Butte Mine Flooding Operable Unit
Water-Level Monitoring and Water-Quality Sampling
2016 Consent Decree Update
Butte, Montana
1982–2016

prepared for

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

Chuck Tatman, Mark Thompson, and John Burk (MBMG photo)

August 2017

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

Contract No. 415008-TO-2
Montana Bureau of Mines and Geology Open-File Report 700

Butte Mine Flooding Operable Unit
Water-Level Monitoring and Water-Quality Sampling
2016 Consent Decree Update
Butte, Montana
1982–2016

prepared for

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

Region VIII

August 2017

Prepared by

Terence E. Duaime
Steven F. McGrath
Gary A. Icopini
and
Paul R. Thale

Montana Bureau of Mines and Geology
1300 West Park Street
Butte, MT 59701-8997

Contract No. 415008-TO-2

Montana Bureau of Mines and Geology Open-File Report 700

Table of Contents

List of Figures

List of Tables

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 2016, integrated with data collected since 1982, when the Anaconda Company suspended underground mine dewatering and mining in the Berkeley Pit.

Major 2016 observations and developments include:

1. Safety concerns about the stability of the southeast corner of the Berkeley Pit following the February 2013 slump precluded the collection of depth water-quality samples from the pit; however, three surface-grab samples were collected from the Berkeley Pit;
2. Water-level monitoring at the Granite Mountain Mine was suspended mid-2016 due to an obstruction in the shaft and surface safety issues;
3. Scheduled maintenance activities at the concentrator and Horseshoe Bend water-treatment plant and short-term power disruptions resulted in approximately 24.1 million gallons discharged from Horseshoe Bend directly to the Berkeley Pit in 2016;
4. The updated annual Berkeley Pit model resulted in the projected date when the 5,410-ft water-level elevation would be reached at the Anselmo Mine being modified from February 2023 (2015 Report) to June 2023, a change of 4 months. The model accounts for the continued diversion of Horseshoe Bend drainage water away from the pit, discharge of sludge from the treatment plant into the pit, and the diversion of storm water flow from the Butte Hill into the pit;
5. Semi-annual water-quality samples were collected from the replacement well (LP-17R) installed in the fall of 2013, with concentrations increasing for many metals; and
6. Montana Resources continued to divert 1,200 to 2,500 gallons per minute (gpm) from the Horseshoe Bend drainage to leach pad operations.

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

Monitoring and sampling activities during 2016 follow the long-term program outlined in the 2002 Consent Decree. Therefore, some monitoring sites that were part of the early monitoring program have been deleted, while others have been added.

List of Acronyms Used in Text

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

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

Butte Mine Flooding Operable Unit
Water-Level Monitoring and Water-Quality Sampling
2016 Consent Decree Update
Butte, Montana
1982–2016

SECTION 1.0 SITE BACKGROUND

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

Mining expanded and mines deepened as companies followed the rich copper veins. With the expanded mining, improved methods to handle groundwater became necessary; therefore, the companies interconnected mines to drain water to central pump stations to improve efficiency (Daly and Berrien, 1923). The Anaconda Copper Mining Company (ACM), which would eventually control a majority of the underground mines, began interconnecting selected mine levels for draining water to a central pump station as early as 1901. The High Ore and Kelley mines served as central pump stations collecting groundwater and pumping it to the surface (figs. 1-1, 1-2). This acidic and highly mineralized water necessitated specialized pumps and piping. The pumps in the High Ore Mine were made of a phosphor–bronze alloy, whereas the discharge pipes (water column) were made of cast iron and lined with either lead or wood (Febles, 1913). The first common drain level was the 2,800 level, followed by the 3,800 level. The High Ore Mine served as the central pump station from 1901 until 1967, when the pump station was moved to the Kelley Mine. Once the water reached the surface, it was routed to a precipitation plant for copper recovery (fig. 1-3). Once the copper was removed, the water was discharged to SBC. The practice of discharging untreated, acidic, metal-laden water to SBC continued until the late 1950s, at which time the Anaconda Company began adding lime to the water to raise the pH and reduce the mineral content of the water (Spindler, 1977).

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

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

The cost of mining increased as the mines deepened and the ore grades lessened. In July 1955, the Anaconda Company began open-pit mining operations in the Berkeley Pit. As open-pit mining expanded, it consumed some of the underground mines important to Butte's early development (fig. 1-4). Figures 1-5 and 1-6 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. 1-6).

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

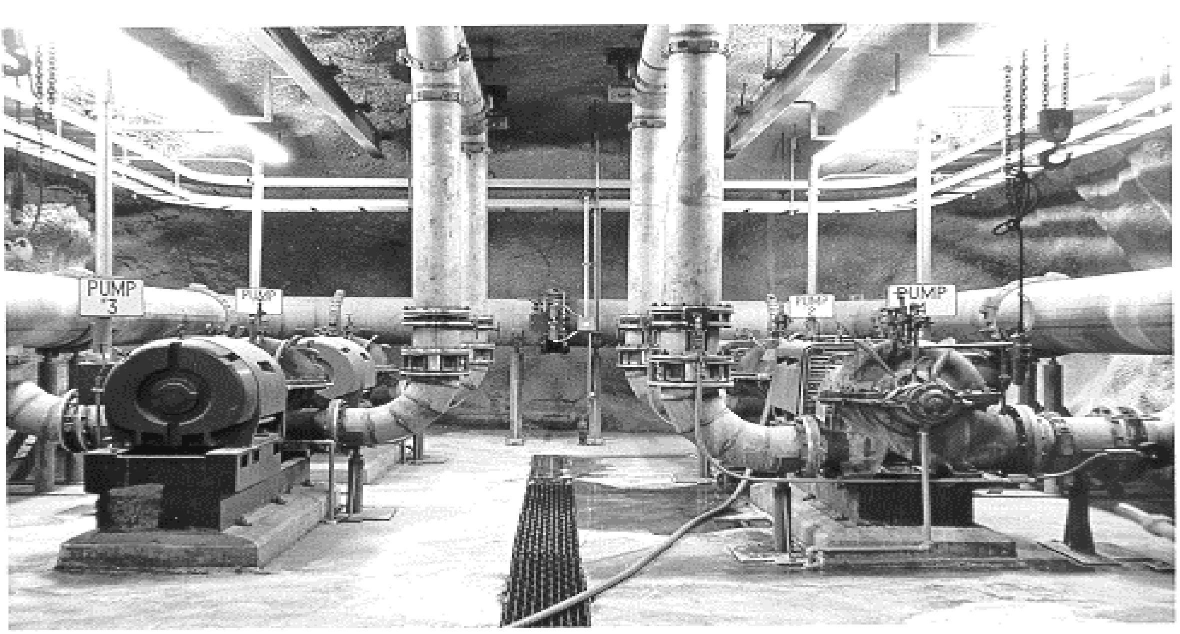


Figure 1-2. Kelley Mine pump station, 3900-ft level. (Photo courtesy World Museum of Mining, Butte, MT.)

Figure 1-3. Flume conveying water pumped from Butte underground mines to precipitation plant. (Photo courtesy World Museum of Mining, Butte, MT.)

Figure 1-4. Location of selected underground mines engulfed by development and expansion of the Berkeley Pit.

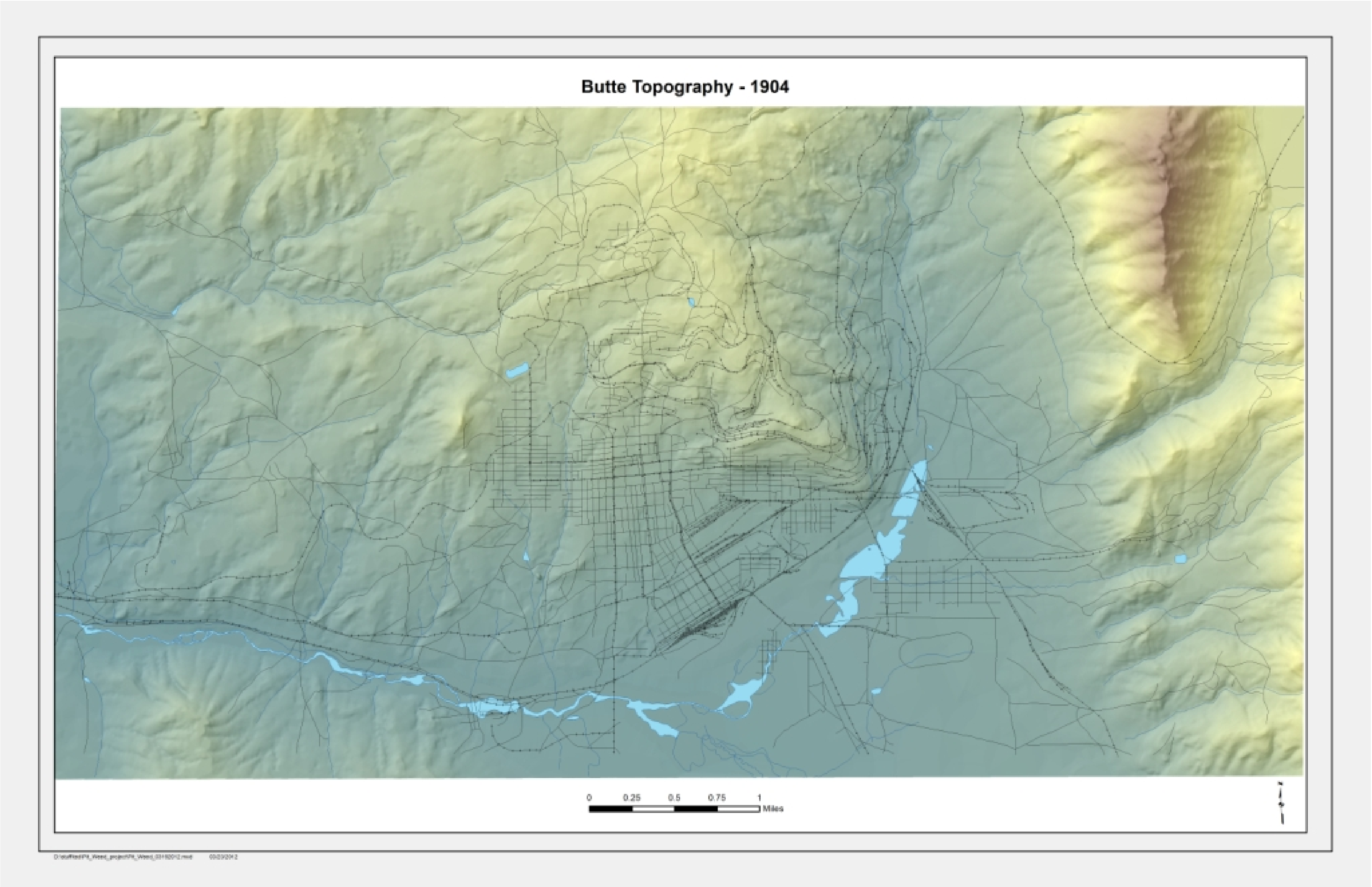


Figure 1-5. Digital elevation model showing Butte topography, 1904.

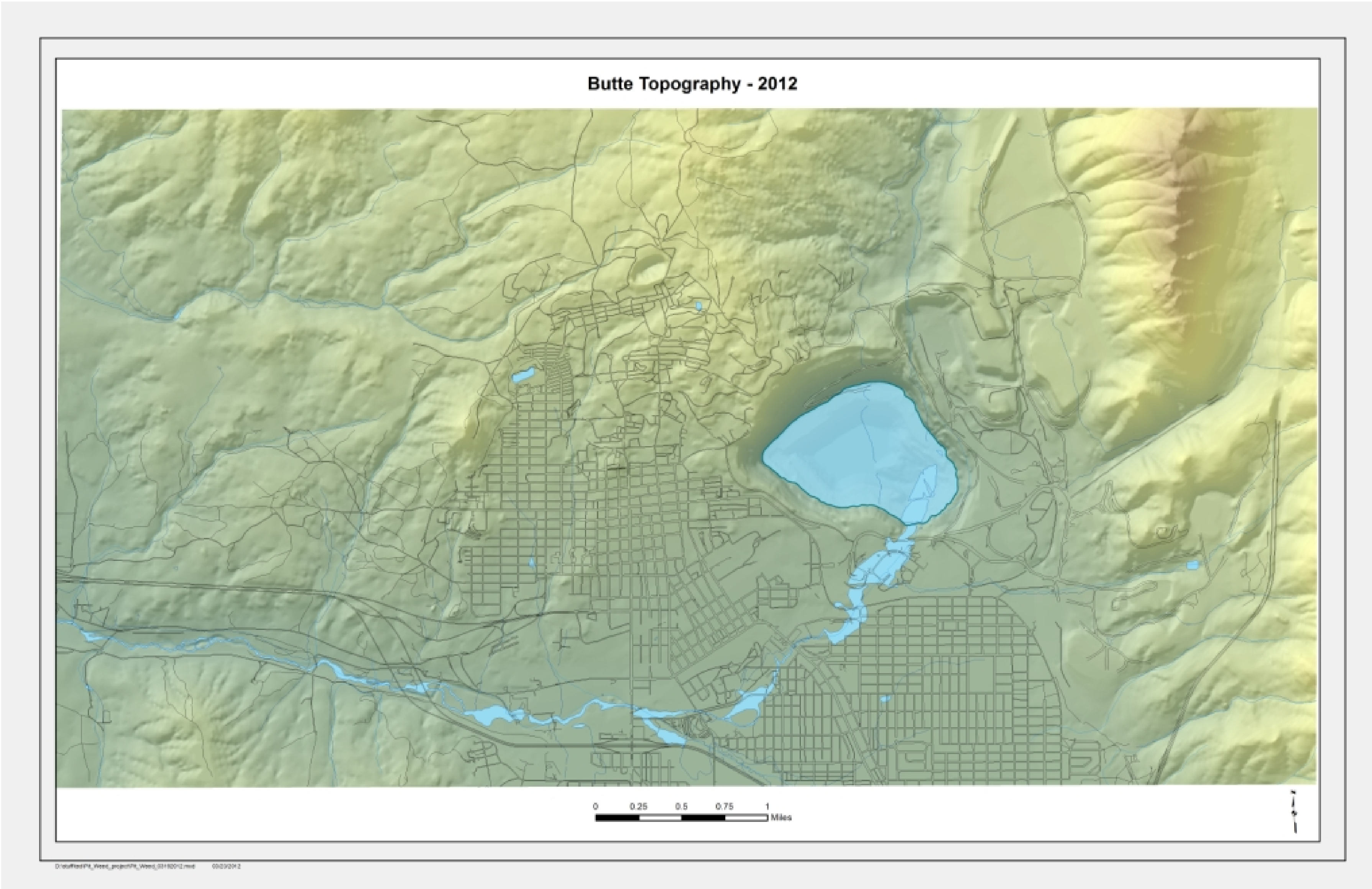


Figure 1-6. Digital elevation model showing Butte topography, 2012.

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

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

The Anaconda Company, which had been purchased by the Atlantic Richfield Company (ARCO) in 1977, sold its Butte operations to Dennis Washington in December 1985, who then formed Montana Resources (MR; Burns, 1994). MR renamed the East Berkeley Pit as the Continental Pit and resumed mining in the Continental Pit 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, Continental Pit, Weed Concentrator, suspension of underground mining, and ancillary activities from 1995 through 2016.

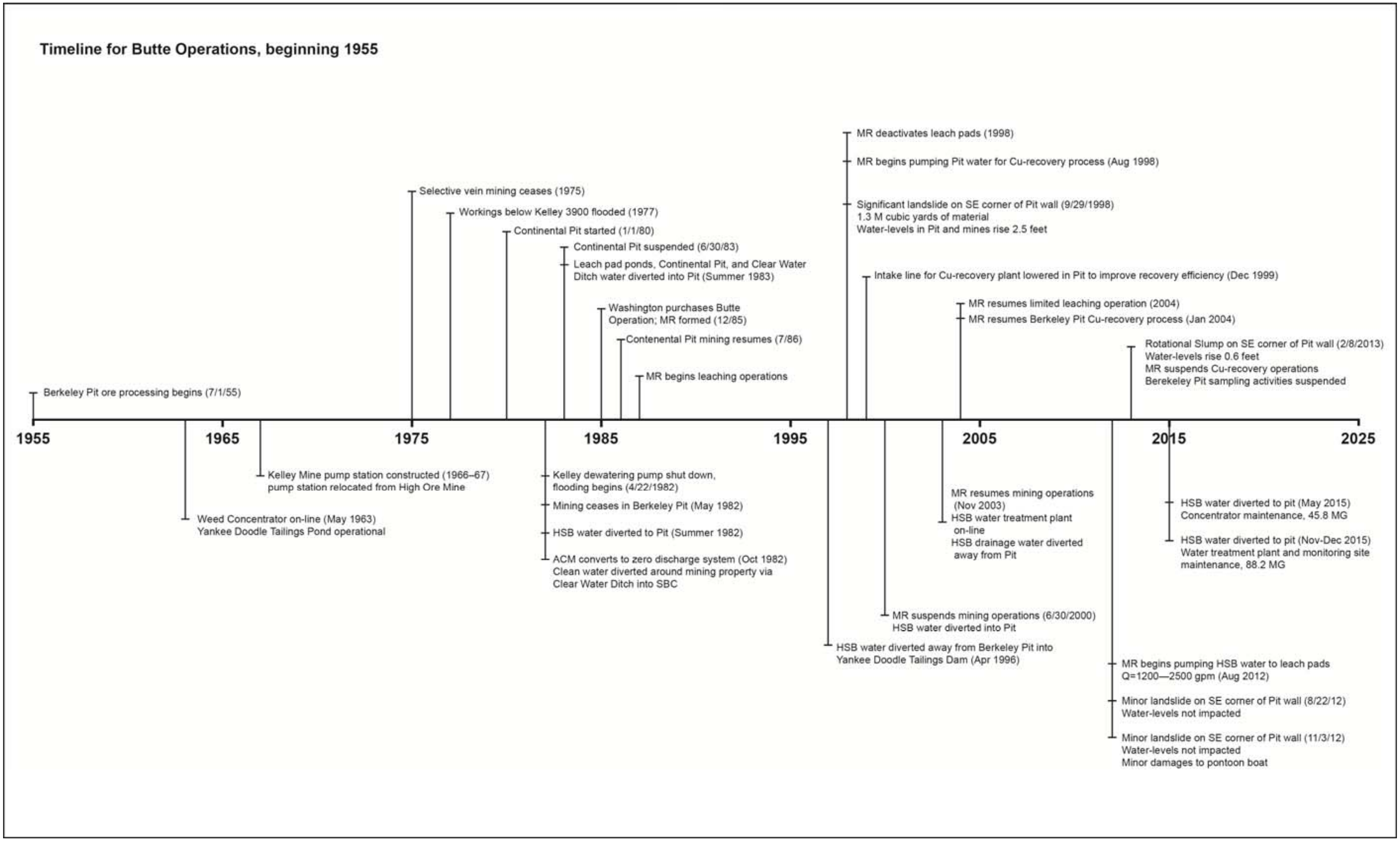


Table 1.0.1 Timeline for Butte operations, 1955–2016.

Section 1.1 Introduction

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

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

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

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

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

(1) East Camp bedrock wells—18;

(2) East Camp Mines—7;

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

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

(5) West Camp mines—3;

(6) West Camp monitoring wells—5; and

(7) Outer Camp mines—2.

The final monitoring network described in the 2002 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 (2016) monitoring program consists of 80 sites, and includes: 61 monitoring wells, 11 mine shafts, and 8 surface-water sites. The Consent Decree monitoring network can be grouped into the following categories:

(1) East Camp bedrock wells—12;

(2) East Camp mines—6;

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

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

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

(6) West Camp mines—3;

(7) West Camp wells—6;

(8) Outer Camp mines—2;

(9) Outer Camp wells—2; and

(10) Surface-water sites—8 (Berkeley Pit, Continental Pit (as appropriate), Horseshoe Bend (2 locations), Clear Water Ditch, Blacktail Creek, Silver Bow Creek, and Outer Camp seep).

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

Butte Mine Flooding Monitoring Sites		Water Level 2002 Consent Decree Monitoring Frequency	**Current Program (2016) WL Monit. Frequency**	Water Quality 2002 Consent Decree Monitoring Frequency	**Current Program (2016) Water Quality Frequency**
East Camp Mines[1]	Anselmo	M	**M**	Annual	**Annual**
	Belmont Well #2	1/4ly	**M**	NS	**NS**
	Granite Mountain	1/4ly	**M**	NS	**NS**
	Kelley	M	**M**	Annual	**Annual**
	Lexington	1/4ly	**M**	NS	**NS**
	Pilot Butte	1/4ly	**M**	NS	**NS**
	Steward	M	**M**	Annual	**Annual**
	Berkeley Pit	M	**M**	Twice/3Depths	**Twice/3Depths**
	HSB[2]	C/M	**C/M**	M	**M**
	Continental Pit[2]	M	**Inactive**	Twice/yr.	**Inactive**
RI/FS Wells - Bedrock	A	C/M	**C/M**	Semi-A	**Semi-A**
	B	M	**C/M**	Semi-A	**Semi-A**
	C	C/M	**C/M**	Semi-A	**Semi-A**
	D-1	1/4ly	**M**	Annual	**Annual**
	D-2	1/4ly	**C/M**	Annual	**Annual**
	E	Annual	**M**	2yrs	**2yrs**
	F	Annual	**M**	2yrs	**2yrs**
	G	C/M	**C/M**	Annual	**Annual**
	J	1/4ly	**C/M**	Annual	**Annual**
DDH Wells	DDH-1	1/4ly	**M/Plugged**	NS	**NS**
	DDH-2	1/4ly	**C/M**	NS	**NS**
	DDH-8	1/4ly	**M**	NS	**NS**
LP Wells	LP-01	1/4ly	**M**	NS	**NS**
	LP-02	1/4ly	**C/M**	NS	**NS**
	LP-03	1/4ly	**P&A**	NS	**NS**
	LP-04	1/4ly	**M**	NS	**NS**
	LP-05	1/4ly	**M**	NS	**NS**
	LP-06	1/4ly	**P&A**	NS	**NS**
	LP-07	1/4ly	**M**	NS	**NS**
	LP-08	M	**M**	Annual	**Annual**
	LP-09	1/4ly	**C/M**	Annual	**Annual**
	LP-10	M	**M**	Semi-A	**Semi-A**
	LP-11	P&A	**P&A**	NS/P&A	**NS/P&A**
	LP-12	M	**C/M**	Semi-A	**Semi-A**
	LP-13	M	**C/M**	Semi-A	**Semi-A**
	LP-14	C/M	**C/M**	Semi-A	**Semi-A**
	LP-15	M	**M**	Semi-A	**Semi-A**
	LP-16	M	**C/M**	Semi-A	**Semi-A**
	LP-17	1/4ly	**P&A**	Annual	**P&A**

Butte Mine Flooding Monitoring Sites		Water Level 2002 Consent Decree Monitoring Frequency	**Current Program (2016) WL Monit. Frequency**	Water Quality 2002 Consent Decree Monitoring Frequency	**Current Program (2016) Water Quality Frequency**
	LP-17R	1/4ly	**C/M**	Annual	**Semi-A**
	MR97-1(3)	1/4ly	**M**	NS	**NS**
	MR97-2(3)	1/4ly	**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**
	AMW-8	1/4ly	**C/M**	NS/Annual	**Annual**
	AMC-10	1/4ly	**M/Dry**	Semi-A	**Semi-A/Dry**
	AMC-12	1/4ly	**M**	Annual	**Annual**
	AMC-13	1/4ly	**M**	NS	**NS**
	AMC-15	1/4ly	**M**	2yrs	**2yrs**
	AMW-22	1/4ly	**M**	NS	**Annual**
GS Wells	GS-41S	C/M	**C/M**	Annual	**Annual**
	GS-41D	C/M	**C/M**	Annual	**Annual**
	GS-44S	C/M	**C/M**	Annual	**Annual**
	GS-44D	C/M	**C/M**	Annual	**Annual**
	GS-46S	C/M	**C/M**	Annual	**Annual**
	GS-46D	C/M	**C/M**	Annual	**Annual**
BMF05 Wells	BMF05-1	M	**C/M**	Semi-A	**Semi-A**
	BMF05-2	M	**C/M**	Semi-A	**Semi-A**
	BMF05-3	M	**C/M**	Semi-A	**Semi-A**
	BMF05-4	M	**C/M**	Semi-A	**Semi-A**
Park Wells	Chester Steele	1/4ly	**M**	Annual	**Annual**
	Hebgen	1/4ly	**M**	NS	**NS**
	Belmont #1	1/4ly	**M**	NS	**NS**
	Parrott	1/4ly	**C/M**	Annual	**Annual**
West Camp Mines	Emma	1/4ly	**M**	Annual	**Annual**
	Ophir	1/4ly	**C/M**	Annual	**Annual**
	Travona	1/4ly	**C/M**	Annual	**Annual**
West Camp Wells	WCPW-1	No	**No**	1/4ly-Pumping	**1/4ly-Pumping**
	BMF96-1D	C/M	**C/M**	NS	**NS**
	BMF96-1S	C/M	**C/M**	NS	**NS**
	BMF96-2	1/4ly	**C/M**	NS	**NS**
	BMF96-3	1/4ly	**C/M**	NS	**NS**
	BMF96-4	C/M	**C/M**	Annual	**Annual**
Outer Camp Mines	Orphan Boy	Replace	**C/M**	Annual	**Semi-A**
	Orphan Girl(4)	M	**Drop**	Annual	**Drop**
	Marget Ann	1/4ly	**M**	2yrs	**2yrs**
Outer Camp Wells	S-4	1/4ly	**M**	NS	**NS**
	Tech Well	1/4ly	**M**	2yrs	**2yrs**

Butte Mine Flooding Monitoring Sites	Water Level 2002 Consent Decree	Current Program (2016)	Water Quality 2002 Consent Decree	Current Program (2016)
	Monitoring Frequency	WL Monit. Frequency	Monitoring Frequency	Water Quality Frequency
Seep	Semi-A	**M**	Semi-A	**Semi-A**

Green Highlighted Cells—identifies increased level of monitoring/sampling from that specified in CD.
(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 re-established at the Orphan Boy Mine; therefore, plans for monitoring using the Orphan Girl Mine were dropped.

M- Monthly

C/M- Continuous and monthly

NS- No Sampling

P&A- Plugged and Abandoned

SA=Semi-A=Semi-Annual

1/4ly- Quarterly

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

(1) Anselmo Mine,

(2) Granite Mountain Mine,

(3) Kelley Mine,

(4) Pilot Butte Mine,

(5) Lexington Mine,

(6) Steward Mine,

(7) Sarsfield Shaft (Continental Pit),

(8) Belmont Well #2,

(9) Bedrock Well A,

(10) Bedrock Well C,

(11) Bedrock Well D-1,

(12) Bedrock Well D-2,

(13) Bedrock Well G, and

(14) Bedrock Well J.

The CWL 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 (1983–2016), the highest POC water-level elevation has always been more than 20 ft above the Berkeley Pit water-level elevation. Based upon this record, at the time a POC water level approaches the 5,410 ft above mean sea level (msl) elevation, the water level within the Berkeley Pit would still be below 5,390 ft msl, more than 50 ft below adjacent alluvial water levels and 100 ft below the lowest point on the pit rim. The water level in the Berkeley Pit would have to rise to an elevation of 5,460 ft msl to reverse the groundwater gradient and cause water to flow away from the pit (fig. 1-7).

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

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

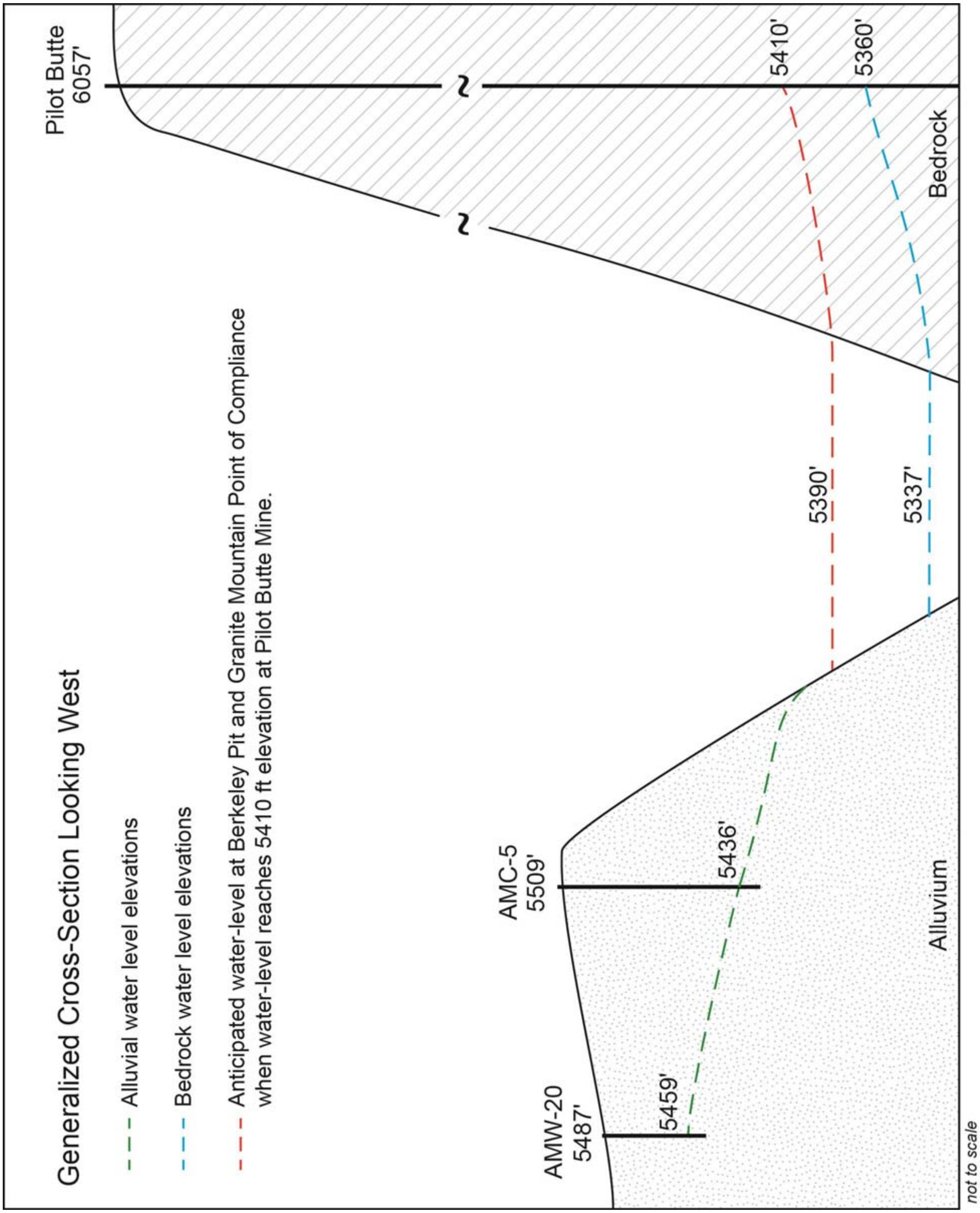


Figure 1-7. Generalized cross section looking west through the Berkeley Pit depicting water-level elevations in bedrock and alluvial systems in December 2016 and projected elevations when the 5,410 Critical Water Elevation is reached at the Pilot Butte Mine.

By the time water levels in the underground mines reached the elevation of the bottom of the Berkeley Pit in late November 1983, more than 66 percent of the underground workings had been flooded. More than 85 percent of the underground mine workings have been inundated with water through 2016. The upper 12 percent of the underground workings will never be flooded, as they are at elevations above the specified CWL; therefore, less than 3 percent of the underground workings remain to be flooded.

This document is the 21st BMFOU report and summarizes 35 years of data collection. Notable changes and an evaluation of water-level and water-quality trends are presented. This report presents a general overview of the history of mining on the Butte Hill and the Superfund processes that have followed since the EPA designated the flooding underground Butte Mines and Berkeley Pit a Superfund site in 1987. Readers are referred to the Butte Mine Flooding RI/FS, Butte Mine Flooding ROD, Butte Mine Flooding CD, and MBMG Open-File Report 376 for additional details and information.

The MBMG continued monitoring activities in 2016 in the East Camp, West Camp, and Outer Camp systems (fig. 1-8). The East Camp System includes mines and mine workings that drained to the Kelley Mine pump station at the time mining and dewatering were suspended in 1982. The West Camp System includes mines and underground workings that historically drained to the East Camp from the southwest portion of the Butte mining district, but were hydraulically isolated from the East Camp by the placement of bulkheads within the mine workings. The Outer Camp System consists of extended western and northern mine workings that were at one time also connected to the East Camp, but hydraulically isolated many decades ago. The hydraulic separation has allowed Outer Camp System water levels to return to, or approach, pre-mining conditions. The MBMG developed a Sampling and Analysis Plan based upon the requirements of the 2002 CD that identifies how the monitoring program is carried out (MBMG, August 2002, updated April 2011). Groundwater monitoring and water-quality sampling follow closely the methods described in the Clark Fork River Superfund Site Investigations Standard Operating Procedures (ARCO, 1992).

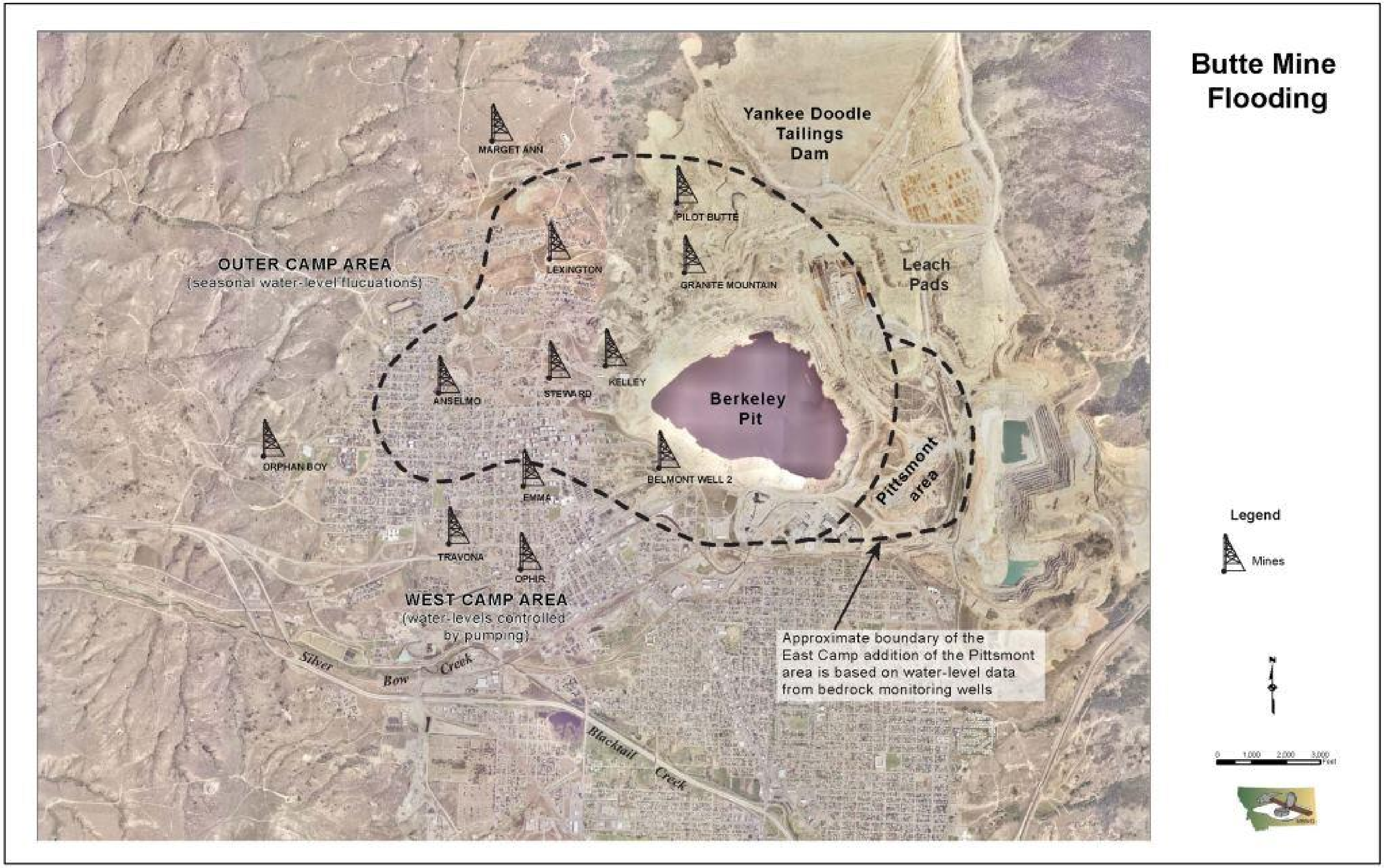


Figure 1-8. The mines of the Butte Hill are currently considered in three groups: the East Camp, which includes the Berkeley Pit and the area to the east; the West Camp, in the southwest; and the Outer Camp, which includes the outlying mines.

Section 1.2 Notable 2016 Activities, Water-Level and Water-Quality Observations

Several mine-operations-related maintenance activities occurred that increased water levels throughout the East Camp bedrock system (which includes the Berkeley Pit). No other significant events occurred in 2016 that influenced water levels, water quality, or monitoring activities. The main activities and observations for 2016 are listed below:

(1) MR continued mining and milling operations throughout 2016.

(2) Water-level monitoring at the Granite Mountain Mine was temporarily suspended due to an obstruction in the shaft at a depth of approximately 420 ft. Unsafe surface conditions preclude safe access to the shaft for further inspection and determination of the cause of the obstruction.

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

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

(5) Berkeley Pit sampling was limited to three opportunistic surface (1-ft depth) grab samples, due to continued safety concerns following the February 2013 rotational slump in the southeast corner of the Berkeley Pit.

(6) Development of a remotely operated boat and sampling/monitoring equipment began as an alternate Berkeley Pit sampling method.

Section 1.3 Precipitation Trends

Total precipitation for 2016 was 10.60 in., compared to 11.91 in. in 2015. The 2016 amount is 2.07 in. below the long-term (1895–2016) average (NOAA 1999 and AccuWeather.com, 2017). Precipitation totals have been below average for 6 of the past 10 years and 20 of the past 35 years. The 2016 precipitation total was a decrease of 14.7 percent from the 1982–2016 average of 12.44 in. Table 1.3.1 contains monthly precipitation statistics from 1982 through 2016, while figure 1-9 shows this information graphically in comparison to the long-term yearly average. Overall precipitation totals since flooding of the mines began are very similar to the long-term average (12.44 in vs. 12.67 in). Figure 1-10 shows departure from normal precipitation from 1895 through 2016.

Table 1.3.1 Butte Precipitation Statistics, 1982–2016.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean	0.43	0.40	0.74	1.08	1.92	2.22	1.34	1.33	1.07	0.81	0.61	0.50	12.44
Std. Dev.	0.31	0.28	0.40	0.65	0.77	1.19	1.00	0.90	0.77	0.58	0.39	0.35	2.80
Maximum	1.40	1.26	1.84	3.20	3.88	4.62	4.18	3.10	2.99	2.31	1.50	1.99	19.96
Minimum	0.09	0.11	0.11	0.00	0.81	0.50	0.00	0.09	0.03	0.00	0.07	0.01	8.32
Years precipitation has been greater than mean													15
Years precipitation less than mean													20

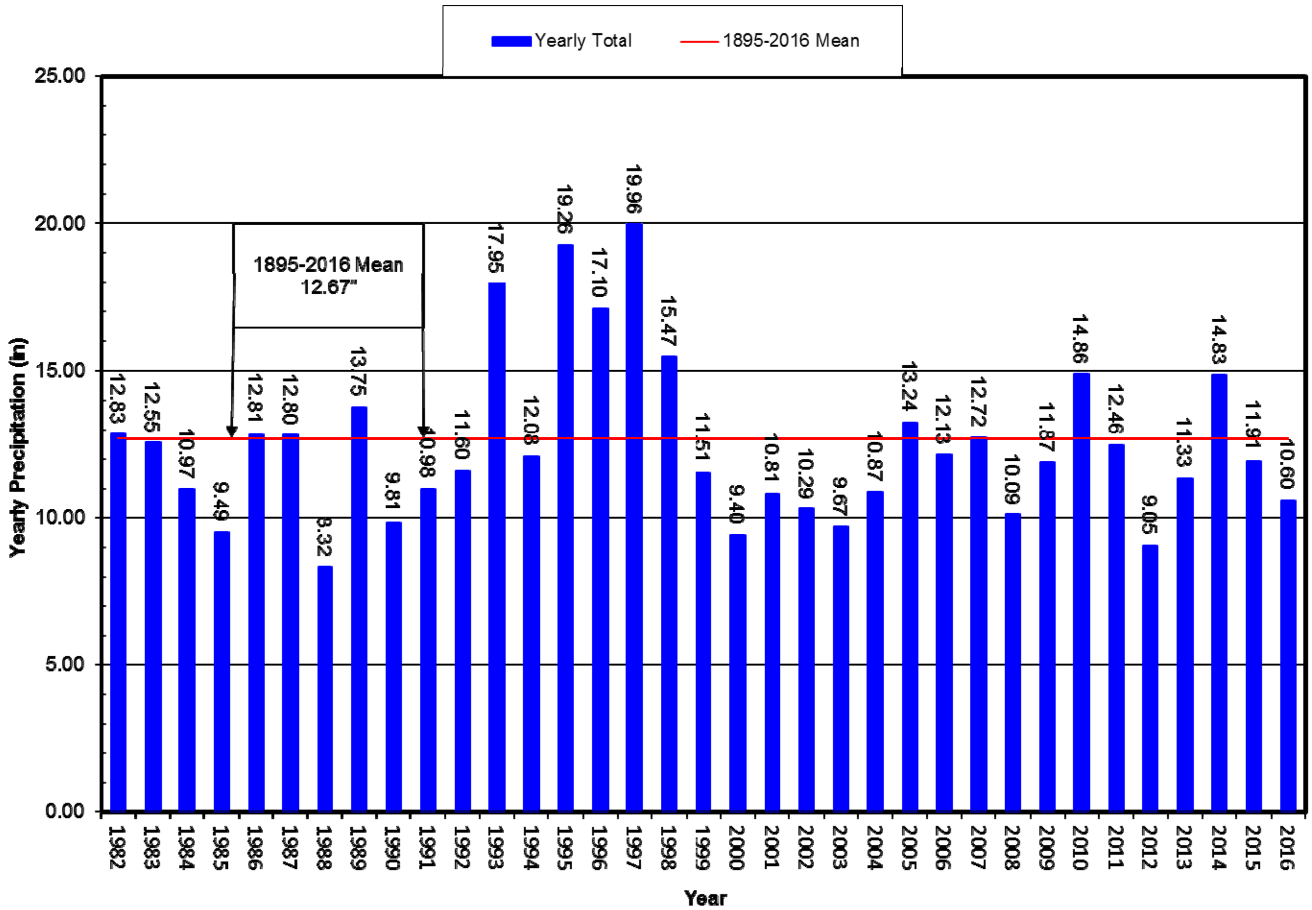


Figure 1-9. Yearly precipitation totals 1982–2016, showing 1895–2016 mean.

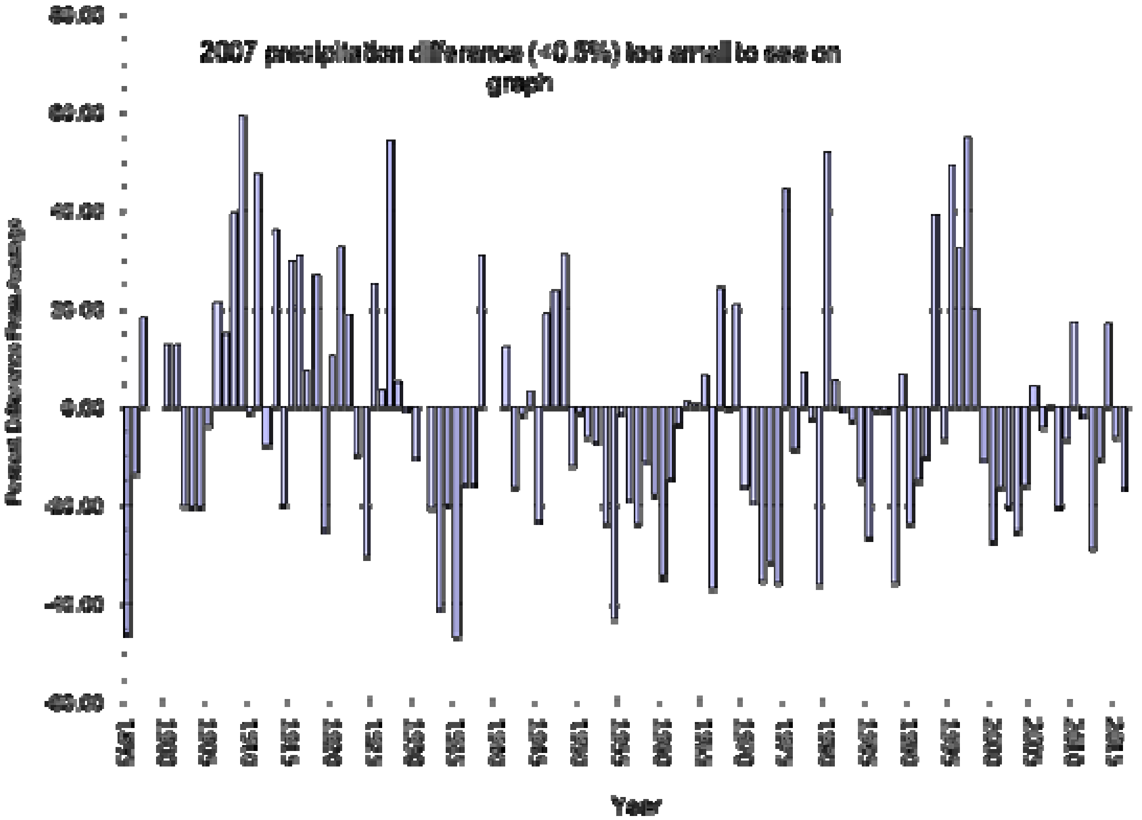


Figure 1-10. Percentage precipitation variation from normal, 1895–2016.

SECTION 2.0 EAST CAMP ALLUVIAL SYSTEM

The East Camp alluvial system includes the alluvial aquifer within the active mine area and a portion of the alluvial aquifer outside the active mine area, primarily to the south (fig. 2-1).

The East Camp alluvial groundwater monitoring system consists of the LP- and MR97-series wells located within the active mine area, and selected AMC, GS, AMW, and BMF05 series wells. All wells in the latter four groups are located south of the active mine area, with the exception of wells AMC-5 and AMC-15, located within the mine area. Each group of wells represents sites installed or monitored during different studies now incorporated into the BMFOU-CD monitoring program.

Four new alluvial monitoring wells were installed within the East Camp system in late 2005 and early 2006 as stipulated in the 2002 Consent Decree. These wells replaced domestic wells that were monitored from 1997 through 2002. The new wells were situated in areas of limited data and were equipped with transducers for increased water-level data collection. The new series was named "BMF05-wells" and is discussed with the GS-series wells. Water-quality samples were collected three times annually throughout 2007 (to help establish baseline conditions) and semi-annually thereafter.

Water-level elevations and monthly precipitation amounts are shown on hydrographs for selected wells. Water-quality results are shown and discussed for the sampled wells. Unlike the water-level monitoring program, water-quality sampling did not occur at every East Camp monitoring well and occurred only once or twice annually.

Water-level conditions and water-quality characteristics vary throughout the alluvial system. Data from wells within or adjacent to historic mining activities show the influence of those activities, i.e., elevated metal concentrations. Data from sites outside historic mining areas reflect conditions typical of the regional hydrogeology.

In late September 1998, a significant landslide occurred in the southeast corner of the Berkeley Pit. The landslide caused an almost immediate 3 ft water-level rise in the Berkeley Pit, East Camp mines, and bedrock groundwater system. However, the landslide influenced water levels in parts of the East Camp alluvial system by causing water levels to fall 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). Labels on hydrographs here and in subsequent sections indicate the date of the landslide and water level in wells just prior to the landslide for the reader’s benefit.

Figure 2-1. East Camp alluvial monitoring wells.

Section 2.1 AMC-Series Wells

The locations of the Anaconda Mining Company (AMC) wells are shown in figure 2-2; table 2.1.1 lists the annual water-level changes for these sites. Water levels decreased in five of seven AMC-series wells for 2016, and well AMC-10 remained dry (it has been dry since its installation in 1983). The general decrease in water levels during 2016 is most likely due to the below-average precipitation. Water levels had a net decline during the first 20 years of monitoring, followed by a net increase the next 10 years; however, water levels have declined in five of six wells in the past 4 years. Over the entire period of record, there are net water-level declines of 3.8 ft to more than 27.5 ft in six wells, with one well dry.

Well AMC-5 is located within the active mine area; wells AMC-6 and AMC-8 are located south of the active mine area and the Butte Concentrator (fig. 2-2). Well AMC-12 is located southwest of these wells. Hydrographs for wells AMC-5 and AMC-12 (fig. 2-3), and AMC-6 and AMC-8 (fig. 2-4), are typical of the data set and show the long-term trends in the shallow alluvial groundwater system south of the pit. Monthly precipitation is shown as bars and plotted on the right-hand y-axis.

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 Emergency (Dredge) and Ecology ponds, located in the southwest corner of the concentrator yard (fig. 2-2). The Emergency (Dredge) Pond was re-flooded in fall 2003 prior to MR's start-up. The water-level trend in AMC-5 for 2003–2005 shown in figure 2-3 is similar to the trend seen in 1986–1987, which coincides with the start-up of mining following ARCO's 1983 suspension. It appears that filling the Emergency (Dredge) Pond with make-up water for milling operations influences nearby alluvial water levels. While periodic water-level increases coincide somewhat with early spring precipitation, the overall water-level trends for 2006 through 2016 do not appear to consistently respond to seasonal precipitation changes; it is more likely a response to operational changes within MR's water-handling system.

Well AMC-12 water levels between 2001 and 2005 generally declined and may have been related to the construction completion of the BPSOU sub-drain, which underlies the SBC channel above the confluence with Blacktail Creek. Water-level increases during 2006–2007 resulted in a net rise of 1.56 ft (fig. 2-3); these water-level increases may be due to the completion of the sub-drain, and the periodic discharge of clean water to the SBC channel. Annual water-level changes were <0.1 ft during 2008–2010; the 2011 change (increase) was the largest (1.13 ft) since 2006, which may be related to MR's cleaning of the Ecology Pond. The 2013 water-level decline may have been in response once again to the draining and discontinued use of the Ecology Pond. Seasonal trends are noticeable on the well hydrograph.

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

Year	AMC-5	AMC-6	AMC-8	AMC-10	AMC-12	AMC-13	AMC-15
1983	-23.75	-2.30	-4.90	DRY	0.20	0.60	-5.80
1984	-4.50	-2.55	-3.75	DRY	-1.80	-1.10	-3.40
1985	-3.60	-4.05	-2.55	DRY	-2.75	-2.15	-2.90
1986	6.10	2.40	-0.40	DRY	0.10	-0.20	-1.60
1987	0.10	0.60	1.30	DRY	0.70	0.20	0.30
1988	0.20	-0.60	-0.20	DRY	-0.10	-1.00	0.80
1989	-2.30	-0.80	-0.90	DRY	-0.20	-0.10	0.10
1990	0.20	0.10	0.30	DRY	1.10	0.00	-0.10
1991	0.00	0.30	0.80	DRY	-0.60	0.30	-0.30
1992	0.40	-0.40	0.50	DRY	-0.30	0.00	-0.10
Change Yrs. 1–10	**-27.15**	**-7.30**	**-9.80**	**0.00**	**-3.65**	**-3.445**	**-13.00**
1993	0.40	0.70	0.80	DRY	1.10	1.00	-0.40
1994	0.64	0.53	0.91	DRY	-0.19	-0.50	0.96
1995	0.64	1.01	0.51	DRY	1.23	1.13	0.97
1996	-0.05	0.62	2.14	DRY	0.74	0.69	2.60
1997	1.80	1.47	2.24	DRY	1.20	0.70	2.80
1998	-1.52	0.42	0.40	DRY	0.18	0.09	0.58
1999	-1.56	-2.03	-1.70	DRY	-1.56	-1.09	-1.50
2000	-2.46	-2.56	-3.88	DRY	-1.77	-1.17	-3.73
2001	-1.89	-1.92	-3.03	DRY	-0.55	-0.36	-2.34
2002	-0.89	-1.25	-1.77	DRY	-0.98	-0.73	-1.65
Change Yrs. 11–20	**-4.89**	**-3.01**	**-3.38**	**0.00**	**-0.60**	**-0.24**	**-1.71**
2003	6.97	3.50	0.97	DRY	0.53	0.03	0.37
2004	-1.13	0.44	1.42	DRY	-0.37	-0.42	0.38
2005	-1.68	-1.06	-0.45	DRY	-0.51	-0.22	-0.76
2006	0.73	0.97	2.72	DRY	1.24	0.72	1.72
2007	1.07	0.63	1.14	DRY	0.32	0.55	1.12
2008	-0.23	-0.50	-0.26	DRY	-0.06	-0.42	0.70
2009	0.05	0.57	2.53	DRY	0.04	1.02	0.35
2010	0.49	-0.03	-0.37	DRY	-0.10	-0.63	1.25
2011	0.41	1.90	1.87	DRY	1.13	0.59	0.86
2012	-0.77	-2.16	-2.10	DRY	-1.08	-0.49	-1.77
Change Yrs. 21–30	**5.91**	4.26	7.47	**0.00**	1.14	0.73	4.22
2013	-1.43	-1.34	-1.87	DRY	-0.83	-0.52	-2.18
2014	1.72	0.57	-0.67	DRY	0.60	0.45	-0.07
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
Change Yrs. 31–40	**-1.43**	**-1.91**	**-0.97**	**0.00**	**-1.28**	**-0.92**	**-3.15**
Net Change	**-27.56**	**-7.96**	**-6.68**	**0.00**	**-4..39**	**-3.88**	**-13.64**

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

Figure 2-2. AMC well location map.

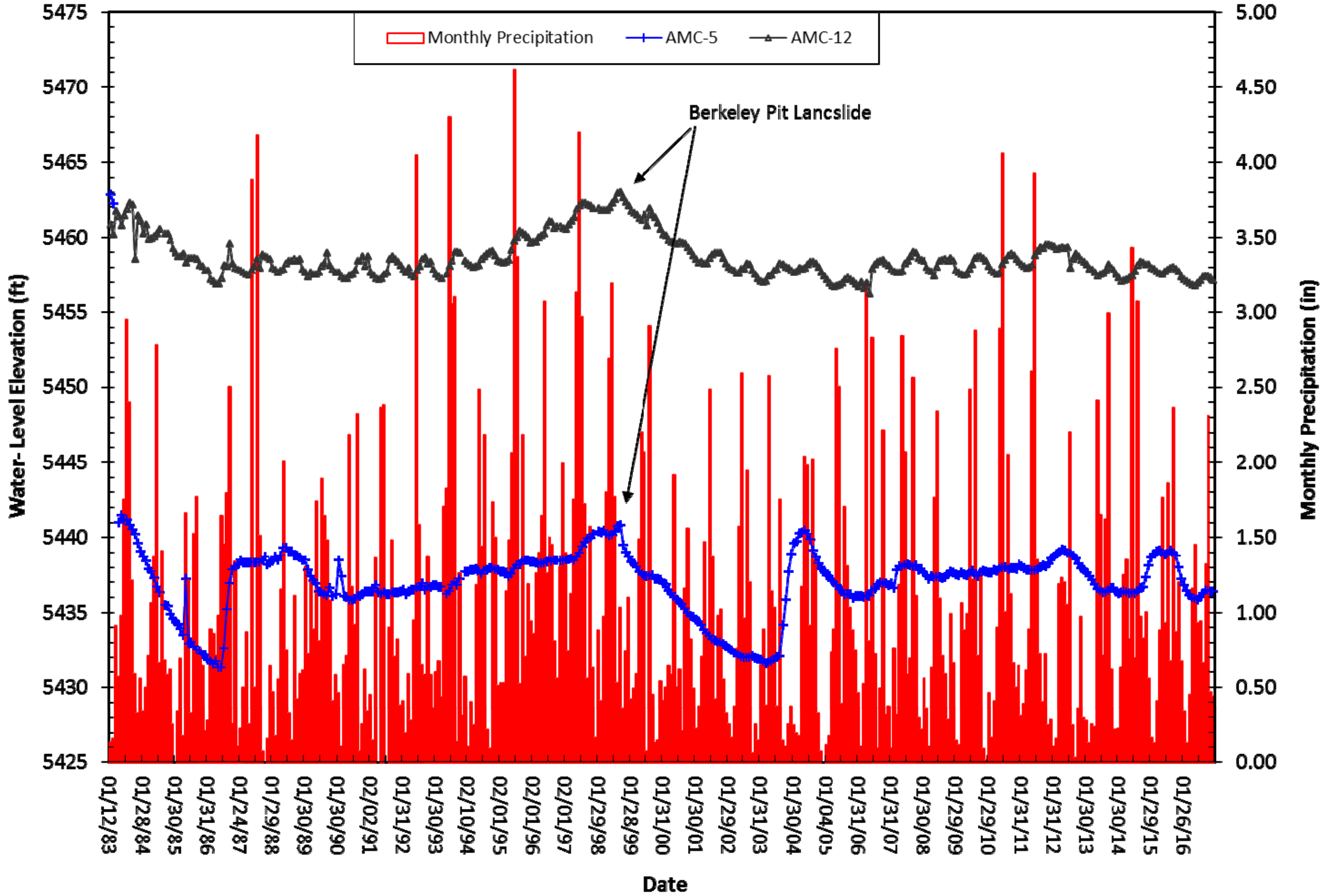


Figure 2-3. Water-level hydrographs for wells AMC-5 and AMC-12.

Well AMC-6 is directly south of the concentrator facility and the Emergency (Dredge) and Ecology ponds. Water-level changes during 2003–2004 were similar to those seen in 1986–1987 following the resumption of mining. During 2011, water levels continued to rise throughout the entire year (May–December), with the increase most likely associated with operational/maintenance activities associated with mining/milling operations. During summer 2011, MR emptied the Ecology Pond to remove accumulated sediment, and then refilled it, resulting in a continued water-level rise beginning in October (fig. 2-4) and continuing throughout the remainder of the year. It appears the removal of sediment from the pond increased leakage and recharge to the shallow alluvial aquifer. MR drained the Ecology Pond in early 2012 followed by capping and re-contouring of the area. The water-level decrease in well AMC-6 during 2012 and 2013 may be the result of 2012 activities. A water-level response in AMC-6 has almost always been 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. Although water levels had a net decline for 2005, they increased slightly during the late fall–early winter in apparent response to precipitation; water levels continued to rise throughout almost all of 2006 and 2007, apparently independent of climatic trends. Water levels continued their upward trend through 2008; however, there was more of a seasonal pattern in 2009–2010 than seen during the past several years. Water levels followed a downward trend similar to those seen in AMC-6, throughout 2013 with no seasonal variation. Water levels exhibited a more seasonal trend during 2014–2015; water levels rose almost continuously throughout 2016, resulting in an almost 2.5 ft rise.

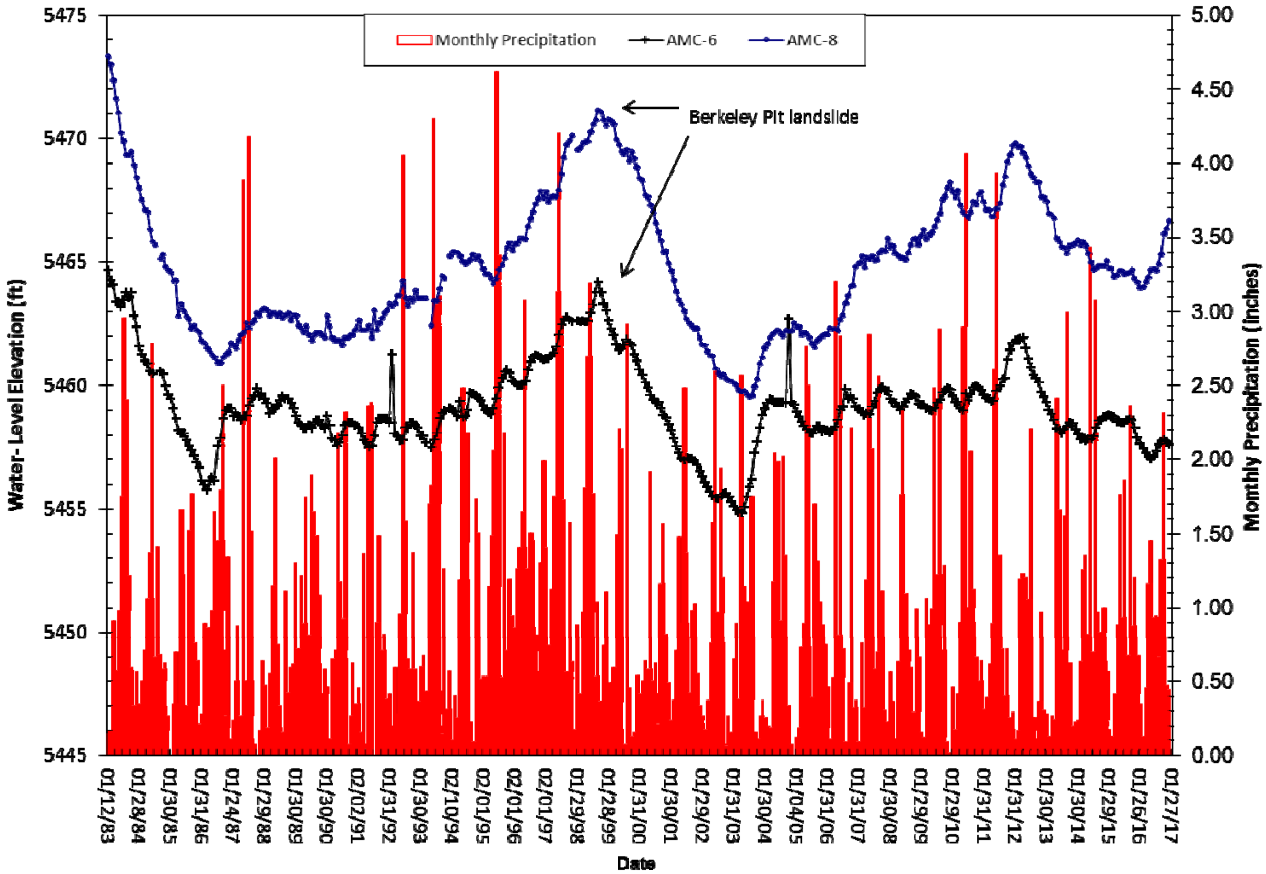


Figure 2-4. Water-level hydrographs for wells AMC-6 and AMC-8.

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

Well AMC-15 is located on the west side of the Hillcrest waste dump (fig. 2-2) in a reclaimed area. Water in this well is much deeper (about 90 ft below land surface) when compared to the other AMC wells, requiring a longer time for infiltration to reach the water table, and the hydrograph reflects this. There were minor seasonal changes in water levels for a number of years. The influence of below-normal precipitation is shown by the steep decline in water levels beginning in late 1999 (fig. 2-6), when this well did not show any significant response to precipitation. The water-level decline began leveling off in mid-2003, when the water level rose almost one-half foot between September and December. These periods correspond to the 1998 Berkeley Pit landslide and the fall 2003 resumption of mining by MR. Water levels showed a continual increase through 2011, with apparent seasonal variations, followed by a steady decline through mid-2014. Water level variations in 2015–2016 exhibited apparent seasonal responses. Peak water levels occur later in the year (November–December) than in other alluvial well sites.

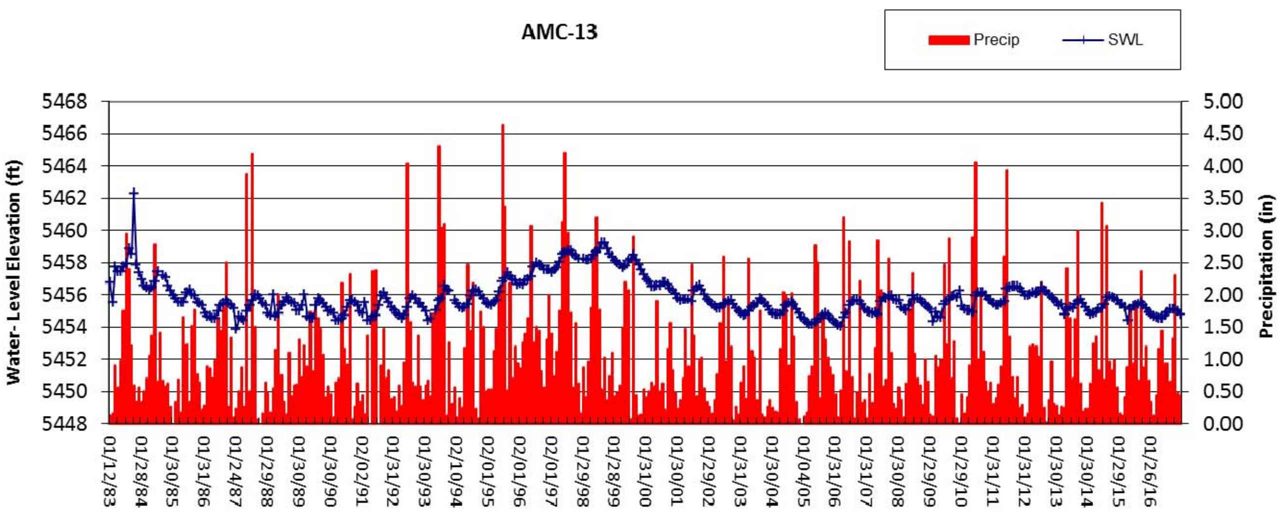


Figure 2-5. Water-level hydrograph for wells AMC-13.

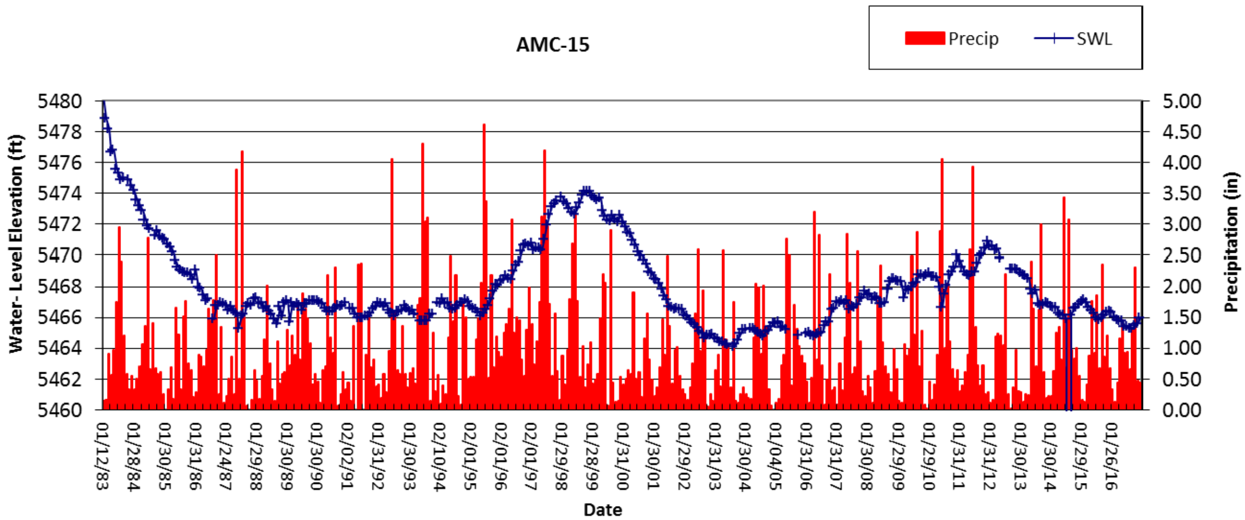


Figure 2-6. Water-level hydrograph for well AMC-15.

Section 2.1.1 AMC-Series Water Quality

Concentration exceedances and trends for chemical constituents in the 2016 data collected from the AMC-series wells are summarized in table 2.1.1.2. Well AMC-5, just south of the Berkeley Pit, has exceeded maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) throughout the period of record. The concentrations of copper and zinc have decreased about 50% from initial concentrations and most of the other dissolved metals have shown a slight downward trend or remained stable in recent years.

Water from AMC-6 shows continued and consistent decreasing concentrations in nearly all dissolved constituents. Cadmium is the only current constituent whose concentrations exceed drinking water MCL; iron and manganese concentrations exceed SMCL. Sulfate concentrations demonstrate the overall improvement in groundwater quality conditions (fig. 2-7a).

The concentrations of dissolved constituents reported in samples collected in 2016 from well AMC-8 are consistent with previous results. Sulfate concentrations doubled from the fall of 2006, increasing from 400 mg/L to more than 800 mg/L in October 2016 (fig. 2-7a). Cadmium concentrations decreased this past year and were below the MCL; sulfate, iron and manganese concentrations are above the SMCL.

Table 2.1.1.2 Water-quality exceedances and trends for AMC-series wells, 2016.

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

Water from AMC-12 has high to very high concentrations of sulfate, iron, manganese, cadmium, copper, and zinc; this well is located just south of the SBC drainage, which received untreated mine and process water for decades. Groundwater samples from this well show the most significant change over time for the AMC-series wells; dissolved concentrations of iron, manganese, sulfate, cadmium, copper, and zinc are one-half or less of maximum concentrations observed in the early 1990s (fig. 2-7b).

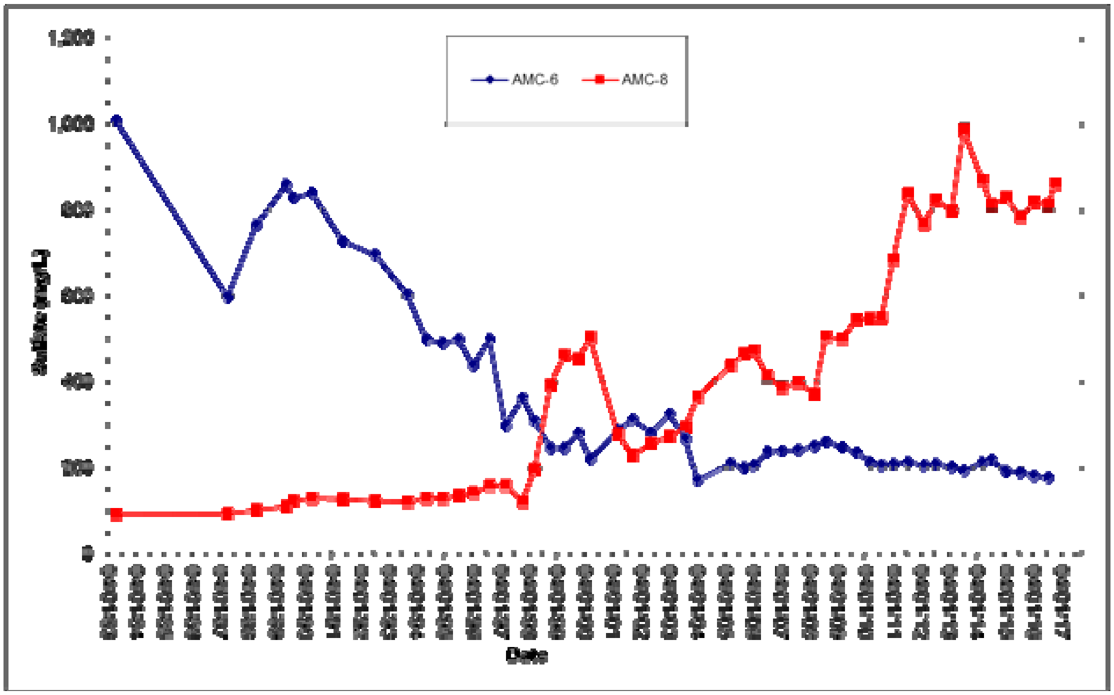


Figure 2-7a. Sulfate concentration changes over time for wells AMC-6 and AMC-8.

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

Overall, metal concentrations in 2016 water samples are little changed from previous years. Wells closest to historic and current mining operations have the highest levels of contamination; wells AMC-5 and AMC-12 have very high levels of iron, manganese, cadmium, copper, and zinc.

Section 2.2 LP-Series Wells

The locations of the 17 LP-series monitoring wells are shown in figure 2-8; table 2.2.1 presents a summary of annual water-level changes for these sites. As discussed in Duaime and others (1998), these wells were installed in 1991 and 1992 as part of the BMFOU RI/FS study. Wells LP-03, LP-06, and LP-11 have been plugged and abandoned for various reasons. Well LP-07 has been dry periodically from 2001 through 2012; it had minimal water-level increases in 2013–2016 (0.05 ft). Well LP-08 was dry from May 2010 to November 2015; it had a 4.15 ft water-level rise in December 2015 and a total rise of 0.61 ft in 2016. Well LP-17 was plugged and abandoned and replaced with LP-17R in fall 2013.

Water-level monitoring and sampling of the LP-series wells continued throughout 2016, with water levels declining in 7 of the remaining 14 wells. Wells near MR dewatering activities continue to exhibit a water-level decline, and wells downgradient of the leach pads exhibit a water-level increase. Since monitoring began in 1991, water levels have declined in 16 of the LP wells, ranging from 2.17 ft in LP-12 to 120.47 ft in well LP-15. Well LP-14 has a net water-level increase of 2.92 ft.

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

Year	LP-01	LP-02	LP-03	LP-04	LP-05	LP-06	LP-07	LP-08	LP-09
1991	1.23	-0.91	-2.02	1.38	4.35	-1.46	-	-	-0.70
1992	-1.14	-1.56	-0.66	-1.75	-1.08	0.80	-3.79	-3.78	-7.16
1993	-0.91	-1.69	1.84	-1.69	-2.42	-0.53	-3.06	-4.83	-2.24
1994	-0.53	-0.80	-1.61	-0.57	-1.42	-2.28	-1.03	-2.11	-2.90
1995	-0.08	-0.19	-1.74	2.94	0.34	0.47	4.91	4.30	3.35
1996	-2.05	-2.00	-0.73	-1.28	-3.40	2.01	-4.30	-1.14	-1.49
1997	-1.58	-1.86	-0.09	-1.73	-3.32	-1.37	-2.24	-2.63	-0.29
1998	0.12	0.23	-2.03	1.01	-0.03	-0.58	2.44	0.99	1.60
1999	-2.24	-1.76	-7.44	-2.64	-3.15	-1.65	-6.47	-3.52	-3.77
2000	-7.55	-7.16	-5.45	-10.83	-7.87	-0.20	-3.10	-14.03	-13.28
Change Years 1–10	**-14.73**	**-17.70**	**-19.93**	**-15.16**	**-18.00**	**-3.79**	**-16.64**	**-26.75**	**-26.88**
2001	-5.13	-4.73	9.51	-8.88	-5.47	Dry	Dry	-12.10	-3.04
2002	-5.21	-3.91	-2.01*	-6.03	-4.86	Dry	Dry	-4.11	-3.46
2003	-2.29	1.60	P&A*	-1.75	-2.00	Dry	Dry	-0.04	-1.15
2004	-0.65	0.46	P&A*	13.06	3.85	3.24	Dry	18.13	2.96
2005	0.81	-0.43	P&A*	4.12	3.40	-3.62	-0.79	2.85	2.08
2006	-1.43	-0.96	P&A*	-2.77	-2.06	Dry	Dry	-2.35	-0.44
2007	-0.09	0.14	P&A*	-3.39	-2.36	Dry	Dry	-5.59	-2.37
2008	-0.02	0.13	P&A*	-3.80	-1.61	Dry	Dry	-7.83	-1.39
2009	0.48	0.13	P&A*	-3.87	-1.59	Dry	Dry	-5.23	-0.07
2010	0.96	0.89	P&A*	-2.13	-1.42	P&A*	Dry	0.01	0.06
Change Years 11–20	**-12.57**	**-6.68**	**-11.52**	**-15.44**	**-14.12**	**-0.38**	**-0.79**	**-16.26**	**-6.82**
2011	0.22	0.05	P&A*	-0.34	0.03	P&A*	Dry	Dry	0.61
2012	1.15	-0.08	P&A*	0.26	0.07	P&A*	Dry	Dry	3.95
2013	3.17	0.43	P&A*	3.16	1.61	P&A*	0.06	Dry	3.72
2014	3.34	0.54	P&A*	1.54	2.11	P&A*	0.11	Dry	3.51
2015	4.19	4.24	P&A*	2.75	3.61	P&A*	0.00	4.15	-1.51
2016	1.95	1.96	P&A*	1.13	-0.12	P&A*	-0.12	0.61	-1.14
Change Years 21–30	**14.02**	**7.14**	P&A*	**8.50**	**7.31**	**P&A***	**0.05**	**4.76**	**9.14**
Net Change	**-13.28**	**-17.24**	**-31.45**	**-22.10**	**-24.81**	**-4.17**	**-17.38**	**-38.25**	**-24.56**

*Plugged and abandoned.

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

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

Year	**LP-10**	**LP-11**	**LP-12**	**LP-13**	**LP-14**	**LP-15**	**LP-16**	**LP-17**	**LP-17R**
1991	-	-	-	-	-	-	-	-	
1992	-0.50	-1.83	0.31	-0.07	0.70	0.54	0.89	-	
1993	-0.83	-2.78	1.42	1.11	1.18	1.62	1.83	-	
1994	-2.14	1.65	-1.41	-1.47	-0.09	0.26	-1.16	-	
1995	-0.57	-0.23	-0.16	0.43	0.18	1.89	3.57	3.10	
1996	1.20	0.23	1.87	1.74	2.07	1.79	1.77	1.66	
1997	0.23	-0.09	2.42	2.24	2.64	1.99	1.77	2.32	
1998	0.92	0.07	1.00	-0.62	0.39	-7.90	-9.69	-2.41	
1999	-2.05	-2.12	-2.94	-2.36	-2.73	-4.39	-4.60	-3.95	
2000	-1.37	-0.28	-3.60	-2.93	-3.64	-1.73	-2.18	-2.86	
Change Years 1–10	**-5.11**	**-5.38**	**-1.09**	**-0.93**	**0.70**	**-5.93**	**-7.80**	**-2.14**	
2001	0.51	P&A*	-1.16	-1.30	-2.31	-0.72	-1.18	-1.50	
2002	-0.15	P&A*	-1.83	-1.21	-1.65	-0.68	-0.86	-0.67	
2003	-2.75	P&A*	-1.74	-0.26	0.46	1.08	0.89	0.09	
2004	-1.41	P&A*	0.20	0.26	0.95	-0.06	0.52	0.71	
2005	4.19	P&A*	1.53	0.78	-0.27	0.27	-0.27	0.26	
2006	3.19	P&A*	4.48	2.78	2.95	1.43	1.33	2.68	
2007	0.73	P&A*	0.87	0.73	1.22	1.51	1.66	2.54	
2008	1.23	P&A*	1.92	1.27	0.29	1.05	0.28	0.94	
2009	-0.83	P&A*	3.23	1.97	3.32	1.70	1.47	2.20	
2010	-0.77	P&A*	0.09	-0.19	0.53	-0.18	0.27	0.32	
Change Years 11–20	**3.94**	**0.00**	**7.59**	**4.83**	**5.49**	**5.40**	**4.11**	**7.57**	
2011	-1.03	P&A*	0.78	0.94	1.61	0.87	0.53	0.16	
2012	-3.12	P&A*	-5.59	-4.46	-3.19	-65.32	-3.53	-4.05	
2013	0.78	P&A*	-2.09	-3.12	-2.05	-15.35	-4.36	-3.37	-0.31
2014	-0.86	P&A*	-0.87	0.42	-0.72	-18.59	0.32	P&A*	0.20
2015	-2.77	P&A*	-1.25	-2.40	-0.64	-20.56	-3.29	P&A*	-2.10
2016	-1.72	P&A*	0.35	0.35	1.72	-0.99	-0.01	P&A*	-0.33
Change Years 21–30	**-8.72**	**P&A***	**-8.67**	**-8.27**	**-3.27**	**-119.94**	**-10.34**	**-7.26**	**-2.54**
Net Change	**-9.89**	**-5.38**	**-2.17**	**-4.37**	**2.92**	**-120.47**	**-14.03**	**-1.83**	**-2.54**

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

Document Path: D:\stuff\ted\BMF\BMF_mapping-East_Camp_Alluvial_Fig_2-8_04042016.mxd

Date: 4/5/2016

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

Water-level rise beginning in 2004 in some of the wells north of the Pittsmont Waste Dump is a substantial change from downward trends observed between 1992 and 2003. The water-level declines appear related to deactivation of the leach pads in 1999. When MR resumed mining in 2003, it began limited-scale leaching operations that continued periodically throughout 2005. The wells with the greatest water-level rise in 2004 and 2005 (LP-04 and LP-8) are located south of the leach pads; some of these rises may have been related to discharges to the McQueen Ditch, which runs between LP-04 and LP-08. MR again operated limited leaching during 2010–2016 as part of their active mining operations, which might have caused continued water-level rises. Figures 2-9 and 2-10 show water levels over time for three LP-series wells, which are located south of the leach pads and north of the Pittsmont Waste Dump.

Wells LP-01 and LP-02 are located near the base of several leach pads and are screened between 129 and 159 ft, and 177 and 197 ft, respectively. Both are completed in a deep section of the alluvial aquifer. As shown in figure 2-9, water levels steadily declined in well LP-01 between 1991 and 2004. Since 2005, water levels have varied slightly, with periodic increases followed by declines. Water-level fluctuations in LP-01 have been less erratic in recent years than those in the shallow well, LP-02, possibly the result of the increased lag time associated with recharge events. Water levels in wells LP-01 and LP-02 show a strong response to leach pad operations and, at best, a muted response to climate. This interpretation is consistent with earlier interpretations about water-level responses made following MR's 1999 deactivation of the leach pads.

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

Wells LP-14, LP-15, and LP-16 are located southwest of the Pittsmont Dump (fig. 2-8). A consistent increase in water levels occurred in these wells between installation in 1992 and the Berkeley Pit landslide of 1998 (fig. 2-11). Post landslide, water levels in all three wells declined until September 2003, when they began to rise. At 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 were 10 ft or more below their pre-landslide levels. Water levels decreased during most of 2012, with no apparent responses following the August or November 2012 landslides or the February 2013 slump in the southeast corner of the Berkeley Pit. The lack of response contrasts with water-level responses following the 1998 landslide. MR installed a series of dewatering wells and began operation of the pump in well LP-15 in the summer of 2012, and transducers were installed in monitoring wells LP-12, LP-13, and LP-16 to better track water-level changes following the November 2012 landslide. Water-level trends since August 2012 are mostly related to dewatering activities undertaken by MR.

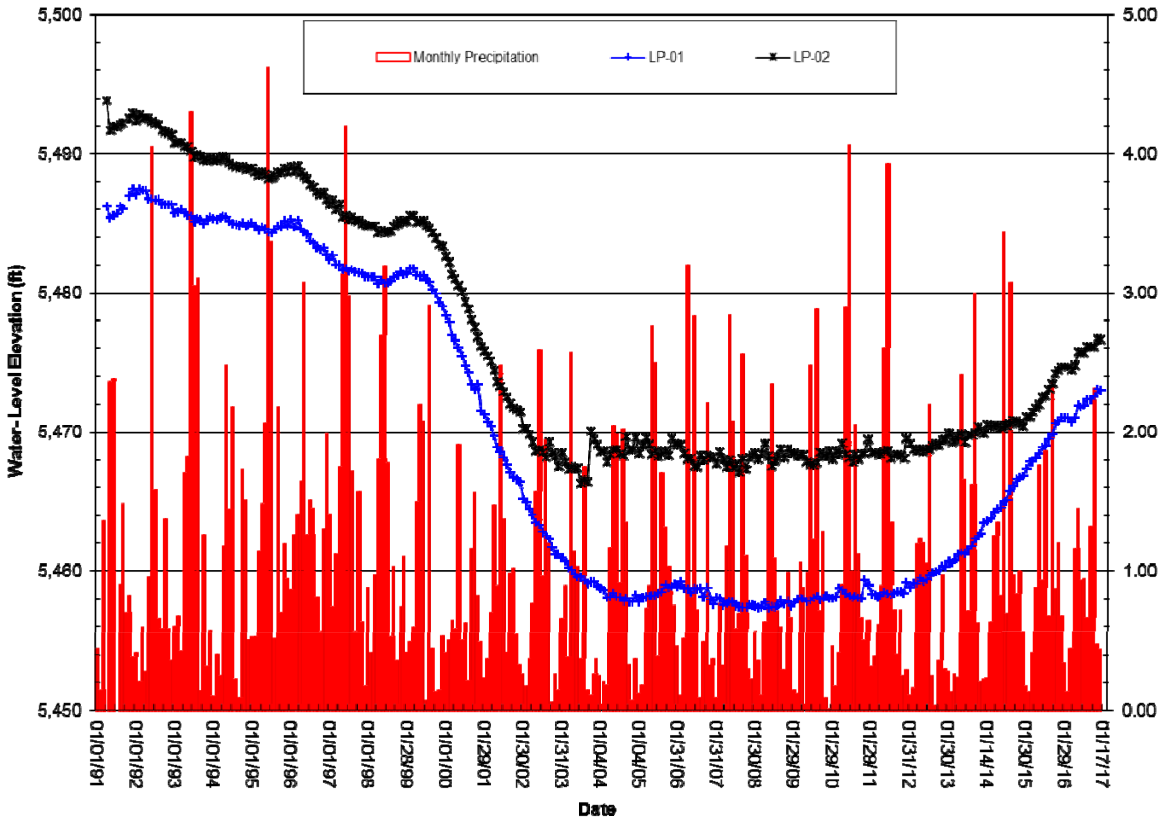


Figure 2-9. Water-level hydrographs for wells LP-01 and LP-02 located north of the Pittsmont Waste Dump and south of the leach pads.

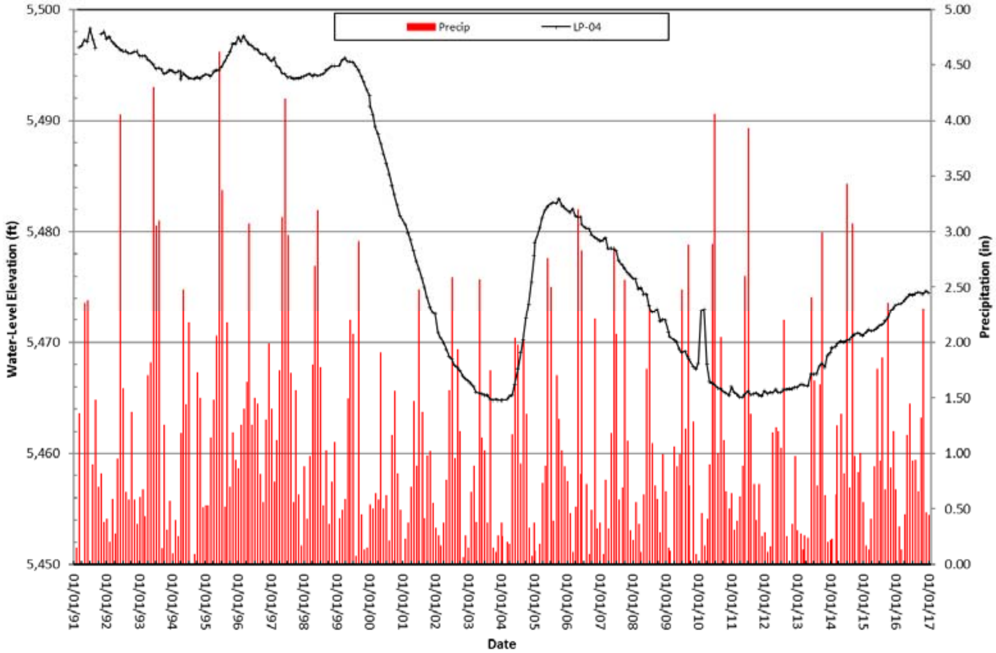


Figure 2-10. Water-level hydrographs for well LP-04 located north of the Pittsmont Waste Dump and south of the leach pads.

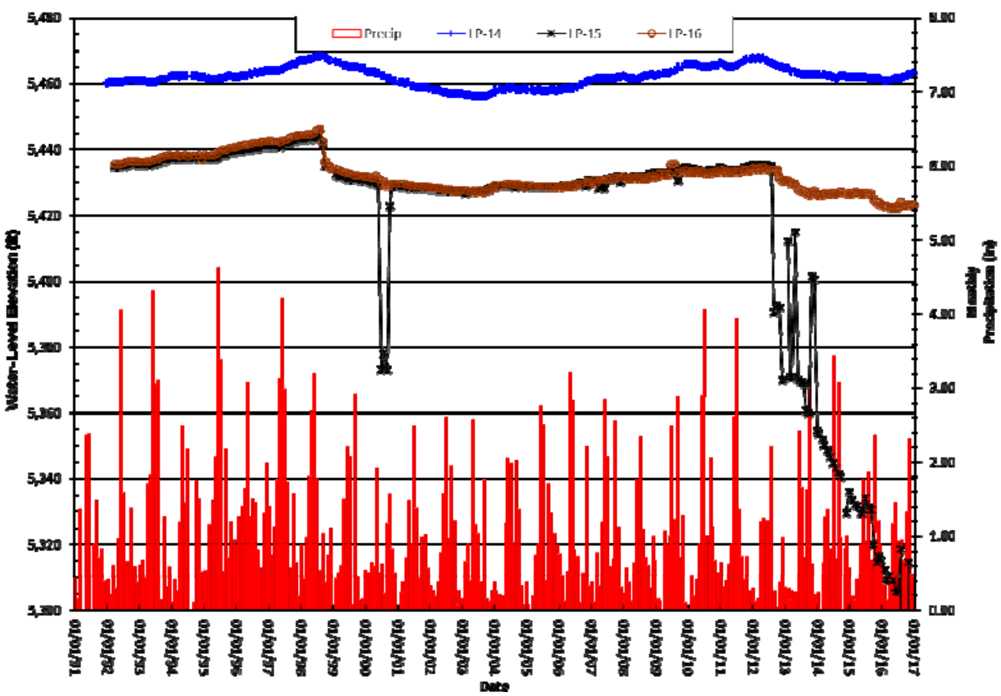


Figure 2-11. Water-level changes for wells LP-14, LP-15, and LP-16 before and after the 1998 Berkeley Pit landslide and response to dewatering activities.

Wells LP-15 and LP-16 are located near one another and completed as a nested pair, with well LP-15 screened from a depth of 215 ft to 235 ft below ground surface and well LP-16 screened from 100 ft to 120 ft below ground surface. Water-level trends are generally similar in these wells and do not show a response to precipitation events. MR began pumping well LP-15 shortly after the August 2012 landslide and continued pumping through 2016. Pumping has caused significant drawdown in this well and well LP-16 (fig. 2-12). MR installed additional dewatering wells in the area, which have operated almost continuously. The result has been a localized decrease in water levels in the alluvial aquifer.

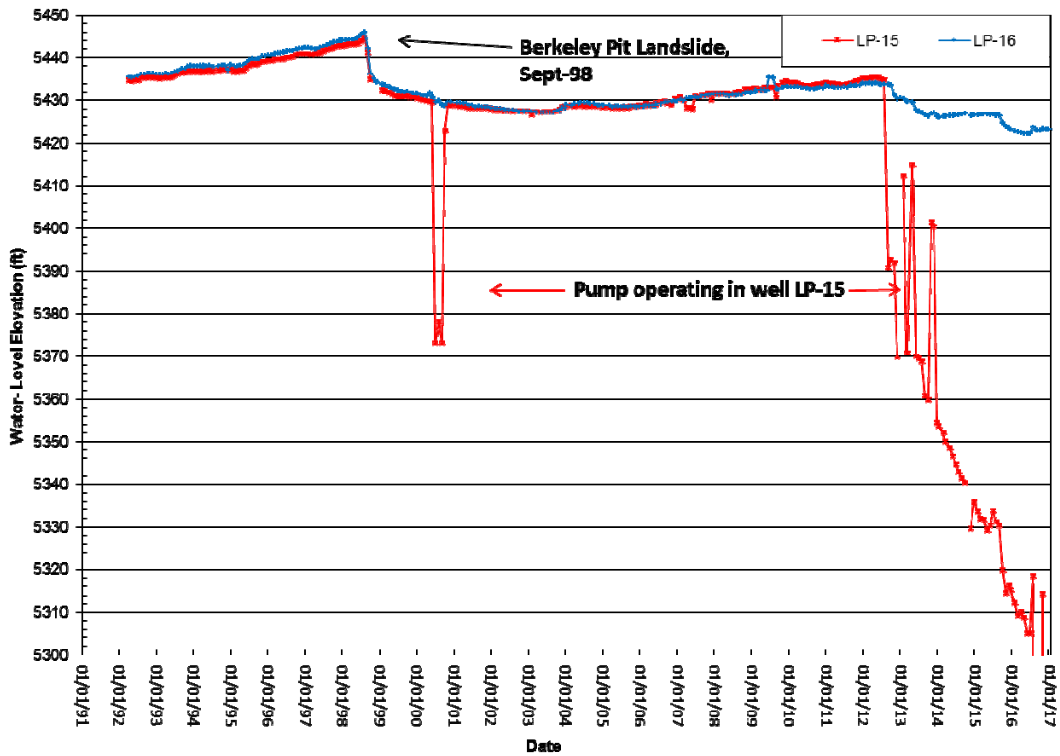


Figure 2-12. Water-level hydrographs showing influence of dewatering on water levels in wells LP-15 and LP-16.

Water levels in the LP-series wells are controlled by: (1) the flooding, dewatering, and subsequent reactivation of the leach pads; (2) operation of the Yankee Doodle Tailings Dam; (3) depressed water levels in the Berkeley Pit; (4) alluvial dewatering activities conducted by MR; (5) periodic releases to the McQueen Ditch; or (6) a combination of all five. Water-level response in wells adjacent and downgradient of limited leaching operations during 2004–2005 and 2009–2016 clearly demonstrates the relationship of leach pad operation and water-level change. The influence of seasonal precipitation events is minimal on water levels in these wells.

An alluvial aquifer potentiometric map (fig. 2-13), constructed using December 2016 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, 2000) is flowing north towards and into the Berkeley Pit, ensuring that there is no southward migration of contaminated water.

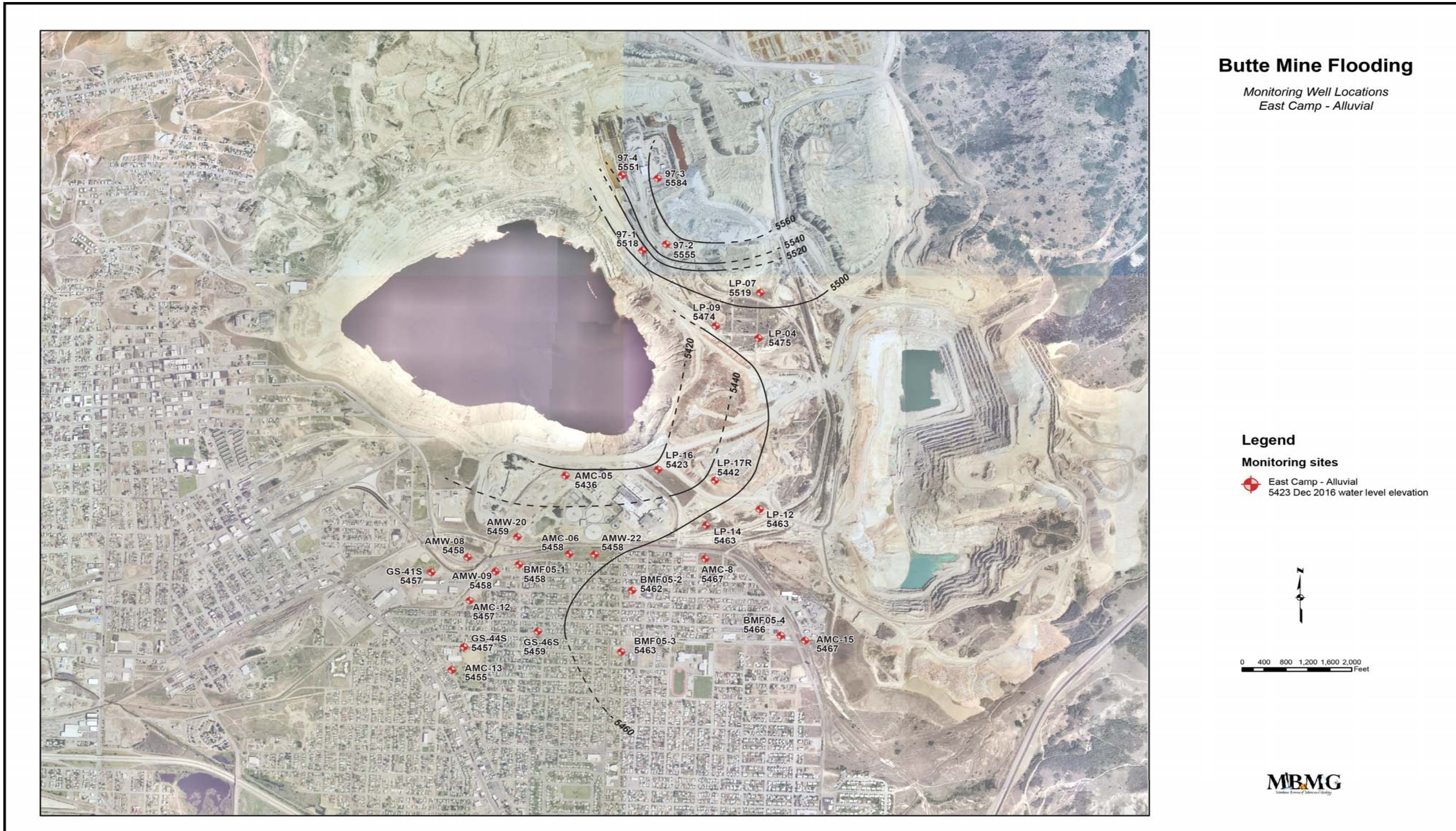


Figure 2-13. Alluvial aquifer potentiometric map for December 2016 (contour interval is 20 ft).

Section 2.2.1 LP-Series Wells Water Quality

Current water-quality monitoring of the LP-series wells is restricted primarily to wells west and south of the Pittsmont Dump (fig. 2-8), with the exception of LP-08 (when it is not dry), LP-09, and LP-10, which are south of the leach pad area and north of the Pittsmont Dump. Analytical results from samples collected in 2016 showed minor changes in several wells; the changes are summarized in table 2.2.2.

Well LP-09 was sampled six times between its installation in 1992 and 1996; after 1996, it was not resampled until April 2003, after which it was resampled annually. Data review indicates large increases in most dissolved constituents starting in 1994. Data collected from 2003 to 2016 show that the concentrations in sulfate and zinc concentrations remain extremely elevated (fig. 2-14). The concentration of cadmium increased from 600 µg/L in 1992 to more than 10,000 µg/L from 2003 to 2013; concentrations since 2014 have declined slightly (6,600–8,600 µg/L). Zinc concentrations increased from 172,000 µg/L in 1992 to more than 1,300,000 µg/L in samples collected between 2003 and 2016. Although zinc concentrations have declined since 2009, they are still an order of magnitude above the 1992 levels. In general, dissolved metals concentrations increased by nearly an order of magnitude since the well was drilled, approaching concentrations observed in the pregnant solutions of the upgradient leach pads.

Water from well LP-16 contained moderate increases of sulfate, copper, cadmium, and zinc in 2010–2013, followed by slight concentration decreases through 2016 (fig. 2-15a). The increases depart from earlier downward trends. No other analytes showed increasing trends.

Water from well LP-17 changed significantly during 2006–2012; concentrations of cadmium, copper, and zinc decreased by 50 percent from 2003–2005 concentrations. Nitrate concentrations were extremely high in the 2006–2009 samples, decreasing in the 2010–2012 samples. However, current nitrate concentrations are still twice the MCL (well LP-17R). Analytical results from water-quality samples collected from LP-17's replacement well in the fall of 2013 and 2014–2016 show-increasing concentrations of aluminum, cadmium, copper, manganese, and zinc from those seen previously in LP-17. Figure 2-15b depicts copper and zinc concentrations in LP-17R since it installation in 2013.

Water quality in the other LP-series wells generally remained the same in 2016 as it has been in recent years. A summary of exceedances and trends is presented in table 2.2.2.

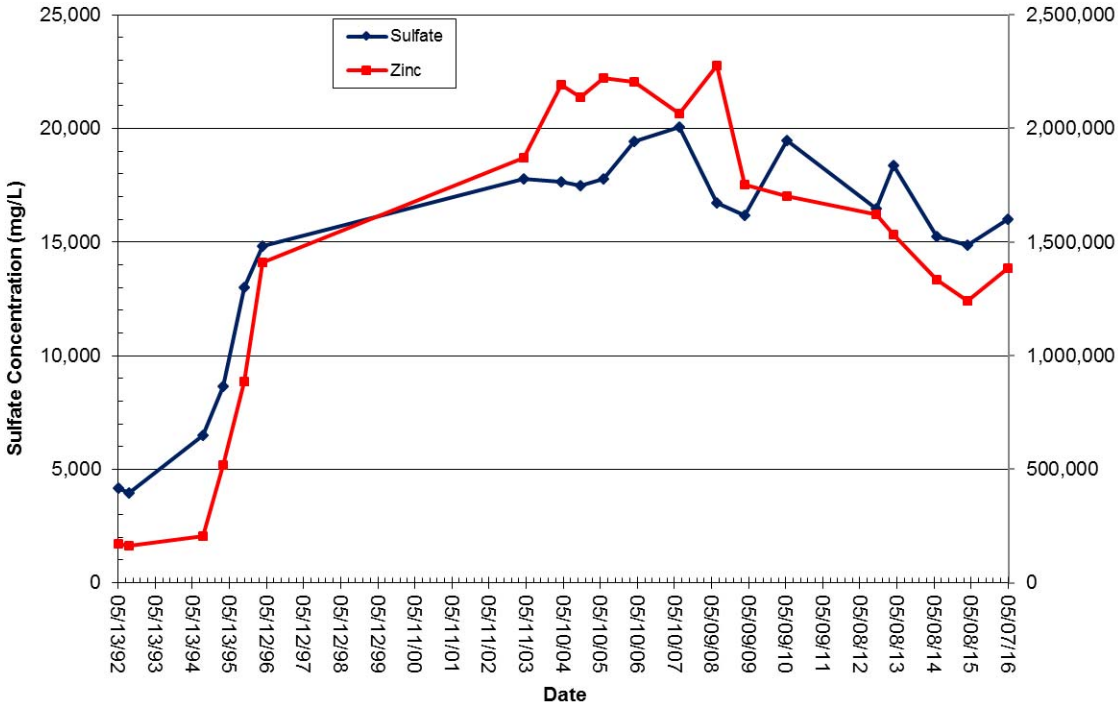


Figure 2-14. Sulfate and zinc concentrations in well LP-09.

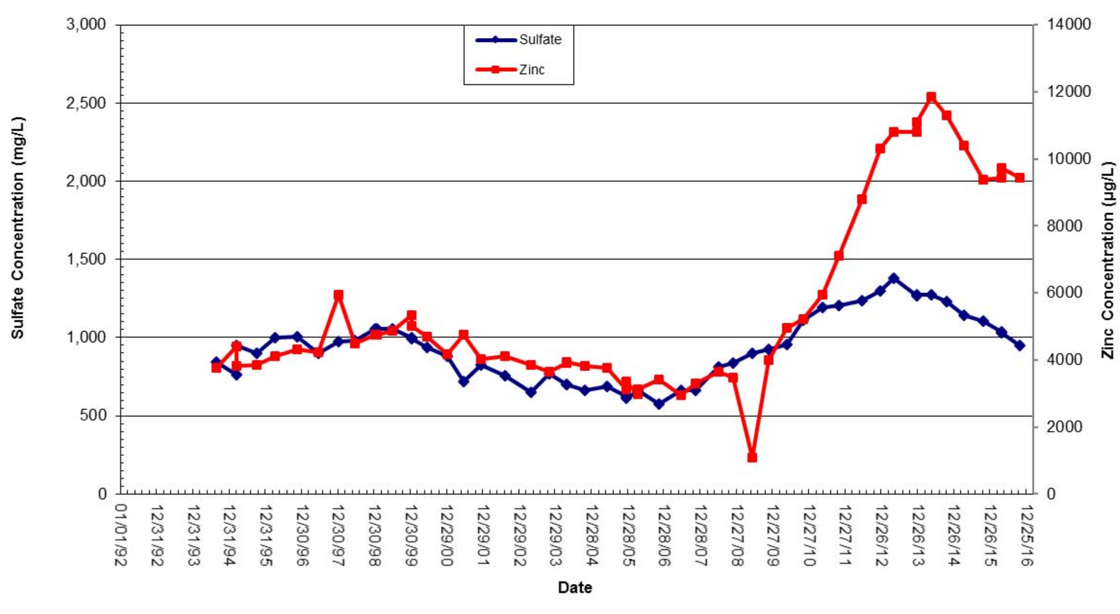


Figure 2-15a. Sulfate and zinc concentrations in well LP-16.

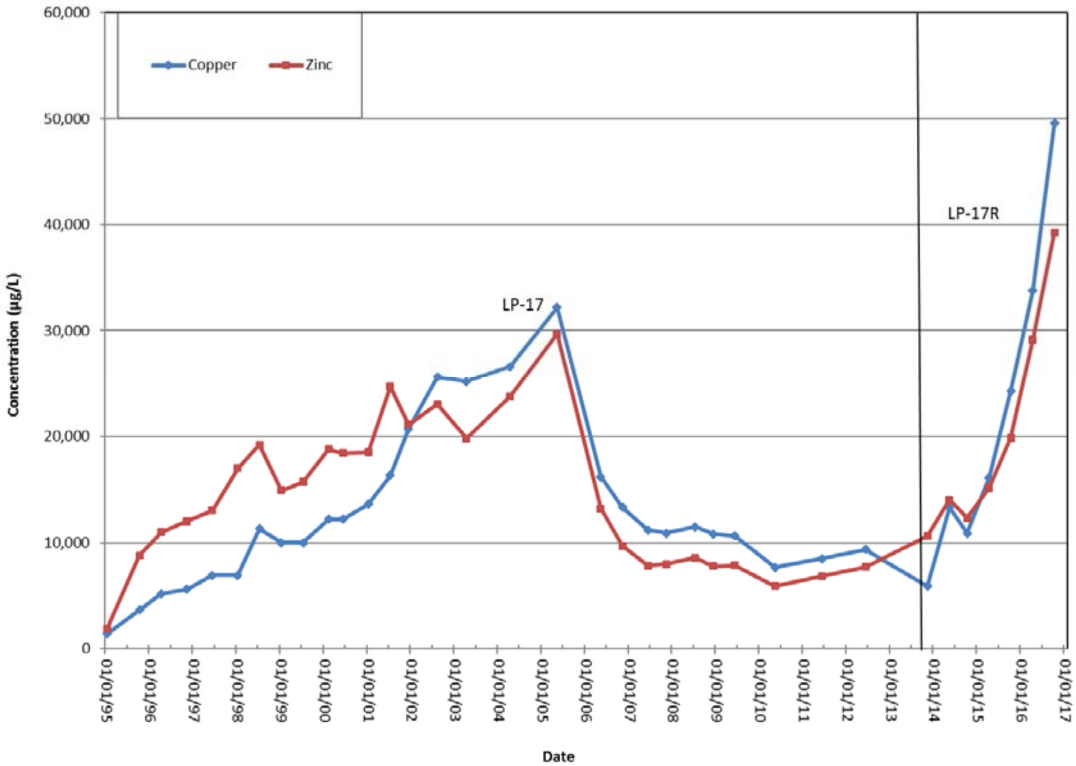


Figure 2-15b. Copper and zinc concentrations in wells LP-17 and LP-17R.

Table 2.2.2 Water-quality exceedances for LP-series wells, 2016.

Well Name	Exceedances (1 or more)	Concentration	Remarks
LP-08	Y	Downward	Very elevated concentrations. No samples since 2009 due to limited volume of water in well.
LP-09	Y	Downward	Large increases since 1992. Cadmium, copper, and zinc show minor decreases since 2009.
LP-10	N	Stable	No significant changes in 2016.
LP-12	Y	Stable	Cadmium exceeds MCL. No significant changes in 2016.
LP-13	N	Downward	No significant changes in 2016. Zinc below SMCL in 2013–2016.
LP-14	Y	Variable	Cadmium exceeds MCL; sulfate exceeds SMCL.
LP-15	Y	Stable	Cadmium exceeds MCL; sulfate exceeds SMCL. Net change is small for most analytes.
LP-16	Y	Upward	Manganese, sulfate, copper, and zinc exceed SMCL; cadmium exceeds MCL.
LP-17/LP-17R	Y	Upward	Manganese, sulfate, copper, and zinc exceed SMCL; cadmium exceeds MCL.

Section 2.3 Precipitation Plant Area Wells

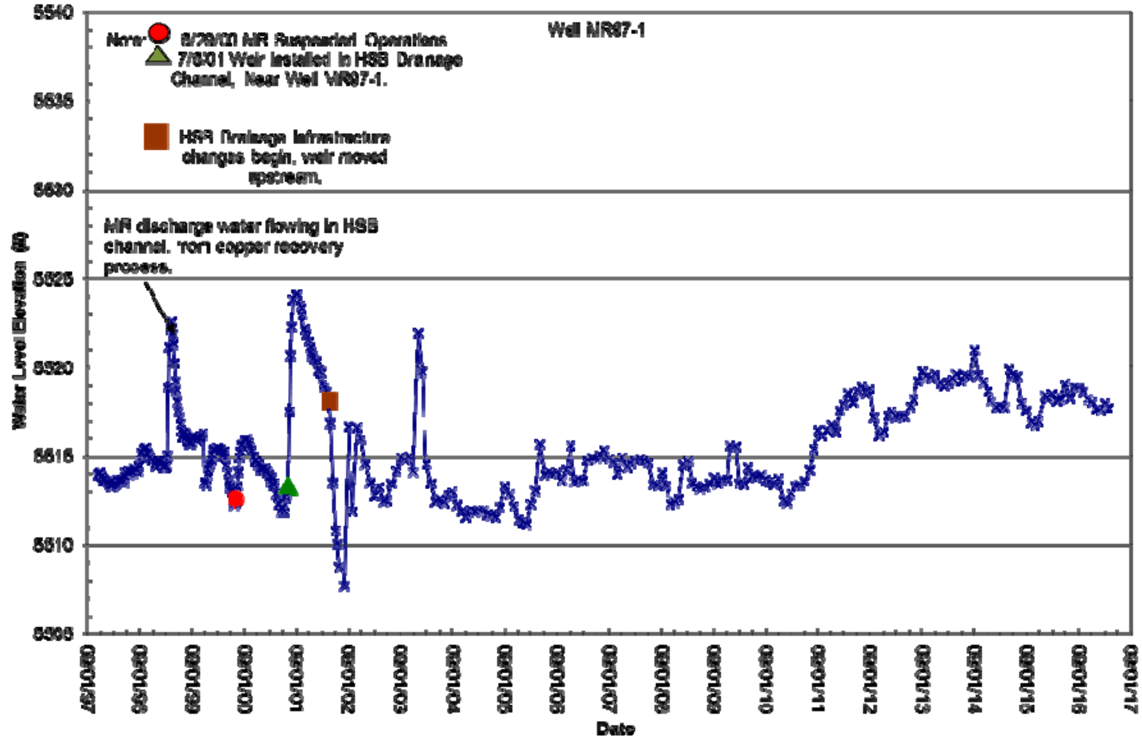
Wells MR97-1, MR97-2, MR97-3, and MR97-4 (fig. 2-8) are adjacent to various structures (drainage ditches, holding ponds, etc.) associated with the leach pads and precipitation plant. Table 2.3.1 lists annual and net water-level changes for these wells. Water-level changes appear to correspond to flow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

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

Year	MR97-1	MR97-2	MR97-3	MR97-4
1997	-0.25	-0.84	-0.40	0.34
1998	1.07	-1.04	-0.67	2.20
1999	-0.27	-4.40	-3.91	0.02
2000	-0.20	-0.89	-2.88	-0.03
2001	6.17	-1.32	-0.29	0.78
2002	-5.88	-1.02	-0.47	1.60
2003	7.43	-0.70	-1.29	-2.45
2004	-10.01	-0.08	-4.28	1.86
2005	-0.67	-0.06	0.60	-1.84
2006	2.27	2.20	1.82	0.41
Change Years 1–10	**-0.34**	**-8.15**	**-11.77**	**2.90**
2007	0.78	0.18	3.88	0.81
2008	-1.73	0.39	-0.10	0.13
2009	2.97	2.46	1.08	-3.71
2010	-3.07	0.05	1.25	-1.97
2011	3.88	5.51	0.24	1.93
2012	0.87	1.29	0.38	-0.21
2013	1.86	2.03	1.95	-0.18
2014	-1.06	-0.26	2.13	2.97
2015	-1.11	-0.84	0.24	-0.19
2016	-0.71	0.37	0.06	0.65
Change Years 11–20	**2.68**	**10.40**	**11.11**	**0.23**
Net Change	**2.34**	**2.25**	**-0.66**	**3.13**

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

Within the MR-group wells, water levels in well MR97-1 have shown the greatest variability of the four wells in this series (fig. 2-16) because of changes in mining operations and infrastructure. Water levels increased when MR began to discharge water from their Berkeley Pit copper recovery project into the pit (spring 1999) and again in June 2000 when water from the HSB drainage that had been pumped to the Yankee Doodle Tailings Dam since April 1996 was allowed to flow into the pit following the mine shutdown. These operational changes caused rapid water-level increases followed by gradual decrease before leveling off. Water levels increased in 2011 and have shown only minor variations since.



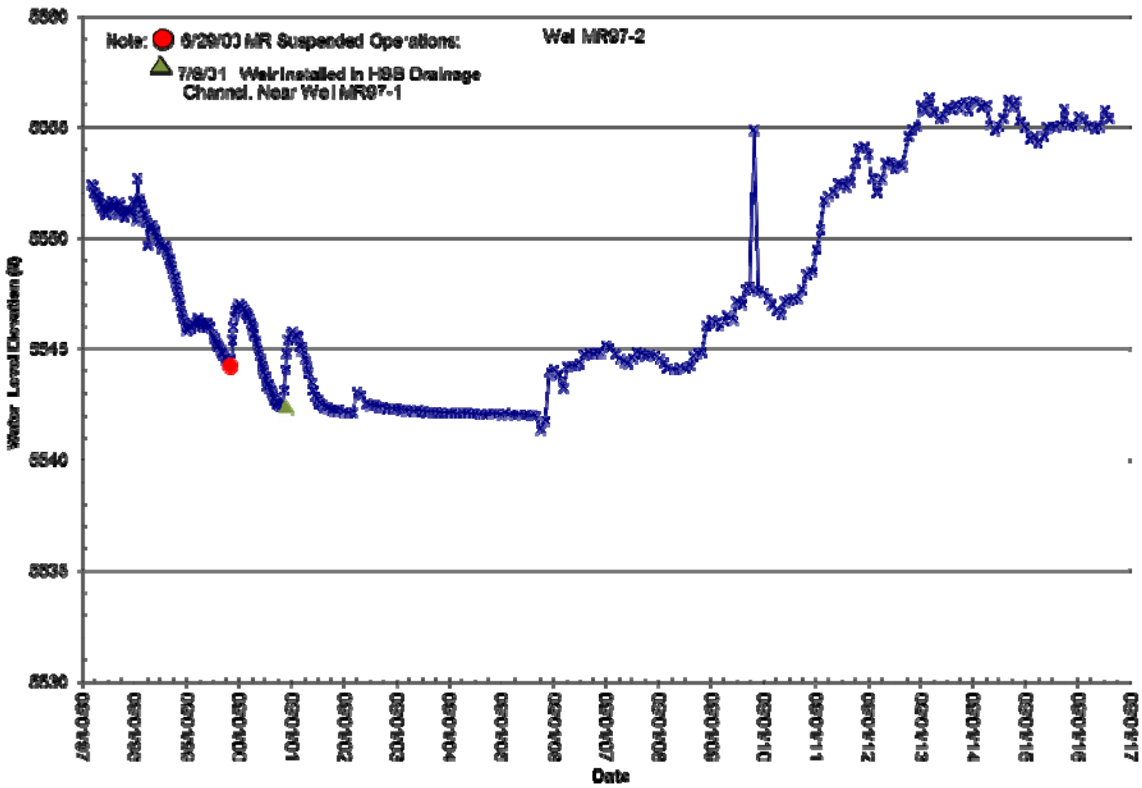


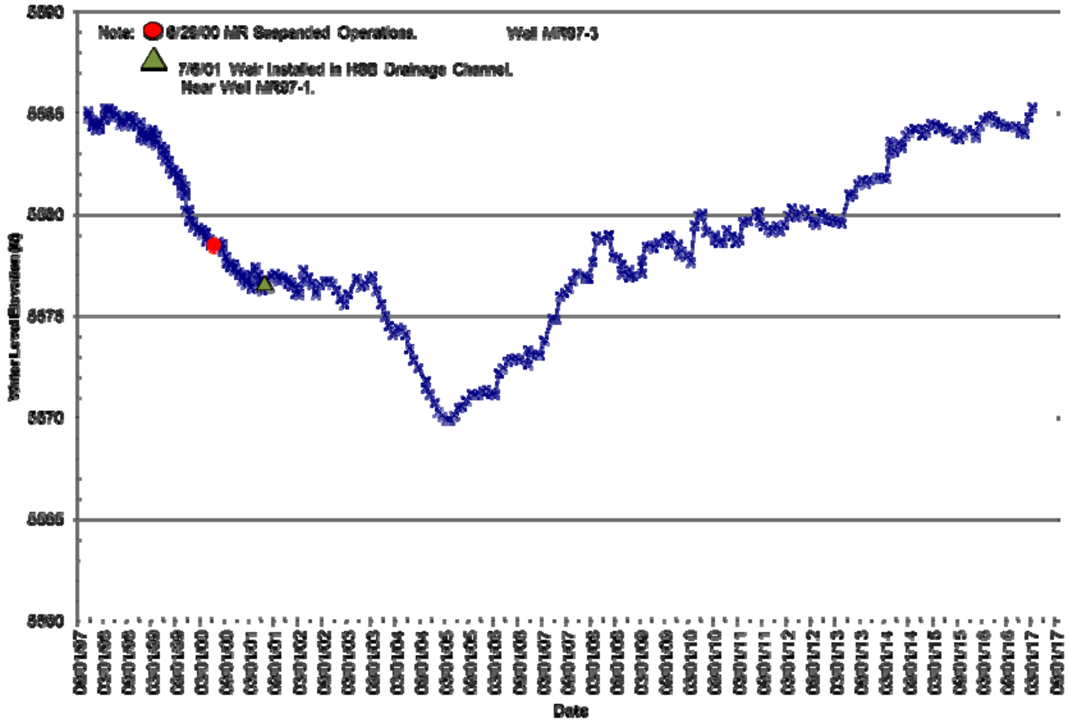
Figure 2-16. Water-level hydrograph for wells MR97-1 (top) and MR97-2 (bottom).

Similar water-level variations were observed in well MR97-1 during July 2001 and August 2002, when during HSB water-treatment plant construction a weir was installed (2001) and then relocated (2002) in the channel. After relocation, the weir was upstream of the outlet historically referred to in MR's precipitation plant operations as Pond 4. The area occupied by Pond 4 was excavated, enlarged, and lined with lime rock. The relocation resulted in water-level declines in MR97-1 because the weir and the accompanying impounded water were moved upgradient of the well. Weir upgrades during late 2015 had only minimal influence on water levels in well MR97-1.

Wells MR97-2 and MR97-3 are adjacent to historic leach pad collection ditches. Water-level changes occurred in these two wells during 1999–2000 when MR made operational changes in leaching operations. The changes resulted in less flow in collection ditches, which were reflected as water-level declines in wells MR97-2 and MR97-3 (figs. 2-16, 2-17). Water-level increases occurred in 2009–2013 and 2016 in MR97-2 and 2009–2016 in MR97-3 when limited leaching operations resumed. Dewatering activities near the HSB water-treatment plant in 2014–2016 may be responsible for the water-level variations/declines observed in well MR97-2.

The well MR97-3 water-level responses were minor during the 2001 and 2002 construction activities (fig. 2-17). Water levels varied between 2008 and 2012 with a general increasing trend; water levels rose steadily from mid-2013 until leveling off in 2015–2016.

Water-level changes in well MR97-4 (fig. 2-17) have shown the least amount of variability as the result of operational activities.



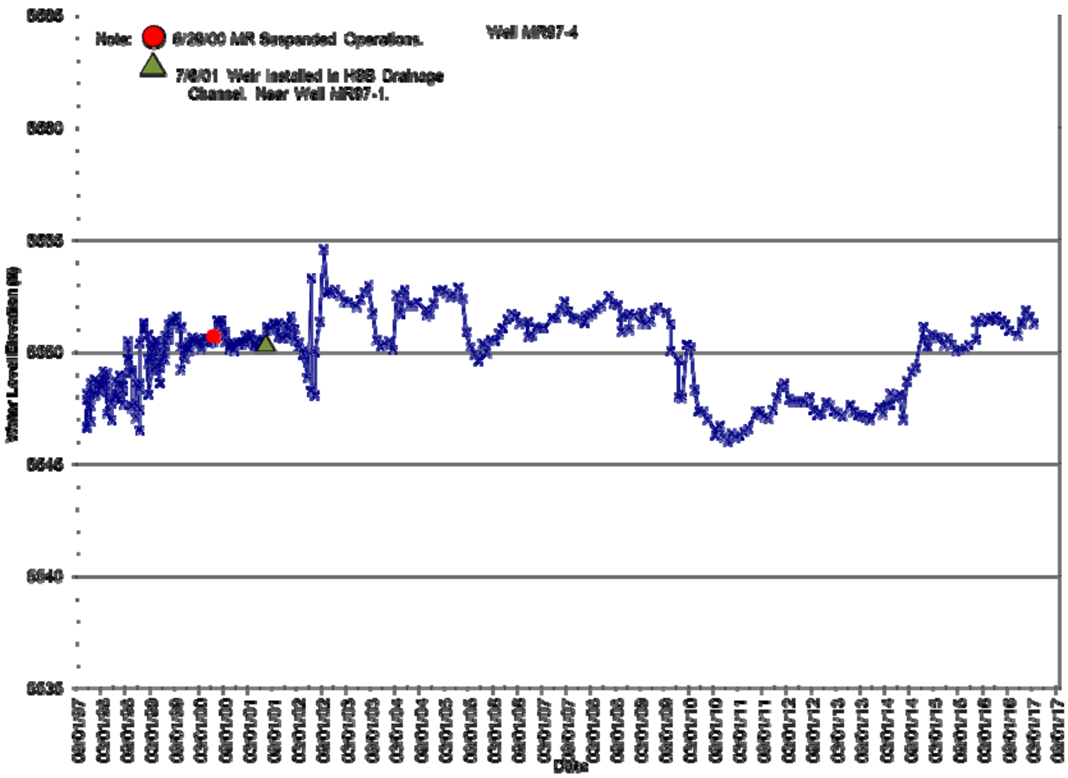


Figure 2-17. Water-level hydrograph for wells MR97-3 (top) and MR97-4 (bottom).

Since well MR97-3's installation in 1997, water levels declined 0.66 ft (table 2.3.1; this well is located nearest the leach pads and ancillary facilities). However, water levels rose between 2.2 and 3.1 ft in the other three wells.

It appears that operation of the precipitation plant and leach pads directly influences the shallow alluvial aquifer. Other changes, such as the weir installation and relocation, have affected past groundwater levels.

No water-quality samples were collected from MR-series wells between 2001 and 2016. Previous sampling documented the presence in groundwater of elevated metals; this contamination most likely resulted from leach pad and precipitation plant operations.

Section 2.4 GS- and BMF05-Series Wells

Continuous and monthly water-level monitoring of the six GS-series and four BMF05-series wells continued throughout 2016. The locations of these wells are shown in figure 2-18; table 2.4.1 contains annual water-level changes. Pairs of wells (GS-41S and D, GS-44S and D, and GS-46S and D) were drilled adjacent to each other, but completed at different depths. The 'S' and 'D' identify the shallow and deep member of each pair. During most years, water-level changes are similar in all six wells. Water levels during the entire period of record in the GS-41 and GS-44 series wells have net decreases ranging from 0.11 to 0.85 ft; the GS-46 series wells have net increases ranging from 0.02 to 0.55 ft.

Figures 2-19 through 2-21 are water-level hydrographs, with monthly precipitation totals shown for the well pairs (GS-41, GS-44, and GS-46). The seasonal water-level variations closely follow annual precipitation trends. Water levels gradually rise in the spring as monthly precipitation increases and then decline throughout the fall.

During 2016, water-level changes in wells GS-41S and GS-41D were similar to those observed in prior years (fig. 2-19), and the influence of seasonal precipitation appears to dominate the hydrograph. Water levels decreased about 0.3 ft in these two wells during 2016.

Net water-level changes in the GS-44 nested pair during 2016 were similar to those seen in the past (fig. 2-20) and to those seen in 2016 in the GS-41 wells. The water levels in wells GS-44S and GS-44D decreased about 0.1 ft during 2016.

Overall, water-level trends were similar during 2016 in wells GS-46S and GS-46D (fig. 2-21), and followed seasonal trends similar to those seen in wells GS-41 and GS-44. Water levels decreased about 0.3 ft during 2016.

At the GS-41 and GS-44 sites, water levels in shallow wells are at higher altitudes than those in the deeper wells, implying that water moves downward in the upper part and provides recharge to the lower portions of the aquifer. Water levels in wells GS-46S and GS-46D show the opposite, with water levels in well

GS-46D at higher altitudes than the water level in GS-46S, which suggests that water at depth moves upwards and can possibly discharge into a surface-water body, such as SBC. However, as noted in the next section, the water quality in well GS-46D is of good quality, and would not cause concern.

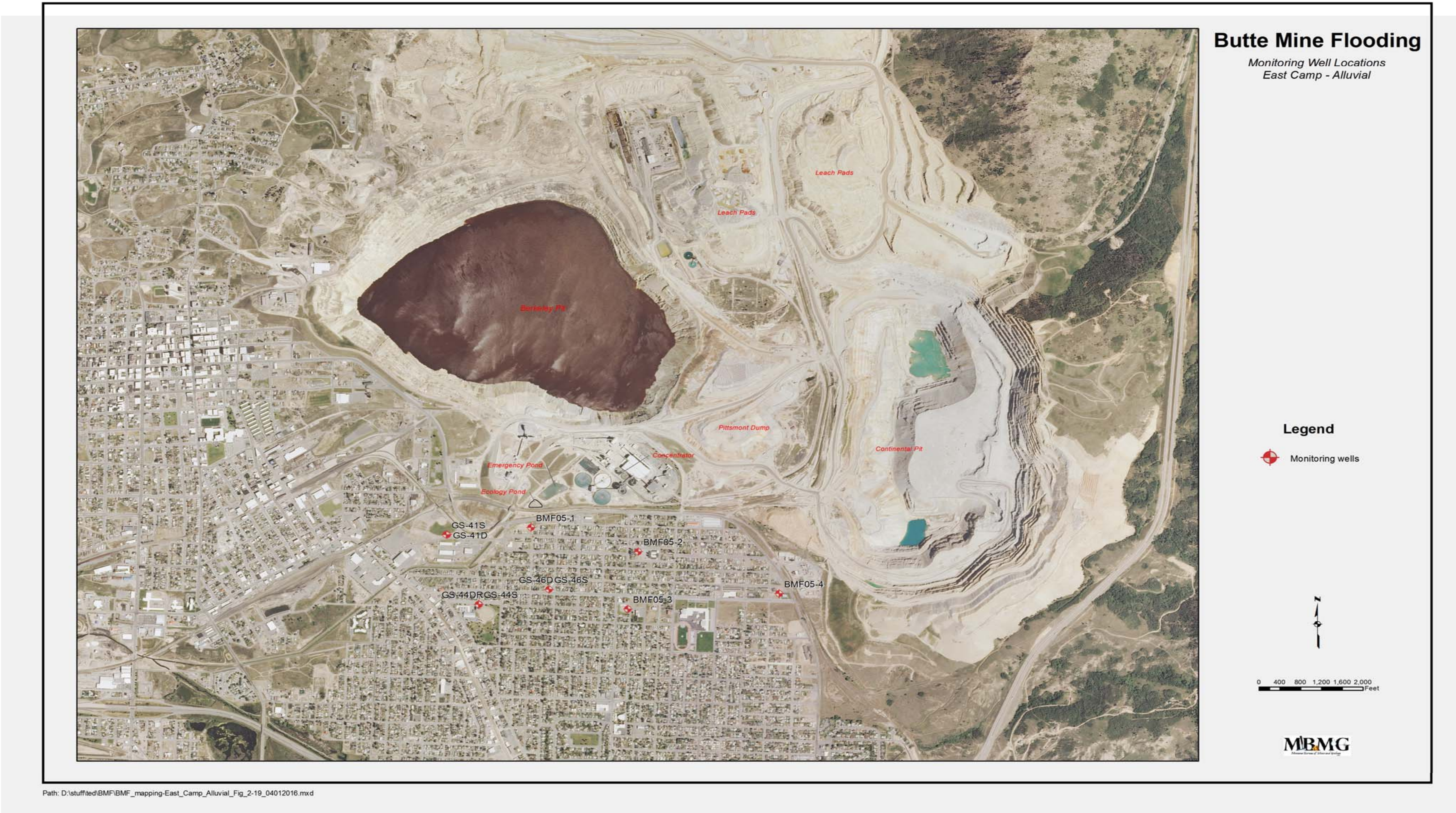


Figure 2-18. Location map for GS- and BMF-series wells.

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

Year	GS-41S	GS-41D	GS-44S	GS-44D	GS-46S	GS-46D	BMF 05-1	BMF 05-2	BMF 05-3	BMF 05-4
1993	0.76	0.78	0.62	0.66	0.80	0.78				
1994	0.20	0.23	0.00	0.00	0.18	0.24				
1995	1.35	1.26	1.32	1.26	1.38	1.30				
1996	0.59	1.65	1.12	0.89	0.98	1.20				
1997	1.32	0.20	0.58	0.79	1.09	1.18				
1998	-0.18	-0.06	0.09	0.07	1.17	0.24				
1999	-1.41	-1.49	-1.28	-1.25	-2.41	-1.65				
2000	-1.91	-1.78	-1.51	-1.39	-1.21	-2.07				
2001	-0.28	-0.41	-0.22	-0.38	-1.64	-0.92				
2002	-0.82	-0.81	-0.94	-0.82	-1.18	-1.18				
Change Years 1–10	**-0.38**	**-0.43**	**-0.22**	**-0.17**	**-0.84**	**-0.88**				
2003	0.19	0.26	0.27	0.17	-0.81	0.77				
2004	-0.31	-0.41	-0.76	-0.52	-0.08	-0.02				
2005	-0.60	-0.53	-0.40	-0.33	-0.59	-0.52				
2006	1.36	1.28	1.01	1.06	1.45	1.28	1.86	1.21	1.71	1.97
2007	0.24	0.22	0.34	0.33	0.20	0.41	-0.25	0.67	0.31	0.63
2008	-0.42	-0.39	0.24	-0.08	0.84	0.20	-0.49	-0.09	0.10	1.04
2009	0.22	0.26	0.41	0.36	0.46	0.50	0.56	0.97	0.65	0.22
2010	0.11	0.14	-0.04	-0.02	-0.20	-0.10	0.00	0.05	0.16	0.49
2011	0.81	0.93	0.68	0.68	0.99	0.98	2.44	1.04	0.63	1.21
2012	-1.02	-1.03	-0.56	-0.60	-0.74	-0.75	-2.76	-1.01	-0.75	-1.71
Change Years 11–20	**0.58**	**0.73**	**1.19**	**1.05**	**3.14**	**2.75**	**1.36**	**2.84**	**2.81**	**3.85**
2013	-0.72	-0.75	-0.65	-0.65	1.01	1.10	-1.11	-1.63	-1.20	-2.10
2014	0.85	0.76	0.50	0.47	0.52	0.41	0.46	0.13	0.56	0.17
2015	-0.84	-0.75	-0.83	-0.81	-0.93	-0.94	-0.68	-0.99	-0.85	-0.76
2016	-0.34	-0.32	-0.10	-0.12	-0.33	-0.22	-0.43	0.29	-0.19	-0.11
Change Years 21–30	**-1.05**	**-1.06**	**-1.08**	**-1.11**	**-1.75**	**-1.85**	**-1.76**	**-2.20**	**-1.68**	**-2.80**
Net Change	**-0.85**	**-0.76**	**-0.11**	**-0.23**	**0.55**	**0.02**	**-0.40**	**0.64**	**1.13**	**1.05**

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

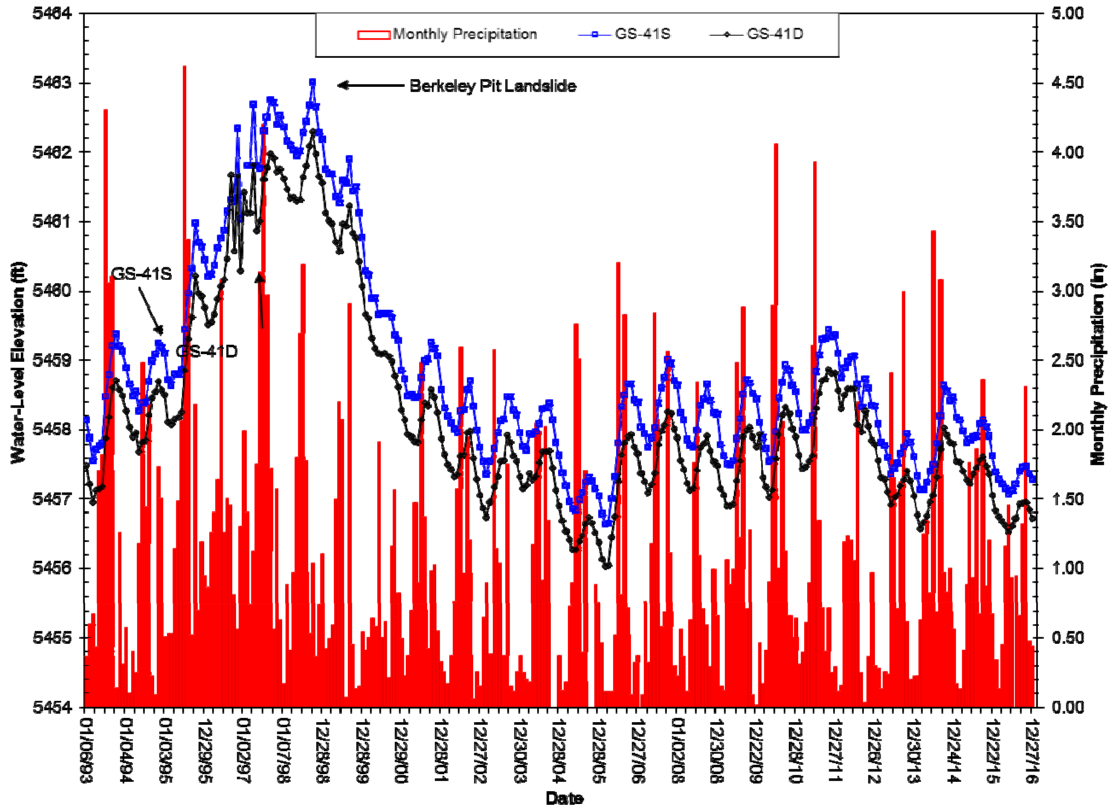


Figure 2-19. Water-level hydrographs for wells GS-41S and GS-41D.

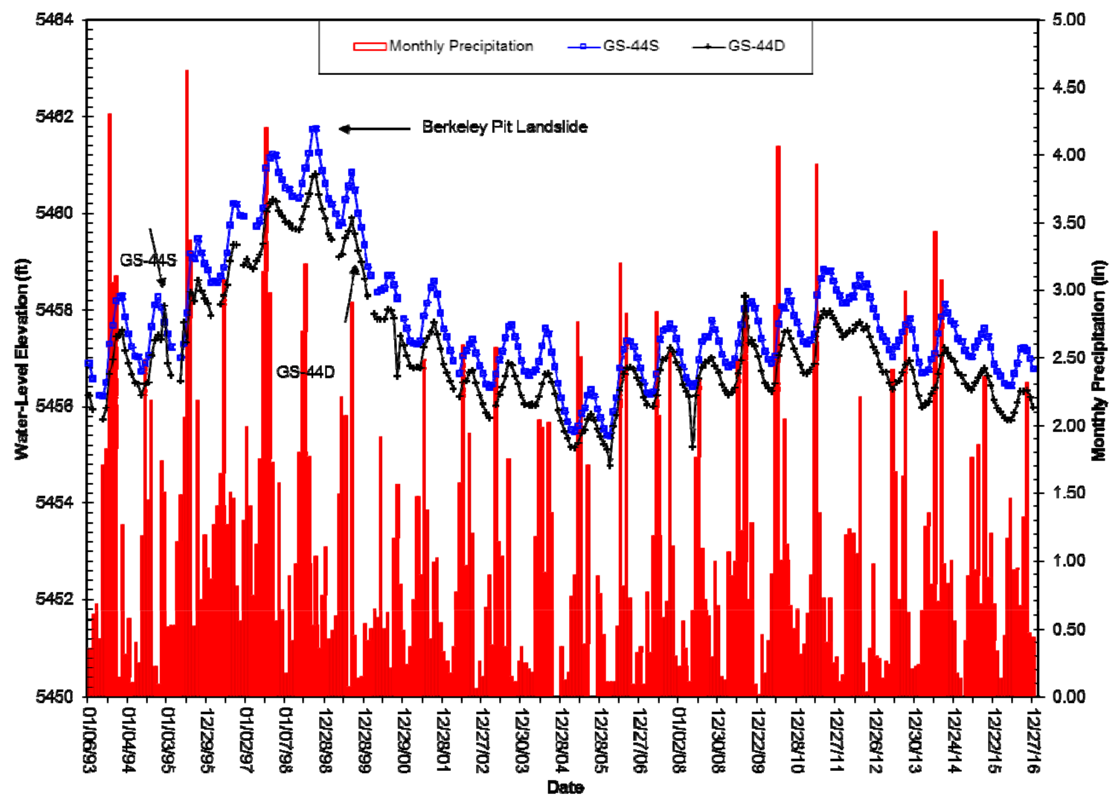


Figure 2-20. Water-level hydrographs for wells GS-44S and GS-44D.

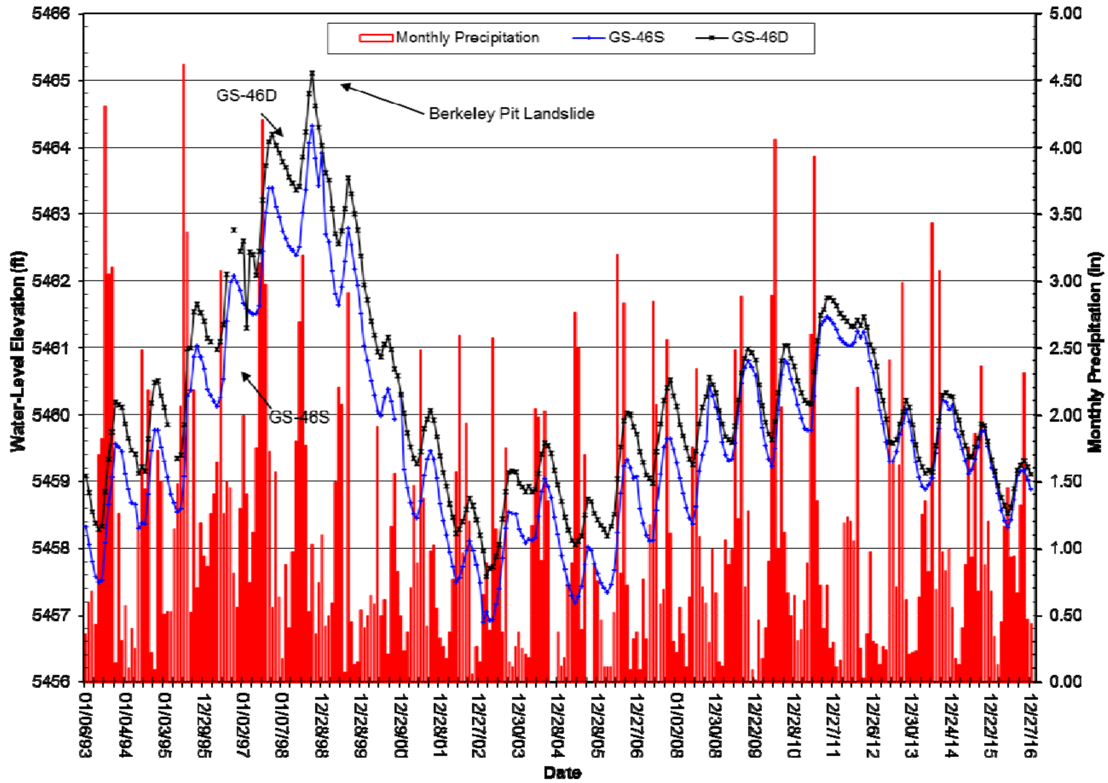


Figure 2-21. Water-level hydrographs for wells GS-46S and GS-46D.

The BMF05-series wells were installed in late 2005 and early 2006 to replace the domestic wells originally part of the post RI/FS monitoring program. The domestic wells were monitored from 1997 through 2002, but data evaluation by DEQ and EPA determined that dedicated monitoring wells would be more reliable for a long-term monitoring program and not be influenced by household usage. The locations of the BMF05-series wells are shown in figure 2-18. The well sites were selected to provide coverage for the same area encompassed by the domestic well network and to provide information for areas south of the Berkeley Pit and active mine area. Monitoring this area is important to better define the alluvial aquifer groundwater divide between the BMFOU and the BPSOU. Pressure transducers were installed in the spring of 2006 in each well for continuous water-level monitoring. Water levels have generally risen in three of the four wells since their installation, ranging between 0.64 ft and 1.13 ft (table 2.4.1); the water level in well BMF05-1 has declined 0.40 ft for the period of record.

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

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

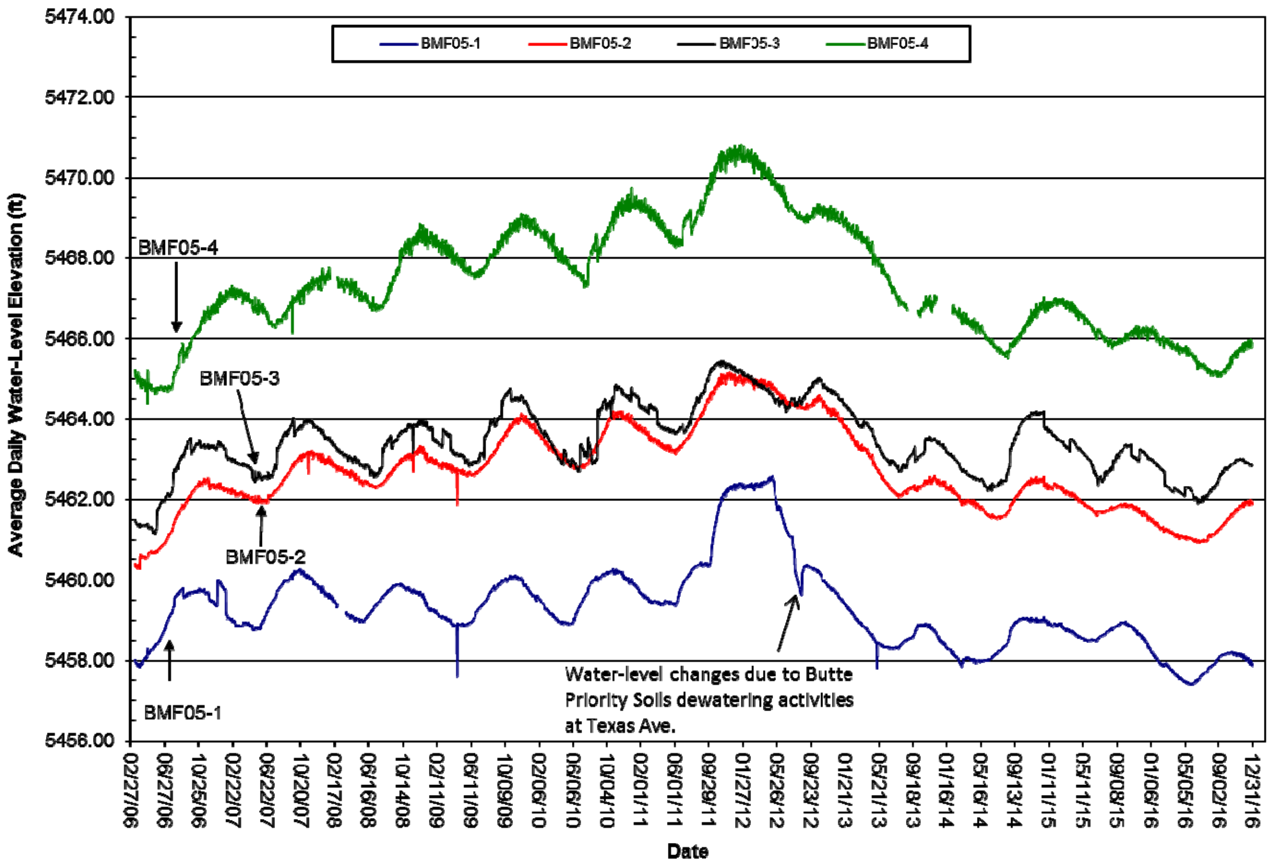


Figure 2-22. Average daily water levels for BMF05-series wells.

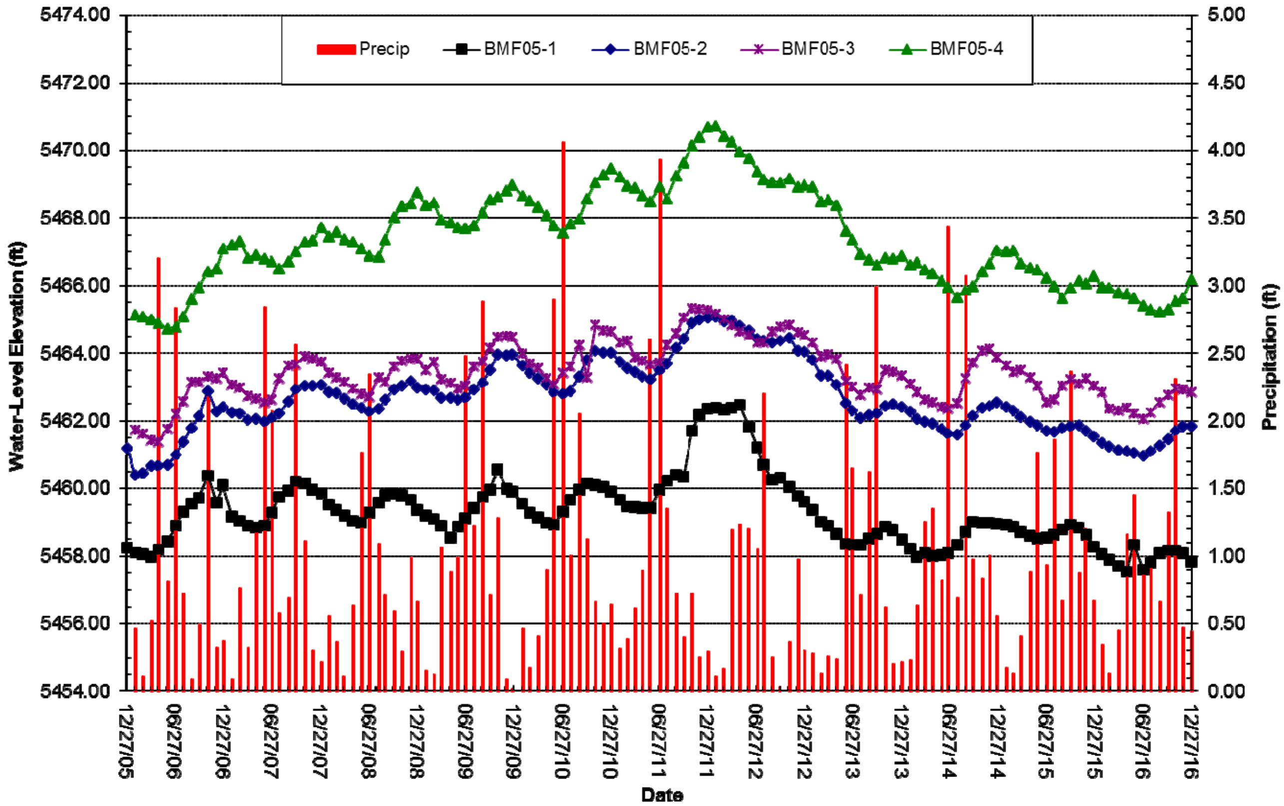


Figure 2-23. Monthly water levels versus precipitation, BMF05-series wells.

Section 2.4.1 GS- and BMF05-Series Wells Water Quality

Water-quality samples were collected during April from GS-series wells as part of the 2016 BMFOU monitoring. The poor water quality in GS-41S and GS-41D comes from their proximity to the Parrot Tailings area; concentrations of dissolved constituents are extremely high. Data collected in 2016 confirm the large increases noted in many of the dissolved constituents since 2004; concentrations were similar to those seen in 2010–2015 data for well GS-41D, while declining in 2015–2016 results for GS-41S.

Concentrations of several dissolved constituents continue to exceed MCLs in wells GS-44S and GS-44D at the north end of Clark Park. Cadmium concentrations continue to increase in well GS-44S and are at levels twice the MCL in 2010–2016 samples, after being below the MCL for the 2003–2004 periods. Nitrate, copper, and zinc exceeded their respective MCLs and SMCLs in 2016 sample results for well GS-44S. Water from well GS-44D also continues to have cadmium concentrations greater than the MCL, but the cadmium concentrations have gradually decreased by as much as 50 percent, or more, during the period of record.

Wells GS-46S and GS-46D, northeast of Clark Park, continued to produce water of good quality in 2016, and constituent concentrations show little upward or downward trend, with the exception of uranium (GS-46S), which exceeds the MCL in the 2005–2009, 2011, and 2014–2016 sample results.

Water-quality samples were collected from the BMF05 wells three times annually during 2006–2007 to establish baseline conditions. Thereafter, semi-annual samples have been collected since 2008. Water from well BMF05-1 is extremely contaminated, with pH less than 5.50 and elevated concentrations of iron, manganese, cadmium, copper, and zinc. Table 2.4.2 shows the mean values for these constituents and the appropriate MCL or SMCL.

Table 2.4.2 Mean concentrations of analytes that exceed water-quality standards, well BMF05-1.

Analyte	**Mean Concentration (mg/L)**	**MCL (mg/L)**	**SMCL (mg/L)**
pH	5.19		6.5–8.5
Iron	6.76		0.30
Manganese	110		0.05
Aluminum	0.592		0.05–0.2
Cadmium	0.186	0.005	
Copper	3.33		1.0
Zinc	43.7		2.0
Sulfate	1,422		250

Based upon the location of BMF05-1, adjacent to the historic SBC channel and downgradient from MR's concentrator (fig. 2-19), it is not surprising that the groundwater at this site is contaminated with mining-related wastes. Contaminant concentrations are similar to those in well AMC-5 located to the north. Mean pH values are below the SMCL in water from wells BFM05-2 and BMF05-4.

SECTION 3.0 EAST CAMP BEDROCK SYSTEM

The East Camp bedrock system is comprised of the underground mines and Berkeley Pit that drained water to the Kelley pump station at the time of mining suspension in 1982, the bedrock monitoring wells installed as part of the RI/FS investigation, and selected diamond drill exploration boreholes located primarily to the east of the Berkeley Pit.

Section 3.1 Underground Mines and Berkeley Pit Water Levels

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). It also includes the bedrock system adjacent to the East Camp mines. Monitoring of water levels in the seven East Camp underground mines continued. During 2016, water levels in the mines rose between 3.28 and 6.61 ft, which were less than the 2015 increases. The Berkeley Pit water level rose 5.52 ft, which is 4.44 ft less than in 2015 (table 3.1.1); the 2015 water-level increases were higher due to several longer-term diversions of HSB water to the pit during mill and water-treatment plant maintenance activities. Figure 3-2 shows the annual water-level changes graphically for these sites. The rate of water-level rise has slowed by 50 to 60 percent since 2003 when MR diverted the Horseshoe Bend drainage water away from the pit.

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

Year	Berkeley Pit	Anselmo	Kelley	Belmont [1]	Steward	Granite Mountain	Lexington[2]	Pilot Butte
1982			1,303.80	117.20	85.10			
1983			877.30	1,054.20	1,069.80			
1984			261.80	269.20	274.00			
1985			122.40	121.50	123.40			
1986		55.90	95.70	101.70	100.50			
1987		76.80	84.42	76.60	79.30	67.00		
1988		52.70	55.50	53.20	51.80	57.00	8.10	
1989		29.10	30.50	30.70	29.47	31.00		
1990		31.50	33.20	33.80	33.28	34.00		
1991	12.00	28.60	32.80	30.40	28.90	31.00		
Change Years 1–10	**12.00**	**274.60**	**2,897.42**	**1,887.50**	**1,875.55**	**220.00**	**8.10**	**00.00**
1992	25.20	22.10	23.77	23.50	23.00	25.00		
1993	25.97	24.30	24.57	25.60	24.60	26.00		
1994	26.86	25.10	25.82	25.34	24.93	27.00		
1995	28.71	27.69	27.05	17.77	27.63	30.00		
1996	18.00	16.47	18.82	4.15	18.43	18.00	1.19	3.07
1997	12.45	13.58	16.09	15.62	14.80	15.68	12.79	18.12
1998	17.08	13.23	14.73	13.89	14.33	14.24	13.71	11.26
1999	12.53	11.07	11.52	12.15	11.82	11.89	10.65	11.61
2000	16.97	14.48	14.55	15.66	14.60	15.09	14.01	14.11
2001	17.97	16.43	11.77	16.96	16.48	16.35	15.95	16.59
Change Years 11–20	**201.74**	**184.45**	**188.69**	**170.64**	**190.62**	**199.12**	**68.30**	**74.76**
2002	15.56	11.60	13.15	13.02	12.60	12.82	12.08	11.33
2003	13.08	13.05	13.94	13.74	13.44	14.23	2.75	14.05
2004	7.68	7.31	7.86	7.54	7.48	7.67		7.53
2005	7.03	7.10	7.37	7.17	7.00	6.98		6.97
2006	7.69	7.70	8.29	7.74	7.99	7.92		8.61
2007	6.90	6.91	7.55	6.38	7.25	7.28		7.39
2008	6.63	5.42	6.28	7.01	5.58	5.68		6.13
2009	7.17	6.69	6.79	7.33	7.13	6.92	52.79	6.38
2010	7.32	7.30	7.83	7.45	7.80	6.48	7.03	7.07
2011	7.20	7.31	8.22	8.46	7.11	8.99	7.91	9.11
Change Years 21–30	**86.26**	**80.39**	**87.28**	**85.84**	**83.38**	**84.97**	**82.56**	**84.57**
2012	6.74	6.54	6.42	6.67	6.43	6.42	7.08	5.96
2013	8.12	6.87	6.98	6.84	6.62	6.72	6.85	6.77
2014	6.95	7.25	8.58	8.08	7.23	7.71	7.49	7.34
2015	9.96	8.70	8.36	8.06	8.15	8.59	8.66	8.76
2016	5.52	6.18	6.61	6.61	6.31	3.28	6.45	4.89
Change Years 31–40	**37.29**	**35.54**	**36.95**	**36.26**	**34.74**	**32.72**	**36.53**	**33.72**
Net Change*	**337.29**	**574.98**	**3,210.34**	**2,180.24**	**2,184.29**	**536.81**	**195.49**	**193.05**

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

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

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

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

Path: D:\stuff\ted\BMF\BMF_mapping-East_Camp_Bedrock_04042016.mxd

Date: 6/13/2016

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

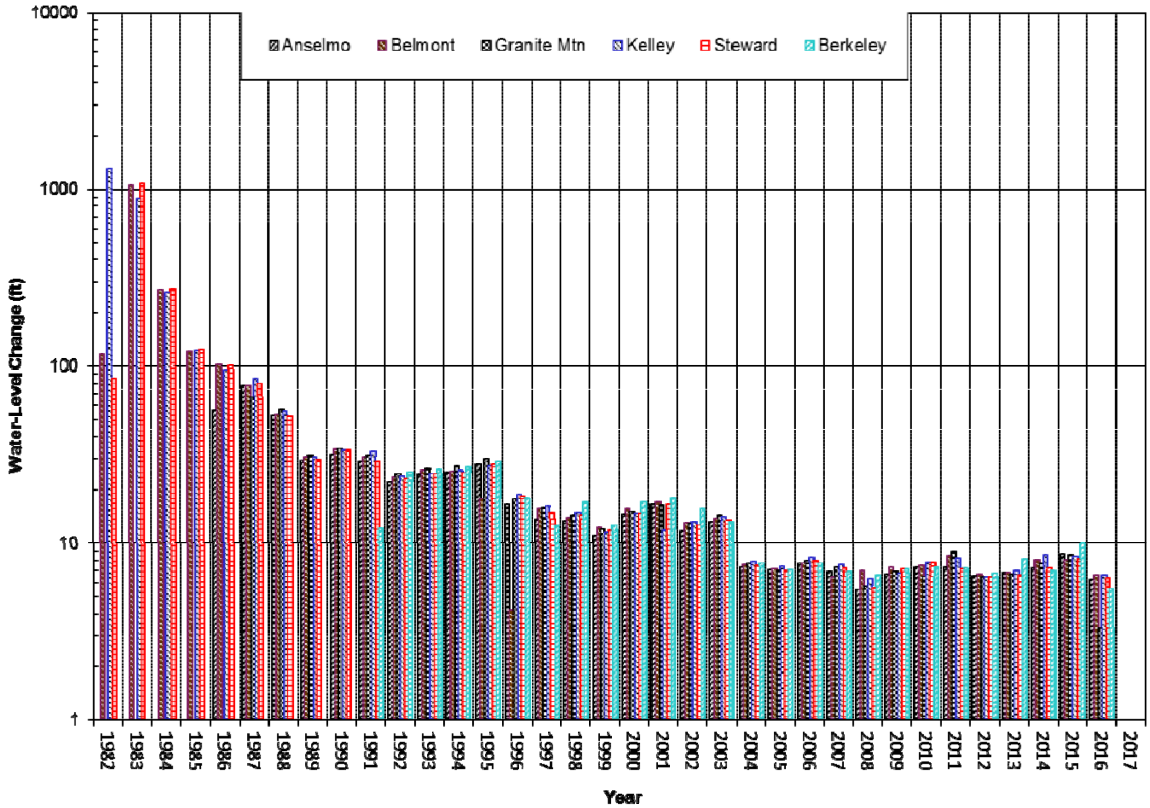


Figure 3-2. East Camp mines annual water-level changes.

Water levels for the Anselmo Mine and Kelley Mine for the period of record are shown in the hydrographs in figure 3-3. Except for the steadily increasing water levels, there are no obvious variations from the upward trend when viewed at this scale; however, when the y-axis scale is expanded and the time limited to 1995 to the present, subtle deviations from the general rate of rise become apparent (fig. 3-4). The removal of HSB drainage water discharging into the pit in April 1996 slowed the rate of water-level rise, but the July 2000 re-diversion of the HSB drainage water to the pit, following MR's suspension of mining, resulted in an increased rate of rise. The slope of the line since 2004, or rate of rise, shown in figure 3-4 remained constant throughout 2016, corresponding to the continued diversion of HSB drainage water to the HSB treatment plant, which came online in late November 2003. Water levels in all the East Camp underground mines react similarly.

There is no apparent influence from monthly precipitation on water levels in the underground mines (fig. 3-3). The water-level rise is a function of the time since historic mine-dewatering activities ceased and the volume to be flooded in the underground mine workings and Berkeley Pit; these signals completely overwhelm any precipitation signal that may be in the data. Based upon volume estimates of the underground mines and December 2016 water-level elevations, 85 percent of the underground workings are flooded. Because approximately 12 percent of the underground workings are above the CWL elevation of 5,410 ft, only 3 percent of the underground workings remain to be flooded.

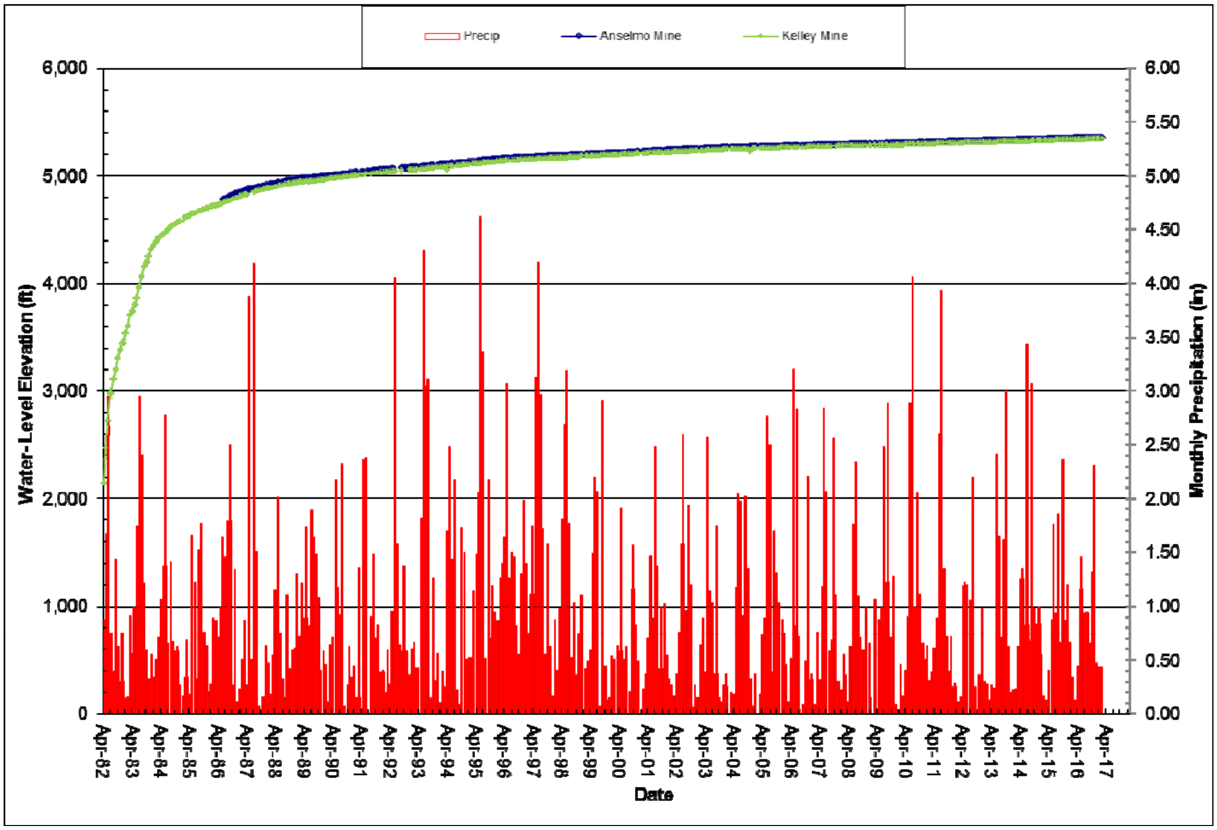


Figure 3-3. Anselmo Mine and Kelley Mine hydrograph versus precipitation, 1982–2016.

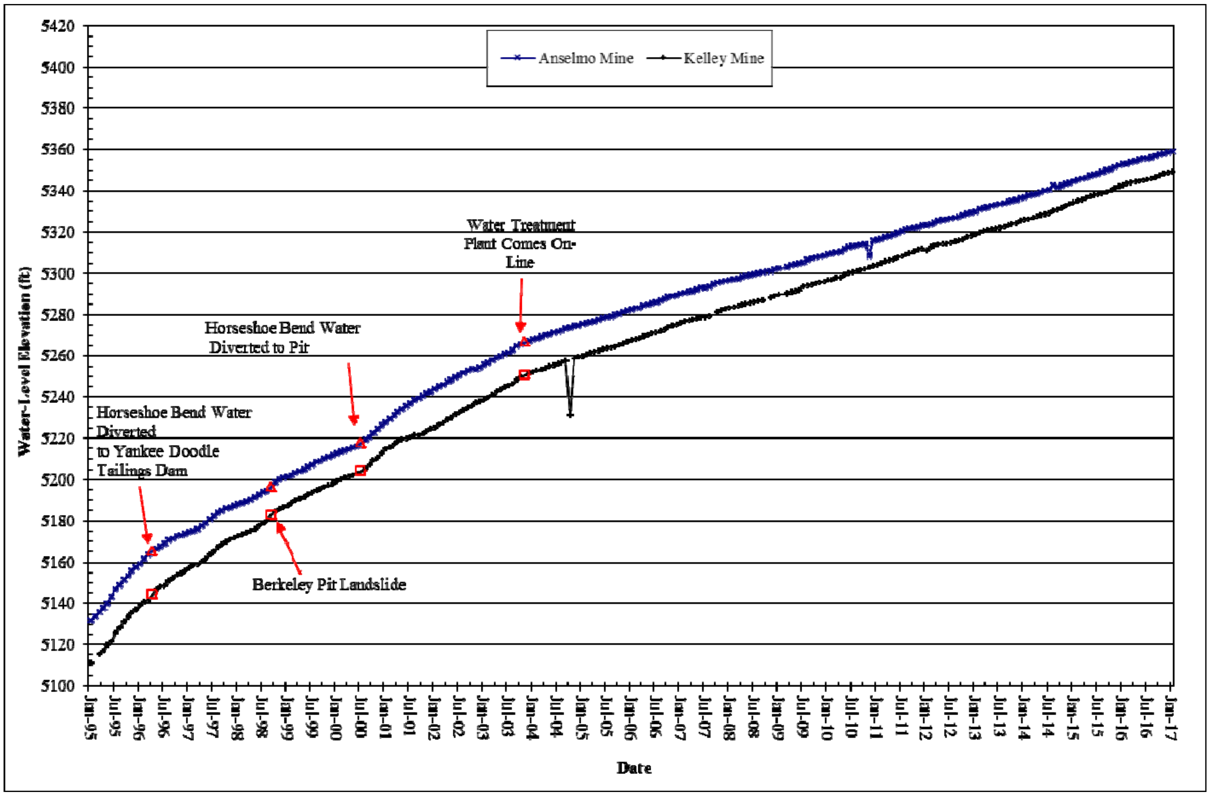


Figure 3-4. Anselmo Mine and Kelley Mine hydrograph, 1995–2016.

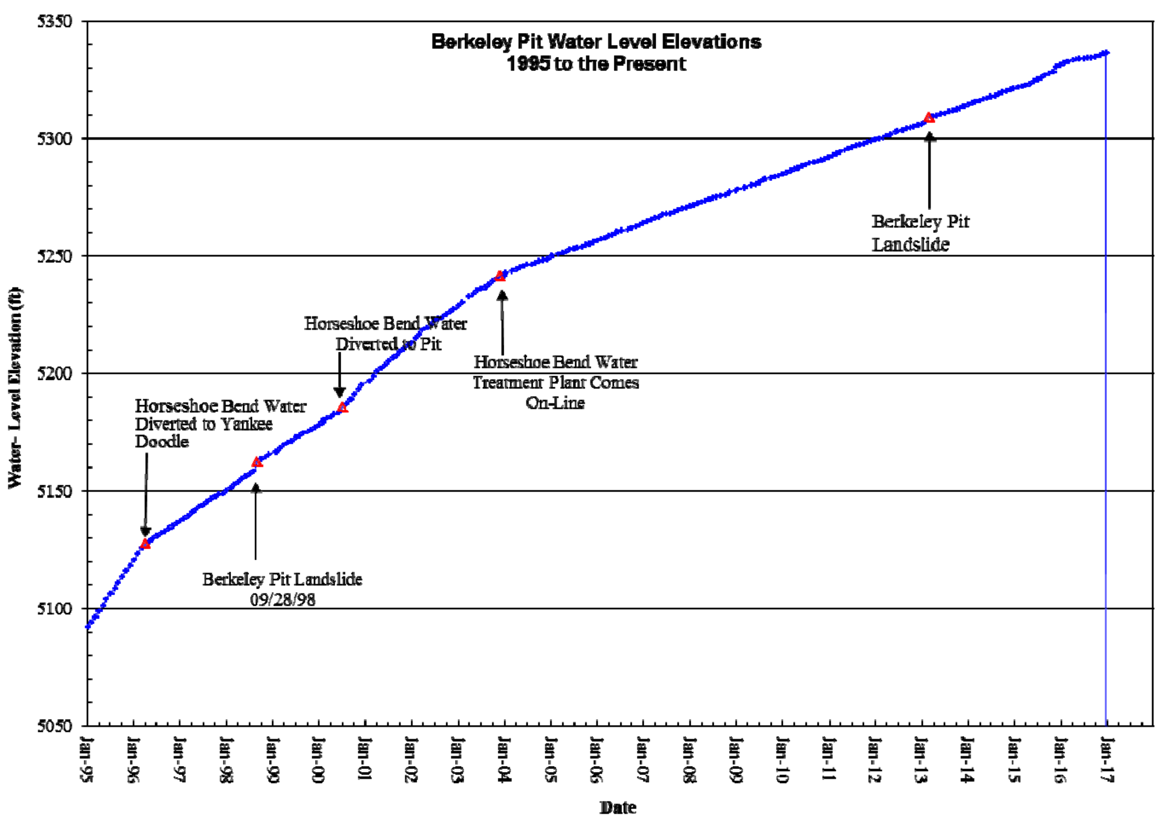


Figure 3-5. Water-level hydrograph for the Berkeley Pit, 1991–2016.

Figure 3-5 shows monthly water-level changes in the Berkeley Pit from 1991 through 2016. Water-level changes resulting from operational changes, e.g., diversion of HSB water in 1996, the 1998 landslide, and the HSB water-treatment plant coming online are noticeable. The rate of rise decreased beginning in the fall of 2003 as a result of the HSB treatment plant coming online and decreasing inflow of water into the pit.

The 1994-ROD and 2002 CD established 14 POCs in the East Camp bedrock system, seven underground mines and seven bedrock monitoring wells. These POCs were selected to verify that contaminated water was contained within the underground mine system and Berkeley Pit. Under the terms specified in the ROD and CD, groundwater levels cannot exceed 5,410 ft above mean sea level at any POC without monetary penalties being applied to the settling parties. The East Camp POC with the highest water level at the end of 2016 was the Pilot Butte Mine, about 0.5 mi north of the Berkeley Pit, at an elevation of 5,359 ft, or 50 ft below the action level. The lowest water level at the end of 2016 was 5,339 ft in the Berkeley Pit, which confirms that groundwater continues to flow towards the pit.

Section 3.2 Underground Mines and Berkeley Pit Water Quality

Earlier reports (Duaime and others, 1996; Duaime and Metesh, 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) from previous trends. Data from the 2016 sampling indicate that the changes in concentration are sustained for yet another year. Most notable are elevated concentration of arsenic, iron, manganese, zinc, and sulfate in the Kelley Mine waters. The Anselmo, Kelley, and Steward mines were sampled during the spring 2016 sample event at a depth of 100 ft below the water surface. No samples were collected from deeper depths in the mines due to obstructions in the shafts. Concentrations varied very little with sample depth in previous years.

Kelley: iron, sulfate, arsenic, zinc, and aluminum increased to near historic concentrations in 2003–2004, decreasing from 2005 to 2016 (fig. 3-6). Copper concentrations increased in the 2010–2016 samples; however, they remain very low.

Anselmo: iron concentrations remain elevated but are less than 2004 concentrations; arsenic concentrations were similar to those in 2004–2015; zinc concentrations have increased slightly since 2007 (fig. 3-7). Copper concentrations remain low (<20 µg/L).

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

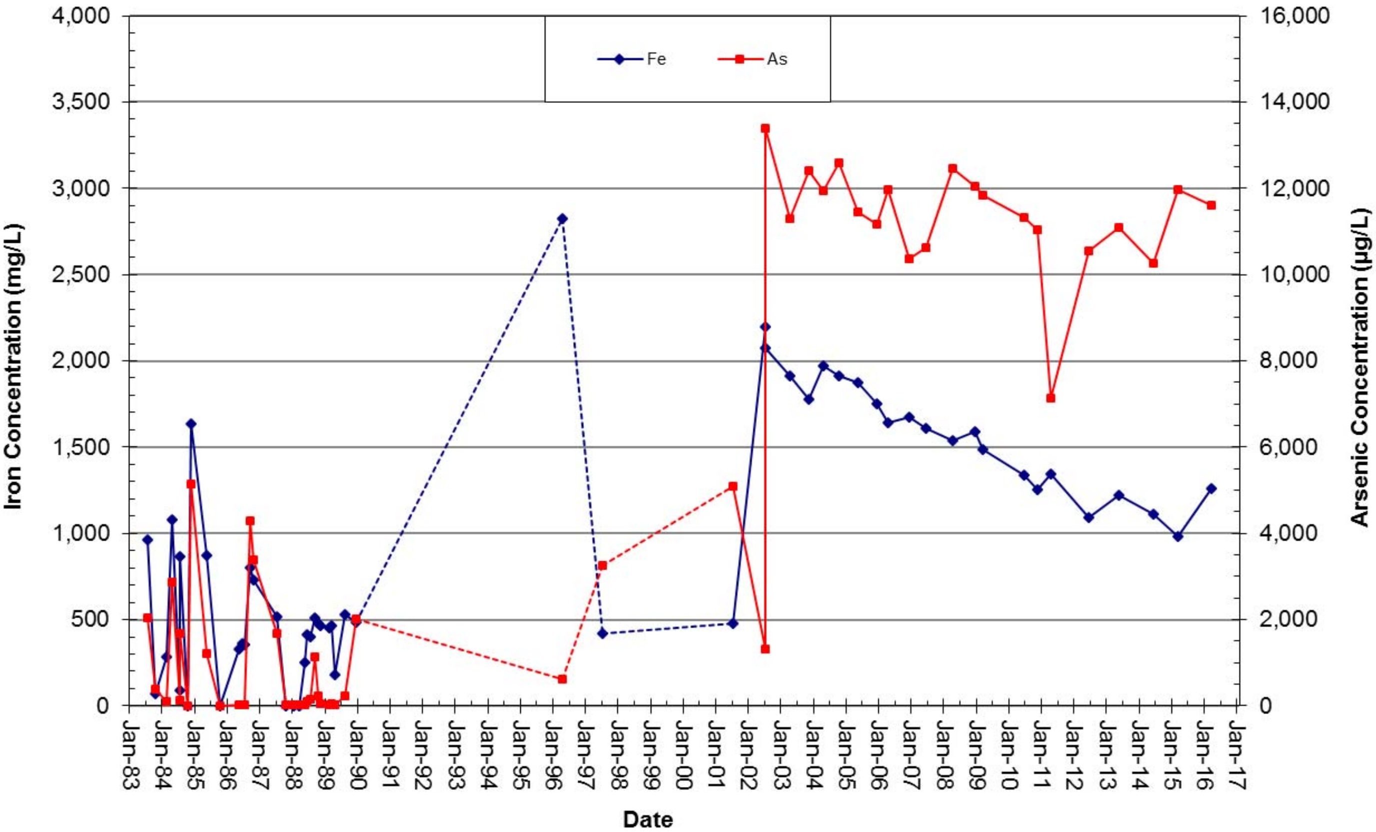


Figure 3-6. Kelley Mine iron and arsenic concentrations over time.

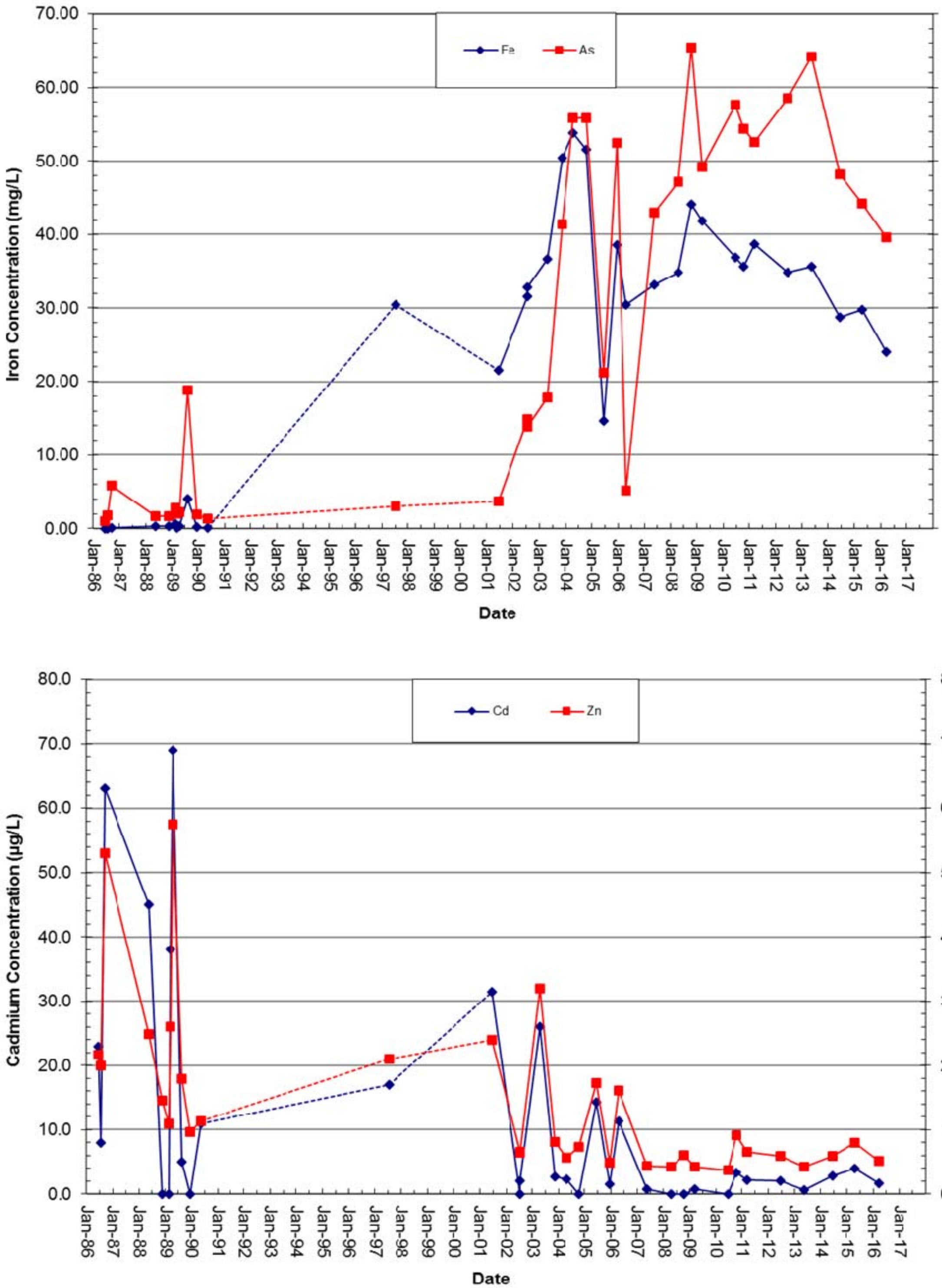
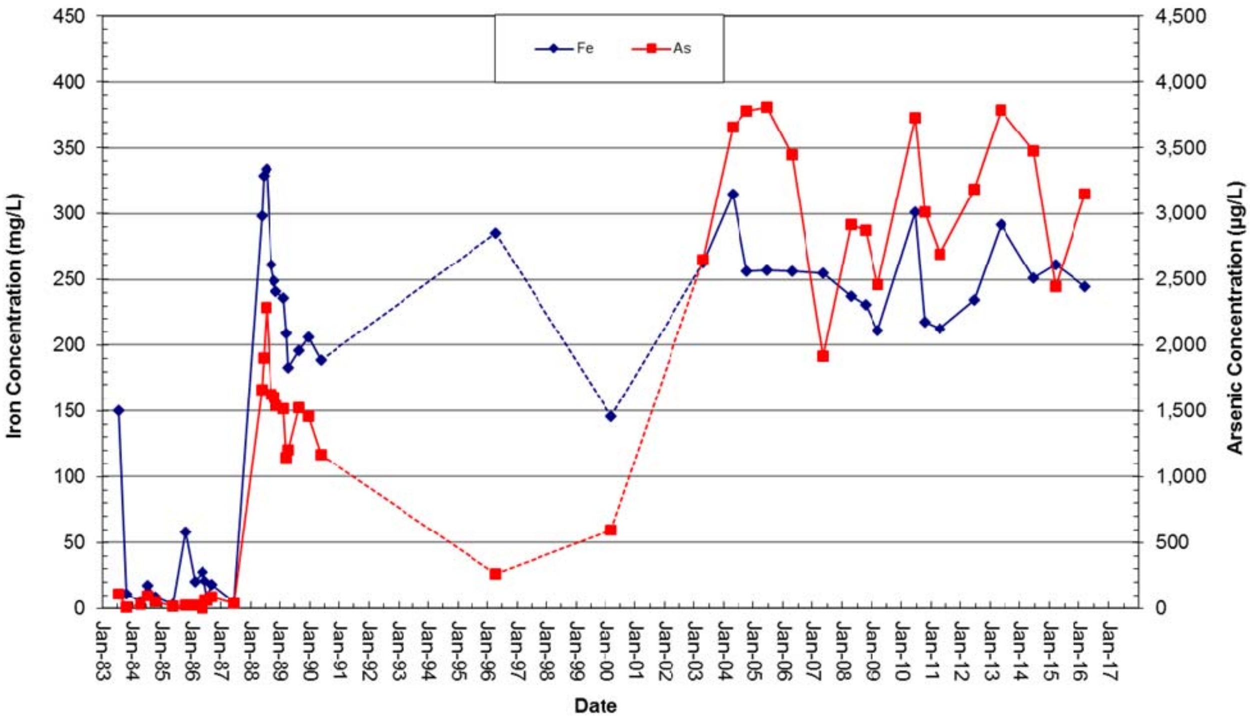


Figure 3-7. Anselmo Mine iron and arsenic concentrations (top) and cadmium and zinc concentrations (bottom) over time.



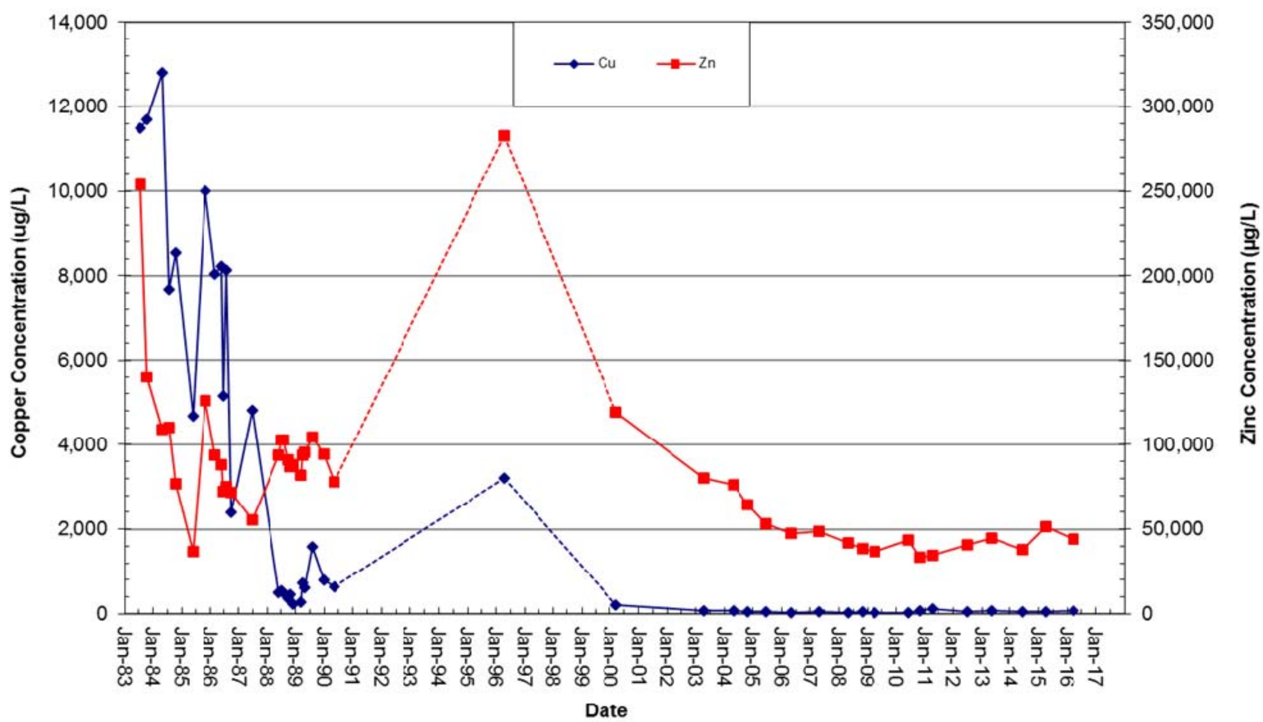


Figure 3-8. Steward Mine iron and arsenic concentrations (top) and copper and zinc concentrations (bottom) over time.

Section 3.3 Bedrock Monitoring Wells

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

Section 3.3.1 Bedrock Well Water Levels

Monitoring of the nine RI/FS and ROD-installed bedrock wells continued. Monitoring well locations are shown in figure 3-1. Water levels rose in wells A, C, D-1, D-2, G, and J at rates similar to those in the East Camp Mine system, while water levels in wells B and E increased at lesser rates. Well F had a water-level decline of 0.35 ft. Table 3.3.1.1 contains yearly water-level changes; figure 3-9 shows these changes graphically.

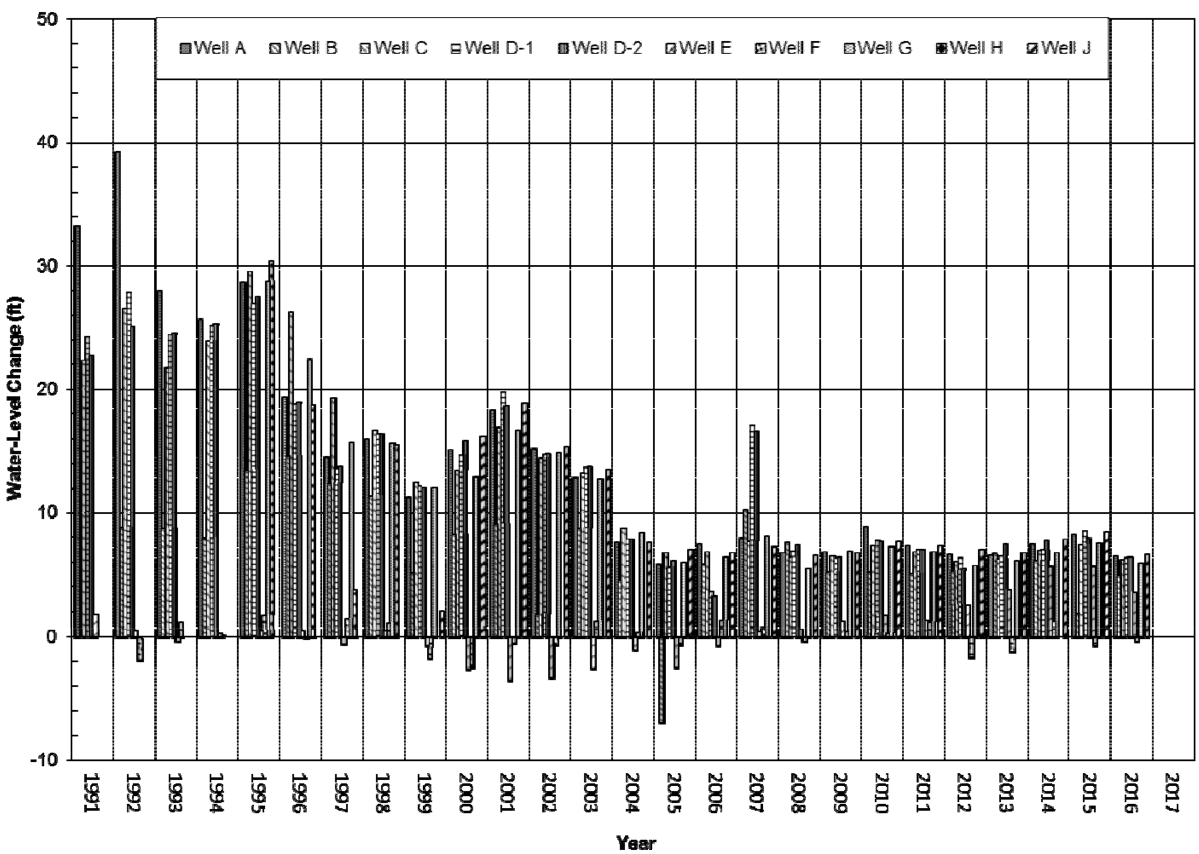


Figure 3-9. Bedrock wells annual water-level change.

Water levels in the bedrock aquifer, which had been affected (lowered) by historic underground mine dewatering, are responding to the cessation of pumping and show no apparent relationship to precipitation or seasonal changes through 2016. Physical changes that affect the flow of water into the Berkeley Pit and underground mines, e.g., the 1996 HSB water diversion and the 2000 addition of the HSB drainage flow, also influence the rate of water-level increase. Figure 3-10 is a hydrograph for well A showing monthly water levels and monthly precipitation totals with the 1996, 2000, and 2003 HSB operational changes identified. The void areas in the mines and Berkeley Pit are the principal controls on the annual rate of rise in this system.

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

	Well A	**Well B**	**Well C**	**Well D-1**	**Well D-2**	**Well E**	**Well F**	**Well G**	**Well H[(1)]**	**Well J[(2)]**
1982										
1983										
1984										
1985										
1986										
1987										
1988										
1989										
1990										
1991	33.18		22..38	24.20	22.68	1.73				
Change Years 1–10	33.18		22.38	24.20	22.68	1.73				
1992	39.22	8.78	26.53	27.89	25.04	0.47	-1.92			
1993	27.95	8.68	21.72	24.41	24.51	-0.37	1.09			
1994	25.65	7.90	23.88	25.12	25.21	0.27	0.11			
1995	28.69	13.41	29.55	26.99	27.50	0.44	1.65	28.74	30.37	
1996	19.31	14.56	26.22	18.77	18.92	0.48	-0.11	2.40	8.72	
1997	4.44	2.35	9.25	13.62	13.68	-0.64	1.41	15.67	3.76	
1998	15.96	11.30	16.68	16.41	16.39	0.44	1.03	15.56	15.44	
1999	11.21	5.11	12.44	12.18	12.03	-0.78	-1.80	12.00	P&A	1.99
2000	15.12	8.20	13.39	14.66	15.79	-2.68	-2.49	12.84	P&A	16.19
2001	18.33	9.08	16.86	19.81	18.61	-3.58	-0.61	16.56	P&A	18.81
Change Years 11–20	215.88	99.37	206.52	199.86	197.68	-5.95	-1.64	123.86	68.29	36.99

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

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

Year	Well A	Well B	Well C	Well D-1	Well D-2	Well E	Well F	Well G	Well H[1]	Well J[2]
2002	15.16	1.73	14.41	14.69	14.76	-3.37	-0.73	14.84	P&A	15.29
2003	12.75	8.70	13.20	13.69	13.72	-2.66	1.16	12.71	P&A	13.48
2004	7.60	4.46	8.71	7.90	7.83	-1.12	0.32	8.31	P&A	7.58
2005	5.82	-7.00	6.76	5.56	6.08	-2.51	-0.73	5.95	P&A	7.03
2006	7.44	5.82	6.81	3.56	3.20	-0.83	1.22	6.39	P&A	6.72
2007	7.93	10.23	7.64	17.01	16.56	0.38	0.67	8.06	P&A	7.23
2008	6.70	7.59	6.40	6.89	7.36	0.59	-0.41	5.47	P&A	6.49
2009	6.79	5.18	6.41	6.37	6.34	1.14	0.39	6.90	P&A	6.70
2010	8.87	5.19	7.29	7.77	7.62	1.69	0.24	7.22	P&A	7.64
2011	7.32	5.04	6.82	7.01	7.00	1.27	1.06	6.77	P&A	7.29
Change Years 21–30	86.38	46.94	84.45	90.46	90.47	-5.42	3.19	82.62	0.00	85.45
2012	6.55	5.24	6.02	6.37	5.44	2.46	-1.72	5.67	P&A	7.03
2013	6.54	6.66	6.24	6.51	7.41	3.74	-1.20	6.07	P&A	6.70
2014	7.44	6.12	6.92	7.03	7.69	5.62	1.45	6.70	P&A	7.86
2015	8.20	1.79	7.33	8.54	7.89	5.59	-0.78	7.52	P&A	8.44
2016	6.43	4.91	6.14	6.31	6.36	3.49	-0.35	5.90	P&A	6.61
Change Years 31–40	**35.16**	**24.72**	**32.65**	**34.76**	**34.79**	**20.90**	**-2.86**	**31.86**	**0.00**	**36.64**
Net Change	**370.60**	**171.03**	**346.00**	**349.28**	**345.62**	**11.26**	**--1.31**	**238.34**	**68.29**	**159.08**

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

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

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

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

Year	DDH-1[(3)]	DDH-2	DDH-4	DDH-5	DDH-8
2002	14.63	14.80	13.14	P&A	13.64
2003	13.05	13.90	NA	P&A	14.49
2004	7.08	7.89	NA	P&A	7.90
2005	4.87	5.89	NA	P&A	57.52
2006	6.30	6.75	NA	P&A	6.03
2007	3.08	8.75	NA	P&A	5.90
2008	P&A	6.58	NA	P&A	4.62
2009	P&A	6.97	NA	P&A	5.15
2010	P&A	7.50	NA	P&A	4.60
2011	P&A	7.44	NA	P&A	4.93
Change Years 21-30	**49.01**	**86.47**	**13.14**	**0.00**	**124.78**
2012	P&A	**7.10**	NA	P&A	**2.51**
2013	P&A	**6.76**	NA	P&A	**3.08**
2014	P&A	**7.84**	NA	P&A	**4.52**
2015	P&A	**8.41**	NA	P&A	**4.40**
2016	P&A	**5.61**	NA	P&A	**4.02**
Change Years 31-40	**0.00**	**35.72**	**0.00**	**0.00**	**18.53**
Net Change	**338.38**	**382.17**	**276.05**	**240.42**	**435.71**

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

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

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

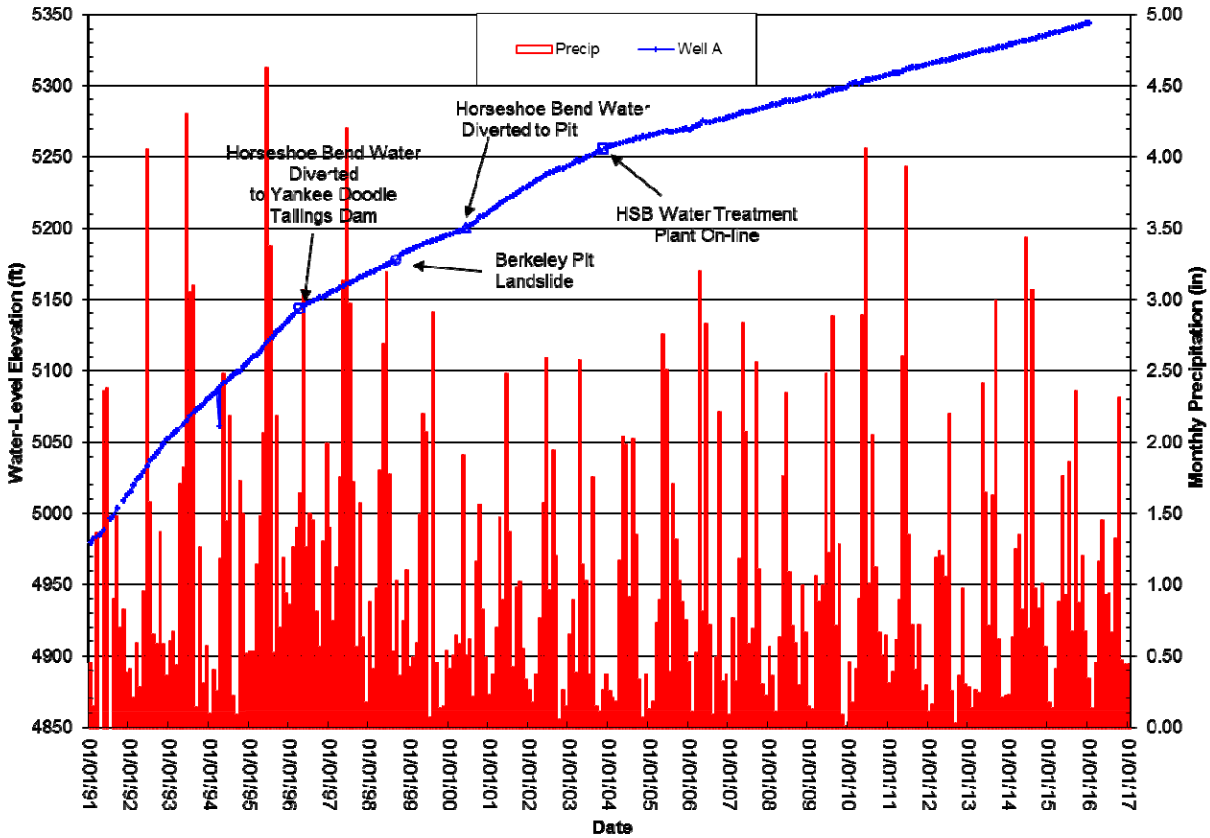


Figure 3-10. Water-level hydrograph for bedrock well A.

The water-level change in well B was about one-half of that in the other bedrock wells and the Berkeley Pit over a number of years. 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 2005 Dillon, MT earthquake and slow recovery from water-quality sampling caused water levels to fall about 7 ft. The 2006 water-level increase was about 75 percent that of the Berkeley Pit, indicating there were no long-term effects in water levels from the 2005 earthquake. The 2007 water-level increase in well B was almost 130 percent that of well A and 150 percent of the Berkeley Pit, which is the first time the annual water-level increase in this well exceeded that of these other sites. The 2013–2014 water-level increases were similar to those of a majority of the other bedrock wells; the 2015 and 2016 water-level rises were about 20 and 75 percent that of the other bedrock wells. Attention will be paid to this site’s water-level changes to see if this trend continues. Hydrographs for wells A and B, showing monthly water-level elevations, are in figure 3-11.

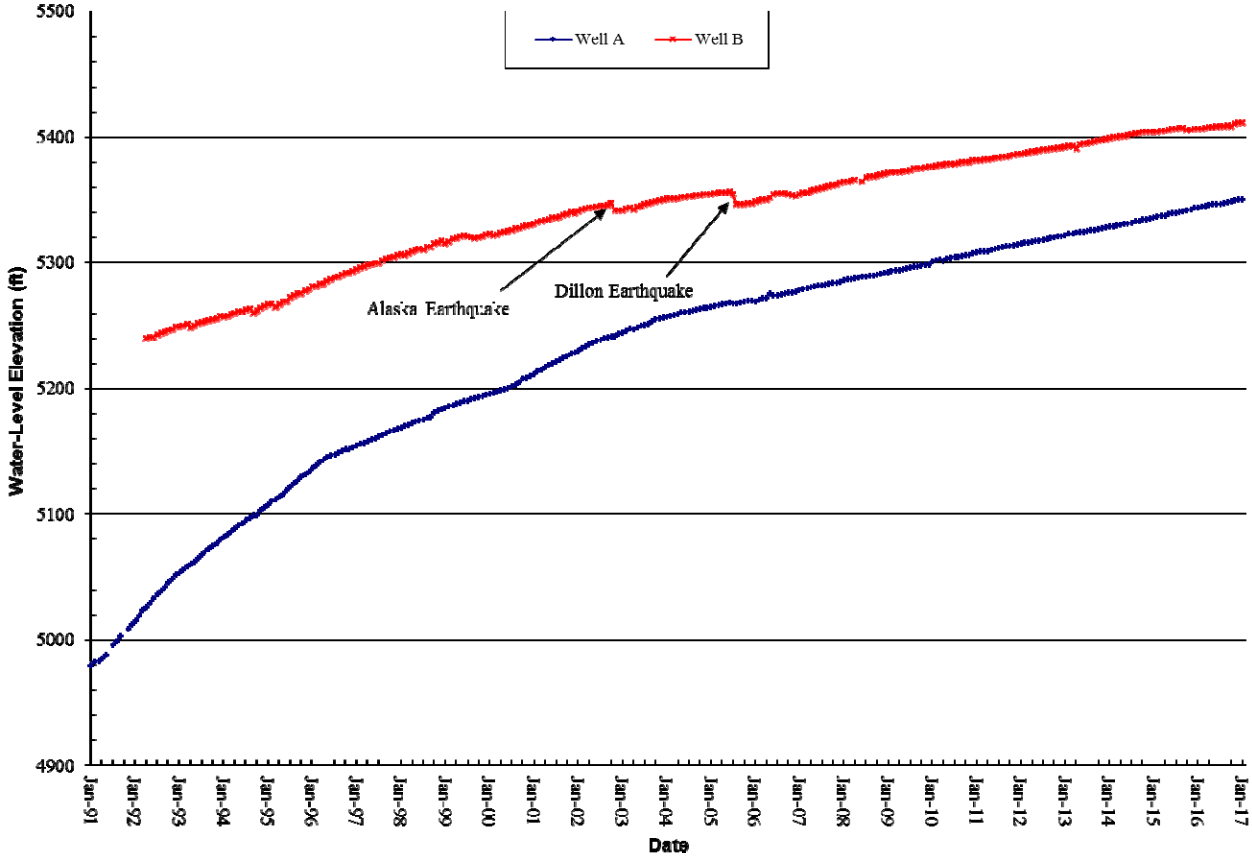


Figure 3-11. Water-level hydrographs for East Camp bedrock wells A and B.

Water levels in wells E and F do not follow the long-term upward patterns observed in most of the other bedrock wells (fig. 3-12). Water levels in these two wells are considerably higher than those in the other bedrock wells, indicating that the bedrock aquifer at these locations was not as affected by dewatering from historic mining activities. The water levels have a net increase of about 11.2 ft in well E and a net decline of 1.31 ft in well F over time. The increase in water levels since 2007 in well E may be in response to rising water levels in the surrounding bedrock system.

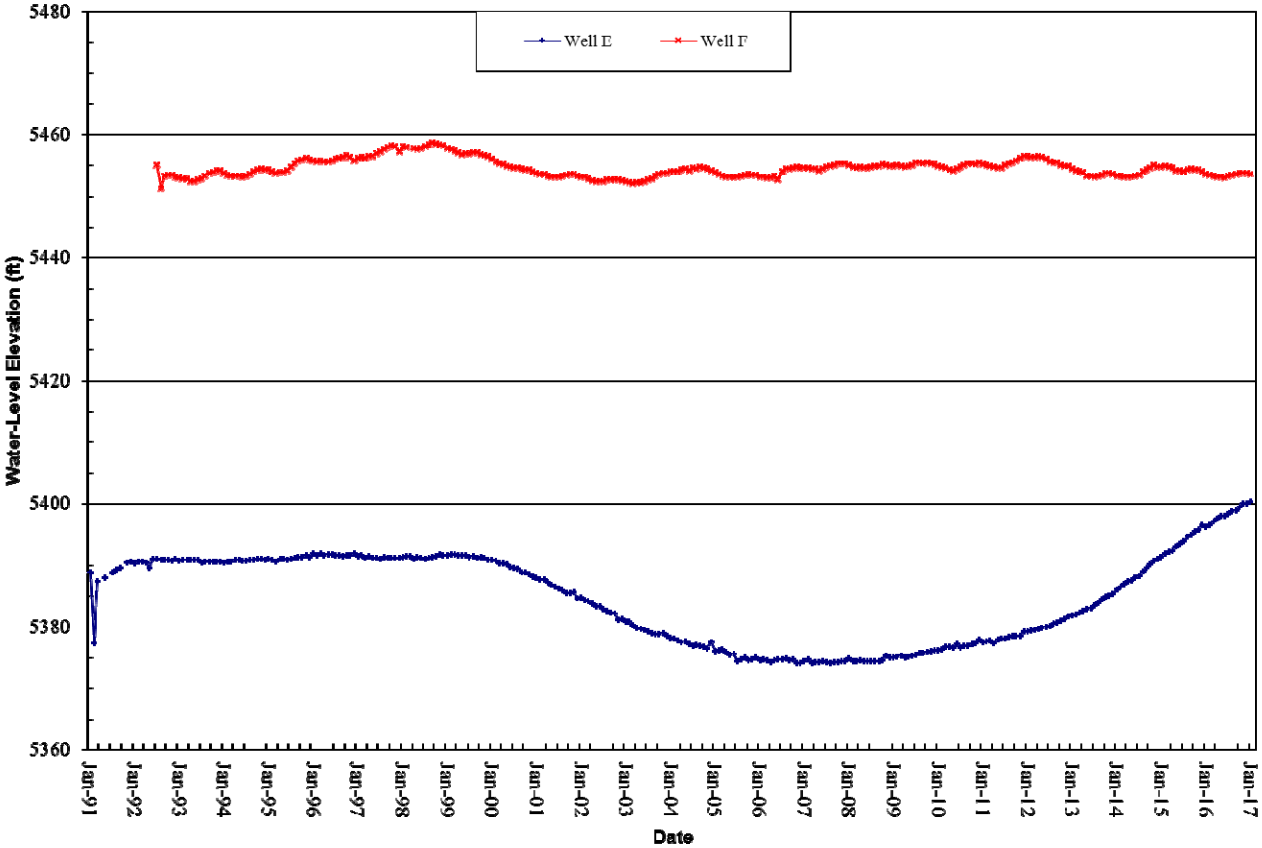


Figure 3-12. Water-level hydrographs for East Camp bedrock wells E and F.

Well H was plugged and abandoned due to casing integrity problems in 1999, and well J was drilled as a replacement. Water-level rises measured in well J since its completion in 1999 have been in the same range as those in other surrounding bedrock wells, and are shown in figure 3-13. Historic water levels for well H are also shown as well as a linear projection through 2016. Water levels for well J initially plotted closely to well H projected levels, verifying that well J was completed in the same bedrock zone as well H. However, in April 2004, the water level for well J plotted below the projected water level for well H because the Berkeley Pit filling rate is slowing due to the diversion and treatment of water from the HSB drainage. The projected water level for well H does not account for the lack of inflow of HSB water to the pit. If water levels had continued to rise, as shown by the projection line for well H, water levels would be more than 100 ft higher than current levels. The diversion of HSB drainage water away from the pit has significantly slowed the pit filling rate.

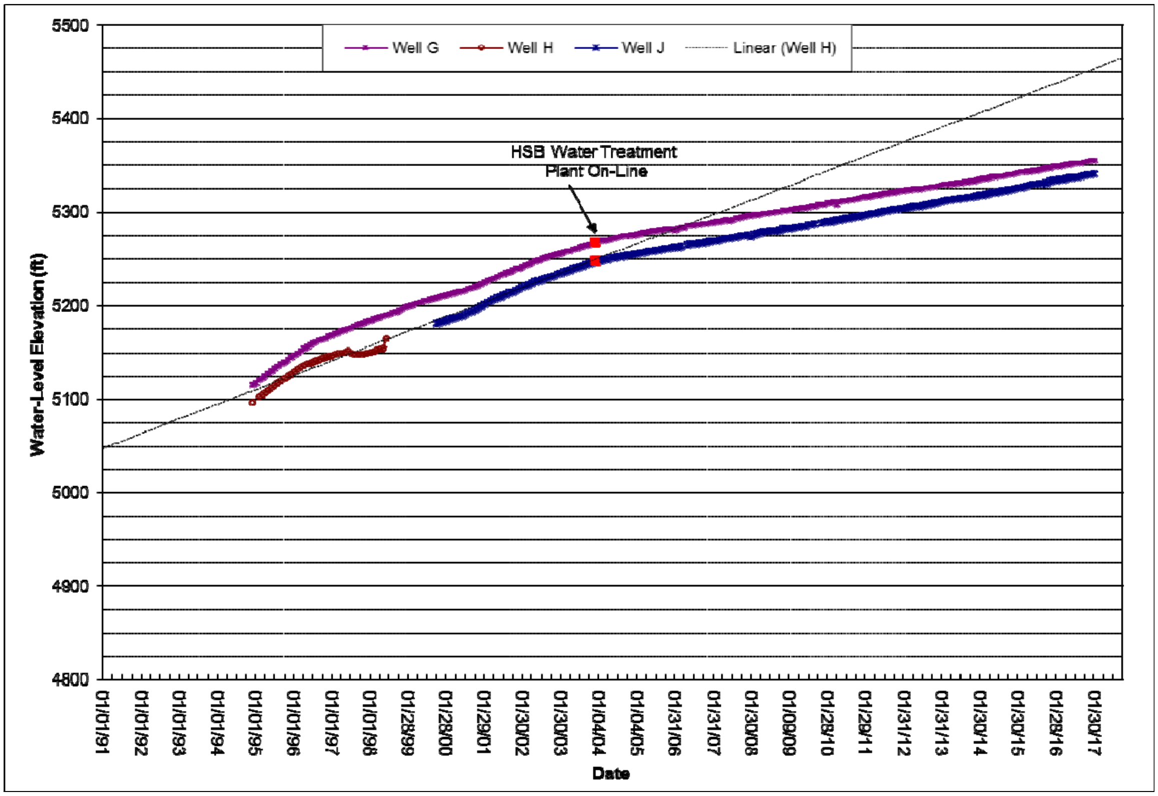
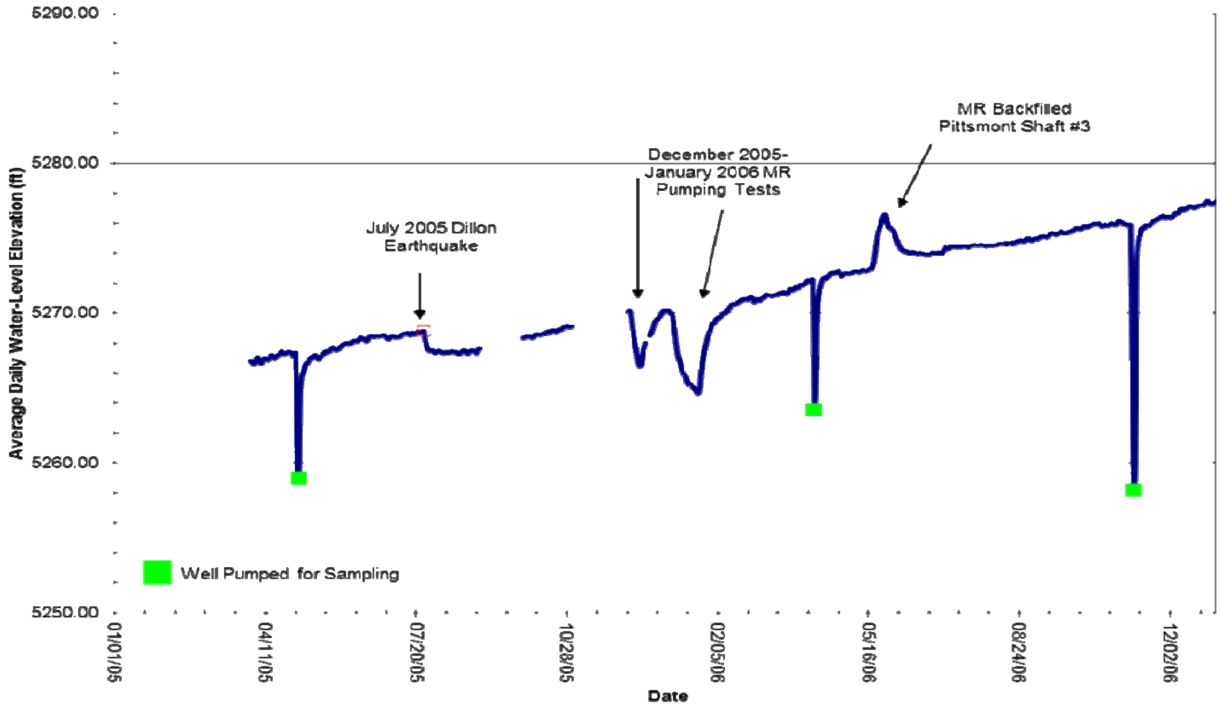


Figure 3-13. Water-level hydrographs for bedrock wells G, H, and J.

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

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



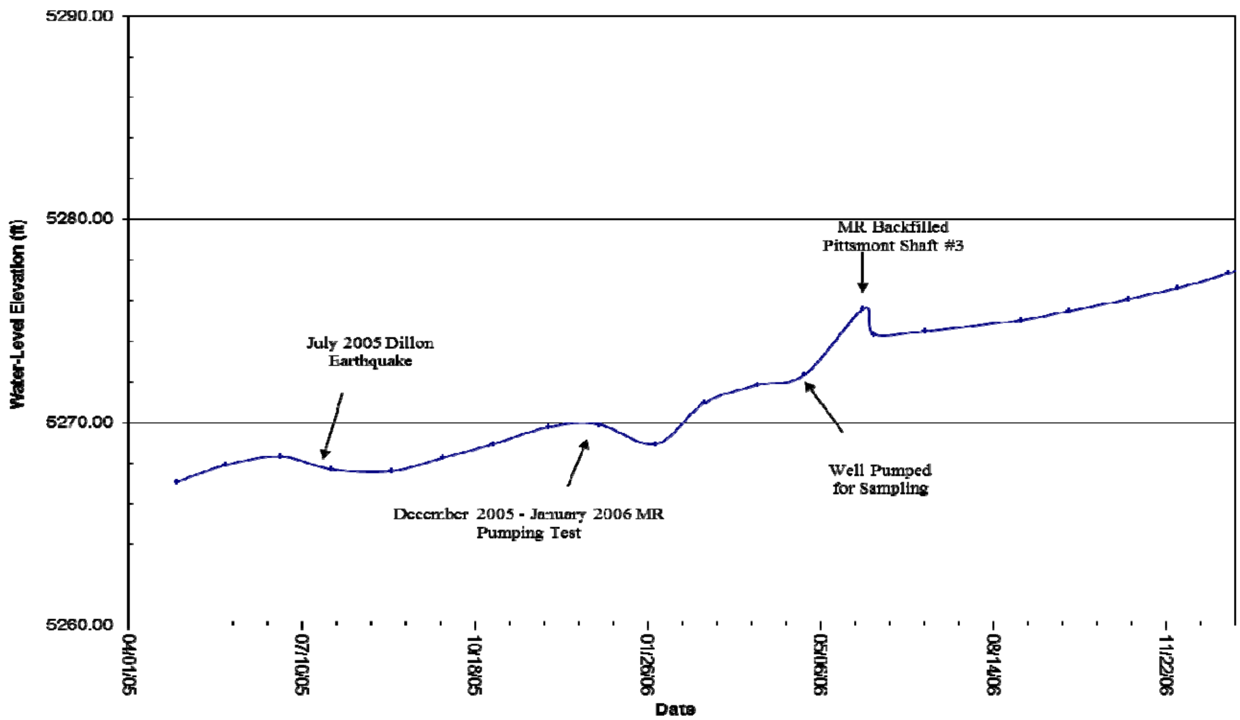


Figure 3-14. Hydrographs for well A comparing (top) daily average water level and (bottom) monthly water-level monitoring frequency.

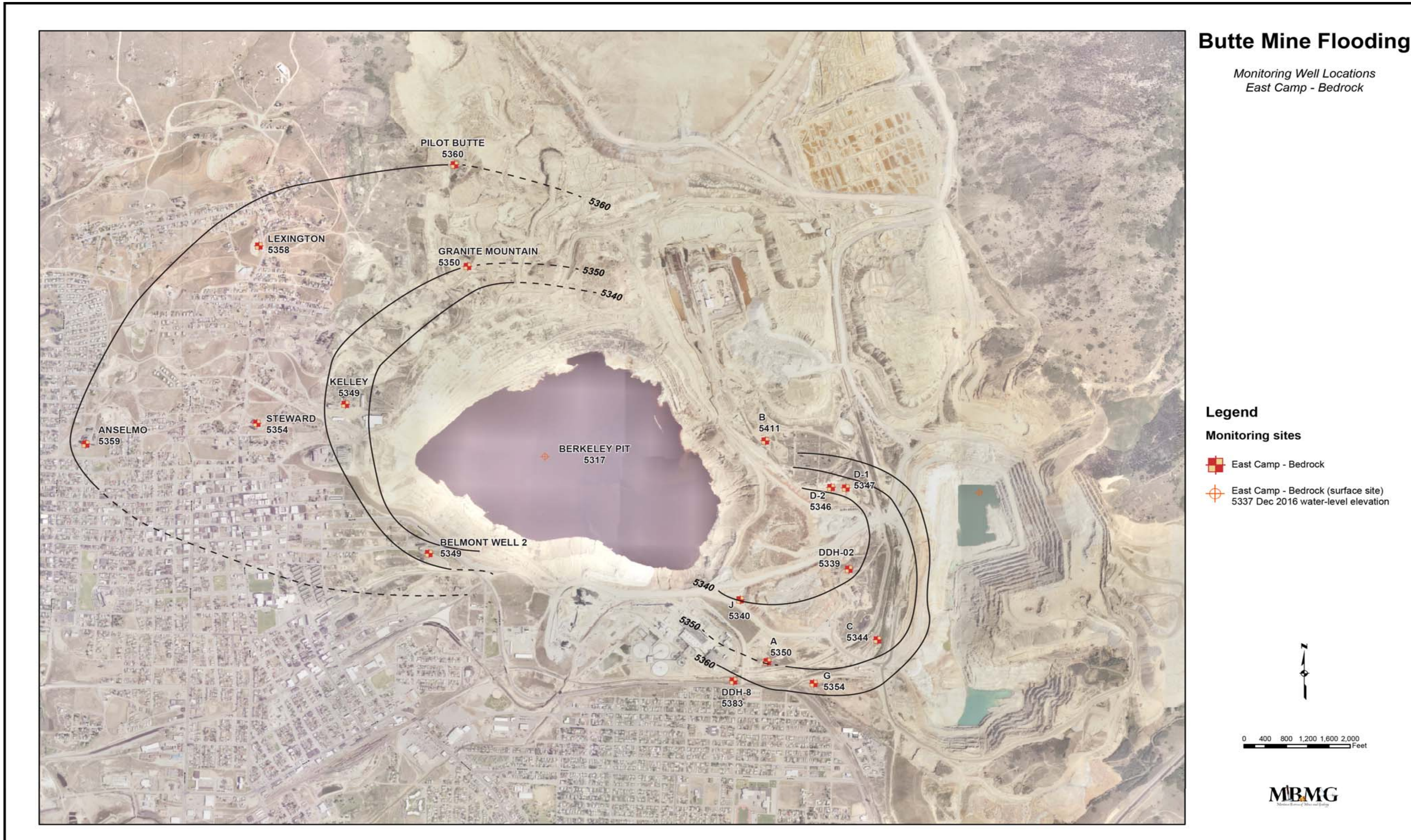


Figure 3-15. Potentiometric map for the East Camp bedrock aquifer, Dec 2016 (contour interval is 10 ft).

Section 3.3.2 Bedrock Well Water Quality

Data collected in 2016 indicate only slight water-quality changes for most wells. Table 3.3.2.1 summarizes water-quality trends over the past few years; as noted in previous reports, the status of water from well B changed with respect to MCLs because EPA changed the arsenic MCL from 18 µg/L to 10 µg/L. In water from most wells, there was little change in the concentration of dissolved constituents. Arsenic and radium were the only MCL exceeded in water from the bedrock wells (excluding well J, where cadmium, lead, and uranium all exceed the MCL); iron, manganese, zinc, and sulfate are the SMCLs most often exceeded. Water from several wells have pH levels below the recommended limit of 6.5.

Although water from the majority of sites exceeds one or more secondary standards, the concentrations between wells vary considerably. Figure 3-16 shows iron and arsenic concentrations for six of the bedrock wells sampled during the spring of 2016. In figure 3-16, iron concentrations vary from 1 mg/L to greater than 300 mg/L, while arsenic concentrations vary from 2 µg/L to greater than 850 µg/L.

Water from well J has the greatest number of exceedances. Water from this well has always been poor quality as expected, considering its close proximity to the pit and interconnected adjacent mine workings. The well is completed approximately 40 ft above workings from the Pittsmont Mine that extend to the pit. Concentrations of iron, sulfate, arsenic, cadmium, copper, and zinc all exhibited minor decreases in 2016 samples. Figure 3-17 compares selected trace metal concentrations in water from well A, well J, and the Berkeley Pit (2016 sample collected 1 ft below the water surface). Well A is the farthest south, and concentrations are orders of magnitude less for most analytes than in sites near the pit; water quality is similar between the pit and well J. Water-quality data confirm the interpretations based on water-level monitoring that bedrock groundwater flow is towards the pit. The extremely high concentrations of copper, cadmium, and zinc in the pit water and well J show that any flow from these sites away from the pit would be easily detected in water samples from more distant wells.

Table 3.3.2.1 Exceedances and recent trends for East Camp bedrock wells, 1989 through 2016.

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

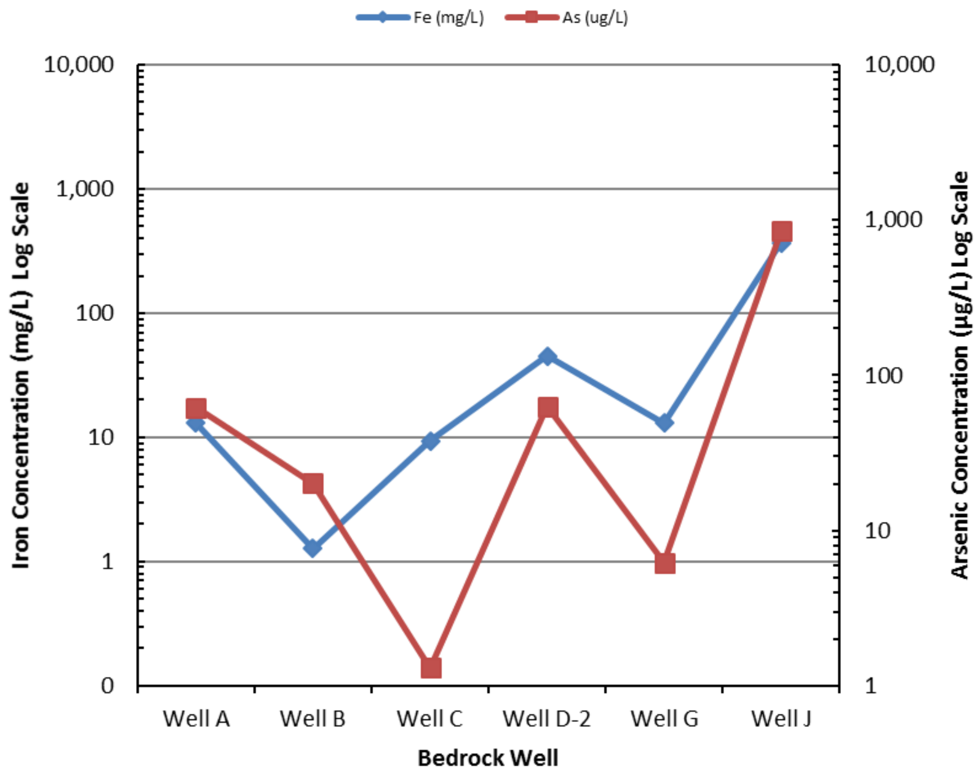


Figure 3-16. Bedrock well iron and arsenic concentration comparisons, spring 2016.

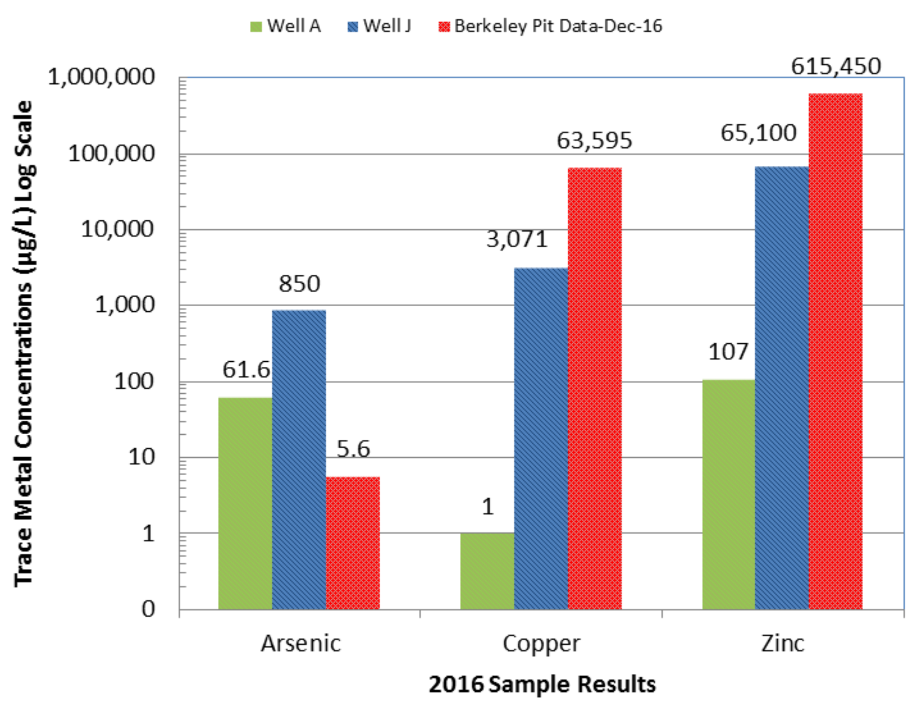


Figure 3-17. Selected trace metal comparisons among bedrock wells A, J, and the Berkeley Pit 1 ft depth sample.

Section 3.4 DDH-Series Wells

Water-level monitoring of the DDH-series wells continued. Five bedrock wells originally constituted the DDH well monitoring network; however, this network now consists of only two wells, DDH-2 and DDH-8. For 2016, water levels rose 5.61 and 4.02 ft, respectively, in the two remaining DDH wells, consistent with those of the RI/FS bedrock wells and East Camp mine shafts. Figure 3-18 is a hydrograph for well DDH-2, showing water-level increases that appear unrelated to precipitation variability.

Well DDH-8 had an unexplained water-level increase during August 2005, at which time water levels rose over 52 ft. The increase occurred at a time the 2-in PVC casing was removed and a submersible pump was installed to test the well yield and water quality for possible irrigation use. The water-level rise began prior to the actual pumping test and continued after its completion. Nothing was noted during the pumping to account for the abnormal water-level change. During the remainder of 2005, upward/downward water-level fluctuations were similar to those observed in the other DDH-series wells. The water-level rise in DDH-8 during 2016 was several feet less (4.02 ft) than the other bedrock wells, and the water-level elevation was over 50 ft higher than the other bedrock wells due to the unexplained 2005 increase. The DDH wells were not installed for monitoring purposes but were exploration holes that extend several thousand feet below ground surface and have various-size casings installed. Because of completion uncertainties and the drilling techniques, it is not surprising to have problems occur with these wells. In the past, well DDH-6 had to be plugged and abandoned due to casing integrity problems.

No water-quality samples were collected from the DDH-series wells, as they are used only for water-level monitoring.

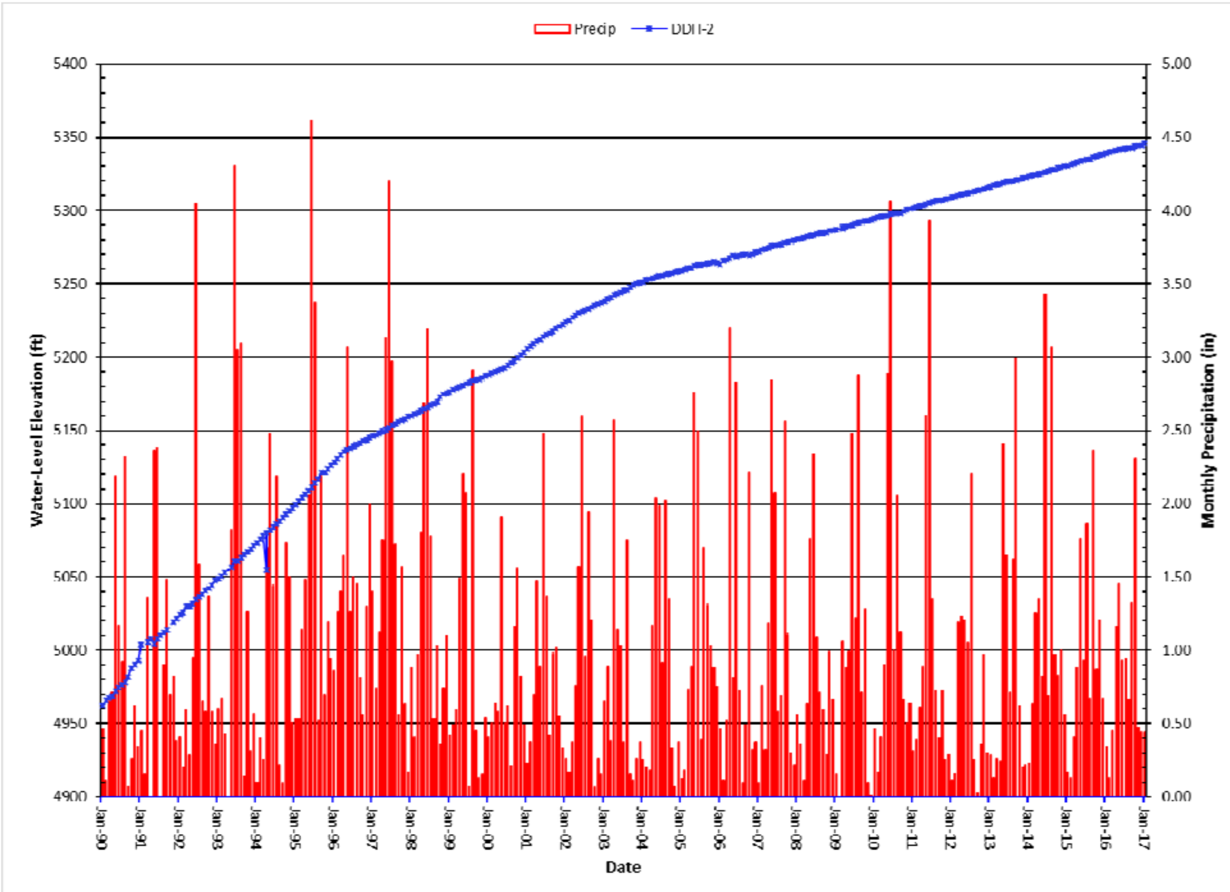


Figure 3-18. Water-level hydrograph for bedrock well DDH-2.

Section 3.5 Berkeley Pit and Horseshoe Bend Drainage

The Berkeley Pit water-level elevation was surveyed each month coincident with monthly water-level monitoring in wells and mine shafts. The hydrograph in figure 3-19 shows the pit's water-level rise since 1995.

The current overall Berkeley Pit water-level elevation trend is similar to that of previous years (7.30 ft average elevation rise per year since 2004). Four changes in slope in figure 3-19 show the influence of HSB diversions and landslides on water-level rise. In April 1996 the filling rate decreased (seen as a change in slope on the graph) when water from the HSB drainage was diverted to the Yankee Doodle Tailings impoundment; the almost instantaneous water-level rise in September 1998 was caused by a landslide. The third change of slope in June 2000 shows that the filling rate increased when MR suspended mining and the HSB water was subsequently allowed to flow into the pit. The final change is a decreased filling rate that resulted from the HSB water-treatment plant coming online in November 2003 and the diversion of HSB drainage water away from the pit. The volume of water allowed to enter the pit exceeded 3.2 billion gallons from July 2000 through November 2003 when the water-treatment plant became operable. This volume of water represents an average flow of 1,820 gpm during the period of mine suspension. The overall Berkeley Pit water-level rise for 2016 was 5.52 ft, compared to 9.96 ft for 2015. The 2015 increased water-level rise was at least partially the result of the HSB water diversions to the pit that occurred several times due to planned maintenance activities at the HSB water-treatment plant and other MR operational facilities; 134 million gallons of HSB water was diverted to the Berkeley Pit during 2015. Total additional flow diverted to the pit during 2016 was approximately 24.1 million gallons from mine operation and water-treatment plant operations. Table 3.5.1 summarizes the changes in handling HSB water and other events that influenced changes in Berkeley Pit water-level filling rates.

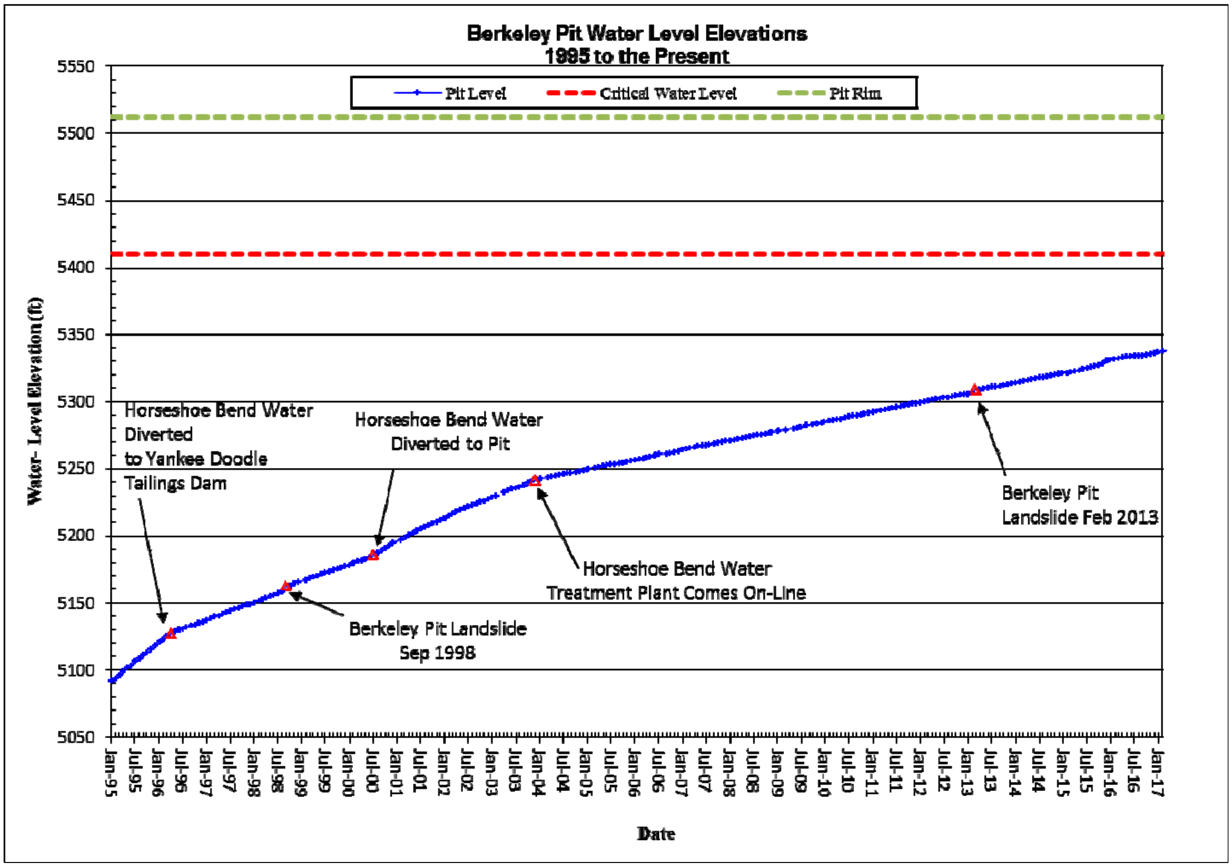


Figure 3-19. Water-level hydrograph of the Berkeley Pit, 1995–2016.

Table 3.5.1 Timeline of events impacting Berkeley Pit filling rates.

Date	Event	Impact
July 1983–April 1996	Horseshoe Bend Drainage water and water from precipitation plant ponds diverted to Berkeley Pit.	Increases pit water-level filling rate.
April 1996	HSB water diverted to MR mining operations for treatment and disposal in Yankee Doodle Tailings Pond.	Slows the pit filling rate.
September 1998	Berkeley Pit southeast corner landslide.	Over 3-foot 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

Two minor landslides occurred in 2012 along the southeast corner high wall of the Berkeley Pit. Both events (August 22, 2012 and November 3, 2012) displaced an unknown but minor volume of material into the Berkeley Pit. The material displaced by the landslides did not affect water levels in the Berkeley Pit, the underground mine workings, the bedrock system, or the surrounding alluvial aquifer. A rotational slump that occurred on February 8, 2013 deposited more waste and alluvial material than the 2012 landslides, resulting in noticeable water-level increases (0.60 ft.) in the Berkeley Pit and several nearby bedrock wells (fig. 3-19). Photographs showing the southeast corner of the Pit before and after the August event and the February event are in figure 3-20.

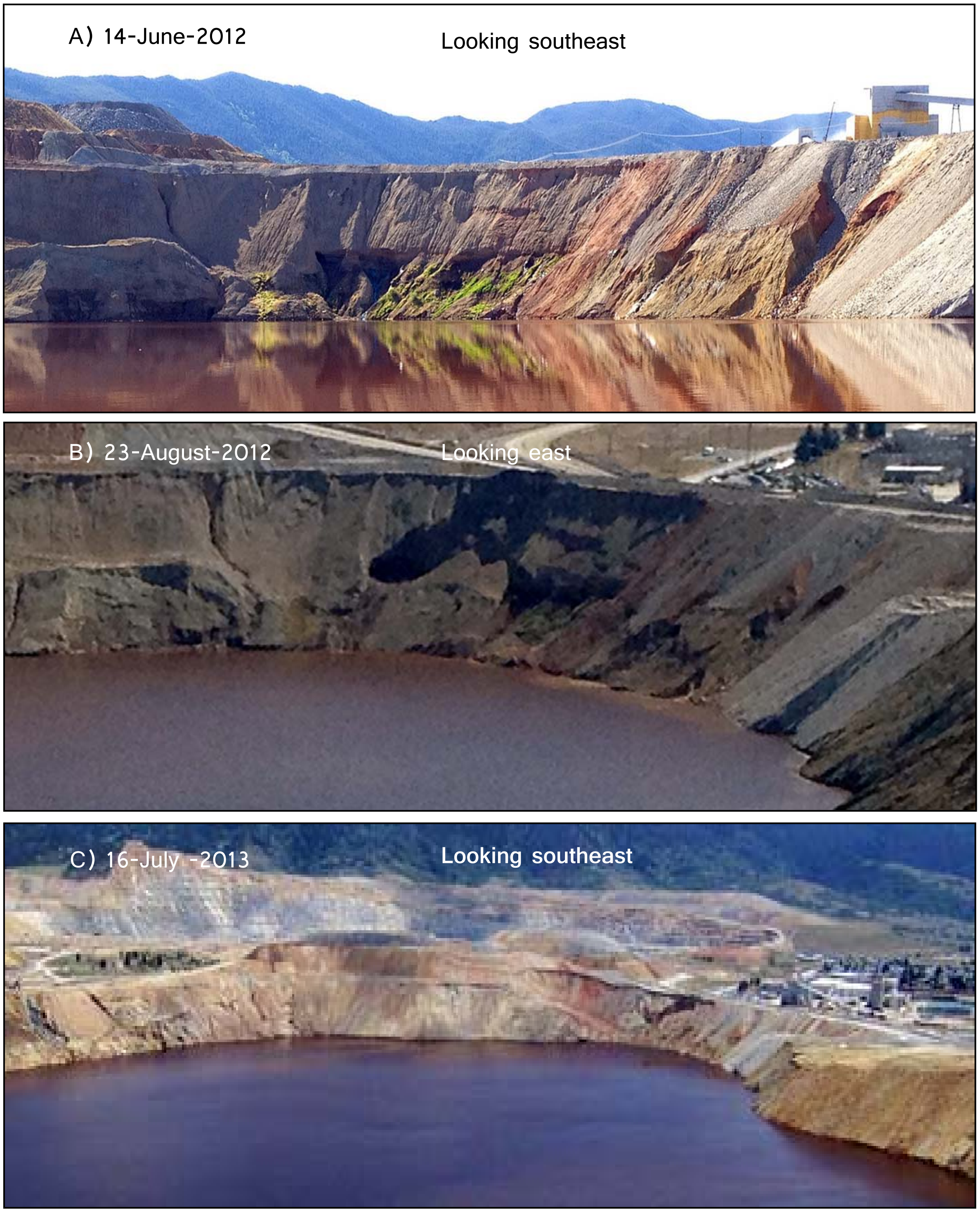


Figure 3-20. Pictures of the southeast corner of the Berkeley Pit prior to the occurrence of the 2012 landslides (A), and after the August 2012 (B) and February 2013 (C) events.

The 2002 CD contains a stipulation that the water level in the Berkeley Pit must remain below seven mines and seven bedrock monitoring wells identified as POCs. Selected POCs are listed in table 3.5.2 along with their December 2016 water-level elevations and the distance below the CWL. 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 CWL is the Pilot Butte Mine, which is located about 0.5 mi north of the pit.

Table 3.5.2. Selected East Camp Points of Compliance and Depth Below CWL, December 2016.

Point of Compliance	**December 2016 Water-Level Elevation (ft)**	**Depth Below CWL (ft)**
Anselmo Mine	5358.78	51.22
Granite Mountain Mine	N/A	N/A
Pilot Butte Mine	5359.83	50.17
Kelley Mine	5348.84	61.16
Belmont Well #2	5348.91	61.09
Well A	5350.10	59.90
Well C	5344.37	65.63
Well G	5354.38	55.62
Berkeley Pit (not a compliance point)	5336.79	73.21

Flow monitoring of the Horseshoe Bend drainage continued throughout 2016. Figure 3-21 shows the daily average flow rate from July 2000 through December 2016. The 2016 average daily flow rate was 3,402 gpm, a decrease of 120 gpm from the prior year. A total of 1.78 billion gallons of water flowed through this site in 2016 for treatment in the HSB water-treatment plant.

A non-contact radar system (Radar Level Sensor™) was installed during the fall of 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 to more accurately record higher flow rates (late November to early December 2015); the location of the radar system was changed to a more stable location. Figure 3-22 shows the new weir and the radar system's new location on the cement retaining wall for the weir plate.

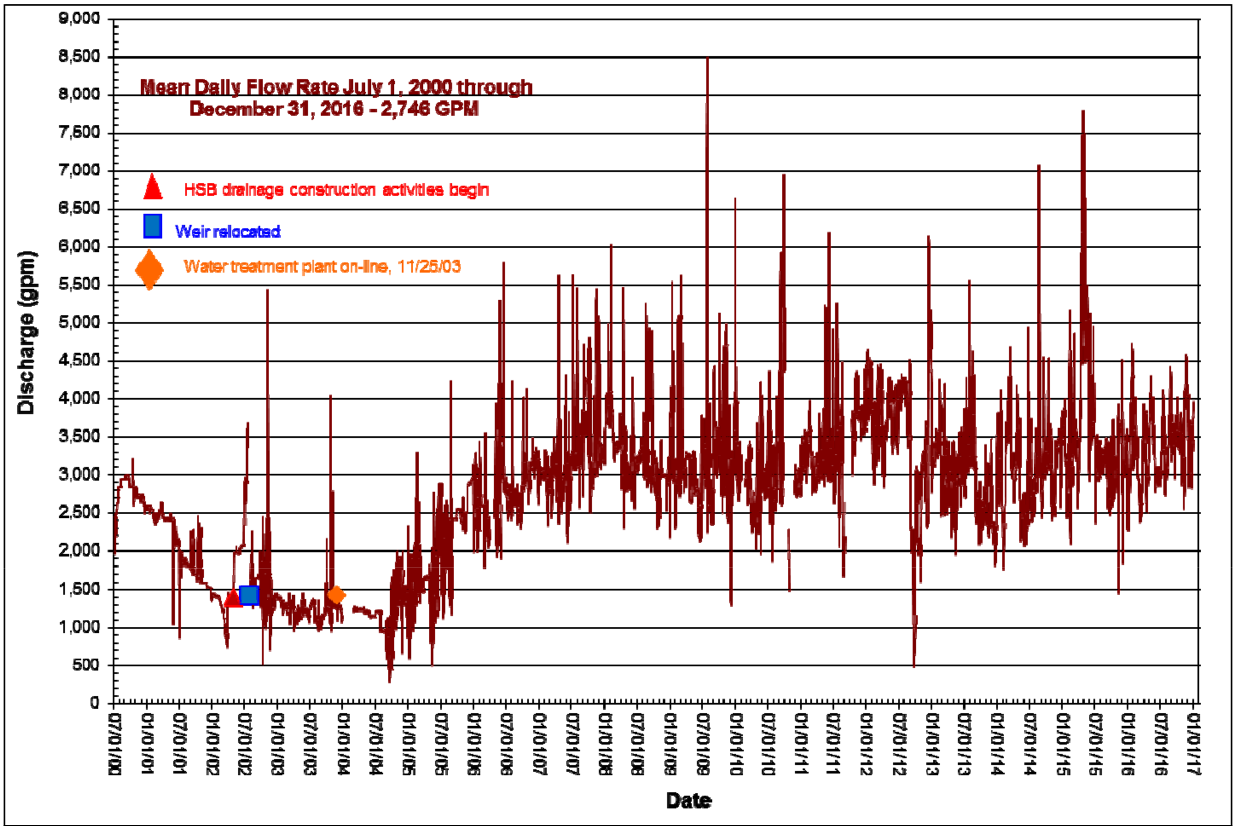


Figure 3-21. Horseshoe Bend Drainage flow rate, July 2000 through December 2016.

Figure 3-22. Radar system installation at the Horseshoe Bend weir monitoring station.

Flows measured at the HSB Falls flume averaged 181 gpm during 2016, an increase of 38 gpm from the 2015 average. The 2010–2016 flows were considerably less than prior years and the historic flow rate of 1,000 gpm or more reported by MR. Figure 3-23 is a hydrograph for the total period of record based on historic flow rates measured when MR operated the site and flow rates since the MBMG began monitoring in 2002. The decreased flow measured at this site since 2010 exceeds any change in flow seen for the entire HSB drainage; it is possible the sources that have contributed to the HSB Falls seeps are emanating at different locations because there is no corresponding significant drop in the overall flow in the HSB drainage.

Based upon the flow data recorded during the 2000–2003 mine suspension and flows since then, the operation of the Yankee Doodle Tailings Dam as a disposal area for mill tailings is important to the amount of water from the HSB drainage.

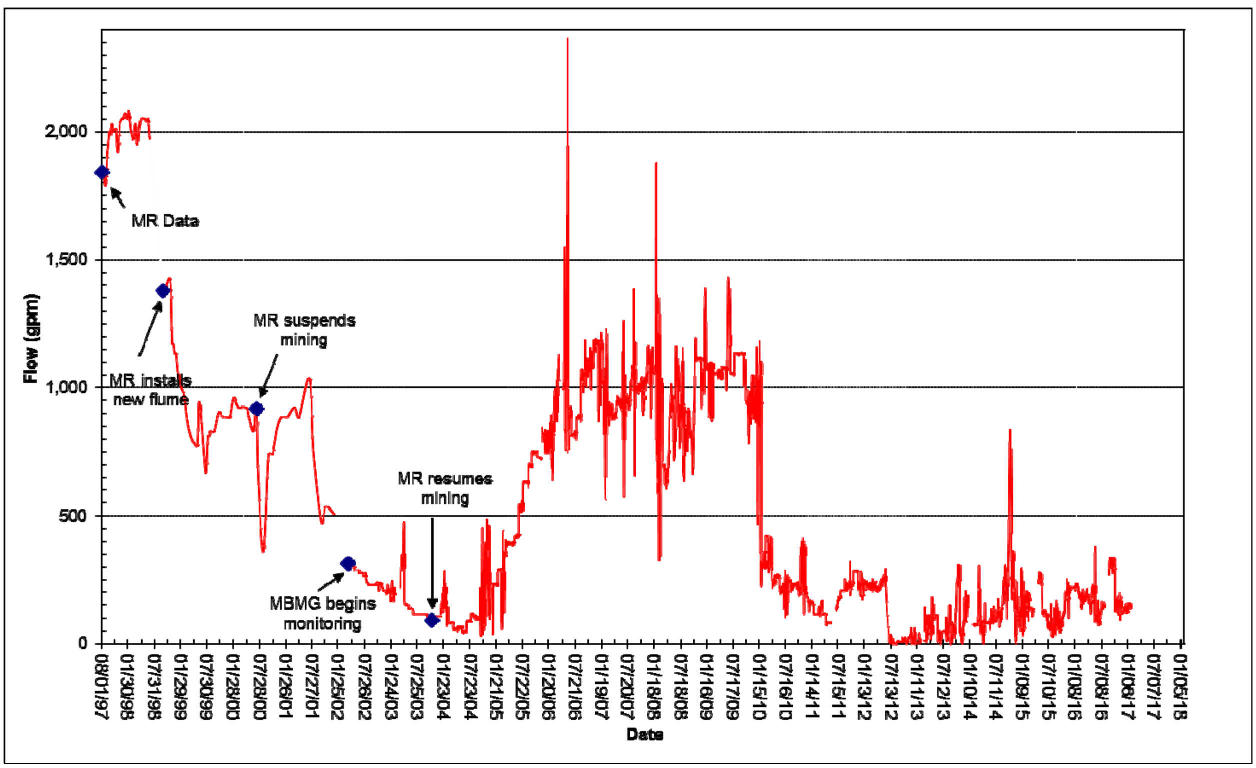


Figure 3-23. Horseshoe Bend Falls long-term daily average flow rates, including both MR and MBMG data.

Section 3.5.1 Berkeley Pit and Horseshoe Bend Drainage Water Quality

(Water sampling of the Berkeley Pit resumed in 2016 on a limited basis after the 2013–2015 safety concern hiatus following the February 2013 slump. Surface-water samples were collected three times during 2016 and a brief data summary is given. For sample data acquired prior to 2013, the reader is referred to Duaime and others, 2016, MBMG 676.)

Water-quality sampling of the Berkeley Pit is scheduled to occur twice per year during late spring and fall, with samples collected at a minimum of three depths. In addition to collecting samples for inorganic analysis, a vertical profile throughout the upper portion (0–650 ft) of the water is normally performed that measures *in situ* physical parameters. The physical parameters measured are: pH, specific conductance, temperature, oxidation-reduction-potential, and dissolved oxygen. Turbidity is measured periodically.

Water-quality samples were collected monthly from the Horseshoe Bend drainage weir used for flow monitoring. This site is just upstream of the influent pond associated with the HSB water-treatment plant. Therefore, this water is representative of the water entering the plant for treatment.

Section 3.5.1.1 Berkeley Pit Water-Quality Sampling and Monitoring Overview

It took 19 months (April 1982–November 1983) for flooding underground mine waters to reach the elevation of the bottom of the Berkeley Pit. However, water had accumulated in the pit bottom from contaminated surface-water sources diverted into the pit by the Anaconda Company in 1982 and again in 1983. The first water samples, in the fall of 1984 and then in 1985, were collected via a point-source bailer lowered from a helicopter hovering above the water surface (fig. 3-24). Sampling in 1986 and 1987 used a helicopter to transport boats to the water surface (fig 3-25). The boats allowed more accurate sampling and vertical profiling of the pit water column than had been possible in 1984–1985. By the summer of 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 had been collected from either temporarily installed stationary platforms or boats.

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

Figure 3-24. 1985 Berkeley Pit sampling event.

Figure 3-25. 1986 Berkeley Pit sampling event.

Subsequent to the suspension of sampling activity for safety concerns in 2013, ARCO and MR commissioned development of a remotely controlled drone watercraft. The boat was launched for off-site trials in 2016 and is expected to perform sample collection on schedule for the 2017 events. Figure 3-26 shows a communication test of the craft underway from the control center to the boat on the opposite side of the pit.

Figure 3-26. Communication test of the drone boat, September 2016.

Section 3.5.1.2 Berkeley Pit Water Chemistry

Currently the Berkeley Pit water is approximately 850 ft deep, consisting of roughly 46.7 billion gallons of low pH, high saline water. Since 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, which produced data from as far back as November 1984. Records dating back to November 1984 are published and can be found on the MBMG Ground-Water Information Center (GWIC) website (GWIC, 2012).

Water quality in the Berkeley Pit had been monitored semi-annually since spring 2001, as per terms of the 2002 CD through 2012. Slumps/landslides that occurred during fall 2012 and early 2013 led to a temporary suspension of sampling/monitoring activities through 2015. Gammons and Duaime (2006) discussed long-term changes in the limnology and geochemistry of the Berkeley Pit Lake System.

Changes in Berkeley Pit water quality may be linked to a number of factors such as seasonal changes, occurrence of landslides, MR copper (Cu) recovery operations, dumping of high-density sludge into the Berkeley Pit from the HSB water-treatment plant, and the diversion of HSB water into and away from the pit.

Section 3.5.1.3 Physical Parameters

Physical parameters of pH, specific conductance (SC), oxidation-reduction potential (ORP), and temperature profiles were not performed in 2016. However, those parameters were acquired for surface grab samples collected during 2016.

Section 3.5.1.4 Chemical Parameters

Samples were collected from the surface of the Berkeley Pit during three events spanning 2016. Some dissolved constituents and corresponding physical parameters for the 2016 events are presented in Table 3.5.1.1 along with results from the 2012 sampling events for comparison.

Table 3.5.1.1 A brief comparison of Berkeley Pit surface-water chemistry between 2012 and 2016.

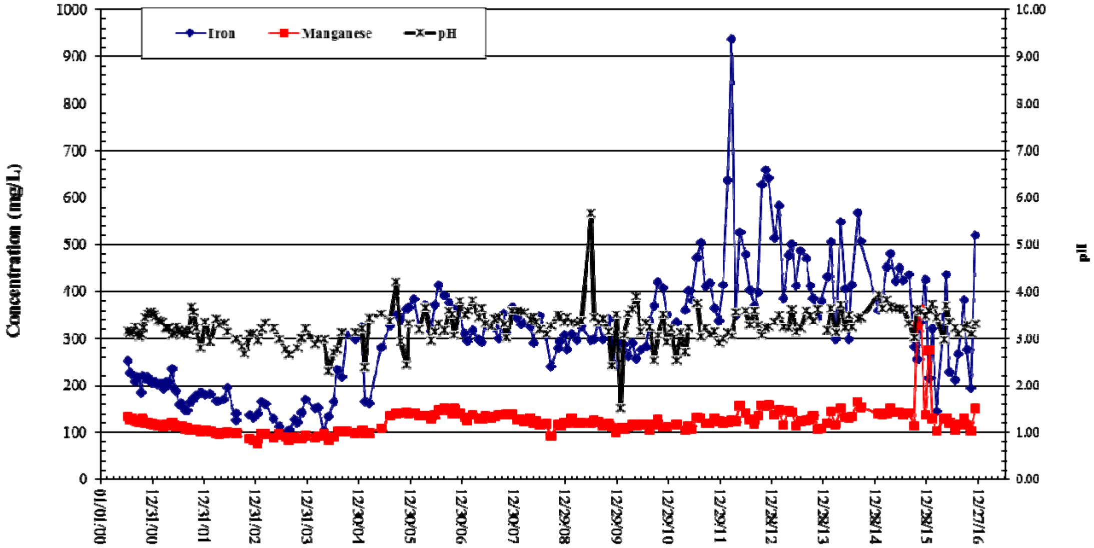
Berkeley Pit Surface Chemistry									
	pH	SC	TDS	Total Acidity	Fe	Cu	Zn	As	SO_4
	(S.U.)	(µS/cm@25º C)	(mg/L)	(mg/L as $CaCO_3$)	(mg/L)	(mg/L)	(mg/L)	(µg/L)	(mg/L)
Jun 2012	2.55	7,652	10,463	3,563	211	49	631	74	7,740
Dec 2012	2.61	7,632	12,229	3,651	204	49	589	64	9,560
Feb 2016	3.38	7,560	9,396	4,430	33.6	58	603	14	6,776
Mar 2016	3.42	7,435	9,603	3,739	18.3	60	605	4	7,099
Dec 2016	3.41	7,545	9,619	3,920	10.7	64	615	6	6,936

The most notable differences are that the pH has risen almost a full unit, while Fe concentrations have decreased an order of magnitude and As has all but disappeared to levels near 5 µg/L. In addition, there appears to be a declining trend in the TDS. During this time, the lake has sat quiescently and the system is approaching a new equilibrium resulting from the mixing and additions caused by the pit copper-recovery operation suspension and slumps. The complete regimen of sampling to be performed in 2017 will provide a more detailed basis upon which to characterize changes that have occurred and to project possible future conditions in the pit as the date to begin treatment of the water nears.

Section 3.5.2 Horseshoe Bend Water Quality

Monitoring of the HSB drainage began in July 2000 following MR's temporary suspension of mining. Similar to the decreases in flow rates during the period of mine suspension, concentrations of a number of the trace metals also decreased. Metal concentrations began to increase in mid-2004 when flow rates increased (fig. 3-27). Copper and zinc concentrations increased through early and mid-2008, respectively, before declining. Copper concentrations are currently about one-third those seen in 2000; zinc concentrations are similar to 2000 concentrations.

In August 2012, MR increased leaching operations, using a significant volume of Horseshoe Bend water as leachate solution. Since then, copper concentrations have continued a steady decline, while zinc concentrations have steadily increased. Iron concentrations have become more erratic, probably in response to flow, but overall, they appear to be neither increasing nor decreasing. The pH has migrated downwards below 3.0 and has risen above 4.0 on occasion, but has remained relatively stable over time and shows no distinct trend since monitoring began (fig. 3-26).



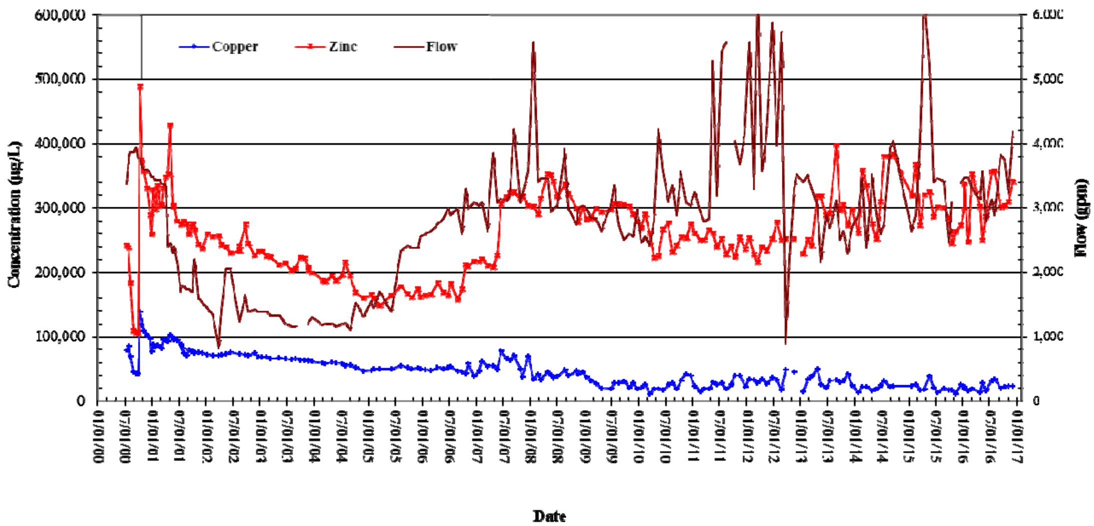


Figure 3-27. Horseshoe Bend water-quality comparisons of selected constituents, 2000–2016.

SECTION 4.0 WEST CAMP SYSTEM

Water-level monitoring continued during 2016 in the three mine shafts and six monitoring wells (fig. 4-1) that constitute the West Camp system. Water-level decreases throughout the underground mine system were less than 1 ft, and at the end of 2016 were 14 ft below the West Camp's critical water-level elevation. The volume of water pumped was just over 242 acre-ft, or 13.7 acre-ft less than that pumped in 2015.

Section 4.1 West Camp Underground Mines

Water levels in the West Camp Mine System continue to be controlled by the pump station located at the BMF-96-1D and BMF-96-1S site. ARCO constructed the West Camp pumping well (WCPW) for dewatering (pumping) purposes in the fall of 1997 and transferred pumping activities from the Travona Mine on October 23, 1998. The pump and pipeline at the Travona Mine were left intact, so that it could serve as a backup pumping system. ARCO modified and upgraded the pump station and support system during the latter portion of 2011 (figs. 4-2 through 4-5). Additional water-level monitoring began prior to the start of the 2013 West Camp study and continued throughout the remainder of the year to ensure water levels were maintained at appropriate levels; figure 4-6 shows water levels in the Travona, Ophir, and well BMF96-1D from mid-2013 through 2015. No long-term negative impacts occurred as a result of the 2013 test; water levels continue to be maintained by pumping and respond to pumping changes similarly.

The quantity of water pumped was comparable to that in 8 of the past 10 years; pumping rates were more variable during 2013 and 2014 as a result of the 2013 West Camp study. Table 4.1.1 shows the annual amount of water pumped in acre-feet, the change in acre-feet from the previous year, and the percent change from 1996 (the first full year of continuous pumping). Figure 4-7 shows the amount of water pumped annually and the percent of average annual precipitation since 1982.

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

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

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

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

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

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

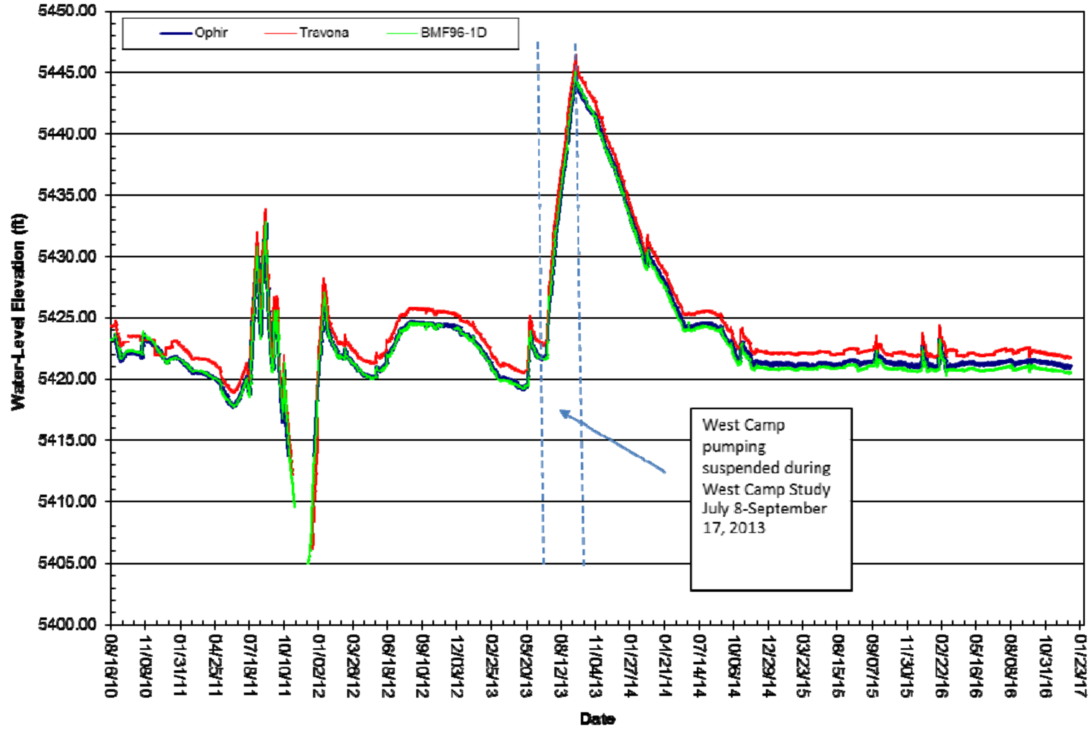


Figure 4-6. Hydrograph showing water levels in the Travona Mine, Ophir Mine, and well BMF96-1D, 2010–2016.

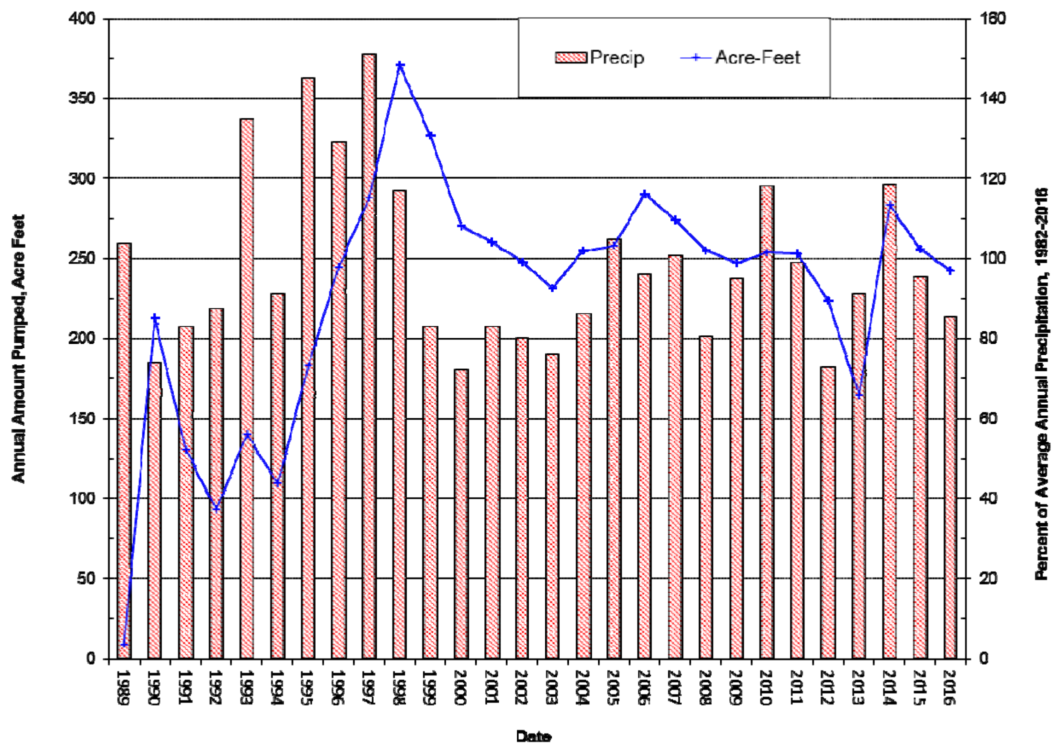


Figure 4-7. Annual amount of water pumped from the West Camp system.

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

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

Water levels decreased less than 0.25 ft during 2016 in all three mines; decreases reflected steady pumping rates at the WCPW. Figure 4-8 shows annual water-level changes for the West Camp sites. Water levels are more than 14 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 4-9. 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.

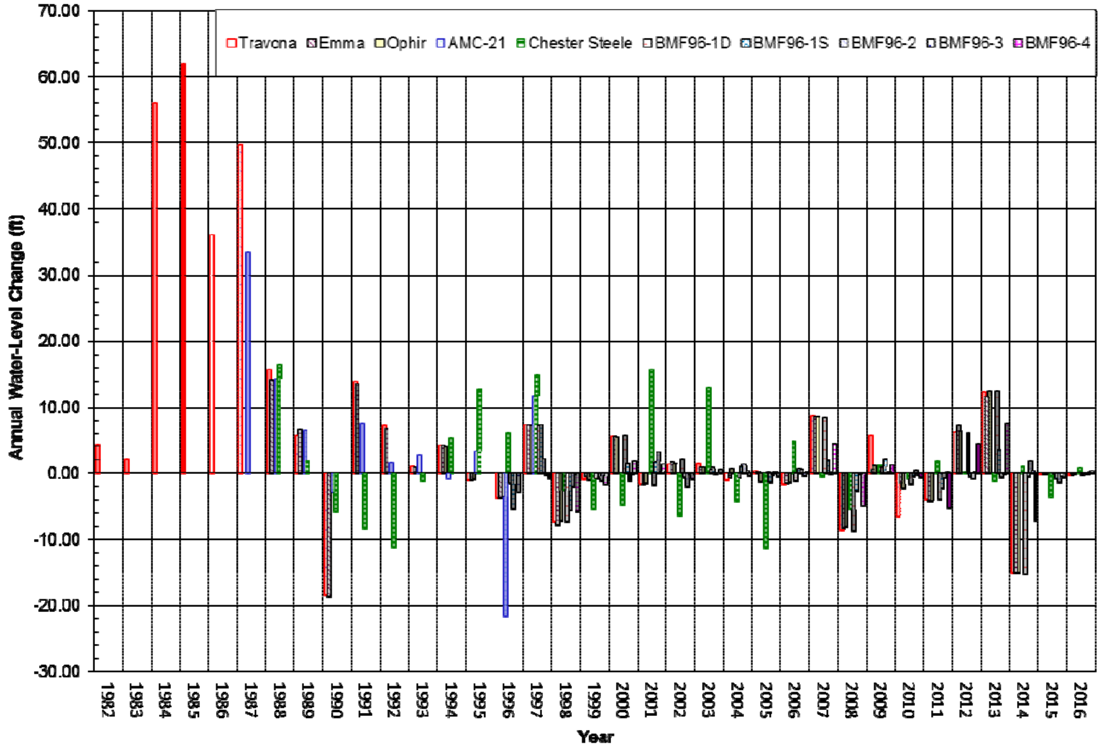


Figure 4-8. Annual water-level changes for West Camp site.

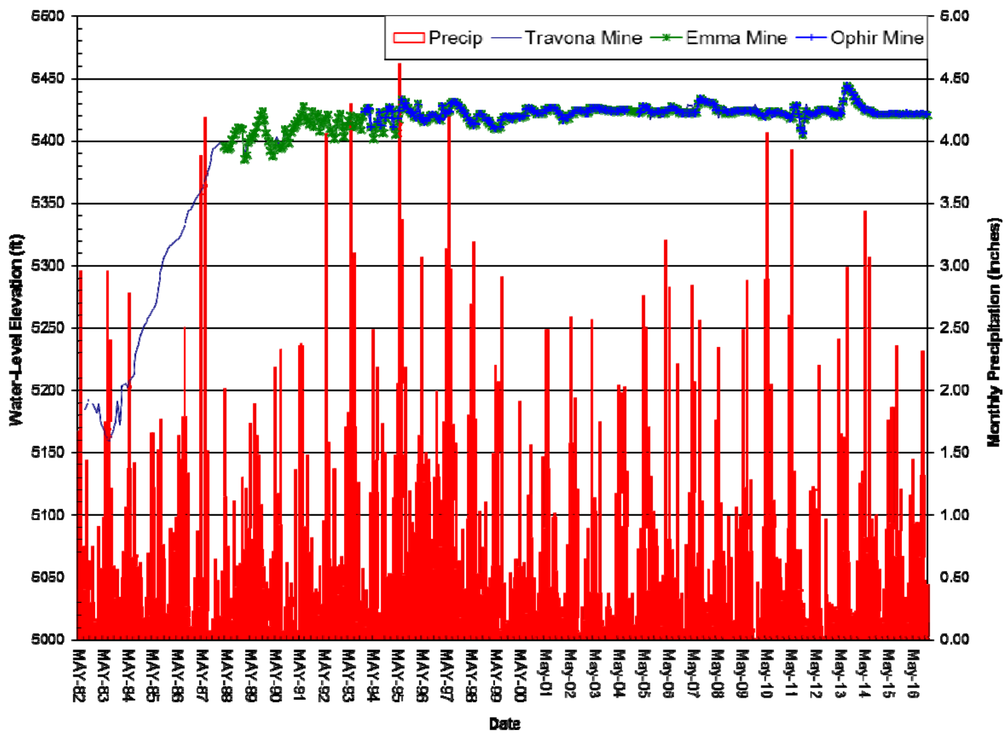


Figure 4-9. Water-level hydrographs for West Camp mines.

Section 4.2 West Camp Monitoring Wells

Water levels decreased in three of the six BMF96 West Camp wells during 2016. Well BMF96-1D, which was completed into the Travona Mine workings, had a water-level decrease similar to that of the West Camp mines. These annual water-level changes are shown in table 4.2.1 and figure 4-8.

Figure 4-10 contains water-level hydrographs for wells BMF96-1D, BMF96-1S, and BMF96-4. Water levels in wells BMF96-1D and BMF96-4 respond similarly to one another, showing the influence pumping has on the system and how interconnected the wells are to the mine workings. There is a lag time between the responses seen in these two wells, which is most likely because well BMF96-4 was not completed into mine workings. This is an important trend since well BMF96-4, while not completed into mine workings, is in the area of the historic 1960s flooding problems that led the Anaconda Company to install well AMC-21 for control of water levels in the West Camp (fig. 4-11). (See Duaime and others, 1998, for a greater discussion of historic flooding problems in the West Camp System.) Well BMF96-1S is located adjacent to well BMF96-1D, but was completed at a much shallower depth in the weathered bedrock. There was no change in longer term trends in any of these wells from those described in the previous reports, with the exception of the temporary water-level increases during the summer 2013 suspension of pumping.

Water levels in wells BMF96-2 and BMF96-3 are 20 ft to 50 ft higher than those in wells BMF96-1D and BMF96-4. Although these wells were completed at depths of 175 ft below ground surface, their water levels are less than 20 ft below ground surface. Hydrographs (fig. 4-12) show that from 1996 to 2001 water levels in BMF96-2 and BMF96-3 moved independently from water levels in BMF96-1S, BMF96-1D, and BMF96-4. Since 2002, water–level changes in BMF96-2 and BMF96-3 have followed trends similar to the other BMF-series wells; however, the magnitude of the responses was less. When hydrographs for BMF96-2 and BMF96-3 are plotted at an expanded scale (fig. 4-13), the detail in water levels becomes apparent and both wells respond quickly to precipitation events. Water-level trends during 2016 were similar to those seen in previous years. No response was seen in these wells due to the reduced pumping activities in the summer and fall of 2013. Water levels rise during the wet season and with infiltration from snowmelt, which is shown by the early season (March–April) water-level increases.

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

Year	Travona	Emma	Ophir	Chester Steele	BMF 96-1D	BMF 96-1S	BMF 96-2	BMF 96-3	BMF 96-4
1982	4.30								
1983	2.00								
1984	55.90								
1985	61.90								
1986	36.10								
1987	49.70								
1988	15.69	14.20		16.42					
1989	5.67	6.60		1.79					
1990	-18.42	-18.66		-5.77					
1991	13.88	13.52		-8.28					
Change Years 1–10	**226.72**	**15.66**		**4.16**					
1992	7.21	6.79		-11.20					
1993	1.01	0.93		-1.11					
1994	4.24	4.26	4.00	5.36					
1995	-0.98	-1.00	-0.96	12.72					
1996	-3.72	-3.76	-3.56	6.14	-1.50	-5.41	0.00	-2.85	
1997	7.29	7.28	7.22	14.82	7.20	7.36	2.13	-0.19	-0.80
1998	-7.31	-7.88	-7.20	-2.51	-7.35	-5.63	-2.00	-0.26	-5.88
1999	-0.97	-0.47	-1.03	-5.37	-0.82	-0.61	-1.15	-0.38	-1.76
2000	5.56	5.61	5.53	-4.64	5.70	1.45	-1.13	-0.07	1.86
2001	-1.65	-1.70	-1.52	15.61	-1.78	1.70	3.23	0.10	1.40
Change Years 11–20	10.68	**10.06**	**2.48**	**29.82**	**1.45**	**-1.14**	**1.08**	**-3.65**	**-5.18**
2002	1.33	1.74	1.51	-6.35	2.03	-0.62	-2.06	-0.21	-0.93
2003	1.45	0.95	0.87	12.94	0.56	0.96	-0.01	0.00	0.54
2004	-1.06	-0.72	0.73**	-4.22	-0.72	1.03	1.41	0.33	-0.31
2005	0.39	0.22	-1.30	-11.35	0.03	-1.42	-0.23	0.18	-0.47
2006	-1.62	-1.49	-1.33	4.76	-1.15	0.65	0.59	-0.31	0.20
2007	8.68	8.56	8.57	-0.41	8.49	1.93	-0.17	0.13	4.41
2008	-8.57	-8.39	-8.15	-5.41	-8.71	-2.65	-0.14	-0.06	-4.96
2009	5.68	0.56	1.09	1.26	0.91	2.05	0.04	0.10	1.22
2010	-6.47	-1.46	-2.27	-0.82	-1.61	-0.41	0.42	-0.23	-0.60
2011	-3.99	-4.27	-4.17	1.77	-3.99	-2.23	-0.67	0.09	-5.24
Change Years 21–30	**-4.18**	**-4.30**	**-4.45**	**-7.83**	**-4.16**	**-0.71**	**-0.82**	**0.02**	**-6.14**
2012	**6.25**	**7.22**	**6.43**	**0.12**	**6.20**	**-0.46**	**-0.82**	**0.21**	**4.47**
2013	**12.35**	**11.52**	**12.49**	**-1.11**	**12.49**	**3.59**	**-0.56**	**-0.07**	**7.50**
2014	**-14.96**	**-14.94**	**-14.95**	**1.01**	**-15.17**	**-0.44**	**1.79**	**0.35**	**-7.21**
2015	**-0.16**	**-0.15**	**-0.08**	**-3.64**	**-0.14**	**-0.82**	**-1.33**	**-0.46**	**-0.55**
2016	**-0.22**	**-0.21**	**-0.16**	**0.79**	**-0.26**	**-0.01**	**-0.17**	**0.02**	**0.32**
Change Years 31–40	**3.26**	**3.44**	**3.73**	**-2.83**	**3.12**	**1.86**	**-0.83**	**0.05**	**4.53**
Net Change*	**236.48**	**24.86**	**1.76**	**23.32**	**0.41**	**0.01**	**-0.83**	**-3.58**	**-6.79**

(Minus sign (-) indicates a decline (drop) in water level.) ***Total water-level change is that measured. Access or obstructions occasionally prevent water-level measurements. **Vandalism to Ophir Mine monitoring point resulted in no water levels being obtained for the last quarter of 2004.

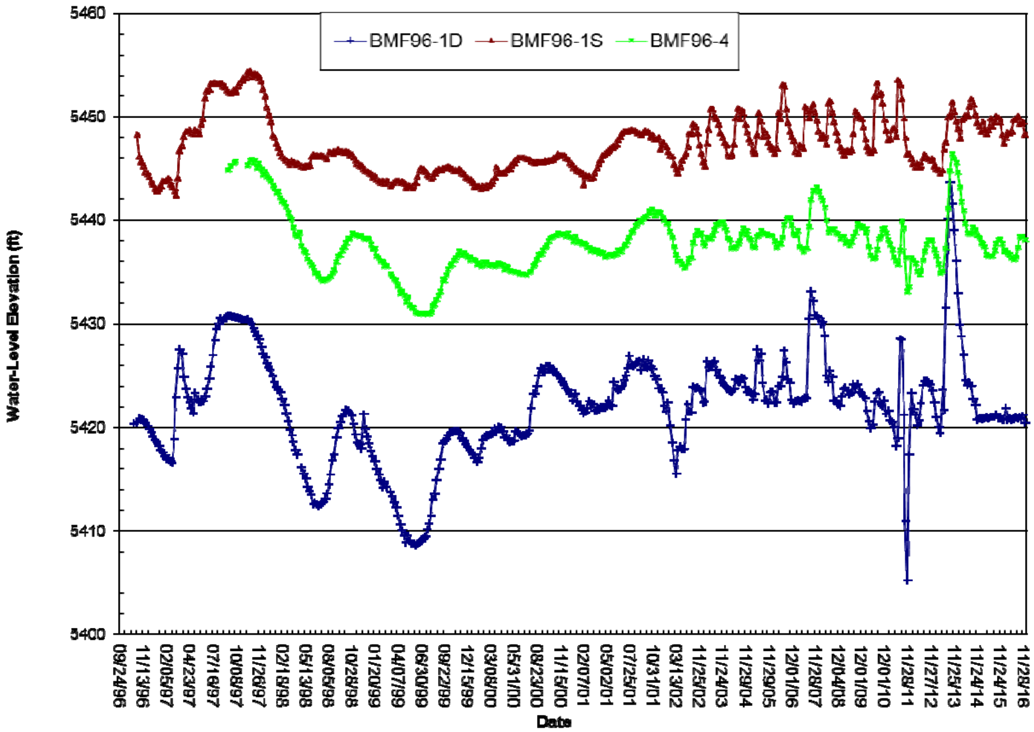


Figure 4-10. Water-level hydrographs for West Camp wells BMF96-1D, BMF96-1S, and BMF96-4.

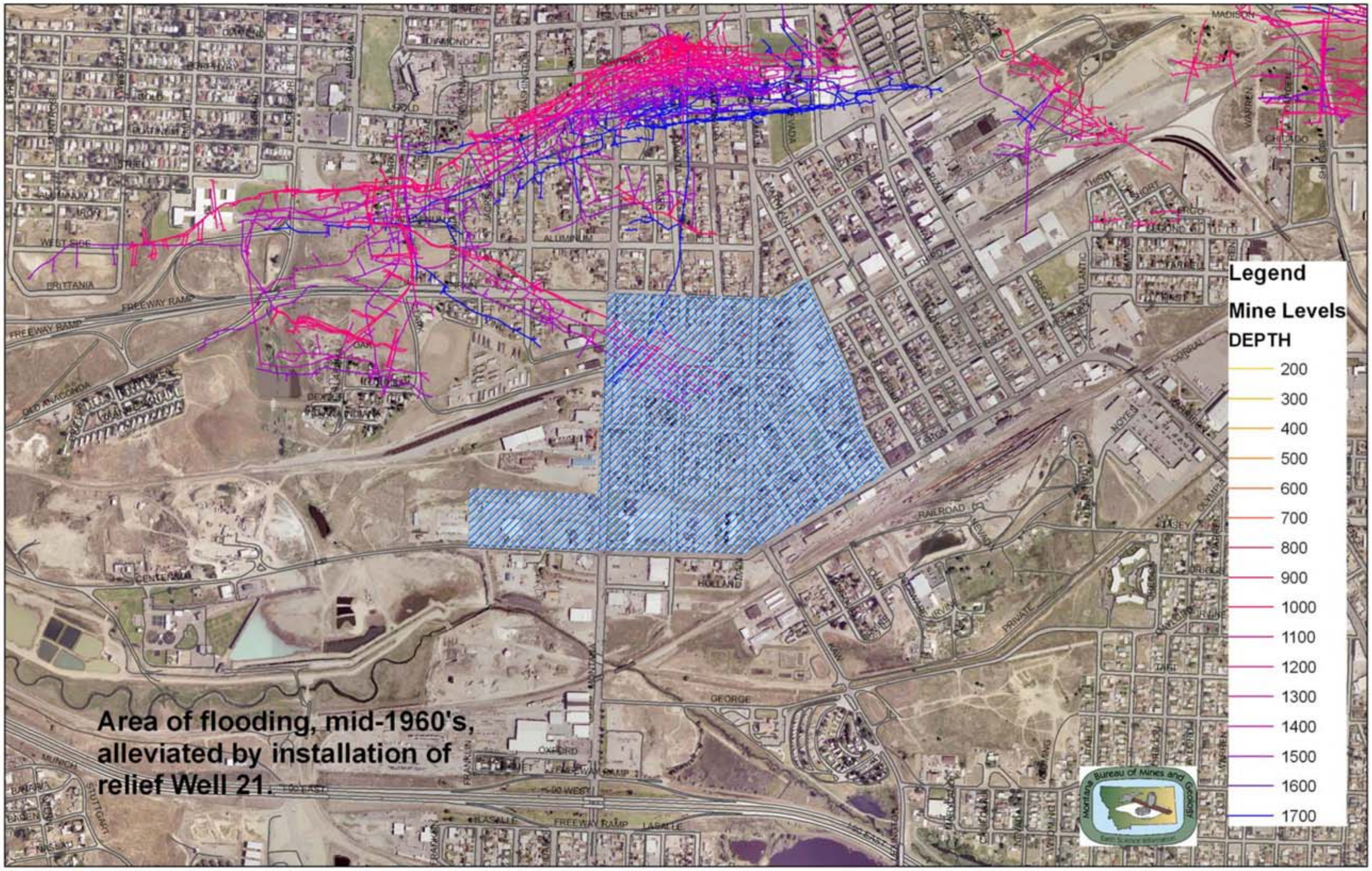


Figure 4-11. Area of the West Camp affected by basement flooding problems, 1960s. Blue hatch area outlines problem locations.

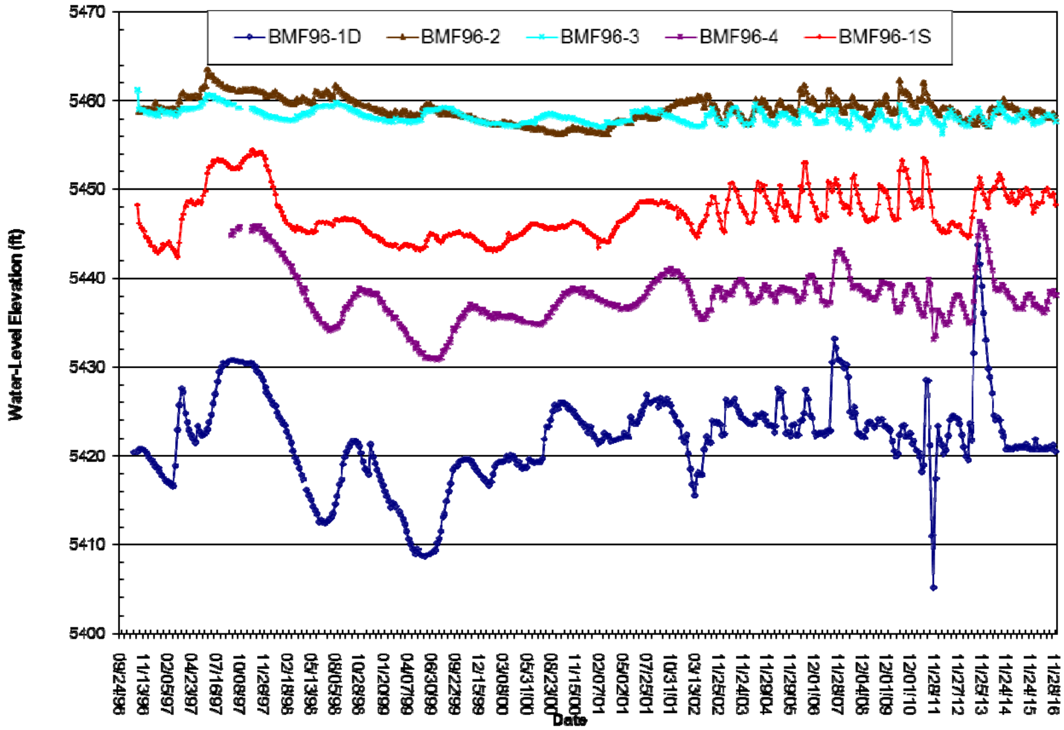


Figure 4-12. Water-level hydrographs for BMF96-series wells.

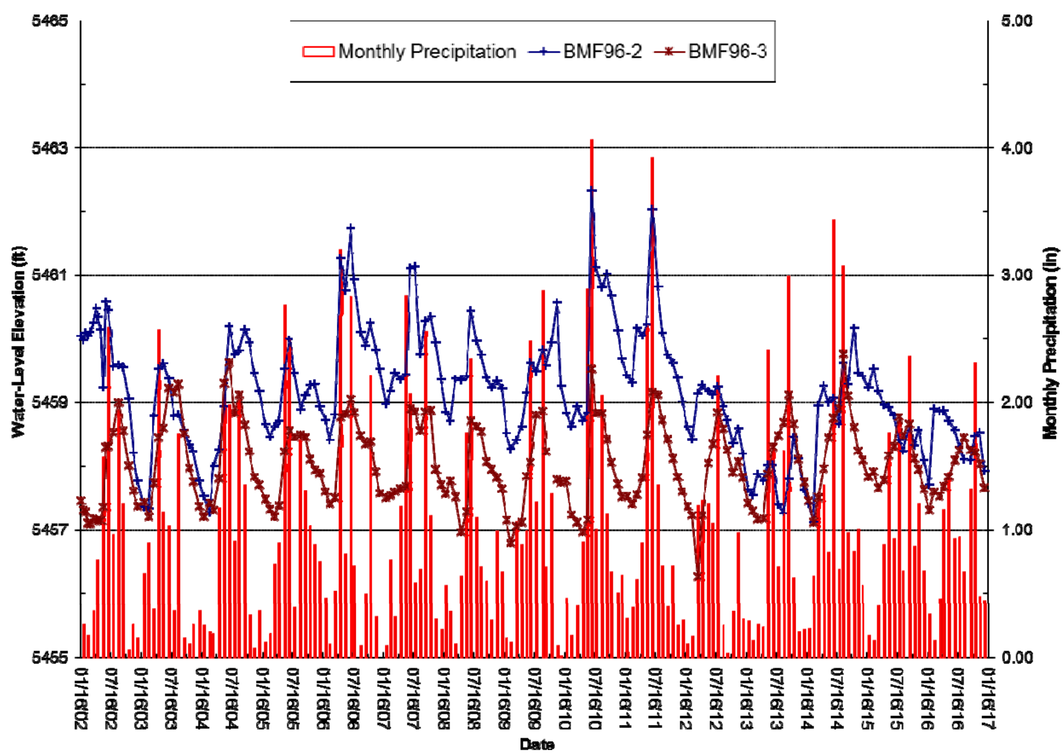


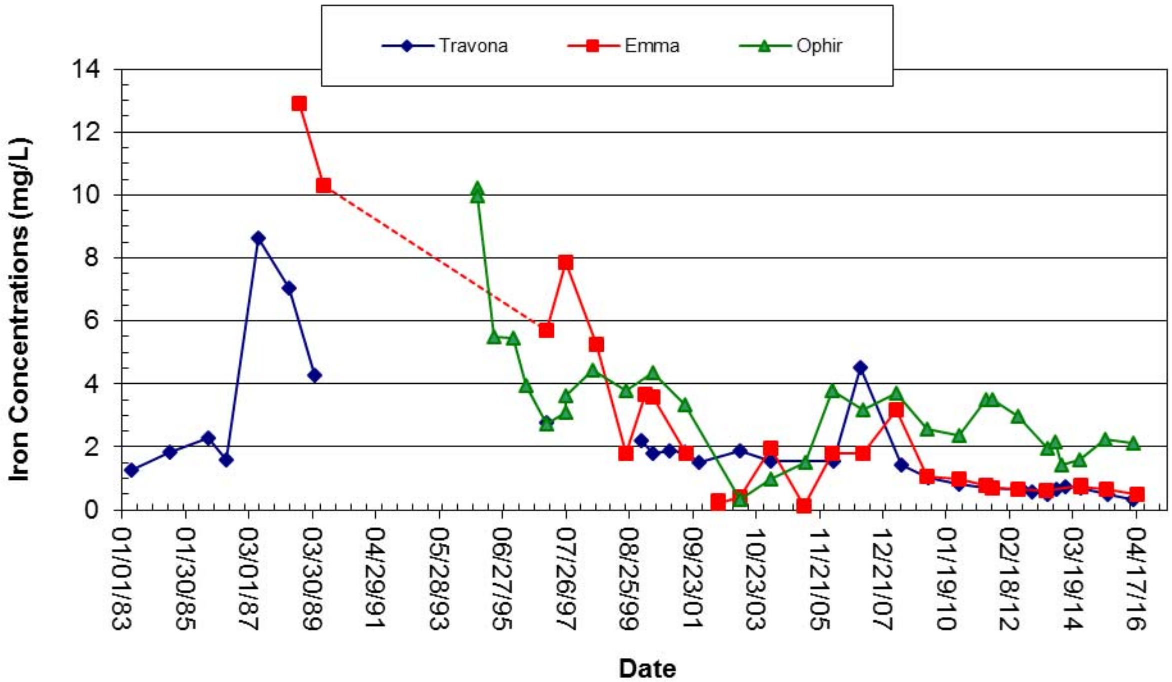
Figure 4-13. Water-level hydrographs for wells BMF96-2 and BMF96-3, 2002–2016.

Section 4.2.1 West Camp Mines and Monitoring Wells Water Quality

In 2016 water-quality data for the West Camp monitoring system was limited to analytical results from spring-season sampling in well BMF96-04 and the Travona, Emma, and Ophir mines.

With the exception of arsenic (50 µg/L in water from the Travona Mine and about 13 µg/L in water from the Emma Mine), the concentrations of most dissolved constituents in the West Camp waters were similar (figs. 4-14, 4-15). Iron and manganese concentrations are above the SMCL in all three mine samples.

The concentrations of most dissolved metals in well BMF96-4 are low and continue a downward trend, or remain stable, through 2016 (fig. 4-16). Concentrations of zinc showed some variation from 2003 to 2007; however, concentrations are well below the SMCL and have returned to pre-2003 levels. Arsenic concentrations continue to range from 5 to 7 µg/L.



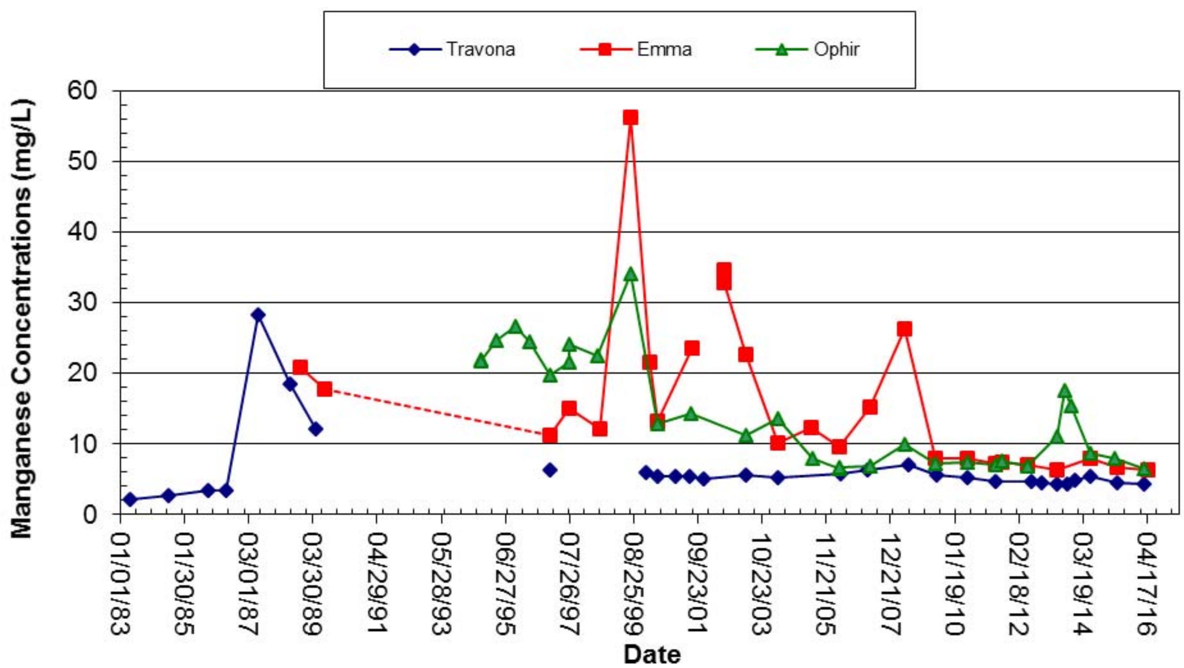


Figure 4-14. Iron and manganese concentrations in the West Camp mines.

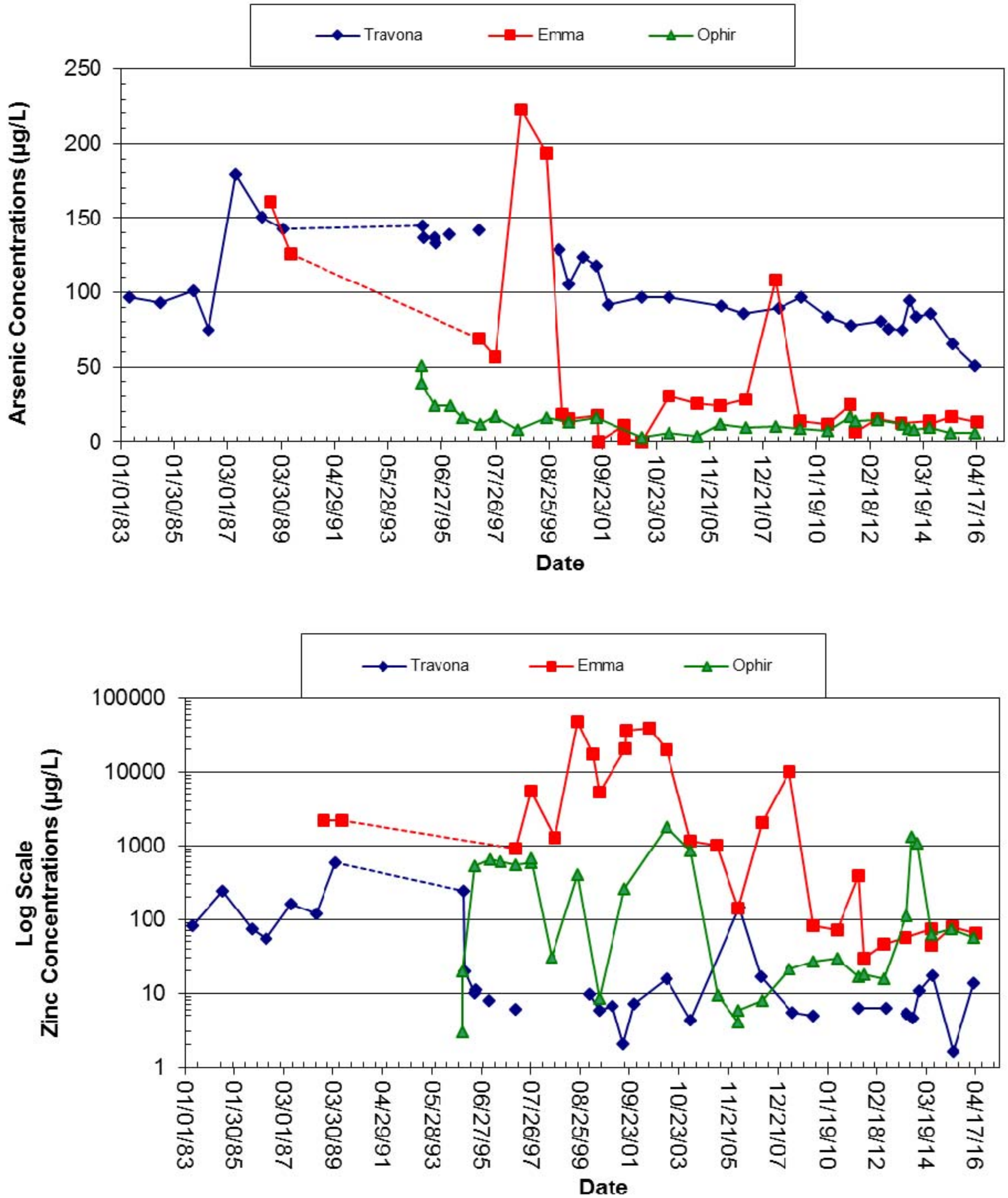
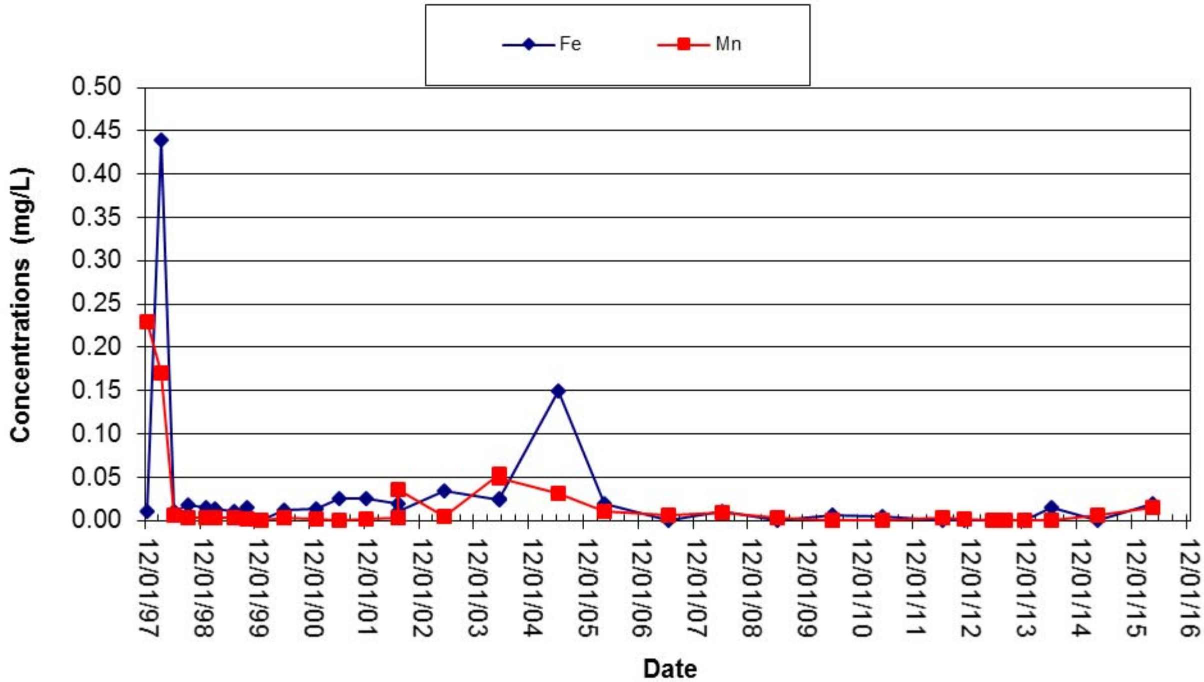


Figure 4-15. Arsenic and zinc concentrations in West Camp mines.



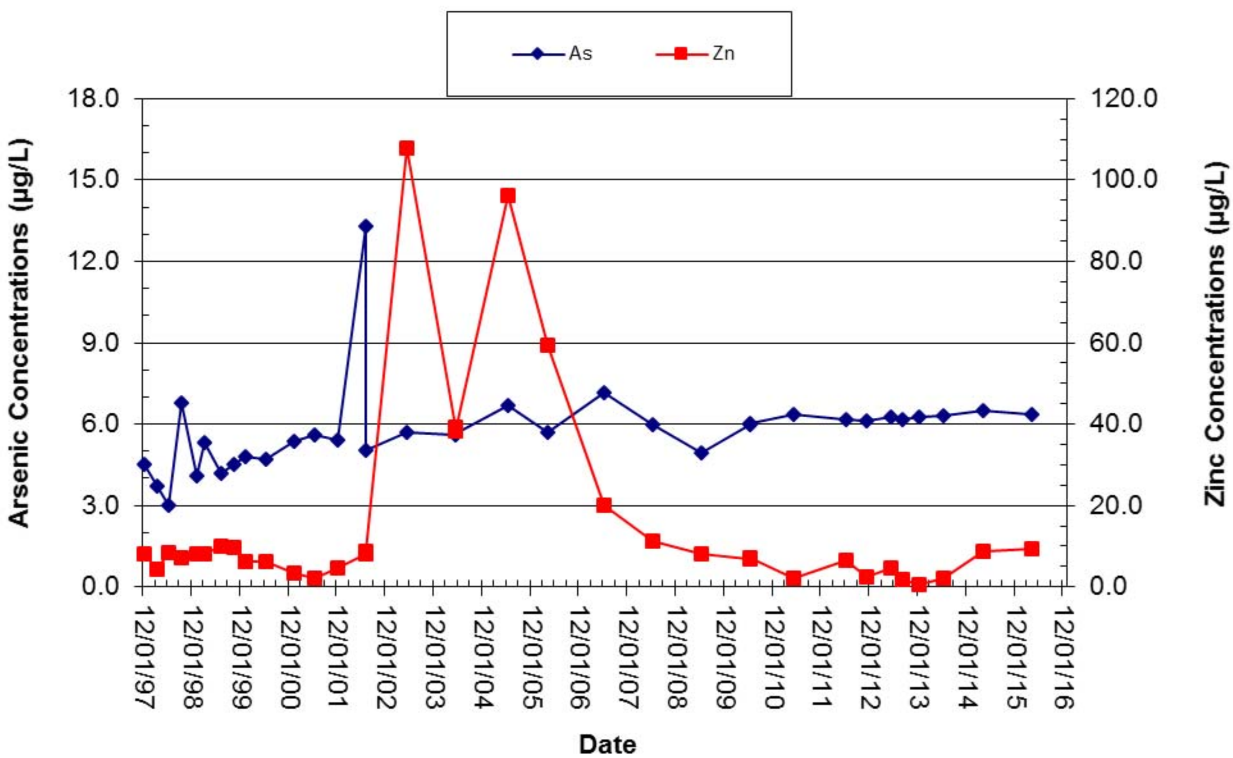


Figure 4-16. Selected water chemistry for West Camp well BMF96-4.

SECTION 5.0 OUTER CAMP SYSTEMS

The Outer Camp System consists of the Orphan Boy Mine, Marget Ann Mine, well S-4, and the Montana Tech well (fig. 5-1). Because the mines in the Outer Camp System had not operated for many years prior to ARCO's suspension of underground mining, water levels have been assumed to be at or near pre-mining levels. That the few connections between the Outer Camp mines and the other Butte Hill mines had been sealed decades earlier by bulkheads supports the contention that water levels in the Outer Camp are at or near pre-mining levels.

Section 5.1 Outer Camp System Water Levels

Outer Camp water levels show a certain amount of variation each year, with a water-level increase one year followed by a decrease the next. Water-level changes in 2016 varied from a rise of 1.24 ft in well S-4 to a decline of 0.04 ft in the Marget Ann Mine. Table 5.1.1 contains yearly water-level change data, and figure 5-2 shows these changes graphically. Water levels in all four of the Outer Camp sites show a net increase. The increases vary from over 17 ft at the Montana Tech well to over 33 ft in the Marget Ann Mine.

Figure 5-3 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.

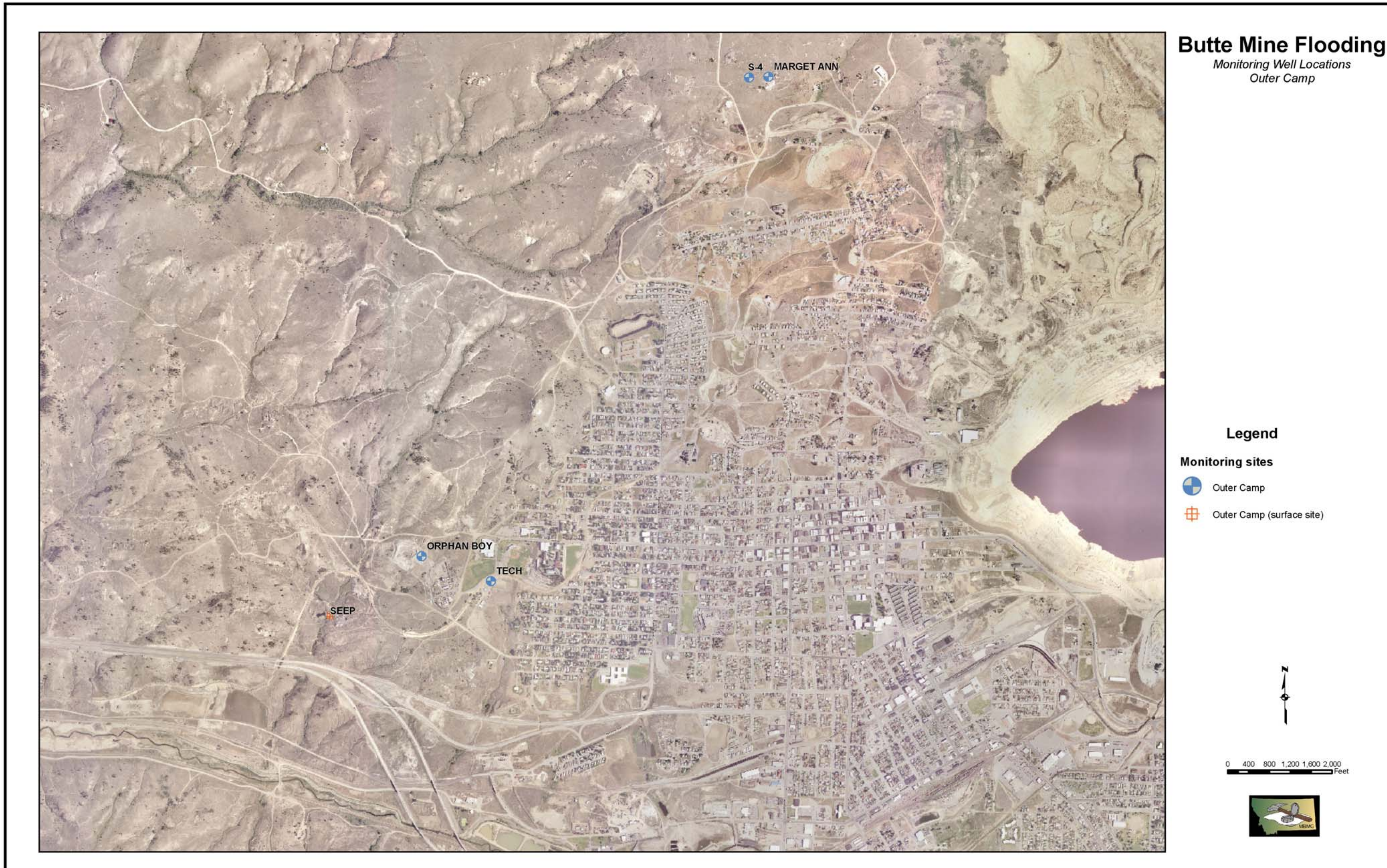
The water-level changes in the Marget Ann Mine and well S-4 are similar. Figure 5-4 shows water-level hydrographs for these two sites, with monthly precipitation. Water levels had a consistent increase regardless of precipitation amounts followed by water-level declines, with little apparent influence from precipitation through 2006. Water-level variations have been less dramatic from 2007 through 2016, with the exception of those observed in 2011. The 2011 water-level rise in both sites was one of the largest increases seen during the period of monitoring. Considerable precipitation occurred in May and June 2011, which may account for the large increases in water levels at these two sites. This same trend was observed in the Montana Tech well and the Orphan Boy Mine.

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

Year	Orphan Boy	Marget Ann	Well S-4	MT Tech Well
1987	2.40			
1988	2.14			
1989	3.83	-3.56	-3.56	
1990		-1.34	-4.23	
1991				
1992	1.41			
1993	5.49			0.36
1994	-0.72	4.66		2.51
1995	5.44	12.41		6.48
1996	-0.96	10.44	18.41	-1.47
Change Years 1–10	**20.43**	**22.61**	**10.62**	**7.88**
1997	7.56	14.50	16.42	7.76
1998	-2.79	0.59	2.17	-2.72
1999	-1.94	-2.87	-2.32	-1.57
2000	NA	-4.71	-4.08	-4.24
2001	NA	-1.49	-1.59	-1.79
2002	NA	-2.99	-3.13	-3.64
2003	NA	1.09	2.23	2.76
2004	NA	-2.18	-3.07	0.23
2005	-0.56	-3.01	-2.85	-1.97
2006	4.51	8.66	7.18	5.44
Change Years 11–20	**6.78**	**7.59**	**10.96**	**0.26**
2007	1.86	1.14	-0.32	1.85
2008	-1.05	0.56	-0.04	-1.68
2009	-0.27	1.09	0.60	0.99
2010	3.14	2.37	4.52	4.72
2011	5.64	7.86	12.08	4.28
2012	-5.77	-6.21	-7.66	-4.76
2013	-3.50	-3.91	-4.98	-2.88
2014	3.77	0.58	-1.45	5.85
2015	1.44	-0.18	0.90	-0.20
2016	0.15	-0.04	1.24	0.71
Change Years 21–30	**5.41**	**3.26**	**4.89**	**8.88**
Net Change*	**32.62**	**33.46**	**26.47**	**17.02**

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

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



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

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

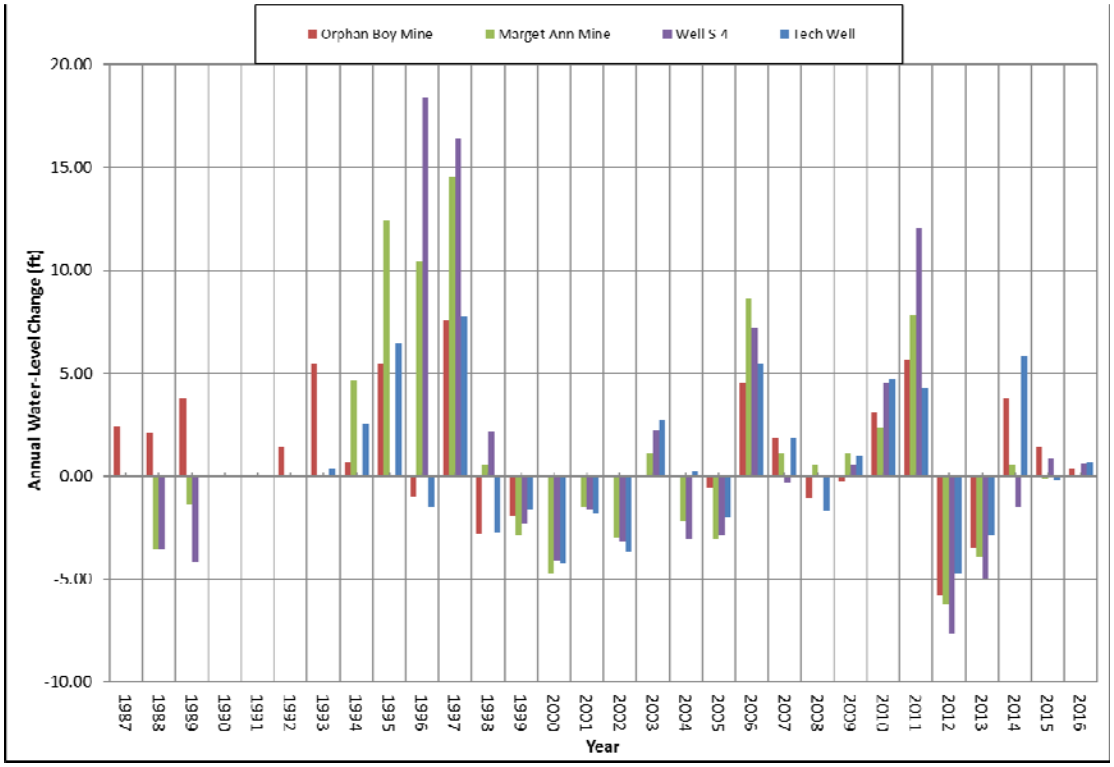


Figure 5-2. Outer Camp sites annual water-level change.

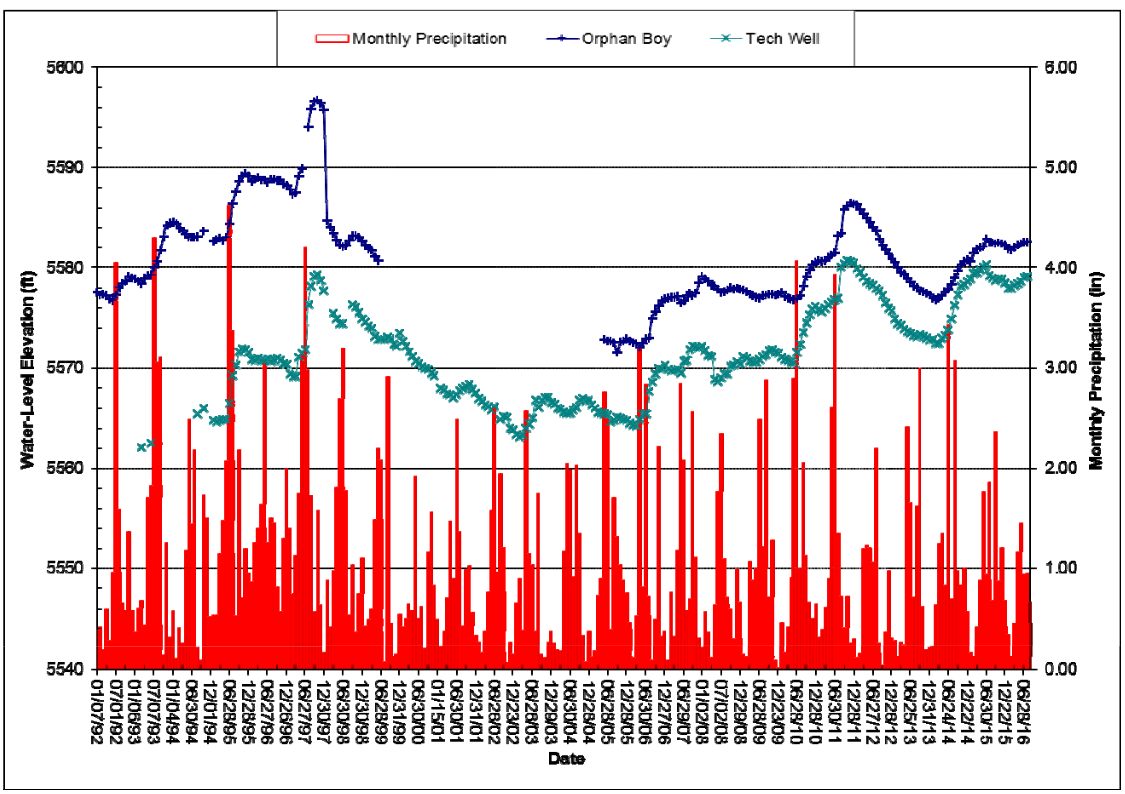


Figure 5-3. Water-level hydrograph for the Orphan Boy Mine and Montana Tech well.

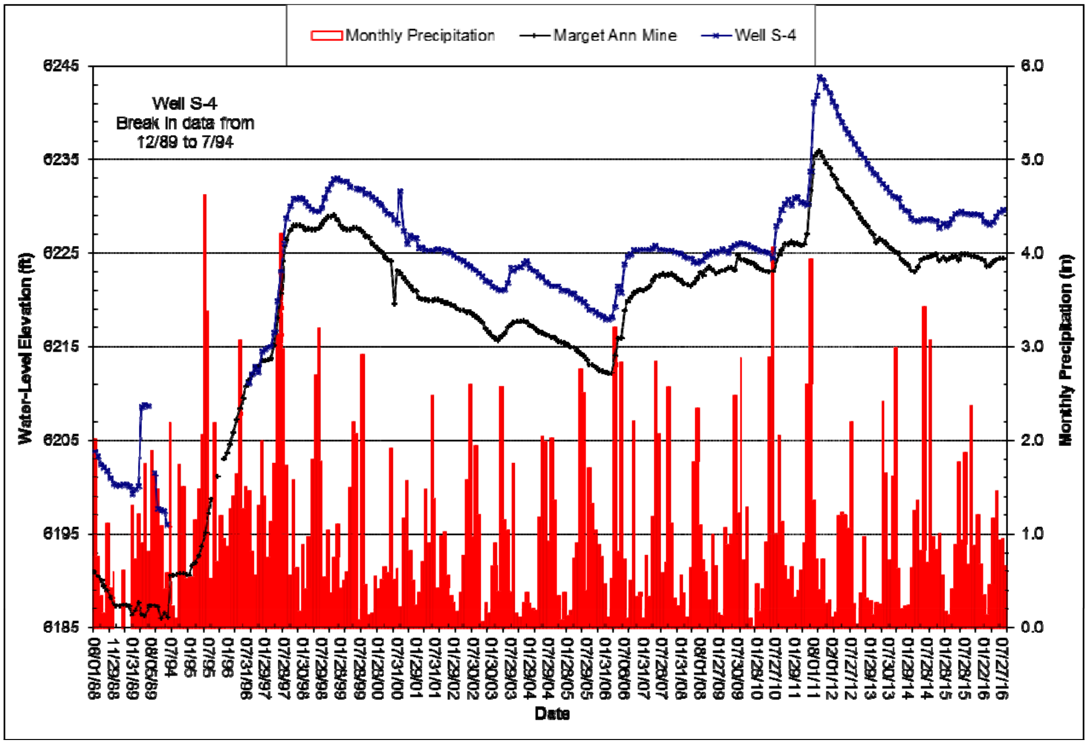


Figure 5-4. Water-level hydrograph for the Marget Ann Mine and well S-4.

Section 5.2 Outer Camp Water Quality

Water-quality samples were collected from the Orphan Boy Mine, Montana Tech well, and Green Lake seep during 2016; the Orphan Boy Mine and Green Lake seep were sampled during both the spring and fall sample events. Figures 5-5 and 5-6 show selected water chemistry for the Orphan Boy Mine. Water-quality trends have been downward or unchanged with the exception being zinc, which increased from 2005 to 2010; concentrations show some variations during 2011–2016 but remain less than 50 µg/L. However, the apparent increase coincides with a change in sampling procedures. The 1987–1998 samples were collected by bailing water from the shaft; samples collected since 2005 were collected following pumping of water from the shaft until stable physical parameters were obtained, or one hour of pumping.

Water quality in the Outer Camp is better than the water quality in the East Camp or West Camp bedrock systems. The better quality is most likely a combination of different geology and geochemical equilibrium being reached as a result of the workings in this area being flooded for a longer period of time.

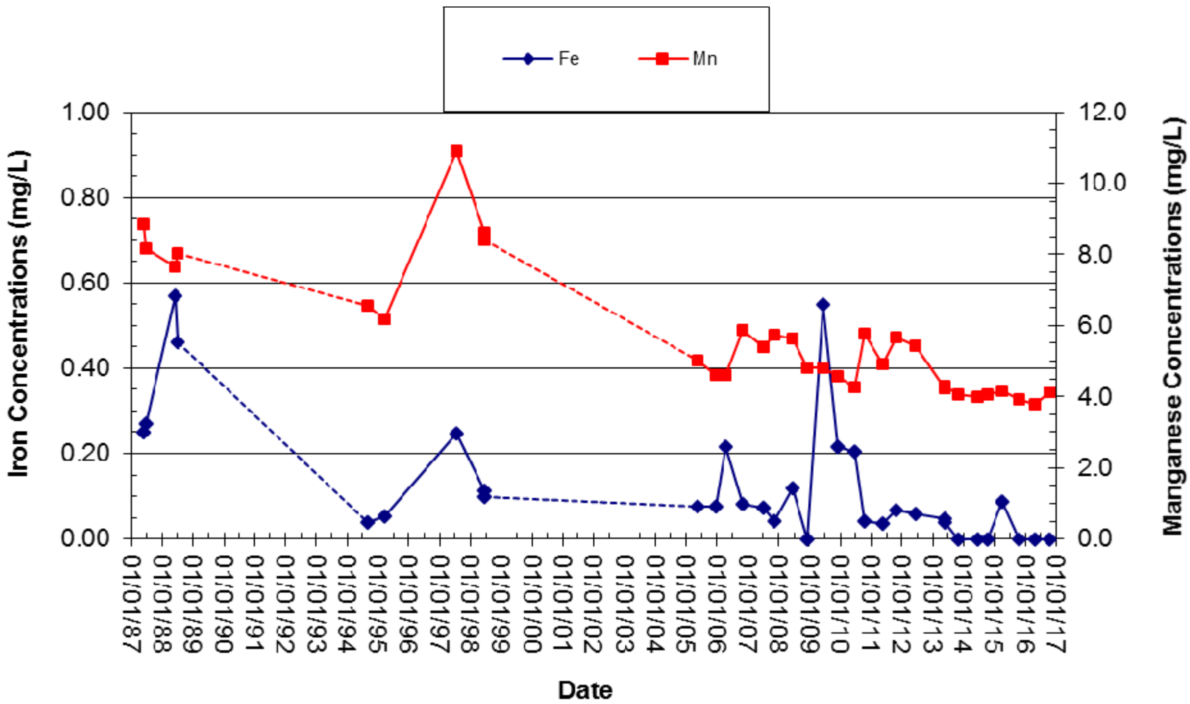


Figure 5-5. Iron and manganese concentrations for the Orphan Boy Mine.

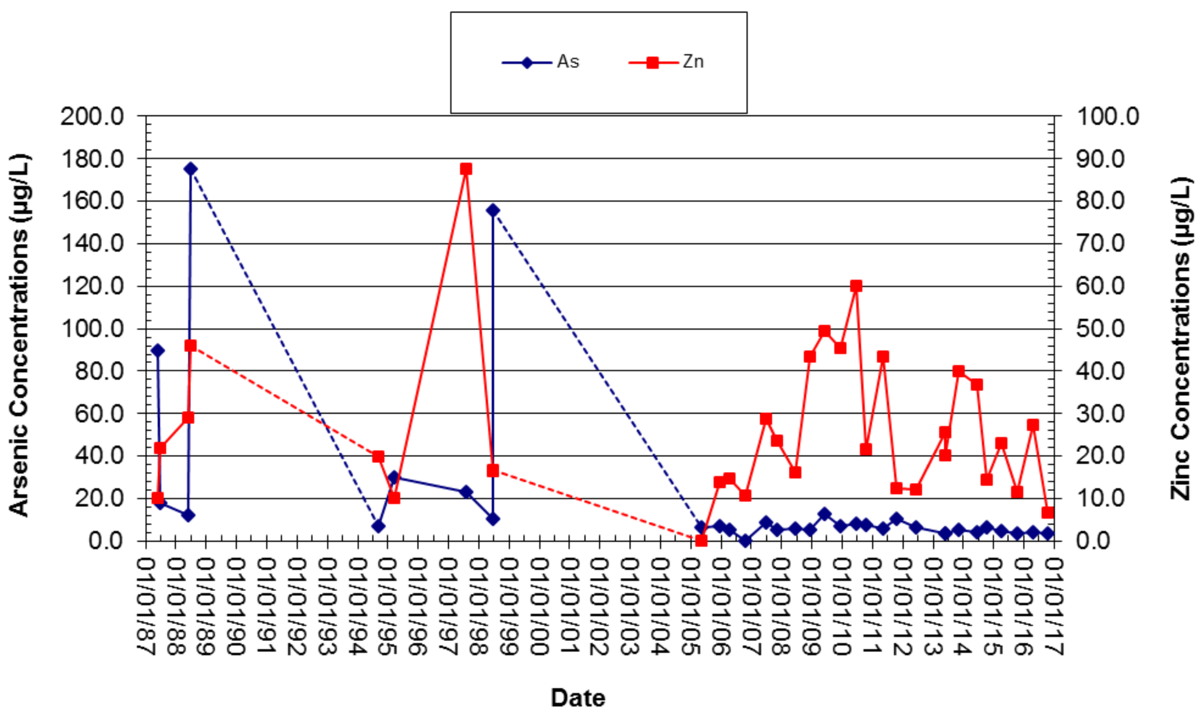


Figure 5-6. Arsenic and zinc concentrations for the Orphan Boy Mine.

SECTION 6.0 PARK WELLS

The locations of the Park monitoring wells are shown in figure 6-1. The Hebgen Park, Belmont Well #1, 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 parks within the East Camp System.

Section 6.1 Park Wells Water Levels

Annual water-level changes are listed in table 6.1.1 and shown in figure 6-2. The yearly water-level changes in Belmont Well #1 since 1997 have generally been much greater than those in the other two wells, with several exceptions in the Parrot Park well record. Whether a water-level change is a rise or fall, its magnitude is typically much greater in the Belmont well than in the others; its water-level changes have been from 10 to 75 ft annually. Since monitoring began at these sites, water levels have risen between 5.5 and 10.7 ft in the Hebgen and Parrot Park wells, while falling more than 29 ft in Belmont Well #1.

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

Year	Hebgen(1)	Parrot	Belmont Well #1	Year	Hebgen(1)	Parrot	Belmont Well #1
1983				1993	6.27	1.39	
1984				1994	-0.25	5.96	
1985				1995	NA	2.67	
1986				1996	2.75	-1.50	-0.74
1987				1997	4.22	4.75	15.05
1988	1.54	1.43		1998	-0.62	-0.33	-15.13
1989	-2.18	0.42		1999	-2.93	-5.34	14.80
1990	-1.90	5.23		2000	-6.07	1.50	-8.11
1991	3.09	-6.10		2001	0.37	5.47	-0.41
1992	-1.40	0.63		2002	-0.41	-3.27	-24.08
Change Years 1–10	**-0.85**	**1.61**	**---**	**Change Years 11–20**	**3.33**	**11.30**	**-18.62**
2003	1.25	3.52	-54.19	2013	-0.24	2.94	6.05
2004	-0.12	-1.12	-39.79	2014	4.37	15.92	-31.51
2005	-2.19	6.76	-5.01	2015	-1.84	-9.72	1.44
2006	2.86	6.95	35.07	2016	2.63	-5.26	5.17
2007	1.40	2.44	-12.15	2017			
2008	-0.98	11.20	-9.45	2018			
2009	0.12	-26.99	9.83	2019			
2010	-0.05	-7.59	73.75	2020			
2011	-0.82	2.10	18.17	2021			
2012	-3.32	-3.28	-8.45	2022			
Change Years 21–30	**-1.85**	**-6.01**	**7.78**	**Change Years 31–40**	**4.92**	**3.88**	**-18.85**
				Net Change*	**5.55**	**10.78**	**-29.69**

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

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

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

NA, no access.

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

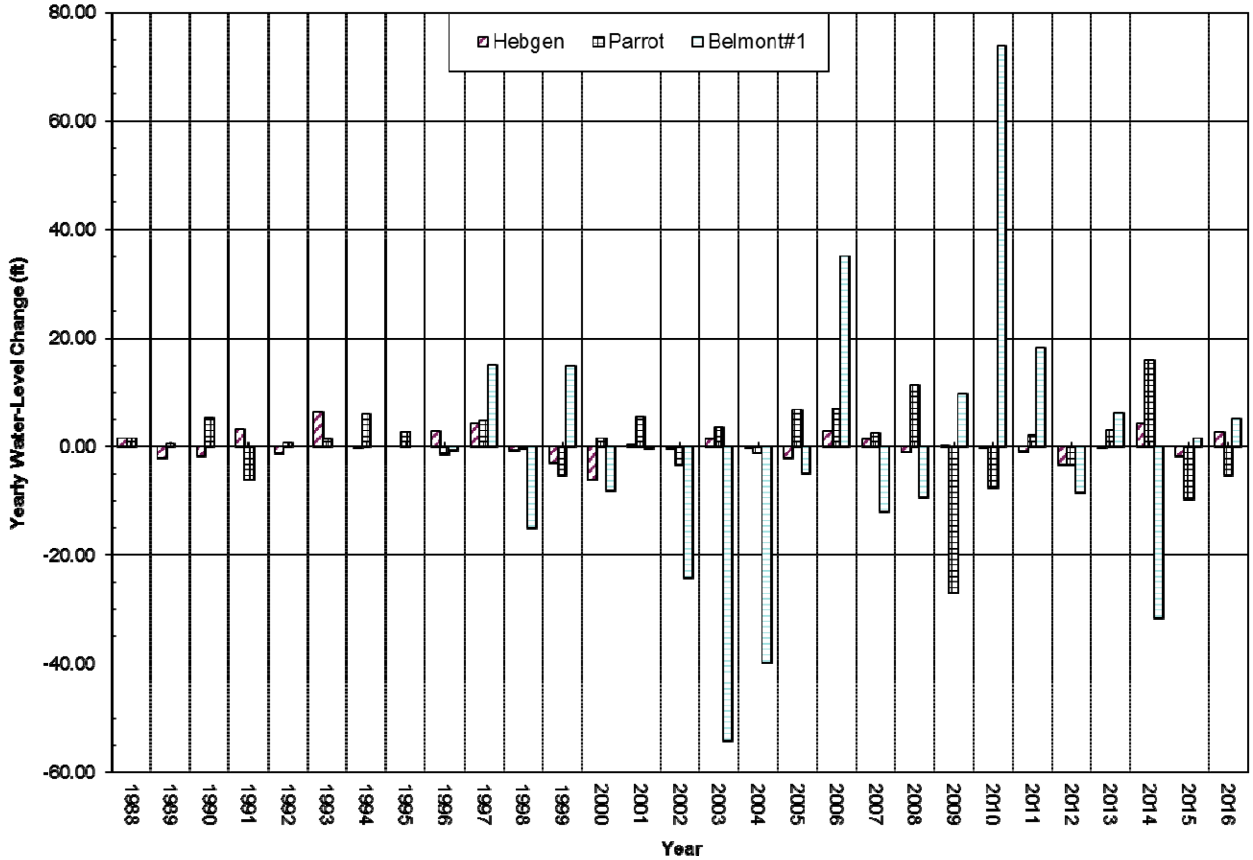


Figure 6-2. Park wells annual water-level changes.

Annual water-level response during 2016 at the Hebgen Park well (fig. 6-3) was similar to responses in prior years. Water levels began to rise during the late spring and continued to rise through the fall, which coincides with summer precipitation and lawn watering of the park grass. Because the water-level rise extends into the fall and early winter, it is probable that a portion of the seasonal water-level increase is due to lawn watering. The water level increased 2.6 ft during 2016; since monitoring began at this site, water levels have increased 5.5 ft.

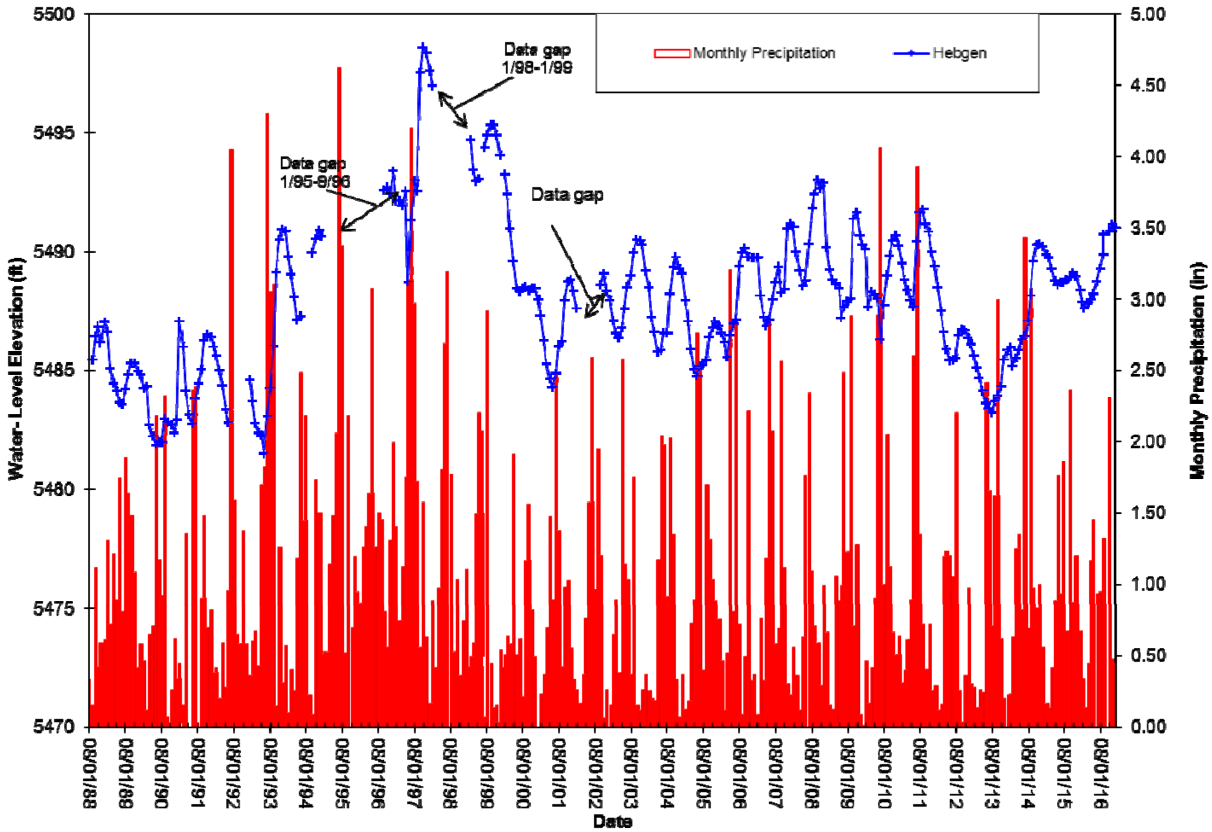


Figure 6-3. Water-level hydrograph for the Hebgen Park well.

The water-level hydrograph for the Parrot Park well is shown in figure 6-4, along with monthly precipitation. Water levels have shown considerable variation throughout the period of monitoring; water levels have exhibited 20- to 30-ft increases followed shortly after by a similar decline. The 2011–2014 water levels had more of a seasonal trend, while mid-2014 through mid-2016 water levels had a large water-level swing. Water levels at this site have risen 10.7 ft since monitoring began in 1988.

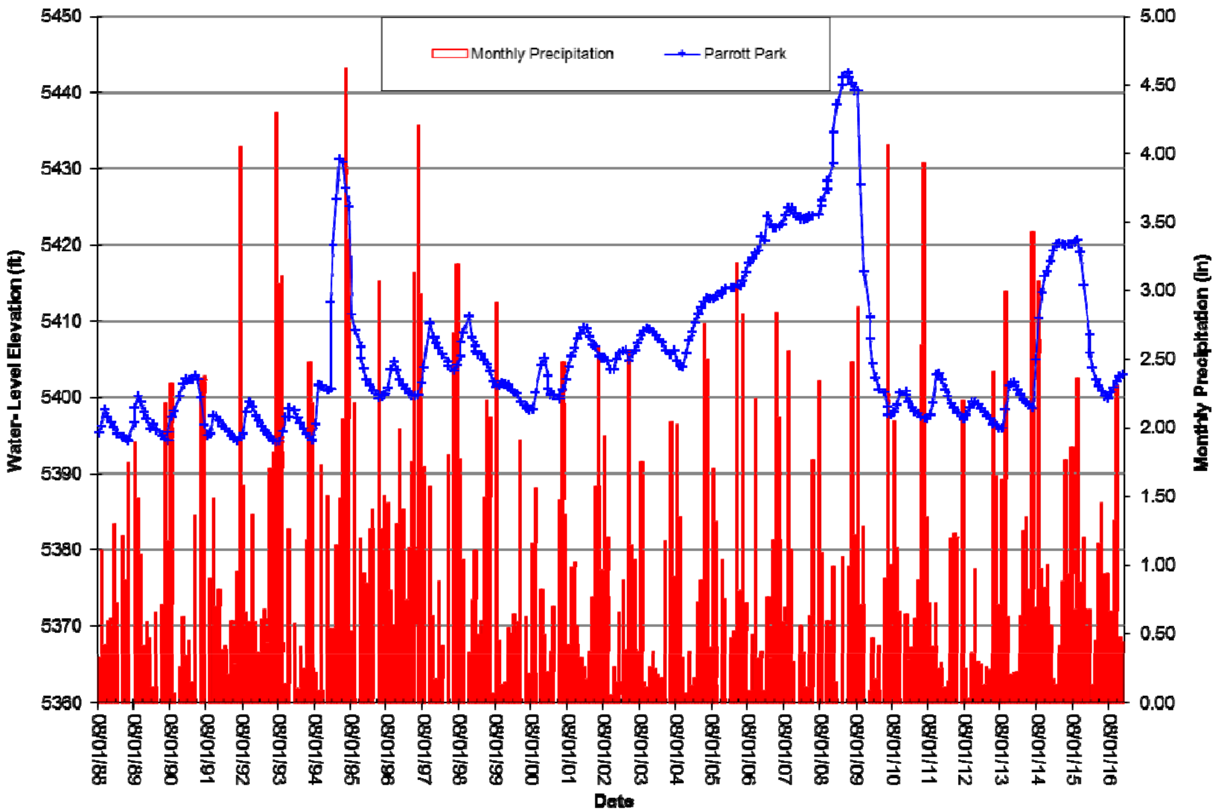


Figure 6-4. Water-level hydrograph for Parrot Park well.

Figure 6-5 compares water levels in the Parrot and Hebgen Park wells. The water-level rise in the Parrot well from 2004 through 2008 did not occur in the Hebgen well, nor did the decline that began mid-2009 and continued into the middle of 2010. Water levels had more of a seasonal trend during 2010–2014. The Hebgen Park well appears to respond to seasonal conditions (snowmelt, precipitation, and lawn irrigation), while the Parrot Park well water levels are less consistent and do not appear to follow seasonal changes.

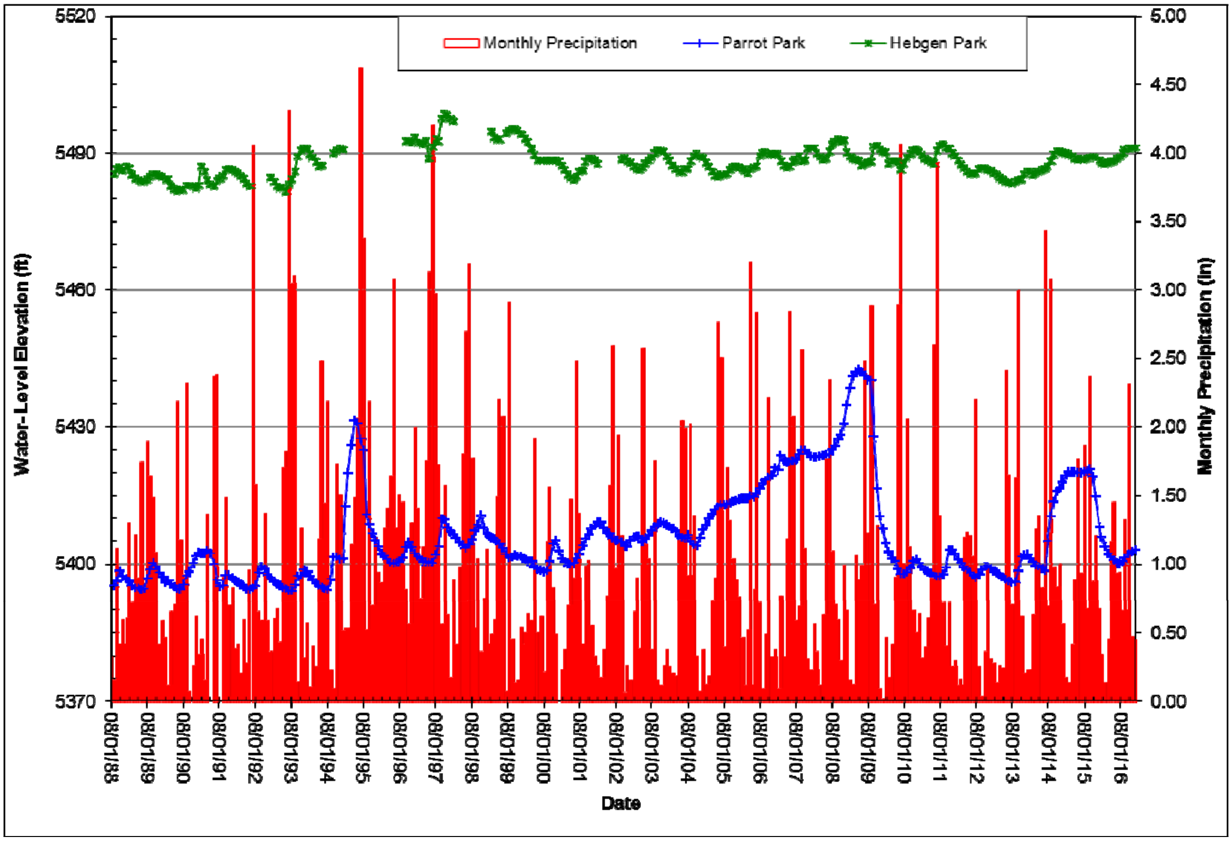


Figure 6-5. Water-level hydrographs for Parrot Park and Hebgen Park wells.

Belmont Well #1 was drilled as an alternative to monitoring water levels in the Belmont Mine. However, during completion a borehole collapse prevented the casing from being installed to proper depth. Instead of abandoning Belmont Well #1 after a new replacement well was drilled (Belmont #2), it was kept as a monitoring site because its water level differed from those of the deeper bedrock (mine) system. Water-level changes in this well do not match those in any other bedrock well. From 2002 through 2005, water levels declined more than 120 ft, before rising 35 ft in 2006; water levels have continued this pattern of variability. The water-level changes between 2003 and 2009 initially appeared to show a response to precipitation and/or lawn irrigation, when water levels and precipitation are compared (fig. 6-6); however, careful evaluation shows that seasonal water-level change is 10 to 20 ft or more. This well has been equipped with a pressure transducer to record water levels hourly since 2003. Figure 6-7 is a hydrograph for this well from August of 1996 through 2016, showing daily average water levels. The seasonal water-level changes are more pronounced in this figure, allowing a closer examination of the periods of change. The magnitude of the seasonal rise is greater than would be expected from both precipitation and lawn irrigation, even in a bedrock system with low porosity. Because this borehole was drilled into the underground mine workings and then collapsed, it is difficult to ascertain what the actual controls on water levels are. However, perched water zones exist in the bedrock system adjacent to the underground mine bedrock system, and the water level in this well is 150 ft or more above the water level in nearby underground mines.

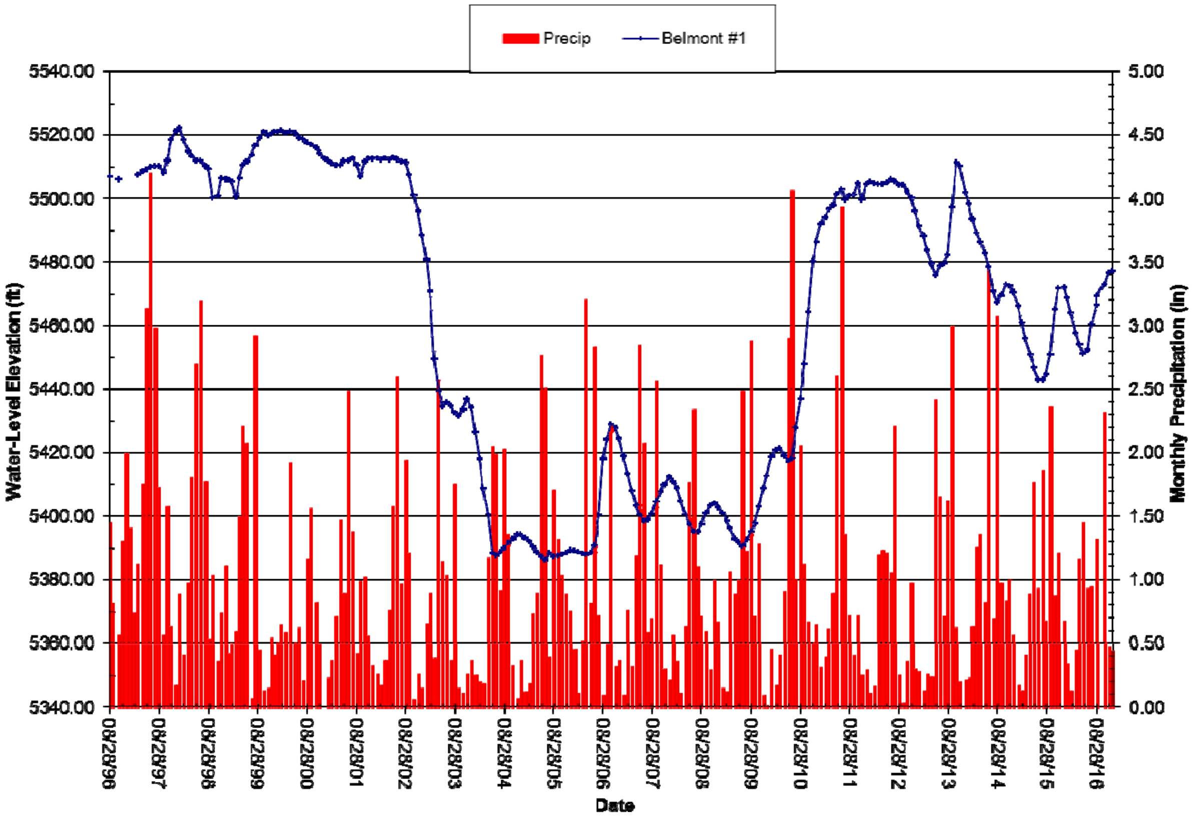


Figure 6-6. Water-level hydrograph for Belmont Well #1.

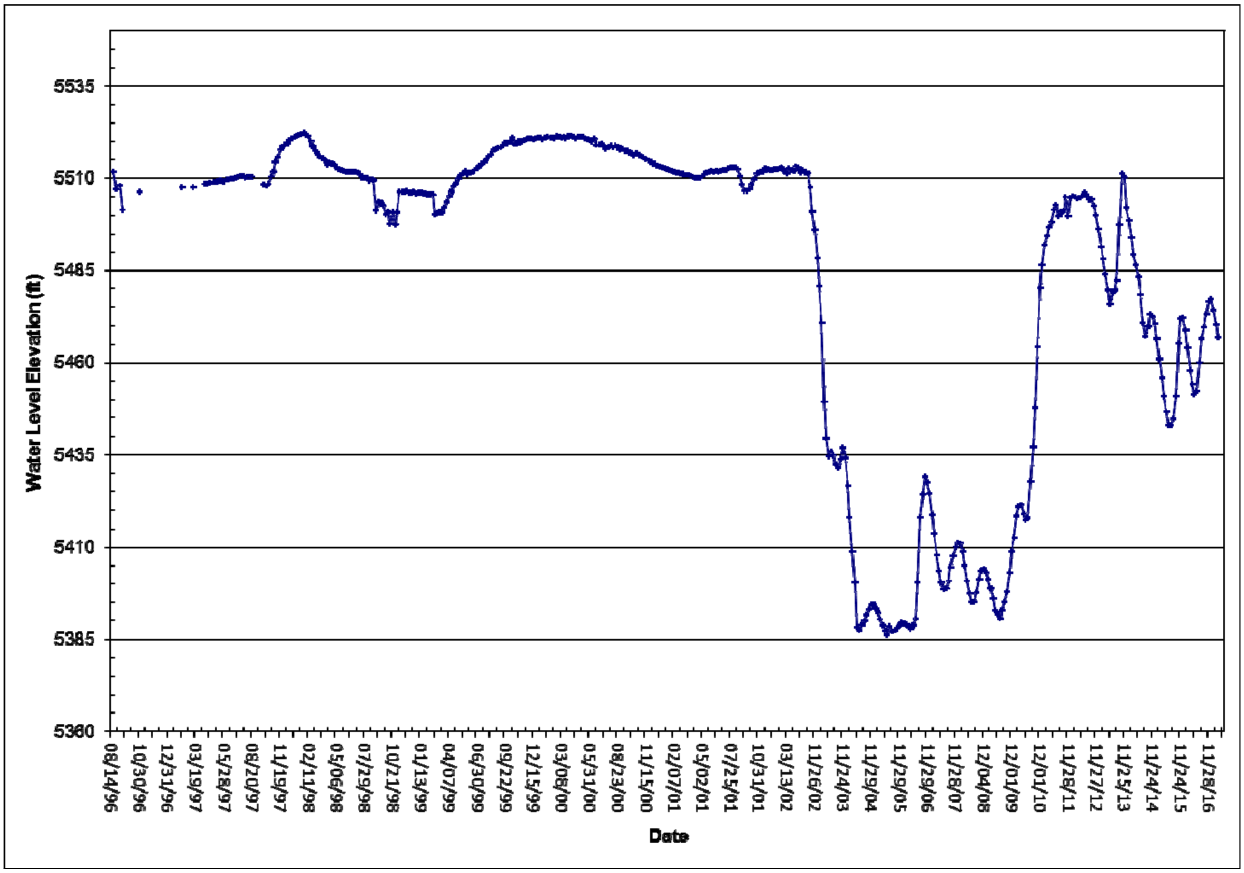


Figure 6-7. Belmont Well #1 hydrograph showing average daily water-level elevations.

Section 6.2 Park Wells Water Quality

Water-quality samples were collected only from the Parrot Park well during 2016. Figure 6-8 shows concentrations of cadmium and copper and figure 6-9 shows arsenic and zinc concentrations. The concentrations of arsenic and cadmium in the sample exceed the MCL. Although cadmium concentrations declined in 2008 to levels below the MCL, concentrations in 2009–2016 were above the MCL. Concentrations decreased for cadmium, copper, and zinc while remaining similar for arsenic in 2016 (figs. 6-8, 6-9).

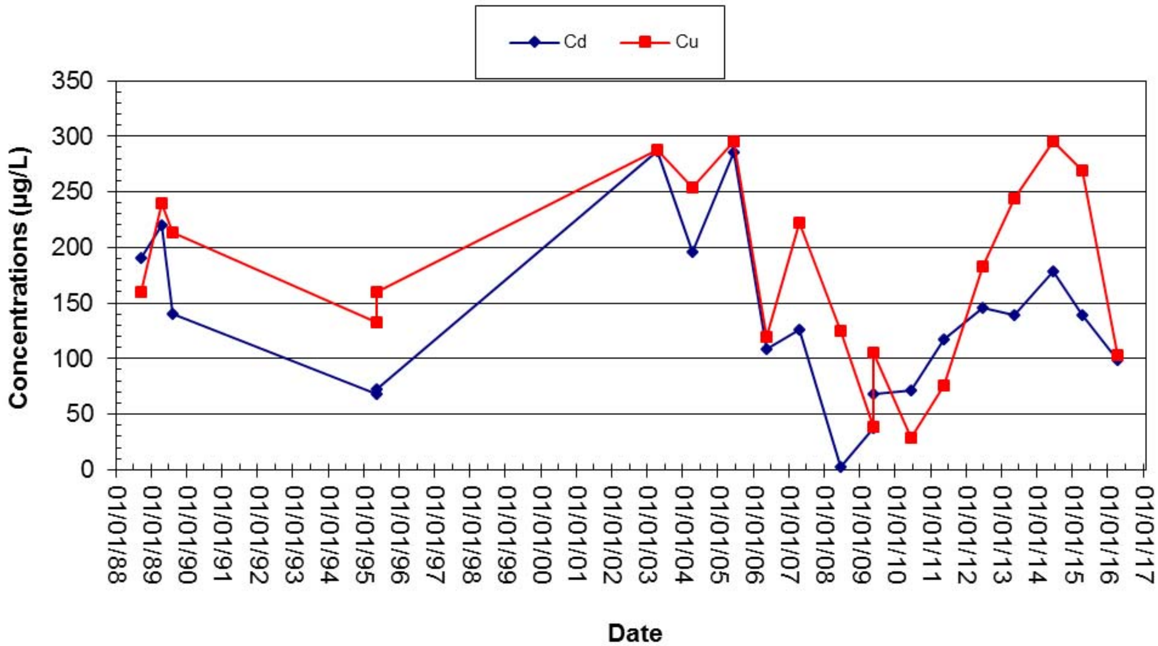


Figure 6-8. Cadmium and copper concentrations for the Parrot Park well.

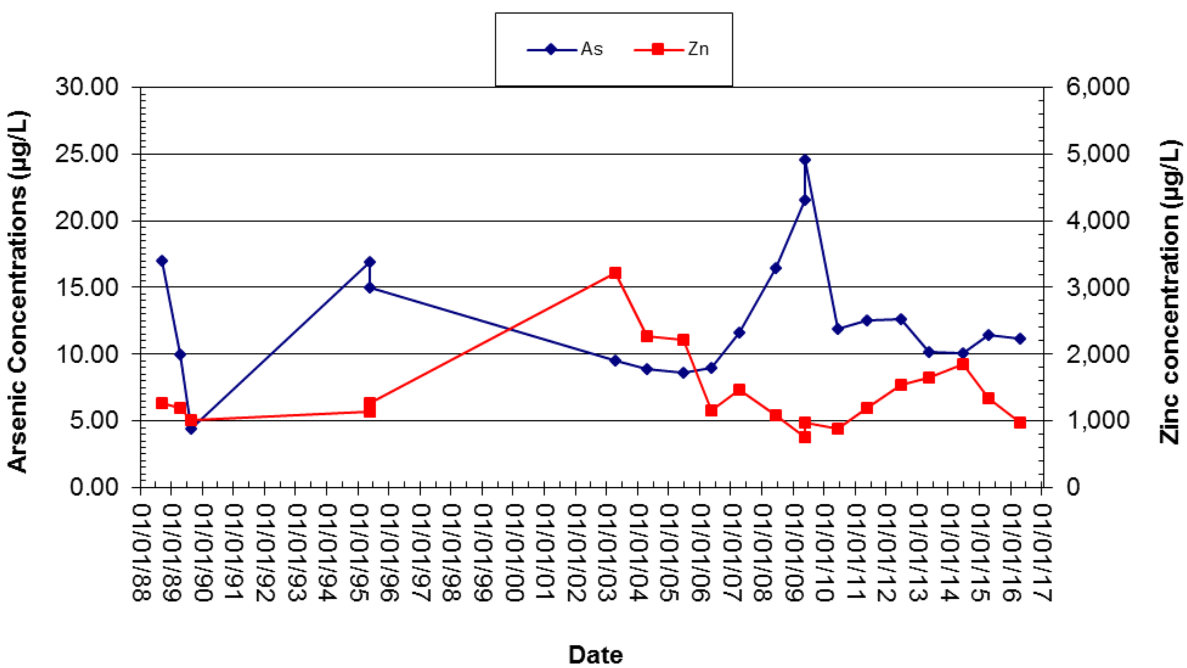


Figure 6-9. Arsenic and zinc concentrations for the Parrot Park well.

SECTION 7.0 BUTTE ALLUVIAL AND BEDROCK CONTROLLED GROUNDWATER AREA

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

The outer perimeter of the BABCGWA is shown in figure 7-1, with major historic mines and landmarks included for reference. The boundaries of the Old Butte Landfill and Clark Tailings areas are also shown near the southern edge of the map. The alluvial portion of the BABCGWA covers 8.11 mi^2, with maximum vertical depths of over 300 ft in the northeast, thinning to less than 10 ft at the western edge. The bedrock portion of the area has a maximum vertical depth of approximately 1,500 ft above MSL (Final Order, DNRC, 2009).

In the Final Order, the following conditions were placed on existing water wells and potential future usage:

- New groundwater wells will only be allowed within the BABCGWA after review and approval from the Butte–Silver Bow (BSB) Board of Health, the EPA, and DEQ. Environmental monitoring/treatment wells are allowed within the BABCGWA, providing they are in compliance with applicable statutory criteria.
- An existing well for irrigation or industrial use may be replaced at the well owner's expense, but only if the replacement well has been shown not to be detrimental to the environment or to human health, and complies with applicable statutory requirements.
- All existing wells that are used as a drinking water supply for human consumption must meet the human health standards established by DEQ-7 for five contaminants of concern (COC): arsenic, lead, cadmium, copper, and zinc. If any of these health standards are exceeded during a sampling event, the well will be retested for verification. If this second sampling event yields results that exceed any of the COC standards, the well will cease being used for such purposes.

Section 7.1 Sampling Activities in 2016

Based upon site requests from the BSB Health Department, the MBMG collected groundwater samples from eight privately owned wells during 2016. General information about each well is found below, in table 7.1.1. The well locations are shown in figure 7-2, and except for one site, are located within the BABCGWA.

Table 7.1.1 General site information for the domestic wells sampled in 2016 for BABCGWA. The elevation, depth, and static water level (SWL) data are listed in feet (USGS datum).

GWIC ID	**SITE NAME**	**LAT**	**LONG**	**ELEVATION**	**DEPTH**	**SWL**
174040	BOWLER	45.99673	-112.55196	5450	32	11.67
269353	MILLER	45.99727	-112.55403	5450	25	16.86
50357	RAWLINS	46.00867	-112.55859	5660	250	N/A
4819	REYNOLDS	46.00623	-112.53776	5505	200	N/A
156158	WEST	45.98796	-112.53646	5480	44	N/A
171276	WHITE-HOUSE	45.98103	-112.54904	5520	160	N/A
171278	ROSIN BROS.	45.98103	-112.54639	5515	160	N/A
255690	WHITE-WEST	45.98206	-112.54939	5520	N/A	N/A

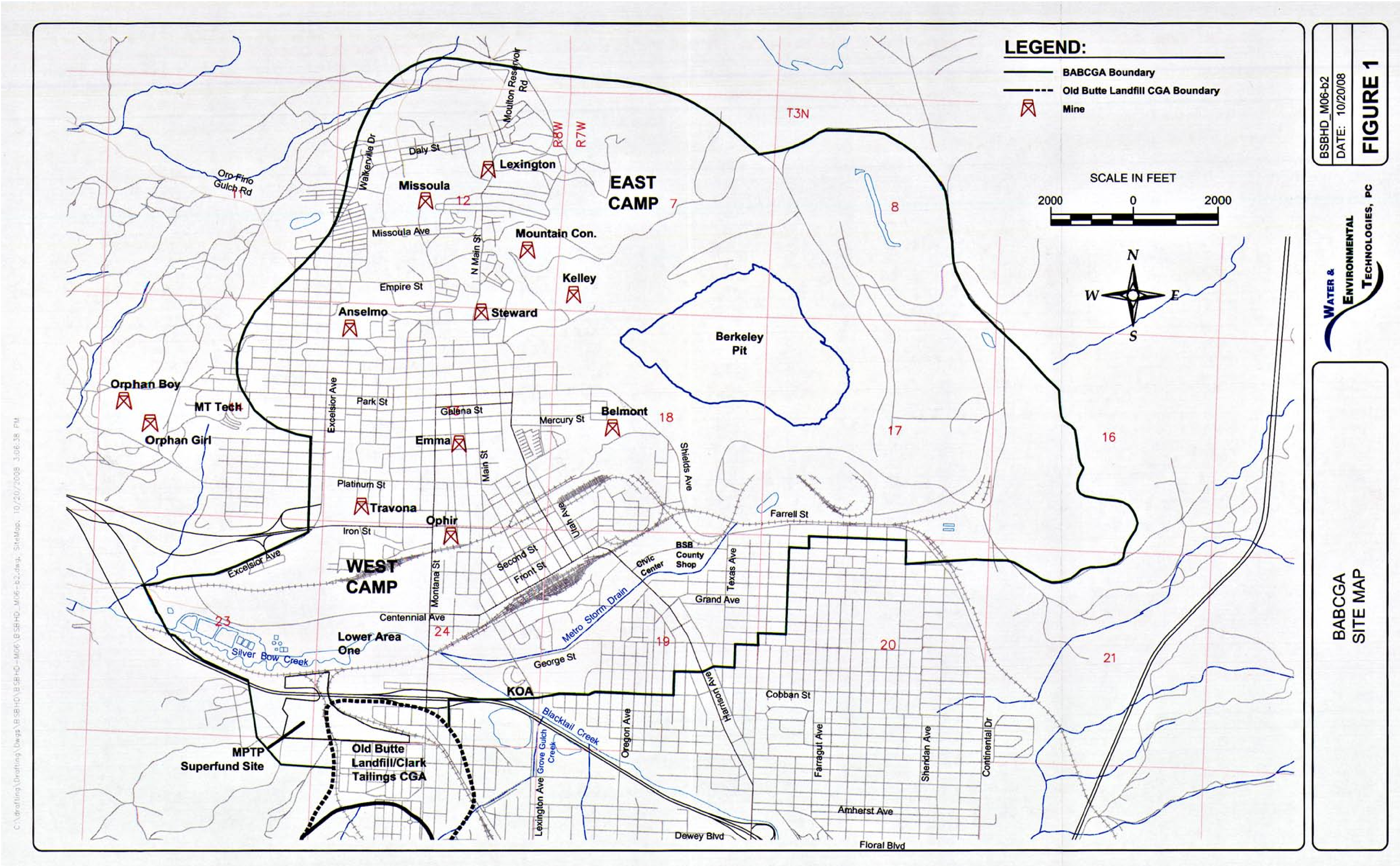


Figure 7-1. Site map for BABCGWA—prepared by Water & Environmental Technologies, included in the Final Order (DNRC).

Prior to purging water from each well, the SWL was measured with an electronic water-level probe, and if possible, the total depth was measured. At the majority of the sites, those measurements were not possible, because the wells were sealed/buried and had no downhole access. When possible, at least three well volumes were purged prior to sampling, with a “well volume” being the volume of standing water within the well prior to pumping. In the wells with unknown SWLs and well volumes, the wells were purged until the parameters stabilized, before collecting samples.

During pumping, the water was measured for physical/chemical parameters [e.g., temperature, pH, oxidation-reduction potential (ORP), SC, and dissolved oxygen (DO)] in 5- to 10-min intervals, using a calibrated Hach Hydrolab Minisonde-5. In the wells with unknown SWLs and well volumes, the wells were purged until the parameters stabilized, before collecting samples. After the parameters stabilized about the mean of three consecutive readings (i.e., temperature <±0.5°C; pH <±0.1; ORP <±20; mV SC <±5%), a series of water samples were collected, in accordance with the following “dissolved analyte” suite:

- 500 mL unfiltered and unpreserved,
- 500 mL filtered (0.45 µm pore-size) and preserved with 1% HNO_3, and
- 250 mL filtered (0.45 µm pore-size) and unpreserved.

Although the Final Order for the BABCGWA identifies only five COCs, a complete analysis of these water samples was conducted in the MBMG laboratory, using methods approved by the EPA for the following species:

1. Cations and trace metals—Ca, Mg, Na, K, SiO_2, Al, As, Co, Cd, Cr, Cu, Fe, Mn, Mo, Ni, U, Zn, Ce, Cs, Ga, La, Nb, Nd, Pb, Pr, Rb, Tl, Th, Sn, Ti, and W (acidified below pH 2 with HNO_3);
2. Anions—SO_4, HCO_3, CO_3, Cl, and NO_3.

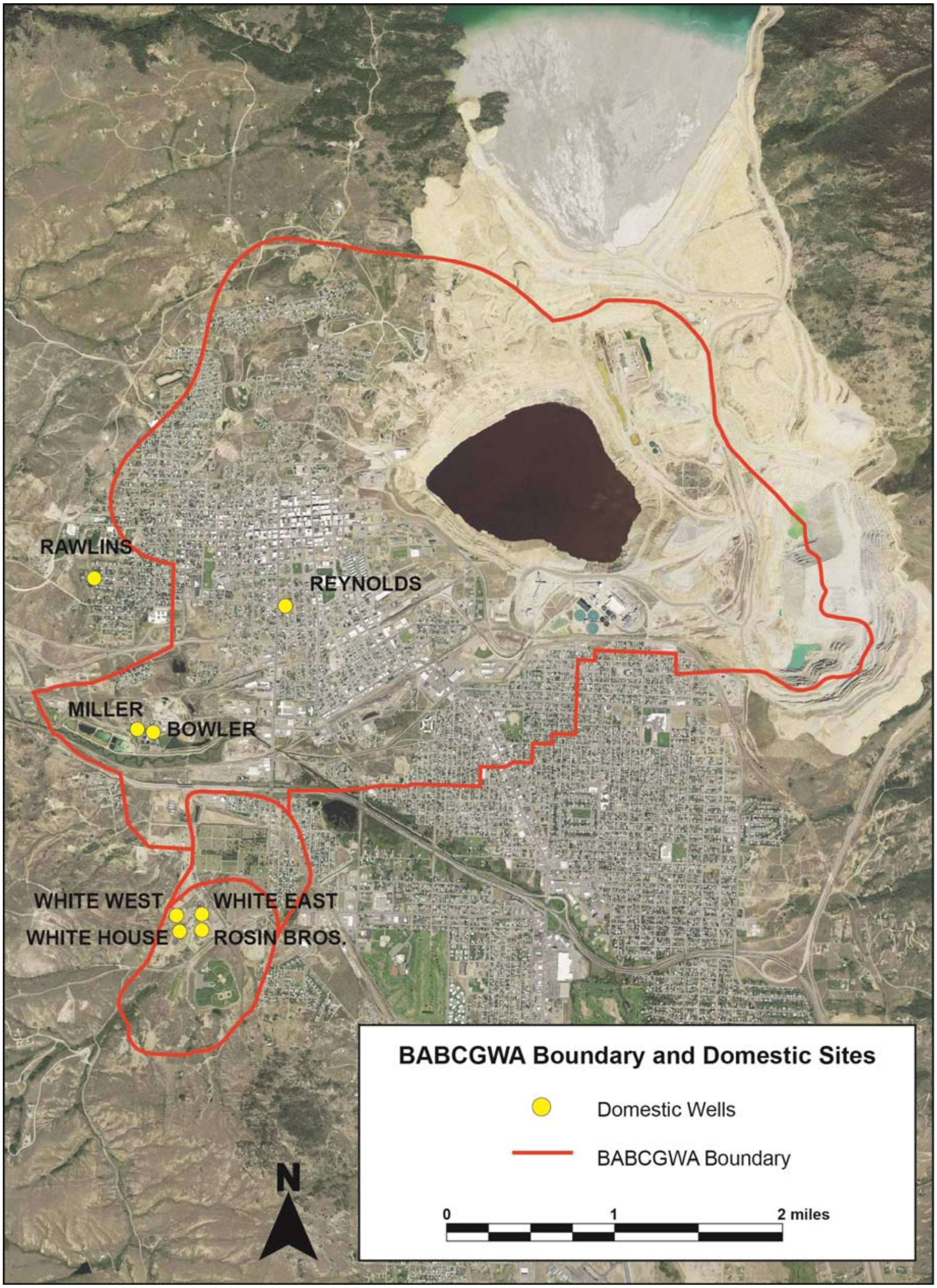


Figure 7-2. Site map for domestic well sampling locations; BABCGWA boundary is shown in red.

Section 7.2 Water-Quality Results

The laboratory results for the five COC (arsenic, cadmium, copper, lead, and zinc) are given for each well in table 7.2.1, with a comparison to the established drinking water MCLs (DEQ-7). The White-East site was not sampled in 2016.

Table 7.2.1. Comparison of DEQ-7 MCLs for COC with 2016 domestic well results.

GWIC Id	Site Name	Sample Date	As (µg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)
-	**DEQ-7 STANDARD**	**-**	**10**	**5**	**1,000**	**15**	**2,000**
174040	BOWLER	07/12/2016	<0.250 U	0.780 J	<1.250 U	<0.150U	98.7
269353	MILLER	07/08/2016	6.47	<0.250 U	4.790 J	<0.150 U	34.7
50357	RAWLINS	07/08/2016	3.77	<0.100 U	11.7	<0.060 U	31.3
4819	REYNOLDS	07/08/2016	1.01	<0.250 U	12.5	<0.150 U	4.76 J
156158	WEST	07/08/2016	0.95	0.300 J	19.4	<0.060 U	197
171276	WHITE-HOUSE	07/13/2016	2.58	<0.100 U	2.52	<0.060 U	30.9
171278	ROSIN BROS.	07/13/2016	1.23	<0.100 U	96.3	0.58	1150
255690	WHITE-WEST	07/13/2016	1.80	<0.100 U	1.88 J	<0.060 U	48.2

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

Every domestic well sampled in 2016 had results below the established MCLs for the five COC, as required in the Final Order. These results are also consistent with the samples that were collected in previous years from the same wells (found in GWIC database). After the MBMG laboratory analyzed the samples and reported the 2016 results, each well owner was sent a letter that described the sampling objectives for the project and included a complete analytical report of their sample and comparison to the DEQ-7 standards. Although there were no exceedances for the five COC, there were some exceedances of the MCLs and SMCLs for other analytes. It should be noted that the SMCLs are based on the aesthetic quality of water, rather than a health standard. The MCL and SMCL exceedances for each well are given in table 7.2.2. There were no exceedances in the Rawlins (#50357) and West (156158) wells.

Table 7.2.2. Comparison of DEQ-7 MCLs and SMCLs with 2016 exceedances.

GWIC Id	Site Name	Exceeded Analyte	2016 Result	MCL	SMCL
174040	BOWLER	Fe	7.6	-	0.30 µg/L
174040	BOWLER	Mn	3.8	-	0.05 µg/L
174040	BOWLER	SO_4	297 mg/L	-	250 mg/L
269353	MILLER	SO_4	365 mg/L	-	250 mg/L
4819	REYNOLDS	SO_4	287 mg/L	-	250 mg/L
4819	REYNOLDS	NO_3	12.3 mg/L	10 mg/L	-
4819	REYNOLDS	U	44.4 µg/L	30 µg/L	-
171276	WHITE-HOUSE	U	47.3 µg/L	30 µg/L	-
255690	WHITE-WEST	U	58.8 µg/L	30 µg/L	-

A number of these wells are not used for drinking water, like the White-East and White-West wells (#171277 and 255690) and the Bowler well (#174040), which was previously used for drinking but is now only used for yard irrigation. The wells sampled during 2016 will continue to be sampled in the future, unless the site list changes after consultation with BSB, EPA, and DEQ.

SECTION 8.0 REVIEW OF THE BERKELEY PIT MODEL

The Berkeley Pit water-level model was updated based upon actual 2016 water-level measurements and HSB flows as measured at the weir upgradient of the water-treatment plant influent pond. The model incorporates monthly water-level rise information from July 1996 through December 2016.

Based upon the 2016 model update, the CWL of 5,410 ft is projected to be reached at the Anselmo Mine in **June 2023**, 4.1 months later than predicted in the 2015 model (February 2023). The model update includes the surface-water inputs from storm water diversions in the Kelley Mine area, the addition of sludge from the HSB water-treatment plant, and previous model filling rates adjusted for the diversion of HSB water away from the pit. The HSB drainage water that flowed into the pit from June 2000 through November 17, 2003 continues to be diverted to the HSB water-treatment plant for treatment and used in MR's mining operations. No major changes in additions or withdrawals of water were made from the Berkeley Pit during 2016, with the exception of the planned diversions of HSB water during concentrator and water-treatment plant maintenance activities that were discussed in section 3.5 and shown in table 3.5.1. The pit contained 46.7 billion gallons of water at the end of 2016, while the projected volume of water in June 2023 is 53.4 billion gallons.

The treatment technology and plant construction time frame for Berkeley Pit water are based upon the schedule listed in the EPA 1994 ROD, and included in the 2002 CD for the BMFOU (EPA, 1994). Based upon the current water-level projections, the submittal of a Technical Memorandum assessing the adequacy of the current treatment plant is due June 2019. Any necessary upgrades would have to be completed by June 2021 (fig. 8-1).

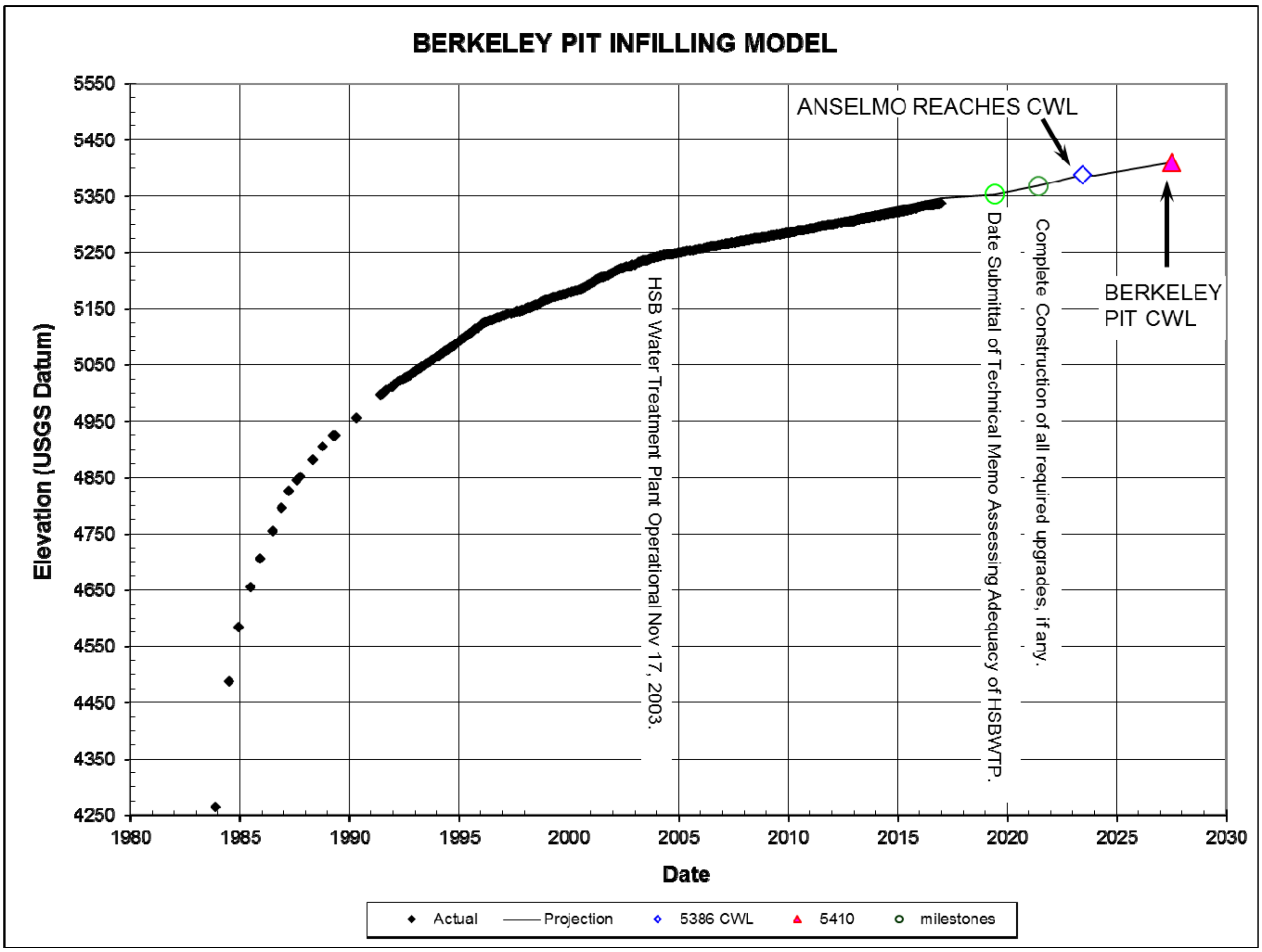


Figure 8-1. Projected Berkeley Pit filling rate & dates of treatment review & upgrades.

SECTION 9.0 RADIUM MONITORING

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

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

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

Section 9.1 Monitoring Results

Table 9.1.1 summarizes the data collected from 2003 to 2016. 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 exceedances of the MCL. Approximately 34% of the sites monitored have mean values for one or both isotopes that are greater than or equal to the specified MCL value of 5 pCi/L. Examination of the data over time for each site does not indicate any trends in radium activity.

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

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2016.

	Radium 226 (pCi/L) MCL[a] 5	**Radium 228 (pCi/L) MCL[a] 5**	**Ra 226+228 (pCi/L) MCL[a] *5***	**Radium 226 (pCi/L) MCL[a] 5**	**Radium 228 (pCi/L) MCL[a] 5**	**Ra 226+228 (pCi/L) MCL[a] 5**
		Anselmo Mine			**Kelley Mine**	
Mean	1.7	2.2	3.2	2.0	2.5	4.3
Min	1.1	1.1	1.1	1.5	1.1	2.3
Max	2.3	5.2	6.9	2.7	4.6	6.9
Number	16	16	16	17	17	17
		Pilot Butte Mine			**Steward Mine**	
Mean	1.7	0.0	1.7	1.9	3.5	4.8
Min	1.7	0.0	1.7	1.3	1.2	1.5
Max	1.7	0.0	1.7	2.5	8.8	10.1
Number	1	1	1	13	13	13
		Well A			**Well B**	
Mean	25.2	8.6	34.7	4.1	4.3	8.0
Min	0.9	1.7	21.4	3.0	1.3	3.1
Max	36.9	12.2	45.7	6.3	7.0	11.0
Number	29	29	29	31	31	31
		Well C			**Well D-2**	
Mean	30.6	19.5	50.1	23.5	17.2	40.7
Min	14.8	10.5	25.3	10.7	7.8	19.6
Max	43.6	30.7	73.8	33.1	26.0	53.3
Number	27	27	27	25	25	25
		Well E			**Well F**	
Mean	5.8	5.1	10.9	7.5	10.2	17.7
Min	4.7	2.8	8.2	5.5	7.7	13.8
Max	6.6	8.4	13.1	12.6	14.3	26.9
Number	7	7	7	9	9	9
		Well G			**Well J**	
Mean	13.8	8.9	22.7	39.9	154.6	194.5
Min	10.7	4.4	18.0	33.6	125.0	158.6
Max	17.5	11.9	28.5	47.3	198.0	242.6
Number	18	18	18	15	15	15

[a]EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards circular 7 2012

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2016 (con't.).

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] *5*	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		Parrot			**LP-8**	
Mean	3.2	4.2	6.8	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	14	14	14	5	5	5
		LP-9			**LP-10**	
Mean	7.3	8.4	14.4	0.7	2.3	3.3
Min	2.2	2.5	2.2	0.3	0.5	0.8
Max	29.1	23.9	47.0	5.3	5.0	9.3
Number	13	13	13	24	24	24
		LP-12			**LP-13**	
Mean	0.6	2.1	2.8	0.5	2.1	2.6
Min	0.2	0.9	1.3	0.2	0.4	1.2
Max	5.5	6.2	6.6	0.9	4.9	5.2
Number	27	27	27	27	27	27
		LP-14			**LP-15**	
Mean	0.3	1.8	2.2	0.3	2.3	2.8
Min	0.1	0.8	0.9	0.1	1.3	1.6
Max	0.8	4.6	4.8	0.6	5.6	6.2
Number	28	28	28	22	22	22
		LP-16			**LP-17**	
Mean	0.5	2.1	2.7	1.3	2.7	3.5
Min	0.2	0.4	0.1	0.6	1.1	1.5
Max	1.1	7.3	8.0	1.9	6.1	7.8
Number	31	31	31	19	19	19
		LP-17R			**AMC-05**	
Mean	1.3	2.9	4.3	6.5	4.4	10.5
Min	0.6	1.1	1.7	5.5	2.7	6.3
Max	1.8	6.1	7.8	8.2	5.8	12.2
Number	7	7	7	13	13	13

[a] EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards circular 7 2012

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2016 (con't.).

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		AMC-6			**AMC-8**	
Mean	0.6	1.8	2.8	0.5	1.6	2.2
Min	0.0	0.2	0.1	0.2	0.8	1.0
Max	5.5	5.4	6.8	1.3	2.9	3.7
Number	27	27	27	26	26	26
		AMC-12			**AMC-13**	
Mean	0.4	1.3	1.2	0.3	1.6	1.9
Min	0.1	0.2	0.3	0.2	1.3	1.5
Max	0.7	2.0	2.1	0.5	1.8	2.3
Number	13	13	13	3	3	3
		AMC-15			**GS-41D**	
Mean	0.6	1.9	2.4	2.1	3.5	4.9
Min	0.4	1.5	1.9	0.8	2.1	1.1
Max	0.7	2.3	2.9	3.7	5.2	8.9
Number	8	8	8	14	14	14
		GS-41S			**GS-44D**	
Mean	2.1	2.8	4.0	0.9	0.9	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	17	17	17	19	19	19
		GS-44S			**GS-46D**	
Mean	0.4	2.3	2.6	0.3	1.6	2.3
Min	0.2	1.4	1.6	0.2	1.0	2.2
Max	1.3	3.6	4.0	0.4	2.1	2.4
Number	16	16	16	16	16	16
		GS-46S			**BMF05-01**	
Mean	0.3	2.0	2.0	0.4	3.2	3.6
Min	0.0	2.0	2.0	0.1	1.9	2.1
Max	0.5	2.0	2.0	0.7	5.1	5.3
Number	15	15	14	21	21	21

[a] EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards circular 7 2012

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2016 (con't.).

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		BMF05-02			**BMF05-03**	
Mean	0.3	1.8	2.1	0.3	2.1	2.3
Min	0.1	-0.1	0.2	0.1	0.7	1.1
Max	0.5	5.7	6.0	0.4	4.4	4.4
Number	24	24	24	21	21	21
		BMF05-04			**BMF 96-1S**	
Mean	2.2	2.2	4.6	0.2	2.2	0.0
Min	0.4	1.2	1.9	0.2	2.2	0.0
Max	25.2	7.7	32.9	0.2	2.2	0.0
Number	20	20	20	2	2	2
		BMF96-4			**WCPW**	
Mean	0.2	0.6	0.6	2.2	1.3	2.9
Min	0.0	0.6	0.6	1.9	1.3	2.5
Max	0.4	0.6	0.6	2.5	1.3	3.2
Number	15	15	15	2	2	2
		Emma Mine			**Ophir Mine**	
Mean	2.3	2.5	4.2	0.5	1.5	2.0
Min	1.2	1.7	2.0	0.3	0.2	0.8
Max	3.4	4.0	6.4	0.8	2.2	2.9
Number	16	16	16	15	15	15
		Travona Mine			**Chester Steele**	
Mean	2.0	2.3	3.9	3.6	3.5	6.3
Min	1.2	1.2	1.2	1.1	1.8	1.7
Max	3.0	4.1	6.4	32.8	7.5	40.3
Number	12	12	12	17	17	17
		Marget Ann Mine			**Orphan Boy Mine**	
Mean	0.5	1.6	2.2	5.4	3.2	8.5
Min	0.3	1.3	1.9	3.6	1.7	6.2
Max	0.7	2.0	2.7	7.5	6.6	13.7
Number	8	8	8	23	23	23

[a] EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards circular 7 2012

Table 9.1.1 The mean, maximum, and minimum values of radium isotope activity collected in the BMFOU monitoring between 2003 and 2016 (con't.).

	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] *5*	Radium 226 (pCi/L) MCL[a] 5	Radium 228 (pCi/L) MCL[a] 5	Ra 226+228 (pCi/L) MCL[a] 5
		Marget Ann Mine			**Orphan Boy Mine**	
Mean	0.5	1.6	2.2	5.4	3.2	8.5
Min	0.3	1.3	1.9	3.6	1.7	6.2
Max	0.7	2.0	2.7	7.5	6.6	13.7
Number	8	8	8	23	23	23
		Tech Well			**Green Seep**	
Mean	2.1	3.0	3.9	2.7	2.3	3.4
Min	0.8	1.0	1.1	0.4	0.3	0.4
Max	7.5	4.9	12.4	16.0	7.9	23.9
Number	10	10	10	28	28	28
		BPit, surface			**HSB Weir**	
Mean	0.9	4.2	5.0	1.4	2.1	3.2
Min	0.4	1.6	2.0	0.3	1.1	2.0
Max	1.8	11.9	12.6	3.2	4.2	4.7
Number	16	16	16	21	21	21

[a] EPA Radionuclides Regulation Final Standard 2000

Montana Numeric Water Quality Standards circular 7 2012

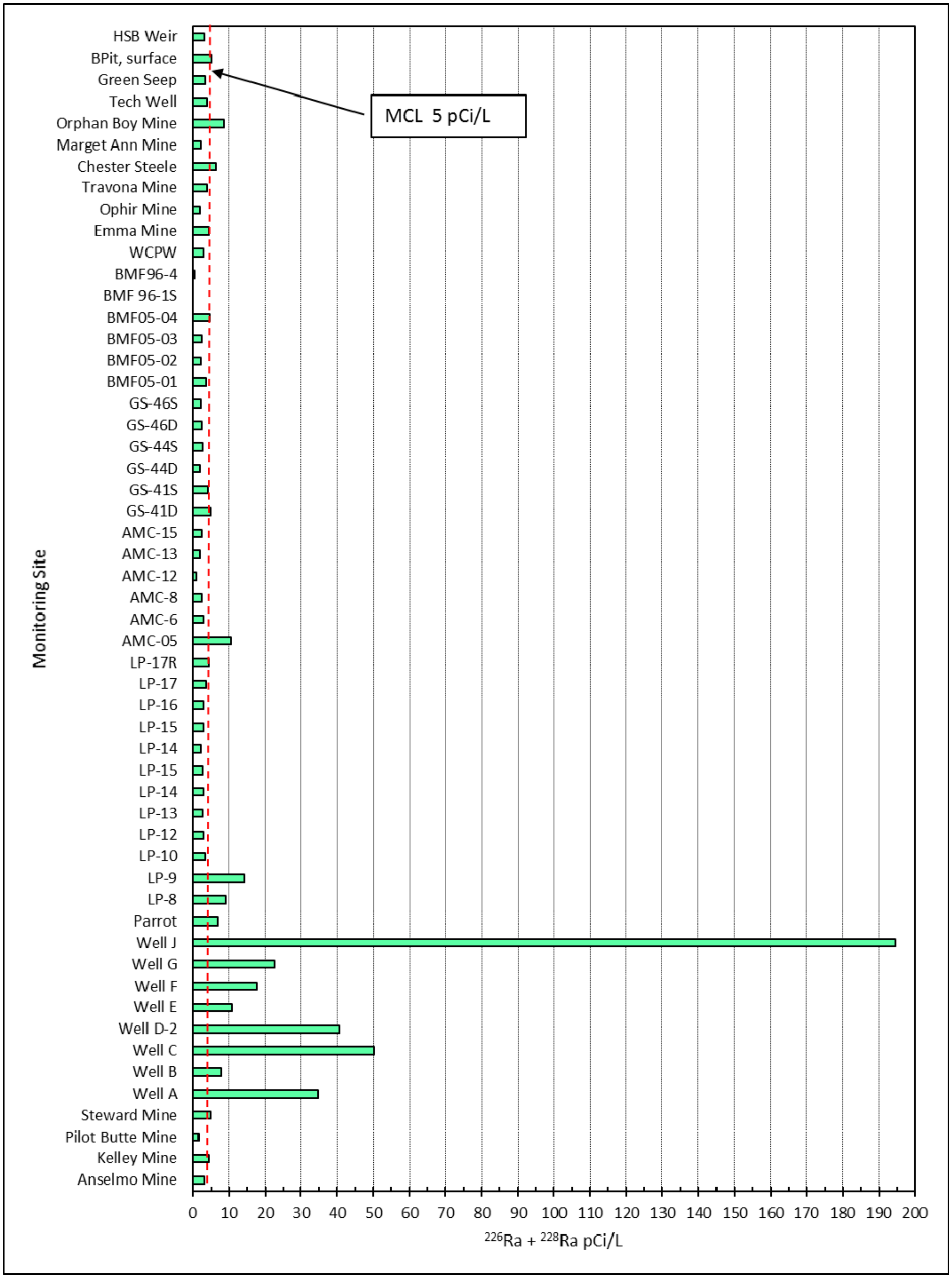


Figure 9-1. Graphical representation of combined radium isotope activity at the BMFOU monitoring sites.

SECTION 10.0 CONCLUSIONS AND SUMMARY

Water-level trends in the alluvial monitoring system within the active mine area were similar to those of 2016, with water levels increasing in a majority of the wells north of the Pittsmont Dump; this is most likely the result of continued leaching operations. This reverses the trend observed from 2004 and earlier and from 2006 through 2009 of water levels decreasing in a majority of the wells in this area. Water levels decreased in a majority of the wells south of the Pittsmont Dump as a result of dewatering activities undertaken by MR.

Seasonal precipitation events still 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 have a greater response to mining (including alluvial dewatering) and leaching operations than precipitation events.

Water levels in a majority of the alluvial monitoring wells located outside the mine area show a response to seasonal precipitation. The response time varies from immediate to a 2- to 3-month lag time. Water-level changes follow 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. A good example of this is the relationship between draining and filling of the MR concentrator Ecology Pond and water-level decreases and increases in several AMC wells. A water-level rise (response) was seen 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 a clay liner and recontoured for use during extreme precipitation run-off events or mill upsets to temporarily store water. Water levels continued to decline following the pond capping, adding additional support for the relationship between operational changes and water-level changes in the vicinity of the active mine area.

The water-level rises in the East Camp bedrock system are independent of precipitation, and result from the 1982 cessation of long-term mine dewatering activities. No notable precipitation influence was seen in any of the bedrock wells or underground mine water levels. However, continued diversion of HSB drainage water away from the Berkeley Pit did influence East Camp bedrock water levels; the water-level rise for 2016 (based upon wells A and G) was about 41 percent that of 2000–2003 when HSB water flowed into the pit. (The diversion of HSB water into the Berkeley Pit resulted in an additional 24 million gallons of water added to the pit volume; the diversion of HSB water to the pit was related to scheduled maintenance activities and is a normal part of yearly activities.) The average water-level rise in the bedrock system from 2004 to 2016 was 46 percent that from 2000 to 2003 during the mine suspension; this reduction in filling rate demonstrates the success of removing HSB water from the pit system in slowing the overall water-level rise in the bedrock system.

The date the East Camp bedrock system water level is predicted to reach the CWL elevation of 5,410 ft in the Anselmo Mine was changed from February 2023 to June 2023, 4.1 months later than predicted in 2015. The CWL at the Anselmo Mine is the anticipated compliance elevation that will keep the water-level elevation in the Berkeley Pit the lowest point in the East Camp bedrock system and ensure that all water in the historic underground mine system will continue to flow towards the Berkeley Pit.

Safety concerns about additional slumps in the Berkeley Pit resulted in the cancellation of 2016 water-quality sampling and vertical profiling of the pit water column. Limited sampling was conducted from the shore of the Berkeley Pit, with grab samples collected at a depth of approximately 1 ft below the water surface.

Pumping of groundwater in the West Camp System continues to control water levels; water levels were about 14 ft below the CWL the end of 2016.

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. As is the case for the past few years, the AMC-series wells show a wide variation and few trends with respect to the concentration of dissolved constituents. The LP-series wells show a continuation of recent trends in most wells for most constituents.

In several cases, chemistry data from the East Camp mines show a strong departure from historic trends, particularly with respect to iron concentrations. It now appears that instead of a sampling or analytical problem, the departure is likely a real change in the chemistry of water in the underground workings.

Recent data from the West Camp monitoring sites generally indicate little (or downward) change in dissolved constituents; concentrations remain below values observed during initial flooding. Arsenic concentrations exceed the MCL standard in the Travona and Emma mine sample results, while radium exceeds the MCL in the Emma Mine and Chester Steele Park well. Iron and manganese exceed the SMCL standards in all three mine water-quality datasets. Water-quality concentrations from monitoring well BMF96-4 remain low and do not exceed any standards.

Monitoring of domestic wells within the CGWA showed no water-quality exceedances for the five COCs; however, several sites were found to have elevated concentrations of such things as iron and uranium. These elevated concentrations are most likely due to local geologic conditions and not related to rising water in the bedrock mine system.

Results in 2016 continue to show that the current water-level and water-quality monitoring program is adequate for confirming that contaminated bedrock groundwater is flowing into the Berkeley Pit, and that West Camp water levels are being sufficiently controlled by West Camp pumping operations. These are two of the main environmental concerns associated with the flooding of Butte's historic underground mines and the Berkeley Pit.

ACKNOWLEDGMENTS

The information contained in this report represents the work of many companies and agencies during the past 34 years. Numerous individuals were responsible for actual data collection prior to the 2002 consent decree; their dedication and creativity in monitoring and sampling of mine waters provided the information that all future work and evaluations relied upon.

The State of Montana, Department of Environmental Quality, and the U.S. Environmental Protection Agency have provided funding for the MBMG to conduct monitoring and sampling activities and preserve continuity between various studies. This support has been invaluable, as has been their realization that flexibility is needed in the monitoring program, allowing modifications in monitoring as conditions change.

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

Special recognition is given to Connie Thomson, Matt Berzel, Jeremy Harwood, and Cathy McKillips, MBMG, for assisting with the preparation of this report. Editing by Susan Barth, MBMG.

Errors and omissions remain the authors’ responsibility.

REFERENCES

AccuWeather 2017, Online database www.accuweather.com [Accessed January 2017].

ARCO, 1992, Clark Fork River Superfund Site Investigations Standard Operating Procedures.

Burns, G., 1994, A review of the geology and historic production of the Butte District: Presented at the 100th Annual Northwest Mining Association, Spokane, Wash., November 29–December 2, 1994.

Daly, W.B., and Berrien, C.L., 1923, Mining methods and installations of the Anaconda Copper Mining Co. at Butte, Montana, 1922 Meeting: Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. LXVIII, 1923.

Duaime, T.E., Metesh, J.J., Kerschen, M.D., and Dunstan, C.B., 1998, The flooding of Butte's underground mines and Berkeley Pit: 15 Years of water-level monitoring (1982–1997): MBMG Open-File Report 376.

Duaime, T.E., and Metesh, J.J., 2000, The flooding of Butte's underground mines and Berkeley Pit, Butte Mine Flooding operable unit annual water-level update, 1998–1999: MBMG Open-File Report 410.

Duaime, T.E., and Metesh, J.J., 2001, The flooding of Butte's underground mines and Berkeley Pit, Butte Mine Flooding operable unit annual water-level update, 1999–2000: MBMG Open-File Report 435.

Duaime, T.E., and Metesh, J.J., 2003, Twenty years of water-level and water-quality sampling Butte's underground mines and Berkeley Pit, Butte, Montana 1982–2001: MBMG Open-File Report 473.

Duaime, T.E., and Metesh, J.J., 2004, 2002 Update of water-level monitoring and water-quality sampling Butte's underground mines and Berkeley Pit, Butte, Montana 1982–2002: MBMG Open-File Report 489.

Duaime, T.E., and Metesh, J.J., 2005, 2003 Update of water-level monitoring and water-quality sampling Butte's underground mines and Berkeley Pit, Butte, Montana 1982–2003: MBMG Open-File Report 518.

Duaime, T.E., and Metesh, J.J., 2005, 2004 Consent Decree update water-level monitoring and water-quality sampling Butte's underground mines and Berkeley Pit, Butte, Montana: MBMG Open-File Report 527.

Duaime, T.E., and Metesh, J.J., 2006, 2005 Consent Decree update water-level monitoring and water-quality sampling Butte's underground mines and Berkeley Pit, Butte, Montana: MBMG Open-File Report 549.

Duaime, T.E., and Tucci, N.J., 2007, History of flooding of the Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2006 Consent Decree update, Butte, Montana, 1982–2006: MBMG Open-File Report 566.

Duaime, T.E., and Tucci, N.J., 2008, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2007 Consent Decree update, Butte, Montana, 1982–2007: MBMG Open-File Report 577.

Duaime, T.E., and Tucci, N.J., 2009, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2008 Consent Decree update, Butte, Montana, 1982–2008: MBMG Open-File Report 589.

Duaime, T.E., and Tucci, N.J., 2011, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2009 Consent Decree update, Butte, Montana, 1982–2009: MBMG Open-File Report 599.

Duaime, T.E., and Tucci, N.J., 2011, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2010 Consent Decree update, Butte, Montana, 1982–2010: MBMG Open-File Report 609.

Duaime, T.E., and Tucci, N.J., 2013, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2012 Consent Decree update, Butte, Montana, 1982–2012: MBMG Open-File Report 641.

Duaime, T.E., and Tucci, N.J., 2015, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2014 Consent Decree update, Butte, Montana, 1982–2014: MBMG Open-File Report 661.

Duaime, T.E., Icopini, G. A., McGrath, S. F. and Thale, P. R., 2016, Butte underground mines and Berkeley Pit, water-level monitoring and water-quality sampling, 2015 Consent Decree update, Butte, Montana, 1982–2015: MBMG Open-File Report 676.

DNRC Final Order, 2009, Petition for Butte Alluvial and Bedrock Controlled Ground Water Area, no. 76G-30043832.

EPA Record of Decision, 1994, Butte Mine Flooding operable unit, Silver Bow Creek/Butte area NPL site, Butte, Montana, September 29, 1994, Three Volumes.

EPA Consent Decree, 2002, Butte Mine Flooding Operable Unit Consent Decree-02-35-BU-SEH.

Gammons, C.H., and Duaime, T.E., 2006, Long term changes in the limnology and geochemistry of the Berkeley Pit Lake, Butte, Montana, mine water and the environment, vol. 25, no. 2, June 2006.

GWIC, 2007, Montana Bureau of Mines and Geology, Ground Water Information Center, online database, 2007.

Metesh, J.J., and Duaime, T.E., 2000, The flooding of Butte's underground mines and Berkeley Pit, 18 years of water-quality monitoring (1982–1999): MBMG Open-File Report 409.

Metesh, J.J., and Duaime, T.E., 2002, The flooding of Butte's underground mines and Berkeley Pit, water-quality monitoring through 2000: MBMG Open-File Report 456.

Miller, R.N., 1978, Production history of the Butte District and geological function, past and present; Guidebook for the Butte Field Meeting of Society of Economic Geologists, August 18–21, 1973, 2nd printing.

Montana Bureau of Mines and Geology, 2002, Butte Mine Flooding Operable Unit, sampling and analysis plan, EPA Dockett No. CERCLA—VIII-96-19, Butte, Mont., August 2002, updated April 2011.

Montana Bureau of Mines and Geology, 2014, Draft West Camp critical water-level review, data summary report, 2013–2014.

Montana Department of Environmental Quality, 2012, Montana Numeric Water Quality Standards, DEQ Circular-7.

National Oceanographic and Atmospheric Administration (NOAA), 1999, Butte Climate Summary.

National Nuclear Data Center, Brookhaven National Laboratory, http://www.nndc.bnl.gov/nudat2/

Radionuclides Rule, 66 FR 76708, December 7, 2000, Vol. 65, No. 236.

Rozanski, K., Araguás-Araguás, L., and Gonfiantini, R., 1993, Isotopic patterns in modern global precipitation, *in* Continental isotope indicators of climate: American Geophysical Union Monograph Series, v. 78.

Sales, R.H., 1914, Ore deposits at Butte, Montana, American Institute of Mining and Metallurgical Engineers: Transactions, v. 46, p. 3–106.

Spindler, J.C., 1977, The clean-up of Silver Bow Creek: Mining Congress Journal, June 1977.

Tilling, R.I., and Gottfried, David, 1969, Distribution of thorium, uranium and potassium in igneous rocks of the Boulder batholith region, Montana, and its bearing on radiogenic heat production and heat flow: U.S. Geol. Survey Prof. Paper 614-E, 29 p.

Vinson, D.S., 2011, Radium isotope geochemistry in groundwater systems: The role of environmental factors, Ph.D. Thesis in the Division of Earth and Ocean Sciences, Duke University.