2.0 Subsurface Conditions

This section summarizes hydraulic and water-quality characteristics of the floodplain and terrace groundwater systems for the April 2009 through March 2010 reporting period, approximately 7 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 2010. Analyses of groundwater level trends, groundwater flow directions, and contaminant distributions in the floodplain are discussed 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 recharge and discharge effects of the floodplain aquifer caused by interaction with the San Juan River's flow dynamics and by the seasonal variability of river flow and precipitation. Results of previous three-point analyses showed very little change in groundwater flow directions and demonstrated that the flow system in the floodplain was operating as expected—that is, the flow of groundwater is predominantly toward the extraction wells (DOE 2008). The recent evaluation of the Trench 2 remediation system corroborates this conclusion (DOE 2009b).

Groundwater levels in the floodplain aquifer are manually recorded during routine groundwater sampling events. Figure 2–1, which plots groundwater levels for a representative subset of these wells, indicates that groundwater level fluctuations over the past 7 years have been on the order of 2 ft. As expected, higher groundwater levels generally coincide with elevated flows in the San Juan River. Apart from this expected variation, no trending is apparent (i.e., water levels in floodplain wells have been generally stable over time).

In addition to manual measurements, groundwater elevations in the floodplain aquifer are also measured every 4 hours by pressure transducers connected to dataloggers that are installed in five monitoring wells—0617, 0736, 0854, 0857, and 1008. These data are plotted in Figure 2–2, along with stream flow in the San Juan River, for comparison. Flow data were obtained from U.S. Geological Survey (USGS) Gaging Station 09368000 (San Juan River at Shiprock), located just east of well 0857 (Figure 1–1). The river flow in March 2003 was 649 cubic feet per second (cfs), and the flow in March 2010 was 944 cfs.[8]

The datalogger plots indicate a close correlation between groundwater levels and the San Juan River's flow patterns, indicating relatively rapid recharge and discharge of the aquifer related to change in river flow and surface water levels (Figure 2–2). It is well established that much of the water entering the floodplain aquifer does so via San Juan River losses along the southernmost tip of the aquifer. Thus, it is logical to assume that inflow from the river increases during high

[8] River flow measurements cited above correspond to the days manual water level measurements were taken at the Shiprock site (corresponding to the average of measurements from March 22 through March 26, 2010).

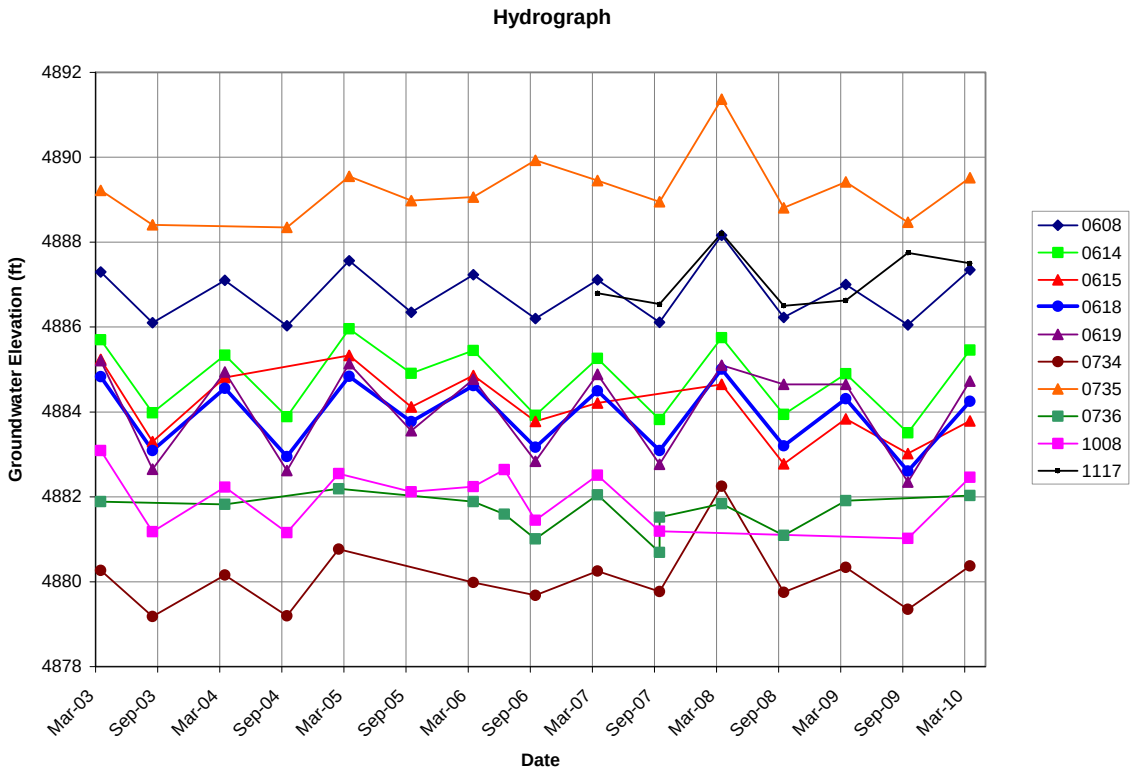

Figure 2–1. Floodplain Groundwater Elevations from Manual Measurements

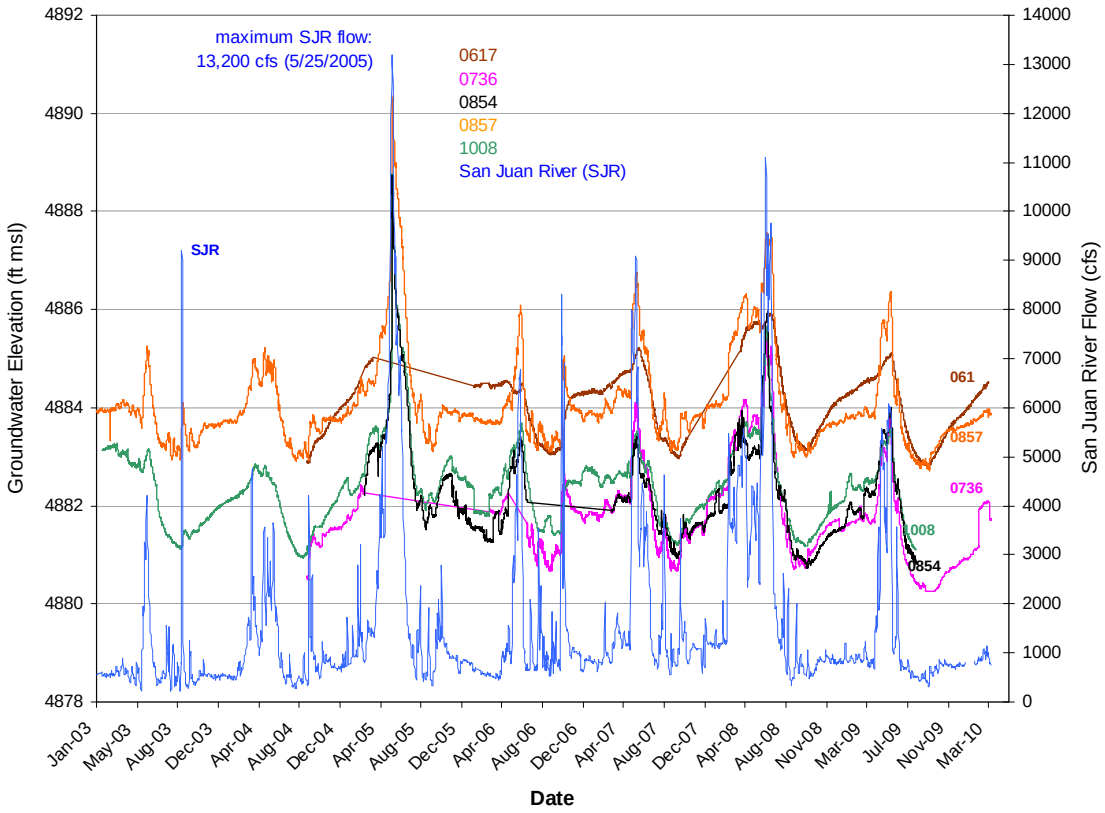

Figure 2–2. Floodplain Groundwater Elevations from Datalogger Measurements

runoff, and that this produces flow directions east of the disposal cell that are in a more northward to northwestward direction than normal. The potential for greater mixing of relatively clean water from the river with contaminated groundwater emanating from the former milling site would likely increase under such circumstances. A more detailed evaluation of floodplain groundwater flow and chemistry is provided in the recent evaluation of the Trench 2 groundwater remediation system (DOE 2009b).

2.1.2 Floodplain Contaminant Distributions and Temporal Trends

Groundwater samples were collected from selected floodplain monitoring wells in September 2009 and March 2010. The locations of these wells are shown in Figure 1–2, which also identifies the zone in which the wells were completed, alluvium (Qal) or Mancos Shale (Km). Variations in constituent concentrations over time from March 2003 (baseline) through March 2010 are plotted in Figures 2–3 through 2–9 for a representative subset of these wells. These wells, marked in Figure 1–2 with a "1" superscript, are:

- 0608—Km, near the disposal cell at the base of the escarpment;
- 0614—Qal/Km, base of escarpment between 0608 and Trench 1;
- 0615—Qal, Trench 1 area;
- 0618—Qal, northeast of Trench 1;
- 0619—Qal, northwest of well 0618;
- 0734—Qal, western floodplain near highway (farthest downgradient of well subset);
- 0735—Qal, upgradient of disposal cell, adjacent to river (farthest upgradient of subset);
- 0736—Qal, western floodplain;
- 1008—Qal, monitoring discontinued in 2006 and replaced by well 1104; and
- 1104—Qal, well 1089 area.

In the time–trend plots, trend lines are shown only for those wells exhibiting apparent trends. As shown in Figure 1–2 (see well locations with a "2" superscript) and summarized in Appendix A (Table A–1), nine new Geoprobe wells were installed in the floodplain during this reporting period. 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. Also, two new alluvial wells (1140 and 1141) were installed about 50 ft from the east side of Trench 1 (nearest the river).

Previous annual reports (e.g., see DOE 2008) did not evaluate time trends for Trench 2 wells because there weren't sufficient data (in terms of number of samples) to draw any definitive conclusions. The following time-trend plots only address the subset of wells listed above (which does not include any Trench 2 area wells; subsequent annual reports will, however). To supplement the data presented in this section, Appendix A provides detailed information regarding historical analytical results for all floodplain wells. Therefore, in reviewing the following plots and interpretations, the reader is referred to this appendix for additional information, as well as the figures in Section 1 which plot the corresponding spatial distributions (see Figure 1–11 in particular).

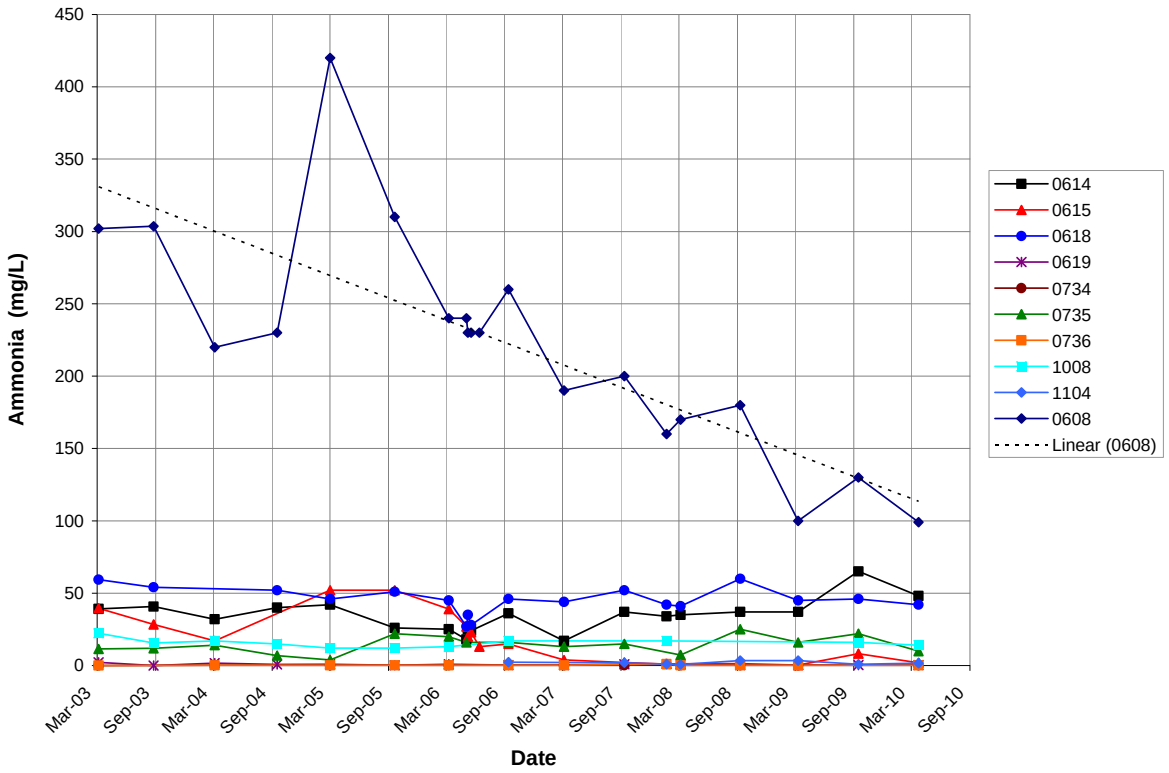

Figure 2–3a. Floodplain Ammonia (Total as Nitrogen) Groundwater Concentrations Versus Time

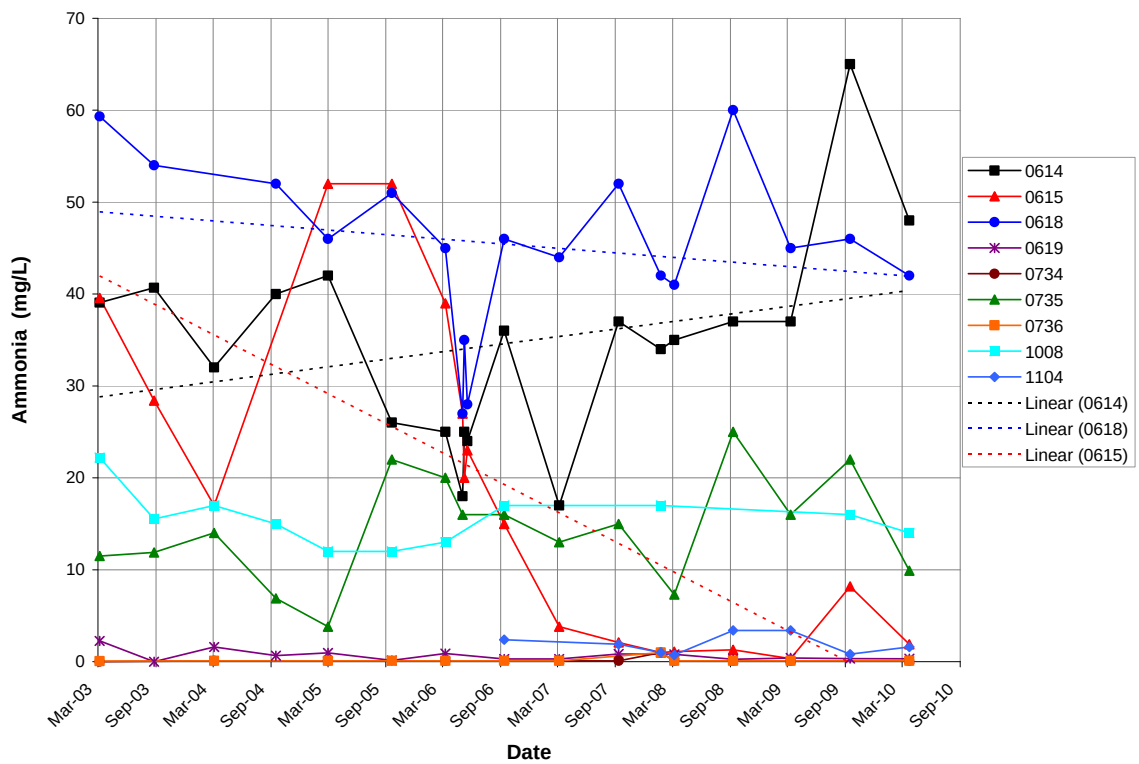

Figure 2-3b. Floodplain Ammonia Groundwater Concentrations Versus Time Excluding Well 0608

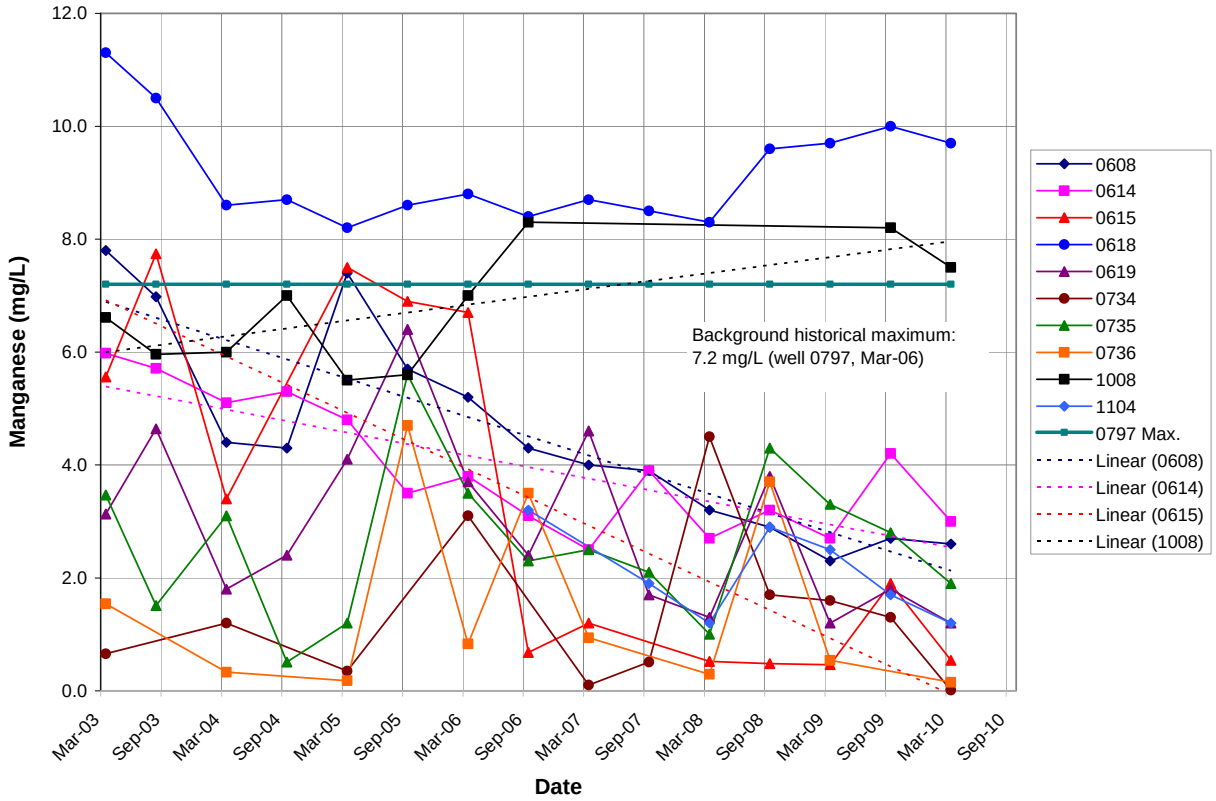

Figure 2–4. Floodplain Manganese Groundwater Concentrations Versus Time

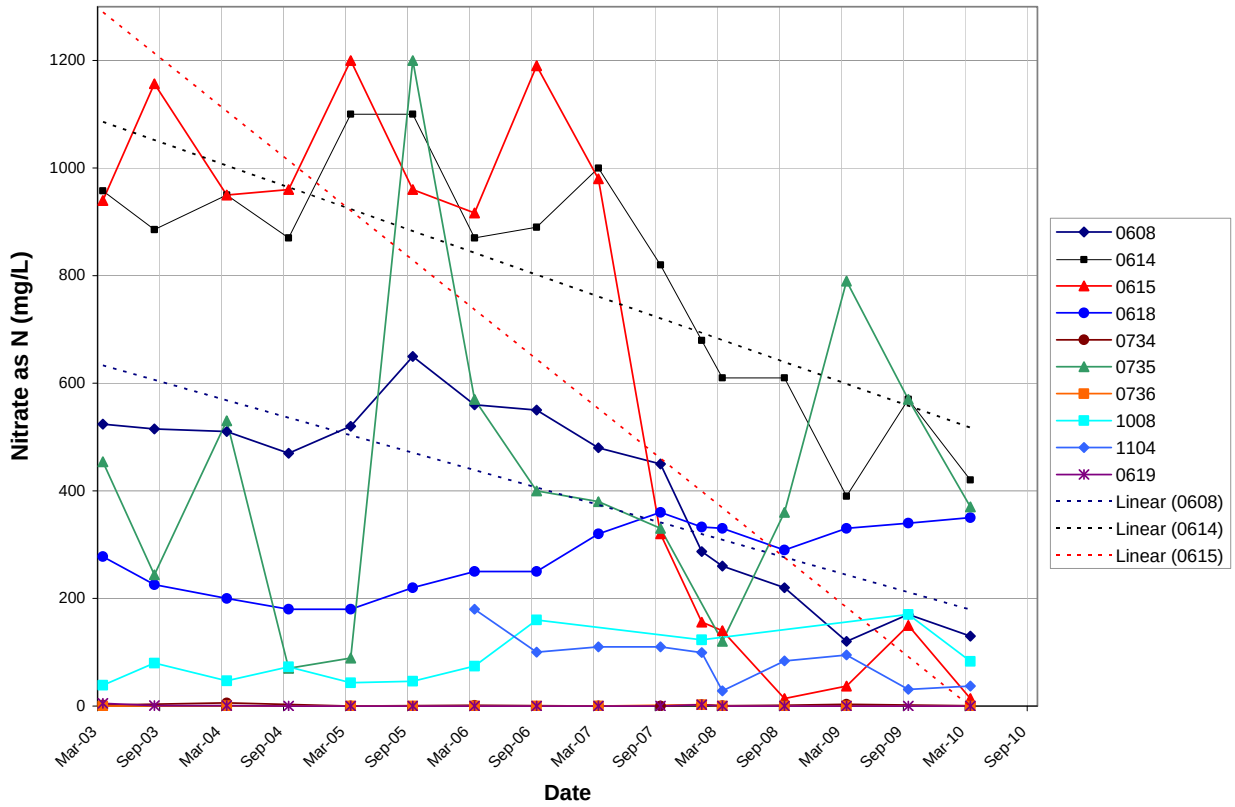

Figure 2–5. Floodplain Nitrate + Nitrite (as Nitrogen) Groundwater Concentrations Versus Time

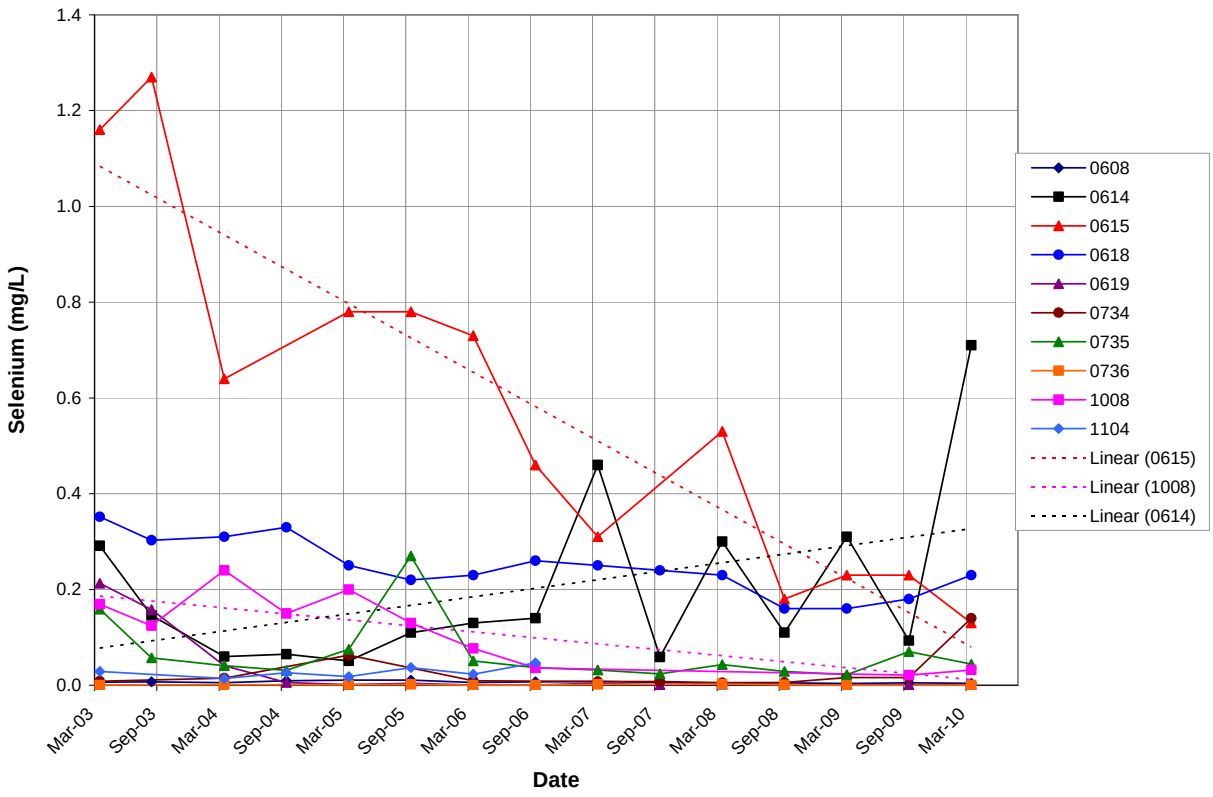

Figure 2–6. Floodplain Selenium Groundwater Concentrations Versus Time

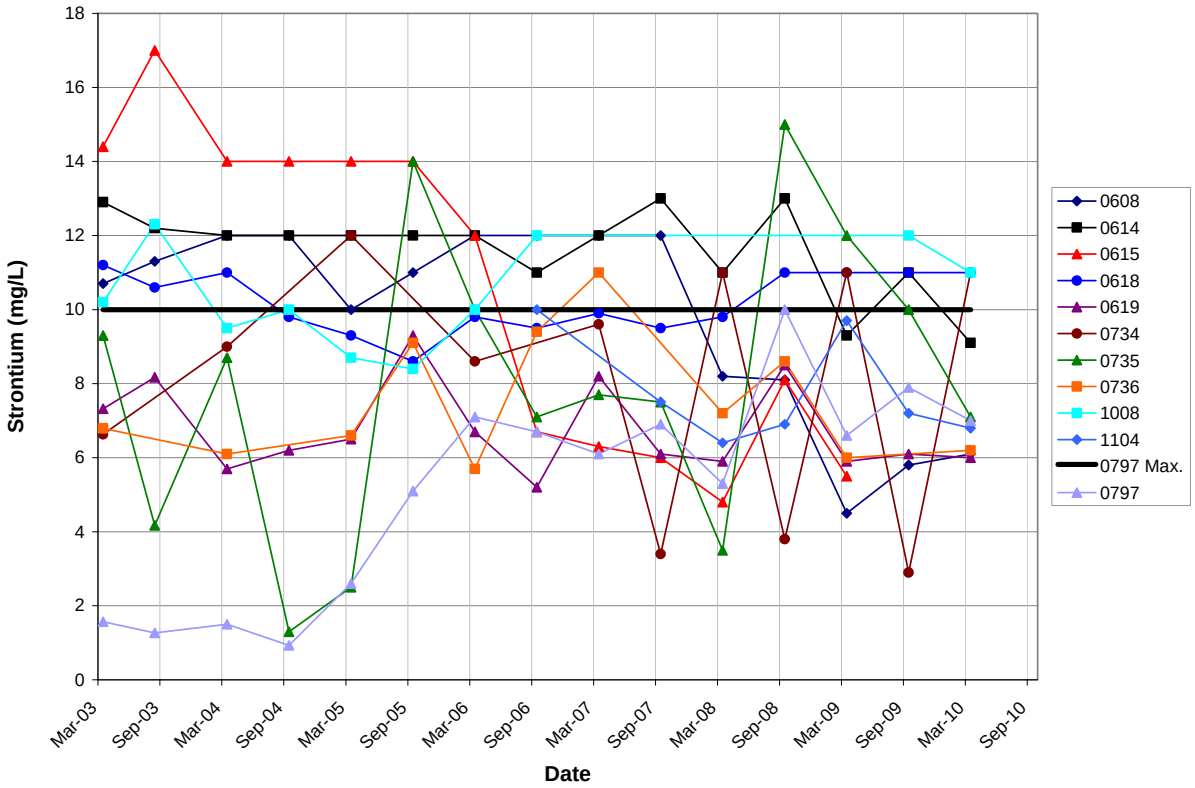

Figure 2–7. Floodplain Strontium Groundwater Concentrations Versus Time

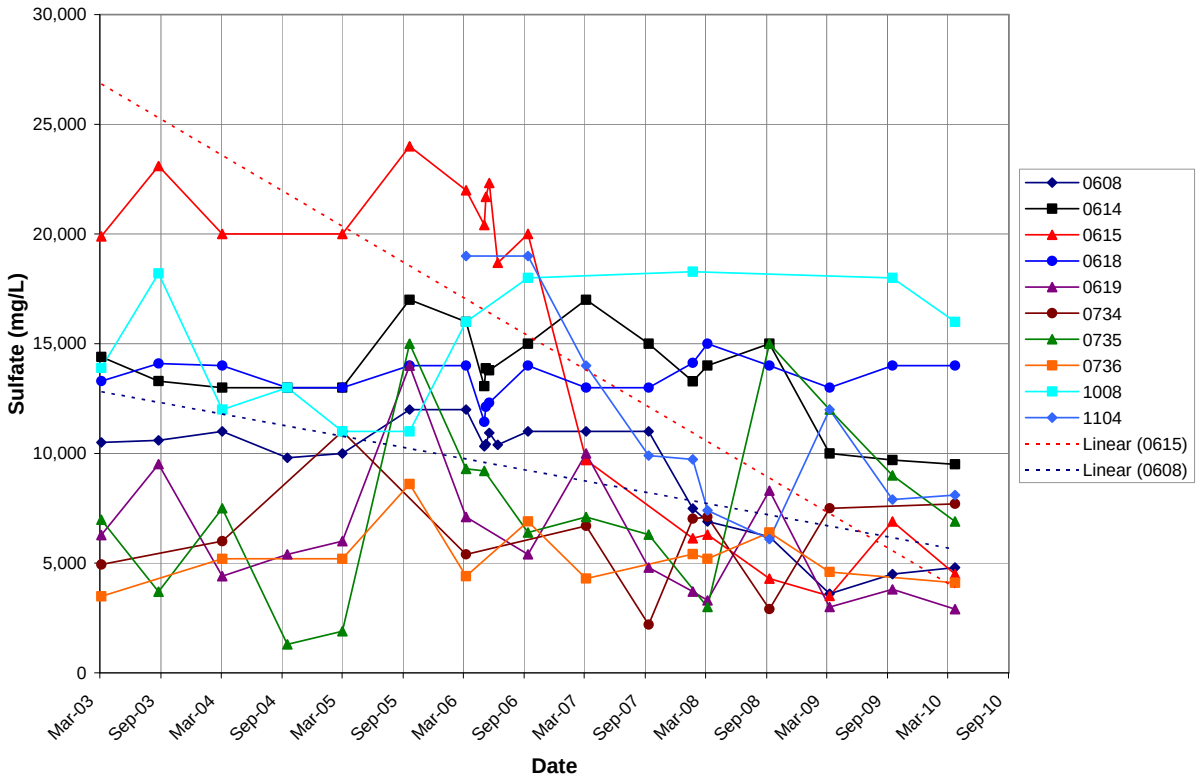

Figure 2–8. Floodplain Sulfate Groundwater Concentrations Versus Time

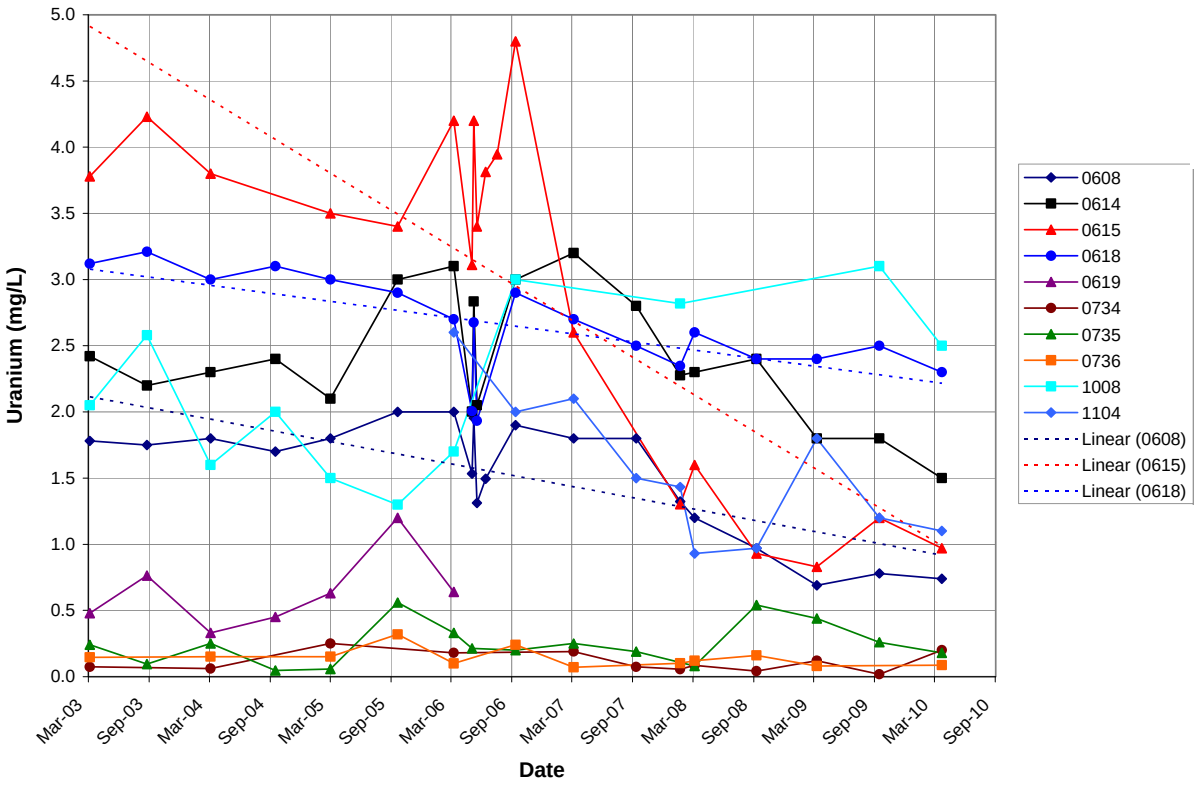

Figure 2–9. Floodplain Uranium Groundwater Concentrations Versus Time

For all COCs, as shown in the preceding figures, periodic variation attributable to meteorological and other influences is apparent in most wells. This small-scale variation is expected, as concentrations of constituents in groundwater in the floodplain alluvium are affected by changes in precipitation and river stage, discharge of groundwater from the artesian well that flows into Bob Lee Wash and then onto the floodplain, and pumping rates of the extraction wells and collection trenches. The following paragraphs discuss general trends observed for individual COCs.

Ammonia

In contrast to trends apparent for most other COCs, ammonia concentrations are highest in the western portion of the Trench 2 area closest to the disposal cell (see Figure 1–3, Figure 1–11, and Appendix A).[9] Concentrations on the east (San Juan River) side are much lower, however. This difference in magnitude could be evidence of the effectiveness of the remediation system in this area. As shown in Figure 2–3a, with the exception of well 0608 (screened in the Mancos Shale, at the base of the escarpment) and Trench 1 area alluvial well 0615, ammonia concentrations in groundwater (in the subset of wells plotted) have not varied significantly over the past 7 years. Ammonia concentrations in well 0608 seem to have stabilized at about 100–150 mg/L for the past year, compared with the 300 mg/L baseline measurement in March 2003 and the historical maximum of 420 mg/L in March 2005. Ammonia concentrations in well 0615, located in the Trench 1 area, have also decreased (Figure 2–3b). Floodplain-wide, ammonia concentrations ranged from 0.1 to 390 mg/L during this reporting period; the maximum was measured at Trench 2 well 1128. Lower, but still elevated ammonia levels occur in other areas of the floodplain (e.g., Trench 1 area and well 1089 area). However, no contamination is apparent in the northwest floodplain.

Manganese

As discussed in Section 1, manganese levels are most elevated on the terrace; on the floodplain, no notable trends are apparent (see Figures 1–4, 1–10, 1–11). Although decreases are apparent (Figure 2–4), these are also not noteworthy, as most decreases are within the range of normal variability measured for floodplain background wells 0797 and 0850. With the exception of Trench 1 area wells 0618 and 1008, manganese levels in the subset of wells plotted in Figure 2–4 are below the maximum floodplain background concentration (7.2 mg/L). This is also the case floodplain-wide, where manganese concentrations for this reporting period range from less than 0.001 to 10 mg/L in well 0618. The average manganese concentration was 2.0 mg/L, which is well below the 7.2 mg/L background maximum.

Nitrate

As observed for ammonia, nitrate concentrations in well 0608 (completed in the Mancos Shale near the escarpment) and Trench 1 area well 0615 have decreased notably since the baseline period. Nitrate (as N) concentrations in well 0608 continue to decrease since installation of the floodplain trenches in 2006—from the maximum of 650 mg/L in September 2005 to a historical low of 130 mg/L in March 2010. Nitrate concentrations in well 0615 also reduced markedly, nearly two orders of magnitude relative to 2003–2005 measurements (Figure 2–5). A similar decrease is apparent for well 0614, located between well 0608 and Trench 1. Nitrate

[9] In this section, when referencing the paired (graduated symbol and bar chart) plots in Section 1, only the main figure number is noted (i.e., Figure 1–3 refers to both Figure 1–3a and Figure 1–3b).

concentrations in well 0735, upgradient of the disposal cell, which had increased during the last reporting period, decreased from 790 mg/L in March 2009 to 370 mg/L in March 2010. Nitrate levels have fluctuated widely in this well historically.

For this reporting period, floodplain-wide, nitrate concentrations ranged from 0.01 mg/L in the northwest floodplain to 650 mg/L at well 1116 (west of Trench 2 near the base of the escarpment [not plotted in Figure 2–5]). As shown in Figure 1–5 and Figure 1–14, the highest concentrations of nitrate occur in wells near the escarpment. As is the case for other COCs (e.g., uranium and sulfate), nitrate concentrations are generally lower in the northwest portion of the floodplain where groundwater is influenced by influx from the artesian well feeding Bob Lee Wash. Nitrate concentrations are also low in central floodplain wells (see Figure 1–11 and Appendix A). The plume maps shown in Figure 1–14 illustrate the reduction in nitrate concentrations in the central floodplain and Trench 2 area since the baseline period.

Selenium

In general, selenium concentrations in floodplain groundwater have not varied significantly over the past 7 years (Figure 2–6; also see Figure 1–11 and Appendix A). However, selenium concentrations in Trench 1 area well 0615 have decreased from a peak of 1.3 mg/L in August 2003 to a historical low of 0.13 mg/L in March 2010. Decreases are also apparent in well 1008. Selenium levels recently increased markedly in well 0614 (located near the base of the escarpment between Trenches 1 and 2), from 0.093 mg/L in September 2009 to the historical maximum of 0.7 mg/L in March 2010 (Figure 2–6). Floodplain-wide, selenium concentrations ranged from 0.001 to 0.71 mg/L (well 0614), and the average concentration was 0.09 mg/L (exceeding both the 40 CFR 192 and EPA MCLs; Table 1−1).

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, which was driven by strontium concentrations in sediments, rather than in groundwater (DOE 1994). The fact that strontium may be naturally occurring at the Shiprock site (rather than associated with former milling processes) is evident in Figure 1–7b, which shows that strontium concentrations are fairly uniform across the site. Although the plots in Appendix A indicate that strontium concentrations in floodplain wells are slightly elevated relative to background, the magnitudes are not noteworthy (see final plot in Appendix A, Figure A–6). [A correlation with calcium is apparent; the latter trend could account for these observations.] No notable temporal trends are evident in Figure 2–7, and all floodplain measurements to date have been below EPA's risk-based screening level for groundwater (22 mg/L) discussed in Section 1.2. For the 2009–2010 reporting period (excluding background), strontium concentrations ranged from 0.5 to 19 mg/L (well 0792); the average concentration was 6.4 mg/L (also see Figure 1–7).

Sulfate

As observed for all other COCs, sulfate concentrations in Trench 1 area well 0615 have decreased notably since installation of the trenches in spring 2006—from the maximum of 24,000 mg/L in September 2006 to a low of 4500 mg/L in March 2010 (Figure 2–8). Between March 2003 and September 2007, sulfate concentrations in well 0608, completed in the Mancos Shale, were stable at about 10,000 mg/L. However, sulfate concentrations in this well have since declined; the most recent (March 2010) measurement was 4800 mg/L. Apart from the expected

variation attributable to river stage and other influences discussed previously, sulfate concentration trends in remaining wells plotted in Figure 2–8 continue to be relatively stable. The best demonstration of changes in sulfate since the onset of remediation is provided in Figure 1–17 (see plume map comparison). In this figure, marked reductions in sulfate concentrations are apparent, in particular at Trenches 1 and 2, in the well 1089 area. Despite these reductions, sulfate concentrations on the floodplain are still elevated relative to background (see Figure 1–8, 1–11, and Appendix A). During this reporting period, sulfate concentrations in floodplain monitoring wells (excluding background) ranged from 75 to 18,000 mg/L (maximum in well 1008).

Historically, sulfate levels in floodplain background wells have been highly elevated relative to EPA's secondary standard of 250 mg/L. Except for a recent anomalously low measurement in September 2009, sulfate levels in well 0797 have generally been increasing; a maximum of 5200 mg/L was measured in September 2008 (Figure 2−10). In addition to considering background, sulfate concentrations must also be evaluated relative to levels detected in terrace artesian well 0648. The water entering the northwest portion of the floodplain from this well has sulfate concentrations ranging between about 2000 and 3000 mg/L (the most recent measurement, in March 2009, was 2200 mg/L). As shown in Figure 1–8, sulfate concentrations in groundwater in the northwest portion of the floodplain are generally consistent with this artesian groundwater component.

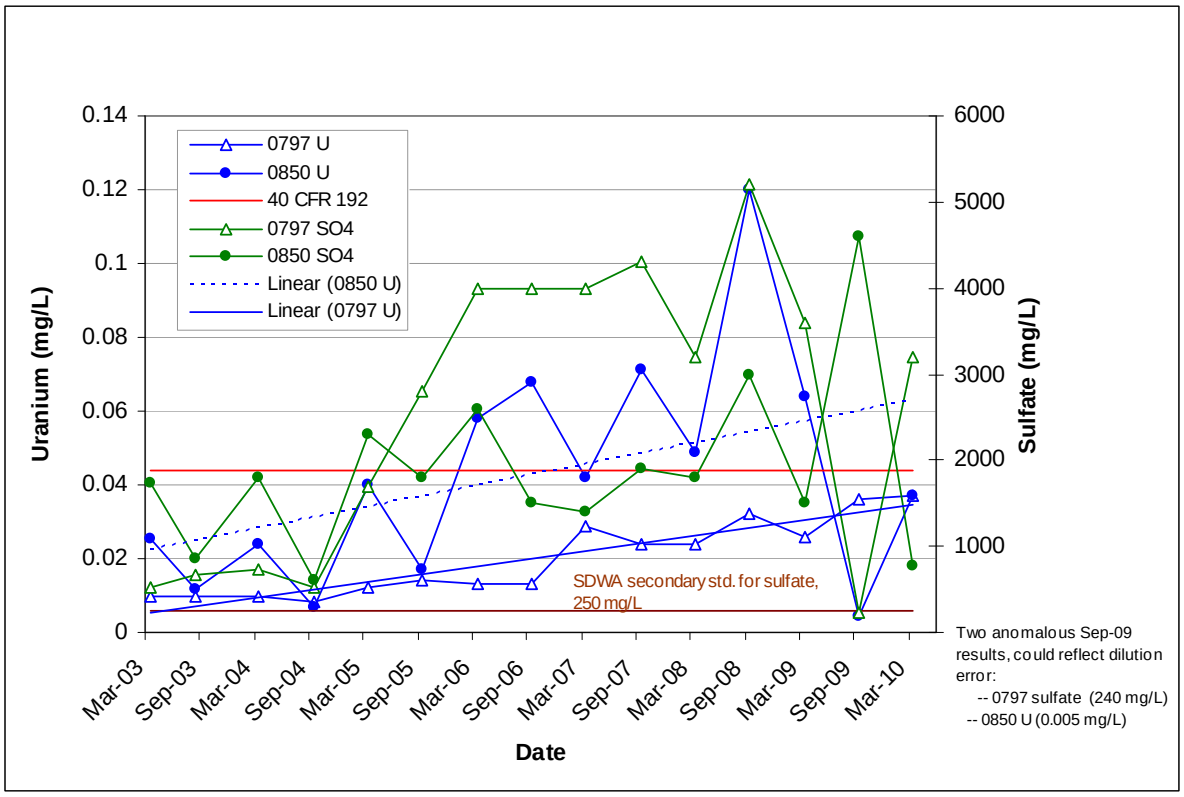

Figure 2–10. Time–Trend Plots of Uranium and Sulfate in Floodplain Background Wells 0797 and 0850

Uranium

As discussed in Figure 1–4 and shown in the corresponding figures (Figures 1–9 through 1–11; Figure 1–18), uranium concentrations are highest around the disposal cell and on the floodplain, at the base of the escarpment and in the Trench 1 and well 1089 areas. In terms of temporal trends, trends for uranium generally parallel those reported for sulfate. As shown in Figure 2–9, for the subset of wells plotted, the most marked decreases are evident in Trench 1 area well 0615. Since the trenches were installed in 2006, uranium concentrations decreased from 4–5 mg/L to about 1 mg/L in the last several years (Figure 2–9). A slight decreasing trend is apparent in wells 0608 and 0618. Uranium concentrations in remaining wells plotted in Figure 2–9 are variable and exhibit no apparent trend. Floodplain-wide, uranium concentrations ranged from 0.005 to 2.5 mg/L in March 2010 (maximum in well 1008). Uranium concentrations are generally highest near the escarpment and between Trench 1 and well 1089 (Figures 1–9 and 1–18). Also, as observed for sulfate and as demonstrated in Figure 2–10, uranium concentrations have been elevated in background wells (relative to the 0.044 mg/L standard), in particular in well 0850.

2.1.3 Floodplain Contaminant Removal

During the remediation system's first 7 years of operation at the Shiprock site, the extraction wells and trenches have removed nearly 750,000 pounds of contaminants from the alluvial groundwater system (see Table 3–2). 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. 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 2–11).

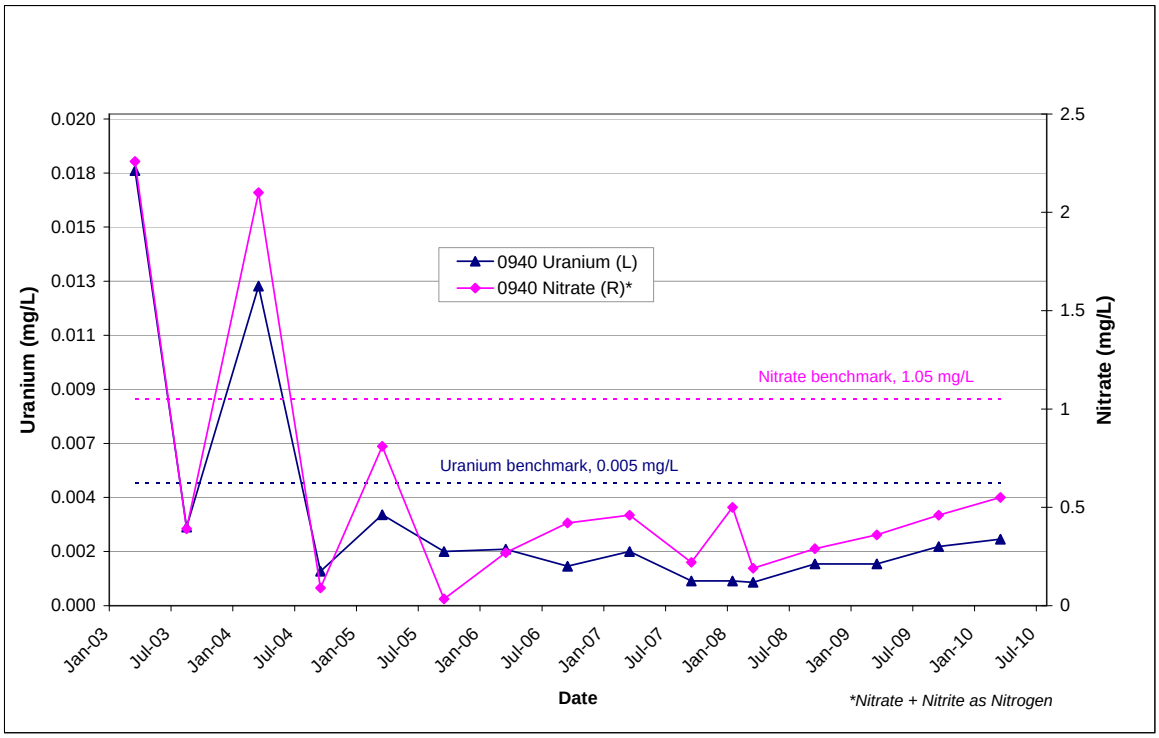

Figure 2–11. Uranium and Nitrate Concentrations in the San Juan River (Location 0940)

As shown in Figure 2–11, uranium and nitrate trends are correlated, and a very slight increase is apparent in recent years (2008 to 2010). To supplement the time-trend plot above, the box plots shown in Figure 2–12 show the historical distribution of uranium and the two other primary COCs, nitrate and sulfate, at all San Juan River sample locations. In these plots, locations are ordered (from left to right) by direction of river flow (upstream to downstream); 0898, the easternmost river sample location in Figure 1–2 is the upstream (background) location. The plots in Figure 1–12 show that, apart from the historical elevated concentrations at 0940 noted previously, 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.

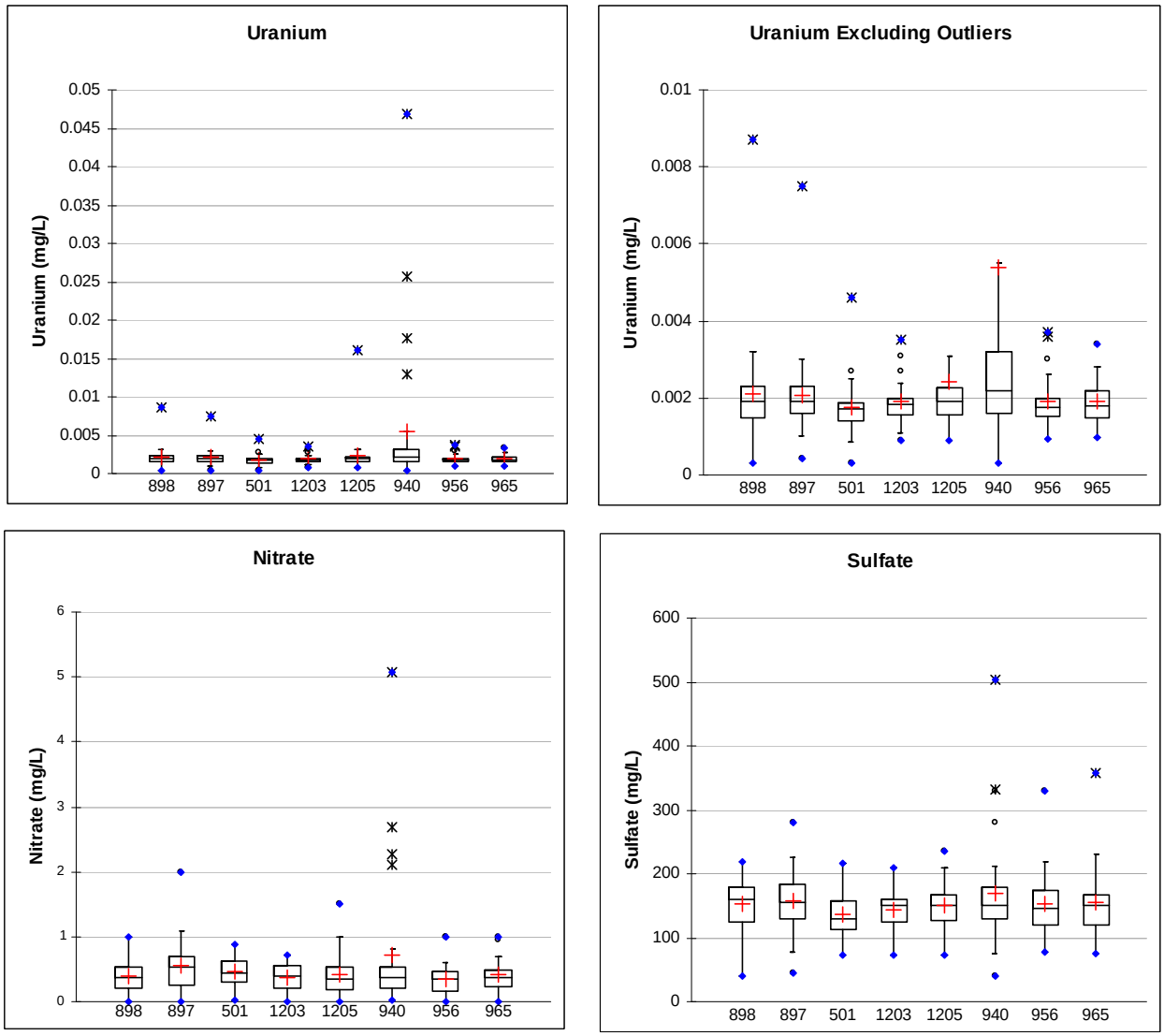

Figure 2–12. Historical Distributions of Uranium, Nitrate, and Sulfate at San Juan River Sample Locations†

† The box plots shown above depict the median, the lower and upper quartiles, and the non-outlier range of uranium nitrate, and sulfate for each San Juan River sampling location; points plotted beyond these limits are outliers. The mean is denoted by +, whereas the median line bisects the box.

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 2010. 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 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

Groundwater level data from the terrace collected during the March 2010 sampling event were compared to baseline groundwater elevation data from March 2003 reported in the Baseline Performance Report (DOE 2003). Figure 2–13 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 the entire terrace groundwater system.

For wells screened in the alluvium, of the 32 groundwater level measurements taken in September 2009 or March 2010, the majority show declines relative to the baseline period of March 2003. Declines ranged from 0.02 ft to a maximum decrease of 6.1 ft in well 0848, located in the west terrace; the average decrease was 1.9 ft. As was the case last year (DOE 2009a), well 0730, located southwest of the disposal cell, was dry at the time of the March 2010 sampling event (a groundwater level decline of 4.7 ft was reported in 2008 [DOE 2008]).

As presented in greater detail in the following section, as of March 2010, the cumulative volume of water removed from the terrace extraction system since pumping began was approximately 21.3 million gallons. Pumping records indicate that approximately 2.7 million gallons were removed between April 2009 and April 2010. In 2010, the water levels in each of these wells had declined both relative to baseline conditions and, at some wells, relative to water level measurements made in 2009. Thus, it can generally be concluded that the extraction well field is resulting in the desired effect on groundwater levels in the terrace.

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 Figure 2−14 and Figure 2–15 for wells screened in shallower (water level elevations greater than 4930 ft) and deeper zones, respectively. Linear trend lines shown in Figure 2–14 indicate a decrease in water levels during the time of observation in most of the wells, although not of the magnitude reflected in Figure 2−13 (based on manual measurements). However, with the exception of well 0836, plots of groundwater elevation data for wells screened in deeper zones show little decrease.

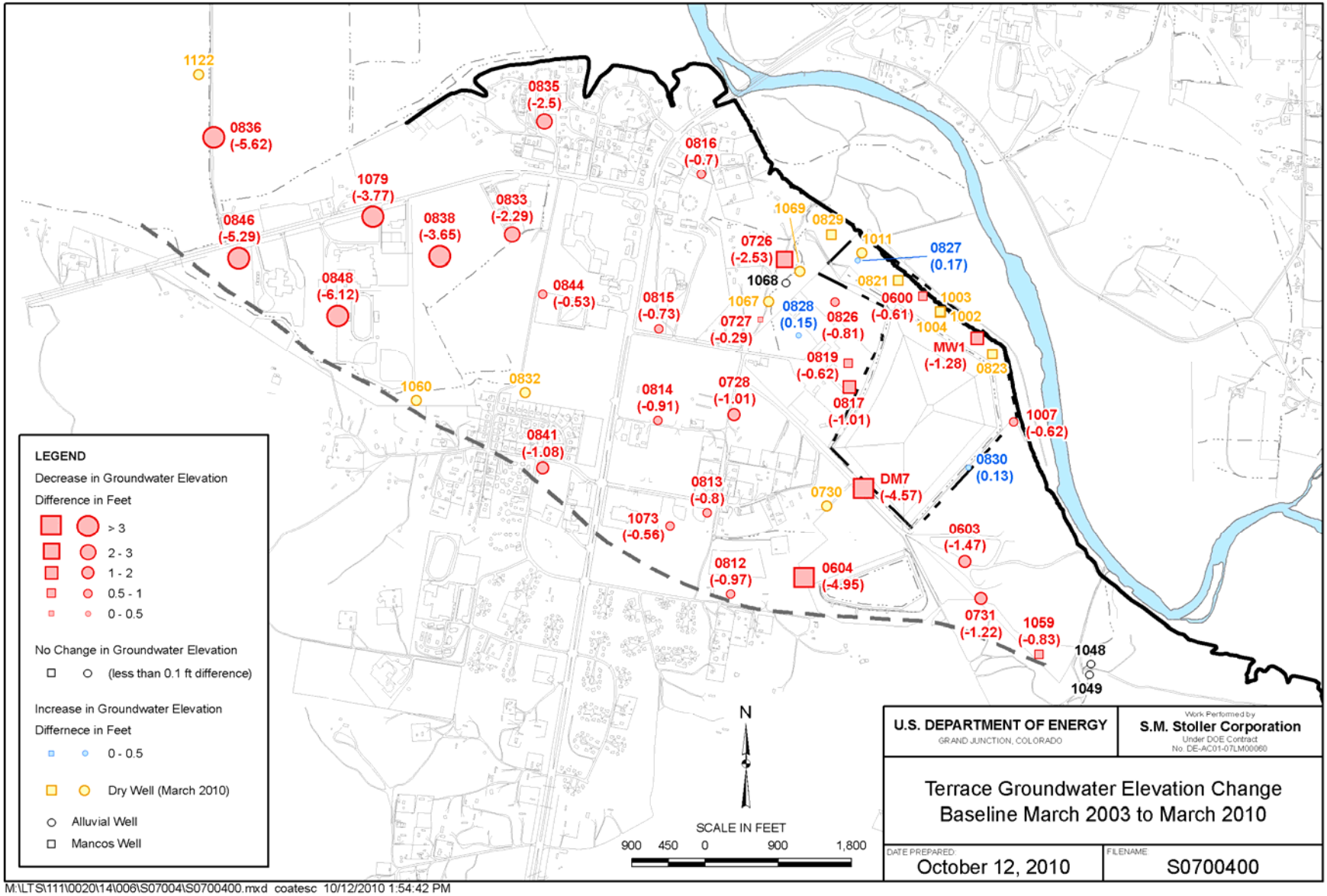

Figure 2–13. Terrace Groundwater Elevation Changes from Baseline (March 2003) to Current (March 2010) Conditions

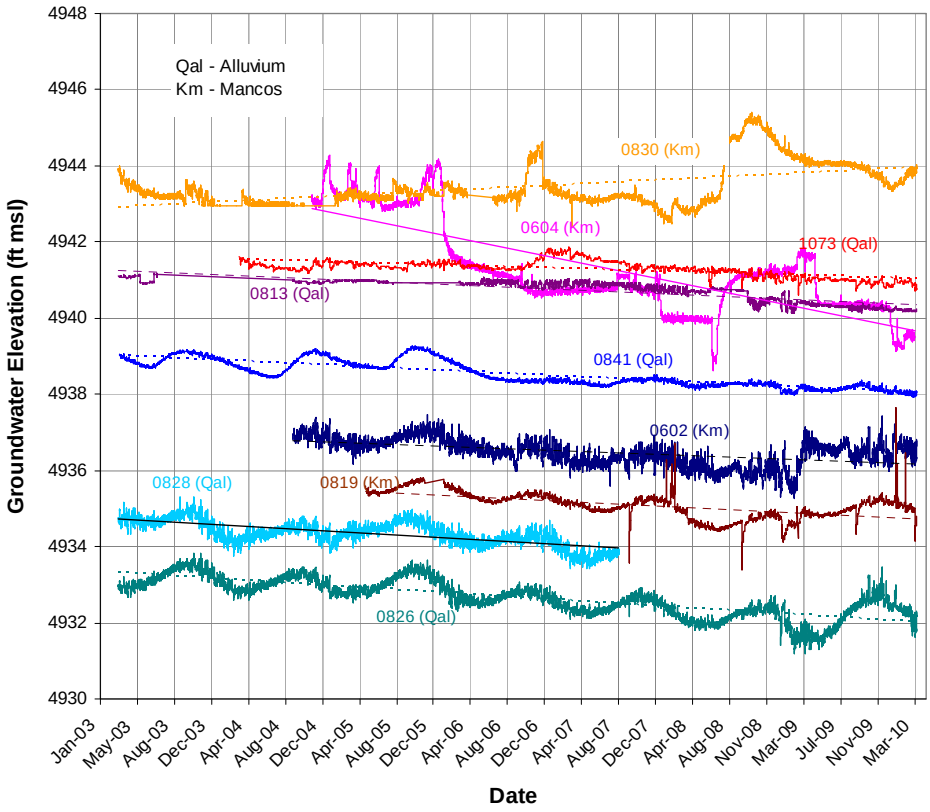

Figure 2–14. Terrace Datalogger Measurements, Wells with Water Elevations above 4930 ft

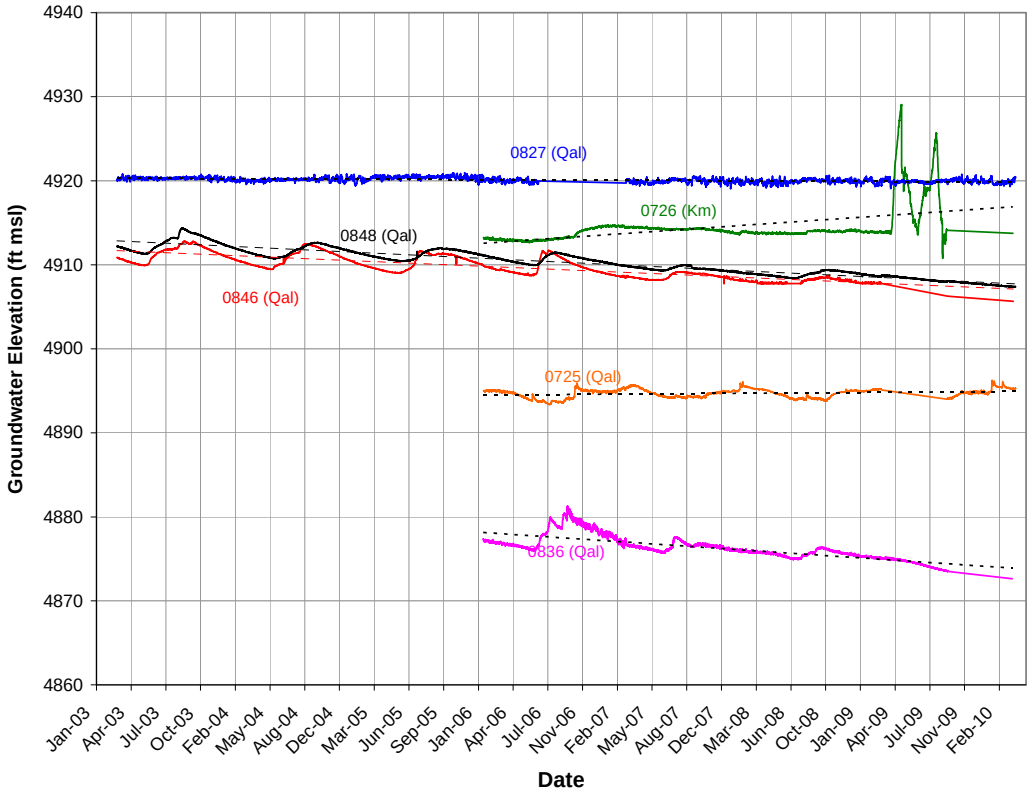

Figure 2–15. Terrace Datalogger Measurements, Deeper Wells

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 2009 and March 2010, the average pumping rate from Bob Lee Wash was 2.6 gpm, comparable to the rate of 2.1 gpm reported last year (refer to Figure 3–16 in the following section) .

The average pumping rate from Many Devils Wash during the performance period was about 1 gpm (see Figure 3–17), about three times greater than the 0.3 gpm rate reported last year. This increased efficiency may be attributable to the installation of a diversion structure in August 2009. This structure was installed because of declining effectiveness of the collection drain and to better capture contaminated surface water in the wash. Shortly after installation, the flow rate of water from the sump 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, monitored via telemetry, is 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.[10]

[10] The only major storm since the sampler was installed occurred in October 2010 (after this reporting period); no samples were collected because the storm damaged the sampler. The sampler was repaired and re-installed.