Montana Bureau of Mines and Geology

The Flooding of Butte's Underground Mines and the Berkeley Pit:
Water-Quality Monitoring Through 2001

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Region VIII

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Section 1.0 Introduction

Monitoring of the water levels and water quality of several shafts and the Berkeley pit began in 1982 after mining was shut down. Various Federal and State agencies including the Montana Department of State Lands (now the Montana Department of Environmental Quality), the U.S. Environmental Protection Agency, the mining companies, and the Montana Bureau of Mines and Geology have collected data from shafts, monitoring wells, domestic wells, surface water sites, and drill holes associated with the Butte Mine Flooding Operable Unit of the Clark Fork River National Priorities List (NPL) site. The record of decision (ROD) for the Butte Mine Flooding Operable Unit requires a periodic review of water-level and water-quality data. This report is an update of the water-quality monitoring and is supplemental to previous reports which include:

Duaime, T.E., Metesh, J.J., Keschen, M.K., and Dunstan, C.B., 1998, The Flooding of Butte's Underground Mines and Berkeley Pit: 15 Years of Water-Level Monitoring (1982-1998), Montana Bureau of Mines and Geology Open-file Report 376, 116p.

Metesh, J.J., and Duaime, T.E., 2000, The Flooding of Butte's Underground Mines and Berkeley Pit, 18 Years of Water-quality Monitoring (1982-1999), Montana Bureau of Mines and Geology Open-file Report 409, 79p. with separate appendix.

Duaime, T.E., and Metesh, J.J., 2000, The Flooding of Butte's Underground Mines and Berkeley Pit, Butte Mine Flooding Operable Unit, Annual Water-level Update, 1998-1999, Montana Bureau of Mines and Geology Open-file Report 410, 88p.

Duaime, T.E., and Metesh, J.J., 2001, The Flooding of Butte's Underground Mines and Berkeley Pit, Butte Mine Flooding Operable Unit, Annual Water-level Update, Montana Bureau of Mines and Geology Open-file Report 435, 94p.

This report relies on information and concepts presented in the more comprehensive report by Metesh and Duaime (2000), and is meant to provide an update of monitoring activities since 1999.

Two principal aquifers have been impacted by mining in the area: 1) the bedrock aquifer which includes both the mineralized and unmineralized rock and, 2) the alluvial aquifer which overlies the bedrock in the small valleys east and south of the Butte hill. Ground water was encountered in early mine shafts at depths of 20 to 100 feet below the surface (Hydrometrics, 1982). As the mines became deeper and more extensive, pumping stations were required to dewater the entire mining district. Sustained pumping rates were as high as 5,000 gallons per minute (Duaime, 1998). When the pumps were shut off in 1982, flooding began immediately and water levels have continued to rise to the present. For various reasons related to safety and economics, the Butte mines had evolved from dozens of isolated, individual mines to a large network of interconnected workings. Again for economic reasons, in the 1950's, some of the workings were bulkheaded to "separate" the mines. Various terms have been used to describe these areas of the Butte mines, but the most common are: East Camp, West Camp, and Outer Camp.

The Berkeley pit, which began in 1955, is the dominant hydrologic feature of the Butte area (figure 1). About 18 months after flooding began in 1982, ground-water levels reached the bottom of the pit. Since 1982, the pit has been the hydraulic sink for ground water in the underground workings, the bedrock and alluvial aquifers near the pit, and for surface drainage on the Butte hill west of the pit and part of the active mine operations east of the pit.

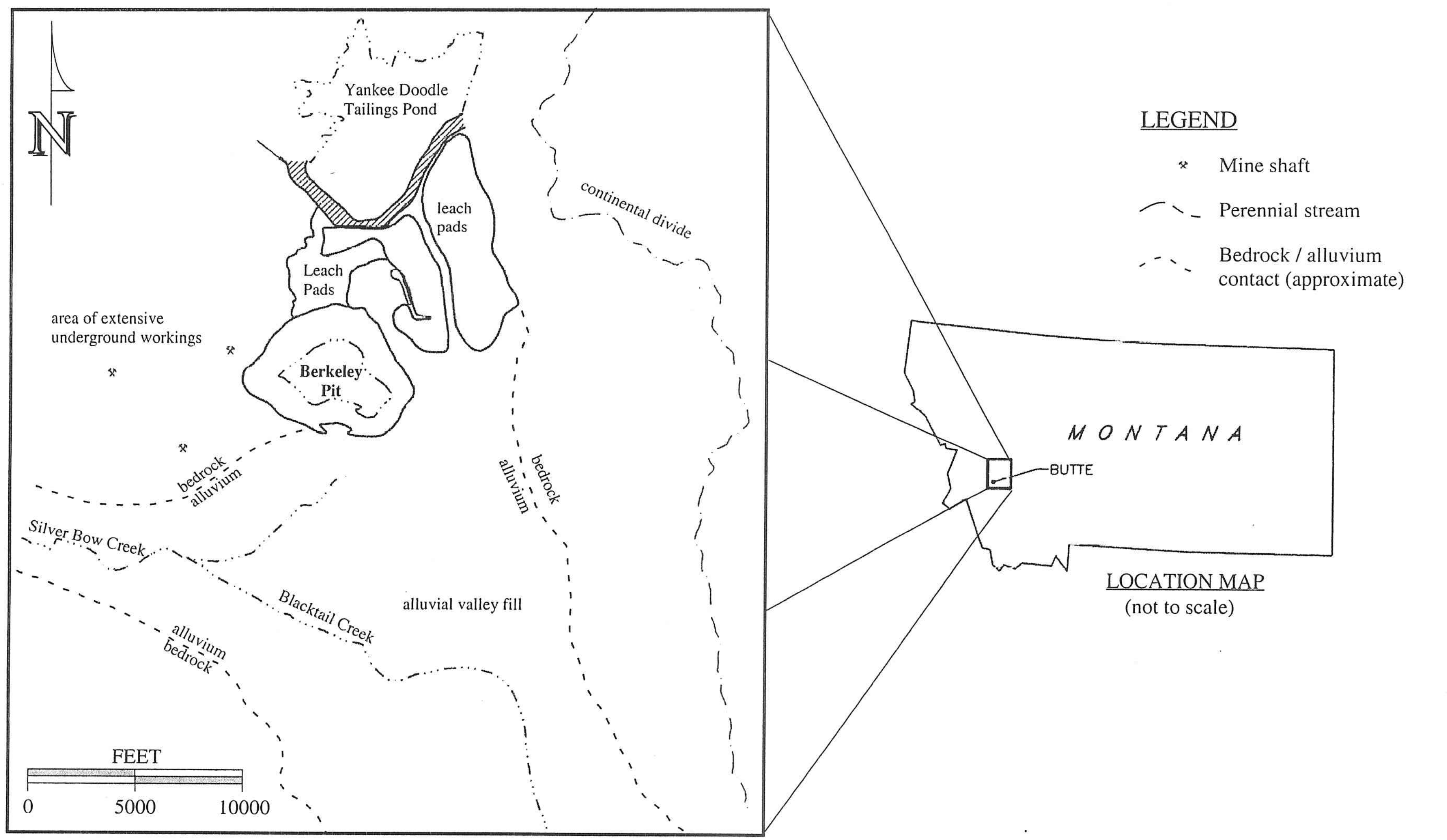


Figure 1. The Berkeley pit is part of an extensive mining complex in Butte, Montana. Important hydrologic features include: the underground workings, the bedrock aquifer, the alluvial aquifer east and south of the pit, the tailings ponds, and the leach pads.

The objective of most studies related to the Mine Flooding Operable Unit has been to determine the impact of mining-related activities on ground-water and surface-water quality. Because background or pre-mining water quality could not be measured, U.S. EPA drinking water standards provide one way to assess the impacts. Table 1 presents the maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) for selected constituents presented in this report.

Table 1. Primary and secondary water-quality standards (drinking water)

Constituent	Standard	Units
Aluminum	**50 - 200	µg/L
Arsenic	* #18	µg/L
Cadmium	* 5	µg/L
Copper	* 1300	µg/L
Iron	** 300	µg/L
Lead	* 15	µg/L
Nickel	* 100	µg/L
Sulfate	** 250	mg/L
Zinc	** 5000	µg/L
pH	** 6.5 - 8.5	s.u.

* MCL: maximum permissible concentration of a contaminant in water which is delivered to any user of a public water system.
** SMCL: non-enforceable guidelines regulating contaminants that may cause cosmetic effects or aesthetic effects in drinking water.
# WQB-7 standard used by State of Montana.

Section 2.0 East Camp

The East Camp includes most of the underground workings, the Berkeley pit, and the active mine area (figure 2). The boundary is generally not well defined and is based on the assumed influence of the East Camp workings on ground-water levels. On the basis of ground-water levels in bedrock wells installed during the remedial investigation (Canonie, 1994), the Pittsmont mine area is included in the East Camp.

2.1 East Camp Alluvial Aquifer

The East Camp alluvium includes the area east of the Berkeley pit and the upper portion of Silver Bow Creek (a.k.a. Metro Storm Drain). In the upper Silver Bow Creek area there is a hydrologic overlap between the Mine Flooding Operable Unit and the Butte Priority Soils Operable Unit. Some wells are monitored for both investigations while others are ignored during the respective activities.

Seventeen LP-series wells, including 3 nested pairs, were installed during the Mine Flooding Remedial Investigation in 1991 and 1992 (figure 3). Specifically, these wells were used to investigate contamination of the alluvial aquifer downgradient of the leach pad operation (figure 2) to the south boundary of MR's active operation near Continental Drive. Completion depths range from 55 feet to 284 feet below ground surface. Ground water in the area of the LP wells flows southward from the leach pads toward the Butte basin; near the ground-water divide just south of the Berkeley Pit, ground water flows toward the pit.

The leach pad operation consisted of pumping acidified water to the flattened piles of low-grade ore. The water flowed down through the ore, dissolved copper and other metals, and was collected at the base for circulation through the cementation plant. In 1999, the leach pad operations ceased, and the pads were allowed to drain. Water levels in wells near the base of the pads have been declining since, and one has gone dry (Duaime and Metesh, 2000 and 2001).

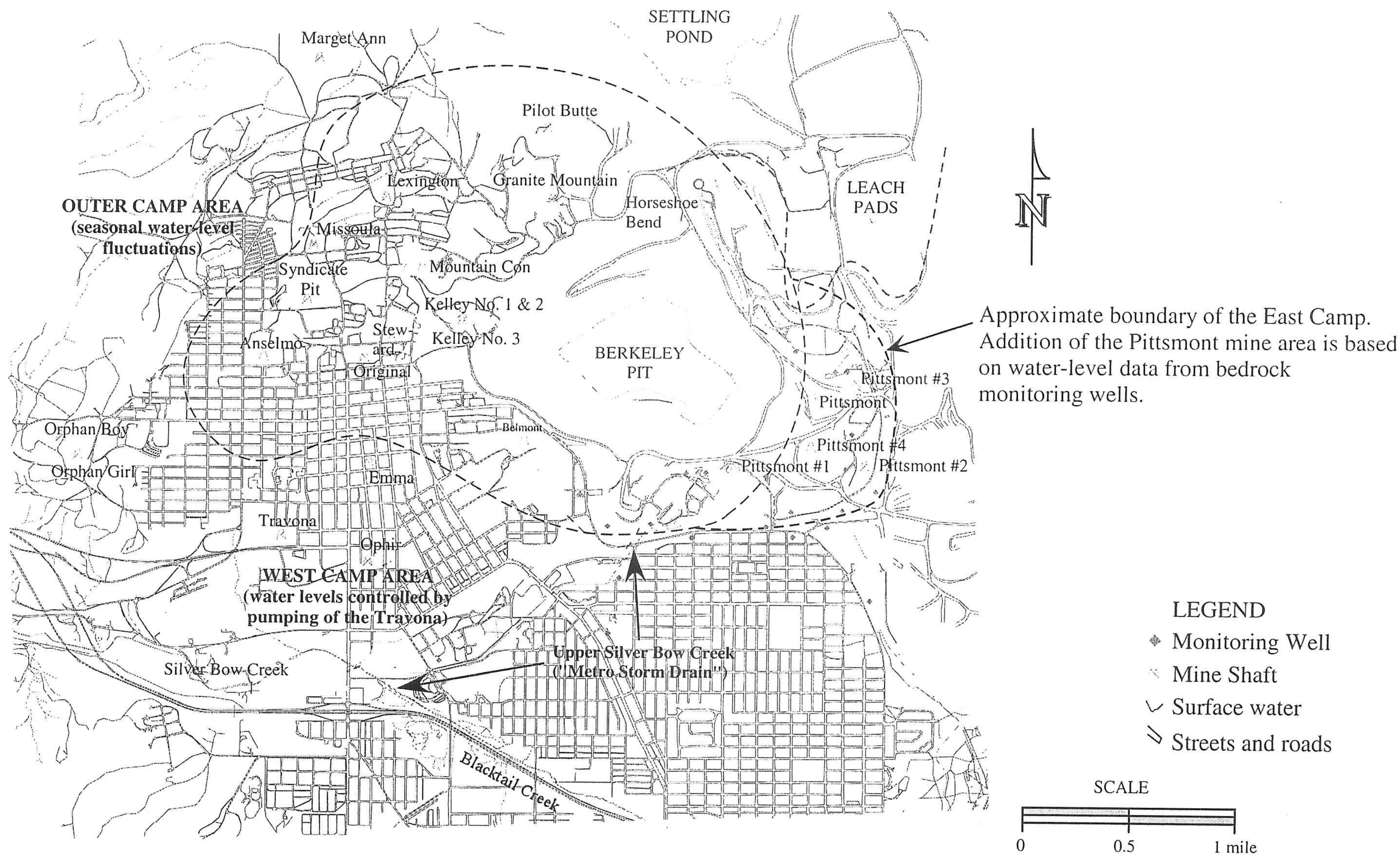


Figure 2. The mines of the Butte hill are presently considered in three groups: the East Camp, which includes the Berkeley pit and the area to the east; the West Camp in the southwest part of the hill; and the Outer Camp which includes the outlying mines.

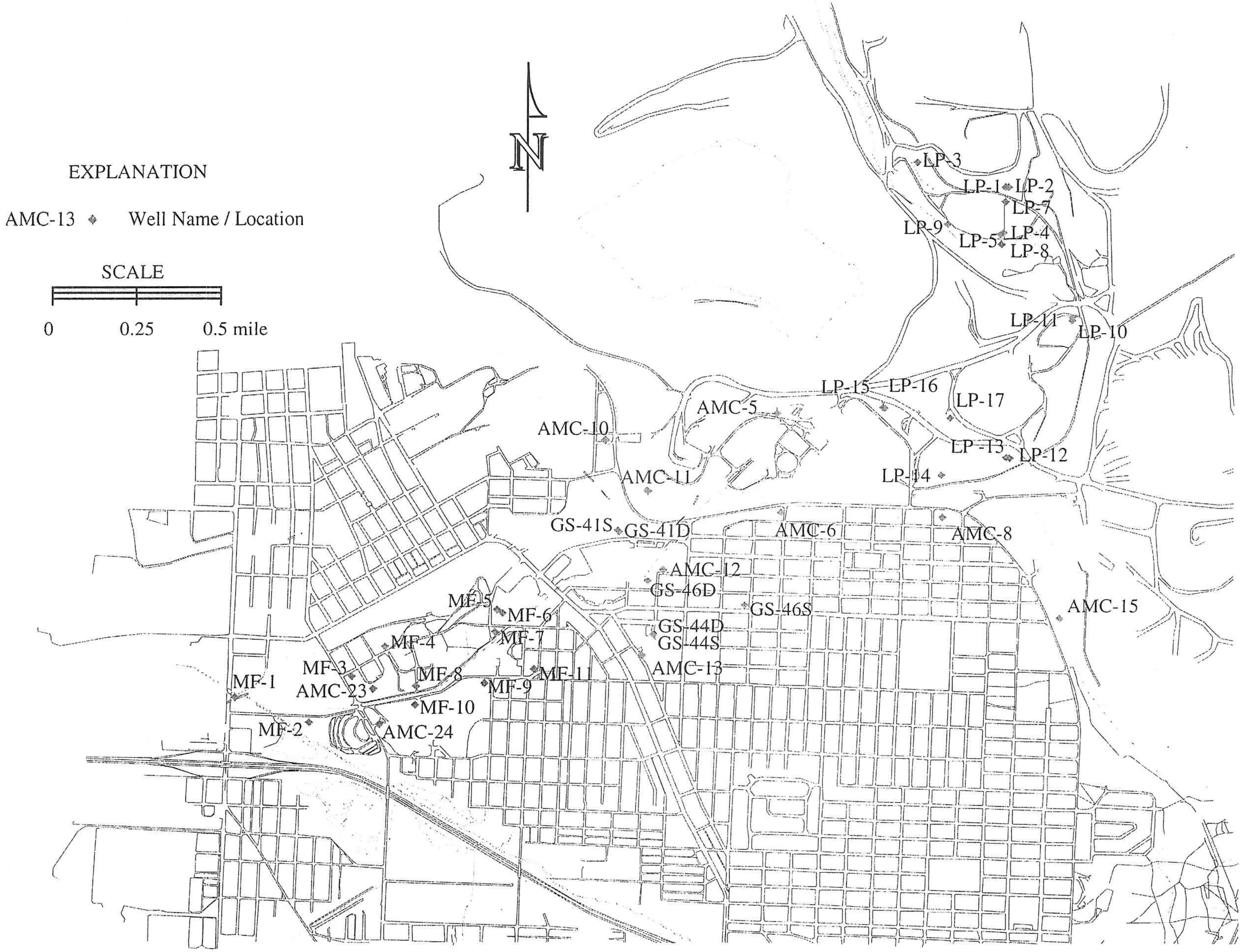


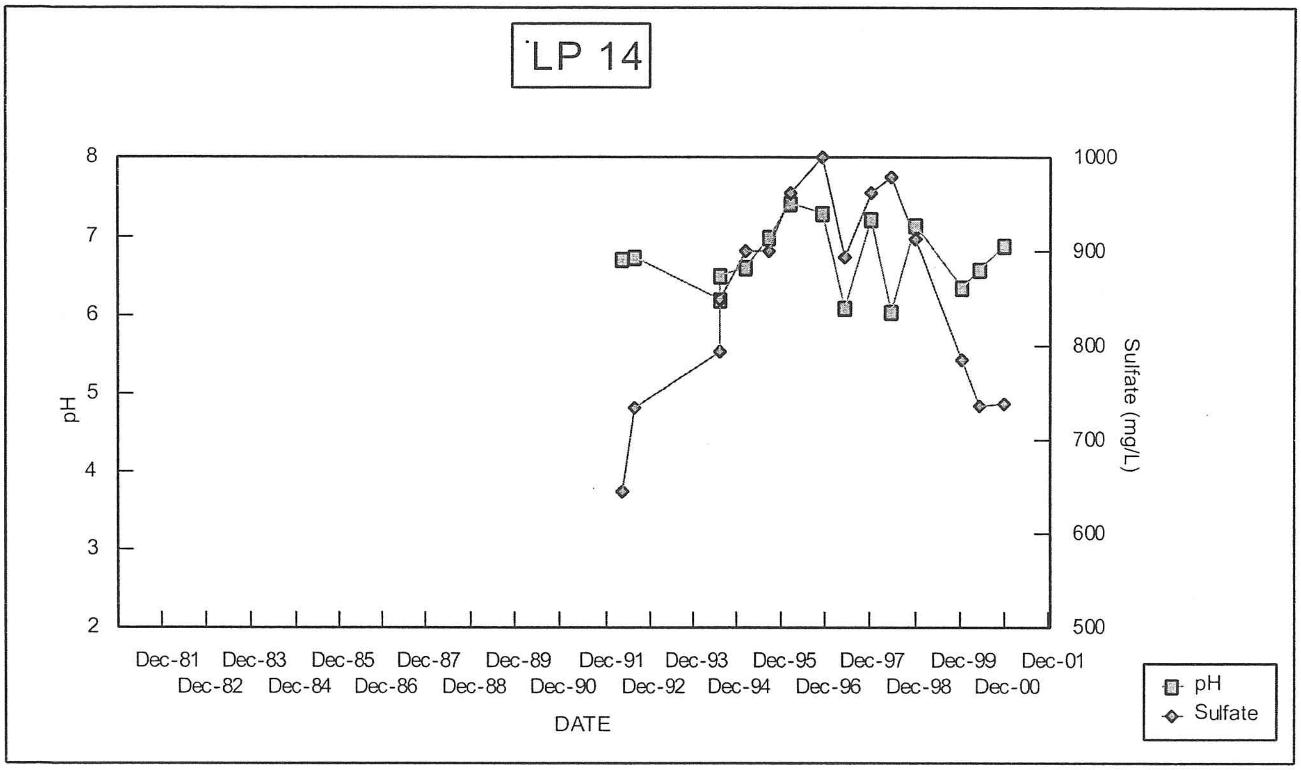
Figure 3. Several groups of wells were installed east and south of the Berkeley Pit to evaluate and monitor impacts by mining. Only the wells used in this report are shown.

In 1982, 25 AMC-series wells were used to monitor water levels and water quality associated with the flooding of the underground workings and the Berkeley pit. All of the wells were completed in unconsolidated material along Silver Bow Creek from the active mine area at Continental Drive downstream to its confluence with Blacktail Creek. Ten of the 25 wells are still monitored at present (figure 3); the completion depths of these range from 24 to 103 feet below ground surface.

The GS-series wells were installed during the Silver Bow Creek Remedial Investigation (RI), Phase I and Phase II in 1988 and 1989. Water-level data from 6 of these wells, whose completion depths range from 29.5 to 60.5 feet, were used in the Mine Flooding RI and for the Post-RI monitoring. Water-quality samples were collected for about 2 years after installation and are discussed in the earlier report (Metesh and Duaime, 2000).

The MF-series wells were installed in 1983 by the Montana Bureau of Mines and Geology to monitor ground-water levels and quality associated with the flooding mines. These are distributed along the upper Silver Bow Creek channel between Harrison Avenue and Blacktail Creek; depths range from 15.5 to 26 feet below ground surface.

The LP-series wells have shown large changes in water quality through the period of record. Sulfate has varied by several hundred mg/L in many of the wells; the concentration of metals has shown similar fluctuations on the order of hundreds of ug/L. Water-quality trends are not comparable between wells, however; some wells show increased concentrations while others show decreased concentrations during the same period. Wells LP-14 and 17 represent the range of trends in the wells: LP-14 shoed only a slight change in concentrations of dissolved constituents including sulfate and LP-17 showed the greatest increase in sulfate concentration (about 120 mg/L) in 2000 (figure 4). Table 2 summarizes water-quality trends of all the LP-wells currently monitored.



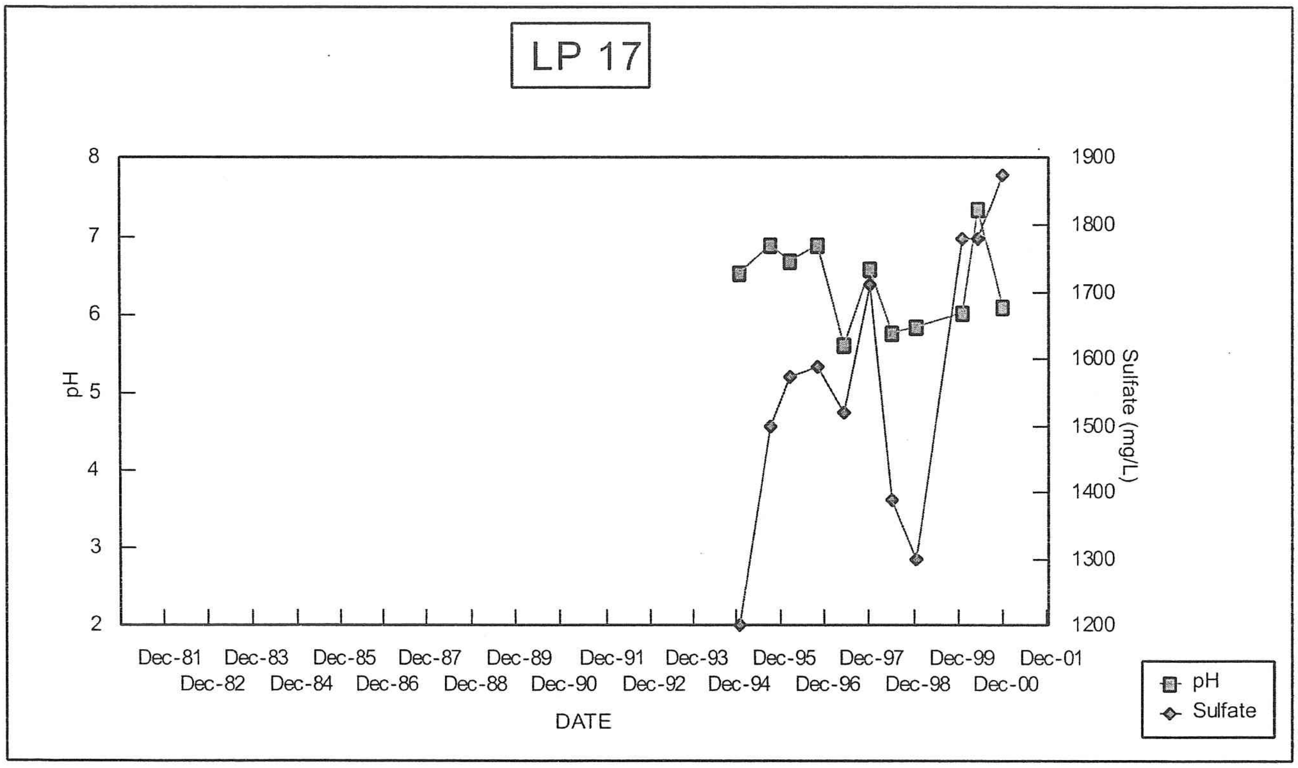
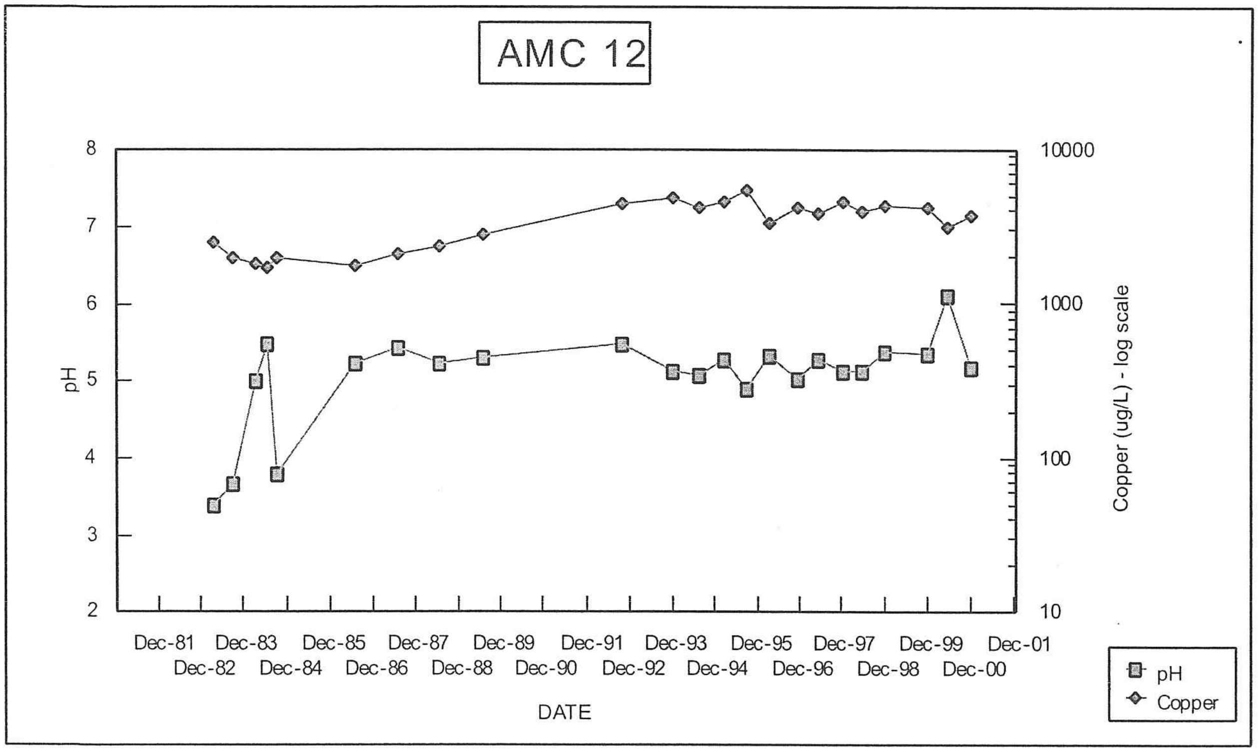


Figure 4. LP-series alluvial wells east of the pit often show different trends in water quality. In this case sulfate is decreasing in LP-14 and increasing in LP-17.

Table 2. Exceedences and trends for LP-Series wells (2000)

Well name	1 or more exceedences	Concentration trend	Remarks
LP-8	Y	upward	especially sulfate
LP-9	Y	upward	several metals and sulfate
LP-10	N	none	concentrations of several metals are just below MCLs; sulfate decreasing
LP-12	Y	variable	no significant changes in 2000
LP-13	Y	variable	sulfate decreasing from 300 to 200 over period of record
LP-14	Y	variable	apparent reversal of sulfate trend: 600 to 1000 to 730 mg/L over period of record
LP-15	Y	none	variable, but net change is small
LP-16	Y	upward	slight trend
LP-17	Y	upward	sulfate varies by 500 mg/L over period of record, increased by 120 mg/L in 2000; copper, arsenic, zinc increasing

The AMC-series wells have shown variable trends in concentrations. Although some trends show reversal of concentrations, there do not appear to be any area-wide trends. Concentrations of several constituents in AMC-23 continue to exceed MCLs and SMCLs, but sulfate is decreasing. In AMC-24, nearby, cadmium has increased from less than 2 ug/L (detection limit) to about 3 µg/L which may only reflect better analytic. AMC wells near the pit (AMC-6, 8, 12, and 13) indicate a slight variation in copper concentrations, both increasing and decreasing. Figure 5 presents the copper concentrations for AMC-12 and 13 for the period of record. AMC-6 and 8, just south of the pit, show similar concentrations in most constituents, including sulfate. AMC-6 has exhibited a steady decrease in sulfate concentrations while AMC-8 has shown a sporadic trend toward increasing sulfate (figure 6). Observations and trends for the AMC-series wells are summarized in Table 3.



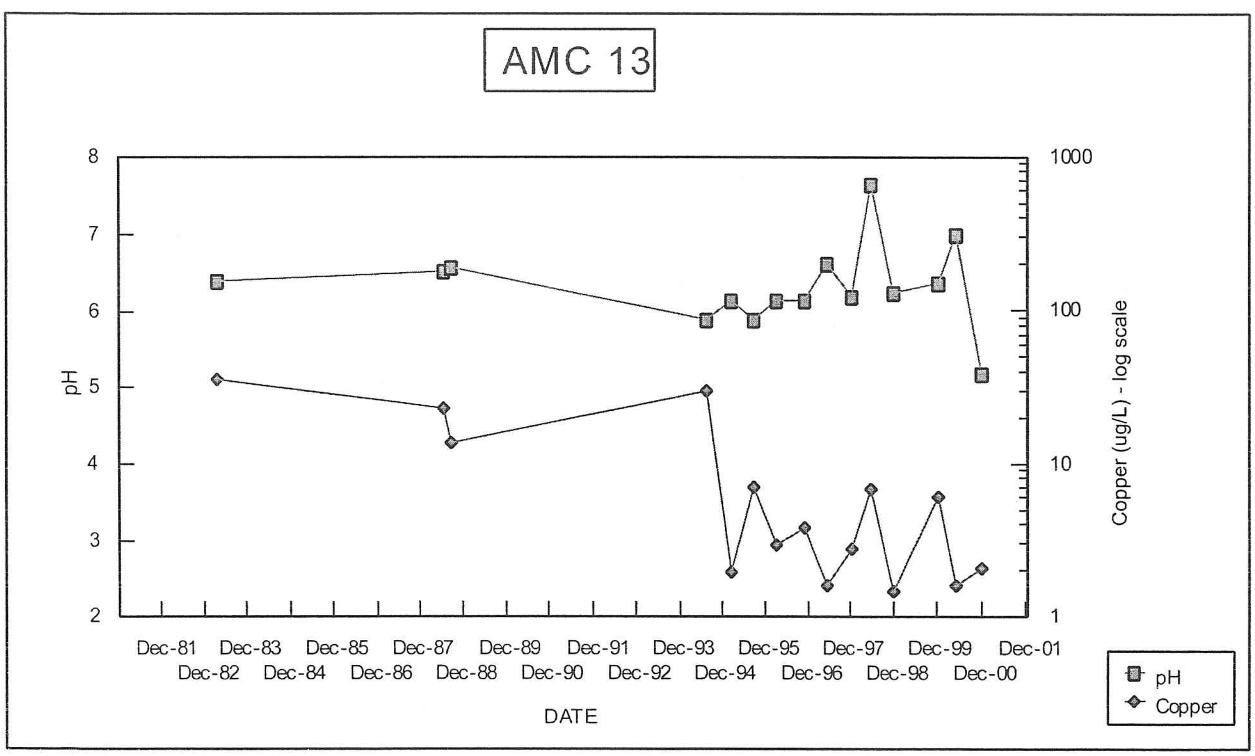
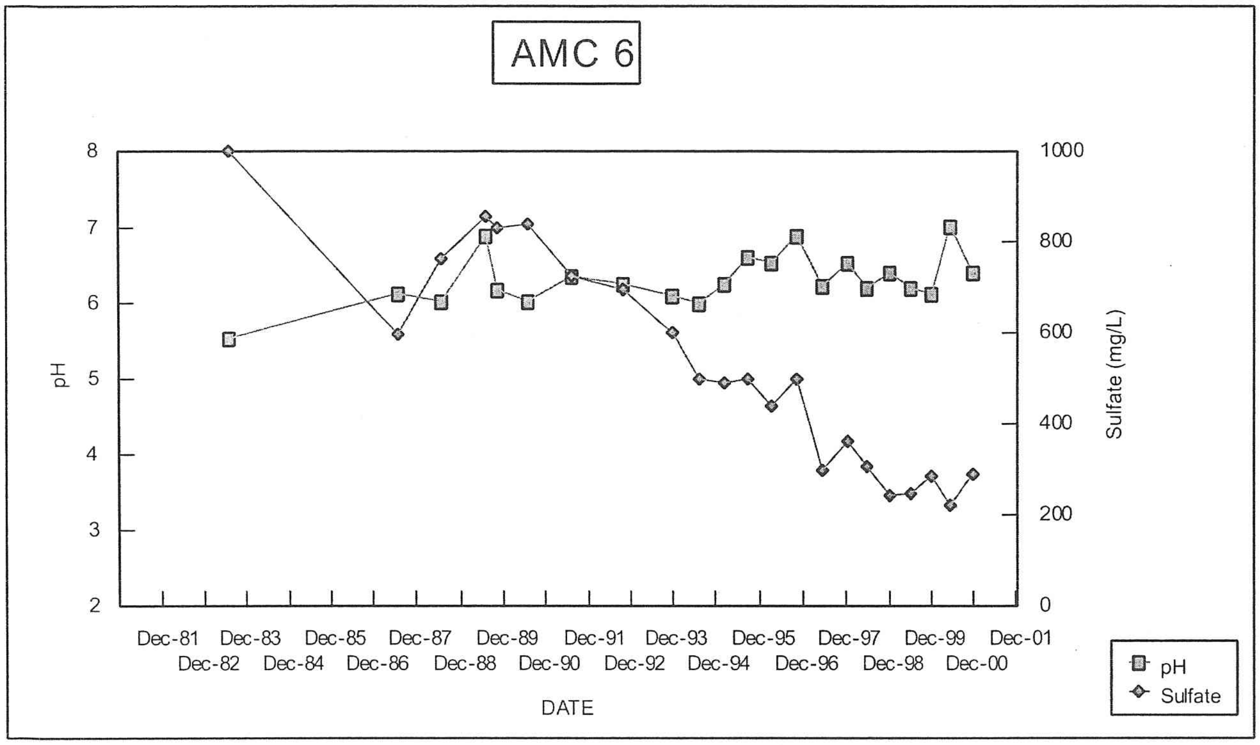


Figure 5. Alluvial wells AMC-12 and 13 are in the upper Silver Bow Creek area.



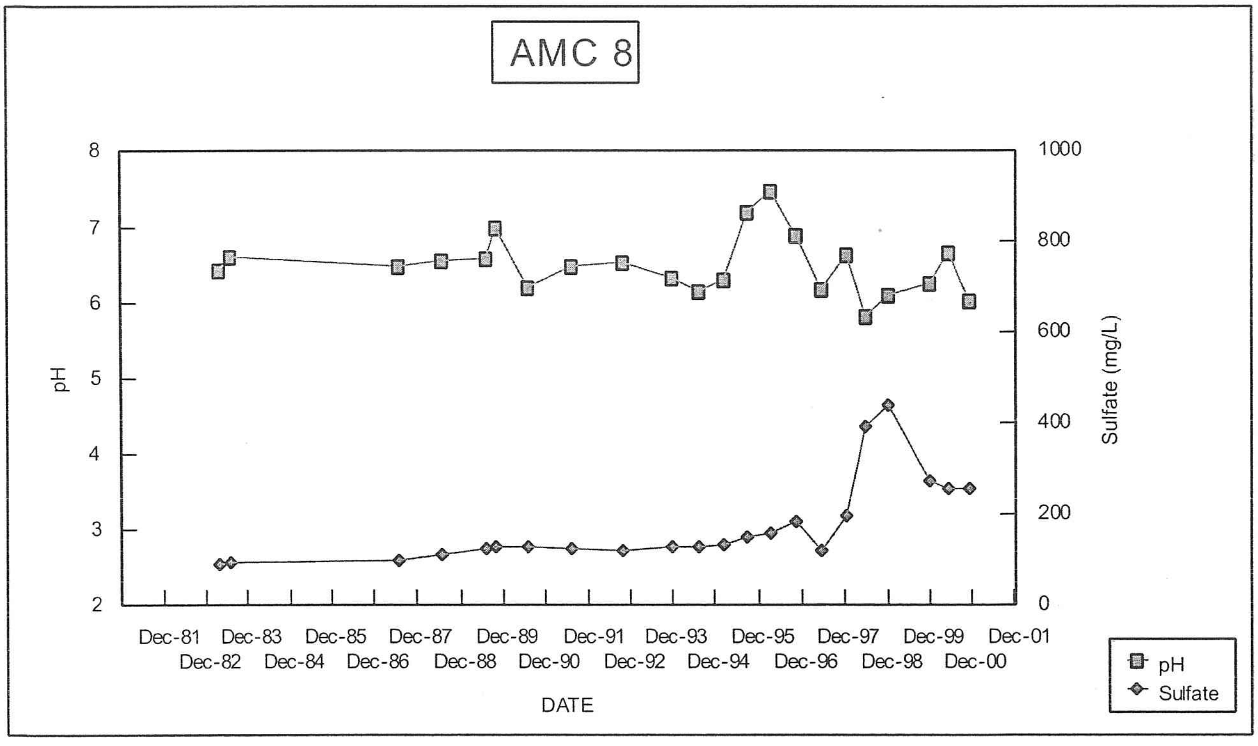


Figure 6. Sulfate concentrations from the 2000 sampling show continuation of trends in alluvial wells AMC-6 and 8, just south of the Berkeley Pit.

Table 3. Exceedences and trends for AMC-Series wells (2000)

Well name	1 or more exceedences	Concentration trend	Remarks
AMC-5	Y	downward	slight trend, except for sulfate which decreased by as much as 900 mg/L
AMC-6	Y	downward	sulfate decreased by 700 mg/L
AMC-8	Y	downward	slight downward trend continues
AMC-12	Y	variable	copper above 3000 µg/L and increasing, sulfate decreased by 400 mg/L
AMC-13	Y	variable	net change is small, but decreasing overall
AMC-15	Y	variable	only sulfate exceeds SMCL; net change is small
AMC-23	Y	variable	net change is small, except sulfate si decreasing
AMC-24	Y	variable	sulfate increasing, greater than 900 mg/L; cadmium increased from <2 to 3 ug/L over period of record

No single trend in dissolved concentrations is apparent for the area east and south of the Berkeley pit; the concentration of several constituents in most wells is quite variable. The variation of concentration in wells east of the pit is likely the result of continued changes in ground-water levels and flow gradients related to the draining of the leach pads, and the shut down of mining- and milling-related activities. The variation south of the pit may be related to changes in ground-water flow through the alluvium in this area. In addition to the shut-down of mining, the most significant events affecting water levels in the alluvial aquifer include:

- The southeast corner of the pit slide into the pit in 1998. Water levels in some wells have not recovered from an abrupt decline attributed to the pit-wall slump. Annual precipitation in the Butte area was as much as 50% above normal from 1995 to 1998.

- The annual precipitation in the Butte area was 10% and 30 % below normal in 1999 and 2000, respectively.

- The water level in the Berkeley Pit has reached the base of the alluvial aquifer in the southeast corner of the pit. This may eventually reduce the ground-water gradient toward the pit and produce a response (rise) in the alluvial aquifer.

2.2 East Camp Bedrock Aquifer

In the spring of 2000, shafts in the East Camp, West Camp, and Outer Camp were sampled (figure 7). A down-hole camera was used to inspect the shaft compartment and to provide a visual record of water conditions. Where access and conditions permitted, a field-parameter recorder was employed to collect and record pH, SC, temperature, dissolved oxygen, and redox with respect to depth. Figures 8 and 9 present these data as a function of elevation for the Anselmo, Steward, Pilot Butte, and Granite Mountain shafts.

Waters in all of the shafts exhibit a distinct and abrupt change in one or more parameters within the upper 50 feet of the water column. The pH of the waters in the Steward and Pilot Butte shafts decreased with depth; the temperatures of the deeper waters were about 6^{O}C warmer at depth. The Anselmo shaft exhibited an increase of almost 1 pH unit and has slightly colder water at depth. The temperatures of the deeper waters in the shafts tend to reflect the geothermal gradient of the mining district which is about 32^{O}C/km (SEM, 1973). The down-hole camera work showed a consistent upward movement of water in all the shafts suggesting upward convection of deeper, warmer waters. The Steward shaft, near the center of the district, had the warmest waters and the Anselmo shaft, on the edge of the East Camp had the coldest. Even though it is on the northeastern margin of the district, the water of the Pilot Butte shaft shows a pronounced temperature rise with depth, whereas the Granite Mountain shaft, near the center of the district, shows little change.

Dissolved oxygen at the water surface of the shafts ranged from greater than 5 mg/L to 1 mg/l. The concentration decreased to effectively zero at depth in all of the shafts sampled. Specific conductance increased by over 1500 µmhos/cm in the Steward and Pilot Butte shafts. The Anselmo and Granite Mountain shafts exhibited little or no change with depth.

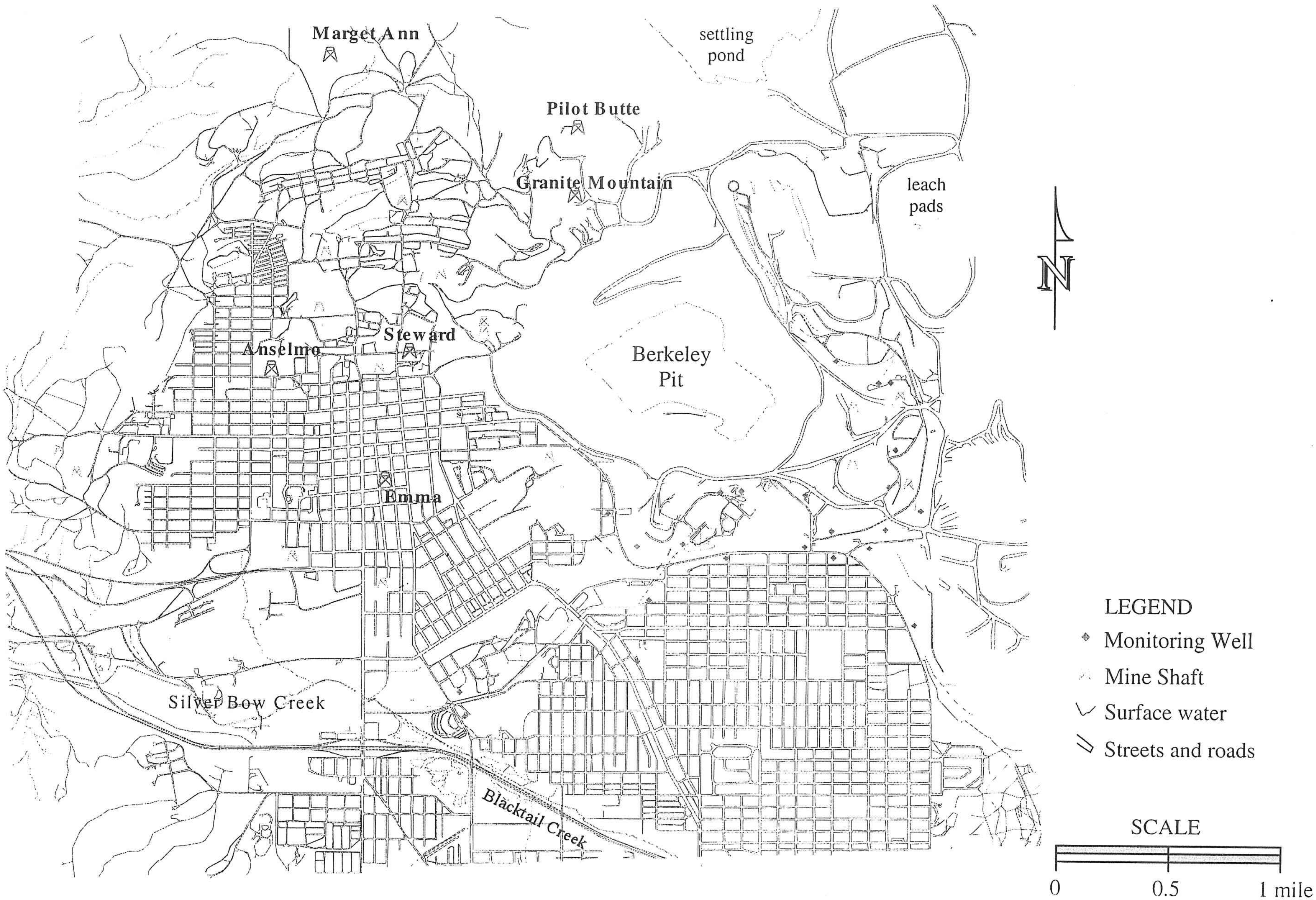
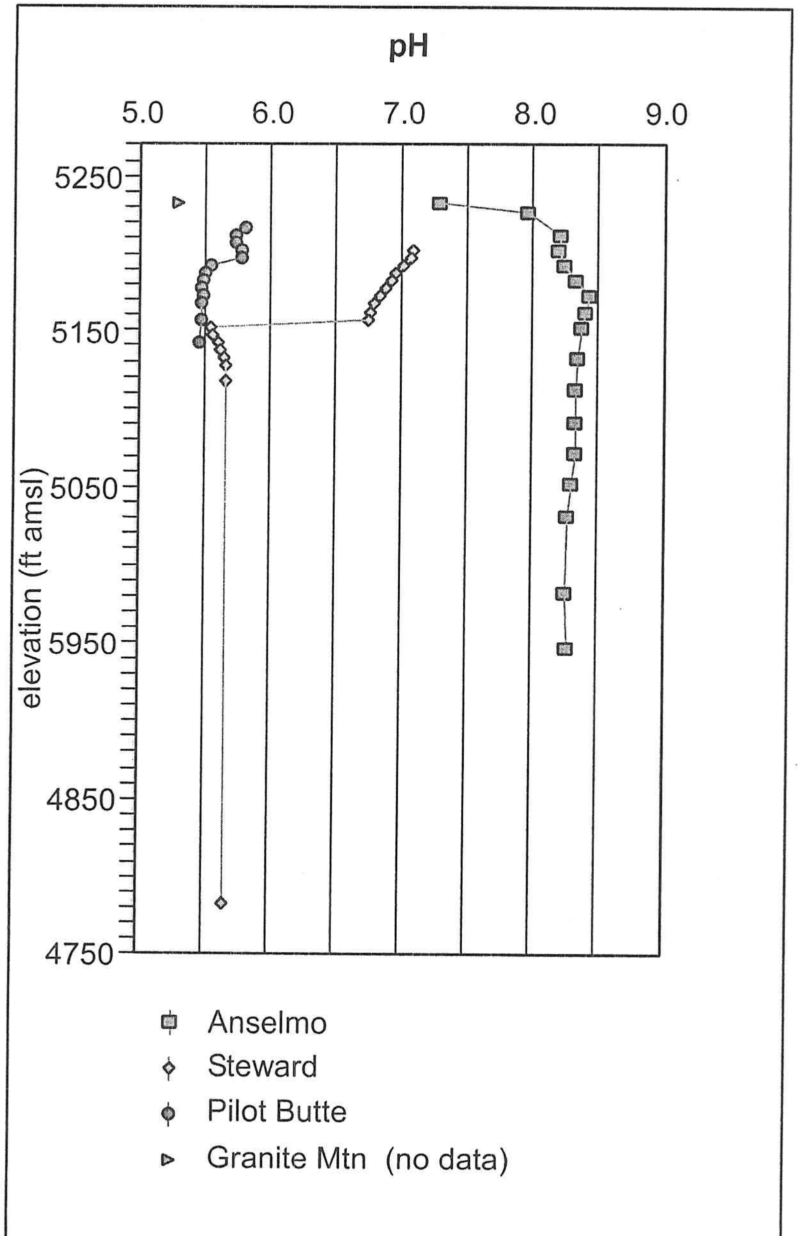


Figure 7. Detailed samples were collected from East Camp, West Camp, and Outer Camp shafts (labelled in bold).



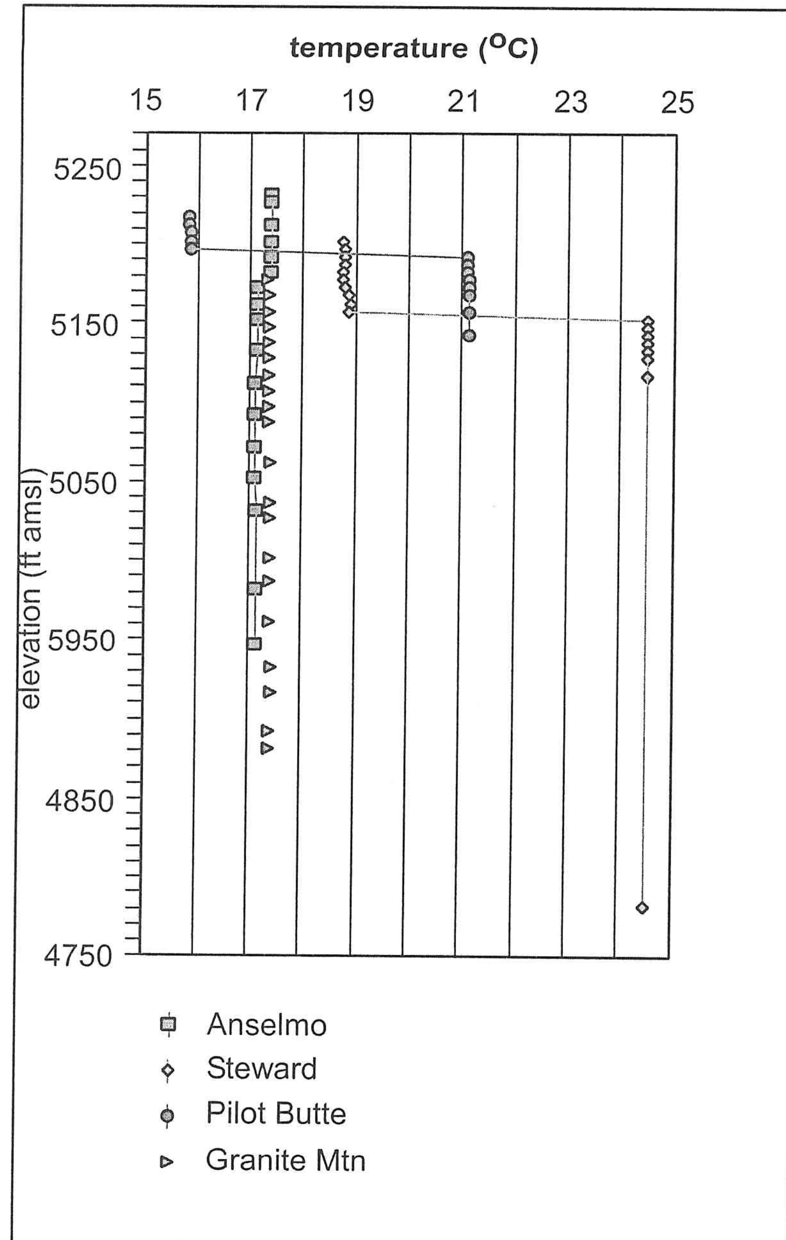
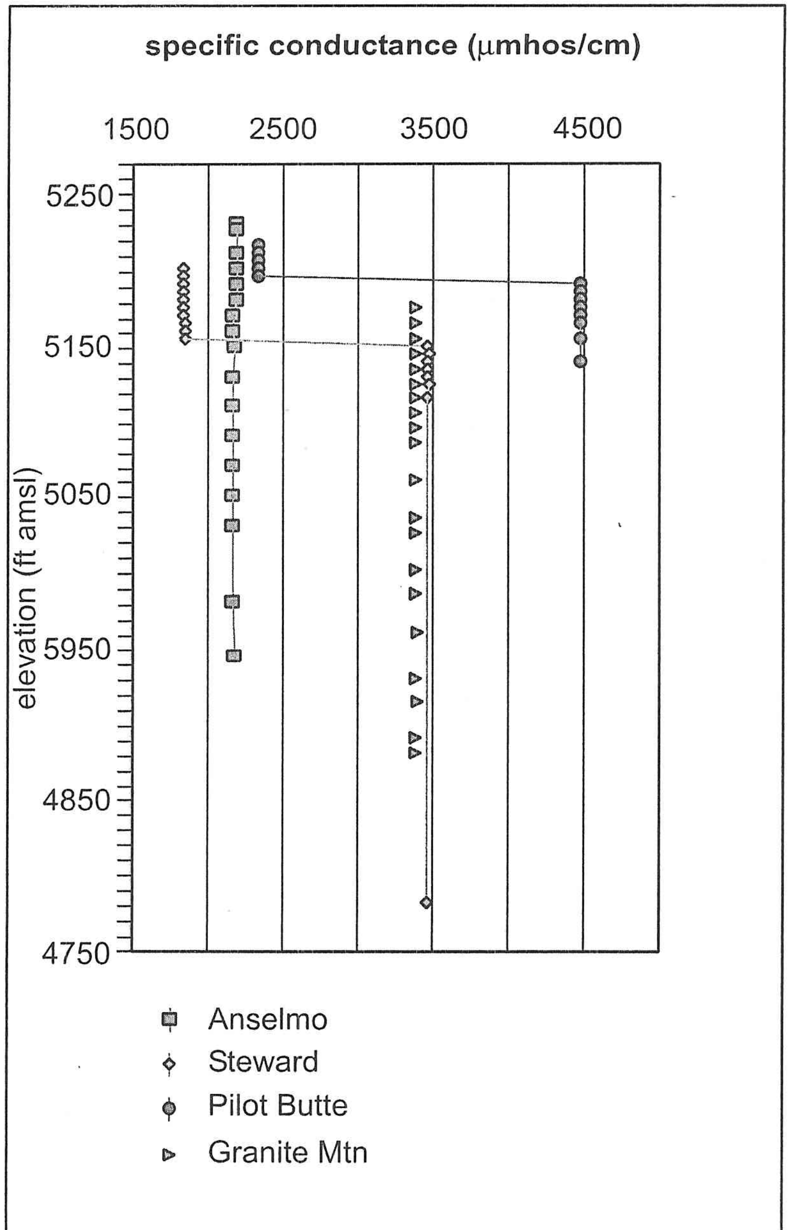


Figure 8. A shift in pH and temperature is evident in all the shafts from which data were collected.



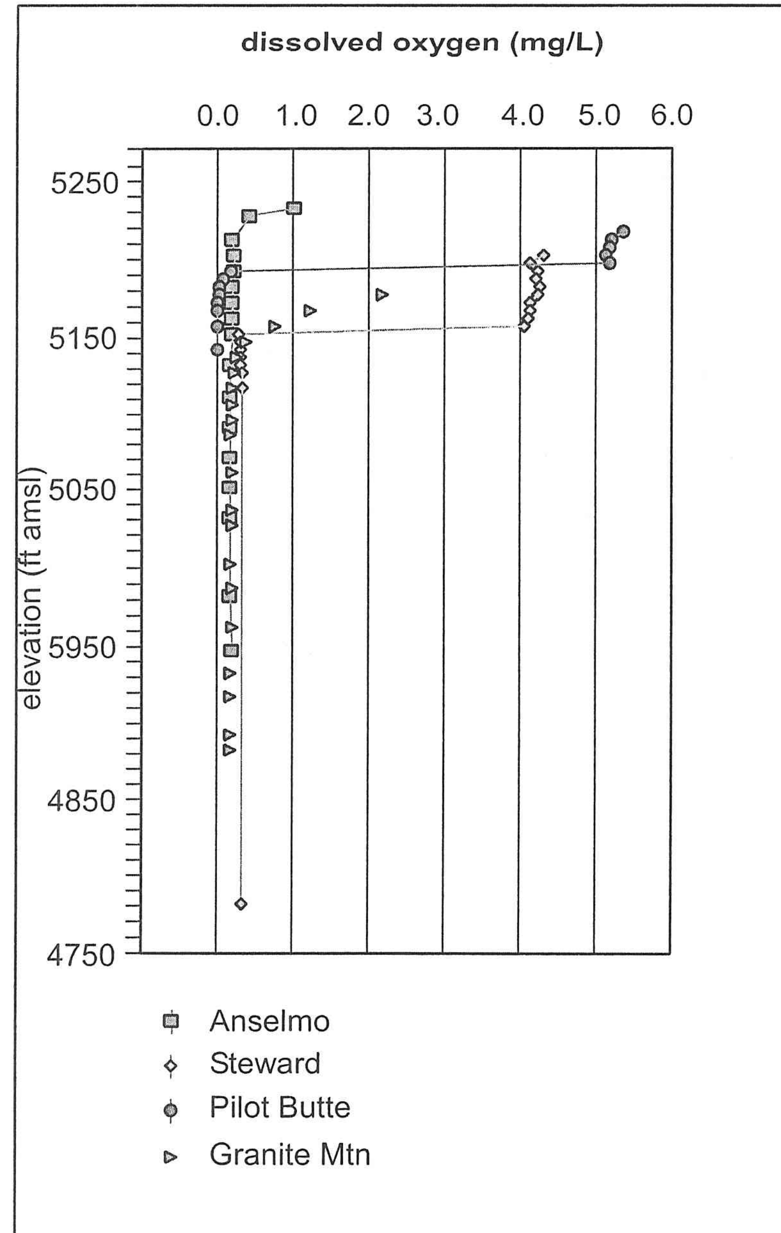


Figure 9. Specific conductance shifted to higher values at depth for the Steward and Pilot Butte shafts, but remained nearly constant for the others. Dissolved oxygen dropped to near zero within the upper 60 feet in all the shafts sampled.

In addition to inorganic chemistry, samples were collected for total organic carbon (TOC) and for bacteria isolation/identification. Bacterial viability (live/dead) tests (Table 4) were conducted within 2 hours of sampling using a two-color fluorescent staining method.

Table 4. Total organic carbon and total live/dead bacteria counts for all sample sites

Site	**Depth*** (feet)	**TOC** (mg/L)	**Live** (count/mL)	**Dead** (count/mL)
Marget Ann	*250	2	290,000	500,000
Emma	*240	6	140,000	400,000
Steward	*675	400	2,700,000	3,400,000
	800	9	300,000	300,000
Granite Mtn	*850	7	300,000	200,000
	1200	6	40,000	140,000
Anselmo	*550	4	40,000	70,000
	900	3	80,000	110,000
Pilot Butte	*840	9	1,000,000	3,000,000

* shallow samples are collected near the water surface

Total organic carbon concentrations ranged from 2 to 9 mg/L for all but the shallow water of the Steward shaft, which had a concentration of 400 mg/L and coincides with the highest bacteria count. The down-hole camera showed a much higher suspended-particle load in the shallow water of the Steward. The timbers in the deeper shaft were matted with what appeared to be a biofilm; as noted, a consistent upward flow was evident throughout the depth of the camera work.

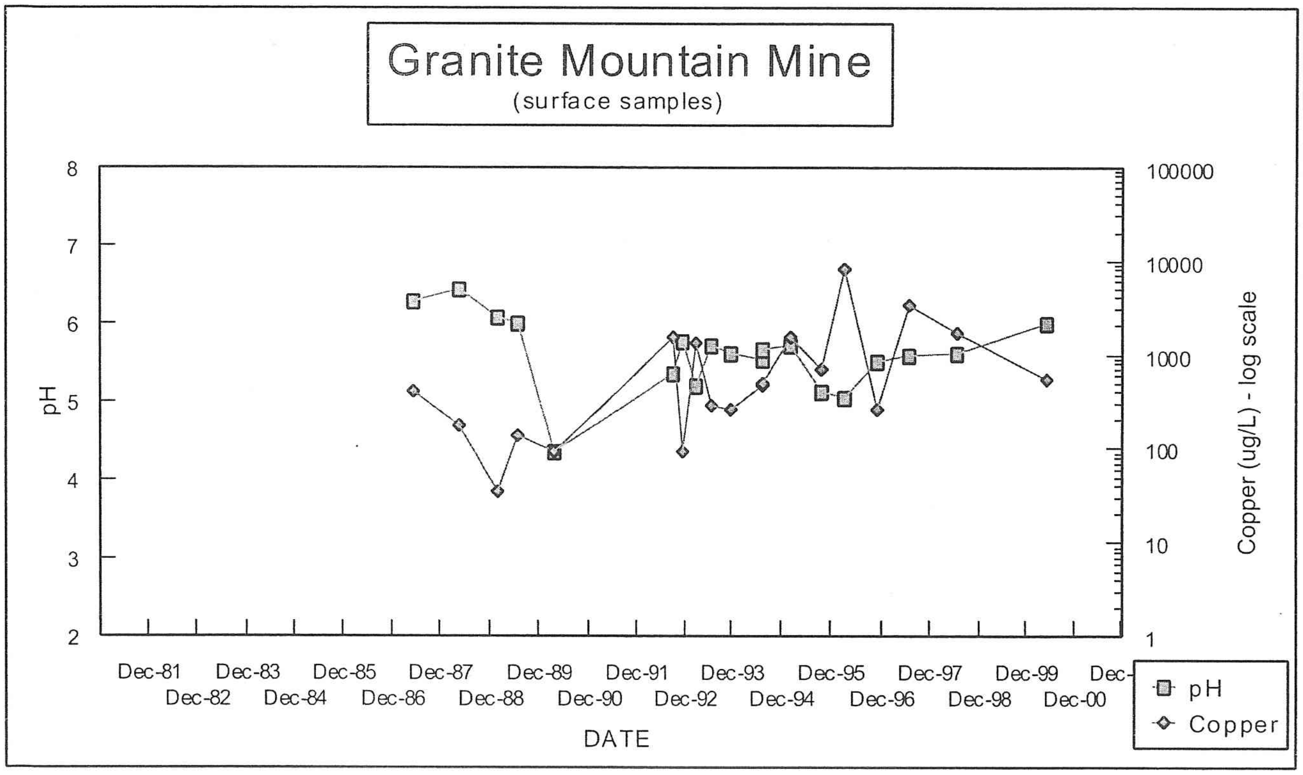
The nutrient agar was used to culture and isolate bacteria under aerobic conditions only. Unique colonies were isolated based on color and morphology. Isolates were submitted for identification by rRNA analysis. Table 5 presents the identity of those bacteria that were successfully isolated and the shafts from which the samples were obtained.

Table 5. Genus and species of bacteria and locations

Genus and Species	Site
Variovorax paradoxus	Emma
Bacillus pumilus	Anselmo, Granite Mtn, Pilot Butte
Microbacterium thalassium	Anselmo, Granite Mtn, Pilot Butte
Arthrobacter oxydans	All sites
Chryseobacterium indologenes	Marget Ann, Steward
Flavobacterium hydatis	Emma
9 species based on Standard Plate Count and isolation **6 species identified from rRNA (Midi Labs)**	

No difference between the species was found in the shallow and deep waters of any of the shafts; the species identified were found in both the shallow and deep waters. As noted, culturing and isolation were done under aerobic conditions; additional work will be needed to determine the presence and species of anaerobic bacteria.

As noted in earlier reports, the chemistry of the waters flooding the underground workings has shown significant change over the period of record. Results from the most recent sampling of the shafts indicate a continuing, general decrease in dissolved metals. Figure 10 presents copper and zinc concentrations for the Granite Mountain shaft over the period of record. The concentrations of both constituents, as well as others, have steadily decreased over the past 3 years. Similarly, the Kelley shaft, adjacent to the pit, has shown a slight decrease in the concentration of copper and zinc in the last sample (figure 11). In both cases, the pH of the waters has increased and, most notably, the change in the concentration of dissolved constituents from one sample to the next has become more consistent in the last few years.



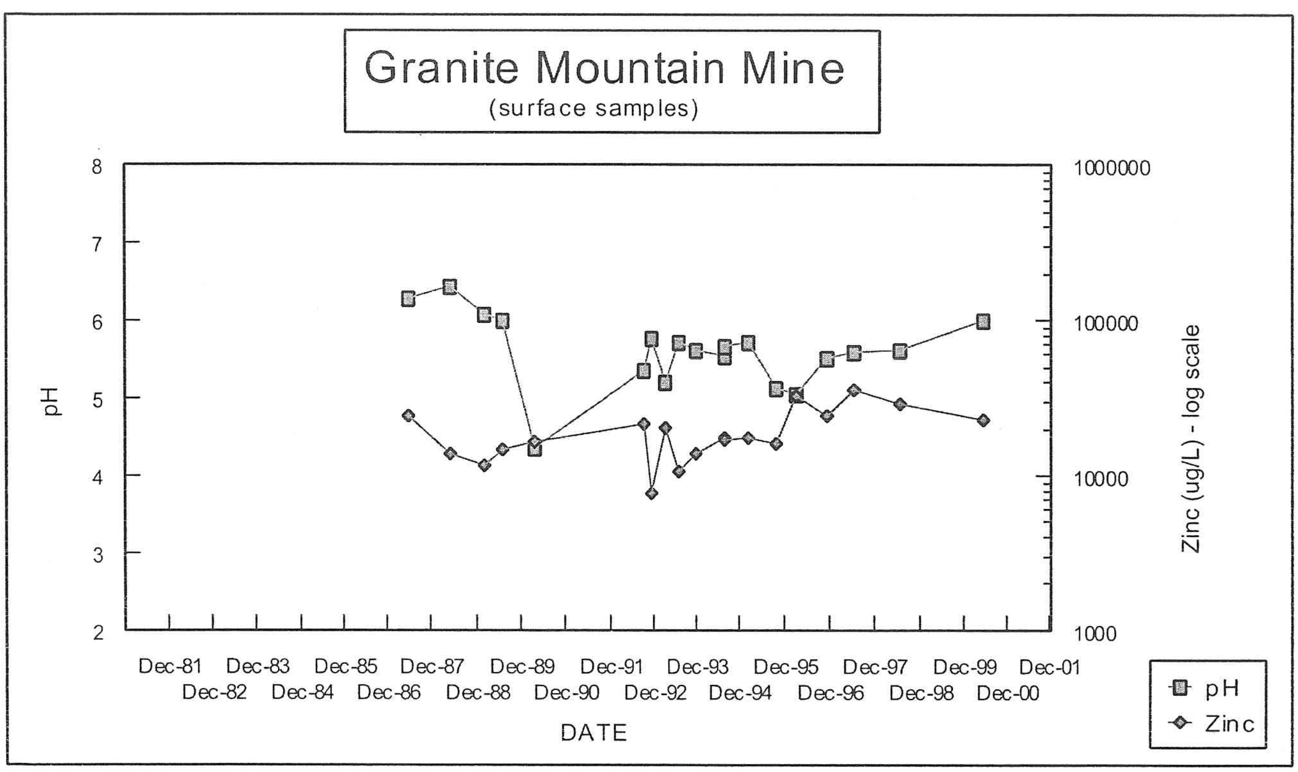
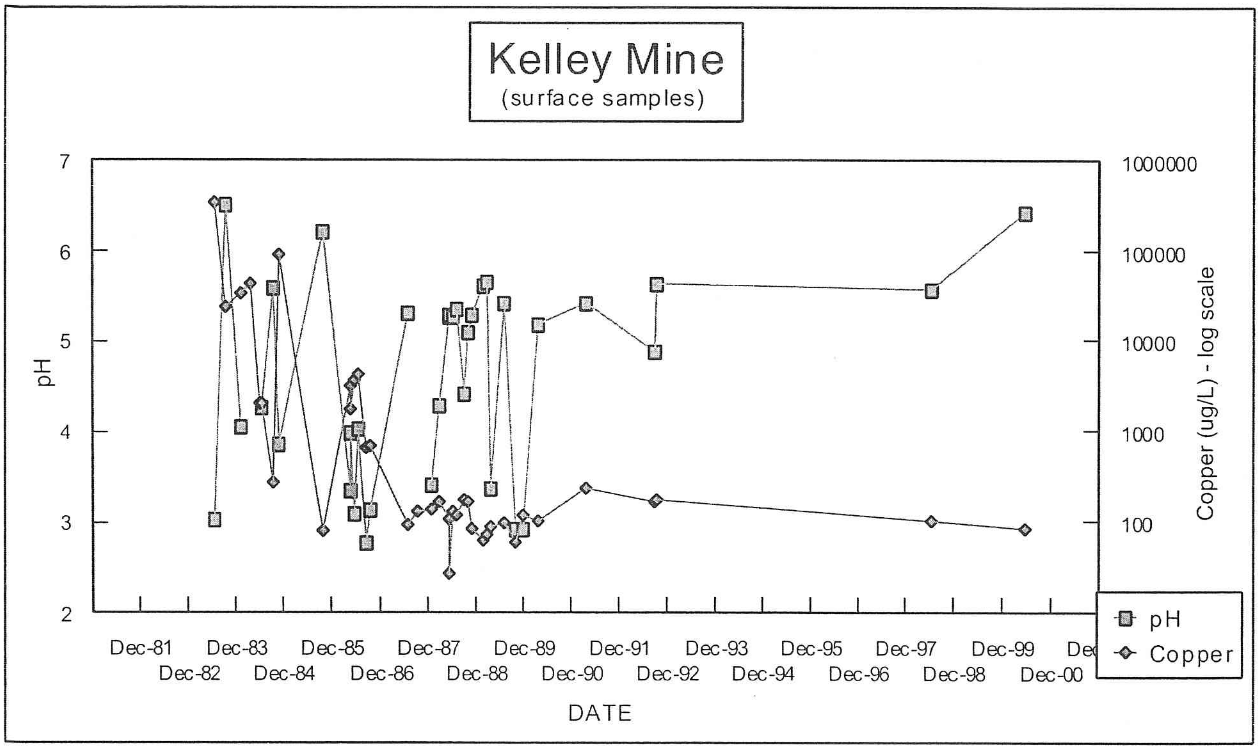


Figure 10. The Granite Mountain shaft shows a slight decrease in copper and zinc concentrations over the last 3 years.



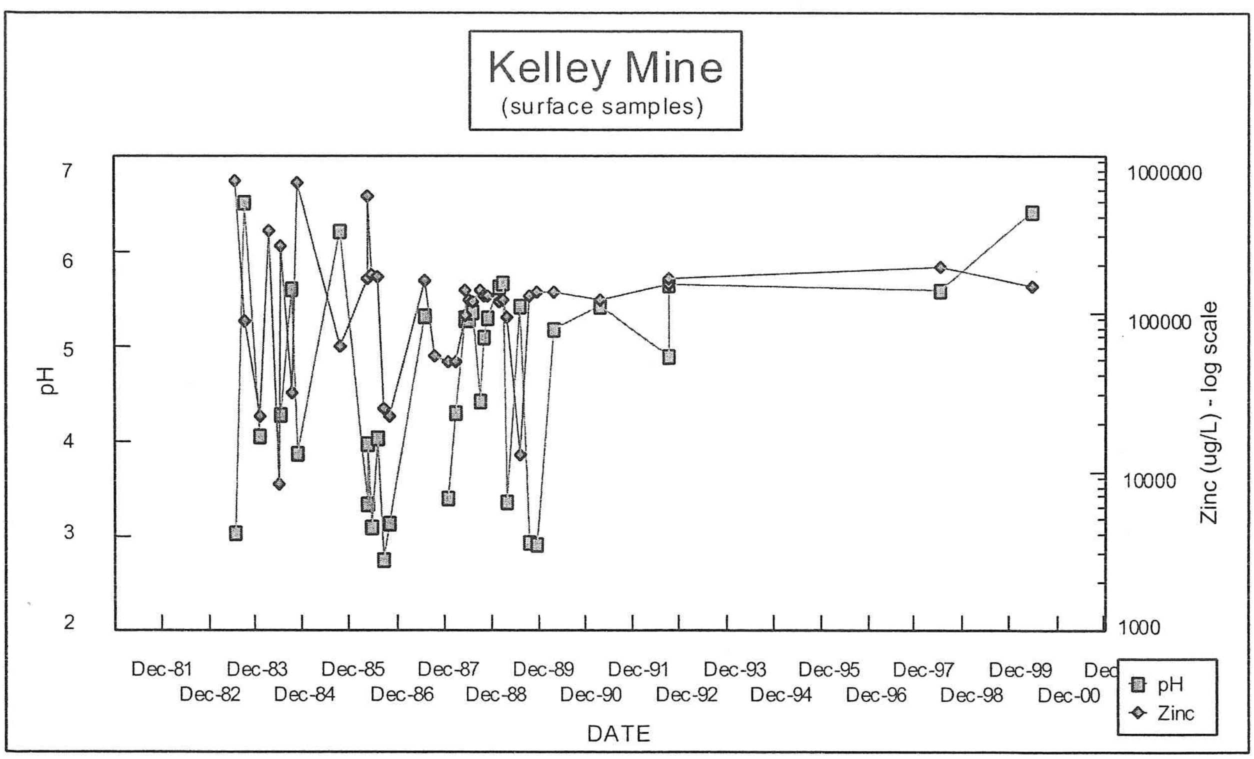


Figure 11. Data for 2000 show a continuation of the slight decrease in copper and zinc concentrations in the Kelley shaft.

Although there appears to be a general improvement in water quality in the underground workings, the concentrations of metals and sulfate are quite variable throughout the district (Table 6). Samples collected in 2000 indicate aluminum concentrations range from less than 30 µg/L in the deeper waters of the Steward and Anslemo shafts to more than 2000 µg/L in the Kelley shaft. The pH of the shaft waters is near 6.5, with the exception of the Granite Mountain which is about 4.4. Sulfate concentrations range from about 1100 mg/L in the Anselmo shaft to about 2600 in the Kelley and, similarly, zinc concentrations range from about 7000 µg/L in the Anslemo to 151,000 µg/L in the Kelley. The Berkeley pit, in contrast, has much greater concentrations of dissolved constituents, with the exception of sulfate.

Table 6. Selected chemistry from East Camp shafts and the Berkeley pit

	Sample Depth (ft)	pH (S.U.)	Al (µg/L)	Cu (µg/L)	Pb (µg/L)	SO_4 (mg/L)	Zn (µg/L)
Kelley	surface	6.43	2,020	87	3	2,600	151,000
Steward	675	6.33	<30	17	<2	1,088	34,600
	800	5.69	976	197	<2	2,106	119,000
Anselmo	550	6.71	<30	4	<2	1,080	7,340
	900	6.43	<30	<2	<2	1,104	7,190
Granite	850	4.39	194	188	<2	2,418	23,900
Mtn.	1,200	4.36	189	189	<2	2,367	23,300
Berkeley	surface	2.42	186,000	199,000	1,390	8,650	469,000

Water levels in the bedrock aquifer east of the Berkeley Pit continue to rise in response to the flooding of the pit and workings. Details of the water-level trends are discussed in a separate report by Duaime and Metesh (2001). Well completion and water-level changes through the period of record are summarized in Table 7.

Table 7. Completion depths for bedrock monitoring wells east of the Berkeley Pit (figure 12)

Well Name	Total Depth (ft)	Screen from	Screen to	Net Water-level Change (1989 to 2000)*
A	745	680	700	231
		720	740	
B	643	568	578	90
		628	638	
C	800	755	795	212
D-1	635	600	635	204
D-2	775	660	670	
		720	740	
		760	770	202
E	355	270	290	
		320	350	-0.64
F	639	614	634	-1.03
G				107
H**				68
J				18

*Duaime and others, 2001
** Well abandoned in 1999; replaced by Well J

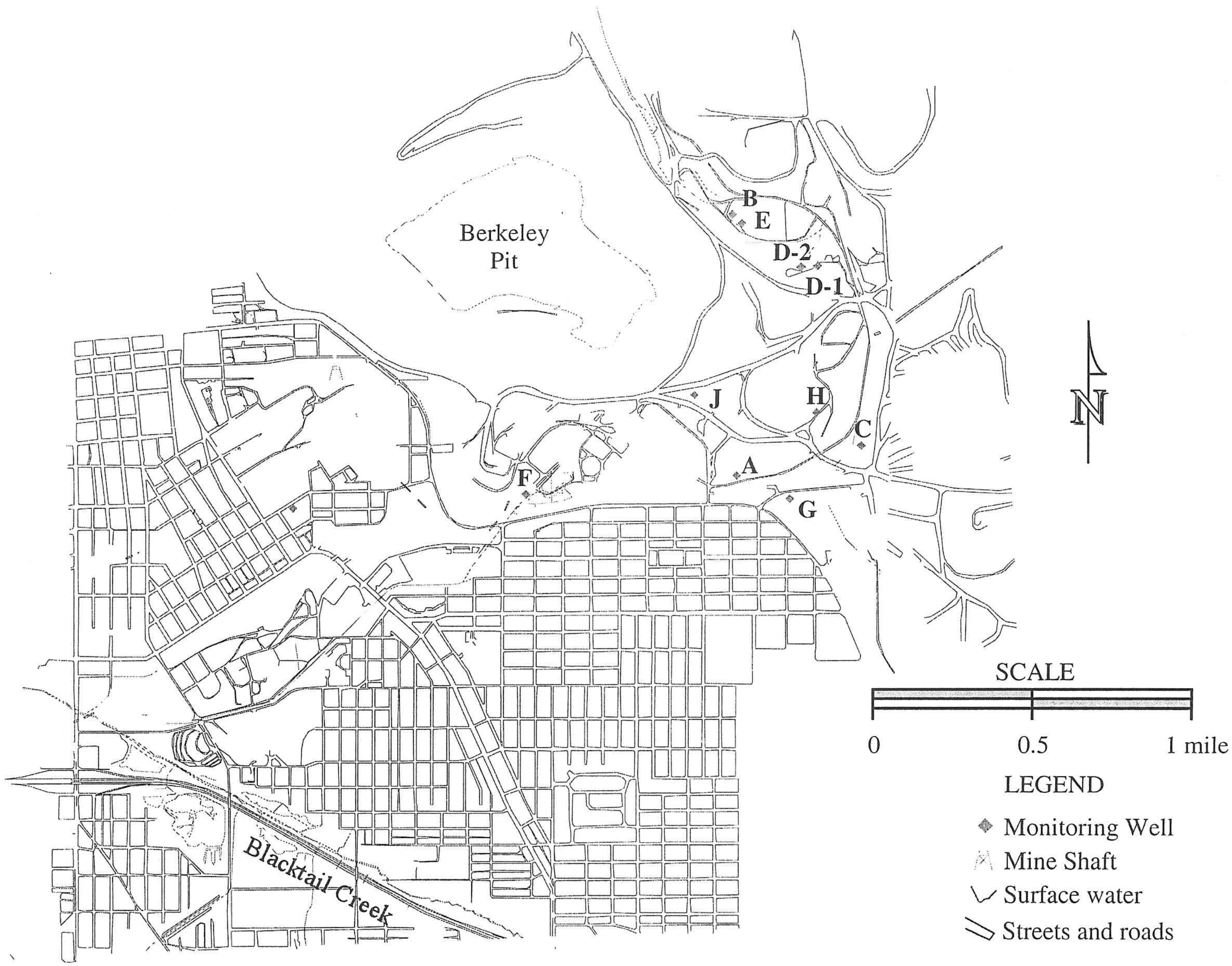


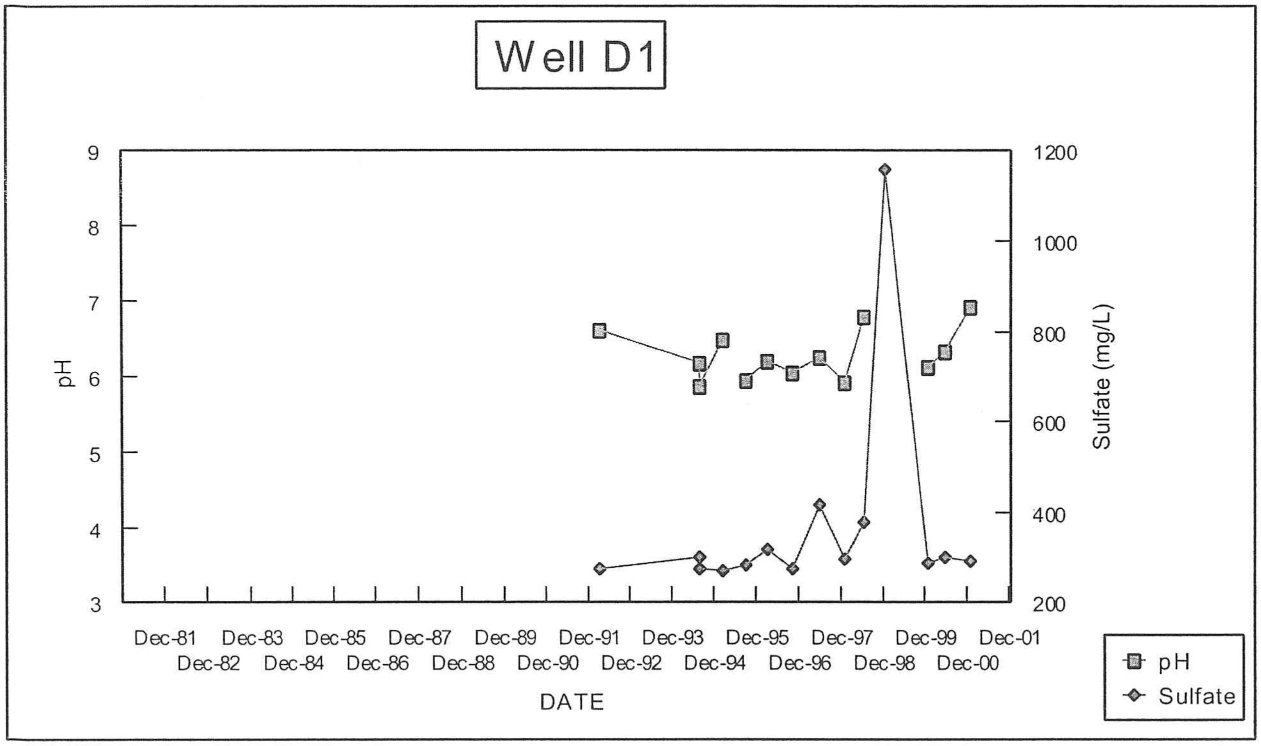
Figure 12. The A-H series of bedrock wells were installed during the Mine Flooding RI/FS to monitor water levels and water quality south and east of the Berkeley pit.

Water-quality trends in the bedrock wells of the East Camp generally follow previous trends. Sulfate concentrations in the bedrock wells east of the pit range from about 300 mg/L in well D1 to 950 mg/L at nearby D2. No trends in sulfate are evident in any wells (for example, well D1, figure 13), except at D2 in which sulfate increased by about 200 mg/L in the last sample (figure 13). Zinc and other dissolved metals have shown only slight changes in concentration in most wells and are below the MCL of 5000 μg/L. Well D2 is the exception, however, and shows an increase throughout the period of record. The last sampling shows a concentration of about 4400 μg/L (figure 14). Table 8 summarizes the water-quality trends over the period of record.

Table 8. Exceedences and trends for East Camp bedrock wells (1989 to 2001)

Well name	1 or more exceedences*	Concentration Trend	Remarks
A	Y	none	arsenic (MCL), sulfate (SMCL)
B	N	variable	sulfate (SMCL)
C	N	none	sulfate (SMCL)
D-1	N	none	sulfate (SMCL)
D-2	N	increase	sulfate (SMCL); zinc approaching MCL
E	N	variable	sulfate (SMCL); pH has increased though the period of record
F	Y	none	very high arsenic (MCL), sulfate (SMCL)
G	N	decrease	sulfate (SMCL); pH increases through period of record
J	Y	none	very poor quality water

* excludes sulfate



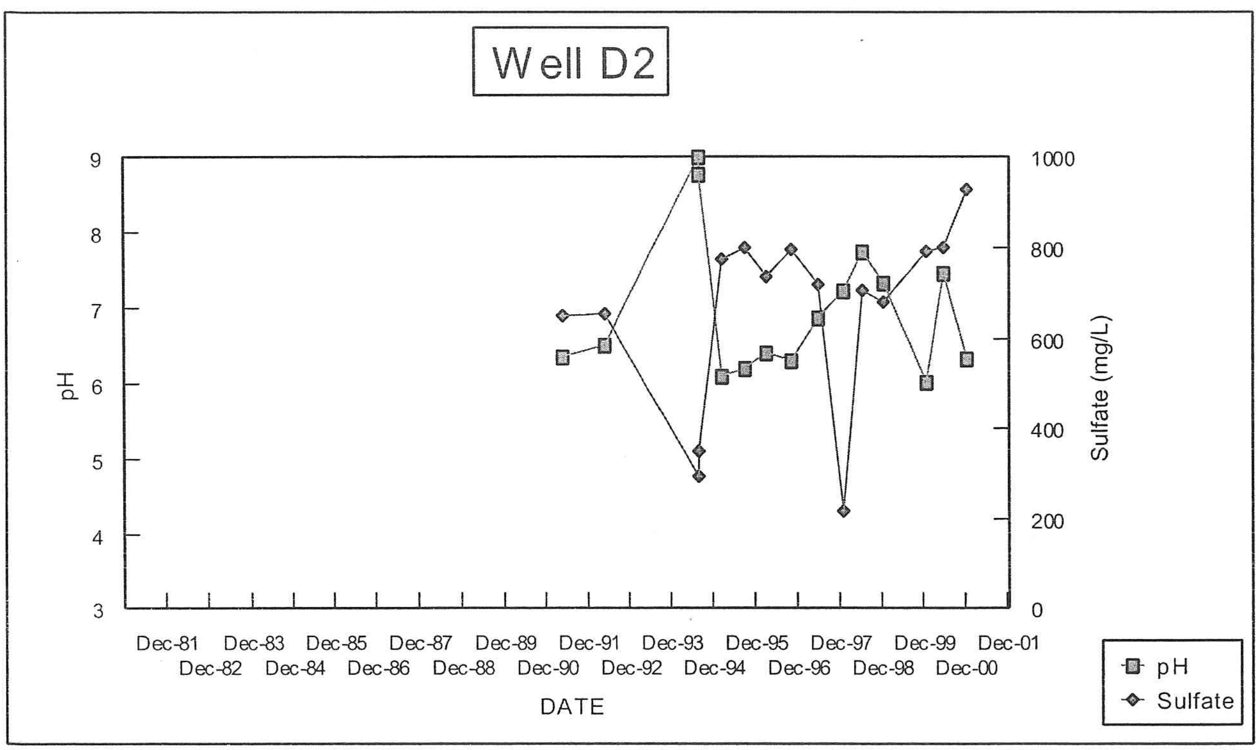
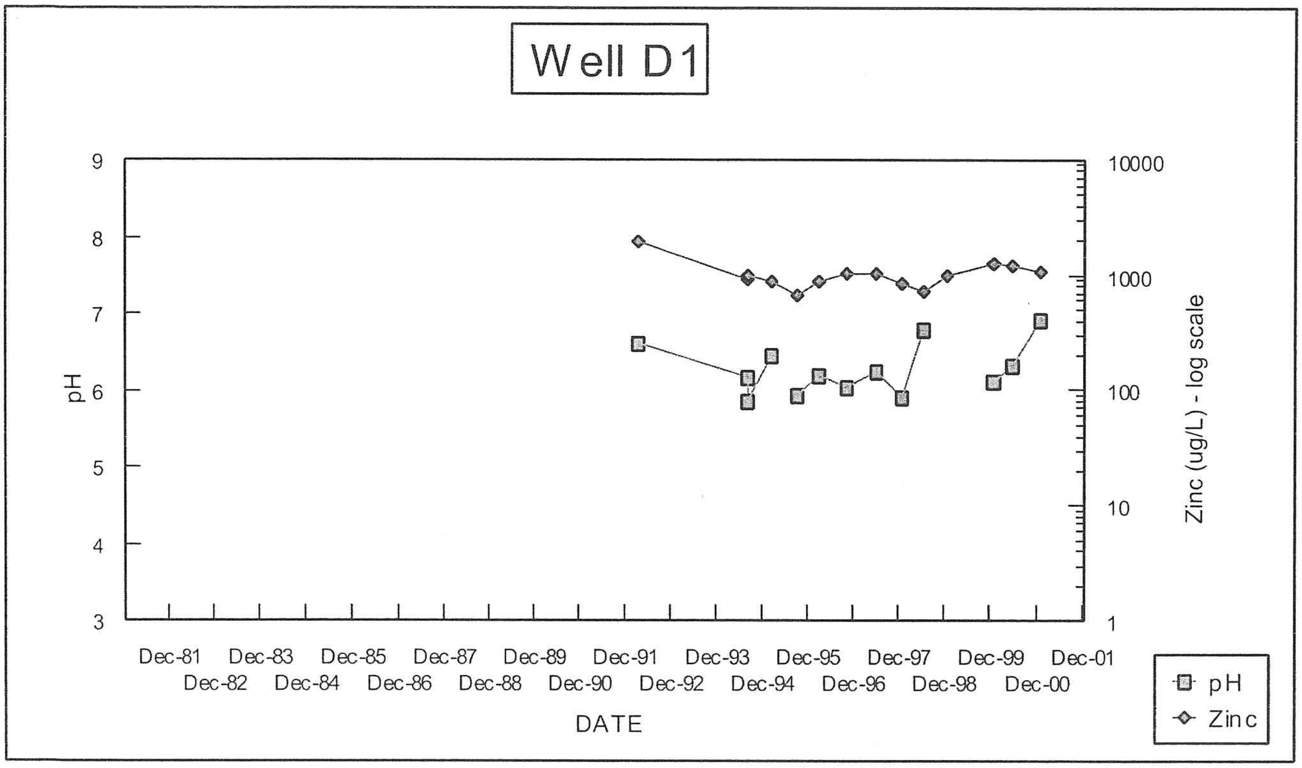


Figure 13. Well D1 shows little trend in sulfate concentrations, but D2 shows an increase of greater than 200 mg/L over the past 3 years.



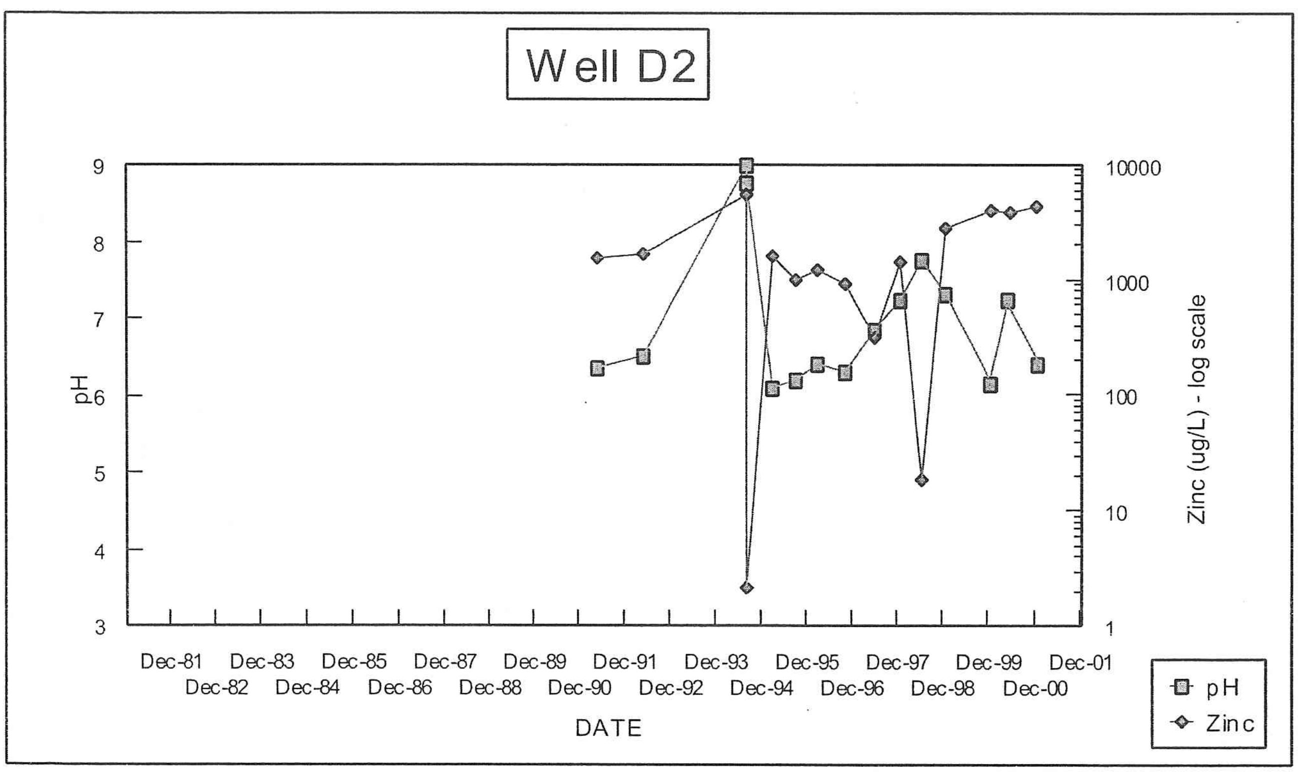


Figure 14. Bedrock well D1 shows little change in the concentration of zinc while well D2, nearby, shows increasing zinc concentration.

2.3 Berkeley Pit

The pit continues to be the hydraulic sink for ground water and surface water in the East Camp. Ground-water levels reached the bottom of the pit some 20 months after flooding of the underground workings began in April of 1982. The chemistry of the water in the pit is a function of both the quality of waters flowing into the pit and the processes within. The largest sources of water flowing into the pit, current and historic, include:

Current (2000)

- precipitation (about 13 inches average annual at Butte Airport),
- ground water from the bedrock aquifer associated with underground workings north, west, and east of the pit,
- ground water from the undisturbed bedrock aquifer east and south of the pit,
- ground water from the alluvial aquifer east and southeast of the pit,
- Horseshoe Bed surface water (coincident with the shut down of mining), and
- Leach pad water (coincident with the shut down of mining),

Historic

- precipitation,
- surface water from a large seep (Horseshoe Bend) at the base of the leach pad /tailings dam (diverted in April,1996),
- drainage from the leach pads (diverted with re-activation of leach pads in 1986),
- surface water originating in the Continental pit area (surface water and discharge from the Sarsfield mine adit), and
- tailings slurry from pipeline breaks between the mill and the tailings pond north of the pit (sporadic).

From mid-1999 to mid-2000 water was pumped from the Berkeley Pit through the copper cementation facility, together with Horseshoe Bend water, as part of the active operation. The intent was to replace the pregnant solution from the leach pads, which had been shut down. In mid-2000, all active operations were suspended; re-circulation of pit water ceased, Horseshoe Bend water and the remaining drainage from the leach pads were allowed to flow into the pit.

Horseshoe Bend is a large spring at the base of the Yankee Doodle tailings dam / leach pad area (figure 3) that flowed into the pit at a rate of 2.4 to 2.9 million gallons per day until April of 1996. From 1996 to mid-2000, when mining and milling operations were shut down, this water was captured and eventually pumped to the tailings dam.

When mining operations were suspended in 1983, the leach pad operation was also suspended and the pregnant solution was allowed to drain into the pit. In 1986, mining operations were re-started and the leach pads were re-activated; pregnant solution from the pads was captured and re-circulated. As with Horseshoe Bend water, this water has been flowing into the pit since mid-2000.

Water from the Continental Pit area (also known as the Continental East Pit) was routed around the active operations and drained into the pit until about 1986 when mining was re-started. All waters in the area are flowing into the Continental Pit. Samples have been collected from the pumping discharge line from the pit and from the Sarsfield shaft, adjacent to the pit (table 9).

Table 9. Selected dissolved-metals concentrations from surface flows near the Continental Pit (1984,2000, and 2001) and the Sarsfield shaft (1994).

Sample	Flow (gpm)	pH	Al (µg/L)	Cd (µg/L)	Cu (µg/L)	SO_4 (mg/L)
Above pit*	45	2.88	59,600	1180	162,000	2340
Sarsfield shaft	-	6.57	<30	5.2	27.4	562
pit (1984)	270	6.68	60	16	440	530
pit (9/13/2000)	285	7.19	<30	3.06	11.6	906
pit (1/23/01)	230	6.93	<300	<20	<20	954

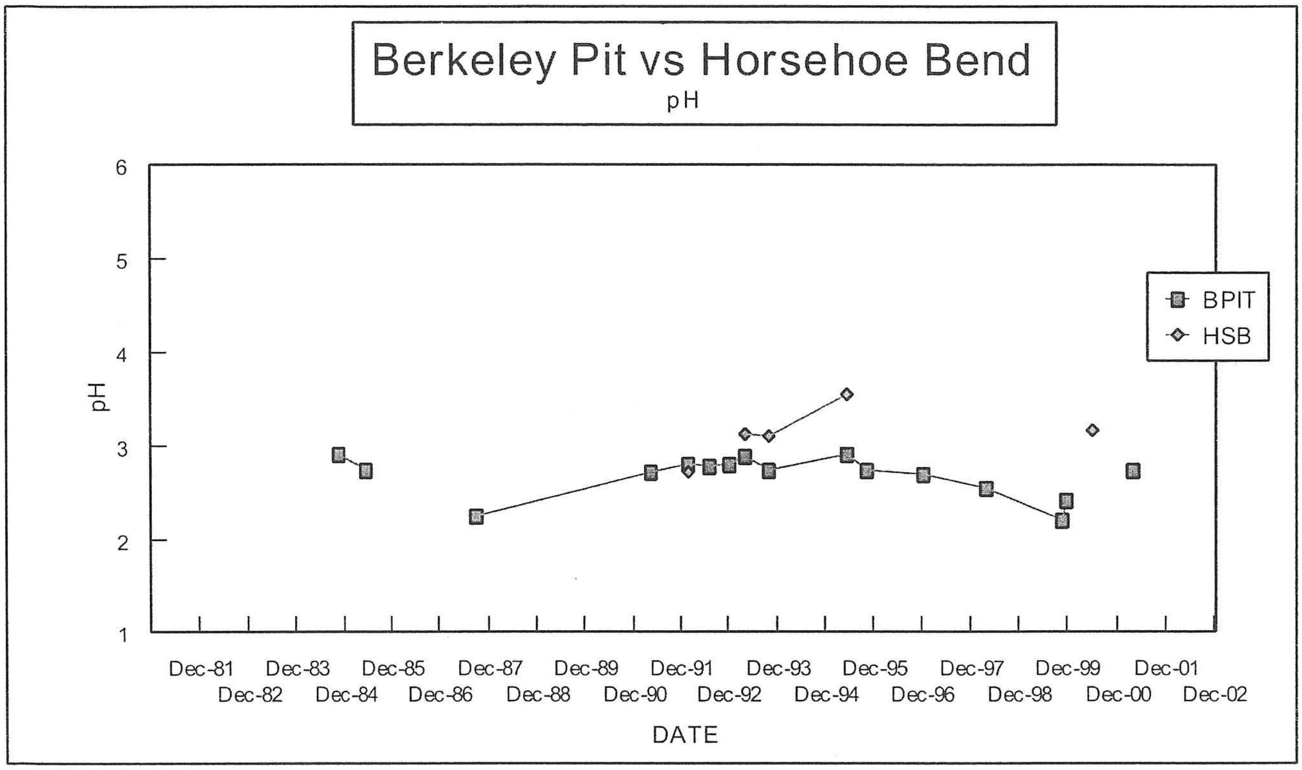
* sample collected below historic waste-rock dumps

Zinc concentrations increased from about 1500 ug/L to 2600 ug/L in 2001; no trends were apparent in the concentrations of other constituents.

In the past 3 or 4 years, changes in quality and quantity of the waters flowing into the Berkeley Pit have outpaced sampling. Evaluating the impact of a year's worth of replacing dissolved copper with ferric iron in the cementation process, followed by another year of uncontrolled flow into the pit, is limited by having only one or two samples. This, combined with the heterogeneity of the pit water, does not allow an evaluation of water-quality trends.

As noted in earlier reports, the chemistry of the Berkeley pit is a function of both the quantity and quality of waters flowing into and the geochemical processes within, the pit. Canonie (1991) estimated that the quantity of water flowing into the pit is nearly equally distributed between surface water and ground water. Diverting surface waters from entering the pit from 1996 to 2000 reduced the rate of pit water-level rise by about one-half. The Horseshoe Bend spring is probably the greatest single source of surface water into the pit. Figures 15, 16, and 17 present a comparison between Horseshoe Bend and Berkeley pit water qualities.

Quality of the Horseshoe Bend water has been significantly better than that of the pit throughout the period of record. The pH has been consistently higher by about 0.5 units and the concentration of dissolved metals and sulfate has always been significantly smaller. At least some influence by Horseshoe Bend on the pit chemistry is suggested by the similarity of changes. The only divergence of note is arsenic concentrations, which have increased in the pit waters from less than 100 to about 1000 μg/L , but have decreased from 10 to less than 1 μg/L in the Horseshoe Bend waters.



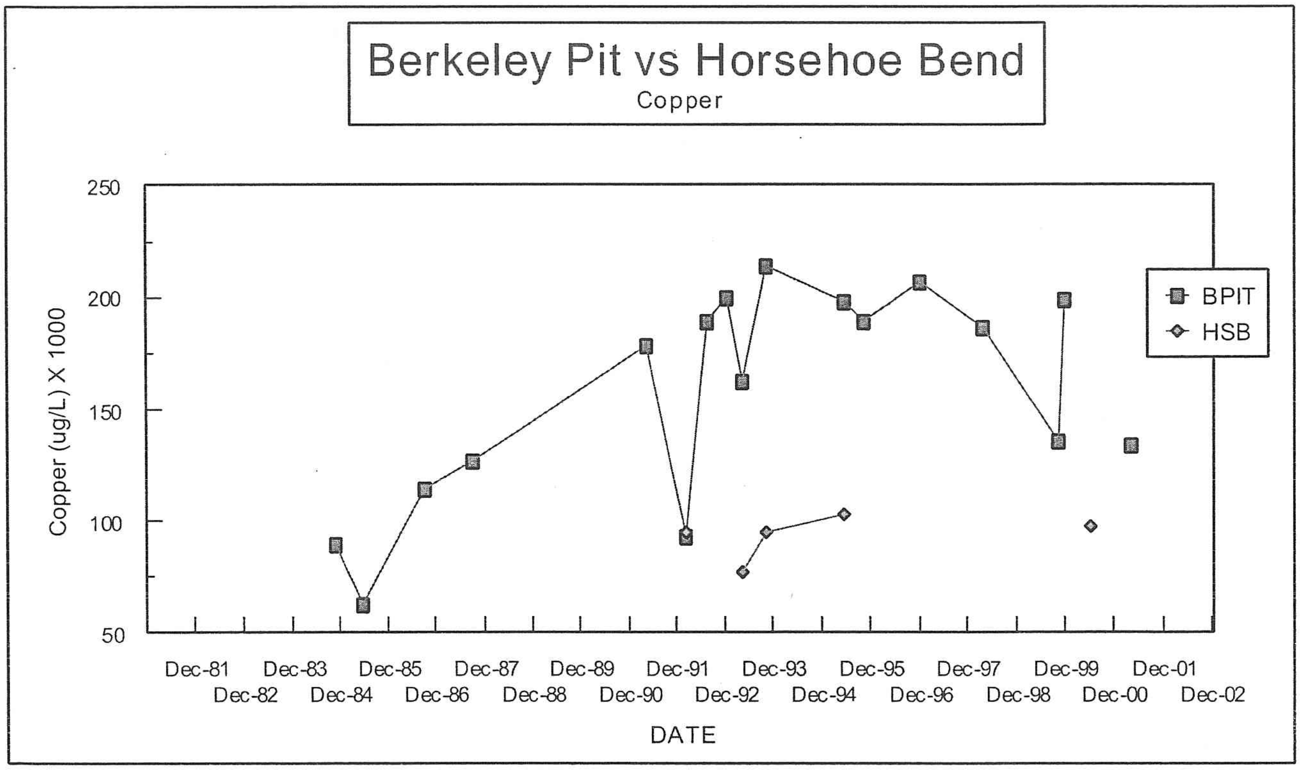
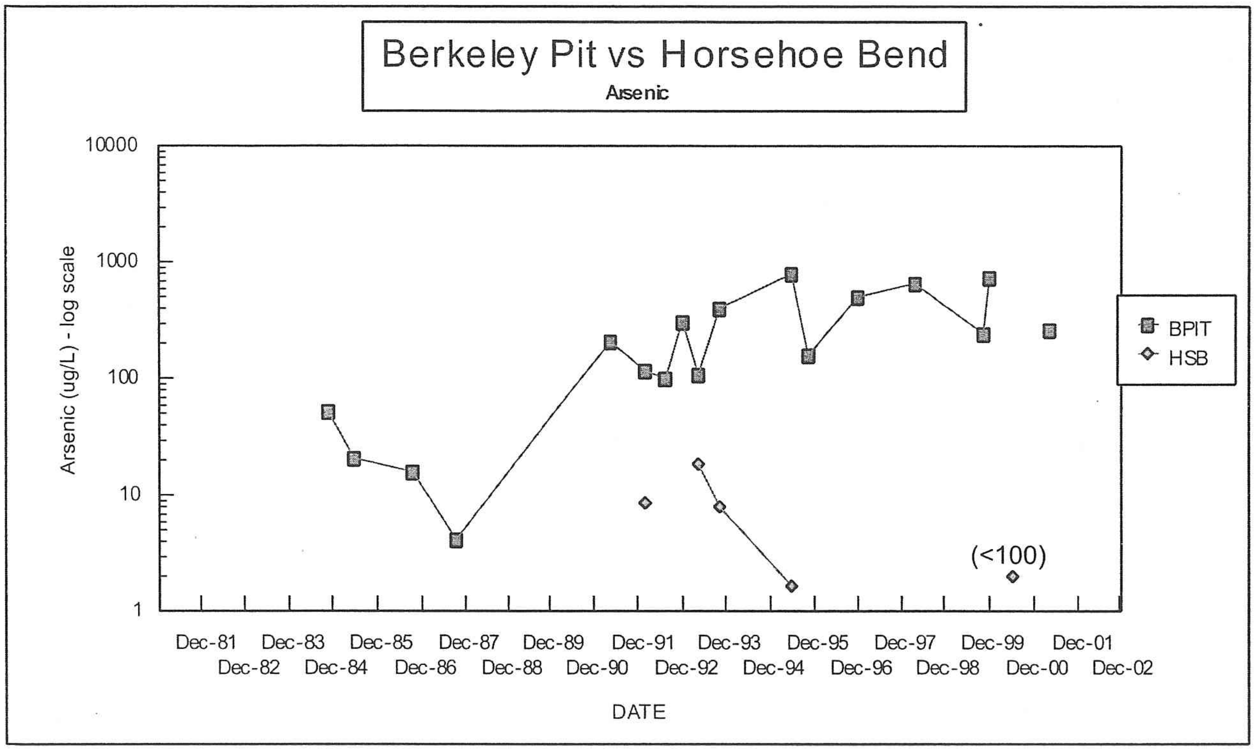


Figure 15. Horseshoe Bend water is consistently of better quality than that of the Berkeley Pit, but trends for most dissolved constituents are similar in the two waters.



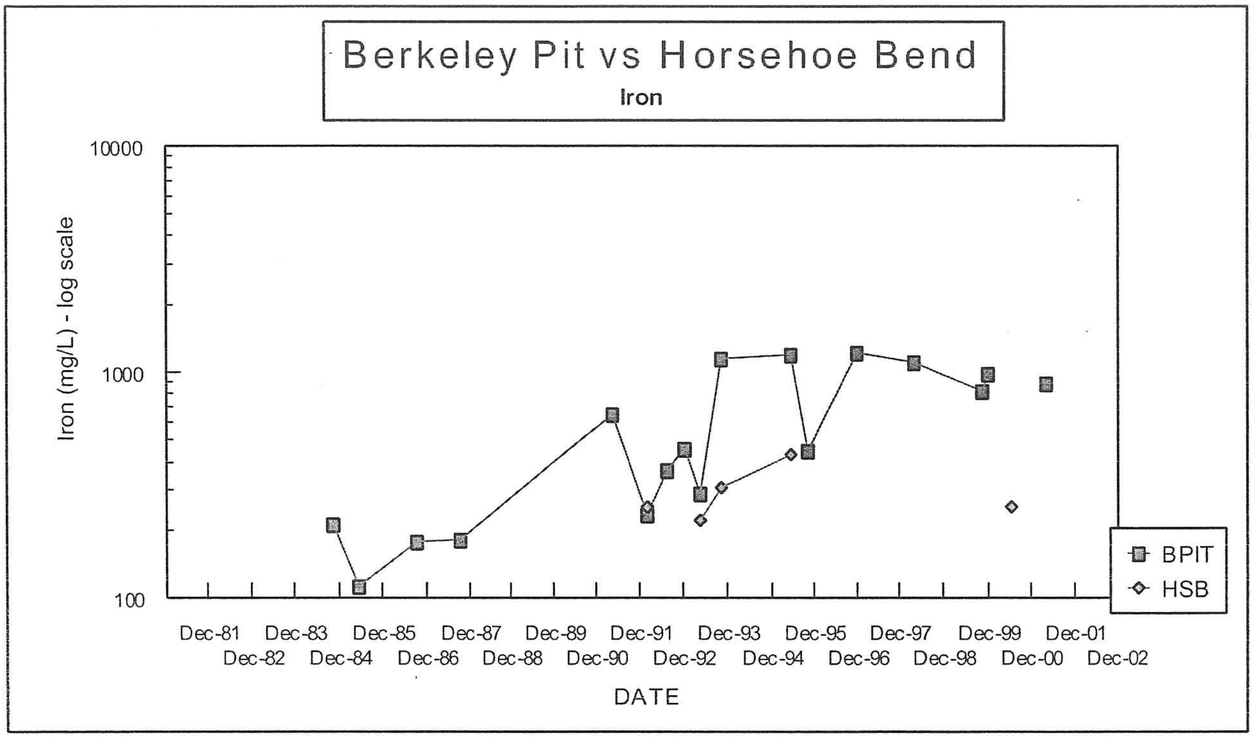
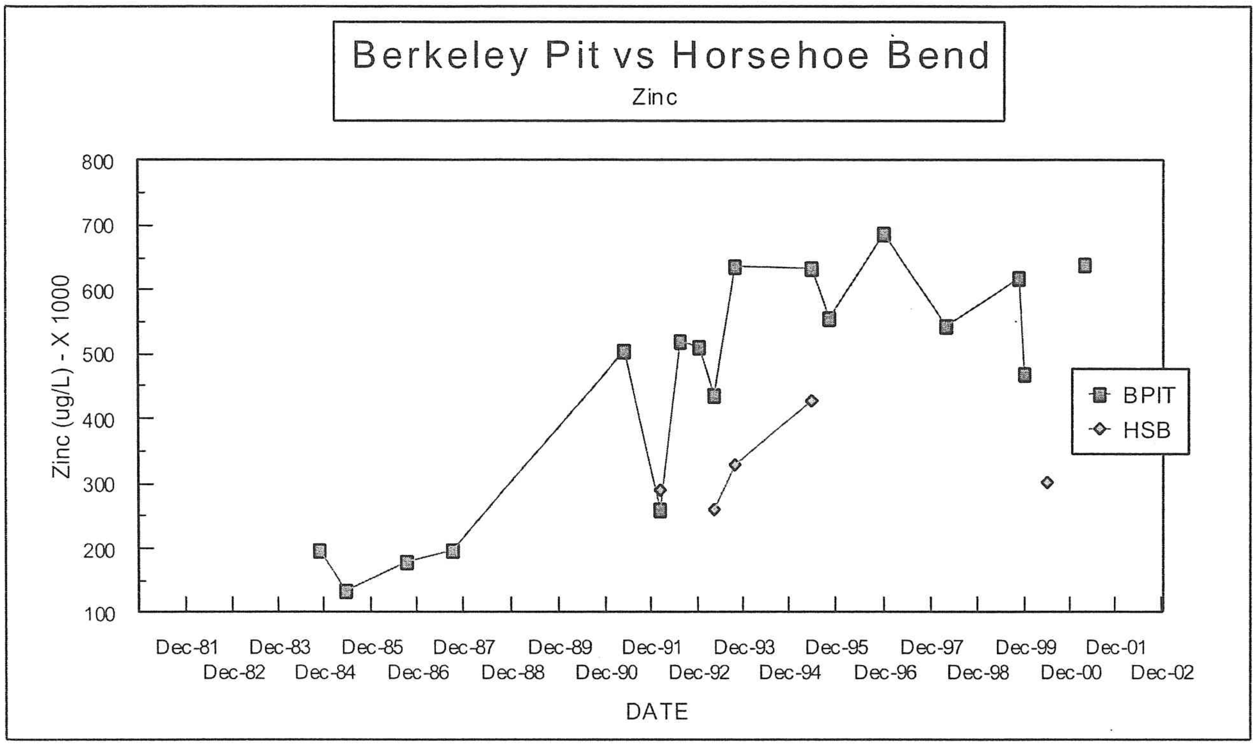


Figure 16. Arsenic concentrations have decreased in the Horseshoe Bend water, but have increased in the pit. Total dissolved iron has followed similar trends in both waters.



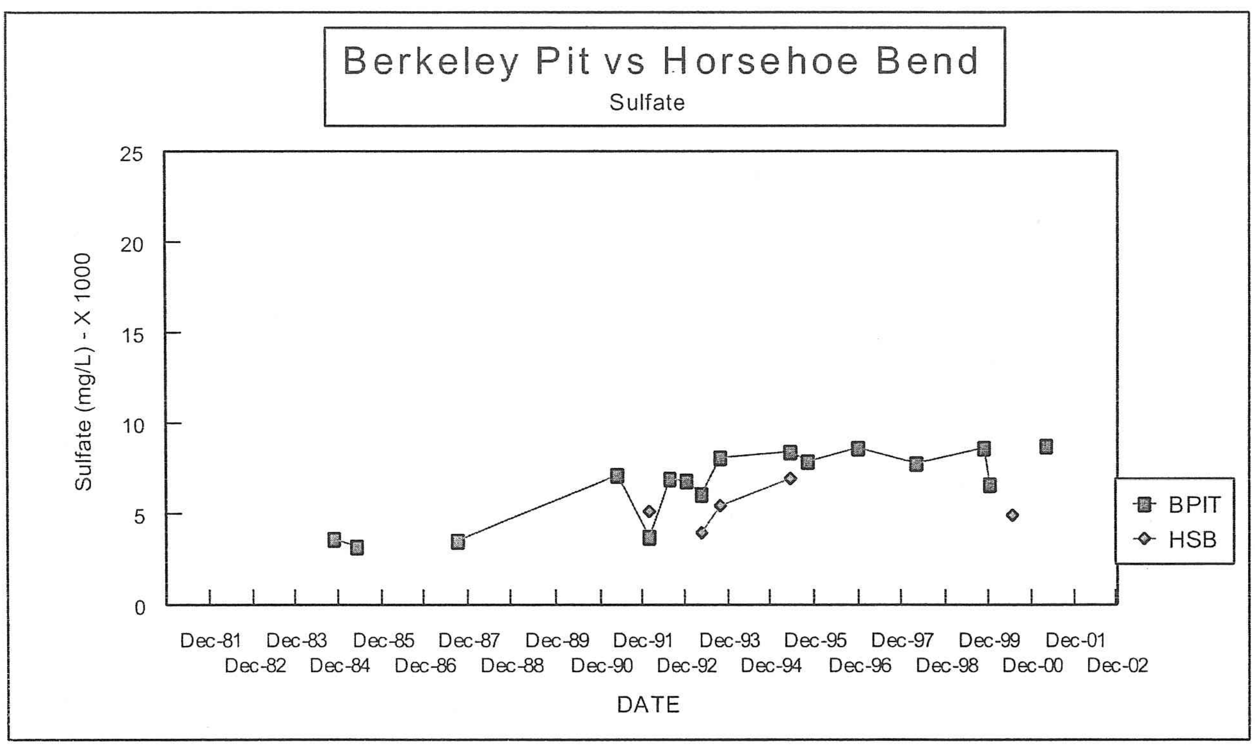


Figure 17. Zinc and sulfate concentrations are higher in the Berkeley pit waters, but follow trends similar to those of the Horseshoe Bend water.

Figures 18 and 19 present a comparison of pH, dissolved copper, zinc, and sulfate concentrations in the Berkeley pit and several shafts between 1983 and 2000. All of the shafts indicate an improvement in water quality although the relative change varies considerably. Conversely, the Berkeley Pit water quality has degraded with respect to pH and the concentrations of several constituents.

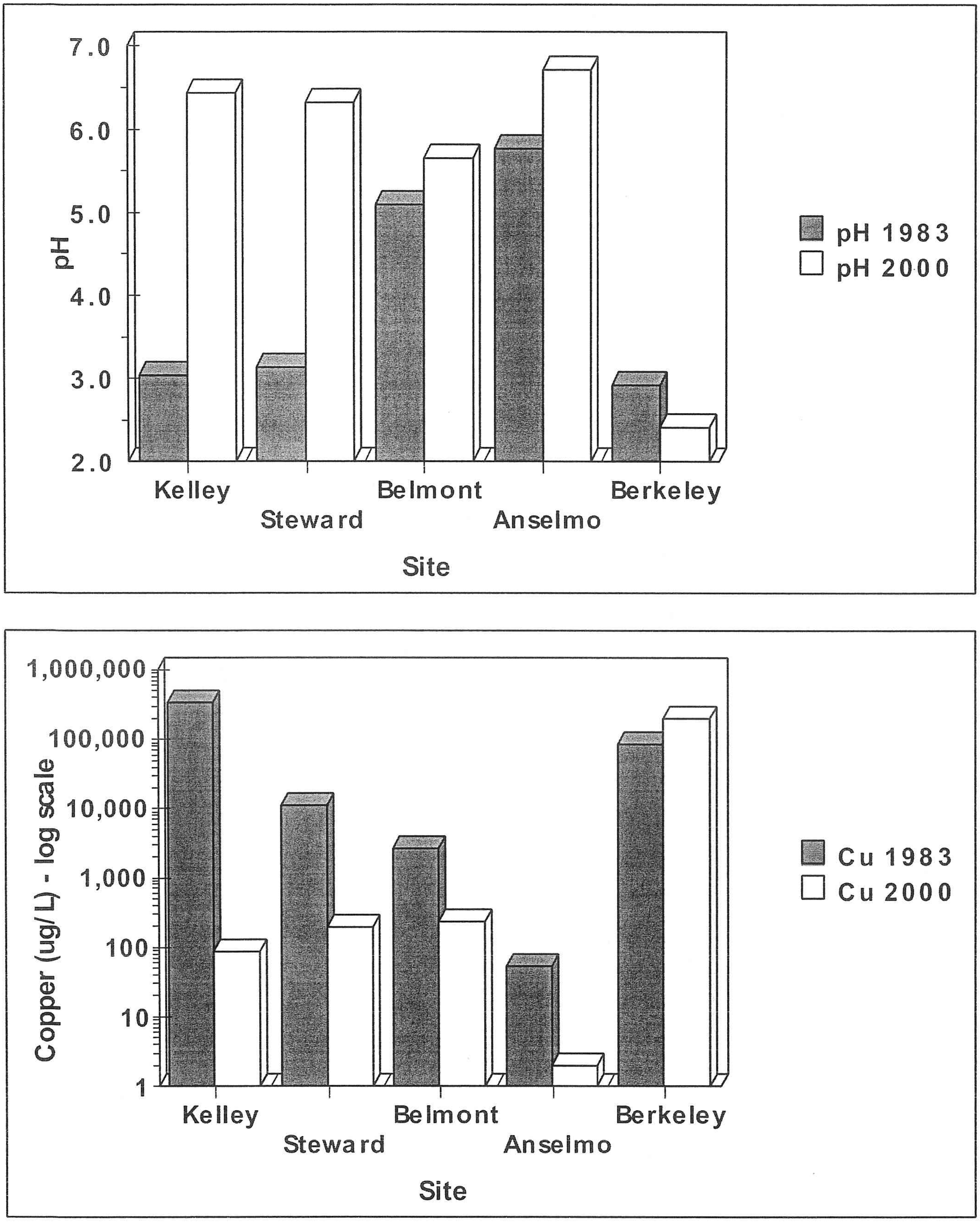
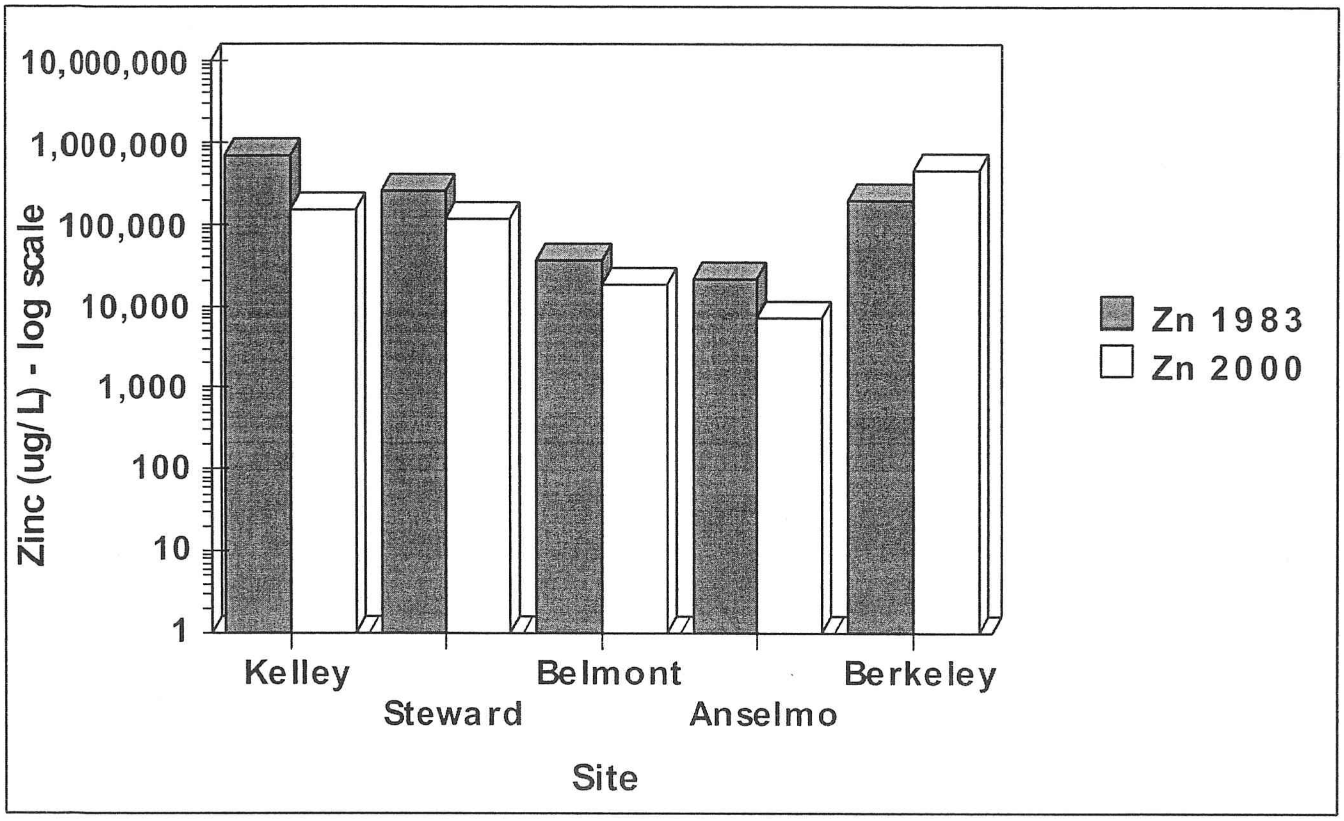


Figure 18. The pH has increased by as much as 3.5 units and copper has decreased by several orders of magnitude in the waters of some shafts. The pit water shows the opposite trends.



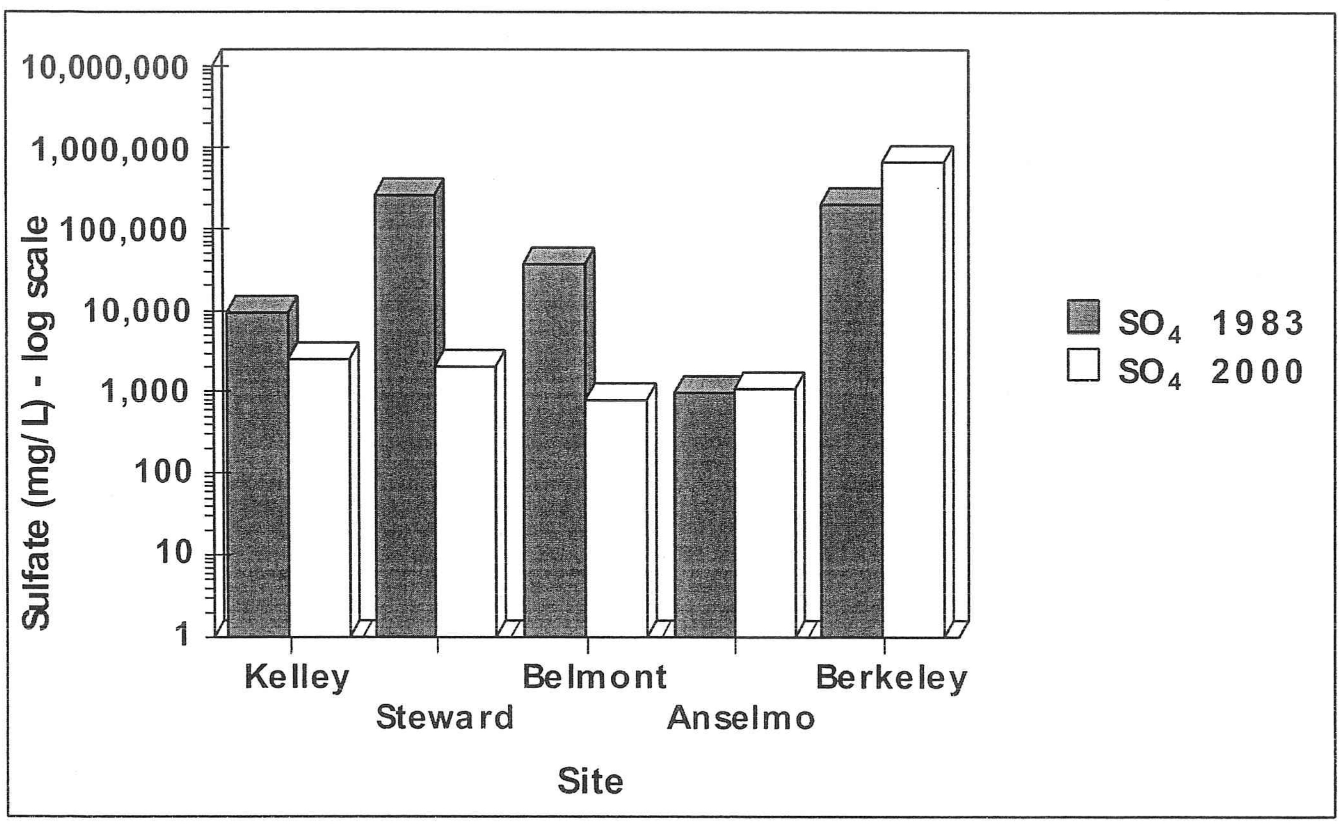


Figure 19. Zinc concentrations have decreased in waters in the shafts, but remain well above the MCL of 5000 ug/L. Sulfate concentrations in the shaft waters have also decreased and are approaching a nearly uniform value of 1,000 mg/L.

Section 3.0 West Camp

Within 2 years of the start of flooding in the East Camp in 1982, the water levels in the Travona shaft began to rise. Water levels in the West Camp have been controlled by pumping from the shaft or from a well completed in the workings since 1989. The shaft was pumped periodically on an "as needed" basis for several years; however, to keep the water elevation below the action level of 5435 feet above mean sea level (amsl), continuous pumping has been required since 1995.

3.1 West Camp Alluvial Aquifer

Alluvium in the area of the West Camp is restricted to Missoula Gulch, a small tributary of Silver Bow Creek. Surface-water flow is restricted to the lowest part of the drainage which has recently undergone reconstruction for storm-water control. The ground water and surface water of this drainage are under the auspices of the Priority Soils Operable Unit. Because there are no hydrologic nor geochemical data to suggest a connection with the West Camp mine workings, there has been no monitoring.

3.2 West Camp Bedrock Aquifer

Monitoring of the West Camp bedrock aquifer includes several shafts and monitoring wells. The action level for water levels in this area was established at 5435 feet amsl in the 1994 Record of Decision. Concerns for maintaining a depressed water table outside the workings prompted installation of wells throughout the area of historic flooding (figure 20).

Water-quality and water-level monitoring of the Travona mine were initially performed at the shaft; this is also the point from which pumping occurred. In 1998, pumping began at a well completed in the workings, but with a lower well-head elevation; the well is referred to as the "west camp pumping well". Water-levels and water-quality monitoring also moved from the shaft to well BMF-1D (figure 20). The pH of the waters in both the shaft and well have varied as much as a full unit over the last 4 years (figure 21), but it is not clear whether samples from the shaft and from the well are the same water. There appears to be a trend toward increasing manganese concentrations at both sites but the overall range is small. Figure 22 presents arsenic and sulfate concentrations for the period of record; again, both the shaft and the well are presented for comparison. Both sites indicate an increase in arsenic concentration from less than 18 µg/L (the current MCL) to over 120 µg/L. Samples collected over the last 2 years confirm the trend.

The other BMF96-series wells were installed to monitor conditions in the bedrock within the West Camp system; the wells are in areas that had suspected flooding problems in the 1950's. With the exception of sulfate, concentrations of dissolved constituents in all of the wells are well below MCLs and SMCLs. Although there is a large variation between some data points, wells BMF96-1S and 96-2 indicate a trend toward increasing sulfate concentrations (figure 23). All of the waters are generally warm (> $8^{o}C$) compared to the mean annual air temperature of $3.8^{o}C$ at the Butte airport, but not warmer than waters from other wells in the area. Although no strong trend is apparent, wells BMF96-1S and 96-4 have shown consistent increases in temperature in the last 3 samples.

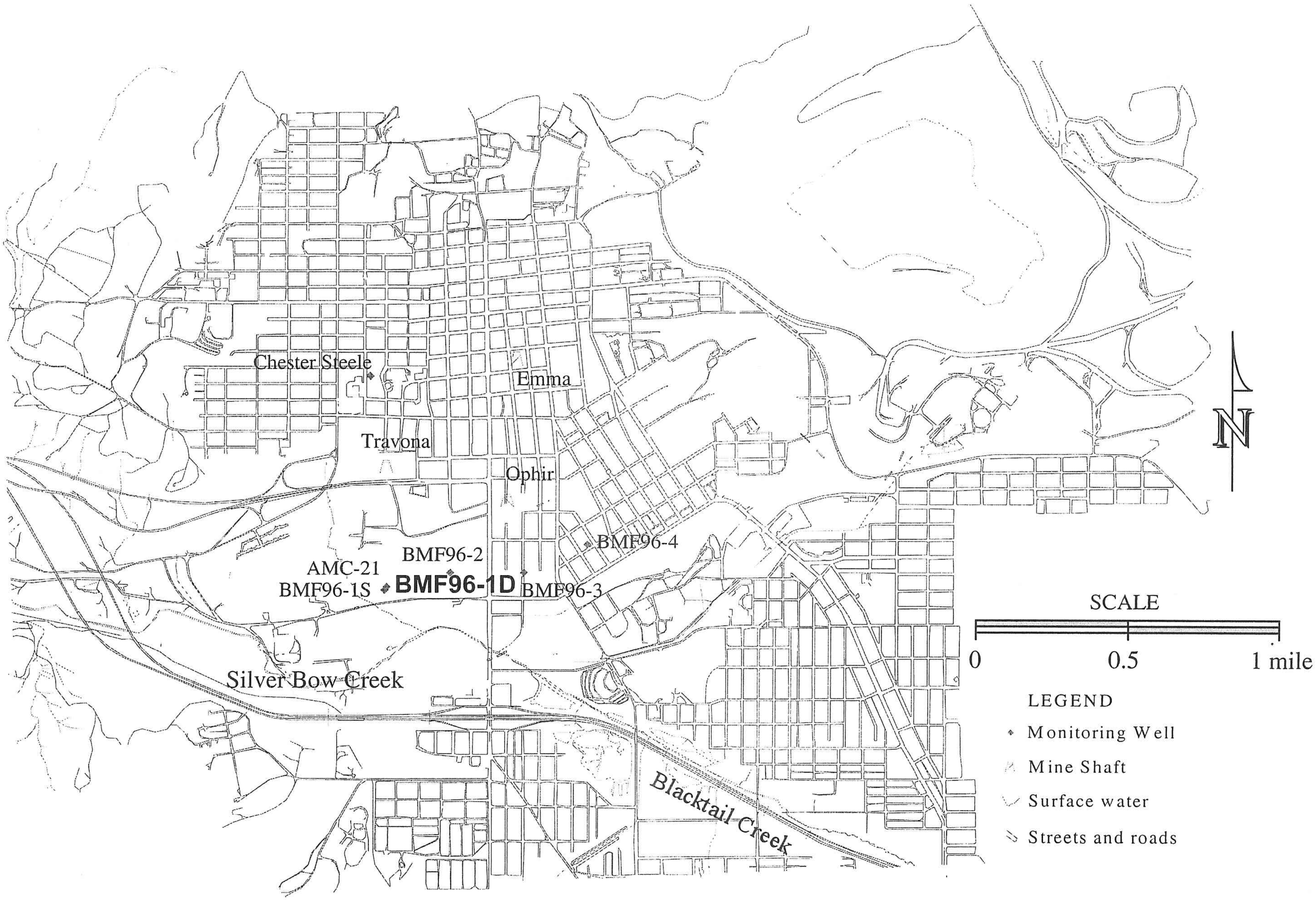
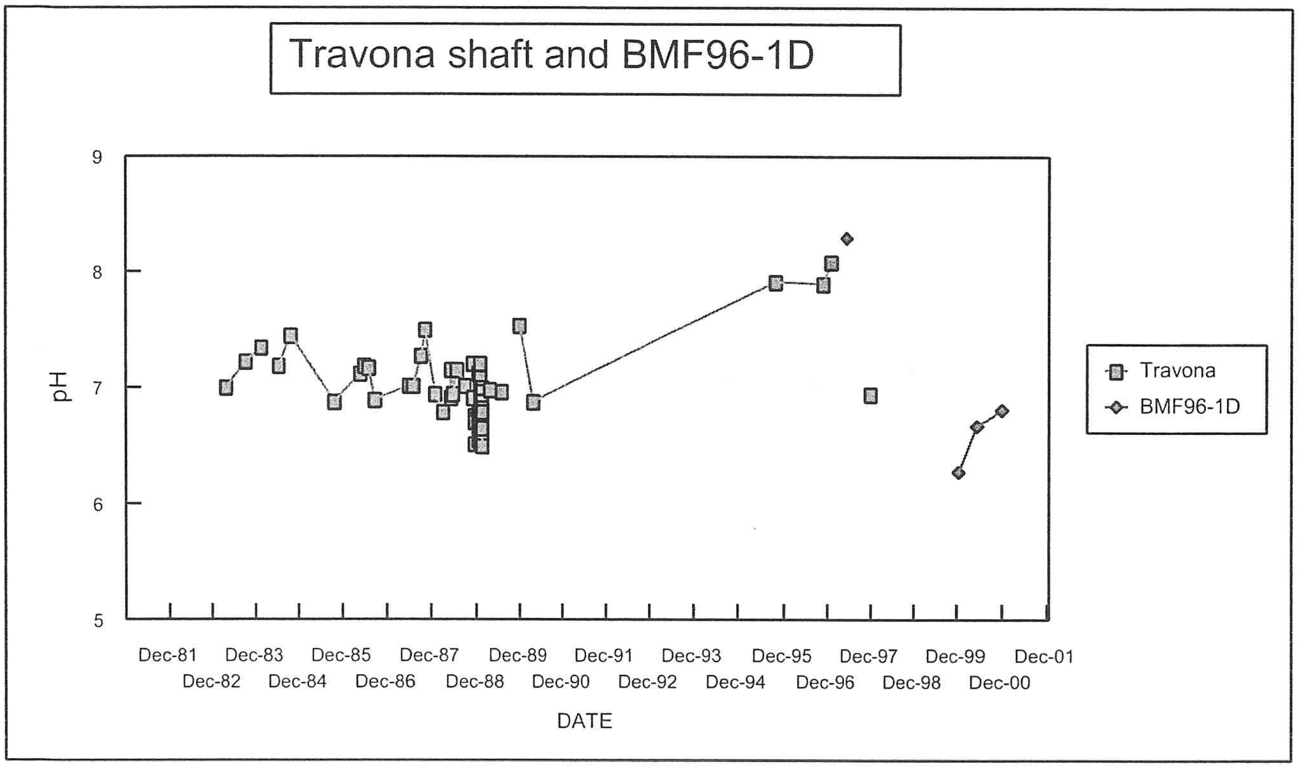


Figure 20. Water-level and water-quality monitoring of the West Camp includes several wells and shafts. Quality of the pumped water has been monitored at BMF96-1D (bold) since 1998.



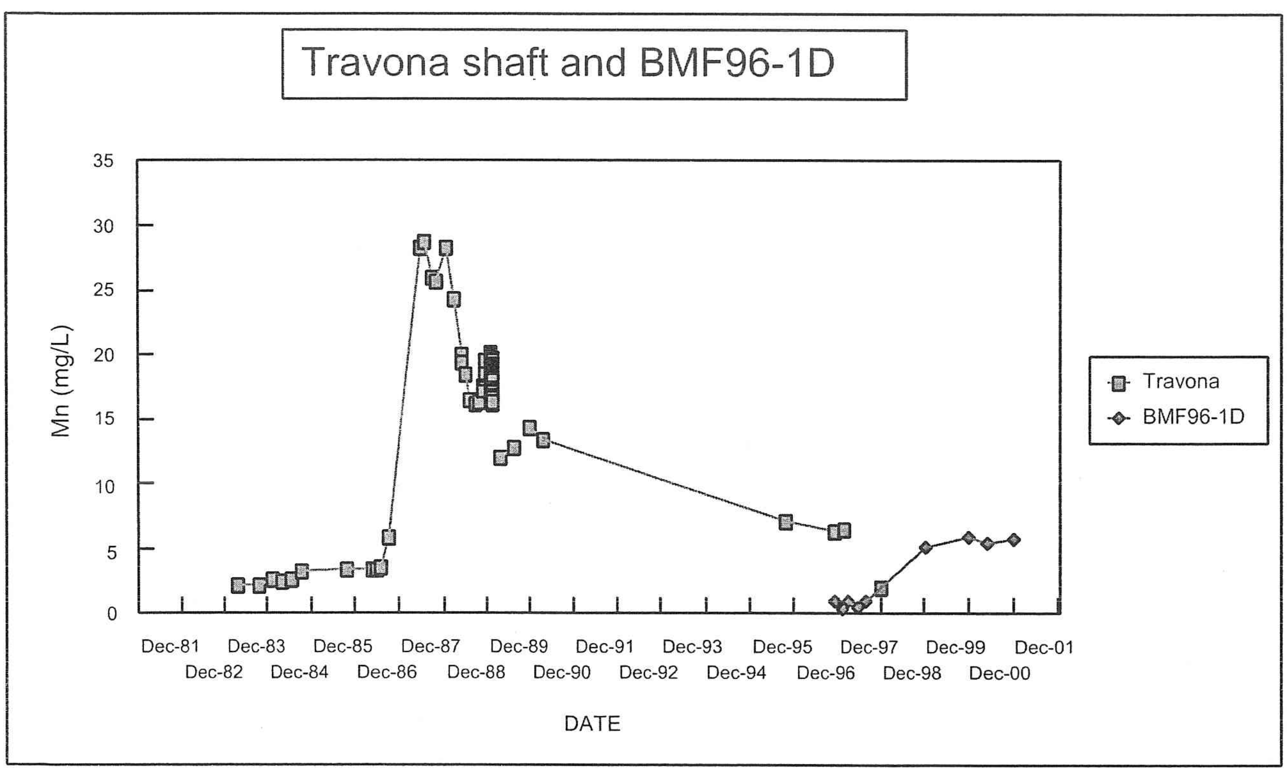
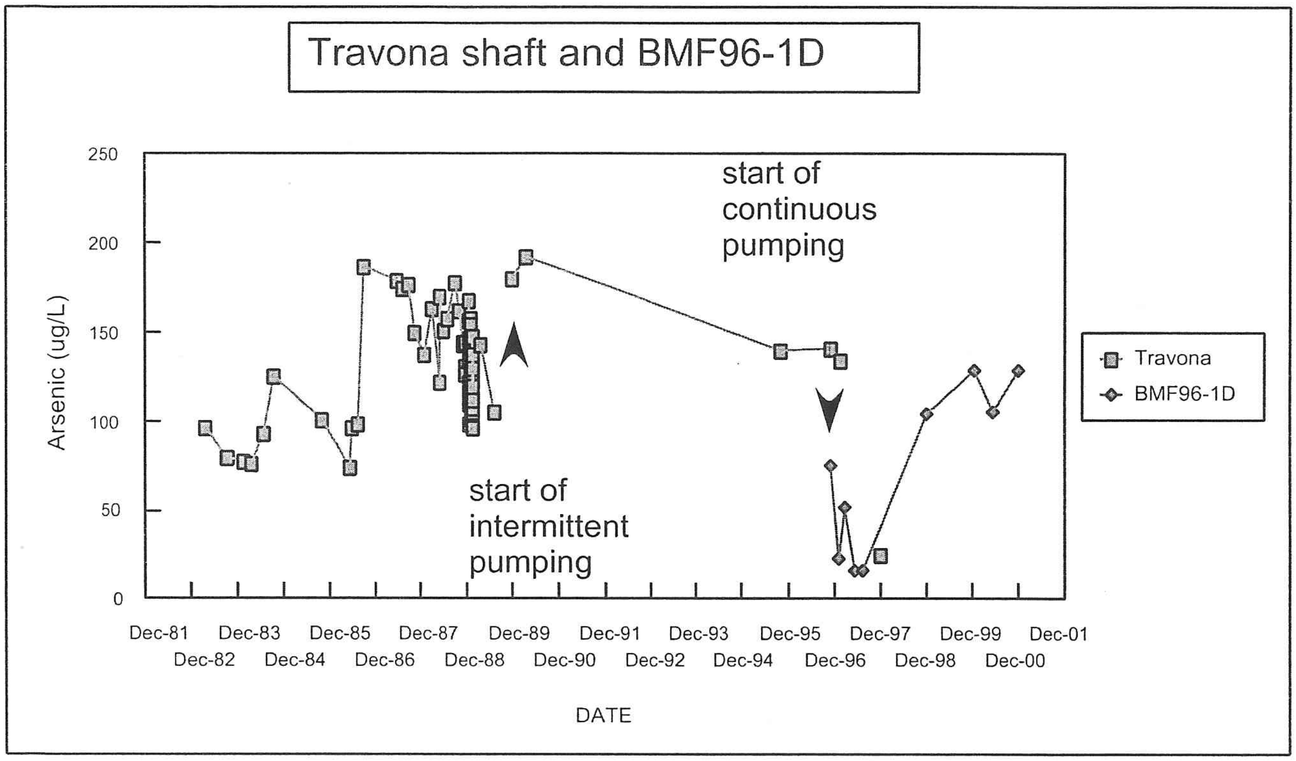


Figure 21. The Travona shaft and replacement well BMF96-1D indicate a change in chemistry possibly due to pumping.



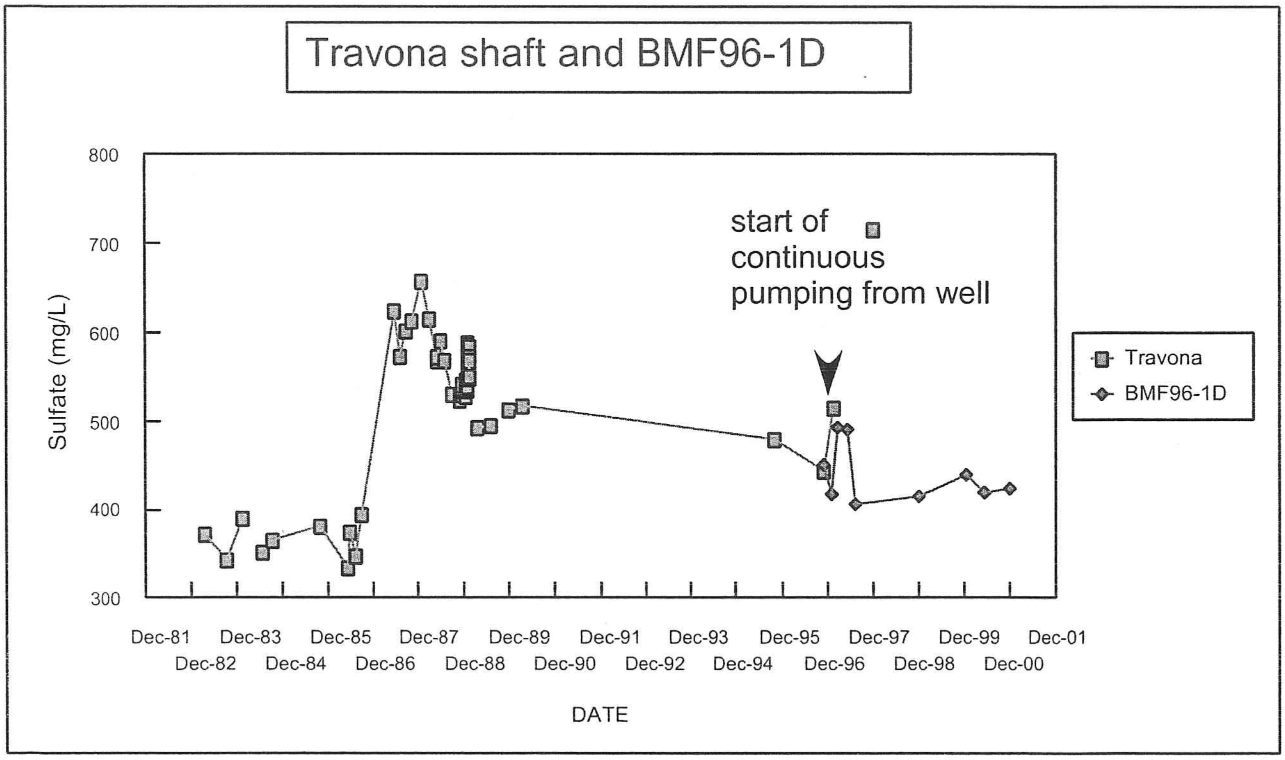
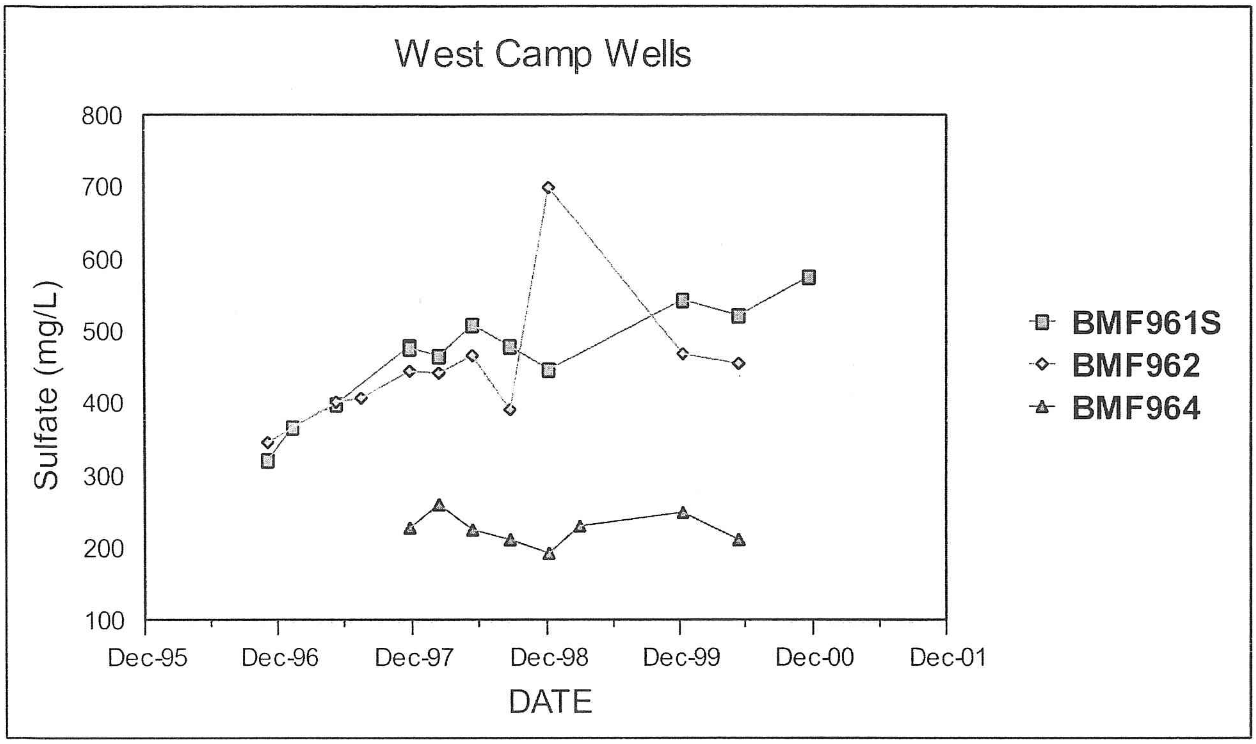


Figure 22. Arsenic and sulfate concentrations show an apparent response to pumping.



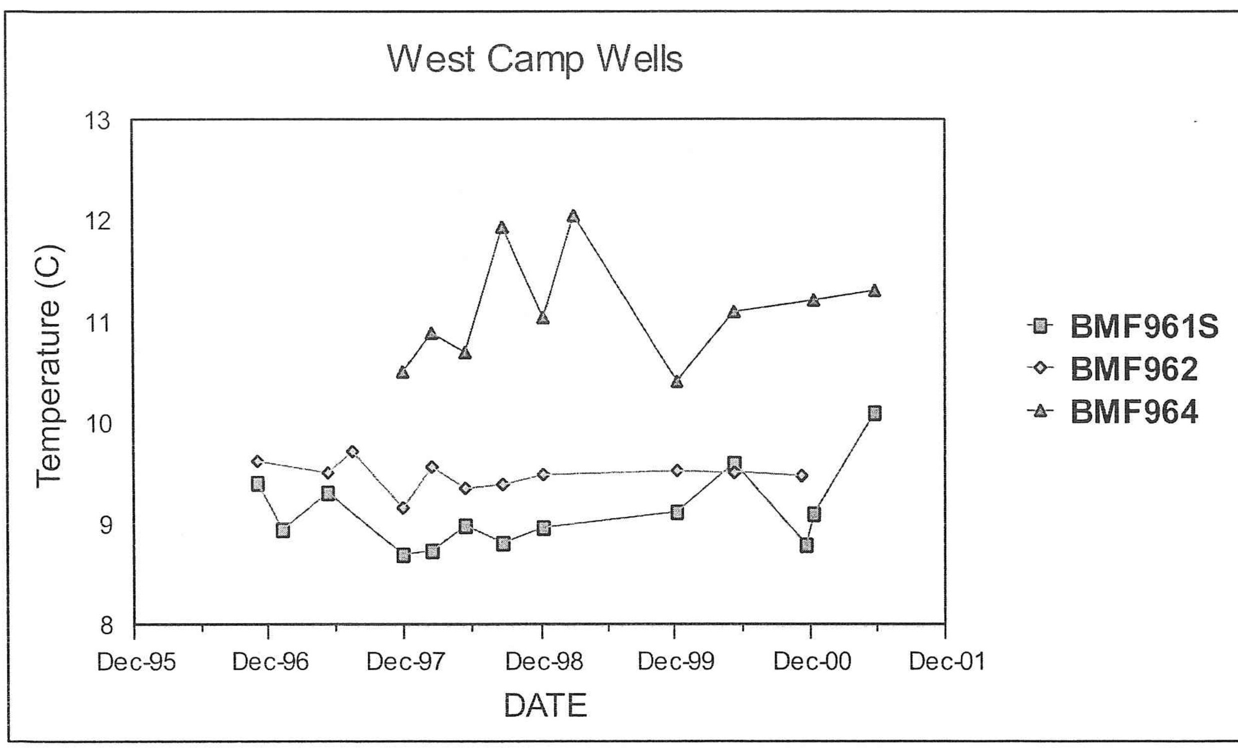


Figure 23. Concentrations of dissolved constituents in the West Camp wells are generally much lower than those found in the shafts. Sulfate concentrations and water temperature have increased over the period of record.

Section 4.0 Outer Camp

The Outer Camp generally refers to the area outside the direct influence of the East or West Camp system. Larger mines in the Outer Camp include the Orphan Boy, Orphan Girl, and Marget Ann mines (figure 24). The Marget Ann mine, north of Walkerville, was never connected to other mines; the Orphan Boy and Orphan Girl mines, west of Montana Tech, connected to the Anselmo mine in the East Camp. The mines of the Outer Camp were flooded in the 1950's; over the period of record (1982-1999), water levels have fluctuated with the seasons and precipitation trends, but there does not appear to be a net rise attributable to the flooding mines of the East Camp.

4.1 Outer Camp Alluvial Aquifer

Alluvium in the Outer Camp is restricted to small tributary drainages in the vicinity of the mines. These include Oro Fino Gulch near the Marget Ann Mine and several other unnamed gulches near the Orphan Boy mine. No monitoring wells have been installed in these areas; boreholes indicate thin alluvium (20 feet or less) and ground water is found only in the lower reaches of the drainage.

4.2 Outer Camp Bedrock Aquifer

Although the Orphan Boy and Orphan Girl mines are connected to the East Camp, bulkheads in the workings prevent a direct flow of water. The Marget Ann is probably typical of mines on the edge of the district in that it is of limited extent and has workings that did not connect with other mines. Water levels in and around these workings are well above those of the flooding East Camp and fluctuate throughout the year. Water-quality data are collected only from the Marget Ann shaft and the S-4 well.

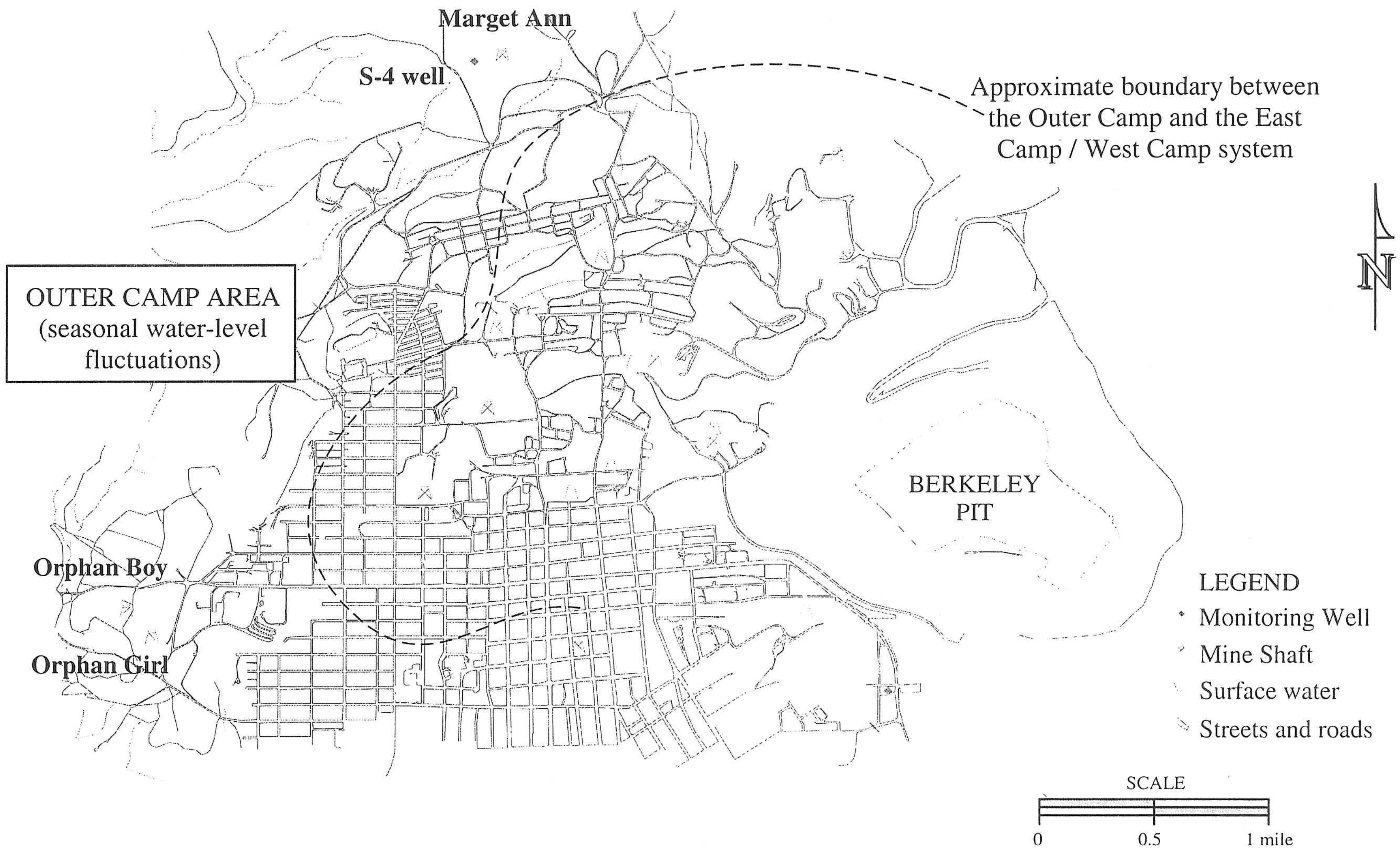
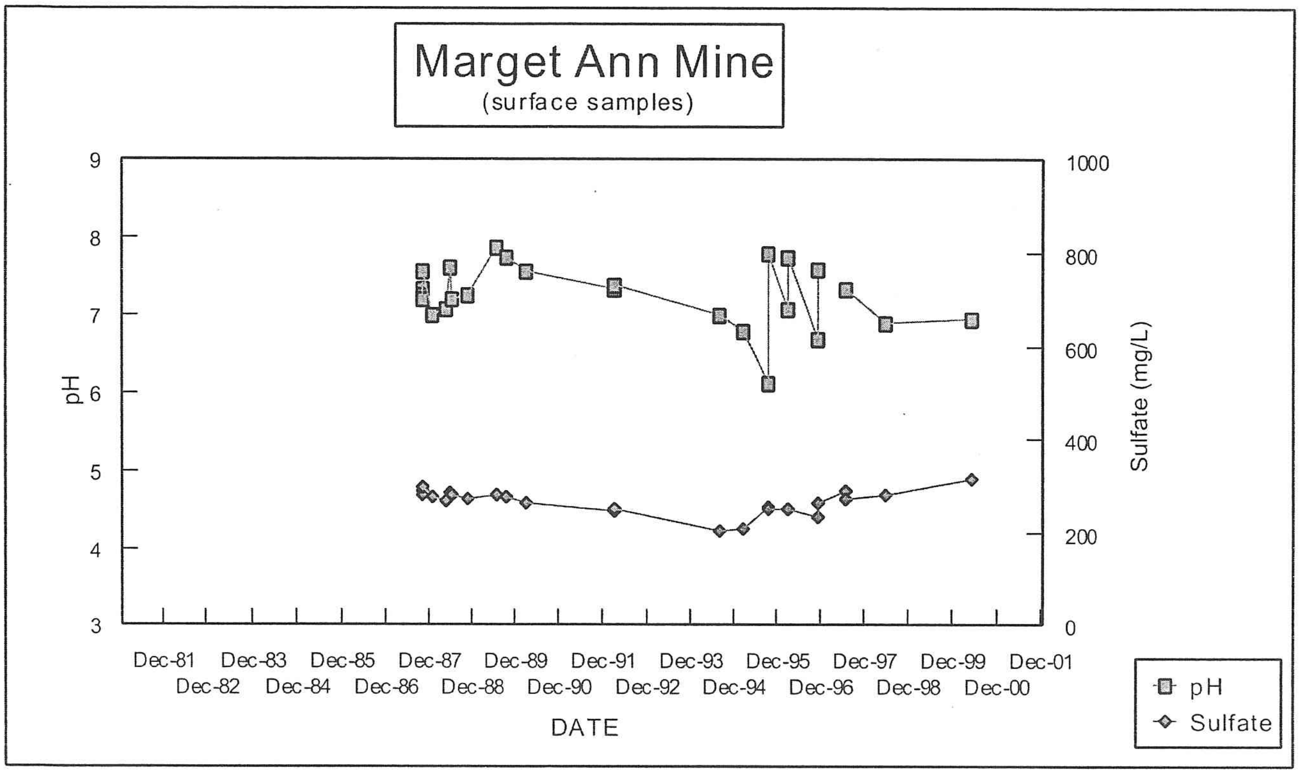


Figure 24. The Outer Camp includes the Orphan Girl and Orphan Boy mines that were separated from the other workings by bulkheads. Also included are mines such as the Marget Ann that are isolated from other workings.

It was reported in Metesh and Duaime (2000) that arsenic concentrations in the Marget Ann mine water consistently exceed the 50 µg/L limit for arsenic in drinking water; this was based on transcription errors and is not true. With the exception of sulfate, the concentrations of dissolved constituents are generally below MCLs and SMCLs, and show little variation. Sulfate has increased from about 200 to 300 mg/L over the last 6 years while the pH of the shaft water is consistently neutral or slightly alkaline (figure 25).

Well S-4 is about 600 feet west of the Marget Ann shaft. Both water-level and water-quality data have been collected at this site since 1989. Similar to the shaft water, the quality of the well wateris consistently good with the exception of sulfate. After an increase from 200 to 350 mg/L in 1998, the concentration of sulfate has remained near 350mg/L (figure 25).



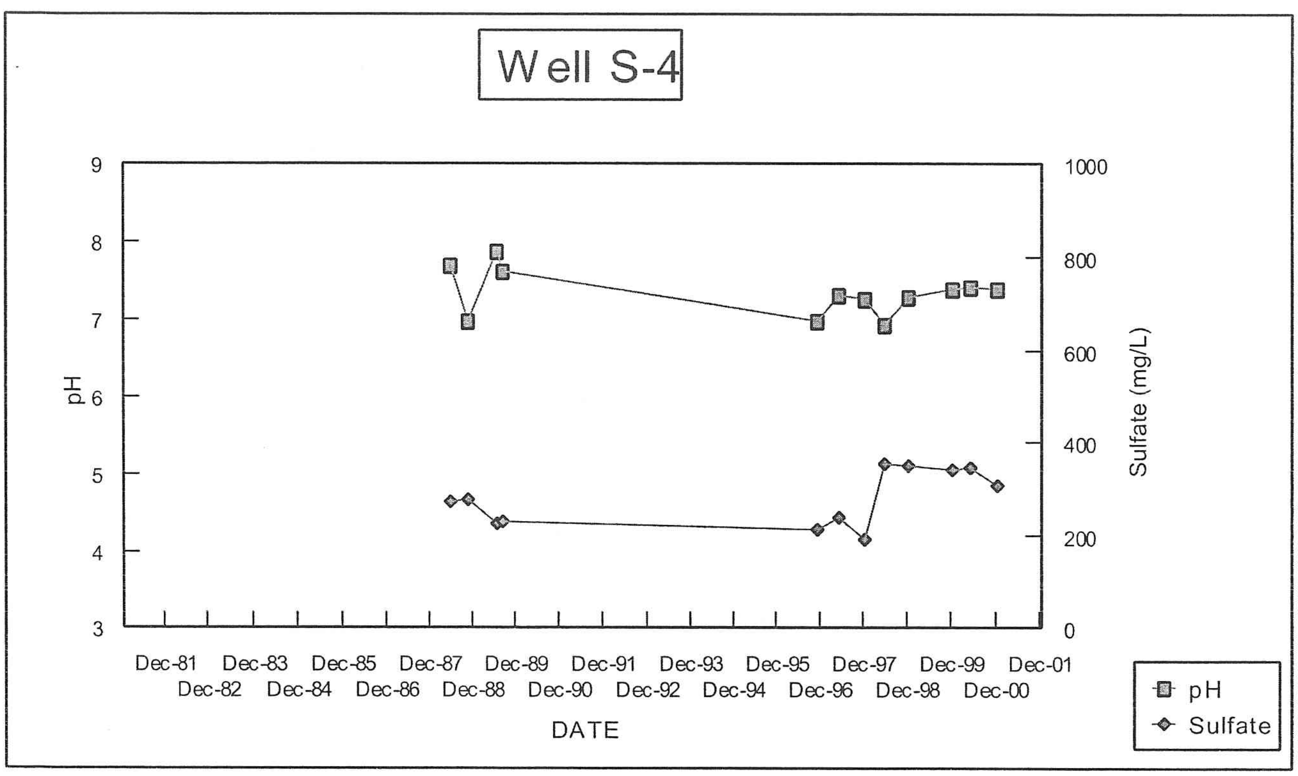


Figure 25. The sulfate concentration in the Marget Ann shaft has increased over the period of record, while well S-4 shows a slight decline after a sharp increase.

Section 5.0 Summary

The most significant change in water chemistry within the Mine Flooding Operable Unit has been that of the Berkeley Pit. After a 4-year hiatus (April of 1996 to June of 2000), surface water from Horseshoe Bend was allowed to flow into the pit starting in June of 2000; this also includes "pregnant solution" water originating from the leach pads.

Changes in ground-water flow resulting from the shut down of the leach pads in 1999 may have some effect on the water quality nearest the pads (LP wells), but the wide range of concentrations between wells and between data points within the same well makes it difficult to discern trends. Water quality in all but one of the LP wells exceeds one or more MCLs or SMCLs. Water levels in the alluvial aquifer south of the pit (AMC and GS wells) have been affected several hydrologic events, but there do not appear to be wide spread changes in water quality.

Trends toward decreased metals concentrations and improving water quality in the East Camp mines have continued over the last few years. Although pH values are near neutral, zinc and sulfate concentrations remain quite high in most shafts. Wells completed in the bedrock aquifer east of the pit have shown little change in water quality. All of these wells exceed the SMCL for sulfate concentrations; wells A and F exceed standards for arsenic.

Pumping to maintain water levels in the West Camp has increased steadily from sporadic to constant pumping since 1989. Shifting the monitoring point from the Travona shaft to the replacement well BMF96-1D makes an evaluation of water-quality trends difficult. The new monitoring point appears to indicate a slight increase in several dissolved constituents including arsenic, sulfate, and manganese.

Outer Camp monitoring sites provide a useful baseline to evaluate changes in the East and West Camp. Over the period of record, data from these sites have indicated little change in water quality.

Section 6.0 References

Canonie, 1994, Butte Mine Flooding Operable Unit Remedial Investigation / Feasibility Study - Draft Remedial Investigation Report: Prepared for ARCO: Canonie Environmental Services, Inc., Volume I, January 1994, 120p.

Duaime, T.E., Metesh, J.J., Keschen, M.K., and Dunstan, C.B., 1998, The Flooding of Butte's Underground Mines and Berkeley Pit: 15 Years of Water-Level Monitoring (1982-1998): Montana Bureau of Mines and Geology Open-file report 376, 116p.

Hydrometrics, 1982, Potential Impacts of Alternative Mine Water Management Plans, prepared for Anaconda Minerals Company, Butte, Montana April, 1982.

Metesh, J.J. and Duaime, T.E., 2000, The Flooding of Butte's Underground Mines and Berkeley Pit: 18 Years of Water-quality Monitoring (1982-1999): Montana Bureau of Mines and Geology Open-file Report 409, 79p.

Robertson, W.D., 1994, The Nature and Role of Microorganisms in the Tailings Environment, *in* Jambor, J.L. and Blowes, D.W., ed., Short Course Handbook on Environmental Geochemistry of Sulfide Mine-wastes, Waterloo, Ontario, Canada, 438p.

Sales, R.H., 1914, Ore Deposits and Butte, Montana, American Institute of Mining Engineering, volume 46, p. 3-109.

SEM, 1973, Guidebook for the Butte Field Meeting of Society of Economic Geologists, Butte, Montana, August 18-21, 203p.

Smith, R.I., 1953, History of the Early Reduction Plants of Butte, Montana: Montana Bureau of Mines and Geology Reprint Series - R2, 17p., 2pl.

Weed, W. H., 1912, Geology and Ore Deposits of the Butte District, Montana: U.S. Geological Survey Professional Paper 74, 262p.