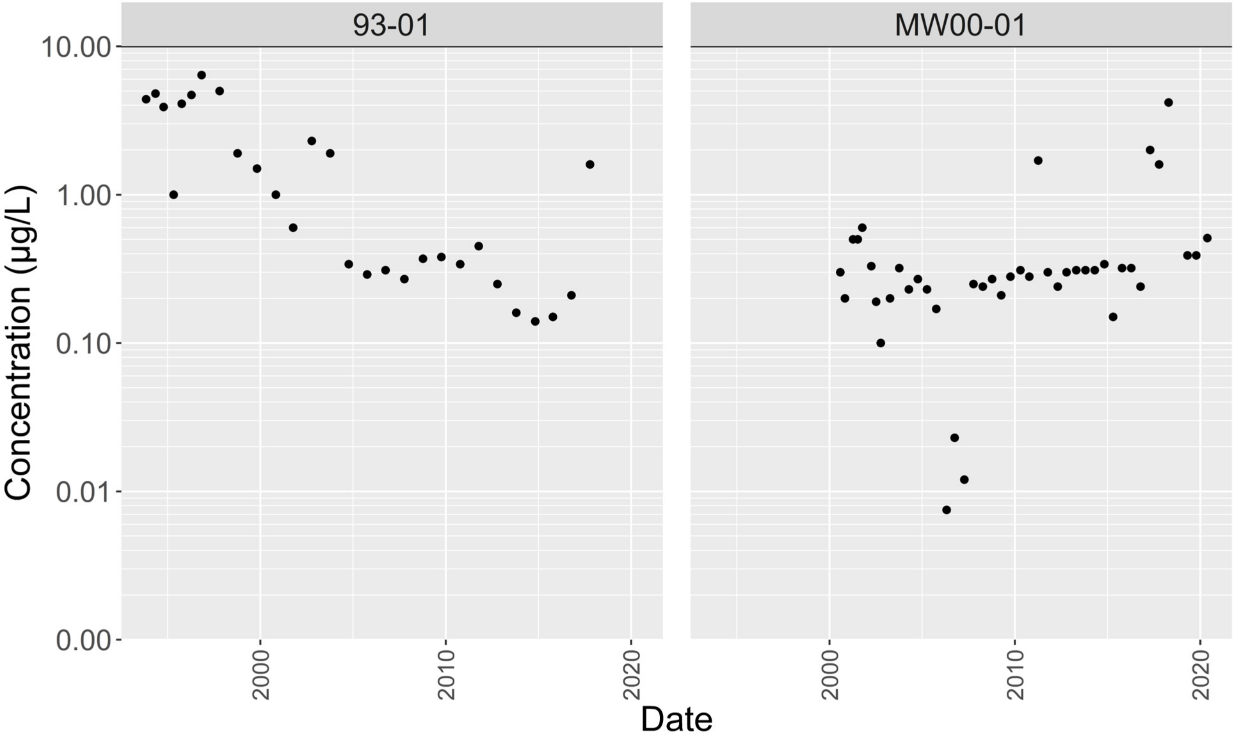
Groundwater Remediation Goal: 10 µg/L

Sample Locations Are Shown in Figure 6

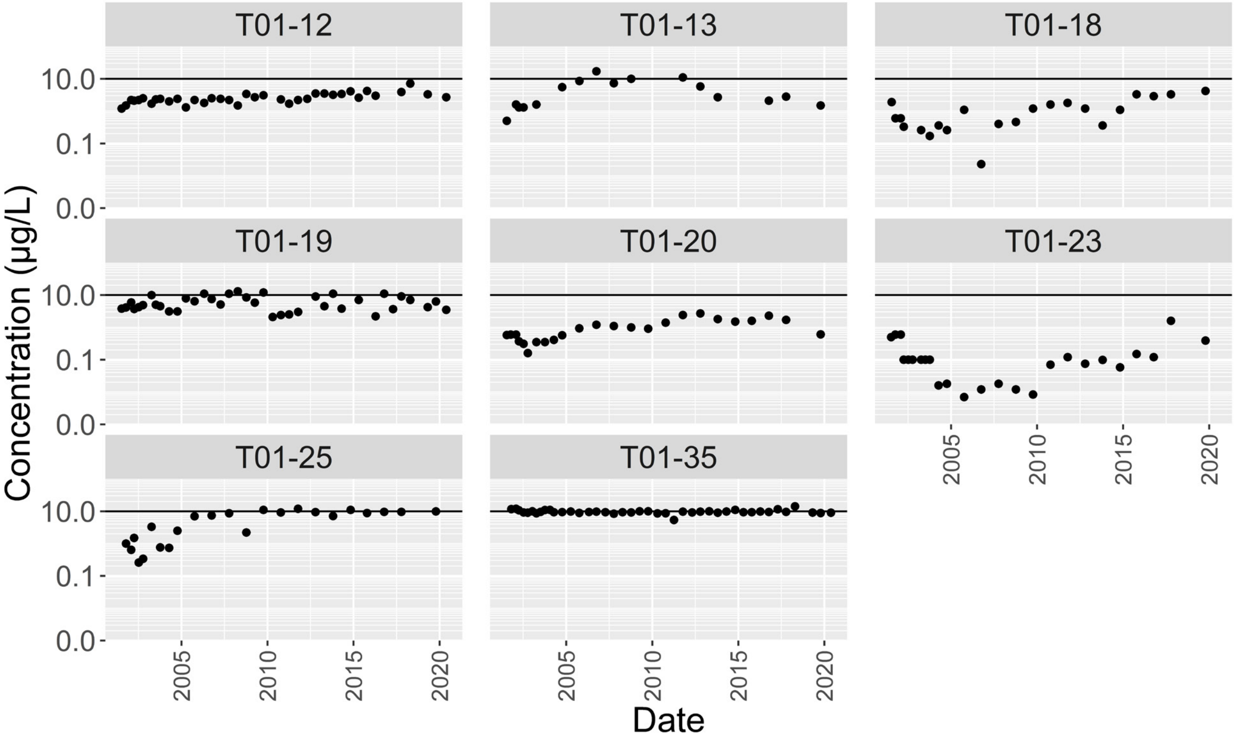
OU III Monitoring Wells Having Arsenic Concentrations Above the Remediation Goal This Performance Period

Well	Sample Date	Arsenic Concentration (µg/L)
88-85	10/15/2019	14.0
88-85	5/19/2020	10.0
PW-17	5/19/2020	11.0
R1-M3	10/15/2019	13.0
R1-M3	5/20/2020	12.0
T01-02	10/19/2019	15.0
T01-02	5/19/2020	13.0
T01-04	10/15/2019	13.0
T01-04	5/19/2020	13.0
T01-05	10/15/2019	12.0
T01-05	5/19/2020	12.0

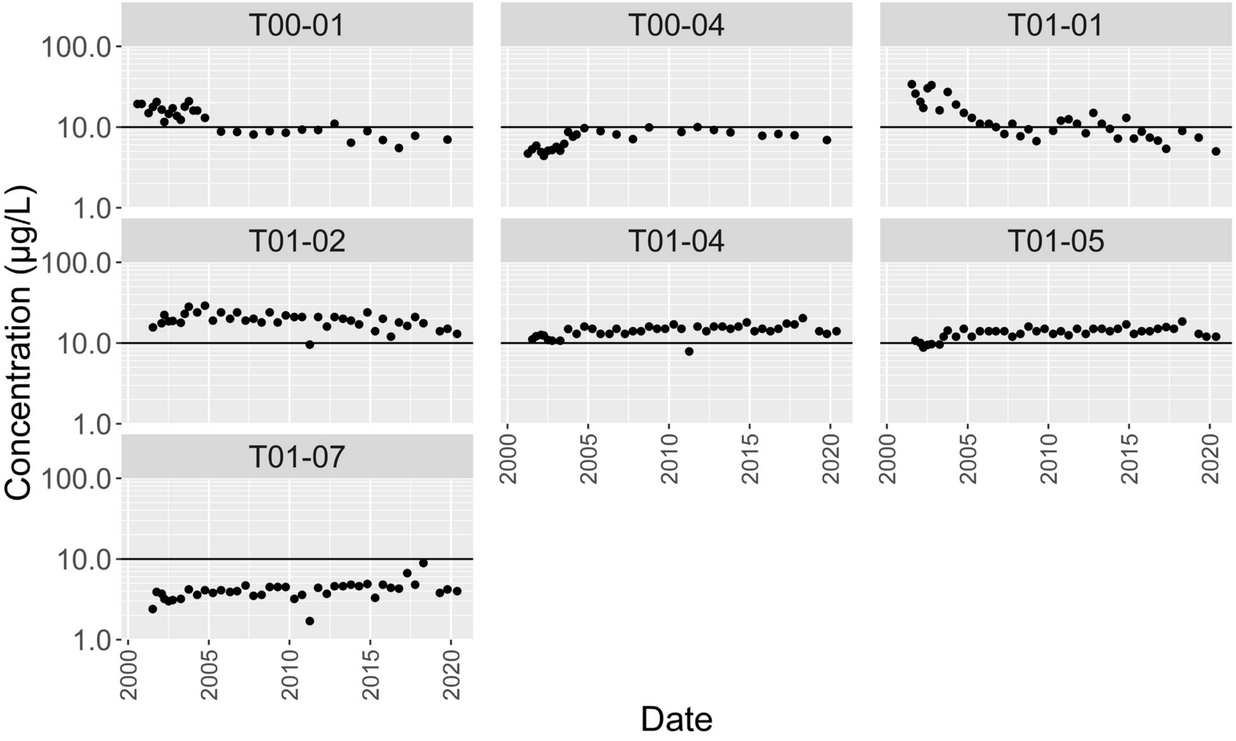
Monticello: Upstream Groundwater Wells (Arsenic)



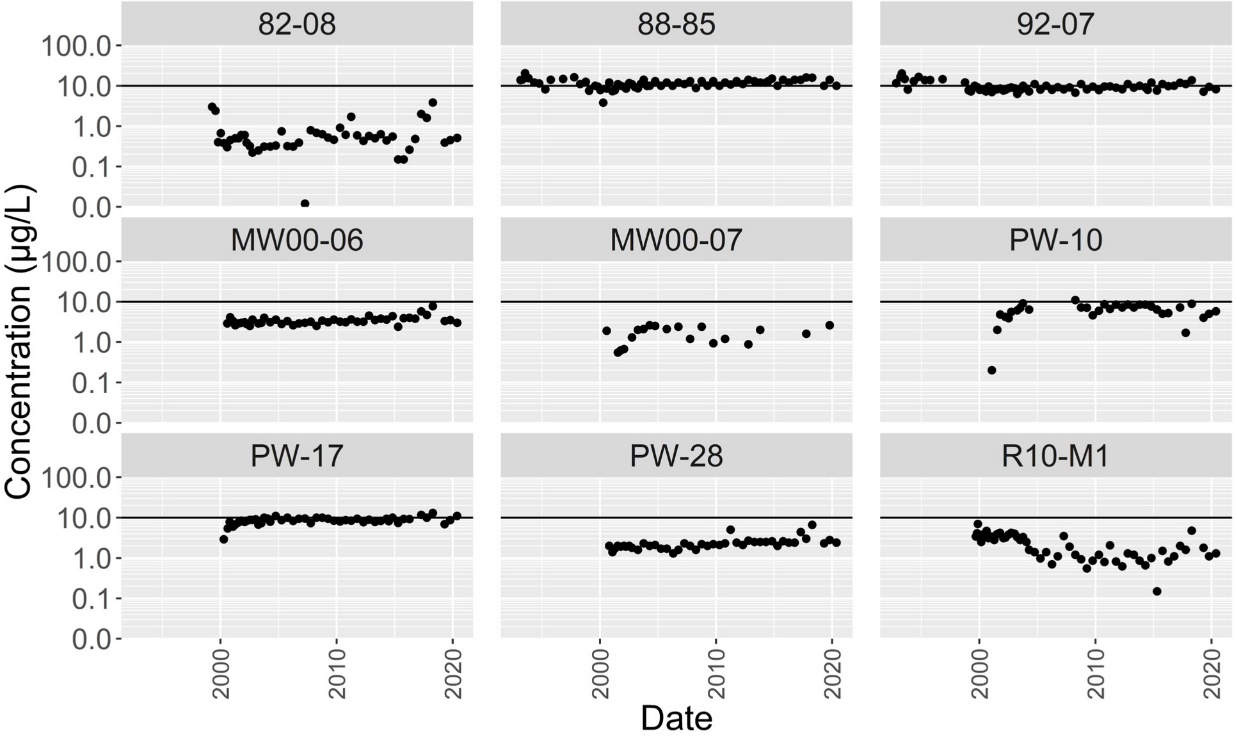
Monticello: Former Mill Site Groundwater Wells (Arsenic)



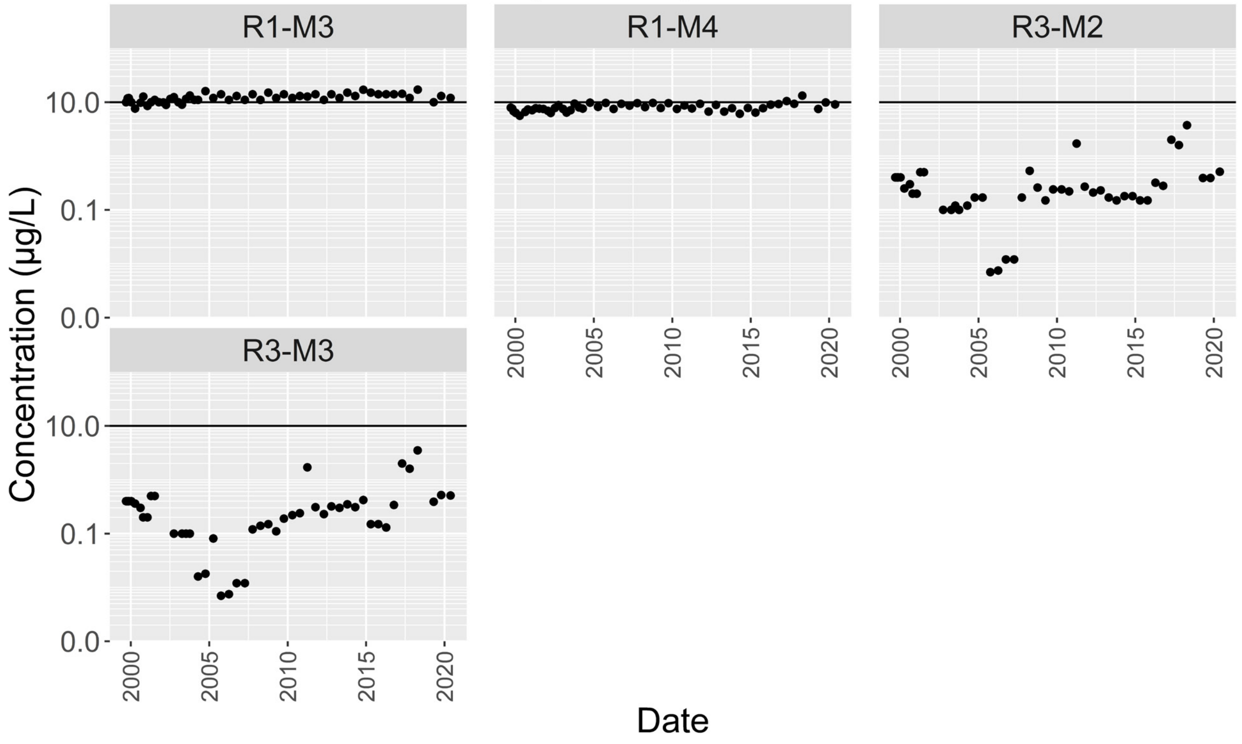
Monticello: Former Mill Site Wells (Arsenic)



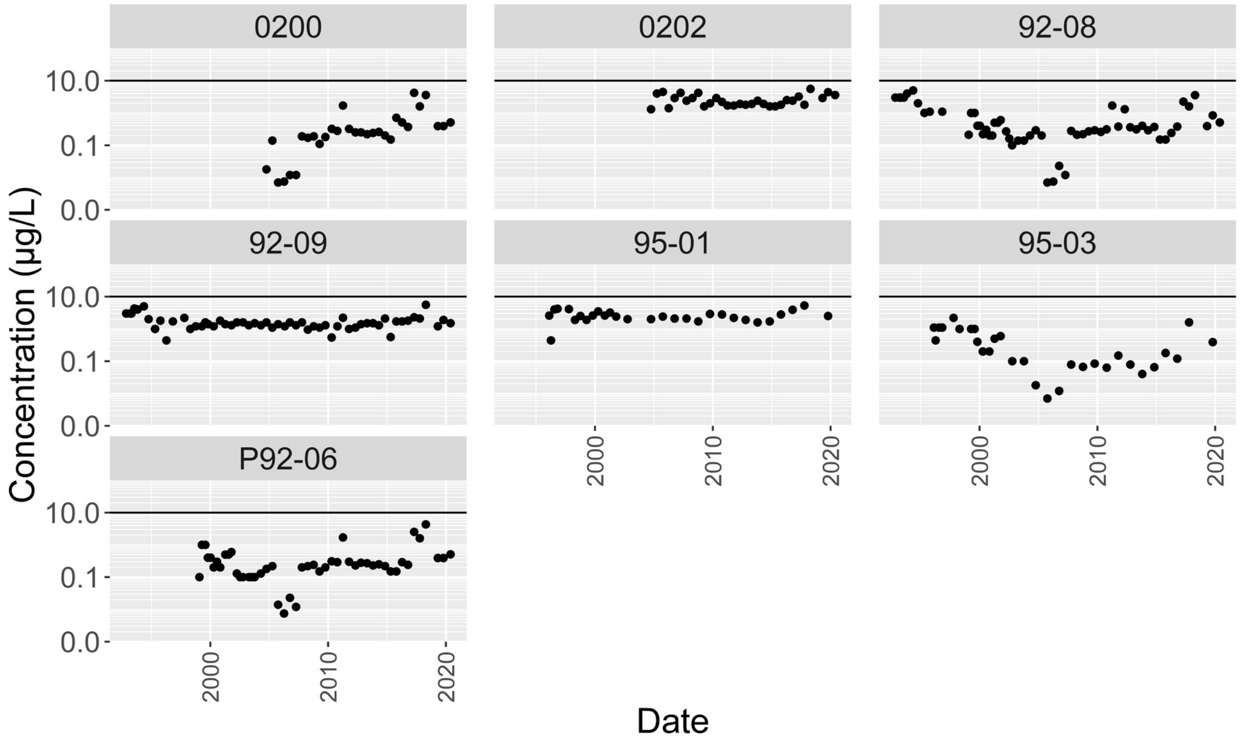
Monticello: Central Groundwater Wells (Arsenic)



Monticello: PRB Wells (Arsenic)



Monticello: Downstream Groundwater Wells (Arsenic)



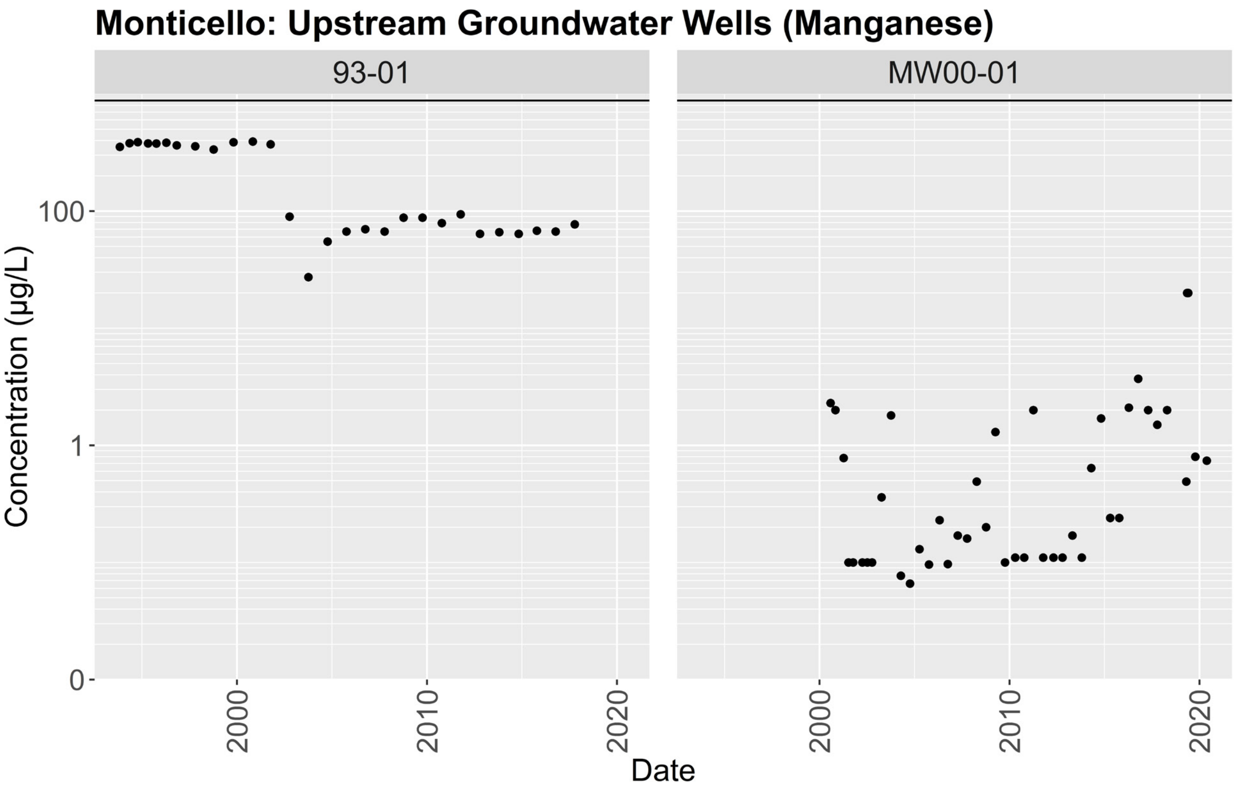
Manganese

Groundwater Remediation Goal: 880 µg/L

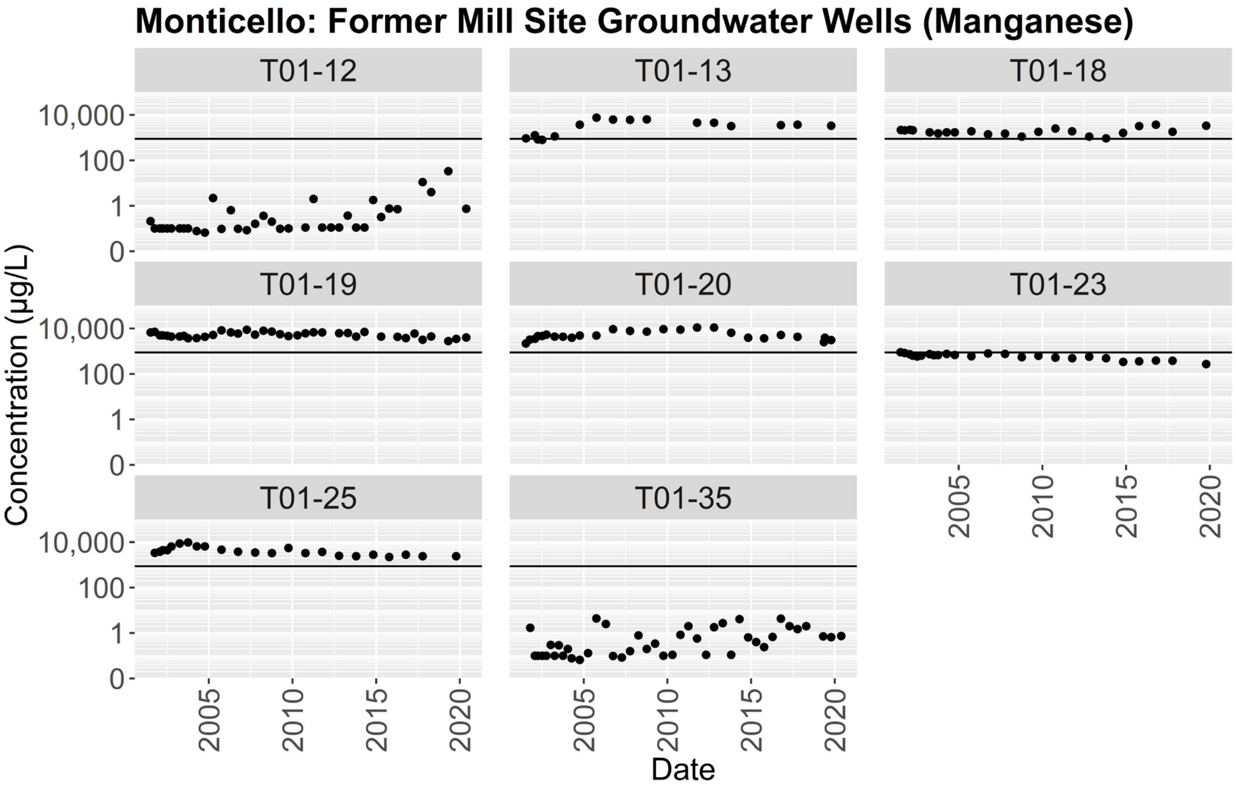
Sample Locations Are Shown in Figure 6

OU III Monitoring Wells Having Manganese Concentrations Above the Remediation Goal This Performance Period

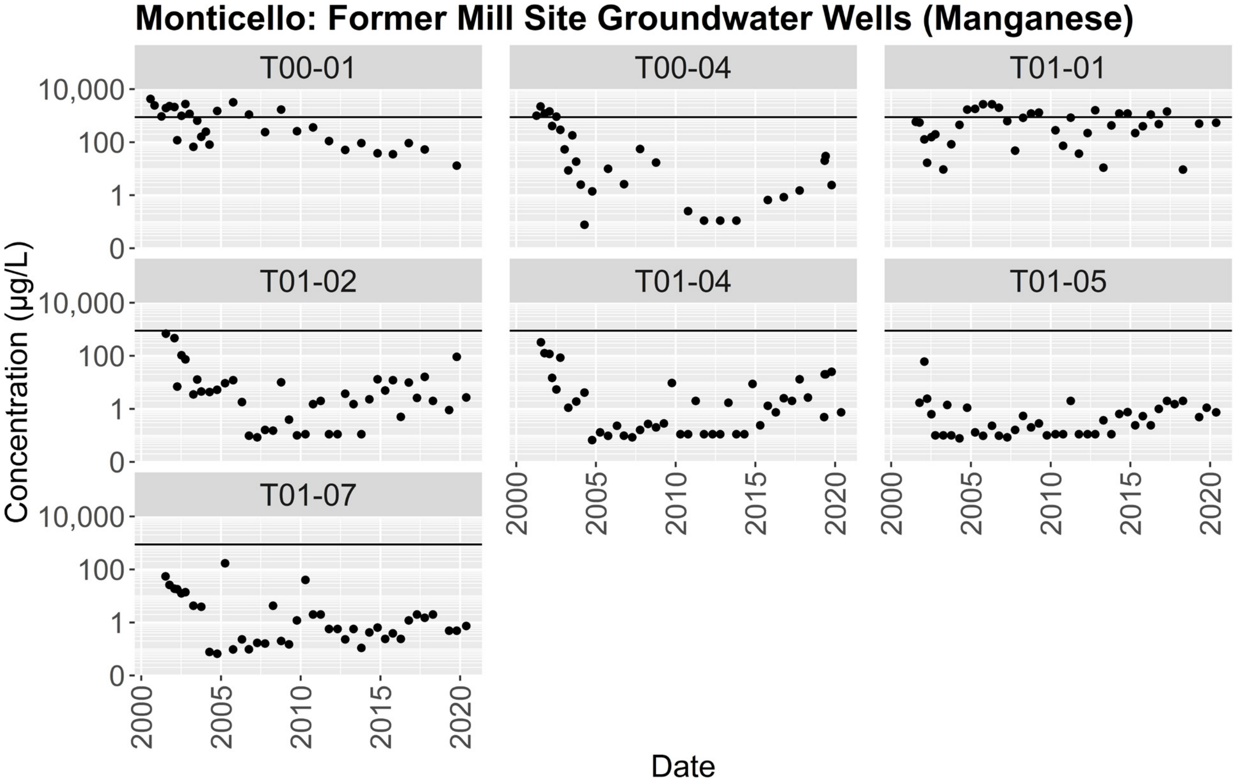
Well	Sample Date	Manganese Concentration (µg/L)
0200	5/8/2019	2500
MW-05	5/19/2020	880
MW-21	10/16/2019	5100
MW-21	5/20/2020	3100
T01-13	10/14/2019	3300
T01-18	10/15/2019	3300
T01-19	10/15/2019	3500
T01-20	5/7/2019	2500
T01-20	5/30/2019	3900
T01-20	10/14/2019	3100
T01-25	10/14/2019	2400

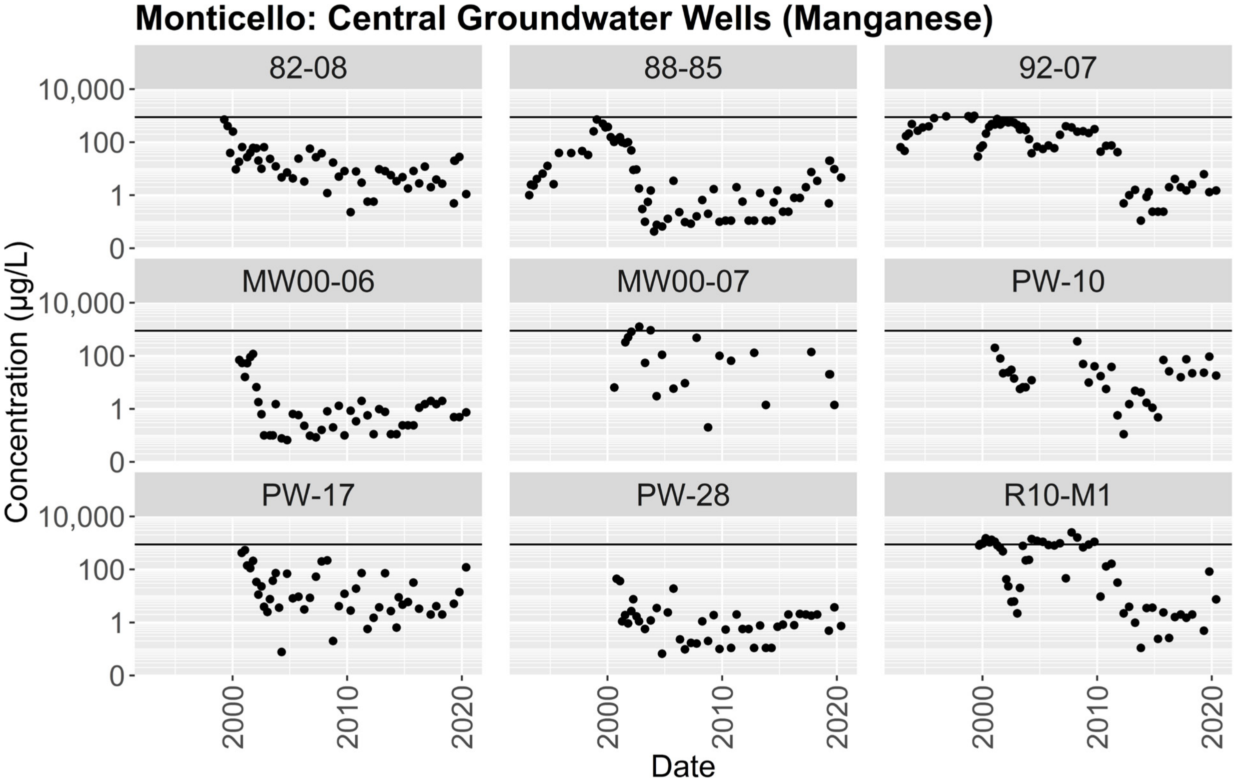


Monticello: Upstream Groundwater Wells (Manganese)
93-01
MW00-01
Concentration (µg/L)
100
1
0
2000
2010
2020
Date

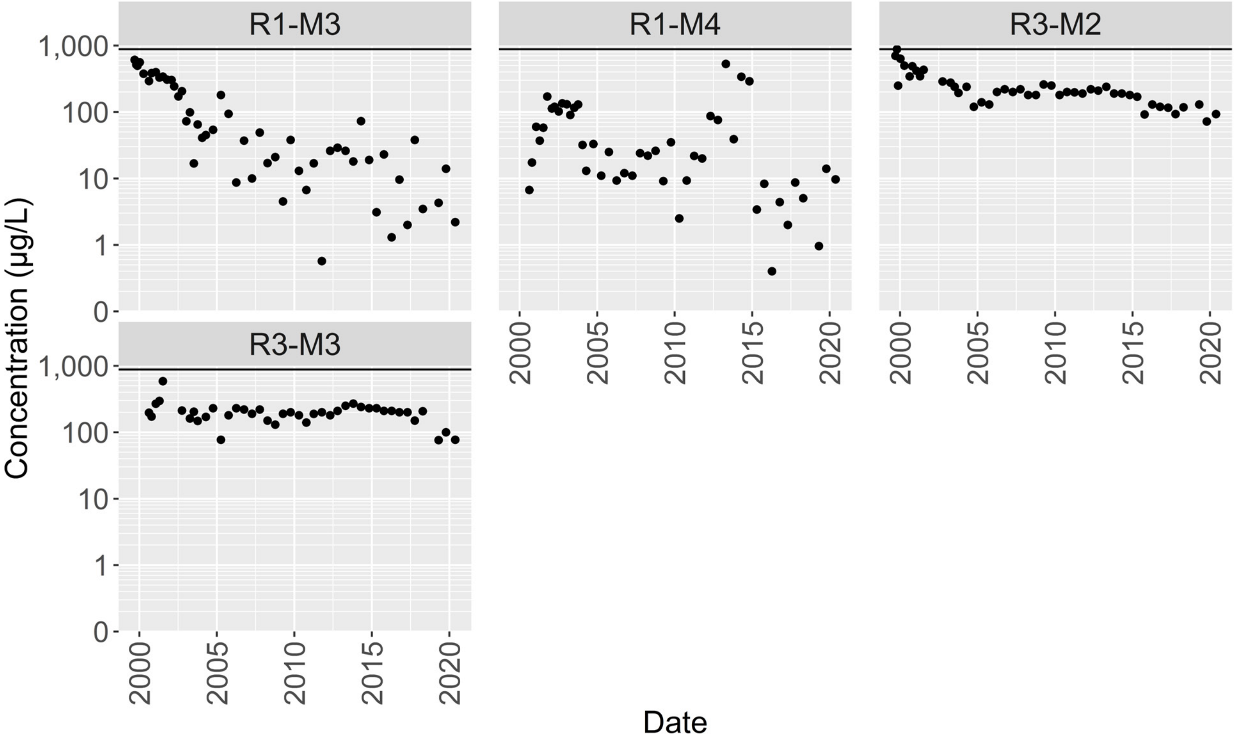


Monticello: Former Mill Site Groundwater Wells (Manganese)
T01-12
T01-13
T01-18
T01-19
T01-20
T01-23
T01-25
T01-35
Concentration (µg/L)
10,000
100
1
0
2005
2010
2015
2020
Date

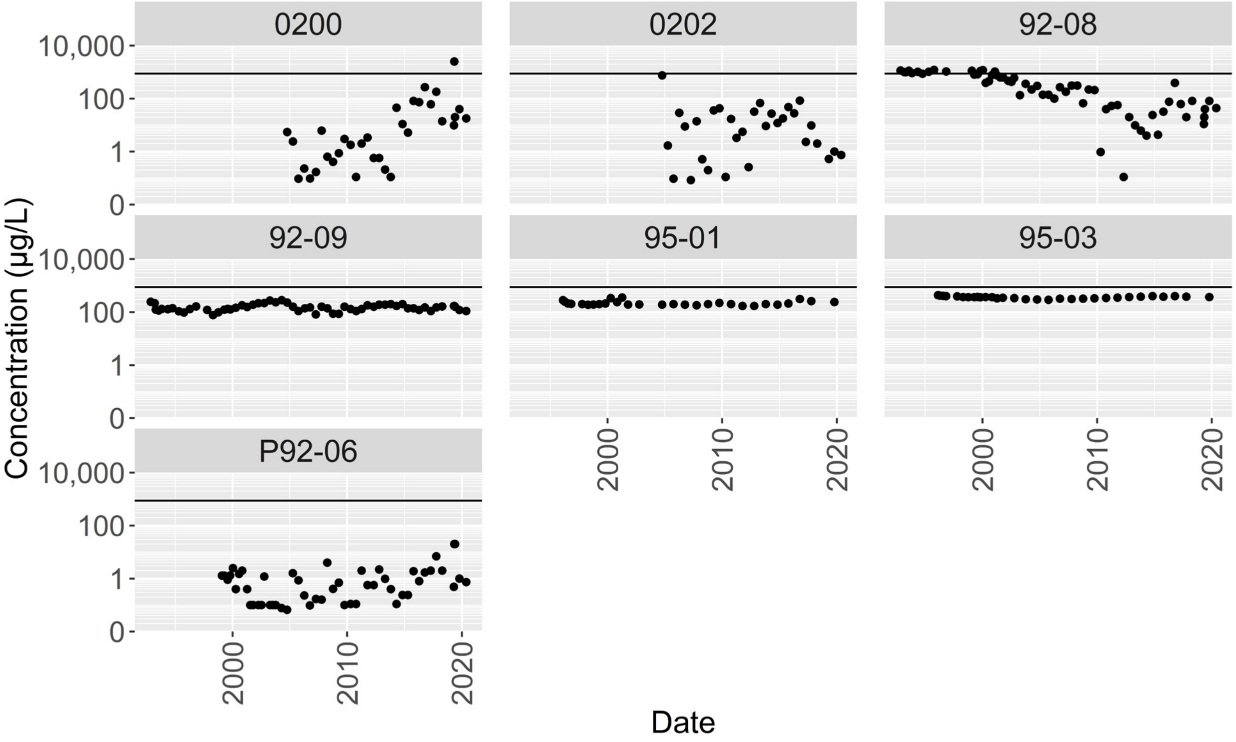

Monticello: Former Mill Site Groundwater Wells (Manganese)


Monticello: Central Groundwater Wells (Manganese)

Monticello: PRB Wells (Manganese)



Monticello: Downstream Groundwater Wells (Manganese)



Molybdenum

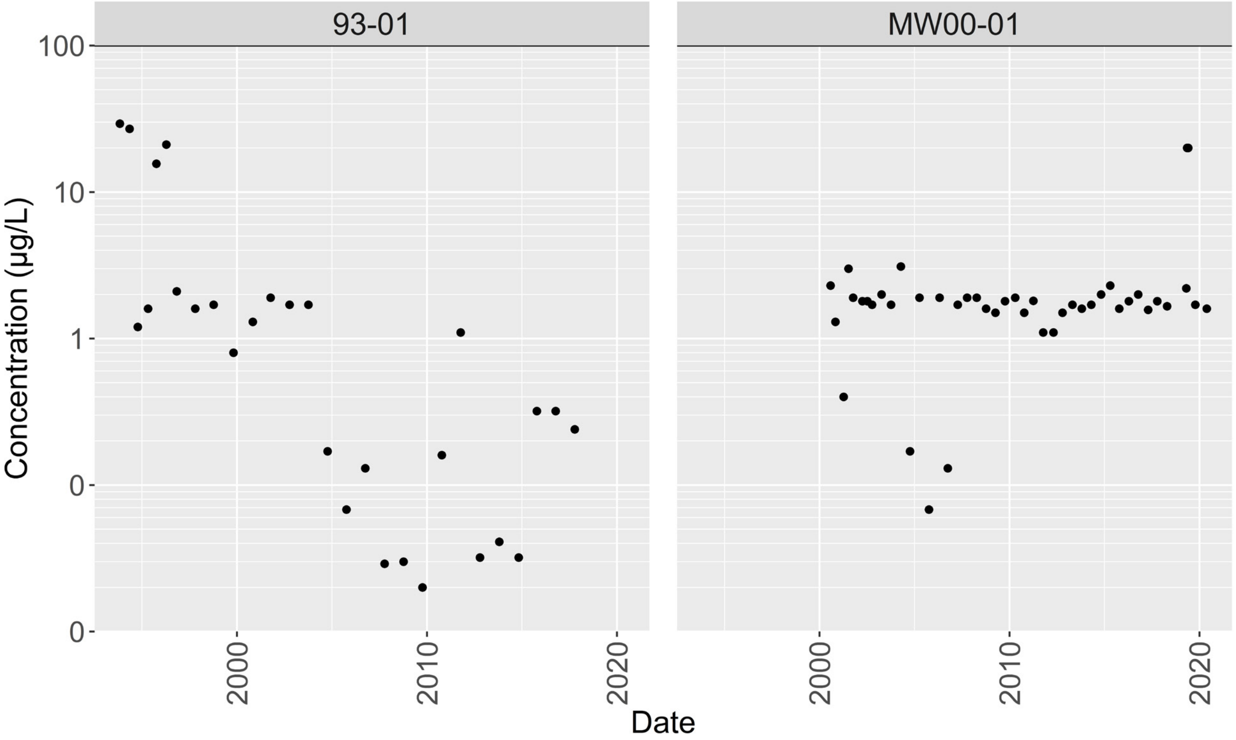
Groundwater Remediation Goal: 100 µg/L

Sample Locations Are Shown in Figure 6

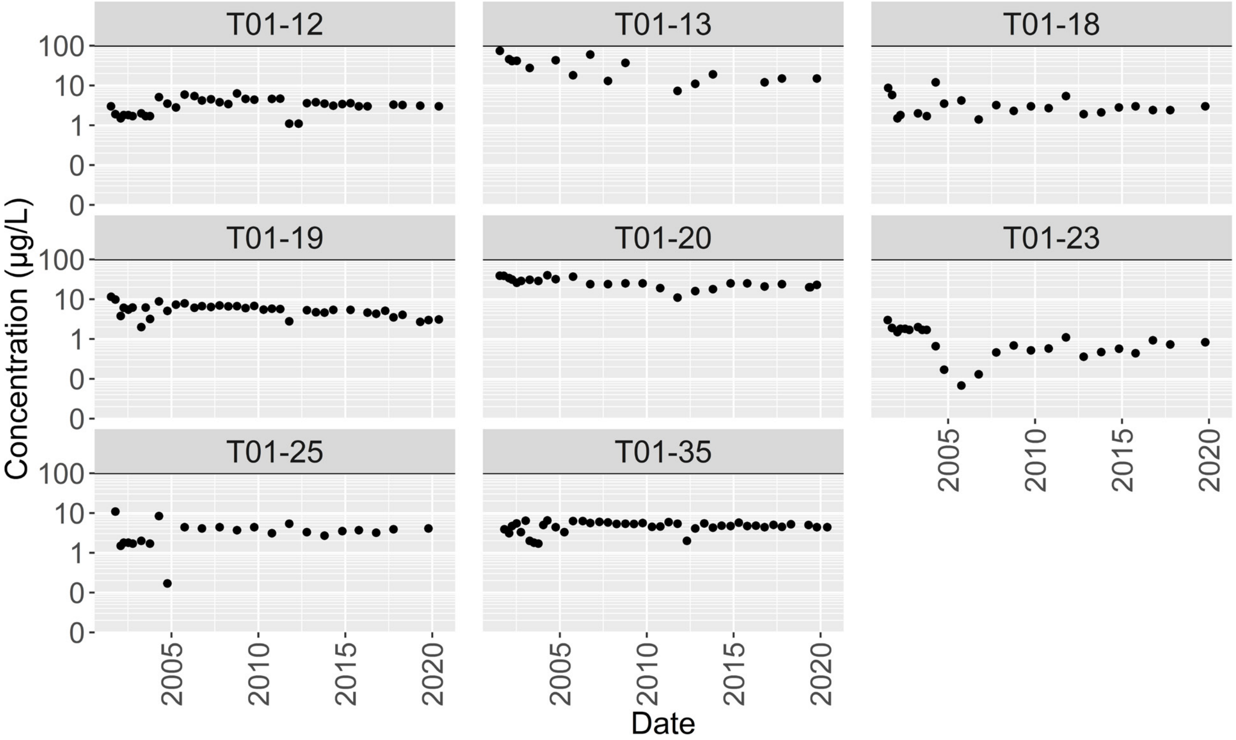
OU III Monitoring Wells Having Molybdenum Concentrations Above the Remediation Goal This Performance Period

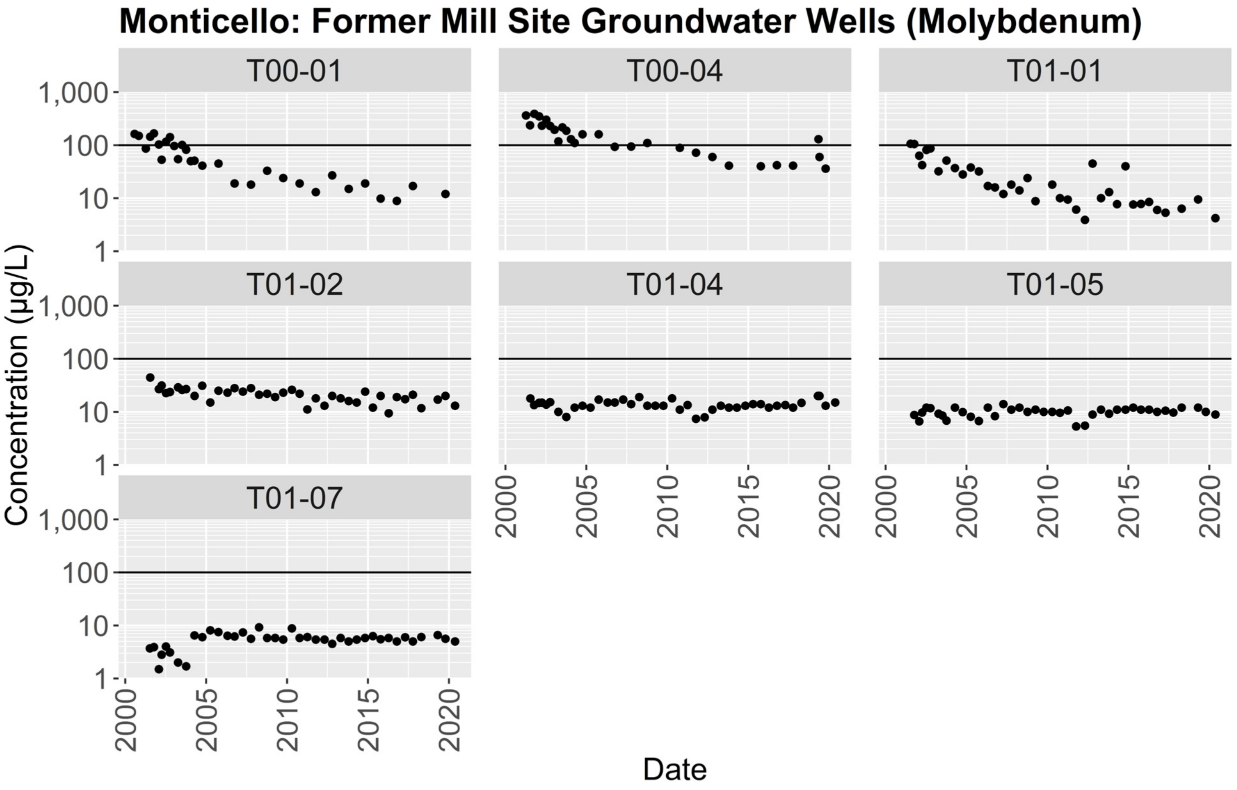
Well	Sample Date	Manganese Concentration (µg/L)
MW-03	10/16/2019	110
MW-04	10/16/2019	210
MW-04	5/18/2020	170
MW-08	10/16/2019	120
MW-08	5/19/2020	100
MW-17	5/18/2020	130
T00-04	5/7/2019	130

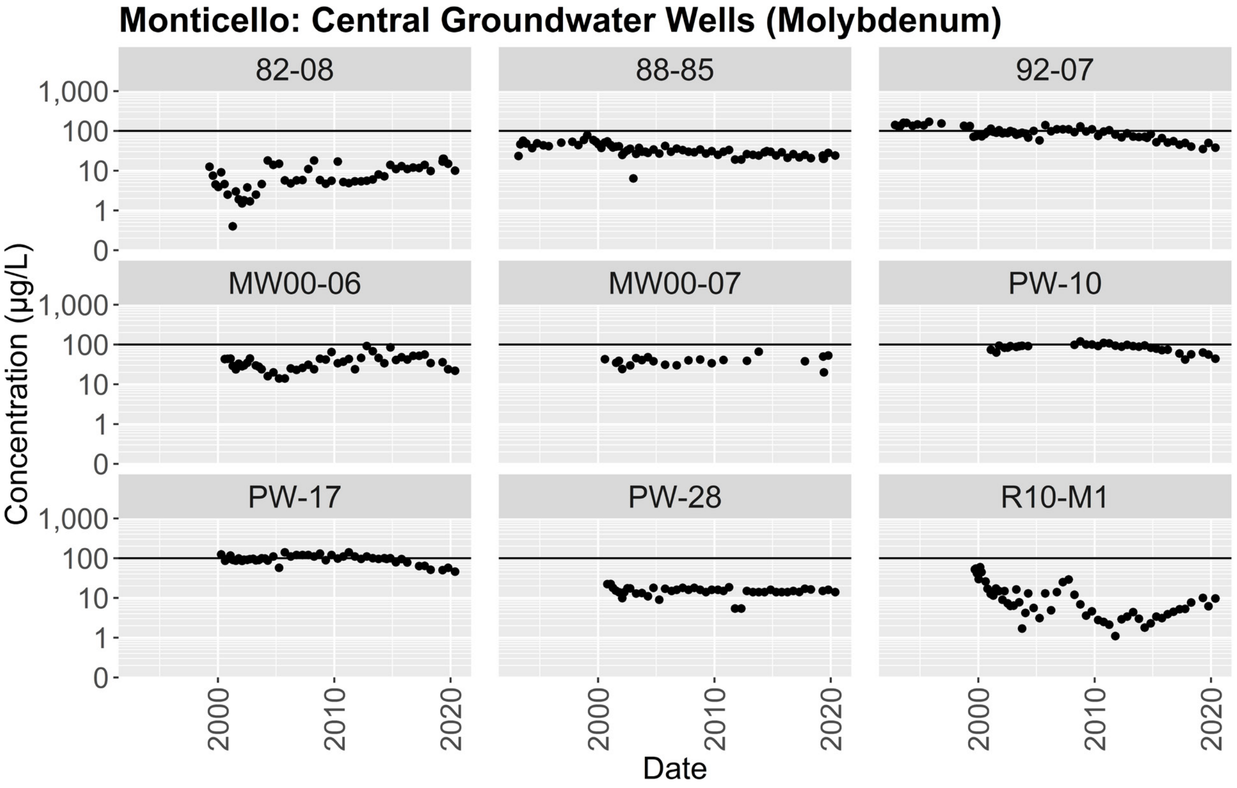
Monticello: Upstream Groundwater Wells (Molybdenum)

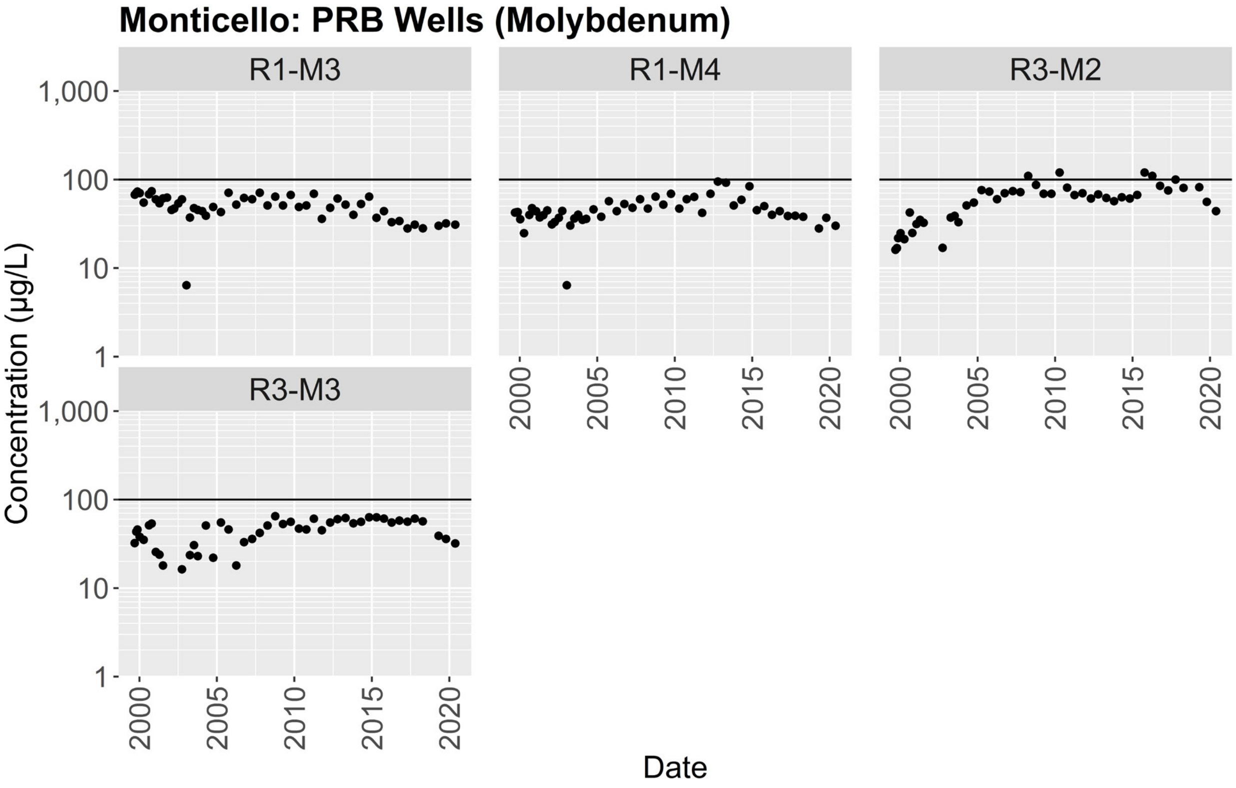


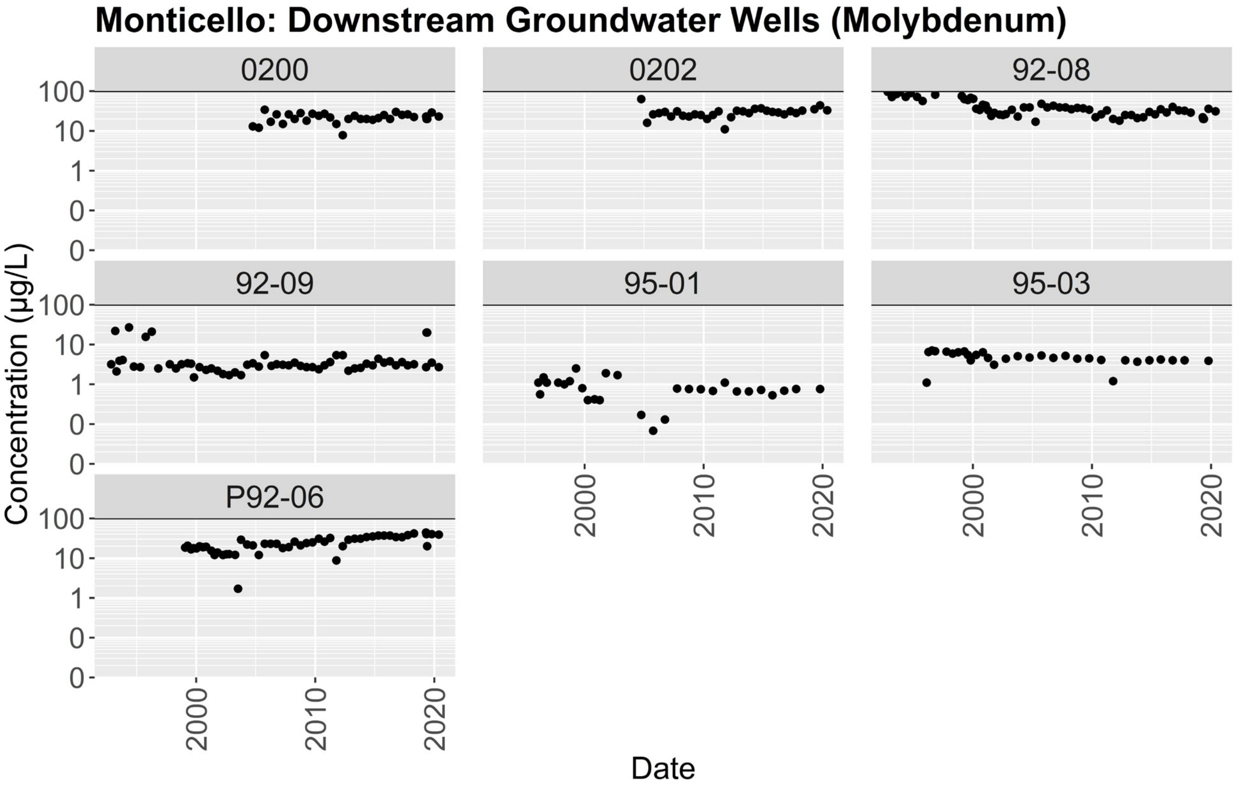
Monticello: Former Mill Site Groundwater Wells (Molybdenum)




Monticello: Former Mill Site Groundwater Wells (Molybdenum)
T00-01
T00-04
T01-01
T01-02
T01-04
T01-05
T01-07
Concentration (µg/L)
1,000
100
10
1
2000
2005
2010
2015
2020
Date


Monticello: Central Groundwater Wells (Molybdenum)
82-08
88-85
92-07
MW00-06
MW00-07
PW-10
PW-17
PW-28
R10-M1
Concentration (µg/L)
1,000
100
10
1
0
2000
2010
2020
Date


Monticello: PRB Wells (Molybdenum)


Monticello: Downstream Groundwater Wells (Molybdenum)

Nitrate

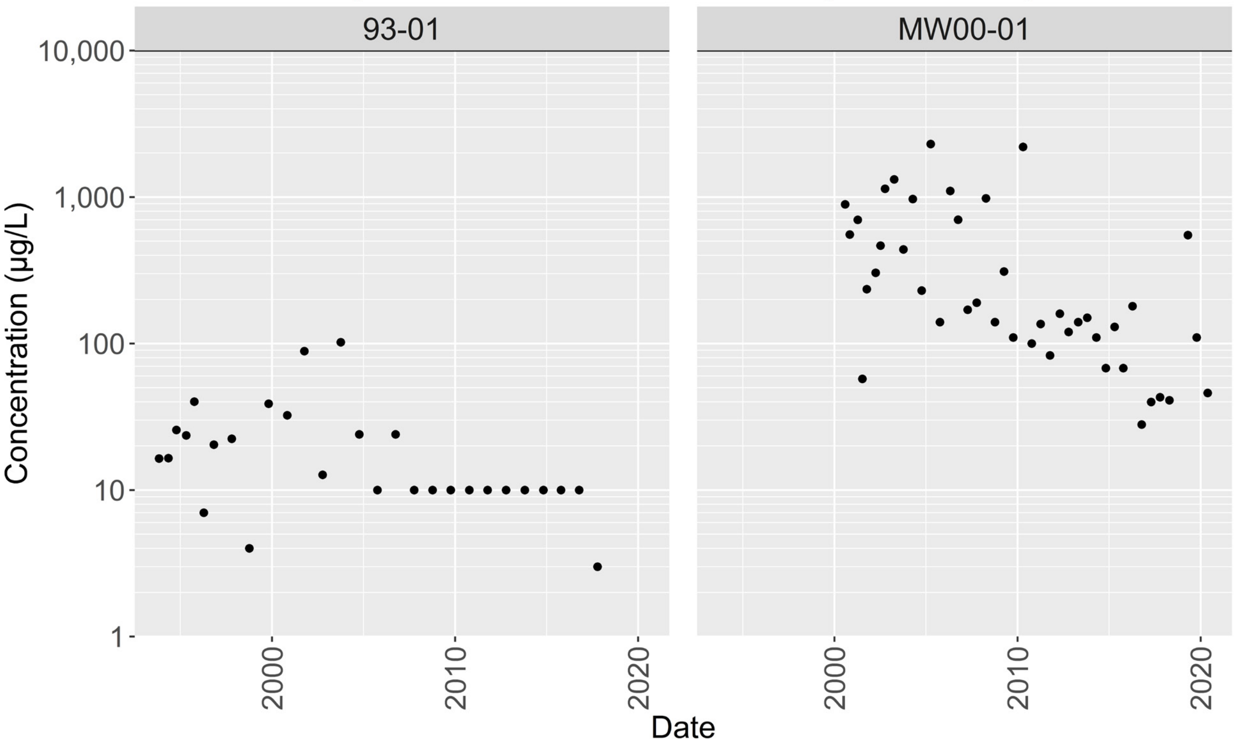
Groundwater Remediation Goal: 10,000 µg/L

Sample Locations Are Shown in Figure 6

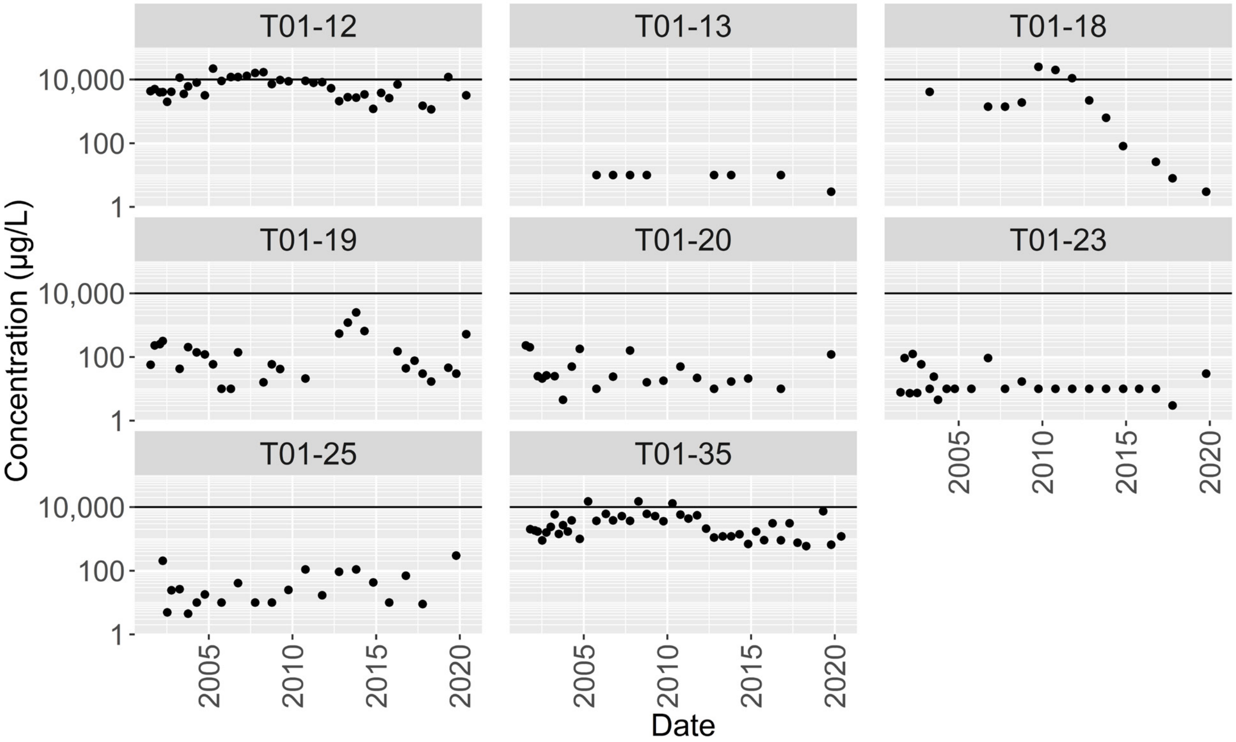
OU III Monitoring Wells Having Nitrate Concentrations Above the Remediation Goal This Performance Period

Well	Sample Date	Nitrate Concentration (µg/L)
0200	5/30/2019	14,000
MW00-07	5/7/2019	14,000

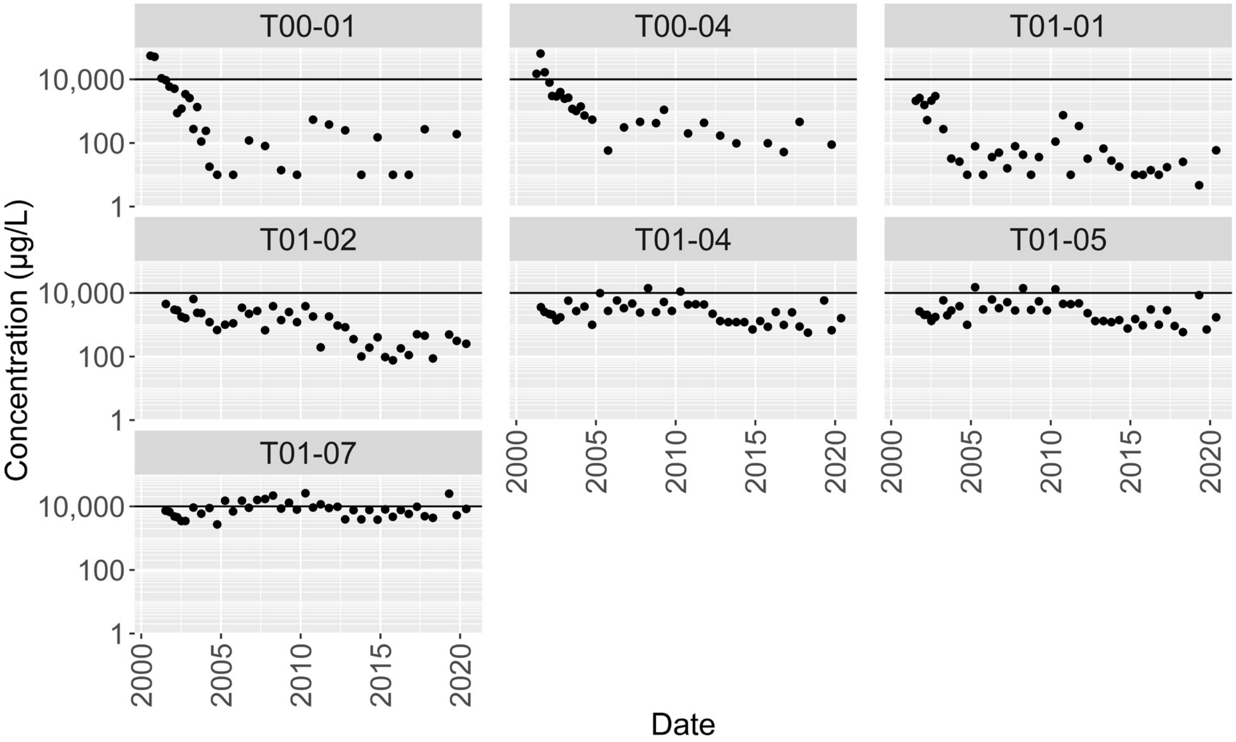
Monticello: Upstream Groundwater Wells (Nitrate as N)



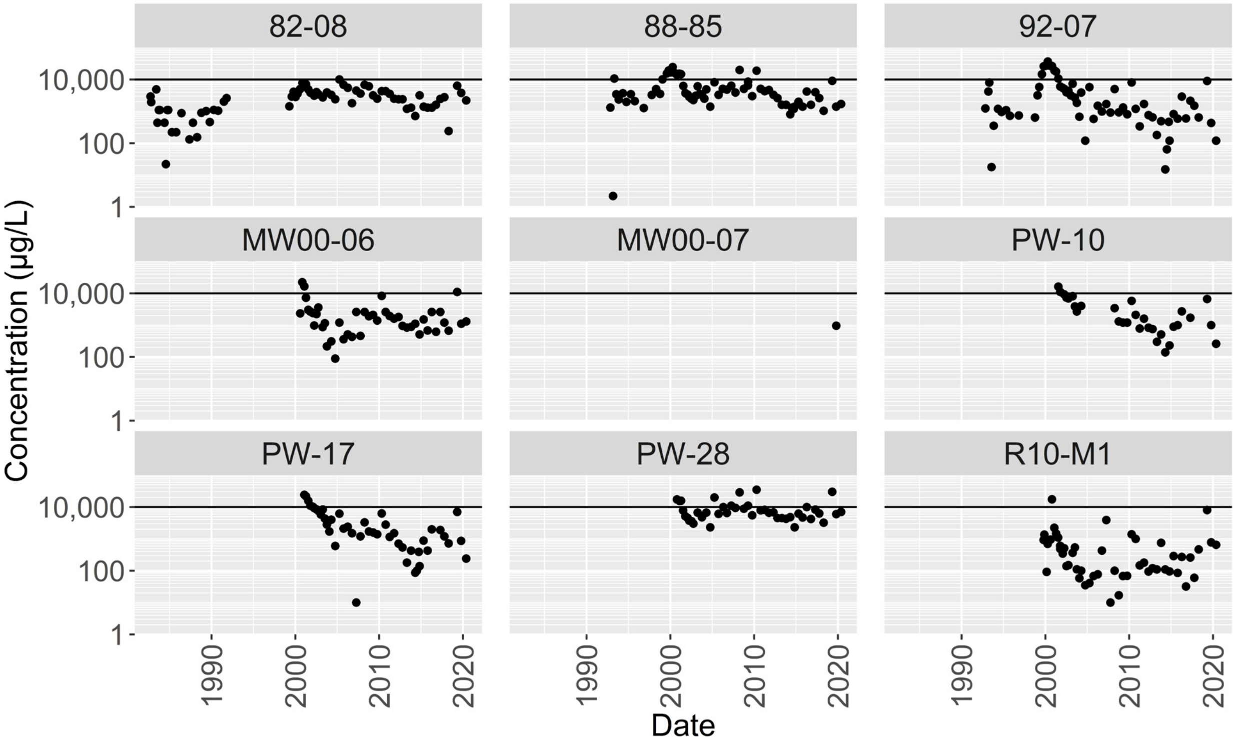
Monticello: Former Mill Site Groundwater Wells (Nitrate as N)



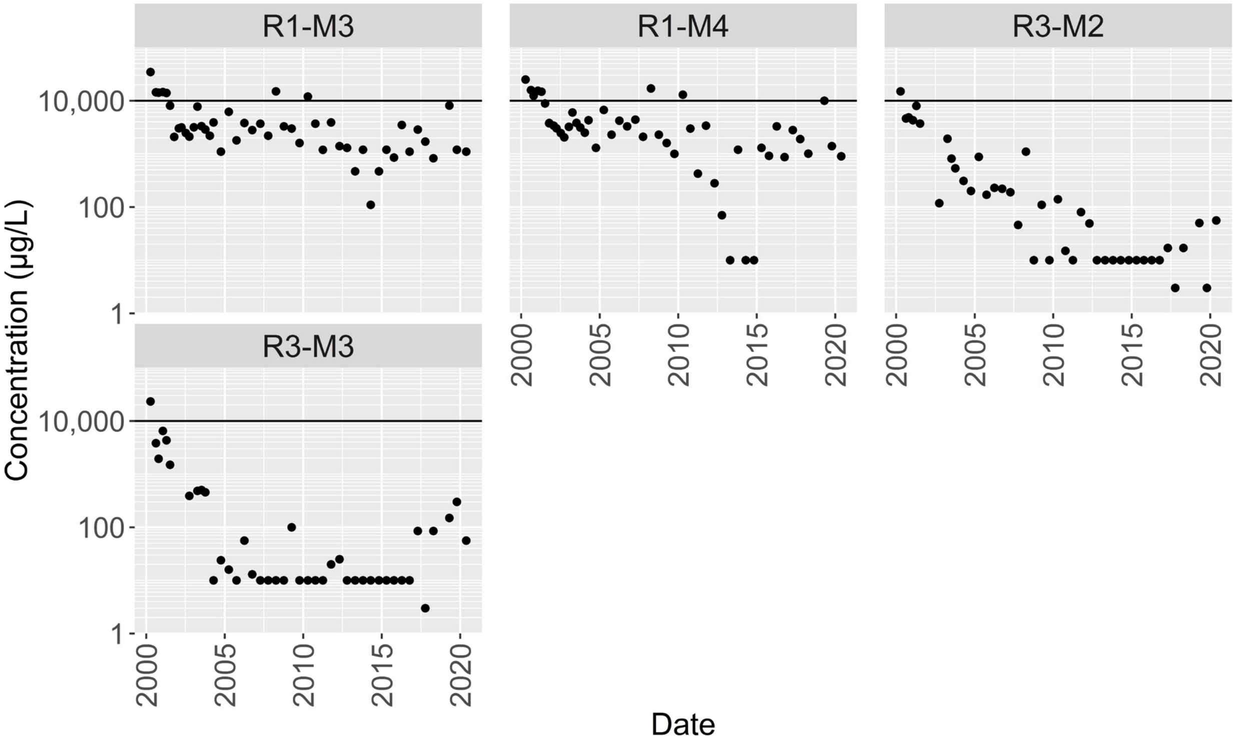
Monticello: Former Mill Site Groundwater Wells (Nitrate as N)



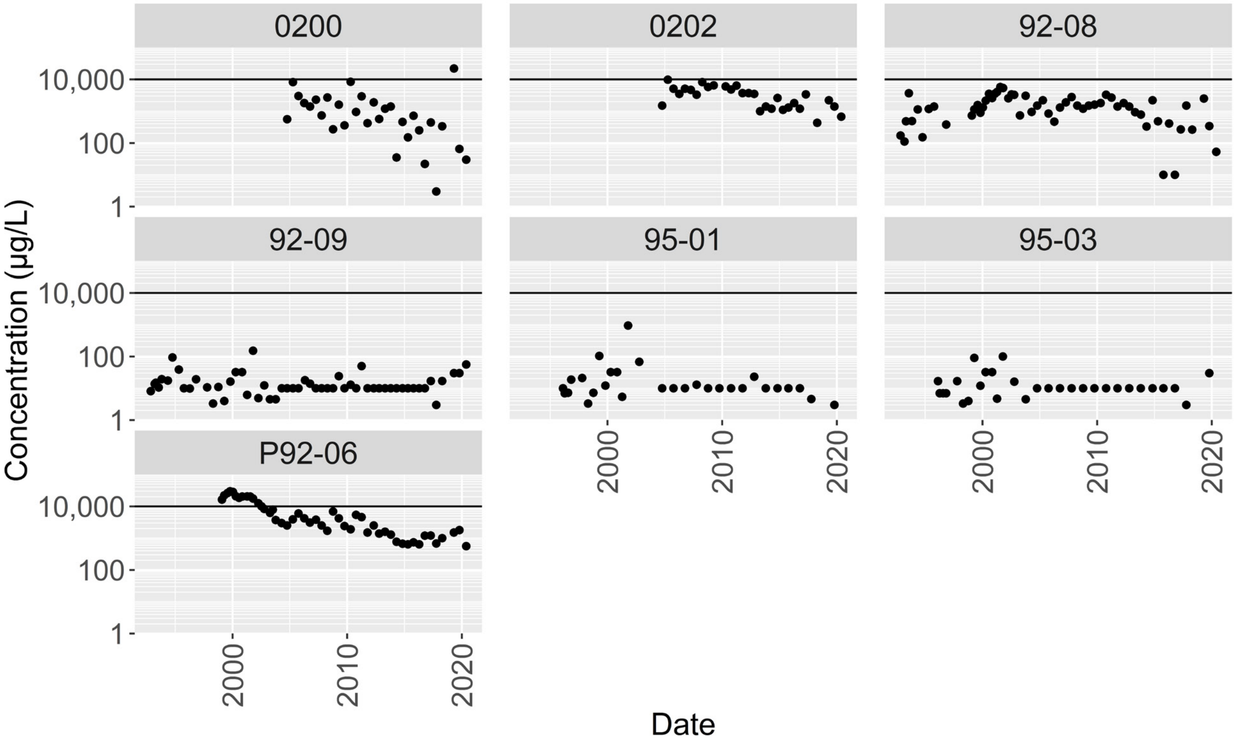
Monticello: Central Groundwater Wells (Nitrate as N)



Monticello: PRB Wells (Nitrate as N)



Monticello: Downstream Groundwater Wells (Nitrate as N)



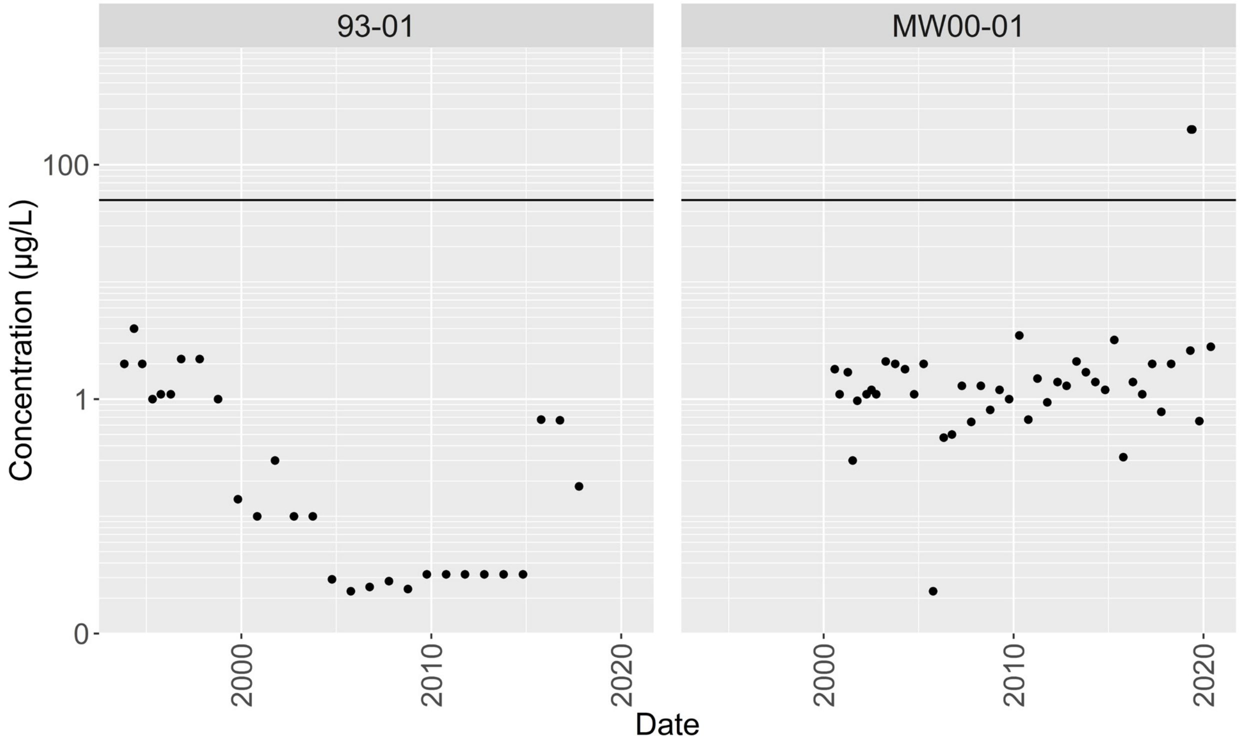
Selenium

Groundwater Remediation Goal: 50 µg/L

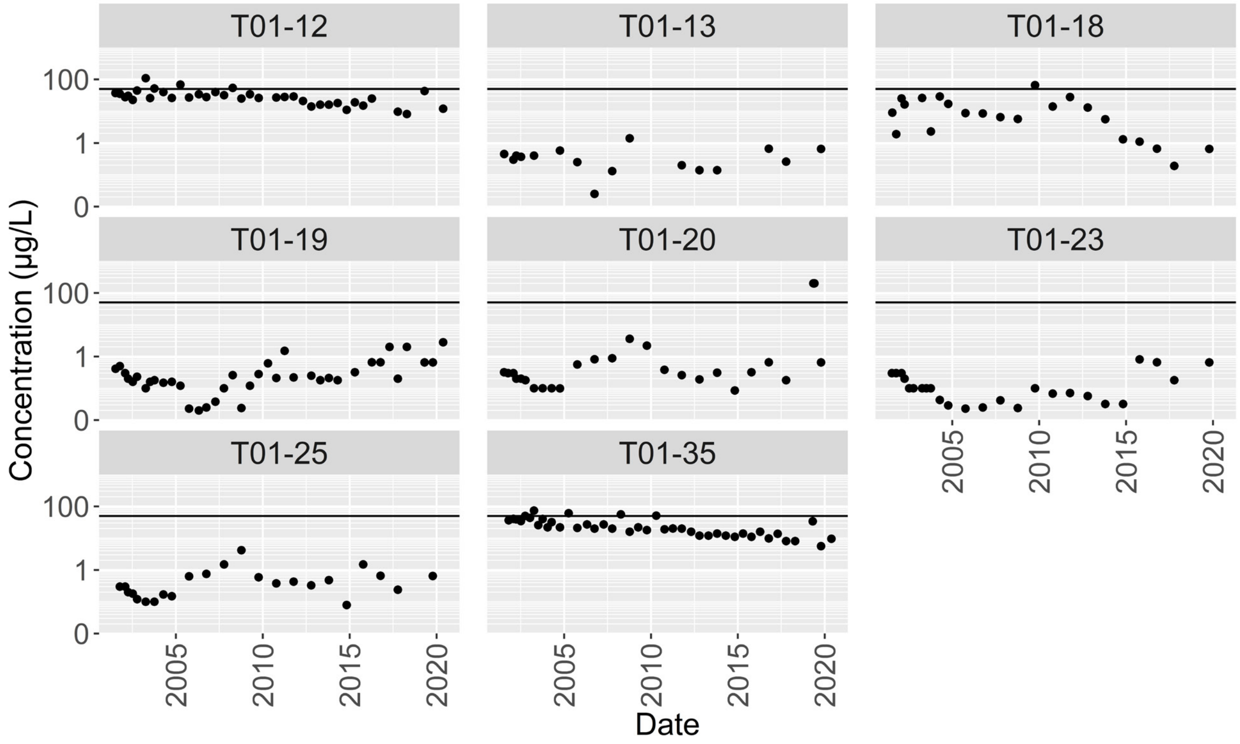
Sample Locations Are Shown in Figure 6

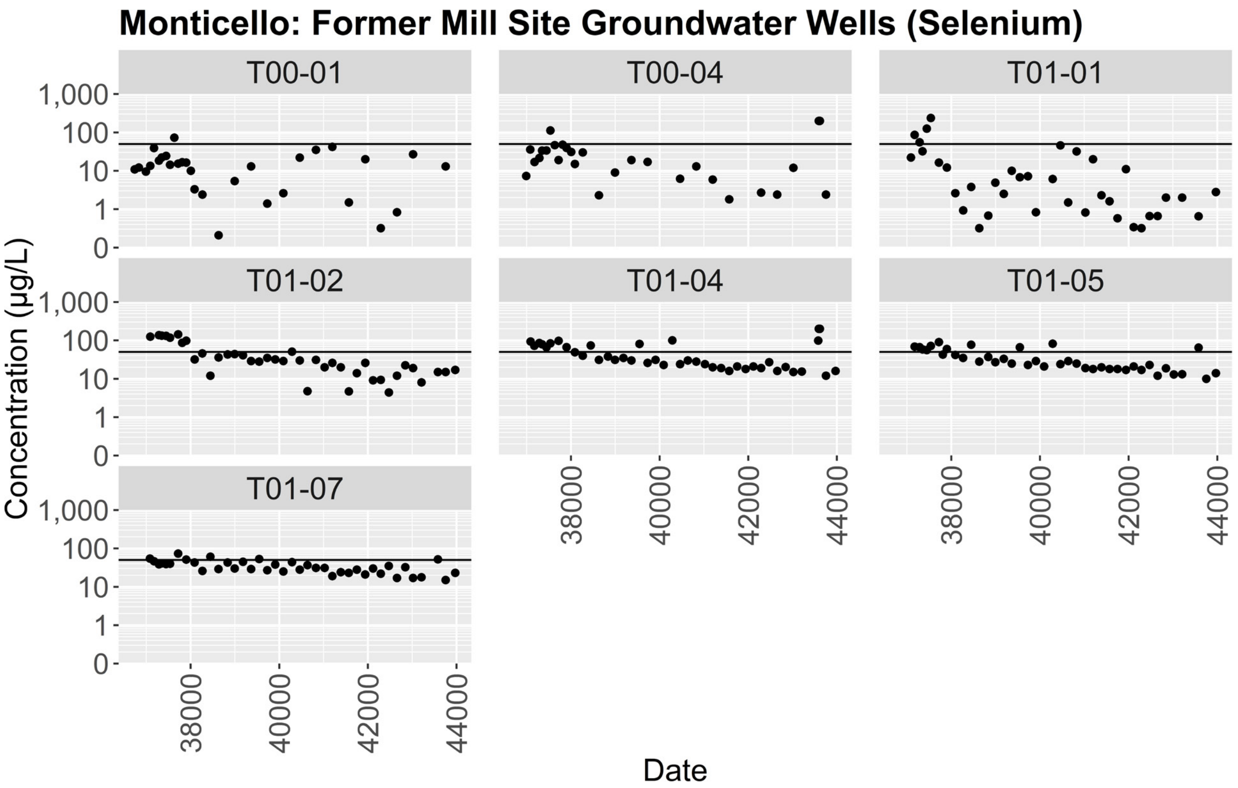
None of the OU III Monitoring Wells Have Concentrations Above the Remediation Goal This Performance Period

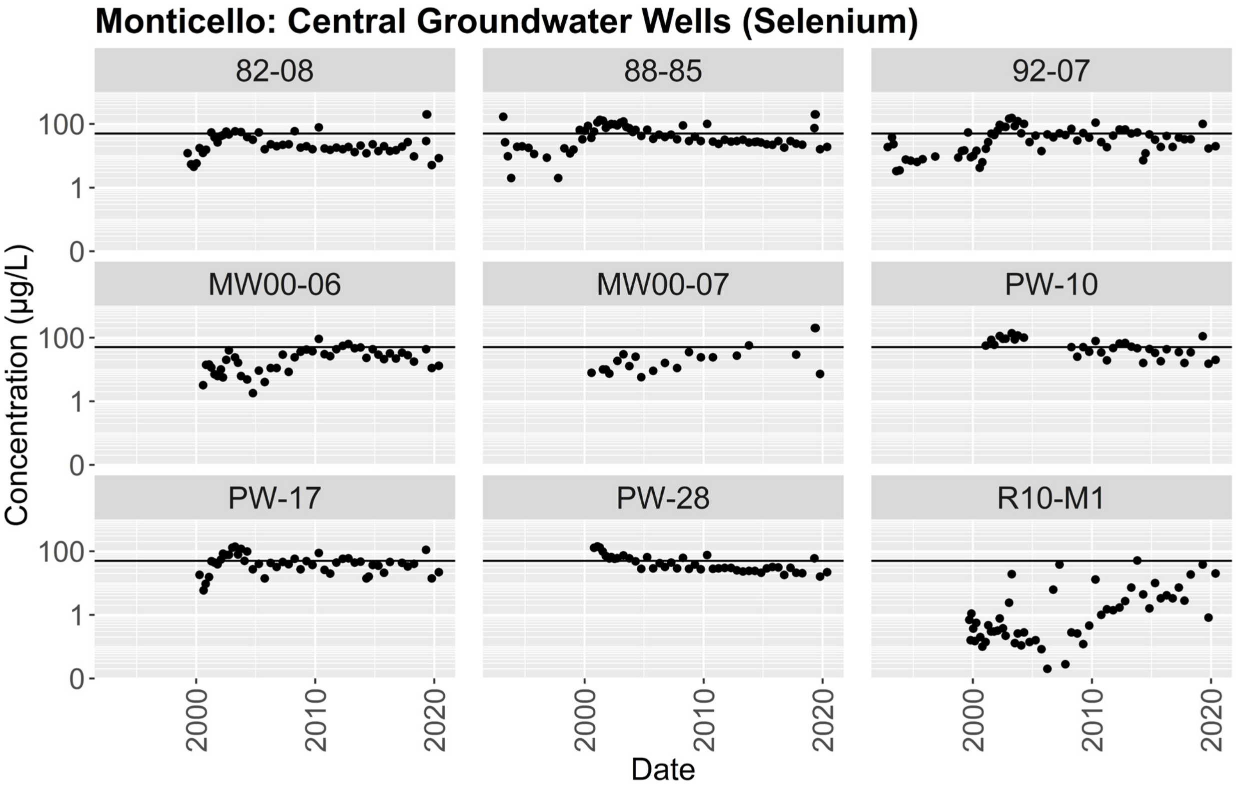
Monticello: Upstream Groundwater Wells (Selenium)



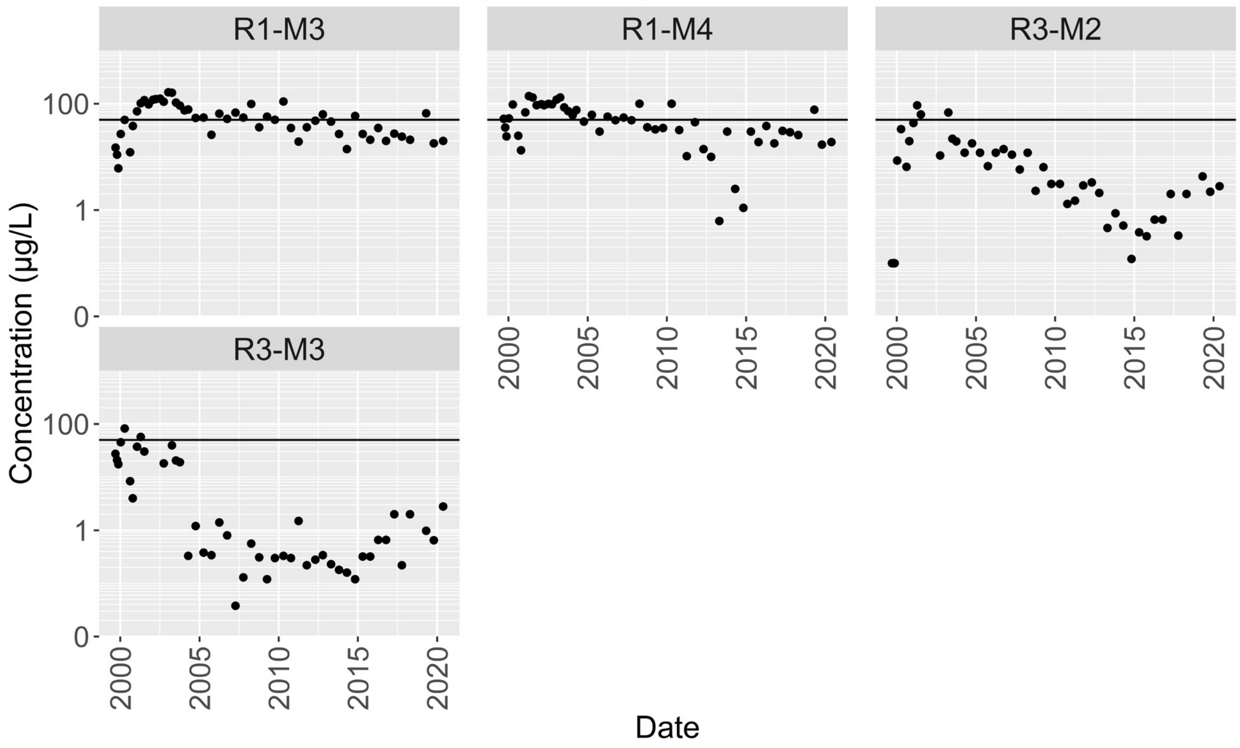
Monticello: Former Mill Site Groundwater Wells (Selenium)



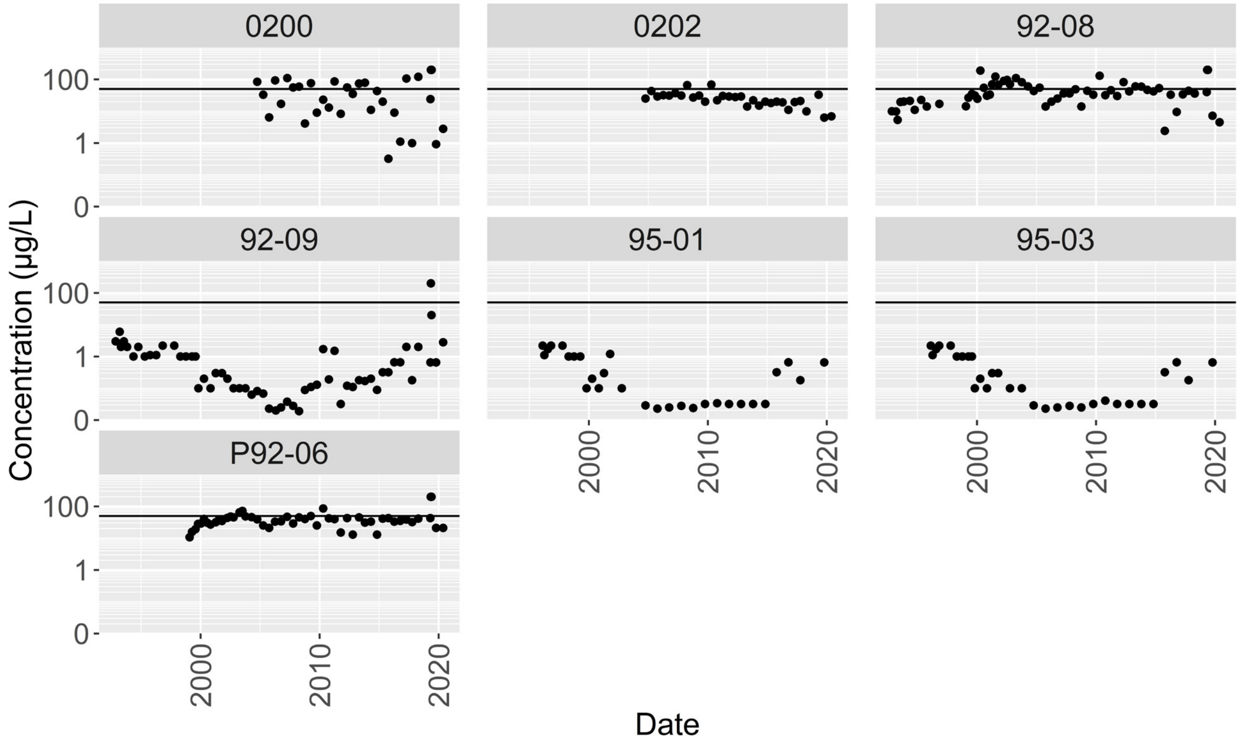

Monticello: Former Mill Site Groundwater Wells (Selenium)
T00-01
T00-04
T01-01
T01-02
T01-04
T01-05
T01-07
Concentration (µg/L)
1,000
100
10
1
0
38000
40000
42000
44000
Date


Monticello: Central Groundwater Wells (Selenium)
82-08
88-85
92-07
MW00-06
MW00-07
PW-10
PW-17
PW-28
R10-M1
Concentration (µg/L)
100
1
0
2000
2010
2020
Date

Monticello: PRB Wells (Selenium)



Monticello: Downstream Groundwater Wells (Selenium)



Vanadium

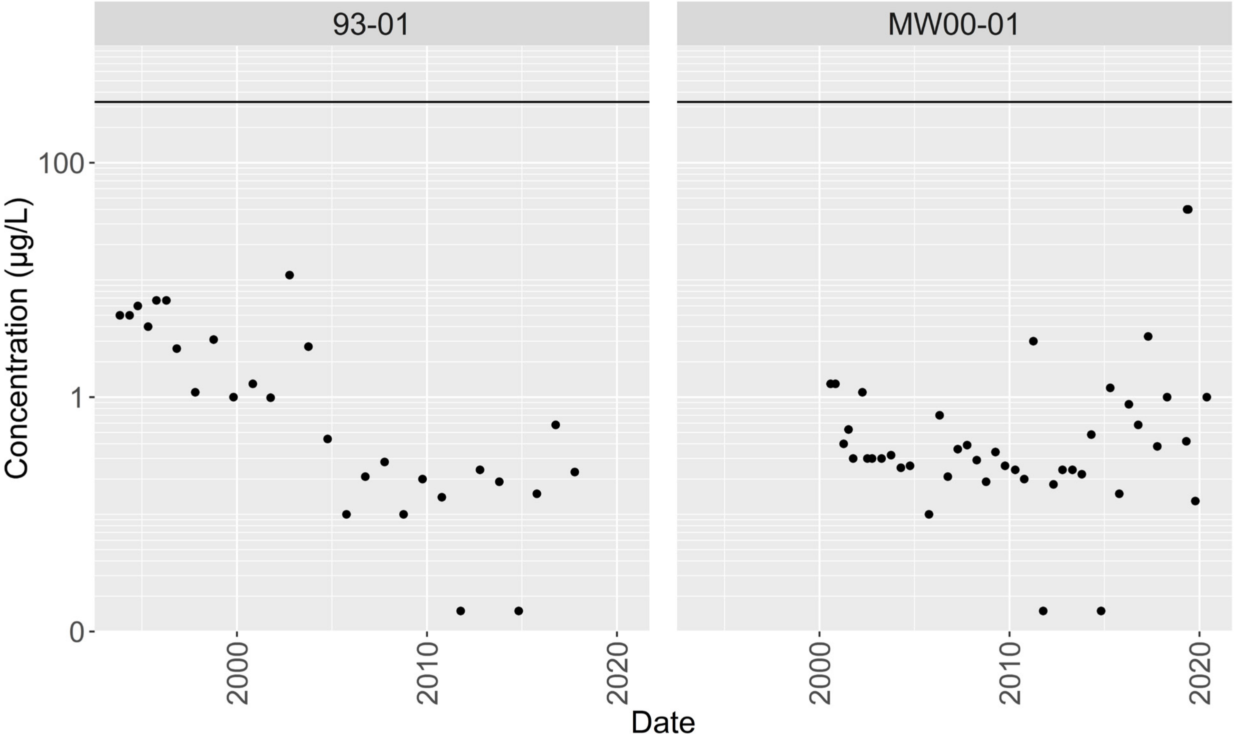
Groundwater Remediation Goal: 330 µg/L

Sample Locations Are Shown in Figure 6

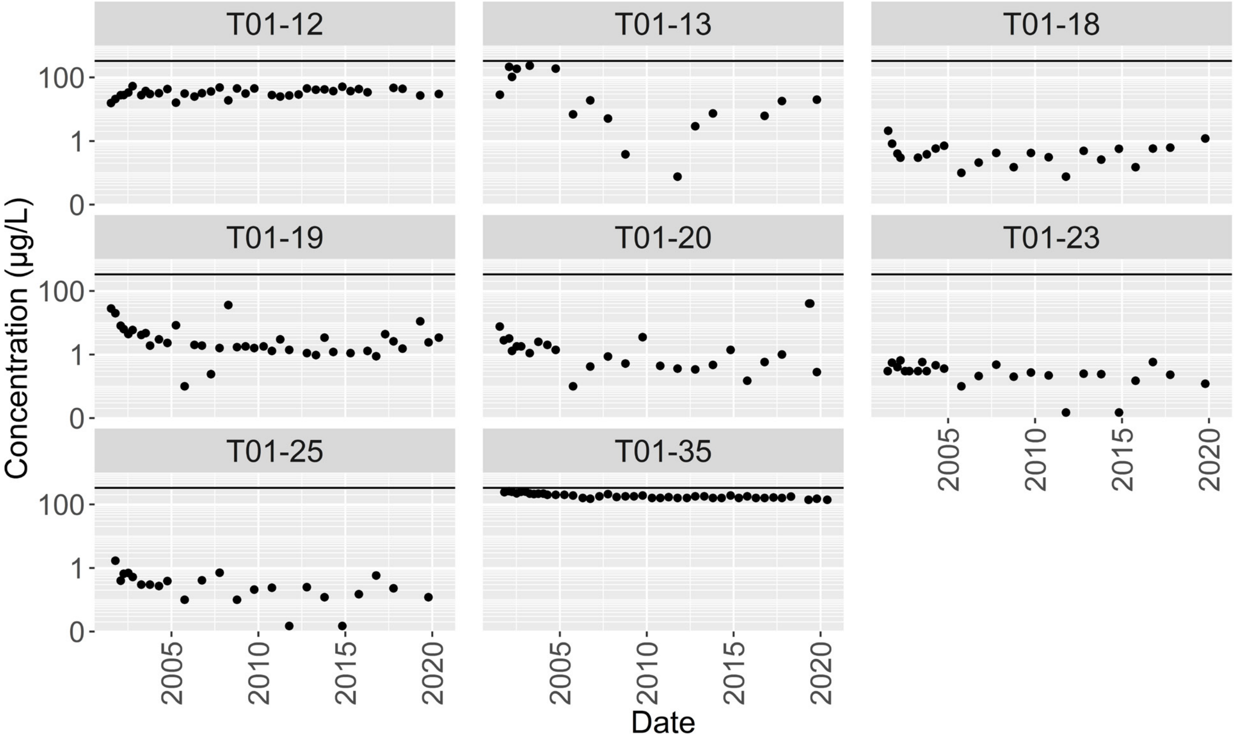
OU III Monitoring Wells Having Concentrations Above the Remediation Goal This Performance Period

Well	Sample Date	Vanadium Concentration (µg/L)
88-85	10/15/2019	340

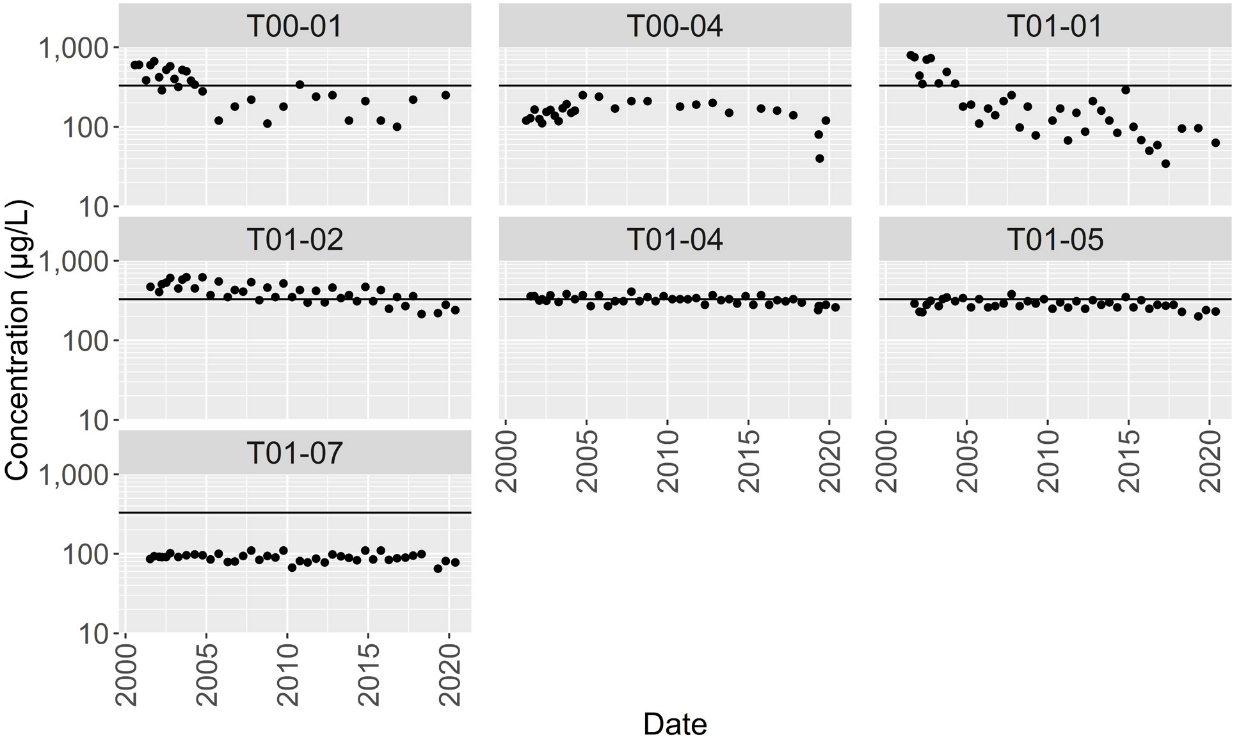
Monticello: Upstream Groundwater Wells (Vanadium)



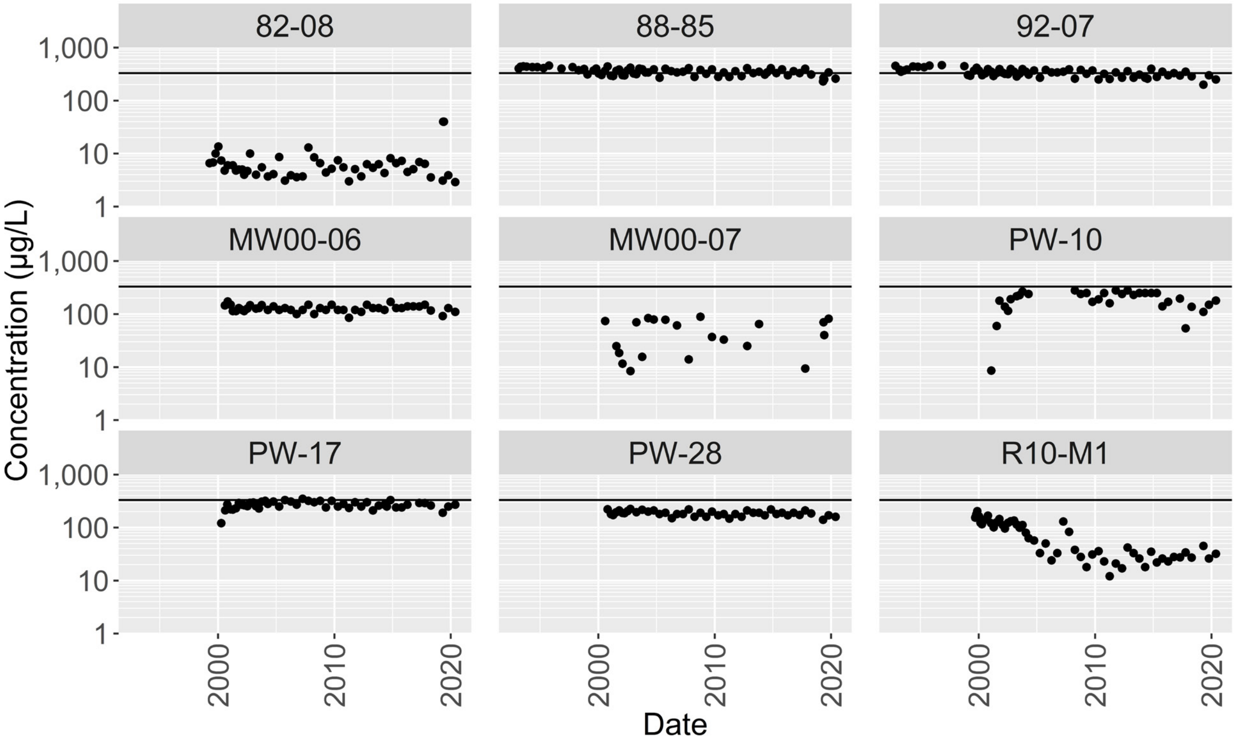
Monticello: Former Mill Site Groundwater Wells (Vanadium)

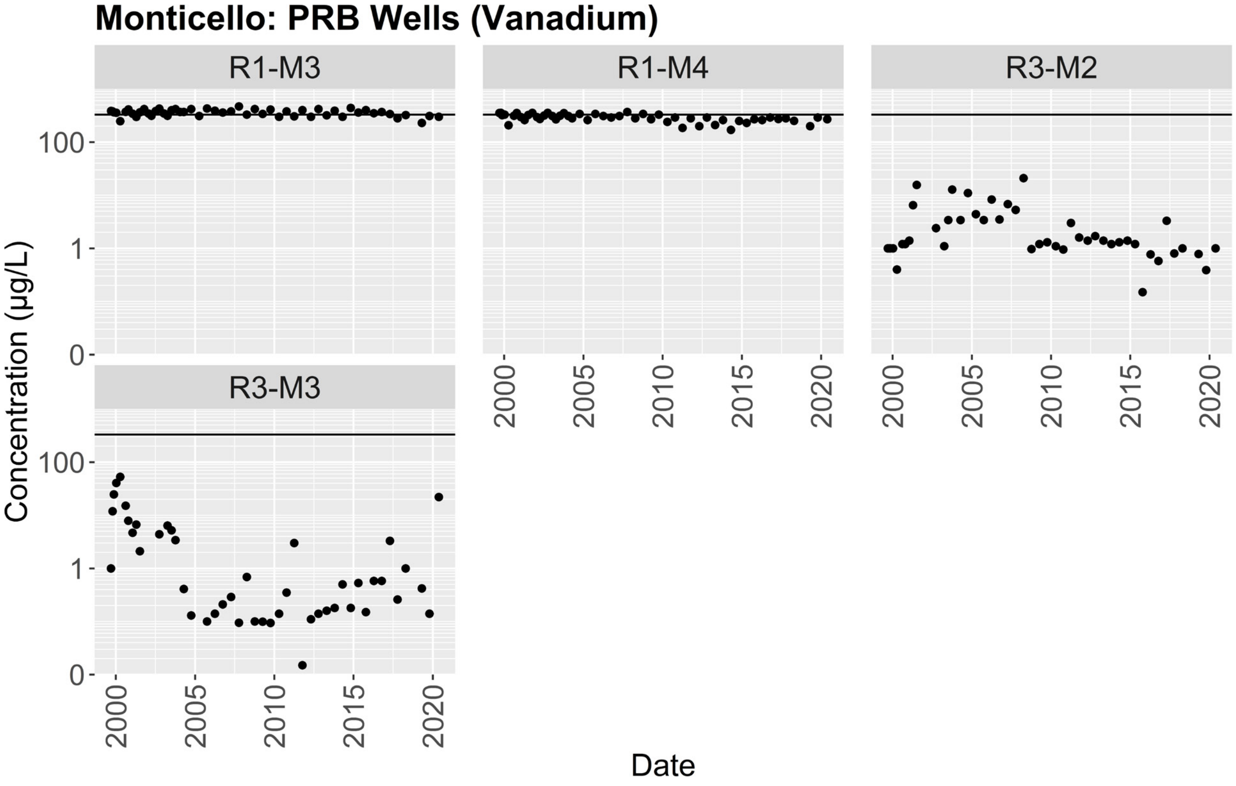


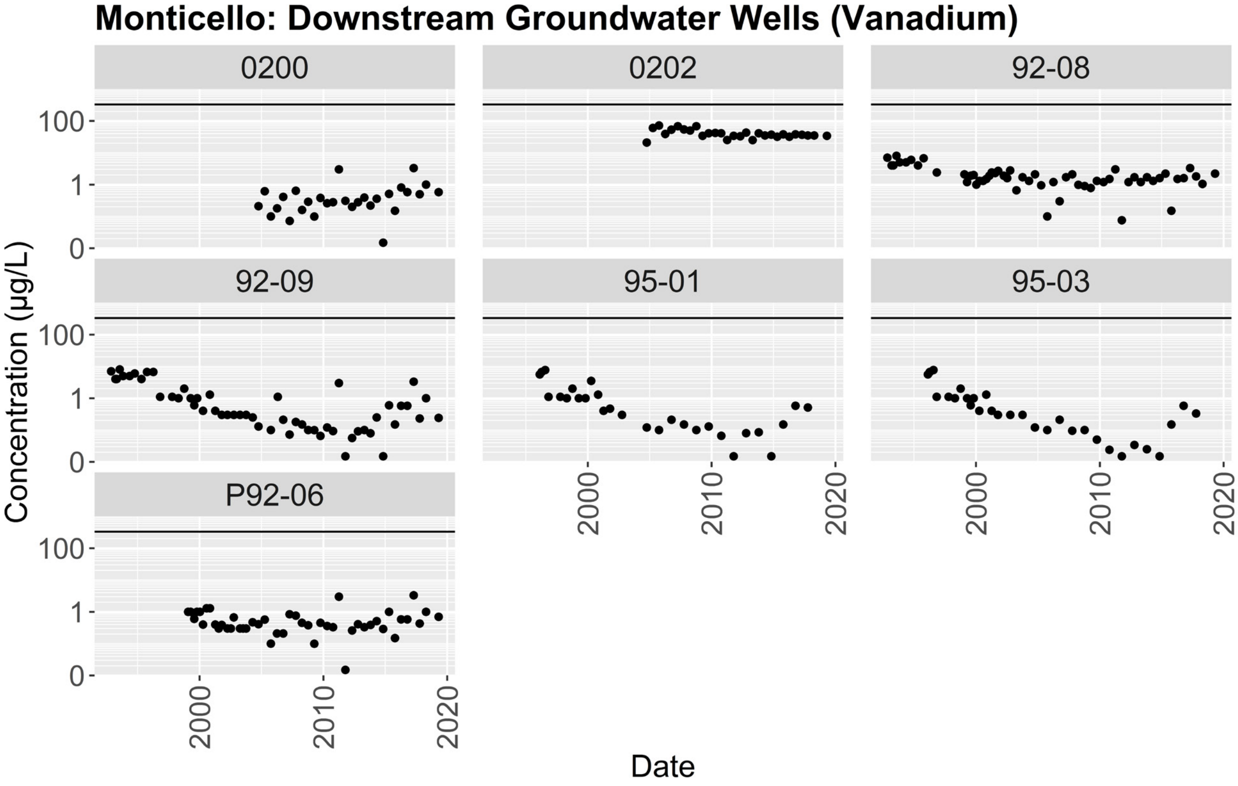
Monticello: Former Mill Site Groundwater Wells (Vanadium)



Monticello: Central Groundwater Wells (Vanadium)




Monticello: PRB Wells (Vanadium)
R1-M3
R1-M4
R3-M2
R3-M3
Concentration (µg/L)
100
1
0
2000
2005
2010
2015
2020
Date


Monticello: Downstream Groundwater Wells (Vanadium)
0200
0202
92-08
92-09
95-01
95-03
P92-06
Concentration (µg/L)
100
1
0
2000
2010
2020
Date

Appendix B

Bedrock Concentration Trends
May 2019–May 2020

Arsenic, Manganese, Molybdenum, Nitrate,
Selenium, Uranium, Vanadium

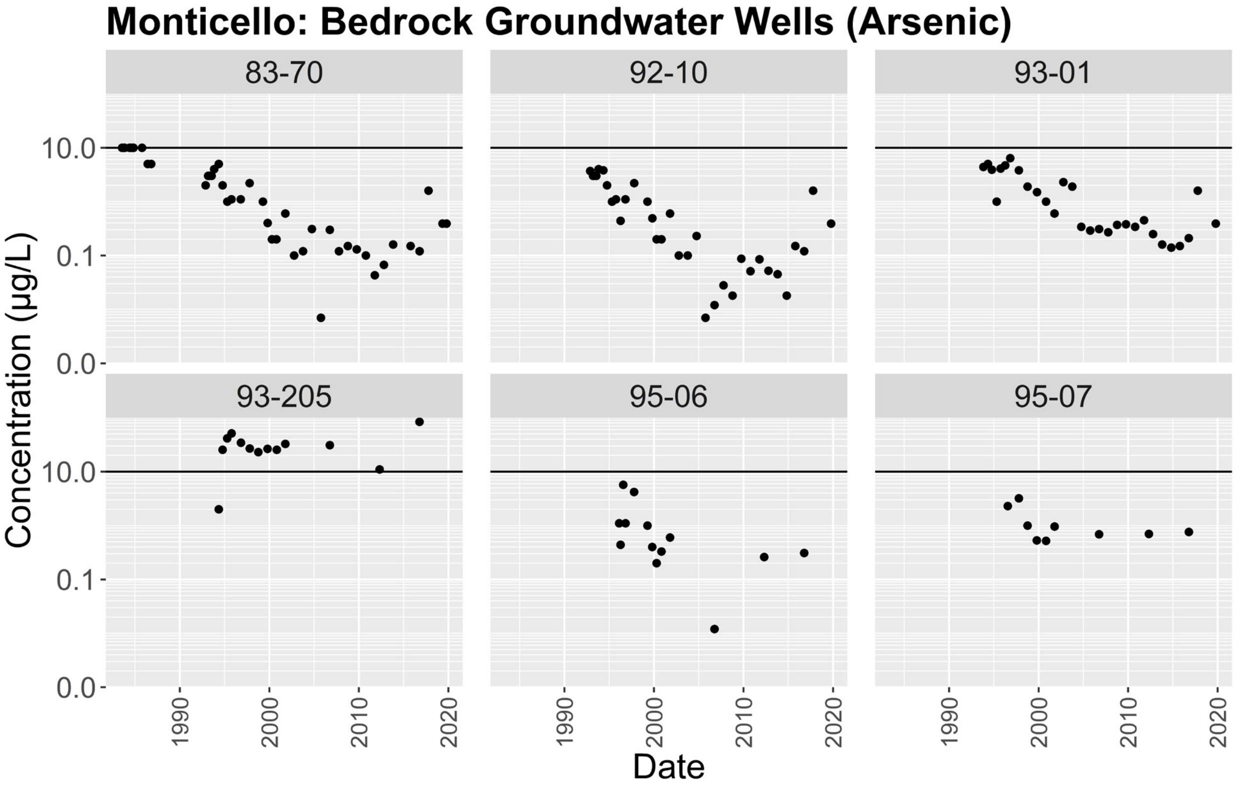
Arsenic

Groundwater Remediation Goal: 10 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Arsenic Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2019 through May 2020 performance period.



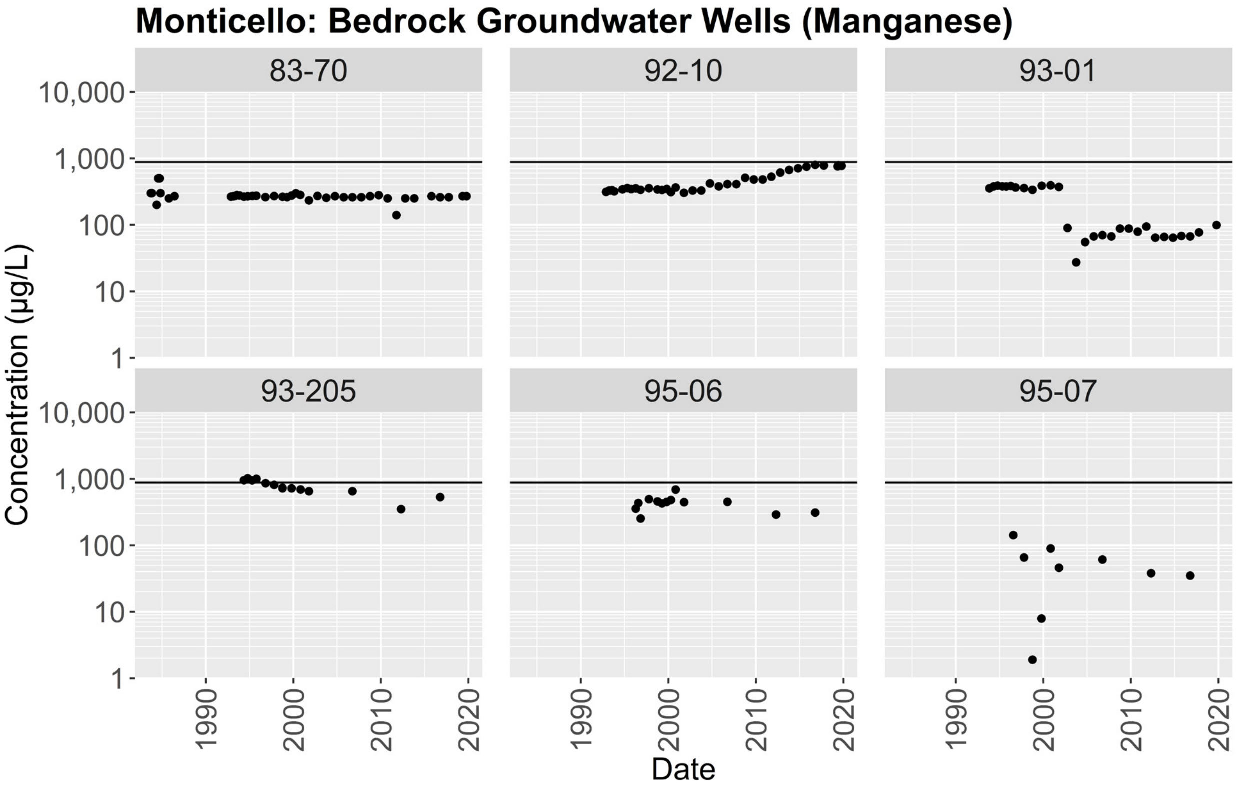
Manganese

Groundwater Remediation Goal: 880 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Manganese Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2019 through May 2020 performance period.



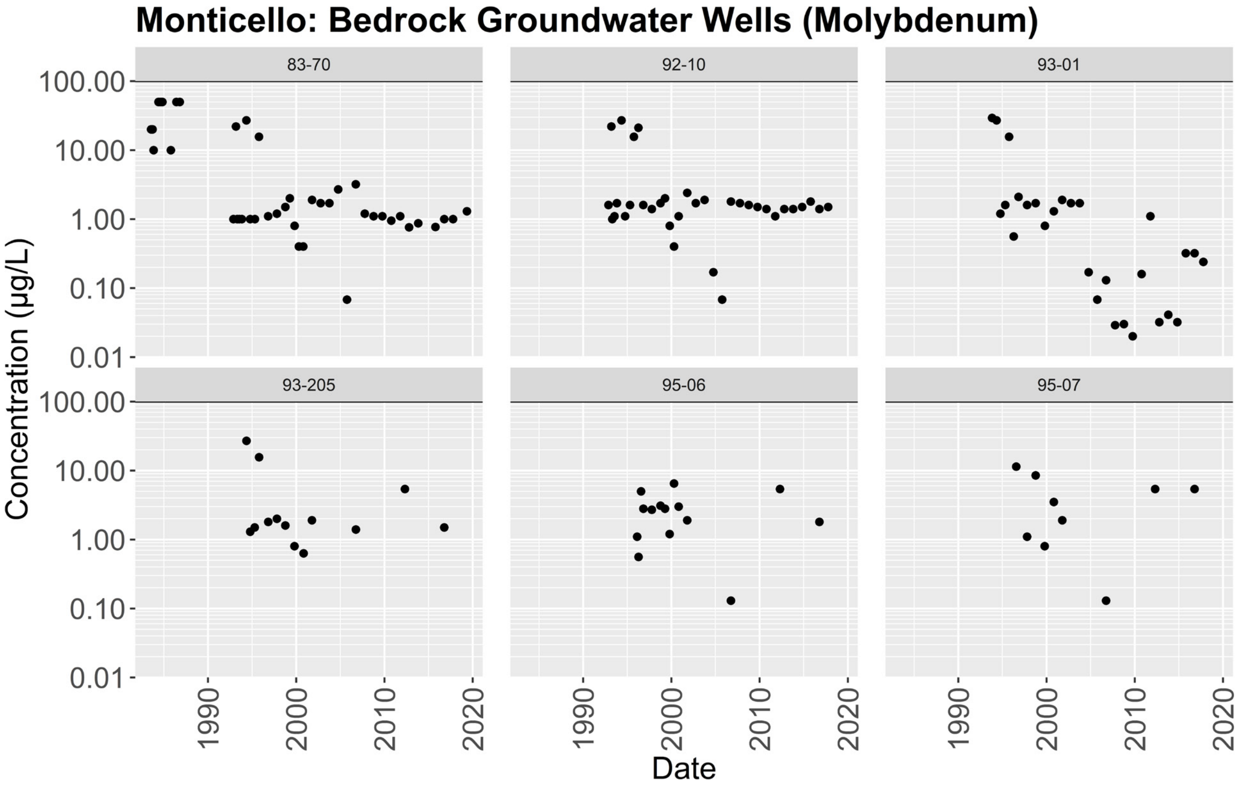
Molybdenum

Groundwater Remediation Goal: 100 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Molybdenum Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2019 through May 2020 performance period.



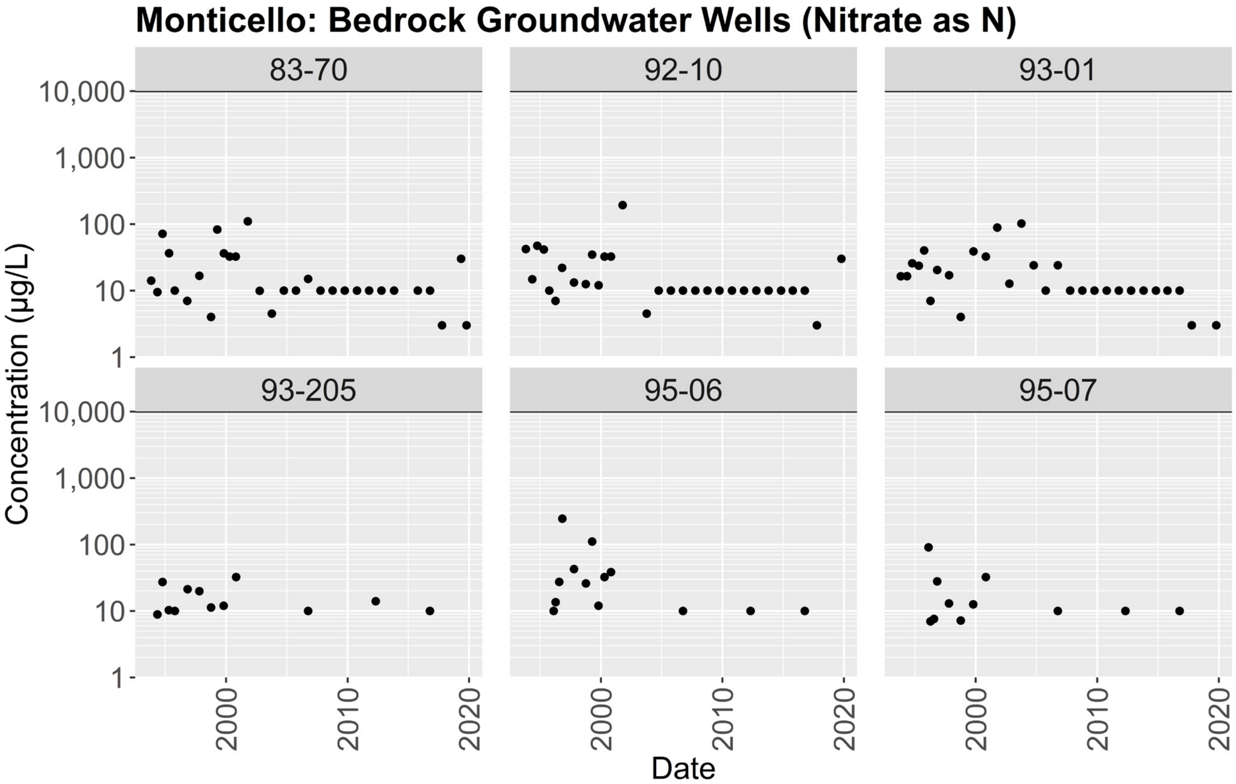
Nitrate as Nitrogen

Groundwater Remediation Goal: 10,000 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Nitrate Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2018 through April 2019 performance period.



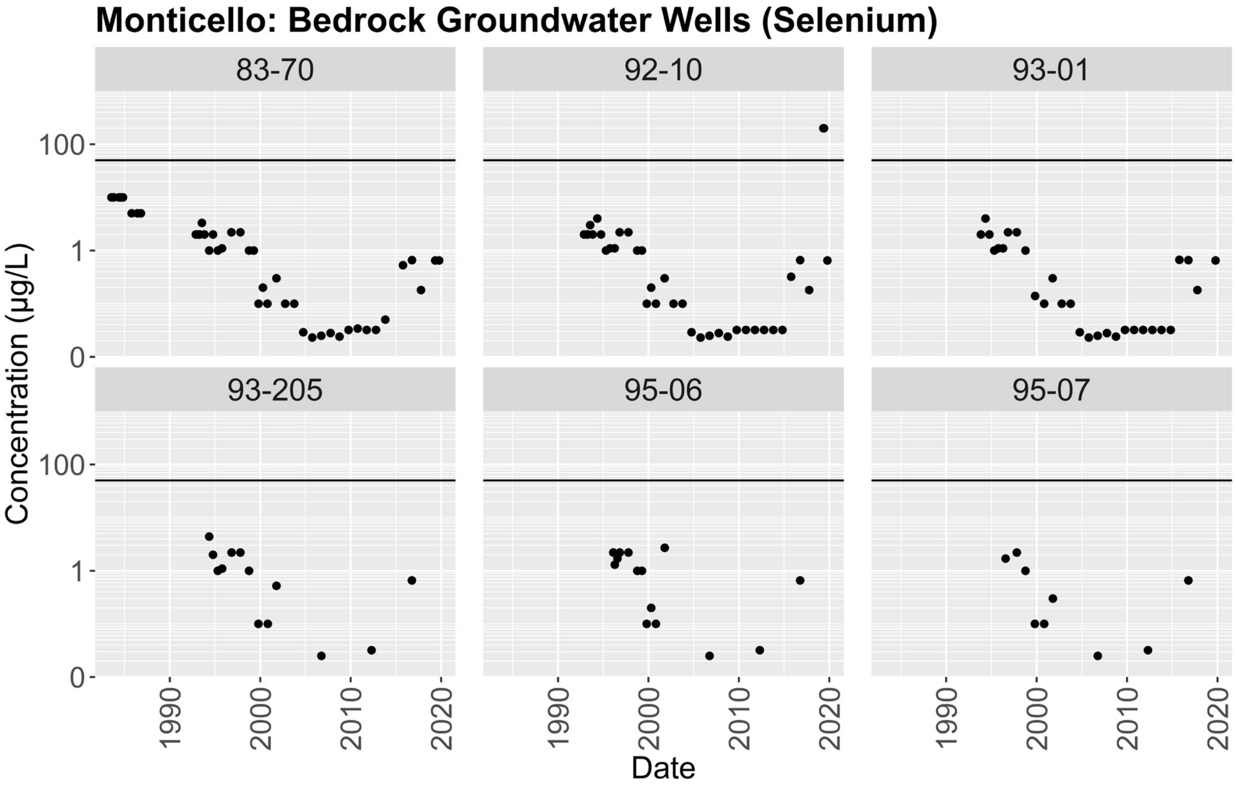
Selenium

Groundwater Remediation Goal: 50 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Selenium Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2019 through May 2020 performance period.



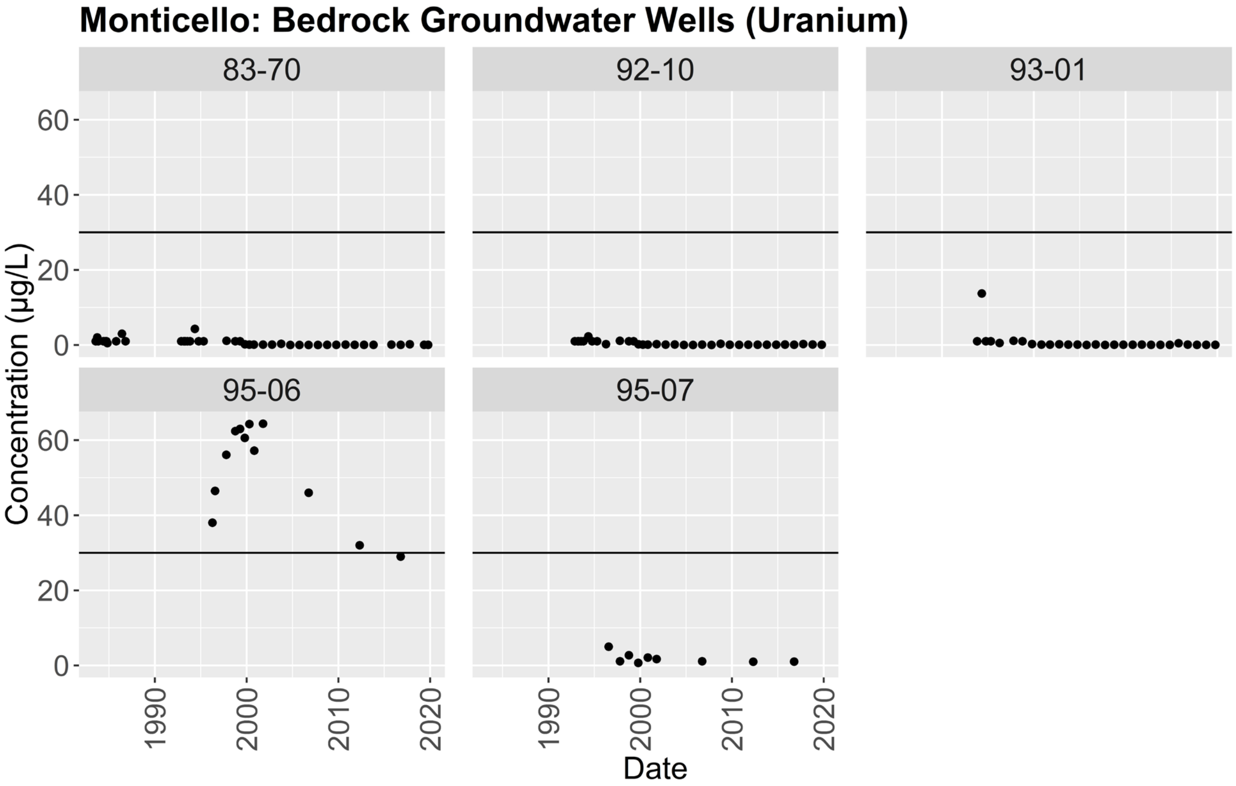
Uranium

Groundwater Remediation Goal: 30 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Uranium Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2019 through May 2020 performance period.



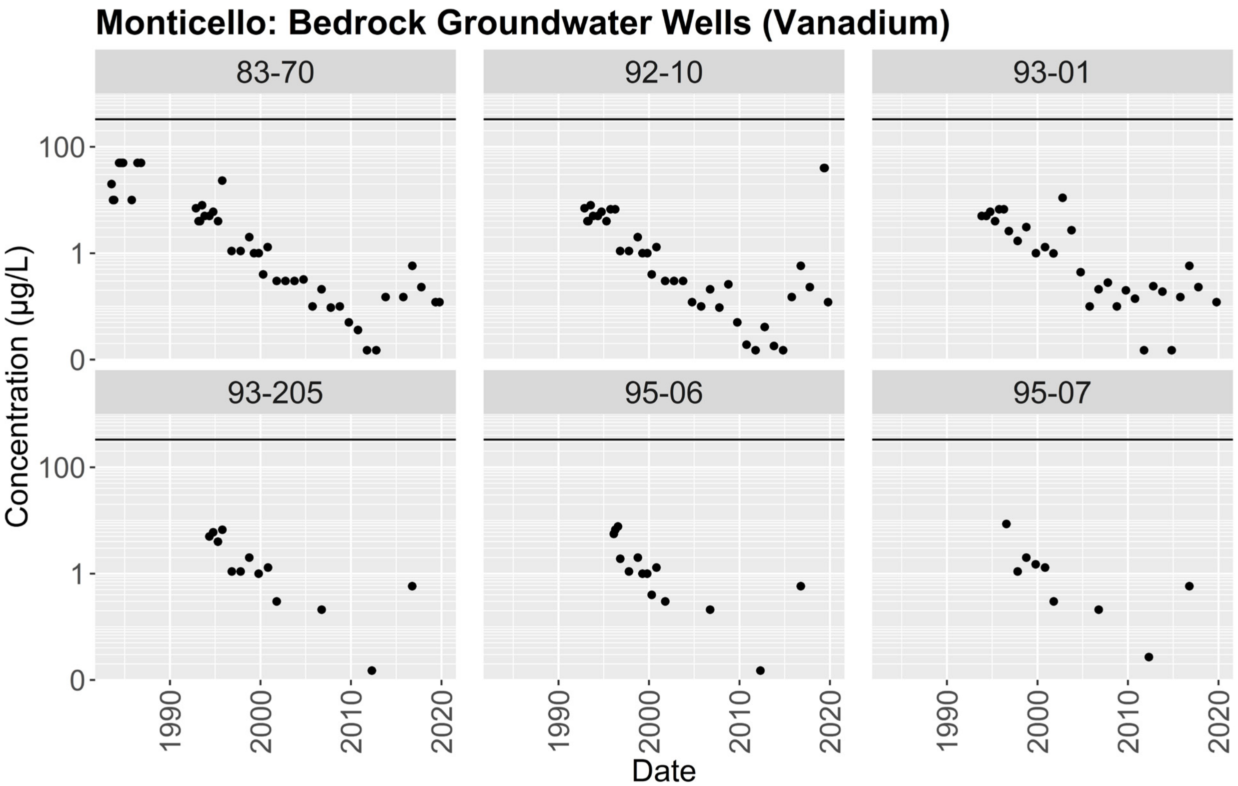
Vanadium

Groundwater Remediation Goal: 330 µg/L

Sample Locations Are Shown in Figure 6

None of the OU III Bedrock Monitoring Wells Have Vanadium Concentrations Above the Remediation Goal for the May 2019 through May 2020 Performance Period

Note: Bedrock wells 93-205, 95-06, and 95-07 with a 5-year sampling frequency were not sampled during the May 2019 through May 2020 performance period.



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Appendix C

Surface Water and Seep Concentration Trends
May 2019–May 2020

Arsenic, Nitrate, Selenium

Arsenic

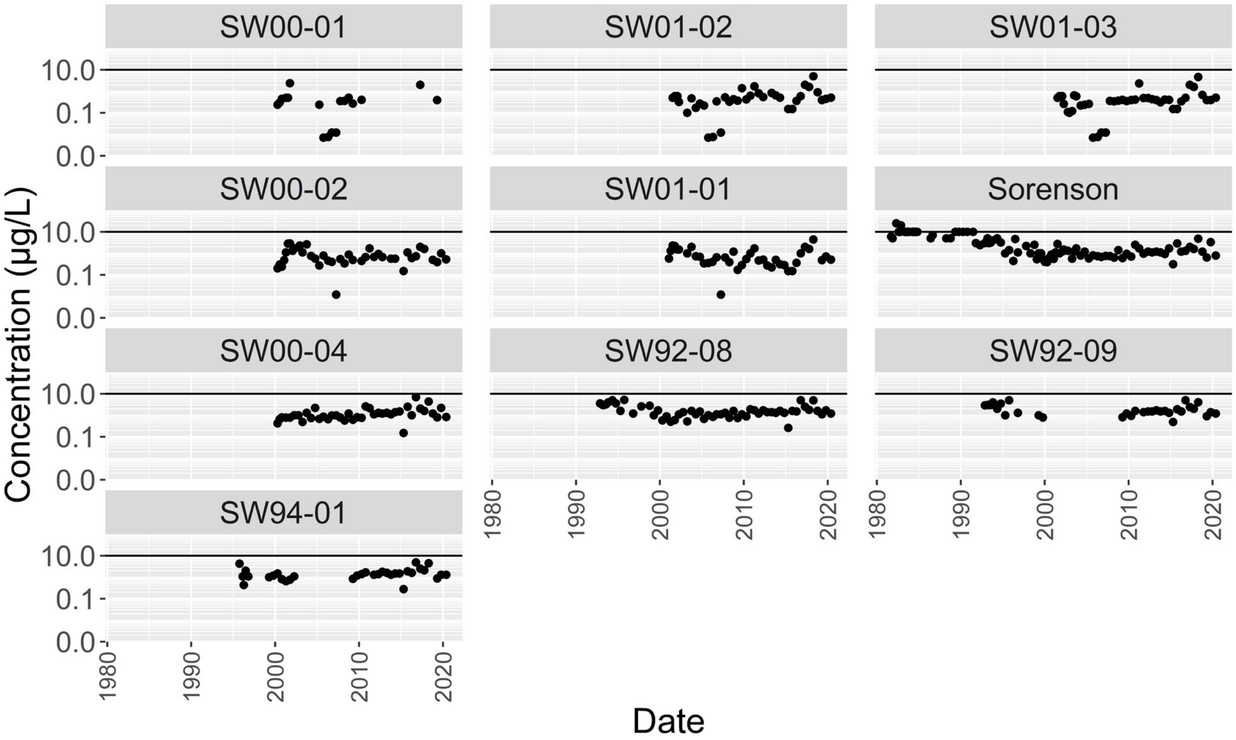
Surface Water Remediation Goal: 10 µg/L

Sample Locations Are Shown in Figure 6

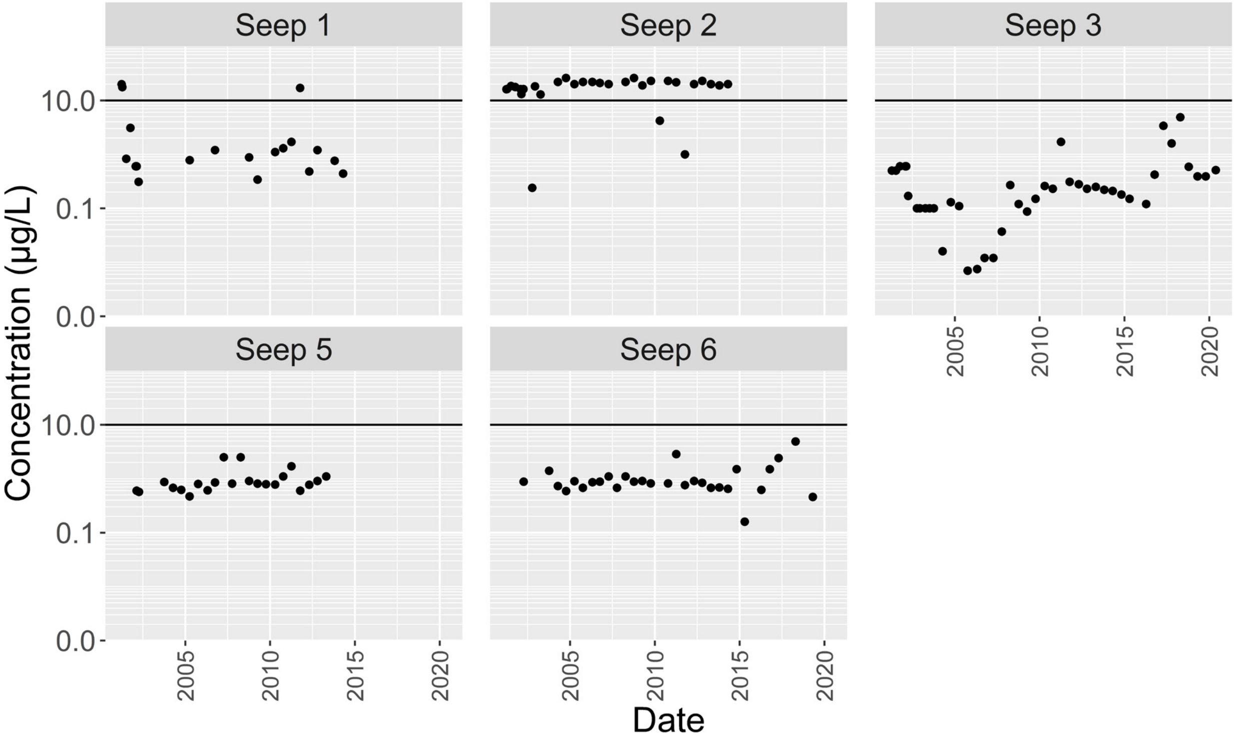
None of the OU III Surface Water or Seep Locations Have Arsenic Concentrations Above the Remediation Goal This Performance Period

Seeps 1, 2, 5, and 6 Were Not Sampled for Arsenic This Performance Period

Monticello: Surface Water (Arsenic)



Monticello: Seep (Arsenic)



Nitrate as Nitrogen

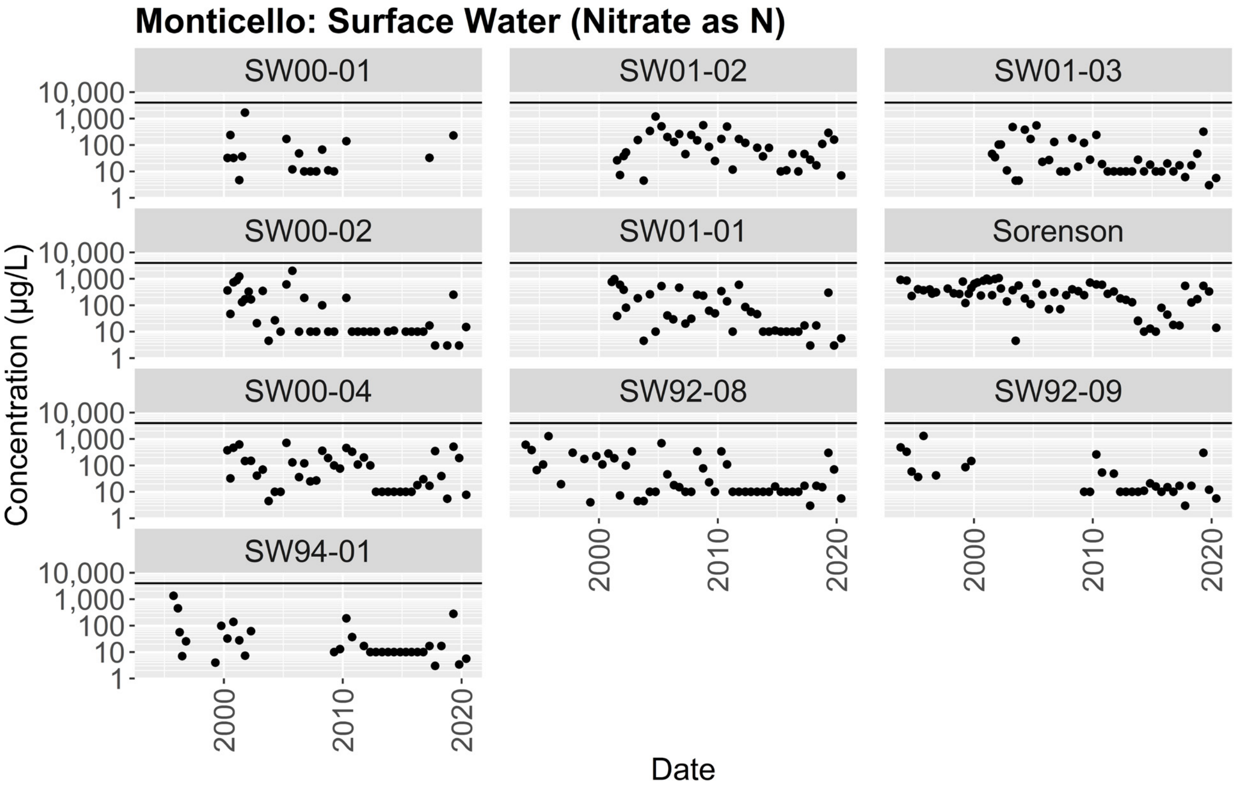
Surface Water Remediation Goal: 4000 µg/L

Sample Locations Are Shown in Figure 6

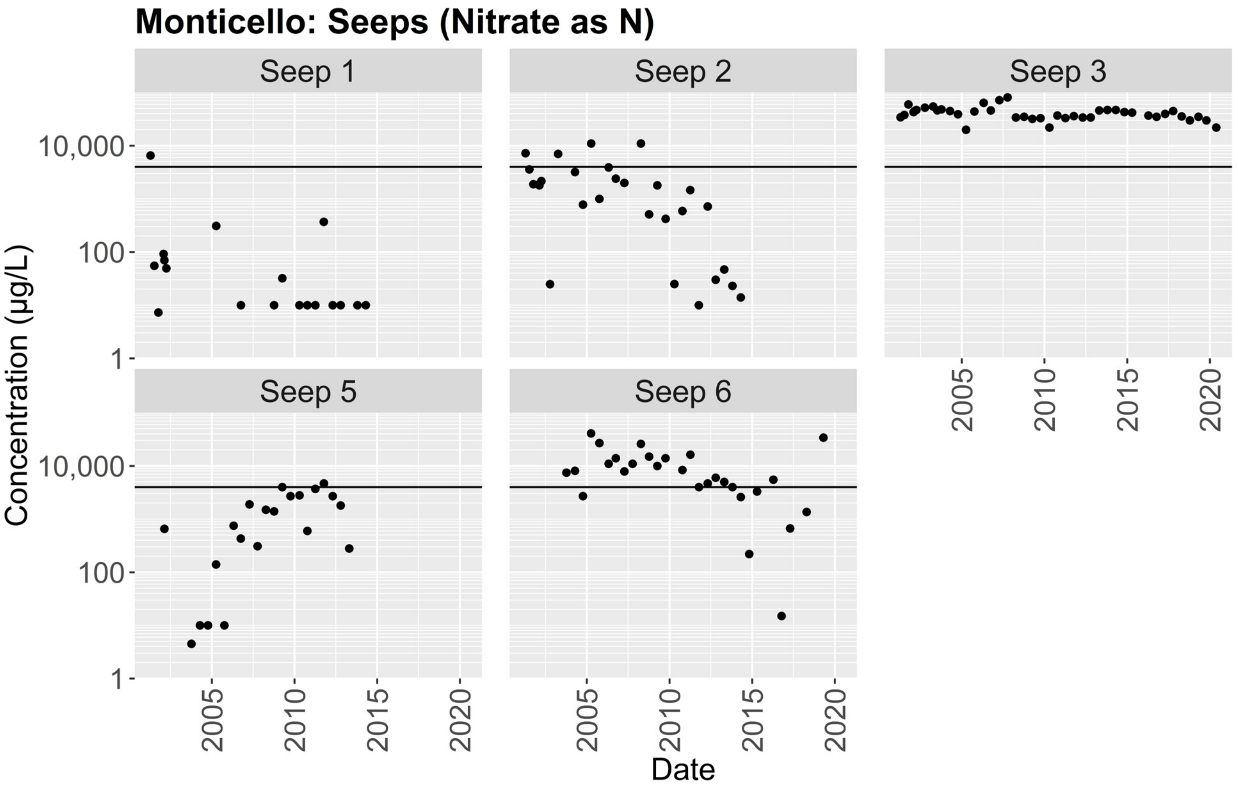
OU III Surface Water and Seep Locations Having Nitrate Concentrations Above the Remediation Goal This Performance Period

Seep	Sample Date	Nitrate Concentration (µg/L)
Seep 3	10/16/2019	30,000
Seep 3	5/20/2020	22,000

Seeps 1, 2, 5, and 6 Were Not Sampled for Nitrate This Performance Period



Monticello: Surface Water (Nitrate as N)



Monticello: Seeps (Nitrate as N)

Selenium

Groundwater Remediation Goal: 5 µg/L

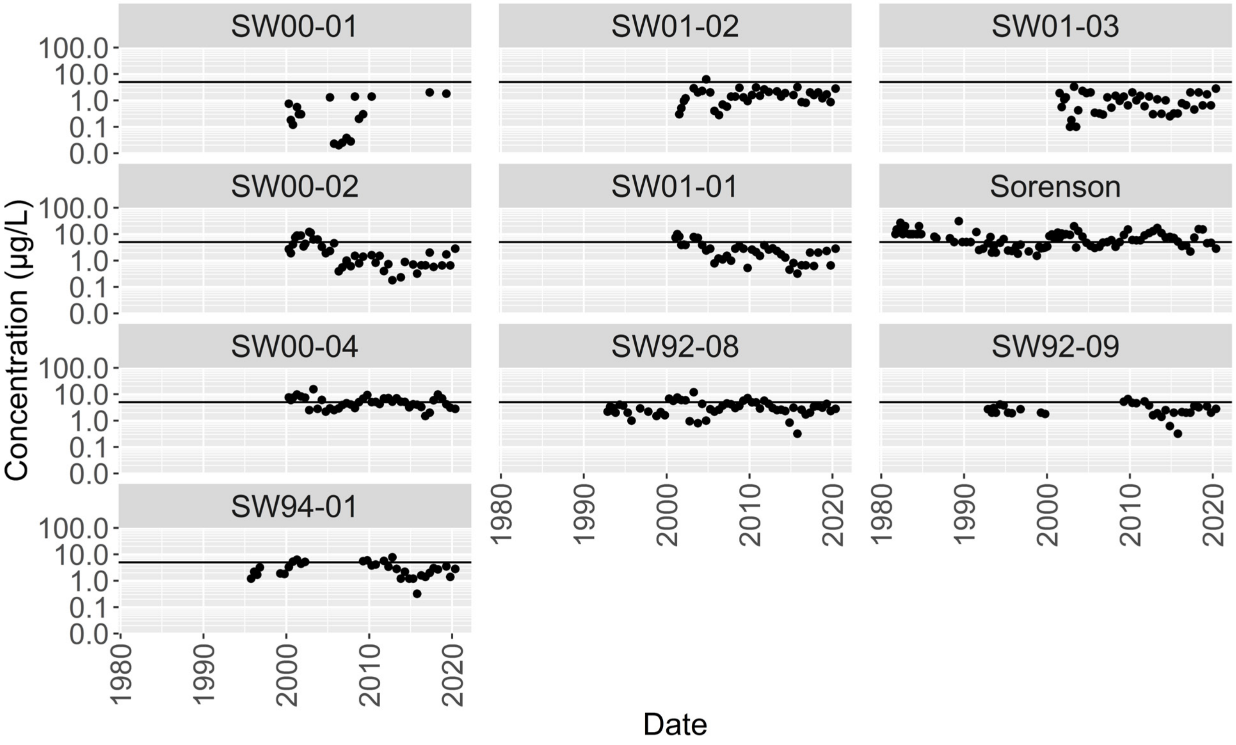
Sample Locations Are Shown in Figure 6

OU III Surface Water and Seep Locations Having Selenium Concentrations Above the Remediation Goal This Performance Period

Seep	Sample Date	Selenium Concentration (µg/L)
Seep 3	10/16/2019	51
Seep 3	5/20/2020	49

Seeps 1, 2, 5, and 6 Were Not Sampled for Selenium This Performance Period

Monticello: Surface Water (Selenium)



Monticello: Seeps (Selenium)