5.0 Conceptual Site Model

The conceptual site model is based on the characterization information and will be used to assess site conditions, evaluate the potential for risk to human health and the environment, assess manageable uncertainties, and determine the compliance strategy for ground water protection at the site.

5.1 Hydrogeology

5.1.1 Geologic Setting

The Dolores River alluvium at the Slick Rock site generally ranges from 15 to 20 ft in thickness, although only 10 ft of alluvial material was measured next to the Dolores River at well 0320. The unconsolidated alluvial material consists primarily of silty sands and silty sandy gravels with an occasional interbedded clay lens. The Dolores River alluvium is laterally restricted by bedrock that forms the terraces and canyon walls adjacent to the river. The Dolores River floodplain is discontinuous and pinches out in areas where the river meets the canyon wall. Alluvial material also occurs on the terraces adjacent to the river and is topographically and hydrologically isolated from the Dolores River alluvium. The terrace alluvial deposits are typically unsaturated as indicated by monitor wells at the UC site (which are dry) and the gravel operation located on the terrace between the two sites (no dewatering required for mining).

5.1.1.1 NC Site

The Salt Wash Member of the Jurassic Morrison Formation and the Jurassic Summerville Formation underlie the alluvium at the NC site. The Salt Wash Member consists of light-buff to light-reddish-brown lenticular fine-grained sandstone layers intercalated with reddish-brown mudstone layers. The ratio of cumulative sandstone to cumulative mudstone thickness most commonly ranges from 1:1 to 2:1. The Summerville Formation, which underlies the Morrison Formation, is mainly composed of evenly bedded reddish-brown mudstone and siltstone with some very fine to fine-grained sandstone (Shawe et al. 1968). A geologic map (Cater 1955) detailing the stratigraphy of the Slick Rock area is shown in Figure 5–1. In the regional geologic setting, the Slick Rock site is situated on the flank of the Disappointment Syncline, with bedrock units dipping 6° to the northeast. A geologic cross section of the NC site is shown in Figure 5–2.

5.1.1.2 UC Site

The hydrostratigraphic units at the UC site are, in descending stratigraphic order, the Quaternary Dolores River alluvium/terrace alluvium, the Jurassic Entrada Sandstone, and the Jurassic Navajo Sandstone. Based on historical drilling programs at the UC site, the Entrada Sandstone is 40 to 60 ft thick in the floodplain area and 20 to 80 ft thick on the terrace. Previous drilling programs did not penetrate the base of the Navajo Formation, but the thickness at the UC site is estimated at 180 ft (Shawe et al. 1968). Figure 5–3 shows a geologic cross section of the UC site.

5.1.2 Hydrologic System

The major components of the hydrologic system near the Slick Rock site includes the Dolores River, alluvial sediments, and bedrock units (Entrada and Navajo aquifers) underlying the alluvial sediments.

5.1.2.1 Alluvial Aquifer

Bedrock outcrops through the Dolores River valley dictate the extent of the alluvial sediments that make up the alluvial aquifer. The Morrison Formation controls the lateral extent of the alluvial aquifer near the NC site. At the UC site, the lateral extent of the alluvial aquifer is controlled by the Entrada Sandstone to the west and the Morrison/Summerville Formations to the east (Figure 5–1).

Ground water is unconfined in the alluvial aquifer underlying the Slick Rock site, with the flow direction controlled by the canyon and terrace walls of the Dolores River Valley. Figure 5–4 shows the alluvial ground water surface contours generated from the March 2001 water level measurements. As shown in the figure, ground water in the vicinity of the NC site flows toward the west-northwest, with a gradient of 0.0047 ft/ft. In the vicinity of the UC site, alluvial ground water flows toward the north-northwest with a gradient of 0.004.

Depth to ground water varies from 7 ft (well 0302) to 13 ft (well 0309) below ground surface in the vicinity of the NC site, which results in a saturated thickness ranging from 4 to 10 ft. In the floodplain between the NC and UC sites, the depth to ground water ranges from 13 ft (wells 0328, 0329, 0330, and 0331) to 15 ft (well 0312) below ground surface. Near the UC site the depth to ground water ranges from 3 ft (wells 0320, 0508, and 0510) to 14 ft (well 0684 cluster) below ground surface, resulting in a saturated thickness ranging from 6 to 12 ft. Historically, the ground water elevations have peaked in the spring months and may fluctuate 2 to 3 ft.

Hydraulic conductivity estimates range from 13 to over 300 ft/day, with a geometric mean of 121 ft/day (Appendix G). Assuming an effective porosity of 0.25 and an average gradient of 0.0043, the average linear ground water velocity for the alluvial sediments is 2.1 ft/day.

5.1.2.2 Entrada Sandstone Aquifer

The Entrada Sandstone aquifer (Entrada aquifer) underlies the alluvium at the UC site; the Morrison and Summerville Formations that directly underlie the NC site were not hydrologically characterized during the field investigation. The only hydrologic information regarding these aquifers is available through the literature.

In the shallow zones of the Entrada aquifer, ground water appears to be unconfined; however, within the deeper zones of the aquifer ground water is expected to be confined. In floodplain wells 0317 and 0324, depth to ground water ranges from 6 to 8 ft below ground surface, which is comparable to the depth to ground water measured in wells screened in the alluvial aquifer in the same area. Depth to water in wells completed in the Entrada aquifer on top of the terrace (wells 0325 and 0326) ranges from 36 to 55 ft below ground surface. Historically, ground water elevations within the Entrada have peaked during the spring with fluctuations of 3 to 4 ft.

Qal	**Alluvium**: Light-red wind-deposited sand and silt on benches and mesa tops, reworked in part by water; Recent valley fill and stream deposits.
Qg	**Terrace gravel**
Kbc	**Burro Canyon Formation**: White, gray, and red sandstone and conglomerate with interbedded green and purplish shale.
Jmb Jms	**Morrison Formation**: Variegated shale and mudstone; white, gray, rusty-red, and buff sandstone; rusty-red conglomerate; local thin limestone beds. At the top is the Brushy Basin Member, Jmb, consisting largely of bentonitic shale but including some sandstone and conglomerate lenses; and at the base, the Salt Wash Member, Jms, with more numerous and thicker sandstone beds.
Js	**Summerville Formation**: Thin-bedded red, gray, green, and brown sandy shale and mudstone.
Je	**Entrada Sandstone**: Orange, buff, and white, fine grained, massive and cross-bedded Entrada Sandstone at the top. Reddish-brown, very fine grained sandstone and siltstone at the base.
Jn	**Navajo Sandstone**: Buff and gray cross-bedded fine grained sandstone.
6000	**Structure contours**: Drawn on top of Entrada Sandstone; dashed where approximately located; short dashes indicate projection above surface. Contour interval 100 feet. Datum is mean sea level.
A —— A′	**Line of cross section**

N

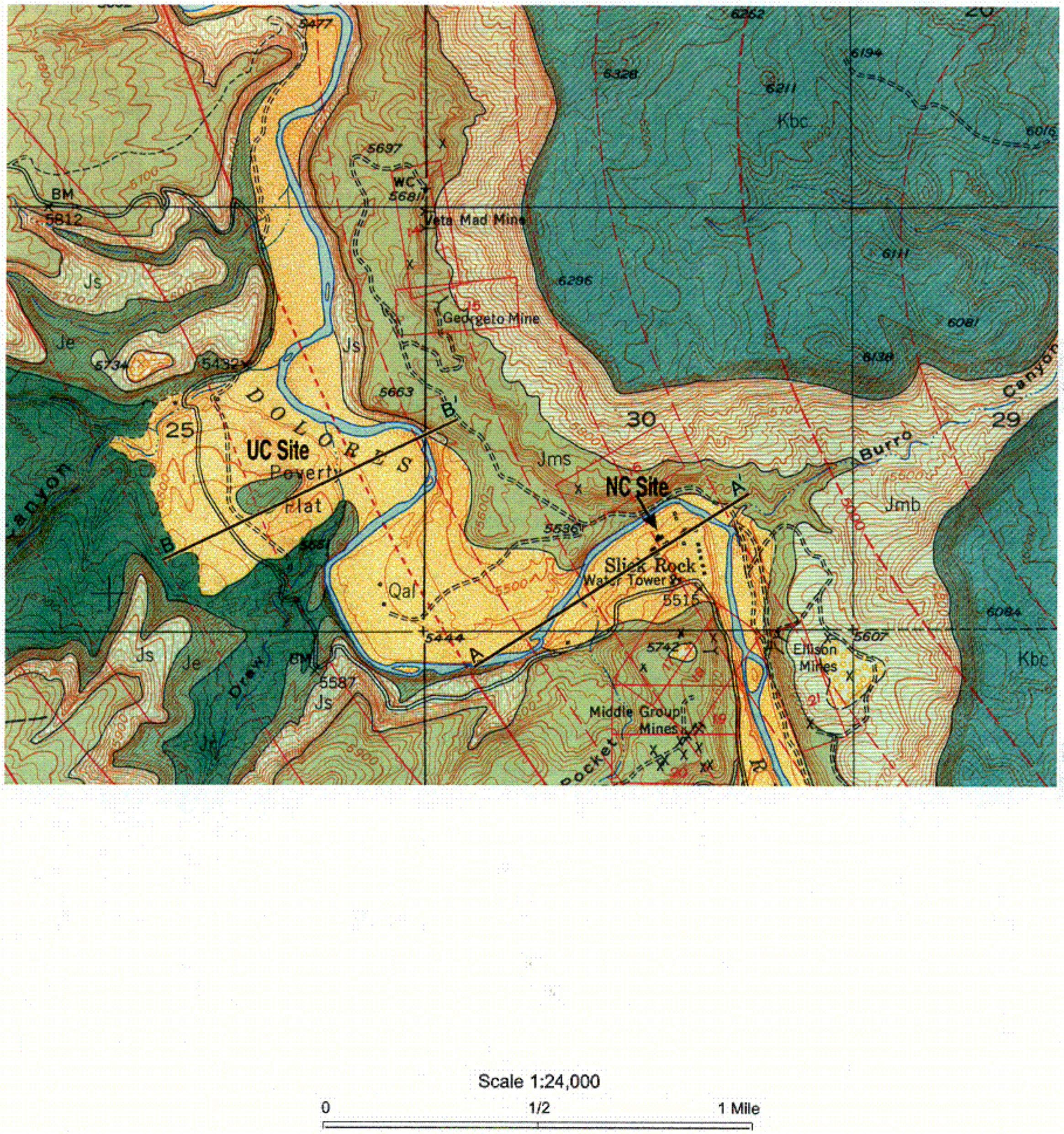

Figure 5–1. Geologic Map of the Slick Rock Area

CD1

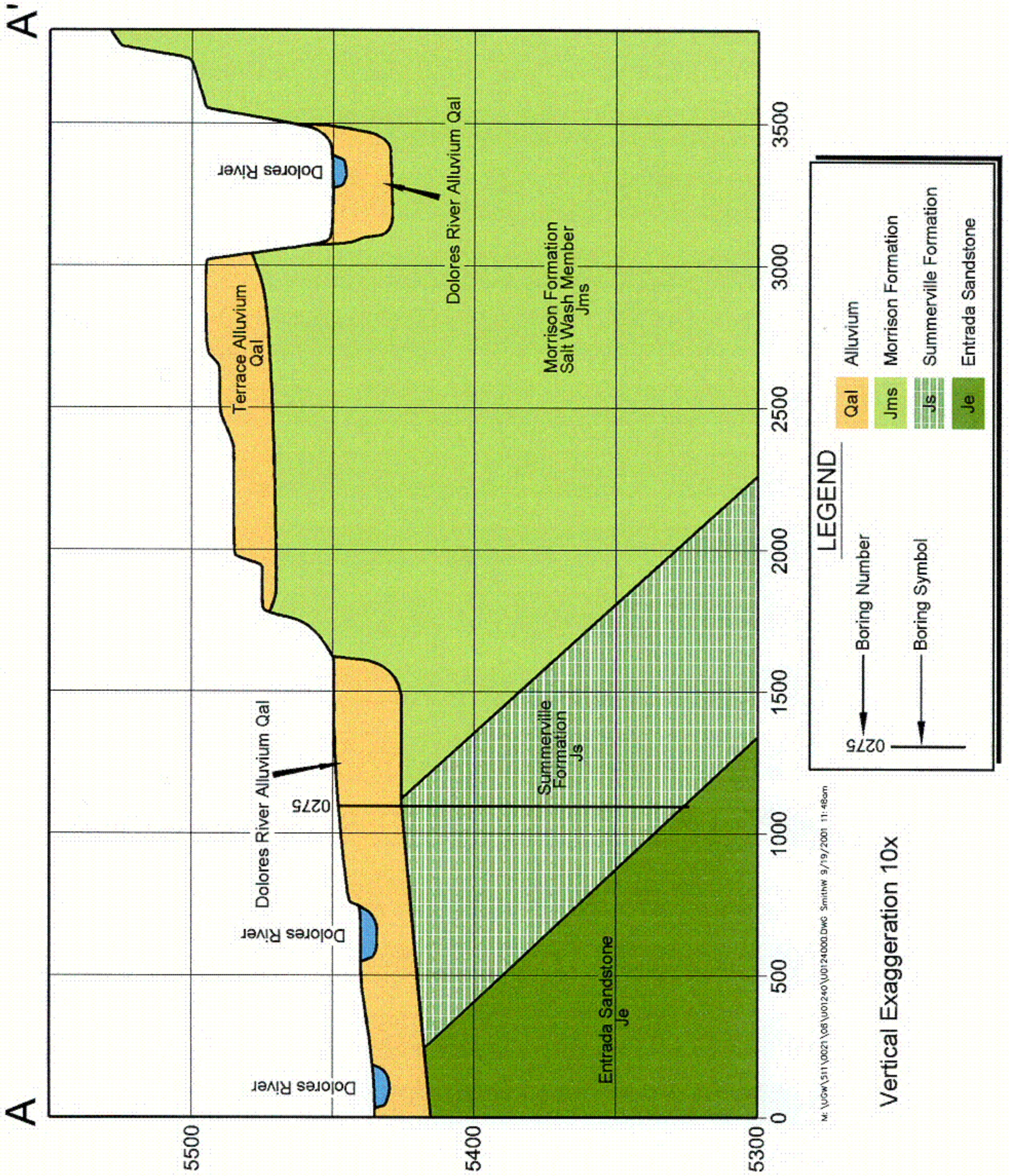

Figure 5–2. Geologic Cross Section of the NC Site

C02

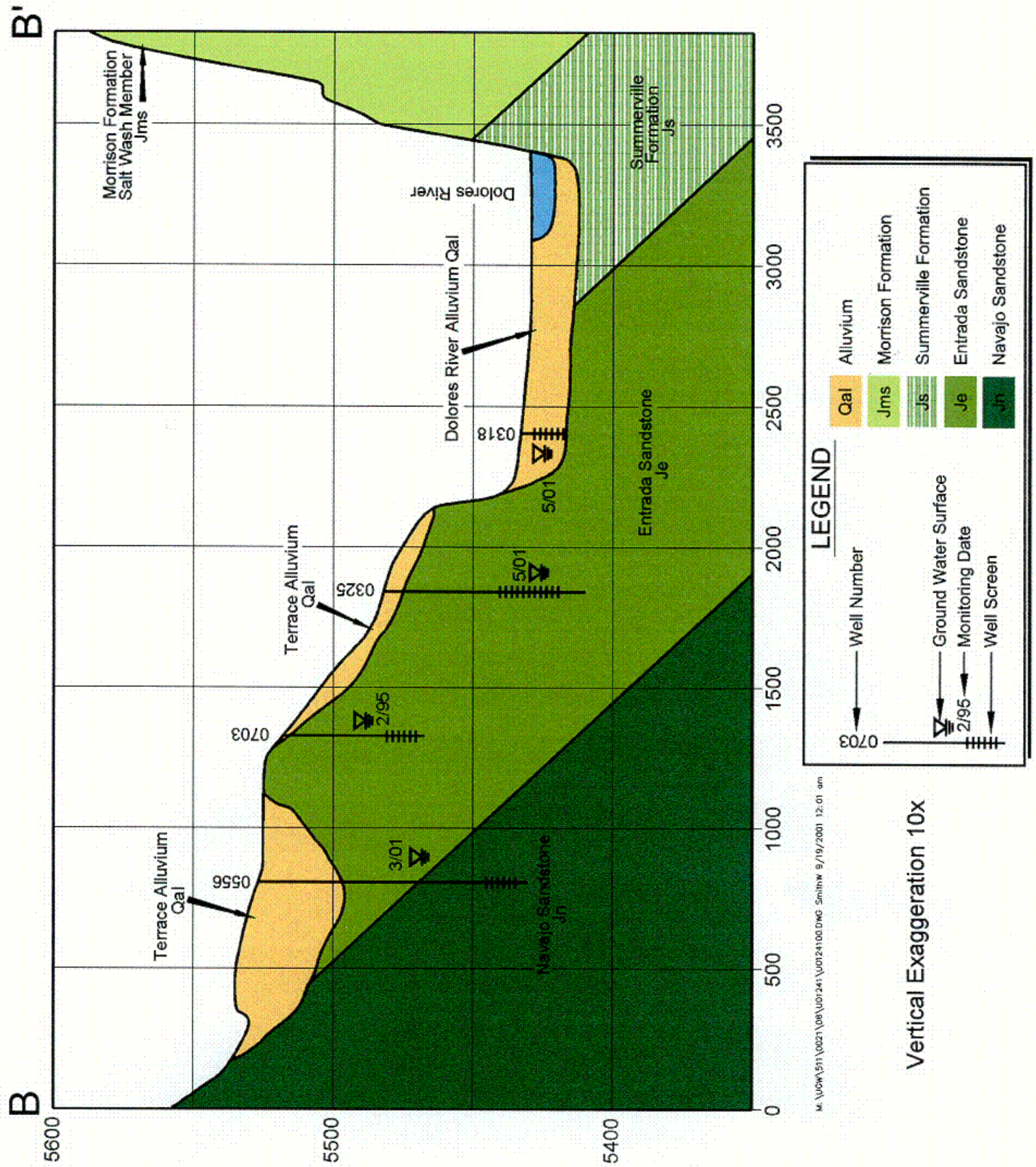

Figure 5–3. Geologic Cross Section of the UC Site

C03

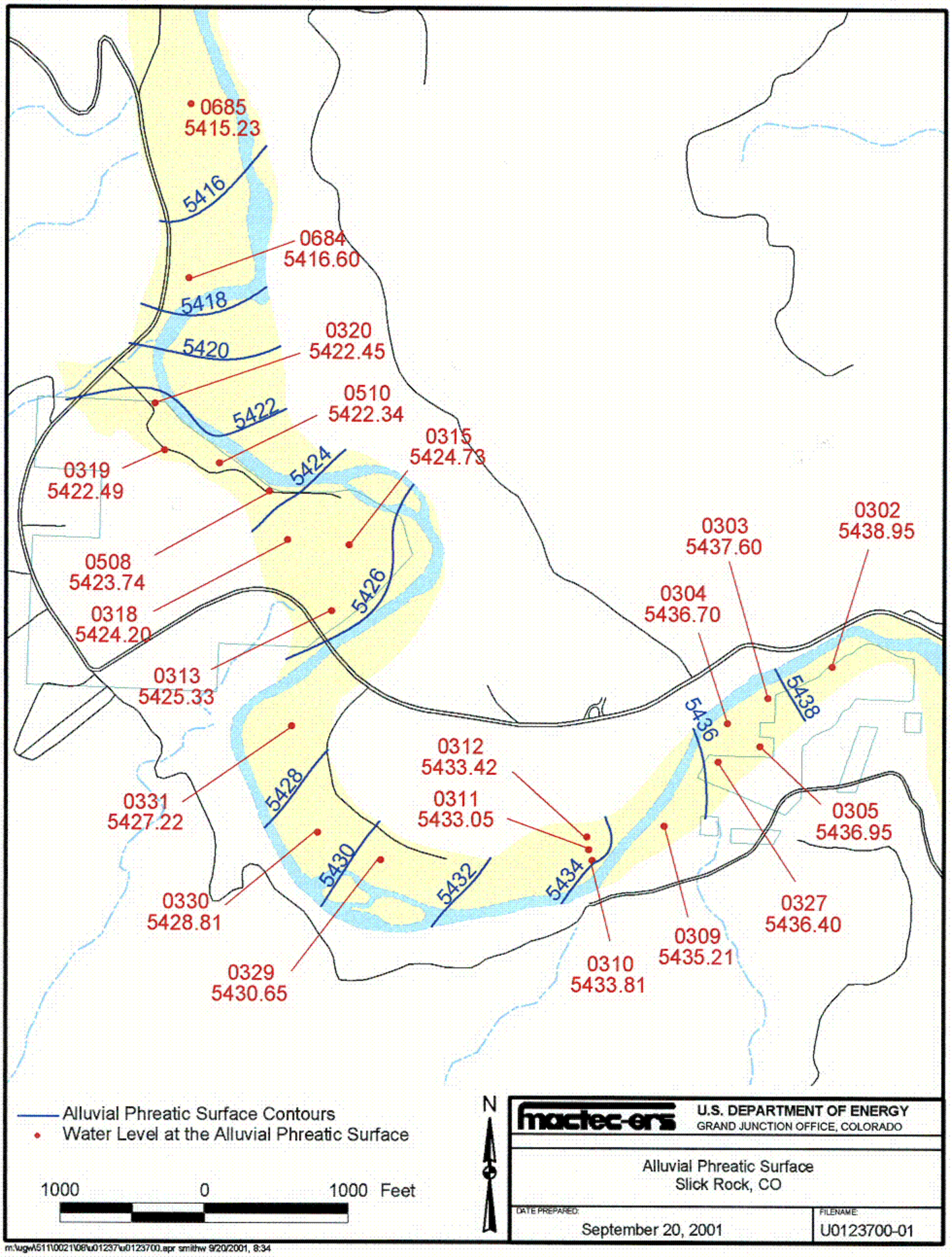

Figure 5–4. Alluvial Aquifer Ground Water Elevation Contour Map

C04

Figure 5–5 is the ground water surface contour map for the Entrada aquifer based on March 2001 water level data. The ground water flow direction is towards the east, which follows the dip direction of the Entrada Sandstone at this location. The average ground water gradient is 0.0125 ft/ft. Limited aquifer testing indicates the hydraulic conductivity of the Entrada is 1.5 ft/day, which is in agreement with values published in the literature. Assuming an effective porosity of 0.15, the average linear velocity of ground water in the Entrada aquifer is 0.1 ft/day.

5.1.2.3 Navajo Sandstone Aquifer

Underlying both Slick Rock site is the confined Navajo Sandstone aquifer (Navajo aquifer). Wells completed in the Navajo aquifer on the floodplain at the UC site (wells 0669 and 0670) are under artesian pressure. Depths to ground water in Navajo aquifer wells located outside the UC floodplain have ranged from 28 ft (well 0688) to 60 ft (well 0668); historical fluctuations vary up to 8 ft. Only one well is completed in the Navajo aquifer at the NC site; well 0687 is located on the terrace above the Dolores River floodplain. Depth to ground water in this well is approximately 40 ft below ground surface; the historical fluctuation is 6 ft. Wells 0690 and 0672 (domestic well) are also completed in the Navajo aquifer and are located on the terrace between the two sites.

Figure 5–6 is the potentiometric surface contour map of the Navajo aquifer generated from March 2001 water level data. Ground water flows toward the north-northeast with an average gradient of 0.021 ft/ft.

5.1.2.4 Aquifer Interaction

Figure 5–7 shows the ground water elevation data collected from October 2000 through April 2001 in wells 0320 (alluvial aquifer), 0324 (Entrada aquifer), and 0688 (Navajo aquifer). The Dolores River flow during this time is also plotted. The water level fluctuations in the alluvial and Entrada aquifers appear to be similar, suggesting a connection between the two units. The fluctuations of the Navajo appear to be independent of the alluvial and Entrada aquifers.

Table 5–1 presents the water level data collected from the well 0509/0317 cluster and the well 0508/0324/0669 cluster, and associated vertical gradients. The data indicate a small upward gradient between the alluvial and Entrada aquifers and, as expected, a stronger upward gradient between the alluvial and Entrada aquifers and the Navajo aquifer. The complete set of water level data is located in Appendix C (CD ROM format).

5.1.2.5 Aquifer Recharge/Discharge

The Dolores River appears to be the main recharge source for the alluvial aquifer and the upper zone of the Entrada aquifer. The Navajo aquifer receives recharge primarily from infiltration of precipitation in upgradient areas where the formation crops out.

Ground water discharges from the alluvial aquifer into the Dolores River during low-flow stages of the river. Another significant source of ground water discharge from the alluvial aquifer is transpiration by the phreatophytes along the Dolores River banks. The shallow zone of the Entrada aquifer contributes discharge through minor leakage into the overlying alluvium, and discharge from the deeper zone appears as seeps in areas downgradient where the Entrada Sandstone crops out. The Navajo aquifer discharges as leakage into the overlying Entrada.

Table 5–1. Vertical Gradients Between the Alluvial, Entrada, and Navajo Aquifers

Well	Aquifer	Screen Mid-point Elevation (ft MSL)	Date of Water Level Measurement			
			09/13/2000	10/20/2000	03/27/2001	05/17/2001
0509	Alluvial	5,417.8	5,424.13	5,424.17	5,424.6	5,424.83
0317	Entrada	5,403.3	5,424.14	5,424.34	5,424.78	5,424.94
Gradient Between the Alluvial and Entrada Aquifers			–0.0007	–0.0117	–0.0124	–0.0076

Well	Aquifer	Screen Mid-point Elevation (ft MSL)	Date of Water Level Measurement			
			09/13/2000	10/20/2000	03/27/2001	05/17/2001
0508	Alluvial	5415.3	5,423.33	5,423.3	5,423.74	5,423.71
0324	Entrada	5403.1	5,423.25	5,423.43	5,423.65	NA
0669*	Navajo	5326.5	5,430.26	5,430.26	5,430.26	5,430.26
Gradient Between the Alluvial and Entrada			0.0066	–0.0107	0.0074	NA
Gradient Between the Entrada and Navajo			–0.0915	–0.0892	–0.0863	NA
Gradient Between the Alluvial and Navajo			–0.0780	–0.0784	–0.0734	–0.0738

Notes: * = Ground water is under artesian conditions; ground water elevation represents the top of the casing.
All ground water elevations are feet above mean sea level.
Negative gradient indicates an upward direction.
NA = not measured or calculated.

5.1.2.6 Surface Water Interaction

The Dolores River significantly influences the alluvial aquifer and the shallow zones of the Entrada. Daily mean streamflow data in cubic feet per second (cfs) are available from the USGS gaging station located just upgradient from the UC site (USGS Station 09168730). Figure 5–8, which shows the peak Dolores River flow from the spring runoff during 2000, also shows a correlation between the alluvial aquifer ground water elevation and the Dolores River streamflow. Although water level data from the Entrada aquifer were not available to include in this figure, Figure 5–7 shows that water level fluctuation in the Entrada aquifer is similar to that in the alluvial aquifer and tends to respond to changes in the Dolores River flow.

Figure 5–8 also shows the response in the Navajo aquifer after the peak Dolores River flow. Although the Navajo aquifer appears to respond to the drop in river flow, the data are insufficient to determine if this is a constant trend.

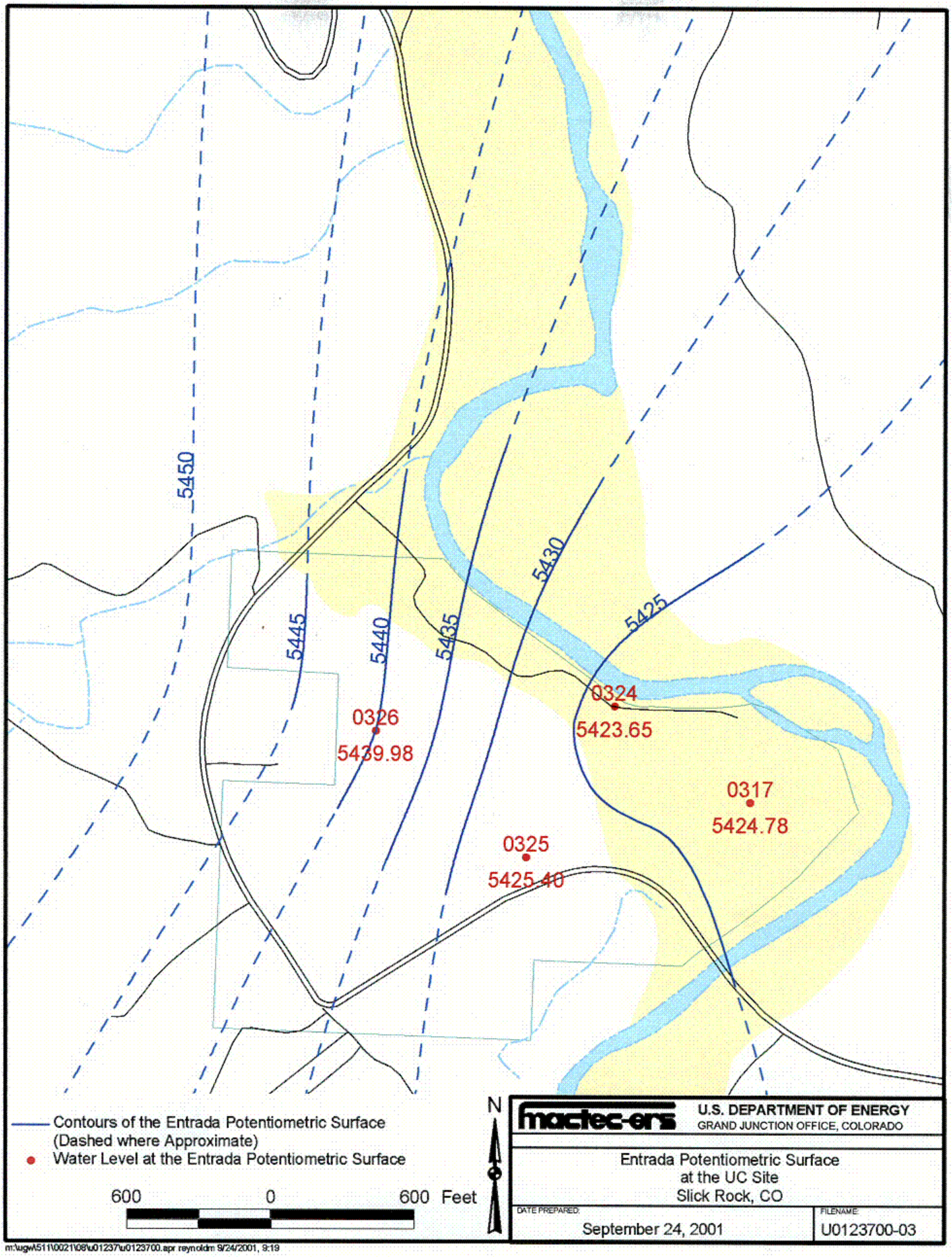

Figure 5–5. Entrada Aquifer Ground Water Elevation Contour Map

C05

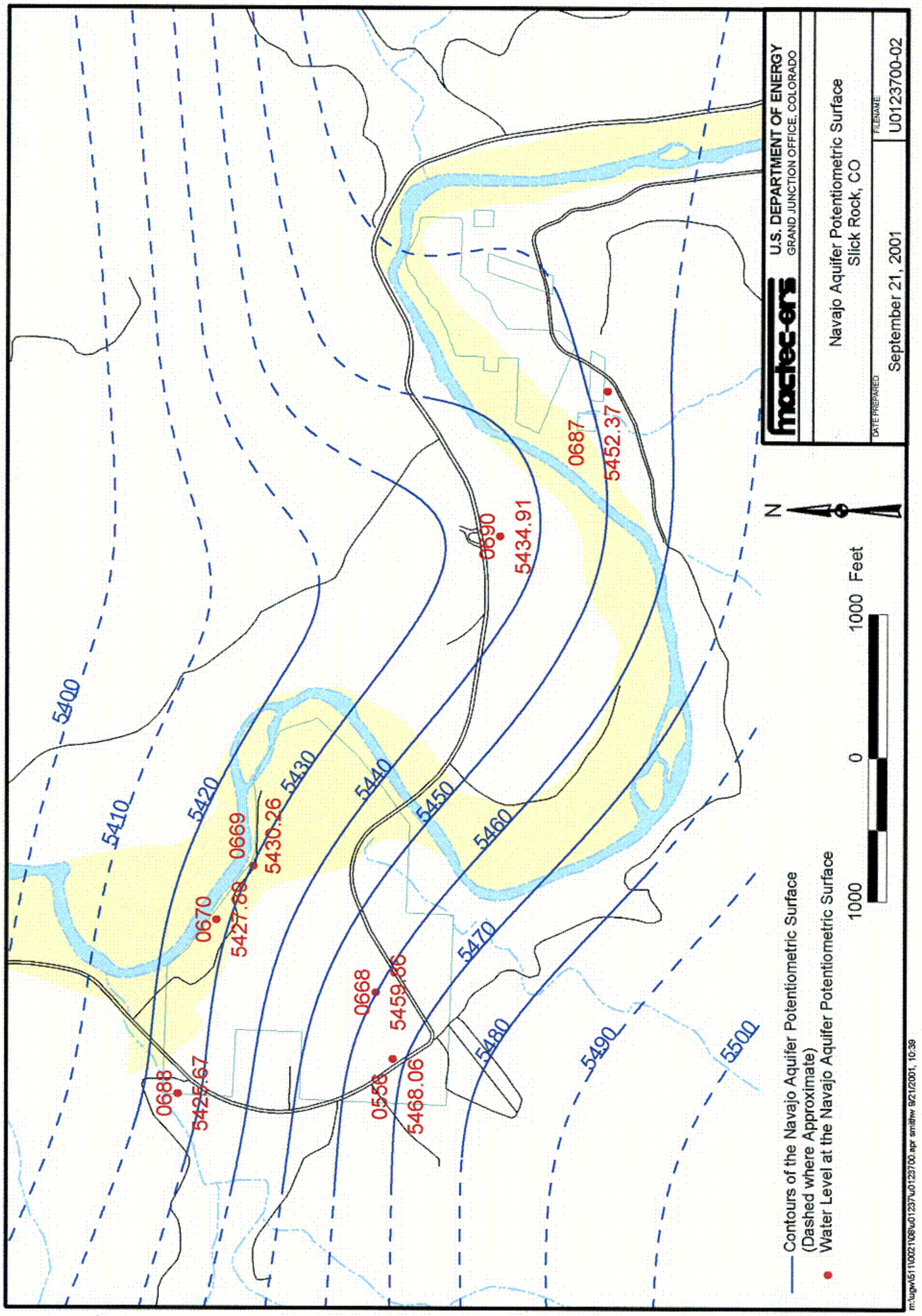

Figure 5–6. Navajo Aquifer Ground Water Contour Map

C06

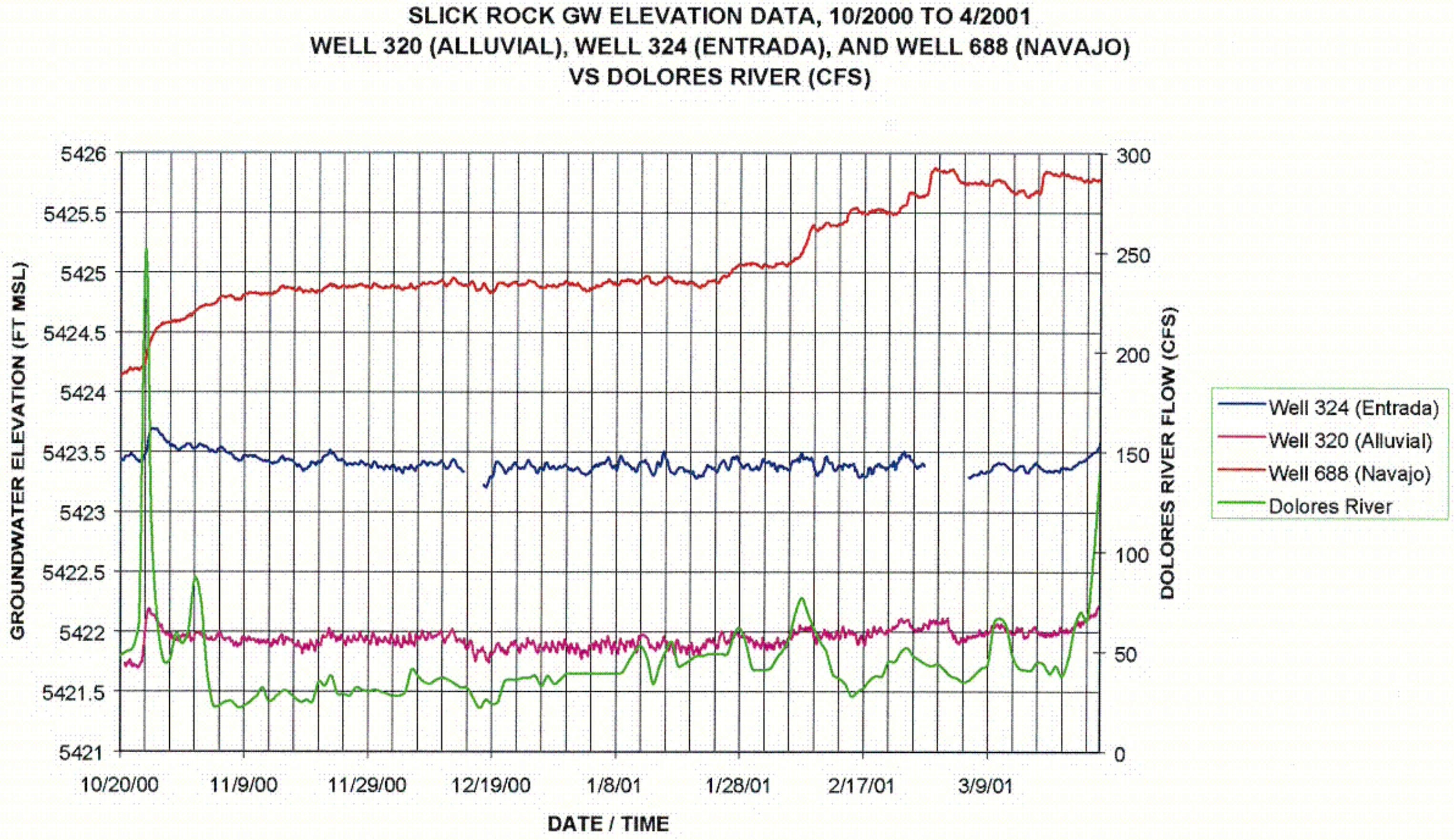

Figure 5–7. Slick Rock Ground Water Elevation Data, October 2000 through April 2001

C07

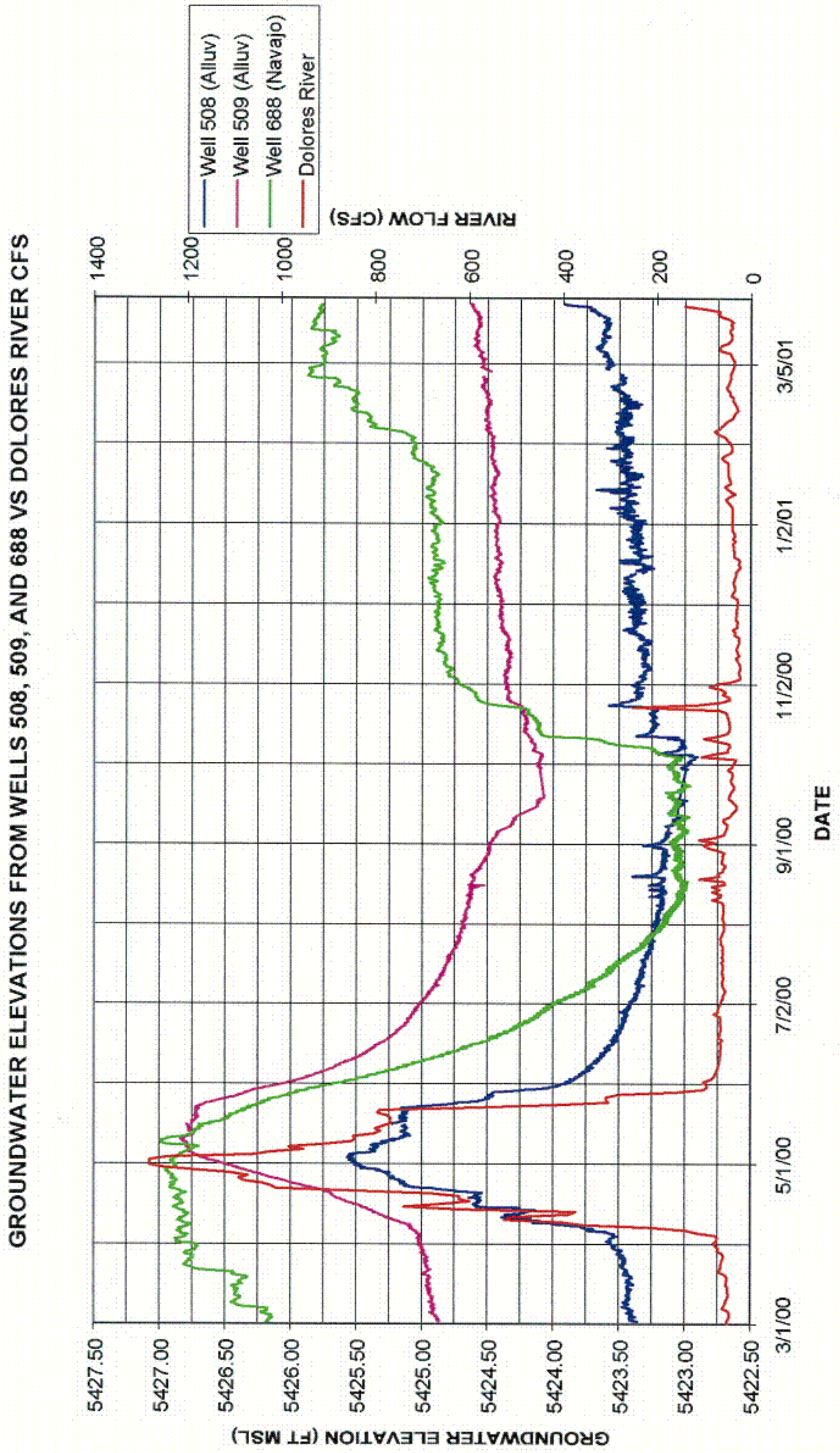

Figure 5–8. Ground Water Elevations During the 2000 Peak Flow

C08

5.2 Geochemistry

DOE has collected ground water, surface water, and soil data at the Slick Rock site for the last 10 years. Data from these sampling events were used to assess the geochemical conditions at the Slick Rock site. The comprehensive data resides in the SEE-Pro database at DOE–GJO.

Monitor well locations are displayed in Figure 4–2 and Figure 4–3, and surface water sampling locations are shown on Figure 4–10 and Figure 4–11. Recent surface water and ground water sample results are presented in Appendix D, and the entire ground water and surface water database is provided in Appendices E and F (CD-ROM format) in this document.

Data used to assess ground water quality were from recent sampling events in the fall and spring of 2000/2001. The comprehensive data set was reviewed to ensure that these data were representative of the long-term record.

5.2.1 Surface Water Quality

The Dolores River is the only perennial surface water feature in the vicinity of the Slick Rock site. Sampling locations on the Dolores River are shown in Figure 4–10 and Figure 4–11; data collected from these sampling locations are summarized in Table 5–2.

A review of the major ion geochemistry (calcium, sodium, sulfate, chloride, and alkalinity) reveals no substantive differences among the sample locations except for an apparent depletion (less than a factor of two) of sodium and sulfate at sample locations 0346, 0347, and 0349 adjacent to the UC site. This apparent difference in the 95 percent upper confidence limit (UCL_{95}) is attributed to the small data set (only three data points) from the locations adjacent to the site. In general, water quality in the Dolores River reflects its high desert environment and the effects of spring runoff from the mountains. For these reasons, general water quality indicators such as total dissolved solids and specific conductance can vary by up to a factor of ten for a particular sample location (Table 5–2).

5.2.1.1 NC Site

The data were examined to determine whether contaminants attributable to the uranium-milling operations were being added to the river. Site-related contaminants that may pose an unacceptable risk to human health or the environment are listed as COPCs in Section 6.0. At the NC site, ground water COPCs are selenium and uranium. Figure 5–9 shows the ratio of UCL_{95} at locations adjacent to and downstream of the site to the UCL_{95} at upstream location 0696. The figure shows that selenium and uranium concentrations do not change significantly as the river flows past the NC site. In addition, selenium and uranium concentrations are well below levels of environmental concern. The surface water sampling program, therefore, demonstrates that the contaminated alluvial ground water at the NC site has no significant effect on water quality in the Dolores River.

5.2.1.2 UC Site

As with the NC site, the data were examined to determine whether contaminants attributable to the former milling operations were being added to the river. Inorganic ground water COPCs at the UC site are manganese, molybdenum, nitrate, selenium, uranium, radium-226, and radium-228. A review of Table 5–2 indicates that there are no significant increases in concentration for molybdenum, selenium, uranium, radium-226, and radium-228 (Figure 5–9) as the river flows across the UC site, and selenium concentrations are less than the ecological risk-based benchmark of 0.005 mg/L.

Table 5–2 and Figure 5–10 show that the UCL_{95} for ammonium, manganese, and nitrate increases adjacent to and downstream of the UC site. Although results indicate that ground water from the UC site is contributing these ions to the Dolores River, the concentrations of these contaminants are well below applicable standards or risk-based benchmarks. Moreover, samples collected alongside the UC site were from locations such as back-eddies where contamination would likely be highest. These concentrations are probably highly localized and persist for only a few feet near the riverbank. The surface water sampling program, therefore, demonstrates that the contaminated ground water at the UC site has no significant effect on water quality in the Dolores River.

5.2.2 Ground Water Quality

Ground water quality of the alluvial aquifer from September 2000 through March 2001 is summarized in Table 5–3 through Table 5–7; these tables contain data from background, NC on site, NC downgradient, UC on site, and UC downgradient wells, respectively.

5.2.2.1 Background Water Quality

Monitor wells 0300 and 0301 were installed to determine background water quality (Figure 4–2). The wells show no evidence of site-related contamination, but contain ground water under conditions more reducing than the wells in the tailings area. This conclusion is based both on measurements of oxidation-reduction potential (ORP) and by the presence of soluble iron and manganese, which are typically soluble only under conditions of low ORP. Although well 0300 has a much higher TDS (7,700 mg/L) than well 0301 (1,700 mg/L), both wells have more dissolved ions than are found in clean alluvial wells within and downgradient of the tailings areas where the TDS is less than 1,000 mg/L.

Several of the COPCs (e.g., nitrate, selenium) were not detected in high concentrations in background samples, and background values can be assumed to be near the detection limits. On the other hand, the background value for uranium is an issue on the Colorado Plateau because natural uranium is present at many locations. Because uranium is a COPC at both the NC and UC sites, the distribution of uranium in wells at the Slick Rock site was reviewed to determine if observed concentrations in off-site wells are indicative of site impacts or represent variations in background.

Alluvial wells 0310 and 0312 are located across the river but downgradient of the NC site (Figure 4–2). Water in these wells has a uranium content greater than 0.01 mg/L, which is an order of magnitude higher than in background well 0301 but similar to the concentrations in background well 0300 and downgradient well 0685, which is assumed to be outside the influence of the UC site. Ground water in well 0311, which is located between 0310 and 0312, has a uranium content of approximately 0.04 mg/L. However, water in wells 0310, 0311, and 0312 have much lower sulfate (by an order of magnitude) and chloride concentrations than the wells at the NC site, indicating that ground water from the NC site has not reached these wells on the opposite side of the river (see Section 5.2.2.3). In addition, there is no other evidence that ground water in well 0311 is contaminated, and the proximity to wells 0310 and 0312 indicates that there is not a contaminant plume present. Therefore, the elevated uranium concentrations are attributable to fluctuations in natural background or possibly a localized source.

Table 5–2. Summary of Dolores River Water Quality[a]

Analyte	Unit[b]	NC Site Upstream[c]				NC Site Adjacent				UC Site Upstream				UC Site Adjacent				UC Site Downstream			
		FOD[d]	Mean[d]	Range	UCL_{95}[e,f]	FOD	Mean	Range	UCL_{95}	FOD	Mean	Range	UCL_{95}	FOD	Mean	Range	UCL_{95}	FOD	Mean	Range	UCL_{95}
Field Measurements																					
Alkalinity as $CaCO_3$	mg/L	6/6	113.8	88–181	142.3	6/6	105.3	82–133	119.8	6/6	102.2	88–117	110.6	3/3	96.67	67–126	146.4	6/6	104.8	89–123	114.8
Oxidation Reduction Potential	mV	7/7	95	-30–234	164.8	8/8	166.9	3–471.1	257.7	9/9	169.9	-76–424	255.2	3/3	205.7	192–226	235.9	8/8	198.6	108–475	276.2
Specific Conductance	µmhos/cm	9/9	527.8	220–1,022	671	16/16	565.6	200–1,420	702.5	16/16	648.6	256–2,140	879.2	3/3	572.3	554–608	624.4	15/15	546.7	158–1673	713.9
Temperature	° C	9/9	7.9	.8–20.7	12.25	16/16	7.75	0.2–21	10.69	16/16	9.088	0.4–20.5	12.41	3/3	3.467	3.4–3.5	3.564	15/15	8.1	0.9–19.5	11.04
Turbidity	NTU	6/6	195.6	4.58–1,000	520.6	6/6	193.4	0.96–1,000	519	6/6	224.3	10.2–1,000	546.2	3/3	76.2	59.6–109	124.1	6/6	193.3	6.48–1,000	519
pH	s.u.	9/9	8.144	7.74–8.47	8.288	16/16	8.243	7.76–8.88	8.362	16/16	8.148	7.61–8.71	8.298	3/3	8.153	8.08–8.25	8.301	15/15	8.199	7.75–8.81	8.331
Major Ions																					
Calcium	mg/L	9/9	54.99	37.5–81.2	63.42	13/13	61.35	38–113	71.43	13/13	57.78	35.7–96.9	66.46	3/3	53.13	51.2–56.3	57.79	13/13	56.9	36.2–84	64.82
Chloride	mg/L	8/8	25.42	6.49–36.2	32.88	12/12	25.05	6.55–49	31.45	12/12	24.03	1.48–44.2	31.24	3/3	27.63	26.3–30.2	31.38	12/12	23.9	6.49–40	29.61
Magnesium	mg/L	9/9	15.17	7.7–36.6	20.8	13/13	17.67	7.49–33.4	22.24	13/13	16.81	7.46–47.6	22.22	3/3	13.8	13.1–14.8	15.3	13/13	16.45	7.56–33	20.81
Potassium	mg/L	8/8	2.094	1.54–2.82	2.384	12/12	2.195	1.51–3.7	2.53	12/12	2.132	1.53–3	2.399	3/3	1.887	1.86–1.92	1.938	12/12	2.146	1.5–3.1	2.437
Sodium	mg/L	8/8	34.55	11–87.7	50.98	12/12	36.83	10.7–79.2	47.96	12/12	38.68	10.7–115	53.43	3/3	31.43	30.2–33.4	34.34	12/12	36.93	11–75.7	48.72
Sulfate	mg/L	8/8	125.7	23.4–335	193.7	12/12	137.1	28.8–316	191.1	12/12	127.4	16–460	194.2	3/3	124.3	111–147	157.6	12/12	136.4	23–334	190.6
Metals																					
Barium	mg/L	2/2	0.09045	0.0539–0.127	0.3212	4/5	0.1052	0.052–0.2	0.1641	4/5	0.1081	0.0547–0.2	0.1675					4/5	0.1067	0.0575–0.2	0.1646
Cadmium	mg/L	1/9	0.00032	<0.0003–0.0003	0.00043	0/12	0.00035	<0.0002–<0.001	0.00044	0/12	0.00035	<0.0002–<0.001	0.00044	0/3	0.00015	<0.0003–<0.0003	0.00015	0/12	0.00035	<0.0002–<0.001	0.00044
Iron	mg/L	2/8	0.01314	<0.006–0.0241	0.01831	4/12	0.01979	<0.006–0.0594	0.0288	6/12	0.02652	<0.006–0.0937	0.04024	3/3	0.1091	0.0122–0.302	0.3908	5/12	0.02939	<0.006–0.177	0.05408
Manganese	mg/L	6/8	0.00566	<0.002–0.01	0.00778	10/12	0.00816	0.00078–0.02	0.01135	10/12	0.00681	0.0017–0.0122	0.008794	3/3	0.01147	0.0046–0.0234	0.02896	9/12	0.00999	0.0017–0.02	0.01375
Molybdenum	mg/L	5/9	0.00213	0.00089–0.0025	0.00320	7/13	0.00886	0.00087–0.02	0.01582	6/13	0.00883	<0.0008–0.02	0.0158	3/3	0.00193	0.0014–0.0028	0.00321	7/13	0.00826	.0011–.02	.01499
Nickel	mg/L					2/4	0.0175	0.01–0.02	0.02338	1/4	0.01875	<0.01–0.03	0.03088					2/4	0.02	0.01–0.03	0.02961
Selenium	mg/L	6/9	0.00153	0.00018–0.0059	0.00271	6/12	0.001538	0.00016–0.0043	0.00222	6/12	0.00156	0.00012–0.0047	0.00231	3/3	0.00076	0.00048–0.001	0.00120	6/12	0.00149	<0.0002–0.0031	0.00207
Strontium	mg/L	7/7	0.6117	0.39–0.928	0.7407	8/8	0.632	0.389–0.885	0.7431	8/8	0.6543	0.39–1.1	0.8033	3/3	0.6007	0.571–0.637	0.6571	8/8	0.6156	0.39–0.868	0.7277
Uranium	mg/L	7/9	0.00098	0.00037–0.0023	0.00136	11/13	0.00144	0.00043–0.003	0.00188	10/13	0.00162	<0.0003–0.006	0.00239	3/3	0.00143	0.0012–0.0017	0.00185	11/13	0.00120	0.00038–0.0023	0.00154
Vanadium	mg/L	0/9	0.00179	0.00098–<0.01	0.00295	1/12	0.01257	0.00046–0.03	0.02747	1/12	0.01261	0.00083–0.03	0.0275	0/3	0.00075	<0.0015–<0.0015	0.00075	1/12	0.0126	<0.001–0.03	0.0275
Zinc	mg/L	0/1	0.025	<0.05–<0.05		0/4	0.00812	<0.005–<0.05	0.02136	1/4	0.016	<0.005–0.034	0.03484					0/4	0.00812	<0.005–<0.05	0.02136
Other																					
Ammonium	mg/L	6/7	0.02952	<0.0047–0.0799	0.05106	6/10	0.03237	<0.0047–0.0569	0.04359	6/10	0.02816	<0.0047–0.0388	0.03923	3/3	0.0433	0.0076–0.0906	0.1153	7/10	0.04519	0.0151–0.0827	0.0583
Bromide	mg/L	1/7	0.03416	<0.008–0.0911	0.05469	3/8	0.05094	<0.022–0.0894	0.06989	3/8	0.05153	<0.008–0.124	0.07865	3/3	0.08107	0.0692–0.0965	0.1047	2/8	0.03848	<0.008–0.0749	0.05522
Dissolved Organic Carbon	mg/L	2/2	4.8	4–5.6	9.851	1/1	5.9	5.9–5.9		2/2	4.75	4–5.5	9.486					2/2	5.35	4–6.7	13.87
Fluoride	mg/L					3/4	0.1225	<0.1–0.2	0.1953	3/4	0.125	<0.1–0.2	0.1985					3/4	0.125	<0.1–0.2	0.1985
Nitrate	mg/L	6/7	0.4326	<0.0314–1.55	0.8267	9/11	0.4473	0.0477–1	0.6388	9/11	0.3914	0.0594–0.766	0.5503	3/3	1.192	0.461–2.23	2.749	9/11	0.8206	0.193–3.7	1.37
Silica	mg/L	2/2	4.32	3.8–4.84	7.603	6/6	4.672	2.8–7.9	6.104	6/6	4.842	3.2–7.7	6.136					6/6	4.837	3–8	6.255
Total Dissolved Solids	mg/L	8/8	361.1	175–683	464.9	12/12	370.3	199–650	450.7	12/12	368.9	175–895	469.7	3/3	341	320–360	374.8	12/12	364.8	178–618	446.6
Total Organic Carbon	mg/L					2/2	24	5–43	144	1/1	38	38–38						1/1	8	8–8	
Total Phosphorus as PO_4	mg/L	1/6	0.02394	<0.0291–0.063	0.03984	1/9	0.03109	<0.0291–0.0342	0.04081	0/9	0.02891	<0.0291–<0.1	0.03916					0/9	0.02891	<0.0291–<0.1	0.03916

Table 5–2 (continued). Summary of Dolores River Water Quality

Analyte	Unit[b]	NC Site Upstream[c]				NC Site Adjacent				UC Site Upstream				UC Site Adjacent				UC Site Downstream			
		FOD[d]	Mean[d]	Range	UCL$_{95}$[e,f]	FOD	Mean	Range	UCL$_{95}$	FOD	Mean	Range	UCL$_{95}$	FOD	Mean	Range	UCL$_{95}$	FOD	Mean	Range	UCL$_{95}$
Radionuclides																					
Gross Alpha	pCi/L	1/8	2.012	0.5–0.5	2.897	2/9	2.043	0.7–2.4	2.691	2/9	2.233	0.9–2.4	3.265	0/3	1.81	<3.53–<3.75	1.907	2/9	1.94	0.3–2.4	2.625
Gross Beta	pCi/L	1/7	3.06	<3–4.37	4.441	3/8	3.5	<3.01–5.26	4.594	2/8	3.417	2.6–5.42	5.104	0/3	1.978	<3.95–<3.97	1.988	2/8	2.866	2.9–3.67	3.822
Lead-210	pCi/L	1/7	0.5364	0.3–0.3	0.6339	3/9	0.6217	0–1.5	0.8625	3/9	0.49	0–0.8	0.6563					3/9	0.5378	0–0.9	0.6926
Polonium-210	pCi/L	0/6	0.05	<0.05–<0.25	0.08078	3/8	0.09563	0–0.4	0.189	2/8	0.06313	0–0.2	0.1067					2/8	0.04313	0–0	0.07063
Radium-226	pCi/L	3/8	0.09	0.1–0.16	0.1119	6/12	0.1033	0–0.4	0.1548	6/11	0.08045	0–0.2	0.1122	0/3	0.06833	<0.13–<0.14	0.0732	6/12	0.1092	0–0.3	0.1521
Radium-228	pCi/L	1/8	0.4525	<0.59–1	0.6031	4/11	0.3805	0–1.4	0.5862	4/11	0.4741	0.1–1.4	0.6711	0/3	0.4383	<0.84–<0.91	0.4679	4/11	0.4191	0.3–0.6	0.4687
Thorium-230	pCi/L	0/6	0.5733	<0.56–<1.7	0.7837	2/8	0.455	0.1–0.1	0.6612	2/8	0.5675	0.1–1	0.7843					2/8	0.455	0.1–0.1	0.6612
Uranium-234	pCi/L	1/2	0.635	<0.56–0.99	2.876	1/2	0.525	<0.56–0.77	2.072	1/2	0.4	0.52–0.52	1.158	2/3	0.46	<0.4–0.69	0.8754	2/2	0.62	0.58–0.66	0.8726
Uranium-238	pCi/L	2/2	0.635	0.54–0.73	1.235	2/2	0.71	0.65–0.77	1.089	2/2	0.67	0.57–0.77	1.301	3/3	0.6	0.52–0.71	0.766	2/2	0.68	0.58–0.78	1.311

[a] Data from filtered (0.45 μm) samples from June 1986 through March 2001

[b] Units: mV = millivolts; μmhos per cm = micromhos/centimeter; °C = degrees centigrade; NTU = nephelometric turbidity units; SU = standard units; pCi/L = picocuries per liter

[c] NC Site Upstream = location 0696; NC Site Adjacent = location 0692; UC Site Upstream = location 0693; UC Site Adjacent = locations 0346, 0347, and 0349; UC Site Downstream = location 0694

[d] FOD = Frequency Of Detection = N Detected / N Total

[e] One-half the detection limit was used in Mean and UCL$_{95}$ calculations for values below the detection limit.

[f] UCL$_{95}$ = 95% Upper Confidence Limit of the mean

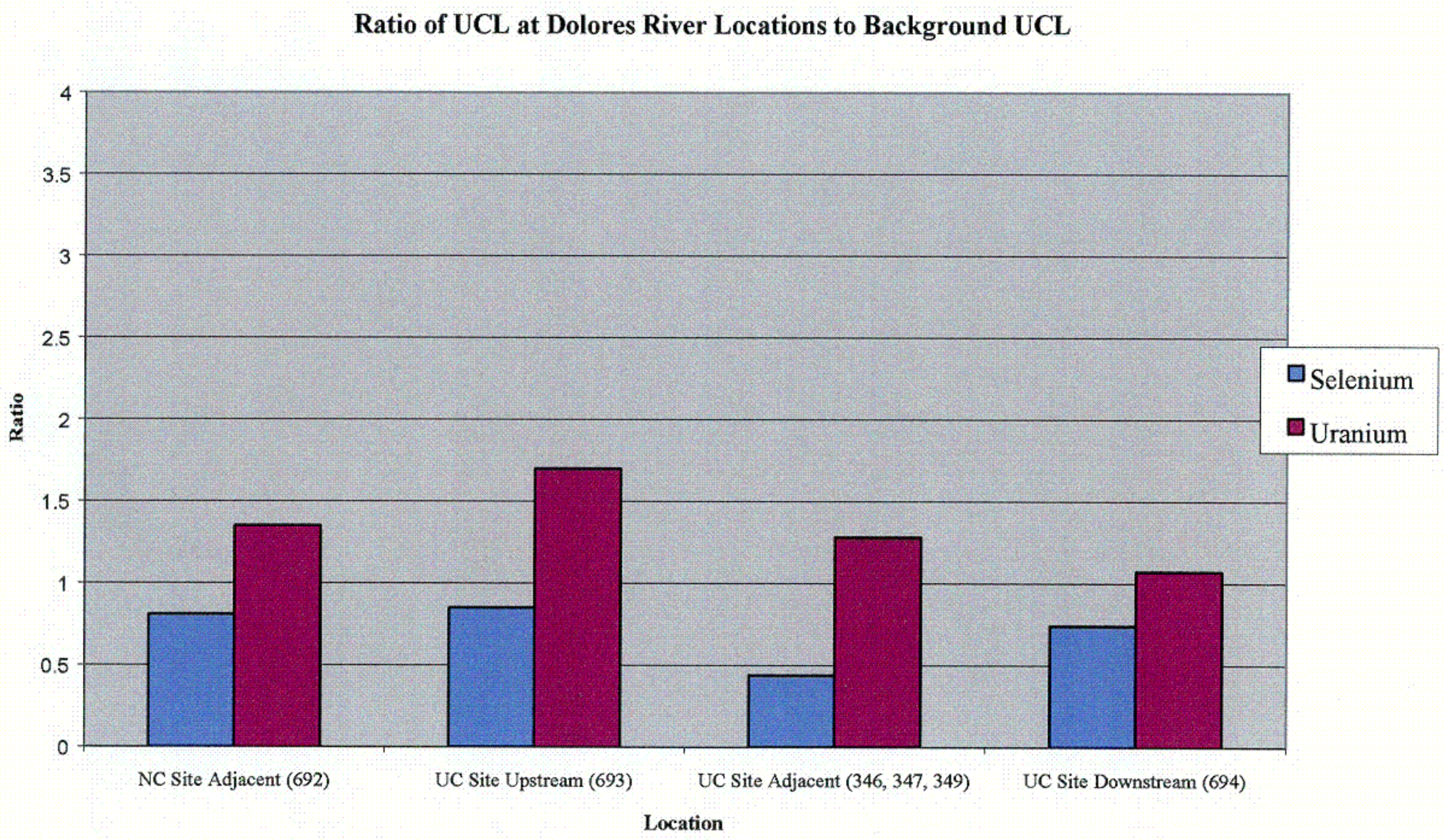

Figure 5–9. Comparison of the UCL_{95} with the Background UCL_{95} for Uranium and Selenium—Dolores River

C09

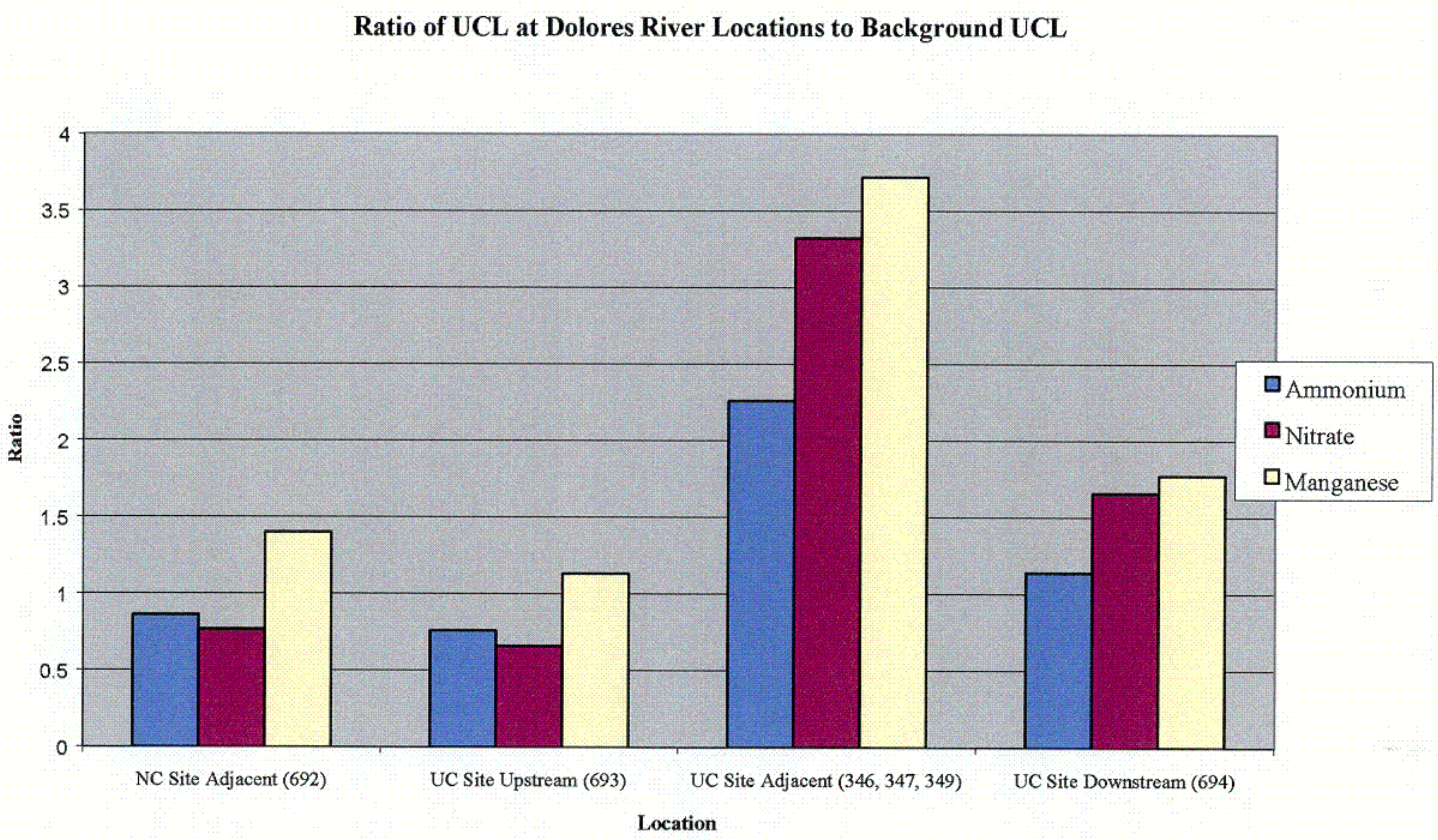

Figure 5–10. Comparison of the UCL_{95} with the Background UCL_{95} for Selected Analytes—Dolores River

C10

Table 5–3. Summary of Background Water Quality for the Alluvial Aquifer

		Alluvial Background[a]			
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL$_{95}$[c,d]**
Field Measurements					
Alkalinity as $CaCO_3$	mg/L	5/5	455.4	351–589	581.8
Oxidation Reduction Potential	mV	6/6	-71	-82– -60	-63.32
Specific Conductance	µmhos/cm	6/6	5,207	1,950–9,490	7,955
Temperature	° C	6/6	12.23	8.9–15.2	14.11
Turbidity	NTU	6/6	49.04	1.77–212	116.9
pH	s.u.	6/6	7.093	6.91–7.37	7.237
Major Ions					
Calcium	mg/L	6/6	338.8	135–587	506.5
Chloride	mg/L	6/6	386.8	138–858	682.1
Magnesium	mg/L	6/6	260	60.7–517	435.1
Potassium	mg/L	6/6	8.247	3.37–14.7	12.06
Sodium	mg/L	6/6	815.7	253–1,560	1,304
Sulfate	mg/L	6/6	2,396	726–4,590	3,904
Metals					
Cadmium	mg/L	1/6	0.0001867	<0.0003–0.00037	0.0002606
Iron	mg/L	6/6	7.705	0.719–19.6	13.54
Manganese	mg/L	6/6	1.876	0.215–3.53	2.95
Molybdenum	mg/L	6/6	0.003483	0.0026–0.0046	0.004134
Selenium	mg/L	5/6	0.0003417	<0.0001–0.0012	0.0006942
Strontium	mg/L	6/6	4.575	1.27–8.84	7.514
Uranium	mg/L	6/6	0.00695	0.0019–0.0139	0.01116
Vanadium	mg/L	0/6	0.0007167	<0.0013–<0.0015	0.0007591
Other					
Ammonium	mg/L	6/6	0.3991	0.0907–1	0.6691
Bromide	mg/L	6/6	1.76	0.402–3.68	2.982
Nitrate	mg/L	5/6	0.3252	<0.0314–0.756	0.5698
Total Dissolved Solids	mg/L	6/6	5,053	1,670–9,790	8,108
Total Phosphorus as PO_4	mg/L	1/4	0.03933	<0.0291–0.0545	0.06528
Radionuclides					
Gross Alpha	pCi/L	0/6	19.9	<12.85–<78.89	31.85
Gross Beta	pCi/L	0/6	19.71	<11.85–<78.33	31.87
Lead-210	pCi/L	0/4	0.6463	<1.24–<1.32	0.6674
Polonium-210	pCi/L	0/4	0.035	<0.05–<0.09	0.04461
Radium-226	pCi/L	1/6	0.0875	<0.12–0.19	0.129
Radium-228	pCi/L	0/6	0.4042	<0.63–<1.03	0.4761
Thorium-230	pCi/L	0/4	0.565	<0.56–<1.7	0.9522
Uranium-234	pCi/L	2/2	4.19	0.88–7.5	25.09
Uranium-238	pCi/L	2/2	3.45	1.3–5.6	17.03
Organic Compounds[e]					
Benzene	µg/L	0/2	2.5	<5–<5	2.5
Ethylbenzene	µg/L	0/2	2.5	<5–<5	2.5
Toluene	µg/L	0/2	2.5	<5–<5	2.5
Total Xylenes	µg/L	0/2	7.5	<15–<15	7.5

[a] Alluvial Background = wells 0300 and 0301

[b] FOD = Frequency of detection = N detected / N total

[c] One-half the detection limit was used in mean and UCL$_{95}$ calculations for values below detection.

[d] UCL$_{95}$ = 95% Upper Confidence Limit of the mean

[e] For volatiles alluvial background = well 0335

Table 5–4. Summary of Water Quality of the Alluvial Aquifer at the NC Site

NC Site Alluvial On-Site[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL$_{95}$[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL$_{95}$**	**Background Range**	**Background UCL$_{95}$**
Field Measurements										
Alkalinity as $CaCO_3$	mg/L	21/21	536.8	251–1,063	618.4	0309	38	38	351–589	581.8
Oxidation Reduction Potential	mV	21/21	-58.81	-180–16	-44.96	0305	57	62	-82– -60	-63.32
Specific Conductance	µmhos/cm	21/21	4,532	1,038–8,100	4,860	0327	0	5	1,950–9,490	7,955
Temperature	°C	21/21	14.53	8.6–19.1	14.96	0303	38	38	8.9–15.2	14.11
Turbidity	NTU	21/21	88.63	3.63–603	105.3	0327	5	14	1.77–212	116.9
pH	s.u.	21/21	7.223	6.99–7.57	7.296	0309	19	38	6.91–7.37	7.237
Major Ions										
Calcium	mg/L	21/21	138.1	67.2–193	139.4	0306	0	0	135–587	506.5
Chloride	mg/L	21/21	436.7	38.6–890	497.5	0309	5	14	138–858	682.1
Magnesium	mg/L	21/21	104.6	28.5–229	107.3	0327	0	0	60.7–517	435.1
Potassium	mg/L	21/21	19.75	1.73–34.9	23.27	0309	52	62	3.37–14.7	12.06
Sodium	mg/L	21/21	870.2	81.5–1,760	954.9	0327	5	24	253–1,560	1,304
Sulfate	mg/L	21/21	1,508	225–3,270	1,577	0327	0	0	726–4,590	3,904
Metals										
Cadmium	mg/L	0/21	0.00015	<0.0003–<0.0003	0.00015	0327	0	0	<0.0003–0.00037	0.00026
Iron	mg/L	21/21	1.623	0.0529–4.07	1.854	0306	0	0	0.719–19.6	13.54
Manganese	mg/L	21/21	0.3948	0.0428–0.739	0.3963	0308	0	0	0.215–3.53	2.95
Molybdenum	mg/L	21/21	0.01393	0.0044–0.0546	0.02042	0309	95	100	0.0026–0.0046	0.00413
Selenium	mg/L	19/21	0.005002	<0.0001–0.0367	0.01048	0305	43	57	<0.0001–0.0012	0.00069
Strontium	mg/L	21/21	3.301	0.988–5.5	3.569	0309	0	0	1.27–8.84	7.514
Uranium	mg/L	21/21	0.551	0.131–1.31	0.718	0305	100	100	0.0019–0.0139	0.01116
Vanadium	mg/L	0/21	0.0006944	<0.0013–<0.0015	0.0007262	0309	0	0	<0.0013–<0.0015	0.00076
Total Dissolved Solids	mg/L	21/21	3,553	695–6,990	3,776	0327	0	0	1,670–9,790	8,108
Total Phosphorus as PO_4	mg/L	0/15	0.0161	<0.0291–0.0545	0.01844	0307	0	0	<0.0291–0.0545	0.06528

Table 5–4 (continued). *Summary of Water Quality of the Alluvial Aquifer at the NC Site*

NC Site Alluvial On-Site[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL_{95}[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL_{95}**	**Background Range**	**Background UCL_{95}**
Other										
Ammonium	mg/L	15/21	0.1302	<0.0047–0.33	0.1533	0307	0	0	0.0907–1	0.6691
Bromide	mg/L	20/21	0.7695	<0.0665–1.52	0.8344	0327	0	0	0.402–3.68	2.982
Nitrate	mg/L	18/21	0.3185	<0.0314–1.09	0.4695	0305	14	24	<0.0314–0.756	0.5698
Radionuclides										
Gross Alpha	pCi/L	21/21	493.8	71.65–1,385.87	684.5	0303	95	100	<12.85–<78.89	31.85
Gross Beta	pCi/L	21/21	158.6	45.96–355.47	200.6	0305	67	100	<11.85–<78.33	31.87
Lead-210	pCi/L	0/15	0.6431	<1.14–<1.49	0.6638	0303	0	0	<1.24–<1.32	0.6674
Polonium-210	pCi/L	0/15	0.03417	<0.05–<0.09	0.03674	0305	0	0	<0.05–<0.09	0.04461
Radium-226	pCi/L	6/21	0.1013	<0.12–0.27	0.1215	0307	10	29	<0.12–0.19	0.129
Radium-228	pCi/L	3/21	0.4906	<0.62–1.27	0.5858	0307	10	14	<0.63–<1.03	0.4761
Thorium-230	pCi/L	0/15	0.66	<0.56–<1.7	0.7534	0327	0	0	<0.56–<1.7	0.9522
Uranium-234	pCi/L	6/6	217.5	71.4–445	353.5	0305	100	100	.88–7.5	25.09
Uranium-238	pCi/L	6/6	210.3	51.7–459	354.3	0305	100	100	1.3–5.6	17.03

[a] NC Site alluvial on-site = wells 0302, 0303, 0304, 0305, 0306, 0307, 0308, 0309, and 0327; alluvial background = wells 0300 and 0301

[b] FOD = frequency of detection = N detected / N total

[c] One-half the detection limit was used in mean and UCL_{95} calculations for values below the detection limit.

[d] UCL_{95} – 95% Upper Confidence Limit of the mean

Table 5–5. Summary of Water Quality of the Alluvial Aquifer Downgradient of the NC Site

NC Site Alluvial Downgradient[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL_{95}[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL_{95}**	**Background Range**	**Background UCL_{95}**
Field Measurements										
Alkalinity as $CaCO_3$	mg/L	19/19	278.5	153–389	308.8	0328	0	0	351–589	581.8
Oxidation Reduction Potential	mV	21/21	16	-104–151	42.22	0330	86	90	-82 – -60	-63.32
Specific Conductance	µmhos/cm	21/21	1,183	619–1,787	1,311	0331	0	0	1,950–9,490	7,955
Temperature	°C	21/21	13.1	10.1–17.7	13.84	0312	14	24	8.9–15.2	14.11
Turbidity	NTU	21/21	138.7	1.19–>1,000	250.3	0329	14	24	1.77–212	116.9
pH	s.u.	21/21	7.417	7.06–7.88	7.506	0312	48	71	6.91–7.37	7.237
Major Ions										
Calcium	mg/L	21/21	83.55	50.3–111	90.14	0331	0	0	135–587	506.5
Chloride	mg/L	21/21	40.39	17.7–67.4	46.49	0312	0	0	138–858	682.1
Magnesium	mg/L	21/21	43.9	15.1–73.1	51.55	0331	0	0	60.7–517	435.1
Potassium	mg/L	21/21	6.144	2.26–16	7.604	0312	5	10	3.37–14.7	12.06
Sodium	mg/L	21/21	123.9	39.6–273	148.1	0312	0	0	253–1,560	1,304
Sulfate	mg/L	21/21	354.1	127–934	423.9	0330	0	0	726–4,590	3,904
Metals										
Cadmium	mg/L	0/21	0.00015	<0.0003–<0.0003	0.00015	0331	0	0	<0.0003–0.00037	0.00026
Iron	mg/L	18/21	0.1149	<0.011–0.641	0.1889	0310	0	0	0.719–19.6	13.54
Manganese	mg/L	20/21	0.3146	<0.003–1.44	0.4666	0329	0	0	0.215–3.53	2.95
Molybdenum	mg/L	21/21	0.0162	0.0071–0.0439	0.01977	0329	100	100	0.0026–0.0046	0.00413
Selenium	mg/L	18/21	0.00272	<0.0001–0.008	0.00376	0331	57	76	<0.0001–0.0012	0.00069
Strontium	mg/L	21/21	1.189	0.68–1.57	1.284	0328	0	0	1.27–8.84	7.514
Uranium	mg/L	21/21	0.02302	0.0116–0.0406	0.02657	0311	86	1000	0.0019–0.0139	0.01116
Vanadium	mg/L	0/21	0.00072	<0.0013–<0.0015	0.00073	0331	0	0	<0.0013–<0.0015	0.00076

Table 5–5 (continued). Summary of Water Quality of the Alluvial Aquifer Downgradient of the NC Site

NC Site Alluvial Downgradient[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL_{95}[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL_{95}**	**Background Range**	**Background UCL_{95}**
Other										
Ammonium	mg/L	13/21	0.02012	<0.0047–0.0823	0.02853	0310	0	0	0.0907–1	.6691
Bromide	mg/L	18/21	0.1522	<0.0665–0.293	0.1805	0331	0	0	0.402–3.68	2.982
Nitrate	mg/L	21/21	0.6237	0.0356–2.45	0.874	0331	24	38	<0.0314–0.756	.5698
Total Dissolved Solids	mg/L	21/21	835.2	382–1,330	936.1	0331	0	0	1,670–9,790	8108
Total Phosphorus as PO_4	mg/L	2/14	0.01913	<0.0291–0.059	0.0251	0329	7	0	<0.0291–0.0545	.06528
Radionuclides										
Gross Alpha	pCi/L	18/21	13.28	5.93–28.76	16.15	0331	0	0	<12.85–<78.89	31.85
Gross Beta	pCi/L	17/21	10.6	5.19–20.63	12.71	0331	0	0	<11.85–<78.33	31.87
Lead-210	pCi/L	0/14	0.6054	<1.14–<1.3	0.6153	0331	0	0	<1.24–<1.32	.6674
Polonium-210	pCi/L	0/14	0.06214	<0.05–<.29	0.08063	0311	0	0	<0.05–<0.09	.04461
Radium-226	pCi/L	4/21	0.09167	<0.13–0.18	0.1071	0330	0	19	<0.12–0.19	.129
Radium-228	pCi/L	0/21	0.4162	<0.63–<1.08	0.4386	0310	0	0	<0.63–<1.03	.4761
Thorium-230	pCi/L	0/14	0.565	<0.56–<1.7	0.705	0331	0	0	<0.56–<1.7	.9522
Uranium-234	pCi/L	7/7	9.543	4.9–14.8	12.28	0311	57	0	0.88–7.5	25.09
Uranium-238	pCi/L	7/7	8.514	4.6–15.8	11.33	0311	86	0	1.3–5.6	17.03

[a] NC site alluvial downgradient = wells 0310, 0311, 0312, 0328, 0329, 0330, and 0331; alluvial background = wells 0300 and 0301

[b] FOD = frequency of detection = N detected / N total

[c] One-half the detection limit was used in mean and UCL_{95} calculations for values below the detection limit.

[d] UCL_{95} = 95% Upper Confidence Limit of the mean

Table 5–6. Summary of Water Quality of the Alluvial Aquifer at the UC Site

UC Site Alluvial On Site[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL_{95}[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL_{95}**	**Background Range**	**Background UCL_{95}**
Field Measurements										
Alkalinity as $CaCO_3$	mg/L	29/29	445.8	287–1407	556.4	0319	10	10	351–589	581.8
Dissolved Oxygen	mg/L	8/8	0.5625	0–2.6	1.17	0333				
Oxidation Reduction Potential	mV	33/33	18.13	-184–243	84.83	0509	67	67	-82 – -60	-63.32
Specific Conductance	µmhos/cm	33/33	6,499	1,089–36,700	7,448	0332	15	15	1,950–9,490	7,955
Temperature	°C	33/33	11.8	6.7–20.1	13.88	0510	30	33	8.9–15.2	14.11
Turbidity	NTU	31/31	205.3	1.5–>1000	199.4	0338	13	23	1.77–212	116.9
pH	s.u.	33/33	6.872	6.38–7.28	6.941	0313	0	3	6.91–7.37	7.237
Major Ions										
Calcium	mg/L	25/25	314	92.3–1,060	432.3	0318	24	36	135–587	506.5
Chloride	mg/L	25/25	500	28.2–5,470	1,088	0319	12	12	138–858	682.1
Magnesium	mg/L	25/25	122.9	38.4–349	171.4	0319	0	0	60.7–517	435.1
Potassium	mg/L	25/25	11.79	5.37–30.1	14.44	0319	12	28	3.37–14.7	12.06
Sodium	mg/L	25/25	314.3	43–2,210	560.7	0319	8	12	253–1,560	1,304
Sulfate	mg/L	24/25	575.9	<0.589–1,160	724.3	0510	0	0	726–4,590	3,904
Metals										
Cadmium	mg/L	9/25	0.00125	<0.0003–0.0097	0.00246	0508	36	36	<0.0003–0.00037	0.00026
Iron	mg/L	16/25	2.921	<0.011–32	6.475	0319	12	12	0.719—19.6	13.54
Manganese	mg/L	25/25	2.559	0.104–12.8	4.298	0318	36	36	0.215–3.53	2.95
Molybdenum	mg/L	25/25	0.497	0.0055–1.83	0.7243	0318	100	100	0.0026–0.0046	0.00413
Selenium	mg/L	24/25	0.4157	<0.0001–2.52	0.7644	0318	72	88	<0.0001–0.0012	0.00069
Strontium	mg/L	25/25	3.433	0.894–11.8	4.87	0319	8	16	1.27-8.84	7.514
Uranium	mg/L	25/25	0.03864	0.00033–0.1	0.05069	0510	88	88	0.0019–0.0139	0.01116
Vanadium	mg/L	9/25	0.09114	<0.0013–0.556	0.1776	0508	36	36	<0.0013–<0.0015	0.00076

Table 5–6 (continued). Summary of Water Quality of the Alluvial Aquifer at the UC Site

UC Site Alluvial On Site[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL$_{95}$[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL$_{95}$**	**Background Range**	**Background UCL$_{95}$**
Other										
Ammonium	mg/L	25/25	44.94	5.71–118	59.05	0319	100	100	0.0907–1	0.6691
Bromide	mg/L	24/25	1.485	0.145–14.7	3.101	0319	12	12	0.402–3.68	2.982
Nitrate	mg/L	24/25	620	<0.0314–3,510	1,086	0318	68	72	<0.0314–0.756	0.5698
Total Dissolved Solids	mg/L	25/25	2,718	570–9,040	3,889	0319	0	8	1,670–9,790	8,108
Total Phosphorus as PO_4	mg/L	4/18	0.0602	<0.0291–0.499	0.1206	0319	11	11	<0.0291–0.0545	0.06528
Radionuclides										
Gross Alpha	pCi/L	17/25	23.9	10.24–61.6	30.8	0510	0	24	<12.85–<78.89	31.85
Gross Beta	pCi/L	16/25	19.12	12.28–37.11	22.35	0510	0	8	<11.85–<78.33	31.87
Lead-210	pCi/L	0/18	0.6553	<1.16–<1.39	0.6704	0319	0	0	<1.24–<1.32	0.6674
Polonium-210	pCi/L	0/18	0.08325	<0.07–<0.43	0.1053	0508	0	0	<0.05–<0.09	0.04461
Radium-226	pCi/L	14/25	0.4899	<0.12–3.22	0.8783	0319	44	56	<0.12–0.19	0.129
Radium-228	pCi/L	5/25	0.748	<0.63–4.04	1.195	0319	20	20	<0.63–<1.03	0.4761
Thorium-230	pCi/L	0/18	0.627	<0.56–<1.8	0.7201	0314	0	0	<0.56–<1.7	0.9522
Uranium-234	pCi/L	7/7	17.68	0.53–35.4	26.08	0510	86	29	0.88–7.5	25.09
Uranium-238	pCi/L	7/7	17.56	0.61–40	28.17	0510	86	43	1.3–5.6	17.03
Volatile Organic Compounds[e]										
Benzene	µg/L	9/9	8,428	594–17,400	12,320	0332	100	100	<5–<5	2.5
Ethylbenzene	µg/L	9/9	333.7	224–584	402.3	0338	100	100	<5–<5	2.5
Toluene	µg/L	7/9	6,564	<500–13,600	9,878	0332	78	78	<5–<5	2.5
Total Xylenes	µg/L	9/9	4,525	3,240–6,540	5,179	0338	100	100	<15–<15	7.5

[a] UC site alluvial on-site = wells 0313, 0314, 0315, 0316, 0318, 0319, 0320, 0332, 0333, 0334, 0335, 0336, 0337, and 0338; alluvial background = Wells 0300 and 0301

[b] FOD = frequency of detection = N detected / N total

[c] One-half the detection limit was used in mean and UCL$_{95}$ calculations for values below the detection limit.

[d] UCL$_{95}$ = 95% Upper Confidence Limit of the mean

[e] For Volatiles: UC Site Alluvial On-Site = wells 0319, 0332, 0333, and 0338; Alluvial Background = well 0335

Table 5–7. Summary of Water Quality of the Alluvial Aquifer Downgradient of the UC Site

UC Site Alluvial Downgradient[a]										
Analyte	Unit	FOD[b]	Mean[c]	Range	UCL_{95}[c,d]	Max Well	Percent Exceeding Upper Limit of Background Range	Percent Exceeding Background UCL_{95}	Background Range	Background UCL_{95}
Field Measurements										
Alkalinity as $CaCO_3$	mg/L	9/9	208.4	166–341	272.6	0685	0	0	351–589	581.8
Oxidation Reduction Potential	mV	9/9	50.6	-85–161	111	0323	89	89	-82 – -60	-63.32
Specific Conductance	µmhos/cm	9/9	787.1	592–1,435	1,077	0685	0	0	1,950–9,490	7,955
Temperature	°C	9/9	13.19	10.1–14	13.59	0684	0	0	8.9–15.2	14.11
Turbidity	NTU	7/7	1.656	0.91–2.89	2.182	0323	0	0	1.77–212	116.9
pH	s.u.	9/9	7.299	6.89–7.64	7.422	0684	44	56	6.91–7.37	7.237
Major Ions										
Calcium	mg/L	9/9	85.85	66.5–133	107.5	0685	0	0	135–587	506.5
Chloride	mg/L	9/9	25.41	17.2–58.9	42.74	0685	0	0	138–858	682.1
Magnesium	mg/L	9/9	28.54	17–60.5	45.06	0685	0	0	60.7–517	435.1
Potassium	mg/L	9/9	6.595	2.57–10.1	9.251	0685	0	0	3.37–14.7	12.06
Sodium	mg/L	9/9	43.9	28.2–104	71.92	0685	0	0	253–1,560	1,304
Sulfate	mg/L	9/9	181.7	121–389	288.6	0685	0	0	726–4,590	3,904
Metals										
Cadmium	mg/L	0/9	0.00015	<0.0003–<0.0003	0.00015	0685	0	0	<0.0003–0.00037	0.00026
Iron	mg/L	5/9	0.1493	<0.011–0.43	0.1879	0322	0	0	0.719–19.6	13.54
Manganese	mg/L	9/9	0.3346	0.0996–0.547	0.4372	0685	0	0	0.215–3.53	2.95
Molybdenum	mg/L	9/9	0.01504	0.0048–0.0211	0.01576	0323	100	100	0.0026–0.0046	0.00413
Selenium	mg/L	5/9	0.00010	<0.0001–0.00035	0.00018	0684	0	0	<0.0001–0.0012	0.00069
Strontium	mg/L	9/9	0.9078	0.65–1.59	1.227	0685	0	0	1.27–8.84	7.514
Uranium	mg/L	9/9	0.00773	0.0035–0.0175	0.01317	0685	33	33	0.0019–0.0139	0.01116
Vanadium	mg/L	0/9	0.00068	<0.0013–<0.0015	0.000731	0685	0	0	<0.0013–<0.0015	0.00076

Table 5–7 (continued). Summary of Water Quality of the Alluvial Aquifer Downgradient of the UC Site

UC Site Alluvial Downgradient[a]										
Analyte	**Unit**	**FOD[b]**	**Mean[c]**	**Range**	**UCL_{95}[c,d]**	**Max Well**	**Percent Exceeding Upper Limit of Background Range**	**Percent Exceeding Background UCL_{95}**	**Background Range**	**Background UCL_{95}**
Other										
Ammonium	mg/L	9/9	0.9503	0.269–2.04	1.55	0685	44	78	0.0907–1	0.6691
Bromide	mg/L	4/9	0.07433	<0.0665–0.231	0.1475	0685	0	0	0.402–3.68	2.982
Nitrate	mg/L	8/9	0.6482	<0.0314–5.7	2.046	0684	22	33	<0.0314–0.756	0.5698
Total Dissolved Solids	mg/L	9/9	552.2	430–1020	796.7	0685	0	0	1,670–9,790	8,108
Total Phosphorus as PO_4	mg/L	1/7	0.02883	<0.0291–0.0924	0.06068	0685	14	14	<0.0291–0.0545	0.06528
Radionuclides										
Gross Alpha	pCi/L	1/9	3.33	<4.16–7.04	4.632	0684	0	0	<12.85–<78.89	31.85
Gross Beta	pCi/L	7/9	7.228	<6.19–14.78	12.01	0685	0	0	<11.85–<78.33	31.87
Lead-210	pCi/L	0/7	0.6035	<1.09–<1.36	0.6387	0321	0	0	<1.24–<1.32	0.6674
Polonium-210	pCi/L	0/7	0.055	<0.06–<0.32	0.1007	0684	0	0	<0.05–<0.09	0.04461
Radium-226	pCi/L	1/9	0.07633	<0.12–0.14	0.09394	0685	0	11	<0.12–0.19	0.129
Radium-228	pCi/L	0/9	0.385	<0.71–<0.99	0.4217	0685	0	0	<0.63–<1.03	0.4761
Thorium-230	pCi/L	0/7	0.736	<0.56–<1.7	0.8914	0685	0	0	<0.56–<1.7	0.9522
Uranium-234	pCi/L	2/2	7.45	4.1–10.8	28.6	0685	50	0	0.88–7.5	25.09
Uranium-238	pCi/L	2/2	4.6	2.9–6.3	15.33	0685	50	0	1.3–5.6	17.03

[a] UC site alluvial downgradient = Wells 0321, 0322, and 0323; alluvial background = wells 0300 and 0301
[b] FOD = frequency of detection = N detected / N total
[c] One-half the detection limit was used in mean and UCL_{95} calculations for values below the detection limit.
[d] UCL_{95} = 95% Upper Confidence Limit of the mean

5.2.2.2 Major Ion Chemistry

Piper or trilinear diagrams were used to examine the characteristics of the ground water associated with the Slick Rock site. Piper diagrams are a combination of cation and anion triangles that lie on a common baseline. Adjacent sides of the triangles are 60° apart. A diamond shape between the triangles is used to replot the analyses as circles with color representing the TDS (Hounslow 1995). The positions of the analyses plotted on Piper diagrams are used to classify and compare water samples.

Background

Figure 5–11 includes data from alluvial wells 0300, 0330, and 0685. Well 0300 is an upgradient background well; well 0685 is far enough downgradient that it was not expected to be affected by the former tailings areas, and well 0330 is located between the NC and UC sites, but on the opposite side of the river (Figure 4–2). Data indicate that well 0330 is not affected by the former milling operations. These three Piper diagrams demonstrate that the alluvial water quality in the area is quite variable. Well 0300 has a much higher TDS content than wells 0685 and 0330 (7,700 versus 975 and 812 mg/L). The figures also show that well 0300 is a Na^+/SO_4^{2-}-type water, and wells 0330 and 0685 have more relative contribution from Ca^{2+} and HCO_3^-. These data indicate that although well 0300 is hydraulically upgradient and contains low concentrations of site-related contaminants, the water quality is inferior to that of the other background locations.

NC Site

Well 0305 (Figure 5–11), is representative of the NC area and has a TDS value (2,450 mg/L) intermediate between the clean alluvial wells, that is, intermediate between wells 0300 and 0685 or 0330. Comparing well 0305 to 0330 and 0685 indicates that the former has more influence from a Na^+/SO_4^{2-}-type water, which may be related to the former site operations or may be a result of being closer to well 0300.

UC Site

Alluvial wells 0508 and 0510 contain contaminants (e.g., ammonia) related to the uranium-ore processing, which is also probably responsible for their elevated TDS. Wells 0508 and 0510 have nearly identical Piper diagrams (Figure 5–11) that indicate the dominance of Ca^{2+} and HCO_3^-. Wells 0508 and 0510 are located between clean wells 0330 and 0685. The fact that the contaminated wells have relatively more calcium and sulfate (Table 5–6) than the nearby clean wells is consistent with the acid-leaching process that was conducted at the UC site (Merritt 1971). Note, however, that the increase in sulfate for wells 0508 and 0510 is not indicated in the Piper diagram because of high (> 1,000 mg/L) nitrate in these wells.

With respect to the Entrada wells, the Piper diagrams show a significant contrast between terrace well 0325 and floodplain well 0317 (Figure 5–12). Well 0325 is a Ca^{2+}/Mg^{2+} and HCO_3^--type water, and well 0317 contains relatively more sodium and sulfate. Wells 0317 and 0324 are in an area of the floodplain where contamination is present in the overlying alluvial aquifer. In contrast, the Entrada Sandstone ground water represented by well 0325 is not in contact with water from an overlying aquifer; hence, the difference in these two samples must be a consequence of the water in well 0317 being in contact with contaminated water in the alluvium.

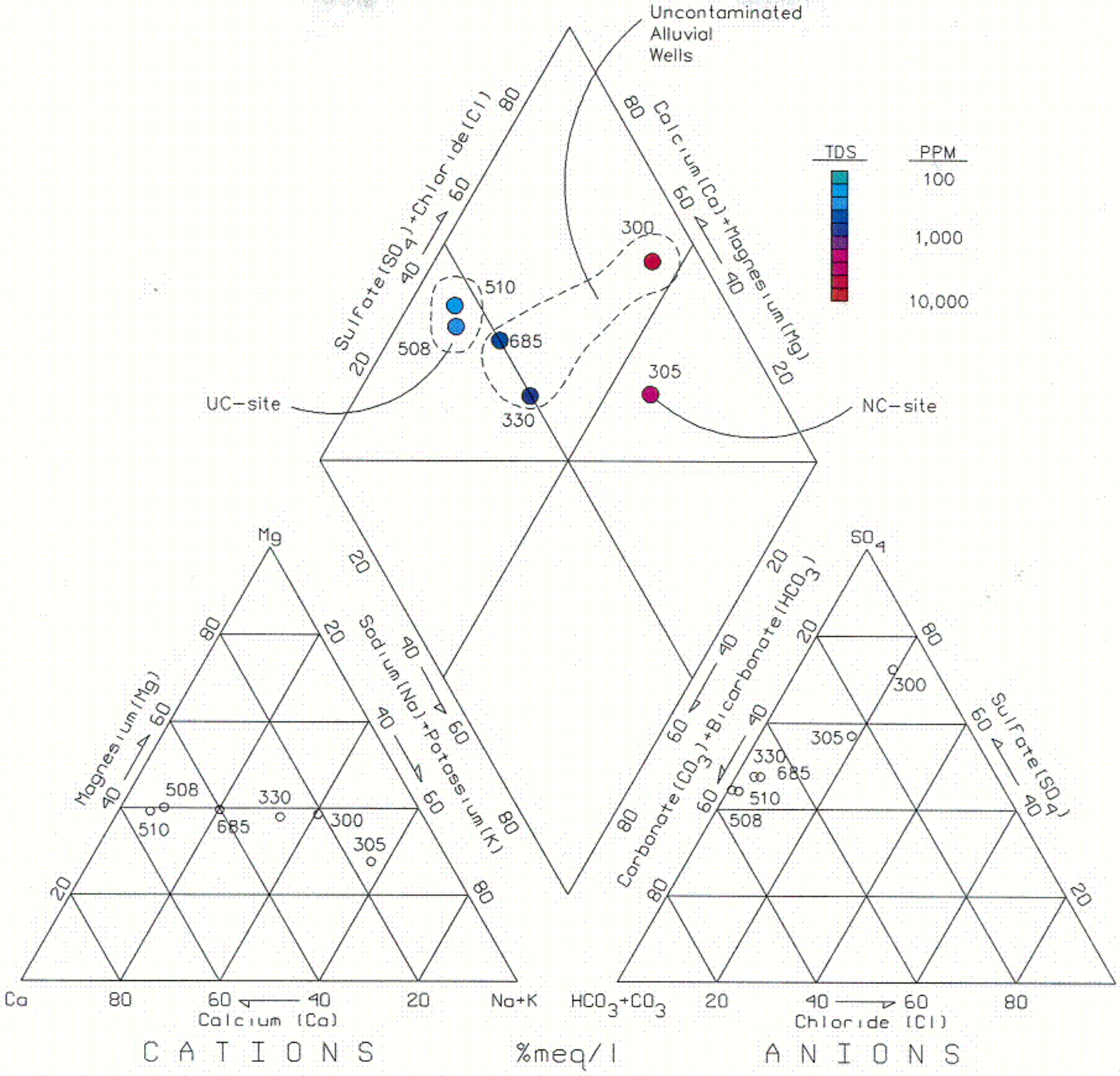

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Figure 5–11. Piper Diagrams for Alluvial Wells

C11

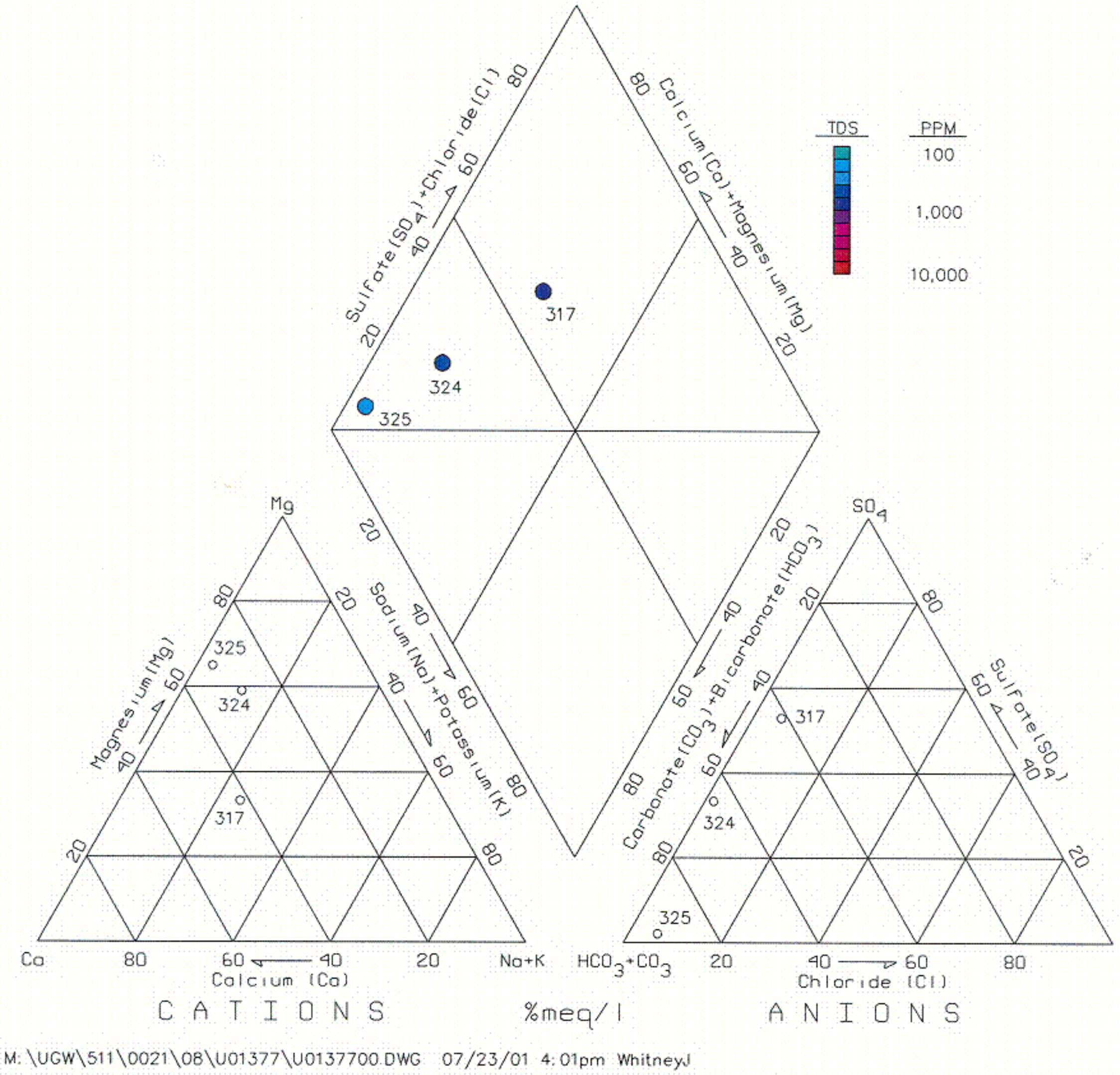

Figure 5–12. Piper Diagrams for Entrada Sandstone Wells

C12

The concentrations of calcium and magnesium are nearly identical in well 0325, but as with water in the overlying alluvium, the calcium concentration is approximately twice as high as magnesium in well 0317. Similarly, the sodium content of well 0317, which is also similar to concentrations in the alluvial wells, has increased relative to calcium. For the anions, there is a large increase in sulfate in well 0317, which also reflects the circumstances in the overlying alluvium.

Piper diagrams can be used to estimate the amount of mixing by two waters; however, the composition of the mixture must lie on a straight line joining the two end members. Such is not the case for either wells 0508 or 0510 and 0325 with respect to producing the composition of water in well 0317. Hence, alluvial well 0313, which is both closer to Entrada well 0317 and less contaminated than wells 0508 and 0510 (Figure 4–3) was also plotted (Figure 5–13). Again, the Piper plots did not show direct mixing of well 0313 with the terrace Entrada water to produce the water quality in well 0317. Most likely, there are some natural differences in the Entrada Sandstone aquifer between the terrace and well 0325 and the floodplain and well 0317. However, the concentration of calcium and sulfate in Entrada well 0317 and alluvial well 0313 are essentially the same.

Entrada well 0324 is adjacent to the Dolores River (Figure 4–3) and has nitrate and selenium concentrations above their respective UMTRA Project standards. An examination of the Piper diagrams, however, does not indicate that contamination in well 0324 is a simple mixture of water from nearby alluvial well 0508 and clean Entrada well 0325 on the terrace. Nevertheless, the contamination in well 0324 is site related. The fact that mixing is not indicated by the Piper diagrams may be related to a different rate of biological change for the nitrogen species in the alluvium versus the Entrada, or the possibility that there are natural differences in the aquifer between terrace well 0325 and floodplain well 0324.

5.2.2.3 Areal Extent of Ground Water Contamination

NC Site

Alluvial Aquifer

Uranium is the primary contaminant in the alluvial ground water at the UC site. The maximum concentrations for those analytes exceeding UMTRA Project standards since September 2000 at the NC site are shown in Figure 5–15. The uranium distribution at the NC site is shown in Figure 5–14. Uranium concentrations in all of the wells at the NC site exceed the UMTRA Project standard of 0.044 mg/L; the maximum concentrations, which are between 1.0 and 1.5 mg/L, are in wells 0303 and 0305. The highest concentrations appear to be in a limited area, but the farthest downgradient well on the site, well 0309, has uranium concentrations greater than 0.13 mg/L, well above the standard.

Samples were also collected from downgradient wells 0310, 0311, 0312, 0328, 0329, 0330, and 0331 and across the river. Uranium concentrations vary by location and approach the standard in some instances (up to 0.04 mg/L in well 0311). Figure 5–13 compares the Piper diagram for well 0310 to the Dolores River water at location 0693 and demonstrates that the major ion chemistry of the waters is very similar, except that the water in well 0310 appears to be a slightly diluted version of the Dolores River. The much lower chloride and sulfate concentrations demonstrate that the alluvial ground water across the river from the NC site is not in contact with that at the NC site; therefore, the elevated uranium concentrations are attributable to fluctuations in natural background or possibly a localized source.

Gross alpha activity in the majority of the samples collected from wells at the NC site exceeded the net alpha standard. The net alpha standard excludes uranium and theoretically represents the sum of all other alpha-emitting nuclides. However, other alpha-emitting nuclides (Po-210, Ra-226, and Th-230) were measured in low concentrations, so the gross alpha activity in these samples is attributed to uranium. The difference in the gross alpha activity and uranium activity is a function of the large analytical error associated with gross alpha analyses. Therefore, distribution of alpha contamination in the ground water is interpreted to coincide with the uranium distribution and will not be addressed separately.

The only other analyte at the NC site present in concentrations that consistently exceed the UMTRA standard is selenium in well 0305, which illustrates that the selenium plume is highly localized. In addition, concentrations are typically near 0.03 mg/L, which is relatively low compared to the UMTRA standard of 0.01 mg/L and the Safe Drinking Water Act (SDWA) standard of 0.05 mg/L. High chloride and sulfate concentrations are also associated with the ground water at the NC site, but as noted above, these constituents have no apparent effect on the Dolores River.

Bedrock Aquifers

Three wells completed in the Navajo Sandstone (0672, 0687, and 0690) are located in the vicinity of the NC site (Figure 5–15). Samples collected from these wells during the recent field investigation contained background concentrations of site-related contaminants and no standards were exceeded.

UC Site

Alluvial Aquifer

A variety of contaminants are found in the alluvial ground water at the UC site. Maximum concentrations of analytes that exceed UMTRA Project standards since September 2000 are shown in Figure 5–16. Uranium concentrations in alluvial ground water are much lower at the UC site (Table 5–6) than at the NC site, probably reflecting the more efficient ore-processing methods used at the UC site (Figure 5–17). Uranium contamination at the UC site is highly localized (chiefly found in and near wells 0318, 0508, and 0510 [which underlie the former tailings area], all of which have a uranium content of 0.1 mg/L or less). Thus, extensive plume development with uranium is not indicated.

Molybdenum contamination at the UC site is shown in Figure 5–18. As with uranium, the highest concentrations are found in and near wells 0318, 0508 and 0510, (Table 5–6 and Figure 5–18). Downgradient of these wells, molybdenum concentrations at on-site well 0320 are below the UMTRA Project standard of 0.01 mg/L and are near background levels.

Selenium contamination at the UC site is shown in Figure 5–19. Once again, the highest concentrations are in wells 0318, 0508, and 0510. Selenium is typically not as mobile as molybdenum and uranium, and concentrations return to background levels at on-site well 0320.

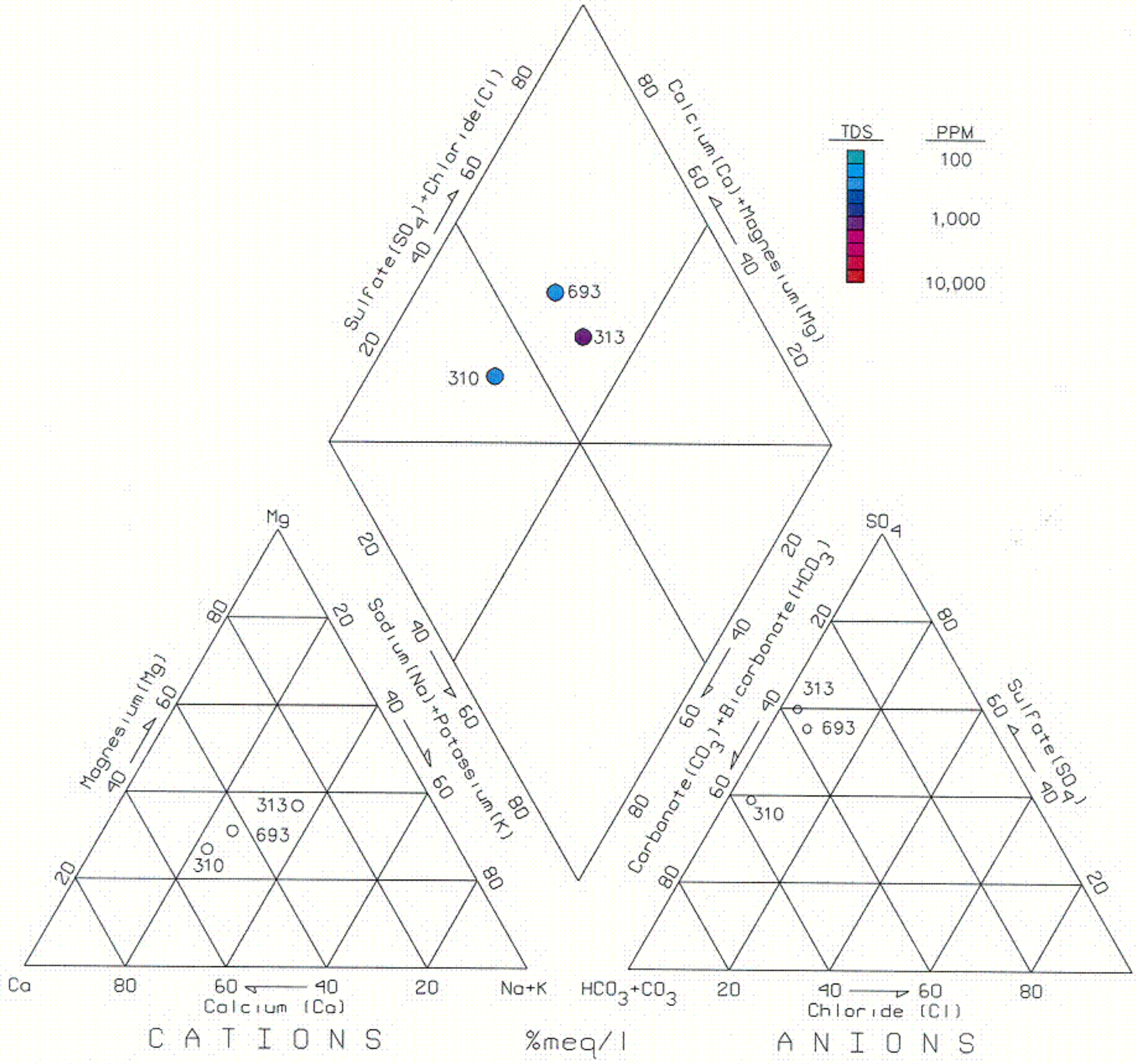

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Figure 5–13. Piper Diagrams for Alluvial Wells and Dolores River

C13

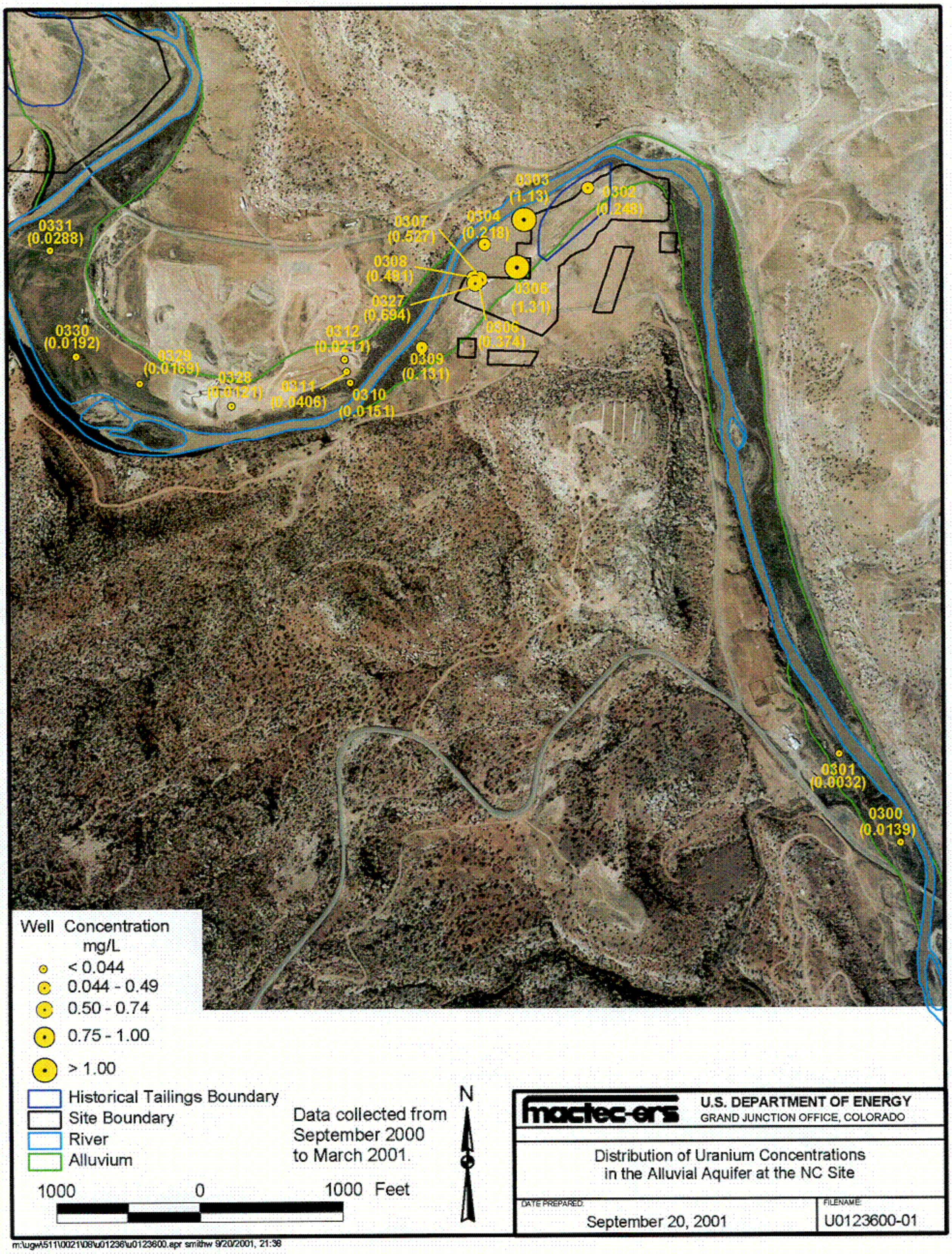

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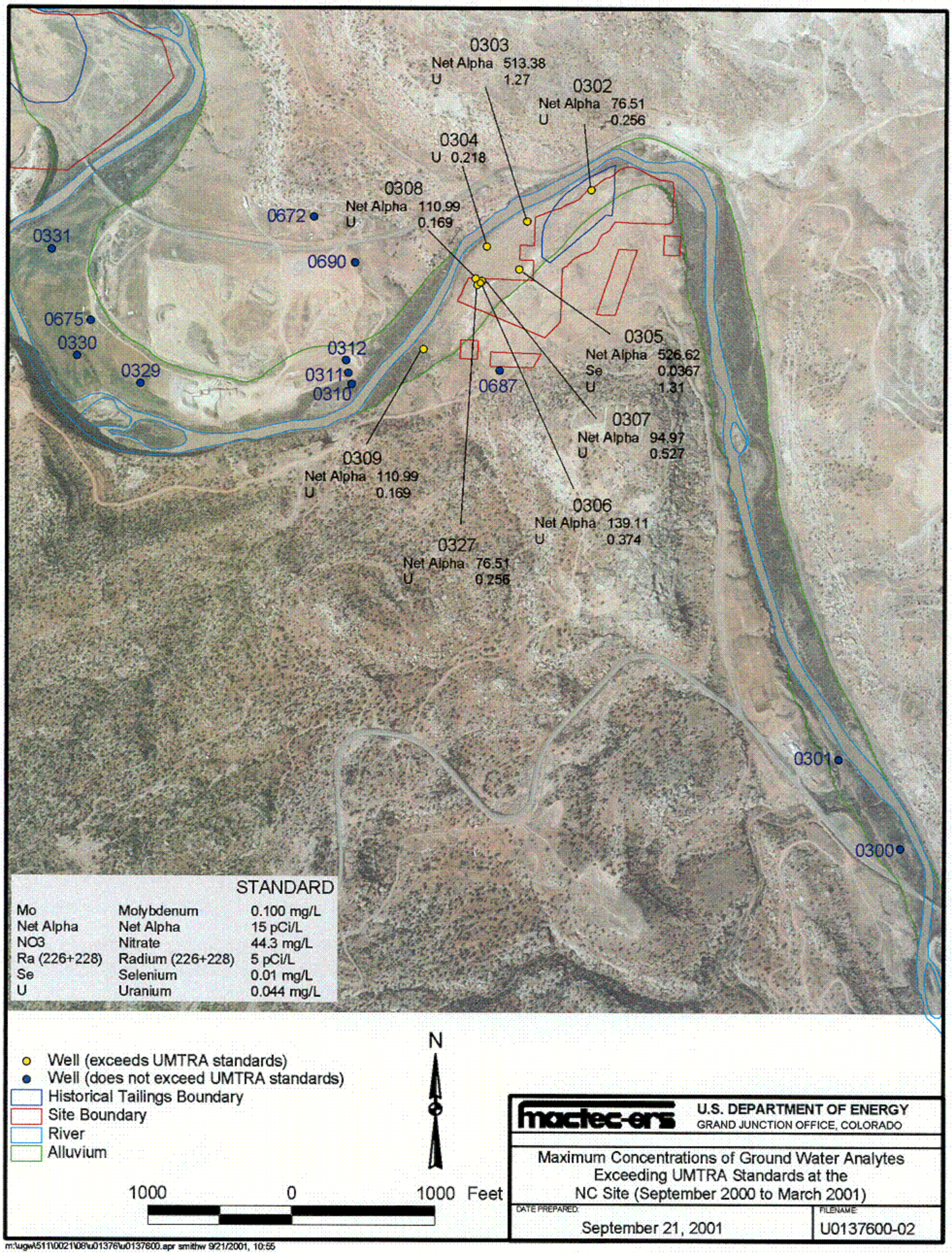
Figure 5–14. Uranium Concentrations at the NC Site

C14



		STANDARD
Mo	Molybdenum	0.100 mg/L
Net Alpha	Net Alpha	15 pCi/L
NO3	Nitrate	44.3 mg/L
Ra (226+228)	Radium (226+228)	5 pCi/L
Se	Selenium	0.01 mg/L
U	Uranium	0.044 mg/L

- ● Well (exceeds UMTRA standards)
- ● Well (does not exceed UMTRA standards)
- ☐ Historical Tailings Boundary
- ☐ Site Boundary
- ☐ River
- ☐ Alluvium

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U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE, COLORADO

Maximum Concentrations of Ground Water Analytes Exceeding UMTRA Standards at the NC Site (September 2000 to March 2001)

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Figure 5–15. Maximum Concentrations of Analytes Exceeding the UMTRA Project Standard at the NC Site Since September 2000

C15

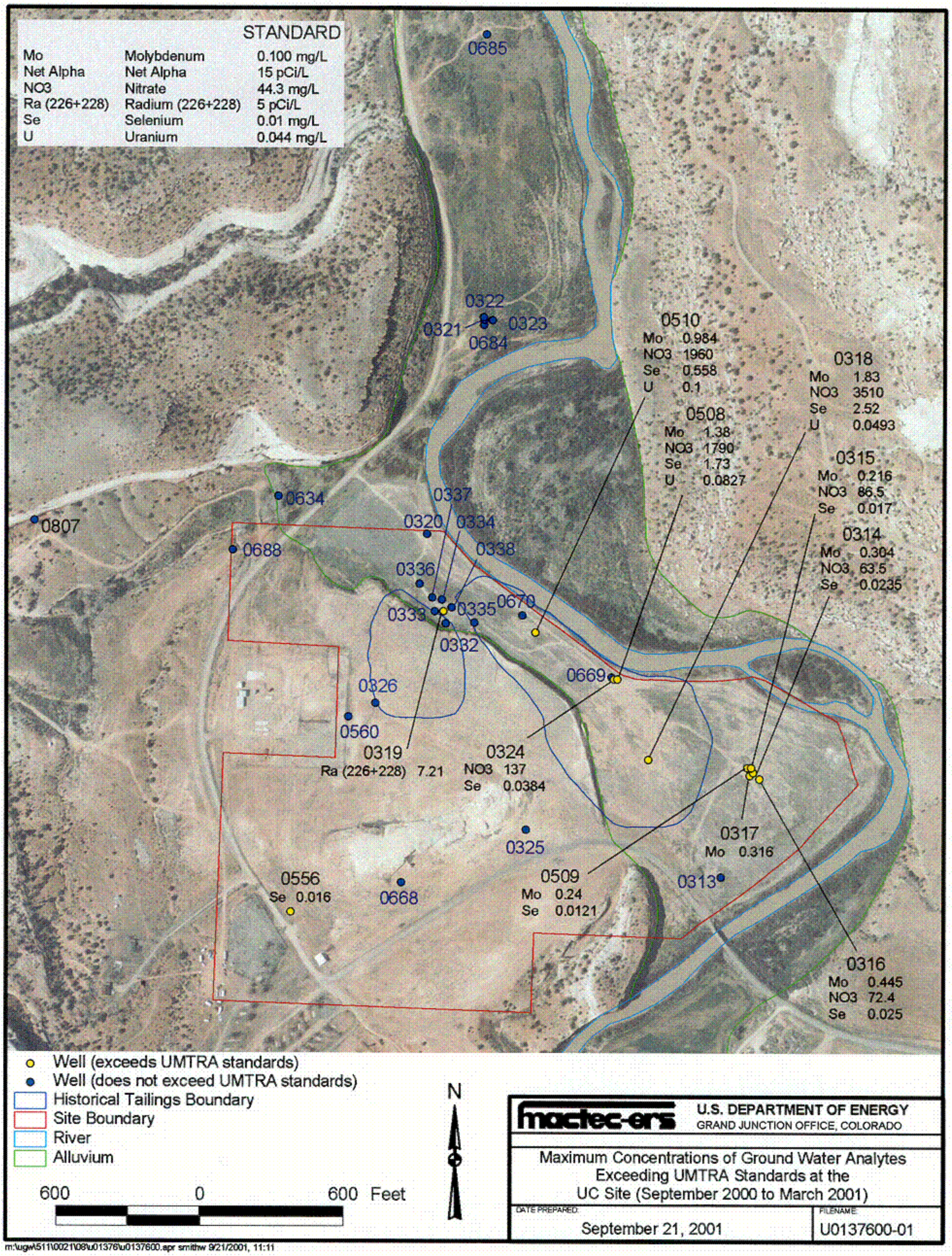

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Figure 5–16. Maximum Concentrations of Analytes Exceeding the UMTRA Project Standard at the UC Site Since September 2000

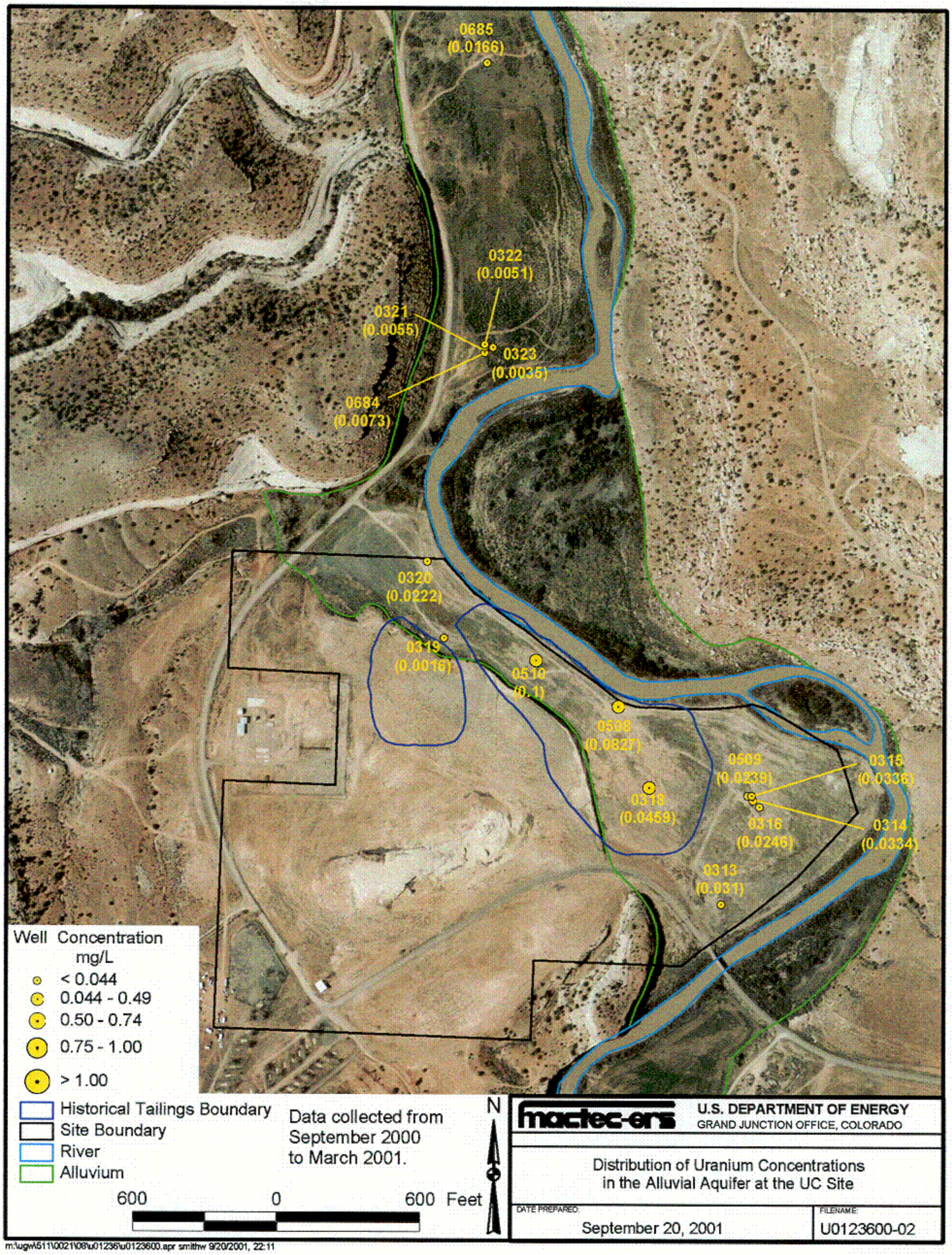

Figure 5–17. Uranium Concentrations at the UC Site

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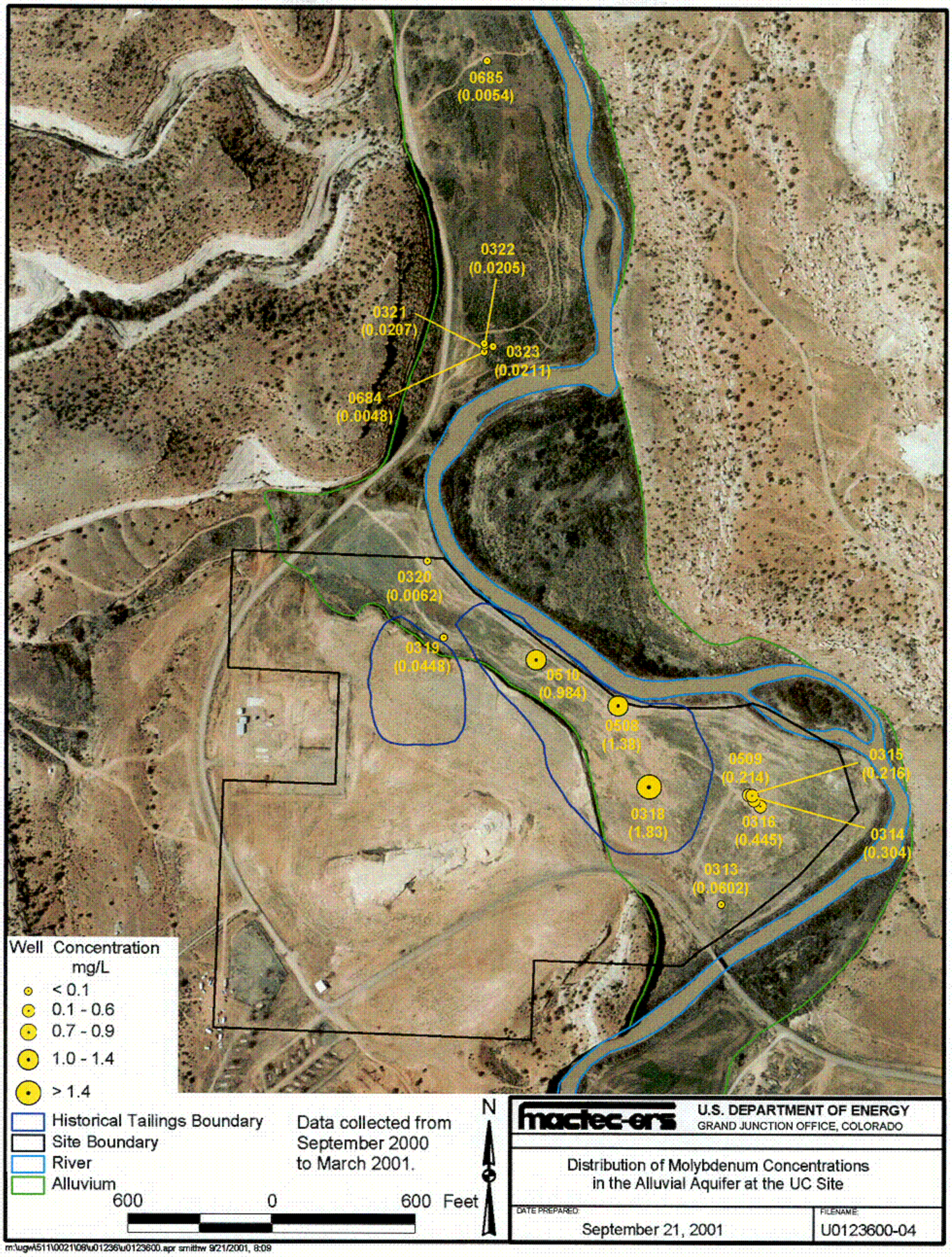

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Figure 5–18. Molybdenum Concentrations at the UC Site

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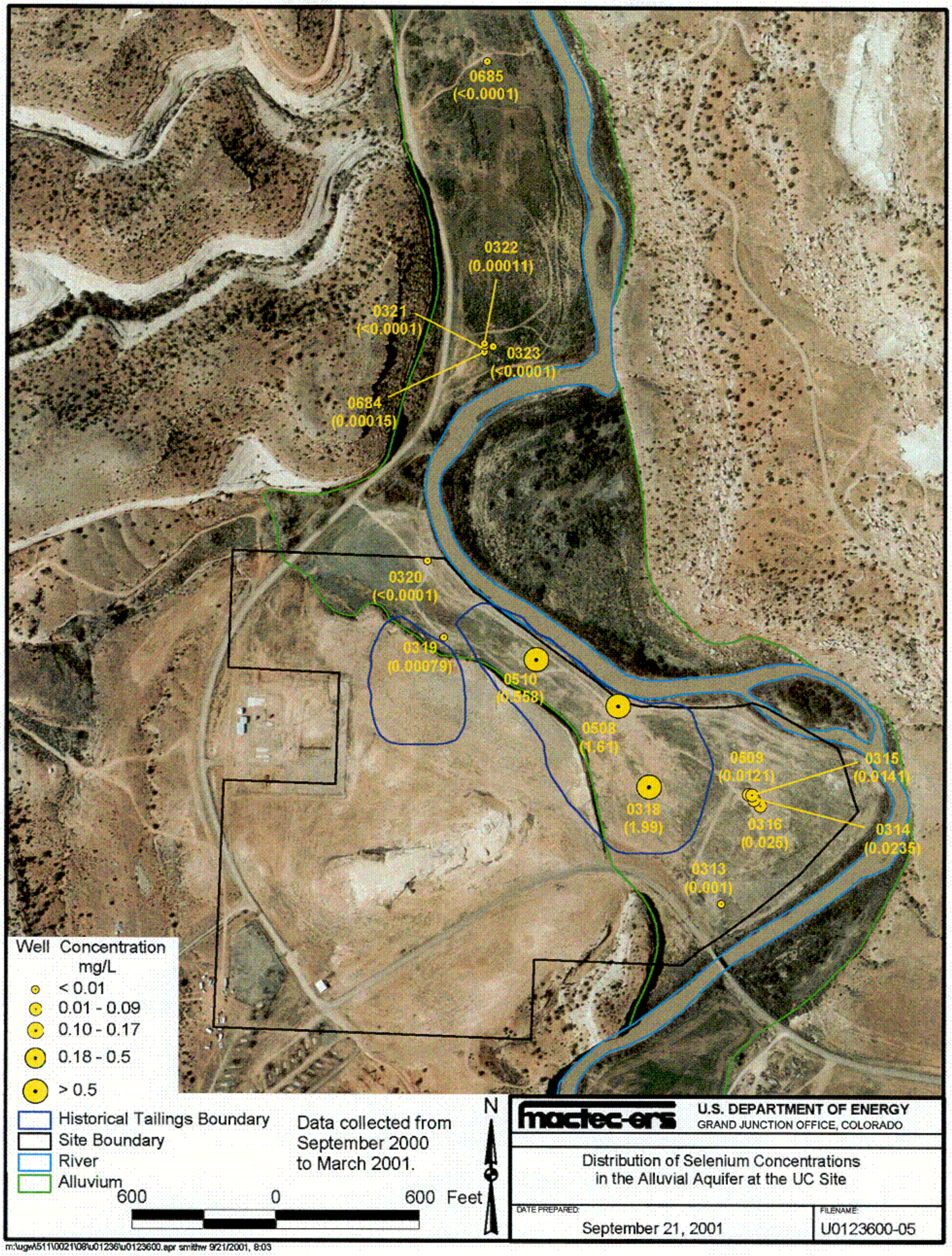

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Figure 5–19. Selenium Concentrations at the UC Site

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Ammonium is not considered a COPC at the UC site because concentrations do not pose an unacceptable risk, but discussion of the distribution of ammonium in the ground water is warranted because it illustrates plume movement of a mobile constituent. Ammonium is distributed more extensively than other contaminants at the UC site. The location with the highest ammonium concentration is farther downgradient (well 0319) compared to the extent of other contaminants at the UC site. Also, ammonium ion concentrations above background are detected downgradient of the UC site in wells 0321, 0322, 0323, and 0684, as shown in Figure 5–20.

It is possible that the nitrate contamination (Figure 5–21) is related to the ammonium contamination. Ammonia was used on site but there is no evidence for nitrate use. Hence, the nitrate may be present as a biological oxidation product of ammonium. The nitrate contamination coincides with ammonium, and traces are also detected in the Dolores River. Both ammonium and nitrate are large soluble ions that are not significantly attenuated by soil materials. Nonetheless, the concentrations in the river are low, suggesting that dilution and removal by biological processes are sufficient to prevent significant surface water contamination from occurring.

Figure 5–22 shows the location of benzene contamination at the UC site. The actual source of this contamination is unknown. There are no records indicating use of organic chemicals as part of the milling processes at the site. It is likely, therefore, that the benzene is a remnant from spilled gasoline. Although gasoline consists primarily of saturated hydrocarbons (e.g., octane), soil microorganisms under oxidizing conditions can utilize such compounds as a sole carbon source (primary food). Because benzene is not consumed as efficiently, it is not uncommon for an old fuel spill to consist primarily of aromatic organic compounds such as benzene. Aged benzene contaminant plumes are often at steady-state, such that biological removal on the fringe of the plume prevents the plume from significant growth. The pattern shown in Figure 5–22 fits the pattern of a steady-state source because of the high concentration in the middle with much lower concentrations radiating downgradient. Thus, although continued monitoring is required, it is likely that the benzene contamination is not growing and will be consumed by microorganisms over time.

The only other standard exceeded at the UC site was the radium-226+228 standard. The radium-226/228 contamination at the UC site is highly localized. Only concentrations in well 0319 exceed the UMTRA Project standard; concentrations in all other wells are near background levels. Concentrations of radium-226+228 in well 0319 are not highly elevated; the average concentration of 6.2 picocuries per liter (pCi/L) is near the standard of 5 pCi/L. Most of the contribution to the radium concentrations in this well is from radium-228.

Bedrock Aquifers

The Entrada Sandstone underlies the alluvium at the UC site. Four wells were installed in the Entrada Sandstone at the UC site during the recent field investigation (Figure 4–3 and Figure 5–16). Wells 0325 and 0326 are located on the terrace above the floodplain, and wells 0317 and 0324 are located on the floodplain. As shown in Table 5–8, the terrace wells have low concentrations of COPCs, indicating minimal effect from site operations. However, sampling results from Entrada Sandstone wells installed on the floodplain indicate that the aquifer has been affected by operations at the UC site.

Table 5–8. Comparison of Selected Analytes in Entrada Sandstone Wells—February/March 2001

Well	Uranium mg/L	Molybdenum mg/L	Selenium mg/L	Nitrate (as NO_3) mg/L	Ammonium mg/L
0317 (floodplain)	0.017	0.242	0.0066	18.9	73.2
0324 (floodplain)	0.016	0.032	0.032	111	6
0325 (terrace)	<0.01	0.003	0.003	3.1	0.012
0326 (terrace)	0.01	0.009	0.009	1.3	0.05

Based on the data in Table 5–8, the floodplain Entrada wells are contaminated with molybdenum, selenium, nitrate, and ammonium. Uranium concentration does not exceed the UMTRA standard of 0.044 mg/L in any of the samples and is in the range of background concentrations. The molybdenum standard (0.1 mg/L) is exceeded in well 0317, and the selenium standard (0.01 mg/L) and nitrate standard (44 mg/L) are exceeded in well 0324.

Table 5–9 compares water quality in the floodplain Entrada Sandstone wells 0317 and 0324 with water quality in adjacent alluvial wells 0314 and 0508, respectively. This table illustrates that the alluvial ground water (with one exception) contains higher concentrations of COPCs than the bedrock ground water immediately below. The one exception is ammonium concentration in well 0317, which is much higher than in adjacent alluvial well 0314 where all other contaminants are less concentrated. A possible explanation is the lower permeability of the Entrada Sandstone. The contaminated ground water migrated to the Entrada Sandstone, but because there is little recharge (low permeability), microorganisms do not have sufficient oxygen to decompose the ammonium and nitrate at the rate that is occurring in the overlying alluvium. Support for this possibility is the fact that the oxidation-reduction potential and the nitrate content (a product of biological oxidation of ammonium) are significantly lower in well 0317 relative to that in the overlying alluvium.

Table 5–9. Comparison of Ground Water Quality in Entrada Sandstone Floodplain Wells with Water Quality in Adjacent Alluvial Wells—September 2000 Data

Analyte	Units	0317 Entrada	0314 Alluvium	0324 Entrada	0508 Alluvium
NH_4	mg/L	118	34.2	17.8	94.9
Mo	mg/L	0.247	0.304	0.0312	1.38
NO_3	mg/L	7.44	63.5	137	1,790
ORP	mV	–86	143	186	108
pH	s.u.	7.43	6.87	7.41	6.70
Se	mg/L	0.0038	0.0235	0.0384	1.73
SO_4	mg/L	705	524	266	1,110
TDS	mg/L	1,140	1,220	793	4,230
U	mg/L	0.0119	0.0334	0.0211	0.0698

Several Navajo sandstone wells are on the terrace (0668, 0556, and 0688), and two Navajo Sandstone wells are on the floodplain (0669, 0670). Wells 0669 and 0670 are located within the footprint of the former tailings pile. These wells have an upward vertical hydraulic gradient and are currently flowing. With the exception of a sample from well 0556 (0.016 mg/L), samples collected from Navajo Sandstone wells at the UC site during the recent field investigation contained background concentrations of COPCs, and no standards were exceeded (Figure 5–16).

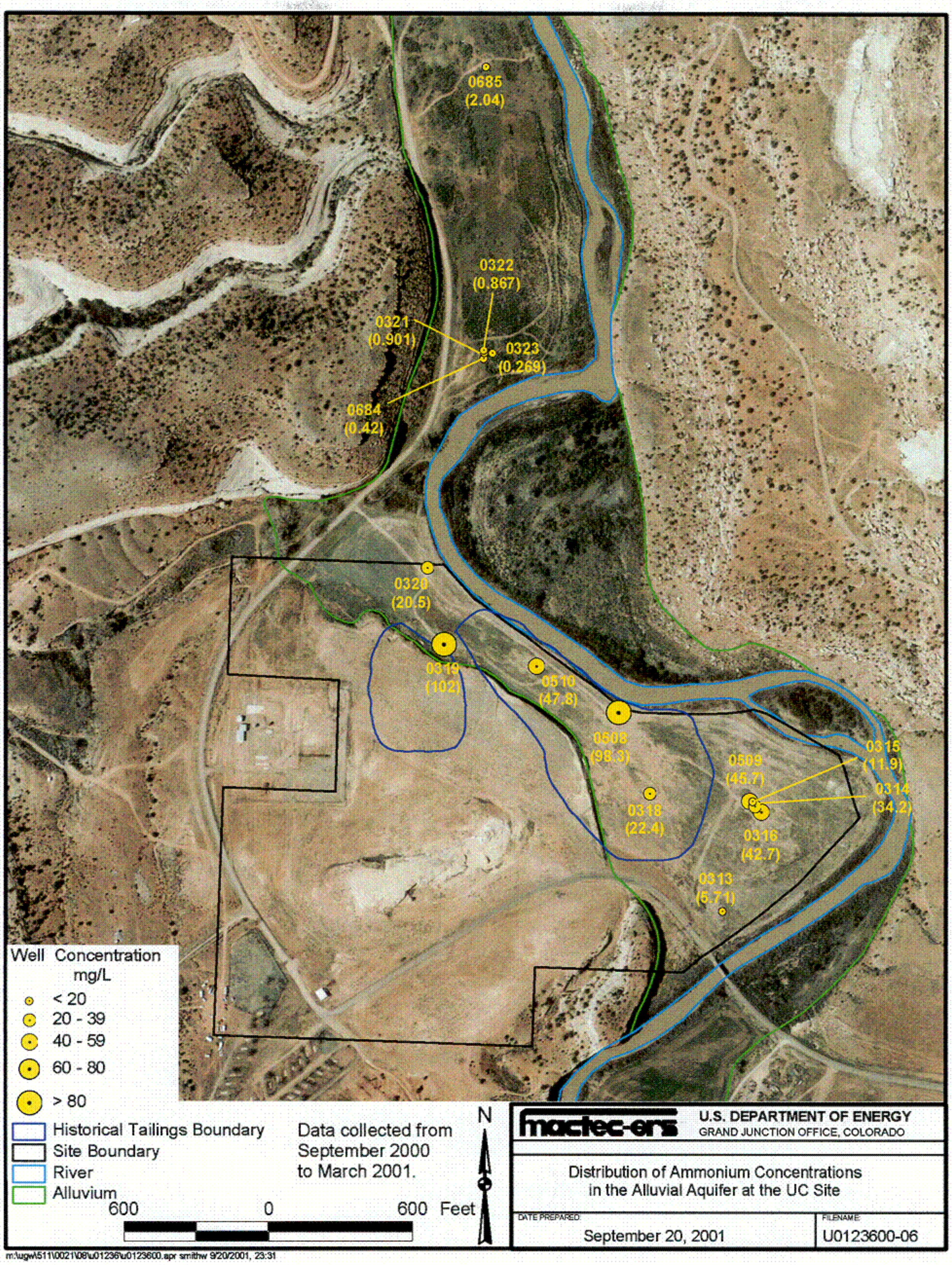

Figure 5–20. Ammonium Concentrations at the UC Site

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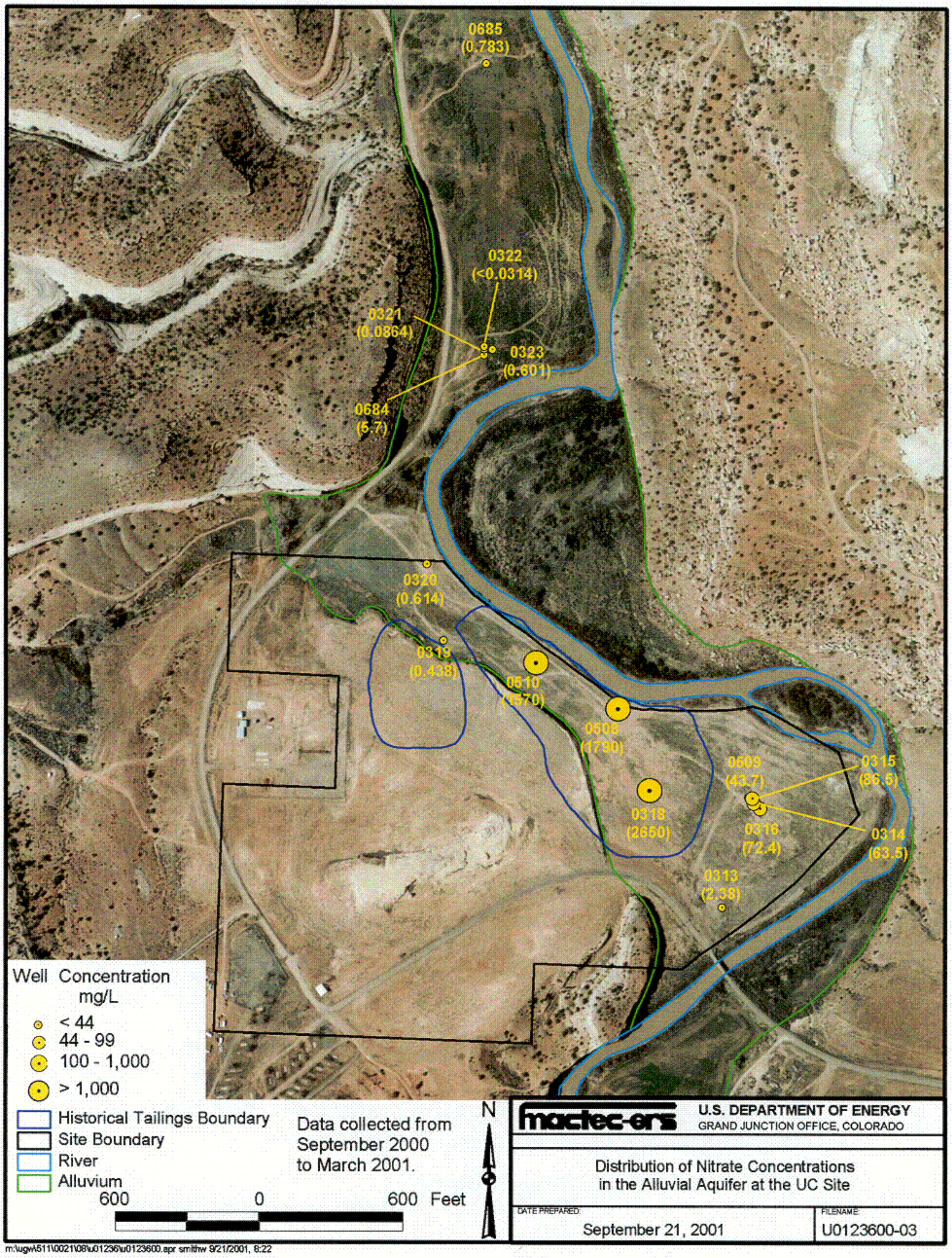

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Figure 5–21. Nitrate Concentrations at the UC Site

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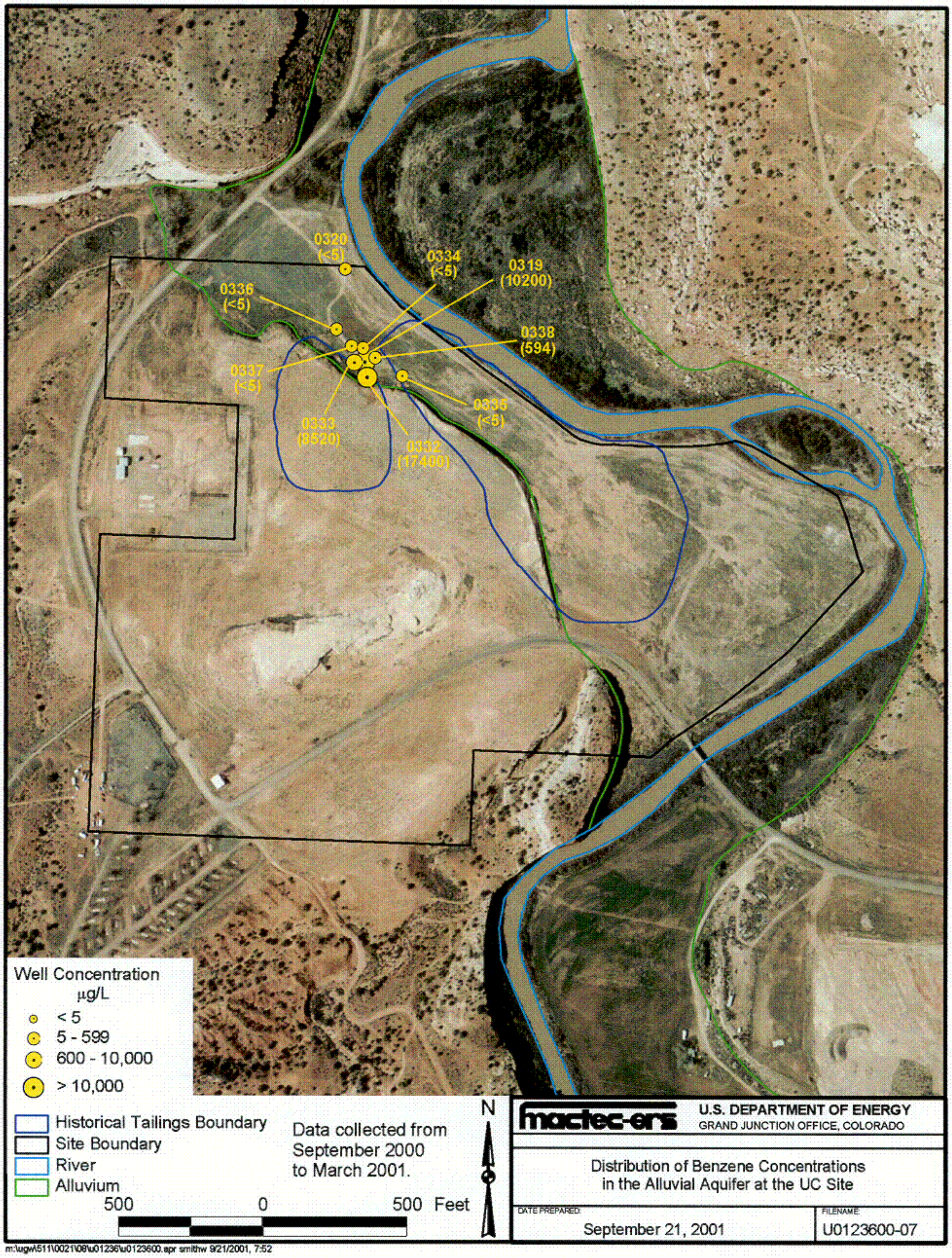

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Figure 5–22. Benzene Concentrations at the UC Site

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5.2.3 Summary of Geochemical Conditions

This section has demonstrated that contamination with one or more milling-related contaminants are present in ground water in alluvial wells at both the NC and UC sites and in Entrada Sandstone wells at the UC site. The data demonstrate that the contaminant plume is smaller at the NC site and is somewhat more widespread at the UC site. Part of the reason for the more widespread distribution at the UC site is the contribution of ammonium at that site. Ammonium and its biodegradation by-product, nitrate, are large ions that are not significantly attenuated by soil materials; hence, a larger area is affected. There is also a localized area of contamination with benzene and other aromatic compounds.

The data clearly show insignificant effect on surface water in the Dolores River. Although some of the contaminants were detected in samples collected alongside the river, concentrations are low and the extent is limited.

Sections 4.3 and 4.4 discussed concentrations in subsurface soils and estimated R_ds for some of the contaminants. Those data demonstrated that uranium and vanadium contents in the soil are, for the most part, relatively low, indicating that the quantity of source materials remaining is limited. The R_d measurements indicate that molybdenum and uranium have little tendency for sorption in the aquifer matrix. Vanadium and selenium, in contrast to uranium and molybdenum, form less soluble compounds and are more easily taken up by soil materials. However, the extent of contamination from ammonium, nitrate, benzene, and related organics is associated with the biological activity in the aquifer. Although no specific study was conducted to estimate the rates of degradation, it is likely that biological activity will ultimately remove these contaminants.

5.3 Ground Water Flow and Transport Modeling

A ground water flow and transport model was developed to evaluate whether natural processes will reduce site-related contaminant concentrations below applicable standards within a 100-year time period. The contaminants modeled were nitrate, manganese, molybdenum, selenium, and uranium. Appendix H contains the details of this modeling effort.

Two versions of the steady state model (deterministic and stochastic) were developed to simulate site conditions. A steady state deterministic flow and transport model was used as the basis for the stochastic model, which was developed to quantify the uncertainty in flow and transport parameters. Of the five contaminants, only selenium was modeled using both versions. The remaining contaminants were modeled using the steady state deterministic flow and transport model. Based on the modeling results, natural flushing appears to be an acceptable compliance strategy that allows natural processes to reduce the ground water contaminant concentrations to levels below applicable UMTRA Project standards for nitrate, molybdenum, and uranium. Modeling results indicate manganese and selenium concentrations will be reduced to below background concentration (for manganese) or a risk-based standard (for selenium) within 100 years.

The existing ground water flow pattern at the Slick Rock site was modeled using the MODFLOW software (McDonald and Harbaugh 1988), a multilayered, three-dimensional hydrologic flow model published by the USGS. Output from the flow model was used as input to MT3DMS (Zheng 1999), a version of a modular three-dimensional transport model that simulates advection, dispersion, and chemical reactions in the ground water system. The codes used are fully described in the references cited and have been verified, benchmarked, and approved for use by most government and regulatory agencies. A summary of the modeling results is provided in the following sections.

5.3.1 Steady State Deterministic Model

Input flow parameters that proved to be most sensitive are horizontal hydraulic conductivity of layer 2, recharge, general head boundary conductance, and the Dolores River stage. Predicted maximum concentrations of the various contaminants for selected times up to 100 years into the future are included in Table 5–10. Appendix H contains concentration distribution maps for various times for each of the five contaminants.

Table 5–10. Predicted Steady State Deterministic Maximum Concentrations for Nitrate, Manganese, Molybdenum, Selenium, and Uranium

	Modeled Contaminant				
	Nitrate	**Manganese**	**Molybdenum**	**Selenium**	**Uranium**
Benchmark/Standard (mg/L)	44	3.5	0.1	0.18	0.044
Source	UMTRA	Background	UMTRA	Risk-Based	UMTRA
Max Concentration @ 5 yrs	832.8	5.82	0.75	1.22	0.435
Max Concentration @ 10 yrs	412.3	5.50	0.526	0.909	0.171
Max Concentration @ 15 yrs	244.9	5.47	0.369	0.715	0.126
Max Concentration @ 25 yrs	151.6	5.11	0.207	0.505	0.065
Max Concentration @ 50 yrs	67.8	3.60	0.097	0.274	0.035
Max Concentration @ 60 yrs	42.5	3.03	NA	0.225	NA
Max Concentration @ 70 yrs	NA	NA	NA	0.211	NA
Max Concentration @ 80 yrs	NA	NA	NA	0.197	NA
Max Concentration @ 90 yrs	NA	NA	NA	0.181	NA
Max Concentration @ 100 yrs	NA	NA	NA	0.166	NA

As shown in Table 5–10, the results of the steady state MT3DMS predictive simulations indicate:

- On average the maximum nitrate concentration in the ground water beneath the Slick Rock site will decrease to below the UMTRA Project standard for nitrate of 44 mg/L within 60 years.

- After 100 years, the maximum predicted manganese concentration is 3.86 mg/L, which is above the maximum observed background concentration of 3.5 mg/L. However, the simulations indicate only one 25 ft by 25 ft grid cell contains ground water concentrations above this standard.

- Molybdenum concentrations drop below the 0.1 mg/L UMTRA Project standard between 25 and 50 years.

- The maximum predicted selenium concentration after 100 years is 0.262 mg/L, which is above the risk-based standard of 0.18 mg/L. After 100 years only 3 cells contain selenium in concentrations above the standard.

- Uranium concentrations drop below the UMTRA Project standard of 0.044 mg/L prior to 50 years of natural flushing.

5.3.2 Steady State Stochastic Model

The distribution coefficient (K_d) and longitudinal dispersivity were identified as the most sensitive transport parameters. As previously mentioned, selenium is the only contaminant modeled using the stochastic model. Table 5–11 presents the maximum average selenium concentration for selected time intervals.

Table 5–11. Stochastic Modeling Results for Selenium

	Time Interval (years)									
	5	**10**	**15**	**25**	**50**	**60**	**70**	**80**	**90**	**100**
Maximum Average Selenium Concentration (mg/L)	0.937	0.621	0.482	0.326	0.194	0.172	0.156	0.143	0.135	0.131

Compared to the deterministic results, the stochastic results predict selenium will be present in lower concentrations. This can be explained by the fact that parameter inputs for the stochastic simulations represent midpoint values calculated from a range, and deterministic inputs represent values dictated by the sensitivity analysis results. Many of the stochastic input values result in a faster cleanup time, which lowers the contaminant concentration. A more detailed explanation is presented in Appendix H, Section 6.2.

Based on the stochastic results, the selenium concentration is expected to drop below the 0.18 mg/L human health risk-based level within 60 years. This stochastic simulation also predicts that there is a 14 percent probability that the maximum average selenium concentration after 100 years will be greater than the 0.18 mg/L benchmark. Selenium concentrations are expected to exceed the UMTRA Project standard of 0.01 mg/L.

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6.0 Baseline Risk Assessment

6.1 Human Health Risks

A BLRA was previously prepared for the Slick Rock site (DOE 1995b). Most of the methodology used in that risk assessment followed standard EPA risk assessment protocol (EPA 1989a), though the BLRA did not calculate single exposure point risks for noncarcinogenic constituents. Instead, a range of calculated exposure intakes was compared with a range of contaminant doses associated with various adverse effects. Data used in that report were collected from 1986 to 1994. Risks for the NC site and UC site were calculated separately. Since that time, additional data have been collected to more completely characterize the site, to represent more recent site conditions, and to better characterize background ground water. Updated and revised toxicological data are also available for some site-related constituents. These new data were used to reevaluate COPC identification and assessment of associated risks.

6.1.1 Summary of 1995 BLRA Methodology and Results

6.1.1.1 Ground Water

The 1995 BLRA identified 33 constituents at the NC site as being detected in ground water. Typically, these concentrations would be compared to background values to determine if concentrations were elevated compared to background ground water. However, for the Slick Rock site, no background data were available at the time the BLRA was completed. Therefore, to provide a conservative evaluation of potential site risks, all detected constituents that were interpreted as mill-related were retained for the screening process. The initial list of detected analytes was screened to first eliminate constituents with concentrations within nutritional or dietary ranges. A second screening step eliminated contaminants of low toxicity or low frequency of detection. The two screening steps eliminated 10 and 15 constituents, respectively, resulting in the following COPC list: manganese, sodium, sulfate, uranium, lead-210, polonium-210, radium-226, and thorium-230. These contaminants were retained for further risk analysis.

The 1995 BLRA identified the same 33 constituents at the Slick Rock UC site as being present due to mill-related processes. This initial list was also screened to first eliminate constituents with concentrations within nutritional or dietary ranges. A second screening step then eliminated contaminants of low toxicity or low frequency of detection. These two screening steps eliminated five and twelve constituents, respectively, resulting in the following COPC list: cadmium, chloride, iron, manganese, molybdenum, nitrate, selenium, sodium, strontium, sulfate, uranium, vanadium, lead-210, polonium-210, radium-226, and thorium-230. These contaminants were retained for further risk analysis.

A number of potential routes of exposure were evaluated for both sites: ingestion of ground water as drinking water in a residential setting, dermal contact with ground water while bathing, and ingestion of garden produce irrigated with ground water. Ingestion of meat and milk from ground-water-fed livestock was also considered. For the UC site, however, nitrate and sulfate concentrations in ground water were so high that livestock could not survive chronic ground water exposure. Therefore, this exposure route was considered not viable and was eliminated from further consideration from a human health perspective. The nitrate and sulfate concentrations *do* constitute a real and current risk to livestock in the area even though ingestion of meat and milk is not a significant pathway for human health. Results of the exposure assessment indicated that intakes for all constituents were negligible from exposure routes other than drinking water. Therefore, only exposure through ingestion of ground water as drinking water was retained for more detailed evaluation. Children and adults were considered as likely receptors; infants were evaluated for exposure to nitrate and sulfate.

Calculated exposure intakes were presented along with contaminant intakes associated with a range of adverse health effects. Potential risks associated with exposure to noncarcinogenic constituents were discussed in a qualitative fashion; carcinogenic risks were quantified and compared to EPA's acceptable risk range of 1×10^{-4} to 1×10^{-6}.

For the NC site, it was concluded that adverse noncarcinogenic effects could result from ingestion of manganese, sulfate, and sodium in ground water. Levels of sulfate present could result in diarrhea and dehydration in infants; adults could also experience laxative effects at those levels. Sodium concentrations were at levels that could contribute to hypertension; manganese concentrations could result in neurological disorders. For additional discussion on the toxicity of these constituents, refer to the original BLRA (DOE 1995b). Pathways other than ground water ingestion (e.g., ingestion of garden vegetables or meat and milk) did not contribute appreciably to site risks. Carcinogenic risks associated with ingestion of ground water at the NC site exceeded EPA's acceptable upper bound risk value of 1×10^{-4} by almost two orders of magnitude; uranium and lead-210 were the major risk contributors. The drinking water pathway was the only pathway of significance in calculating carcinogenic risks.

For the UC site, it was determined that adverse noncarcinogenic health effects could result from chronic ingestion of nitrate, sulfate, manganese, chloride, sodium, molybdenum, selenium, and iron in drinking water. Nitrate levels were high enough that they could be potentially lethal to infants; sulfate levels could cause severe dehydration and diarrhea in infants. Sodium and chloride concentrations would contribute to hypertension, and manganese levels could lead to neurological disorders. The levels of molybdenum present could lead to a deficiency of other essential nutrients. Adverse noncarcinogenic effects were not expected from exposure to vanadium, cadmium, strontium, and uranium. For additional toxicological information, refer to the original BLRA (DOE 1995b). Pathways other than ground water ingestion did not contribute appreciably to site risks. Carcinogenic risks for the UC site were calculated to be three times the upper bound of EPA's acceptable risk range. The major contributors to this risk were uranium and lead-210. Only the ground water ingestion pathway contributed significantly to carcinogenic risks.

6.1.2 BLRA Update

As noted in the previous section, the original BLRA considered several potential routes of exposure to contaminants and eliminated all but one, ingestion of ground water in a residential setting, as insignificant. Based on this analysis, only the ground water ingestion pathway is evaluated in this BLRA update. It is possible that incidental exposure to ground water could occur as it discharges to the Dolores River, but concentrations of site-related constituents are so low in the river that risks would be negligible.

Risk calculations presented here follow EPA's *Risk Assessment Guidance for Superfund Methodology* (EPA 1989a), which involves determining a point estimate for excess cancer risk from current or potential carcinogenic exposures (risk is equal to lifetime intake times cancer slope factor) and a hazard quotient (HQ) for noncarcinogenic exposures (HQ is equal to exposure intake divided by reference dose). EPA's acceptable carcinogenic risk range is 1×10^{-6} to 1×10^{-4}, which is an excess cancer risk of 1 in 1,000,000 to 1 in 10,000 compared to the general population. Risks exceeding this range are generally unacceptable. For noncarcinogenic exposures, an HQ exceeding 1 is generally unacceptable. HQs from multiple contaminants and/or pathways are often summed to estimate cumulative noncarcinogenic risks; these summed HQs are referred to as a hazard index (HI). HIs greater than 1 also represent generally unacceptable exposures. Therefore, it is possible for a number of individual contaminants to each have "acceptable" HQs of less than 1 that, when summed, represent a potentially unacceptable cumulative risk. Figure 6–1 provides exposure intake equations and default assumptions used in calculations for this BLRA update.

Residential Exposure Scenario—Ground Water Ingestion

Chemicals: Intake (chronic daily in mg/kg-day) = (Cw × IRw × EF × ED)/(BW × AT)

Radionuclides: Intake (lifetime in picocuries) = Cw × IRw × EF × ED

Where

Cw = contaminant concentration in water; UCL_{95} values used
IRw = ingestion rate for water (2 L/day default for adults; 1.5 L/day for children age 6–12; 0.64 L/day for infants)
EF = exposure frequency (350 days/year)
ED = exposure duration (30 years for adults; 7 years for children; 1 year for infants)
BW = body weight (70 kg for adults; 38.4 kg for children; 4 kg for infants)
AT = averaging time (365 days × ED for noncarcinogens; 365 days × 70 years for carcinogens)

Noncarcinogens: Hazard Quotient (HQ) = Intake/Reference Dose (RfD)

Carcinogens: Risks = Slope Factor (SF) x Intake

Figure 6–1. Exposure Intake and Risk Equations and Default Assumptions

Toxicological values used to estimate risks (reference doses and slope factors) are conservative values with uncertainty factors built in to be protective of sensitive populations. Therefore, risks presented here are reasonable worst-case estimates and are quite likely much higher than those that actually could exist.

In this update, which uses point-exposure doses, single values are used for each parameter required in the risk calculations. Calculations to determine contaminant intakes use standard exposure factors (EPA 1989b). The ground water data used to assess risks in this document are from the last three rounds of sampling at the site—from September 2000 through March 2001. These data were used to give an up-to-date look at the site. Risk calculations performed for ground water use the UCL_{95} on the mean concentrations to provide reasonable worst-case risk estimates for probable future ground water uses.

The same methodology was used to calculate carcinogenic risks for this BLRA update as was used in the original BLRA (i.e., receptors are adults with exposure averaged over 70 years). For all risk calculations, benchmarks for acceptable contaminant intakes (e.g., reference doses and slope factors) are best available data from standard EPA sources (e.g., Integrated Risk Information System, Region III Risk-Based Concentration Table [EPA 2001]).

Analytical results for nitrate presented in this document are concentrations of nitrate reported as NO_3. Other references may report nitrate values as N (nitrogen), also referred to as nitrate-nitrogen. The conversion factor for these different reported quantities is 1 mg N (or nitrate-nitrogen) is equal to 4.4 mg nitrate (as NO_3). Thus, the UMTRA ground water standard for nitrate is 10 mg/L as N or 44 mg/L as NO_3. For consistency in this BLRA update and for ease in use of reported analytical data, all concentrations of nitrate are expressed as NO_3.

Background data, unavailable during the completion of the initial BLRA, have been collected since that time. Additional wells have been installed to better define the spatial extent of ground water contaminants. Although it would be preferable to repeat the earlier screening process completed in the initial BLRA using these additional data, this is not possible because many of the analytes were dropped from additional monitoring on the basis of the original screening. Because the screening process in the original BLRA was sufficiently conservative, this update uses the COPC list from the original BLRA as a starting point to evaluate current data for ground water with two exceptions. Selenium, eliminated during the screening process for the NC site, is included as a COPC because it does exceed the UMTRA standard at some locations. Radium-228 was not an analyte in the original BLRA. However, because the UMTRA radium standard is combined radium 226 and 228, it has been analyzed recently. Therefore it is also included in the BLRA update for both sites.

6.1.2.1 North Continent Site

As noted previously, the COPCs for the NC site were manganese, sodium, sulfate, uranium, lead-210, polonium-210, radium-226, and thorium-230. The addition of selenium and radium-228 brings the total number of COPCs to ten. Table 6–1 presents the minimum, maximum, mean, and UCL_{95} values for each COPC that was detected in the NC on-site alluvial ground water plume and for background ground water. Lead-210, polonium-210, and thorium-230 were not detected in any sample analyzed; these constituents can be dropped as COPCs for further evaluation and are not reported in Table 6–1.

Also included in Table 6–1 for comparison are the applicable UMTRA ground water standards (if available) or other potentially relevant water quality standards or benchmarks, including risk-based concentrations (RBCs [EPA 2001]). The RBC for a given contaminant represents a concentration in drinking water that would be protective of human health provided that

- Residential exposure is appropriate,
- Ingestion of contaminated drinking water is the only exposure pathway,
- The contaminant contributes nearly all the health risk, and
- EPA's risk level of 1×10^{-6} for carcinogens and an HQ of 1 for noncarcinogens is appropriate.

If any of these assumptions is *not* true, contaminant levels at or below RBCs cannot automatically be assumed to be protective. For example, if multiple contaminants are present in drinking water, a single contaminant may be below its RBC but still be a significant contributor to the total risk posed by drinking the water. However, if an RBC is exceeded, it is an indication that further evaluation of the contaminant is warranted. RBCs are intended for use in screening-level evaluations.

Table 6–1. Slick Rock NC On-Site Alluvial Ground Water Data Summary 2000–2001

Contaminant	FOD[a]	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	UCL$_{95}$ (mg/L)	UMTRA std (mg/L)	RBC (mg/L)
Manganese						0.05[f]	1.7N[e]
Background[b]	6/6	0.215	3.53	1.88	2.95		
Current plume[c]	21/21	0.0428	0.739	0.395	0.396		
Historical Plume[d]	9/9	0.29	0.75	0.47			
Selenium						0.01	
Background	5/6	<0.0001	0.0012	0.00034	0.0007		
Current plume	19/21	<0.0001	0.0367	0.005	0.011		
Historical Plume	1/8	<0.005	0.015	na	na		
Sodium							
Background	6/6	253	1,560	816	1,304		
Current plume	21/21	81.5	1,760	870	955		
Historical Plume	9/9	513	646	555			
Sulfate						250[f]	
Background	6/6	726	4,590	2,396	3,904		
Current plume	21/21	225	3,270	1,508	1,577		
Historical Plume	9/9	945	1,650	1,380			
Uranium						0.044	0.11N
Background	6/6	0.0019	0.0139	0.00695	0.0112		
Current plume	21/21	0.131	1.31	0.551	0.718		
Historical Plume	9/9	2.9	3.9	3.6			
Radium-226(pCi/L)							
Background	1/6	<0.012	0.19	na	na	5 pCi/L	
Current plume	6/21	<0.12	0.27	na	na	Ra-226 + Ra-228	
Historical Plume	7/7	0.3	2.4	0.6			
Radium-228(pCi/L)							
Background	0/6	<0.63	na	na	na		
Current plume	3/21	<0.62	1.27	na	na		
Historical Plume	na	na	na	na	na		

Current plume wells: 0302–0309, 0327

[a] Frequency of detection

[b] Current background data collected September 2000 through March 2001 for wells 0300 and 0301

[c] Current plume data collected September 2000 through March 2001

[d] Historical data from the 1995 BLRA, collected 1986 through 1994 for well 0503

[e] N= noncarcinogenic risks

[f] Secondary drinking water standard (Safe Drinking Water Act)

Comparing data for the NC site to background data indicates that manganese and sulfate concentrations in alluvial ground water associated with the NC site are consistently lower than background concentrations. On this basis, these constituents can be eliminated as COPCs for the BLRA update. Thus the contaminants retained for evaluation in this update are radium-226, radium-228, selenium, sodium, and uranium.

6.1.2.2 Union Carbide Site

The COPCs used as a starting point for evaluating the UC site, as identified in the original BLRA, are cadmium, chloride, iron, manganese, molybdenum, nitrate, selenium, sodium, strontium, sulfate, uranium, vanadium, lead-210, polonium-210, radium-226, and thorium-230. Radium-228 was added to this list for the same reason as the NC site.

Summary data for the UC site are presented in Table 6–2 for COPCs detected in on-site ground water. As with the NC site, lead-210, polonium-210, and thorium-230 analyses were all below detection, and these constituents can be dropped as COPCs for further evaluation. Sulfate concentrations were within the range of background, and it can also be dropped as a COPC. The highest on-site concentrations of iron, sodium, and strontium exceed the highest background concentrations. However, background means and UCL_{95} values for these constituents are all higher than those for the on-site wells, justifying their elimination as COPCs. Therefore the COPCs retained for evaluation of the UC site in this BLRA update are cadmium, chloride, manganese, molybdenum, nitrate, selenium, uranium, vanadium, radium-226, and radium-228. In addition, site characterization conducted after the initial BLRA found elevated levels of some organic constituents, probably gasoline, based on the chemical signature of the analyses. The source of the organic contamination is not known. It may have come from a spill at a fueling area or a leak from a fuel storage tank. Analysis of samples from this limited area indicate the presence of benzene, toluene, ethylbenzene, and xylenes (BTEX). Therefore these organic constituents have also been added as COPCs for further evaluation of the UC site.

Table 6–2. Slick Rock UC On-Site Alluvial Ground Water Data Summary 2000–2001

Contaminant	FOD[a]	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	UCL_{95} (mg/L)	UMTRA std (mg/L)	RBC (mg/L)
Cadmium						0.01	0.018N[e]
Background[b]	1/6	<0.0003	0.00037	na	na		
Current plume[c]	9/25	<0.0003	0.0097	na	na		
Historical Plume[d]	4/6	<0.002	0.027	0.018			
Chloride						250[f]	
Background	6/6	138	858	386	682		
Current plume	25/25	28.2	5,470	500	1,088		
Historical Plume	8/8	430	3,980	1,125			
Iron							11N
Background	6/6	0.719	19.6	7.705	13.54		
Current plume	16/25	<0.011	32	2.92	6.48		
Historical Plume	8/8	2.4	14	9.3			
Manganese						0.05[f]	1.7N
Background	6/6	0.215	3.53	1.876	2.95		
Current plume	25/25	0.104	12.8	2.56	4.30		
Historical Plume	8/8	4.7	7.5	6.6			
Molybdenum						0.1	0.18N
Background	6/6	0.0026	0.0046	0.0035	0.0041		
Current plume	25/25	0.0055	1.83	0.47	0.724		
Historical Plume	7/7	1.1	2.2	1.4			

Table 6–2 (continued). Slick Rock UC On-Site Alluvial Ground Water Data Summary 2000-2001

Contaminant	FOD[a]	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	UCL_{95} (mg/L)	UMTRA std (mg/L)	RBC (mg/L)
Nitrate						44 as NO_3	255 N as NO_3
Background	5/6	<0.0314	0.756	0.325	0.57		
Current plume	24/25	<0.0314	3,510	620	1,086		
Historical Plume	7/7	290	1,600	1,200			
Selenium						0.01	0.18N
Background	5/6	<0.0001	0.0012	0.00034	0.0007		
Current plume	24/25	<0.0001	2.52	0.416	0.764		
Historical Plume	8/8	0.012	1.2	0.99			
Sodium							
Background	6/6	253	1,560	816	1,304		
Current plume	25/25	43	2,210	314	561		
Historical Plume	8/8	479	1,580	899			
Strontium							
Background	6/6	1.27	8.84	4.58	7.51		22N
Current plume	25/25	0.894	11.8	3.43	4.87		
Historical Plume	5/5	5.3	8.6	7.6			
Sulfate						250[f]	
Background	6/6	726	4,590	2,396	3,904		
Current plume	24/25	<0.589	1,160	576	724		
Historical Plume	8/8	2,080	3,160	2,080			
Uranium						0.044	0.11N
Background	6/6	0.0019	0.0139	0.00695	0.0112		
Current plume	25/25	0.00033	0.1	0.039	0.0507		
Historical Plume	8/8	0.013	0.24	0.038			
Vanadium							0.33N
Background	0/6	<0.0013	na	na	na		
Current plume	9/25	<0.0013	0.556	na	na		
Historical Plume	5/5	0.44	0.66	0.59			
Radium-226 (pCi/L)							
Background	1/6	<0.12	0.19	na	na		
Current plume	14/25	<0.12	3.22	0.4899	0.878	5 pCi/L	
Historical Plume	20/20	0.0	3.3	0.6		Ra-226+Ra-228	
Radium-228 (pCi/L)							
Background	0/6	<0.63	na	na	na		
Current plume	5/25	<0.63	4.04	na	na		
Historical Plume	na	na	na	na	na		
Benzene (µg/L)						5 µg/L	0.32 µg/L-C
Background	na	na	na	na	na		
Current plume	10/19	<5	17,400	3,748	6,462		
Historical Plume	na	na	na	na	na		

Table 6–2 (continued). Slick Rock UC On-Site Alluvial Ground Water Data Summary 2000-2001

Contaminant	FOD[a]	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	UCL_{95} (mg/L)	UMTRA std (mg/L)	RBC (mg/L)
Ethylbenzene (µg/L)						680 µg/L	1,300 µg/L-N
Background	na	na	na	na	na		
Current plume	10/19	<5	584	150	234		
Historical Plume	na	na	na	na	na		
Toluene (µg/L)						1,000 µ/L	750 µg/L-N
Background	na	na	na	na	na		
Current plume	7/19	<5	13,600	na	na		
Historical Plume	na	na	na	na	na		
Xylenes (µg/L)						10,000 µg/L	12,000 µg/L-N
Background	na	na	na	na	na		
Current plume	10/19	<15	6,540	2,019	3,135		
Historical Plume	na	na	na	na	na		

Current plume wells for inorganic constituents: 0313–0316, 0318–0320, 0332–0338, 0508–0510
Wells for organic constituents: 0319, 0320, 0332–0338
[a] Frequency of detection
[b] Current background data collected September 2000 through March 2001 for wells 0300 and 0301
[c] Current plume data collected September 2000 through March 2001
[d] Historical data from the 1995 BLRA collected 1986 through 1994 for wells 0506, 0508, and 0510
[e] N = noncarcinogenic risks
[f] Secondary drinking water standard (Safe Drinking Water Act)

For both sites, contaminant concentrations in the current plume are mostly lower than those for the historical plume. Where current plume concentrations exceed historical plume concentrations, it is most likely a result of more complete characterization data rather than actual increases in contamination. Historical plume data were based on only one and three wells for the NC and UC sites, respectively. Many more wells have since been installed to characterize the current plumes.

No standards or benchmarks have been established for chloride or sodium based on human-health concerns. The secondary standard for chloride is based on considerations of taste and corrosivity and not on effects to human health. Because of the lack of toxicity data, potential risks from exposure to these two constituents cannot be quantified. Exposure intakes are calculated for these constituents, but potential adverse effects are considered only qualitatively.

For pathways evaluated quantitatively in this BLRA update, children (age 6 to 12) and adults were evaluated as the primary receptor groups for noncarcinogenic constituents. Children represent a more sensitive receptor group because of their higher intake to body weight ratio. Infants were also evaluated for exposure to nitrate in residential scenarios because they represent the most sensitive receptor population to that constituent. Because carcinogenic risks are averaged over a lifetime, they were calculated for adults only. Ingestion of ground water in a residential setting was the only pathway analyzed. Risks were calculated using default exposure parameters for a residential setting (EPA 1989b).

6.1.3 Results

6.1.3.1 North Continent Site

Results of risk calculations performed for the NC site are presented in Table 6–3. Calculations indicate that essentially all risks—carcinogenic and noncarcinogenic—associated with the site can be attributed to uranium. Risks are slightly higher for children than adults. Although sulfate intakes were not calculated because concentrations are within the range of background, concentrations are high enough that dehydration due to severe diarrhea could occur in infants consuming formula prepared with contaminated water (EPA 1999). However, these same effects would occur with the consumption of background ground water. Intakes of sodium would be within or below the average range of sodium intakes for most American adults (FDA 1995). However, EPA is currently evaluating health effects of sodium in drinking water and is expected to issue additional guidance by August 2001 (63 FR 10274). Although it is not believed that sodium concentrations at the NC site are of concern, sodium may be reevaluated as a COPC pending publication of further guidance by EPA.

Table 6–3. Intake/Risk Calculation Spreadsheet (ground water ingestion pathway)

Slick Rock NC Site—Residential Exposure

Noncarcinogens—Ground Water Ingestion Only (children)

Contaminant	Cw[a]	IRw	EF	ED	BW	AT	Intake	RfD[b]	HQ
Selenium	0.011	1.5	350	7	38.3	2,555	0.0004	0.005	0.083
Sodium	955	1.5	350	7	38.3	2,555	35.8650		
Uranium	0.718	1.5	350	7	38.3	2,555	0.0270	0.003	8.988
								HI=	9.071

Noncarcinogens—Ground Water Ingestion Only (adults)

Contaminant	Cw	IRw	EF	ED	BW	AT	Intake	RfD[b]	HQ
Selenium	0.011	2	350	30	70	10,950	0.0003	0.005	0.060
Sodium	955	2	350	30	70	10,950	26.1644		
Uranium	0.718	2	350	30	70	10,950	0.0197	0.003	6.557
								HI =	6.617

Carcinogens—Ground Water Ingestion Only (adults)

Contaminant	Cw	ITw	EF	ED	BW	AT	Intake	SF	Risk
U-234+238[b]	492.548	2	350	30	na	na	1.03E+07	4.36E-11	4.51E-04
Radium-226	0.1215	2	350	30	na	na	2.55E+03	2.95E-10	7.53E-07
Radium-228	0.5858	2	350	30	na	na	1.23E+04	2.46E-10	3.03E-06

[a] Water concentrations used are UCL_{95}

[b] Assumes equilibrium; 1 mg = 686 pCi; slope factor is average of U-234 and U-238

6.1.3.2 Union Carbide Site

Results of risk calculations performed for the UC site are presented in Table 6–4. Risks were calculated separately for the inorganic and the organic constituents due to the limited extent and differing nature of the BTEX plume. The highest noncarcinogenic risks are associated with exposure of infants to nitrate. Effects of nitrate consumption by infants are potentially lethal. Levels far exceed those shown to produce methemoglobinemia (also known as "blue baby syndrome") in infants through ingestion of formula made with ground water elevated in nitrate. For child and adult receptors, risks associated with nitrate also are unacceptable. The other noncarcinogens that make up the majority of the potential risks are manganese, molybdenum, and selenium. Cadmium and vanadium together make up less than 5 percent of the total risk. Although sulfate intakes were not calculated because concentrations are within the range of background, concentrations are high enough that dehydration due to diarrhea could occur in infants consuming formula prepared with contaminated water (EPA 1999). Again, these same effects would be expected with consumption of background ground water.

For the organic constituents, total potential noncarcinogenic risks are slightly above acceptable levels for children but are below the highest acceptable level for adults. Carcinogenic risks associated with benzene account for the majority of carcinogenic risks. Total risk calculated without benzene is within EPA's acceptable risk range.

Table 6–4. Intake/Risk Calculation Spreadsheet (ground water ingestion pathway)

Slick Rock UC Site—Residential Exposure

Noncarcinogens—Ground Water Ingestion Only (children)

Contaminant		Cw[a]	IRw	EF	ED	BW	AT	Intake	RfD[b]	HQ
Cadmium		0.00246	1.5	350	7	38.3	2,555	0.0001	0.0005	0.185
Chloride		1088	1.5	350	7	38.3	2,555	40.8598		
Manganese		4.3	1.5	350	7	38.3	2,555	0.1615	0.047	3.436
Molybdenum		0.724	1.5	350	7	38.3	2,555	0.0272	0.005	5.438
Nitrate		1086	1.5	350	7	38.3	2,555	40.7847	7	5.826
	infants	1086	0.64	350	1	4	365	166.6192	7	23.803
Selenium		0.764	1.5	350	7	38.3	2,555	0.0287	0.005	5.738
Uranium		0.0507	1.5	350	7	38.3	2,555	0.0019	0.003	0.635
Vanadium		0.178	1.5	350	7	38.3	2,555	0.0067	0.009	0.743
								HI (inorganics) =		22.001
Ethylbenzene		0.244	1.5	350	7	38.3	2,555	0.0092	0.1	0.092
Toluene		5.151	1.5	350	7	38.3	2,555	0.1934	0.2	0.967
Xylenes		3.135	1.5	350	7	38.3	2,555	0.1177	2	0.059
								HI (organics only) =		1.118
									HI total =	23.119

Table 6–4 (continued). Intake/Risk Calculation Spreadsheet (ground water ingestion pathway)

Noncarcinogens—Ground Water Ingestion Only (adults)

Contaminant	Cw	IRw	EF	ED	BW	AT	Intake	RfD[b]	HQ
Cadmium	0.00246	2	350	30	70	10,950	6.74E-05	0.0005	0.135
Chloride	1088	2	350	30	70	10,950	29.808219		
Manganese	4.3	2	350	30	70	10,950	0.1178082	0.047	2.507
Molybdenum	0.724	2	350	30	70	10,950	0.0198356	0.005	3.967
Nitrate	1086	2	350	30	70	10,950	29.753425	7	4.250
Selenium	0.764	2	350	30	70	10,950	0.0209315	0.005	4.186
Uranium	0.0507	2	350	30	70	10,950	0.001389	0.003	0.463
Vanadium	0.178	2	350	30	70	10,950	0.0048767	0.009	0.542
							HI (inorganics) =		16.050
Ethylbenzene	0.244	2	350	30	70	10,950	0.0066849	0.1	0.067
Toluene	5.151	2	350	30	70	10,950	0.1411233	0.2	0.706
Xylenes	3.135	2	350	30	70	10,950	0.0858904	2	0.043
							HI (organics only) =		0.815
								HI total =	16.866

Carcinogens—Ground Water Ingestion Only (adults)

Contaminant	Cw	IRw	EF	ED	BW	AT	Intake	SF	Risk
Benzene	6.462	2	350	30	70	25,550	0.0758748	0.055	4.17E-03
Radium-226	0.878	2	350	30	na	na	1.84E+04	2.95E-10	5.44E-06
Radium-228	1.195	2	350	30	na	na	2.51E+04	2.46E-10	6.17E-06
U-234+238[b]	34.7802	2	350	30	na	na	7.30E+05	4.36E-11	3.18E-05
							Total risk without benzene =		4.35E-05
							Total with benzene =		4.22E-03

[a] Water concentrations used are UCL_{95}

[b] Assumes equilibrium; 1 mg = 686 pCi; slope factor is average of U-234 and U-238

6.1.3.3 Summary and Recommendations

The BLRA update started with the COPC lists for the NC and UC sites and evaluated more recent data collected for these constituents against newly collected background data. Based on the reevaluation of data, the following observations and conclusions can be made.

- Concentrations of lead-210, polonium-210, and thorium-230 have decreased to levels below detection for all wells at both the NC and UC sites. It is recommended that these constituents be eliminated as COPCs for both sites.

- Sulfate at both the NC and UC sites is within the range of background. Manganese at the NC site is also within the range of background. It is recommended that sulfate be dropped as a COPC at both sites and manganese be eliminated at the NC site.

- The highest iron, sodium, and strontium concentrations at the UC site exceeded the range of background. However, background means and UCL_{95} values for these constituents were higher for background than for the plume. Therefore, it is recommended that iron, sodium, and strontium be dropped as COPCs at the UC site.

- Uranium accounts for nearly all of the potential risk at the NC site. Selenium does not pose an unacceptable risk, though concentrations at some locations exceed the UMTRA standard of 0.01 mg/L.

- Manganese, molybdenum, nitrate, and selenium account for the majority of potential noncarcinogenic risks associated with the UC site. Cadmium and vanadium together account for less than 5 percent of the total risk. It is recommended that cadmium and vanadium be eliminated as COPCs for the UC site. Uranium risks associated with the UC site are acceptable, though several locations exceed the UMTRA standard. For organic constituents, risks associated with toluene are marginally acceptable.

- At the UC site, benzene accounts for most of the potential carcinogenic risks. Potential risks from radium and uranium are within EPA's acceptable risk range, though both concentrations of constituents exceed UMTRA standards.

Table 6–5 summarizes recommended COPCs for the NC and UC sites and the basis for that recommendation. Table 6–6 summarizes the justification for the elimination of the other COPCs included in this BLRA update.

Table 6–5. Recommended COPCs for the Slick Rock Site

Contaminant	North Continent Site			Union Carbide Site		
	COPC?	Based on std?	Based on risk?	COPC?	Based on std?	Based on risk?
Manganese	N[a]			Y		✓
Molybdenum	na[b]			Y	✓	✓
Nitrate	na			Y	✓	✓
Selenium	Y	✓		Y	✓	✓
Uranium	Y	✓	✓	Y	✓	
Radium-226+228	N[c]			Y	✓	
Benzene	na			Y	✓	✓
Toluene	na			Y	✓	

[a] eliminated as a COPC because concentrations are below background
[b] na = not applicable
[c] eliminated as a COPC because concentrations are below standard and risks are acceptable

Table 6–6. Rationale for Elimination of COPCs in BLRA Update

Contaminant	North Continent (NC) Site	Union Carbide (UC) Site
Cadmium	na	Makes up <1% of site risks. HQ is acceptable.
Chloride	na	No toxicity data to quantitatively evaluate risk. Background concentrations are above the secondary drinking water standard. Should flush from the system to background levels.
Iron	na	Mean and UCL_{95} concentrations are well below background.
Sodium	No toxicity data to quantitatively evaluate risks. Intakes within dietary ranges. Only marginally above background concentrations.	Mean and UCL_{95} concentrations are well below background.
Strontium	na	Mean and UCL_{95} concentrations are below background.
Sulfate	Plume concentrations within the range of background.	Plume concentrations within the range of background.
Vanadium	na	Makes up <3% of site risks. HQ is acceptable.
Lead-210	Not detected in any sample	Not detected in any sample
Polonium-210	Not detected in any sample	Not detected in any sample
Thorium-230	Not detected in any sample	Not detected in any sample
Ethylbenzene	na	Risks well below acceptable threshold. Benzene can be used as an indicator.
Xylenes	na	Risks well below acceptable threshold. Benzene can be used as an indicator.

na = not applicable

6.2 Ecological Risks

Ecological risk assessment (ERA) is a process that evaluates the likelihood of adverse ecological effects occurring in the future as a result of exposure to one or more environmental stressors. A stressor is defined as any physical, chemical, or biological entity that can induce an adverse ecological response. The risk assessment process is outlined in EPA guidance documents, particularly the "Guidelines for Ecological Risk Assessment" (EPA 1998) and the "Framework for Ecological Risk Assessment" (EPA 1992). The ERA for the Slick Rock site generally follows this framework and guidance.

The overall goal of this risk assessment is to identify ecological contaminants of potential concern (E-COPCs) that can be related to the dispersal of contaminants in the ground water underlying the NC and UC sites and to characterize the potential for adverse effects of these E-COPCs on the ecosystems at these sites and along the Dolores River. In particular, potential effects on special status species and sensitive environments are considered. This assessment is an update and expansion of the BLRA screening-level assessment conducted in 1995 (DOE 1995b). However, it is still primarily a screening assessment to identify E-COPCs and areas for which future monitoring may be necessary. This section summarizes the BLRA findings and evaluates any data collected since the BLRA. This section will also apply data from new studies as well as updated ecological benchmarks and regulatory requirements that have been developed since completion of the BLRA.

Predicting the effects of chemicals on ecological receptors is complicated by the variable interactions and influences within an ecosystem. To a great extent, ERA is an emerging science; little data exists for most chemicals and their effects on ecological receptors. Therefore, attempting to integrate and evaluate individual and synergistic chemical effects with other stressors (predation, drought, disease, etc.) is problematic. Generally speaking, for ecological risks to occur now or in the future there must be a contaminant source, which is assumed to be limited to ground water, and a pathway must exist for exposure of ecological receptors to contaminated ground water. The simplified ecological risk scenario gives a generalized overview of the ERA process.

Simplified Ecological Risk Scenario

Contamination Source	→	**Release**	→	**Contaminated Media**	→	**Pathway**	→	**Receptor**	→	**Effect**
(NC and UC sites)		(Migration into soil and ground water)		(Ground Water, Surface Water, and Sediments)		(Ingestion or Absorption)		(Plants, Wildlife)		(No effect, non-lethal effects, or mortality)

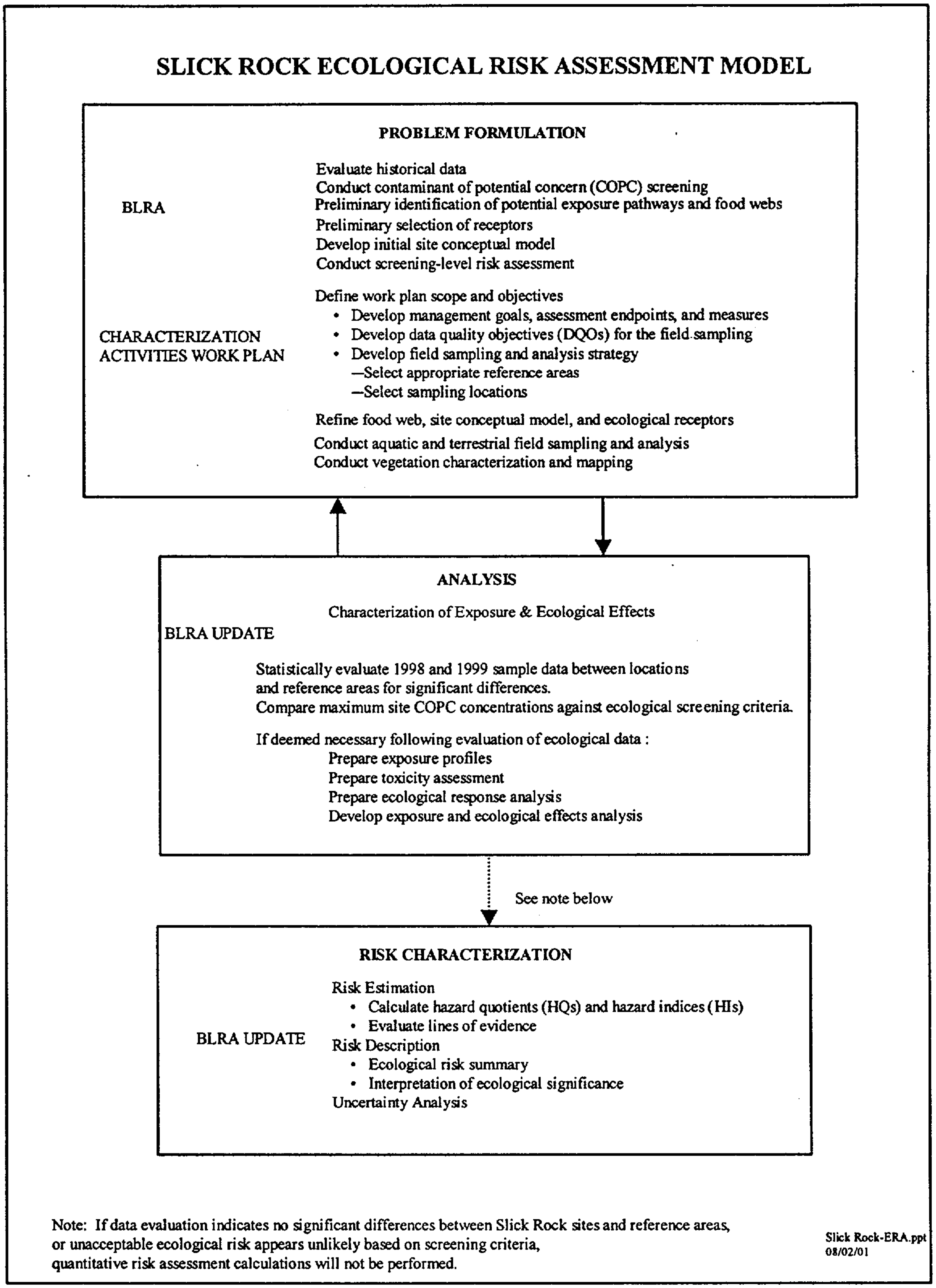
The following sections provide a summary of the BLRA and evaluation of potential risks based on a review of all relevant data, with emphasis on the 2000–2001 data.

6.2.1 Ecological Risk Assessment Process

As shown in Figure 6–2, the framework of the ERA contains three main components: (1) problem formulation; (2) analysis; and (3) risk characterization. The overall goal of the problem formulation is to "set the stage" for the analysis and risk characterization phases of the process. In the problem formulation, the need for a risk assessment is identified and the scope of the problem is defined. Available data are evaluated to identify potential stressors (in this case, the potential stressors are E-COPCs associated with the ground water at the Slick Rock site), key ecological receptors, and potential exposure pathways linking the receptors to the stressors. This information is used to develop a site conceptual model and risk hypotheses. Finally, assessment and measurement endpoints are defined for the specific determination of risk to these receptors and the environmental resources they represent. These endpoints are directly tied to overall management goals for the site.

The analysis phase of the ERA includes two concurrent steps—the exposure assessment and the effects characterization. In the exposure assessment, the potential for each receptor to be exposed to each stressor is evaluated and, where possible, quantified. The effects characterization describes the potential for the stressor to adversely affect the receptors that are exposed to it. Because the stressors at the Slick Rock site are chemical in nature, the principal effects to ecological receptors will be toxicological; however, they may also include physical effects, such as those related to radiation.

The risk characterization phase evaluates (either qualitatively or quantitatively) the combined results of the exposure assessment and effects characterization to determine the potential for risk to the receptors due to their exposure to the stressors. A critical aspect of the risk characterization is the analysis of uncertainties associated with predictions of potential risk. Typically, uncertainties result from data gaps which necessitate the incorporation of assumptions into the analysis and risk characterization phases. In general, these assumptions are conservatively biased toward results that will lead to overestimations rather than underestimations of risk. The uncertainty analysis provides an analysis of these assumptions in terms of their potential for introducing significant bias in the risk estimation.



SLICK ROCK ECOLOGICAL RISK ASSESSMENT MODEL

PROBLEM FORMULATION

BLRA

Evaluate historical data
Conduct contaminant of potential concern (COPC) screening
Preliminary identification of potential exposure pathways and food webs
Preliminary selection of receptors
Develop initial site conceptual model
Conduct screening-level risk assessment

CHARACTERIZATION ACTIVITIES WORK PLAN

Define work plan scope and objectives

- Develop management goals, assessment endpoints, and measures
- Develop data quality objectives (DQOs) for the field sampling
- Develop field sampling and analysis strategy
  —Select appropriate reference areas
  —Select sampling locations

Refine food web, site conceptual model, and ecological receptors

Conduct aquatic and terrestrial field sampling and analysis
Conduct vegetation characterization and mapping

ANALYSIS

Characterization of Exposure & Ecological Effects

BLRA UPDATE

Statistically evaluate 1998 and 1999 sample data between locations and reference areas for significant differences.
Compare maximum site COPC concentrations against ecological screening criteria.

If deemed necessary following evaluation of ecological data :
Prepare exposure profiles
Prepare toxicity assessment
Prepare ecological response analysis
Develop exposure and ecological effects analysis

See note below

RISK CHARACTERIZATION

BLRA UPDATE

Risk Estimation

- Calculate hazard quotients (HQs) and hazard indices (HIs)
- Evaluate lines of evidence

Risk Description

- Ecological risk summary
- Interpretation of ecological significance

Uncertainty Analysis

Note: If data evaluation indicates no significant differences between Slick Rock sites and reference areas, or unacceptable ecological risk appears unlikely based on screening criteria, quantitative risk assessment calculations will not be performed.

Slick Rock-ERA.ppt
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Figure 6–2. Slick Rock Ecological Risk Assessment Model

As described in the EPA guidance (EPA 1998), ERA is an iterative process in which the evaluation of potential risks to ecological receptors is refined as additional data are collected to fill data gaps and reduce uncertainties. At the conclusion of each iteration (or "tier") in the process, decisions are made whether sufficient data have been collected and analyzed to proceed with risk management actions (if required), or whether additional data should be collected. Such a tiered approach to the ERA process was initiated at the Slick Rock site in 1995 by the performance of the screening-level BLRA (DOE 1995b).

Subsequently, additional data have been collected from key environmental media specifically for the purpose of characterizing potential ecological risk. The ERA presented here provides an analysis of these new data as a refinement of the screening-level assessment. Sampling of ground water and surface water (from the Dolores River) for chemical analysis was conducted between 2000 and 2001 as discussed in Section 4.6, "Ecological Field Investigations." Samples of sediment were collected and analyzed in September 1993 and February 1994; however, no sediment samples have been collected subsequent to that time.

6.2.2 Problem Formulation Phase

Appendix I details the three phases described in Figure 6–2 on the basis of E-COPCs at the Slick Rock site. The Problem Formulation section describes potentially affected habitats and populations, and summarizes the results of the 1995 BLRA. The BLRA had identified 26 ground water-based E-COPCs (Table 1, Appendix I). Of these cadmium, uranium, and zinc were identified as E-COPCs in surface water. Cadmium, copper, molybdenum, selenium, uranium, vanadium, and zinc were identified as E-COPCs in sediments. Problem formulation also discusses data collected since 1995 that requires consideration for current ERA. Of the 26 BLRA constituents, 17 were monitored and analyzed in recent sampling events. Five additional radiological constituents (gross alpha, gross beta, radium-228, uranium-234, and uranium-238) and four organic constituents (benzene, ethylbenzene, toluene, and total xylenes) were obtained. A comprehensive re-evaluation of ground water, surface water, and sediment concentrations for both the NC and UC sites resulted in the final list of E-COPCs shown in Table 6–7. The list is location and media-specific.

Because contaminated ground water may have reached, and may have contact with, the Dolores River, potential contamination of this media is addressed in Appendix I, Section 1.2. The habitat in the vicinity of the site is primarily riparian. Therefore, wetland and riparian plants, aquatic species, and wetland wildlife species are considered key ecological receptors.

6.2.3 Analysis Phase

The Analysis section in Appendix I discusses exposure pathways, key receptors, and effects characterization. Ingestion and direct contact are considered the primary pathways for surface water, sediments, and dietary intake (e.g., forage, prey). For purposes of exposure assessment, E-COPCs are conservatively assumed to be 100 percent bioavailable at all times, regardless of home range or seasonal use.

Table 6–7. Summary of Ecological Contaminants of Potential Concern at the Two Sites Associated with the Slick Rock Site as Based on Most Recent Analytical Data

Dolores River				Ground Water	
North Continent Site		**Union Carbide Site**		**North Continent Site**	**Union Carbide Site**
surface water	**sediment**	**surface water**	**sediment**		
Chloride	Molybdenum	Ammonium	Cadmium	Chloride	Ammonium
Iron	Selenium	Bromide	Copper	Molybdenum	Bromide
Manganese	Uranium	Chloride	Molybdenum	Nitrate	Cadmium
Molybdenum	Vanadium	Iron	Selenium	Selenium	Chloride
Uranium	Zinc	Manganese	Vanadium	Uranium	Iron
Vanadium		Molybdenum	Zinc	Gross Alpha	Manganese
Gross Alpha		Nitrate		Gross Beta	Molybdenum
Gross Beta		Vanadium		Radium-226	Nitrate
Lead-210		Gross Alpha		Radium-228	Selenium
Polonium-210		Lead-210		Uranium-234	Strontium
Radium-226		Radium-226		Uranium-238	Sulfate
Radium-228		Uranium-238			Uranium
Uranium-238					Vanadium
					Benzene
					Ethylbenzene
					Toluene
					Xylenes
					Radium-226
					Radium-228
					Uranium-234
					Uranium-238

Key receptors are selected based on their actual or potential presence, and potential for exposure to E-COPCs and includes flora and fauna receptors for terrestrial, wetland, and aquatic habitats.

Effects characterization evaluates the potential for adverse effects to receptors resulting from exposure to E-COPCs. Concentrations of E-COPCs in various media are compared to toxicity-based benchmarks, which are gathered from numerous sources.

6.2.4 Risk Characterization

Once effects have been characterized, the potential for risk is determined through HQs. HQs are receptor, contaminant, and media-specific. HQs greater than 1 indicate potential risk based on conservative calculations and comparisons. Comparisons are typically made using the maximum and UCL_{95} concentrations for each media.

6.2.4.1 Surface Water and Sediment Risks

For aquatic receptors exposed to surface waters (i.e., Dolores River) at the NC and UC sites, ammonium (UC site) and vanadium (NC and UC sites) exceeded water quality benchmarks. However, HQs were low (less than 3.5). In addition, the low frequency of detection makes the potential for adverse effects questionable. For sediments, although cadmium and molybdenum were elevated (HQ less than 3) above benchmarks, these constituents were only marginally above upstream (background) samples. On this basis, sediments are not believed to have potential adverse effects to benthic receptors. Because maximum upstream concentrations exceeded plant toxicity benchmarks for four constituents, only marginal effects to plants would be anticipated.

Vanadium was the only surface water constituent that indicated potential risk to wetland wildlife. However, the low frequency of detection makes actual risk questionable. No potential risk to terrestrial wildlife and livestock is anticipated as a result of ingestion of surface waters.

6.2.4.2 Ground Water Risk

The most likely exposure pathway between ground water and receptors is potential contact with deep-rooted plants. While a potential for a pathway between ground water and wildlife receptors exists, it is not likely. A hypothetical situation is addressed in Section 3.1.2 of Appendix I. No risk to plants is anticipated at the NC site on the basis of HQs and low toxicities. Potential risk to plants at the UC site due to concentrations of manganese, molybdenum, and selenium exists. All three constituents had HQs greater than 1.

Using ecological benchmarks for radiological E-COPCs in surface water and ground water, it was found that no potential risks to aquatic species in surface waters are present at either site. Although radiological E-COPCs in ground water do not appear to present potential risk to aquatic receptors, it should not be used as a surface water source.

6.2.4.3 Risk to Sensitive Species

The only E-COPC in surface water is vanadium, which presents a potential risk to the river otter and flycatcher. However, based on the frequency of detection and localized affect, actual risk to these species is questionable. Potential risks to these receptors based on exposure to sediments are considered low based on home ranges and potential frequency of actual contact with contaminated sediments.

6.2.5 Risk Summary

Appendix I provides a detailed evaluation of potential risks and rationale for inclusion or exclusion of E-COPCs. It is important to emphasize the conservative nature of risk assessment. Typically, the criteria and process to evaluate risk overestimates actual risk. Nonetheless, the potential for risks associated with E-COPCs helps establish the need for, and level of, remedial actions. On the basis of this ERA, the potential for risk to ecological receptors in the Dolores River (surface waters) was considered low. Some potential risk to wetland plants as a result of exposure to vanadium concentrations in sediments exists.

Ground water at the NC site presents low potential risk. Likewise, ground water at the UC site does not appear to present significant risk to deep-rooted plants or terrestrial wildlife. While concentrations of E-COPCs are elevated at the UC site, the potential for an exposure pathway is marginal.

6.3 Summary of Human Health and Ecological Risks

This section summarizes human health and ecological risks and recommends COPCs to be retained for further monitoring at the UC and NC sites. There are no unacceptable risks to ecological receptors due to site-related contamination. Based on likely future use of ground water, no future ecological risks are expected. Therefore, no further monitoring is recommended for ecological COPCs.

Selenium and uranium at the NC site exceed ground water standards. Molybdenum, nitrate, selenium, uranium, radium, benzene, and toluene exceed ground water standards at the UC site. Manganese present at the UC site presents unacceptable human health risks.

Based on the results of human health and ecological risks, Table 6–8 presents the recommended COPCs for both the UC and NC sites.

Table 6–8. Recommended Human Health and Ecological COPCs for the Slick Rock Site

Contaminant	North Continent (NC) Site			Union Carbide (UC) Site		
	COPC?	Based on std?	Based on risk?	COPC?	Based on std?	Based on risk?
Manganese	N[a]			Y		✓/HH
Molybdenum	na[b]			Y	✓	✓/HH
Nitrate	na			Y	✓	✓/HH
Selenium	Y	✓		Y	✓	✓/HH
Uranium	Y	✓	✓/HH[d]	Y	✓	
Radium-226+228	N[c]			Y	✓	
Benzene	na			Y	✓	✓/HH
Toluene	na			Y	✓	

[a] eliminated as a COPC because concentrations are below background

[b] na = not applicable

[c] eliminated as a COPC because concentrations are below standard and risks are acceptable

[d] HH = based on human health risks

End of current text

7.0 Ground Water Compliance Strategy

7.1 NC Site Compliance Strategy

To achieve compliance with Subpart B of 40 CFR 192 at the NC site, the proposed compliance strategy is natural flushing in conjunction with ICs and continued monitoring. Ground water flow and transport modeling has predicted that site-related concentrations of selenium and uranium in the uppermost aquifer beneath the site will decrease to levels below the MCL within 100 years. For compliance purposes, the uppermost aquifer is understood to be the alluvial aquifer. Because ICs will be maintained during the flushing period, this compliance strategy will be protective of human health by eliminating the potential for ground water use. This compliance strategy is protective of the environment as documented by sampling results from the Dolores River. Future monitoring of the river will be conducted to verify continued protection of the environment. This proposed action has been determined by applying the compliance strategy flowchart from the PEIS (Figure 7–1). The response for each step in the compliance strategy flowchart is shown in Table 7–1.

Table 7–1. Explanation of the Decision Path for the Compliance Strategy Flowchart at the NC Site

Box (Figure 7–1)	Action or Question	Response
1	Characterize plume and hydrologic conditions	Review historical data and identify data gaps in the Summary of Site Conditions and Work Plan. Additional field investigation conducted to address the data gaps lead to the production of this SOWP. Move to Box 2.
2	Is ground water contamination present in excess of UMTRA MCLs or background?	Selenium and uranium concentrations exceed the respective UMTRA MCLs. Move to Box 4.
4	Does contaminated ground water qualify for supplemental standards on the basis of limited use?	The ground water does not qualify for limited use designation because the background TDS is less than 10,000 mg/L, the aquifer will yield more than 150 gallons per day, and background selenium and uranium concentrations are low. Move to Box 6.
6	Does contaminated ground water qualify for ACLs based on acceptable human health and environmental risks and other factors?	Current uranium concentrations would result in unacceptable human health and environment risk. Selenium concentrations would qualify for an ACL based on risk; however, ground water flow and transport modeling indicates that natural flushing will be effective for both constituents. Move to Box 8.
8	Does contaminated ground water qualify for supplemental standards due to excessive environmental harm from remediation?	Although the applicability has not been formally addressed, it is unlikely that remedial action would cause excessive harm to the environment. Move to Box 10.
10	Will natural flushing result in compliance with UMTRA MCLs, background, or ACLs within 100 years?	Ground water flow and transport modeling predicts that selenium and uranium concentrations will be reduced to less than the MCL within the 100 year time frame. Move to Box 11.
11	Can institutional controls be maintained during the flushing period and is the compliance strategy protective of human health and the environment?	The selenium and uranium plumes are within the site boundary, which will facilitate maintaining institutional controls to prevent use of ground water This compliance strategy will be protective of human health and the environment and ground water will be available for use without restriction after 100 years. Move to Box 12—implement natural flushing.

7.2 UC Site Compliance Strategy

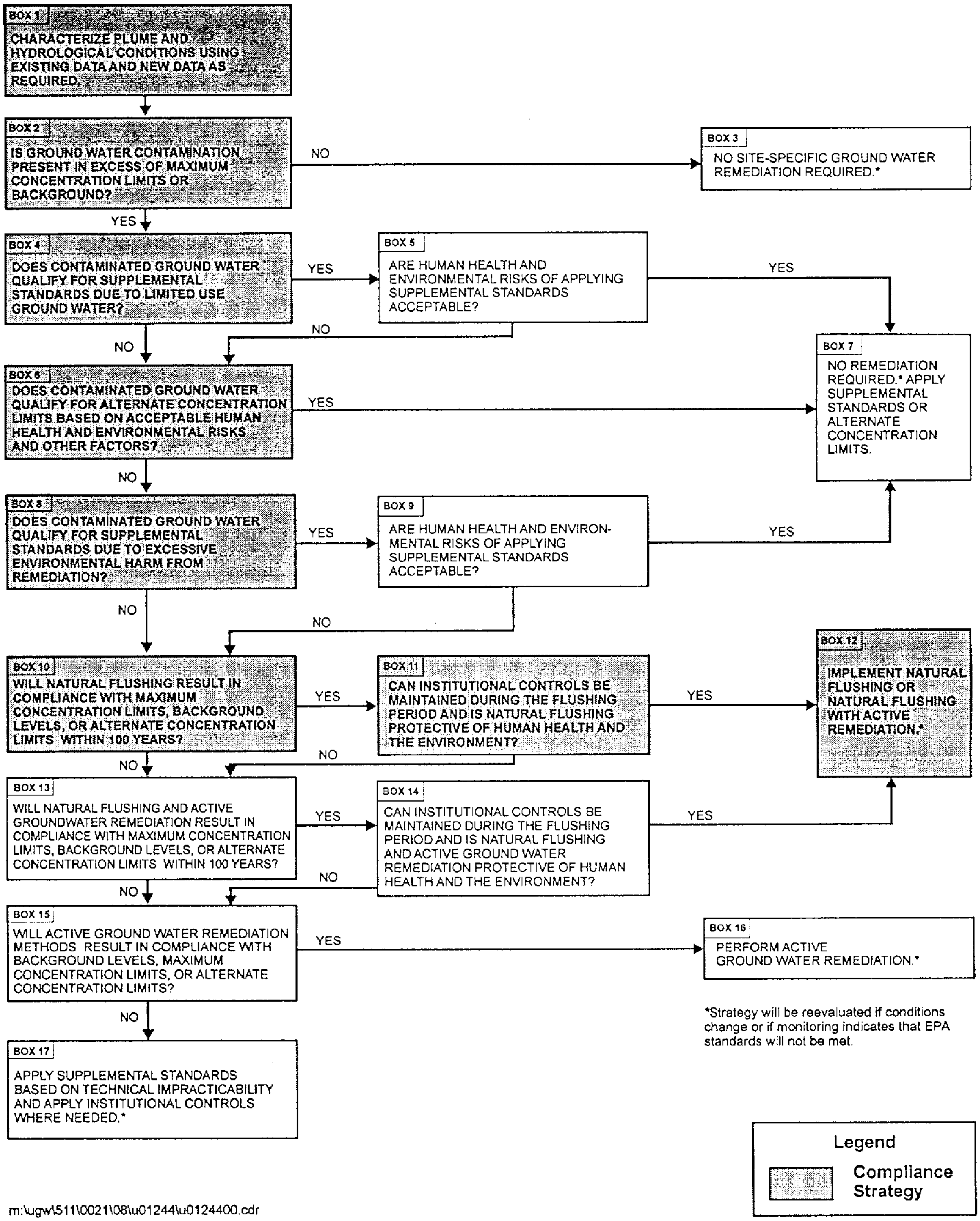
To achieve compliance with Subpart B of 40 CFR 192 at the UC site, the proposed compliance strategy is natural flushing for all COPCs in conjunction with an ACL for selenium. This strategy will involve an IC and continued monitoring. For compliance purposes, the uppermost aquifer at the UC site is understood to be the alluvial aquifer and the underlying, hydraulically connected, Entrada Sandstone aquifer.

7.2.1 Natural Flushing

For molybdenum, manganese, nitrate, and uranium, the proposed compliance strategy is natural flushing in conjunction with an IC and continued monitoring. Ground water flow and transport modeling has predicted that site-related concentrations of these COPCs in the uppermost aquifer will decrease to levels below the respective MCLs (background for manganese) within 100 years. Manganese was included in the ground water transport model. However, the potential for manganese to migrate is typically not predicted by means of a K_d because the fate and movement of manganese in the ground water is strongly controlled by oxidation-reduction reactions. Manganese is one of the few elements that is a predominant participant in oxidation-reduction processes (Stumm and Morgan 1981). For example, manganese tends to precipitate in the presence of oxygenated water, which will effectively remove manganese from the ground water when it reaches oxygenated ground water or the Dolores River. Nonetheless, manganese was included in the ground water transport model, which should provide a conservative time estimate for ground water remedition. The model predicted that concentrations of manganese will flush to background levels (3.5 mg/L) within the 100-year time frame.

The natural flushing strategy will also apply to benzene, toluene, and radium-226/radium-228; however, these COPCs have special considerations that are discussed below. Benzene and toluene were not included in the ground water transport model because it is anticipated that biodegradation, rather than ground water transport, will be the dominant process that controls the fate of these COPCs in the environment. A conservative half-life for benzene in the ground water is two years, and the half-life for toluene is less than a year (Mackay et al. 1992). Therefore, these COPCs should degrade within the 100-year regulatory time frame. Because ICs will be maintained during the flushing period, this compliance strategy will be protective of human health by eliminating the potential for ground water use.

Radium-226 and radium-228 were also not included in the ground water transport model. Radium movement in ground water is typically controlled by its limited solubility rather than ground water transport. The radium-226/228 contamination in the ground water is highly localized; only one well (0319) had a concentration exceeding the UMTRA standard. The magnitude of the radium contamination is relatively low; the average concentration (6.2 pCi/L) is close to the standard (5 pCi/L). Because of its low concentration, radium concentrations are expected to fall below the standard within the 100-year time frame.



*Strategy will be reevaluated if conditions change or if monitoring indicates that EPA standards will not be met.

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Figure 7–1. Ground Water Compliance Strategy Flowchart for the NC Site

This compliance strategy is also protective of the environment as documented by sampling results from the Dolores River. Future monitoring of the river will be conducted to verify continued protection of the environment. This proposed action has been determined by applying the compliance strategy flowchart from the PEIS (Figure 7–2). The response for each step in the compliance strategy flowchart is shown in Table 7–2.

Table 7–2. Explanation of the Decision Path for the Compliance Strategy Flowchart for Natural Flushing at the UC Site

Box (Figure 7–2)	Action or Question	Response
1	Characterize plume and hydrologic conditions	Review historical data and identify data gaps in the Summary of Site Conditions and Work Plan. Additional field investigation conducted to address the data gaps lead to the production of this SOWP. Move to Box 2.
2	Is ground water contamination present in excess of UMTRA MCLs or background?	Molybdenum, nitrate, radium-226 + radium-228, and uranium exceed the respective UMTRA MCLs; benzene and toluene exceed the SDWA MCL, and manganese exceeds the maximum background concentration. Move to Box 4.
4	Does contaminated ground water qualify for supplemental standards on the basis of limited use?	The ground water does not qualify for limited use designation because the background TDS is less than 10,000 mg/L, the aquifer will yield more than 150 gallons per day, and background COPC concentrations are generally low. Move to Box 6.
6	Does contaminated ground water qualify for ACLs based on acceptable human health and environmental risks and other factors?	Current concentrations would result in unacceptable human health and environmental risks. Ground water flow and transport modeling indicates that natural flushing will be effective. Move to Box 8.
8	Does contaminated ground water qualify for supplemental standards due to excessive environmental harm from remediation?	Although the applicability has not been formally addressed, it is unlikely that remedial action would cause excessive harm to the environment. Move to Box 10.
10	Will natural flushing result in compliance with UMTRA MCLs, background, or ACLs within 100 years?	Ground water flow and transport modeling predicts that concentrations of molybdenum, manganese, nitrate, and uranium will be reduced to less than the MCL benchmark within the 100 year time frame. Other COPCs are expected to attain acceptable concentrations via flushing and biological/chemical processes. Move to Box 11.
11	Can institutional controls be maintained during the flushing period and is the compliance strategy protective of human health and the environment?	The COPC plumes are within the site boundary, which will facilitate maintaining institutional controls to prevent use of ground water. Ground water can be used without restriction after 100 years and will be protective of human health and the environment at that time. Move to Box 12—implement natural flushing.

7.2.2 Alternate Concentration Limits

Because the selenium concentration in ground water will likely exceed the UMTRA Project standard after 100 years of natural flushing, an ACL will be required for this constituent. The proposed ACL will be set at the EPA human health risk-based benchmark for drinking water of 0.18 mg/L. This proposed action has been determined by applying the compliance strategy flowchart from the PEIS (Figure 7–2). The response for each step in the compliance strategy flowchart is shown in Table 7–3.

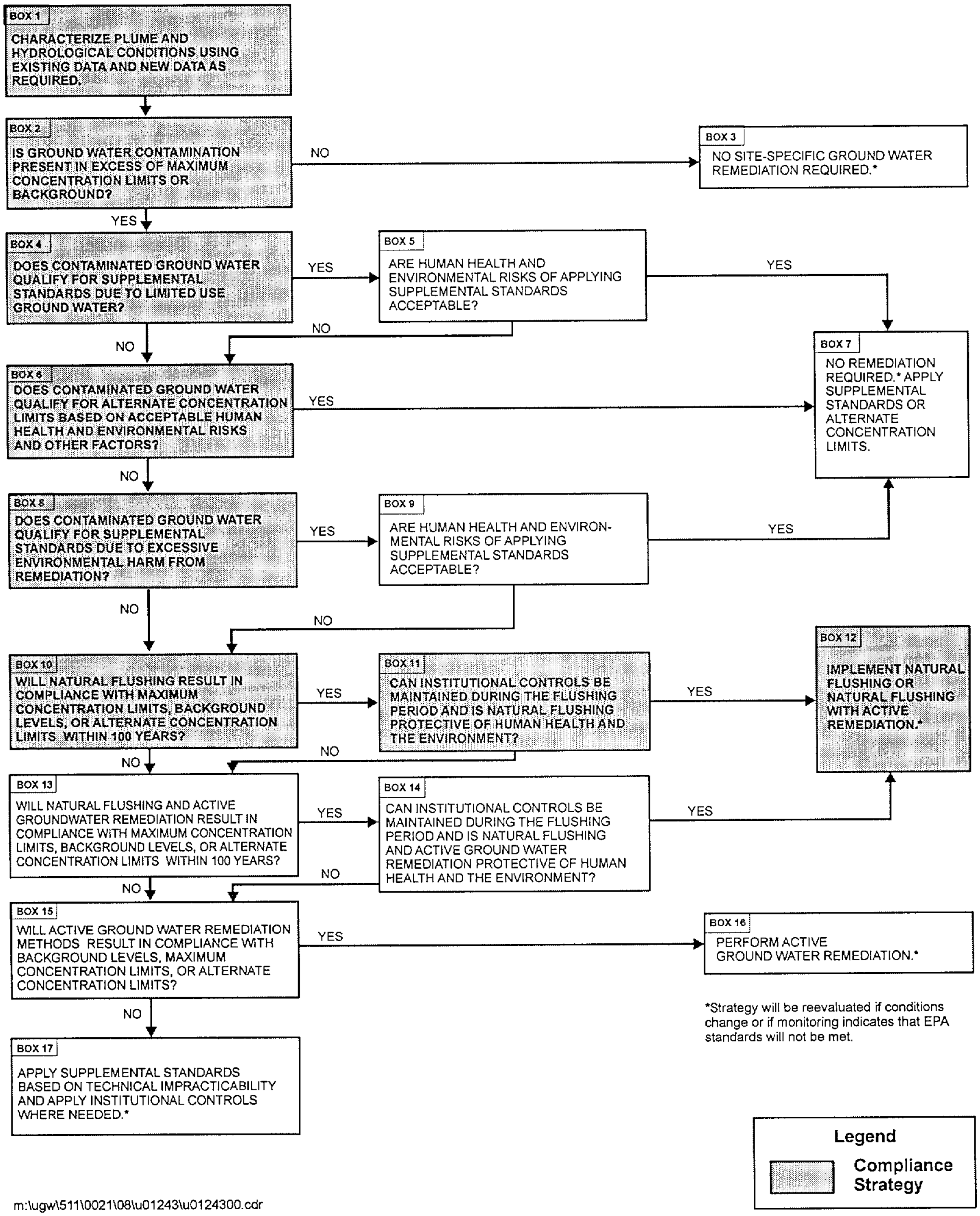
Table 7–3. Explanation of the Decision Path for the Compliance Strategy Flowchart for a Selenium ACL at the UC Site

Box (Figure 7–2)	Action or Question	Response
1	Characterize plume and hydrologic conditions	Review historical data and identify data gaps in the Summary of Site Conditions and Work Plan. Additional field investigation conducted to address the data gaps lead to the production of this SOWP. Move to Box 2.
2	Is ground water contamination present in excess of UMTRA MCLs or background?	Selenium concentration exceeds the UMTRA MCL and the human health risk-based benchmark. Move to Box 4.
4	Does contaminated ground water qualify for supplemental standards on the basis of limited use?	The ground water does not qualify for limited use designation because the background TDS is less than 10,000 mg/L, the aquifer will yield more than 150 gallons per day, and background selenium concentrations are low. Move to Box 6.
6	Does contaminated ground water qualify for ACLs based on acceptable human health and environmental risks and other factors?	A human health risk-based benchmark of 0.18 mg/L has been established by the EPA. Ground-water flow and transport modeling indicates that natural flushing will remove selenium from the aquifer to less than the human health risk-based benchmark. Move to Box 8.
8	Does contaminated ground water qualify for supplemental standards due to excessive environmental harm from remediation?	Although the applicability has not been formally addressed, it is unlikely that remedial action would cause excessive harm to the environment. Move to Box 10.
10	Will natural flushing result in compliance with UMTRA MCLs, background, or ACLs within 100 years?	Ground water flow and transport modeling predicts that concentrations of selenium will be reduced to less than the proposed ACL within the 100 year time frame. Move to Box 11.
11	Can institutional controls be maintained during the flushing period and is the compliance strategy protective of human health and the environment?	The COPC plumes are within the site boundary, which will facilitate maintaining institutional controls to prevent use of ground water. Ground water can be used without restriction after 100 years and will be protective of human health and the environment at that time. Move to Box 12—implement natural flushing.

In order for this ACL to be valid, it must be protective of human health and the environment. Ground water flow and transport modeling predicts that selenium concentrations will be reduced to below the proposed ACL after 60 years with a maximum predicted concentration of 0.172 mg/L. The probability of selenium concentration exceeding the 0.18 mg/L risk-based benchmark is less than 25 percent.

Ground water modeling also predicts that the centroid of the selenium plume will move past well 0508, and the selenium plume remaining after 100 years will be in the vicinity of well 0508. Therefore, the point of compliance for the ACL will be at well 0508. Currently, well 0508 contains the second highest selenium concentrations (approximately 1.6 mg/L).

Modeling results indicate that the human health risk from consumption of alluvial ground water would be acceptable after 60 years. In addition, the potential for installing a domestic well in the alluvial aquifer is very low. A well installed on the floodplain at the UC site, with the ground water intended for human consumption, would likely be completed in the Navajo Sandstone rather than the alluvial aquifer for the following reasons.



*Strategy will be reevaluated if conditions change or if monitoring indicates that EPA standards will not be met.

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Figure 7–2. Ground Water Compliance Strategy Flowchart for the UC Site

- Background alluvial ground water quality is poor. High sulfate (>3,000 mg/L), manganese (>3 mg/L), and TDS (>7,000 mg/L) in background well 0300 indicate alluvial ground water would be undesirable for human consumption.

- Navajo Sandstone water quality is excellent. Concentrations of sulfate (<40 mg/L) and TDS (<350 mg/L) are typically low. Domestic wells in the area are typically completed in the Navajo Sandstone. The old mill production wells, the former post office well, and domestic well 0672 are all completed in the Navajo Sandstone.

- The Navajo Sandstone is shallow (40 to 60 ft below ground surface) beneath the floodplain, and current Navajo Sandstone wells on the floodplain have artesian flow.

- Production from the alluvial aquifer would be limited (10 gallons per minute) compared to the production from the Navajo Sandstone. Saturated thickness of the alluvium is typically 8 ft compared to 180 ft in the Navajo Sandstone (Shawe et al. 1968).

This strategy is also protective of the environment, as demonstrated by current selenium concentrations in the Dolores River. Current concentrations are below the ecological risk benchmark of 0.005 mg/L. The future monitoring program will include sampling at the point of exposure in the Dolores River at sampling location 0347, which is adjacent to well 0508.

7.3 Implementation

Implementation of the proposed compliance strategy includes ICs and continued monitoring of ground water and surface water.

7.3.1 Institutional Controls

There are currently no users of the alluvial aquifer for domestic purposes in the area of either Slick Rock site. To ensure that this remains true for the period of natural flushing, DOE would work with the affected parties to establish ICs.

ICs are restrictions that effectively protect public health and the environment by limiting access to a contaminated medium; for the Slick Rock site, alluvial ground water. ICs typically depend on administrative legal action such as zoning, ordinances, and laws to ensure that protection is effective and enforceable. For the UMTRA Ground Water Project, ICs reduce exposure and health risks by preventing intrusion into contaminated ground water or by restricting access to or use of contaminated ground water for unacceptable purposes. EPA standards permit the use of ICs at sites where natural flushing will return the ground water to acceptable levels within 100 years. Figure 7–3 shows the proposed IC boundaries

EPA standards require that ICs have a high degree of permanence, protect human health and the environment, satisfy beneficial uses of ground water, are enforceable by administrative or judicial branches of government entities, and can be effectively maintained and verified. The need for, and duration of, ICs depends on the compliance strategy selected for a site, the level of risk to humans and the environment, and existing site conditions. As risks decrease over time, so should the restrictiveness of ICs. Therefore, to ensure protection of human health and the environment, it is important that the effectiveness of ICs be verified and modified as necessary.

ICs are mandated to be effective for a period not to exceed 100 years during the period of natural flushing. Current data indicate that contamination at both sites will decrease to acceptable levels within the 100-year time frame.

Since the property overlying the contaminant plumes at both sites is owned by UMETCO, a covenant is being proposed to attach to the respective property deeds that will restrict access to the surficial ground water for the 100-year time frame or until such time as monitoring shows that the ground water compliance objectives have been met. DOE is working with UMETCO to develop deed restriction language similar to that attached to the deeds of other former millsite properties in Colorado that have been conveyed from the State of Colorado to a local municipality. These restrictions contain the following language:

"Grantee [UMETCO] covenants ... not to use ground water from the site for any purpose, and not to construct wells or any means of exposing ground water to the surface unless prior written approval for such use is given by the Grantor [Colorado Department of Public Health and the Environment] and the U.S. Department of Energy."

Although this language may seem to limit access to all ground water beneath the affected property, DOE would work with UMETCO to restrict access to the surficial aquifer for only the uses that pose risk to human health and the environment. The final language will become a part of the deed, will establish an environmental covenant, and will ensure that any future landowner is subject to the same restrictions. This language fulfills the requirements for degree of permanence and enforceability by government entities.

Long-term monitoring of environmental covenants has recently become a responsibility of the State of Colorado. The State of Colorado passed into law Senate Bill 01-145 to "...provide an effective and enforceable means of ensuring the conduct of any required maintenance, monitoring, or operation, and of restricting future uses of the land, including placing restrictions on drilling for or pumping groundwater for as long as any residual contamination remains hazardous" (legislative declaration to SB 01-145). This law compels the Colorado Department of Public Health and Environment (CDPHE) to enter into an agreement with local municipalities to oversee and monitor any instrument that restricts the use of land or ground water because of contamination left in place or other environmental concerns. The instruments, such as ordinances, deed restrictions, and restrictive easements, are recorded with the appropriate municipality as environmental covenants, follow the property deed, and are binding on future owners of the property. The law requires that all plans for construction or drilling on property with an environmental covenant must receive concurrence from CDPHE to ensure that the proposed actions do not violate the restrictions in the covenant. Should any violation of the environmental covenant occur, the State may bring suit against the owner or violator of the covenant. This law provides assurance that the ICs established for the Slick Rock site are in effect and will be enforced for the entire period of natural flushing.

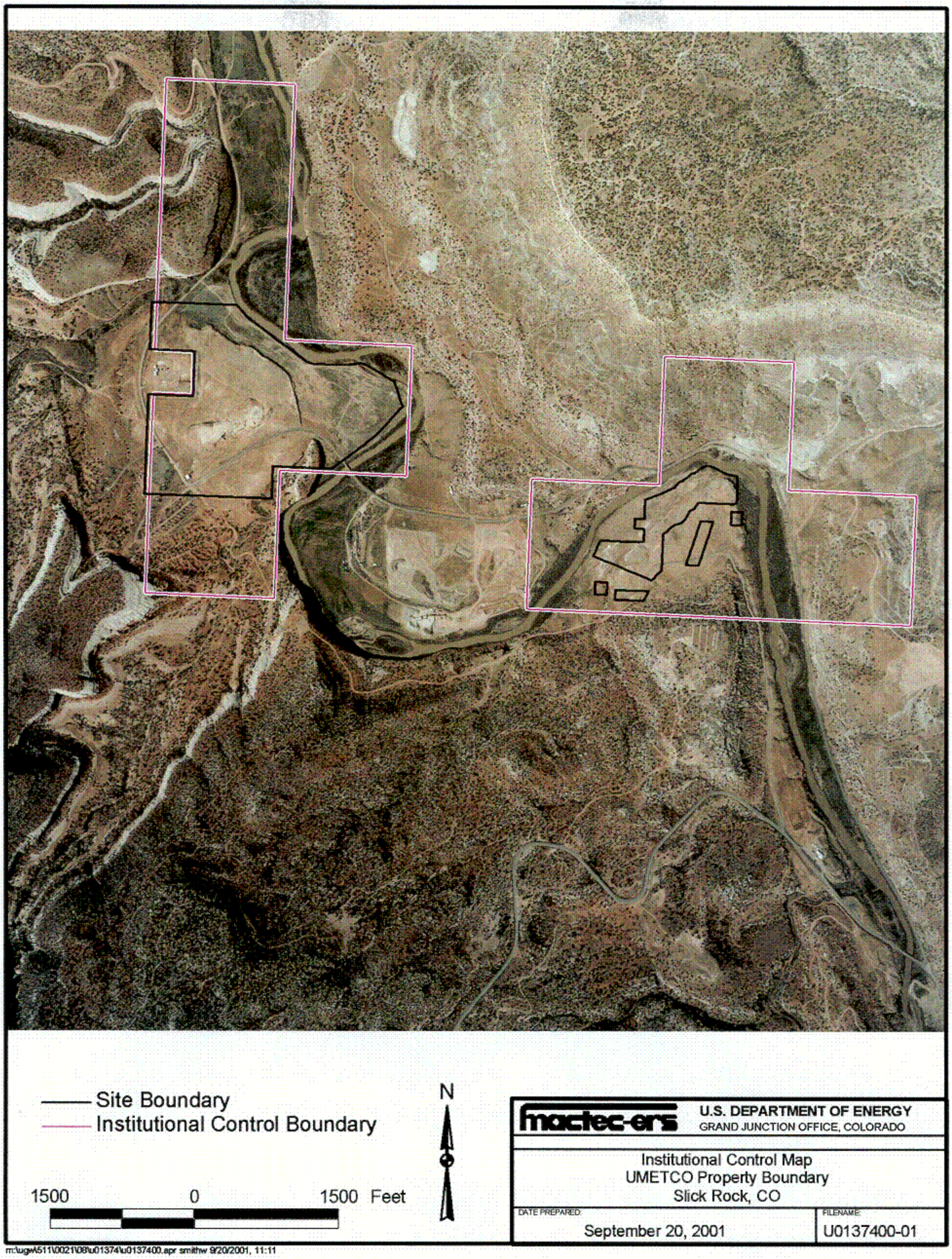

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Figure 7–3. Institutional Control Map—UMETCO Property Boundary

7.3.2 Monitoring

7.3.2.1 NC Site

Ground water will be monitored during the period of natural flushing to verify modeling results, that is, that concentrations of uranium and selenium in the ground water are decreasing, and to assess compliance with MCLs. In addition, surface water in the Dolores River will be monitored to verify that the natural flushing strategy is protective of the environment. The proposed ground water and surface water monitoring program is summarized in Table 7–4. Because selenium concentrations are currently below the SDWA MCL of 0.05 mg/L, and the UMTRA MCL is exceeded in only one well, extensive monitoring for selenium is not warranted. Selenium will be monitored in well 0305 until the concentration is below the UMTRA MCL. Samples will be collected on an annual basis for 10 years; after 10 years, the sampling frequency will be reduced to every 5 years.

Samples will be analyzed for uranium at all locations listed in Table 7–4.

Table 7–4. Proposed Monitoring Program at the NC Site

ID	Matrix	Location	Rationale	Analytes
0696	Surface Water	Upstream	Background for NC site	Uranium
0692	Surface Water	Adjacent to site	Predicted location where the centroid of the uranium plume intersects the river.	Uranium
0303	Ground Water	On site	Hot spot for uranium.	Uranium
0305	Ground Water	On site	Hot spot for uranium; selenium above the UMTRA MCL.	Uranium, Selenium
0307	Ground Water	On site	Downgradient of hot spots, monitor plume migration	Uranium, Selenium
0309	Ground Water	On site	Farthest downgradient well on site	Uranium
0311	Ground Water	Downgradient	Off site across the river. Monitor migration of the uranium plume between sites.	Uranium

7.3.2.2 UC Site

Ground water will be monitored during the period of natural flushing to verify modeling results, that is, that concentrations of COPCs in the ground water are decreasing. Ground water will also be monitored to assess compliance with MCLs and the selenium ACL at point-of-compliance well 0508. In addition, the surface water in the Dolores River will be monitored to verify that the compliance strategy is protective of the environment. Samples will be collected on an annual basis for 10 years; after 10 years, the sampling frequency will be reduced to every 5 years. The proposed ground water and surface water monitoring program is summarized in Table 7–5.

Table 7–5. Proposed Monitoring Program at the UC Site

ID	Matrix	Location	Rationale	Analytes
0693	Surface Water	Upstream	Background for UC site	Mn, Mo, NO_3, Se, and U
0347	Surface Water	Adjacent to site	Predicted location where the centroid of the selenium plume intersects the river. Point of exposure for selenium	Mn, Mo, NO_3, Se, and U
0349	Surface Water	Adjacent to site	Predicted location where centroid of contaminant plumes intersect the river	Mn, Mo, NO_3, Se, and U
0694	Surface Water	Downstream	Potential for contaminant plumes to discharge to the river at this location	Mn, Mo, NO_3, and U annually; Se quarterly
0318	Ground Water	On site	Hot spot for several COPCs	Mn, Mo, NO_3, Se, and U
0508	Ground Water	On site	High selenium, nitrate, molybdenum; point of compliance for selenium	Mn, Mo, NO_3, Se, and U
0510	Ground Water	On site	Edge of former tailings pile, high COPC concentrations	Mn, Mo, NO_3, Se, and U
0317	Ground Water	On site	Entrada Sandstone well, exceeds molybdenum standard	Mn, Mo, NO_3, Se, and U
0324	Ground Water	On site	Entrada Sandstone well, exceeds nitrate and selenium standards	Mn, Mo, NO_3, Se, and U
0319	Ground Water	On site	Hot spot for benzene, toluene and Ra-226/Ra-228	BTEX, Ra-226, Ra-228
0320	Ground Water	On site	Farthest downgradient well on site; monitor plume movement	Mn, Mo, NO_3, Se, and U

8.0 References

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