Montana Bureau of Mines and Geology

The Flooding of Butte's Underground Mines and the Berkeley Pit 18 Years of Water-Quality Monitoring (1982-1999)

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Acknowledgments

The authors greatly appreciate the support provided by the Montana Department of Environmental Quality and the United States Environmental Protection Agency. We are also grateful for the support of our efforts by the mining companies, particularly Montana Resources for providing physical access and their expertise toward understanding the magnitude and complexities of the Butte mines. Data used in the preparation of this report includes not only those collected by the MBMG, but those of the many contractors who have worked for ARCO and MR over the last 18 years.

Section 1.0 Introduction

Butte is in southwest Montana at the headwaters of the Clark Fork and Columbia River drainage. At an elevation of about 6,000 feet, the climate of the area is cold and semi-arid with a mean annual air temperature of 38.7^{O} F (1948-1993) and an annual precipitation of 12.9 inches (1890-1999). The population of the Butte area peaked at about 100,000 in 1917 and is about 30,000 at present. By far the dominant industry of the area has been mining; Butte was one of the largest mining centers in the United States. Butte is also the home to the nation's largest Superfund site (Clark Fork River National Priorities List [NPL] Site) that extends from Butte, 120 miles northwestward, to the Milltown Dam near Missoula. The Clark Fork NPL site was divided into smaller "operable units" for administrative purposes. The Butte Mine Flooding operable unit includes the underground workings and the open pit mines (active and inactive) affected by the flooding by ground water (figure 1).

1.1 Geology

The Butte area is on the southern end of a large (2300 square miles) batholith emplaced during the late Cretaceous and early Tertiary periods. The batholith, composed of up to 15 separate plutons, extends from the Highland Mountains, south of Butte about 70 miles to Helena and from Pipestone, east of Butte, about 30 miles to Deerlodge. Although economic mineral deposits have been discovered and mined throughout the batholith, the Butte area is a world-class porphyry copper-molybdenite deposit. The geologic history of the ore body is complex and is the subject of many investigations. In general the ore body is composed of a quartz monzonite country rock that hosts several extensive vein "systems" referred to as the pre-main stage and main stage. The main stage is further described as having two sub-systems: the Anaconda and Blue vein system. The more dominant ore minerals in these veins include copper sulfides (bornite, covelite, chalcocite, enargite, and chalcopyrite), sphalerite, and galena. Pyrite, gangue mineral and the main culprit in acid mine drainage, runs 13 wt% in the center of the district. Alteration of the country rock ranges from weak, green argillic (chloritic) alteration throughout the district to intense sericitic alteration near the vein (SEM, 1973). Sales (1914) recognized the zonation of the deposit based on mineral assemblages: 1) the central (copper) zone, 2) the intermediate (silver-lead-zinc) zone, and the peripheral (manganese) zone. These zones played an important role in the mining of the "richest hill on earth".

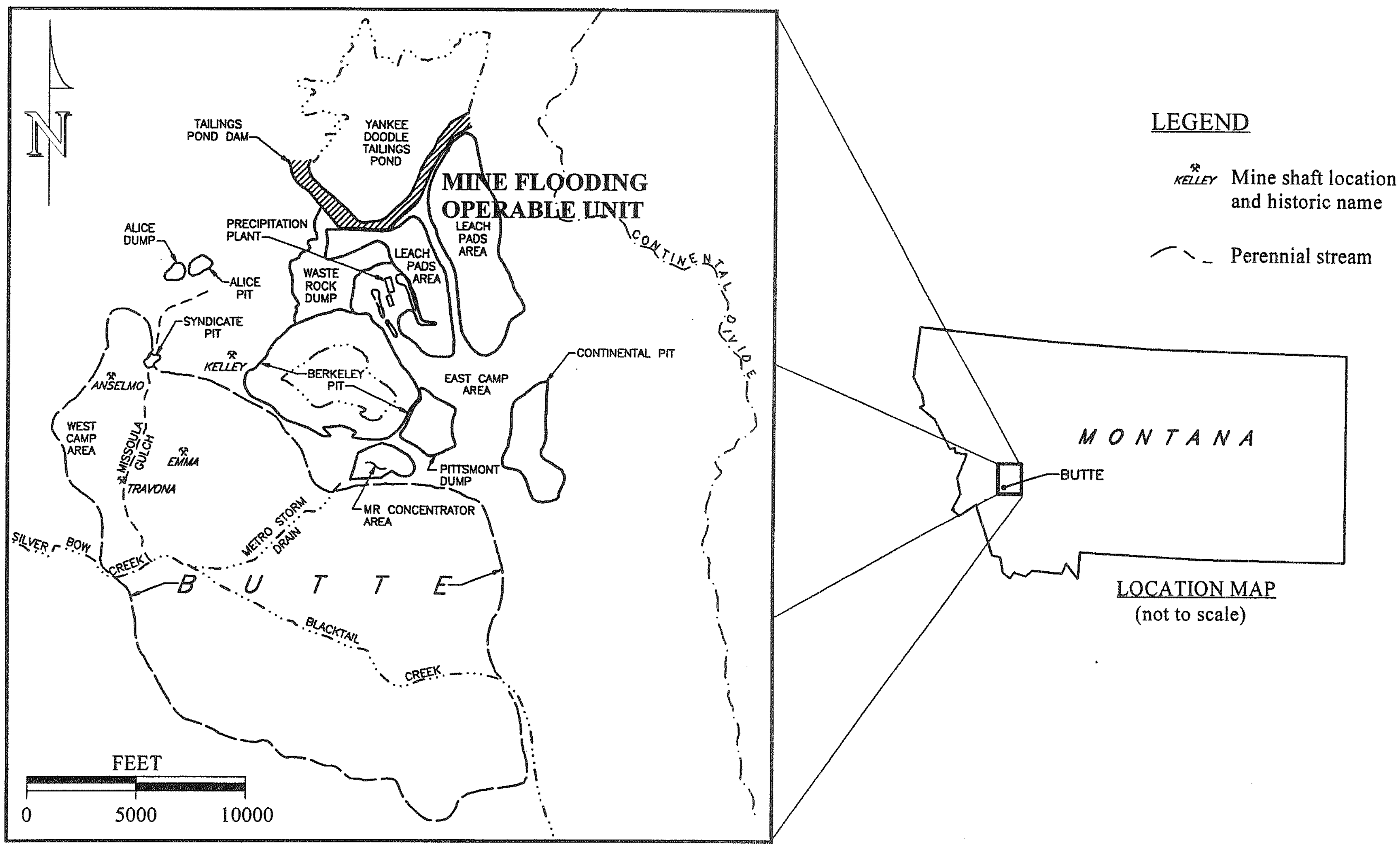

Figure 1. The Mine Flooding Operable Unit on the Butte hill includes the underground workings, the Berkeley pit, and the active mine area.

1.2 Mining History

Mining in the Butte area began in the early 1860's as gold placers in the area now known as Silver Star. By 1865, several placer claims were established in Missoula Gulch, Buffalo Gulch, and Parrot Gulch on the Butte hill (Weed, 1912). The first sustained underground mining venture occurred at the Asteroid claim (presently the Travona mine) which exploited the "black reefs" for silver in 1864; the silver-rich Rainbow lead in Walkerville was discovered soon after.

The Original, Colusa, Mountain Chief, and Gambetta mines owned by W.A. Clark produced the first appreciable quantities of copper ore in the early 1870's. The Colorado & Montana Smelter, operational in 1879, eliminated the need for shipping ore to Utah; Butte became a "boom town" for copper mining. As many as 12 smelters were in operation along Silver Bow Creek by the turn of the century (Smith, 1953). A synopsis of milestones in Butte's mining history demonstrates the magnitude and diversity of the industry:

1866-68	Several small smelters and concentrators plus a wet-process mill were in operation. Mining activities primarily involved silver and minor amounts of copper.
1868-74	Demand for silver dropped - little mining activity - most mills and smelters closed. Davis Mill closed by 1869.
1878	Mining rejuvenated, several small smelters in operation.
1879-85	Butte is major mining center: 6-8 smelters (including Anaconda smelter), 300 mines, 4000 mining claims, 9 quartz mills built.
1910	All but the Pittsmont Smelter are bought and closed by Anaconda Copper Mining Company, ore is shipped to Anaconda.
1911	The Warm Springs Ponds are built.
1916-59	Two more ponds added in Warm Springs area.
1930	The Pittsmont Smelter closed.
1930's	The Metro Storm Drain is constructed as WPA project.
1955	The Berkeley pit began operations.

1963 Berkeley Pit ore processed at Weed Concentrator.

1960's Precipitation plant / leach pads constructed northeast of Berkeley Pit.

1972 Waste-water treatment plant added to Weed Concentrator. Raw mining/milling wastes no longer discharged to Silver Bow Creek.

1977 Berkeley Pit producing 50,000 tons per day of ore. All corporate assets of the Anaconda Copper Mining Company sold to Atlantic Richfield Oil Company (ARCO).

1980 Smelters in Anaconda and Great Falls closed.

1975 Underground mining ceased.

1982 Berkeley Pit ceased operations. Flooding of the underground workings began at midnight on April 22.

1983 Continental Pit ceased operations. Ground water flooding the underground workings reaches the bottom of the Berkeley Pit near the end of the year - a rise of nearly 2,200 feet.

1983 Upper Clark Fork River (Butte to Missoula) named to the U.S. EPA's National Priorities List (NPL) - Superfund.

1986 Washington Construction of Missoula, Montana purchases ARCO assets; mining of East Berkeley pit resumes under Montana Resources Incorporated.

1987 Underground properties purchased by New Butte Mining. The Clark Fork Superfund is area expanded to include the Butte mines.

1994 The U.S. EPA and the Montana DEQ release the Record of Decision for the Mine Flooding Operable Unit.

1996 An estimated 1.5 million gallons per day of surface water (known as Horseshoe Bend water) is diverted from flowing into the Berkeley Pit.

1998 A portion of the southeast wall of the Berkeley Pit slumps; approximately 1.5 million cubic yards of material enters the pit.

1999 MR begins pumping Berkeley Pit water at 5,000 gallons per minute through its copper recovery system; this is later increased to 10,000 gallons per minute.

1.3 Ground-water levels

Monitoring of the levels and quality of the flooding waters began almost immediately after the pumps were shut down in 1983. 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. Duaime and others (1998) have detailed the results of the past 18 years (1982 - 1999) of water-level monitoring.

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 through 1999. 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 (Figure 2). 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.

1.4 Water Chemistry

Samples for water-quality analyses have been collected by various agencies for various investigations within the Mine Flooding Operable Unit. This review of the past 18 years incorporates data from the Montana Bureau of Mines and Geology, the mining companies, and their consultants. As there are nearly one thousand records of detailed chemistry data, these are presented in table form in the appendixes under a separate cover.

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. Since background or pre-mining water quality could not be measured, U.S. EPA drinking water standards provides 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	* 50 / #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.

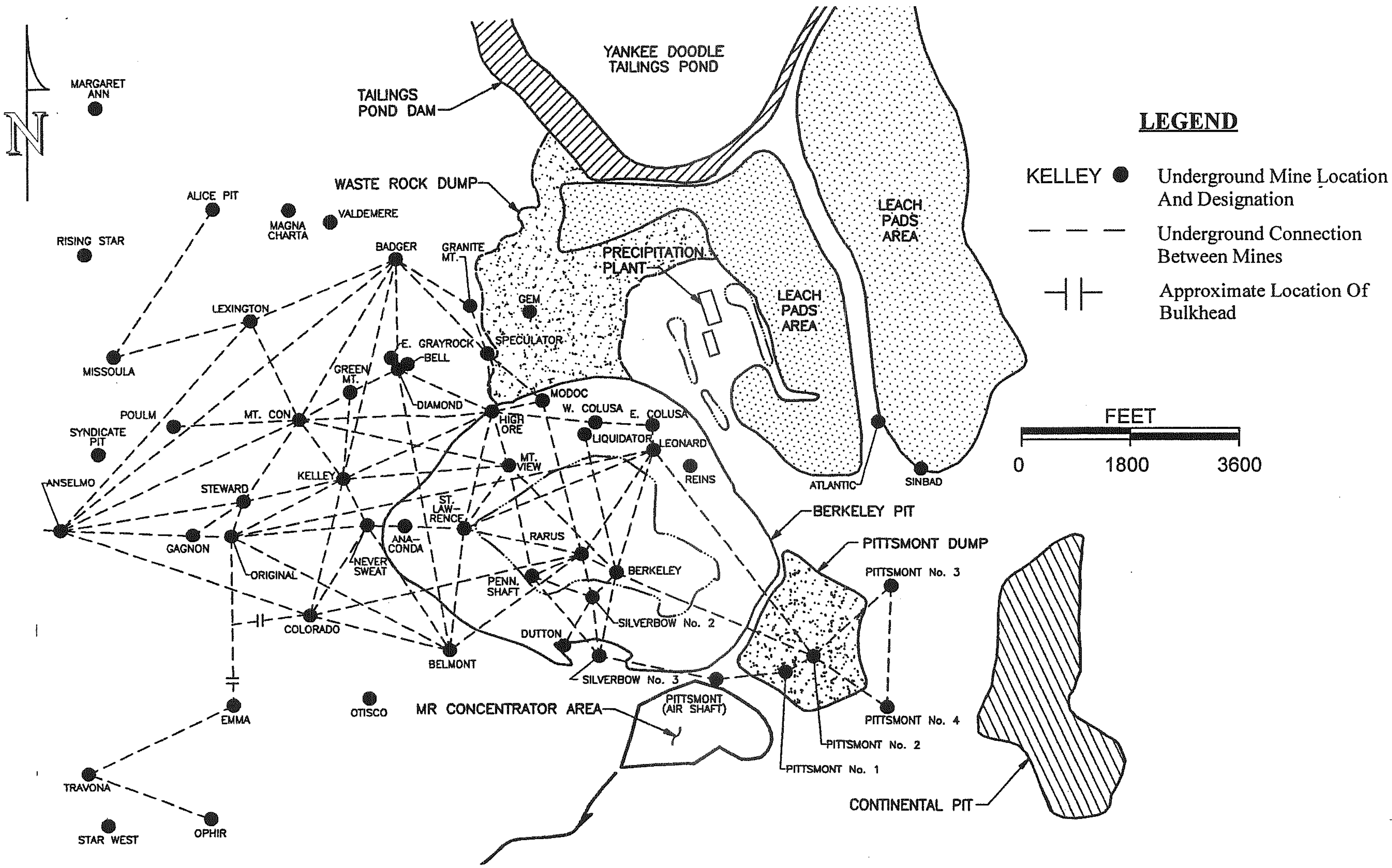

Figure 2. The Butte mines are interconnected, often on several levels. Bulkheads were installed in the 1950's to separate the mines on the outer margins from those in the center of the district. This was done to reduce pumping and air ventilation costs.

Section 2.0 East Camp

The East Camp includes most of the underground workings, the Berkeley pit, and the active mine area (Figure 3). 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 alluvial aquifer includes unconsolidated sediments derived from country rock within the upper Silver Bow Creek basin. The lithology of these sediments range from coarse gravel composed of quartz monzonite to clay derived from near-surface weathering of the quartz monzonite or from weathering of hydrothermal alteration zones. The aquifer is generally unconfined, but confined units associated with clay deposits are common within the present-day flood plain.

Ground-water flow patterns in the alluvial aquifer have been dramatically altered by the leach pad operation, the Berkeley Pit, and reconstruction of the Silver Bow Creek channel upstream of its confluence with Blacktail Creek (figure 3). At present, there exists a ground-water divide between the Berkeley Pit and the main portion of the Butte basin (Duaime and others, 1998). Ground water north of this divide flows into the pit and is evidenced by springs on the east and southeast pit walls. Ground water south of the divide flows toward Silver Bow Creek.

2.1.1 Monitoring Wells (LP, AMC, GS, and MF series)

Seventeen LP-series wells, which includes 3 nested pairs, were installed during the Mine Flooding Remedial Investigation in 1991 and 1992 (figure 4). Specifically, these wells were used to investigate contamination of the alluvial aquifer down-gradient of the leach pad operation to the south boundary of MR's active operation. Completion depths range from 55 feet to 284 feet below ground surface. Ground-water flow in the area of the LP wells is generally southward from the leach pads toward the basin; near the ground-water divide just south of the Berkeley Pit, ground-water flows toward the pit.

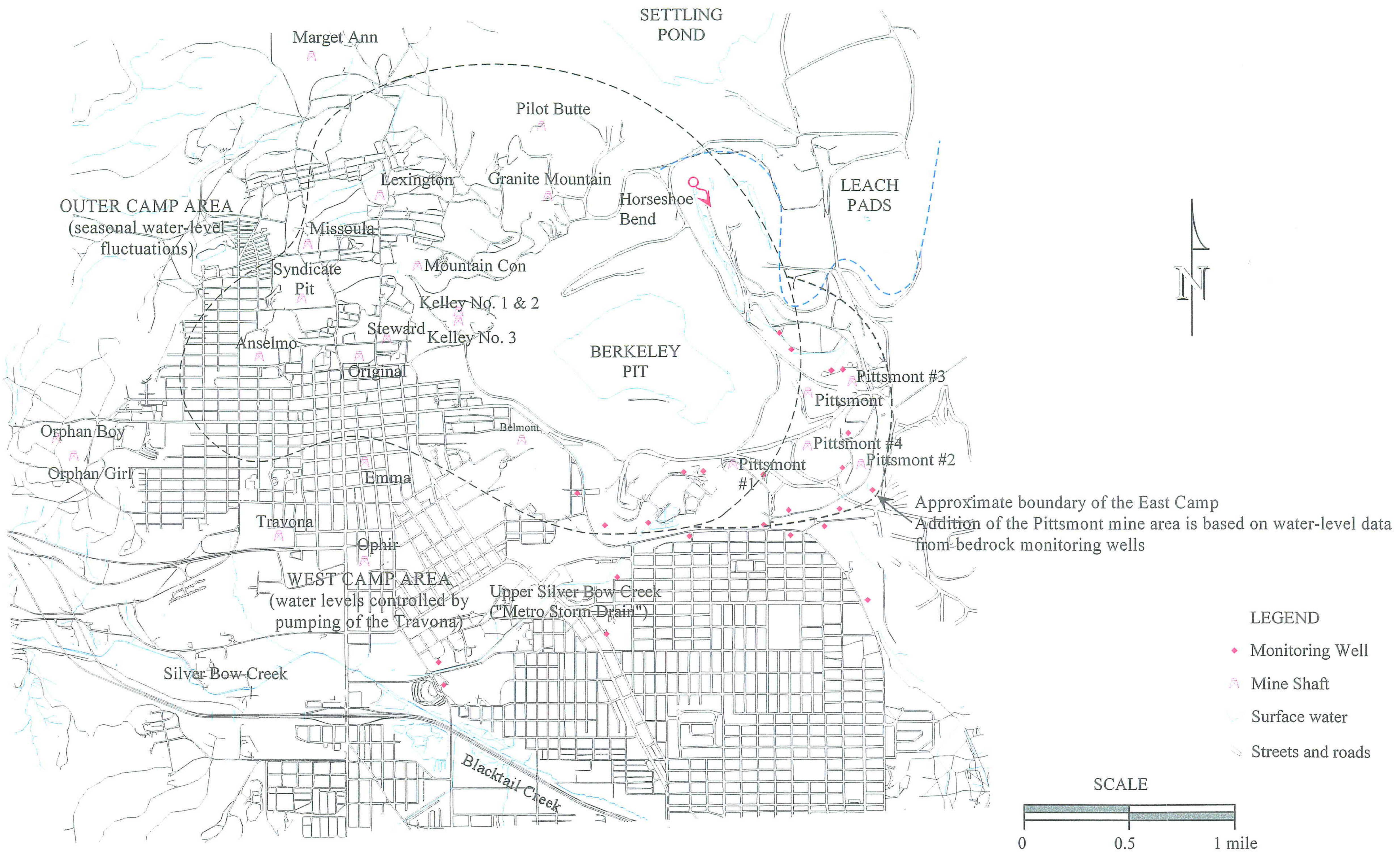

Figure 3. The mines of the Butte hill are presently considered in three groups: the East Camp, which includes the Berkeley pit and the area east; the West Camp in the southwest part of the hill; and the Outer Camp which includes the outlying mines.

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 4); the completion depths of the remaining wells 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, having depths ranging 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; these data are presented in the appendix.

The MF-series wells were installed in 1983 by the Montana Bureau of Mines and Geology to monitor ground-water level 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. Six water-quality samples were collected between 1986 and 1989. These data are presented in the appendix.

2.1.1.2 Water-Quality Trends

The wells LP-1 through 9 were sampled through 1996 and the rest have been monitored through the present. All of the LP-series wells indicate the exceedence of one or more Maximum Contaminant Levels (MCL) or Secondary Maximum Contaminant Levels (SMCL). Through time, the concentrations of dissolved metals, sulfate, and arsenic have changed - some by several orders of magnitude. Wells within 1500 feet of the leach pads (e.g. LP-9 and LP-8) suggest degradation of water quality in that area (figure 5 and 5a) since monitoring began; at a distance of about 3000 feet, well LP-10 indicates only small changes in water quality. Nearly all of the LP-wells in the area south of the Pittsmont dump and southeast of the Berkeley pit show an increase in concentration of at least one constituent - most commonly sulfate (figures 6 and 6a; figures 7 and 7a). The change in chemistry is independent of depth (table 2) and of position along the flow path described by Duaime and others (1998). In addition to a plume of degraded water from the leach pads, there are several potential sources for additional loading, including the Pittsmont waste rock dump, the Pittsmont smelter, and several other waste rock dumps that predate the Berkeley pit.

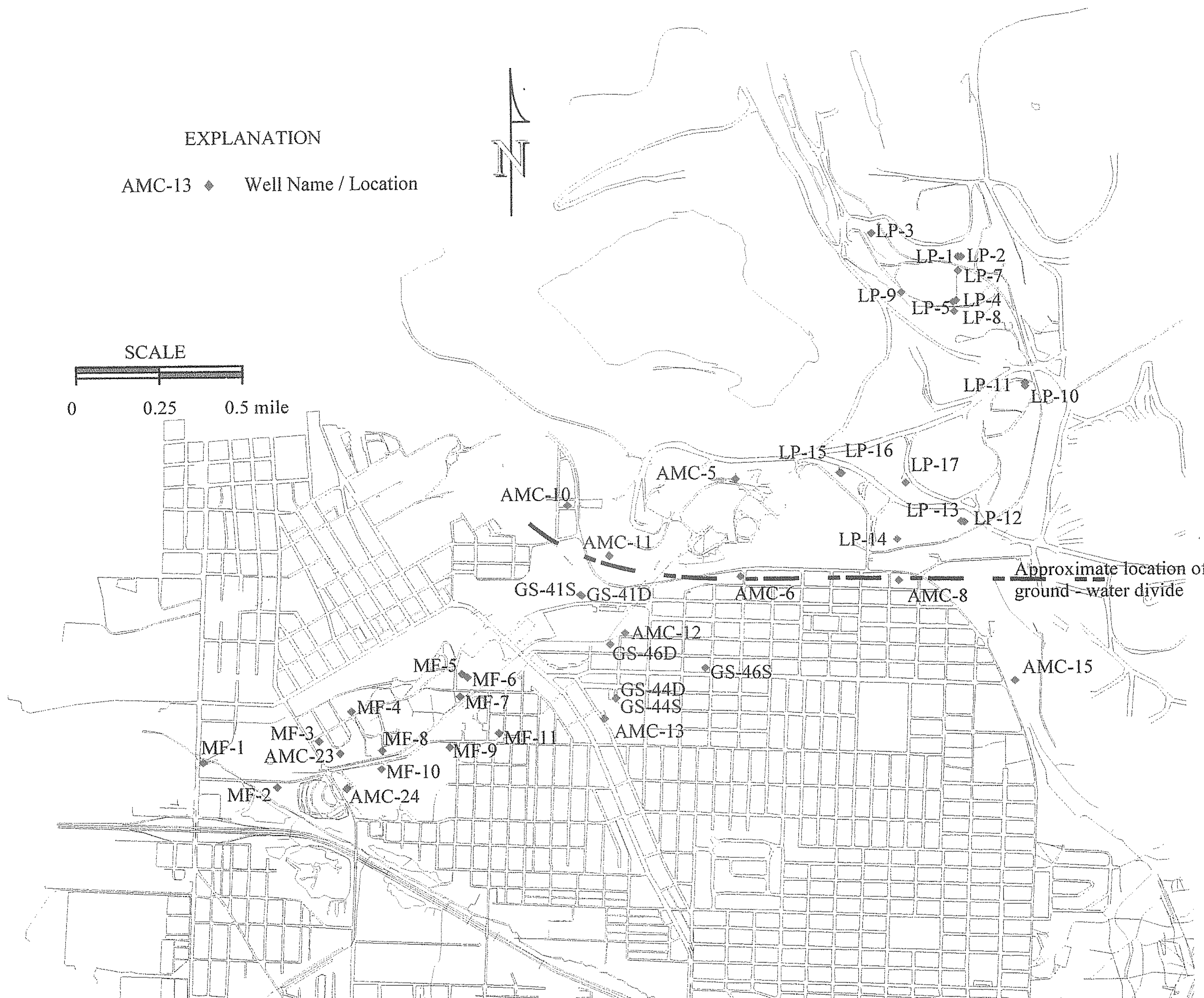

Figure 4. Several groups of wells were installed to monitor various potential impacts by mining in the Butte area. Only those wells used to evaluate potential impacts caused by mine flooding are shown.

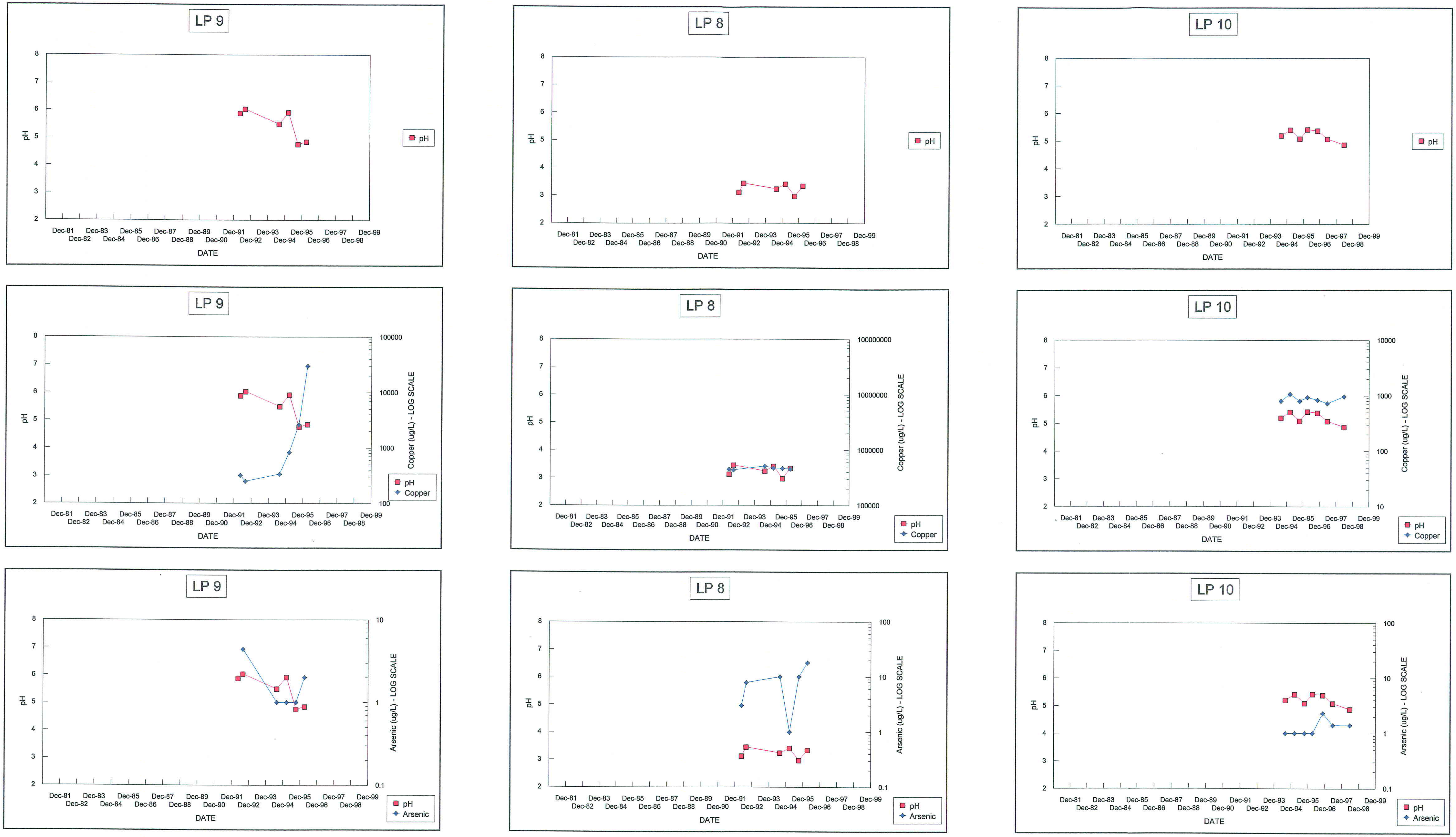

Figure 5. The water quality near the leach pads is generally poor and exceeds several MCLs or SMCLs.

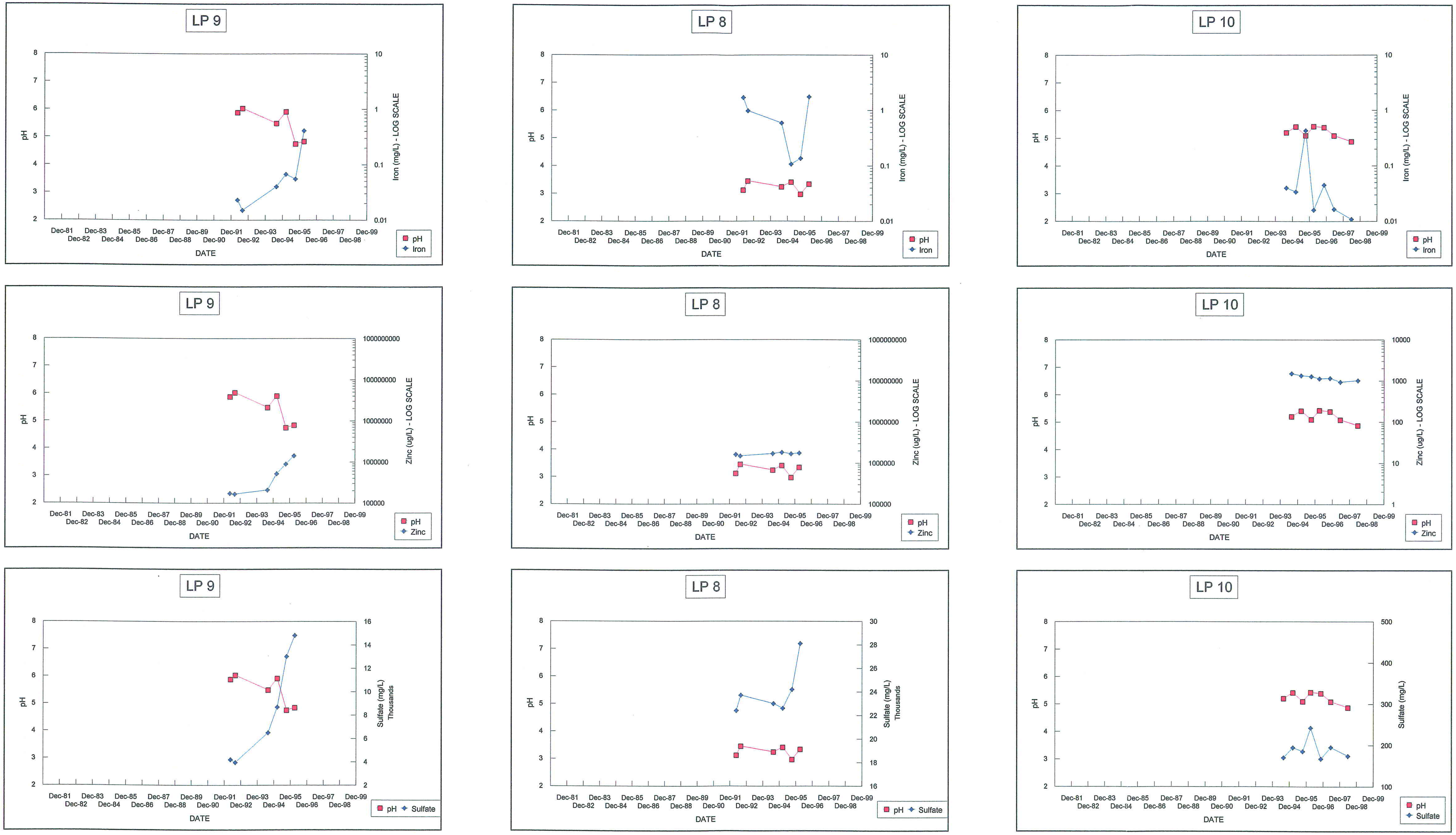

Figure 5a. Wells LP-8 and 9 exhibit degradation of water quality while well LP-10 shows little change.

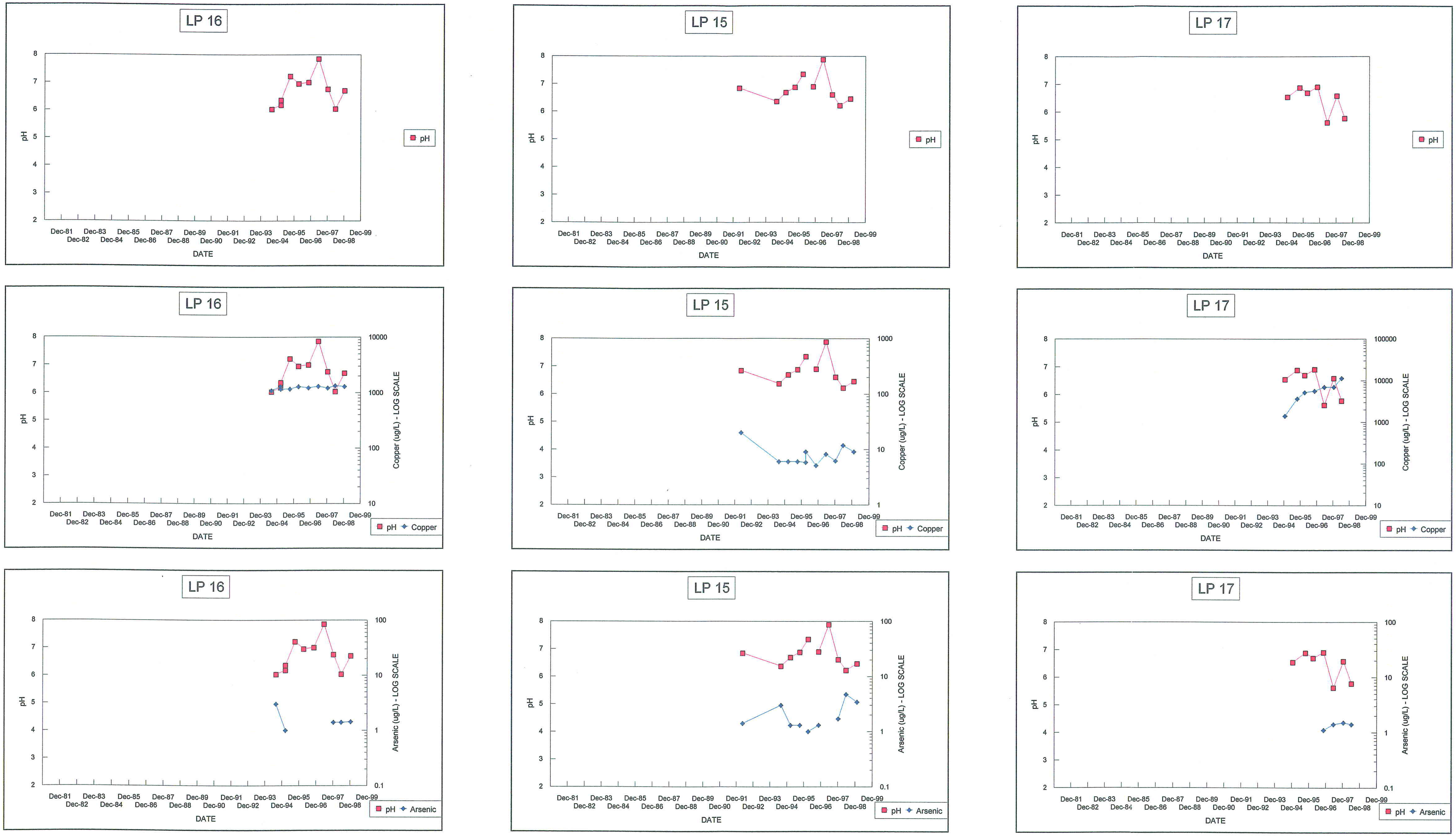

Figure 6. Wells Lp-16, -15, and -17 are southeast of the Berkeley pit. The objective of these wells was to determine ground-water gradients and water quality in that area.

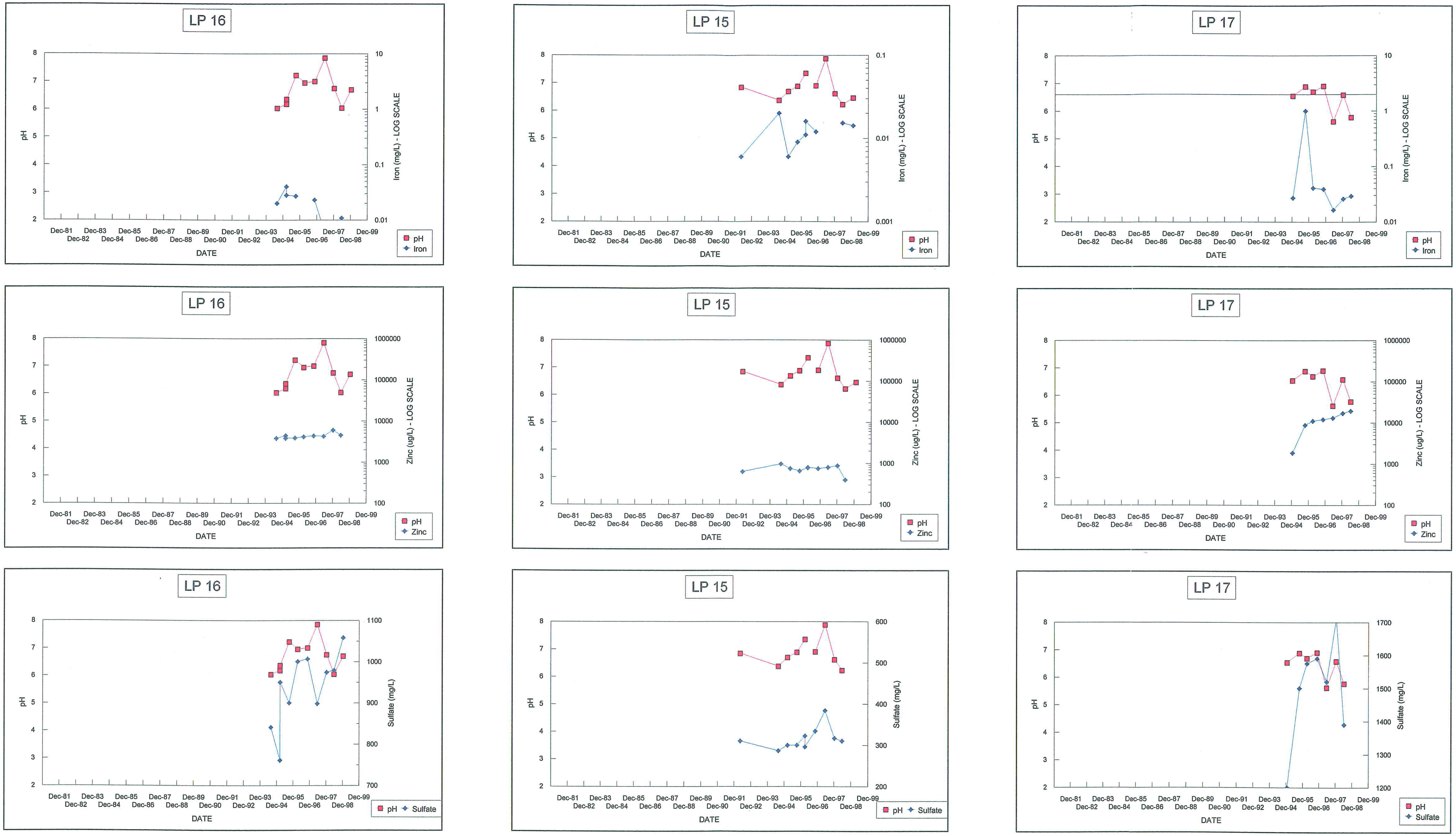

Figure 6a. All of the wells exceed one or more MCLs or SMCLs. In general, the concentrations of dissolved consistuents are increasing.

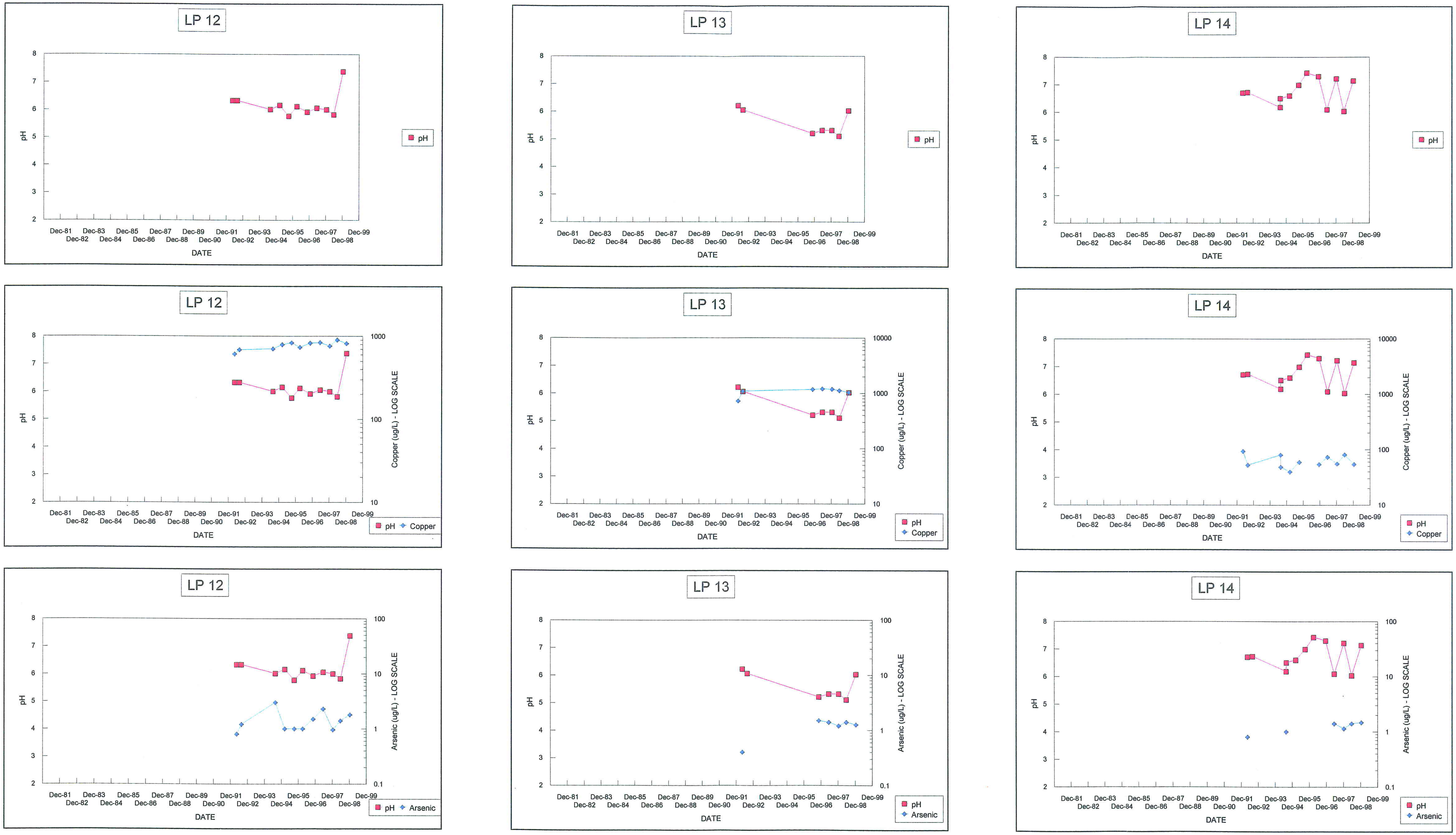

Figure 7. Wells LP-12, -13, and -14 are southeast of the Berkeley pit and south (down gradient) of the Pittsmont dump/smelter.

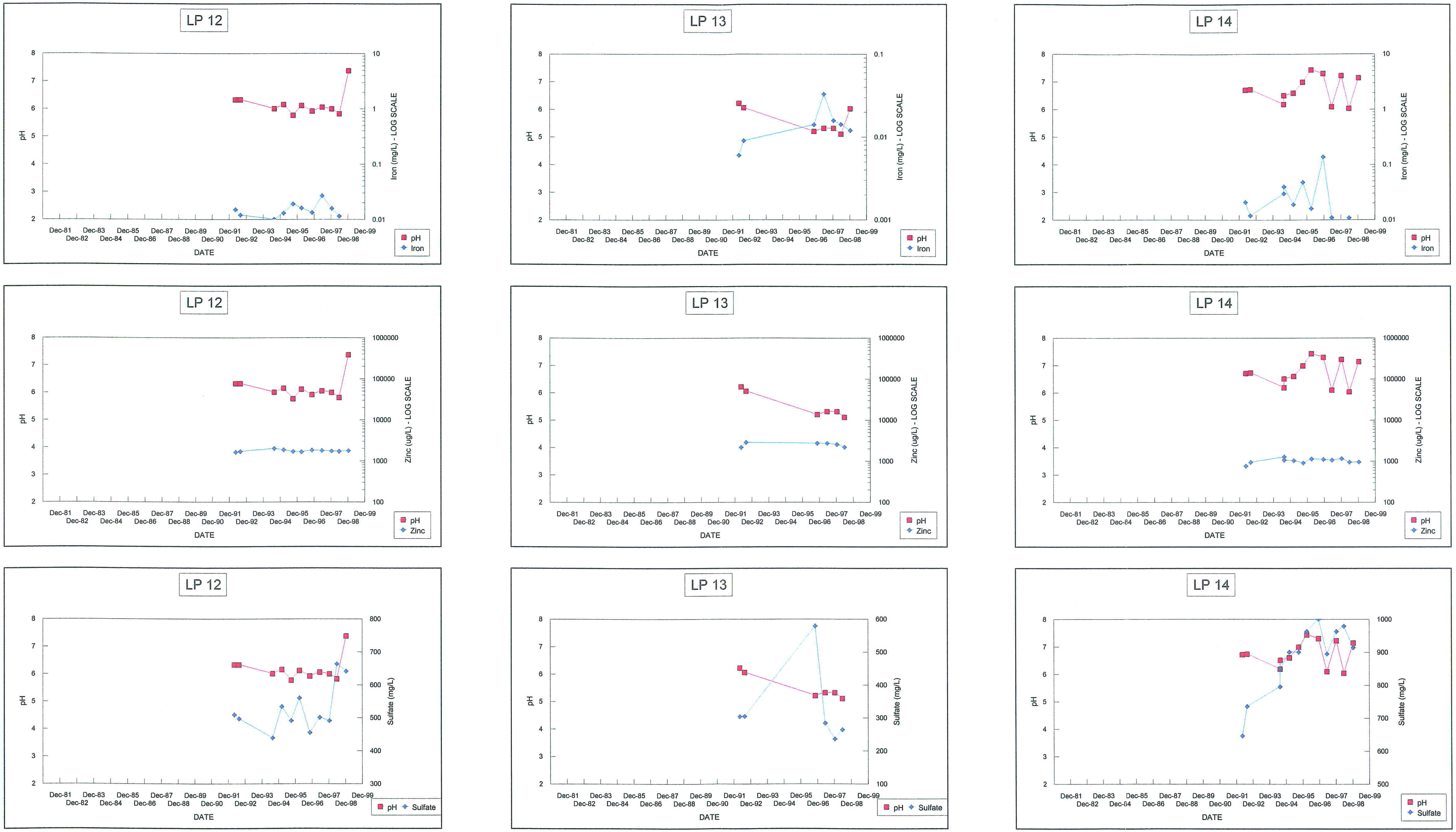

Figure 7a. The concentration of sulfate shows the greatest variation and the SMCL is exceeded in all three wells.

Table 2. Chemistry change from 1992 to 1999 compared to total depth and screen intervals for LP-series wells.

Well Name	Total Depth (ft)	Screen from	Screen to	Relative Depth	Change*
LP 8	100.0	79.0	94.0	Shallow	increase
LP 9	107.0	80.0	100.0	Shallow	increase
LP 10	169.0	130.0	160.0	Deep	none
LP 12	133.0	107.0	127.0	Deep	none
LP 13	242.0	216.5	236.5	Deep	increase
LP 14	108.5	82.5	102.5	Shallow	increase
LP 15	242.5	215.0	235.0	Deep	increase
LP 16	126.0	100.0	120.0	Deep	increase
LP 17	222.0	197.0	222.0	Deep	increase

*an increase in concentration of one or more constituents

As noted, ground water in the area east and just southeast of the pit (represented by the LP-series wells) flows into the pit and is manifested as springs along the pit walls. The quality of water from these springs is poor; the water is acidic (pH=3.4) and contains concentrations of metals and other constituents similar to that of the leach pad water. The springs are dicussed in more detail in Section 2.3 describing the Berkeley Pit.

The AMC-series wells are in areas subject to a variety of hydrogeologic and geochemical conditions. AMC-5 is between the ore concentrator and the Berkeley pit. Ground-water flow in this area is northward toward the pit. Although there has been a general improvement of water quality (figures 8 and 8a), the concentrations of several constituents far exceed standards; the concentration of copper exceeds the MCL by an order of magnitude. Well AMC-6 and -8 are on the ground-water divide between the pit and the Silver Bow Creek basin. Ground-water flow along the divide is westward under a small hydraulic gradient; water-levels declined about 2 and 3 feet, respectively, since 1983, but increased 5 and 7 feet, respectively, since 1993 (Duaime and others, 1998). Dissolved constituents have generally decreased or remain unchanged in both wells (figures 8 and 8a). Both wells exhibit concentrations of metals and sulfate that exceed standards, but the constituents of exceedences are not common between the two.

Wells AMC-12, -13, and -15 are south of the Berkeley pit - upper Silver Bow Creek ground water divide and east (upgradient) of the upper Silver Bow Creek channel. Ground-water flow in this area is generally eastward. The trend of concentrations of constituents is quite variable for both AMC-12 and -13 and water quality is generally poor (figures 9 and 9a). AMC-15 is upgradient of most potential sources of mine-waste impacted waters; the Hillcrest waste-rock dump is immediately east and upgradient. The water chemistry in this well has shown only slight trends and is generally of good quality; sulfate exceeds the SMCL with a concentration of 300 mg/L.

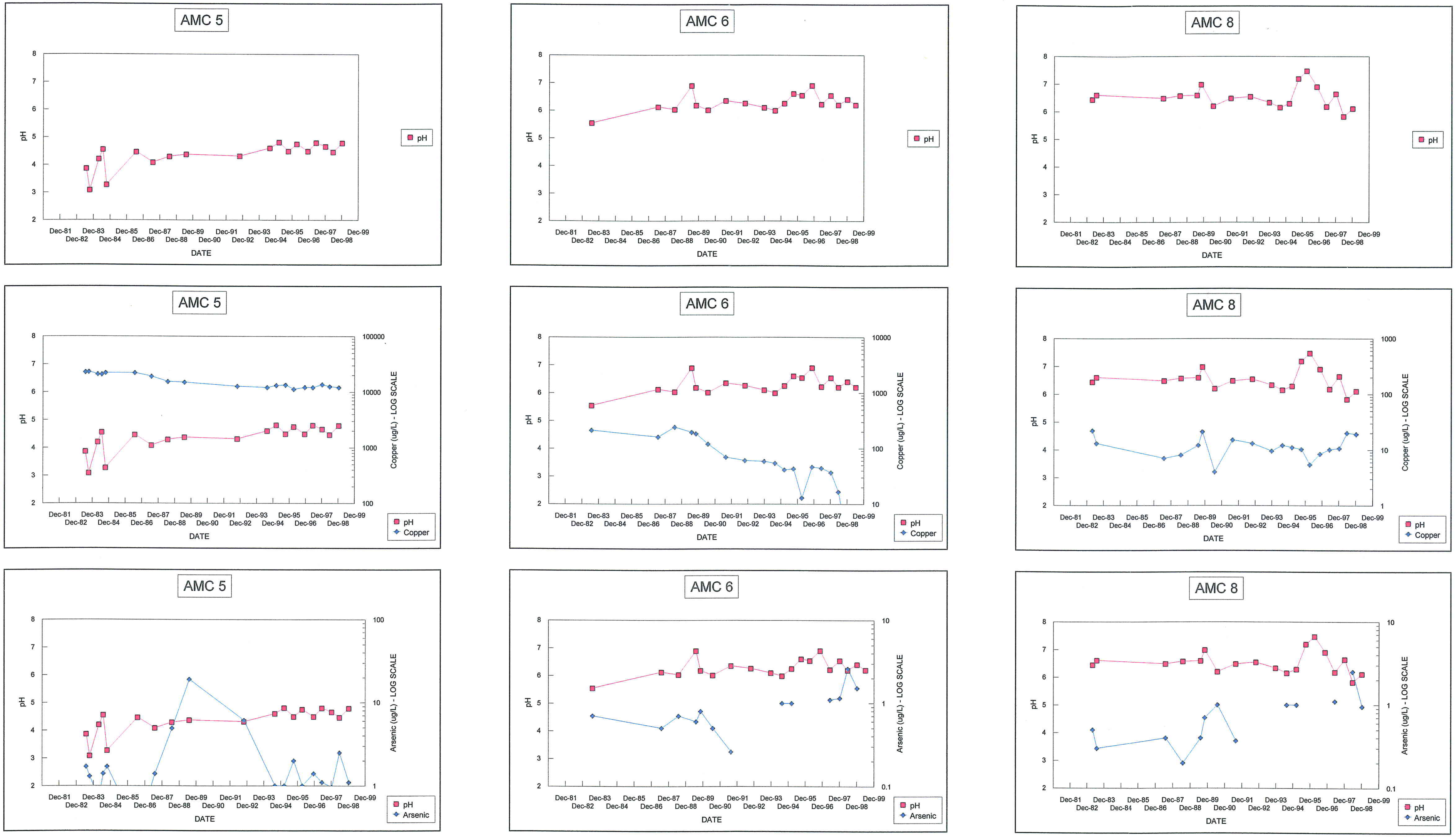

Figure 8. Well AMC-5 is between the conentrator and the Berkeley pit. Wells AMC-6 and -8 are on the ground-water divide south of the pit.

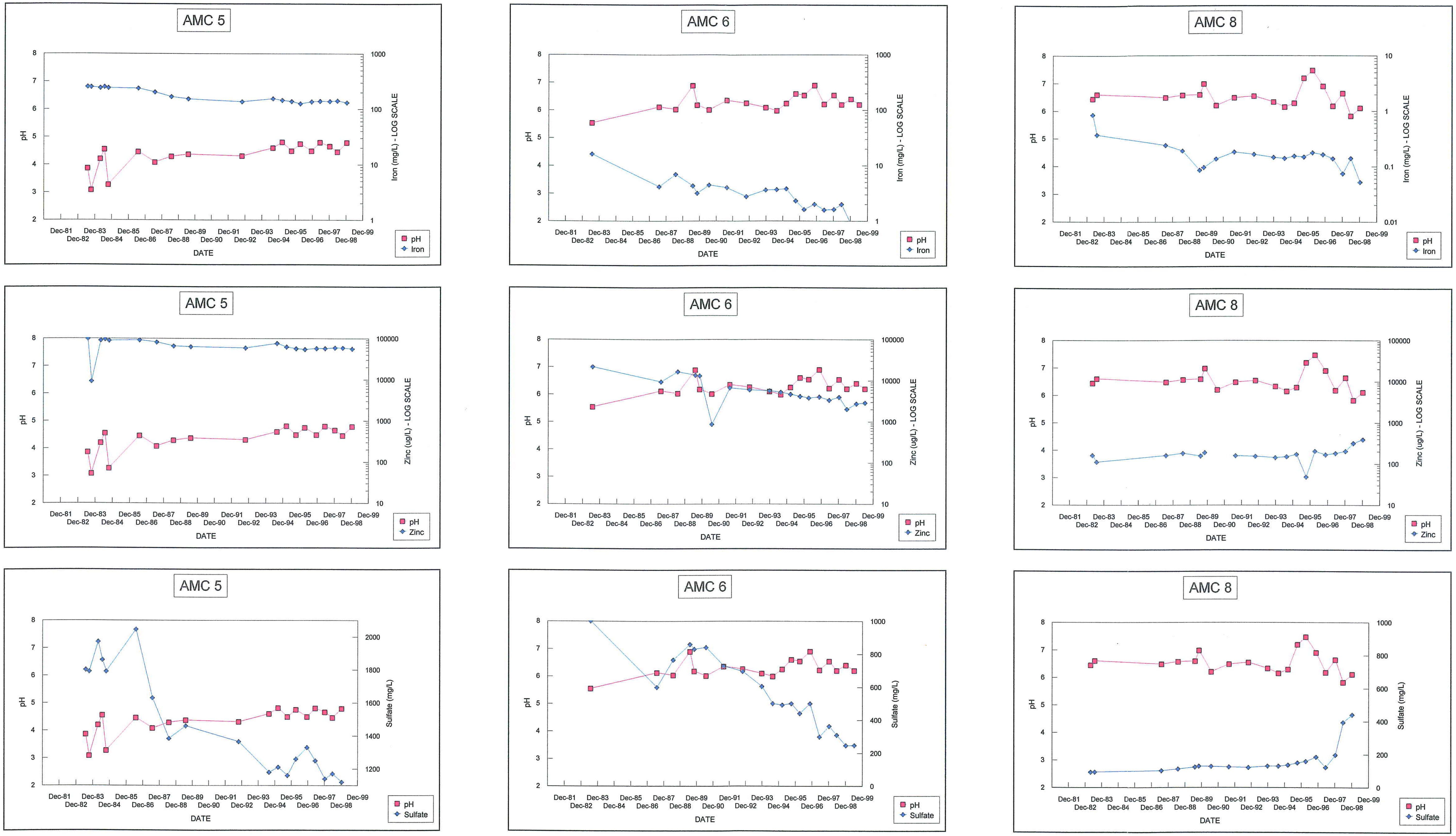

Figure 8a. All of the wells exhibit concentrations of metals and other dissolved constituents in excess of MCLs or SMCLs.

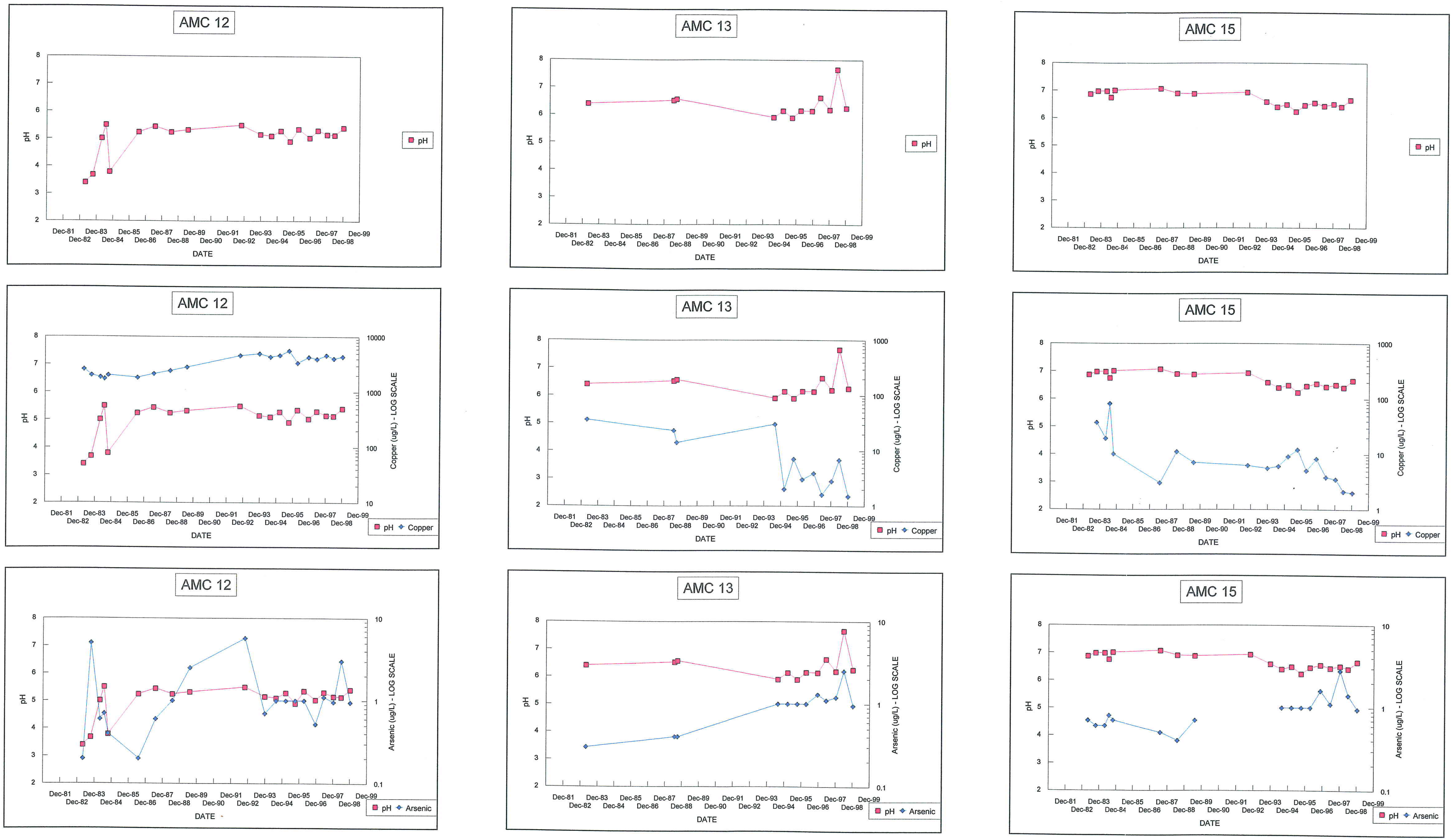

Figure 9. Wells AMC-12, -13, and -15 are south of the ground-water divide.

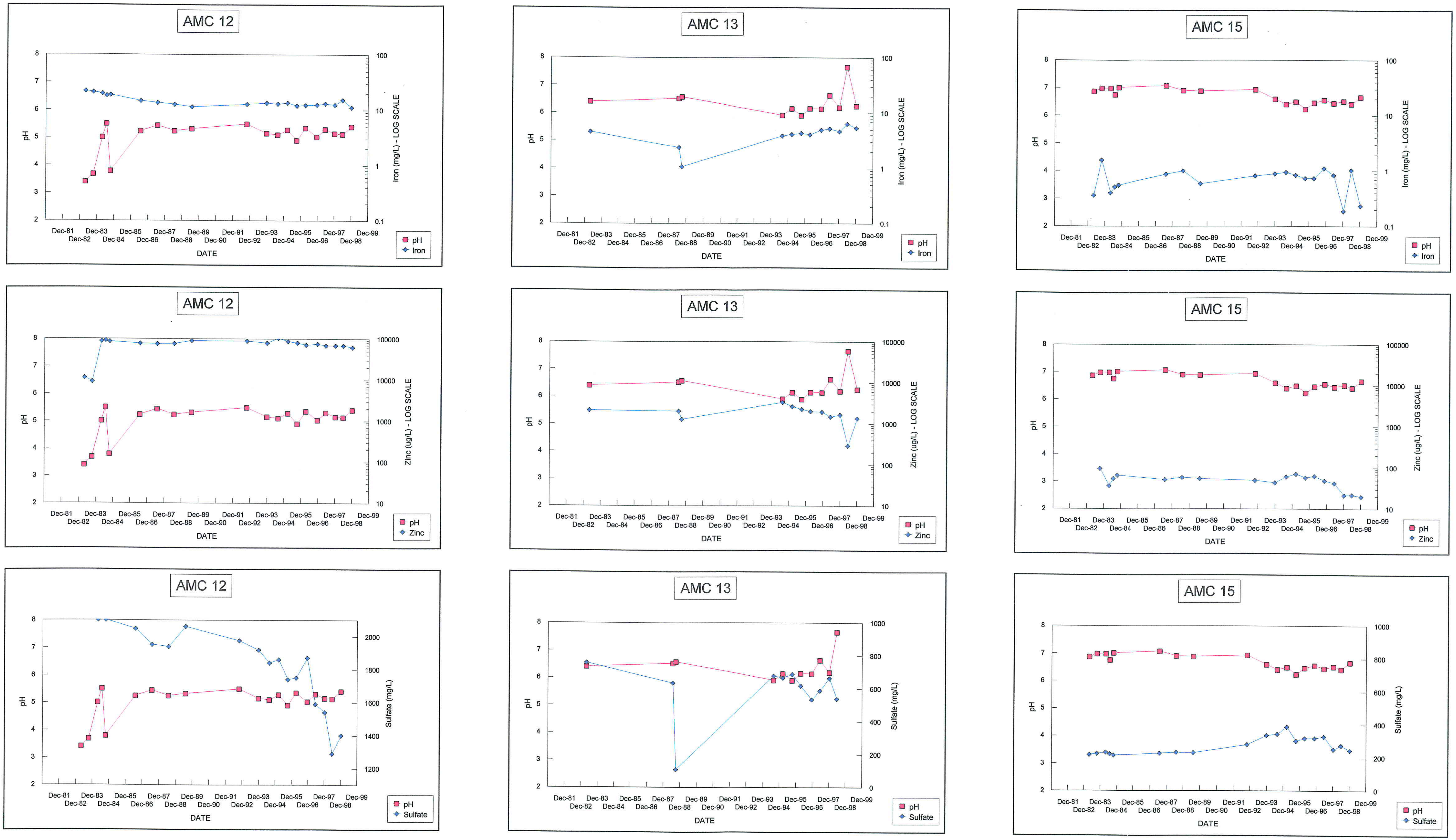

Figure 9a. Water quality in all three wells has been variable throughout the period of record.

Wells AMC-23 and 24 are near the confluence of upper Silver Bow Creek and Blacktail Creek. The concentrations of dissolved constituents show little change in AMC-23; only sulfate has changed significantly (decreased by about 600 mg/L). Well AMC-24 exhibited a greater variability in concentrations, but with the exception of an increasing sulfate concentration, the net change was small (figures 10 and 10a).

The overall water quality of the East Camp alluvial wells and the trends in water quality is summarized in Table 3. Figures 11, 12, and 13 present the concentrations of cadmium, copper, and sulfate for January, 1999 for the LP wells and July, 1999 for the AMC wells.

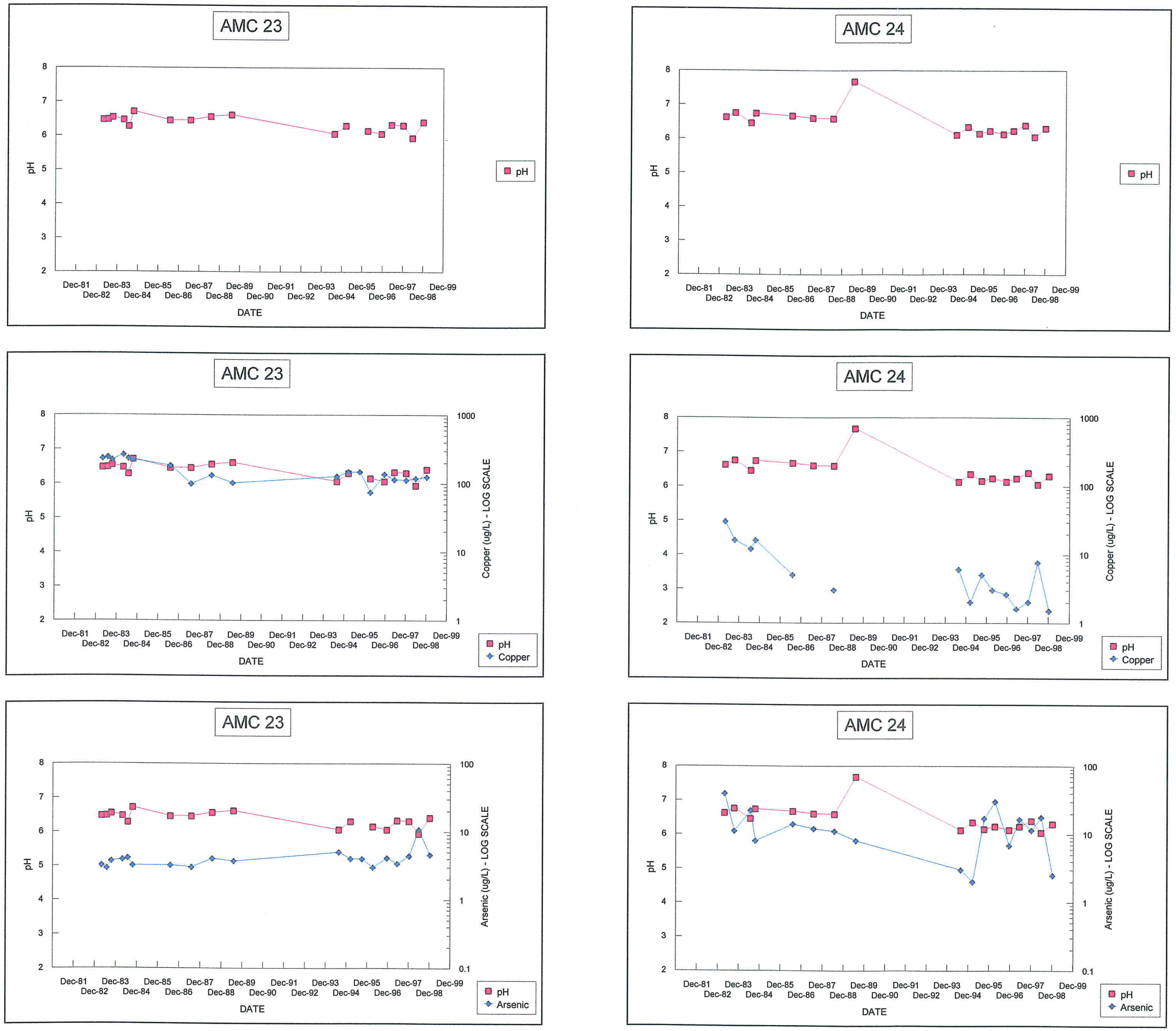

Figure 10. Wells AMC-23 and 24 are near the confluence of upper Silver Bow Creek and Blacktail Creek.

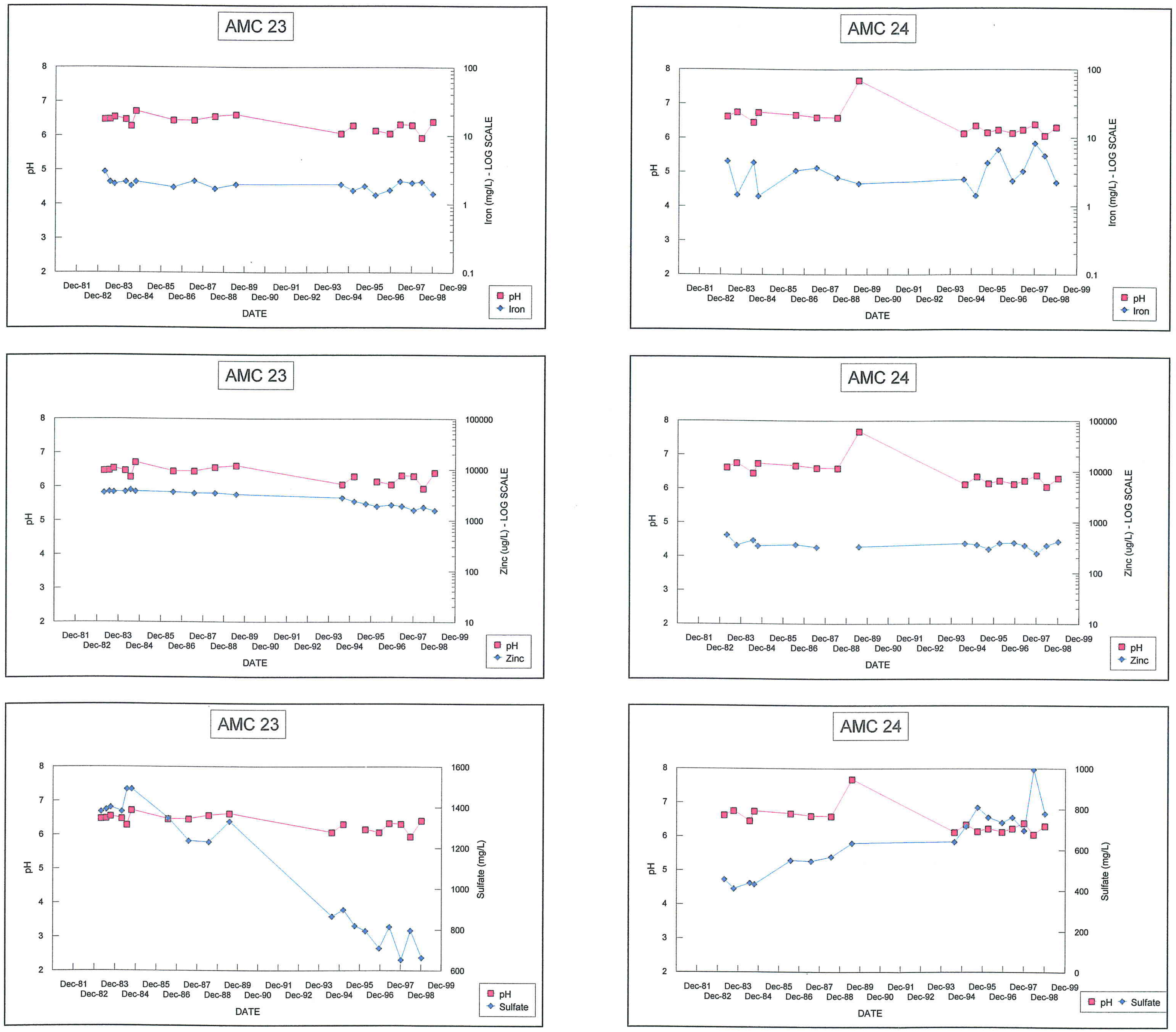

Figure 10a. The net change in concentrations in both wells is generally small, with the exception of sulfate.

Table 3. Exceedences and trends for East Camp wells (1999)

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
LP-12	Y	variable	only sulfate shows upward trend
LP-13	Y	variable	
LP-14	Y	upward	especially sulfate
LP-15	Y	none	variable, but net change is small
LP-16	Y	upward	slight trend
LP-17	Y	upward	sulfate varied by 500 mg/L over period of record
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	upward	slight trend
AMC-12	Y	variable	sulfate decreased by 400 mg/L
AMC-13	Y	variable	net change is small
AMC-15	Y	variable	only sulfate exceeds SMCL; net change is small
AMC-23	Y	variable	net change is small, except sulfate
AMC-24	Y	variable	sulfate increasing

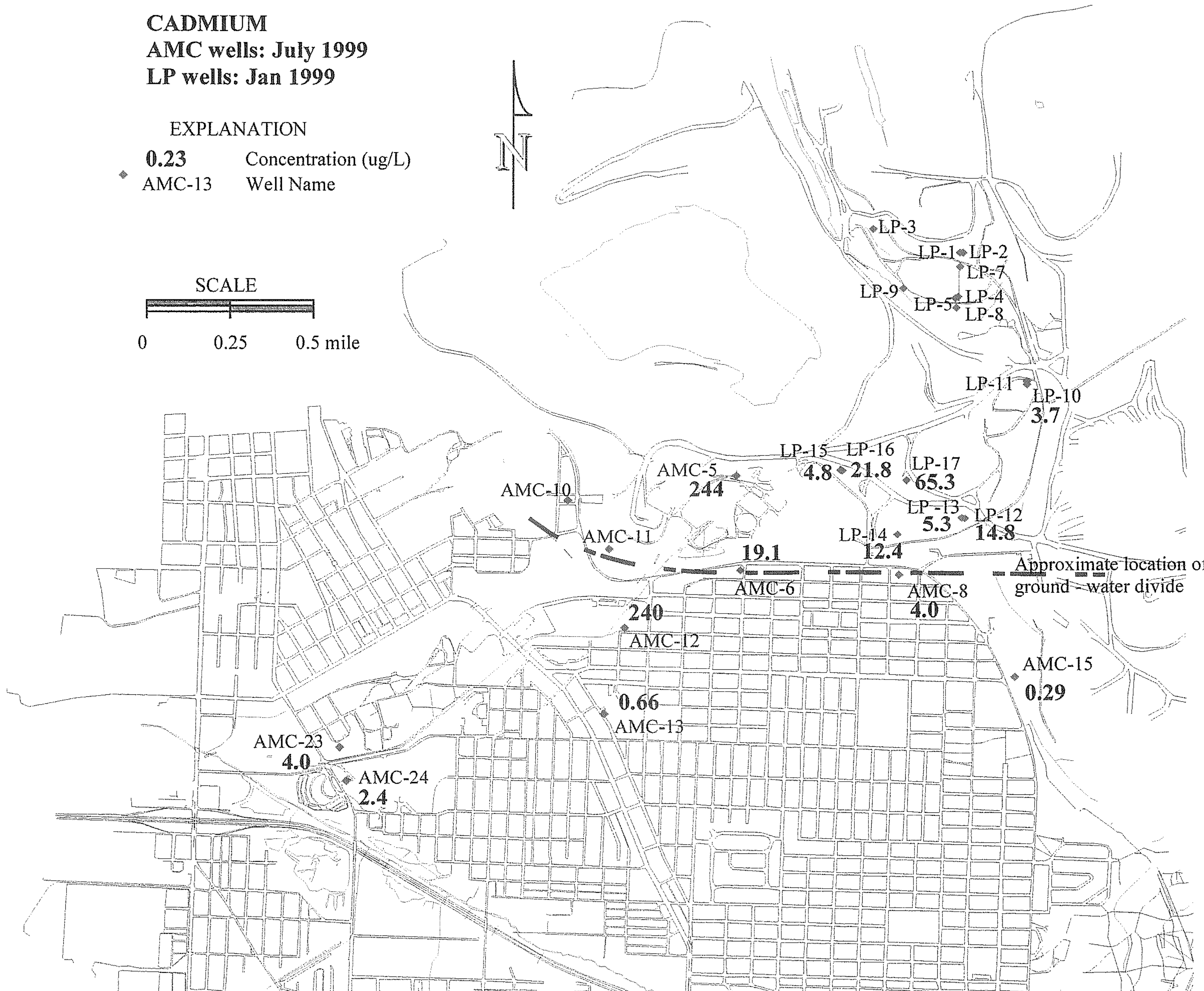

Figure 11. The concentration of cadmium varies widely throughout the East Camp alluvial aquifer. The MCL for dissolved Cd is 5 ug/L.

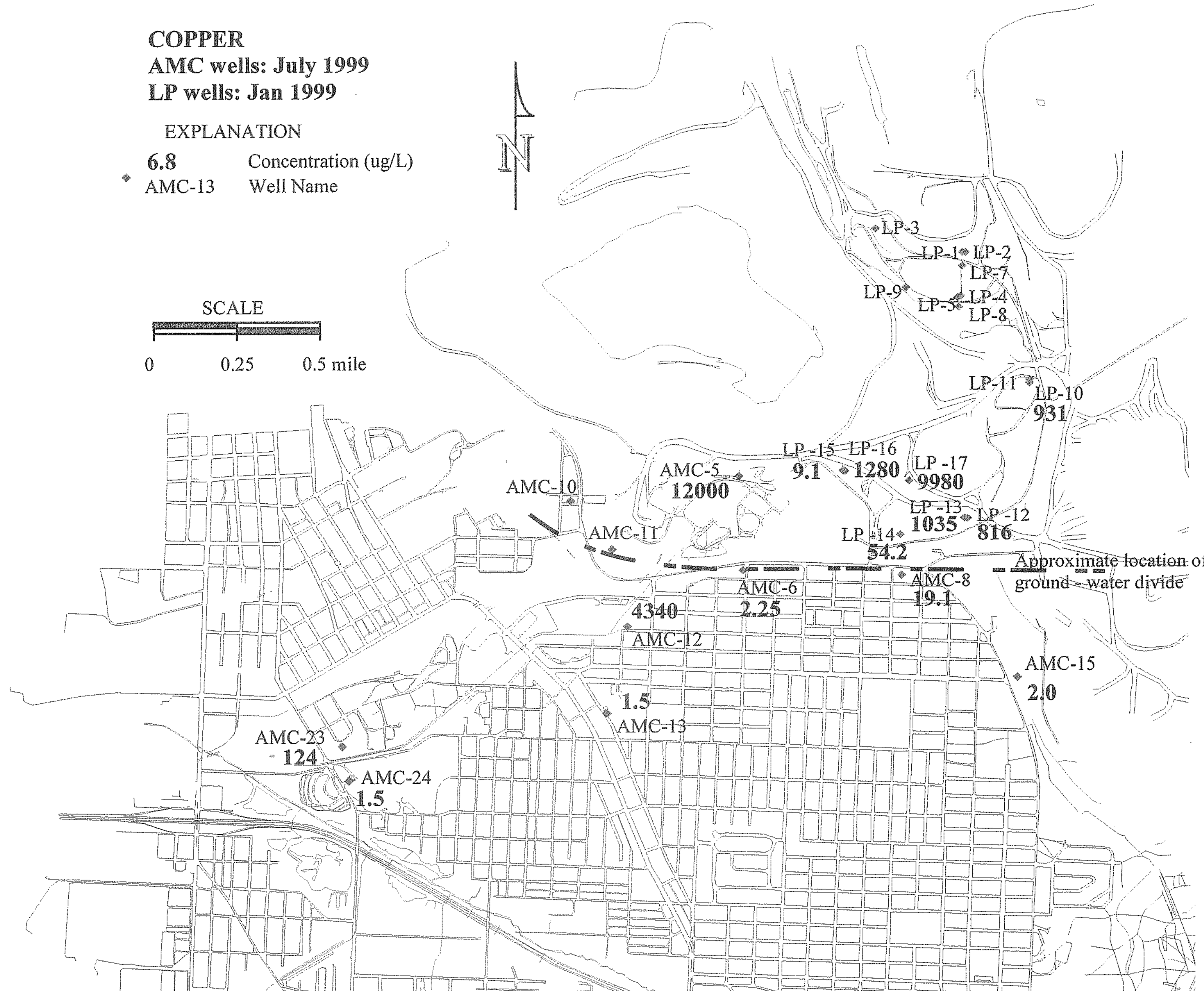

Figure 12. The concentration of copper ranges from 2.1 to 12000 ug/L. The MCL for dissolved Cu is 1300 ug/L.

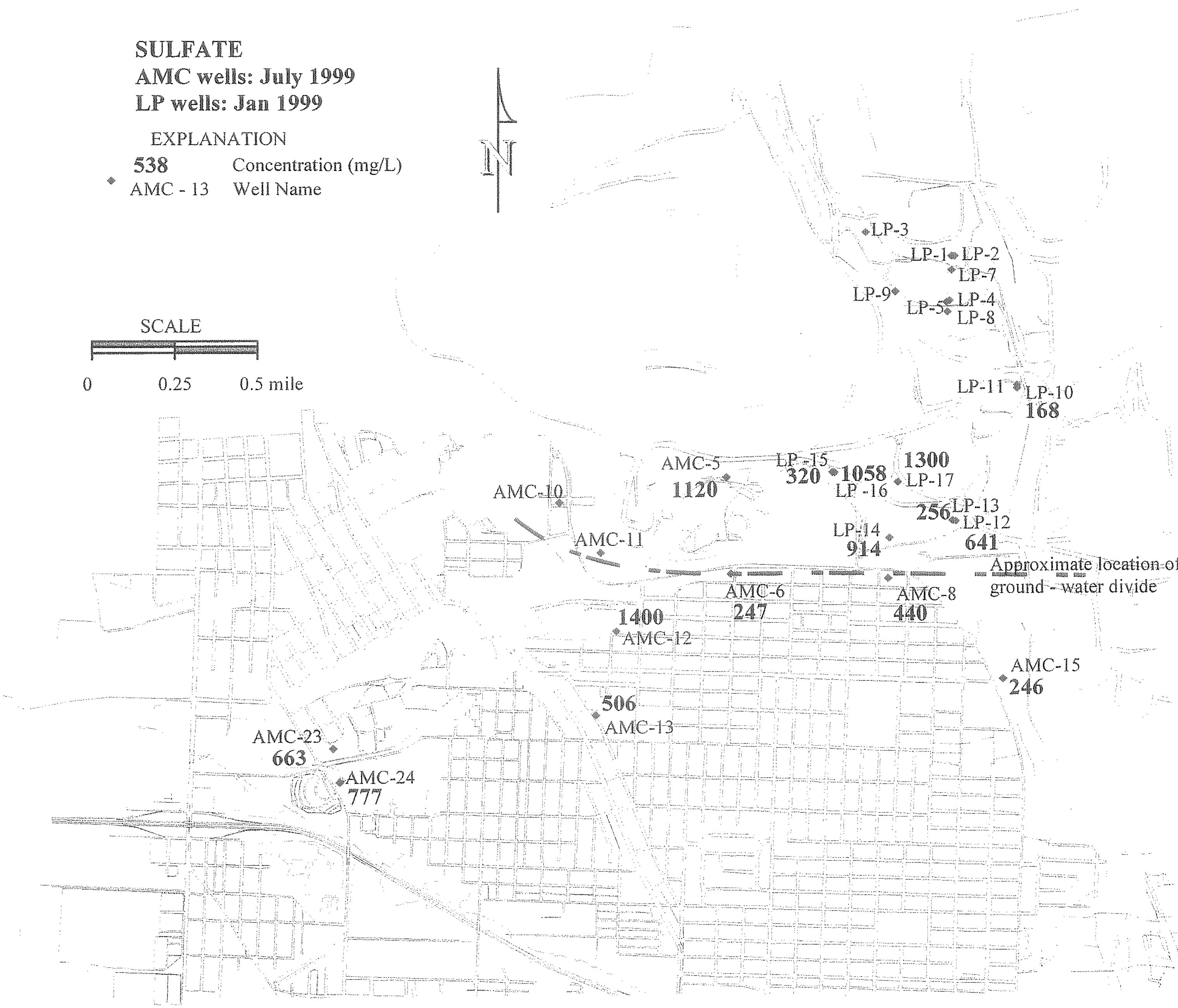

Figure 13. With the exception of well LP-10, all the wells sampled in 1998 exceeded the SMCL (250 mg/L) for sulfate.

2.1.3 Summary of East Camp Alluvial Aquifer

Duaime and others (1998) concluded that water-level trends in the East Camp alluvial aquifer are thus far unaffected by mine flooding. Water-level trends are seasonal and respond to variation in annual precipitation, but do not show trends consistent with the rising ground-water levels associated with mine flooding. Ground-water quality throughout the area is generally poor and commonly exceeds water-quality standards. Long-term trends of dissolved constituents are variable, but generally indicate continued degradation of water quality down-gradient of the leach pads. Down-gradient of the ground-water divide, water quality generally remains poor, but only slight changes are indicated. In the absence of new contaminant sources or reclamation of existing sources, these conditions (degradation north of the divide and no change south of the divide) would be expected to continue as long as the ground-water divide remains in its present position.

2.2 East Camp Bedrock Aquifer

The East Camp bedrock aquifer includes the volume of bedrock affected by the underground workings of the East Camp and the Berkeley Pit. This also encompasses the area south and east of the Berkeley Pit which, based on water-level data, has been influenced by dewatering during mining. This aquifer comprises, in essence, the central and intermediate mineralization zones of the ore body described by Sales (1914) and is coincident with the control structures installed during mining.

In general, the aquifer is composed of moderately to highly altered quartz monzonite. Ground-water flow is controlled by joints and fractures of three types: 1) near-vertical northeast and northwest trending joints, 2) discrete fractures associated with post- ore deposition faulting, and 3) fractures induced by mining. The hydraulic conductivity ranges from about 1 foot per day at depth in the unmined aquifer to about 5 feet per day near the workings and near the surface.

Water-level data from several of the shafts and from monitoring wells indicate that ground water flows from the aquifer toward the underground workings and toward the Berkeley Pit; the latter is the hydraulic sink or low point in the area. Since pumping ceased in April of 1982, the water level has risen 3061 feet in the Kelley mine adjacent to the Berkeley Pit; the water-level rise was about 15 feet in 1998 and about 11.5 in 1999.

2.2.1 Underground Workings

When flooding began in 1982, 3 shafts were monitored for water levels and were sampled for water quality: Belmont, Kelley, and Steward mines (figure 3). Other shafts were added to the monitoring effort as access became available. The Record of Decision identified 4 additional shafts to be monitored for water level and water quality: Anselmo, Granite Mountain, and Lexington mines (figure 3). The shaft of the Belmont mine collapsed in 1995; this monitoring point was replaced by a well drilled into the workings east of the shaft in 1996.

There are several potential controls on the water chemistry in a particular mine: 1) Although the mines are generally well connected, these connections were designed for efficient ore/waste hauling, water drainage, and ventilation. Thus, mines such as the Anselmo and the Missoula have more workings in common with the Kelley mine than with each other. 2) The East Camp mines are within both the central zone and intermediate zone as defined by mineral asseblages. Local mineralogic controls are probable; particularly the amount of pyrite, sphalerite, and copper sulfides. 3) The quality of water entering a mine varies with respect to its position relative to other mines. Those mines on the outer margins of the camp are recharged by a greater percent of uncontaminated ground water than those in the center of the camp which receive water from other mines.

2.2.1.1 Water-Quality Trends

The Kelley mine represents a special case for sampling; samples have been collected from the surface of the water column and from depths below the surface (figure 14 and 14a). In the early period of flooding, the water throughout the column was acidic and contained very high concentrations of dissolved constituents. Almost immediately after flooding began, however, the difference in chemistry between the surface and depths became apparent. The pH and the concentrations of metals varied widely at the top of the water column; likely due to the many sources and thus, the variable quality of waters entering the mine. Conversely, at a depth of 300 feet where conditions are more stable, water quality improved in a relatively consistent manner. At a depth of 900 feet, the chemistry has varied, but the range of concentrations is not as wide as at the surface. All three depths show significant changes in water quality since flooding began. Copper concentrations have declined from nearly 100,000 μg/L to about 100 μg/L - three orders of magnitude. Conversely, the concentration of arsenic has increased by ten-fold. It is further noted that pH and the concentrations of several constituents are approaching the same value at all three depths.

In addition to the Kelley mine, the Belmont, Steward, and Granite Mountain mines (figure 3) are within the central zone described by Sales (1914); all are connected by horizontal workings on several levels. The concentrations of several constituents including copper, arsenic, and zinc have decreased in the Belmont mine. The Steward mine and, to a greater degree, the Granite Mountain mine exhibit increases in concentrations of the same constituents (figure 15 and 15a).

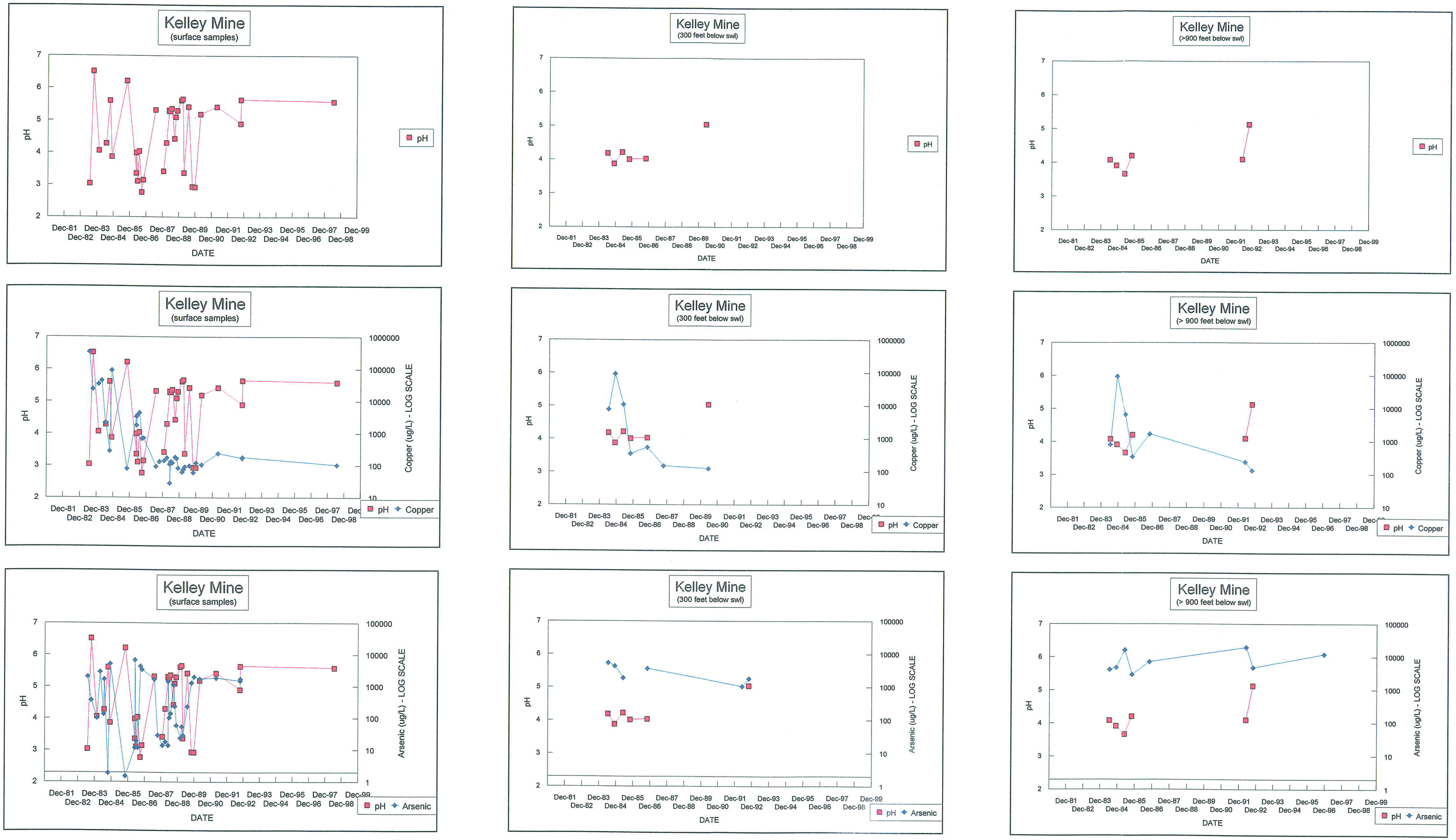

Figure 14. The Kelley mine was sampled at three depths throughout the period of record.

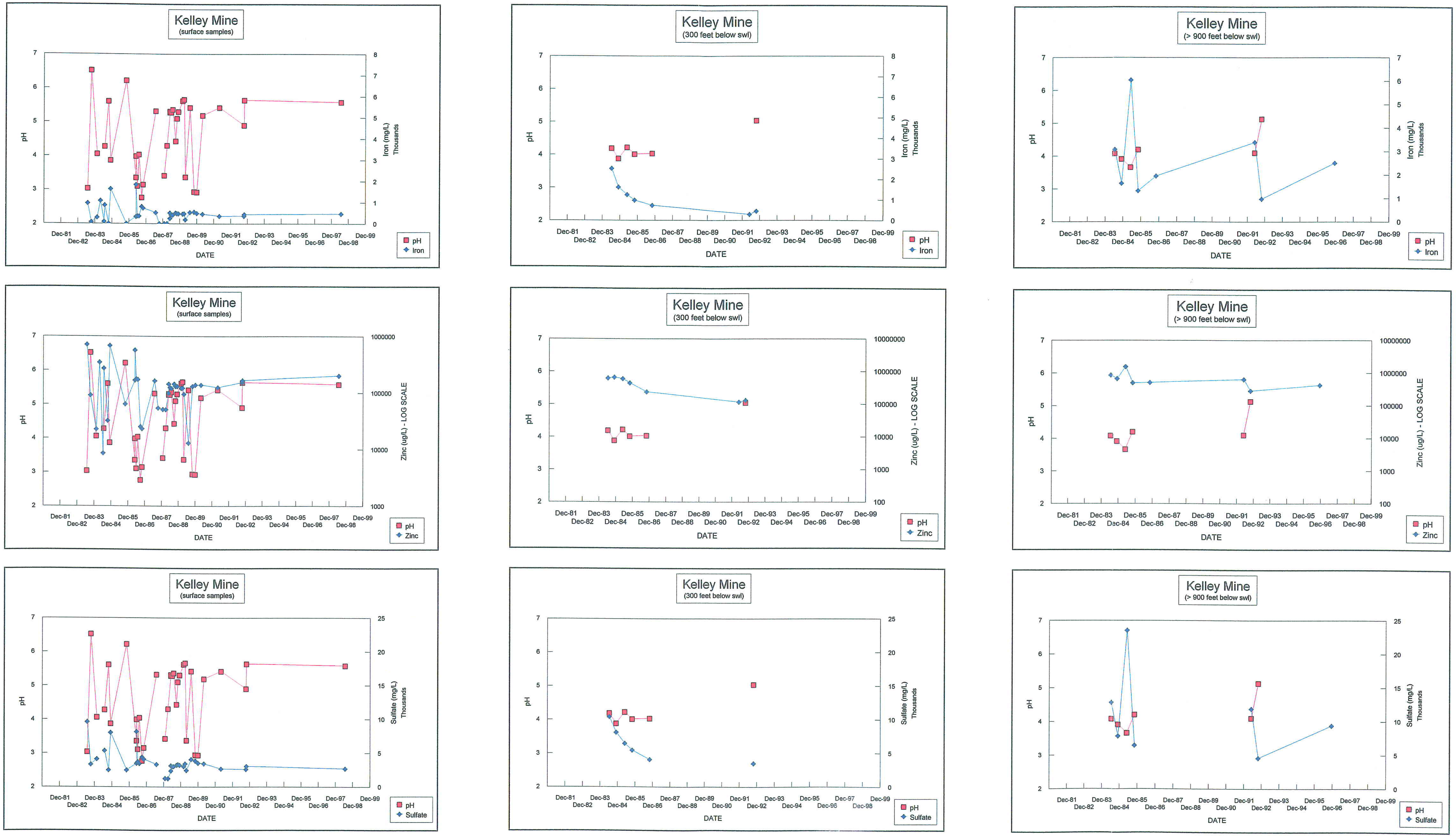

Figure 14a. The chemistry of the Kelley shaft has varied significantly with both time and depth.

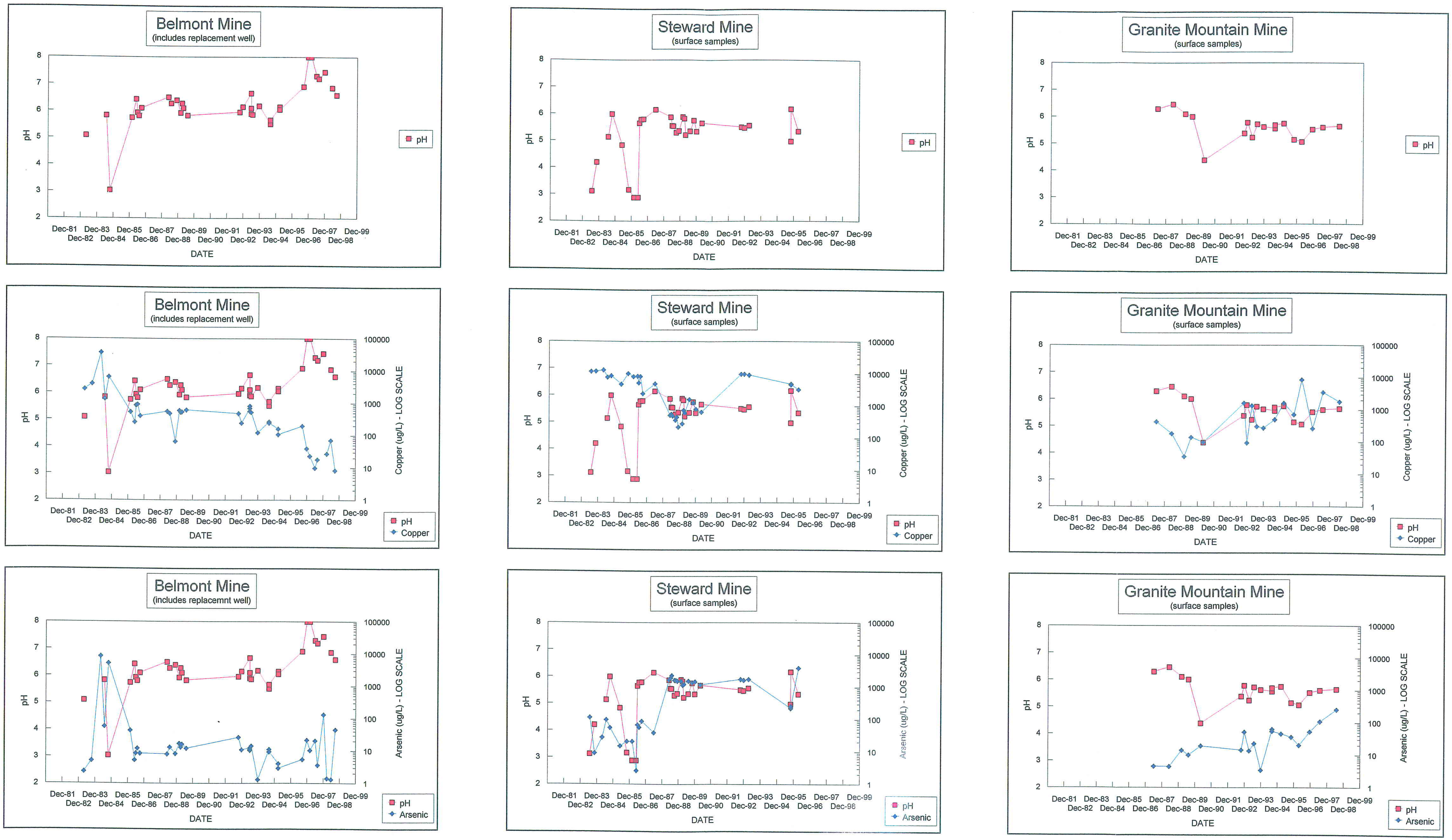

Figure 15. The Belmont, Steward, and Granite Mountain mines are within the central zone described by Sales (1914).

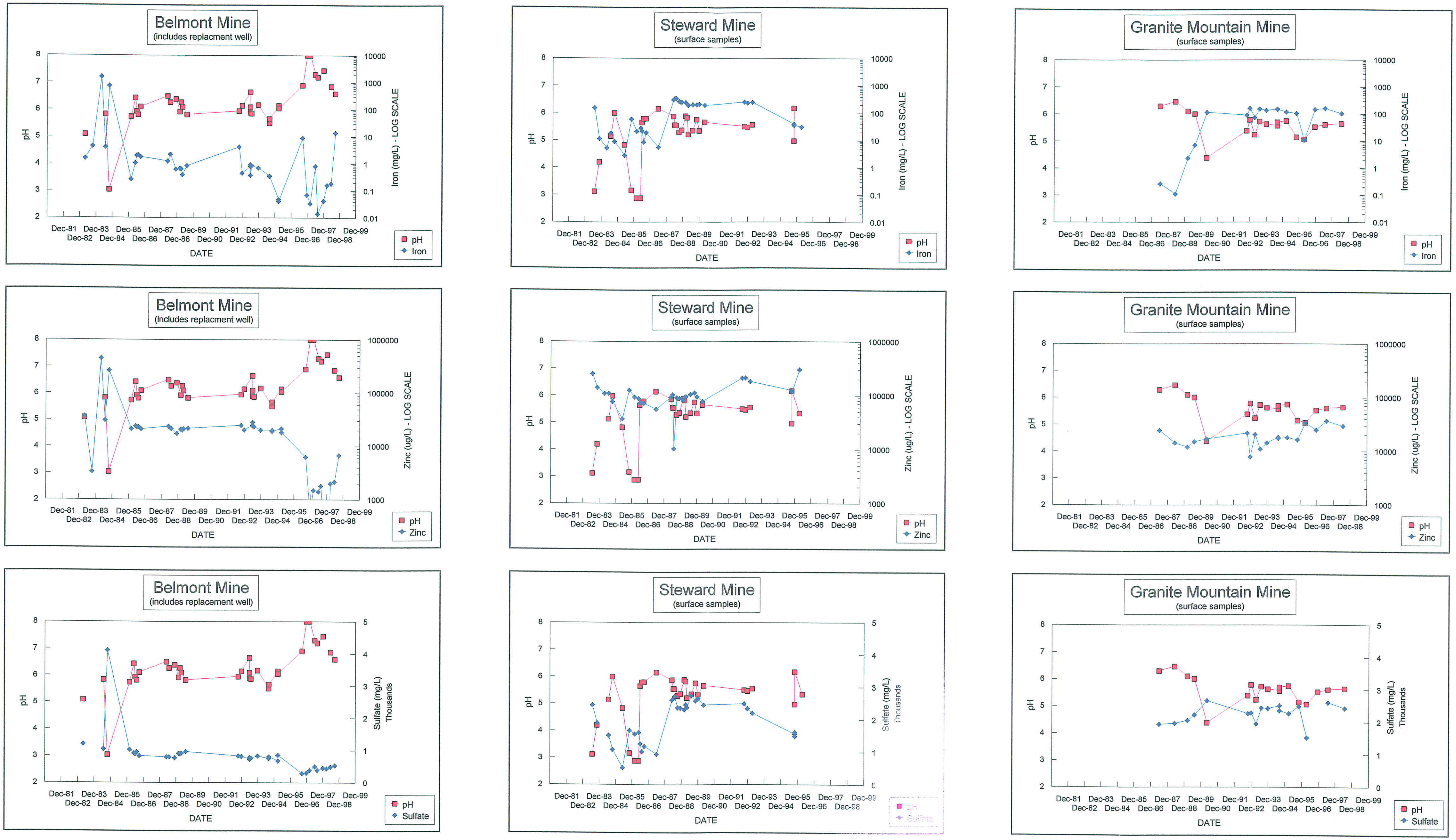

Figure 15a. The chemistry in all three mines has varied since flooding began. Water quality in the Belmont mine has improved while that of the Steward and Granite Mountain mines have shown only a slight change.

It is interesting to note that, although the pH of the water in the Steward shaft has increased by about 3 units, the concentrations of metals have not decreased as might be expected. It is further noted that the Eh (redox) of the Steward shaft is consistently low (less than -50 millivolts) and hydrogen sulfide gas is sometimes apparent during sampling - a condition not found at any other shaft in the East Camp.

The Anselmo, Missoula, and Lexington mines (figure 3) are on the outer margins of the East Camp mine system. There are several differences in water chemistry between the mines of the intermediate zone and those of the central zone - dissolved concentrations of copper, arsenic, and iron are generally much lower in the mines of the intermediate zone. Conversely, the concentration of zinc is generally higher in the intermediate zone. As noted, Sales (1914) described the intermediate zone as having less copper and greater zinc than the central zone - the chemistry of the waters suggest these mineralogic controls are present. Water-chemistry trends of the mines in the intermediate zone are more subdued than those of the central zone. The Anselmo mine waters indicate a net decrease in pH and increases of several dissolved constituents. The Missoula and Lexington mines show the same trend as the Anselmo mine during their brief period of record (figures 16 and 16a).

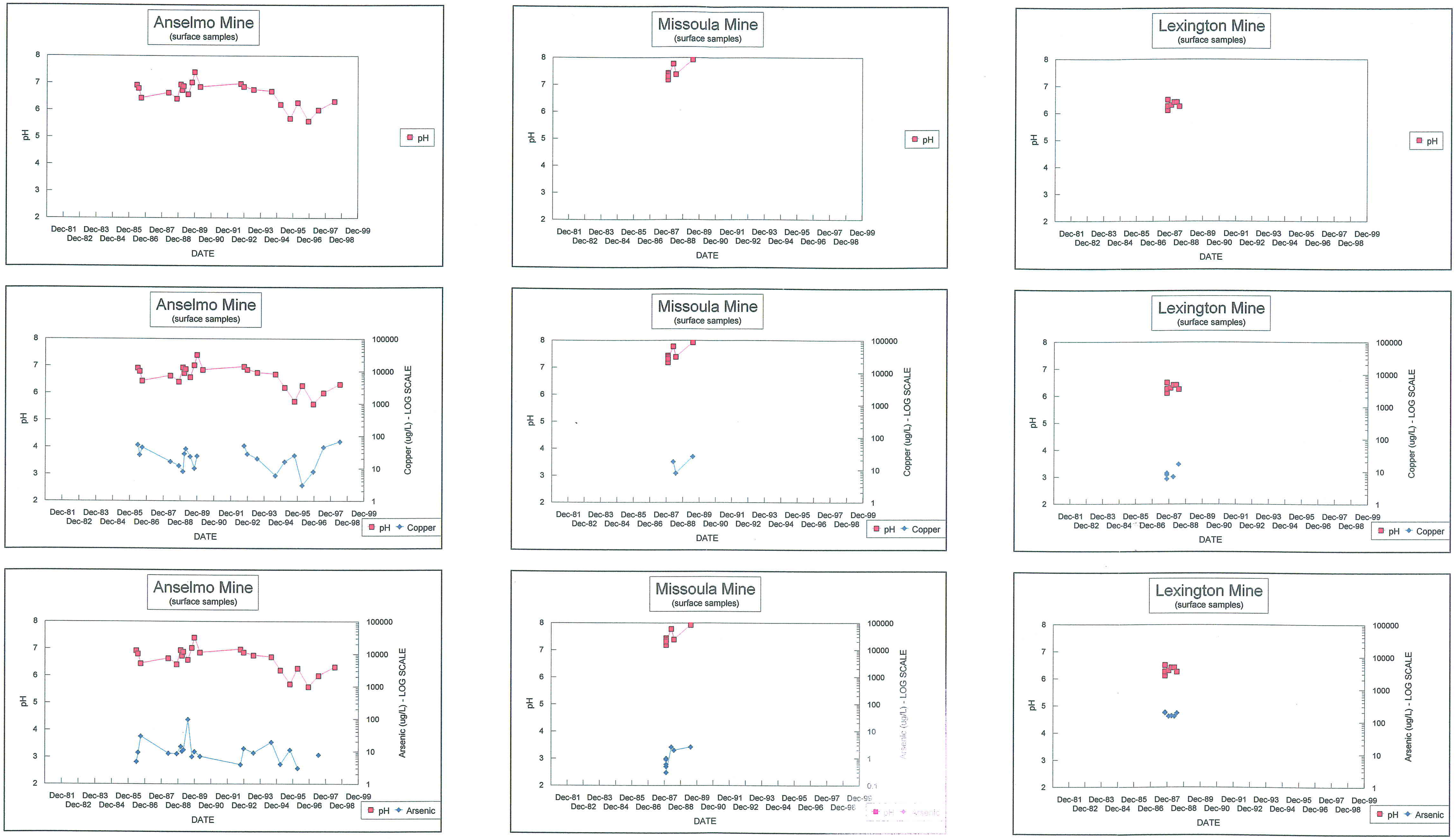

Figure 16. The Anselmo, Missoula, and Lexington mines are within the intermediate zone described by Sales (1914)

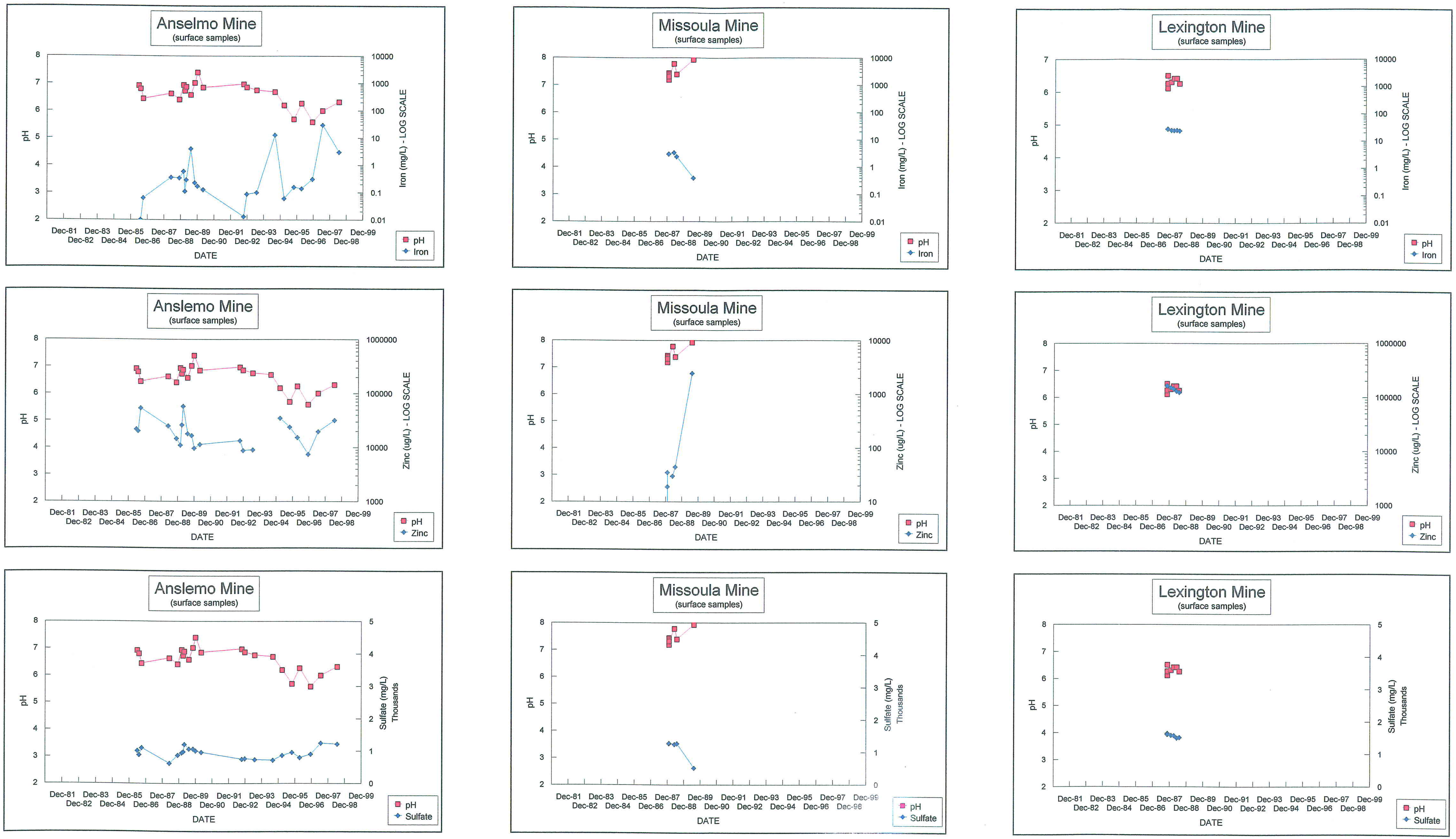

Figure 16a. The concentration of dissolved constituents is generally lower than those shafts in the central zone of the East Camp.

2.2.2 Monitoring Wells (A-H series and park wells)

Exploration holes were utilized in the first water-level monitoring efforts east of the pit. These initial water-level and chemistry data confirmed the influence of dewatering in that area and established the need for additional bedrock wells east and south of the pit. The 7 RI/FS wells (A through H) were completed in competent bedrock east and south of the Berkeley pit (figure 17) to determine water quality and to monitor water levels. The depths of these wells range from 355 to 1071 feet below ground surface (table 4); wells A, C, D-1, and D-2 have exhibited increases in water levels consistent with mine flooding, while wells B, E and F have shown much smaller increases (table 3). In should be noted that these wells are completed in the upper portion of a supergene ore zone targeted by the Berkeley pit; pyrite coated with chalcocite (CuS) was observed in the drill cuttings from several of the wells.

Table 4. Completion depths for bedrock monitoring wells east of the Berkeley Pit

Well Name	Total Depth (ft)	Screen from	Screen to	Net Water-level Change (1989 to 1997)*
A	745	680	700	188
		720	740	
B	643	568	578	66
		628	638	
C	800	755	795	171
D-1	635	600	635	161
D-2	775	660	670	
		720	740	
		760	770	159
E	355	270	290	
		320	350	2.38
F	639	614	634	2.23
G				67
H				53

*Duaime and others, 1998

In 1988, irrigation wells were installed in Parrott Park (270 feet deep), near the Belmont mine, Hebgen Park (300 feet deep), and Chester Steele Park (700 feet deep), north of the Travona mine (figure 17). Only the Hebgen Park well produced water in sufficient volume for irrigation; soon after, these wells were used for monitoring water levels and water quality in shallow bedrock near the mines.

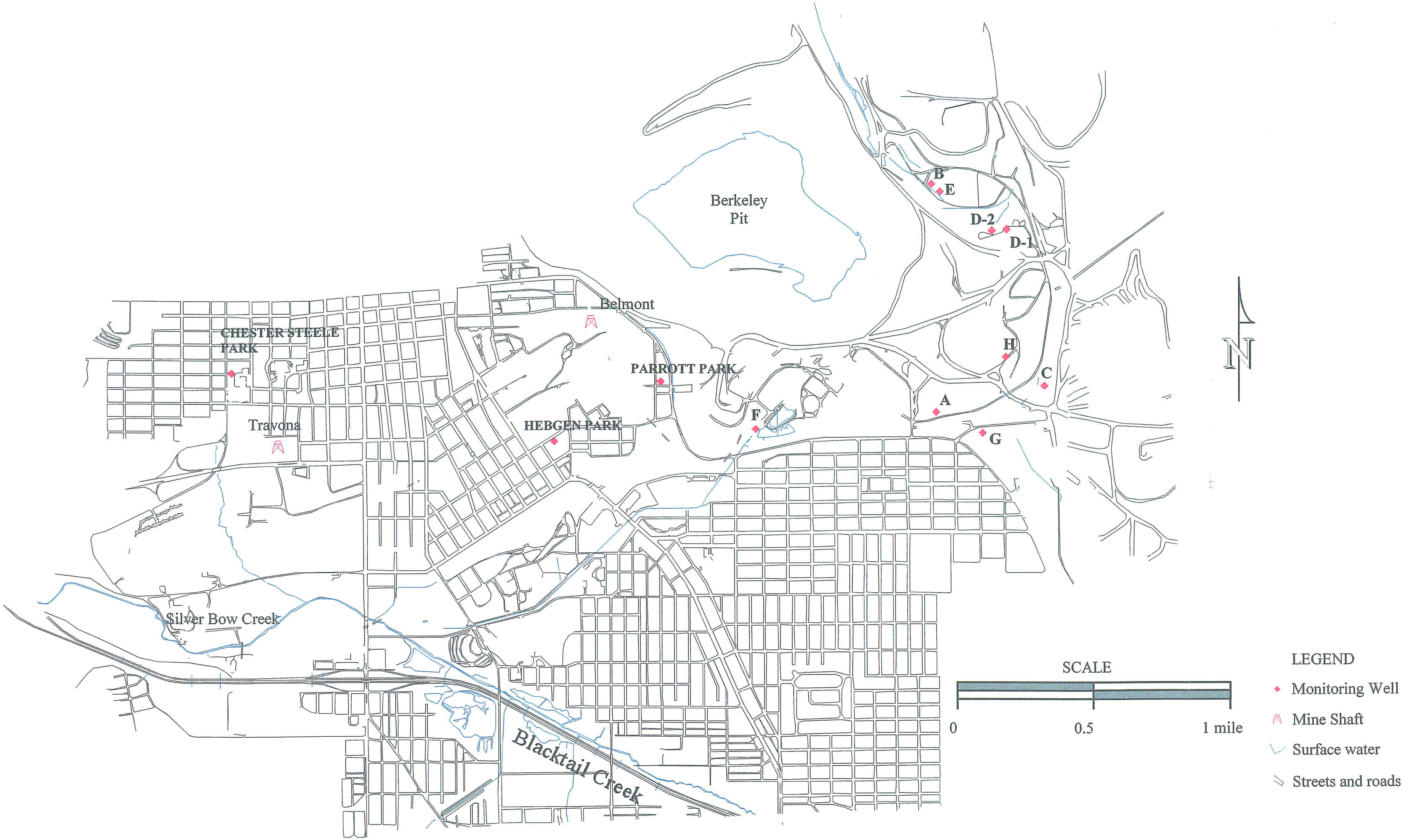

Figure 17. The A-H series of bedrock wells were installed during the Mine Flooding RI/FS to monitor water levels and water quality south and east of the Berkeley pit. The park wells, installed in 1988, have been used to monitor the shallow bedrock aquifer.

The depth to water and seasonal fluctuation of the water levels in these wells suggest little relationship tc the underground workings, at present. They do, however, offer the best opportunity to observe any impacts to the shallow bedrock aquifer as the mine waters continue to rise.

2.2.2.1 Water-Quality Trends

Water in all of the A-H series wells exceeds the SMCL for sulfate (table 5). With the exception of arsenic in wells A, F and H, the concentrations of other constituents are well below the regulatory limits.

Table 5. Exceedences and trends for East Camp Bedrock Wells (1989 to 1999)

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	none	sulfate (SMCL)
E	N	variable	arsenic (MCL), sulfate (SMCL); pH has increased by nearly two units
F	Y	none	arsenic (MCL), sulfate (SMCL)
G	N	decrease	sulfate (SMCL); pH increased nearly 3 units
H (prior to 1997)	Y	none	arsenic (MCL), very high sulfate, pH (SMCL)

* excludes sulfate

In those wells where water levels have changed in a manner similar to the flooding mines (wells A, C, D-1and, D-2), water quality has generally remained unchanged throughout the period of record. Those wells whose water levels are shallow and show only small changes (wells E, F, G, and H) show a greater range of concentrations as well as noticeable trends in concentrations (figures 18 and 18a; 19 and 19a; and 20 and 20a). Well H is a special case where a breach in the upper part of

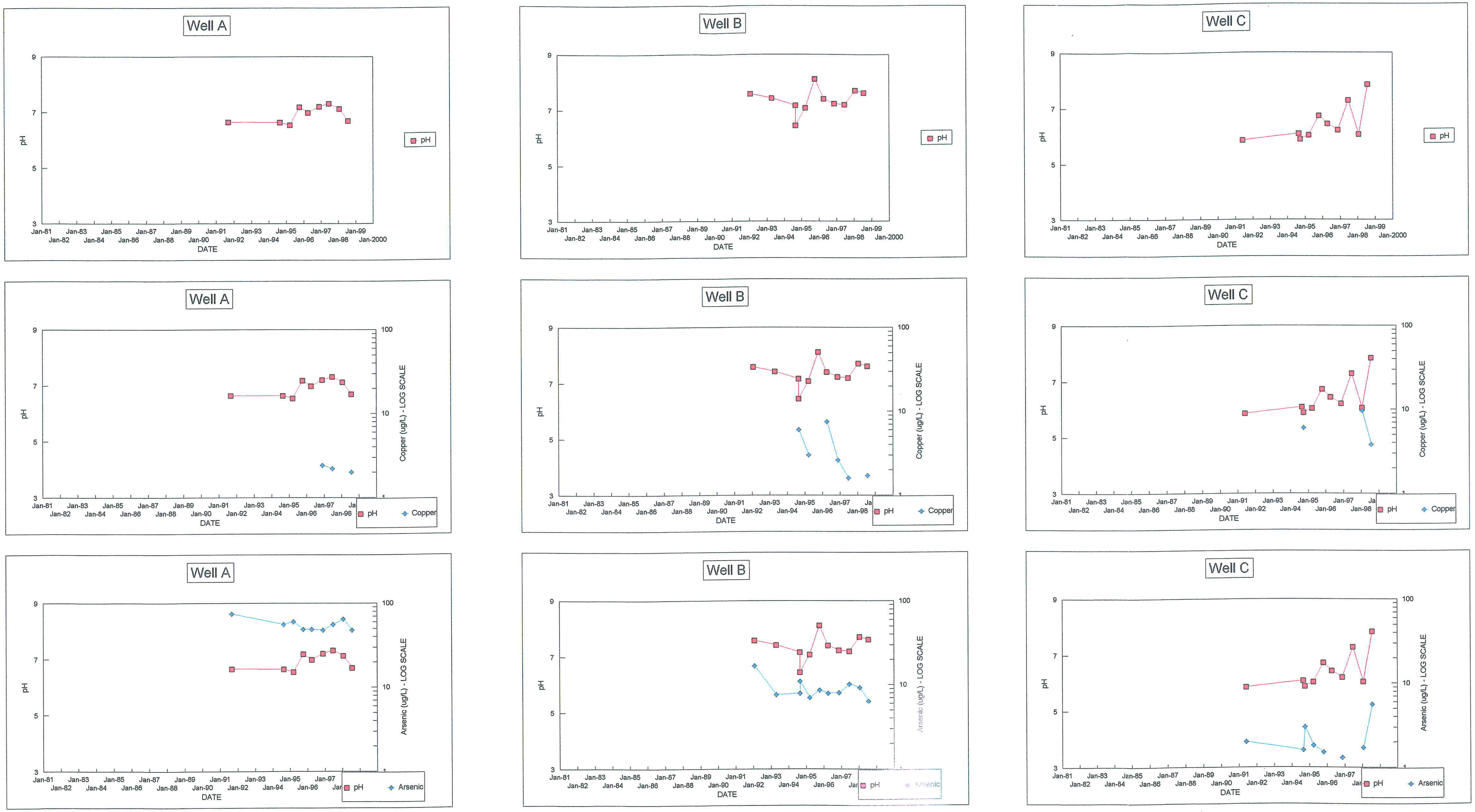

Figure 18. The A-H series of wells are east and south of the Berkeley pit.

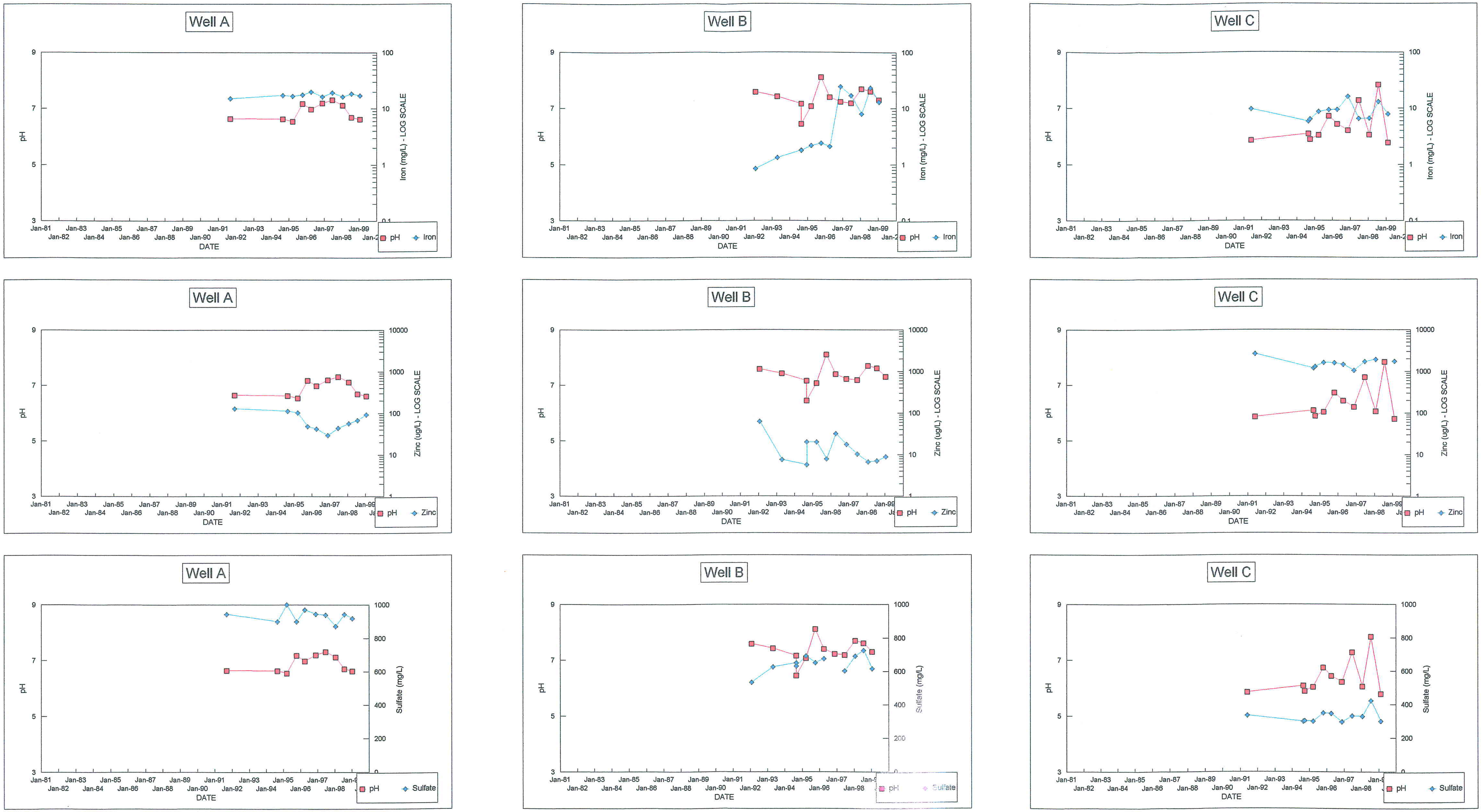

Figure 18a. Water quality varies between wells and varies with time, but most dissolved consistuents are at or below MCLs and SMCLs.

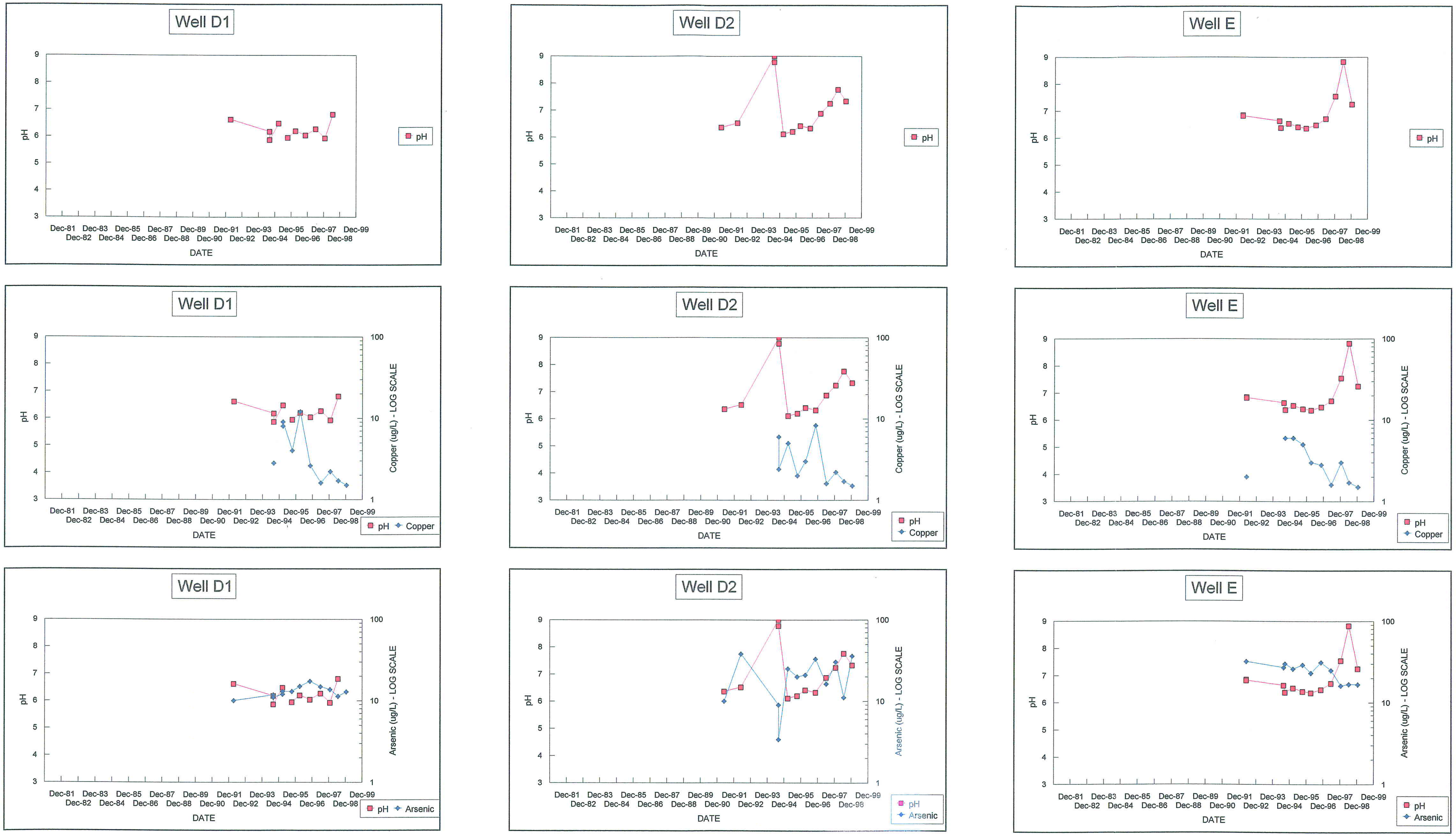

Figure 19. The A-H series of wells are east and south of the Berkeley pit.

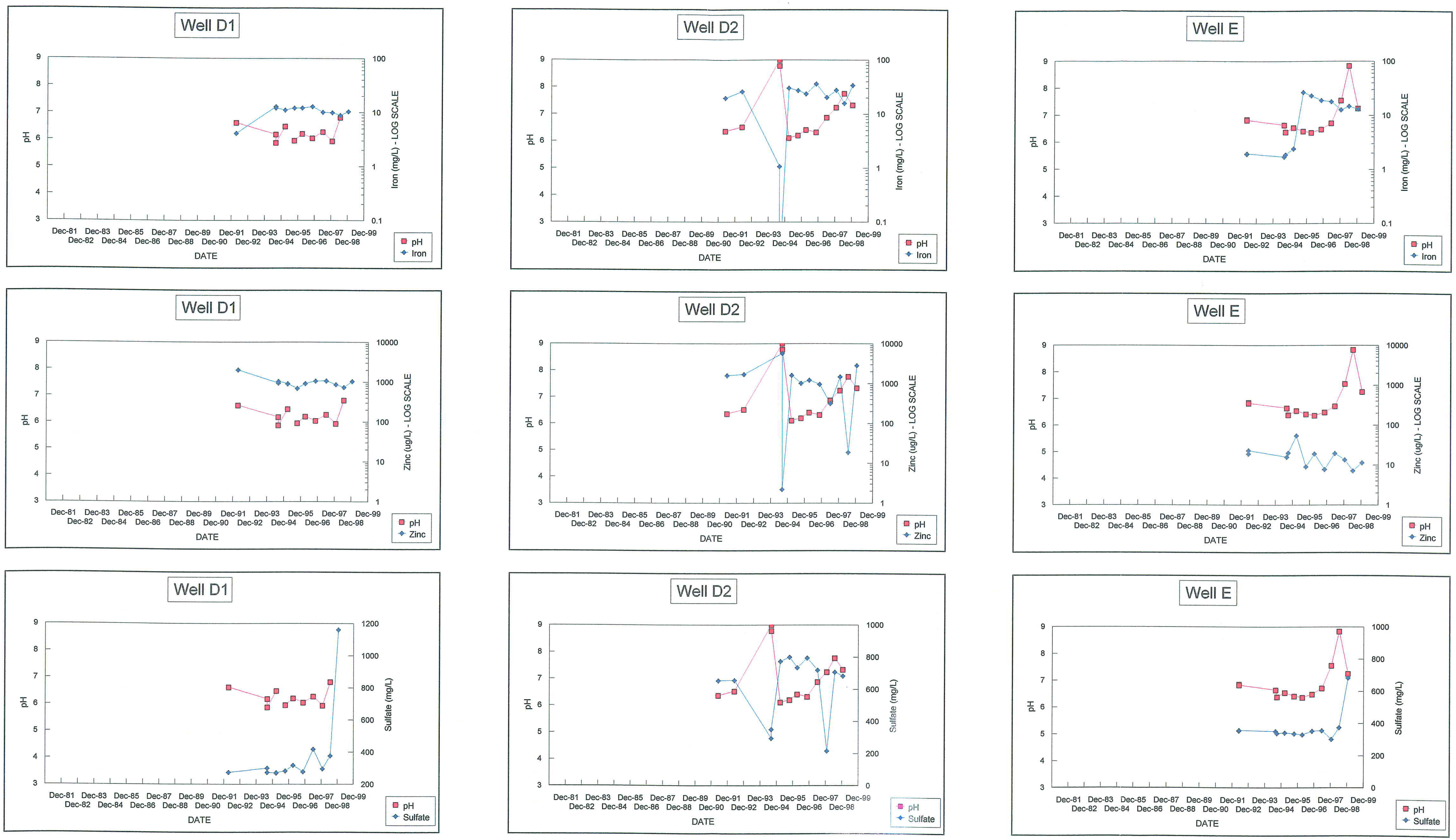

Figure 19a. Wells D-1 and D-2 are close in proximity, but differ in screen-interval depth. The difference in water quality demonstrates the variablity of ground-water quality in the bedrock aquifer.

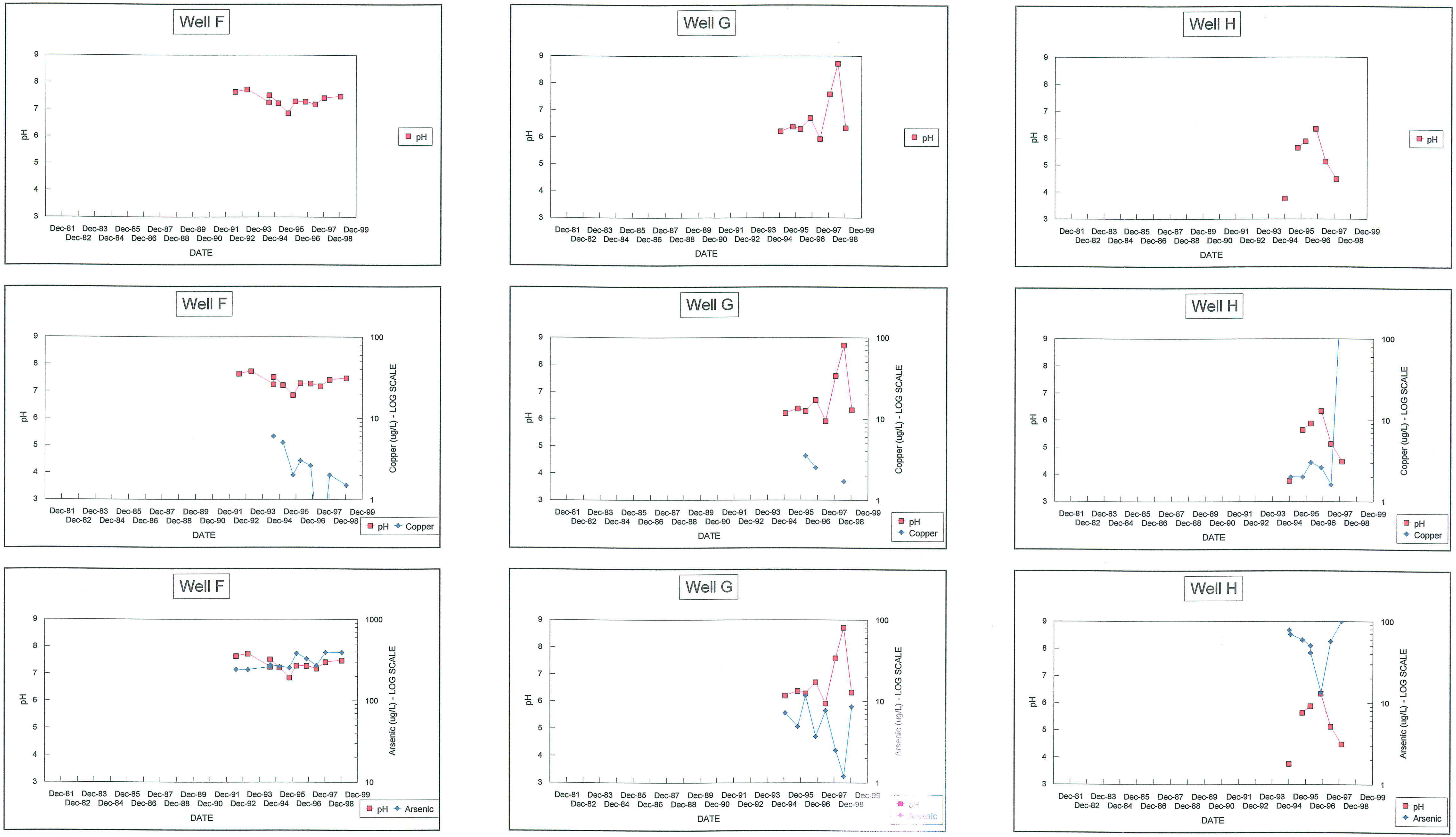

Figure 20. Well F is south of the pit; the water level is several hundered feet higher than other bedrock wells. Wells G and H are southeast of the Berkeley pit and the active mine area: water levels indicate they are within the influence of the mine flooding.

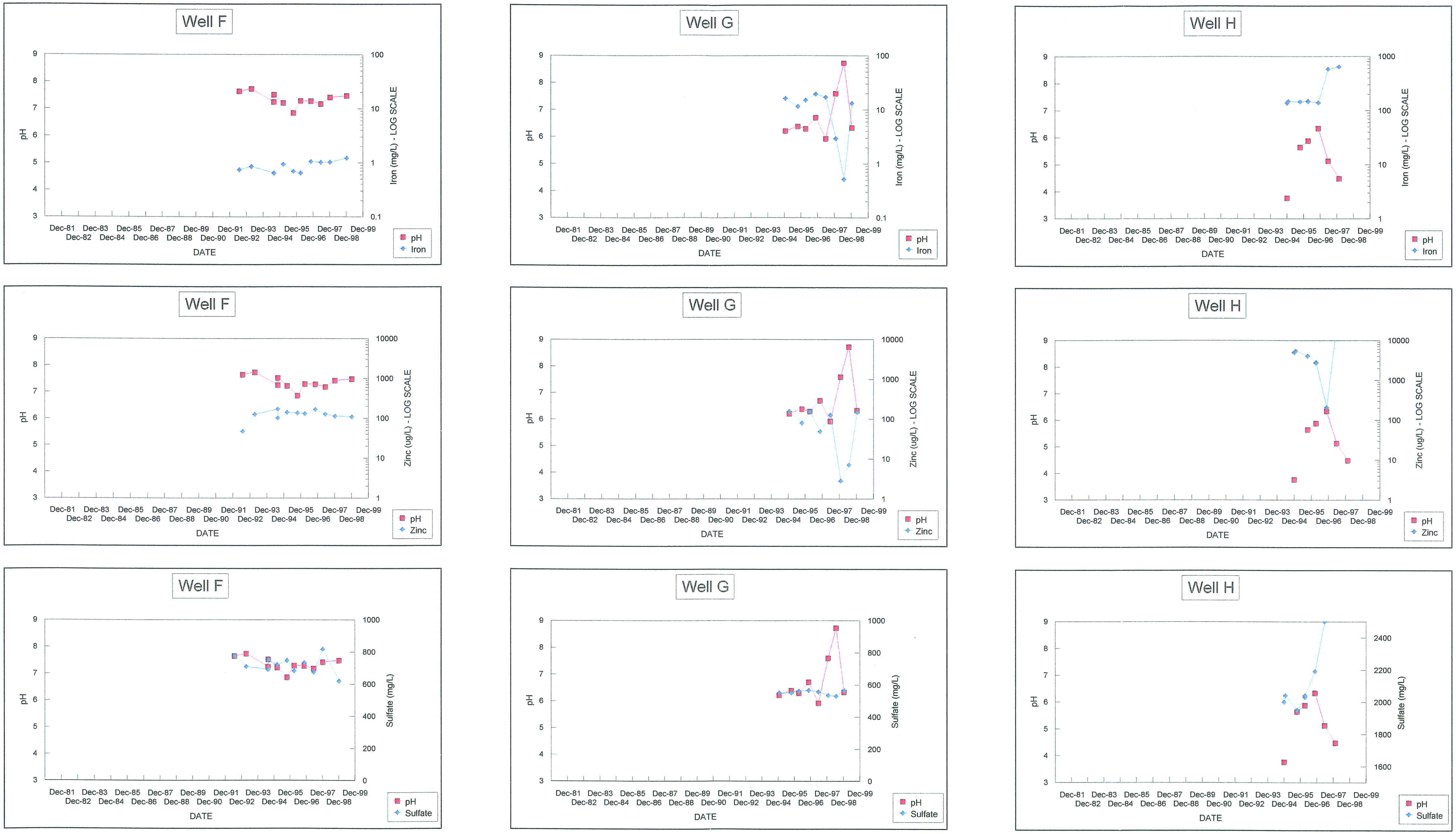

Figure 20a. Well H exhibited anomalous water levels beginning in 1997; a breach in the casing was allowing alluvial ground water and Berkeley pit water to enter the well. The well was abandoned in 1998 and replaced by Well I in 1999.

the casing allowed shallow ground water to enter the well. Another breach in the casing at a depth of 954 feet below ground surface allowed poor-quality water from the Pittsmont mine and Berkeley Pit to enter the well. Down-hole-camera video suggested acidic waters in the unconsolidated material and near the mine workings at depth corroded the casing - this is reflected in the dramatic change in water quality beginning in January of 1997 (figures 20 and 20a). This well was abandoned in 1998 and replaced by Well I completed in 1999.

The high sulfate concentrations in all of the wells may be the result of lowering the water level rather than the result of contamination by mine waters. As noted, the area east and south of the Berkeley pit is within a supergene ore zone. Sulfate is produced in the process of pyrite oxidation; in the absence of sufficient dissolved oxygen at depths of several hundred feet, only a small amount of acid and sulfate would be produced. The net result is a near-neutral pH and an elevated sulfate concentration. These conditions would be expected to remain until ground water reached historic levels.

With the exception of samples collected in late 1996 and early 1997, the wells in Chester Steel Park, Parrott Park, and Hebgen Park show little change in water quality (figures 21a and 21b). The Chester Steele Park well is particularly notable because of large decreases in pH coincident with large increases in copper, iron, zinc and sulfate concentrations in 1996 and 1997. The concentrations of dissolved constituents in the Chester Steele and Hebgen Park wells are well below MCLs throughout the rest of the period of record.

2.2.3 Summary of the East Camp Bedrock Aquifer

In spite of the many connections between the mines of the East Camp, differences in concentrations of dissolved constituents on the order of one to two orders of magnitude are common. No single control will explain the differences; it appears there are several controls which may include relative position of the shaft along the flow path, local mineralogy, the amount of recharge, and the source of recharge for each shaft. In the initial period of flooding, waters in the shafts were oxidized, acidic, and contained very high concentrations of metals. As flooding progressed, the water became more neutral, more reduced, and the concentrations of metals decreased several orders of magnitude.

The bedrock wells of the East Camp are generally up-gradient of mine workings, but water quality has likely been impacted by de-watering. Sulfate concentrations are above SMCLs in nearly all the wells and arsenic concentrations exceed MCLs in 4 wells. No water-quality trends are strongly evident thus far as water levels continue to rise.

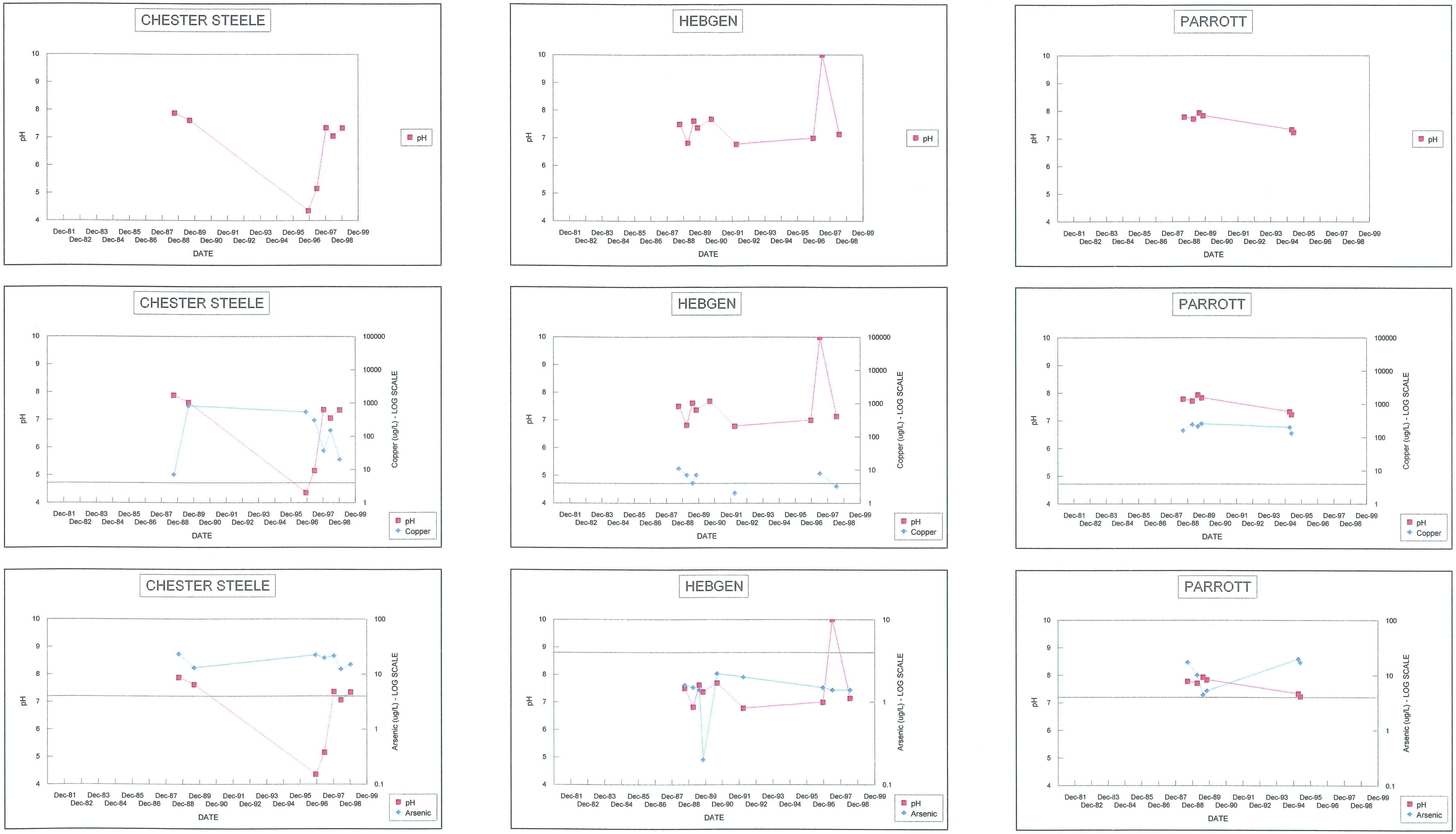

Figure 21. The Chester Steele, Hebgen, and Parrott Park wells are completed in the shallow bedrock aquifer above the underground workings.

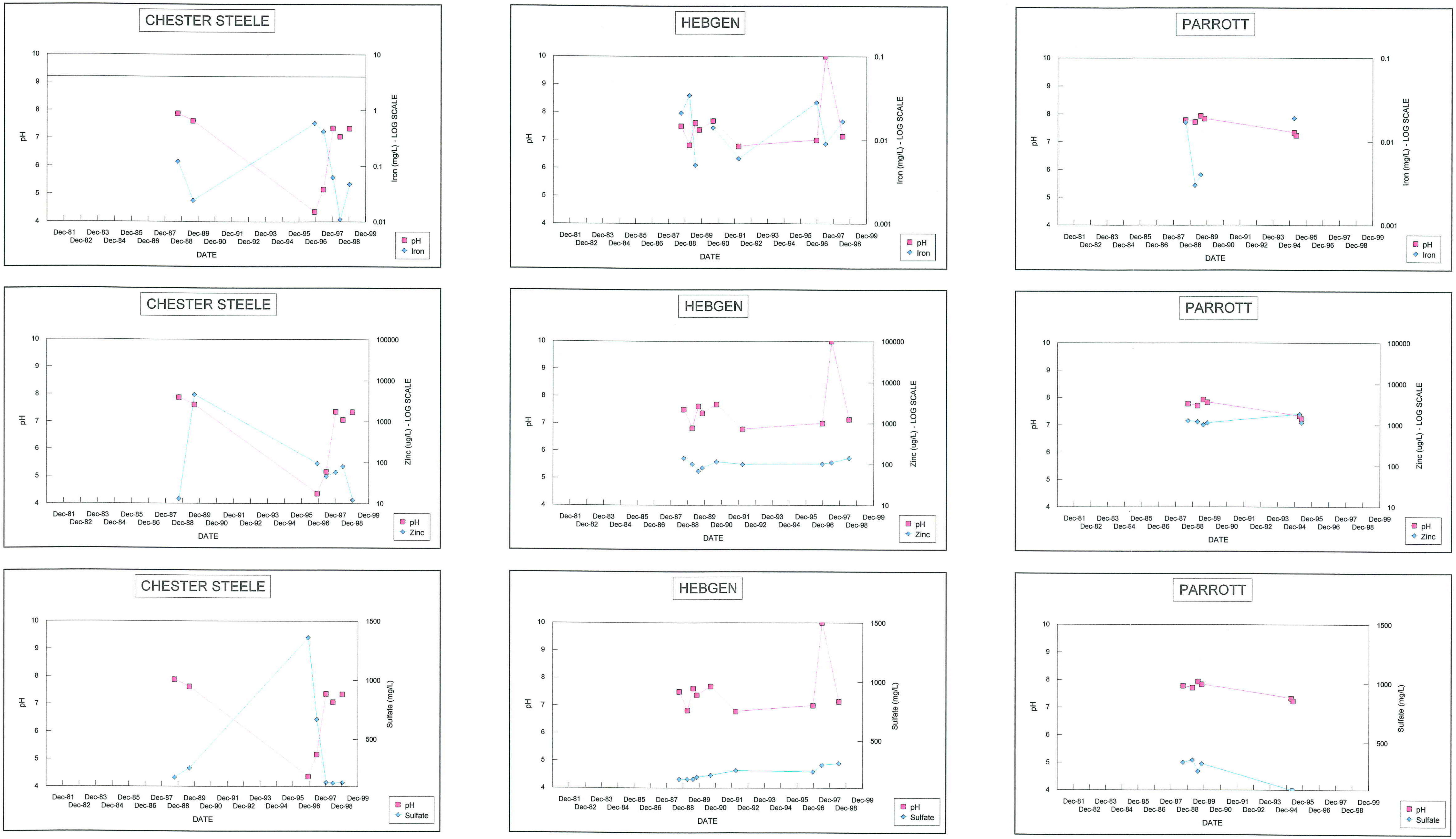

Figure 21a. Although no net change in chemistry is evident, Chester Steele and Hebgen Park wells exhibited a large change in pH and the concentration of metals in late 1997 and early 1996.

2.3 Berkeley Pit

The pit is currently 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 as much a function of the quality of waters flowing into the pit as the processes within. The largest sources of water flowing into the pit, current and historic, include:

Current (1999)

- precipitation (about 13 inches annually),
- 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, and
- ground water from the alluvial aquifer east and southeast of the pit.

Historic

- precipitation,
- surface water from a large seep (Horseshoe Bend) at the base of the leach pad /tailings dam (diverted in Aprill,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),
- tailings slurry from pipeline breaks between the mill and the tailings pond north of the pit (sporadic),

Each of these sources have varied in quality, quantity, and duration throughout the period of record. With the exception of evaporation and sampling, no water is removed from the pit. However, MR is presently pumping about 10,000 gallons per minute for copper recovery; this water is returned to the pit with little or no net loss.

As discussed in previous sections, the quantity of ground water entering the pit has varied substantially since flooding began. Canonie (1994) estimated about 2.5 million gallons per day entering the pit from the bedrock aquifer near the pit and underground workings. This will decrease with decreasing head difference between the mines and the pit.

Ground water from the alluvial aquifer discharges as seeps on the east and southeast walls of the pit. Estimates of this discharge range from 0.3 to 0.6 million gallons per day. Two of the larger, accessible seeps on the east wall of the pit were sampled for water quality in 1997. Both samples indicated very poor quality water (table 6).

Table 6. Selected dissolved-metals concentrations from seeps.

Sample	Flow (gpm)	pH	Al (µg/L)	Cd (µg/L)	Cu (µg/L)	SO_4 (mg/L)
Seep 1A	125	3.30	805,000	7001	299,000	15,000
Seep 2A	77	3.54	140,000	6467	580,000	19,000

Horseshoe Bend is a large spring at the base of the Yankee Doodle tailings dam / leach pad area (Figure 3). With exception of brief periods when some of this water was diverted to the leach pad operations, this water flowed into the pit at a rate of 2.4 to 2.9 million gallons per day until April of 1996. Since that time, this water has been 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 by MR; pregnant solution from the pads was captured and re-circulated. There is no record of the rate of discharge.

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. Samples were collected from a site above the pit and at the point of discharge from the pit (table 7). Water was also pumped from the Sarsfield shaft to de-water the Continental pit. This was also routed to the Berkeley pit prior to 1986. The shaft was sampled in 1994 (table 7).

Table 7. Selected dissolved-metals concentrations from surface flows near the Continental East Pit (1984) 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
pit discharge	270	6.68	60	16	440	530
Sarsfield shaft	-	6.57	<30	5.2	27.4	562

* sample collected below historic waste-rock dumps

With the reactivation of milling in 1986, the active operation experienced a series of slurry-line breaks during the period from 1986 to about 1992. These slurry lines pump tailings from the concentrator south of the pit to the tailings pond north of the pit. The tailings slurry is a mixture of solid from the milling process and about 75% water by weight. No details on the chemistry of this water is available, however the pH ranged from 11.2 to 12.4 and alkalinity ranged from 316 to more than 700 mg/L as $CaCO_3$. About 2,360 million gallons of this slurry entered the pit between March, 1991 to November, 1991 (Canonie, 1994).

2.3.1 Water Quality with Depth

The earliest data collected from the Berkeley pit indicated that there are at least two distinct layers or chemoclines in the water column. These layers are marked by dramatic changes in both field parameters and dissolved constituents.

In the absence of an ice cover, the upper 30 feet of the water in the Berkeley pit is in near-equilibrium with atmospheric oxygen. Wave and wind action combined with a large surface area promotes the mixing of atmospheric gases in water at the surface of the pit. In addition, from the time the pit began filling to April of 1996, about half of all the water entering the pit was surface water cascading down the side. This equilibrium is exhibited by a dissolved oxygen concentration on the order of 6 to 8 ppm and an Eh on the order of 500 to 600 millivolts, consistent with surface waters. At the same time, the pit water has opportunity to react with the walls of the pit. Oxygenated water with a high FeIII/FeII ratio is an optimum condition for a high pyrite oxidation rate. Some buffering is likely to occur with the equilibration of the pit surface with atmospheric CO_2, silica minerals in the wallrock, minor amounts of secondary gypsum in the wallrock, and dilution by "clean" ground water discharging into the pit.

Although it varies with the season, there is a significant change in change in water chemistry at a depth of about 30 feet most likely due to the lack of interaction with the atmosphere. Dissolved oxygen concentrations decrease to less than 0.05, the pH increases by as much as 0.25 units, and Eh decreases to about 350 to 400 mv. Acid generation in the deeper portions of the pit continues under two processes:

1) pyrite oxidation by FeIII by gravity settling of iron-sulfate precipitates (K-jarosite and/or schwertmanite) through the water column (this settling phenomena was documented with a submerged camera). Scanning Electron Microscope analysis of these minerals captured in submerged cones indicate that these particles are mostly jarosite (personal communication, James Madison, MBMG), and

2) pyrite oxidation in the absence of dissolved oxygen due to low FeIII/FeII ratios. At a depth of 200 feet, the Berkeley pit has an FeIII/FeII ratio of about 0.4; at the surface, the ratio is about 3.0. The absence of sufficient quantities of "reducing agents" such as organic carbon, seasonal turnover of the upper 100 feet of the water column, and slumping along the sides of the pit maintain an oxidizing potential throughout the water column.

As noted, reaction rates in the shallow and deep waters of the pit are likely controlled by the FeIII/FeII ratio, which is much higher in the shallow water. Also as noted, the dissolved oxygen content is most often near saturation in the shallow and nearly depleted in the deeper waters. Robertson (1994) suggests that the rates are actually higher under anoxic (deep pit) conditions with ferrous iron. The reaction rate for anoxic conditions is:

$$10^{-8.58} * \frac{[Fe^{3+}]^{0.3}}{[Fe^{2+}]^{0.47}\,[H^{+}]^{0.32}}$$

And in the presence of oxygen (at the surface of the pit) the reaction rate is given by:

$$10^{-6.07} * \frac{[Fe^{3+}]^{0.93}}{[Fe^{2+}]^{0.40}}$$

Based on an Fe^{3+} concentration of 0.179E-03m/L, and an Fe^{2+} concentration of 16.116m/L, and a pH of 2.64, the rate for the deeper water is 9.62E-9 m/L m^{-2}s-1 The rate for the shallow water based on 3.6401E-03m/L, and an Fe^{2+} concentration of 3.6304E-4m/L is 1.09E-7 m/L m^{-2}s-1. Thus, reactions rates are about 10 times higher at the surface than at depth. This may be due to the large amount (about half of all the water) of FeIII-rich surface water flowing into the pit from Horseshoe Bend. Although Horseshoe Bend has been diverted, it has been replaced with FeIII-rich water from the copper recover operations at MR. If, in the future, surface-water inflow is eliminated, the inflow will be dominated by FeII-rich ground water and the relative reaction rates between the shallow and deep waters may reverse.

2.3.1.1 Water-Quality Trends

three trends in the pH and the concentration of dissolved constituents in the shallow water of Berkeley pit are apparent. From 1984 to early 1987, the pH decreased by nearly one unit; this trend reversed sometime in late 1987 (figure 22). The inflection is coincident with the re-activation of mining, which included the re-activation of the leachpads and the sporadic release of tailings slurry. The upward trend of pH continued until 1995; pH increased by about one unit. The downward inflection in 1995 is coincident with the diversion of Horsehoe Bend.

Samples collected in 1984 show that the pH of the pit water was lower by 1.5 to 2 units and dissolved metals concentrations were higher than that of the water in the underground workings. Although the relative inflows of ground water and surface water changed, water entering the pit as ground water has been of better quality than that in the pit; the further degradation of water quality in the pit has been due to additional reactions within the pit.

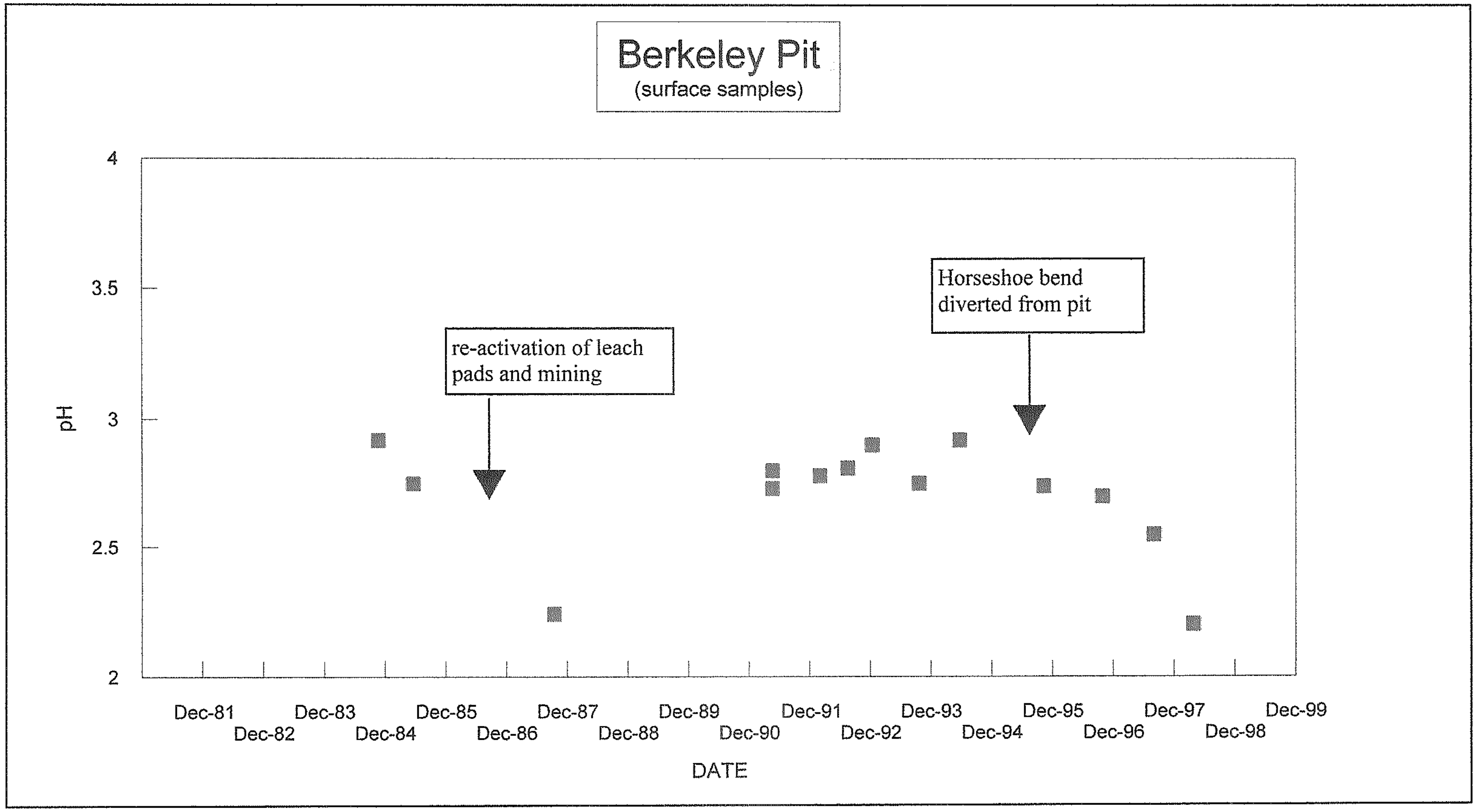

Figure 22. There are two apparent trends in pH in the Berkeley pit; one associated with the re-activation of mining and the other with the diversion of Horseshoe Bend.

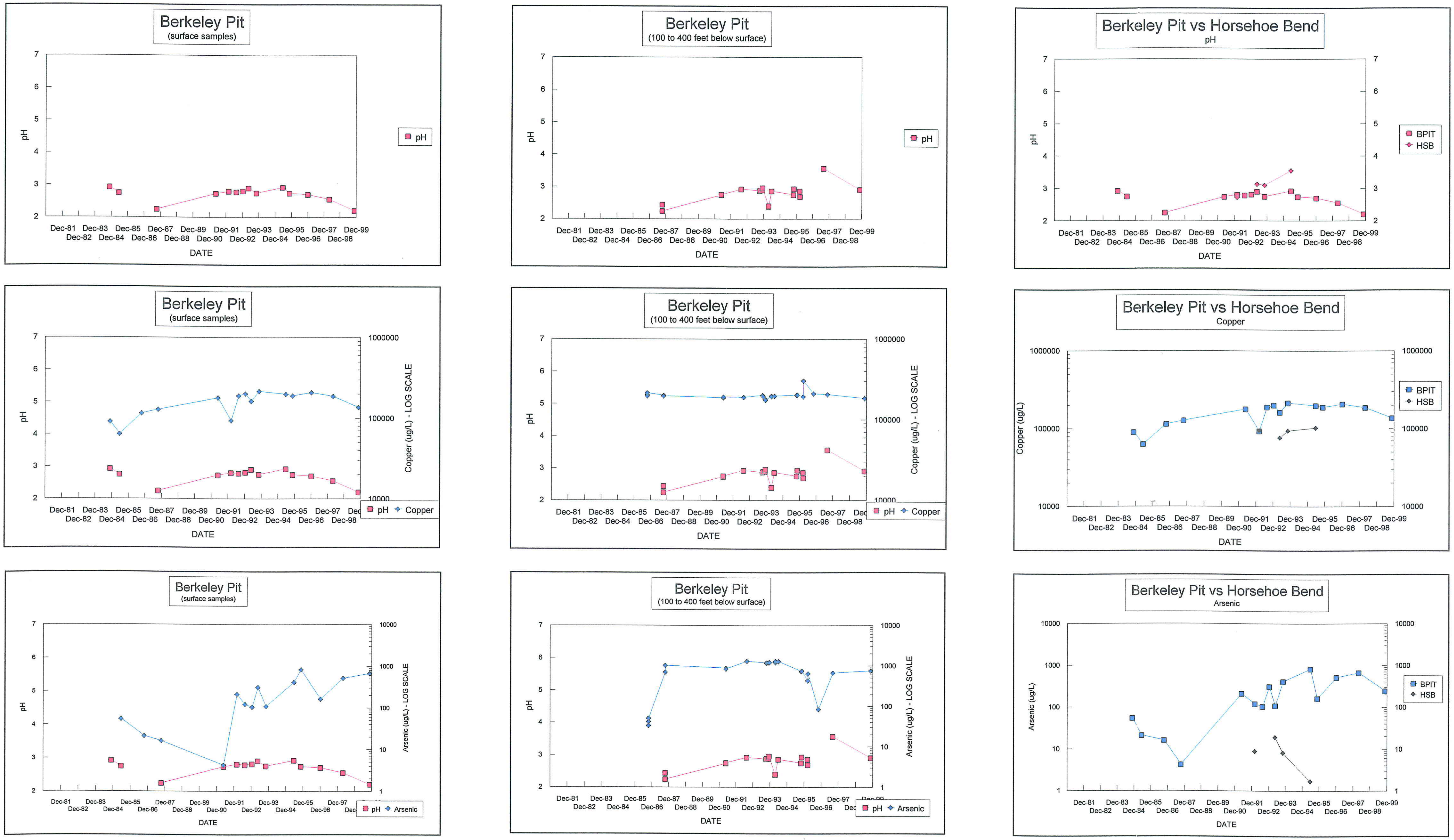

Figure 23. The concentration of dissolved constituents in the near surface and deep waters of the Berkeley pit are generally similar, but the trends are not.

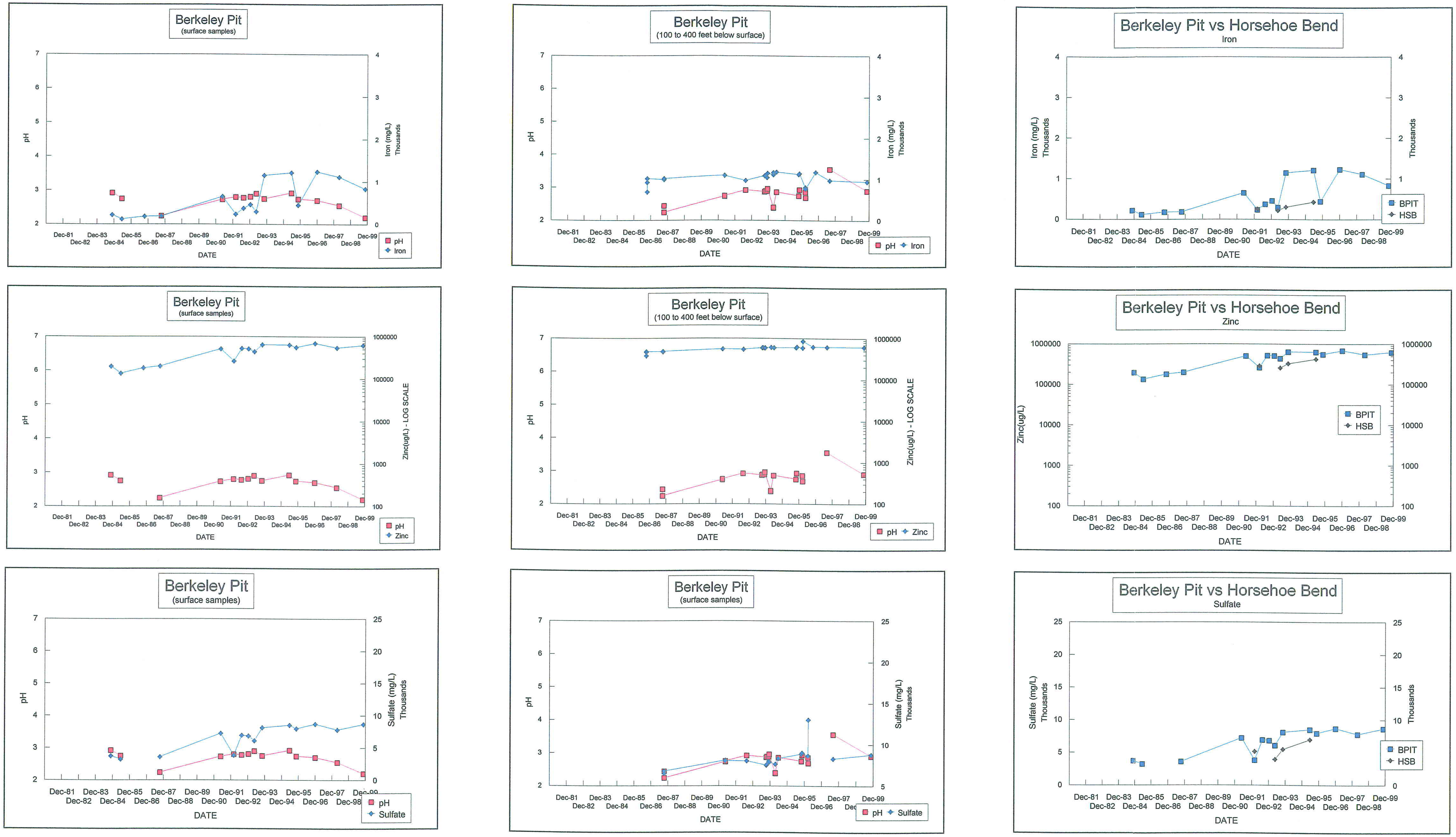

Figure 23a. The influence of Horseshoe Bend water is demonstrated by a comparison of its chemistry over time with that of the shallow pit water.

The pH of the pit has shown a downward trend and the concentration of dissolved metals has also shown an upward trend (figures 23 and 23a). The change in concentration of a given constituent is often associated with a change in pH. The trends of concentrations of dissolved constituents differ between the surface of the pit and the deeper pit water. The influence of the season (ice cover, wind, etc.) is likely the reason for large differences.

The concentrations of dissolved constituents in Horseshoe Bend water were generally similar or lower than that of the pit; however, the influence of this large volume of inflow water is demonstrated in a comparison of the concentrations time (figure 23 and 23a).

Another demonstration of the changing chemistry of the pit water lies in the examination of field parameters with depth (figures 24 and 24a). In the years 1991 through 1993, the pH of the deeper water of the pit was most often higher than the shallow water, except when covered with ice; conversely, measurements made of pH in 1997 and 1998 show that the pH is consistently lower in the deep water (table 8).

Table 8. Temperature and pH trends with depth for Berkeley Pit

Date of Measurement	Trend with Depth (temperature)	pH of deep water relative to surface
5/91	lower	higher
10/91	lower	higher
3/92(ice cover)	higher	lower
9/92	lower	higher
11/93	lower	higher
9/97	higher	lower
5/98	lower	lower
7/98	lower	lower
12/98	lower	lower

The redox potential (presented as Eo) and dissolved oxygen have also shown a wide range of variability. As with other parameters, there is always a significant change at a depth of about 30 feet (10 meters) at any time of the year (figures 24 and 24a). The redox potential is always much higher at the surface than at depth, but the difference between the two ranged from about 75 millivolts to more than 150 millivolts. The dissolved oxygen concentration at the surface is similar to that of other surface water, while at depth, it decreases to nearly zero in all measurements.

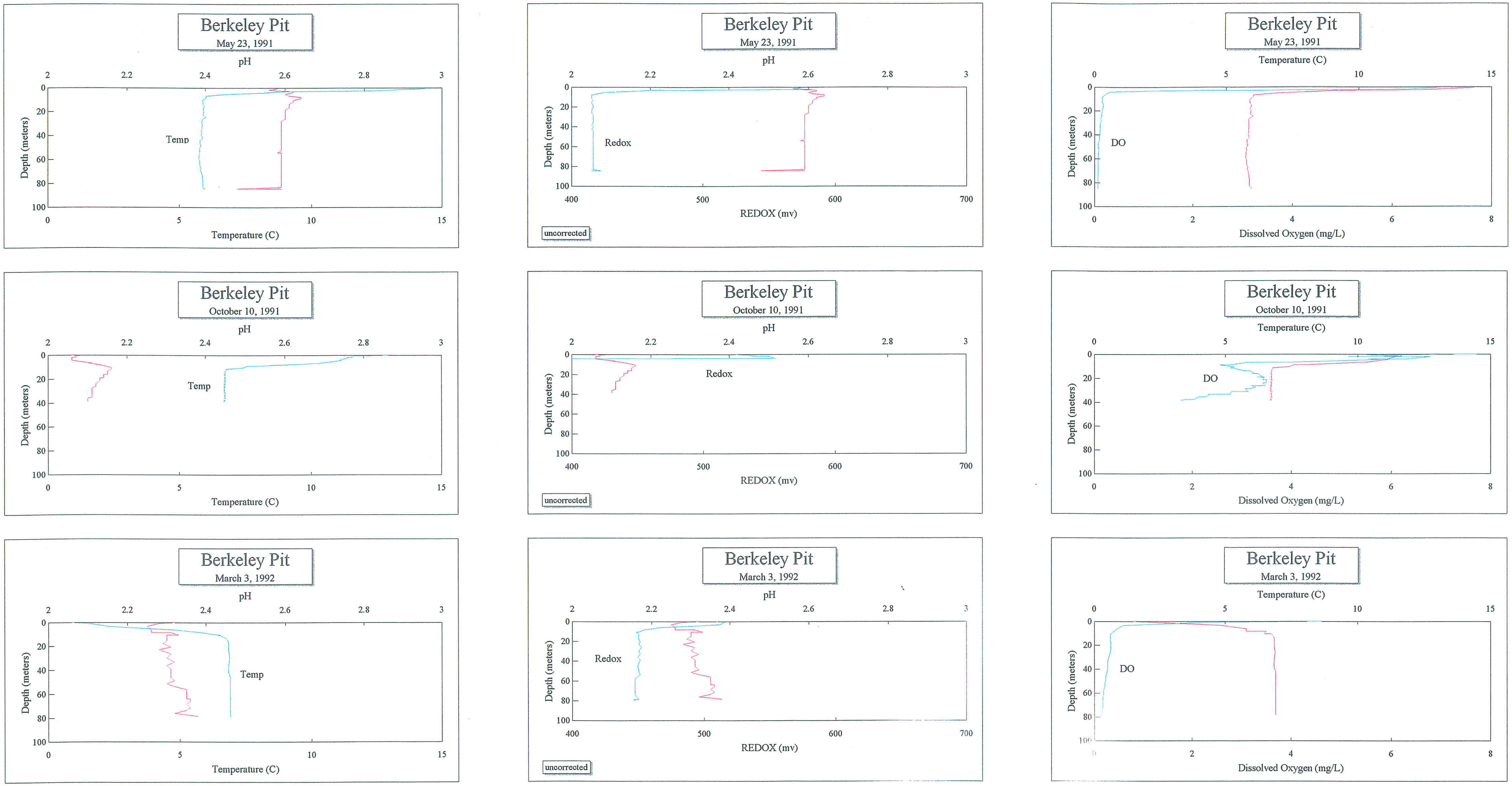

Figure 24. Profiles of the Berkeley pit were conducted throughout the year since access was first gained in 1991.

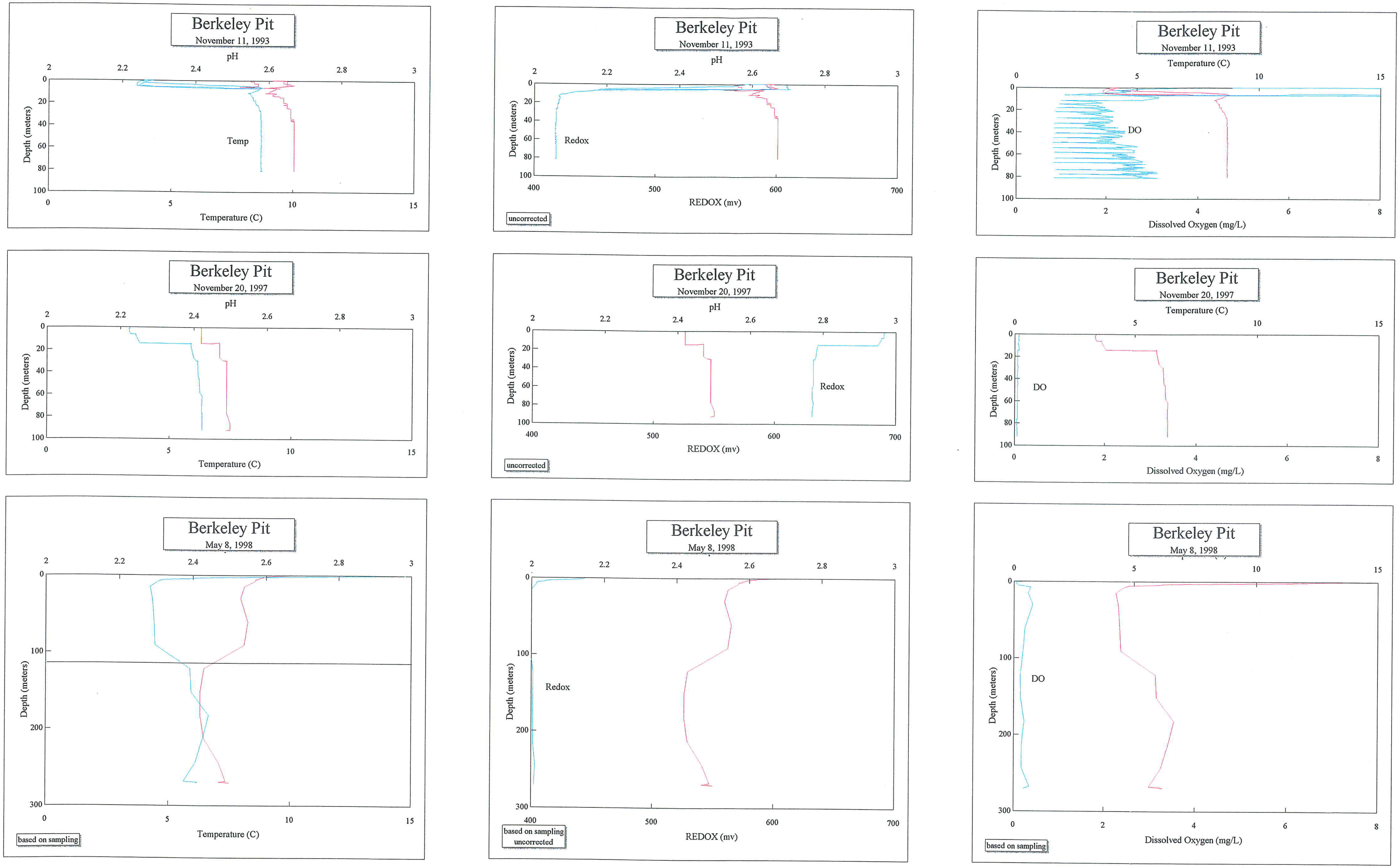

Figure 24a. Field parameters of the Berkeley pit vary with both time and depth. The thermocline and chemocline is at consistent depth of about 10 meters (30 feet).

2.3.2 Summary of the Berkeley Pit

As noted, the chemistry of the Berkeley pit has been greatly influenced by the waters entering the pit. The quantity and quality of ground water and surface water has changed significantly over the period of record:

1) ground water entering from the undergound workings has become less acidic and dissolved concentrations of metals have decreased by several orders of magnitude. Similarly, the inflow of ground water from the mines has declined and will continue to decline as the mines flood.

2) changes in the management of surface waters in the active mine area have eliminated all surface water sources. Water from Horseshoe Bend has been diverted and tailings slurry is no longer allowed to flow into the pit when pipelines break.

As new influences are exerted on the pit, there is a period of re-equilibration required to measure the effects. However, it appears the changes occur more rapidly than re-equilibration. On September 29, 1998, a large-scale slump occurred on the southeast rim of the pit. An estimated 1.5 million cubic yards of material entered the pit. The short-term response was a 3-foot rise in water level within the pit, a water-level drop in the alluvial aquifer near the pit, and a nearly complete mixing of the water within the pit. In 1999 operation of the leach pads was discontinued. At present, Berkeley pit water is circulated through the precipitation plant for copper recover and returned. This removes much of the copper in solution and replaces it with oxidized iron. The effect of such a project on the water quality in pit will take several years to evaluate.

Section 3.0 West Camp

The West Camp includes the area in the lower westside of Butte and includes the Travona, Emma, Star West, and Ophir mines (figure 3). These mines were connected to East Camp by workings until watertight bulkheads were installed in the 1950's to reduce water flow and, subsequently, pumping in the East Camp. Flooding problems occurred in 1965 when the rising water level in the area of the Travona mine reached the basement of homes. "Relief Well 21" (AMC-21) was drilled into the workings of the Travona - the well discharged several hundred gallons per minute for several months until water levels in the area declined and then stabilized. Within two years of the start of flooding in the East Camp in 1982, the water levels in the Travona began to rise again. Water levels in the West Camp have been controlled by pumping since 1989.

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 is under the auspices of the Priority Soils Operable Unit. Since there exists 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

The West Camp is coincident with the peripheral zone described by Sales (1914). The Travona, Emma, and Ophir mines produced silver in their earlier history and later, provided a rich source of manganese. Sulfide ores and pyrite, are generally in much lower percentages than the East Camp (central and intermediate zones).

As with the East Camp, the aquifer is composed of moderately to highly altered quartz monzonite. The alteration, however is of lower grade and dominated by the colder, drier pre-main stage intrusion events. Ground-water flow is controlled by joints and fractures similar to those of the East Camp, but the western extent of the aquifer is bounded by an unmineralized rhyolite intrusive.

Hydraulic conductivity of the quartz monzonite ranges from about 1 foot per day at depth in the unmined aquifer to about 5 feet per day near the workings and near the surface. Water-level data from several of the shafts and from monitoring wells indicate that ground water flows from the aquifer toward the underground workings. Bulkheads separate the West Camp from the East Camp, but given the water-level response in the Travona mine when flooding began in the East Camp, there is certainly a hydraulic connection.

Prior to the Mine Flooding Remedial Investigation and the record of decision in 1994, monitoring of the West Camp bedrock aquifer was limited to the Travona shaft and well AMC-21 which, as noted, was drilled into the workings of the Travona mine. Water level changes and water chemistry of the well have been similar to those of the shaft. Additional water-level and water-quality data were collected from the Emma shaft (beginning in 1988) and Ophir shaft (beginning in 1994).

In 1996, 5 additional bedrock wells (BMF1S, 1D and BMF2 ,3 and 4) were installed at the base of the Butte hill, in both the East and West Camps to monitor water levels. The chemistry of the waters in these wells is typical of bedrock ground water unaffected by mine waste. Iron and manganese are slightly elevated compared to alluvial ground water, but well below SMCLs. In addition to the monitoring wells, the Emma mine and Ophir mine shafts were added to the long term monitoring program.

3.1.1 Underground Workings

Water levels and water quality of the West Camp workings has been monitored at the Travona shaft since flooding of the East Camp began and at the Emma shaft since 1988. Water elevations in these two mines are nearly identical and water-level response to pumping suggests a very good hydraulic connection. As with the well-connected mines of the East Camp, however, the chemistry differs slightly between the two.

3.1.1.2 Water-Quality Trends

In general, the water quality of the West Camp workings has been of much better quality than that of the East Camp. The pH is near neutral, metals concentrations are near detection limits - well below MCLs and SMCLs. The notable exceptions are the arsenic concentration which has varied from about 60 to nearly 200 µg/L and the sulfate concentration which has ranged from 350 to as high as 700 mg/L in the Travona mine (figure 25). Both arsenic and sulfate have increased in concentration over the period of record for a net gain of about 60 µg/L and 350 mg/L, respectively; the trend since 1990, however, has been relatively flat. The concentrations of other dissolved constituents such as calcium and manganese have increased as well and correspond with the increasing pH. Until 1998, water was pumped from the shaft of the Travona mine; since in 1998, water has been pumped from a well (BMF96-1D) completed in the workings of the mine near AMC-21. Subsequently, samples collected since 1998 are of the discharge from the well rather than the shaft and are not included in figure 25.

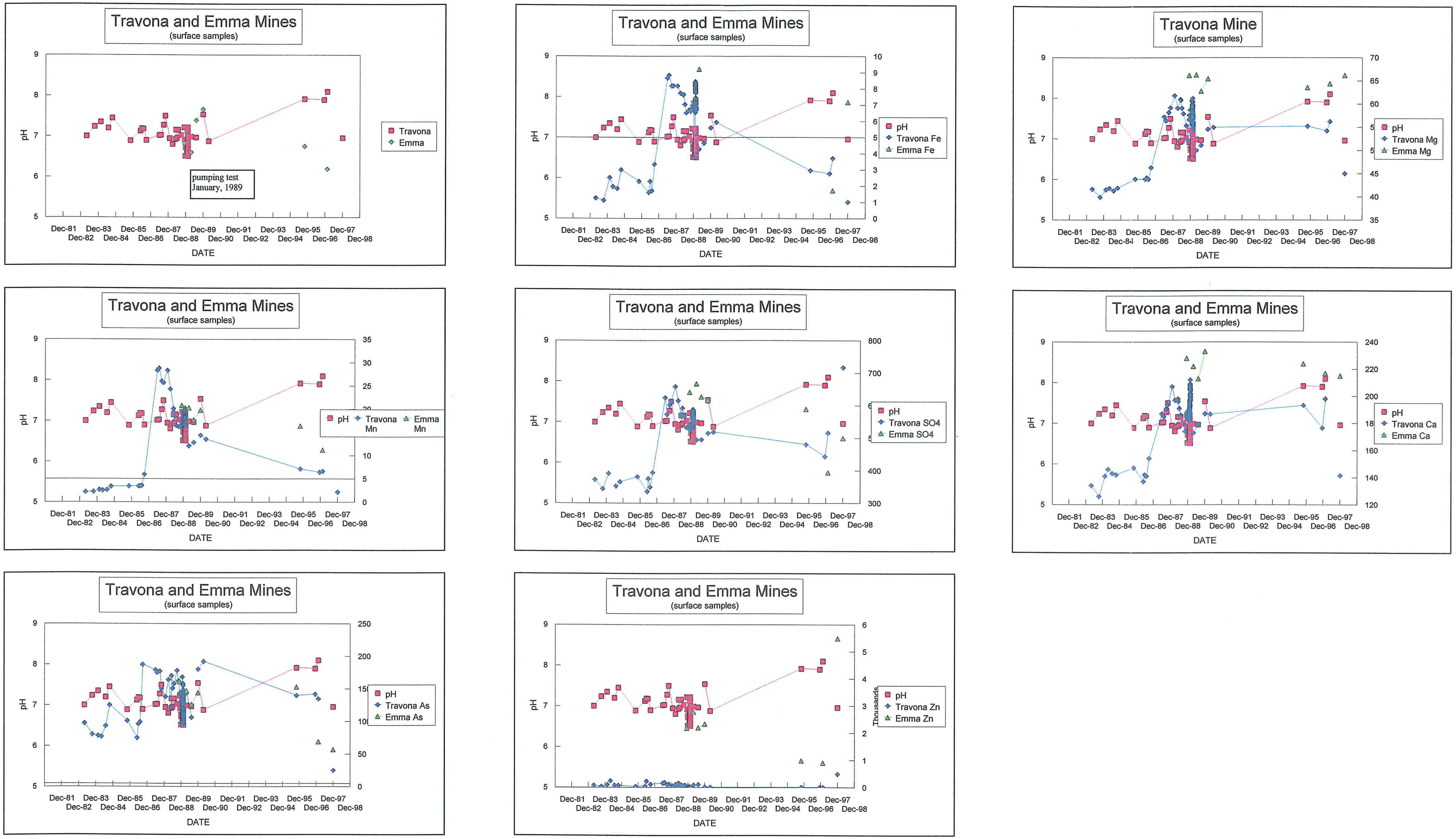

Figure 25. The principle monitoring points in the West Camp are the Travona and Emma mines. The chemistry of the West Camp is much different than that of the East Camp.

3.2.2 Summary of the West Camp Bedrock Aquifer

The period of record for the bedrock wells completed outside the workings is short. The 2 years of sampling of these wells has shown no significant trend in water quality. Water levels in the West Camp mine workings are presently controlled by continuous pumping of water from the Travona mine via well BMF96-1D. This water is discharged to the local water treatment plant before discharging to Silver Bow Creek. Although dissolved metals concentrations are low and indicate no significant trends, the concentration of arsenic and sulfate have increased over the period of record, but have remained relatively steady since 1990,

Section 4.0 Outer Camp

The Outer Camp refers to those mines that, at the time of closure, were separated from the main group of mines on the Butte Hill. These mines include the Marget Ann mine north of Walkerville which was never connected by workings and the Orphan Boy mine west of Montana Tech which was 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 consists of 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 a 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

The Outer Camp is coincident with the peripheral zone described by Sales (1914). The Orphan Boy, Orphan Girl, and Marget Ann mines are the largest of many small mines that explored pre-main stage veins for silver. Sulfide ores and pyrite, are limited to small veins, but where economic densities of veins occur, pyrite can run several percent by weight.

The aquifer is composed of moderately to highly altered quartz monzonite. The most intense alteration, however extends only a limited distance from the veins. Ground-water flow is controlled by joints and fractures similar to those of the East and West Camps; an unmineralized rhyolite intrusive separates the Orphan Boy from the rest of the mines to the east. Hydraulic conductivity of the quartz monzonite ranges from about 1 foot per day at depth in the unmined aquifer to about 5 feet per day near the workings and near the surface. Ground-water flow is likely nearly that of pre-mining conditions. Water levels are well above those of the flooding East Camp and fluctuate throughout the year.

4.2.1 Underground Workings

The Orphan Boy mine extends to a depth of about 1500 feet and is connected by workings on several levels with the Orphan Girl mine to the south and with the Anselmo mine in the East Camp. As with the West Camp mines, the Orphan Boy and Orphan Girl mines were bulkheaded from the East Camp in the 1950's. The Marget Ann mine, in North Walkerville, was mined in the 1940's and 1950's and extends to a depth of 550 feet. Other mines in the area include the Jessie S, Eagle, Glenngary, and Florida mines, but there is no known interconnection of the workings.

4.2.1.1 Water-Quality Trends

Waters in both shafts are reduced; degassing of hydrogen sulfide from pumped or bailed samples is common as is a black to green tint to the water. The pH of the waters is near neutral with only a negligible net change over the period of record. With the exception of iron, which increased from about 0.5 to over 100 mg/L, the concentrations of dissolved constituents in the Orphan Boy mine have remained nearly constant or decreased slightly (figures 26 and 26a). Samples collected in the first few years of monitoring indicated a wide range of arsenic concentrations that sometimes exceeded the MCL; the latter period of record shows concentrations are consistently below the MCL. As of 1999, only sulfate exceeded drinking water limits.

Arsenic concentrations in the Marget Ann mine water consistently exceed the 50 µg/L limit for arsenic in drinking water. The concentration of other dissolved constituents are generally below MCLs and SMCLs although concentrations have varied throughout the period of record (figures 26 and 26a). The concentration of zinc has declined, but the net change of most concentrations is near zero.

4.1.2 Monitoring wells

Several exploration holes were drilled in the Outer Camp in the mid-1980's; in addition to the Marget Ann mine area, the Tzarina mine west of the Travona mine and south of the Orphan Bow mine were the primary targets. Several of these angle drill holes were used for water-level monitoring, but none were sampled for water quality. An older drill hole near the Marget Ann mine, designated as S-4 has been used for water-level and water- quality monitoring since 1989. The quality of water in this well is generally good; metals are near detection limits, but sulfate exceeded the SMCL in the last sample collected. The concentrations of most dissolved constituents have decreased over the period of record; notable exceptions are iron, arsenic, and sulfate concentrations.

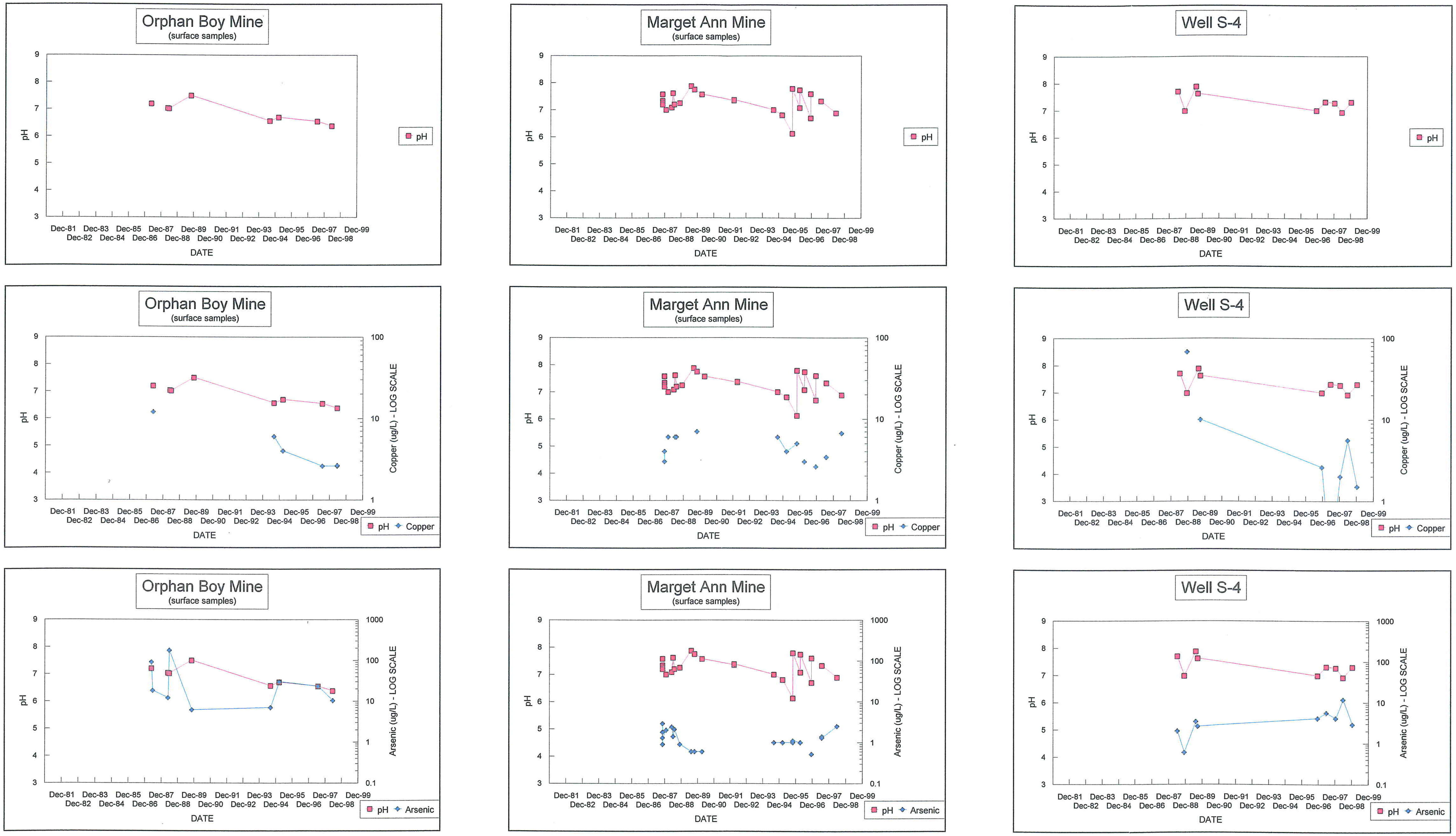

Figure 26. Monitoring sites in the Outer Camp include the Orphan Boy mine west of Butte and Marget Ann mine / Well S-4 in north Walkerville.

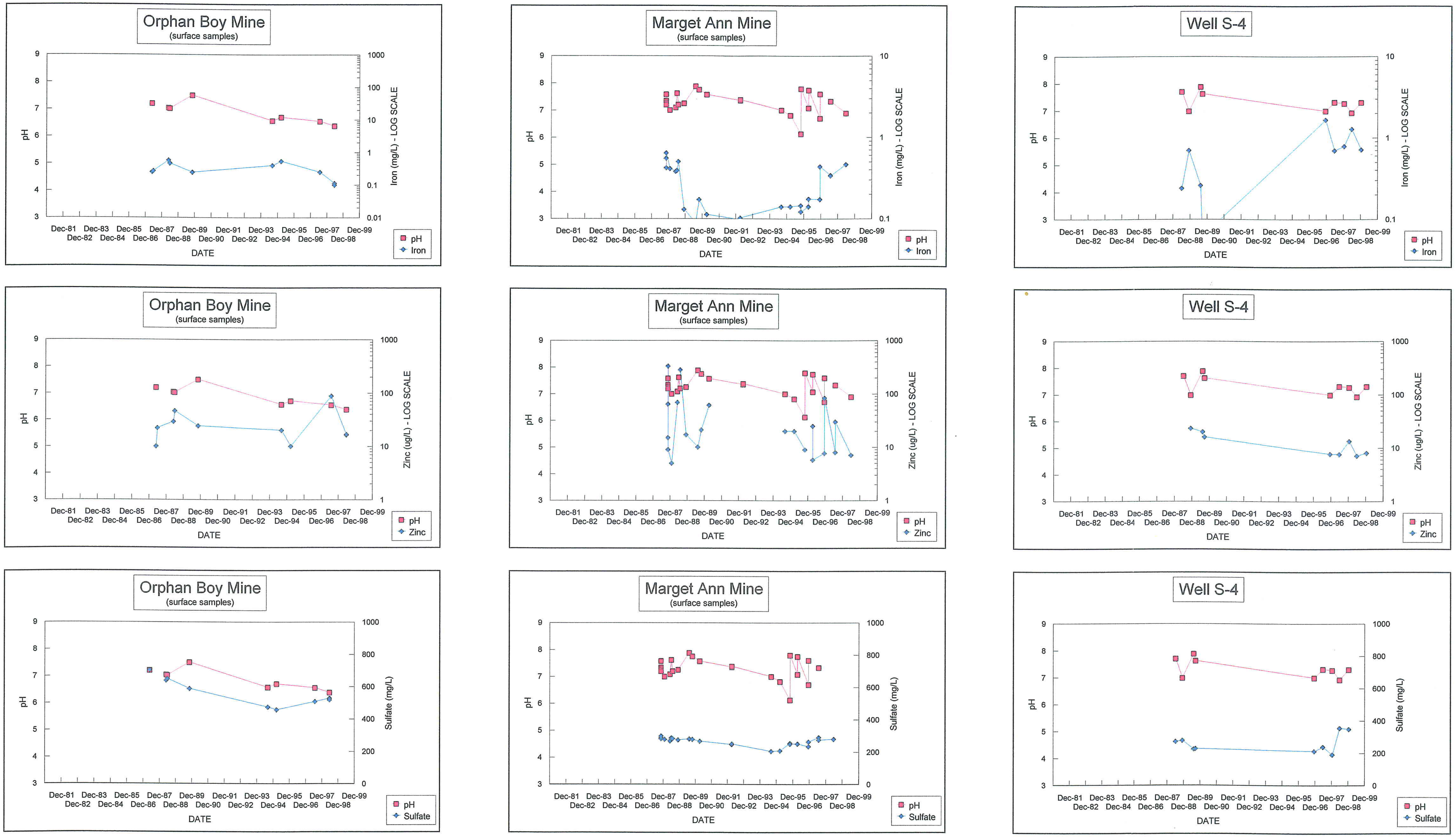

Figure 26a. Concentrations of dissolved constituents are gererally stable in the Outer Camp. Sulfate exceeds SMCL at all three sites.

Section 5.0 Summary

After 18 years of flooding, the Butte mines are far from equilibrium with respect to water levels and water chemistry. The water in the underground workings of the East Camp has evolved from an oxidizing, strongly acidic, metal-laden solution to one that is reduced, near neutral, and relatively low in dissolved metals. Although the precise data are is not available, it is likely that the chemistry of the bedrock ground water prior to mining was of good quality. If flooding to historic levels were possible, pre-mining water quality might be re-established. Because flooding will be limited to several hundred feet below historic levels, a significant portion of the ore body will be exposed. As such, without detailed geochemical modeling, the final chemistry of the underground mine waters is not readily determinate.

The chemistry of water in the Berkeley pit remains a complex interaction of in-pit processes and influent ground water and surface water. As the quantity of water from the leach pads declines after operations cease and the re-circulation of pit water through the copper-cementation process continues, the change in pit-water chemistry will likely be significant.

The alluvial aquifer associated with the East Camp is also subject to dramatic changes. As water levels in the bedrock aquifer, the underground workings, and the Berkeley Pit rise, there may be a response in the overlying alluvium. A change in water levels in the alluvial aquifer east and southeast of the pit will certainly change the position of the ground water divide. There may also be a significant change in water chemistry as a result of the change in water levels and ground-water flow directions.

The water levels in the West Camp are currently controlled by pumping. However, it has been necessary to increase the rate of pumping as the system responds to the rising levels of the East Camp. The chemistry of the water in the West Camp has been relatively stable through most of the period of record; however, the results of recent sampling suggest a significant change in the future.

The Outer Camp probably represents future water-quality conditions for the East Camp. These mines have been flooded for some 45 years and, with a few exceptions, concentrations are stable. The period of record is too short, however, to evaluate climatic changes. The annual precipitation for water years 1995 through 1998 was nearly double the long-term average. Ground-water levels in the Butte area outside the influence of mine flooding have risen. The same is true for the Orphan Boy and Marget Ann mines. Any resulting change in water chemistry has yet to be manifested.

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