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).

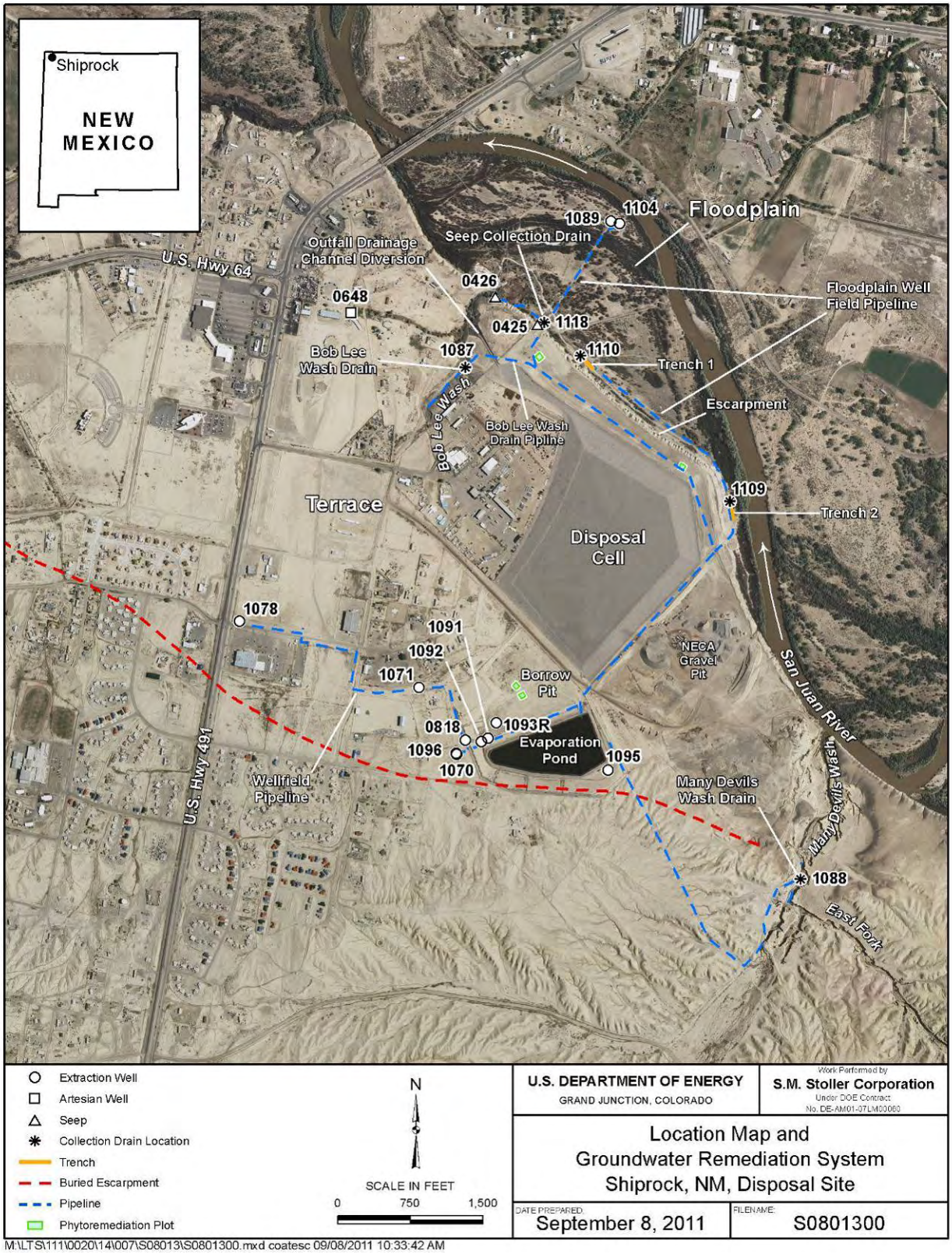

Figure 1. Location Map and Groundwater Remediation System

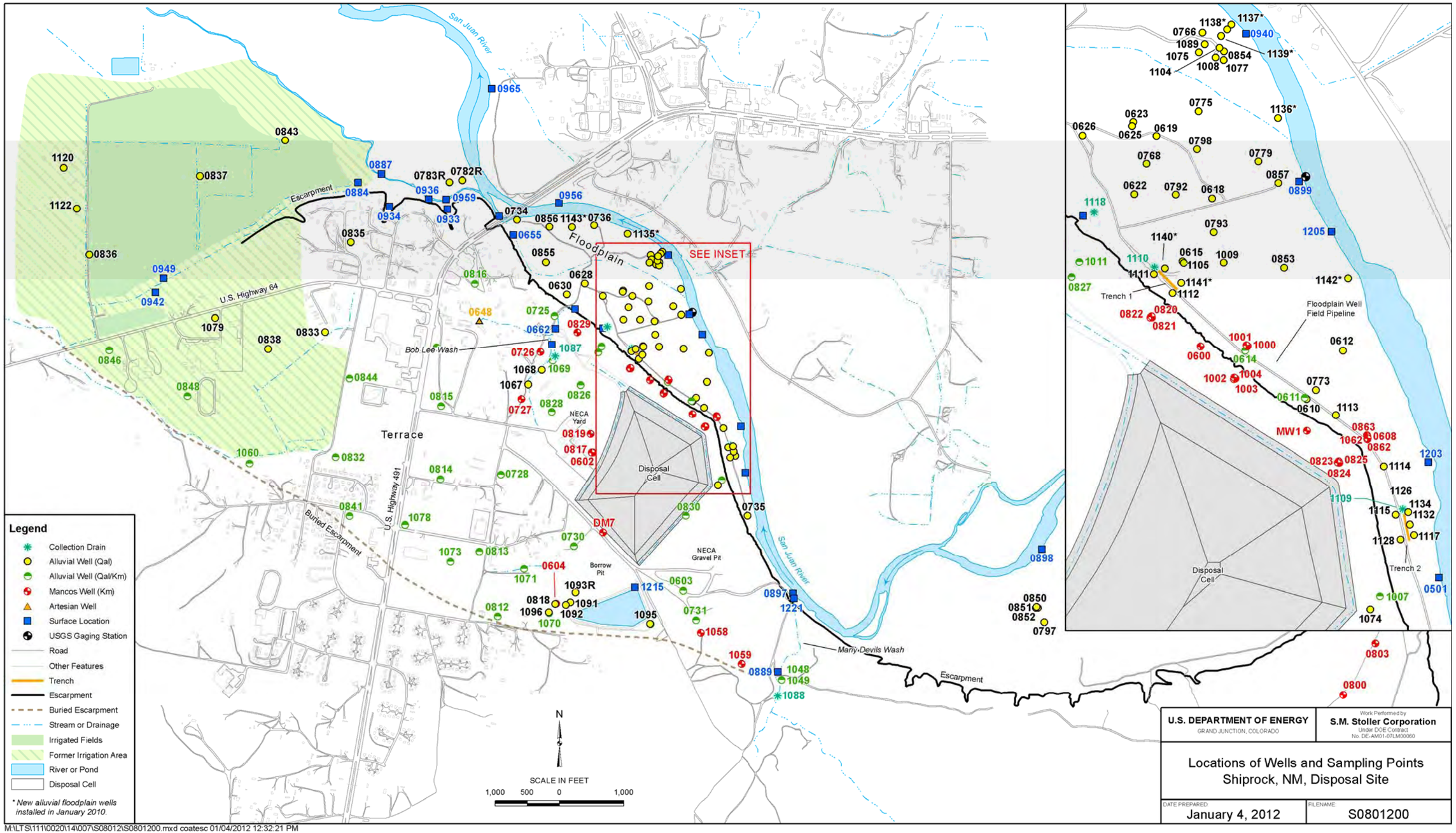

Figure 2. Locations of Wells and Sampling Points at the Shiprock Site

Figure 3. Shiprock Site Surface Water Monitoring Locations

1.1 Remediation System Performance Standards

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

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

Specific performance standards established for the terrace groundwater remediation system in the 2003 baseline 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.

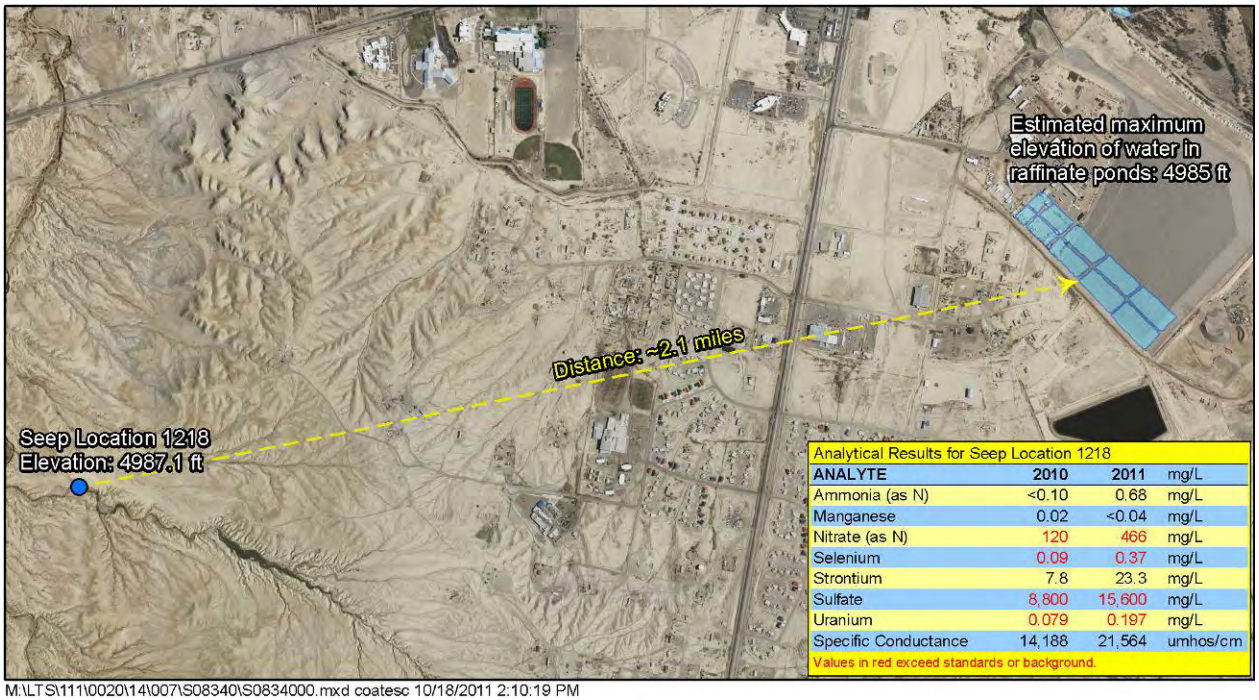
Table 2. Results of 2010–2011 Sampling at Candidate Terrace Background Locations

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.



Analytical Results for Seep Location 1218

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

Values in red exceed standards or background.

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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.

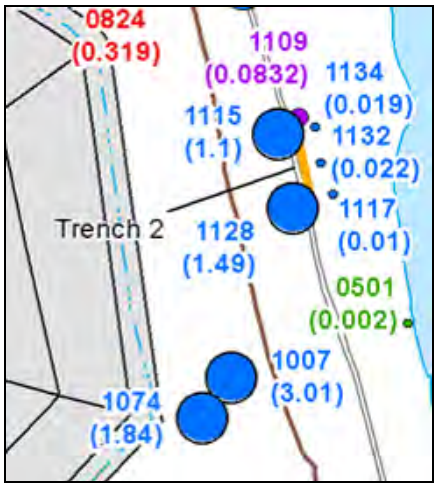
Sulfate

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)

Summary

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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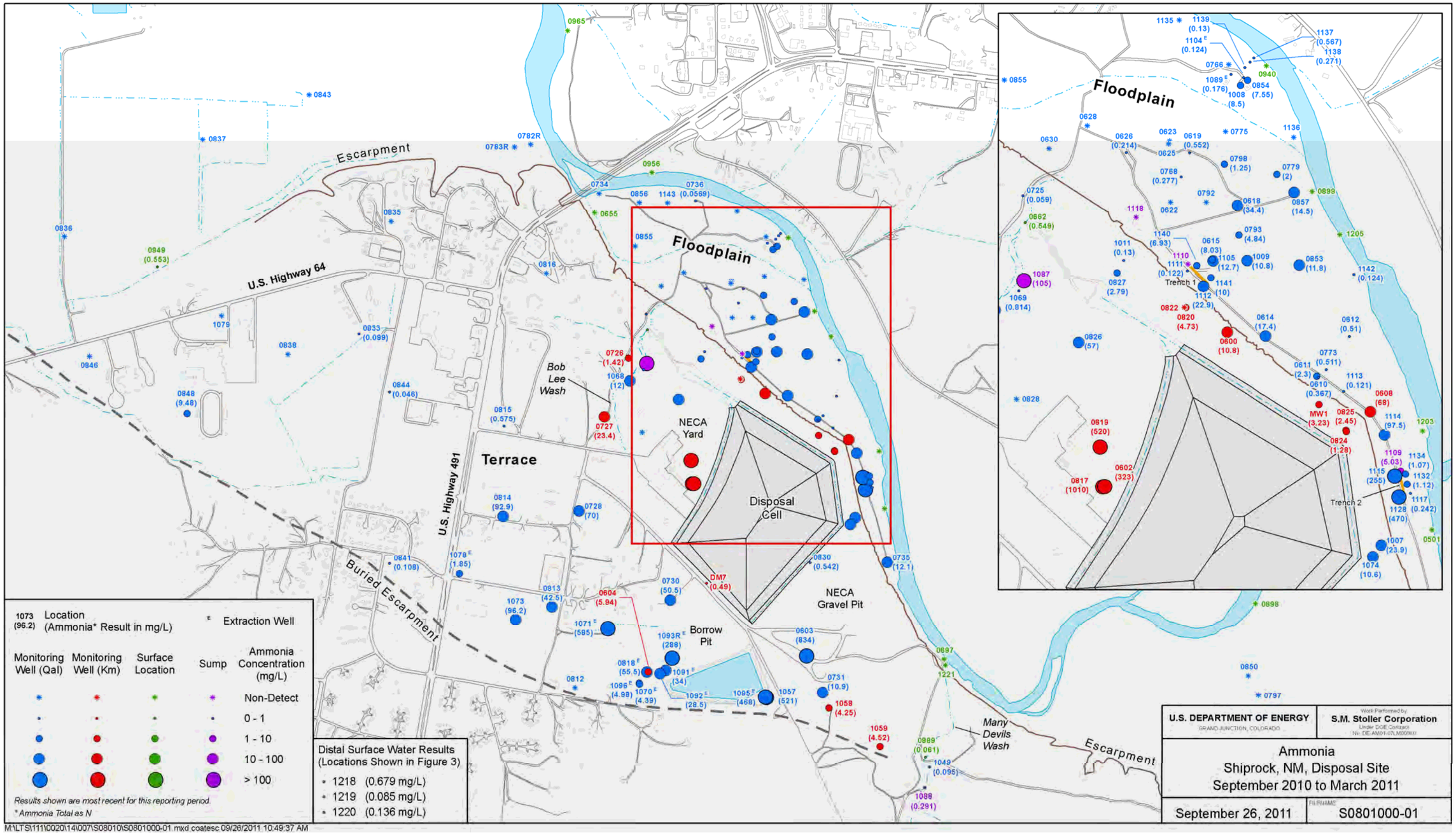

Figure 5a. Concentrations of Ammonia in Groundwater and Surface Water, September 2010–March 2011

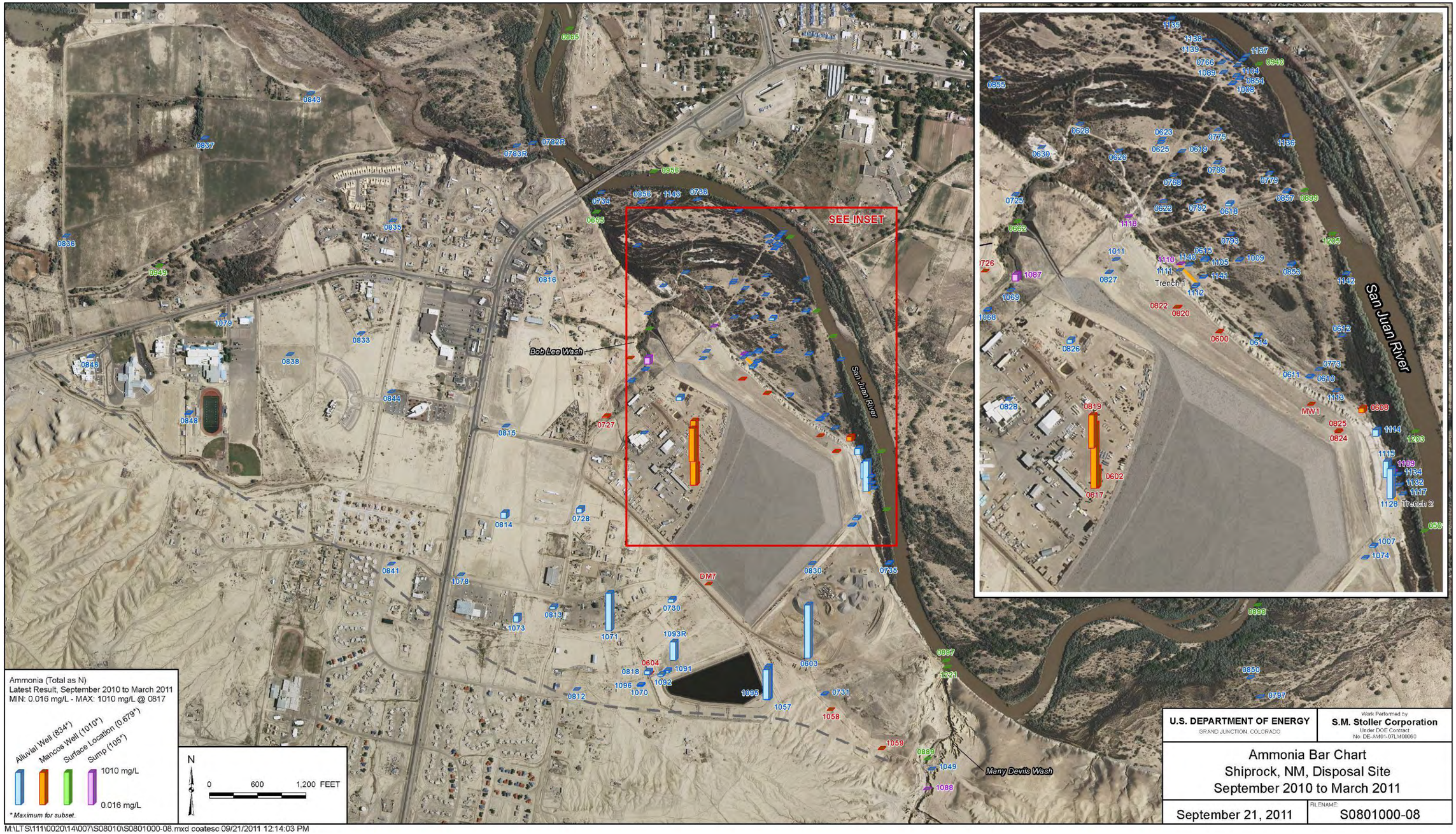

Figure 5b. Relative Distribution of Ammonia in Groundwater and Surface Water, September 2010–March 2011

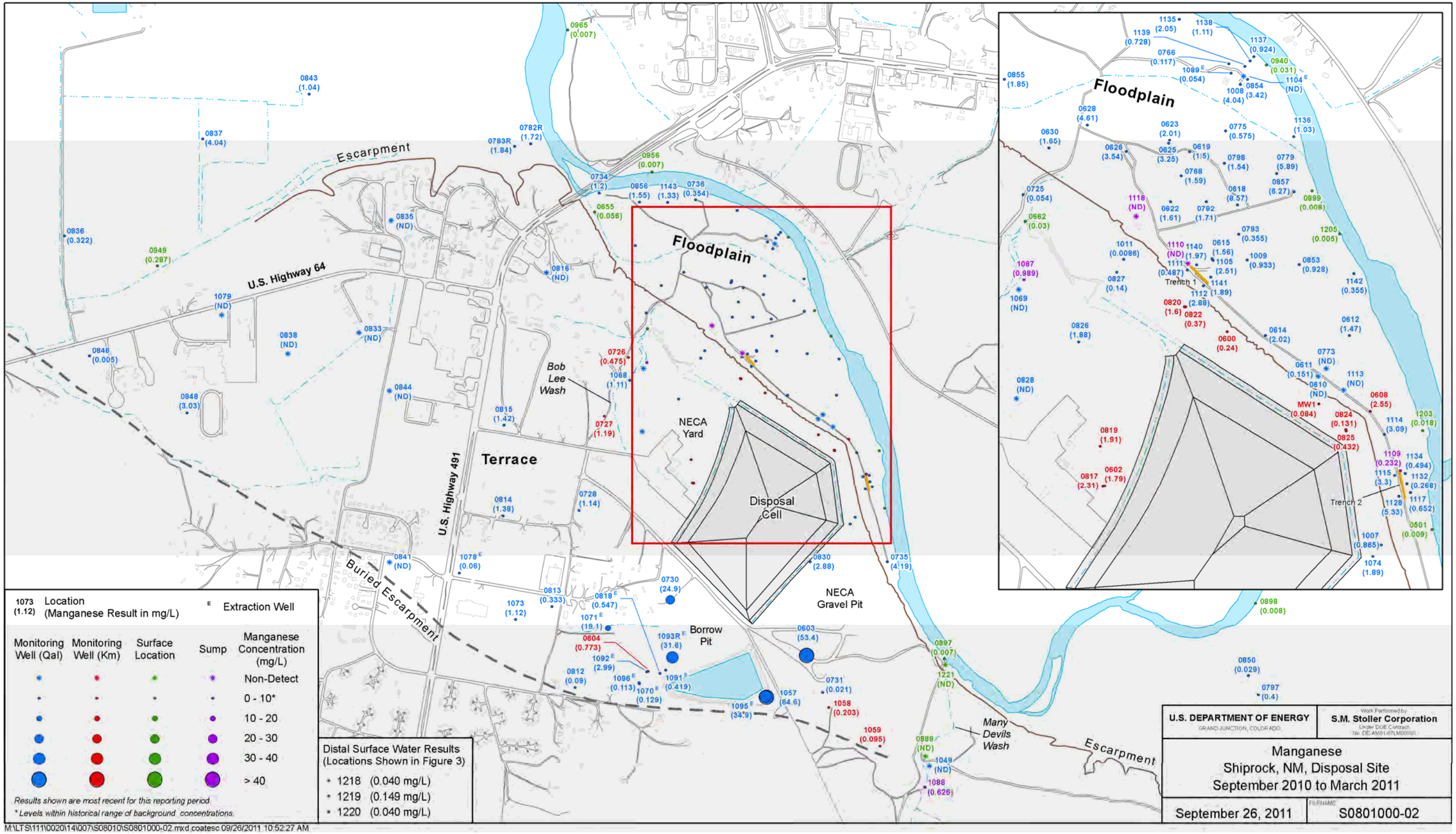

Figure 6a. Manganese Concentrations in Groundwater and Surface Water, September 2010–March 2011

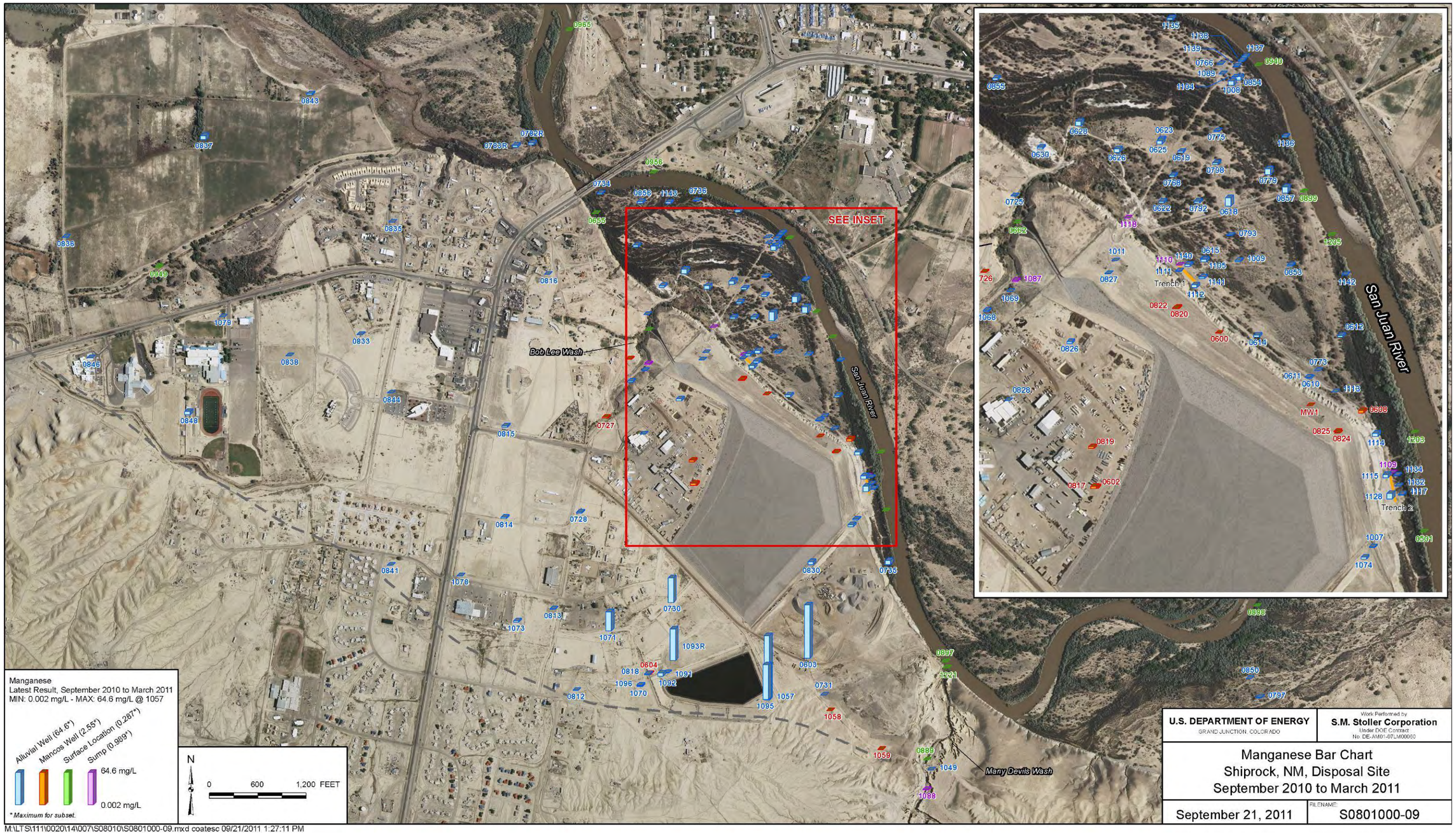

Figure 6b. Relative Distribution of Manganese in Groundwater and Surface Water, September 2010–March 2011

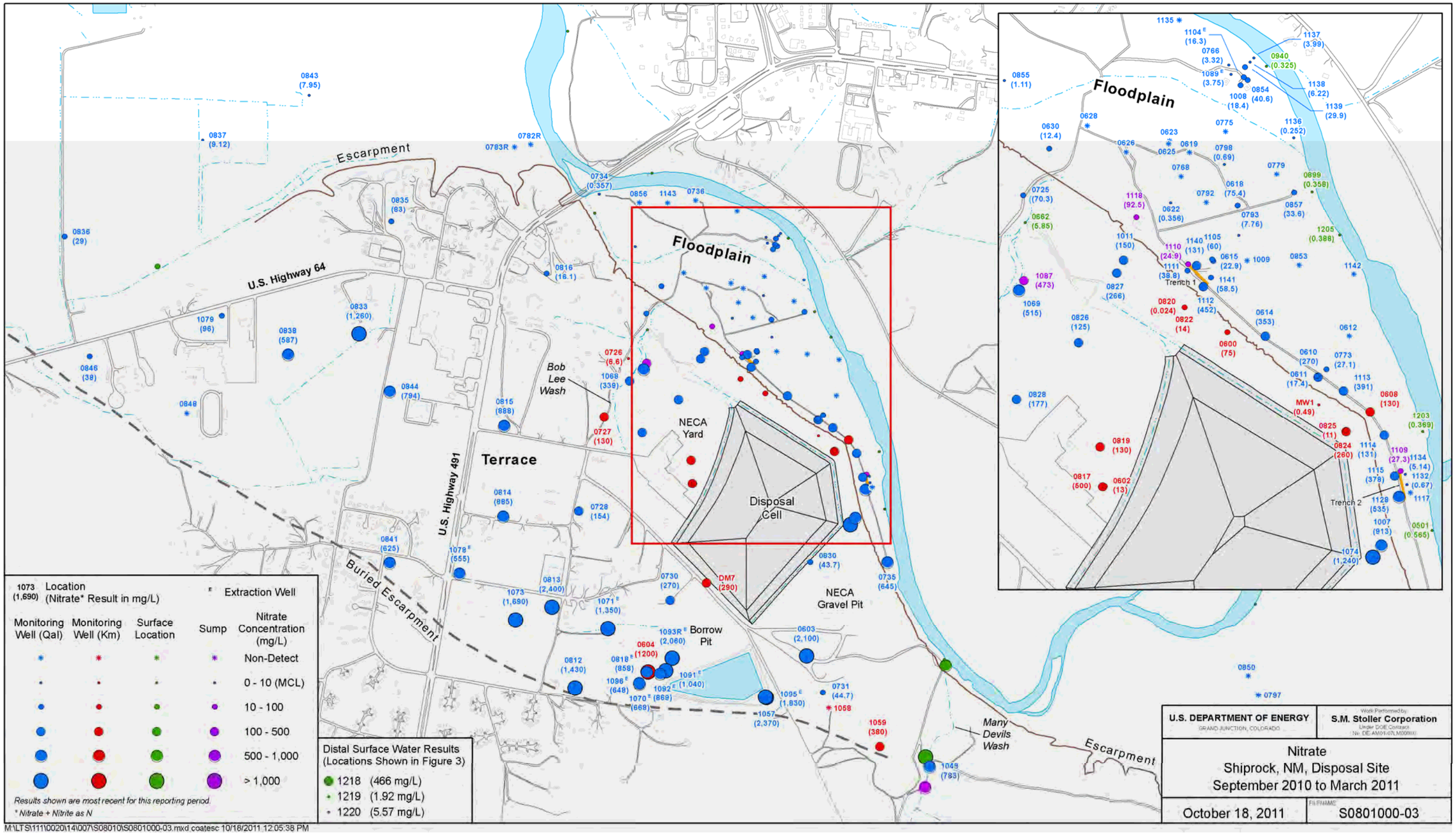

Figure 7a. Nitrate Concentrations in Groundwater and Surface Water, September 2010–March 2011

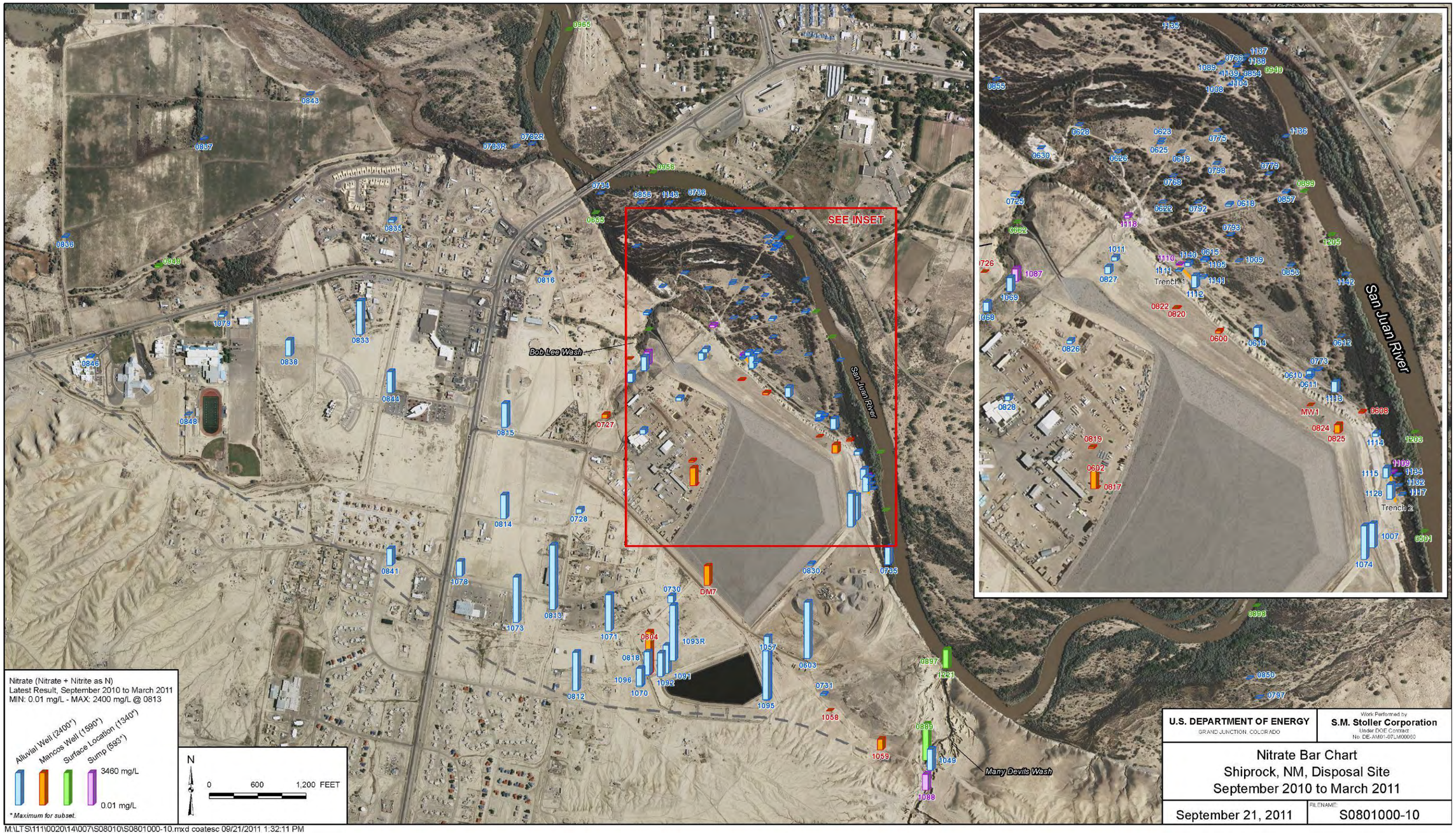

Figure 7b. Relative Distribution of Nitrate in Groundwater and Surface Water, September 2010–March 2011

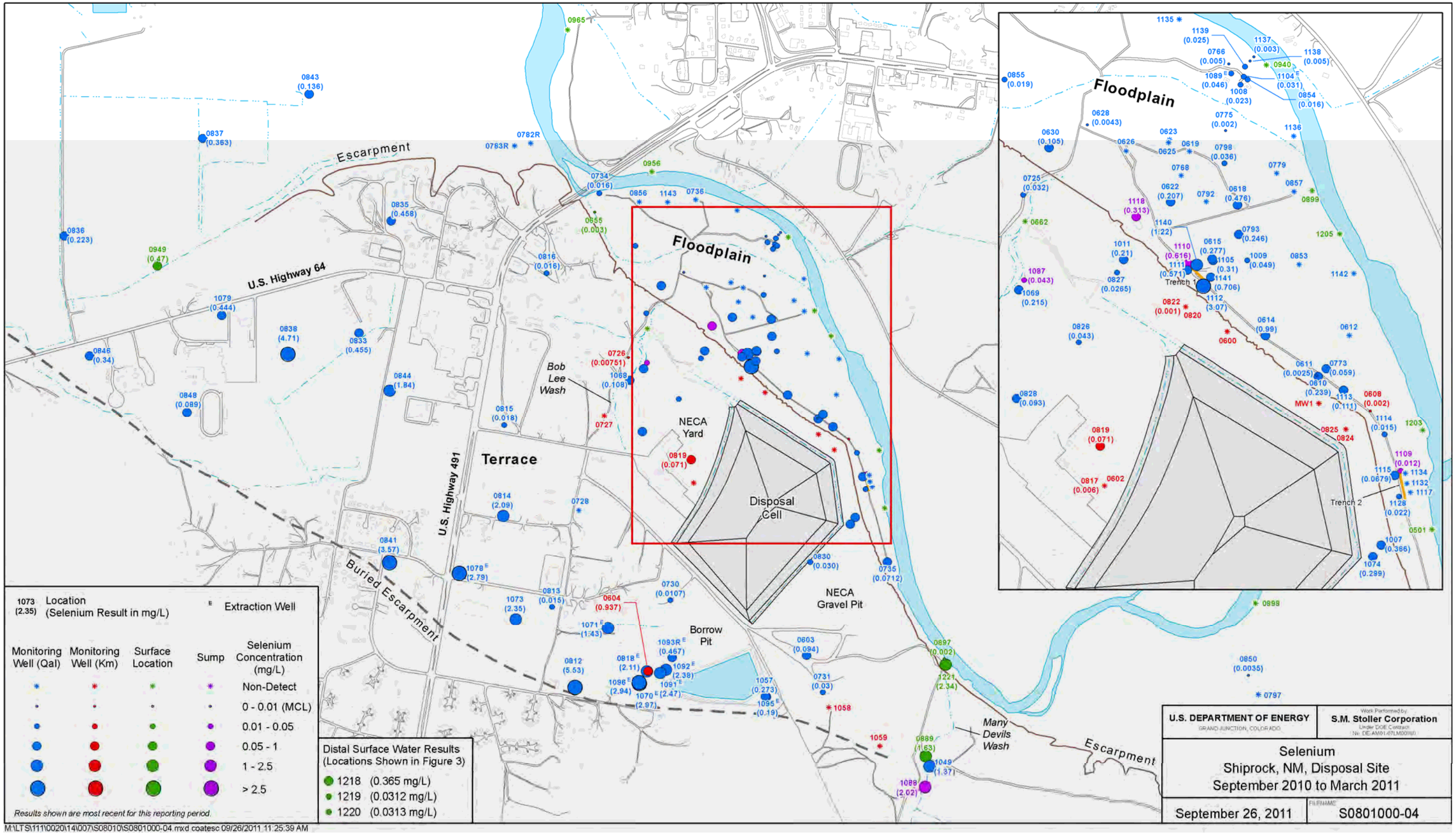

Figure 8a. Selenium Concentrations in Groundwater and Surface Water, September 2010–March 2011

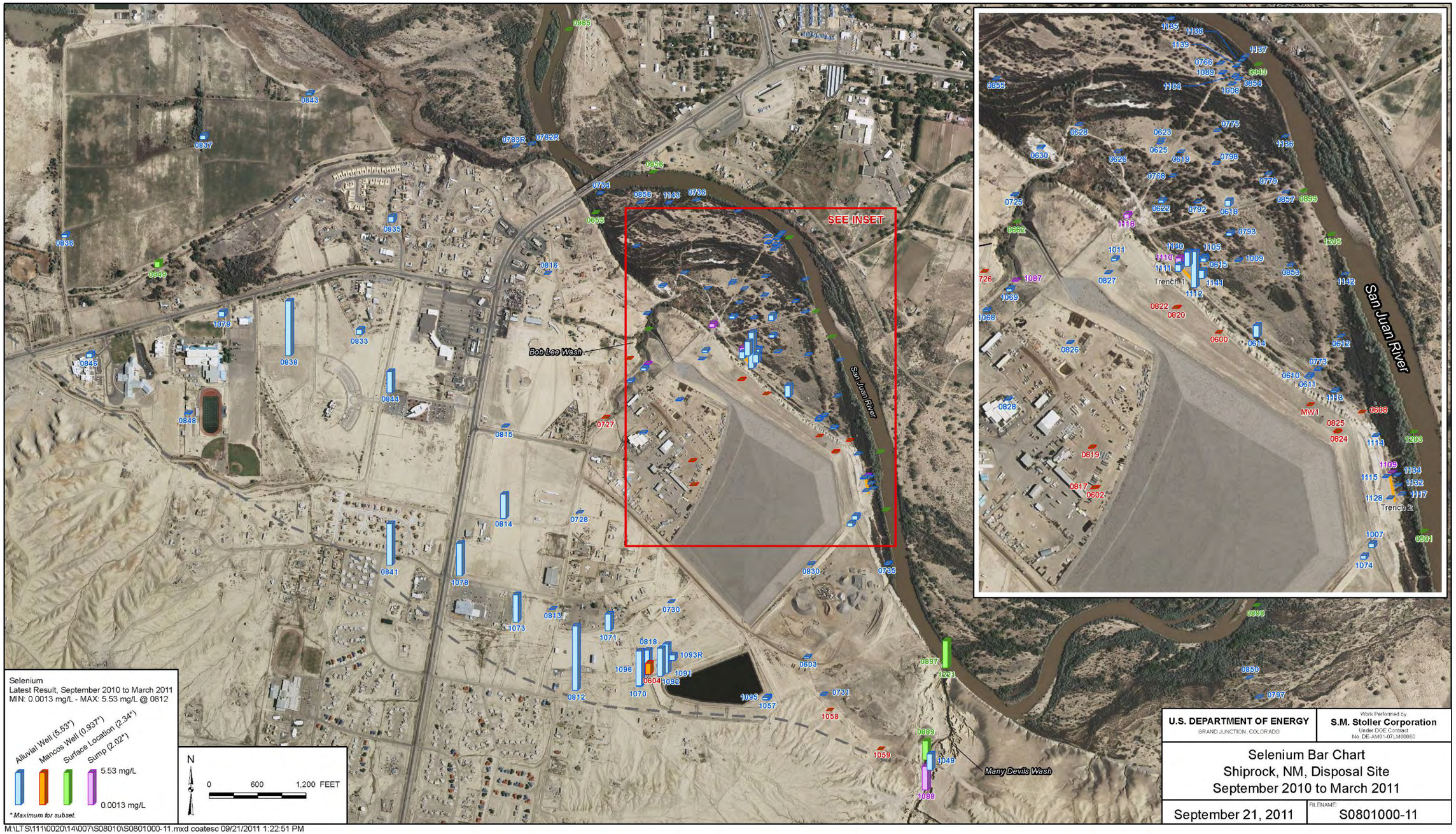

Figure 8b. Relative Distribution of Selenium in Groundwater and Surface Water, September 2010–March 2011

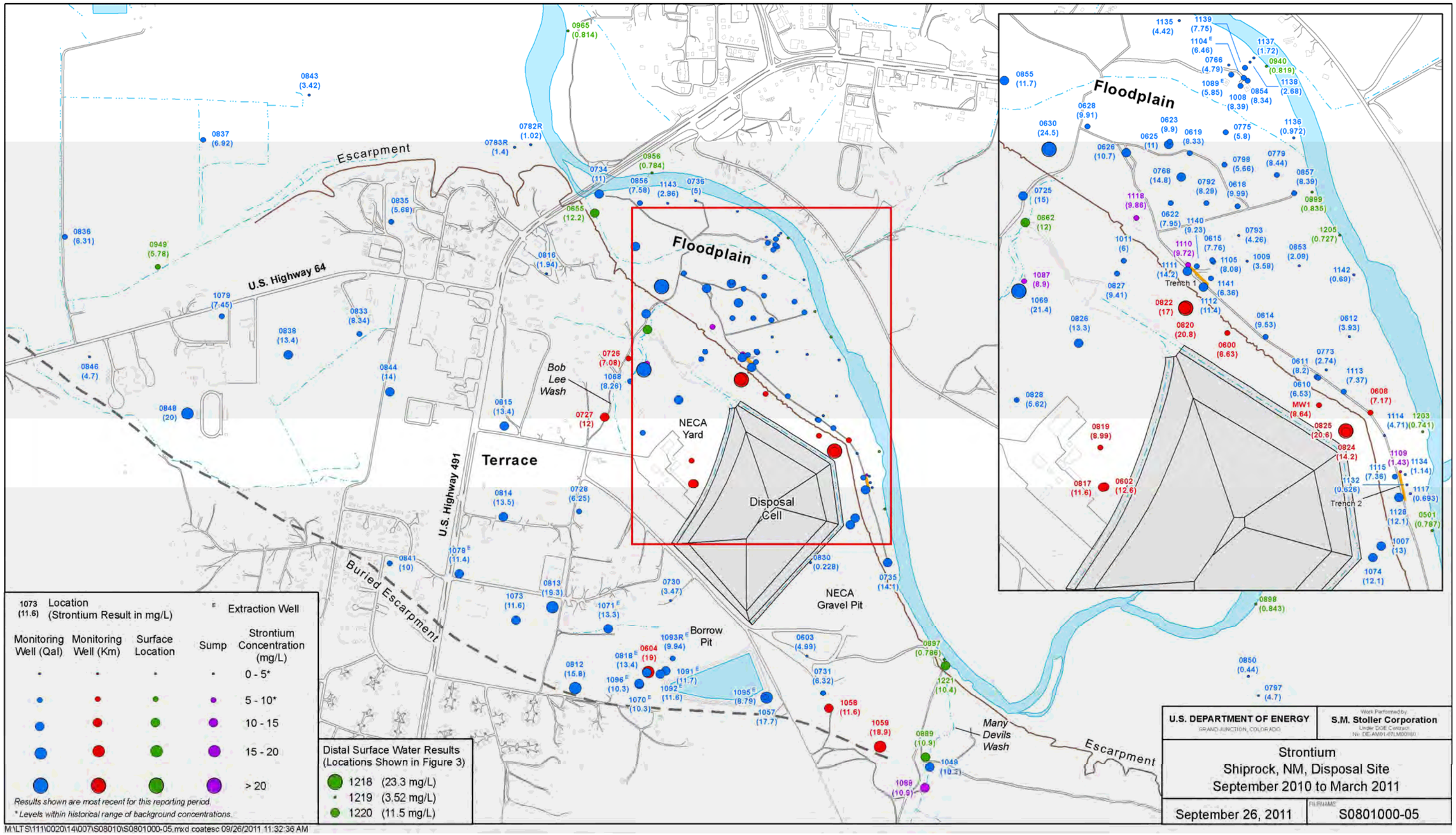

Figure 9a. Strontium Concentrations in Groundwater and Surface Water Samples, September 2010–March 2011

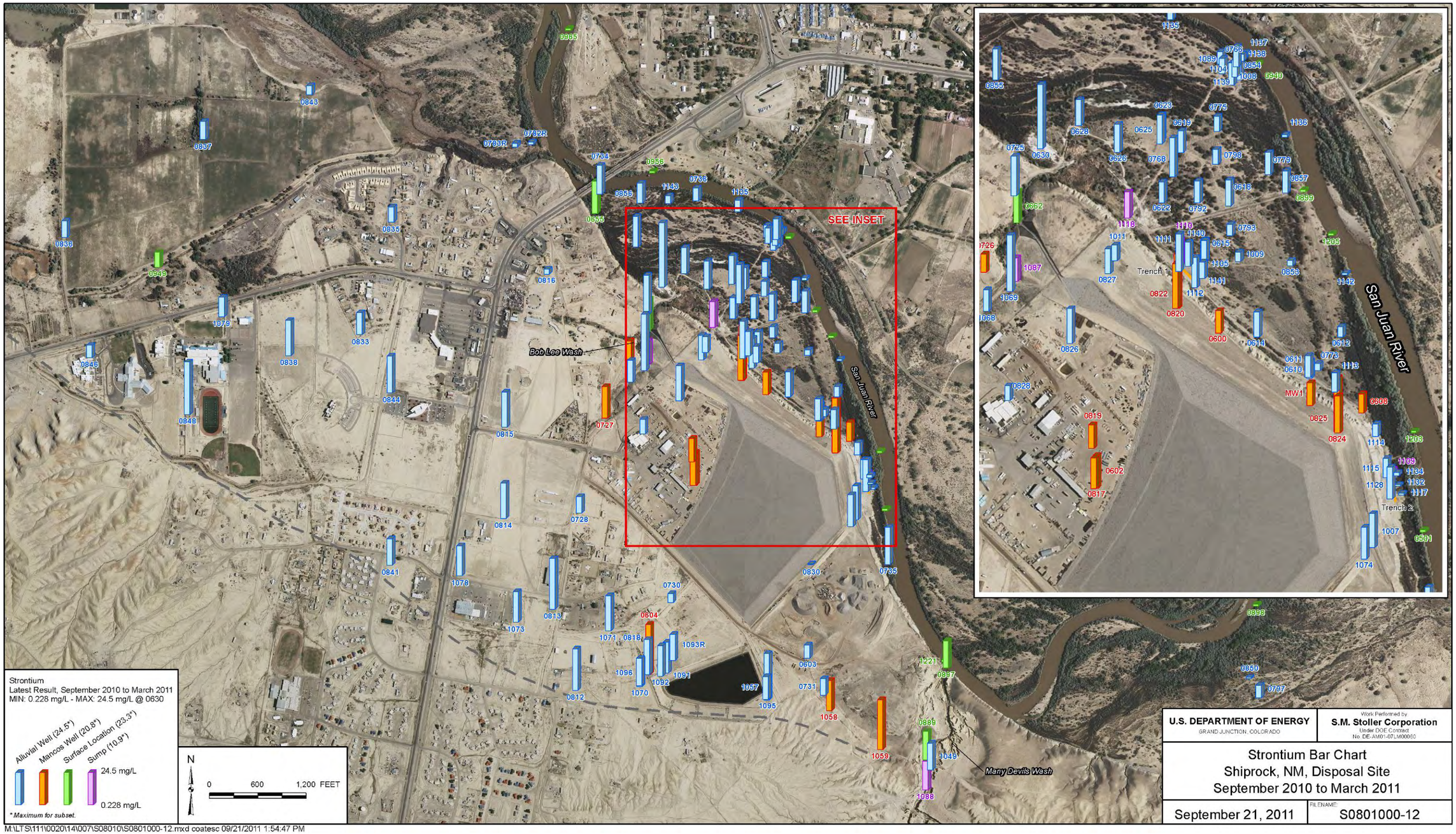

Figure 9b. Relative Distribution of Strontium in Groundwater and Surface Water Samples, September 2010–March 2011

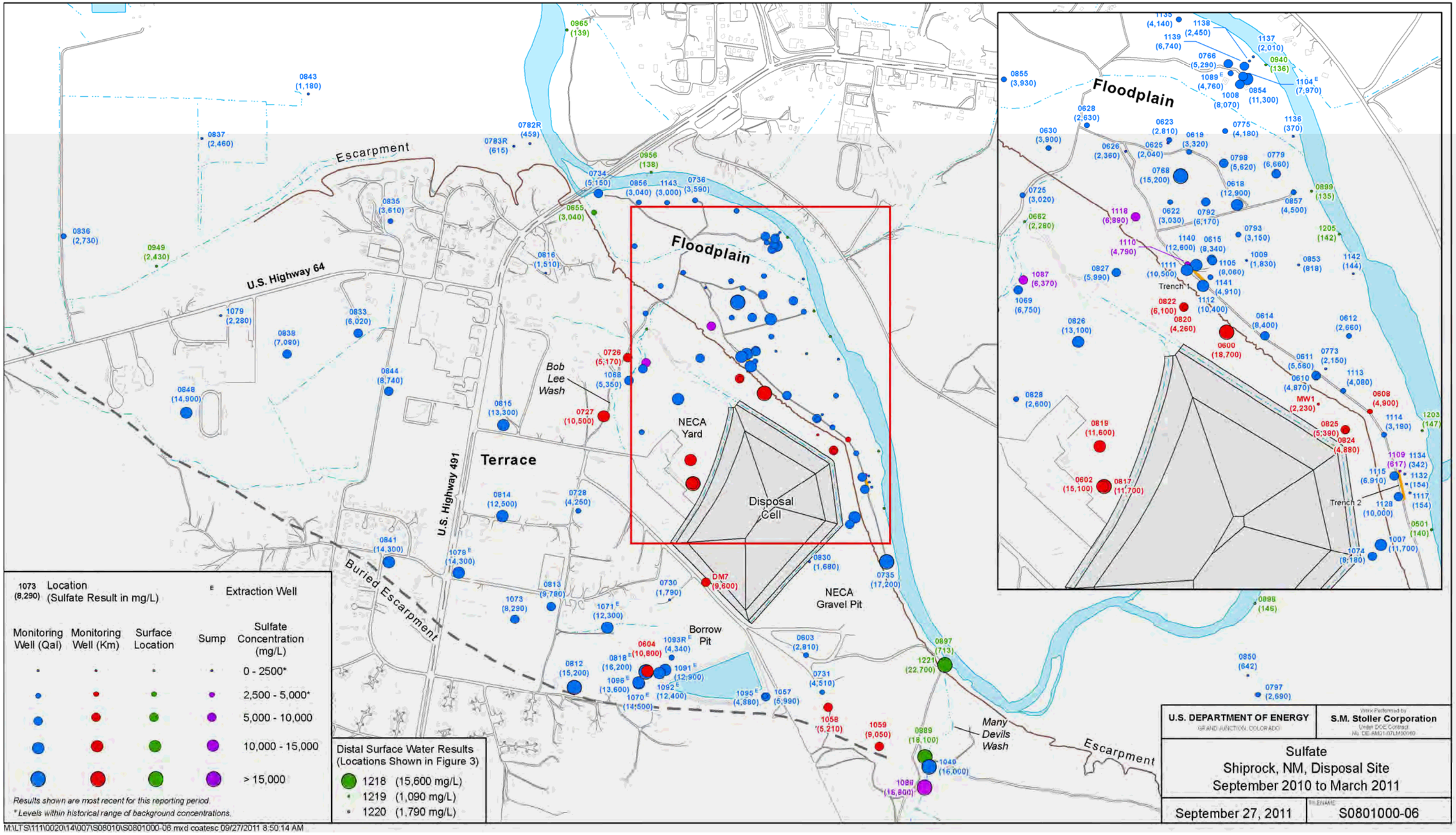

Figure 10a. Sulfate Concentrations in Groundwater and Surface Water Samples, September 2010–March 2011

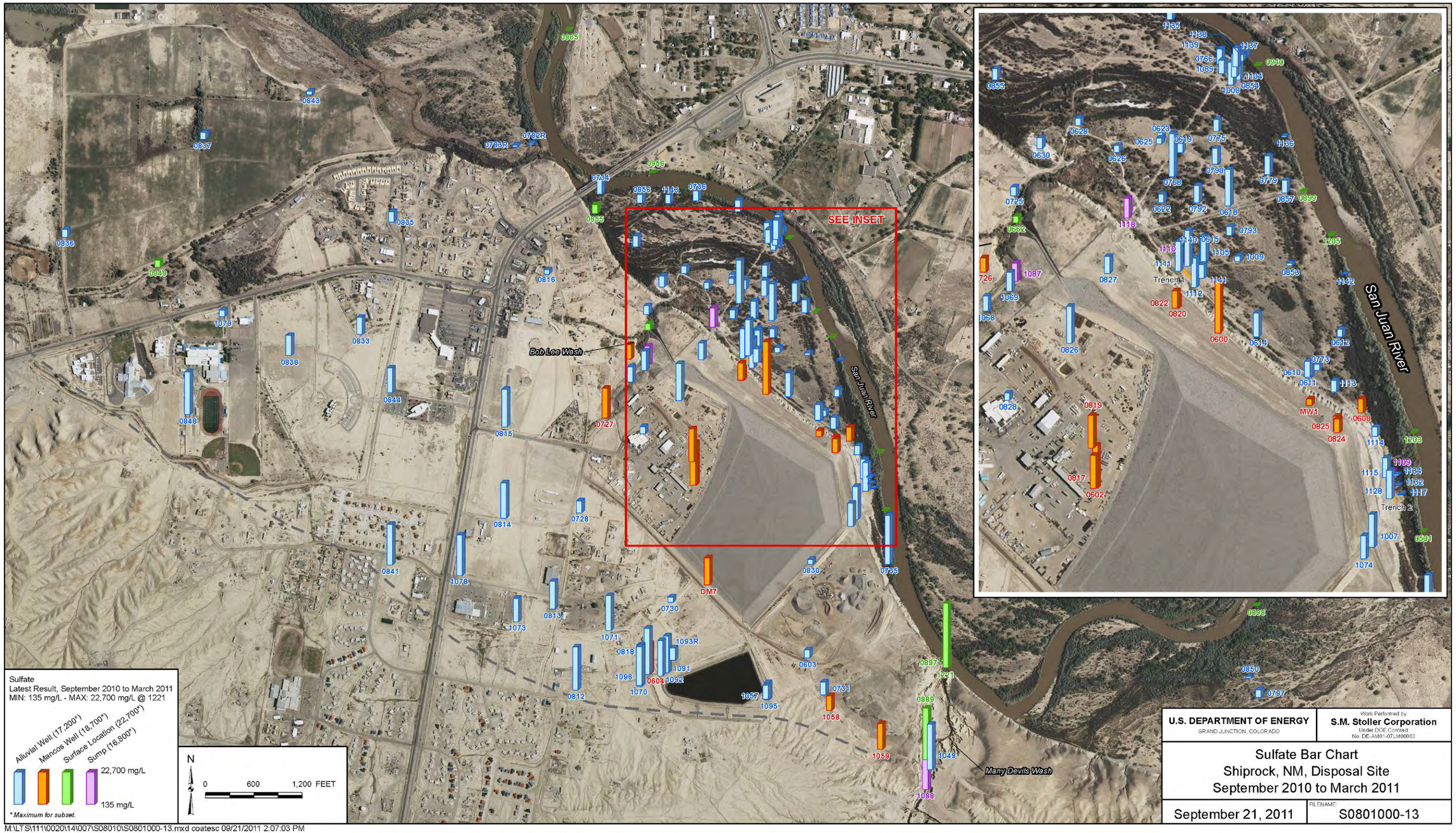

Figure 10b. Relative Distribution of Sulfate in Groundwater and Surface Water Samples, September 2010–March 2011

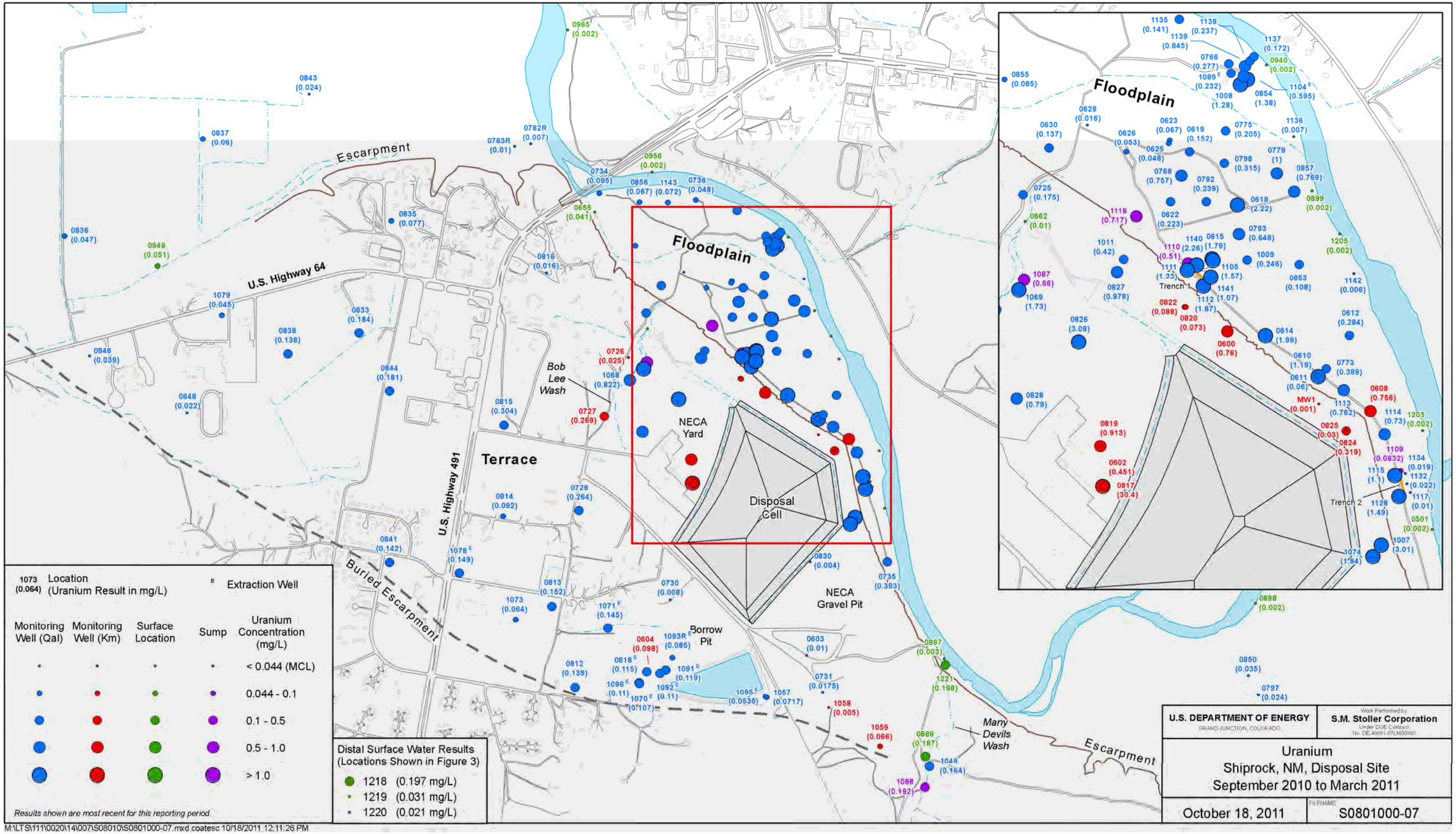

Figure 11a. Uranium Concentrations in Groundwater and Surface Water Samples, September 2010–March 2011

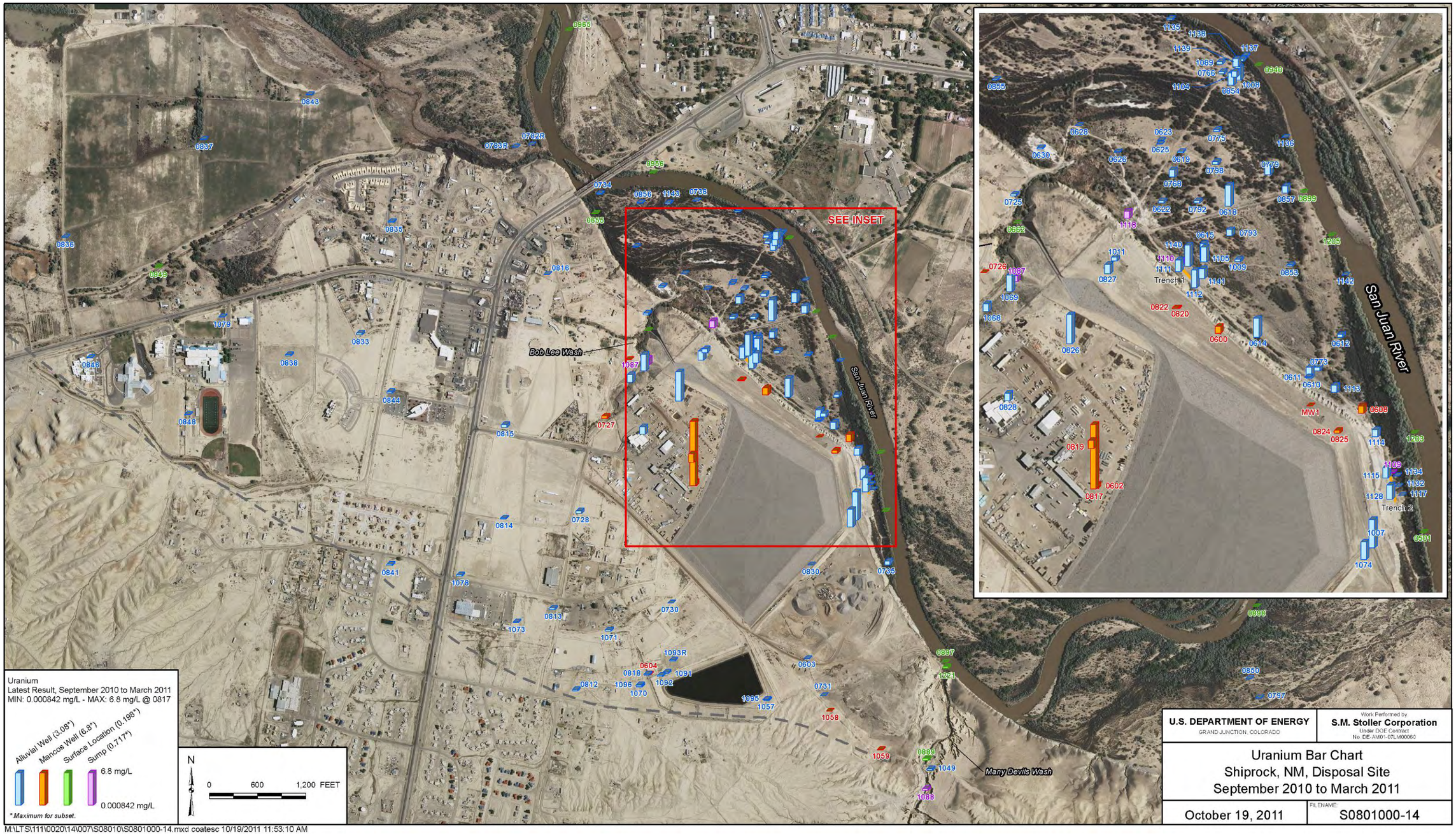

Figure 11b. Relative Distribution of Uranium in Groundwater and Surface Water Samples, September 2010–March 2011

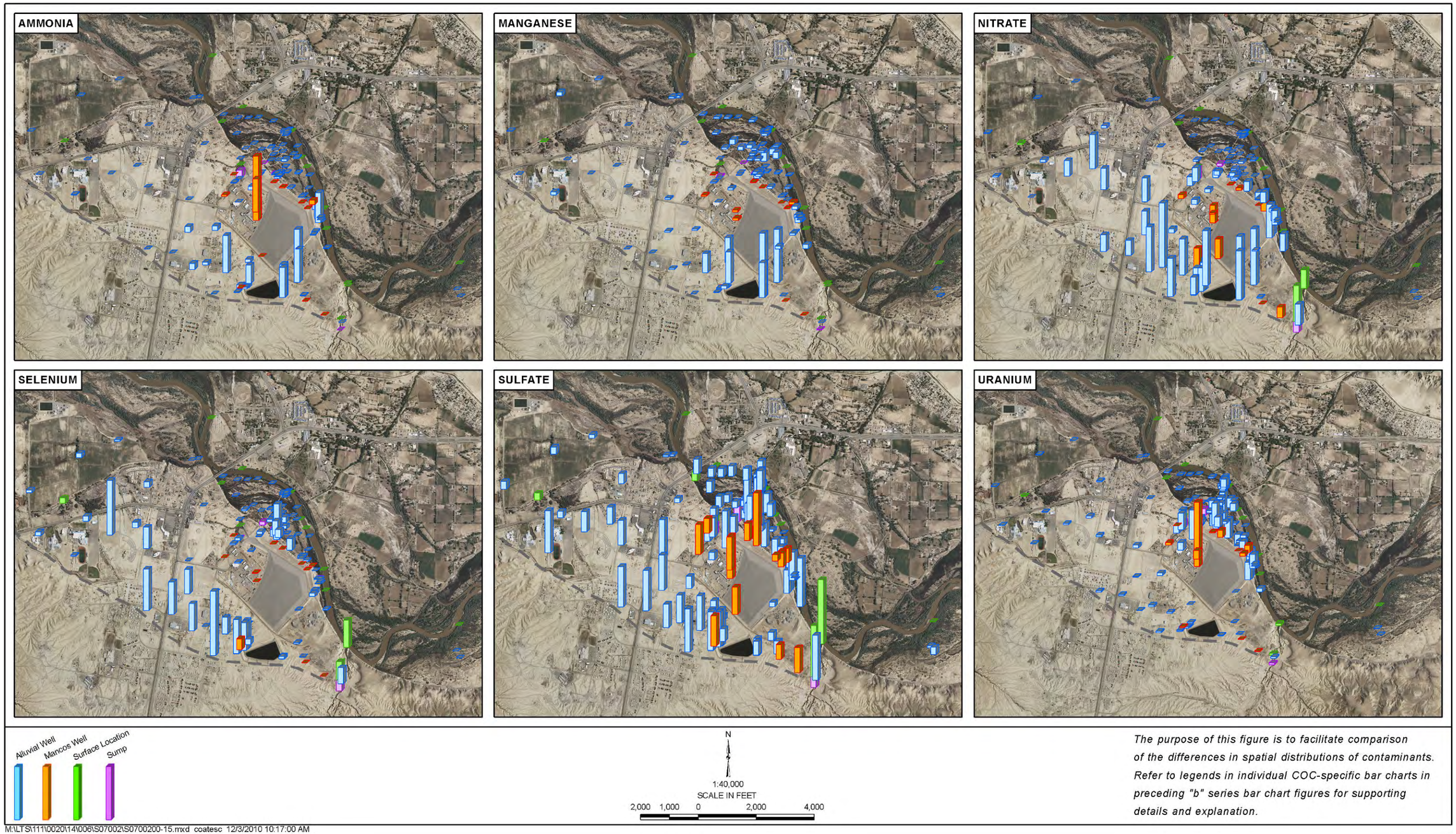

Figure 12. Side-By-Side Comparison of Relative Contaminant Distributions for the Primary COCs

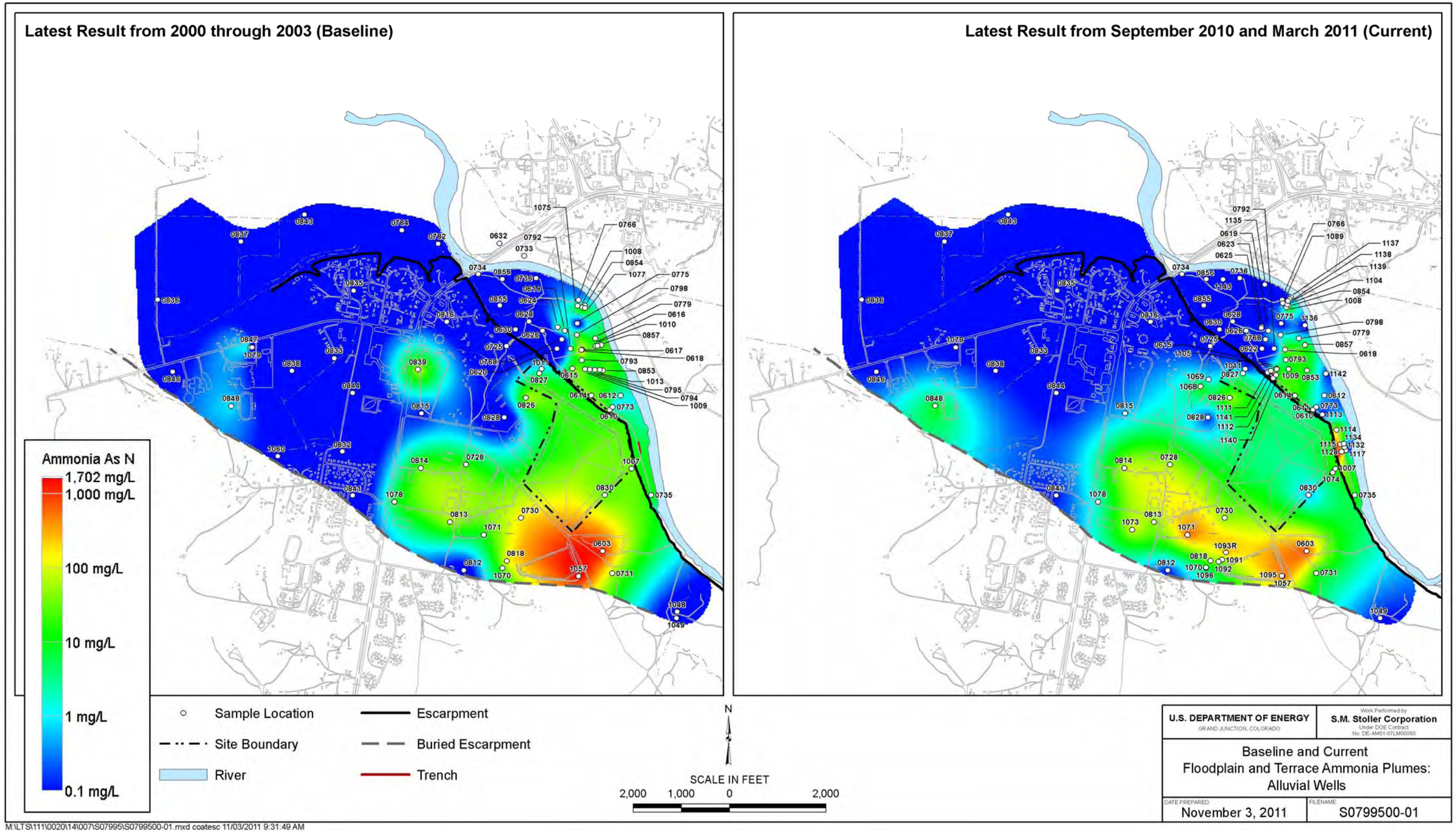

Figure 13. Baseline (2000–2003) and March 2011 Floodplain and Terrace Ammonia Plumes

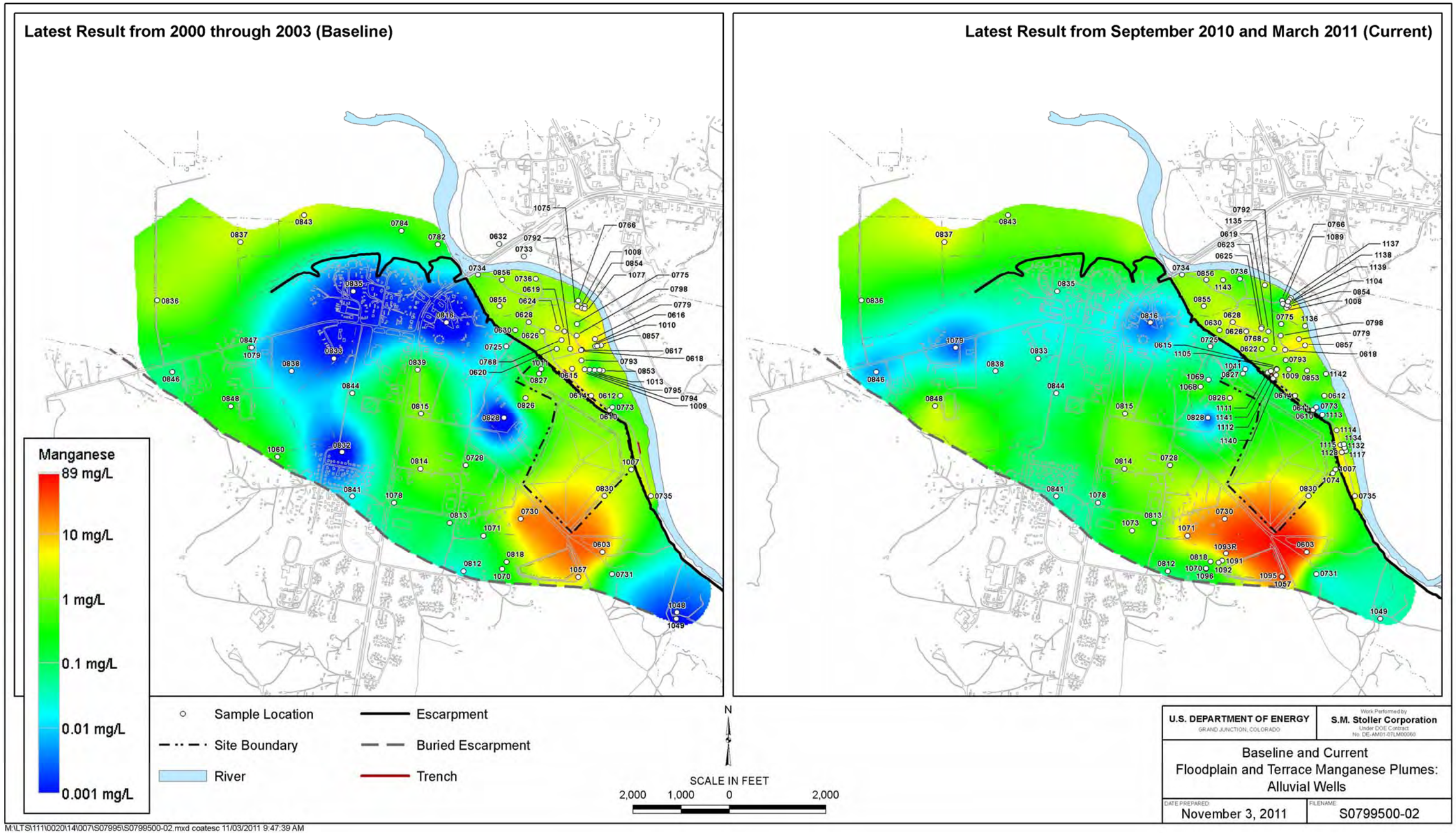

Figure 14. Baseline (2000–2003) and March 2011 Floodplain and Terrace Manganese Plumes

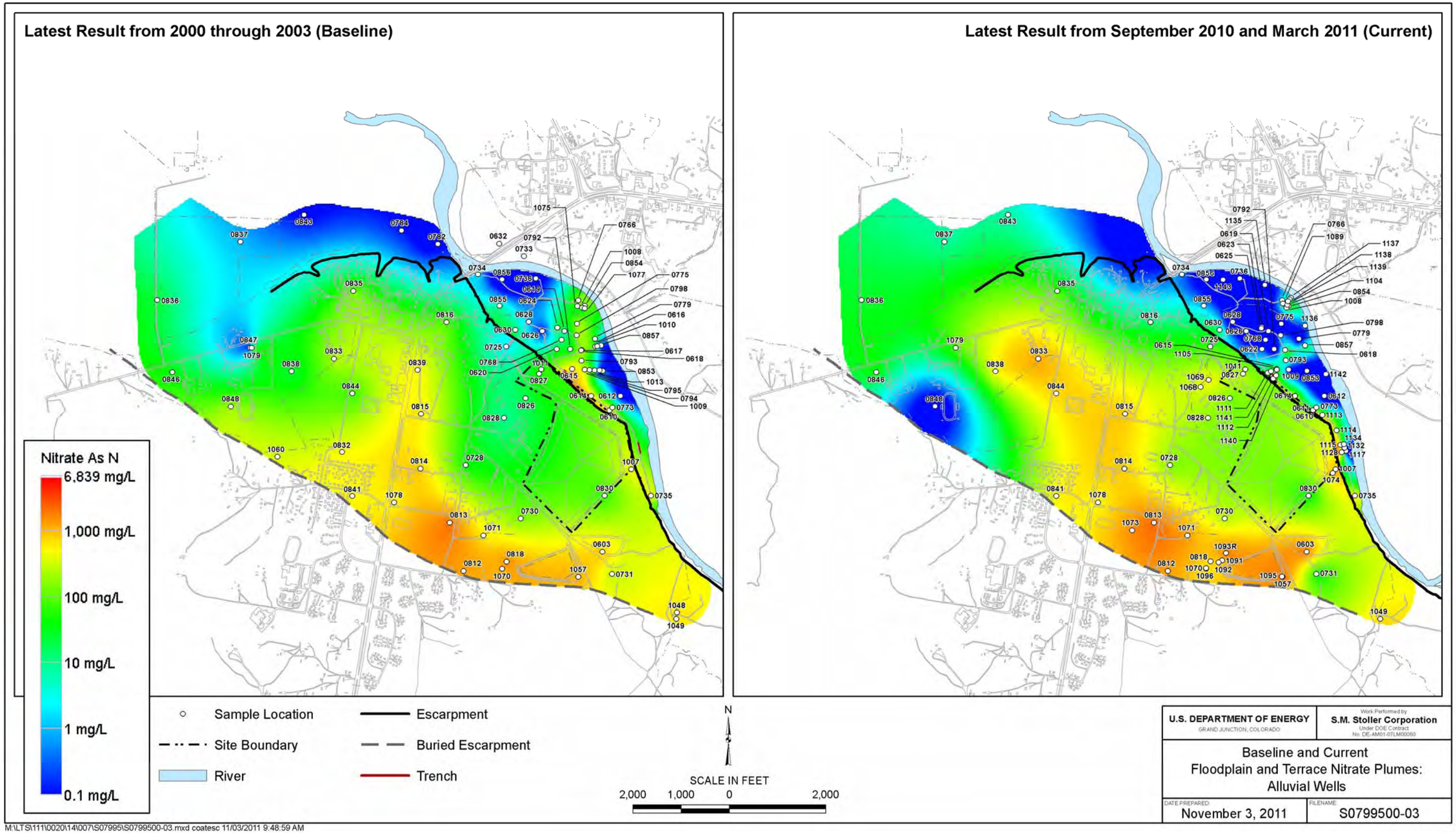

Figure 15. Baseline (2000–2003) and March 2011 Floodplain and Terrace Nitrate Plumes

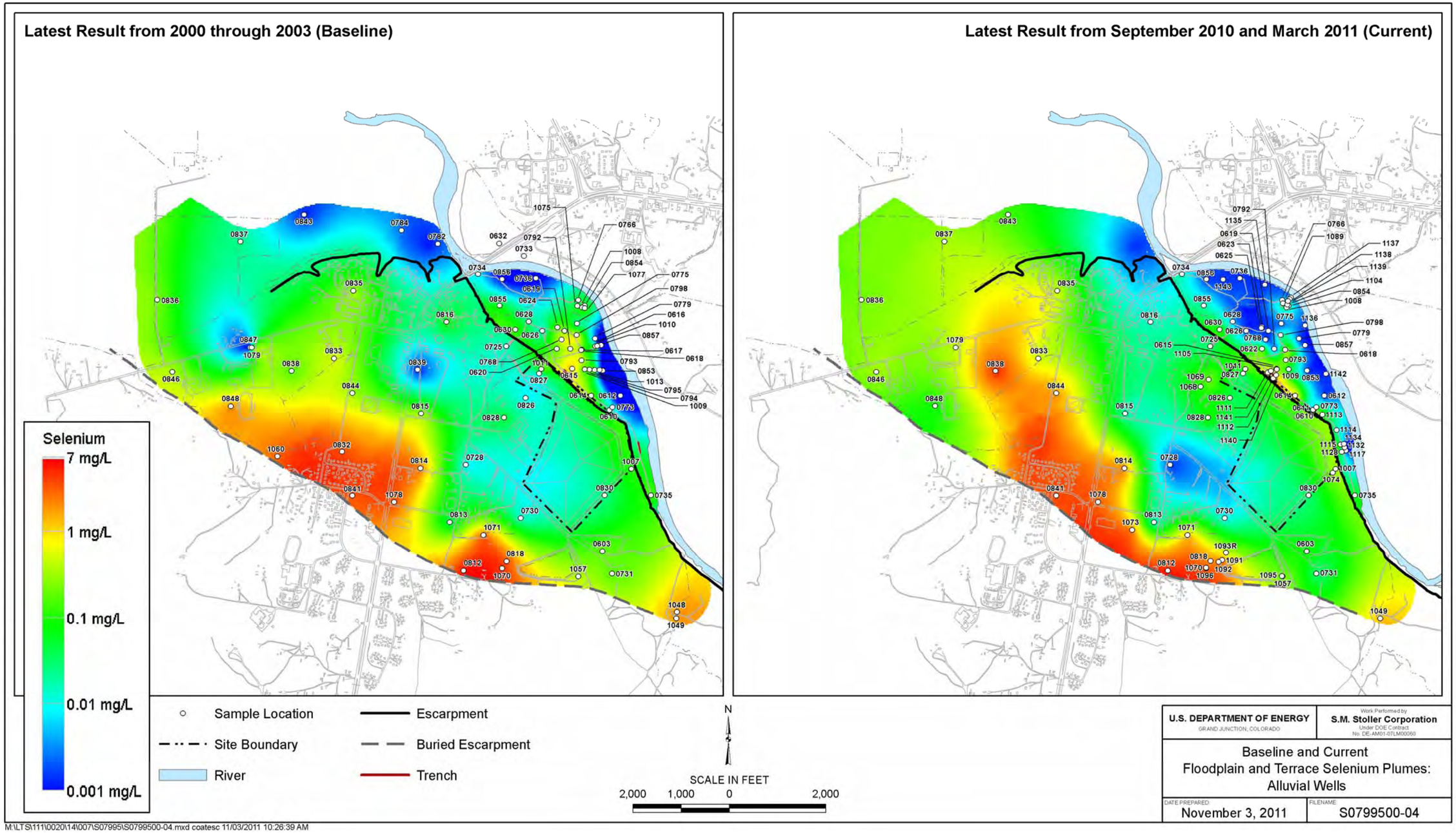

Figure 16. Baseline (2000–2003) and March 2011 Floodplain and Terrace Selenium Plumes

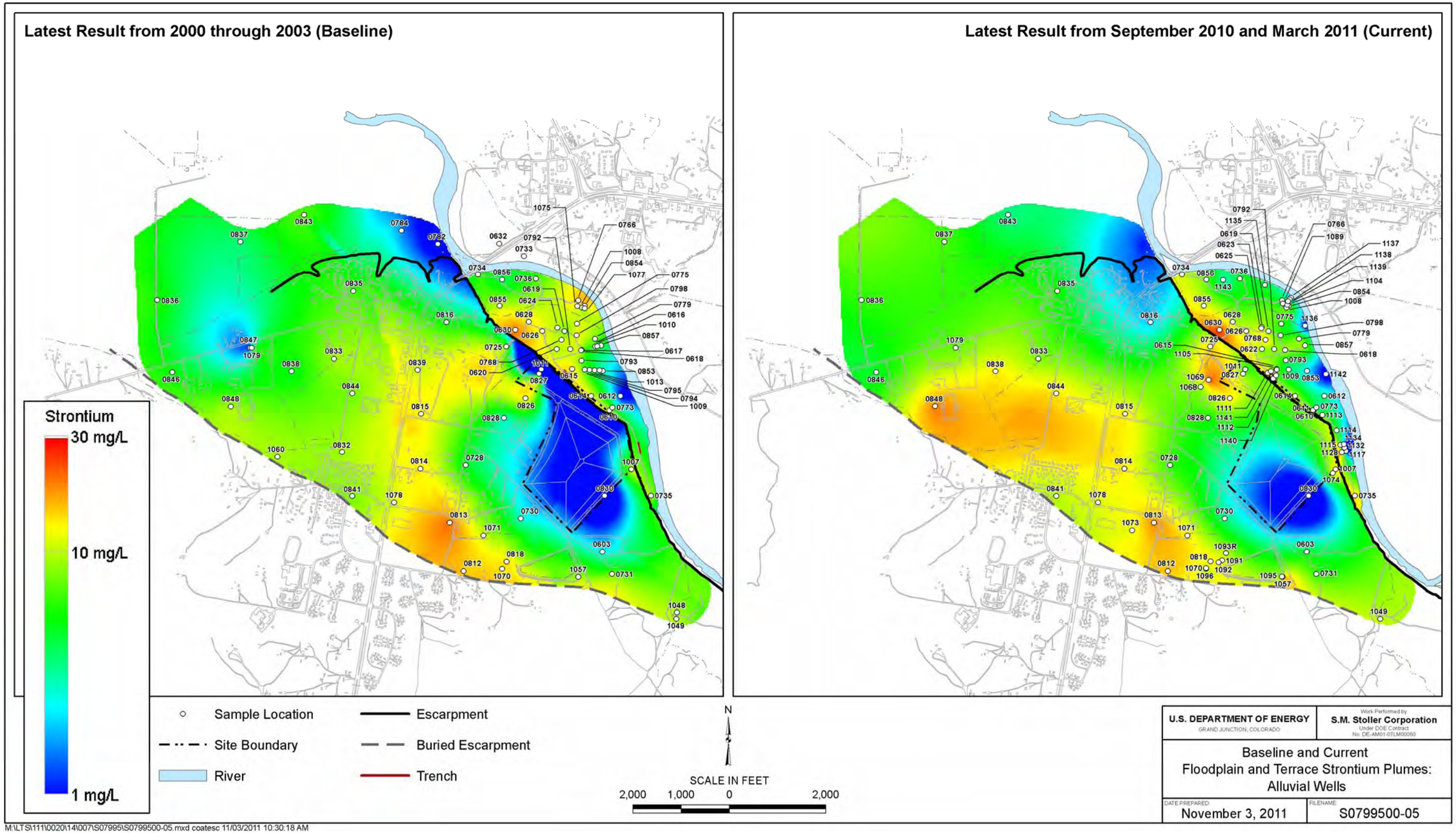

Figure 17. Baseline (2000–2003) and March 2011 Floodplain and Terrace Strontium Plumes

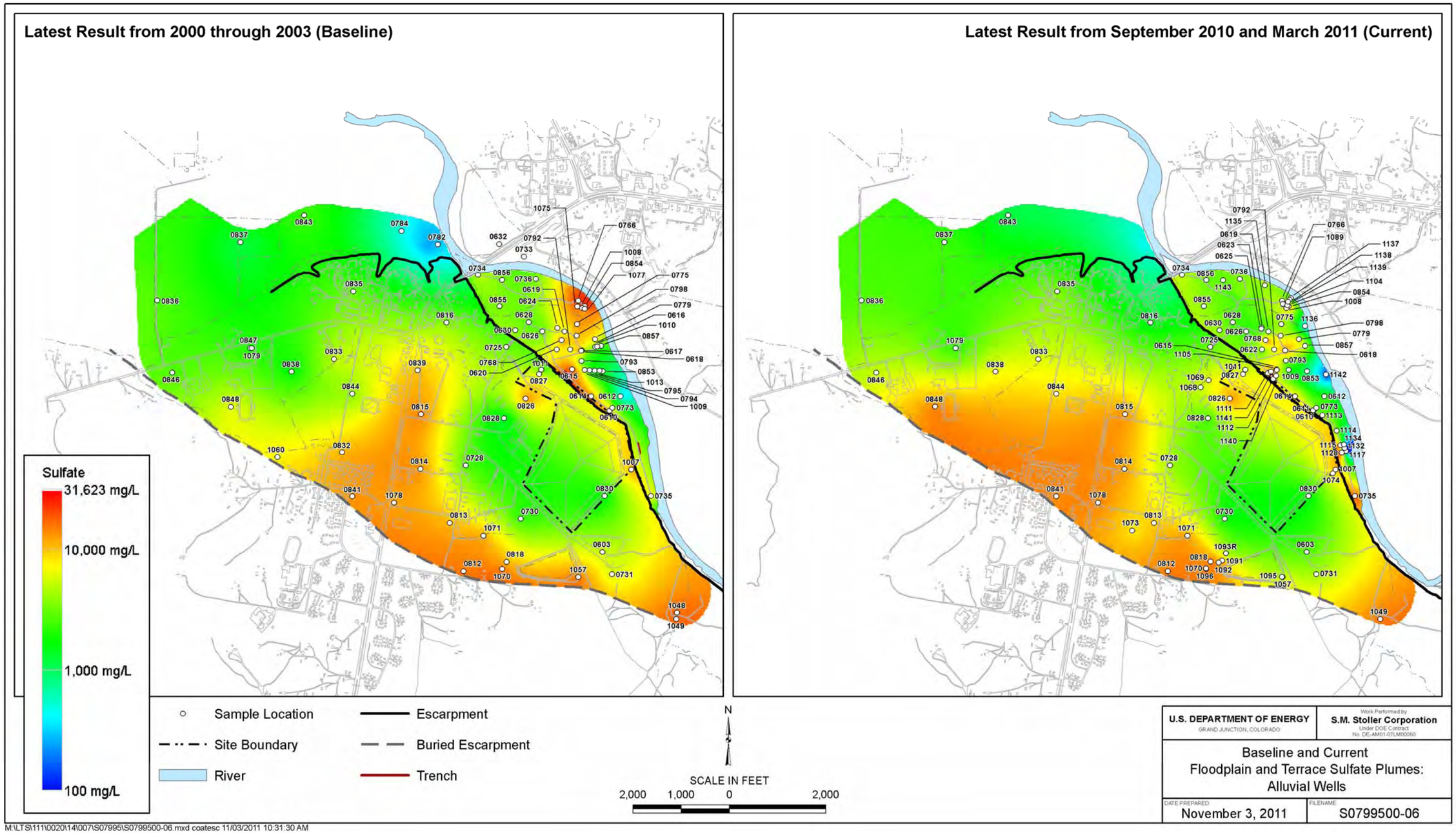

Figure 18. Baseline (2000–2003) and March 2011 Floodplain and Terrace Sulfate Plumes

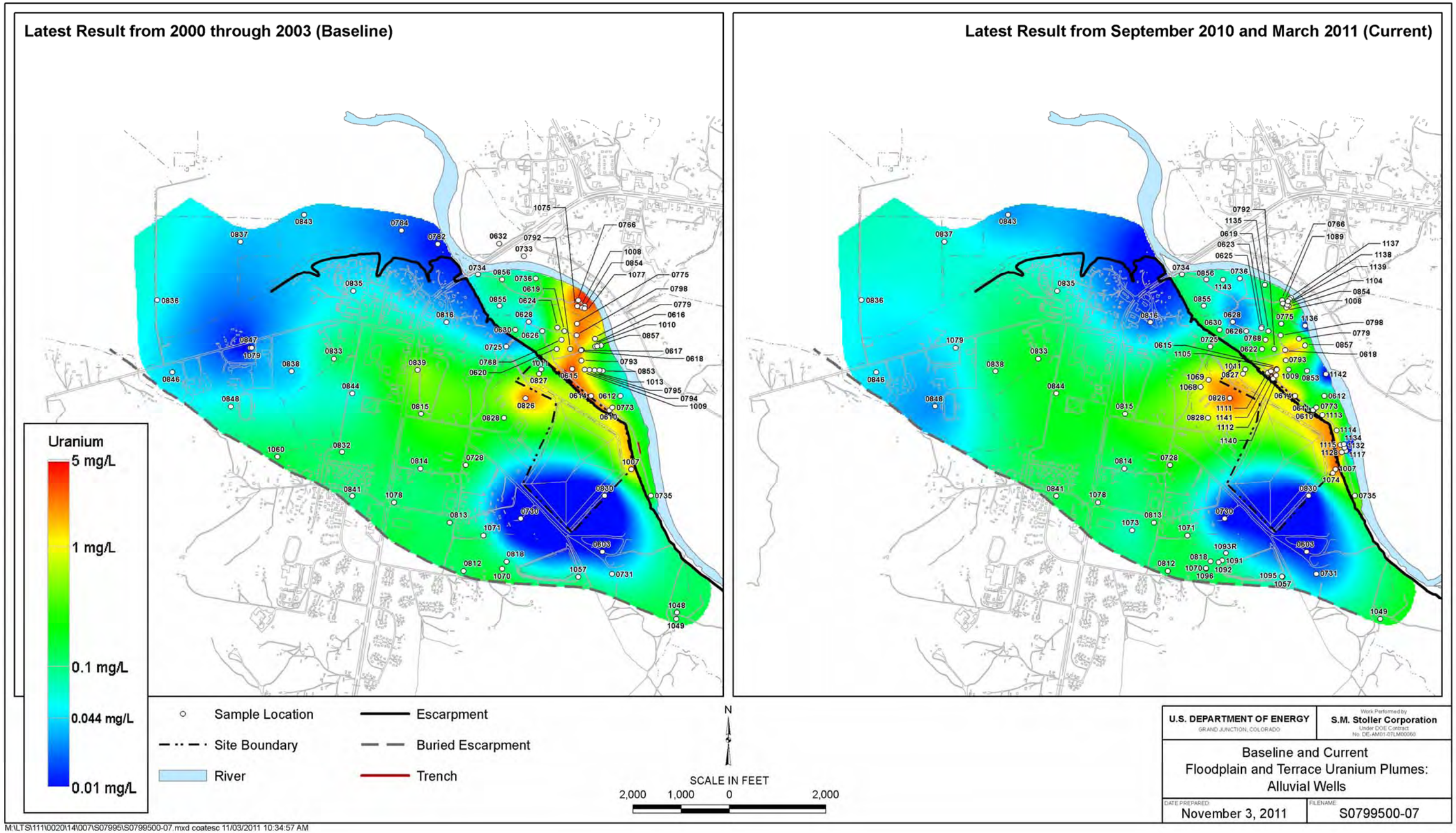

Figure 19. Baseline (2000–2003) and March 2011 Floodplain and Terrace Uranium Plumes