LMS/TUB/S11803

Annual Groundwater Report April 2013 Through March 2014 Tuba City, Arizona, Disposal Site

September 2014

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Abbreviations

CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
ft	feet
GCAP	Groundwater Compliance Action Plan
gpm	gallons per minute
lb	pounds
LM	(DOE) Office of Legacy Management
mg/L	milligrams per liter
NNEPA	Navajo Nation Environmental Protection Agency
NO_3	nitrate
TDS	total dissolved solids

Executive Summary

This report evaluates the progress of groundwater remediation at the U.S. Department of Energy (DOE) Office of Legacy Management Tuba City, Arizona, Disposal Site (site) from April 2013 through March 2014, and cumulatively since the start of remediation in 2002. The progress of water quality restoration is evaluated and reported annually. The report does not address performance of the disposal cell as a waste isolation system or the process of operating the groundwater extraction and treatment systems.

The site is within the Navajo Nation and near Hopi Reservation land. A uranium-ore-processing mill operated at the site from 1956 until 1966. DOE conducted surface remedial actions to encapsulate mill-related contaminated wastes in an onsite, engineered disposal cell between 1988 and 1990. A remnant plume of groundwater contamination, presumed to have originated from mill process liquids, extends off the site approximately 1,500 feet to the south in the underlying sandstone aquifer.

The primary contaminants in the groundwater are nitrate, sulfate, and uranium. DOE constructed a pump-and-treat remediation system, operational by mid-2002, to remove these and other site-related contaminants from the aquifer with the objective of achieving water quality restoration targets established in the Groundwater Compliance Action Plan (GCAP; DOE 1999). Duration of operating the remediation system was not specified.

The year in summary finds that:

- When fully operational, the treatment system (distillation) achieves design criteria for groundwater extraction and treatment rates, distillate quality, waste generation, and infiltration rate of treated water. The groundwater extraction system also meets design criteria in capturing the bulk of the contaminant plume.
- The net on-stream factor for distillate production was 53 percent during the review period. During sustained operation, the annual on-stream factor approaches 90 percent.
- Approximately 27 million gallons of contaminated groundwater was extracted from the aquifer during the period. This compares to about 40 million gallons extracted and treated annually during sustained operation.
- Treatment system shutdowns were partially offset by discharging some extracted groundwater directly to the solar evaporation pond for evaporative treatment.
- Measureable progress in removing contaminant mass from the aquifer is not accompanied by sitewide decreases in contaminant concentrations. This suggests a prolonged period of active remediation, requiring the removal of multiple pore volumes from the contaminant plume.
- The absence of widespread decreases in contaminant concentrations is attributed more to hydrogeologic factors than to limitations of the groundwater extraction design.
- Plume expansion into uncontaminated regions of the aquifer is not evident.
- Analysis of groundwater flow and plume capture is complicated under the conditions of intermittent remediation system operation.

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1.0 Introduction

1.1 Background Information

This report evaluates the progress of groundwater remediation at the U.S. Department of Energy (DOE) Office of Legacy Management (LM) Tuba City, Arizona, Disposal Site for the period April 2013 through March 2014, as well as cumulatively since the start of remediation in 2002. The progress of water quality restoration is evaluated and reported annually.

The site is located near Tuba City, Arizona, within the Navajo Nation and near Hopi Reservation land (Figure 1). A uranium-ore-processing mill operated at the site from 1956 until 1966. DOE conducted surface remedial actions, consisting of encapsulating contaminated solid waste in an onsite engineered disposal cell, between 1988 and 1990. A remnant plume of groundwater contamination, presumed to have originated from process water stored in solar evaporation ponds and slurry-impounded tailings during mill operation, extends beneath and off the site approximately 1,500 feet (ft) to the south in the underlying sandstone aquifer.

The primary contaminants in the groundwater are nitrate, sulfate, and uranium. DOE implemented pump-and-treat remediation, operational by mid-2002, to remove these and other site-related contaminants from the aquifer with the objective of meeting water quality restoration goals established in the Groundwater Compliance Action Plan (GCAP; DOE 1999; also see Section 1.3 of this report). The GCAP did not specify duration of active groundwater remediation to meet those goals but identified potential limitations to the technology.

1.2 Groundwater Remediation System

The groundwater remediation system comprises 37 extraction wells completed within the contaminated region of the aquifer. Seventy-eight monitoring wells that are used to evaluate water quality and water level trends are situated within and surrounding the network of extraction wells. Figures 2a through 2c depict the locations of extraction and monitoring wells and the primary features of the site. Figure 2a shows all well locations, Figure 2b shows extraction wells only, and Figure 2c shows monitoring wells only. (These figures may be referred to collectively as Figure 2 in this report.) Figure 3 shows an aerial view of the site, identifying all Tuba City site sample locations and associated sampling frequencies. Monitoring and extraction well completion information is provided in Appendix A in tabular and schematic form.

The extracted groundwater is conveyed in underground piping to an onsite treatment plant, where it is distilled following ion exchange pretreatment to reduce mineral precipitation during the distillation process. The operating capacity of the treatment system is approximately 100 to 120 gallons per minute (gpm). A lined solar evaporation pond receives the waste liquid (brine) and the softener regeneration waste. An infiltration trench located upgradient of the contaminant plume and the onsite disposal cell receives the treated water (distillate), where it is returned to the aquifer. Figure 2 shows the location of the infiltration trench and associated treatment system features.

Six groundwater remediation wells (wells 1003 through 1008; Figure 2a) were originally installed downgradient of the contaminant plume to receive a portion of the treated water

(distillate) and create a hydraulic barrier to plume movement on the lower terrace. These intended injection wells remain unused for that purpose because contamination does not extend to the area of these wells, nor is there evidence of plume movement toward this area.

Figures 2 and 3 include monitoring wells that were installed by the Navajo Nation Environmental Protection Agency (NNEPA) in September 2010 (iiná bá 2011) to assess water quality and flow direction in the west and north-northwest areas of the site. These wells, are identified by the NMW prefix. LM continues to monitor these wells since the original NNEPA study (iiná bá 2011) and has found no evidence of groundwater contamination (see also Section 3.0 of this report).

1.2.1 Groundwater Extraction Well Details

In Figures 2a and 2b, the extraction wells labeled 1101 to 1125, installed in 1999, are constructed of 6-inch-diameter Schedule 40 PVC solid casing and 6-inch, continuous V-wrap stainless-steel screen (0.017-inch slot). A filter pack of 20−40 mesh silica sand fills the 2-inch annulus to 30 or 40 ft above the screen. Screen lengths are 150 ft, extending from the bottom half of Horizon B to the mid-depth of Horizon E, except for wells 1116, 1117, and 1118, which have 100 ft screens to a depth near the base of Horizon D.

Eight extraction wells, wells 1126 through 1133, were installed in fall 2004 to expand the capture zone of the original 25 wells (1101–1125). These more recently installed wells became operational in 2005 and are constructed of 4-inch-diameter casing. Each has a 30 ft to 50 ft screen that is placed across most of Horizon B. The extraction well pumps are positioned 10 to 15 ft above the bottom of the well.

Former monitoring wells 935, 936, 938, and 942 (4-inch-diameter PVC wells) were converted to extraction wells in summer 2005. The pumps in these wells are at the bottom of the well because these wells are much shallower and so have much less potential drawdown. Refer to Appendix A for well completion details (Tables A-1 and A-2; Figure A-2).

1.2.2 Infiltration Trench Details

The infiltration trench (see Figure 2 for location) is constructed into bedrock along the north side of the site, upgradient of the contaminant plume and the disposal cell. Distillate enters at the midpoint of the trench and flows toward each end in 8-inch-diameter perforated pipe that is embedded in a 3 ft thick gravel pack. The trench is approximately 4 ft wide and extends to a depth of about 6 ft below ground surface. In-line valves allow flow regulation to either end of the trench, although the flow rate to either side of the trench is not metered. Monitoring wells 284 and 285 are paired with wells 946 and 943 (Figure 2c), respectively, to monitor water table conditions at the contact between the terrace deposits and the Navajo Sandstone immediately downgradient of the trench. Monitoring is also conducted at wells 686, 687, 688, and 945 to evaluate the effects of distillate infiltration on the water table and water quality near the trench.

1.3 Groundwater Compliance Strategy

The groundwater compliance strategy for the Tuba City site (DOE 1999) is to restore groundwater quality through active remediation of those portions of the aquifer affected by

previous site activities. Cleanup levels for the aquifer (Table 1) consist of restoration standards (requirements of Title 40 *Code of Federal Regulations* Part 192 [40 CFR 192], "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings") and restoration goals (cleanup levels requested by the Navajo Nation but not required by 40 CFR 192). Nitrate, uranium, and sulfate are the most widespread contaminants and contributors to potential risk from groundwater ingestion and are therefore the focus of this report.

Table 1. Groundwater Remediation Standards and Goals

Constituent/Property	Cleanup Level	Baseline Concentrations in Plume
Nitrate[a] as NO_3	44 mg/L as NO_3	840–1,500 mg/L as NO_3
Molybdenum[a]	0.10 mg/L	0.01–0.58 mg/L
Selenium[a]	0.01 mg/L	0.01–0.10 mg/L
Uranium[a]	30 pCi/L (0.044 mg/L) U-234 + U-238	0.3–0.6 mg/L
Sulfate[b]	250 mg/L	1,700–3,500 mg/L
Total Dissolved Solids (TDS)[b]	500 mg/L	3,500–10,000 mg/L
Chloride[b]	250 mg/L	20–440 mg/L
pH[b]	6.5–8.5	6.3–7.6
Corrosivity[b]	not corrosive	not applicable

[a] Restoration standard
[b] Restoration goal
mg/L = milligrams per liter
pCi/L = picocuries per liter

Source: DOE 1999

1.4 Performance Monitoring and Reporting

The effectiveness of the remediation system in removing contaminants from the aquifer and progressing toward cleanup levels is evaluated yearly, mainly on the basis of groundwater monitoring conducted in August and February of each year. During these events, samples are collected at monitoring wells for water quality analysis, and water levels are measured. The data are then compared to baseline conditions determined between 1998 and March 2002 (DOE 2003) to evaluate the capture zone of the extraction system, to evaluate plume movement within the aquifer, and to evaluate contaminant removal rates and concentration trends.

Extraction wells are also sampled during the August event, as are several distal monitoring wells that have no history of contamination. Other information used in evaluating the effectiveness of the groundwater remediation system includes treatment plant operations data, such as (1) flow metering for each extraction well, (2) flow metering of the bulk influent to the treatment plant, (3) flow metering of the separate outflow streams, (4) approximately weekly chemical analysis of the treatment system influent (bulk groundwater inflow) and effluent (distillate and brine), and (5) approximately monthly chemical analysis of groundwater composition at each extraction well.

1.5 Hydrogeologic Setting

The Tuba City site lies on the middle of three alluvial terraces that formed during ancestral flow in Moenkopi Wash, located about 1.5 miles southeast of the disposal cell (Figures 2 and 3). The terrace surfaces are generally covered by a thin mantle of loose, modern dune sand. Coarse, well-indurated Quaternary alluvium (terrace gravels) underlies the dune sand over much of the site area. The terrace and dune deposits unconformably overlie the regionally extensive

Navajo Sandstone, a massively cross-bedded, friable, fine-grained to very fine-grained sandstone and siltstone of Jurassic age deposited in an arid dune complex or erg (sand sea). Escarpments that separate the terraces are formed by slopes or cliffs of the Navajo Sandstone. The regional dip of the bedrock is about 1 degree or less to the northeast.

At about 200 ft below ground, the massive eolian dune deposits typifying "classic" Navajo Sandstone become interbedded with fine-grained alluvium more typical of the deeper Kayenta Formation. This "intertonguing interval," (from Cooley et al. 1969) reflecting a transition to a more fluvial setting, is 400 to 450 ft thick. More recent investigators identify this interval as the KNTZ (or Kayenta/Navajo Transition Zone). Occasional thin (≤2 ft), resistant limestone beds thought to be remnant playa lake deposits occur in the classic and transition intervals. Three such beds have been identified in outcrops near Moenkopi Wash south of the disposal site. One such bed extends a distance of nearly 1 mile near the base of the cliff along the wash. The lateral continuity of the deposits toward the disposal site (north) is not known. The Kayenta Formation consists of approximately 100 ft of less-resistant, thin-bedded, red silt and fine sand and lacks the characteristic cross-bedding of the Navajo Sandstone.

Groundwater beneath the Tuba City site occurs in the regionally extensive "N" multiple-aquifer (Cooley et al. 1969), which in the site area comprises the classic and transition intervals of the Navajo Sandstone. Because of the fine-grained composition of the Kayenta Formation locally, it is not water bearing and is considered the base of the N-aquifer in the site area. The local water table occurs within the Navajo Sandstone; the terrace and dune deposits in the site area are not saturated. Groundwater saturation extends from the water table, about 50 to 60 ft below ground surface on the upper and middle terraces, to the contact with the Kayenta Formation, accounting for a saturated thickness on the order of 500 ft.

Except for the local effects of groundwater withdrawal at the site, groundwater flow is generally south to Moenkopi Wash. Groundwater discharge occurs at Moenkopi Wash from a laterally extensive (10–20 miles) spring zone near the exposed base of the transition interval. Groundwater seepage commonly occurs along discrete bedding planes, and commonly above a limestone bed. Discharge of groundwater from higher in the formation may occur in some areas through transpiration by desert phreatophytes. One such area is noted in Figures 2 and 3 as the "greasewood area," where the depth to water is approximately 20 ft, coincident with the contact between loose dune sand and the upper, weathered bedrock surface. Phreatophytes also occupy the floodplain and riparian zone along the wash and are thought to consume groundwater that is discharging from the Navajo Sandstone aquifer.

Figure A-1 in Appendix A illustrates the hydrogeologic setting of the site in cross-section view along the direction of groundwater flow to show the relationship between surface topography, subsurface geology, and groundwater flow.

1.5.1 Vertical Discretization of the N-Aquifer

In the absence of laterally continuous stratigraphic marker beds in the Navajo Sandstone, the subsurface at the site is discretized into 50 ft horizons, each with a letter designation. This designation provides a reference system for evaluating site hydrogeology and extent of contamination in the vertical dimension. Ground surface of the middle terrace, nominally 5,050 ft in elevation, marks the top of the uppermost horizon (Horizon A). Horizons A, B, C, and

possibly D span the interval of classic Navajo Sandstone beneath the site. The depths of Horizons E through J vertically span the intertonguing interval. The stratigraphic relationships to aquifer horizons are shown in Figure A-1 of Appendix A.

Horizons K, L, and M include the lower intertonguing interval and possibly the upper portion of the Kayenta Formation. Because of surface topography, the uppermost horizon on the lower terrace progresses from Horizon C to D, north to south (see Figure A-1 of Appendix A). The steep topography at Moenkopi Wash intersects Horizons E through G. Contamination of the aquifer is limited in depth to Horizons A, B, and C; therefore, groundwater remediation at the site focuses primarily on the upper 150 ft of the bedrock aquifer. Groundwater flow and water level drawdown are affected in the deeper horizons by remedial actions and so continue to be monitored.

In Figure 2, color-coding identifies the corresponding horizon in which the midpoint of the well screen is located for extraction wells (round symbols) and monitoring wells (square symbols). Well screen depths in relation to aquifer horizon and elevation for all project wells are shown schematically in Figure A-2 of Appendix A. Tables A-1 and A-2 of Appendix A include additional well completion information, such as screen length and screen intake elevations.

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2.0 Treatment System Operating Parameters

2.1 Operations History

Full-scale operation of the groundwater remediation system began in mid-2002 (April or May) and continued through October 2010 with only minor interruption. Operation of the system was then suspended through September 2011 for treatment process upgrades. The system resumed operation in October 2011 but has since operated intermittently because of maintenance requirements.

2.2 Bulk Treatment Parameters and Water Budget

Operation of the treatment system during April 2013 through March 2014 resulted in an on-stream factor of 53 percent. The on-stream factor derives from a ratio of actual time of treatment plant operation to total elapsed time. The net rate of groundwater extraction was 51 gpm. Approximately 26.9 million gallons of water was extracted from the aquifer, and approximately 22.6 million gallons of water was returned to the aquifer as distillate. Brine generation accounted for approximately 5.6 percent (1.5 million gallons) of the total volume of groundwater that was extracted and treated by distillation. Approximately 4.5 percent (1.2 million gallons) of the extracted water was sent to the pond as softener regeneration waste, and 5.9 percent (1.6 million gallons) of the extracted water was diverted to the evaporation pond without distillation while the treatment system was not in operation.

Figure 4 plots annual treatment volumes and net on-stream rates since the baseline period. Between 2002 and 2010, annual extraction volumes averaged about 40 million gallons at a net operating factor of about 85 percent. While treatment process upgrades were ongoing, the annual volume of groundwater extracted decreased to about 10 million gallons. The treatment volume has since been restored to about 30 million gallons annually, 70 percent of the operating capacity.

Figure 5 plots weekly extraction volumes for three periods: pre-plant shutdown (2003 through September 2010), the extended plant shutdown corresponding to treatment plant upgrades (October 2010 to September 2011), and the period since then. The operating capacity of the treatment system is about 100 to 120 gpm, corresponding to a 1 million–1.2-million-gallon weekly treatment plant capacity. As with Figure 4, Figure 5 reveals a return to the maximal operating efficiency of the remediation system that can be expected as was demonstrated during 2002 and 2010.

2.2.1 Extract Feed Rate

Figures 6 and 7 show the weekly feed rate to the treatment plant and the corresponding concentration of nitrate, sulfate, and uranium determined from weekly composite samples since the start of remediation. These figures indicate that during periods of sustained operation (e.g., 2002 through 2009), the bulk extraction rate (represented by inflow), maintains between about 80 and 100 gpm. This is the limit of aquifer yield for the existing extraction system and does not surpass the capacity of the treatment system (up to 120 gpm).

The inflow rates plotted in Figures 6 and 7 have decreased over time from about 100 gpm to about 85 gpm while the system is in full operation. This apparent trend may correspond to aquifer dewatering/release from storage. Water level drawdown information indicates that the cone of depression has reached steady state. Groundwater extraction wells are currently undergoing a phase of redevelopment using cyclical swabbing and purging methods. The effects of the well redevelopment on inflow capacity are indeterminate at this time because the program is ongoing, and operation of the extraction system has been intermittent.

2.2.2 Extract Composition and Contaminant Mass Removal

Nitrate (as NO_3) concentrations in the bulk extract have remained relatively static at about 400 milligrams per liter (mg/L) throughout the remedial action. An apparent rebound effect is noted following the inactive period of remediation in 2011. Sulfate concentrations trend upward from about 1,000 mg/L to about 1,300 mg/L for reasons that are uncertain.

Uranium concentrations in the bulk extract decreased from initial values of about 300 micrograms per liter (µg/L) to about 200 µg/L by 2008. This trend was followed by rising concentrations that are now consistent with initial values. This trending parallels that of the bulk extraction rate. The trend of increasing uranium concentrations since 2008−2009 may reflect a rebound effect, whereby during this period of interrupted extraction, mass transfer may be favored by re-saturation or by diffusion from zones of contrasting hydraulic conductivity.

Extracted masses of nitrate, sulfate, and uranium, estimated from the weekly monitoring of bulk inflow to the treatment plant, were (rounded) 68,000 pounds (lb), 231,000 lb, and 53 lb, respectively (Table 2). The estimated mass of contaminant removed during the period is based on the extraction volume of approximately 27 million gallons.

Table 2. Treatment System Performance Summary, April 2013−March 2014

Contaminant	Mass Removed During Review Period (lb)	Average Feed Concentration (mg/L)	Average Distillate Concentration (mg/L)	Range of Distillate Concentrations (mg/L)
Nitrate (as NO_3)	67,853	382	3.3	0.5–27.2
Sulfate	230,679	1,310	13.7	0.5–106
Uranium	52.5	0.32	0.002	0.002–0.016

Reporting period mean chloride and total dissolved solids (TDS) in distillate: 5.8 and 40 mg/L, respectively.

2.2.3 Distillate Quality

Figure 8a and Figure 8b plot weekly averaged concentrations of nitrate, sulfate, uranium, chloride, and total dissolved solids (TDS) in the distillate over time. Table 2 summarizes distillate quality for nitrate, sulfate, and uranium. Average concentrations indicate that distillate quality did not exceed treatment objectives.

3.0 Extent of Groundwater Contamination

3.1 Horizontal Extent of Contamination

Figures 9 through 17 illustrate the concentrations of nitrate (as NO_3), sulfate, and uranium in groundwater in the respective aquifer horizons before the start of remediation (baseline period). The "a" series figures show the baseline concentrations, and the "b" series figures show concentrations in either August 2013 or February 2014, depending on which is most recent sampling date.

In Figures 9 through 17, each well location sampled for the respective period is shown, but a concentration value is posted only when the applicable remediation goal or standard was exceeded. In a comparison of the "a" and "b" series, the present extent of contamination is seen to be similar to baseline conditions, indicating that the contaminant plume has not expanded or diminished significantly. Consistent with previous annual reporting, the plume geometry and the magnitude of contaminant concentrations have not changed significantly in response to the groundwater remedial action. Section 4.0 provides information on contaminant concentration trending.

To complement Figures 9b through 17b, which display contaminant distributions as "spot plots," Figures B-1, B-2, and B-3 in Appendix B display current nitrate, sulfate, and uranium distribution as plumes of contamination based on computer interpolation of contaminant distribution between monitoring well control points. The analysis focuses on Horizons A and B for the middle terrace and Horizons C and D for the lower terrace because contamination is limited to those horizons beneath those terraces.

The data indicate that groundwater contamination, with minor exception, is limited to the middle terrace within about 1,500 ft south-southwest (downgradient) of the disposal cell. Groundwater contamination on the lower terrace is comparatively minor in extent and magnitude; the exception is that low-level contamination remains in the area of paired wells 0691 and 1006.

3.2 Vertical Extent of Contamination

The vertical extent of groundwater contamination is within about 100–150 ft in depth (Horizons A, B, and C). This depth limitation is evident in the spot plots corresponding to Figures 9 through 17 and was documented in previous investigations (DOE 1998). Apparent contamination at greater depths is attributed to downward movement of groundwater induced by extraction well operation. The extraction wells have intake lengths of 150 ft and span the lower half of Horizon B through most of Horizon E. Samples collected at the extraction wells therefore represent a blend of groundwater drawn from the upper horizons (contaminated) and lower horizons (uncontaminated) and so are not indicative of plume depth. An example of downward flow of contamination induced by extraction well operation may be evident at monitoring well 268 (Horizon E). Contamination was absent at that location through 2004, but concentrations have since increased to exceed the restoration goals (see Section 4.0 for comparison of time-varying concentrations).

Figure 18 shows the distribution of uranium at all monitoring wells and all horizons for the period July 2012 through February 2013 (extraction wells are excluded because of long screen

lengths and the potential for solute blending within the screened interval during operation and sampling). As shown in this figure and the preceding horizon-specific spot plots (Figures 17a through 17c), the depth of groundwater contamination is generally limited to Horizons A, B, and C beneath the middle terrace. Contamination of Horizon D is limited to the areas nearest the disposal cell and evaporation pond where groundwater extraction and drawdown is most focused. Apparent contamination in Horizon D in these areas may be the effect of downward movement of groundwater from upper horizons induced by groundwater withdrawal at nearby extraction wells.

3.3 NNEPA Investigation

Contaminant distribution to the north and west of the LM site was investigated in an independent study by NNEPA in 2010. With LM support, NNEPA installed nine groundwater monitoring wells (shallow and deep) west and north of the site in fall 2010 at the locations shown in Figure 2c and Figure 3 prefixed as "NMW." Five of the wells (NMW-1A, -6S, -7D, -8S, and -9D) are near the west side of the disposal cell and cross-gradient to the predominant direction of groundwater flow (north to south). Four of the wells (NMW-2A, -3A, and -4A) are located hydraulically upgradient of the LM disposal site. The ninth well was installed (well NMW-5) several miles west of the site (location shown in Figure 3) and is unrelated to the LM disposal site.

The NNEPA wells were first sampled by iiná bá (contractor to NNEPA) in December 2010 and February 2011, and then periodically by LM through this reporting period. The monitoring data confirm (1) background conditions north of the LM disposal cell, and (2) background conditions west of the disposal site, thus closing the western margin of the contaminant plume (see DOE 2011; iiná bá 2011).

3.4 Surface Water Quality

The Navajo Sandstone aquifer discharges to Moenkopi Wash. Water quality monitoring at the locations shown in Figure 3 indicates that the water is not contaminated by site-related constituents. The groundwater contaminant plume associated with past mill site activities terminates more than 1 mile upgradient of the surface water sampling locations at Moenkopi Wash. Groundwater monitoring wells are located between the downgradient extent of the groundwater plume and Moenkopi Wash to detect plume movement toward the wash. Plume migration toward the wash is not significant.

4.0 Groundwater Capture Analysis

4.1 Water Table Configuration

Figure 19 shows the estimated water table for the baseline period (August 2001) using water levels in Horizons A and B monitoring wells for the middle terrace and Horizon C wells for the lower terrace. On the middle terrace, water levels at deeper wells are not representative of water table conditions because of pronounced vertical hydraulic gradients and so are not appropriate for constructing a water table map. On the lower terrace, the water table occurs within Horizon C nearest the escarpment and progresses to deeper horizons, mimicking surface topography eastward. The water table contours depicted in Figure 19 imply that the horizontal direction of groundwater flow was predominantly south during the baseline period and indicate a steepened hydraulic gradient at the escarpment between the middle and lower terraces.

Figure 20 shows the estimated water table for February 2014. As shown in annual reports submitted prior to system interruption between October 2010 and September 2011, operation of the extraction wells resulted in a water table cone of depression of several tens of feet in depth central to the region of extraction south and east of the disposal cell. During that time, the implied direction of groundwater flow was inward to the extraction wells from a large extent of the contaminant plume. Discharge of distillate to the infiltration trench accounted for as much as 25 ft of groundwater mounding along the axis of the trench.

The current water table configuration (Figure 20) reflects a temporal condition during a period of intermittent operation of the remediation system. This complicates an analysis of the extraction system capture zone because the water level data reflect only an instance in time during multiple periods of aquifer drawdown and recovery that may extend over days to weeks. One persistent aspect of the water table configuration, however, is the apparent groundwater mounding at well 262 near the southeast corner of the disposal cell. Groundwater mounding at this location may indicate water harvesting by the disposal cell cover, which slopes to the south. Flow gradients indicate south to southeast flow toward Moenkopi Wash with distance from the extraction wells.

4.1.1 Groundwater Flow West of the Disposal Cell

The February 2014 water table depicted in Figure 20 includes data obtained at eight monitoring wells installed to the north and west of the disposal cell by NNEPA in September 2010. These wells were installed because of NNEPA concerns of flow direction and contaminant distribution north and west of the LM disposal site. Water level data obtained from these wells indicate a southerly to southeast flow direction, thus dispelling concerns of extended contaminant migration to the west and north from the disposal cell.

4.1.2 Water Table at Alluvium/Navajo Sandstone Contact at Infiltration Trench

Monitoring wells 0284 and 0285 are paired with wells 0946 and 0943, respectively, to monitor water table conditions at the contact between terrace alluvium and the Navajo Sandstone immediately downgradient of the infiltration trench (see Figure 2b for well and trench locations). Wells 0284 and 0285 are screened across the alluvium–sandstone contact and have remained dry

since installation in 2004, indicating that groundwater mounding at the infiltration trench has not risen above the trench to saturate the overlying alluvium.

Figure C-1 in Appendix C presents water level hydrographs for monitoring wells in the area of the trench. This graph indicates that groundwater mounding near the trench has uniformly decreased on both east and west sections of the trench during recent years of intermittent operation of the treatment system. The data also suggest that at current settings, water levels are slightly higher along the east section of the trench. The infiltration trench has thus far maintained adequate capacity to receive and distribute the quantity of distillate produced.

4.2 Aquifer Response to Groundwater Extraction and Distillate Infiltration

Figure 21 illustrates the effect of groundwater extraction and infiltration by showing the difference in water levels in Horizons A and B between the baseline period and February 2014. Figures 22 and 23 plot the water level differences between the same periods for the deeper horizons. Positive values identify locations where the water level in February 2014 is less than the baseline value. Negative values, such as those at the wells surrounding the infiltration trench (Figure 22), indicate that water levels at the respective locations are presently higher than during the baseline period.

4.2.1 Radial Groundwater Flow Pattern

Prior to October 2010 when active treatment was suspended, and as presented in previous annual reports, the pattern of water level drawdown in the area of groundwater extraction reflected 3-dimensional converging flow to the extraction wells; the greatest drawdown (as much as 70 ft, Horizon E) was observed at the monitoring wells nearest to the extraction well intakes, both horizontally and vertically. That pattern is less apparent for February 2014 because of the recent history of intermittent groundwater extraction.

4.2.2 Water Level Drawdown at Distance

The drawdown data for February 2014, and as presented in previous annual reports, indicate significant water level drawdown at great distance from the extraction wells. For example, drawdowns of up to 8 ft are indicated at several lower terrace wells (Figure 22) at distances of 500 to 1,000 ft from the nearest extraction well. Greater drawdowns were recorded at these locations before the interruption of groundwater extraction. The pattern of large drawdowns extending over these distances at a relatively low extraction rate suggests an aquifer with properties of low hydraulic conductivity and low storage capacity.

4.2.3 Capture Zone Stability

Well hydrographs provided in Appendix C depict water level variation over time at selected monitoring wells. These hydrographs indicate that, since the start of groundwater remediation and through 2008, the predominantly downward trend in groundwater levels indicated an expanding groundwater capture zone (or cone of depression), particularly in the shallow horizons (e.g., see Figures C-2 and C-3). Subsequent water level increases through most of 2011 demonstrate aquifer response to the increased frequency of operational shutdown period or complete system shutdown (October 2010 through September 2011) for system repairs

(e.g., see Figure 5). Large variations since operation resumed in September 2011 reflect aquifer response to intermittent plant operation.

4.2.4 Water Level Drawdown and Recovery

Between October 2010 and late 2011 when the treatment system was not in operation, the water table in the areas of maximum drawdown recovered by 10 to 20 ft, or approximately by 50 percent of the drawdown observed during peak operation of the plant. Water level recovery during and since that time may be augmented several feet by a regional rise in the water table, as indicated at background monitoring wells 901, 910, and 947 (Figure C-1). Water level response since intermittent operation began in late 2011 indicates that the rate of water level drawdown and recovery is most rapid within the central portion of the cone of depression and decreases with distance from the extraction wells.

4.3 Horizontal Capture

Figure 24 depicts the estimated zone of groundwater capture in lateral extent in Horizons A and B, where the bulk of contamination resides. In this figure, which was generated using groundwater elevation data obtained before the remediation system was shut down in October 2010, all groundwater within the blue line (the inner line), the approximate extent of plume capture, is predicted to flow to an extraction well. This prediction is based on slope analysis of the water table using the computer program SURFER, a grid-based interpolation and contouring application for irregularly spaced 3-dimensional data. The capture line (inner line) in Figure 24 corresponds to the division between the vectors that converge inward to the extraction wells and those that do not. Extrapolated to field conditions, the capture line represents a groundwater flow divide: water within the line flows to an extraction well; water outside the line escapes capture.

The slope analysis of the 2010 water level data indicated that the full width of the contaminant plume along the south edge of the disposal cell was within the capture zone. The capture zone encompasses the region of greatest contamination; however, the area encompassing extraction wells 1126 through 1129 apparently escapes capture (the outer line in Figure 24 represents the approximate extent of groundwater contamination in map view). As reported in 2010 and previously, water level drawdown in this area is significant and was increasing before the remediation system was shut down (Figures C-4, C-5, and C-6 in Appendix C).

The capture analysis was completed using the 2010 data to illustrate the capture zone during full and sustained operation of the treatment system. Cessation of groundwater extraction and treatment beginning in October 2010 and intermittent operations since September 2011 is not expected to have significantly compromised plume management. This is because (1) the plume developed over a long period (decades) relative to the shutdown period (1 year); (2) the plume presumably developed under an artificial, exaggerated hydraulic driving force that is now absent (recharge by infiltration of mill process water); (3) the low hydraulic conductivity of the aquifer does not promote rapid groundwater movement; (4) a period of water level recovery occurred by which water flowed into the cone of depression rather than farther downgradient; and (5) downgradient plume movement is not apparent in the subsequent monitoring data.

4.4 Vertical Capture

Hydrographs included in Appendix C for selected sets of co-located monitoring wells illustrate that at a given location the hydraulic head in the aquifer varies with well intake depth. As in the horizontal plane, the potential for vertical groundwater flow is directed from high to low hydraulic head.

With few exceptions, vertical flow potentials during the baseline period were downward throughout the monitored thickness of the aquifer. Since that time (mid-2002), and until remediation was suspended in October 2010, the magnitude of downward flow in Horizons A, B, and C generally increased, as exemplified by the greater vertical separation in the hydrographs for the respective locations of well pairs 263/264, 265/266, 909/932, and 908/912 (see Figures C-4 through C-7 in Appendix C). In the main region of contamination, the increased gradients during active remediation imply capture of groundwater from the upper, most-contaminated horizons of the aquifer (Horizons A, B, and C).

Relative to the baseline condition, groundwater extraction has generally induced upward vertical gradients from the deeper horizons to the extraction well intakes. For example, the vertical flow potentials reversed to upward between Horizons M, I, and E at co-located wells 268/256/257 (Figure C-8). A similar trend for Horizons E and I is apparent at the location of wells 251/252 (see Figure C-9) until active remediation was suspended in October 2010, at which time the gradient direction reversed to pre-remediation conditions. Flow reversal generally did not occur in response to groundwater extraction at co-located wells 948 (Horizon B), 912 (Horizon C), and 913 (Horizon G), where the flow gradient is predominantly downward (Figure C-7). Horizon C at this location (well 912) contains minor sulfate and nitrate contamination (uranium contamination is not present); however, the deeper well (913) remains uncontaminated.

A downward flow potential was present between Horizons I and M into 2005 at former paired wells 254/255 (Figure C-10; wells 254 and 255 were co-located with well 941 [Horizon B] until decommissioned in August 2005). Groundwater elevation data for well 273, installed in August 2004 near the location of former wells 254 and 255, imply vertically upward flow from Horizon I to Horizon D (Figure C-10). Groundwater extraction has reduced but not reversed the downward flow gradient between Horizons D and G at wells 915 and 916 (Figure C-11). This region of the aquifer remains uncontaminated.

Flow potentials in lower terrace groundwater were downward, extending possibly through Horizon I, during and since the baseline period, as exemplified at the lower terrace well cluster identified in Figure C-12. At that location, groundwater extraction resulted in increasing the downward hydraulic gradient between Horizons C and E and decreasing the potential between Horizons E and I (Figure C-12), owing to the greater water level drawdown in Horizon E (well 920). Despite the predominant downward flow potential on the lower terrace, with and without groundwater extraction, the slight amount of contamination in lower terrace groundwater remains limited primarily to Horizon C. Deeper groundwater horizons do not appear to be at risk of contamination.

Although flow potentials were predominantly downward during the baseline period, and presumably during the time of plume development, groundwater contamination remains

generally limited to about the upper 100 to 150 ft of the aquifer. Because the observed vertical influence of the extraction wells extends deeper than the presumed depth of contamination, it is likely that the remediation system captures the full vertical extent of the contaminant plume.

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5.0 Remediation Progress

Remediation progress is assessed in the following sections by (1) evaluating time-trending of contaminant concentrations toward meeting established remediation goals (Sections 5.1 and 5.2), and (2) evaluating the cumulative removal of contaminant mass from the aquifer (Section 5.3).

5.1 Concentration Trends at Monitoring Wells

Appendix D contains time-series graphs for nitrate, sulfate, and uranium at selected monitoring wells within, marginal to, and beyond the extent of groundwater contamination. Concentration trending is addressed in the following sections based on location (terrace) and vertical depth (horizon).

Middle Terrace Horizon A and B Monitoring Wells

The time-series plots (Figures D-1 through D-3) suggest that contaminant concentrations fluctuate widely at a given monitoring well, but uniform trending, particularly in a downward direction, is not apparent. Instead, contaminant concentrations are seen to increase, decrease, or remain static over time at concentrations that in many cases are well above the remediation goal. Persistent and widespread contaminant trending, upward or downward, is not evident for the major contaminants.

Groundwater monitoring is conducted at the site with the use of dedicated sampling pumps and strict purge criteria. Therefore, the observed concentration fluctuations are less likely related to a sampling procedural bias than to the possibility of non-steady groundwater movement in response to non-uniform pumping rates among the extraction wells (ranging between approximately 0.1 to 5 gpm), non-uniform distribution of contamination in the aquifer, and intermittent operation of the treatment system.

Sentinel Monitoring Wells: Middle and Lower Terrace

Horizon A, B, and C wells 271, 683, 684, 914, 929, and NMW-1A are located beyond but near the downgradient or crossgradient extent of contamination (see Figure 2 for well locations). At these "sentinel" wells, groundwater has generally not been contaminated since monitoring began in 1999 (Figures D-4 through D-6). Sentinel wells 689 and 692 are completed in Horizons C and D on the lower terrace just upgradient of the greasewood area. As shown in Figures D-4 through D-6, contamination is absent at all sentinel wells except well 929, where minor nitrate contamination of about 1.5 to 2 times the remediation target remains. Nitrate levels in this well continue to vary widely (Figure D-4). The general and continued absence of contamination at the sentinel wells indicates that migration of the contaminant plume to the respective locations is not significant.

Middle Terrace Horizon C and D Monitoring Wells

On the middle terrace, contaminant concentrations are generally stable and below remediation standards in Horizon C and D wells (Figures D-7 through D-9; see Figure 2b for monitoring well locations). This distribution over time indicates that the plume is not expanding laterally or vertically at the corresponding depths of Horizons C and D in the aquifer. In Figures D-7 and

D-8, historically elevated nitrate and sulfate concentrations at well 912 (Horizon C) have decreased appreciably since 2002 but remain above remediation goals at concentrations of about 300 mg/L for nitrate and 500 mg/L for sulfate. Uranium concentrations also have decreased at this location, from about 0.035 mg/L (less than the remediation goal) to present values of about 0.02 mg/L (see Figure D-9).

Lower Terrace Monitoring Wells

Figures D-10 through D-12 are time-series plots of nitrate, sulfate, and uranium for selected lower terrace monitoring wells. As discussed in Section 3.1 (also refer to graduated symbol plots, Figures 9 through 17), groundwater contamination beneath the lower terrace is minor in extent and relative magnitude above remediation goals.

Nitrate concentrations have risen at wells 903 and 930 and at paired wells 691 and 1003 since about 2007 and now exceed the remediation goal. Following the sustained period of remediation system operation, nitrate concentrations have risen at these wells (particularly at wells 691 and 1003) to pre-remediation levels (Figure D-10).

Sulfate and uranium contamination is absent in lower terrace wells except at wells 691 (Horizon C) and paired well 1003 (Horizon D; no uranium contamination). Similar to nitrate, concentrations of sulfate and uranium at this location decreased sharply between about 2003 through 2007, followed by steep increases to pre-2003 levels at present. The most recent (February 2014) uranium result for well 691, 0.095 mg/L, is the historical maximum at this location, but remains at about twice the remediation goal. The pattern of nitrate, sulfate, and uranium may represent a concentration rebound effect spanning a period of sustained groundwater extraction to one of relatively intermittent operation.

Monitoring Wells Completed Below Horizon D

Appendix D Figures D-13 through D-15 show that contaminant concentrations at monitoring wells screened below Horizon D on the middle and lower terraces are stable and below remediation standards except at well 268. This Horizon E well is located just south of the evaporation pond within the prominent drawdown cone created by the extraction well withdrawals. At this well, concentrations of nitrate, sulfate, and uranium were less than remediation goals but began to increase in 2004. By 2005, nitrate concentrations exceeded the remediation goal, but sulfate and uranium concentrations remained below their respective goals.

Concentrations for each of these contaminants stabilized until sharply increasing in August 2011, such that the sulfate and uranium goals were also exceeded. These recent increases are not attributed to concentration rebound that could occur in response to intermittent operation of the remediation system; the magnitude of the rebound would far surpass all previous concentrations at this location. Rather, a compromised annular seal or leaking well casing may exist that would allow preferential downward movement of contaminated water from Horizons A and B into the well intake during extraction system operation.

5.1.1 Mann-Kendall Trend Analysis

Contaminant concentrations over time were evaluated to determine if statistically significant trending was evident at individual monitoring wells using the Mann-Kendall test (see Gilbert 1987). This is a nonparametric test (independent of data distribution) used to recognize the presence or absence of trends in a given data set.[1] Although Mann-Kendall tests were applied for nitrate and sulfate (results of which generally confirmed the absence of consistent trending for these constituents), the following analysis focuses on uranium because it is likely to be the most limiting constituent at the site from a groundwater remediation standpoint and the greatest contributor to potential health risk.

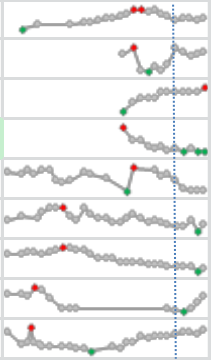
Tables 3 and 4 document the test results for uranium for middle terrace wells. In Table 3, Horizons A and B wells are distinguished by spatial region (e.g., wells at or near the site boundary versus distal wells). Table 4 shows the results for Horizons C and deeper wells, also similarly distinguished by spatial region and depth horizon. Tables 3 and 4 include summary statistics and graphical summaries (sparklines) to facilitate review (see notes following Table 3).

Although sparkline graphical summaries plot all data from February 1999 through February 2013, the Mann-Kendall test was run only on data through July 2010, the last sampling before the October 2010 plant shutdown (the Mann-Kendall analysis was not updated for this report to include monitoring data through March 2014). This approach was used because fairly consistent plant operation occurred during 2002−July 2010, thus avoiding potential bias from variable groundwater flow and concentration rebound effects during times of intermittent system operation.

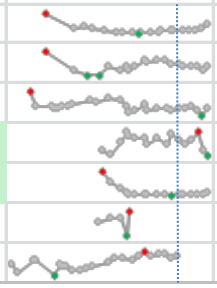
[1] The Mann-Kendall test generates all possible differences between pairs of sequential observations; however, the *relative magnitude of the difference* is not considered. Rather, any difference, large or small, is assigned either a positive or negative direction (refer to Gilbert [1987] for additional information).

Table 3. Uranium Trends in Middle Terrace Groundwater, Horizon A and B Monitoring Wells

Wells at or near the Site Boundary

	Summary Statistics: Uranium (mg/ L)					Sparklines	Mann-Kendall Test Results: Baseline – July 2010			
Well ID	***n***	**Baseline**	**Minimum**	**Maximum**	**Current**	**Feb-99 to Current**	***n***	**Test Value (S)**	***p*-value**	**Test Interpretation**
0262B	21	0.38	0.13	1.40	0.88		15	75.0	0.0001	Upward Trend
0286B	12	0.365[a]	0.004	0.52	0.40		7	Wells installed in March 2007. Insuffient number of observations for trend analysis.		
0287B	12	0.106[a]	0.11	0.27	0.27		7			
0288B	12	0.034[a]	0.011	0.034	0.011		7			
0906A	22	0.95	0.42	1.00	0.46		12	6.0	0.37	No Trend
0908B	27	0.12	0.072	0.12	0.087		18	(90.0)	0.0003	Downward Trend
0934B	28	0.31	0.13	0.36	0.15		18	(128.0)	<0.0001	Downward Trend
0940A	15	0.55	0.39	0.67	0.56		5	Insufficient data for trend analysis.		
0941A	27	0.089	0.049	0.27	0.25		15	59.0	0.002	Upward Trend

Distal Middle Terrace Wells

	Summary Statistics: Uranium (mg/ L)					Sparklines	Mann-Kendall Test Results: Baseline – July 2010			
Well ID	***n***	**Baseline**	**Minimum**	**Maximum**	**Current**	**Feb-99 to Current**	***n***	**Test Value (S)**	***p*-value**	**Test Interpretation**
0263B	20	0.49	0.10	0.49	0.26		15	(28.0)	0.084	No Trend
0265B	20	0.09	0.045	0.09	0.062		15	34.0	0.046	Upward Trend
0267B	26	0.073	0.06	0.11	0.071		17	(37.0)	0.076	No Trend
0281B	17	0.006[b]	0.005	0.009	0.005		12	9.0	0.32	No Trend
0282B	17	0.054[b]	0.004	0.054	0.01		12	(64.0)	<0.0001	Downward Trend
0283B	5	0.027[b]	0.023	0.030	Dry		5	Insufficient data for trend analysis.		
0909B	23	0.039	0.018	0.063	Dry		18	91.0	0.0003	Upward Trend

0.004 Value < 0.044 mg/ L restoration standard.

n = number of samples. Consistent with Figure 15a, baseline values listed in the third column are the most recent for the period February 1999 through March 2002. Sparklines (see notes below) plot all baseline period results (i.e., since February 1999).

[a] In lieu of baseline data, result from May 2007

[b] February 2005 result

Notes:

Well IDs are followed by a letter denoting depth horizon. Summary statistics are from the beginning of the baseline period (February 1999) through February 2013. The sparklines shown in the center column are well-specific line charts that have no axes or date scale (in contrast, refer to the grouped time-trend plots in Appendix D). The purpose of these line charts is to show, for individual wells, general concentration trends over time. In these plots, the *x*-axis is hidden but corresponds to a common date scale for all wells—February 1999 through February 2013. The gray markers correspond to individual measurements; minimum and maximum results are denoted by green and red markers, respectively. In all cases, the *y*-axis is condensed, and scales are unique to each well. Therefore, magnitudes of temporal trends are somewhat masked and should not be compared across wells. The vertical dashed line bisecting the sparklines corresponds to the August 2010 time frame, just before the extended (Oct 2010 to Sept 2011) plant shutdown.

Trend analysis was performed using the Mann-Kendall test (see Gilbert 1987) using ProUCL version 4.1 http://www.epa.gov/osp/hstl/tsc/software.htm. The test was used only for data through July 2010, the last sampling before the October 2010 plant shutdown, as this corresponds to a period of fairly consistent plant operation. Subsequent data are not considered reliable indicators of treatment progress due to the intermittent extraction and treatment rates since then. Under the Test Interpretation column, "No Trend" means insufficient evidence to identify a significant trend at the specified level of significance ($p < 0.05$). Upward and downward trends mean statistically significant evidence of an increasing or decreasing trend at the $p < 0.05$ level. The S-statistic is conventional output from the Mann-Kendall test: the higher the absolute value, the more significant the result. Negative S test values are listed in parentheses.

Table 4. Uranium Trends in Middle Terrace Groundwater, Horizons C and Deeper

Uranium Trends in Monitoring Wells South of the Disposal Cell

	Summary Statistics: Uranium (mg/ L)					Sparklines	Mann-Kendall Test Results: Baseline – July 2010			
Well ID	***n***	**Baseline**	**Minimum**	**Maximum**	**Current**	**Feb-99 to Current**	***n***	**Test Value (S)**	***p*-value**	**Test Interpretation**
0258D	18	0.002	0.001	0.002	0.001		13	21.0	0.13	No Trend
0272D	17	0.0001[a]	0.001	0.002	0.002		12	18.0	0.13	No Trend
0273D	17	0.056[a]	0.028	0.086	0.044		12	6.0	0.37	No Trend
0274C	17	0.001[a]	0.001	0.002	0.002		12	32.0	0.016	Upward Trend**
0289C	12	0.068[b]	0.012	0.068	0.013		7	Insufficient data for trend analysis.		
0912C	13	0.034	0.020	0.035	0.024		9	(10.0)	0.18	No Trend
0915D	11	0.002	0.000003	0.002	0.000004		8	(22.0)	0.002	Downward Trend**
0261D	13	0.002	0.001	0.003	0.001		9	2.0	0.46	No Trend
0264D	20	0.003	0.003	0.004	0.004		15	30.0	0.07	No Trend
0266D	20	0.002	0.0012	0.002	0.002		15	47.0	0.01	Upward Trend**
0932C	28	0.002	0.001	0.004	0.002		18	27.0	0.17	No Trend
0251E	28	0.048	0.001	0.048	0.002		18	39.0	0.076	No Trend
0913G	13	0.002	0.00091	0.002	0.00120		9	0.0	0.54	No Trend
0916G	10	0.001	0.00001	0.001	0.00002		8	(24.0)	0.001	Downward Trend**
0252I	27	0.002	0.001	0.004	0.002		19	2.0	0.47	No Trend

Uranium Trends in Monitoring Wells East of the Disposal Cell

	Summary Statistics: Uranium (mg/ L)					Sparklines	Mann-Kendall Test Results: Baseline – July 2010			
Well ID	***n***	**Baseline**	**Minimum**	**Maximum**	**Current**	**Feb-99 to Current**	***n***	**Test Value (S)**	***p*-value**	**Test Interpretation**
0290B[c]	12	0.0034[b]	0.001	0.06	0.06		7	Insufficient data for trend analysis.		
0275D	17	0.44[a]	0.160	0.52	0.420		12	25.0	0.058	No Trend
0276C	17	0.0013[a]	0.001	0.002	0.002		12	16.0	0.155	No Trend
0683C	18	0.0012	0.0009	0.0017	0.0012		11	8.0	0.27	No Trend
0684C	17	0.0019	0.001	0.0026	0.0013		11	2.0	0.44	No Trend
0685C	17	0.0012	0.001	0.0016	0.0012		11	11.0	0.22	No Trend
0268E	27	0.0014	0.0014	0.085	0.082		19	68.0	0.008	Upward Trend**

0.056 Value ≥ 0.044 mg/ L restoration standard (formatting different from Table 3, given intent to highlight exceptions within well groups).

n = number of samples. Consistent with Figures 15a, 16a, and 17a, baseline values listed in the third column are the most recent for the period February 1999 through March 2002. Sparklines plot all results since February 1999 through February 2013.

[a] In lieu of baseline data, result from February 2005;

[b] May 2007 result

[c] Although screened in Horizon B, well 290 is included in this table given co-location with other evaporation pond area wells.

**Although significant, these results must be considered within the context of the relative magnitude of change (very low in the case of 916G) or against criteria levels (e.g., relative to the 0.044 mg/L restoration standard).

Notes:

See detailed notes following Table 3. Table partitions in the uppermost table separate Horizon C–D wells at or near site or disposal cell boundary (upper portion), lower middle terrace Horizon C–D wells (middle portion), and wells screened in the deepest zones (Horizons E or deeper, bottom portion).

Although Mann-Kendall tests were run for sentinel and lower-terrace wells, with the exceptions noted previously, contamination in these wells is generally absent (refer to Appendix D, Figures D-4 through D-7 and D-10 through D-13). Given the potential for trending artifacts (stemming from low concentrations), test results are not reported here. Appendix D provides time-trend plots to facilitate review and interpretation of all Mann-Kendall test findings.

In summary, despite measureable progress in removing contaminant mass from the aquifer (see Section 4.3), Mann-Kendall trend analysis indicates no widespread decreases in uranium concentrations in groundwater at the site through the most sustained period of treatment system operation (Tables 3 and 4).

5.2 Concentrations at Extraction Wells Over Time

Figures 25 to 27 illustrate concentration variation over time at the extraction wells for nitrate, sulfate, and uranium, respectively. Each figure has three separate plots based on location to show the variation for the area east of the disposal cell (figure "a"), the area immediately south of the disposal cell (figure "b"), and the area encompassing the southernmost portion of the plume (figure "c").

5.2.1 Eastern Extraction Area

Figure 25a indicates that except for wells 1120 and 1122, no uniform decrease in nitrate concentration is observed in the eastern area of the extraction well field. Between February 2003 and 2007, nitrate concentrations in many of eastern wells declined but later rebounded to concentrations that generally remain above the remediation standard by a factor of 10. Sulfate concentrations in eastern area extraction wells (Figure 26a) do not show a definite trend. Concentrations generally range between about 1,000 and 2,500 mg/L, well above the 250 mg/L remediation goal.

Uranium concentrations in the eastern area have decreased relative to baseline conditions—from an average of approximately 0.5 mg/L (baseline) to about 0.25 mg/L (Figure 27a). The most significant decreases are apparent in wells 1120, 1121, and 1122 (see also Figure 28). Figure 28 depicts baseline versus July 2010 uranium concentration in extraction wells by spatial region as a two-point slope. Consistent with the approach used for the Mann Kendall test, 2010 measurements were considered the best recent indicators of treatment progress given subsequent extended plant shutdown periods. Although called "slopegraphs," the lines in Figure 28 are *no*t trend lines and exclude variation between the endpoints.

5.2.2 Near-South Extraction Area

Contaminant concentrations at extraction wells in the area immediately south of the disposal cell are shown in Figures 25b, 26b, and 27b. Current concentrations of nitrate, sulfate, and uranium do not appear different in magnitude or range compared to baseline conditions. Concentrations in these extraction wells remain well above remediation goals. Wide variation in uranium concentrations observed at wells 1105, 1106, and 1132 may be explained by transient pumping conditions and plume movement within the capture zone.

5.2.3 Far-South Extraction Area

Nitrate, sulfate, and uranium in the southernmost extraction wells exhibit no apparent trending (Figures 25c, 26c, and 27c). Nitrate and sulfate concentrations remain 5 to 10 times the respective remediation target. Wide variations are notable, particularly at wells 1118 and 1130.

Uranium concentrations have remained relatively stable at the southernmost extraction wells except at wells 1129 and 1130. Variability at these locations may be attributed to plume shifting during transient operating conditions. Otherwise, uranium concentration in the extract at most of the wells in this area is relatively low.

5.2.4 Extraction Wells Meeting Cleanup Goals

Table 5 lists the extraction wells where a primary contaminant concentration was below the remediation standard in the extract during this reporting period. Although some wells lack recent measurements, there was no extraction well where the concentration of the three primary contaminants was below a corresponding remediation standard. However, the February 2014 data indicate that several of the southernmost extraction wells (wells 1112, 1116, 1118, 1127, and 1133) could be candidates for reduced operation because of relatively low levels of contamination.

Table 5. Extraction Wells with Concentrations Less Than a Remediation Standard, February 2014

Extraction Well[a]	Nitrate	Sulfate	Uranium
1112	–	X (190)	X (0.037)
1116	–	X (140)	X (0.006)
1118	–	–	X (0.025)
1125	–	X (84)	X (0.013)
1127	–	X (240)	X (0.006)
1133	–	X (180)	–

[a] This table shows only those extraction wells where the remediation standard was not exceeded for at least one contaminant. Contaminant values in mg/L are shown in parentheses.

5.2.5 Breakthrough of Distillate from the Infiltration Trench

The infiltration trench was designed to deliver uncontaminated water that would flow beneath the disposal cell and thus promote contaminant flushing and recovery at the extraction wells. To date there is no evidence of decreased solute concentration at extraction and monitoring wells located immediately downgradient of the disposal cell that would indicate displacement or dilution of contaminated water by the distillate.

The estimated travel time from the infiltration trench to well 940 is about 17 years based on application of Darcy's Law, assuming a water table gradient of 0.04 ft/ft during full-time operation of the remediation system, a hydraulic conductivity of 1 ft/day (from DOE 1998), and 25 percent porosity. With these inputs, the average linear flow velocity computes to about 60 ft/year. Ignoring hydrodynamic dispersion, the estimated travel time exceeds the cumulative remediation period to date. This implies that breakthrough of the distillate by advective transport is not expected for at least several years (or more considering intermittent operation of the treatment system).

5.3 Contaminant Mass Removal and Restoration Progress

Table 6 lists the cumulative amounts of nitrate, sulfate, and uranium removed from the aquifer through March 2014, reflecting about 12 years since implementing the active groundwater remedy. Table 6 also provides the estimated quantities of contamination initially present in the aquifer and the amount of contaminant removed as a percent of the initial quantity. Calculation methods for these estimates of initial contaminant mass and initial volume of contaminated groundwater were provided in previous annual reports (e.g., see DOE 2010, Appendix G [Calculation Set 1]) and are not reproduced or modified in this report.

Estimates of initial contaminant mass are based on dissolved contaminant distribution and do not account for a possible sorbed phase of the contaminant. The potential for sorbed contaminant mass in the aquifer is particularly relevant to uranium, relative to nitrate and sulfate, because uranium is generally recognized as having a greater potential to interact with an aquifer substrate. The presence of a sorbed phase would increase the amount of a contaminant in the aquifer and may prolong aquifer restoration time relative to that of a conservative species.

Table 6. Summary of Cumulative Mass and Volume Recovery as of April 1, 2013

Contaminant	Initial Mass (lb)	Cumulative Mass Removed (lb)	Cumulative Percent Mass Reduction	Initial Volume (gallons)	Cumulative Volume Treated (gallons)	Percent Plume Volume Reduction
Nitrate	9,500,000	1,306,700	14	1.2×10^9	4.1×10^8	34
Sulfate	20,150,000	3,414,750	17	1.2×10^9	4.1×10^8	34
Uranium	2,300	852	37	1.2×10^9	4.1×10^8	34

Notes:
For the preceding review period (ending April 1, 2013), cumulative mass reductions were 13.0, 15.8, and 34.7 percent, respectively, for nitrate, sulfate, and uranium.

Table 7 summarizes the cumulative mass of uranium and volume of groundwater removed for all review periods since the start of active remediation. The mass reduction values imply that approximately 4 percent of the initial dissolved mass is removed annually during sustained active remediation (through 2010). Linear projection of this removal rate indicates a restoration period of 27 years to remove the estimated mass of dissolved uranium contained in one pore volume of the plume. The corresponding volume of groundwater extracted after 27 years, assuming constant withdrawal of 85 gpm, is 1.2 billion gallons, or one estimated pore volume of the contaminant plume.

Table 7. Annual Cumulative Mass and Volume Recovery of Uranium

Year Ending (through March)[a]	Cumulative Mass Removed, Uranium[b] (lb)	Cumulative Percent Mass Reduction	Cumulative Volume Treated[c] (million gallons)	Percent Plume Volume Reduction
2003	132	6	50	4
2004	234	10	92	8
2005	325	14	136	11
2006	412	18	180	15
2007	493	21	224	19
2008	574	25	266	22
2009	650	28	307	26

Table 7(continued). Annual Cumulative Mass and Volume Recovery of Uranium

Year Ending (through March)[a]	Cumulative Mass Removed, Uranium[b] (lb)	Cumulative Percent Mass Reduction	Cumulative Volume Treated[c] (million gallons)	Percent Plume Volume Reduction
2010	721	31	338	28
2011	751	33	350	29
2012	774	34	360	30
2013	800	35	370	31
2014	852	37	401	34

[a] Values reported from the end of each annual reporting period (all values are rounded)
[b] Estimated initial dissolved mass: 2,300 lb
[c] Estimated initial contaminated pore volume: 1,200 million gallons

This projection ignores factors that could produce nonlinear recovery of uranium over time that could result from rate-limited mass transfer processes. Such limitations to pump-and-treat remediation are cited in the GCAP (DOE 1999) and the scientific literature, and are not unique to the Tuba City site.

As addressed previously in this report, contaminant concentration trends generally do not indicate that remediation goals are achievable in the near-term. Despite operation of an extraction system for more than 10 years that effectively captures the main region of contamination, groundwater quality has not significantly improved. This conclusion is based on observations of a remedial action that has not yet removed one estimated pore volume of the contaminant plume.

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6.0 Year in Review Summary

- The net on-stream factor for distillate production was 53 percent during the review period. During sustained operation, the on-stream factor approaches 90 percent.
- The net treatment rate for the period was approximately 50 gpm. By comparison, during sustained operation, the net annual treatment rate is about 80 gpm.
- Aquifer yield has decreased from about 100 gpm in previous years to about 85 gpm.
- Approximately 27 million gallons of contaminated groundwater was extracted from the aquifer during the period. This compares to about 40 million gallons treated annually in years of sustained operation.
- Treatment system shutdowns were partially offset by discharging the extracted groundwater directly to the solar evaporation pond for evaporative treatment.
- The treatment system achieves design criteria for quality of the distillate and waste-stream percentage of total feed.
- The infiltration trench is accepting distillate without excessive groundwater mounding.
- When operational, the extraction system meets design objectives to capture the lateral region of maximum groundwater contamination and the full vertical extent of groundwater contamination.
- Significant and widespread decreases in contaminant concentrations in groundwater are not apparent. This is despite the measureable progress in groundwater treatment, as indicated by cumulative contaminant mass and volumes extracted from the aquifer.
- The absence of widespread decreases in contaminant concentrations is attributed more to rate-limiting mass transfer processes in the subsurface than to limitations of the recovery design.
- Persistent elevated contaminant concentrations in the groundwater suggest a prolonged period of active remediation, requiring the removal of multiple pore volumes from the contaminant plume.
- Analysis of groundwater flow and plume capture is complicated under the conditions of intermittent remediation system operation.
- The source of contamination in well 268 merits additional investigation. Contamination at this depth is inconsistent with water quality at other deep wells. Well integrity could be evaluated using downhole video in combination with electrical conductivity logging for evidence of a compromised well seal or casing.
- Redevelopment of extraction and monitoring wells was initiated during this review period. The planned scope of well redevelopment is not yet completed. Analysis of possible effects of well redevelopment (extraction rates and water quality) will benefit future evaluation of restoration system performance.

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7.0 References

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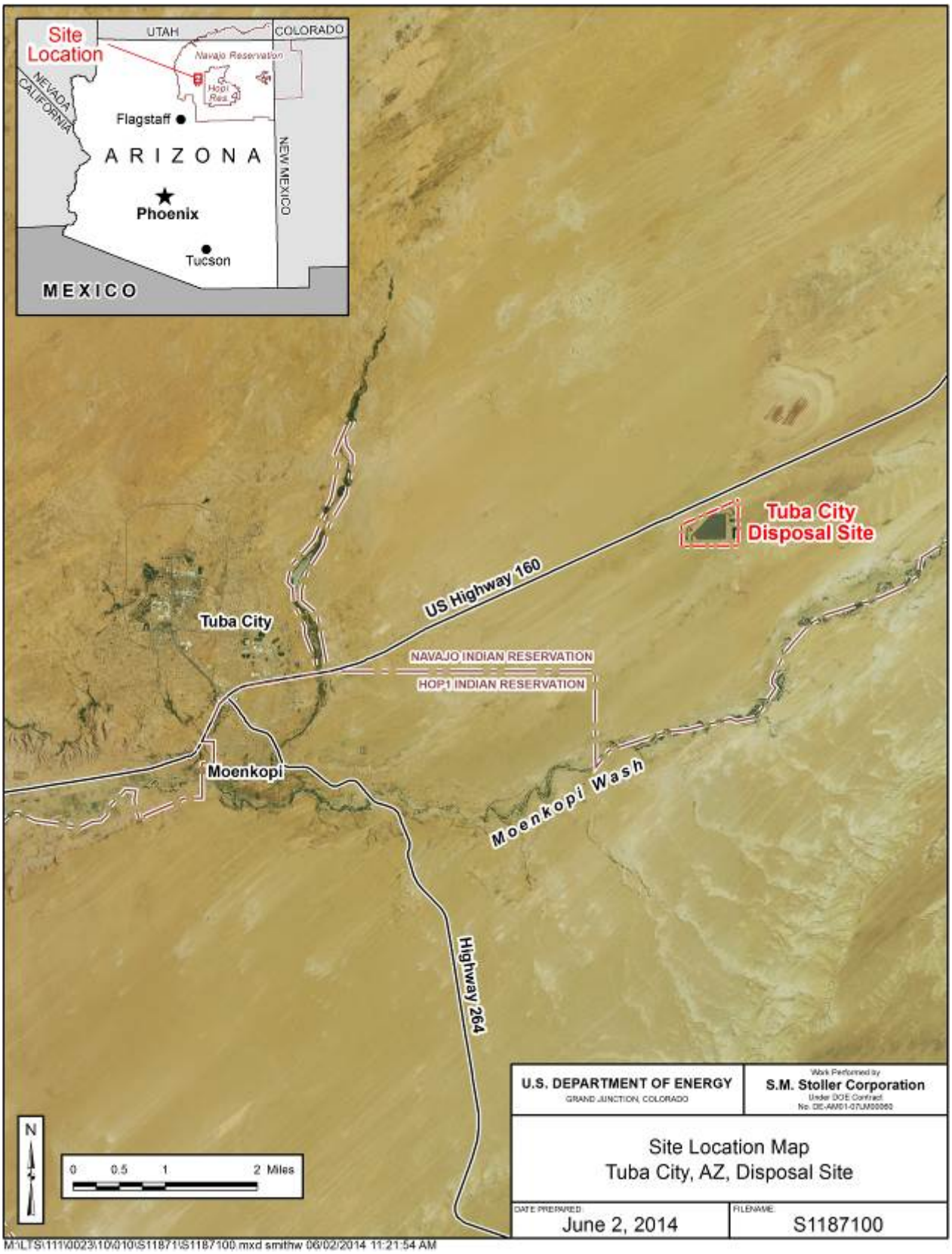

Figure 1. Tuba City Site Location Map

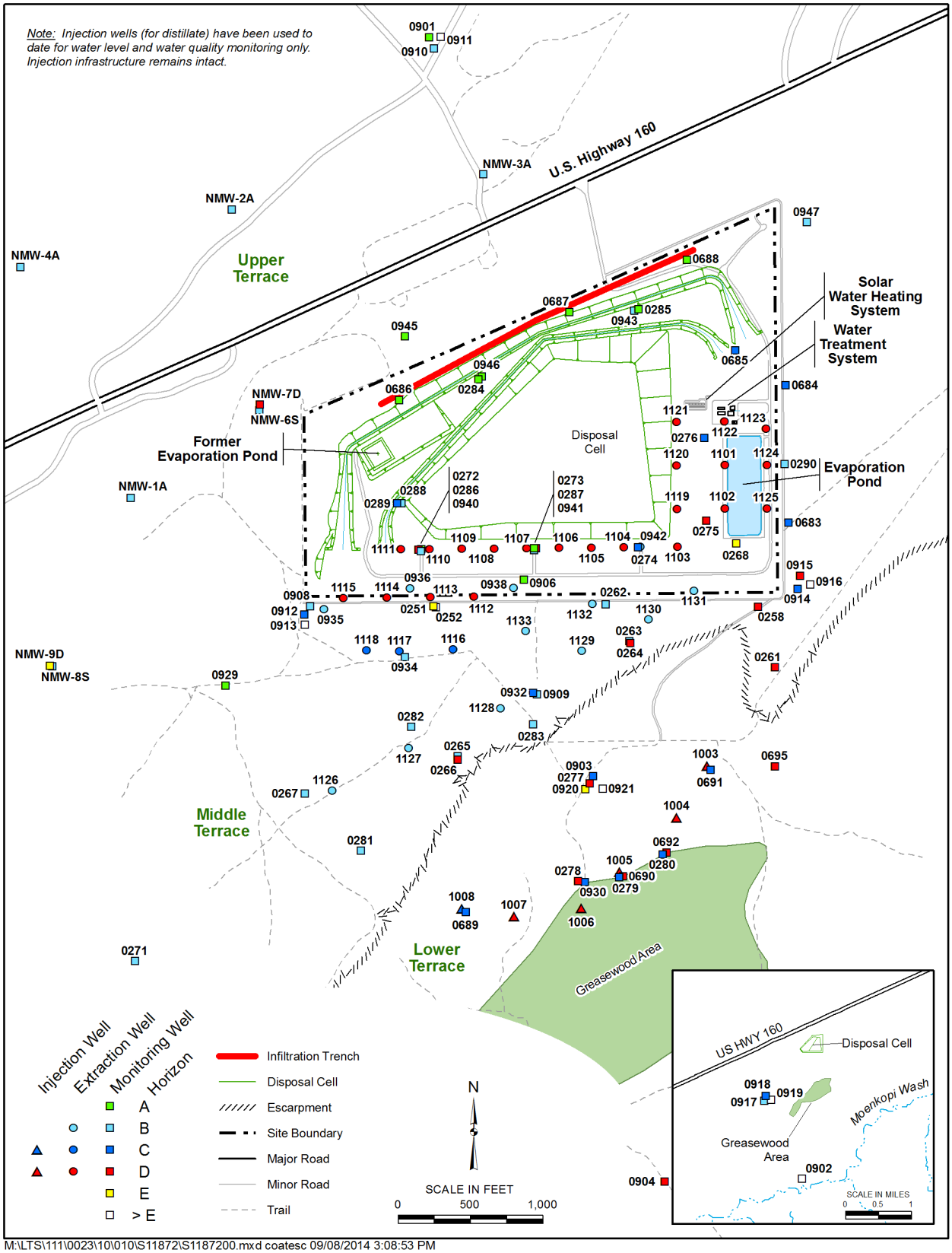

Figure 2a. Tuba City Site Features and Well Locations

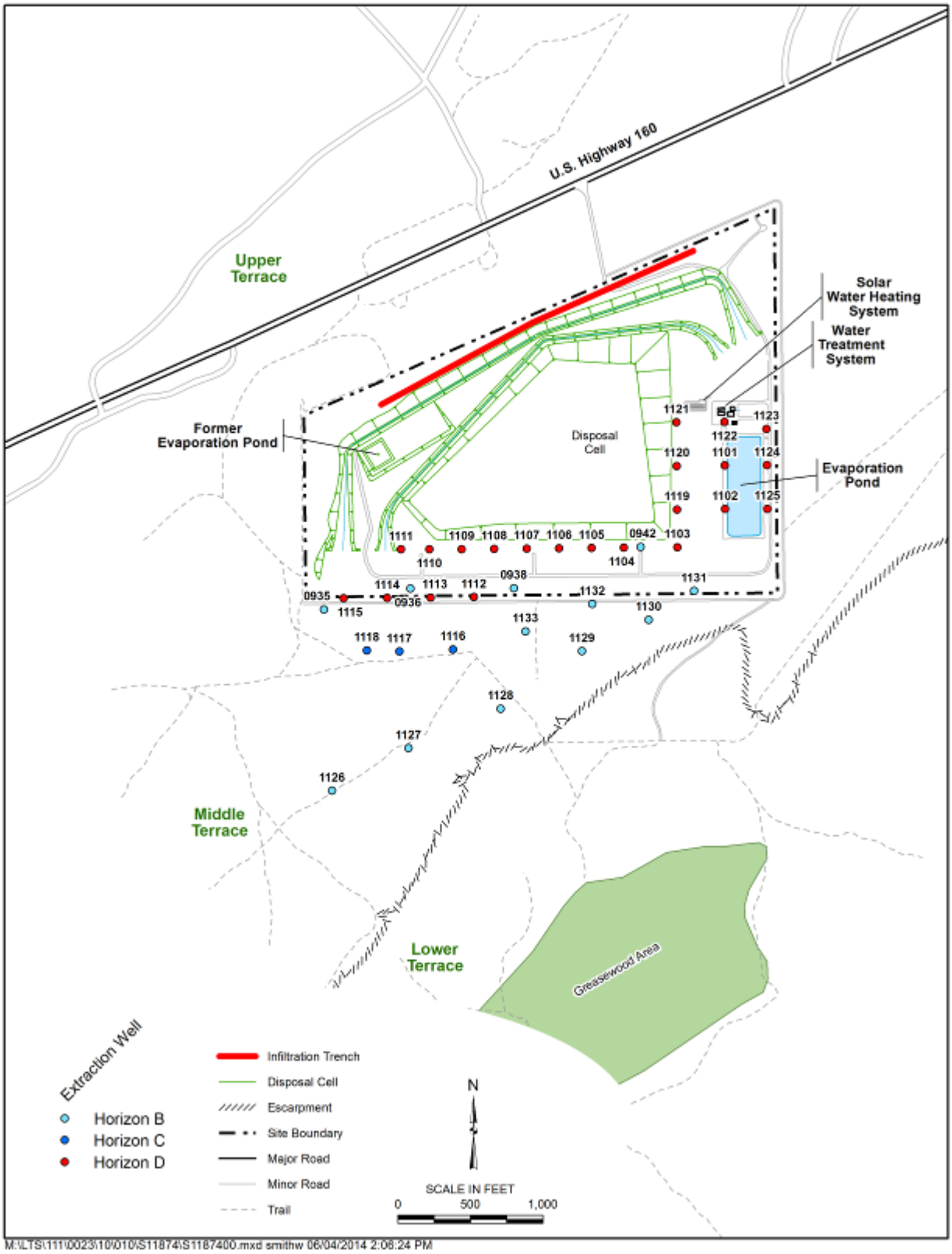

Figure 2b. Tuba City Site Features and Well Locations—Extraction Wells Only

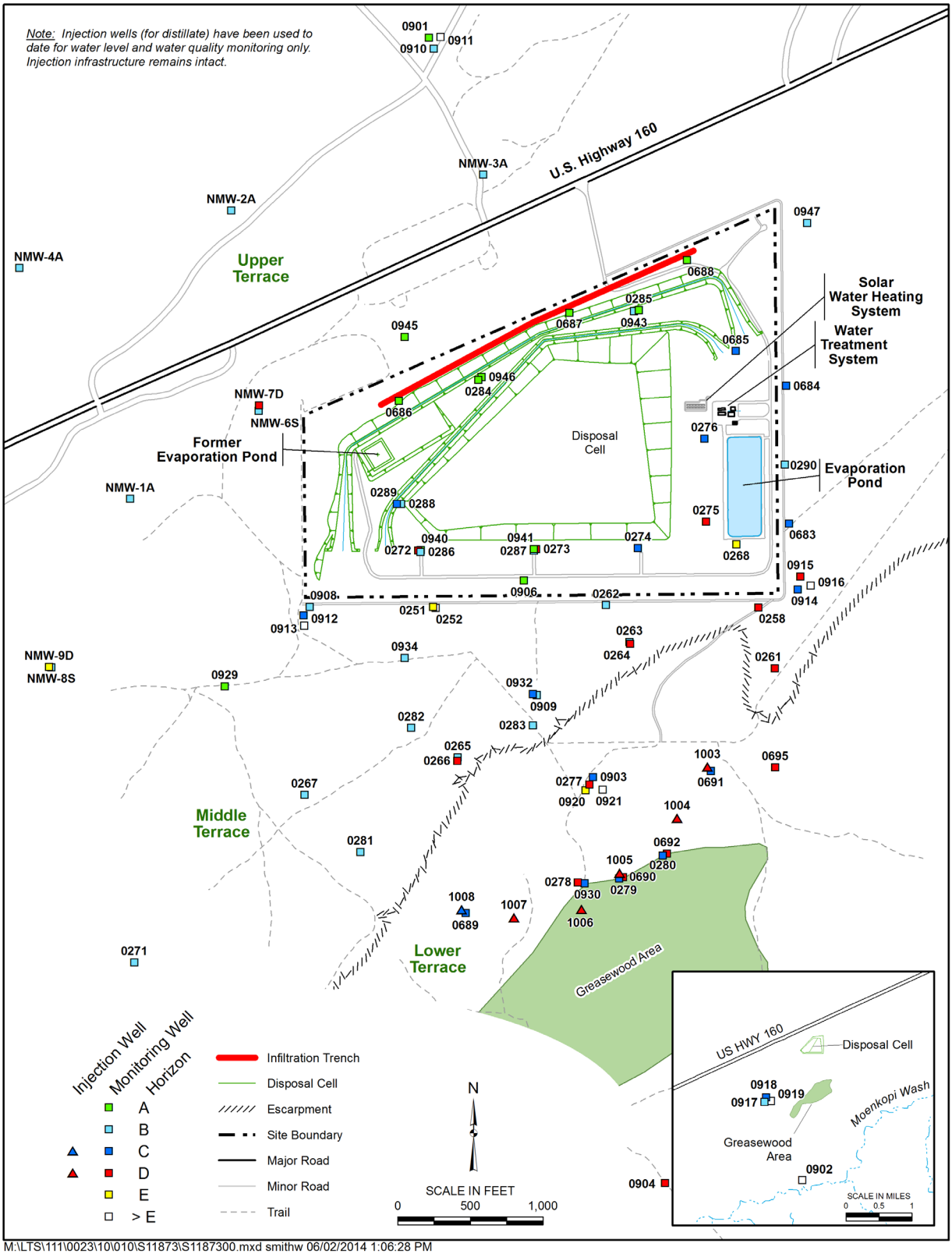

Figure 2c. Tuba City Site Features and Well Locations—Monitoring Wells Only

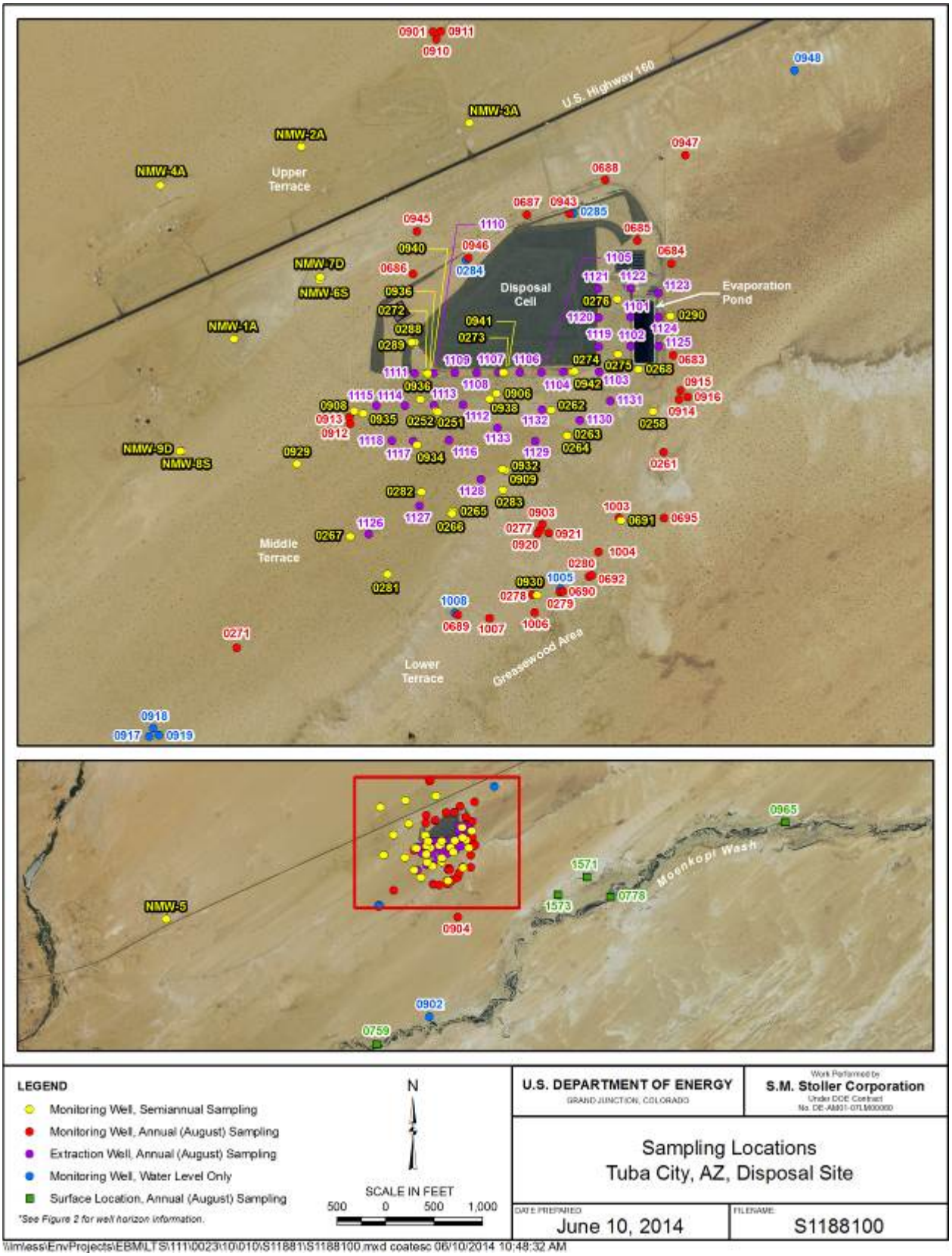

Figure 3. 2013–2014 Sampling Locations

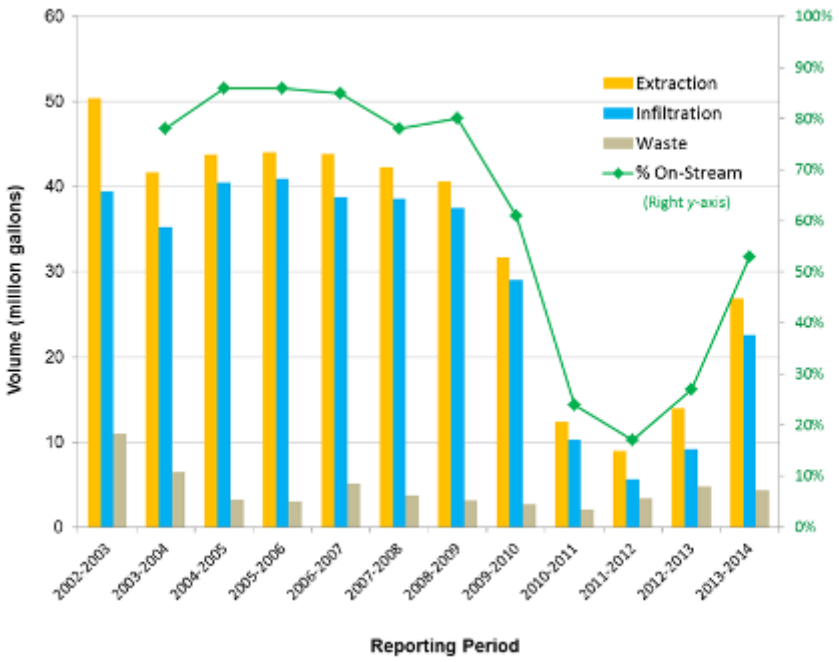

Figure 4. Annual Treatment Volumes and On-Stream Rates Since the Baseline Period

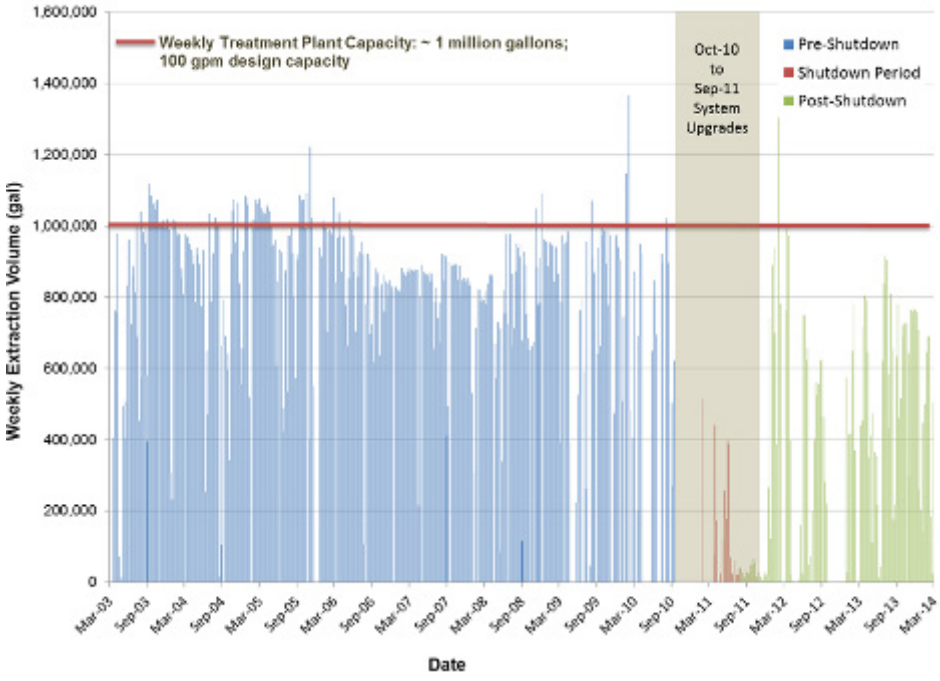

Figure 5. Weekly Extraction Volumes Since Baseline Period

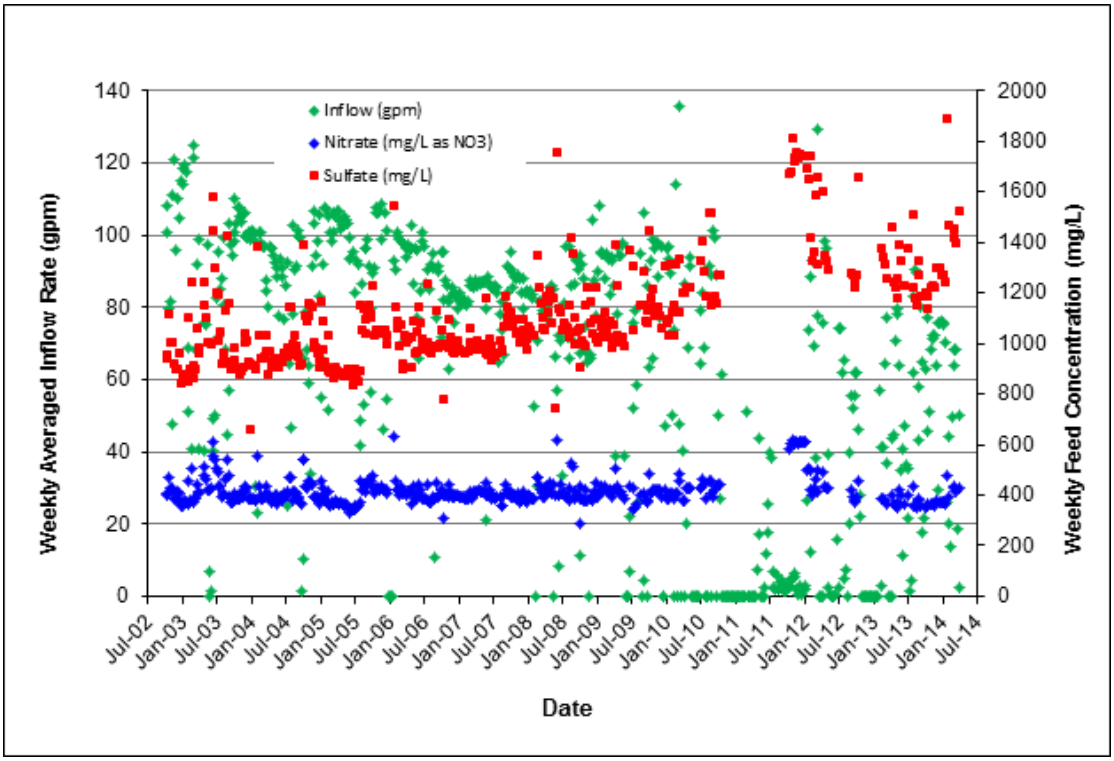

Figure 6. Treatment Plant Inflow Rates and Nitrate and Sulfate Concentrations

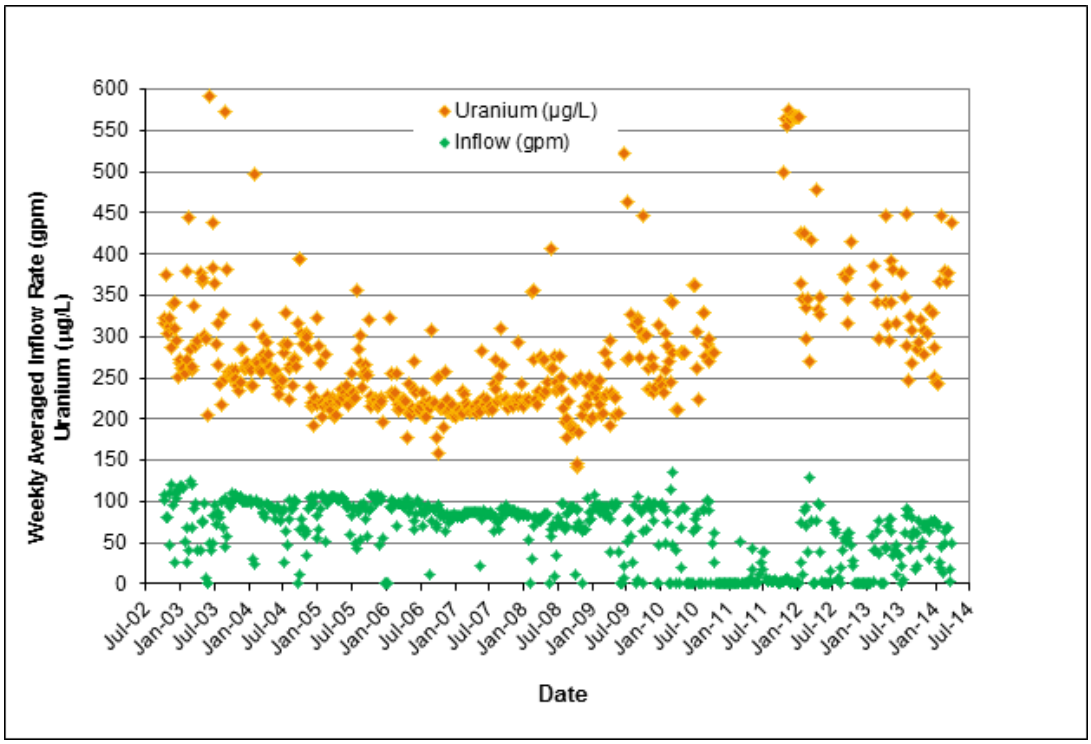

Figure 7. Treatment Plant Inflow Rates and Uranium Concentrations

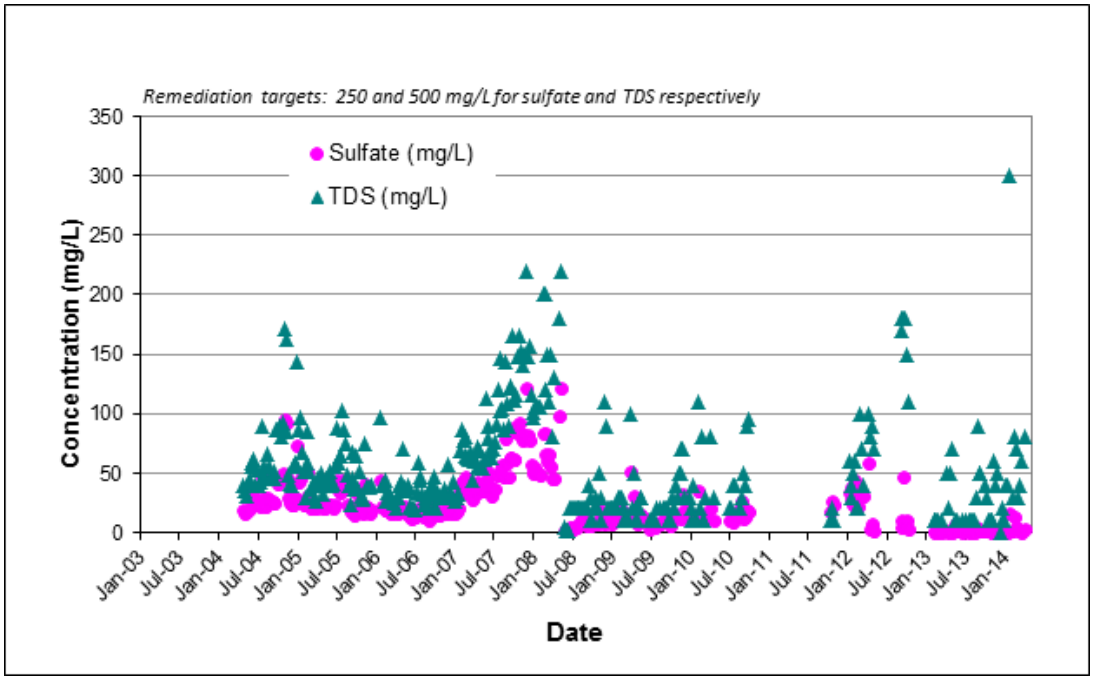

Figure 8a. Treatment Plant Distillate Quality—Sulfate and TDS

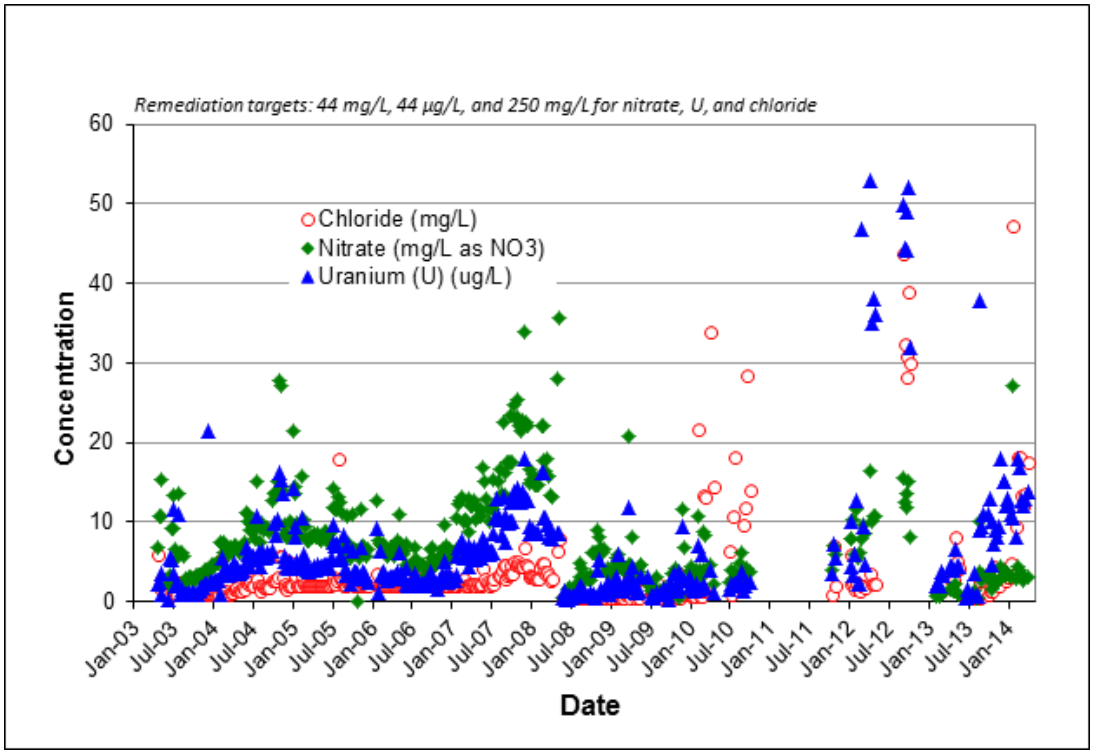

Figure 8b. Treatment Plant Distillate Quality—Nitrate, Uranium, and Chloride

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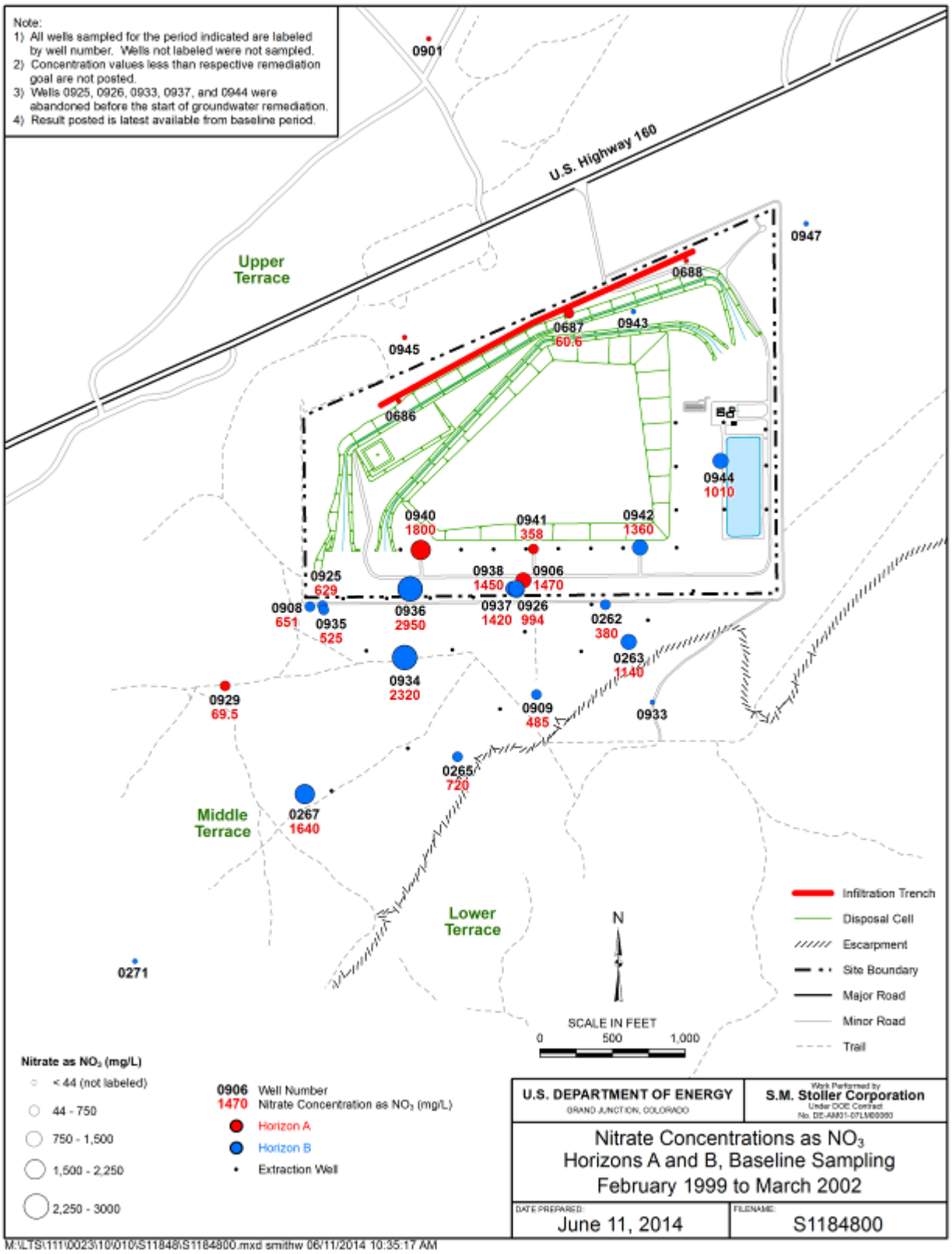

Figure 9a. Nitrate Concentrations as NO_3, Horizons A and B, Baseline Period

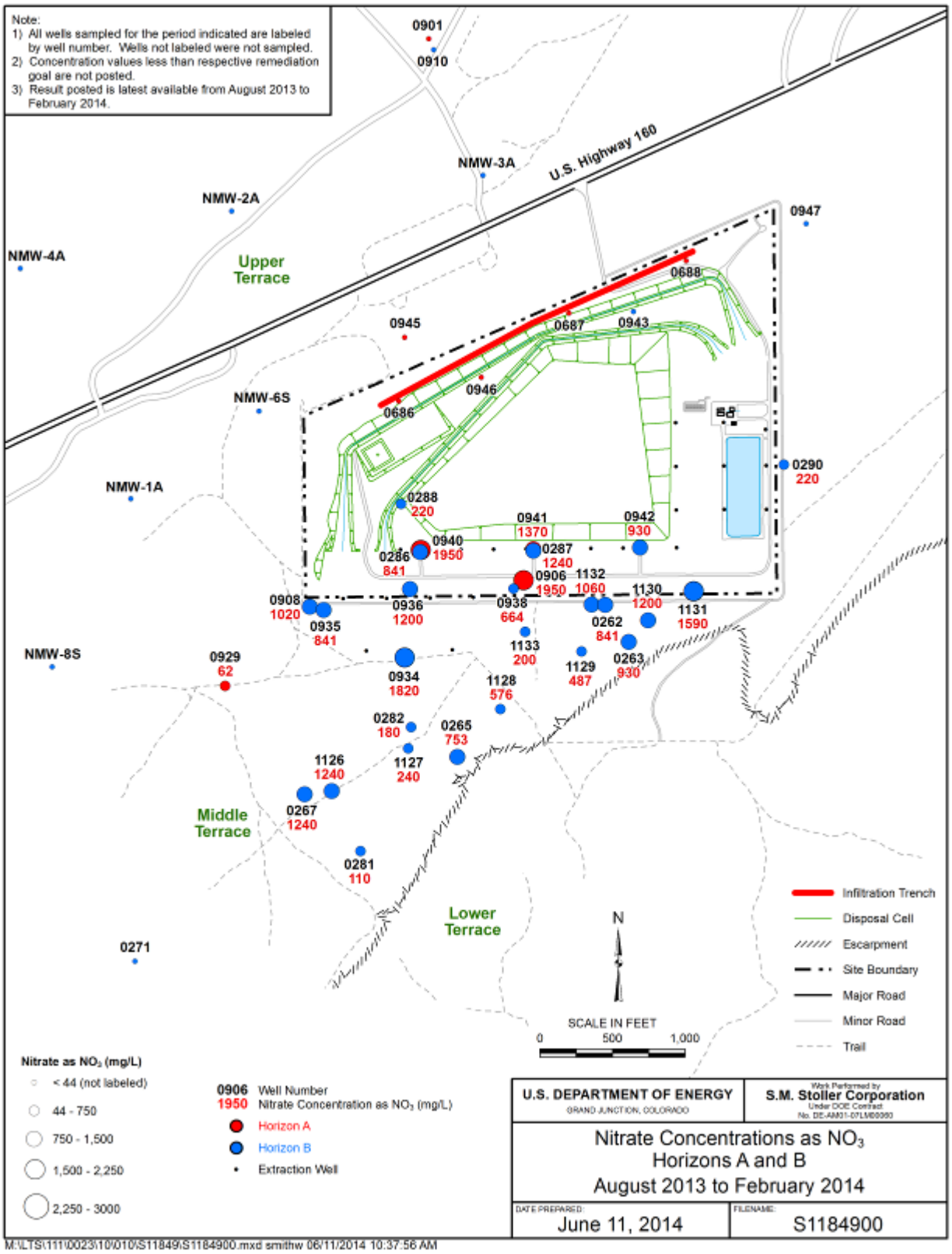

Figure 9b. Nitrate Concentrations as NO_3, Horizons A and B, February 2014

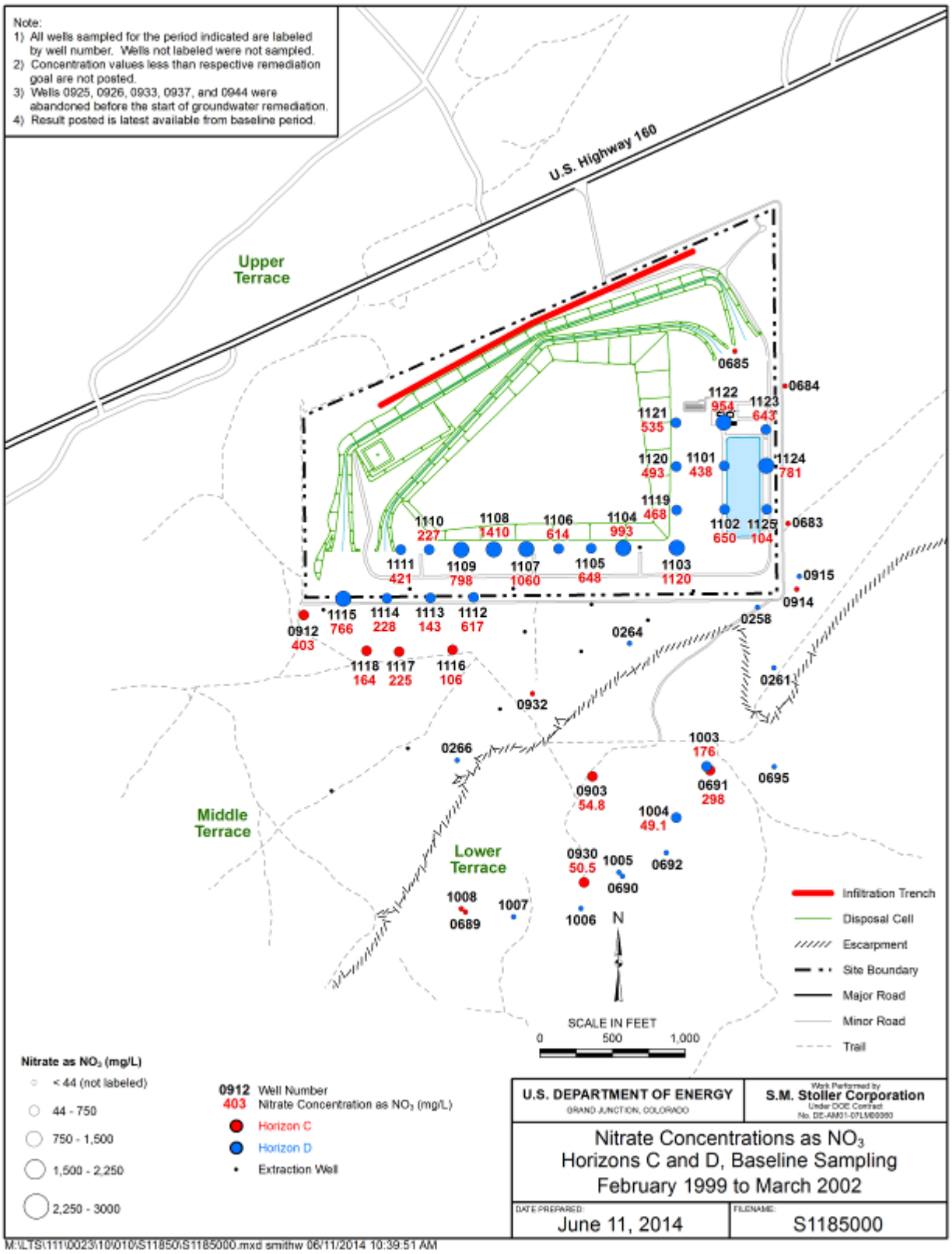

Figure 10a. Nitrate Concentrations as NO_3, Horizons C and D, Baseline Period

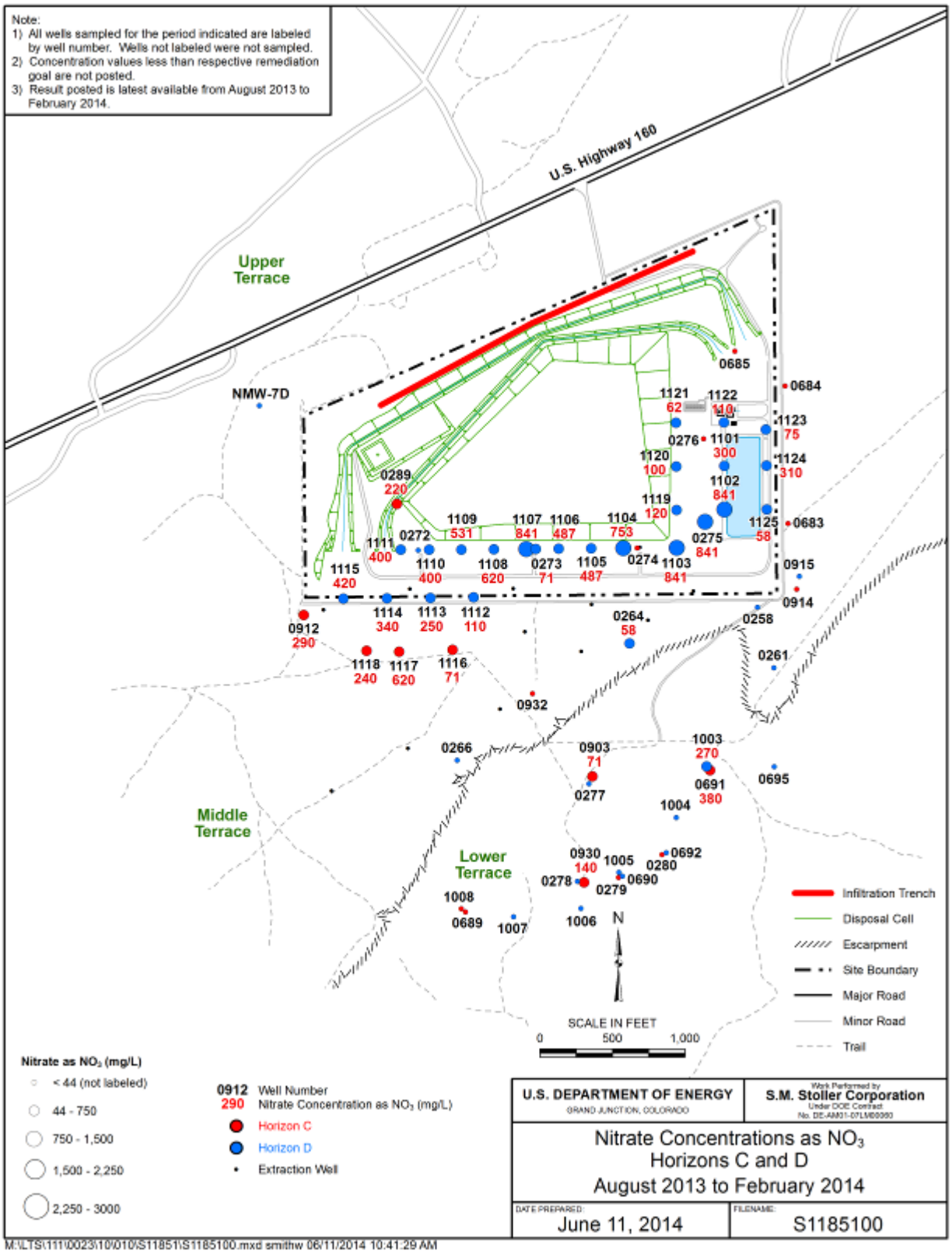

Figure 10b. Nitrate Concentrations as NO_3, Horizons C and D, February 2014

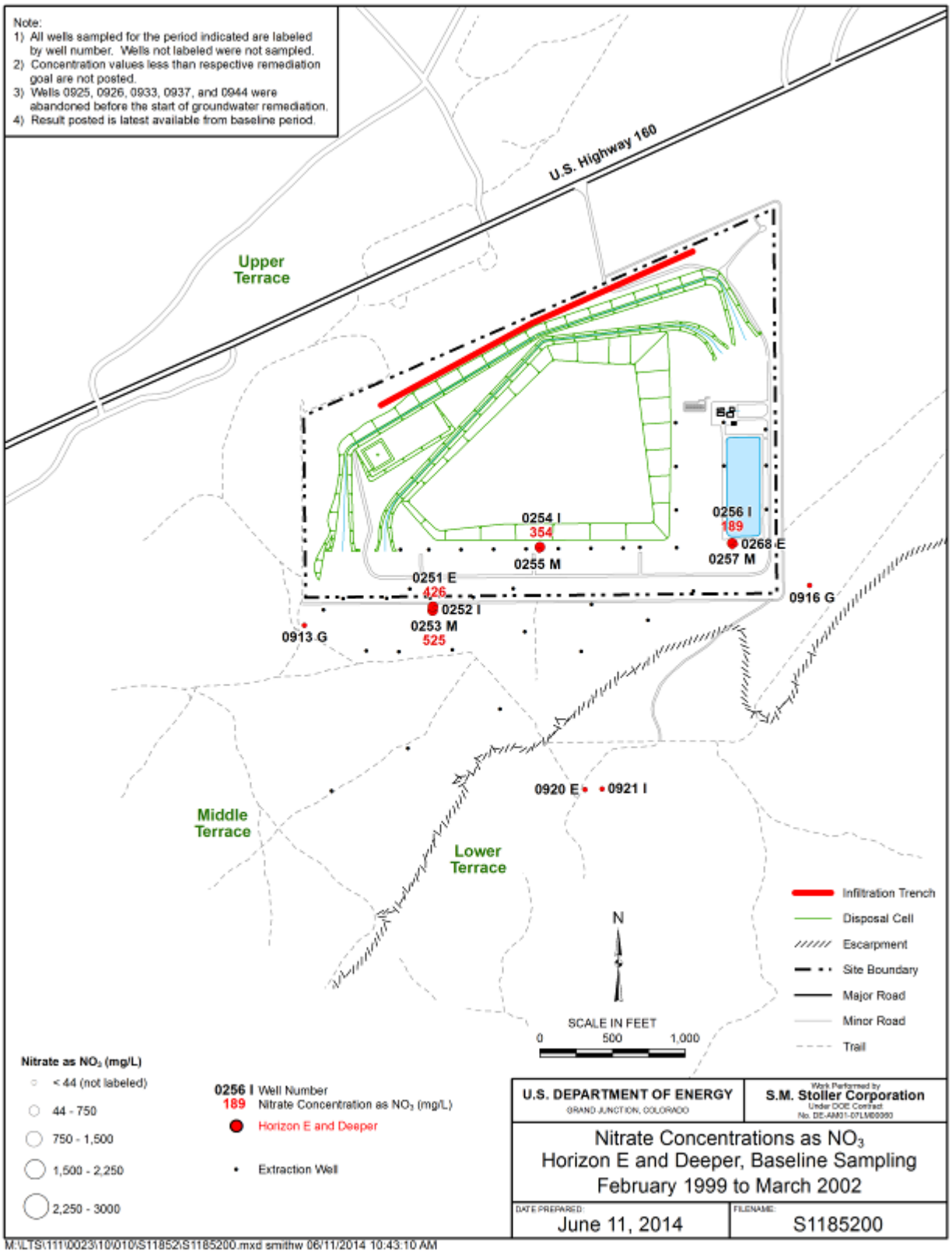

Figure 11a. Nitrate Concentrations as NO_3, Horizons E and Deeper, Baseline Period

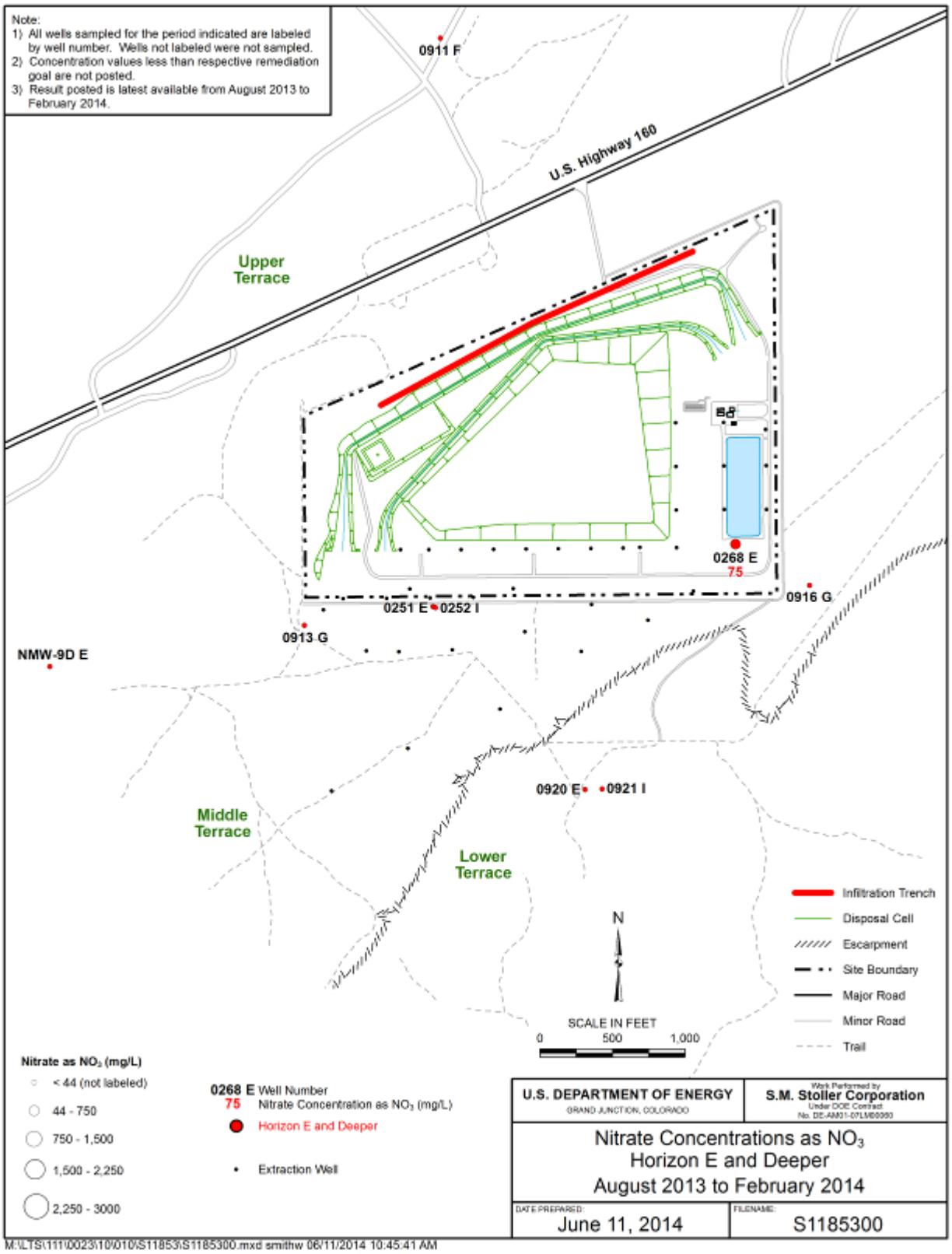

Figure 11b. Nitrate Concentrations as NO_3, Horizons E and Deeper, February 2014

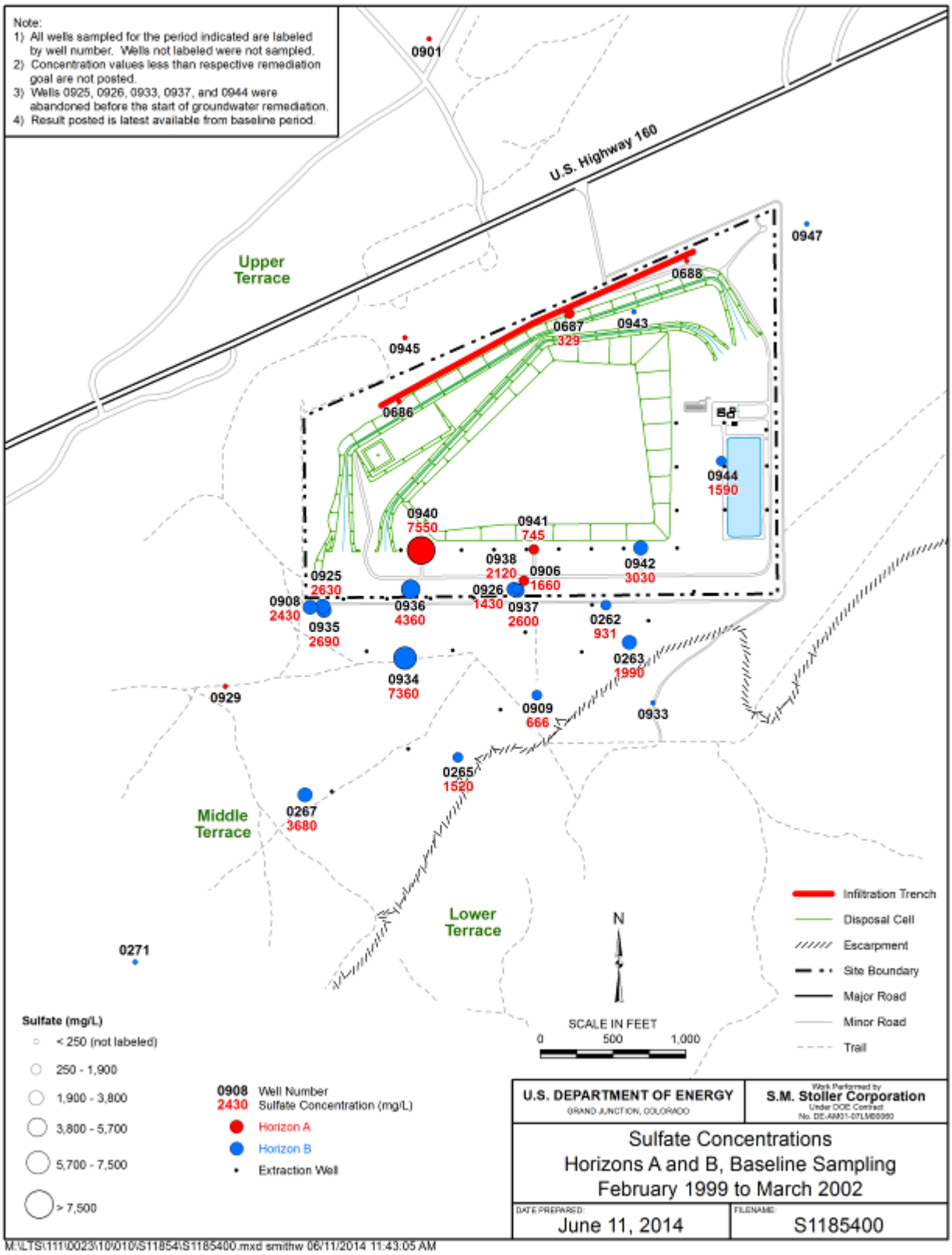

Figure 12a. Sulfate Concentrations in Groundwater, Horizons A and B, Baseline Period

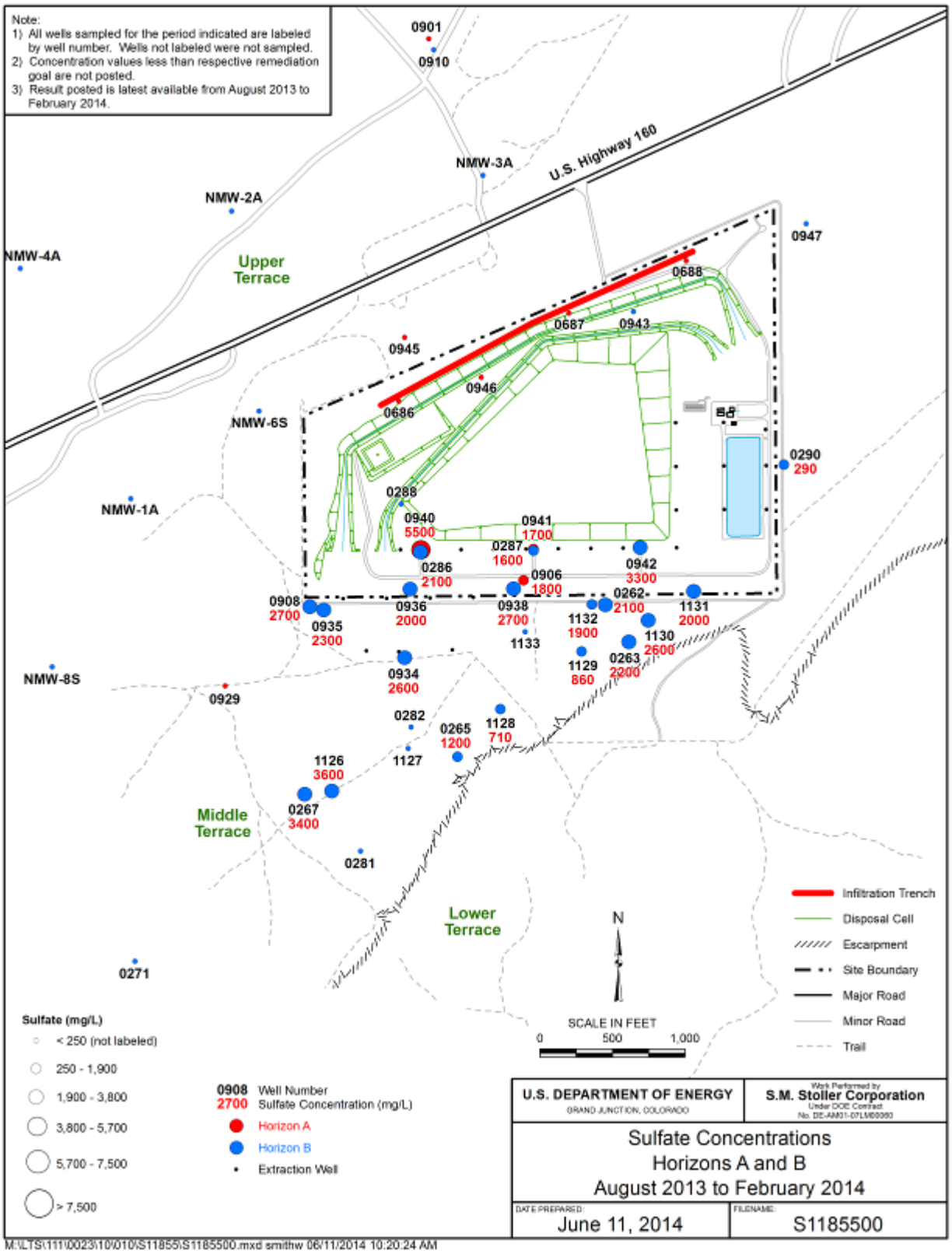

Figure 12b. Sulfate Concentrations in Groundwater, Horizons A and B, February 2014

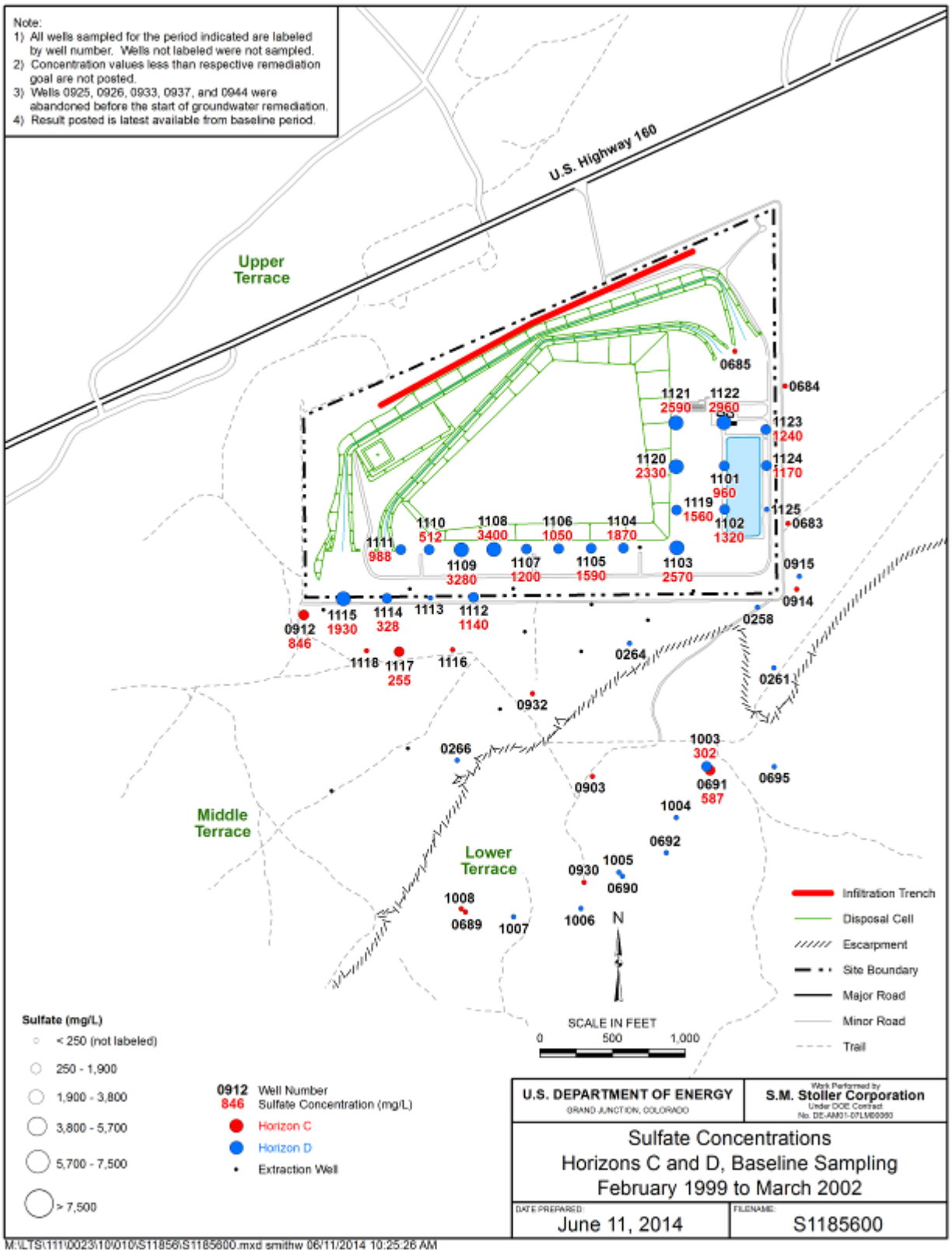

Figure 13a. Sulfate Concentrations in Groundwater, Horizons C and D, Baseline Period

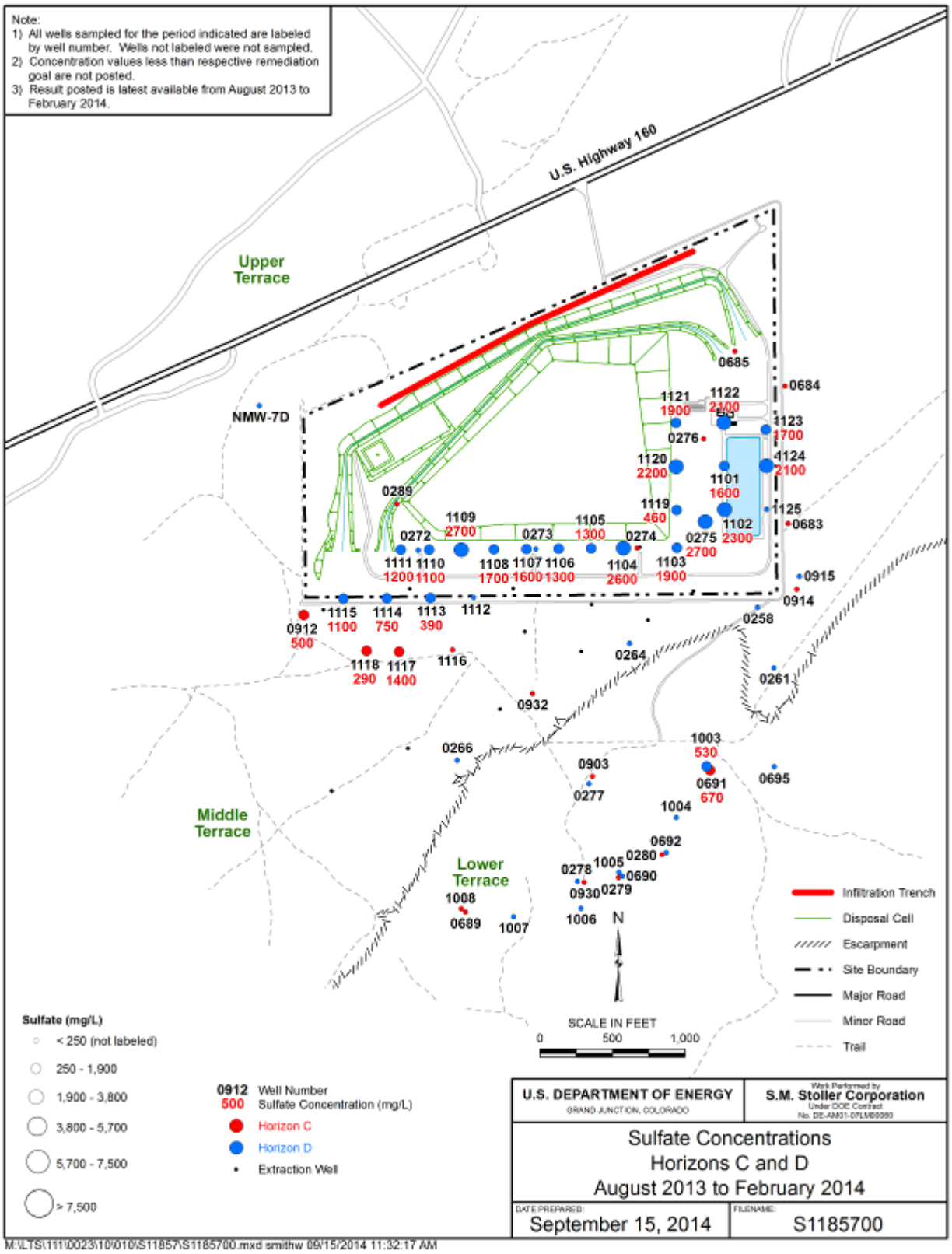

Figure 13b. Sulfate Concentrations in Groundwater, Horizons C and D, February 2014

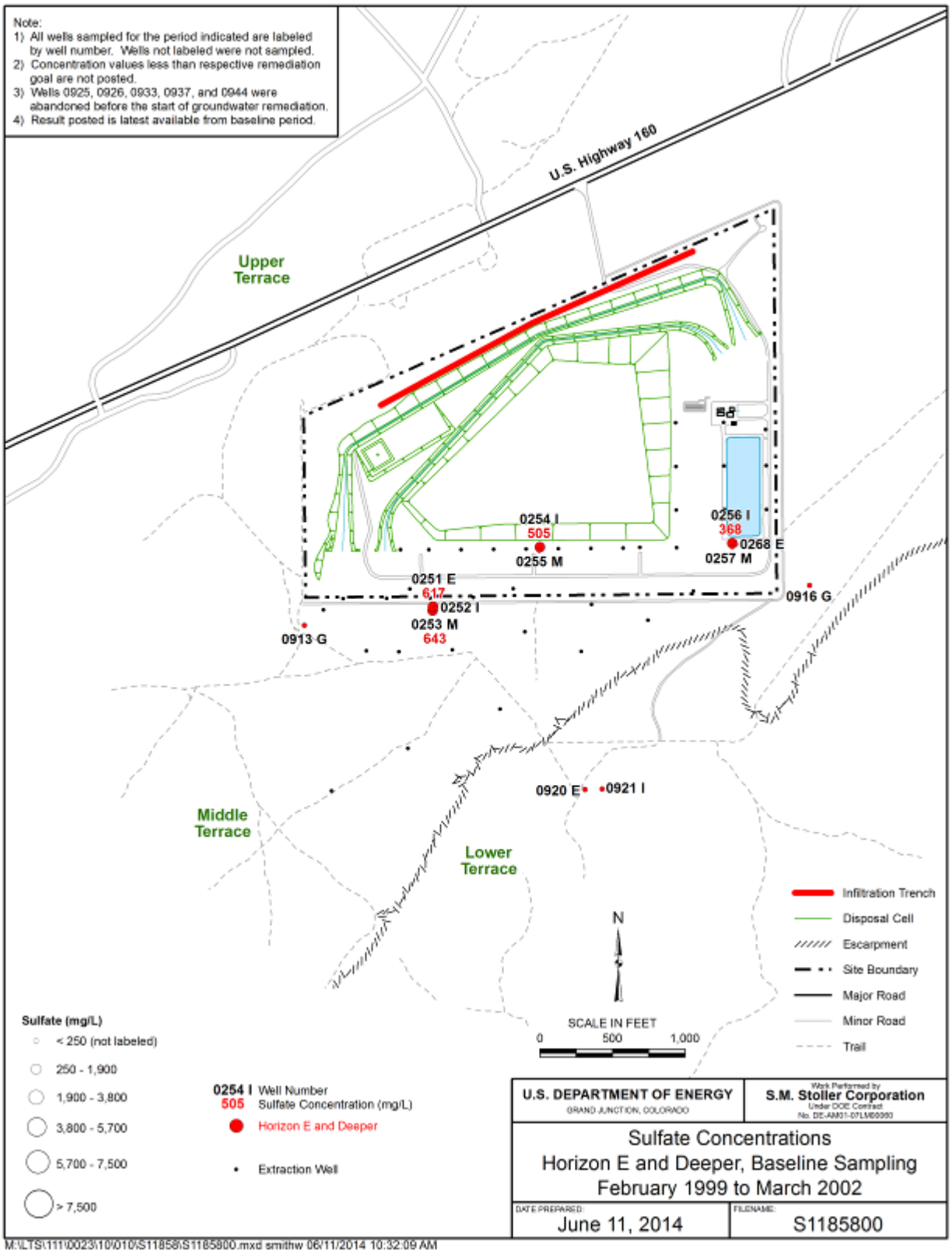

Figure 14a. Sulfate Concentrations in Groundwater, Horizon E and Deeper, Baseline Period

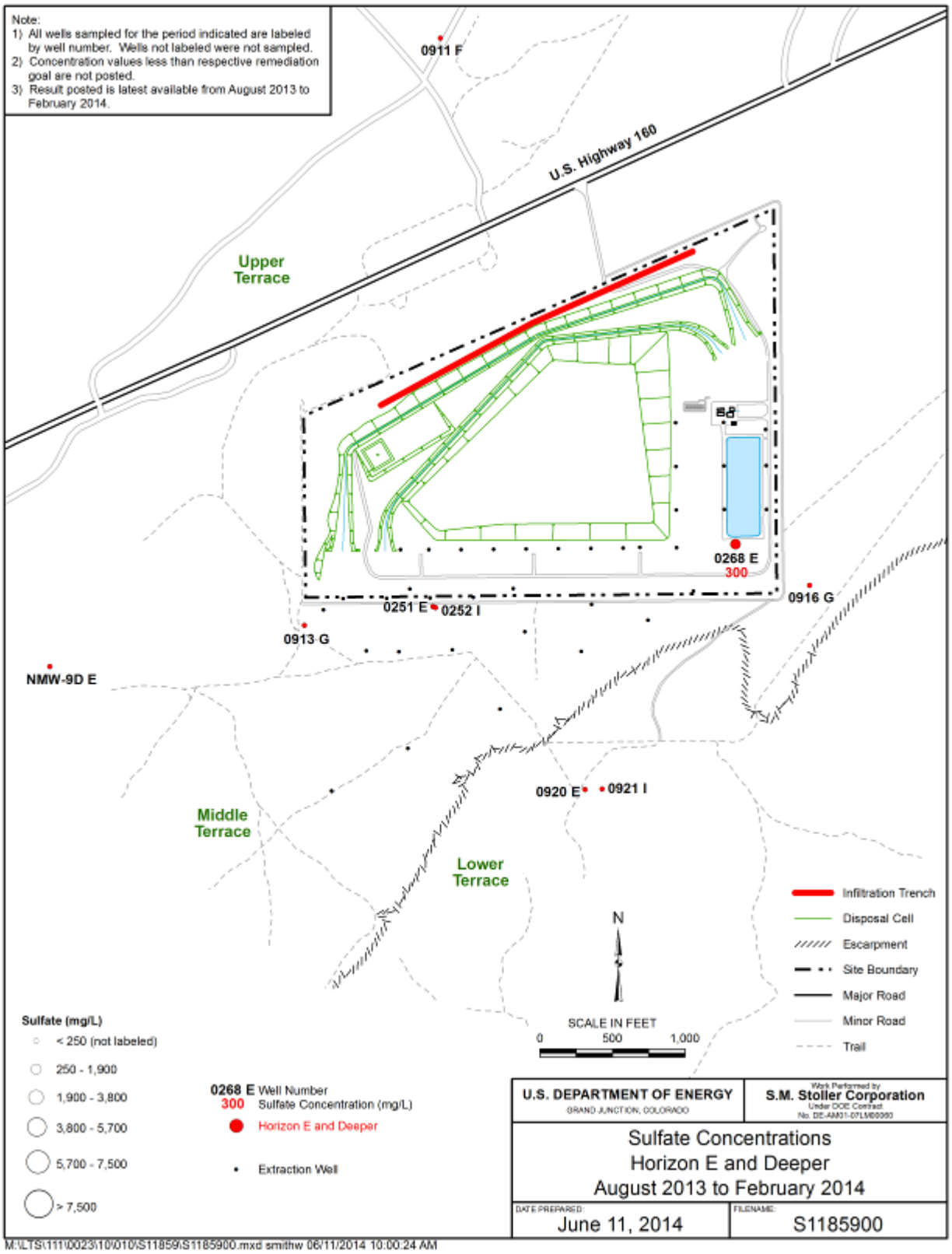

Figure 14b. Sulfate Concentrations in Groundwater, Horizon E and Deeper, February 2014

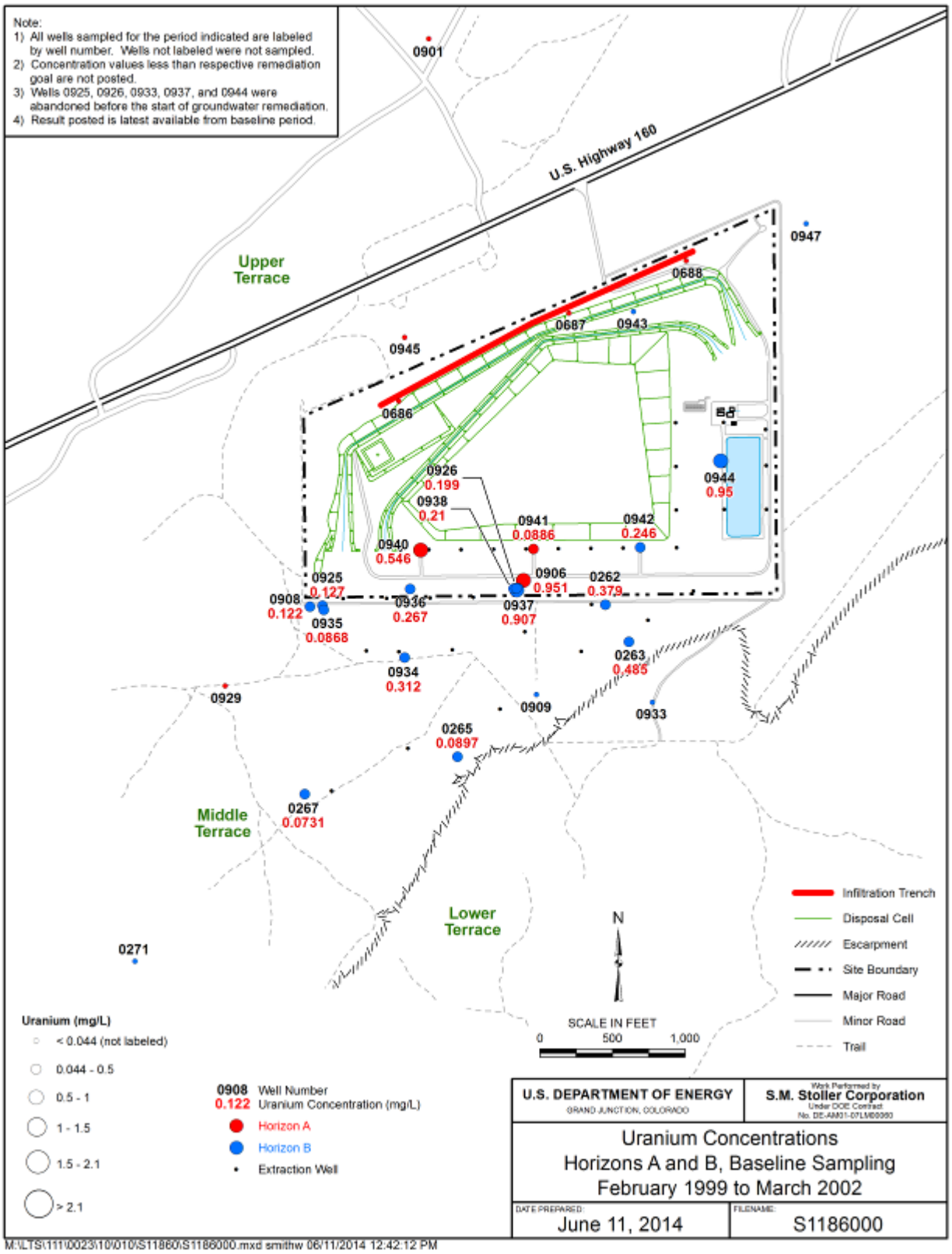

Figure 15a. Uranium Concentrations in Groundwater, Horizons A and B, Baseline Period

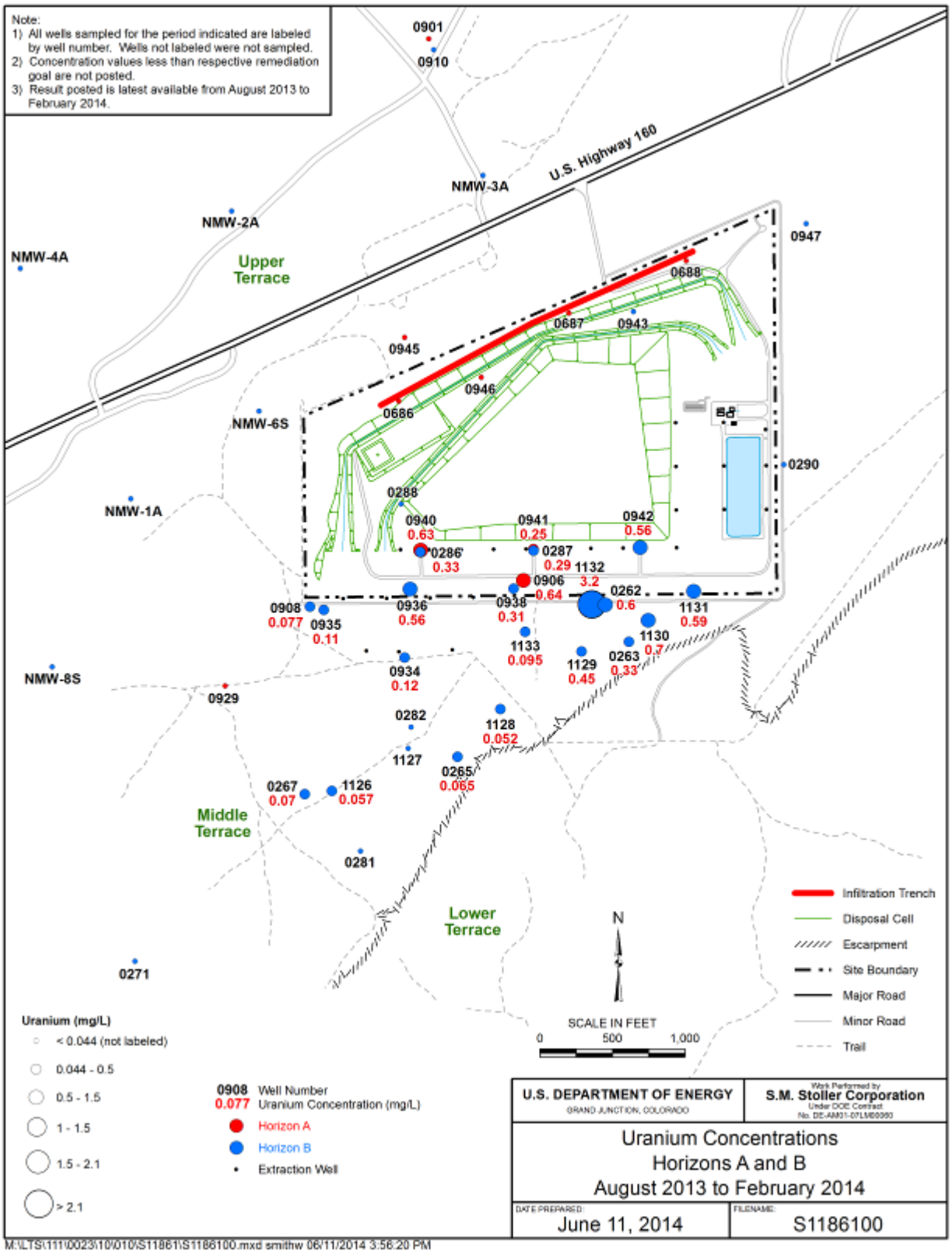

Figure 15b. Uranium Concentrations in Groundwater, Horizons A and B, February 2014

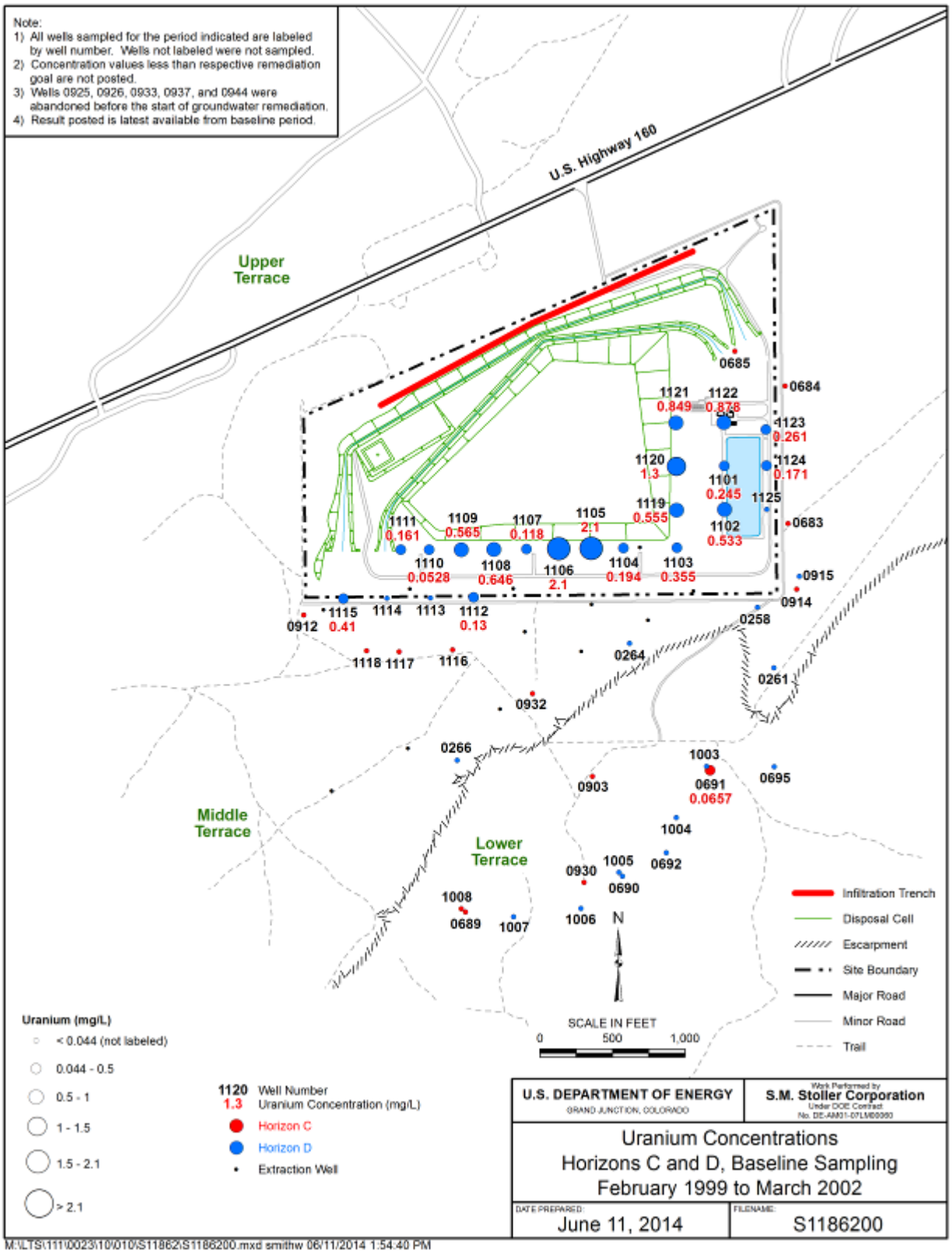

Figure 16a. Uranium Concentrations in Groundwater, Horizons C and D, Baseline Period

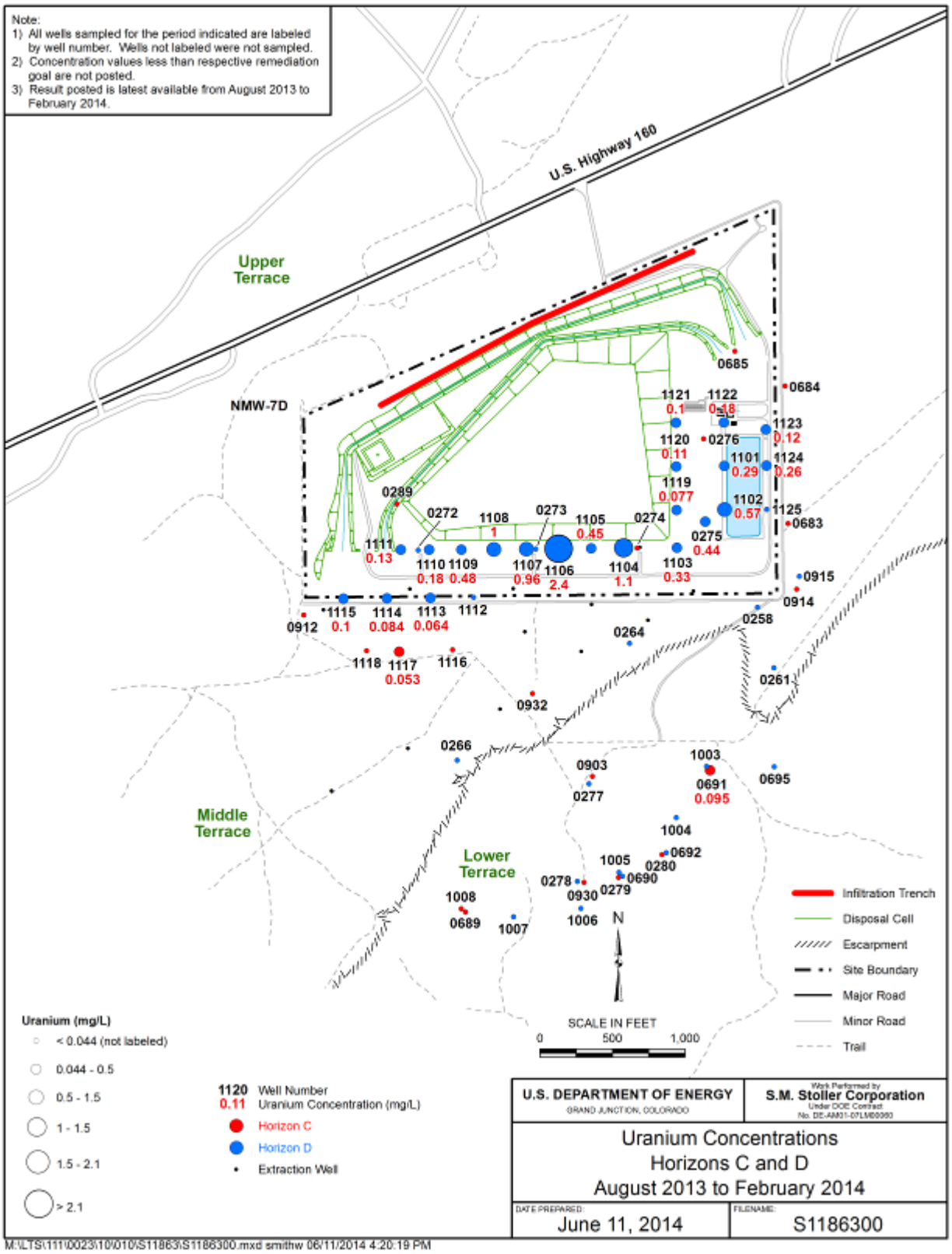

Figure 16b. Uranium Concentrations in Groundwater, Horizons C and D, February 2014

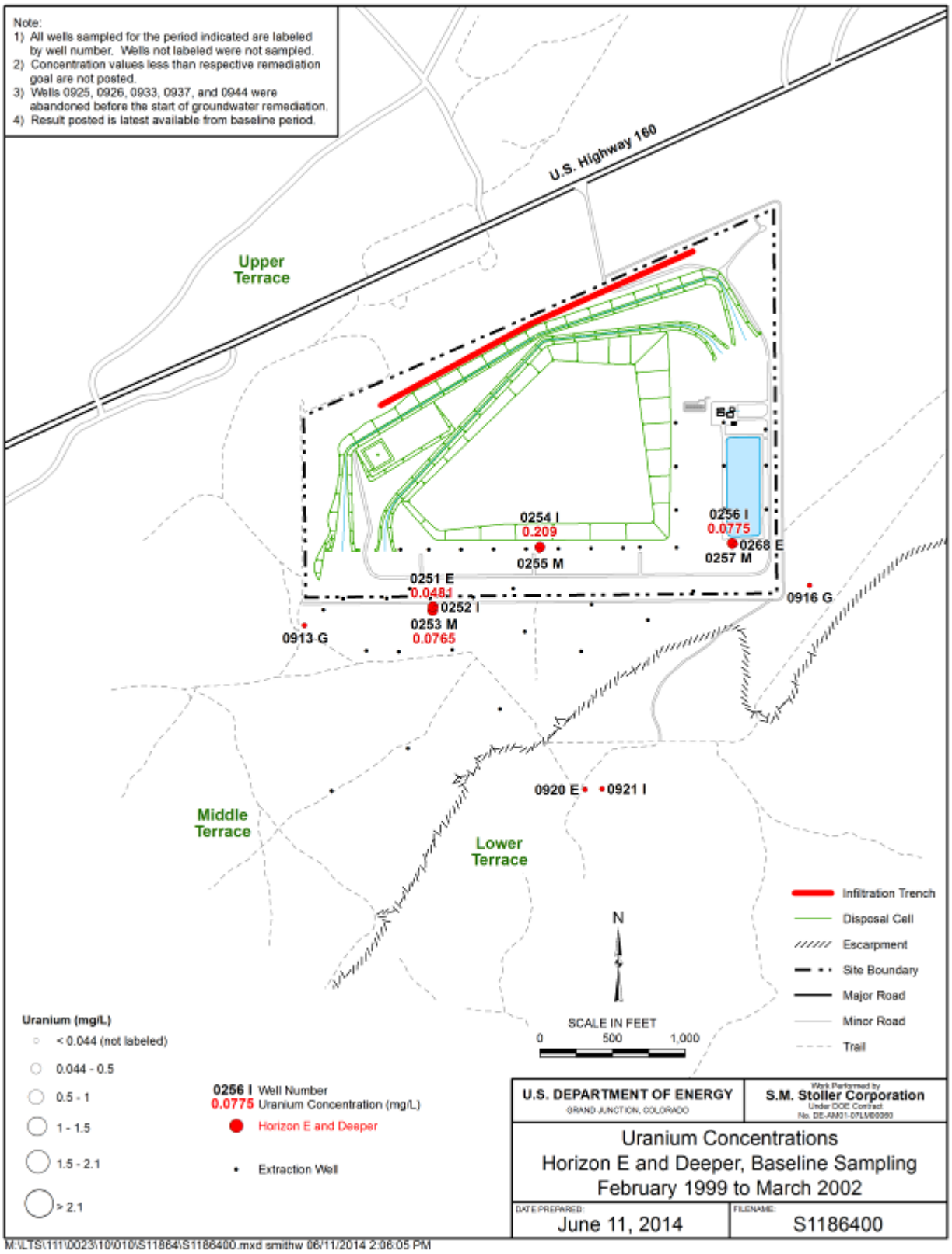

Figure 17a. Uranium Concentrations in Groundwater, Horizon E and Deeper, Baseline Period

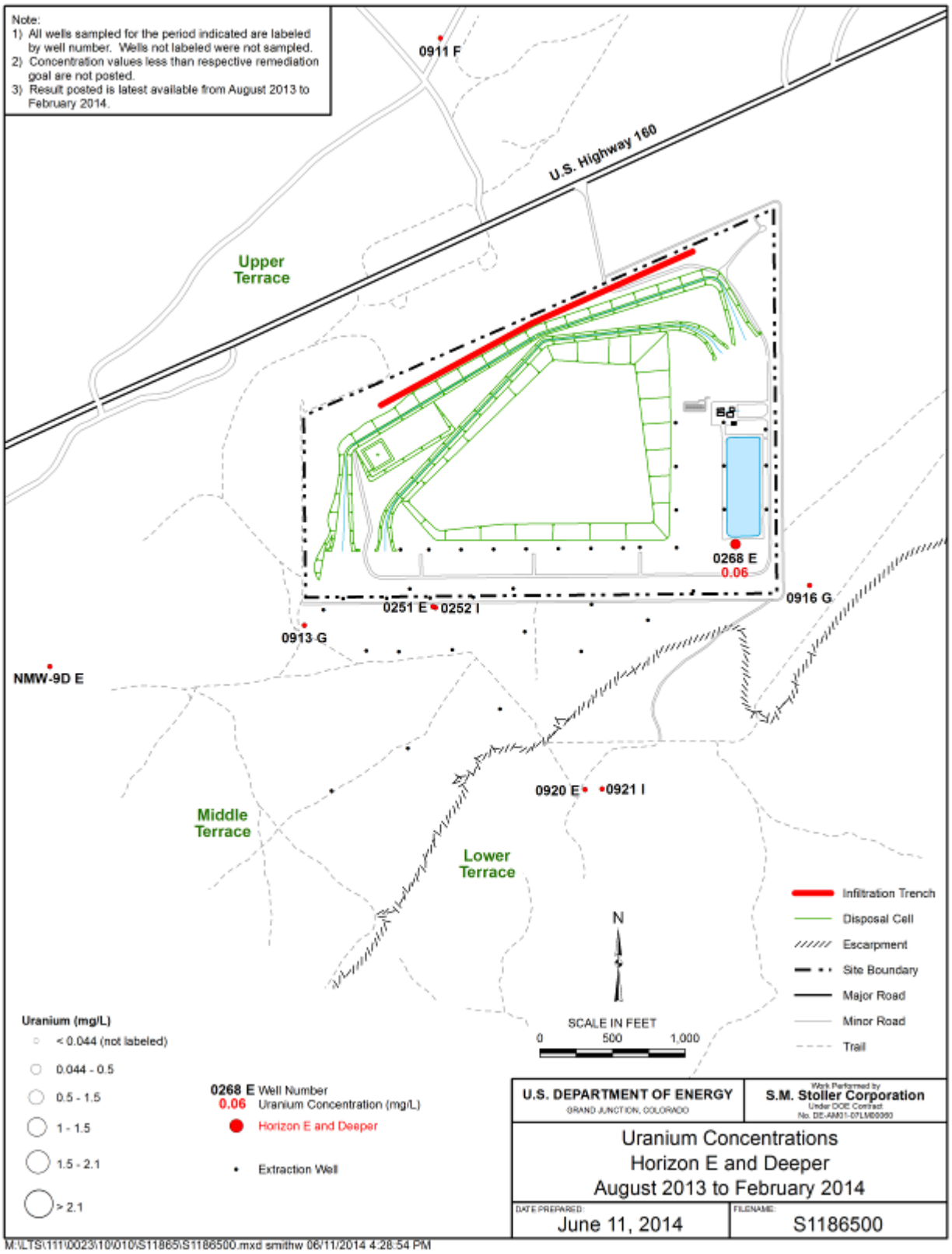

Figure 17b. Uranium Concentrations in Groundwater, Horizon E and Deeper, February 2014

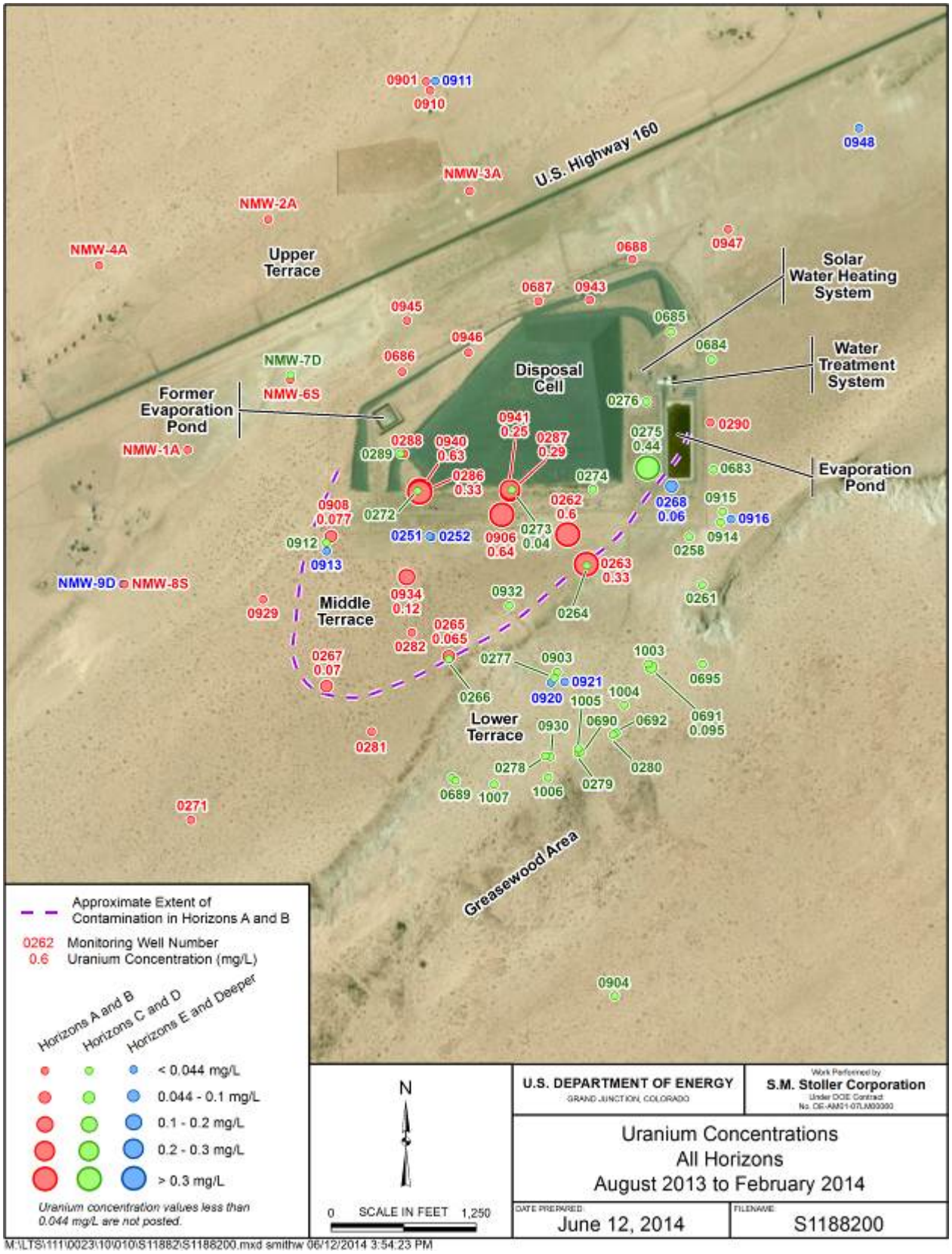

Figure 18. Uranium Concentrations in all Monitoring Wells (All Horizons), August 2013–February 2014

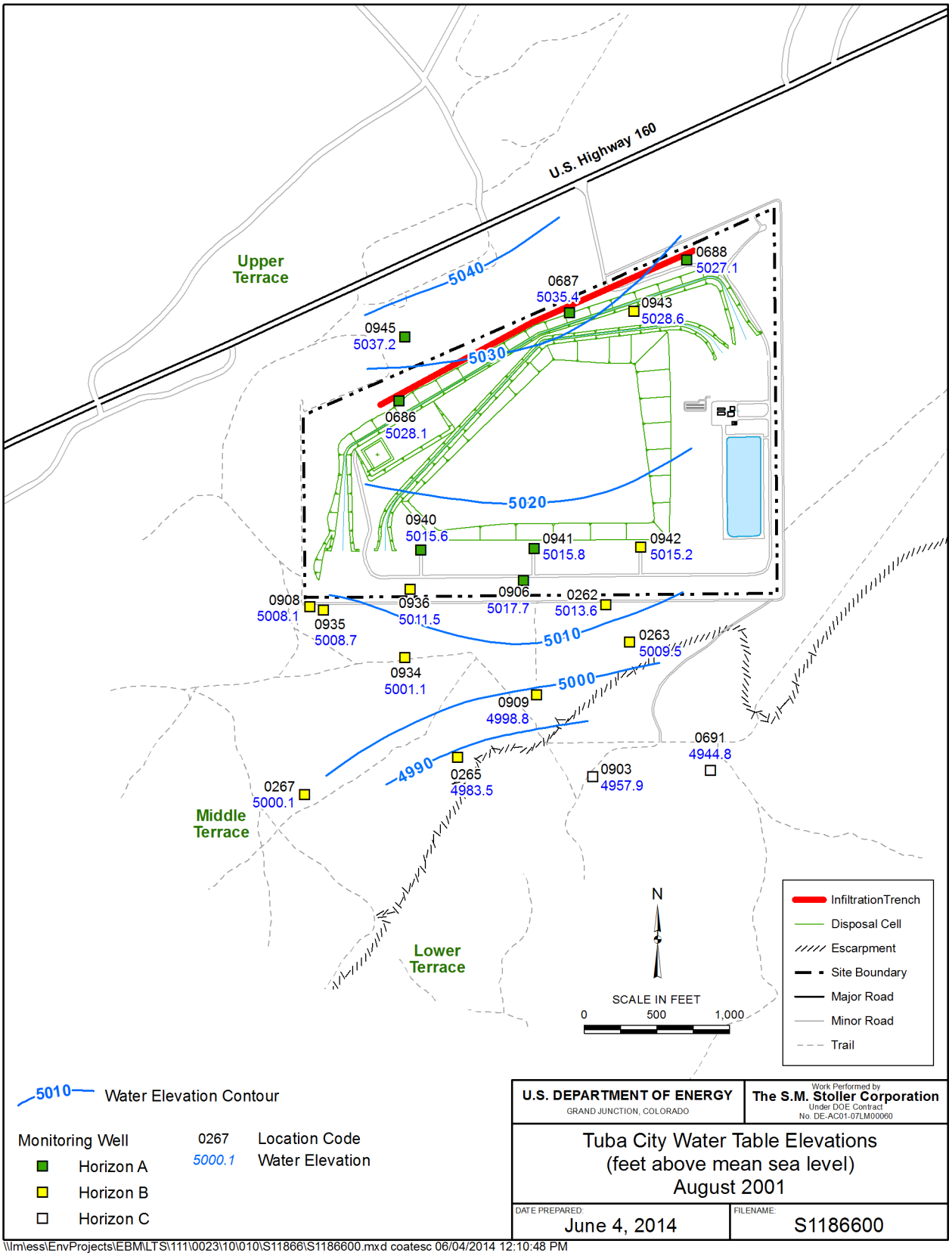

Figure 19. Water Table Elevations, Tuba City Site, August 2001

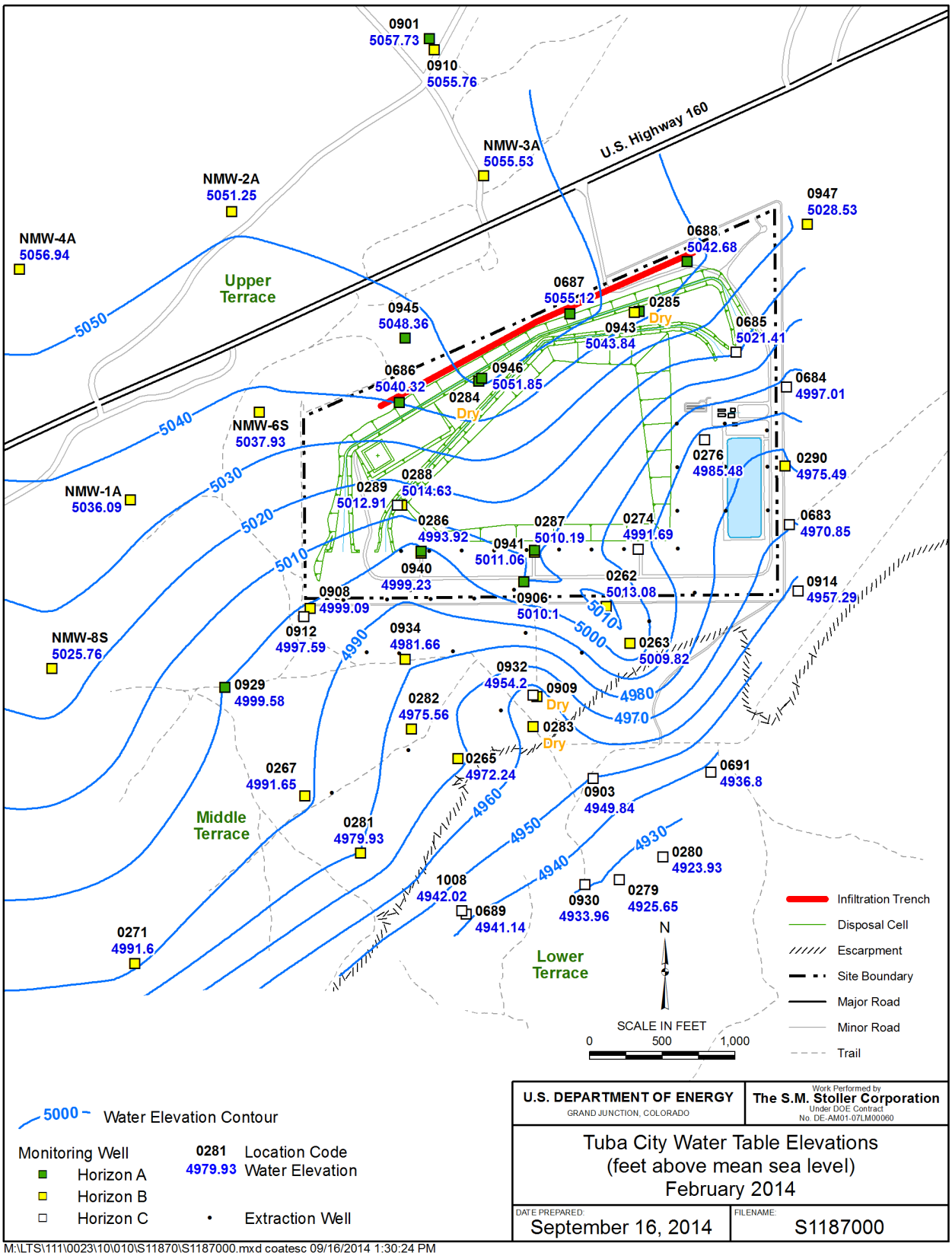

Figure 20. Water Table Contour Map, Tuba City Site, February 2014

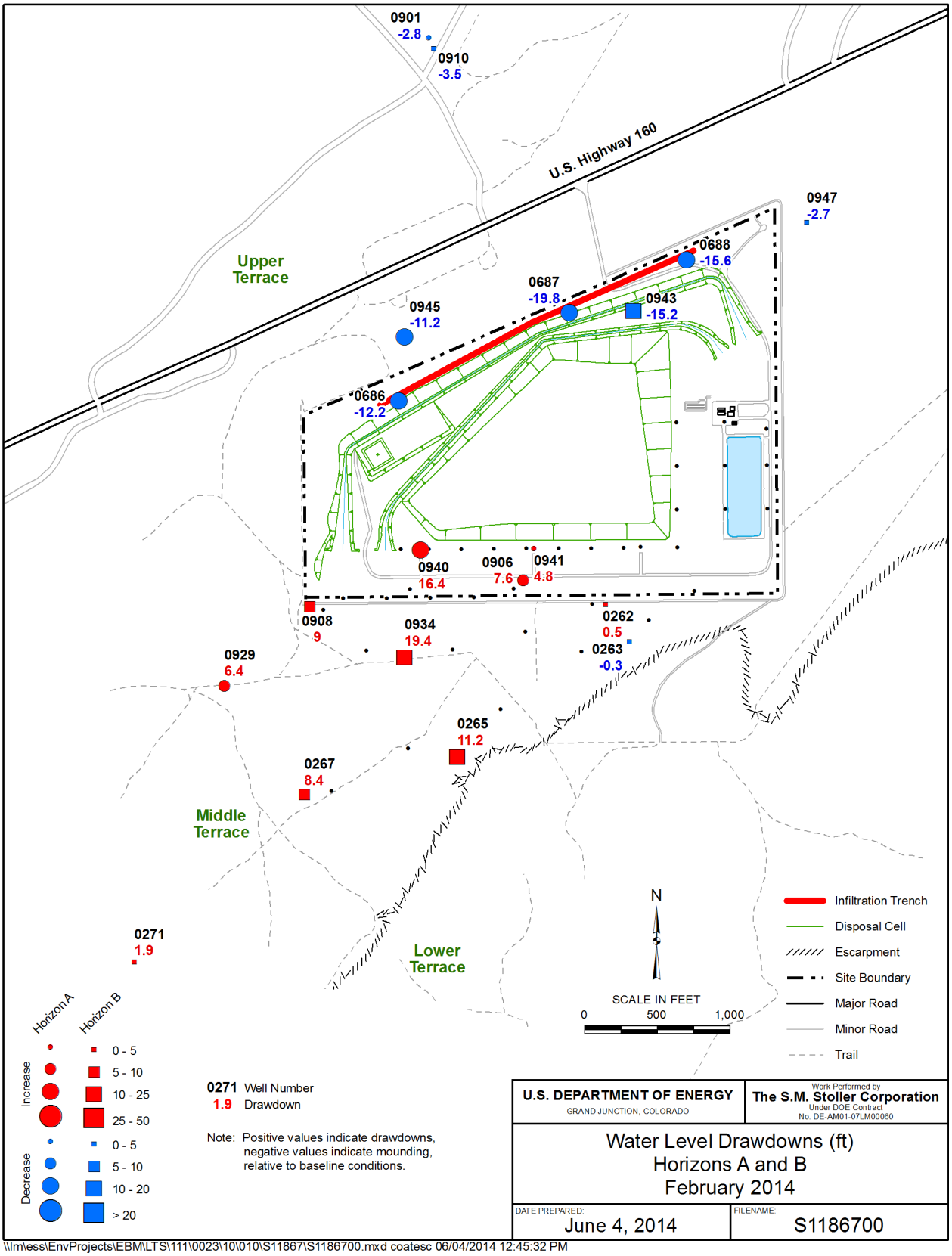

Figure 21. Water Level Drawdowns, Horizons A and B, February 2014

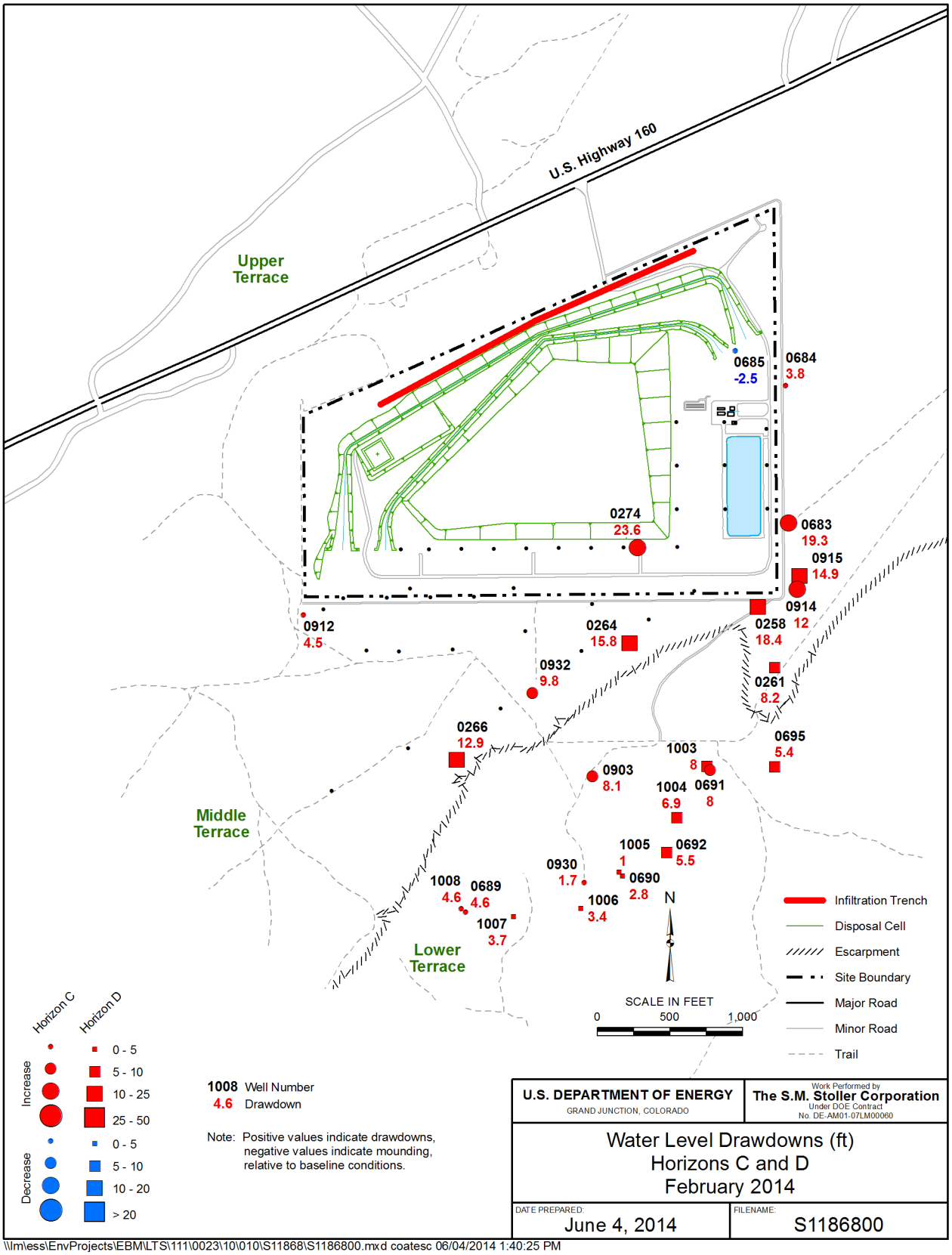

Figure 22. Water Level Drawdowns, Horizons C and D, February 2014

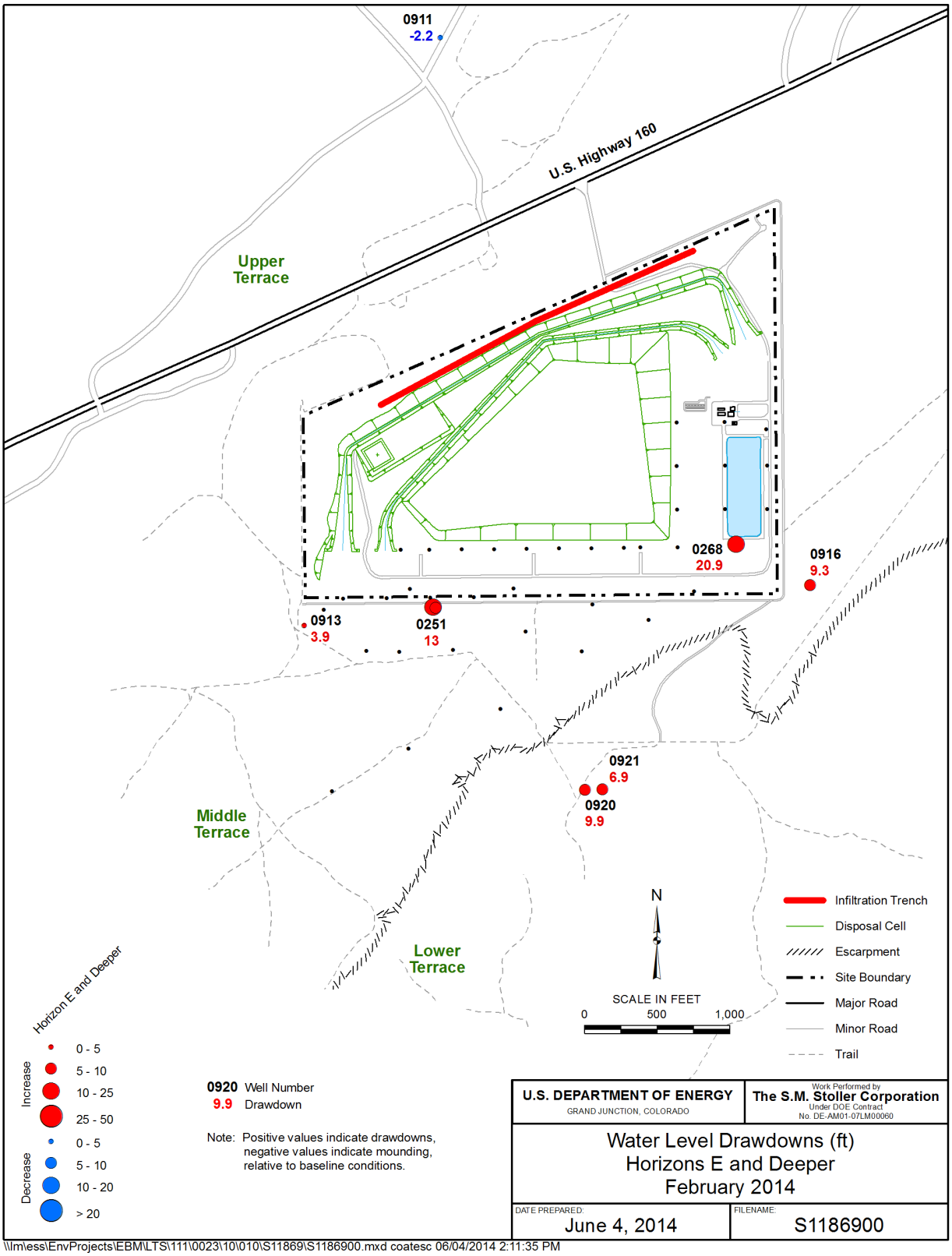

Figure 23. Water Level Drawdowns, Horizons E and Deeper, February 2014

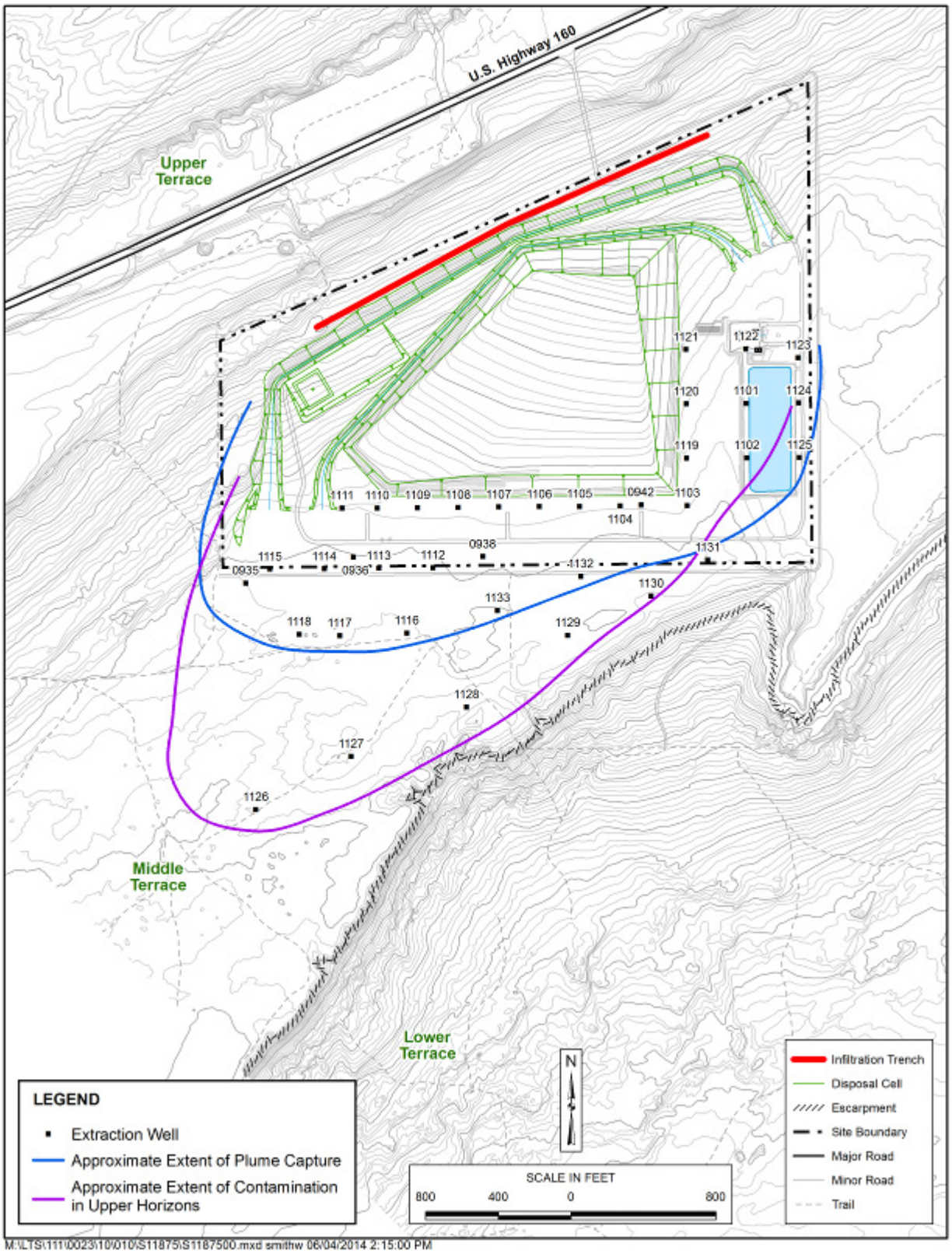

Figure 24. Approximate Extent of Groundwater Contamination and Extraction System Capture Zone, Horizons A and B

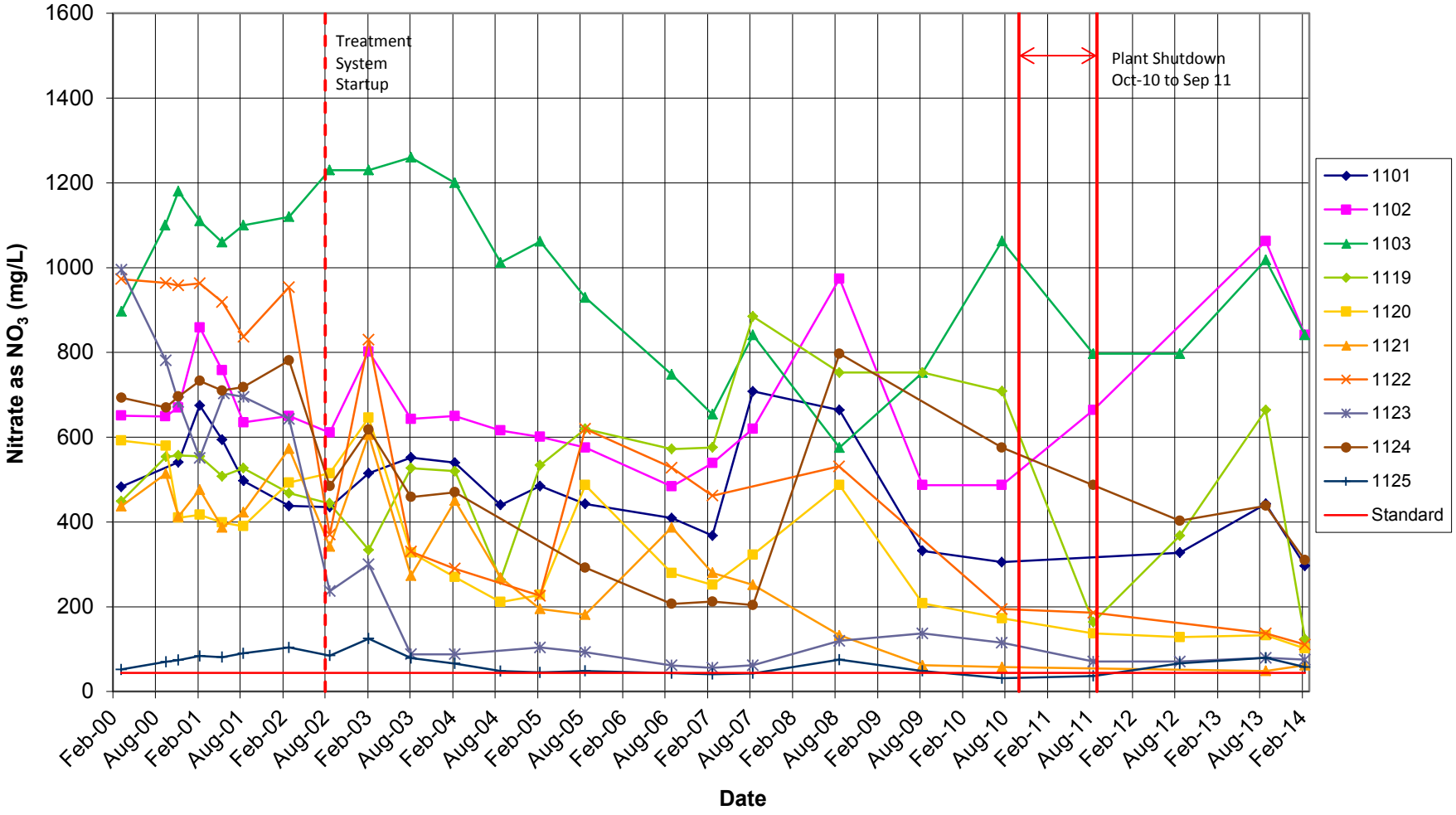

Figure 25a. Nitrate Concentration Trends at Extraction Wells 1101–1103, 1119–1125 (East of Disposal Cell)

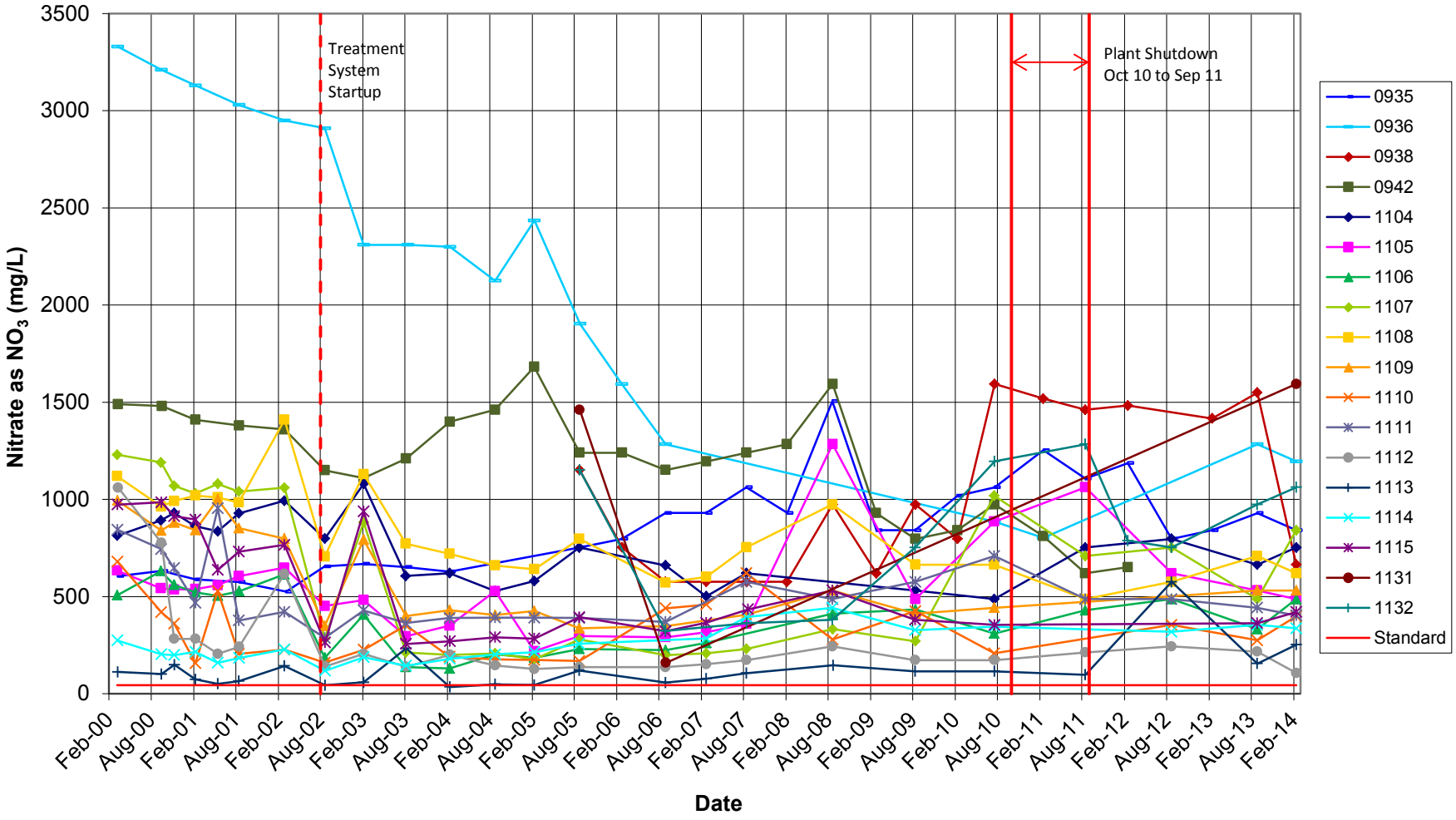

Figure 25b. Nitrate Concentration Trends at Extraction Wells 935–936, 938, 942, 1104–1115, 1131–1132 (South of Disposal Cell at or within Site Boundary)

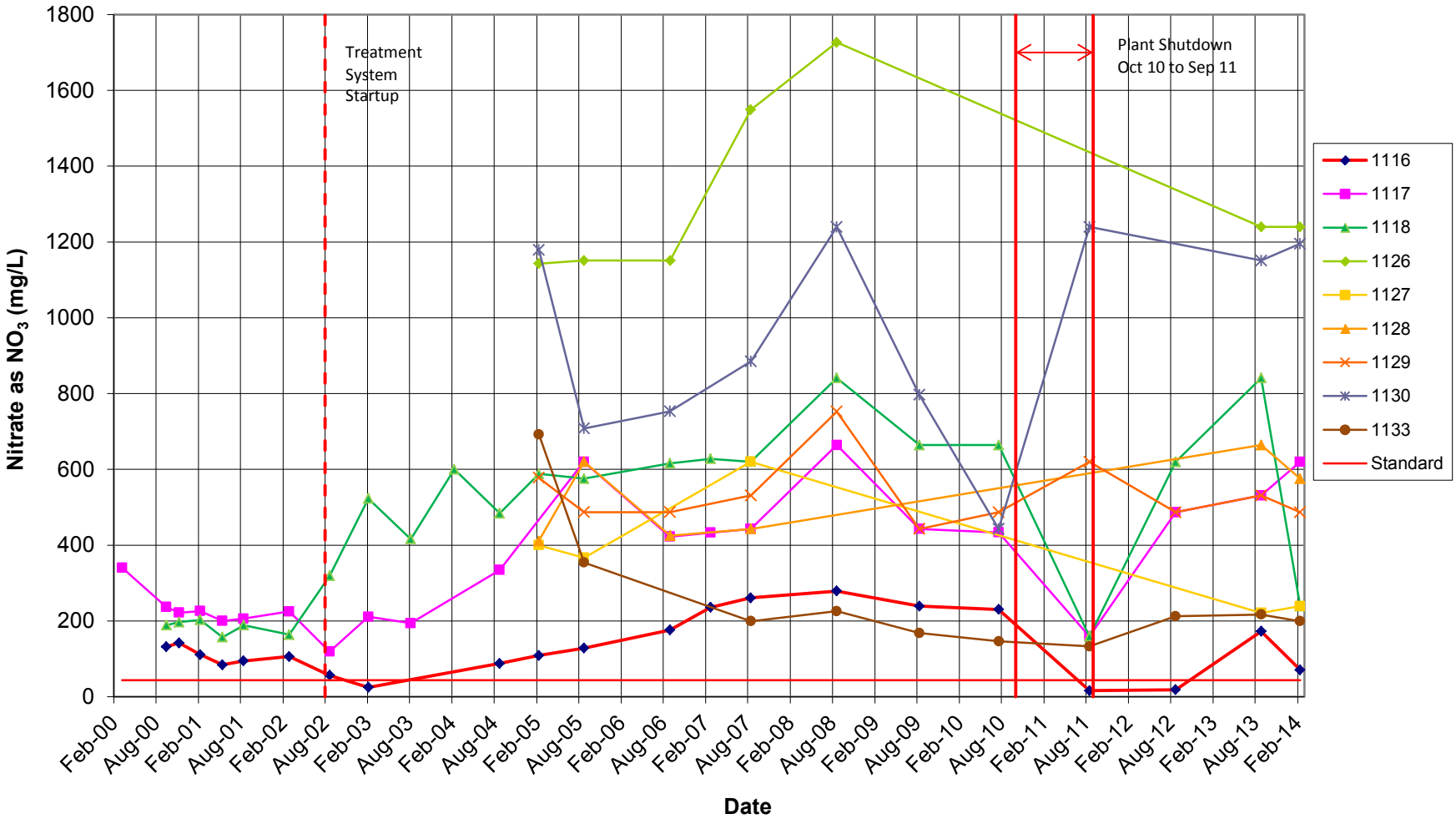

Figure 25c. Nitrate Concentration Trends at Southernmost Extraction Wells 1116–1118, 1126–1130, 1133

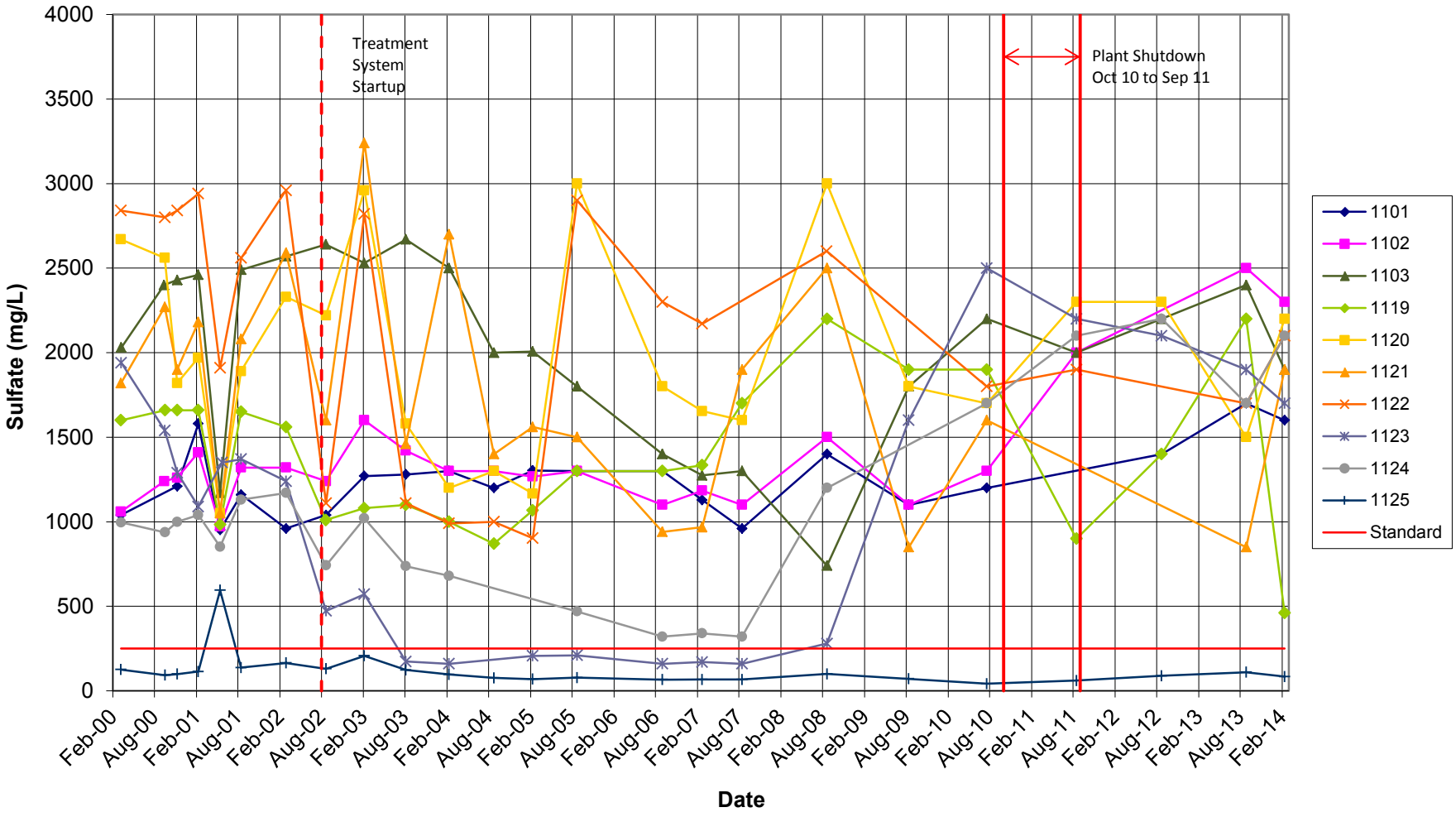

Figure 26a. Sulfate Concentration Trends at Extraction Wells 1101–1103, 1119–1125 (East of Disposal Cell)

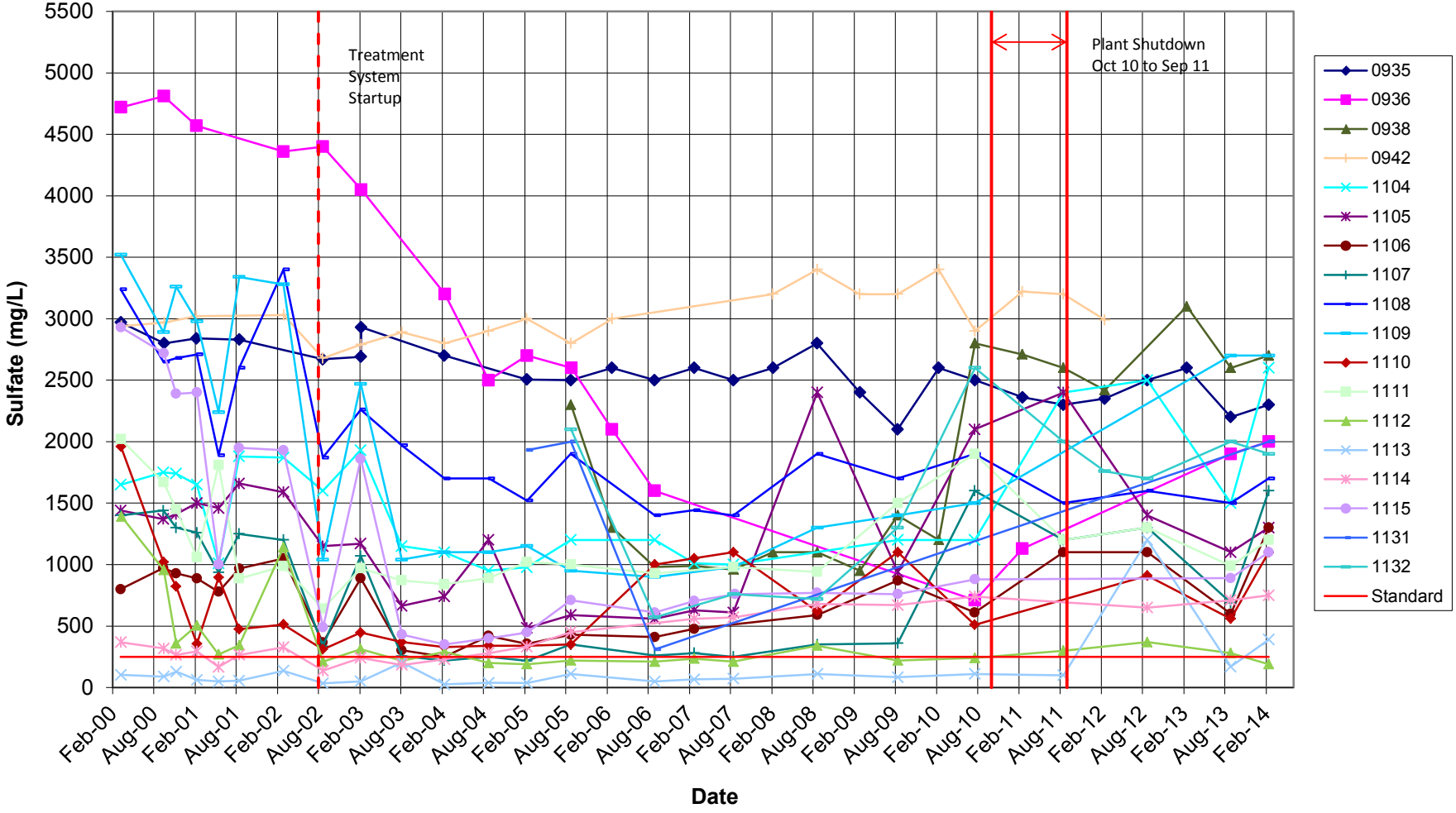

Figure 26b. Sulfate Concentration Trends at Extraction Wells 935–936, 938, 942, 1104–1115, 1131–1132 (South of Disposal Cell at or within Site Boundary)

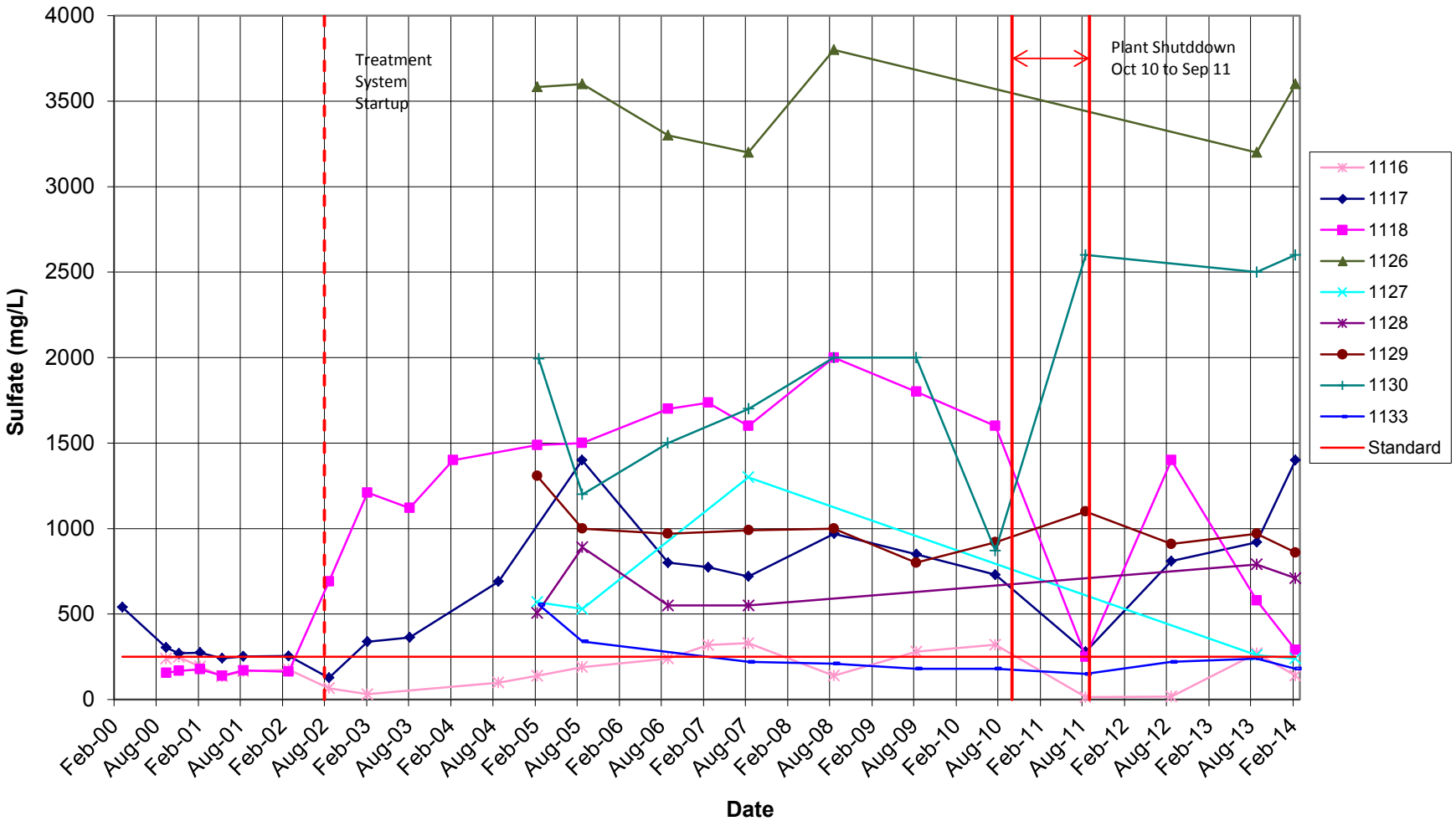

Figure 26c. Sulfate Concentration Trends at Southernmost Extraction Wells 1116–1118, 1126–1130, 1133

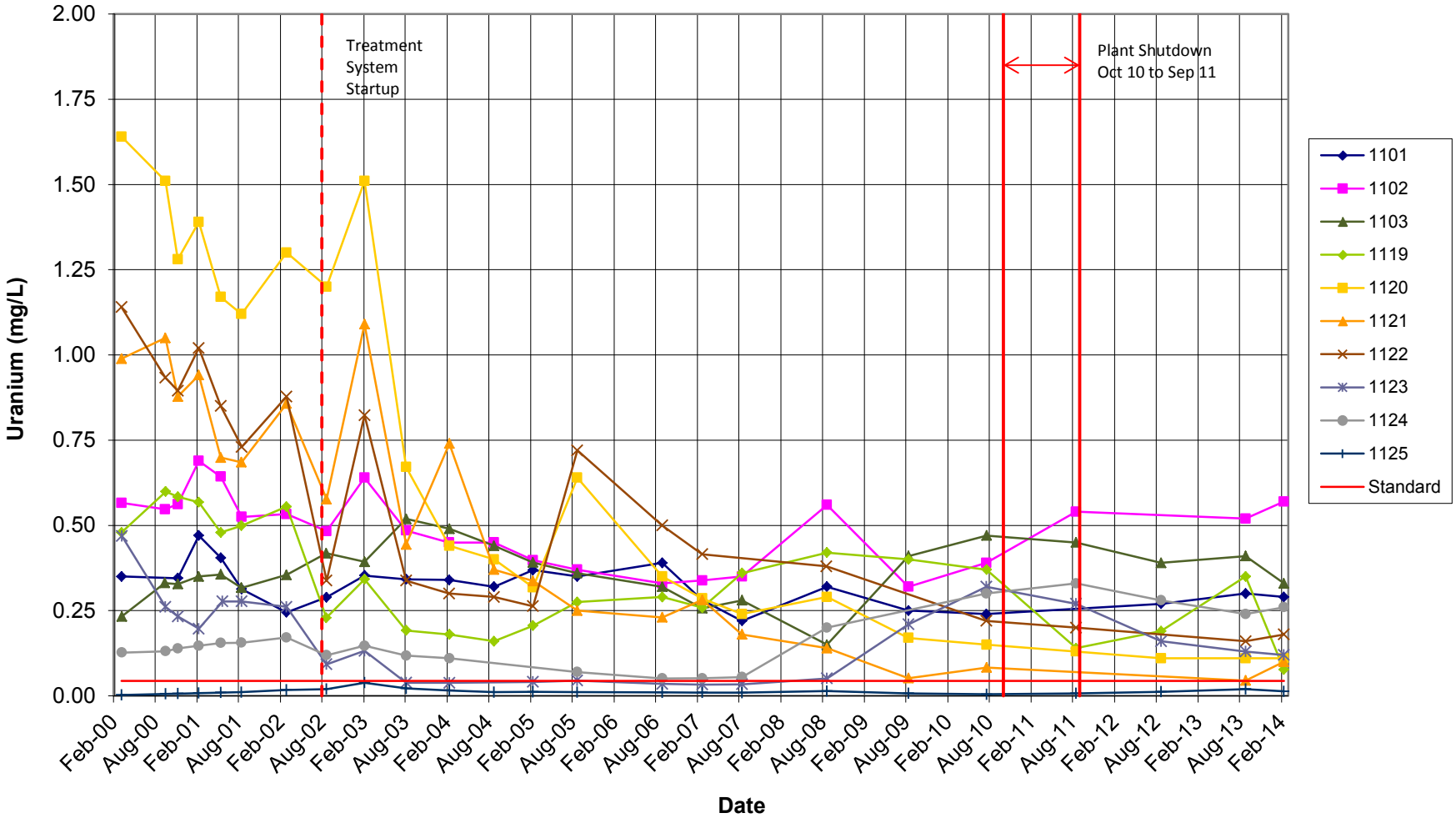

Figure 27a. Uranium Concentration Trends at Extraction Wells 1101–1103, 1119–1125 (East of Disposal Cell)

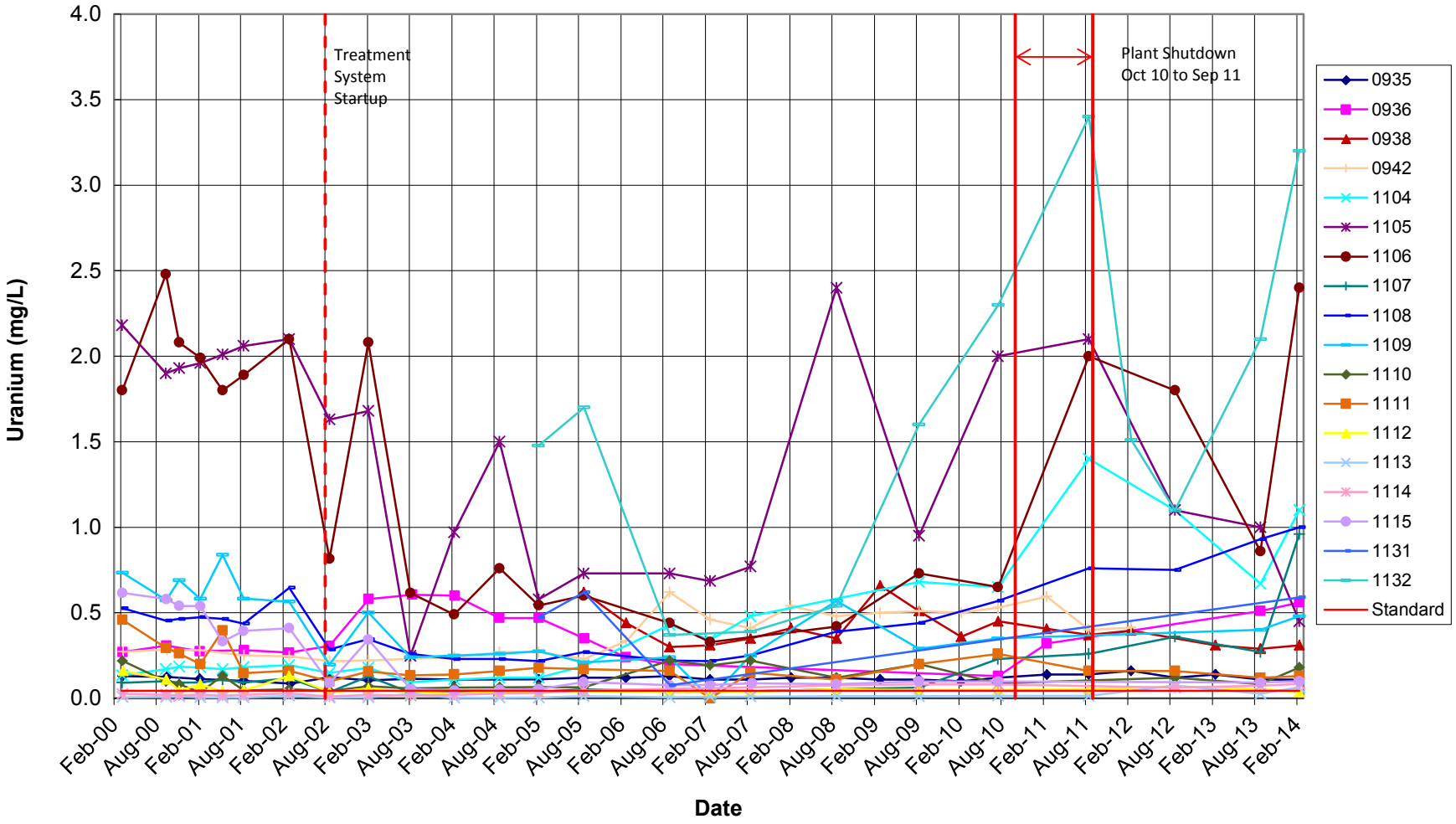

Figure 27b. Uranium Concentration Trends at Extraction Wells 935–936, 938, 942, 1104–1115, 1131–1132 (South of Disposal Cell at or within Site Boundary)

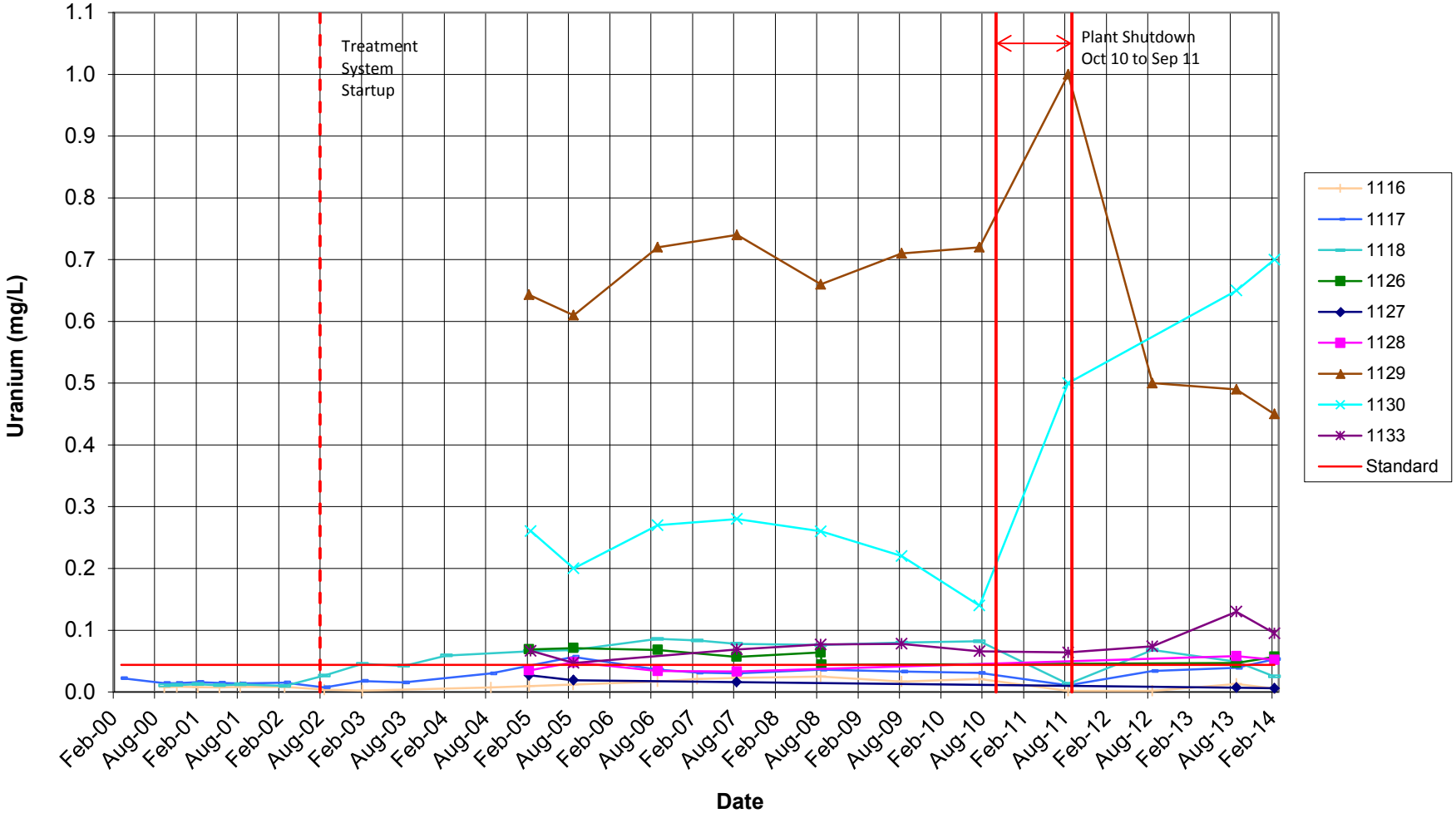

Figure 27c. Uranium Concentration Trends at Southernmost Extraction Wells 1116–1118, 1126–1130, 1133

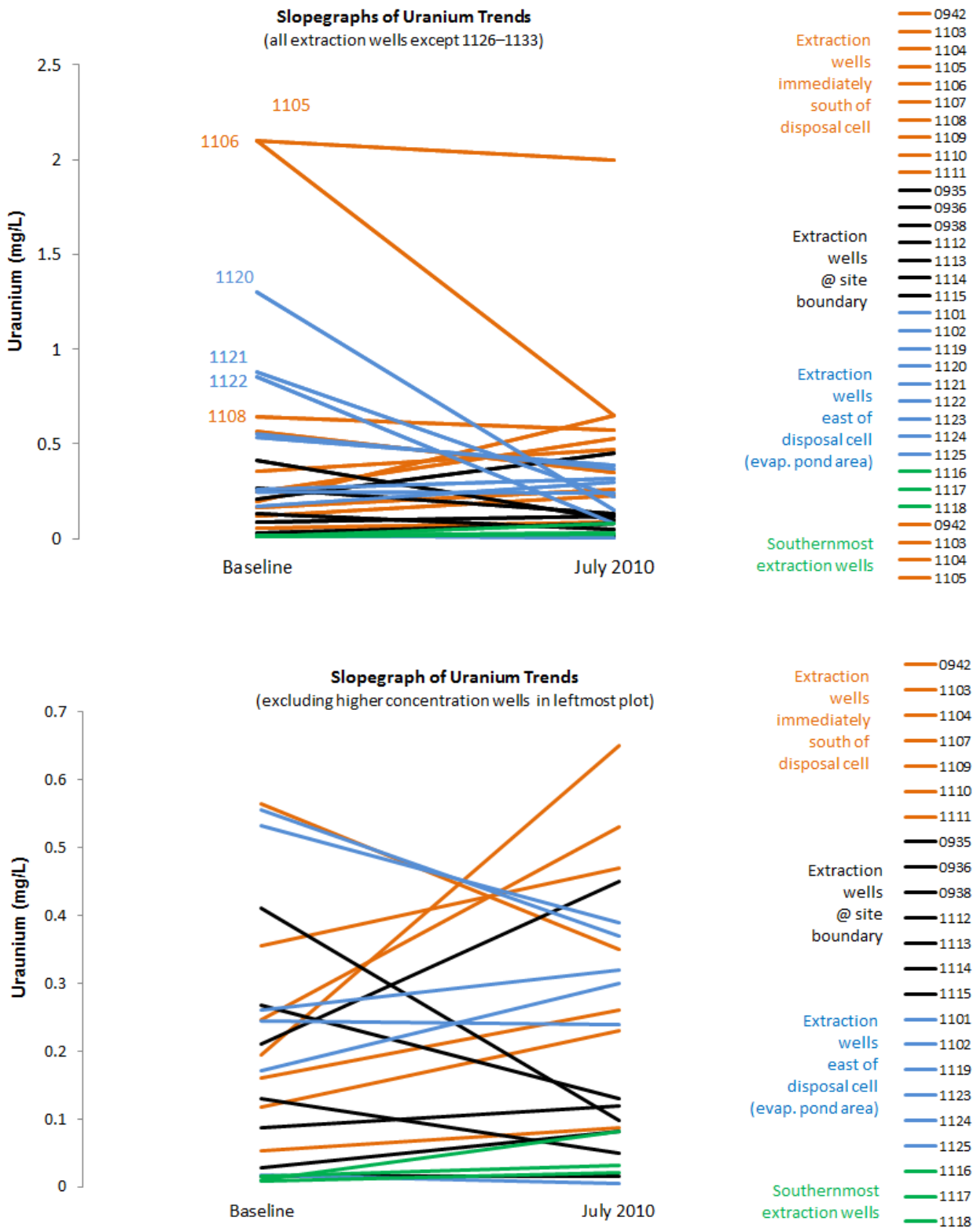

Figure 28. Slopegraph Overview of Trends at Extraction Wells: Baseline vs. Current Concentrations

Appendix A

Well Completion Information and Conceptual Site Model

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Figures

Figure A-1. Conceptual Model of the Site Hydrogeology A-1
Figure A-2. Well Completions Schematic A-2

Tables

Table A-1. Well Completion Information, Sorted on Well ID A-3
Table A-2. Well Completion Information, Sorted on Horizon, Well ID A-7

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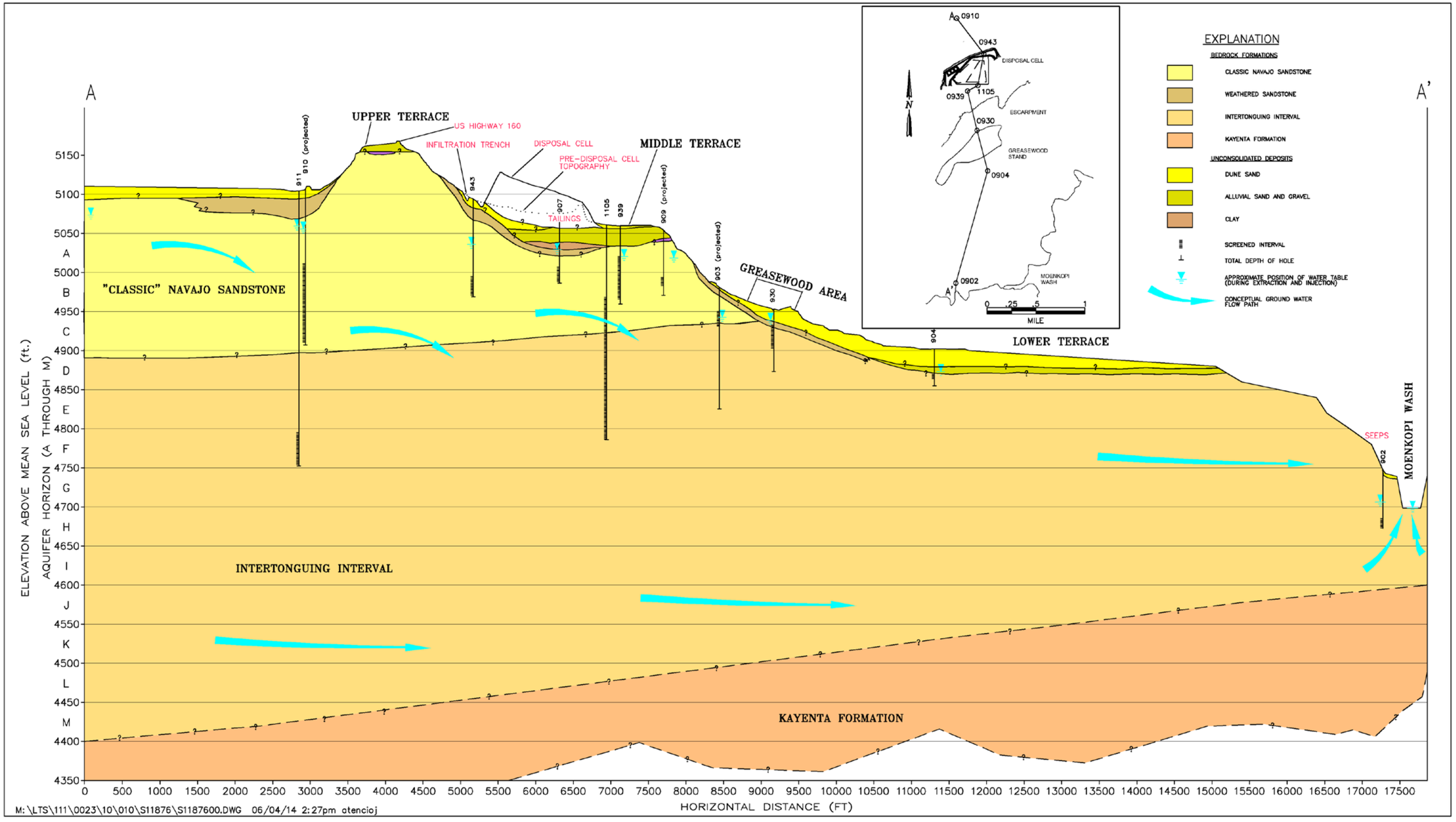

Figure A-1. Conceptual Model of the Site Hydrogeology

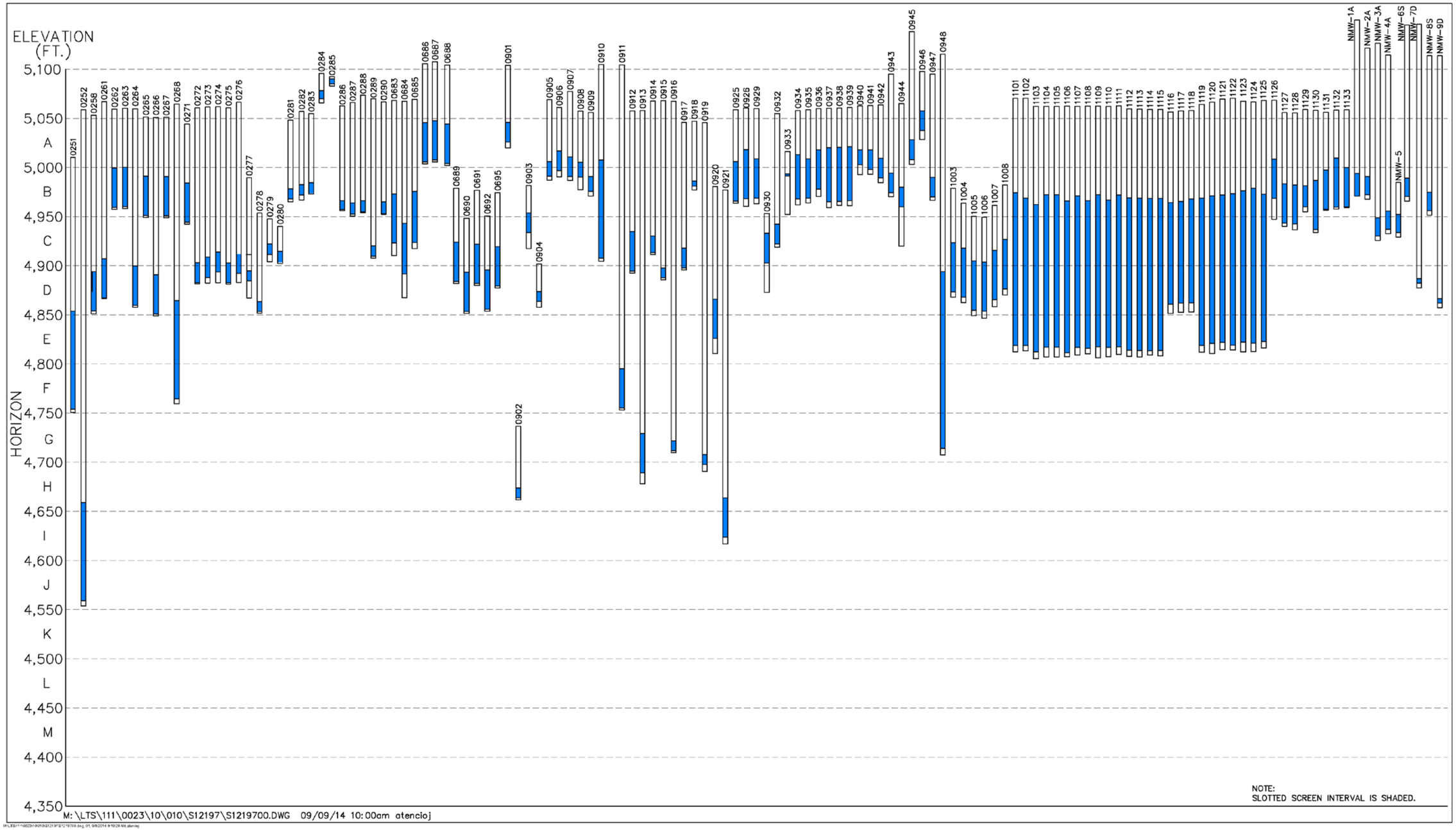

Figure A-2. Well Completions Schematic

Table A-1. Well Completion Information, Sorted on Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
251	MW	E	Semiannual	4858.9	4808.9	4758.9	200	250	300	100	0.3	300.3	5061.25		5058.9		2	28-Apr-00		730215	1871999
252	MW	I	Semiannual	4658.9	4608.9	4558.9	400	450	500	100	0.4	500.4	5061.3		5058.9		4	26-Apr-00		730232	1871993
253	MW	M	DECOM	4458.8	4408.8	4358.8	600	650	700	100	0.4	700.4	5061.11		5058.8		4	18-Apr-00	11-Apr-01	730213	1871974
254	MW	I	DECOM	4662.7	4612.7	4562.7	400	450	500	100	0.4	500.4	5065.38		5062.7		4	3-May-00	13-Aug-05	730951	1872411
255	MW	M	DECOM	4462.3	4412.3	4362.3	600	650	700	100	0.4	700.4	5064.89		5062.3		4	1-May-00	12-Aug-05	730947	1872387
256	MW	I	DECOM	4664	4614	4564	400	450	500	100	0.4	500.4	5066.58		5064		4	13-May-00	14-Aug-05	732277	1872437
257	MW	M	DECOM	4463.4	4413.4	4363.4	600	650	700	100	0.4	700.4	5066.4		5063.4		4	11-May-00	11-Aug-05	732278	1872414
258	MW	D	Semiannual	4894	4874	4854	159	179	199	40	0.3	199.3	5055.56		5053		2	13-Apr-00		732452	1871996
261	MW	D	Annual	4907	4887	4867	160	180	200	40	0.3	200.3	5069.69		5067		2	1-Apr-00		732565	1871578
262	MW	B	Semiannual	4999.2	4979.2	4959.2	60	80	100	40	0.3	100.3	5061.99		5059.2		2	3-Apr-00		731402	1872012
263	MW	B	Semiannual	5000.2	4980.2	4960.2	60	80	100	40	0.3	100.3	5063.1		5060.2		2	4-Apr-00		731565	1871757
264	MW	D	Semiannual	4899.6	4879.6	4859.6	160	180	200	40	0.3	200.3	5062.19		5059.6		2	3-Apr-00		731569	1871746
265	MW	B	Semiannual	4991.1	4971.1	4951.1	60	80	100	40	0.3	100.3	5053.88		5051.1		2	16-Apr-00		730382	1870964
266	MW	D	Semiannual	4890.6	4870.6	4850.6	160	180	200	40	0.3	200.3	5053.32		5050.6		2	15-Apr-00		730380	1870941
267	MW	B	Semiannual	4990.8	4970.8	4950.8	60	80	100	40	0.3	100.3	5053.4		5050.8		2	14-Apr-00		729329	1870707
268	MW	E	Semiannual	4864.5	4814.5	4764.5	200	250	300	100	0.3	300.3	5067.24		5064.5		2	15-May-00		732301	1872430
271*	MW	B	Annual	4984	4964	4944	60	80	100	40	0.3	100.3	5046.72		5044		2	29-Apr-00		728160	1869555
272	MW	D	Semiannual	4902.8	4892.8	4882.8	159.1	169.1	179.1	20	1.5	180.6	5064.24		5061.9		2	28-Aug-04		730112	1872389
273	MW	D	Semiannual	4909.4	4899.4	4889.4	153	163	173	20	1.5	174.5	5064.74		5062.4		2	29-Aug-04		730922	1872397
274	MW	C	Semiannual	4913.6	4903.6	4893.6	149	159	169	20	1.5	170.5	5064.42		5062.6		2	30-Aug-04		731623	1872403
275	MW	D	Semiannual	4903	4893	4883	158.2	168.2	178.2	20	1.5	179.7	5062.64		5061.2		2	1-Sep-04		732092	1872586
276	MW	C	Semiannual	4910	4900	4890	154.5	164.5	174.5	20	1.5	176	5067.55		5064.5		2	1-Sep-04		732081	1873158
277	MW	D	Annual	4884	4879	4874	95.7	100.7	105.7	10	1.5	107.2	4982.35		4979.7		2	12-Aug-04		731290	1870777
278	MW	D	Annual	4862.9	4857.9	4852.9	90.5	95.5	100.5	10	1.5	102	4956.09		4953.4		2	14-Aug-04		731210	1870104
279	MW	C	Annual	4922.1	4917.1	4912.1	26.5	31.5	36.5	10	1.5	38	4951.04		4948.6		2	15-Aug-04		731494	1870132
280	MW	C	Annual	4922.6	4917.6	4912.6	26.5	31.5	36.5	10	1.5	38	4951.52		4949.1		2	15-Aug-04		731794	1870289
281	MW	B	Semiannual	4977.8	4972.8	4967.8	70.5	75.5	80.5	10	1.5	82	5051		5048.3		2	11-Aug-04		729714	1870315
282	MW	B	Semiannual	4983.3	4978.3	4973.3	74.1	79.1	84.1	10	1.5	85.6	5060.04		5057.4		2	10-Aug-04		730062	1871168
283†	MW	B	Semiannual	4984.8	4979.8	4974.8	70.5	75.5	80.5	10	1.5	82	5057.97		5055.3		2	3-Aug-04		730901	1871185
284	MW	A	WL only	5079.8	5074.8	5069.8	16.5	21.5	26.5	10	1.5	28	5098.72		5096.3		2	16-Aug-04		730525	1873562
285	MW	A	WL only	5090.8	5088.3	5085.8	3	5.5	8	5	0.1	8.1	5096.47		5093.8		2	16-Aug-04		731629	1874042
286	MW	B	Semiannual	4968.8	4963.8	4958.8	93.2	98.2	103.2	10	0.4	103.6	5063.99		5062		2	13-Mar-07		730128	1872377
287	MW	B	Semiannual	4962.3	4957.3	4952.3	100.7	105.7	110.7	10	0.4	111.1	5065.65		5063		2	15-Mar-07		730908	1872386
288	MW	B	Semiannual	4965.9	4960.9	4955.9	104	109	114	10	0.5	114.5	5072.54		5069.9		2	18-Mar-07		729995	1872709
289	MW	C	Semiannual	4920.3	4915.3	4910.3	148.3	153.3	158.3	10	0.4	163	5070.82		5068.6		6	28-Mar-07		729965	1872709
290	MW	B	Semiannual	4964.3	4959.3	4954.3	102.7	107.7	112.7	10	0.4	113.1	5068.91		5067		2	17-Mar-07		732633	1872979
683	MW	C	Annual	4973.2	4948.2	4923.2	95	120	145	50	3	148	5070.64		5068.2		6	31-Aug-99		732661	1872574
684	MW	C	Annual	4943.1	4917.4	4891.8	124.2	149.9	175.5	51.3	2.5	178	5070.05		5067.3		6	20-Aug-99		732642	1873521
685	MW	C	Annual	4975.6	4949.7	4923.8	93.7	119.6	145.5	51.8	2.5	148	5072.44		5069.3		6	19-Aug-99		732295	1873760
686	MW	A	Annual	5045.5	5025.5	5005.5	60	80	100	40	0.3	100.3	5107.97		5105.5		2	28-Mar-00		729978	1873416
687	MW	A	Annual	5047.6	5027.6	5007.6	60	80	100	40	0.3	100.3	5109.82		5107.6		2	29-Mar-00		731152	1874024
688	MW	A	Annual	5044.1	5024.1	5004.1	60	80	100	40	0.3	100.3	5106.98		5104.1		2	29-Mar-00		731961	1874385

Table A-1 (continued). Well Completion Information, Sorted on Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
689*	MW	C	Annual	4923.9	4903.9	4883.9	55	75	95	40	0.3	95.3	4981.63		4978.9		2	31-Mar-00		730439	1869893
690	MW	D	Annual	4893.3	4873.3	4853.3	55	75	95	40	0.3	95.3	4950.87		4948.3		2	30-Mar-00		731521	1870140
691	MW	C	Semiannual	4921.9	4901.9	4881.9	55	75	95	40	0.3	95.3	4979.41		4976.9		2	30-Mar-00		732124	1870872
692*	MW	D	Annual	4895.6	4875.6	4855.6	55	75	95	40	0.3	95.3	4953.31		4950.6		2	5-Apr-00		731821	1870303
695	MW	D	Annual	4919.3	4899.3	4879.3	55	75	95	40	0.3	95.3	4976.83		4974.3		2	6-Apr-00		732566	1870896
901	MW	A	Annual	5045.8	5035.8	5025.8	58	68	78	20	2	80	5105.46		5103.8		2	16-Oct-84		730185	1875918
902	MW	H	WL only	4673.7	4668.7	4663.7	63	68	73	10	2	75	4737.42		4736.7		2	2-Dec-84		730179	1862292
903	MW	C	Annual	4953.5	4943.5	4933.5	28	38	48	20	2	50	4983.33		4981.5		2	30-Oct-84		731314	1870829
904	MW	D	Annual	4873.8	4868.8	4863.8	28	33	38	10	2	40	4904.11		4901.8		2	7-Nov-84		731808	1868036
905	MW	B	DECOM	5006	4998.5	4991	63	70.5	78	15	2	80	5072.8		5069		2	14-Nov-84	24-May-00	732933	1873200
906	MW	A	Semiannual	5016.9	5006.9	4996.9	44	54	64	20	2	66	5062.1		5060.9		2	19-Nov-84		730838	1872181
907	MW	A	DECOM	5010.7	5000.7	4990.7	66.5	76.5	86.5	20			5079.17		5077.2		2	30-Nov-84	19-Apr-88	731252	1872920
908	MW	B	Semiannual	5005.3	4997.8	4990.3	52	59.5	67	15	2	69	5058.14		5057.3		2	17-Nov-84		729366	1871999
909	MW	B	Semiannual	4990.8	4983.3	4975.8	65	72.5	80	15	2	82	5057.17		5055.8		2	18-Nov-84		730927	1871393
910	MW	B	Annual	5007.6	4957.6	4907.6	97	147	197	100	1	198	5106.7		5104.6		4	26-Jul-85		730219	1875840
911	MW	F	Annual	4795.2	4775.2	4755.2	309.4	329.4	349.4	40	2	351.4	5106.96		5104.6		4	18-Jul-85		730265	1875920
912	MW	C	Annual	4934.7	4914.7	4894.7	123	143	163	40	2	165	5059.97		5057.7		4	12-Aug-85		729324	1871942
913	MW	G	Annual	4729.2	4709.2	4689.2	328.7	348.7	368.7	40	2	370.7	5060.16		5057.9		4	2-Aug-85		729327	1871871
914*	MW	C	Annual	4930.3	4921.8	4913.3	137.2	145.7	154.2	17	2	156.2	5070.1		5067.5		4	16-Aug-85		732723	1872119
915	MW	D	Annual	4897.8	4892.8	4887.8	170	175	180	10	2	182	5070.84		5067.8		4	24-Aug-85		732740	1872209
916	MW	G	Annual	4721.7	4716.7	4711.7	345.7	350.7	355.7	10	2	357.7	5070		5067.4		4	22-Aug-85		732811	1872146
917	MW	C	WL only	4917.8	4907.8	4897.8	128	138	148	20	2	150	5048.02		5045.8		4	14-Aug-85		727255	1868642
918	MW	B	WL only	4986.2	4983.7	4981.2	61	63.5	66	5	2	68	5049.63		5047.2		4	15-Aug-85		727294	1868724
919	MW	G	WL only	4707.9	4702.9	4697.9	337.7	342.7	347.7	10	2	349.7	5048.56		5045.6		4	26-Aug-85		727353	1868654
920	MW	E	Annual	4866	4846	4826	114.4	134.4	154.4	40	2	156.4	4982.97		4980.4		4	30-Jul-85		731262	1870737
921	MW	I	Annual	4663.7	4643.7	4623.7	313.2	333.2	353.2	40	2	355.2	4979.08		4976.9		4	22-Jul-85		731379	1870742
925	EXT	B	DECOM	5005.8	4985.8	4965.8	53	73	93	40	0.5	93.5	5060.87		5058.8		6	21-Oct-95	24-May-00	729452	1872006
926	EXT	B	DECOM	5018.3	4993.3	4968.3	42.2	67.2	92.2	50	3	95.2	5062.85		5060.5		6	25-Oct-95	17-May-00	730790	1872126
928	MW	A	DECOM	5022.1	5009.6	4997.1	30	42.5	55	25	3	58	5053.99		5052.1		4	20-Oct-95	24-May-00	729401	1870814
929*	MW	A	Semiannual	5010.4	4990.4	4970.4	48.2	68.2	88.2	40			5060.82		5058.6		4			728780	1871453
930	MW	C	Semiannual	4933	4918	4903	20	35	50	30	3	53	4954.96		4953		4	23-Oct-95		731257	1870099
932	MW	C	Semiannual	4942.3	4932.3	4922.3	112.5	122.5	132.5	20	2.7	135.2	5057.32		5054.8		4	29-Oct-95		730900	1871401
933	MW	B	DECOM	4993.3	4992.3	4991.3	23	24	25	2			5018.03		5016.3		4	18-Oct-95	24-May-00	731727	1871341
934	MW	B	Semiannual	5013	4990.5	4968	45	67.5	90	45	3	93	5059.73		5058		4	2-Nov-95		730018	1871649
935	MW/EXT	B	Semiannual	5008.8	4988.8	4968.8	50	70	90	40	3	93	5061.5		5058.8		4	28-Oct-95		729461	1871978
936	MW/EXT	B	Semiannual	5017.9	4997.9	4977.9	42	62	82	40	3	85	5062.3		5059.9		6	26-Oct-95		730055	1872121
937	MW	B	DECOM	5020.2	4992.7	4965.2	40	67.5	95	55	3	98	5062.8		5060.2		4	9-Nov-95	24-May-00	730790	1872116
938	MW/EXT	B	Semiannual	5020.4	4992.9	4965.4	40	67.5	95	55	3	98	5063.64		5060.4		4	26-Oct-95		730769	1872124
939	EXT	B	DECOM	5021.1	4993.6	4966.1	40	67.5	95	55	3	98	5063.23		5061.1		6	23-Oct-95	16-May-00	731403	1872132
940	MW	A	Semiannual	5017.9	5010.4	5002.9	45	52.5	60	15	3	68	5064.77		5062.9		4	1-Nov-95		730130	1872391
941	MW	A	Semiannual	5018	5008	4998	45	55	65	20	3	68	5065.97		5063		4	10-Nov-95		730908	1872398
942	MW/EXT	B	Semiannual	5009.5	4999.5	4989.5	54	64	74	20	3	77	5066.45		5063.5		4	3-Nov-95		731642	1872409
943	MW	B	Annual	4994.1	4984.1	4974.1	101	111	121	20	3	124	5098.05		5095.1		4	13-Oct-95		731596	1874034

Table A-1 (continued). Well Completion Information, Sorted on Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
944	MW	B	DECOM	4979.9	4969.9	4959.9	85	95	105	20	2	107	5067		5064.9		4	4-Nov-95	28-Jul-99	732199	1873007
945	MW	A	Annual	5028.1	5018.1	5008.1	110	120	130	20	3	133	5140.49		5138.1		4	11-Oct-95		730019	1873857
946	MW	A	Annual	5057.6	5047.6	5037.6	40	50	60	20	3.3	63.3	5100.5		5097.6		4	2-Nov-95		730547	1873582
947	MW	B	Annual	4990	4980	4970	105	115	125	20	3.3	128.3	5097.01		5095		4	3-Nov-95		732786	1874642
948	EXDS	E	WL only	4893.9	4803.9	4713.9	221.5	311.5	401.5	180	5	406.5	5117.8		5115.4		4	17-Oct-95		733915	1875516
1003	INJ-MW	D	Annual	4923.4	4898.4	4873.4	55.5	80.5	105.5	50	2.5	108	4976.58		4978.9		6	26-Jul-99		732101	1870898
1004	INJ-MW	D	Annual	4918.1	4893.1	4868.1	45.5	70.5	95.5	50	2.5	98	4961.55		4963.6		6	27-Jul-99		731892	1870544
1005	INJ-MW	D	WL only	4904.7	4879.7	4854.7	45.5	70.5	95.5	50	2.5	98	4947.83		4950.2		6	25-Jul-99		731496	1870168
1006	INJ-MW	D	Annual	4903.7	4878.7	4853.7	45.7	70.7	95.7	50	2.5	98.2	4947.08		4949.5		6	24-Jul-99		731233	1869918
1007	INJ-MW	D	Annual	4915.6	4890.5	4865.4	45.8	70.9	96	50.2	2.5	98.5	4958.56		4961.4		6	23-Jul-99		730770	1869861
1008	INJ-MW	C	WL only	4926.8	4901.6	4876.4	55.6	80.8	106	50.4	2.5	108.5	4980.52		4982.3		6	23-Jul-99		730410	1869916
1101	EXT	D	Annual	4974.2	4896.5	4818.9	96.1	173.8	251.5	155.4	2.5	254	5067.29		5070.4		6	24-Aug-99		732223	1872970
1102	EXT	D	Annual	4968.8	4893.8	4818.8	101.5	176.5	251.5	150	2.5	254	5066.76		5070.3		6	24-Aug-99		732225	1872670
1103	EXT	D	Annual	4962.3	4887.3	4812.3	100	175	250	150	2.5	252.5	5059.56		5062.3		6	30-Jul-99		731896	1872407
1104	EXT	D	Annual	4972.3	4894.8	4817.3	90	167.5	245	155	3	248	5059.57		5062.3		6	1-Aug-99		731527	1872404
1105	EXT	D	Annual	4972.1	4894.6	4817.1	90	167.5	245	155	3	248	5059.33		5062.1		6	2-Aug-99		731304	1872401
1106	EXT	D	Annual	4966	4888.7	4811.4	96.5	173.8	251.1	154.6	2.9	254	5059.73		5062.5		6	3-Aug-99		731081	1872400
1107	EXT	D	Annual	4971.2	4894	4816.8	91.1	168.3	245.5	154.4	2.5	248	5059.51		5062.3		6	3-Aug-99		730858	1872398
1108	EXT	D	Annual	4966.1	4891.1	4816.1	96.3	171.3	246.3	150	2.5	248.8	5059.62		5062.4		6	3-Aug-99		730634	1872396
1109	EXT	D	Annual	4972.1	4894.7	4817.3	90.3	167.7	245.1	154.8	2.9	248	5059.64		5062.4		6	4-Aug-99		730410	1872394
1110	EXT	D	Annual	4966.8	4891.8	4816.8	95.5	170.5	245.5	150	2.5	248	5059.47		5062.3		6	7-Aug-99		730187	1872392
1111	EXT	D	Annual	4971.9	4894.7	4817.5	90.7	167.9	245.1	154.4	2.5	247.6	5059.87		5062.6		6	6-Aug-99		729993	1872392
1112	EXT	D	Annual	4969.1	4891.6	4814.1	90.5	168	245.5	155	2.5	248	5057.08		5059.6		6	17-Aug-99		730494	1872064
1113	EXT	D	Annual	4968.7	4891.2	4813.7	90.5	168	245.5	155	2.5	248	5058.54		5059.2		6	17-Aug-99		730196	1872061
1114	EXT	D	Annual	4968.5	4891	4813.6	90.6	168	245.5	154.9	2.5	248	5056.25		5059.1		6	11-Aug-99		729896	1872057
1115	EXT	D	Annual	4968.6	4891.2	4813.7	90.5	168	245.5	155	2.5	248	5056.36		5059.2		6	7-Aug-99		729596	1872055
1116	EXT	C	Annual	4964.1	4912.5	4861	92.4	143.9	195.5	103.1	2.5	198	5053.74		5056.5		6	8-Aug-99		730350	1871702
1117	EXT	C	Annual	4965.3	4913.7	4862.1	92.3	143.9	195.5	103.2	2.5	198	5054.95		5057.6		6	11-Aug-99		729981	1871688
1118	EXT	C	Annual	4967.9	4915.1	4862.3	89.9	142.7	195.5	105.6	2.5	198	5055.11		5057.8		6	12-Aug-99		729756	1871695
1119	EXT	D	Annual	4968.7	4893.7	4818.7	95.3	170.3	245.3	150	2.5	247.8	5061.19		5064		6	31-Jul-99		731894	1872667
1120	EXT	D	Annual	4971	4896	4821	95.5	170.5	245.5	150	2.5	248	5063.6		5066.5		6	28-Jul-99		731891	1872967
1121	EXT	D	Annual	4972	4897	4822	97.5	172.5	247.5	150	2.5	250	5066.61		5069.5		6	28-Jul-99		731889	1873267
1122	EXT	D	Annual	4973.4	4896.3	4819.2	96.9	174	251.1	154.2	2.9	254	5067.31		5070.3		6	26-Aug-99		732221	1873269
1123	EXT	D	Annual	4976.2	4899.2	4822.2	91	168	245	154	3	248	5064.54		5067.2		6	2-Sep-99		732508	1873222
1124	EXT	D	Annual	4978.7	4899.9	4821.1	87.9	166.7	245.5	157.6	2.5	248	5063.86		5066.6		6	23-Aug-99		732512	1872972
1125	EXT	D	Annual	4972.8	4897.8	4822.8	95.5	170.5	245.5	150	2.5	248	5065.47		5068.3		6	25-Aug-99		732515	1872671
1126	EXT	B	Annual	4991.9	4971.9	4951.9	60	80	100	40	3.3	103.3	5051.9	**	5051.9	**	4	9-Sep-04		729517	1870728
1127	EXT	B	Annual	4984.2	4964.2	4944.2	72.7	92.7	112.7	40	3.3	116	5056.9	**	5056.9	**	4	11-Sep-04		730044	1871022
1128	EXT	B	Annual	4982.3	4962.3	4942.3	72.7	92.7	112.7	40	3.3	116	5055	**	5055	**	4	12-Sep-04		730679	1871294
1129	EXT	B	Annual	4990.9	4975.9	4960.9	68.2	83.2	98.2	30	3.3	101.5	5059.1	**	5059.1	**	4	30-Aug-04		731237	1871690
1130	EXT	B	Annual	4987.3	4962.3	4937.3	71.7	96.7	121.7	50	3.3	125	5059	**	5059	**	4	29-Jul-04		731699	1871907
1131	EXT	B	Annual	4998.1	4978.1	4958.1	59.7	79.7	99.7	40	3.3	103	5057.8	**	5057.8	**	4	8-Sep-04		732011	1872106
1132	EXT	B	Annual	5009.1	4984.1	4959.1	49.7	74.7	99.7	50	3.3	103	5058.8	**	5058.8	**	4	31-Aug-04		731310	1872015

Table A-1 (continued). Well Completion Information, Sorted on Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
1133	EXT	B	Annual	4999.4	4979.4	4959.4	59.7	79.7	99.7	40	3.3	103	5059.1	**	5059.1	**	4	2-Sep-04		730850	1871827
NMW-1A*	MW	B	Semiannual	4980.7	4970	4960.7	167.5	177.5	187.5	20	5	192.5	5150.95		5148.2		4	25-Sep-10		728130	1872744
NMW-2A	MW	B	Annual	4978.7	4968	4958.7	140.5	150.5	160.5	20	5	165.46	5121.69		5119.15		4	27-Sep-10		728826	1874729
NMW-3A	MW	B	Semiannual	4975.1	4965	4955.1	190.6	200.6	210.6	20	5	215.62	5168.51		5165.73		4	10-Oct-10		730559	1874974
NMW-4A	MW	B	Semiannual	4964.2	4954	4944.2	170.5	180.5	190.5	20	5	195.46	5137.44		5134.68		4	7-Oct-10		727368	1874332
NMW-5	MW	C	Semiannual	4948.2	4938	4928.2	35	45	55	20	5	59.95	4985.85		4983.1		4	8-Oct-10		715095	1867920
NMW-6S	MW	B	Semiannual	4975.1	4965	4955.1	167.6	177.6	187.6	20	5	192.62	5145.93		5142.74		4	23-Sep-10		729015	1873349
NMW-7D	MW	D	Semiannual	4865.7	4863	4860.7	278.2	280.7	283.2	5	5	288.19	5147.13		5143.92		4	21-Sep-10		729017	1873387
NMW-8S	MW	B	Semiannual	4962.4	4952	4942.4	149.4	159.4	169.4	20	5	174.43	5114.87		5112.3		4	6-Oct-10		727588	1871585
NMW-9D	MW	E	Semiannual	4847.6	4845	4842.6	265.5	268	270.5	5	5	275.52	5115.92		5113.14		4	4-Oct-10		727573	1871587

All dimensions in feet except well diameter in inches; all depths are relative to ground surface.

* Sentinel well, to monitor plume boundary. For this annual report, the sentinel well subset was revised to include NMW-1A and lower terrace wells 0689 and 0692. Wells 683 and 684, located east of the disposal cell and identified as sentinel wells in previous annual reports, are no longer considered sentinel wells.

** Approximate (elevation).

DECOM Decommissioned well.

EXDS Extraction well domestic supply, completed in Navajo Sandstone. EXDS well 0948 (single sampling in 1995), located about 1,500 ft east of the site, is used to supply the Tuba City site treatment facility with domestic non-potable water.

EXT Groundwater remediation extraction well.

INJ-MW Groundwater remediation injection well, used as monitoring well. Although the injection infrastructure remains intact, to date these lower terrace wells (1003–1008) have only been used for water quality and/or water level monitoring purposes.

MW Monitoring well.

MW/EXT Extraction well converted to monitoring well in August 2005.

NMW Wells owned by Navajo Nation Environmental Protection Agency (NNEPA).

WL Water Levels—Semiannual.

Sampling Frequencies: Annual–August only; Semiannual–February and August.

[†]Monitoring well 283 has been dry since February 2007.

Table A-2. Well Completion Information, Sorted on Horizon, Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
929*	MW	A	Semiannual	5010.4	4990.4	4970.4	48.2	68.2	88.2	40			5060.82		5058.6		4			728780	1871453
284	MW	A	WL only	5079.8	5074.8	5069.8	16.5	21.5	26.5	10	1.5	28	5098.72		5096.3		2	16-Aug-04		730525	1873562
285	MW	A	WL only	5090.8	5088.3	5085.8	3	5.5	8	5	0.1	8.1	5096.47		5093.8		2	16-Aug-04		731629	1874042
686	MW	A	Annual	5045.5	5025.5	5005.5	60	80	100	40	0.3	100.3	5107.97		5105.5		2	28-Mar-00		729978	1873416
687	MW	A	Annual	5047.6	5027.6	5007.6	60	80	100	40	0.3	100.3	5109.82		5107.6		2	29-Mar-00		731152	1874024
688	MW	A	Annual	5044.1	5024.1	5004.1	60	80	100	40	0.3	100.3	5106.98		5104.1		2	29-Mar-00		731961	1874385
901	MW	A	Annual	5045.8	5035.8	5025.8	58	68	78	20	2	80	5105.46		5103.8		2	16-Oct-84		730185	1875918
906	MW	A	Semiannual	5016.9	5006.9	4996.9	44	54	64	20	2	66	5062.1		5060.9		2	19-Nov-84		730838	1872181
907	MW	A	DECOM	5010.7	5000.7	4990.7	66.5	76.5	86.5	20			5079.17		5077.2		2	30-Nov-84	19-Apr-88	731252	1872920
928	MW	A	DECOM	5022.1	5009.6	4997.1	30	42.5	55	25	3	58	5053.99		5052.1		4	20-Oct-95	24-May-00	729401	1870814
940	MW	A	Semiannual	5017.9	5010.4	5002.9	45	52.5	60	15	3	68	5064.77		5062.9		4	1-Nov-95		730130	1872391
941	MW	A	Semiannual	5018	5008	4998	45	55	65	20	3	68	5065.97		5063		4	10-Nov-95		730908	1872398
945	MW	A	Annual	5028.1	5018.1	5008.1	110	120	130	20	3	133	5140.49		5138.1		4	11-Oct-95		730019	1873857
946	MW	A	Annual	5057.6	5047.6	5037.6	40	50	60	20	3.3	63.3	5100.5		5097.6		4	2-Nov-95		730547	1873582
271*	MW	B	Annual	4984	4964	4944	60	80	100	40	0.3	100.3	5046.72		5044		2	29-Apr-00		728160	1869555
NMW-1A*	MW	B	Semiannual	4980.7	4970	4960.7	167.5	177.5	187.5	20	5	192.5	5150.95		5148.2		4	25-Sep-10		728130	1872744
NMW-8S	MW	B	Semiannual	4962.4	4952	4942.4	149.4	159.4	169.4	20	5	174.43	5114.87		5112.3		4	6-Oct-10		727588	1871585
NMW-6S	MW	B	Semiannual	4975.1	4965	4955.1	167.6	177.6	187.6	20	5	192.62	5145.93		5142.74		4	23-Sep-10		729015	1873349
NMW-4A	MW	B	Semiannual	4964.2	4954	4944.2	170.5	180.5	190.5	20	5	195.46	5137.44		5134.68		4	7-Oct-10		727368	1874332
NMW-3A	MW	B	Semiannual	4975.1	4965	4955.1	190.6	200.6	210.6	20	5	215.62	5168.51		5165.73		4	10-Oct-10		730559	1874974
NMW-2A	MW	B	Annual	4978.7	4968	4958.7	140.5	150.5	160.5	20	5	165.46	5121.69		5119.15		4	27-Sep-10		728826	1874729
262	MW	B	Semiannual	4999.2	4979.2	4959.2	60	80	100	40	0.3	100.3	5061.99		5059.2		2	3-Apr-00		731402	1872012
263	MW	B	Semiannual	5000.2	4980.2	4960.2	60	80	100	40	0.3	100.3	5063.1		5060.2		2	4-Apr-00		731565	1871757
265	MW	B	Semiannual	4991.1	4971.1	4951.1	60	80	100	40	0.3	100.3	5053.88		5051.1		2	16-Apr-00		730382	1870964
267	MW	B	Semiannual	4990.8	4970.8	4950.8	60	80	100	40	0.3	100.3	5053.4		5050.8		2	14-Apr-00		729329	1870707
281	MW	B	Semiannual	4977.8	4972.8	4967.8	70.5	75.5	80.5	10	1.5	82	5051		5048.3		2	11-Aug-04		729714	1870315
282	MW	B	Semiannual	4983.3	4978.3	4973.3	74.1	79.1	84.1	10	1.5	85.6	5060.04		5057.4		2	10-Aug-04		730062	1871168
283†	MW	B	Semiannual	4984.8	4979.8	4974.8	70.5	75.5	80.5	10	1.5	82	5057.97		5055.3		2	3-Aug-04		730901	1871185
286	MW	B	Semiannual	4968.8	4963.8	4958.8	93.2	98.2	103.2	10	0.4	103.6	5063.99		5062		2	13-Mar-07		730128	1872377
287	MW	B	Semiannual	4962.3	4957.3	4952.3	100.7	105.7	110.7	10	0.4	111.1	5065.65		5063		2	15-Mar-07		730908	1872386
288	MW	B	Semiannual	4965.9	4960.9	4955.9	104	109	114	10	0.5	114.5	5072.54		5069.9		2	18-Mar-07		729995	1872709
290	MW	B	Semiannual	4964.3	4959.3	4954.3	102.7	107.7	112.7	10	0.4	113.1	5068.91		5067		2	17-Mar-07		732633	1872979
905	MW	B	DECOM	5006	4998.5	4991	63	70.5	78	15	2	80	5072.8		5069		2	14-Nov-84	24-May-00	732933	1873200
908	MW	B	Semiannual	5005.3	4997.8	4990.3	52	59.5	67	15	2	69	5058.14		5057.3		2	17-Nov-84		729366	1871999
909	MW	B	Semiannual	4990.8	4983.3	4975.8	65	72.5	80	15	2	82	5057.17		5055.8		2	18-Nov-84		730927	1871393
910	MW	B	Annual	5007.6	4957.6	4907.6	97	147	197	100	1	198	5106.7		5104.6		4	26-Jul-85		730219	1875840
918	MW	B	WL only	4986.2	4983.7	4981.2	61	63.5	66	5	2	68	5049.63		5047.2		4	15-Aug-85		727294	1868724
925	EXT	B	DECOM	5005.8	4985.8	4965.8	53	73	93	40	0.5	93.5	5060.87		5058.8		6	21-Oct-95	24-May-00	729452	1872006
926	EXT	B	DECOM	5018.3	4993.3	4968.3	42.2	67.2	92.2	50	3	95.2	5062.85		5060.5		6	25-Oct-95	17-May-00	730790	1872126
933	MW	B	DECOM	4993.3	4992.3	4991.3	23	24	25	2			5018.03		5016.3		4	18-Oct-95	24-May-00	731727	1871341
934	MW	B	Semiannual	5013	4990.5	4968	45	67.5	90	45	3	93	5059.73		5058		4	2-Nov-95		730018	1871649
935	MW/EXT	B	Semiannual	5008.8	4988.8	4968.8	50	70	90	40	3	93	5061.5		5058.8		4	28-Oct-95		729461	1871978

Table A-2 (continued). Well Completion Information, Sorted on Horizon, Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
936	MW/EXT	B	Semiannual	5017.9	4997.9	4977.9	42	62	82	40	3	85	5062.3		5059.9		6	26-Oct-95		730055	1872121
937	MW	B	DECOM	5020.2	4992.7	4965.2	40	67.5	95	55	3	98	5062.8		5060.2		4	9-Nov-95	24-May-00	730790	1872116
938	MW/EXT	B	Semiannual	5020.4	4992.9	4965.4	40	67.5	95	55	3	98	5063.64		5060.4		4	26-Oct-95		730769	1872124
939	EXT	B	DECOM	5021.1	4993.6	4966.1	40	67.5	95	55	3	98	5063.23		5061.1		6	23-Oct-95	16-May-00	731403	1872132
942	MW/EXT	B	Semiannual	5009.5	4999.5	4989.5	54	64	74	20	3	77	5066.45		5063.5		4	3-Nov-95		731642	1872409
943	MW	B	Annual	4994.1	4984.1	4974.1	101	111	121	20	3	124	5098.05		5095.1		4	13-Oct-95		731596	1874034
944	MW	B	DECOM	4979.9	4969.9	4959.9	85	95	105	20	2	107	5067		5064.9		4	4-Nov-95	28-Jul-99	732199	1873007
947	MW	B	Annual	4990	4980	4970	105	115	125	20	3.3	128.3	5097.01		5095		4	3-Nov-95		732786	1874642
1126	EXT	B	Annual	4991.9	4971.9	4951.9	60	80	100	40	3.3	103.3	5051.9	**	5051.9	**	4	9-Sep-04		729517	1870728
1127	EXT	B	Annual	4984.2	4964.2	4944.2	72.7	92.7	112.7	40	3.3	116	5056.9	**	5056.9	**	4	11-Sep-04		730044	1871022
1128	EXT	B	Annual	4982.3	4962.3	4942.3	72.7	92.7	112.7	40	3.3	116	5055	**	5055	**	4	12-Sep-04		730679	1871294
1129	EXT	B	Annual	4990.9	4975.9	4960.9	68.2	83.2	98.2	30	3.3	101.5	5059.1	**	5059.1	**	4	30-Aug-04		731237	1871690
1130	EXT	B	Annual	4987.3	4962.3	4937.3	71.7	96.7	121.7	50	3.3	125	5059	**	5059	**	4	29-Jul-04		731699	1871907
1131	EXT	B	Annual	4998.1	4978.1	4958.1	59.7	79.7	99.7	40	3.3	103	5057.8	**	5057.8	**	4	8-Sep-04		732011	1872106
1132	EXT	B	Annual	5009.1	4984.1	4959.1	49.7	74.7	99.7	50	3.3	103	5058.8	**	5058.8	**	4	31-Aug-04		731310	1872015
1133	EXT	B	Annual	4999.4	4979.4	4959.4	59.7	79.7	99.7	40	3.3	103	5059.1	**	5059.1	**	4	2-Sep-04		730850	1871827
689*	MW	C	Annual	4923.9	4903.9	4883.9	55	75	95	40	0.3	95.3	4981.63		4978.9		2	31-Mar-00		730439	1869893
914*	MW	C	Annual	4930.3	4921.8	4913.3	137.2	145.7	154.2	17	2	156.2	5070.1		5067.5		4	16-Aug-85		732723	1872119
NMW-5	MW	C	Semiannual	4948.2	4938	4928.2	35	45	55	20	5	59.95	4985.85		4983.1		4	8-Oct-10		715095	1867920
274	MW	C	Semiannual	4913.6	4903.6	4893.6	149	159	169	20	1.5	170.5	5064.42		5062.6		2	30-Aug-04		731623	1872403
276	MW	C	Semiannual	4910	4900	4890	154.5	164.5	174.5	20	1.5	176	5067.55		5064.5		2	1-Sep-04		732081	1873158
279	MW	C	Annual	4922.1	4917.1	4912.1	26.5	31.5	36.5	10	1.5	38	4951.04		4948.6		2	15-Aug-04		731494	1870132
280	MW	C	Annual	4922.6	4917.6	4912.6	26.5	31.5	36.5	10	1.5	38	4951.52		4949.1		2	15-Aug-04		731794	1870289
289	MW	C	Semiannual	4920.3	4915.3	4910.3	148.3	153.3	158.3	10	0.4	163	5070.82		5068.6		6	28-Mar-07		729965	1872709
683	MW	C	Annual	4973.2	4948.2	4923.2	95	120	145	50	3	148	5070.64		5068.2		6	31-Aug-99		732661	1872574
684	MW	C	Annual	4943.1	4917.4	4891.8	124.2	149.9	175.5	51.3	2.5	178	5070.05		5067.3		6	20-Aug-99		732642	1873521
685	MW	C	Annual	4975.6	4949.7	4923.8	93.7	119.6	145.5	51.8	2.5	148	5072.44		5069.3		6	19-Aug-99		732295	1873760
691	MW	C	Semiannual	4921.9	4901.9	4881.9	55	75	95	40	0.3	95.3	4979.41		4976.9		2	30-Mar-00		732124	1870872
903	MW	C	Annual	4953.5	4943.5	4933.5	28	38	48	20	2	50	4983.33		4981.5		2	30-Oct-84		731314	1870829
912	MW	C	Annual	4934.7	4914.7	4894.7	123	143	163	40	2	165	5059.97		5057.7		4	12-Aug-85		729324	1871942
917	MW	C	WL only	4917.8	4907.8	4897.8	128	138	148	20	2	150	5048.02		5045.8		4	14-Aug-85		727255	1868642
930	MW	C	Semiannual	4933	4918	4903	20	35	50	30	3	53	4954.96		4953		4	23-Oct-95		731257	1870099
932	MW	C	Semiannual	4942.3	4932.3	4922.3	112.5	122.5	132.5	20	2.7	135.2	5057.32		5054.8		4	29-Oct-95		730900	1871401
1008	INJ-MW	C	WL only	4926.8	4901.6	4876.4	55.6	80.8	106	50.4	2.5	108.5	4980.52		4982.3		6	23-Jul-99		730410	1869916
1116	EXT	C	Annual	4964.1	4912.5	4861	92.4	143.9	195.5	103.1	2.5	198	5053.74		5056.5		6	8-Aug-99		730350	1871702
1117	EXT	C	Annual	4965.3	4913.7	4862.1	92.3	143.9	195.5	103.2	2.5	198	5054.95		5057.6		6	11-Aug-99		729981	1871688
1118	EXT	C	Annual	4967.9	4915.1	4862.3	89.9	142.7	195.5	105.6	2.5	198	5055.11		5057.8		6	12-Aug-99		729756	1871695
692*	MW	D	Annual	4895.6	4875.6	4855.6	55	75	95	40	0.3	95.3	4953.31		4950.6		2	5-Apr-00		731821	1870303
NMW-7D	MW	D	Semiannual	4865.7	4863	4860.7	278.2	280.7	283.2	5	5	288.19	5147.13		5143.92		4	21-Sep-10		729017	1873387
258	MW	D	Semiannual	4894	4874	4854	159	179	199	40	0.3	199.3	5055.56		5053		2	13-Apr-00		732452	1871996
261	MW	D	Annual	4907	4887	4867	160	180	200	40	0.3	200.3	5069.69		5067		2	1-Apr-00		732565	1871578
264	MW	D	Semiannual	4899.6	4879.6	4859.6	160	180	200	40	0.3	200.3	5062.19		5059.6		2	3-Apr-00		731569	1871746
266	MW	D	Semiannual	4890.6	4870.6	4850.6	160	180	200	40	0.3	200.3	5053.32		5050.6		2	15-Apr-00		730380	1870941

Table A-2 (continued). Well Completion Information, Sorted on Horizon, Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
272	MW	D	Semiannual	4902.8	4892.8	4882.8	159.1	169.1	179.1	20	1.5	180.6	5064.24		5061.9		2	28-Aug-04		730112	1872389
273	MW	D	Semiannual	4909.4	4899.4	4889.4	153	163	173	20	1.5	174.5	5064.74		5062.4		2	29-Aug-04		730922	1872397
275	MW	D	Semiannual	4903	4893	4883	158.2	168.2	178.2	20	1.5	179.7	5062.64		5061.2		2	1-Sep-04		732092	1872586
277	MW	D	Annual	4884	4879	4874	95.7	100.7	105.7	10	1.5	107.2	4982.35		4979.7		2	12-Aug-04		731290	1870777
278	MW	D	Annual	4862.9	4857.9	4852.9	90.5	95.5	100.5	10	1.5	102	4956.09		4953.4		2	14-Aug-04		731210	1870104
690	MW	D	Annual	4893.3	4873.3	4853.3	55	75	95	40	0.3	95.3	4950.87		4948.3		2	30-Mar-00		731521	1870140
695	MW	D	Annual	4919.3	4899.3	4879.3	55	75	95	40	0.3	95.3	4976.83		4974.3		2	6-Apr-00		732566	1870896
904	MW	D	Annual	4873.8	4868.8	4863.8	28	33	38	10	2	40	4904.11		4901.8		2	7-Nov-84		731808	1868036
915	MW	D	Annual	4897.8	4892.8	4887.8	170	175	180	10	2	182	5070.84		5067.8		4	24-Aug-85		732740	1872209
1003	INJ-MW	D	Annual	4923.4	4898.4	4873.4	55.5	80.5	105.5	50	2.5	108	4976.58		4978.9		6	26-Jul-99		732101	1870898
1004	INJ-MW	D	Annual	4918.1	4893.1	4868.1	45.5	70.5	95.5	50	2.5	98	4961.55		4963.6		6	27-Jul-99		731892	1870544
1005	INJ-MW	D	WL only	4904.7	4879.7	4854.7	45.5	70.5	95.5	50	2.5	98	4947.83		4950.2		6	25-Jul-99		731496	1870168
1006	INJ-MW	D	Annual	4903.7	4878.7	4853.7	45.7	70.7	95.7	50	2.5	98.2	4947.08		4949.5		6	24-Jul-99		731233	1869918
1007	INJ-MW	D	Annual	4915.6	4890.5	4865.4	45.8	70.9	96	50.2	2.5	98.5	4958.56		4961.4		6	23-Jul-99		730770	1869861
1101	EXT	D	Annual	4974.2	4896.5	4818.9	96.1	173.8	251.5	155.4	2.5	254	5067.29		5070.4		6	24-Aug-99		732223	1872970
1102	EXT	D	Annual	4968.8	4893.8	4818.8	101.5	176.5	251.5	150	2.5	254	5066.76		5070.3		6	24-Aug-99		732225	1872670
1103	EXT	D	Annual	4962.3	4887.3	4812.3	100	175	250	150	2.5	252.5	5059.56		5062.3		6	30-Jul-99		731896	1872407
1104	EXT	D	Annual	4972.3	4894.8	4817.3	90	167.5	245	155	3	248	5059.57		5062.3		6	1-Aug-99		731527	1872404
1105	EXT	D	Annual	4972.1	4894.6	4817.1	90	167.5	245	155	3	248	5059.33		5062.1		6	2-Aug-99		731304	1872401
1106	EXT	D	Annual	4966	4888.7	4811.4	96.5	173.8	251.1	154.6	2.9	254	5059.73		5062.5		6	3-Aug-99		731081	1872400
1107	EXT	D	Annual	4971.2	4894	4816.8	91.1	168.3	245.5	154.4	2.5	248	5059.51		5062.3		6	3-Aug-99		730858	1872398
1108	EXT	D	Annual	4966.1	4891.1	4816.1	96.3	171.3	246.3	150	2.5	248.8	5059.62		5062.4		6	3-Aug-99		730634	1872396
1109	EXT	D	Annual	4972.1	4894.7	4817.3	90.3	167.7	245.1	154.8	2.9	248	5059.64		5062.4		6	4-Aug-99		730410	1872394
1110	EXT	D	Annual	4966.8	4891.8	4816.8	95.5	170.5	245.5	150	2.5	248	5059.47		5062.3		6	7-Aug-99		730187	1872392
1111	EXT	D	Annual	4971.9	4894.7	4817.5	90.7	167.9	245.1	154.4	2.5	247.6	5059.87		5062.6		6	6-Aug-99		729993	1872392
1112	EXT	D	Annual	4969.1	4891.6	4814.1	90.5	168	245.5	155	2.5	248	5057.08		5059.6		6	17-Aug-99		730494	1872064
1113	EXT	D	Annual	4968.7	4891.2	4813.7	90.5	168	245.5	155	2.5	248	5058.54		5059.2		6	17-Aug-99		730196	1872061
1114	EXT	D	Annual	4968.5	4891	4813.6	90.6	168	245.5	154.9	2.5	248	5056.25		5059.1		6	11-Aug-99		729896	1872057
1115	EXT	D	Annual	4968.6	4891.2	4813.7	90.5	168	245.5	155	2.5	248	5056.36		5059.2		6	7-Aug-99		729596	1872055
1119	EXT	D	Annual	4968.7	4893.7	4818.7	95.3	170.3	245.3	150	2.5	247.8	5061.19		5064		6	31-Jul-99		731894	1872667
1120	EXT	D	Annual	4971	4896	4821	95.5	170.5	245.5	150	2.5	248	5063.6		5066.5		6	28-Jul-99		731891	1872967
1121	EXT	D	Annual	4972	4897	4822	97.5	172.5	247.5	150	2.5	250	5066.61		5069.5		6	28-Jul-99		731889	1873267
1122	EXT	D	Annual	4973.4	4896.3	4819.2	96.9	174	251.1	154.2	2.9	254	5067.31		5070.3		6	26-Aug-99		732221	1873269
1123	EXT	D	Annual	4976.2	4899.2	4822.2	91	168	245	154	3	248	5064.54		5067.2		6	2-Sep-99		732508	1873222
1124	EXT	D	Annual	4978.7	4899.9	4821.1	87.9	166.7	245.5	157.6	2.5	248	5063.86		5066.6		6	23-Aug-99		732512	1872972
1125	EXT	D	Annual	4972.8	4897.8	4822.8	95.5	170.5	245.5	150	2.5	248	5065.47		5068.3		6	25-Aug-99		732515	1872671
NMW-9D	MW	E	Semiannual	4847.6	4845	4842.6	265.5	268	270.5	5	5	275.52	5115.92		5113.14		4	4-Oct-10		727573	1871587
251	MW	E	Semiannual	4858.9	4808.9	4758.9	200	250	300	100	0.3	300.3	5061.25		5058.9		2	28-Apr-00		730215	1871999
268	MW	E	Semiannual	4864.5	4814.5	4764.5	200	250	300	100	0.3	300.3	5067.24		5064.5		2	15-May-00		732301	1872430
920	MW	E	Annual	4866	4846	4826	114.4	134.4	154.4	40	2	156.4	4982.97		4980.4		4	30-Jul-85		731262	1870737
948	EXDS	E	WL only	4893.9	4803.9	4713.9	221.5	311.5	401.5	180	5	406.5	5117.8		5115.4		4	17-Oct-95		733915	1875516
911	MW	F	Annual	4795.2	4775.2	4755.2	309.4	329.4	349.4	40	2	351.4	5106.96		5104.6		4	18-Jul-85		730265	1875920
913	MW	G	Annual	4729.2	4709.2	4689.2	328.7	348.7	368.7	40	2	370.7	5060.16		5057.9		4	2-Aug-85		729327	1871871

Table A-2 (continued). Well Completion Information, Sorted on Horizon, Well ID

Well	Type	Horizon	Sampling Frequency	Top of Screen Elev.	Mid Screen Elev.	Bottom of Screen Elev.	Top of Screen Depth	Mid Screen Depth	Bottom of Screen Depth	Screen Length	Sump Length	Well Depth	Top of Casing Elev.	Note	Ground Elev.	Note	Well Diameter	Boring Started	Decommission Date	State Plane East	State Plane North
916	MW	G	Annual	4721.7	4716.7	4711.7	345.7	350.7	355.7	10	2	357.7	5070		5067.4		4	22-Aug-85		732811	1872146
919	MW	G	WL only	4707.9	4702.9	4697.9	337.7	342.7	347.7	10	2	349.7	5048.56		5045.6		4	26-Aug-85		727353	1868654
902	MW	H	WL only	4673.7	4668.7	4663.7	63	68	73	10	2	75	4737.42		4736.7		2	2-Dec-84		730179	1862292
252	MW	I	Semiannual	4658.9	4608.9	4558.9	400	450	500	100	0.4	500.4	5061.3		5058.9		4	26-Apr-00		730232	1871993
254	MW	I	DECOM	4662.7	4612.7	4562.7	400	450	500	100	0.4	500.4	5065.38		5062.7		4	3-May-00	13-Aug-05	730951	1872411
256	MW	I	DECOM	4664	4614	4564	400	450	500	100	0.4	500.4	5066.58		5064		4	13-May-00	14-Aug-05	732277	1872437
921	MW	I	Annual	4663.7	4643.7	4623.7	313.2	333.2	353.2	40	2	355.2	4979.08		4976.9		4	22-Jul-85		731379	1870742
253	MW	M	DECOM	4458.8	4408.8	4358.8	600	650	700	100	0.4	700.4	5061.11		5058.8		4	18-Apr-00	11-Apr-01	730213	1871974
255	MW	M	DECOM	4462.3	4412.3	4362.3	600	650	700	100	0.4	700.4	5064.89		5062.3		4	1-May-00	12-Aug-05	730947	1872387
257	MW	M	DECOM	4463.4	4413.4	4363.4	600	650	700	100	0.4	700.4	5066.4		5063.4		4	11-May-00	11-Aug-05	732278	1872414

All dimensions in feet except well diameter in inches; all depths are relative to ground surface.

* Sentinel well, to monitor plume boundary. For this annual report, the sentinel well subset was revised to include NMW-1A and lower terrace wells 0689 and 0692. Wells 683 and 684, located east of the disposal cell and identified as sentinel wells in previous annual reports, are no longer considered sentinel wells.

** Approximate (elevation).

DECOM Decommissioned well.

EXDS Extraction well domestic supply, completed in Navajo Sandstone. EXDS well 0948 (single sampling in 1995), located about 1,500 ft east of the site, is used to supply the Tuba City site treatment facility with domestic non-potable water.

EXT Groundwater remediation extraction well.

INJ-MW Groundwater remediation injection well, used as monitoring well. Although the injection infrastructure remains intact, to date these lower terrace wells (1003–1008) have only been used for water quality and/or water level monitoring purposes.

MW Monitoring well.

MW/EXT Extraction well converted to monitoring well in August 2005.

NMW Wells owned by Navajo Nation Environmental Protection Agency (NNEPA).

WL Water Levels—Semiannual.

Sampling Frequencies: Annual–August only; Semiannual–February and August.

† Monitoring well 283 has been dry since February 2007.

Appendix B

Nitrate, Sulfate, and Uranium Plume Maps

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Figures

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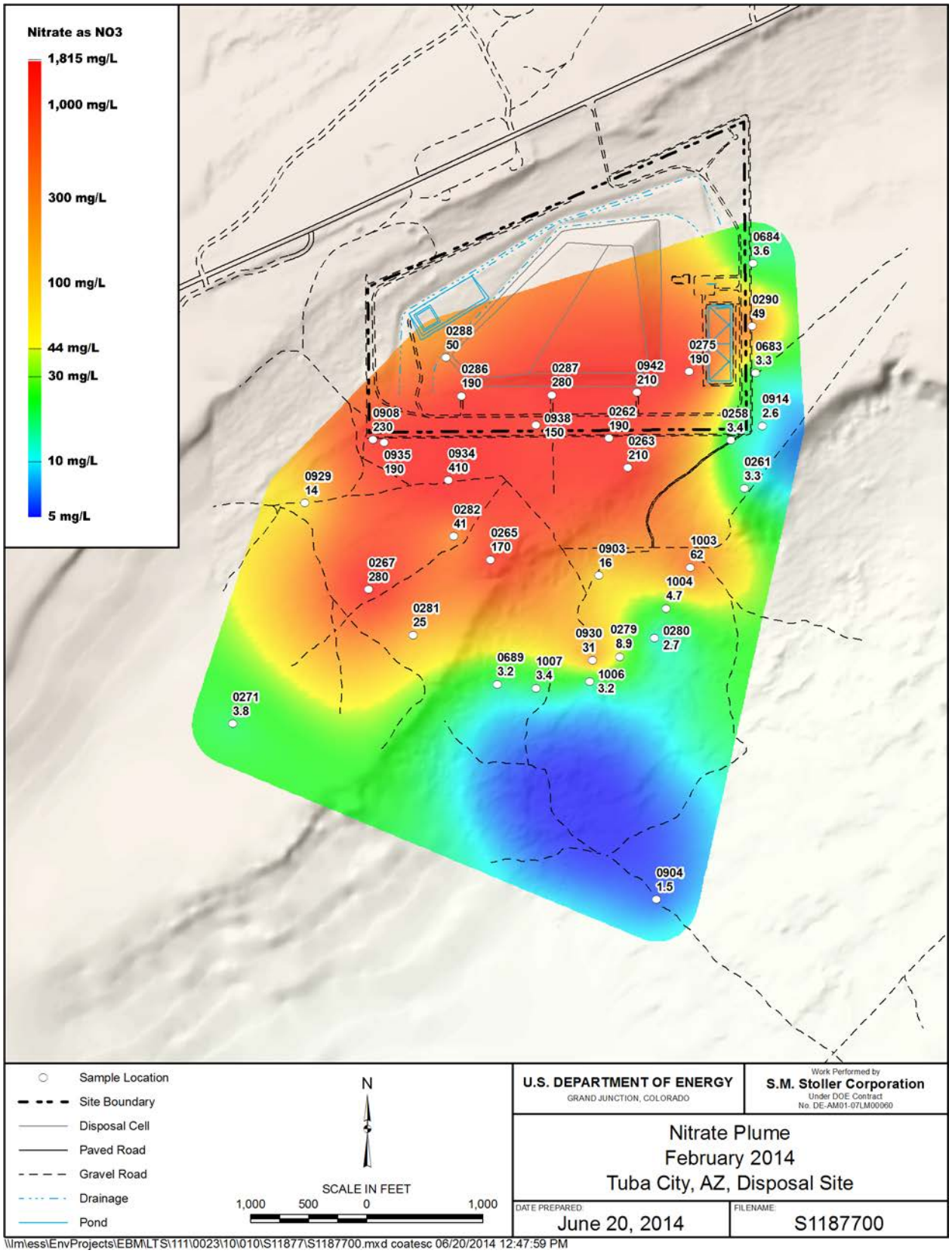

Figure B-1. Nitrate (mg/L as NO_3) Plume Map: August 2013–February 2014

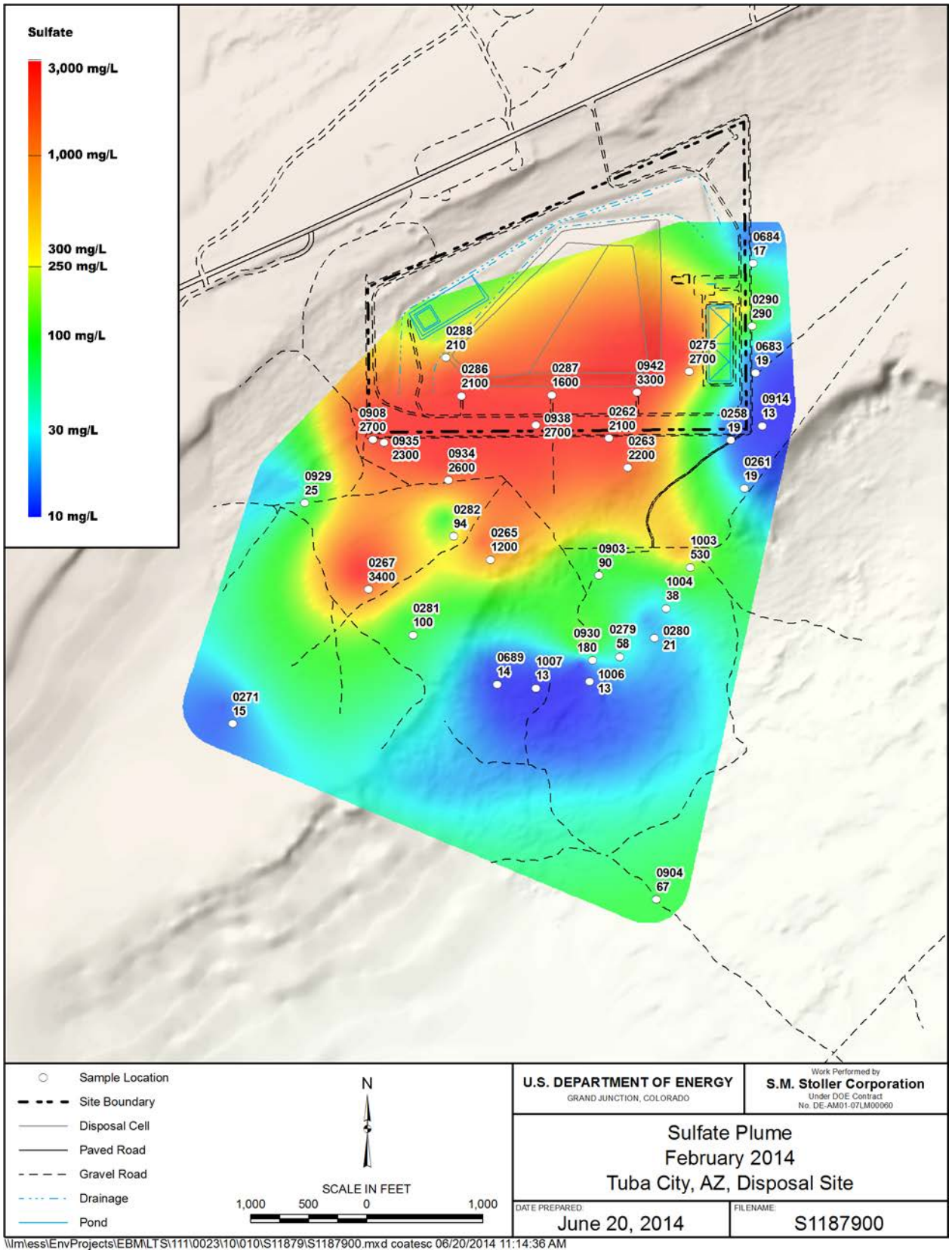

Figure B-2. Sulfate (mg/L) Plume Map: August 2013–February 2014

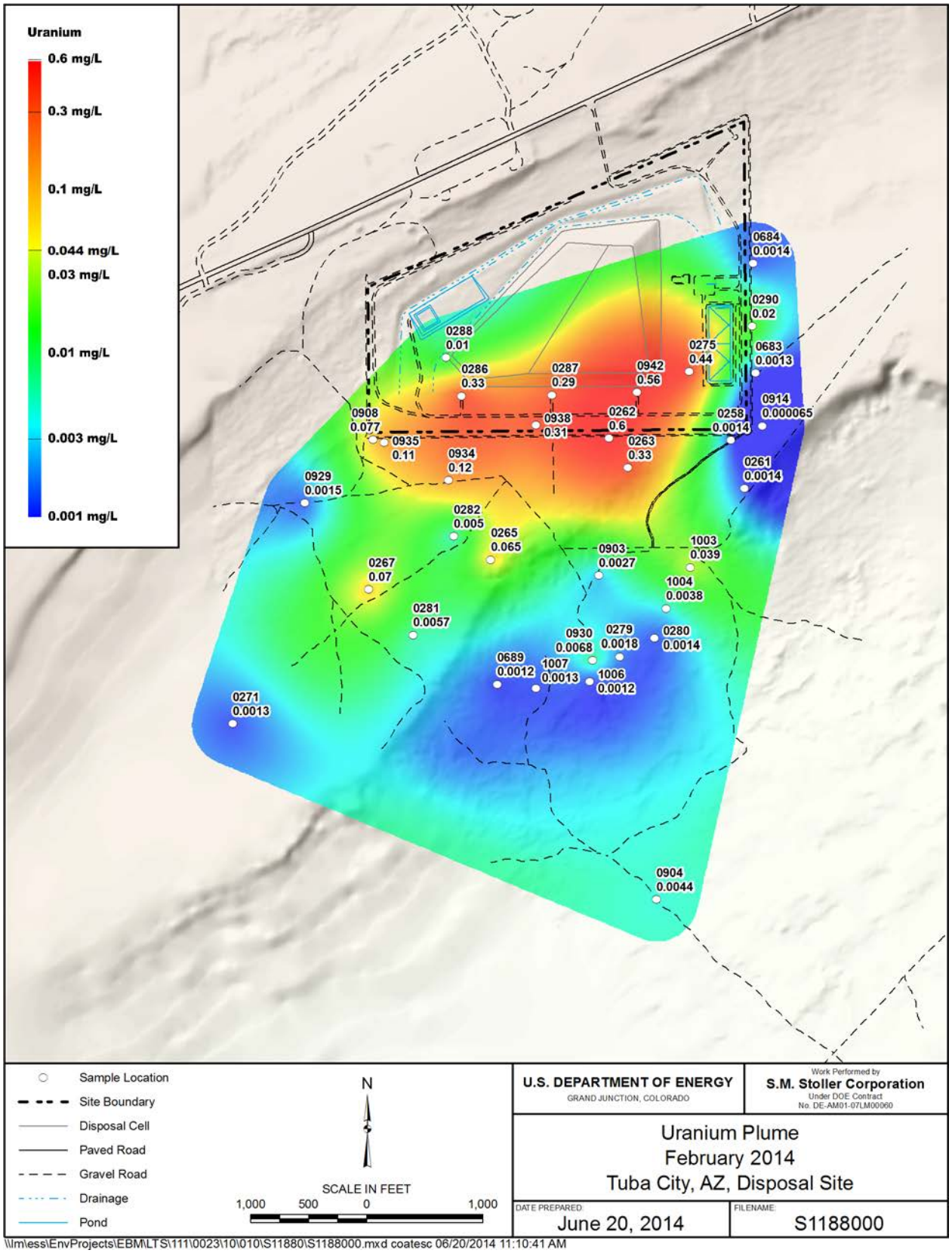

Figure B-3. Uranium (µg/L) Plume Map: August 2013–February 2014

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Appendix C

Monitoring Well Water Level Hydrographs

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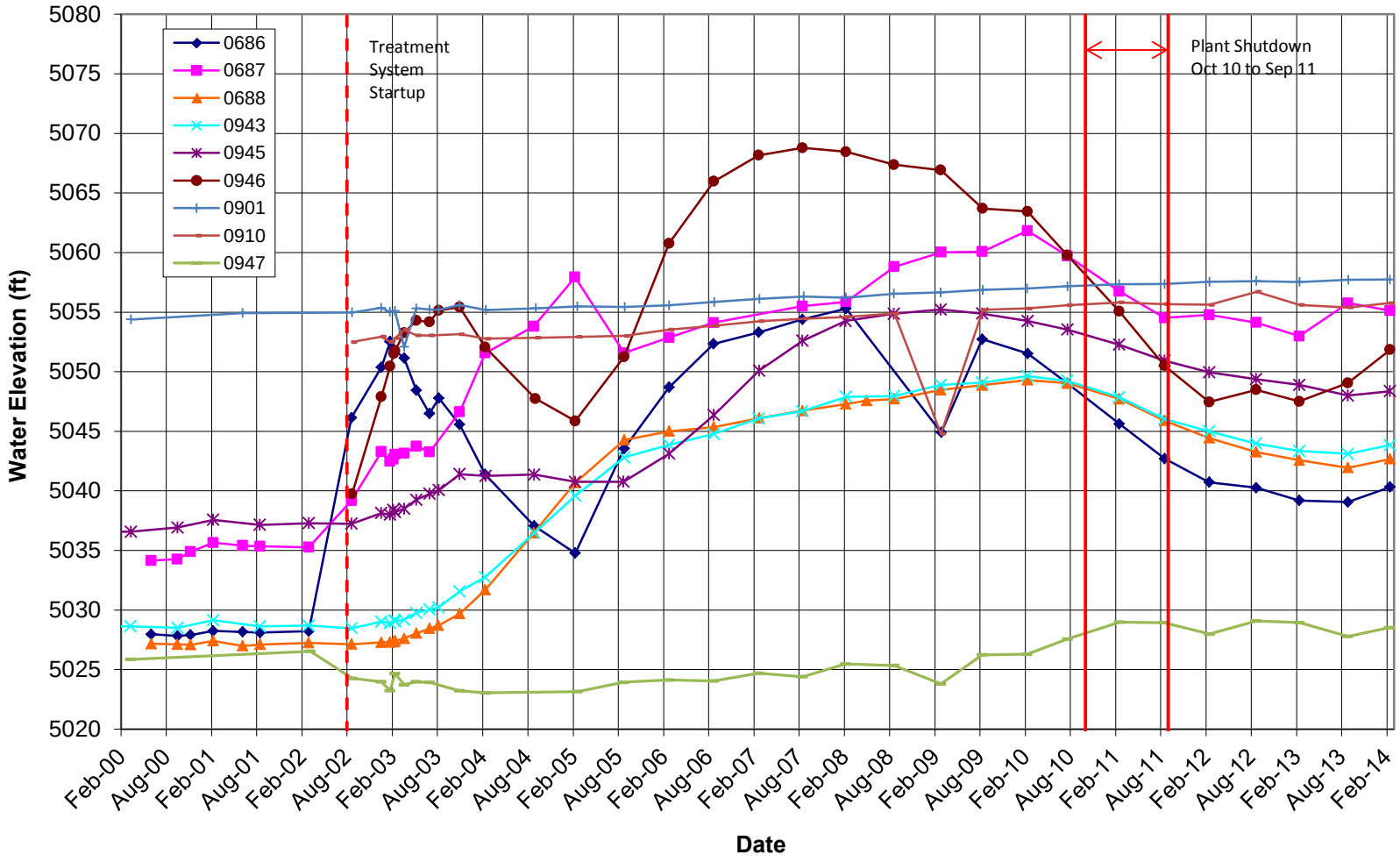


Figure C-1. Monitoring Wells at Infiltration Trench (686–688, 943, 945, 946) and Background Wells 901, 910, and 947

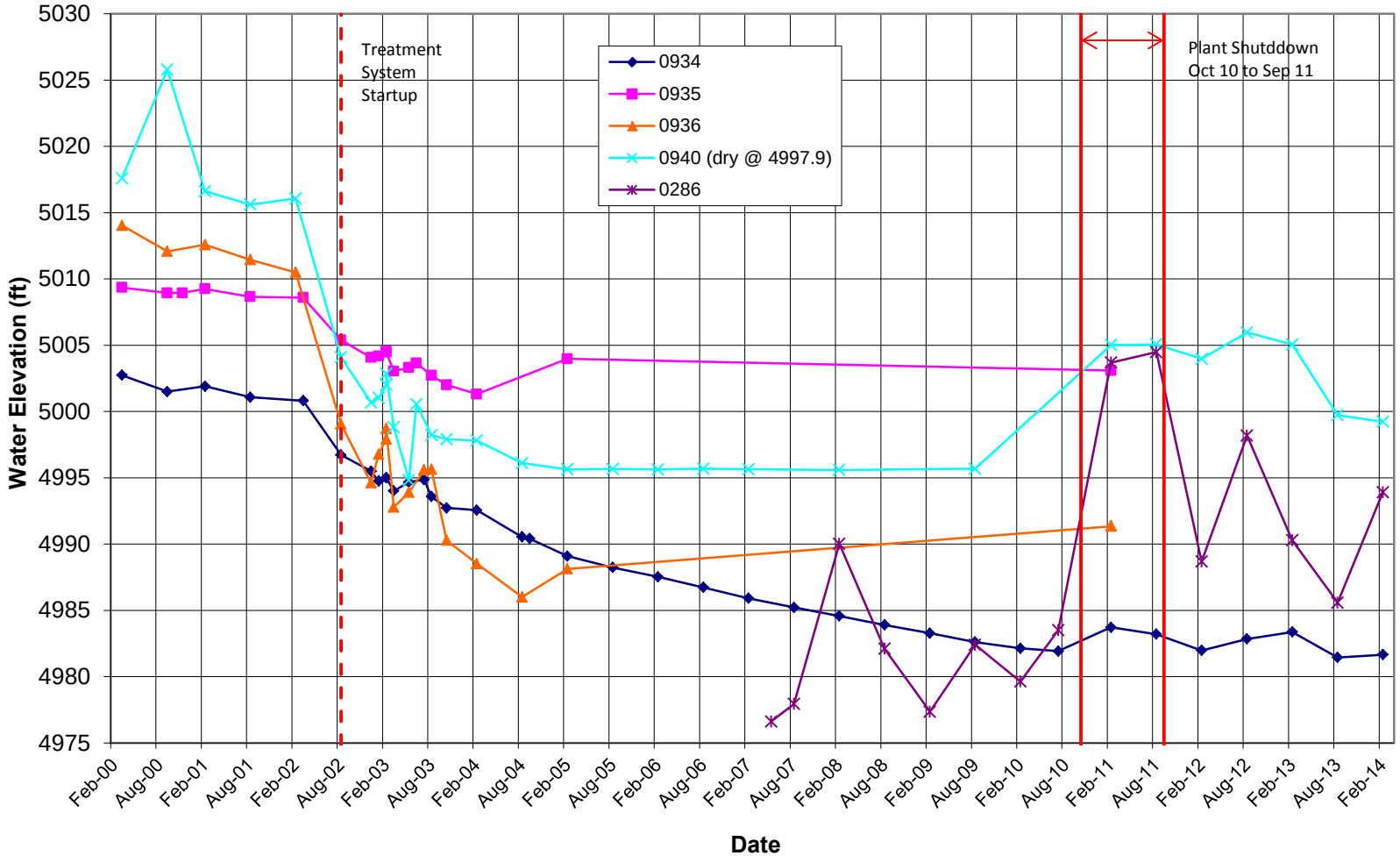
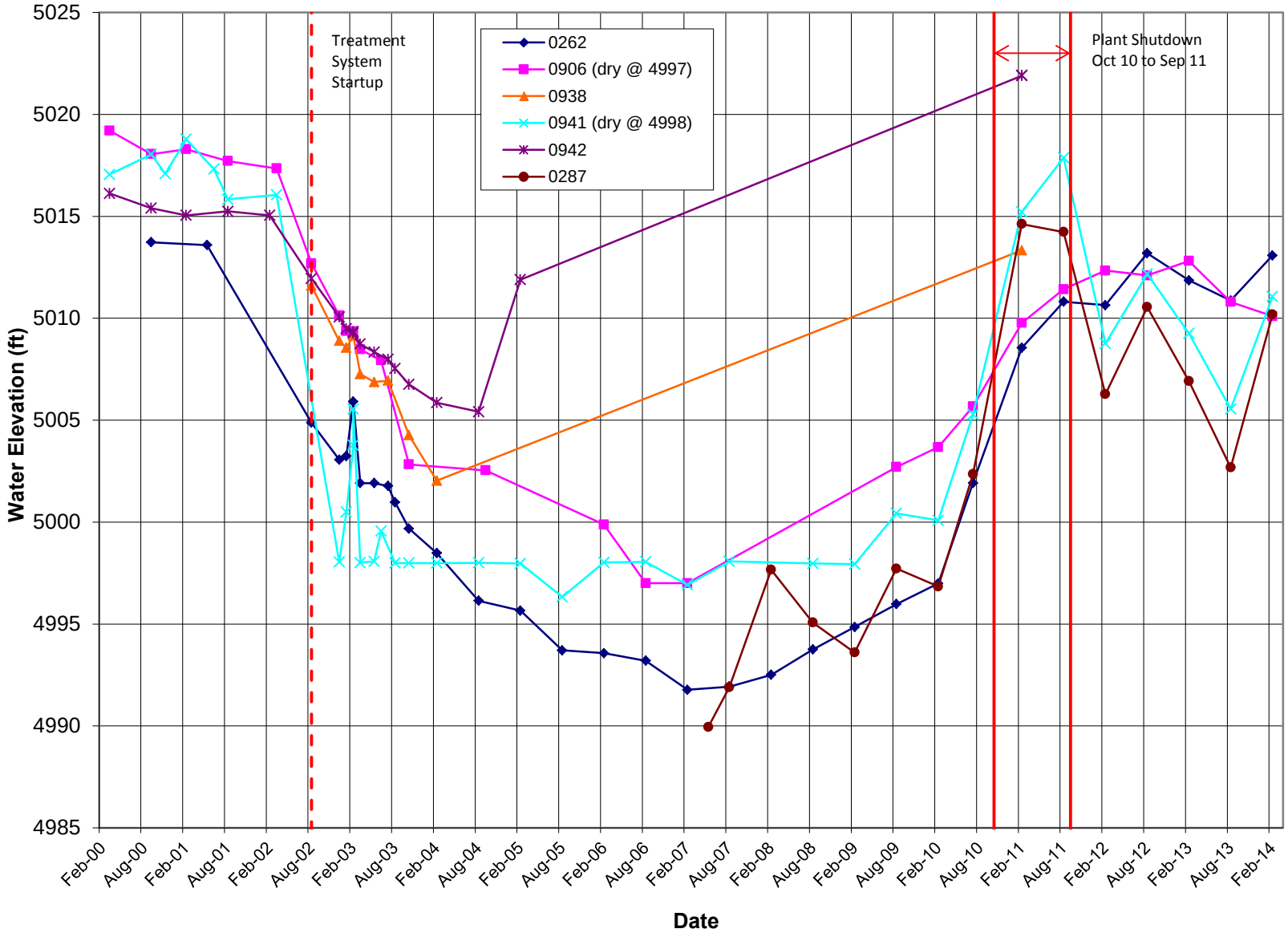


Figure C-2. Horizon A and B Monitoring Wells 286, 934–936, 940



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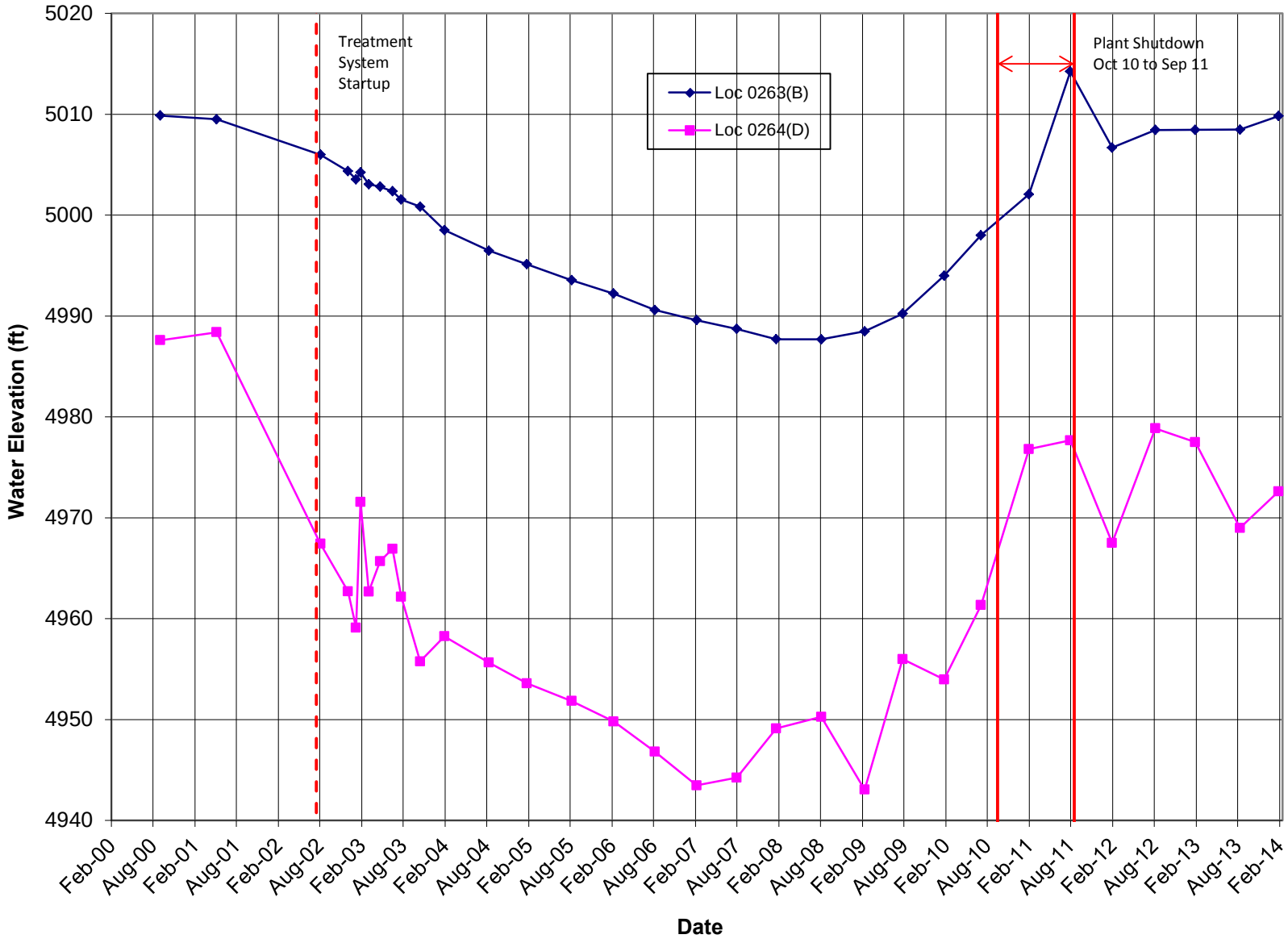

Figure C-4. Middle Terrace Well Pair 263 and 264

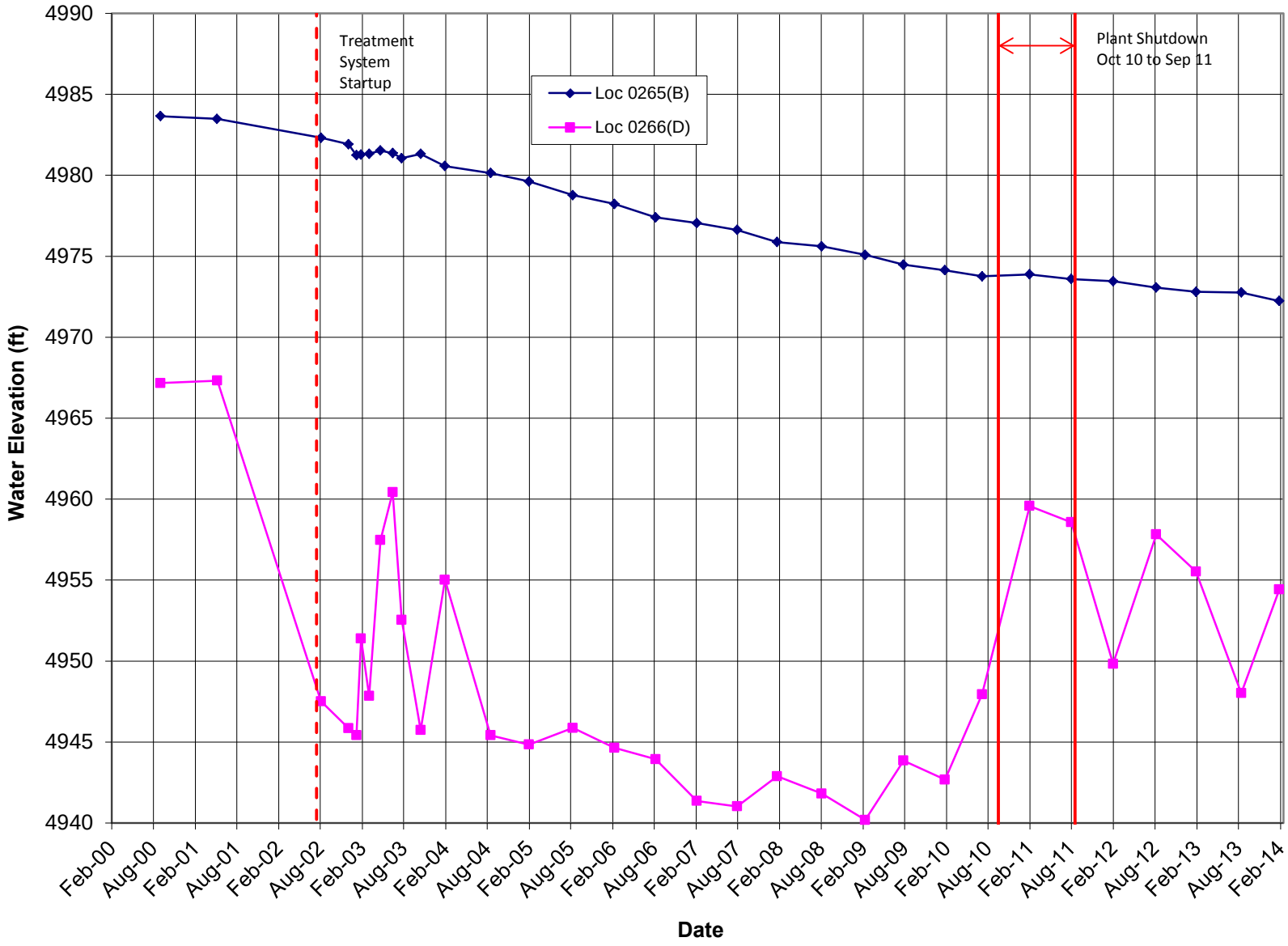

Figure C-5. Middle Terrace Well Pair 265 and 266

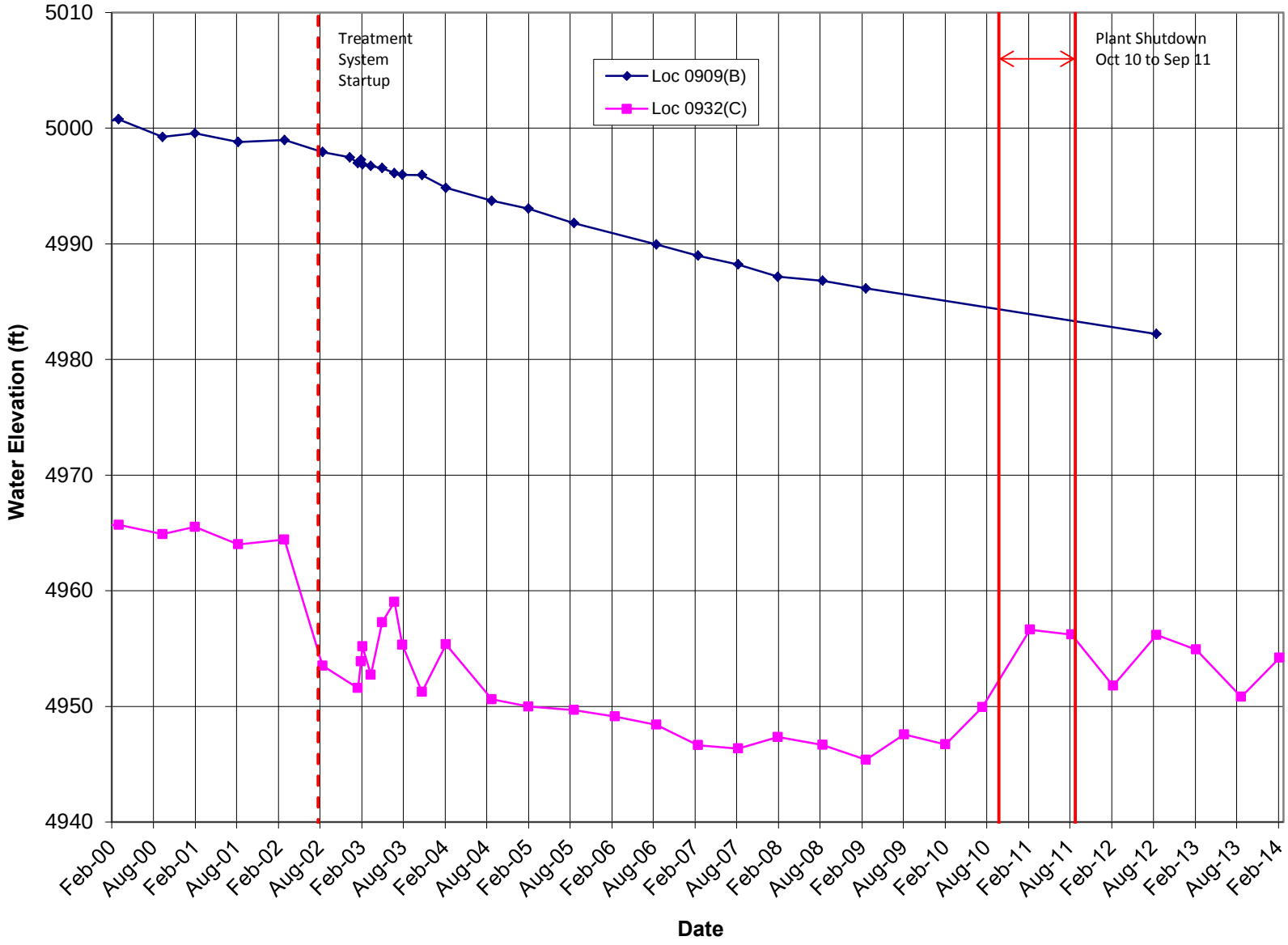

Figure C-6. Middle Terrace Well Pair 909 and 932

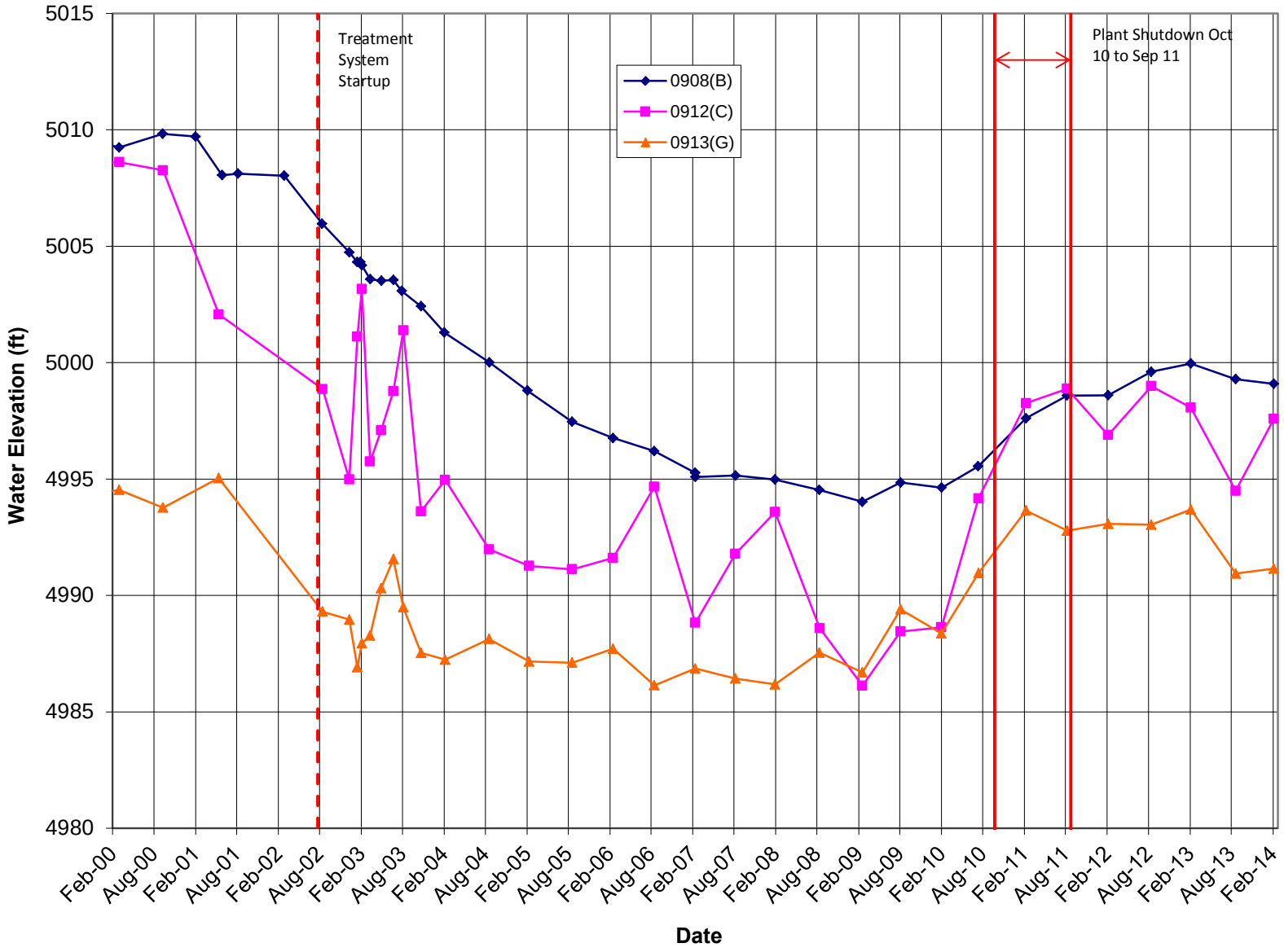

Figure C-7. Middle Terrace Well Cluster 908, 912, and 913

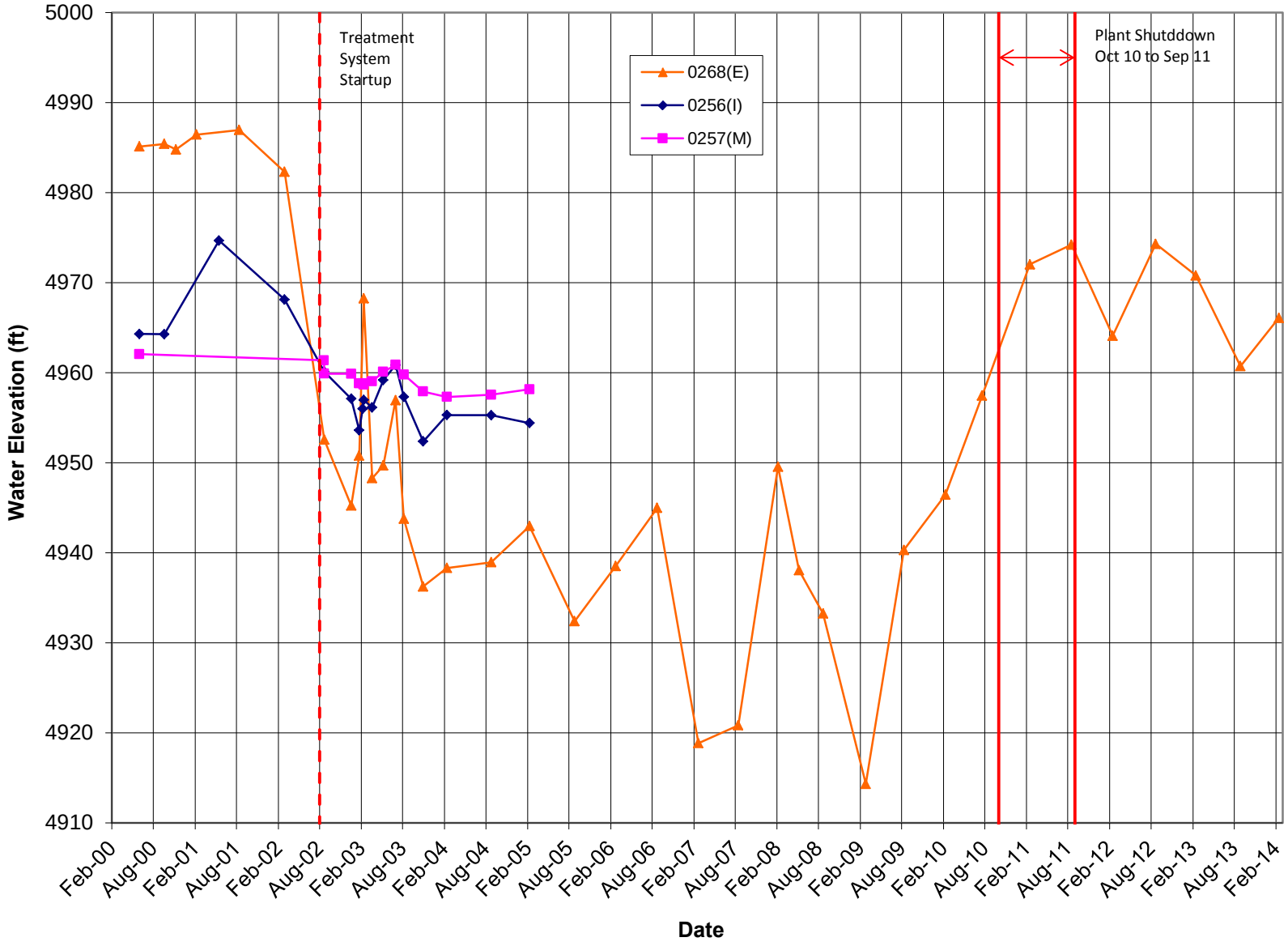

Figure C-8. Middle Terrace Well Cluster 256, 257, and 268

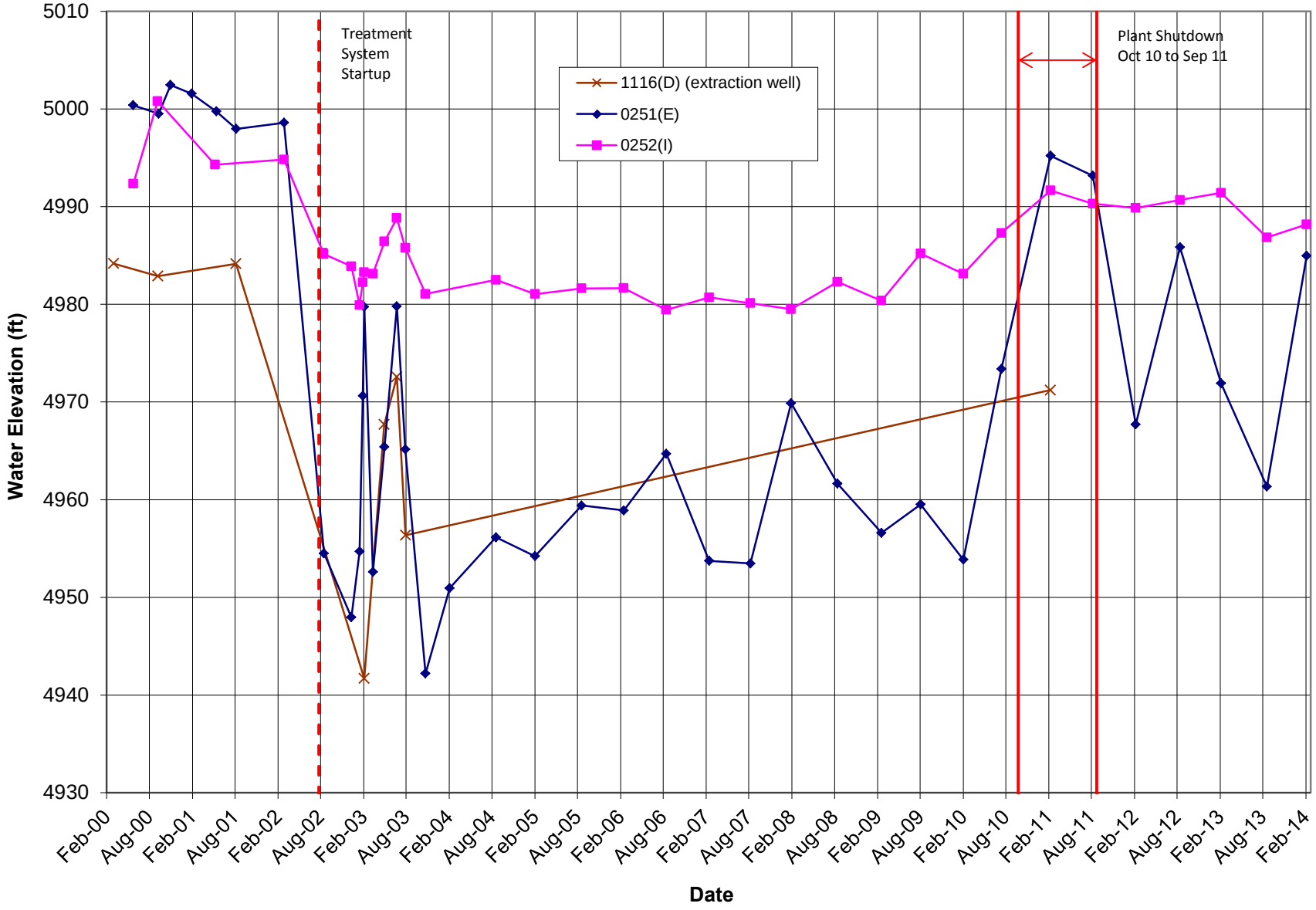

Figure C-9. Middle Terrace Well Cluster 251, 252, and 1116

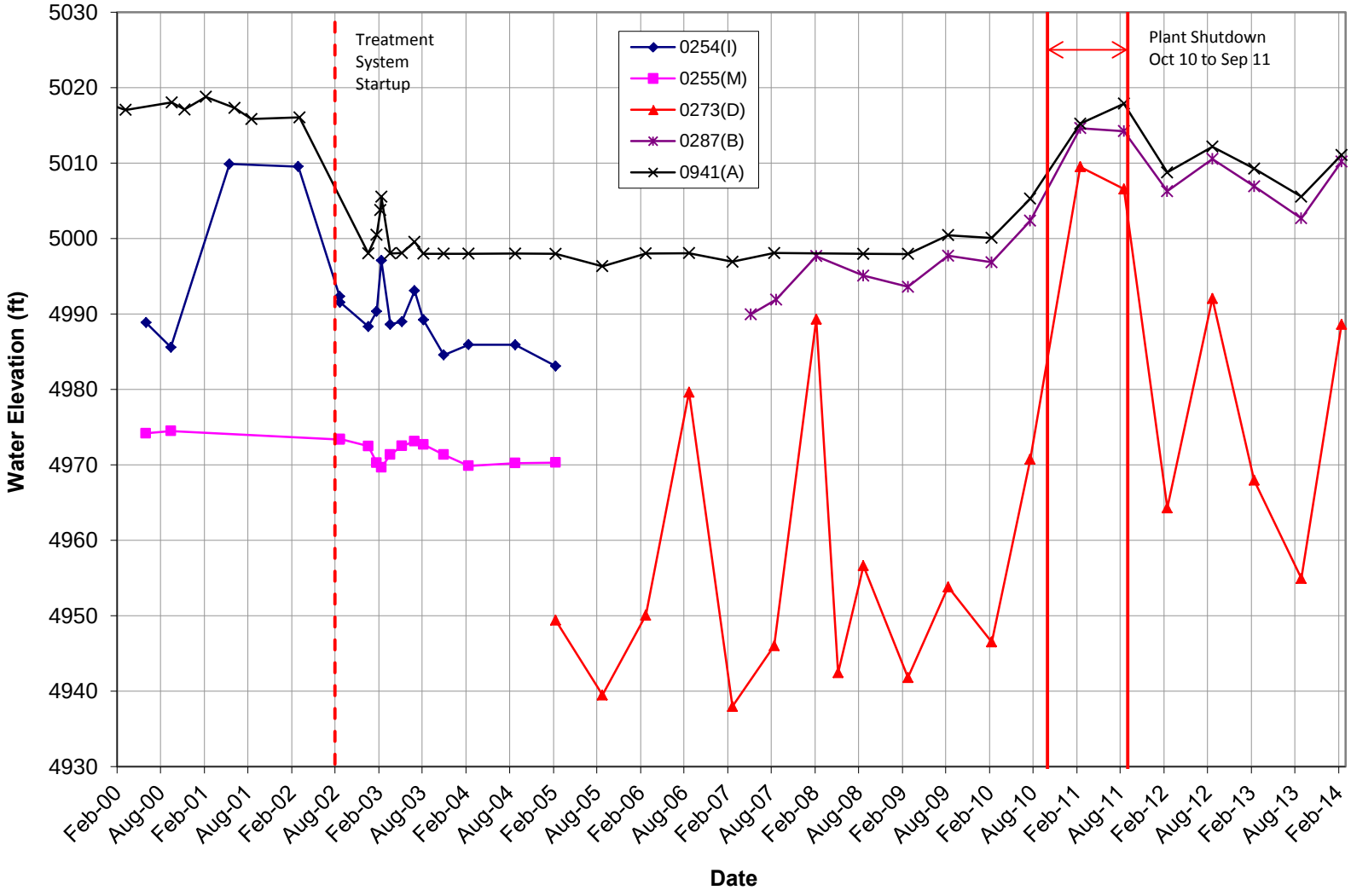

Figure C-10. Middle Terrace Well Cluster 254, 255, 273, 287, and 941

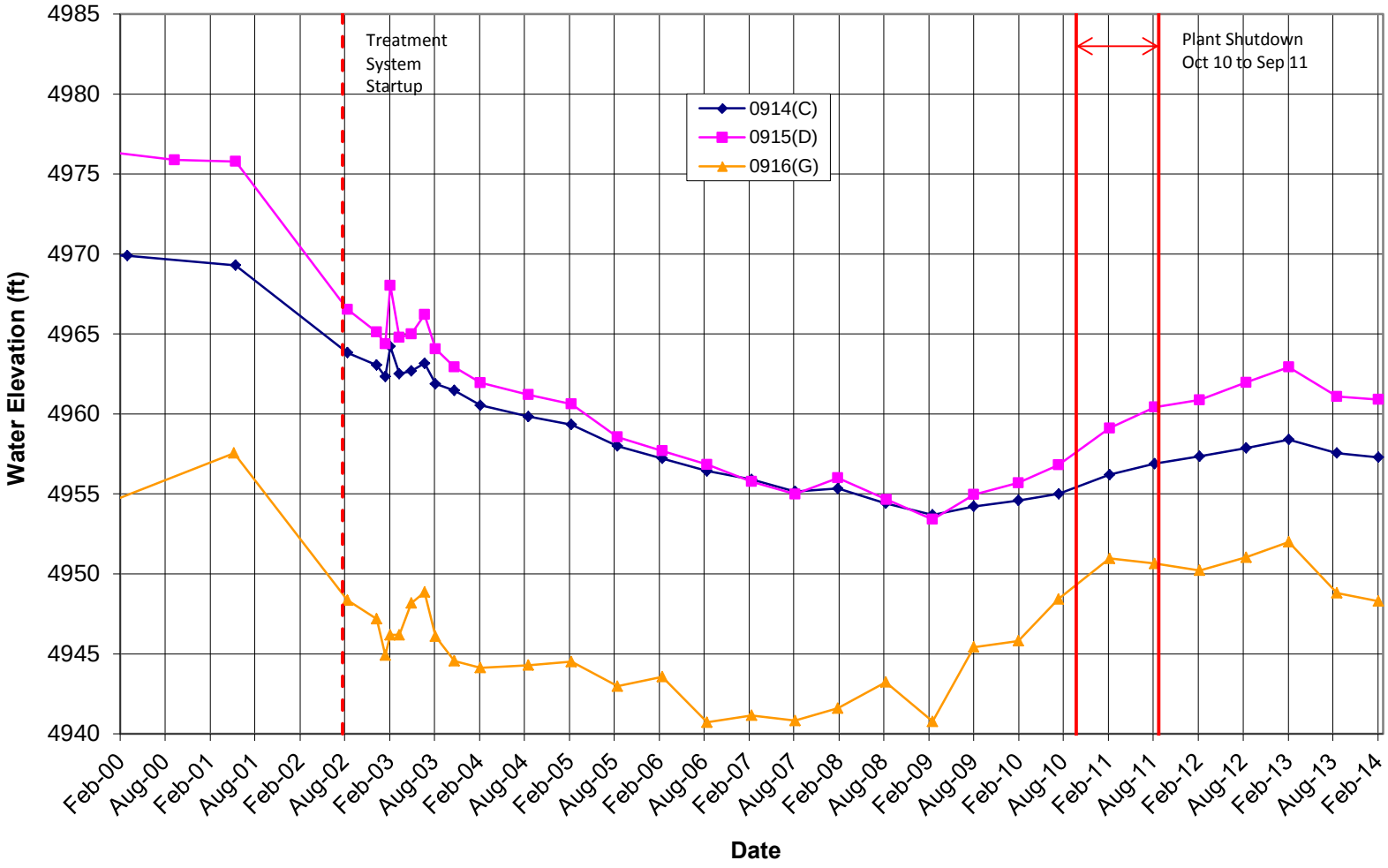

Figure C-11. Middle Terrace Well Cluster 914, 915, and 916

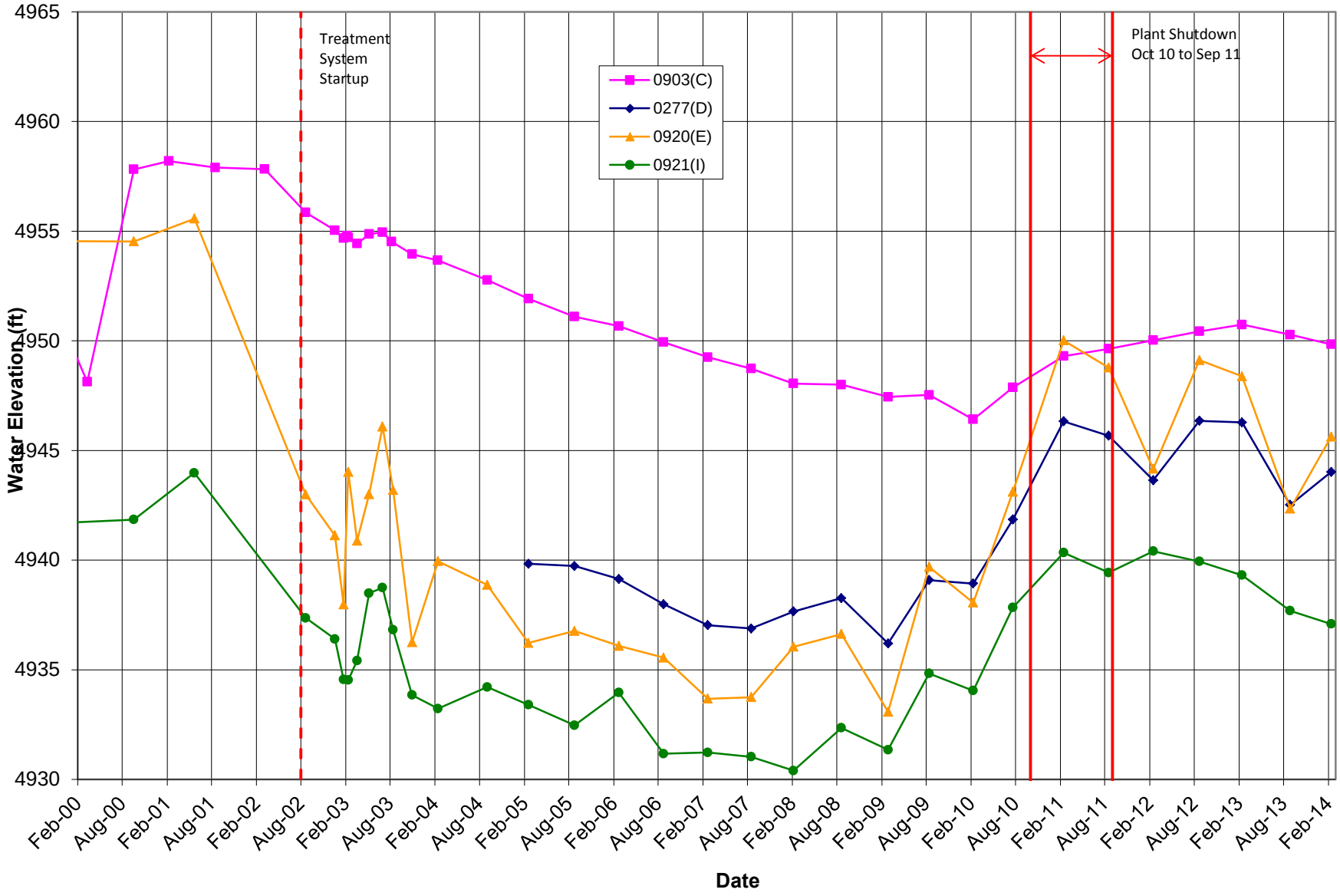

Figure C-12. Lower Terrace Well Cluster 277, 903, 920, and 921

Appendix D

Contaminant Concentration Trends at Monitoring Wells

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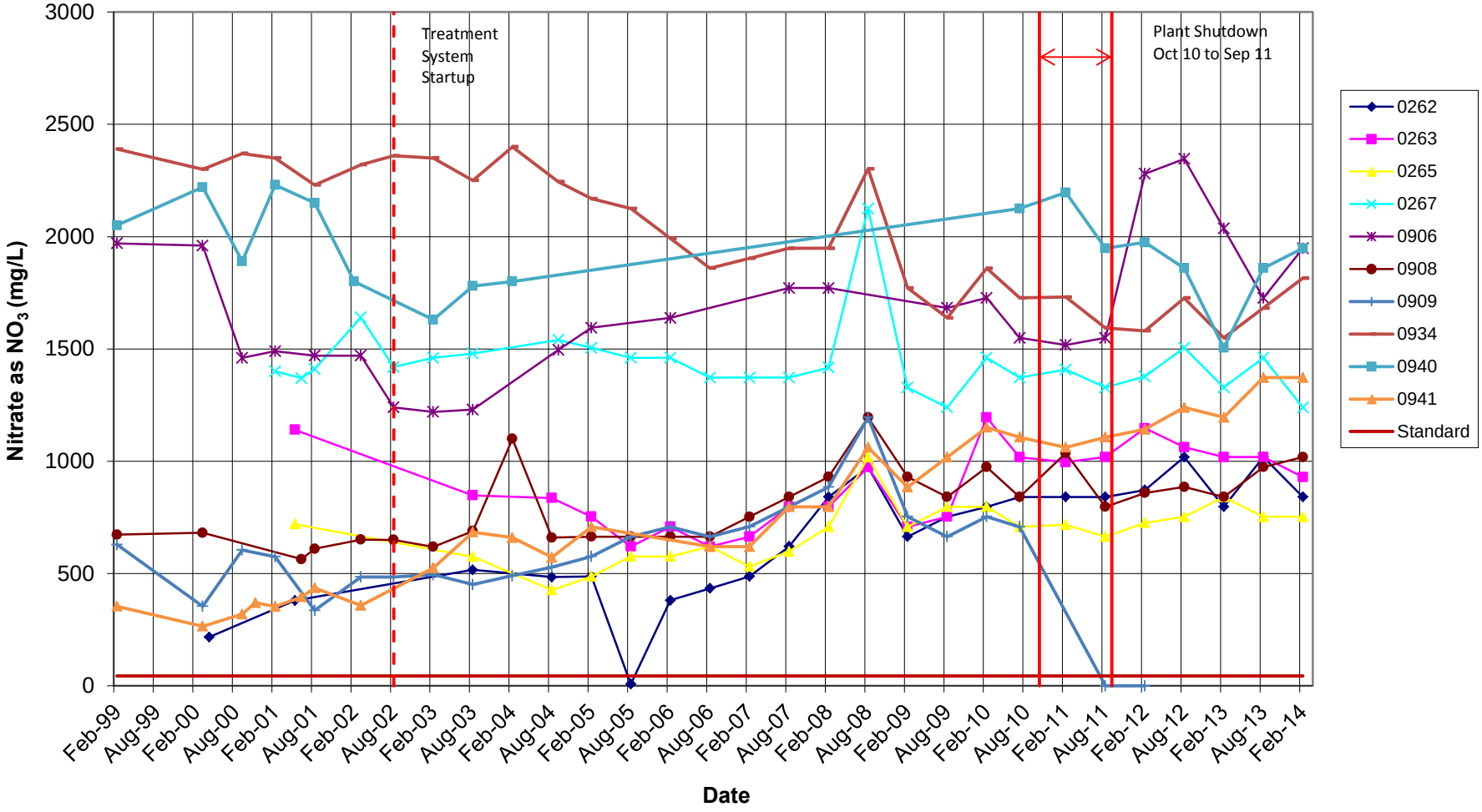
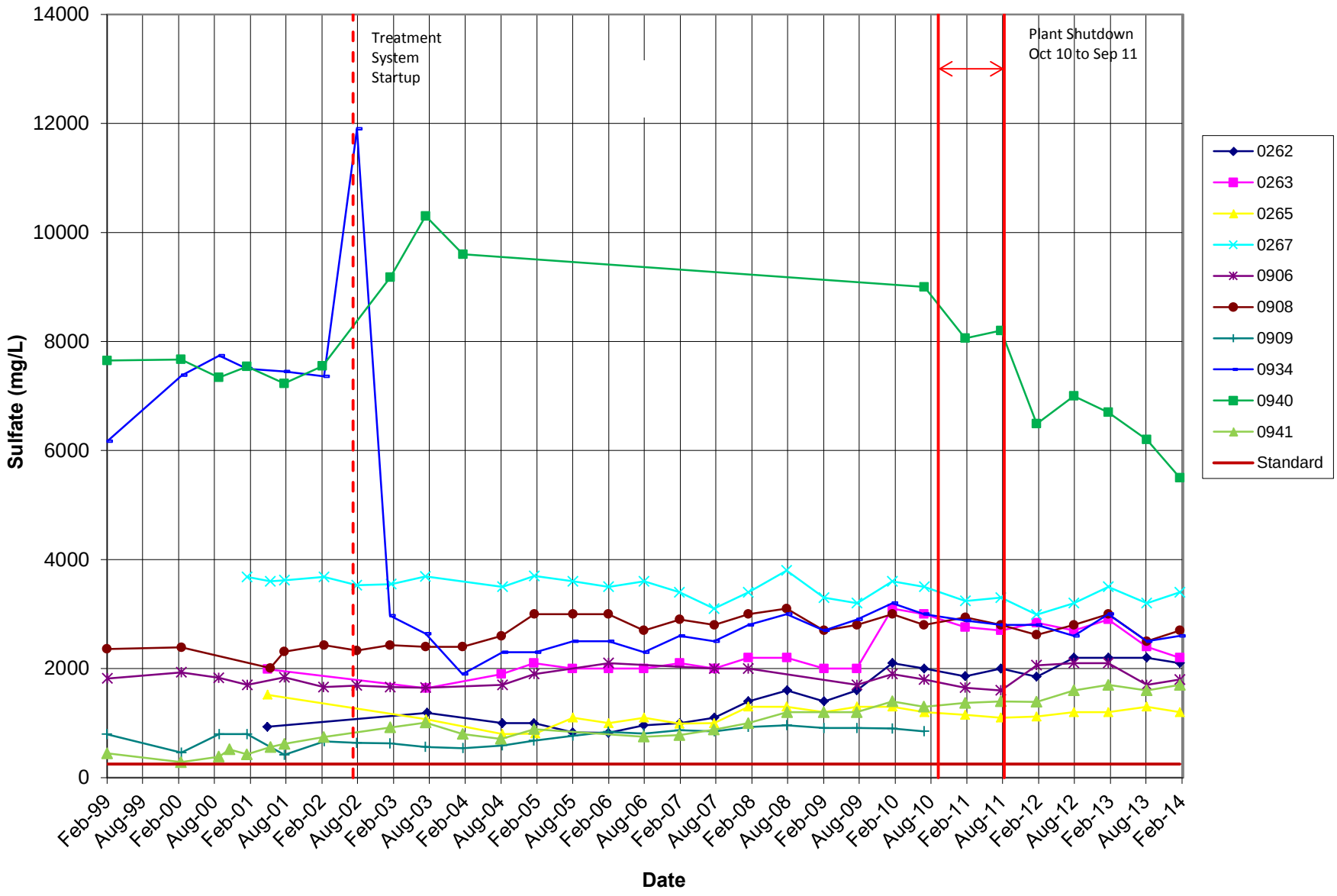


Figure D-1. Nitrate as NO_3 Concentrations in Horizons A and B Monitoring Wells



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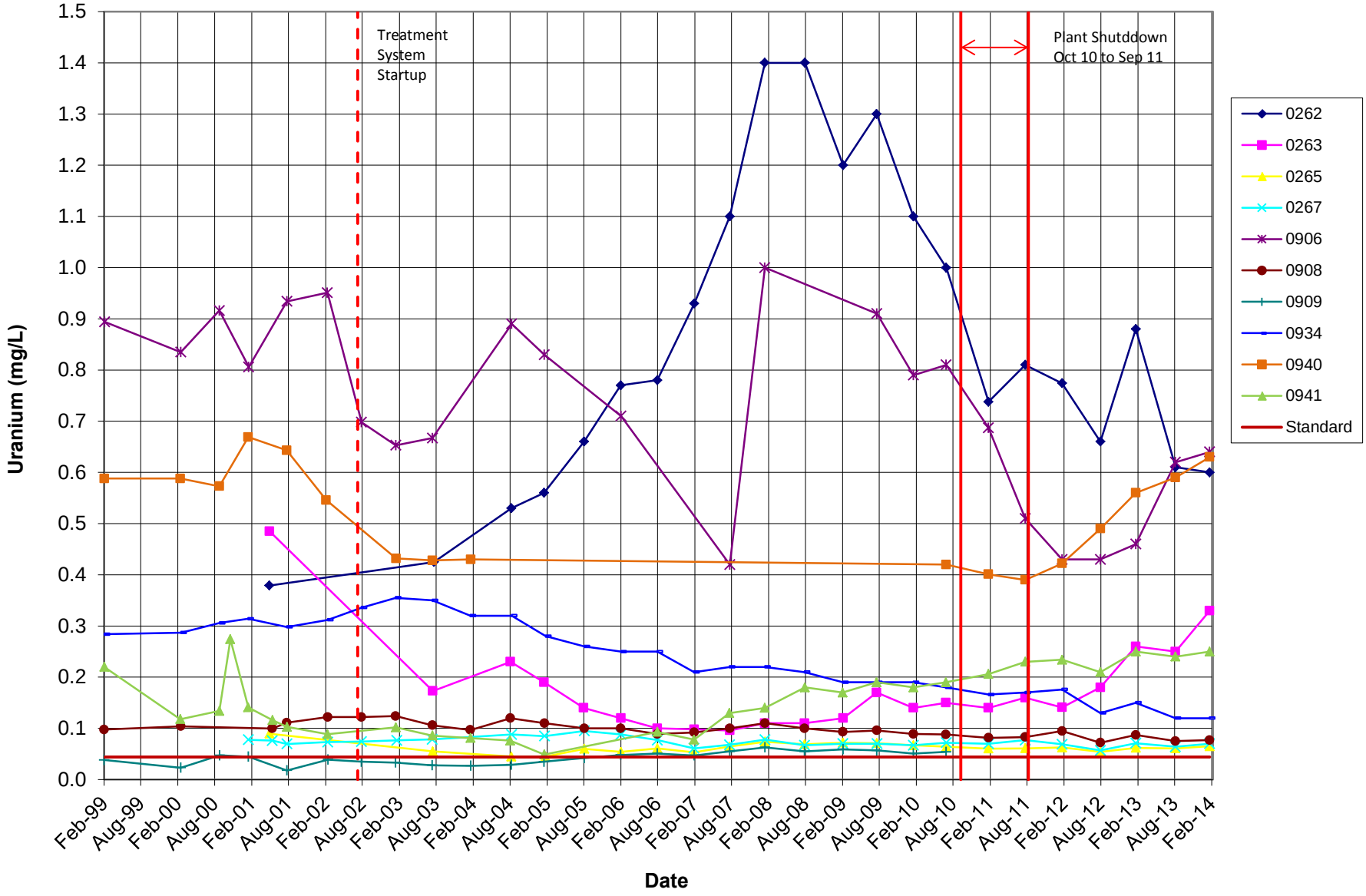

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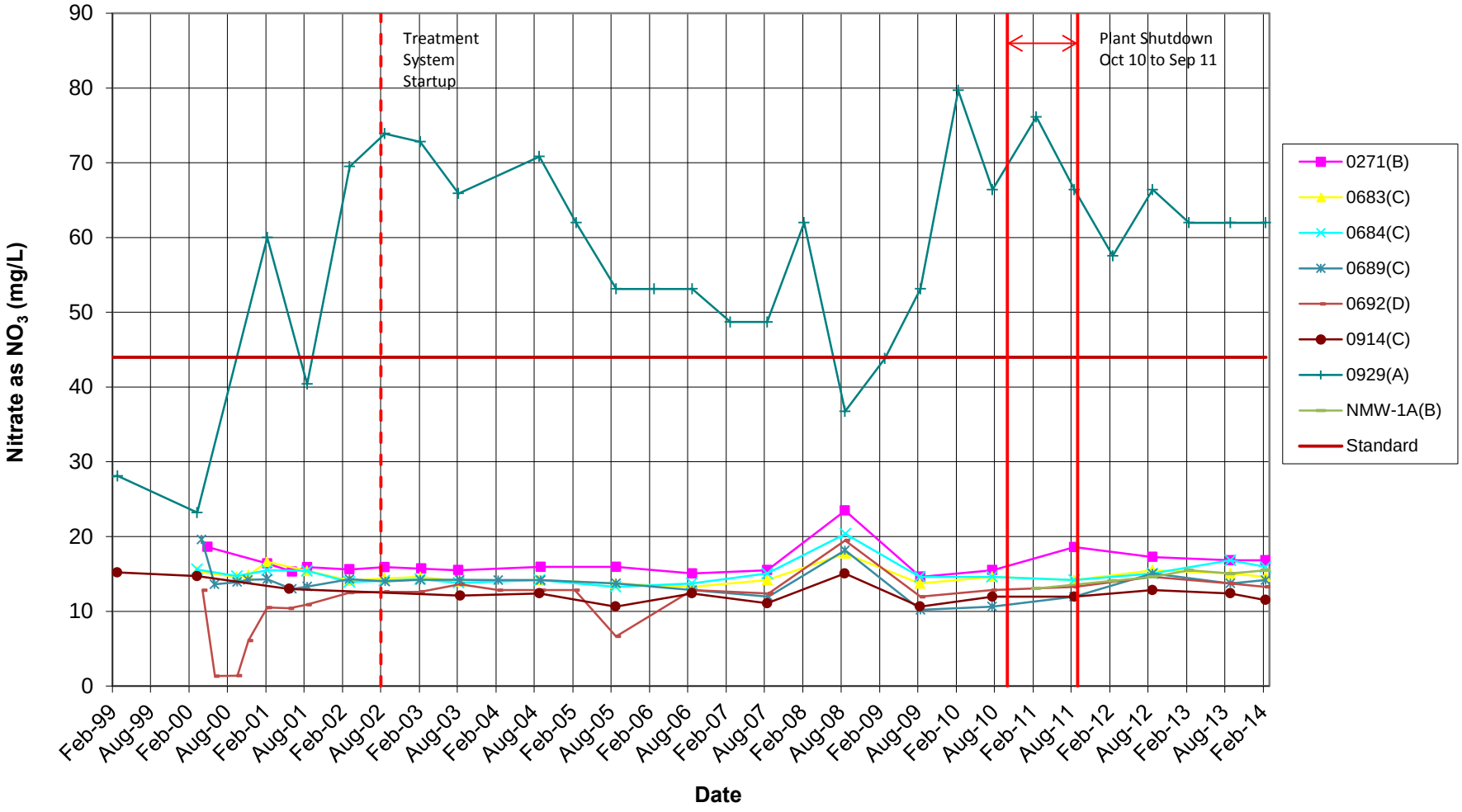

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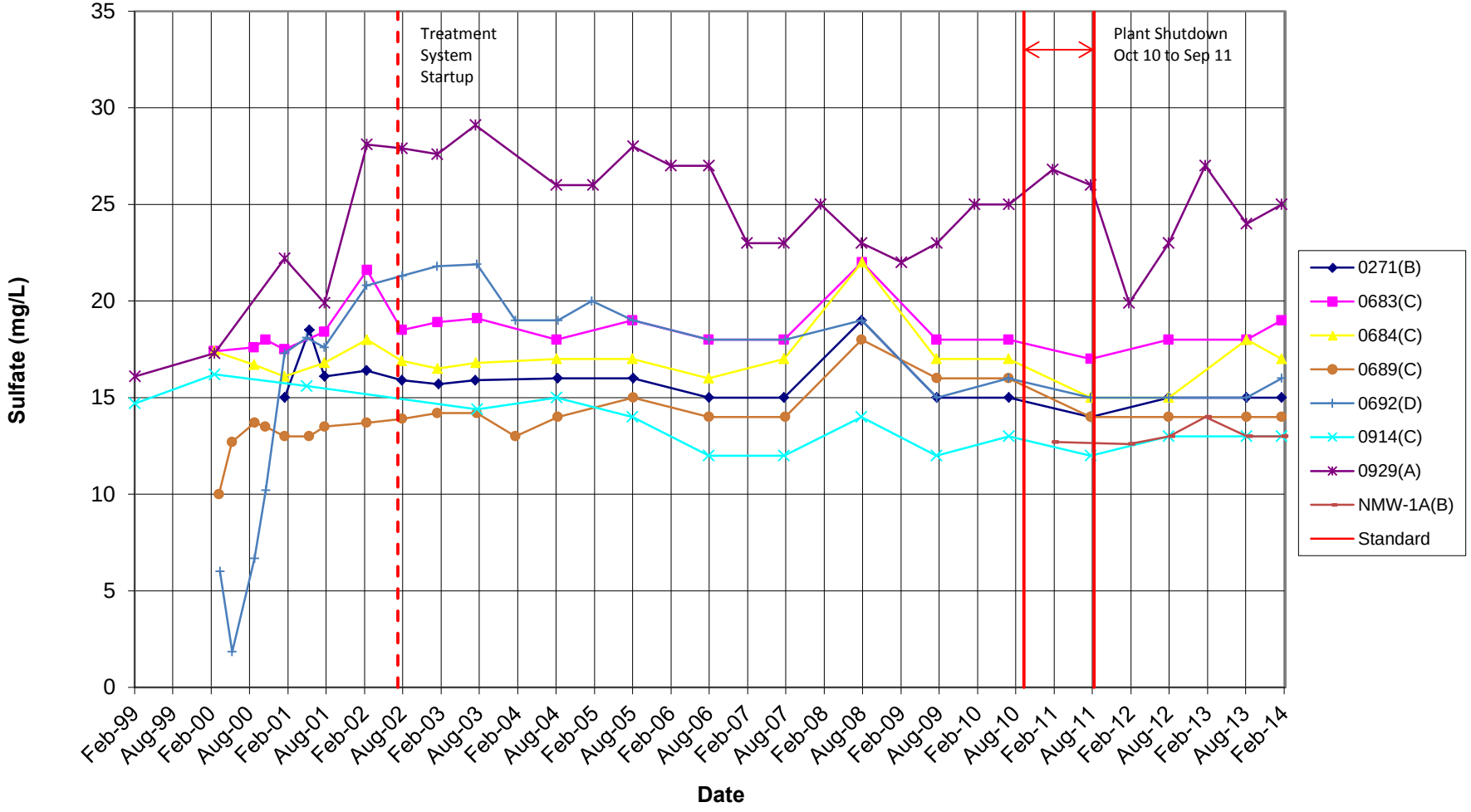

Figure D-5. Sulfate Concentrations in Horizons A–D Sentinel Wells

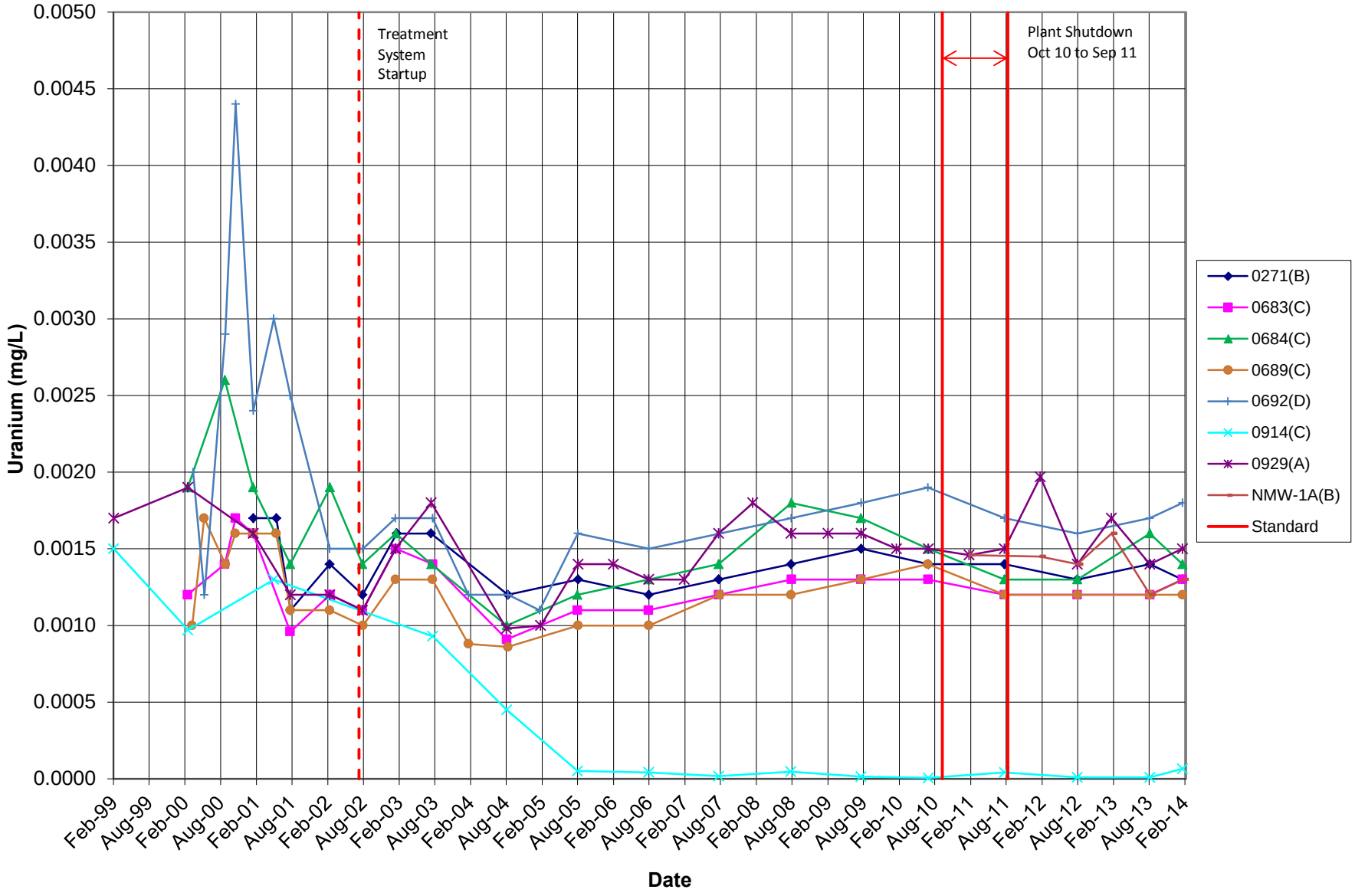

Figure D-6. Uranium Concentrations in Horizons A–D Sentinel Wells

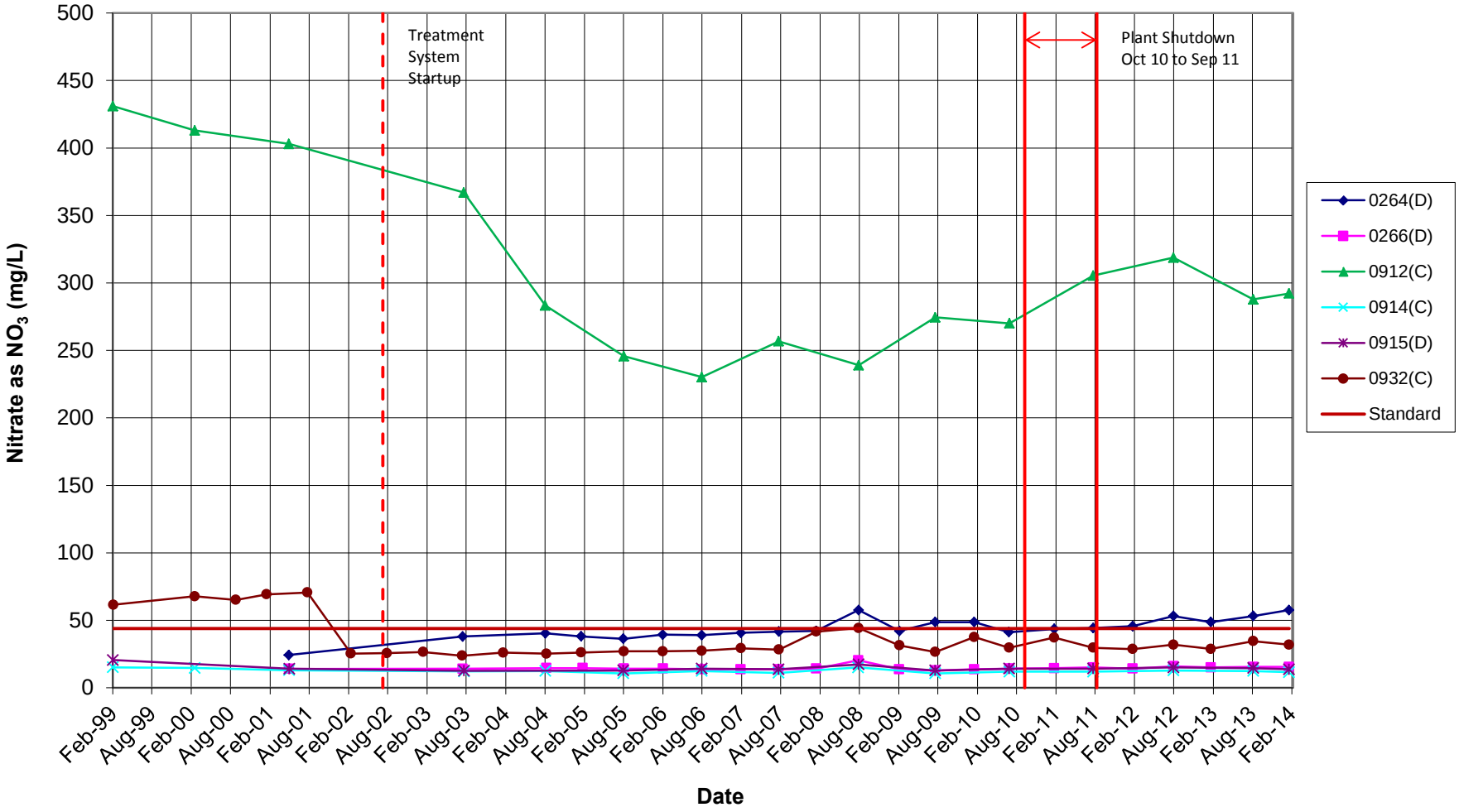

Figure D-7. Nitrate as NO_3 Concentrations in Horizons C–D Middle Terrace Monitoring Wells

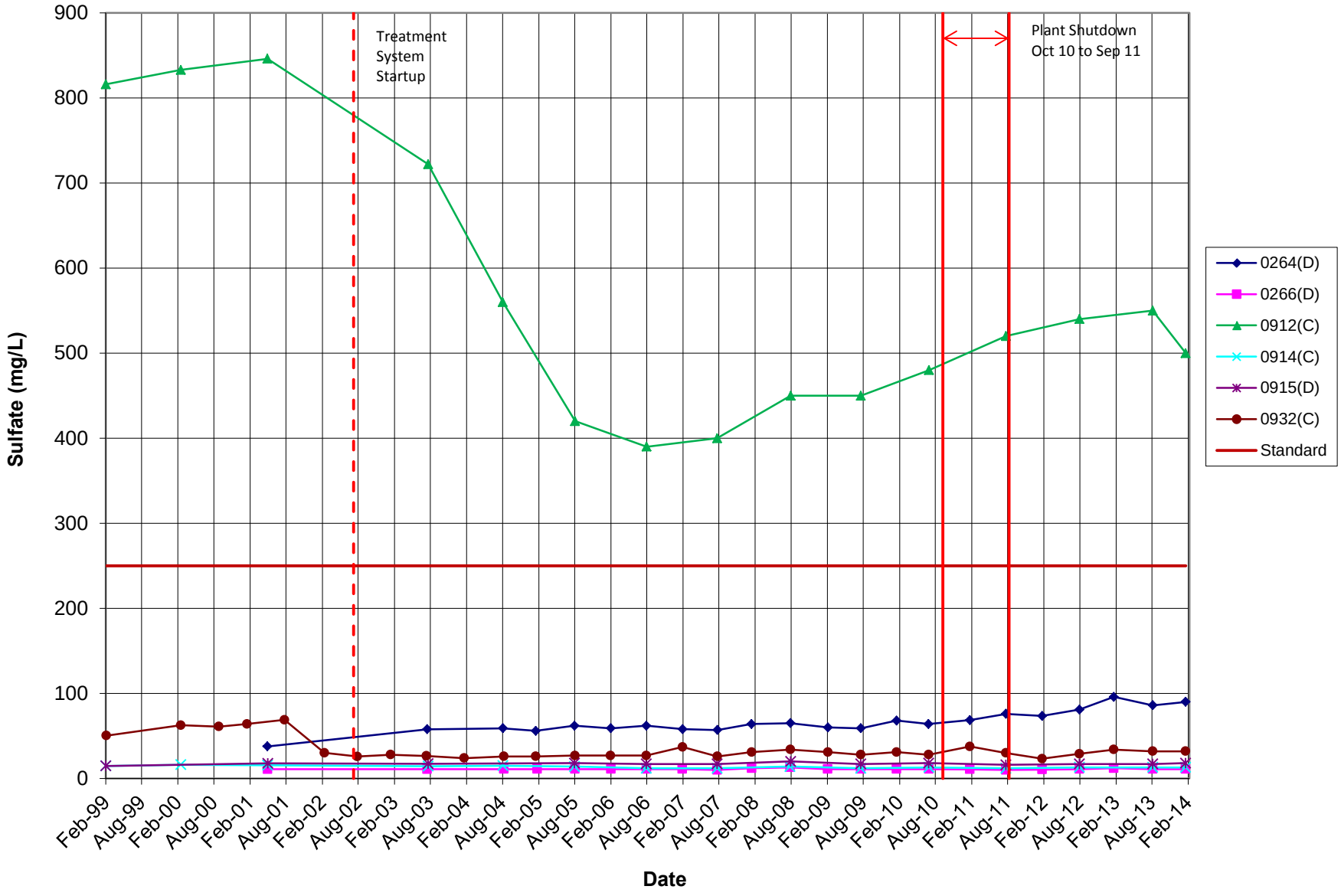

Figure D-8. Sulfate Concentrations in Horizons C–D Middle Terrace Monitoring Wells

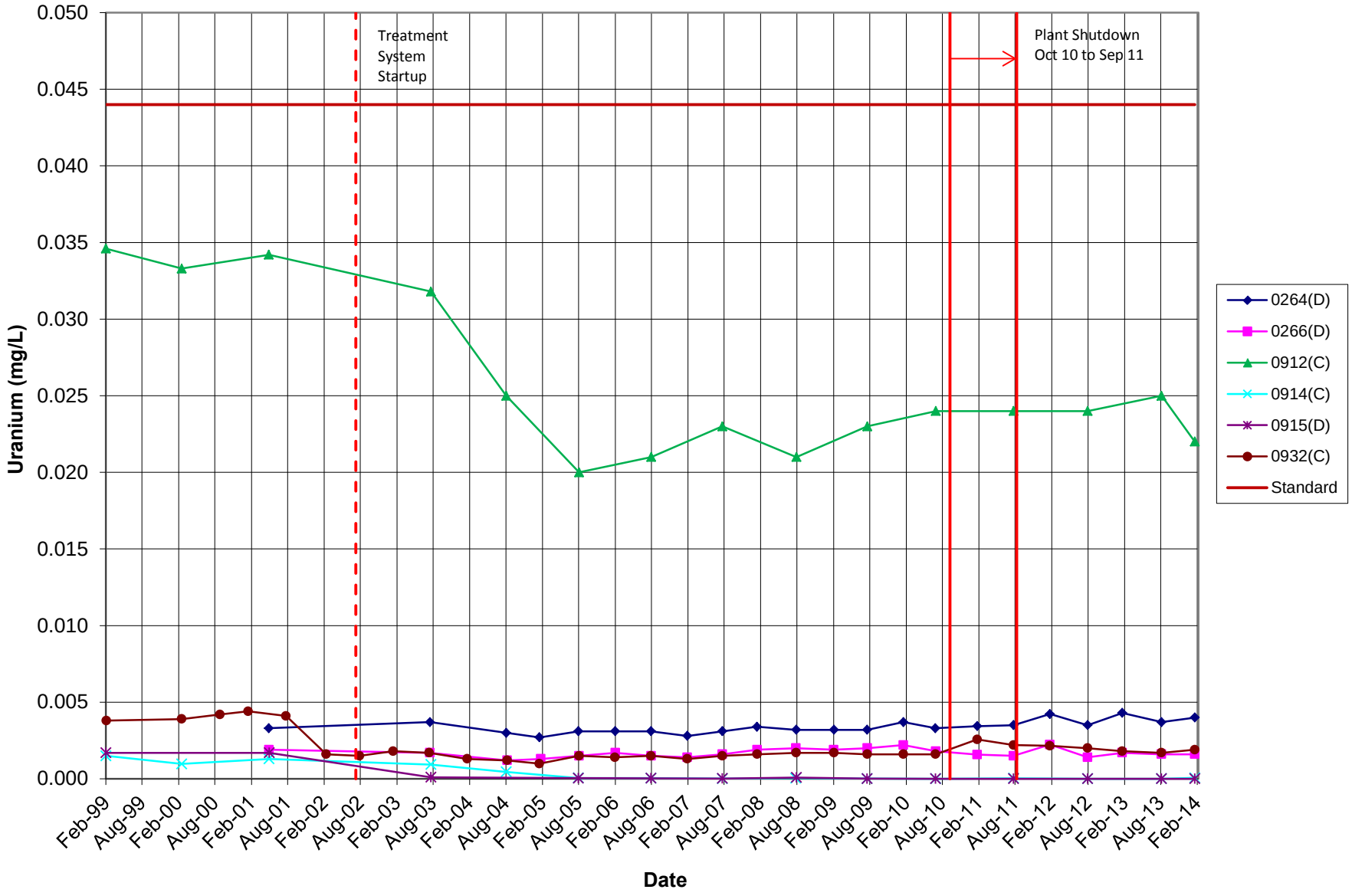

Figure D-9. Uranium Concentrations in Horizons C–D Middle Terrace Monitoring Wells

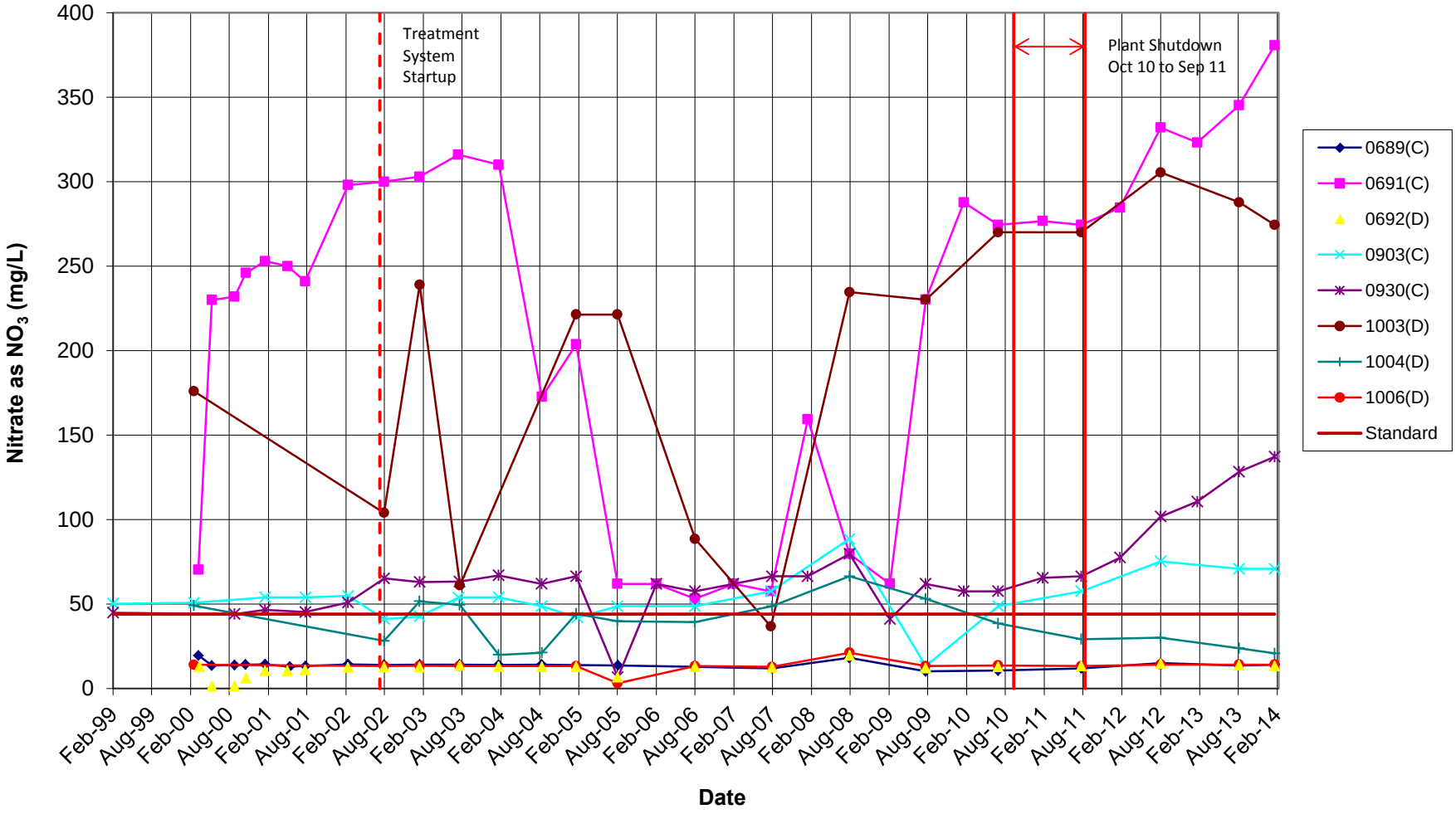

Figure D-10. Nitrate as NO_3 Concentrations in Horizons C–D Lower Terrace Monitoring Wells

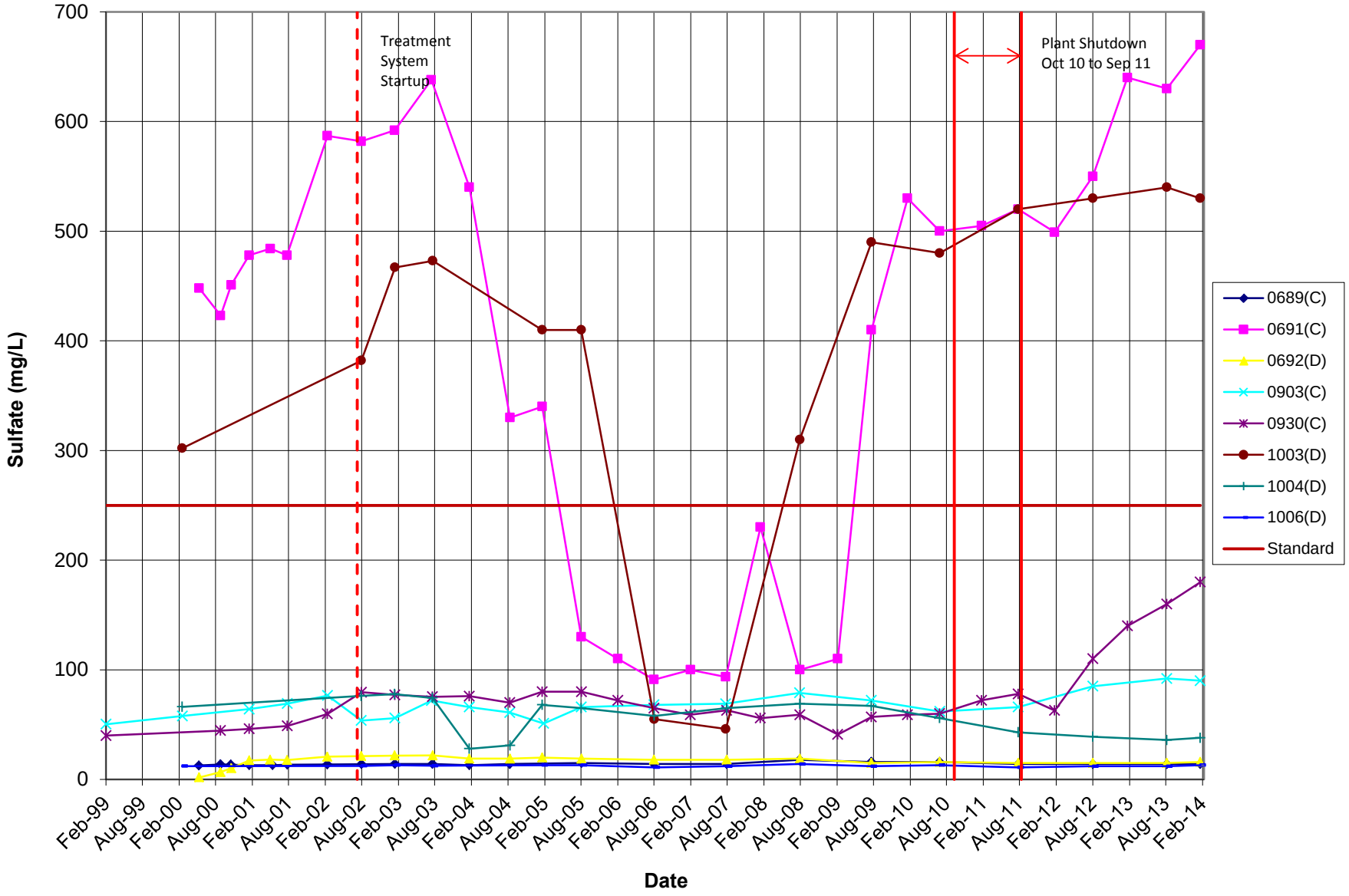

Figure D-11. Sulfate Concentrations in Horizons C–D Lower Terrace Monitoring Wells

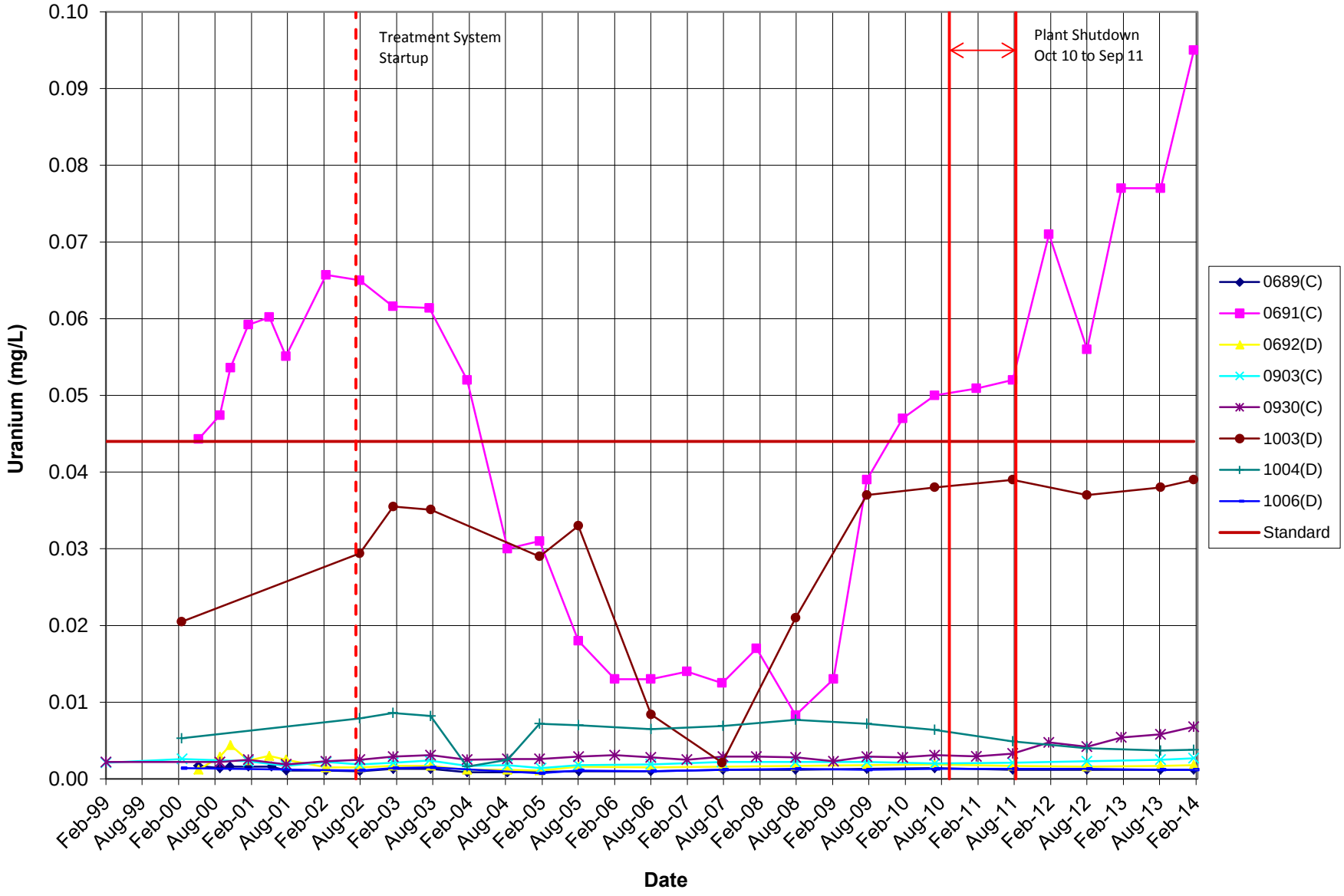

Figure D-12. Uranium Concentrations in Horizons C–D Lower Terrace Monitoring Wells

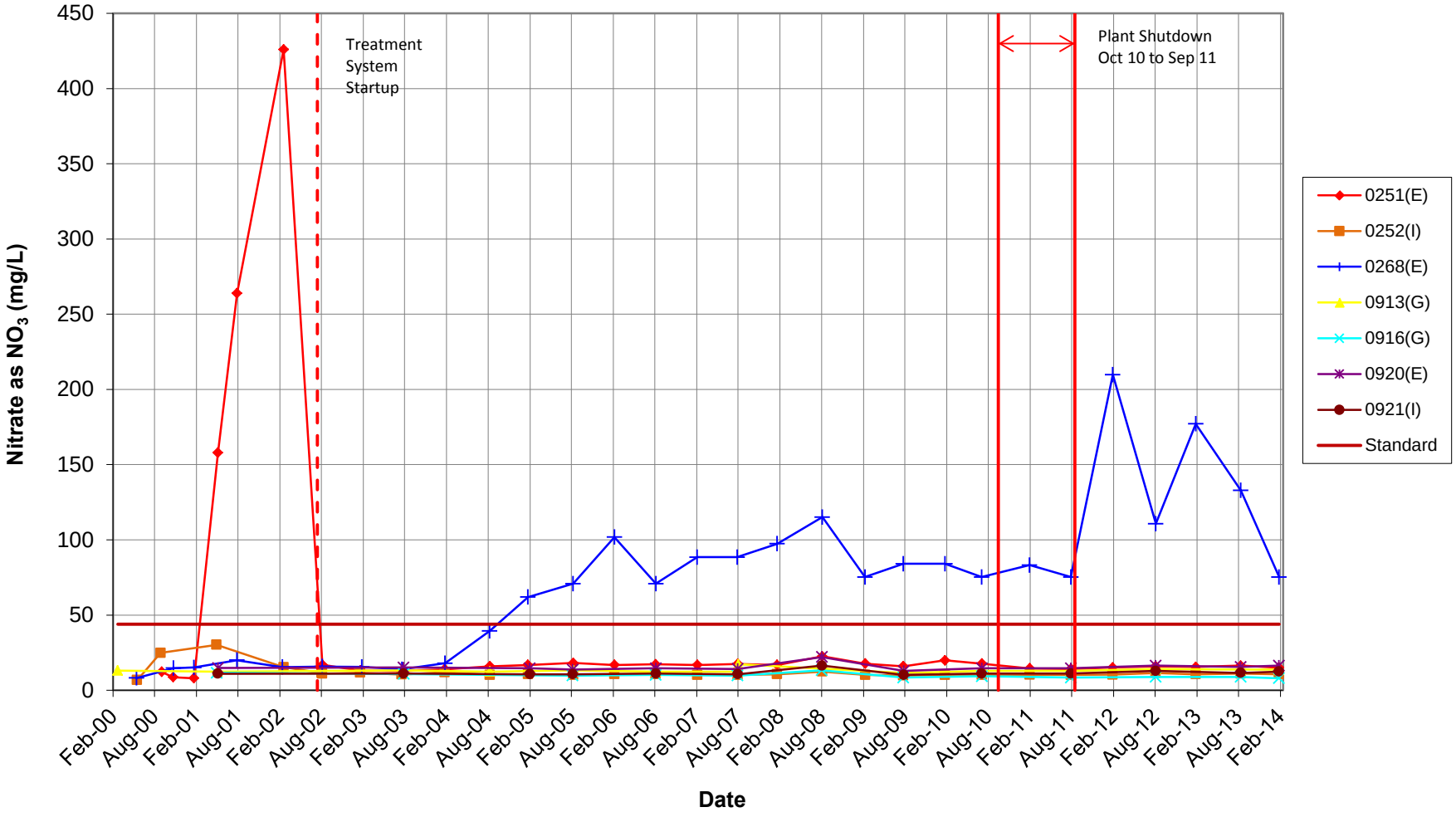

Figure D-13. Nitrate as NO_3 Concentrations in Deep Monitoring Wells

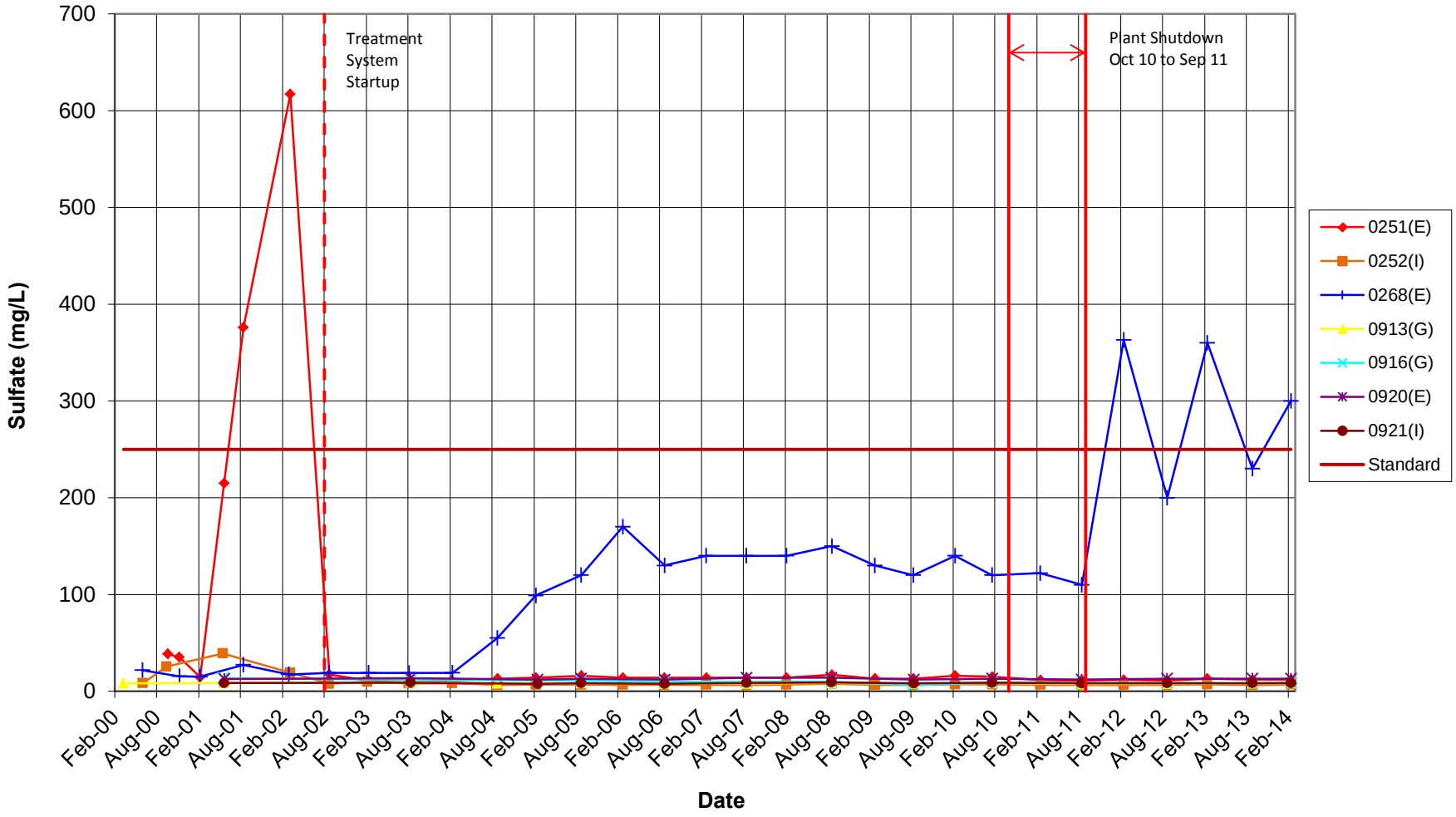

Figure D-14. Sulfate Concentrations in Deep Monitoring Wells

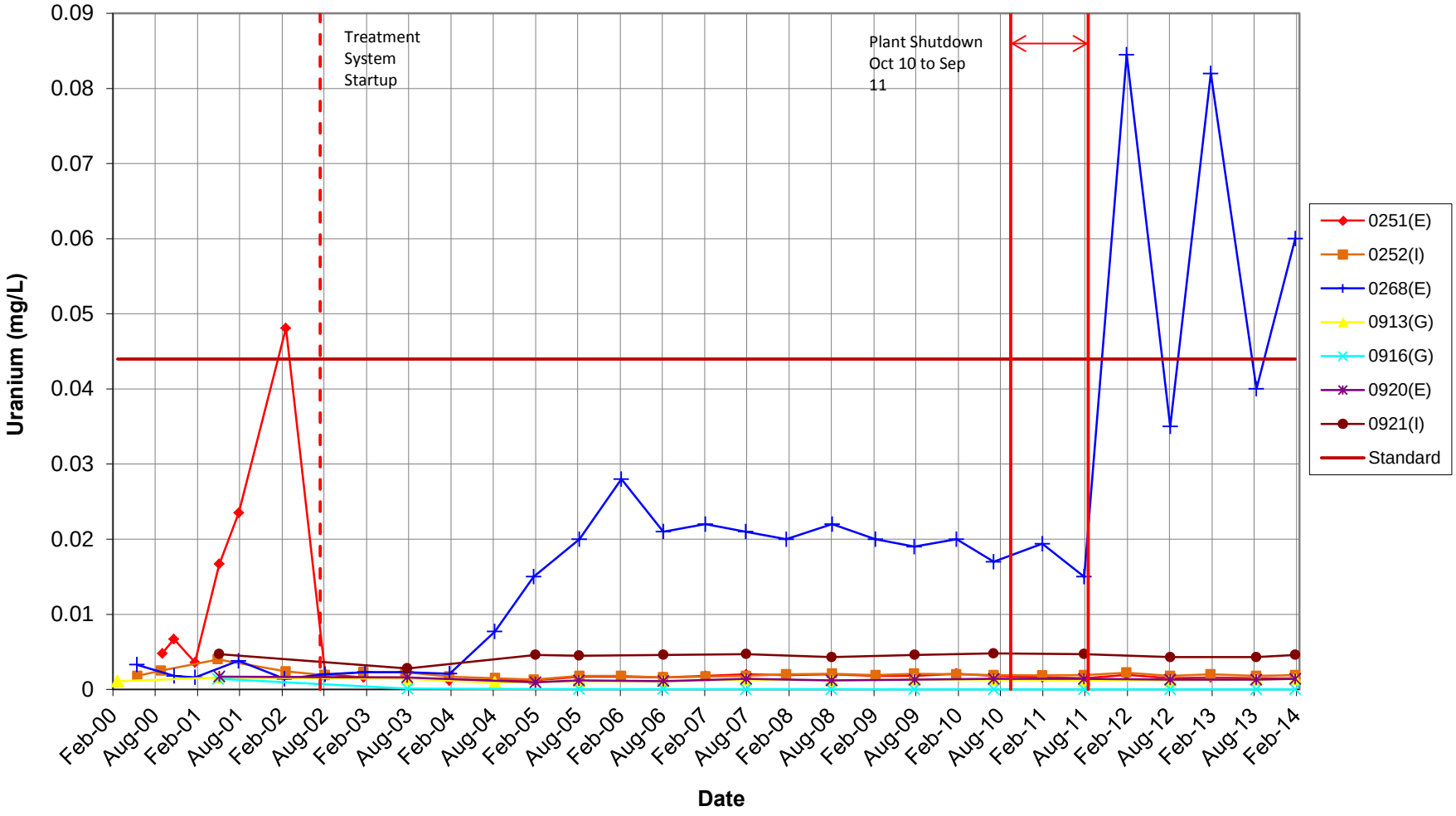

Figure D-15. Uranium Concentrations in Deep Monitoring Wells

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