Butte Mine Flooding Operable Unit

Water-Level Monitoring and Water-Quality Sampling
2018 Consent Decree Update
Butte, Montana
1982–2018

prepared for

The Montana Department of Environmental Quality, Remediation Division
and
U.S. Environmental Protection Agency, Region VIII

Photo courtesy of Montana Resources

July 2020

prepared by

Terence E. Duaime, Steven F. McGrath, Gary A. Icopini, and Paul R. Thale
Montana Bureau of Mines and Geology
1300 West Park Street
Butte, MT 59701-8997

Contract No. 415008-TO-2

Montana Bureau of Mines and Geology Open-File Report 731

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Executive Summary

The Record of Decision and Consent Decree for the Butte Mine Flooding Operable Unit stipulates that a yearly update of data collected from the Post Remedial Investigation/Feasibility Study and Consent Decree monitoring program be prepared. This report presents data collected during 2018, integrated with data collected since 1982, when the Anaconda Company suspended underground mine dewatering and mining in the Berkeley Pit.

Major 2018 observations and developments include:

1. Water-quality sampling and vertical profiling of the Berkeley Pit continued using the automated–autonomous (drone) sample boat. Two sampling/monitoring events were conducted;
2. Changes in Berkeley Pit water quality and physical parameters observed during 2017 continued in 2018 samples and vertical profiles. Iron and arsenic concentrations remain lower by an order of magnitude or more from those measured in 2011 and 2012, while the pH of the pit water column increased by about two-tenths of a unit from fall 2017 to fall 2018;
3. Four monitoring wells in the East Camp area were plugged and abandoned in 2018. Two alluvial wells (GS-41-S and GS-41D) were abandoned as part of the State of Montana restoration efforts at the Parrot Tailings; bedrock wells (DDH-2 and DDH-8) were abandoned as part of active mine operations;
4. Water-level monitoring at the Granite Mountain Mine was suspended mid-2016 and has not resumed, due to an obstruction in the shaft and surface safety issues;
5. Scheduled maintenance activities at the concentrator and Horseshoe Bend water-treatment plant, and short-term power disruptions, resulted in approximately 11.6 million gallons discharged from Horseshoe Bend directly to the Berkeley Pit in 2018;
6. External review of the Berkeley Pit filling rate model identified an error in the evaporation tables used to project future dates for pumping and treatment options. The correction extended by 508 days the projected date for reaching the 5,410-ft water-level elevation at the Pilot Butte Mine, to November 24, 2024. The model accounts for the continued diversion of Horseshoe Bend drainage water away from the pit, discharge of sludge from the treatment plant into the pit, and the diversion of stormwater flow from the Butte Hill into the pit;
7. Semi-annual water-quality samples collected from the replacement well (LP-17R) installed in fall 2013 show concentrations increasing for many metals; and

8. Montana Resources continued to divert 1,200 to 2,500 gallons per minute (gpm) from the Horseshoe Bend drainage to leach pad operations.

This document presents cumulative and annual water-level changes for all sites along with hydrographs for selected sites. Where water-quality data are available, they follow the presentation of water-level data.

Monitoring and sampling activities during 2018 follow the long-term program outlined in the 2002 Consent Decree, with some modifications. Therefore, some monitoring sites that were part of the early monitoring program are no longer in use, and others have been added.

EPA has replaced the term “critical water level” with “protective water level” to more accurately reflect the relationship of the 5,410 bedrock water-level elevation to adjacent alluvial aquifer water levels in the East Camp System and the relationship of the 5,435 bedrock water-level elevation to adjacent alluvial aquifer water levels in the West Camp System. This change is implemented throughout this document for consistency.

List of Acronyms Used in Text

ACM	Anaconda Copper Mining Company
AMC	Anaconda Mining Company
ARCO	Atlantic Richfield Company
BABCGWA	Butte Alluvial and Bedrock Controlled Groundwater Area
BMFOU	Butte Mine Flooding Operable Unit
BPSOU	Butte Priority Soils Operable Unit
BSB	Butte–Silver Bow
COC	Contaminants of Concern
CD	Consent Decree
CWL	Critical Water Level
DEQ	Montana Department of Environmental Quality
DNRC	Montana Department of Natural Resources and Conservation
DO	Dissolved Oxygen
EPA	U.S. Environmental Protection Agency
fbs	Feet below Ground Surface
gpm	Gallons per Minute
GWIC	MBMG Ground Water Information Center
HSB	Horseshoe Bend Drainage
HSB Falls	Horseshoe Bend Falls
MBMG	Montana Bureau of Mines and Geology
MCL	Maximum Contaminant Level
MGD	Million Gallons per Day
MPTP	Montana Pole and Treatment Plant NPL Site
MR	Montana Resources
MSD	Metro Storm Drain
MSL	Mean Sea Level
NAVD29	North American Vertical Datum of 1929
NAVD88	North American Vertical Datum of 1988
ORP	Oxidation Reduction Potential
POC	Points of Compliance

PWL	Protective Water Level
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SBC	Silver Bow Creek
SC	Specific Conductance at 25°C
SMCL	Secondary Maximum Contaminant Level
SWL	Static Water Level
WCPW	West Camp Pumping Well

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1982–2018

SECTION 1.0 SITE BACKGROUND

Butte has a long history of mining, dating back to 1864 with the development of gold placers in Missoula and Dublin gulches and along Silver Bow Creek (SBC; Miller, 1978). Placer mining was short-lived and quickly followed in 1866 by the development of silver mining (Miller, 1978). The major silver deposits were developed by the early 1870s and included mines such as the Alice, Travona, Lexington, and Colusa. However, with the repeal of the Sherman Silver Purchase Act in 1893, and the presence of high-grade copper veins, Butte mining shifted its focus to the development of copper deposits.

Mining expanded and mines deepened as companies followed the rich copper veins. With the expanded mining, improved methods to handle groundwater became necessary; therefore, the companies interconnected mines to drain water to central pump stations to improve efficiency (Daly and Berrien, 1923). The Anaconda Copper Mining Company (ACM), which would eventually control a majority of the underground mines, began interconnecting selected mine levels for draining water to a central pump station as early as 1901. The High Ore and Kelley mines served as the primary central pump stations collecting groundwater and pumping it to the surface (figs. 1-1, 1-2). This acidic and highly mineralized water necessitated specialized pumps and piping. The pumps in the High Ore Mine were made of a phosphor–bronze alloy, whereas the discharge pipes (water column) were made of cast iron lined with either lead or wood (Febles, 1914). The first common drain level was the 2,800 level, followed by the 3,800 level (fig. 1-3). The High Ore Mine served as the main central pump station from 1901 until 1967, when the pump station was moved to the Kelley Mine. Once the water reached the surface, it was routed to a precipitation plant for copper recovery (figs. 1-4, 1-5). After the copper was removed, the water was discharged to SBC. The practice of discharging untreated, acidic, metal-laden water to SBC continued until the late 1950s, at which time the Anaconda Company began adding lime to the water to raise the pH and reduce the mineral content of the water (Spindler, 1977).

Mines located in the areas described by Sales (1914) as the Intermediate and Peripheral Zones were shut down and eventually sealed off from the then-operating mines. These areas were isolated to reduce the amount of water pumped from the underground workings and to lessen the required amount of fresh air brought into the mines for worker safety.

The recovery of copper precipitate from underground mine water had been a common practice on the Butte Hill since the 1890s (Febles, 1914). Leaching of copper from old mill tailings and upper portions of underground mine workings occurred on the Butte Hill to various degrees. Some of the leaching was a by-product of water introduced into the underground workings to fight mine fires. The water percolating through the underlying workings was found to contain substantial quantities of copper and was pumped to precipitation plants for processing (Gillie, 1943). At various times precipitation plants were associated with the High Ore, Leonard, and Silver Bow mines for copper recovery. Febles (1913) reported that about 1,200 gallons per minute (gpm) of water was delivered to the High Ore precipitation plant; he also stated that the plant produced approximately 2,200,000 pounds of pure copper annually from this water.

The cost of mining increased as the mines deepened and the ore grades lessened. In July 1955, the Anaconda Company began open-pit mining operations in the Berkeley Pit. As open-pit mining expanded, it consumed some of the underground mines important to Butte's early development (fig. 1-6). Figures 1-7 and 1-8 compare Butte's land-surface topography between 1904 and 2012. The impacts of open-pit mining and associated waste facilities are obvious north and northeast of the Berkeley Pit (fig. 1-8).

Figure 1-1. High Ore Mine pump station, 2800-ft level. (Photo courtesy World Museum of Mining, Butte, MT.)

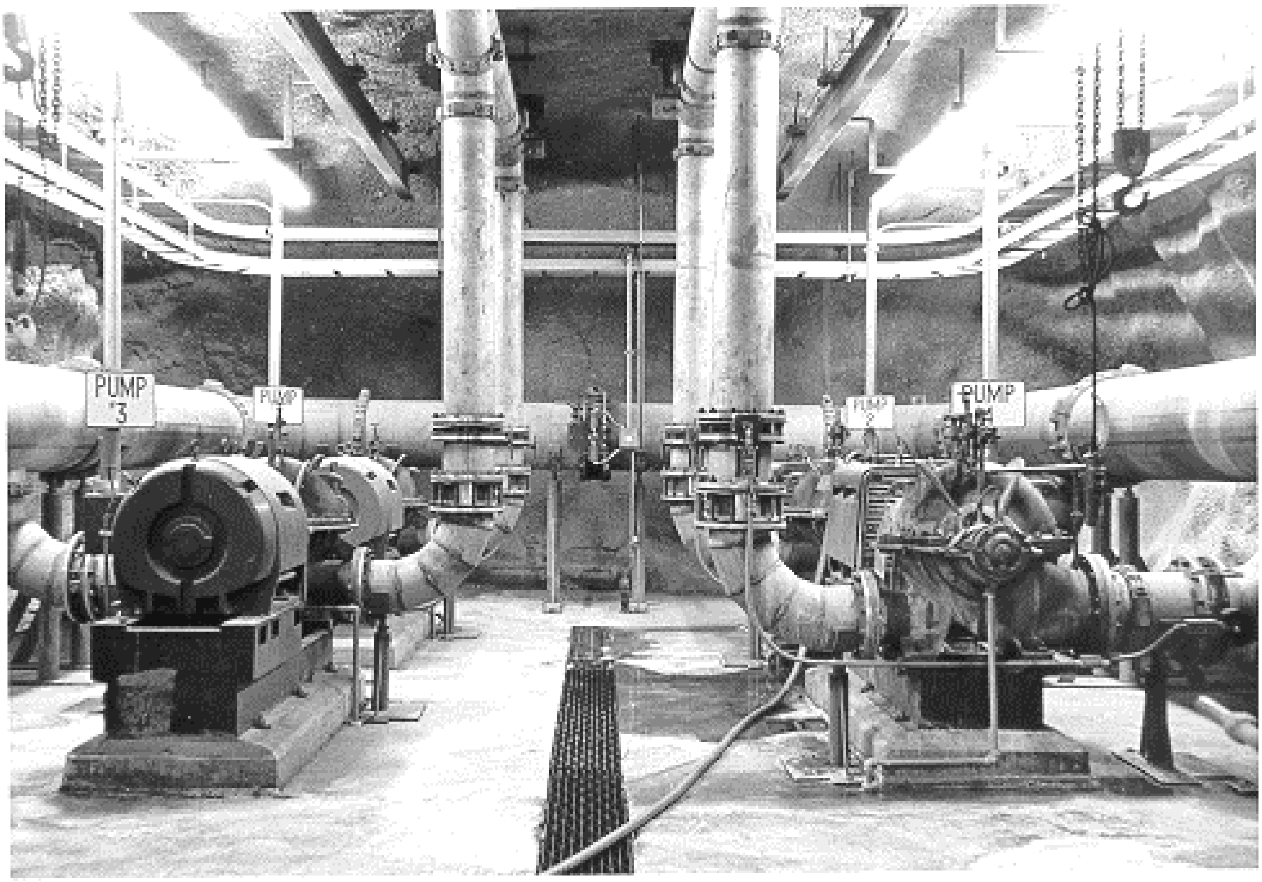


Figure 1-2. Kelley Mine pump station, 3900-ft level. (Photo courtesy World Museum of Mining, Butte, MT.)

Figure 1-3. Underground mine drainage from Belmont Mine to High Ore Mine. (Photo courtesy World Museum of Mining, Butte, MT.)

Figure 1-4. Flume conveying water pumped from Butte underground mines to precipitation plant. (Photo courtesy World Museum of Mining, Butte, MT.)

Figure 1-5. Precipitation plant scrap iron in contact with underground mine discharge water. (Photo courtesy World Museum of Mining, Butte, MT.)

Figure 1-6. Location of selected underground mines engulfed by development and expansion of the Berkeley Pit.

Figure 1-7 Digital elevation model showing Butte topography, 1904.

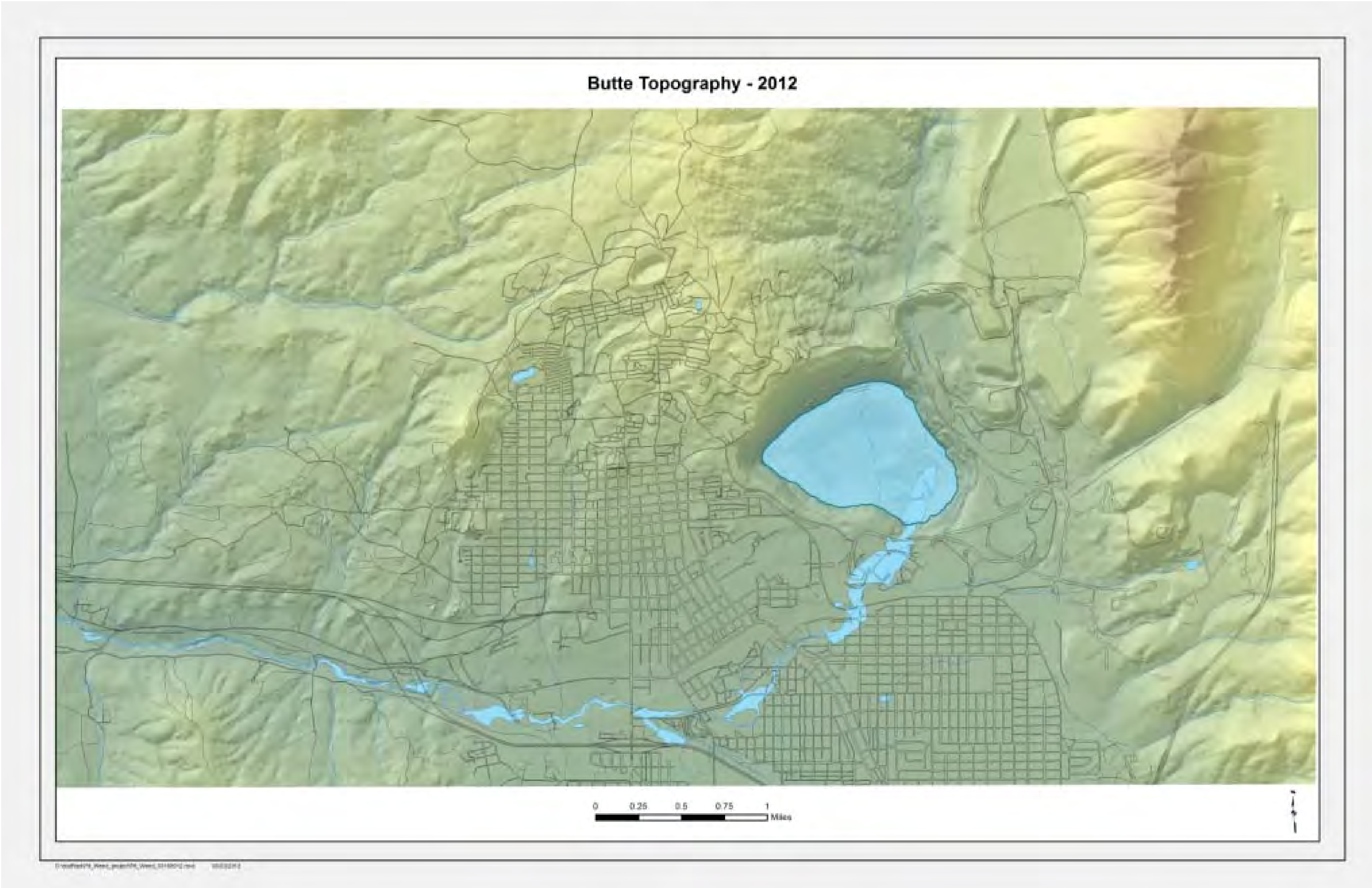


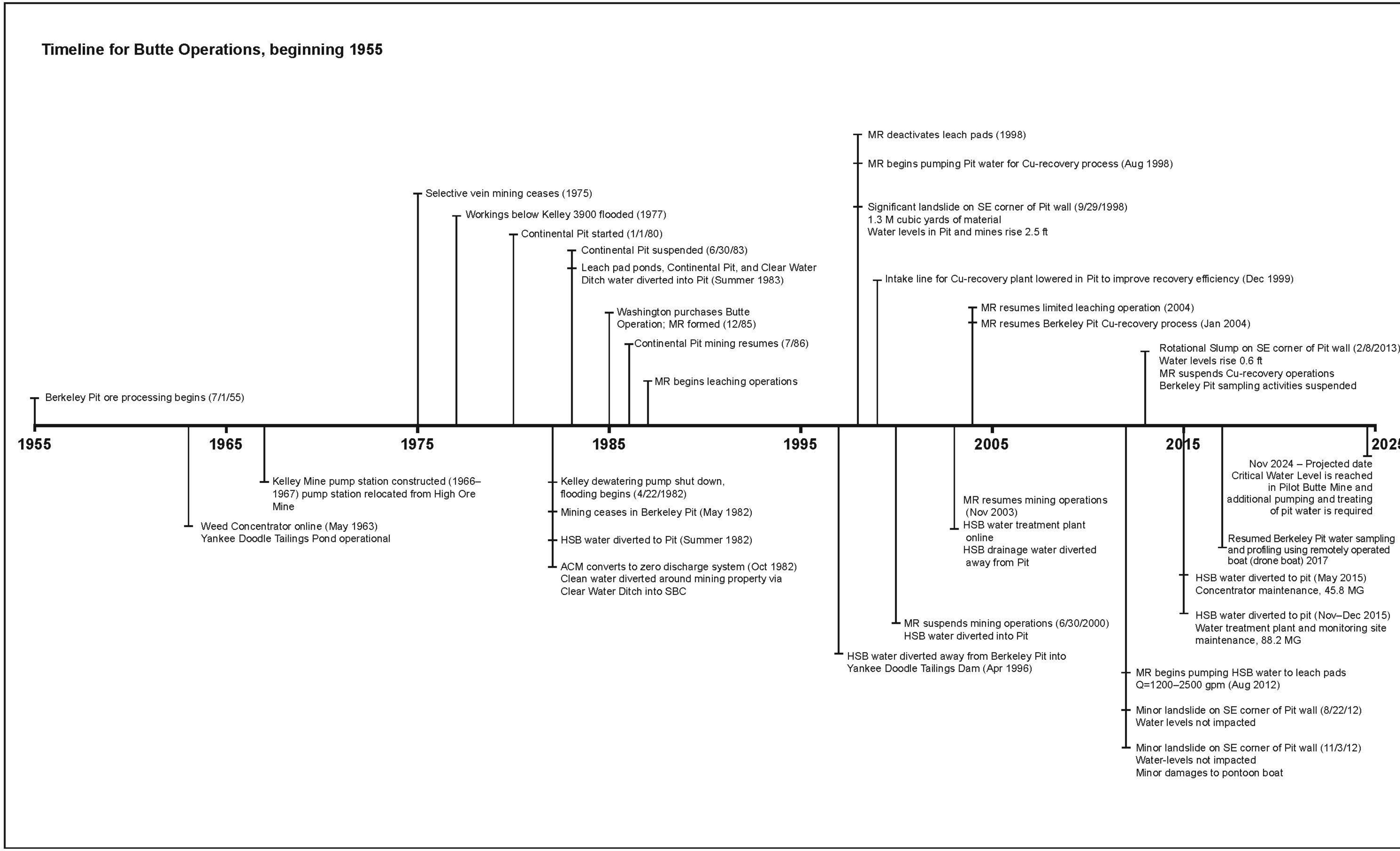
Figure 1-8. Digital elevation model showing Butte topography, 2012.

Active underground mining continued in the Kelley and Steward Mines until 1975 (Burns, 1994); in 1977, the lowermost mine workings were allowed to flood up to just below the 3,900-level pump station. The Anaconda Company continued to operate the underground pumping system, which not only kept the upper mine workings dewatered but also did the same for the Berkeley Pit, until April 23, 1982 when the pumps were shut off.

Open-pit mining expanded to the east with the development of the East Berkeley Pit in 1980 (Burns, 1994). This open-pit mine was developed to remove both copper and molybdenum reserves. The original Berkeley Pit operated until June 1982, while the East Berkeley Pit continued to operate until June 30, 1983, when the Anaconda Company closed all of its Butte mine operations.

In December 1985, the Anaconda Company, which had been purchased by the Atlantic Richfield Company (ARCO) in 1977, sold a portion of its Butte operations to Dennis Washington, who then formed Montana Resources (MR; Burns, 1994). MR renamed the East Berkeley Pit the Continental Pit and resumed mining there in July 1986. Table 1.0.1 presents a timeline of selected activities relating to Butte mining operations, beginning with the development of the Berkeley Pit, Weed Concentrator, Continental Pit, and the suspension of underground mining, and ancillary activities from 1995 through 2018.

Table 1.0.1 Timeline for Butte operations, 1955–2018.



Section 1.1 Introduction

On April 23, 1982, the Anaconda Company announced the suspension of pumping operations at the 3,900-level Kelley Mine pump station, approximately 3,600 ft below ground surface. At the same time, the Anaconda Company announced that it would suspend mining in the Berkeley Pit, beginning May 1982. However, they continued to operate the East Berkeley Pit (currently known as the Continental Pit) until June 30, 1983, when the company suspended all mining operations in Butte.

The Anaconda Company developed and implemented a groundwater-monitoring program following the 1982 suspension of mining. This program included mine shafts, alluvial dewatering wells, and existing domestic and irrigation wells, along with newly installed alluvial monitoring wells. Initial monitoring included water-level measurements and water-quality sampling. This monitoring program continued until changes were made as part of the Butte Mine Flooding Operable Unit (BMFOU) Superfund investigation.

The U.S. Environmental Protection Agency (EPA) and the Montana Department of Environmental Quality (DEQ) approved and oversaw the BMFOU Remedial Investigation/Feasibility Study (RI/FS) between fall 1990 and spring 1994. Major RI/FS tasks included installation of new bedrock and alluvial monitoring wells. Access was also gained into several previously capped underground mines for monitoring purposes. The 1994 EPA Record of Decision (ROD) defined a monitoring program that included portions of the 1982 Anaconda Company monitoring network, portions of the RI/FS monitoring network, and portions of a supplemental surface-water and groundwater network that had been operated by the MBMG since the summer of 1983.

The ROD included provisions for: (1) continued monitoring and sampling of groundwater and surface water, (2) diversion of the Horseshoe Bend Drainage (HSB) water away from the Berkeley Pit (to slow the pit-water filling rate), (3) incorporation of the HSB water in the MR mining operations for treatment, (4) construction of a water-treatment plant if changes in mining operations prevent treatment of HSB water (e.g., mine shutdown), and (5) establishment of a maximum water level to which water in the underground mines and Berkeley Pit could rise before a pumpage/treatment plant must be built and in operation.

The ROD monitoring program consisted of 73 monitoring wells, 12 mine shafts, and 3 surface-water-monitoring sites, grouped as follows:

(1) East Camp bedrock wells—18;

(2) East Camp mines—7;

(3) East Camp alluvial wells within active mine area—19;

(4) East Camp alluvial wells outside active mine area—31;

(5) West Camp mines—3;

(6) West Camp monitoring wells—5; and

(7) Outer Camp mines—2.

The final monitoring network described in the 2002 EPA Consent Decree (CD) replaced the ROD monitoring network; minor changes have been made to the 2002 CD Program and are shown in table 1.1.1. The current (2018) monitoring program consists of 80 sites, and includes: 61 monitoring wells, 11 mine shafts, and 8 surface-water sites. The Consent Decree monitoring network is grouped into the following categories:

(1) East Camp bedrock wells—12;

(2) East Camp mines—6;

(3) East Camp alluvial wells within active mine area—20;

(4) East Camp alluvial wells outside active mine area—17;

(5) Bedrock wells outside active mine area—4;

(6) West Camp mines—3;

(7) West Camp wells—6;

(8) Outer Camp mines—2;

(9) Outer Camp wells—2; and

(10) Surface-water sites—8 [Berkeley Pit, Continental Pit (when mining is suspended), Horseshoe Bend (2 locations), Clear Water Ditch (near the Montana Resources guard shack), Blacktail Creek, Silver Bow Creek, and Outer Camp seep].

Table 1.1.1. Current approved monitoring program (comparison to 2002 CD program).

Butte Mine Flooding Monitoring Sites		Water Level 2002 Consent Decree Monitoring Frequency	Current Program (2018) Water Level Frequency	Water Quality 2002 Consent Decree Monitoring Frequency	Current Program (2018) Water Quality Frequency
East Camp Mines[1]	Anselmo	M	**C/M**	Annual	**Annual**
	Belmont Well #2	1/4ly	**C/M**	NS	**NS**
	Granite Mountain [5]	1/4ly	**C/M**	NS	**NS**
	Kelley	M	**C/M**	Annual	**Annual**
	Lexington	1/4ly	**C/M**	NS	**NS**
	Pilot Butte	1/4ly	**C/M**	NS	**NS**
	Steward	M	**C/M**	Annual	**Annual**
	Berkeley Pit	M	**M**	Twice/3Depths	**Twice/3Depths**
	HSB[2]	C/M	**C/M**	M	**M**
	Continental Pit[2]	M	**Inactive**	Twice/yr.	**Inactive**
RI/FS Wells - Bedrock	A	C/M	**C/M**	Semi-A	**Semi-A**
	B	M	**C/M**	Semi-A	**Semi-A**
	C	C/M	**C/M**	Semi-A	**Semi-A**
	D-1	1/4ly	**M**	Annual	**NS**
	D-2	1/4ly	**C/M**	Annual	**Semi-A**
	E	Annual	**M**	2 yr	**2 yr**
	F	Annual	**C/M**	2 yr	**2 yr**
	G	C/M	**C/M**	Annual	**Annual**
	J	1/4ly	**C/M**	Annual	**Annual**
DDH Wells	DDH-1	1/4ly	**P&A**	NS	**NS**
	DDH-2	1/4ly	**M**	NS	**NS**
	DDH-8	1/4ly	**M**	NS	**NS**
LP Wells	LP-01	1/4ly	**M**	NS	**NS**
	LP-02	1/4ly	**C/M**	NS	**NS**
	LP-03	1/4ly	**P&A**	NS	**NS**
	LP-04	1/4ly	**M**	NS	**NS**
	LP-05	1/4ly	**M**	NS	**NS**
	LP-06	1/4ly	**P&A**	NS	**NS**
	LP-07	1/4ly	**M**	NS	**NS**
	LP-08	M	**M**	Annual	**Annual**
	LP-09	1/4ly	**C/M**	Annual	**Annual**
	LP-10	M	**M**	Semi-A	**Semi-A**
	LP-11	P&A	**P&A**	NS/P&A	**NS/P&A**
	LP-12	M	**C/M**	Semi-A	**Semi-A**
	LP-13	M	**C/M**	Semi-A	**Semi-A**
	LP-14	C/M	**C/M**	Semi-A	**Semi-A**
	LP-15	M	**M**	Semi-A	**Semi-A**
	LP-16	M	**C/M**	Semi-A	**Semi-A**

Table 1.1.1. Current approved monitoring program (comparison to 2002 CD program)—*Continued*.

Butte Mine Flooding Monitoring Sites	Water Level 2002 Consent Decree	**Current Program (2018)**	Water Quality 2002 Consent Decree	**Current Program (2018)**	
		Monitoring Frequency	**Water Level Frequency**	Monitoring Frequency	**Water Quality Frequency**
LP Wells (cont.)	LP-17	1/4ly	**P&A**	Annual	**P&A**
	LP-17R	1/4ly	**M**	Annual	**Semi-A**
	MR97-1[(3)]	1/4ly	**M**	NS	**NS**
	MR97-2[(3)]	1/4ly	**C/M**	NS	**NS**
	MR97-3[(3)]	1/4ly	**M**	NS	**NS**
	MR97-4[(3)]	1/4ly	**M**	NS	**NS**
AMC Wells	AMC-5	1/4ly	**M**	Annual	**Annual**
	AMC-6	C/M	**C/M**	Semi-A	**Semi-A**
	AMC-8	C/M	**C/M**	Semi-A	**Semi-A**
	AMC-10	1/4ly	**M/Dry**	Semi-A	**Semi-A/Dry**
	AMC-12	1/4ly	**C/M**	Annual	**Annual**
	AMC-13	1/4ly	**M**	NS	**NS**
	AMC-15	1/4ly	**M**	2 yr	**2 yr**
	AMW-8	1/4ly	**C/M**	NS/Annual	**Annual**
	AMW-20		**C/M**		**Semi-A**
	AMW-22	1/4ly	**M**	NS	**Annual**
GS Wells	GS-41S	C/M	**C/M**	Annual	**Annual**
	GS-41D	C/M	**C/M**	Annual	**Annual**
	GS-44S	C/M	**C/M**	Annual	**Annual**
	GS-44D	C/M	**C/M**	Annual	**Annual**
	GS-46S	C/M	**C/M**	Annual	**Annual**
	GS-46D	C/M	**C/M**	Annual	**Annual**
BMF05 Wells	BMF05-1	M	**C/M**	Semi-A	**Semi-A**
	BMF05-2	M	**C/M**	Semi-A	**Semi-A**
	BMF05-3	M	**C/M**	Semi-A	**Semi-A**
	BMF05-4	M	**C/M**	Semi-A	**Semi-A**
Park Wells	Chester Steele	1/4ly	**M**	Annual	**Annual**
	Hebgen	1/4ly	**M**	NS	**NS**
	Belmont #1	1/4ly	**M**	NS	**NS**
	Parrott	1/4ly	**C/M**	Annual	**Annual**
West Camp Mines	Emma	1/4ly	**M**	Annual	**Annual**
	Ophir	1/4ly	**C/M**	Annual	**Annual**
	Travona	1/4ly	**C/M**	Annual	**Annual**
West Camp Wells	WCPW-1	No	**No**	1/4ly-Pumping	**1/4ly-Pumping**
	BMF96-1D	C/M	**C/M**	NS	**NS**
	BMF96-1S	C/M	**C/M**	NS	**NS**

Table 1.1.1. Current approved monitoring program (comparison to 2002 CD program)—*Continued*.

Butte Mine Flooding Monitoring Sites	Water Level 2002 Consent Decree	**Current Program (2018)**	Water Quality 2002 Consent Decree	**Current Program (2018)**	
		Monitoring Frequency	**Water Level Frequency**	Monitoring Frequency	**Water Quality Frequency**
West Camp Wells (cont.)	BMF96-2	1/4ly	**C/M**	NS	**NS**
	BMF96-3	1/4ly	**C/M**	NS	**NS**
	BMF96-4	C/M	**C/M**	Annual	**Annual**
Outer Camp Mines	Orphan Boy	Replace	**C/M**	Annual	**Semi-A**
	Orphan Girl[4]	M	**Drop**	Annual	**Drop**
Outer Camp Wells	Marget Ann	1/4ly	**C/M**	2 yr	**2 yr**
	S-4	1/4ly	**M**	NS	**NS**
	Tech Well	1/4ly	**C/M**	2 yr	**2 yr**
	Seep	Semi-A	**C/M**	Semi-A	**Semi-A**

Note. Green Highlighted Cells identify increased level of monitoring/sampling from that specified in CD. M, monthly; C/M, continuous and monthly; NS, no sampling; P&A, plugged and abandoned; SA, Semi-A, semi-annual; 1/4ly, quarterly.

(1) The safety of each mine will be reviewed, and if unsafe conditions exist, repairs will be made, or another site will be substituted for the unsafe location.

(2) MBMG monitoring and sampling will occur only when pumping and treatment is not taking place. Otherwise, monitoring and sampling will be part of the water treatment plant operations.

(3) MR97-series wells will be monitored until steady-state conditions occur. A review of continued monitoring will be undertaken at that time.

(4) 2002 CD proposed replacing the Orphan Boy Mine due to access problems with the Orphan Girl Mine. Access was reestablished at the Orphan Boy Mine, therefore, plans for monitoring using the Orphan Girl Mine were dropped.

(5) Safety concerns and obstruction in shaft currently prevent monitoring activities at Granite Mountain Mine.

The 1994 ROD and 2002 CD established separate maximum water levels (referred to as Protective Water Levels (PWL)) for the East Camp and West Camp bedrock systems. In addition, the 2002 CD specified compliance points that groundwater levels could not exceed. In the East Camp bedrock system, the maximum water level cannot exceed an elevation of 5,410 ft (mean sea level, msl, USGS NAVD29 datum) at any of the 14 compliance points, while in the West Camp bedrock system, the maximum water level cannot exceed an elevation of 5,435 ft msl (USGS NAVD29 datum) at well BMF96-1D. The points of compliance (POC) in the East Camp consist of the following mine shafts and bedrock monitoring wells:

(1) Anselmo Mine,

(2) Granite Mountain Mine,

(3) Kelley Mine,

(4) Pilot Butte Mine,

(5) Lexington Mine,

(6) Steward Mine,

(7) Sarsfield Shaft (Continental Pit),

(8) Belmont Well #2,

(9) Bedrock Well A,

(10) Bedrock Well C,

(11) Bedrock Well D-1,

(12) Bedrock Well D-2,

(13) Bedrock Well G, and

(14) Bedrock Well J.

The PWL is based on the lowest elevation in the Butte Basin where SBC exits to the west, at the Butte Priority Soils Operable Unit (BPSOU) boundary. During the entire monitoring period (1983–2018), the highest POC water-level elevation has always been more than 20 ft above the Berkeley Pit water-level elevation. Based upon this record, at the time a POC water level approaches the 5,410 ft above mean sea level (msl) elevation, the water level within the Berkeley Pit would still be below 5,390 ft msl, more than 50 ft below adjacent alluvial water levels and 100 ft below the lowest point on the pit rim. The water level in the Berkeley Pit would have to rise to an elevation of 5,460 ft msl to reverse the groundwater gradient and cause water to flow away from the pit (fig. 1-9).

In addition to the compliance point stipulations, water levels in the East Camp bedrock system must be maintained at lower elevations than West Camp water levels. (Refer to the 2002 CD's *Explanation of Significant Differences* document to see the entire scope of activities addressed in the CD and how they differ from the 1994 ROD.)

The CD addressed all current and future BMFOU activities and reimbursed EPA and DEQ for past BMFOU costs. British Petroleum/Atlantic Richfield Company (BP/ARCO) and the Montana Resources Group agreed in the CD to be responsible for all costs associated with the design, construction, operation, and maintenance of water-treatment facilities to treat HSB, Berkeley Pit, and other contaminated waters. Funding to continue the long-term groundwater, surface-water, and Berkeley Pit/Continental Pit monitoring were included in the CD. The monitoring performed by the MBMG is under the direction of DEQ and EPA.

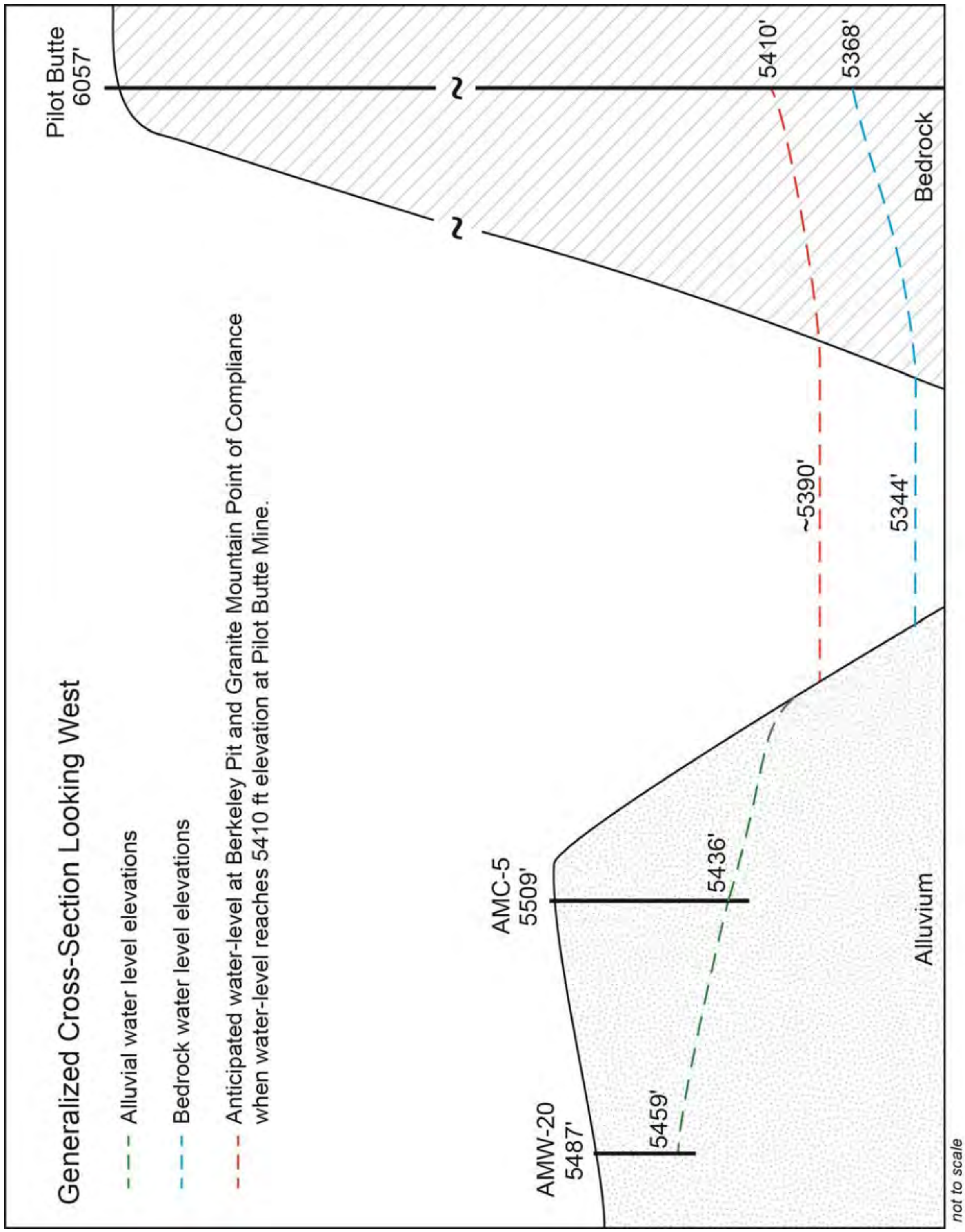


Figure 1-9. Generalized cross section looking west through the Berkeley Pit depicting water-level elevations in bedrock and alluvial systems in December 2018 and projected elevations when the 5,410 Protective Water Elevation is reached at the Pilot Butte Mine (location shown in fig. 1-10).

By the time water levels in the underground mines reached the elevation of the bottom of the Berkeley Pit in late November 1983, more than 66 percent of the underground workings had been flooded. More than 85 percent of the underground mine workings have been inundated with water through 2018. The upper 12 percent of the underground workings are at elevations above the specified PWL; therefore, less than 3 percent of the underground workings remain to be flooded.

This document is the 23rd BMFOU report and summarizes 37 years of data collection. Notable changes and an evaluation of water-level and water-quality trends are presented. This report also presents a general overview of the history of mining on the Butte Hill and the Superfund processes that have followed since the EPA designated the flooding underground Butte Mines and Berkeley Pit a Superfund site in 1987. Readers are referred to the Butte Mine Flooding RI/FS, Butte Mine Flooding ROD, Butte Mine Flooding CD, and MBMG Open-File Report 376 for additional details and information. Duaime and McGrath (2019) provide a comprehensive history of monitoring the Berkeley Pit.

The MBMG continued monitoring activities in 2018 in the East Camp, West Camp, and Outer Camp systems (fig. 1-10). The East Camp System includes mines and mine workings that drained to the Kelley Mine pump station at the time mining and dewatering were suspended in 1982. The West Camp System includes mines and underground workings that historically drained to the East Camp from the southwest portion of the Butte mining district, but were hydraulically isolated from the East Camp by the placement of bulkheads within the mine workings. The Outer Camp System consists of mine workings extended to the west and north that were at one time also connected to the East Camp and were hydraulically isolated with bulkheads many decades ago. The hydraulic separation has allowed Outer Camp System water levels to return to, or approach, pre-mining conditions. The MBMG developed a Sampling and Analysis Plan (MBMG, 2017) based upon the requirements of the 2002 CD that identifies how the monitoring program is carried out (MBMG, August 2002, updated June 2017). Groundwater monitoring and water-quality sampling follow closely the methods described in the Clark Fork River Superfund Site Investigations Standard Operating Procedures (ARCO, 1992).

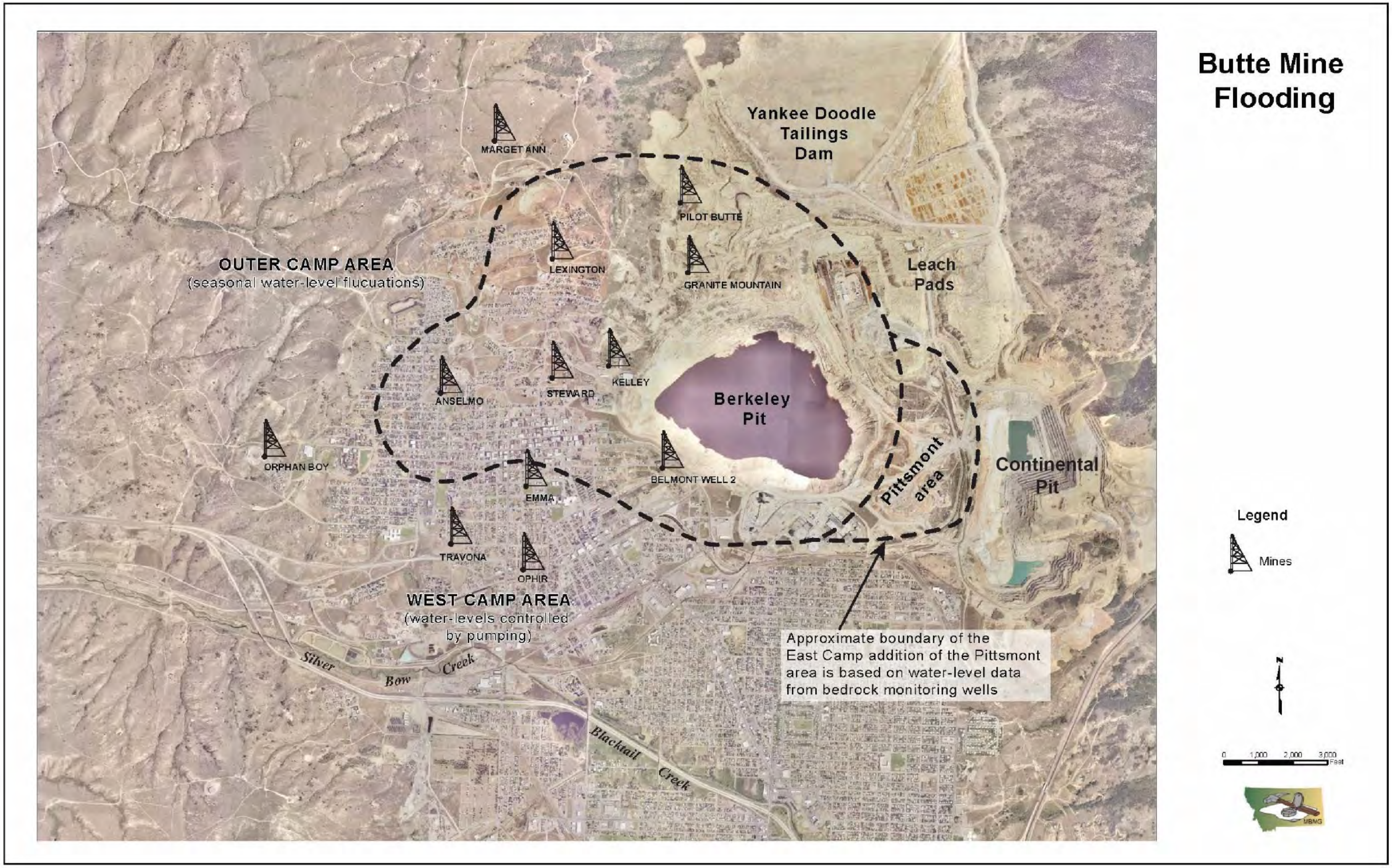


Figure 1-10. The mines of the Butte Hill are currently considered in three groups: the East Camp, which includes the Berkeley Pit and the area to the east; the West Camp, in the southwest; and the Outer Camp, which includes the outlying mines.

Section 1.2 Notable 2018 Activities, Water-Level and Water-Quality Observations

Maintenance activities related to mine operations that required HSB water to be diverted to the Berkeley Pit were minimal in 2018. These resulted in minor water-level increases throughout the East Camp bedrock system (which includes the Berkeley Pit). No significant events occurred in 2018 that influenced water levels, water quality, or monitoring activities. The main activities and observations for 2018 are listed below:

(1) MR continued mining and milling operations throughout 2018.

(2) Water-level monitoring at the Granite Mountain Mine has not resumed, due to an obstruction in the shaft at a depth of approximately 420 ft. Unsafe surface conditions preclude safe access to the shaft for further inspection, thus the cause of the obstruction is unknown. Plans are in development for replacing this monitoring site.

(3) MR continued to use water from the HSB drainage to flood the leach pads. Flows from 1,200 to 2,500 gpm were diverted to the leach pads, a process begun in 2012. Water levels increased in several LP wells downgradient of the reactivated leach pads, and water-quality changes were observed in several of the constituents analyzed as part of monthly monitoring of the HSB water.

(4) MR operated three pumping wells to lower alluvial groundwater levels adjacent to the sites of landslides/slumps in the Berkeley Pit wall in August and November 2012 and February 2013. Monitoring well LP-15 was also used for dewatering purposes.

(5) Berkeley Pit sampling and profiling with the remotely operated drone boat was conducted twice during 2018.

(6) Alluvial monitoring wells GS-41S and GS-41D were plugged and abandoned mid-year to allow for construction activities related to the State of Montana–Parrot Tailings removal project.

(7) Bedrock wells DDH-2 and DDH-8 were plugged and abandoned mid-year as part of active mine operations and disposal of Parrot Tailings waste material from the area surrounding wells GS-41D and GS-41S in figure 2-1.

Section 1.3 Precipitation Trends

Total precipitation for 2018 was 13.91 in, compared to 11.97 in for 2017. The 2018 amount is 1.23 in above the long-term (1895–2018) average [NOAA, 1999; AccuWeather.com, 2019 (Butte airport weather station)]. Precipitation totals have been below average for 7 of the past 10 years and 22 of the past 37 years. The 2018 precipitation total was an increase of 9.7 percent from the 1982–2018 average of 12.47 in. Table 1.3.1 contains monthly precipitation statistics from 1982 through 2018, while figure 1-11 shows this information in comparison to the long-term yearly average. Overall precipitation totals since flooding of the mines began are very similar to the long-term average (12.44 in vs. 12.67 in). Figure 1-12 shows departure from normal precipitation from 1895 through 2018.

Table 1.3.1. Butte Precipitation Statistics, 1982–2018.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean	0.43	0.41	0.73	1.12	1.94	2.27	1.29	1.30	1.08	0.78	0.62	0.49	12.47
Std. Dev.	0.31	0.28	0.39	0.66	0.77	1.17	1.00	0.90	0.76	0.57	0.38	0.34	2.73
Maximum	1.40	1.26	1.84	3.20	3.88	4.62	4.18	3.10	2.99	2.31	1.50	1.99	19.96
Minimum	0.09	0.11	0.11	0.00	0.81	0.50	0.00	0.09	0.03	0.00	0.07	0.01	8.32
Years precipitation has been greater than mean													15
Years precipitation less than mean													22

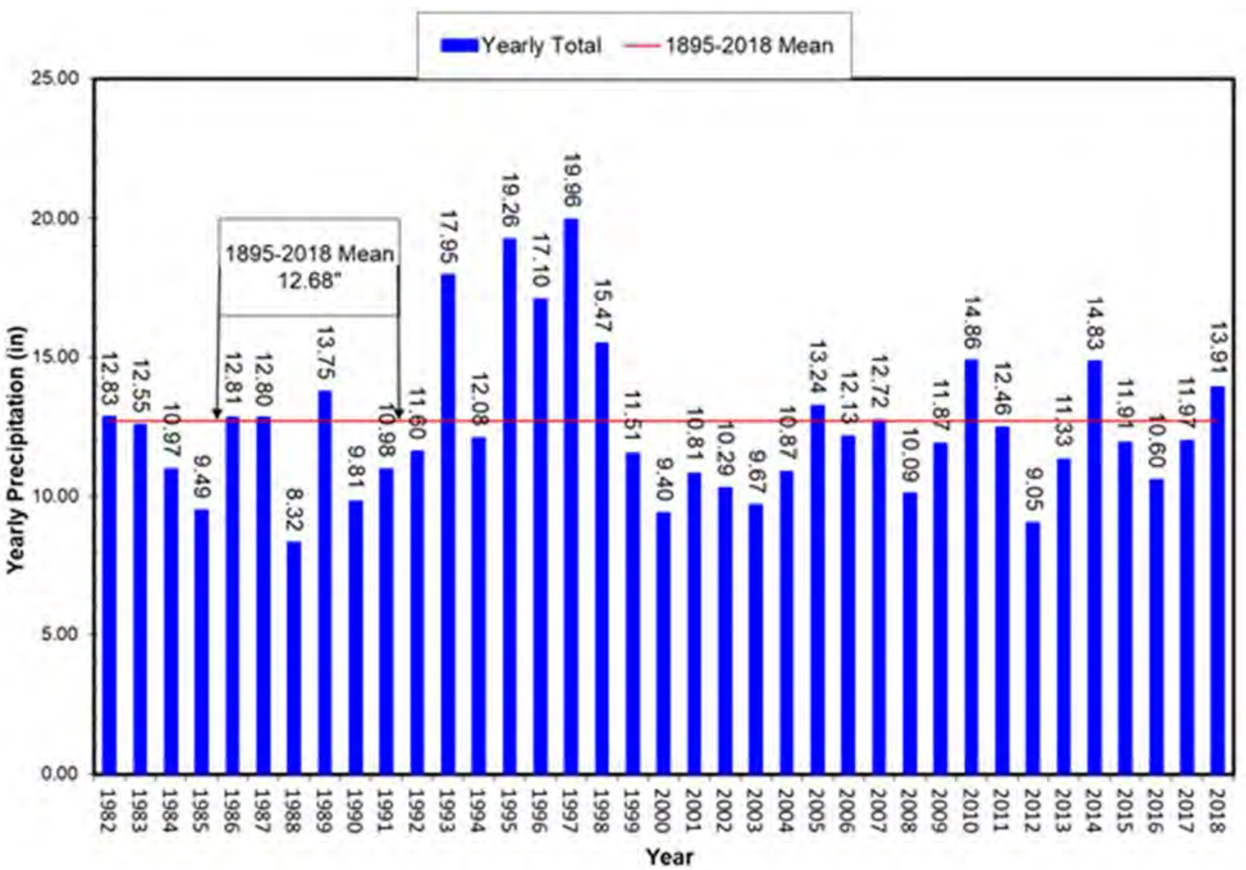


Figure 1-11. Annual precipitation totals 1982–2018, showing 1895–2018 mean.

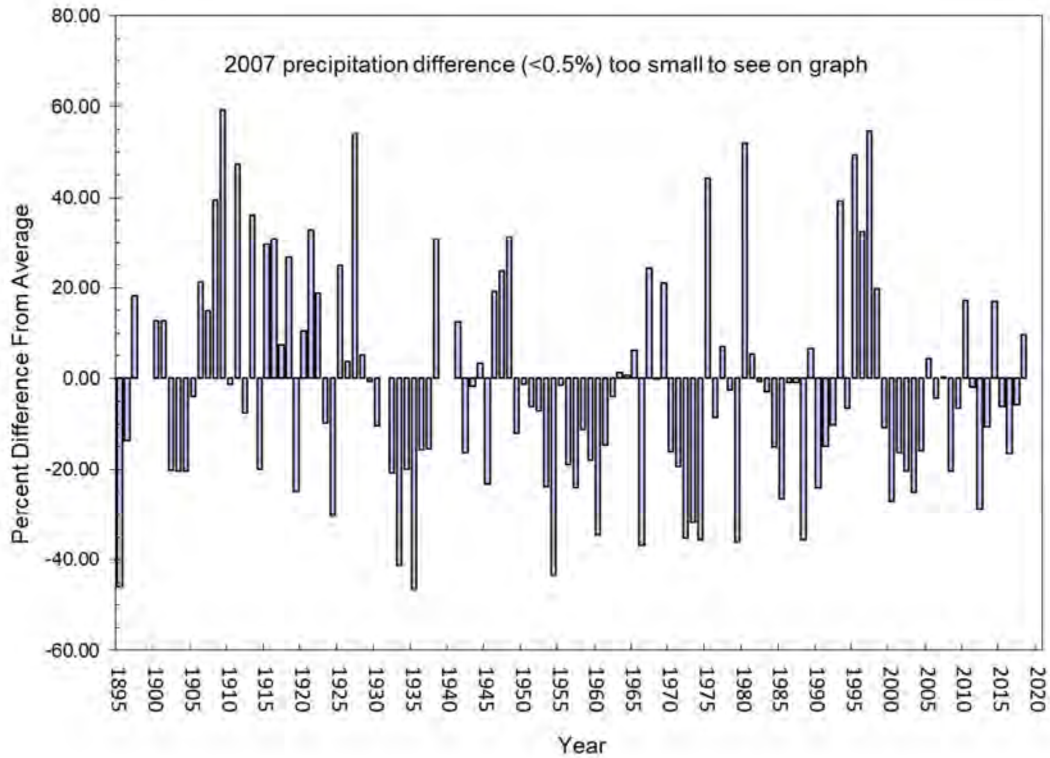


Figure 1-12. Percentage precipitation variation from normal, 1895–2018.

SECTION 2.0 EAST CAMP ALLUVIAL SYSTEM

The East Camp alluvial system includes the alluvial aquifer within the active mine area and a portion of the alluvial aquifer outside the active mine area, primarily to the south (fig. 2-1). The East Camp alluvial groundwater monitoring system consists of the LP- and MR97-series wells located within the active mine area, and selected AMC-, GS-, AMW-, and BMF05-series wells. All wells in the latter four groups are located south of the active mine area, with the exception of wells AMC-5 and AMC-15, located within the mine area. Each group of wells represents sites installed or monitored during earlier studies now incorporated into the BMFOU-CD monitoring program.

Four alluvial monitoring wells were installed within the East Camp system in late 2005 and early 2006 as stipulated in the 2002 CD. These wells replaced domestic wells monitored from 1997 through 2002. The alluvial wells are situated in areas with limited historical data and are equipped with transducers to improve water-level monitoring. These wells, named “BMF05-wells,” are discussed with the GS-series wells. The BMF05-wells were sampled three times annually throughout 2007 to establish baseline water-quality conditions and semi-annually thereafter.

Water-level elevations and monthly precipitation amounts are shown on hydrographs for selected wells. Water-quality results are shown and discussed for the sampled wells. Unlike the water-level monitoring program, water-quality sampling has been conducted annually or semi-annually at a subset of East Camp monitoring wells.

Water-level conditions and water-quality characteristics vary throughout the alluvial system. Data from wells within or adjacent to historic mining activities exhibit elevated metal concentrations, which we attribute to their proximity to those operations. Data from sites outside historic mining areas reflect conditions typical of the regional hydrogeology.

In late September 1998, a large landslide occurred in the southeast corner of the Berkeley Pit. The landslide caused a rapid response in water levels, with a 3 ft water-level rise in the Berkeley Pit, East Camp mines, and bedrock groundwater system. Following this response, water levels in parts of the East Camp alluvial system declined through mid-2003. Seasonal precipitation responses are noticeable on many well hydrographs (GS-series wells), although the overall water-level trend during those years was downward; little seasonal response is noticeable in other well hydrographs (i.e., AMC-series wells). Hydrographs here and in subsequent sections indicate the date of the landslide and pre-landslide water levels for the reader's benefit.

Figure 2-1. East Camp alluvial monitoring wells.

Section 2.1 AMC-Series Wells

The locations of the Anaconda Mining Company (AMC) wells are shown in figure 2-2; table 2.1.1 lists the annual water-level changes for these sites. Water levels decreased in one of seven AMC-series wells for 2018, and well AMC-10 has remained dry since its installation in 1983. The general increase in water levels during 2018 is attributed to above-average precipitation following dry conditions in 2016–2017. Water levels had a net decline during the first 20 years of monitoring, followed by a net increase the next 10 years. Water levels have a net decline in six wells over the past 6 years. Over the entire period of record, net water-level declines range from 3.2 ft to more than 26.5 ft in six wells, with one well dry.

Well AMC-5 is located within the active mine area; wells AMC-6 and AMC-8 are located south of the active mine area and the Butte Concentrator (fig. 2-2). Well AMC-12 is located southwest of these wells. Hydrographs for wells AMC-5 and AMC-12 (fig. 2-3), and AMC-6 and AMC-8 (fig. 2-4), are typical of the data set and show the long-term trends in the shallow alluvial groundwater system south of the pit. Water levels in AMC-6 and AMC-8 generally track the trends in monthly precipitation shown in figure 2-4.

Well AMC-5 exhibited the greatest water-level increase following MR's resumption of mining in 2003. The increase was followed by 2 yr of water-level decline. This well is located just north of the Emergency (Dredge) and Ecology ponds, located in the southwest corner of the concentrator yard (fig. 2-2). The Emergency (Dredge) Pond was reflooded in fall 2003 prior to MR's start-up. The water-level trend in AMC-5 for 2003–2005 (fig. 2-2) is similar to the trend seen in 1986–1987, which coincides with the start-up of mining following ARCO's 1983 suspension. These data indicate that filling the Emergency (Dredge) Pond with make-up water for milling operations influences water levels in the nearby alluvial aquifer. While periodic water-level increases coincide somewhat with early spring precipitation, the overall water-level trends from 2006 through 2018 do not appear to consistently respond to seasonal precipitation. Water-level change at this location is likely a response to operational changes within MR's water-handling system.

The annual change in water levels at well AMC-12 shows a seasonal pattern (fig. 2-3). However, longer-term water levels reflect operational activities at the mine. Water levels between 2001 and 2005 generally declined and may have been related to the construction of the BPSOU sub-drain that underlies the SBC channel above the confluence with Blacktail Creek. Water-level increases during 2006–2007 resulted in a net rise of 1.56 ft (fig. 2-3); these water-level increases may be due to the completion of the sub-drain, and the periodic discharge of clean water to the SBC channel. Water-level variations from 2011 to 2013 may be related to MR's cleaning, refilling, and subsequent draining and reclaiming of the Ecology Pond.

Table 2.1.1. Net annual water-level changes in the AMC-series wells.

Year	AMC-5	AMC-6	AMC-8	AMC-10	AMC-12	AMC-13	AMC-15
1983	-23.75	-2.30	-4.90	DRY	0.20	0.60	-5.80
1984	-4.50	-2.55	-3.75	DRY	-1.80	-1.10	-3.40
1985	-3.60	-4.05	-2.55	DRY	-2.75	-2.15	-2.90
1986	6.10	2.40	-0.40	DRY	0.10	-0.20	-1.60
1987	0.10	0.60	1.30	DRY	0.70	0.20	0.30
1988	0.20	-0.60	-0.20	DRY	-0.10	-1.00	0.80
1989	-2.30	-0.80	-0.90	DRY	-0.20	-0.10	0.10
1990	0.20	0.10	0.30	DRY	1.10	0.00	-0.10
1991	0.00	0.30	0.80	DRY	-0.60	0.30	-0.30
1992	0.40	-0.40	0.50	DRY	-0.30	0.00	-0.10
Change Years 1–10	-27.15	-7.30	-9.80	0.00	-3.65	-3.445	-13.00
1993	0.40	0.70	0.80	DRY	1.10	1.00	-0.40
1994	0.64	0.53	0.91	DRY	-0.19	-0.50	0.96
1995	0.64	1.01	0.51	DRY	1.23	1.13	0.97
1996	-0.05	0.62	2.14	DRY	0.74	0.69	2.60
1997	1.80	1.47	2.24	DRY	1.20	0.70	2.80
1998	-1.52	0.42	0.40	DRY	0.18	0.09	0.58
1999	-1.56	-2.03	-1.70	DRY	-1.56	-1.09	-1.50
2000	-2.46	-2.56	-3.88	DRY	-1.77	-1.17	-3.73
2001	-1.89	-1.92	-3.03	DRY	-0.55	-0.36	-2.34
2002	-0.89	-1.25	-1.77	DRY	-0.98	-0.73	-1.65
Change Years 11–20	-4.89	-3.01	-3.38	0.00	-0.60	-0.24	-1.71
2003	6.97	3.50	0.97	DRY	0.53	0.03	0.37
2004	-1.13	0.44	1.42	DRY	-0.37	-0.42	0.38
2005	-1.68	-1.06	-0.45	DRY	-0.51	-0.22	-0.76
2006	0.73	0.97	2.72	DRY	1.24	0.72	1.72
2007	1.07	0.63	1.14	DRY	0.32	0.55	1.12
2008	-0.23	-0.50	-0.26	DRY	-0.06	-0.42	0.70
2009	0.05	0.57	2.53	DRY	0.04	1.02	0.35
2010	0.49	-0.03	-0.37	DRY	-0.10	-0.63	1.25
2011	0.41	1.90	1.87	DRY	1.13	0.59	0.86
2012	-0.77	-2.16	-2.10	DRY	-1.08	-0.49	-1.77
Change Years 21–30	5.91	4.26	7.47	0.00	1.14	0.73	4.22
2013	-1.43	-1.34	-1.87	DRY	-0.83	-0.52	-2.18
2014	1.72	0.57	-0.67	DRY	0.60	0.45	-0.07

Table 2.1.1. Net annual water-level changes in the AMC-series wells—*Continued.*

2015	-0.88	-0.87	-0.89	DRY	-0.78	-0.76	-0.44
2016	-0.84	-0.27	2.46	DRY	-0.27	-0.09	-0.46
2017	0.00	0.42	-1.31	DRY	0.45	0.41	0.42
2018	0.63	0.22	-2.19	DRY	0.52	0.26	0.52
Change Years 31–40	-0.80	-1.27	-4.47	0.00	-0.31	-0.25	-2.21
Net Change	-26.93	-7.32	-10.18	0.00	-3.42	-3.21	-12.70

Note. Minus sign (-) indicates a decline (drop) in water level.

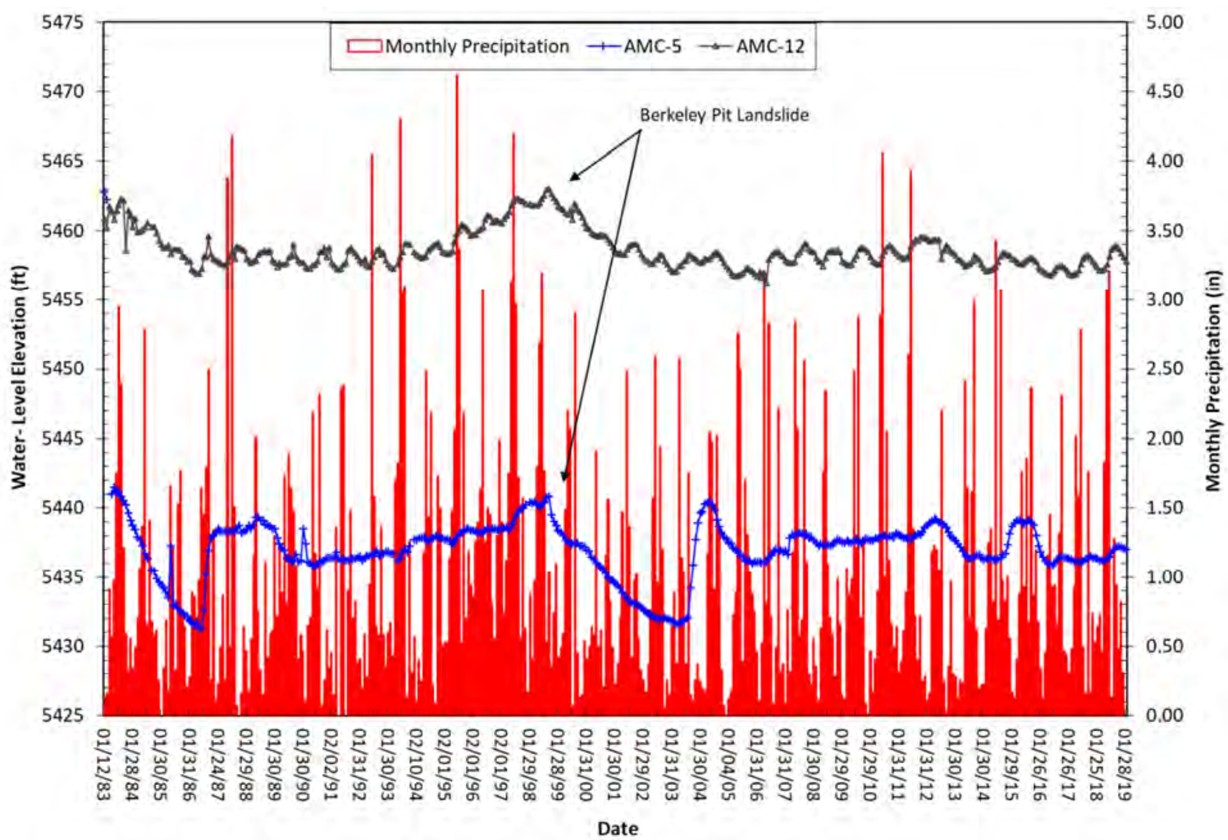


Figure 2-2. Water-level hydrographs for wells AMC-5 and AMC-12.

Figure 2-3. AMC well location map.

Well AMC-6 is directly south of the concentrator facility and the Emergency (Dredge) and Ecology ponds. Water-level changes during 2003–2004 were similar to those seen in 1986–1987 following the resumption of mining, which is attributed to operational/maintenance activities associated with mining/milling operations. MR emptied the Ecology Pond in the summer of 2011 to remove accumulated sediment, and then refilled it, resulting in water-level rise from October through mid-2012 (fig. 2-4). Removal of sediment from the pond apparently increased leakage and recharge to the shallow alluvial aquifer. MR drained the Ecology Pond in early 2012 followed by capping and re-contouring of the area, and the water-level decrease in well AMC-6 during 2012 and 2013 appears related to these activities. Water-level response in AMC-6 is typically strongly influenced by seasonal precipitation.

The water-level trend from 2003 through 2005 in well AMC-8 (fig. 2-4) was similar to that of the 1986–1988 period, with water levels declining followed by a period of water-level increases associated with the resumption of mining. Water levels continued to mostly rise, apparently independent of climatic trends, through early 2012. Water levels followed a downward trend similar to those seen in AMC-6, early 2012 to early 2016, with no seasonal variation. Water levels rose almost continuously throughout the remainder of 2016, resulting in an almost 2.5 ft rise. Water levels fell throughout most of 2017–2018, with no relationship to climatic conditions.

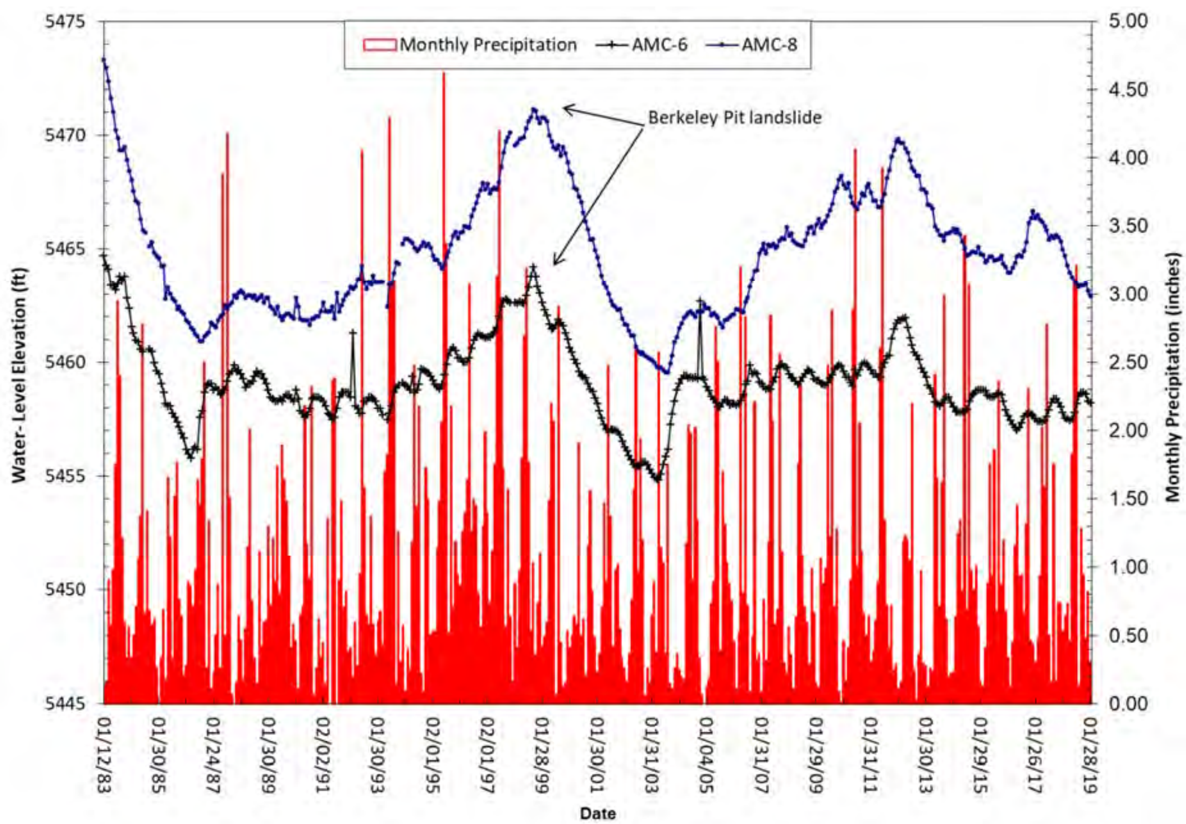


Figure 2-4. Water-level hydrographs for wells AMC-6 and AMC-8.

Well AMC-13 is located on the west side of Clark Park (fig. 2-2). This well's hydrograph shows a response to both precipitation events and possibly lawn watering (fig. 2-5). Water levels begin to rise yearly in late spring and continue to rise throughout the summer, suggesting some recharge from watering the grass fields, and decline each fall.

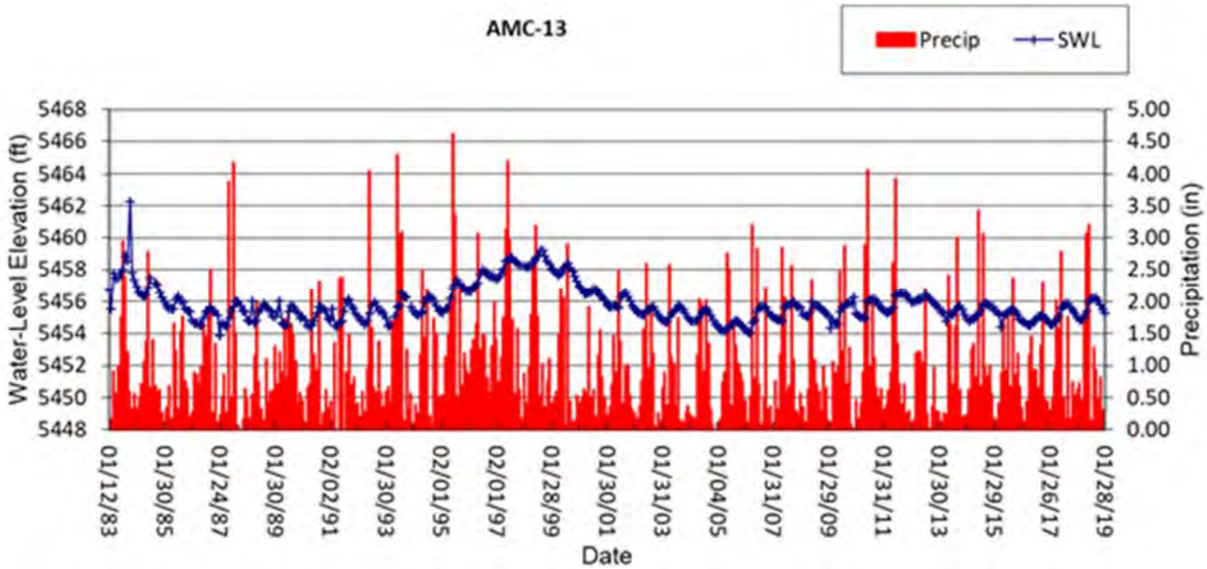


Figure 2-5. Water-level hydrograph for wells AMC-13.

Well AMC-15 is located on the west side of the Hillcrest waste dump (fig. 2-2) in a reclaimed area of the mine site. The water table is much deeper (about 90 ft below land surface) here compared to other AMC wells, dampening the hydrograph response to infiltration. The influence of below-normal precipitation and the Berkeley Pit 1998 landslide is shown by the steep decline in water levels beginning in mid-1999 (fig. 2-6). During this period, the well did not show any significant response to precipitation. The water-level decline began leveling off in mid-2003 when the water level rose almost one-half foot between September and December. This period corresponds to the fall 2003 resumption of mining by MR. Water levels show an apparent seasonal variation, with peak water levels occurring later in the year (November–December) than in other alluvial well sites.

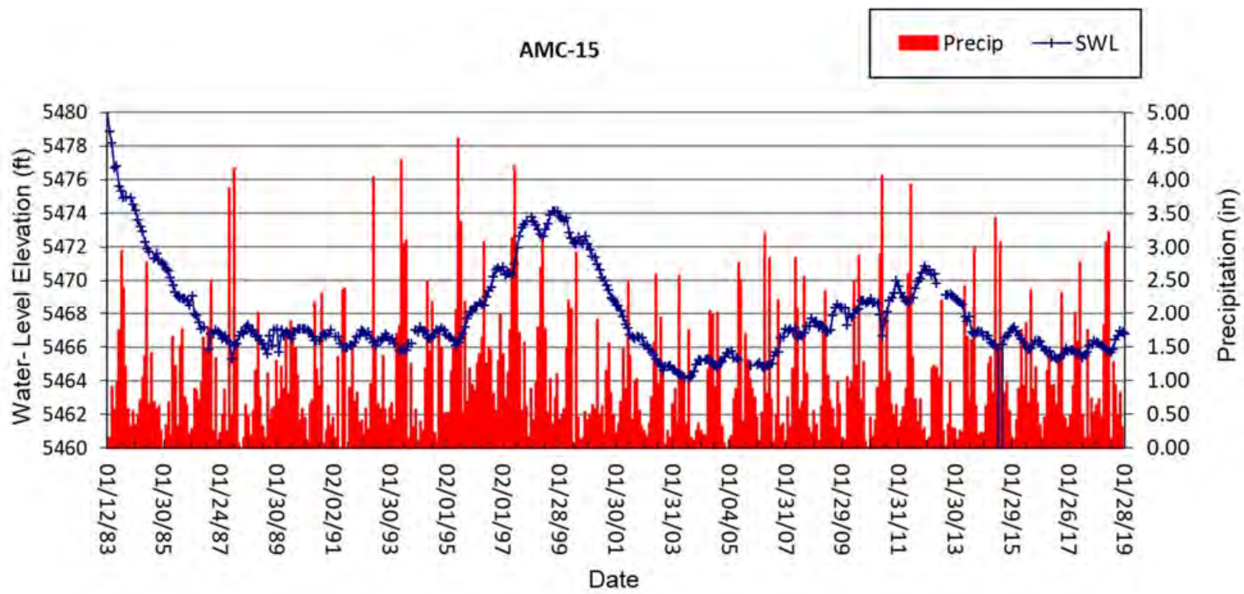


Figure 2-6. Water-level hydrograph for well AMC-15.

Section 2.1.1 AMC-Series Water Quality

Concentration exceedances and trends for chemical constituents in the 2018 data collected from the AMC-series wells are summarized in table 2.1.1.2. Complete sample results for the AMC-series wells are available from the MBMG Groundwater Information Center (GWIC) website at the following location: http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=MINEFLO-ACTIVE-ECALL&datatype=wq&.

Groundwater in well AMC-5, just south of the Berkeley Pit, has exceeded maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) throughout the period of record. The concentrations of copper and zinc have decreased about 50% from initial concentrations; most other dissolved metals have shown a slight downward trend or remained stable in recent years.

Groundwater from AMC-6 shows continued and consistent decreasing concentrations in nearly all dissolved constituents. Cadmium is the only constituent with concentrations exceeding an MCL; iron and manganese concentrations exceed SMCLs, while zinc concentrations are periodically above the SMCL. Sulfate concentrations demonstrate the overall improvement in groundwater quality conditions (fig. 2-7a).

The concentrations of dissolved constituents reported in samples collected in 2018 from well AMC-8 are consistent with earlier results. Sulfate concentrations have doubled from the fall of 2006, increasing from 400 mg/L to more than 1,000 mg/L in October 2018 (fig. 2-7a). Cadmium concentrations increased this past year, with the fall sample exceeding the MCL; sulfate, iron, and manganese concentrations are above the respective SMCLs.

Table 2.1.1.1 Water-quality exceedances and trends for AMC-series wells, 2018.

Well Name	Exceedances	Concentration Trends	Remarks
AMC-5	Y	Variable	High sulfate, iron, manganese, cadmium, copper, and zinc.
AMC-6	Y	Downward/stable	Downward trend continues; iron and manganese exceed SMCL and cadmium exceeds MCL.
AMC-8	Y	Variable/increasing	Sulfate concentrations have doubled since 2006; sulfate, iron, and manganese exceed the SMCL; Cd periodically exceeds MCL.
AMC-12	Y	Downward/stable	Sulfate, iron, manganese, cadmium, copper, and zinc exceed MCL and SMCL. Cadmium, copper, and zinc have downward trends.
AMC-15	Y	Variable	Unchanged in recent years, currently only sampled every 2 yr; Fe and Mn exceed SMCL.

Water from AMC-12 has elevated concentrations of sulfate, iron, manganese, cadmium, copper, and zinc; this well is located just south of the SBC drainage that received untreated mine and process water for decades. Groundwater quality has improved over the 35-yr record; dissolved concentrations of iron, manganese, sulfate, cadmium, copper, and zinc are one-half or less of maximum concentrations observed in the early 1990s (fig. 2-7b).

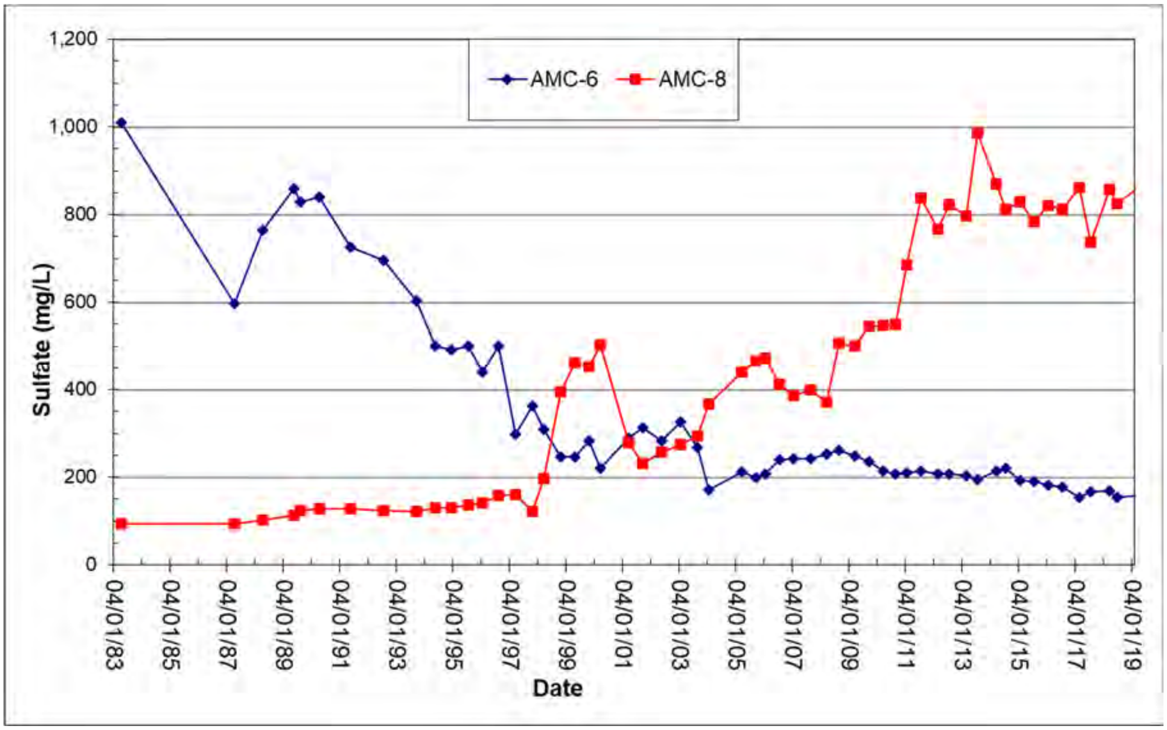


Figure 2-7a. Sulfate concentration changes over time for wells AMC-6 and AMC-8.

Figure 2-7b. Copper and zinc concentration changes over time for well AMC-12.

Overall, dissolved metals concentrations in 2018 water samples are little changed from recent years. Wells closest to historic and current mining operations have the highest levels of contamination; wells AMC-5 and AMC-12 have very high, but decreasing, levels of iron, manganese, cadmium, copper, and zinc.

Section 2.2 LP-Series Wells

The locations of the 17 LP-series monitoring wells are shown in figure 2-8; table 2.2.1 presents a summary of annual water-level changes for these sites. These wells were installed in 1991 and 1992 as part of the BMFOU RI/FS study (Duaime and others, 1998). Wells LP-03, LP-06, and LP-11 have been plugged and abandoned for various reasons. Well LP-17 was plugged, abandoned, and replaced with LP-17R in fall 2013. Well LP-07 has been dry periodically from 2001 through 2012; it had water-level increases of 1 ft or less in 2013–2018. Well LP-08 was dry from May 2010 to November 2015; it had a 4.15 ft water-level rise in December 2015 and a total rise of 1.5 ft in 2016–2018.

Water-level monitoring and sampling of the LP-series wells continued throughout 2018, with water levels declining in 7 of the remaining 14 wells. Wells near MR dewatering activities continue to exhibit a water-level decline, and wells downgradient of the leach pads exhibit a water-level increase. Since monitoring began in 1991, water levels have declined in all 17 of the LP wells, ranging from 0.60 ft in LP-14 to 92.69 ft in well LP-15.

Table 2.2.1. Net annual water-level changes in the LP-series wells (ft).

Year	**LP-01**	**LP-02**	**LP-03**	**LP-04**	**LP-05**	**LP-06**	**LP-07**	**LP-08**	**LP-09**
1991	1.23	-0.91	-2.02	1.38	4.35	-1.46	-	-	-0.70
1992	-1.14	-1.56	-0.66	-1.75	-1.08	0.80	-3.79	-3.78	-7.16
1993	-0.91	-1.69	1.84	-1.69	-2.42	-0.53	-3.06	-4.83	-2.24
1994	-0.53	-0.80	-1.61	-0.57	-1.42	-2.28	-1.03	-2.11	-2.90
1995	-0.08	-0.19	-1.74	2.94	0.34	0.47	4.91	4.30	3.35
1996	-2.05	-2.00	-0.73	-1.28	-3.40	2.01	-4.30	-1.14	-1.49
1997	-1.58	-1.86	-0.09	-1.73	-3.32	-1.37	-2.24	-2.63	-0.29
1998	0.12	0.23	-2.03	1.01	-0.03	-0.58	2.44	0.99	1.60
1999	-2.24	-1.76	-7.44	-2.64	-3.15	-1.65	-6.47	-3.52	-3.77
2000	-7.55	-7.16	-5.45	-10.83	-7.87	-0.20	-3.10	-14.03	-13.28
Change Years 1–10	**-14.73**	**-17.70**	**-19.93**	**-15.16**	**-18.00**	**-3.79**	**-16.64**	**-26.75**	**-26.88**
2001	-5.13	-4.73	9.51	-8.88	-5.47	Dry	Dry	-12.10	-3.04
2002	-5.21	-3.91	-2.01*	-6.03	-4.86	Dry	Dry	-4.11	-3.46
2003	-2.29	1.60	P&A*	-1.75	-2.00	Dry	Dry	-0.04	-1.15
2004	-0.65	0.46	P&A*	13.06	3.85	3.24	Dry	18.13	2.96
2005	0.81	-0.43	P&A*	4.12	3.40	-3.62	-0.79	2.85	2.08
2006	-1.43	-0.96	P&A*	-2.77	-2.06	Dry	Dry	-2.35	-0.44
2007	-0.09	0.14	P&A*	-3.39	-2.36	Dry	Dry	-5.59	-2.37
2008	-0.02	0.13	P&A*	-3.80	-1.61	Dry	Dry	-7.83	-1.39
2009	0.48	0.13	P&A*	-3.87	-1.59	Dry	Dry	-5.23	-0.07
2010	0.96	0.89	P&A*	-2.13	-1.42	P&A*	Dry	0.01	0.06
Change Years 11–20	**-12.57**	**-6.68**	**-11.52**	**-15.44**	**-14.12**	**-0.38**	**-0.79**	**-16.26**	**-6.82**
2011	0.22	0.05	P&A*	-0.34	0.03	P&A*	Dry	Dry	0.61
2012	1.15	-0.08	P&A*	0.26	0.07	P&A*	Dry	Dry	3.95
2013	3.17	0.43	P&A*	3.16	1.61	P&A*	0.06	Dry	3.72
2014	3.34	0.54	P&A*	1.54	2.11	P&A*	0.11	Dry	3.51
2015	4.19	4.24	P&A*	2.75	3.61	P&A*	0.00	4.15	-1.51
2016	1.95	1.96	P&A*	1.13	-0.12	P&A*	-0.12	0.61	-1.14
2017	2.20	1.56	P&A	0.68	1.08	P&A*	1.08	-0.25	0.65
2018	0.36	0.40	P&A	0.78	0.13	P&A*	0.13	1.14	-0.79
Change Years 21–30	**16.58**	**9.10**	P&A*	**9.96**	**8.52**	**P&A***	**1.26**	**5.65**	**9.00**
Net Change	**-10.72**	**-15.28**	**-31.45**	**-20.64**	**-23.60**	**-4.17**	**-16.17**	**-37.36**	**-24.70**

Note. Minus sign (-) indicates a decline (drop) in water level.
*Plugged and abandoned.

Table 2.2.1. Net annual water-level changes in the LP-series wells (ft)—*Continued*.

Year	**LP-10**	**LP-11**	**LP-12**	**LP-13**	**LP-14**	**LP-15**	**LP-16**	**LP-17**	**LP-17R**
1991	-	-	-	-	-	-	-	-	
1992	-0.50	-1.83	0.31	-0.07	0.70	0.54	0.89	-	
1993	-0.83	-2.78	1.42	1.11	1.18	1.62	1.83	-	
1994	-2.14	1.65	-1.41	-1.47	-0.09	0.26	-1.16	-	
1995	-0.57	-0.23	-0.16	0.43	0.18	1.89	3.57	3.10	
1996	1.20	0.23	1.87	1.74	2.07	1.79	1.77	1.66	
1997	0.23	-0.09	2.42	2.24	2.64	1.99	1.77	2.32	
1998	0.92	0.07	1.00	-0.62	0.39	-7.90	-9.69	-2.41	
1999	-2.05	-2.12	-2.94	-2.36	-2.73	-4.39	-4.60	-3.95	
2000	-1.37	-0.28	-3.60	-2.93	-3.64	-1.73	-2.18	-2.86	
Change Years 1–10	**-5.11**	**-5.38**	**-1.09**	**-0.93**	**0.70**	**-5.93**	**-7.80**	**-2.14**	
2001	0.51	P&A*	-1.16	-1.30	-2.31	-0.72	-1.18	-1.50	
2002	-0.15	P&A*	-1.83	-1.21	-1.65	-0.68	-0.86	-0.67	
2003	-2.75	P&A*	-1.74	-0.26	0.46	1.08	0.89	0.09	
2004	-1.41	P&A*	0.20	0.26	0.95	-0.06	0.52	0.71	
2005	4.19	P&A*	1.53	0.78	-0.27	0.27	-0.27	0.26	
2006	3.19	P&A*	4.48	2.78	2.95	1.43	1.33	2.68	
2007	0.73	P&A*	0.87	0.73	1.22	1.51	1.66	2.54	
2008	1.23	P&A*	1.92	1.27	0.29	1.05	0.28	0.94	
2009	-0.83	P&A*	3.23	1.97	3.32	1.70	1.47	2.20	
2010	-0.77	P&A*	0.09	-0.19	0.53	-0.18	0.27	0.32	
Change Years 11–20	**3.94**	**0.00**	**7.59**	**4.83**	**5.49**	**5.40**	**4.11**	**7.57**	
2011	-1.03	P&A*	0.78	0.94	1.61	0.87	0.53	0.16	
2012	-3.12	P&A*	-5.59	-4.46	-3.19	-65.32	-3.53	-4.05	
2013	0.78	P&A*	-2.09	-3.12	-2.05	-15.35	-4.36	-3.37	-0.31
2014	-0.86	P&A*	-0.87	0.42	-0.72	-18.59	0.32	P&A*	0.20
2015	-2.77	P&A*	-1.25	-2.40	-0.64	-20.56	-3.29	P&A*	-2.10
2016	-1.72	P&A*	0.35	0.35	1.72	-0.99	-0.01	P&A*	-0.33
2017	-0.66	P&A*	-1.25	0.27	-1.06	29.27	1.36	P&A*	0.24
2018	-0.38	P&A*	-2.37	-1.03	-2.46	-1.49	0.43	P&A*	-0.73
Change Years 21–30	**-9.76**	**P&A***	**-12.29**	**-9.03**	**-46.79**	**-92.16**	**-8.55**	**-7.26**	**-3.03**
Net Change	**-10.93**	**-5.38**	**-5.79**	**-5.13**	**-0.60**	**-92.69**	**-12.24**	**-1.83**	**-3.03**

Note. Minus sign (-) indicates a decline (drop) in water level.
*Plugged and abandoned.

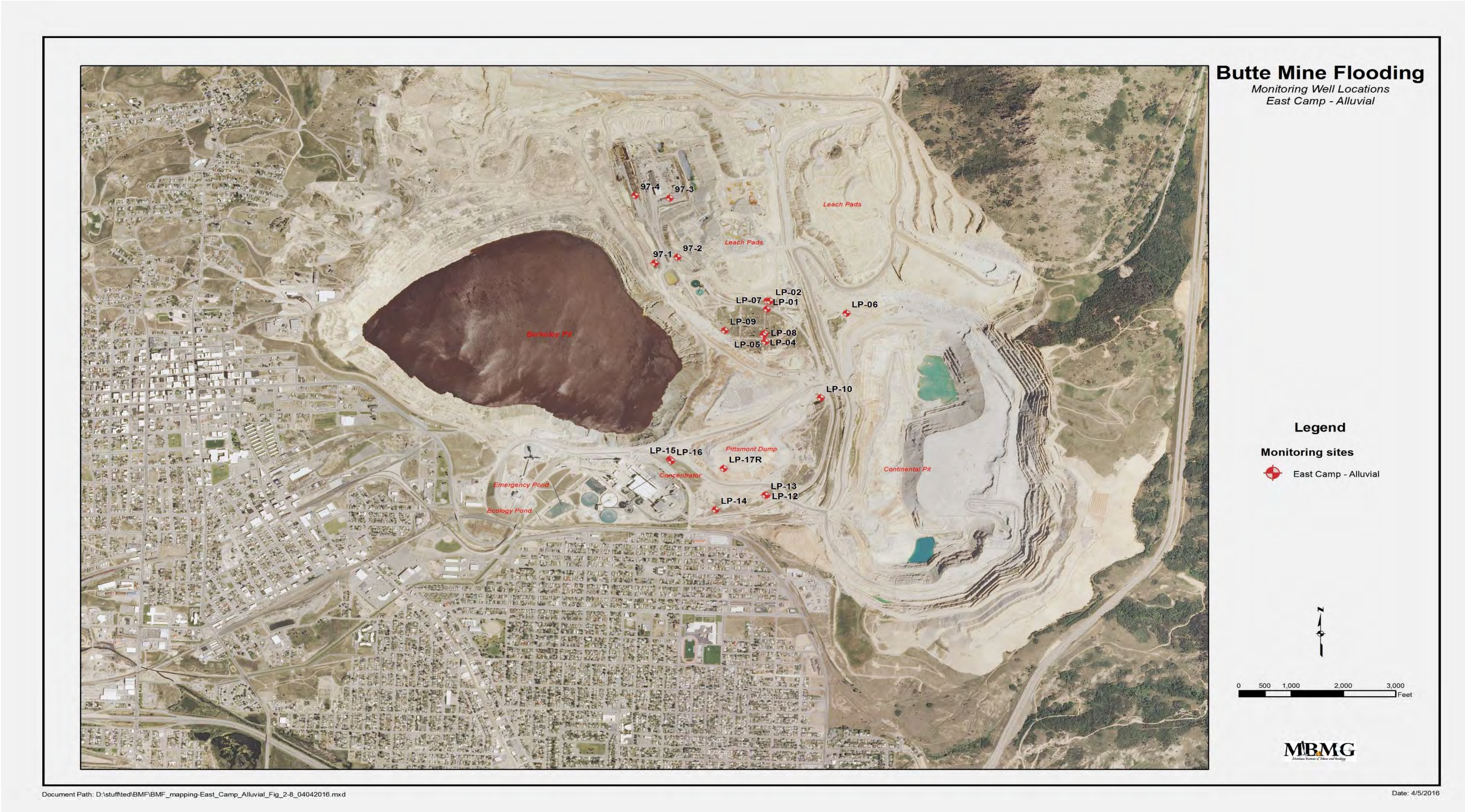


Figure 2-8. LP-series and MR97 wells location map.

Water-level rise began in 2004 in some of the wells north of the Pittsmont Waste Dump. This was a substantial change from downward trends observed between 1992 and 2003. The water-level declines prior to 2004 are attributed to the deactivation of the leach pads in 1999. MR resumed mining in 2003 and began limited leaching operations in 2004 that continued throughout 2018. The wells with the greatest water-level rise in 2004 and 2005 (LP-04 and LP-8) are located south of the leach pads.

Figures 2-9 and 2-10 show water levels over time for three LP-series wells, which are located south of the leach pads and north of the Pittsmont Waste Dump. Wells LP-01 and LP-02, located near the base of several leach pads, are screened between 175 and 195 ft, and 127 and 157 ft, respectively, at depth in the alluvial aquifer. As shown in figure 2-9, water levels steadily declined in these wells between 1991 and 2004. Since 2005, water levels have varied slightly, with periodic increases followed by declines. Water-level fluctuations in LP-01 have been less erratic in recent years than those in the shallow well, LP-02, possibly the result of an increased lag time in response to recharge events. Water levels in wells LP-01 and LP-02 indicate that temporal trends in the water table elevation are related to leach pad operations; the effect of climate appears muted. This interpretation is consistent with observations of water-level responses following MR's 1999 deactivation of the leach pads.

Figure 2-10 shows water levels over time for well LP-04, which is located south of wells LP-01 and LP-02, and north of the Pittsmont Waste Dump (fig. 2-8). Well LP-04 is screened from 125 ft to 145 ft below ground surface. There is very little seasonal variation noticeable in figure 2-10. Water-level responses in this well may also be related to leach pad operations.

Wells LP-14, LP-15, and LP-16 are located southwest of the Pittsmont Dump (fig. 2-8). Water levels trended up in these wells between installation in 1992 and the Berkeley Pit landslide of 1998 (fig. 2-11). Post landslide, water levels in all three wells declined until September 2003, when they began to rise. By the end of 2011, the water level in well LP-14 was within 0.5 ft of its water-level elevation just prior to the landslide; however, water levels in LP-15 and LP-16 remained 10 ft or more below their pre-landslide levels. Water levels decreased during most of 2012, with no apparent responses to landslides in August or November 2012, or the February 2013 slump in the southeast corner of the Berkeley Pit. Transducers were installed in monitoring wells LP-12, LP-13, and LP-16 to better track water-level changes following the November 2012 landslide. MR installed a series of dewatering wells and initiated pumping from well LP-15 in summer 2012. MR had briefly dewatered LP-15 by pumping immediately after the 1998 landslide. Water-level trends since August 2012 are attributed to these dewatering activities (fig. 2-12).

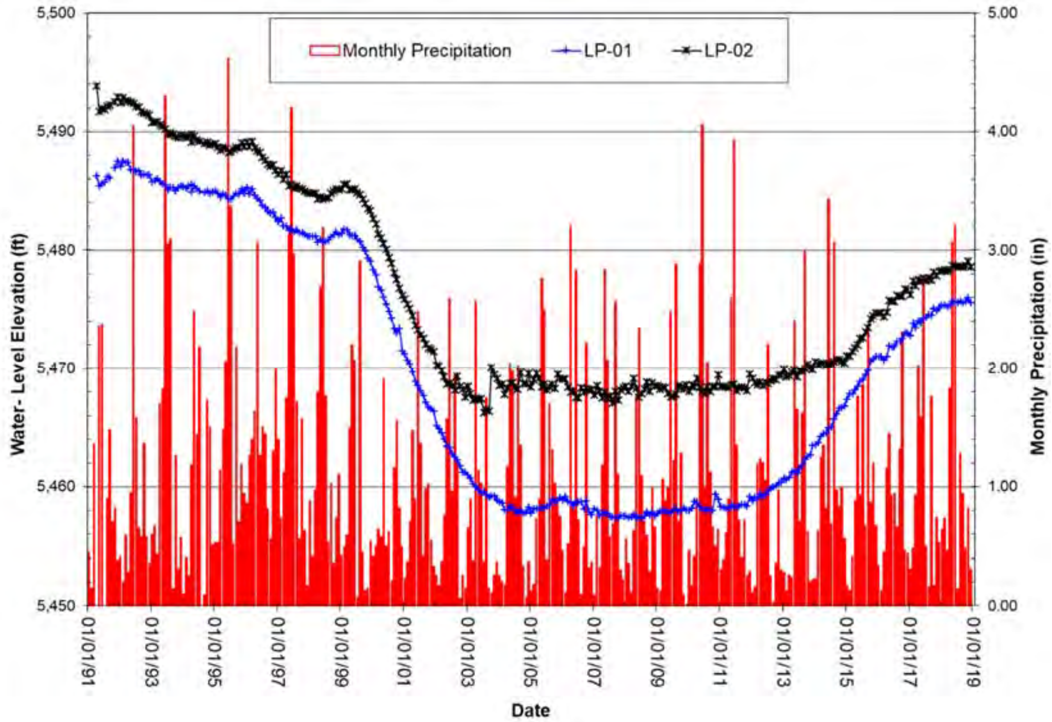


Figure 2-9. Hydrographs for wells LP-01 and LP-02 located north of the Pittsmont Waste Dump and south of the leach pads.

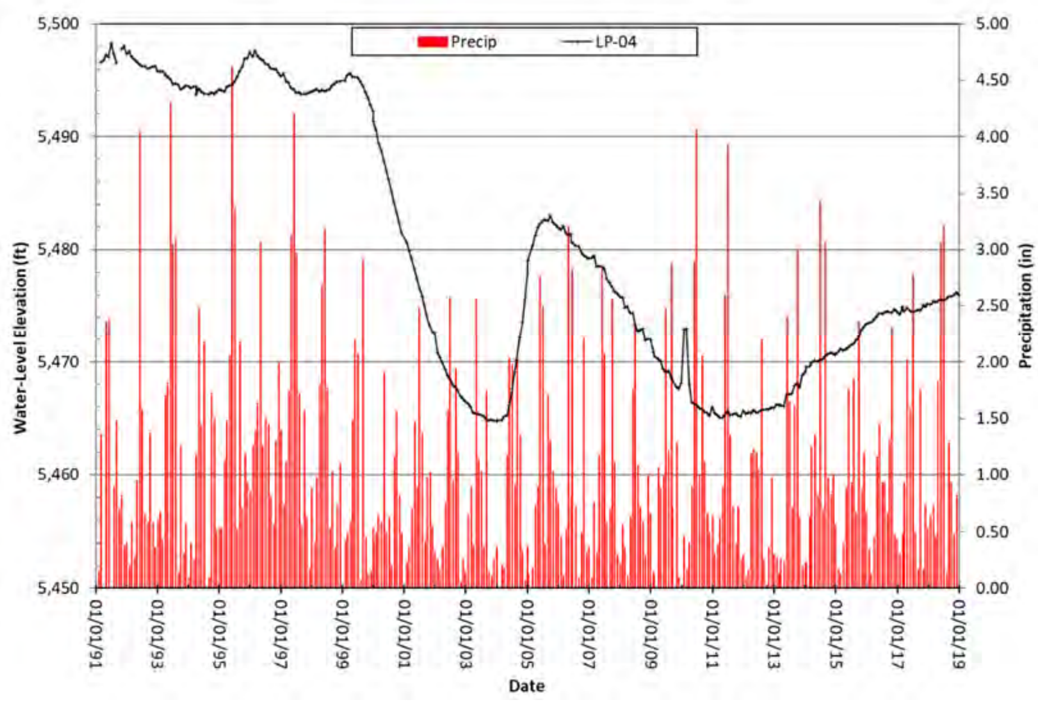


Figure 2-10. Hydrographs for well LP-04 located north of the Pittsmont Waste Dump and south of the leach pads.

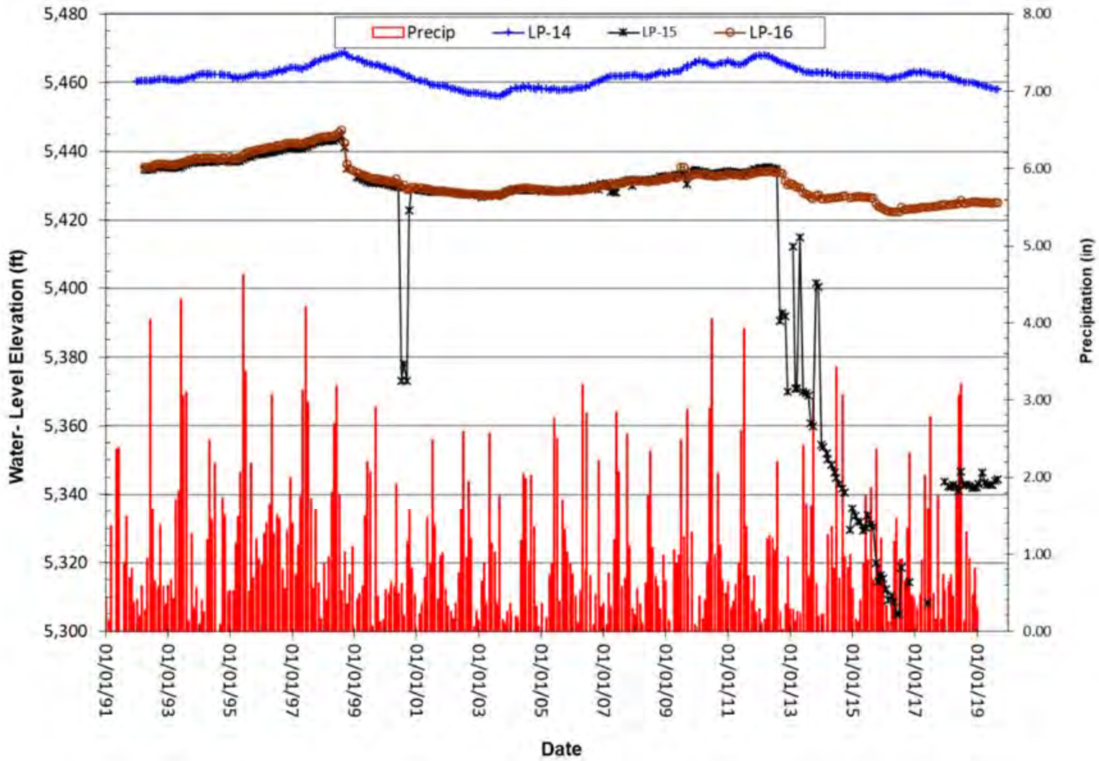


Figure 2-11. Water-level changes for wells LP-14, LP-15, and LP-16 before and after the 1998 Berkeley Pit landslide and response to dewatering activities in 2000 and again in 2012.

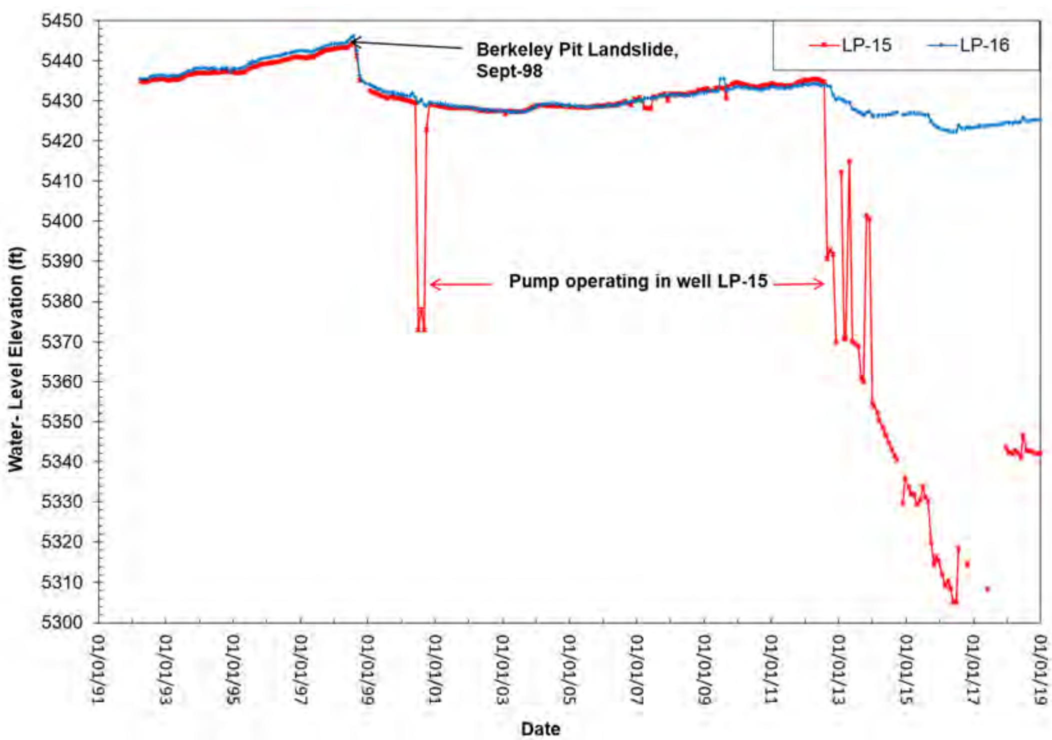


Figure 2-12. Hydrographs showing influence of dewatering on water levels in wells LP-15 and LP-16.

Multiple factors related to mine operations may affect water levels in the alluvial aquifer LP-series wells. These include:

(1) The flooding, dewatering, and subsequent reactivation of the leach pads;

(2) operation of the Yankee Doodle Tailings Dam;

(3) depressed water levels in the Berkeley Pit;

(4) alluvial dewatering activities conducted by MR;

(5) periodic releases to the McQueen Ditch (near well LP-14 in fig. 2-13); or

(6) a combination of all five.

Water-level response in wells adjacent and downgradient of limited leaching operations during 2004–2005 and 2009–2018 demonstrate the relationship of leach pad operation and water-level change. The influence of seasonal precipitation events is minimal on water levels in these wells.

An alluvial aquifer potentiometric map (fig. 2-13), based on December 2018 water levels (BMF monitoring well network sites only), shows that alluvial groundwater flows towards the Berkeley Pit from the north, east, and south. Groundwater in alluvium south of the Berkeley Pit and contaminated by historic mining activities (Metesh and Duaime, 2000) is flowing north to the Berkeley Pit, suggesting that there is no southward migration of contaminated water.

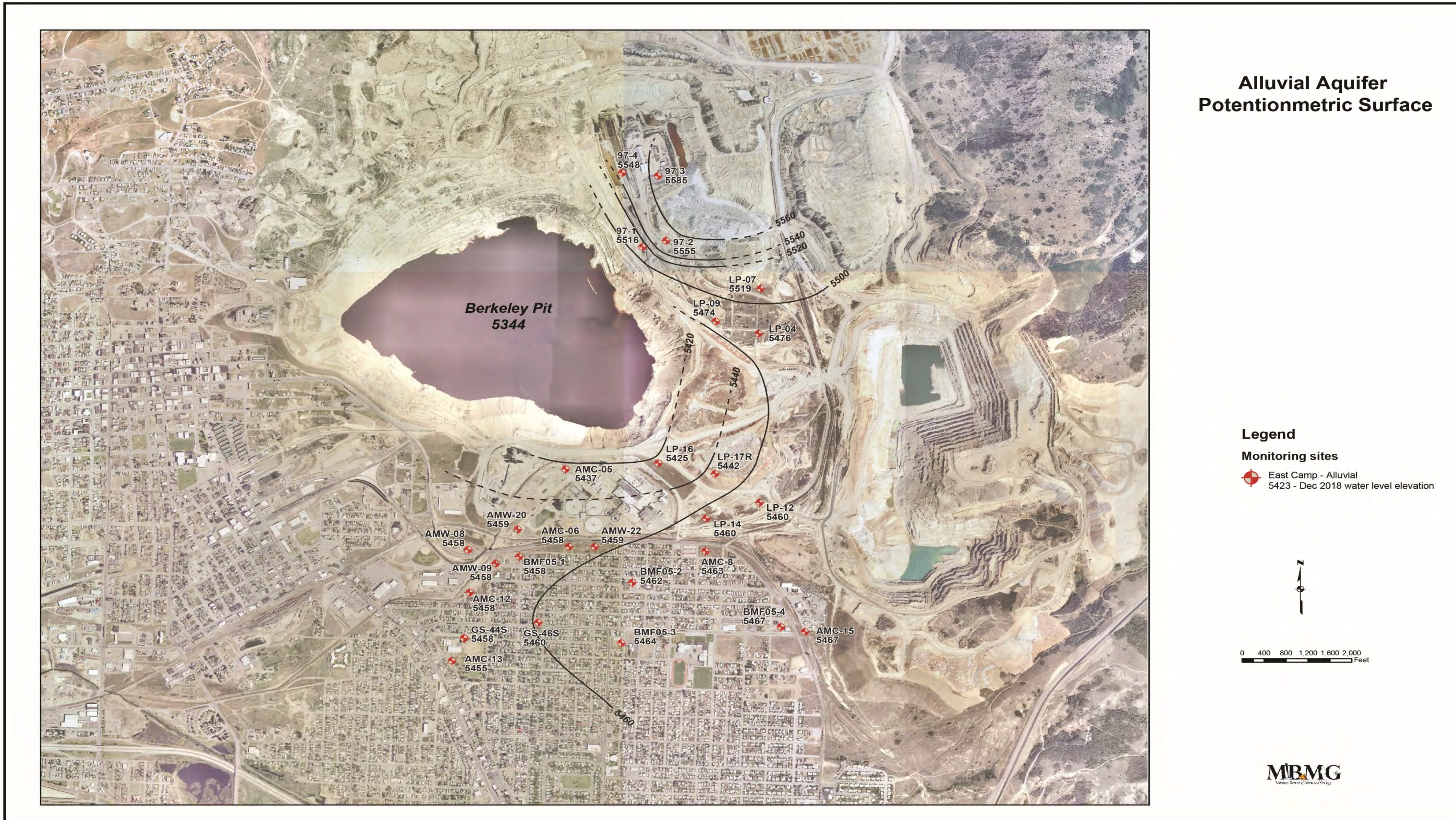


Figure 2-13. Alluvial aquifer potentiometric map for December 2018 (contour interval is 20 ft).

Section 2.2.1 LP-Series Wells Water Quality

Current water-quality monitoring of the LP-series wells is restricted primarily to wells west and south of the Pittsmont Dump (fig. 2-8), with the exception of LP-08 (when it is not dry), LP-09, and LP-10, which are south of the leach pad area and north of the Pittsmont Dump. Analytical results from samples collected in 2018 showed minor chemical concentration changes in several wells; the changes are summarized in table 2.2.1.1. Complete sample results for the LP-series wells are available from the GWIC website at the following location: http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=MINEFLO-ACTIVE-ECALL&datatype=wq&.

Historical sampling of well LP-09 includes six samples between its installation in 1992 and 1996; no sampling occurred from 1997 until April 2003, when annual sampling was reinitiated. Data review indicates large increases in most dissolved constituents starting in 1994. Results from 2003 to 2018 show that sulfate and zinc concentrations, although extremely elevated, have declined somewhat over the past decade (fig. 2-14). The concentration of cadmium increased from 600 µg/L in 1992 to more than 10,000 µg/L from 2003 to 2013; concentrations since 2014 have declined (6,600–8,600 µg/L). Zinc concentrations increased from 172,000 µg/L in 1992 to more than 1,100,000 µg/L in samples collected between 2003 and 2018. Although zinc concentrations have declined since 2009, they remain an order of magnitude above the 1992 levels. In general, dissolved metals concentrations increased sharply since well installation, approaching concentrations observed in the pregnant solutions of the upgradient leach pads.

Concentrations of sulfate, copper, cadmium, and zinc increased in well LP-16 from 2010 to 2013, followed by decreasing concentrations since then (fig. 2-15a). No other analytes showed increasing trends.

Water quality at well LP-17 changed in 2006, with concentrations of cadmium, copper, and zinc decreasing by almost 70 percent from 2003–2005 concentrations. Analytical results from LP-17 replacement well LP-17R show increased concentrations of cadmium, copper, manganese, and zinc from 2013. Figure 2-15b depicts copper and zinc concentrations in LP-17R since installation in 2013. Nitrate concentrations were elevated in samples collected from 2006–2009 and decreased from 2010 to 2012. However, current nitrate concentrations remain at twice the MCL of 10 mg/L (well LP-17R).

Water quality in the other LP-series wells was generally similar in 2018 to that in recent years. Table 2.2.1.1 includes a summary of exceedances and trends.

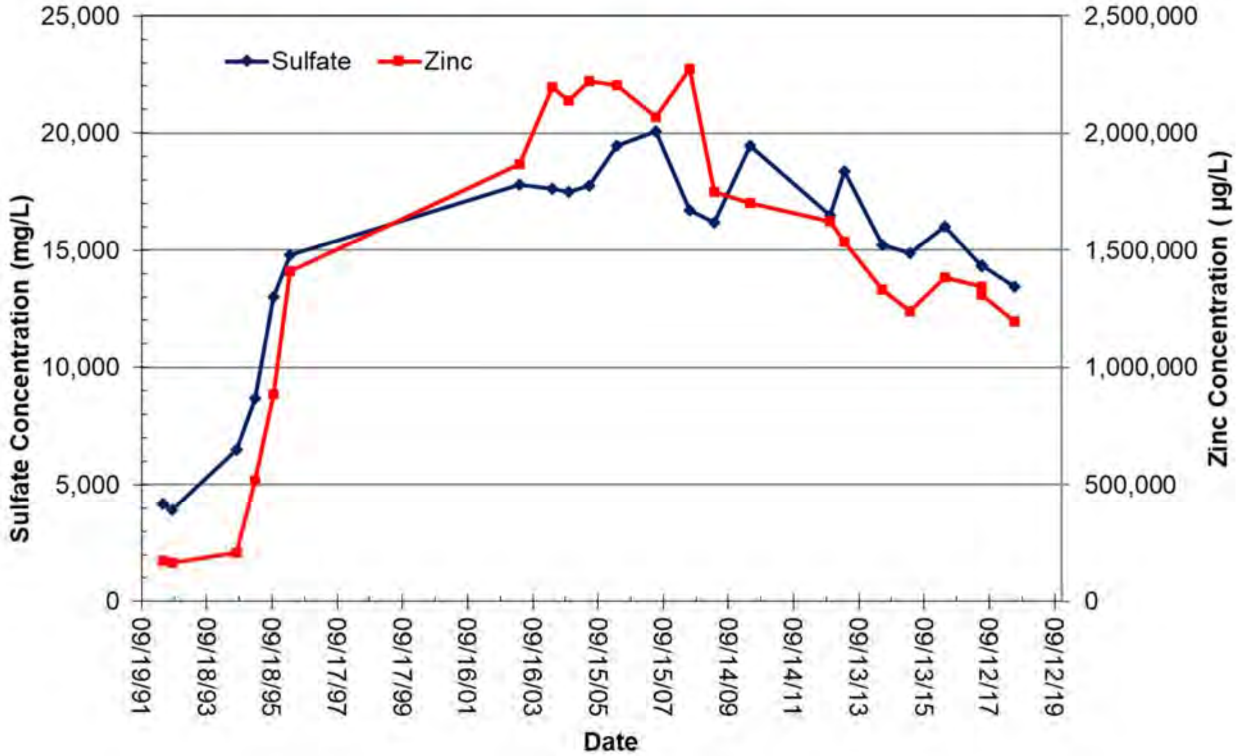


Figure 2-14. Sulfate and zinc concentrations in well LP-09.

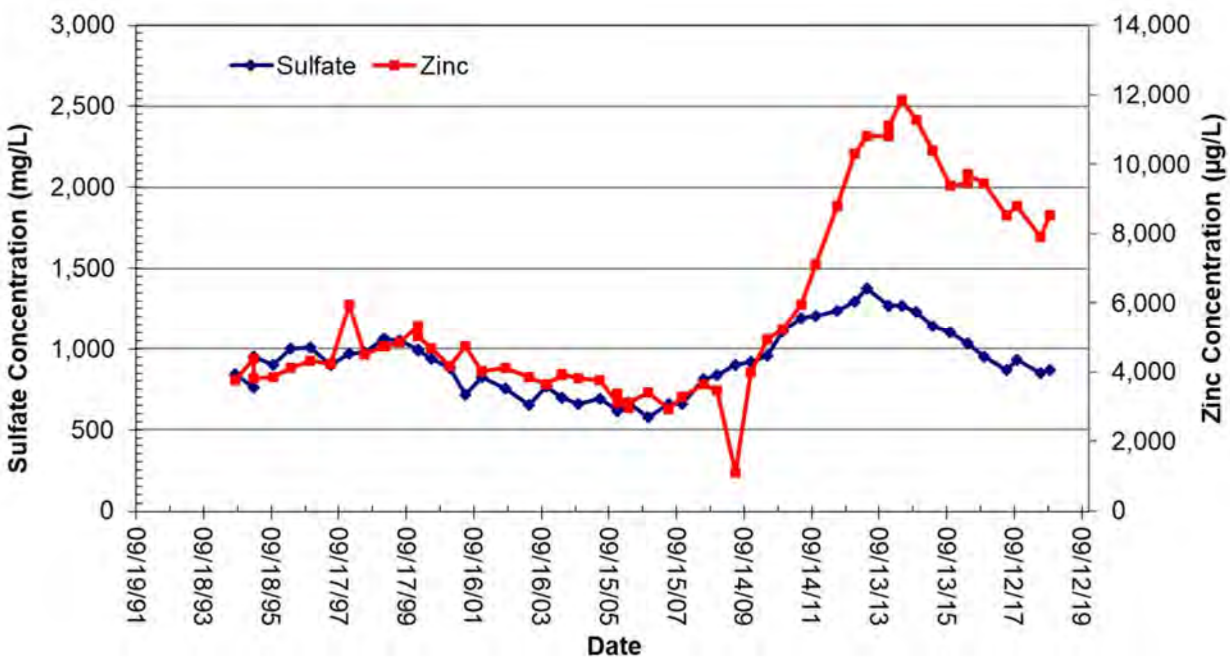


Figure 2-15a. Sulfate and zinc concentrations in well LP-16.

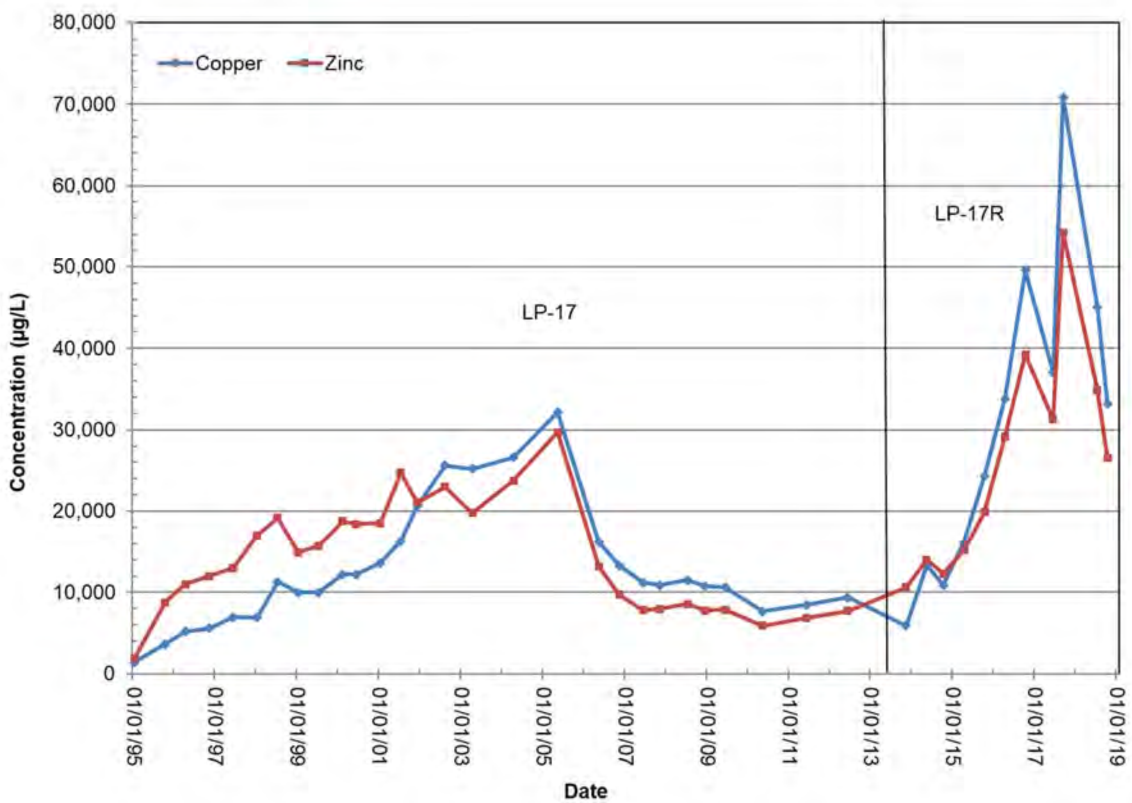


Figure 2-15b. Copper and zinc concentrations in wells LP-17 and LP-17R.

Table 2.2.1.1. Water-quality exceedances for LP-series wells, 2018.

Well Name	Exceedances (1 or more)	Concentration	Remarks
LP-08	Y	Downward	Very elevated concentrations. No samples since 2009 because of limited volume of water in well.
LP-09	Y	Downward	Large increases from 1992 to 2009. Cadmium, copper, and zinc show minor decreases since 2009.
LP-10	N	Stable	No significant changes in 2018.
LP-12	Y	Stable	Cadmium exceeds MCL. No significant changes in 2018.
LP-13	N	Stable	No significant changes in 2018. Zinc below SMCL in 2013–2018.
LP-14	Y	Stable	Cadmium exceeds MCL; sulfate exceeds SMCL.
LP-15	Y	Stable	Cadmium exceeds MCL; sulfate exceeds SMCL. Net change is small for most analytes.
LP-16	Y	Downward	Manganese, sulfate, copper, and zinc exceed SMCL; cadmium exceeds MCL.
LP-17/LP-17R	Y	Downward	Manganese, sulfate, copper, and zinc exceed SMCL; nitrate and cadmium exceeds MCL.

Section 2.3 Precipitation Plant Area Wells

Wells MR97-1, MR97-2, MR97-3, and MR97-4 (fig. 2-8) are adjacent to various structures (drainage ditches, holding ponds, etc.) associated with the leach pads and precipitation plant. Table 2.3.1 lists annual and net water-level changes for these wells. Water-level changes appear to correspond to flow in nearby ditches and water levels in ponds.

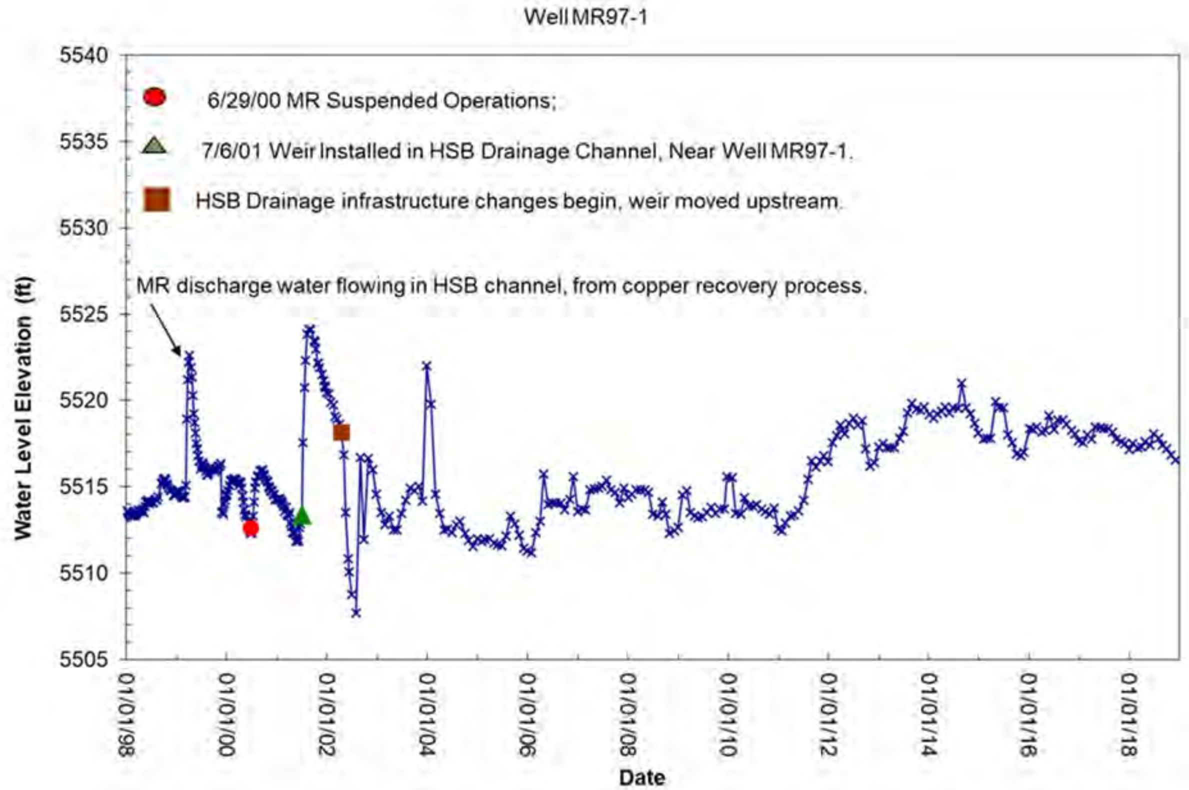
Table 2.3.1. Annual water-level changes in MR97-series wells (ft).

Year	MR97-1	MR97-2	MR97-3	MR97-4
1997	-0.25	-0.84	-0.40	0.34
1998	1.07	-1.04	-0.67	2.20
1999	-0.27	-4.40	-3.91	0.02
2000	-0.20	-0.89	-2.88	-0.03
2001	6.17	-1.32	-0.29	0.78
2002	-5.88	-1.02	-0.47	1.60
2003	7.43	-0.70	-1.29	-2.45
2004	-10.01	-0.08	-4.28	1.86
2005	-0.67	-0.06	0.60	-1.84
2006	2.27	2.20	1.82	0.41
Change Years 1–10	**-0.34**	**-8.15**	**-11.77**	**2.90**
2007	0.78	0.18	3.88	0.81
2008	-1.73	0.39	-0.10	0.13
2009	2.97	2.46	1.08	-3.71
2010	-3.07	0.05	1.25	-1.97
2011	3.88	5.51	0.24	1.93
2012	0.87	1.29	0.38	-0.21
2013	1.86	2.03	1.95	-0.18
2014	-1.06	-0.26	2.13	2.97
2015	-1.11	-0.84	0.24	-0.19
2016	-0.71	0.37	0.06	0.65
Change Years 11–20	**2.68**	**10.40**	**11.11**	**0.23**
2017	-0.53	0.01	1.00	0.68
2018	-0.69	-0.37	-0.36	-3.55
Change Years 21–30	**-1.22**	**-0.36**	**0.64**	**-2.87**
Net Change	**1.12**	**1.89**	**-0.02**	**3.81**

Note. Minus sign (-) indicates a decline (drop) in water level.

Water levels in well MR97-1 have shown the greatest variability of the four wells in the MR series (fig. 2-16), and this is attributed to changes in mining operations and infrastructure. Water levels increased when MR began to discharge water from the Berkeley Pit copper recovery project into the pit (spring 1999). Water levels increased again in June 2000, when mining operations ceased and HSB drainage was directed to the pit. Prior to this, from April 1996, HSB water was pumped to the Yankee Doodle Tailings Dam. Overall, these operational changes caused rapid increases in groundwater levels, followed by gradual decreases before leveling off. A water-level increase observed in July 2001 is attributed to the installation of a weir near well MR97-1 as part of the HSB water-treatment plant construction. In August 2002, the weir was moved upstream and further from MR97-1, which resulted in a decline in groundwater levels. Since the completion of the HSB water-treatment plant in 2003, water levels increased in 2006 and 2011, and have shown only minor variations otherwise. The late 2015 weir upgrades had only minimal influence on water levels in well MR97-1.

Wells MR97-2 and MR97-3 are adjacent to historic leach pad collection ditches and respond to operational changes near the wells. These include 1999–2000, when changes resulted in less flow in collection ditches and levels declined (figs. 2-16, 2-17). Water-level increases occurred in 2009–2013 and 2016 in MR97-2 and 2009–2016 in MR97-3 when limited leaching operations resumed. Dewatering activities near the HSB water-treatment plant in 2014–2018 may be responsible for the water-level variations/declines observed in well MR97-2.



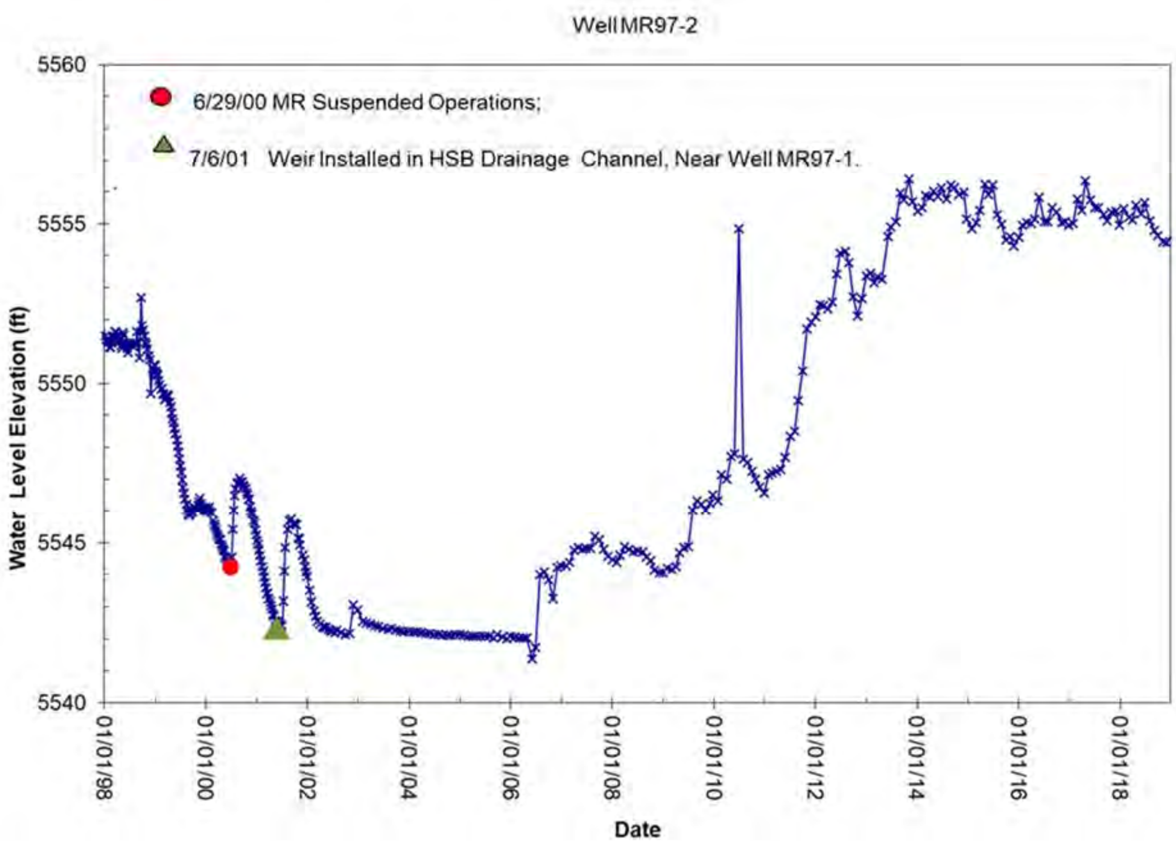
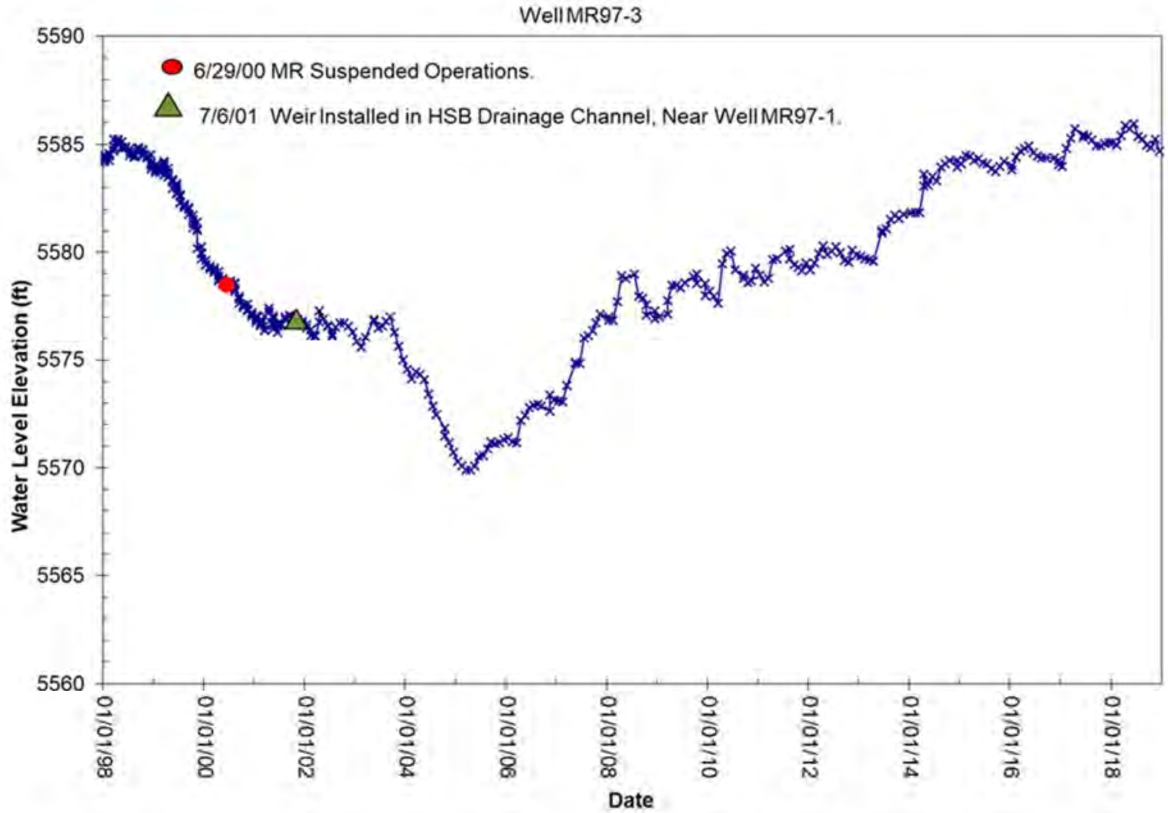


Figure 2-16. Water-level hydrograph for wells MR97-1 (top) and MR97-2 (bottom).

Well MR97-3 water-level responses during the 2001 and 2002 construction activities were minor (fig. 2-17). Water levels varied between 2008 and 2012 with a general increasing trend; water levels rose steadily from mid-2013 until leveling off in 2015–2018. Water-level changes in well MR97-4 (fig. 2-17) have shown the least amount of variability as the result of operational activities. Since installation of the MR97 well series in 1997, water levels have risen between 0.26 and 1.89 ft in three wells, while decreasing 0.02 ft in a fourth well. It appears that operation of the precipitation plant and leach pads directly influences the shallow alluvial aquifer. Other changes, such as the weir installation and relocation, have affected past groundwater levels. No water-quality samples were collected from MR-series wells between 2001 and 2018. Previous sampling documented the presence in groundwater of elevated metals; this contamination most likely resulted from leach pad and precipitation plant operations.



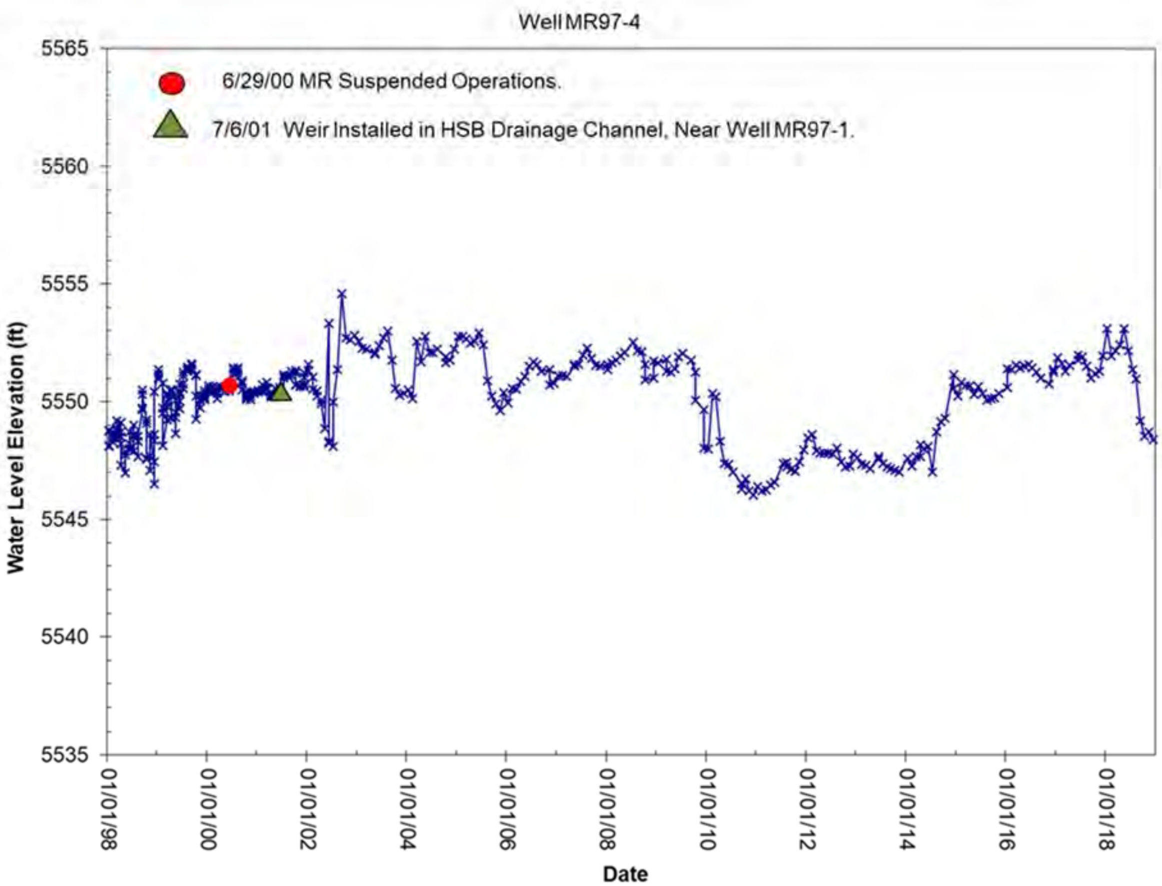


Figure 2-17. Water-level hydrograph for wells MR97-3 (top) and MR97-4 (bottom).

Section 2.4 GS- and BMF05-Series Wells

Continuous and monthly water-level monitoring of the six GS-series and four BMF05-series wells continued throughout 2018; however, wells GS-41S and GS-41D were plugged and abandoned mid-year to allow for the removal of the Parrot Tailings. The locations of these wells are shown in Figure 2-18; Table 2.4.1 contains annual water-level changes. Pairs of wells (GS-41S and D, GS-44S and D, and GS-46S and D) were drilled adjacent to each other but completed at different depths. The 'S' and 'D' identify the shallow and deep member of each pair. During most years, water-level changes are similar in all six wells. Water levels during the entire period of record in the GS-41 series wells have net increases ranging from 0.18 to 0.39 ft; the GS-44 and GS-46 series wells have net increases ranging from 0.50 to 1.45 ft.

Figures 2-19 through 2-21 show hydrographs with monthly precipitation totals for the well pairs (GS-41, GS-44, and GS-46). The seasonal water-level variations closely follow annual precipitation trends. Water levels gradually rise in the spring as monthly precipitation increases and then decline throughout the fall. During 2018, water-level changes in wells GS-42S and GS-42D were similar to those observed in prior years (fig. 2-20), and the influence of seasonal precipitation appears to dominate the hydrograph. Water levels increased about 0.3 ft in these two wells during 2018. Overall, water-level trends were similar during 2018 in wells GS-46S and GS-46D (fig. 2-21) and followed seasonal trends similar to those seen in wells GS-41 and GS-44. Water levels increased about 0.4 ft during 2018.

Vertical gradients at the well pairs differ. At the GS-41 and GS-44 sites, water levels in shallow wells are at higher altitudes than those in the deeper wells; these downward gradients indicate that groundwater flow is from shallow to deep portions of the aquifer. Water levels in wells GS-46S and GS-46D show the opposite, with water levels in well GS-46D at higher altitudes than the water level in GS-46S. This suggests that groundwater flow is upwards. As noted in the next section, the water quality in well GS-46D is good, and upward gradients are not problematic.

Figure 2-18. Location map for GS- and BMF-series wells.

Table 2.4.1. Annual water-level changes in GS- and BMF05-series wells (ft).

Year	**GS-41S**	**GS-41D**	**GS-44S**	**GS-44D**	**GS-46S**	**GS-46D**	**BMF 05-1**	**BMF 05-2**	**BMF 05-3**	**BMF 05-4**
1993	0.76	0.78	0.62	0.66	0.80	0.78				
1994	0.20	0.23	0.00	0.00	0.18	0.24				
1995	1.35	1.26	1.32	1.26	1.38	1.30				
1996	0.59	1.65	1.12	0.89	0.98	1.20				
1997	1.32	0.20	0.58	0.79	1.09	1.18				
1998	-0.18	-0.06	0.09	0.07	1.17	0.24				
1999	-1.41	-1.49	-1.28	-1.25	-2.41	-1.65				
2000	-1.91	-1.78	-1.51	-1.39	-1.21	-2.07				
2001	-0.28	-0.41	-0.22	-0.38	-1.64	-0.92				
2002	-0.82	-0.81	-0.94	-0.82	-1.18	-1.18				
Change Years 1–10	**-0.38**	**-0.43**	**-0.22**	**-0.17**	**-0.84**	**-0.88**				
2003	0.19	0.26	0.27	0.17	-0.81	0.77				
2004	-0.31	-0.41	-0.76	-0.52	-0.08	-0.02				
2005	-0.60	-0.53	-0.40	-0.33	-0.59	-0.52				
2006	1.36	1.28	1.01	1.06	1.45	1.28	1.86	1.21	1.71	1.97
2007	0.24	0.22	0.34	0.33	0.20	0.41	-0.25	0.67	0.31	0.63
2008	-0.42	-0.39	0.24	-0.08	0.84	0.20	-0.49	-0.09	0.10	1.04
2009	0.22	0.26	0.41	0.36	0.46	0.50	0.56	0.97	0.65	0.22
2010	0.11	0.14	-0.04	-0.02	-0.20	-0.10	0.00	0.05	0.16	0.49
2011	0.81	0.93	0.68	0.68	0.99	0.98	2.44	1.04	0.63	1.21
2012	-1.02	-1.03	-0.56	-0.60	-0.74	-0.75	-2.76	-1.01	-0.75	-1.71
Change Years 11–20	**0.58**	**0.73**	**1.19**	**1.05**	**3.14**	**2.75**	**1.36**	**2.84**	**2.81**	**3.85**
2013	-0.72	-0.75	-0.65	-0.65	1.01	1.10	-1.11	-1.63	-1.20	-2.10
2014	0.85	0.76	0.50	0.47	0.52	0.41	0.46	0.13	0.56	0.17
2015	-0.84	-0.75	-0.83	-0.81	-0.93	-0.94	-0.68	-0.99	-0.85	-0.76
2016	-0.34	-0.32	-0.10	-0.12	-0.33	-0.22	-0.43	0.29	-0.19	-0.11
2017	0.57	0.53	0.42	0.41	0.49	0.47	0.43	0.30	0.47	0.15
2018	0.46	0.62	0.33	0.32	0.41	0.43	0.44	0.07	0.70	0.68
Change Years 21–30	**-0.02**	**0.09**	**-0.33**	**-0.38**	**-0.85**	**-0.95**	**-0.89**	**-1.83**	**-0.51**	**-1.97**
Net Change	**0.18**	**0.39**	**0.64**	**0.50**	**1.45**	**0.92**	**0.47**	**1.01**	**2.30**	**1.88**

Note. Minus sign (-) indicates a decline (drop) in water level.

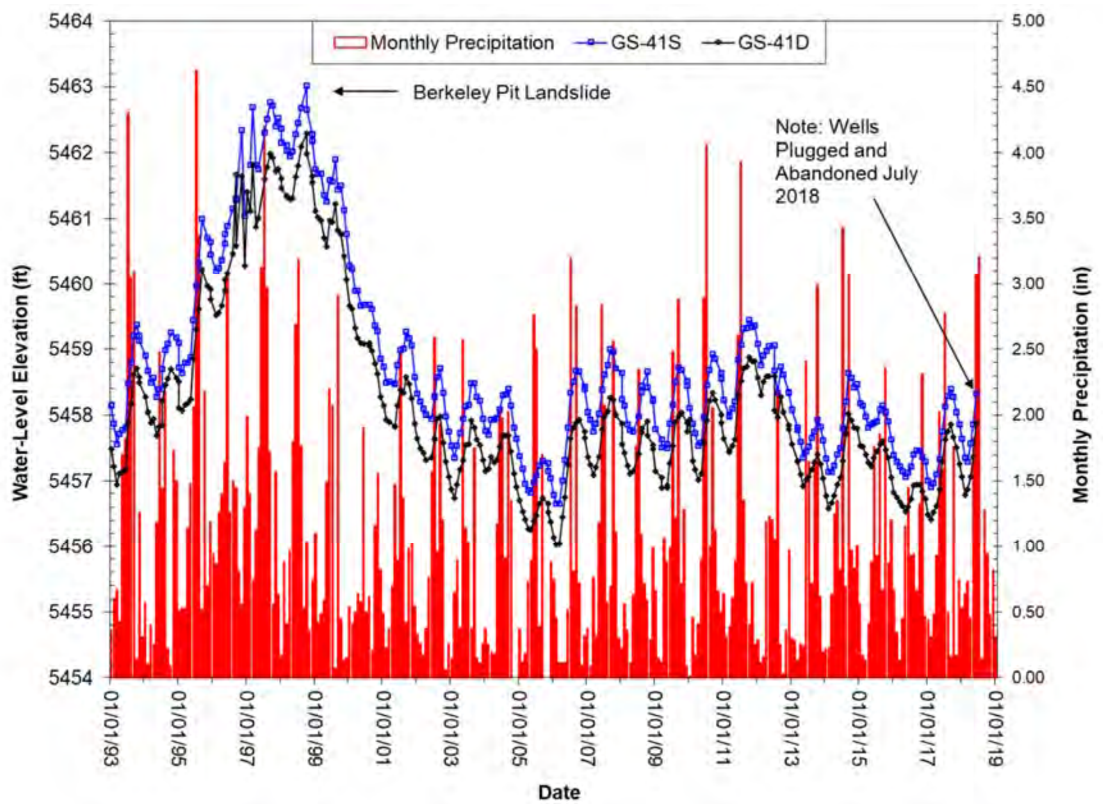


Figure 2-19. Water-level hydrographs for wells GS-41S and GS-41D.

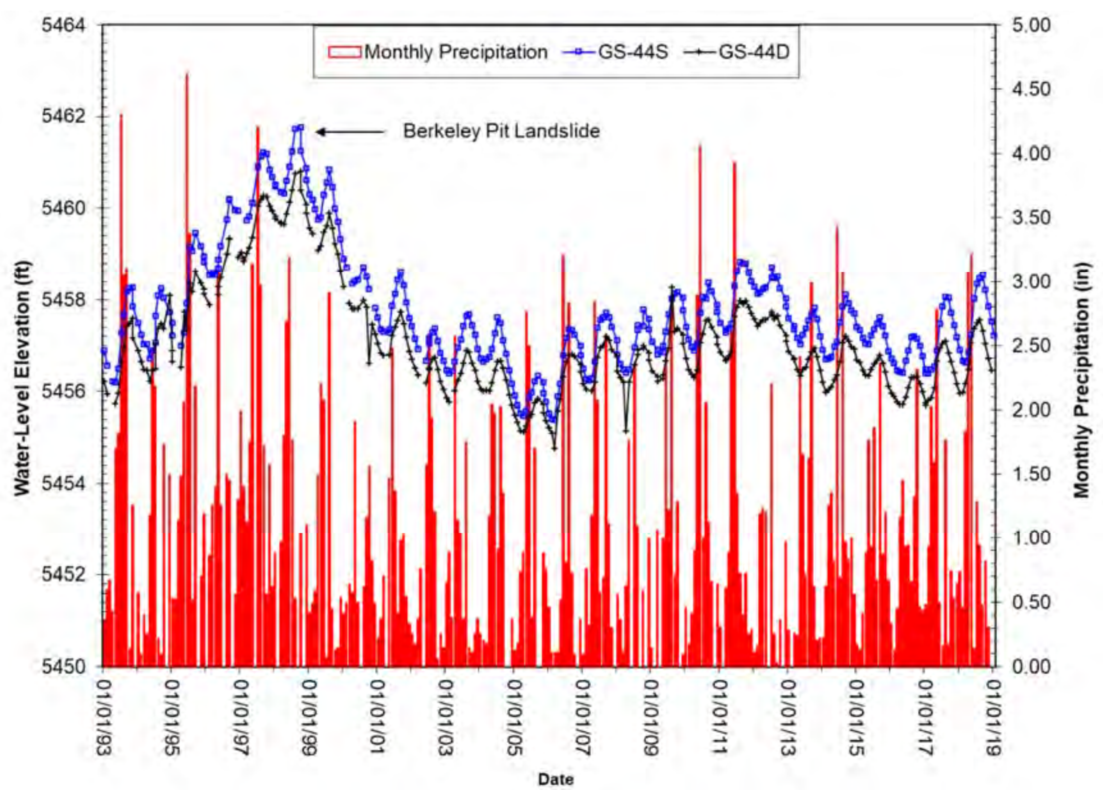


Figure 2-20. Water-level hydrographs for wells GS-44S and GS-44D.

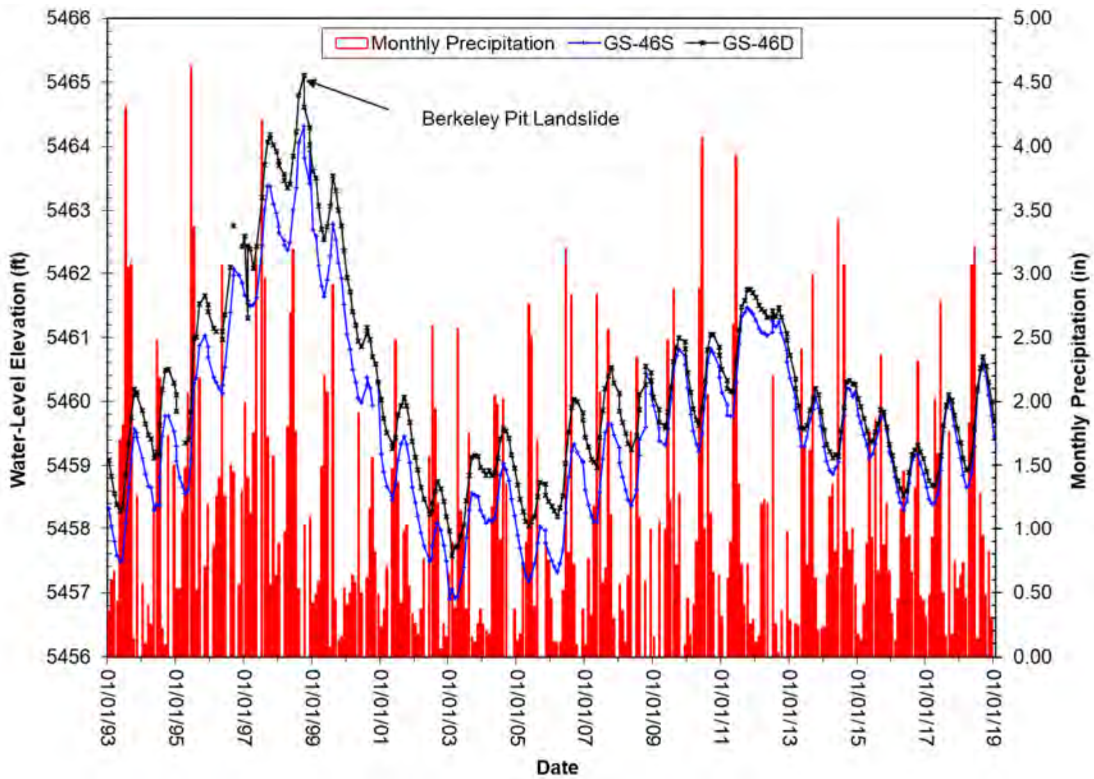


Figure 2-21. Water-level hydrographs for wells GS-46S and GS-46D.

The BMF05-series wells were installed in late 2005 and early 2006 to replace the domestic wells originally part of the post-RI/FS monitoring program. The domestic wells were monitored from 1997 through 2002, but data evaluation by DEQ and EPA determined that dedicated monitoring wells would be more reliable for a long-term monitoring program and would not be influenced by household usage. The locations of the BMF05-series wells are shown in figure 2-18. The well sites were selected to provide coverage for the same area encompassed by the domestic well network and to provide information for areas south of the Berkeley Pit and active mine area. Monitoring this area is important to better define the alluvial aquifer groundwater divide between the BMFOU and the BPSOU. Pressure transducers were installed in the spring of 2006 in each well, and water levels have generally risen since then, ranging between 0.47 ft and 2.30 ft (table 2.4.1).

Figure 2-22 shows daily average water levels for the BMF05-series wells, based upon hourly data recorded by the pressure transducers. The data show a slight overall upward trend in three of the four wells. Well BMF05-1 saw a larger than normal water-level increase during the last quarter of 2011 that corresponds to the refilling of MR’s Ecology Pond following maintenance activities. The water-level decline in 2012 corresponds to draining of the pond and BPSOU dewatering activities along Texas Avenue. Water-level patterns in BMF05-1 were similar to those noted in well AMC-6, located nearby.

Figure 2-23 portrays hydrographs for BMF-series wells based upon monthly water-level measurements and monthly precipitation. Each well's response time to precipitation events varies, most likely as a result of the different depths to water; the deeper the water level, the longer it takes for recharge from snowmelt and precipitation to reach the water table. The seasonal variability is not as pronounced in BMF-series alluvial wells as in the GS-series wells.

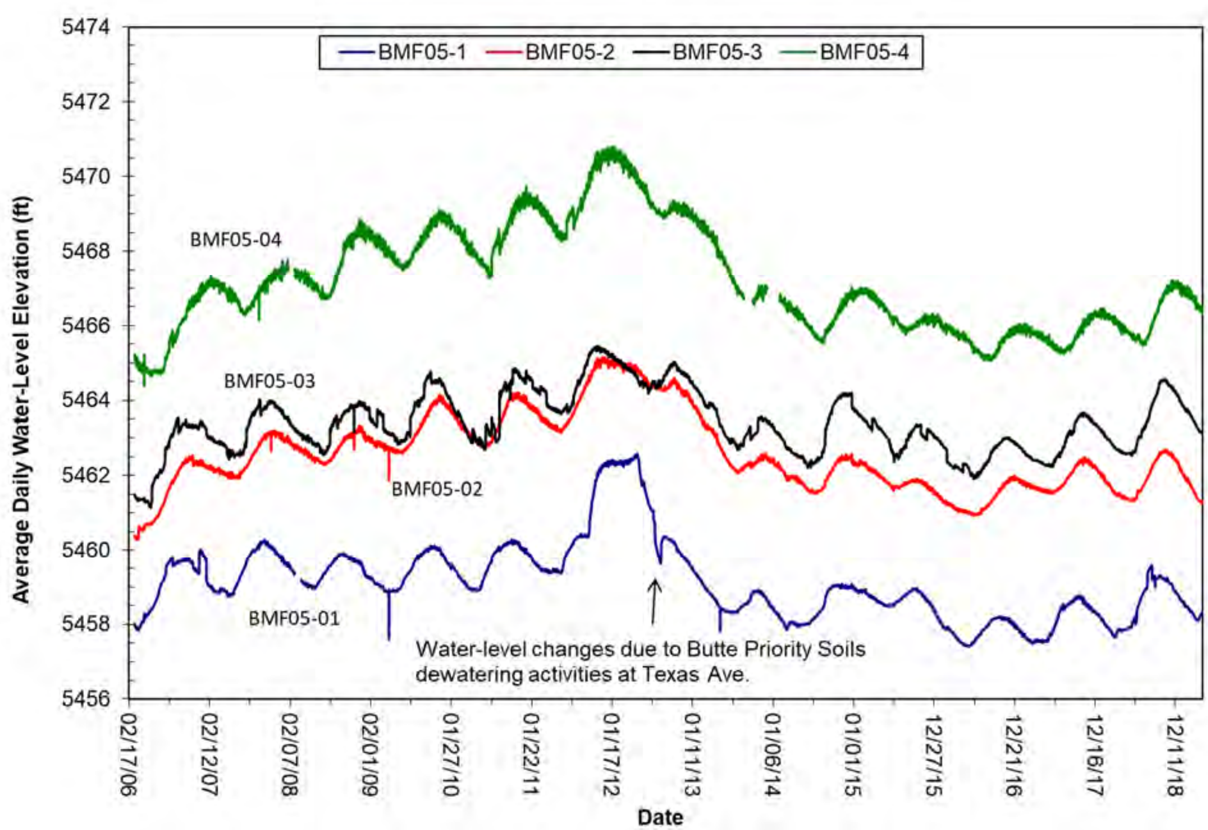


Figure 2-22. Average daily water levels for BMF05-series wells.

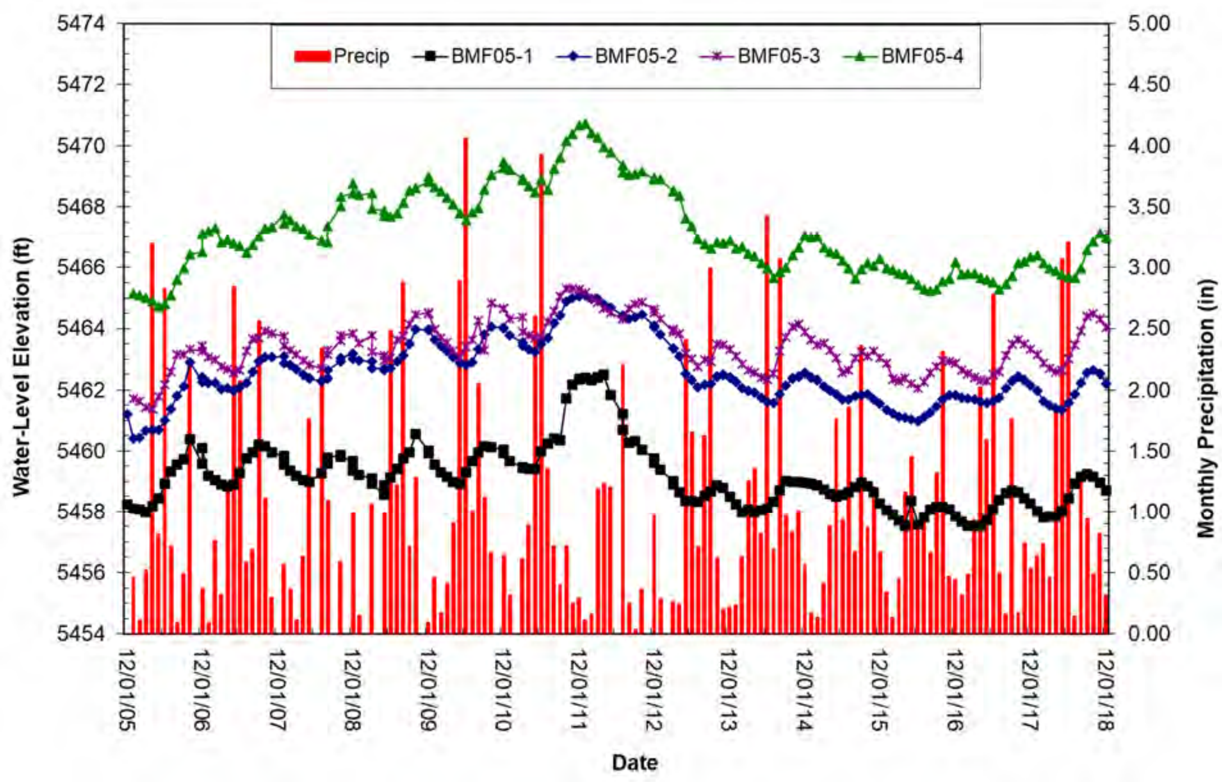


Figure 2-23. Monthly water levels versus precipitation, BMF05-series wells.

Section 2.4.1 GS- and BMF05-Series Wells Water Quality

Water-quality samples were collected during May and June from GS-series wells as part of the 2018 BMFOU monitoring. Complete sample results for the GS- and BMF-series wells are available from the GWIC website at the following location:

http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=MINEFLO-ACTIVE-ECALL&datatype=wq&.

The poor water quality in GS-41S and GS-41D comes from their proximity to the Parrot Tailings area; concentrations of dissolved constituents are extremely high. Data collected in 2018 continue to show a gradual decline of dissolved concentrations in both wells since 2010, following the large concentrations increases seen in 2004.

Concentrations of several dissolved constituents continue to exceed MCLs in wells GS-44S and GS-44D at the north end of Clark Park. Cadmium concentrations in 2018 declined in well GS-44S and are at levels three to six times the MCL in 2010–2018 samples, after being below the MCL for the 2003–2004 periods. Water from well GS-44D also continues to have cadmium concentrations greater than the MCL. Still, the cadmium concentrations have gradually decreased by as much as 50 percent, or more, during the period of record. Manganese and zinc exceeded their SMCLs in 2018 sample results for wells GS-44S and GS-44D.

Wells GS-46S and GS-46D, northeast of Clark Park, continued to produce water of good quality in 2018, and constituent concentrations show little upward or downward trend, with the exception of uranium (GS-46S), which exceeds the MCL in the 2005–2009, 2011, and 2014–2018 samples.

The BMF05 wells were sampled three times each year during 2006–2007 to establish baseline conditions. Semi-annual samples have been collected since 2008. Water from well BMF05-1 is extremely contaminated, with pH less than 5.50 and elevated concentrations of sulfate manganese, cadmium, copper, and zinc; however, concentrations of iron, manganese, and sulfate have been trending down since 2013 (fig 2-24). Table 2.4.1.1 shows the mean values for these constituents and the appropriate MCL or SMCL.

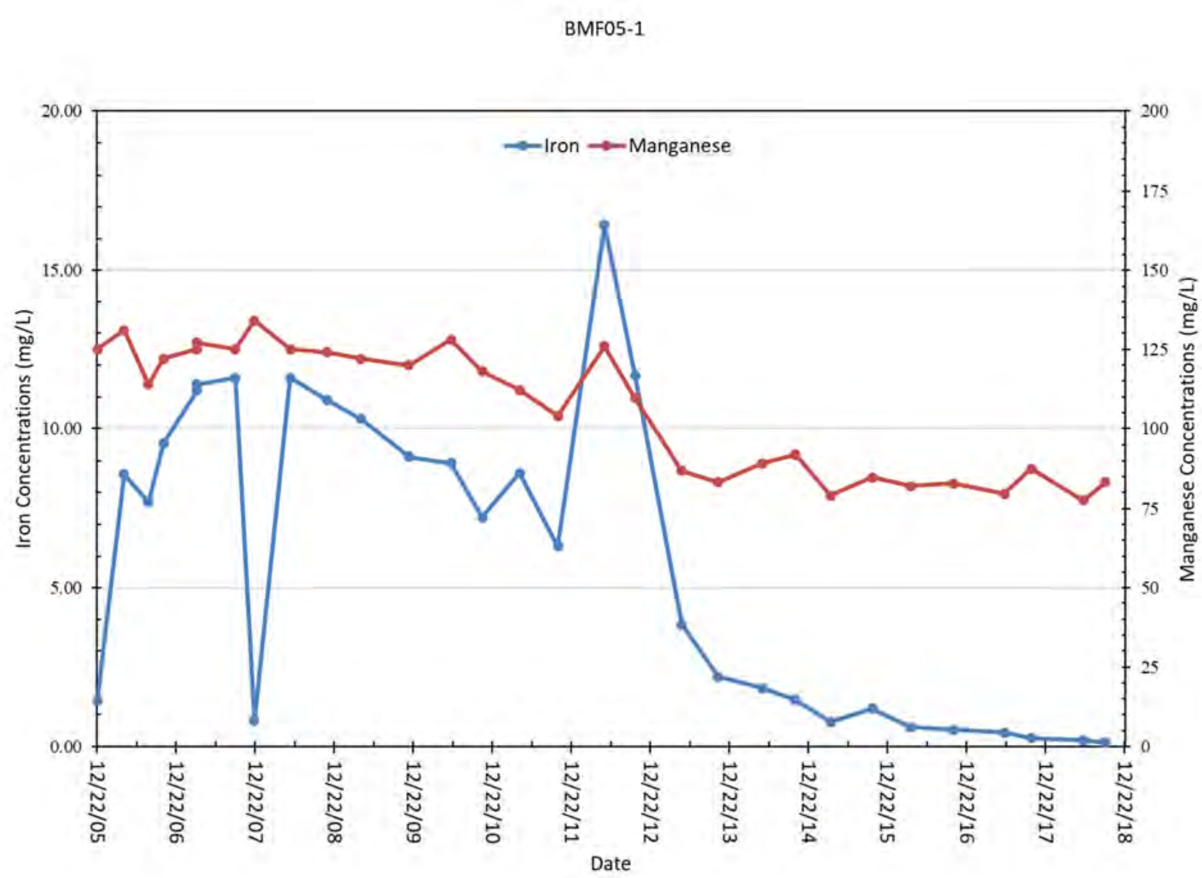


Figure 2-24. Iron and manganese concentration trends in well BMF05-1.

Table 2.4.1.1. Mean concentrations of analytes that exceed water-quality standards, well BMF05-1.

Analyte	Mean Concentration (mg/L)	MCL (mg/L)	SMCL (mg/L)
pH	5.18		6.5–8.5
Iron	5.90		0.30
Manganese	107		0.05
Aluminum	0.629		0.05–0.2
Cadmium	0.185	0.005	
Copper	3.41		1.0
Zinc	43.7		2.0
Sulfate	1,369		250

Well BMF05-1 is adjacent to the historic SBC channel and downgradient from MR's concentrator (fig. 2-18), and it is not surprising that groundwater at this site is contaminated with mining-related wastes. Contaminant concentrations are similar to those in well AMC-5, located to the north. Mean pH values are below the SMCL in water from wells BFM05-2 and BMF05-4; no other analytes exceed MCL or SMCL standards for wells BMF05-2, BMF05-3, and BMF05-4.

SECTION 3.0 EAST CAMP BEDROCK SYSTEM

The East Camp Bedrock Monitoring System consists of the Anselmo, Belmont, Granite Mountain, Kelley, Steward, Lexington, and Pilot Butte mines, and the Berkeley Pit (fig. 3-1), all areas that drained water to the Kelley pump station at the time of mining suspension in 1982. It also includes the bedrock system adjacent to the East Camp mines. The bedrock monitoring wells installed as part of the RI/FS investigation, and selected diamond drill exploration boreholes located primarily to the east of the Berkeley Pit, are part of the system.

Section 3.1 Underground Mines and Berkeley Pit Water Levels

Monitoring of water levels in the seven East Camp underground mines continued during 2018. Water levels in the mines rose between 6.31 and 8.55 ft in 2018, while the Berkeley Pit water level rose 7.21 ft, all similar to the 2017 increases (table 3.1.1). Figure 3-2 shows the annual water-level changes for these sites. The rate of water-level rise has slowed by 50 to 60 percent since 2003 when MR diverted the HSB drainage water away from the pit.

Table 3.1.1. Annual water-level changes in East Camp mines (ft).

Year	Berkeley Pit	Anselmo	Kelley	Belmont[1]	Steward	Granite Mountain	Lexington[2]	Pilot Butte
1982			1,303.80	117.20	85.10			
1983			877.30	1,054.20	1,069.80			
1984			261.80	269.20	274.00			
1985			122.40	121.50	123.40			
1986		55.90	95.70	101.70	100.50			
1987		76.80	84.42	76.60	79.30	67.00		
1988		52.70	55.50	53.20	51.80	57.00	8.10	
1989		29.10	30.50	30.70	29.47	31.00		
1990		31.50	33.20	33.80	33.28	34.00		
1991	12.00	28.60	32.80	30.40	28.90	31.00		
Change Years 1–10	**12.00**	**274.60**	**2,897.42**	**1,887.50**	**1,875.55**	**220.00**	**8.10**	**00.00**
1992	25.20	22.10	23.77	23.50	23.00	25.00		
1993	25.97	24.30	24.57	25.60	24.60	26.00		
1994	26.86	25.10	25.82	25.34	24.93	27.00		
1995	28.71	27.69	27.05	17.77	27.63	30.00		
1996	18.00	16.47	18.82	4.15	18.43	18.00	1.19	3.07
1997	12.45	13.58	16.09	15.62	14.80	15.68	12.79	18.12
1998	17.08	13.23	14.73	13.89	14.33	14.24	13.71	11.26
1999	12.53	11.07	11.52	12.15	11.82	11.89	10.65	11.61
2000	16.97	14.48	14.55	15.66	14.60	15.09	14.01	14.11
2001	17.97	16.43	11.77	16.96	16.48	16.35	15.95	16.59
Change Years 11–20	**201.74**	**184.45**	**188.69**	**170.64**	**190.62**	**199.12**	**68.30**	**74.76**
2002	15.56	11.60	13.15	13.02	12.60	12.82	12.08	11.33
2003	13.08	13.05	13.94	13.74	13.44	14.23	2.75	14.05
2004	7.68	7.31	7.86	7.54	7.48	7.67		7.53
2005	7.03	7.10	7.37	7.17	7.00	6.98		6.97
2006	7.69	7.70	8.29	7.74	7.99	7.92		8.61
2007	6.90	6.91	7.55	6.38	7.25	7.28		7.39
2008	6.63	5.42	6.28	7.01	5.58	5.68		6.13
2009	7.17	6.69	6.79	7.33	7.13	6.92	52.79	6.38
2010	7.32	7.30	7.83	7.45	7.80	6.48	7.03	7.07
2011	7.20	7.31	8.22	8.46	7.11	8.99	7.91	9.11
Change Years 21–30	**86.26**	**80.39**	**87.28**	**85.84**	**83.38**	**84.97**	**82.56**	**84.57**
2012	6.74	6.54	6.42	6.67	6.43	6.42	7.08	5.96
2013	8.12	6.87	6.98	6.84	6.62	6.72	6.85	6.77
2014	6.95	7.25	8.58	8.08	7.23	7.71	7.49	7.34
2015	9.96	8.70	8.36	8.06	8.15	8.59	8.66	8.76
2016	5.52	6.18	6.61	6.61	6.31	3.28	6.45	4.89
2017	7.25	7.11	7.27	6.77	6.48	NA	6.14	8.48
2018	7.21	6.31	7.48	7.22	7.33	NA	7.52	8.55
Change Years 31–40	**51.75**	**48.96**	**51.70**	**50.25**	**48.55**	**NA**	**50.19**	**50.75**
Net Change*	**351.75**	**588.4**	**3,225.09**	**2,194.23**	**2,198.1**	**NA**	**209.15**	**210.08**

Note. Minus sign (-) indicates a decline (drop) in water level.

[1]Mine shaft collapsed in 1995; a replacement well was drilled adjacent to the mine, into mine workings, in 1997. Since the well was drilled into the Belmont Mine workings, it is assumed that this water level represents conditions in the Belmont shaft.

[2]No water-level measurements from February 2003 to April 2009, due to obstruction in shaft at 366 ft below surface.

*Total change is the measured change in water level. Access or an obstruction has prevented continuous water-level measurements at some sites.

Figure 3-1. East Camp mines and bedrock wells location map.

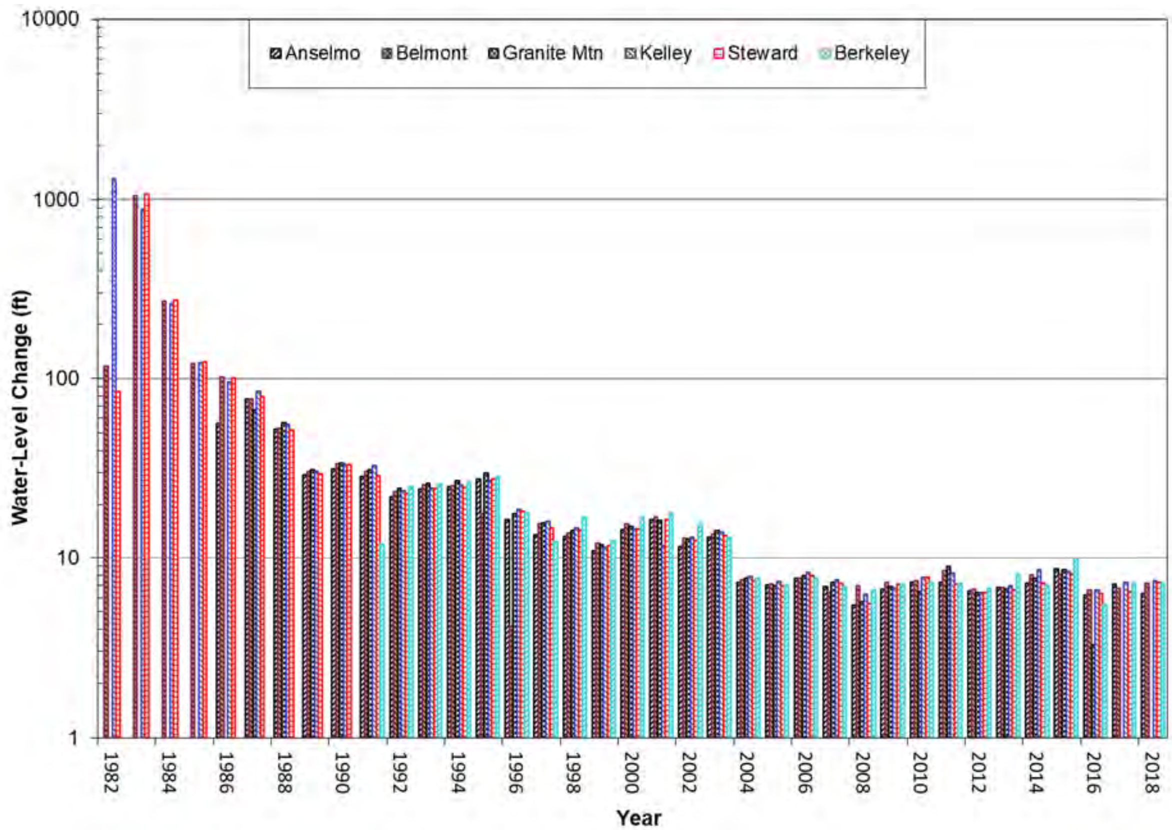


Figure 3-2. East Camp mines annual water-level changes.

Water levels for the Anselmo Mine and Kelley Mine for the period of record are shown in the hydrographs in figure 3-3. At this scale, there is a consistent upward trend. Deviations from the general rate of rise become apparent (fig. 3-4) from 1995 to the present. The removal of HSB drainage water discharging into the pit in April 1996 slowed the rate of water-level rise, but the July 2000 re-diversion of the HSB drainage water to the pit, following MR's suspension of mining, resulted in an increased rate of rise. The slope of the line since 2004, or rate of rise, shown in figure 3-4, remained constant throughout 2018, corresponding to the continued diversion of HSB drainage water to the HSB treatment plant, which came online in late November 2003. Water levels in all the East Camp underground mines reacted similarly.

There is no apparent influence from monthly precipitation on water levels in the underground mines (fig. 3-3). The water-level rise is a function of the time since mine-dewatering activities ceased, and the volume flooded in the underground mine workings and Berkeley Pit; these signals overwhelm any precipitation signal. Based upon volume estimates of the underground mines and December 2018 water-level elevations, 85 percent of the underground workings are flooded. Because approximately 12 percent of the underground workings are above the PWL elevation of 5,410 ft, less than 3 percent of the underground workings remain to be flooded.

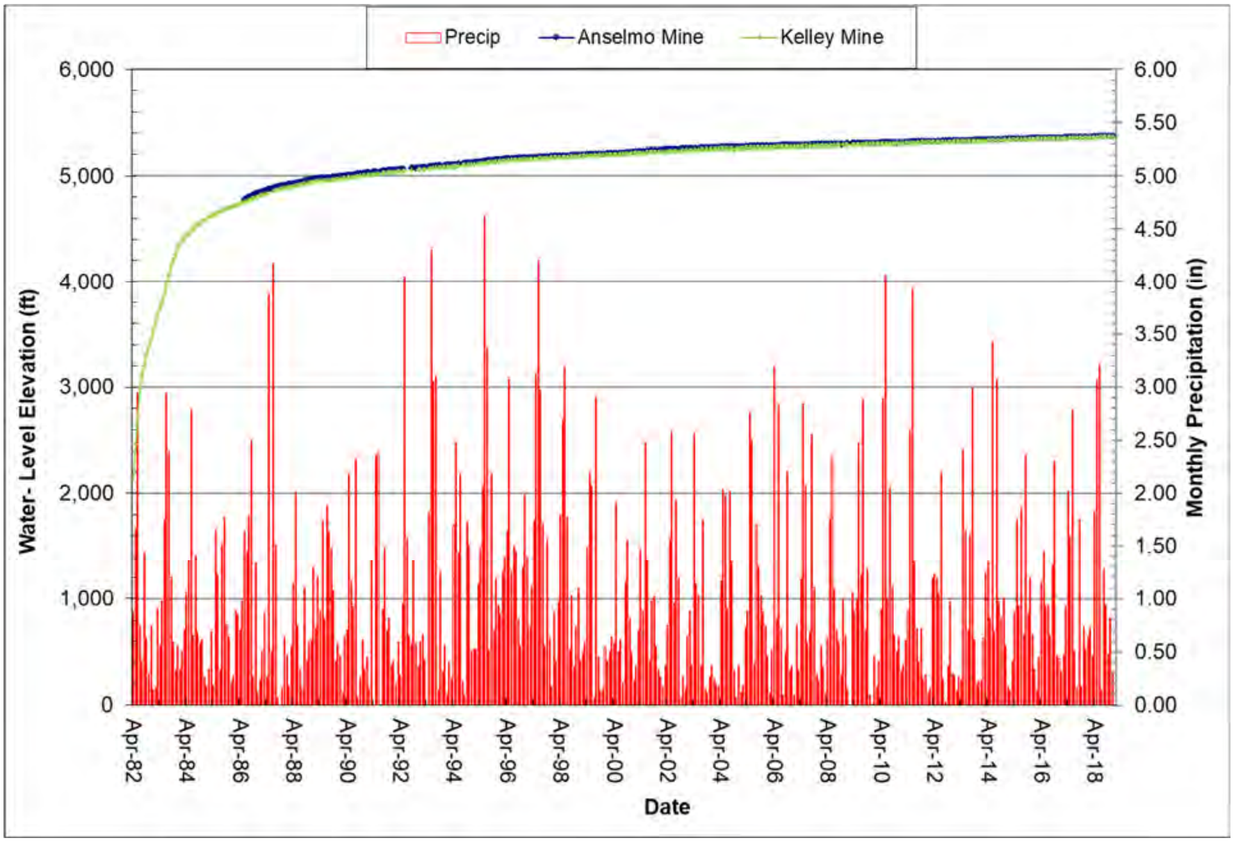


Figure 3-3. Anselmo Mine and Kelley Mine hydrographs versus precipitation, 1982–2018.

Figure 3-5 shows monthly water-level changes in the Berkeley Pit from 1991 through 2018. Water-level changes resulting from operational changes, e.g., diversion of HSB water in 1996, the 1998 landslide, and the HSB water-treatment plant coming online, are noticeable. The rate of rise decreased beginning in the fall of 2003, a result of the HSB treatment plant coming online and decreasing inflow of water into the pit.

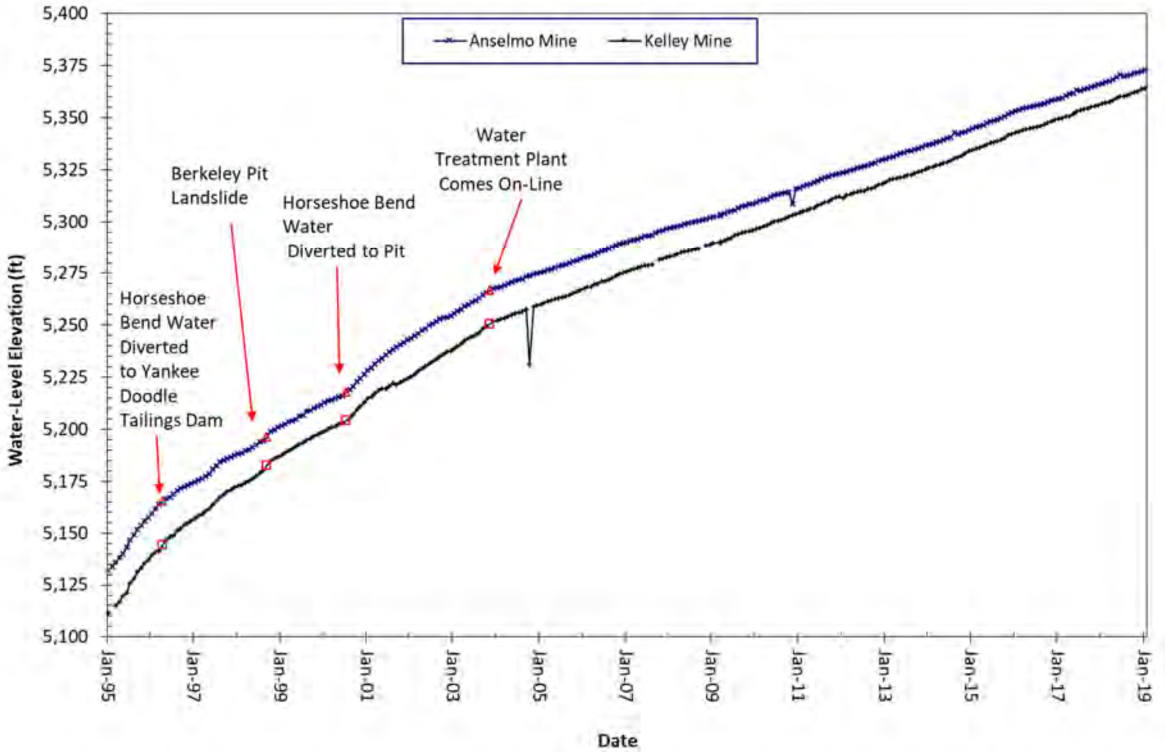


Figure 3-4. Anselmo Mine and Kelley Mine hydrographs, 1995–2018.

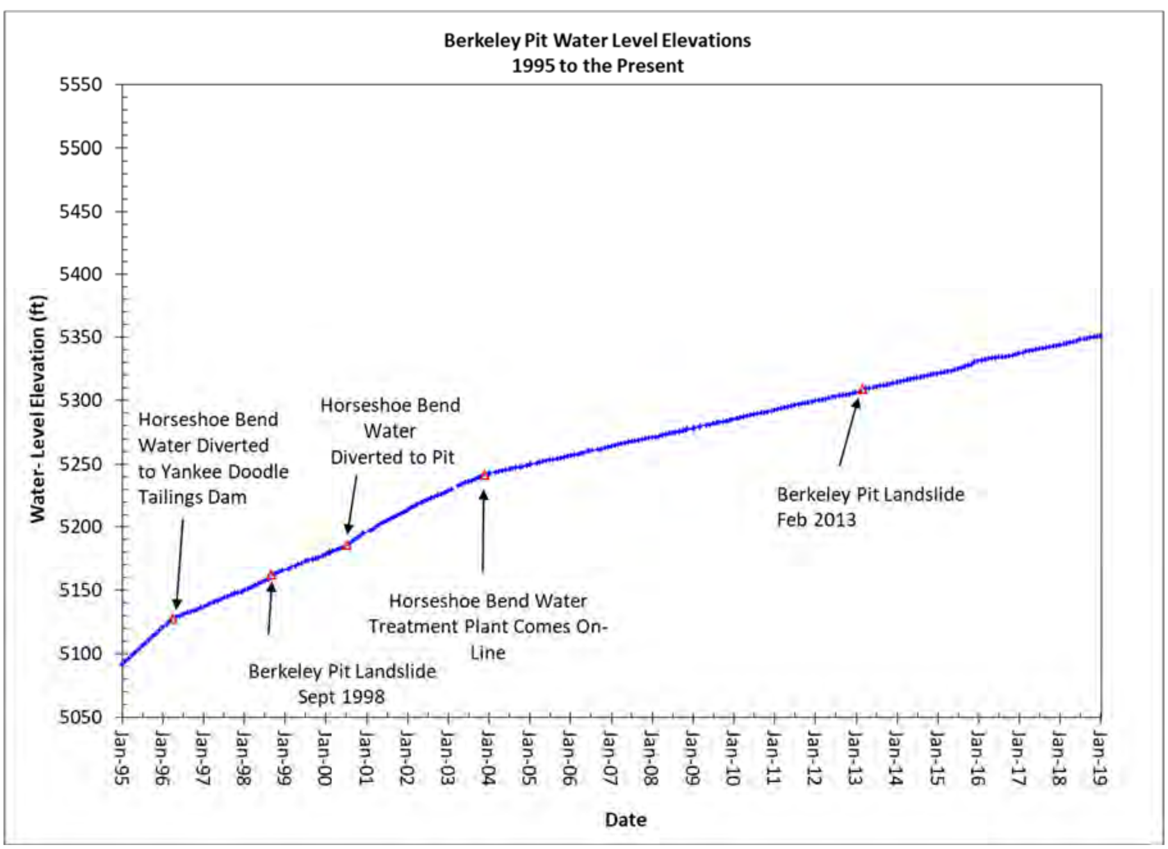


Figure 3-5. Water-level hydrograph for the Berkeley Pit, 1995–2018.

The 1994 ROD and 2002 CD established 14 POCs in the East Camp bedrock system, seven underground mines and seven bedrock monitoring wells. These POCs were selected to verify that contaminated water was contained within the underground mine system and Berkeley Pit. Under the terms specified in the ROD and CD, groundwater levels cannot exceed 5,410 ft above mean sea level at any POC without monetary penalties being applied to the settling parties. The East Camp POC with the highest water level at the end of 2018 was the Pilot Butte Mine, about 0.5 mi north of the Berkeley Pit, at an elevation of 5,377 ft, or 33 ft below the action level. The lowest water level at the end of 2018 was 5,351 ft in the Berkeley Pit, which confirms that groundwater continues to flow towards the pit.

Section 3.2 Underground Mines and Berkeley Pit Water Quality

Earlier reports (Duaime and others, 1998; Metesh and Duaime, 2002) discussed the lack of appreciable change in water quality within the East Camp mines until 2002, when water quality in several of the shafts exhibited significant departure (increases of contaminant concentrations) from previous trends. Data from the 2018 sampling indicate that the changes in concentration are sustained for yet another year. Most notable are elevated concentration of arsenic, iron, and manganese in the Kelley Mine waters; concentrations of zinc and sulfate have gradually decreased the past few years and are approaching pre-2002 concentrations. The Anselmo, Kelley, and Steward mines were sampled during the spring 2018 sample event at a depth of 100 ft below the water surface. No samples were collected from deeper depths in the mines due to obstructions in the shafts. Concentrations varied very little with sample depth in previous years. Complete sample results for the LP-series wells are available from the GWIC website at the following location: http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=MINEFLO-ACTIVE-ECBED&datatype=well&.

Kelley: Iron, sulfate, arsenic, zinc, and aluminum increased to near historic concentrations in 2003–2004, and have shown a gradual decline from 2005 to 2018 (fig. 3-6). Copper concentrations increased in the 2010 samples and remained stable through 2016. 2018 sample results were similar to the 2010–2016 results; however, they remain well below the SMCL.

Anselmo: Iron concentrations remain elevated (>20 mg/L); arsenic concentrations were similar to those in 2004–2017 (>100 µg/L); zinc concentrations almost doubled between the 2017 and 2018 sample results (7,600 versus 14,600 µg/L; fig. 3-7). Copper concentrations remain low (<20 µg/L).

Steward: Iron, manganese, and arsenic concentrations remain high, following the increase seen in 1988. The trend has been downward for zinc since 1996, with a slight increase in 2015 and 2017–2018 (fig. 3-8).

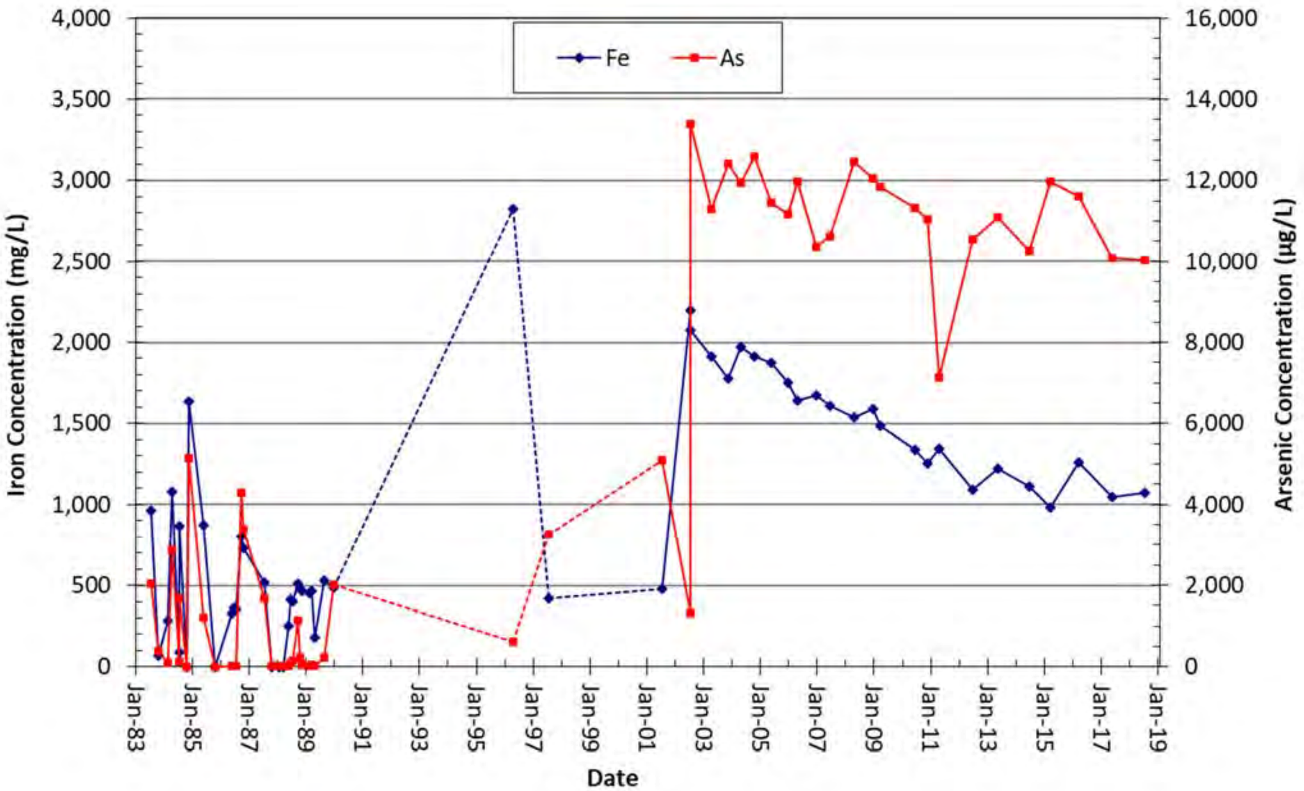


Figure 3-6. Kelley Mine iron and arsenic concentrations over time.

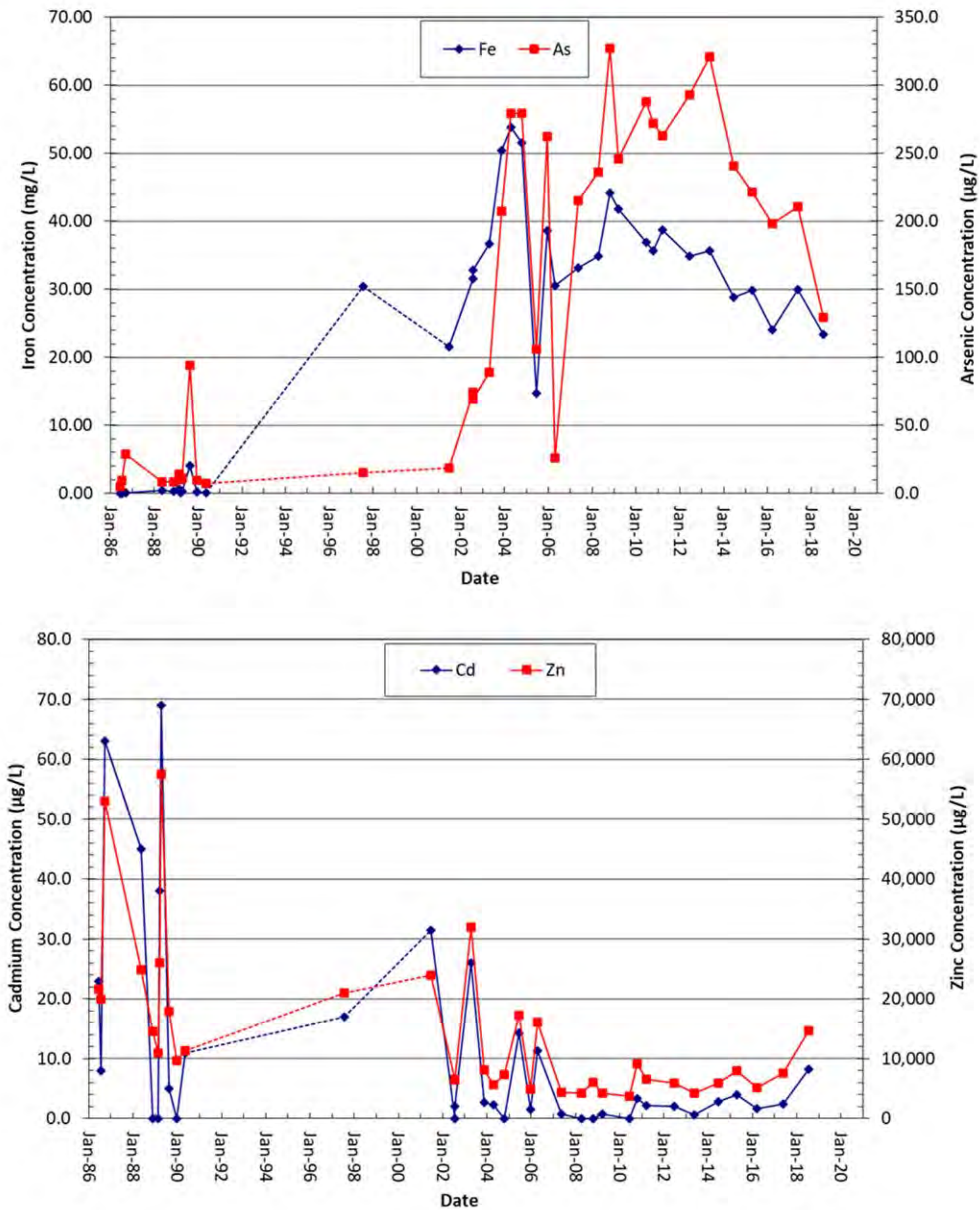
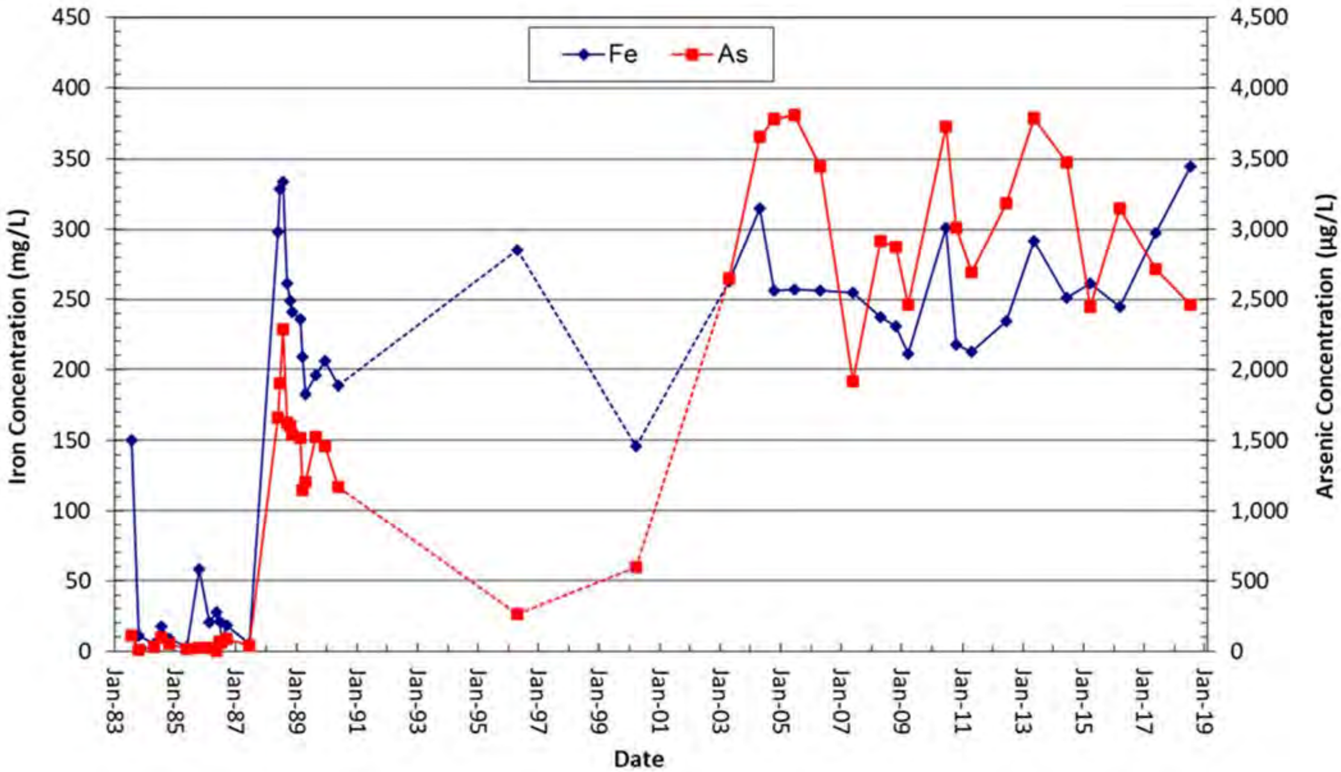


Figure 3-7. Anselmo Mine iron and arsenic concentrations (top) and cadmium and zinc concentrations (bottom) over time.



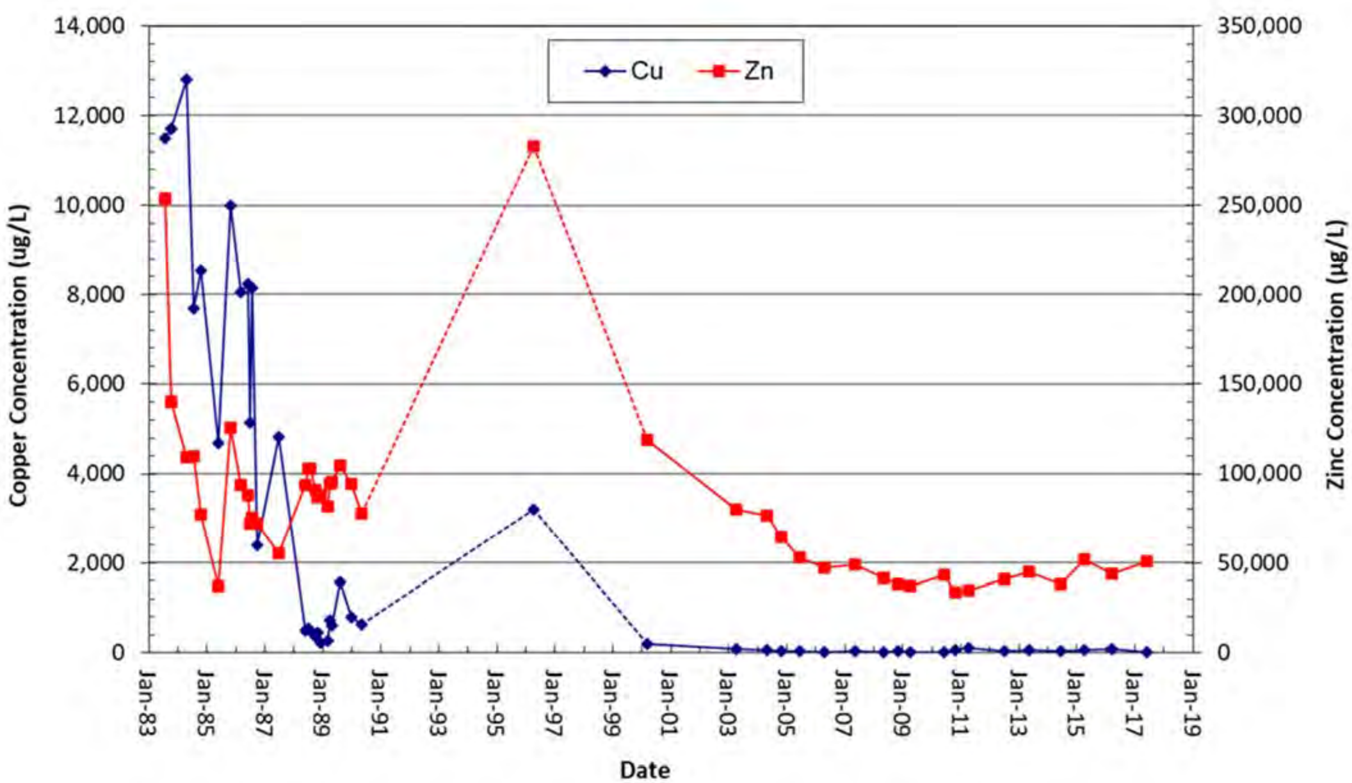


Figure 3-8. Steward Mine iron and arsenic concentrations (top); copper and zinc concentrations (bottom) over time.

Section 3.3 Bedrock Monitoring Wells

The bedrock-monitoring network consists of nine wells installed during the RI/FS investigation and two wells from previous AMC exploration activities in the late 1970s. These wells are mostly located in the area east of the Berkeley Pit.

Section 3.3.1 Bedrock Well Water Levels

Monitoring of the nine RI/FS and ROD-installed bedrock wells continued. Monitoring well locations are shown in figure 3-1. Water levels rose in wells A, B, C, D-1, D-2, G, and J at rates similar to those in the East Camp Mine system, while water levels in wells E and F increased at lesser rates. Table 3.3.1.1 contains yearly water-level changes; figure 3-9 shows these changes graphically.

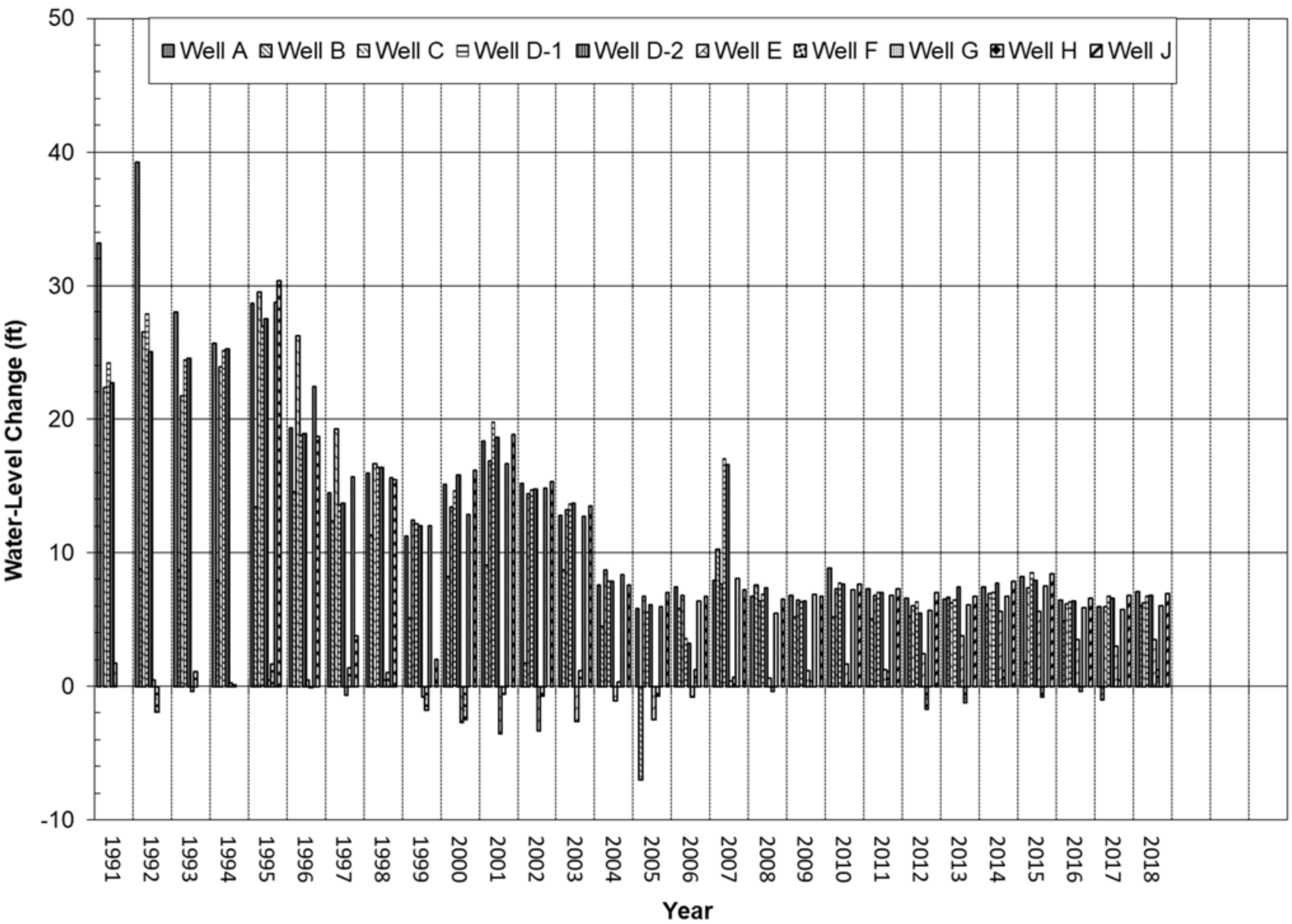


Figure 3-9. Annual water-level change in bedrock wells initially decreased then stabilized since about 2004.

Water levels in the bedrock aquifer, which had been lowered by historic underground mine dewatering, are responding to the cessation of pumping and show no apparent relationship to precipitation or seasonal changes through 2018. Physical changes that affect the flow of water into the Berkeley Pit and underground mines, e.g., the 1996 HSB water diversion and the 2000 addition of the HSB drainage flow, also influence the rate of water-level increase. Figure 3-10 is a hydrograph for well A showing monthly water levels and monthly precipitation totals with the 1996, 2000, and 2003 HSB operational changes identified. The void areas in the mines and Berkeley Pit are the principal controls on the annual rate of rise in this system. Minor, short-term water-level declines were observed in several bedrock wells following the July 6, 2017 Lincoln, Montana earthquake. Bedrock well B is the only site where the effects of the earthquake were longer-term.

Table 3.3.1.1. Bedrock well annual water-level change (ft).

	Well A	Well B	Well C	Well D-1	Well D-2	Well E	Well F	Well G	Well H[(1)]	Well J[(2)]
1982										
1983										
1984										
1985										
1986										
1987										
1988										
1989										
1990										
1991	33.18		22.38	24.20	22.68	1.73				
Change Years 1–10	33.18		22.38	24.20	22.68	1.73				
1992	39.22	8.78	26.53	27.89	25.04	0.47	-1.92			
1993	27.95	8.68	21.72	24.41	24.51	-0.37	1.09			
1994	25.65	7.90	23.88	25.12	25.21	0.27	0.11			
1995	28.69	13.41	29.55	26.99	27.50	0.44	1.65	28.74	30.37	
1996	19.31	14.56	26.22	18.77	18.92	0.48	-0.11	2.40	8.72	
1997	4.44	2.35	9.25	13.62	13.68	-0.64	1.41	15.67	3.76	
1998	15.96	11.30	16.68	16.41	16.39	0.44	1.03	15.56	15.44	
1999	11.21	5.11	12.44	12.18	12.03	-0.78	-1.80	12.00	P&A	1.99
2000	15.12	8.20	13.39	14.66	15.79	-2.68	-2.49	12.84	P&A	16.19
2001	18.33	9.08	16.86	19.81	18.61	-3.58	-0.61	16.56	P&A	18.81
Change Years 11–20	215.88	99.37	206.52	199.86	197.68	-5.95	-1.64	123.86	68.29	36.99

Note. Minus sign (-) indicates a decline (drop) in water level.

Table 3.3.1.1. Bedrock well annual water-level change (ft)—*Continued.*

Year	Well A	Well B	Well C	Well D-1	Well D-2	Well E	Well F	Well G	Well H[1]	Well J[2]
2002	15.16	1.73	14.41	14.69	14.76	-3.37	-0.73	14.84	P&A	15.29
2003	12.75	8.70	13.20	13.69	13.72	-2.66	1.16	12.71	P&A	13.48
2004	7.60	4.46	8.71	7.90	7.83	-1.12	0.32	8.31	P&A	7.58
2005	5.82	-7.00	6.76	5.56	6.08	-2.51	-0.73	5.95	P&A	7.03
2006	7.44	5.82	6.81	3.56	3.20	-0.83	1.22	6.39	P&A	6.72
2007	7.93	10.23	7.64	17.01	16.56	0.38	0.67	8.06	P&A	7.23
2008	6.70	7.59	6.40	6.89	7.36	0.59	-0.41	5.47	P&A	6.49
2009	6.79	5.18	6.41	6.37	6.34	1.14	0.39	6.90	P&A	6.70
2010	8.87	5.19	7.29	7.77	7.62	1.69	0.24	7.22	P&A	7.64
2011	7.32	5.04	6.82	7.01	7.00	1.27	1.06	6.77	P&A	7.29
Change Years 21–30	86.38	46.94	84.45	90.46	90.47	-5.42	3.19	82.62	0.00	85.45
2012	6.55	5.24	6.02	6.37	5.44	2.46	-1.72	5.67	P&A	7.03
2013	6.54	6.66	6.24	6.51	7.41	3.74	-1.20	6.07	P&A	6.70
2014	7.44	6.12	6.92	7.03	7.69	5.62	1.45	6.70	P&A	7.86
2015	8.20	1.79	7.33	8.54	7.89	5.59	-0.78	7.52	P&A	8.44
2016	6.43	4.91	6.14	6.31	6.36	3.49	-0.35	5.90	P&A	6.61
2017	5.94	-1.02	5.92	6.73	6.57	2.97	0.46	5.76	P&A	6.80
2018	7.07	6.02	6.21	6.75	6.82	3.52	1.26	6.01	P&A	6.97
Change Years 31–40	**48.17**	**29.72**	**44.78**	**48.24**	**48.18**	**27.39**	**-0.88**	**43.63**	**0.00**	**50.41**
Net Change	**383.61**	**176.03**	**358.13**	**362.76**	**359.01**	**17.75**	**0.67**	**250.11**	**68.29**	**172.85**

Note. Minus sign (-) indicates a decline (drop) in water level.
[1]Well plugged and abandoned (P&A) due to integrity problems.
[2]Well J was drilled as a replacement for well H.

Table 3.3.1.1. Bedrock well annual water-level change (ft)—*Continued.*

Year	DDH-1[3]	DDH-2	DDH-4	DDH-5	DDH-8
1982					
1983					
1984					
1985					
1986					
1988					
1989	29.53			34.83	30.48
1990	36.24	30.99	5.44	217.61	35.96
1991	27.03	28.20	39.81	27.01	28.96
Change Years 1–10	**92.80**	**59.19**	**45.25**	**89.45**	**95.40**
1992	28.25	26.09	37.66	21.07	26.16
1993	24.33	24.16	26.88	24.40	24.46
1994	25.00	25.65	28.34	19.78	15.97
1995	27.66	28.74	28.80	26.10	---
1996	18.53	18.97	2.24	12.41	55.68
1997	13.33	14.09	14.32	15.89	13.38
1998	15.03	16.20	16.25	16.50	16.50
1999	11.66	12.00	11.88	4.85	15.50
2000	14.64	16.11	14.77	P&A	10.42
2001	18.14	18.78	18.52	P&A	18.93
Change Years 11–20	**196.47**	**200.79**	**217.66**	**150.97**	**197.00**

Table 3.3.1.1 Bedrock well annual water-level change (ft)—*Continued.*

Year	DDH-1[3]	DDH-2	DDH-4	DDH-5	DDH-8
2002	14.63	14.80	13.14	P&A	13.64
2003	13.05	13.90	NA	P&A	14.49
2004	7.08	7.89	NA	P&A	7.90
2005	4.87	5.89	NA	P&A	57.52
2006	6.30	6.75	NA	P&A	6.03
2007	3.08	8.75	NA	P&A	5.90
2008	P&A	6.58	NA	P&A	4.62
2009	P&A	6.97	NA	P&A	5.15
2010	P&A	7.50	NA	P&A	4.60
2011	P&A	7.44	NA	P&A	4.93
Change Years 21-30	**49.01**	**86.47**	**13.14**	**0.00**	**124.78**
2012	P&A	7.10	NA	P&A	2.51
2013	P&A	6.76	NA	P&A	3.08
2014	P&A	7.84	NA	P&A	4.52
2015	P&A	8.41	NA	P&A	4.40
2016	P&A	5.61	NA	P&A	4.02
2017	P&A	7.67	NA	P&A	3.86
2018	P&A	6.32	NA	P&A	3.79
Change Years 31-40	**0.00**	**49.71**	**0.00**	**0.00**	**26.18**
Net Change	**338.28**	**396.16**	**276.05**	**240.42**	**443.36**

Note. Minus sign (-) indicates a decline (drop) in water level.

*Total change is the measured change. Access or obstructions prevented continuous water-level measurements at some sites.

[3]Well DDH-1 plugged, no data after July 2007.

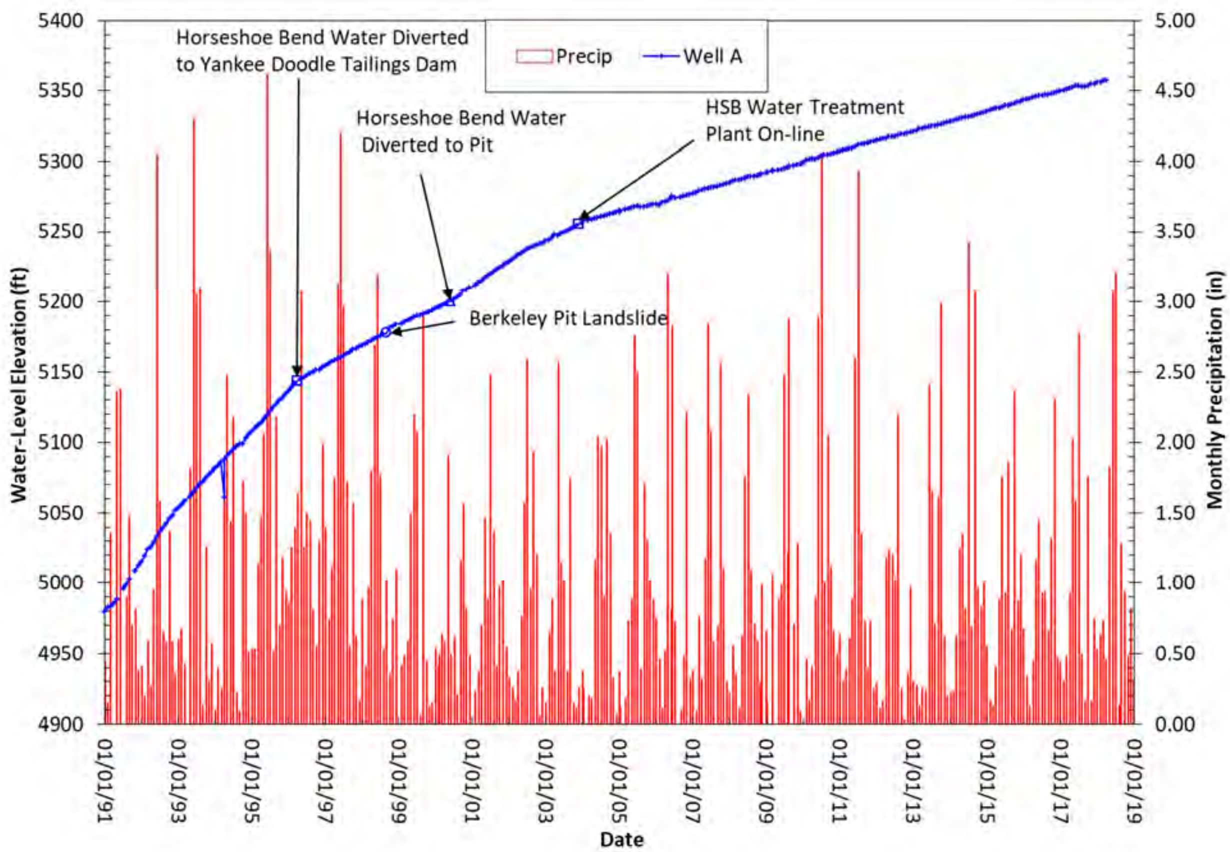
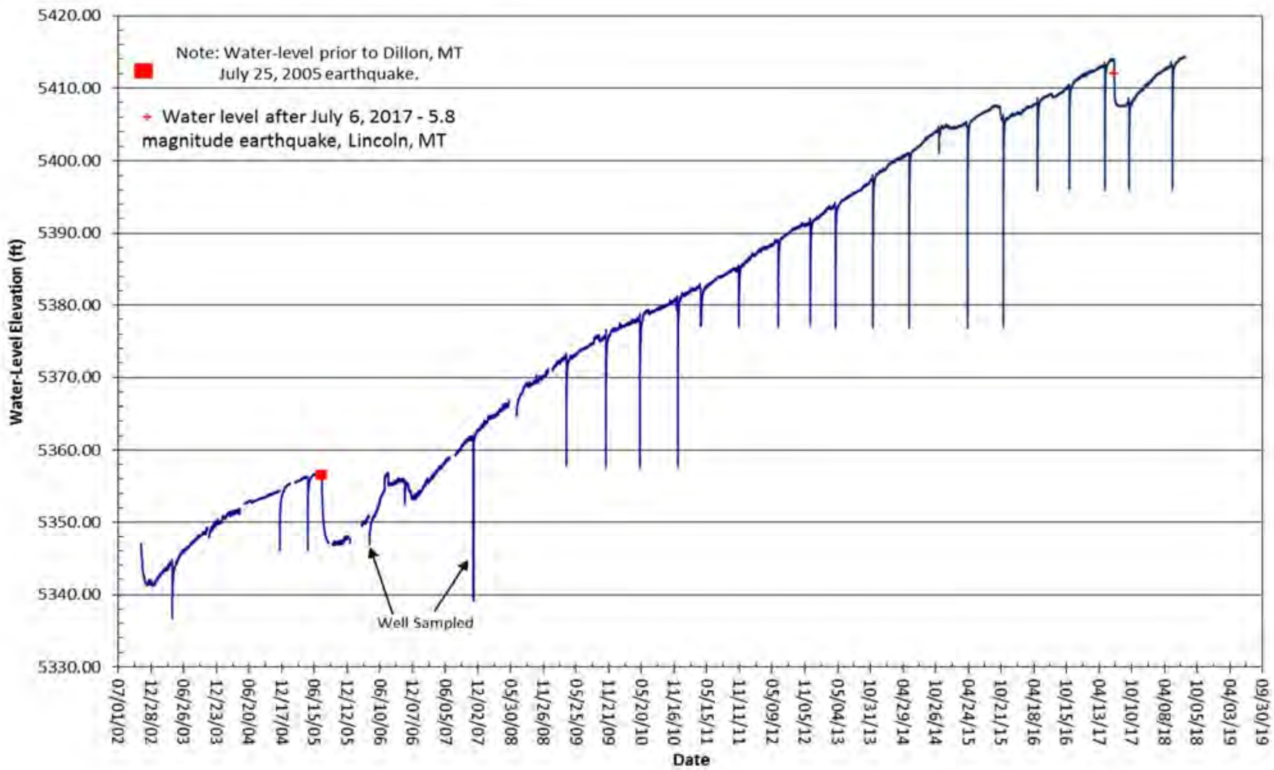


Figure 3-10. Water-level hydrograph for bedrock well A.

The water-level change in well B over a number of years was about one-half of that in the other bedrock wells and the Berkeley Pit. Beginning in 2003 and 2004, water-level increases were closer to 60 percent that of the other bedrock wells; however, the apparent influence of the July 25, 2005 Dillon, Montana earthquake and slow recovery from water-quality sampling caused water levels to fall about 7 ft. The 2006 water-level increase was about 75 percent that of the Berkeley Pit, indicating there were no long-term effects in water levels from the 2005 earthquake. The 2007 water-level increase in well B was almost 130 percent that of well A and 150 percent of the Berkeley Pit, which is the first time the annual water-level increase in this well exceeded that of these other sites. The 2013–2016 and 2018 water-level increases varied from 20 and 100 percent that of the other bedrock wells. Water levels in this well dropped immediately following the July 6, 2017 Lincoln, Montana earthquake and because of additional drawdown caused by pumping and sampling, had not returned to pre-earthquake levels by year-end. Figure 3-11 (top) shows the water-level response to both the 2005 Dillon and 2017 Lincoln earthquakes over the long-term hydrograph for well B; figure 3-11 (bottom) shows the comparison in water-level response between wells A and B.



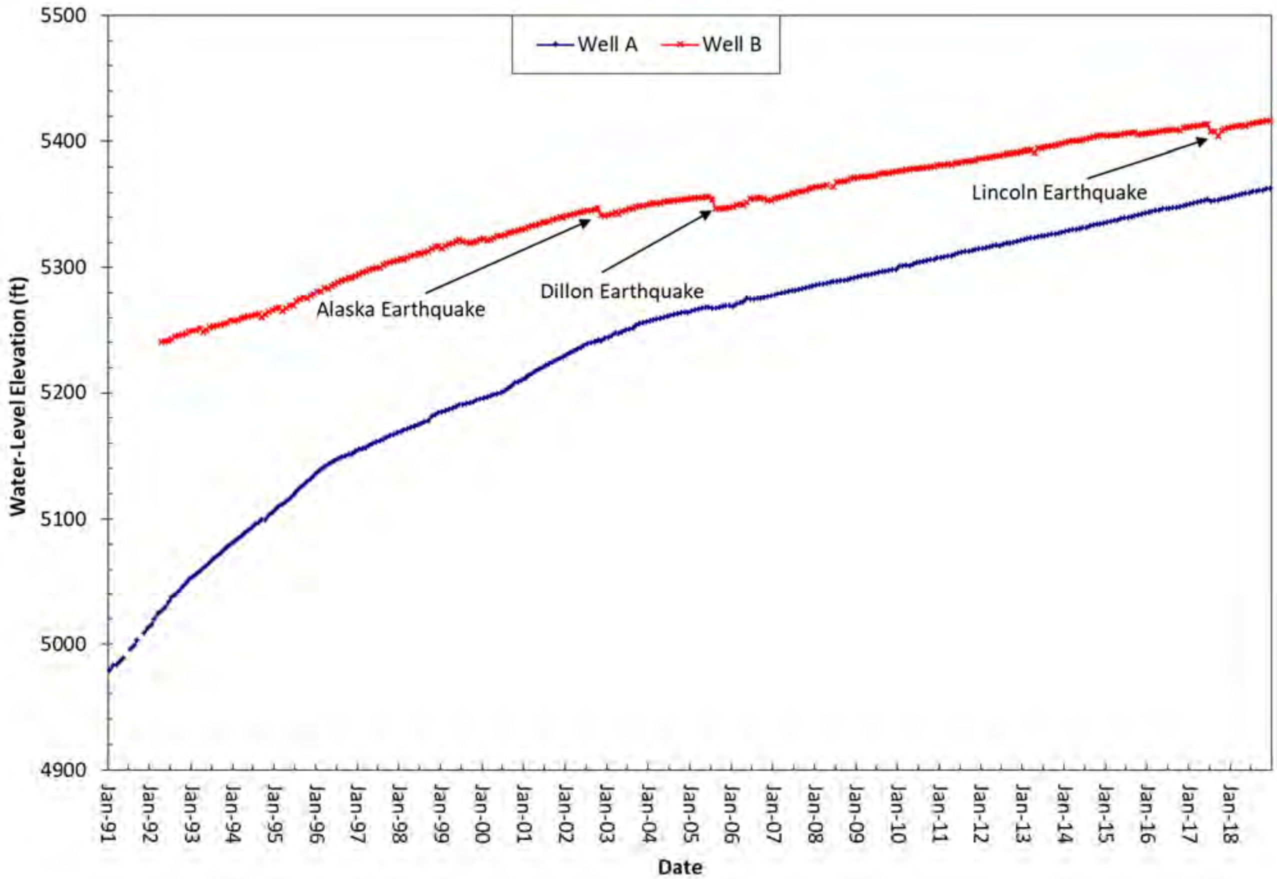


Figure 3-11. Water-level hydrographs for East Camp bedrock wells B (top) showing water-level response to earthquakes and (bottom) showing a comparison of bedrock wells A and B earthquake responses.

Water levels in wells E and F do not follow the long-term upward patterns observed in most of the other bedrock wells (fig. 3-12). Water levels in these two wells are considerably higher than those in the other bedrock wells, indicating that the bedrock aquifer at these locations was not as affected by dewatering from historic mining activities. The water levels have a net increase of about 17.7 ft in well E and 0.41 ft in well F over time. The increase in water levels since 2007 in well E may be in response to rising water levels in the surrounding bedrock system.

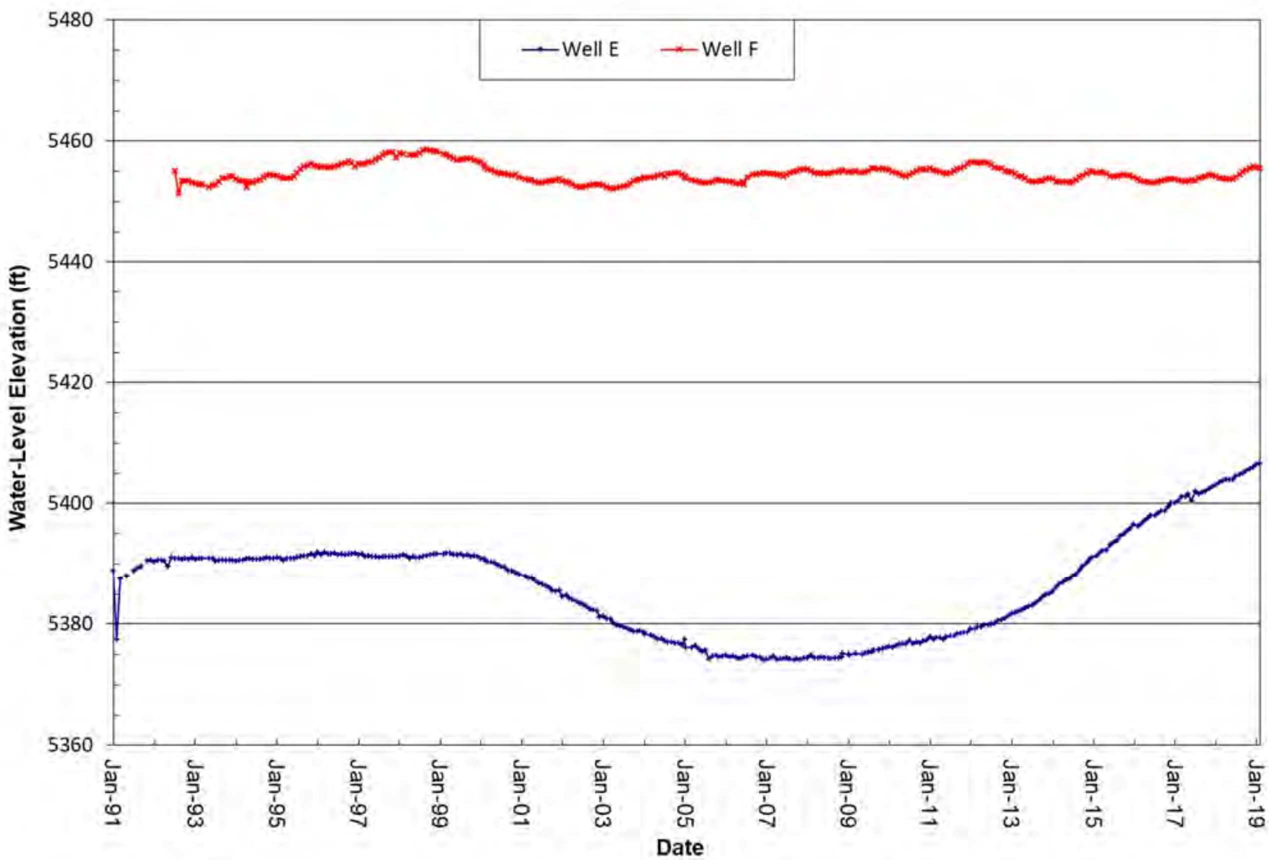


Figure 3-12. Water-level hydrographs for East Camp bedrock wells E and F.

Well H was plugged and abandoned due to casing integrity problems in 1999, and well J was drilled as a replacement. Water-level rises measured in well J since its completion in 1999 have been in the same range as those in other surrounding bedrock wells (fig. 3-13). Historic water levels for well H are also shown as well as a linear projection through 2018. Water levels for well J initially plotted closely to well H projected levels, verifying that well J was completed in the same bedrock zone as well H. However, in April 2004, the water level for well J plotted below the projected water level for well H because the Berkeley Pit filling rate is slowing due to the diversion and treatment of water from the HSB drainage. The projected water level for well H does not account for the lack of inflow of HSB water to the pit. If water levels had continued to rise, as shown by the projection line for well H, water levels would be more than 100 ft higher than current levels. The diversion of HSB drainage water away from the pit has significantly slowed the pit-filling rate.

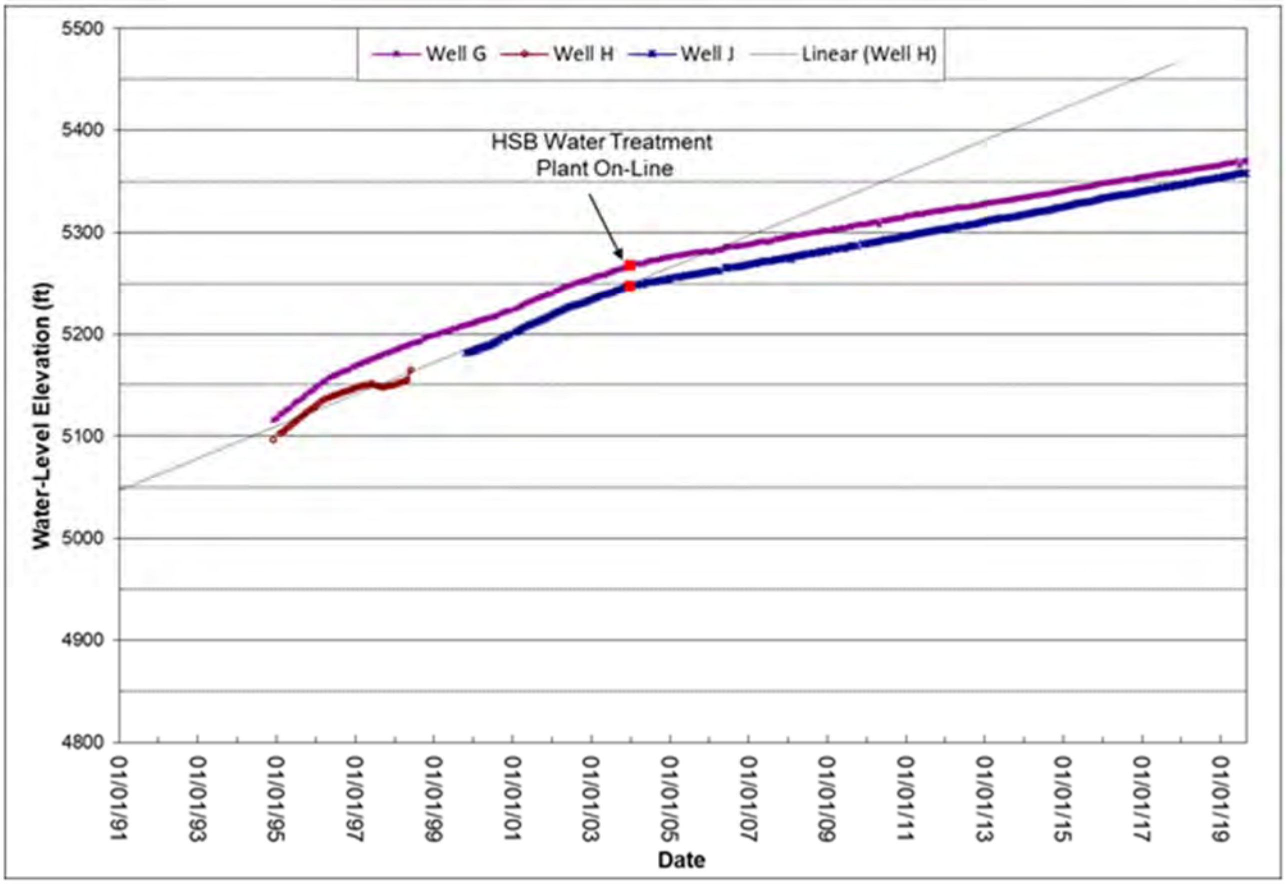
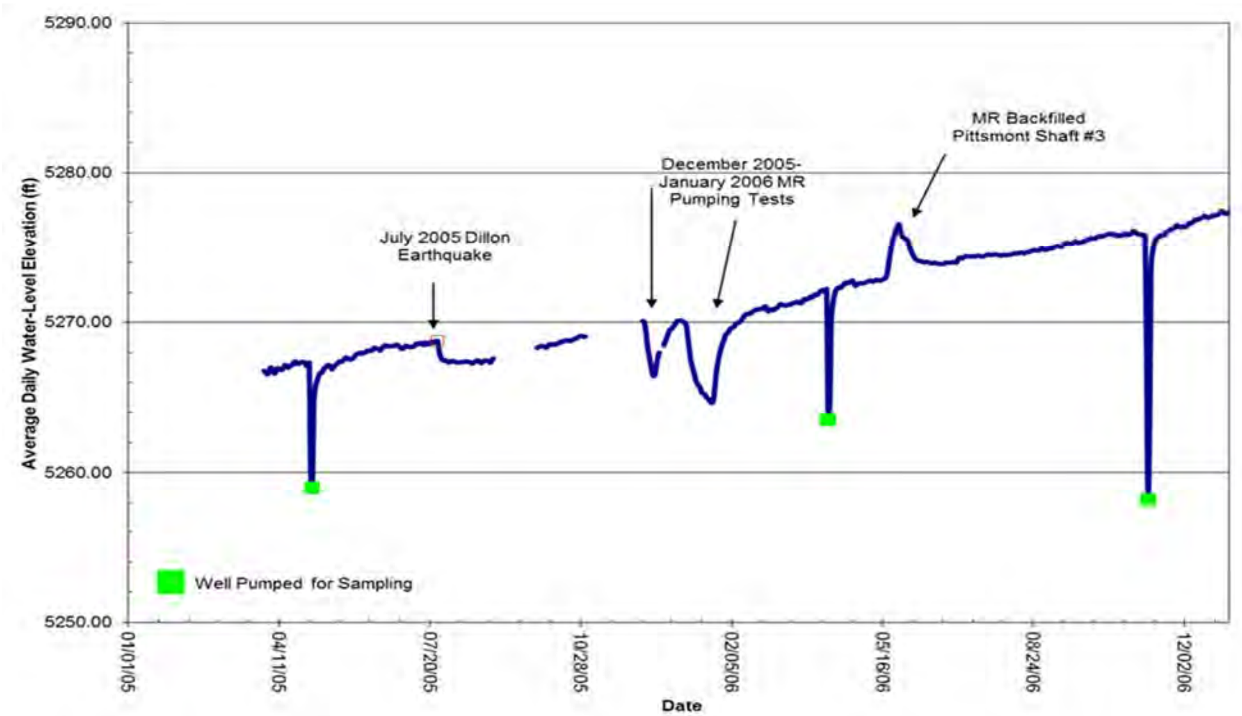


Figure 3-13. Water-level hydrographs for bedrock wells G, H, and J.

The 2002 CD monitoring program specified that water levels be monitored on a semi-continuous basis in bedrock wells A, B, C, and G. Water-level transducers were installed in each of these wells and set to collect hourly water-level data. This detailed level of monitoring allows recording of changes in water levels not seen when only one water-level measurement is taken monthly. Figure 3-14 is a hydrograph for a selected time period during which a number of different events influenced water levels in bedrock well A. The top graph shows water-level data collected by a transducer and specific times for each event, while the bottom graph shows monthly measurements and much less detail. The transducer data allow the time a change occurs to be resolved to a 1-hr time interval and a better determination of its magnitude. The more frequent monitoring allows more accurate separation of natural water-level changes, (i.e., earthquakes or slumps) or human-induced changes (i.e., pumping). Water-level transducers have been installed in additional bedrock wells, beyond those specified in the 2002 CD, to better track how water-level changes in the East Camp bedrock system respond to various activities, i.e., grouting and backfilling of underground mine workings, and the MERDI/MSE pumping test at the Belmont Mine site. The wells with an increased level of monitoring are D-2, F, J, Belmont well #1, Belmont well #2, and the Parrot Park.

Water-level monitoring continues to confirm that the flow of water in the affected bedrock aquifer is towards the Berkeley Pit. The potentiometric-surface map (fig. 3-15) for the East Camp bedrock aquifer shows the flow of water from all directions is towards the pit. Although there have been short-term influences on water levels in a number of these wells, the overall direction of groundwater flow has not changed.



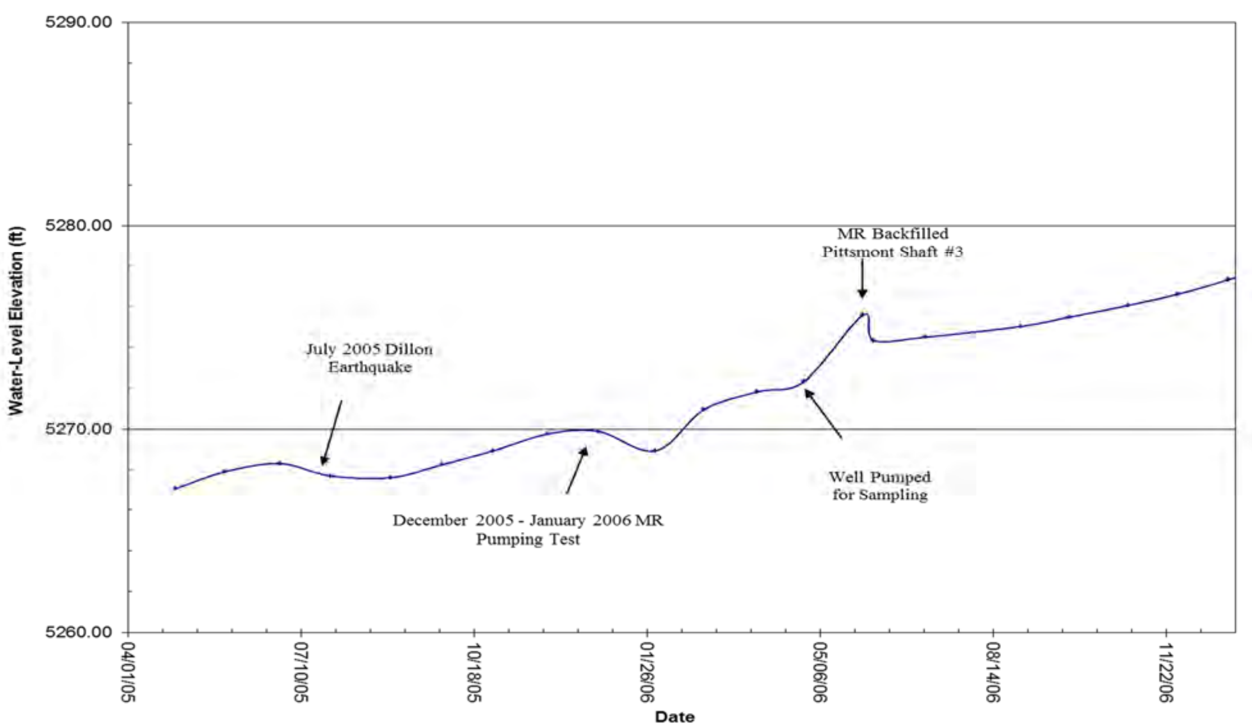


Figure 3-14. Hydrographs for well A comparing (top) daily average water level and (bottom) monthly water-level monitoring frequency.

Figure 3-15. Potentiometric map for the East Camp bedrock aquifer, December 2018 (contour interval is 10 ft).

Section 3.3.2 Bedrock Well Water Quality

Data collected in 2018 indicate only slight water-quality changes for most wells. Table 3.3.2.1 summarizes water-quality trends over the past few years; as noted in previous reports, the status of water from well B changed with respect to MCLs because EPA changed the arsenic MCL from 18 µg/L to 10 µg/L. There was little change in the concentration of dissolved constituents in water from most wells. Arsenic and radium were the only MCL exceeded in water from the bedrock wells (excluding well J, where cadmium, lead, and uranium all exceed the MCL); iron, manganese, zinc, and sulfate are the SMCLs most often exceeded. Water from four of the wells have pH levels below the recommended limit of 6.5. Complete sample results for the bedrock wells are available from the GWIC website at the following location: http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=MINEFLO-ACTIVE-ECBED&datatype=well&.

Although water from the majority of sites exceeds one or more secondary standards, the concentrations between wells vary considerably. Figure 3-16 shows iron and arsenic concentrations for six of the bedrock wells sampled during the spring of 2018. In figure 3-16, iron concentrations vary from 1 mg/L to greater than 400 mg/L, while arsenic concentrations vary from 2 µg/L to greater than 950 µg/L.

Water from well J has the greatest number of exceedances. Water from this well has always been poor quality as expected, considering its close proximity to the pit and interconnected adjacent mine workings. The well is completed approximately 40 ft above workings from the Pittsmont Mine that extend to the pit. Figure 3-17 compares selected trace metal concentrations in water from well A, well J, and the Berkeley Pit (2018 sample collected 1 ft below the water surface). Well A is the farthest south, and concentrations are orders of magnitude less for most analytes than in sites near the pit; water quality is similar between the pit and well J. Water-quality data confirm the interpretations based on water-level monitoring that bedrock groundwater flow is towards the pit. The extremely high concentrations of copper, cadmium, and zinc in the pit water and in well J show that any flow from these sites away from the pit would be easily detected in water samples from more distant wells.

Table 3.3.2.1. Exceedances and recent trends for East Camp bedrock wells, 1989 through 2018.

Well Name	Exceedances (1 or more)	Concentration Trend	Remarks
A	Y	Unchanged	Arsenic and radium (MCL); sulfate, iron, and manganese (SMCL).
B	Y	Unchanged	Arsenic and radium (MCL); sulfate, iron, and manganese (SMCL).
C	Y	Unchanged	Radium (MCL), pH, iron, manganese (SMCL). Zinc concentrations variable, exceed SMCL occasionally.
D-1	Y	Unchanged	No longer sampled, replaced by well D-2.
D-2	Y	Unchanged	Arsenic and radium (MCL); pH, sulfate, iron, manganese, and zinc (SMCL).
E	Y	Unchanged	Sampled every 2 yr; arsenic and radium (MCL); iron and manganese (SMCL).
F	Y	Unchanged	Sampled every 2 yr, arsenic and radium (MCL); iron and manganese (SMCL).
G	Y	Unchanged	Radium (MCL); pH, iron, and manganese (SMCL).
J	Y	Variable	Very poor quality water; arsenic, cadmium, radium (MCL); sulfate, iron, manganese, copper, and zinc (SMCL).

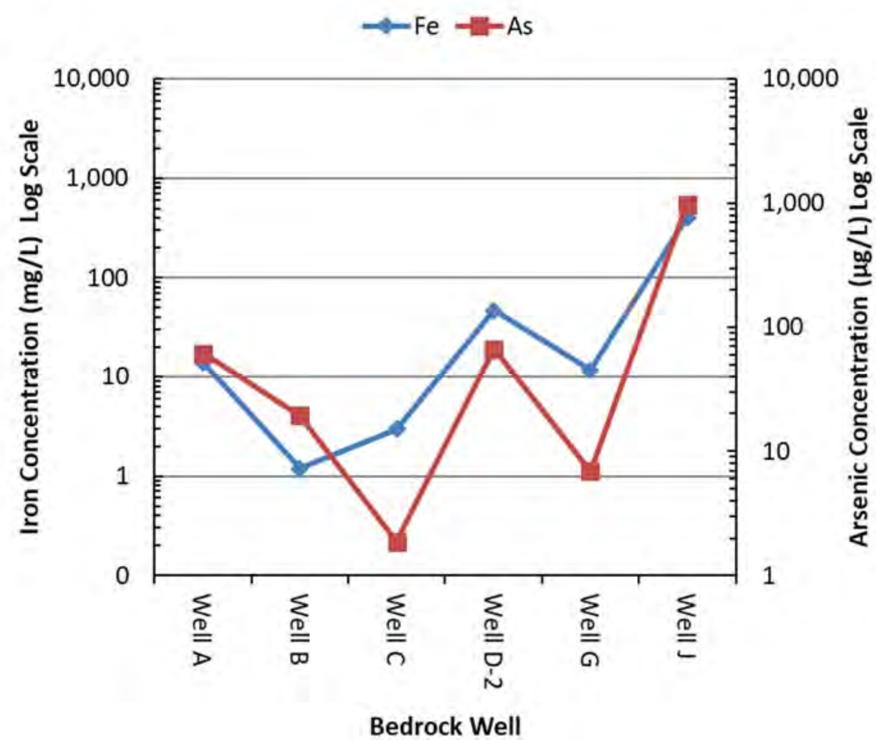


Figure 3-16. Bedrock well iron and arsenic concentration comparisons, spring 2018.

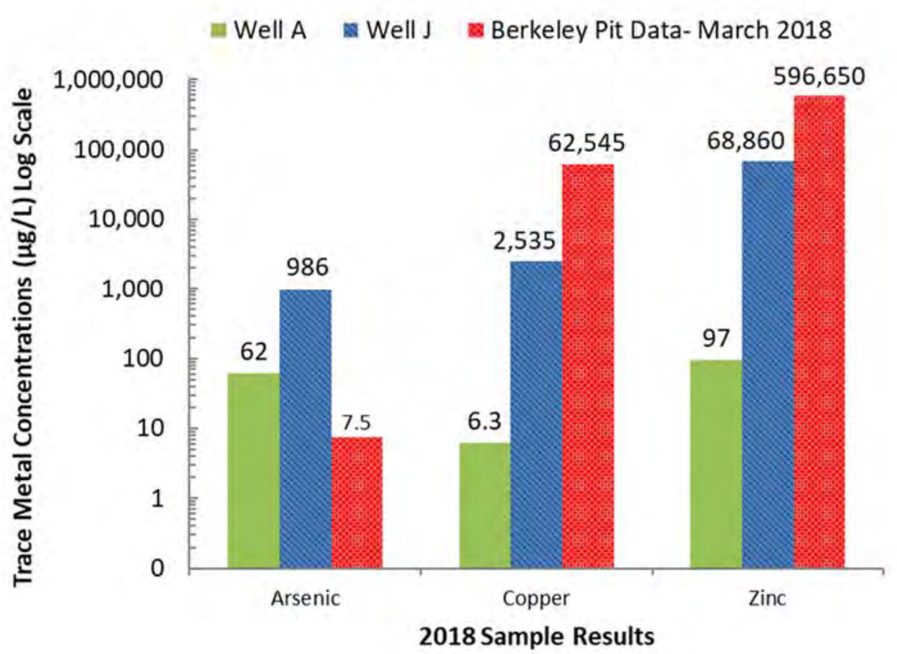


Figure 3-17. Selected trace metal comparisons among bedrock wells A, J, and the Berkeley Pit 1-ft depth sample.

Section 3.4 DDH-Series Wells

The DDH wells were not installed for monitoring purposes but were exploration holes that extend several thousand feet below ground surface and have various-size casings installed. Because of completion uncertainties and the drilling techniques, these wells were used only for water-level monitoring. Five bedrock wells originally constituted the DDH well monitoring network. Water-level monitoring of the DDH-series wells continued through August 2018 when the last two remaining DDH wells were plugged and abandoned. Since these wells were abandoned mid-year, no discussion of 2018 water level trends is warranted.

Section 3.5 Berkeley Pit and Horseshoe Bend Drainage

The Berkeley Pit water-level elevation was surveyed each month coincident with monthly water-level monitoring in wells and mine shafts. The hydrograph in figure 3-18 shows the pit's water-level rise since 1995.

The current overall Berkeley Pit water-level elevation trend is similar to that of previous years (7.29 ft average elevation rise per year since 2004). Four changes in slope in figure 3-18 show the influence of HSB diversions and landslides on the water-level rise. In April 1996, the filling rate decreased (seen as a change in slope on the graph) when water from the HSB drainage was diverted to the Yankee Doodle Tailings impoundment; the almost instantaneous water-level rise in September 1998 was caused by a landslide. The third change of slope in June 2000 shows that the filling rate increased when MR suspended mining and the HSB water was subsequently allowed to flow into the pit. The final change is a decreased filling rate that resulted from the HSB water-treatment plant coming online in November 2003 and the diversion of HSB drainage water away from the pit.

The volume of water allowed to enter the pit exceeded 3.2 billion gallons from July 2000 through November 2003 when the water-treatment plant became operable. This volume of water represents an average flow of 1,820 gpm during the period of mine suspension. The overall Berkeley Pit water-level rise for 2018 was 7.21 ft, compared to 7.25 ft for 2017. Total additional flow diverted to the pit during 2018 was approximately 11.65 million gallons from mine operation and water-treatment plant operations. Table 3.5.1 summarizes the changes in handling HSB water and other events that influenced changes in Berkeley Pit water-level filling rates.

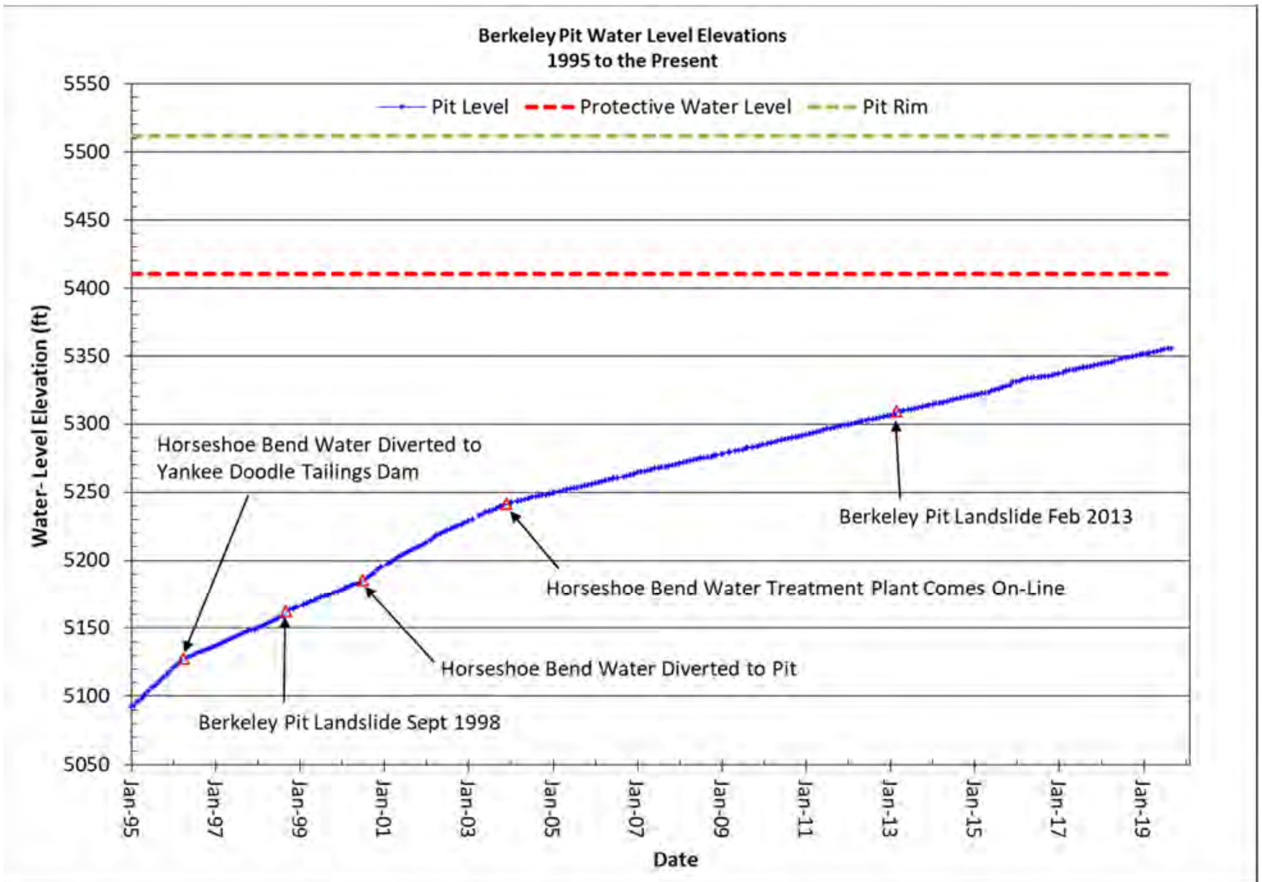


Figure 3-18. Water-level hydrograph of the Berkeley Pit, 1995–2018.

Table 3.5.1 Timeline of events impacting Berkeley Pit filling rates.

Date	Event	Impact
July 1983–April 1996	Horseshoe Bend Drainage water and water from precipitation plant ponds diverted to Berkeley Pit.	Increases pit water-level filling rate.
April 1996	HSB water diverted to MR mining operations for treatment and disposal in Yankee Doodle Tailings Pond.	Slows the pit filling rate.
September 1998	Berkeley Pit southeast corner landslide.	Over 3 ft water-level increase.
June 2000	MR suspends mining operations; HSB water diverted to Berkeley Pit. Water from Continental Pit diverted to Berkeley Pit.	Increases pit water-level filling rate.
November 2003	MR resumes operations and HSB water-treatment plant comes online.	Slows the pit filling rate.
February 2013	Rotational slump in southeast corner of Berkeley Pit.	0.60 ft water-level increase.
May 2015	Planned shutdown of concentrator and water-treatment plant; ~45.8 million gallons HSB water diverted to pit.	Increase in pit water level.
November and December 2015	Planned water-treatment plant and weir maintenance; ~88.2 million gallons of HSB water diverted to pit.	Increase in pit water level.
Calendar year 2016	Planned water-treatment plant and mill maintenance activities; ~24.1 million gallons of HSB water diverted to pit.	Minor increase in pit water level.
Calendar year 2017	Planned water-treatment plant and mill maintenance activities; ~4 million gallons of HSB water diverted to pit.	No impact on water level.
Calendar year 2018	Planned water-treatment plant and mill maintenance activities; ~11.65 million gallons of HSB water diverted to pit.	No impact on water level.

Two minor landslides occurred in 2012 along the southeast corner high wall of the Berkeley Pit. Both events (August 22, 2012 and November 3, 2012) displaced an unknown but minor volume of material into the Berkeley Pit. The material displaced by the landslides did not affect water levels in the Berkeley Pit, the underground mine workings, the bedrock system, or the surrounding alluvial aquifer. A rotational slump that occurred on February 8, 2013 deposited more waste and alluvial material than the 2012 landslides, resulting in noticeable water-level increases (0.60 ft) in the Berkeley Pit and several nearby bedrock wells (fig. 3-19). Photographs showing the southeast corner of the Pit before and after the August event and the February event are in figure 3-19.

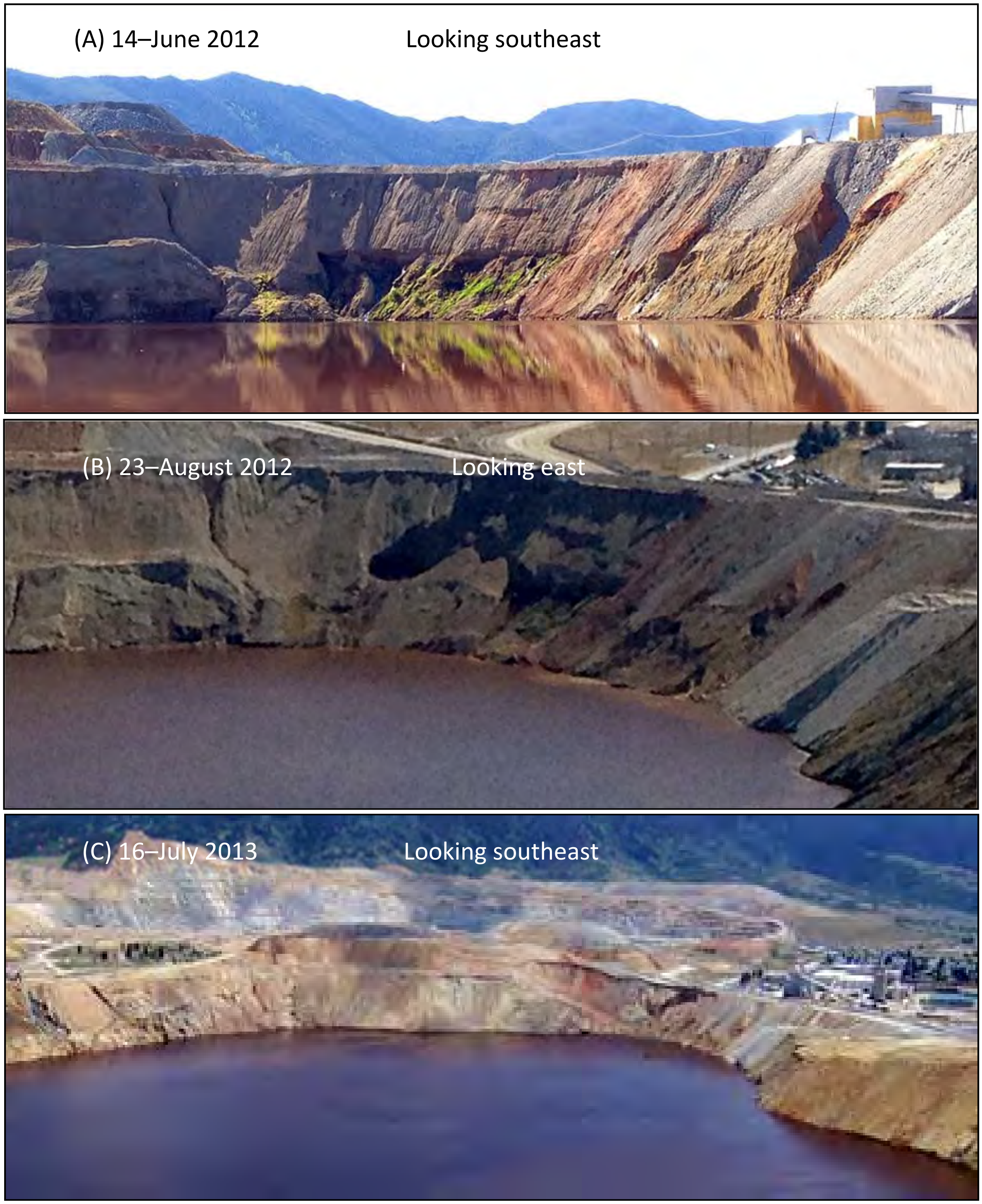


Figure 3-19. Pictures of the southeast corner of the Berkeley Pit prior to the occurrence of the 2012 landslides (A), and after the August 2012 (B) and February 2013 (C) events.

The 2002 CD contains a stipulation that the water level in the Berkeley Pit must remain below seven mine shafts and seven bedrock monitoring wells identified as POCs. Selected POCs are listed in table 3.5.2 along with their December 2018 water-level elevations and the distance below the PWL. The Berkeley Pit water-level elevation is included in this table for reference only. Based upon this information, the compliance point water-level elevation currently closest to the PWL is the Pilot Butte Mine, which is located about 0.5 mi north of the pit.

Table 3.5.2. Selected East Camp Points of Compliance and depth below PWL, December 2018.

Point of Compliance	**December 2018 Water-Level Elevation (ft)**	**Depth Below PWL (ft)**
Anselmo Mine	5372.20	37.80
Granite Mountain Mine	N/A	N/A
Pilot Butte Mine	5376.86	33.14
Kelley Mine	5363.59	46.41
Belmont Well #2	5362.90	47.10
Well A	5363.11	46.89
Well C	5356.50	53.50
Well G	5366.15	43.85
Berkeley Pit (not a compliance point)	5351.25	58.75

Flow monitoring of the Horseshoe Bend drainage continued throughout 2018. Figure 3-20 shows the daily average flow rate from July 2000 through December 2018. The 2018 average daily flow rate was 2,831 gpm, a decrease of 474 gpm from the prior year. A total of 1.49 billion gallons of water flowed through this site in 2018 for treatment in the HSB water-treatment plant.

A non-contact radar system (Radar Level Sensor) was installed during fall 2011 to collect more reliable flow data. The unit sends radar signals emitted onto the water surface (16 pulses per second) and the distance to the water surface is calculated over a 25-sec interval once every 15 min. The weir used to monitor the HSB flow was changed from a V-notch to a 5-ft rectangular weir (late November to early December 2015) to record higher flow rates more accurately; the location of the radar system was changed to a more stable location. Figure 3-21 shows the new weir and the radar system's new location on the cement retaining wall for the weir plate.

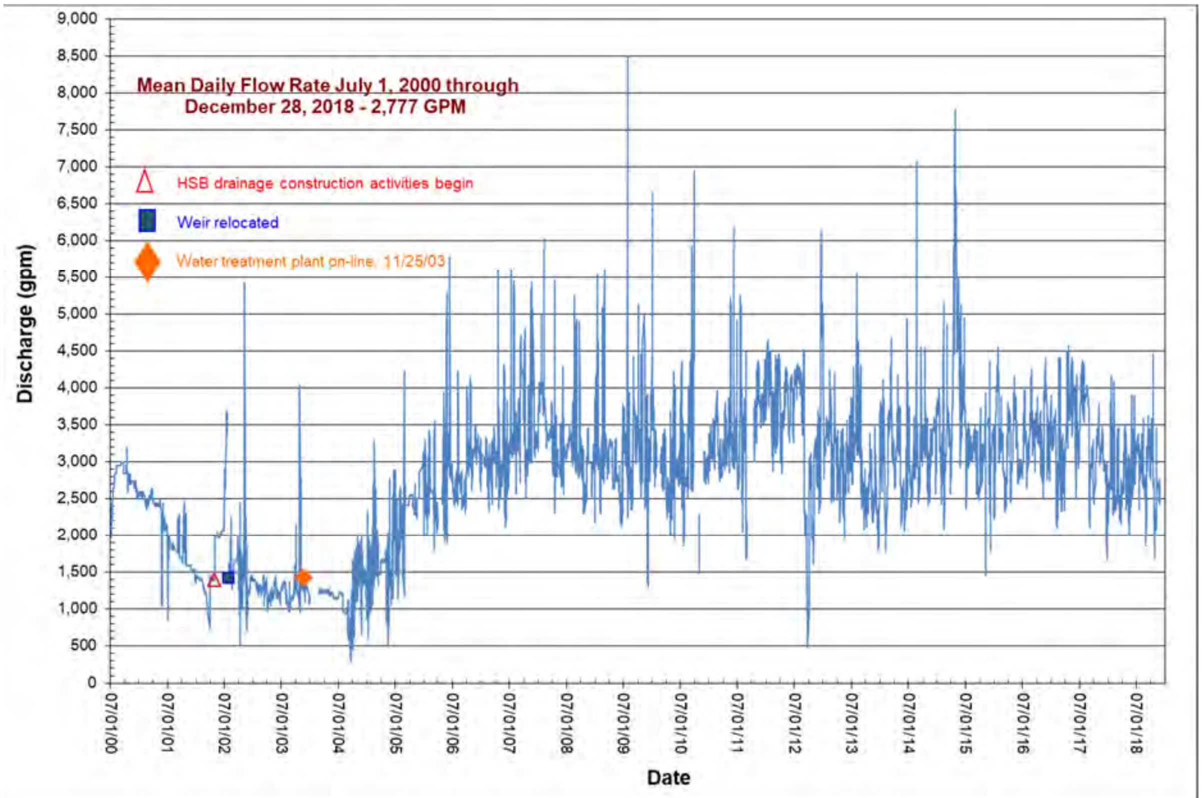


Figure 3-20. Horseshoe Bend Drainage flow rate, July 2000 through December 2018.

Figure 3-21. Radar system installation at the Horseshoe Bend weir monitoring station.

No flow was observed at the HSB Falls flume site during 2018. MR installed an access road near the monitoring site and removed the flume; therefore, monitoring at this site was discontinued.

Section 3.5.1 Berkeley Pit and Horseshoe Bend Drainage Water Quality

Water sampling of the Berkeley Pit continued in 2018 using the semi-autonomous (drone) boat. Depth sampling and vertical profiling were conducted twice, keeping the pit sample schedule in compliance with the requirements of the 2002 CD. Samples were collected from three depths during March and four depths during the November sample events. A surface grab sample from the south bank was also collected during September site activities. In addition to collecting samples for inorganic analysis, a vertical profile throughout the upper portion (~0–600 ft) of the water was performed to measure *in situ* physical parameters. The physical parameters measured were: pH, specific conductance, temperature, oxidation reduction potential (reported as Eh), dissolved oxygen, and turbidity.

Water-quality samples were collected monthly from the HSB drainage weir used for flow monitoring. This site is just upstream of the influent pond associated with the HSB water-treatment plant. Therefore, this water is representative of the water entering the plant for treatment. Complete sample results for the Berkeley Pit and Horseshoe Bend are available from the GWIC website at the following location: http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=MINEFLO-ACTIVE-ECBED&datatype=well&.

Section 3.5.1.1 Berkeley Pit Water-Quality Sampling and Monitoring Overview

It took 19 months (April 1982–November 1983) for flooding underground mine waters to reach the elevation of the bottom of the Berkeley Pit. However, water had accumulated in the pit bottom from contaminated surface-water sources diverted into the pit by the Anaconda Company in 1982 and again in 1983. The first water samples, in fall 1984 and then in 1985, were collected via a point-source bailer lowered from a helicopter hovering above the water surface (fig. 3-22). Sampling in 1986 and 1987 used a helicopter to transport boats to the water surface (fig 3-23). The boats allowed more accurate and detailed sampling and vertical profiling of the pit water column than had been possible in 1984–1985. By summer 1991, the water level reached an elevation that allowed old haul roads to be safely reopened, and sample crews could drive to the water’s edge. From 1991 through 2012, samples were collected from either temporarily installed stationary platforms or boats.

Figure 3-22. 1985 Berkeley Pit sampling event via helicopter.

Figure 3-23. 1986 Berkeley Pit sampling event, with helicopter transporting boat and personnel.

In 1996, MR purchased a pontoon boat for use in their waterfowl-monitoring program and made the boat available to MBMG personnel for monitoring and sampling activities. This boat was used for sampling through 2012 when sampling was suspended due to safety concerns.

Subsequent to suspending sampling in 2013, ARCO and MR commissioned the development of a remotely controlled drone watercraft. The boat was used to perform the 2018 sample collection. Figure 3-24 shows the boat being deployed for a 2017 sample event.

Figure 3-24. Drone boat after launch, moving out to sample location on the Berkeley Pit water surface.

Section 3.5.1.2 Berkeley Pit Water Chemistry

Currently (December 2018), the Berkeley Pit water is approximately 850 ft deep, consisting of roughly 48.8 billion gallons of low pH, high saline water. Since the flooding of the Berkeley Pit commenced in 1982, the MBMG has been the primary agency to collect, analyze, and interpret the water-quality data. Prior to 2001, water-quality samples were collected when deemed necessary, i.e., during the RI/FS investigation. Records dating back to November 1984 are published and can be found on the

MBMG Ground-Water Information Center (GWIC) website (GWIC, 2019).

Water quality in the Berkeley Pit had been monitored semi-annually from spring 2002 through 2012, as per terms of the 2002 CD. Slumps/landslides that occurred during fall 2012 and early 2013 led to a temporary suspension of sampling/monitoring activities from 2013 through 2015. Limited grab samples from the shoreline were obtained from the pit in 2016; a full-scale sampling of the pit resumed in 2017 with the collection of semi-annual depth samples.

Changes have been observed in Berkeley Pit water quality since the recent resumption of depth profiling and sampling. These changes may be linked to a number of factors such as:

(1) seasonal changes;

(2) occurrence of landslides;

(3) MR copper (Cu) recovery operations;

(4) discharge of high-density sludge into the Berkeley Pit from the HSB water-treatment plant; and

(5) diversion of HSB water into and away from the pit.

Section 3.5.1.3 Physical Parameters

Physical parameters of pH, specific conductance (SC), oxidation reduction potential (ORP) reported as Eh, temperature, and turbidity profiles were performed during May, September, and November 2018, at depths up to 600 ft. Figures 3-25 through 3-30 present the physical parameter data graphically.

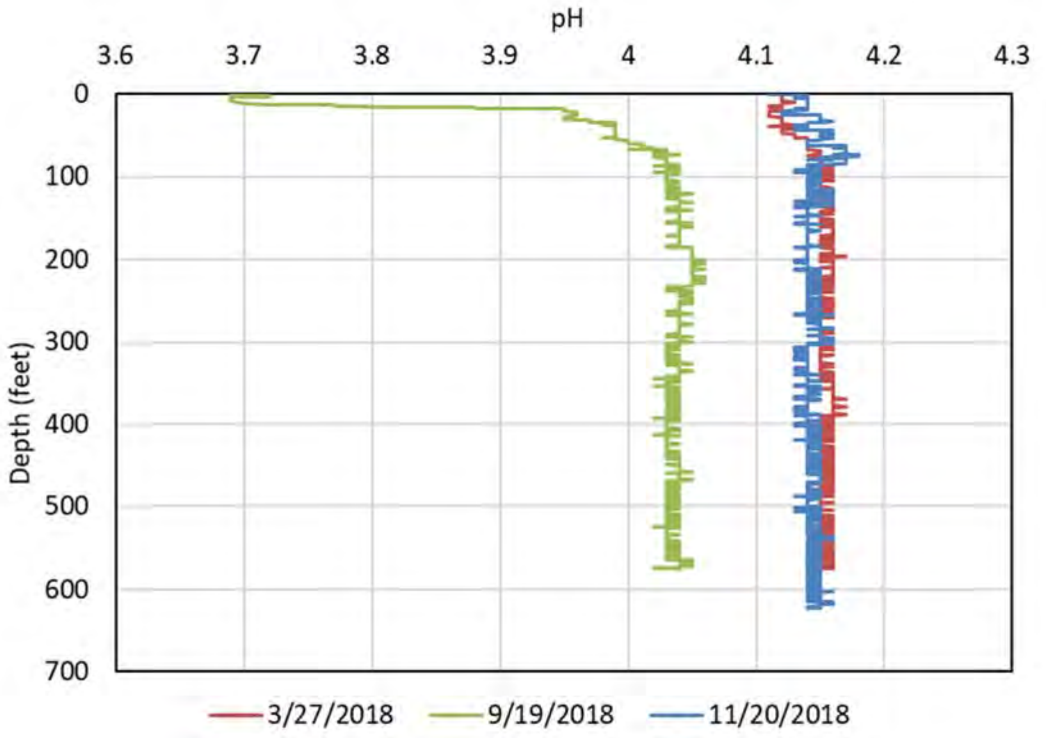


Figure 3-25. Berkeley Pit 2018 pH profiles.

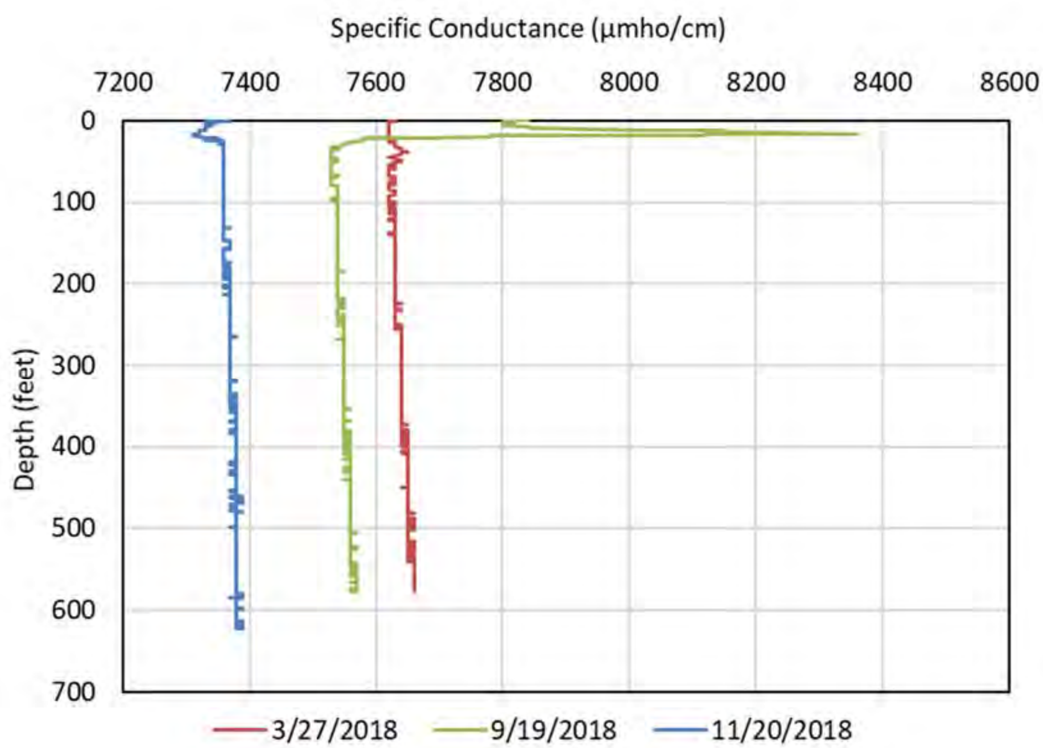


Figure 3-26. Berkeley Pit specific conductance profiles.

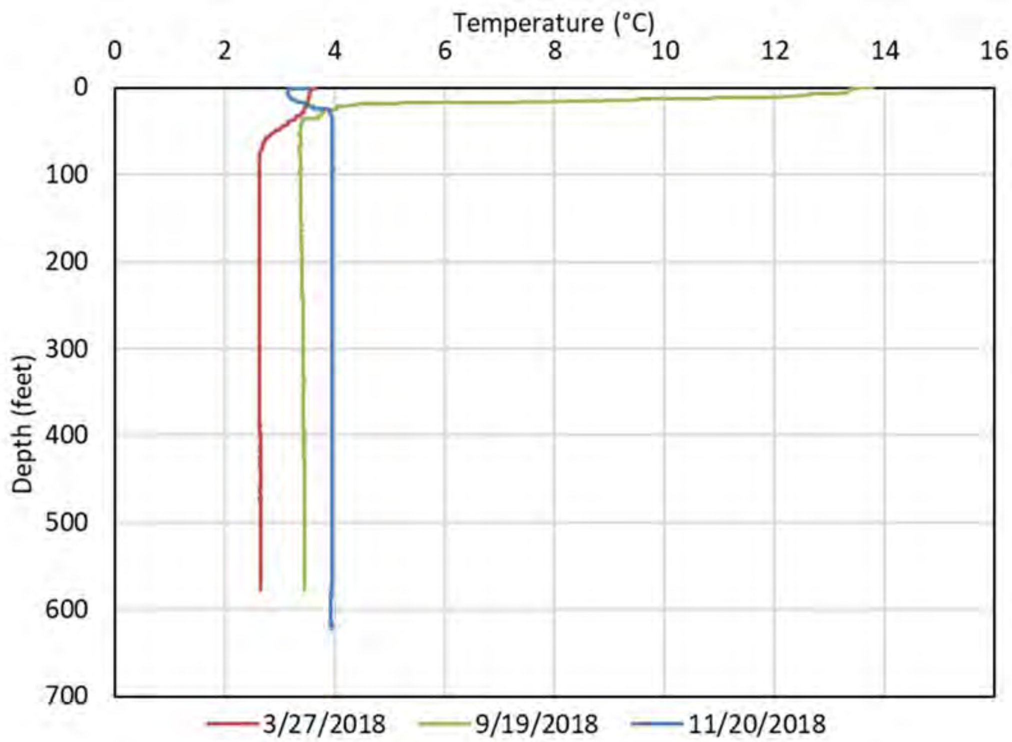


Figure 3-27. Berkeley Pit temperature profiles.

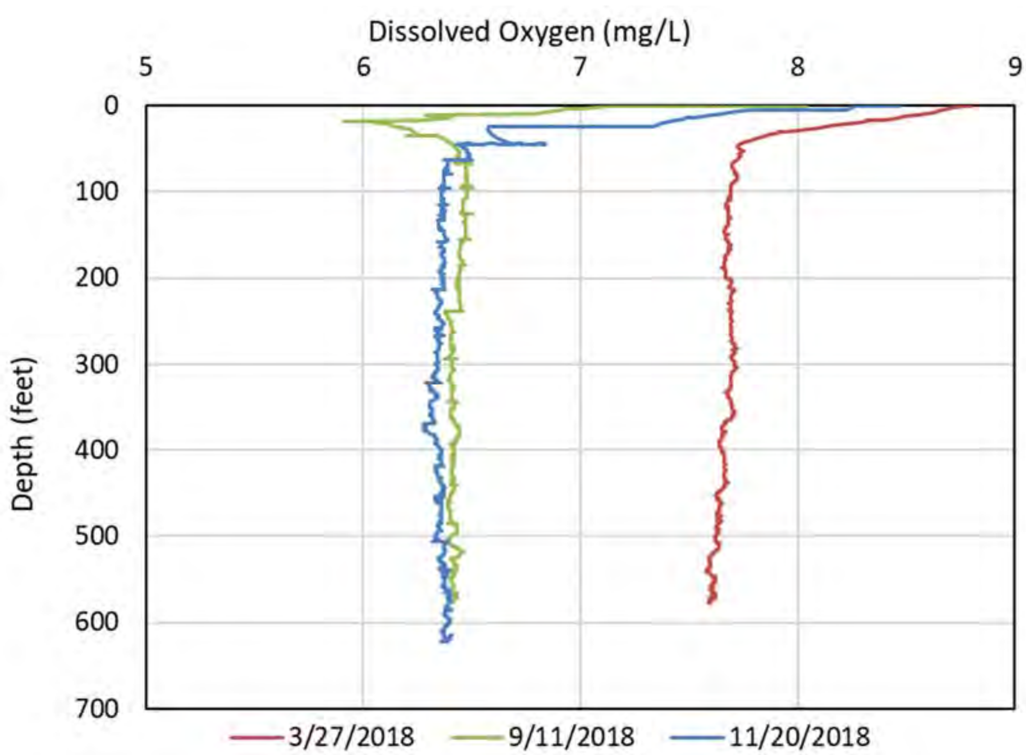


Figure 3-28. Berkeley Pit dissolved oxygen profiles.

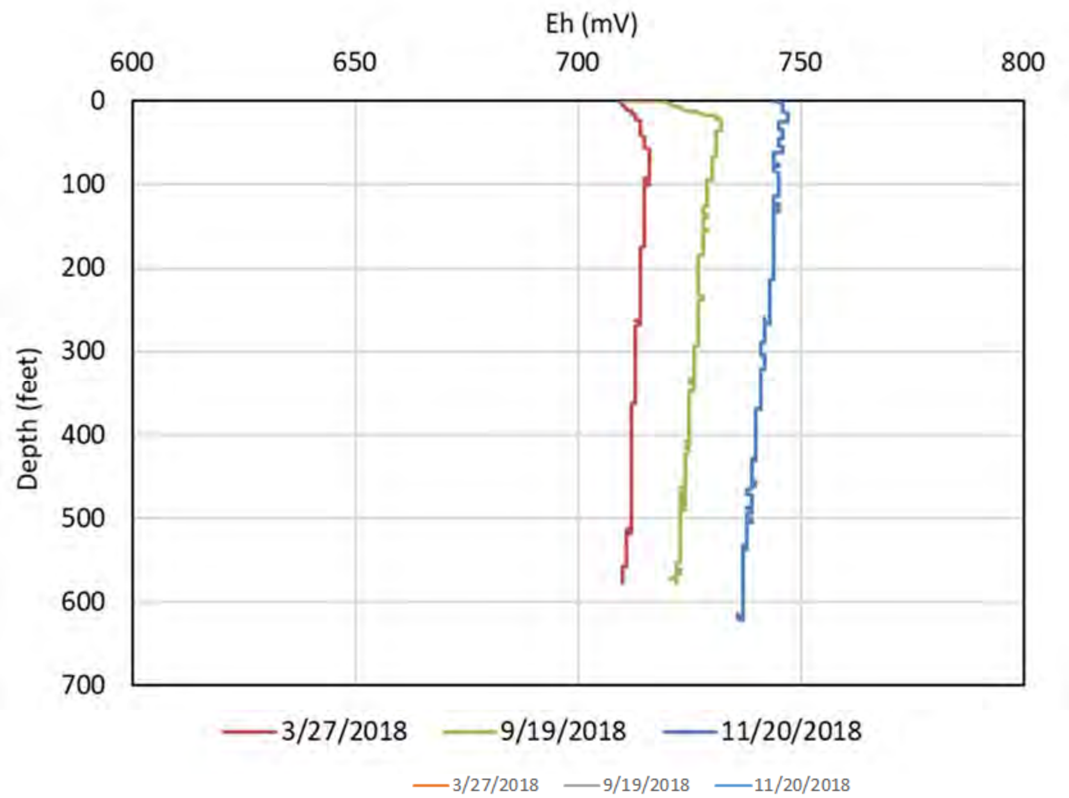


Figure 3-29. Berkeley Pit oxidation reduction profiles (Eh).

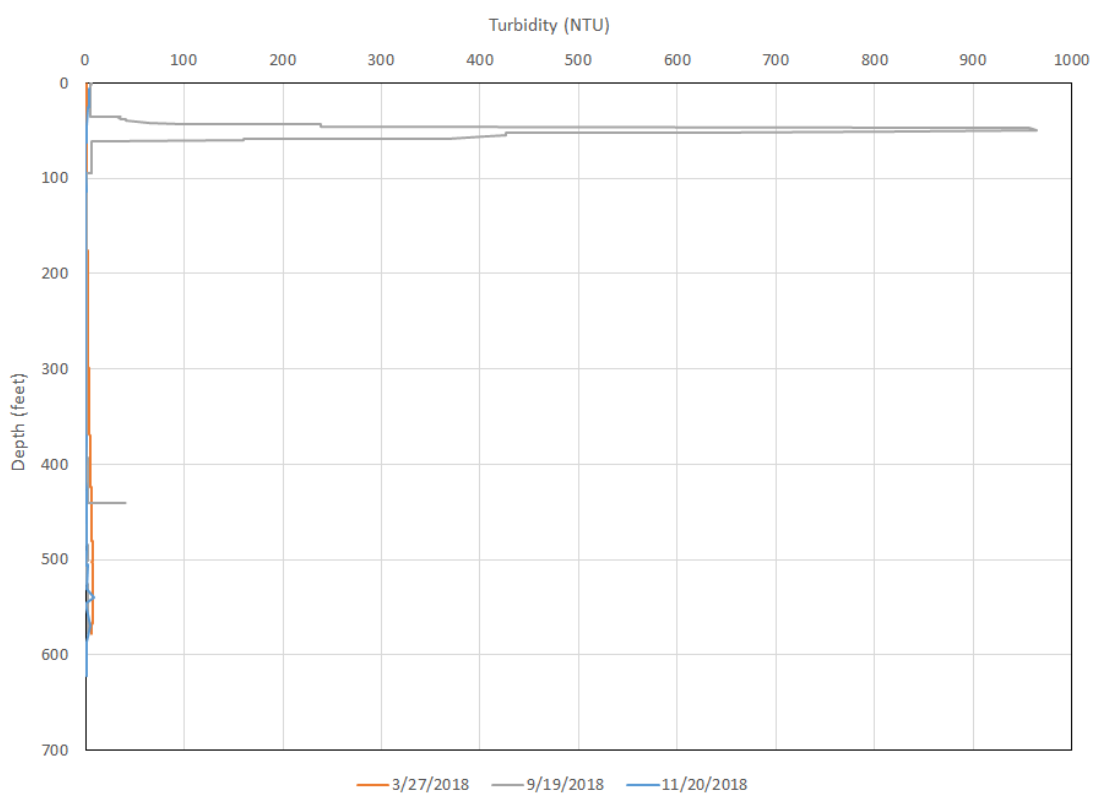


Figure 3-30. Berkeley Pit turbidity profiles.

A comparison of the temperature and dissolved oxygen at each 2018 sampling event show surface stratification in the upper 100 ft that is not present in the other parameter graphs. PH and SC show little variation throughout the vertical water column. However, pH values through the entire water column did increase by about 0.15 units between the spring and fall profiles.

The 2017 and 2018 physical parameter data show changes in several parameters and parameter trends compared to conditions prior to the 2012 landslides and subsequent suspension of monitoring and sampling. Discussion of changes in pit water chemistry is provided below.

Section 3.5.1.4 Chemical Parameters

Samples were collected at up to four depths in Berkeley Pit during 2018 semi-annual sampling; in September 2018, samples were also collected from 1 ft below the water surface. Some dissolved constituents and physical parameters from near-surface depths (1–5 ft) during 2018 are presented in table 3.5.1.4.1, along with results from 2012 and 2017 for comparison.

Table 3.5.1.4.1. A brief comparison of Berkeley Pit surface-water chemistry between 2012, 2017, and 2018.

Berkeley Pit Surface (1–5 ft) Chemistry									
	pH	SC	TDS	Total Acidity	Fe	Cu	Zn	As	SO_4
	(S.U.)	(µS/cm@25ºC)	(mg/L)	(mg/L as $CaCO_3$)	(mg/L)	(mg/L)	(mg/L)	(µg/L)	(mg/L)
Jun 2012	2.55	7,652	10,463	3,563	211	49	631	74	7,740
Dec 2012	2.61	7,632	12,229	3,651	204	49	589	64	9,560
May 2017	3.47	7,510	9,360	3,438	8.4	59	582	5	7,033
Jul 2017	3.44	7,510	9,511	3,689	11.2	62	607	8	6,895
Nov 2017	3.93	7,300	9,526	3,532	1.9	57	598	5	6,932
Mar 2018	4.12	7,620	9,746	3,503	2.7	63	597	8	7,180
Sept 2018	3.08	6,915	9,835	3,827	4.0	66	604	5	7,210
Nov 2018	4.13	7,330	9,476	3,882	3.2	59	573	6	7,019

Notable differences between 2012 and the 2017–2018 sample events include a pH rise of almost a full unit, a decrease in Fe concentrations of an order of magnitude, and a decrease in As concentrations to less than 10 µg/L. In addition, TDS concentrations appear to be declining. Between 2012 and 2018, the pit lake sat quiescent, and the system appears to be approaching a new equilibrium following changes likely caused by suspension of the MR pit copper-recovery operation, addition of alkaline sludge from the HSB water-treatment plant, and pit wall slumps.

Factors that may have influenced the rise in pH are the ongoing addition of alkaline sludge from the HSB water-treatment plant and the addition of carbonate minerals from slumps and landslides of pit wall alluvial sediment in 2012 and 2013. The Berkeley Pit Infilling Model (MBMG, unpublished correspondence) was used to predict when the pit water may reach a pH of 4.5. Input to the model included acidity titration data collected by the MBMG laboratory over this period, the estimated volume of added sludge, and the measured sludge alkalinity. Model results indicate that a pH of 4.5 could be reached in 15 yr of plant operation. In 2018, the plant had been operating for 15 yr and the mean pH measured in the Berkeley Pit vertical water profile has risen above 4.0.

Another striking difference between these time periods is the uniformly higher dissolved oxygen in 2018 compared to 2012 throughout the water column (fig. 3-31). Near the surface, the concentration in both years approaches saturation because of the contribution of meteoric water with high DO and wind mixing of near-surface water. However, the concentration does not change appreciably with depth in either profile. The apparent uniformly low DO in the 2012 profile reflects a DO concentration near zero due to the presence of excess ferrous iron, which maintains a high oxygen demand when present. The higher DO concentration in 2018 through the entire profile reflects the absence of ferrous iron. Seasonal turnover likely maintains the uniformity of concentration in the 2018 profile, mixing oxygenated water from the surface to depth.

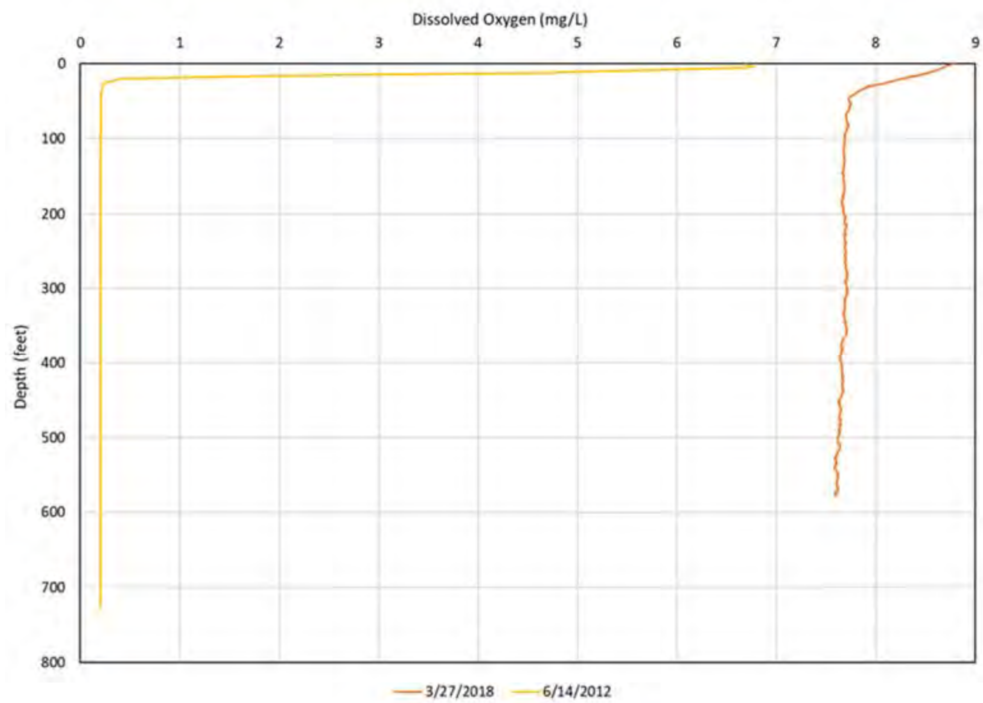


Figure 3-31. Comparison of DO profiles in the pit during spring 2012 and spring 2018.

The 2018 data provided a basis to confirm and characterize changes initially noted in 2016 and 2017 data and to assess future conditions in the pit as the date for treatment of pit water nears. The combination of the physical parameter profiles and chemistry of water samples from various depths verify water-quality changes throughout the Berkeley Pit system between the suspension of sampling and monitoring in 2012 and the resumption of those activities in 2017.

Section 3.5.2 Horseshoe Bend Water Quality

Monitoring of the HSB drainage (HSB in fig. 3-1) began in July 2000 following MR's temporary suspension of mining. This time period saw a decrease in HSB discharge rates and a decrease in the concentrations of a number of the trace metals. Metal concentrations began to increase in mid-2004 when discharge rates increased to rates similar to pre-suspension of mining (fig. 3-32). Copper concentrations are currently back to about one-third those seen in 2000, and zinc concentrations are similar to 2000 concentrations.

In August 2012, MR increased leaching operations, using a significant volume of Horseshoe Bend water as a leachate solution. Since then, copper concentrations in HSB water have continued a steady decline, while zinc concentrations have steadily increased. Iron concentrations have become more erratic, probably in response to changes in discharge, but no distinct trends emerge. Manganese has remained near 100 mg/L with periodic increases to 300 mg/L. pH migrated below 3.0 and rose above 4.0 at times during the monitored period, but has remained relatively stable over time and shows no distinct trend since monitoring began (fig. 3-32).

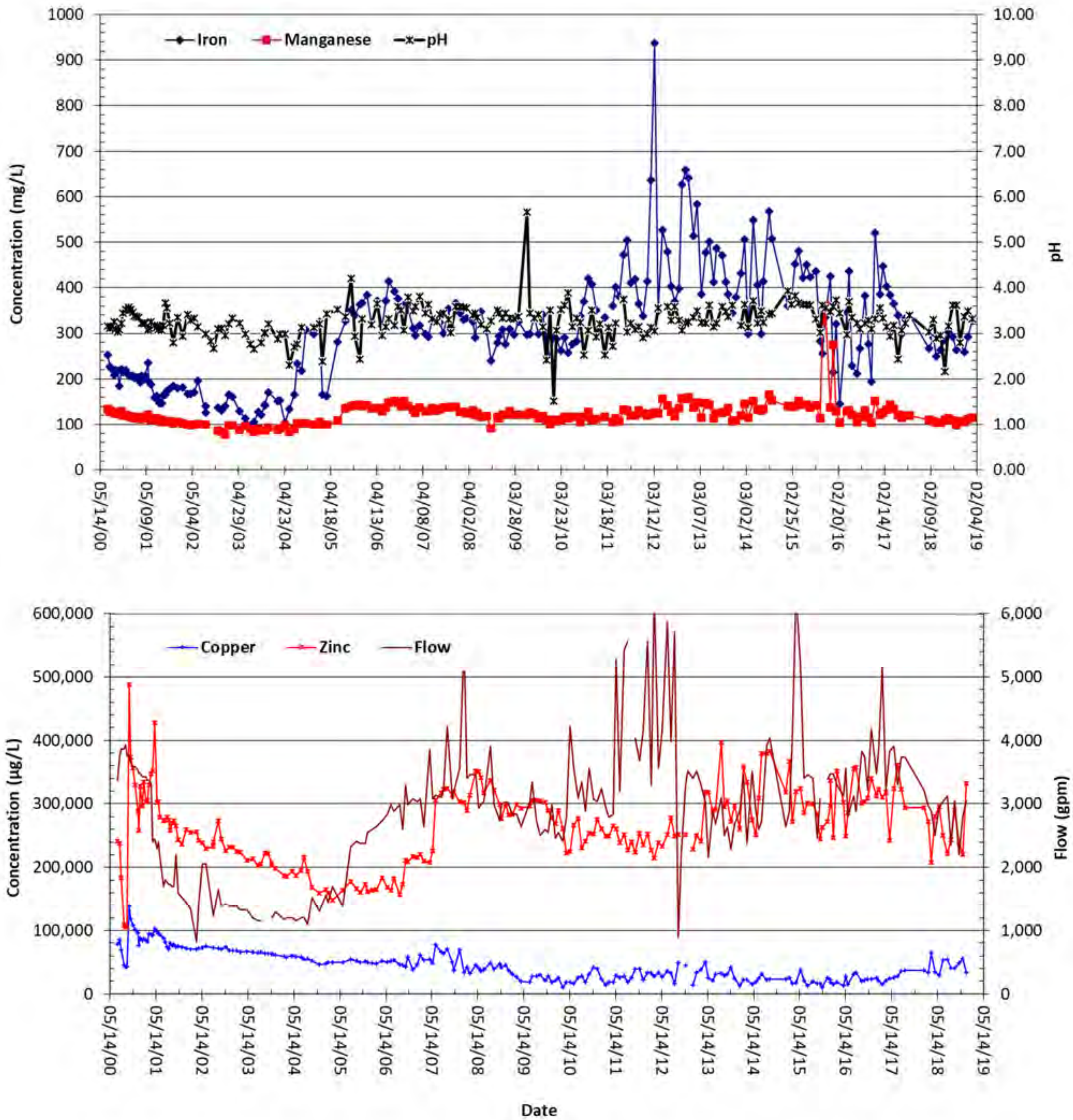


Figure 3-32. A comparison of Fe and Mn concentrations with flow (top), and Cu and Zn concentrations with flow (bottom) in Horseshoe Bend discharge during the monitoring period 2000–2018.

SECTION 4.0 WEST CAMP SYSTEM

During 2018 water-level monitoring continued in the three mine shafts and six monitoring wells that constitute the West Camp system (fig. 4-1). Water-level increases throughout the underground mine system varied between 0.2 and 0.4 ft during 2018, and at the end of 2018 were 12 ft below the West Camp's Protective water-level elevation. The volume of water pumped was just over 350 acre-ft, or 43.2 acre-ft greater than that pumped in 2017.

Section 4.1 West Camp Underground Mines

Water levels in the West Camp Mine System continue to be controlled by the pump station located at the BMF-96-1D and BMF-96-1S monitoring site. ARCO constructed the West Camp pumping well (WCPW) for dewatering (pumping) purposes in fall 1997 and transferred pumping activities from the Travona Mine on October 23, 1998. The pump and pipeline at the Travona Mine were left intact, to serve as a backup pumping system. ARCO modified and upgraded the pump station and support system during the latter portion of 2011 (figs. 4-2 through 4-5). Table 4.1.1 shows the annual amount of water pumped in acre-feet, the change in acre-feet from the previous year, and the percent change from 1996 (the first full year of continuous pumping). Figure 4-6 shows the amount of water pumped annually and the percent of average annual precipitation since 1982.

Path: D:\stuff\ted\BMF\BMF_mapping-West_Camp_Outer_Camp_01222012.mxd

Figure 4-1. West Camp monitoring sites location map.

Figure 4-2. West Camp pump station 1997–2011.

Figure 4-3. West Camp pumping well, discharge line, and monitoring well exposed during 2011 construction activities.

Figure 4-4. West Camp construction activities showing a new pump station foundation and infrastructure improvements surrounding the pumping well and discharge line.

Figure 4-5. New West Camp pump station, 2011.

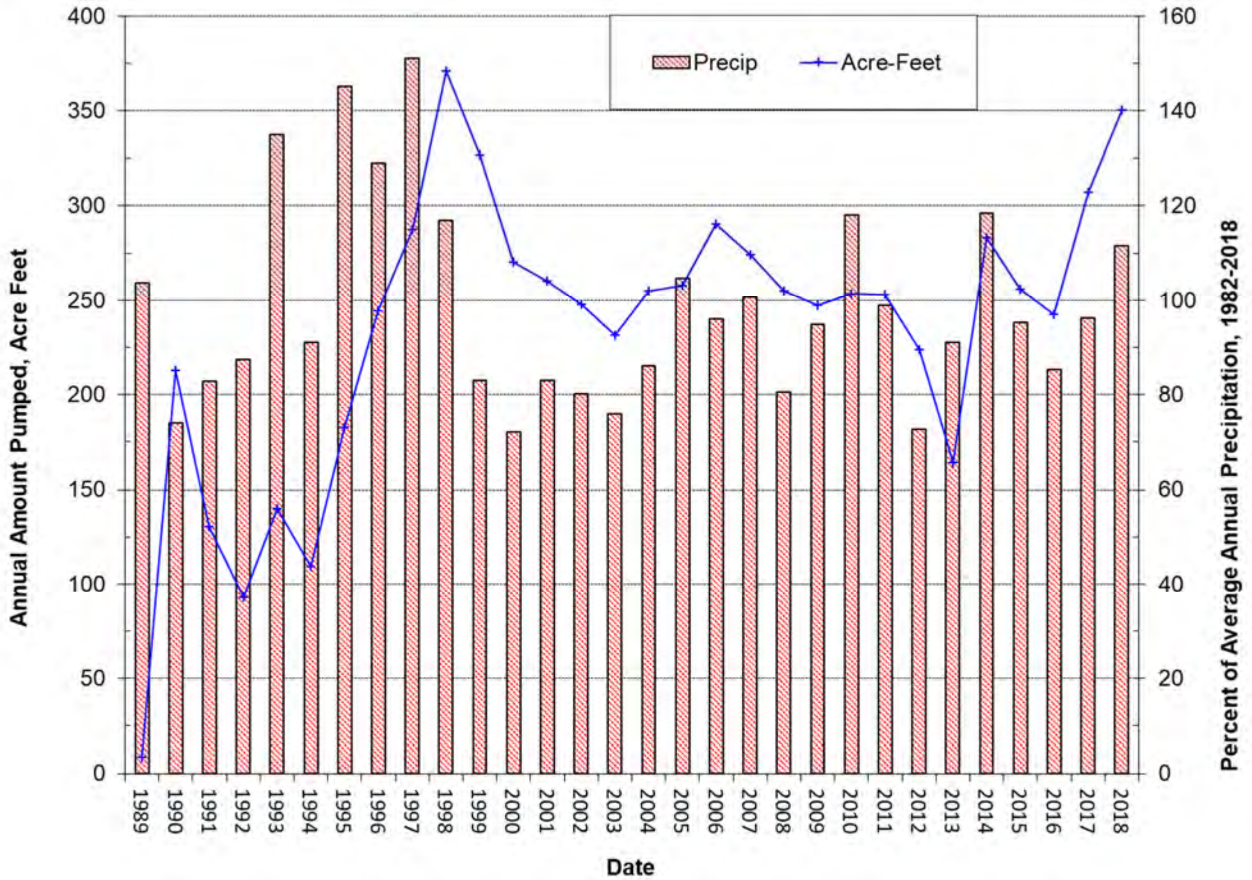


Figure 4-6. Annual amount of water pumped from the West Camp system compared to the average annual precipitation during the period 1982–2018.

Table 4.1.1. Annual quantity of water pumped from the West Camp, in acre-ft.

Year	Total Amount Pumped (acre-ft)	Change From Prior Year (acre-ft)	Percent Change From 1996
1989	8.50		
1990	212.54	+204.04	
1991	130.16	-82.38	
1992	92.82	-37.34	
1993	140.18	+47.36	
1994	109.31	-30.87	
1995	182.54	+73.23	
1996	244.56	+62.02	
1997	287.70	+43.14	1.18
1998	370.72	+83.02	1.52
1999	326.56	-44.16	1.34
2000	270.20	-56.36	1.10
2001	260.37	-9.83	1.06
2002	247.66	-12.71	1.01
2003	231.43	-16.23	0.95
2004	254.70	+23.26	1.04
2005	257.82	+3.12	1.05
2006	290.33	+32.51	1.19
2007	273.96	-16.37	1.12
2008	255.16	-18.79	1.04
2009	247.03	-8.13	1.01
2010	253.49	6.46	1.04
2011	252.93	-0.56	1.03
2012	223.64	-29.29	0.91
2013	164.53	-59.11	0.67
2014	283.42	118.89	1.16
2015	256.04	-27.37	1.05
2016	242.31	-13.74	0.99
2017	307.21	64.90	1.26
2018	350.36	43.15	1.43

Water levels increased over 0.19 ft during 2018 in all three mines. Figure 4-7 shows annual water-level changes for the West Camp sites. Water levels are more than 12 ft below the West Camp action level of 5,435 ft stipulated in the 1994 ROD and 2002 CD.

Water-level elevations for the three West Camp mines are shown in figure 4-8. Water levels in these mines are almost identical and continue to follow the trends of previous years. Pumping rates and the amount of water pumped are the most important controls on water levels.

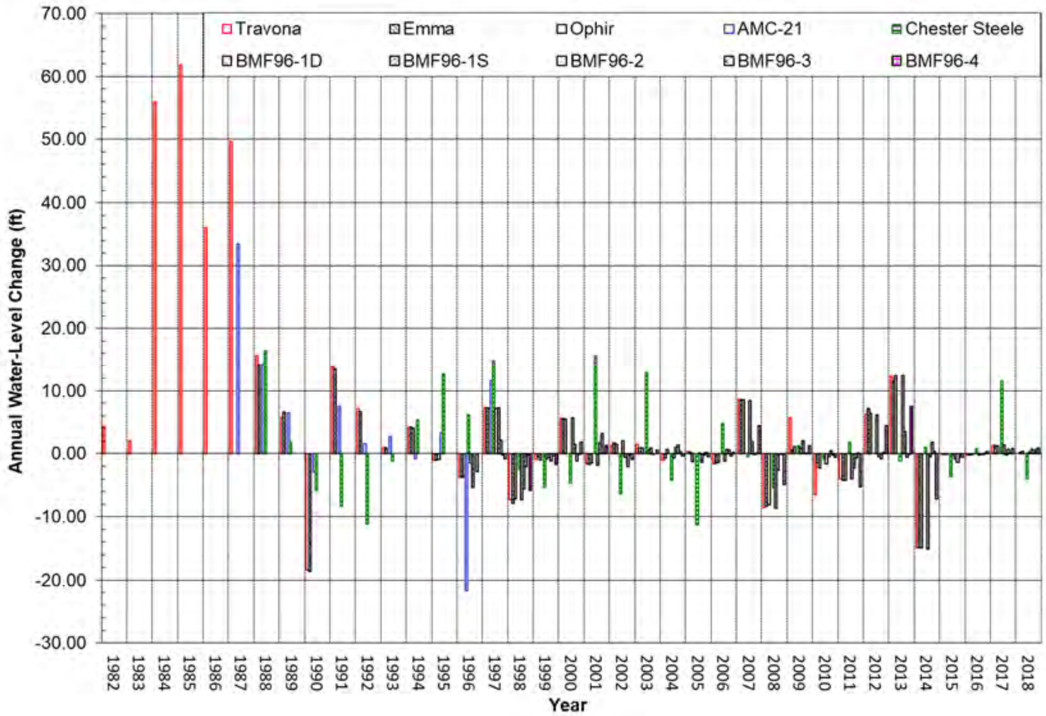


Figure 4-7. Annual water-level changes (from previous year) for West Camp site.

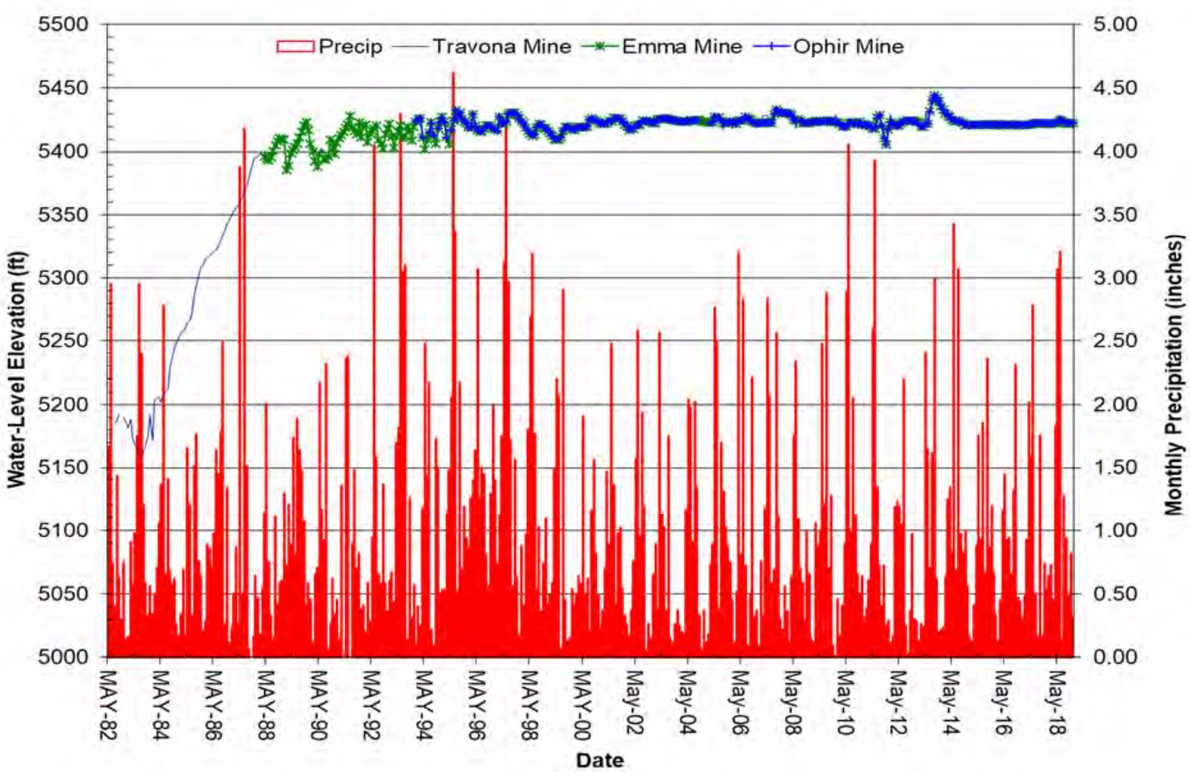


Figure 4-8. Water-level hydrographs for West Camp mines compared to monthly precipitation.

Section 4.2 West Camp Monitoring Wells

Water levels increased in four of the five BMF96 West Camp groundwater wells during 2018. Well BMF96-1D, completed into the Travona Mine workings, had a water-level increase similar to that of the West Camp mines. The annual water-level changes are shown in table 4.2.1 and figure 4-9.

Figure 4-9 contains water-level hydrographs for wells BMF96-1D, BMF96-1S, and BMF96-4. Water levels in wells BMF96-1D and BMF96-4 respond similarly to one another, showing the influence pumping has on the system and how interconnected the wells are to the mine workings. There is a lag time between the responses seen in these two wells; this is attributed to completion of well BMF96-4 in fractured bedrock within the groundwater system and not in mine workings. This is an important trend since well BMF96-4, while not completed into mine workings, is in the area of the historic 1960s flooding problems that led the Anaconda Company to install well AMC-21 for control of water levels in the West Camp (fig. 4-10). Duaime and others (1998) discuss the historic flooding problems in the West Camp System. Well BMF96-1S is located adjacent to well BMF96-1D, but is completed at a shallower depth, within the weathered bedrock. There was no change in long-term trends in any of these wells from those described in previous reports.

Water levels in wells BMF96-2 and BMF96-3 are 20 ft to 50 ft higher than those in wells BMF96-1D and BMF96-4. Although these wells were completed at depths of 175 ft below ground surface, their water levels are less than 20 ft below ground surface. Hydrographs (fig. 4-11) show that from 1996 to 2001 water levels in BMF96-2 and BMF96-3 moved independently from water levels in BMF96-1S, BMF96-1D, and BMF96-4. Since 2002, water-level changes in BMF96-2 and BMF96-3 have followed trends similar to the other BMF-series wells; however, the magnitude of the responses was less. When hydrographs for BMF96-2 and BMF96-3 are plotted at an expanded scale (fig. 4-12), the detail in water levels becomes apparent and shows both wells respond quickly to precipitation events. Water-level trends during 2018 were similar to those seen in previous years. Water levels rise during the wet season and with infiltration from snowmelt, which is shown by the early season (March–April) water-level increases.

Table 4.2.1. Annual water-level changes for the West Camp sites (ft).

Year	Travona	Emma	Ophir	Chester Steele	BMF 96-1D	BMF 96-1S	BMF 96-2	BMF 96-3	BMF 96-4
1982	4.30								
1983	2.00								
1984	55.90								
1985	61.90								
1986	36.10								
1987	49.70								
1988	15.69	14.20		16.42					
1989	5.67	6.60		1.79					
1990	-18.42	-18.66		-5.77					
1991	13.88	13.52		-8.28					
Change Years 1–10	**226.72**	**15.66**		**4.16**					
1992	7.21	6.79		-11.20					
1993	1.01	0.93		-1.11					
1994	4.24	4.26	4.00	5.36					
1995	-0.98	-1.00	-0.96	12.72					
1996	-3.72	-3.76	-3.56	6.14	-1.50	-5.41	0.00	-2.85	
1997	7.29	7.28	7.22	14.82	7.20	7.36	2.13	-0.19	-0.80
1998	-7.31	-7.88	-7.20	-2.51	-7.35	-5.63	-2.00	-0.26	-5.88
1999	-0.97	-0.47	-1.03	-5.37	-0.82	-0.61	-1.15	-0.38	-1.76
2000	5.56	5.61	5.53	-4.64	5.70	1.45	-1.13	-0.07	1.86
2001	-1.65	-1.70	-1.52	15.61	-1.78	1.70	3.23	0.10	1.40
Change Years 11–20	**10.68**	**10.06**	**2.48**	**29.82**	**1.45**	**-1.14**	**1.08**	**-3.65**	**-5.18**
2002	1.33	1.74	1.51	-6.35	2.03	-0.62	-2.06	-0.21	-0.93
2003	1.45	0.95	0.87	12.94	0.56	0.96	-0.01	0.00	0.54
2004	-1.06	-0.72	0.73**	-4.22	-0.72	1.03	1.41	0.33	-0.31
2005	0.39	0.22	-1.30	-11.35	0.03	-1.42	-0.23	0.18	-0.47
2006	-1.62	-1.49	-1.33	4.76	-1.15	0.65	0.59	-0.31	0.20
2007	8.68	8.56	8.57	-0.41	8.49	1.93	-0.17	0.13	4.41
2008	-8.57	-8.39	-8.15	-5.41	-8.71	-2.65	-0.14	-0.06	-4.96
2009	5.68	0.56	1.09	1.26	0.91	2.05	0.04	0.10	1.22
2010	-6.47	-1.46	-2.27	-0.82	-1.61	-0.41	0.42	-0.23	-0.60
2011	-3.99	-4.27	-4.17	1.77	-3.99	-2.23	-0.67	0.09	-5.24
Change Years 21–30	**-4.18**	**-4.30**	**-4.45**	**-7.83**	**-4.16**	**-0.71**	**-0.82**	**0.02**	**-6.14**
2012	6.25	7.22	6.43	0.12	6.20	-0.46	-0.82	0.21	4.47
2013	12.35	11.52	12.49	-1.11	12.49	3.59	-0.56	-0.07	7.50
2014	-14.96	-14.94	-14.95	1.01	-15.17	-0.44	1.79	0.35	-7.21
2015	-0.16	-0.15	-0.08	-3.64	-0.14	-0.82	-1.33	-0.46	-0.55
2016	-0.22	-0.21	-0.16	0.79	-0.26	-0.01	-0.17	0.02	0.32
2017	1.32	1.30	1.26	11.49	1.34	-0.25	0.69	0.63	0.85
2018	0.19	0.22	0.38	-3.95	0.20	0.74	0.11	-0.40	0.88
Change Years 31–40	**4.77**	**4.96**	**5.37**	**4.71**	**4.66**	**2.35**	**-0.29**	**0.28**	**6.26**
Net Change*	**237.99**	**26.38**	**3.40**	**30.86**	**1.95**	**0.50**	**-0.03**	**-3.35**	**-5.06**

Note. Minus sign (-) indicates a decline (drop) in water level.

*Total water-level change is that measured. Access or obstructions occasionally prevent water-level measurements.

**Vandalism to Ophir Mine monitoring point resulted in no water levels being obtained for the last quarter of 2004.

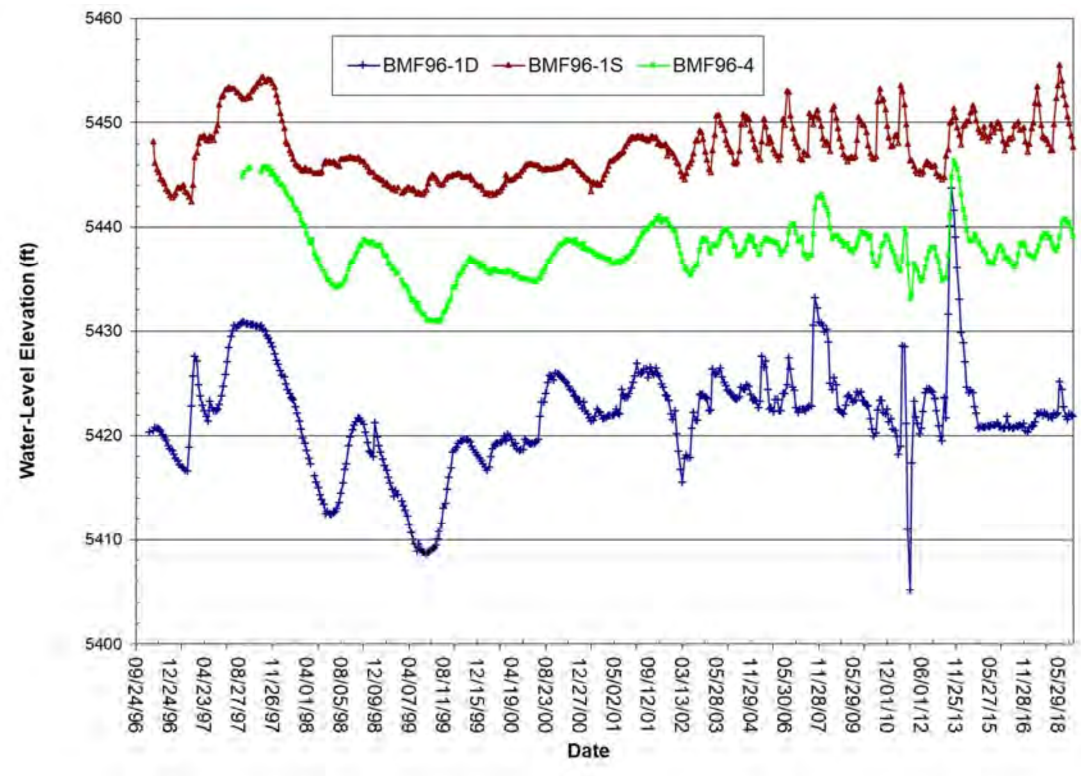


Figure 4-9. Water-level hydrographs for West Camp wells BMF96-1D, BMF96-1S, and BMF96-4.

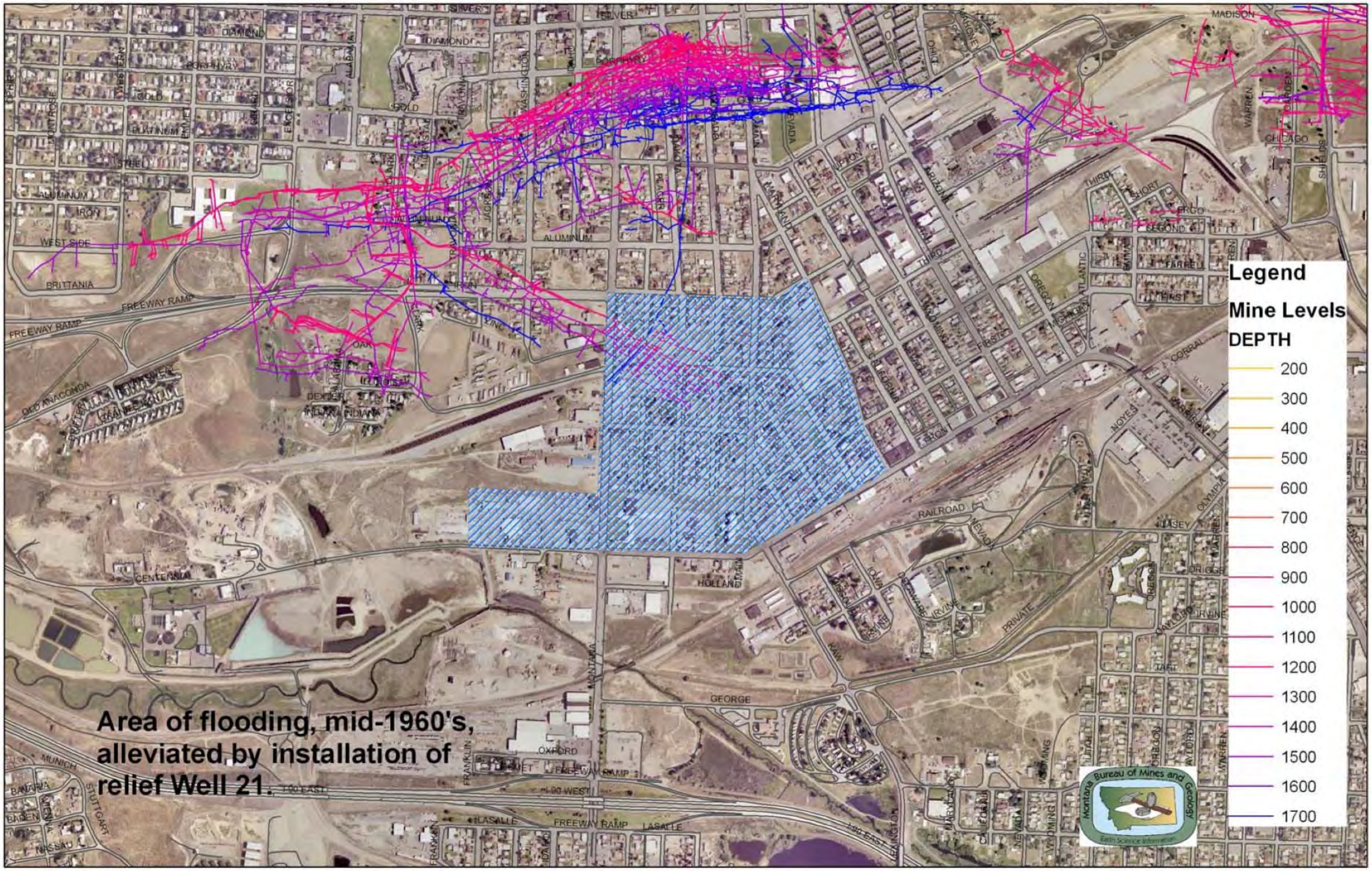


Figure 4-10. Area of the West Camp affected by basement flooding problems in the 1960s. The blue hatched area outlines flooding locations.

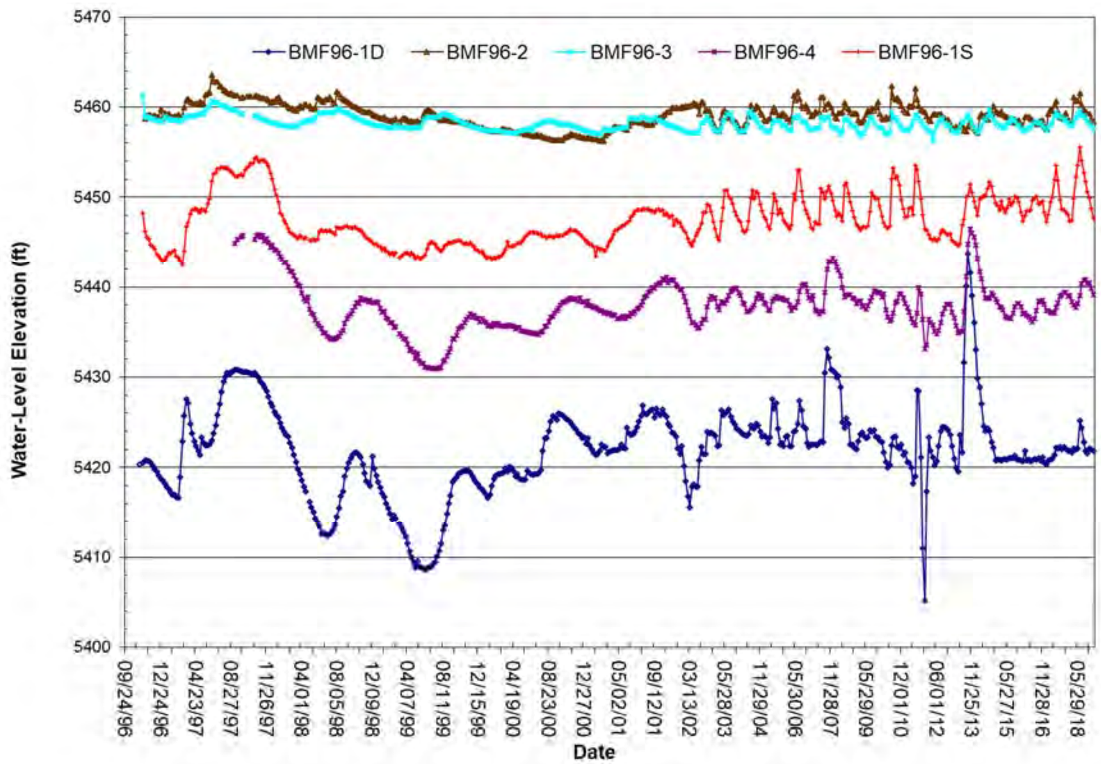


Figure 4-11. Water-level hydrographs for BMF96-series wells.

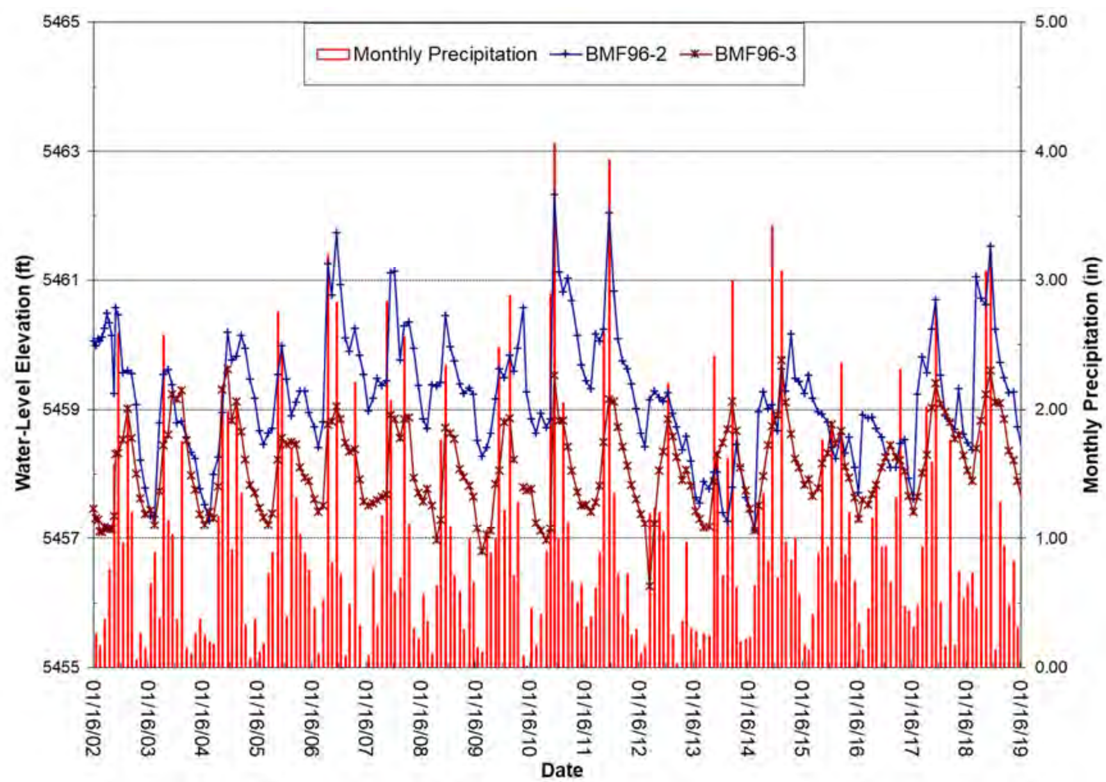


Figure 4-12. Water-level hydrographs for wells BMF96-2 and BMF96-3, 2002–2018.

Section 4.2.1 West Camp Mines and Monitoring Wells Water Quality

In 2018 water-quality data for the West Camp monitoring system was limited to analytical results from spring-season sampling in BMF96-04 and Chester Steele Park wells, and the Travona, Emma, and Ophir shafts. With the exception of arsenic (23 µg/L in water from the Chester Steele Park well, 49 µg/L in water from the Travona shaft, about 10 µg/L in water from the Emma shaft), the concentrations of most dissolved constituents in the West Camp waters were similar to each other (figs. 4-13, 4-14). Iron and manganese concentrations are above the SMCL in all three samples from shafts.

Through 2018, the concentrations of most dissolved metals in well BMF96-4 are relatively low and continue a downward trend (as iron, etc.). Concentrations of zinc show some variation and a slight increase in recent years but remain well below the SMCL; arsenic concentrations continue to range from 5 to 9 µg/L (fig. 4-15). Manganese concentrations increased from less than 0.1 mg/L in prior years to greater than 1.4 mg/L in 2018.

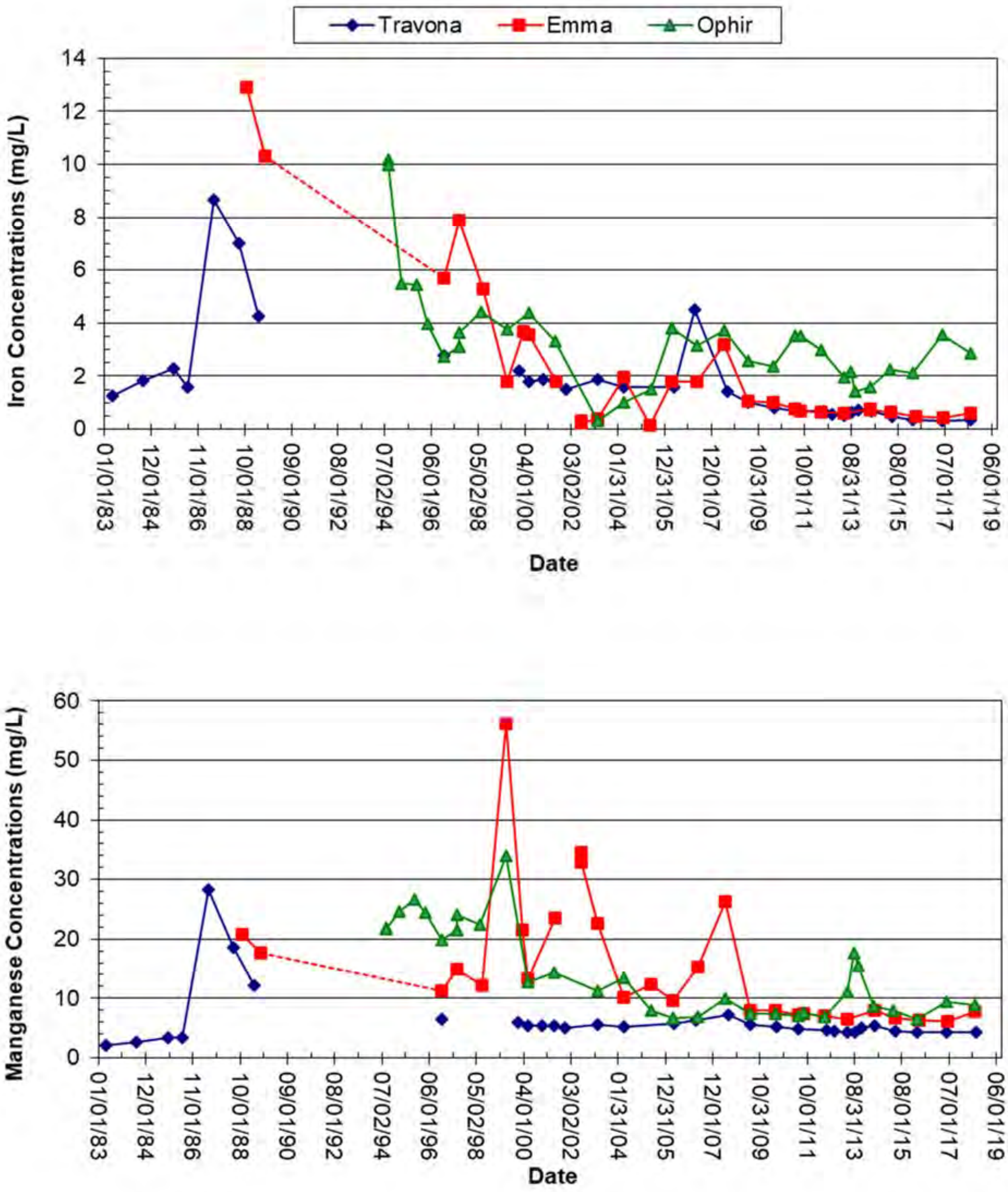
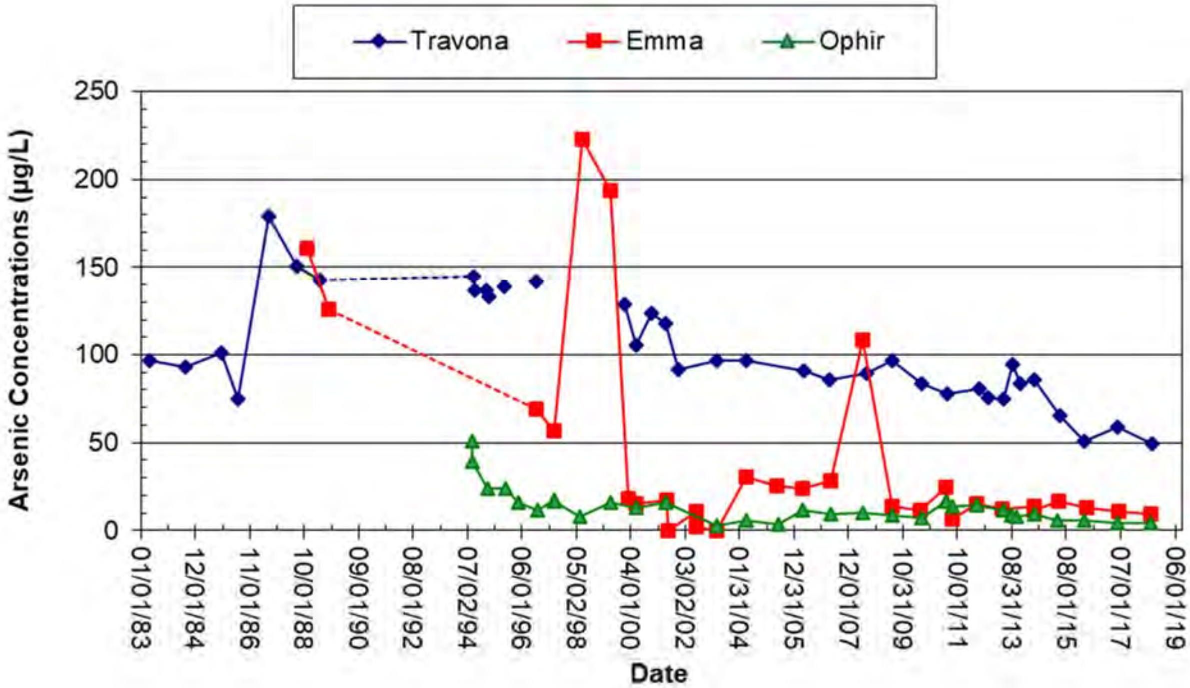


Figure 4-13. Iron (top) and manganese (bottom) concentrations in the West Camp mines.



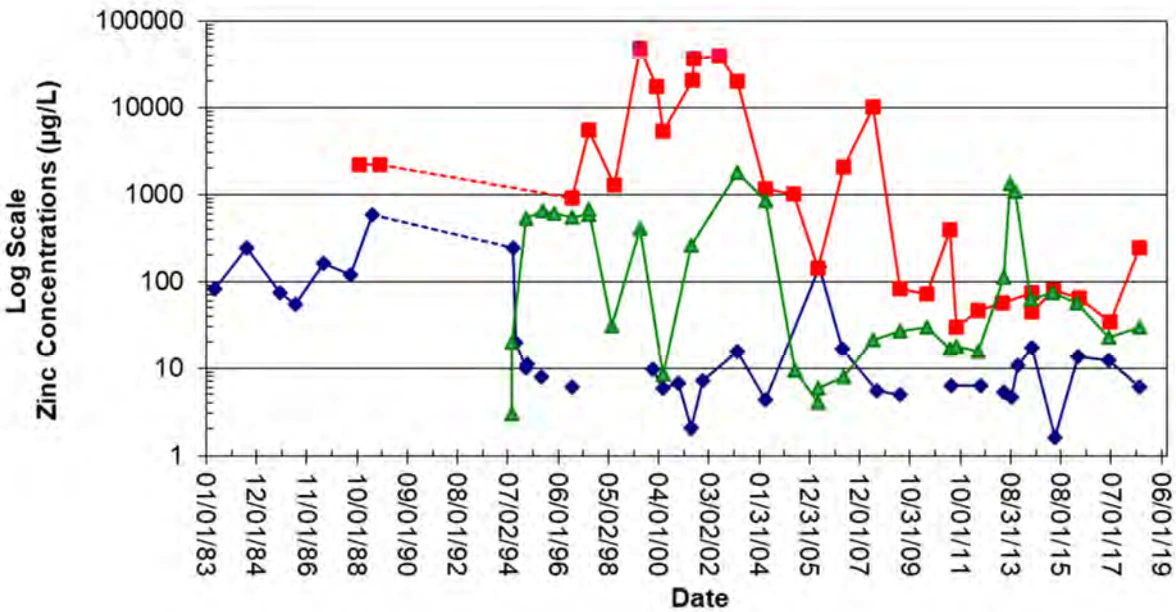
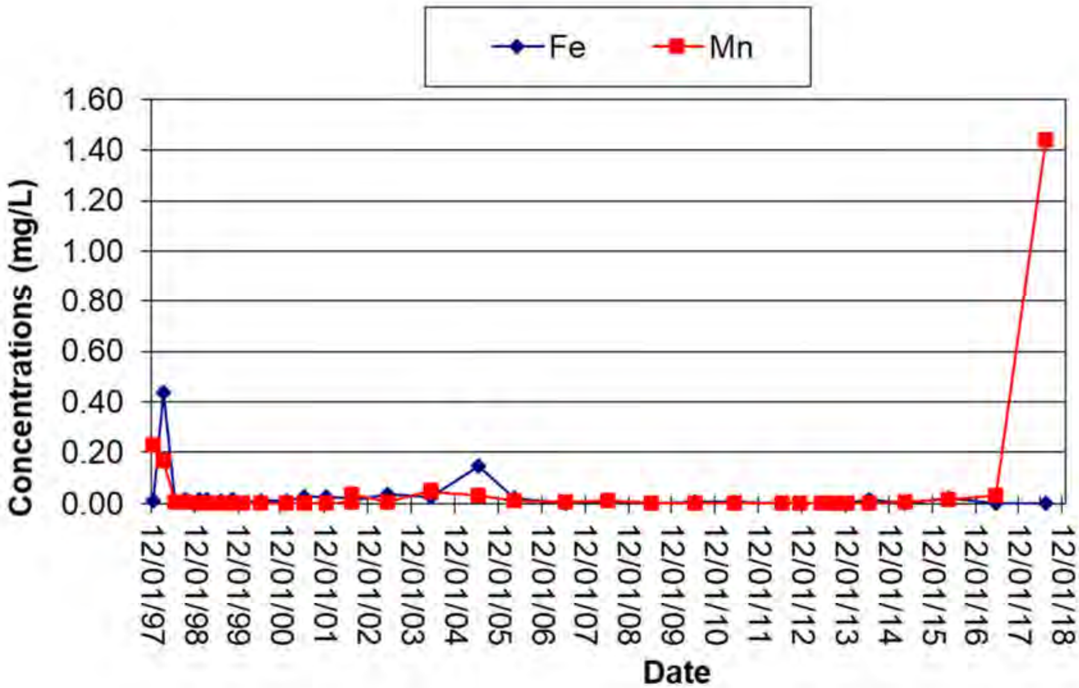


Figure 4-14. Arsenic (top) and zinc (bottom) concentrations in West Camp mines. Note that the zinc concentrations are plotted in the log-scale.



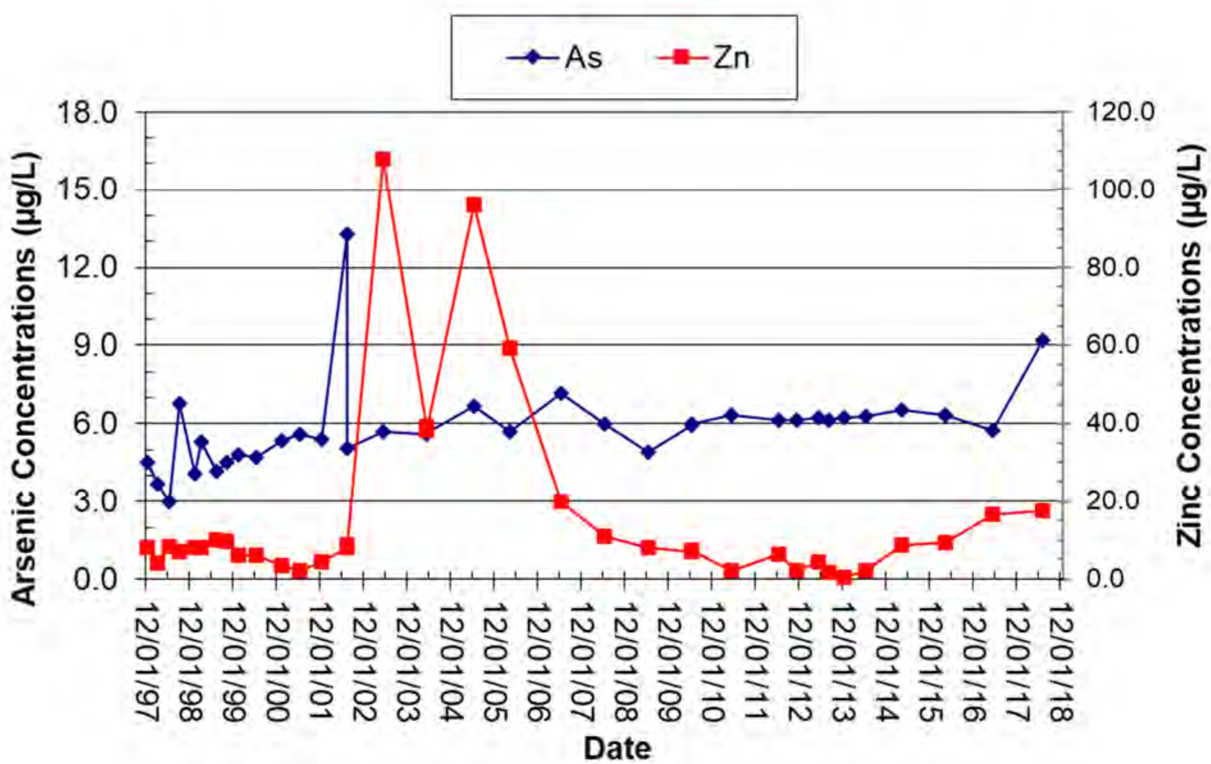


Figure 4-15. Selected water chemistry for West Camp well BMF96-4.

SECTION 5.0 OUTER CAMP SYSTEMS

The Outer Camp monitoring system consists of the Orphan Boy mine, Marget Ann mine, well S-4, the Montana Tech well, and Green Seep. These monitoring sites are located in two distant areas of the BMFOU: (1) the Marget Ann and well S-4 are in the far northwest portion, and (2) the Orphan Boy, Montana Tech well, and Green Seep are located in the far western portion (fig. 5-1). The mines in the Outer Camp System had not operated for many years (mid-1950s) prior to ARCO's suspension of underground mining in other areas of the Butte Hill. Additionally, the Outer Camp mines have been separated from the other Butte Hill mines by bulkheads for decades. Wells S-4 and Montana Tech were not designed as monitoring wells. Well S-4 was an abandoned exploration well, with unknown completion information. The Montana Tech well was installed as part of an educational program. Due to the lack of monitoring points in the Outer Camp, these sites were added to the CD monitoring programs.

The long period since the end of active mining in the Outer Camp and the physical separation of the groundwater systems (Outer Camp and East Camp) support the idea that the water levels in the Outer Camp mines are at or near pre-mining levels. The Green Seep is a surface-water monitoring location; an overgrowth of vegetation limited flow data collection during 2018.

Section 5.1 Outer Camp System Water Levels

Outer Camp water levels show a certain amount of variation each year, with water levels increasing one year, followed by a decrease the next. Water-level changes in 2018 varied from a rise of 1.84 ft in the Orphan Boy Mine to a rise of 10.49 ft in well S-4. Table 5.1.1 contains yearly water-level change data; figure 5-2 shows these changes graphically. Water levels in all four of the Outer Camp sites show a net increase. The net increases vary from over 19 ft of rise at the Montana Tech well to over 45 ft of rise in the Marget Ann Mine. Montana Tech's Mining Engineering Department pumped water from the Orphan Boy Mine periodically during 2018 to keep their underground mine lab on the 100-ft level of the mine dry. This pumping affected the water-level changes observed in both the Orphan Boy Mine and Montana Tech well (fig. 5-3).

Figure 5-4 shows water levels for the Orphan Boy Mine and the Montana Tech well, along with monthly precipitation. Water levels in these wells show a similar response, while their response to precipitation events varies with time.

The water-level changes in the Marget Ann Mine and well S-4 are similar. Figure 5-5 shows water-level hydrographs for these two sites, with monthly precipitation. Water levels had a consistent increase regardless of precipitation amounts followed by water-level declines, with little apparent influence from precipitation through 2006. Water-level variations have been less dramatic from 2007 through 2018, with the exception of those observed in 2011 and 2018. The 2011 and 2018 water-level increases in both sites were one of the largest increases seen during the period of monitoring. Considerable precipitation occurred in May and June both years, which may account for the large increases in water levels at these two sites. This same trend was observed in the Montana Tech well and the Orphan Boy Mine.

Table 5.1.1. Annual water-level changes for the Outer Camp sites (ft).

Year	Orphan Boy	Marget Ann	Well S-4	MT Tech Well
1987	2.40			
1988	2.14			
1989	3.83	-3.56	-3.56	
1990		-1.34	-4.23	
1991				
1992	1.41			
1993	5.49			0.36
1994	-0.72	4.66		2.51
1995	5.44	12.41		6.48
1996	-0.96	10.44	18.41	-1.47
Change Years 1–10	**20.43**	**22.61**	**10.62**	**7.88**
1997	7.56	14.50	16.42	7.76
1998	-2.79	0.59	2.17	-2.72
1999	-1.94	-2.87	-2.32	-1.57
2000	NA	-4.71	-4.08	-4.24
2001	NA	-1.49	-1.59	-1.79
2002	NA	-2.99	-3.13	-3.64
2003	NA	1.09	2.23	2.76
2004	NA	-2.18	-3.07	0.23
2005	-0.56	-3.01	-2.85	-1.97
2006	4.51	8.66	7.18	5.44
Change Years 11–20	**6.78**	**7.59**	**10.96**	**0.26**
2007	1.86	1.14	-0.32	1.85
2008	-1.05	0.56	-0.04	-1.68
2009	-0.27	1.09	0.60	0.99
2010	3.14	2.37	4.52	4.72
2011	5.64	7.86	12.08	4.28
2012	-5.77	-6.21	-7.66	-4.76
2013	-3.50	-3.91	-4.98	-2.88
2014	3.77	0.58	-1.45	5.85
2015	1.44	-0.18	0.90	-0.20
2016	0.15	-0.04	1.24	0.71
Change Years 21–30	**5.41**	**3.26**	**4.89**	**8.88**
2017	3.09	2.97	4.76	-0.68
2018	1.84	8.80	10.49	2.85
Change Years 31-40	**4.93**	**11.77**	**15.25**	**2.17**
Net Change*	**37.55**	**45.23**	**41.72**	**19.19**

Note. Minus sign (-) indicates a decline (drop) in water level.
*Total water-level change is that measured. Access or obstructions occasionally prevent water-level measurements.

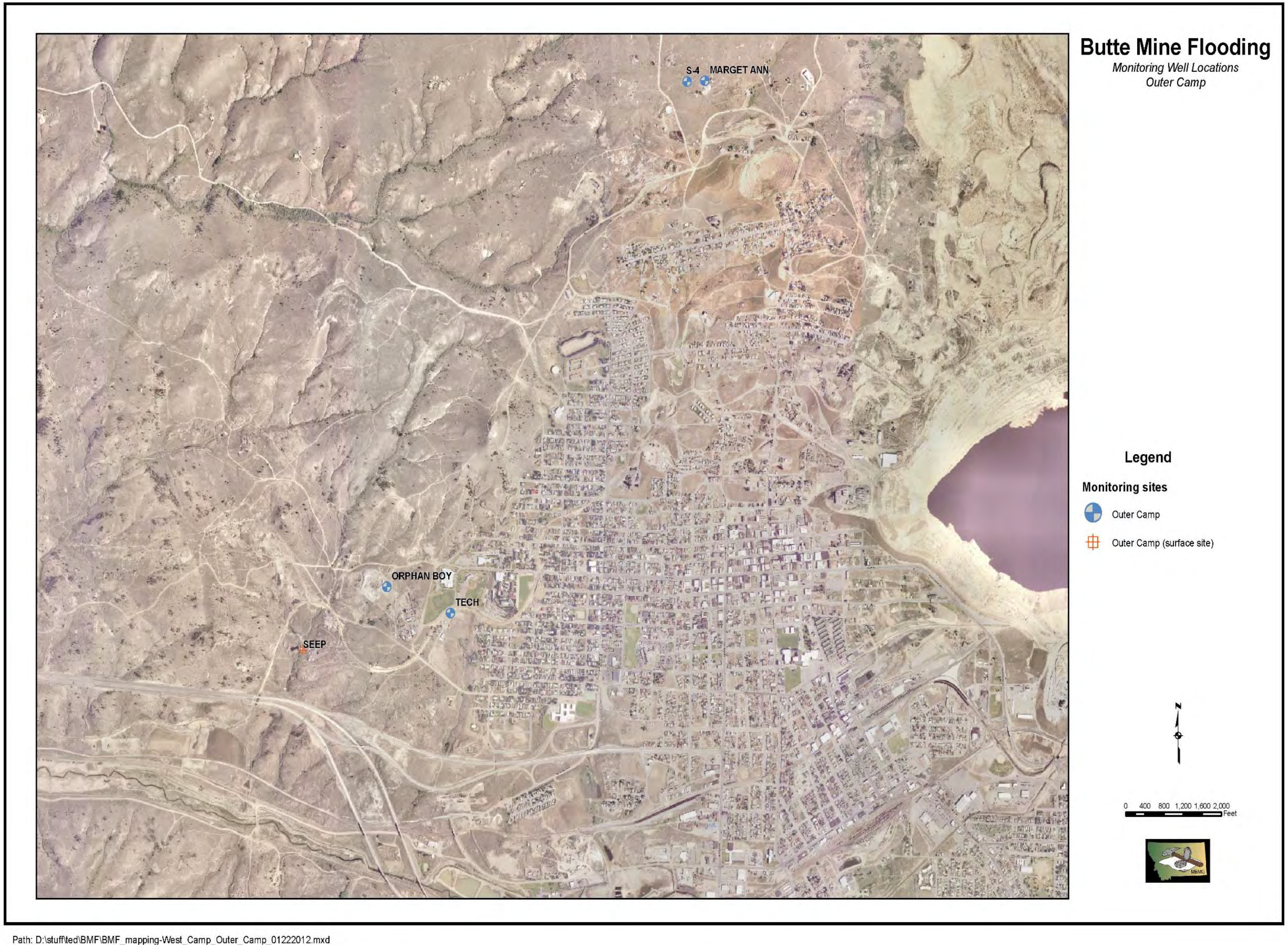


Figure 5-1. Outer Camp monitoring sites location map.

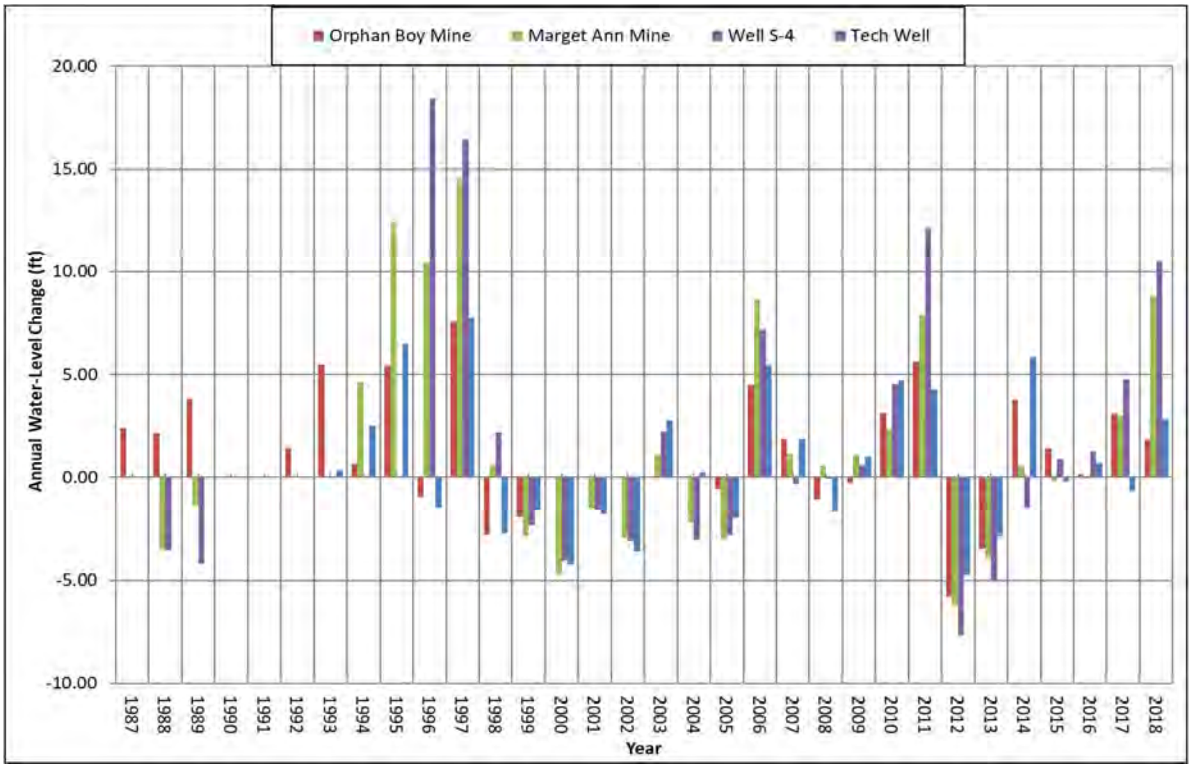


Figure 5-2. Outer Camp sites annual water-level change.

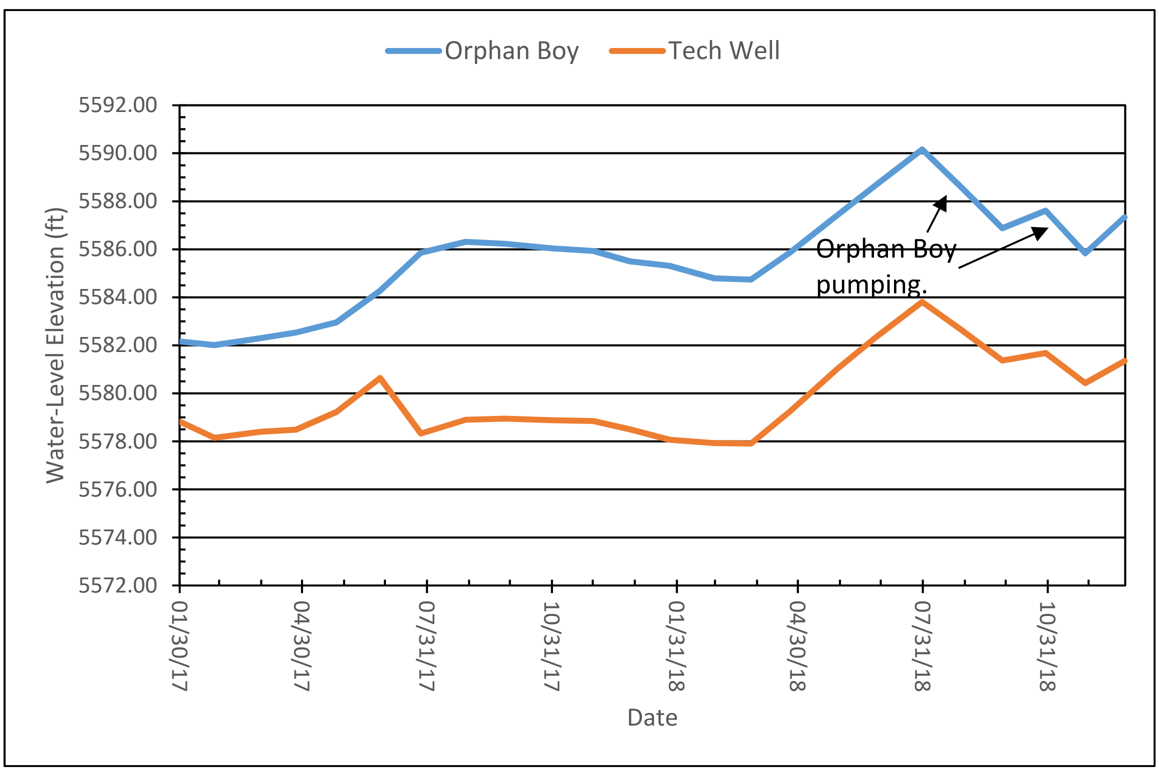


Figure 5-3. Hydrograph for 2017–2018 showing the influence of 2018 Orphan Boy water pumping events.

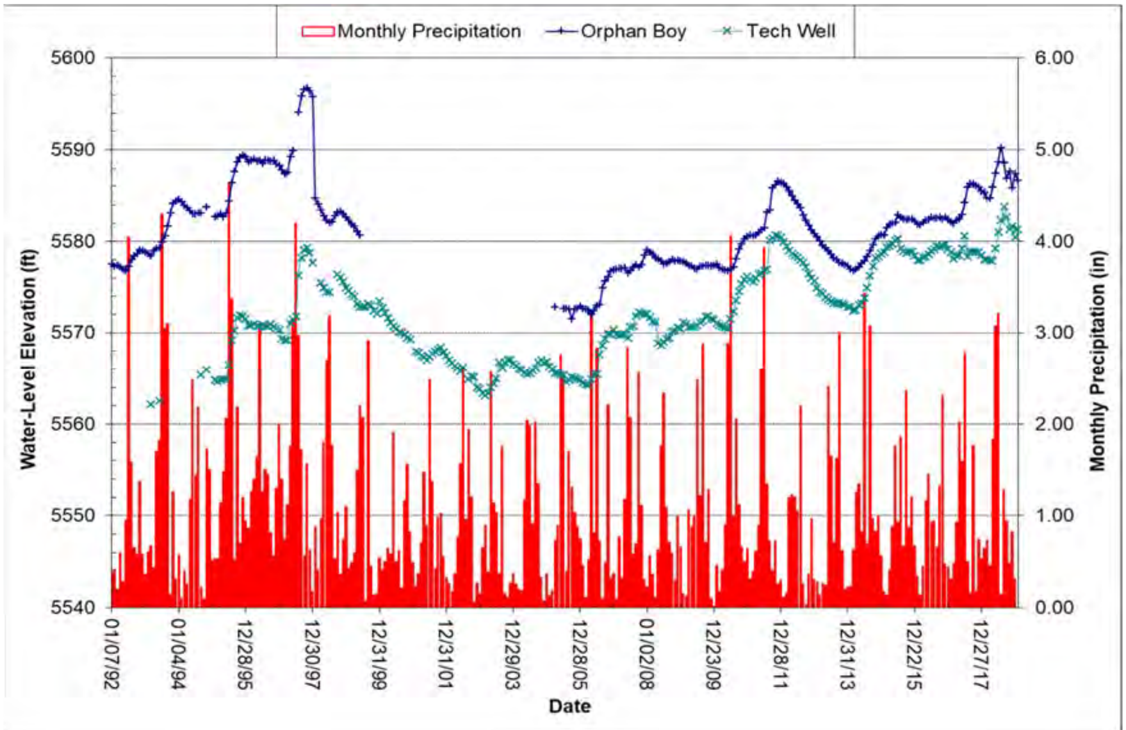


Figure 5-4. Water-level hydrograph for the Orphan Boy Mine and Montana Tech well.

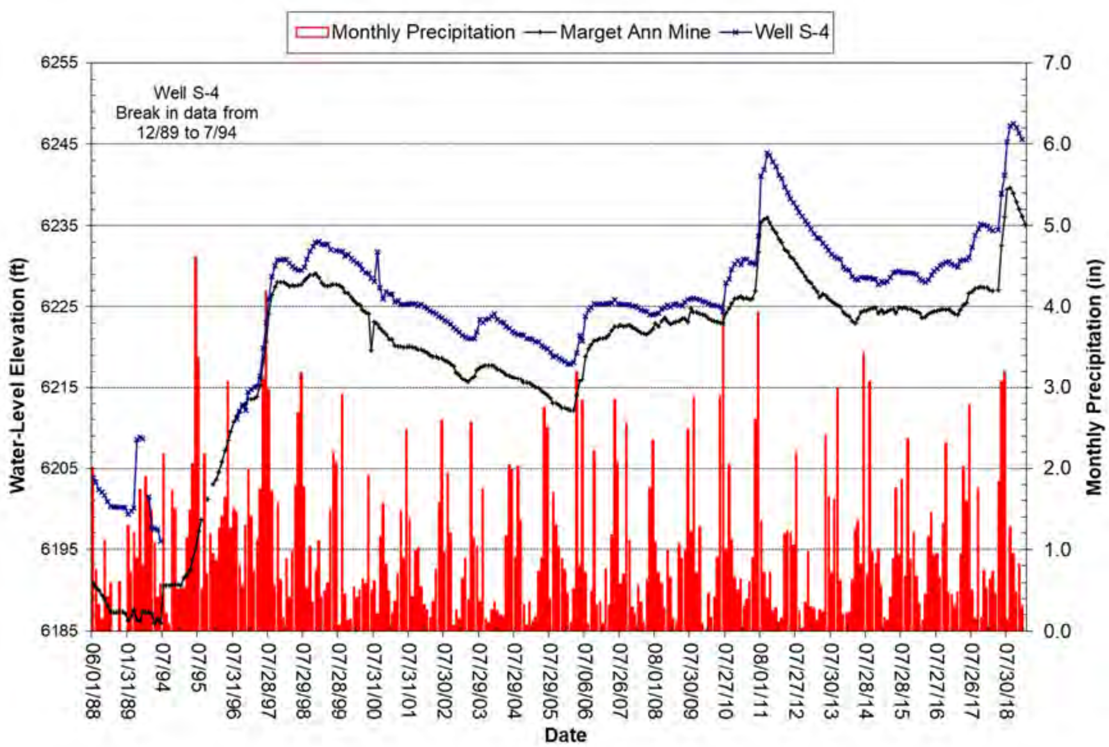


Figure 5-5. Water-level hydrograph for the Marget Ann Mine and well S-4.

Section 5.2 Outer Camp Water Quality

Water-quality samples were collected from the Orphan Boy Mine, Montana Tech well, and Green Seep during 2018; the Orphan Boy Mine and Green Seep were sampled during both the spring and fall sampling events. Figures 5-6 and 5-7 show selected water chemistry for the Orphan Boy Mine. Concentrations of Fe, Mn, and As have decreased or remained unchanged. However, the concentration of zinc increased from 2005 to 2010. Zinc concentrations show some variation during 2011–2018 but remain less than 50 µg/L. The apparent increase in concentration coincides with a change in sampling procedures. The 1987–1998 samples were collected by bailing water from the shaft; samples collected since 2005 were collected following pumping water from the shaft until stable physical parameters were obtained, or one hour of pumping. This suggests that the concentration of zinc is not increasing in groundwater but reflects the change in sampling procedures.

Water quality in the Outer Camp is better than water quality in the East Camp or West Camp bedrock systems, based on higher pH and alkalinity, and lower metal concentrations. The better quality is attributed to differences in geology and a geochemical equilibrium being reached. The workings in this area have been flooded for a longer period, and the groundwater is isolated from the rest of the Butte Hill mines.

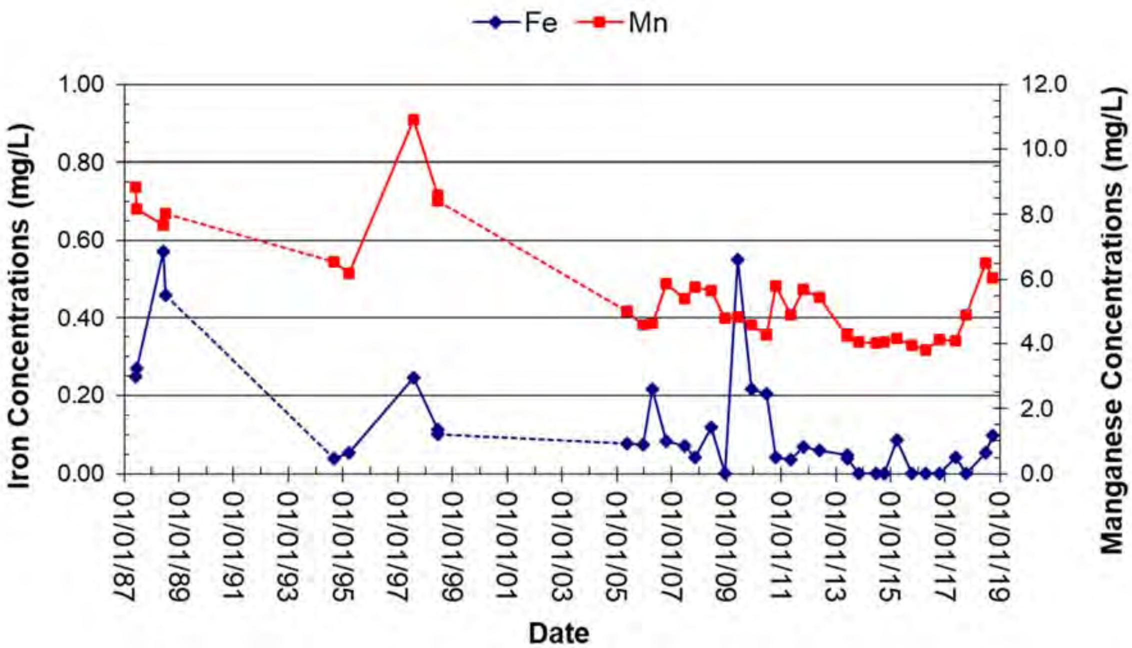


Figure 5-6. Iron and manganese concentrations for the Orphan Boy Mine.

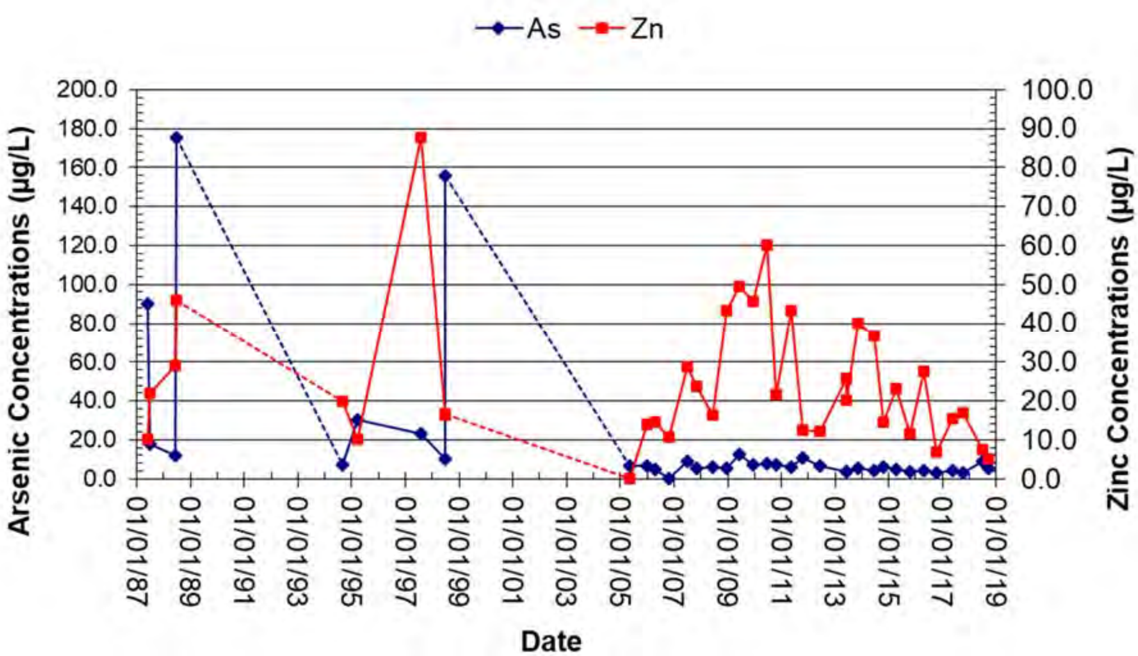


Figure 5-7. Arsenic and zinc concentrations for the Orphan Boy Mine.

SECTION 6.0 PARK WELLS

The locations of the Park monitoring wells are shown in figure 6-1. The Belmont Well #1 (the well that replaced shaft monitoring), Hebgen Park, and Parrot Park wells are bedrock wells and are part of the monitoring program specified in the 2002 CD. All three wells are located at city parks and are within the East Camp System.

Section 6.1 Park Wells Water Levels

Annual water-level changes are listed in table 6.1.1 and shown in figure 6-2. Since 1997, variations in water levels in Belmont Well #1 have generally been much greater than those in the other two wells, with several exceptions in the Parrot Park well record. Water-level changes in Belmont Well #1 have ranged from 10 to 75 ft annually. Since monitoring began at these sites, water levels have risen in the Hebgen and Parrot Park wells between 9.1 and 14.8 ft, while falling more than 23 ft in Belmont Well #1.

Table 6.1.1. Annual water-level change for park wells (ft).

Year	Hebgen[1]	Parrot	Belmont Well #1	Year	Hebgen[1]	Parrot	Belmont Well #1
1983				1993	6.27	1.39	
1984				1994	-0.25	5.96	
1985				1995	NA	2.67	
1986				1996	2.75	-1.50	-5.61
1987				1997	4.22	4.75	15.05
1988	1.54	1.43		1998	-0.62	-0.33	-15.13
1989	-2.18	0.42		1999	-2.93	-5.34	14.80
1990	-1.90	5.23		2000	-6.07	1.50	-8.11
1991	3.09	-6.10		2001	0.37	5.47	-0.41
1992	-1.40	0.63		2002	-0.41	-3.27	-24.08
Change Years 1–10	**-0.85**	**1.61**	**---**	**Change Years 11–20**	**3.33**	**11.30**	**-23.49**
2003	1.25	3.52	-54.19	2013	-0.24	2.94	6.05
2004	-0.12	-1.12	-39.79	2014	4.37	15.92	-31.51
2005	-2.19	6.76	-5.01	2015	-1.84	-9.72	1.44
2006	2.86	6.95	35.07	2016	2.63	-5.26	5.17
2007	1.40	2.44	-12.15	2017	0.19	1.90	5.71
2008	-0.98	11.20	-9.45	2018	3.40	2.15	4.88
2009	0.12	-26.99	9.83	2019			
2010	-0.05	-7.59	73.75	2020			
2011	-0.82	2.10	18.17	2021			
2012	-3.32	-3.28	-8.45	2022			
Change Years 21–30	**-1.85**	**-6.01**	**7.78**	**Change Years 31–40**	**8.51**	**7.93**	**-8.26**
				Net Change*	**914**	**14.83**	**-23.97**

Note. Minus sign (-) indicates a decline (drop) in water level. NA, no access.

[1]Hebgen Park well: No data from 06-1992 to 01-1993, 01-1995 to 09-1996, and 01-1998 to 01-1999.

*Total water-level change is that measured. Access or obstructions occasionally prevent water-level measurements.

Figure 6-1. East Camp Park monitoring wells location map.

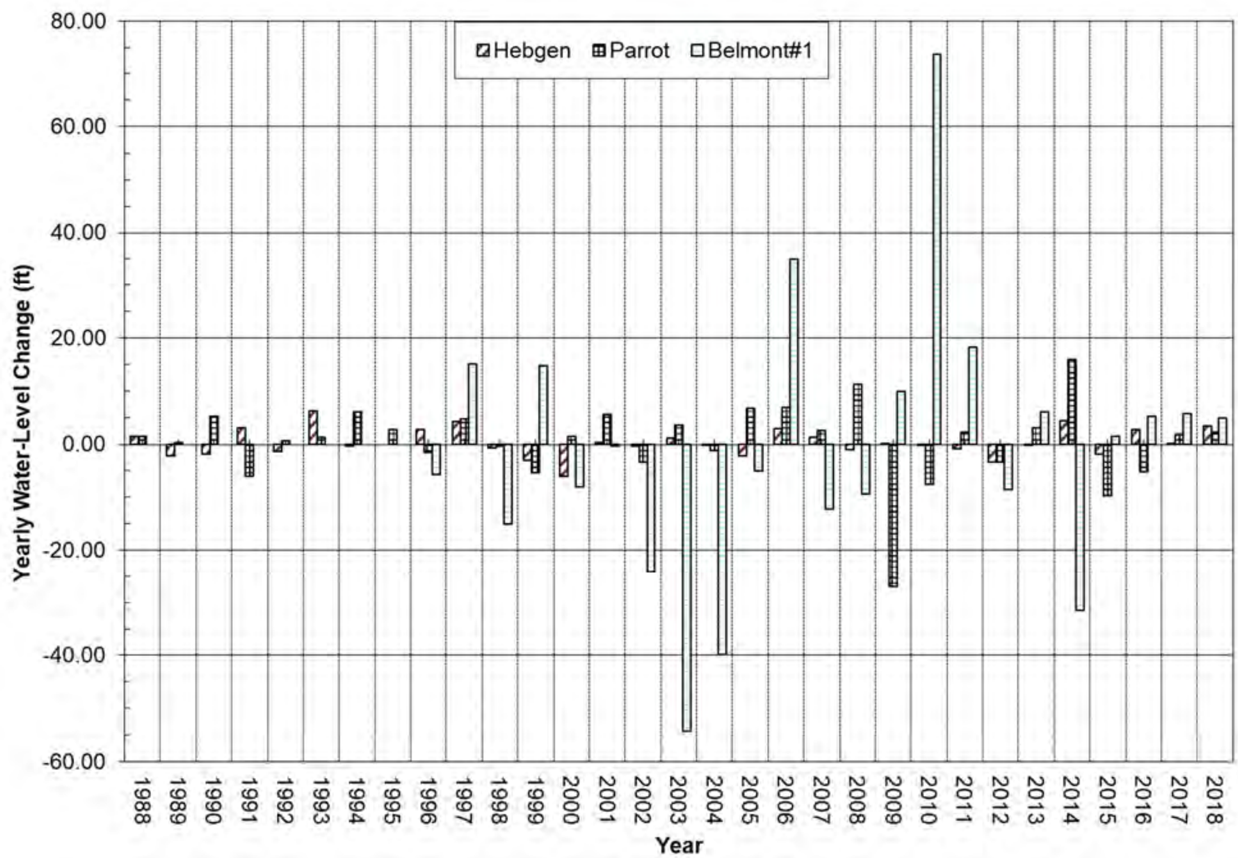


Figure 6-2. Park wells annual water-level changes.

Annual water-level response during 2018 at the Hebgen Park well (fig. 6-3) was similar to responses in prior years. Water-level rise began during the late spring and continued through the fall, which coincides with summer precipitation and watering of the park grass. Because the water-level rise extends into the fall and early winter, a portion of the seasonal water-level increase is attributed to lawn irrigation. The water level increased 3.4 ft during 2018 and has increased 9.1 ft since monitoring began.

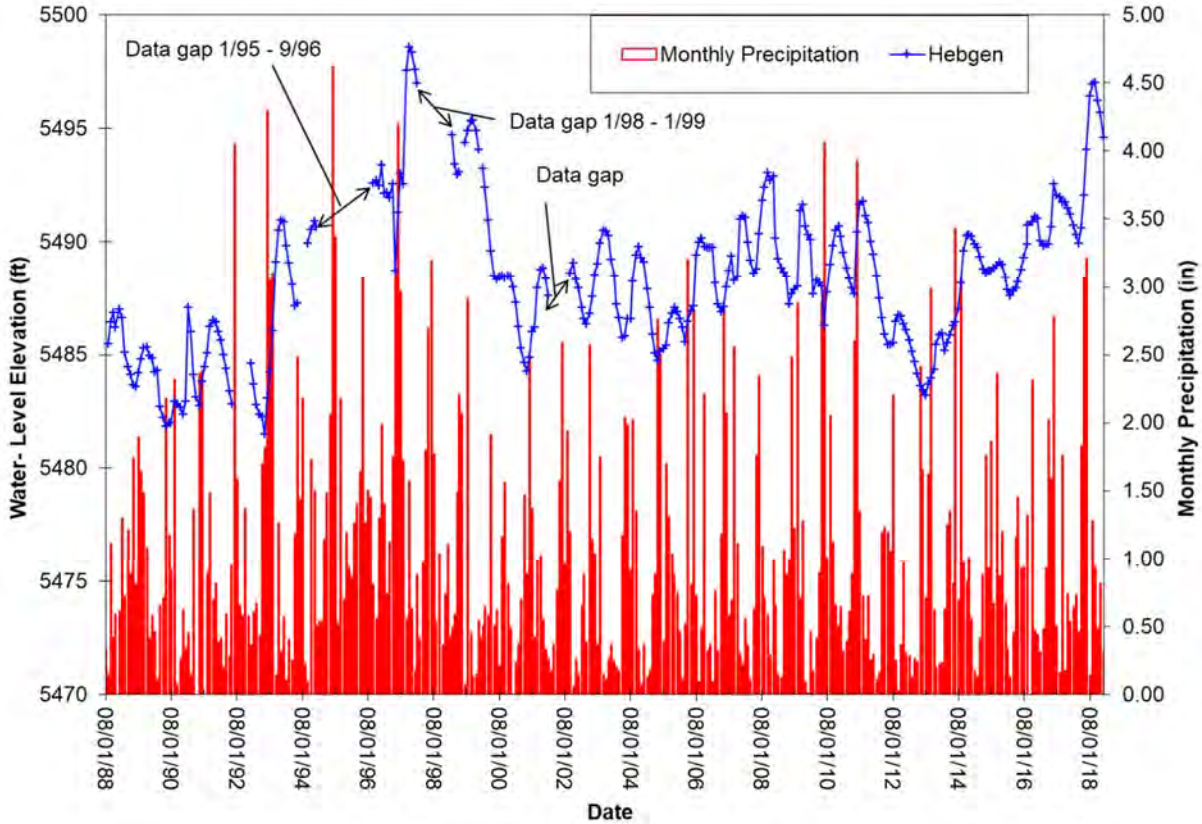


Figure 6-3. Water-level hydrograph for the Hebgen Park well.

The hydrograph for the Parrot Park well is shown in figure 6-4, along with monthly precipitation. Water levels in the Parrot Park well show considerable fluctuations at times. On three occasions between 1994 and 2016, the water level rose 20 to 30 ft, followed shortly after by a similar decline. The 2011–2014 water levels show a seasonal trend, while mid-2014 through mid-2016 water levels rose about 20 ft. The base water level at this site has risen 14.8 ft since monitoring began in 1988.

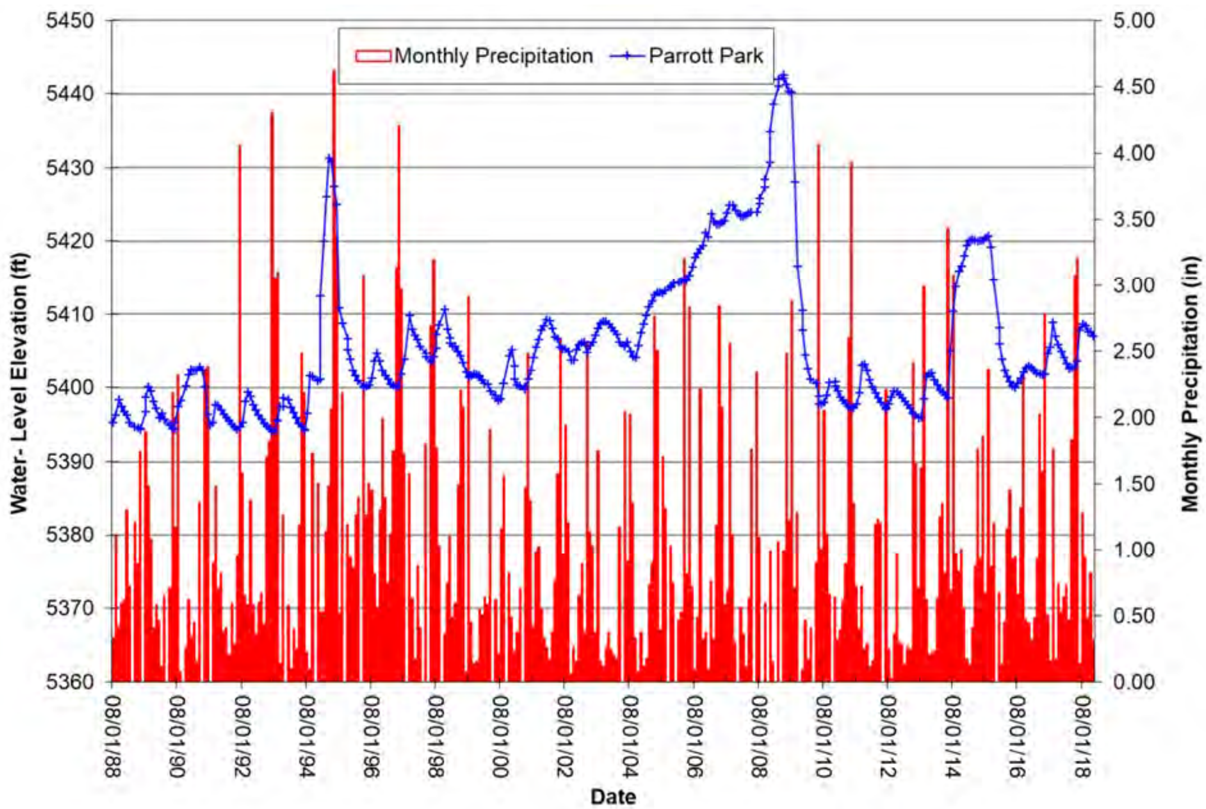


Figure 6-4. Water-level hydrograph for Parrot Park well.

Figure 6-5 compares water levels in the Parrot and Hebgen Park wells. The water-level rise in the Parrot well from 2004 through 2008 did not occur in the Hebgen well, nor did the decline that began mid-2009 and continued into the middle of 2010. Water levels in both wells show seasonal trends during 2010–2014. Water levels in the Hebgen Park well appear to respond to seasonal conditions (snowmelt, precipitation, and lawn irrigation). Additional factors likely affect the Parrot Park well water levels, which are less consistent, at times experiencing large changes not related to climate or seasonal irrigation.

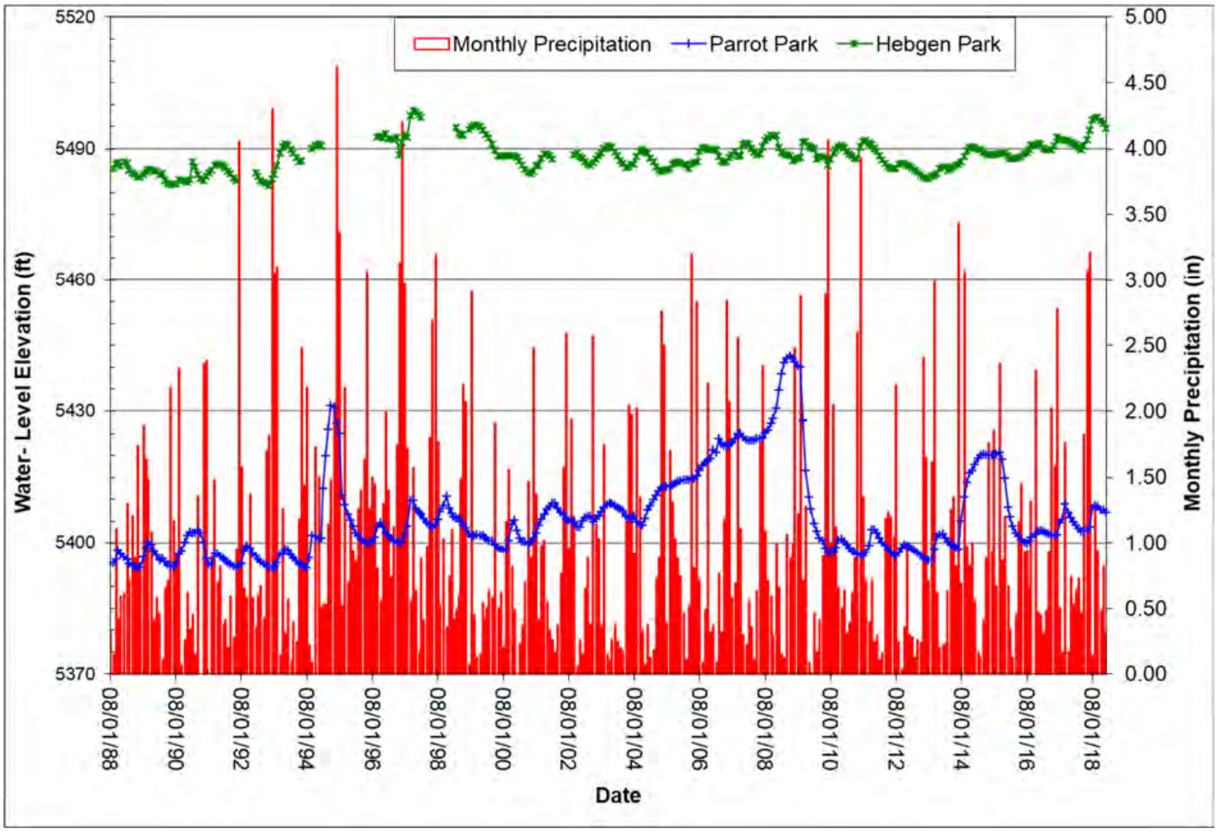


Figure 6-5. Water-level hydrographs for Parrot Park and Hebgen Park wells.

Belmont Well #1 was drilled as an alternative to monitoring water levels in the Belmont Mine, which had collapsed near the surface and became unstable. However, during completion, a borehole collapse prevented the casing from being installed to the design depth, within the mine workings. Belmont Well #1 was kept as a monitoring site that reflects groundwater levels in the bedrock outside of the mine workings. A pressure transducer has recorded hourly water levels in Belmont #1 since 2003. Figure 6-6 is a hydrograph of daily average water levels from August 1996 through 2018. Water levels in Belmont #1 differed from those of the mine workings. A second replacement well, Belmont #2, was completed in the mine workings to replace the Belmont Shaft monitoring site. Water-level changes in Belmont #1 do not match those in Belmont #2 or in any other bedrock well. Figure 6-6 shows that from 2002 through 2005, water levels in the well declined more than 120 ft, before rising 35 ft in 2006. The well water levels have continued this pattern of variability. Examination of water-level changes between 2003–2009 and 2013–2018 (fig. 6-7) and precipitation shows that seasonal water-level change is 10 to 20 ft or more. Because this borehole was drilled into the underground mine workings and then collapsed, it is difficult to ascertain what the actual controls on water levels are. However, hydraulically isolated groundwater appears present in some bedrock fractures adjacent to the underground mine workings. The water level in the Belmont #1 well is 130 ft or more above the water level in the nearby Belmont #2 well, completed in the underground mine workings.

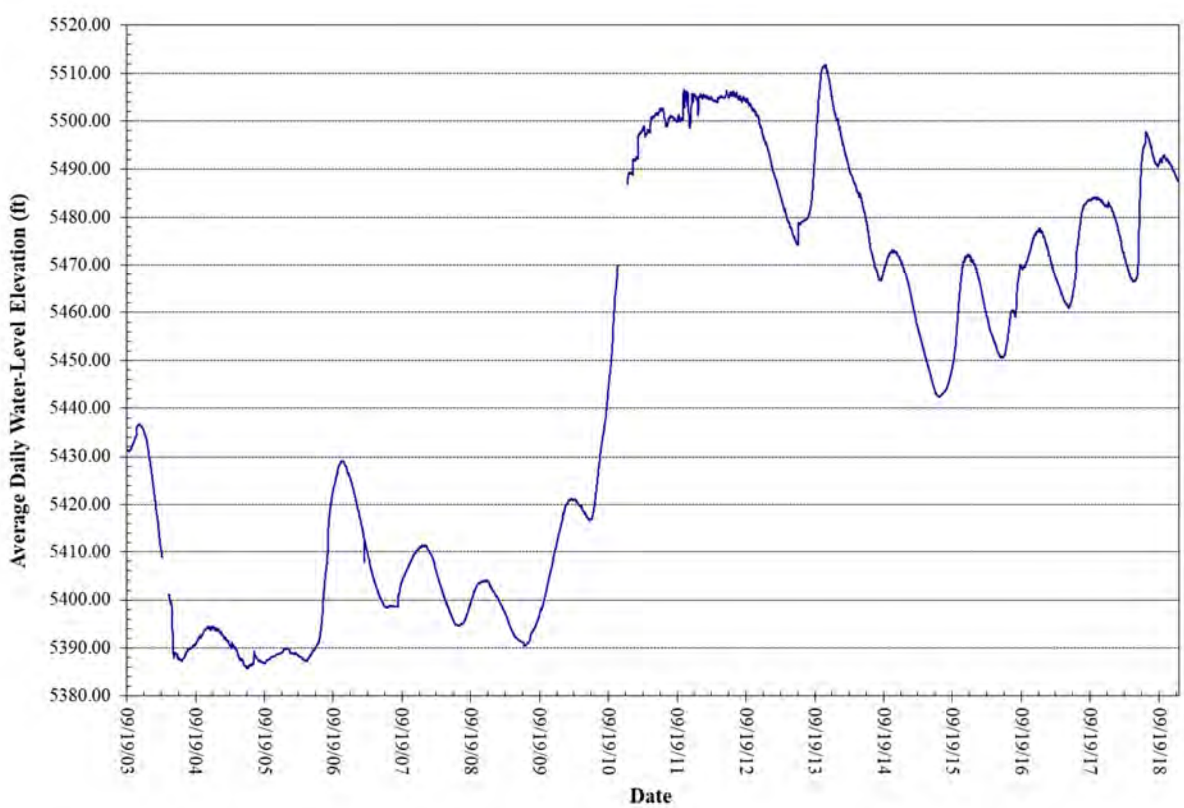


Figure 6-6. Hydrograph for Belmont Well #1.

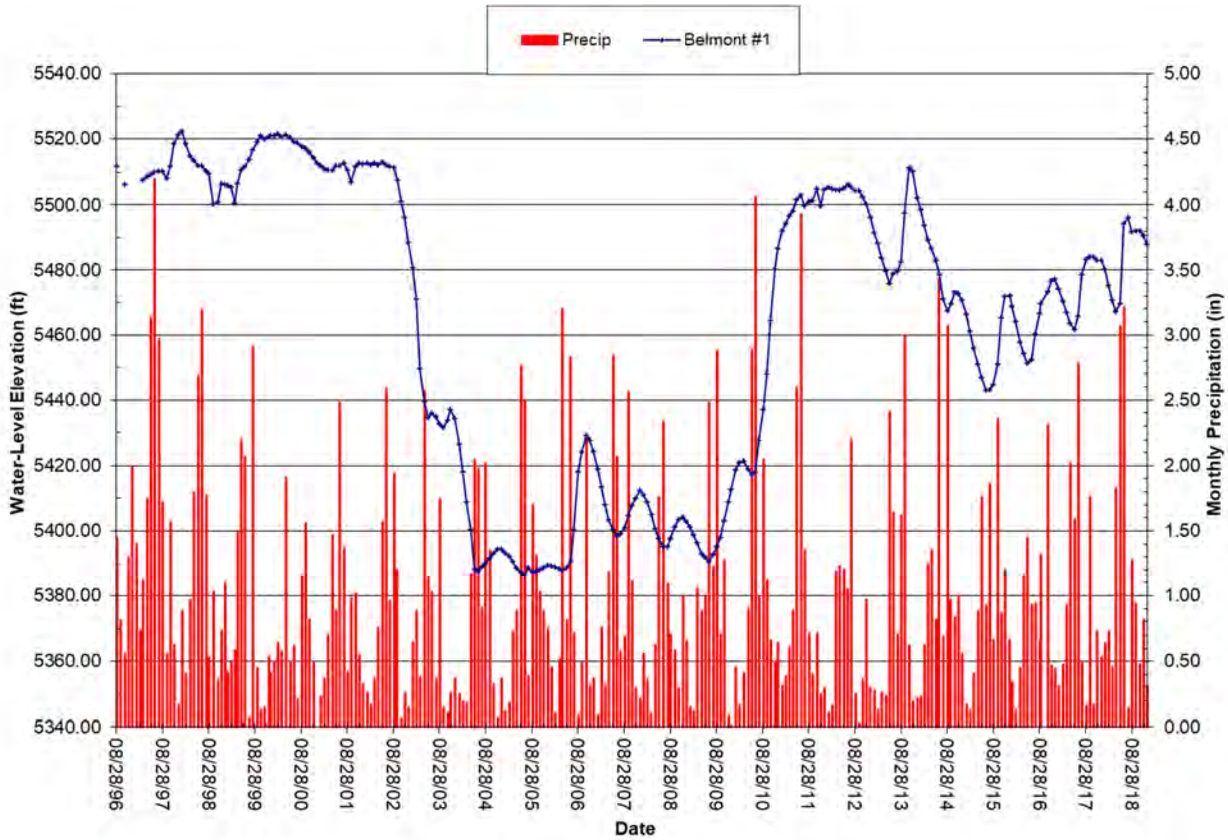


Figure 6-7 The hydrograph of Belmont #1 compared with precipitation trends during the monitoring period.

Section 6.2 Park Wells Water Quality

Water-quality samples were collected only from the Parrot Park well during 2018. Figure 6-8 shows concentrations of cadmium and copper, and figure 6-9 shows arsenic and zinc concentrations. Arsenic and cadmium exceed the respective MCLs of 10 and 5 µg/L. Although cadmium concentrations declined in 2008 to levels below the MCL, concentrations in 2009–2018 were considerably above the MCL. Concentrations increased for arsenic, cadmium, copper, and zinc in 2018 (figs. 6-8, 6-9).

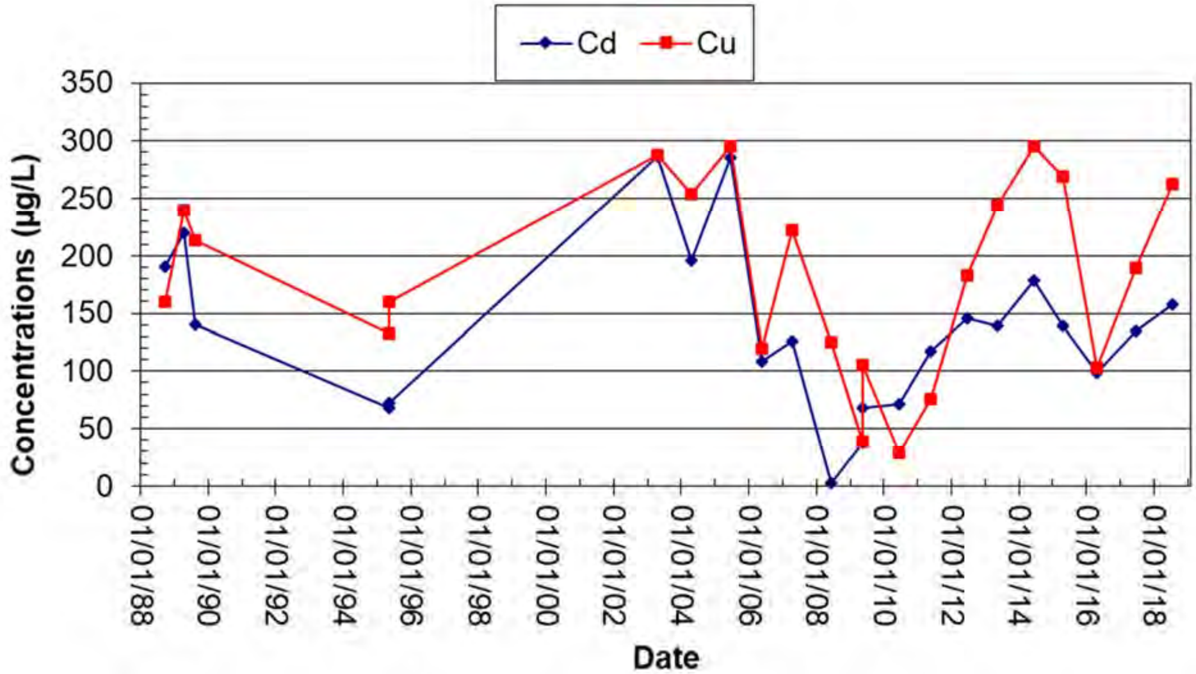


Figure 6-8. Cadmium and copper concentrations for the Parrot Park well.

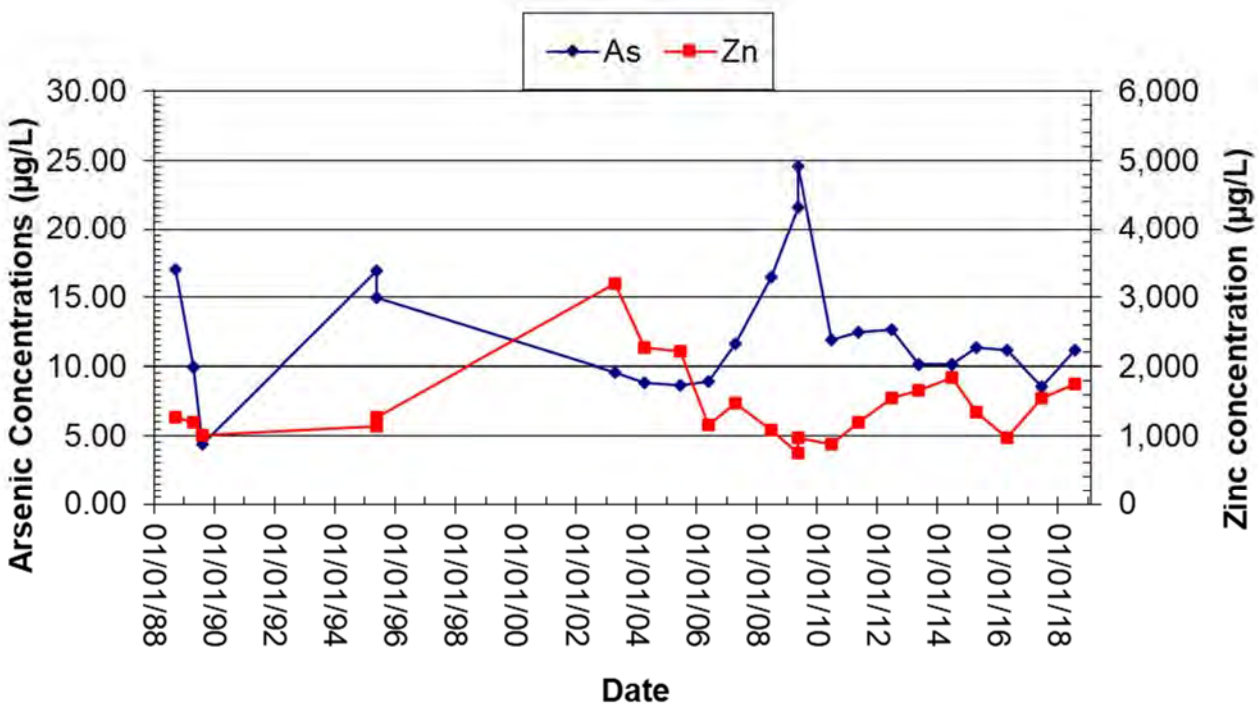


Figure 6-9. Arsenic and zinc concentrations for the Parrot Park well.

SECTION 7.0 BUTTE ALLUVIAL AND BEDROCK CONTROLLED GROUNDWATER AREA

The Butte Alluvial and Bedrock Controlled Groundwater Area (BABCGWA) was established by the Water Resources Division of the Montana Department of Natural Resources and Conservation (DNRC) in October 2009. This area was designated as a controlled groundwater area because the alluvial and bedrock aquifers have been impacted by over a century of mining and associated activities. The restrictions in the BABCGWA were established to meet the requirements of the ROD or CD for the BMFOU, BPSOU, and Montana Pole and Treatment Plant NPL Site (MPTP), ensuring that contaminants associated with historic mining activities are not present in harmful concentrations in groundwater supplies.

The outer perimeter of the BABCGWA is shown in figure 7-1, with major historic mines and landmarks included for reference. The boundaries of the Old Butte Landfill and Clark Tailings areas, near the southern edge of the map, are also shown. The alluvial aquifer portion of the BABCGWA covers 8.11 mi^2, and extend to depths of over 300 ft in the northeast, thinning to less than 10 ft in thickness at the western edge. Bedrock within this extends below surface to an elevation of about 1,500 MSL (DNRC Final Order, 2009).

Section 7.1 Sampling Activities in 2018

Based upon site requests from the BSB Health Department, the MBMG collected groundwater samples from eight privately owned wells during 2018. General information about each well is found below, in table 7.1.1. The well locations are shown in figure 7-2, and except for one site, are located within the BABCGWA.

Table 7.1.1 General site information for the domestic wells sampled in 2018 for BABCGWA. The elevation, depth, and static water level (SWL) data are listed in feet (USGS datum).

GWIC ID	SITE NAME	LAT	LONG	ELEVATION	DEPTH	SWL
174040	BOWLER	45.99673	-112.55196	5450	32	N/A
269353	MILLER	45.99727	-112.55403	5450	25	N/A
50357	RAWLINS	46.00867	-112.55859	5660	250	N/A
4819	REYNOLDS	46.00623	-112.53776	5505	200	N/A
156158	WEST	45.98796	-112.53646	5480	44	N/A
171276	WHITE-HOUSE	45.98103	-112.54904	5520	160	N/A
171278	ROSIN BROS.	45.98103	-112.54639	5515	160	41.99
255690	WHITE-WEST	45.98206	-112.54939	5520	N/A	N/A

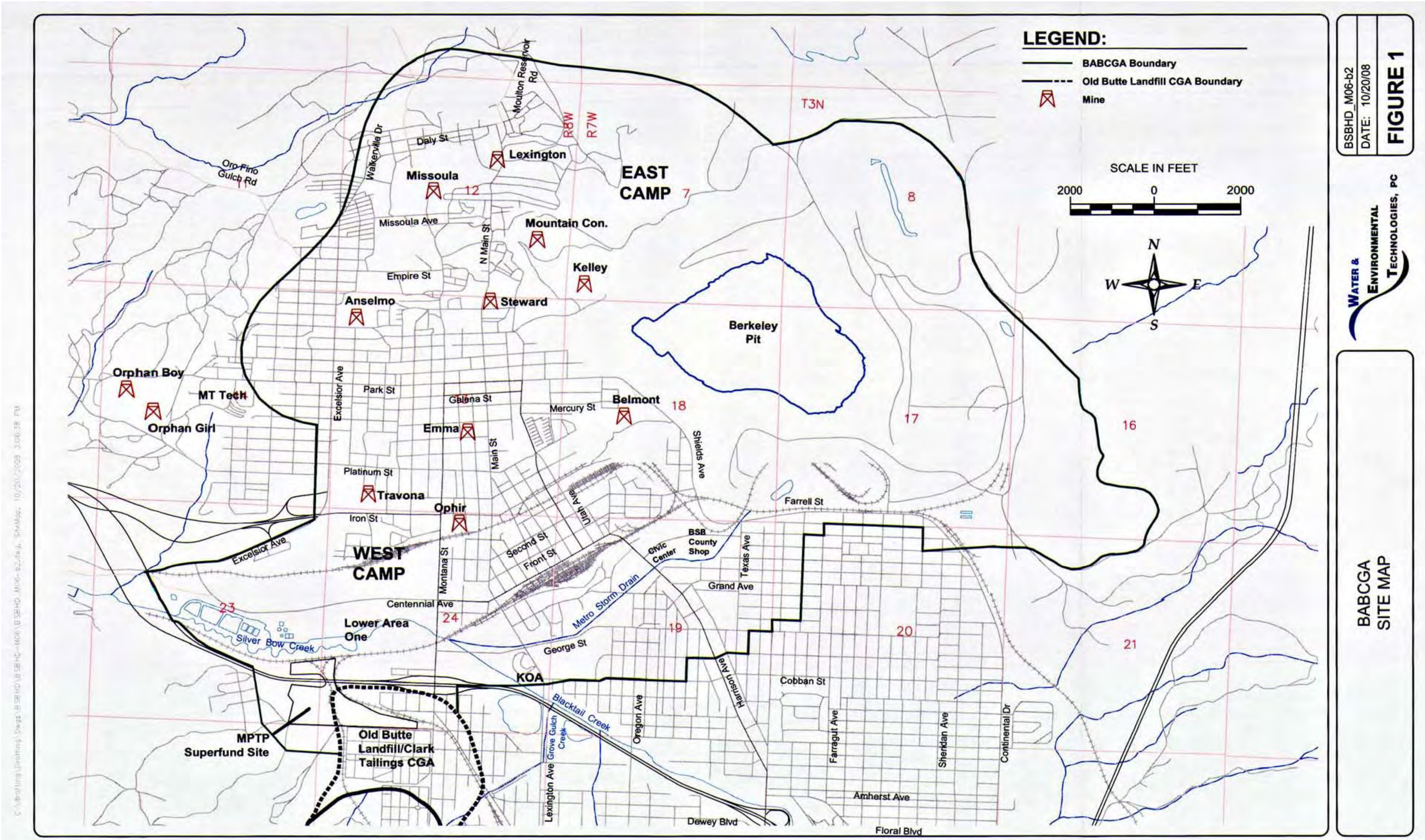


Figure 7-1. Site map for BABCGWA—prepared by Water & Environmental Technologies, included in the Final Order (DNRC).

Where possible, the SWL in each private well was measured with an electronic water-level probe. If possible, the total depth was measured before purging water from the well. If possible, at least three well volumes were purged prior to sampling, with a "well volume" being the volume of water within the well casing prior to pumping. At the majority of the sites, SWL and total depth measurements were not possible because of restricted access due to well seals or buried conditions.

Physical parameters [e.g., temperature, pH, oxidation reduction potential (ORP), SC, and dissolved oxygen (DO)] were measured in groundwater during pumping at 5- to 10-min intervals, using a calibrated Hach Hydrolab Minisonde-5. Wells with unknown SWLs and well volumes were purged until the parameters stabilized prior to sampling. After the parameters stabilized about the mean of three consecutive readings (i.e., temperature <±0.5°C; pH <±0.1; ORP <±20; mV SC <±5%), a series of water samples were collected for "dissolved analytes."

A separate sample was collected this year for total recoverable analysis (unfiltered-acidified with HNO_3) to comply with changes in the Superfund monitoring programs.

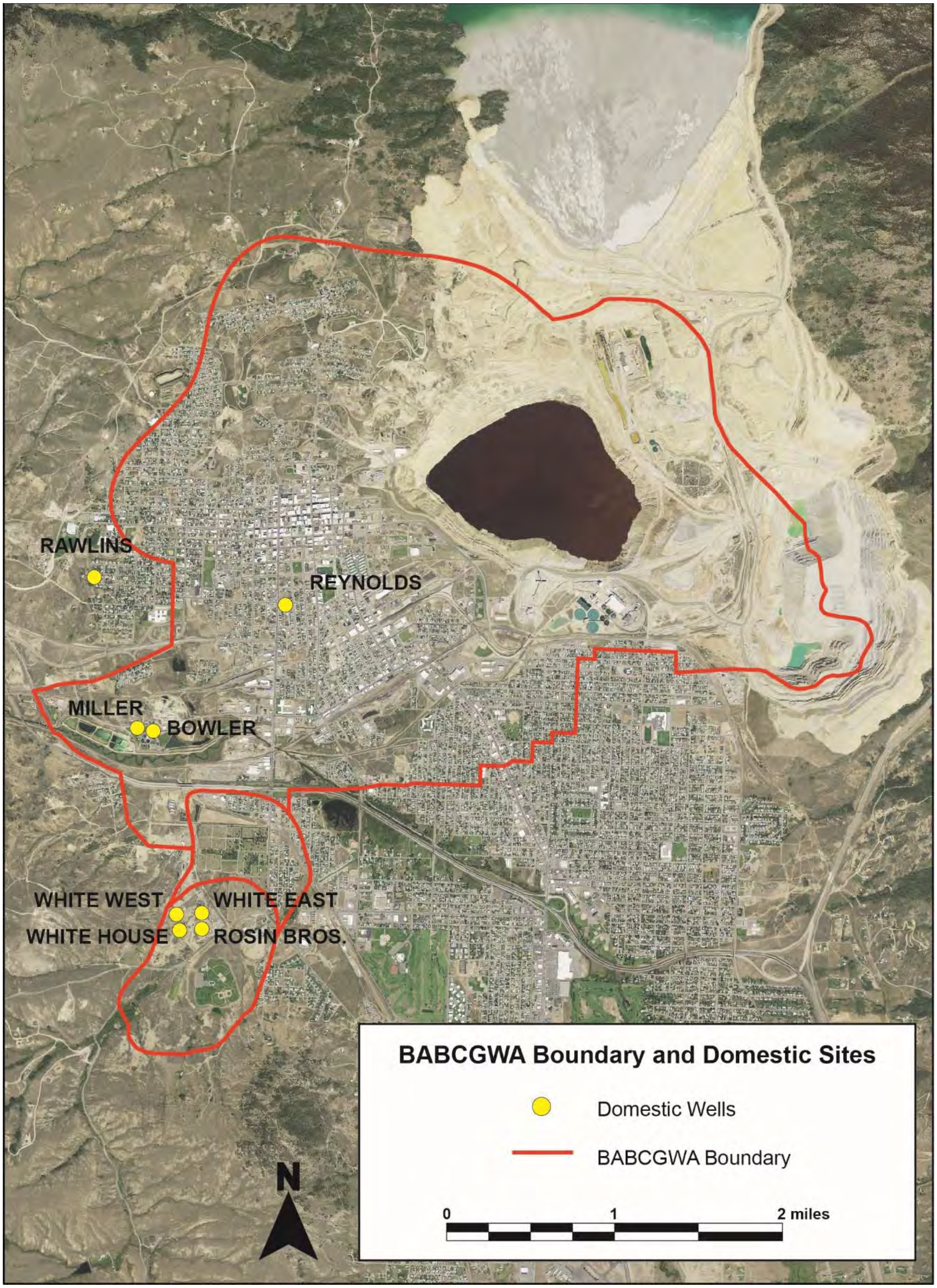


Figure 7-2. Site map for domestic well sampling locations; BABCGWA boundary is shown in red.

Section 7.2 Water-Quality Results

The laboratory results for the five COC (arsenic, cadmium, copper, lead, and zinc) are compared to the drinking water MCLs (DEQ-7) in tables 7.2.1 (dissolved) and 7.2.2 (total recoverable).

Table 7.2.1 Comparison of DEQ-7 MCLs for dissolved COC with 2018 domestic well results.

GWIC Id	Site Name	Sample Date	As (µg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)
-	**DEQ-7 STANDARD**	**-**	**10**	**5**	**1,000**	**15**	**2,000**
174040	BOWLER	8/20/18	0.64 J	0.56 J	<1.25 U	<0.15 U	109.7
269353	MILLER	8/20/18	7.88	<0.25 U	15.65	<0.15 U	18.7
50357	RAWLINS	8/20/18	4.21	<0.10 U	5.22	<0.06	15.0
4819	REYNOLDS	8/20/18	1.25	<0.25 U	15.43	<0.15 U	4.23 J
156158	WEST	8/20/18	1.17	0.34 J	21.34	<0.06 U	181.0
171276	WHITE-HOUSE	8/21/18	2.63	<0.10 U	<0.50 U	<0.06 U	9.59
255690	WHITE-WEST	8/21/18	3.60	<0.25 U	9.02	<0.15 U	16.38
171278	ROSIN BROS.	8/21/18	3.43	<0.25 U	1.68 J	<0.15 U	6.81

Table 7.2.2 Comparison of DEQ-7 MCLs for total recoverable COC with 2018 domestic well results.

GWIC Id	Site Name	Sample Date	As (µg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)
-	**DEQ-7 STANDARD**	**-**	**10**	**5**	**1,000**	**15**	**2,000**
174040	BOWLER	8/20/18	<0.25 U	1.33	<1.25 U	<0.15 U	106.8
269353	MILLER	8/20/18	8.00	<0.25 U	32.33	<0.15 U	21.1
50357	RAWLINS	8/20/18	4.39	<0.25 U	5.84	<0.15 U	18.5
4819	REYNOLDS	8/20/18	1.04	<0.25 U	14.63	<0.15 U	3.66 J
156158	WEST	8/20/18	1.23	<0.25 U	34.54	<0.15 U	192.5
171276	WHITE-HOUSE	8/21/18	2.75	<0.25 U	<1.25 U	<0.15 U	12.61
255690	WHITE-WEST	8/21/18	3.43	<0.25 U	8.97	<0.15 U	20.06
171278	ROSIN BROS.	8/21/18	3.44	<0.25U	1.82J	<0.15U	15.75

Note. J, estimated quantity above detection limit but below reporting limit. U, Undetected quantity below detection limit. NS-well not sampled

Results from all domestic wells sampled in 2018 were below the established MCLs for the five COCs required in the Final Order. This is consistent with the results at these wells in previous years (results are recorded in MBMG's GWIC database). Each well owner was sent a letter that described the sampling objectives for the project and included a complete analytical report of their sample and comparison to the DEQ-7 standards. Although none of the samples exceeded the five COCs, concentrations of some of the other analytes exceeded MCLs or SMCLs. SMCLs are based on the aesthetic quality of water and are not a health standard. All MCL and SMCL exceedances are given in table 7.2.3. There were no exceedances in the Rawlins (#50357) well.

Table 7.2.3 Comparison of DEQ-7 MCLs and SMCLs with 2018 exceedances.

GWIC Id	Site Name	Exceeded Analyte	2018 Result (Diss./Tot. Rec.)	MCL	SMCL
174040	BOWLER	Fe	2.62/2.93 mg/L	-	0.3 mg/L
174040	BOWLER	Mn	3.64/4.05 mg/L	-	0.05 mg/L
174040	BOWLER	SO_4	304/NA mg/L	-	250 mg/L
269353	MILLER	SO_4	344/NA mg/L	-	250 mg/L
269353	MILLER	NO_3	11.95/NA mg/L	10 mg/L	-
269353	MILLER	U	35.4/31.2 µg/L	30 µg/L	-
4819	REYNOLDS	NO_3	15.6/NA mg/L	10 mg/L	-
4819	REYNOLDS	U	31.7/- µg/L	30 µg/L	-
156158	WEST	Mn	0.09/0.09	-	0.05 mg/L
171276	WHITE-HOUSE	U	42.7/38.2 µg/L	30 µg/L	-
255690	WHITE-WEST	U	95.6/89.3 µg/L	30 µg/L	-
171278	ROSIN BROS.	U	95.8/80.6 µg/L	30 µg/L	-

Some of these wells are not used for drinking water, like the White-East (#171277) and the Bowler wells (#174040). The Bowler well was previously used for potable water but use is currently restricted to lawn watering. The wells sampled during 2018 will continue to be sampled, unless the site list changes after consultation with BSB, EPA, and DEQ.

SECTION 8.0 REVIEW OF THE BERKELEY PIT MODEL

The Berkeley Pit water-level model was updated with 2018 water-level data and HSB flows measured at the weir upgradient of the water-treatment plant influent pond. The model incorporates monthly water-level rise information (as surveyed each month) in the pit and measured in East Camp mine shafts from July 1996 through December 2018.

In 2018, an error in the evaporation tables used in the model was discovered that affected the dates predicted by the model. The error consisted of an incorrect unit conversion from cubic feet per day to million gallons per day. Tables 8.0.1 and 8.0.2 contain the uncorrected and corrected evaporation values, respectively. The evaporation rates shown under “Evaporation (MGPD)” in table 8.0.1 were multiplied by

7.48 to complete the unit conversion. The corrected values, shown in table 8.0.2, increase the amount of estimated evaporation and extend the dates for the expected milestones described in the 2002 CD.

Table 8.0.1 Evaporation Table 5 from 2018 Berkeley Pit In-Fill Model Report (Duaime, 2019).

Elevation (USGS Datum)	Bench Volume (M ft^3)	Bench Mid-line Area (M ft^2)	Net Inflow Rate for Elevation (MGPD)	Evaporation (MGPD)
5146 - 5186	505.5630	12.6391	5.00	0.0336
5186 - 5226	544.4095	13.6102	5.00	0.0362
5226 - 5266	575.3680	14.3842	4.99	0.0383
5266 - 5306	631.3270	15.7832	4.98	0.0420
5306 - 5346	760.3455	19.0086	4.97	0.0506
5346 - 5386	820.3295	20.5082	4.95	0.0545
5386 - 5426	876.9210	21.9230	4.92	0.0583
5426 - 5466	929.6945	23.2424	4.89	0.0618

Table 8.0.2 Corrected evaporation Table 5 for Berkeley Pit In-Fill Model.

Elevation (USGS Datum)	Bench Volume (M ft^3)	Bench Mid-line Area (M ft^2)	Net Inflow Rate for Elevation (MGPD)	Evaporation (MGPD)
5146 - 5186	505.5630	12.6391	5.00	0.2515
5186 - 5226	544.4095	13.6102	4.98	0.2708
5226 - 5266	575.3680	14.3842	4.95	0.2862
5266 - 5306	631.3270	15.7832	4.88	0.3140
5306 - 5346	760.3455	19.0086	4.76	0.3782
5346 - 5386	820.3295	20.5082	4.60	0.4080
5386 - 5426	876.9210	21.9230	4.42	0.4362
5426 - 5466	929.6945	23.2424	4.20	0.4624

Based upon the **corrected** 2018 model, the PWL of 5,410 ft at the Pilot Butte Mine is projected in **November 2024**, 508 days (16.7 months) later than June 2023, predicted in the 2017 model. (The point of compliance for the PWL was changed from the Anselmo Mine to the Pilot Butte Mine since the water level is highest at that location.) The model update includes the surface-water inputs from stormwater diversions in the Kelley Mine area, the addition of sludge from the HSB water-treatment plant, and previous model filling rates adjusted for the diversion of HSB water away from the pit. Although HSB drainage water flowed into the pit from June 2000 through November 17, 2003, it is currently diverted to the HSB water-treatment plant for treatment and subsequent use in MR's mining operations. No major changes in additions or withdrawals of water were made at the Berkeley Pit during 2018, with the exception of the planned diversions of HSB water during concentrator and water-treatment plant maintenance activities, as discussed in section 3.5 and table 3.5.1 of this report. The pit contained 48.8 billion gallons of water at the end of 2018, with a projected volume of 53.4 billion gallons in November 2024.

The treatment technology for Berkeley Pit water treatment and the treatment plant construction time frame is based upon the schedule listed in the EPA 1994 ROD (EPA, 1994) and included in the 2002 CD for the BMFOU. Based upon the current water-level projections, the submittal of a Technical Memorandum assessing the adequacy of the existing treatment plant is due November 2020 (fig. 8-1). Any necessary upgrades would have to be completed by November 2022.

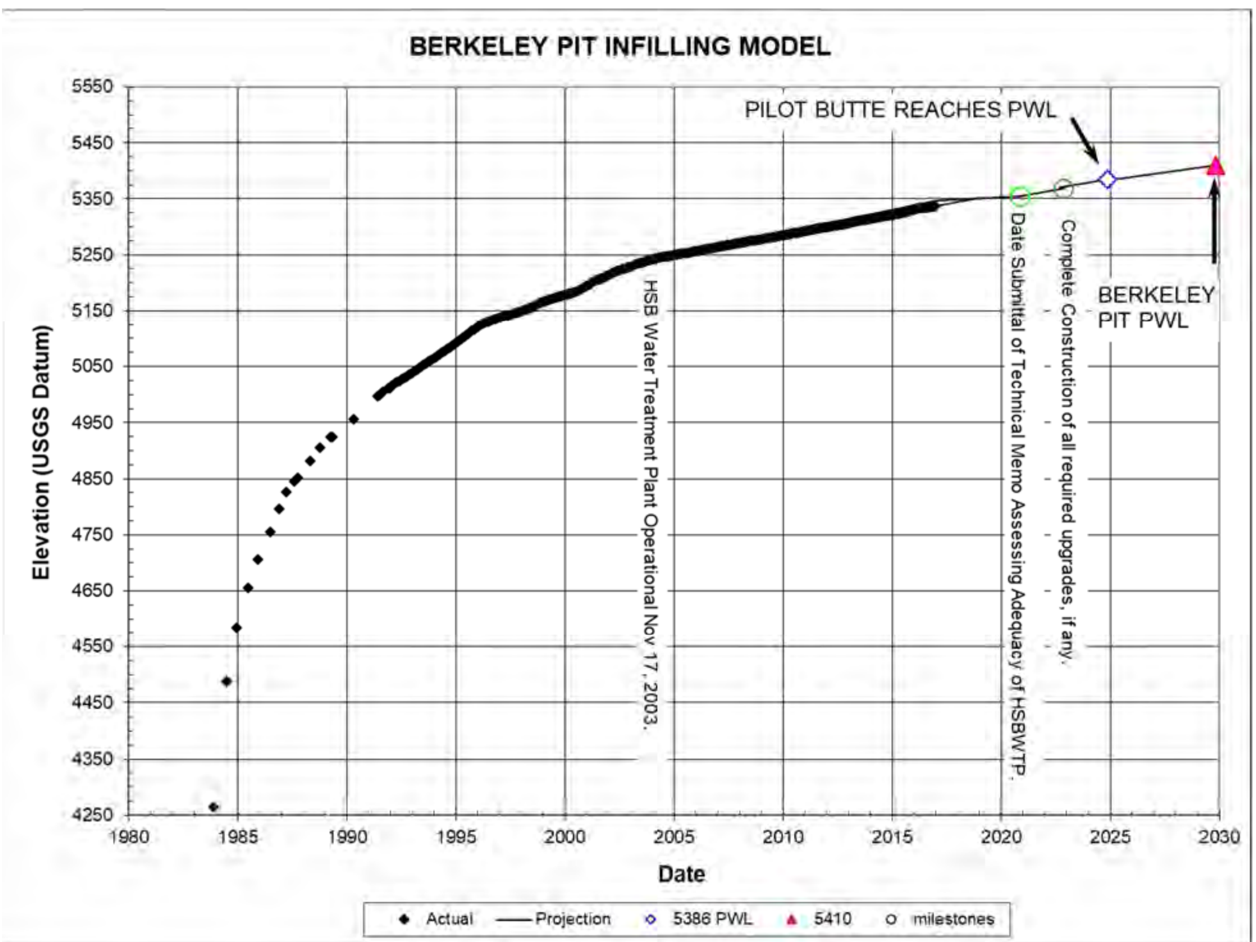


Figure 8-1. Projected Berkeley Pit filling rate with dates of treatment review and upgrades.

SECTION 9.0 RADIUM MONITORING

Since 2003, radionuclide monitoring has been a component of the BMFOU water-quality monitoring program. The Boulder Batholith, the host rock for the mineral occurrences that supported mining activity, contains a unique signature of uranium (U) and thorium (Th) that gives rise to radium (Ra) isotopes responsible for the emission of alpha and beta particles. ^{226}Ra, an alpha emitter, is a member of the ^{238}U decay series and ^{228}Ra, a beta emitter, is a member of the ^{232}Th decay series (National Nuclear Data Center, Nudat 2.6). Both uranium and thorium are uniformly distributed with depth in the rock of the batholith in the Butte mining district. Uranium is present at about 3.5 mg/kg and thorium at about 15.4 mg/kg, with a Th/U ratio of 4.7 (Tilling and Gottfried, 1969).

In waters that interact with the batholith rock, the ratio is reversed, with uranium [as U(VI)] being more abundant than thorium [as Th (IV)] by about a factor of ten, as evidenced by the Berkeley Pit, which contains uranium at about 800 µg/L and thorium at 80 µg/L. In waters with a pH above 3, the ratio increases because of the hydrolysis of the Th (IV) ion, causing it to precipitate out of solution. The abundance of radium in the water at an individual sampling location is the result of many factors, from production to dispersion and geochemical segregation. The primary source mechanism for radium production is alpha recoil, in which the parent thorium or uranium isotope ejects the radium daughter into solution. When dissolved, radium behaves like other members of the alkaline earth group, such as calcium, and has similar controls on its solubility (Vinson, 2011).

Radium isotope monitoring became mandatory for drinking water supply systems after the promulgation of the federal Radionuclides Rule (Radionuclides Rule, 66 FR 76708 2000). This established MCLs of 5 pCi/L (picocuries per liter) for combined radium 226/228 activity and 30 µg/L for uranium concentration. The EPA directed all states to begin monitoring background levels by December 2003 and, depending on data collected during the succeeding 4 years, determine a monitoring schedule. Since the contaminated mine waters were routinely above the MCL, an annual monitoring schedule became part of the BMFOU program.

Section 9.1 Monitoring Results

Table 9.1.1 summarizes the radionuclide data collected from 2003 to 2018. The average, maximum, and minimum activity for each isotope at each site are reported, as well as the number of samples contributing to those statistics. Values in red indicate the mean value of combined radium in samples from the site exceeded the MCL. Approximately 34% of the sites monitored have mean values for one or both isotopes that are greater than or equal to the specified MCL value of 5 pCi/L. The examination of the data over time for each site shows radium activity remains stable.

Figure 9-1 shows the mean activity of the combined radium isotopes at every monitoring site. The graphical representation conveys the distribution of radium activity in monitored waters throughout the BMFOU. The chart shows that the mean activity of the combined radioisotopes at 18 of the 52 sampled sites exceed the MCL. The sites that have markedly higher values of radium isotope activity are clustered near the location of the historic Pittsmont workings near the eastern boundary of the BMFOU.

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2018.

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
	Anselmo Mine			**Kelley Mine**		
Mean	1.9	2.3	3.7	1.9	2.7	4.4
Min	1.1	1.1	1.1	0.9	1.1	2.3
Max	6.2	5.2	11.9	2.7	4.6	6.9
Number	19	19	19	20	20	20
	Pilot Butte Mine			**Steward Mine**		
Mean	1.7	0.0	1.7	2.2	3.7	5.4
Min	1.7	0.0	1.7	0.7	1.2	1.5
Max	1.7	0.0	1.7	5.9	8.8	13.1
Number	1	1	1	16	16	16
	Well A			**Well B**		
Mean	25.1	8.6	34.4	4.2	4.4	8.1
Min	0.9	1.7	21.4	3.0	1.3	3.1
Max	36.9	12.2	45.7	6.3	7.4	12.5
Number	33	33	33	35	35	35
	Well C			**Well D-2**		
Mean	30.7	19.6	50.3	23.8	16.6	40.4
Min	14.8	10.5	25.3	10.7	3.7	19.6
Max	43.6	30.7	73.8	33.7	26.0	53.3
Number	32	32	32	29	29	29
	Well E			**Well F**		
Mean	6.2	4.9	11.1	7.6	10.2	17.8
Min	4.7	2.6	8.2	5.5	7.7	13.8
Max	8.8	8.4	15.2	12.6	14.3	26.9
Number	9	9	9	11	11	11
	Well G			**Well J**		
Mean	13.7	9.0	22.7	39.3	154.4	193.7
Min	10.7	4.4	18.0	32.5	125.0	158.6
Max	17.5	11.9	28.5	47.3	198.0	242.6
Number	21	21	21	17	17	17

[a]EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards Circular-7, May 2017

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2018—*Continued.*

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		Parrot			**LP-8**	
Mean	3.3	4.3	7.1	2.5	6.5	9.0
Min	1.1	0.8	1.9	1.4	2.2	3.6
Max	9.0	8.7	17.7	3.4	10.2	12.0
Number	17	17	17	5	5	5
		LP-9			**LP-10**	
Mean	6.3	7.3	12.7	0.7	2.2	3.1
Min	2.2	2.0	2.2	0.2	0.5	0.8
Max	29.1	23.9	47.0	5.3	5.0	9.3
Number	17	17	17	28	28	28
		LP-12			**LP-13**	
Mean	0.6	2.2	2.9	0.5	2.3	2.8
Min	0.2	0.9	1.3	0.2	0.4	1.2
Max	5.5	6.2	6.6	0.9	4.9	5.2
Number	31	31	31	32	32	32
		LP-14			**LP-15**	
Mean	0.3	1.9	2.3	0.3	2.3	2.8
Min	0.1	0.8	0.9	0.1	1.3	1.6
Max	0.8	4.6	4.8	0.6	5.6	6.2
Number	35	35	35	29	29	29
		LP-16			**LP-17**	
Mean	0.5	2.5	3.1	1.3	2.4	3.0
Min	0.2	0.4	0.1	0.6	1.5	1.5
Max	1.1	7.3	8.0	1.9	4.2	5.4
Number	35	35	35	12	12	12
		LP-17R			**AMC-05**	
Mean	1.4	2.9	4.3	6.5	4.5	10.4
Min	0.6	1.1	1.7	5.3	2.7	6.3
Max	2.0	6.1	7.8	8.2	6.6	12.7
Number	12	12	12	17	17	17

[a]EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards Circular–7, May 2017

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2018—*Continued.*

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		AMC-6			**AMC-8**	
Mean	0.5	2.0	2.8	0.5	1.7	2.2
Min	0.0	0.2	0.1	0.2	0.7	1.0
Max	5.5	5.4	6.8	1.3	3.3	3.7
Number	32	32	32	31	31	31
		AMC-12			**AMC-13**	
Mean	0.4	1.2	1.2	0.3	1.6	1.9
Min	0.1	0.2	0.3	0.2	1.3	1.5
Max	0.7	2.0	2.1	0.5	1.8	2.3
Number	16	16	16	3	3	3
		AMC-15			**GS-41D**	
Mean	0.6	3.0	3.5	2.1	3.7	5.1
Min	0.4	1.5	1.9	0.8	2.1	1.1
Max	0.7	5.3	5.8	3.7	5.6	8.9
Number	10	10	10	16	16	16
		GS-41S			**GS-44D**	
Mean	2.0	2.7	3.9	0.7	0.9	1.7
Min	0.8	1.2	1.2	0.1	0.0	0.1
Max	4.8	4.7	6.5	3.6	1.9	3.6
Number	19	19	19	22	22	22
		GS-44S			**GS-46D**	
Mean	0.4	2.0	2.3	0.3	1.6	2.3
Min	0.2	0.3	0.7	0.2	1.0	2.2
Max	1.3	3.6	4.0	0.5	2.1	2.4
Number	18	18	18	18	18	18
		GS-46S			**BMF05-01**	
Mean	0.3	1.6	1.7	0.4	3.32	3.8
Min	0.0	1.1	1.4	0.1	1.9	2.1
Max	0.5	2.0	2.0	0.7	5.1	5.6
Number	18	18	18	27	27	27

[a]EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards Circular–7, May 2017

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2018—*Continued.*

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		BMF05-02			**BMF05-03**	
Mean	0.3	2.1	2.4	0.2	2.1	2.3
Min	0.1	-0.1	0.2	0.1	0.7	1.1
Max	0.5	5.7	6.0	0.4	4.4	4.4
Number	30	30	30	27	27	27
		BMF05-04			**BMF 96-1S**	
Mean	1.8	2.2	4.4	0.2	2.2	0.0
Min	0.4	1.2	1.9	0.2	2.2	0.0
Max	25.2	7.7	32.9	0.2	2.2	0.0
Number	26	26	26	2	2	2
		BMF96-4			**West Camp Pumping Well**	
Mean	0.3	1.6	1.4	2.2	1.3	2.9
Min	0.0	0.6	0.4	1.9	1.3	2.5
Max	0.7	2.6	3.3	2.5	1.3	3.2
Number	18	18	18	2	2	2
		Emma Mine			**Ophir Mine**	
Mean	2.4	2.6	4.4	0.6	1.3	2.0
Min	1.2	1.7	2.0	0.3	0.2	0.8
Max	3.4	4.0	6.4	0.9	2.2	2.9
Number	19	19	19	19	19	19
		Travona Mine			**Chester Steele**	
Mean	2.0	2.2	4.1	3.3	3.7	6.3
Min	1.2	1.2	1.2	1.1	1.8	1.7
Max	3.0	4.1	6.4	32.8	7.5	40.3
Number	15	15	15	20	20	20
		Marget Ann Mine			**Orphan Boy Mine**	
Mean	0.6	1.4	2.0	5.5	3.2	8.7
Min	0.3	0.8	1.5	3.6	0.6	6.6
Max	0.8	2.0	2.7	7.5	6.6	13.7
Number	10	10	10	27	27	27

[a]EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards Circular – 7, May 2017

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2018—*Continued.*

	Radium 226 (pCi/L) MCL[a] 5	**Radium 228 (pCi/L) MCL[a] 5**	**Ra 226+228 (pCi/L) MCL[a] 5**	**Radium 226 (pCi/L) MCL[a] 5**	**Radium 228 (pCi/L) MCL[a] 5**	**Ra 226+228 (pCi/L) MCL[a] 5**
	Tech Well			**Green Seep**		
Mean	1.9	3.7	4.2	3.1	2.5	5.2
Min	0.8	1.0	1.1	0.4	0.3	0.8
Max	7.5	6.0	12.4	16.0	7.9	23.9
Number	12	12	12	33	33	33
	BPit, surface			**HSB Weir**		
Mean	0.9	4.2	5.0	1.4	1.9	3.2
Min	0.4	1.6	2.0	0.3	0.8	2.0
Max	1.8	11.9	12.6	3.2	4.2	4.7
Number	16	16	16	26	26	26

[a]EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards Circular-7, May 2017

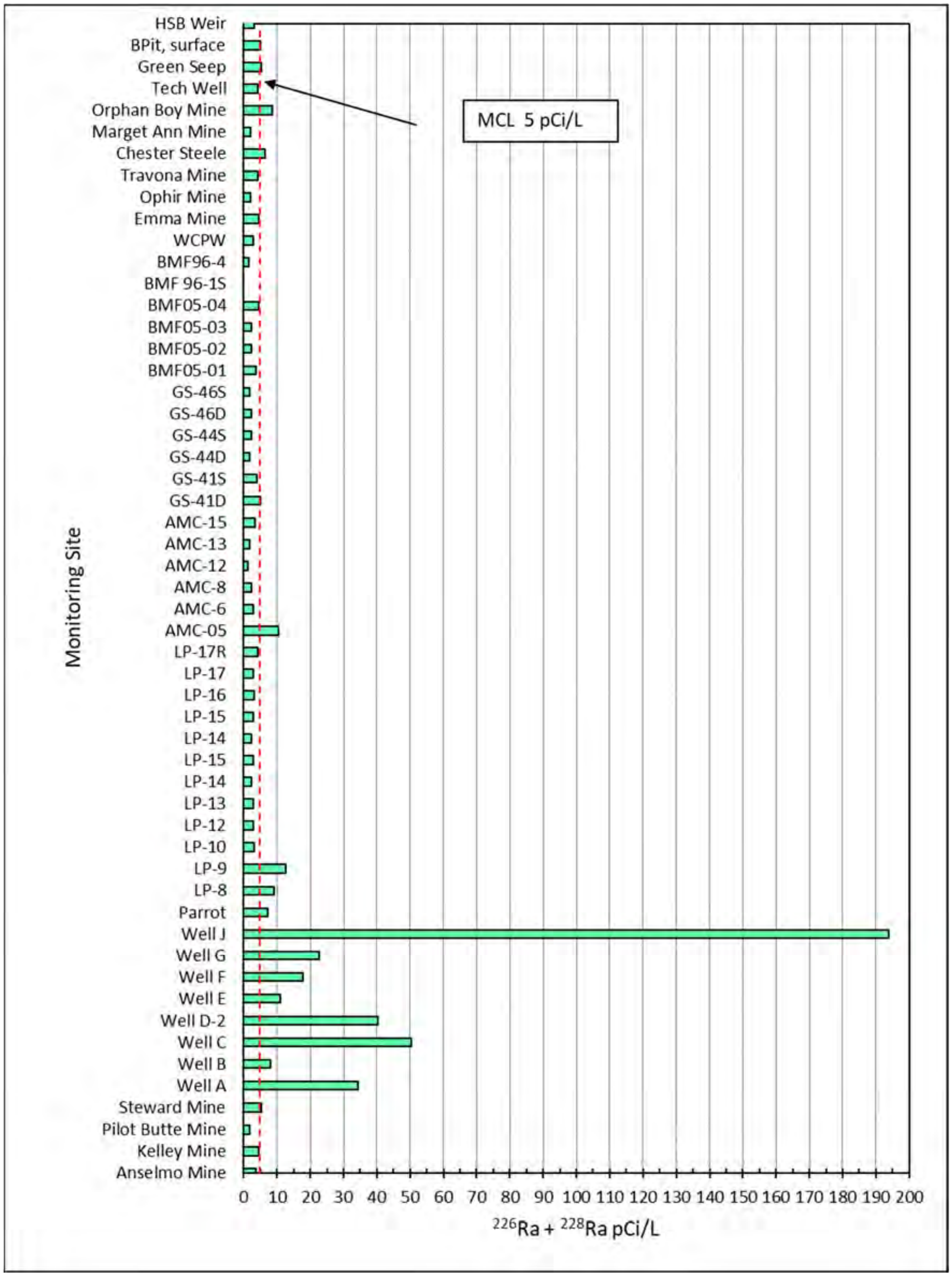


Figure 9-1. Graphical representation of combined radium isotope activity at the BMFOU monitoring sites. A red dashed line shows the MCL limit of 5 pCi/L.

SECTION 10.0 CONCLUSIONS AND SUMMARY

Water-level trends in the alluvial monitoring system within the active mine area were similar to those of 2017, with water levels increasing in a majority of the wells north of the Pittsmont Dump; this is most likely the result of continued leaching operations that provide additional recharge water to the localized groundwater system. This reverses the trend observed from 2004 and earlier and from 2006 through 2009 of water levels decreasing in a majority of the wells in this area. Water levels decreased in a majority of the wells south of the Pittsmont Dump during those years because of dewatering activities undertaken by MR.

Seasonal precipitation events continue to have little or no influence on water levels in the LP-series alluvial wells near the Berkeley Pit and leach pads. Water-level variations in these wells respond more to mining (including alluvial dewatering) and leaching operations than precipitation events.

Water levels in a majority of the alluvial monitoring wells located outside the mine area show a response to seasonal precipitation. The response time varies from immediate to a 2- to 3-month lag time. Alluvial groundwater levels change following mine operations in a number of wells to the south of the mine property, as shown by water-level declines during periods of mine suspension followed by water-level increases once mining resumes. Water-level decreases and increases in several AMC wells demonstrate this relationship in response to draining and filling of the MR concentrator Ecology Pond. Water levels rose in 2011 in several wells (AMC- and BMF05-series) following MR's cleaning and deepening of the Ecology Pond. MR drained this pond in 2012, resulting in a corresponding water-level decline. During 2013, the pond was capped with clay and recontoured for use as a stormwater runoff catchment and for mill upsets (unplanned discharge of mill tailings). Groundwater levels continued to decline following the pond capping, further supporting the relationship between operations and water-level changes in the vicinity of the active mine.

Water-level rise in the East Camp bedrock system is independent of precipitation and results from the 1982 cessation of long-term mine dewatering. There is no notable precipitation influence in any of the bedrock wells or underground mine water levels. However, continued diversion of HSB drainage water away from the Berkeley Pit influenced East Camp bedrock water levels; the water-level rise for 2018 (based upon wells A and G) was about 40 percent that of 2000–2003 when HSB water flowed into the pit. The diversion of HSB water into the Berkeley Pit during scheduled maintenance activities and unplanned powered outages resulted in an additional 11.7 million gallons of water added to the pit and is a typical annual activity. The average water-level rise in the bedrock system from 2004 to 2018 was 46 percent of that from 2000 to 2003, during suspension of mining. This reduction in the filling rate demonstrates that diverting HSB water from the pit system slows the overall water-level rise in the bedrock system.

Recent updates to the Berkeley Pit model indicate that the East Camp bedrock system water level will reach the PWL elevation of 5,410 ft in the Pilot Butte Mine in November 2024. The previous estimate contained an error that was corrected in the 2018 model run. The PWL at the Pilot Butte Mine is the anticipated compliance elevation that maintains the water-level elevation in the Berkeley Pit as the lowest point in the East Camp bedrock system. This will ensure that water in the historic underground mine system will continue to flow towards the Berkeley Pit. The Pilot Butte Mine replaced the Anselmo Mine as the POC with the highest water-level elevation in the 2018 filling model evaluation.

Semi-annual sampling and vertical profiling in the Berkeley Pit Lake resumed in 2017 and continued throughout 2018, bringing the monitoring program back into compliance with the 2002 CD. Sampling and profiling were completed in 2018 using an unmanned, autonomous boat (drone boat) developed by the Electrical Engineering Department at Montana Tech and the MBMG. Sampling and profiling show continued increasing trends in pH and DO in the water column. Decreases in iron and arsenic concentrations noted in the 2017 sampling/profiling data continued in 2018. Concentrations of cadmium, copper, and zinc remained similar to those seen in 2011, 2012, and 2017 samples.

Pumping of groundwater in the West Camp System continues to control water levels; water levels were about 12 ft below the PWL at the end of 2018.

Monitoring wells in the alluvial aquifers associated with the Mine Flooding Operable Unit continue to show a wide range in spatial and temporal water quality. Similar to the past few years, the AMC-series wells show a wide range and few trends with respect to the concentration of dissolved constituents. Recent trends continue in most of the LP-series wells for most constituents.

In several cases, chemistry data from the East Camp mines show a large departure from historical trends, particularly with respect to iron concentrations. Based on recent data, the departure likely indicates a change in the chemistry of water in the underground workings as opposed to reflecting changes in sampling or analytical procedures.

Recent data from the West Camp monitoring sites generally indicate either no change, or a small decrease, in dissolved constituents. Dissolved constituent concentrations remain below values observed during initial flooding of the West Camp mine workings. Arsenic concentrations exceed the MCL in samples from the Chester Steele Park well and Travona and Emma Mines, while radium exceeds the MCL in the Emma Mine and Chester Steele Park well. Iron and manganese exceed the SMCLs in all three mine water-quality constituent datasets. Concentrations in monitoring well BMF96-4 remain low and do not exceed any standards.

There were no water-quality exceedances of the five COCs in domestic wells within the CGWA. However, several sites have elevated concentrations of other constituents, such as iron and uranium. These findings are attributed to local geologic conditions and are not likely related to rising water levels in the bedrock mine workings.

2018 monitoring results support the conclusion that the current water-level and water-quality monitoring program is adequate to verify that contaminated bedrock groundwater discharges into the Berkeley Pit, and that West Camp water levels are sufficiently controlled by West Camp pumping operations. These are two primary environmental concerns associated with the flooding of Butte's historic underground mines and the Berkeley Pit.

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The information contained in this report represents the work of many companies and agencies during the past 35 years. Numerous individuals were responsible for data collection prior to the 2002 consent decree; their dedication and creativity in monitoring and sampling of mine waters provided the information that subsequent work and evaluations relied upon.

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The continued cooperation of Montana Resources and Atlantic Richfield Company is greatly appreciated, while representatives of New Butte Mining continue to allow access to their properties for monitoring purposes. Special appreciation is extended to the property owners who allowed access to alluvial monitoring wells: Gilman Construction, Continental Public Land Trust, Ingraham Environmental Inc., and Race Track Volunteer Fire Department. The cooperation of private landowners who allowed sampling of their domestic wells is recognized and appreciated.

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Errors and omissions remain the authors' responsibility.

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