Potential environmental impact of the abandoned La Bajada uranium mine near Cochiti Lake, Santa Fe and Sandoval Counties, New Mexico

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Abstract

There has been some concern that the abandoned La Bajada uranium mine may pose an environmental risk to Cochiti Lake. The U.S. Forest Service (USFS) is currently planning remediation of this site. This paper summarizes available environmental data concerning La Bajada mine site and evaluates potential impact of the mine on Cochiti Lake. If flood waters along the Santa Fe River were to wash large amounts of mine waste downstream into Cochiti Lake, it is likely that water quality in Cochiti Lake would be adversely impacted. However, the USFS remediation plan is adequate and, once implemented, should prevent mine waste from reaching Cochiti Lake. Before establishment of La Bajada mine, the Santa Fe River appears to have naturally eroded a significant amount of La Bajada uranium deposit and washed it downstream. Thus, significant amounts of any radioactive elements present in fluvial deposits of the Santa Fe River downstream from the mine may be naturally emplaced and not the result of mining operations at La Bajada mine. On the basis of an inspection of La Bajada mine site, acid mine drainage potential seems low. Only minor oxidation of pyrite and marcasite was observed. Therefore, because of buffering capacity of the slightly alkaline Santa Fe River waters, it is unlikely that acid mine drainage could adversely impact Cochiti Lake. Remediation should further reduce the potential for acid mine drainage. It is unlikely that ground water from La Bajada mine site could impact Cochiti Lake because Cochiti Lake typically acts as a ground-water recharge source.

Introduction

The abandoned La Bajada uranium mine is adjacent to the Santa Fe River in the NW¼ sec. 9 T15N R7E, Santa Fe County, New Mexico. The Santa Fe River flows a little south of west past the mine and, after leaving Santa Fe Canyon, turns and flows approximately northwest into the lower reservoir of Cochiti Lake in Sandoval County (Fig. 1).

There has been some concern in New Mexico that La Bajada uranium mine may pose an environmental risk to Cochiti Lake. At present, the U.S. Forest Service (USFS) is planning remediation of the site. This paper summarizes data currently available for La Bajada mine site and evaluates the potential environmental impact of La Bajada uranium mine on Cochiti Lake. Because available data were limited, conclusions presented in this paper should be considered preliminary.

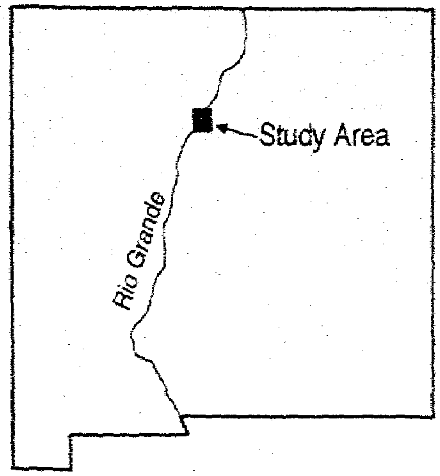
La Bajada deposit is believed to be a low-temperature, base-metal vein deposit that formed during Oligocene or Miocene time. Thin veins of uranium mineralization and base-metal sulfides occur along a limburgite (a dark basaltic rock) dike that was emplaced along a north-trending fault in the Oligocene Espinaso Formation (McLemore and North, 1984).

La Bajada mine (Fig. 2) was first operated as a copper mine in either 1915 or 1916. In 1928–29, La Bajada was mined by two shafts and 17 tons of ore were produced (McLemore and North, 1984). Uranium was discovered at the mine in 1950. The underground workings were found unsafe in 1957, and further mining was by open pit (Chenoweth, 1979). The pit is still present and is filled with water. Between 1956 and 1966, 9,649 tons of uranium were produced (McLemore and North, 1984). Interestingly, much of the orebody appears to have been removed via erosion by the Santa Fe River prior to discovery of the deposit (McLemore, oral comm. 1994).

Discussion

Hydrology

Surface-water bodies in the study area are Cochiti Lake, the Rio Grande, and the Santa Fe River. Cochiti Lake consists of



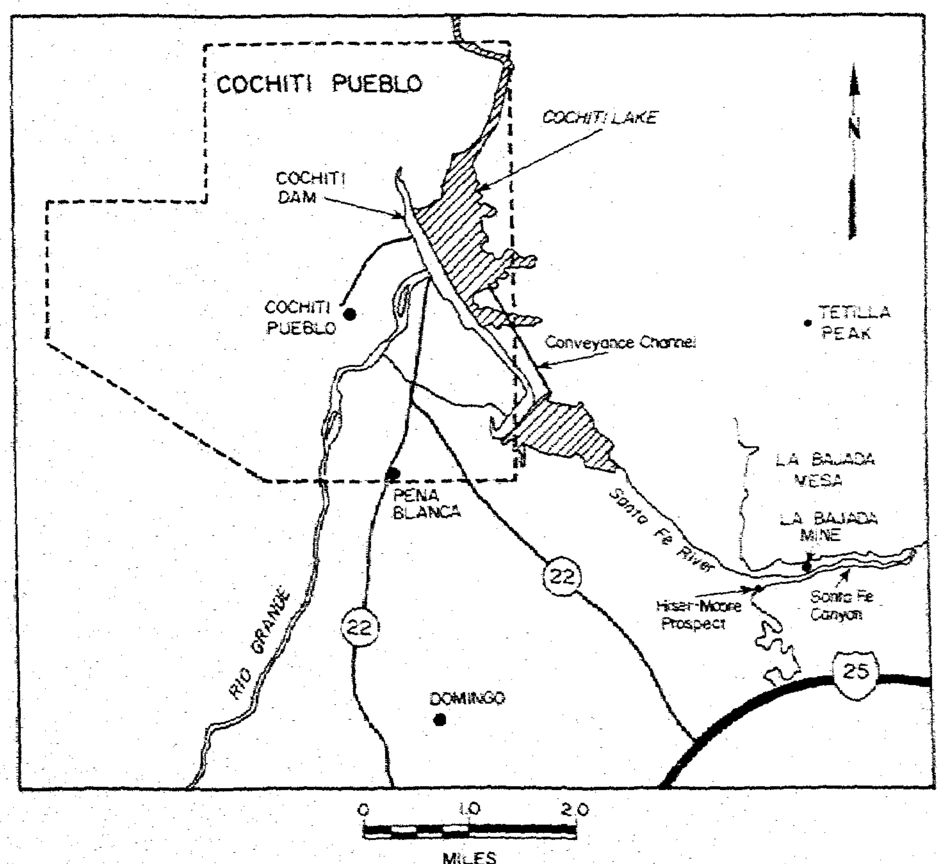


FIGURE 1—Location map of study area.

FIGURE 2—Lone Star Mining and Development Corporation was the last to undertake mining operations at LaBajada mine. This photograph was taken in the mid-1950s and shows La Bajada #1 mine and hoist house (NMBMMR Photo Collection #1737).

two arms, the Rio Grande arm and the Santa Fe arm (Fig. 1), each primarily fed by its namesake river. The two arms are connected by a conveyance channel. The altitude of the conveyance channel inlet is 5,355 ft above mean sea level (Blanchard, 1993). When the water level in the Rio Grande arm is above an elevation of 5,355 ft, water flows from the Rio Grande arm through the conveyance channel into the Santa Fe arm. When the water level in the Rio Grande arm is below an elevation of 5,355 ft, water flows into the Rio Grande arm from the Santa Fe arm (Blanchard, 1993).

The Santa Fe River is a perennial stream for approximately 3 mi in the Santa Fe arm of Cochiti Lake. Prior to the filling of Cochiti Lake, the Santa Fe River was not perennial in this reach (Geohydrology Associates, Inc., 1982). The flow in the Santa Fe River is highly variable, ranging from periods of no flow to a recorded high flow of 11,400 cfs in 1971.

No information on ground-water quality in the vicinity of La Bajada mine was available. However, Blanchard (1993) presented maps of the ground-water surface in the Cochiti Dam–Peña Blanca area for 1982, 1988, and 1989. Blanchard's maps indicate that the direction of ground-water flow downstream of La Bajada mine is generally westward and approximately parallel to the course of the Santa Fe River. No major changes in ground-water flow direction are indicated during the period 1982–1989. It is reasonable to assume the ground-water flow in the vicinity of La Bajada mine site is also generally westward along Santa Fe Canyon. According to Blanchard (1993), after entering the Rio Grande valley sediments, ground water begins to flow southwest toward the Rio Grande.

CH2M Hill and Resource Technology, Inc. (1984) estimated the volume of recharge to the ground-water system from Cochiti Lake. They calculated the seepage volume to be 84,000 acre-ft/yr when the water level in Cochiti Lake is at an elevation of 5,387 ft, and 21,000 acre-ft/yr when the water level is near 5,323 ft elevation.

Applicable New Mexico Water Quality Regulations

Drinking water standards do not apply to La Bajada mine pit water, the Santa Fe River, or Cochiti Lake (New Mexico Water Quality Control Commission, 1991). The designated uses for each of these water bodies are **Cochiti Lake**: livestock and wildlife watering, warm-water fishery, cold-water fishery, and primary contact recreation; **Santa Fe River**: irrigation, livestock and wildlife watering, marginal cold-water fishery, secondary contact recreation, and warm-water fishery; and **La Bajada mine pit**: not specifically classified under New Mexico water-quality regulations. However, because this small water body is adjacent to the Santa Fe River, it is assumed that the same water-quality standards apply to it as to the river.

There are three general water-quality concerns for the surface waters discussed in this report. The first is the State of New Mexico's antidegradation policy that states in part:

> "Degradation of waters the quality of which is better than the stream standards established by the New Mexico Water Quality Control Commission is not reasonable degradation and is subject to abatement under the authority granted the Commission by the New Mexico Water Quality Act, as amended, unless it is justifiable as a result of necessary economic and social development. Existing instream water uses and water quality necessary to sustain existing uses shall be maintained and protected in all surface waters of the State. No degradation shall be allowed in high quality waters of designated national and state monuments, parks and wildlife refuges including waters designated by the U. S. Congress under the Wild and Scenic Rivers Act, if such degradation would impair any of the qualities which caused designation of these waters, parks and wildlife refuges. To protect the existing quality of water, the Commission under the act will require the highest and best degree of effluent treatment practicable..."

Thus, the expectation of the State is surface waters are not to be unnecessarily degraded even though such degradation might meet minimum water-quality standards.

Second are general standards that apply to all surface waters of New Mexico. Only general standards that concern potential contaminants discussed in this paper are given. (LC-50 means the concentration of a substance that is lethal to 50% of test organisms within a defined time period. The length of the time period, which may vary from 24 hours to one week or more, depends on the test method selected to yield the information desired.)

> "Hazardous substances: Toxic substances, such as, but not limited to, pesticides, herbicides, heavy metals, and organics, shall not be present in receiving waters in concentrations which will change the ecological conditions of receiving waters to an extent detrimental to man or other organisms of direct or indirect commercial, recreational, or aesthetic value. Toxicities of substances in receiving waters will be determined by appropriate bioassay techniques, or other acceptable means, for the particular form of aquatic life which is to be preserved with the concentrations of toxic substances not to exceed 5% of the LC-50 provided that: toxic substances which, through uptake in the aquatic food chain and/or storage in plant and animal tissues, can be magnified to levels which are toxic to man or other organisms, shall not be present in concentrations which result in this biological magnification or exceed 1% of the LC-50...
>
> Radioactivity: The radioactivity of surface waters shall be maintained at the lowest practical level and shall in no case exceed the standards set forth in Part 4 of New Mexico Environmental Improvement Board Radiation Protection Regulations, filed March 10, 1989."

Thus, the only radioactivity standard that applies to surface waters discussed in this paper is 30 pCi/l for combined radium-226 and radium-228.

Third, specific water-quality regulations that apply to each of the surface waters are

> "Cochiti Lake: un-ionized ammonia (as N)

TABLE 1—Results of mine-waste batch extraction at pH 5.0. (Data from Appendix A, data source 1). The < sign to the left of the numbers means that the concentration in the extract was less than the detection limit for the analytical method used.

Analysis	Sample 87.01713 Extract Concentration	Sample 87.01714 Extract Concentration	Sample 87.01715 Extract Concentration
Ag	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l
As	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l
Ba	0.80 ± 0.50 mg/l	0.50 ± 0.50 mg/l	0.60 ± 0.50 mg/l
Cd	< 0.01 ± 0.01 mg/l	< 0.2 ± 0.02 mg/l	< 0.01 ± 0.01 mg/l
Cl	3.2 ± 0.6 mg/l	2.4 ± 0.4 mg/l	2.6 ± 0.4 mg/l
CN	0.01 ± 0.01 mg/l	0.01 ± 0.01 mg/l	0.01 ± 0.01 mg/l
Co	0.52 ± 0.05 mg/l	0.44 ± 0.04 mg/l	0.55 ± 0.06 mg/l
Cr	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l
Cu	< 2.0 ± 2.0 µg/l	< 2.0 ± 2.0 µg/l	13.5 ± 4.0 µg/l
F	0.537 ± 0.054 mg/l	0.553 ± 0.055 mg/l	0.633 ± 0.063 mg/l
Fe	135.0 ± 13.0 mg/l	70.0 ± 7.0 mg/l	200.0 ± 20.0 mg/l
Hg	< 0.002 ± 0.002 mg/l	< 0.002 ± 0.002 mg/l	< 0.002 ± 0.002 mg/l
Mn	9.7 ± 0.97 mg/l	8.98 ± 0.9 mg/l	10.7 ± 1.1 mg/l
Mo	0.002 ± 0.001 mg/l	0.002 ± 0.001 mg/l	0.002 ± 0.001 mg/l
NH_3-N	4.0 ± 0.4 mg/l	1.99 ± 0.199 mg/l	4.12 ± 0.412 mg/l
Ni	1.22 ± 0.12 mg/l	1.12 ± 0.11 mg/l	1.28 ± 0.13 mg/l
NO_3-N	< 0.20 ± 0.20 mg/l	< 0.20 ± 0.20 mg/l	< 0.20 ± 0.20 mg/l
P	< 0.20 ± 0.20 mg/l	< 0.20 ± 0.20 mg/l	< 0.20 ± 0.20 mg/l
Pb	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l
pH	4.47 ± 0.1 units	4.39 ± 0.1 units	4.46 ± 0.1 units
Ra-226	23.5 ± 2.3 pci/l	9.2 ±0.9 pci/l	21.5 ± 2.1 pCi/l
Se	9.1 ± 1.0 µg/l	< 1.0 ± 1.0 µg/l	1.0 ± 1.0 µg/l
SO_4	21.3 ± 2.1 mg/l	39.1 ± 3.9 mg/l	37.3 ± 3.7 mg/l
TDS	2518 ± 252 mg/l	2826 ± 283 mg/l	2685 ± 269 mg/l
Th	0.001 ± 0.001 mg/l	0.001 ± 0.001 mg/l	0.001 ± 0.001 mg/l
U	0.008 ± 0.005 mg/l	0.02 ± 0.005 mg/l	0.009 ± 0.005 mg/l
V	< 0.01 ± 0.01 mg/l	0.017 ± 0.01 mg/l	< 0.01 ± 0.01 mg/l
Zn	0.187 ± 0.038 mg/l	0.425 ± 0.043 mg/l	0.193 ± 0.019 mg/l

shall not exceed 0.03 mg/l, dissolved oxygen shall be greater than 6.0 mg/l, pH shall be in the range of 6.6 to 8.8, temperature shall be less than 25°C, turbidity shall be less than 25 NTU, and total chlorine residual shall be less than 0.002 mg/l."

"Santa Fe River: dissolved oxygen shall be greater than 4.0 mg/l, pH shall be in the range of 6.6 to 8.8, temperature shall be less than 30°C, and turbidity shall be less than 50 NTU."

Thus, other than specific regulations for total radium and pH, no other constituents are clearly regulated under New Mexico Law. However, all hazardous and radioactive constituents are regulated under the general degradation rule in addition to the regulatory limits for specific uses listed in Tables 1, 2, and 3.

Results of water analyses

Standards that apply to La Bajada mine pit are a limit of 30 pCi/l for combined radium-226 and radium-228 and a pH range from 6.6 to 8.8. The total radium standard is met by the pit waters (Table 4). The pH of the pit water has historically ranged between 7.8 and 8.8 and meets the pH standard.

Drinking water standards do not apply to La Bajada mine pit water. However, because specific New Mexico standards for some parameters are lacking, it is informative to compare mine pit water to drinking-water standards to obtain an idea of relative water quality. Drinking-water regulatory limits for radioactive elements are as follows: gross alpha radiation, 15 pCi/l; total radium-226 and radium-228, 5 pCi/l; radium-226, 3.0 pCi/l, gross beta radiation, 50 pCi/l; and uranium, 30 pCi/l (currently proposed by the U. S. Environmental Protection Agency [USEPA] as a drinking-water standard). Analyses of radioactive elements for La Bajada mine pit are summarized in Table 5. Gross alpha activity is consistently over the drinking-water limit. However, gross beta radiation and total uranium are not always over drinking-water limits, and total radium is often under the limit. Total uranium typically exceeds 30 pCi/l in pit waters. In conclusion, even though La Bajada mine pit water does not meet drinking-water standards, it does not pose an immediate and life-threatening danger because the water only marginally exceeds drinking-water standards, which are designed to be relatively conservative.

Parameters that are at or below the detection limits for all samples examined include silver, barium, beryllium, cadmium, cobalt, nickel, lead, and vanadium. Results at the detection limit have a very large uncertainty (typically ±100%). For this reason the actual concentration may be significantly less than the detection limit. Therefore, results close to the detection limit are often inconclusive and should be used with extreme caution, or the samples should be reanalyzed using a method with a lower detection limit. Arsenic, boron, cyanide, copper, and selenium concentrations were below those in New Mexico water quality regulations for the Santa Fe River. On the basis of available data, only aluminum and mercury can conclusively be shown to be above New Mexico regulatory standards. Examination of chemical analyses in Tables 5 and 6 suggest water in La Bajada mine pit should not be used for drinking or swimming. However, USFS diver Don Duff did an aquatic life survey in the mine pit in 1970. Don Duff has suffered no ill effects (Bruce Sims, oral comm. 1995).

Radioactivity analyses were also available for four sites other than La Bajada mine pit. These are (1) the Santa Fe River 0.25 mi upstream of the mine, (2) the U.S. Geological Survey (USGS) gaging station on the Santa Fe River below the mine, (3)

TABLE 2—New Mexico regulatory standards for waters used for irrigation (New Mexico Water Quality Control Commission, 1991).

Parameter	Regulatory Standard (mg/l)
Dissolved aluminum	5.0
Dissolved arsenic	0.10
Dissolved boron	0.75
Dissolved cadmium	0.01
Dissolved chromium	0.10
Dissolved cobalt	0.05
Dissolved copper	0.20
Dissolved lead	5.0
Dissolved selenium	0.13
Dissolved selenium in the presence of < 500 mg/l SO_4	0.25
Dissolved vanadium	0.1
Dissolved zinc	2.0

TABLE 3—New Mexico regulatory standards for waters used for livestock and wildlife watering (New Mexico Water Quality Control Commission, 1991). *The criteria for chromium shall be applied to an analysis that measures both the trivalent and hexavalent ions.

Parameter	Regulatory Standard (mg/l except as noted)
Dissolved aluminum	5.0
Dissolved arsenic	0.02
Dissolved boron	5.0
Dissolved cadmium	0.05
Dissolved chromium*	1.0
Dissolved cobalt	1.0
Dissolved copper	0.5
Dissolved lead	0.1
Total mercury	0.01
Dissolved selenium	0.05
Dissolved vanadium	0.1
Dissolved zinc	25.0
Radium-226 + Radium-228	30 pCi/l

TABLE 4—New Mexico regulatory standards for waters used in fisheries (New Mexico Water Quality Control Commission, 1991). [1]For numeric standards dependent on hardness, hardness (as mg $CaCO_3$/l) shall be determined as needed from available verifiable data sources including, but not limited to, the U.S. Environmental Protection Agency's STORET water quality database. [2]The criteria for chromium shall be applied to an analysis that measures both the trivalent and hexavalent ions.

Chronic Criteria

Parameter	Regulatory Standard (mg/l)
Dissolved aluminum	0.087
Dissolved beryllium	0.0053
Total mercury	0.000012
Dissolved selenium	0.005
Dissolved silver	0.00012
Total cyanide	0.0052
Total chlordane	0.0000043
Dissolved cadmium[1]	exp(0.7852 (ln (hardness)) – 3.49)
Dissolved chromium[2]	exp(0.819 (ln (hardness)) + 1.561)
Dissolved copper	exp(0.8545 (ln (hardness)) – 1.465)
Dissolved lead	exp(1.273 (ln (hardness)) – 4.705)
Dissolved nickel	exp(0.846 (ln (hardness)) – 1.1645)
Dissolved zinc	exp(0.8473 (ln (hardness)) + 0.7614)

Acute Criteria

Parameter	Regulatory Standard (mg/l)
Dissolved aluminum	0.750
Dissolved beryllium	0.130
Total mercury	0.0024
Dissolved selenium	0.0200
Dissolved silver	exp(1.72 (ln (hardness)) – 6.52)
Total cyanide	0.0220
Total chlordane	0.0024
Dissolved cadmium	exp(1.128 (ln (hardness)) – 3.828)
Dissolved chromium[2]	exp(0.819 (ln (hardness)) + 3.688)
Dissolved copper	exp(0.9422 (ln (hardness)) – 1.464)
Dissolved lead	exp(1.273 (ln (hardness)) – 1.46)
Dissolved nickel	exp(0.76 (ln (hardness)) + 0.4.02)
Dissolved zinc	exp(0.8473 (ln (hardness)) + 0.8604)

a spring or infiltration gallery approximately 1,000 ft east of the mine pit, and (4) the drinking-water supply at Domingo. These data are tabulated in Table 7.

The Santa Fe River upstream of Cochiti Lake is not designated as a drinking-water supply. As designated, the only radioactive standard that applies is that radium-226 plus radium-228 must be below 30 pCi/l (New Mexico Water Quality Control Commission, 1991). This standard is met in the Santa Fe River.

The uranium content of the Santa Fe River seems to be slightly higher upstream of La Bajada mine than downstream. Records available at the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) in the Mineral Data Archives show that another uranium prospect, La Majada, is approximately 3 mi upstream of La Bajada mine site in the NE¼ sec. 2 T15N R7E (geologic map of La Bajada area showing uranium deposits adapted and modified after Disbrow and Stoll, 1957 in NMBMMR collection). La Majada uranium prospect is also on the banks of the Santa Fe River. La Majada site is a potential source of naturally derived, dissolved uranium and other possible contaminants in the Santa Fe River. However, if analytical uncertainties for the analyses (which generally were not available) were considered, there may be no significant difference in the upstream and downstream values. Another uranium prospect is also south of the Santa Fe River about 3,000 ft downstream of La Bajada mine site. This is known as the Hiser-Moore prospect and is depicted on the same map as La Majada prospect. No further information is available on either La Majada or the Hiser-Moore prospects in the NMBMMR files.

In general, the uranium content of the Santa Fe River is only one-tenth that of the average uranium concentration of La Bajada mine pit water. The maximum uranium concentration in the Santa Fe River, which occurred upstream of the mine, is only about one-sixth of the proposed USEPA 30 pCi/l drinking-water limit. The radium-226 concentrations in the Santa Fe River are only one-quarter of the radium-226 concentrations in the mine pit. All reported concentrations of radium-226 in the Santa Fe River are below the EPA suggested limit of 3.0 pCi/l for drinking water. Both gross alpha and gross beta radiation are much lower than the drinking-water regulatory limits of 15 pCi/l for gross alpha radiation and 50 pCi/l for gross beta radiation. Even the waters of the mine seep or infiltration gallery, although higher in uranium than the waters of the Santa Fe River, are well below suggested EPA drinking-water standards for uranium, even though drinking-water standards do not apply to these waters.

Potter (1985) concluded that all water-quality standards in the Santa Fe River were met upstream of Cochiti Lake between May 27 and May 29, 1985. Water data in sources in Appendix A demonstrate that the Santa Fe River water generally meets drinking-water standards with three occasional exceptions. These are nitrate, fecal colliform, and lead. In 1986, Potter found that total nitrogen and fecal colliform were high in Cienega Creek, which enters the Santa Fe River upstream of La Bajada mine. She stated that action was taken the same year to correct the problem. Lead has been reported at 42 micrograms per liter (µg/l) upstream of Cochiti Pueblo and La Bajada mine from the Santa Fe River at the Tetilla Peak access road bridge in La Cienega on 07-08-1984. This is above the 15 µg/l drinking-water standard but below New Mexico standards for irrigation, livestock and wildlife watering, and fisheries. However, lead analyses reported for 08-06-1986 and 02-25-1988 at the same location were well below 15 µg/l. The source of lead is unknown but may be natural.

Potential environmental impact

Mine-waste characterization

Mine-waste characterization involves determining the potential of the waste to impact beneficial water uses (Hutchison and Ellison, 1992). Normally, mine waste characterization is done using either batch extraction or column leach tests. Batch tests are generally easier to conduct, but column tests may be more representative of actual site conditions (Hutchison and Ellison, 1992). Ideally, fluids used in waste characterization should closely resemble the pH of the waste itself. However, deionized water or a simulated rainwater at a pH of 5 to 5.5 is often used (Hutchison and Ellison, 1992).

The only data on mine waste characterization testing for La Bajada mine are from Los Alamos National Laboratory (Appendix A, data source 1) and Radian Corporation (Appendix A, data source 9). Los Alamos reported results of mine waste batch extraction at a pH of 5.0 (Table 7). Silver, arsenic, cadmium, chromium, mercury, nitrate, phosphorous, and lead concentrations in the extract are consistently below the detection limit in these extrac-

TABLE 5—Analyses for radioactive constituents from La Bajada mine pit; some of the copies of laboratory reports provided were indecipherable so were excluded. *Analysis reported simply as gross alpha radiation. Note: in some cases total uranium has been converted from mg/l to pCi/l by the following equation (Milvey and Cothern, 1990): Total uranium (pCi/l) = X mg/l . (1000 µg/mg) . (0.67 pCi/µg). The symbol — means no data given in source. Each analysis is listed only once although the same analysis was sometimes present in more than one data source.

Gross Alpha (ref U-238) pCi/l	Gross Alpha (ref Am-241) pCi/l	Gross Beta pCi/l	^{226}Ra pCi/l	^{228}Ra pCi/l	Total Ra pCi/l	Total uranium pCi/l	Sample #	Date	Appendix A data source
—	—	—	0.21 ± 0.021	—	—	8 ± 0.7	87.01708	05-19-87	1
—	—	—	0.19 ± 0.190	—	—	57.6 ± 6	97.01709	05-19-87	1
45 ± 6	32 ± 3	19 ± 3	0.17 ± 0.02	0.4 ± 0.2	0.57	46.64	0049	03-87	3
111 ± 14	82 ± 8	194 ± 14	3.93 ± 0.23	0.9 ± 0.3	4.83	56.64	0050	03-87	3
42 ± 6	32 ± 4	42 ± 6	0.98 ± 0.06	1.1 ± 0.4	2.08	47.67	0051	03-87	3
131 ± 16	95 ± 9	111 ± 11	5.5 ± 0.3	1.2 ± 0.3	6.7	69.04	0052	03-87	3
—	—	—	0.7 ± 0.4	—	—	37.5	—	11-09-82	12
44.8 ± 6*	—	—	—	—	—	—	82176	06-04-81	12
—	—	—	0.22 ± 0.06	—	—	14.8	—	01-26-79	8
—	—	—	2.8	—	—	48.7	—	01-11-79	3
—	—	—	0.1	—	—	60.1	—	12-27-78	3
—	—	—	—	—	—	56.5	—	12-13-78	12
—	—	—	0.22 ± 0.2	0.6 ± 0.8	—	—	KA-0280	07-11-74	8

tions. Of the heavy metals, only cobalt, copper, manganese, radium-226, selenium, zinc, and possibly vanadium show significant concentration increases during extraction.

Several mine byproducts may be present at mines. Soil is not enriched in ore metals, mine waste is slightly enriched in metals, protore is of higher grade but cannot be processed economically, and ore, of course, has the highest ore metal concentrations of all. Whitworth (1995) estimated there may be between 20,000 and 100,000 tons of mine waste and approximately 1,433 tons of ore present at La Bajada mine site. Whitworth (1995) also estimated the average concentrations of radioactive elements present in the mine waste and ore present at La Bajada mine site from available data (Table 8). Even though the surface mine waste at La Bajada mine site has not been thoroughly characterized, sufficient information exists to draw preliminary conclusions.

TABLE 6—Inorganic analyses from La Bajada mine pit.

Appendix A data source	1	1	6	8
Parameter	**Concentration**	**Concentration**	**Concentration**	**Concentration**
Ag	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.1 mg/l	—
Al	0.19 ± 0.10 mg/l	0.35 ± 0.10 mg/l	< 0.1 mg/l	—
As	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	0.009 mg/l	—
B	0.20 ± 0.10 mg/l	0.20 ± 0.10 mg/l	0.3 mg/l	—
Ba	< 0.50 ± 0.50 mg/l	< 0.50 ± 0.50 mg/l	< 0.1 mg/l	—
Be	—	—	< 0.1 mg/l	—
Ca	—	—	55 mg/l	62.0 mg/l
Cd	<0.010 ± 0.010 mg/l	<0.010 ± 0.010 mg/l	< 0.1 mg/l	—
Cl	52.0 ± 5.0 mg/l	59.0 ± 6.0 mg/l	—	42.0 mg/l
CN	0.0 ± 0.01 mg/l	0.0 ± 0.01 mg/l	—	—
Co	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.05 mg/l	—
Cr	< 1.00 ± 1.00 µg/l	< 1.00 ± 1.00 µg/l	< 0.1 mg/l	—
Cu	5.60 ± 0.60 µg/l	3.0 ± 0.30 µg/l	< 0.1 mg/l	—
F	1.50 ± 0.30 mg/l	1.50 ± 0.30 mg/l	—	—
Fe	—	—	< 0.1 mg/l	—
HCO_3	—	—	—	333.3 mg/l
Hg	0.90 ± 0.20 µg/l	0.20 ± 0.20 µg/l	—	—
K	—	—	—	9.75 mg/l
Mg	—	—	40 mg/l	—
Mn	4.50 ± 2.0 µg/l	0.183 ± 0.018 mg/l	< 0.05 mg/l	—
Mo	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.1 mg/l	—
Na	—	—	—	98.9 mg/l
NH_3-N	0.0 ± 0.04 mg/l	0.0 ± 0.04 mg/l	—	
Ni	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.1 mg/l	—
NO_3-N	< 0.20 ± 0.20 mg/l	< 0.20 ± 0.20 mg/l	—	—
P	< 0.20 ± 0.20 mg/l	< 0.30 ± 0.20 mg/l	—	—
Pb	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.1 mg/l	—
pH	8.63 ± 0.1 units	8.15 ± 0.1 units	—	—
Se	1.70 ± 1.0 µg/l	1.50 ± 1.0 µg/l	< 0.005 mg/l	—
Si	—	—	2.7 mg/l	—
Sn	—	—	< 0.1 mg/l	—
SO_4	201 ± 20 mg/l	226 ± 23 mg/l	—	209.4 mg/l
Sr	—	—	0.5 mg/l	—
TDS	646 ± 65 mg/l	672 ± 67 mg/l	—	626 mg/l
V	< 0.05 ± 0.05 mg/l	< 0.05 ± 0.05 mg/l	< 0.1 mg/l	—
Zn	3.0 ± 0.2 µg/l	14.4 ± 2.0 µg/l	< 0.1 mg/l	—

Total hardness (mg/l CaCO3) = 2.497 (Ca in mg/l) + 4.118 (Mg in mg/l)

Acid mine drainage potential

No data were found that would allow quantification of acid mine drainage potential. However, several scattered, discolored patches on the surface were observed during the site visit. These rusty-colored patches are indicative of pyrite or marcasite oxidation. Acid mine drainage is the result of exposure of pyrite to oxygen at the surface following excavation and subsequent oxidation (rusting) of pyrite. Water in contact with oxidizing pyrite becomes acidic, with pH values lower than 4.5 (Drever, 1988). At these low pH's, water is still not particularly harmful to man. Coca Cola®, for example, has a pH between 2.0 to 3.0. The problem is that heavy metals such as lead and copper, are more soluble at low pH than they are in a near-neutral pH range from 6.0 to 8.5. Consequently, acidic waters tend to mobilize heavy metals. In addition, aquatic plants and animals can be quite sensitive to pH fluctuations.

However, low-pH waters produced by acid mine drainage should be buffered by the more alkaline waters of the Santa Fe

TABLE 7—Background surface water analyses for radioactive constituents/parameters.

Location	Gross Alpha (ref AM-241) (pCi/l)	Gross Alpha (ref Unat) (pCi/l)	Gross Beta (ref Cs-137) (pCi/l)	Gross Beta (ref Sr/Y-90) (pCi/l)	Uranium, total (pCi/l)	^{226}Ra (pCi/l)	Date	Appendix A data source
Santa Fe River ¼ mi	—	—	—	—	3.8	0.08	12-27-78	3
upstream of mine site	—	—	—	—	5.1	0.51	01-11-79	3
Santa Fe River at USGS	—	—	—	—	2.9	0.31	12-27-78	3
gaging station below mine	—	—	—	—	3.5	2.9	01-11-79	3
Domingo drinking water	2.9 ± 0.66	4.5 ± 1.1	7.6 ± 1.0	7.6 ± 1.0	—	—	03-87	3
Spring 50′ east of mine pit	—	—	—	—	14.5	0.3	12-27-78	3
	—	—	—	—	13.5	0.31	01-11-79	3

TABLE 8—Average radioactive constituent concentrations in mine waste and protore (Whitworth, 1995). Note: all concentrations are in pCi/l.

	^{238}U	^{234}U	Uranium, total	^{230}Th	^{226}Ra	^{210}Pb
Mine waste	24.4	24.3	48.76	29	28.2	27.1
Protore	75	81	156	293.5	613.5	570.5

River. This should cause most heavy metals to precipitate; thus they would no longer be transported in solution. Because of the presence of the Santa Fe River with its alkaline waters and the distance between Cochiti Lake and the mine, it is unlikely that acid mine drainage could significantly affect Cochiti Lake even without mine remediation. Placing pyrite-free cover material over La Bajada mine site will help to slow or prevent production of acid mine waters and potential transference of heavy metals and radioactive constituents to the Santa Fe River.

Acid mine drainage entering ground water should also be buffered by water-rock interaction to pH values ranging approximately 7.0–8.5. This typically results in precipitation of solids such as amorphous $Fe(OH)_3$ and $Al(OH)_3$ in the soil (Peterson et al., 1986). Uranium, other radioactive elements, and heavy metals tend to adsorb to these precipitates, as well as to clays and iron compounds in the soil and thus are, at least partially, prevented from further migration. However, if the source of acid mine waters is large, the buffering capacity of ground water and sediments may be exhausted, causing the pH to drop. As a result, previously precipitated solids will dissolve, freeing contaminants into solution once more. At La Bajada mine site however, the small volume of acid mine drainage that may be produced as a result of infiltration of meteoric water in the semiarid climate is not likely to have a significant impact on the regional ground-water system. Because Cochiti Lake is typically a ground-water recharge source (Blanchard, 1993), ground water from the mine should have no significant impact on Cochiti Lake.

Potential environmental impact on Cochiti Lake

Contaminant concentrations in La Bajada mine pit provide a "worst case" prediction of the concentrations that could result in Cochiti Lake if large volumes of mine waste were to be carried into the lake. Mass balance calculations by Whitworth (1995) suggest such quantities of potential contaminants are present at the mine. Therefore, La Bajada mine pit can be considered a pilot test for the maximum possible degradation of Cochiti Lake water quality. Because it is unlikely that the pH of lake waters would be highly acidic, radioactive and heavy-metal concentrations should be similar to those in La Bajada mine pit. This would constitute degradation of the water quality in Cochiti Lake for recreational purposes. Swimming would probably have to be banned. Also, because of the potential for particulate heavy metals and radioactive elements to enter the food chain, fishing might also be significantly impacted as well.

Remediation plan evaluation

In brief, the USFS remediation plan is to (1) cover the mine waste with a minimum of 2 ft of soil to reduce radiation levels at the surface, (2) regrade and armor the channel of the Santa Fe River to prevent erosion of mine waste at flows of over 15,000 cfs, (3) fill the mine pit and replace it with a constructed wetland, and (4) reestablish vegetation at the site.

Metzger–Keele (Appendix A, data source 2) conducted a radiological survey of La Bajada mine site and determined that approximately 16 inches of soil cover is necessary at La Bajada mine site to reduce radiation emission to acceptable levels. However, additional soil cover may be necessary because of anticipated erosion. If vegetation is established to reduce erosion on the two or more feet of soil cover, radiation levels at the soil surface will be reduced for a long period of time.

At present, the USFS plans to let the mine pit water soak into the surrounding alluvium as the pit is filled with soil. The pit and its soil fill will then be covered as a part of the remediation. On the basis of mass balance calculations, this procedure should not be a problem (Whitworth, 1995).

The design flow for the Santa Fe River suggested by the USFS is in excess of 15,000 cfs. Thus the channel of the Santa Fe River would be regraded and armored to handle a maximum flow of greater than 15,000 cfs. The 100-year flood for this site is 10,300 cfs, and the design value of 15,000 cfs is larger than the highest recorded flow of 11,400 cfs (Bruce Sims, USFS, written comm. 1994). However, it should be noted flow records have only been kept at the USGS gauging station below the mine since 1970. On the basis of the information available, the 15,000 cfs design flow seems reasonable and is certainly a much more conservative design criterion than the often-used 100-year flood.

Covering the mine waste with a layer of soil will significantly diminish the hazard of mine waste being washed into the river during precipitation events. However, care must be taken to grade contours such that soil cover will not be easily eroded. After remediation is complete, the soil cover should be regularly inspected so that minor erosion damage can be repaired before major problems occur.

Conclusions

If Santa Fe River flood waters were to wash large amounts of La Bajada mine waste into Cochiti Lake, it is likely that water quality would be degraded for recreational use. Swimming might have to be banned, and fishing might be adversely impacted if particulate heavy metals and radioactivity enter the food chain.

However, the USFS remediation plan is adequate and, once implemented, should prevent mine waste from reaching Cochiti Lake.

Before establishment of La Bajada mine, the Santa Fe River appears to have eroded a significant amount of the uranium deposit and washed it downstream. Thus, significant amounts of radioactive elements present in fluvial deposits of the Santa Fe River downstream from the mine may be naturally emplaced and may not be the result of mining operations at La Bajada mine. On the basis of an inspection of La Bajada mine site, acid mine drainage potential seems low. Only minor pyrite oxidation was observed. Therefore, because of the buffering capacity of the slightly alkaline Santa Fe River waters, it is unlikely that acid mine drainage could adversely impact Cochiti Lake. Remediation should further reduce potential for acid mine drainage. It is unlikely that ground water from La Bajada mine site could impact Cochiti Lake because Cochiti Lake typically acts as a ground-water recharge area.

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Appendix A
Data sources used to prepare report

These data sources are available as part of the New Mexico Bureau of Mines and Mineral Resources Open-file Report 409.

1. Report dated April 28, 1988 from William D. Purtymun of Los Alamos National Laboratory to Corey Wong, Española Ranger District, USFS containing analytical results of water and sediment samples from La Bajada mine pit.

2. Report dated September 14, 1987 from J. Margo Metzger-Keele, PhD, Program Manager, Surveillance and Monitoring Section, New Mexico Health and Environment Department to Robert Salter, Bureau Chief, Abandoned Mine Land Program, Energy and Minerals Department, Mining and Minerals Division.

3. Report dated May 29, 1987 from J. Margo Metzger-Keele, PhD, Program Manager, Surveillance and Monitoring Section, New Mexico Health and Environment Department to Robert Salter, Bureau Chief, Abandoned Mine Land Program, Energy and Minerals Department, Mining and Minerals Division.

4. Analytical report for water sample from Domingo/La Bajada dated March 25, 1987 from the Radiochemistry Section of the Scientific Laboratory Division of the New Mexico Health and Environment Department to the Water Supply Section, New Mexico Health and Environment Department, Santa Fe, New Mexico.

5. Analytical report for water sample from La Bajada mine pit dated April 8, 1987 from the Radiochemistry Section of the Scientific Laboratory Division of the New Mexico Health and Environment Department to the Ground Water/Hazardous Waste Bureau, Environmental Improvement Division, New Mexico Health and Environment Department, Santa Fe, New Mexico.

6. Analytical report for water sample from La Bajada mine pit dated April 24, 1987 from the Radiochemistry Section of the Scientific Laboratory Division of the New Mexico Health and Environment Department to the Ground Water/Hazardous Waste Bureau, Environmental Improvement Division, New Mexico Health and Environment Department, Santa Fe, New Mexico.

7. Two printouts of STORET data (water analyses) from the Santa Fe River through June 8, 1994.

8. Eleven water analyses from the Energy Development Monitoring program from the USGS gaging station below La Bajada mine and La Bajada mine pit from 1974–79 reported to the Water Pollution Control Section, Environmental Improvement Division, Health and Environment Department, Santa Fe, New Mexico.

9. Report of analyses for soil samples Pecos and La Bajada mine site done by Radian Corporation, Radian Analytical Services, 10395 Old Placerville Rd., Sacramento, CA 95827 on August 2, 1990 for the Santa Fe National Forest.

10. Printout of La Bajada mine history apparently provided by Bill Hatchell, Chief, Bureau of Economic Geology, Mining and Minerals Division, State of New Mexico dated June 12, 1989.

11. Radiological survey of the La Bajada mine, New Mexico Radiation Protection Bureau, August, 1987

12. Memorandum from John M. Andrews, Jr., Environmental Scientist, Albuquerque District Mining Office, USFS concerning surface reclamation of site with attached water analyses.

13. La Bajada Quarry Fishery Investigation by Donald A. Duff, Wildlife Management Biologist and L. Eric Silvers, Hydrologist dated March 19, 1970, USFS. □