4.0 Summary of Recent Field Investigations

Historical characterization data for the Durango processing site are presented in the RAP (DOE 1991) and the BLRA (DOE 1995a). An evaluation of this data at the Durango processing site indicated additional investigations were needed to complete the SOWP and select the strategy for compliance with EPA ground water protection standards in 40 CFR 192. Additional investigations were needed to (1) further define hydraulic properties of the alluvial and bedrock aquifers for use in ground water flow and transport modeling, (2) determine the extent of contamination in the ground water, and (3) determine whether the ground water constituents in the alluvial and bedrock aquifers will flush naturally within 100 years. The fieldwork included installing monitor wells for ground water sampling and aquifer testing (slug tests) and installing stilling wells to determine Animas River water elevations. Other work included subpile soil sampling and analysis to evaluate potential residual source term beneath the site, determination of distribution coefficients, collection and analysis of ground water and surface water from locations on site and downgradient from the site, and sediment sampling from surface water locations. Results of these investigations, along with more recent water quality analytical data, are presented in this section.

4.1 Ground Water Monitor Well Installation

Monitor wells were installed to collect water samples for the characterization of ground water quality and to provide a means to determine hydraulic properties of the alluvial and bedrock aquifers. Wells were drilled using the SONIC drilling method, which enabled collection of continuous samples through the entire interval drilled. Installation procedures, construction details, and locations for the wells are described in this section. The following procedures from the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998) were used for monitoring well installation.

- GN–13 (P), “Standard Practice for Equipment Decontamination”
- LQ–14(P), “Technical Comments on ASTM D 5092—Standard Practice for Design and Installation of Ground Water Monitor Wells in Aquifers”

After installation of the monitor wells, the top of each casing was surveyed for elevation and location coordinates. Completion diagrams and lithologic descriptions for each well installed during the 2000 field investigation are provided in Appendix A and summarized in Table 4–1. Figure 4–1 shows a construction diagram of a typical monitor well installed during the Durango field investigation.

4.1.1 Mill Tailings Area

Four monitor wells and two stilling wells were installed at the mill tailings area during the field investigation (Figure 4–2). In addition, five locations were drilled and soil samples were collected, but wells were not installed. All alluvial wells were completed using 2-inch inside diameter (i.d.), flush-joint, threaded, poly vinyl chloride (PVC) casing and wire-wrapped screen (0.02-inch slot size). All the alluvial monitor wells were screened over the entire saturated thickness, which was 20 ft or less. Two wells (0859 and 0863) were installed on site to characterize the nature and extent of ground water contamination and to determine the hydrologic properties of the aquifers.

Table 4–1. Durango Field Investigation Monitor Well Installation Summary

Well Number	Site	Formation/Location	Well Depth (ft)	Screened Interval (ft)	Purpose
0857	Mill tailings	Alluvium/Background	19	12–17	Background water quality
0859	Mill tailings	Alluvium/On site	32	21.5–31.5	Water quality/water level
0863	Mill tailings	Colluvium/On site	68	58–67.5	Water quality/water level
0866	Mill tailings	Alluvium/Background	22	12–21.5	Background water quality
0867	Mill tailings	Alluvium/Animas River	NA	NA	Animas River stilling well
0868	Mill tailings	Alluvium/Animas River	NA	NA	Animas River stilling well
0875	Raffinate ponds	Point Lookout/Background	122.5	82–122	Background water quality
0876	Raffinate ponds	Fault/On site	75	54.5–74.5	Water quality/water level
0878	Raffinate ponds	Menefee/On site	47	37–46.5	Water quality/water level
0879	Raffinate ponds	Menefee/On site	37	27–36.9	Water quality/water level
0880	Raffinate ponds	Menefee/ On site	37	27–36.9	Water quality/water level
0881	Raffinate ponds	Point Lookout/On site	37	27–36.9	Water quality/water level
0882	Raffinate ponds	Menefee/Downgradient	35	24.5–34.5	Water quality/water level
0883	Raffinate ponds	Menefee/Downgradient	55	45–55	Water quality/water level
0884	Raffinate ponds	Menefee/Downgradient	47	36.5–46.5	Water quality/water level
0886	Raffinate ponds	Cliff House and Alluvium/Downgradient	30	19.5–29.5	Water quality/water level
0887	Raffinate ponds	Fault/On site	93.2	82.7–92.7	Water quality/water level
0888	Raffinate ponds	Fault/On site	148	133–147.5	Water quality/water level
0889	Raffinate ponds	Point Lookout/Downgradient	90.5	80–90	Water quality/water level
0890	Raffinate ponds	Menefee/On site	73	63.0–72.5	Water quality/water level
0891	Raffinate ponds	Menefee/On site	75	64.5–74.5	Water quality/water level
0892	Raffinate ponds	Fault/On site	80	69.5–79.5	Water quality/water level
0893	Raffinate ponds	Point Lookout/On site	75	64.5–74.5	Water quality/water level
0902	Raffinate ponds	Menefee/On site	148	128–148	Water quality/water level
0903	Raffinate ponds	Menefee/Background	65.4	34.9–64.9	Background water quality
0905	Raffinate ponds	Point Lookout/Off site	172	161.5–172	Water quality/water level
0906	Raffinate ponds	Alluvium/Animas River	NA	NA	Animas River stilling well

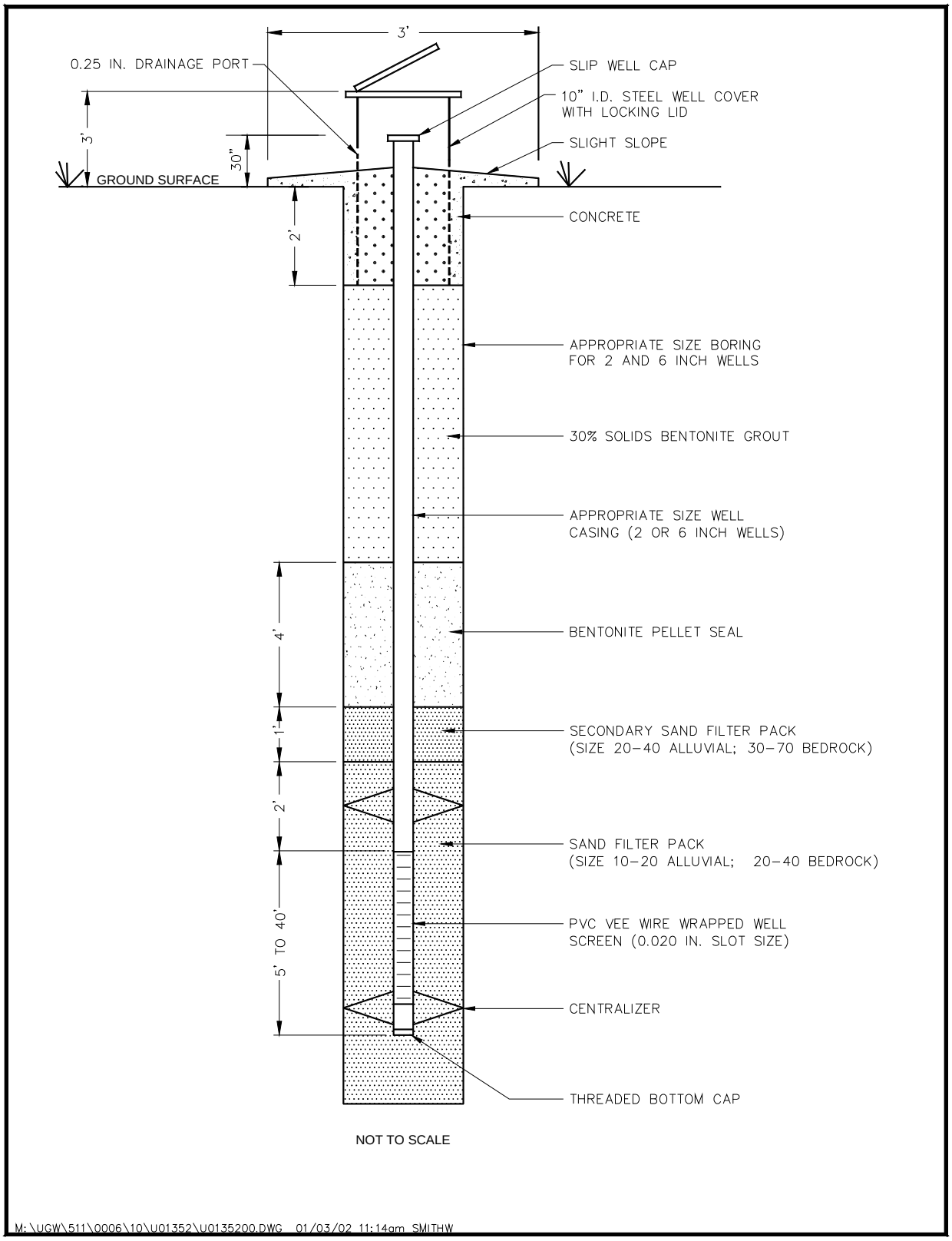

Figure 4–1. Typical Well Completion Diagram

Prior to the field investigation, two background wells (0629 and 0658) had been established for determining background water quality at the mill tailings area. Well 0658 is a privately owned well in a campground approximately 0.75 mile west of the mill tailings area and is screened in the Lightner Creek alluvium. Because this well is in use it cannot be purged before sampling; the well is periodically treated with chlorine. Well 0629 is on site, upgradient from the former small tailings pile and is completed in colluvium overlying the Mancos Shale bedrock. Because this monitor well is completed in clay-rich colluvial material, it contains very little water and tends to pump dry during sampling events. In addition, although well 0629 is upgradient on the site, it is within the area where surface remediation activities were performed.

Because of uncertainties about these existing background locations, and because neither well was completed in the Animas River alluvium (where most of the ground water at the mill tailings area occurs), two additional background wells were installed at the mill tailings area. Wells 0857 and 0866 were installed in background areas that were not affected by site processes and were both screened in Animas River alluvium (Figure 4–2). A slight petroleum odor was noted during the drilling of well 0857, indicating it may have been affected by an anthropogenic source other than the previous milling operations; although this location was outside the influence of the millsite operations, it may not represent true background conditions.

Two wells were completed as stilling wells for the Animas River. These wells were completed by installing data loggers into 2-inch PVC casing. The PVC casings for these wells were left with the bottom ends uncapped, approximately 1 ft below the low-flow water level elevation of the Animas River.

Boreholes at two off-site locations and three on-site locations (Figure 4–2) did not intersect any alluvial ground water above the top of the Mancos Shale bedrock. The off-site boreholes (0864 and 0865) were drilled east of the Animas River. The on-site boreholes (0860, 0861, and 0862) were drilled along the western edge of the mill tailings area near the base of Smelter Mountain.

4.1.2 Raffinate Ponds Area

Twenty monitor wells and one stilling well were installed in the raffinate ponds area (Figure 4–3). Alluvial ground water does not occur in the raffinate ponds area (except at well 0607) therefore, all the wells installed were screened in bedrock formations. All bedrock wells were completed using 2-inch i.d., flush-joint, threaded, PVC casing and wire-wrapped screen (0.02-inch slot size).

Two of the wells (0875 and 0903) were installed in background areas west of the site to characterize the upgradient bedrock ground water that is unaffected by the former processing operations. Wells 0875 and 0903 were screened in the Point Lookout Sandstone and Menefee Formations, respectively.

Eleven wells were installed on site, and seven wells were installed off site to characterize the nature and extent of ground water contamination and to determine the hydrologic properties of the aquifers. Twelve wells were completed in the Menefee Formation, three wells were completed in the Point Lookout Sandstone, and three wells were screened across the Bodo Fault zone, which traverses the raffinate ponds area (Figure 4–3).

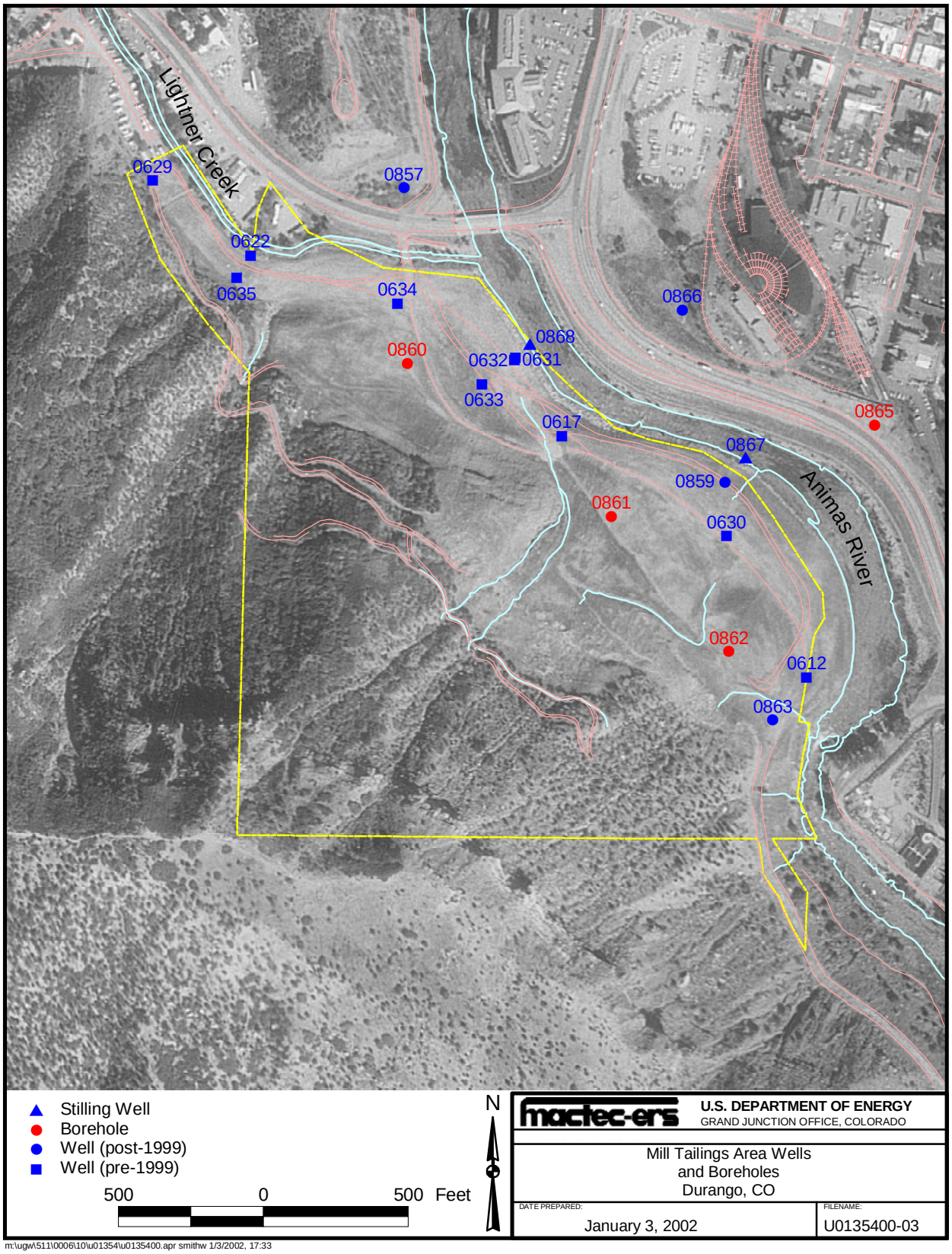

Figure 4–2. Mill Tailings Area Wells and Boreholes

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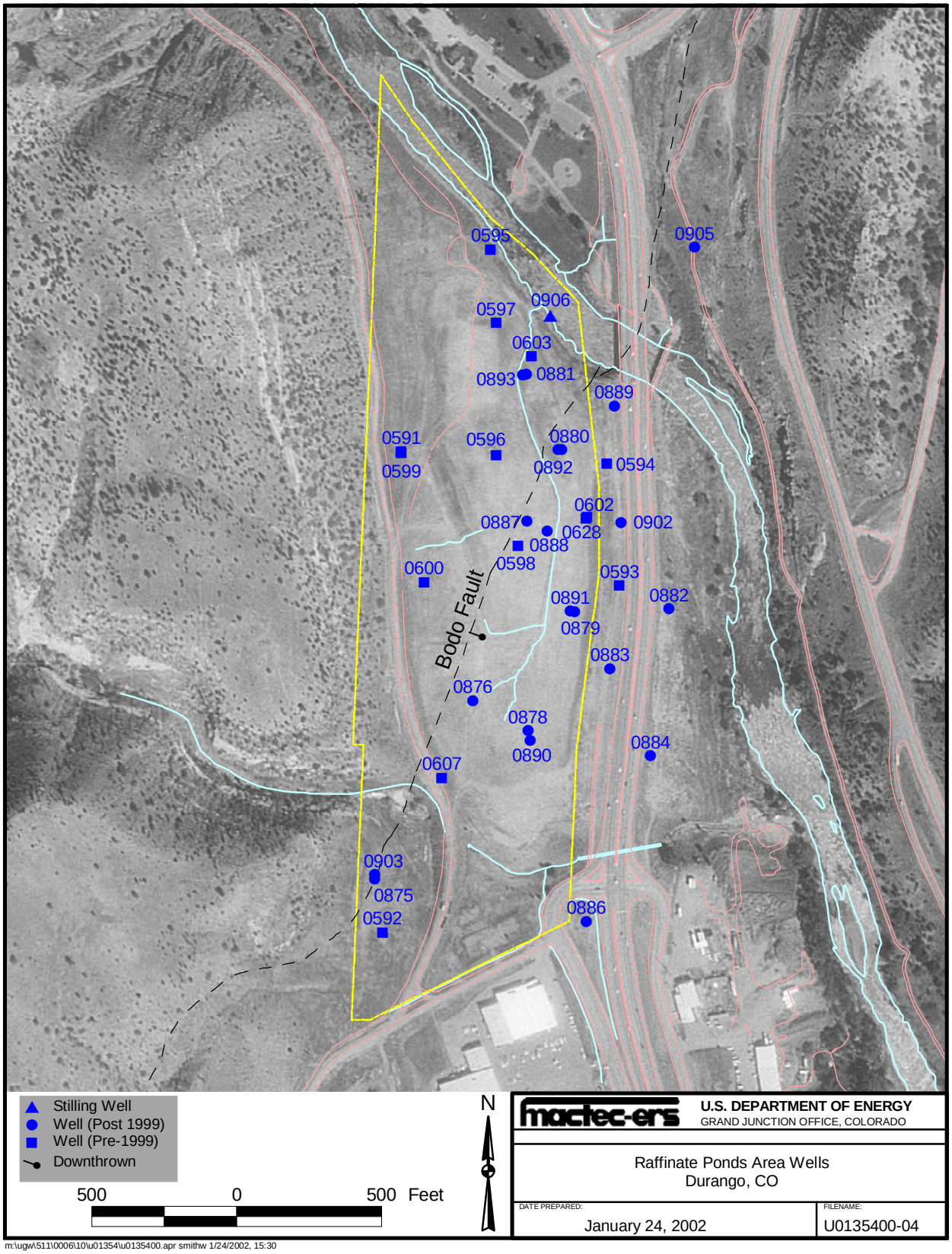

Figure 4–3. Raffinate Ponds Area Wells

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4.1.2.1 Status of Existing Monitor Wells at the Raffinate Ponds Area

The U.S. Bureau of Reclamation (BOR) performs sampling at the raffinate ponds area (for purposes related to the proposed Animas-La Plata project) and has installed wells 0599 and 0600 as upgradient background wells. However, it was determined that because of the cross-gradient proximity of well 0600 to the former location of the southernmost raffinate pond, this well would not be considered a background location for this site investigation.

In the *Preliminary Hydrogeochemical Characterization of the Durango, Colorado, Tailings and Raffinate Ponds Areas* (DOE 1983), monitor well 0607 was identified as a background well (based on statements of individuals who worked at the mill during its operation, only the northern raffinate ponds ever contained any effluent from the mill). Because of its proximity to the former location of the southernmost raffinate ponds, well 0607 was not considered a background location for this site investigation.

Monitor well 0602 was installed in the Menefee Formation in the central portion of the raffinate ponds area prior to site remediation. This well was completed with two separate screened intervals, and an inflatable packer was installed to separate the screened areas. The upper section of the well has a 10-ft screen within a massive sandstone of the Menefee Formation. The lower section of the well has a 5-ft screen across a coal bed below the sandstone unit. Appendix A presents the monitor well logs and lithologic descriptions. It is not known when the packer was installed (sometime prior to 1995), but the supply lines to the surface have deteriorated and fallen down the well annulus. Attempts to retrieve the lines have been unsuccessful, resulting in the lines breaking farther down the well. Attempts to insert a down-hole camera into the well were also unsuccessful. It is not known if the packer is still inflated or to what degree the packer itself may have deteriorated over time. Results from this well are included in the following sections with the caveat that the source of water sampled from this well cannot be clearly determined.

Monitor well 0628 is adjacent to well 0602. The original lithologic log for this well identifies it as being completed in the Cliff House Sandstone. However, the Cliff House Sandstone is not present within the boundaries of the raffinate ponds area. This well is actually completed within the Menefee Formation in what is believed to be massive, fine-grained sandstone. The well is screened continuously from its total depth of 32 ft to the surface. A visual investigation of the well using the down-hole camera showed the screened interval begins 2 ft below the surface. The protective concrete surface pad shown in the well completion log is no longer intact. Below the concrete pad the completion log indicates 3 ft of bentonite pellets were installed, extending down into the upper portion of the screen. The screened interval beginning only 2 ft below the surface adversely affects the integrity of analytical results from the well. Concentrations detected in samples from well 0628 may not be indicative of actual ground water conditions at depth, but may reflect the transport of surface or near surface materials into the well by precipitation or snowmelt. Results from well 0628 are not considered to be a valid representation of the constituent concentrations actually present or the geochemical conditions of ground water at this location.

The GCAP will be prepared to document the remediation decision. It is anticipated that this document will recommend abandoning wells 0602 and 0628 and replacing them with a well that will yield valid and technically defensible ground water analyses.

4.1.3 Soil and Rock Sampling

Soil and rock samples were collected during the installation of the monitor wells for lithologic logging and chemical analysis. Soil and rock samples were collected for chemical analysis to determine distribution coefficients (K_d) and mobile fractions of site-related constituents in the subpile soils to aid in characterizing subsurface contaminant transport.

Continuous core samples of the alluvium at the mill tailings area and of the bedrock formations at the raffinate ponds area were collected. Samples were collected in 10-ft intervals within the SONIC drill stem as the drill pipe was advanced through the formation. Clean water was used as needed to cool the advancing drill stem. Recovered core was vibrated out of the drill stem and placed in plastic bags within longitudinal separators. The uppermost portion of the sample was inspected, and all slough was discarded. After the site geologist described the cores, samples of selected intervals were placed in clean bags and labeled for analysis in the Grand Junction Office (GJO) Environmental Sciences Laboratory (ESL).

All soil and rock sampling was performed in accordance with the following procedures from the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998):

- GN–8(P), “Standard Practice for Sample Labeling”
- GN–9(P), “Standard Practice for Chain-of-Sample-Custody Control and Physical Security of Samples”
- GN–13(P), “Standard Practice for Equipment Decontamination”
- SL–9(P), “Technical Comments on ASTM D 2113–83(93)—Standard Practice for Diamond Core Drilling for Site Investigation”

4.1.4 Lithologic Logging

Lithologic descriptions of the alluvium and bedrock formations were recorded by the site geologist and are presented in the borehole summaries in Appendix A. All lithologic logging was performed in accordance with the following procedures from the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998):

- SL–19(P), “Technical Comments on ASTM D 2488–93—Standard Practice for Description and Identification of Soils”
- SL–24(P), “Technical Comments on ASTM D 2487–93—Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)”

4.2 Geology Investigation

The *Summary of Site Conditions and Work Plan, Durango Colorado* (DOE 2000b) presents geologic information as it was known from the preliminary hydrogeochemical characterization conducted by Bendix Field Engineering Corporation (Bendix) (DOE 1983), a hydrogeochemical site characterization by the BOR (1990), and the baseline risk assessment (DOE 1995a). Additional geologic characterization in fall 2000 was conducted mainly in the raffinate ponds area in conjunction with borehole drilling for monitor well installations. Recent geologic mapping by the Colorado Geological Survey for the Durango West and Durango East 7.5 minute quadrangles (Kirkham and others 1999, and Carroll and others 1999, respectively) covered the site areas, which are mostly on the Durango West quadrangle, and provided additional

information on stratigraphic and structural characteristics. The recent doctoral dissertation by Gillam (1998) on the late Cenozoic geology and soils of the lower Animas River valley also provided information in the recognition and description of Quaternary terrace deposits in the site areas.

4.2.1 Mill Tailings Area

Figure 4–4 is a geologic map of the mill tailings area. This map, compiled mainly from Kirkham and others (1999), shows the area to be underlain by the upper part of the gray, marine Mancos Shale. The presence of scattered gypsum crystals in the calcareous Mancos Shale verifies its high content of sulfate; the shale is also widely known for its high selenium content. Several hundred feet up the north slope of Smelter Mountain above the site is the gradational contact of the overlying Point Lookout Sandstone, in the lower part of which thin sandstone beds are interbedded with shale. The Mancos and Point Lookout are covered in most places in the mill tailings area by recent (active) and old (inactive) colluvial deposits emplaced by gravity and sheetwash. Drilling of boreholes in this site area for monitor wells in fall 2000 confirmed earlier interpretation of geologic conditions.

4.2.2 Raffinate Ponds Area

Figure 4–5 is a geologic map of the more stratigraphically varied and structurally complex raffinate ponds area. Bedrock units slightly younger than those at the mill tailings area are exposed at the raffinate ponds area. These units are part of the Mesaverde Group and include, in ascending order, the Point Lookout Sandstone, the Menefee Formation, and the Cliff House Sandstone. Just southwest of the area, along the Bodo Fault in Bodo Canyon, a small area of Lewis Shale (overlying the Cliff House Sandstone) outcrops. The Bodo Fault, named on the map by Kirkham and others (1999), cuts diagonally through the raffinate ponds area and has a displacement of about 200 ft. Generally, in this area the Point Lookout Sandstone is in the footwall (west, or upthrown, side) of the fault, and the Menefee Formation is in the hanging wall (east, or downthrown, side) of the fault. Except for bedrock outcrops along the steep east flank of Smelter Mountain and along some of the west bank of the Animas River, most of the area is covered by Quaternary colluvial material or fill material emplaced during reclamation.

Stratigraphic descriptions of bedrock formations in the site area are provided in the Bendix (DOE 1983) and BOR (1990) reports. Bedrock mapping units used in preparation of the geologic map (Figure 4–5) were adopted mainly from the new Colorado Geological Survey maps by Kirkham and others (1999) and Carroll and others (1999). A large-scale (1 inch = 200 ft), more detailed geologic map of the area shown in Figure 4–5 is provided as Plate 2.

The Point Lookout Sandstone represents an eastward prograding shoreline between the sea in which the Mancos Shale was deposited and the coastal plain where the Menefee Formation was accumulating (Kirkham and others 1999). The Point Lookout is subdivided into two units, a lower part and an upper massive part. The lower part is 250 to 300 ft thick and consists of interbedded thin sandstone and shale beds. Sandstone beds are less than 1 ft thick and are more frequent in the upper part of the unit; shale beds are gray, fossiliferous, bioturbated, and slightly carbonaceous, and become more predominant in the lower part of the unit. The few exposures of the lower Point Lookout in the area are west of the Bodo Fault along the bank of the Animas River and in a small north-flowing tributary drainage (Figure 4–5).

The upper massive part of the Point Lookout Sandstone is mainly composed of two thick, light gray to yellowish gray, fine- to medium-grained sandstone beds, each about 35 ft thick. A carbonaceous shale and siltstone bed several feet thick with limonite concretions separates the two sandstone beds. Total thickness of the upper Point Lookout is 75 to 80 ft, and it forms two distinctive cliffs along the east side of Smelter Mountain. Other exposures in the site area are just west of the Bodo Fault in the canyon of South Creek where several old quarries mined the sandstone, on the south abutment of the U.S. Highways 160 and 550 bridge just east of the Bodo Fault, and east of the Animas River on the slope above well 0905 (Plate 2). The topmost sandstone is typically bleached nearly white because of the reducing environment of the basal coal bed of the Menefee Formation lying immediately above. The relationship of the Point Lookout Sandstone to the Bodo Fault and the overlying Menefee Formation is shown in the 1,700-ft-long, north-south cross section (Plate 3) along the east side of the raffinate ponds area. The location of this cross section A–A' is shown in Figure 4–5.

The Menefee Formation is present in the raffinate ponds area east of the Bodo Fault. It is approximately 200 to 250 ft thick and consists of interbedded gray, brown, and black carbonaceous shale, fine-grained sandstone, and coal. Sandstone beds in many places contain abundant carbonaceous debris. Coal beds may be up to 5 ft thick, and one several feet thick occurs at the base of the formation. The coal and carbonaceous shale beds typically contain naturally high concentrations of selenium.

The Menefee Formation is exposed in only a few places in the raffinate ponds area. Exposures are of sandstone in the north part of the area just west of the highway, along the Animas River bank, and a distinctive basal coal bed just west of the highway bridge. Other Menefee outcrops are along the south flank of Smelter Mountain and on the hill south of South Creek where there is an old coal prospect. East of the highway across from the south part of the site area is another Menefee coal and sandstone outcrop area near an old slag pile. An excellent section of Menefee Formation is exposed east of the site area and east of the Animas River on the slope above the old railroad grade. Visible on this slope is an approximate division of the formation into four coal-carbonaceous shale layers and four sandstone layers. Even though these layers are somewhat lenticular and cannot be traced over distances of miles, they appear to be roughly correlated along strike to the west in the subsurface of the raffinate ponds area.

Numerous boreholes and wells penetrate parts of the Menefee Formation in the raffinate ponds area east of the Bodo Fault. From this abundant subsurface data and nearby exposures of the formation just east of the Animas River, a north-south cross section (Plate 3) was prepared showing an approximate stratigraphic framework of the Menefee. Correlations in this section were based heavily on the presence of coal and carbonaceous shale zones in the boreholes. The dip of strata in the cross section is approximately 12 degrees to the south; and strike of the beds is approximately due east; these strike and dip approximations were derived from those shown in the geologic maps of Kirkham and others (1999) and Carroll and others (1999). Individual borehole stratigraphic data were projected from various distances onto the line of the cross section. Although several approximations were made in constructing the cross section, it provides a relative thickness and stratigraphic framework for the Menefee Formation in the site area south and east of the Bodo Fault. Screened intervals in the Menefee wells indicate that ground water occurs both in the thick coal and carbonaceous shale units (that are probably well fractured) as well as in the thick permeable sandstone units.

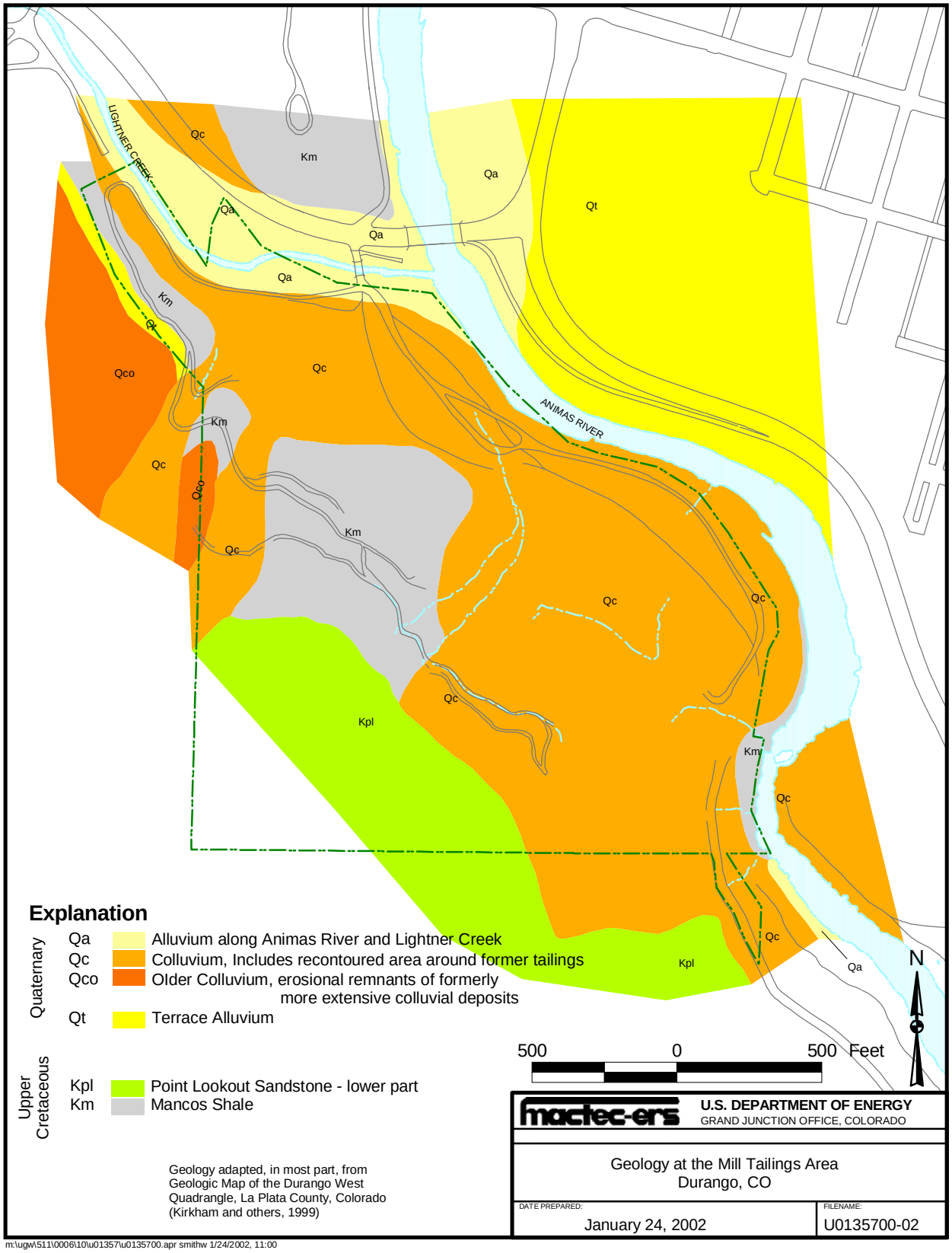

Figure 4–4. Geology at the Mill Tailings Area

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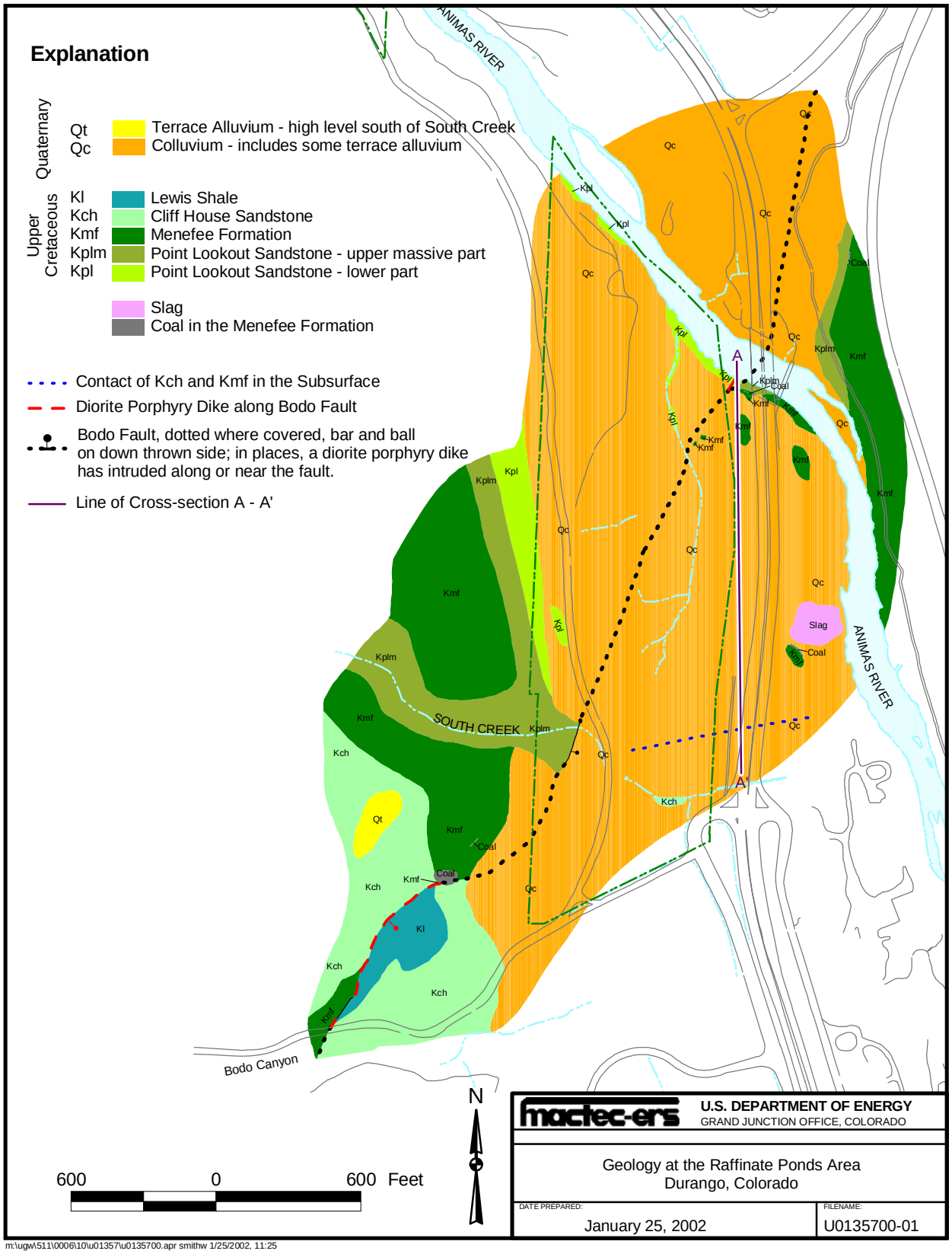

Figure 4–5. Geology at the Raffinate Ponds Area

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The lower Cliff House Sandstone consists of red brown (rust-colored) fine- to medium-grained sandstone beds with abundant fossil burrows. This formation represents a transgressive shallow marine barrier island beach front environment (Kirkham and others 1999). The contact between the Cliff House Sandstone and Menefee Formation is covered; its approximate position is about 200 ft north of South Creek (Figure 4–5).

Quaternary material mapped as colluvium covers much of the site area. Included with the colluvium are sheetwash deposits, alluvium along the Animas River, fill material and soil associated with surface re-contouring during remediation, glacial outwash, and terrace gravels 20 to 100 ft above the Animas River. These various Quaternary materials may be as much as 30 ft thick in the site area.

The Bodo Fault cuts through the site area but is exposed only at the north end of the area (just west of the U.S. Highways 160 and 550 bridge) and just southwest of the area for several hundred feet north of County Road 211 up Bodo Canyon. Also, the fault is obvious in the bottom of South Creek where massive sandstone of the Point Lookout Sandstone abruptly ends and colluvial material is present downstream (Figure 4–5). The buried location of the fault across the site was fairly well established from magnetometer surveys conducted by Bendix (DOE 1983). Good descriptions of the fault and associated alteration and intrusive dike rock are given in the BOR 1990 report from several boreholes drilled through the fault. North of the Animas River, the fault position is less certain. During this investigation, evidence for the fault was sought in the deep borehole for well 0905, but none was found, indicating the fault is farther to the west. From field locations and subsurface borehole penetrations of the fault across the site, its dip ranges from 45 to 65 degrees and it trends from due north to nearly due east.

Dikes of diorite porphyry have intruded the Bodo Fault along much of its length; they are probably associated with early Laramide intrusive rocks of the La Plata Mountains to the west. Up to several feet thick, the dikes may occur alone or branch into several dikes along the fault zone. Where exposed north of the Bodo Canyon road, the dikes are red brown, well oxidized, and moderately to highly weathered. Gray siltstone and shale adjacent to a dike in the fault zone west of the U.S. Highways 160 and 550 bridge has been altered to resistant hornfels by contact metamorphism.

Cored material from boreholes during the investigation in fall 2000 displayed subsurface characteristics of the fault zone and the diorite porphyry intrusions. Where fresh, the diorite porphyry was resistant and medium brown to medium gray. In most cases, the diorite showed propylitic alteration with hornblende altering to chlorite. Effects of the fault and diorite porphyry dikes on the adjacent sedimentary rocks include baking of gray shales to hornfels and, in some cases, to light-colored porcelaneous material. Sandstone near the fault was usually well fractured with limonite, pyrite, and calcite present along fractures. Black sooty material and soft gray gouge material was present near the fault. Pyrite occurred in vugs in some sandstone, which was metamorphosed to quartzite-like material. Also, pyrite occurred in unaltered sandstone and shales in segregations as large as 2 inches in diameter and as finely disseminated material. The pyrite likely contains a significant amount of selenium as is commonly associated with igneous intrusive rock. Effects of the fault zone and associated diorite porphyry dikes in the form of increased fracturing and alteration extend up to an estimated 50 ft or more from the fault.

Joint directions in bedrock in the raffinate ponds area were measured by Kirkham and others (1999). They found an orthogonal pattern with the oldest and most prevalent joint set trending north-northeast and a younger, secondary joint set trending east-northeast.

4.3 Aquifer and Slug Tests

Aquifer tests at the Durango site were performed by Bendix in 1983 (DOE 1983), BOR in 1990 (BOR 1990), and MACTEC–ERS in 2001. Appendix F presents the details of the MACTEC–ERS tests and summarizes the results from the Bendix and BOR tests.

Aquifer testing at the former mill tailings area is hampered by thin saturated zones and depths to water that exceed of 25 ft. These conditions prevent conventional pumping tests because where the saturated alluvium is thin, multiple well testing is impractical because of limited available drawdown. If the depth to water exceeds 25 ft, a centrifugal pump cannot be used because the required lift exceeds the capability of the pump. In consequence, only slug tests were conducted at the former mill tailings area by MACTEC–ERS and previous investigators. MACTEC–ERS performed slug tests in the mill tailings area at wells shown in Figure 4–6.

At the raffinate ponds area, ground water occurs in bedrock units of the Menefee Formation and the Point Lookout Sandstone. Except where the Bodo Fault crosses the raffinate ponds area, the well yields in the bedrock formations are so low that it would be impractical to conduct conventional aquifer tests. Along the Bodo Fault, Bendix (DOE 1983) performed a pumping test; results from that test are presented in Appendix F. Because the bedrock formations were anticipated to have low yields, slug tests were recommended for characterizing the hydraulic conductivity at the raffinate ponds area. Slug tests were performed at wells 0602, 0876, 0878, 0879, 0881, 0882, 0883, 0888, 0889, 0890, and 0902 (Figure 4–6) at the raffinate ponds area.

In November 1990, BOR performed slug tests and packer tests at the former raffinate ponds area as part of the design of the pumping plant for the Animas-La Plata water project. Results of the BOR tests are presented in Appendix F.

Table 4–2 presents the results of the MACTEC–ERS slug tests for the former mill tailings area and the raffinate ponds area. As shown in Table 4–2, the hydraulic conductivity ranged from 1 to 28 ft/day for the Animas River alluvium and was 66 ft/day for the Lightner Creek alluvium. Table 4–2 also shows that the hydraulic conductivity of the Menefee Formation ranges from a minimum of 0.003 ft/day at well 0902 to 5.3 ft/day for the duplicate test at well 0882. Hydraulic conductivity of the Point Lookout Sandstone was low at locations 0881 and 0889 where it was measured by MACTEC–ERS. Slug test and packer test results described by BOR (Appendix F) indicate that the Point Lookout Sandstone has a uniformly low hydraulic conductivity.

Within the Bodo Fault, the slug test for well 0888 indicates a hydraulic conductivity of 6.4 ft/day. This result for the Bodo Fault confirms earlier tests by Bendix (DOE 1983) when a value of 4.4 ft/day was determined. The slug test results indicate that the Bodo Fault is a potential conduit for ground water flow at the site.

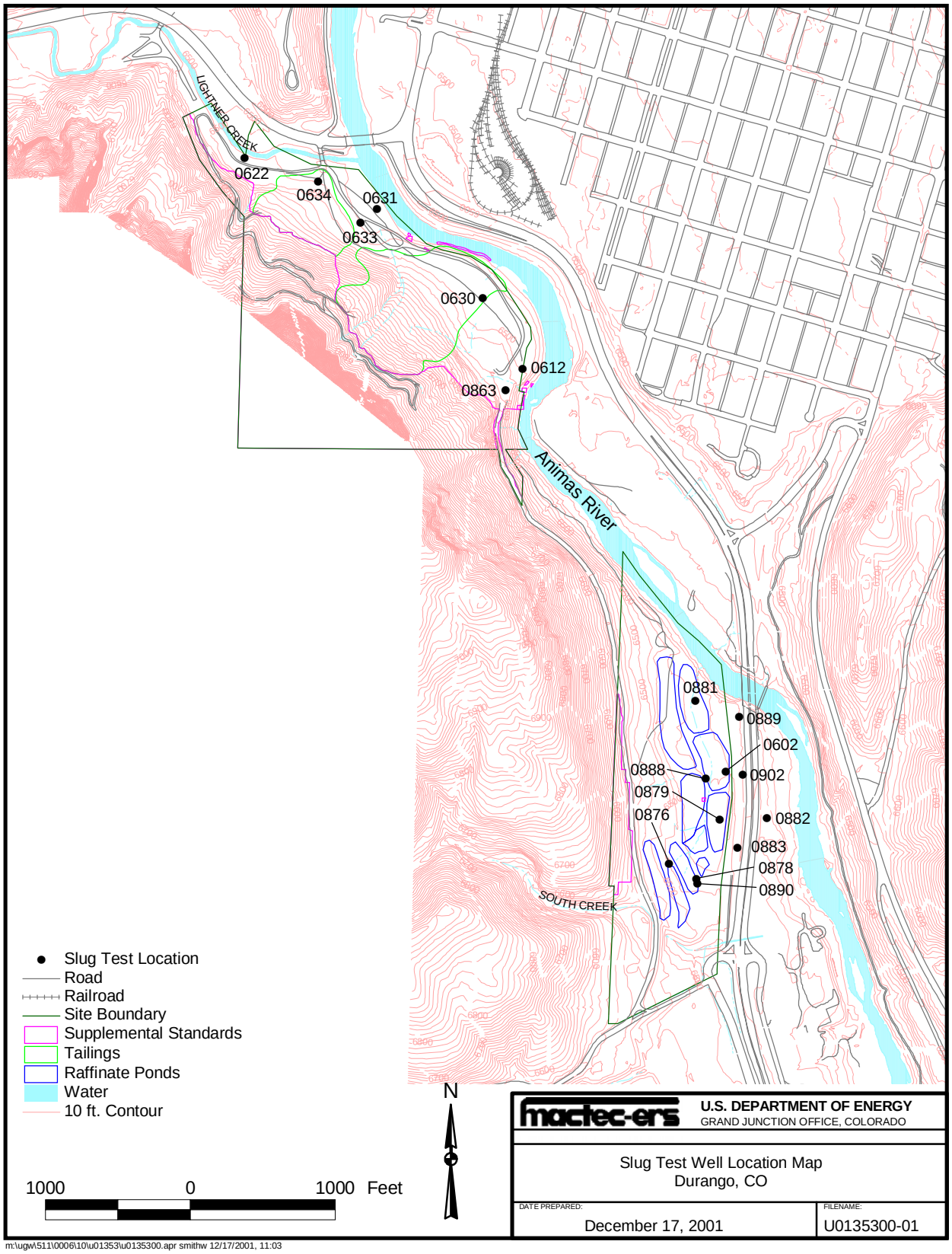

Figure 4–6. Slug Test Well Location Map

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Table 4–2. Summary of Slug Tests Performed at the Durango Sites by MACTEC–ERS

	Well	Hydraulic Conductivity (ft/day)	Formation		Well	Hydraulic Conductivity (ft/day)	Formation
DUR–01 Mill Tailings Area	0612	10	Alluvium	DUR–02 Raffinate Ponds Area	0602	0.26	Menefee
	0612-dup	13	Alluvium		0876	0.09	Menefee
	0622	66	Lightner Cr. Alluvium		0878	1	Menefee
	0630	13	Alluvium		0879	0.043	Menefee
	0631	27	Alluvium		0881	0.016	Point Lookout
	0631-dup	26	Alluvium		0882	4.7	Menefee (coal)
	0633	1	Alluvium		0882-dup	5.3	Menefee (coal)
	0634	8	Alluvium		0883	0.017	Menefee
	0863	26	Alluvium		0888	6.4	Menefee (fault)
	0863-dup	28	Alluvium		0889	0.014	Point Lookout
					0890	0.3	Menefee
					0902	0.003	Menefee

Note: All alluvium is derived from the Animas River unless noted otherwise.
dup = duplicate sample

4.4 Subpile Soil Sampling

A study of subpile soils was done to determine if cadmium, lead, molybdenum, selenium, or uranium are present in soils in sufficient concentrations to be a source of contamination to the ground water at the Durango site. Thirty-nine soil samples were analyzed. Nineteen samples were obtained from the mill tailings area, including three background samples (Figure 4–7). Twenty samples were collected from the raffinate ponds area, including four background samples (Figure 4–8).

4.4.1 Subpile Soil Sampling Methods

Soil samples were collected as individual grab samples by backhoe from locations most likely to be contaminated. Two samples were collected above the water table at each location. Samples were taken from the backhoe bucket at depths ranging from 2 to 6 ft. Samples 0913 from 3.5 ft deep and 0914 from 3 ft deep were rock samples obtained from the Menefee Formation and Point Lookout Sandstone, respectively. The two rock samples were crushed to obtain leachable samples.

Background samples were collected from areas off site. Two samples of colluvium (0931–COL and 0932–COL) were collected upgradient from the site along the base of Smelter Mountain. One sample of alluvium (0930–AL) was collected about 1,500 ft upstream from the site along the Animas River.

4.4.2 Subpile Soil Sampling Chemical Extraction Methods

Concentrations of constituents in soil are determined through sample digestion, separation of the liquid phase by centrifuging or filtering, analysis of liquid phase constituent concentrations, and calculation of the concentrations in the solid phase. The most suitable digestion methods are those that remove only the loosely bound constituents because they have the highest potential for contaminating ground water and being accessible to plants and animals. The choice of extraction

method and leaching fluid determines which specific constituents can be extracted. The kinds of liquid media used to digest samples range from deionized water to strong acids combined with hot fluxing agents. Numerous digestions with different solutions would be needed to provide a complete picture of constituent distribution in a soil.

This project was intended to provide data for a screening-level assessment of soil accessible to plants and animals. A five percent solution of nitric acid (HNO_3) was used for digestion. This acidic solution should release the adsorbed cations and dissolve the carbonate minerals. Although anions adsorb more strongly at low pH, they should also be released because the acid dissolves most of the amorphous oxyhydroxide adsorbent phases. Five-percent HNO_3 will not dissolve most silicate minerals, which is desirable because the constituents in silicate minerals are not readily available to ground water. Analytical methods for the soil sampling are discussed in greater detail in the *Contaminants in Subpile Soils* report (Appendix J).

4.4.3 Mill Tailings Area Subpile Soil Sampling Results

Nineteen samples were collected from 11 locations (Figure 4–7). Two samples from different depths were collected from each location, except samples from locations 0930, 0931, and 0932, where each is a single surface sample. All sample pairs have similar lithology. One sample, 0918–5 ft, contains slag, which is solid waste material left from the operation of the lead smelter.

Mill tailings area subpile soil data are listed in Table 4–3. Three surface soil samples, 0930–AL, 0931–COL, and 0932–COL, are background samples. Cadmium concentrations in these three samples are greater than the mean crustal concentration of 0.2 milligrams per kilogram (mg/kg). Selenium concentrations in background samples exceed both the detection limit of 0.35 mg/kg and the mean crustal concentration of 0.05 mg/kg. Lead concentrations in background samples 0931–COL and 0930–AL also are greater than the crustal mean. The presence of lead in concentrations greater than the crustal mean in background samples indicates that lead is available in the environment and the soils are able to adsorb it. The elevated cadmium, lead, and selenium concentrations in background samples suggests these constituents are natural components of the rocks and soil. Concentrations of molybdenum and uranium in background samples are less than the mean crustal concentrations, which indicates that these constituents are not natural rock and soil components. Significantly elevated concentrations of cadmium, lead, and selenium and elevated concentrations (greater than the crustal mean) of molybdenum and uranium indicate an anthropogenic source.

Nine of the 16 nonbackground samples have cadmium concentrations greater than the crustal mean of 0.2 mg/kg. Lead concentrations in five nonbackground samples are greater than the mean crustal composition of 13 mg/kg. All 16 nonbackground samples have selenium concentrations greater than the crustal mean of 0.05 mg/kg and the detection limit 0.35 mg/kg. Only two samples have molybdenum concentrations that are greater than the mean crustal concentration of 1.5 mg/kg. Five samples have uranium concentrations greater than the mean crustal concentration of 1.80 mg/kg. Elevated molybdenum and uranium concentrations may be attributable to milling activity.

Slag was collected with soil in sample 0918–5 ft, and no slag was collected in sample 0918–3 ft. The slag is associated with the operation of the lead smelter and could be expected to contain high concentrations of lead. Therefore, the source of lead contamination cannot be solely attributable to uranium milling activity.

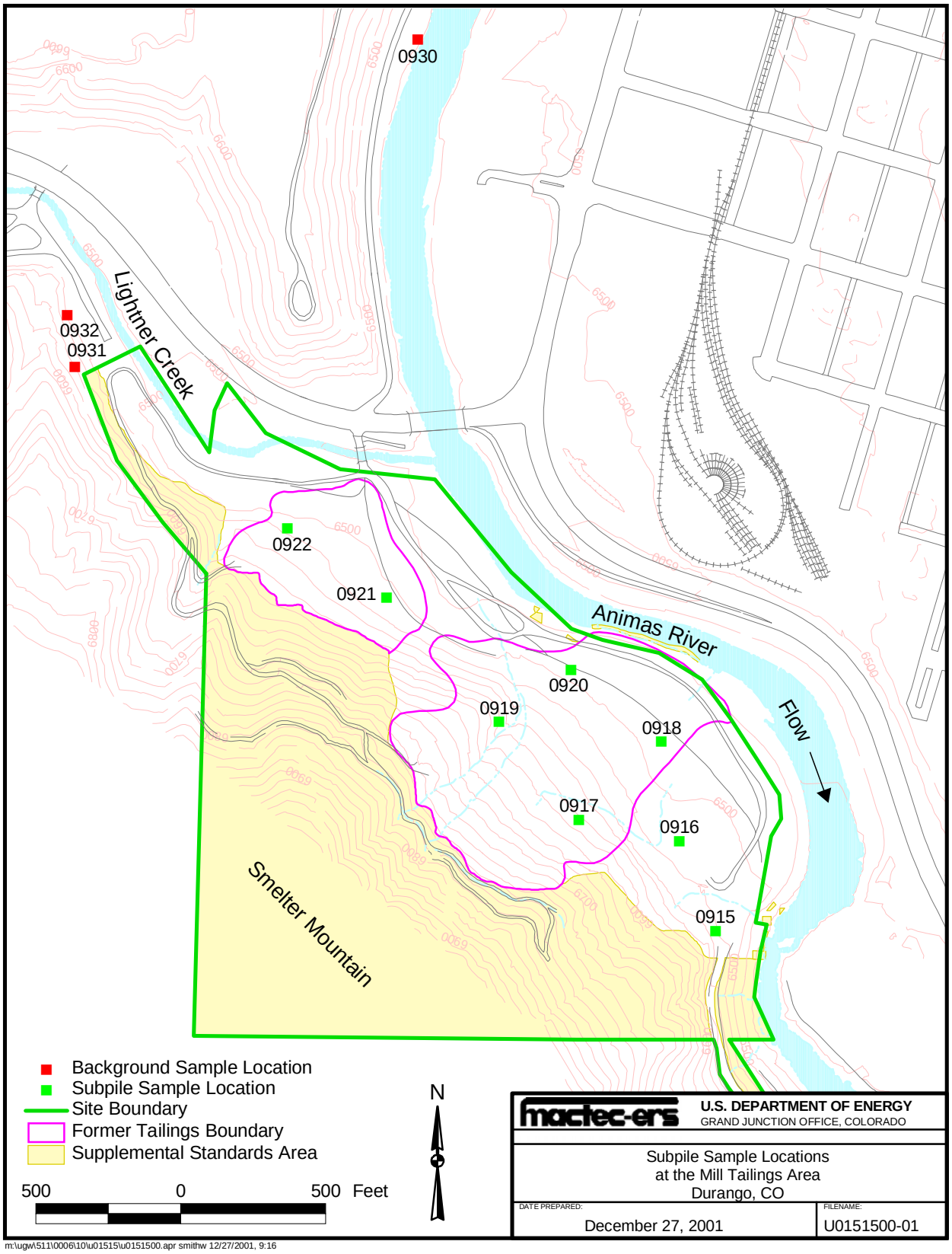

Figure 4–7. Subpile Soil Sample Locations at the Mill Tailings Area

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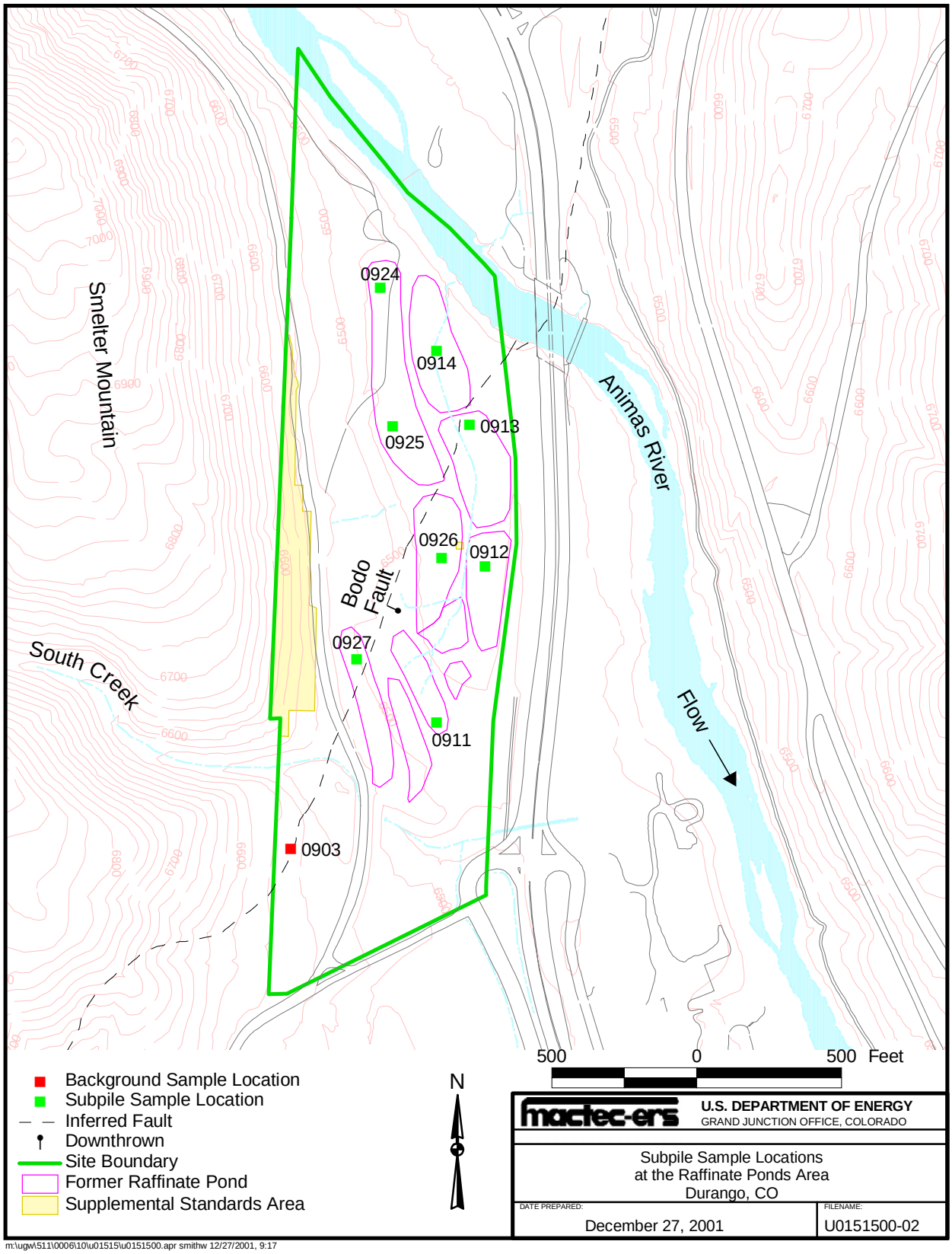

Figure 4–8. Subpile Soil Sample Locations at the Raffinate Ponds Area

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Table 4–3. Constituent Concentrations in Durango Mill Tailings Area Subpile Soil Samples

Sample		Cadmium		Lead	Molybdenum		Selenium		Uranium
Well	Depth (ft)	(mg/kg)	DQ[a]	(mg/kg)	(mg/kg)	DQ	(mg/kg)	DQ	(mg/kg)
0915	-3[b]	0.14		8.58	0.08	U	**0.41**	B	0.36
0915	-5	0.10		6.98	0.08	U	**0.49**	B	0.34
0916	-3	**0.25**[c]		**13.8**	0.08	U	**0.35**	U	0.48
0916	-5	**0.21**		12.7	0.08	U	**0.35**	U	0.49
0917	-2	**7.20**		**79.6**	0.88	B	**1.31**		**21.8**
0917	-4	**4.17**		**42.5**	**2.18**		**1.29**		**10.7**
0918	-3	0.096	B	5.67	0.096	B	**0.68**		0.35
0918	-5	**5.15**		**6660**	**10.8**		**2.00**		**42.4**
0919	-2	**0.76**		9.23	0.087	B	**0.56**		**6.90**
0919	-4	0.18		7.37	0.08	U	**0.47**	B	**3.24**
0920	-2	**0.25**		**14.7**	0.08	U	**0.35**	U	0.50
0920	-5	0.17		6.47	0.08	U	**0.92**		0.30
0921	-2	**0.22**		9.35	0.091	B	**0.64**		1.72
0921	-4	0.17		9.10	0.08	U	**0.86**	.72	0.72
0922	-2	0.20		11.4	0.08	U	**0.37**	B	0.76
0922	-3	**0.28**		11.7	0.08	U	**0.35**	U	0.75
0930	-AL	**1.27**		**141**	0.50	B	**0.60**		0.77
0931	-COL	**0.85**		**13.6**	0.66	B	**0.88**		1.22
0932	-COL	**0.57**		6.95	0.13	B	**0.72**		0.54
Crustal average[d]		0.2		13	1.5		0.05		1.8

[a]Data Qualifiers: B signifies that the reported value is less than the required detection limit but is greater than or equal to the actual instrument detection limit. U signifies that the value is less than the detection limit.
[b]Sample collection depth (ft) below ground surface. Depths labeled as –AL and –COL are surface samples. AL is from the alluvium and COL is from the colluvium.
[c]**Bold type** indicates that concentrations are greater than the average crustal value.
[d]From Mason and Moore 1982.

Elevated constituent concentrations at some locations, (such as 0917), indicate milling processes may have influenced soil chemistry. Although concentrations of cadmium, lead, and selenium appear to be naturally greater than the crustal mean, significantly elevated constituent concentrations, such as those in sample 0918–5 ft, appear to be limited to small, separate areas. Likewise, elevated concentrations of molybdenum and uranium appear to be limited in area. Samples with elevated concentrations are sufficiently few and separated that the concentrations may not be a significant, continuing source of contamination.

4.4.4 Raffinate Ponds Area Subpile Soil Sampling Results

Twenty samples were collected from nine locations (Figure 4–8). Two samples were collected from each location except location 0903, where four background samples were collected at depths of 4 ft, 14 ft, 23 ft, and 28 ft. Two samples, 0913–4 ft and 0914–3 ft, were rock core samples and were crushed to obtain the required less than 2- millimeter (mm) fraction. The lithology of the samples is similar, except in samples 0913–4 ft and 0914–3 ft. Sample 0913–4 ft was collected as a consolidated core sample of unweathered, medium-grained, light-gray sandstone from the Menefee Formation. Sample 0914–3 ft was collected as a consolidated sample of shale from the Point Lookout Sandstone. The remaining samples have similar

lithology with minor variations in the amount of silt, degree of rounding, and type of rock material present.

Raffinate ponds area subpile soil data are listed in Table 4–4**.** The selenium concentrations of all samples are greater than the mean crustal concentration. Background concentrations of cadmium, lead, molybdenum, and uranium are less than the mean crustal concentrations. The higher concentrations of cadmium and lead in samples from the mill tailings area are not present in samples from the raffinate ponds area.

Table 4–4. Constituent Concentration in Durango Raffinate Ponds Area Subpile Soil Samples

Sample		Cadmium		Lead	Molybdenum		Selenium		Uranium
Well	Depth (ft)	(mg/kg)	DQ[a]	(mg/kg)	(mg/kg)	DQ	(mg/kg)	DQ	(mg/kg)
0903	-4[b]	0.041	B	4.40	0.12	B	**0.35**	U	0.18
0903	-14	0.057	B	4.81	0.11	B	**0.35**	U	0.18
0903	-23	**2.17**[c]		4.50	0.13	B	**0.35**	U	0.29
0903	-28	0.11		10.0	0.12	B	**0.35**	U	0.21
0911	-2	0.19		8.45	0.08	U	**0.35**	U	0.41
0911	-6	**0.38**		6.62	0.08	U	**0.39**	B	0.90
0912	-2	**3.39**		5.21	0.23	B	**1.51**		**2.30**
0912	-5	**1.79**		5.96	0.31	B	**1.50**		**2.09**
0913	-2	**1.31**		12.6	0.093	B	**1.00**		**2.03**
0913	-4	0.081	B	6.14	0.33	B	**0.53**		0.29
0914	-2	**13.4**		7.63	0.08	U	**2.77**		**15.1**
0914	-3	**0.21**		**13.6**	0.39	B	**0.89**		0.61
0924	-2	**0.84**		10.7	0.096	B	**0.66**		**2.05**
0924	-5	**2.03**		9.34	0.12	B	**1.19**		**6.50**
0925	-2	**0.42**		10.6	0.18	B	**1.10**		1.27
0925	-5	**0.60**		9.95	0.15	B	**0.47**	B	1.17
0926	-2	**7.85**		5.96	0.11	B	**1.22**		**19.5**
0926	-4	**6.98**		7.71	0.16	B	**1.16**		**4.60**
0927	-3	**0.51**		6.46	0.08	U	**0.59**		**6.07**
0927	-5	**0.74**		7.16	0.08	U	**0.52**		**4.79**
Crustal average[d]		0.2		13	1.5		0.05		1.8

[a]Data Qualifiers: B signifies that the reported value is less than the required detection limit but is greater than or equal to the actual instrument detection limit. U signifies that the value is less than the detection limit.
[b]Sample collection depth (ft) below ground surface. Depths labeled as –AL and –COL are surface samples. AL is from the alluvium and COL is from the colluvium.
[c]**Bold type** indicates that concentrations are greater than the average crustal value.
[d]From Mason and Moore 1982.

Both samples from locations 0912, 0924, 0926, and 0927 have cadmium and uranium concentrations greater than the mean crustal concentrations. Both samples from locations 0914 and 0925 have cadmium concentrations greater than the crustal mean. The uranium concentration in samples 0914–2 ft and 0913–2 ft, and the lead concentration of 0914–3 ft are greater than the mean crustal concentrations. Cadmium concentration in samples 0903–23 ft, 0911–6 ft, and 0913–2 ft are greater than the crustal mean.

Elevated concentrations of cadmium, lead, molybdenum, and uranium suggest that milling processes influenced soil chemistry. As in the mill tailings area, high constituent concentrations

are limited to small, separate areas. Overall, the concentrations may not be significant enough to be a continuing source of contamination.

4.5 Distribution Coefficient

As contaminated ground water migrates through soil and rock, contamination is distributed between the solid and liquid phases. This phenomenon causes the contamination to travel at a slower rate than the average ground water velocity. Chemical processes that retard the migration rate of the contaminant plume can include adsorption, absorption, mineral precipitation, diffusion into immobile porosity, attachment to microbes, and transfer to vapor phases. It is generally not possible to differentiate among these processes. However, a bulk parameter (K_d) has been used with some success to model the retardation of contaminant movement for many aquifer systems. Most numerical ground water models use the K_d concept in simulations of contaminant transport. Site-specific K_d values are approximated from R_d values that are empirically determined. This laboratory study was conducted to determine R_d values for four stratigraphic units at the Durango site.

4.5.1 Definitions and Calculations

R_d is defined as the concentration of a constituent on the solid fraction divided by the concentration in the aqueous phase:

$$R_d = \frac{\text{(mass of solute sorbed per unit mass of solids)}}{\text{(mass of solute per volume of solution)}}$$

R_d values are calculated from experimental data as

$$R_d = \frac{(A-B)V}{M_s B}$$

where

A = initial concentration of the constituent in milligrams per liter (mg/L),
B = final concentration of the constituent,
V = volume of solution [100 milliliters (mL) in all cases],
M_s = mass of soil used in grams (g), and
R_d = distribution ratio in milliliters per gram (mL/g).

K_d is numerically equivalent to R_d if the system is at equilibrium and R_d is constant for the range of conditions being considered. If R_d is constant over a large range of contaminant concentrations, it is said to be linear because a plot of aqueous concentration against solid-phase concentration forms a straight line on an arithmetic plot. R_d data are often displayed on log-log concentration plots. A linear plot of R_d (referred to as a linear isotherm because temperature is held constant) is a line with a slope of one on a log-log plot.

At elevated concentrations of a constituent, R_d often varies with the aqueous concentration. In this case, the isotherm is said to be nonlinear and cannot be accurately represented by K_d.

4.5.2 Methods

Surface samples were collected by shovel and bedrock samples were collected with a rotasonic drill rig. Samples were collected from background areas to avoid the complication of contamination in the solid phases before analyses. If contamination is present in the solids, it must be accounted for by measuring concentrations in both the solid and aqueous phases. If no contamination is present in the solid phase, only the aqueous solution requires analysis, making the procedure less complicated and less prone to analytical error. It is believed the lithology and mineralogy in the background areas are similar to those in contact with the contaminant plume.

R_d data were collected using ESL Procedure CB(R_d –1) (DOE 1999b). Surface water was collected from the Animas River to use for leaching the mill tailings area samples, and ground water was collected from well 0592 to use for leaching the raffinate ponds area samples. The collected waters were spiked with known amounts of cadmium, lead, molybdenum, selenium, and uranium concentrates to produce a target concentration of each constituent; these waters are called control samples.

Several rounds of determinations, changes in the target solution concentrations, and the use of synthetic ground water for Round 3 of the raffinate ponds area determinations were necessary because of the instability of the control solutions. Table 4–5 through Table 4–7 list the constituent concentrations of the control samples and the target concentrations for each study area and for each round of analyses. Due to the number of samples, the concentrations of the control solutions were measured for each batch of samples in Round 1 of the raffinate ponds area determinations. As a result, there are five control solutions in Round 1 of the raffinate ponds area determinations. As listed in Round 1 determinations, the target concentrations were 1 mg/L for cadmium, lead, molybdenum, selenium, and uranium. In Round 2, the target concentration of uranium changed to 0.5 mg/L and lead was not included. In Round 3, determinations were conducted on raffinate ponds area samples using synthetic ground water, and the target concentrations of cadmium and molybdenum changed to 0.5 mg/L and the selenium and uranium concentrations did not change.

A six-point isotherm was determined for each sample in Round 1. Samples in Rounds 2 and 3 were single-point determinations. Samples were analyzed for cadmium, lead, molybdenum, and uranium by inductively coupled plasma-mass spectrometry (ICP–MS), and selenium was determined by inductively coupled plasma-atomic emission spectrometer (ICP–AES) by the GJO Analytical Laboratory.

Table 4–5. Control Solution Stability for Mill Tailings Area Samples

Listed are target concentrations, control solution compositions, and percent of the target concentration recovered for mill tailings area determinations.

Analyte	Units	Animas River Water					
		Round 1			Round 2		
		Target[a]	Control	% of Target	Target	Control	% of Target
Cadmium	mg/L	1.0	0.985	**98.5** [b]	1.0	0.999	**99.9**
Lead	mg/L	1.0	0.151	15.1	NA [c]	NA [c]	NA [c]
Molybdenum	mg/L	1.0	0.609	60.9	1.0	1.01	**101**
Selenium	mg/L	1.0	1.15	**115**	1.0	1.04	**104**
Uranium	mg/L	1.0	0.485	48.5	0.5	0.456	**91.2**

[a]Calculated desired concentration.
[b] Bold type indicates control concentration is within 15 percent of target concentration.
[c]NA = Constituent not added

Table 4–6. Control Solution Stability for Raffinate Ponds Area Samples, Round 1.

Listed are control solution compositions, which used water from well 0592, for Round 1. The mean concentrations are calculated from these data and are listed.

Analyte	Units	Target[a]	Round 1: Water from Well 0592					
			Control 1	% of Target	Control 2	% of Target	Control 3	% of Target
Cadmium	mg/L	1.0	0.945	**94.5** [b]	0.936	**93.6**	0.899	**89.9**
Lead	mg/L	1.0	0.0443	4.43	0.026	2.62	0.0076	0.76
Molybdenum	mg/L	1.0	0.633	63.3	0.595	59.5	0.604	60.4
Selenium	mg/L	1.0	0.451	45.1	0.736	73.6	1.10	**110**
Uranium	mg/L	1.0	0.0061	0.61	0.0061	0.61	0.0058	0.58

[a]Calculated desired concentration.
[b] Bold type indicates control concentration is within 15 percent of target concentration.

Table 4–7. Control Solution Stability for Raffinate Ponds Area Samples, Rounds 2 and 3

The control solution compositions of Round 2, which used water from well 0592, and of Round 3, which used synthetic ground water, are listed.

Analyte	Units	Round 2: Well 0592			Round 3: Synthetic		
		Target	Control	% of Target	Target [a]	Control	% of Target
Cadmium	mg/L	1.0	0.0084	0.84	0.5	0.358	71.6
Lead	mg/L	NA [c]	NA [c]	NA [c]	NA [c]	NA [c]	NA [c]
Molybdenum	mg/L	1.0	0.104	10.4	0.5	0.525	**105**
Selenium	mg/L	1.0	0.0038	0.38	1.0	1.150	**115**
Uranium	mg/L	0.5	0.465	**93** [b]	0.5	0.466	**93.2**

[a]Calculated desired concentration.
[b] Bold type indicates control concentration is within 15 percent of target concentration.
[c]NA = Constituent not added

4.5.3 Solution Stability of Lead

All control solutions created from surface and ground waters were unstable with regard to lead. Sufficient lead was added to produce a lead concentration of 1 mg/L. The measured concentration in the spiked Animas River sample, which was used to leach mill tailings area samples, was 0.151 mg/L. The concentration of lead in water from well 0592, which was used to leach raffinate ponds area samples, ranged from 0.0076 to 0.0443 mg/L. The low concentrations may be due to solubility constraints; lead may have reached its solubility limit in solution. For example, it is possible that interaction with sulfate in the water and/or interaction with iron in the water resulted in the precipitation of lead. If so, the filtration of the water prior to submitting the samples to the GJO Analytical Laboratory may have removed the lead from the water and produced the data results shown.

4.5.4 Solution Stability - Mill Tailings Area

Water collected from the Animas River was used to leach samples from the mill tailings area. Sample locations are shown in Figure 4–9. As listed in Table 4–5, the control solutions used in Round 1 of the R_d determinations were stable with regard to cadmium and selenium. A constituent is considered stable if the measured concentration in the control sample is within 15 percent of the target concentration. The stable constituents are shown in bold type. In Round 2, the solutions were stable with regard to cadmium, molybdenum, selenium, and uranium. The results obtained from stable constituent concentrations are used to determine the R_d values.

4.5.5 Solution Stability Raffinate Ponds Area

In Rounds 1 and 2, solid samples from the raffinate ponds area were leached with water from well 0592 (Figure 4–10). In Round 3, the samples were leached with laboratory prepared synthetic ground water. The pH and oxidation-reduction potential (ORP) of the water from well 0592 when it arrived at the ESL was 7.55 and –322 millivolts (mV), respectively, and it had a very strong sulfur odor. By the end of the Round 1 determinations, the pH was 7.00, the ORP was –135 mV, and the sulfur odor had decreased. These changes indicate a change in redox conditions in the water affected the stability of the control solutions. As a result, the final round of determinations, Round 3, were conducted using synthetic ground water to ensure stable redox conditions.

In Round 1, the constituent concentrations of the control solutions were measured for each batch of samples. For the raffinate ponds area, there are five control solutions and the constituent concentrations vary in each solution (Table 4–6). A constituent is considered stable if the measured concentration in the control sample is within 15 percent of the target concentration. The stable constituents are shown in bold type. Control 1 is the solution used with the first batch of samples, which comprised seven samples, and control 5 is the composition of the solution when used with the last batch of samples, which comprised four samples. The changes in cadmium and selenium concentrations from control solution 1 through control solution 5 indicate the influence of redox conditions on constituent concentrations. Cadmium concentrations decreased with each successive control solution, and selenium concentrations increased with each successive control solution. The control solution concentrations of Round 1 were stable with regard to cadmium in controls 1 through 3 and were stable with regard to selenium in controls 3 and 4.

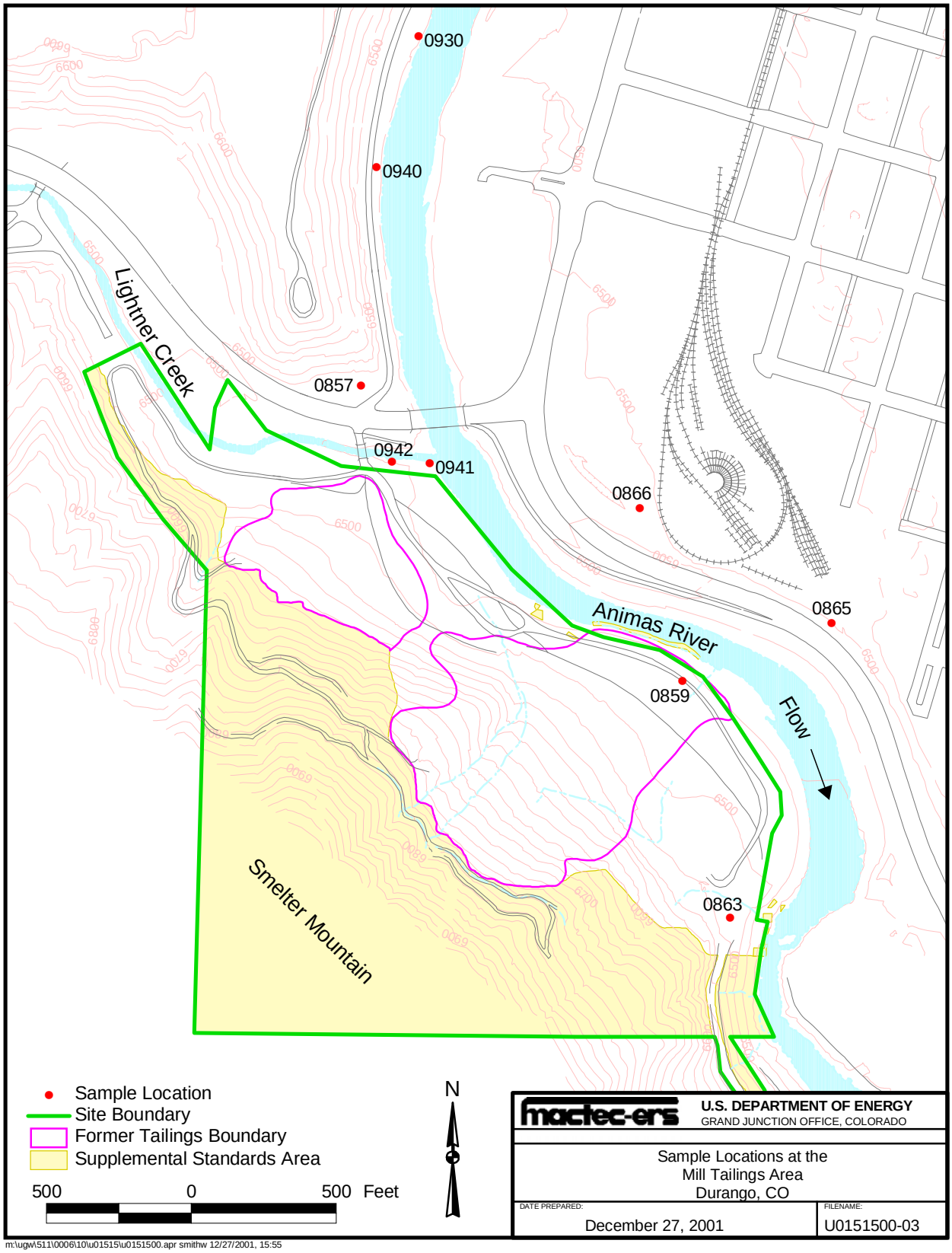

Figure 4–9. Distribution Coefficient Sample Locations at the Mill Tailings Area

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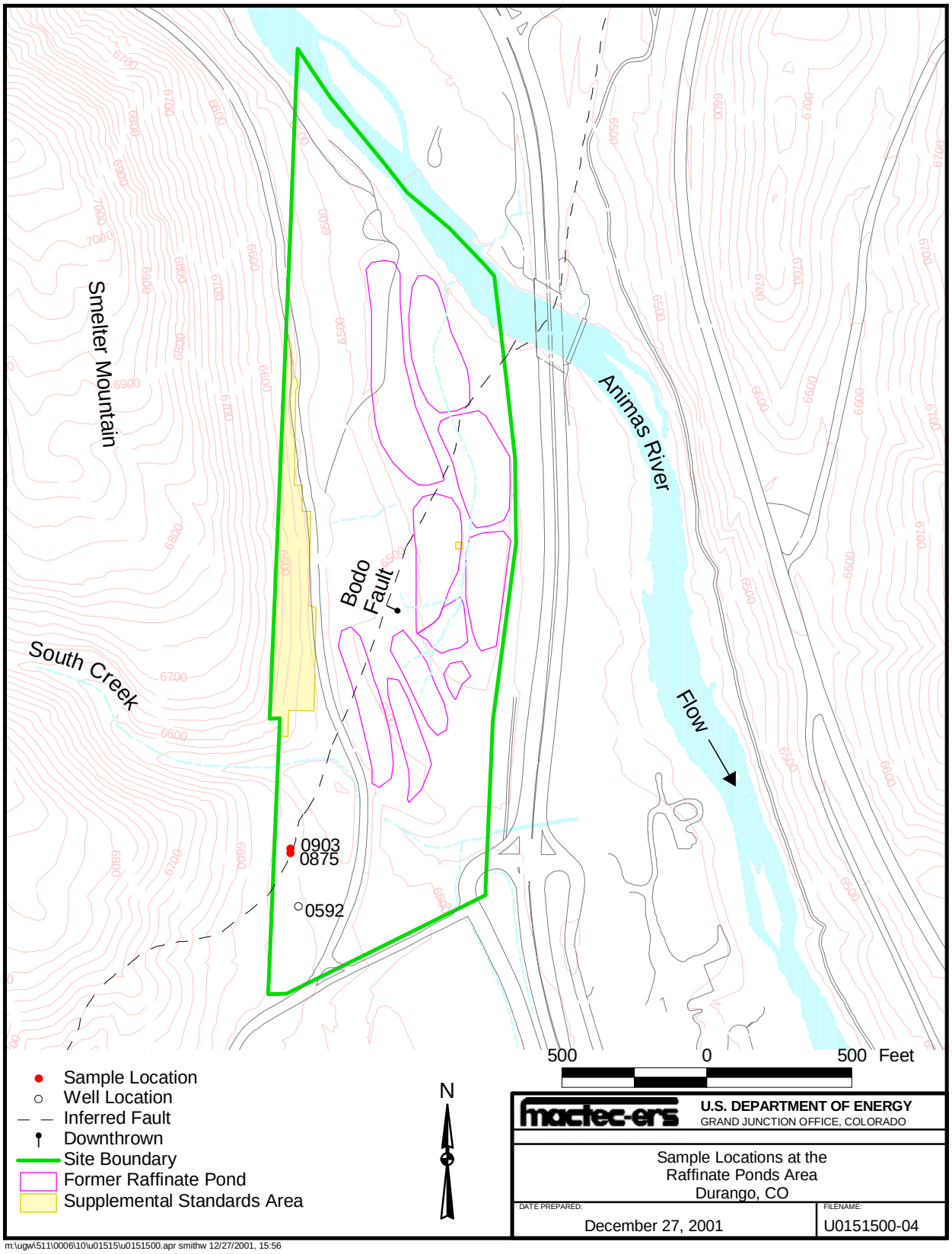

Figure 4–10. Distribution Coefficient Sample Locations at the Raffinate Ponds Area

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The data for the raffinate ponds area control solutions for Rounds 2 and 3 are listed in Table 4–7. In Round 2, the control solution was stable with regard to uranium. In Round 3, the synthetic ground water control solution was stable with regard to molybdenum, selenium, and uranium.

4.5.6 Results

Sample locations are shown in Figure 4–7. Results of the R_d determinations are listed in Table 4–8. The data obtained from using solutions stable with regard to cadmium, molybdenum, selenium, and uranium are included in Table 4–8. In the table, R_d data show the range of values for each constituent and each stratigraphic unit. In addition, R_d values obtained from graphing the results of Round 1 determinations are provided. In the column labeled "Data from graphs," each value derived from the graphs is the most linear of all the results with stable control solutions. The R_d values are compared to those measured at the Shiprock, New Mexico, UMTRA Project site.

Table 4–8. Results of R_d Determinations

Stratigraphic Unit	Analyte	R_d (mL/g)[a]				Data from graphs[b]		Comparison to Shiprock site[c]		
		Low	Mean	Median	High	R_d (mL/g)	Sample	Weathered	Unweathered	Floodplain
Durango Mill Tailings Area										
Mancos Shale	Cadmium	23.8	66.9	74.6	97.0	62.0	865–17 ft	214	132	
	Molybdenum	0.753	0.753	0.753	0.753					
	Selenium	15.5	23.1	23.6	26.0	24.3	865–17 ft	68	47	
	Uranium	3.90	3.90	3.90	3.90			1.13	1.97	
Quaternary alluvium	Cadmium	17.0	130	121	418	42	866–21 ft			23
	Molybdenum	0.190	1.90	1.28	6.21					
	Selenium	6.29	35.9	42.5	96.9	52.2	930–AL			11
	Uranium	0.685	4.21	2.89	10.0					2.15
Durango Raffinate Ponds Area										
Menefee Formation	Cadmium	8.36	82.8	64.7	292	8.86	875–64 ft			
	Molybdenum	-0.30	2.08	0.45	19.5					
	Selenium	2.98	35.9	23.4	104	22.8	903–53 ft			
	Uranium	0.30	1.44	1.14	5.20					
Point Lookout Sandstone	Cadmium	9.50	36.5	16.5	148	12	875–68 ft			
	Molybdenum	-0.34	0.07	0.15	0.39					
	Selenium	4.31	8.45	9.79	11.25					
	Uranium	0.00	1.59	1.88	2.35					

[a]The listed R_d values, in milliliters per gram (mL/g), have been adjusted for grain size, where appropriate.
[b]The R_d value is obtained from the most linear six-point isotherm stable control solution with regard to the constituent of interest.
[c]DOE 1999a

4.5.6.1 Mill Tailings Area: Mancos Shale Results

The cadmium R_d results range from 23.8 to 97.0 mL/g. The result of the six-point isotherm is 62.0 mL/g, which is near the mean R_d of 66.9 mL/g. The R_d values are less than those measured in Mancos Shale at the Shiprock, New Mexico, UMTRA site.

The R_d result from a control solution stable with regard to molybdenum is 0.753 mL/g. R_d values for molybdenum were not measured at the Shiprock site.

R_d values for selenium range from 15.5 to 26.0 mL/g. The result of the six-point isotherm is 24.3 mL/g, which is near the mean and median values of 23.1 and 23.6 mL/g, respectively. This highest R_d value of 26.0 mL/g is less than all values for the Shiprock site.

The R_d value from a control solution stable with regard to uranium is 3.90 mL/g. This value is higher than those at the Shiprock site, which were 1.13 mL/g in the weathered Mancos Shale and 1.97 mL/g in the unweathered Mancos Shale.

4.5.6.2 Mill Tailings Area: Quaternary Alluvium

R_d values for cadmium range from 17.0 to 418 mL/g. The result of the six-point isotherm is 42.0 mL/g, which is less than the mean and median values of 130 and 121 mL/g, respectively. The R_d value for cadmium in floodplain alluvium at the Shiprock site is 23 mL/g.

The R_d results for molybdenum range from 0.190 to 6.21 mL/g. Determination of R_d values for molybdenum was not performed at the Shiprock site.

R_d values for selenium range from 6.29 to 96.9 mL/g. The R_d result obtained from the six-point isotherm is 52.2 mL/g, which is greater than the mean R_d value of 35.9 mL/g and the median R_d value of 42.5 mL/g. The R_d value for selenium in floodplain alluvium at the Shiprock site is 11 mL/g.

The R_d results for uranium range from 0.685 to 10.0 mL/g. The mean R_d value is 4.21 mL/g and the median R_d value is 2.89 mL/g. In comparison, R_d values obtained for the Quaternary alluvium at other UMTRA Project sites range from 0.5 to 11.4 mL/g (Table 4–9). The R_d value of 11.4 mL/g was an alluvium sample collected from a depth of 30 ft at Gunnison, Colorado, UMTRA Project site that was leached with actual ground water. The R_d value from the Grand Junction, Colorado, site is 2.15 mL/g, at the New Rifle, Colorado, site the value is 0.7 mL/g, and at the Old Rifle site the R_d value is 0.5 mL/g.

4.5.6.3 Raffinate Ponds Area: Menefee Formation

The cadmium R_d results range from 8.36 to 292 mL/g. The mean R_d value is 82.8 mL/g, and the median R_d value is 64.7 mL/g. The result of the six-point isotherm is 8.86 mL/g, which is near the lowest R_d value. R_d values for molybdenum range from -0.30 to 19.5 mL/g. The mean R_d value is 2.08 mL/g, and the median R_d value is 0.45 mL/g. The R_d values for selenium range from 2.98 to 104 mL/g. The R_d result obtained from the six-point isotherm is 22.8 mL/g; this value is near the median R_d value of 23.4 mL/g. R_d values for uranium range from 0.30 to 5.20 mL/g. The mean R_d value is 1.44 mL/g, and the median R_d value is 1.14 mL/g.

4.5.6.4 Raffinate Ponds Area: Point Lookout Sandstone

The R_d values for cadmium range from 9.50 to 148 mL/g. The R_d result obtained from the six-point isotherm is 12 mL/g and is less than the median value of 16.5 mL/g and the mean value of 36.5 mL/g. R_d values for molybdenum range from –0.34 to 0.39 mL/g. The mean R_d value is 0.07 mL/g, and the median R_d value is 0.15 mL/g. R_d values for selenium range from 4.31 mL/g to 11.2 mL/g. The mean R_d value is 8.45 mL/g, and the median value is 9.79 mL/g. The R_d values of uranium range from 0.00 to 2.35 mL/g. The mean R_d value is 1.59 mL/g, and the median R_d value is 1.88 mL/g.

Table 4–9. Quaternary Alluvium Uranium R_d Values from Other UMTRA Project Sites

Site	Sample[a]	R_d (mL/g)	Report
Durango Mill Tailings Area		< 10	DOE 2001b
Grand Junction, Colorado		2.15	DOE 1999e
Gunnison, Colorado	AGW–30 ft[b]	11.4	DOE 2000a
Gunnison, Colorado	AGW–54 ft	4.73	DOE 2000a
Old Rifle, Colorado		0.5	DOE 1999d
New Rifle, Colorado		0.7	DOE 1999c
Shiprock, New Mexico		2.15	DOE 1999a

[a]A sample name is provided when there are R_d values for more than one sample. The value for the Durango Mill Tailings Area is a summary of all values.
[b]AGW is actual ground water and the sample collection depth is listed.

4.6 Water Sampling and Analysis

Each newly completed monitor well was left undisturbed for at least 48 hours before it was developed. Development was performed according to the *Drilling Statement of Work* (DOE 2000c). After the wells were properly developed, monitor wells and surface water locations were sampled during four separate events. Samples were collected during November/December 2000, March/April 2001, June 2001, and August 2001 to represent the range of conditions from periods of low to high river flow. Additional sampling of background monitor wells and surface water locations was performed during the first week of May 2001 and the last week of June 2001. All samples collected during these sampling events were submitted to the GJO Analytical Laboratory for analyses. The following sections describe the sampling and analysis procedures and results.

4.6.1 Water Sampling Procedures and Quality Assurance

Ground water and surface water sampling was performed in accordance with the *Sampling and Analysis Plan for the UMTRA Ground Water Project* (DOE 1999f) and procedures in the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998). The following procedures were used:

- GN–8(P), “Standard Practice for Sample Labeling”
- GN–9(P), “Standard Practice for Chain-of-Sample-Custody and Physical Security of Samples”
- GN–13(P), “Standard Practice for Equipment Decontamination”
- LQ–2(T), “Standard Test Method for the Measurement of Water Levels in Ground Water Monitor Wells”
- LQ–3(P), “Standard Practice for Purging Monitor Wells”
- LQ–4(T), “Standard Test Method for the Field Measurement of pH”
- LQ–5(T), “Standard Test Method for the Field Measurement of Specific Conductance”
- LQ–6(T), “Standard Test Method for the Field Measurement of the Oxidation-Reduction Potential (Eh)”
- LQ–7(T), “Standard Test Method for the Field Measurement of Alkalinity”
- LQ–8(T), “Standard Test Method for the Field Measurement of Temperature”
- LQ–9(T), “Standard Test Method for the Field Measurement of Dissolved Oxygen”

- LQ–10(T), “Standard Test Method for Turbidity in Water”
- LQ–11(P), “Standard Practice for Sampling Liquids”
- LQ–12(P), “Standard Practice for the Collection, Filtration, and Preservation of Liquid Samples”

Sample preservation consisted of storing the samples in an ice chest with ice to cool samples during field sampling, packaging, and shipping. Ground water and surface water samples were submitted to the GJO Analytical Laboratory. At least 10 percent of the samples collected and analyzed were field quality-control samples, which included equipment rinsate blanks and duplicates. These samples were submitted for the same analyses as other field samples.

Analyses of water samples submitted to the GJO Analytical Laboratory also were checked for accuracy through internal laboratory quality-control checks, such as blind duplicates, splits, and known standards as specified in relevant EPA guidelines or the *Handbook of Analytical and Sample Preparation Procedures,* Volumes I, II, and III (WASTREN, Inc., undated).

Final analytical results were entered into the SEE_PRO database, and an independent data validation assessment was performed on all results from each sampling event. Results of the ground water and surface water analyses are presented in Appendices D and E, respectively.

4.6.2 Ground Water Quality at the Mill Tailings Area

At the mill tailings area, samples were collected from the four alluvial background monitor wells 0629, 0658, 0857, and 0866 (Figure 4–11). Background location 0658 is an off-site privately owned domestic well. On-site samples were collected from ten locations: 0612, 0617, 0622, 0630, 0631, 0633, 0634, 0635, 0859, and 0863. Monitor well 0632 is completed in the Mancos Shale and is not sampled because it is dry. Surface water sampling results for the mill tailings area are presented in Section 4.6.4.

4.6.2.1 Background

Constituent concentrations in the new background wells (0857 and 0866) are within the range of concentrations from background wells 0629 and 0658 and support the 1995 BLRA assessment that two distinctly different water types and sources contribute to the ground water in the colluvium and gravel material at the mill tailings area. Selenium is the exception; selenium concentrations above the MCL (0.01 mg/L) have been detected in samples from the recently installed background wells; a maximum concentration of 0.011 mg/L was detected in well 0857, and a maximum concentration of 0.0148 mg/L was detected in well 0866.

It is expected that elevated selenium concentrations could occur naturally in wells not associated with the former uranium processing activities. Selenium is commonly found in high natural concentrations in the western United States. Most occurrences are related to Cretaceous sedimentary deposits (Seiler 1998), although elevated selenium levels are found in rocks from the Pennsylvanian to Quaternary in age (Stephens and others 1992). The river-laid sand and gravel deposits that compose both the mill tailings alluvium and the alluvium in the background locations occur over Mancos Shale bedrock. Concentrations, distribution, and sources of selenium in west-central Colorado have been studied extensively by the U.S. Geological Survey (USGS). The USGS found the highest concentrations of naturally occurring selenium (1.3 mg/L) were in shallow wells completed in alluvium overlying Mancos Shale (Wright and Butler 1993).

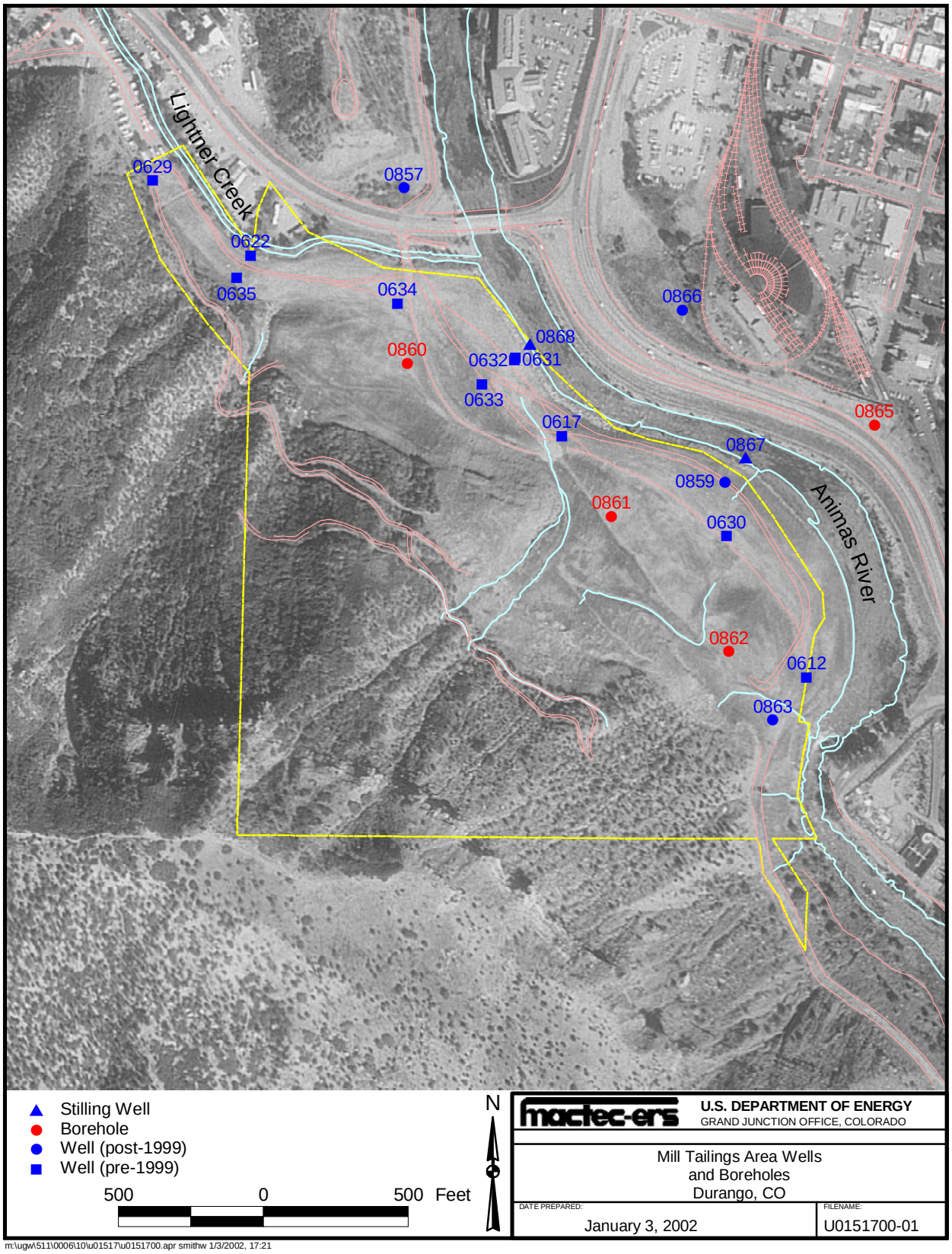

Figure 4–11. Mill Tailings Area Wells and Boreholes

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The key factors controlling mobilization of dissolved selenium are redox potential (measured as ORP) and pH (Masscheleyn and others 1990). At background well 0857 one selenium result (0.011 mg/L) exceeded the UMTRA standard of 0.01 mg/L. Because the pH did not change significantly, an increase in naturally occurring selenium in ground water would require an increase in the ORP. The elevated selenium concentration at this location occurred during the same period when the highest historical ORP and highest water levels were reported. The correlation between selenium concentrations, ORP, and water levels (Figure 4–12) demonstrates how naturally occurring selenium can be mobilized by oxidized water during periods of high flow. As the water table lowers, geochemical conditions become more reducing (by the action of naturally occurring microorganisms), which tends to remove selenium from solution in the ground water system (Butler and others 1994). Six samples have been collected from background well 0866 since November 2000, and selenium results from all of these samples (ranging from 0.0138 to 0.0148 mg/L) have exceeded the MCL. Selenium values and water levels in well 0866 do not show significant variation, and the ORP values are positive, reflecting oxidizing conditions.

4.6.2.2 Site-Related Contamination

Figure 4–13 through Figure 4–16 are spot plots of on-site and background alluvial wells showing concentrations of contaminants that exceed the MCL. These data are based on the sampling conducted in August 2001.

The primary sources of ground water contamination in the mill tailings area were the large and small tailings piles (Figure 4–17). Following completion of surface remediation, concentrations of arsenic, cadmium, lead, molybdenum, net alpha, radium-226+228, selenium, and uranium continued to exceed the MCL in on-site ground water. Results of ground water samples collected since November 2000 (four sampling events) show that arsenic, lead, and radium-226+228 are no longer detected in concentrations above the MCL, and net alpha has been detected only sporadically in a few wells. Locations where constituent levels still exceed the MCLs based on data from the August 2001 sampling event are presented in Table 4–10. As shown, concentrations of cadmium and molybdenum remain elevated in only one location (well 0612), and concentrations of selenium and uranium continue to exceed the standards in several locations.

In addition to the above constituents, antimony, manganese, sodium, sulfate, and vanadium were identified as COPCs in the BLRA (DOE 1995a). Since November 2000:

- All antimony results have been below the detection limit.
- With the exception of results from monitor wells 0612, 0630 and 0859, manganese results have been less than the maximum background ground water concentration of 1.05 mg/L. The highest concentration at well 0612 was 5.4 mg/L. The highest concentration at well 0630 was 2.68 mg/L. The highest concentration at well 0859 was 1.5 mg/L; however, the most recent value at well 0859 of 0.803 mg/L is below the background maximum of 1.05 mg/L.
- The highest concentration of sodium (765 mg/L) occurred in monitor well 0612.
- The highest concentration of sulfate (3,510 mg/L in August 2001) occurred in monitor well 0633. Monitor well 0633 is completed in the Mancos Shale, which commonly has ground water with elevated levels of sulfate.
- With the exception of one result of 0.0109 mg/L from well 0631, the only concentrations of vanadium above the detection limit occur in monitor wells 0612 and 0630; the highest (0.448 mg/L) is in well 0612.

Table 4–10. Ground Water Constituents with Concentrations that exceed the UMTRA Standards in August 2001 at the Durango Mill Tailings Area

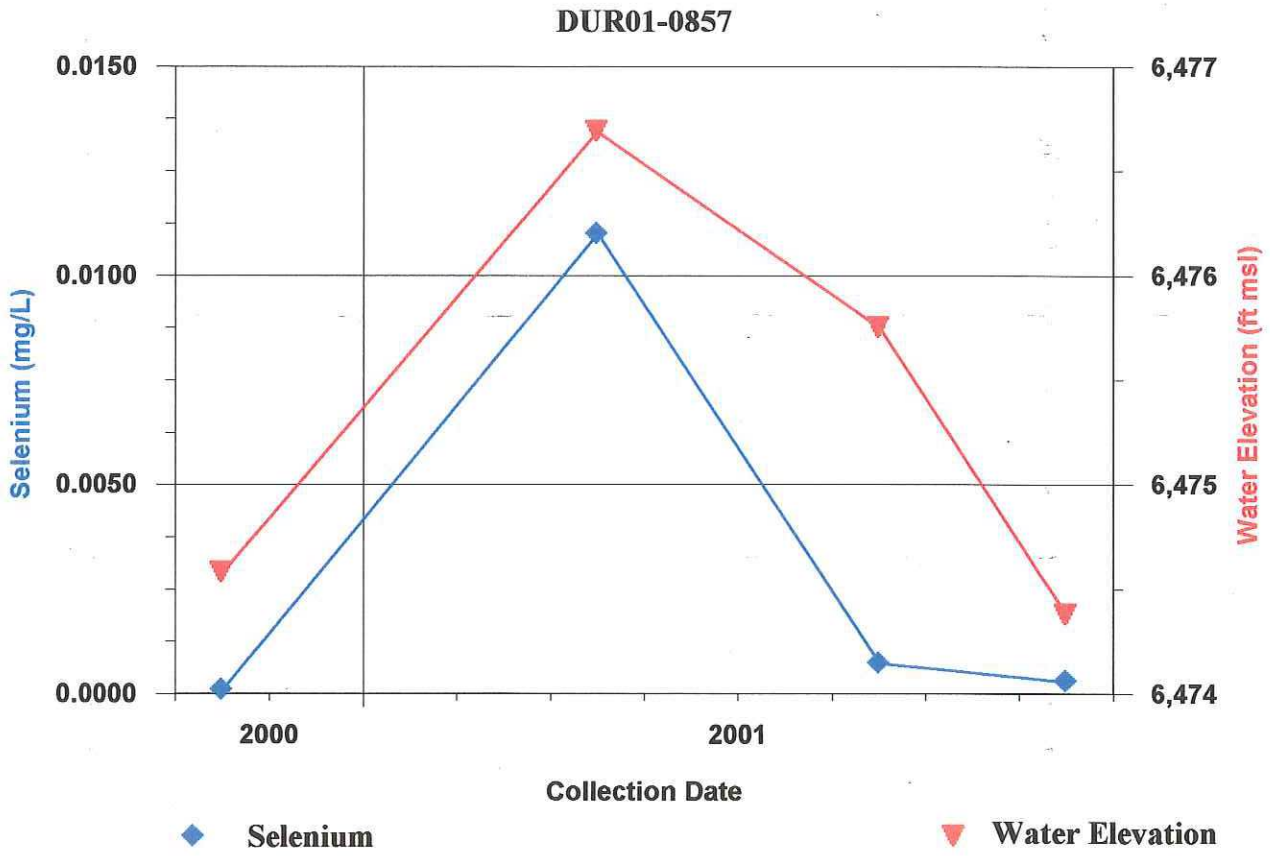
Analyte	UMTRA Standard (mg/L)	Location (well)	Concentration in August 2001 (mg/L)
Cadmium	0.01	0612	0.0369
Molybdenum	0.1	0612	0.1160
Selenium	0.01	0617	0.0501
Selenium	0.01	0633	0.0445
Selenium	0.01	0635	0.0155
Selenium	0.01	0866 Background	0.0148
Uranium	0.044	0612	1.970
Uranium	0.044	0617	0.211
Uranium	0.044	0630	0.203
Uranium	0.044	0631	0.344
Uranium	0.044	0633	1.270
Uranium	0.044	0634	0.0585

Historically, monitor well 0612 has consistently shown the highest levels of contamination. This well is completed through the slag pile from the old lead smelter that remained in place following surface remediation. The slag in this area is 20 to 30 ft thick, and the occurrence of cadmium, molybdenum, and uranium (Table 4–10) in this well is believed to be associated with the alluvial material below the slag that remained in place following surface remediation. The Final Completion Report for the surface remediation project (DOE 1994b, Appendix K) documented that a thin lens of uranium precipitate identified below the slag was thought to be a result of an old spill on the slag pile that was slowly leaching through the slag. The material under the slag was sampled along the riverbank during surface remediation, and the volume-averaged concentrations were below NRC's unrestricted disposal guidelines (DOE 1994b, Appendix K). However, due to difficulties with excavating and drilling in the slag, the extent of potentially contaminated material beneath the slag was not fully characterized. Figure 4–18 shows the location of well 0612 and the slag pile as it was exposed during surface remediation.

Although some of the selenium concentrations at the mill tailings area may be a result of former processing activities, elevated concentrations can also be attributed to naturally occurring selenium, as evidenced by the concentrations above the MCL in background wells (Section 4.6.2.1).

4.6.3 Ground Water Quality at the Raffinate Ponds Area

At the raffinate ponds area, samples were collected from background bedrock well locations 0592, 0599, 0875, 0886, and 0903 (Figure 4–19). Eighteen on-site wells and seven off-site downgradient wells were sampled. Monitor wells 0891, 0893, and 0905 were not routinely sampled because these wells are either dry or purge dry and do not recover. Surface water sampling results for the raffinate ponds area is presented in Section 4.6.4.



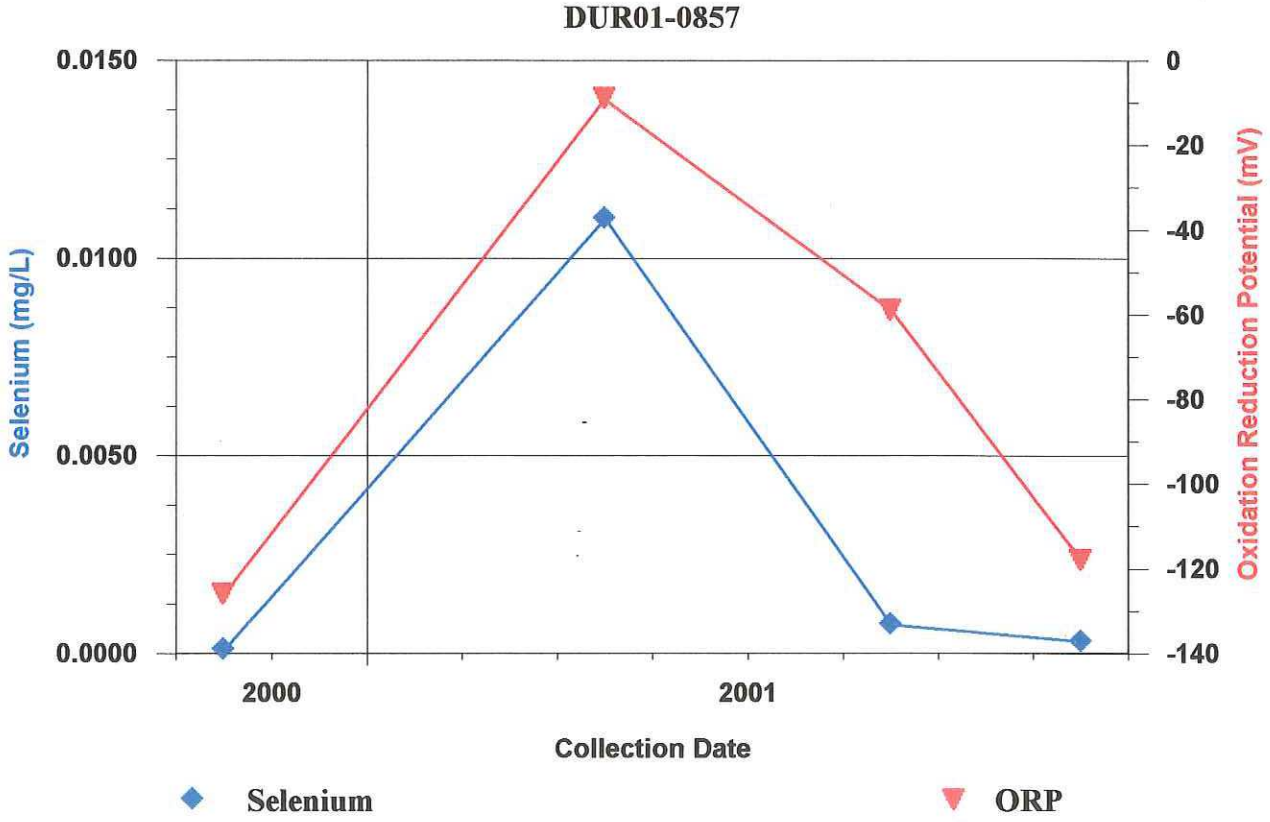


Figure 4–12. Selenium, ORP, and Water Levels at Durango Mill Tailings Area Background Well 857

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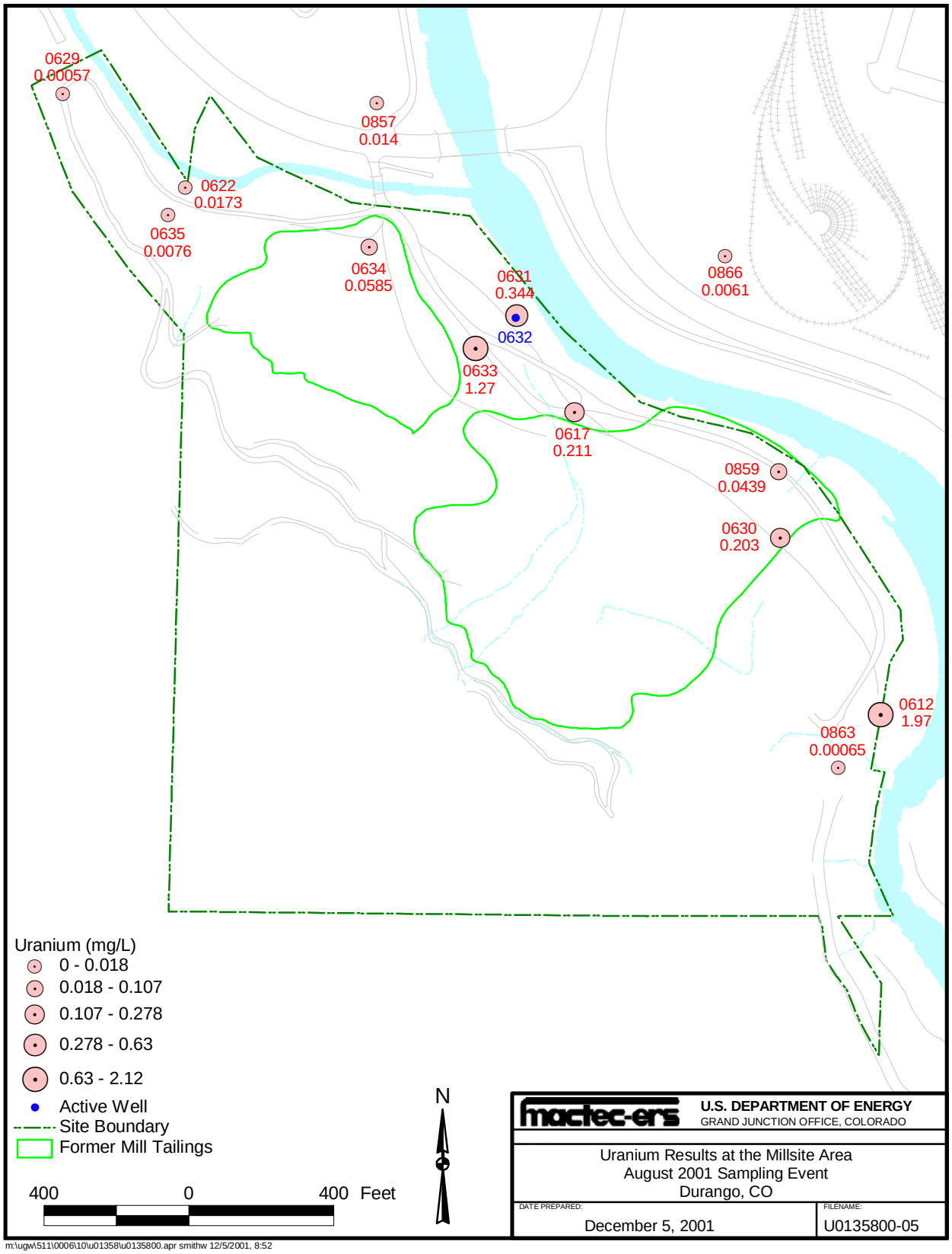

Figure 4–13. Uranium Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

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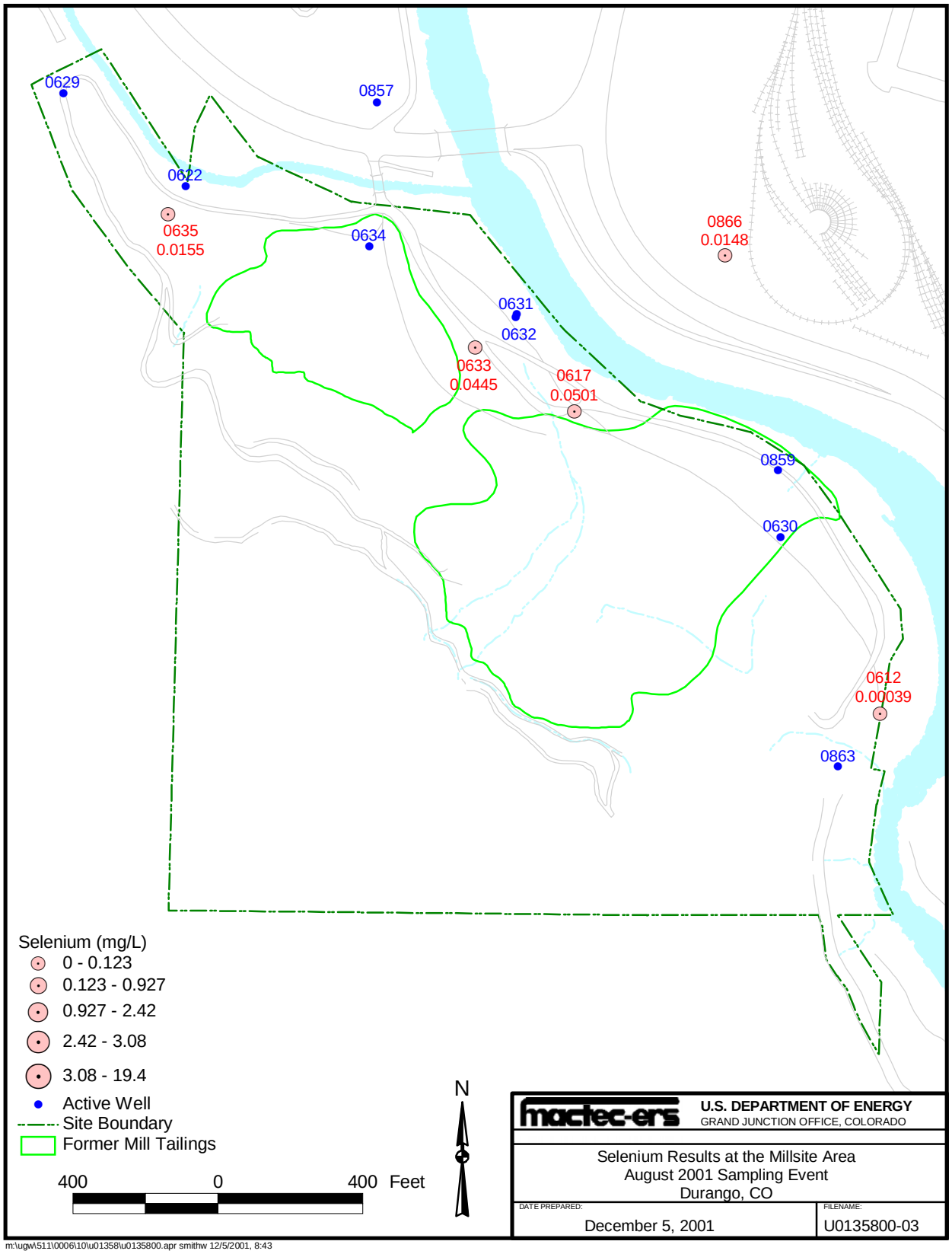

Figure 4–14. Selenium Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

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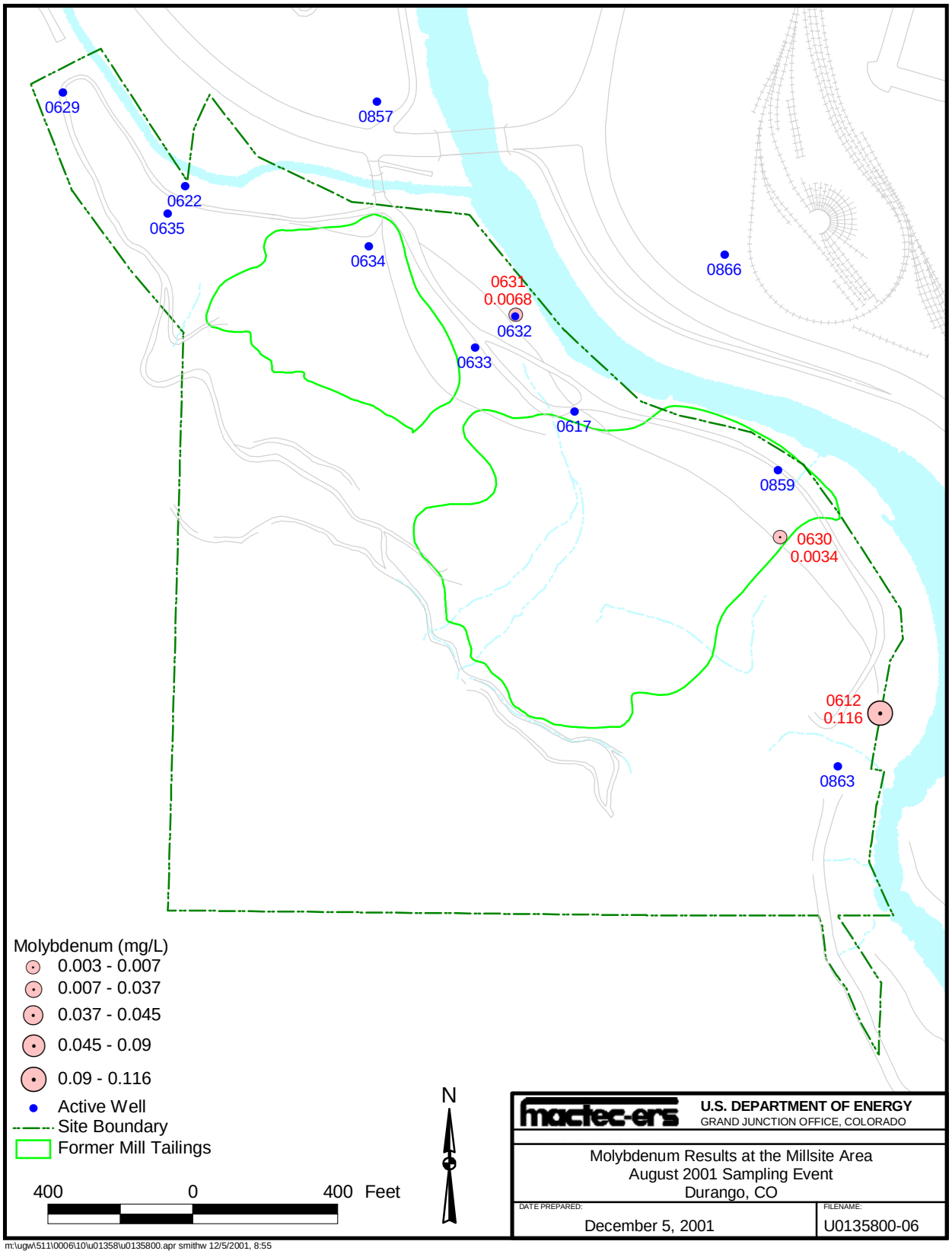

Figure 4–15. Molybdenum Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

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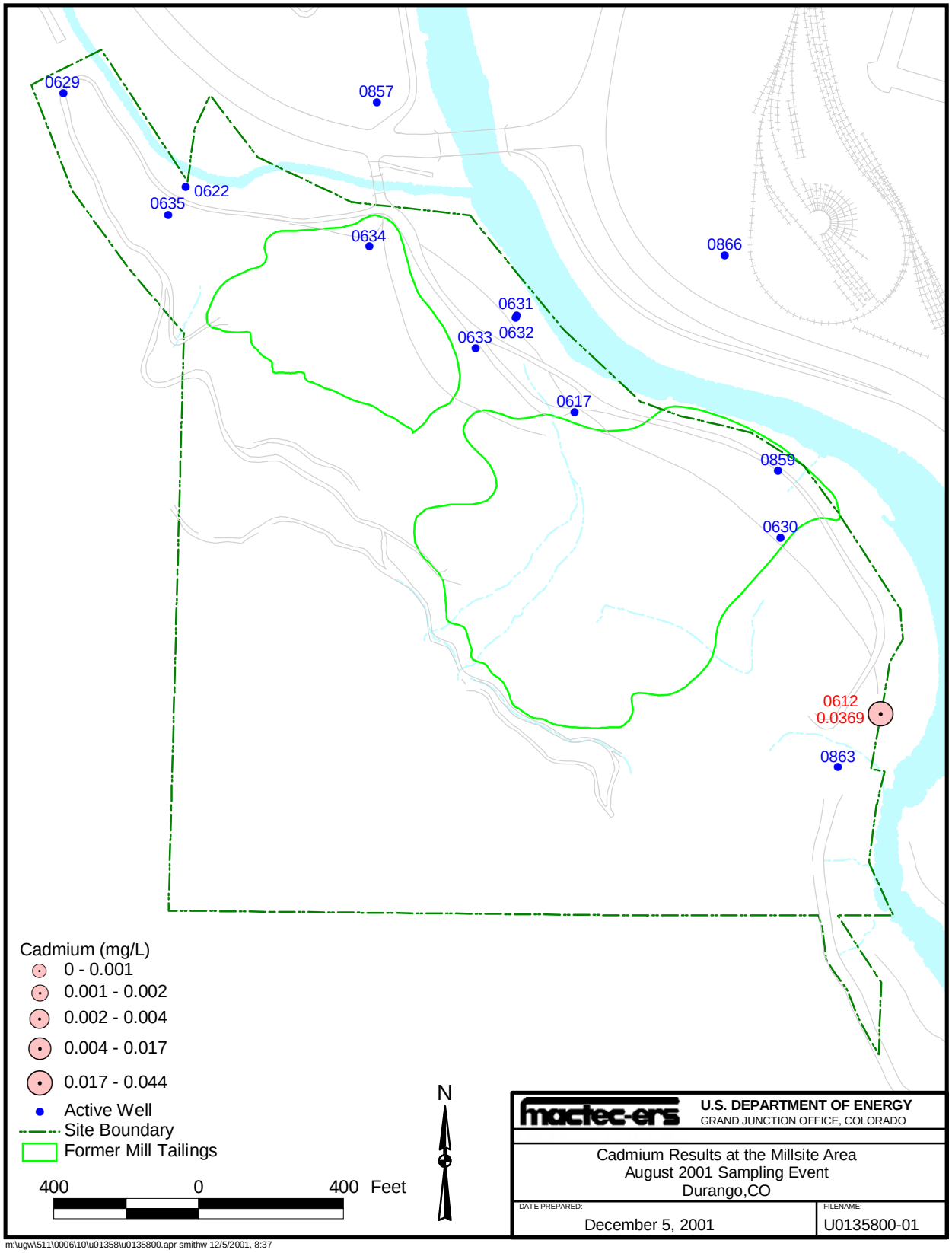

Figure 4–16. Cadmium Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

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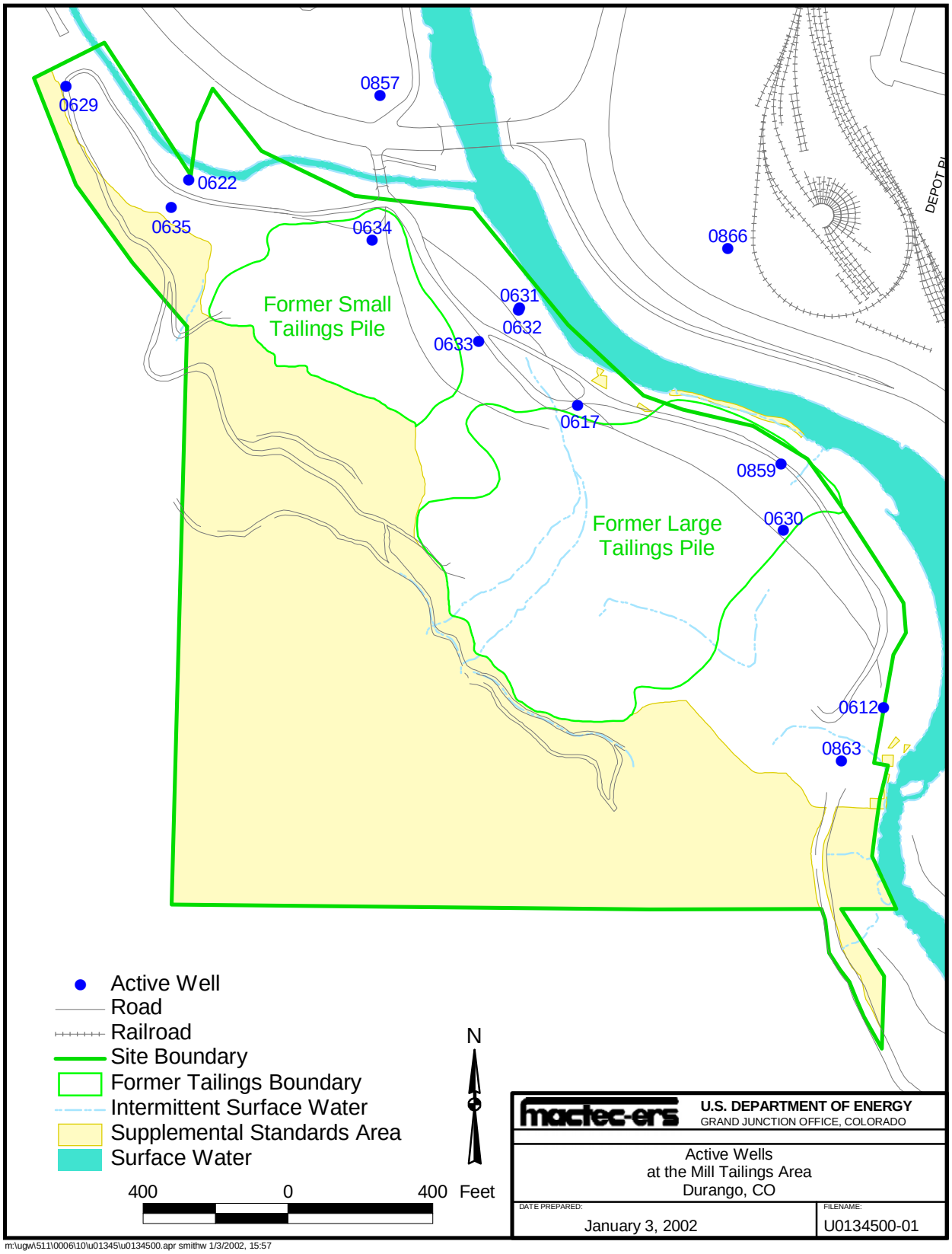

Figure 4–17. Active Wells at the Mill Tailings Area

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Figure 4–18. Occurrence of Lead Smelter Slag and Well 0612 Location at the Mill Tailings Area

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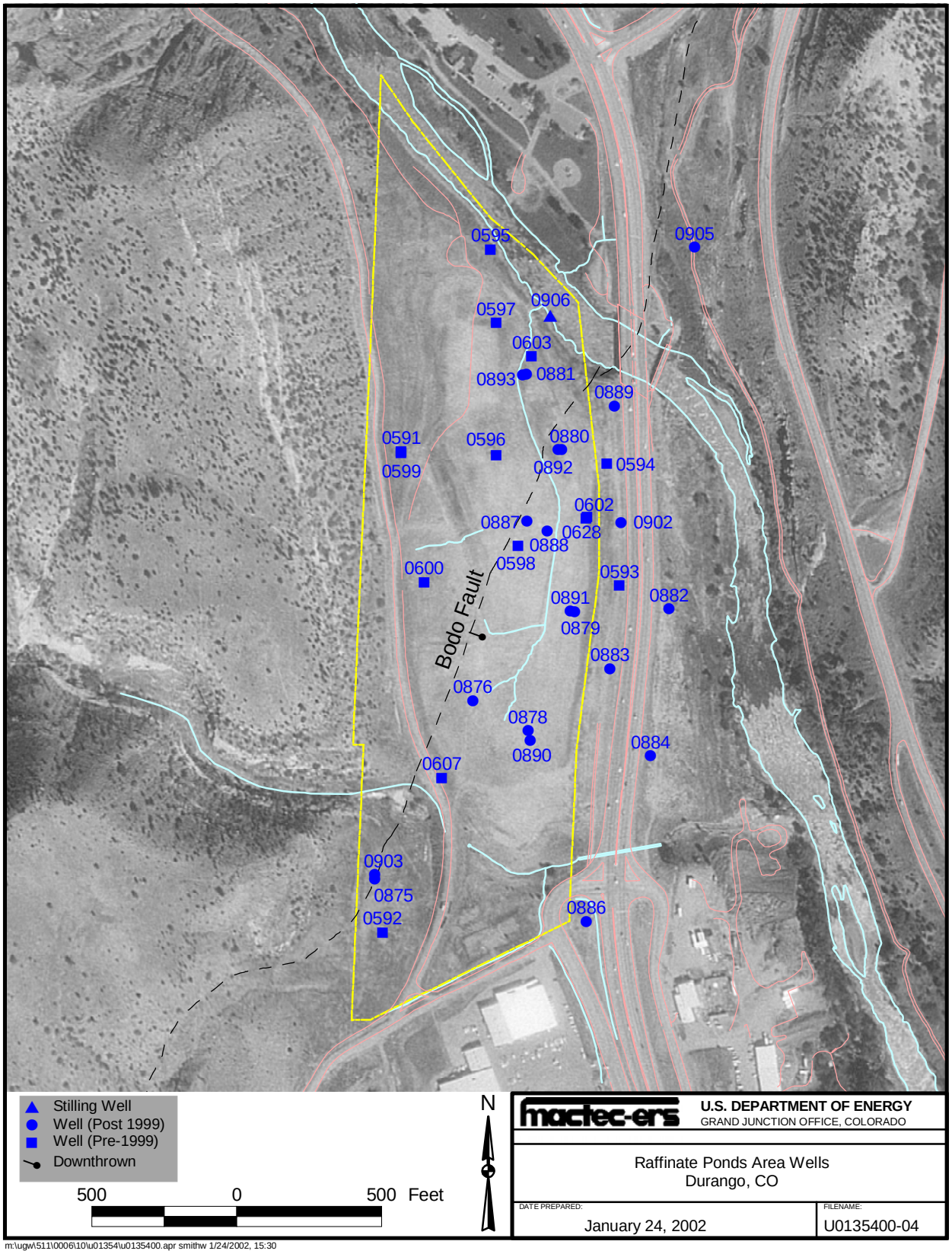

Figure 4–19. Raffinate Ponds Area Wells

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4.6.3.1 Background

Prior to the field investigation, background water quality data for the raffinate ponds area was available from monitor well (0592) in the far southwest corner of the site and upgradient of the raffinate ponds area, and monitor well 0599 west of the former raffinate ponds (Figure 4–20). This well is screened across the Menefee Formation, Point Lookout Sandstone, and the Bodo Fault zone. A comparison of the water quality from this well to regional water quality in the Mesaverde Group indicates that ground water from well 0592 is within the range of regional ground water quality for all measured constituents (DOE 1995a). However, because the water from this well has a strong hydrogen sulfide odor and black discoloration, additional samples for sulfide were collected in November 2001.

Three additional wells were installed for determining background water quality as part of the field investigation and have been routinely sampled since November 2000. All of these wells are in areas unaffected by surface remediation and the former processing facility. Two of these monitor wells are near monitor well 0592 in the far southwest corner of the site. Well 0903 is completed in the Menefee Formation, and well 0875 is completed in the Point Lookout Sandstone. Well 0886 is completed in the Cliff House Sandstone outside the southeast corner of the site. A comparison of background water quality at these locations is presented in Section 5.3.1.

Background monitor well 0599 is completed in the Point Lookout Sandstone and, with the exception of selenium, the concentrations of constituents in well 0599 are comparable to concentrations in the other background well (0875) completed in the Point Lookout Sandstone. Selenium concentrations in background well 0599 ranged from 0.062 to 0.087 mg/L; all other constituents associated with the milling operations (arsenic, molybdenum, uranium, and vanadium) have had concentrations below the MCL at this location.

Selenium

Not unlike the mill tailings area, elevated selenium concentrations in background locations at the raffinate ponds area are not unexpected. Selenium concentrates in the pyrite-rich marine shales and sedimentary rocks of Late Cretaceous age (USGS 1999), which underlie the raffinate ponds area. In addition to the carbonaceous shales, numerous coal deposits are within the vicinity of the raffinate ponds area (Plate 3). Selenium concentrations in various coals are 10 to 20 times higher than the levels estimated for the earth’s crust (Oldfield 1974). EPA and others reported selenium concentrations in coals of the United States in concentrations ranging from 0.4 to 10.65 mg/kg with an average concentration of 3.3 mg/kg (Oldfield 1974). Elevated selenium concentrations are not detected in background monitor wells locations, other than well 0599 at the raffinate ponds area. However, the ORP values are negative at the other background locations, indicating strongly reducing conditions. Therefore, even though selenium may be present in source rock, the geochemical conditions prevent it from being mobilized into the ground water in significant quantities at other background locations. Selenium at the raffinate ponds area is discussed in further detail in Section 5.4.

Sulfide

During the purging and sampling of wells, the field team noted the water had a black discoloration and an odor indicating the presence of hydrogen sulfide gas, most notably in background well 0592. Hydrogen sulfide gas is produced by the oxidation of organic matter through sulfide reduction. Sulfide sampling of selected wells was conducted in November 2001.

Samples were collected for analysis at the GJO Analytical Laboratory, and duplicate samples were analyzed on site.

Analyses of samples on site were performed using a colorimetric method (approved by EPA for waste water). Duplicate samples were analyzed in the field to achieve a lower detection limit (see Section 5.3.1.6). The detection limit for the Analytical Laboratory method is 1.0 mg/L, and the detection limit for the colorimetric field method is 0.01 mg/L. The lower detection limit was necessary because the risk-based default value for hydrogen sulfide as a contaminant in drinking water is 0.11 mg/L.

The concentration of sulfide in background well 0592 was 45.9 mg/L. Sulfide was also detected in background wells 0599 (0.02 mg/L), 0875 (0.1 mg/L), and 0886 (0.5 mg/L). Sulfide was not detected in well 0884. Although this was a limited sample set of data from background wells, the strong odor and black discoloration occur at many locations on site. It was also reported in the original BLRA (DOE 1995a) that when an attempt was made to collect a sample from the downgradient well nearest the site (0.2 mile), it was found to no longer be in use because of black discoloration of the water. The *Preliminary Hydrogeochemical Characterization of the Durango, Colorado, Tailings and Raffinate Ponds Areas* (DOE 1983) also reported the strong presence of hydrogen sulfide during the drilling of well 0601.

4.6.3.2 Site-Related Contamination

Before surface remediation was completed, ground water in the area of the raffinate ponds occurred in both the surficial deposits and the bedrock. At present, ground water in the raffinate ponds area occurs primarily in the bedrock units. The primary sources of ground water contamination at the raffinate ponds area were the spent raffinate liquids from the milling process that were pumped into a ditch and carried to the settling ponds (Figure 4–20) at the raffinate ponds area. There, the raffinate was disposed of through evaporation and seepage.

Since completion of surface remediation, uranium and selenium are the only constituents with concentrations that have consistently exceeded the UMTRA Project standards at the raffinate ponds area. Net alpha has been detected sporadically in only a few wells. The highest concentrations of selenium and uranium are detected in the central portion of the site east of the Bodo Fault, in the shallow wells screened in the Menefee Formation. Outside this central plume area, selenium concentrations above the MCL are also detected in wells 0607 and 0884; and uranium concentrations above the MCL are also detected in wells 0598 and 0884. With the exception of well 0628 (see Section 4.1.2), locations where constituent concentrations exceed the UMTRA Project standards, based on data from the sampling in August 2001, are presented in Table 4–11.

Figure 4–21 and Figure 4–22 are spot plots of on-site and downgradient bedrock well locations showing concentrations of selenium and uranium based on the sampling conducted in August 2001. As shown, uranium above the MCL occurs at well 0598, which is completed in the Bodo Fault zone. However, uranium concentrations in adjacent wells 0887 and 0888 are below background concentrations. Monitor well 0887 is completed in the Point Lookout Sandstone and screened at the same depth as well 0598. Monitor well 0888 is completed in the Bodo Fault zone and screened approximately 40 ft below the screened depth of well 0598 in the Bodo Fault. At monitor well 0598 (Figure 4–23) the concentration of uranium has been steadily decreasing since remediation was completed in 1991 and is nearing the MCL of 0.044 mg/L. Figure 4–23 and Figure 4–24 are time-concentration plots of uranium results at the raffinate ponds area.

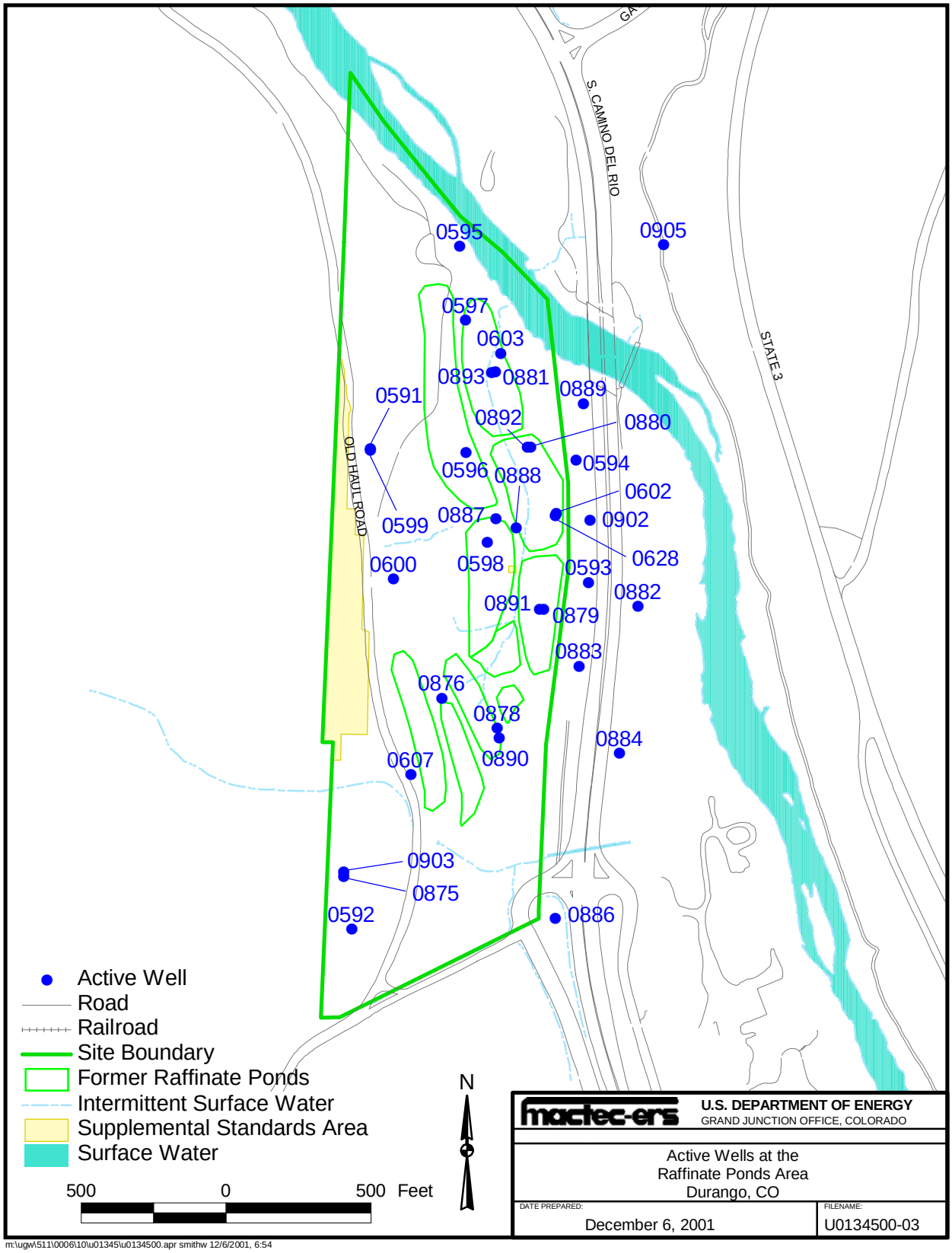

Figure 4–20. Active Wells at the Raffinate Ponds Area

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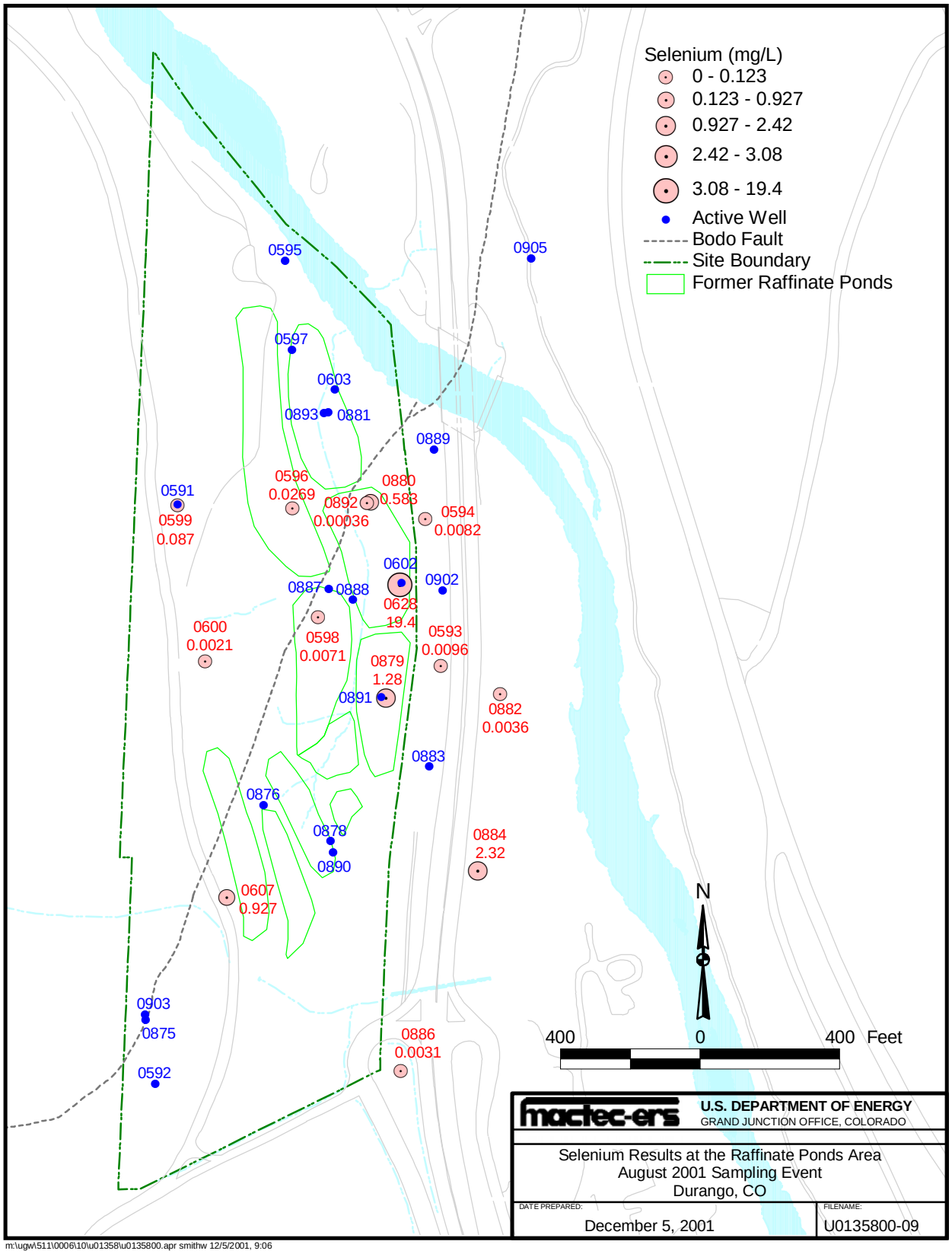

Figure 4–21. Selenium Concentrations in Ground Water at the Raffinate Ponds Area, August 2001

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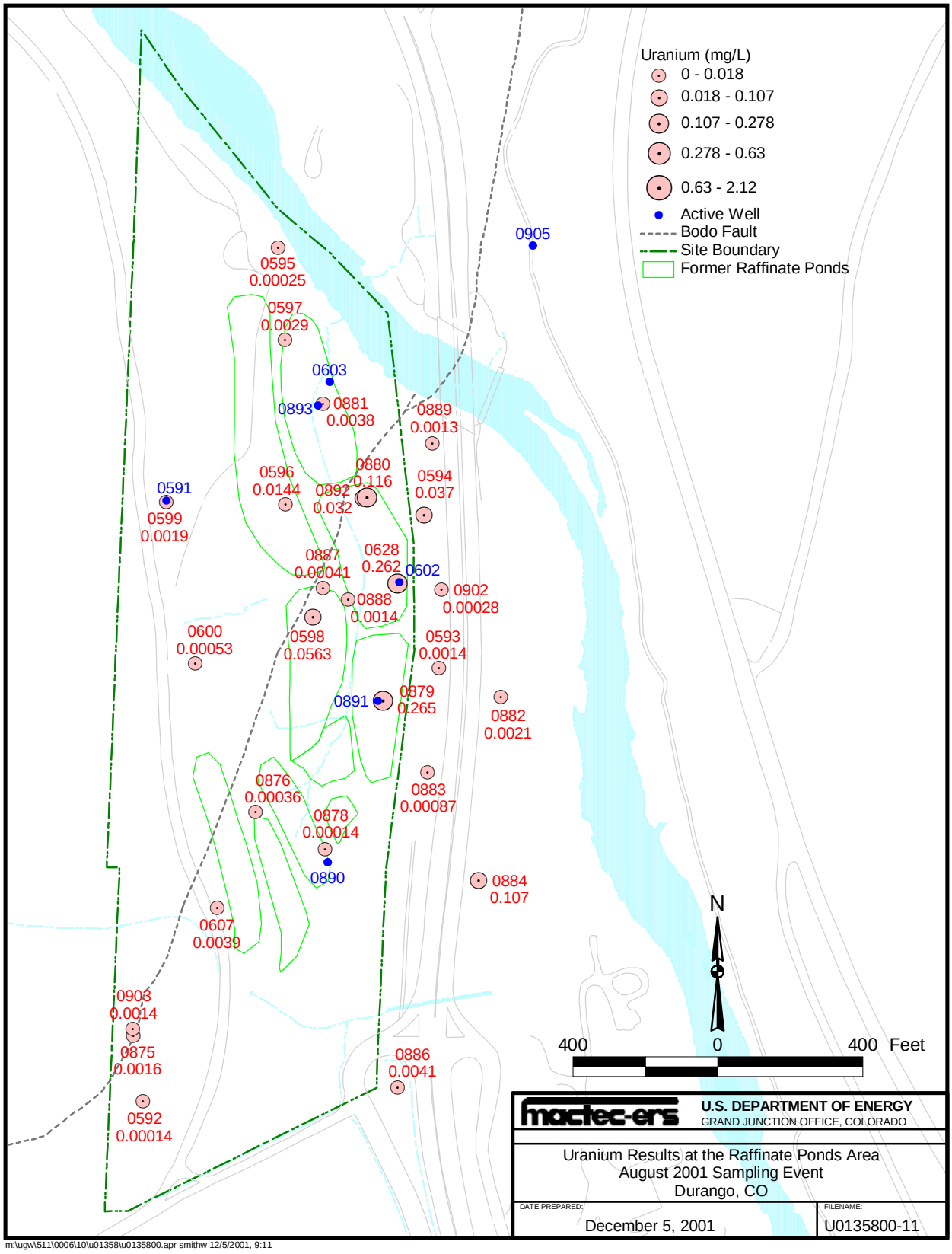

Figure 4–22. Uranium Concentrations in Ground Water at the Raffinate Ponds Area, August 2001

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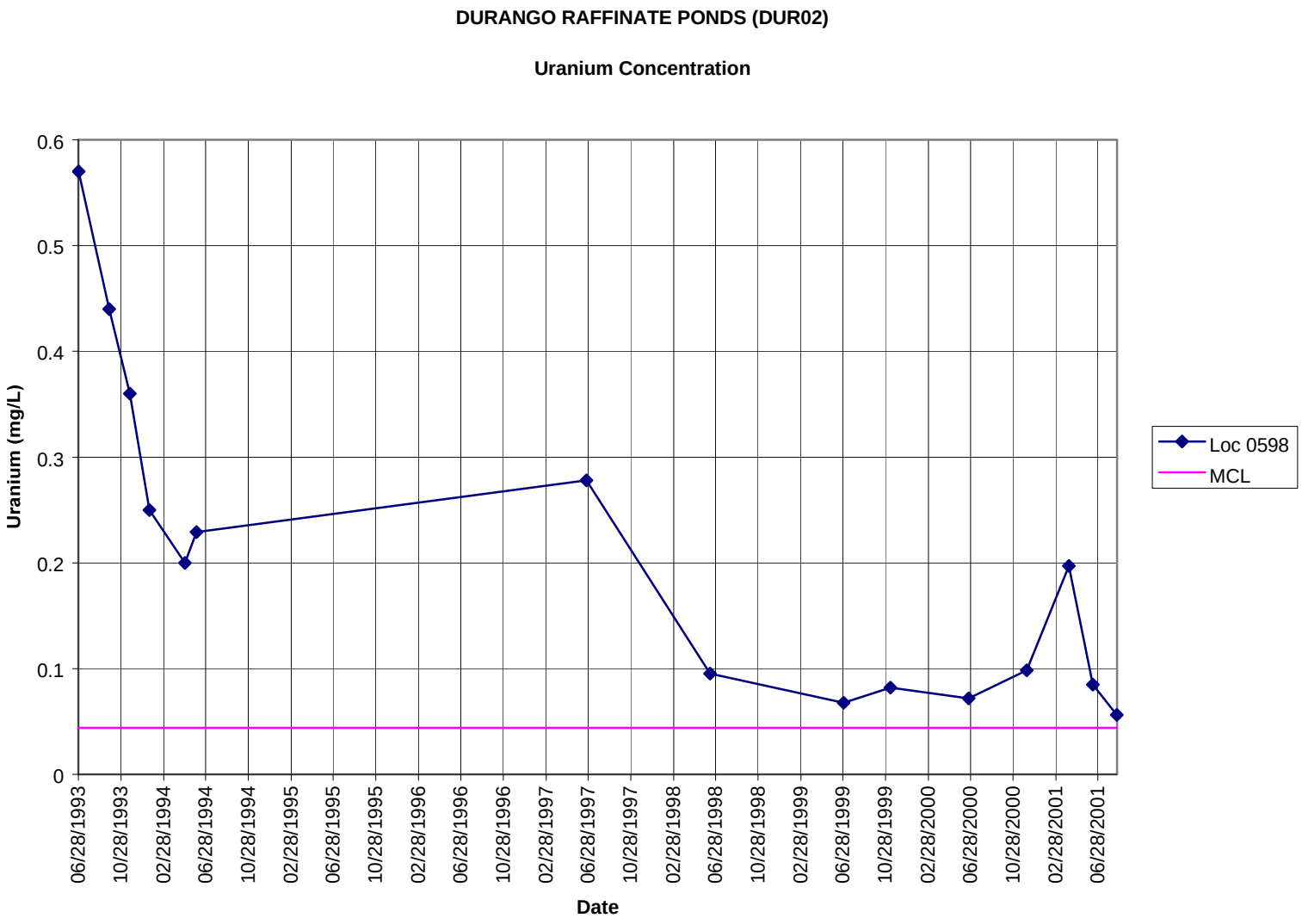

Figure 4–23. Uranium Concentration In Fault Well 598 at the Durango Raffinate Ponds Area

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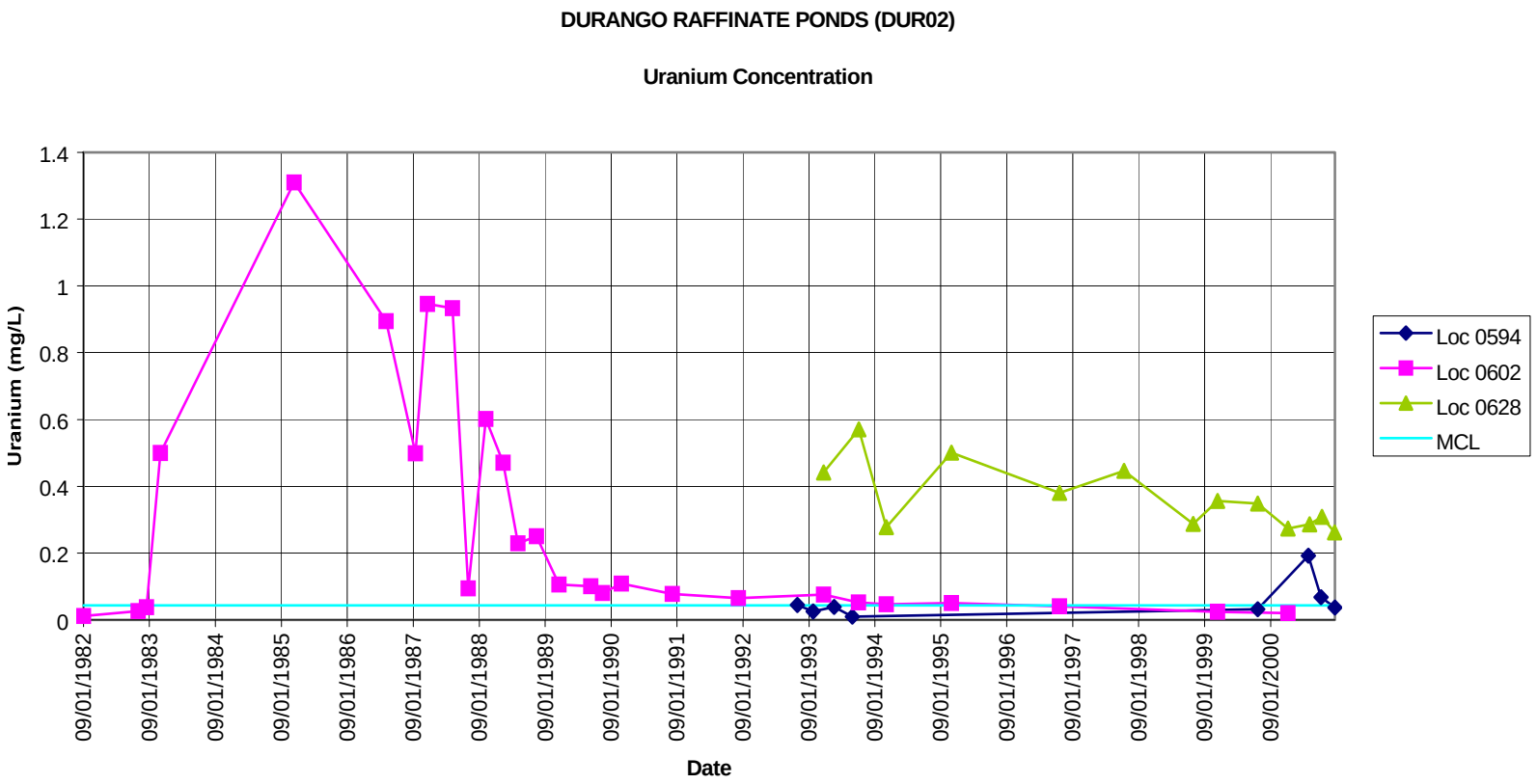

Figure 4–24. Uranium Concentration at the Durango Raffinate Ponds (DUR02)

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Table 4–11. Constituents with Concentrations That Exceeded the UMTRA Ground Water Standards in August 2001 at the Durango Raffinate Ponds Area

Analyte	UMTRA Standard (mg/L)	Location[a] (well)	Concentration in August 2001 (mg/L)
Selenium	0.01	0596	0.0269
Selenium	0.01	0598	0.010
Selenium	0.01	0599[b]	0.087
Selenium	0.01	0607	0.927
Selenium	0.01	0879	1.280
Selenium	0.01	0880	0.583
Selenium	0.01	0884	2.320
Uranium	0.044	0598	0.0563
Uranium	0.044	0879	0.265
Uranium	0.044	0880	0.116
Uranium	0.044	0884	0.107

[a]Monitor well 628 is not included because the results are not considered to be valid (see Section 4.1.2).
[b] Monitor well 0599 is a background location.

With the exception of well 0598 in the Bodo Fault, all locations where uranium concentrations continue to exceed the MCL are completed at depths of 50 ft or less. Uranium above the MCL occurs in new monitor wells 0879, 0880, 0884, and in monitor well 0628. Immediately following remediation, uranium concentrations in monitor wells 0594 and 0602 consistently exceeded the MCL. However, results from the August 2001 sampling are below the MCL at both locations (0.037 mg/L and 0.0203 mg/L, respectively), as shown in Figure 4–24.

Concentrations of both selenium (2.32 mg/L) and uranium (0.107 mg/L) are above the MCLs at off-site well 0884, these elevated concentrations are isolated from the central on-site plume area. Monitor well 0884 is cross-gradient to downgradient from the former raffinate ponds (Figure 4–20), and between this well and the central plume area are monitor wells 0882, 0883, 0878, and 0890. Sample results have not shown any elevated concentrations of selenium or uranium in any of these in-between wells. Well 0884 is screened predominantly within a coal bed, and the fact that the well is isolated from the central on-site plume area suggests naturally occurring coal deposits may be a source of the elevated concentrations. In addition to selenium (see Section 5.4), various coal deposits have been well documented as containing high concentrations of uranium (IAEA 1974). No occurrences of other mill-related constituents (arsenic, cadmium, molybdenum, or vanadium) have concentrations exceeding MCLs at well 0884.

In addition to selenium and uranium, constituents identified as COPCs in the BLRA (DOE 1995a) included antimony, arsenic, cadmium, chloride, lead, manganese, molybdenum, sodium, sulfate, and thallium. Of these:

- Antimony concentrations have not exceeded the contract required detection limit (CRDL) at any location since 1995.
- Thallium concentrations have not exceeded the instrument detection limit (IDL) at any location since 1995.

- Arsenic, cadmium, lead, and molybdenum concentrations have not exceeded the MCLs at any location since 1995.
- Chloride concentrations have decreased (in wells that existed prior to 2000) from historical maximum concentrations. The highest chloride result from the sampling in August 2001 was 1,520 mg/L at well 0883.
- Manganese concentrations do not indicate any clear trends, either increasing or decreasing. The highest manganese result from the August 2001 sampling was 6.5 mg/L at well 0593.
- Sodium concentrations have decreased (in wells that existed prior to 2000) from historical maximum concentrations. The highest sodium result from the August 2001 sampling was 3,140 mg/L at well 0593.
- Sulfate concentrations have decreased (in wells that existed prior to 2000) from historical maximum concentrations. The most dramatic decrease in sulfate concentration has occurred at well 0602, where concentrations have decreased from a high of 17,000 mg/L (highest at the raffinate ponds area) in 1985 to a concentration of 4,570 mg/L during the sampling in August 2001.

4.6.4 Surface Water Quality

At the mill tailings area, surface water was sampled along Lightner Creek from two locations upgradient of the site (0506 and 0650) and from one location adjacent to the site (0651). The Animas River was sampled at two upgradient locations (0515 and 0652), at four locations adjacent to the site (0583, 0584, 0690 and 0691), and at one downgradient location (0586). Surface water sample locations are shown in Figure 4–25.

Manganese is the only constituent identified as a COPC for the mill tailings area in the BLRA (DOE 1995a) that was detected in concentrations statistically elevated above background concentrations (95 percent upper confidence limit [UCL_{95}]). Manganese concentrations exceeded the UCL_{95} sporadically during two sampling events; the maximum concentration was 0.158 mg/L at location 0583 during low-flow (November 2000). No manganese concentrations were greater than the maximum observed background value of 0.205 mg/L.

At the raffinate ponds area, surface water was sampled along South Creek, from one location upgradient of the site (0588). The Animas River was sampled at two locations adjacent to the site (0656 and 0657), and at one downgradient location (0654). Because of the proximity of the mill tailings area to the raffinate ponds area, the Animas River sample locations 0515 and 0652 were used to establish background for both sites. Raffinate ponds area surface water sample locations are shown in Figure 4–26.

Manganese was the only COPC identified for the raffinate ponds area that was detected in concentrations statistically elevated above background concentrations (UCL_{95}). Manganese concentrations exceeded the UCL_{95} sporadically during three sampling events; the maximum concentration was 0.139 mg/L at location 0657 during low-flow (November 2000). No manganese concentrations were greater than the maximum observed background value of 0.205 mg/L.

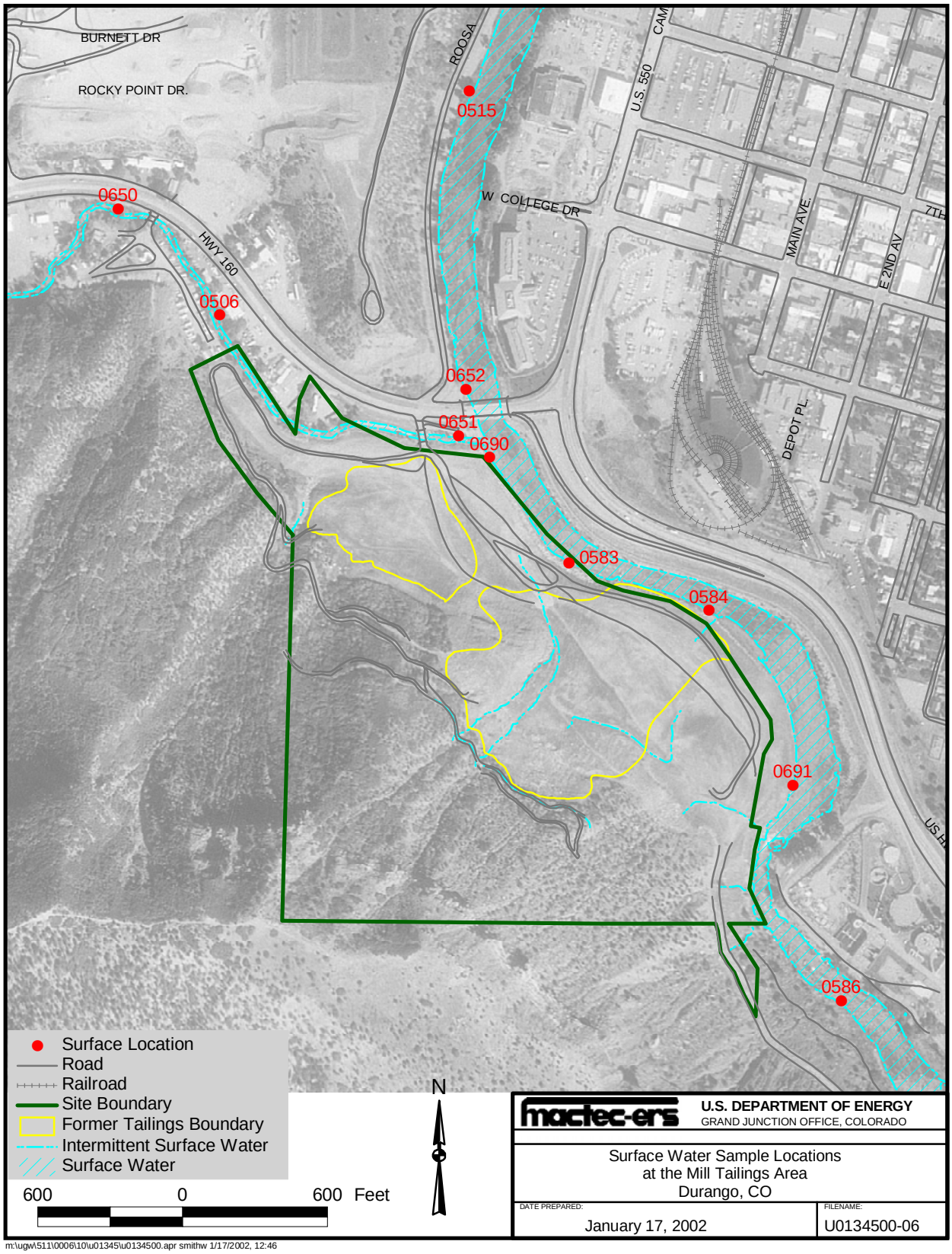

Figure 4–25. Surface Sample Locations at the Mill Tailings Area

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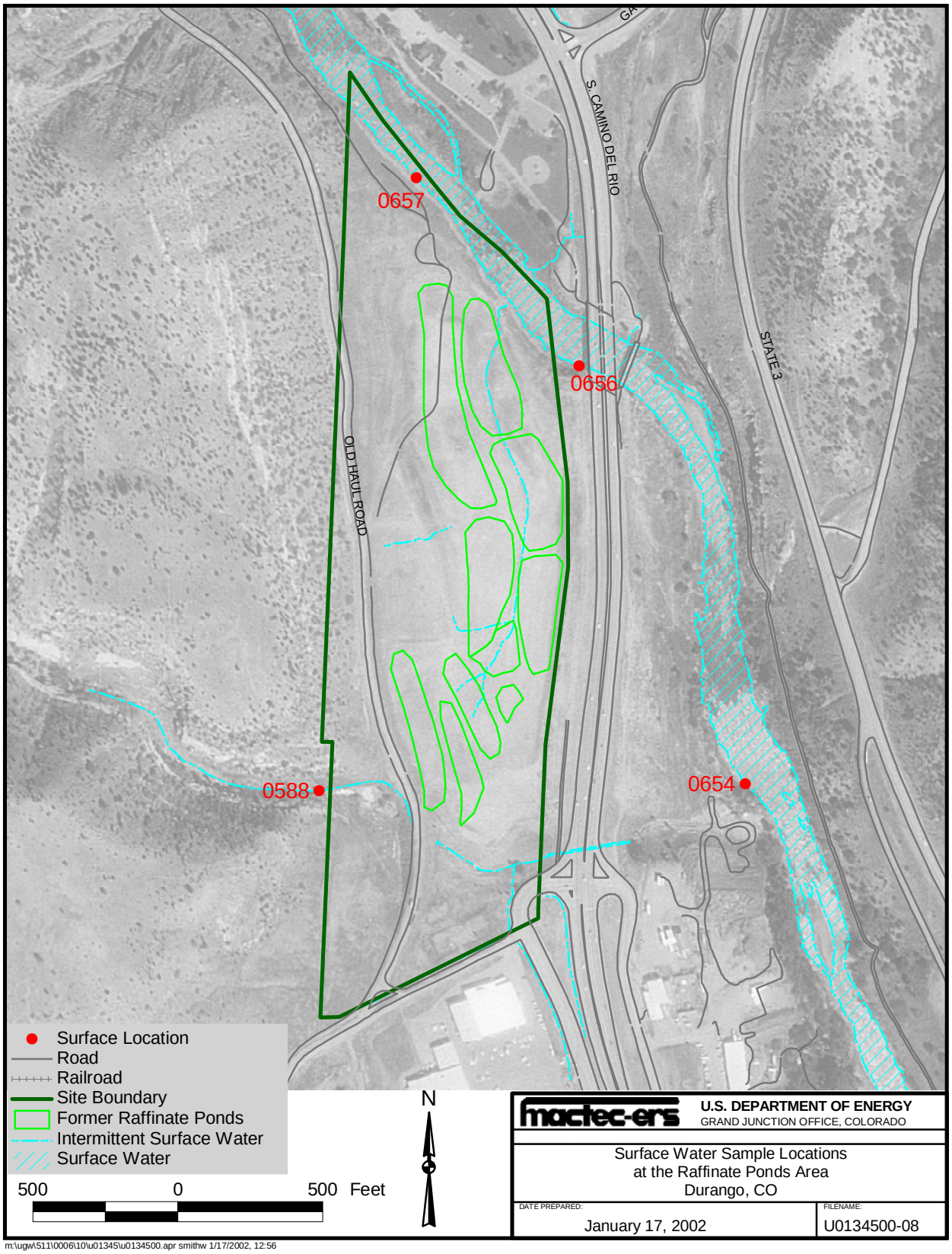

Figure 4–26. Surface Locations at the Raffinate Ponds Area

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The South Creek samples serve as background samples for recharge entering the raffinate ponds area. Compared with other surface waters, these samples show a significant increase in TDS (1,700 mg/L) and sulfate. This is partly because South Creek is an intermittent drainage. The longer residence time for ground water contributing to surface flow, plus the drainage area composed of coal, shale, and sandstone units of the Menefee Formation, are responsible for the increase in TDS and sulfate concentrations in South Creek. Uranium concentration has also been relatively high (0.0333 mg/L) for a background source, especially for a surface drainage. The Menefee coal beds in the South Creek drainage appear to be the source of the higher uranium values. By way of comparison, the average trace element concentration of uranium in coal for the Rocky Mountain region ranges as high as 23.8 mg/kg (DOE 1983).

During the August 2001 sampling, both filtered and unfiltered samples were collected from all surface water locations. Results of the surface water sampling are discussed further in Section 6.0.

4.7 Ecological Investigation

In general, the goal of ecological field investigations under the UMTRA Project is to acquire data to determine if site-related contamination may adversely affect ecological receptors (flora and fauna). To this end, surface waters and sediments were sampled for two primary reasons: (1) to determine if surface waters are being influenced by ground water contaminants, and (2) to determine if contaminants are present at concentrations that would result in a potential human health or ecological risk.

The BLRA (DOE 1995a) stated that South Creek was assumed not to be influenced by ground water from the raffinate ponds area. Because of this and the fact the creek is ephemeral, it was not sampled prior to June 2000. Lightner Creek and the Animas River have been sampled since 1982. In June 2000, a sampling location (0588) was established on South Creek above the raffinate ponds area, and an additional background surface water location (0515) was established on the Animas River. Both of these locations were included in the routine water sampling described in Section 4.6.4. Results of the surface water sampling indicate mill-related constituents have a negligible effect on surface waters and are discussed further in Section 6.2.

4.7.1 Sediment Sampling

The former Durango uranium-ore processing mill was next to the Animas River and Lightner Creek. Both bodies of water received contaminated fluids and sediments from the millsite while the mill was in operation. Sediment may contain contamination from three sources: (1) uptake from contaminated water in contact with it, (2) residual contamination (e.g., tailings) incorporated during milling, and (3) recently deposited contaminated sediments eroded from the millsite.

Sediment sampling was completed for the following 12 constituents along the Animas River, Lightner Creek, and South Creek adjacent to the surface water sampling locations:

Arsenic	Cadmium	Iron	Lead
Manganese	Mercury	Molybdenum	Nitrate
Selenium	Sulfate	Uranium	Zinc

However, the samples were analyzed by the laboratory without first being dried. As a consequence, the results represent concentrations of sediment and water together. The BLRA (DOE 1995a) identified cadmium, lead, and zinc as having elevated concentrations in downstream sample locations by a factor of 10. Some of this can be explained by the presence of naturally elevated levels of these constituents in lead-zinc ores, which are common in this area. The BLRA also concluded that most constituents are not anticipated to adversely affect the Animas River and Lightner Creek sediments. The results of sediment sampling are discussed further in Section 6.2.

4.7.2 EPA Investigation.

EPA conducted an ecological investigation at the former lead smelter in the mill tailings area under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1997. The site characterization included 10 surface water samples, 10 colocated sediment samples, 12 brown trout fillet samples, 12 rainbow trout fillet samples, and seven quality assurance/quality control samples. That EPA report is included as Appendix H.

Surface water and sediment analytical results of the EPA study indicated that aluminum was detected at concentrations significantly above background in surface water samples at seven locations along the Animas River below the mill tailings area. Within this same downstream area mercury was detected significantly above background in one sediment sample, and silver occurred above background in one sediment sample. The EPA study concluded that the mercury in the water sample was not related to the millsite and attributed the elevated concentration to a more widespread problem arising from elevated mercury concentrations in the southern Colorado mountains from area power plants. The occurrence of aluminum and silver were also determined not to be mill-related because these constituents were not detected on site as source contaminants.

The EPA site investigation also performed statistical analysis of the inorganic fish tissue data to determine the range of concentrations for each analyte in upstream and downstream tissue samples based on a 95 percent confidence level. The concentrations in upstream and downstream tissue samples were then compared to identify significant differences between upstream and downstream fish tissue. No elements were detected in fish tissue samples at statistically elevated levels.

The Colorado State Engineers Office has records of 90 household-use-only well permits for wells completed in the alluvium and bedrock within 4 miles of the mill tailings area. In trying to determine exposure pathways, EPA attempted to sample the closest of these wells and was unsuccessful. Although records for these wells exist, EPA discovered these residences are all now supplied by municipal water from the Florida and Animas Rivers. Development and utility policies for the city of Durango currently prohibit drilling of private wells within the city limits.