Butte Mine Flooding Operable Unit

Water-Level Monitoring and Water-Quality Sampling
2021 Consent Decree Update
Butte, Montana
1982–2021

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

Setting the Kelley Mine Collar, 1948 (Photo Courtesy The World Museum of Mining.)

September 2022
prepared by

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Contract 415008-TO-21

Montana Bureau of Mines and Geology Open-File Report 751

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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 2021, integrated with data collected since 1982, when the Anaconda Company suspended underground mine dewatering and mining in the Berkeley Pit.

Major 2021 observations and developments include:

1. Berkeley Pit and Discharge Pilot Project that began September 2019 continued throughout 2021. Approximately 1.19 billion gallons of pit water were incorporated into the Montana Resources mining/milling process and combined with other process waters in the Yankee Doodle Impoundment. A portion of the Yankee Doodle Impoundment return water is diverted to the Discharge Pilot Plant for treatment, before being discharged into Silver Bow Creek;
2. Water-quality sampling and vertical profiling of the Berkeley Pit continued using the automated-autonomous (drone) sample boat. Two sampling/monitoring events were conducted;
3. Changes in Berkeley Pit water quality and physical parameters observed during 2017–2020 continued in 2021 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 2021;
4. Scheduled maintenance activities at the concentrator and Horseshoe Bend water-treatment plant, and short-term power disruptions, resulted in approximately 12.4 million gallons discharged from Horseshoe Bend directly to the Berkeley Pit in 2021;
5. The Berkeley Pit infilling model was updated with data through 2021. Results from the model suggest that the Protective Water Level elevation of 5,410 feet will be reached in 1,626 days

(4.5 years) at the Pilot Butte Mine, using a model input that assumes that pumping for the Berkeley Pit Pilot Project is suspended in January 2022;

6. Semi-annual water-quality samples collected from the replacement well (LP-17R) installed in fall 2013 show concentrations increasing for many metals;
7. July 2021 Montana Resources began the process to discontinue the leaching operations by stopping the application of Horseshoe Bend drainage water to the leach pads; and
8. Montana Resources stopped dewatering activities near the Horseshoe Water Treatment Plant (December 2021) due to low water levels in wells. Water levels declined due to deactivation of leach pads earlier in 2021.

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 2021 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. The 2021 Quality Assurance Project Plan further refines monitoring and sampling procedures.

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

2021 monitoring results support the conclusion that the current water-level and water-quality monitoring program is adequate to verify that contaminated groundwater within bedrock 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.

List of Acronyms Used in Text

ACM	Anaconda Copper Mining Company
AMC	Anaconda Mining Company
AR	Atlantic Richfield Company
BMFOU	Butte Mine Flooding Operable Unit
BPSOU	Butte Priority Soils Operable Unit
CD	Consent Decree
DEQ	Montana Department of Environmental Quality
DEQ-7	Montana Department of Environmental Quality, Circular 7
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
FBGS	Feet below ground surface
gpm	Gallons per minute
GWIC	MBMG Ground Water Information Center
HsB	Horseshoe Bend Drainage
HsB/CS	Horseshoe Bend Capture System
MBMG	Montana Bureau of Mines and Geology
MR	Montana Resources
MSL	Mean sea level
NAVD29	North American Vertical Datum of 1929
ORP	Oxidation reduction potential
Pilot Project	Berkeley Pit Discharge Pilot Project
POC	Points of Compliance
PWL	Protective Water Level

QAPP	Quality Assurance Project Plan
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SBC	Silver Bow Creek
SC	Specific conductance at 25°C
WCPW	West Camp pumping well
USGS	United States Geological Survey
YDTI	Yankee Doodle Tailings Impoundment

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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 central pump stations as early as 1901. The High Ore, Leonard No. 2, and Kelley Mines served as the primary central pump stations collecting groundwater and pumping it to the surface (figs. 1-1, 1-2, 1-3). 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 2800 level, followed by the 3800 level (fig. 1-4). The High Ore shaft was deepened to the 3900 level and a new pump station was installed with six centrifugal pumps in 1943 (Corbett and Ralph, 1968). 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. Water collected on the 3900 level of the High Ore mine flowed through an almost half-mile new drainage tunnel to the Kelley Mine. The new pump station at the Kelley was equipped with eight 1,5000 horsepower stainless steel centrifugal pumps, each capable of pumping 1,000 gallons per minute (gpm) of water to the surface (Anaconda Company Trailsman, 1969). Once the water reached the surface, it was routed to a precipitation plant for copper recovery (figs. 1-5, 1-6). 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).

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 byproduct 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 (1914) reported that about 1,200 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.

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 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. 1-7). Figures 1-8 and 1-9 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 1-9).

Figure 1-1. High Ore Mine pump station, 2,800-ft level. (Photo courtesy World Museum of Mining, Butte, Montana.)

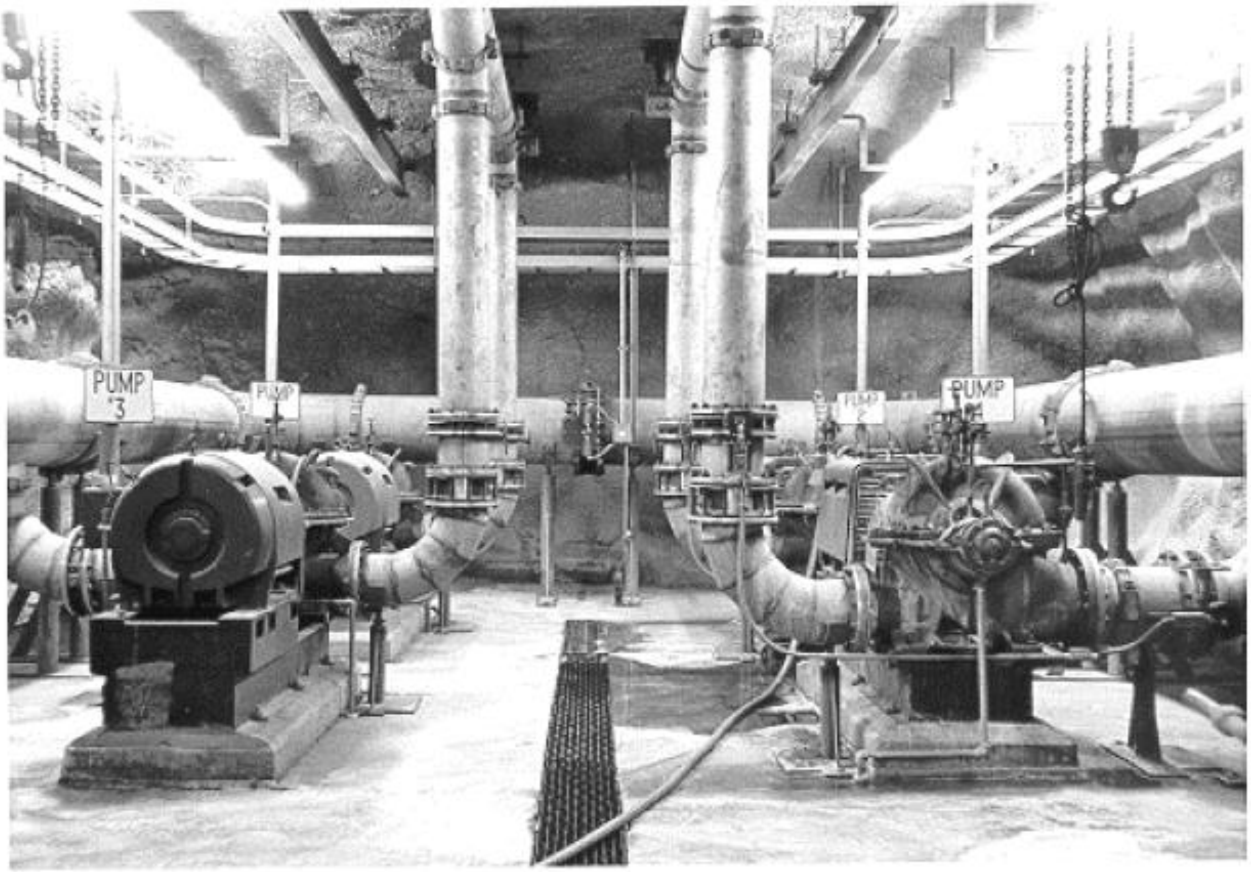
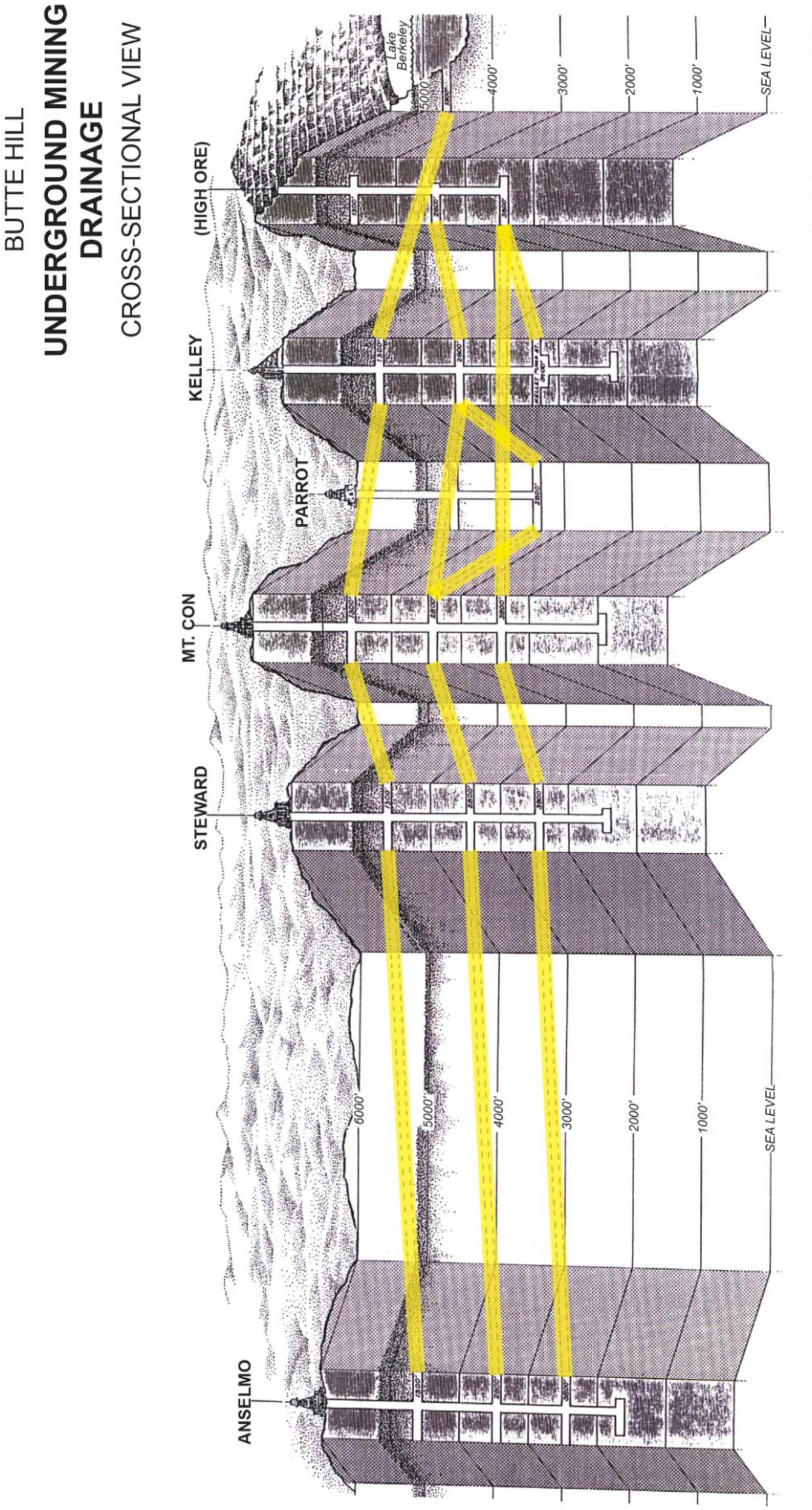


Figure 1-2. Kelley Mine pump station, 3,900-ft level. (Photo courtesy World Museum of Mining, Butte, Montana.)

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



Modified from Canonie, 1993.

Figure 1-4. Cross section of Butte Hill showing underground mine levels for water drainage.

Figure 1-5. Flume conveying water pumped from Butte underground mines to precipitation plant. (Photo courtesy World Museum of Mining, Butte, Montana.)

Figure 1-6. Precipitation plant scrap iron in contact with underground mine discharge water. (Photo courtesy World Museum of Mining, Butte, Montana.)

Figure 1-7. Location of selected underground mines engulfed by development and expansion of the Berkeley Pit.

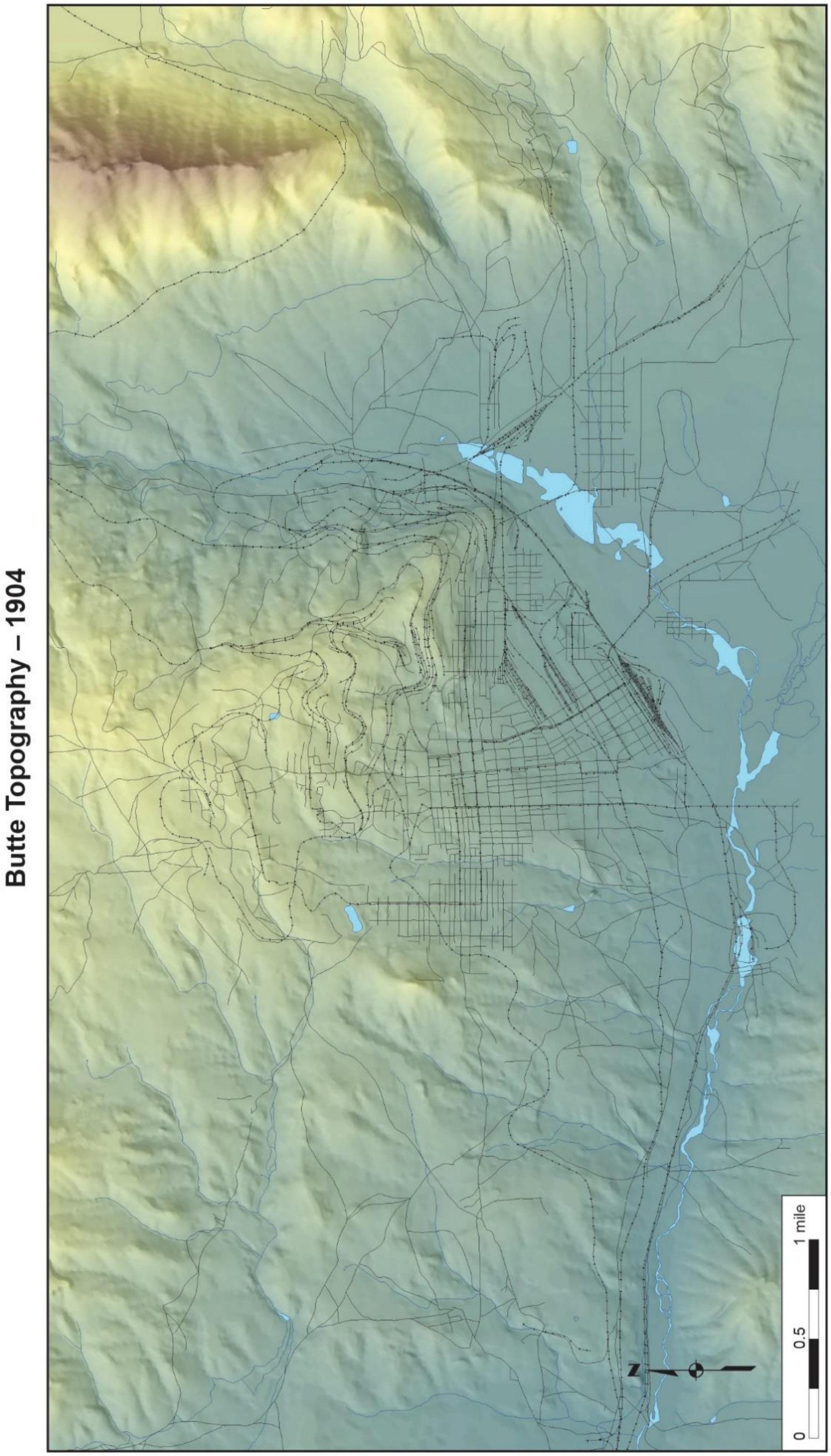


Figure 1-8. Digital elevation model showing Butte topography, 1904.

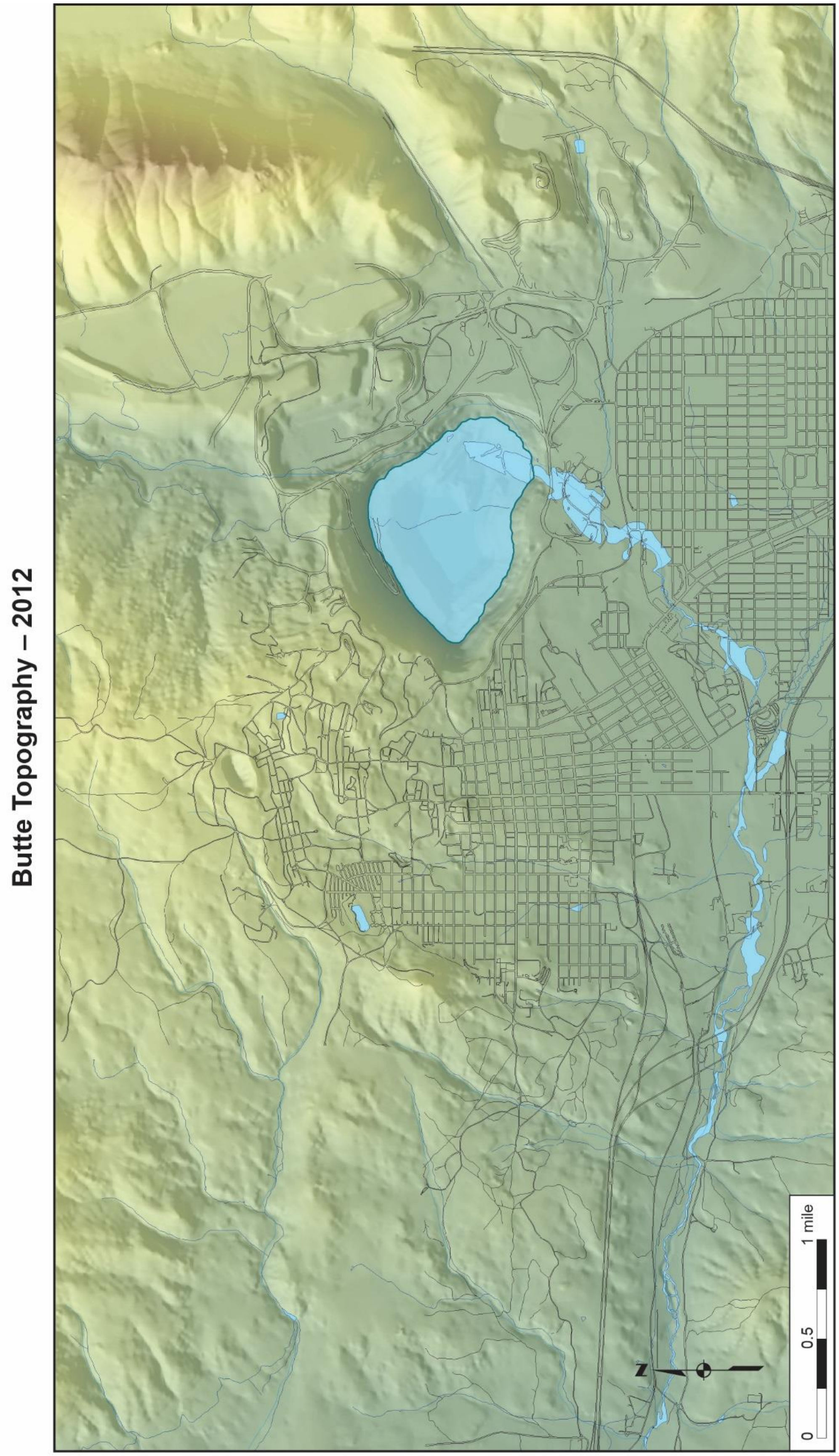


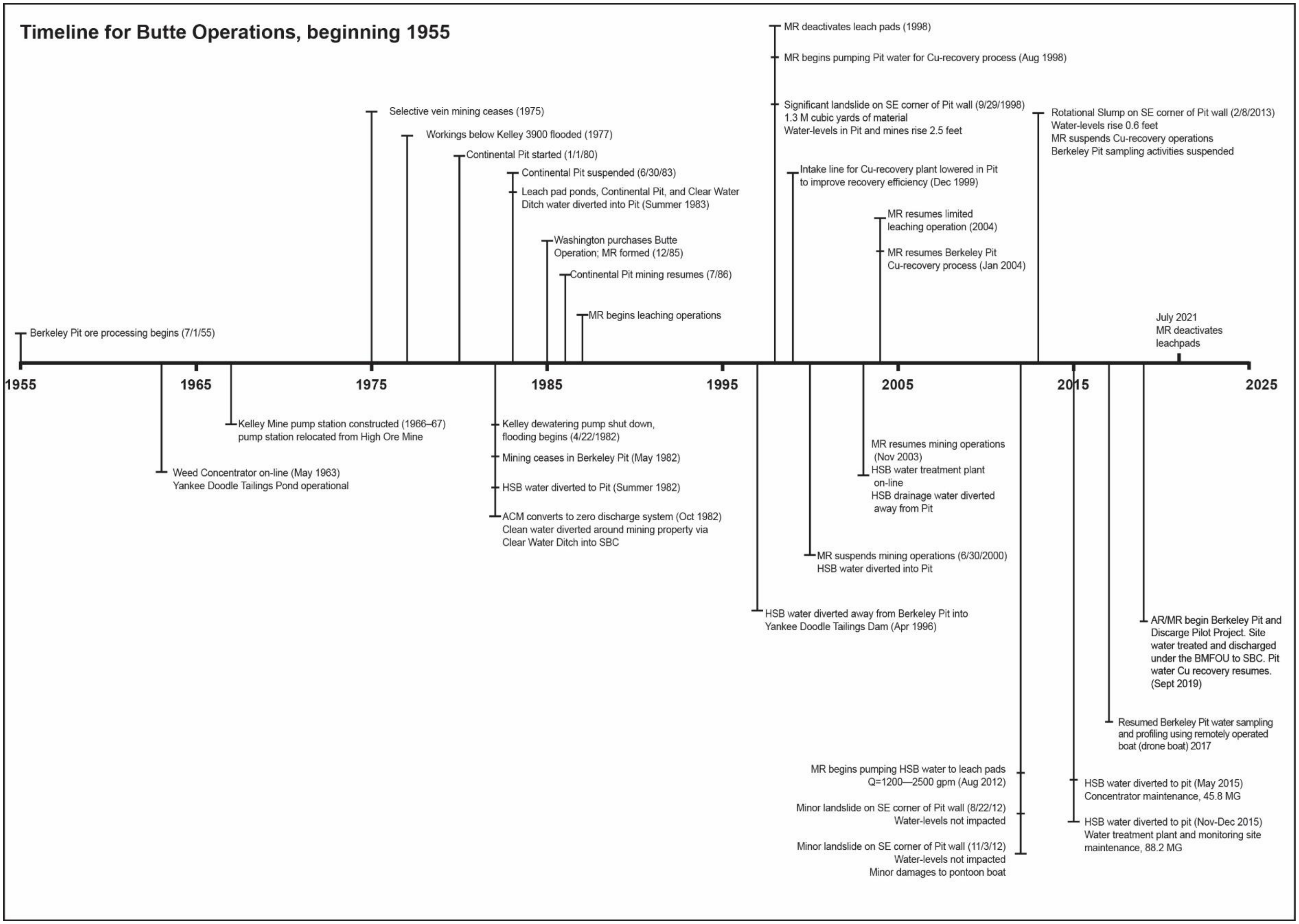
Figure 1-9. Digital elevation model showing Butte topography, 2012.

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 3900-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 May 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 (AR) 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 1955 through 2021.

Table 1.0.1. Timeline for Butte operations, 1955–2021.



Section 1.1 Introduction

On April 23, 1982, the Anaconda Company announced the suspension of pumping operations at the 3900-level Kelley Mine pump station, approximately 3,600 ft below ground surface (FBGS). At the same time, the Anaconda Company announced that it would suspend mining in the Berkeley Pit, beginning May 1982. However, the East Berkeley Pit (currently known as the Continental Pit) operated until June 30, 1983, when all of the Anaconda Company Butte mining operations closed.

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 and analysis for selected analytes, i.e., copper and zinc. 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 Montana Bureau of Mines and Geology (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 and 12 mine shafts 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 areas—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 (2021) monitoring program consists of 75 sites, and includes 56 monitoring wells, 12 mine shafts, and seven surface-water sites. The CD monitoring network is grouped into the following categories:

1. East Camp bedrock wells—12;
2. East Camp mines—7;
3. East Camp alluvial wells within active mine areas—20;

4. East Camp alluvial wells outside active mine areas—16;
5. West Camp mines—3;
6. West Camp wells—6;
7. Outer Camp mines—2;
8. Outer Camp wells—2; and
9. Surface-water sites—7 [Berkeley Pit, Continental Pit (when mining is suspended), Horseshoe Bend, Clear Water Ditch (near MR’s guard shack), Blacktail Creek, SBC, 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**	**Current Program (2021)**	**Water Quality 2002 Consent Decree**	**Current Program (2021)**
		Monitoring Frequency	Water-Level Frequency	Monitoring Frequency	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	**P&A**	NS	**P&A**
	GM-1(6)	----	**C/M**	----	**Semi-A**
	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**	Semi-A	**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	**P&A**
	DDH-2	1/4ly	**P&A**	NS	**P&A**
	DDH-8	1/4ly	**P&A**	NS	**P&A**
LP Wells	LP-01	1/4ly	**M**	NS	**NS**
	LP-02	1/4ly	**C/M**	NS	**NS**
	LP-03	1/4ly	**P&A**	NS	**P&A**
	LP-04	1/4ly	**M**	NS	**NS**
	LP-05	1/4ly	**M**	NS	**NS**
	LP-06	1/4ly	**P&A**	NS	**P&A**
	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	**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 (2021)**	**Water Quality 2002 Consent Decree**	**Current Program (2021)**
		Monitoring Frequency	Water-Level Frequency	Monitoring Frequency	Water-Quality Frequency
LP Wells (cont.)	LP-17	1/4ly	**P&A**	Annual	**P&A**
	LP-17R	----	**M**	----	**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**	Annual	**Annual**
	AMW-20	----	**C/M**	**----**	**Semi-A**
	AMW-22	1/4ly	**M**	NS	**Annual**
GS Wells	GS-41S	C/M	**P&A**	Annual	**P&A**
	GS-41D	C/M	**P&A**	Annual	**P&A**
	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	**C/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	NS	**NS**	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 (2021)**	**Water Quality 2002 Consent Decree**	**Current Program (2021)**
		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[4]	**C/M**	Annual	**Semi-A**
	Orphan Girl[4]	M	**--**	Annual	**Drop**
	Marget Ann	1/4ly	**C/M**	2 yr	**2 yr**
Outer Camp Wells	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, --, No monitoring.

[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 prevent monitoring activities at Granite Mountain Mine.

[6] Deep bedrock well to replace the Granite Mountain Mine. Well drilled adjacent to Granite Mountain and Speculator Mines targeting the 800-level workings.

The 1994 ROD and 2002 CD established separate maximum water levels (referred to as Protective Water Level, 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; United States Geological Survey (USGS) North American Vertical Datum of 1929 (NAVD29)] 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) at well

BMF96-1D (refer to fig. 4-1). The West Camp System is described in detail in Section 4.0. The points of compliance (POC) in the East Camp are shown in figure 1-10 and consist of the following mine shafts and bedrock monitoring wells:

1. Anselmo Mine,
2. Granite Mountain Mine (replaced by well GM-1),
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 (1983–2021), 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 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. 1-11).

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 and the MR 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. Current monitoring and sampling locations and procedures are described in the site Quality Assurance and Project Plan (QAPP, MBMG, 2021), which is updated and approved by EPA and DEQ yearly. The QAPP also describes sample handling and analysis requirements.

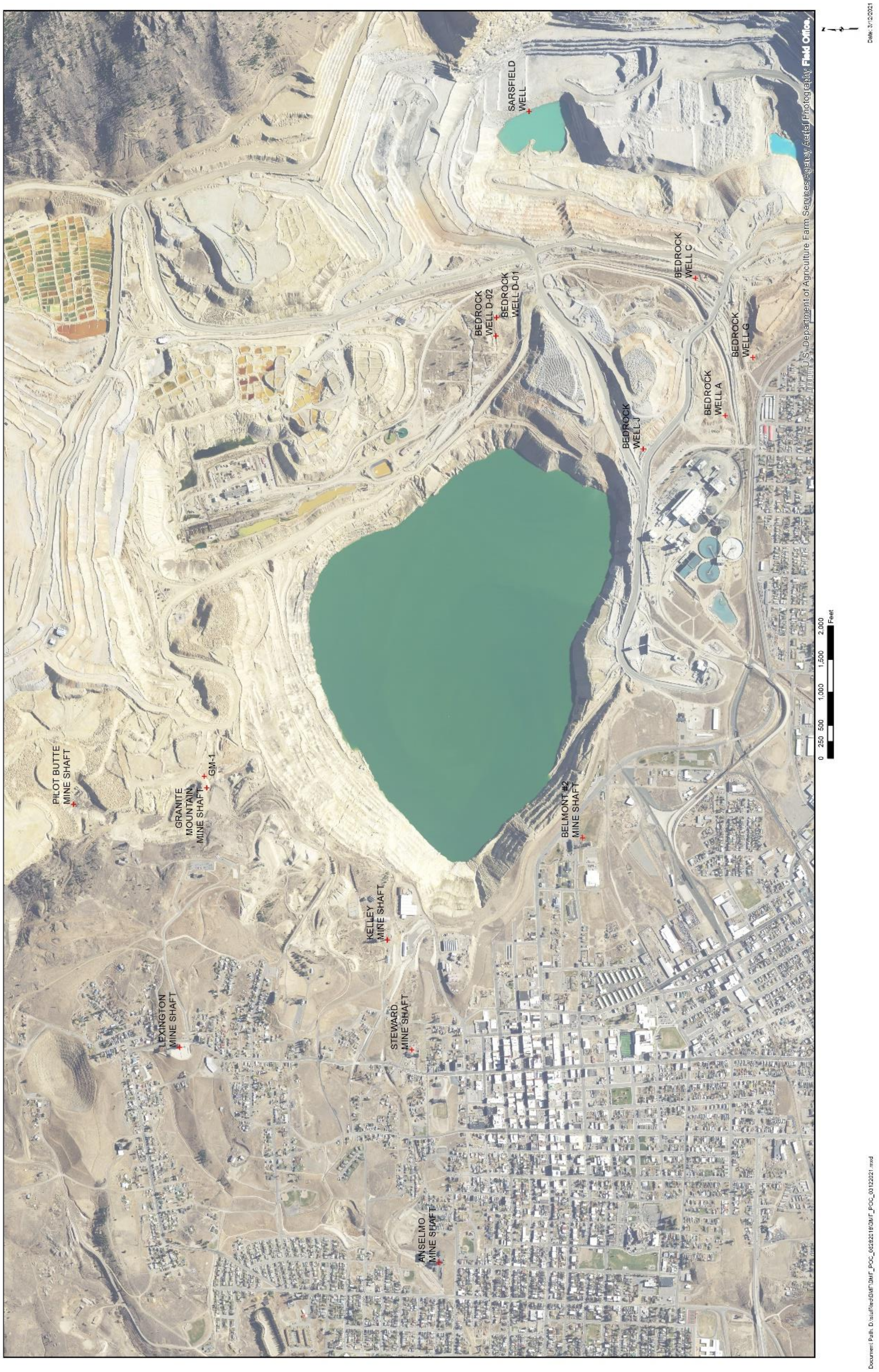


Figure 1-10. Location map for points of compliance.

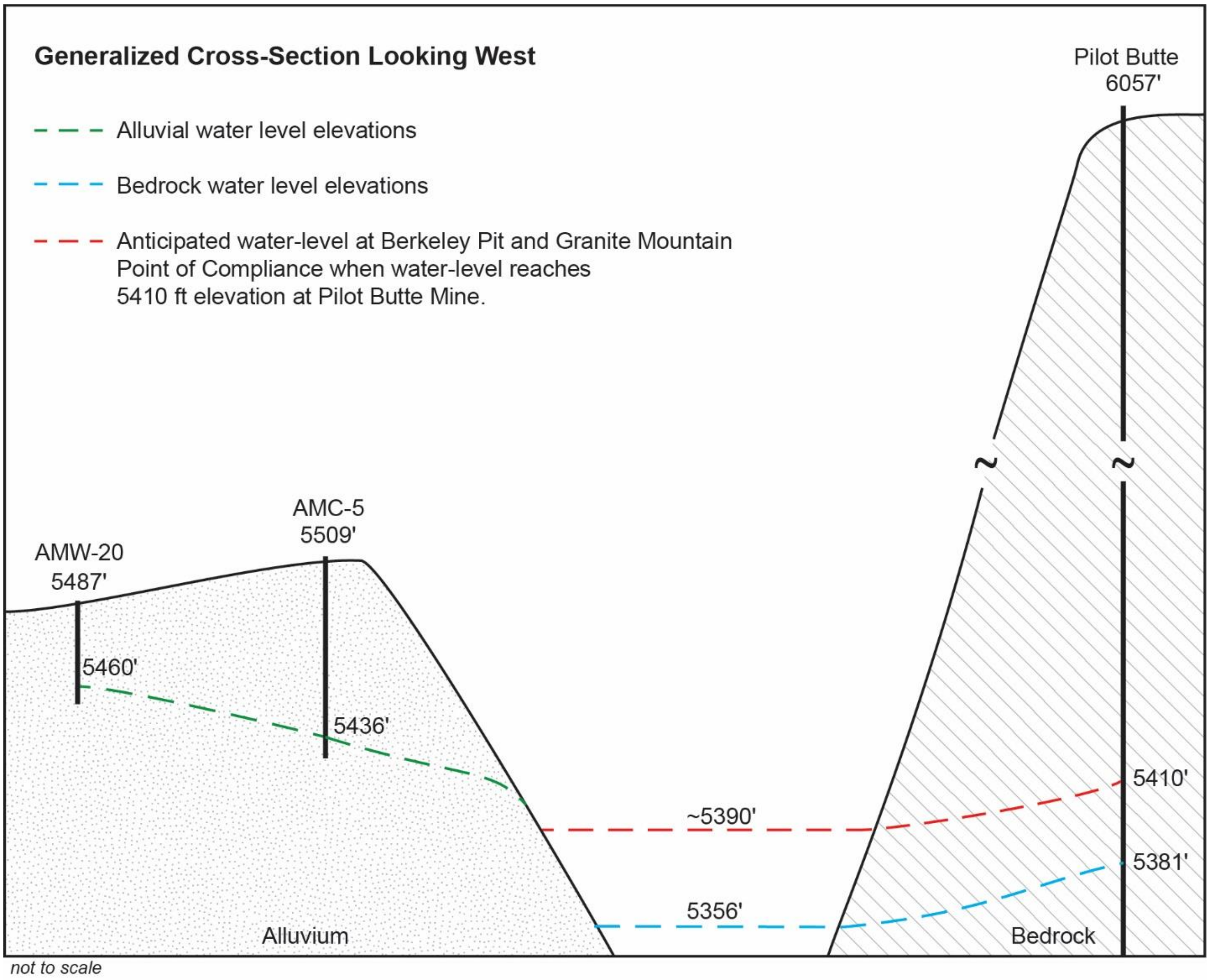
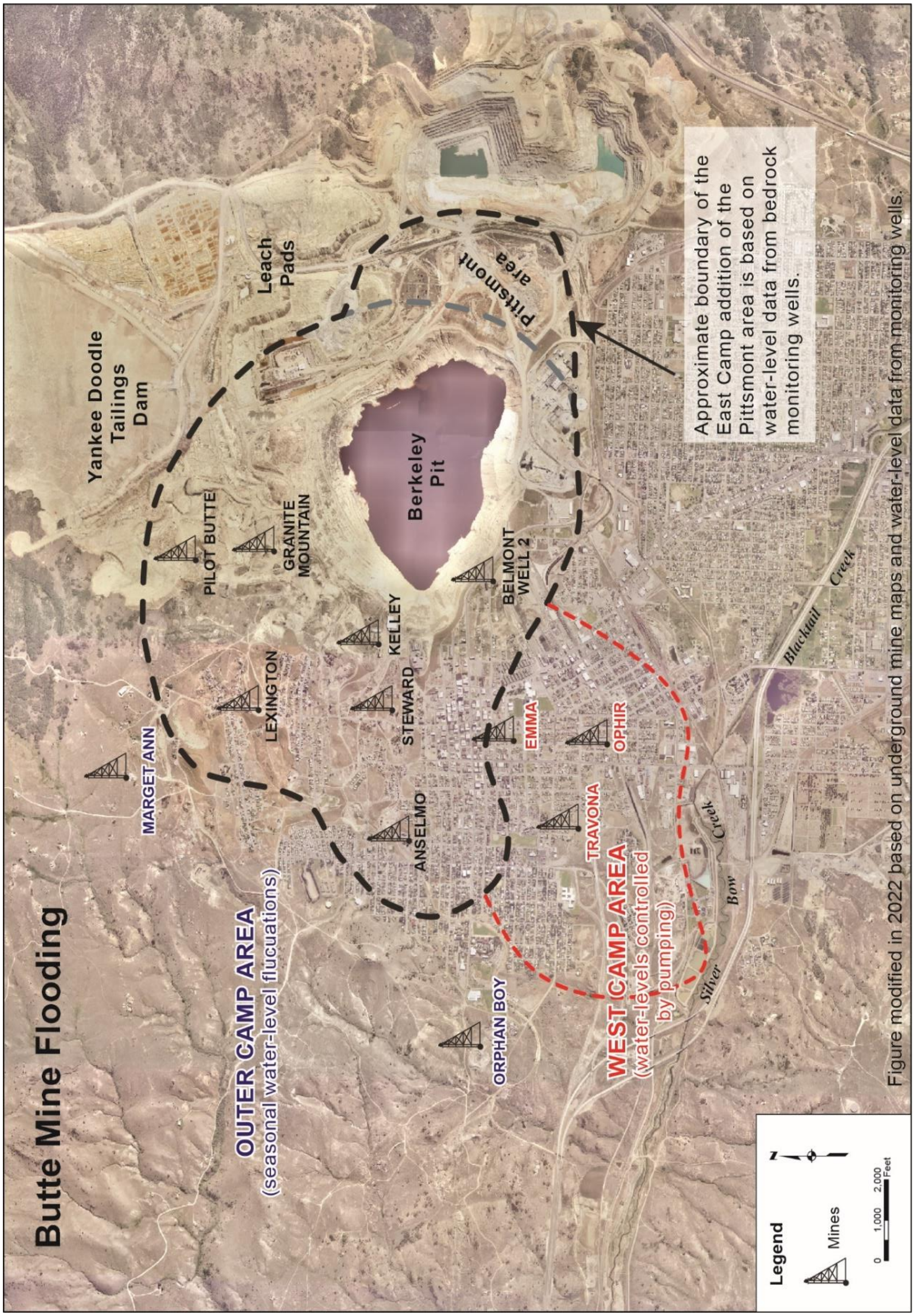


Figure 1-11. Generalized cross section looking west through the Berkeley Pit depicting water-level elevations in bedrock and alluvial systems in December 2021 and projected elevations when the 5,410 Protective Water Elevation is reached at the Pilot Butte Mine (location shown in Figure 1-10).

By the time water levels in the underground mines reached the elevation of the bottom of the Berkeley Pit in late November 1983, over 66 percent of the underground workings had been flooded. More than 85 percent of the underground mine workings have been inundated with water through 2021. The upper 12 percent of the underground workings are at elevations above the specified PWL; therefore, less than three percent of the underground workings have the potential to flood.

This document is the 26th BMFOU report and summarizes 39 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 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) provides a comprehensive history of monitoring the Berkeley Pit.

The MBMG continued monitoring activities in 2021 in the East Camp, West Camp, and Outer Camp systems (fig. 1-12). The East Camp System includes mines and mine workings that drained to the Kelley Mine pump station (fig. 1-4) 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. Water levels measured in 1988 confirmed the separation of these areas with water levels in the Outer Camp being more than 1,200 ft above those in the East Camp (as measured in the Marget Ann and Kelley Mines, respectively). 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). The 2021 QAPP supersedes the sampling and analysis plan and is a more comprehensive document that includes information on analytical methods, changes to monitoring locations, and data validation. Groundwater monitoring and water-quality sampling follow closely the methods described in the Clark Fork River Superfund Site Investigations Standard Operating Procedures (ARCO, 1992). All water-quality data presented are for dissolved concentrations unless otherwise noted.



Approximate boundary of the East Camp addition of the Pittsmont area is based on water-level data from bedrock monitoring wells.

Figure modified in 2022 based on underground mine maps and water-level data from monitoring wells.

Figure 1-12. The mines of the Butte Hill are currently considered in three groups: East Camp, which includes the Berkeley Pit and the area to the east; West Camp, in the southwest, and Outer Camp, which includes the outlying mines.

Section 1.2 Notable 2021 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 minor in 2021. MR suspended operation of the leach pads beginning July 2021, leading to a decrease in water levels in nearby alluvial monitoring wells. No other significant events occurred in 2021 that influenced water levels, water quality, or monitoring activities.

EPA approved well GM-1 as a replacement to the Granite Mountain Mine as a POC in the Long-Term Monitoring Program (EPA, 2021).

The main activities and observations for 2021 are listed below:

1. MR and AR continued to operate the Pilot Project that began in late September 2019. Berkeley Pit water continued to be pumped from the Berkeley Pit for treatment [water is typically treated in the Horseshoe Bend water treatment plant, but can be pumped directly to the Yankee Doodle Tailings Impoundment (YDTI)] and is then returned to the YDTI. A portion of the YDTI return water is diverted to the Polishing Facility and then discharged to SBC, near Montana Street (Atlantic Richfield Company and Montana Resources, 2020).
2. MR continued mining and milling operations throughout 2021.
3. MR continued to use water from the HsB to flood the leach pads through June 2021. Flows from 1,200 to 2,500 gpm were diverted to the leach pads, a process begun in 2012. MR discontinued operation of the leach pads beginning July 2021.
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 2021.

6. A small landslide occurred in the southeast corner of the Berkeley Pit on January 26, 2021, containing approximately 12,400 cubic yards of material. None of the material reached the water surface; therefore, there were no impacts on water levels in the pit or surrounding bedrock monitoring sites.

Section 1.3 Precipitation Trends

Total precipitation for 2021 was 6.49 in compared to 10.21 in for 2020. The 2021 amount is 6.12 in below the long-term (1895–2021) average [NOAA, 1999; Accuweather.com, 2022 (Butte Airport Weather Station)]. Precipitation totals have been below average for 7 of the past 10 years and 23 of the past 40 years; 2021 precipitation totals were the lowest recorded during the past 40 years. Table 1.3.1 contains monthly precipitation statistics for 1982 through 2021, while figure 1-13 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 (12.27 in vs. 12.61 in). Figure 1-14 shows departure from normal precipitation from 1895 through 2021.

Table 1.3.1. Butte Precipitation Statistics 1982–2021.

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**Annual**
Mean	0.41	0.44	0.72	1.11	1.92	2.24	1.25	1.28	1.06	0.77	0.60	0.47	12.27
Std. Dev.	0.30	0.29	0.38	0.66	0.76	1.24	0.98	0.88	0.76	0.56	0.38	0.34	2.81
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	0.36	0.00	0.09	0.03	0.00	0.07	0.01	6.49
Years precipitation has been greater than mean													17
Years precipitation has been less than mean													23

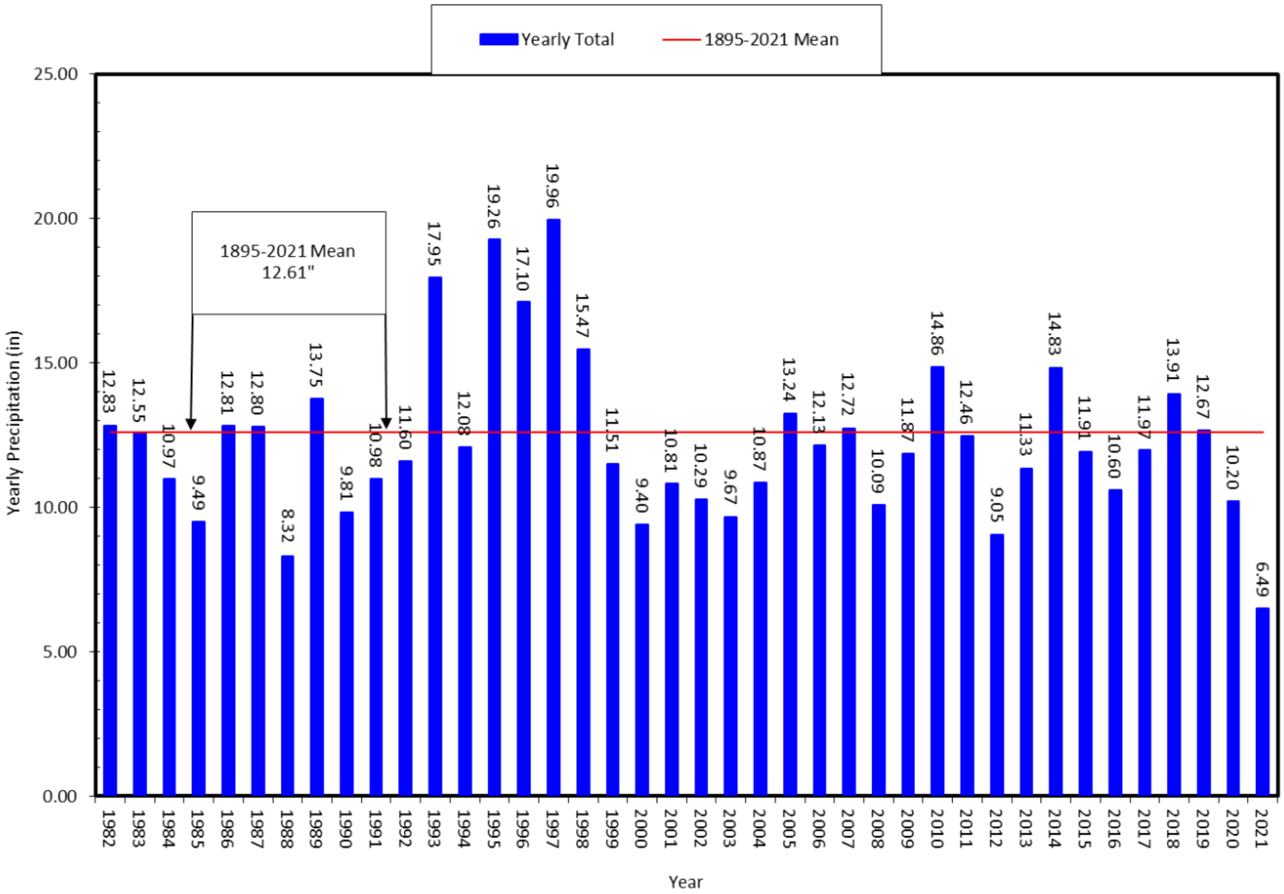


Figure 1-13. Annual precipitation totals 1982–2021, showing 1895–2021 mean.

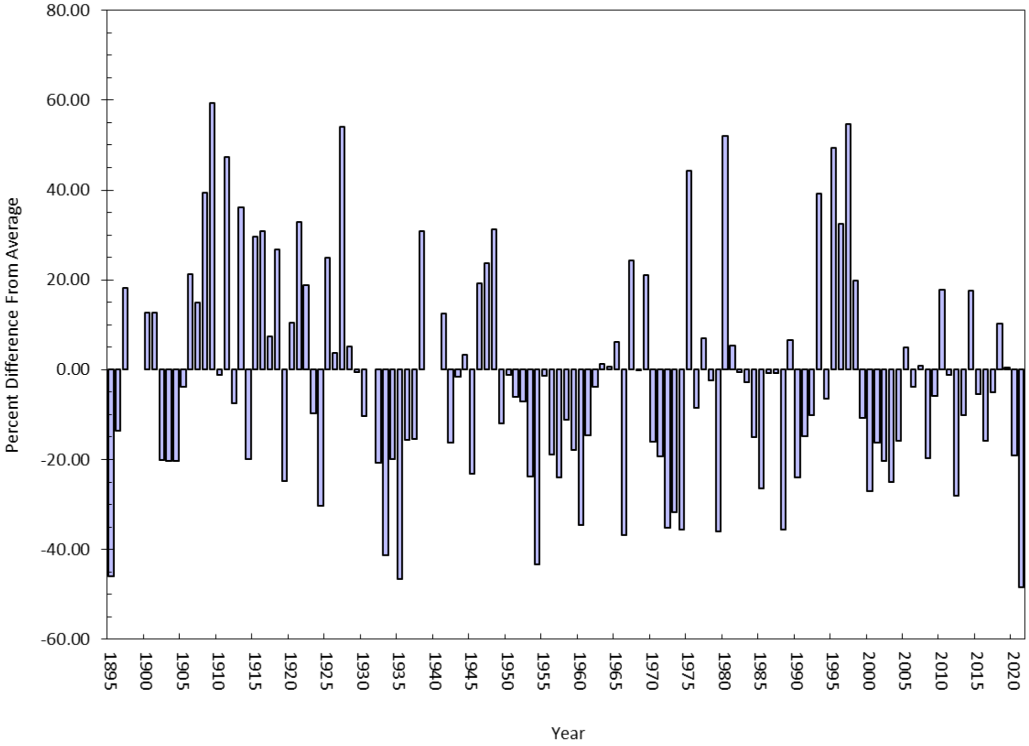


Figure 1-14. Percentage precipitation variation from normal, 1895–2021.

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 active 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 (BMF05-series) were installed within the East Camp System in late 2005 and early 2006 as stipulated in the 2002 CD, and replaced domestic wells monitored from 1997 through 2002. These alluvial wells are situated in areas with limited historical data and are equipped with transducers to improve water-level monitoring. These 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 monthly 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.

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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 water-level changes for these sites. Water levels decreased in six of the seven AMC-series wells for 2021; well AMC-10 has remained dry since its installation in 1983. Water levels had a net decline during the first 20 years of monitoring, followed by a net increase the next 10 years. Water levels had a net decline in six wells over the past 9 years. Over the entire period of record, net water-level declines ranged from 5 ft to more than 28 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. 2-3). 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 dataset 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 years of water-level decline. This well is located just north of the Dredge and Ecology ponds, located in the southwest corner of the concentrator yard (fig. 2-3). The 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 AMC's 1983 suspension. These data indicate that filling the 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 2021 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. 2-2). 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. 2-2); 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. Water-level changes in the AMC-series wells.

Year	AMC-5	AMC-6	AMC-8	AMC-10	AMC-12	AMC-13	AMC-15
Change 1983–1992	**-27.15**	**-7.30**	**-9.80**	**DRY**	**-3.65**	**-3.445**	**-13.00**
Change 1993–2002	**-4.89**	**-3.01**	**-3.38**	**DRY**	**-0.60**	**-0.24**	**-1.71**
Change 2003–2012	**5.91**	**4.26**	**7.47**	**DRY**	**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
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
2019	0.03	-0.47	-1.77	DRY	-0.45	-0.26	0.07
2020	-1.12	-1.36	-1.35	DRY	-1.20	-0.81	-1.64
2021	-0.94	-1.17	-0.92	DRY	-1.43	-0.73	-1.88
Change Years 2013–2021	**-2.83**	**-4.27**	**-8.51**	**DRY**	**-3.39**	**-2.05**	**-5.66**
Net Change	**-28.96**	**-10.32**	**-14.22**	**DRY**	**-6.50**	**-5.01**	**-16.15**

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

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Figure 2-2. AMC well location map.

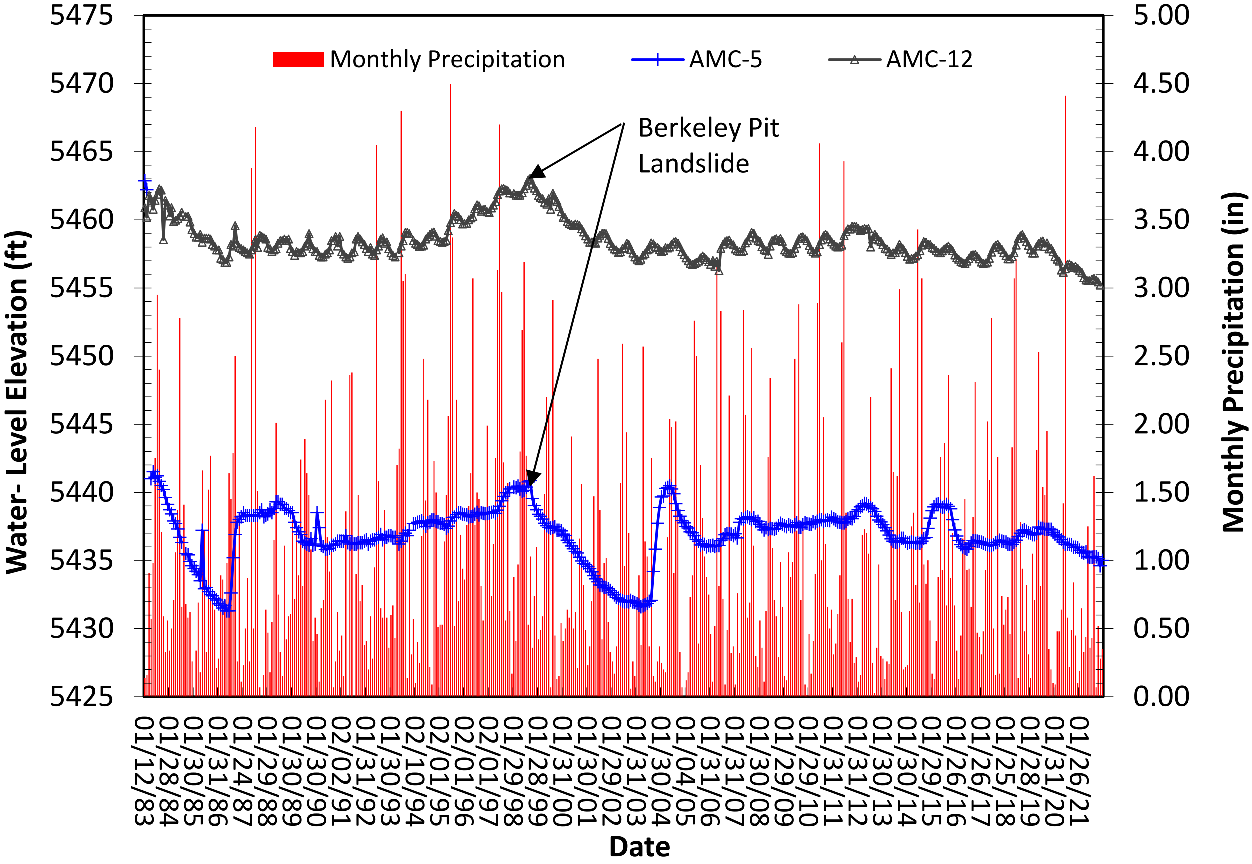

Figure 2-3. Water-level hydrographs for wells AMC-5 and AMC-12.

Well AMC-6 is directly south of the concentrator facility and the 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 infiltration and recharge to the shallow alluvial aquifer. MR drained the Ecology Pond in early 2012. 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). 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 limited 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 2017–2021, with limited response to precipitation events.

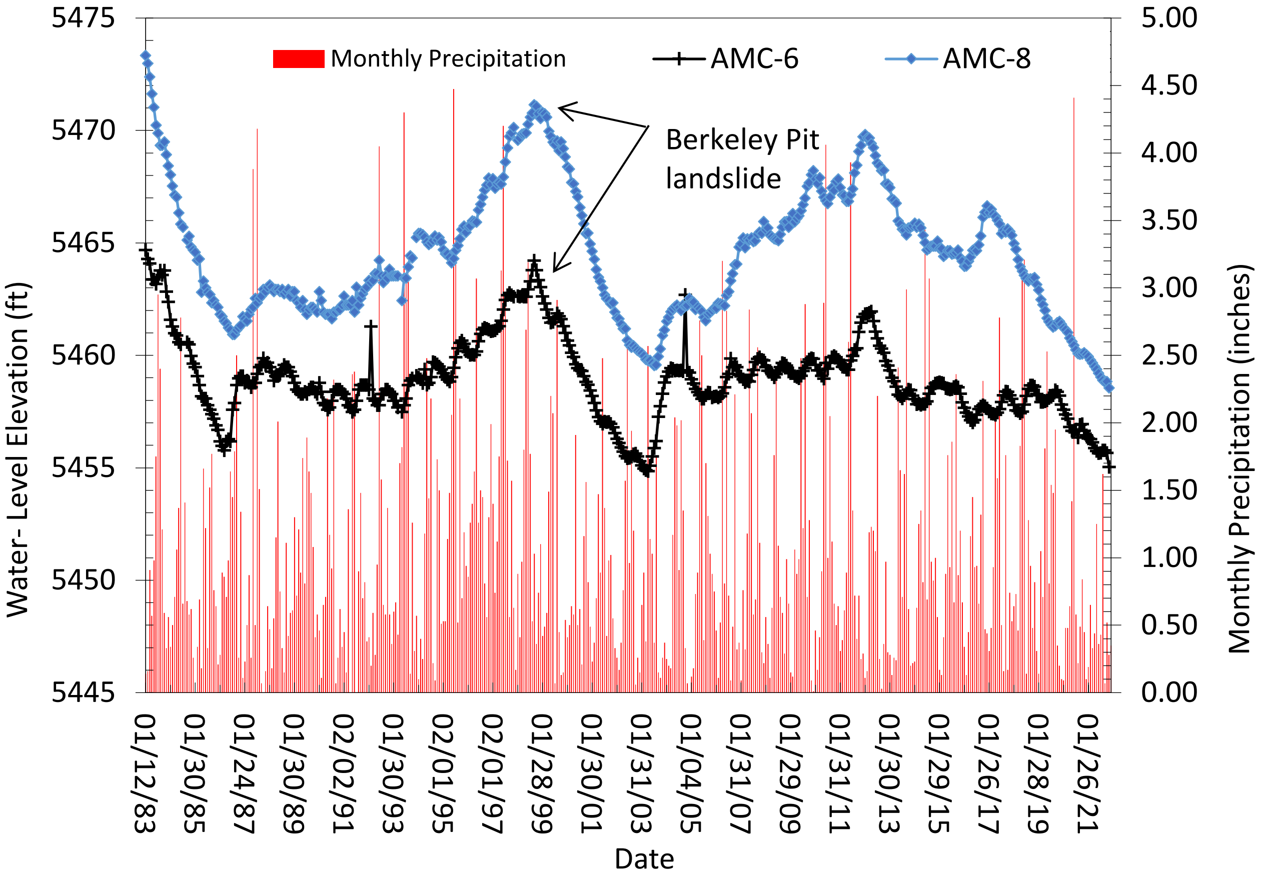

Figure 2-4. Water-level hydrographs for wells AMC-6 and AMC-8.

Well AMC-13 is located on the west side of Clark Park (fig. 2-3). This well's hydrograph shows a response to both precipitation events and possibly lawn watering (fig. 2-5). Water levels begin to rise in late spring and continue to rise throughout the summer, suggesting some recharge from watering the grass, and decline each fall.

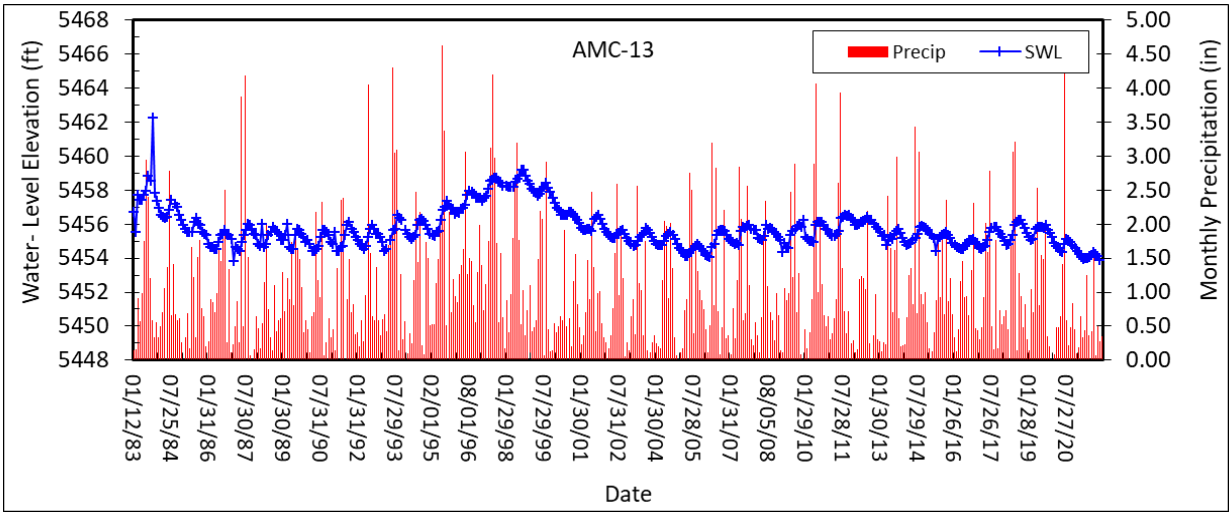

Figure 2-5. Water-level hydrograph for well AMC-13.

Well AMC-15 is located on the west side of the Hillcrest waste dump (fig. 2-3) 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 1/2 ft 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.

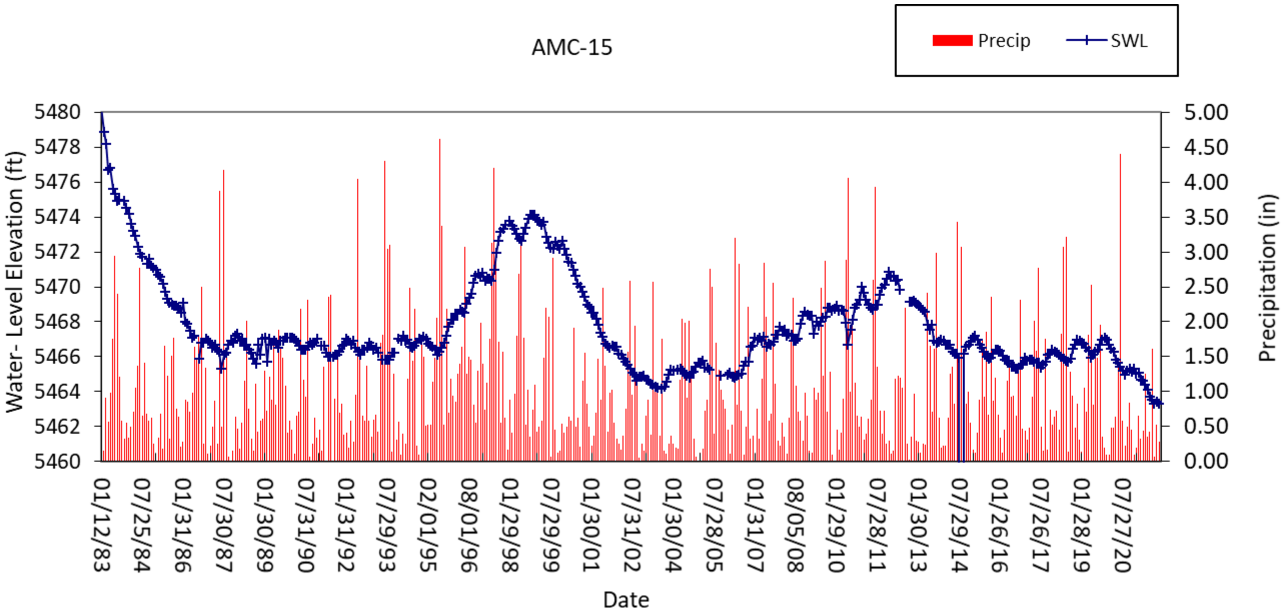

Figure 2-6. Water-level hydrograph for well AMC-15.

Section 2.1.1 AMC-Series Water Quality

Concentration exceedances and trends for chemical constituents in the 2021 data collected from the AMC-series wells are summarized in table 2.1.1.1. Complete sample results for the AMC-series wells are available from the MBMG Ground Water 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 Montana Department of Environmental Quality, Circular 7 (DEQ-7) standards throughout the period of record. The concentrations of cadmium, copper, nickel, and zinc have decreased about 50 percent 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; figure 2-7 shows sulfate concentrations over time. Cadmium is the only constituent with concentrations consistently exceeding DEQ-7 criteria; zinc concentrations exceed DEQ-7 criteria periodically, most recently in 2017.

No 2021 groundwater samples were collected from well AMC-8 due to low water levels. Prior sample results show some minor variations in sample results. Sulfate concentrations doubled from the fall of 2006, increasing from 400 mg/L to more than 1,000 mg/L in October 2017; concentrations declined in 2018 and 2019 (fig. 2-7). Cadmium concentrations continued to decline, with the 2018–2019 samples below the DEQ-7 standard. Overall, water quality is better than most other AMC-series wells.

Table 2.1.1.1. Water-quality exceedances and trends for AMC-series wells, 2021.

Well Name	Exceedances	Concentration Trends	Remarks
AMC-5	Y	Downward/stable	High sulfate, iron, manganese, cadmium, copper, nickel, and zinc.
AMC-6	Y	Downward/stable	Cadmium and zinc (periodically) exceed DEQ-7 standards.
AMC-8	N	Variable	Sulfate, iron, and zinc concentrations show variation; cadmium periodically exceeds DEQ-7.
AMC-12	Y	Downward/stable	Cadmium, copper, nickel, zinc, iron and manganese exceed DEQ-7 standards. Sulfate, cadmium, copper, nickel, zinc, and manganese have downward trends.
AMC-15	Y	Variable	Unchanged in recent years, no exceedances, currently only sampled every 2 yr.

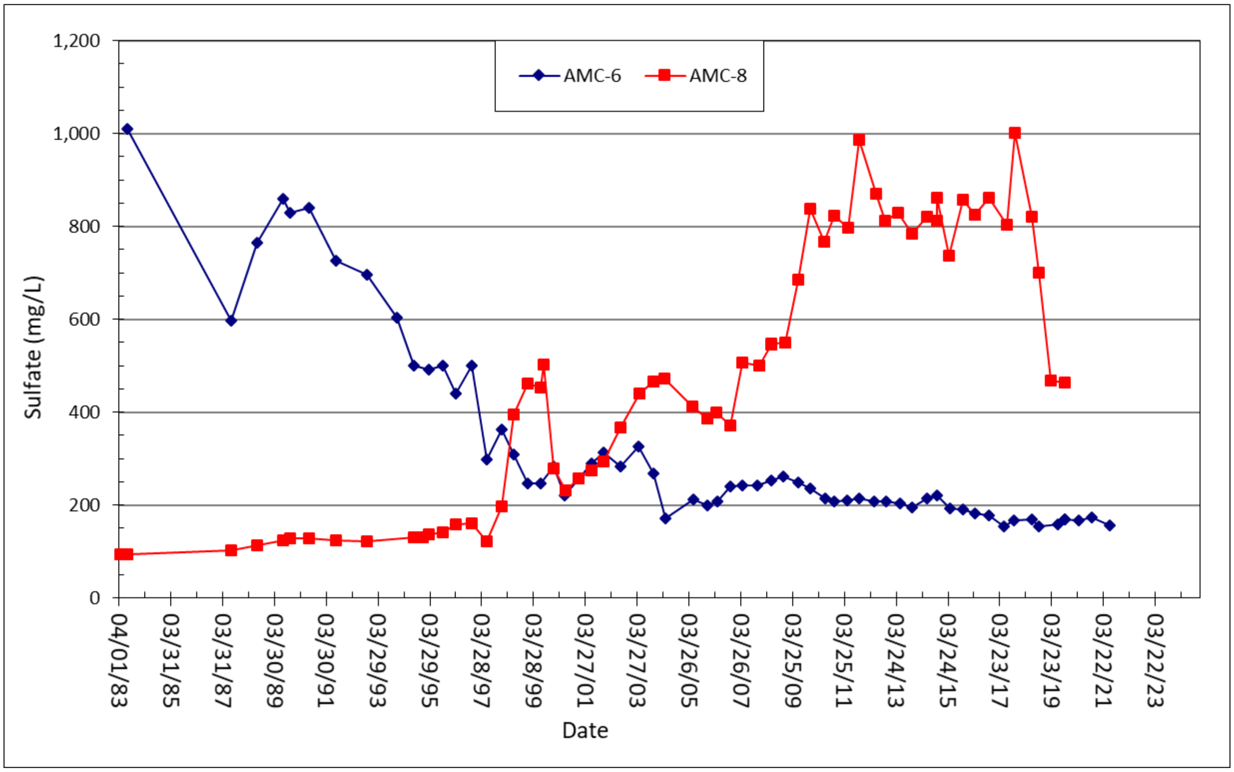

Figure 2-7. Sulfate concentration changes over time for wells AMC-6 and AMC-8.

Water from AMC-12 is located just south of the SBC drainage that received untreated mine and mill-process water for decades and has elevated concentrations of iron, manganese, cadmium, copper, nickel, and zinc. Groundwater quality has improved over the 39-year record; dissolved concentrations of iron, manganese, sulfate, cadmium, copper, nickel, and zinc are one-half or less concentrations observed in the early 1990s (fig. 2-8).

Figure 2-8. Copper and zinc concentration changes over time for well AMC-12.

Overall, dissolved metals concentrations in 2021 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 2-9; table 2.2.1 presents a summary of 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 0.5 ft or less in 2013–2021. Well LP-08 was dry from May 2010 to November 2015; it has a total rise of 6.4 ft from 2016 to 2021.

Water-level monitoring and sampling of the LP-series wells continued throughout 2021, with water levels declining in 12 of the remaining 14 wells. Wells near MR dewatering activities continue to exhibit a water-level decline. Wells downgradient of the leach pads exhibited a water-level decline also, which is a change from years past; the decline is most likely due to the suspension of leaching operations. Since monitoring began in 1991, water levels have declined in all 17 of the LP wells, ranging from 4.61 ft in LP-14 to 32.87 ft in well LP-15, which is used as a dewatering well by MR.

Table 2.2.1. 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**
Change 1991–2000	**-14.73**	**-17.70**	**-19.93**	**-15.16**	**-18.00**	**-3.79**	**-16.64**	**-26.75**	**-26.88**
Change 2000–2010	**-12.57**	**-6.68**	**-11.52**	**-15.44**	**-14.12**	**-0.38**	**-0.79**	**-16.26**	**-6.82**
Change 2011–2020	**16.91**	**9.57**	P&A*	**13.73**	**8.90**	**P&A***	**0.43**	**14.00**	**8.53**
2021	-3.33	-2.40	P&A*	-2.69	-2.84	P&A*	0.02	-3.47	-2.36
Change 2021–2030	**-3.33**	**-2.40**	P&A*	**-2.69**	**-2.84**	P&A*	**0.02**	**-3.47**	**-2.36**
Net Change	**-13.72**	**-17.21**	**-31.45**	**-19.56**	**-26.06**	**-4.17**	**-16.98**	**-32.48**	**-27.53**

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

Table 2.2.1. 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**
Change 1991–2000	**-5.11**	**-5.38**	**-1.09**	**-0.93**	**0.70**	**-5.93**	**-7.80**	**-2.14**	
Change 2001–2010	**3.94**	**0.00**	**7.59**	**4.83**	**5.49**	**5.40**	**4.11**	**7.57**	
Change 2011–2020	**-10.34**	**P&A***	**-14.66**	**-10.52**	**-9.56**	**-116.47**	**-8.28**	**-7.26**	**-4.45**
2021	-0.08	P&A*	-1.32	-0.94	-1.24	84.13	-0.46	P&A*	-0.58
Change 2021–2030	-0.08	P&A*	-1.32	-0.94	-1.24	84.13	-0.46	P&A*	-0.58
Net Change	**-11.59**	**-5.38**	**-9.48**	**-7.56**	**-4.61**	**-32.87**	**-12.43**	**-1.83**	**-5.03**

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

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Figure 2-9. 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 mid-2021. The wells with the greatest water-level rise in 2004 and 2005 (LP-04 and LP-08) are located south of the leach pads. While these wells showed the greatest water-level increase during operation of the leach pads, they exhibited some of the largest declines following the 2021 suspension of leach pad operations.

Figures 2-10 and 2-11 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 2-10, water levels steadily declined in these wells between 1991 and 2004, before leveling off. Between 2005 and 2020, water levels have varied slightly, with periodic increases followed by declines; this trend changed in 2021 with water levels declining following the suspension of leach pad operations. 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 2-11 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. 2-9). Well LP-04 is screened from 125 ft to 145 FBGS. There is very little seasonal variation noticeable in figure 2-11. 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. 2-9). Water levels trended up in these wells between installation in 1992 and the Berkeley Pit landslide of 1998 (fig. 2-12). 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 the summer of 2012. MR had briefly dewatered LP-15 by pumping immediately after the 1998 landslide. Water-level trends since August 2012 are attributed primarily to these dewatering activities (fig. 2-13).

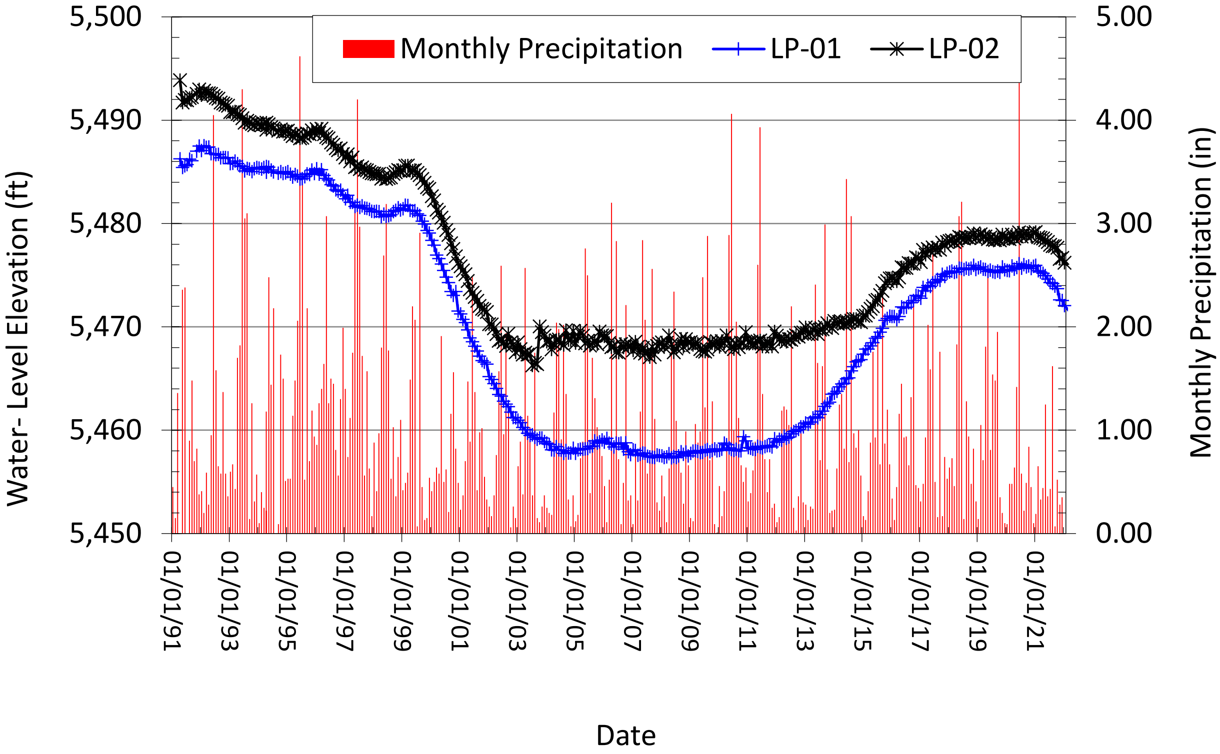


Figure 2-10. Hydrographs for wells LP-01 and LP-02 located north of the Pittsmont Waste Dump and south of the leach pads.

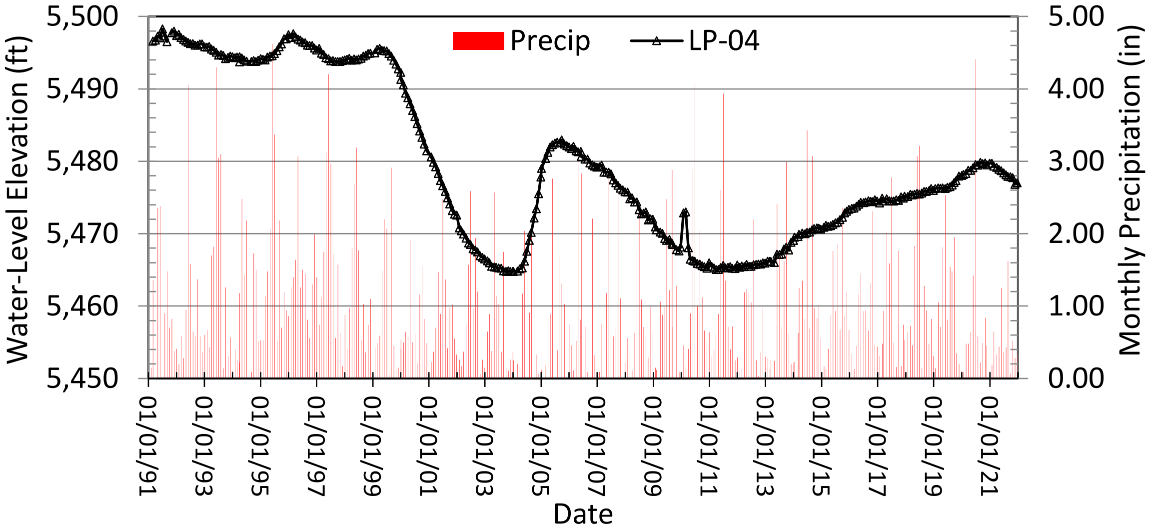


Figure 2-11. Hydrograph for well LP-04 located north of the Pittsmont Waste Dump and south of the leach pads.

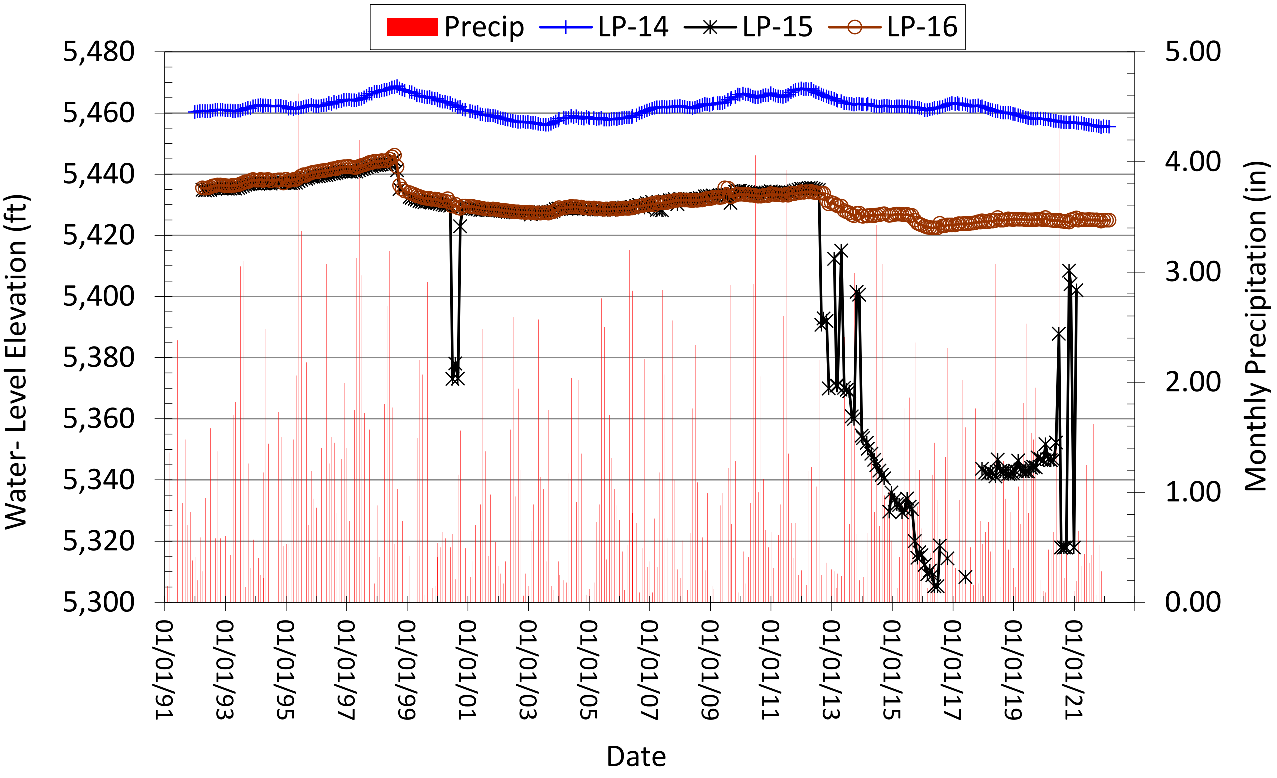


Figure 2-12. Water-level changes for wells LP-14, LP-15, and LP-16 before and after the 1998 Berkeley Pit landslide and response to dewatering activities in 2000 and again in 2012.

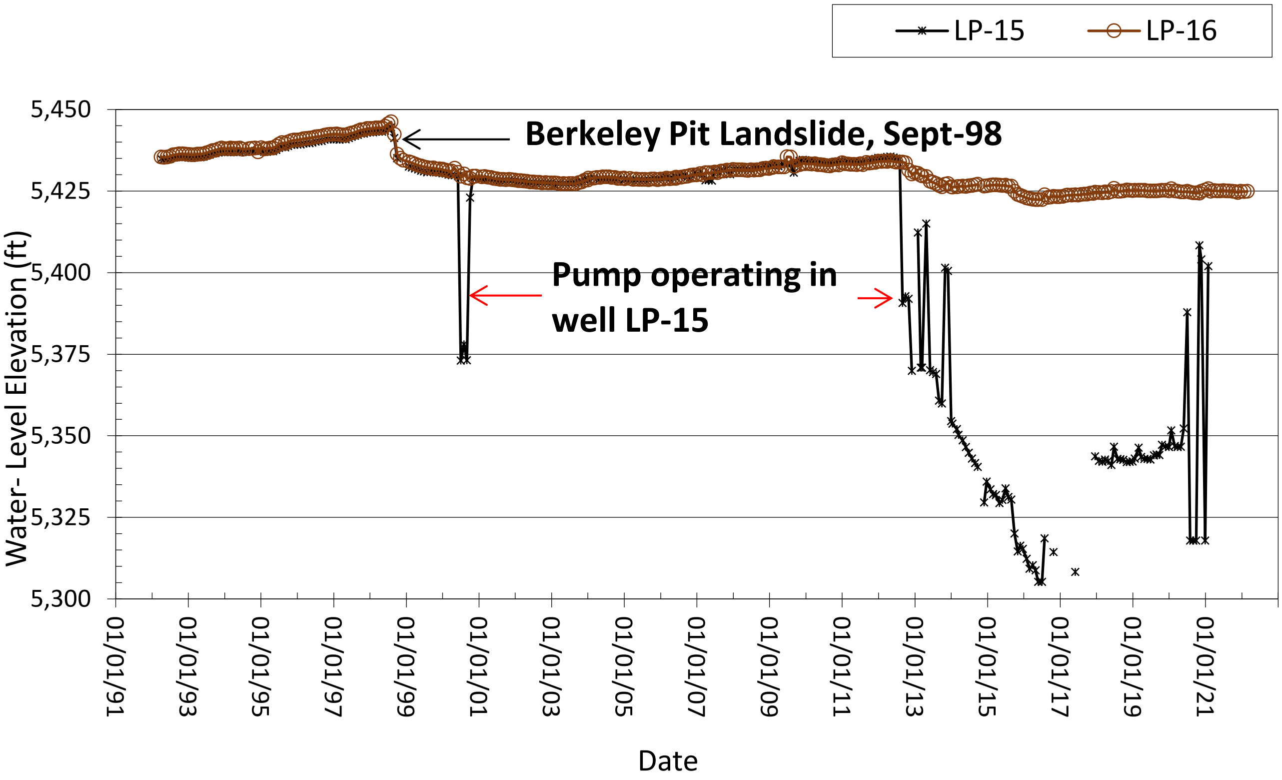


Figure 2-13. Hydrographs showing influence of dewatering on water levels in wells LP-15 and LP-16.

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 and deactivation (mid-2021) of the leach pads;
2. Operation of the YDTI;
3. Depressed water levels in the Berkeley Pit;
4. Alluvial dewatering activities conducted by MR; or
5. A combination of all four.

Water-level response in wells adjacent to and downgradient of limited leaching operations during 2004–2005 and 2009–2021 demonstrate the relationship of leach pad operation and water-level change. This relationship was observed during the latter part of 2021 when MR suspended operation of the leach pads by the immediate decline of water levels in nearby wells. The influence of seasonal precipitation events is minimal on water levels in these wells.

An alluvial aquifer potentiometric map (fig. 2-14), based on December 2021 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.

U.S. Department of Agriculture Farm Services Agency Aerial Photography Field Office

Figure 2-14. Alluvial aquifer potentiometric map for December 2021 (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. 2-9), 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 2021 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 2021 show that sulfate and zinc concentrations, although extremely elevated, have declined almost 50 percent over the past decade (fig. 2-15). 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 (~8,600 µg/L) have declined through 2021 (~4,600 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; concentrations have been gradually decreasing. Although zinc concentrations have declined since 2009, they remain four times above the 1992 levels. Copper concentrations have increased from just over 300 µg/L in 1992 to more than 170,000 µg/L in 2021. 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. 2-16). 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, nickel, and zinc from 2013. Figure 2-17 depicts copper and zinc concentrations in LP-17R since installation in 2013. Nitrate concentrations were elevated in samples collected from 2006 to 2009 and decreased from 2010 to 2012. However, current nitrate concentrations remain at, or near, twice the DEQ-7 standard of 10 mg/L (well LP-17R).

Water quality in the other LP-series wells was generally similar in 2021 to that in recent years. Table 2.2.1.1 includes a summary of exceedances and trends.

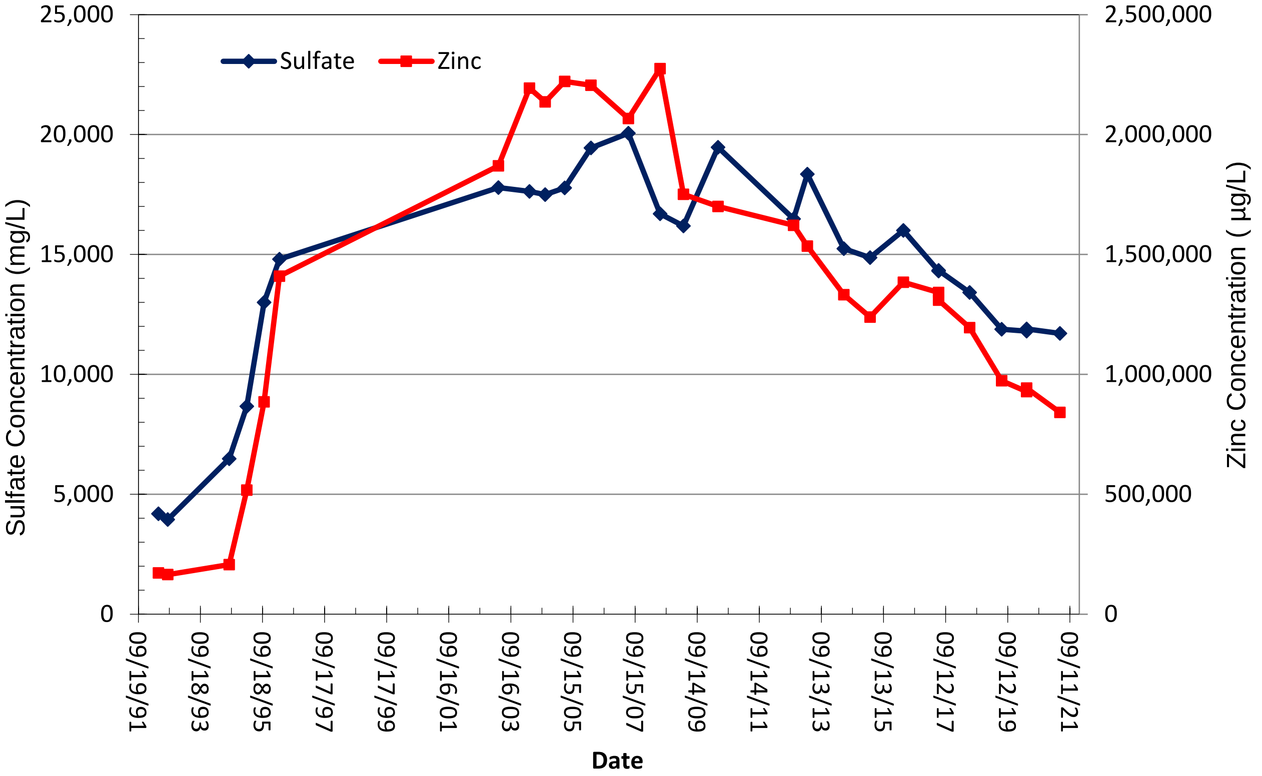


Figure 2-15. Sulfate and zinc concentrations in well LP-09.

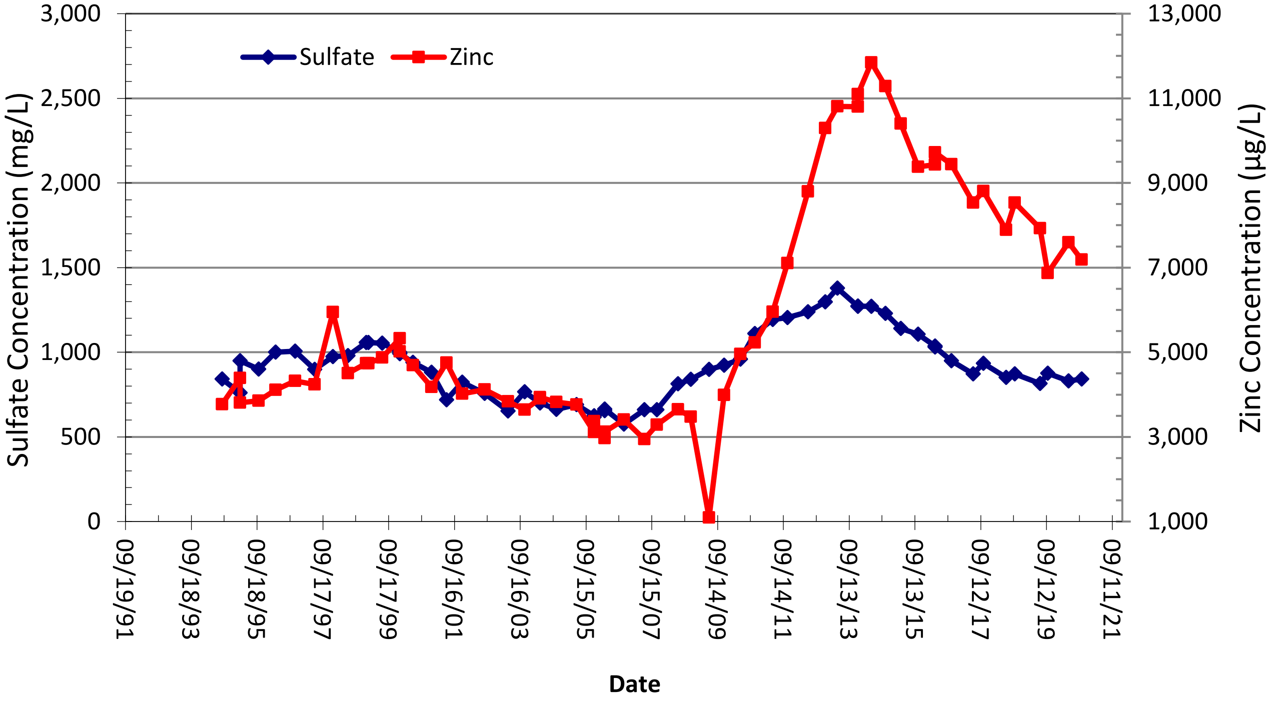


Figure 2-16. Sulfate and zinc concentrations in well LP-16.

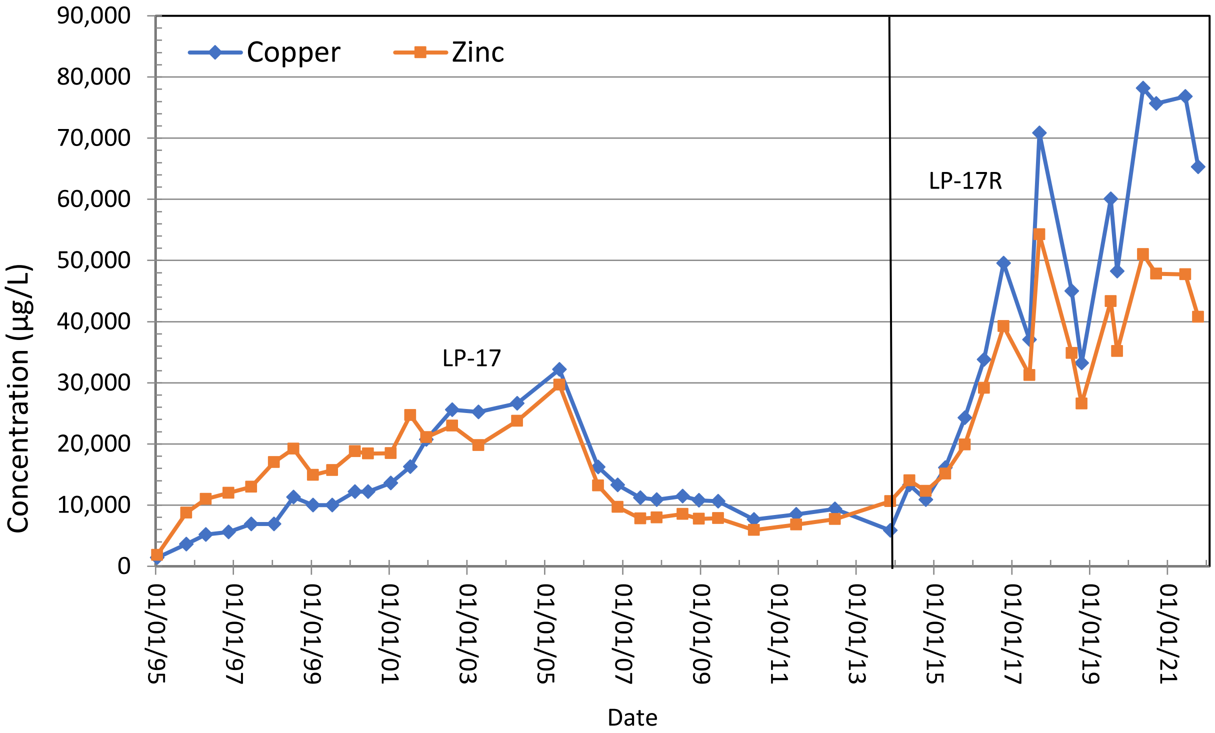


Figure 2-17. Copper and zinc concentrations in wells LP-17 and LP-17R.

Table 2.2.1.1. Water-quality exceedances for LP-series wells, 2021.

Well Name	Exceedances (1 or more)	Concentration Trends	Remarks
LP-08	Y	Downward	Very elevated concentrations. No samples from 2009–2020 because of limited volume of water in well. Concentrations in 2021 exceed DEQ-7 up to an order of magnitude (or more) for cadmium, copper, nickel, and zinc.
LP-09	Y	Downward	Large increases from 1992 to 2009. Cadmium, copper, nickel, uranium, and zinc show decreases since 2009, still exceed DEQ-7 standards by order(s) of magnitude.
LP-10	N	Stable	No significant changes in 2021.
LP-12	Y	Stable	Cadmium exceeds DEQ-7 standard. No significant changes in 2021.
LP-13	N	Stable	No significant changes in 2021. Zinc below DEQ-7 standard in 2013–2021.
LP-14	Y	Stable/Increasing	Cadmium exceeds DEQ-7 standard; sulfate increasing.
LP-15	Y	Stable	Cadmium exceeds DEQ-7 standard, net change is small for most analytes.
LP-16	Y	Downward	Cadmium, copper, and zinc exceed DEQ-7 standards.
LP-17/LP-17R	Y	Downward	Nitrate, cadmium, copper, nickel, and zinc exceed DEQ-7 standards.

Section 2.3 Precipitation Plant Area Wells

Wells MR97-1, MR97-2, MR97-3, and MR97-4 (fig. 2-9) are adjacent to various structures (drainage ditches, holding ponds, etc.) associated with the leach pads and precipitation plant. Table 2.3.1 lists water-level changes for these wells. Water-level changes appear to correspond to flow in nearby ditches and water levels in ponds, with wells MR92-2 and 97-3 showing considerable declines in 2021, most likely due to their proximity to the leach pads.

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

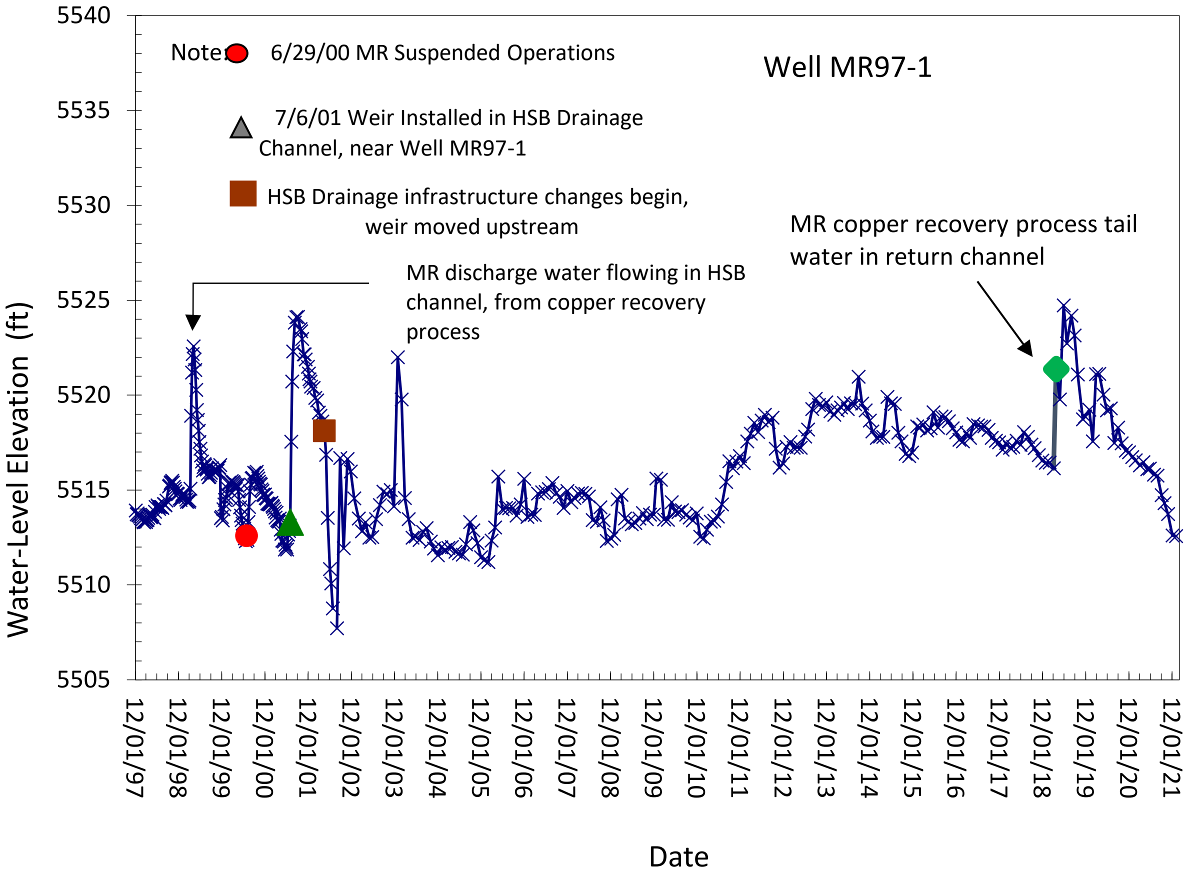
Year	MR97-1	MR97-2	MR97-3	MR97-4
Change 1997–2006	**-0.34**	**-8.15**	**-11.77**	**2.90**
Change 2007–2016	**4.07**	**10.68**	**10.92**	**0.47**
2017	-0.53	0.01	1.00	0.68
2018	-0.69	-0.37	-0.36	-3.55
2019	2.80	0.29	0.99	1.00
2020	-2.49	-1.60	-0.65	-0.33
2021	-1.88	-7.46	-3.45	-0.21
Change 2017–2021	**-2.79**	**-9.13**	**-2.47**	**-2.41**
Net Change	**0.94**	**-6.60**	**-3.32**	**0.96**

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

Water levels in well MR97-1 exhibit considerable variability, which is attributed to changes in mining operations and infrastructure changes (figs. 2-18, 2-19). Water levels increased when MR began to discharge water from the Berkeley Pit copper recovery project into the pit (spring 1999) and again in June 2000, when mining operations ceased and HsB water was directed to the pit. Prior to this, from April 1996, HsB water was pumped to the YDTI. Overall, these operational changes caused rapid increases in groundwater levels, followed by gradual decreases before leveling off. The

Pilot Project necessitated changes in water handling in the HsB area and increased flows periodically in ditches adjacent to MR97-1, resulting in an almost 3 ft water-level rise in 2019. Water levels declined by 2.49 ft and 1.88 ft, respectively, in 2020 and 2021, as flows returned to more normal operating conditions.

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. 2-18, 2-19). Water-level increases occurred in 2009–2013 and 2016 in MR97-2 and 2009–2016 in MR97-3 when limited leaching operations resumed. The cessation of leaching operations mid-2021 led to an almost 7.5 ft water-level decline for the year. Dewatering activities near the HsB water-treatment plant in 2014–2021 may have been responsible for additional water-level variations/declines observed in MR97-2. Those activities were suspended in December 2021 as a result of declining water levels in the pumping wells.



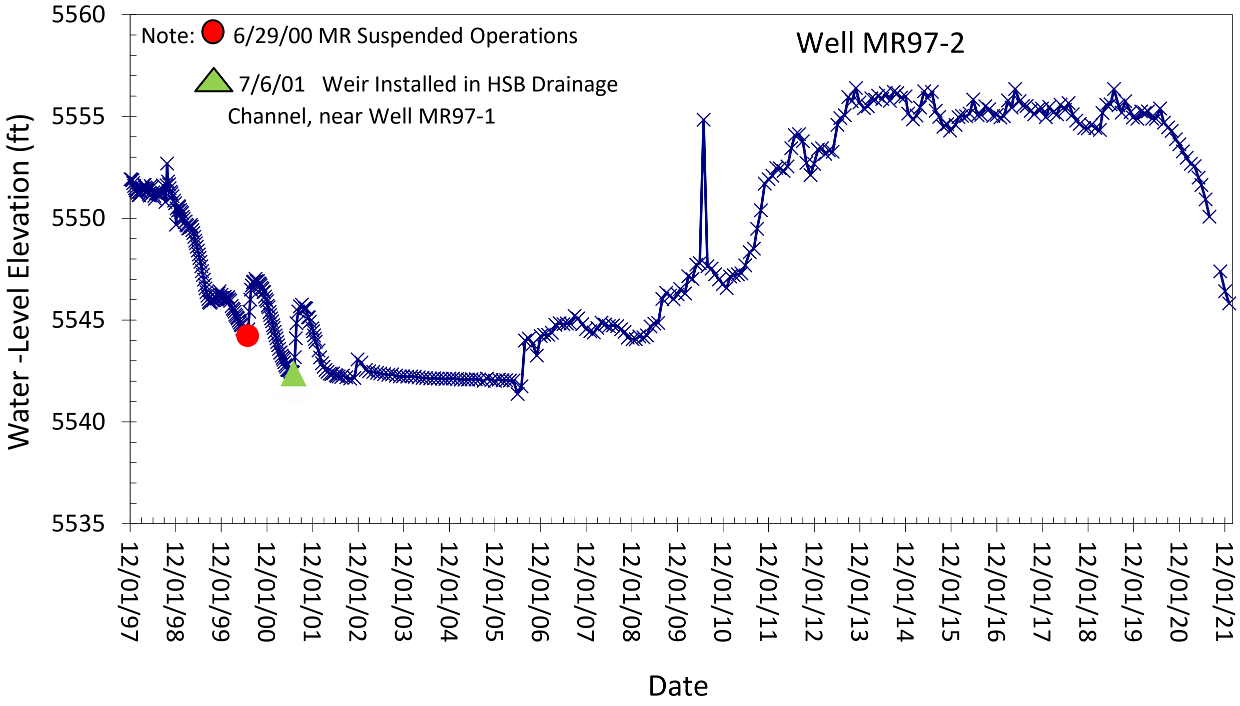
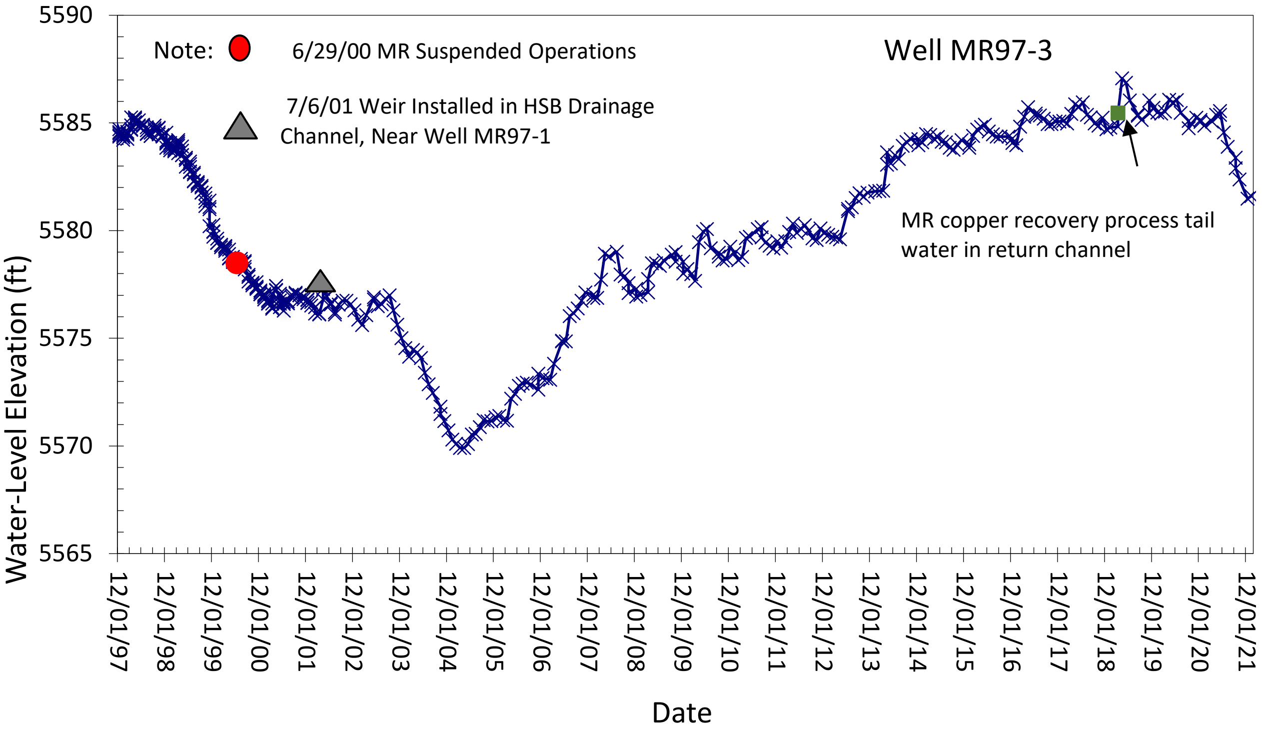


Figure 2-18. Water-level hydrograph for wells MR97-1 (top) and MR97-2 (bottom).

Well MR97-3 water-level responses during the 2001 and 2002 construction activities were minor (fig. 2-19). Water levels varied between 2008 and 2012 with a general increasing trend; water levels rose steadily from mid-2013 until leveling off in 2015–2017. Seasonal water-level changes in 2017 and 2018 may be due to operational changes related to higher spring flows in the mine operations; 2019 water-level increases correspond to operational changes related to the Berkeley Pit Pumping/Discharge Pilot Project operations. 2020 water levels showed only minor variations, while 2021 water levels declined by almost 3.5 ft, which is attributed to the suspension of leaching operations and a decline of flow in nearby ditches. Water-level changes in well MR97-4 (fig. 2-19) 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 almost 1ft in wells MR97-1 and 97-4, while declining between 6.6 ft and 3.3 ft in wells MR97-2 and 97-3. 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 the MR-series wells between 2001 and 2021. Previous sampling documented the presence of elevated metals; this contamination most likely resulted from leach pad and precipitation plant operations.



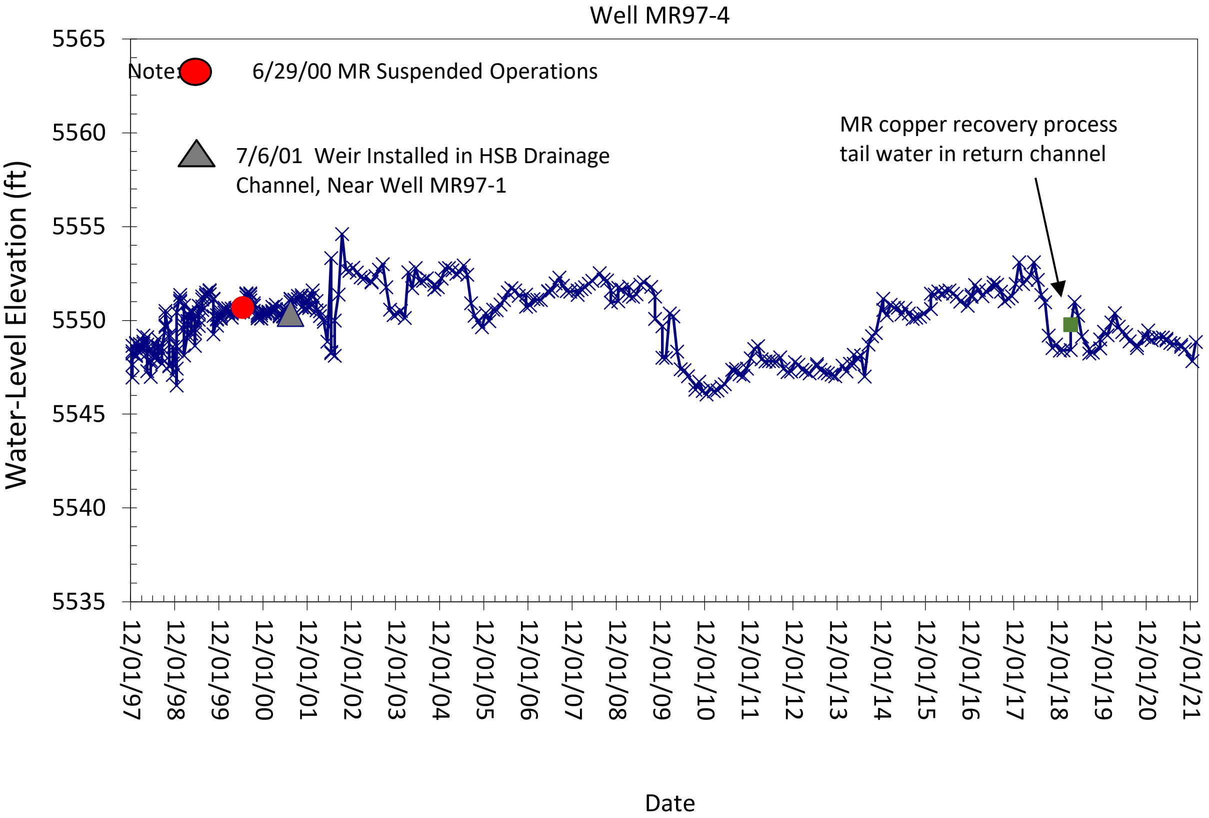


Figure 2-19. Water-level hydrograph for wells MR97-3 (top) and MR97-4 (bottom).

Section 2.4 GS- and BMF05-Series Wells

Continuous and monthly water-level monitoring of the four GS-series and four BMF05-series wells continued throughout 2021. The locations of these wells are shown in figure 2-20; table 2.4.1 contains water-level changes. Pairs of wells (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 four wells. Water levels during the entire period of record in the GS-44 and GS-46 series wells have net decreases ranging from 1.2 to 1.8 ft.

Figures 2-21 and 2-22 show hydrographs with monthly precipitation totals for the well pairs (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 2021, water-level changes in wells GS-44S and GS-44D were similar to those observed in prior years and the influence of seasonal precipitation appears to dominate the hydrograph. Water levels decreased from 0.8 ft and 1.2 ft in these four wells during 2021.

Vertical gradients at the well pairs differ. At the GS-44 site, 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 water levels 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 2-20. Location map for GS- and BMF05-series wells.

Table 2.4.1. 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
Change 1993–2002	**-0.38**	**-0.43**	**-0.22**	**-0.17**	**-0.84**	**-0.88**				
Change 2003–2012	**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
2019	P&A*	P&A*	-0.35	-0.33	-0.35	-0.37	0.09	-1.28	-0.07	0.12
2020	P&A*	P&A*	-1.04	-0.94	-1.20	-1.20	-1.41	-1.32	-1.36	-1.62
2021	P&A*	P&A*	-0.80	-0.85	-1.10	-1.18	-1.16	-1.37	-1.52	-1.87
Change Years 2013–2021	**-0.02**	**0.09**	**-2.52**	**-2.50**	**-3.50**	**-3.70**	**-3.37**	**-5.80**	**-3.46**	**-5.34**
Net Change	**0.18**	**0.39**	**-1.55**	**-1.62**	**-1.20**	**-1.83**	**-2.01**	**-2.96**	**-0.65**	**-1.49**

Note. Minus sign (-) indicates a decline (drop) in water level.
*Well plugged and abandoned, 2018. GS-41 wells were removed as part of a tailings remediation project.

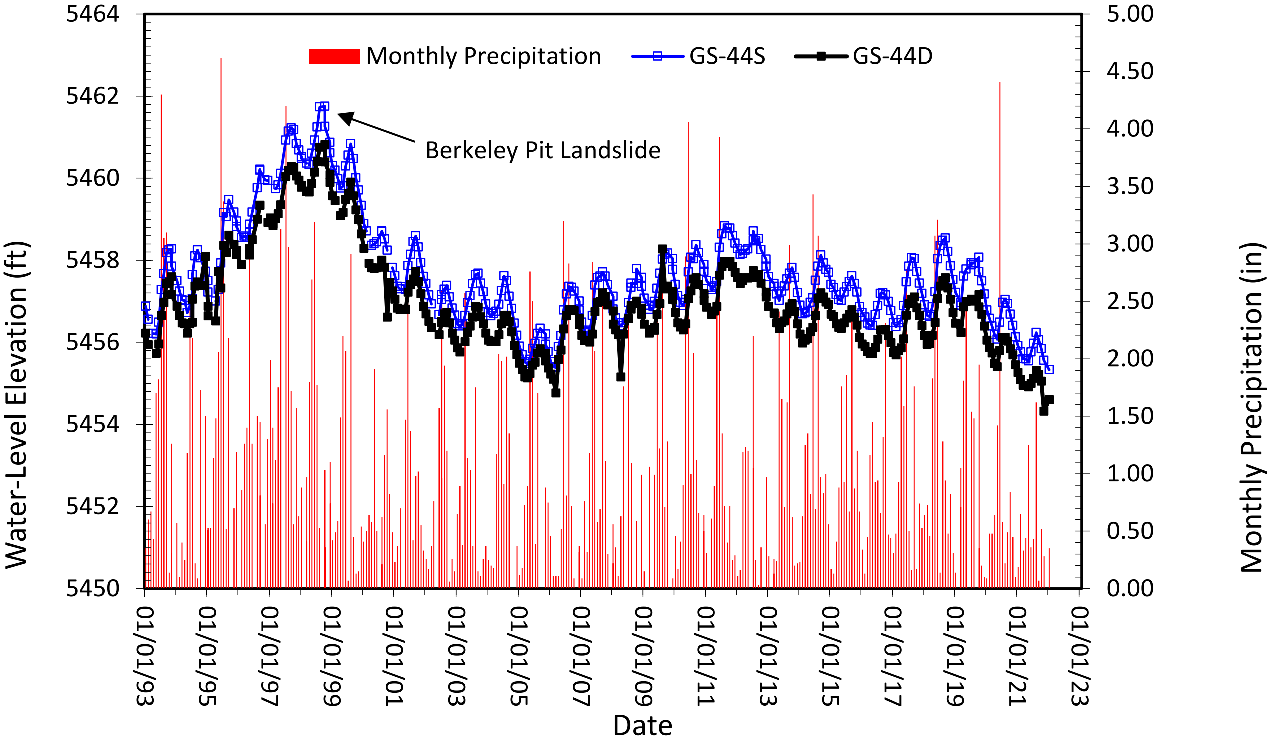


Figure 2-21. Water-level hydrographs for wells GS-44S and GS-44D.

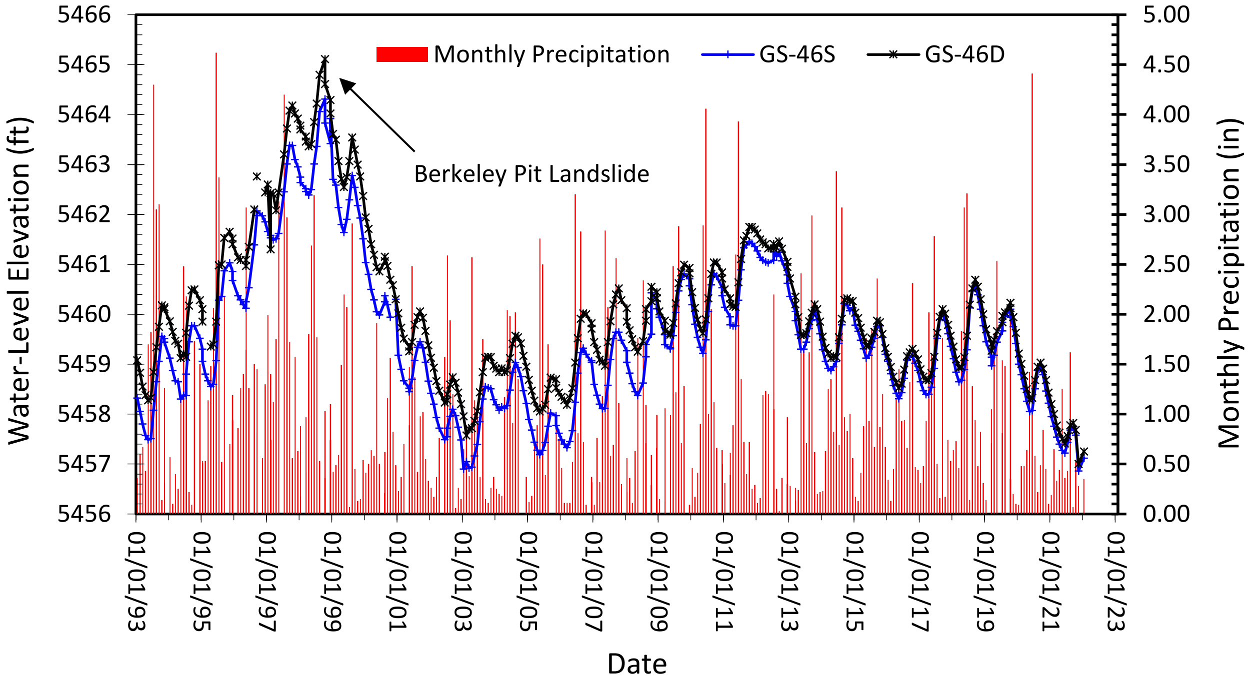


Figure 2-22. Water-level hydrographs for wells GS-46S and GS-46D.

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 2-20. 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. Water levels have decreased in all four wells over the period of monitoring, with declines ranging from 0.65 ft and 2.96 ft (table 2.4.1). Figure 2-23 shows daily average water levels for the BMF05-series wells, based upon hourly data recorded by the pressure transducers. 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 2-24 portrays hydrographs for BMF05-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 BMF05-series alluvial wells as in the GS-series wells.

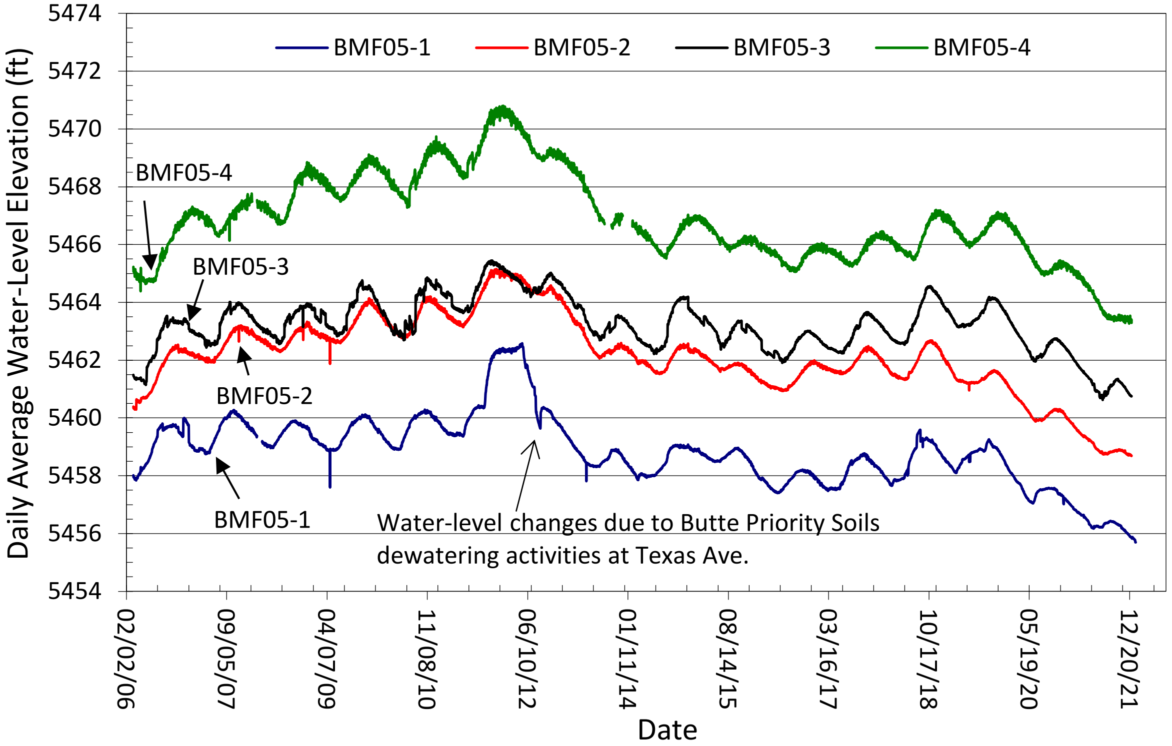


Figure 2-23. Average daily water levels for BMF05-series wells.

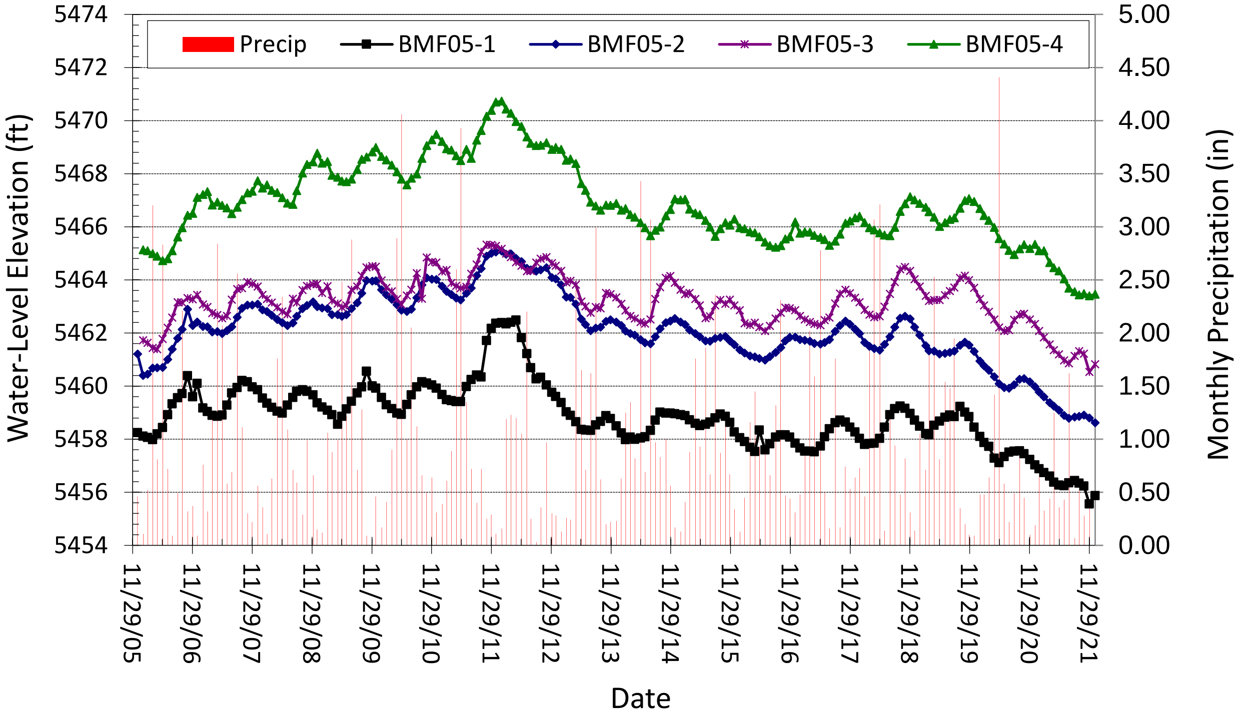


Figure 2-24. Monthly water levels versus precipitation, BMF05-series wells.

Section 2.4.1 GS- and BMF05-Series Wells Water Quality

Water-quality samples were collected in the spring from GS-series wells and in the spring and fall from the BMF05-series wells as part of the 2021 BMFOU monitoring. Complete sample results for the GS- and BMF05-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&.

Concentrations of several dissolved constituents continue to exceed DEQ-7 criteria in wells GS-44S and GS-44D at the north end of Clark Park. Cadmium concentrations in 2020 and 2021 increased in well GS-44S and are currently four times the DEQ-7 standard; this compares to 2010–2018 samples being three to six times the standard (fig. 2-25). Zinc concentrations also increased in 2020–2021; they follow a similar long-term trend as cadmium (fig. 2-25). Water from well GS-44D continues to have cadmium concentrations five times greater than the DEQ-7 standard. Still, the cadmium concentrations have gradually decreased by as much as 50 percent, or more, during the period of record. Zinc exceeded the DEQ-7 standard by over a factor of 2 in 2020–2021 sample results for both GS-44S and GS-44D.

Wells GS-46S and GS-46D, northeast of Clark Park, continued to produce water of good quality in 2021, and constituent concentrations show little upward or downward trend, with the exception of uranium (GS-46S), which exceeds the DEQ-7 standard in the 2005–2009, 2011, and 2014–2021 samples.

The BMF05-series 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 varying between 5.0 and 5.50 and elevated concentrations of sulfate, manganese, cadmium, copper, and zinc; however, concentrations of

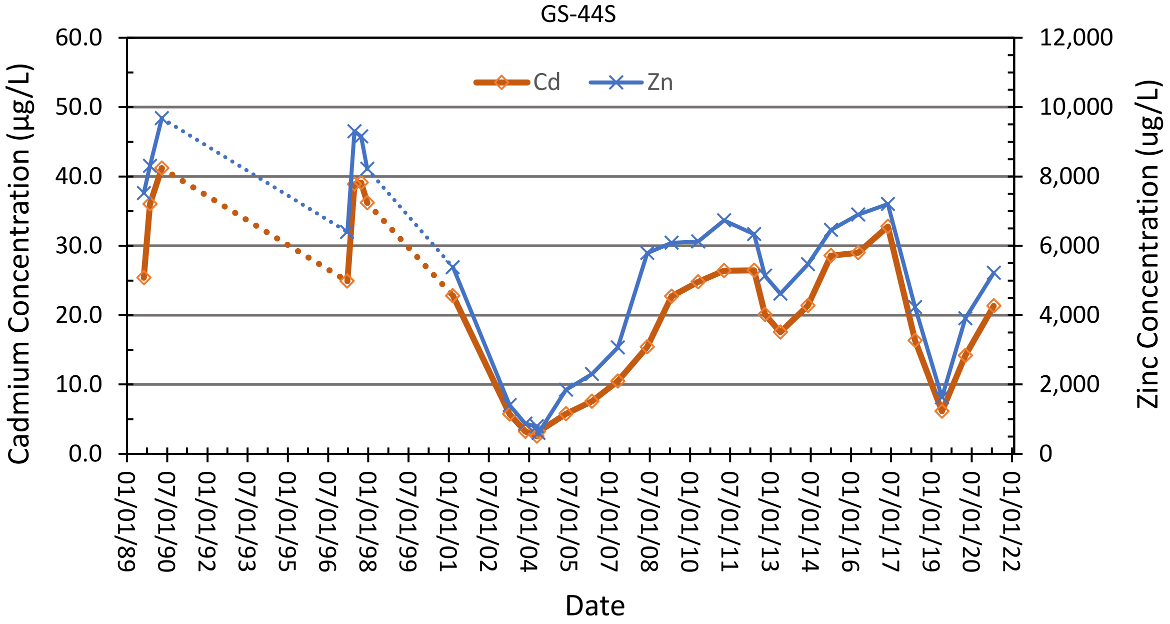


Figure 2-25. Cadmium and zinc concentration trends in well GS-44S.

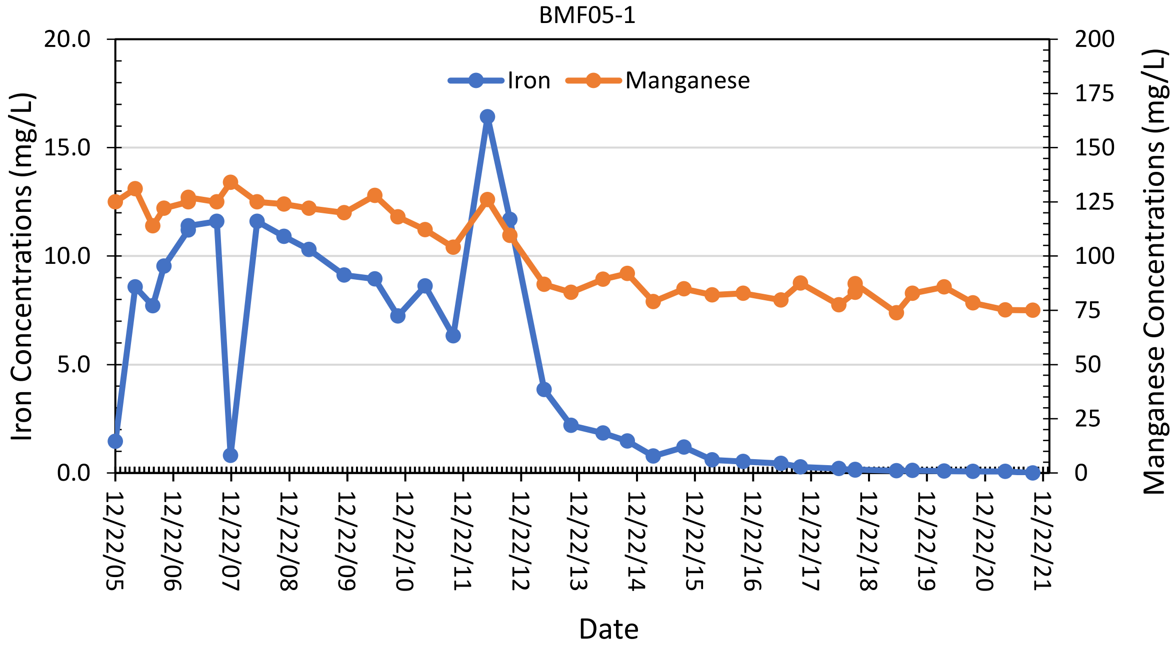


Figure 2-26. Iron and manganese concentration trends in well BMF05-1.

iron, manganese, and sulfate have been trending down since 2013 (fig. 2-26). Cadmium and zinc concentrations have a downward trend for the period of record and appear to be leveling off (fig. 2-27). Table 2.4.1.1 shows the mean values for constituents that exceed DEQ-7 standards.

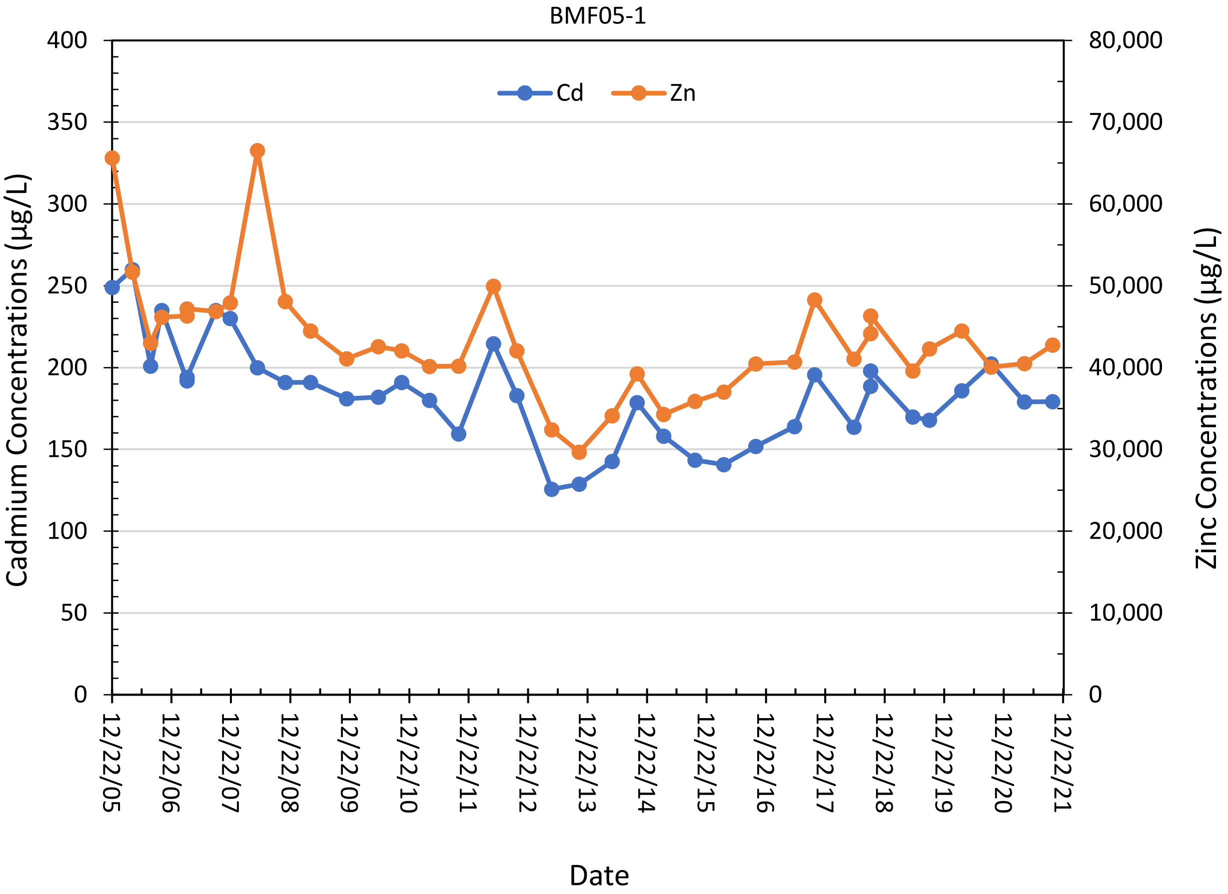


Figure 2-27. Cadmium and zinc concentration trends in well BMF05-1.

Table 2.4.1. 1. Mean concentrations of analytes that exceed DEQ-7 water-quality standards, well BMF05-1.

Analyte	**Mean Concentration (mg/L)**	**DEQ-7 Standard (mg/L)**
Cadmium	0.185	0.005
Copper	3.52	1.3
Zinc	43.4	2.0

Well BMF05-1 is adjacent to the historic SBC channel and downgradient from MR’s concentrator (fig. 2-20), 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. No analytes exceed DEQ-7 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 and the bedrock monitoring wells installed as part of the RI/FS investigation, located primarily to the east of the Berkeley Pit.

Section 3.1 Underground Mines and Berkeley Pit Water Levels

Monitoring of water levels in the seven East Camp underground mines (includes well GM-1, which replaces the Granite Mountain Mine) continued during 2021. Water levels in the mines changed very little in 2021 as a result of the ongoing Pilot Project. Whereas water levels rose between 4.75 and 5.90 ft in 2019, they vary from no increase to a decline of 0.55 ft in 2021 (table 3.1.1). (Note: well GM-1 was drilled as a replacement monitoring site for the Granite Mountain Mine and has been added to table 3.1.1.) The Kelley Mine has the best record of water-level change over time, and its water level has risen over 3,200 ft since 1982. Water-level increases during the first 3 years of flooding were the largest and coincide with the filling of the deeper portion of the underground mines and bottom of the Berkeley Pit (fig. 3-2). The rate of water-level rise between 2004 and 2018 slowed by 50 to 60 percent when MR diverted the HsB water away from the pit in the fall of 2003. Water-level changes in 2020–2021 are attributed to the Pilot Project that began the latter part of September 2019.

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

Year	Berkeley Pit	Anselmo	Kelley	Belmont[1]	Steward	Granite Mountain	GM-1[3]	Lexington[2]	Pilot Butte
Change Years 1982–1991	**12.00**	**274.60**	**2,897.42**	**1,887.50**	**1,875.55**	**220.00**		**8.10**	**0.00**
Change Years 1992–2001	**201.74**	**184.45**	**188.69**	**170.64**	**190.62**	**199.12**		**68.30**	**74.76**
Change Years 2002–2011	**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
2019	4.89	4.75	5.13	5.05	5.40	NA		5.90	5.22
2020	-0.09	-0.46	-0.60	-0.81	-0.86	NA	0.09	-0.08	-1.15
2021	-0.63	0.03	-0.15	0.00	-0.15	NA	-0.08	-0.10	-0.52
Change Years 2012-2021	**55.92**	**53.28**	**56.08**	**54.49**	**52.94**	**32.72**	**0.01**	**56.58**	**54.30**
Net Change*	**355.92**	**592.72**	**3,229.47**	**2,198.47**	**2,202.49**	**536.91**	**0.01**	**215.54**	**213.63**

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.

[3] Well GM-1 was drilled in 2021 to replace Granite Mountain Mine, which had an obstruction in the mine shaft.

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

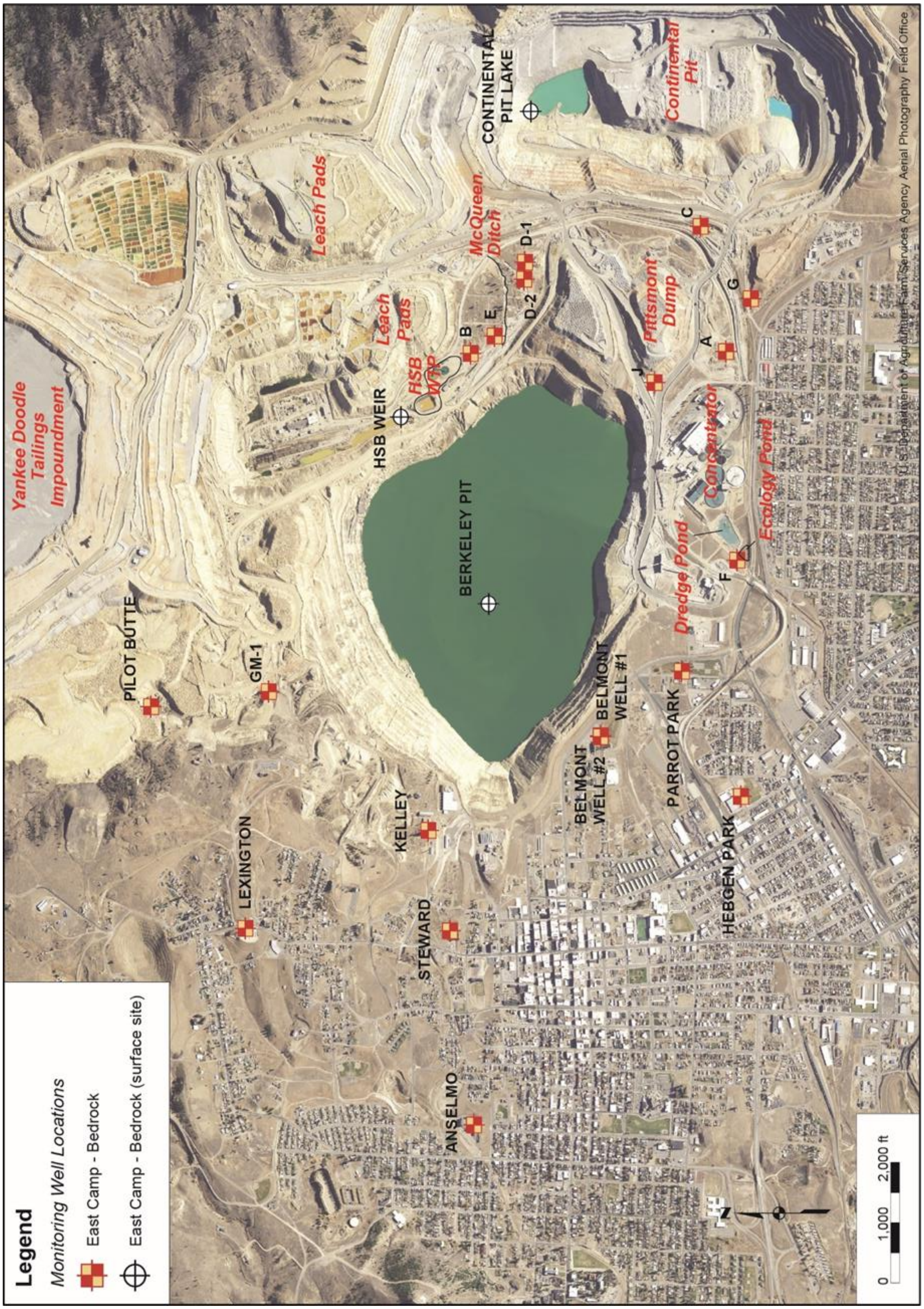


Figure 3-1. East Camp mines and bedrock wells location map.

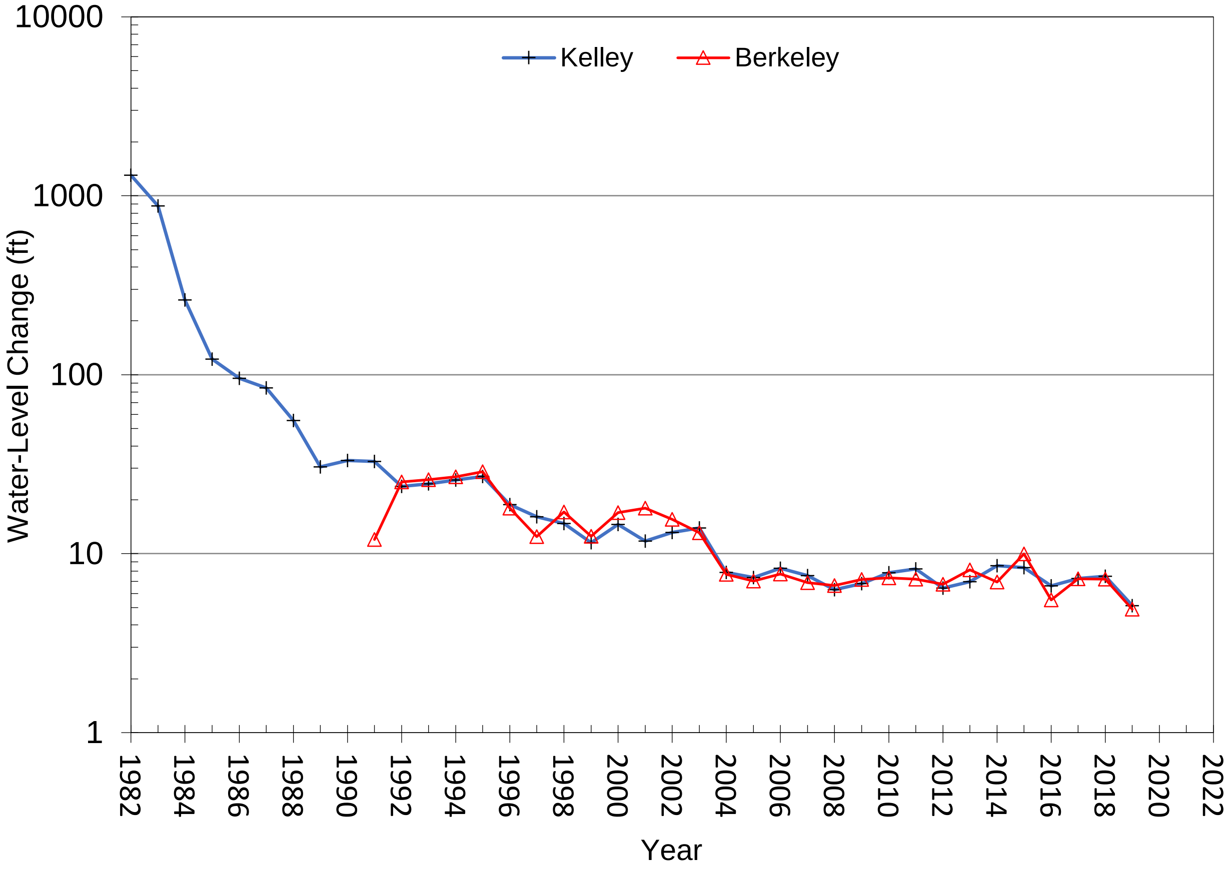


Figure 3-2. Kelley Mine and Berkeley Pit annual water-level changes. 2020–2021 data are not shown on chart since values are negative.

Water levels for the Anselmo Mine and Kelley Mine from 1995 to the present are shown in the hydrographs in figure 3-3 with deviations from the general rate of rise identified. The April 1996 removal of HsB water discharging into the pit slowed the rate of water-level rise, but the July 2000 re-diversion of the HsB 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 3-3, remained constant throughout mid-2019, corresponding to the continued diversion of HsB water to the HsB treatment plant. The rate of filling and water table rise (i.e., slope of the line) decreased following the September start of the Pilot Project and continued through 2021. Water levels in all the East Camp underground mines reacted similarly.

Figure 3-4 depicts the Berkeley Pit filling rate from 1995 through 2021, showing water levels in comparison to the PWL and the elevation of the lowest point of the pit rim. The slowing of the water-level rise following the start of the Pilot Project is very apparent. Based upon volume estimates of the underground mines in December 2021 water-level elevations, 85 percent of the underground workings are flooded. Approximately 12 percent of the underground workings are above the PWL elevation of 5,410 ft, leaving less than three percent of the remaining underground workings unflooded.

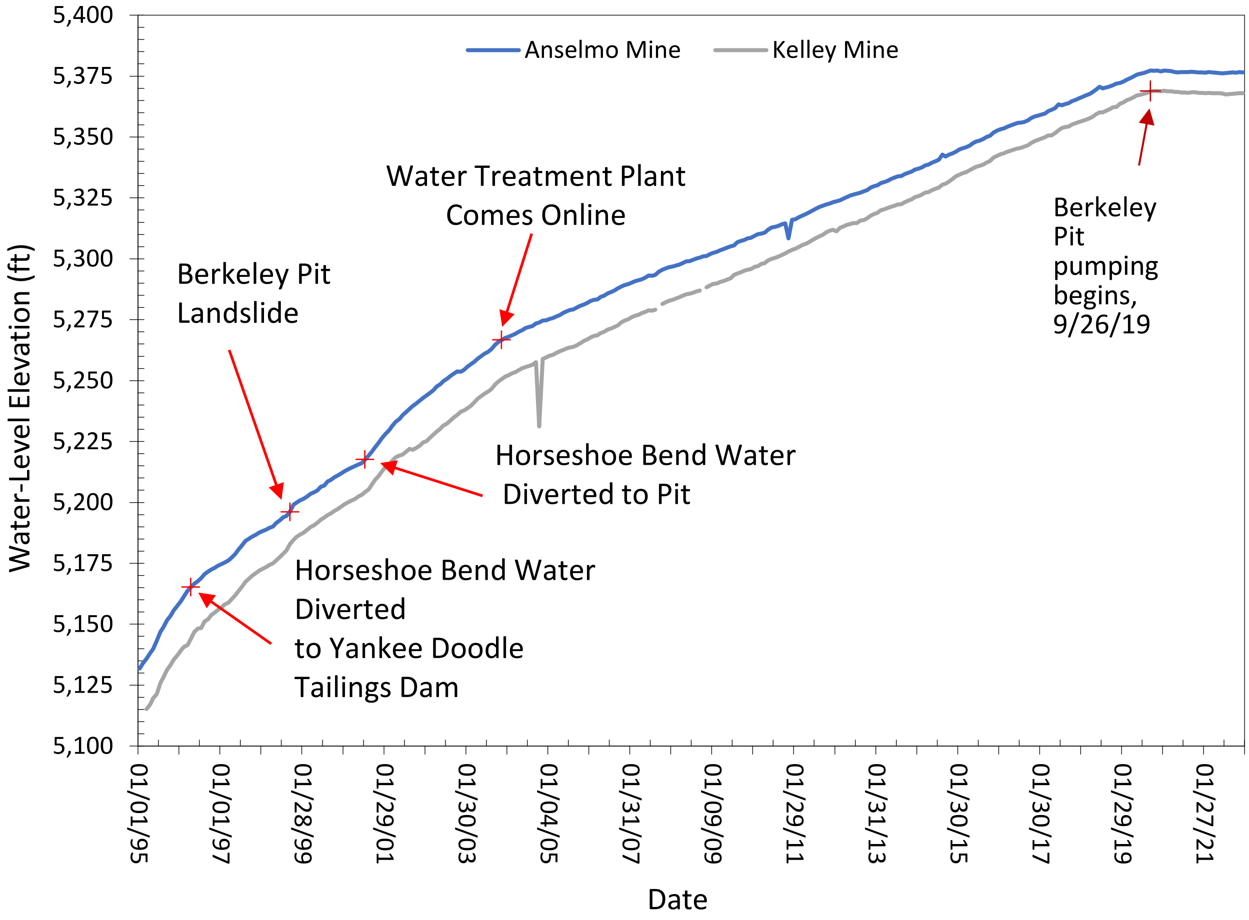


Figure 3-3. Water-level hydrograph for the Anselmo and Kelley mines from 1995 to 2021, and significant events that affected the rate of water-level rise.

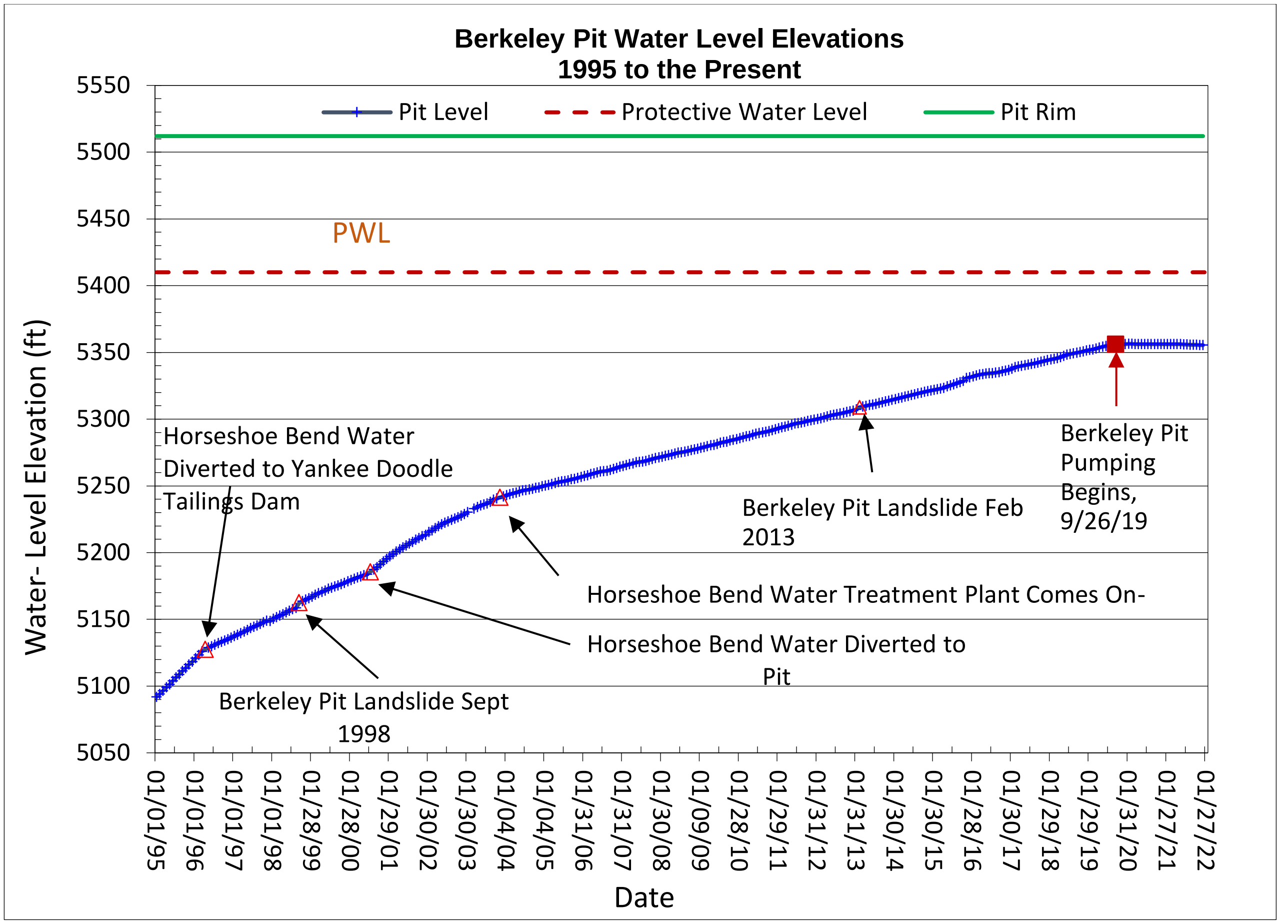


Figure 3-4. Berkeley Pit water-level hydrograph from 1995 to 2021.

The 1994 ROD and 2002 CD established 14 POCs in the East Camp bedrock system: 7 underground mines and 7 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 MSL 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 2021 was the Pilot Butte Mine, about 0.5 mi north of the Berkeley Pit, at an elevation of 5,381 ft or 29 ft below the PWL. The lowest water level at the end of 2021 was 5,356 ft in the Berkeley Pit, which confirms that groundwater continues to flow towards the pit. Figure 3-5 compares the water level for the Pilot Butte Mine, Anselmo Mine, and bedrock well G POCs and Berkeley Pit from 2017 to 2021, showing the higher water level in the POCs compared to the Berkeley Pit. The PWL is shown for reference.

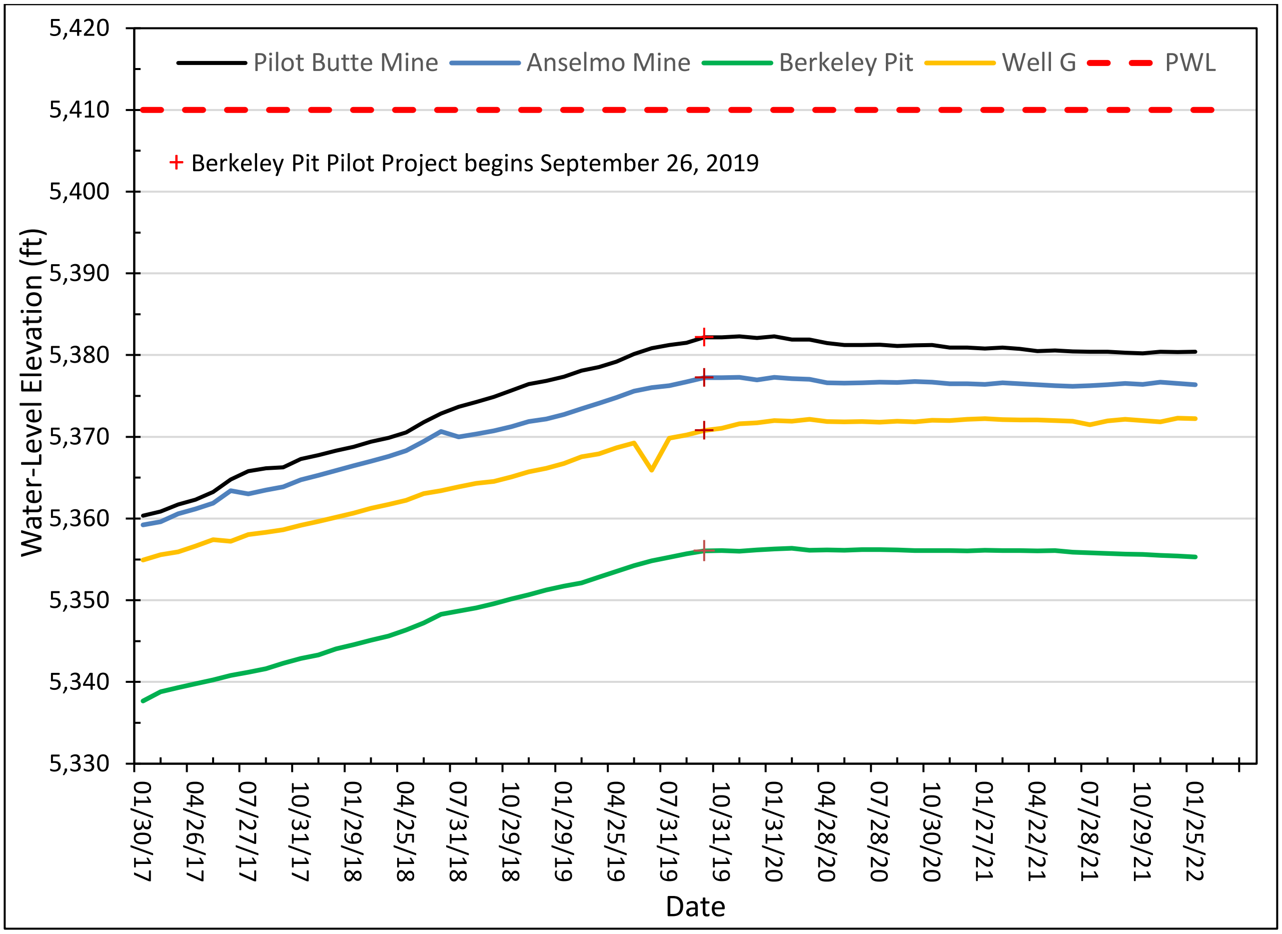


Figure 3-5. Water-level hydrograph for the Berkeley Pit and other selected bedrock monitoring sites, 2017–2021.

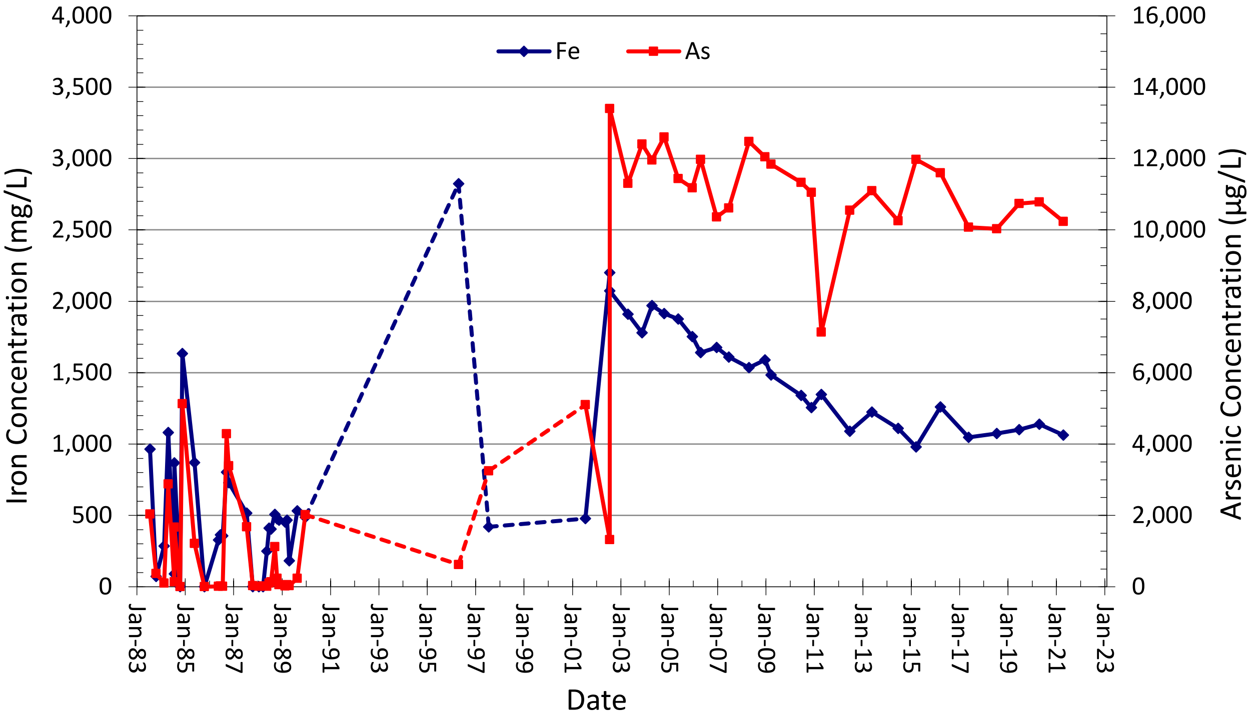
Section 3.2 Underground Mines and Berkeley Pit Water Quality

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. The Anselmo, Kelley, and Steward Mines were sampled during the spring 2021 sample event at a depth of 100 ft below the water surface. Iron and arsenic concentrations remain elevated in the Kelley Mine water; however, concentrations of zinc and sulfate have gradually decreased the past few years and are approaching pre-2002 concentrations in the Kelley samples. The mines could not be sampled at deeper depths due to concerns about obstructions in the shafts. Concentrations varied very little with sample depth in previous years. Complete sample results for the mines and Berkeley Pit 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, arsenic, zinc, and aluminum increased to near-historic concentrations in 2003–2004, and have gradually declined from 2005 to 2021 (fig. 3-6). Sulfate concentrations changed in a similar manner.

Anselmo: Iron concentrations remain elevated (>20 mg/L); arsenic concentrations have increased the past 3 years from 130 µg/L to 230 µg/L; zinc concentrations almost doubled between the 2017 and 2018 sample results (7,600 versus 14,600 µg/L, which has been followed by a steady decline to 6,000 µg/L; fig. 3-7). Cadmium concentrations are hovering near 20 µg/L, while copper concentrations remain low (<20 µg/L).

Steward: Iron and arsenic concentrations remain high, following an increase in 2019; however, they have shown a slight downward trend the past 2 years. The trend has been downward for zinc since 1996, with a slight increase in 2015 and 2019. Copper concentrations remain below 100 µg/L (fig. 3-8).



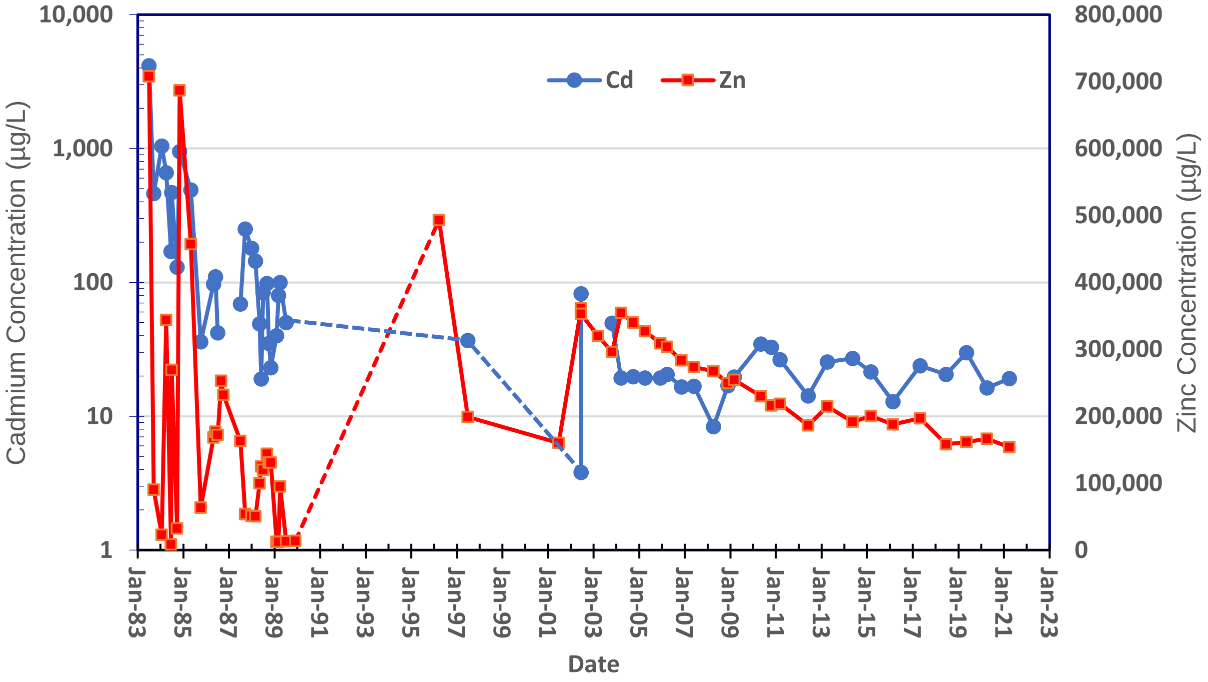
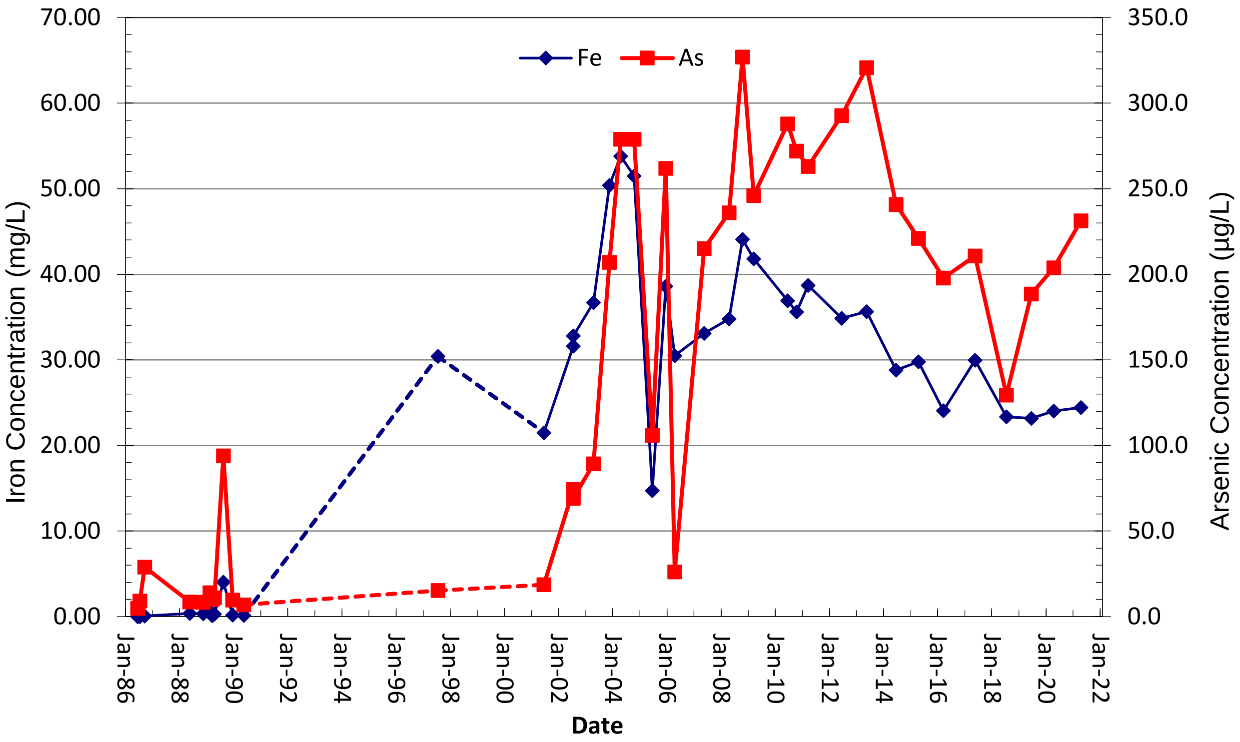


Figure 3-6. Kelley Mine iron and arsenic concentrations (top) and cadmium and zinc concentrations (bottom) over time.



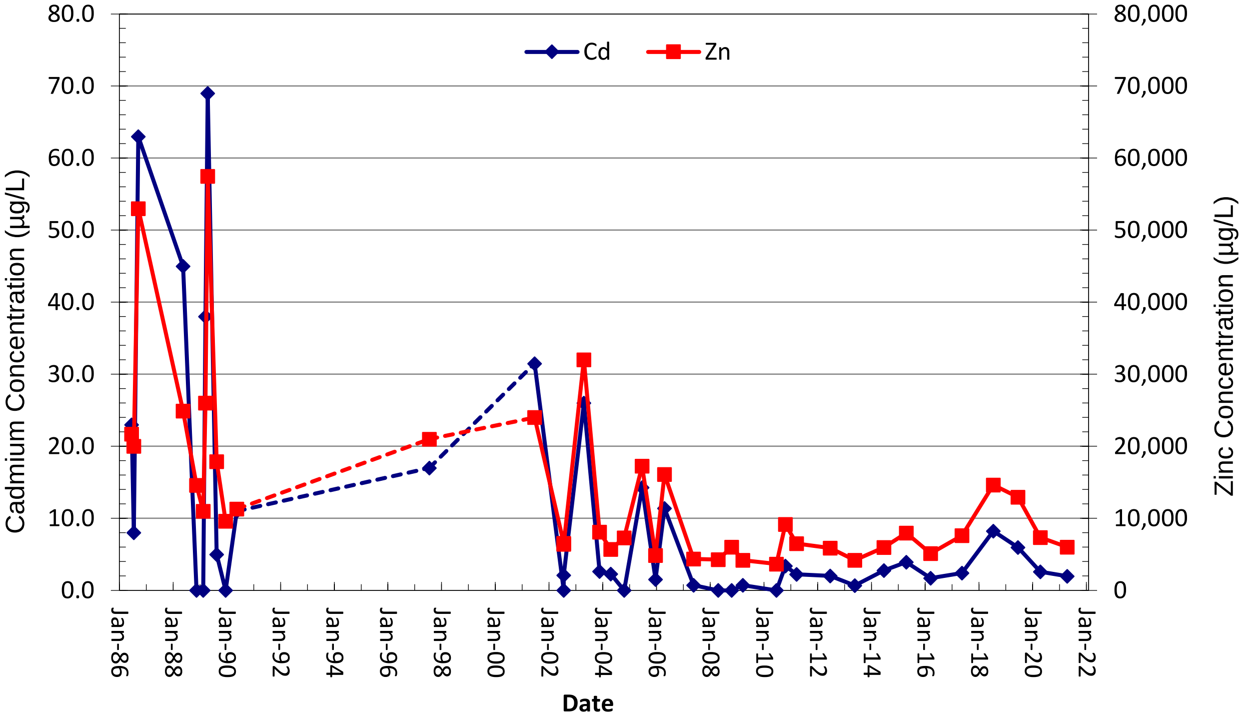


Figure 3-7. Anselmo Mine iron and arsenic concentrations (top) and cadmium and zinc concentrations (bottom) over time.

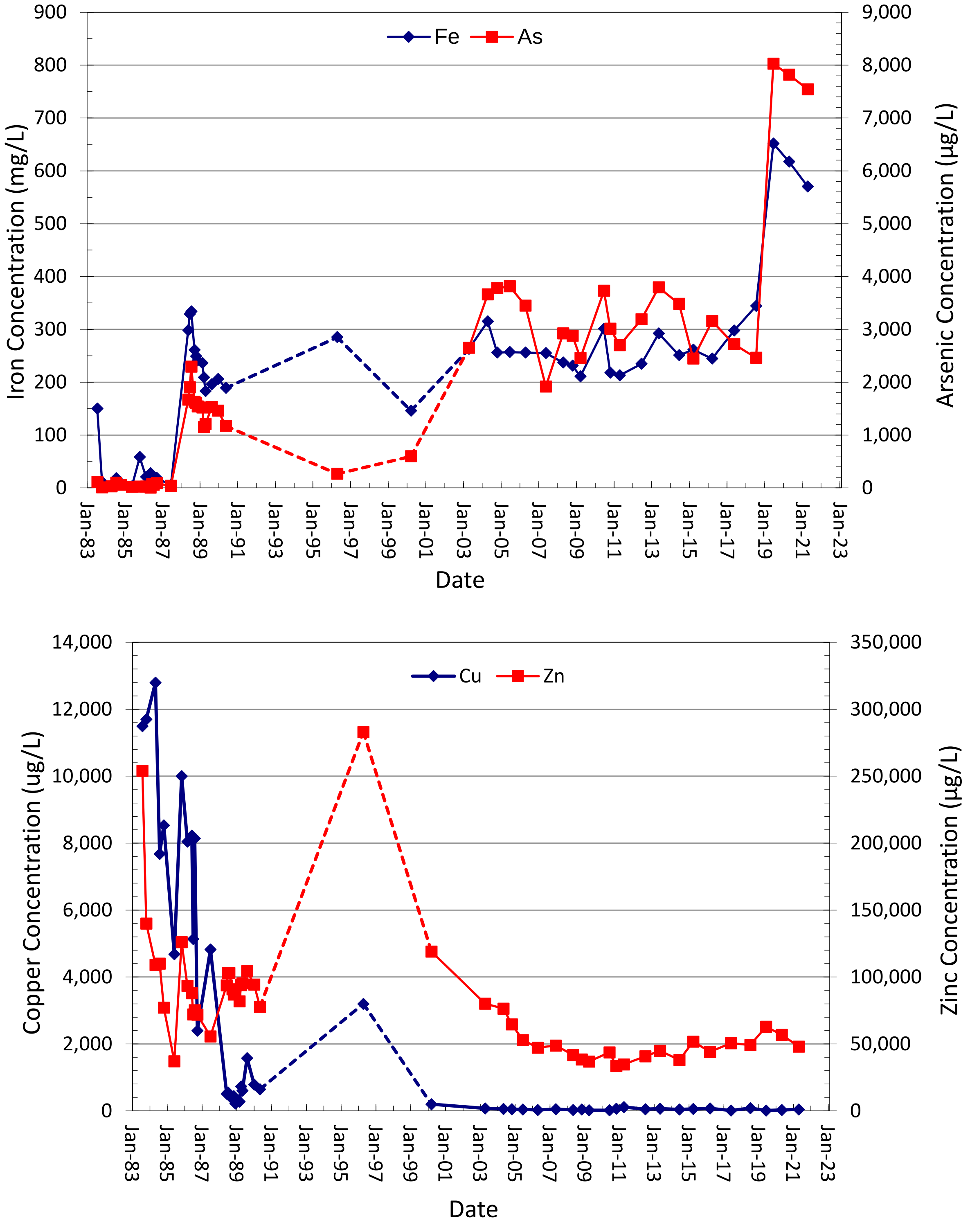


Figure 3-8. Steward Mine iron and arsenic concentrations (top), copper and zinc concentrations (bottom) over time.

Section 3.3 Bedrock Monitoring Wells

The bedrock monitoring network consists of nine wells installed during the RI/FS investigation and three wells installed previously at local parks and shown in figure 3-1. The RI/FS wells are mostly located in the area east of the Berkeley Pit and the park wells are located southwest of the Berkeley Pit.

Section 3.3.1 RI/FS Bedrock Well Water Levels

Water-level changes in bedrock wells followed a pattern similar to those in the East Camp Mine system during 2021. All wells exhibited a slowing in the rate of water-level rise, with some declining. The changes in water levels continue the trend observed in late 2019 and throughout 2020 and appear to be influenced by the Pilot Project. Table 3.3.1.1 contains yearly water-level changes; figure 3-9 shows changes from 2010 graphically.

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

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]
Change 1982–1991	**33.18**		**22.38**	**24.20**	**22.68**	**1.73**				
Change 1992–2001	**215.88**	**99.37**	**206.52**	**199.86**	**197.68**	**-5.95**	**-1.64**	**123.86**	**68.29**	**36.99**
Change 2002–2011	**86.38**	**46.94**	**84.45**	**90.46**	**90.47**	**-5.42**	**3.19**	**82.62**	**P&A**	**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
2019	5.31	3.99	5.24	5.55	5.55	3.15	-0.79	5.57	P&A	4.96
2020	-0.20	1.07	0.53	0.30	0.29	1.20	-1.20	0.42	P&A	-0.58
2021	0.12	-0.86	0.34	0.29	0.58	-0.35	-1.68	0.14	P&A	0.35
Change 2012–2021	**53.40**	**33.92**	**50.89**	**54.38**	**54.60**	**31.39**	**-4.81**	**49.76**	**P&A**	**55.14**
Net Change	**388.84**	**180.23**	**364.24**	**368.90**	**365.43**	**21.75**	**-3.26**	**256.24**	**68.29**	**177.58**

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.

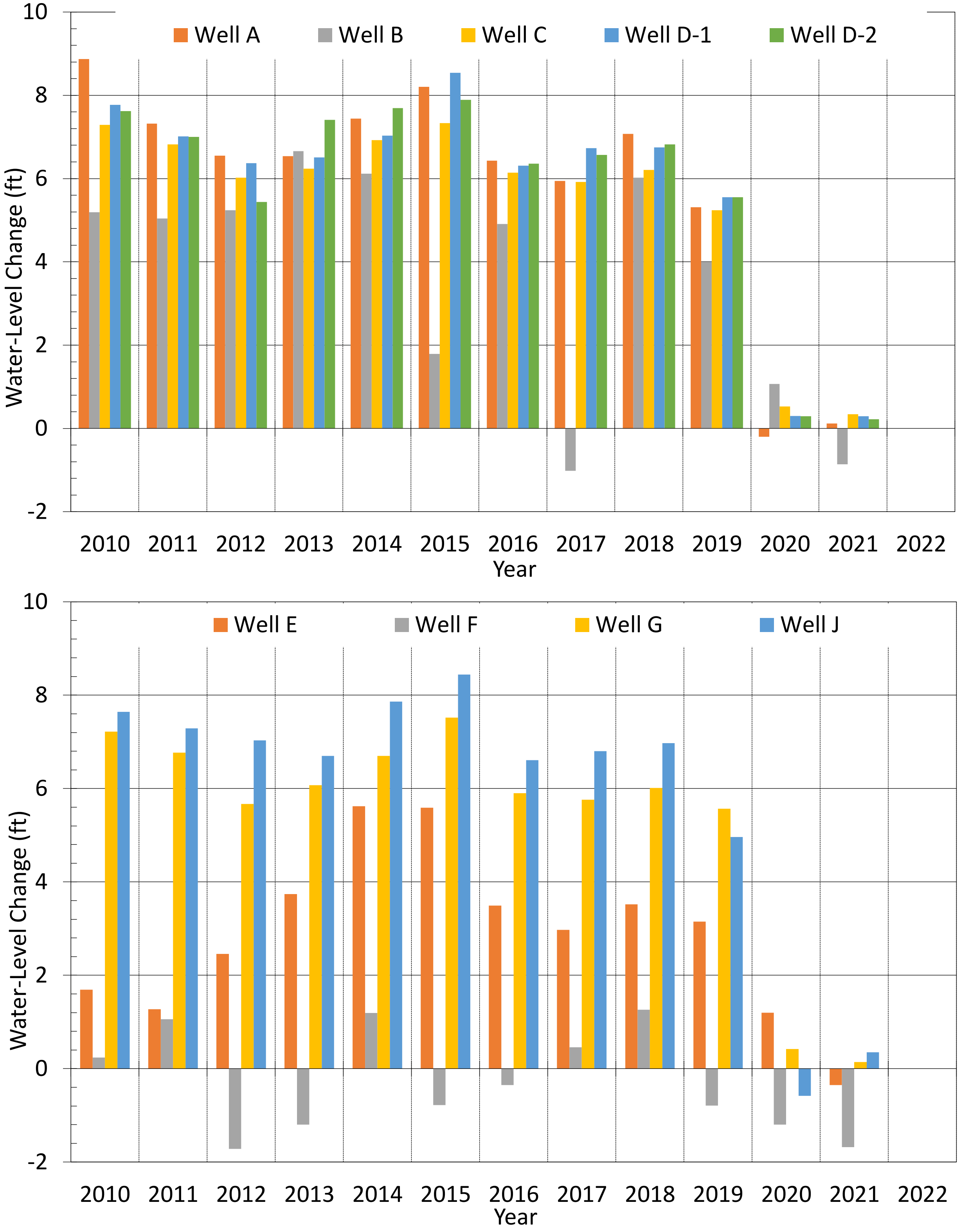


Figure 3-9. Annual water-level change in bedrock wells from 2010 to 2021.

Water levels in the bedrock aquifer lowered by historic underground mine dewatering responded to the cessation of pumping, showing no apparent relationship to precipitation or seasonal changes through 2021. Physical changes affecting 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 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; 2019 Berkeley Pit pumping (Pilot Project) is also noted. The void areas in the mines and Berkeley Pit were the principal controls on the annual rate of rise in this system; the Pilot Project has changed that dynamic and, in the future, may be the controlling factor determining the Berkeley Pit and surrounding bedrock water level changes (fig. 3-5).

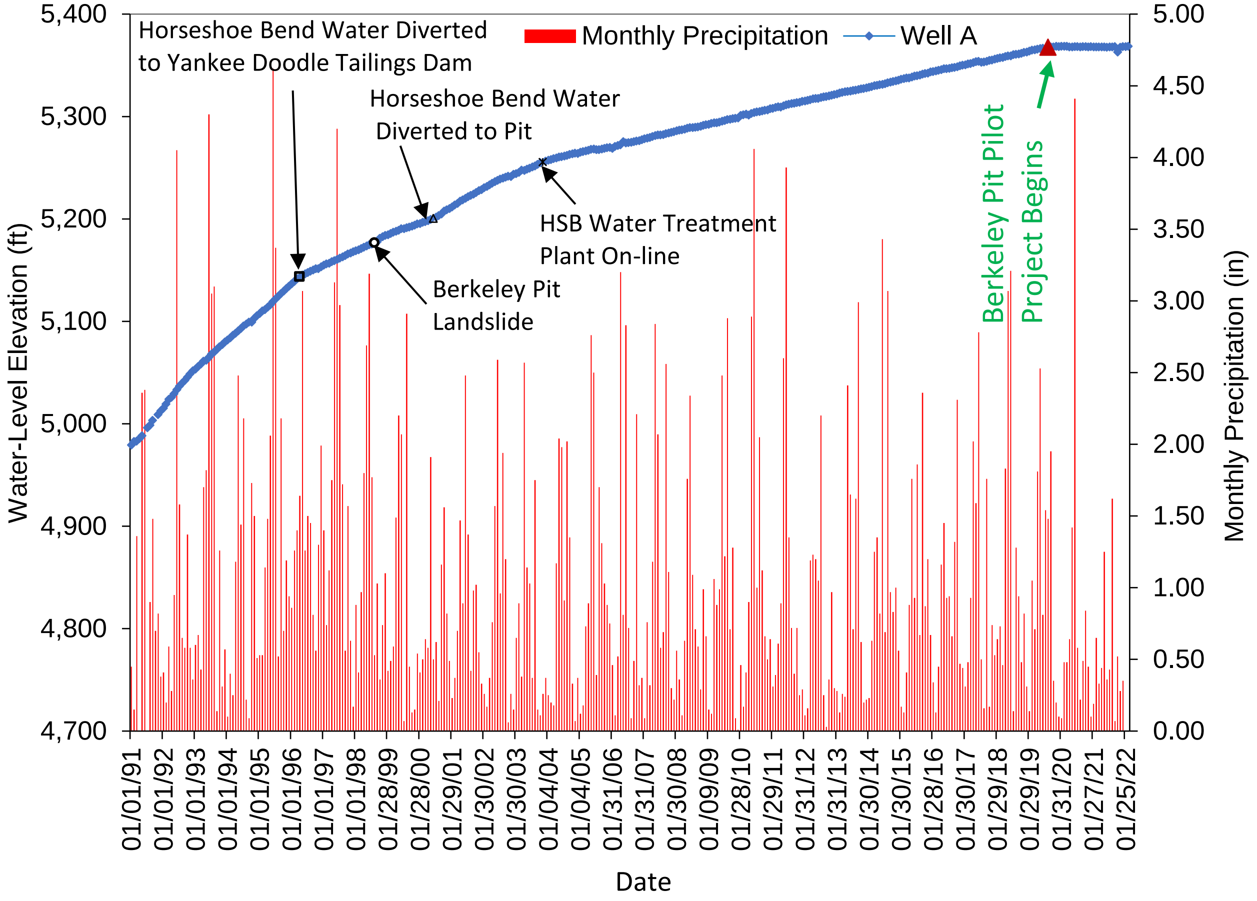


Figure 3-10. Water-level hydrograph for bedrock well A compared to monthly precipitation.

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. A similar response was seen immediately following the July 6, 2017 Lincoln, Montana earthquake, and because of additional drawdown caused by pumping and sampling, water levels had not returned to pre-earthquake levels by year-end. An earthquake near Challis, Idaho occurred March 31, 2020, causing a minor response in well B, but was not noticed in any other bedrock well. Continued water-level monitoring indicates there were no long-term effects in water levels from the 2005, 2017, or 2020 earthquakes. Figure 3-11 (top) shows the water-level response to the 2005 Dillon, 2017 Lincoln, and 2020 Challis, Idaho 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. The 2013–2016 and 2018–2019 water-level increases in well B varied from 70 to 100 percent that of the other bedrock wells. Water-level changes in wells A and B were similar, for the most part, in 2021.

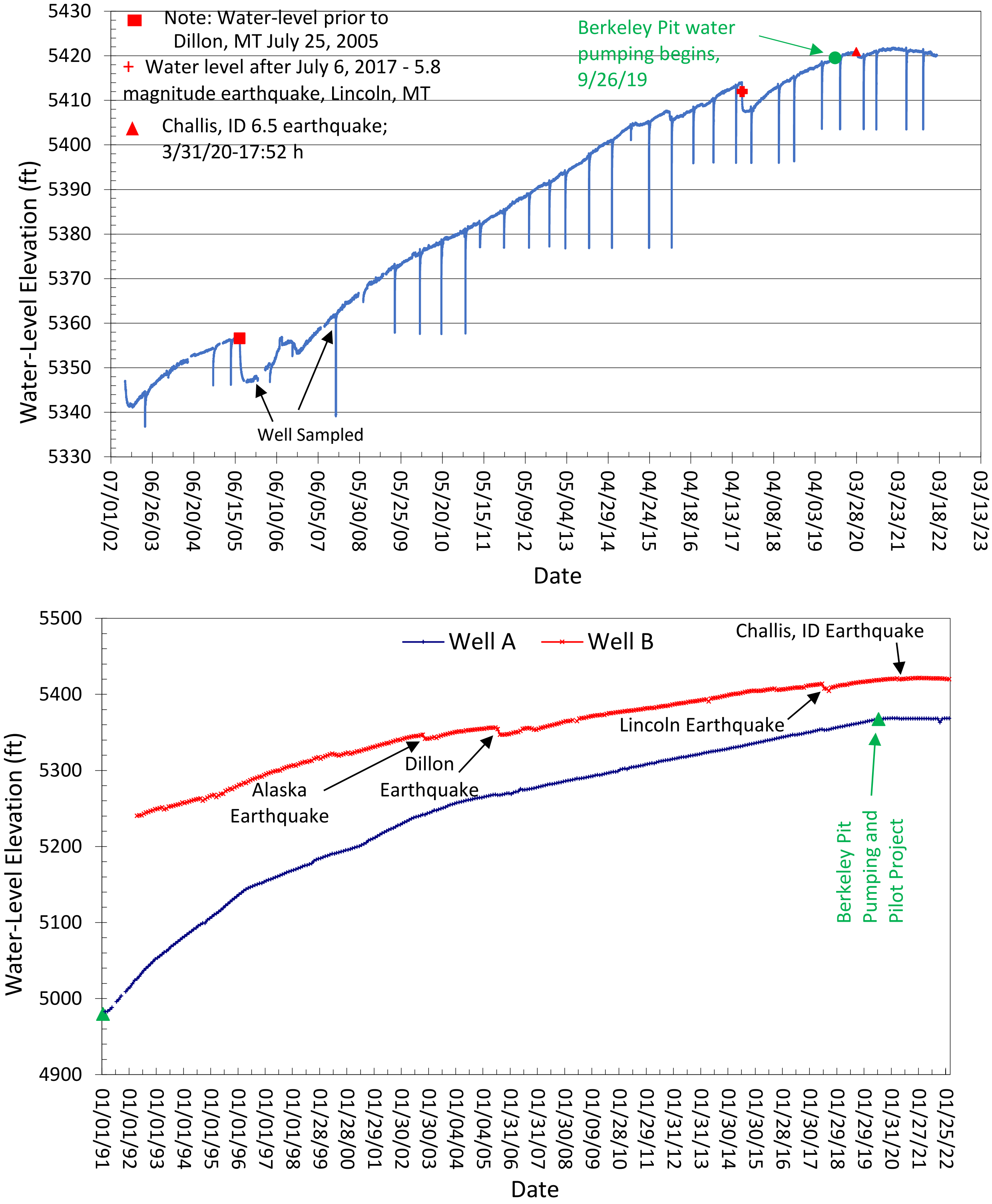


Figure 3-11. Water-level hydrographs for East Camp bedrock well B (top) show water-level response to earthquakes and (bottom) a comparison of earthquake responses in hydrographs from bedrock wells A and B.

Water levels in wells E and F do not follow the long-term increasing trends 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 21 ft in well E and a decline of 3.25 ft in well F over time; both wells had water-level declines during 2021. The increase in water levels between 2007 and 2020 in well E may have been in response to rising water levels in the surrounding bedrock system; the stabilization and subsequent decline in water level corresponds to the Pilot Project.

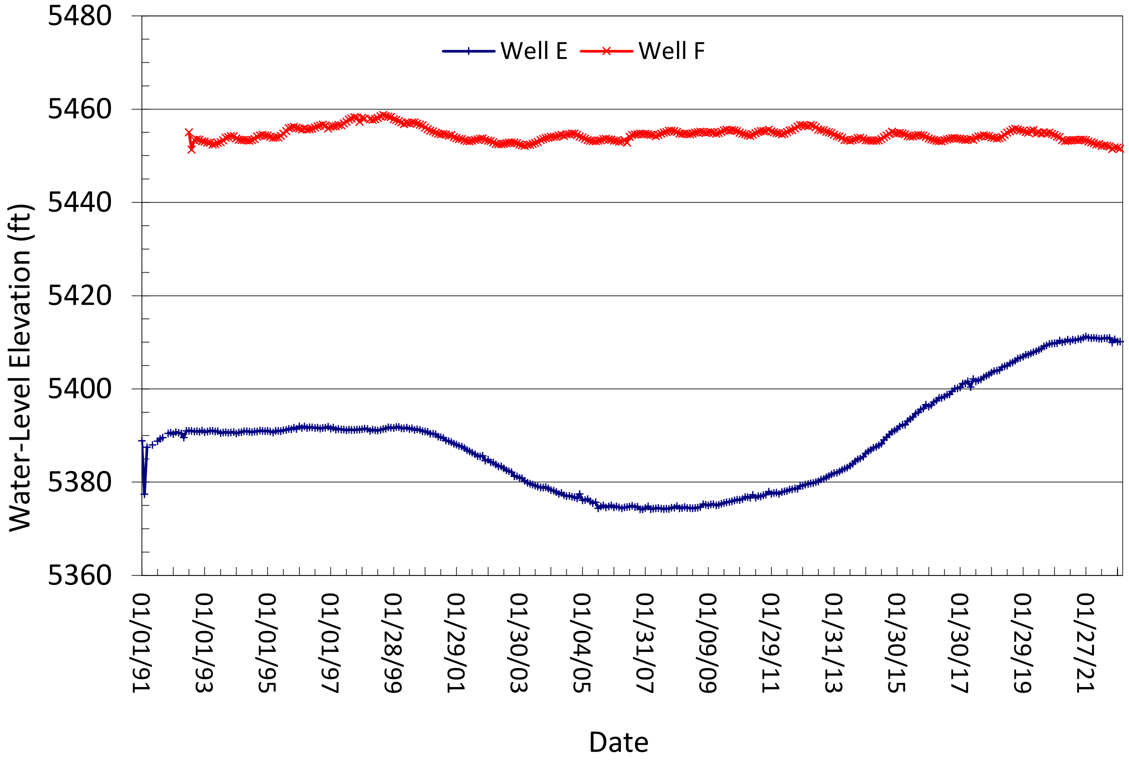


Figure 3-12. Water-level hydrographs for East Camp bedrock wells E and F.

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 nearby bedrock wells (fig. 3-13). Historic water levels for well H are also shown along with a linear projection through 2021. 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. 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 water away from the pit significantly slowed the pit-filling rate, while water levels and pit-filling from late in 2019 through 2021 appear influenced by the implementation of the Pilot Project in September 2019.

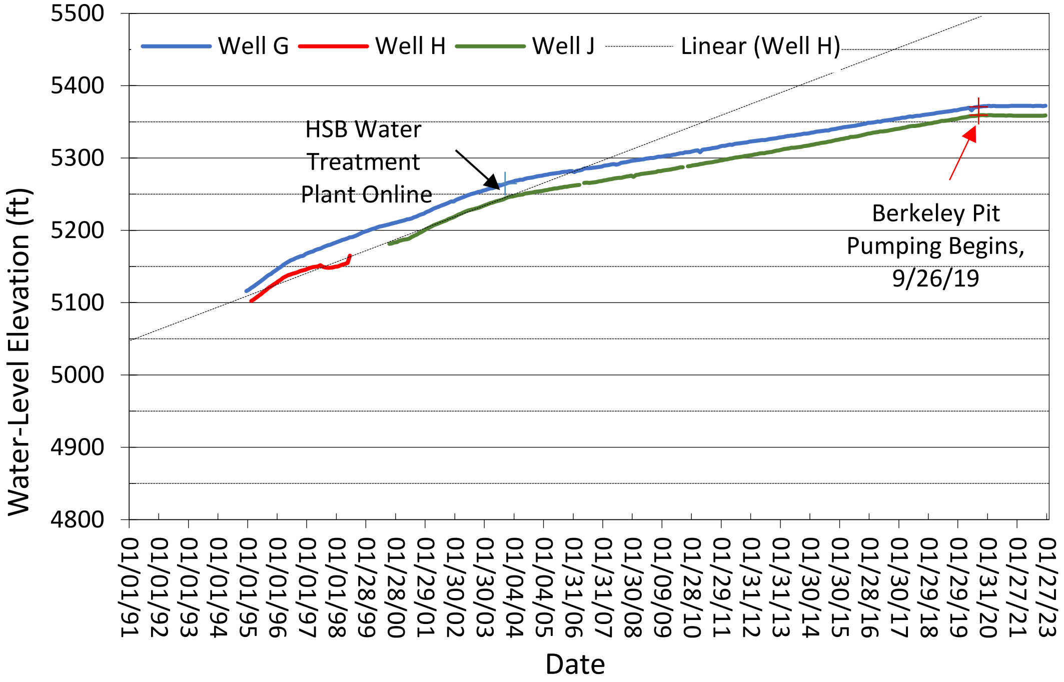
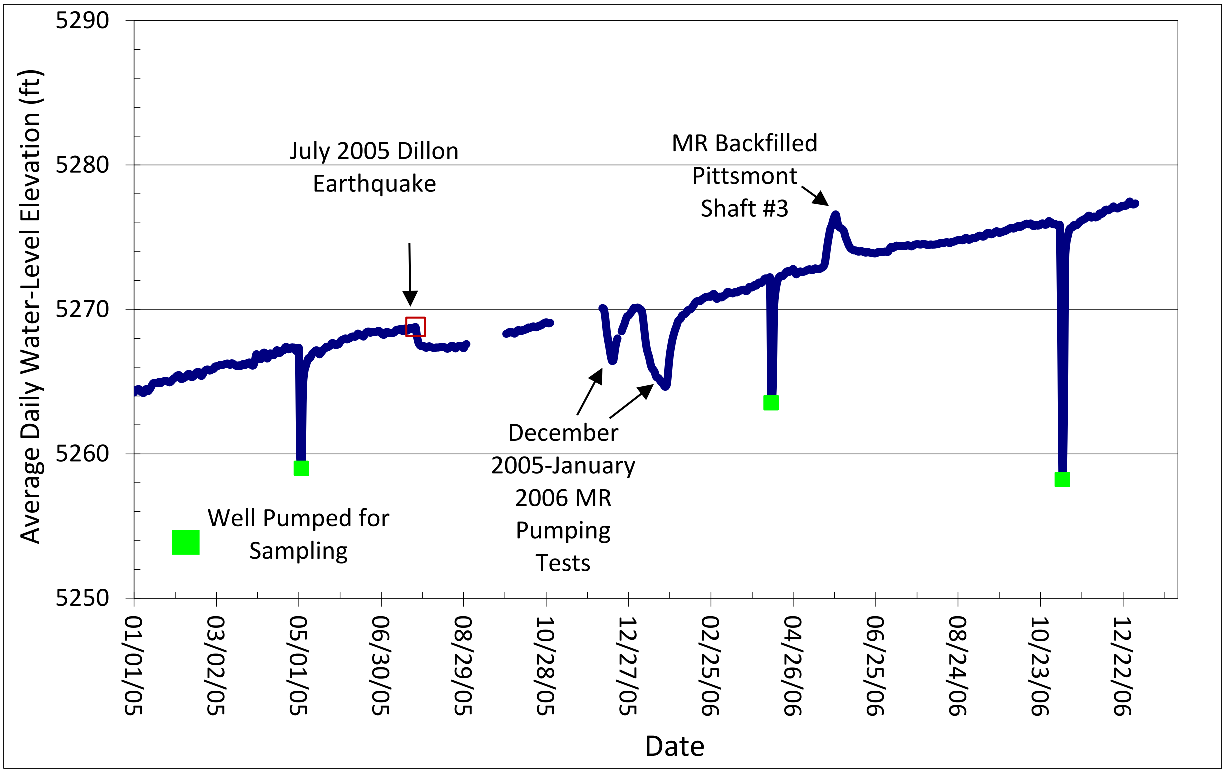


Figure 3-13. Water-level hydrographs for bedrock wells G, H, and J.

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 degree of monitoring reveals precise changes in water levels compared to monthly water-level measurements. Figure 3-14 shows hydrographs for a selected time period during which a number of 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 provide hourly resolution and improve the determination of the magnitude of change. The more frequent monitoring improves separation of natural water-level changes (i.e., earthquakes or slumps) or human-induced operational changes (i.e., pumping). Water-level transducers have been installed in additional bedrock wells, beyond those specified in the 2002 CD, to improve tracking of water-level response in the East Camp bedrock system to various activities, i.e., grouting and backfilling of underground mine workings, and the MERDI/MSE pumping test at the Belmont Mine site. Wells now monitored with transducers are: A, B, C, D-2, F, G, J, Belmont Well #1, Belmont Well #2, and the Parrot Park.

Water-level monitoring continues to confirm that hydraulic gradients in the affected bedrock aquifer are directed toward 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.



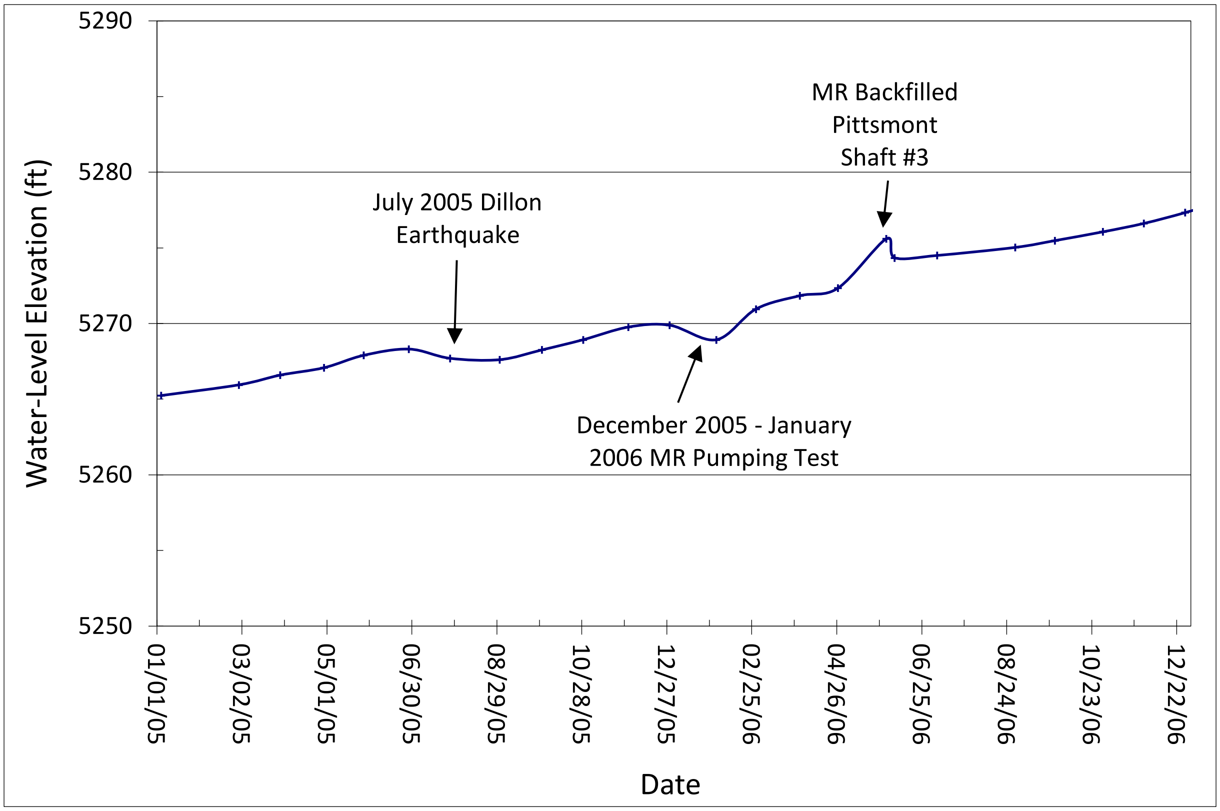


Figure 3-14. Hydrographs for well A developed from daily average water levels (top) and monthly water-level monitoring frequency (bottom).

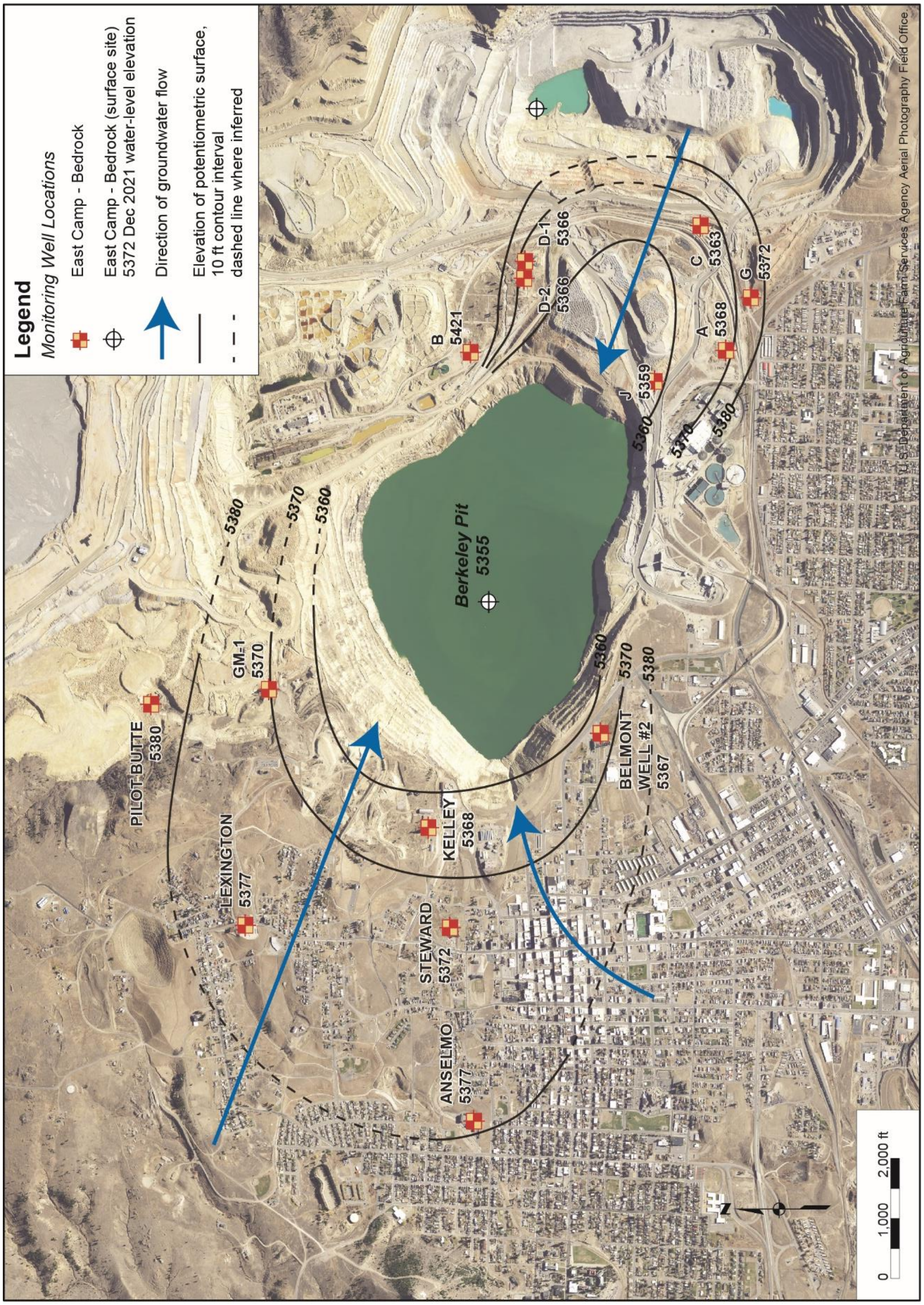


Figure 3-15. Potentiometric map for the East Camp bedrock aquifer, December 2021 (contour interval is 10 ft).

Section 3.3.1.1 Bedrock Well Water Quality

Data collected in 2021 indicate slight water-quality changes for most wells. Table 3.3.1.1.1 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 DEQ-7 criteria because EPA changed the arsenic human health standard from 18 µg/L to 10 µg/L. Arsenic and radium were the only DEQ-7 standards exceeded in water from the bedrock wells (excluding well F, where arsenic and strontium exceed DEQ-7 criteria and well J, where arsenic, cadmium, lead, nickel, strontium, uranium, and zinc all exceed DEQ-7 criteria). 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 DEQ-7 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 2021. In Figure 3-16, iron concentrations vary from 1 mg/L to almost 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. The poor water quality in this well is expected, considering its close proximity to the pit and interconnected adjacent mine workings. The well is completed approximately 40 ft above Pittsmont Mine workings that extend to the pit. Figure 3-18 compares selected trace metal concentrations in water from well A, well J, and the Berkeley Pit (2021 sample collected 4 ft below the water surface). Well A is located southeast of the pit 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 support the water-level monitoring interpretations that hydraulic gradients in the bedrock are 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 likely be detected in water samples from more distant wells.

Table 3.3.1.1.1. Exceedances and recent trends for East Camp bedrock wells, 1989 through 2021.

Well Name	Exceedances (1 or more)	Concentration Trend	Remarks
A	Y	Unchanged	Arsenic and radium exceed DEQ-7 standards.
B	Y	Unchanged	Arsenic and radium exceed DEQ-7 standards.
C	Y	Unchanged	Radium exceeds DEQ-7 criteria. Zinc concentrations variable, exceed DEQ-7 criteria occasionally.
D-1	Y	Unchanged	No longer sampled, replaced by well D-2.
D-2	Y	Unchanged	Arsenic, zinc, and radium exceed DEQ-7 standards.
E	Y	Unchanged	Sampled every 2 yr; arsenic and zinc exceed DEQ-7 standards.
F	Y	Unchanged	Sampled every 2 yr, arsenic, strontium, and radium exceed DEQ-7 standards.
G	Y	Unchanged	Radium exceeds DEQ-7 standards.
J	Y	Variable	Very poor-quality water; arsenic, cadmium, copper, nickel, strontium, zinc, and radium exceed DEQ-7 standards.

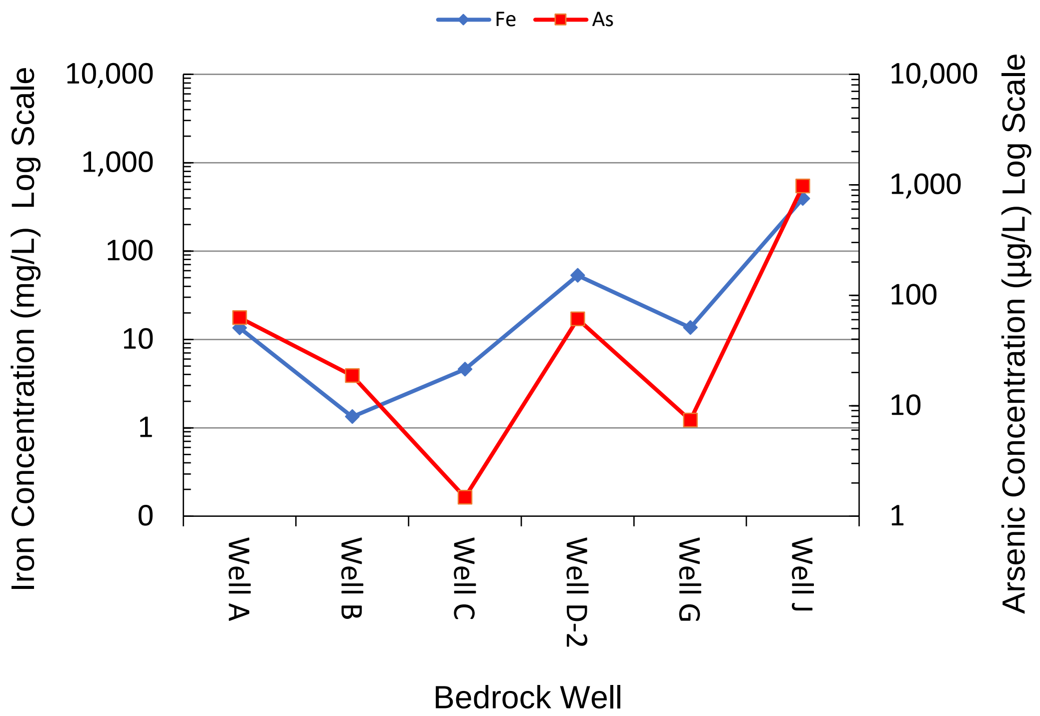


Figure 3-16. Bedrock well iron and arsenic concentration comparisons, spring 2021.

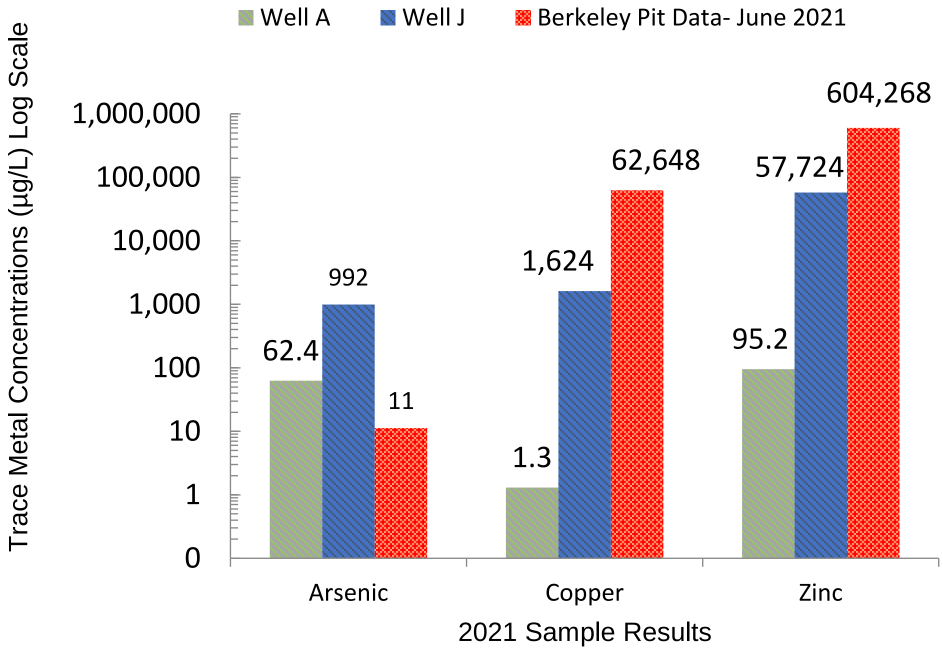


Figure 3-17. Selected trace metal comparisons among bedrock wells A, J, and the Berkeley Pit 4-ft depth sample.

Section 3.3.2 Park Bedrock Wells Water Levels

The locations of the Park monitoring wells are shown in figure 3-1. The Belmont Well #1 (originally planned to replace Belmont Mine shaft monitoring but completion problems resulted in the well being finished at a shallower depth), 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. Water-level changes are listed in table 3.3.2.1 and shown in figure 3-18. 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 Parrot Park well almost 9 ft, while falling in the Hebgen well about 1.25 ft and more than 43 ft in Belmont Well #1.

Table 3.3.2.1. Water-level change for park wells (ft).

Year	Hebgen[1]	Parrot	Belmont Well #1
Change 1983–1992	**-0.85**	**1.61**	**---**
Change 1993–2002	**3.33**	**11.30**	**-23.49**
Change 2003–2012	**-1.85**	**-6.01**	**7.78**
2013	-0.24	2.94	6.05
2014	4.37	15.92	-31.51
2015	-1.84	-9.72	1.44
2016	2.63	-5.26	5.17
2017	0.19	1.90	5.71
2018	3.40	0.22	4.88
2019	-2.93	2.94	-1.04
2020	-3.26	-3.16	-2.96
2021	-4.19	-2.94	-15.33
Change 2013–2021	**-1.87**	**2.05**	**-27.59**
Net Change	**-1.24**	**8.95**	**-43.30**

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

[1] Hebgen Park well: No data from 6/1992 to 1/1993, 1/1995 to 9/1996, and 1/1998 to 1/1999.

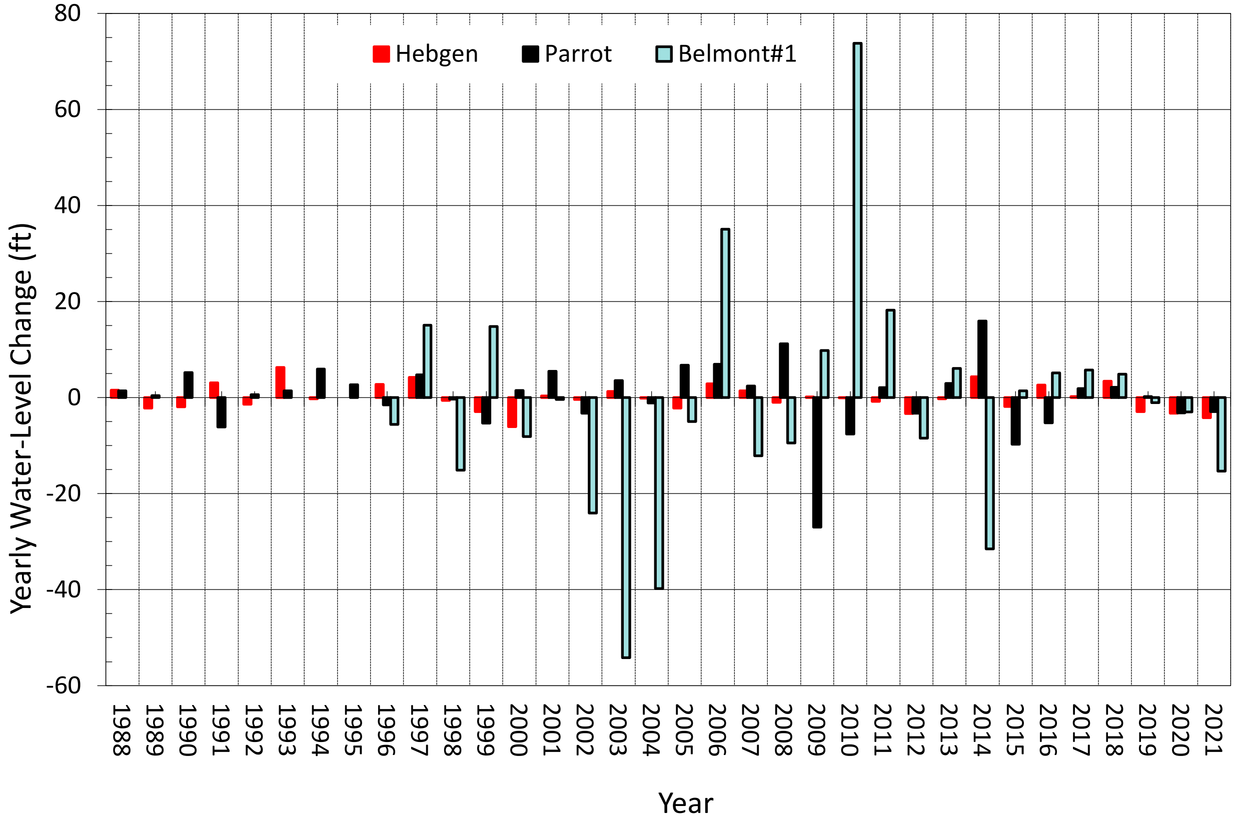


Figure 3-18. Park wells annual water-level changes.

Water-level response during 2021 at the Hebgen Park well (fig. 3-19), while similar to responses in prior years, was more muted due to the below normal precipitation, with a water-level rise beginning during the late spring and continuing through the fall. This trend coincides with spring and 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 change is attributed to lawn irrigation. The water level decreased 4.1 ft during 2021 and has decreased almost 1.25 ft since monitoring began.

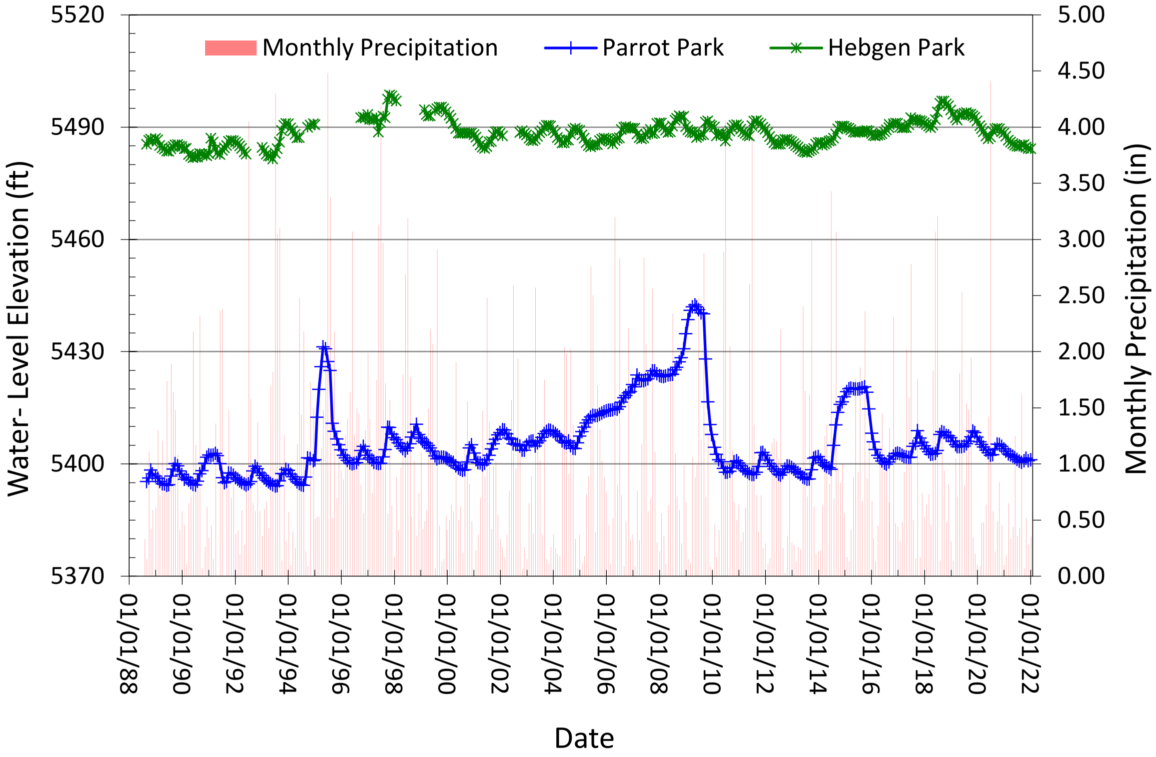


Figure 3-19. Water-level hydrograph for the Parrot Park and Hebgen Park wells.

The hydrograph for the Parrot Park well is also shown in figure 3-19, along with monthly precipitation. Water levels in the Parrot Park well show considerable fluctuations at times. On three occasions between 1994 and 2021, 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 almost 9 ft since monitoring began in 1988. 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, and at times show large changes unrelated to climate or seasonal irrigation.

Belmont Well #1 was drilled as an alternative to monitoring water levels in the Belmont Mine shaft. The surface area around the Belmont mine shaft had collapsed and other adjacent areas became unstable (fig. 3-20). However, during completion of Belmont Well #1, 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. Since 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 (fig. 3-27). Because the Belmont #1 borehole was drilled into the underground mine workings and then collapsed, it is difficult to ascertain what the actual controls on water levels are.

Figure 3-20. Mine shaft and adjacent area collapse at the Belmont Mine.

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 currently 110 ft or more above the water level in the nearby Belmont #2 well, completed in the underground mine workings, and does not show any response to the Pilot Project and its control on bedrock water levels as seen in Belmont #2 (fig. 3-21).

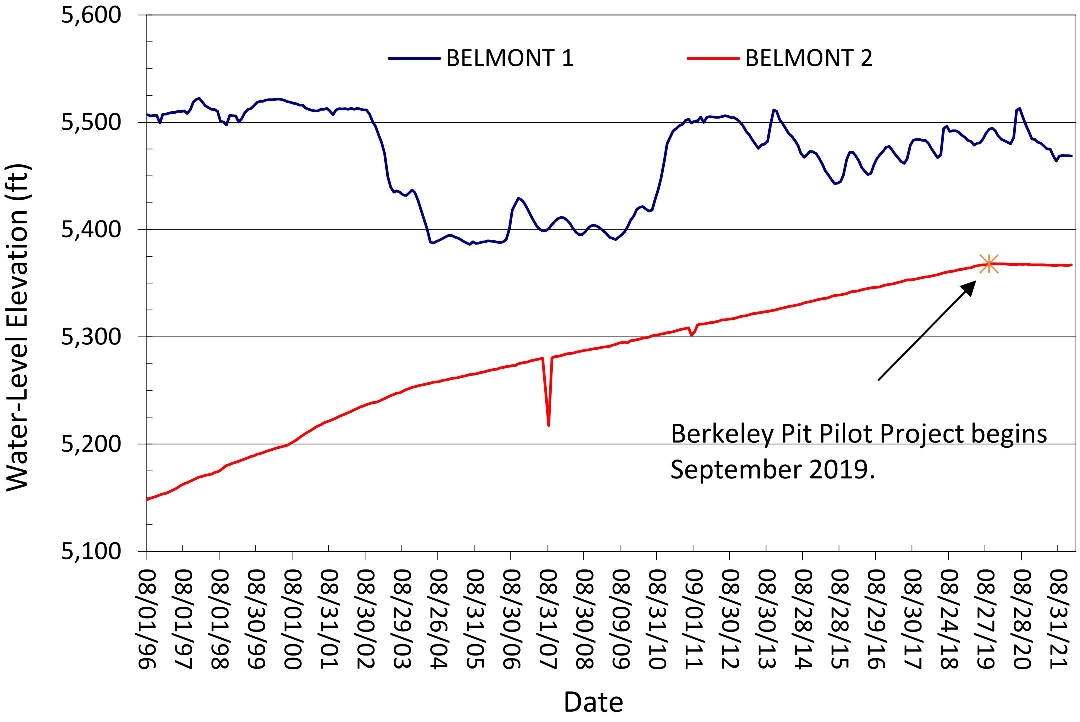


Figure 3-21. Water-level hydrograph comparisons between Belmont Well #1 and Belmont Well #2.

Section 3.3.2.1 Park Bedrock Wells Water Quality

Water-quality samples were collected only from the Parrot Park well during 2021. Figure 3-22 shows concentrations of cadmium and copper, and figure 3-23 shows arsenic and zinc concentrations. Arsenic concentrations dropped below the DEQ-7 standard of 10 µg/L during 2021, while cadmium continues to exceed the DEQ-7 standard of 5 µg/L by more than an order of magnitude. Although cadmium concentrations declined in 2008 to levels below the DEQ-7 standard, concentrations in 2009–2021 were considerably above the standard. Concentrations increased slightly for cadmium and zinc in 2021 (figs. 3-23, 3-24).

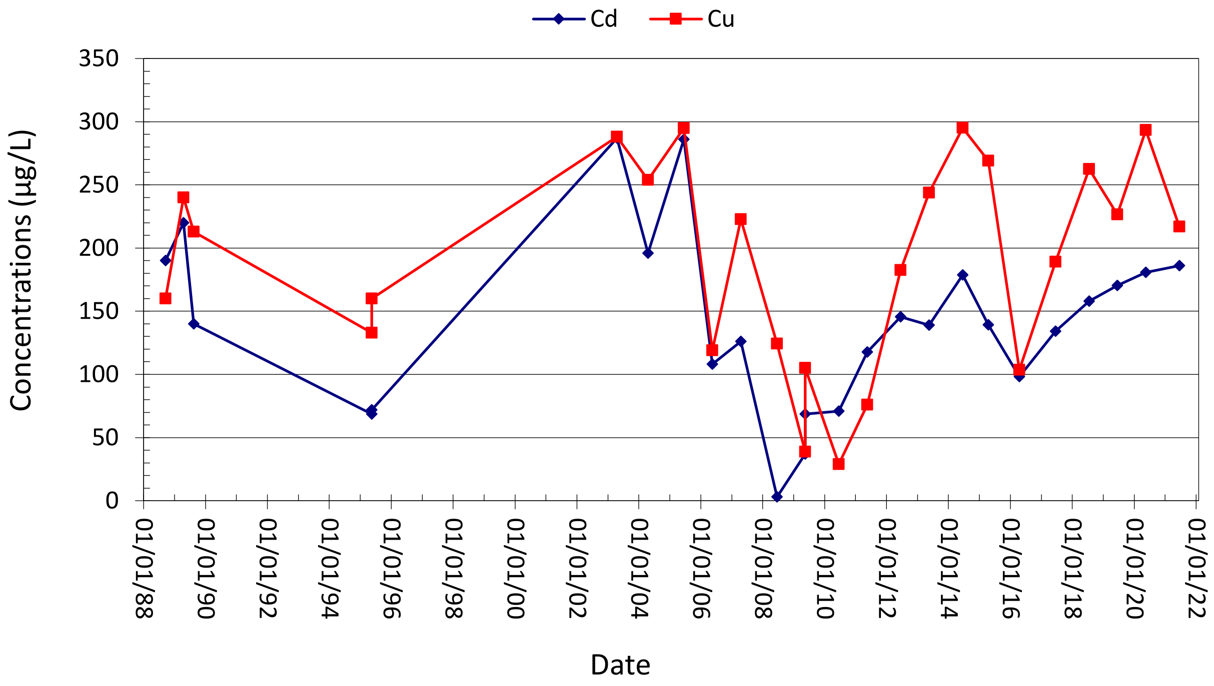


Figure 3-22. Cadmium and copper concentrations for the Parrot Park well.

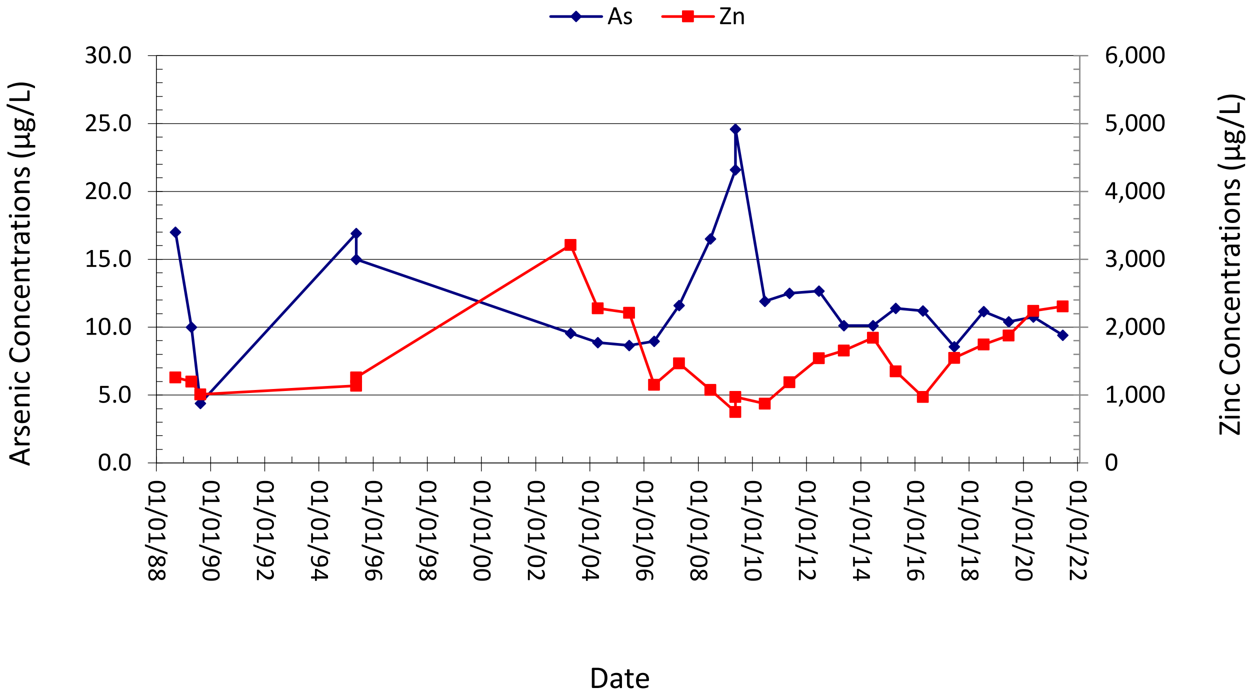


Figure 3-23. Arsenic and zinc concentrations for the Parrot Park well.

Section 3.4 Berkeley Pit and Horseshoe Bend Drainage

The Berkeley Pit water-level elevation is surveyed each month coincident with monthly water-level monitoring in wells and mine shafts. The hydrograph in figure 3-24 shows the pit's water-level rise since 1995.

The 2021 Berkeley Pit water-level elevation trend was similar to that of the last three months of 2019 and 2020 following the start of the Pilot Project that began on September 26, 2019. Approximately 2.57 billion gallons of water was removed from the pit from September 2019 through the end of 2021. Figure 3-24 shows the impact of the pit pumping (Pilot Project) along with four other changes in slope (filling rate), the result of MR operational changes and highwall slumps. The events shown on the graph and their dates are:

1. April 1996, the filling rate decreased (seen as a change in slope on the graph) when water from the HsB was diverted to the YDTI;
2. September 1998, the almost instantaneous water-level rise was caused by a landslide;
3. June 2000, the filling rate increased when MR suspended mining and the HsB water subsequently flowed into the pit;
4. November 2003, a decreased filling rate resulted from the HsB water-treatment plant coming online and the diversion of HsB water away from the pit; and
5. September 2019, MR/AR began operation of the Pilot Project. This typically consists of a sustained pumping rate of approximately 2,100–2,500 gpm of Berkeley Pit water to the HsB capture system. Water is then incorporated in mine/mill operations and discharged to the YDTI along with mill tailings. A portion of the YDTI mill return water is diverted to the Polishing Facility where it is further treated and discharged to SBC, near Montana Street.

The overall Berkeley Pit water-level change for 2021 was a decline of 0.63 ft, compared to a decline of 0.09 ft for 2020. Total additional flow diverted to the pit during 2021 was approximately 12.4 million gallons from mine/mill and water-treatment plant operations. Table 3.4.1 summarizes the changes in handling HsB water and other events that influenced Berkeley Pit water-level filling rates.

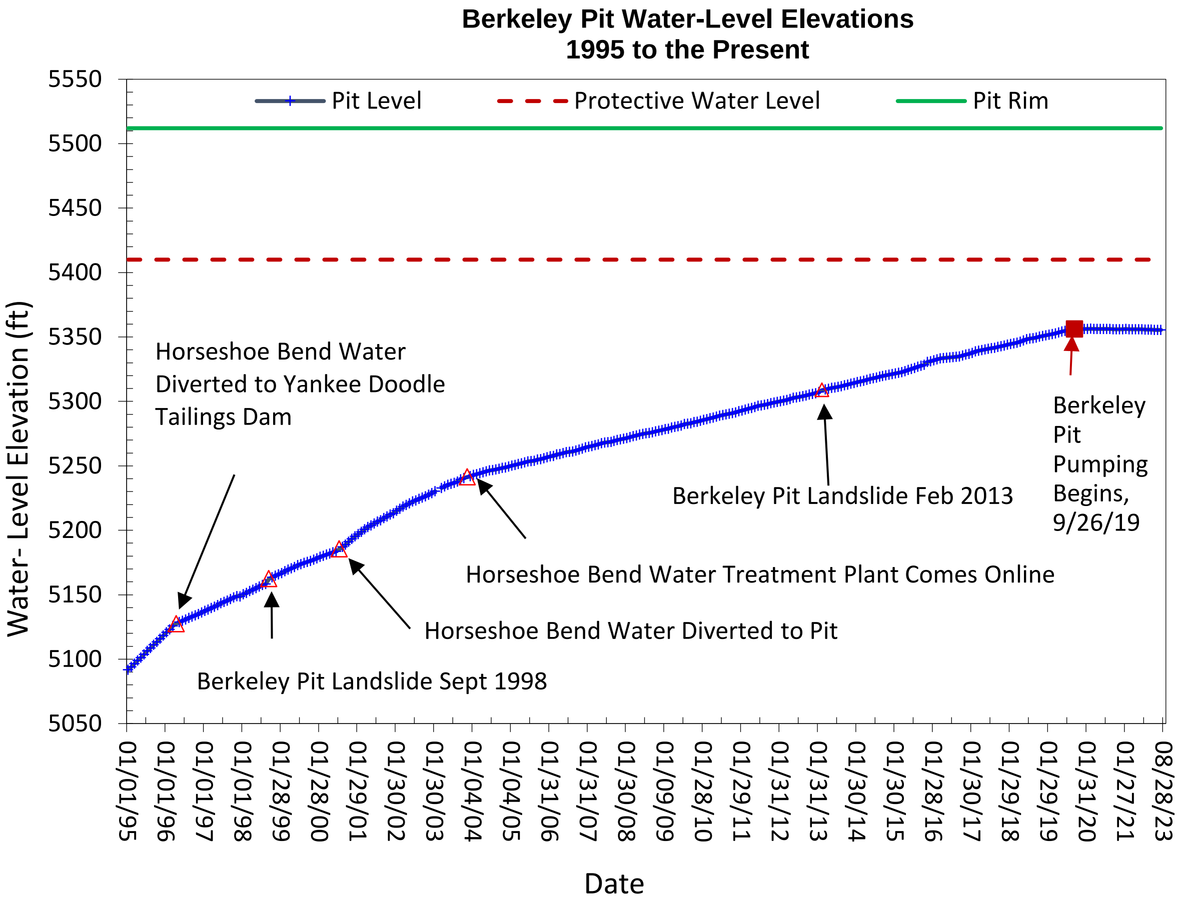


Figure 3-24. Water-level hydrograph of the Berkeley Pit, 1995–2021.

Table 3.4.1. 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 measurable 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 measurable impact on water level.
Calendar year 2019	Planned water-treatment plant and mill maintenance activities; ~35.6 million gallons of HsB water diverted to pit.	No measurable impact on water level.
September 2019-Ongoing	Berkeley Pit Pilot Project comes online, September 26, 2019.	Controlled pit water level rise
Calendar year 2020	Planned water-treatment plant and mill maintenance activities; ~17.2 million gallons of HsB water diverted to pit.	No measurable impact on water level.
Calendar year 2021	Planned water-treatment plant and mill maintenance activities; ~12.4 million gallons of HsB water diverted to pit.	No measurable 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 (fig. 3-24) and several nearby bedrock wells. Photographs showing the southeast corner of the pit before and after the August event and the February event are in figure 3-25. A small slump occurred on December 11, 2020 in the same area as the 2013 slump. No noticeable water-level changes were observed. This slump occurred shortly after a 4.1 magnitude earthquake near Stanley, Idaho (approximately 165 mi southwest of Butte). The relationship of the slump and earthquake are uncertain. A small slump occurred in the same SE corner of the pit on January 26, 2021; however, the material did not reach the water surface.

Figure 3-25. Pictures of the southeast corner of the Berkeley Pit prior to 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. The POCs are listed in table 3.4.2 along with their December 2021 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 3.4.2. East Camp Points of Compliance and depth below PWL, December 2021.

Point of Compliance	December 2021 Water-Level Elevation (ft)	Depth Below PWL (ft)
Anselmo Mine	5376.35	33.65
GM-1*	5370.07	39.93
Pilot Butte Mine	5380.41	29.59
Kelley Mine	5368.12	41.88
Lexington Mine	5376.81	33.19
Steward Mine	5372.52	37.48
Belmont Well #2	5367.05	42.95
Well A	5368.56	41.44
Well C	5362.73	47.27
Well D-1	5366.43	43.57
Well D-2	5365.88	44.12
Well G	5372.27	37.53
Well J	5359.04	50.96
Continental Pit/Sarsfield Shaft**	NA	NA
Berkeley Pit (not a compliance point)	5355.72	54.28

*Well GM-1 replaced the Granite Mountain Mine POC, April 2021.

**Sites are only monitored when active mining in the Continental Pit is suspended.

Flow monitoring of the HsB continued throughout 2021. Figure 3-26 shows the daily average flow rate from July 2000 through December 2021. The 2021 average daily flow rate was 3,113 gpm, an increase of 357 gpm from the prior year. A total of 1.65 billion gallons of water flowed through this site in 2021 for treatment and incorporated in the mine/mill operations.

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 3-28 shows the new weir and the radar system’s new location on the cement retaining wall for the weir plate.

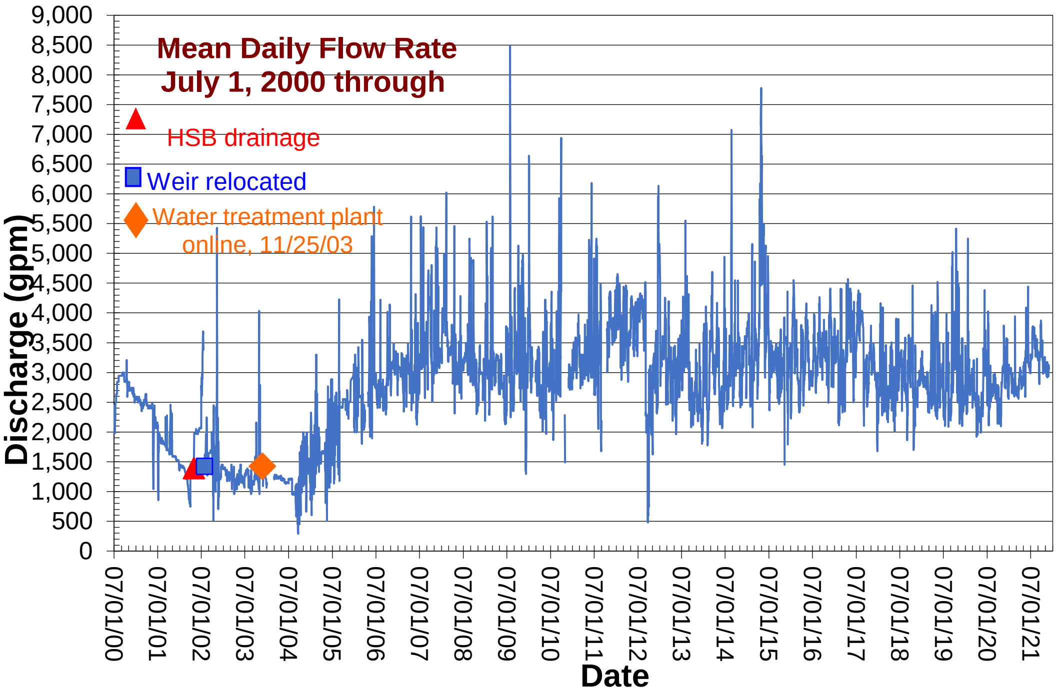


Figure 3-26. Horseshoe Bend Drainage flow rate, July 2000 through December 2021.

Figure 3-27. Radar system installation at the Horseshoe Bend weir monitoring station.

Section 3.4.1 Berkeley Pit and Horseshoe Bend Drainage Water Quality

Water sampling of the Berkeley Pit continued in 2021 using the semi-autonomous (drone) boat. Depth sampling and vertical profiling were conducted twice, in compliance with the requirements of the 2002 CD. Samples were collected from three depths during June and four depths during October sampling events. 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 at 25°C (SC), temperature, oxidation reduction potential (reported as Eh), dissolved oxygen (DO), and turbidity.

Water-quality samples were collected monthly from the HsB weir used for flow monitoring. This site is just upstream of the influent pond associated with the HsB water-treatment plant. MR implemented a number of infrastructure changes in the HsB as part of the Pilot Project. As a result of those changes, a new naming convention was derived, renaming this the Horseshoe Bend Capture System (HsB/CS). During 2021, HsB water was primarily treated in the water-treatment plant and then combined with mine process water. Treated water was then combined with other process waters in the YDTI. These changes in water handling and treatment did not affect water sampling activities. Complete sample results for the Berkeley Pit and HsB/CS 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 3.4.1.1 Berkeley Pit Water-Quality Sampling and Monitoring Overview

It took 19 months (April 1982–November 1983) following the cessation of dewatering 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. 3-28). Sampling in 1986 and 1987 used a helicopter to transport boats to the water surface (fig. 3-29). 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 a temporarily installed stationary platform or boats.

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, AR and MR commissioned the development of a remotely controlled drone watercraft. The boat was placed in service in 2017 and was used to perform the 2021 sample collection. Figure 3-30 shows the boat being deployed for a 2017 sample event.

Duaime and McGrath (2019) provide additional details about changes in methods that have been used to monitor the chemistry and hydrology of the Berkeley Pit.

Figure 3-28. 1985 Berkeley Pit sampling event via helicopter.

Figure 3-29. 1986 Berkeley Pit sampling event with helicopter transporting boat and personnel.

Figure 3-30. Drone boat after launch, moving out to sample location on the Berkeley Pit water surface.

Section 3.4.1.2 Berkeley Pit Water Chemistry

Currently (December 2021), the Berkeley Pit water is more than 900 ft deep, consisting of roughly 49.4 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 GWIC website (GWIC, 2022).

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; 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 3.4.1.3 Physical Parameters

Physical parameters of pH, SC, temperature, oxidation reduction potential (ORP) reported as Eh, and turbidity profiles were performed during June and October 2021, at depths up to 600 ft. Figures 3-31 through 3-36 present parameter data graphically.

A comparison of the physical parameters in the June and October 2021 sampling event shows surface stratification in the upper 50 ft for all parameters in June and DO and ORP in October. Little variation is seen below the upper 50 ft throughout the vertical water column, except for ORP and turbidity. The June 2021 near-surface pH values were a little lower than those observed in October 2021. These variations are within the level of probe accuracy and therefore may not be significant.

The 2019–2021 physical parameter data show changes in several parameters and parameter trends compared to conditions in 2012, prior to the 2012–2013 landslides and subsequent suspension of monitoring and sampling (fig. 3-37). Discussion of changes in pit water chemistry is provided below.

Section 3.4.1.4 Chemical Parameters

Samples were collected at four depths in the Berkeley Pit during 2021 semi-annual sampling. Some dissolved constituents and physical parameters from near-surface depths (4 ft) during 2021 are presented in table 3.4.1.4.1, along with results from 2012 and 2017–2019 for comparison.

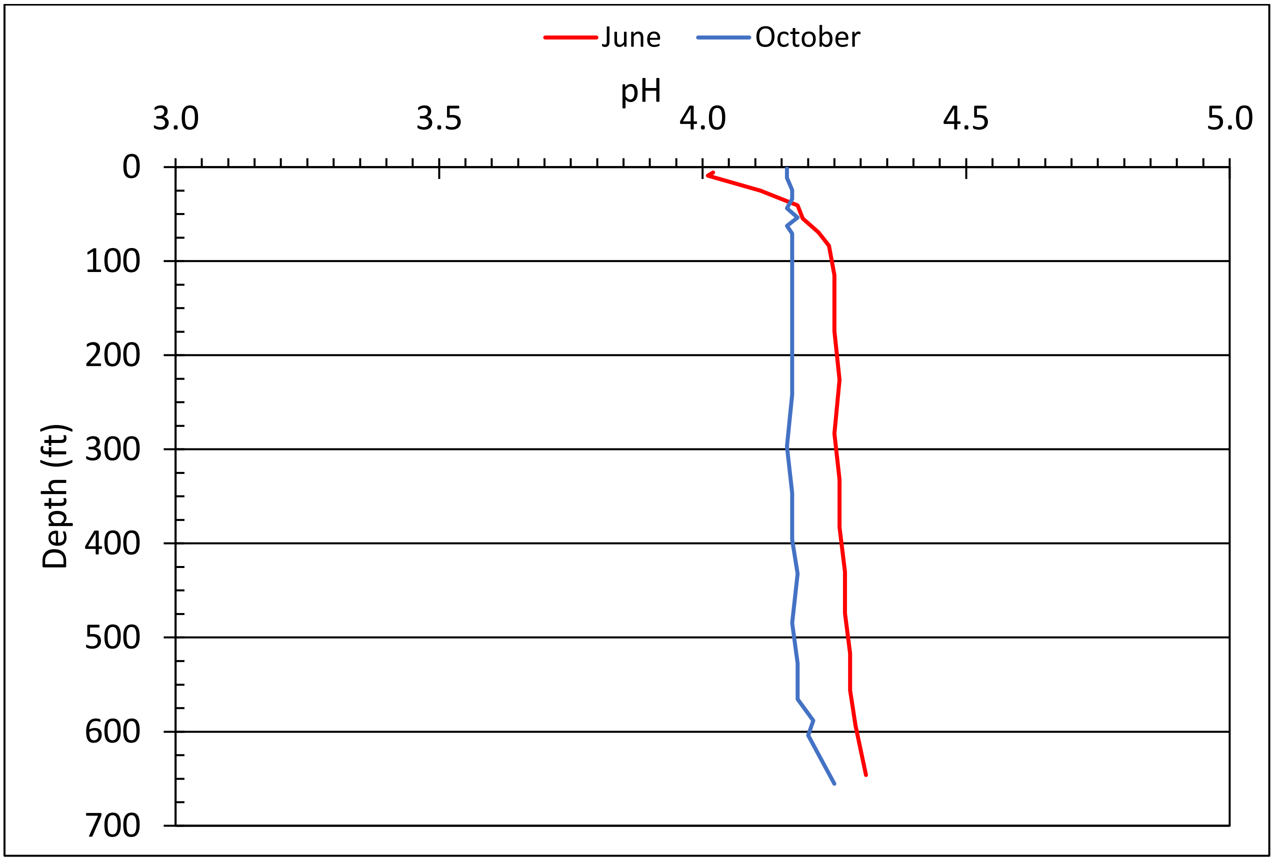


Figure 3-31. Berkeley Pit 2021 pH profiles.

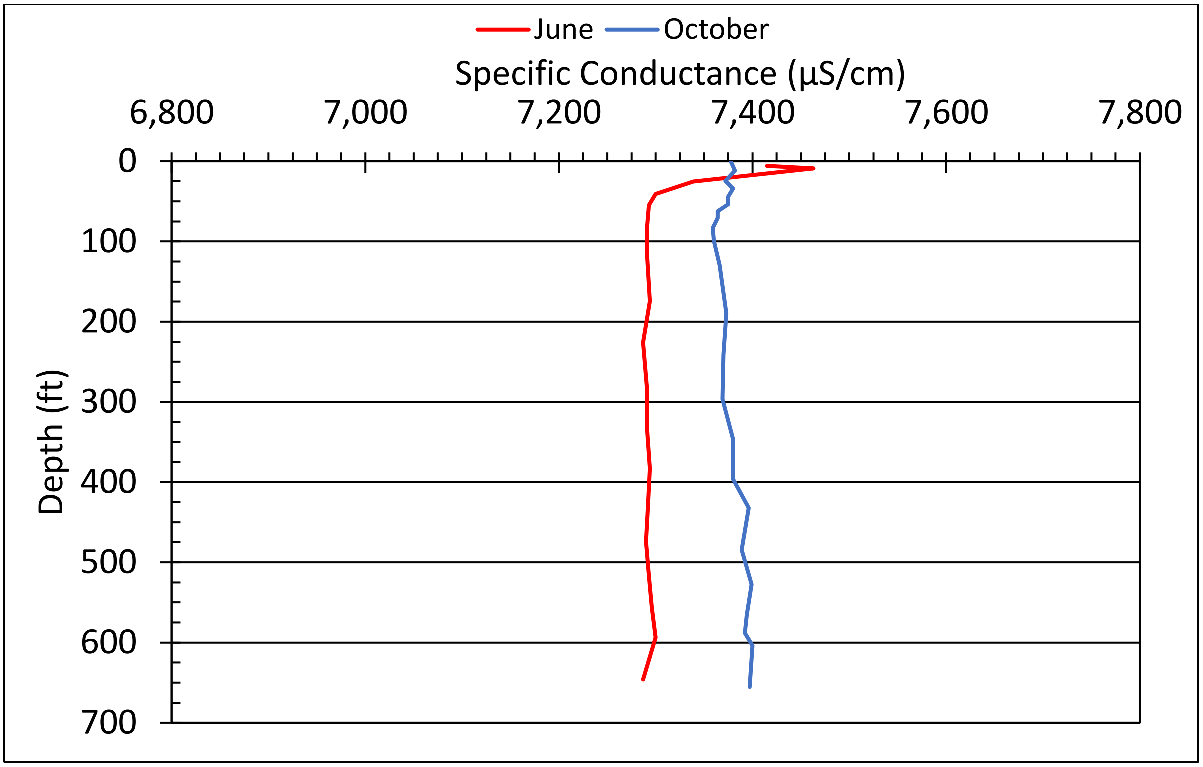


Figure 3-32. Berkeley Pit 2021 specific conductance profiles.

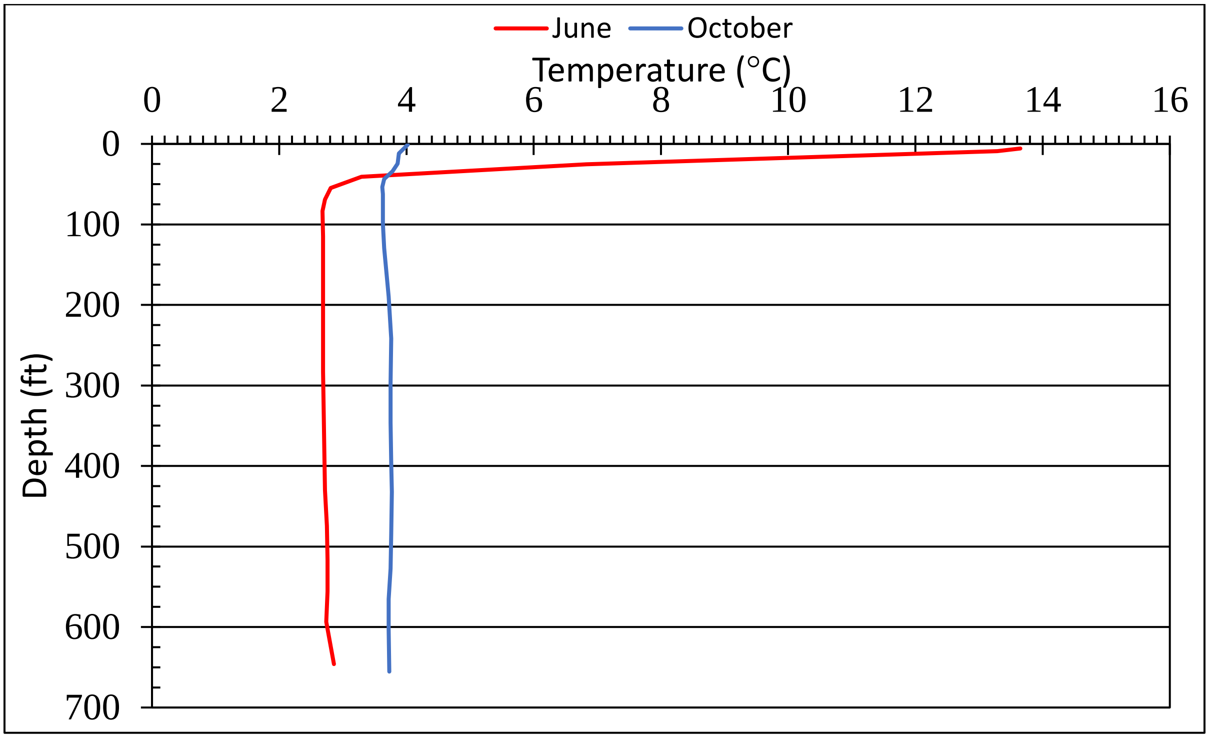


Figure 3-33. Berkeley Pit 2021 temperature profiles.

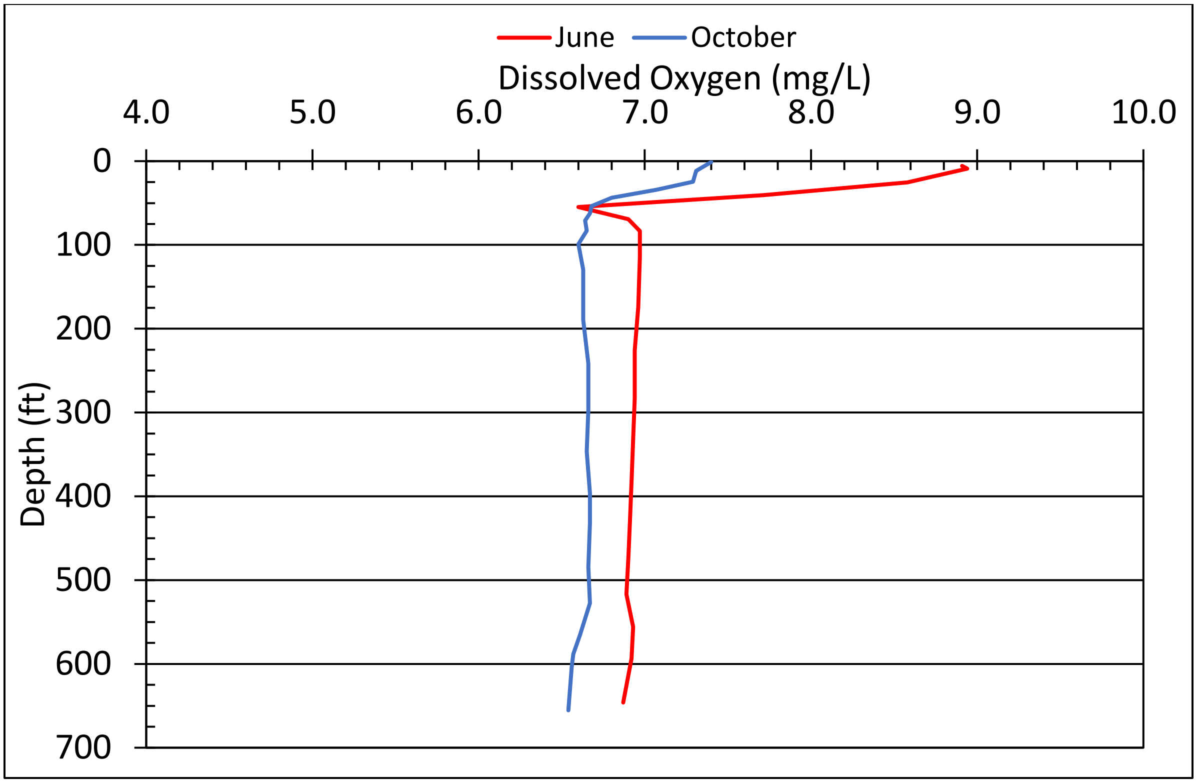


Figure 3-34. Berkeley Pit 2021 dissolved oxygen profiles.

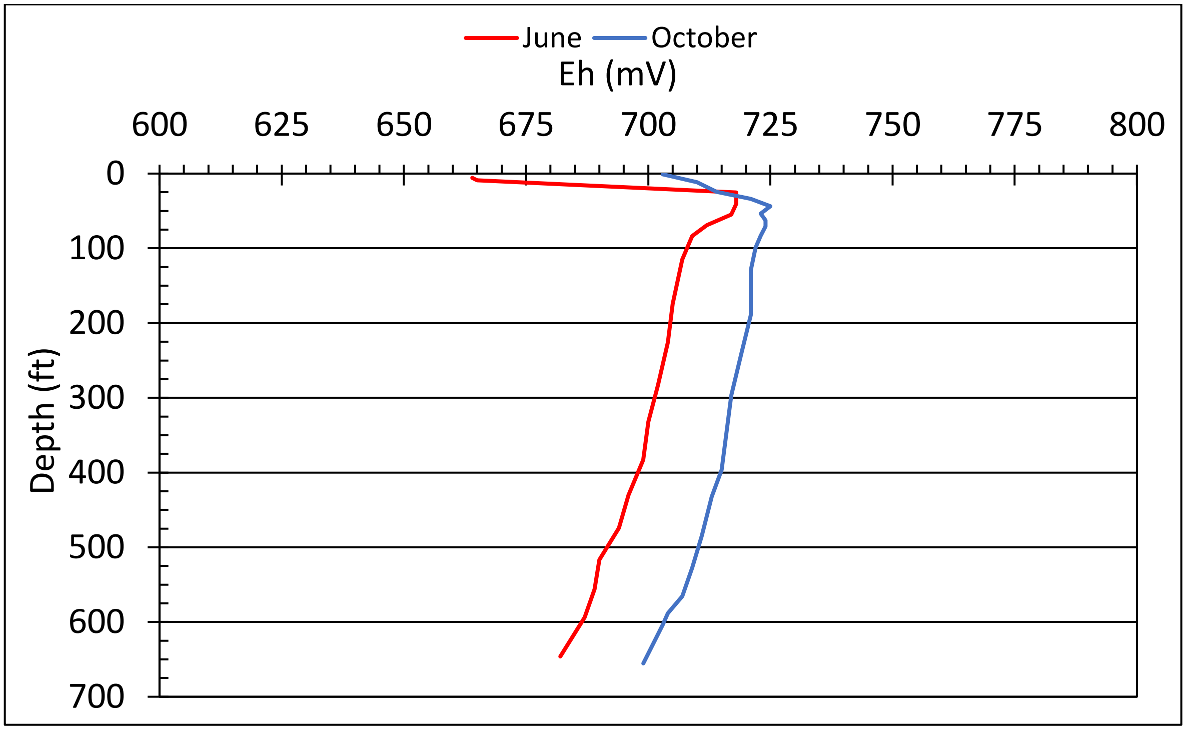


Figure 3-35. Berkeley Pit 2021 oxidation reduction profiles (Eh).

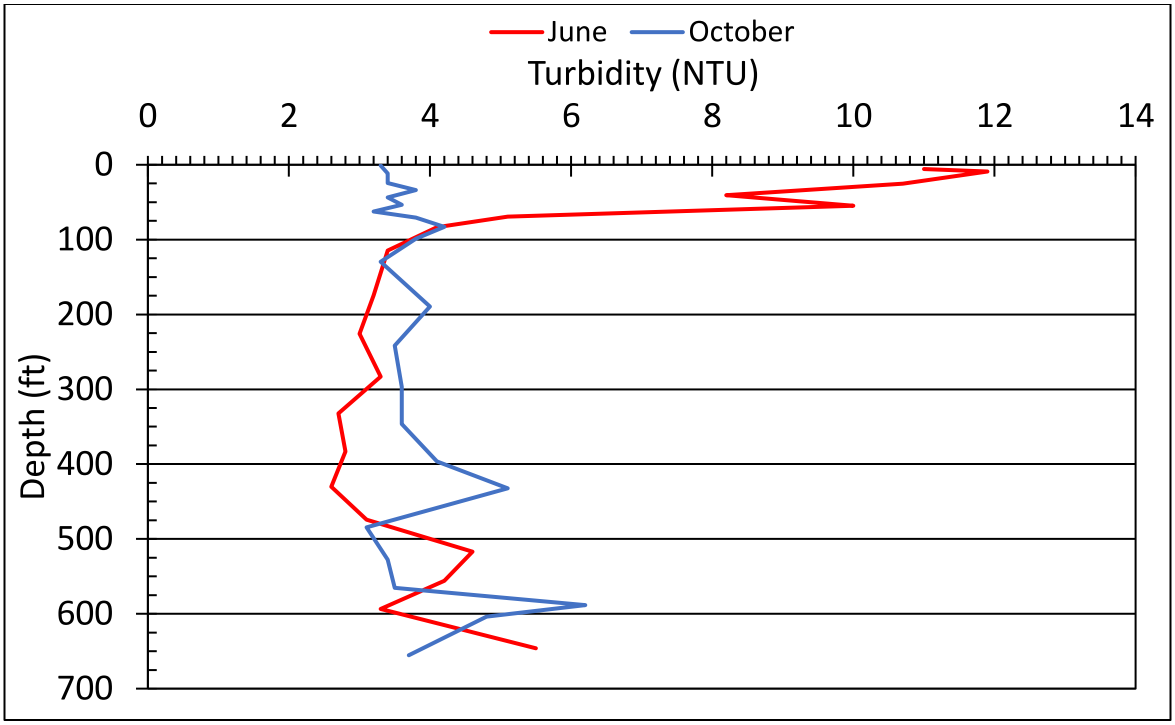


Figure 3-36. Berkeley Pit 2021 turbidity profiles.

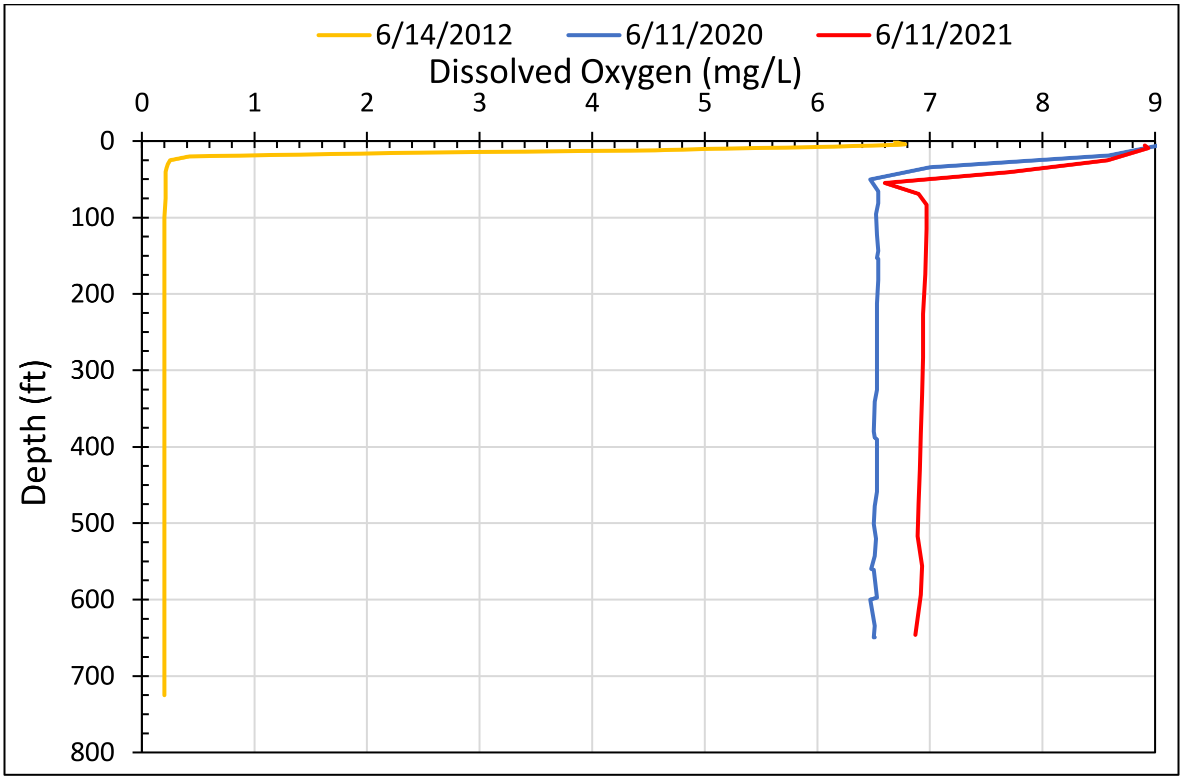


Figure 3-37. Comparison of dissolved oxygen profiles in the pit during spring 2012 and spring 2020 and 2021.

Table 3.4.1.4.1. Comparison of Berkeley Pit surface-water chemistry between 2012, 2017, 2018, 2019, 2020, and 2021.

Berkeley Pit Surface (1–5 ft) Chemistry

	pH* (S.U.)	SC (µS/cm@25ºC)	TDS (mg/L)	Total Acidity (mg/L as $CaCO_3$)	Fe (mg/L)	Cu (mg/L)	Cd (mg/L)	Zn (mg/L)	As (µg/L)	SO_4 (mg/L)
Jun 2012	2.55	7,652	10,463	3,563	211	49	2.0	631	74	7,740
Dec 2012	2.61	7,632	12,229	3,651	204	49	2.0	589	64	9,560
May 2017	3.47	7,510	9,360	3,438	8.4	59	1.9	582	5	7,033
Jul 2017	3.44	7,510	9,511	3,689	11.2	62	1.9	607	8	6,895
Nov 2017	3.93	7,300	9,526	3,532	1.9	57	2.0	598	5	6,932
Mar 2018	4.12	7,620	9,746	3,503	2.7	63	2.0	597	8	7,180
Sept 2018	3.08	6,915	9,835	3,827	4.0	66	2.2	604	5	7,210
Nov 2018	4.13	7,330	9,476	3,882	3.2	59	2.2	573	6	7,019
Apr 2019	3.95	7,070	9,177	3,763	4.1	58	2.0	570	4	6,735
Nov 2019	4.03	7,340	9,585	4,067	2.8	64	1.96	571	12	6,974
Jun 2020	3.84	7,315	9,535	3,638	5.3	63	2.4	566	14	6,990
Oct 2020	4.08	7,580	10,373	4,060	3.0	61	2.3	603	8	7,726
Jun 2021	4.02	7,415	10,091	5,536	2.2	63	2.6	604	11	7,436
Oct 2021	4.16	7,380	9,618	4,680	1.0	59	2.2	598	6	7,076

*pH is presented as recorded. While any given reading may be accurate to ±0.2, data collection procedures specify that a reading has to be stable to ±0.1 before being recorded.

Notable differences between 2012 and the 2017–2021 sample events include a pH rise of almost a full unit (2017) or more, a decrease in iron concentrations of an order of magnitude, and a decrease in arsenic concentrations to less than 15 µg/L. In addition, total dissolved solid (TDS) concentrations are generally declining or stabilizing. Between 2012 and mid-2019, the pit lake sat quiescent, and by 2017 the system appeared 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. MR began pumping from the pit as part of the Pilot Project operational testing in mid-2019. Following the September 2019 start of the Pilot Project and continuing through 2021, the pit water was pumped to the precipitation plant for copper removal, then routed to the HsB/CS for incorporation with other mine-operations water. The annual pit-water turnover, combined with subsequent effects of pumping and discharge since 2012, likely increased the degree of mixing in the pit profile.

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 Geochemistry 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 years of plant operation. In 2021, the plant has been operating for 15 years and the mean pH measured in the Berkeley Pit vertical profile has risen to 4.0.

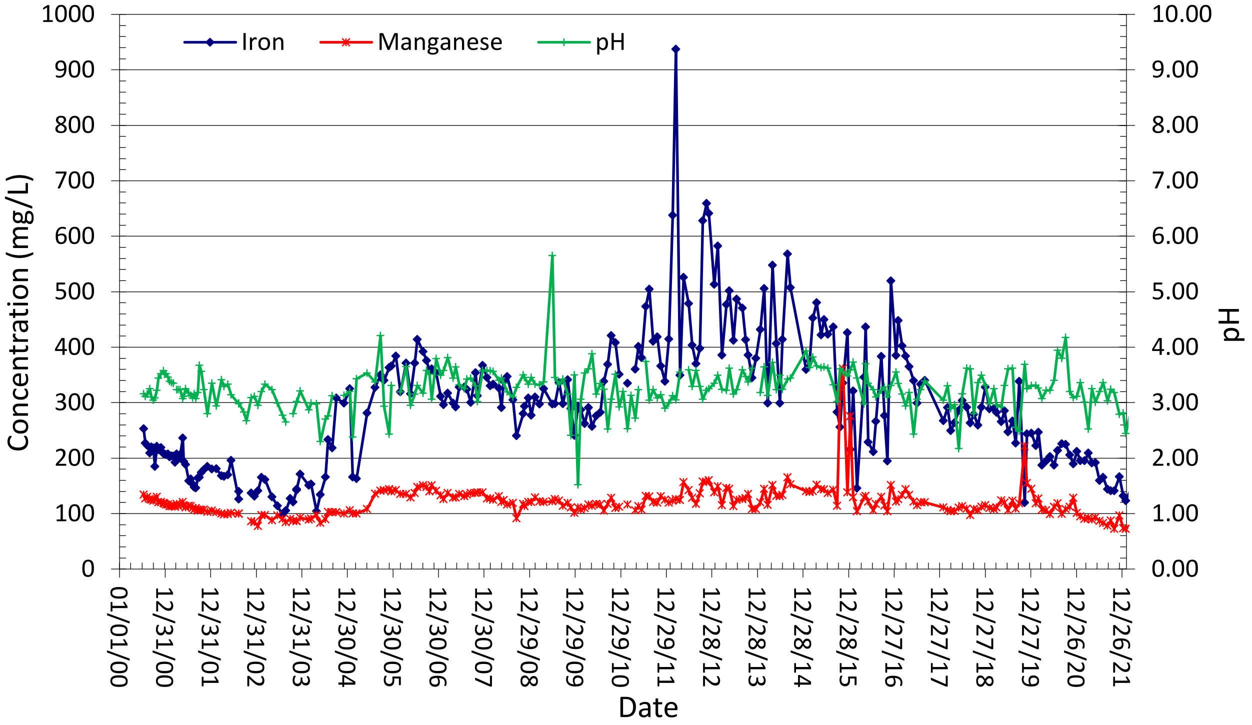
Another striking difference between 2012 and 2021 time periods is the uniformly higher DO concentration throughout the water column (fig. 3-37). Near the surface, the concentration in both years approaches saturation because of the contribution of high DO-meteoric water and wind mixing of near-surface 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 2021 through the entire profile reflects the absence of ferrous iron, which oxidized and precipitated out of solution, carrying adsorbed arsenic with it. Seasonal turnover likely maintains the uniformity of concentration in the 2021 profile, mixing oxygenated water from the surface to depth.

The 2018–2021 data provided a basis to confirm and characterize changes initially noted in 2016–2017 data and to assess future conditions in the pit. 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 3.4.2 Horseshoe Bend Water Quality

Monitoring of the HsB (HSB in fig. 3-1) began in July 2000 following MR's temporary suspension of mining. During this time period, HsB discharge rates decreased, as did the concentrations of a number of the trace metals. Metal concentrations began to increase in mid-2004 when discharge rates increased to levels similar to those before the suspension of mining. Copper concentrations are currently about one-third of those measured in 2000, and zinc concentrations are about two-third those observed in 2000 following a steady decline throughout 2021 (fig. 3-38).

In August 2012, MR increased leaching operations, using a significant volume of HsB water as a leachate solution. MR began to deactivate leach pad operations in July 2021; therefore, HsB was no longer diverted to the leach pads. Between 2012 and July 2021, copper concentrations in HsB water declined, with occasional-short-term fluctuations; a slight increase was noted the last several months of 2021. Iron concentrations have become more erratic, probably in response to leaching and precipitation plant operations; concentrations show a gradual decrease from late 2016 (>500 mg/L) through 2021 (~125 mg/L). Manganese has remained near 100 mg/L with periodic increases to 300 mg/L. The pH dropped 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. 3-38).



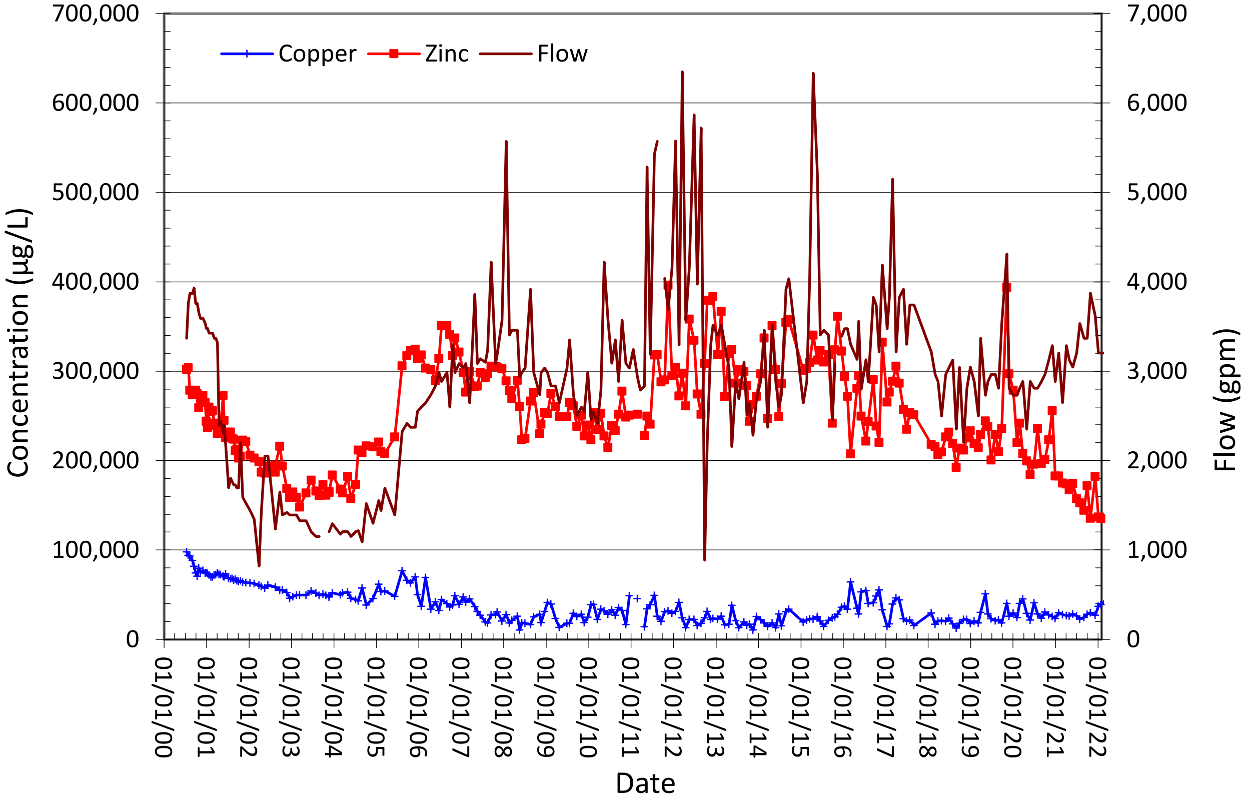


Figure 3-38. A comparison of iron and manganese concentrations with pH (top), and copper and zinc concentrations with flow (bottom) in Horseshoe Bend discharge from 2000 to 2021.

SECTION 4.0 WEST CAMP SYSTEM

During 2021 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 0.18 and 0.35 ft during 2021, and at the end of 2021 water levels were 13 ft below the West Camp’s PWL elevation. The volume of water pumped was just over 277 acre-ft, or 33 acre-ft less than that pumped in 2020 (1 acre-ft equals 325,851 gal).

Section 4.1 West Camp Underground Mine

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. AR 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 remain in place and serve as a backup pumping system. AR 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-ft, the change in acre-ft 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.

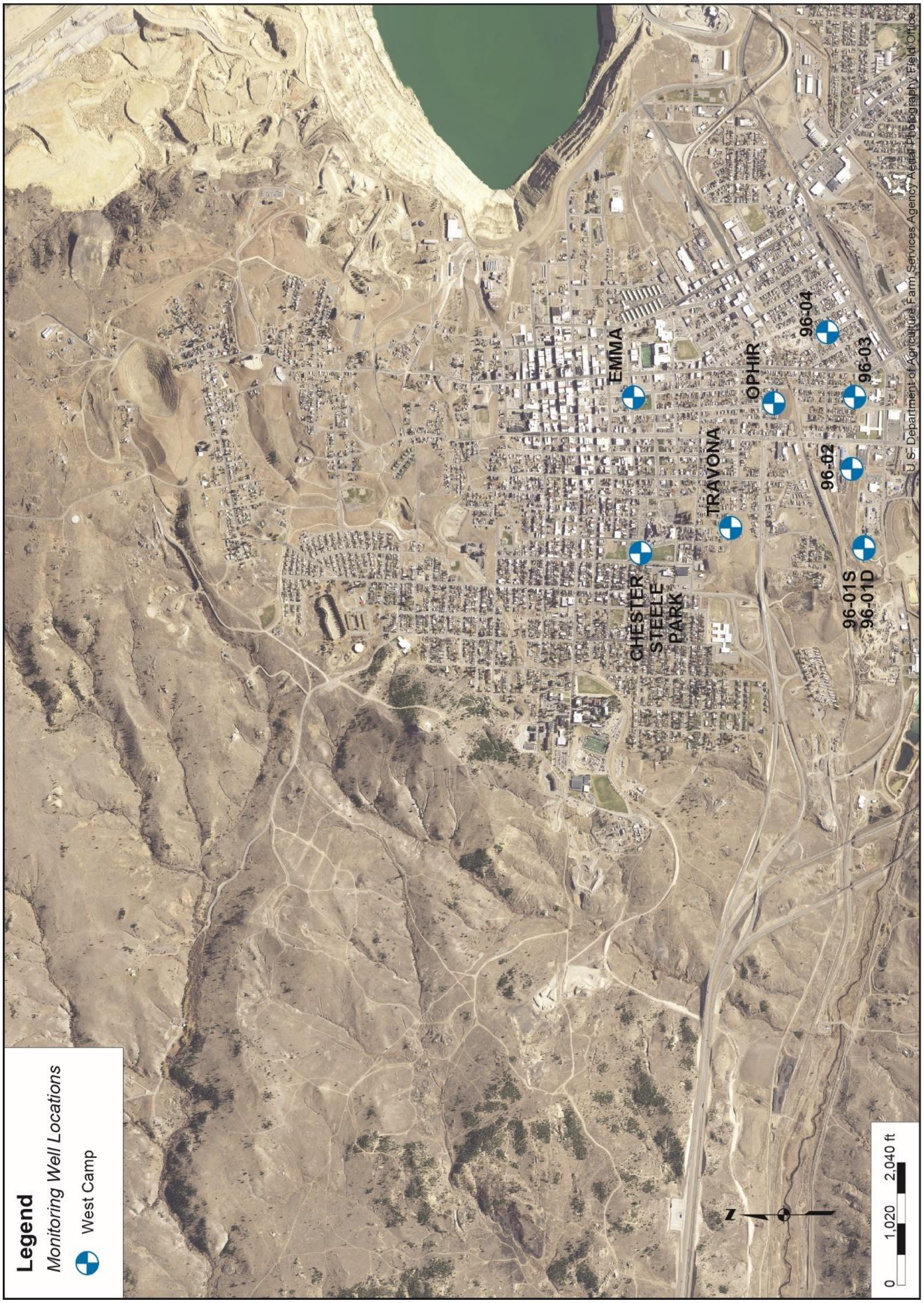


Figure 4-1. West Camp monitoring sites location map.

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. West Camp pump station upon completion in 2011.

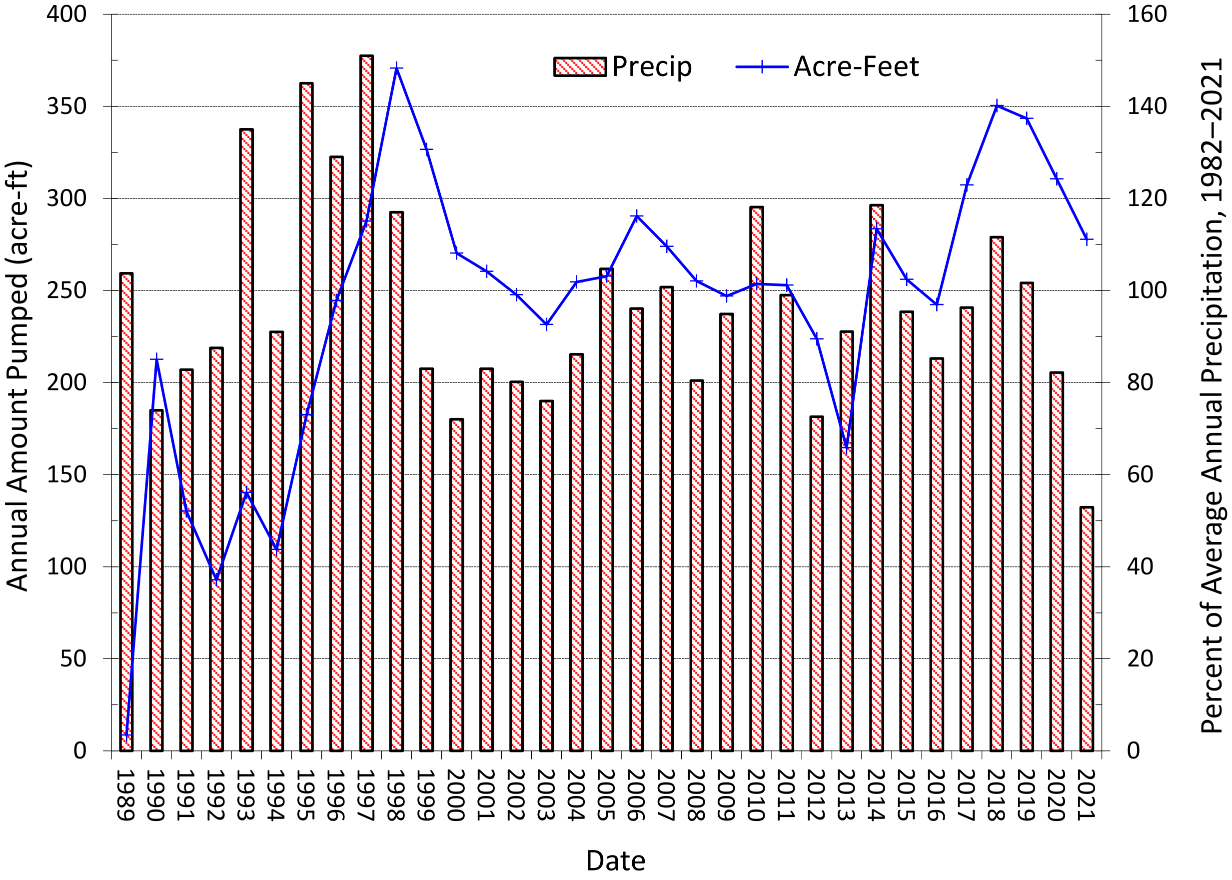


Figure 4-6. Annual amount of water pumped from the West Camp System compared to the average annual precipitation during the period 1982–2021.

Table 4.1.1. Annual quantity of water pumped from the West Camp (acre-ft).

Year	Total Amount Pumped (acre-ft)	Change From Prior Year (acre-ft)	Change Relative to 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
2019	343.46	-6.89	1.40
2020	310.53	-32.93	1.27
2021	277.75	-32.78	1.14

Water levels showed a minor increase (less than 0.40 ft) during 2021 in all three mines. Figure 4-7 shows water-level changes for the West Camp sites. Water levels are more than 13 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.

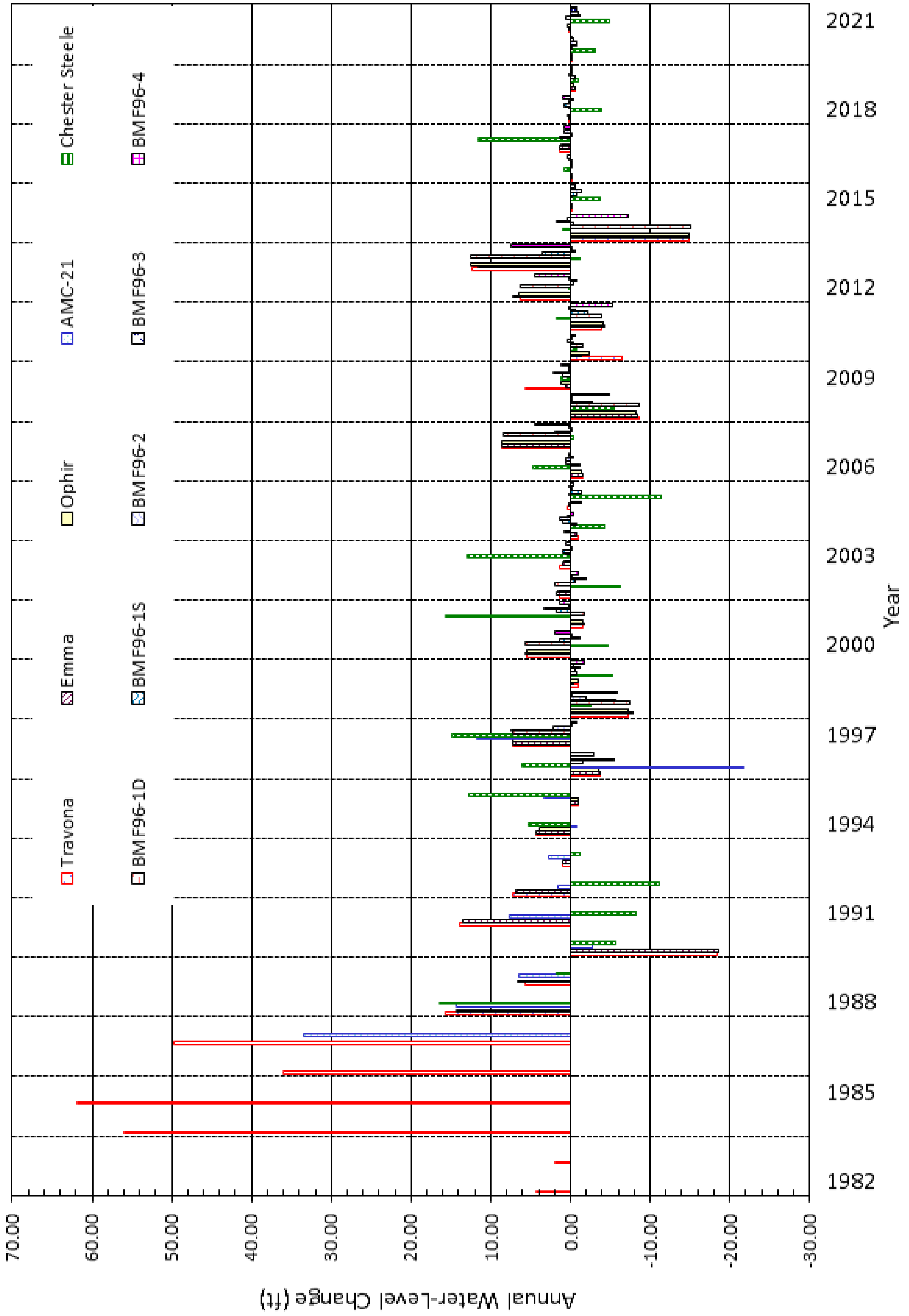


Figure 4-7. Annual water-level changes (from previous year) for West Camp sites.

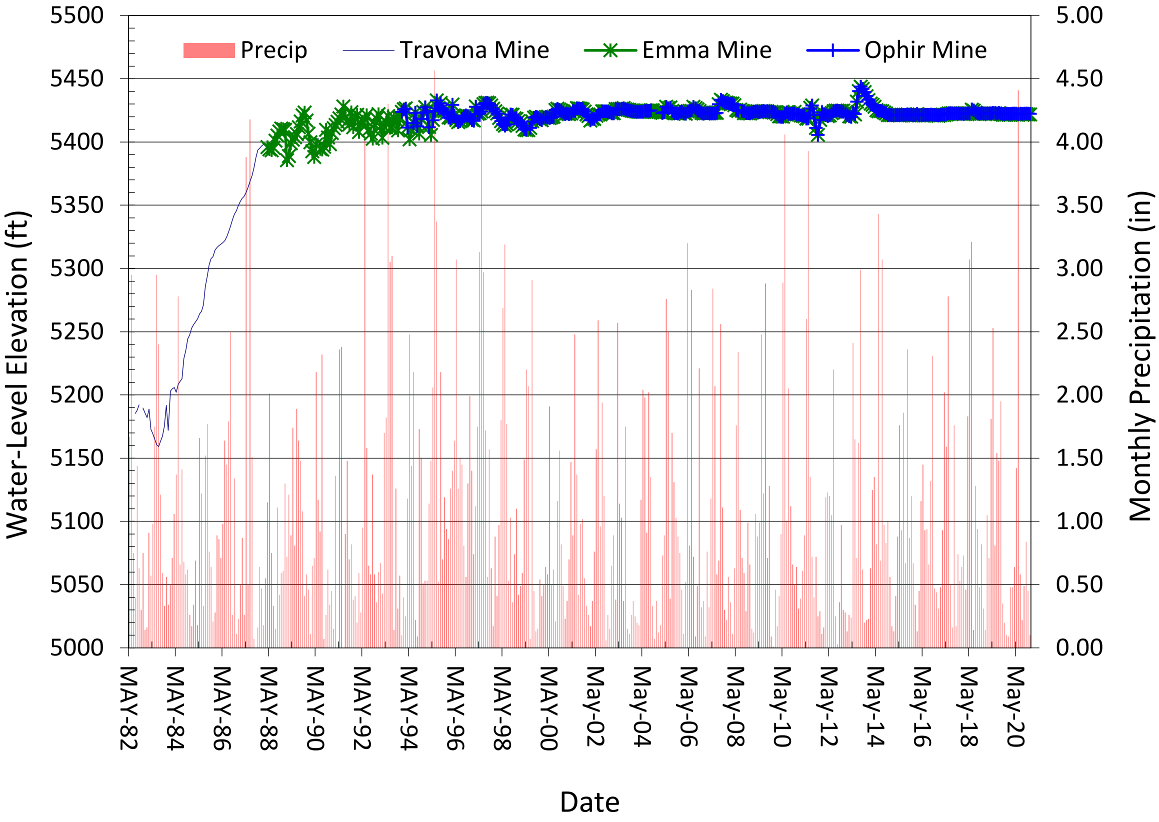


Figure 4-8. Water-level hydrographs for West Camp mines compared to monthly precipitation.

Section 4.2 West Camp Monitoring Wells

Water levels decreased in four of the five BMF96 West Camp groundwater wells during 2021. Water levels increased in well BMF96-1D, completed into the Travona Mine workings, similar to that of the West Camp mines. The water-level changes are shown in table 4.2.1 and figure 4-7.

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 of pumping and the interconnections between wells and 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 and not directly in mine workings. This is an important trend since well BMF96-4, while not completed into mine workings, monitors conditions within the area of the historic 1960s flooding that led the Anaconda Company to install well AMC-21 to control 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 FBGS, their water levels are less than 20 FBGS. 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 those of the other BMF-series wells; however, the magnitude of 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 2021 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. 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
Change 1982–1991	**226.72**	**15.66**		**4.16**					
Change 1992–2001	**10.68**	**10.06**	**2.48**	**29.82**	**1.45**	**-1.14**	**1.08**	**-3.65**	**-5.18**
Change 2002–2011	**-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
2019	-0.58	-0.57	-0.38	-1.05	-0.55	0.10	-0.13	-0.05	-0.30
2020	-0.14	-0.16	-0.08	-3.10	-0.12	-0.81	-0.81	-0.35	-0.07
2021	0.18	0.22	0.35	-4.83	0.58	-1.16	-1.06	-0.74	-0.84
Change Years 2012–2021	**4.23**	**4.45**	**5.26**	**-4.27**	**4.57**	**0.48**	**-2.29**	**-0.86**	**5.05**
Net Change*	**237.45**	**25.87**	**3.29**	**21.88**	**1.86**	**-1.37**	**-2.03**	**-4.49**	**-6.27**

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.

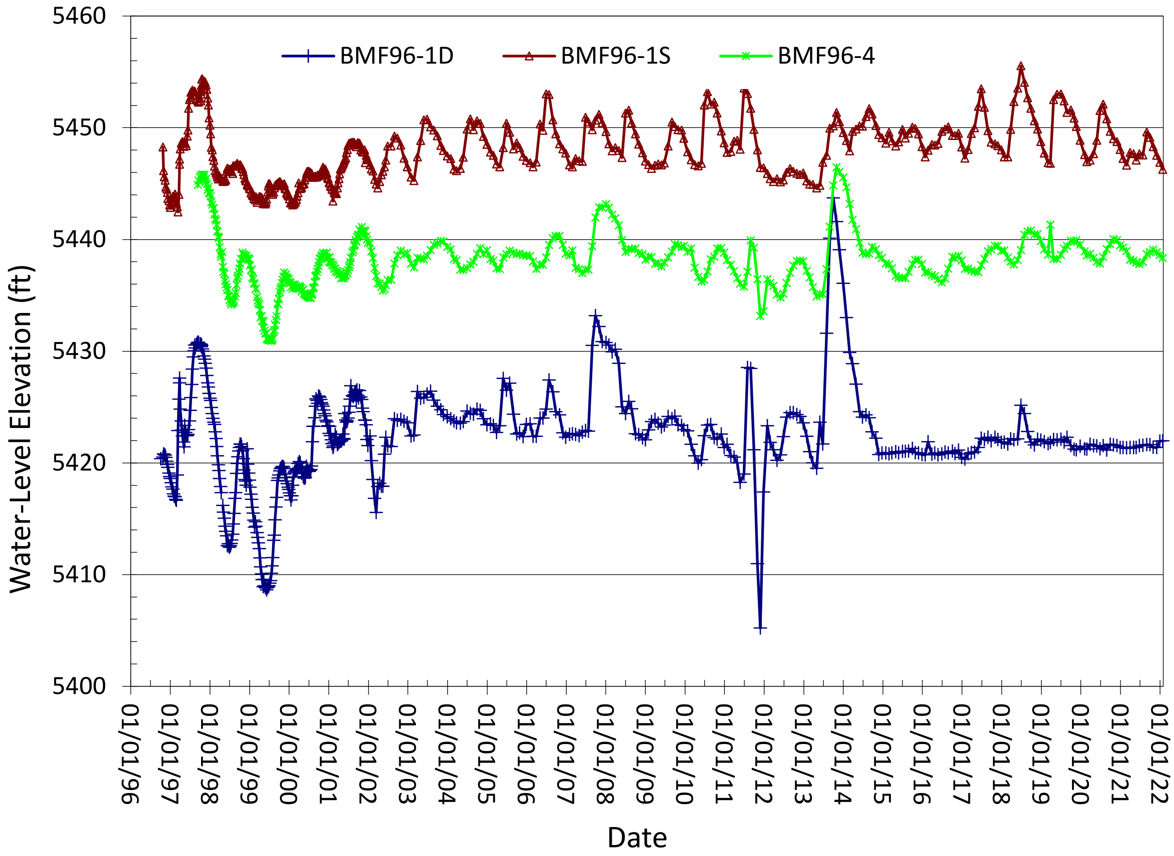


Figure 4-9. Water-level hydrographs for West Camp wells BMF96-1D, BMF96-1S, and BMF96-4.

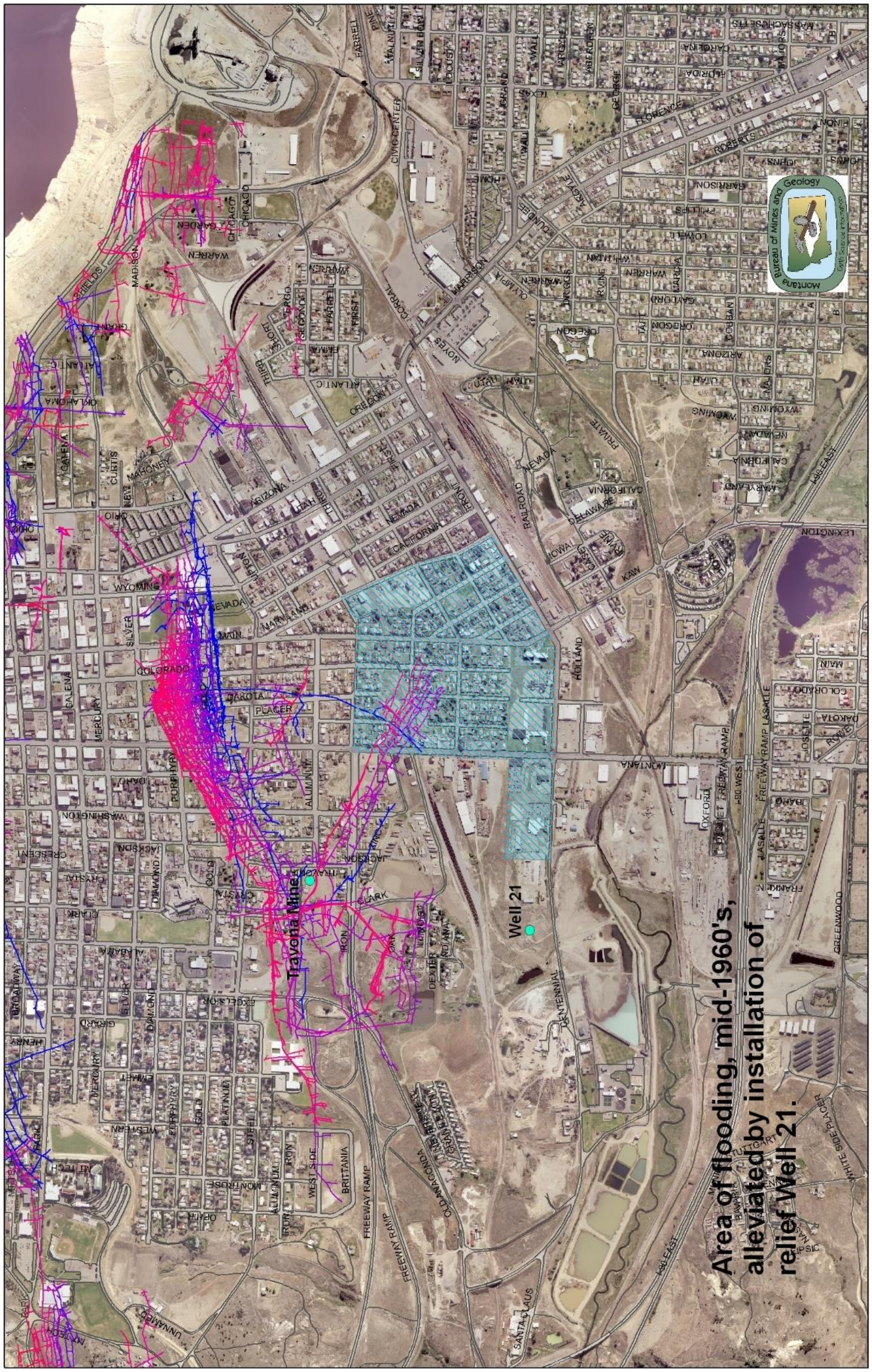


Figure 4-10. Area of the West Camp affected by basement flooding problems in the 1960s. The blue hatched area outlines flooding locations; pink and purple lines show areas of underground mine workings.

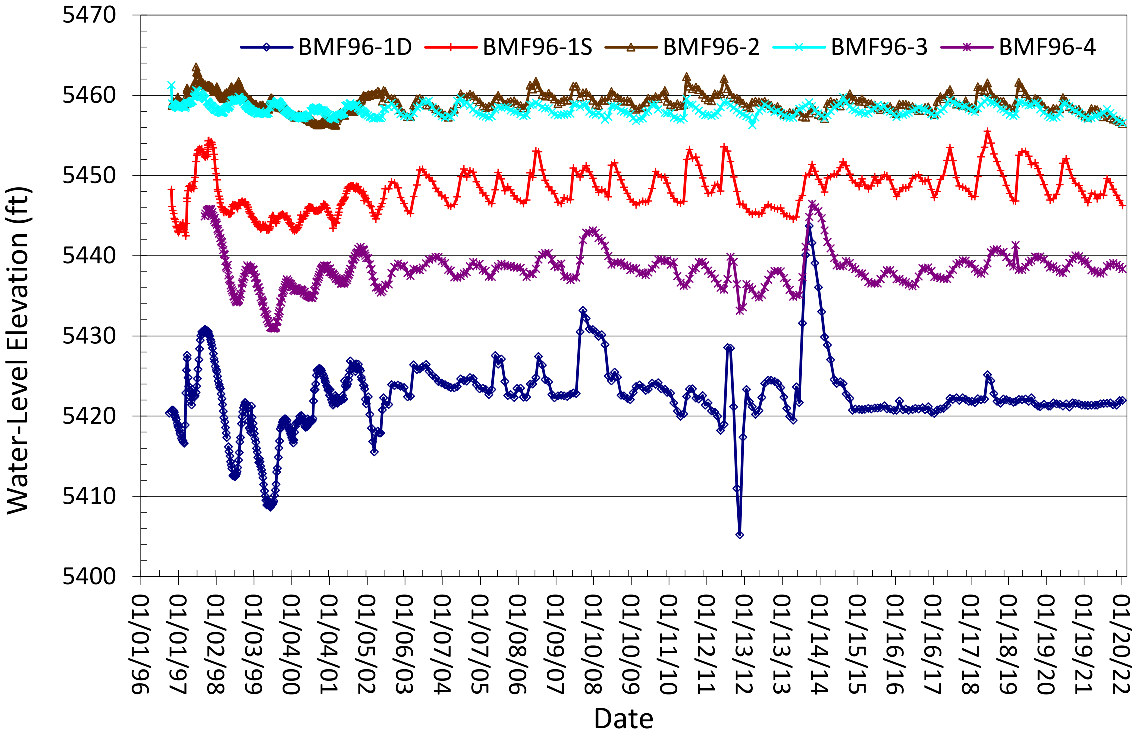


Figure 4-11. Water-level hydrographs for BMF96-series wells, 1996–2021.

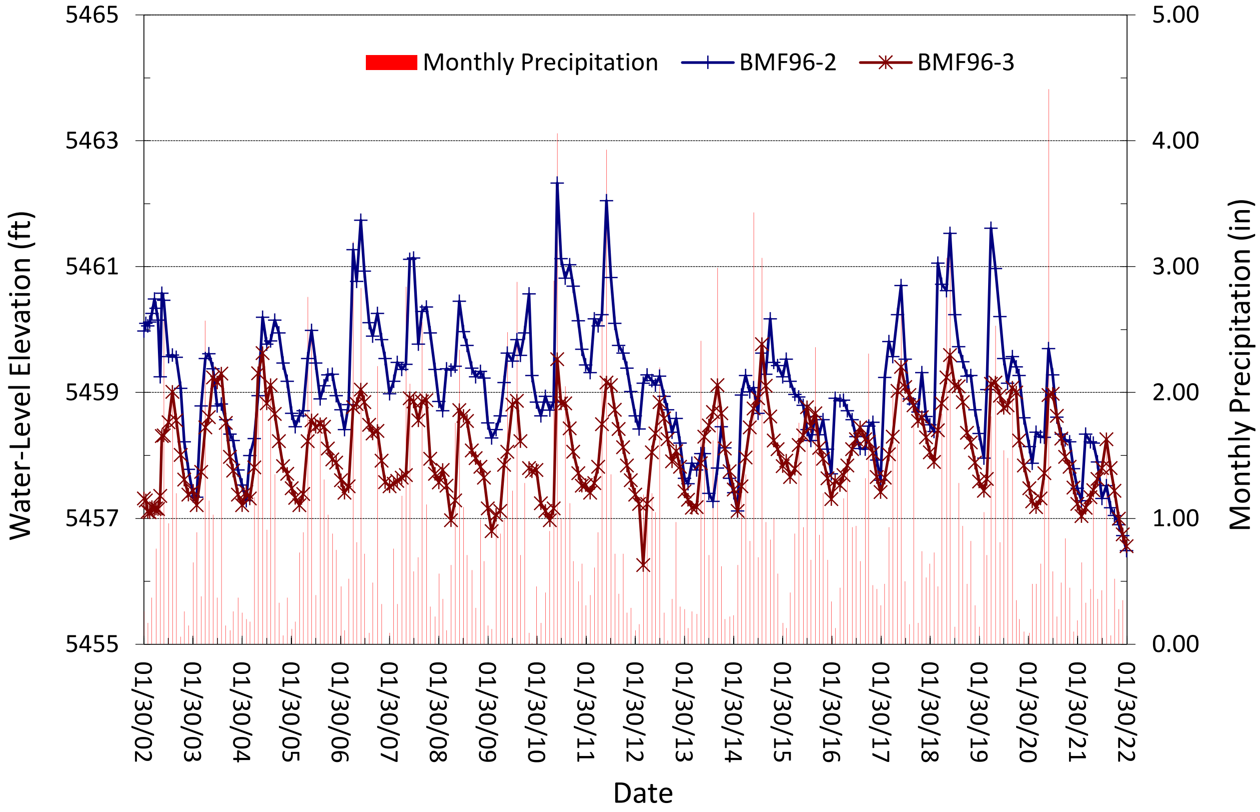
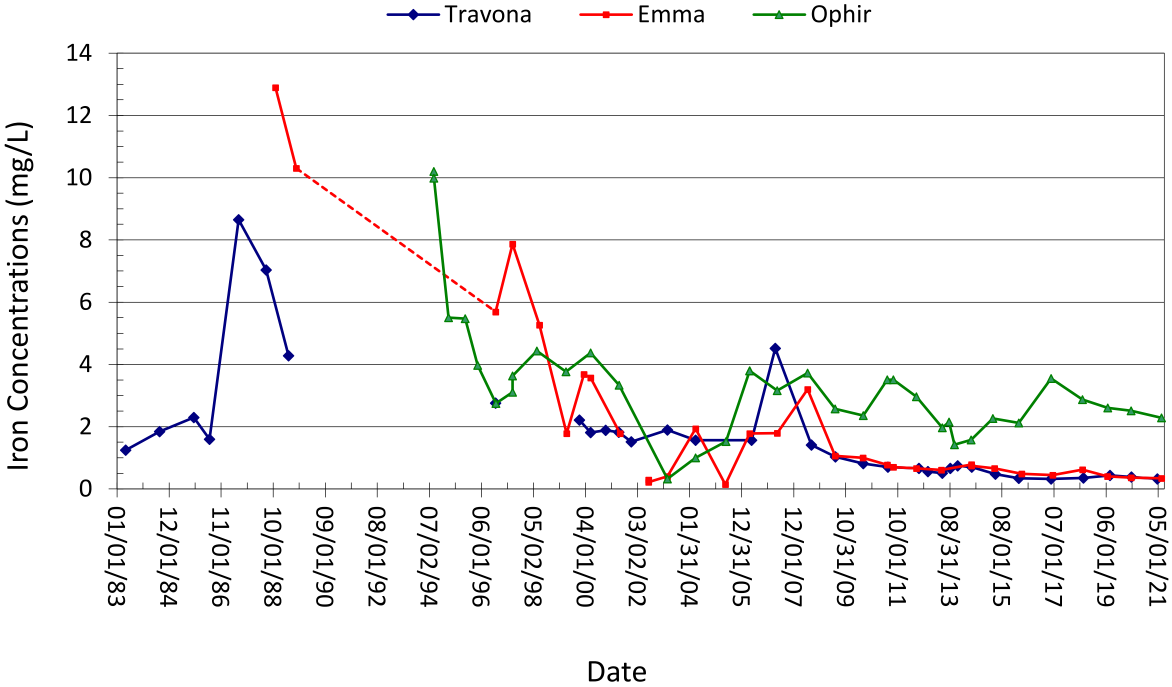


Figure 4-12. Water-level hydrographs for wells BMF96-2 and BMF96-3, 2002–2021.

Section 4.2.1 West Camp Mines and Monitoring Wells Water Quality

In 2021 water-quality data for the West Camp monitoring system was limited to analytical results from spring-season sampling in BMF96-4 and Chester Steele Park wells, and the Travona, Emma, and Ophir shafts. With the exception of arsenic (22 µg/L in water from the Chester Steele Park well, and 55 µg/L in water from the Travona shaft), the concentrations of most dissolved constituents in the West Camp waters were similar to each other (figs. 4-13, 4-14). The arsenic concentration in the Travona Mine sample was comparable to the 2013–2019 concentrations and about one-half those from 2019–2020.

Through 2021, the concentrations of most dissolved metals in well BMF96-4 are relatively low and remain generally stable. Arsenic concentrations were above the DEQ-7 standard of 10 µg/L in 2021 for the second time since sampling began in 1997; typically arsenic ranges from 5 to 9 µg/L (fig. 4-15).



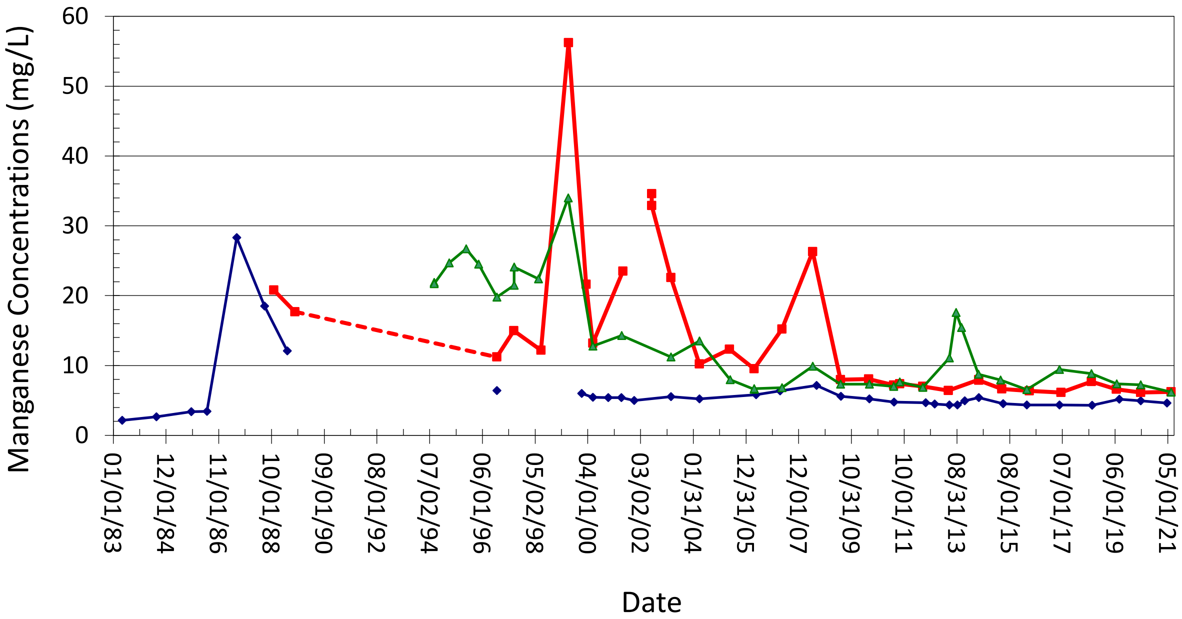
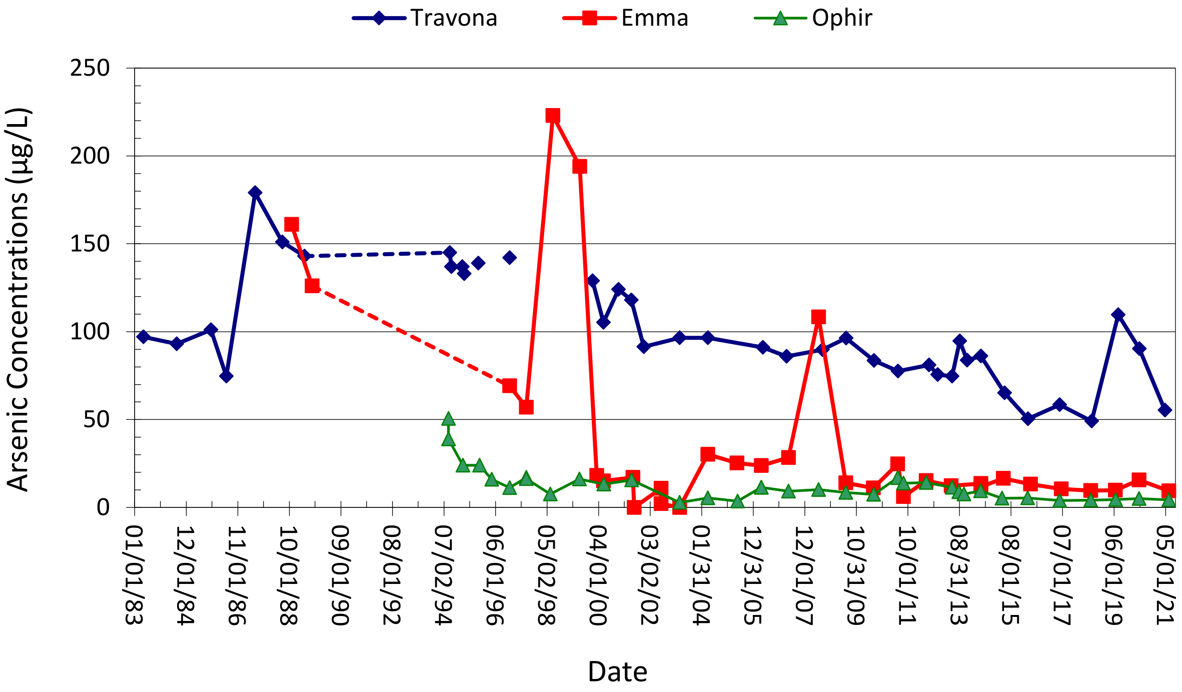


Figure 4-13. Iron (top) and manganese (bottom) concentrations in the West Camp mines.



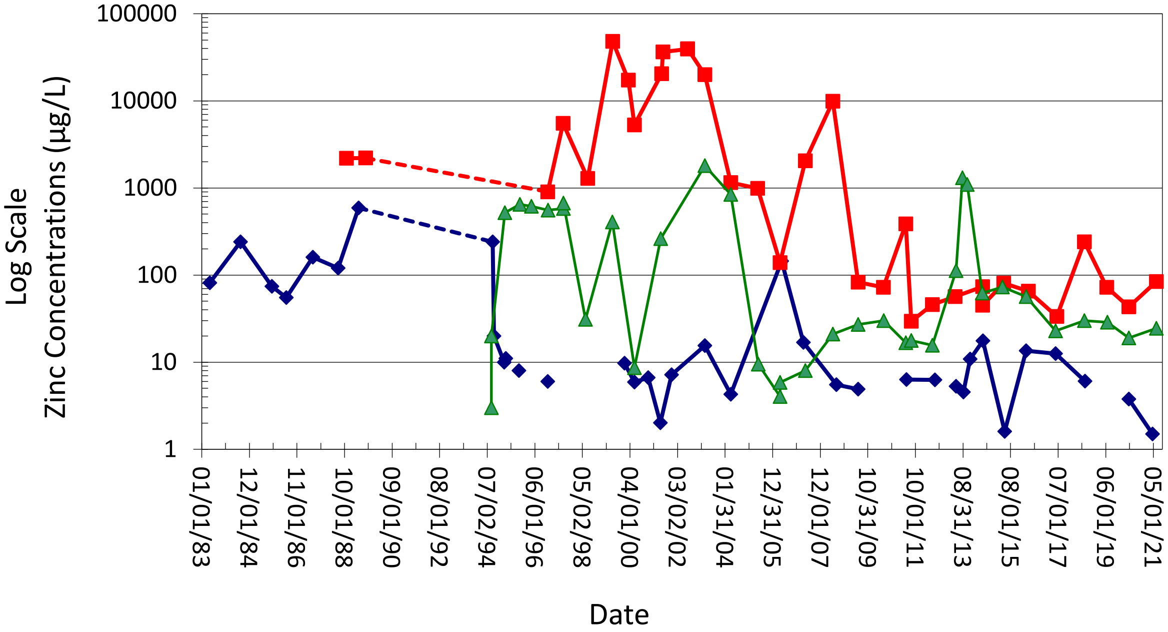
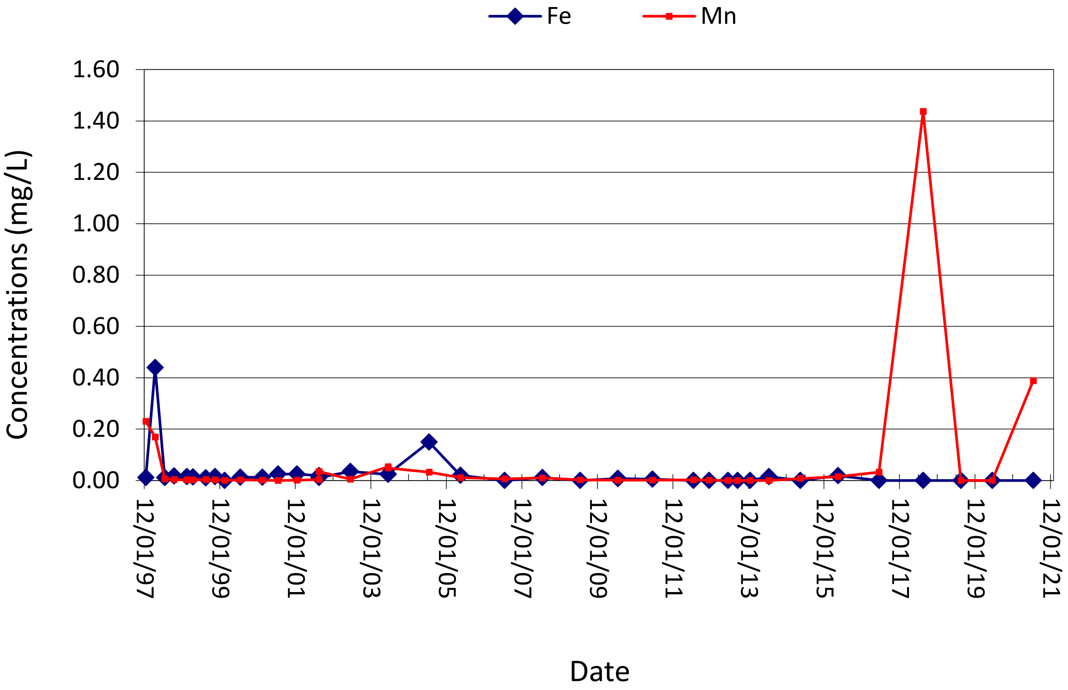


Figure 4-14. Arsenic (top) and zinc (bottom) concentrations in the West Camp mines. Note that the zinc concentrations are plotted in the log-scale and Travona concentration was below the instrument detection limit and is not plotted.



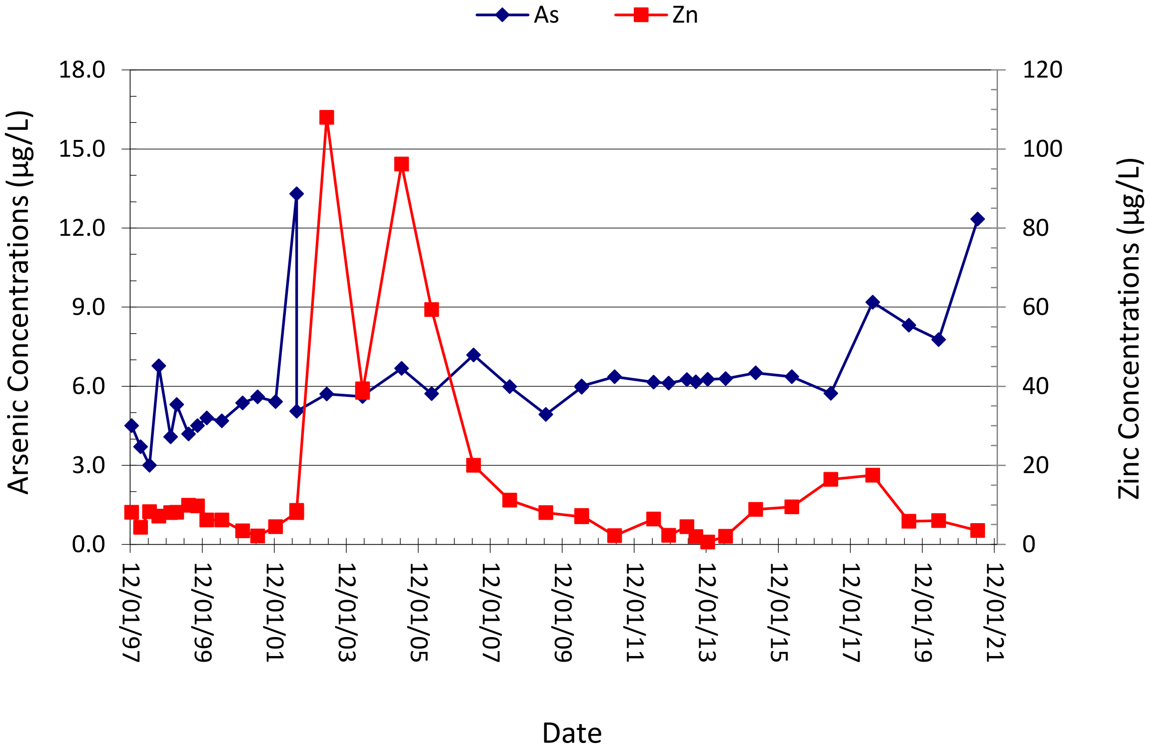


Figure 4-15. Selected water chemistry for West Camp well BMF96-4.

SECTION 5.0 OUTER CAMP SYSTEMS

The Outer Camp monitoring system consists of the Orphan Boy Mine, Marget Ann Mine, well S-4, 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 northwestern 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 AR'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 is 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 obstruction of the mine workings as conduits of groundwater transfer between the systems (Outer Camp and East Camp) support the premise that the water levels in the Outer Camp mines are at or near pre-mining levels. Water levels in the Outer Camp remain between 200 ft and 850 ft above those in the East Camp. The Green Seep is a surface-water monitoring location; an overgrowth of vegetation limited flow data collection from 2016 to mid-2019. AR and MR initiated repairs and improvements to the Green Seep at the request of EPA and DEQ during 2019 with a new flume installed to better monitor flows. 2021 monitoring indicates the 2019 repairs and flume installation are working as designed.

Section 5.1 Outer Camp System Water Levels

Outer Camp water levels show variation from year to year, with water levels increasing one year, followed by a decrease the next. Water-level changes in 2021 varied from an increase of 1.12 ft in the Orphan Boy Mine to a decline of 4.99 ft in well S-4. Table 5.1.1 contains 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, varying from over 13 ft of rise at the Montana Tech well to over 37 ft of rise in the Marget Ann Mine. Montana Tech's Mining Engineering department continued to pump water from the Orphan Boy Mine intermittently during 2021 to keep their underground mine lab, located on the 100-ft level of the mine, dry. This pumping affected the water levels in both the Orphan Boy Mine and Montana Tech well (fig. 5-3), as shown by hourly water-level data provided by pressure transducers installed in these sites.

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 2021, 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
Change 1987–1996	**20.43**	**22.61**	**10.62**	**7.88**
Change 1997–2006	**6.78**	**7.59**	**10.96**	**0.26**
Change 2007–2016	**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
2019	-4.06	-0.16	1.62	-2.76
2020	-3.38	-4.35	-5.91	-2.84
2021	1.12	-3.18	-4.99	0.40
Change Years 2017–2021	**-1.39**	**4.08**	**5.97**	**-3.03**
Net Change*	**31.23**	**37.54**	**32.44**	**13.99**

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.

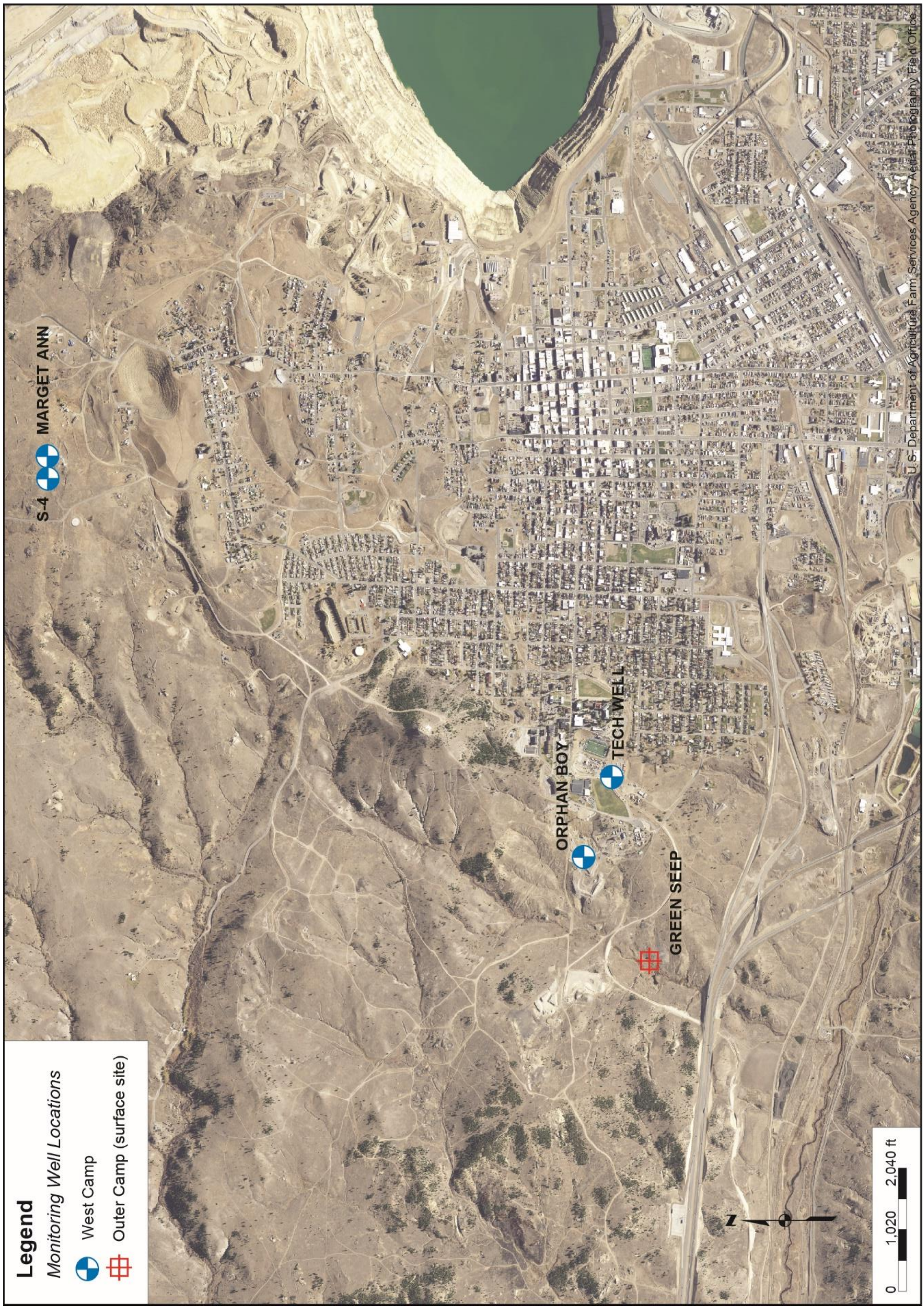


Figure 5-1. Outer Camp monitoring sites location map.

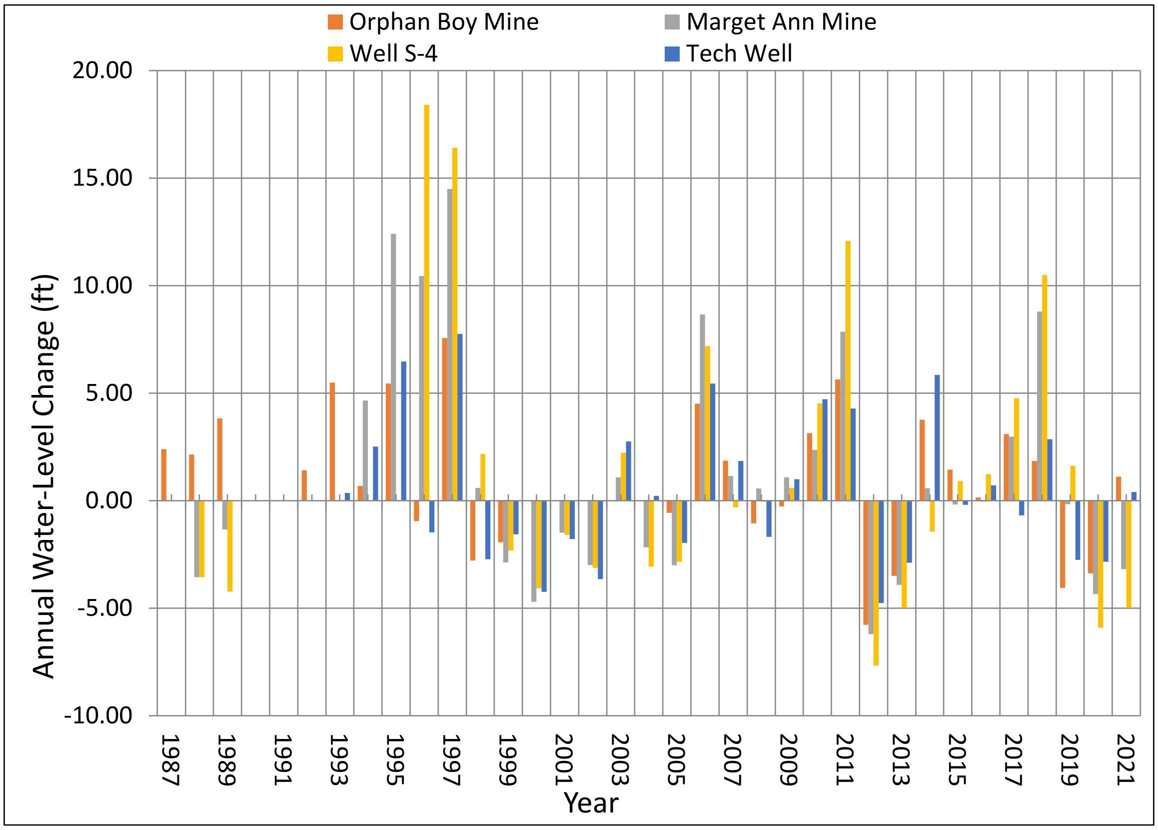


Figure 5-2. Outer Camp sites annual water-level change.

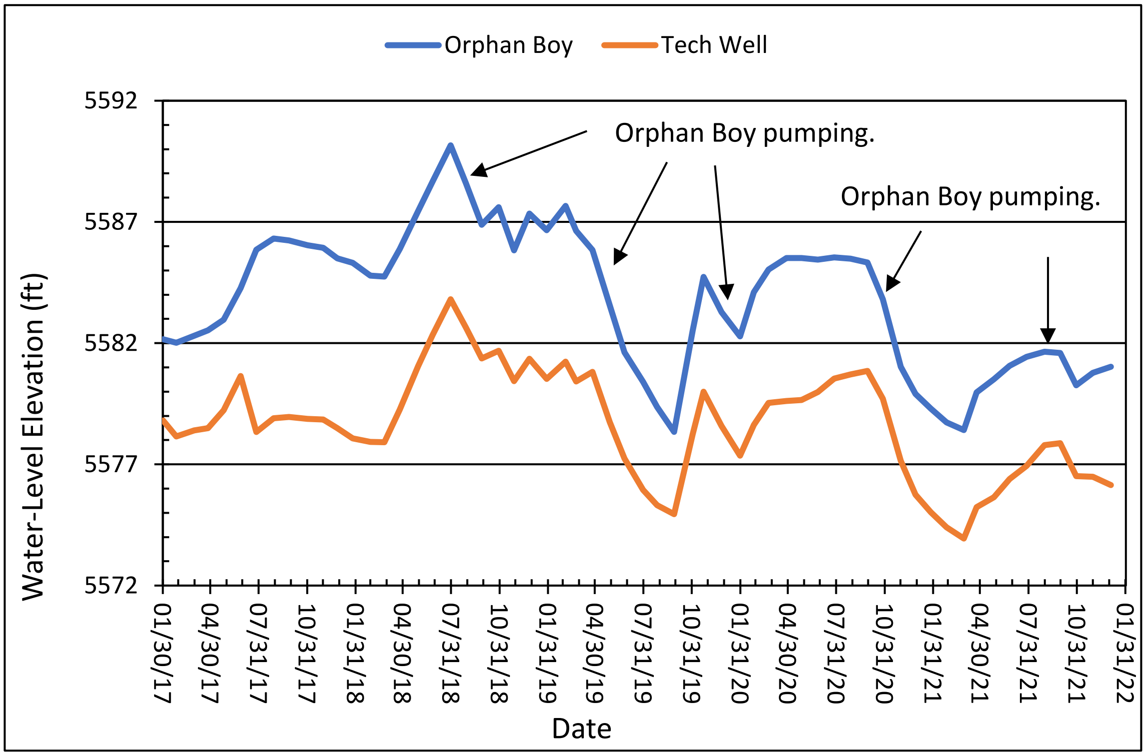


Figure 5-3. Hydrographs from Orphan Boy and Tech well show the influence of 2018–2021 Orphan Boy pumping events, monthly water-level readings, 2017–2021.

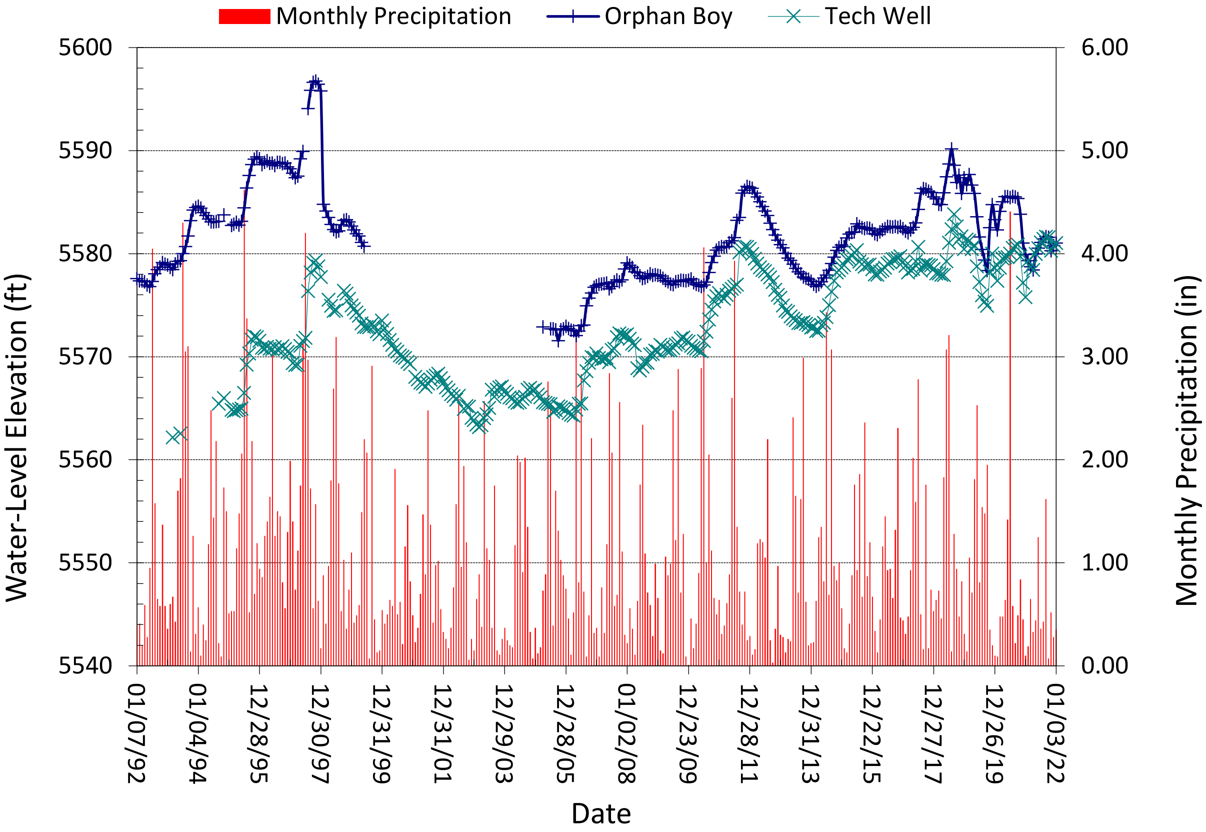


Figure 5-4. Water-level hydrograph for the Orphan Boy Mine and Montana Tech well.

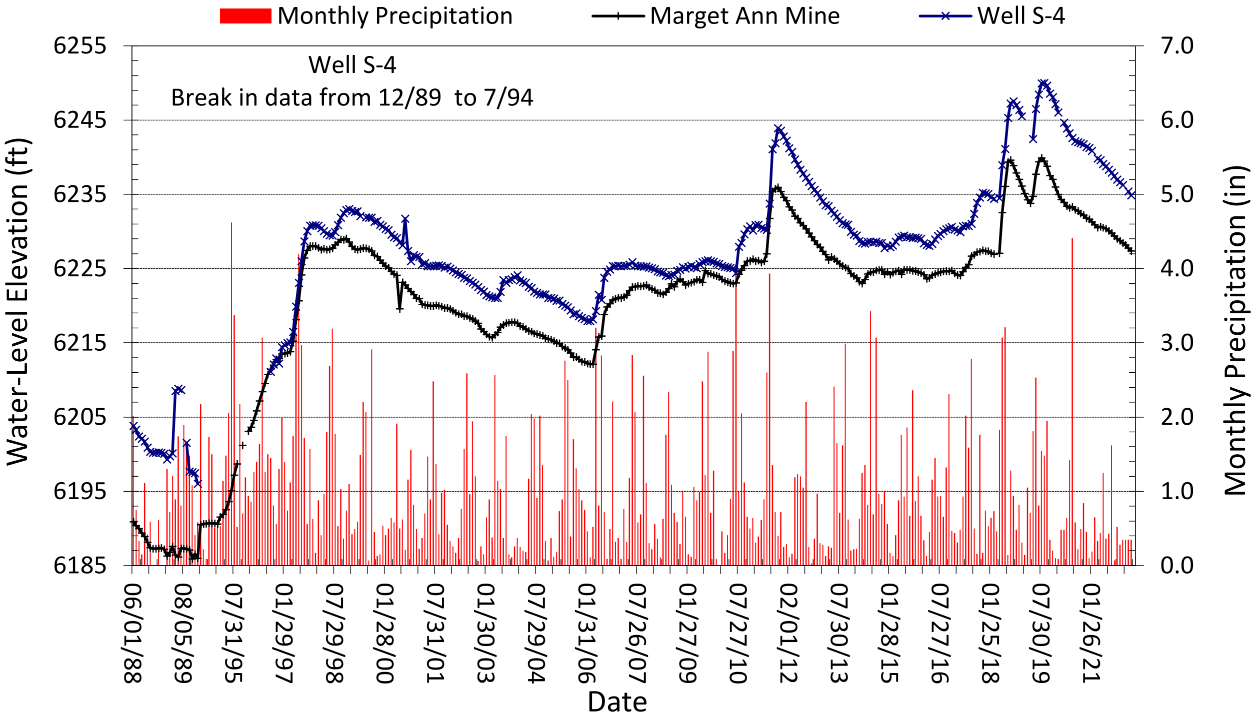


Figure 5-5. Water-level hydrograph for the Marget Ann Mine and well S-4.

Section 5.2 Outer Camp Water Quality

Water-quality samples were collected from the Orphan Boy and Green Seep during both the spring and fall sampling events, and from the Marget Ann Mine during the spring event. Figures 5-6 and 5-7 show selected water chemistry for the Orphan Boy Mine. Concentrations of iron, manganese, and arsenic have decreased or remained unchanged. Zinc concentrations show some variation during 2011–2021 but remain less than 50 µg/L.

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 mine workings through bulkheads that prevent the flow of contaminated water through the mine workings.

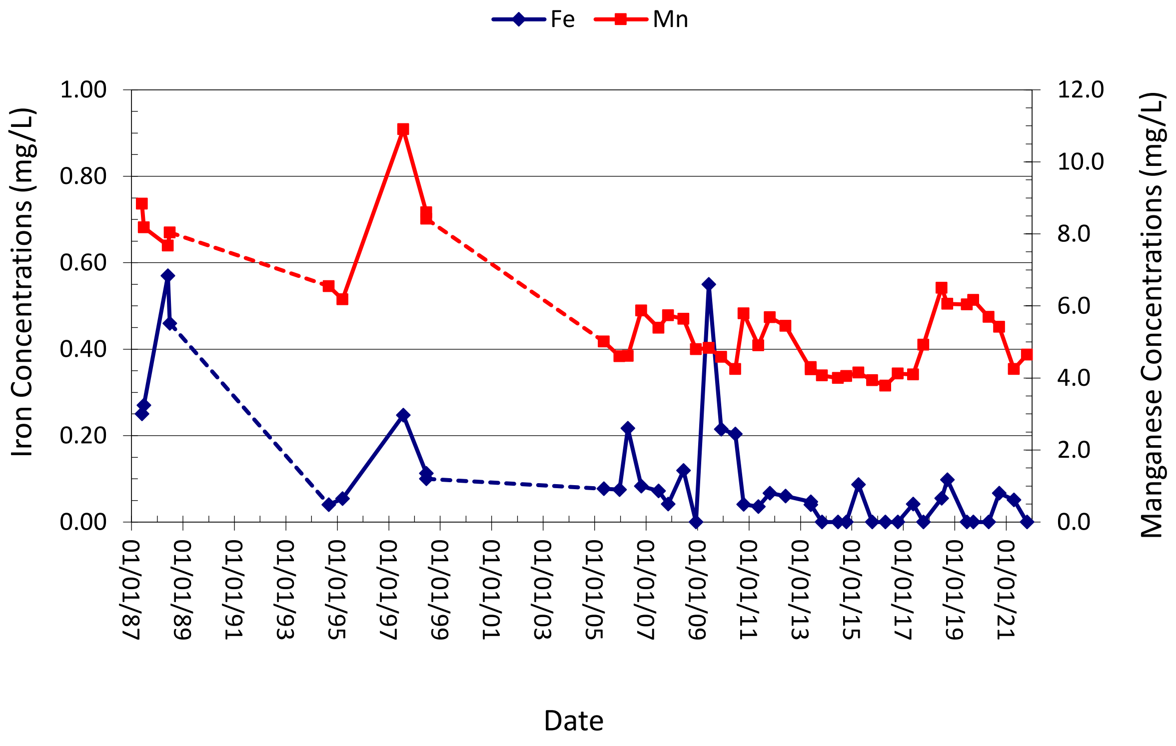


Figure 5-6. Iron and manganese concentrations in water sampled from the Orphan Boy Mine.

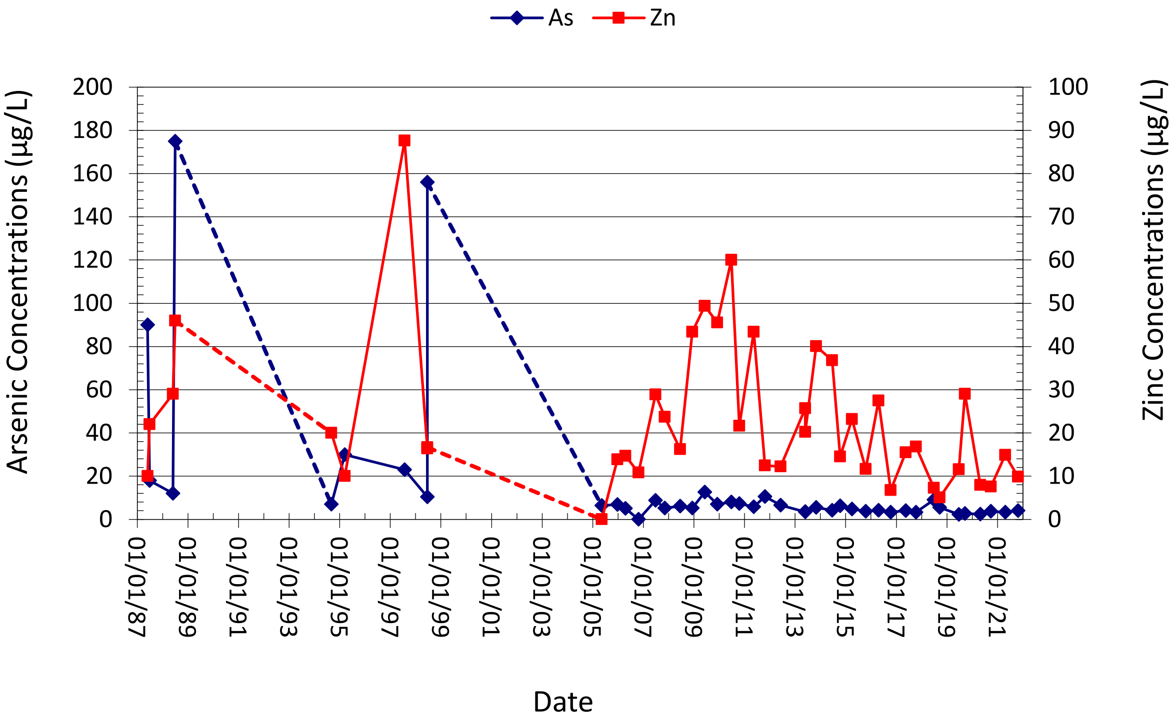


Figure 5-7. Arsenic and zinc concentrations in water sampled from the Orphan Boy mine.

SECTION 6.0 BERKELEY PIT PROTECTIVE LEVEL PREDICTION MODEL

An update to the Berkeley Pit water-level model was completed, updating the model with 2021 data. A new model was developed in 2019 that better addresses current conditions and the implementation of the Pilot Project (Duaime, 2022). The model uses data beginning in 2004 as that coincides with MR's fall 2003 resumption of mining and the start-up of the Horseshoe Bend water-treatment plant. Figure 6-1 shows Berkeley Pit water-level evaluations from 2004 through December 2021 and the start date of the Pilot Project.

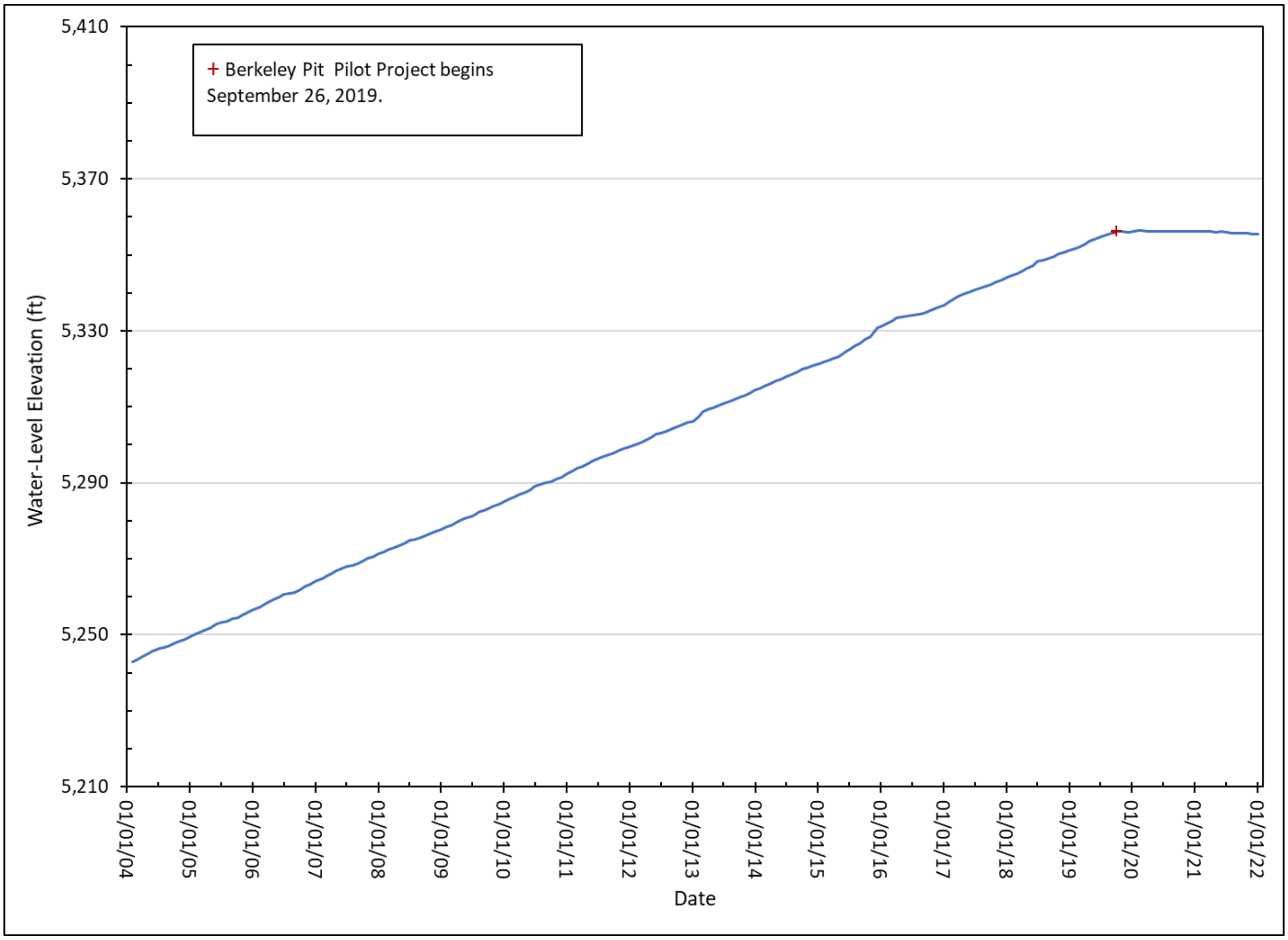


Figure 6-1. Berkeley Pit water-level elevation from 2004 through 2021. The Horseshoe Bend water-treatment plant came online in late 2003 and Horseshoe Bend water was no longer allowed to flow into the Berkeley Pit. The beginning of the Berkeley Pit Pilot Project is also shown.

The Pilot Project controls the filling rate of the pit as shown in figure 6-2, with filling rates remaining below 1 million gallons per day for 2021. Based upon the 2021 model projections, if the Berkeley Pit water pumping (Pilot Project) was suspended on January 3, 2022 (Berkeley Pit water elevation 5,355.42 ft, MSL), the PWL of 5,410 ft at the Pilot Butte Mine would be reached in 4.5 years (1,626 days). (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 the Pilot Butte Mine.) The pit contained 49.4 billion gallons of water at the end of 2021, with a projected volume of 53.4 billion gallons if the PWL is reached. The volume of water in the pit was reduced by 90.4 million gallons in 2021 through the operation of the Pilot Project. Since the Pilot Project began, the volume of water in the pit has been reduced by over 1 billion gallons.

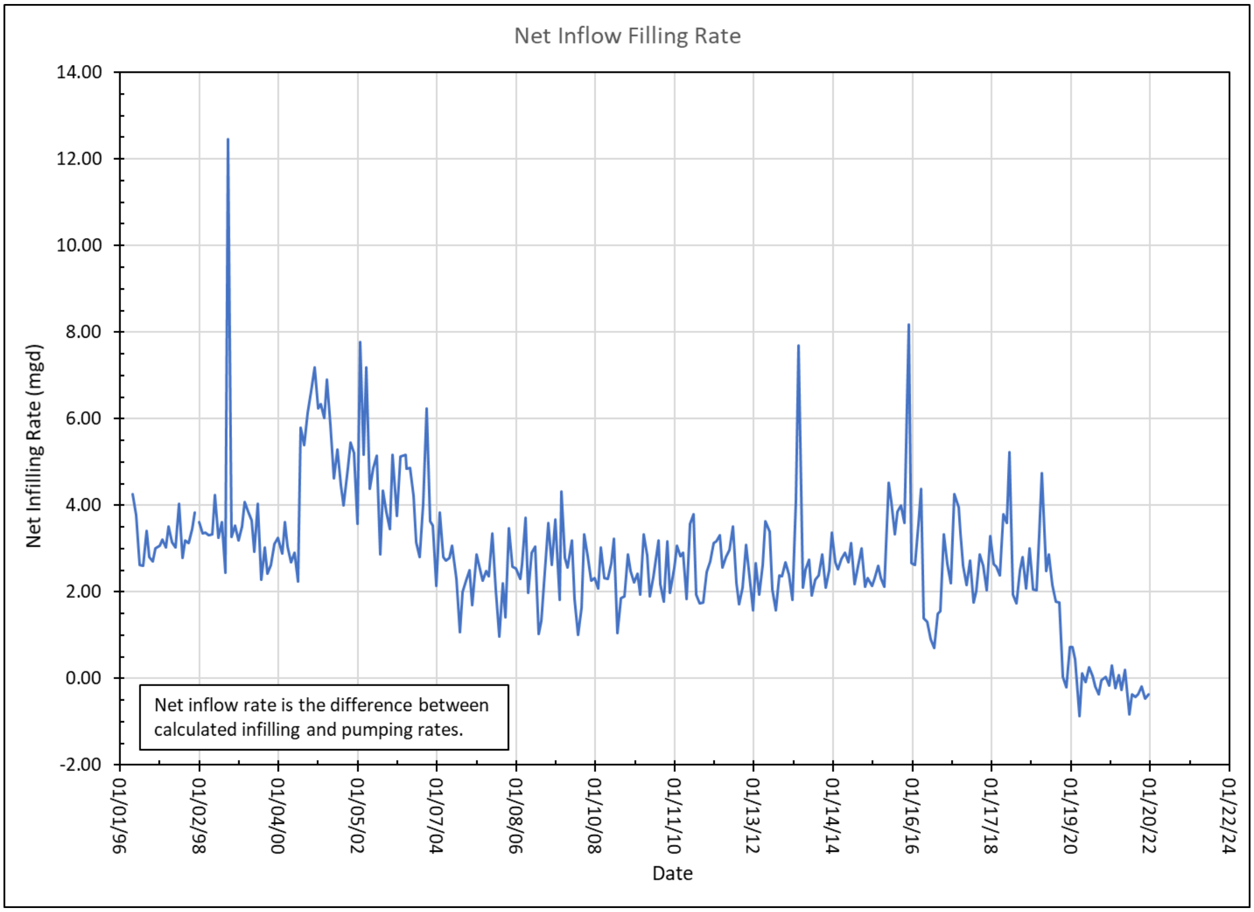


Figure 6-2. Berkeley Pit net filling rate, 1996–2021.

SECTION 7.0 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 and thorium that gives rise to radium isotopes responsible for the emission of alpha and beta particles. ^{226}Radium, an alpha emitter, is a member of the ^{238}Uranium decay series, and ^{228}Radium, a beta emitter, is a member of the ^{232}Thorium 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 thorium/uranium 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 10, 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 and decay 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 (except that it undergoes decay), 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 the DEQ-7 standard 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 DEQ-7 standard, an annual monitoring schedule became part of the BMFOU program.

Section 7.1 Monitoring Results

Table 7.1.1 summarizes the radionuclide data collected from 2003 to 2021. 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 DEQ-7 standard. Approximately 34 percent of the sites monitored have mean values for one or both isotopes that are greater than or equal to the specified DEQ-7 value of 5 pCi/L. The examination of the data over time for each site shows radium activity remains stable, and that sites having markedly higher values of radium isotope activity are clustered near the location of the historic Pittsmont workings near the eastern boundary of the BMFOU (fig. 3.-1).

Table 7.1.1. The mean, maximum, and minimum values of radium isotope activity collected in BMFOU monitoring between 2003 and 2021.

	Radium 226 (pCi/L) DEQ-7[a]	Radium 228 (pCi/L) DEQ-7[a]	Ra 226+228 (pCi/L) DEQ-7[a]	Radium 226 (pCi/L) DEQ-7[a]	Radium 228 (pCi/L) DEQ-7[a]	Ra 226+228 (pCi/L) DEQ-7[a]
	5	5	5	5	5	5
	Anselmo Mine			**Kelley Mine**		
Mean	1.9	2.3	3.7	1.8	2.7	4.4
Min	1.1	1.1	1.1	0.9	1.1	2.3
Max	6.2	5.7	11.9	2.7	4.6	6.9
Number	21	21	21	22	22	22
	Pilot Butte Mine			**Steward Mine**		
Mean	1.7	0.0	1.7	2.2	3.6	5.2
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	18	18	18
	Well A			**Well B**		
Mean	25.4	8.7	34.7	4.2	4.3	8.5
Min	0.9	1.7	21.4	3.0	3.0	3.1
Max	36.9	12.2	45.7	6.3	6.3	12.5
Number	39	39	39	38	41	41
	Well C			**Well D-2**		
Mean	31.0	19.5	50.5	23.7	16.65	40.3
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	36	36	36	35	35	35
	Well E			**Well F**		
Mean	6.3	4.9	11.1	7.6	10.1	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	10	10	10	12	12	12
	Well G			**Well J**		
Mean	13.7	8.9	22.6	39.4	154.7	196.8
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	23	23	23	20	20	20
	Well GM-1					
Mean	1.2	2.1	3.3			
Min	0.7	1.5	2.3			
Max	1.6	2.6	4.2			
Number	6	6	6			

[a] EPA Radionuclides Regulation Final Standard, 2000.

Montana Numeric Water Quality Standards Circular-7, June 2019.

Table 7.1.1.—*Continued.*

	Radium 226 (pCi/L) DEQ-7[a]	**Radium 228 (pCi/L) DEQ-7[a]**	**Ra 226+228 (pCi/L) DEQ-7[a]**	**Radium 226 (pCi/L) DEQ-7[a]**	**Radium 228 (pCi/L) DEQ-7[a]**	**Ra 226+228 (pCi/L) DEQ-7[a]**
	5	**5**	***5***	**5**	**5**	**5**
	Parrot			**LP-8**		
Mean	3.4	4.6	7.5	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	19	19	19	5	5	5
	LP-9			**LP-10**		
Mean	5.8	6.9	12.0	0.7	2.0	2.8
Min	1.7	2.0	2.2	0.2	0.5	0.8
Max	29.1	23.9	47.0	5.3	5.0	9.3
Number	20	20	20	32	32	32
	LP-12			**LP-13**		
Mean	0.6	1.9	2.5	0.5	2.1	2.5
Min	0.2	0.4	0.8	0.2	0.4	0.7
Max	5.5	6.2	6.6	1.0	4.9	5.2
Number	36	36	36	36	36	36
	LP-14			**LP-15**		
Mean	0.3	1.6	1.9	0.3	1.9	2.2
Min	0.1	0.5	0.7	0.1	0.3	0.5
Max	0.8	4.6	4.8	0.6	5.6	6.2
Number	39	39	39	33	33	33
	LP-16			**LP-17**		
Mean	0.5	2.3	2.7	1.3	2.4	3.0
Min	0.2	0.3	0.1	0.6	1.5	1.5
Max	1.1	7.3	8.0	1.9	4.2	5.4
Number	40	40	40	12	12	12
	LP-17R			**AMC-05**		
Mean	1.6	2.9	4.5	6.5	4.3	10.4
Min	0.6	1.1	1.7	5.3	2.7	6.3
Max	2.5	6.1	7.8	8.2	6.6	12.7
Number	16	16	16	19	19	19

[a] EPA Radionuclides Regulation Final Standard, 2000.

Montana Numeric Water Quality Standards Circular-7, June 2019.

Table 7.1.1.—*Continued.*

	Radium 226 (pCi/L) DEQ-7[a] 5	**Radium 228 (pCi/L) DEQ-7[a] 5**	**Ra 226+228 (pCi/L) DEQ-7[a] *5***	**Radium 226 (pCi/L) DEQ-7[a] 5**	**Radium 228 (pCi/L) DEQ-7[a] 5**	**Ra 226+228 (pCi/L) DEQ-7[a] 5**
	AMC-6			**AMC-8**		
Mean	0.5	1.8	2.5	0.4	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	37	37	37	32	32	32
	AMC-12			**AMC-13**		
Mean	0.3	1.2	1.0	0.3	1.6	1.9
Min	0.1	0.2	0.2	0.2	1.3	1.5
Max	0.7	2.0	2.1	0.5	1.8	2.3
Number	18	18	18	3	3	3
	AMC-15			**GS-41D**		
Mean	0.5	2.4	2.8	2.1	3.7	5.1
Min	0.1	0.4	0.6	0.8	2.1	1.1
Max	0.7	5.3	5.8	3.7	5.6	8.9
Number	11	11	11	16	16	16
	GS-41S			**GS-44D**		
Mean	2.0	2.7	3.9	0.6	1.3	1.9
Min	0.8	1.2	1.2	0.1	-2.0	0.1
Max	4.8	4.7	6.5	3.6	1.9	3.6
Number	19	19	19	25	25	25
	GS-44S			**GS-46D**		
Mean	0.4	1.9	2.3	0.4	1.6	2.3
Min	0.2	0.3	0.7	0.2	1.0	2.2
Max	1.3	3.6	4.0	0.7	2.1	2.4
Number	20	20	20	21	21	21
	GS-46S			**BMF05-01**		
Mean	0.3	1.2	1.4	0.5	3.2	3.7
Min	0.0	0.4	0.9	0.1	1.6	2.0
Max	0.5	2.0	2.0	0.7	5.1	5.6
Number	22	22	212	30	30	30

[a] EPA Radionuclides Regulation Final Standard, 2000.
Montana Numeric Water Quality Standards Circular-7, June 2019.

Table 7.1.1.—*Continued.*

	Radium 226 (pCi/L) DEQ-7[a] 5	**Radium 228 (pCi/L) DEQ-7[a] 5**	**Ra 226+228 (pCi/L) DEQ-7[a] *5***	**Radium 226 (pCi/L) DEQ-7[a] 5**	**Radium 228 (pCi/L) DEQ-7[a] 5**	**Ra 226+228 (pCi/L) DEQ-7[a] 5**
	BMF05-02			**BMF05-03**		
Mean	0.3	1.8	2.0	0.2	1.9	2.0
Min	0.1	-0.1	0.2	0.1	0.3	0.6
Max	0.9	5.7	6.0	0.4	4.4	4.4
Number	34	34	34	31	31	31
	BMF05-04			**BMF 96-1S**		
Mean	1.7	2.2	4.3	0.2	2.2	0.0
Min	0.4	0.7	1.4	0.2	2.2	0.0
Max	25.2	7.7	32.9	0.2	2.2	0.0
Number	29	29	29	2	2	2
	BMF96-4			**West Camp Pumping Well**		
Mean	0.3	1.2	1.3	2.2	1.4	2.9
Min	0.0	0.5	0.4	1.9	0.2	2.5
Max	0.7	2.6	3.3	2.5	2.2	3.2
Number	20	20	20	2	2	2
	Emma Mine			**Ophir Mine**		
Mean	2.4	2.7	4.4	0.6	1.3	2.1
Min	1.2	1.7	2.0	0.3	0.2	0.8
Max	3.4	4.2	6.4	0.9	2.2	2.9
Number	21	21	21	20	20	20
	Travona Mine			**Chester Steele**		
Mean	2.0	2.4	4.2	3.1	3.7	6.0
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	17	17	17	22	22	22
	Marget Ann Mine			**Orphan Boy Mine**		
Mean	0.6	1.4	2.1	5.5	3.1	8.6
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	11	11	11	31	31	31

[a] EPA Radionuclides Regulation Final Standard, 2000.

Montana Numeric Water Quality Standards Circular-7, June 2019.

Table 7.1.1.—*Continued.*

	Radium 226 (pCi/L) DEQ-7[a] 5	**Radium 228 (pCi/L) DEQ-7[a] 5**	**Ra 226+228 (pCi/L) DEQ-7[a] 5**	**Radium 226 (pCi/L) DEQ-7[a] 5**	**Radium 228 (pCi/L) DEQ-7[a] 5**	**Ra 226+228 (pCi/L) DEQ-7[a] 5**
		Tech Well			**Green Seep**	
Mean	1.8	3.0	3.9	3.5	2.3	5.6
Min	0.8	0.3	1.0	0.4	0.3	0.8
Max	7.5	6.0	12.4	16.0	7.9	23.9
Number	13	13	13	37	37	37
		BPit, surface			**HsB Weir**	
Mean	0.9	4.2	5.0	1.4	1.6	2.9
Min	0.4	1.6	2.0	0.3	0.8	1.6
Max	1.8	11.9	12.6	3.2	4.2	4.7
Number	16	16	16	31	31	31

[a] EPA Radionuclides Regulation Final Standard, 2000.
Montana Numeric Water Quality Standards Circular-7, June 2019.

SECTION 8.0 CONCLUSION AND SUMMARY

Water-level trends in the alluvial monitoring system within the active mine area changed from those observed in recent years, with water levels decreasing in 12 of the 14 LP-series wells, including those wells north of the Pittsmont Dump. This change is most likely the result of the cessation of leaching operations by MR. Leaching operations provide additional recharge water to the localized groundwater system, resulting in water-level increases. This follows the trends observed from 2004 and earlier, and from 2006 through 2009, of declining water levels 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 to precipitation.

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 changes 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.

The Granite Mountain Mine POC monitoring site was replaced by the installation of a deep bedrock monitoring well (GM-1), located just south of the mine. While the well did not intercept the underground mine workings associated with the Granite Mountain and Speculator Mines, water-level and water-quality monitoring indicate that data collected from well GM-1 are representative of the underground mine system.

Water-level changes in the East Camp bedrock system are independent of precipitation and results from the 1982 cessation of long-term mine dewatering and the implementation of the Pilot Project. The Pilot Project that MR and AR initiated in September 2019 continues to control the water level of the pit, East Camp underground mines, and surrounding bedrock aquifer. Water-level changes throughout the bedrock system varied from a rise of 0.35 ft in well J to a decline of 1.68 ft in well E. The Berkeley Pit water elevation declined 0.63 ft in 2021. The Pilot Project removed over 90.4 million gallons of water from the Berkeley Pit storage during 2021. The diversion of HsB water into the Berkeley Pit during scheduled maintenance activities and unplanned power outages resulted in an additional 12.4 million gallons of water added to the pit and is a typical annual activity.

The revised Berkeley Pit model indicates that the East Camp bedrock system water level would reach the PWL elevation of 5,410 ft in the Pilot Butte Mine in 4.5 years (1,626 days) under the assumption that pumping from the Berkeley Pit was suspended on January 3, 2022. 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 replaces the Anselmo Mine as the POC with the highest water-level elevation.

Semi-annual sampling and vertical profiling in the Berkeley Pit Lake resumed in 2017 and continued throughout 2021, keeping the monitoring program in compliance with the 2002 CD. Sampling and profiling were completed in 2021 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 dissolved iron and arsenic concentrations noted in the 2017–2020 sampling/profiling data continued in 2021. Concentrations of cadmium, copper, and zinc remained similar to those seen in 2011, 2012, and 2017–2020 samples.

Groundwater pumping in the West Camp System continues to control water levels; water levels were about 13 ft below the PWL, as measured in well BMF96-1D, at the end of 2021.

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 large departures from historical trends, particularly with respect to iron concentrations. Based on recent data, the departure likely indicates a change in the chemistry of the 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 DEQ-7 standards in samples from the Chester Steele Park well and Travona and Emma Mines, while radium exceeds the DEQ-7 standards in the Emma Mine and Chester Steele Park well. Concentrations in monitoring well BMF96-4 remain low; however, arsenic exceeded DEQ-7 standards for just the second time since the well was installed in 1996.

The long-term monitoring program continues to provide the level of information required to assess the success of the BMFOU remedy and the ongoing activities undertaken to ensure East Camp and West Camp water levels are maintained below their respective PWL.

SECTION 9.0 ACKNOWLEDGMENTS

The information contained in this report represents the work of many companies and agencies during the past 39 years. Numerous individuals were responsible for data collection prior to the 2002 CD; their dedication and creativity in monitoring and sampling of mine waters provided the information that subsequent work and evaluation relied upon.

The DEQ and the EPA have provided funding for the MBMG to monitor and sample, and to preserve continuity between various studies. This support has been invaluable, as has been their realization that flexibility is needed to conduct this program, allowing modifications in monitoring as conditions change.

The continued cooperation of MR and AR 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.

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Errors and omissions remain the authors’ responsibility.

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