

**Annual Performance Report  
April 2011 Through March 2012  
for the  
Shiprock, New Mexico, Site**

**August 2012**



U.S. DEPARTMENT OF  
**ENERGY**

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Management

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## Abbreviations

COC	contaminant of concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESL	Environmental Sciences Laboratory
ft	feet
GCAP	Groundwater Compliance Action Plan
gpm	gallons per minute
kg	kilogram
Km	Mancos Shale
lb	pounds
LM	DOE Office of Legacy Management
MCL	maximum concentration limit
mg/L	milligrams per liter
msl	mean sea level
N	nitrogen
Qal	Quaternary alluvium
SDWA	Safe Drinking Water Act
Se	selenium
SOARS	System Operation and Analysis at Remote Sites
SOWP	Site Observational Work Plan
Sr	strontium
U	uranium
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act

## **Executive Summary**

This annual performance report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal and Processing Site (Shiprock site) for April 2011 through March 2012. The Shiprock site, a former uranium-ore processing facility remediated under the Uranium Mill Tailings Radiation Control Act, is managed by the U.S. Department of Energy (DOE) Office of Legacy Management (LM). This annual report is based on an analysis of groundwater quality and groundwater level data obtained from site monitoring wells in addition to groundwater flow rates associated with the extraction wells, drains, and seeps.

### **Background**

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

The Shiprock site is divided into two distinct areas, the floodplain and the terrace. The floodplain remediation system consists of two groundwater extraction wells, a seep collection drain, and two collection trenches (Trench 1 and Trench 2). The terrace remediation system consists of nine groundwater extraction wells, two collection drains (Bob Lee Wash and Many Devils Wash), and a terrace drainage channel diversion structure. All extracted groundwater is pumped into a lined evaporation pond on the terrace.

### **Compliance Strategy and Remediation System Performance Standards**

The performance standards established in the Baseline Performance Report (DOE 2003) are based on the compliance strategy documented in the Groundwater Compliance Action Plan (GCAP; DOE 2002). In the GCAP, the U.S. Nuclear Regulatory Commission–approved compliance strategy for the floodplain is natural flushing supplemented by active remediation by extraction of groundwater from the floodplain aquifer adjacent to the San Juan River. However, active remediation (pumping from extraction wells and trenches) is now considered the dominant strategy for the floodplain, as the influence of natural flushing is not certain (see DOE 2011a).

DOE is reevaluating the compliance strategy for the terrace (DOE 2011a). The U.S. Nuclear Regulatory Commission–approved compliance strategy in the GCAP is active remediation on the terrace to dewater the terrace and eliminate potential exposure pathways and risks to humans and the environment. Performance standards established to meet this objective include reduction of terrace groundwater elevations and concomitant drying of seeps in Bob Lee Wash and Many Devils Wash and at the base of the escarpment (DOE 2003).

## **Contaminants of Concern, Remediation Goals, and Background Conditions**

The contaminants of concern (COCs) are ammonia (total as nitrogen), manganese, nitrate (nitrate + nitrite as nitrogen), selenium, strontium, sulfate, and uranium. The compliance standards for nitrate, selenium, and uranium are listed in Title 40 *Code of Federal Regulations* Part 192. Regulatory standards are not available for the remaining COCs; remediation goals for these constituents are either risk-based alternate cleanup standards or background levels. These standards and background levels apply to the compliance strategy for the floodplain; the compliance strategy for the terrace is to eliminate exposure pathways at the washes and seeps and to apply supplemental standards in the western section (DOE 2002). In the previous decade (2000–2010), background groundwater quality for the terrace had not been well established because wells drilled in locations considered to be suitable analogs for terrace background conditions were dry. Recent efforts undertaken by DOE, including ongoing investigations by LM's Long-Term Surveillance Operations and Maintenance program, suggest that some of the water in Many Devils Wash may originate from locations beyond the influence of the former mill site (DOE 2012a, 2012b).

## **Contaminant Distributions and Temporal Trends**

For this reporting period, 116 monitoring wells (59 on the floodplain and 57 on the terrace) and 18 surface water locations were sampled. Contaminant distributions are generally the same as those observed in previous years. A uranium plume underlies the disposal cell and extends into the floodplain. The highest-concentration portions of the uranium plume are located in the terrace alluvium and weathered Mancos close to the disposal cell, on the floodplain near the southern portion of the escarpment, and in a zone traversing the floodplain in a line trending northward from the disposal cell. In contrast, concentrations of nitrate, selenium, and sulfate are higher in the area adjacent to the buried escarpment and Many Devils Wash. Ammonia concentrations are highest in the radon cover borrow pit/evaporation pond area and in Mancos wells west of the disposal cell. Manganese and strontium are of less interest because most concentrations are within the range of floodplain background concentrations and, in general, no temporal trends are evident.

Contaminant concentrations continue to decrease in floodplain wells in response to pumping—most notably in the Trench 1 area. COC concentrations in easternmost Trench 2 area wells (closest to the San Juan River) are still lower than those nearer the escarpment, demonstrating the effectiveness of the Trench 2 system. Finally, COC concentrations in samples collected from the San Juan River are still well below established benchmarks and are comparable to upstream (background) results.

## **Summary of Remediation Performance and Site Evaluation Progress**

Groundwater in the floodplain system is currently being extracted from two wells (wells 1089 and 1104) adjacent to the San Juan River north of the disposal cell, the two collection trenches, and a seep collection sump. Approximately 11.5 million gallons of groundwater were extracted from the floodplain aquifer system during this performance period, yielding a cumulative total of about 85.6 million gallons extracted from the floodplain since March 2003.

Groundwater in the terrace system is currently being extracted from two drainage trenches (in Bob Lee and Many Devils Washes) and nine wells. From April 2011 through March 2012, approximately 3.3 million gallons of groundwater were extracted from the terrace system, yielding a total cumulative volume of about 30 million gallons.

The cumulative volume removed from both terrace and floodplain combined (as of April 1, 2012) is approximately 116 million gallons. Estimated masses of sulfate, nitrate, and uranium removed from the floodplain and terrace well fields during this performance period were (rounded) 742,000 pounds, 18,000 pounds, and 60 pounds, respectively.

The floodplain extraction system continues to be effective, as evidenced by the removal of contaminant mass from groundwater, the decreasing contaminant concentrations in many floodplain wells (most notably in the Trench 1 and well 1089 areas), and the lack of elevated contamination in wells nearest the San Juan River (particularly in the Trench 2 area).

Terrace-wide, groundwater levels in the majority of alluvial wells sampled during this performance period declined relative to the baseline (2000–2003) period; average and maximum decreases were 2.9 feet (ft) and 7.7 ft, respectively. Decreases in some far west terrace wells could be partly or even largely attributable to the previous phasing out of irrigation in the area (circa 2003–2004). Nonetheless, declines in groundwater elevations in west terrace wells are widespread, and many seeps on the west terrace have been dry for the last several years.

Natural phytoremediation techniques (i.e., with no human intervention) and hydraulic control using plants are under evaluation at the Shiprock site. DOE began phytoremediation pilot studies in 2006 by planting native phreatophytes on the terrace between the disposal cell and the escarpment north of the disposal cell, where a uranium plume enters the floodplain, and in the radon cover borrow pit south of the disposal cell, where nitrate levels are elevated in alluvial sediments.

## **Recommendations**

Based on the current status of remediation progress and the findings of more recent investigations, DOE recommends the following activities to improve the performance and evaluation of the Shiprock remediation system and to minimize potential risks to human health and the environment:

- Update the compliance strategy for the terrace (see DOE 2011a).
- Continue to monitor the fluid level in the evaporation pond (periodic cessation of pumping is necessary to maintain sufficient freeboard), evaluate ways to enhance evaporation, and investigate potential upgrades to the remediation system.
- To optimally manage available storage volume in the evaporation pond, temporarily cease pumping at Trench 1, Trench 2, and the newly proposed pumping wells as necessary during the period of high snowmelt runoff in the river.

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## 1.0 Introduction

This report evaluates the performance of the groundwater remediation system at the Shiprock, New Mexico, Disposal and Processing Site for the period April 2011 through March 2012. The Shiprock site, a former uranium-ore processing facility remediated under the Uranium Mill Tailings Radiation Control Act (UMTRCA), is managed by the U.S. Department of Energy (DOE) Office of Legacy Management (LM).

The mill operated from 1954 to 1968; mill tailings were contained in an engineered disposal cell in 1986. As a result of milling operations, groundwater in the mill site area was contaminated with uranium, nitrate, sulfate, and associated constituents. In March 2003, DOE initiated active remediation of the groundwater using extraction wells and interceptor drains. At that time, a baseline performance report was developed (DOE 2003). That report established specific performance standards for the Shiprock groundwater remediation system and documented the site conditions that form the basis for comparisons drawn herein.

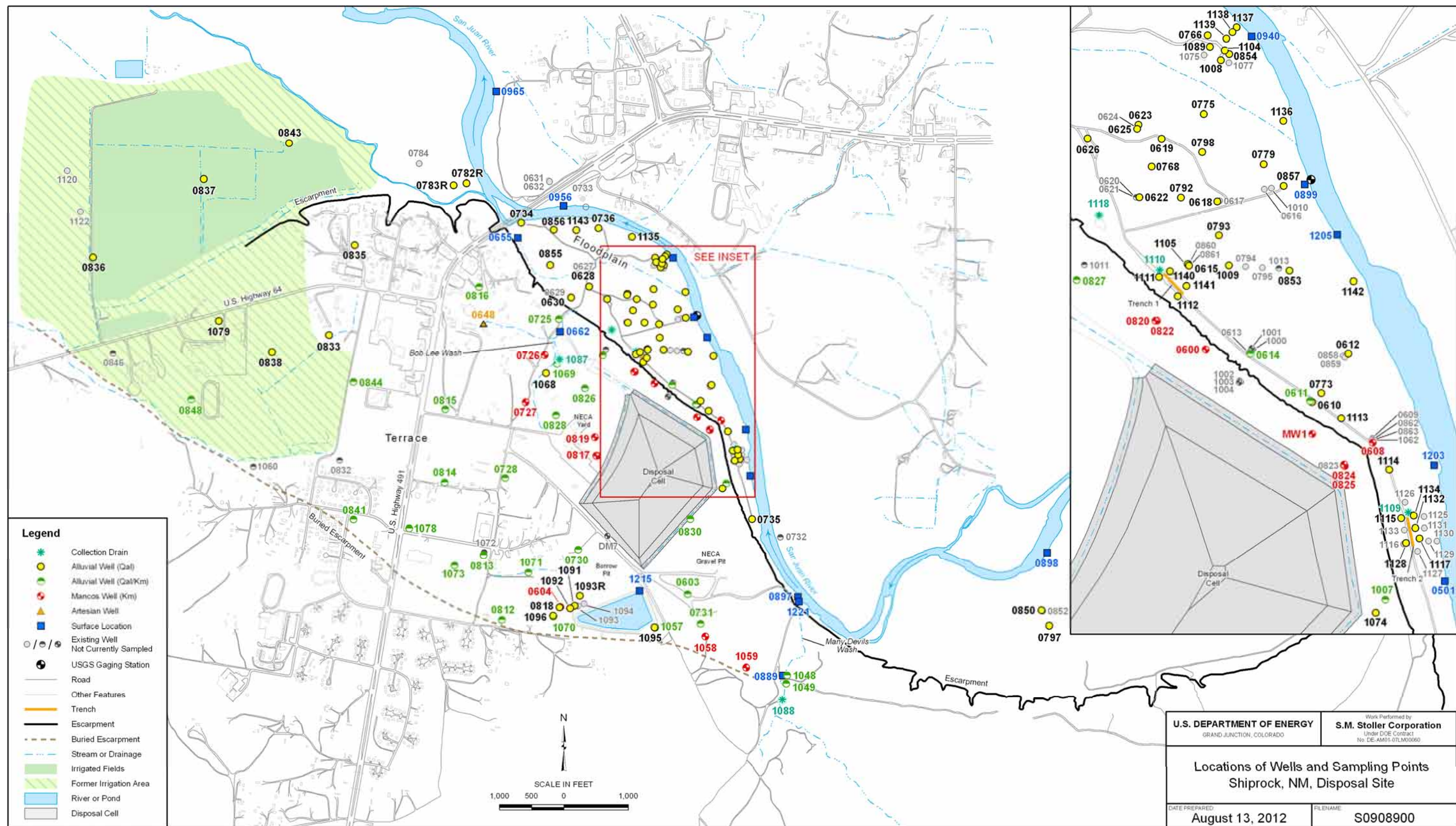
The Shiprock site is divided into two distinct areas—the floodplain and the terrace; an escarpment forms the boundary between the two areas. The floodplain remediation system consists of two groundwater extraction wells, a seep collection drain, and two collection trenches (Trench 1 and Trench 2). The terrace remediation system consists of nine groundwater extraction wells, two collection drains (Bob Lee Wash and Many Devils Wash), and a terrace drainage channel diversion structure. All extracted groundwater is pumped into a lined evaporation pond on the terrace. Figure 1 shows the site layout and the major components of the floodplain and terrace groundwater remediation systems. Figure 2 shows the locations of monitoring wells and surface water sampling locations at the site. Figure 3 shows surface water monitoring locations only, including the candidate background locations for the terrace established in March 2010 (locations 1218, 1219, and 1220).

A detailed description of the Shiprock site conditions is presented in the Site Observational Work Plan (SOWP; DOE 2000), and the compliance strategy is presented in the Groundwater Compliance Action Plan (GCAP; DOE 2002). Since these initial reports were developed, DOE has undertaken additional evaluations, including the *Refinement of Conceptual Model and Recommendations for Improving Remediation Efficiency at the Shiprock, New Mexico, Site* (DOE 2005), an evaluation of the Trench 2 groundwater remediation system (DOE 2009), and a mid-term evaluation of the site remediation strategy (DOE 2011a).

In the last 2 years DOE has issued several key reports. The first two, developed by DOE's Environmental Sciences Laboratory (ESL) in Grand Junction, Colorado—*Natural Contamination in the Mancos Shale* (DOE 2011c) and *Geology and Groundwater Investigation at Many Devils Wash* (DOE 2011b)—laid the groundwork for ongoing technical evaluations of contamination on the terrace. In March 2012, more-focused research investigating potential sources of contamination in Many Devils Wash was undertaken, as documented in *Application of Environmental Isotopes to the Evaluation of the Origin of Contamination in a Desert Arroyo: Many Devils Wash, Shiprock, New Mexico* (DOE 2012b).







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





Figure 3. Shiprock Site Surface Water Monitoring Locations



## 1.1 Remediation System Performance Standards

This performance assessment is based on an analysis of groundwater quality and groundwater level data obtained from site monitoring wells, in addition to groundwater flow rates associated with the extraction wells, drains, and seeps. Specific performance standards or metrics established for the Shiprock floodplain groundwater remediation system in the Baseline Performance Report (DOE 2003) are summarized as follows:

- Groundwater flow directions in the vicinity of the extraction wells should be toward the extraction wells to maximize the zones of capture; and
- Pumping on the floodplain should intercept contaminants of concern (COCs) that would otherwise discharge to the San Juan River.

Specific performance standards established for the terrace groundwater remediation system in the 2003 Baseline Performance Report (DOE 2003) are:

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

The performance standards summarized above, and representing the catalyst for this report, are based on the compliance strategy documented in the GCAP (DOE 2002). The compliance strategy for the floodplain is natural flushing supplemented by active remediation by extraction of groundwater from the floodplain aquifer adjacent to the San Juan River. Besides reduced flow to the floodplain through the pumping of the terrace, additional extraction of groundwater in the floodplain was expected to accelerate reduction in contaminant concentrations. As discussed in the *2010 Review and Evaluation of the Shiprock Remediation Strategy* (DOE 2011a), active remediation (pumping from extraction wells and trenches) is now considered the dominant strategy for the floodplain, as the influence of natural flushing is not certain.

DOE is currently reevaluating the compliance strategy for the terrace (DOE 2011a). The current dual strategies for the east and west portions of the terrace—active remediation and supplemental standards, respectively (DOE 2002)—are based on an assumption of a groundwater divide between the two different areas of the terrace (DOE 2011a). However, extensive data collected since that assumption was made indicate that the spatial distinction may not be valid. Until a new terrace compliance strategy is developed and receives concurrence from the U.S. Nuclear Regulatory Commission, the current strategy of active remediation by extraction of groundwater from the terrace alluvium will be applied to the entire terrace. Currently, the objective of active remediation on the terrace is to essentially dewater the terrace (reduce groundwater levels) until potential risks to humans and the environment have been eliminated by removal of potential exposure pathways. As reflected in the performance standards established in the Baseline Performance Report (DOE 2003), meeting this objective requires drying of seeps in Bob Lee Wash and Many Devils Wash and at the base of the escarpment (seeps 425 and 426; see Figure 1).

Initially, it was assumed that numerical standards for COCs on the terrace would not apply because exposure pathways would be eliminated. However, after 9 years of active remediation, despite some notable reductions in groundwater levels on the terrace (this could be due to a number of influences and cannot be attributed solely to pumping), it is unlikely that potential exposure pathways will be completely eliminated. Therefore, it may be necessary to establish new metrics for evaluating the performance of terrace remediation, a factor that should be considered when reviewing Sections 2.2, “Terrace Subsurface Conditions,” and 3.2, “Terrace Remediation System,” of this report.

## 1.2 Contaminants of Concern and Remediation Goals

This section documents the remediation goals established for site COCs and presents the available data for background levels on the floodplain and the terrace.

### 1.2.1 Groundwater COCs, Remediation Goals, and Floodplain Background

The COCs for both the floodplain and terrace, defined in the GCAP (DOE 2002), are ammonia (total as nitrogen), manganese, nitrate (nitrate + nitrite as nitrogen), selenium, strontium, sulfate, and uranium. These constituents are listed in Table 1 along with corresponding floodplain background data and maximum concentration limits (MCLs) established in Title 40 *Code of Federal Regulations* Part 192 (40 CFR 192), which apply to UMTRCA sites.

Table 1. Groundwater COCs for the Shiprock Site

Contaminant	40 CFR 192 MCL (mg/L)	Historical Range in Floodplain Background Wells <sup>a</sup>	Comments
Ammonia as N (mg/L)	NA	0.074–0.102	All results for floodplain background wells have been nondetects (<0.1 mg/L) except for the most recent (March 2011) measurements.
Manganese (mg/L)	NA	0.001–7.2	Compliance standard and cleanup goal for the floodplain is 2.74 mg/L as identified in the GCAP (DOE 2002).
Nitrate as N (mg/L)	10	0.01–3.3	As identified in the GCAP (DOE 2002), the compliance standard for Nitrate in the floodplain is 44 mg/L. This is equivalent to 10 mg/L of Nitrate (as N), which is the UMTRA standard (40 CFR 192).
Selenium (mg/L)	0.01	0.0001–0.018	Compliance standard and cleanup goal for the floodplain is 0.05 mg/L as identified in the GCAP (DOE 2002). This is also the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act maximum contaminant level.
Strontium (mg/L)	NA	0.18–10	EPA's Drinking Water Equivalent Level for lifetime exposure is 20 mg/L.
Sulfate (mg/L)	NA	210–5,200	Given elevated levels in artesian well 0648 (1,810–2,340 mg/L), an alternate cleanup goal of 2,000 mg/L for the floodplain was proposed in the GCAP (DOE 2002).
Uranium (mg/L)	0.044	0.004–0.12	Uranium levels measured in floodplain background wells have varied widely (0.004–0.12 mg/L) and have exceeded the MCL at times.

<sup>a</sup> Data are from floodplain background wells 0797 and 0850 (locations shown in Figure 2).

mg/L = milligrams per liter

NA = Not applicable (contaminant does not have an MCL in 40 CFR 192)

As listed in Table 1, the compliance standards for nitrate, uranium, and selenium are the respective 40 CFR 192 standards of 10 milligrams per liter (mg/L), 0.044 mg/L, and 0.01 mg/L. If the relatively high selenium concentrations in floodplain groundwater originate on the terrace, it may be unlikely that the 40 CFR 192 standard of 0.01 mg/L for this constituent could be met. Therefore, an alternate concentration limit for selenium of 0.05 mg/L was proposed for the floodplain in the GCAP (DOE 2002), which is the maximum contaminant level for drinking water established under the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA). This alternate level may still be too conservative, given the potential influence from natural sources addressed in recent DOE ESL evaluations (DOE 2011b, 2011c).

Regulatory standards are not available for ammonia and manganese (Table 1). An alternate cleanup standard has not been established for ammonia (EPA has not developed any toxicity values upon which to base an associated risk-based standard), and levels measured in floodplain background wells have been low. The cleanup goal for manganese is 2.7 mg/L for the floodplain, as specified in the GCAP.

Regulatory standards are also not available for strontium, a constituent typically not associated with uranium milling sites. Strontium was selected as a COC in the Baseline Risk Assessment (DOE 1994) primarily because of concentrations measured in sediment (rather than groundwater) and a conservatively modeled agricultural uptake scenario. The form present at the Shiprock site is stable (nonradioactive) strontium, a naturally occurring element, and is distinguished from the radioactive and much more toxic isotope strontium-90, a nuclear fission product (ATSDR 2004). EPA's Drinking Water Equivalent Level for lifetime exposure is 20 mg/L.<sup>1</sup>

Because sulfate levels have also been elevated in groundwater entering the floodplain from flowing artesian well 0648 (up to 2,340 mg/L), the GCAP proposed an alternate cleanup goal for sulfate of 2,000 mg/L for the floodplain. This alternate goal is conservative given the elevated levels in floodplain background wells.

### **1.2.2 Terrace Background Characterization Efforts**

As part of early site characterization efforts conducted for the SOWP (DOE 2000), an analog site with comparable geologic and hydrologic features was studied on an adjacent terrace about 1 to 2 miles east-southeast of the disposal cell (see DOE 2000, Plates 1 and 2). Four test wells (800 through 803) were drilled on the analog terrace site, but no groundwater was found either in the terrace gravel section or in the upper part of the Mancos Shale in these test wells. At that time, isotopic and other data suggested that some groundwater contamination (in particular, uranium, selenium, and sulfate) in the irrigated area west of Highway 491 was not mill site related; rather, it was attributable to dissolution of Mancos Shale components (DOE 2000). However, this assumption was not fully supported by the available data, and confirmation has been confounded by the inability to find a suitable analog terrace background location (given that all wells drilled were dry).

After consultation with the Navajo Nation Environmental Protection Agency and Navajo Nation Abandoned Mine Lands/Uranium Mill Tailings Remedial Action (UMTRA) Office in

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<sup>1</sup> United States Environmental Protection Agency, 2012 edition of the *Drinking Water Standards and Health Advisories*.

March 2010, three new terrace seep locations not influenced by the former mill that emanate from Mancos Shale were identified and sampled. These locations, shown in Figure 3 (see inset), are:

- Location 1218 (sometimes referred to as Washing Machine Draw)<sup>2</sup>, which is approximately 2 miles southwest of the site. The elevation where water from location 1218 seeps from the ground—4,987.1 feet (ft) above mean sea level (msl)—is 2 ft higher than the highest possible water elevations in the mill site raffinate ponds during milling years (4,985 ft msl<sup>3</sup>). The highest groundwater elevations currently observed in the alluvial system overlying the Mancos Shale in the vicinity of the mill site are on the order of 4,945 ft msl.
- Location 1219, a seep about 5 miles northwest of the site across the San Juan River, located below an irrigation canal; and
- Location 1220, a seep at the Eagle Nest Arroyo, approximately 5 miles east of the site across the San Juan River, also located in an area influenced by irrigation.

Although these seeps occur in Mancos Shale and the water was not likely influenced by the former mill, all three locations have characteristics that are not completely representative of conditions on the terrace before operation of the mill. Because of the unique circumstances of the site, it is possible that a truly representative background location does not exist. As documented in the 2010–2011 Annual Performance Report (DOE 2012a; Table 2) and shown later in Figure 4 through Figure 10, COC concentrations in samples from locations farthest from the mill site—locations 1219 and 1220 (Eagle Nest Arroyo)—are fairly low. However, at seep location 1218, concentrations of nitrate, selenium, and uranium have been above MCLs. Sulfate (36,000 mg/L) far exceeds the 210–5,200 mg/L floodplain background range. These elevated concentrations could reflect some evaporation.

## 1.3 Hydrogeological Setting

This section presents a brief summary of the floodplain and terrace groundwater systems. More detailed descriptions are provided in the SOWP (DOE 2000), the refinement of the site conceptual model (DOE 2005), and floodplain remediation system evaluations (DOE 2011d, DOE 2009).

### 1.3.1 Floodplain Alluvial Aquifer

The thick Mancos Shale of Cretaceous age forms the bedrock underlying the entire site. A floodplain alluvial aquifer occurs in unconsolidated medium- to coarse-grained sand, gravel, and cobbles that were deposited in former channels of the San Juan River above the Mancos Shale. The floodplain aquifer is hydraulically connected to the San Juan River; the river is a source of groundwater recharge to the floodplain aquifer in some areas, and it receives groundwater discharge in other areas. In addition, the floodplain aquifer receives some inflow from

<sup>2</sup> For ease of reference, location 1218 is referred to as a seep. However, although technically seep water (i.e., originating from groundwater), location 1218 samples were collected from pools rather than from flowing water, so some evaporation could have taken place prior to sampling.

<sup>3</sup> This estimate is based on a 4,975 ft contour from a pre-remediation topographical map and assumes that the pond berms were 10 ft high).



groundwater in the terrace area. The floodplain alluvium is up to 20 ft thick and overlies Mancos Shale, which is typically soft and weathered for the first several feet below the alluvium.

Most groundwater contamination in the floodplain lies close to the escarpment east and north of the disposal cell. Contaminant distributions in the alluvial aquifer are best characterized by elevated concentrations of sulfate and uranium. Lower levels of contamination occur along the escarpment base in the northwest part of the floodplain because relatively uncontaminated surface water from Bob Lee Wash discharges to the floodplain at the wash's mouth, recharging the local subsurface, then flowing to the north and west between the wash and the river. Surface water in Bob Lee Wash originates primarily from the Morrison Formation as deep groundwater that flows to the land surface via artesian well 0648. Well 0648 flows at approximately 65 gallons per minute (gpm) and drains eastward into lower Bob Lee Wash. Historically, background groundwater quality in the floodplain aquifer, discussed in Section 1.2.1 (Table 1), has been defined by the water chemistry in monitoring wells 0797 and 0850, installed in the floodplain approximately 1 mile upriver from the site.

### **1.3.2 Terrace Groundwater System**

The terrace groundwater system occurs partly in unconsolidated alluvium in the form of medium- to coarse-grained sand, gravel, and cobbles deposited in the floodplain of the ancestral San Juan River. Terrace alluvial material is Quaternary in age; it varies from 0 to 20 ft in thickness and caps the Mancos Shale. Although less well mapped, some terrace groundwater also occurs in weathered Mancos Shale underlying the alluvium. The Mancos Shale is exposed in the escarpment adjacent to the San Juan River floodplain.

The terrace groundwater system is bounded on its south side by an east-west trending buried bedrock (Mancos Shale) escarpment, about 1,500 ft south of the southernmost tip of the disposal cell. The terrace system extends more than a mile west and northwestward. Terrace alluvial material is exposed at ground surface in the vicinity of the terrace–floodplain escarpment; south and southwest of the former mill, the terrace alluvium is covered by eolian silt, or loess, which increases in thickness with proximity to the buried bedrock escarpment. Up to 40 ft of loess overlies the alluvium along the base of the buried escarpment. Terrace alluvium consists of coarse-grained ancestral San Juan River deposits, primarily in the form of coarse sands and gravels.

Mancos Shale underlying the alluvium in the terrace area is weathered several feet below the shale-alluvium contact. Groundwater is known to occur in the weathered shale and, in some areas, flows through deeper portions of the shale, within fractures and along bedding surfaces.

## **1.4 Contaminant Distributions**

The objective of the floodplain remediation strategy is to reduce COC concentrations and decrease (minimize) the contaminant mass discharging to the San Juan River. Therefore, subsequent discussions of contaminant distributions and temporal trends focus primarily on floodplain wells. Contamination trends on the terrace receive less focus in this annual report because the compliance strategy is based on hydrologic control—active remediation to reduce groundwater elevations, with the ultimate goal of eliminating potential exposure pathways (e.g., in seeps and washes). Therefore, concentration-driven performance standards for the

terrace system have not been developed. However, as a best management practice, contaminant concentrations are measured at each extraction well, drain, and seep.

The remainder of this section presents a snapshot of current conditions (in the form of graduated symbol and bar chart plots) and (in the plume maps) a comparison of that snapshot with baseline (pre-remediation) conditions. Section 2.1.2 presents corresponding temporal trending data. Detailed information, including time-concentration graphs for both terrace and floodplain monitoring locations and supporting quality assurance documentation, is provided in the corresponding Data Validation Package reports (DOE 2012c, 2012d).

Figure 4 through Figure 10 plot concentrations of COCs in terrace and floodplain groundwater and surface water based on results of the most recent sampling event (September 2011 or March 2012). Figure 11 presents a side-by-side comparison of relative contaminant distributions for the primary COCs.

Figures 12 through 25 plot changes in the floodplain contaminant plumes. These plume maps plot interpolated data for wells sampled between 2000 and 2003 (representing baseline conditions) and the maximum result for this evaluation period (September 2011 through March 2012). There are two maps for each COC. The first map shows the baseline conditions and the current conditions using only the wells that were sampled during both periods. The second map shows the current conditions using all wells that were sampled September 2011 through March 2012. All the plume maps use interpolation for predicting concentrations of COCs at unsampled sites based on measurements made at the closest surrounding sites. The compliance standard or cleanup goal established in the GCAP was added to the color scale, and the break between blue and green was set at this value. All locations and interpolated areas that are below the compliance standard or cleanup goal are colored blue, and all locations above the standard are colored green, yellow, or red based on concentration. Strontium and ammonia do not have compliance standards or cleanup goals in the GCAP. The EPA Drinking Water Equivalent Level for lifetime exposure to strontium discussed in Section 1.2.1 was used for the strontium map. Ammonia has no comparable benchmark value; therefore, the ammonia map has no set value for the blue to green color break.

As shown in Figure 2, the Shiprock well network is dense. For this reporting period, 116 monitoring wells were sampled (59 on the floodplain and 57 on the terrace). Eighteen surface water locations, including seeps, and eight San Juan River sampling points (Figure 3) are also routinely sampled if water is present. During this reporting period, at least half the terrace and floodplain seep locations were dry. Given the density of the site sampling network and the number of COCs evaluated, contaminant distributions are complex both spatially and temporally. However, based on the plots in Figures 4 through 25, several global trends are apparent, as summarized below.

### Ammonia

Ammonia concentrations are highest in the radon cover borrow pit/evaporation pond area, in Mancos wells west of the disposal cell (0602, 0817, and 1819), and on the floodplain in the area of the trenches and at the base of the escarpment (Figure 4). On the floodplain, ammonia concentrations continue to be highest in Trench 2 wells 1115 and 1128 (340 and 440 mg/L, respectively). These wells are located on the disposal cell side of the trench. Ammonia

concentrations on the eastern (river) side of the trench are much lower (Figure 13). The maximum ammonia concentration of 920 mg/L for this reporting period was measured in terrace Mancos well 0817, just west of the disposal cell (Figure 4). The plume maps in Figure 12 show no notable differences between baseline and current periods. Apparent increases in the Trench 2 area (Figure 13) are attributable to the fact that no data (wells) were available for this area during the baseline (2000–2003) period.

### Manganese

Manganese, which is at or near background concentrations across much of the site, is elevated only in the borrow pit/evaporation pond area (Figure 5). Concentrations in well 0603 nearly doubled between September 2008 and March 2009—from about 27 to 55 mg/L; concentrations have been stable since then. However, this magnitude is consistent with a very early (1990) measurement (69 mg/L). The reason for the recent increase is not known but could be related to large volumes of water introduced into the alluvial aquifer during the nearby gravel pit operations beginning in 2008. The only other wells with elevated manganese concentrations are extraction wells 1093 and 1095 (18 and 32 mg/L, respectively) and well 0730 (23 mg/L) south of the disposal cell (Figure 5). The plume maps in Figure 14 show a decrease in manganese concentrations along the base of the escarpment and along the river. Most manganese concentrations are within the historical floodplain background range listed in Table 1, except wells 0792 and 0618 (Figure 15).

### Nitrate

As shown in Figure 6, nitrate concentrations are most elevated in the terrace radon cover borrow pit and paleochannel areas (i.e., along the buried escarpment), as well as in Many Devils Wash. Although still elevated on the floodplain (relative to the 44 mg/L GCAP compliance standard or cleanup goal for the floodplain), nitrate concentrations are much lower since the installation of trenches in 2006 (Figure 16). The plume maps in Figure 16 show demonstrable progress on the floodplain (reductions in nitrate concentrations) when comparing baseline versus current results. This is most evident in the Trench 1 and well 1089 areas. As is the case for most COCs, nitrate concentrations measured in wells near the San Juan River are low or below detection limits (Figure 17).

### Selenium

Selenium's spatial distribution is very similar to that observed for nitrate in that concentrations are most elevated along the terrace buried escarpment (swale area) and in Many Devils Wash (Figure 7 and Figure 11). The plume maps in Figure 18 indicate some reductions in selenium concentrations on the floodplain, but these do not appear to be significant. Selenium concentrations on the floodplain, although much lower than on the terrace, are still elevated in many wells. This is especially the case for the Trench 1 area and in wells located at the base of the escarpment (Figure 19). Closer to the river, however, selenium concentrations are generally below the 0.05 mg/L GCAP compliance standard or cleanup goal for the floodplain, and a number of results are below detection limits.

## Strontium

As discussed in Section 1.2, strontium is not typically associated with uranium milling sites but was selected as a COC based on a conservative risk assessment. The symbol categories used in Figure 8 are based on historical floodplain background concentrations (0–10 mg/L). Strontium concentrations appear to be fairly uniform within the range of background except for Mancos wells, alluvial wells in the swale area and west terrace, and floodplain alluvial well 0630. Apart from a possible association with Mancos wells (Figure 8), no spatial pattern appears. Given these observations, strontium may be naturally occurring at the Shiprock site rather than associated with former milling processes. The plume maps in Figure 20 and Figure 21 indicate reductions in strontium concentrations on the floodplain.

## Sulfate

Sulfate concentrations are elevated at most locations at the Shiprock site, but like nitrate and selenium, sulfate is most concentrated in the swale area and in Many Devils Wash (Figure 9). The maximum concentration (36,000 mg/L) was measured in the recently established location 1218. Sulfuric acid was used during milling, and, coupled with the concentration data, there is no question that sulfate onsite is attributable to former milling processes. However, sulfate's distribution in Many Devils Wash is puzzling and could be partly or perhaps largely attributable to naturally occurring contamination (see DOE 2011b, DOE 2011c). Reductions in sulfate concentrations are evident on the floodplain along the river and in the trench 1 area (see plume maps in Figure 22 and Figure 23).

## Uranium

Uranium's distribution differs from that of the other COCs in that it is most concentrated in terrace Mancos wells near the disposal cell and, in particular, on the floodplain (Figure 10, Figure 24 and Figure 25). For this reason, uranium receives the most focus in later discussions of temporal floodplain contamination trends (Section 2.1.2).

A uranium plume underlies the disposal cell and extends into the floodplain. The highest-concentration portions of the uranium plume are in the terrace alluvium and weathered Mancos close to the disposal cell, on the floodplain near the southern portion of the escarpment, and in a zone traversing the floodplain in a line trending northward from the disposal cell. As observed for nitrate and sulfate, reductions in uranium concentrations are evident in the (baseline vs. current) plume maps (Figure 24), and concentrations in wells nearer the river are markedly lower, especially in the area of Trench 2 (Figure 25).



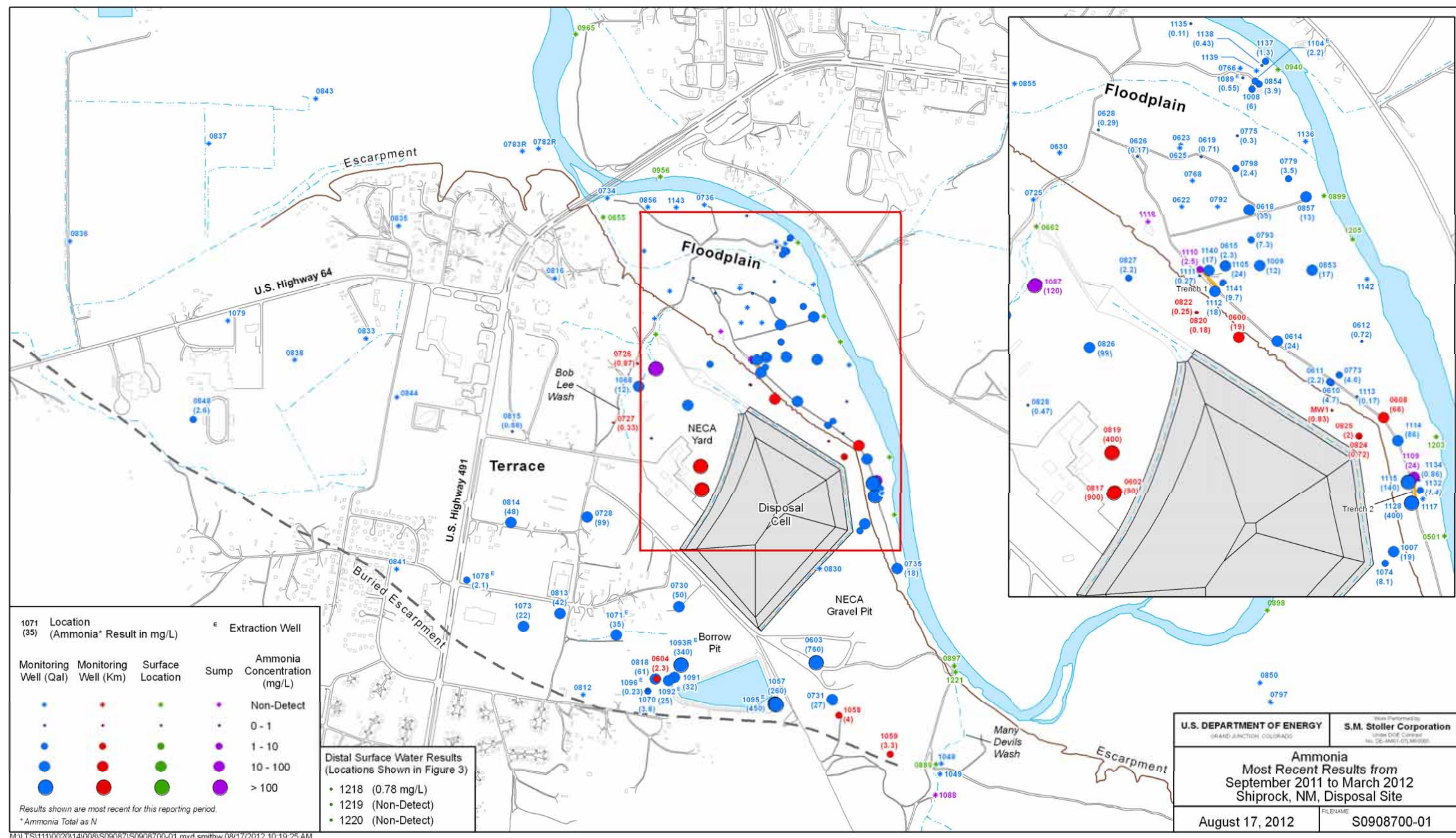


Figure 4. Ammonia Concentrations in Groundwater and Surface Water Samples, September 2011–March 2012



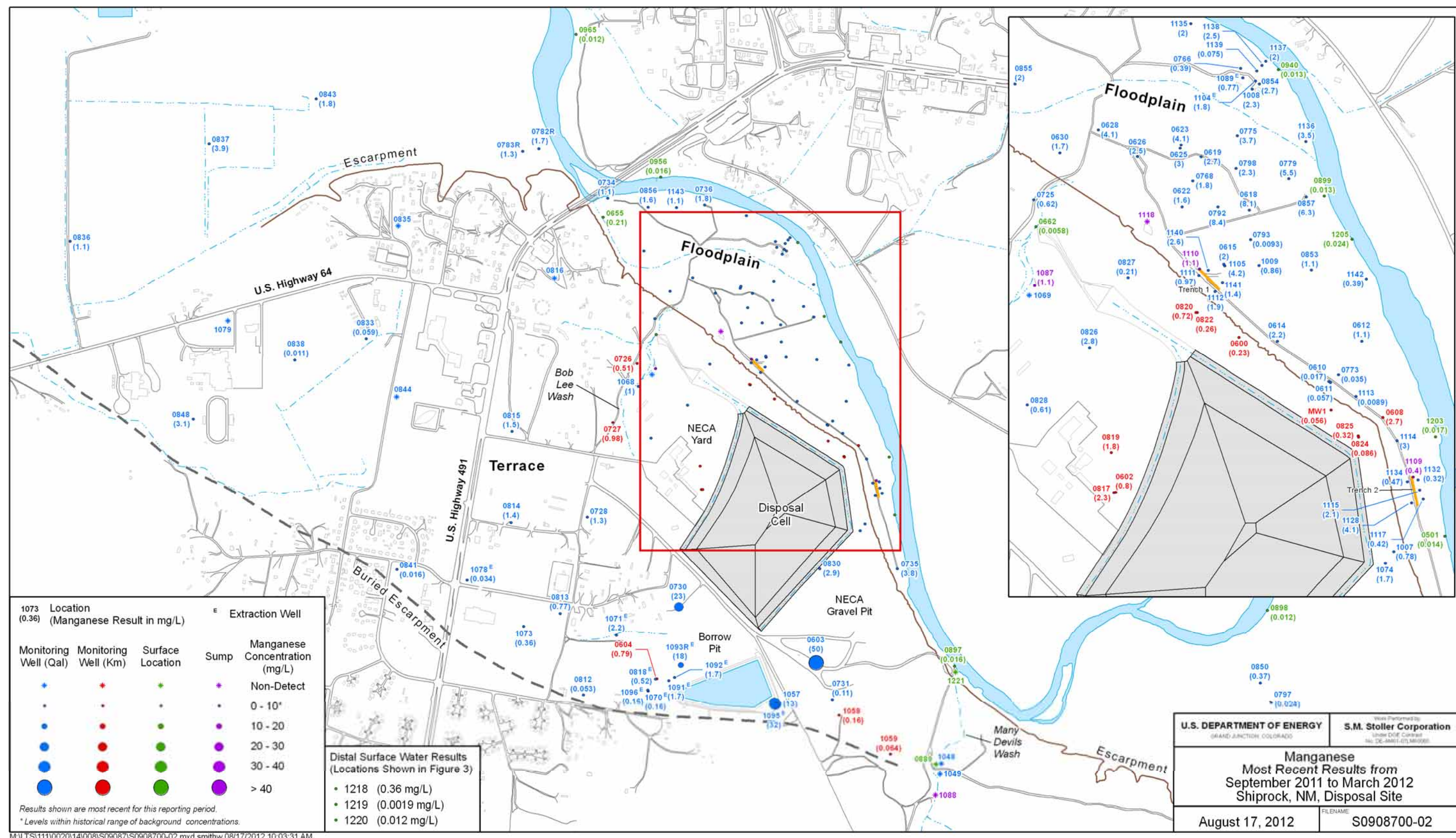






Figure 6. Nitrate Concentrations in Groundwater and Surface Water Samples, September 2011–March 2012



















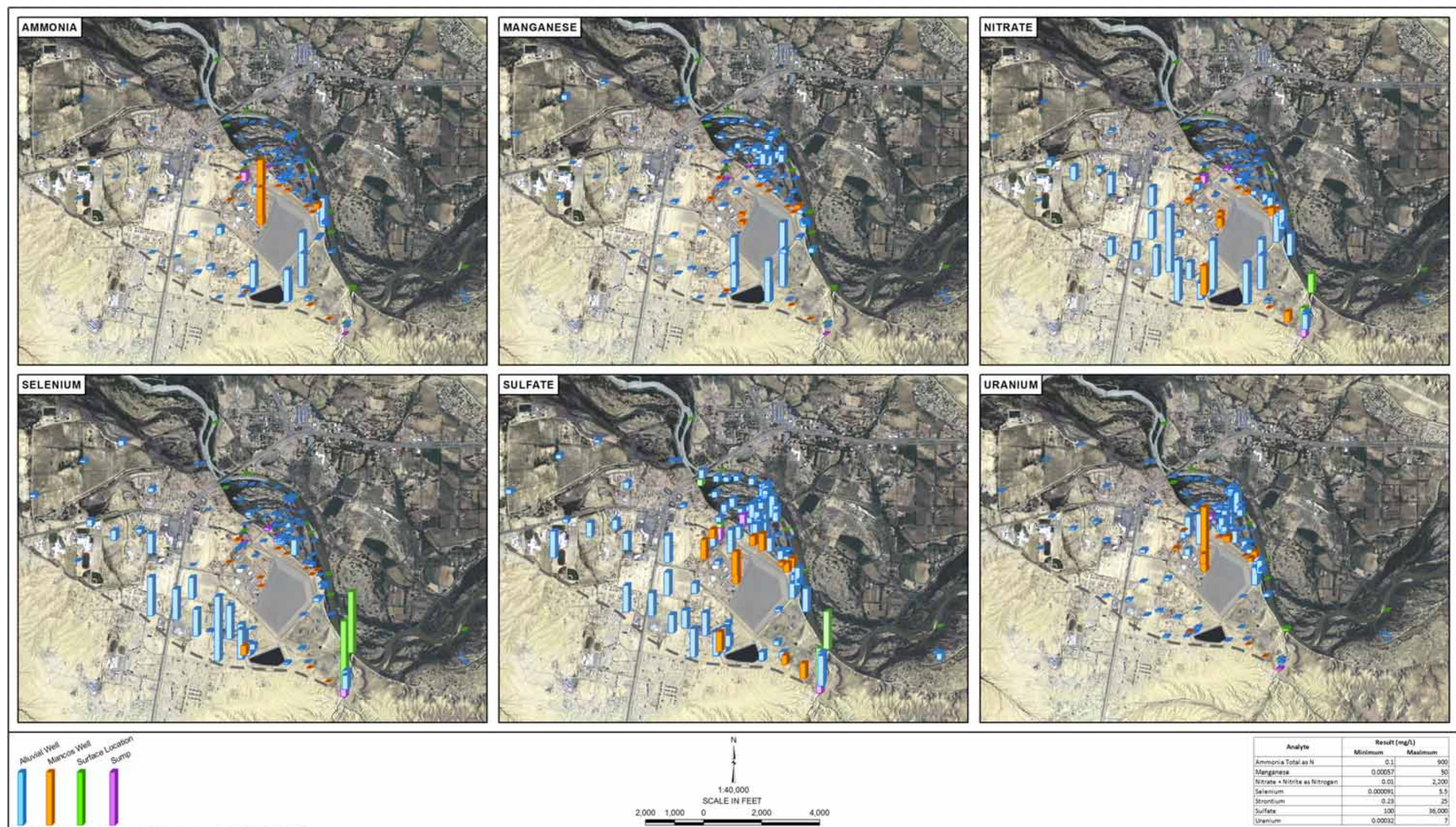


Figure 11. Comparison of Relative Contaminant Distributions for the Primary COCs, September 2011–March 2012



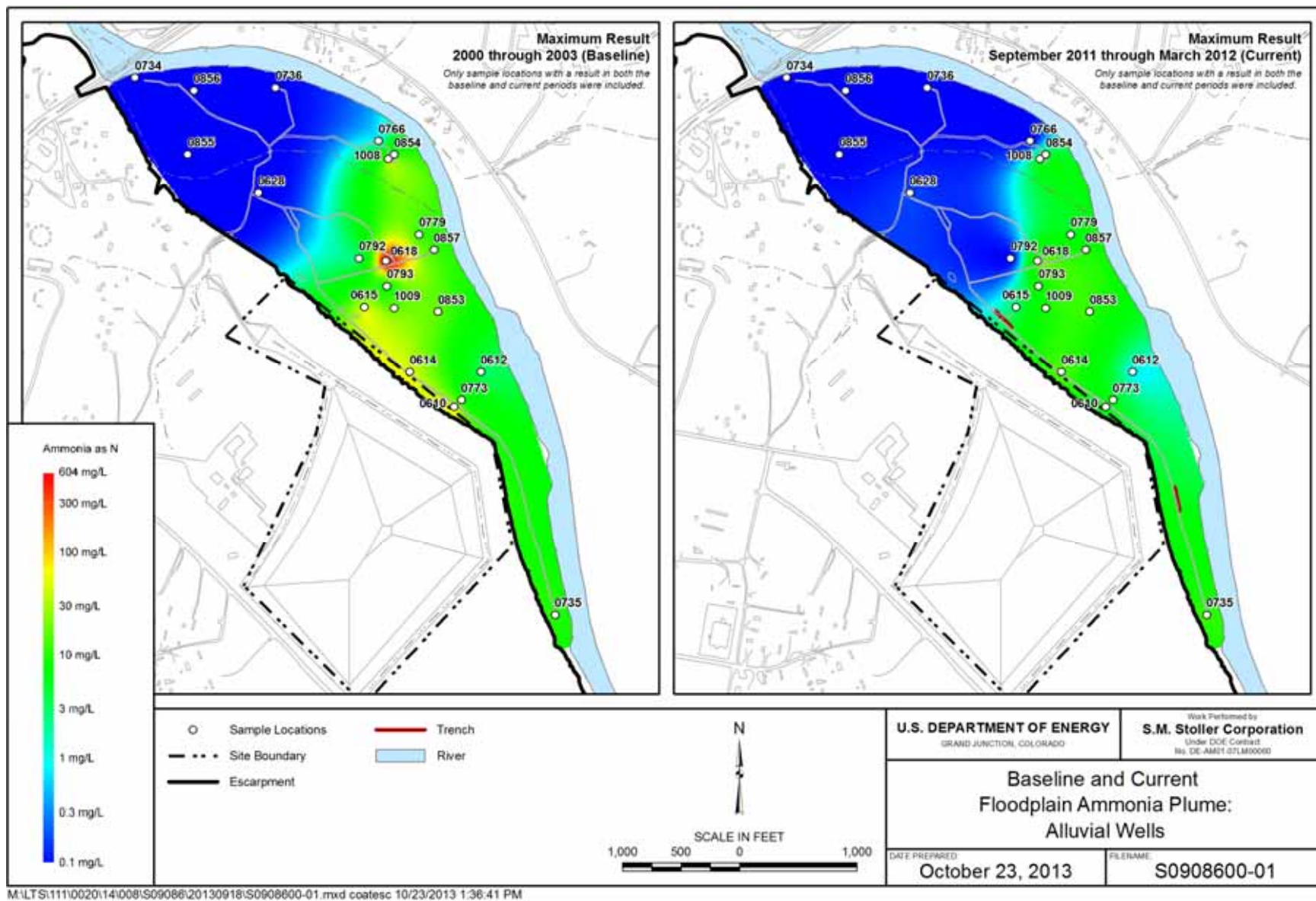


Figure 12. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Ammonia Plumes

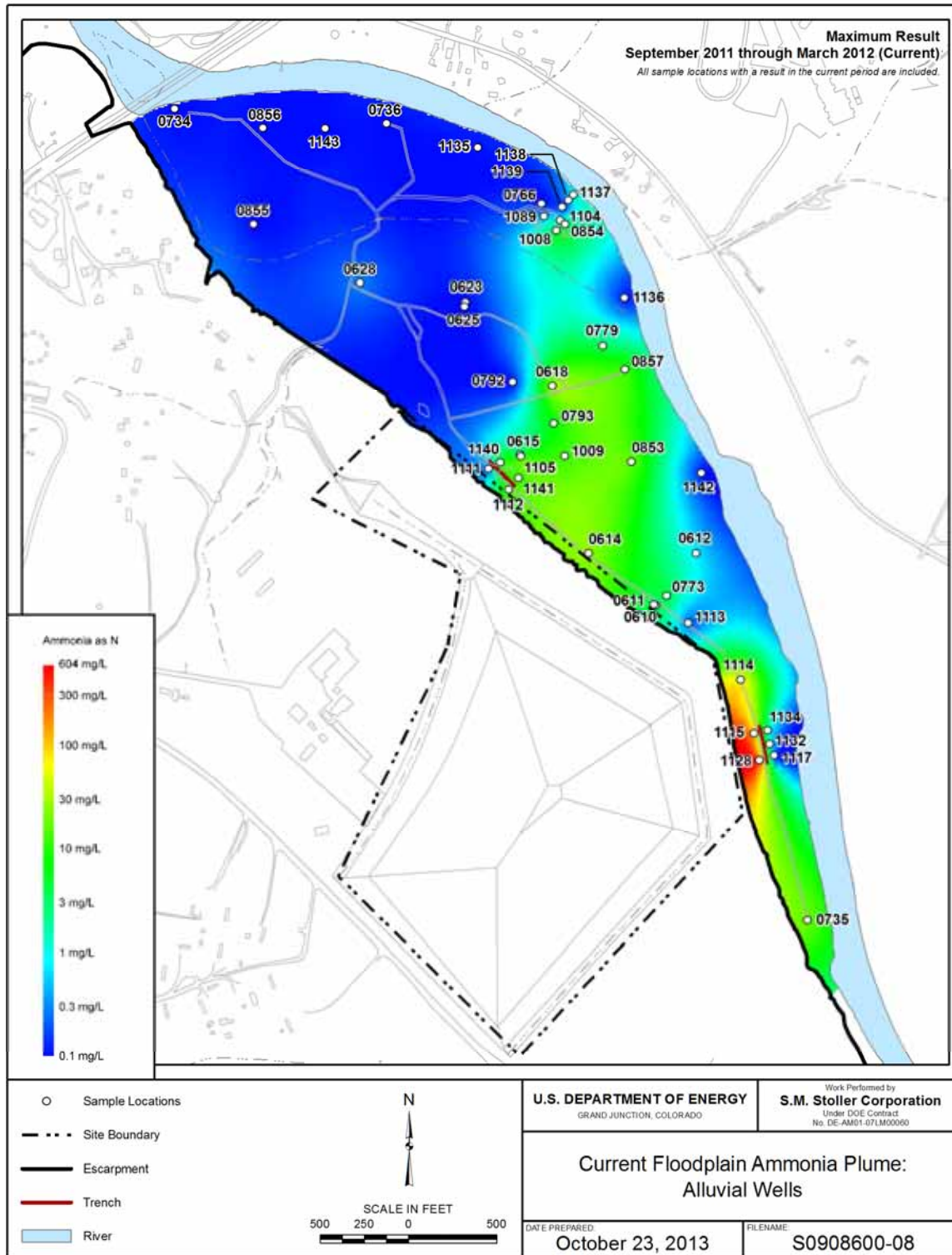


Figure 13. September 2011 through March 2012 Floodplain Ammonia Plume – All Sampled Wells

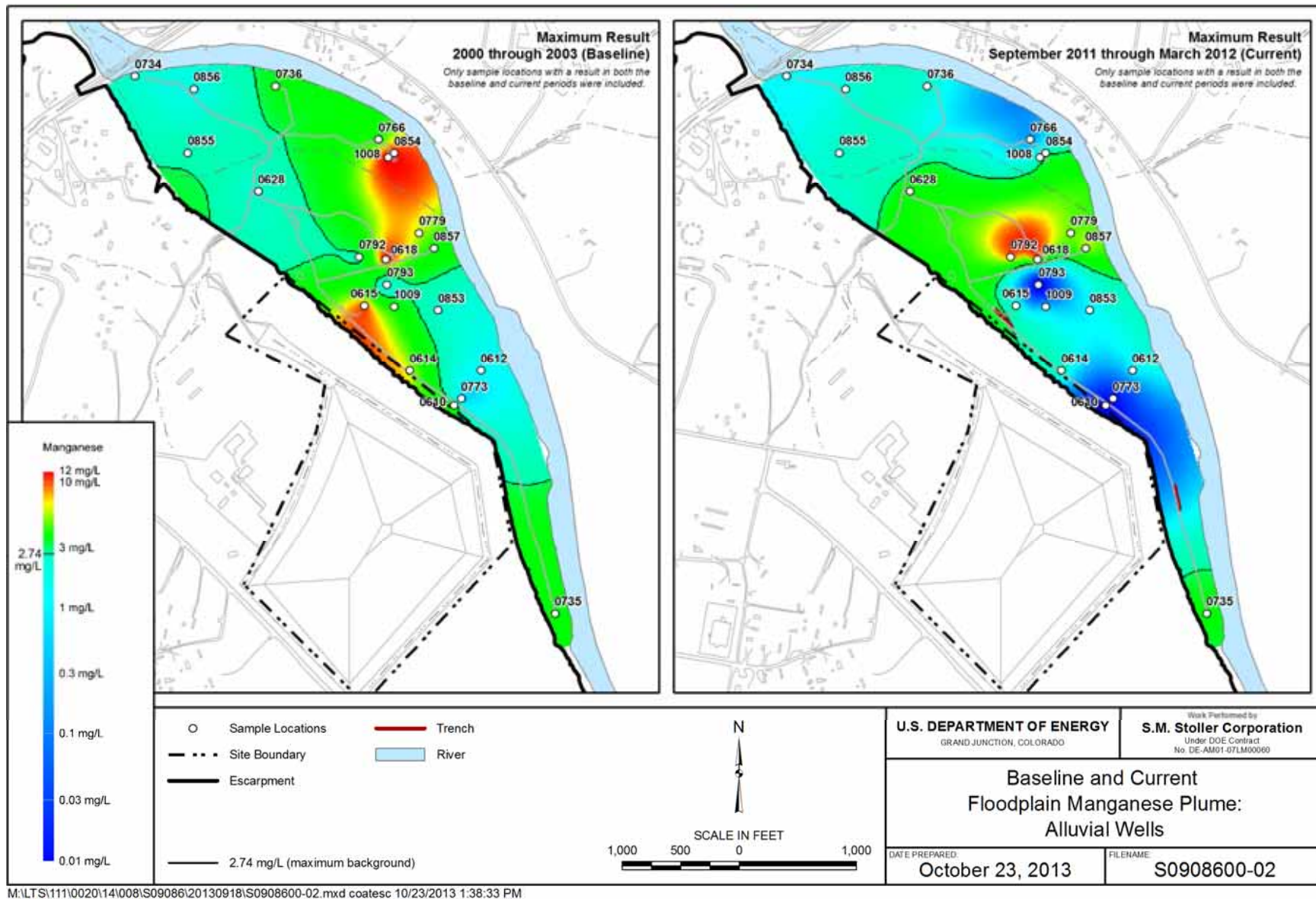


Figure 14. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Manganese Plumes



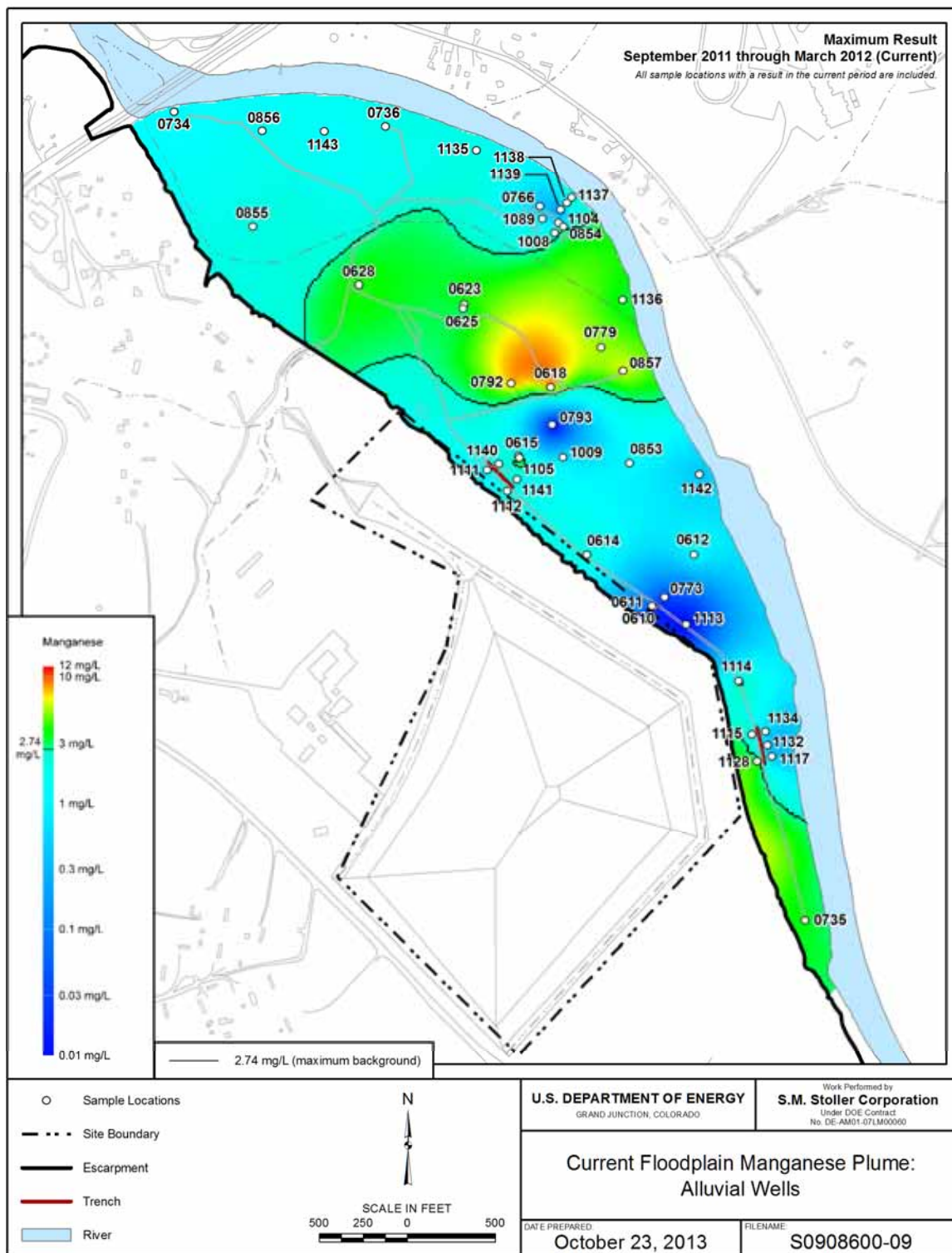


Figure 15. September 2011 through March 2012 Floodplain Manganese Plume—All Sampled Wells



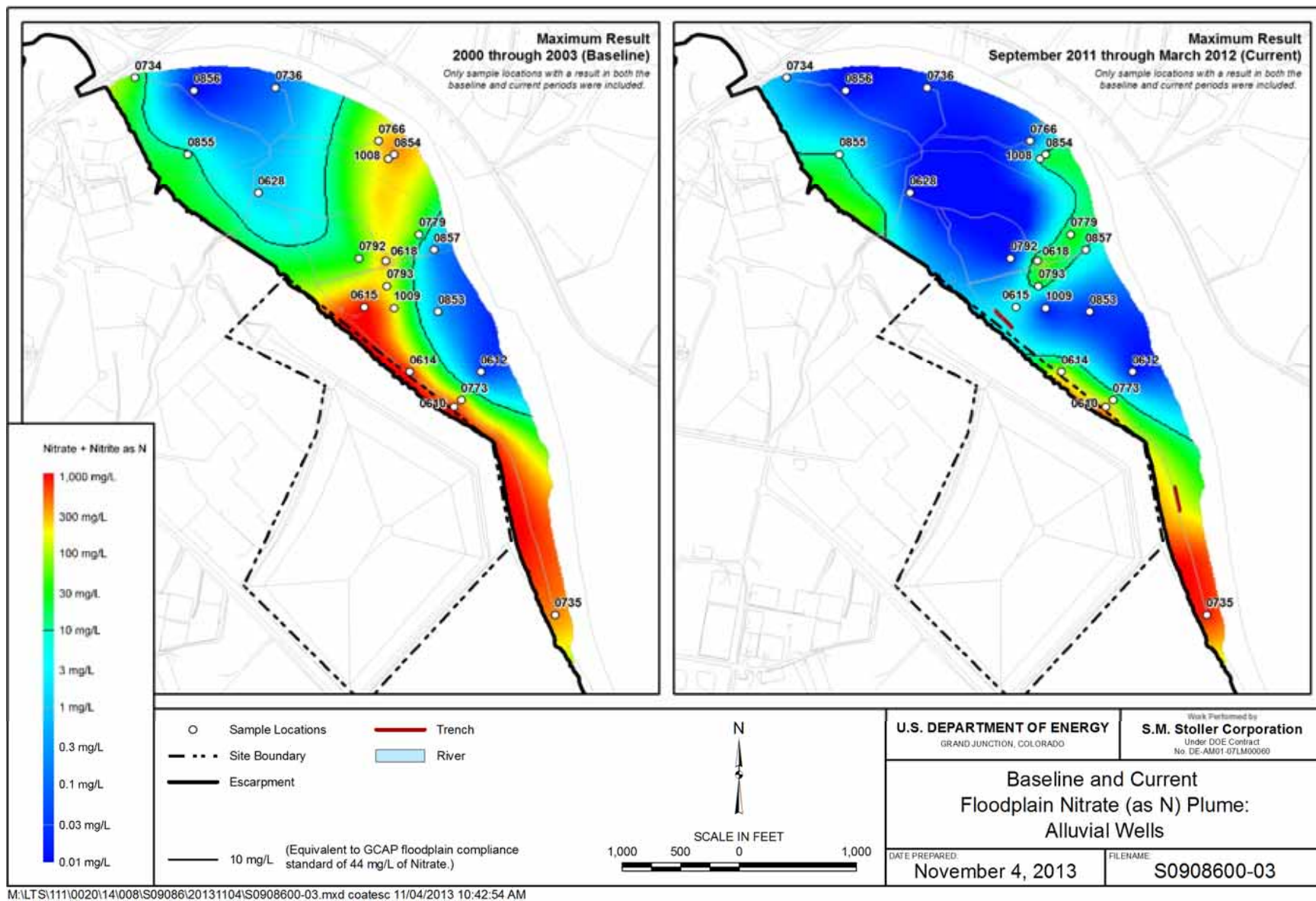


Figure 16. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Nitrate Plumes

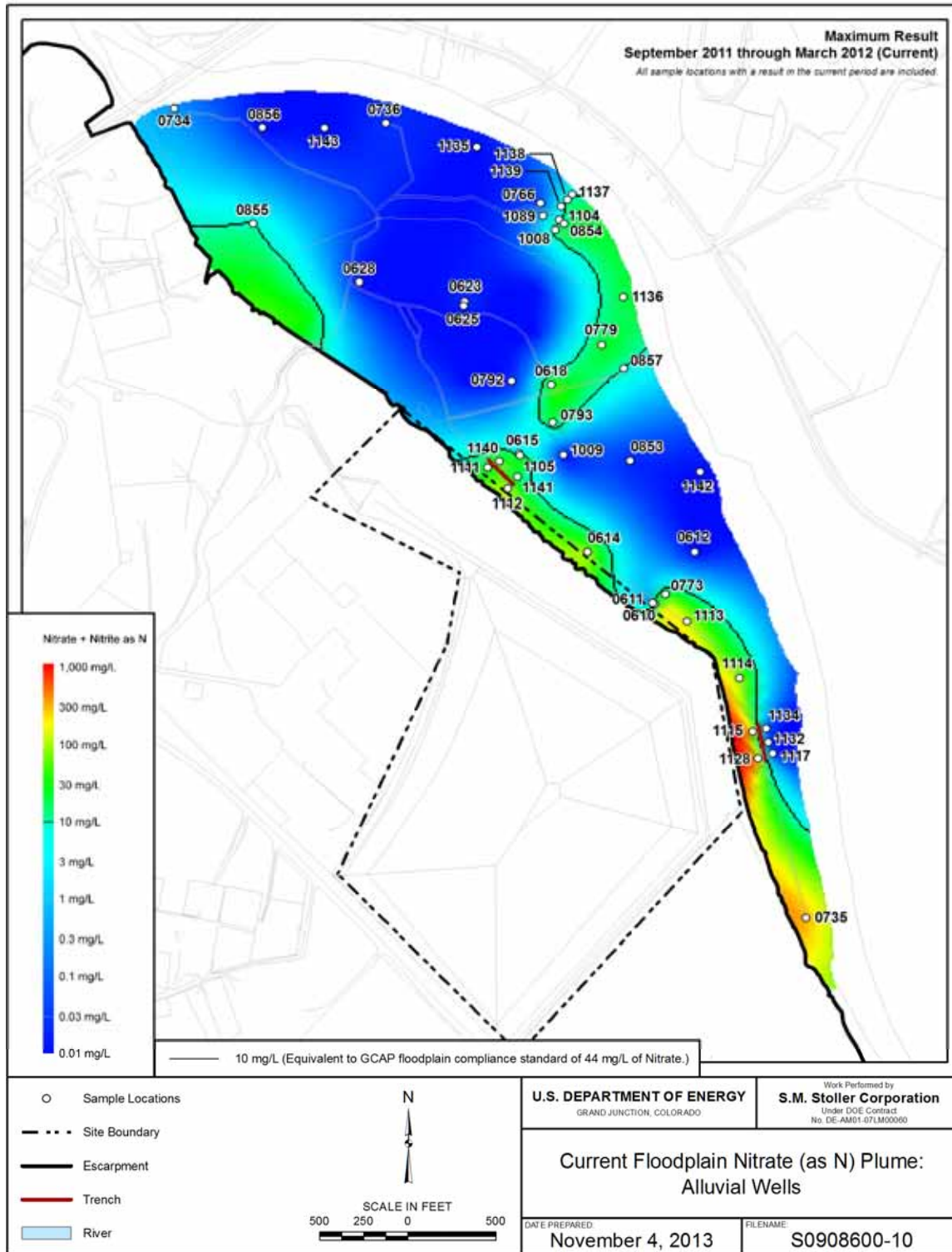


Figure 17. September 2011 through March 2012 Floodplain Nitrate Plume – All Sampled Wells

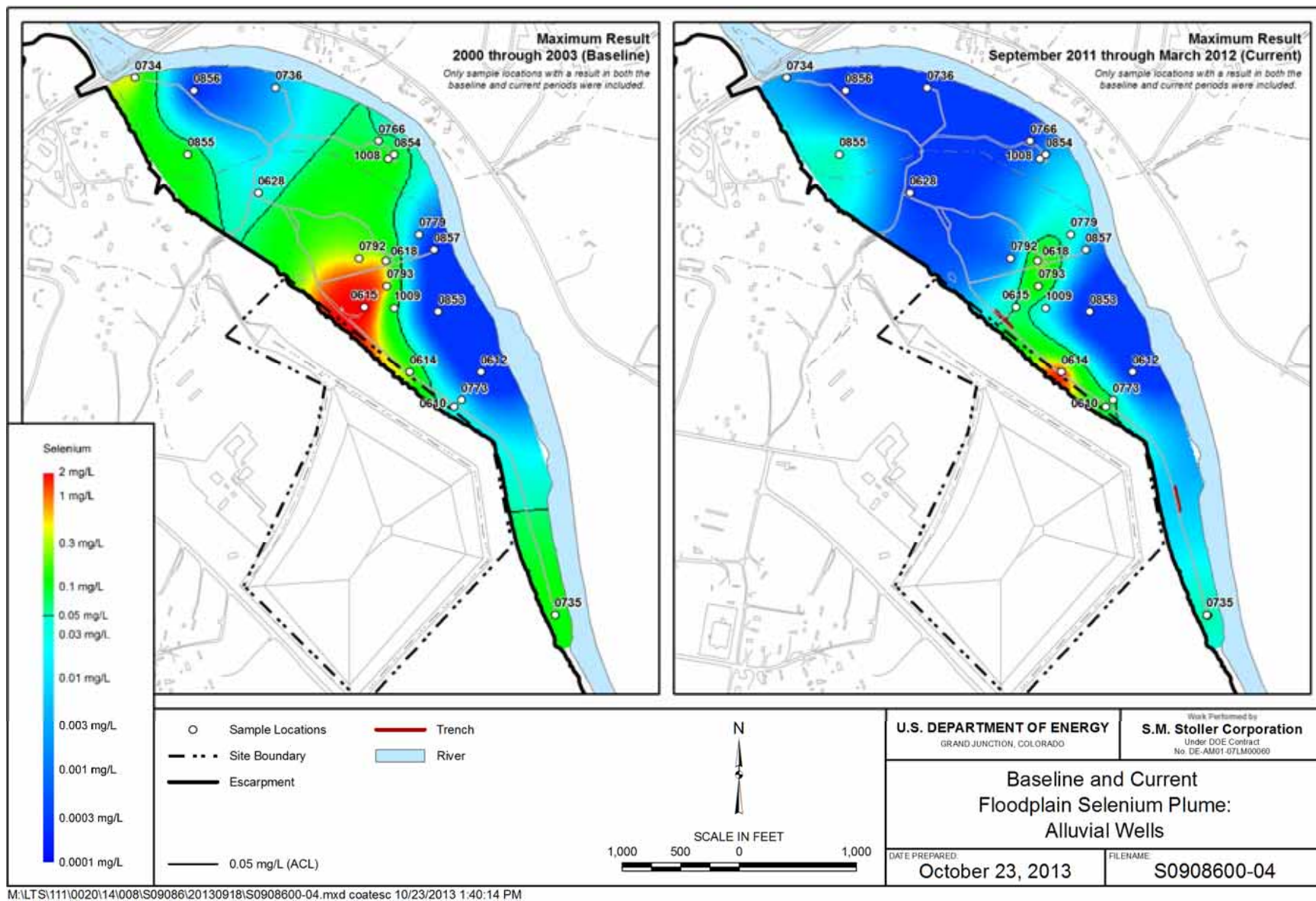


Figure 18. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Selenium Plumes



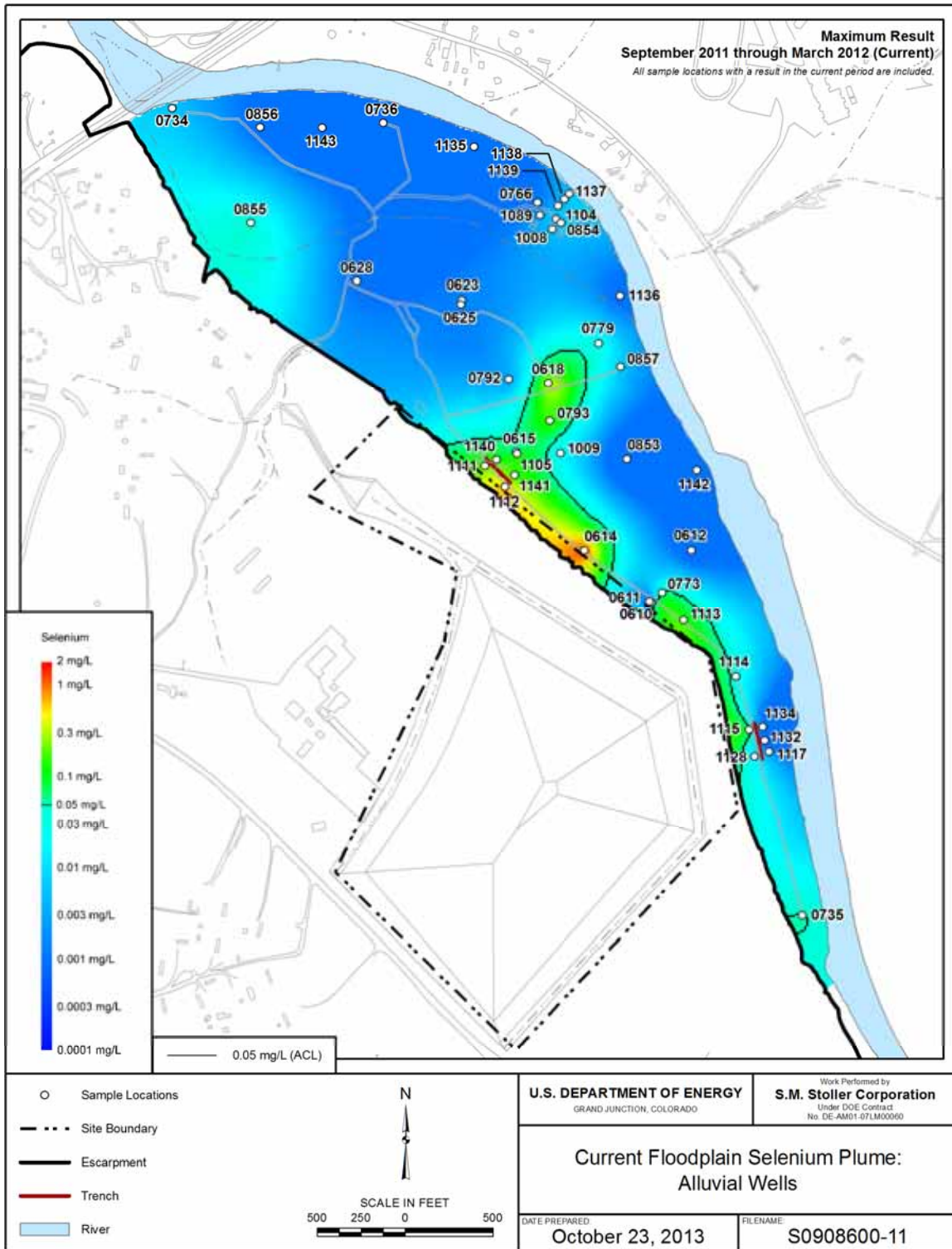


Figure 19. September 2011 through March 2012 Floodplain Selenium Plume—All Sampled Wells

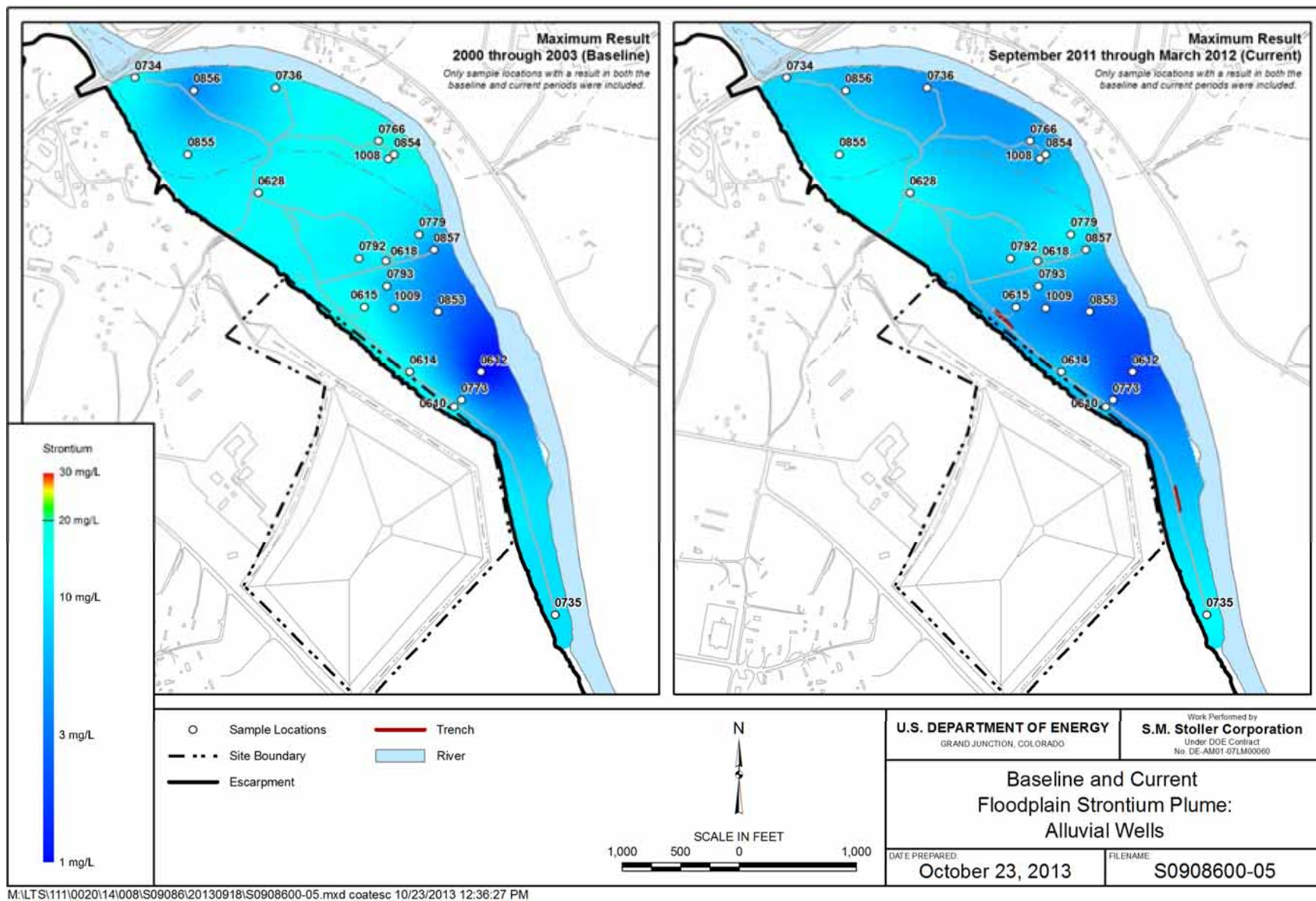


Figure 20. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Strontium Plumes

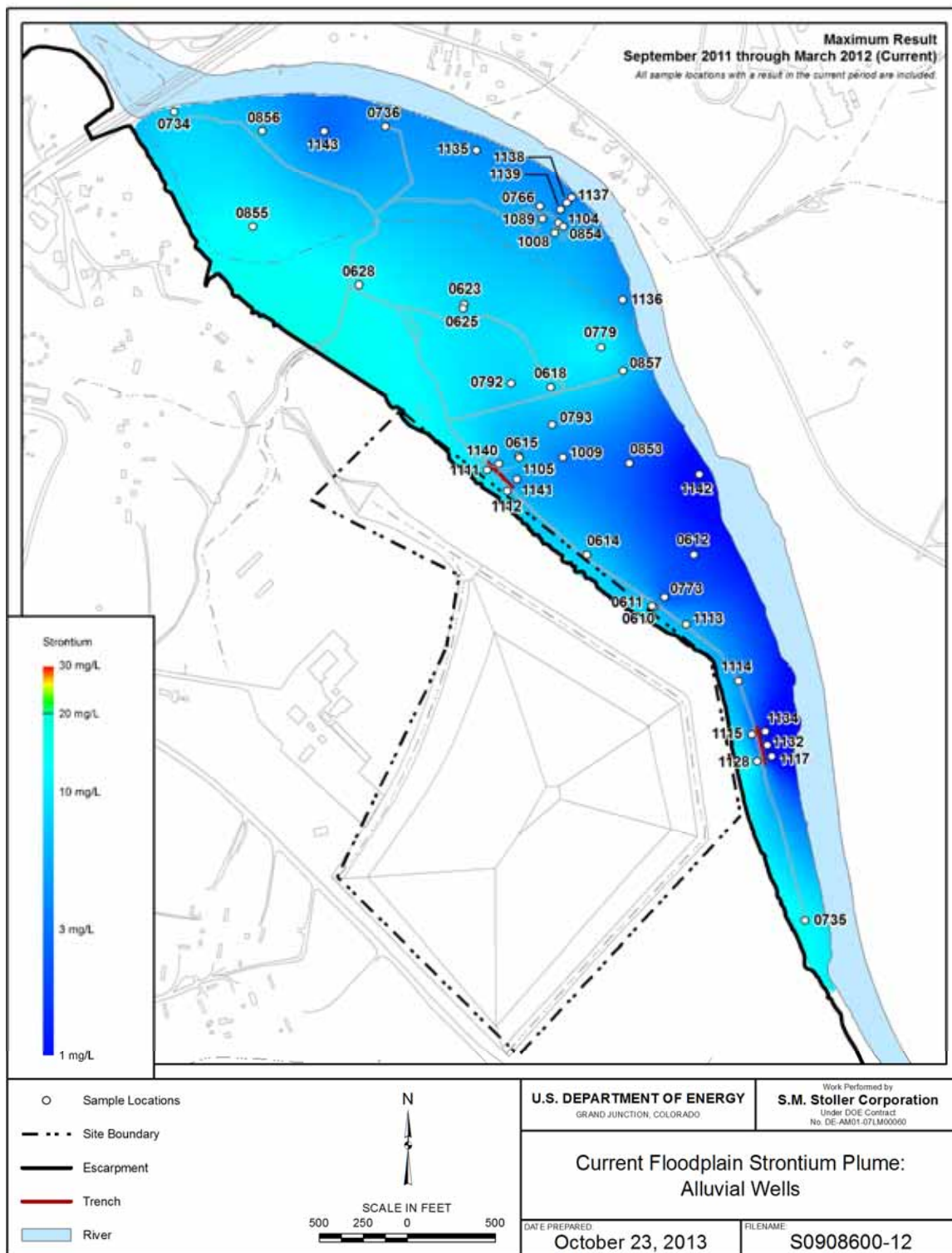


Figure 21. September 2011 through March 2012 Floodplain Strontium Plume—All Sampled Wells



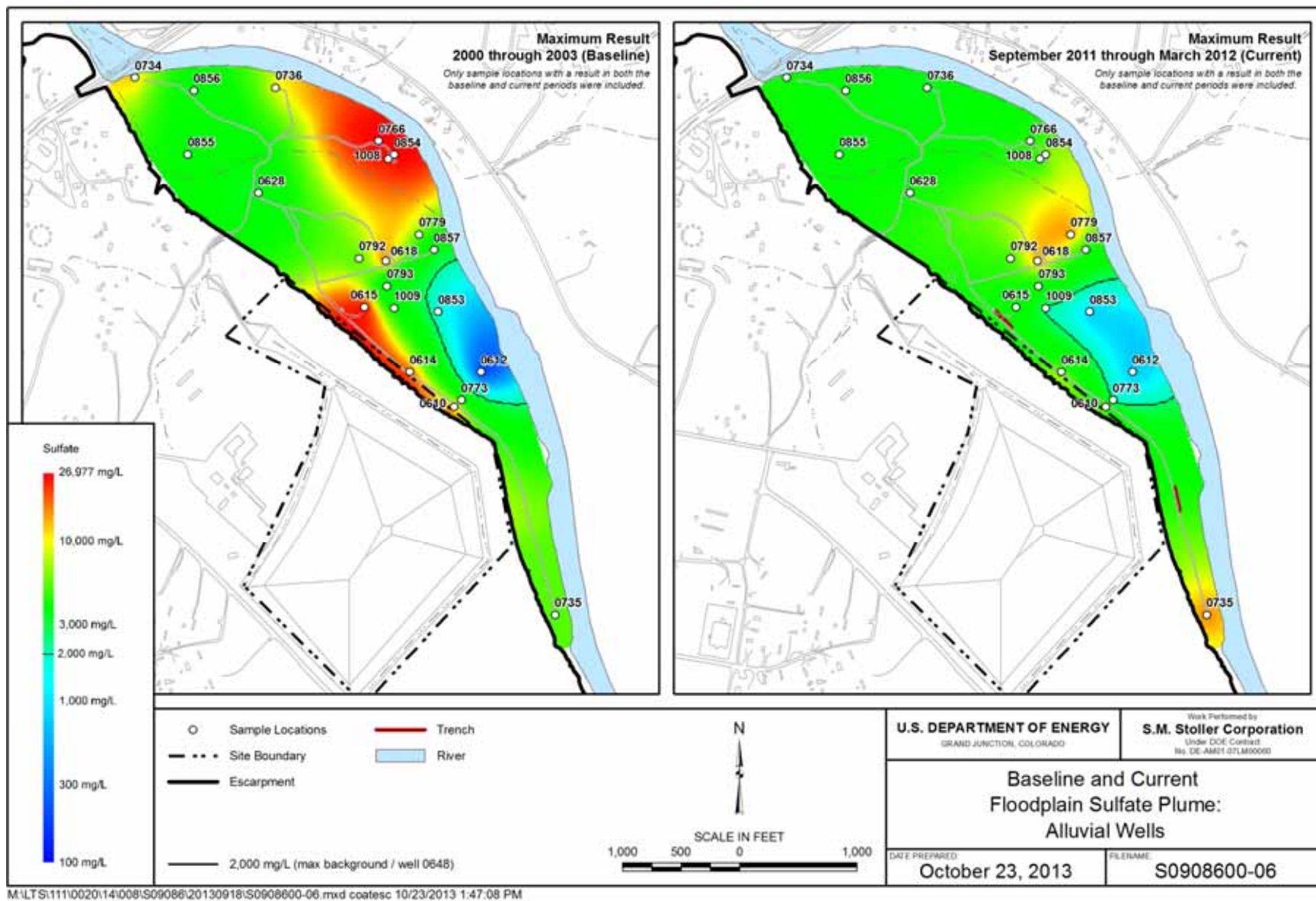


Figure 22. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Sulfate Plumes

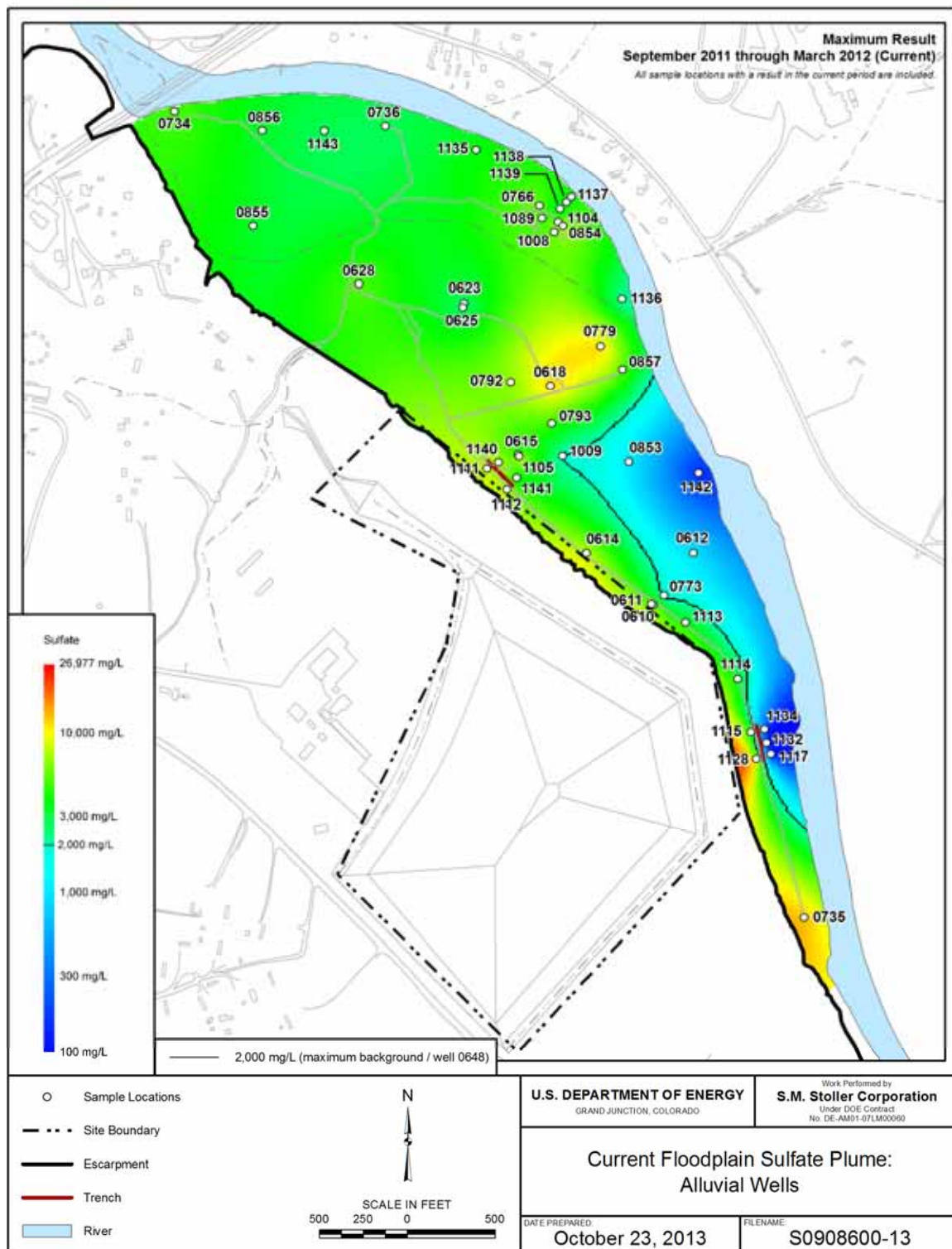


Figure 23. September 2011 through March 2012 Floodplain Sulfate Plume—All Sampled Wells



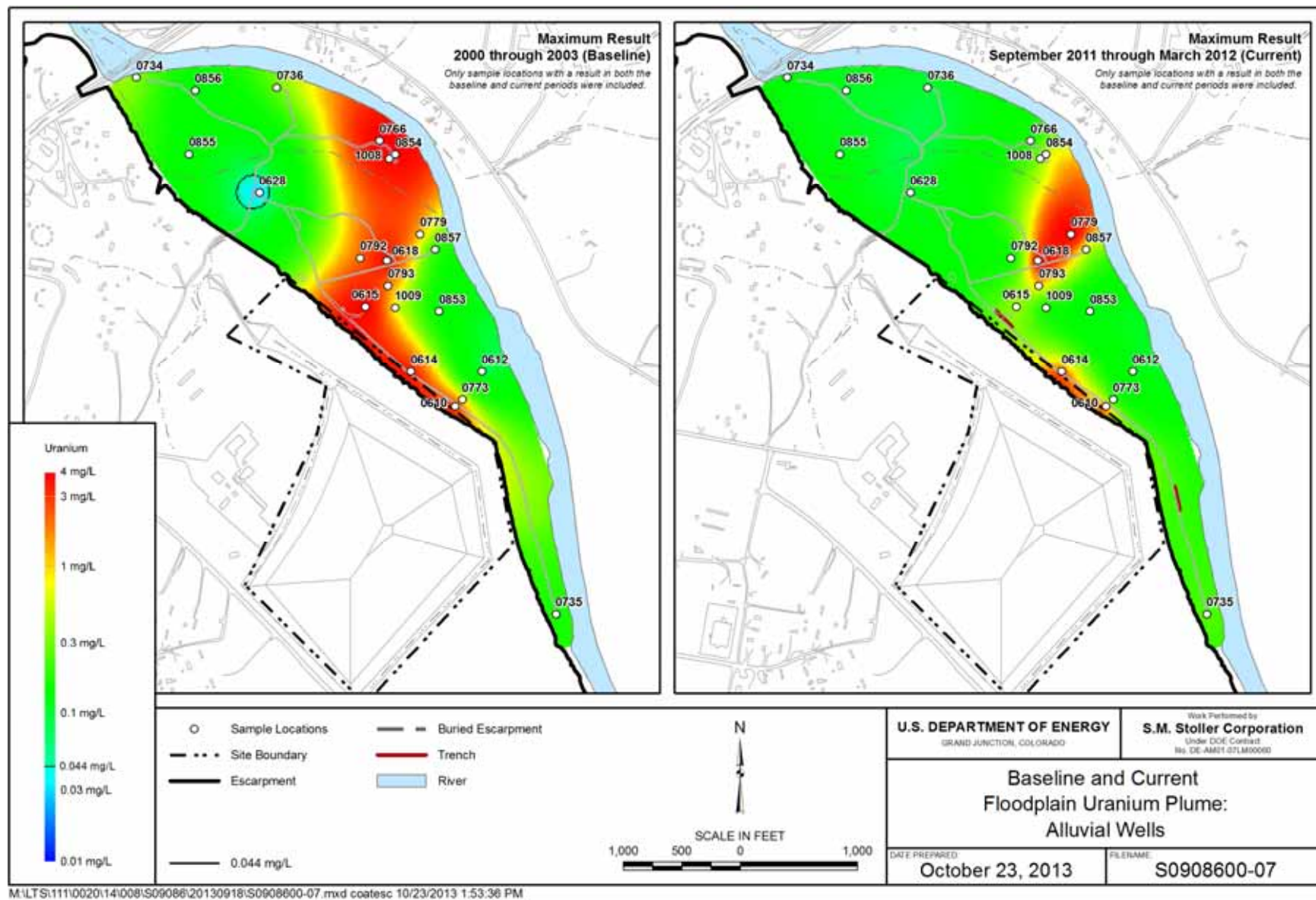


Figure 24. Baseline (2000–2003) and September 2011 through March 2012 Floodplain Uranium Plumes

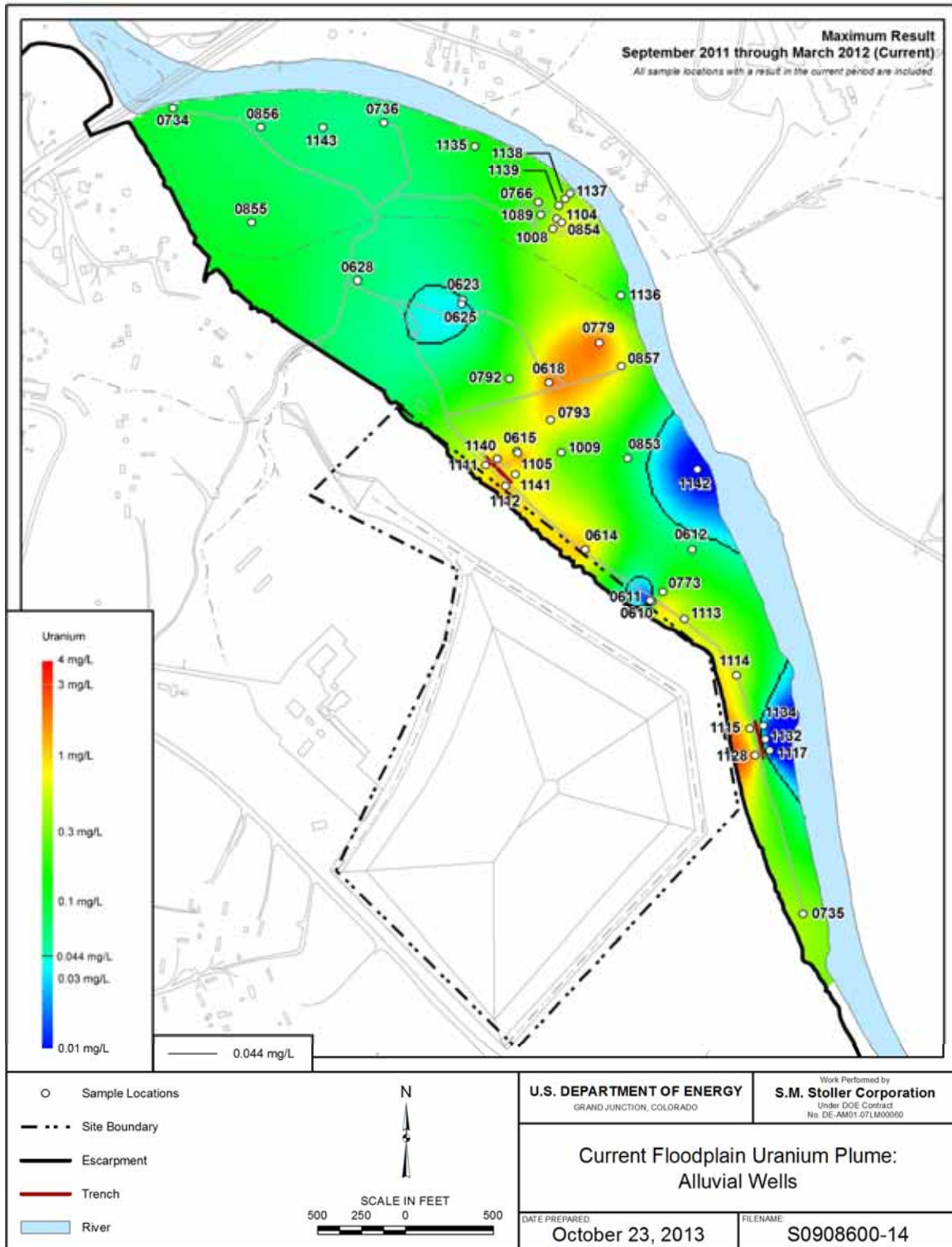


Figure 25. September 2011 through March 2012 Floodplain Uranium Plume – All Sampled Wells

## **2.0 Subsurface Conditions**

This section summarizes hydraulic and water-quality characteristics of the floodplain and terrace groundwater systems for the April 2011 through March 2012 reporting period, approximately 9 years after startup of the treatment system.

### **2.1 Floodplain Subsurface Conditions**

The following discussion of current subsurface conditions in the floodplain is based on the collection and analysis of groundwater samples and groundwater level data through March 2012. Analyses of groundwater level trends, groundwater flow directions, and contaminant distributions in the floodplain are presented below. Results are compared to baseline conditions established in the Baseline Performance Report (DOE 2003) to evaluate the effectiveness of the floodplain treatment system.

#### **2.1.1 Floodplain Groundwater Level Trends**

Analysis of groundwater level data is important for evaluating flow in the floodplain aquifer, including changes in flow direction induced by variable flows in the San Juan River. Historically, three-point analyses, based on water levels collected semiannually (September and March), were used to ascertain flow directions. The analyses demonstrated that flow in the floodplain generally behaves as expected in response to pumping from extraction wells and remediation trenches; that is, the flow of groundwater is predominantly toward these pumping locations (DOE 2008). An evaluation of the Trench 2 remediation system (DOE 2009) and a more recent evaluation of the Trench 1 system (DOE 2011d) support this observation.

Groundwater levels in the floodplain aquifer continue to be manually recorded during routine semiannual groundwater sampling events in March and September. Figure 26, which plots groundwater elevations for a representative subset of the floodplain wells, indicates that annual groundwater level fluctuations over the past 9 years have been on the order of 2 ft, with the March elevations generally being higher than those measured in September. In addition to manual measurements, relatively continuous groundwater elevations are measured in a subset of floodplain monitoring wells. Much of this type of data was historically collected using pressure transducers connected to dataloggers. In recent years, the traditional datalogger network has been replaced with a set of wells instrumented for DOE's remote telemetry (System Operations and Analysis at Remote Sites, or SOARS) network. In March 2011, six additional wells were added to the existing SOARS network near the trenches and the well 1089/1104 complex. SOARS water level data indicate a close correlation between subsurface water levels and the San Juan River's flow cycles, indicating relatively rapid responses of groundwater to changes in river flow and river stage.



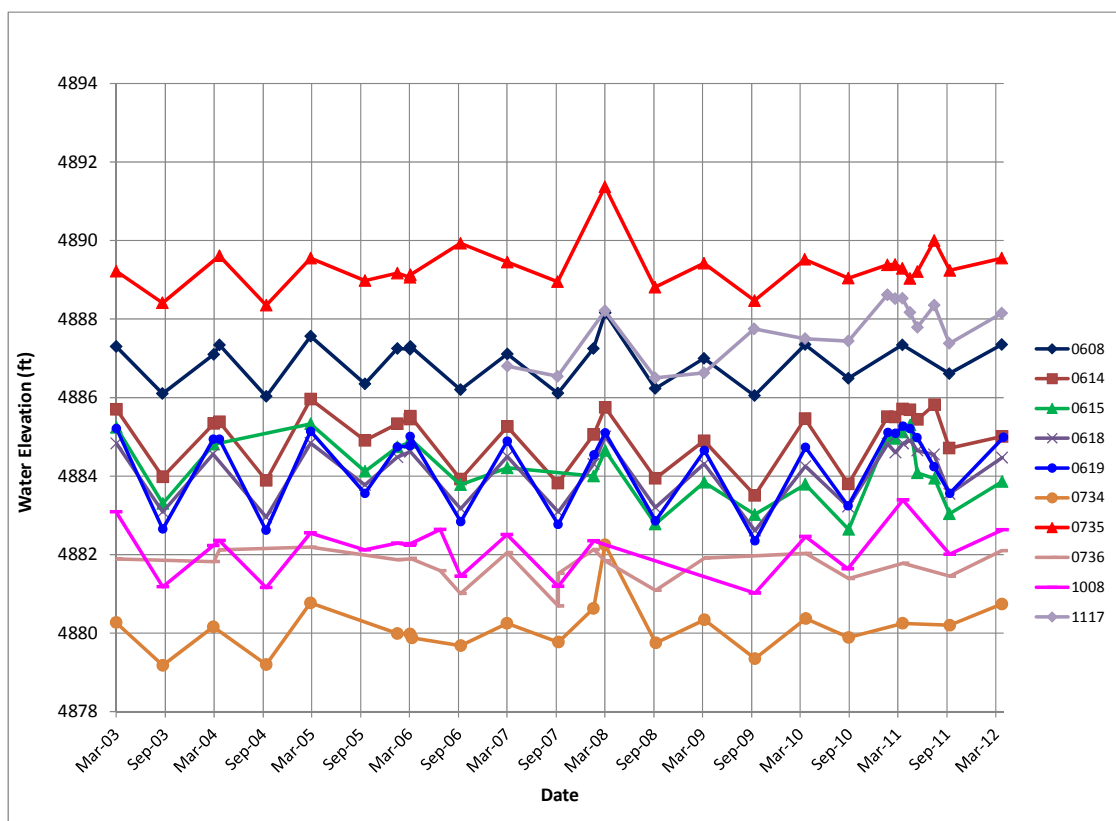


Figure 26. Floodplain Groundwater Elevations from Manual Measurements

The recent evaluations of the Trench 1 and Trench 2 groundwater remediation systems (DOE 2011d; DOE 2009) provide more detailed evaluations of groundwater chemistry in portions of the floodplain affected by river losses to the subsurface.

### 2.1.2 Floodplain Contaminant Distributions and Temporal Trends

Groundwater samples were collected from 59 floodplain monitoring wells in September 2011 and March 2012. This section uses the floodplain well groupings shown in Figure 27 to describe the changes that have occurred in the concentrations of floodplain contaminants since the last Annual Performance Report. Emphasis is placed on those areas that best reflect remediation progress and those with some of the highest COC concentrations—namely, Trenches 1 and 2 and the well 1089 area.

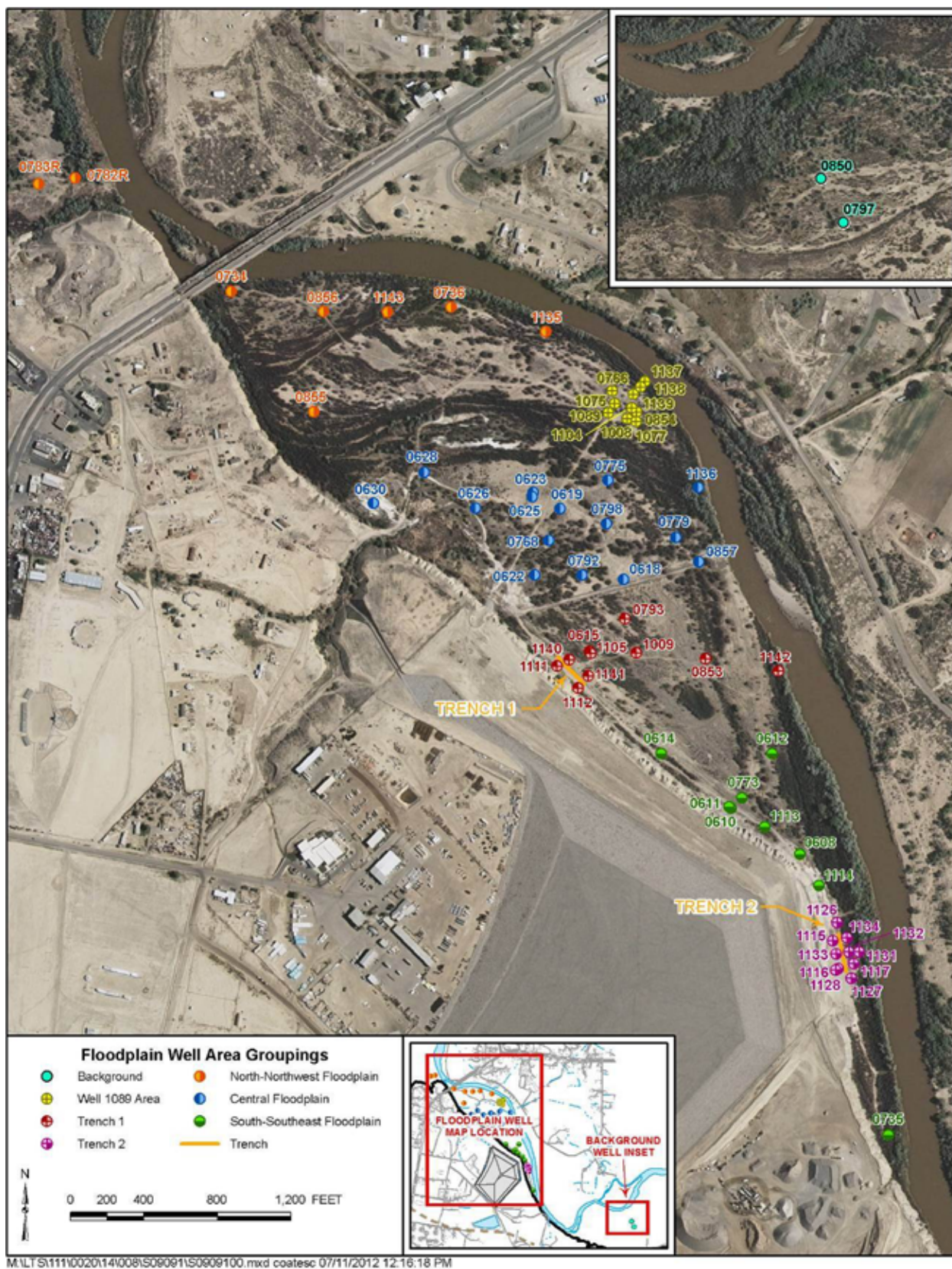


Figure 27. Shiprock Site Floodplain Area Well Groupings

Of all the COCs, uranium, sulfate, and nitrate receive the most attention because they are widespread and most representative of site contamination trends. Trends for ammonia and selenium are apparent in only a small subset of floodplain wells. In contrast to previous annual reports, temporal plots of manganese and strontium levels in floodplain wells are omitted from this assessment because trending has not been evident, and, in most cases, observed concentrations for these constituents fall within the range of measured background values.

### ***Trench 1 Area***

Figure 28, which presents temporal plots of uranium, nitrate, and sulfate concentrations in Trench 1 area wells, shows marked reductions in the levels of all three constituents since the trench was installed in 2006. The most significant declines are observed at wells 0615 and 1105, about 150 ft from the trench on its river side. At wells closer to the river, concentration decreases are less apparent, and contaminant levels are much lower and appear relatively stable since the start of trench pumping. COC concentrations in well 1111, between the trench and the escarpment, are lower than those in well 1112, also on the escarpment side of Trench 1.

A rebound in uranium and sulfate concentrations in early 2011 was apparent at wells 1111 and 1112 (Figure 28), but concentrations again decreased in 2012. In addition, the nitrate concentration increased at well 1112 in early 2011 prior to a discernible decrease in following months. Examination of water levels measured simultaneously at wells located close to Trench 1 suggests that the temporary rebound phenomena were associated with a few extended periods of non-pumping at the trench in late 2010 and early 2011.

Percent reductions in ammonia and selenium concentration in the Trench 1 area since pumping began at the trench (Figure 29) were less than those observed for uranium, nitrate, and sulfate. In addition, ammonia concentrations at wells in the area during the past 3 to 4 years were erratic and showed no significant trends. This is also true for selenium, although selenium concentration at well 0615 since the start of trench pumping did show a notable decrease over time. Similar to the recent rebound in monitored uranium, nitrate, and sulfate levels in the Trench 1 area, significant increases in selenium concentration since September 2010 at wells 1112, 1140, and 1141 (Figure 29) appear to be related to extended periods of non-pumping at the trench, beginning in late 2010 and extending into 2011.

### ***Well 1089 Area***

Figure 30 plots uranium, nitrate, and sulfate concentrations in well 1089 area wells. Although concentration decreases in this area are not of the magnitude and consistency as those observed at Trench 1 area wells, decreases since remediation pumping began in 2003 are nevertheless evident. A comparison of measured sulfate concentrations in the area during baseline years (2000–2003) with more recent concentrations indicates that average sulfate concentrations in the area have decreased by nearly 10,000 mg/L (from about 18,000 mg/L to just above 8,000 mg/L). Such a decrease indicates that sulfate levels in this part of the alluvial aquifer have dropped more than 50 percent over a period of about 9 years, further suggesting that dissolved sulfate mass in this locale has been greatly reduced.



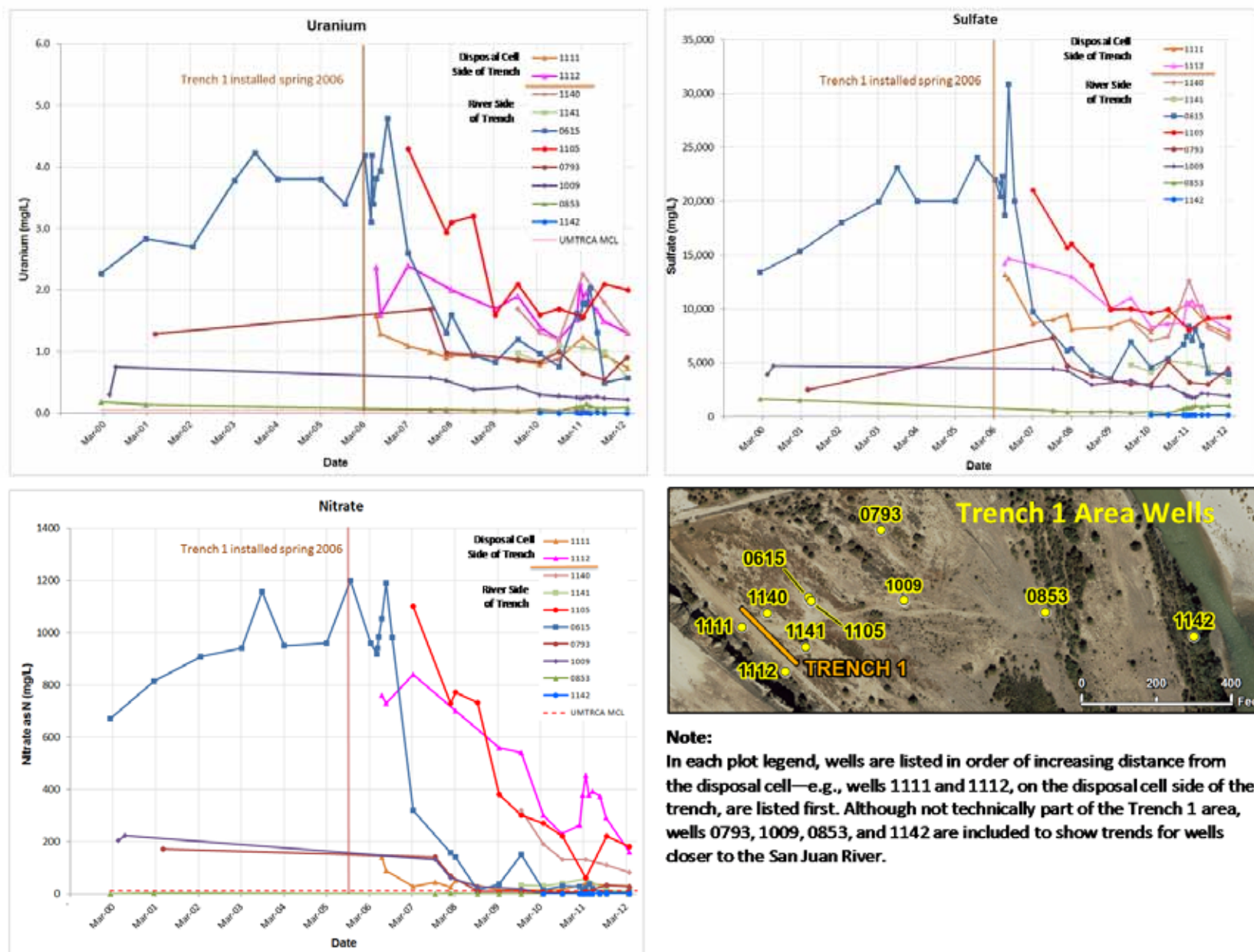


Figure 28. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 1 Area Wells

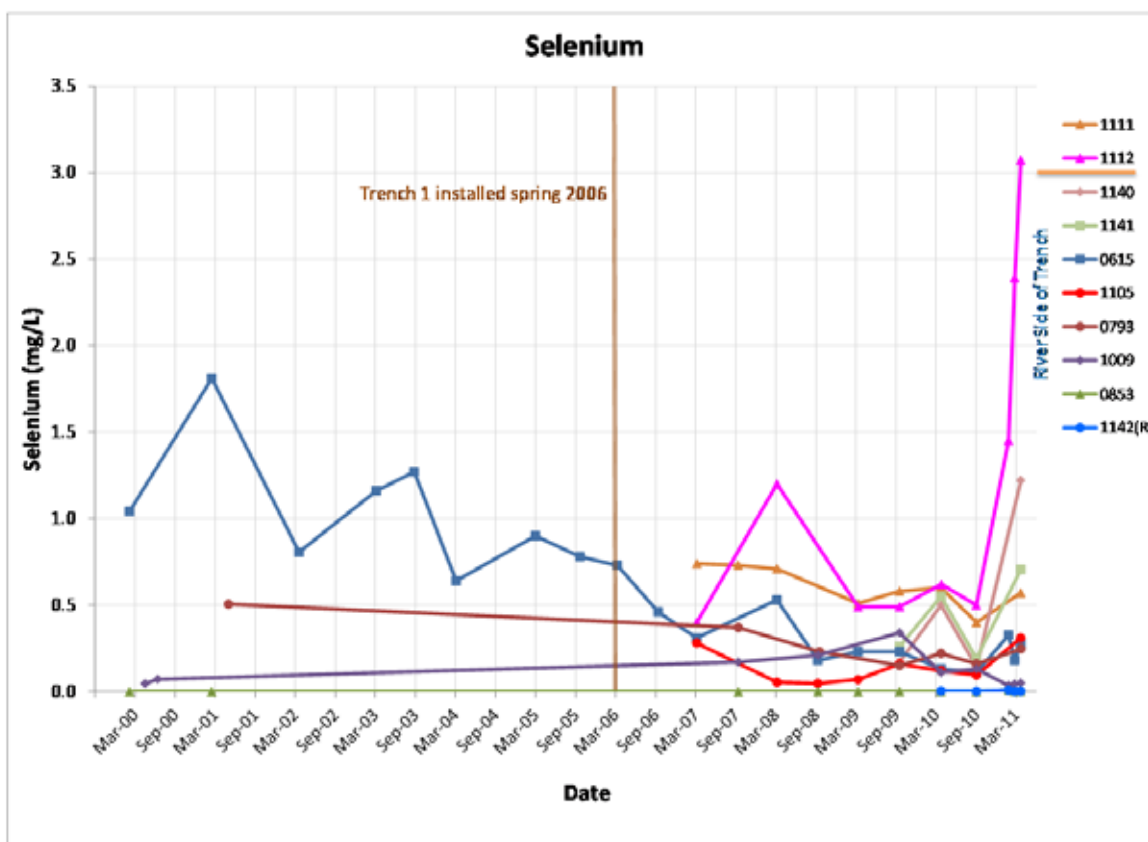
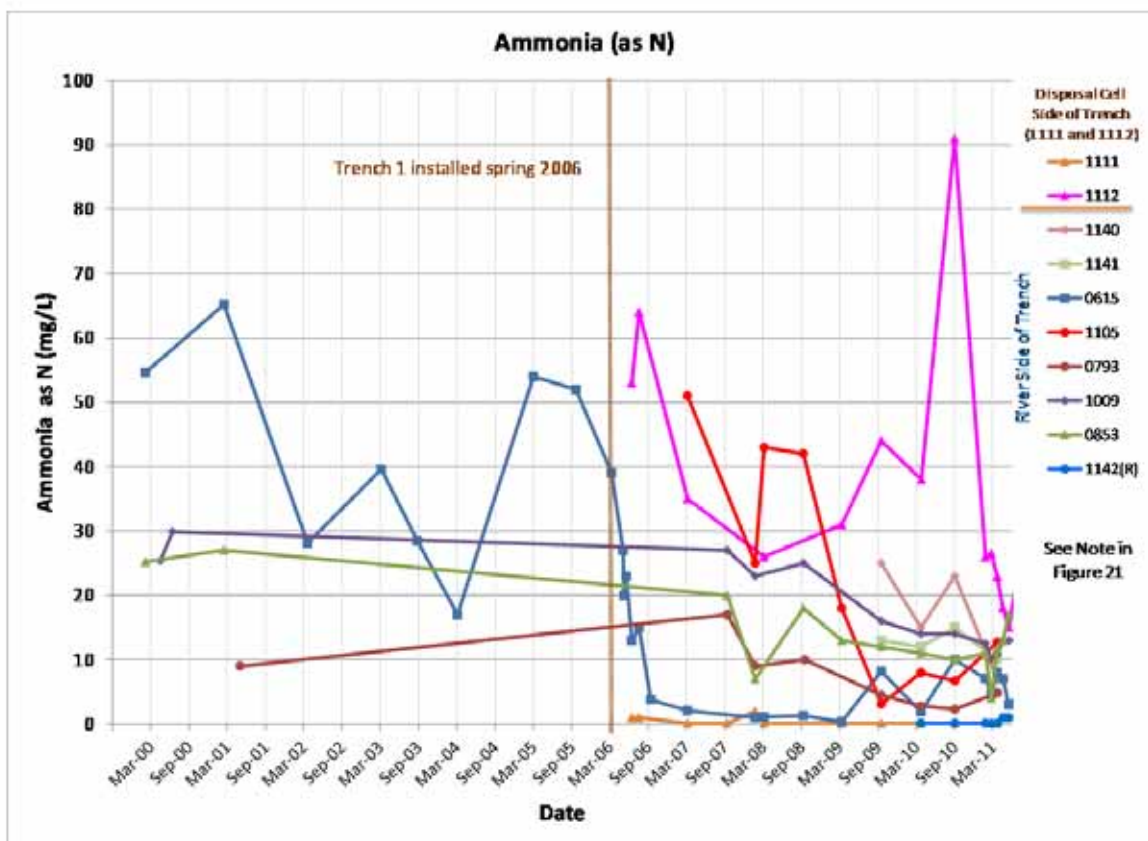


Figure 29. Ammonia and Selenium Concentration Trends in Trench 1 Area Wells

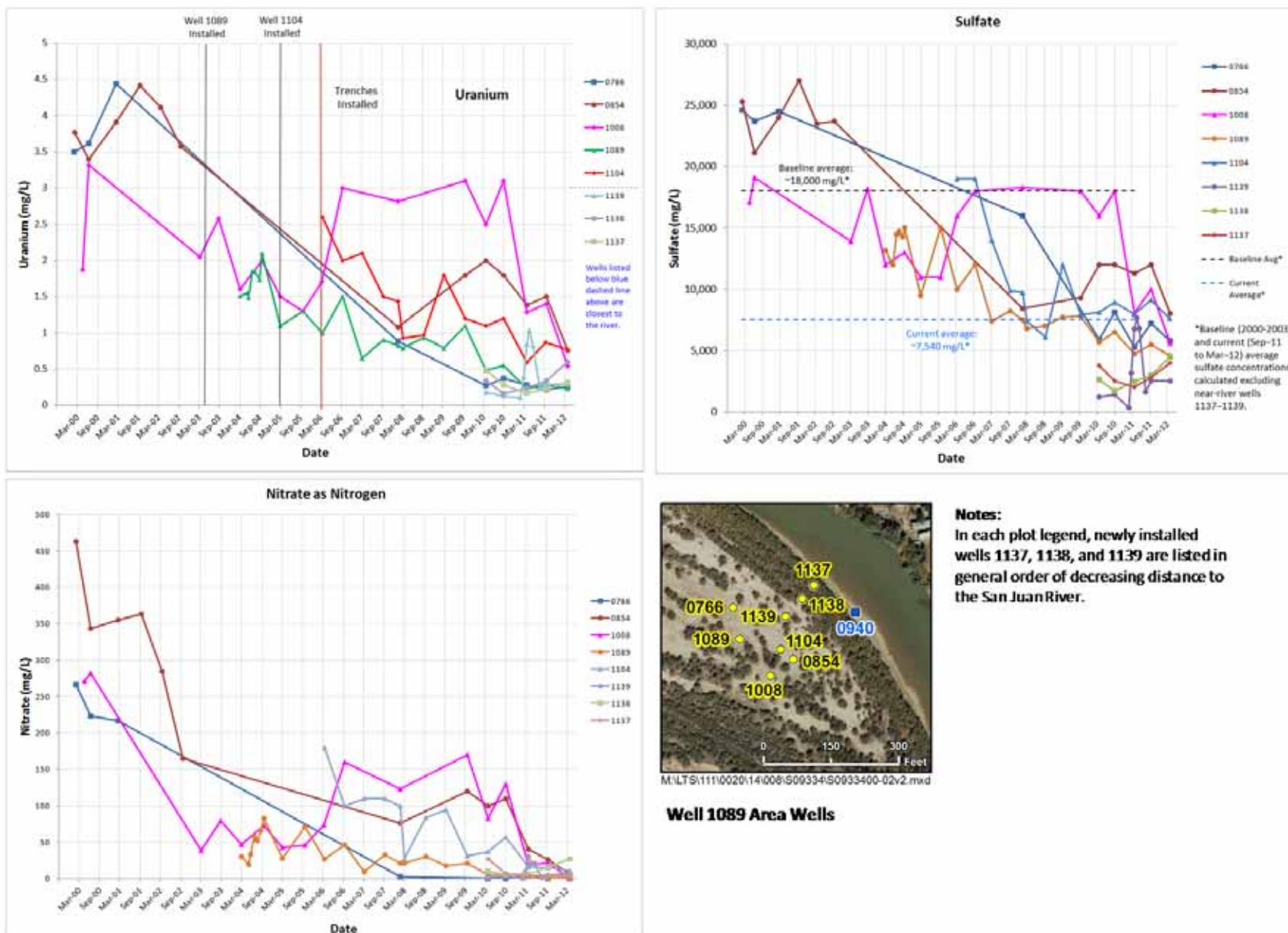


Figure 30. Uranium, Nitrate, and Sulfate Trends in the Well 1089 Area



Although the concentration plots in Figure 30 indicate that pumping at pumping wells 1089 and 1104 is gradually removing contaminant mass in nearby locations, levels of uranium, nitrate, and sulfate tend to fluctuate from year to year. Measured concentrations at well 1008 have been noticeably erratic, as observed previously in the preliminary evaluation of the Trench 1 system and surrounding areas (DOE 2011d).

### ***Trench 2 Area***

Figure 31, which plots uranium, nitrate, and sulfate concentrations in wells surrounding the trench, illustrates a marked difference in contaminant levels between wells on the escarpment side of the trench and wells on the river side of the trench. As shown in this set of graphs, uranium concentrations in wells located on the river side of the trench have remained below the 0.044 mg/L MCL since spring 2006. Uranium levels at two of the escarpment-side wells (1115 and 1128) have varied between 2009 and 2012. The causes of these variations are unclear, although changes in pumping rate from the trench may play a role.

Nitrate and sulfate trends in the Trench 2 area tend to parallel those noted for uranium. Variation in wells 1115 and 1128 are correlated with those noted for uranium, and concentrations in wells located on the river side of the trench are orders of magnitude lower than those on the escarpment side of the trench.

### ***Southeast Floodplain***

Figure 32 plots uranium concentrations in the south-southeast well subset shown in Figure 27. Declines are evident for wells 0608 (screened in shallow Mancos Shale), 0610, 0611, 0614, 0773, and 1113, located at or relatively close to the base of the escarpment. Concentrations in remaining wells are relatively stable. Although some of the wells in the southeast floodplain area show increases in uranium concentrations in 2010, 2011, and 2012, it is unclear whether these increases are due to rebound effects stemming from periods of non-pumping at Trench 1 in late 2010 and early 2011. The relatively large distances separating the trench from the monitoring wells in this area suggests that hydraulic effects of trench pumping on groundwater in the vicinity of wells would be very minor and, therefore, not conducive to rebound phenomena. Temporal trends in concentrations at wells in the southeast floodplain group, particularly at the base of the escarpment, are important because they are the most reliable indicators of decreases, if any, of contaminant discharge from the terrace to the floodplain via fractures in the Mancos Shale. The flow paths created by pumping of Trench 1 induce inflows of relatively fresh (uncontaminated) water from the river (DOE 2012b).

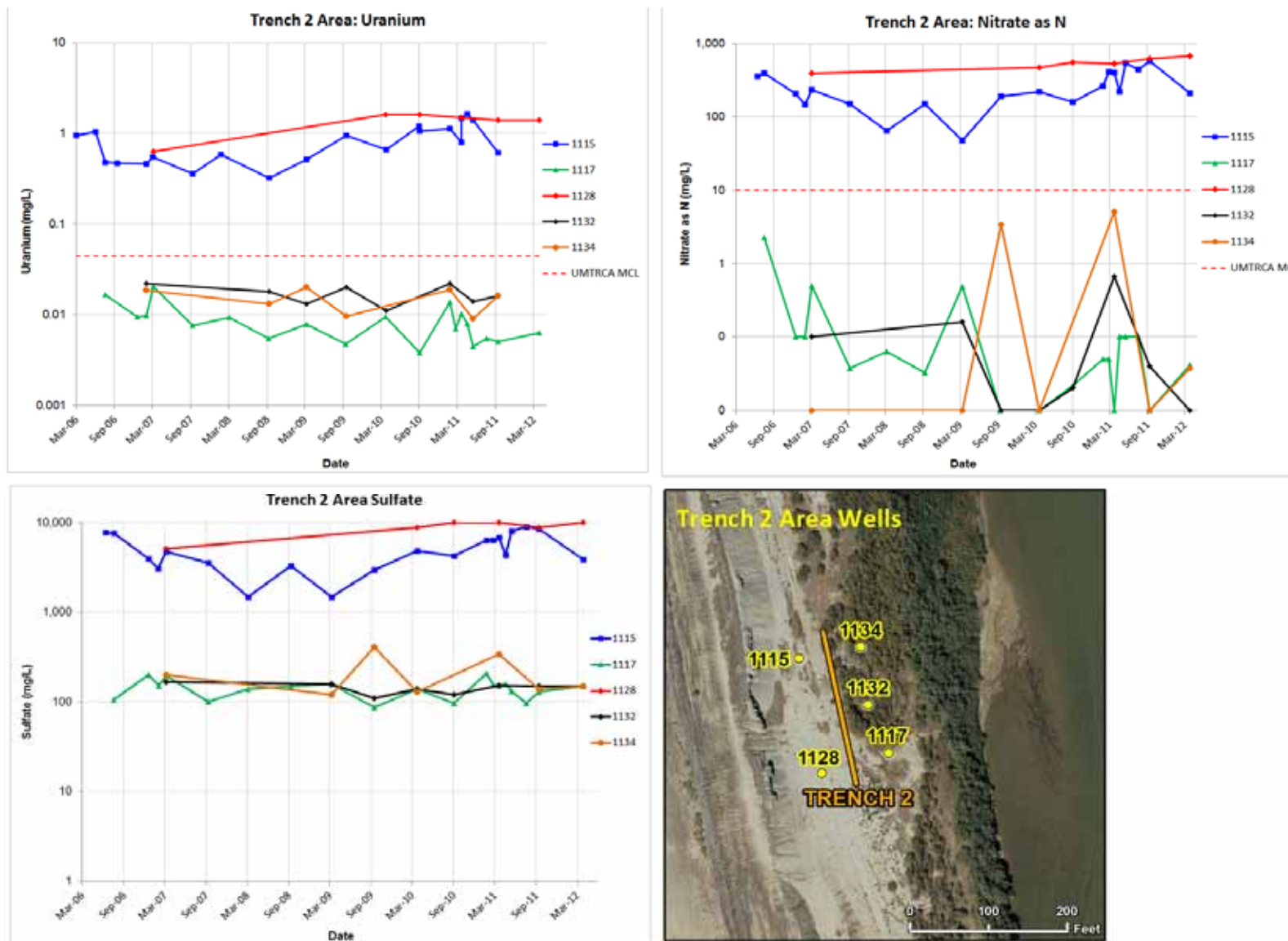


Figure 31. Uranium, Nitrate, and Sulfate Trends in Trench 2 Area Wells

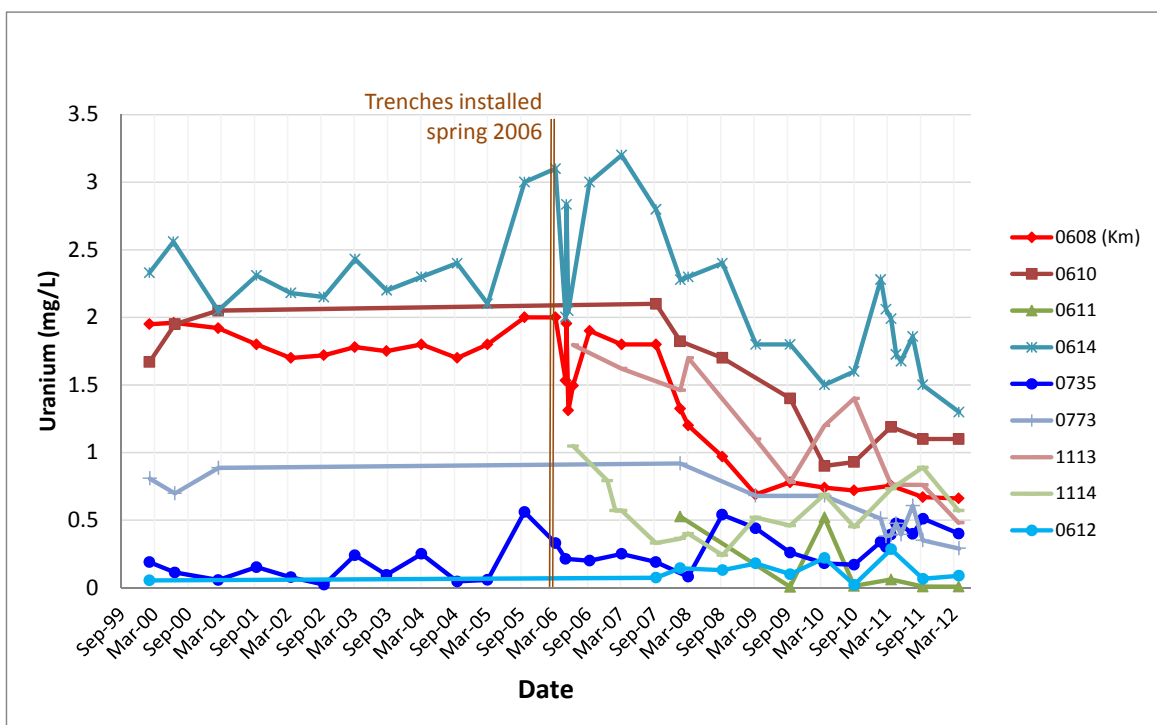


Figure 32. Uranium Trends in South-Southeast Floodplain Wells

### Other Floodplain Areas and COCs

This section has focused primarily on uranium because, of all the COCs, it is most prevalent on the floodplain and a reliable indicator of remediation progress. Because the floodplain well network is so vast, it is difficult to distill all monitoring results in a way that meaningfully (and succinctly) captures both spatial and temporal trends. A more complete interpretation is possible by examining Figure 4 through Figure 25 in conjunction with the corresponding Data Validation Packages (DOE 2012c, DOE 2012d) and data available in the Geospatial Environmental Mapping System (GEMS) on the LM website.

#### 2.1.3 Floodplain Contaminant Removal

The floodplain trenches removed approximately 478,000 pounds of contaminants from the floodplain groundwater system during the 2011–2012 reporting period (Table 3 in Section 3.2.3). On the basis of monitoring results for wells recently installed adjacent to the river in the 1089 area (Figure 30) and wells on the river side of Trench 2 (Figure 31), it is likely that pumping of groundwater from the floodplain aquifer is greatly limiting contaminant discharge to the San Juan River.

As prescribed in the GCAP (DOE 2002), DOE currently monitors eight river locations, including one upgradient background location (0898). Consistent with previous annual reports (e.g., DOE 2012a), Figure 33 plots concentrations of uranium (left y-axis) and nitrate (right y-axis) for location 0940, which was identified as a key river monitoring location in the GCAP. It is located just north of pumping wells 1089 and 1104, where contaminant plumes in



the alluvial aquifer likely discharge to the river under background, nonpumping conditions (DOE 2002).

As shown in Figure 33, uranium and nitrate trends correlate with each other and with trends at the upstream (background) 0898 location. Concentrations of nitrate and uranium at the 0940 location have remained below previously established background benchmark values (1.05 and 0.005 mg/L, respectively) since 2004. Location 0940 is the only one where measured concentrations have exceeded background benchmarks for a COC. Surface water samples collected at location 0940 in March 2004 were the last to contain uranium and nitrate at concentrations exceeding the benchmarks.

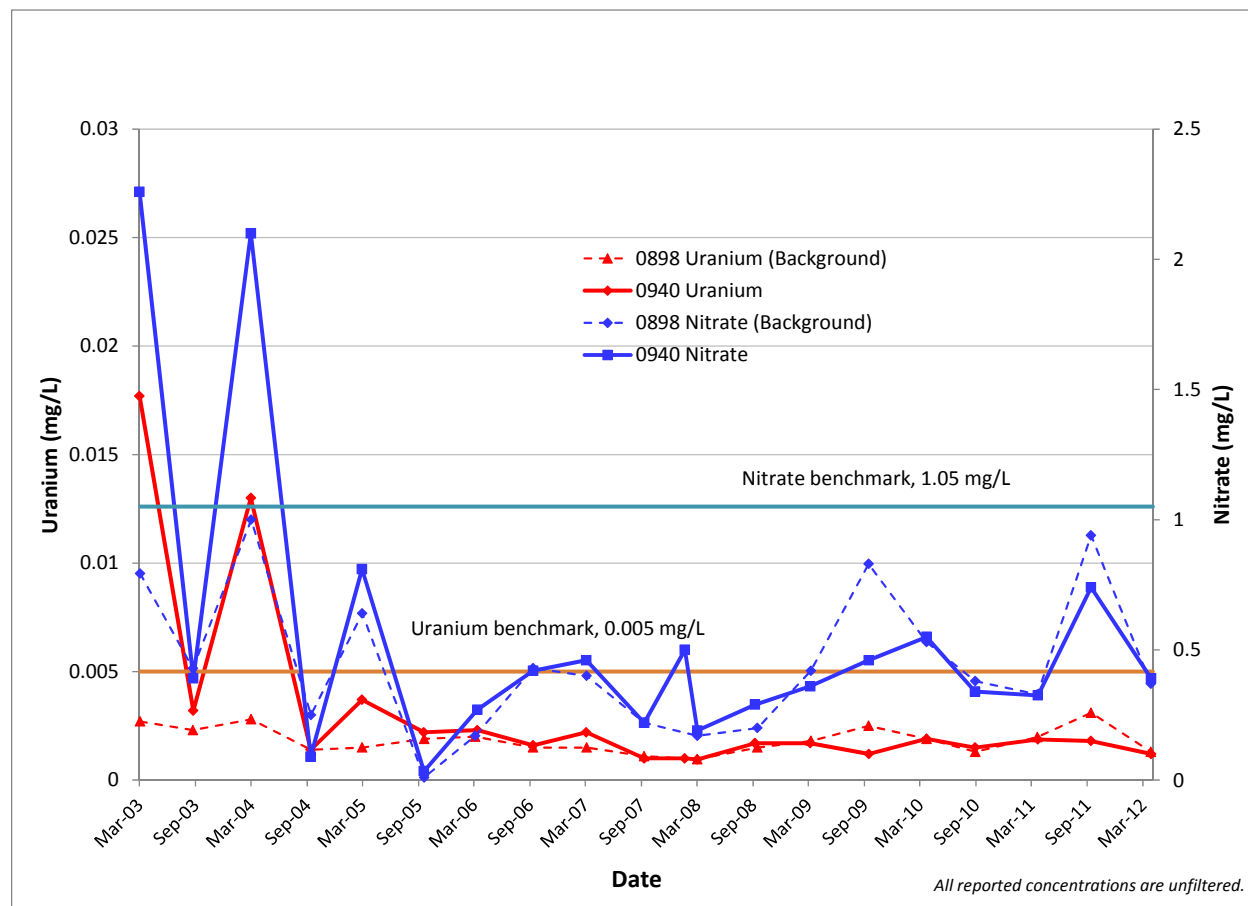


Figure 33. Uranium and Nitrate Concentrations in San Juan River Location 0940 and Background Location 0898

## 2.2 Terrace System Subsurface Conditions

The discussion of current subsurface conditions on the terrace is based on collection and analysis of groundwater level data through March 2012. Analyses of water level trends and drain flow rates associated with the terrace are discussed below. Results are compared to baseline conditions established in the Baseline Performance Report (DOE 2003) to evaluate the effectiveness of the terrace treatment system.

Currently, there are no concentration-driven performance standards for the terrace system because the compliance strategy is active remediation (hydrologic control) to eliminate exposure pathways at escarpment seeps and at Bob Lee and Many Devils Washes. As a best management practice, selected contaminant concentrations are measured at each extraction well, drain, and seep. Estimates of mass removal via the terrace remediation system, compiled for this performance period, are presented in Section 3.2.3 of this report.

### **2.2.1 Terrace Groundwater Level Trends**

As presented in greater detail in Section 3, as of March 2012, the cumulative volume of water removed from the terrace extraction system since pumping began was approximately 30 million gallons. Pumping records indicate that approximately 3.3 million gallons (Table 3) were removed from the terrace between April 2011 and April 2012. Groundwater level data from the terrace collected during the March 2012 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). Figure 34 presents a qualitative map view of some of the changes in groundwater elevation during this period. This figure demonstrates that groundwater elevations have declined across much of the terrace groundwater system. Of the 30 water level measurements taken in September 2011 or March 2012 at wells screened in terrace alluvium, the majority showed declines relative to the baseline period of March 2003. Declines ranged from 0.2 ft to maximum decreases of 7.6–7.7 ft in west terrace wells 0836 and 0837; the average decrease was 2.9 ft. As observed last year (DOE 2012a), five alluvial west terrace wells (0832, 0846, 1060, 1120, and 1122) were dry at the time of the March 2012 sampling event.

Water levels have also been monitored using pressure transducers connected to dataloggers in selected wells on the terrace. Plots of datalogger-based water elevations versus time are shown in Figure 35 and Figure 36. Figure 35 plots water level elevations for wells greater than 4,930 ft msl; most of the wells in this category are on the east side of Highway 491. Although some of the hydrographs in Figure 35 indicate that groundwater levels near the former mill and tailings pile generally decreased between 2003, when groundwater remediation was initiated on the terrace, and early 2009, upward trends tend to be seen at these locations in following years.

Figure 36 presents datalogger-derived water elevations for wells with water elevations below 4,930 ft msl. Three of the wells in this category (0836, 0846, and 0848) are located west of Highway 491, in a part of the terrace that was irrigated in earlier years. The hydrographs for these three locations indicate that water levels west of the highway have been gradually declining.

### **2.2.2 Drain Flow Rates**

As discussed in the Baseline Performance Report (DOE 2003), the flow rates of the pumps removing water from the drains installed in Bob Lee Wash and Many Devils Wash were expected to decrease as groundwater levels in the terrace declined. Between April 2011 and March 2012, the average pumping rate from Bob Lee Wash was 3.1 gpm, about half the rate reported for 2010–2011 (refer to Figure 51 in the following section). The average pumping rate from the drain in Many Devils Wash during the performance period was about 0.6 gpm (see Figure 52).

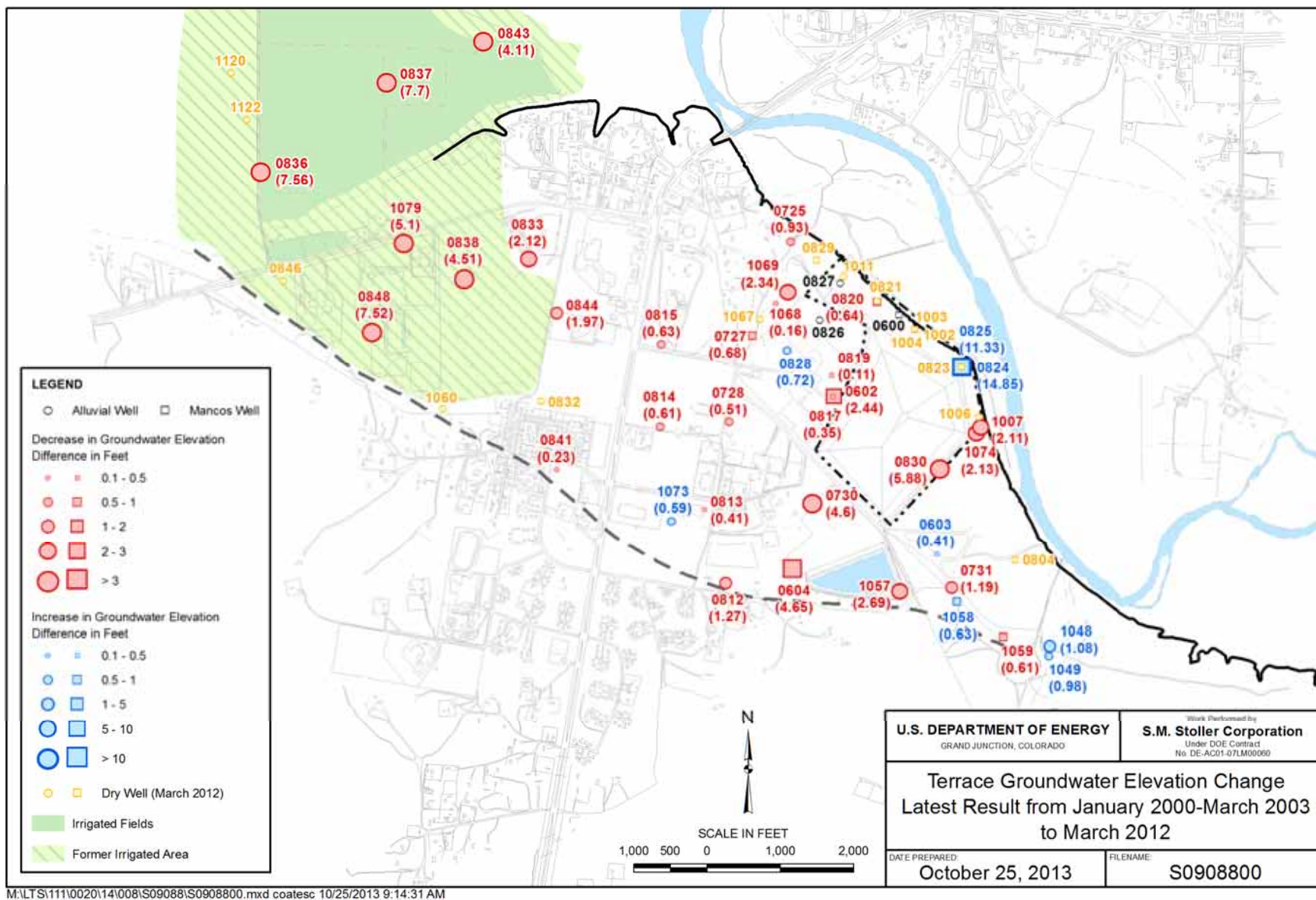


Figure 34. Terrace Groundwater Elevation Changes from Baseline (2000-2003) to Current (March 2012) Conditions



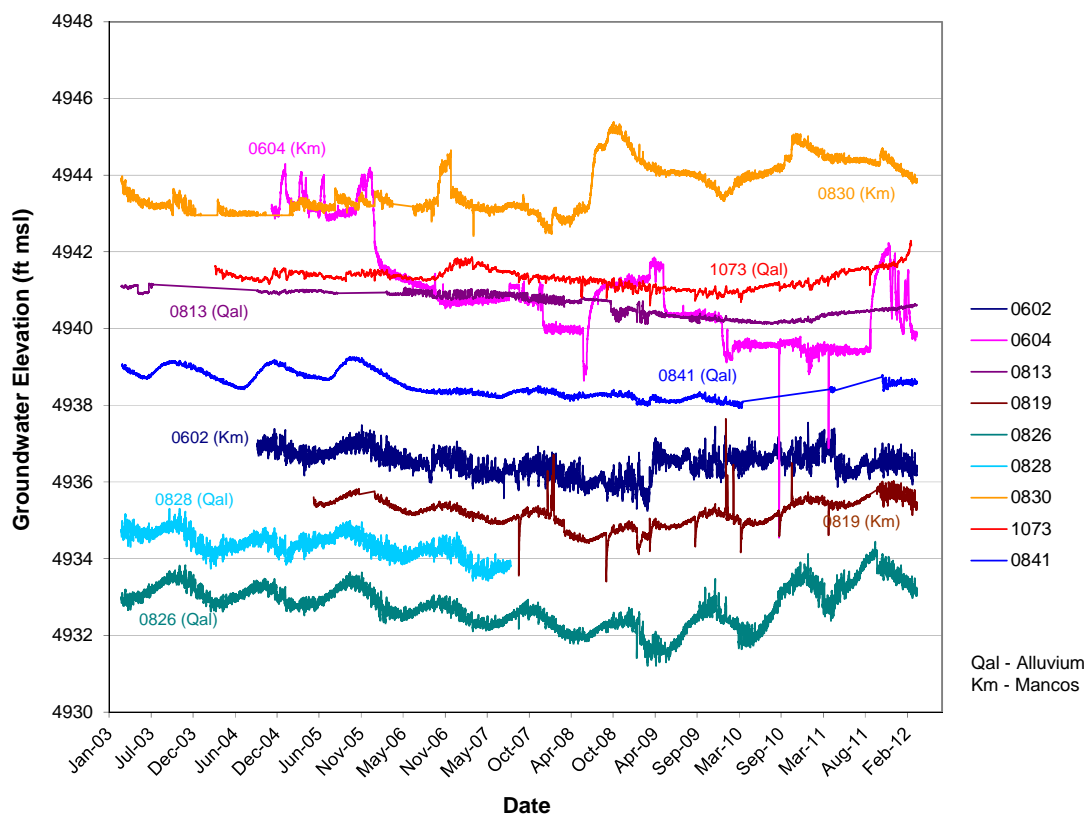


Figure 35. Terrace Datalogger Measurements, Wells with Water Elevations above 4,930 ft msl

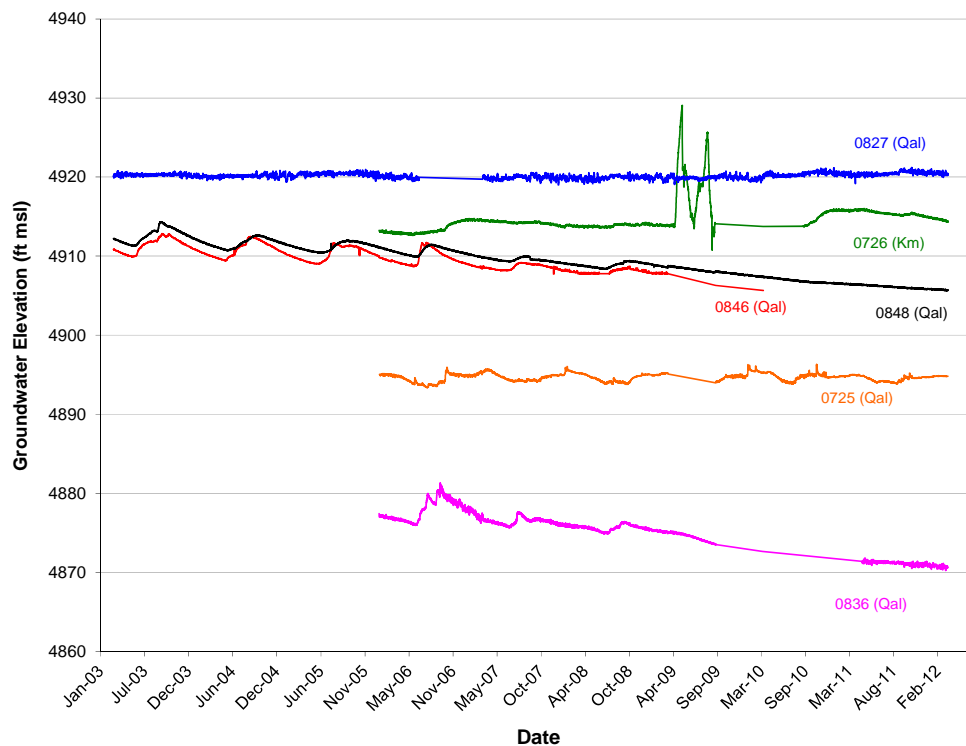


Figure 36. Terrace Datalogger Measurements, Wells with Water Elevations less than 4,930 ft msl

## **3.0 Remediation System Performance**

This section describes the key components of the floodplain and terrace groundwater remediation systems and summarizes their performance for the 2011–2012 reporting period.

### **3.1 Floodplain Remediation System**

The floodplain remediation system consists of the three major components shown in Figure 1: two extraction wells (wells 1089 and 1104); two drainage trenches (horizontal wells), Trench 1 and Trench 2; and a sump (collection drain) used to collect discharges from seeps 0425 and 0426 on the escarpment. The objective of the floodplain groundwater extraction system is to reduce the mass of COCs in alluvial groundwater near the San Juan River and to lessen exposure and potential risks to aquatic life. All groundwater collected from the floodplain extraction wells and trenches is piped south to the terrace and discharged into the evaporation pond.

#### **3.1.1 Extraction Well Performance**

The floodplain extraction well system consists of wells 1089 and 1104 (Figure 1). These wells were constructed using slotted culverts placed in trenches excavated to bedrock. Corresponding pumping rates and cumulative volumes of groundwater extracted are plotted in Figure 7 and Figure 8. From April 2011 through March 2012, approximately 2.2 million gallons of water were removed from well 1089 at an average pumping rate of 5.8 gpm.<sup>4</sup> Pumping rates at well 1104 averaged about 2.1 gpm; the cumulative extraction volume was about 970,000 gallons. During the 9-year period since the start of operations in March 2003 through the end of March 2012, totals of approximately 24.9 million and 5 million gallons of water have been removed from wells 1089 and 1104, respectively.

#### **3.1.2 Floodplain Drain System Performance**

In spring 2006, two drainage trenches—Trench 1 (1110) and Trench 2 (1109)—were installed in the floodplain just below the escarpment to enhance the extraction of groundwater from the alluvial system (Figure 1). Pumping began in April 2006. From April 2011 through March 2012, approximately 4.6 million gallons of water were removed from Trench 1 at an average pumping rate of 10.8 gpm (Figure 39). This volume is higher than the 2.8 million gallons reported in last year's performance report (DOE 2012a).

In 2011–2012, nearly 3.6 million gallons of water were removed from Trench 2 at an average pumping rate of 8.0 gpm (Figure 40). This rate, which reflects pumping days only, is comparable to the rate reported last year (8.4 gpm average, DOE 2012a). However, the annual extracted volume is greater than the approximately 1.9 million gallons pumped in 2010–2011.

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<sup>4</sup> In the text of this report, total volumes are rounded (e.g., to the nearest thousand or larger); corresponding nonrounded values are shown in the figures and are listed in Table 3.

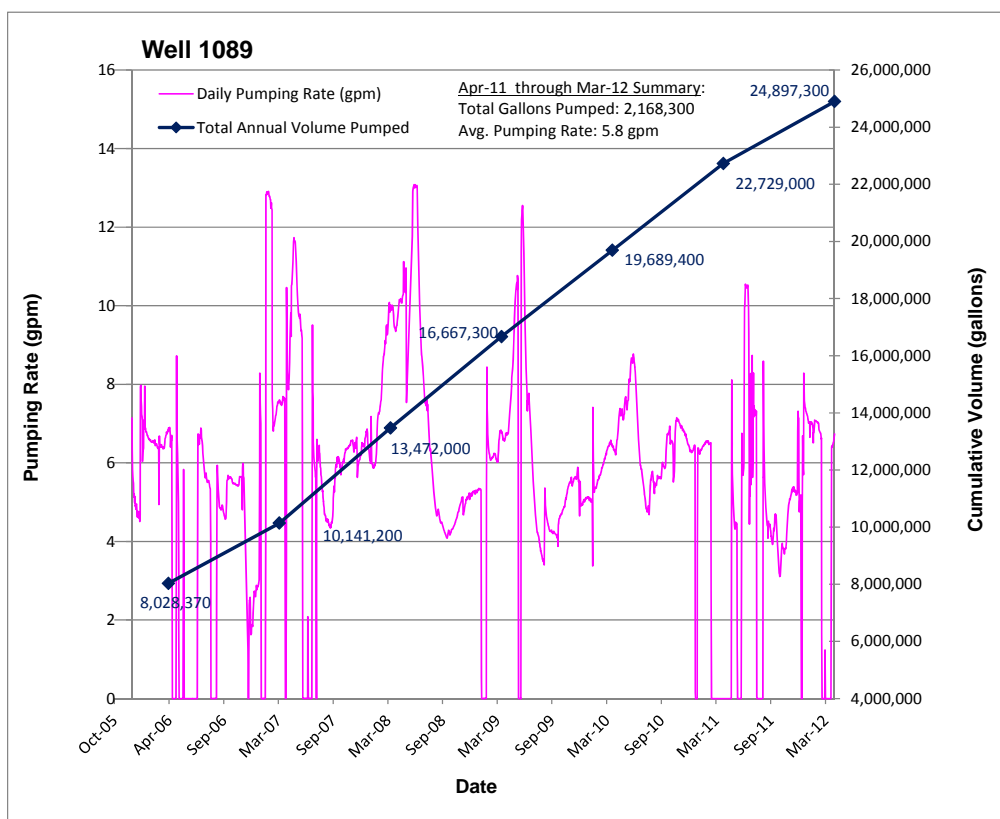


Figure 37. Floodplain Well 1089 Pumping Rate and Cumulative Groundwater Volume Extracted

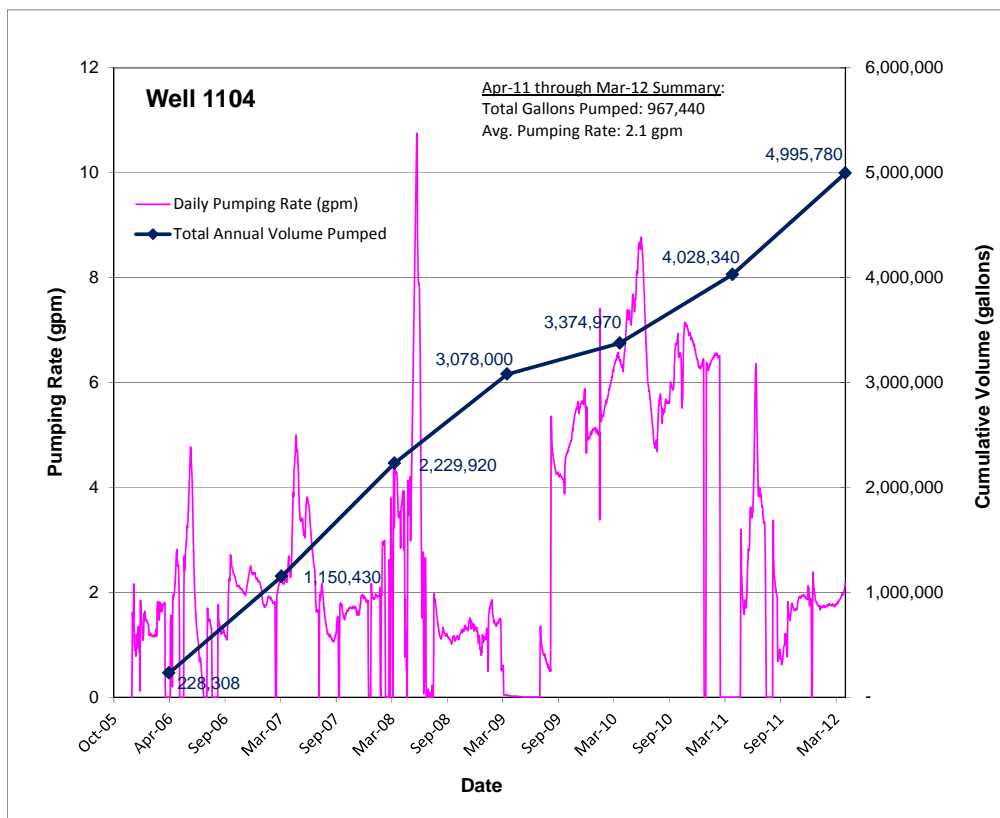


Figure 38. Floodplain Well 1104 Pumping Rate and Cumulative Groundwater Volume Extracted



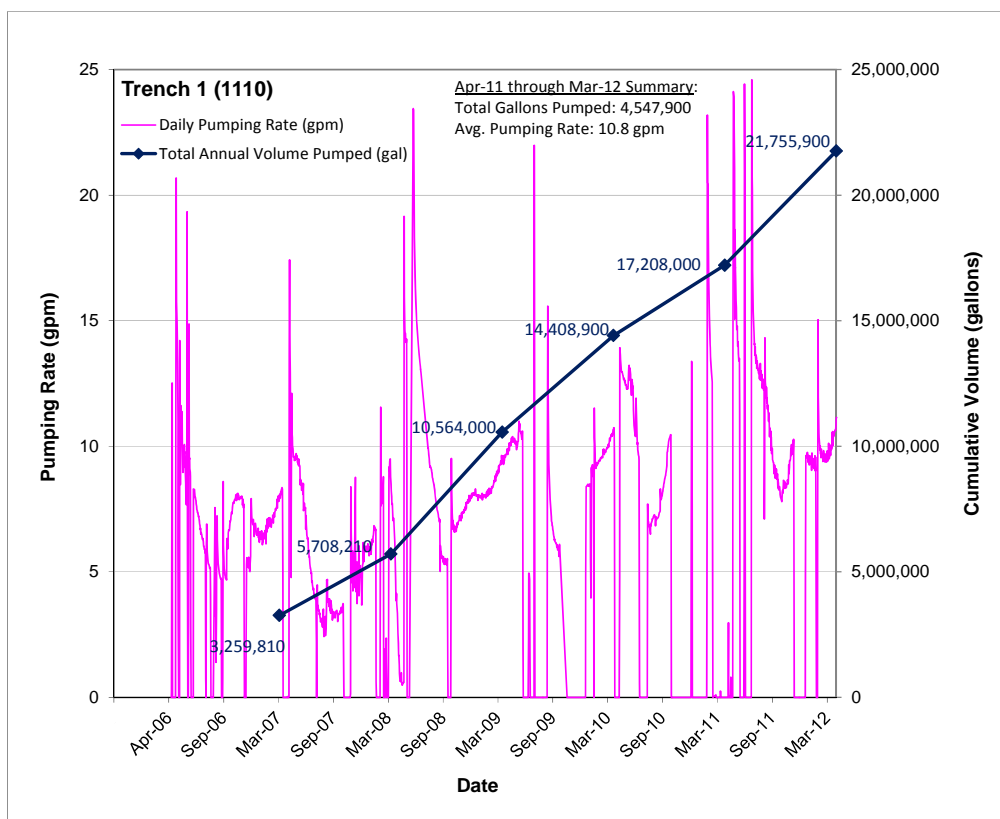


Figure 39. Floodplain Trench 1 Pumping Rate and Cumulative Groundwater Volume Extracted

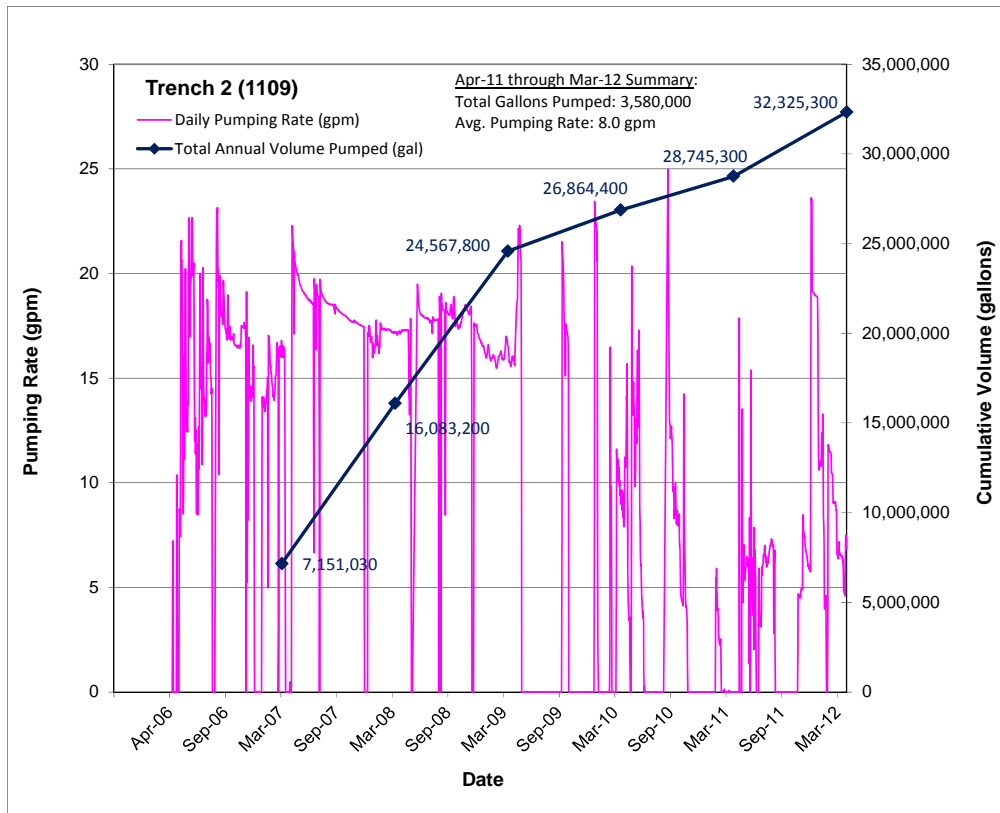


Figure 40. Floodplain Trench 2 Pumping Rate and Cumulative Groundwater Volume Extracted

### 3.1.3 Floodplain Seep Sump Performance

In August 2006, seeps 0425 and 0426 were incorporated into the remediation system. Groundwater discharge from these two seeps is piped into a collection drain (1118 in Figure 1) and then pumped to the evaporation pond. From April 2011 through March 2012, the average discharge rate from the seep collection drain was 0.4 gpm, similar to the average rates reported in the last several years. Approximately 212,000 gallons were pumped from the seeps during this period, yielding a total cumulative volume of about 1.65 million gallons. Figure 41 plots the historical rates of groundwater discharge from the escarpment seeps.

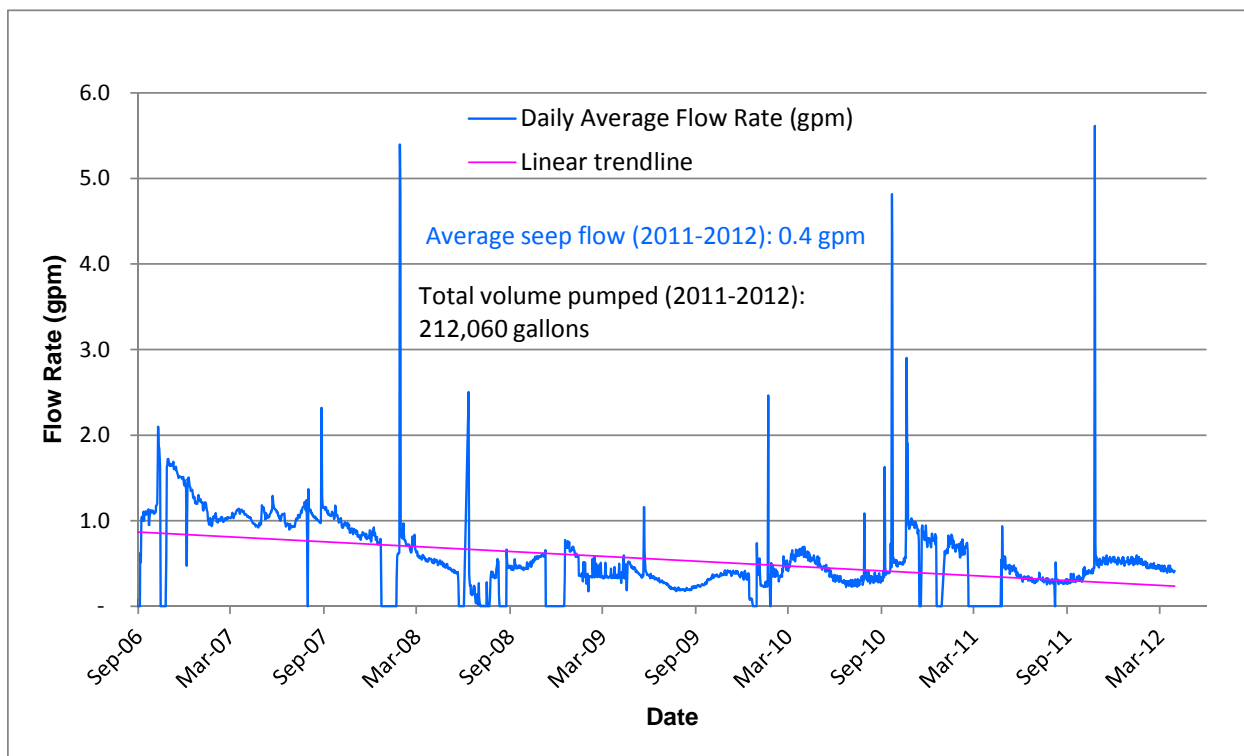


Figure 41. Historical Seep Flows (Seeps 0425 and 0426)

## 3.2 Terrace Remediation System

The objective of the terrace remediation system is to remove groundwater from the southern portion of the terrace area so that potential exposure pathways at seeps and at Bob Lee Wash and Many Devils Wash are eventually eliminated, and the flow of groundwater from the terrace to the floodplain is reduced. The terrace remediation system consists of four major components shown in Figure 1: the extraction wells, the evaporation pond, the terrace drains (Bob Lee Wash and Many Devils Wash), and the terrace outfall drainage channel diversion.

### 3.2.1 Extraction Well Performance

During the current period, the terrace remediation well field consisted of wells 0818, 1070, 1071, 1078, 1091, 1092, 1093, 1095, and 1096 (Figure 1). Table 2 compares the average pumping rate and total groundwater volume removed from each extraction well for the current (2011–2012) and previous (2010–2011) reporting periods.

Table 2. Terrace Extraction Wells: Average Pumping Rates and Total Groundwater Volume Removed

Well	Previous Period (April 1, 2010, through March 31, 2011)		Current Period (April 1, 2011, through March 31, 2012)	
	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818	0.66	346,041	0.68	357,381
1070	0.018	9483	0.022	11,355
1071	0.002	435	0.007	3,553
1078	0.6	302,690	0.59	311,880
1091	0.013	2887	0.016	8,665
1092	0.0002	115	0.002	933
1093R	1.0	542,570	0.57	301,580
1095	0.62	213,830	0.59	215,230
1096	0.42	217,230	0.42	222,790
<b>Total</b>	<b>3.3</b>	<b>1,635,281</b>	<b>2.9</b>	<b>1,433,367</b>

As shown in Table 2, the current-period average pumping rates for terrace extraction wells ranged from 0.002 gpm to 0.68 gpm, and the total groundwater volume removed from each well during this period ranged from 933 gallons to about 357,000 gallons. The cumulative total volume removed from pumping the terrace extraction wells, about 1.4 million gallons, is comparable to the volume extracted during the 2010–2011 reporting period.

Pumping rates and corresponding cumulative groundwater volumes removed from individual terrace extraction wells are presented in Figure 42 through Figure 50. Although active remediation began in March 2003, these figures plot data after 2004–2005, when site remediation system wells and drains were instrumented with LM’s automated telemetry data collection system (SOARS).

### 3.2.2 Terrace Drain System Performance

The terrace extraction system collects seepage from Bob Lee Wash and Many Devils Wash using subsurface interceptor drains. These drains, which consist of perforated pipe surrounded by drain rock and lined with geotextile filter fabric, are offset from the centerline of each wash to minimize the infiltration of surface water. All water collected by these drains is pumped through a pipeline to the evaporation pond.

Extraction rates and cumulative flow volumes for the pump installed in the Bob Lee Wash (location 1087) drain are plotted in Figure 51. During the current performance period, both pumping rates and cumulative flow volumes decreased since the last reporting period. In 2011–2012, the average pumping rate from Bob Lee Wash was 3.1 gpm, and the groundwater interceptor drain removed approximately 1.6 million gallons of water.



The pumping rates and volume of water removed from the groundwater interceptor drain in Many Devils Wash (location 1088) are plotted in Figure 52. During the current performance period, the average pumping rate from Many Devils Wash was 0.55 gpm, and the groundwater interceptor drain removed approximately 287,000 gallons of water.

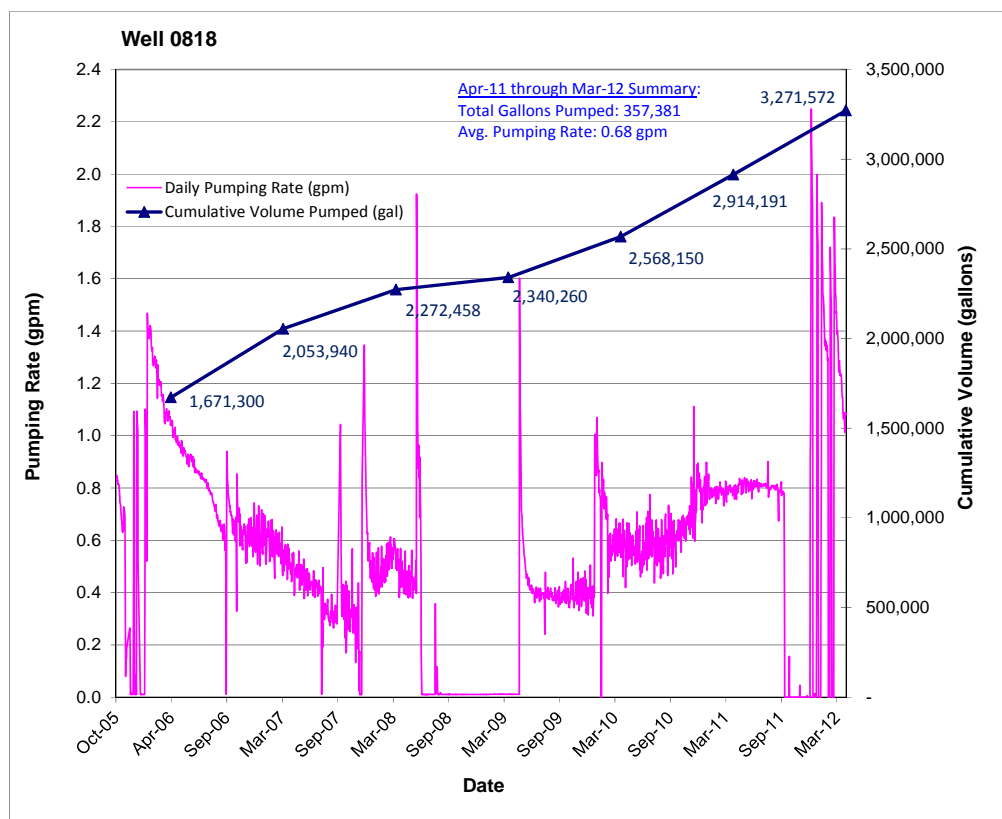


Figure 42. Terrace Well 0818 Pumping Rate and Cumulative Groundwater Volume Extracted

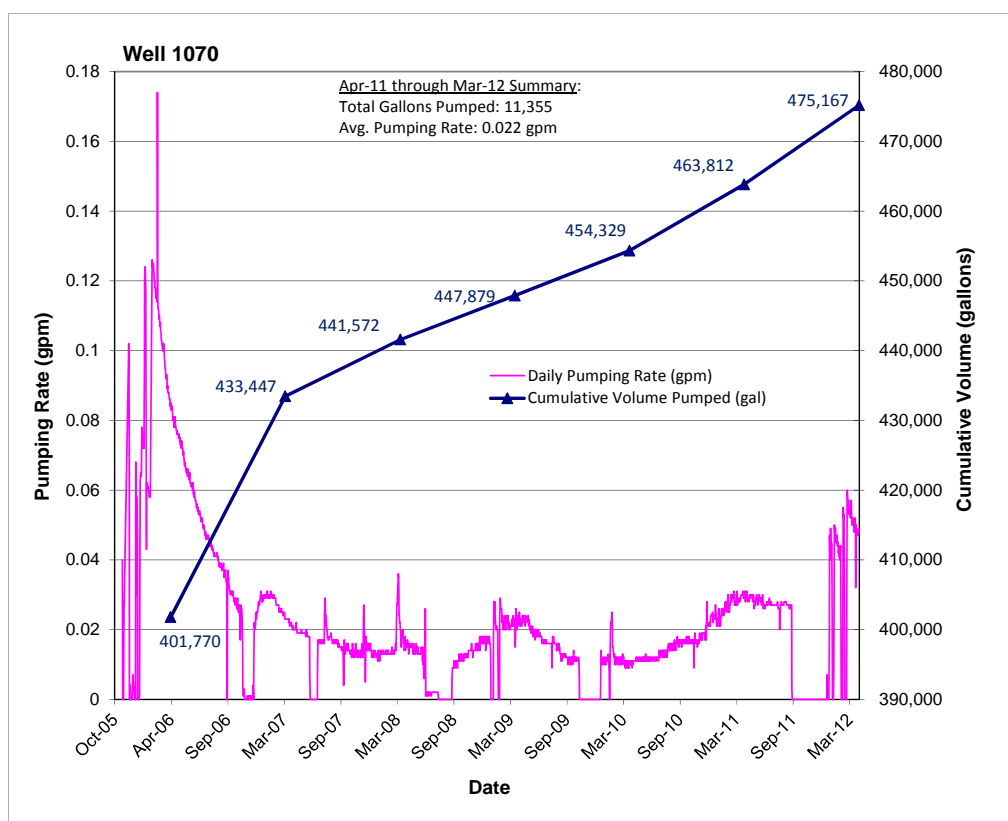


Figure 43. Terrace Well 1070 Pumping Rate and Cumulative Groundwater Volume Extracted

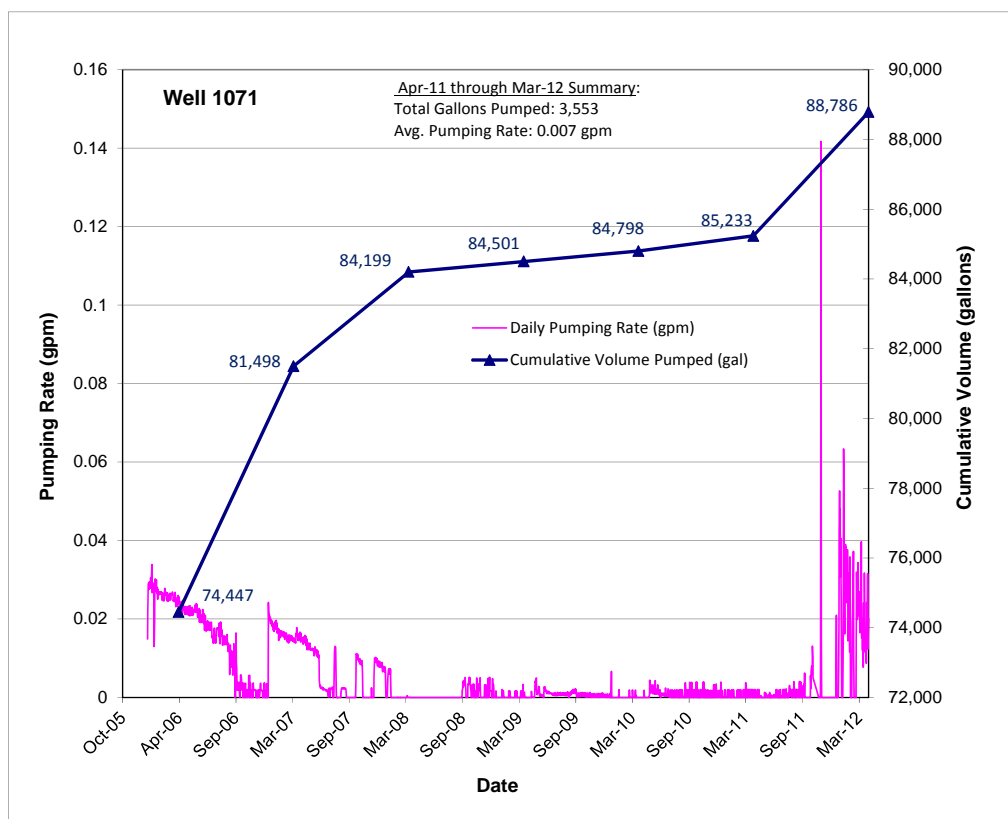


Figure 44. Terrace Well 1071 Pumping Rate and Cumulative Groundwater Volume Extracted

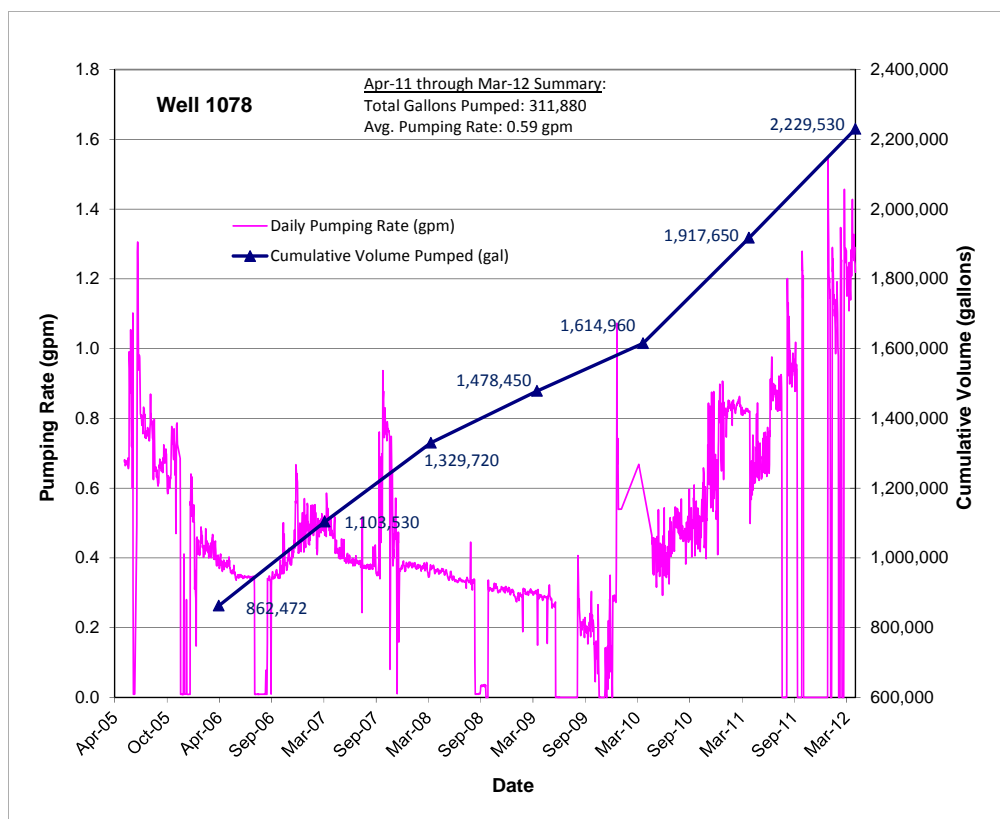


Figure 45. Terrace Well 1078 Pumping Rate and Cumulative Groundwater Volume Extracted

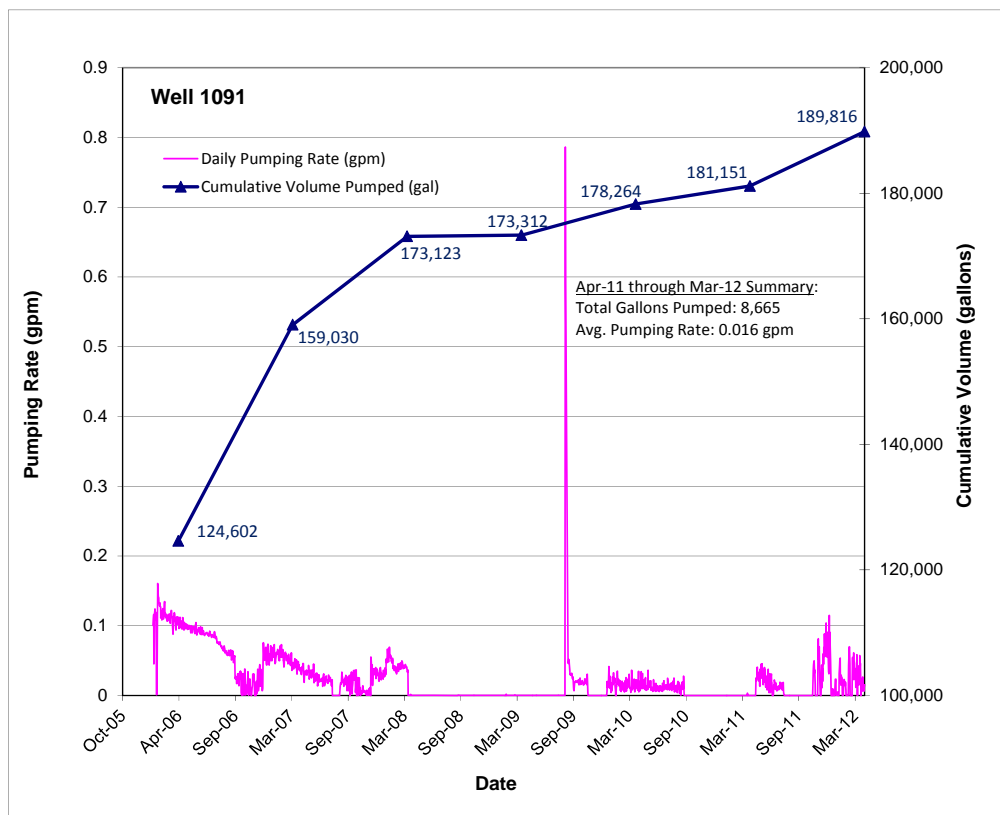


Figure 46. Terrace Well 1091 Pumping Rate and Cumulative Groundwater Volume Extracted



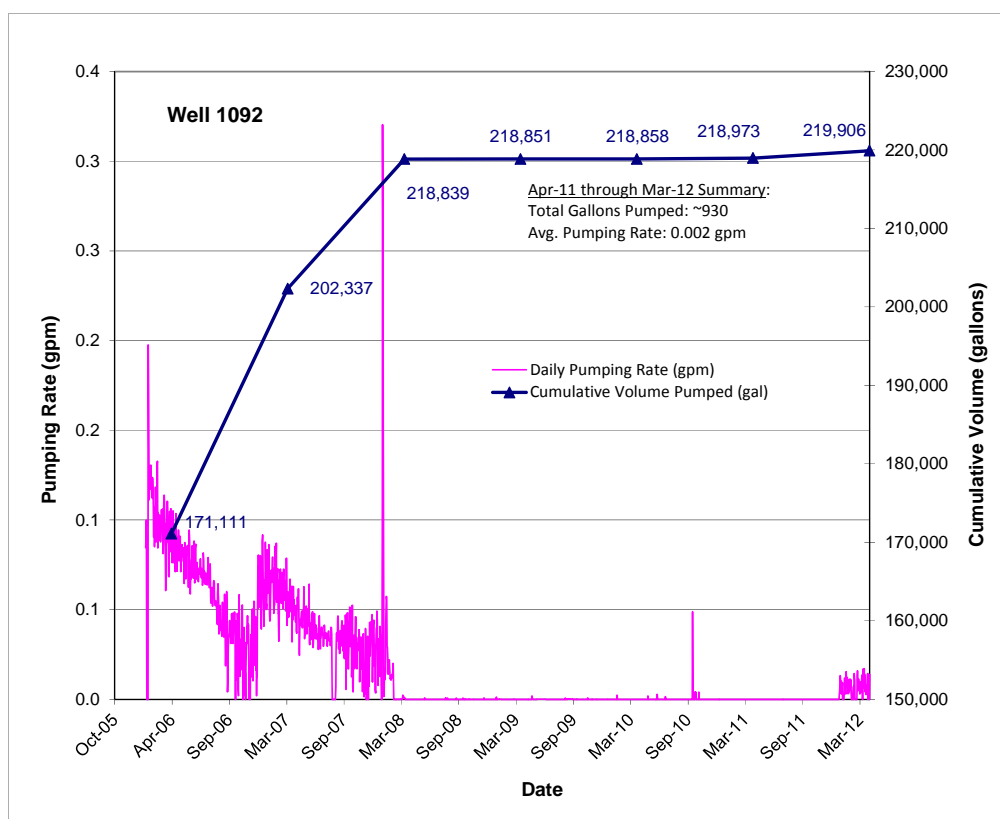


Figure 47. Terrace Well 1092 Pumping Rate and Cumulative Groundwater Volume Extracted

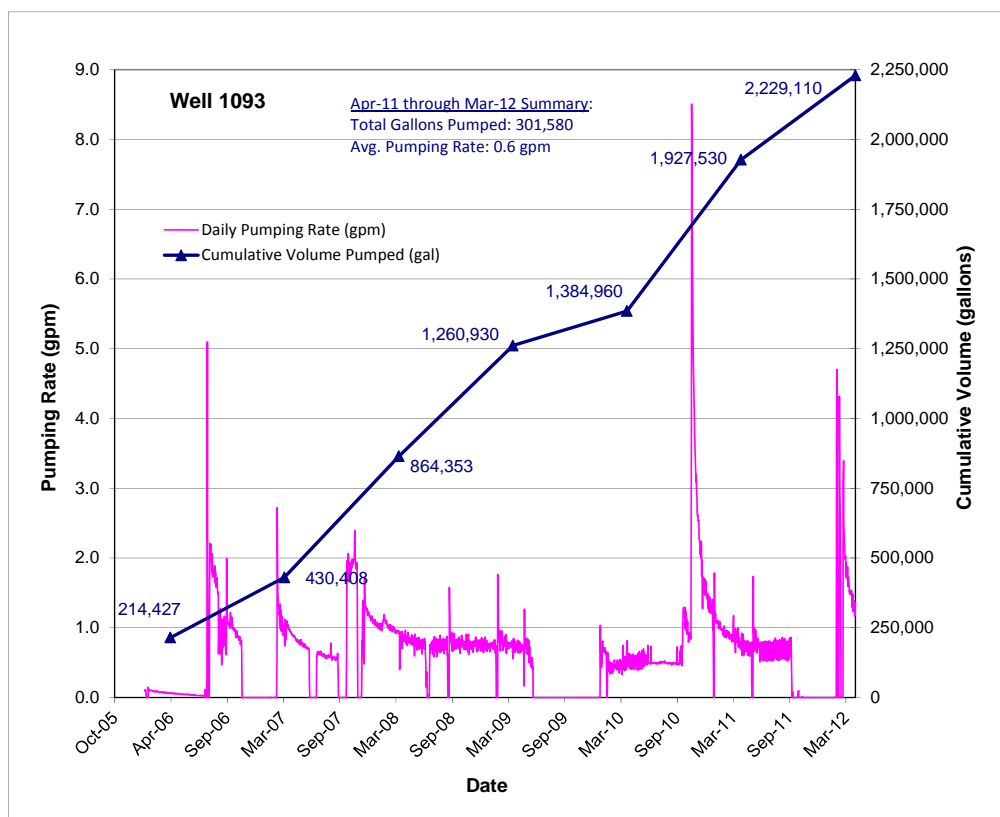


Figure 48. Terrace Well 1093 Pumping Rate and Cumulative Groundwater Volume Extracted

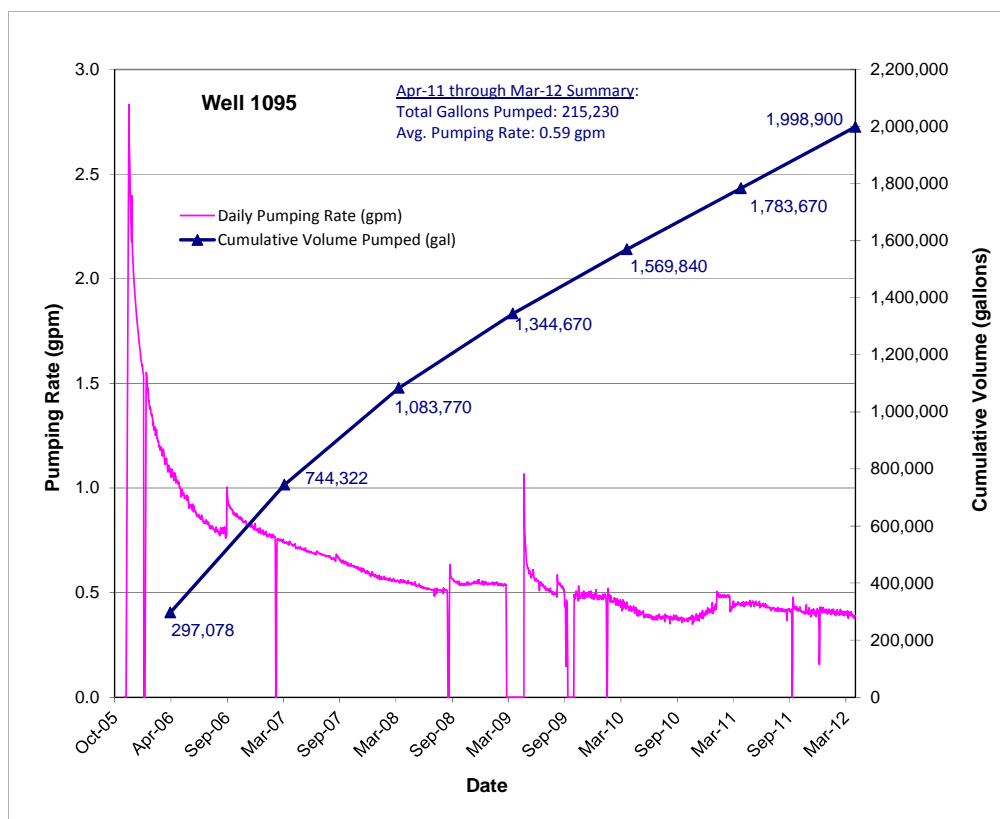


Figure 49. Terrace Well 1095 Pumping Rate and Cumulative Groundwater Volume Extracted

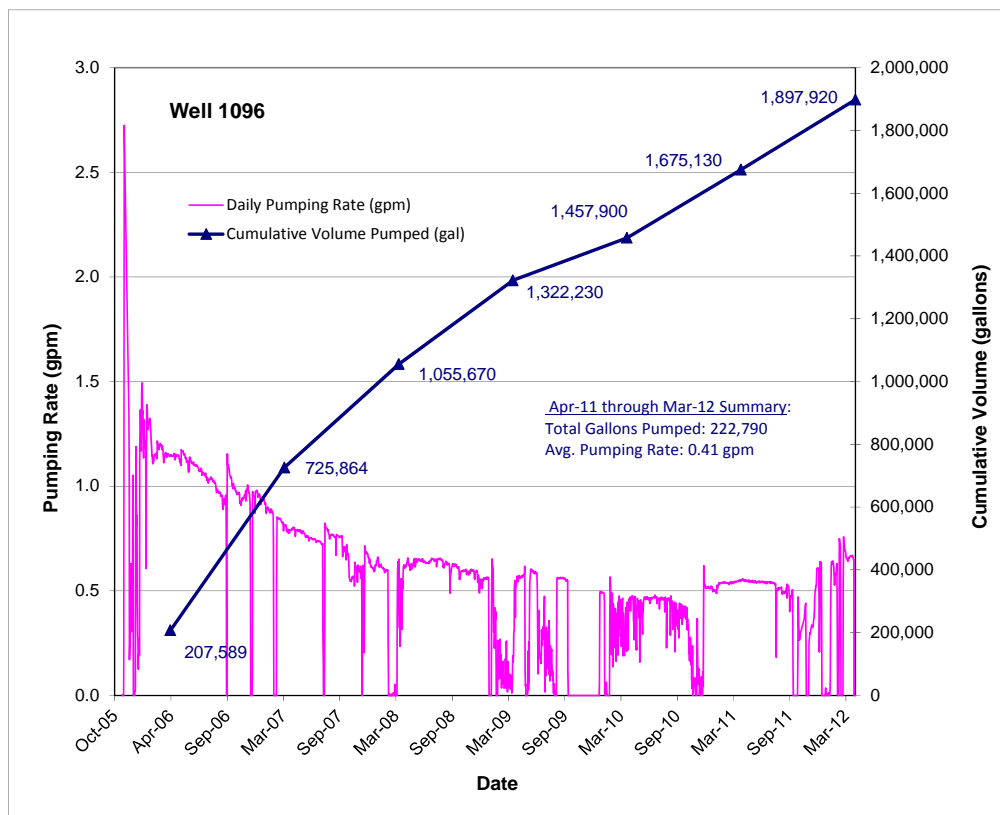


Figure 50. Terrace Well 1096 Pumping Rate and Cumulative Groundwater Volume Extracted

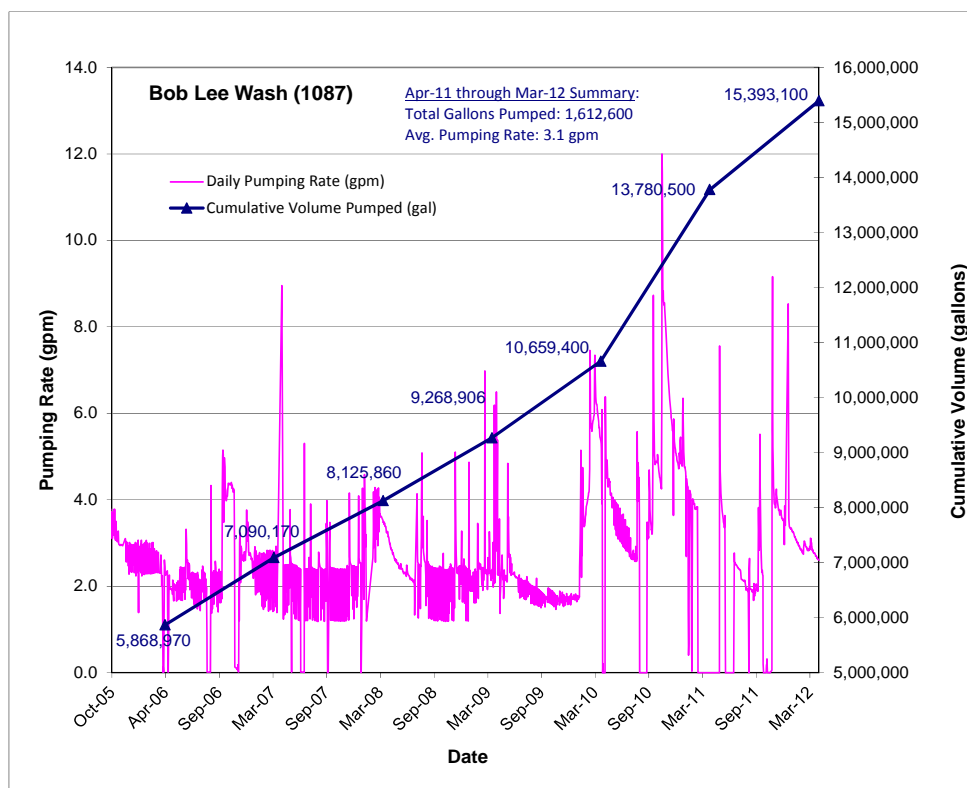


Figure 51. Bob Lee Wash Pumping Rate and Cumulative Groundwater Volume Extracted

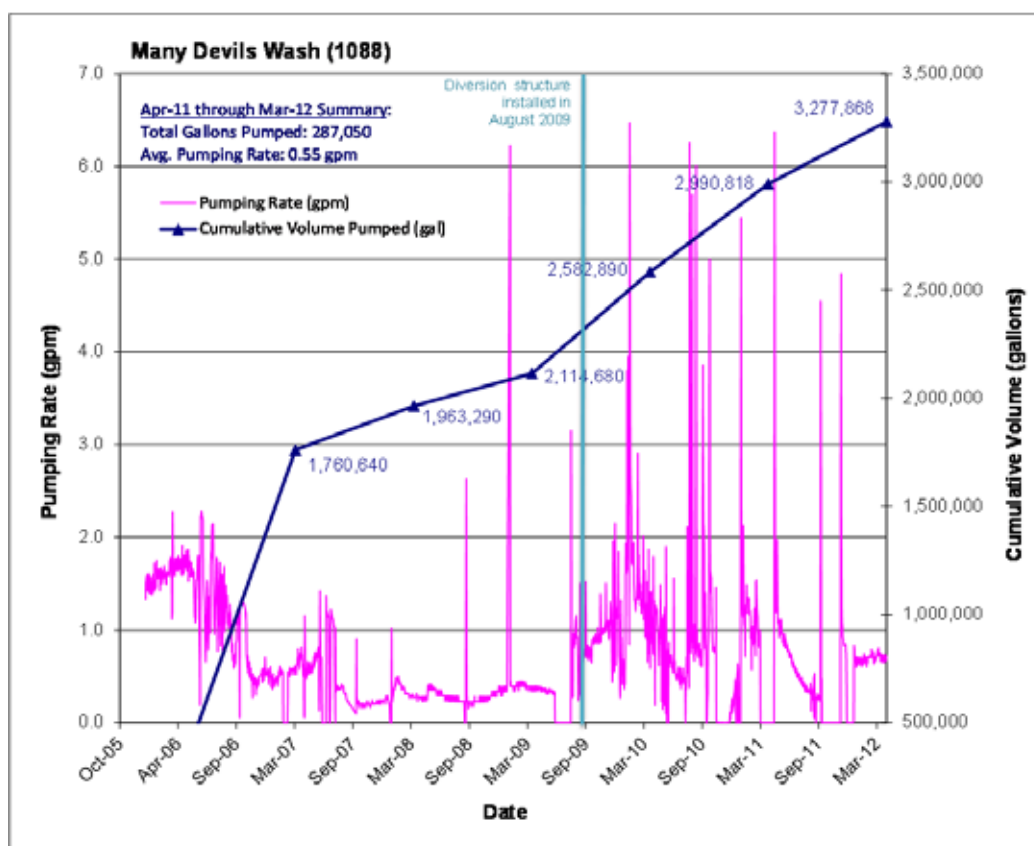


Figure 52. Many Devils Wash Pumping Rate and Cumulative Groundwater Volume Extracted



### 3.2.3 Evaporation Pond

The selected method for handling groundwater from the interceptor drains and extraction wells is solar evaporation. The contaminated groundwater is pumped to an 11-acre lined evaporation pond in the south part of the radon cover borrow pit area (Figure 1). The average water level in the evaporation pond was 5.1 ft in March 2012 (measured as the distance above transducers), leaving approximately 2.9 ft of unfilled pond capacity.

From April 2011 through March 2012, approximately 14.8 million gallons of extracted groundwater were pumped to the evaporation pond. Of the influent liquids entering the pond, 77.5 percent (11.5 million gallons) were from the floodplain aquifer, and 22.5 percent (3.3 million gallons) originated from the terrace groundwater system (Table 3). This annual input to the pond is about 7 percent higher than the 13.8 million gallons reported for 2010–2011. As shown in Figure 53, at the end of the 2011–2012 reporting period, a cumulative volume of nearly 115.6 million gallons of water has been pumped to the evaporation pond from all sources since the start of operations in March 2003 (cumulative contributions of 26 percent and 74 percent from the terrace and floodplain, respectively).

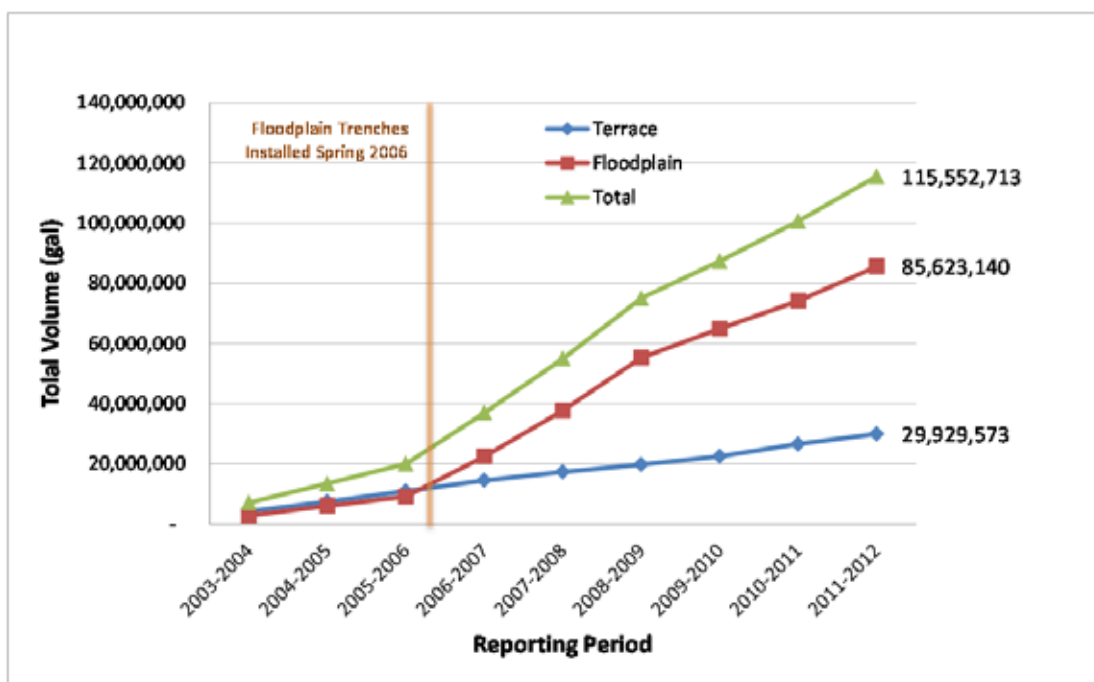


Figure 53. Total Groundwater Volume Pumped to the Evaporation Pond

Table 3. Estimated Total Mass of Selected Constituents Pumped from Terrace and Floodplain

Location	Annual Cumulative Volume (gallons) <sup>a</sup>	Percent Contribution	Nitrate—Average Concentration (mg/L)	Nitrate Mass Contribution per Location (kilograms) <sup>b</sup>	Nitrate Mass Contribution per Location (pounds) <sup>c</sup>	Sulfate—Average Concentration (mg/L)	Sulfate Mass Contribution per Location (kilograms) <sup>b</sup>	Sulfate Mass Contribution per Location (pounds) <sup>c</sup>	Uranium—Average Concentration (mg/L)	Uranium Mass Contribution per Location (kilograms) <sup>b</sup>	Uranium Mass Contribution per Location (pounds) <sup>c</sup>
Terrace											
0818	357,381	2.42	765	1,035	2,281	12,500	16,909	37,277	0.135	0.183	0.403
1070	11,355	0.08	660	28.4	62.5	15,000	645	1,421	0.088	0.004	0.008
1071	3,553	0.02	640	8.6	19.0	13,500	181.5	400.2	0.155	0.002	0.0046
1078	311,880	2.1	565	667	1,470	13,500	15,936	35,133	0.130	0.153	0.34
1091	8,665	0.06	1,200	39.4	86.8	13,000	426.4	940	0.115	0.004	0.008
1092	933	<0.01	715	2.5	5.6	13,000	45.9	101.2	0.101	<0.001	<0.001
1093	301,580	2.0	1,950	2,226	4,907	5,750	6,564	14,470	0.115	0.131	0.29
1095	215,230	1.4	1,600	1,303	2,874	4,700	3,829	8,441	0.050	0.041	0.09
1096	227,790	1.5	575	496	1,093	13,500	11,639	25,660	0.087	0.075	0.165
1087 (BLW)	1,612,600	10.9	305	1,862	4,104	7,450	45,472	100,249	0.540	3.36	7.27
1088 (MDW)	287,050	1.9	615	668	1,473	19,000	20,643	45,510	0.165	0.179	0.395
Floodplain											
1089	2,168,300	14.6	0.8	7	15	5,050	41,445	91,371	0.260	2.13	4.70
1104	967,440	6.5	13.0	48	105	8,350	30,576	67,407	0.820	3.00	6.62
Trench 1 (1110)	4,547,900	30.7	99.0	1,704	3,757	7,250	124,800	275,134	0.960	16.53	36.43
Trench 2 (1109)	3,580,000	24.2	46.5	630	1,389	850	11,518	25,392	0.125	1.69	3.73
Seep sump (1118)	212,060	1.4	65.0	52	115	7,500	6,020	13,271	0.655	0.53	1.16
			Total Masses:	8,336	18,376		336,650	742,178		28	62
Total Terrace	3,338,017	22.5									
Total Floodplain	11,475,700	77.5									
Total to Pond	14,813,717										

<sup>a</sup> Annual cumulative volumes derived from data used to generate plots in Figure 37 through Figure 52 (data from April 1, 2011, through March 31, 2012).

<sup>b</sup> Mass in kilogram (kg) derived = annual volume × 3.785 (liters to gallons) × average concentration × (1/1,000,000).

<sup>c</sup> Conversion to pounds (lb) = kg × 2.2046.

MDW = Many Devils Wash; BLW = Bob Lee Wash

As shown in Table 3, the estimated masses of nitrate, sulfate, and uranium pumped to the evaporation pond from the floodplain extraction wells and trenches and terrace groundwater extraction system during the 2011–2012 performance period were approximately 18,000 pounds (nitrate as N), 742,000 pounds (SO<sub>4</sub>), and 60 pounds (U). These mass estimates were computed using the average concentrations measured in each extraction well and the corresponding annual cumulative volume pumped. In terms of mass, sulfate is the dominant COC that enters the evaporation pond because of its high concentrations in both the floodplain and terrace groundwater systems.

### **3.2.4 Passive and Enhanced Phytoremediation**

A pilot study of natural phytoremediation (no human intervention) and hydraulic control is ongoing at the Shiprock site. DOE began the pilot studies in 2006 to evaluate the feasibility of enhancing natural phytoremediation by planting native phreatophytes on the terrace between the disposal cell and the escarpment north of the disposal cell, where a uranium plume enters the floodplain, and in the radon cover borrow pit south of the disposal cell, where nitrate levels are elevated in alluvial sediments. The potential goal of phytoremediation in these areas would be hydraulic control (as opposed to contaminant removal), to enhance plant transpiration of groundwater, thereby limiting the spread of contaminants in groundwater. The four irrigated 15-square-meter phytoremediation test plots were established in 2006; locations are shown on Figure 1. To date, all work has been done in concert with the Diné Environmental Institute at Diné College in Shiprock.

DOE is currently examining the added value of phytoremediation at Shiprock in light of recent groundwater remediation studies and monitoring data and will decide before 2013 whether to continue or conclude the pilot studies. The status of phytoremediation has not changed much since the last annual report (DOE 2012a). That report provides more detailed historical information.



## 4.0 Performance Summary

This section summarizes the findings of the most recent (April 2011 through March 2012) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the ninth year of active groundwater remediation.

- Groundwater in the floodplain system is currently being extracted from two wells (wells 1089 and 1104) adjacent to the San Juan River north of the disposal cell, two collection trenches (Trench 1 and Trench 2), and a seep collection sump. Approximately 11.5 million gallons of groundwater were extracted from the floodplain aquifer system during this performance period, yielding a cumulative total of about 86 million gallons extracted from the floodplain since March 2003.
- Groundwater in the terrace system is currently being extracted from two drainage trenches (in Bob Lee and Many Devils Washes) and nine wells. From April 2011 through March 2012, approximately 3.3 million gallons of groundwater were extracted from the terrace system, yielding a total cumulative volume (extracted since March 2003) of about 30 million gallons. The cumulative volume removed from both terrace and floodplain combined (as of April 1, 2012) approaches 116 million gallons (Figure 53).
- Terrace-wide, groundwater levels in the majority of alluvial wells sampled during this performance period declined relative to the baseline (2000–2003) period (Figure 34); average and maximum decreases were 2.9 ft and 7.7 ft, respectively. Relative to baseline conditions, decreases in the eastern portion of the terrace are negligible. Five alluvial west terrace wells were dry during the March 2012 sampling event. Also, many seeps on the west terrace have been dry for the last several years (in 2011–2012, all seeps west of the high school were dry).
- The remediation system is intercepting contaminated groundwater that could potentially discharge to the San Juan River. This contaminated groundwater is pumped to the evaporation pond on the terrace just south of the disposal cell. The estimated masses of sulfate, nitrate, and uranium removed from the floodplain and terrace well fields during this performance period were 742,000 pounds, 18,000 pounds, and 60 pounds, respectively.

As observed for the last several years, marked decreases in contaminant concentrations are evident in selected floodplain wells—most notably in the Trench 1 area. Since Trench 1 was installed in 2006, reductions in concentrations of the primary COCs (nitrate, sulfate, and uranium) are apparent in surrounding wells, especially those on the river side of the trench. Based on monitoring results and results from the 2009 evaluation of the Trench 2 remediation system (DOE 2009), Trench 2, when pumped, appears to be successfully intercepting contaminated groundwater emanating from the terrace across the escarpment, thereby preventing the contamination from discharging to the river in areas farther to the north. Decreases in COC concentrations in the well 1089 area since remediation pumping began in 2003 are also evident. Finally, COC concentrations in samples collected from the San Juan River samples are still well below established benchmarks and are comparable to upstream (background) concentrations.

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## 5.0 Recommendations

Based on the current status of remediation progress and findings of recent investigations (DOE 2009, 2011d), DOE recommends the following activities to improve the performance and evaluation of the Shiprock remediation system and to minimize potential risks to human health and the environment.

- Update the compliance strategy for the terrace.
- Continue to evaluate the longevity of the pond liner and the remediation infrastructure and implement upgrades as needed. Continue adding dye to the evaporation pond to mitigate potential ecological risks associated with the pond.
- To optimally manage available storage volume in the remediation system's evaporation pond, temporarily cease pumping at Trench 1, Trench 2, and the newly proposed pumping wells as necessary during the period of high snowmelt runoff in the river.

DOE continues to underscore the importance of institutional controls and seeks cooperation and assistance from the Navajo Nation Environmental Protection Agency, Navajo Nation Department of Justice, and the Navajo UMTRA Office to maintain protection of human health and the environment.



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