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.

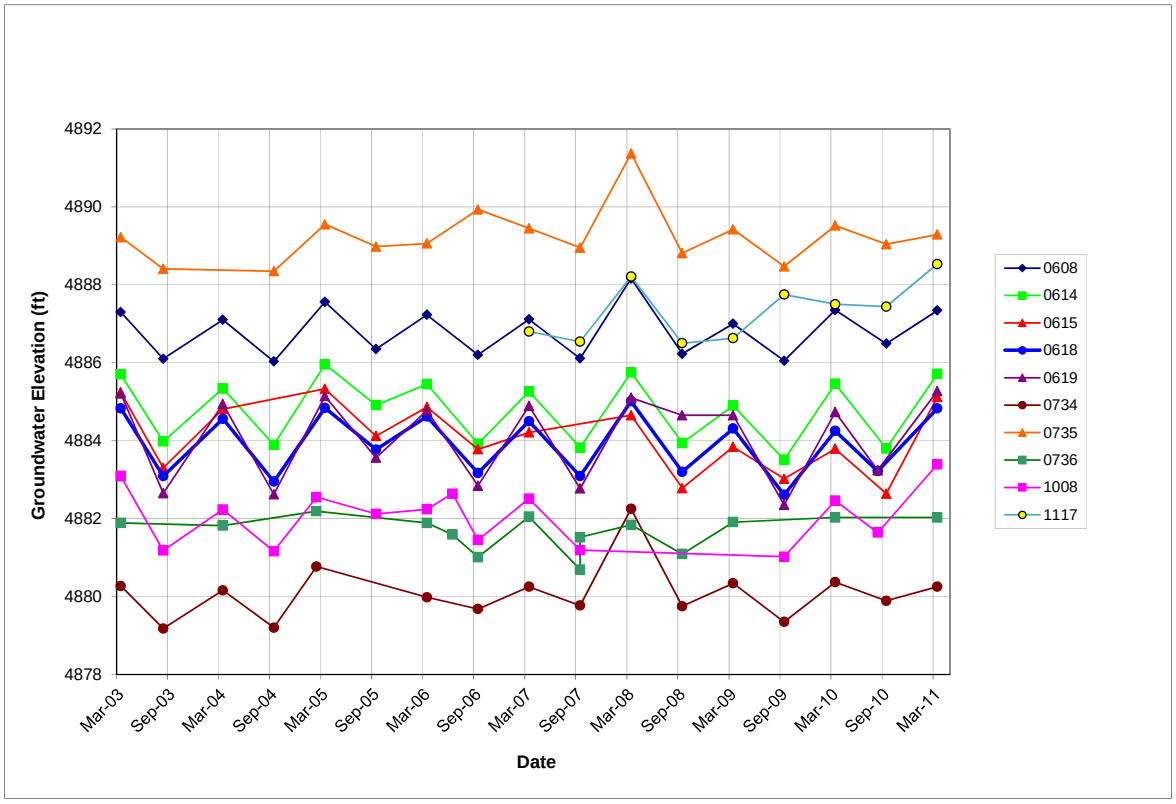


Figure 20. Floodplain Groundwater Elevations from Manual Measurements

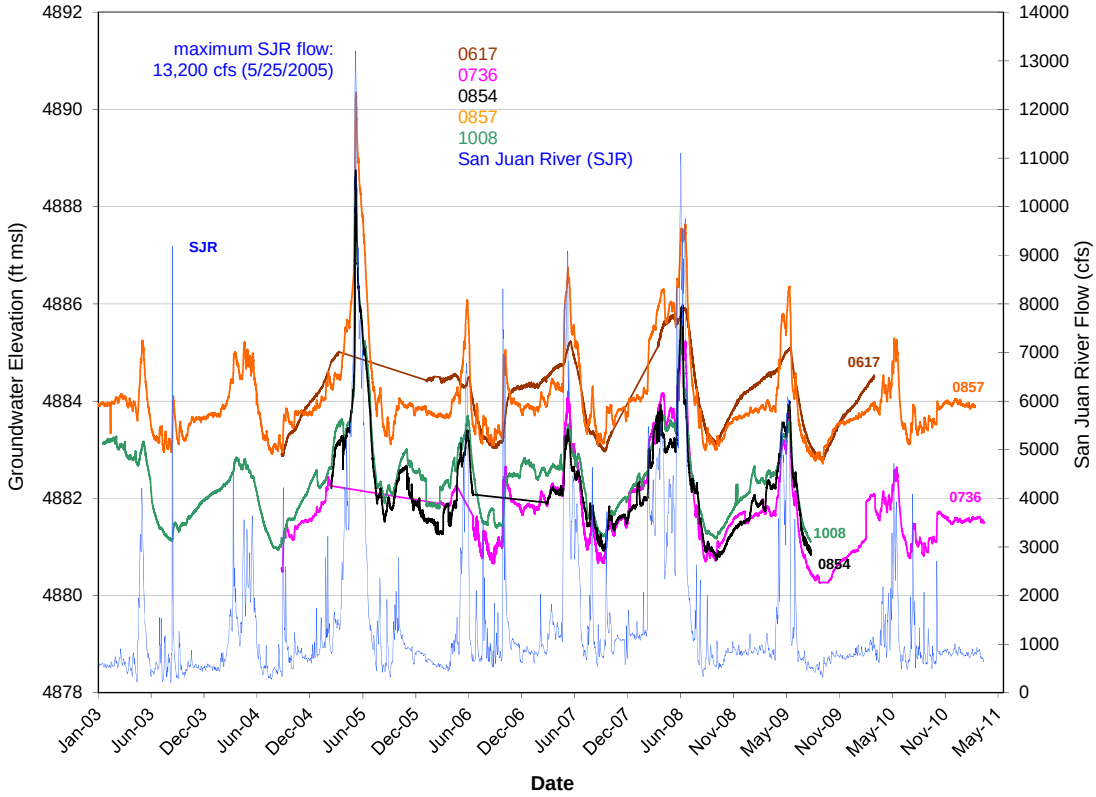


Figure 21. Floodplain Groundwater Elevations from Datalogger Measurements

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.

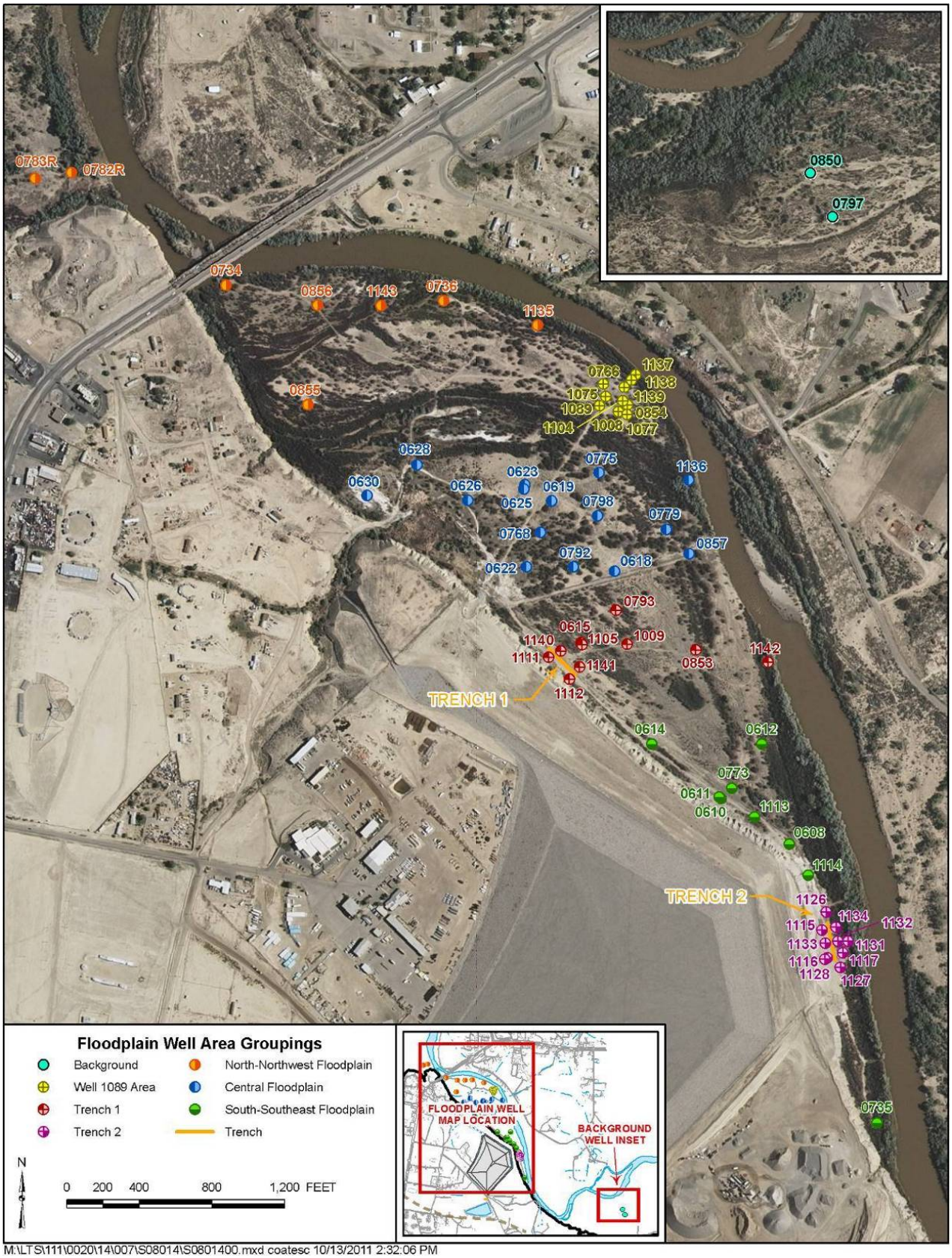


Figure 22. Shiprock Site Floodplain Area Well Groupings

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).

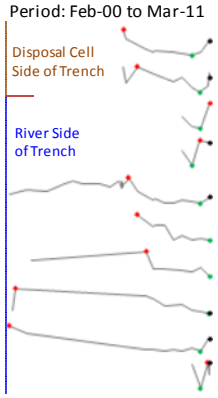
To expand upon the simplified global schematic in Figure 23, subsequent (area-specific) plots (e.g., Figures 24 through 27) better capture the changes in concentrations of uranium and other COCs in selected floodplain wells. The following discussion focuses on those areas exhibiting the most pronounced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

[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).

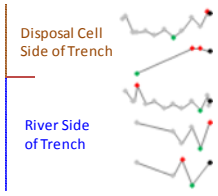
Floodplain Trench 1 Area: Uranium (mg/L)



Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
1111		1.59	0.79	1.23	11
1112		2.40	1.20	1.87	11
1140		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

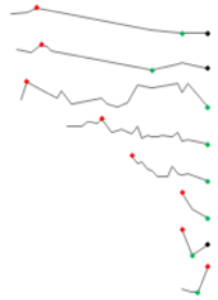
Wells are listed in approximate order of increasing distance from the disposal cell. Wells 0793, 1009, 0853, and 1142 are more distal but designated as Trench 1 area wells for reporting purposes.

Floodplain Trench 2 Area: Uranium (mg/L)



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

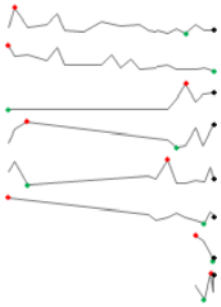
Floodplain Well 1089 Area: Uranium (mg/L)



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

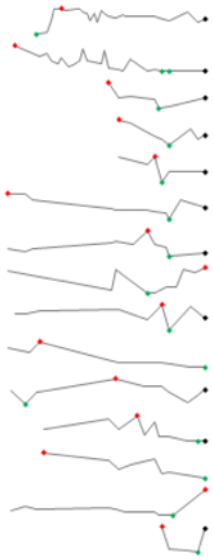
Note: Wells 1075 and 1077 are not shown here as these have not been regularly sampled.

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



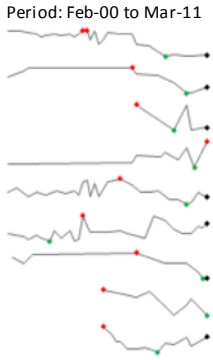
Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0734		0.53	0.02	0.10	19
0736		0.48	0.05	0.05	19
0782/0782R		0.010	0.003	0.007	8
0783/0783R		0.011	0.007	0.010	9
0855		0.15	0.06	0.09	13
0856		0.13	0.04	0.07	11
1135		0.24	0.13	0.14	5
1143		0.07	0.06	0.07	5

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

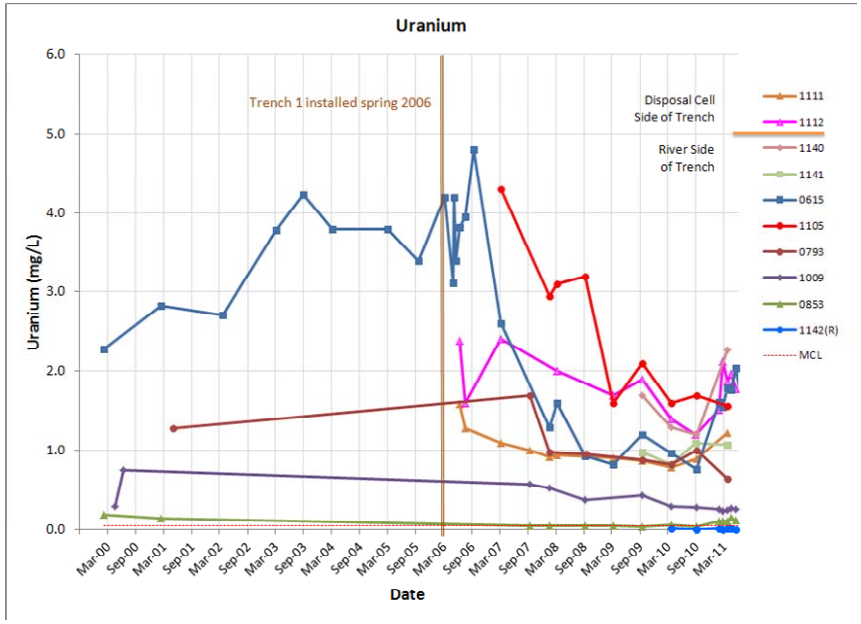
Floodplain Background Wells: Uranium (mg/L)

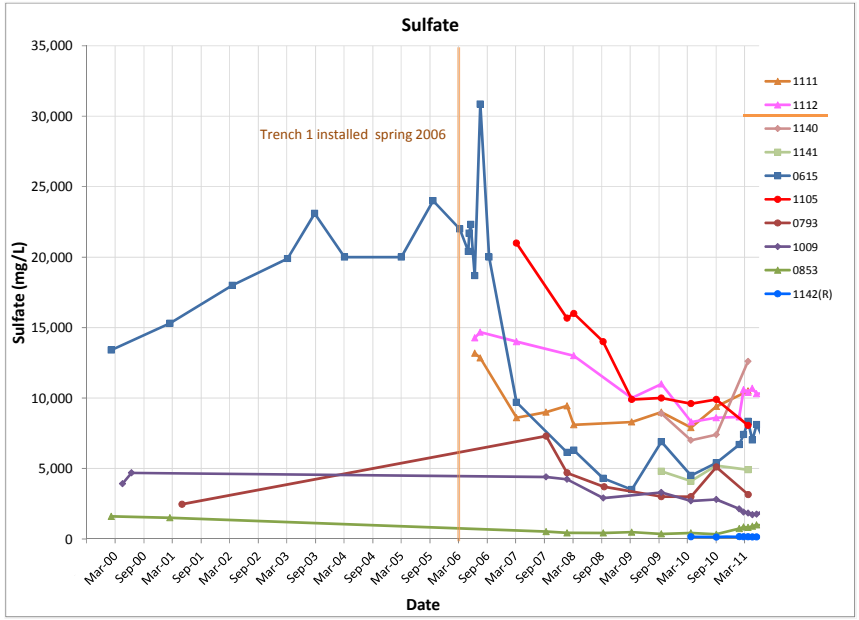
Well ID	Period: Feb-00 to Mar-11	Max	Min	Current	N
0797		0.037	0.008	0.024	21
0850		0.12	0.004	0.035	23

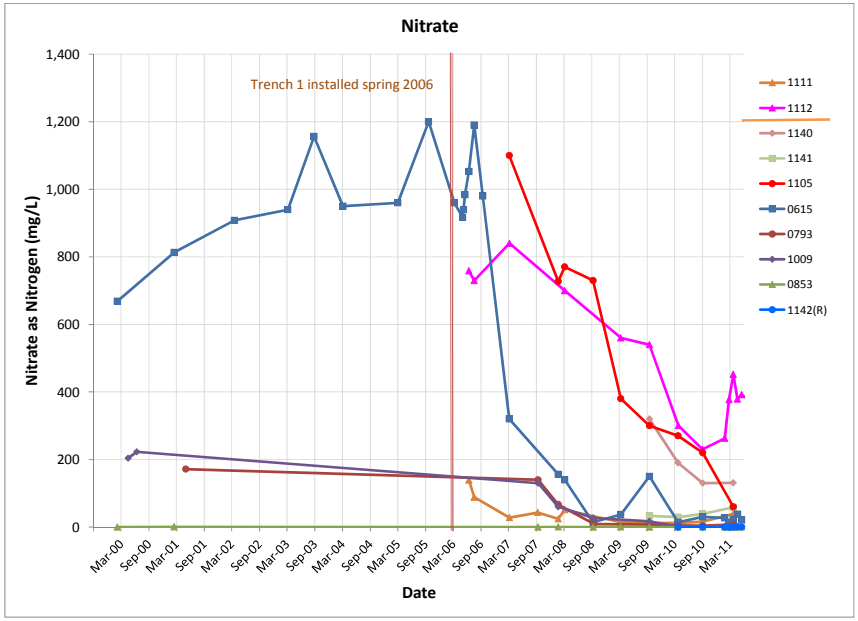
Legend

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



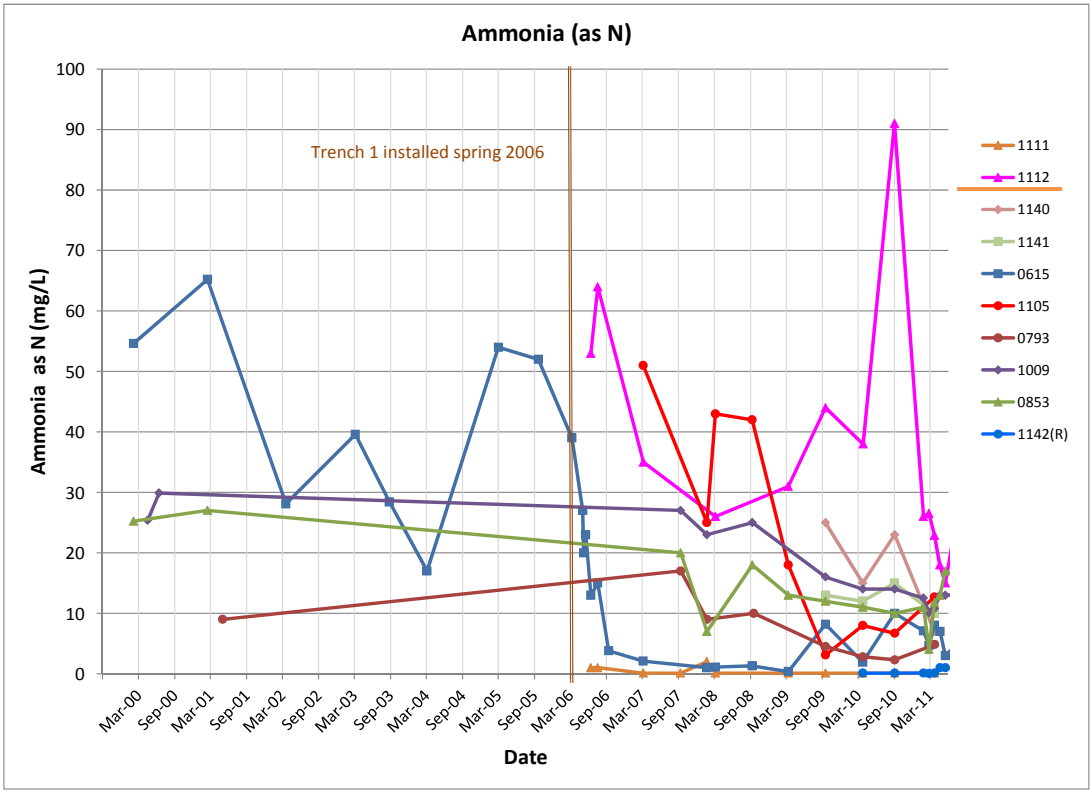




Trench 1 Area Wells (adapted from Figure 21)

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



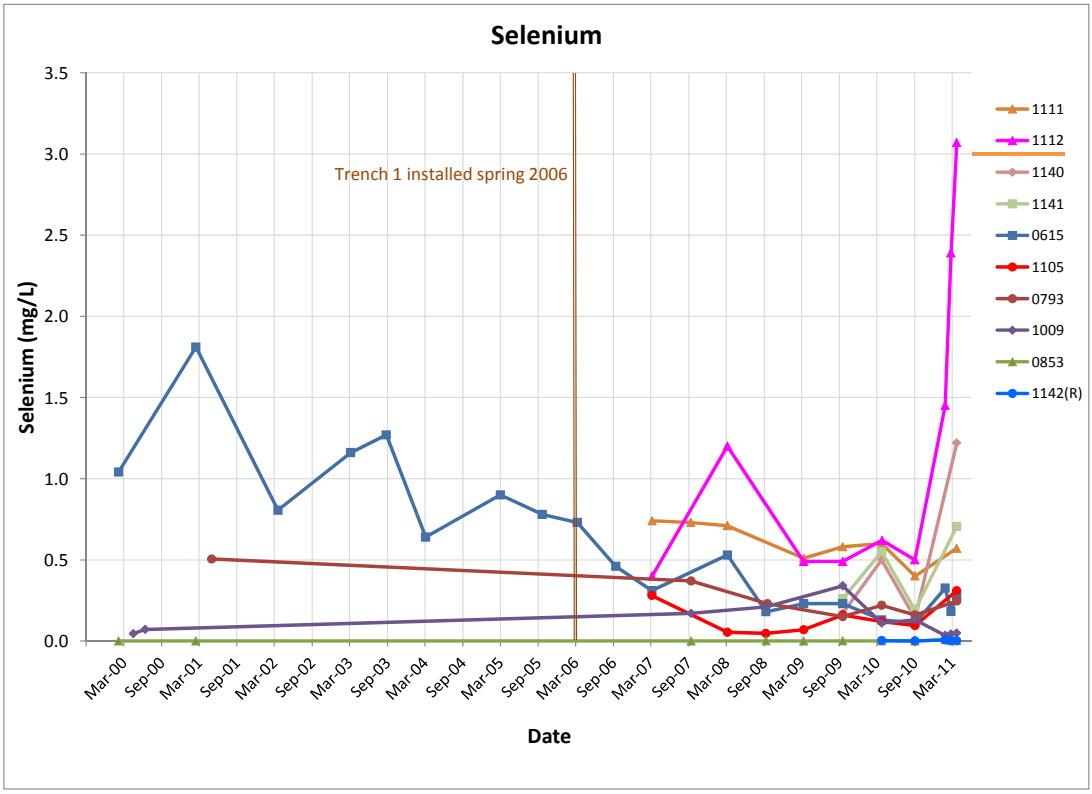
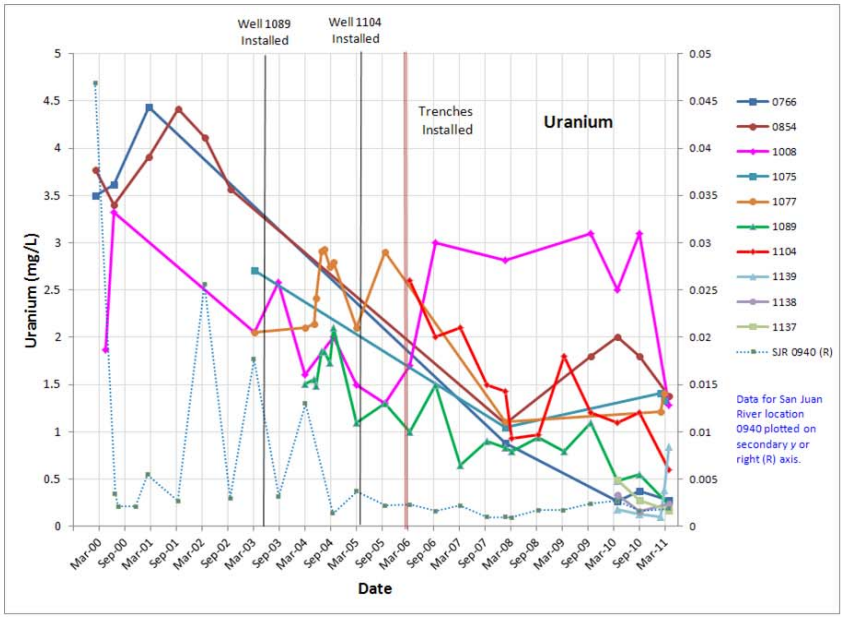
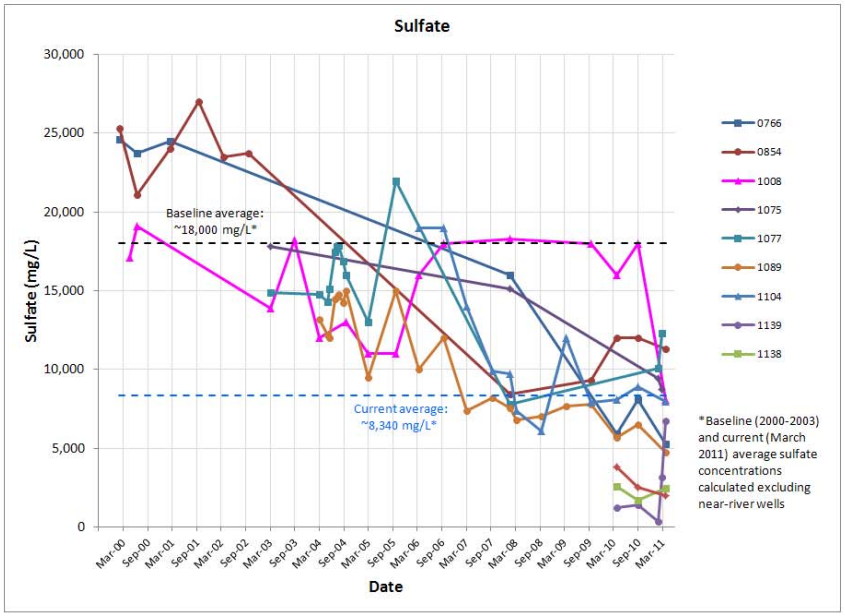
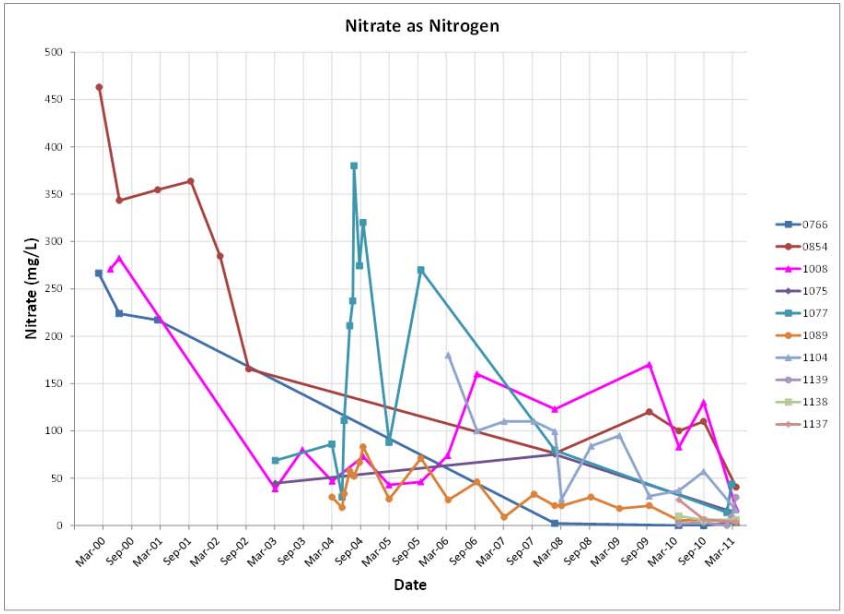
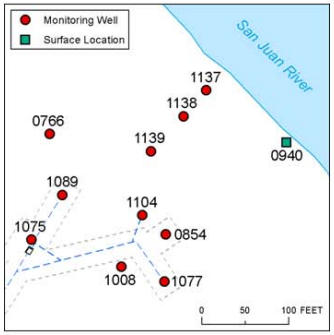


Figure 25. Ammonia and Selenium Concentration Trends in Trench 1 Area Wells





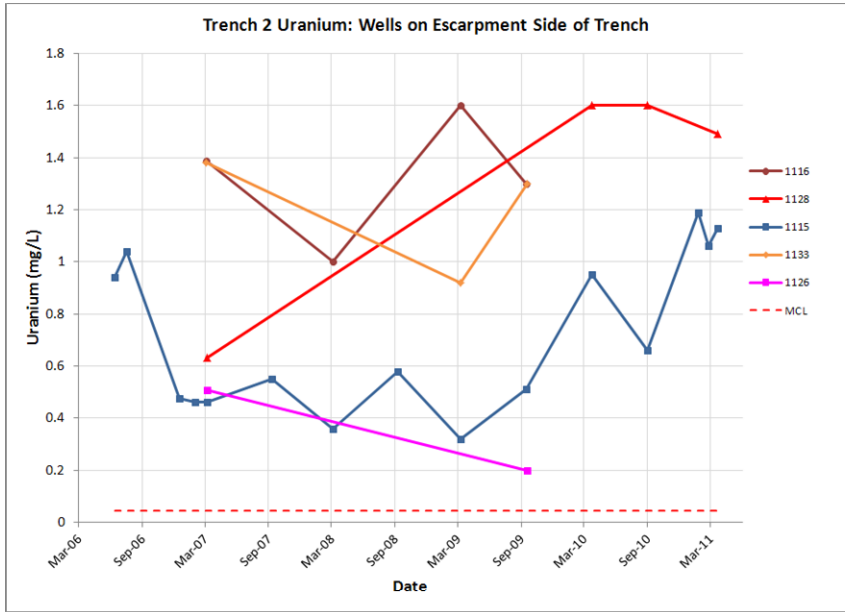


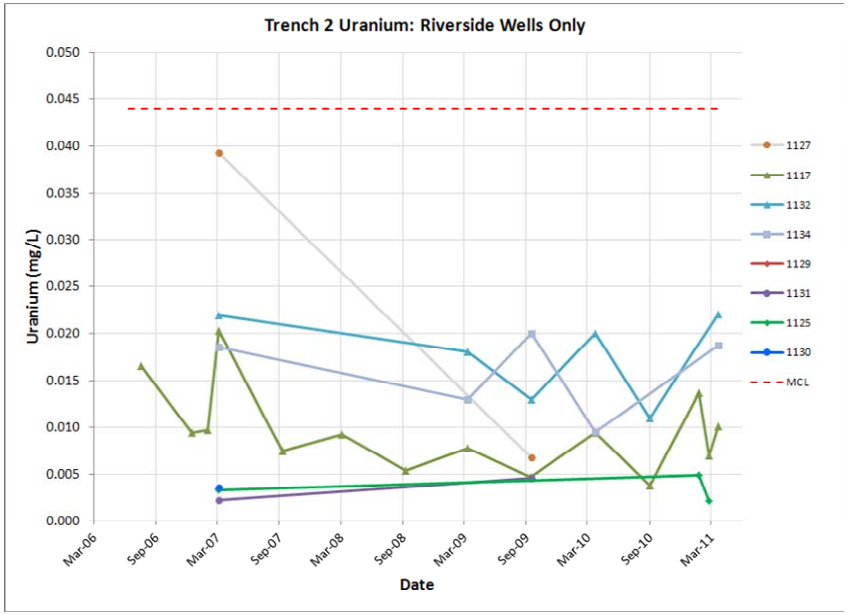


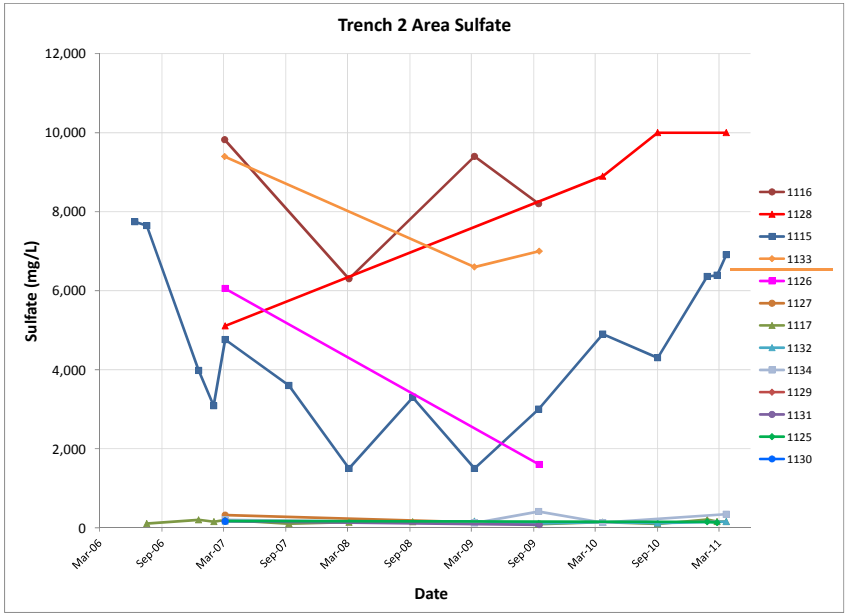
Well 1089 Area Wells

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.

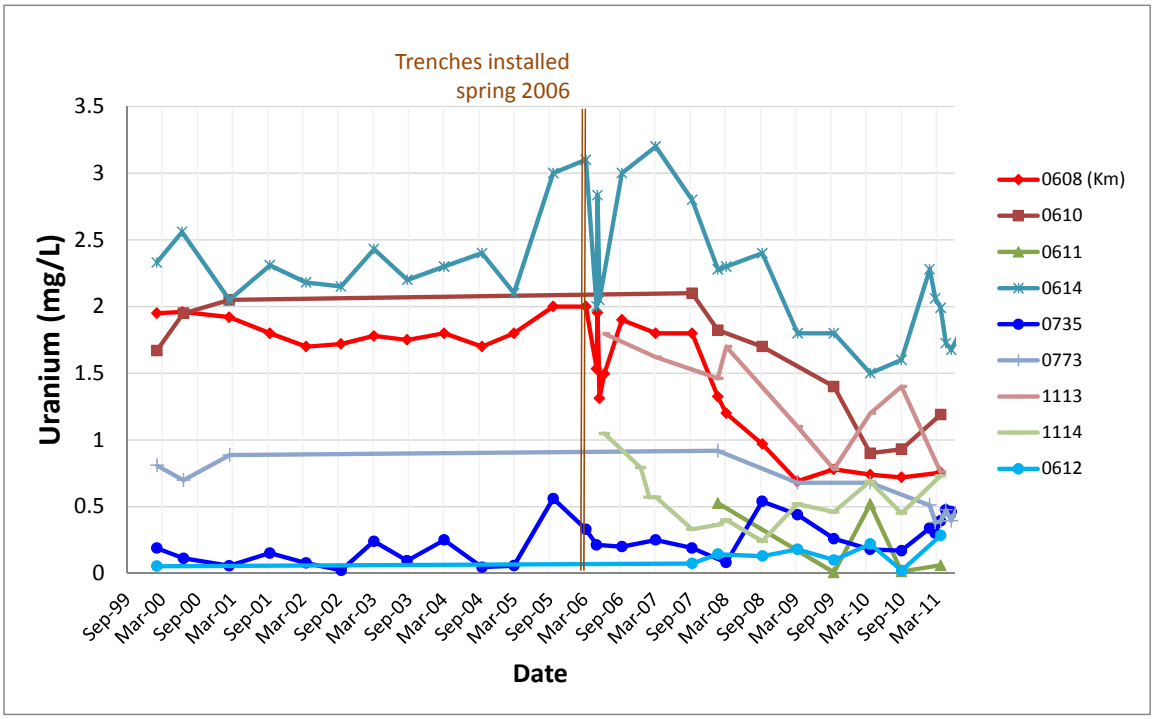


Figure 28. Uranium Trends in Southeastern Floodplain Wells

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).

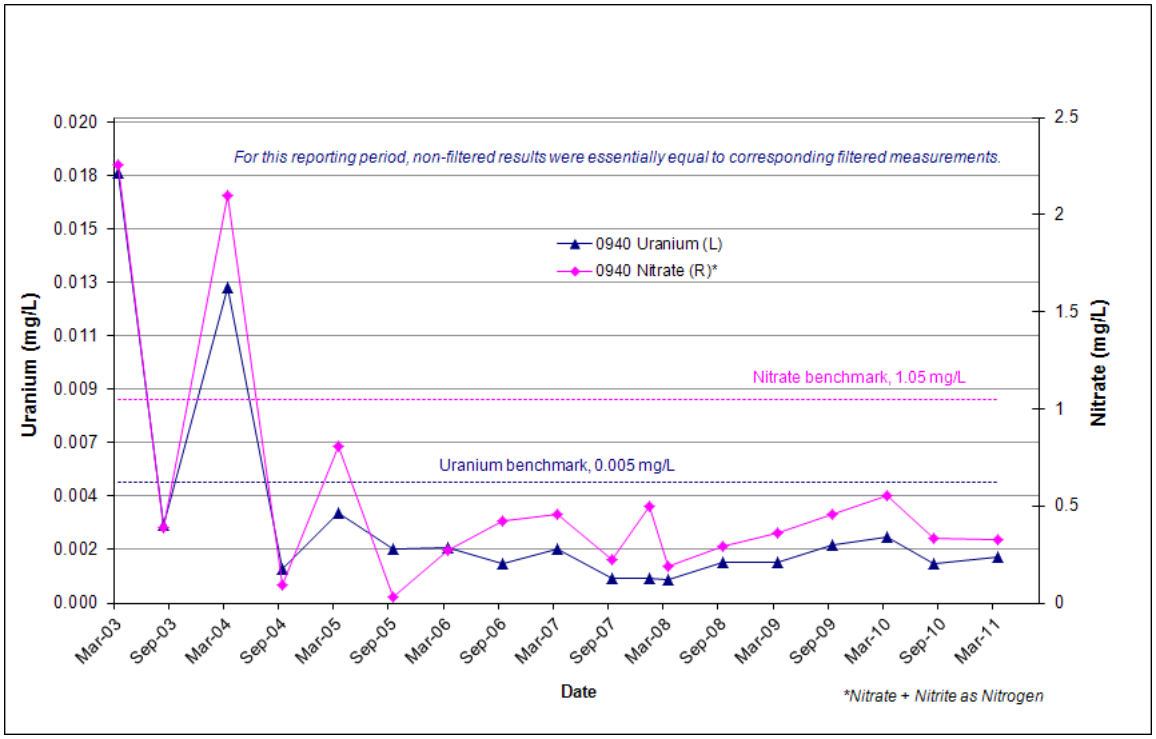


Figure 29. Uranium and Nitrate Concentrations in the San Juan River (Location 0940)

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.

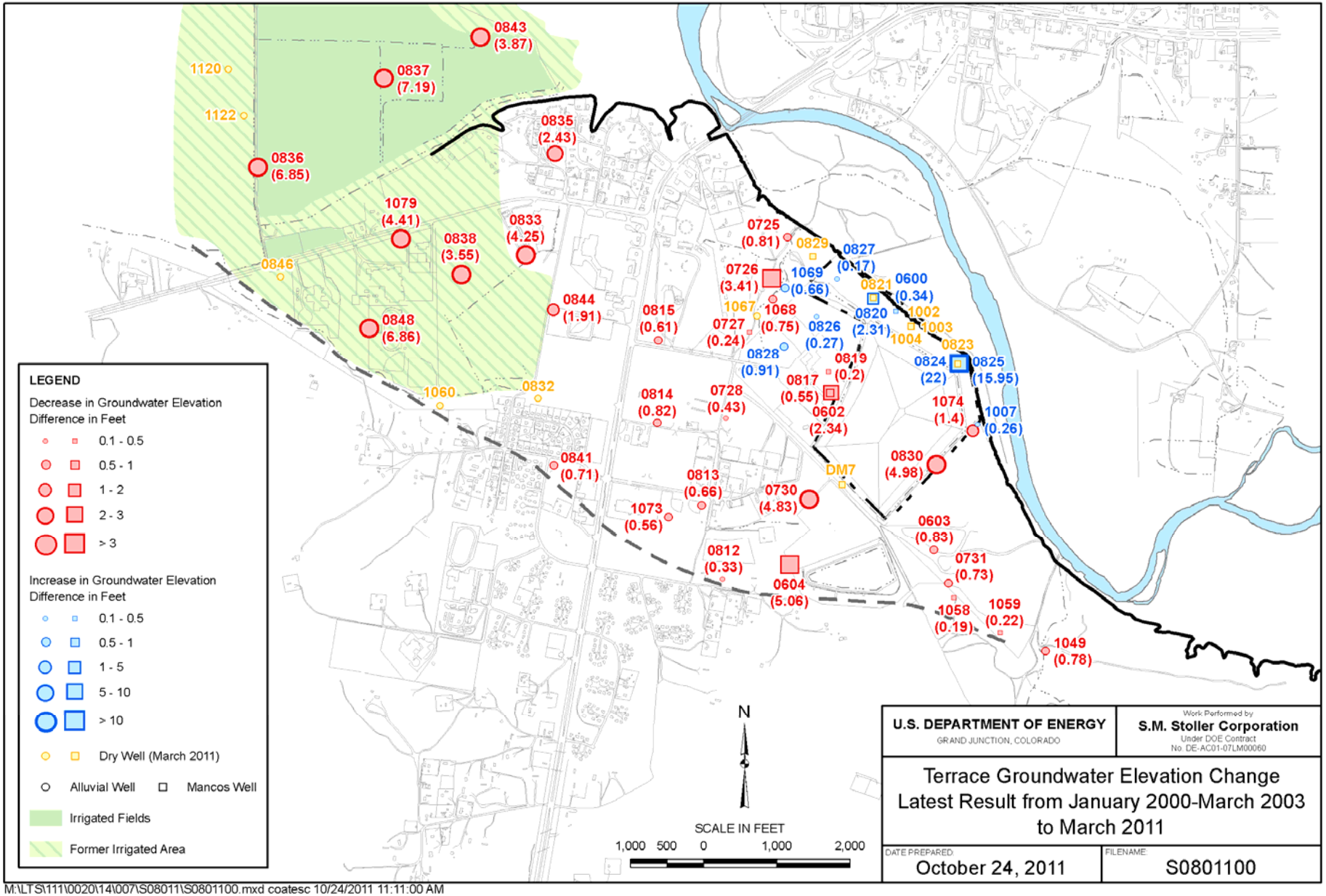


Figure 30. Terrace Groundwater Elevation Changes from Baseline (2000–2003) to Current (March 2011) Conditions

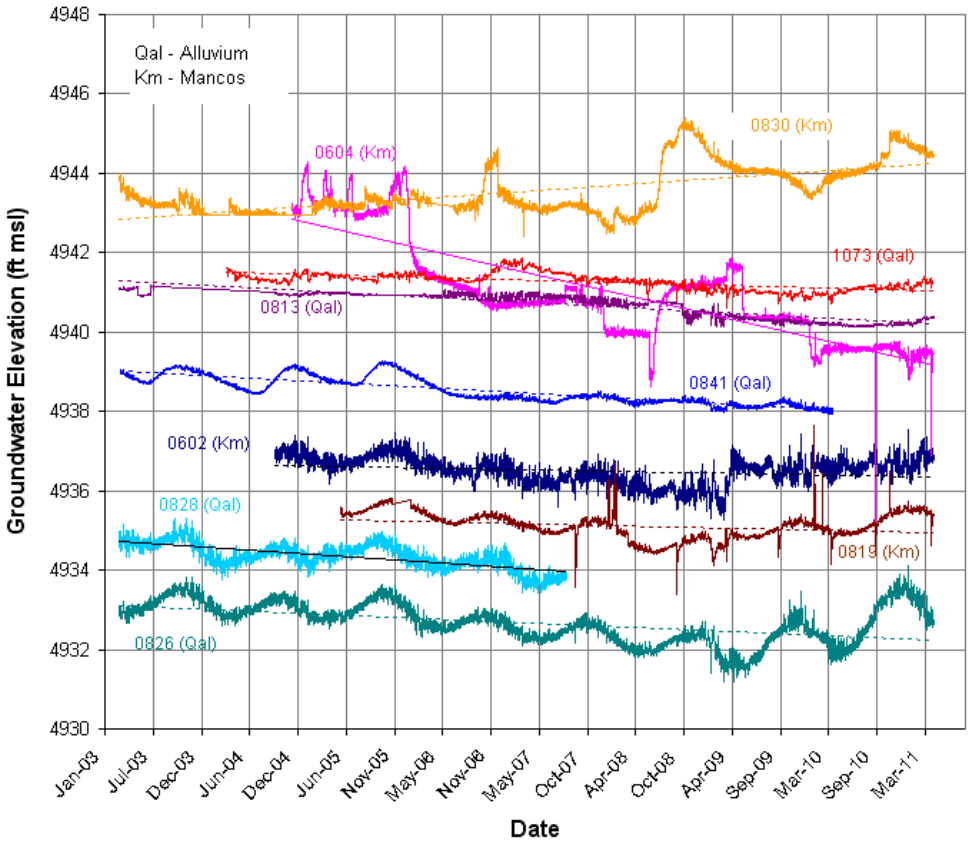


Figure 31. Terrace Datalogger Measurements, Wells with Water Elevations above 4930 ft

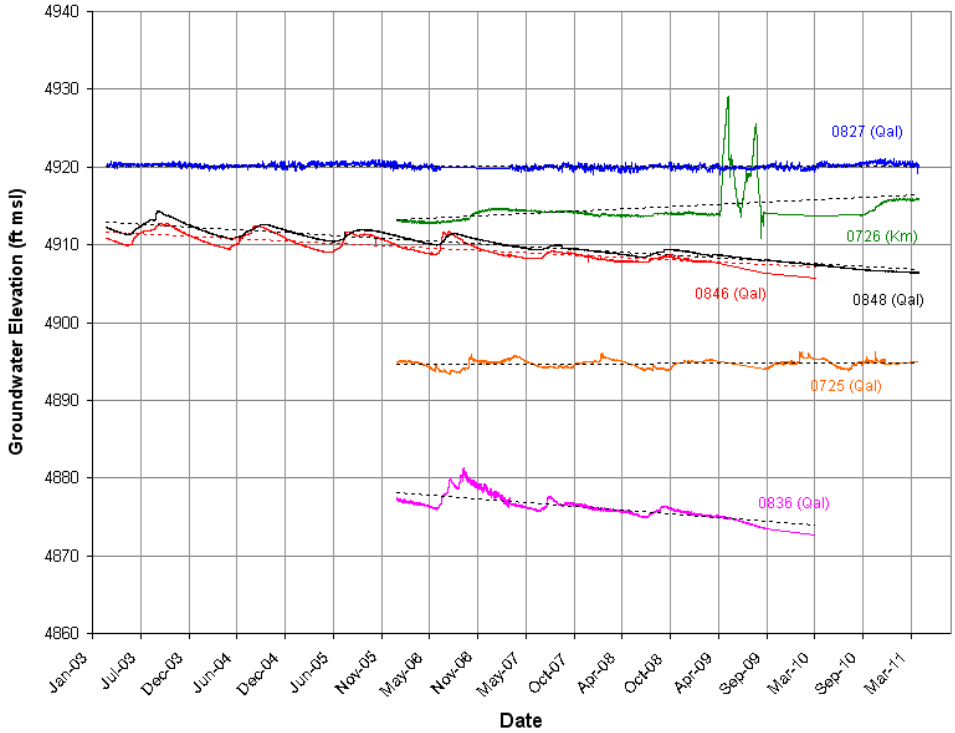
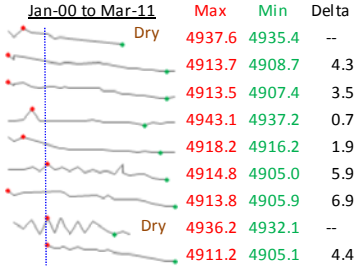


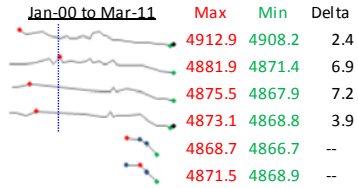
Figure 32. Terrace Datalogger Measurements, Deeper Wells

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)



Northwest Terrace Subset (North of Hwy 64)



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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