LMS/SHP/S07834

Annual Performance Report April 2010 Through March 2011 for the Shiprock, New Mexico, Site

January 2012

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Contents

Figures

Tables

Appendix

Abbreviations

COCs	contaminants 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
lb	pounds
LM	DOE Office of Legacy Management
MCL	maximum concentration limit
mg/L	milligrams per liter
amsl	above mean sea level
N	nitrogen
SDWA	Safe Drinking Water Act
Se	selenium
SOARS	System Operation and Analysis at Remote Sites
SOWP	Site Observational Work Plan
Sr	strontium
U	uranium
UMTRCA	Uranium Mill Tailings Radiation Control Act

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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 2010 through March 2011. 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). This performance evaluation 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 (NRC) 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 2010a).

DOE is reevaluating the compliance strategy for the terrace (DOE 2010a). The current objective of active remediation on the terrace is 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) for both the floodplain and terrace 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 (UMTRCA). Regulatory standards are not available for the remaining COCs; remediation goals for these constituents are either risk-based alternate cleanup standards or background levels. Background groundwater quality for the terrace has been very difficult to establish because wells drilled in locations considered to be suitable analogs for terrace background conditions have been dry. This report documents additional efforts to find potential background locations for the terrace, in light of recent attempts to define natural contamination in the Mancos Shale (DOE 2011b).

Contaminant Distributions and Temporal Trends

For this reporting period, 115 monitoring wells (59 on the floodplain and 56 on the terrace) and 32 surface water locations were sampled. One of the difficulties in evaluating the analytical results from this site is that the highest concentrations of individual COCs do not occur in the same location. For example, concentrations of nitrate, selenium, and sulfate are highest on the terrace in the radon borrow pit area, along the buried escarpment, and in Many Devils Wash, while the highest concentrations of uranium are generally in floodplain alluvial wells rather than in terrace alluvial wells. Ammonia concentrations are highest in the terrace 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—most notably in the Trench 1 and well 1089 areas. 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 samples 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 8.6 million gallons of groundwater were extracted from the floodplain aquifer system during this performance period, yielding a cumulative total of about 74 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 2010 through March 2011, approximately 5.2 million gallons of groundwater were extracted from the terrace system, yielding a total cumulative volume of about 26.6 million gallons.

The cumulative volume removed from both terrace and floodplain combined (as of April 1, 2011) is approximately 101 million gallons. Estimated masses of sulfate, nitrate, and uranium removed from the floodplain and terrace well fields during this performance period were 734,000 pounds, 33,000 pounds, and 50 pounds, respectively.

The floodplain extraction system appears 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 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 2.5 ft and 7.2 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 are widespread, and many seeps on the west terrace have been dry for the last several years.

Natural phytoremediation (that is, with no human intervention) and hydraulic control using phytoremediation are ongoing 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 barrier 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:

- Continue to assess the floodplain-wide flow and transport processes. (Studies are in progress.)
- Update the compliance strategy for the terrace (see DOE 2010a). (DOE is proposing active remediation as the interim remediation strategy for the entire terrace.)
- Continue to monitor the fluid level in the evaporation pond (with the understanding that periodic cessation of pumping is necessary to maintain sufficient freeboard), evaluate ways to enhance evaporation, and investigate potential upgrades to the remediation system.
- Develop a specific plan for phytoremediation pending analysis of the overall findings and data when pilot studies end. (Pilot studies are in progress.)
- Continue to investigate the source of contamination in Many Devils Wash (see DOE 2011b, DOE 2011c) and focus on ways to minimize exposures and risks to contaminants in the wash.

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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 2010 through March 2011. The Shiprock site, a former uranium-ore processing facility 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 newly established candidate background locations for the terrace (1218, 1219, and 1220, shown in Figure 3 inset).

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 midterm evaluation of the site remediation strategy (DOE 2010a).

This year (2011), DOE has issued three key reports, developed by DOE's Environmental Sciences Laboratory (ESL) in Grand Junction, Colorado. The first two—*Natural Contamination in the Mancos Shale* (DOE 2011b) and *Geology and Groundwater Investigation at Many Devils Wash* (DOE 2011c)—lay the groundwork for ongoing technical evaluations of contamination on the terrace. The third report, a preliminary evaluation of the Trench 1 collection drain area on the floodplain (DOE 2011d), is the precursor to a more extensive evaluation of the floodplain groundwater remediation system (in progress).

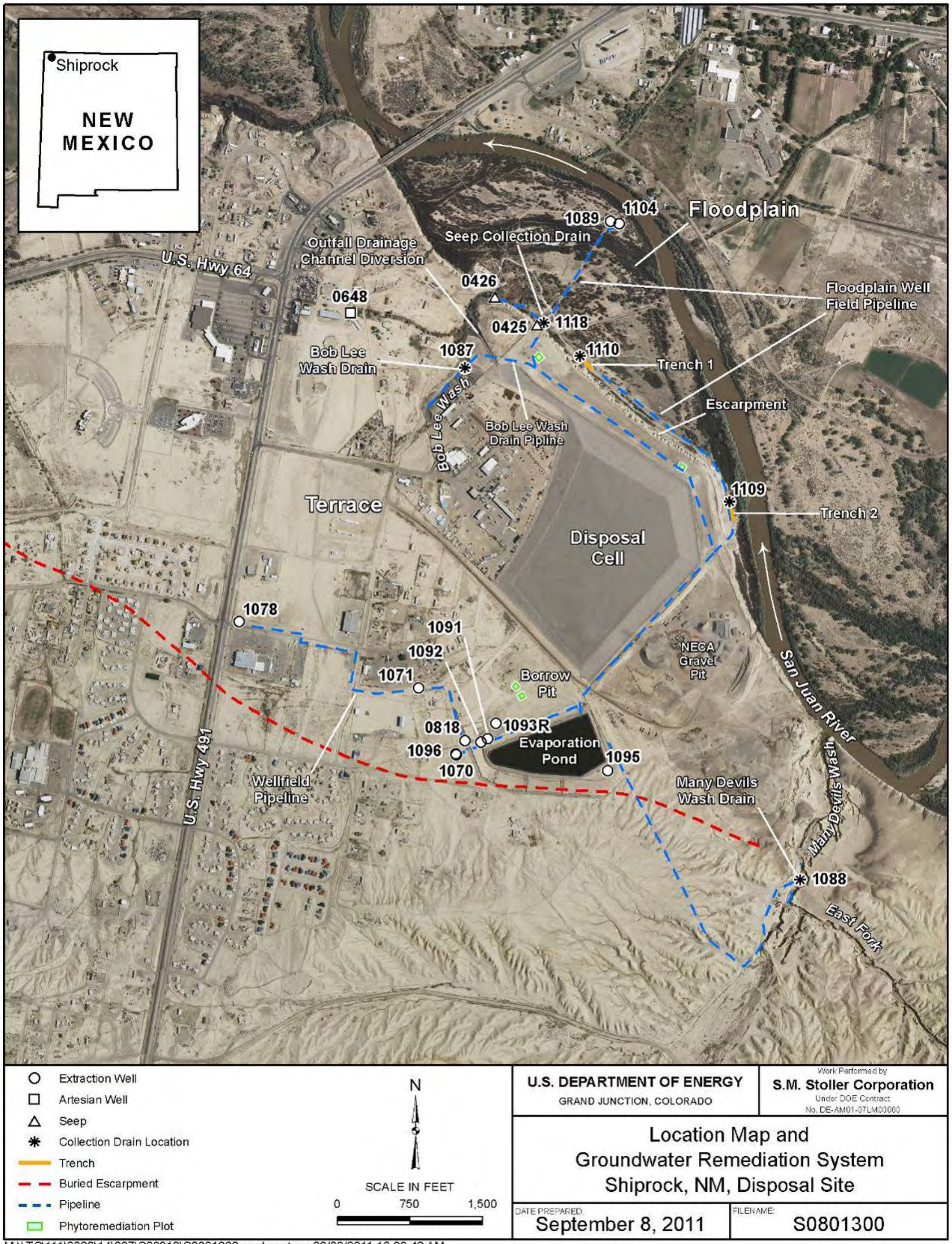

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Figure 1. Location Map and Groundwater Remediation System

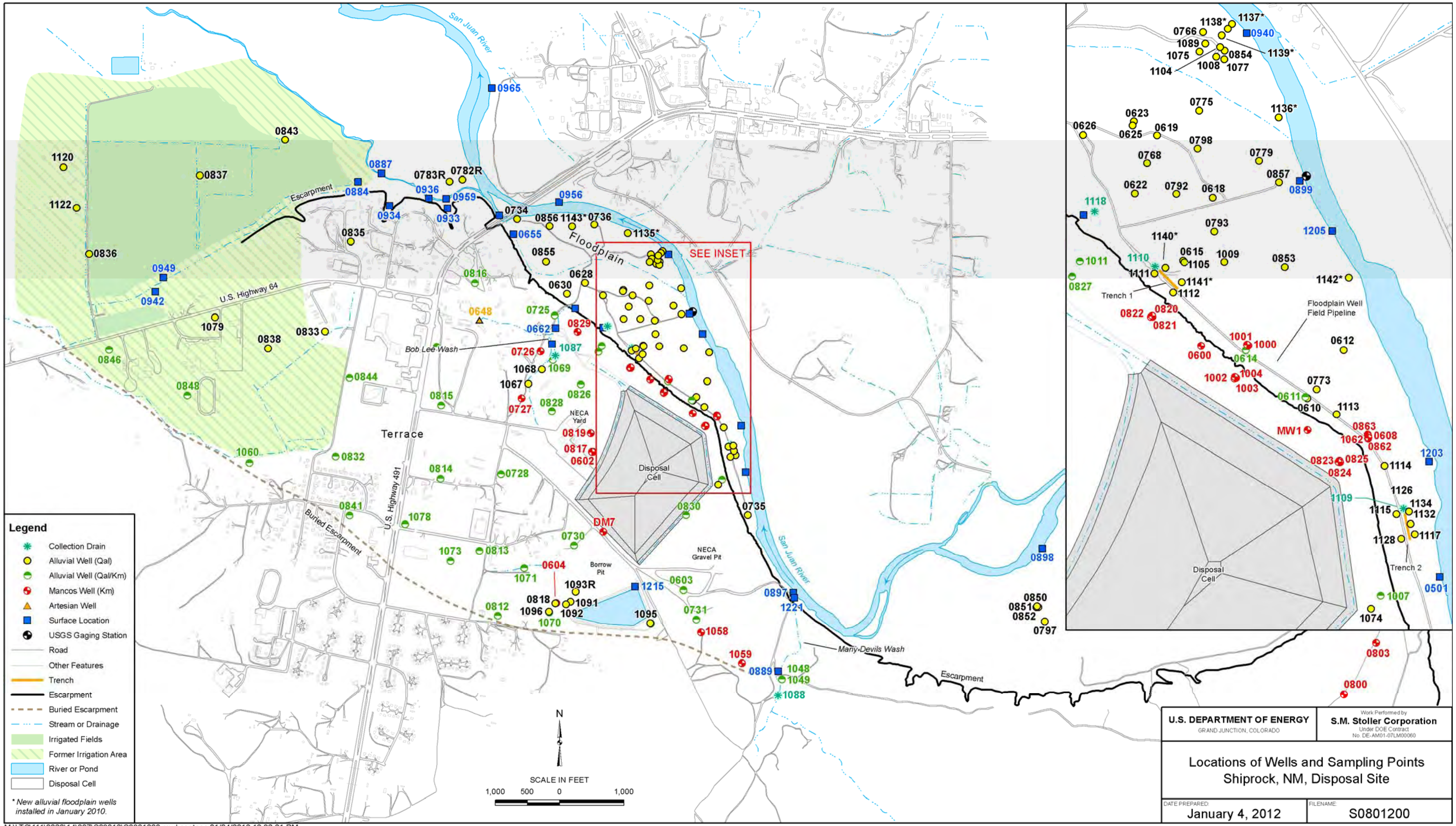

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Figure 2. Locations of Wells and Sampling Points at the Shiprock Site

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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 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 2010a), 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 2010a). 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 2010a). 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 8 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 which 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 respective UMTRCA standards and corresponding floodplain background data.

Table 1. Groundwater COCs for the Shiprock Site

Contaminant	40 CFR 192 MCL[a]	SOWP Floodplain Background Value	Historical Range in Floodplain Background Wells[b] (Mean)	Comments
Ammonia, as N (mg/L)	NA	0.045	0.074–0.102 (0.099)	All results for floodplain background wells have been nondetects (<0.1) except for the most recent (March 2011) measurements.
Manganese (mg/L)	NA	1.2	0.001–7.2 (1.2)	Maximum background level of 7.2 mg/L measured in March 2006 (well 0797).
Nitrate (mg/L)	10	0.12	0.01–3.3 (0.13)	Reporting units are nitrate + nitrite as nitrogen [N]).
Selenium (mg/L)	0.01	<0.001	0.0001–0.018 (0.001)	U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) maximum contaminant level is 0.05 mg/L.
Strontium (mg/L)	NA	2.3	0.18–10 (3.0)	At most site monitoring locations, strontium concentrations are within the range of floodplain background, and most are below EPA's risk-based value for ingestion of groundwater (22 mg/L).
Sulfate (mg/L)	NA	1432	210–5200 (1940)	Given elevated levels in terrace artesian well 0648 (1870–2340 mg/L), an alternate cleanup goal of 2000 mg/L was proposed in the GCAP (DOE 2002).
Uranium (mg/L)	0.044	0.007	0.004–0.12 (0.03)	Uranium levels measured in floodplain background wells have varied widely (0.004–0.12 mg/L) and have exceeded the MCL at times (see Figure 23).

[a] Title 40 *Code of Federal Regulations* Part 192 (40 CFR 192) maximum concentration limit (MCL).
[b] Data are from floodplain background wells 0797 and 0850 (locations shown in Figure 2). Mean values (in parentheses following ranges) were calculated assuming nondetects equivalent to detection limit value.
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. The relatively high selenium concentrations in the floodplain (originating on the terrace) make it unlikely that the 40 CFR 192 standard of 0.01 mg/L for this constituent can be met while contaminated water from the terrace is still providing a source.[1] Therefore, an interim alternate concentration limit for selenium of 0.05 mg/L was proposed 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 and the results of sampling at a recently established terrace seep background location (location 1218; refer to discussion at the conclusion of this section and Table 2).

Regulatory standards are not available for ammonia, manganese, strontium, and sulfate (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 (≤0.1 mg/L). Although the SOWP (DOE 2000) established a background level for manganese of 1.24 mg/L, this value was later determined to be impractical because it is well below established background levels. Therefore, the cleanup objective for manganese is now based on the maximum background concentration measured in floodplain background wells (7.2 mg/L; see Table 1).[2]

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 has developed a risk-based screening level for stable strontium in groundwater of 22 mg/L (assuming groundwater is used for drinking water)[3]. As discussed in Section 1.4.2, almost all historical groundwater results at the Shiprock site have been below this risk-based value, and most have been below the maximum background level measured in floodplain background well 0797 (10 mg/L in September 2008).

EPA has established an SDWA secondary standard of 250 mg/L for sulfate. However, with only two exceptions, sulfate concentrations in floodplain background wells 0797 and 0850 have exceeded this standard (range of 210–5200 mg/L; average of 1976 mg/L). Because sulfate levels have also been elevated in groundwater entering the floodplain from flowing artesian well 0648 (up to 2340 mg/L), the GCAP proposed an alternate cleanup goal for sulfate of 2000 mg/L (DOE 2002). This alternate goal is conservative given the elevated levels in floodplain background wells (also see Table 2).

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[1] Although selenium concentrations in groundwater and surface water are clearly elevated in some areas at the site, the extent to which this constituent is attributable to former milling processes rather than natural sources is not clear (DOE 2010a). Evidence suggests that selenium could have been leached from the Mancos Shale or soils derived from the shale (for a broader geological perspective on this issue, reference DOE 2011b).

[2] At the time the GCAP (DOE 2002) was developed, the maximum background value for manganese was 2.7 mg/L; this 2010–2011 updated annual report reflects the most updated historical background range (0.001–7.2 mg/L).

[3] http://www.epa.gov/reg3hscd/risk/human/rb-concentration_table/Generic_Tables/index.htm. Last revision June 2011; accessed September 2011.

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 millsite related, but rather 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).

These complexities have made it difficult to identify applicable "background" concentrations for groundwater COCs so that progress in meeting remediation goals can be reliably assessed. Ideally, background levels would be derived from measured concentrations in the same groundwater system associated with the former mill but at locations hydraulically upgradient of the mill. However, because the hydrogeology of the Shiprock area does not comport with these ideal conditions, DOE has attempted to derive background concentrations for other groundwater systems in the region.

After consulting with the Navajo Nation Environmental Protection Agency (NNEPA) and Navajo Nation Abandoned Mine Lands/Uranium Mill Tailings Remedial Action Office (NN AML/UMTRA), DOE recently sampled three new terrace seep locations not influenced by the former mill and that emanate from Mancos Shale. These locations, shown in Figure 3 (see inset), are:

- Location 1218 (sometimes referred to as "Washing Machine" [WM] Draw)[4], which is approximately 2 miles southwest of the site (also see Figure 4). The elevation where water from location 1218 seeps from the ground—4987.1 feet (ft) above mean sea level (amsl)—is 2 ft higher than the highest possible water elevations in the mill site raffinate ponds during milling years (4985 ft amsl[5]), which indicates that it was very likely not influenced by the former mill. 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 4945 ft amsl.
- 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 Eagles 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

[4] 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.

[5] This estimate is based on a 4975 ft contour from a pre-remediation topographical map and assumes that the pond berms were 10 ft high).

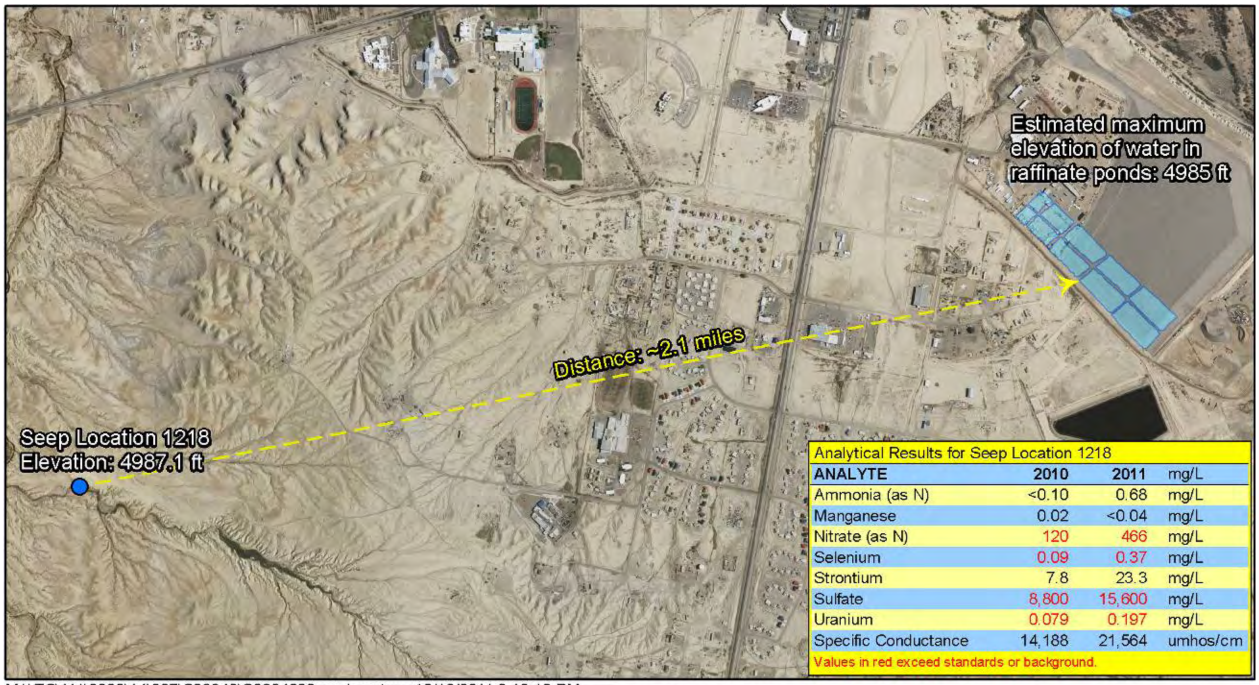
conditions on the terrace before operation of the mill. Because of the unique circumstances of the site, it's possible that a truly representative background location may not exist.

Analytical results for water samples from these locations are summarized in Table 2. As shown in this table, COC concentrations in more distal samples from locations 1219 and 1220 (Eagles Nest Arroyo) are fairly low. However, concentrations of nitrate, selenium, and uranium at seep location 1218 have been above corresponding MCLs, and those for sulfate far exceed EPA's secondary standard of 250 mg/L and the 210–5200 mg/L floodplain background range.

Table 2. Results of 2010–2011 Sampling at Candidate Terrace Background Locations

Contaminant	Location 1218 (WM Draw)	Location 1219	Location 1220 (Eagles Nest Arroyo)	Comment
Ammonia, as N (mg/L)	<0.1–0.68	0.14	<0.1	Similar to floodplain background results, ammonia levels are low at terrace background locations.
Manganese (mg/L)	<0.04	<0.04	0.15–0.37	Levels are low relative to floodplain background levels listed in Table 1.
Nitrate, as N (mg/L)	120–466	5.57	0.04–1.9	Nitrate levels in seep 1218 exceed the 40 CFR 192 standard.
Selenium (mg/L)	0.085–0.365[a]	0.03[a]	0.002–0.03E	Selenium concentrations in terrace seep 1218 exceed both EPA SDWA standard and the 40 CFR 192 MCL.
Strontium (mg/L)	7.8–23.3	11.5	2.8–4.4	The recent sample result for seep 1218 (23.3 mg/L) is the highest strontium level measured in site background.
Sulfate (mg/L)	8800–15,600	1790	760–1400	Sulfate levels at all locations exceed the SDWA secondary standard of 250 mg/L; levels in seep 1218 are particularly elevated.
Uranium (mg/L)	0.079–0.197[a,b]	0.031[a,b]	0.017–0.028	Like nitrate, selenium, and sulfate, uranium levels in seep 1218 are elevated.

Surface location 1218 was sampled in March 2010 and again in March 2011; location 1219 was sampled in March 2011 (only); location 1220 was sampled three times (March and September 2010; March 2011). Values in red exceed MCLs or alternate standards (e.g., EPA SDWA or risk-based values). In most cases, maximum concentrations were measured in the most recent (March 2011) samples.
[a] Estimated value because of interference.
[b] Both replicate analysis and spike sample recoveries were not within control limits.



ANALYTE	2010	2011	mg/L
Ammonia (as N)	<0.10	0.68	mg/L
Manganese	0.02	<0.04	mg/L
Nitrate (as N)	120	466	mg/L
Selenium	0.09	0.37	mg/L
Strontium	7.8	23.3	mg/L
Sulfate	8,800	15,600	mg/L
Uranium	0.079	0.197	mg/L
Specific Conductance	14,188	21,564	umhos/cm

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Figure 4. Surface (Seep) Location 1218: Location (Zoom View) and Results

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 the recent (Trench 1 and Trench 2) 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 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. This plume configuration is best characterized by elevated concentrations of sulfate and uranium. Contamination does not 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, recharging local groundwater and then flowing to the north and west. Surface water in Bob Lee Wash originates primarily as deep groundwater from the Morrison Formation 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.

Background groundwater quality in the floodplain aquifer, discussed in Section 1.2.1 (Table 1) is defined by 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. Though 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 extends southwestward from the escarpment separating the terrace from the floodplain for up to about 1 mile, where it is bounded by a buried escarpment. Terrace alluvial material is exposed at the terrace–floodplain escarpment, but to the southwest, it is covered by an increasing thickness of eolian silt, or loess. At the southwest edge of the terrace aquifer, along the base of the buried escarpment, up to 40 ft of loess overlies the alluvium; the alluvium in this area consists of coarse ancestral San Juan River deposits.

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

1.4 Contaminant Distributions

This section provides an overview of sitewide 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 2011a, DOE 2011e).

1.4.1 Data Presentation and Visualization Approach

Concentrations of COCs in terrace and floodplain groundwater, based on results of the most recent sampling event (September 2010 or March 2011), are shown in Figures 5 through 11. As in Figure 2, these figures distinguish between sample type (e.g., monitoring well, surface location, or treatment system collection drain/sump locations). For monitoring wells, these figures also identify the zone in which the wells were completed—alluvium (Qal) or Mancos Shale (Km). [Figure 2 includes a Qal/Km category, denoting wells screened in both formations. For simplicity, these are considered alluvial wells in Figures 5 through 11.]

In Figures 5 through 11, each figure is presented as a pair (e.g., Figures 5a and 5b). Figures with an "a" suffix plot contaminant concentrations using graduated symbols defined for discrete categories. Categories (or interval classes) are based on defined increments above or below a regulatory criterion (e.g., 40 CFR 192 MCLs, if available), the floodplain background data listed in Table 1, and/or the sitewide contaminant distribution. Companion figures (with a "b" suffix) plot the same data, but in an alternate form, using bar charts that reflect the actual (continuous vs. discrete) distribution of the data, overlying an aerial photograph. In these "b" series figures, each bar denotes the COC magnitude at a given location relative to the maximum detected concentration at the site for all sample types (e.g., monitoring well or surface location).[6]

The bar chart data visualization method is provided to facilitate identification of "hot spots" and, more importantly, to better depict the overall distribution of contaminants across the site (and across media). (Because the figures are large, and so as not to interrupt the discussion, all remaining figures in this section [Figures 5 through 19] are provided following Section 1.4.2).

Figures 7a and 7b, which plot nitrate concentrations, provide a good example of the two (spot plot vs. bar chart) data presentation methods. In Figure 7a, it is apparent that nitrate concentrations are elevated on the terrace in the radon borrow pit area in the paleochannel near the buried escarpment, in Many Devils Wash, and on the floodplain at the base of the escarpment and in the well 1089 area. But only by reviewing Figure 7b is it apparent how nitrate concentrations at most site locations (including the disposal cell area) are much lower than those measured in the radon borrow pit and paleochannel area. Also, nitrate concentrations in Many Devils Wash are higher than most concentrations on the floodplain.

Another example is found in Figures 11a and 11b, which plot the distribution of uranium. Figure 11a shows that uranium concentrations in floodplain alluvial wells are in general much higher than those in terrace alluvial wells. However, Figure 11b highlights the magnitude of uranium in terrace Mancos (Km) well 0817 relative to all other site well locations.[7]

Figure 12, a side-by-side comparison of relative contaminant distributions for the primary COCs, combines the individual "b" series figures discussed above (except for strontium). Figures 13 through 19 plot changes in the extent of the floodplain and terrace contaminant plumes and present interpolated data for wells sampled between 2000 and 2003 (representing baseline conditions) and the most recent result for this evaluation period (September 2010 or March 2011). Because these interpolations consist of predicting concentrations of COCs at an unsampled site based on measurements made at the closest surrounding sites, these figures are

[6] Data values are not labeled in the "b" series figures because the purpose of these figures is to show the relative magnitude and overall distribution of contaminants rather than specific values. Although bar charts are considered a useful data visualization tool, for some adjacent or colocated data points (e.g., Mancos wells 0602 and 0817, located west of the disposal cell), if one datum (0817) is elevated, its neighbor (0602) may be obscured. In these cases, the reader is referred to the "a" version of the figure pair for clarification.

[7] The most recent (March 2011) uranium result for well 0817—30.4 mg/L—is anomalous and must be verified. Therefore, Figure 11b plots the September 2010 result (6.8 mg/L), which is consistent with previous measurements from 0817, as well as independent ESL analyses (11.8 and 9.2 mg/L for April and August 2011, respectively).

most useful for examining changes in plume extent for floodplain monitoring wells (given the density of wells in this area). Interpolations for areas with a lower well density should be interpreted with some caution.

1.4.2 Overview of Findings

As shown in Figure 2, the Shiprock well network is dense. For this reporting period, 115 monitoring wells were sampled (59 on the floodplain and 56 on the terrace). Thirty-two (32) surface water locations, including seeps and 8 San Juan River sampling points as shown in Figure 3, are also routinely sampled if water is present. [During this reporting period, at least half of 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 5 through 19, several global trends are apparent, as summarized below.

<u>Ammonia</u>
Ammonia concentrations are highest in the terrace 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 (Figures 5a and 5b). On the floodplain, ammonia is most elevated in Trench 2 wells 1115 and 1128 (255 and 470 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 (≤1 mg/L). Sitewide, for this reporting period, the maximum ammonia concentration (1110 mg/L) was measured in terrace Mancos well 0817, just west of the disposal cell. The plume maps in Figure 13 show no notable differences between baseline and current periods. Apparent increases in the Trench 2 area are attributable to the fact that no data (wells) were available for this area during the baseline (2000–2003) period.

<u>Manganese</u>
Manganese, which is at or near background concentrations across much of the site, is elevated only in the borrow pit/evaporation pond area (Figures 6a and 6b; also see Figure 14). Concentrations in wells 0603 and 1057 have increased significantly since September 2008—from about 27 to 53 mg/L in well 0603 and from 14 to 65 mg/L in well 1057. The reason for these recent increases is not known, but could likely be related to large volumes of water introduced into the alluvial aquifer during the nearby gravel pit operations beginning in 2008. Apart from these wells, most concentrations are within the historical floodplain background range listed in Table 1.

<u>Nitrate</u>
As shown in Figures 7a, 7b, and Figure 15, 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 (see discussion regarding selenium below). Although still elevated on the floodplain (relative to the 10 mg/L MCL), nitrate concentrations are much lower since the installation of trenches in 2006 (Figure 15; also see Figure 24). The plume maps in Figure 15 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.

Selenium

Selenium's spatial distribution is very similar to that observed for nitrate in that concentrations are most elevated along the terrace buried escarpment and in Many Devils Wash (Figures 8a and 8b; also see Figure 12). As discussed in Section 1.2 (see Table 2 and Figure 4), selenium is also elevated at seep 1218, located about 2 miles southwest of the site. The extent to which selenium is attributable to the site or naturally occurring is the subject of an ongoing investigation (preliminary results documented in DOE 2011c). The plume maps in Figure 16 indicate some reductions in selenium concentrations on the floodplain, but these do not appear to be significant. Selenium has actually increased in some west terrace wells, a finding that may be attributable to declining water levels.

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. Closer to the river, however, selenium concentrations are generally below the 0.05 mg/L SDWA standard, 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 9a are based on historical floodplain background concentrations (0–10 mg/L). However, 23 mg/L was recently measured in distal terrace seep location 1218 (Table 2), which exceeds all strontium concentrations measured during the 2010–2011 reporting period except in floodplain alluvial well 0630 (24.5 mg/L). In the bar chart diagram (Figure 9b), unlike other COCs, strontium concentrations are fairly uniform across the site. Given this uniform distribution, strontium may be naturally occurring at the Shiprock site rather than associated with former milling processes.

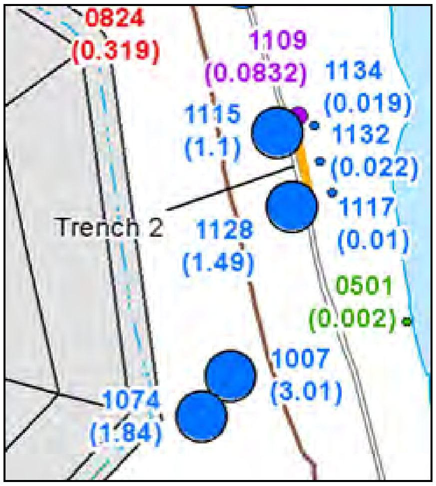
Sulfate

Sulfate is elevated at most locations at the Shiprock site, but like nitrate and selenium, it is most elevated along the terrace buried escarpment and in Many Devils Wash (Figures 10a and 10b). In fact, the maximum concentration was measured in the recently established location 1221. (The most recent sulfate measurement in San Juan River location 0897, 713 mg/L, was also elevated relative to historical measurements, which average about 165 mg/L.) Sulfuric acid was used during milling and, coupled with the concentration data, there is no question that sulfate on site 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). As observed for nitrate and uranium, reductions in sulfate concentrations are evident on the floodplain (see plume maps in Figure 18); this is not the case on the terrace.

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 (Figures 11a and 11b). For this reason, uranium receives the most focus in later discussions of temporal floodplain contamination trends (Section 2.1.2). On the floodplain, uranium concentrations are highest at the base of the escarpment (including Trenches 1 and 2) and in the well 1089 areas. In terms of relative magnitude, uranium concentrations at the remainder of the site are much lower (see discussion below).

As observed for nitrate and sulfate, reductions in uranium are evident in the (baseline vs. current) plume maps (Figure 19), and concentrations in wells nearer the river are markedly lower. The best example of this is found in the Trench 2 area, as shown in the schematic below (adapted from Figure 11a inset).



Zoom view of Uranium Concentrations in Trench 2 Area (see Figure 11a inset)

<u>Summary</u>

Although DOE has considered initiating a pilot groundwater hot-spot remediation study at locations where concentrations of one or more contaminants are elevated (DOE 2010a), as shown in Figures 5−19 and in particular the bar chart compendium in Figure 12, a complicating factor for such an evaluation is that maximum concentrations of individual COCs do not occur in the same location. The extent to which the differing distributions reflect prior milling practices, differences in contaminant chemistry and mobility, and/or influences from background is not clear at this time. To address these unknowns, DOE is conducting more targeted characterization efforts to address key issues and site areas, such as Many Devils Wash (e.g., see DOE 2011b; DOE 2011c). Therefore, the current interpretation is likely to continue to evolve as ongoing and planned studies yield additional information.

The plume maps in Figures 13 through 19 (comparing baseline and current snapshots) demonstrate the success of the floodplain remediation, in particular for the primary COCs (nitrate, sulfate, and uranium). In these figures, an arcuate plume extends northward from the contaminated area at the base of the disposal cell, crosses the floodplain and approaches the San Juan River near the floodplain extraction wells. This plume configuration is best characterized by elevated concentrations of sulfate and uranium. In general, contamination does not occur along the escarpment base in the northwest part of the floodplain (Figure 12). Additional discussion of floodplain contaminant trends is provided in Section 2.1.2.

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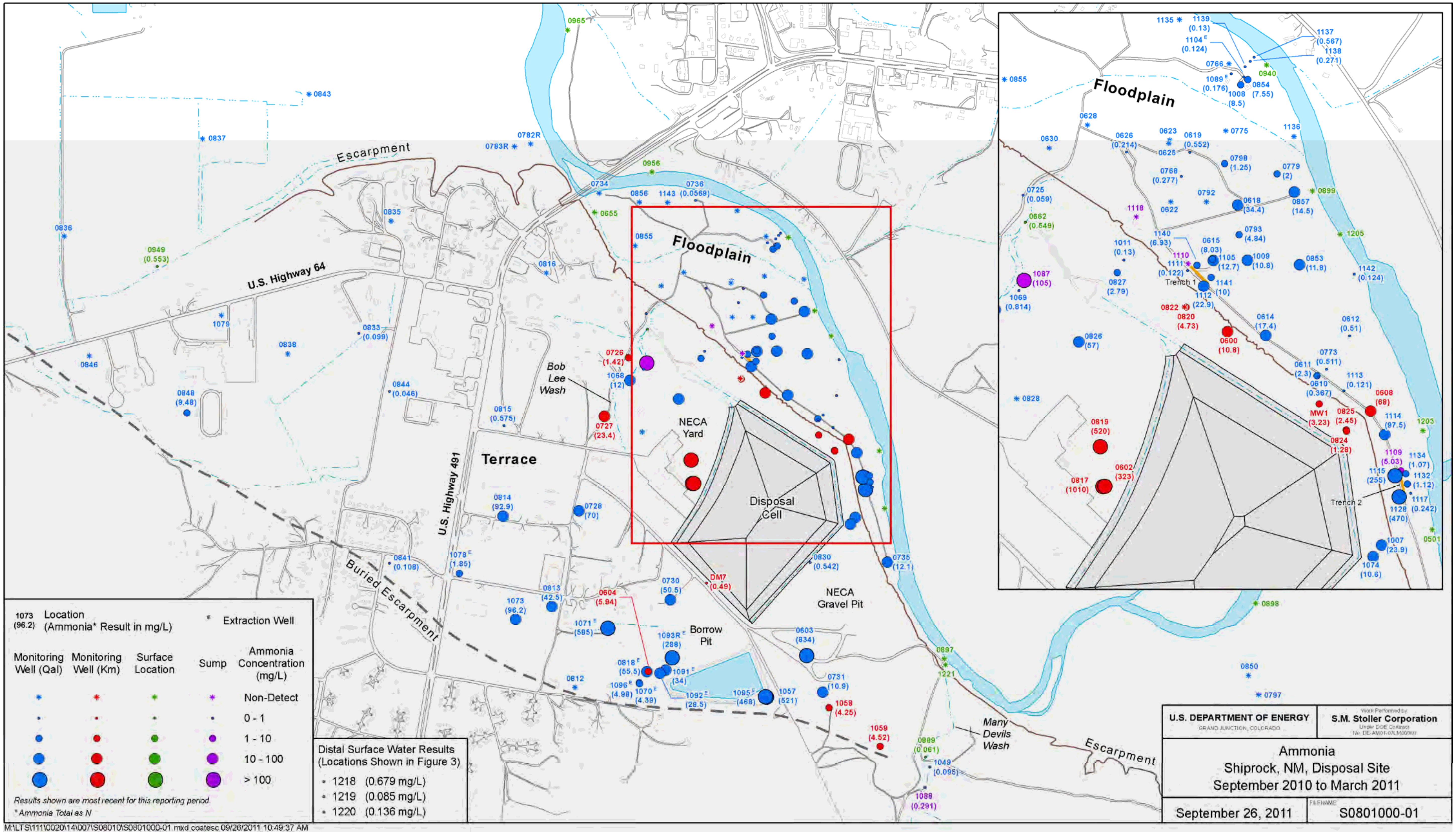

Figure 5a. Concentrations of Ammonia in Groundwater and Surface Water, September 2010–March 2011

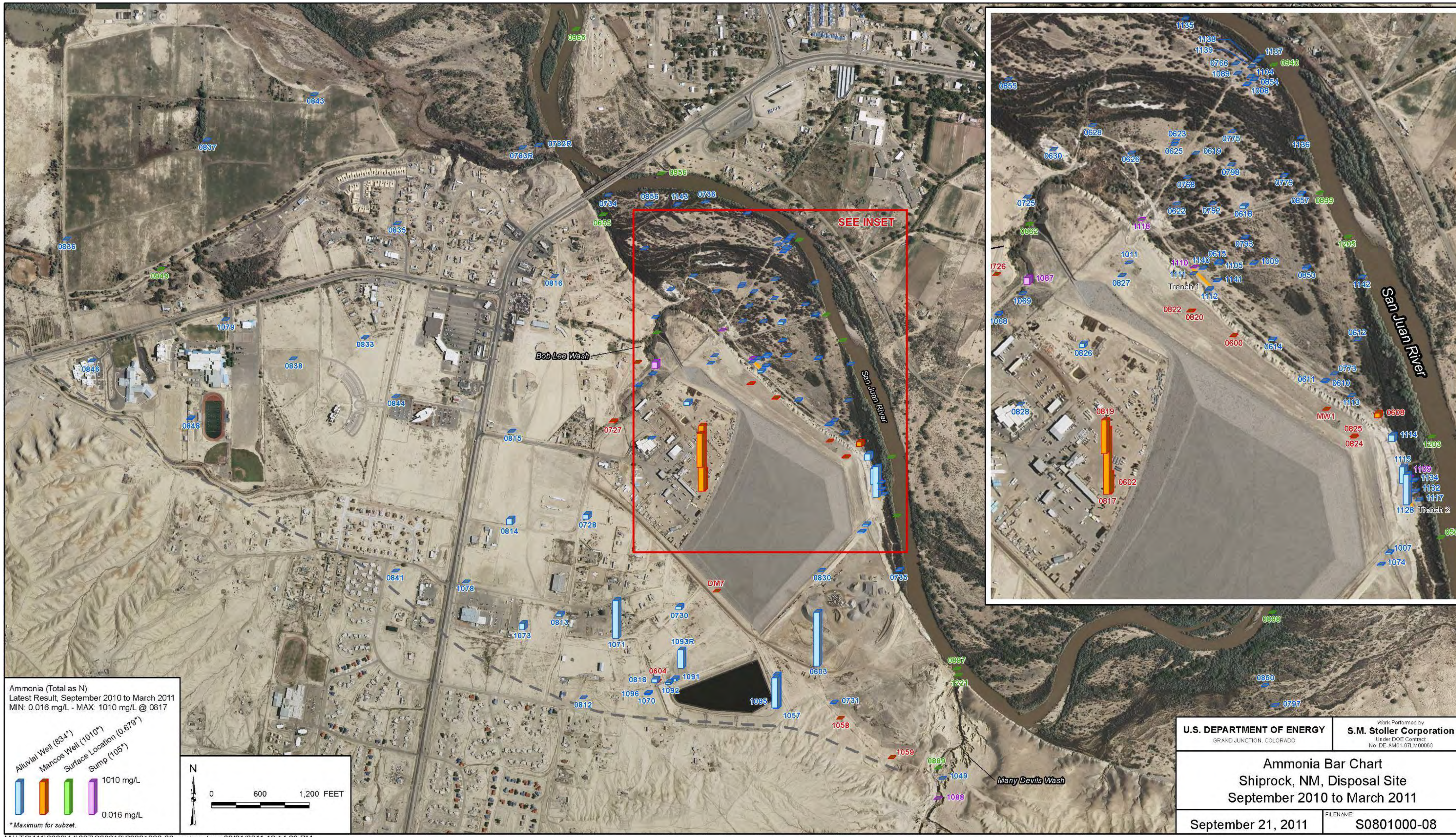

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Figure 5b. Relative Distribution of Ammonia in Groundwater and Surface Water, September 2010–March 2011

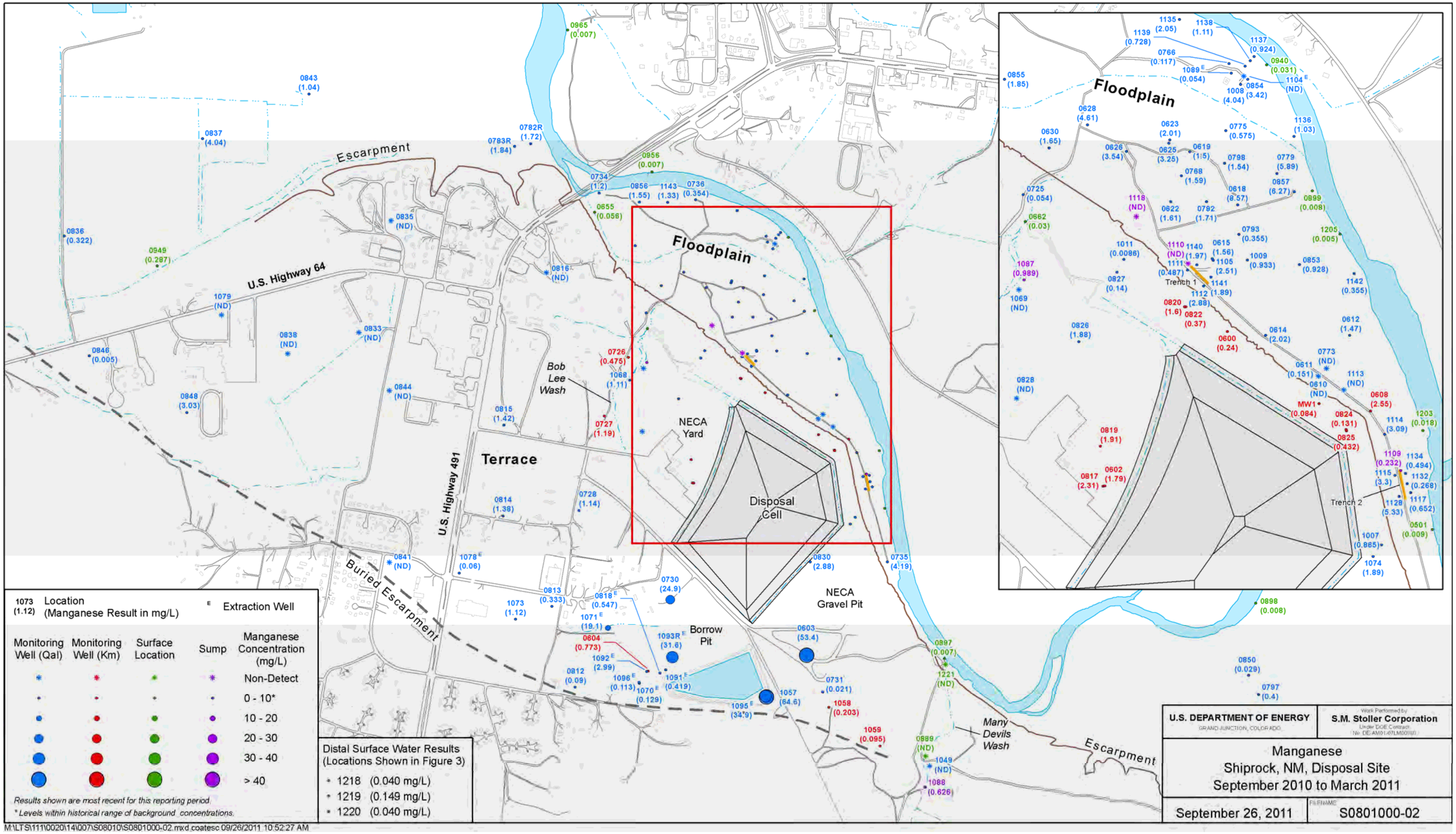

Figure 6a. Manganese Concentrations in Groundwater and Surface Water, September 2010–March 2011

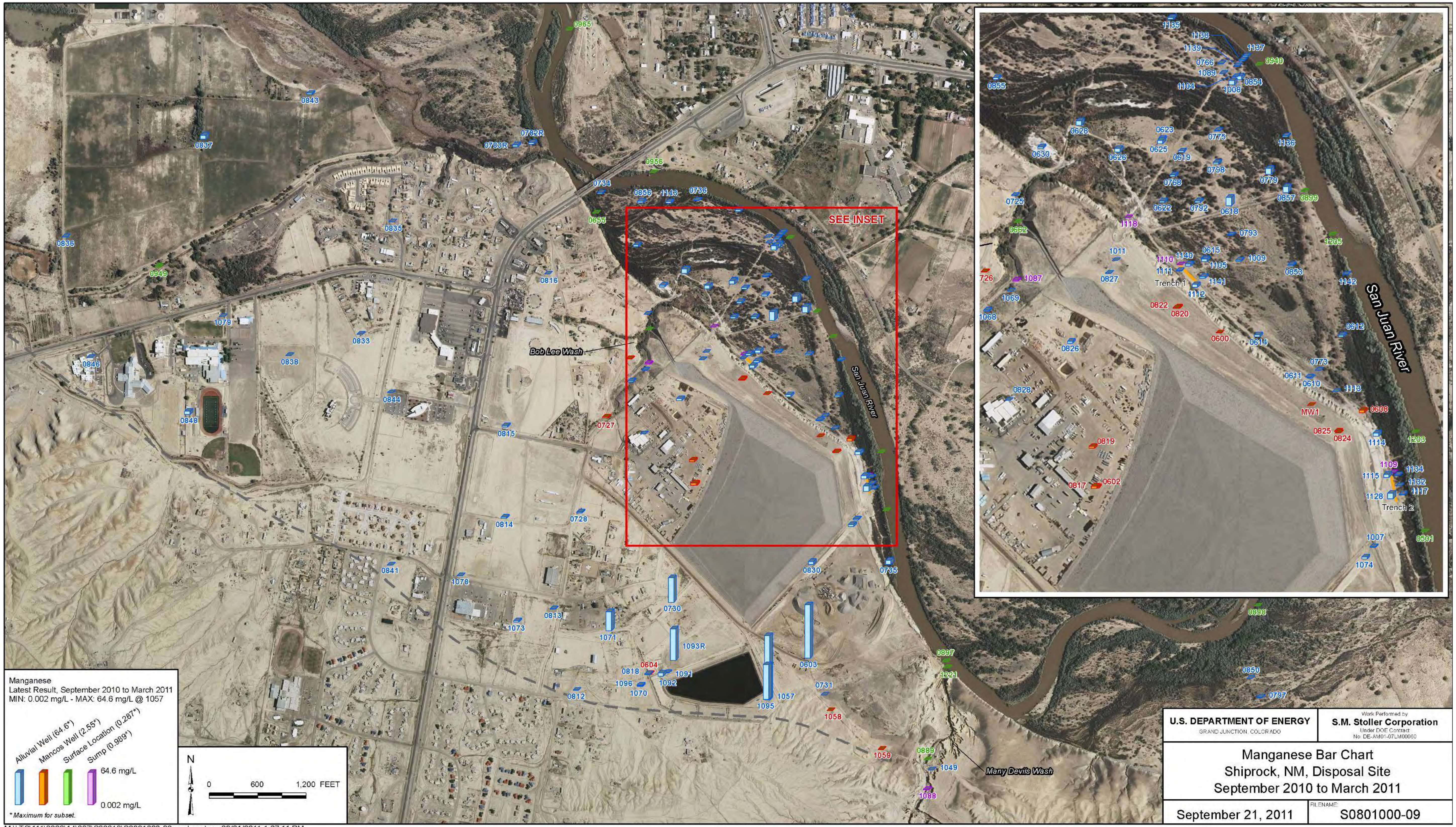

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Figure 6b. Relative Distribution of Manganese in Groundwater and Surface Water, September 2010–March 2011

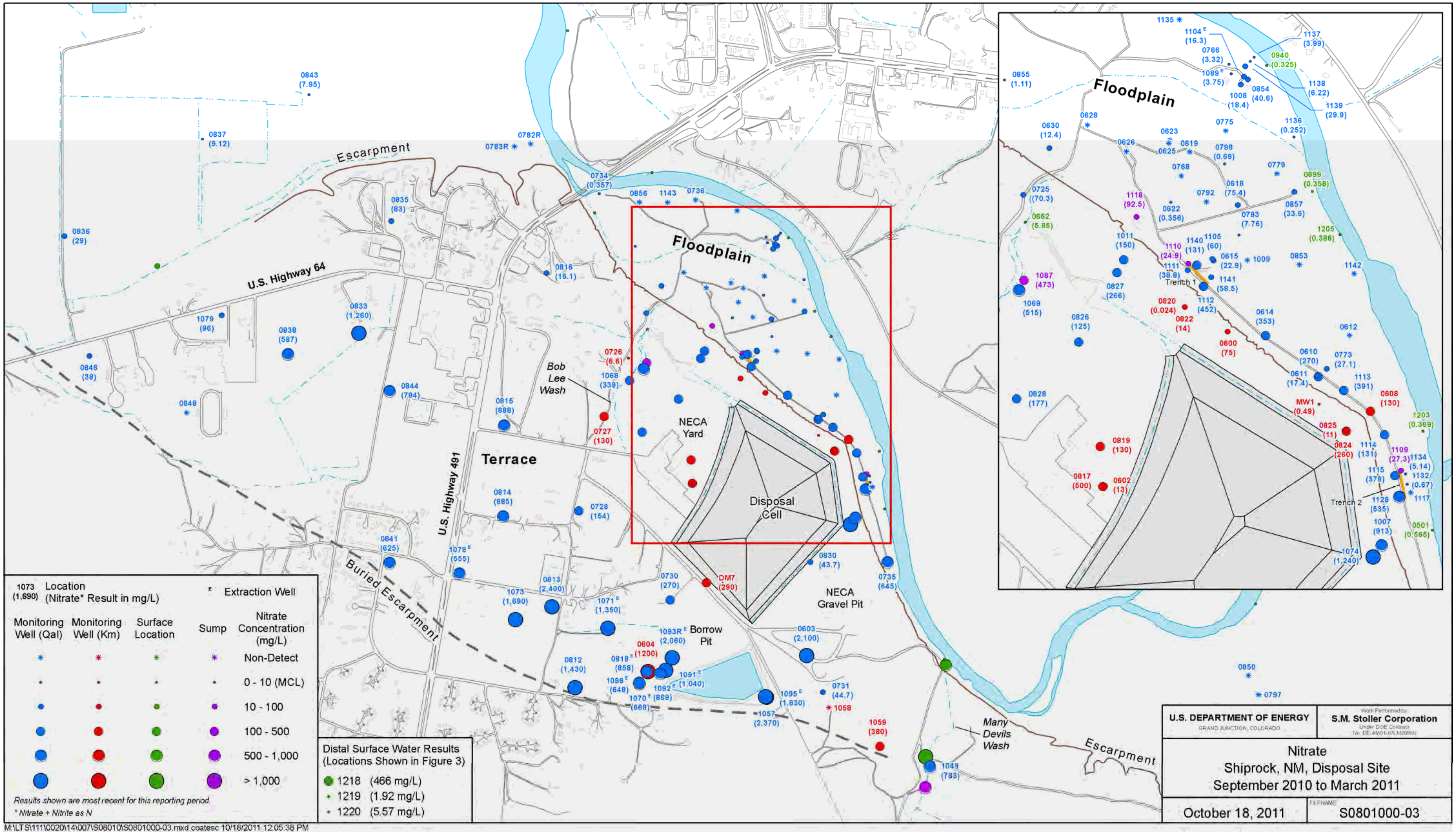

Figure 7a. Nitrate Concentrations in Groundwater and Surface Water, September 2010–March 2011

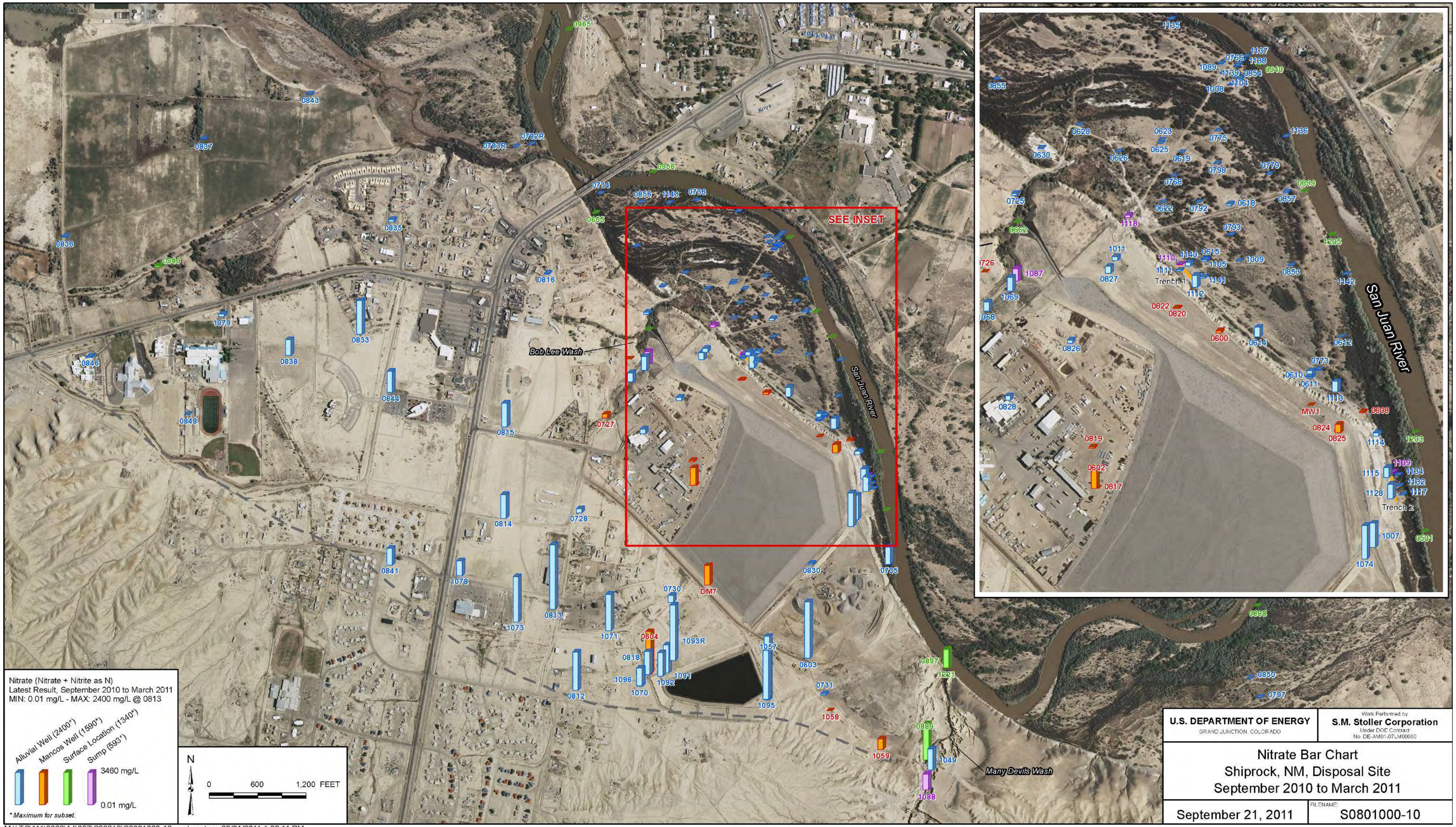

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Figure 7b. Relative Distribution of Nitrate in Groundwater and Surface Water, September 2010–March 2011

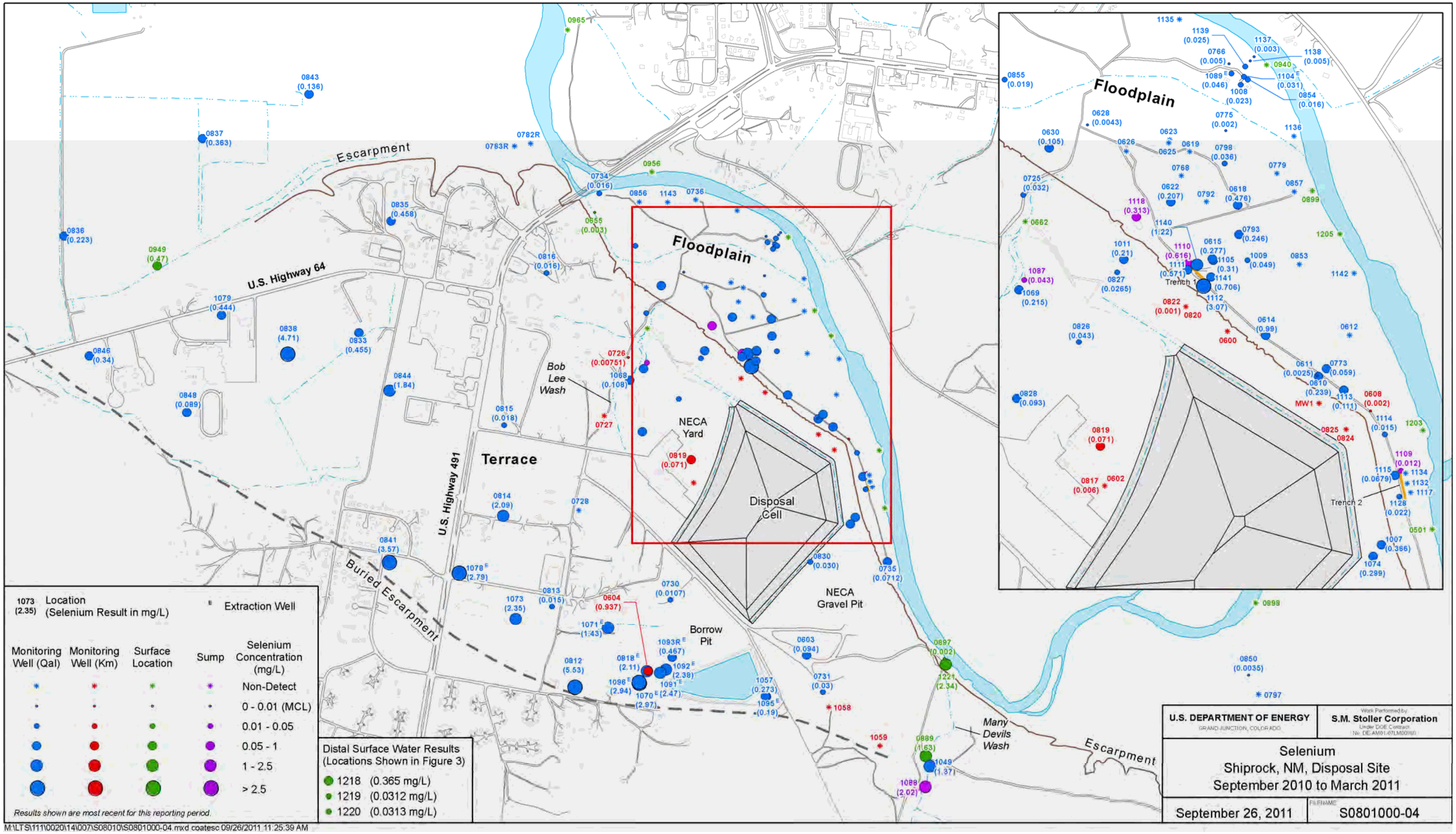

Figure 8a. Selenium Concentrations in Groundwater and Surface Water, September 2010–March 2011

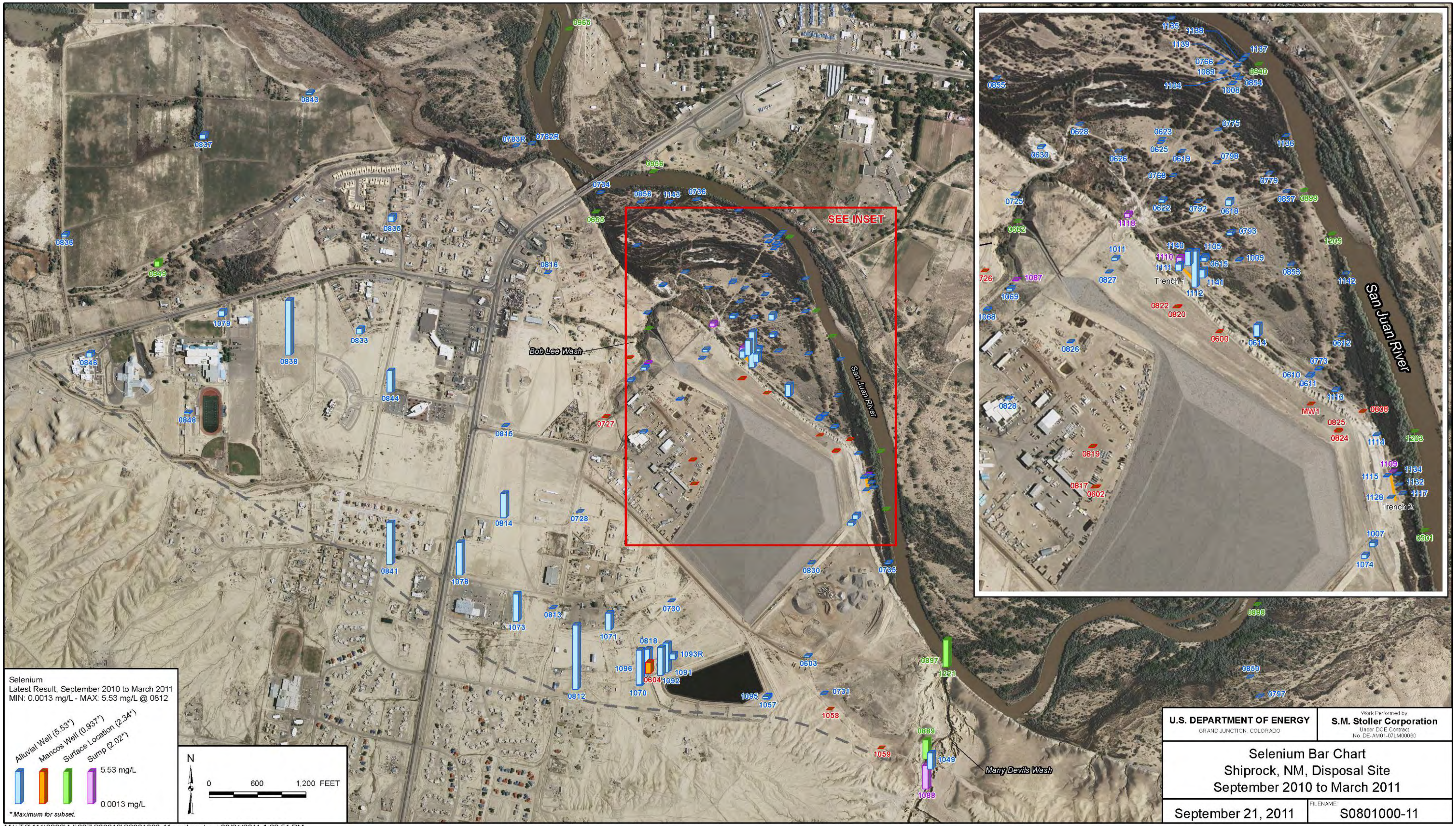

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Figure 8b. Relative Distribution of Selenium in Groundwater and Surface Water, September 2010–March 2011

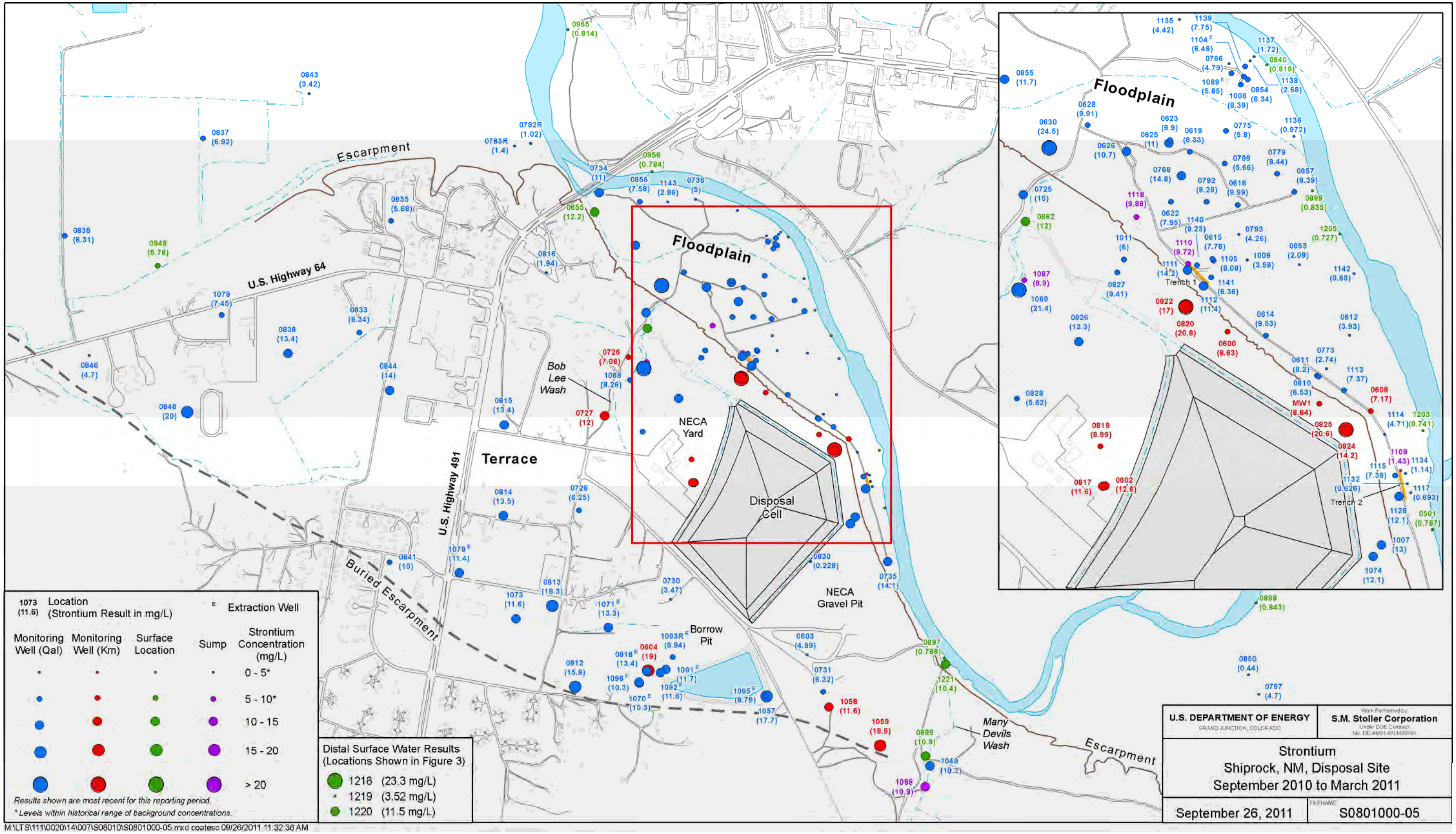

Figure 9a. Strontium Concentrations in Groundwater and Surface Water Samples, September 2010–March 2011

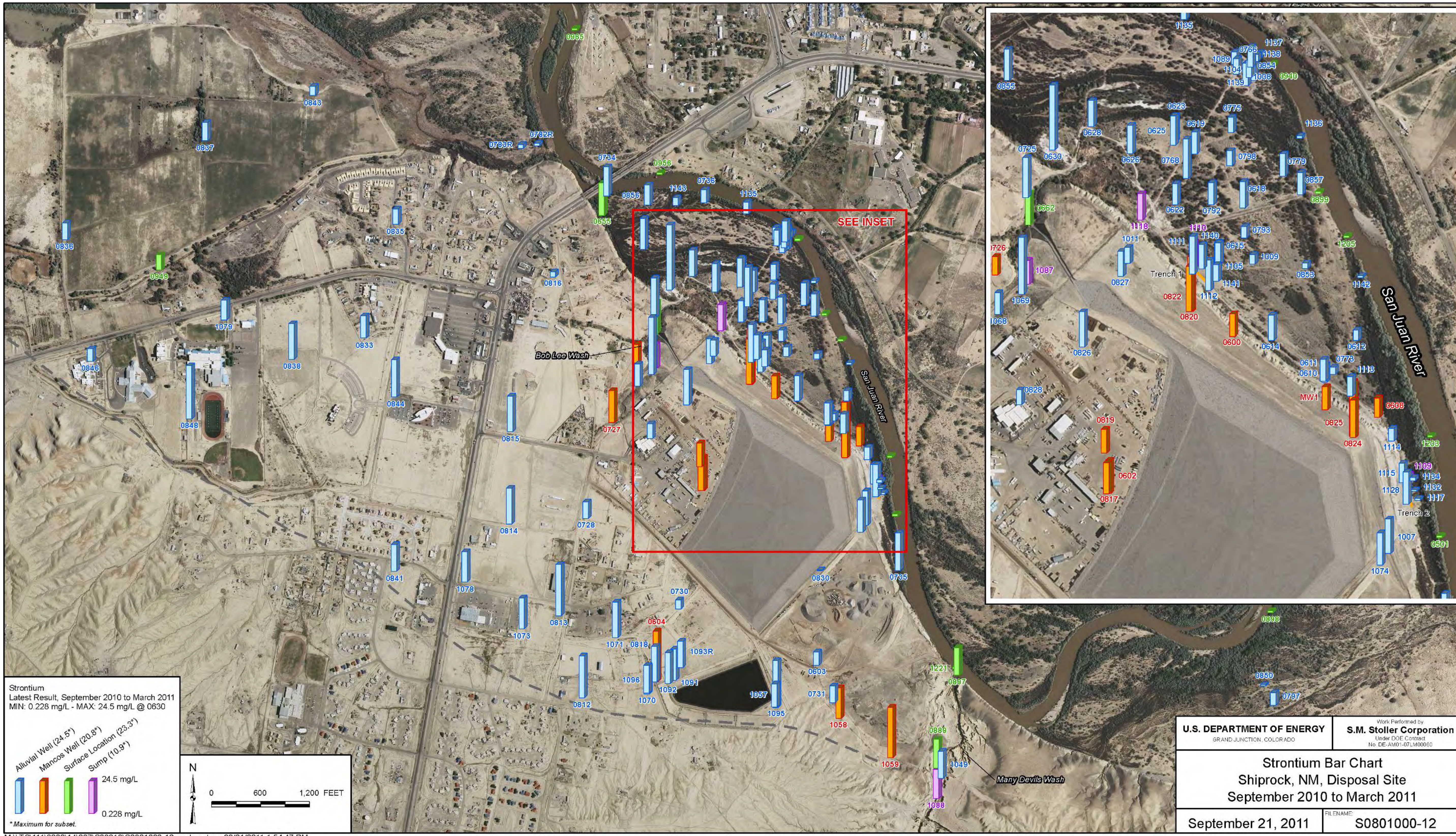

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Figure 9b. Relative Distribution of Strontium in Groundwater and Surface Water Samples, September 2010–March 2011

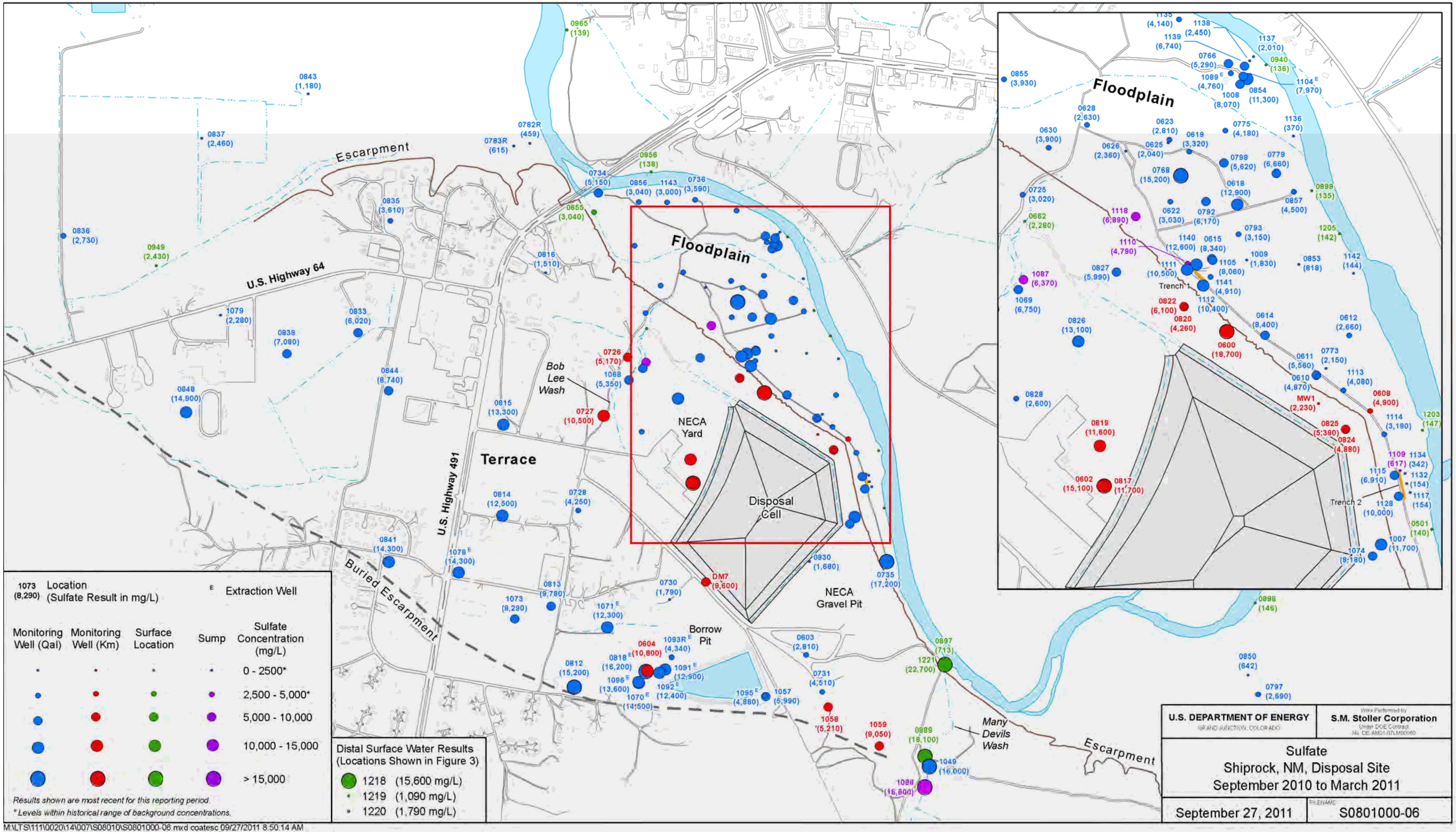

Figure 10a. Sulfate Concentrations in Groundwater and Surface Water Samples, September 2010–March 2011

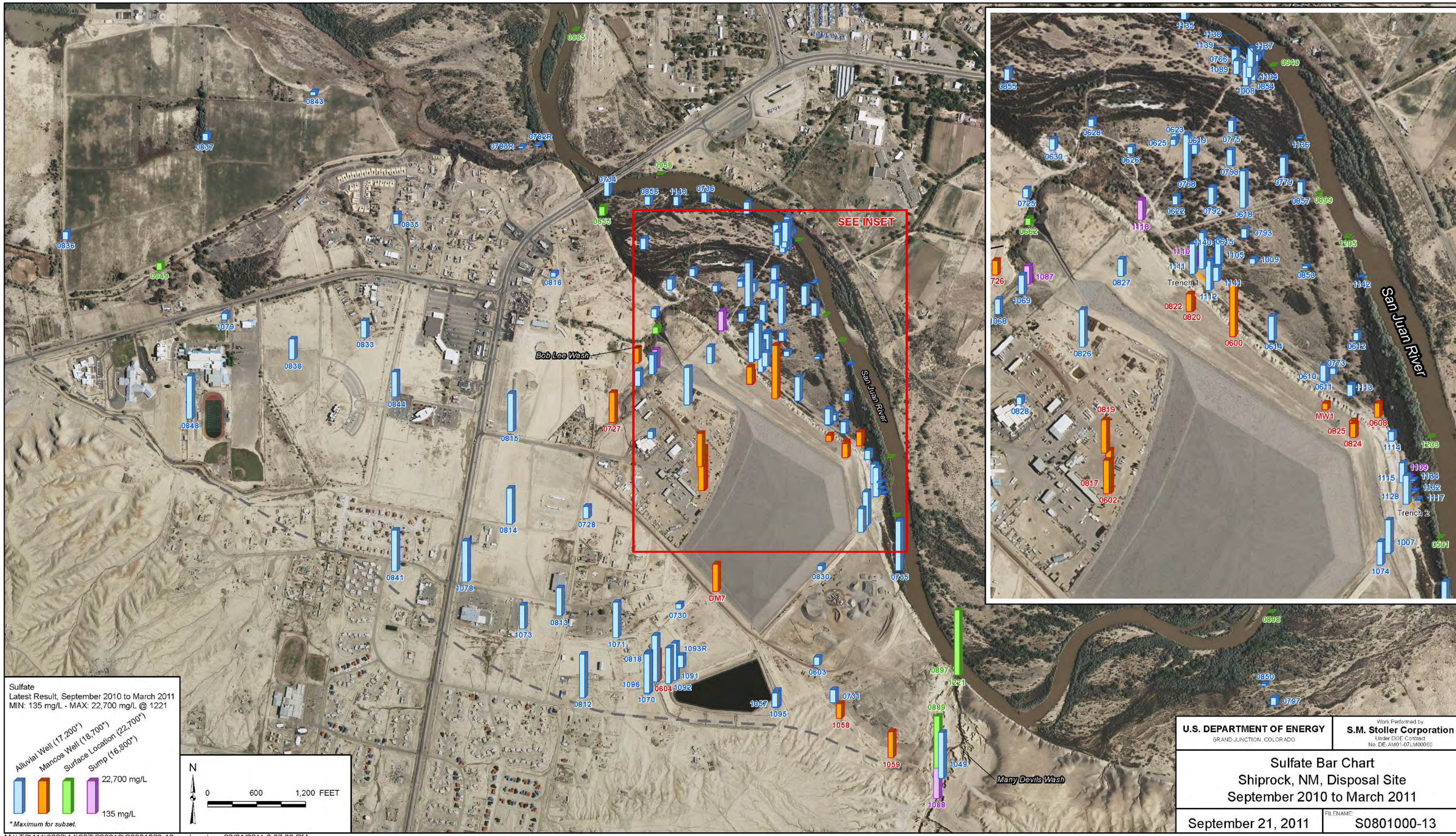

Figure 10b. Relative Distribution of Sulfate in Groundwater and Surface Water Samples, September 2010–March 2011

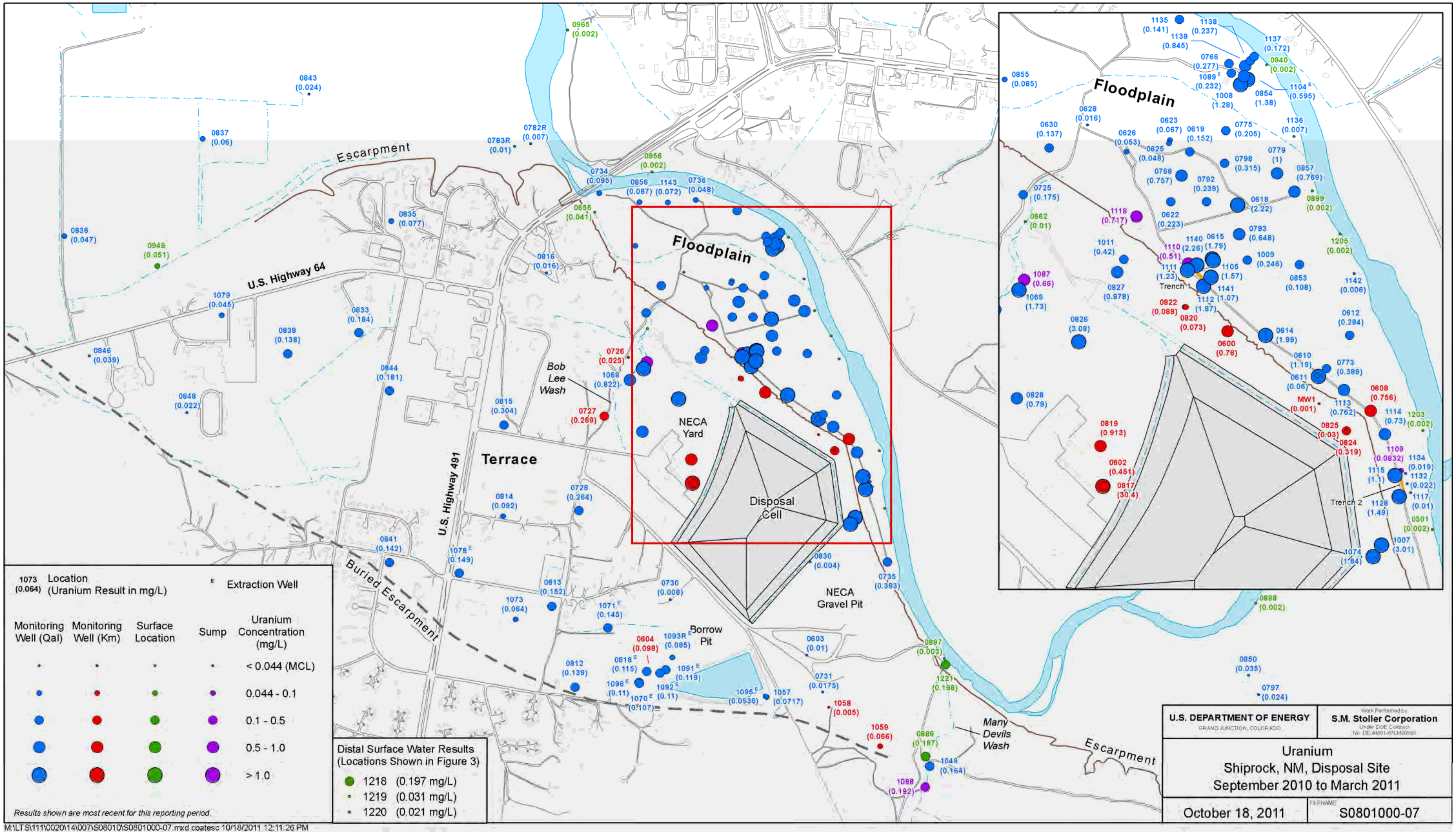

Figure 11a. Uranium Concentrations in Groundwater and Surface Water Samples, September 2010–March 2011

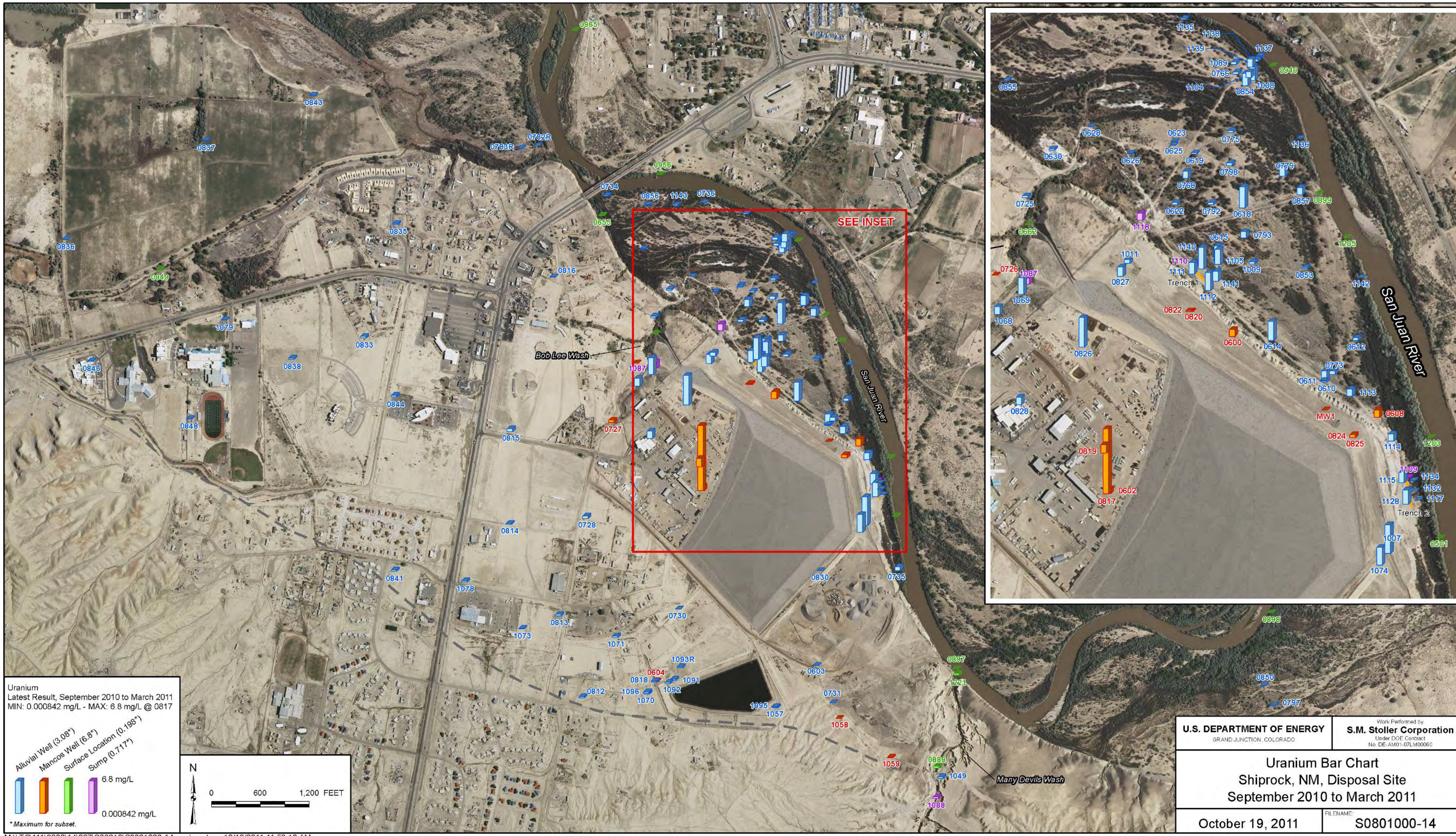

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Figure 11b. Relative Distribution of Uranium in Groundwater and Surface Water Samples, September 2010–March 2011

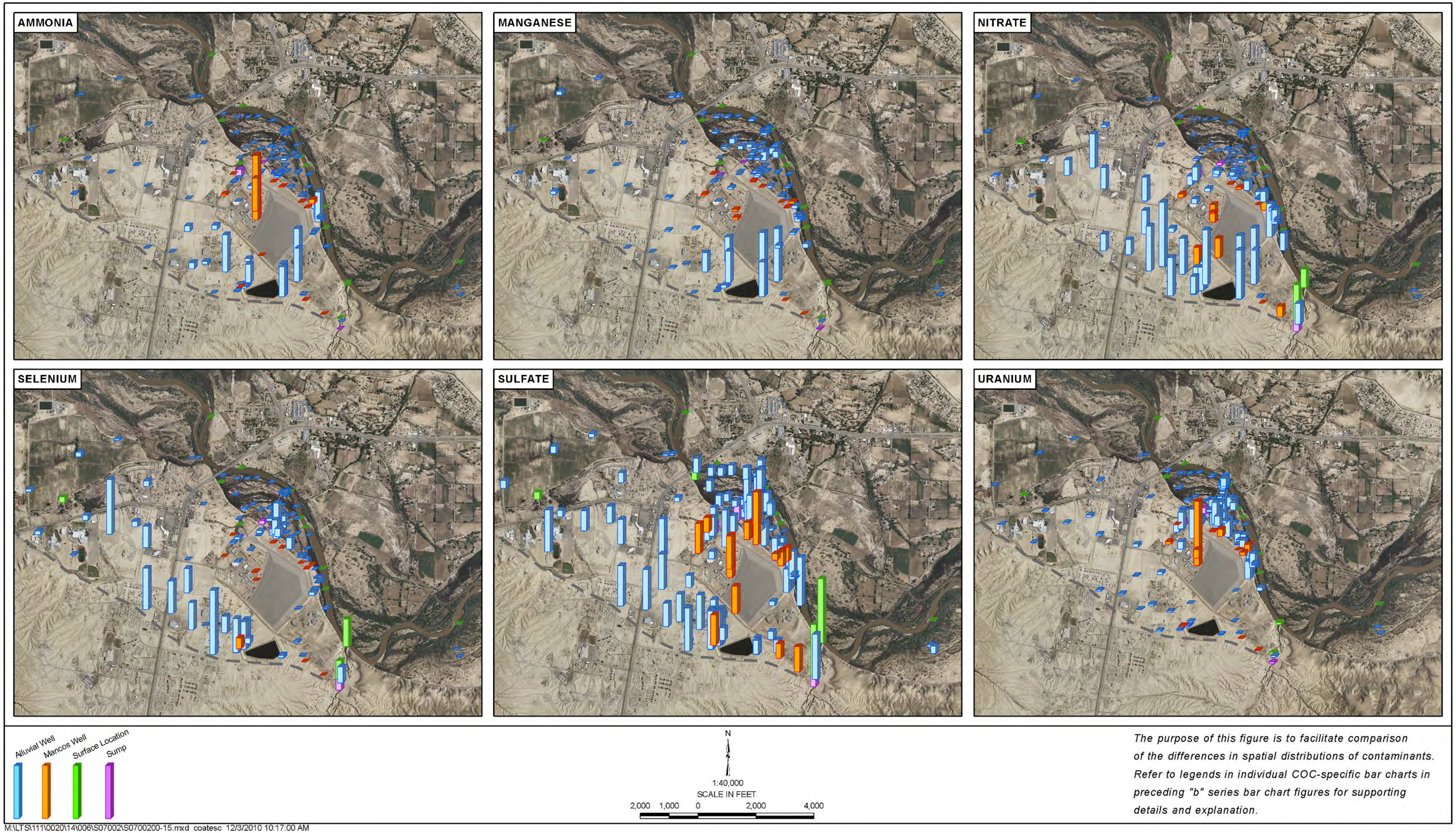

Figure 12. Side-By-Side Comparison of Relative Contaminant Distributions for the Primary COCs

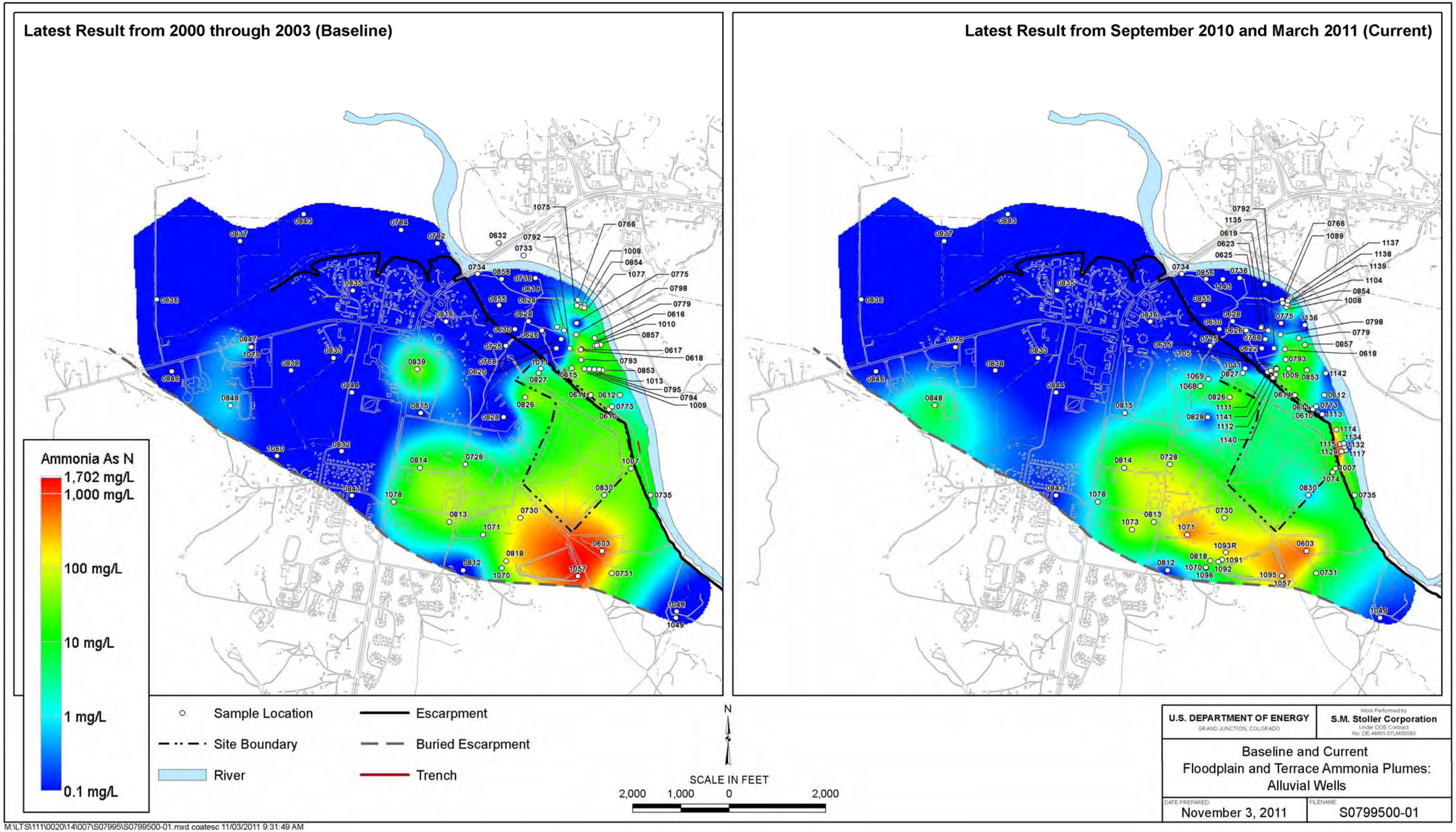

Figure 13. Baseline (2000–2003) and March 2011 Floodplain and Terrace Ammonia Plumes

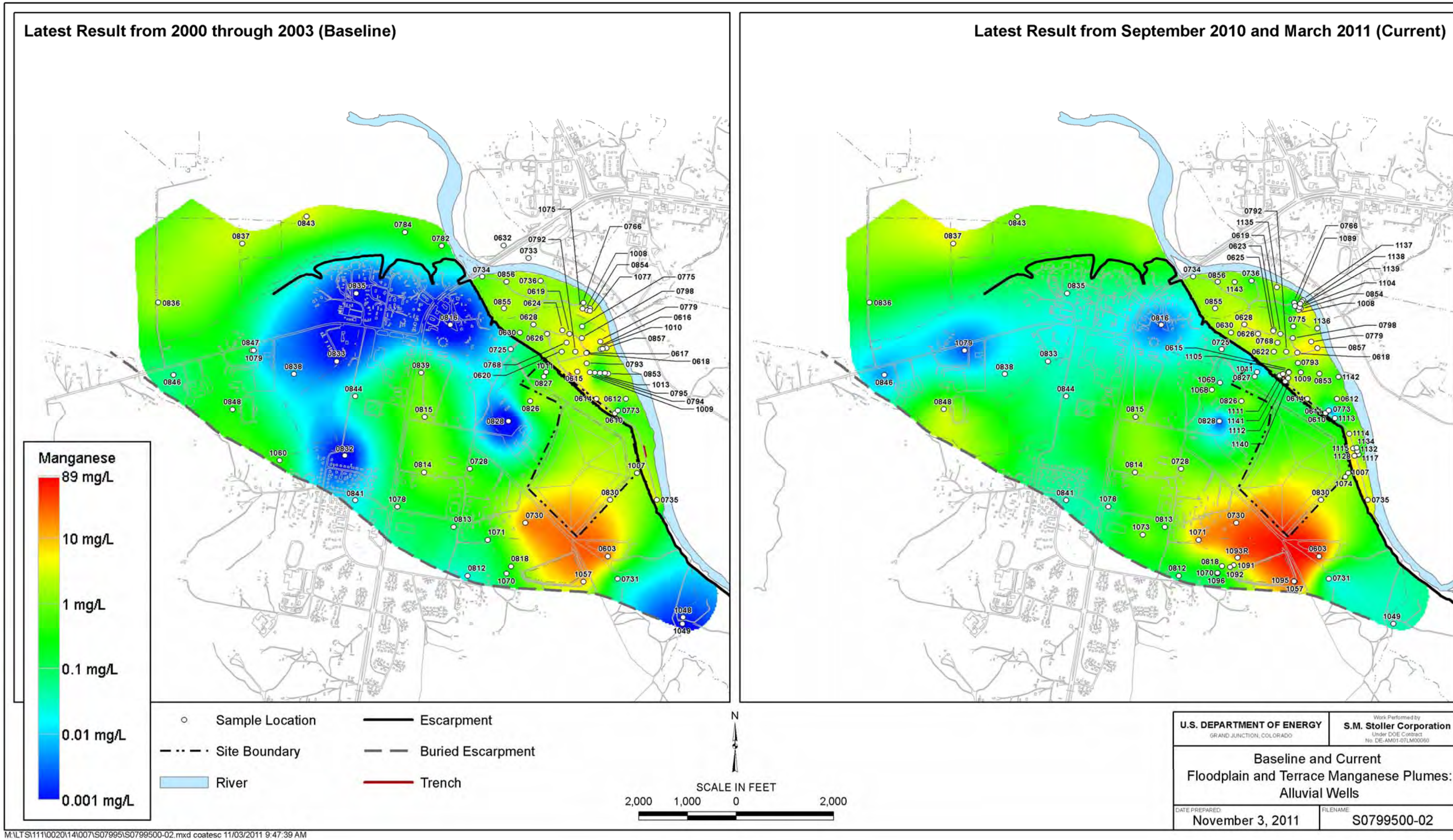

Figure 14. Baseline (2000–2003) and March 2011 Floodplain and Terrace Manganese Plumes

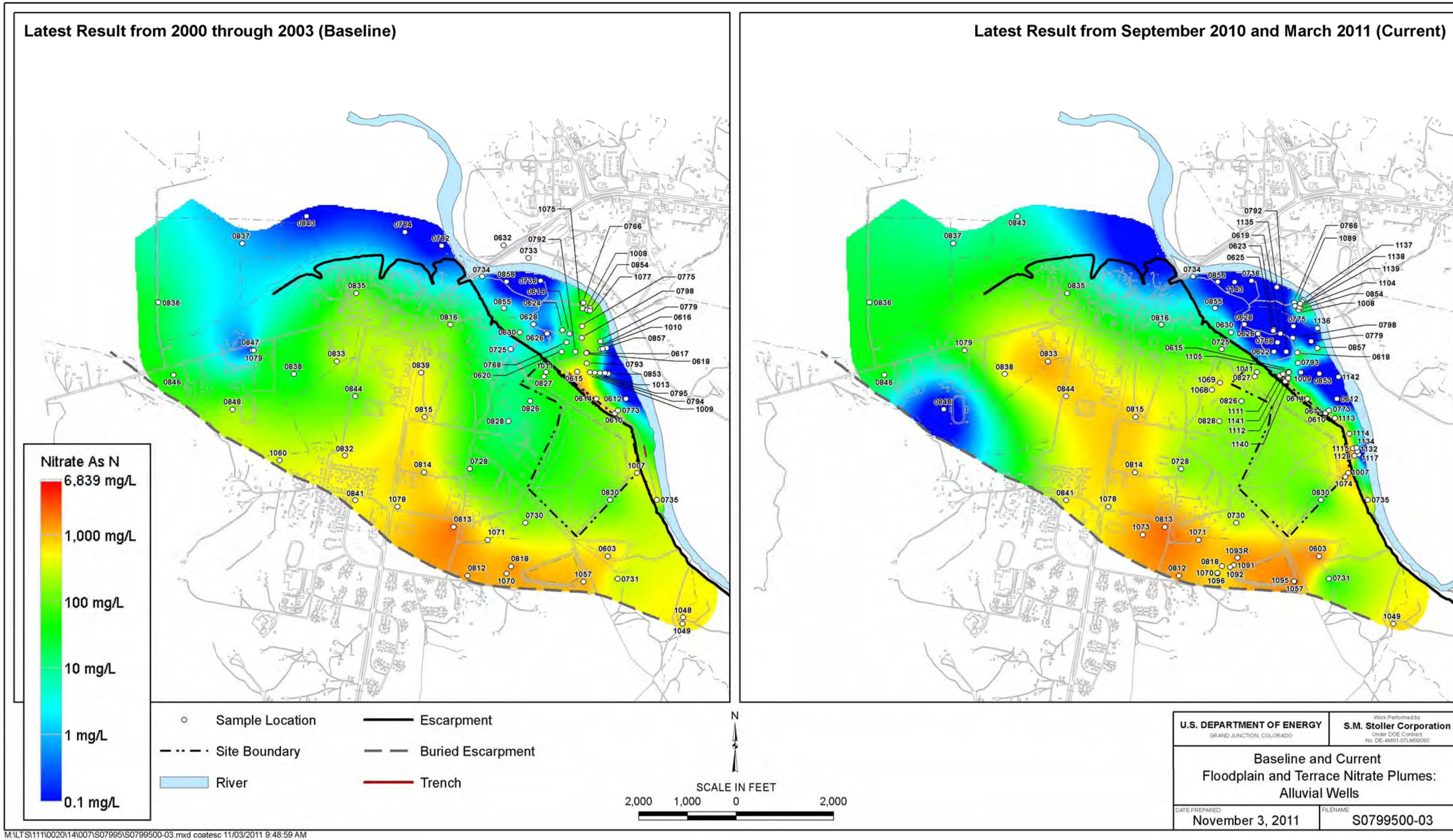

Figure 15. Baseline (2000–2003) and March 2011 Floodplain and Terrace Nitrate Plumes

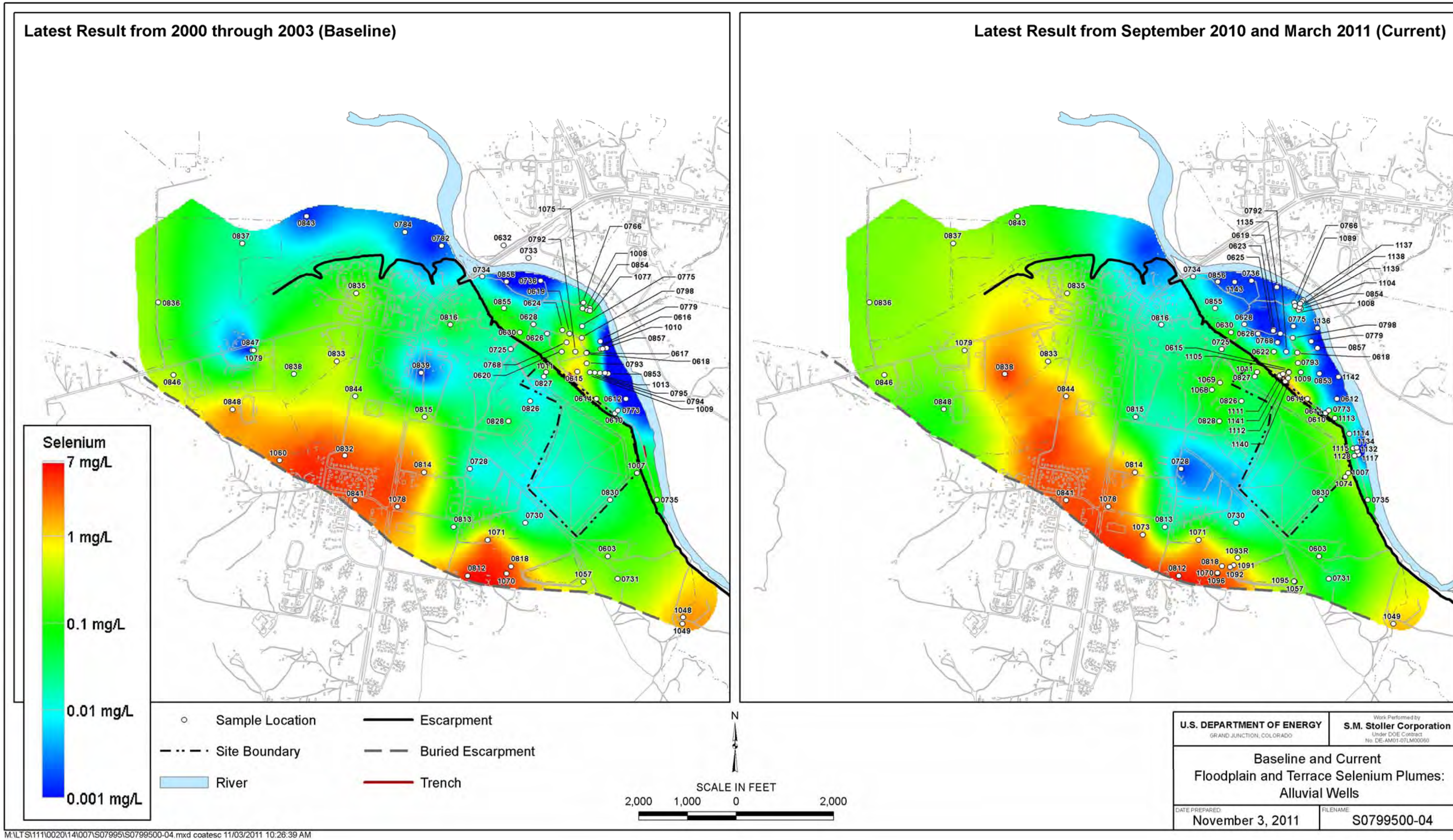

Figure 16. Baseline (2000–2003) and March 2011 Floodplain and Terrace Selenium Plumes

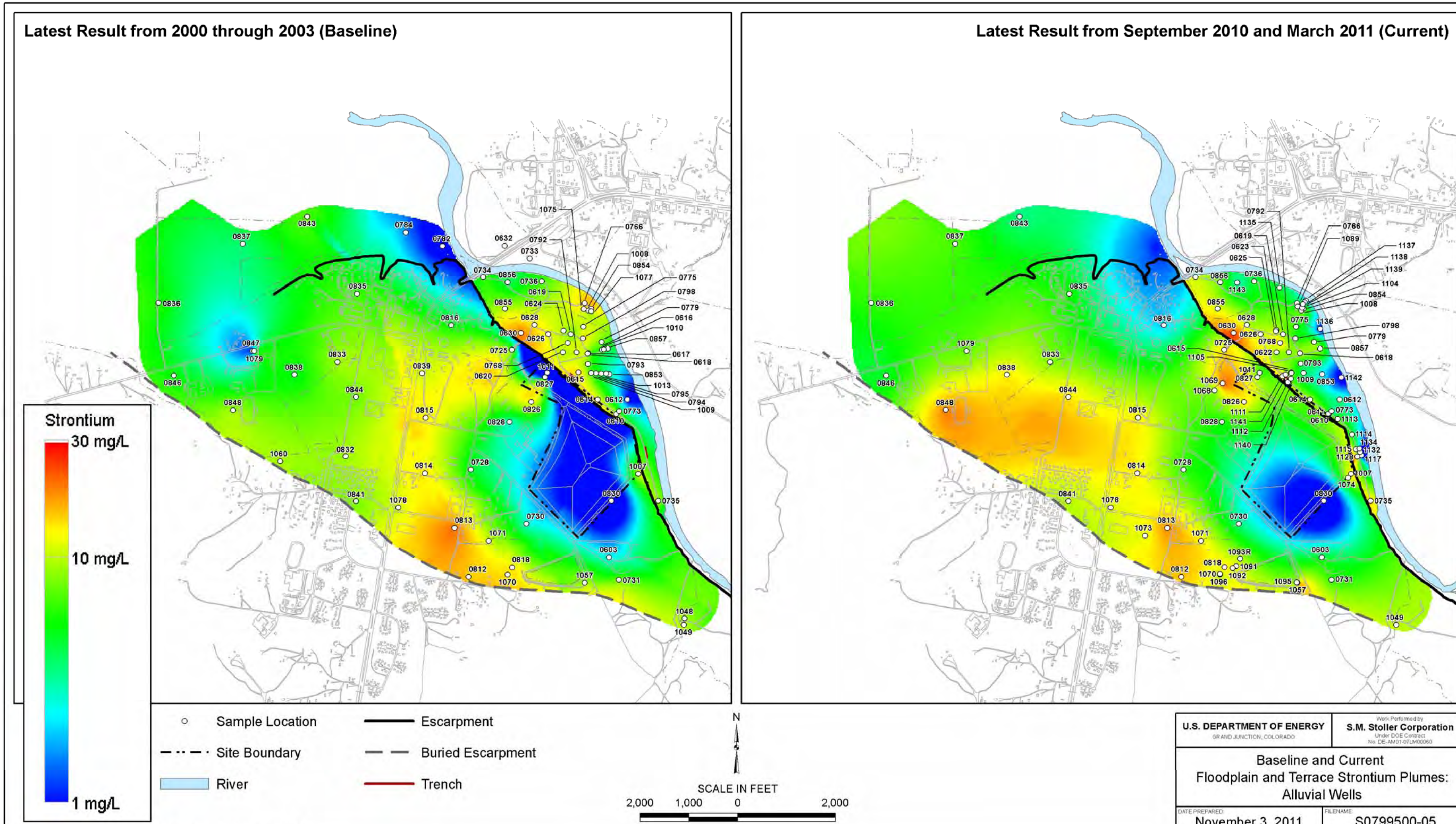

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Figure 17. Baseline (2000–2003) and March 2011 Floodplain and Terrace Strontium Plumes

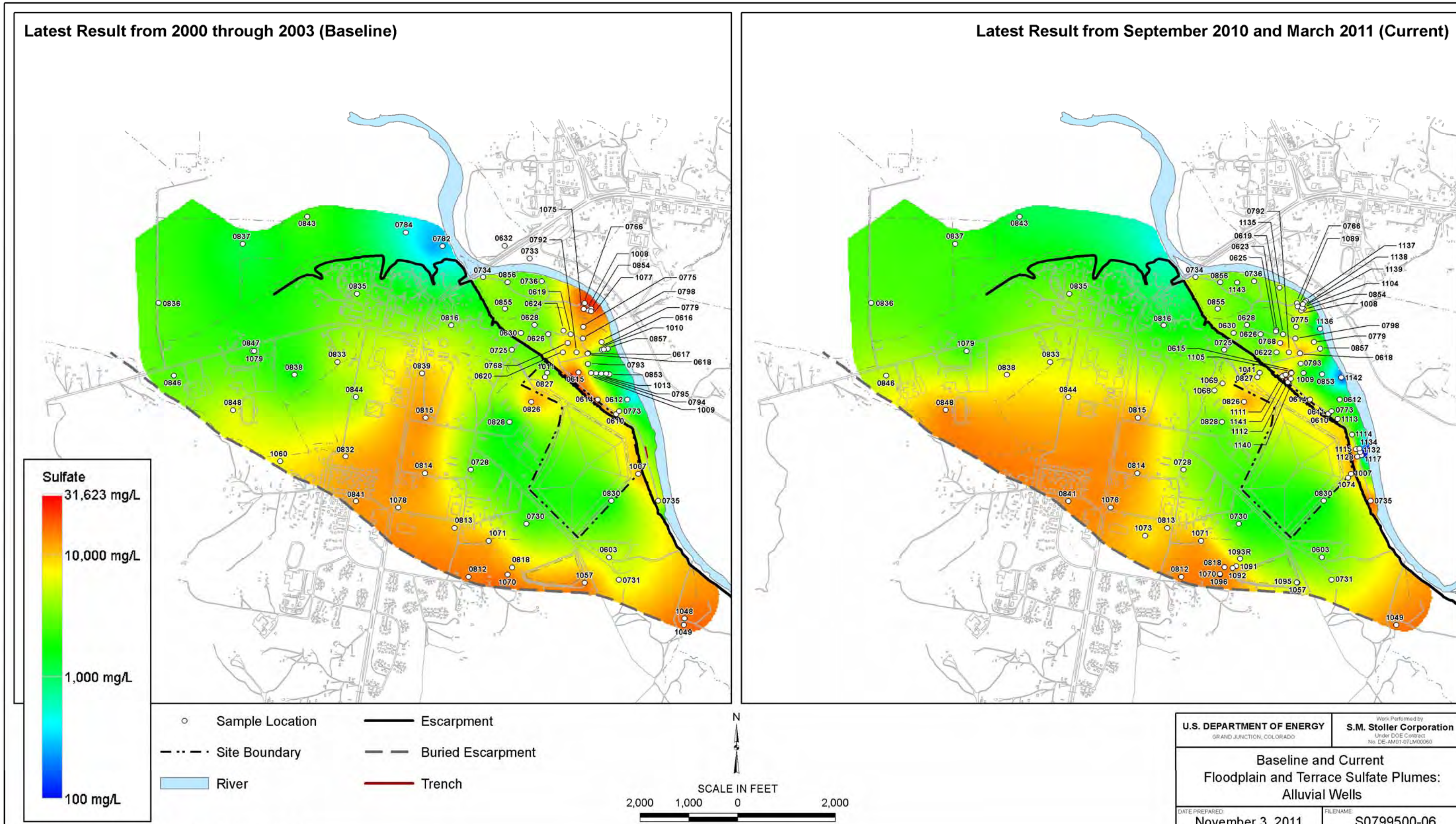

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Figure 18. Baseline (2000–2003) and March 2011 Floodplain and Terrace Sulfate Plumes

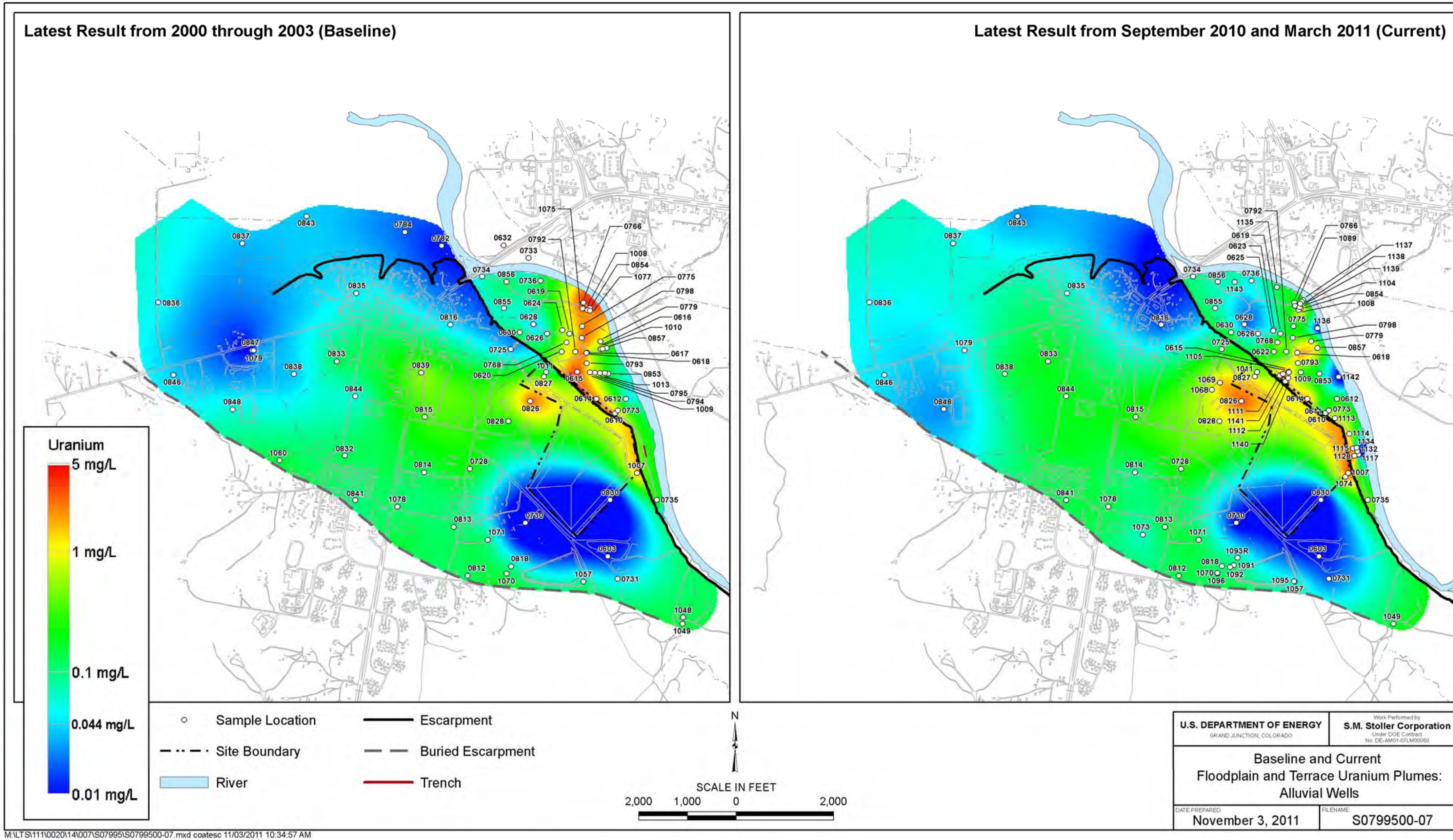

Figure 19. Baseline (2000–2003) and March 2011 Floodplain and Terrace Uranium Plumes

2.0 Subsurface Conditions

This section summarizes hydraulic and water-quality characteristics of the floodplain and terrace groundwater systems for the April 2010 through March 2011 reporting period, approximately 8 years after the 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 2011. 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 and Flow Directions

Analysis of groundwater-level (horizontal gradients) and flow data is important in evaluating the floodplain-aquifer behavior as affected by interaction with the San Juan River. Results of previous three-point analyses, based on water levels collected semiannually (September and March), indicated very little change in groundwater flow directions and demonstrated that the flow system in the floodplain was behaving as expected in response to pumping from extraction wells and remediation trenches—that is, the flow of groundwater is predominantly toward the extraction wells and trenches (DOE 2008). Recent focused evaluations of Trench 1 (DOE 2011d) and Trench 2 (DOE 2009) corroborate this conclusion, as does a more comprehensive assessment of flow and transport processes in the entire floodplain alluvial aquifer (in progress).

Groundwater levels in the floodplain aquifer continue to be manually recorded during routine semiannual groundwater sampling events. Figure 20, which plots groundwater levels for a representative subset of the floodplain wells, indicates that groundwater level fluctuations over the past 8 years have been on the order of 2 ft. Higher groundwater levels are generally observed in March, apparently because the floodplain is not subject in early spring to the water-lowering effects of evapotranspiration, which are prevalent in September.

In addition to manual measurements, groundwater elevations in a small subset of floodplain monitoring wells have been measured every 4 hours by pressure transducers connected to dataloggers. These data are plotted in Figure 21 along with stream flow measurements obtained from U.S. Geological Survey Gaging Station 09368000 (San Juan River at Shiprock), located just east of well 0857 (Figure 2). Although historically (since 2003), datalogger data were collected from 5 wells (0617, 0736, 0854, 0857, and 1008), for this reporting period, datalogger data were collected only at wells 0736 and 0857 (Figure 21). This is because the old datalogger network is being replaced with a new set of wells instrumented for DOE's remote telemetry (System Operations at Remote Sites, or SOARS) network. In March 2011, six additional wells—0735, 0779, 0853, 0857, 1135, 1136—were instrumented and added to the existing SOARS network (the trenches and well 1089/1104 complex) as part of the recently initiated study of floodplain-wide flow and transport processes. Water level data from all SOARS-instrumented wells will be documented in future annual reports.

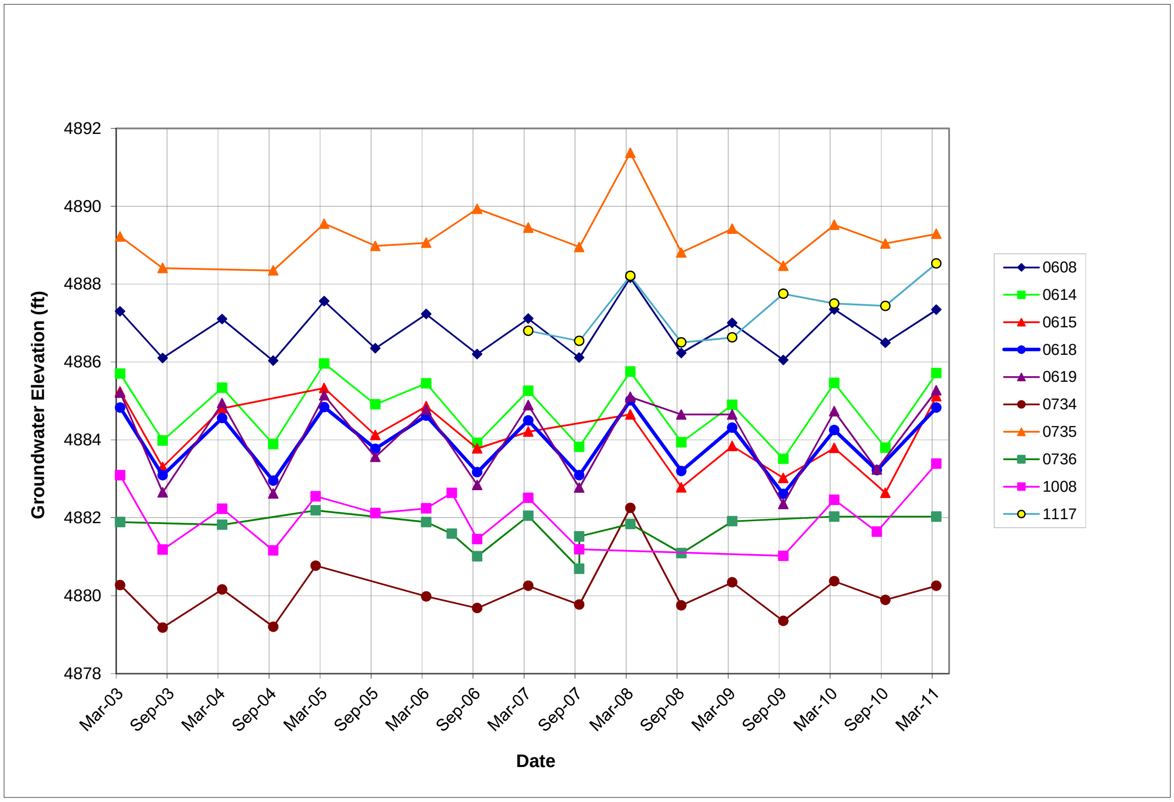

Figure 20. Floodplain Groundwater Elevations from Manual Measurements

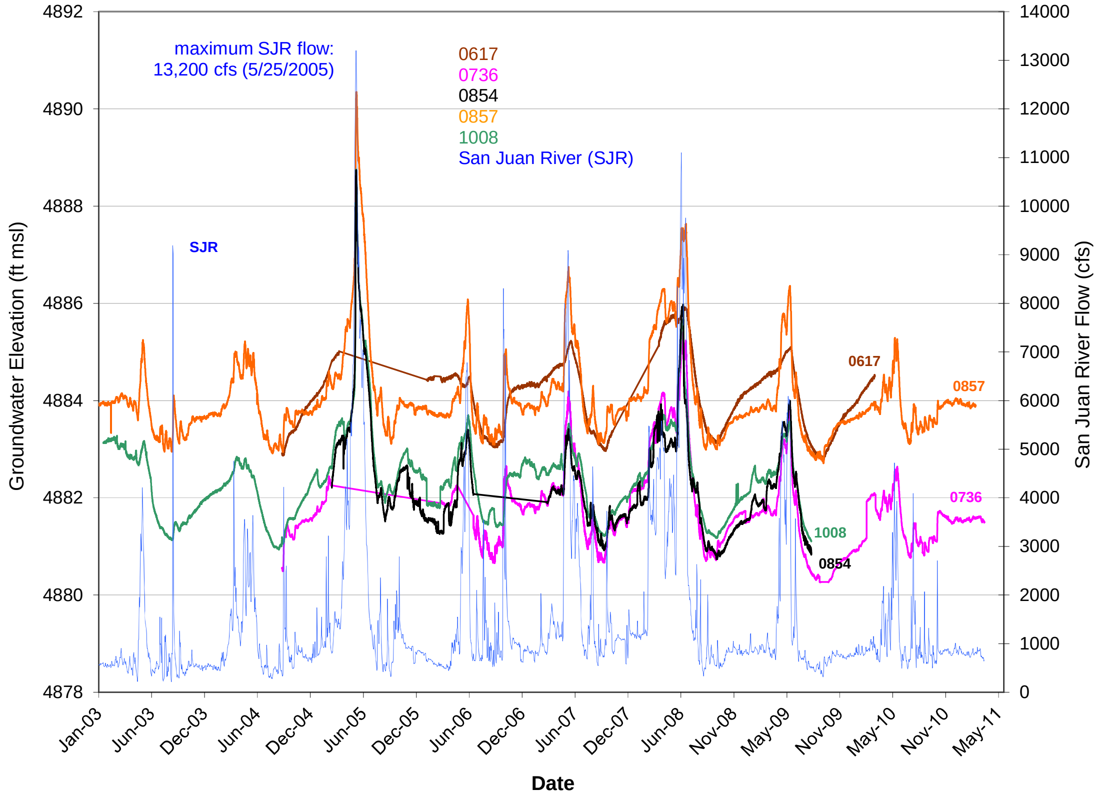

Figure 21. Floodplain Groundwater Elevations from Datalogger Measurements

As has been the case historically, the datalogger plots 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 21). Close examination of continuously monitored river flows and water levels at the subset of floodplain wells included in Figure 21 shows that annual variations in groundwater elevation in some areas of the floodplain often exceed 2 ft.

The Trench 2 evaluation established that much of the water entering the floodplain aquifer does so via San Juan River losses along the southernmost tip of the aquifer. Previous maps of the potentiometric surface in the floodplain (e.g., Figure 4–13 in the SOWP [DOE 2000]) suggest that there are additional river reaches north of the Trench 2 study area where the river loses significant amounts of water to the aquifer. It is logical to assume that inflow from the river increases at all points along the river during the surface water high runoff months of May and June. These latter additions of river water to the aquifer are a temporary phenomenon referred to as bank storage (Freeze and Cherry 1979) that has the capacity to significantly change flow directions in the aquifer for 2 months or more. Greater mixing of relatively clean water from the river with contaminated groundwater emanating from the former milling site also likely occurs under such circumstances. More detailed evaluations of groundwater flow and chemistry in local portions of the floodplain are provided in the recent evaluations of the Trench 1 and Trench 2 groundwater remediation systems (DOE 2011d; DOE 2009). A comprehensive assessment of groundwater processes over the entire floodplain, particularly as impacted by river-aquifer interaction, will be presented in the floodplain-wide study currently in progress.

2.1.2 Floodplain Contaminant Distributions and Temporal Trends

Groundwater samples were collected from 59 floodplain monitoring wells in September 2010 and March 2011. As shown in Figure 2 (see well locations marked with an asterisk), nine new Geoprobe wells were installed in the floodplain in January 2010. Seven, including three in a line toward the river from the well 1089 complex, were installed near the San Juan River to evaluate groundwater flow and monitor contaminant levels in groundwater that could enter the river downgradient of pumping wells 1089 and 1104. Also, two new alluvial wells (1140 and 1141) were installed about 50 ft from the east side of Trench 1 (nearest the river).

In previous annual performance reports, temporal trends have been plotted for each COC for a subset of 10 floodplain wells. This subset, which now represents about 20 percent of all wells sampled on the floodplain, included wells with the most data points representing different spatial regions. Trench 2 area wells had not been addressed, however, because too few data points were available to assess temporal trends. Although this well subset represented a good spatial cross section, well-specific trends were difficult to identify because of differences in scale. For example, trends in wells with lower magnitude concentrations were masked by higher-magnitude wells (see DOE 2010b, Section 2.1.2 and Figures 2–3 through 2–9). Therefore, in developing this updated annual report, DOE is modifying the data presentation. This section begins by plotting contaminant concentrations by area using the floodplain well groupings shown in Figure 22. The focus is on those areas that best reflect remediation progress and/or those with some of the highest COC concentrations—namely, Trenches 1 and 2 and the well 1089 area.

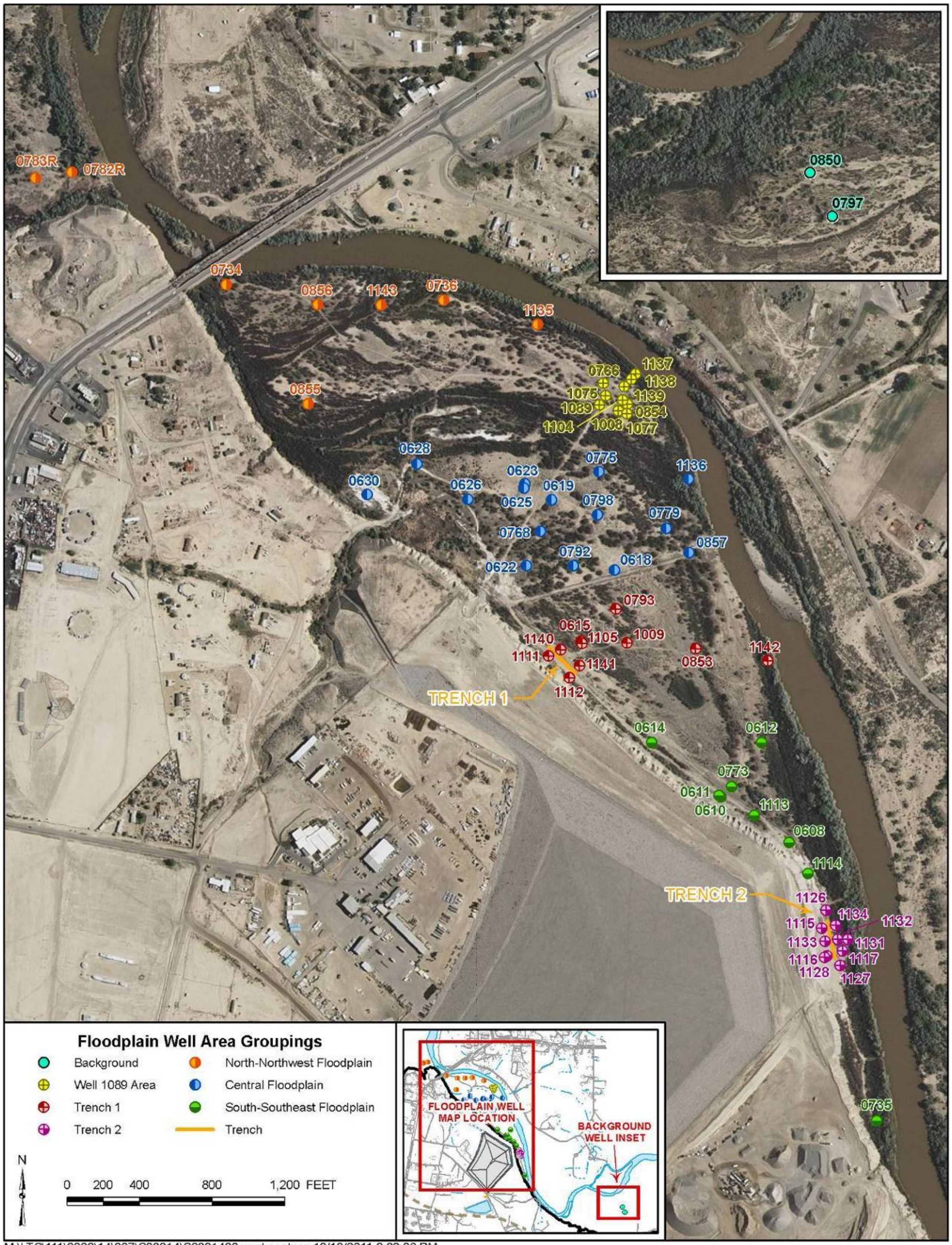

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Figure 22. Shiprock Site Floodplain Area Well Groupings

In terms of COCs, uranium, sulfate, and nitrate receive the most focus because they are the most widespread and illustrative of site contamination trends. Trends for ammonia and selenium are apparent in only a small subset of floodplain wells (so these receive less focus). In contrast to previous annual reports, temporal trends for manganese and strontium in floodplain wells are not plotted because (1) no significant trends are evident and (2) as shown in Figures 6 (a/b) and 9 (a/b), most concentrations are within the range of background concentrations measured for each constituent (Table 1).

Figure 23 plots temporal data for uranium in all floodplain wells, using the well group categories shown in Figure 22. This figure is a compendium of sparklines, which are simple condensed plots intended as a big-picture overview. Essentially, this figure combines data that might require 10 graphs to present adequately. In all individual plots, the *x*-axis is hidden but corresponds to a common date scale—January 2000 through March 2011 (so newly installed wells are clearly apparent). Individual data points are not plotted except for minimum and maximum concentrations (denoted by green and red markers, respectively[8]) and the most recent result (black markers, which in some cases is the minimum historical measurement). In all cases, the *y*-axis is condensed (scales are not common), so magnitudes of temporal trends are somewhat masked. However, the main point illustrated in Figure 23 is that, in general, uranium concentrations in most floodplain wells have decreased since the baseline period (e.g., see trends for well 1089 area). This is most apparent for the Trench 1 and well 1089 areas. Exceptions are found in wells located on the disposal cell side of Trenches 1 and 2, in wells with lower-magnitude beginning uranium concentrations (e.g., northwest floodplain area wells), and in other wells where there have been recent increases (e.g., in central floodplain well 0857).

To expand upon the simplified global schematic in Figure 23, subsequent (area-specific) plots (e.g., Figures 24 through 27) better capture the changes in concentrations of uranium and other COCs in selected floodplain wells. The following discussion focuses on those areas exhibiting the most pronounced trends and that are most indicative of remediation “performance” on the floodplain.

Trench 1 Area

Figure 24 plots uranium, nitrate, and sulfate concentrations in Trench 1 area wells. This figure shows the marked reduction in concentrations for all three constituents since the trench was installed in 2006. The most significant declines are apparent for riverside wells 0615 and 1105, whereas COC concentrations in wells closer to the river are stable and much lower in magnitude. COC concentrations in well 1111, between the trench and the escarpment, are low relative to those in well 1112, also on the escarpment side of Trench 1. A recent rebound (increase in concentrations) since September 2010 is apparent at wells 1111 and (in particular) 1112. Examination of corresponding water levels in relation to pumping times suggests that this rebounding may be related to a few extended periods of non-pumping at the trench in late 2010 and early 2011. However, this conclusion is preliminary and will be explored further in the floodplain evaluation in progress (also see DOE 2011d).

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[8] Although not a conventional presentation of data range, maximum concentrations are listed first in Figure 23 to better parallel the graphic (i.e., for the majority of wells, maxima occur earlier in the monitoring period).

Floodplain Trench 1 Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1111	Disposal Cell Side of Trench	1.59	0.79	1.23	11
1112		2.40	1.20	1.87	11
1140	River Side of Trench	2.26	1.20	2.26	4
1141		1.10	0.83	1.07	4
0615		4.80	0.76	1.79	26
1105		4.30	1.57	1.57	9
0793		1.70	0.65	0.65	8
1009		0.75	0.24	0.25	11
0853		0.19	0.04	0.11	12
1142		0.006	0.004	0.006	5

Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1115	Disposal Cell Side of Trench	1.19	0.32	1.13	15
1128		1.60	0.63	1.49	4
1117	River Side of Trench	0.020	0.004	0.01	14
1132		0.022	0.011	0.02	6
1134		0.020	0.010	0.02	5

Floodplain Well 1089 Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0766		4.44	0.27	0.28	7
0854		4.42	1.08	1.38	11
1008		3.32	1.28	1.28	15
1089		2.10	0.23	0.23	21
1104		2.60	0.60	0.60	12
1137		0.49	0.17	0.17	3
1138		0.34	0.16	0.24	3
1139		0.85	0.10	0.85	5

Note: Wells 1075 and 1077 are not shown here as these have not been regularly sampled.

North-Northwest Floodplain Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		0.53	0.02	0.10	19
0736		0.48	0.05	0.05	19
0782/0782R		0.010	0.003	0.007	8
0783/0783R		0.011	0.007	0.010	9
0855		0.15	0.06	0.09	13
0856		0.13	0.04	0.07	11
1135		0.24	0.13	0.14	5
1143		0.07	0.06	0.07	5

Central Floodplain Wells: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0618		3.21	0.79	2.22	27
0619		1.38	0.13	0.15	25
0622		0.44	0.07	0.22	7
0623		0.09	0.05	0.07	8
0625		0.06	0.04	0.05	6
0626		0.10	0.01	0.05	13
0628		0.08	0.01	0.02	11
0630		0.14	0.03	0.14	11
0768		1.40	0.16	0.76	10
0775		2.50	0.21	0.21	9
0779		1.39	0.52	1.00	10
0792		3.10	0.20	0.24	11
0798		2.78	0.32	0.32	8
0857		0.77	0.08	0.77	10
1136		0.007	0.004	0.007	5

South-Southeast Floodplain Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0608		2.00	0.69	0.69	28
0610		2.10	0.90	0.90	10
0611		0.53	0.01	0.01	5
0612		0.28	0.02	0.02	9
0614		3.20	1.50	1.50	29
0735		0.54	0.02	0.02	26
0773		0.92	0.38	0.38	9
1113		1.80	0.76	0.76	9
1114		1.05	0.24	0.24	13

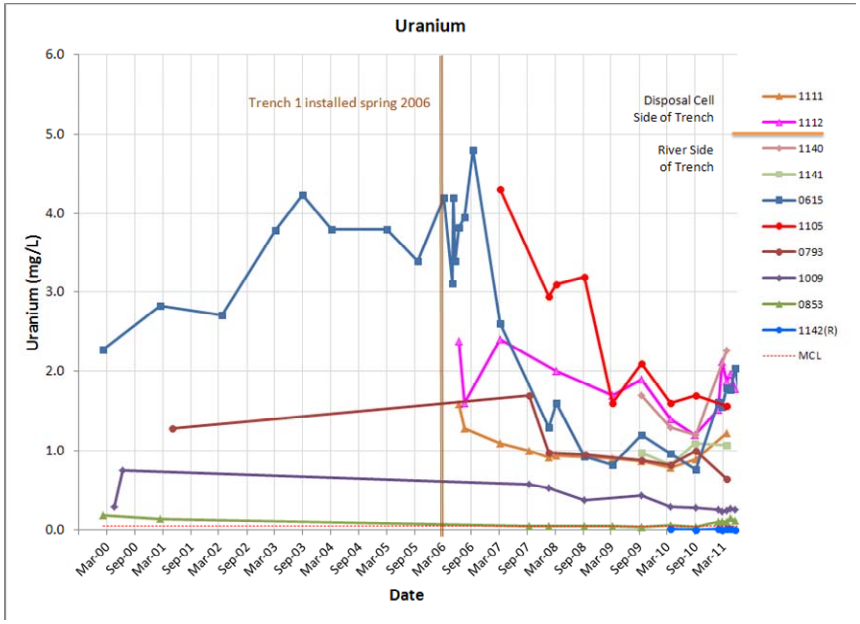
Floodplain Background Wells: Uranium (mg/L)

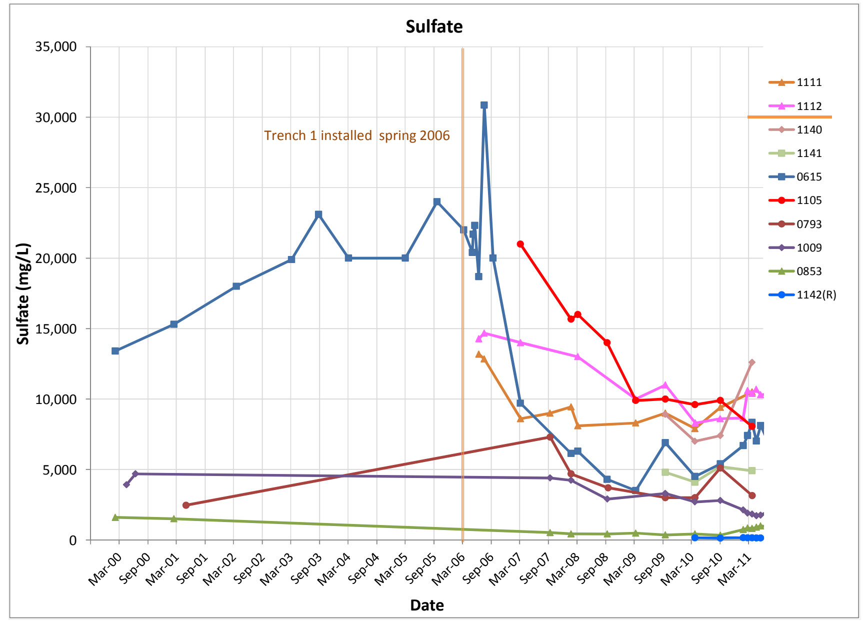
Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		0.037	0.008	0.024	21
0850		0.12	0.004	0.035	23

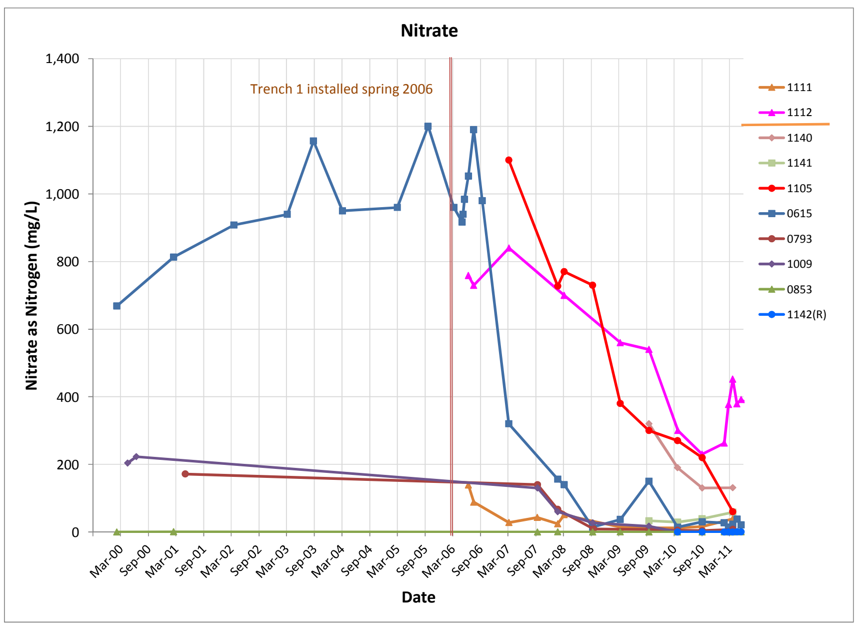
Legend

In these sparkline diagrams, red markers denote maximum (max) concentrations and green markers denote minima (min); black markers denote the most recent (current) March 2011 measurement. The x-axis is hidden but corresponds to the Feb-00 to Mar-11 date range noted above each plot. Vertical (y-) axis scales are automatic for each individual well, so magnitudes should not be compared across wells (instead refer to summary statistics).

Figure 23. Summary of Uranium Concentration Trends in All Floodplain Wells



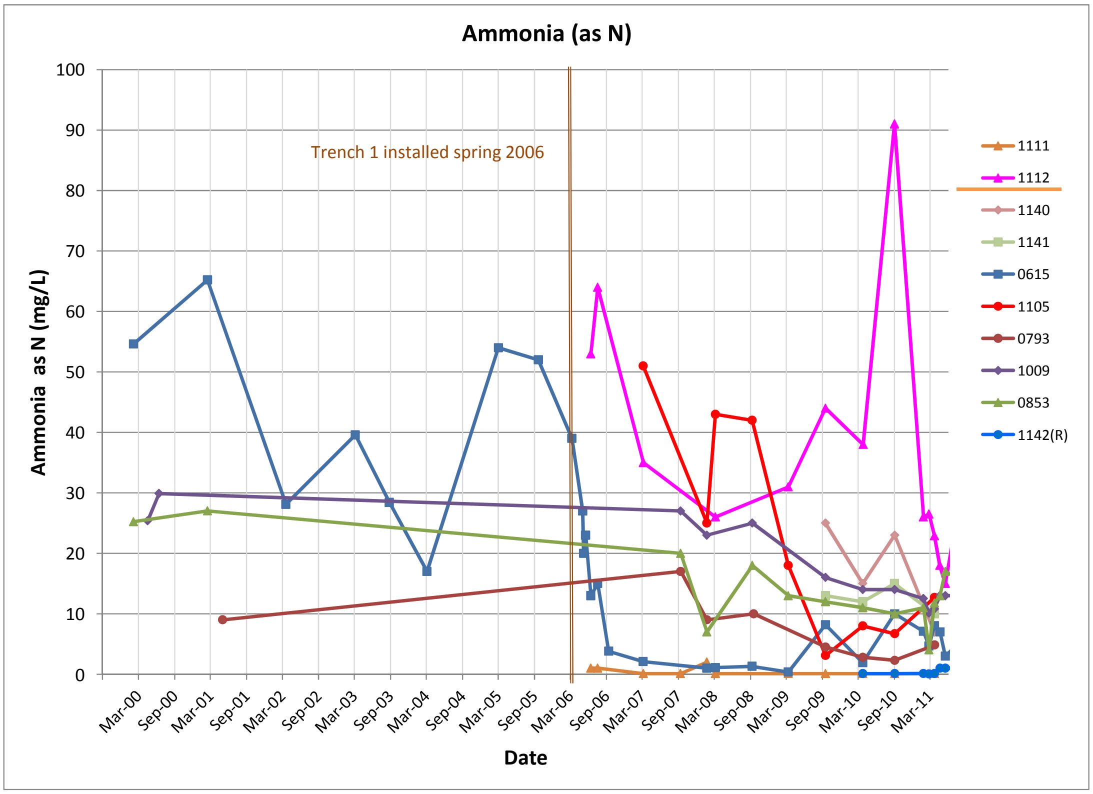




Trench 1 Area Wells (adapted from Figure 21)

Note:
In each plot legend, wells are listed in order of increasing distance from the disposal cell. For example, 1111 and 1112 (on the disposal side of Trench 1) are listed first. Although not technically considered part of the Trench 1 area (see DOE 2011d), for purposes of this report—more distal wells 0793, 1009, 0853, and 1142 are also included in this well grouping. (The "R" following location 1142 denotes that well is adjacent to the San Juan River.)

Figure 24. Uranium, Nitrate, and Sulfate Concentration Trends in Trench 1 Area Wells



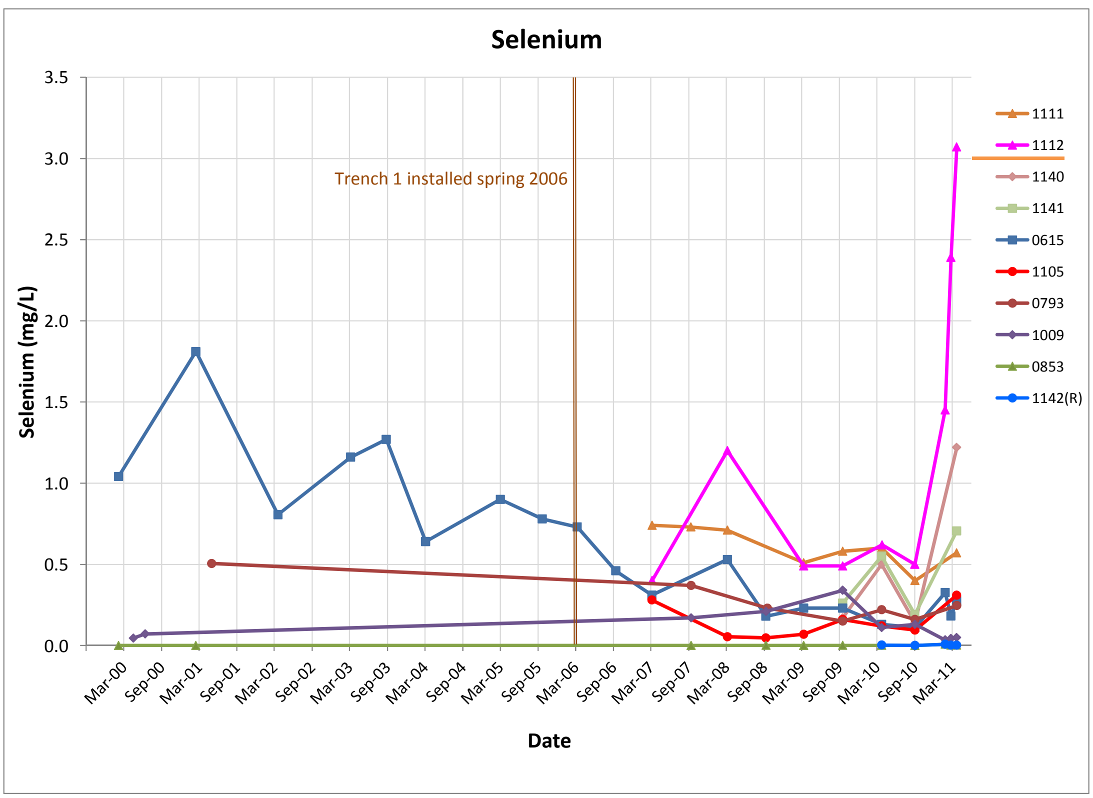
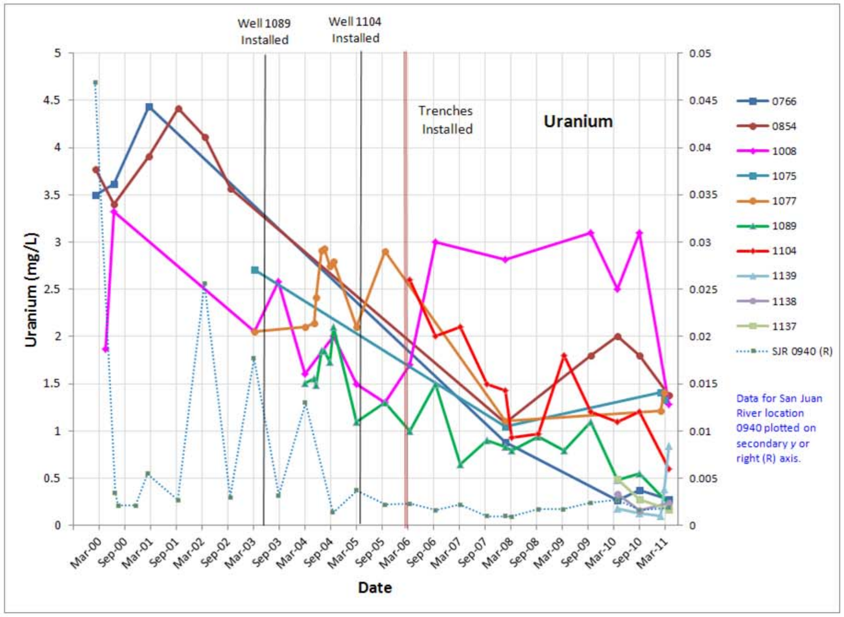
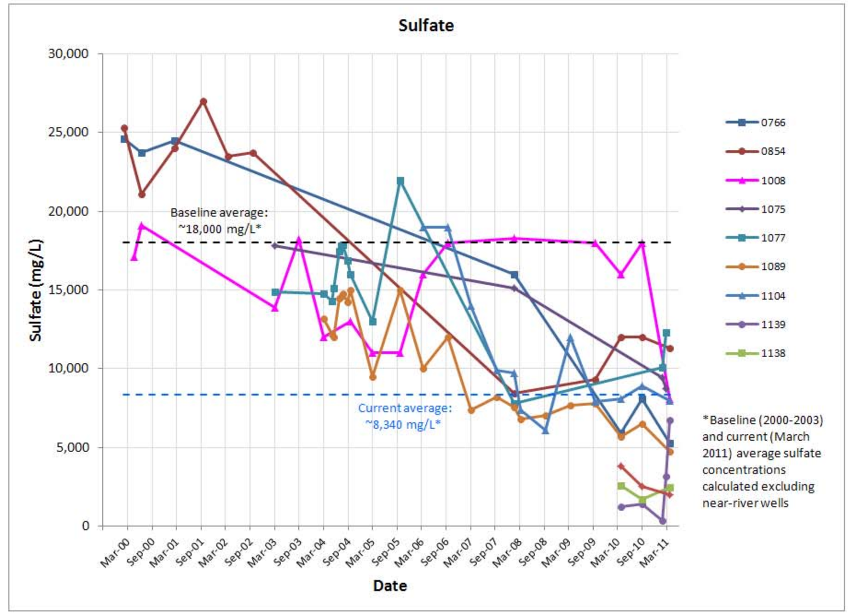
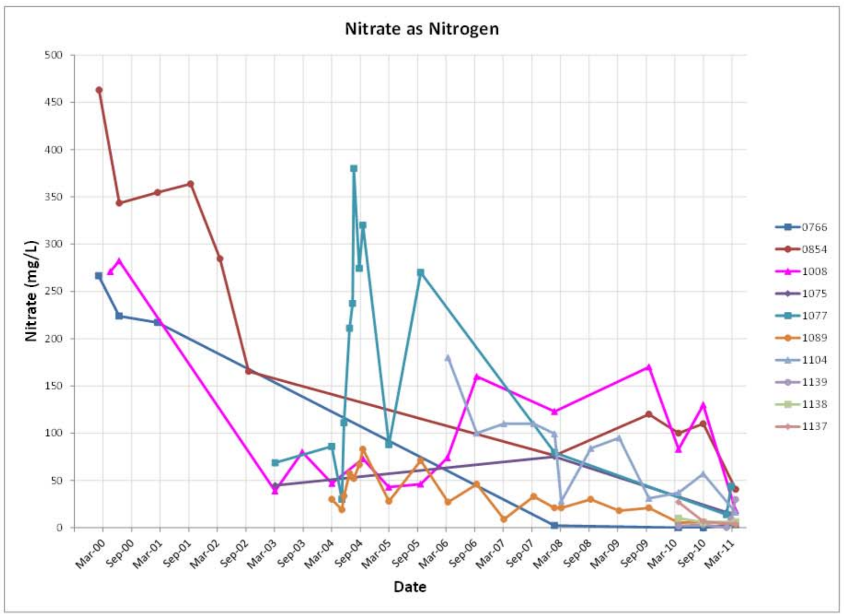
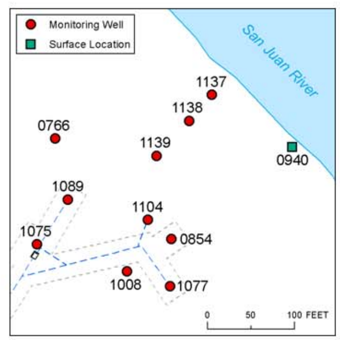


Figure 25. Ammonia and Selenium Concentration Trends in Trench 1 Area Wells





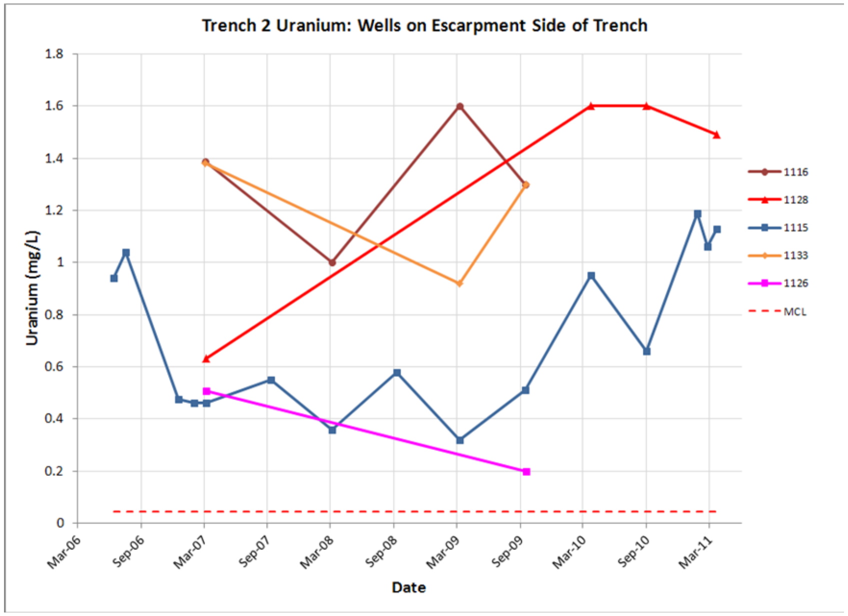


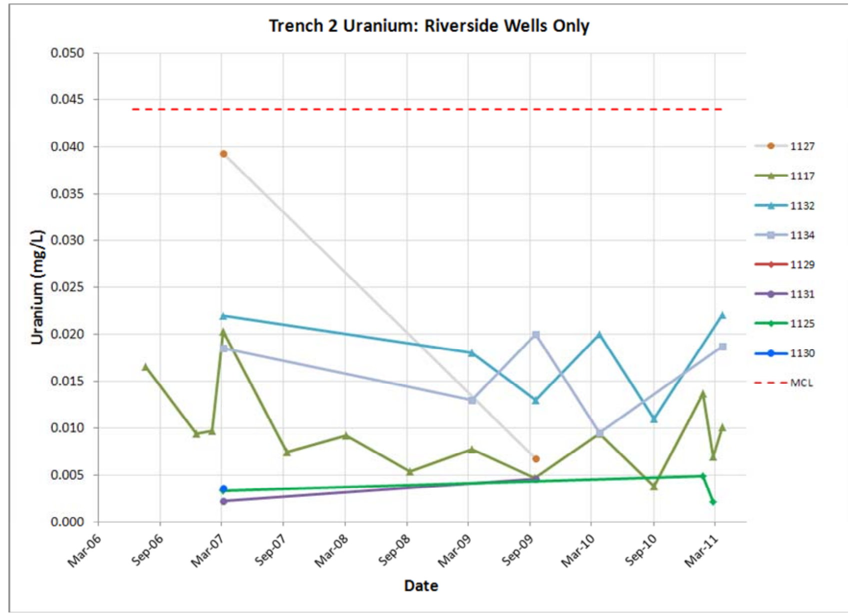


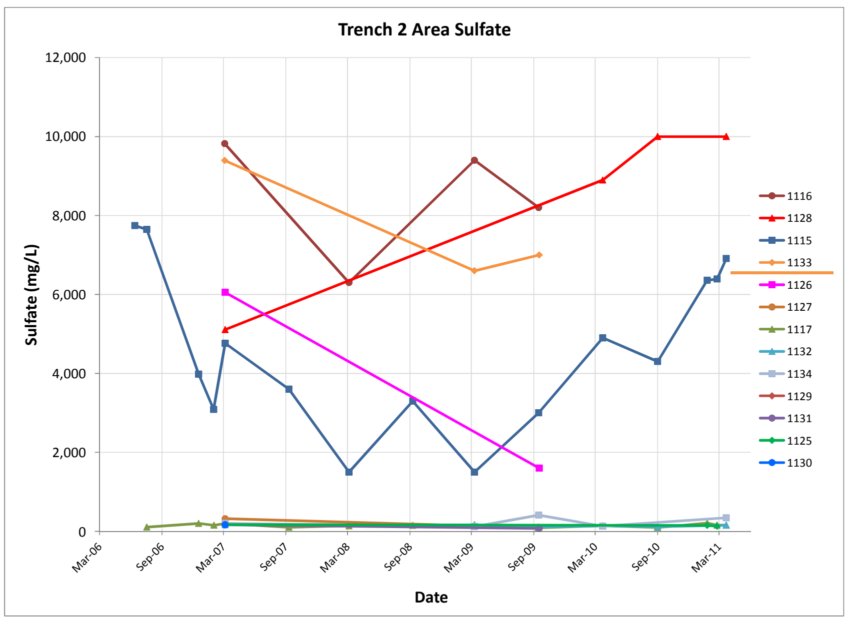
Well 1089 Area Wells

Note:
In each plot legend, newly installed wells 1137, 1138, and 1139 are listed in general order of decreasing distance to the San Juan River. The plot for uranium (upper left-hand corner) also includes data for river monitoring location 0940, for which data are plotted on the secondary or right y-axis.

Figure 26. Uranium, Nitrate, and Sulfate Trends in the Well 1089 Area







Trench 2 Area Wells

Note:
Similar to the format shown for Trench 1, in each plot legend, wells are listed in general order of increasing distance from the disposal cell (and decreasing distance to the San Juan River).

Although wells 1126, 1127, and 1133 are not routinely sampled, results are shown here to provide a comprehensive view of historical Trench 2 area contamination trends. Wells 1126 and 1127, located north and south of the trench but not necessarily on either (east/west) side, are included in the escarpment- and river-side categories in the two upper uranium plots (given concentration magnitudes).

The orange line in the inset denotes the approximate location (not to scale) of Trench 2.

Figure 27. Uranium and Sulfate Trends in Trench 2 Area Wells

The significant decreases in nitrate, sulfate, and uranium concentrations in Trench 1 area wells are not mirrored for ammonia and selenium (Figure 25). Ammonia concentrations in the area are erratic and show no significant trends. This is also true for selenium, except for a notable decrease in selenium in well 0615 and recent rebounds in wells 1112, 1140, and 1141, all apparently in response to extended periods of non-pumping in late 2010 and early 2011.

Well 1089 Area

Figure 26 plots uranium, nitrate, and sulfate concentrations in well 1089 area wells. Although decreases are not of the magnitude and consistency as those shown in Figure 24, decreases are still evident. For example, in a comparison of baseline (2000–2003) to current conditions, average sulfate concentrations decreased by nearly 10,000 mg/L. For all COCs, concentrations in well 1008 have been erratic (also see DOE 2011d).

Trench 2 Area

Previous annual reports did not evaluate time trends for Trench 2 wells because available data were insufficient (in terms of number of samples) to draw any definitive conclusions. However, after over 4 years of monitoring Trench 2 wells, sufficient data are now available to document findings regarding time trends in this area. Figure 27, which plots uranium and sulfate concentrations in wells surrounding the trench, highlights the marked difference in concentrations between wells on the escarpment side of the trench and wells on the river side of the trench. All uranium concentrations in river-side wells are below the 0.044 mg/L MCL. Uranium concentrations in wells 1115 and 1128 (on the escarpment side of the trench) have increased, although this is not unexpected and it may still be too early to draw any conclusions regarding trends in these wells. Sulfate trends parallel those noted for uranium—increases 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.

Southeastern Floodplain

Figure 28 plots uranium concentrations in the south-southeast well subset shown in Figure 22. Declines are evident for wells 0608 (screened in the Mancos), 0610, 0614, and 1113, located at the base of the escarpment. Concentrations in remaining wells are relatively stable but, as observed for the well subsets discussed above, a recent slight rebound is evident, presumably because of periods of non-pumping at Trench 1 in late 2010 and early 2011. Temporal trends in concentrations at wells in the southeastern 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. Such decreases can only be identified after Trench 1 pumping has been stopped for several months because the water drawdowns created by the pumping induce inflows of relatively fresh (uncontaminated water) from near the river.

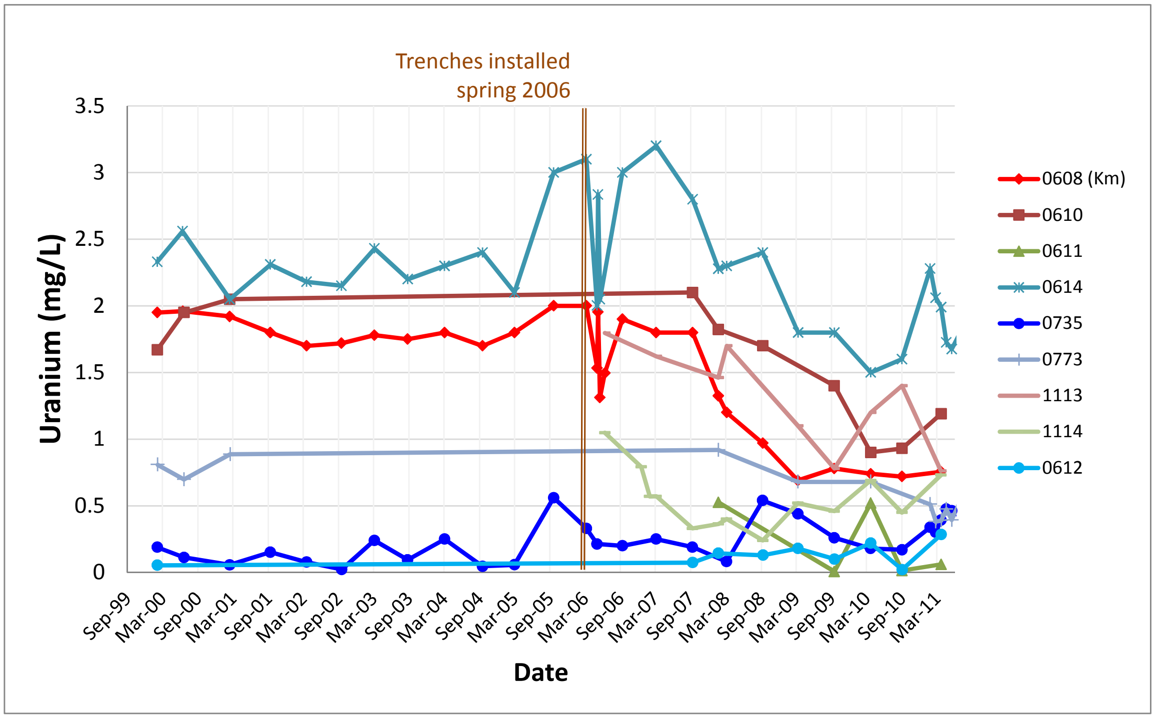


Figure 28. Uranium Trends in Southeastern Floodplain Wells

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 therefore probably most indicative 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. Therefore, the reader should refer to Figures 5–19, the corresponding Data Validation Packages (DOE 2011a, DOE 2011e), and the Geospatial Environmental Mapping System (GEMS) link on the LM website (http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp?default_site=SHP). Supplementary plots are provided in Appendix A for most areas and COCs not addressed above.

2.1.3 Floodplain Contaminant Removal

The terrace extraction wells and trenches have removed approximately 766,000 pounds of contaminants from the alluvial groundwater system during the 2010–2011 reporting period; the majority (close to 536,000 pounds) was removed from the floodplain (refer to Table 4 in following section). The addition of the two drainage trenches in spring 2006 has enhanced the amount of groundwater and mass of constituents removed from the alluvial system (e.g., see Figure 24). It is also likely that pumping of groundwater from the floodplain is preventing contaminant discharge to the San Juan River, as concentrations of nitrate and uranium in river samples have remained below previously established upgradient background benchmark values, including during low-flow periods, since 2004 (Figure 29).

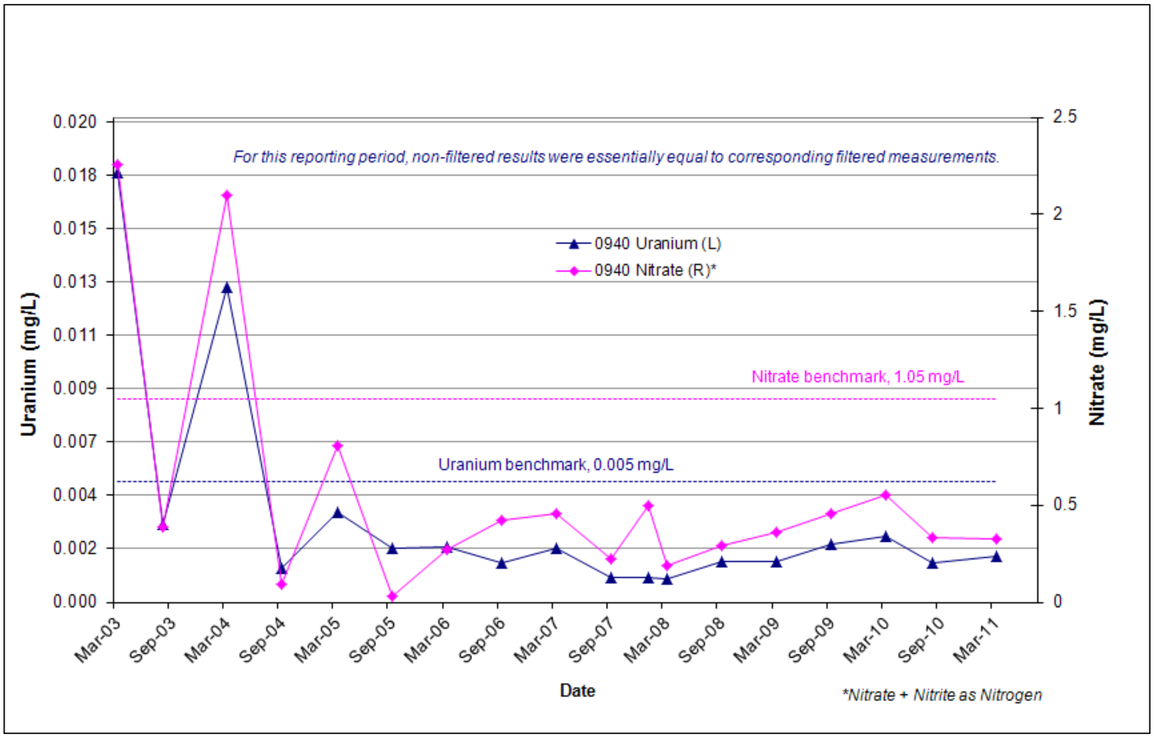


Figure 29. Uranium and Nitrate Concentrations in the San Juan River (Location 0940)

As shown in Figure 29, uranium and nitrate trends are correlated—although concentrations of both constituents increased slightly between March 2008 and March 2010, levels have since decreased (to about 0.002 mg/L and 0.25 mg/L for uranium and nitrate, respectively). Given the low magnitude of these concentrations, these slight trends could just reflect natural variation.[9] The data in this figure from surface sample location 0940 on the San Juan River represent the only location where historical concentrations in the river were ever found to exceed a background concentration; concentrations have never exceeded background benchmarks for any COC at any other location on the San Juan River.

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 2011. Analyses of groundwater level trends and flow directions, drain flow rates, and seep flow rates associated with the terrace are discussed below. Results are compared to baseline conditions established in March 2003 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

[9] For additional information, refer to Figure 2–12 in the 2000–2010 annual report (DOE 2010b). This figure shows the historical distributions of uranium, nitrate, and sulfate at all San Juan River sample locations, including the 0898 upstream (background) location. It also demonstrates that, apart from the peak (2003–2004) elevated concentrations at 0940 shown in Figure 29 above, there are no significant differences between the upstream and downstream locations. For all COCs plotted, historical distributions are very similar, indicating no apparent significant influence from the site. This remains true for the current (2010–2011) reporting period.

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 from the terrace system, compiled during 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 the following section, as of March 2011, the cumulative volume of water removed from the terrace extraction system since pumping began was approximately 26.5 million gallons. Pumping records indicate that approximately 5.2 million gallons were removed from the terrace between April 2010 and April 2011.

Groundwater level data from the terrace collected during the March 2011 sampling event were compared to corresponding groundwater elevation data for the baseline period (most recent from 2000 to March 2003). Figure 30 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. For wells screened in the alluvium, of the 30 groundwater level measurements taken in September 2010 or March 2011, the majority show declines relative to the baseline period of March 2003. Declines ranged from 0.3 ft to maximum decreases of about 7 ft in west terrace wells 0836, 0837, and 0848; the average decrease was 2.5 ft. As shown in Figure 30, five alluvial west terrace wells (0832, 0846, 1060, 1120, and 1122) were dry at the time of the March 2011 sampling event.

Water levels have also been monitored using pressure transducers connected to dataloggers in selected wells on the terrace. Plots of groundwater elevations versus time are shown in Figures 31 and 32 for wells screened in shallower (water level elevations greater than 4930 ft) and deeper zones, respectively. Linear trend lines shown in Figure 31 indicate a decrease in water levels during the time of observation in most of the shallower wells. In Figure 32, which plots groundwater elevation data for wells screened in deeper zones, decreases for terrace alluvial wells 0836, 0846, and 0848 are apparent.

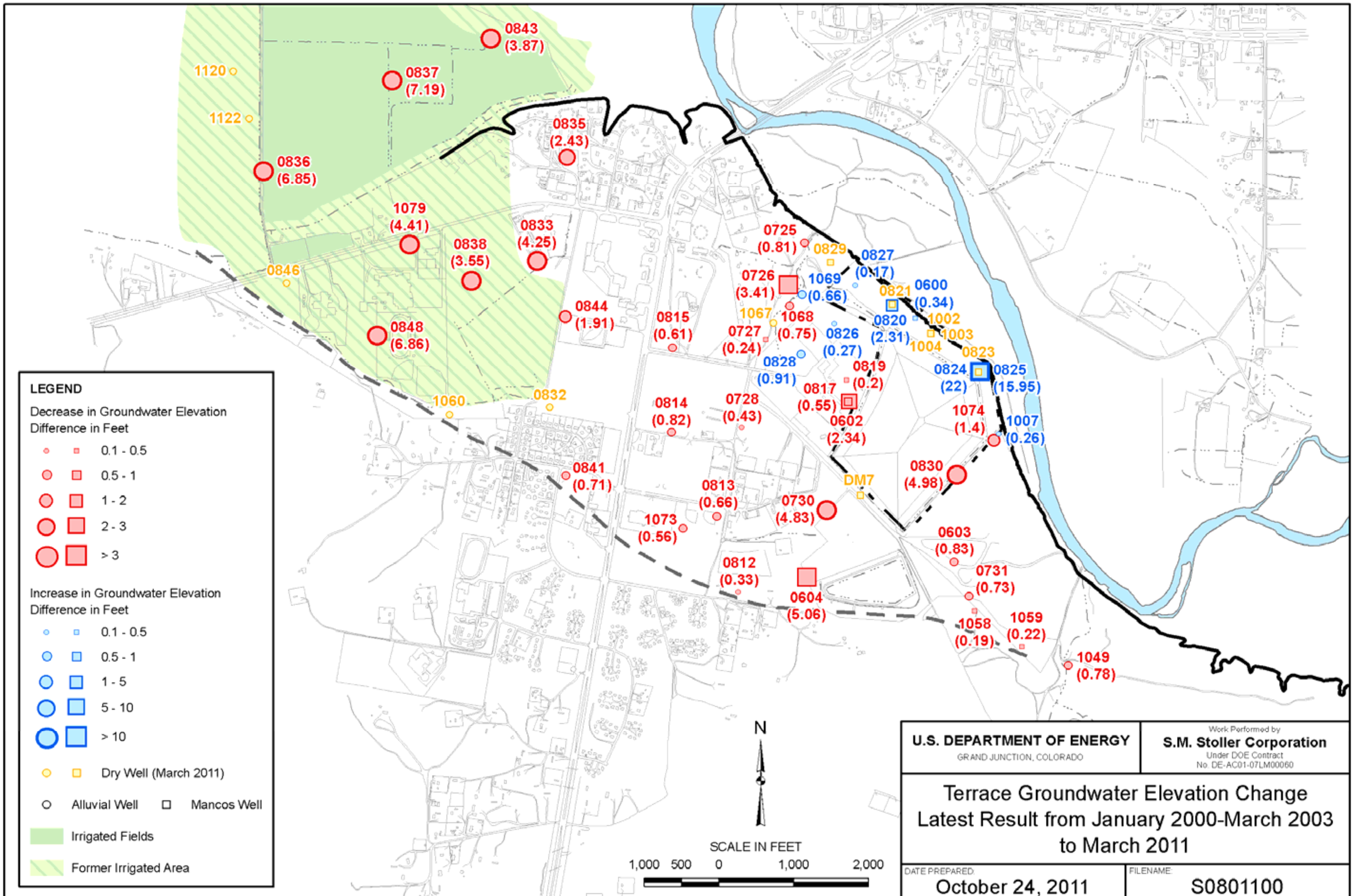


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Figure 30. Terrace Groundwater Elevation Changes from Baseline (2000–2003) to Current (March 2011) Conditions

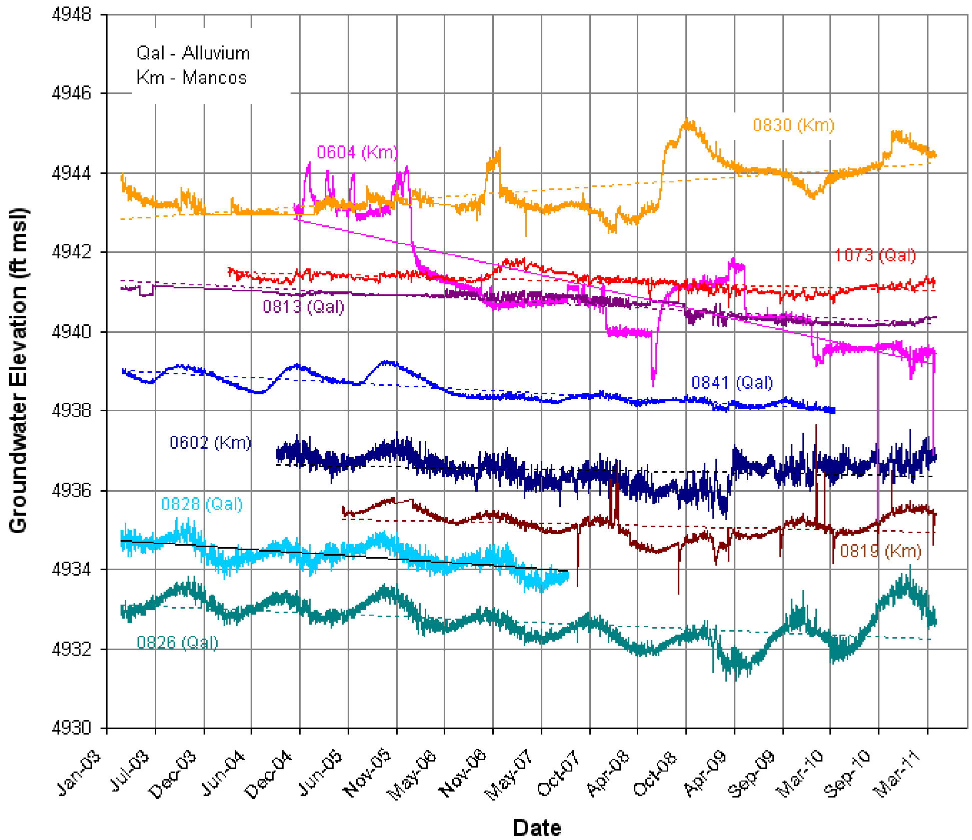

Figure 31. Terrace Datalogger Measurements, Wells with Water Elevations above 4930 ft

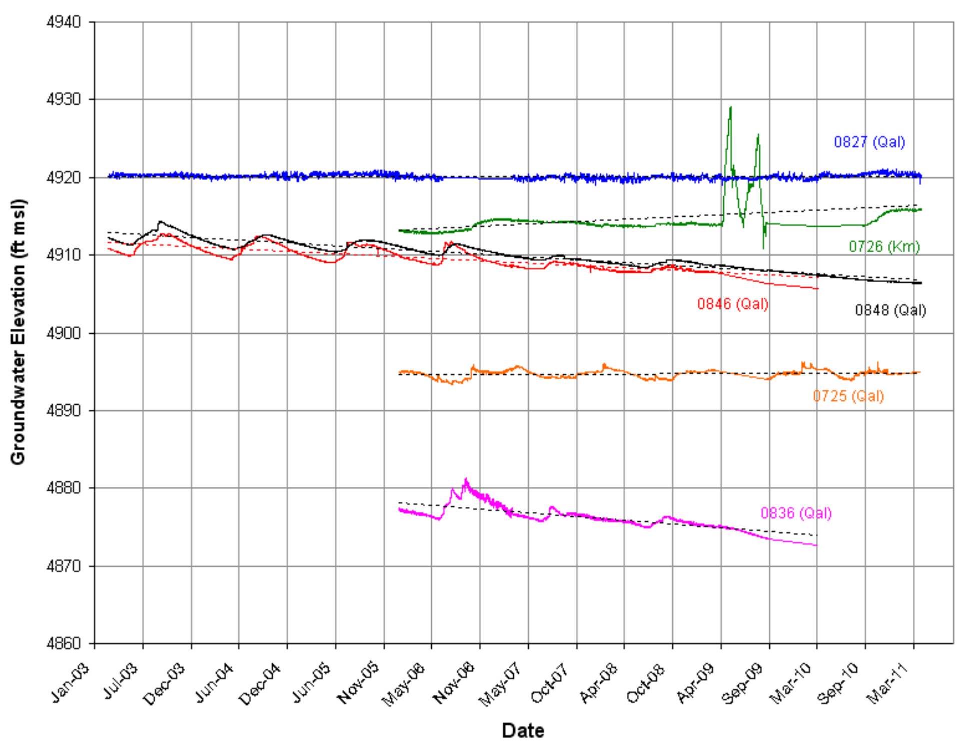

Figure 32. Terrace Datalogger Measurements, Deeper Wells

Figure 30 shows that the highest groundwater elevation declines have been in west terrace wells, and predominantly those wells in areas that were formerly irrigated. Although decreases in some far west terrace wells could be partly or even largely attributable to the previous phasing out of irrigation (circa 2003–2004), declines have been fairly gradual as shown in the simplified (sparkline) schematic below (see legend in Figure 23 for explanation).

West Terrace Subset (West of Hwy 491, South of Hwy 64)

Well ID	Jan-00 to Mar-11	Max	Min	Delta
0832	Dry	4937.6	4935.4	--
0833		4913.7	4908.7	4.3
0838		4913.5	4907.4	3.5
0841		4943.1	4937.2	0.7
0844		4918.2	4916.2	1.9
0846		4914.8	4905.0	5.9
0848		4913.8	4905.9	6.9
1060	Dry	4936.2	4932.1	--
1079		4911.2	4905.1	4.4

Northwest Terrace Subset (North of Hwy 64)

Well ID	Jan-00 to Mar-11	Max	Min	Delta
0835		4912.9	4908.2	2.4
0836		4881.9	4871.4	6.9
0837		4875.5	4867.9	7.2
0843		4873.1	4868.8	3.9
1120		4868.7	4866.7	--
1122		4871.5	4868.9	--

To elucidate horizontal (date) scale, the vertical dashed line in the above plots correspond to the September 2002 measurement.

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 2010 and March 2011, the average pumping rate from Bob Lee Wash was 5.9 gpm, about double the rate reported for 2009–2010 (refer to Figure 47 in the following section).

The average pumping rate from Many Devils Wash during the performance period was about 0.8 gpm (see Figure 48), comparable to the 0.96 gpm rate reported last year. Prior to the installation of a diversion structure in August 2009, the flow rates of water pumped from the Many Devils Wash sump were about half what they have been the last 2 years. The diversion structure was installed because of declining effectiveness of the collection drain and to better capture contaminated surface water in the wash. Shortly after installation, pumping rates increased from about 0.4 gpm to 0.8 gpm.

In response to stakeholder concerns that large storms could generate runoff from Many Devils Wash and result in contaminant loading to the San Juan River, DOE installed an automated sampling system in the lower end of the wash in May 2009. The automated sampler, which was monitored via telemetry, was designed to begin collecting samples with any increase in flow resulting in a surface water elevation increase of 2 inches, and to collect additional samples for each subsequent 2-inch increase in surface water elevation. The automated sampler was removed during this reporting period due to repeated damage after storm events and occasional vandalism.

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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 2010–2011 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 Figures 33 and 34. From April 2010 through March 2011, approximately 3 million gallons of water were removed from well 1089 at an average pumping rate of 6.5 gpm.[10] These values are comparable to those reported last year (DOE 2010b). Pumping rates at well 1104 averaging about 6.5 gpm (pumping periods only); the total cumulative extracted was about 653,000 gallons. During the 8-year period since the start of operations in March 2003 through the end of March 2011, totals of approximately 22.7 and 4 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 2010 through March 2011, approximately 2.8 million gallons of water were removed from Trench 1 at an average pumping rate of 10.2 gpm (Figure 35). Although the average pumping rate is comparable to that reported for the 2009–2010 performance evaluation period (9 gpm; DOE 2010b), the cumulative volume pumped was lower than last year's production of 3.8 million gallons, due to extended periods when pumping was stopped for maintenance and repairs during the past year.

In 2010–2011, nearly 1.9 million gallons of water were removed from Trench 2 at an average pumping rate of 8.4 gpm (Figure 36). This rate, which reflects pumping days only, is about half the rate reported last year (15.2 gpm average, DOE 2010b). The annual extracted volume is also lower than the approximately 2.3 million gallons pumped in 2009–2010. Again, this reduction in annual extracted volume is attributable to the fact that pumping at Trench 2 was shut down for maintenance and repairs, and to increase evaporation pond capacity and maintain safe pond water levels (see Section 3.2.3 for further discussion).

[10] 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 4.

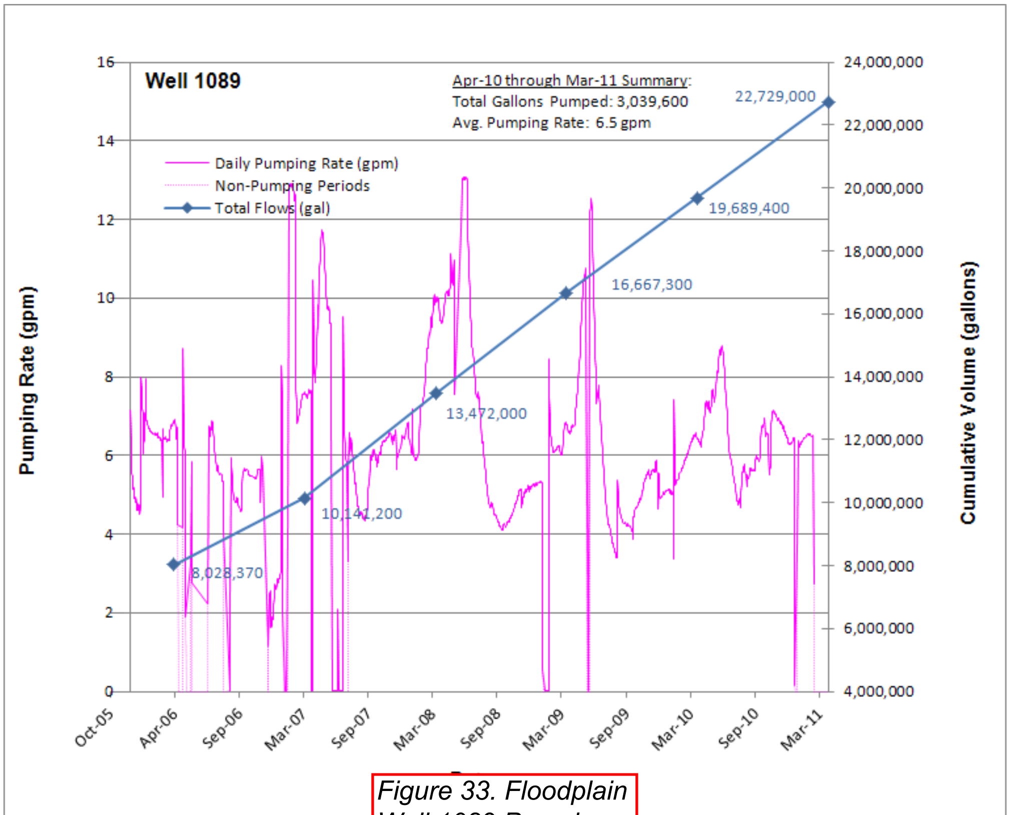

Figure 33. Floodplain Well 1089 Pumping Rate and Cumulative Groundwater Volume Extracted

Figure 33. Floodplain Well 1089 Pumping Rate and Cumulative Groundwater Volume Extracted

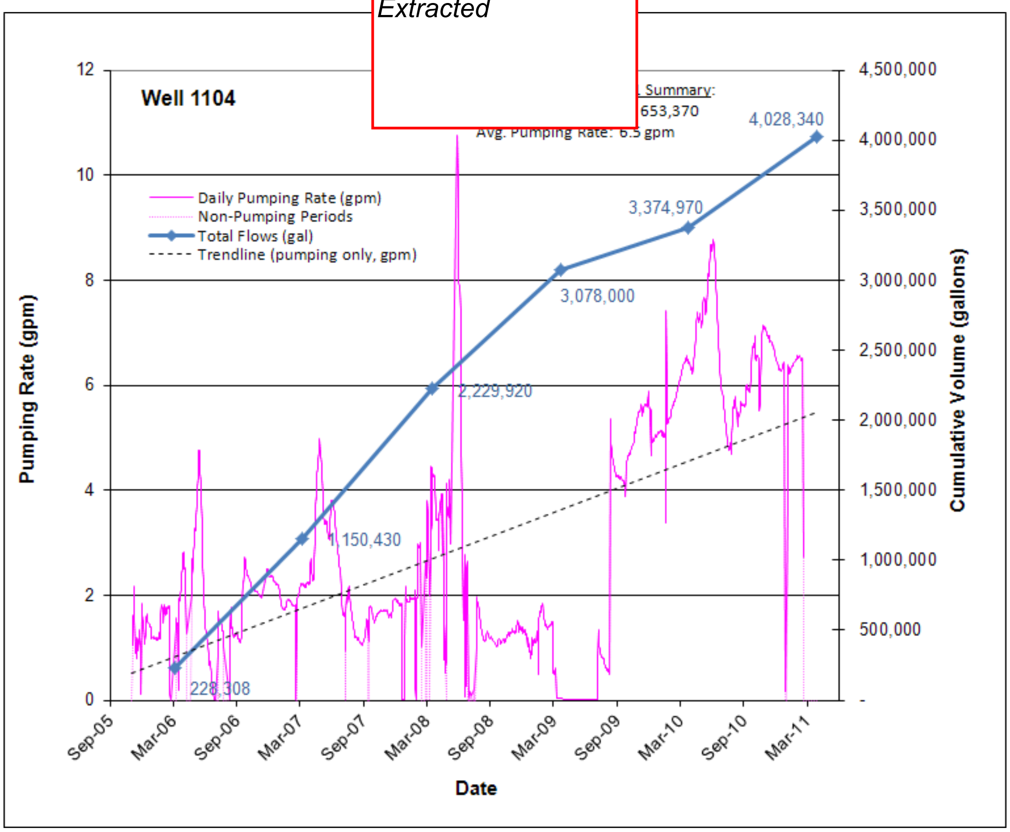

Figure 34. Floodplain Well 1104 Pumping Rate and Cumulative Groundwater Volume Extracted

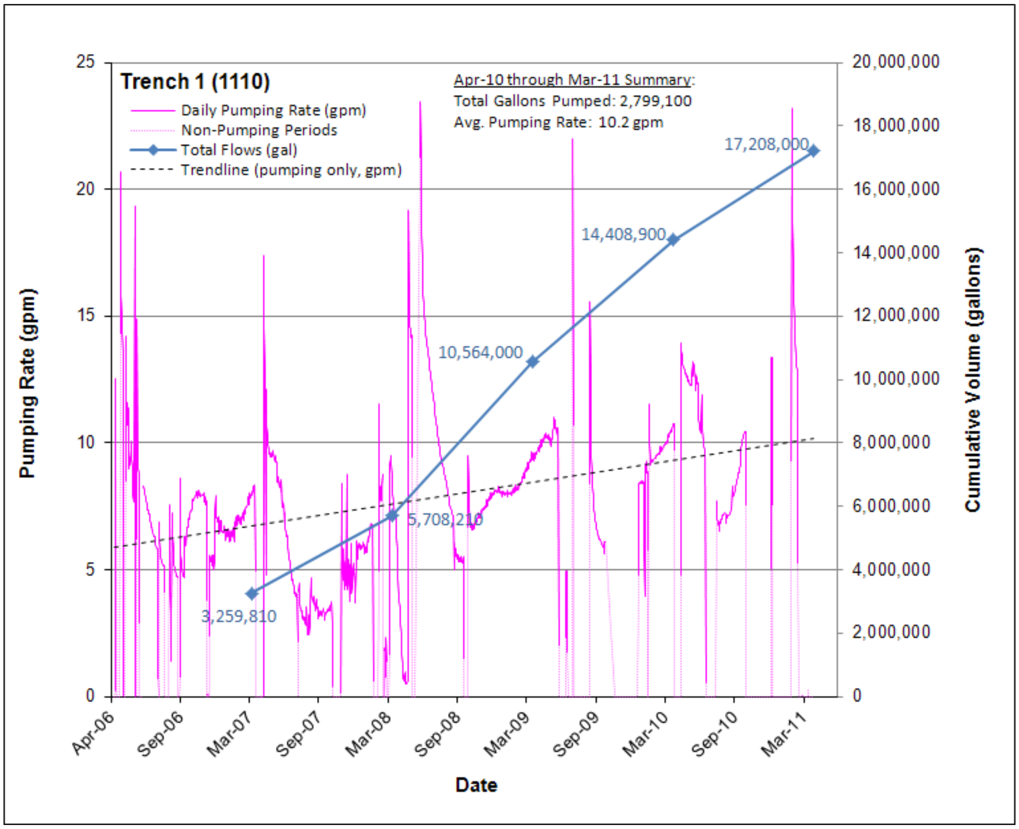

Figure 35. Floodplain Trench 1 Pumping Rate and Cumulative Groundwater Volume Extracted

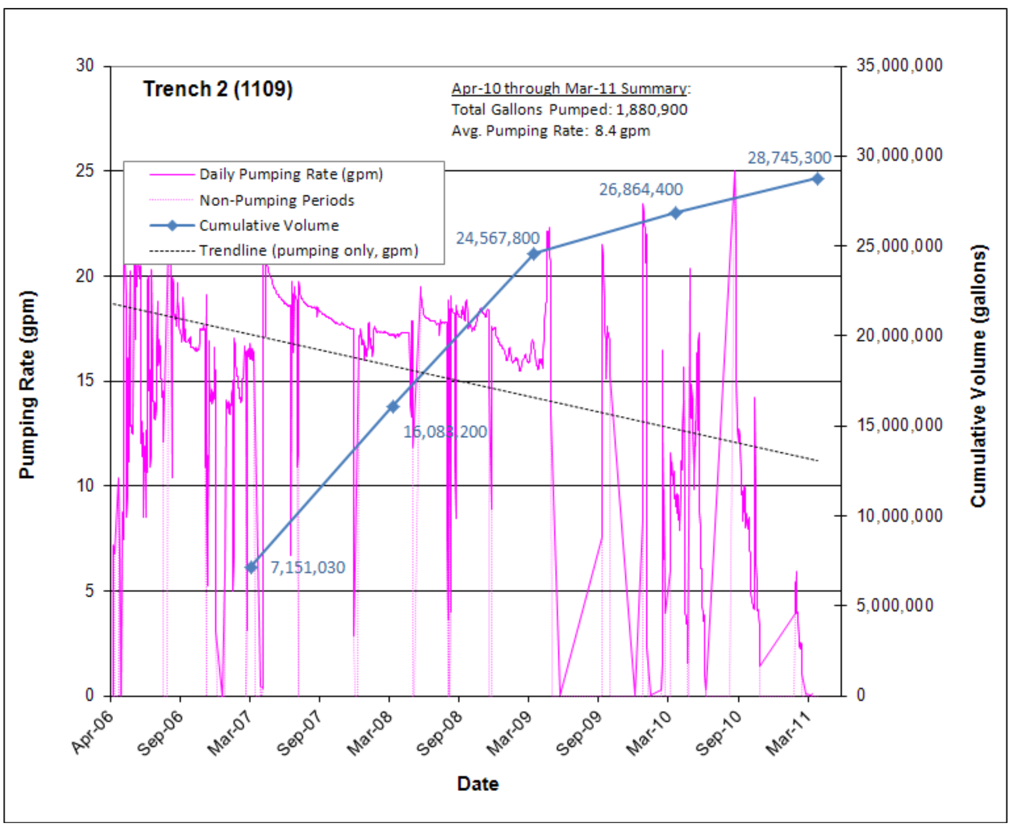

Figure 36. Floodplain Trench 2 Pumping Rate and Cumulative Groundwater Volume Extracted

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 2010 through March 2011, the average discharge rate from the seep collection drain was 0.5 gpm, just marginally higher than the 0.35 gpm rate reported for 2009–2010. Approximately 257,600 gallons were pumped from the seeps during this period, yielding a total cumulative volume of about 1.4 million gallons. Figure 37 plots the historical rates of groundwater discharge from the escarpment seeps. This figure shows that, with few exceptions, flows have generally been below the previously established goal of 0.9 gpm since spring 2008.

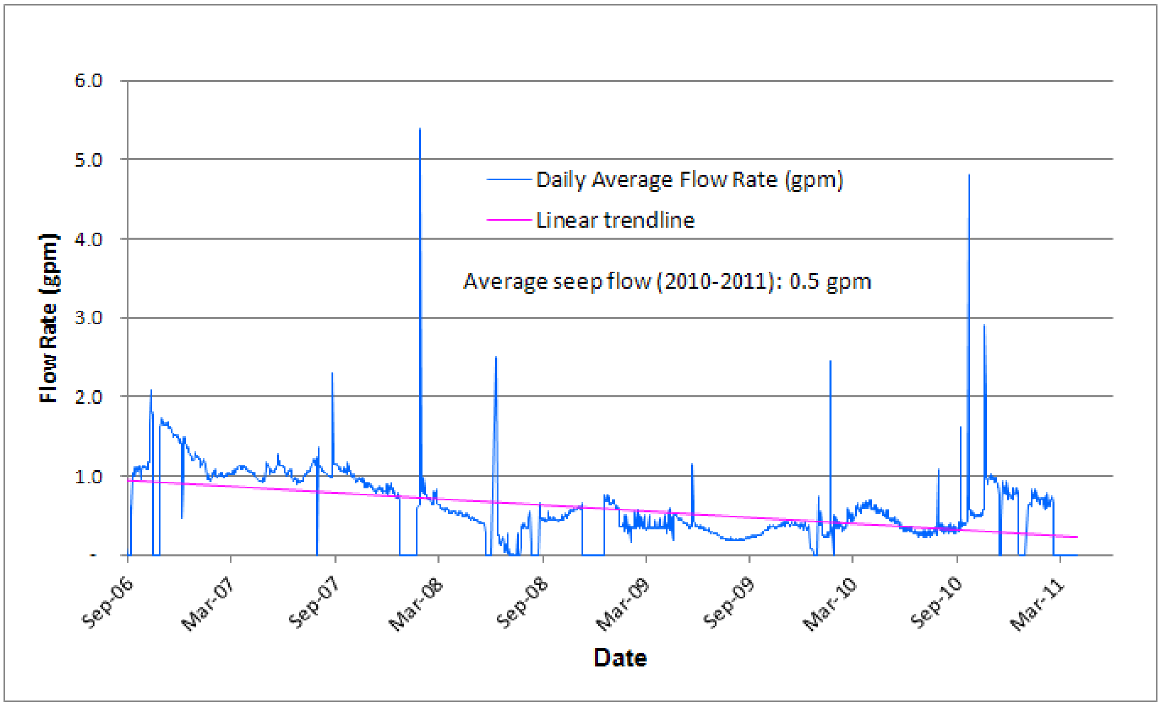

Figure 37. Historical Seep Flows (Seeps 0425 and 0426)

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. DOE also continues to evaluate the feasibility of phytoremediation on the terrace, using deep-rooted plants to enhance evapotranspiration in the radon barrier borrow pit area south of the disposal cell, and also between the disposal cell and the escarpment. As explained in Section 3.2.4, the goal of phytoremediation in these areas is hydraulic control (versus contaminant removal), to enhance plant transpiration of groundwater, thereby limiting the spread of contaminants in groundwater.

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 (2010-2011) and previous (2009–2010) reporting periods.

Table 3. Terrace Extraction Wells: Average Pumping Rates and Total Groundwater Volume Removed

Well	Previous Period (April 1, 2009, through March 31, 2010)		Current Period (April 1, 2010, through March 31, 2011)	
	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818	0.44	227,890	0.66	346,041
1070	0.015	6450	0.018	9483
1071	0.001	297	0.002	435
1078	0.25	136,510	0.6	302,690
1091	0.019	4952	0.013	2887
1092	0.00001	7	0.0002	115
1093R	0.6	124,030	1.0	542,570
1095	0.5	225,170	0.62	213,830
1096	0.38	135,670	0.42	217,230
Total	**2.2**	**860,976**	**3.3**	**1,635,281**

As shown in Table 3, the current-period average pumping rates ranged from 0.0002 gpm to 1 gpm, and the total groundwater volume removed from each well during this period ranged from 115 gallons (well 1092, historically the lowest producer) to nearly 543,000 gallons in well 1093R. The cumulative total volume removed from pumping the terrace extraction wells (about 1.6 million gallons) is almost double the volume extracted during the 2009–2010 reporting period. The increase during this reporting period may in part be attributable to increased preventive maintenance that reduced the number of shutdown periods for repairs.

As discussed in greater detail in the recent review of the Shiprock remediation strategy (DOE 2010b), one of the initial objectives for the terrace remediation system was attainment of a cumulative 8 gpm extraction rate, a goal based on groundwater modeling conducted for the SOWP (see DOE 2000, DOE 2002, and DOE 2005). To help meet this objective, DOE expanded the terrace extraction well network between 2005 and 2007. Two new wells (1095 and 1096) were installed near the evaporation pond in March 2005. In September 2007, DOE installed a new large-diameter well (1093R) to increase the probability of collecting a larger volume of water. Despite these enhancements to the terrace extraction system, the 8 gpm objective has not been achieved. Historically, the combined pumping rate from terrace extraction wells has ranged between 2 and 4 gpm, below the 8 gpm objective.

Pumping rates and corresponding cumulative groundwater volumes removed from individual terrace extraction wells are presented in Figures 38 through 46. Although active remediation began in March 2003, these figures only plot data after 2004–2005, when site remediation system wells and drains were instrumented with LM's automated telemetry data collection system (SOARS).

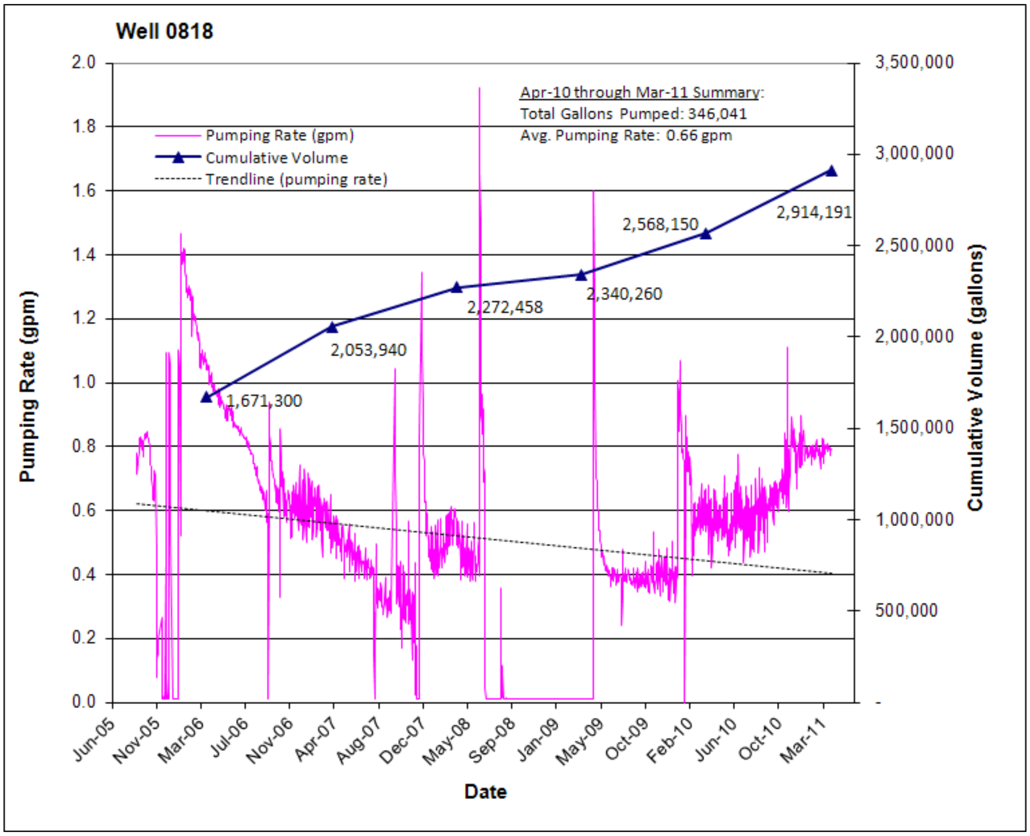

Figure 38. Terrace Well 0818 Pumping Rate and Cumulative Groundwater Volume Extracted

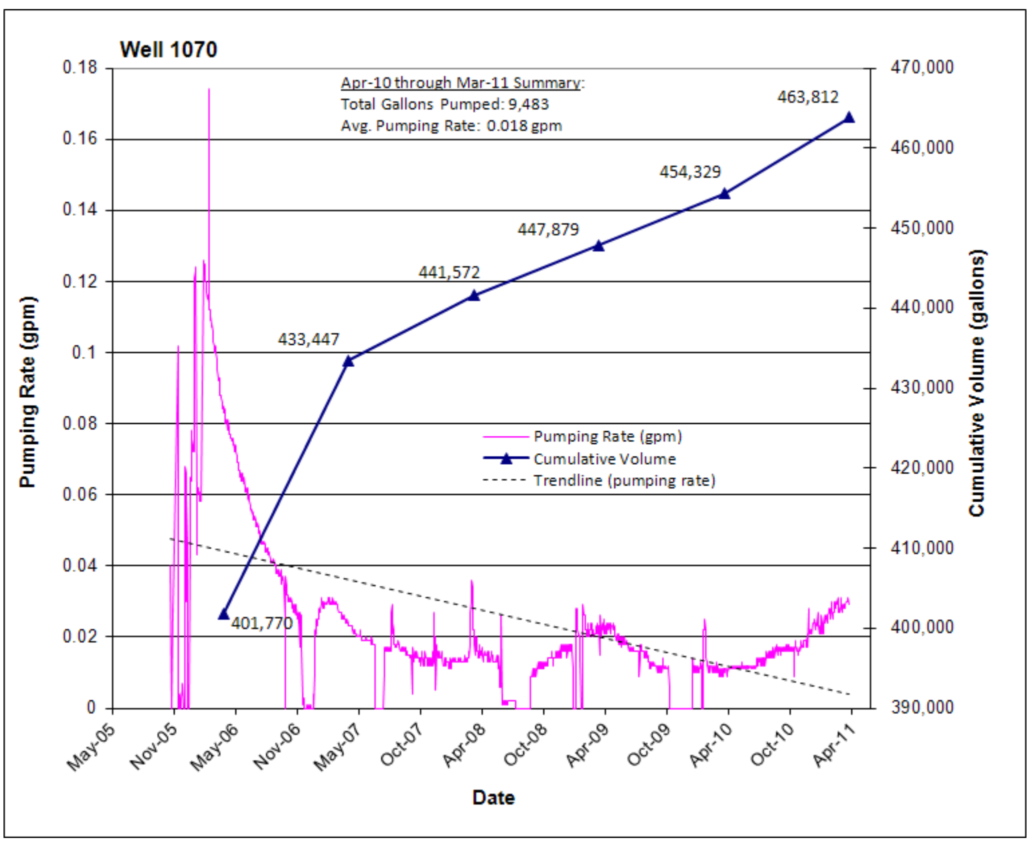

Figure 39. Terrace Well 1070 Pumping Rate and Cumulative Groundwater Volume Extracted

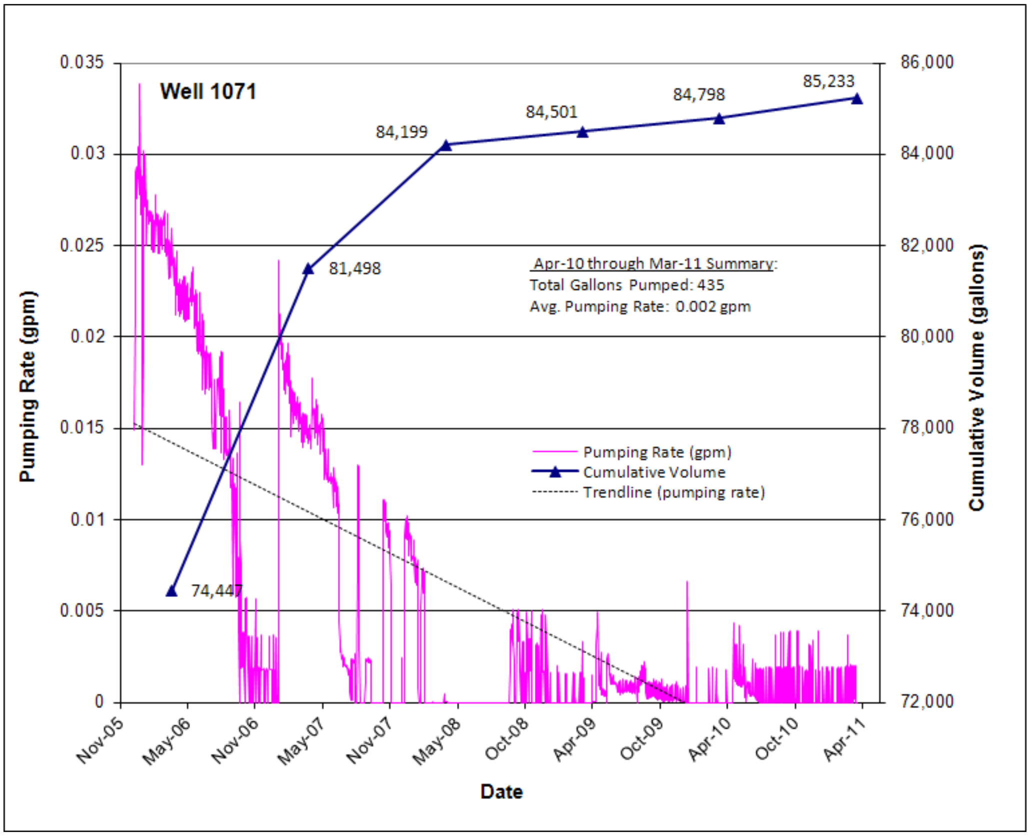

Figure 40. Terrace Well 1071 Pumping Rate and Cumulative Groundwater Volume Extracted

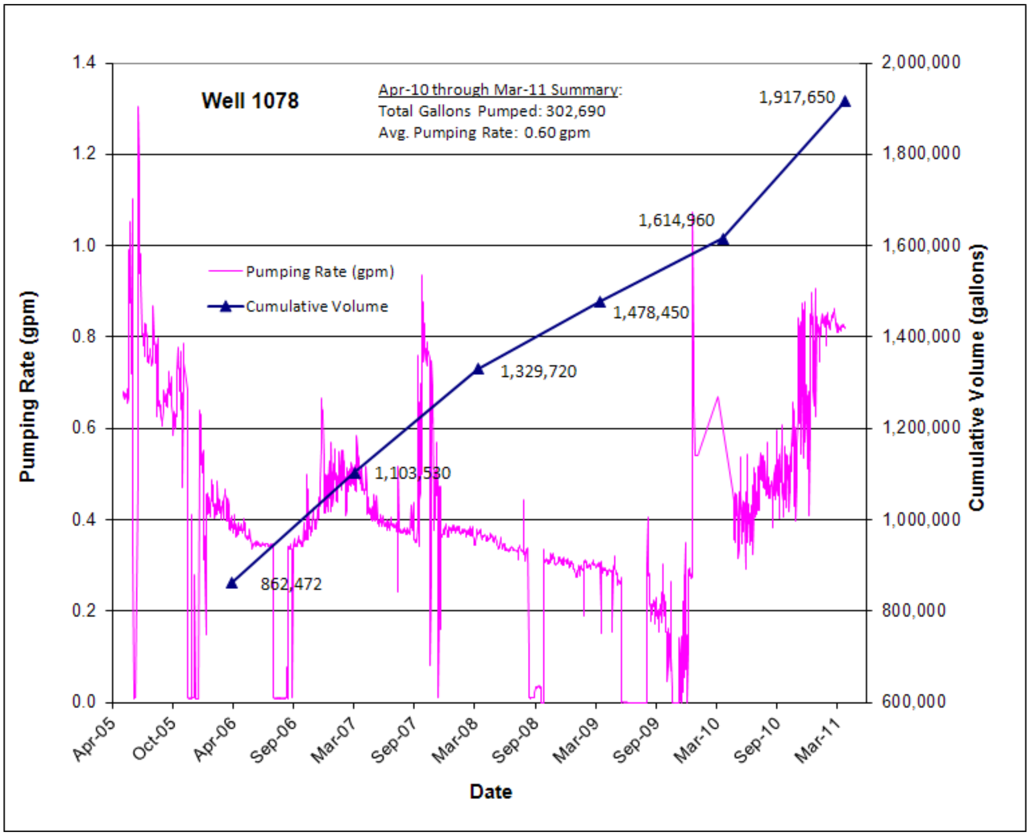

Figure 41. Terrace Well 1078 Pumping Rate and Cumulative Groundwater Volume Extracted

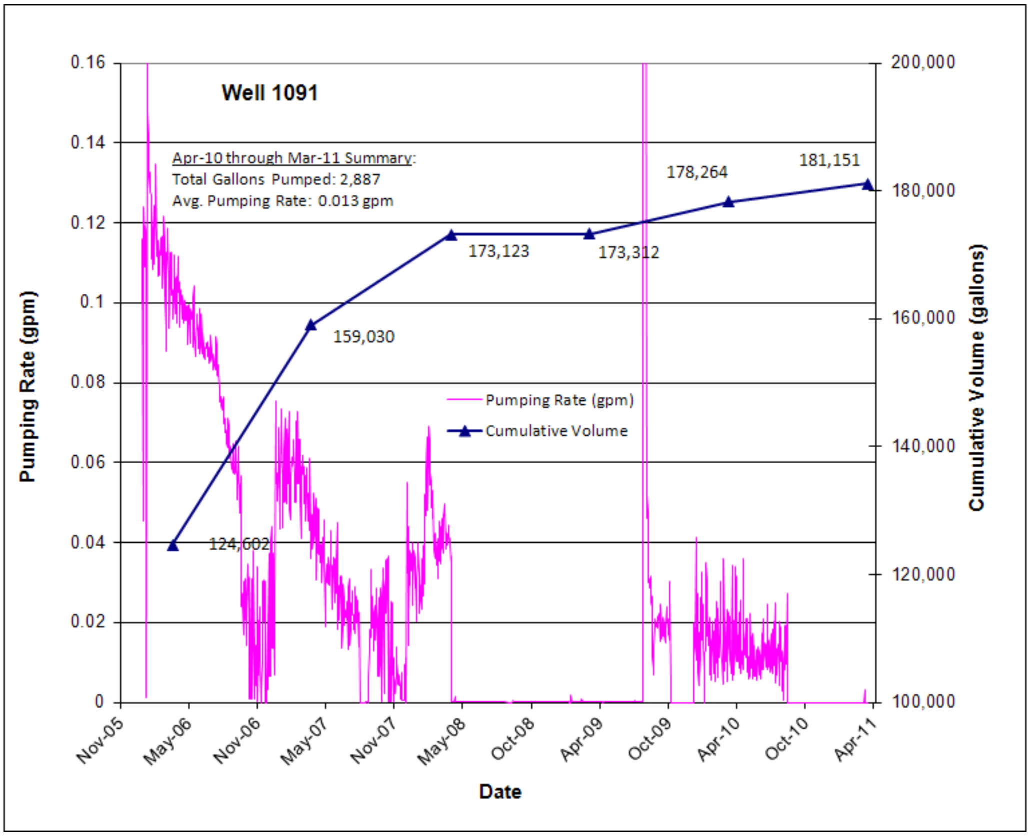

Figure 42. Terrace Well 1091 Pumping Rate and Cumulative Groundwater Volume Extracted

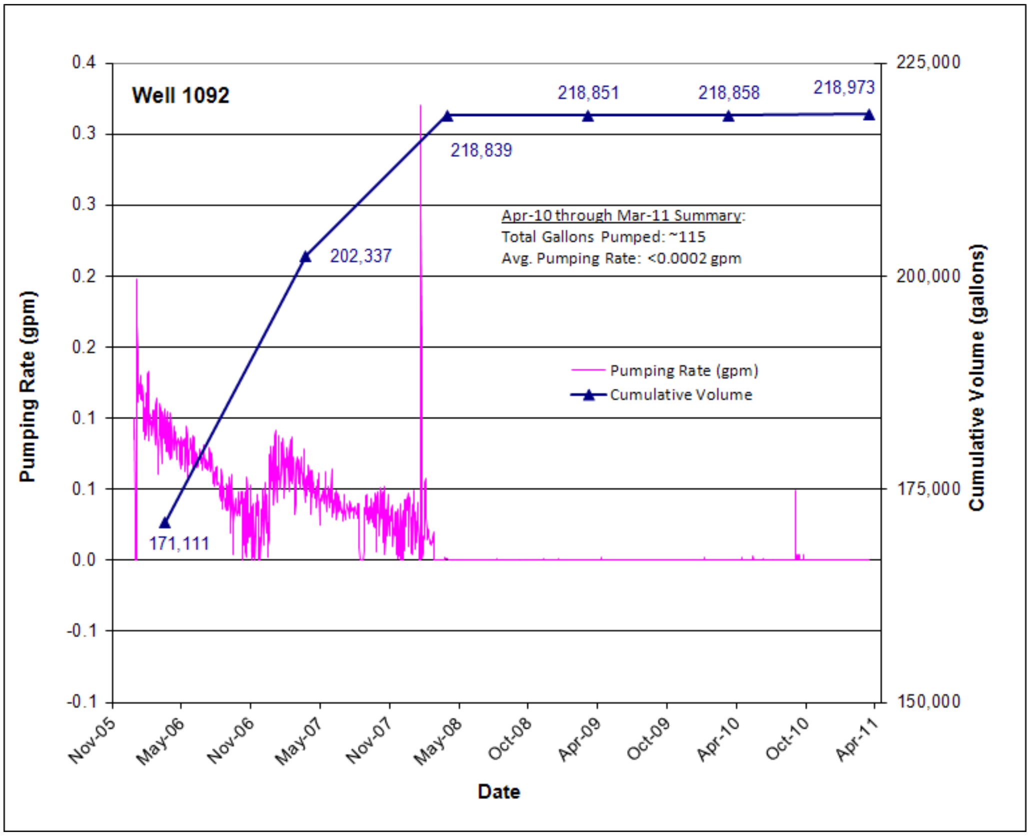

Figure 43. Terrace Well 1092 Pumping Rate and Cumulative Groundwater Volume Extracted

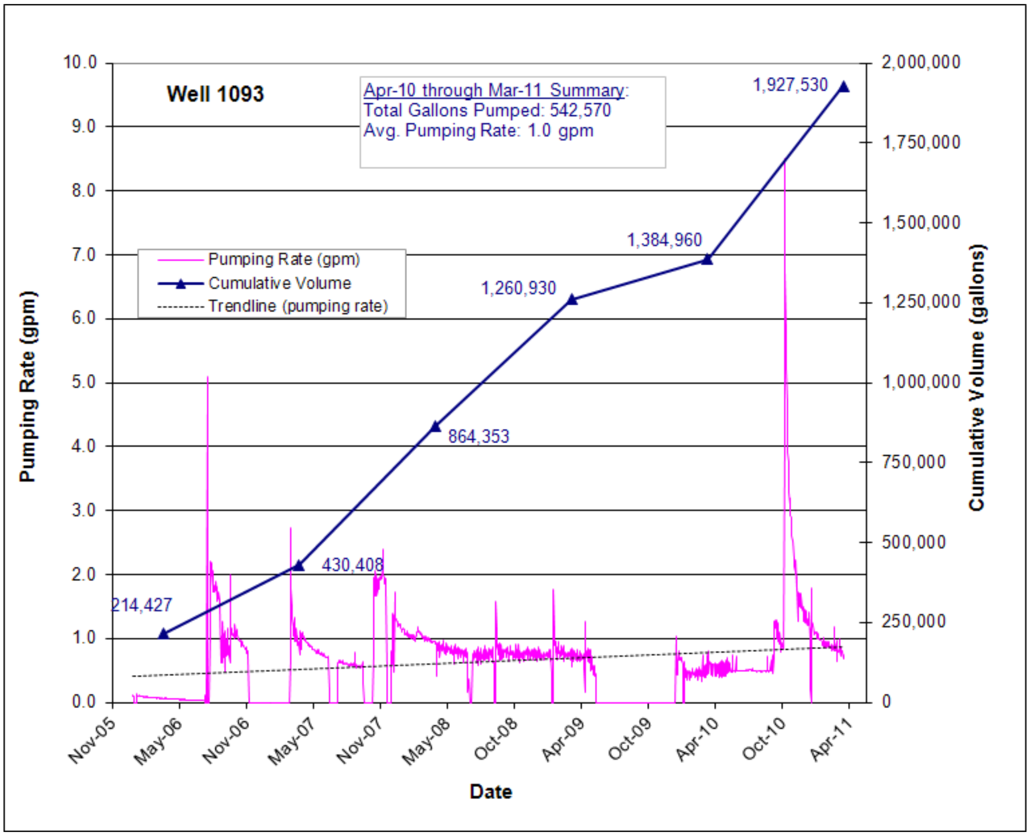

Figure 44. Terrace Well 1093 Pumping Rate and Cumulative Groundwater Volume Extracted

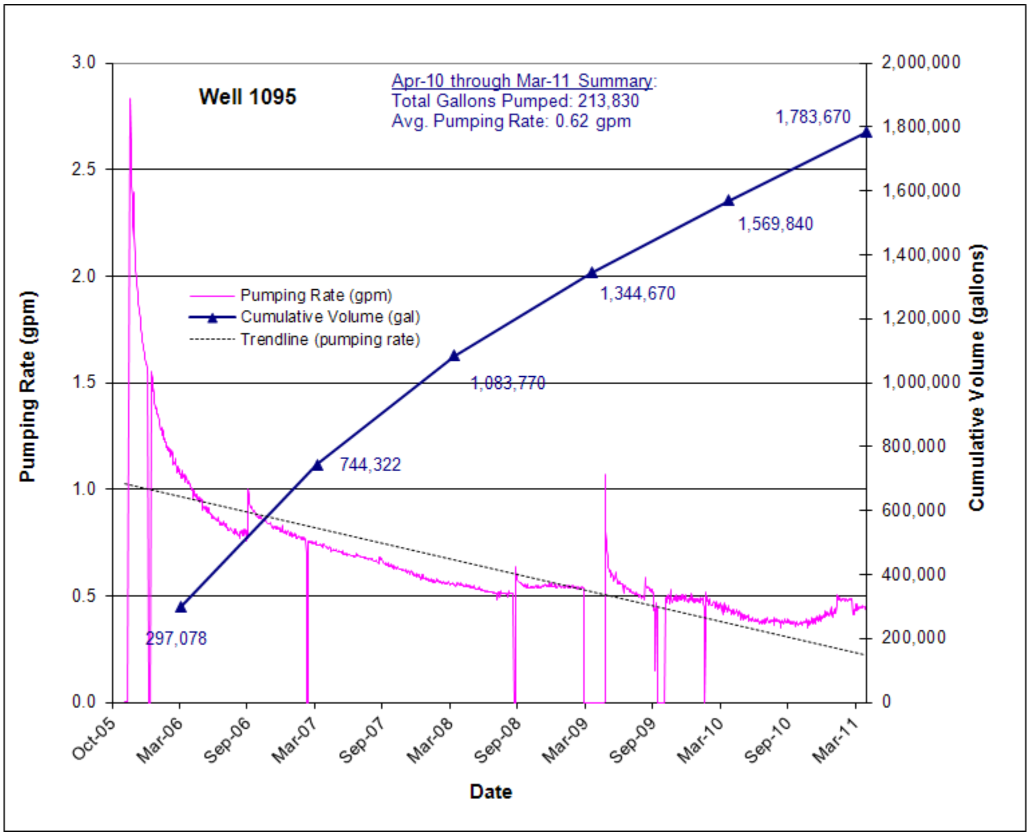

Figure 45. Terrace Well 1095 Pumping Rate and Cumulative Groundwater Volume Extracted

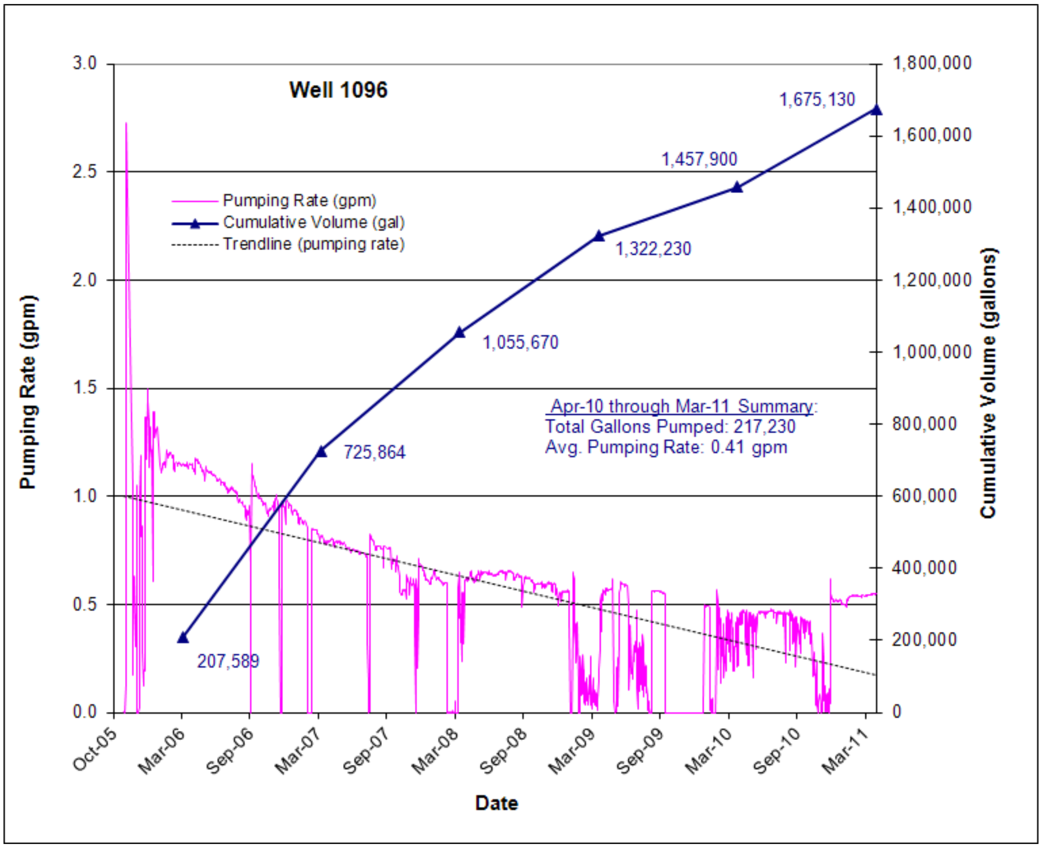

Figure 46. Terrace Well 1096 Pumping Rate and Cumulative Groundwater Volume Extracted

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 impermeable geomembrane and 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 47. During the current performance period, both pumping rates and cumulative flow volumes increased since the last reporting period. In 2010−2011, the average pumping rate from Bob Lee Wash was 5.9 gpm (vs. 2.6 gpm in 2009−2010), and the groundwater interceptor drain removed approximately 3.1 million gallons of water (vs. 1.4 million gallons in 2009–2010).

The pumping rates and volume of water removed from the groundwater interceptor drain in Many Devils Wash (location 1088) are plotted in Figure 48. During the current performance period, the average pumping rate from Many Devils Wash was 0.78 gpm, and the groundwater interceptor drain removed approximately 408,000 gallons of water. As discussed in the previous section, because of increasing flows and apparent decreased effectiveness of the drain, DOE installed a diversion structure in August 2009.

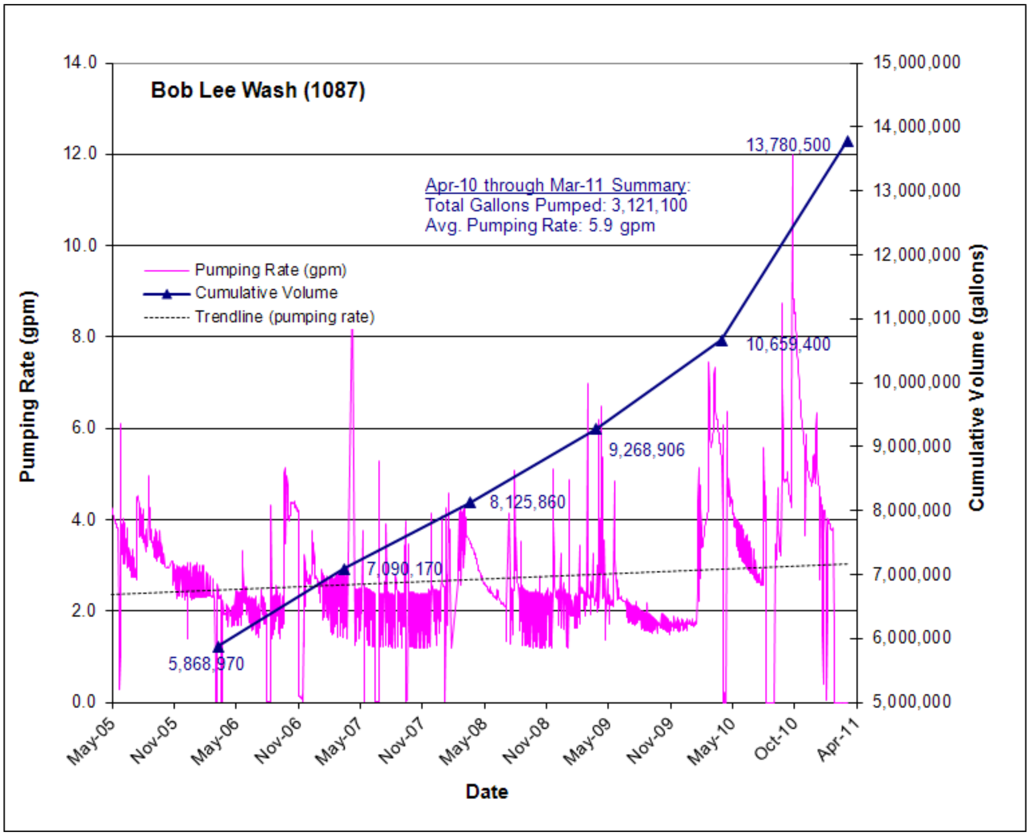

Figure 47. Bob Lee Wash Pumping Rate and Cumulative Groundwater Volume Extracted

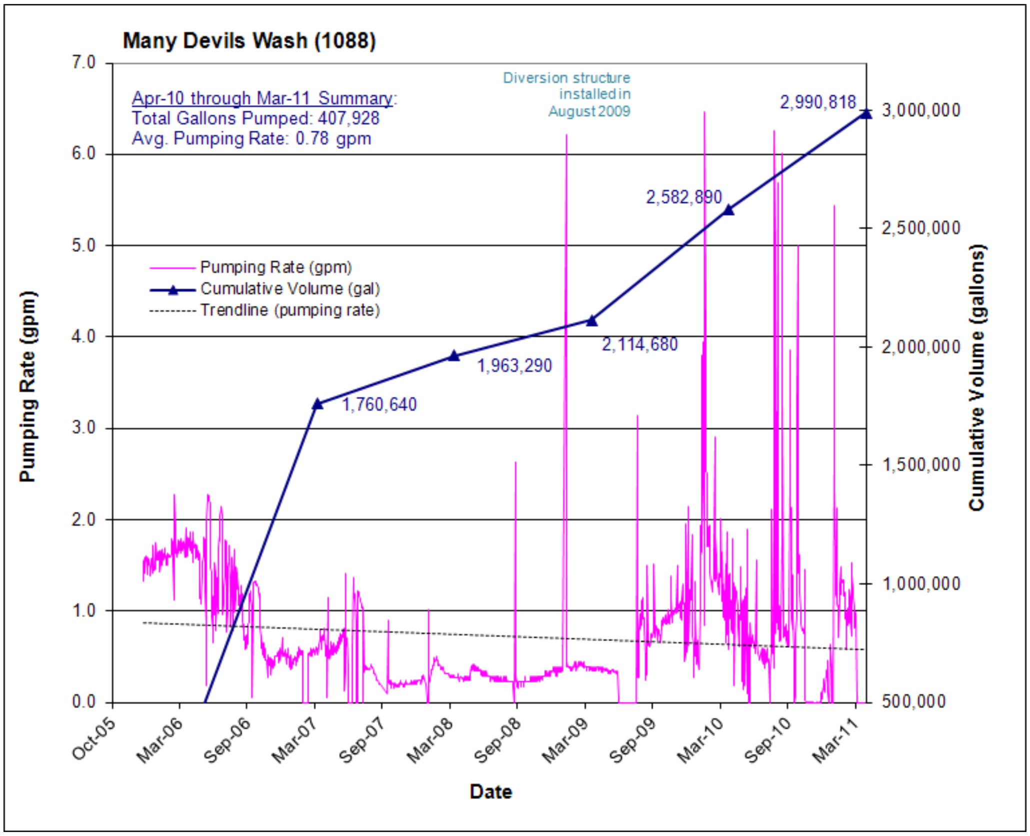

Figure 48. Many Devils Wash Pumping Rate and Cumulative Groundwater Volume Extracted

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 a lined evaporation pond in the south part of the radon cover borrow pit area (Figure 1). The average water level in this 11-acre pond was 5.8 ft in March 2011 (measured as the distance above transducers), leaving approximately 2.2 ft of unfilled pond capacity.

From April 2010 through March 2011, approximately 13.8 million gallons of extracted groundwater were pumped to the evaporation pond. The majority (8.6 million gallons, 63 percent) of the influent liquids entering the pond were from the floodplain aquifer, whereas 37 percent (5.2 million gallons) of the inflow originated from the terrace groundwater system (Table 4). This annual input to the pond is about 10 percent higher (1.4 million gallons) than the 12.4 million gallons reported for 2009–2010. As discussed in Section 3.1.2, pumping at Trench 2 was shut down periodically to increase pond capacity and to maintain safe water levels in the pond.

At the end of the 2010–2011 reporting period, a cumulative volume of nearly 100.8 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 49 plots the total volume of water pumped to the pond and the relative contributions from the floodplain and terrace systems.

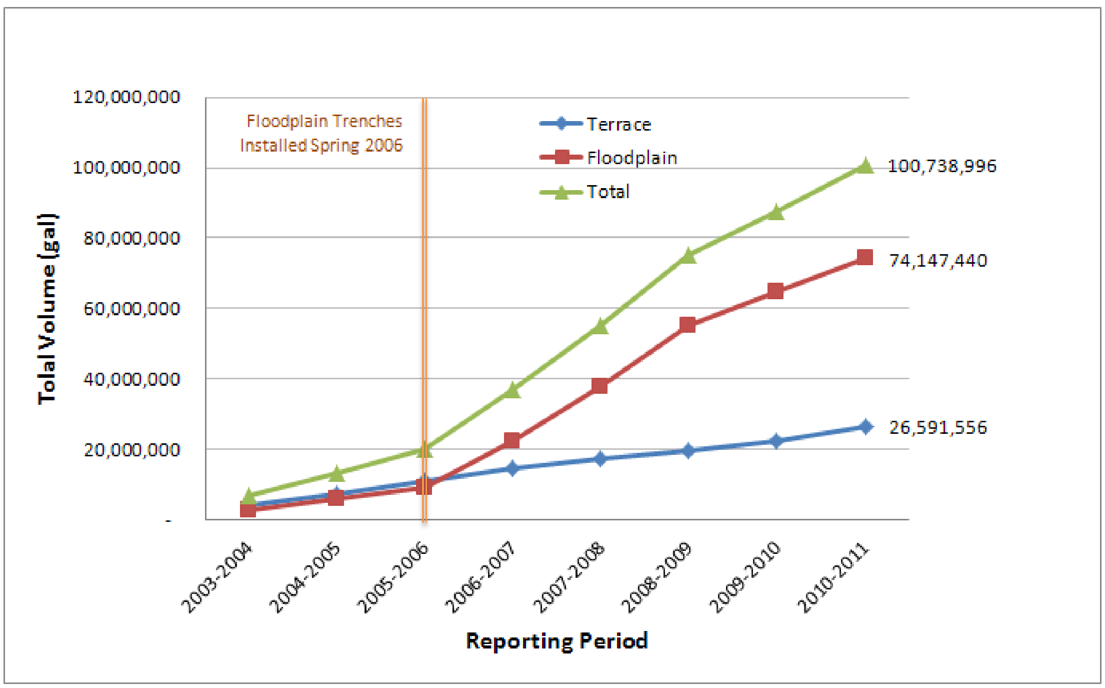

Figure 49. Total Groundwater Volume Pumped to the Evaporation Pond

Table 4. Estimated Total Mass of Selected Constituents Pumped from Terrace and Floodplain

Location	Annual Cumulative Volume (gal)[a]	Percent Contribution	Nitrate - Average Concentration (mg/L)	Nitrate Mass Contribution per Location (kg)[b]	Nitrate Mass Contribution per Location (lb)[c]	Sulfate - Average Concentration (mg/L)	Sulfate Mass Contribution per Location (kg)[b]	Sulfate Mass Contribution per Location (lb)[c]	Uranium - Average Concentration (mg/L)	Uranium Mass Contribution per Location (kg)[b]	Uranium Mass Contribution per Location (lb)[c]
Terrace											
0818	346,041	2.2	869	1138	2509	14,600	19,123	42,158	0.113	0.147	0.325
1070	9483	0.06	689	24.7	54.5	15,250	547	1,207	0.097	0.003	0.008
1071	435	0.003	1150	1.9	4.2	10,600	17.4	38.4	0.123	0.0002	0.0004
1078	302,690	1.96	598	685	1509	14,150	16,211	35,740	0.135	0.154	0.34
1091	2887	0.02	1070	11.69	25.78	13,450	147.0	324.01	0.115	0.0013	0.003
1092	115	<0.01	1085	0.47	1.0	10,750	4.68	10.32	0.078	<0.001	<0.001
1093	542,570	3.5	2230	4580	10,096	5970	12,260	27,029	0.103	0.211	0.46
1095	213,830	1.4	1715	1388	3060	4990	4,039	8904	0.051	0.042	0.09
1096	217,230	1.4	629	517	1140	14,300	11,758	25,921	0.105	0.086	0.19
1087 (BLW)	3,121,100	20.2	362	4271	9415	6185	73,066	161,081	0.540	6.379	14.1
1088 (MDW)	407,928	2.6	657	1014	2235	18,900	29,182	64,334	0.186	0.287	0.633
Floodplain											
1089	3,039,600	19.7	4.8	56	122	5630	64,773	142,797	0.391	4.5	9.92
1104	653,370	4.2	36.7	91	200	8435	20,860	45,988	0.898	2.22	4.89
Trench 1 (1110)	2,799,100	18.1	44.0	466	1027	6095	64,574	142,360	0.640	6.78	14.95
Trench 2 (1109)	1,880,900	12.2	63.7	453	999	1259	8960	19,752	0.167	1.19	2.62
Seep sump (1118)	257,600	1.7	64.3	63	138	7395	7210	15,896	0.674	0.66	1.45
			Total Masses:	14,758	32,536		332,730	733,537		23	50
Total Terrace	5,164,309	37.4									
Total Floodplain	8,630,570	62.6									
Total to Pond	13,794,879										

[a] Annual cumulative volumes derived from data used to generate plots in Figures 33 through 48 (data from April 1, 2010, through March 31, 2011).
[b] Mass in kilogram (kg) derived = annual volume × 3.785 (liters to gallons) × average concentration × (1/1,000,000).
[c] Conversion to pounds (lb) = kg × 2.2046.
MDW = Many Devils Wash; BLW = Bob Lee Wash

As shown in Table 4, 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 2010–2011 performance evaluation period were approximately 33,000 pounds (nitrate as N), 734,000 pounds (SO_4), and 50 pounds (U). These mass estimates (rounded to nearest thousand) were computed using the average concentrations measured in each extraction well and the corresponding annual cumulative volume pumped. Sulfate is the dominant COC (in terms of mass) 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

Natural phytoremediation (no human intervention) and hydraulic control are ongoing at the Shiprock site. DOE began phytoremediation 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 barrier borrow pit south of the disposal cell, where nitrate levels are elevated in alluvial sediments. The goal of phytoremediation in these areas is hydraulic control (as opposed to contaminant removal), to enhance plant transpiration of groundwater, thereby limiting the spread of contaminants in groundwater. The four irrigated phytoremediation test plots, established in 2006 and measuring 15 meters by 15 meters, are shown on Figure 1 and in the Figure 50 schematic below. To date, all work has been done in concert with the Diné Environmental Institute at Diné College in Shiprock.

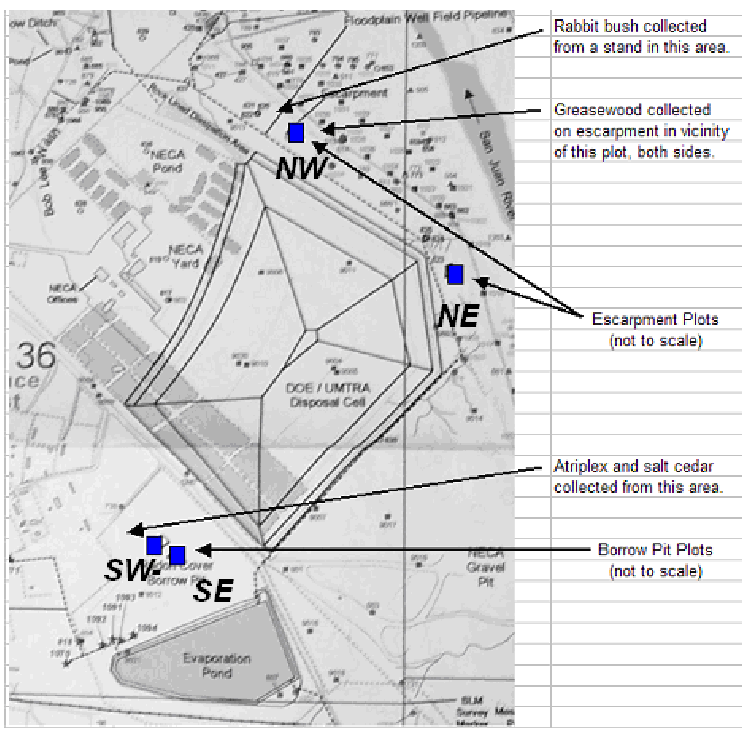

Figure 50. Map of Phytoremediation Test Plots in the Radon Barrier Borrow Pit and on the Terrace above the San Juan River Escarpment

As obligatory and facultative phreatophytes, the volunteer tamarisk, black greasewood, and fourwing saltbush currently growing in the borrow pit area are likely extracting groundwater, nitrate, and possibly other groundwater constituents. A few scattered black greasewood plants that have established on the terrace above the escarpment are also likely removing water that might otherwise daylight in contaminated seeps at the base of the escarpment. Higher rates of water extraction by woody plants in both locations may improve hydraulic control. More recently, DOE began evaluating the feasibility of enhanced phytoremediation, which entails deliberate planting of the areas (versus the volunteer growth). This technique, still in early experimental stages, may be an economical addition to the current groundwater compliance strategy.

Three objectives of the phytoremediation pilot studies have been established. These objectives and the associated findings and progress to date are summarized below.

Objective 1—Establish native phreatophytic shrubs by transplanting seedlings started in a greenhouse and then irrigating transplants until roots have accessed plume groundwater.

<u>Findings and status:</u>

- Diné College students irrigate and maintain the plantings and annually measure plant growth. Irrigated transplants have grown larger in the escarpment plots than in the radon cover borrow pit plots.
- On the escarpment, oxygen and deuterium isotope studies indicate that volunteer black greasewood plants, typically difficult to establish from transplants, are rooted down to groundwater. To date, analyses indicate that transplanted black greasewood and fourwing saltbush growing in the test plots have not intercepted contaminated groundwater.
- In contrast, plants are not doing well in the radon cover borrow pit area, where oxygen and deuterium isotope studies indicate that volunteer saltbush and rabbitbrush have not reached groundwater, and irrigated transplants are not expected to. Given these findings, the objective of these plots has changed. The objective now is to establish native vegetation, control the soil water balance, and limit recharge and, hence, the volume of the plume water.
- The four test plots were modified in 2011 to evaluate plant survival without irrigation. The purpose was to acquire additional evidence of plants rooting into groundwater and, overall, the sustainability of phytoremediation. Half of the plants in each plot are irrigated while the other half receive only ambient precipitation. Diné College students will evaluate plant growth and mortality after the growing season. Survival and growth of non-irrigated plants would indicate that their roots are accessing groundwater. Non-irrigated plants that are stressed or dying would indicate that their roots have not accessed groundwater—that the phytoremediation plantings are not sustainable without irrigation.

Objective 2—Once plant roots have accessed groundwater, evaluate the human health and ecological risks associated with uptake of groundwater constituents and accumulation in aboveground plant tissue.

Findings and status:

- For a preliminary evaluation of plant uptake, Diné College students harvested stem and leaf tissue from volunteer and transplanted phreatophytic shrubs in the escarpment plots in 2010. In 2011, students evaluated the results with a focus on uranium uptake. For all plants sampled (volunteer black greasewood and rubber rabbitbrush and transplanted black greasewood and fourwing saltbush), concentrations of uranium in stem and leaf tissue were within a reported range of background values for terrestrial vegetation.
- In 2012, Diné College students will harvest stem and leaf tissue of non-irrigated plants in the escarpment plots (if the plants survive) and compare uranium concentrations with the same species growing in reference areas.
- Plants in the radon cover borrow pit plots were not sampled because prior evidence indicated that they are not rooted in groundwater.

Objective 3—Evaluate the potential beneficial effects of phytoremediation on plume water volume, plume migration, and flow in existing contaminated seeps at the base of the escarpment and in floodplain groundwater.

If results from the escarpment studies addressing objectives 1 and 2 are favorable, DOE will calculate potential annual transpiration rates based on plant leaf area and biomass, and coordinate with project hydrologists to evaluate potential benefits with respect to the hydrologic control of terrace groundwater and its potential impact on the seeps and floodplain groundwater plume.

In summary, as part of the overall phased remediation approach DOE is applying at the Shiprock site, the phytoremediation pilot study will continue. DOE will evaluate a specific plan for phytoremediation pending analysis of overall findings and data when pilot studies end.

Uranium Uptake in the Diné College Orchard

In response to a request by the Navajo Nation, in 2010 DOE and Diné College students harvested stem, leaf, and fruit tissue from apricot, peach, and apple trees growing in the Diné College orchard west of Shiprock. For all samples, dry-weight concentrations of uranium were either nondetects or were within a reported range of background values for terrestrial vegetation.

4.0 Performance Summary

This section summarizes the findings of the most recent (April 2010 through March 2011) assessment of the floodplain and terrace groundwater remediation systems at the Shiprock site, marking the end of the eighth 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 8.6 million gallons of groundwater were extracted from the floodplain aquifer system during this performance period, yielding a cumulative total of about 74 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 2010 through March 2011, approximately 5.2 million gallons of groundwater were extracted from the terrace system, yielding a total cumulative volume (extracted since March 2003) of about 26.6 million gallons. The cumulative volume removed from both terrace and floodplain combined (as of April 1, 2011) is approximately 101 million gallons.
- Terrace-wide, groundwater levels in the majority of alluvial wells sampled during this performance period declined relative to the baseline (2000–2003) period (Figure 30); average and maximum decreases were 2.5 ft and 7.2 ft, respectively. Five alluvial west terrace wells were dry during the March 2011 sampling event. 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 are widespread, and many seeps on the west terrace have been dry for the last several years (in 2010–2011, all but one seep west of the high school were dry).
- Contaminated groundwater that could potentially discharge to the San Juan River is being intercepted by the remediation system. 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 734,000 pounds, 33,000 pounds, and 50 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 and well 1089 areas, but this is also generally the case floodplain-wide. 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 samples are still well below established benchmarks and are comparable to upstream (background) results.
- A more detailed assessment of floodplain remediation system performance is documented in the recently issued preliminary evaluation of the Trench 1 collection drain area (DOE 2011d). This analysis is the precursor to a more extensive evaluation of flow and transport processes in the floodplain alluvial aquifer (in progress).
- As shown in Figure 2, the sampling network at the Shiprock site is dense—for this reporting period, 115 monitoring wells were sampled (59 on the floodplain and 56 on the terrace). However, contaminant trends evaluated in this and previous reports indicate that at some locations on both the terrace and the floodplain (and for some constituents in particular), no

trending is apparent. Therefore, DOE recently initiated a detailed evaluation of the current sampling program to assess potential temporal and spatial redundancies in order to optimize the efficiency of the sampling program (work in progress, scheduled for submittal by early 2012).

- In addition to the preliminary Trench 1 evaluation referenced above, DOE issued two other reports in early 2011—*Natural Contamination in the Mancos Shale* (DOE 2011b) and *Geology and Groundwater Investigation at Many Devils Wash* (DOE 2011c). These investigations lay the groundwork for ongoing technical evaluations of potential contributions from natural sources, particularly in Many Devils Wash.
- As has been the case for the last several years, pumping from Trench 2 was shut down periodically during 2010–2011 (mostly during spring runoff) to minimize the loss of available pond capacity. The water level in the pond filled to approximately 2 feet below capacity in early 2011. A drip line was installed to enhance evaporation.

5.0 Recommendations

The floodplain extraction system appears to be functioning as expected. The addition of the two trenches at the base of the escarpment enhances the removal of contaminant mass from groundwater in the alluvium. Based on the current status of remediation progress and findings of more recent investigations (DOE 2009; DOE 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:

- Continued assessment of floodplain-wide flow and transport processes is warranted (studies are in progress). Supporting modeling will be used to address key issues regarding management of the alluvial aquifer, including (1) the capacity of groundwater extraction components to prevent contaminant discharge to the river; (2) optimal pumping cycles for Trench 1 and Trench 2; (3) the relative benefits of a third trench between Trench 1 and the well 1089 area (see below); and (4) the likely floodplain impacts of terminating flows from artesian well 0648.
- The objective of the recent Trench 1 evaluation was not only to assess the performance of the system, but also to determine if additions or modifications to the remediation system would be beneficial (DOE 2011d). Based on the findings of this study, DOE may explore the feasibility of installing another collection drain in the central area of the floodplain between the Trench 1 and the 1089 areas near well 0798.
- Additional studies in the well 1089 area may be useful to improve estimates of local aquifer hydraulic properties (e.g., hydraulic conductivity), evaluate differences in pumping rates between the vertical extraction wells 1089 and 1104, and evaluate groundwater interaction (including water exchange) with the San Juan River.
- The terrace extraction system is operating adequately, and groundwater levels are gradually declining. Therefore, no additions to the terrace system are recommended at this time (see DOE 2010a). However, as discussed in Section 1.1 and in the recent strategy evaluation (DOE 2010a), the compliance strategy for the terrace needs to be updated. DOE is proposing active remediation as the interim remediation strategy for the entire terrace. Therefore, in future annual reports, it may be prudent to focus not just on groundwater elevation changes (decreases), but on contamination trends as well (e.g., factors underlying COC increases in some terrace wells).
- Continued monitoring of the fluid level in the evaporation pond is recommended, along with periodic cessation of pumping as necessary to maintain sufficient freeboard. However, efforts to enhance evaporation rates (e.g., additional drip lines or spray systems) may be warranted. Also, given that the remediation system has been operating over 8 years, the longevity of the pond liner—and the remediation infrastructure as a whole—may soon warrant evaluation and/or necessary upgrades.
- To mitigate potential ecological risks associated with the pond, in June 2010 DOE began adding dye to the evaporation pond to block sunlight as a way to kill algae and thus remove a potential food source for birds. This has been effective in reducing the algae, and DOE recommends that this practice continue.
- Develop a specific plan for phytoremediation pending analysis of overall findings and data when pilot studies end (in progress).

- The recently issued investigation of Many Devils Wash (DOE 2011c) identified a channel that could be a pathway for groundwater to migrate from a tributary southeast of the wash (Tributary 1, off of East Fork) northward to the knickpoint seeps. However, additional investigation is needed and is planned for late 2011.
- Probably the most prevailing issue in Many Devils Wash is defining the source of the contamination (see DOE 2011b, DOE 2011c). Ultimately, irrespective of the origin of contamination in Many Devils Wash (whether naturally occurring, mill-related, or a combination of both), DOE will continue to focus on ways to minimize exposures and risks to contaminants in the wash as well as other areas of the site. DOE continues to underscore the importance of institutional controls and seeks cooperation and assistance from NNEPA and Navajo UMTRA on this issue.

6.0 References

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Appendix A

Supplementary Time-Trend Sparkline Plots

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Floodplain Trench 1 Area: Ammonia (mg/L)

Well ID		Period: Feb-00 to Mar-11	Max	Min	Current	N
1111	Disposal Cell Side of Trench		65.2	0.35	8.0	26
1112			17.0	2.3	4.8	8
1140	River Side of Trench		27.0	4.0	11.8	12
1141			29.9	10.1	10.8	11
0615			51.0	3.1	12.7	9
1105			2.00	0.10	0.12	11
0793			91.0	22.9	22.9	11
1009			25.0	6.9	6.9	4
0853			15.0	10.0	10.0	4
1142			0.13	0.07	0.12	5

Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Ammonia (mg/L)

Well ID		Period: Feb-00 to Mar-11	Max	Min	Current	N
1115	Disposal Cell Side of Trench		410	65	268	15
1128			2.0	0.10	0.24	14
1117	River Side of Trench		470	130	470	4
1132			6.0	0.88	1.1	6
1134			2.0	0.56	1.1	5

Floodplain Well 1089 Area: Ammonia (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0766		1.0	0.09	0.09	6
0854		21.7	2.0	7.6	10
1008		51.4	8.5	8.5	15
1089		6.0	0.18	0.18	16
1104		3.4	0.12	0.12	10
1137		0.78	0.54	0.57	3
1138		0.42	0.27	0.27	3
1139		0.17	0.05	0.13	5

North-Northwest Floodplain Area: Ammonia (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		1.0	0.003	0.091	17
0736		1.0	0.011	0.057	18
0782/0782R		0.100	0.028	0.072	8
0783/0783R		0.100	0.004	0.040	9
0855		1.0	0.004	0.055	12
0856		1.0	0.046	0.073	11
1135		0.100	0.064	0.064	5
1143		0.100	0.050	0.050	5

Central Floodplain Wells: Ammonia (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0618		75.5	27.0	34.4	26
0619		27.0	0.01	0.55	25
0622		1.0	0.06	0.06	7
0623		1.0	0.10	0.10	8
0625		1.0	0.06	0.06	6
0626		1.0	0.01	0.21	12
0628		1.0	0.02	0.05	10
0630		1.0	0.01	0.03	11
0768		1.31	0.02	0.28	9
0775		2.21	0.02	0.06	8
0779		18.0	0.96	2.0	9
0792		1.71	0.06	0.08	11
0798		22.3	0.60	1.25	8
0857		19.2	3.8	14.5	9
1136		0.10	0.04	0.04	5

South-Southeast Floodplain Area: Ammonia (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0608		436	70	70	27
0610		66.5	0.37	0.37	9
0611		10.0	1.6	2.3	5
0612		1.9	0.10	0.51	9
0614		79.0	17.0	17.4	29
0735		25.0	3.8	14.8	25
0773		10.0	0.02	0.51	8
1113		98.0	0.12	0.12	9
1114		440	82.0	103	13

Floodplain Background Wells: Ammonia (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		0.10	0.003	0.10	21
0850		0.10	0.004	0.07	22

All but most recent results are nondetects, where result = DL value.

Legend

In these sparkline diagrams, red markers denote maximum (max) concentrations and green markers denote minima (min); black markers denote the most recent (current) March 2011 measurement. The x-axis is hidden but corresponds to the Feb-00 to Mar-11 date range noted above each plot. Vertical (y-) axis scales are automatic for each individual well, so magnitudes should not be compared across wells (instead refer to summary statistics).

Figure A–1. Ammonia Concentration Trends in Floodplain Monitoring Wells

Floodplain Trench 1 Area: Nitrate as N (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1111	Disposal Cell Side of Trench	1,200	14.0	23	26
1112		171	4.0	7.8	8
1140	River Side of Trench	0.49	0.01	0.01	12
1141		223	0.01	0.05	11
0615		1,100	60	60	9
1105		139	12	38.8	11
0793		840	230	452	11
1009		320	130	131	4
0853		58.5	29.0	58.5	4
1142		0.08	0.01	0.01	5

Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Nitrate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1115	Disposal Cell Side of Trench	409	48	400	15
1128		2.300	0.01	0.01	14
1117	River Side of Trench	560	392	535	4
1132		0.67	0.01	0.67	6
1134		5.14	0.01	5.14	5

Floodplain Well 1089 Area: Nitrate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0766		267	0.01	3.3	7
0854		463	40.6	40.6	11
1008		282	18.4	18.4	15
1089		83	3.8	3.8	22
1104		180	16.3	16.3	12
1137		27.0	4.0	4.0	3
1138		10.0	5.8	6.2	3
1139		29.9	0.1	29.9	5

North-Northwest Floodplain Area: Nitrate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		50.4	0.01	0.36	18
0736		2.3	0.01	0.01	19
0782/0782R		0.03	0.01	0.01	8
0783/0783R		0.82	0.01	0.01	9
0855		16.9	0.01	1.1	13
0856		1.0	0.01	0.01	11
1135		0.05	0.01	0.01	5
1143		0.08	0.01	0.01	5

Central Floodplain Wells: Nitrate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0618		402	71.0	75	27
0619		29.4	0.01	0.05	25
0622		3.4	0.01	0.36	7
0623		2.3	0.01	0.01	8
0625		2.3	0.01	0.01	6
0626		2.6	0.01	0.01	13
0628		2.3	0.01	0.01	11
0630		28	0.02	12	11
0768		14	0.01	0.01	10
0775		248	0.01	0.01	9
0779		122	0.01	0.01	10
0792		30.0	0.01	0.01	11
0798		203	0.01	0.69	8
0857		33.6	0.01	33.6	10
1136		0.3	0.01	0.25	5

South-Southeast Floodplain Area: Nitrate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0608		650	83	83	28
0610		780	190	270	10
0611		178	0.5	17	5
0612		0.56	0.01	0.01	9
0614		1,100	353	353	29
0735		1,200	7.1	738	26
0773		370	23.0	27.1	9
1113		1,175	96	391	9
1114		420	27	131	13

Floodplain Background Wells: Nitrate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		0.11	0.004	0.010	21
0850		3.30	0.004	0.010	22

Legend

In these sparkline diagrams, red markers denote maximum (max) concentrations and green markers denote minima (min); black markers denote the most recent (current) March 2011 measurement. The x-axis is hidden but corresponds to the Feb-00 to Mar-11 date range noted above each plot. Vertical (y-) axis scales are automatic for each individual well, so magnitudes should not be compared across wells (instead refer to summary statistics).

Figure A–2. Nitrate Concentration Trends in Floodplain Monitoring Wells

Floodplain Trench 1 Area: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1111	Disposal Cell	1.8	0.11	0.28	20
1112	Side of Trench	0.51	0.15	0.25	7
1140	River Side	0.008	0.0001	0.002	11
1141	of Trench	0.34	0.035	0.049	10
0615		0.31	0.047	0.31	8
1105		0.74	0.40	0.57	8
0793		3.07	0.40	3.1	9
1009		1.2	0.14	1.2	4
0853		0.71	0.19	0.71	4
1142		0.008	0.001	0.002	5

Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1115	Disposal Cell	0.12	0.01	0.07	10
1128	Side of Trench	0.008	0.0002	0.002	10
1117		0.03	0.02	0.02	3
1132	River Side of Trench	0.002	0.0004	0.002	5
1134		0.006	0.0001	0.002	4

Floodplain Well 1089 Area: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0766		0.053	0.001	0.005	6
0854		0.076	0.005	0.016	10
1008		0.240	0.009	0.023	14
1089		0.094	0.015	0.046	11
1104		0.047	0.014	0.031	9
1137		0.003	0.002	0.003	3
1138		0.005	0.001	0.005	3
1139		0.025	0.004	0.025	5

North-Northwest Floodplain Area: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		50.4	0.01	0.36	18
0736		2.3	0.01	0.01	19
0782/0782R		0.03	0.01	0.01	8
0783/0783R		0.82	0.01	0.01	9
0855		16.9	0.01	1.1	13
0856		1.0	0.01	0.01	11
1135		0.05	0.01	0.01	5
1143		0.08	0.01	0.01	5

Central Floodplain Wells: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0618		0.51	0.160	0.48	23
0619		0.48	0.0004	0.002	24
0622		0.29	0.024	0.21	6
0623		0.008	0.001	0.002	7
0625		0.002	0.002	0.002	5
0626		0.037	0.0004	0.002	12
0628		0.027	0.0003	0.004	10
0630		0.123	0.005	0.11	10
0768		0.77	0.001	0.002	9
0775		0.12	0.002	0.002	8
0779		0.024	0.001	0.002	9
0792		1.3	0.002	0.002	10
0798		0.87	0.020	0.036	7
0857		0.002	0.0001	0.002	9
1136		0.008	0.0001	0.002	5

South-Southeast Floodplain Area: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0608		0.031	0.002	0.002	23
0610		0.239	0.014	0.239	9
0611		0.084	0.001	0.002	4
0612		0.002	0.000	0.002	8
0614		2.660	0.044	0.990	25
0735		0.270	0.022	0.076	25
0773		0.290	0.012	0.059	8
1113		0.320	0.009	0.111	6
1114		0.016	0.004	0.016	8

Floodplain Background Wells: Selenium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		0.01	0.0001	0.002	21
0850		0.02	0.0001	0.004	22

Legend

In these sparkline diagrams, red markers denote maximum (max) concentrations and green markers denote minima (min); black markers denote the most recent (current) March 2011 measurement. The x-axis is hidden but corresponds to the Feb-00 to Mar-11 date range noted above each plot. Vertical (y-) axis scales are automatic for each individual well, so magnitudes should not be compared across wells (instead refer to summary statistics).

Figure A–3. Selenium Concentration Trends in Floodplain Monitoring Wells

Floodplain Trench 1 Area: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1111	Disposal Cell Side of Trench	13,185	7,900	10,500	11
1112		14,676	8,300	10,400	11
1140	River Side of Trench	12,600	7,000	12,600	4
1141		5,200	4,100	4,910	4
0615		30,868	3,500	8,340	26
1105		21,000	8,060	8,060	9
0793		7,300	2,460	3,150	8
1009		4,690	1,830	1,830	11
0853		1,600	330	818	12
1142		156	130	144	5

Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1115	Disposal Cell Side of Trench	7,742	1,500	6,910	15
1128		208	87	154	14
1117	River Side of Trench	10,000	5,109	10,000	4
1132		168	110	154	6
1134		410	120	342	5

Floodplain Well 1089 Area: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0766		24,600	5,290	5,290	7
0854		27,000	8,421	11,300	11
1008		19,100	8,070	8,070	15
1089		15,000	4,760	4,760	22
1104		19,000	6,100	7,970	12
1137		3,800	2,010	2,010	3
1138		2,600	1,700	2,450	3
1139		6,740	1,200	6,740	4

North-Northwest Floodplain Area: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		11,100	2,200	5,150	18
0736		9,950	3,480	3,590	19
0782/0782R		630	183	459	8
0783/0783R		615	138	615	9
0855		5,300	2,700	3,930	13
0856		3,340	2,600	3,040	11
1135		6,100	4,140	4,140	5
1143		3,090	2,800	3,000	5

Central Floodplain Wells: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0618		15,000	5,560	12,900	27
0619		14,000	2,900	3,320	25
0622		5,600	2,600	3,030	7
0623		3,092	2,700	2,810	8
0625		2,973	2,040	2,040	6
0626		3,990	2,360	2,360	13
0628		4,800	2,200	2,630	11
0630		3,900	2,200	3,900	11
0768		18,600	4,300	15,200	10
0775		13,300	4,180	4,180	9
0779		9,191	3,950	6,660	10
0792		27,000	6,170	6,170	11
0798		18,000	5,620	5,620	8
0857		4,500	470	4,500	10
1136		370	190	370	5

South-Southeast Floodplain Area: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0608		12,000	3,600	5,130	28
0610		11,300	4,800	4,870	10
0611		6,964	4,900	5,560	5
0612		2,660	250	2,660	9
0614		17,000	8,400	8,400	29
0735		17,200	707	17,200	26
0773		5,630	2,110	2,150	9
1113		13,595	4,080	4,080	9
1114		10,093	1,500	3,190	13

Floodplain Background Wells: Sulfate (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		5,200	240	2,690	21
0850		4,600	210	642	22

Legend

In these sparkline diagrams, red markers denote maximum (max) concentrations and green markers denote minima (min); black markers denote the most recent (current) March 2011 measurement. The x-axis is hidden but corresponds to the Feb-00 to Mar-11 date range noted above each plot. Vertical (y-) axis scales are automatic for each individual well, so magnitudes should not be compared across wells (instead refer to summary statistics).

Figure A–4. Sulfate Concentration Trends in Floodplain Monitoring Wells

Floodplain Trench 1 Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1111	Disposal Cell Side of Trench	1.59	0.79	1.23	11
1112		2.40	1.20	1.87	11
1140	River Side of Trench	2.26	1.20	2.26	4
1141		1.10	0.83	1.07	4
0615		4.80	0.76	1.79	26
1105		4.30	1.57	1.57	9
0793		1.70	0.65	0.65	8
1009		0.75	0.24	0.25	11
0853		0.19	0.04	0.11	12
1142		0.006	0.004	0.006	5

Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1115	Disposal Cell Side of Trench	1.19	0.32	1.13	15
1128		1.60	0.63	1.49	4
1117		0.020	0.004	0.01	14
1132	River Side of Trench	0.022	0.011	0.02	6
1134		0.020	0.010	0.02	5

Floodplain Well 1089 Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0766		4.44	0.27	0.28	7
0854		4.42	1.08	1.38	11
1008		3.32	1.28	1.28	15
1089		2.10	0.23	0.23	21
1104		2.60	0.60	0.60	12
1137		0.49	0.17	0.17	3
1138		0.34	0.16	0.24	3
1139		0.85	0.10	0.85	5

Note: Wells 1075 and 1077 are not shown here as these have not been regularly sampled.

North-Northwest Floodplain Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		0.53	0.02	0.10	19
0736		0.48	0.05	0.05	19
0782/0782R		0.010	0.003	0.007	8
0783/0783R		0.011	0.007	0.010	9
0855		0.15	0.06	0.09	13
0856		0.13	0.04	0.07	11
1135		0.24	0.13	0.14	5
1143		0.07	0.06	0.07	5

Central Floodplain Wells: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0618		3.21	0.79	2.22	27
0619		1.38	0.13	0.15	25
0622		0.44	0.07	0.22	7
0623		0.09	0.05	0.07	8
0625		0.06	0.04	0.05	6
0626		0.10	0.01	0.05	13
0628		0.08	0.01	0.02	11
0630		0.14	0.03	0.14	11
0768		1.40	0.16	0.76	10
0775		2.50	0.21	0.21	9
0779		1.39	0.52	1.00	10
0792		3.10	0.20	0.24	11
0798		2.78	0.32	0.32	8
0857		0.77	0.08	0.77	10
1136		0.007	0.004	0.007	5

South-Southeast Floodplain Area: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0608		2.00	0.69	0.69	28
0610		2.10	0.90	0.90	10
0611		0.53	0.01	0.01	5
0612		0.28	0.02	0.02	9
0614		3.20	1.50	1.50	29
0735		0.54	0.02	0.02	26
0773		0.92	0.38	0.38	9
1113		1.80	0.76	0.76	9
1114		1.05	0.24	0.24	13

Floodplain Background Wells: Uranium (mg/L)

Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		0.037	0.008	0.024	21
0850		0.12	0.004	0.035	23

Legend

In these sparkline diagrams, red markers denote maximum (max) concentrations and green markers denote minima (min); black markers denote the most recent (current) March 2011 measurement. The x-axis is hidden but corresponds to the Feb-00 to Mar-11 date range noted above each plot. Vertical (y-) axis scales are automatic for each individual well, so magnitudes should not be compared across wells (instead refer to summary statistics).

*Figure A–5. Uranium Concentration Trends in Floodplain Monitoring Wells**
**Repeated from Figure 23 in main body of report.*

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