THE NATURAL DEFENSES OF COPPER FLAT SIERRA COUNTY, NEW MEXICO[1]

J. Steven Raugust[2] and Virginia T. McLemore

Abstract. Copper Flat, located in southwestern New Mexico, approximately 23 miles southwest of Truth or Consequences, is a porphyry copper deposit with associated gold, silver, molybdenum, and sulfide minerals. The stock contains a 75 million-year-old quartz monzonite breccia pipe forming the center of an eroded andesite strato-volcano. Quintana Minerals Corporation mined the property for three months in 1982 producing 7.4 million pounds of copper, 2,306 ounces of gold, and 55,966 ounces of silver. Mining activities ceased because of low copper prices. The mining equipment was dismantled and sold.

Since no mining activities have occurred since 1982, the site is an excellent field laboratory for studying the behavior of metals and sulfide minerals exposed with waste rock and tailings in the arid southwest. There is a 12.8-acre pit and pit lake on site that is located near the center of the breccia pipe. The entire study undertaken at Copper Flat focused on the potential impact of the pit lake, the waste rock piles, and the tailing impoundment on the local surface and groundwater quality; however, this paper focuses on the pit lake.

The pit lake has been sampled at least 65 times between 1989 and 1997. The pH of the lake is typically neutral to alkaline, with exception occurring in 1992 and 1993, where the pH dropped as low as 4.4. At least one intermittent seep from the pit wall has been sampled and the results reported a pH of 2.64, a total dissolved solid concentration (TDS) of 12,770 milligrams per liter (mg/L), and a sulfate concentration of 790 mg/L. The andesitic host rocks surrounding the ore body and groundwater inflow have a high acid buffering capacity as shown by the partial dissolution of calcite and the precipitation of gypsum and goethite. The alkalinity of the groundwater and host rocks quickly neutralizes and dilutes acidic discharges into the pit lake. Groundwater samples collected from monitoring wells located down gradient from the pit lake indicate groundwater chemistry is similar before and after the excavation of the pit.

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Introduction

History of Hillsboro Mining District. Ore was first discovered in the Hillsboro district, 23 miles southwest of Truth of Consequences and 5 miles northeast of Hillsboro (Fig. 1) in April 1877 along one of the veins that extend southwest of the Copper Flat stock (Jones, 1904; Dunn, 1982). Several exploration activities occurred at Copper Flat between 1952 and 1982 (Raugust, 2003). In 1982, the Copper Flat Partnership, Ltd. with Quintana Minerals Corporation (QMC) as the mine operator, developed and operated an open pit copper mine, including a 15,000-ton-per-day flotation mill and a tailings impoundment, at the Copper Flat site. The mine operated for 3 months before it ceased operation due to unfavorable economic conditions. During three months of operation, the mine produced 7.4 million pounds of copper, 2,306 ounces of gold, and 55,966 ounces of silver (Hedlund, 1985). The plant was placed on a "care and maintenance" status until 1986 when the facilities were sold and dismantled. The mining leases were returned to Inspiration and the site was partially reclaimed. Fig. 2 presents an aerial photograph that shows the contoured property in 1988.

Gold Express Corporation of Denver, Colorado acquired the property in 1991 and prepared a draft environmental assessment. In 1993, the Bureau of Land Management (BLM) notified Gold Express Corporation that an environmental impact statement (EIS) would be required due to concerns related to water resources issues (BLM, 1999).

In 1994, the Alta Gold Company (Alta Gold) of Henderson, Nevada acquired the Copper Flat Project from Gold Express. Alta Gold and consultant, ENSR of Fort Collins, Colorado prepared a Final Draft EIS in 1999. The EIS was never released because Alta Gold declared bankruptcy in 1999 (BLM, 1999). Hydro Resources, Inc. (Hydro Resources) of Albuquerque, New Mexico now owns the property (Hydro Resources, 2002).

Purpose of the Copper Flat Investigation. The purpose of this investigation was to compile and assess the existing ground- and surface-water quality in the vicinity of an existing mine pit lake, waste rock piles, and mine tailings impoundment at Copper Flat, Hillsboro district, New Mexico (Fig. 1). Data from existing historical reports and documents were reviewed, interpreted, and integrated. Raugust (2003) summarizes the potential for environmental impacts of the mine pit lake, waste rock piles, and tailings impoundment based on existing conditions (Raugust, 2003). This paper focuses only on the pit lake. Water quality data associated with this research have been incorporated into an electronic format that will become part of the New Mexico Mines Database (McLemore et al., 2003).

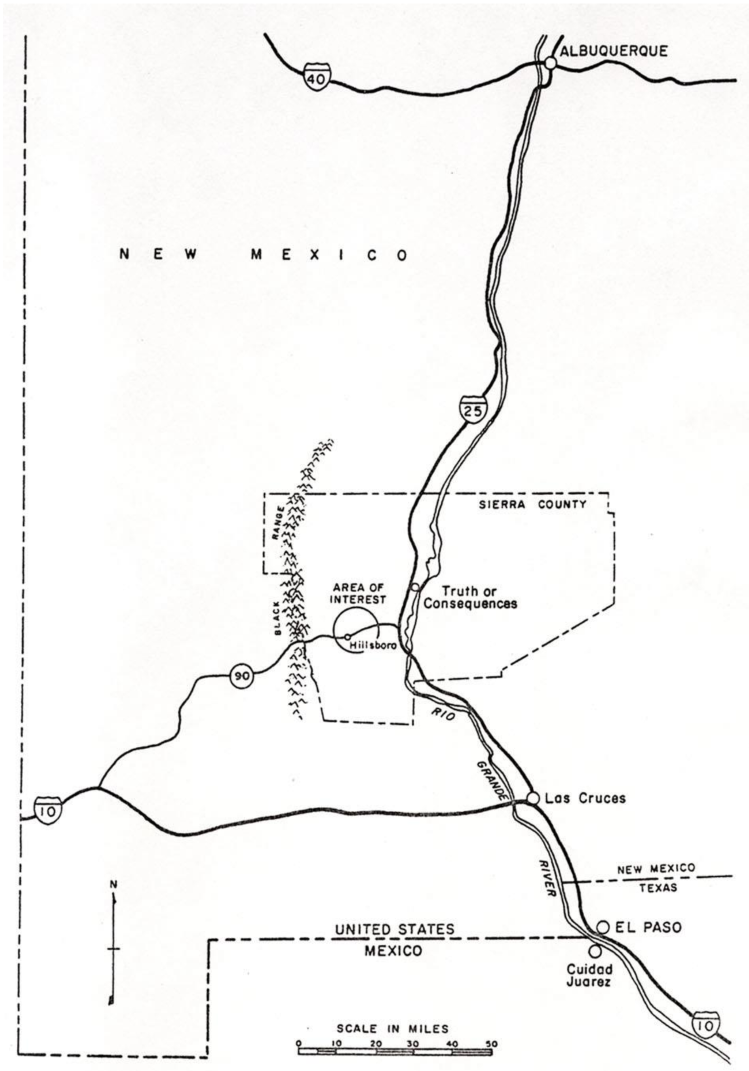

Figure 1. Site Location Map, Copper Flat, New Mexico (from BLM, 1978).

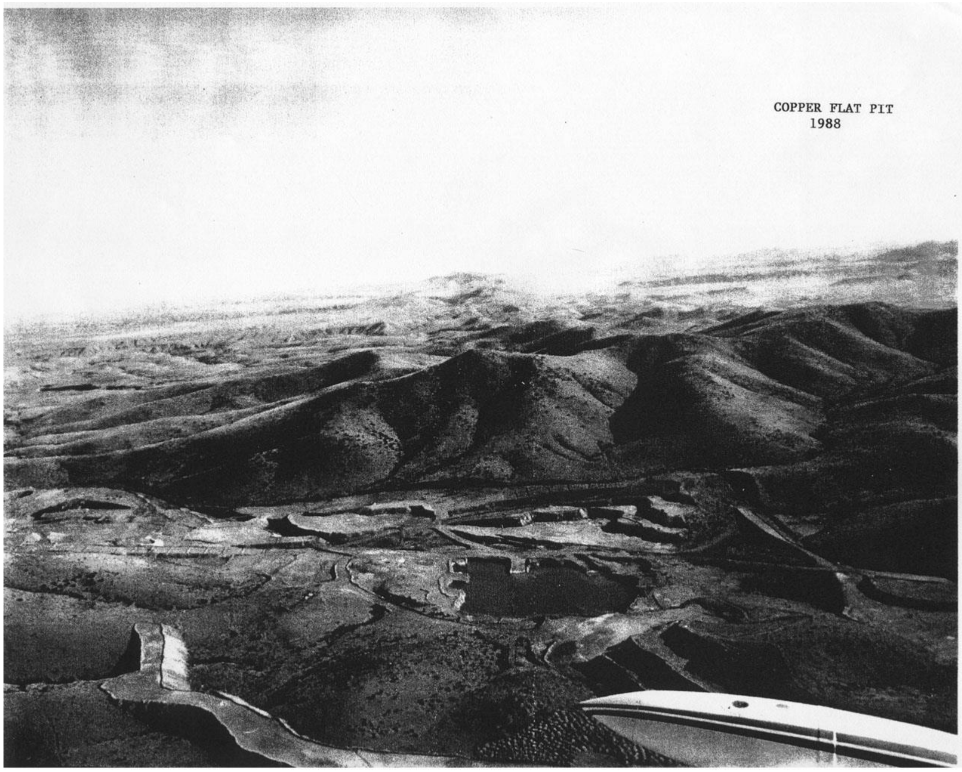

Figure 2. Copper Flat Mine Site, 1988, Copper Flat, New Mexico (from Alta Gold Corporation, 1995).

Study Area Investigations

Geology. The predominant geologic feature of the Hillsboro district is the Cretaceous Copper Flat strato-volcano (Fig. 3). This structure is eroded to a topographic low and is approximately 4 miles in diameter (Hedlund, 1985).

The core of the volcanic complex is intruded by a quartz monzonite stock, the Copper Flat Quartz Monzonite (CFQM). The CFQM stock has a surface expression of approximately 0.4 square miles and has been dated by the argon-argon ($^{40}Ar/^{39}Ar$) techniques to be 74.93 +/- 0.66 million years old (McLemore et al., 2000). The surrounding andesites also have been dated using argon-argon techniques to be 75.4 +/- 3.5 million years old (McLemore et al., 2000). At least 34 dikes radiate out from the quartz monzonite intrusion.

The Copper Flat porphyry copper deposit is one of the older Laramide porphyry copper deposits in the Arizona-Sonora-New Mexico porphyry copper belt and is characterized by low-grade hypogene mineralization that is concentrated within a breccia pipe in the CFQM stock.

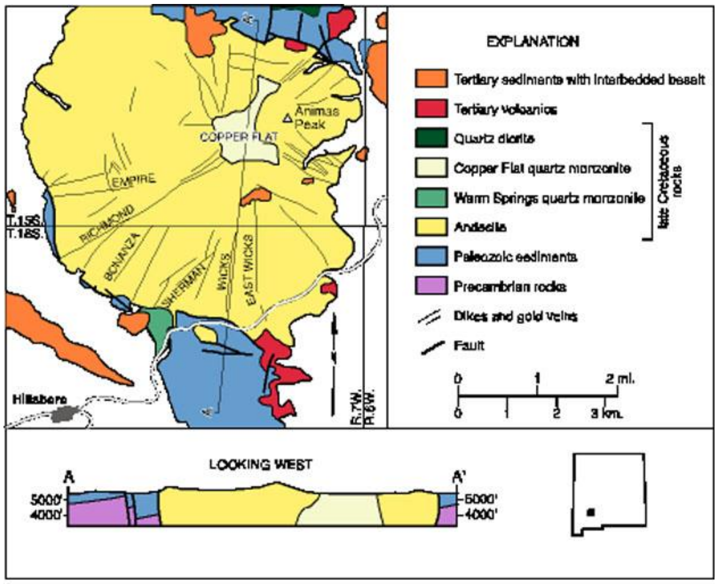

Figure 3. Geology of the Hillsboro District, Copper Flat, New Mexico (from McLemore et al., 2000, Dunn, 1982, Hedlund, 1985).

The CFQM is a medium to coarse-grained, holocrystalline, porphyritic intrusion that consists of potassium feldspar, plagioclase, hornblende, biotite, and trace amounts of magnetite, apatite, zircon, and rutile with local concentrations of pyrite, chalcopyrite, and molybdenite (McLemore et al., 2000). Current proven and probable reserves are 50,210,000 tons of ore containing 0.45 percent copper (Hydro Resources, 2002).

Surface Features. Surface features of the Copper Flat mine area include a mine pit lake, rock storage piles, the former mine and mill areas, and a tailings impoundment area. Land disturbed by the Copper Flat mine includes 358 acres of public land managed by the BLM and 331 acres of private lands (Fig. 4). The pit and the pit lake compose an area approximately 12.8 acres, with a depth of approximately 40 ft. The elevation of the pit bottom in 1986 was 5,380 ft. The surface water elevation in 1999 was 5,420 ft (BLM, 1999). The existing overburden waste rock piles have been identified as the north, west, south, and east (SRK, July 1998) (Fig. 4).

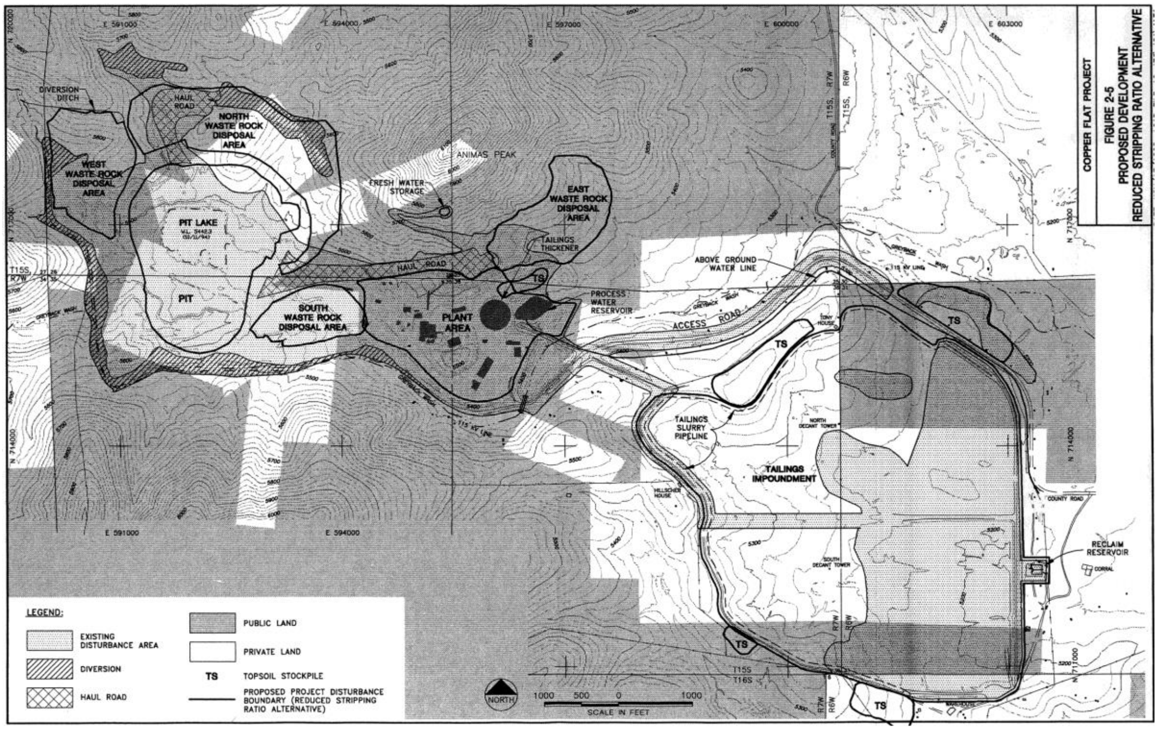

Figure 4. Copper Flat Mine Layout and Property Ownership, Copper Flat, New Mexico (from BLM, 1999, after SRK).

Mine Pit Lake Investigations. The water chemistry of the waters of the mine pit lake is influenced by:

- surface water discharge to the pit, occurring almost exclusively during times of heavy precipitation,
- geochemistry of the pit wall rock and surrounding rock storage piles, and
- groundwater recharge.

Mine Pit Lake and Grayback Gulch Surface Water. The pit lake has been sampled 65 times between 1989 and 1998 (BLM, 1999; Bakkom and Salvas, 1997) (Table 1). Samples were collected at various locations and depths. Typically, the samples were analyzed for pH, major cations and anions, and metals. Sample analytical suites varied and sometimes the samples were filtered and sometimes not.

Table 1. Pit lake water sample collection summary (BLM, 1999; Bakkom and Salvas, 1997).

Investigator	Number of Samples	Sampling Time Interval
New Mexico Environmental Improvement Board (NMEIB)	2	April 3, 1989
Gold Express	16	February 11, 1991-March 17, 1997
Alta Gold	31	May 24, 1994-October 1, 1997
Bakkom and Salvas	16	November 15, 1996 And October 8, 1997

There are several unnamed springs and seeps in the area west of the pit in the Animas Hills and along Grayback Gulch. As observed by Newcomer et al. (1993), these springs and seeps were flowing in March, but dry by early May and are therefore ephemeral. The springs west of the pit drain into the bowl-shaped Copper Flat area (Newcomer et al., 1993). In 1993, attempts were made to measure the discharge of these springs and seeps. Where possible, the flows were measured with a 60 degree-notch weir. In cases where the weir could not be used due to lack of flow or proper weir positioning, flow was estimated (Newcomer et al., 1993). Seeps and springs sampled by Newcomer et al (1993) are named SWQ-1, SWQ-2, SWQ-3, BG, BG-2, and Warm Spring (Fig. 5), and a seep denoted as Acid Drainage. This seep appears to have been an intermittent seep slowly discharging from a rock storage pile, however, the map showing the location of this seep is not presently available.

Surface-water samples were first collected from Grayback Gulch in 1977, prior to the mining activities of QMC (BLM, 1978). These surface water-samples appear to have been collected quarterly during 1976 and 1977, and sample locations are identified as Station A, where the creek enters the QMC property; Station B, approximately 300 ft east of the present mine pit rim; and Station C, where the creek leaves the QMC property (BLM, 1978). An accurate map showing the locations of Stations A, B, and C is not available.

In August of 1997, Alta Gold’s consultant, Steffen, Robertson, and Kirsten (SRK), observed and sampled seeps in the pit wall at locations PW-1 and PW-2 (Fig. 6). Also in August of 1997, SRK observed and sampled a seep from the toe of the West rock storage pile. These were the first recorded seeps in four years of site study by SRK (SRK, Dec., 1997, and July, 1998).

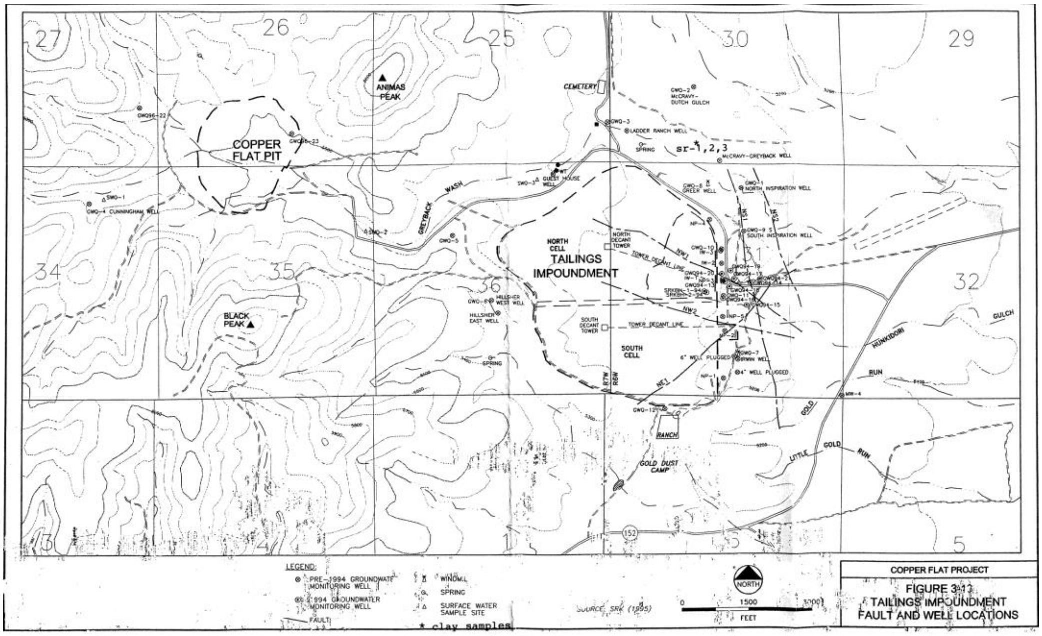

Figure 5. Well and Spring Locations, Copper Flat, New Mexico (from BLM, 1999, After SRK).

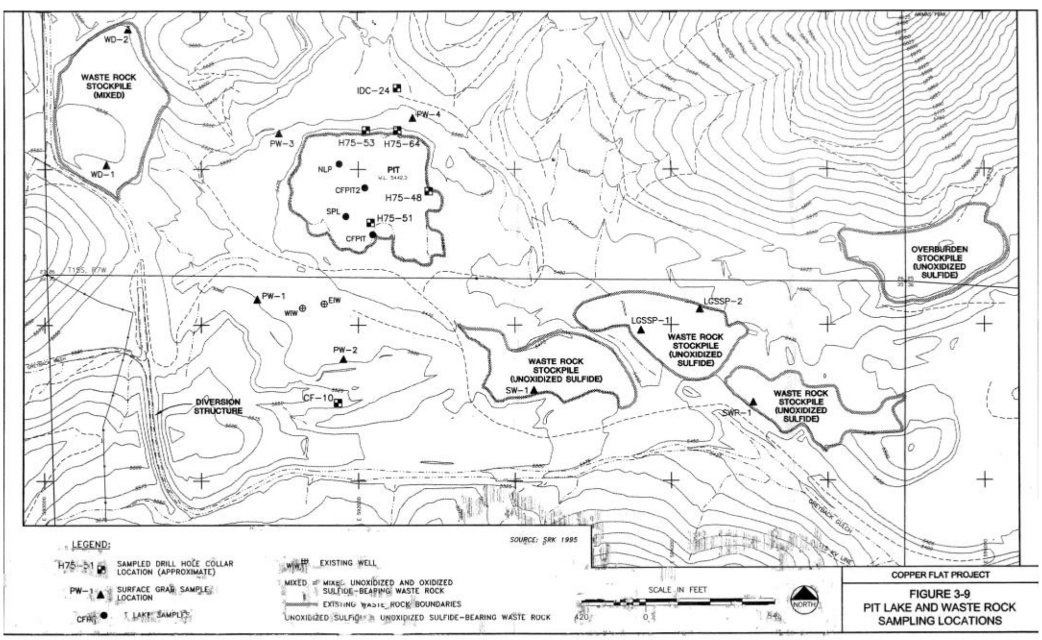

Figure 6. Pit Wall, Waste Rock, and Drill Core Locations, Copper Flat, New Mexico (from BLM, 1999, After SRK).

Mine Pit Lake and Groundwater. Prior to 1996, only one well was available for sampling groundwater in the vicinity of the pit lake. This monitoring well, GWQ-4, is located approximately one-half mile east of the existing pit. SRK drilled two new monitoring wells, each with dual completion, in 1996. Monitoring well GWQ96-22 was drilled up-gradient of the mine pit and well GWQ96-23 was drilled down-gradient (Fig. 5). GWQ96-22A is the shallow completion and GWQ96-22B is the deep completion of the GWQ96-22 well cluster. GWQ96-23A is the shallow completion and GWQ96-23B is the deep completion of the GWQ96-23 well cluster (SRK, Dec., 1997). Table 2 presents a summary of the sampling activities of GWQ96-22 and GWQ96-23 wells.

Table 2. GWQ96-22 and GWQ96-23 groundwater sample collection summary (BLM, 1999).

Investigator	Monitoring Well	Number of Samples	Sampling Time Interval
Alta Gold	GWQ96-22A	16	July 13, 1996- October 15, 1998
Alta Gold	GWQ96-22B	2	July 13, 1996 and February 5, 1997
Alta Gold	GWQ96-23A	16	July 14, 1996- October 15, 1998
Alta Gold	GWQ96-23B	4	July 14, 1996- April 1, 1997

Mine Pit Lake Investigative Results

Mine Pit Lake Surface Water. Pit lake water analyses per sample varied from pH only to anions, cations, and metals. Only copper concentrations exceeded the New Mexico Water Quality Control Commission (NMWQCC) water quality standards for surface water (NMWQCC, 2001). The NMWQCC surface water standard for livestock and wildlife is 0.5 milligrams per liter (mg/L). The pit lake was sampled and analyzed for copper 31 times (Fig. 7). Three times the concentration exceeded livestock and wildlife surface water standards; August 29, 1991, December 15, 1992, and February 12, 1993. The concentrations of copper that were reported from these three sampling events are 0.64 mg/L, 3.21 mg/L, and 2.6 mg/L, respectively.

Typically, water pH has been neutral to alkaline and indicates that the pit lake has been in a neutral to alkaline state for the last ten years (Fig. 8). However, from March 1992 to October

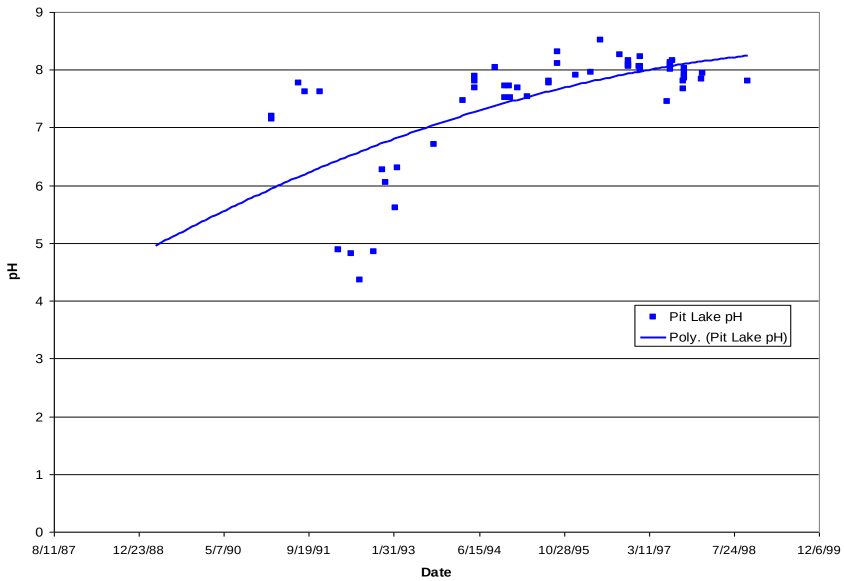

Figure 7. Copper Concentrations in the Mine Pit Lake, Copper Flat, New Mexico.

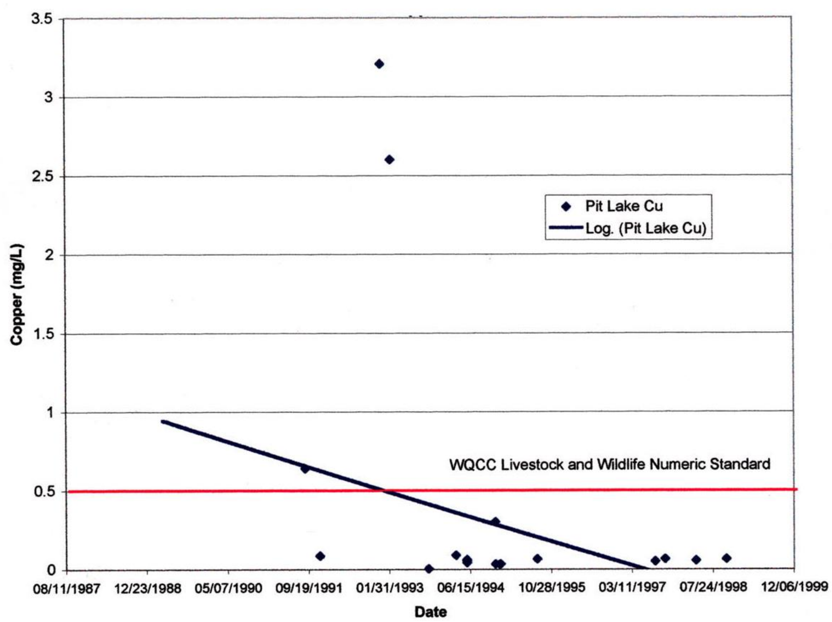

Figure 8. pH in the Mine Pit Lake, Copper Flat, New Mexico.

1992, the pH of the pit lake dropped below 5, with a low of pH = 4.4 in July 1992 A steady increase in the TDS concentrations of the pit lake was observed from April 1989 to October 1997 from approximately 3500 mg/L to 5850 mg/L (Fig. 9). A gradual increase in sulfate in the pit lake waters over the same time from 2340 mg/L to 4300 mg/L (Fig. 10) was also recorded. The TDS and sulfate results show some water quality degradation; however, the NMWQCC does not

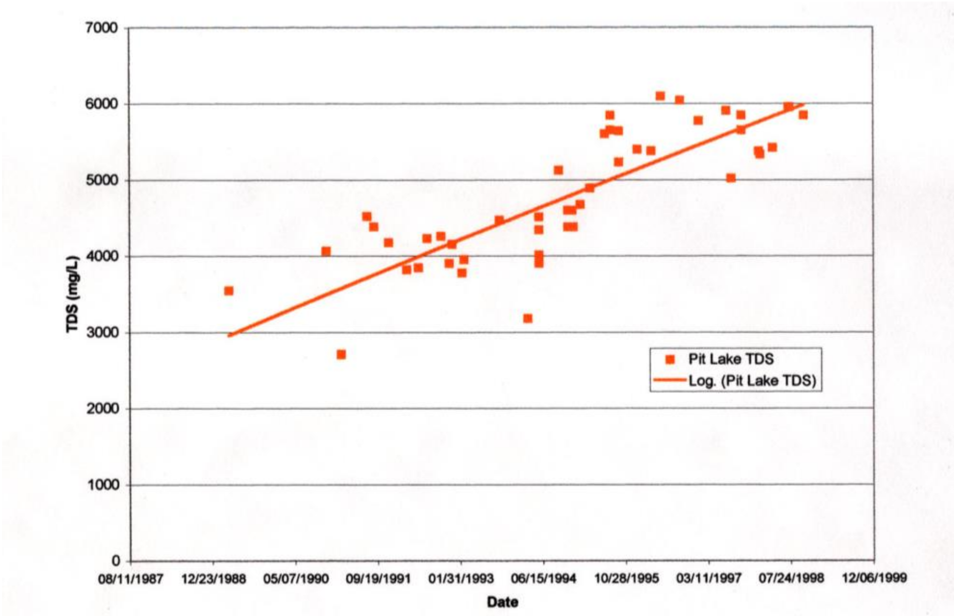

Figure 9. Total Dissolved Solid Concentrations in the Mine Pit Lake, Copper Flat, New Mexico.

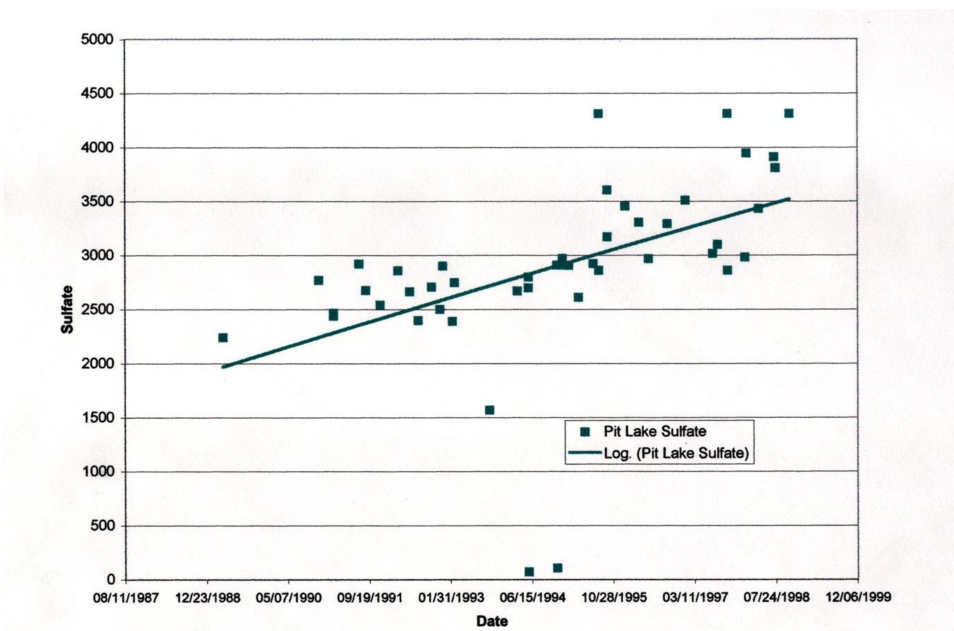

Figure 10. Sulfate Concentrations in the Mine Pit Lake, Copper Flat, New Mexico.

regulate either TDS or sulfate in New Mexico surface waters. The chemistry of the pit lake does not change significantly laterally or with depth (SRK, Dec. 1997).

Sources of water to the pit lake are groundwater inflow, direct precipitation, and surface runoff. The major sources of dissolved solids are from reactions between oxidizing pit lake waters and reduced minerals in the pit walls, surface water runoff, and evaporation of the pit lake water. The remainder of the sulfate must be derived directly from sulfide oxidation or from the dissolution of secondary minerals such as jarosite and gypsum (SRK, Dec. 1997).

Because the pit lake is a topographic low, it is a hydraulic sink. Historic seeps have been described and sampled along the mine pit wall and rock storage piles. Newcomer et al. (1993) described a seep initiating from a sulfide-bearing rock pile having a discharge rate less than 1 gpm. This seep was sampled on May 7, 1993, but the location of this seep is uncertain because the associated sample location map is not available. However, SRK identified a small area of sulfate precipitation near the base of the East rock storage pile, which they suggest is the site of the seep that Newcomer reported (BLM, 1996) (Seep 1). Table 3 summarizes the pH, TDS and sulfate concentrations of the seep water samples. Another small seep was identified by SRK during a site visit in 1997. This seep flowed into a small, acidic, ferruginous pool located along the southern pit wall (Seep 2). A pit wall sample was collected near this area and denoted as PW-1 (Fig. 6) (SRK, Dec. 1997). This seep, observed in August of 1997, was the first recorded seep in the pit wall in four years of study by SRK and is believed to be the result of unusually high precipitation events during June and July 1997 (SRK, Dec. 1997). A second pit wall seep was sampled by SRK in August 1997, denoted as PW-2 (Fig. 6) (Seep 3). SRK collected a seep sample from the West rock storage pile also in August of 1997 (Seep 4).

Table 3. Summary of seep water analyses for pH, TDS, and sulfate (BLM, 1999, SRK, Dec. 1997, SRK, July, 1998).

Seep	Investigator	Date	pH	TDS (mg/L)	Sulfate (mg/L)
Seep 1	Newcomer et al./Gold Express	May 7, 1993	1.9	17,020	10,000
Seep 2	SRK/Alta Gold	August 1997	2.64	11,430	16,850
Seep 3	SRK/Alta Gold	August 1997	8.16	5,020	3,100
Seep 4	SRK/Alta Gold	August 1997	3.03	25,440	22,100

Greyback Gulch Surface Water. Greyback Gulch is an ephemeral stream that is dry most of the year except for runoff from storm events. The earliest surface water sampling was in 1976 and 1977 in support of the environmental assessment prepared for QMC. These surface water samples pre-date the 1982 mining activities by QMC, but post-date less extensive historical mining activities. Surface water results are available for January, March, and July 1977. They were collected from 3 stations described as Station A, where the creek enters the QMC property; Station B, approximately 300 feet east of the estimated mine rim; and Station 3, where the creek leaves the QMC property (BLM, 1978). The water quality of these samples is good compared to post-mining samples collected from similar locations.

Three surface water locations have been sampled frequently in Grayback Gulch. These locations are SWQ-1, upstream of the mine pit; SWQ-2, downstream of the pit in the former plant area; and SWQ-3, north of the tailing dam (Fig. 5). The SWQ-1 location was sampled five times between 1982 and 1993, SWQ-2 35 times between 1982 and 1998, and SWQ-3 26 times between 1991 and 1998.

All pH measurements at locations SWQ-1, SWQ-2, and SWQ–3 were neutral to alkaline (Fig. 11). Figure 12 presents the TDS measured in these three locations. Samples collected from SWQ-1 were all less than 1000 mg/L. A logarithmic trend line placed through the five points of the SWQ-1 data set indicates a gradual increase in TDS over time. Samples collected from SWQ-2 ranged from 1000 mg/L in the early 1980s to as high as approximately 4500 mg/L in the late 1990s. A logarithmic trend line placed through the 35 points of the SWQ-2 data set indicates a more pronounced increase in TDS over time. The 26 points from the SWQ-3 data set ranged from 1866 mg/L to 4432 mg/L. Sample frequencies and dates for sulfate are the same as the TDS (Fig. 13). Sulfate results for SWQ-1 were all less than 325 mg/L and the trend line increases slightly over time. The scatter of the data sets from SQW-2 and SWQ-3 was similar to the TDS results. Sulfate concentrations in waters sampled from SWQ-2 ranged from 445 mg/L to 2566 mg/L. The sulfate trend line increases with time. Sulfate concentrations in waters sampled from SWQ-3 ranged from 952 mg/L to 2382 mg/L, and sulfate appears to increase with time.

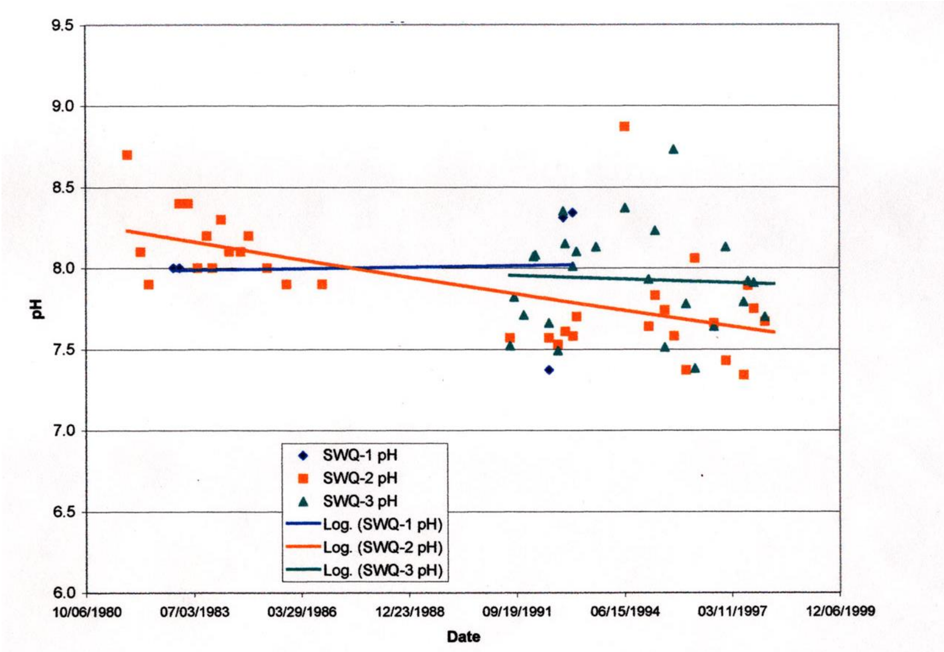

Figure 11. pH from Greyback Gulch Surface Water, Copper Flat, New Mexico.

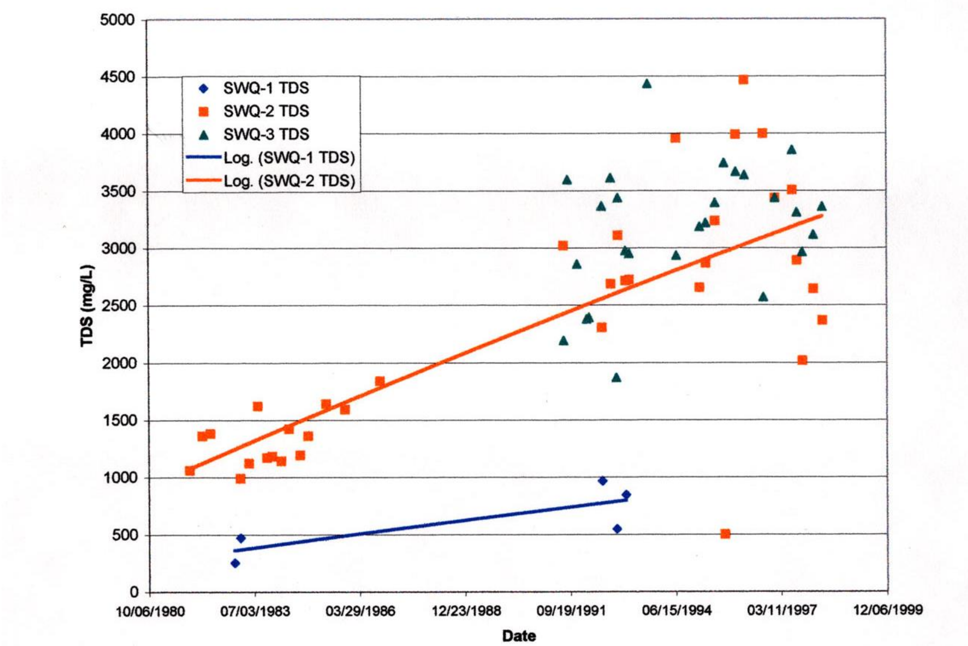

Figure 12. TDS Concentrations from Grayback Gulch Surface Water, Copper Flat, New Mexico.

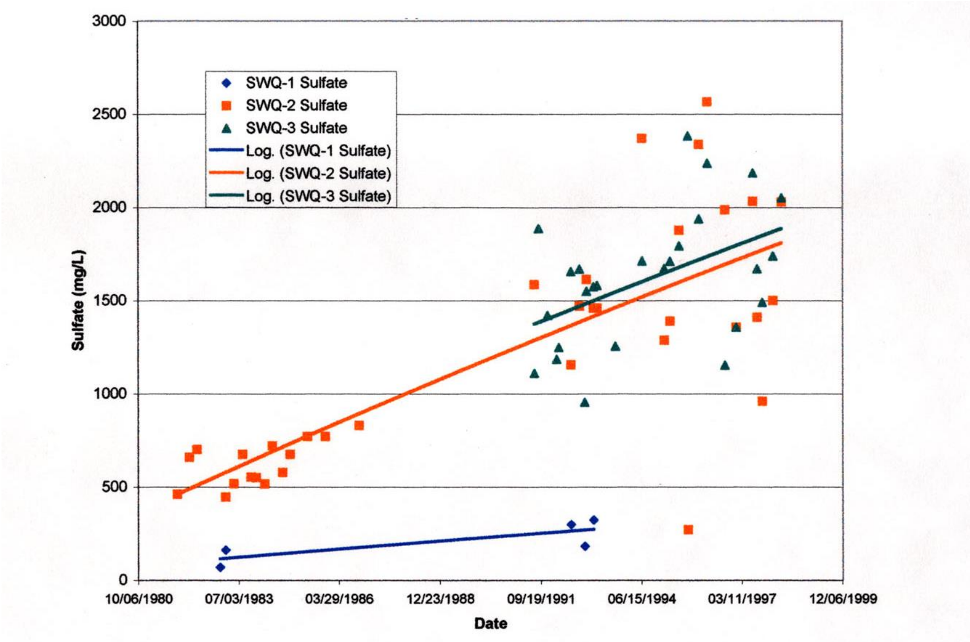

Figure 13. Sulfate Concentrations from Grayback Gulch Surface Water, Copper Flat, New Mexico.

Groundwater. A set of nested monitoring wells exists up gradient of the mine pit lake, GWQ-96-22A (shallow) and GWQ-96-22B (deep), and a set of nested wells exist down-gradient, GWQ-96-23A (shallow) and GWQ-96-23B (deep). The down-gradient wells are referred to as GWQ-5 and GWQ-6. Well construction details and surveyed location are not available for these wells; however, they are shown on Figure 5.

Fig. 14, 15, and 16 show the results of groundwater sample results for pH, TDS, and sulfate respectively. The wells were sampled several times from 1996 to 1998 (Table 2). The pH is neutral in the GWQ-96-22A and slightly alkaline in GWQ-96-22B (Fig. 14). TDS is below the NMWQCC groundwater numeric standard of 1000 mg/L (NMWQCC, 1995) (Fig. 15). TDS concentrations found in the samples collected from both GWQ-96-22A and B are below 700 mg/L. TDS concentrations found in groundwater sampled from GWQ-96-23A and B also are less than 1000 mg/L. However, there may be a trend showing that TDS is increased gradually over time in the shallow down-gradient well. Sulfate concentrations are below the NMWQCC numeric standard of 600 mg/L in both shallow and deep up-gradient and down-gradient wells (Fig. 16). In groundwater sampled from GWQ-96-22A, sulfate concentrations do not exceed 300 mg/L. In GWQ-96-22B, the single sulfate concentration was found to be 79 mg/L. In groundwater sampled from GWQ-96-23A, sulfate concentrations do not exceed 450 mg/L. In

GWQ-96-23B, the sulfate concentrations were found to be less than 240 mg/L. However, the sulfate concentrations from the down-gradient shallow well indicate that the sulfate concentrations are gradually increasing over time.

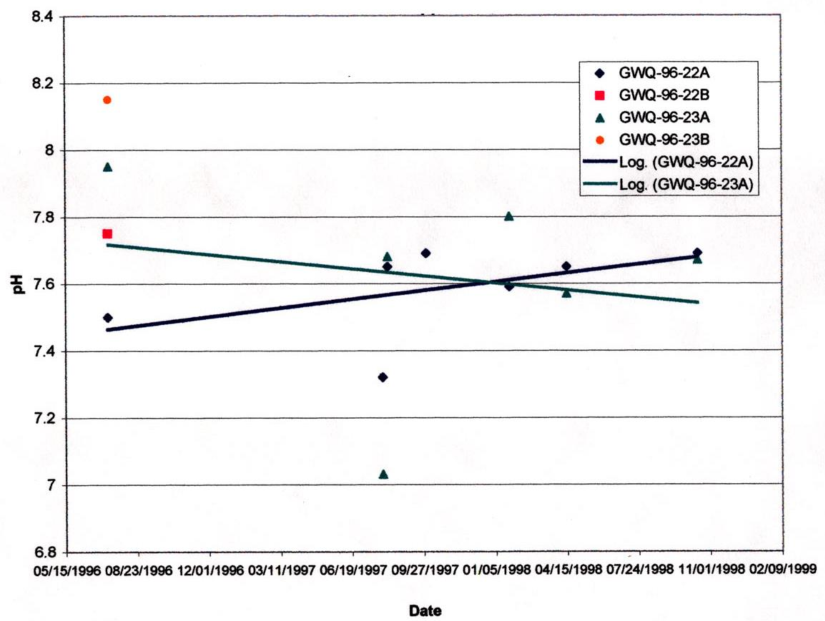

Figure 14. Groundwater pH, Mine Pit Vicinity, Copper Flat, New Mexico.

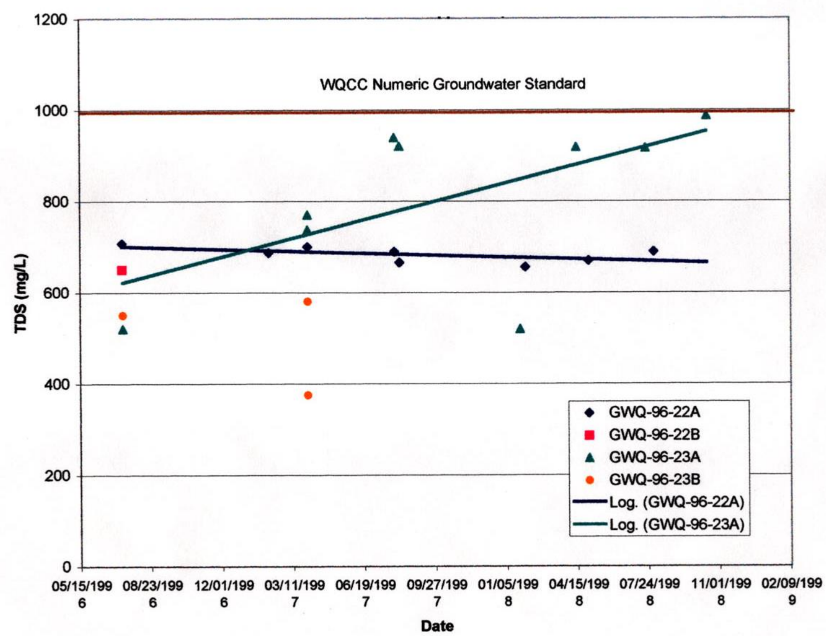

Figure 15. Groundwater TDS Concentrations, Mine Pit Vicinity, Copper Flat, New Mexico.

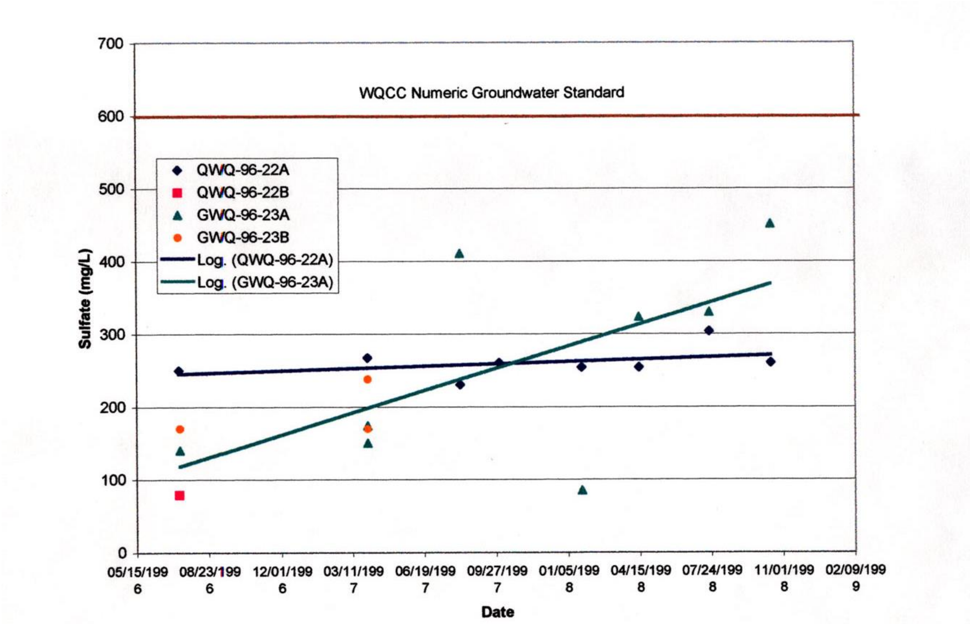

Figure 16. Groundwater Sulfate Concentrations, Mine Pit Vicinity, Copper Flat, New Mexico.

Conclusions

Surface Water Quality, Mine Pit Lake. The water quality of the pit lake does not exceed NMWQCC surface water numeric standards for livestock and wildlife as of 1998. Historically, only copper concentrations exceeded the NMWQCC numeric standard of 0.5 mg/L. The most recent surface water sample to exceed this standard was collected in February 1993, with a concentration of 2.6 mg/L.

Since 1994, pH measurements have consistently remained neutral to alkaline (Fig. 8). Copper has not exceeded the numeric standard for livestock and wildlife since 1993 (Fig. 7). Although sulfate and TDS are gradually increasing over time; there are no numeric surface water quality standards for these parameters (Figs. 9, 10). The drop in the elevation of the surface of the lake in recent years may explain the increase in TDS. From 1993 to 1997, the water level in the lake dropped approximately 10 ft, which has caused the evaporative concentration of salts in the pit lake (SRK, Dec. 1997).

Analysis of the anions and cations from pit water sample data collected on April 3, 1989, September 21, 1995, and July 21, 1998 indicate that even though the water quality is poor, the pit water does not exceed any livestock or wildlife standards. Figure 17 presents a Piper diagram showing that the pit water has consistently high contents of calcium, chloride, and sulfate relative to surface water in Greyback Gulch and local groundwater.

The surface water chemistry found in the lake can be explained by:

- The inflow of neutral to alkaline groundwater has relatively low concentrations of TDS and sulfate (SRK Dec. 1997).
- The composition of the host rock is acid buffering. The composition of the host rocks includes approximately 5 percent calcite, 30 percent feldspar, and one percent other carbonate minerals. The dissolution of the calcite in the host rocks and the precipitation of gypsum and geothite around the pit lake indicates that acid buffering is occurring (SRK Dec. 1997).
- The typical volume of disseminated pyrite in the rocks surrounding the pit lake is 1 to 5 percent. The pyrite is disseminated throughout the groundmass of the host rock limiting access of water and air to allow oxidation. In addition the pyrite is coarse grained, which limits the surface area pyrite crystal, when it is exposed to oxidation (SRK, Dec. 1997).
- Low precipitation in the area is probably the most important reason for the relatively good quality of the pit lake surface water, with respect to pH and concentration of metals. Low precipitation limits the flushing of the oxidized products into the environment via runoff, seep, and discharges (Chavez, 2003).

The net effect is that while sulfide oxidation is occurring, the transport of the oxidation products is slow, except locally in the Copper Flat area.

Surface Water Quality, Greyback Gulch and Local Seeps. Surface water samples collected from locations along the ephemeral Greyback Gulch, SWQ-1, SWQ-2, and SWQ-3 indicate higher quality runoff upstream of the mine site (SWQ-1) than downstream (SWQ-2 and SWQ-3). Although pH measurements remain neutral to alkaline in samples collected from both upstream and downstream location (Fig. 11), TDS and sulfate concentrations are greater downstream and have increased over time (Figs. 12, 13). In SWQ-2, downstream of the mine pit, nitrate has exceeded domestic use NMWQCC numeric standard (10 mg/L) four times from 1981 to 1998, with a maximum nitrate concentration of was 14.5 mg/L. No numeric standard for livestock or wildlife has ever been exceeded in samples from these three locations.

The Piper diagram (Fig. 17) indicates that the downstream surface water in Greyback Gulch has higher proportions of calcium, chloride, and sulfate than upstream surface water for one set of data collected from SWQ-1, SWQ-2, and SWQ-3 in March/April 1993. The upstream surface water has a higher proportion of bicarbonate. This may indicate that some of the alkalinity upstream is being consumed by acid via neutralization as surface water move over and through the Copper Flat ore body.

Possible reasons for the lower surface water quality in the downstream sample locations in Greyback Gulch are:

- evaporative concentration of dissolved load of anions and cations,
- gypsum dissolution, which is regionally widespread,
- water-mineral interactions within the copper-porphyry deposit, and
- disturbance from the construction of roads and rock storage piles and stream diversion (SRK, Dec. 1997).

There have been a few intermittent seeps from the pit wall and rock storage piles. Typically, these seeps do not flow except following heavy precipitation. When they do flow, they are typically acidic and have high concentrations of anions, cations, and metals. Historically seeps have been identified on the southern wall of the mine pit (PW-1 and PW-2) and from the East and West waste rock piles (Fig. 6). Typically, surface water from these seeps are characterized with pH concentrations of 2 to 3, except PW-2 with a pH of 8.16, high TDS concentrations of 5,000 to 25,000 mg/L, and high sulfate concentrations of 3,000 to 22,000 mg/L. Concentrations of surface water from these seeps have exceeded NMWQCC surface water livestock and wildlife numeric standards for aluminum, cadmium, copper, cobalt, selenium, and zinc.

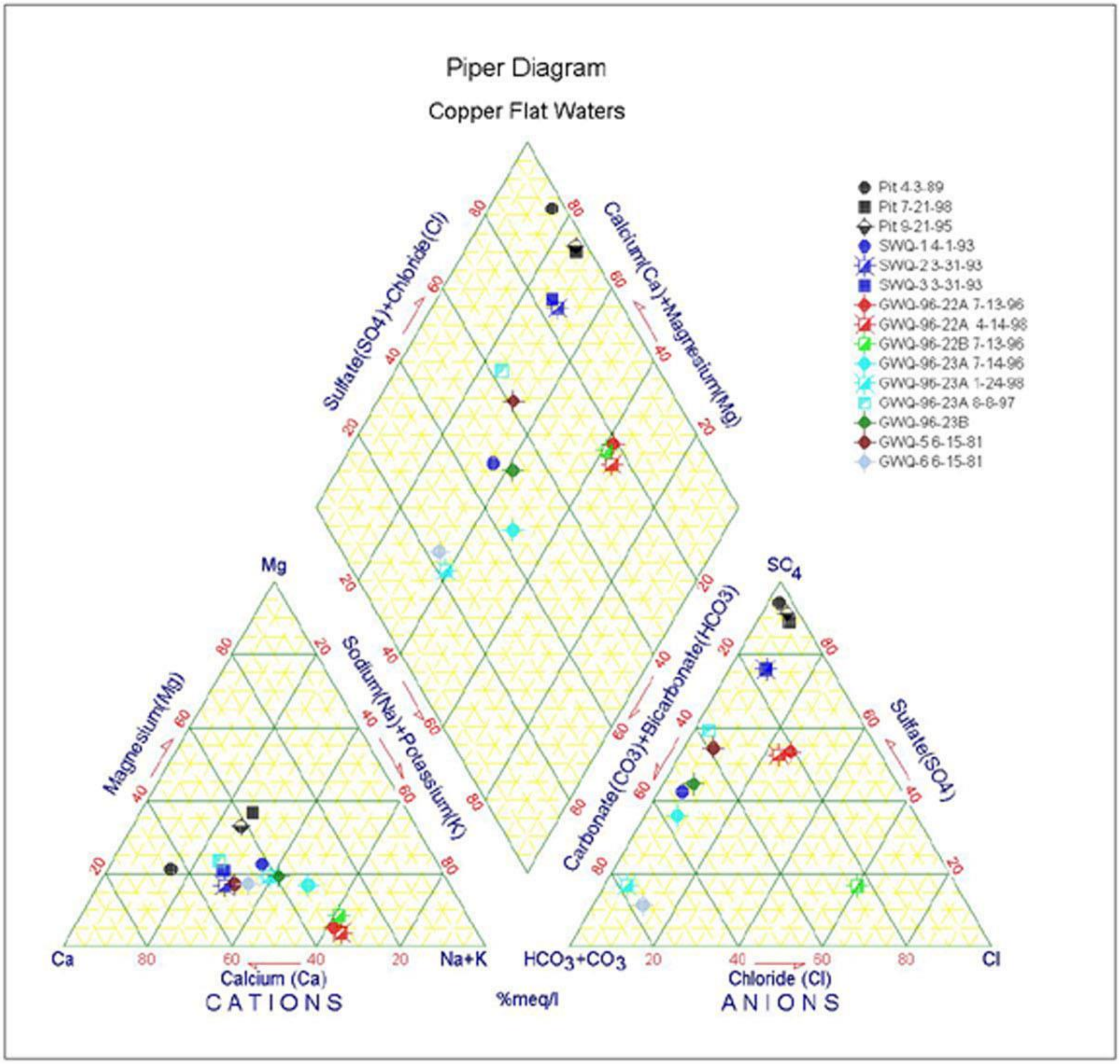

Figure 17. Piper Diagram, Copper Flat Surface and Groundwater, Copper Flat, New Mexico.

Ground Water Quality. The pH measurements both up- and down-gradient range from approximately 7 to 8.2 (Fig. 14). TDS is less than the NMWQCC numeric groundwater standard of 1,000 mg/L (Fig. 15). However, the TDS concentration of the groundwater down-gradient of the mine pit is increasing gradually over time and approaching the numeric standard. Sulfate concentrations also are lower than the NMWQCC numeric groundwater standard of 600 mg/L (Fig. 16); however, the sulfate concentrations in the down-gradient well are increasing with time.

An appropriate conceptual model of the Copper Flat mine pit lake is that of a local hydraulic sink. Figure 18 presents groundwater contours below the mine area (BLM, 1999, ABC, 1997). Historical sampling of well GWQ-5, further to the east (Fig. 5), indicate that water quality in the vicinity may have been affected naturally by the presence of the ore body prior to mining in 1982 (BLM, 1999). Concentrations of sulfate sampled in 1981 by SHB from GWQ-5 range from 477 mg/L to 575 mg/L, which is higher than the sulfate concentrations in well GWQ-96-23A immediately down-gradient of the pit (<450 mg/L). Concentrations of TDS also sampled in 1981 by SHB from GWQ-5 range from 1,070 mg/L to 1,260 mg/L, which is higher than the TDS concentrations in the well GWQ-96-23A (<1,000 mg/L).

The Piper diagram (Fig. 17) indicates that the groundwater up gradient of the mine pit (well GWQ-96-22A and B) is high quality with relatively high proportions of chloride and sulfate. Groundwater down-gradient of the pit (GWQ-96-23A and B) shows relatively higher proportions of bicarbonate and calcium and relatively lower proportions of sulfates. Pre-Quintana mining (June 15, 1981) groundwater data collected from down-gradient wells GWQ-5 and GWQ-6 show similar anions and cation distributions to post Quintana mining activities (1996 and 1998). This indicates that groundwater quality down-gradient of the ore body reflects the natural weathering of the Copper Flat porphyry system.

Recommendations

Mine Pit Lake. The mine pit lake appears to be geochemically stable under existing conditions. Presently, the surface water appears to be fit for livestock and wildlife. Although the surface water does not exceed NMWQCC domestic or irrigation standards, it is not recommended for that use because of occasional geochemical variability from irregular, heavy precipitation. Such heavy precipitation and water level fluctuation does affect the chemistry of pit lake water; therefore, periodic monitoring of water quality is reasonable, especially because it is currently a source of water for livestock and wildlife.

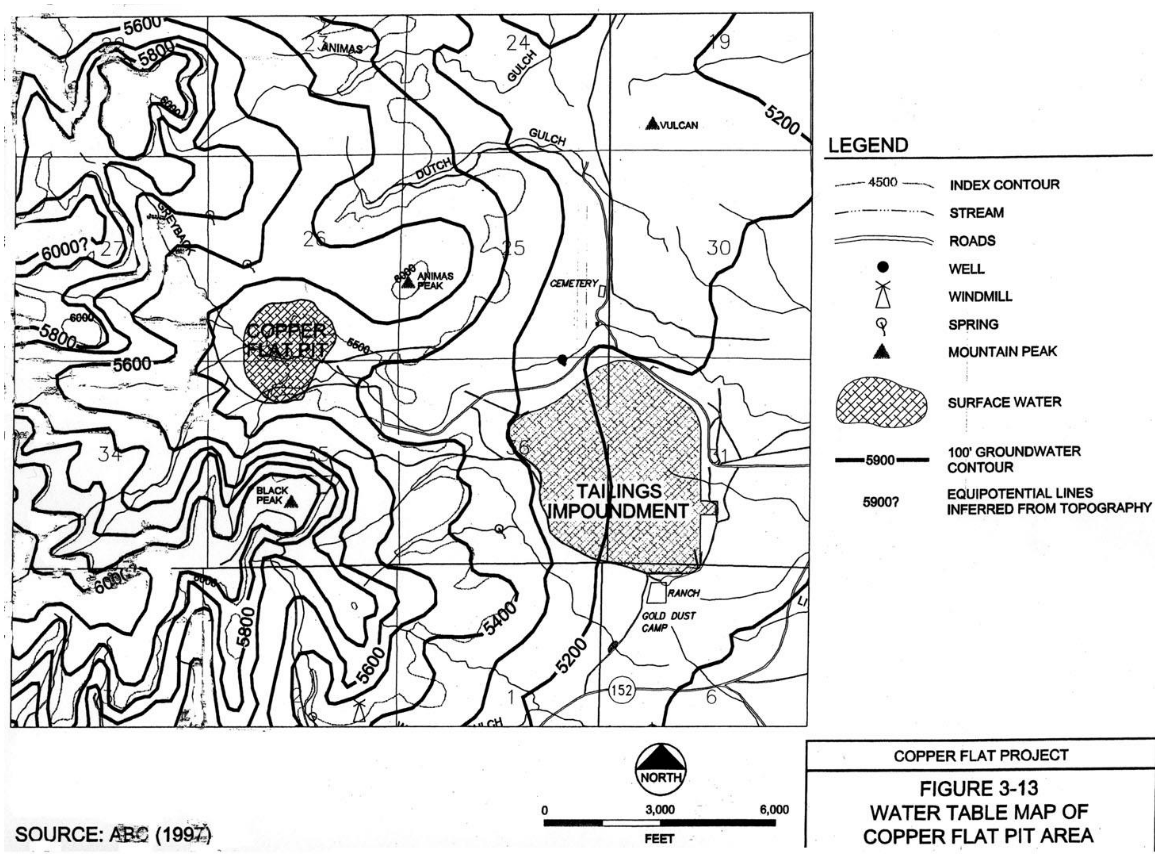

Figure 18. Groundwater Contours Beneath the Mine Site, Copper Flat, New Mexico (from BLM, 1999, after Adrian Brown Consultants).

Surface Water Quality. The surface water quality in Greyback Gulch does not exceed any NMWQCC numeric standards. However, nitrate has been exceeded in the past at location SWQ-2. The quality of the surface water is lower downstream of the mine pit; however, the contributing factors to the water quality degradation is probably from naturally occurring processes such as evaporation and weathering exposure to the copper porphyry ore body. Certain re-contouring, re-vegetation, and soil amendments might improve the surface water quality in downstream reaches, but such actions are difficult to justify considering the current land use of cattle grazing and potential mineral development.

Low water quality seeps only occur during times of high precipitation. Although infiltration of rainwater might be arrested by significant restoration program of re-contouring, re-vegetation, and soil amendments, most of the documented seeps drain into the bowl-shaped mine pit lake.

Groundwater. Groundwater quality down-gradient of the mine pit deteriorated with respect to sulfate and TDS from 1996 to 1998; however, more time-based sampling data would be required to ascertain whether this is a real trend or transient phenomenon. Annual monitoring of monitoring wells GWQ-96-22A, GWQ-96-22B, GWQ-96-23A, GWQ-96-23B, GWQ-5, and GWQ-6 would be very useful in establishing groundwater quality trends over time. It appears from the existing data that the ore body is likely the most significant contributor to water quality down-gradient of the pit, and that additional data would be useful in evaluating this hypothesis.

References

Bakkom, E. and Salvas, S., 1997, Copper Flats reclamation plan, phase I, senior thesis presented to the Departments of Mineral and Environmental Engineering, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

BLM, 1978, Environmental assessment record on Quintana Minerals Corporations' proposed open pit copper mine at Copper Flat, Sierra County, New Mexico, United States Bureau of Land Management, Las Cruces, New Mexico.

BLM, 1996, Draft environmental assessment, Copper Flat Project, United States Department of the Interior, Bureau of Land Management, Las Cruces, New Mexico, Prepared by Steffen, Robertson, and Kirsten, Inc., Reno, Nevada.

BLM, March 1999, Preliminary final, environmental impact statement, Copper Flat Project, United States Department of the Interior, Bureau of Land Management, Las Cruces, New Mexico, Prepared by ENSR, Fort Collins, Colorado.

Dunn, P.G., 1982, Geology of the Copper Flat porphyry copper deposit, Hillsboro, Sierra County, New Mexico. *In* Advances in Geology of the Porphyry Copper Deposits, Southwestern North America: University of Arizona Press, Tucson, Arizona, p. 313-325..

Hedlund, D., 1985, Economic geology of some selected mines in the Hillsboro and San Lorenzo Quadrangles, Grant and Sierra Counties, New Mexico. U. S. Geological Survey, Open File Report OF-85-0456, 76 p.

Hydro Resources, Inc., 2002, Copper Flat, unpublished report by Hydro Resources, Inc., Albuquerque, New Mexico.

Jones, F.A., 1904, New Mexico Mines and Minerals, Santa Fe, New Mexico Printing Company, p. 349 p.

McLemore, V.T., Raugust, J.S., Hoffman, G.E., Wilks, M., Johnson, P., Krueger, C.B., and Jones, G.K., 2003, Use of the New Mexico Mining Database in reclamation studies. *In* Working together for innovative reclamation, Joint Conference of the 9th Billings Land Reclamation Symposium, and the 20th Annual Meeting of the American Society of Mining and Reclamation, Billings, Montana, p. 795-808.

https://doi.org/10.21000/JASMR03010795

McLemore, V.T., Munroe, E.A., Heizler, M.T., and McKee, C., 2000, Geology and evolution of the mineral deposits in the Hillsboro District, Sierra County, New Mexico. *In* J.K. Cluer et.al (ed). Geology and Ore Deposits 2000: The Great Basin and Beyond: Geological Society of Nevada Symposium, Reno/Sparks, May 2000, p 643-649.

Newcomer, R.W., 1993, Hydrologic assessment, Copper Flat Project, Sierra County, New Mexico, John W. Shomaker, Inc., Albuquerque, New Mexico.

New Mexico Water Quality Control Commission, 1995, Title 20, Chap 6, Part 2, ground and surface water protection, New Mexico Water Quality Control Commission, Santa Fe, New Mexico.

New Mexico Water Quality Control Commission, 2001, Standards for interstate and intrastate surface waters, New Mexico Water Quality Control Commission, Santa Fe, New Mexico.

Raugust, J.S., 2003, The natural defenses of Copper Flat, Sierra County, New Mexico, New Mexico Bureau of Geology and Mineral Resources Open File Report No. 475, New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico.

Steffen, Robertson and Kirsten, Inc., December 1997, Copper Flat mine, compilation of pit lake studies, Steffen, Robertson and Kirsten, Inc, Reno, Nevada.

Steffen, Robertson and Kirsten, Inc., July 1998, Copper Flat mine, waste rock management plan, Steffen, Robertson and Kirsten, Inc, Reno, Nevada.