Butte Mine Flooding Operable Unit

Water-Level Monitoring and Water-Quality Sampling

2011 Consent Decree Update

Butte, Montana

1982–2011

prepared for

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

November 2012

Prepared by

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1300 West Park Street

Butte, MT 59701-8997

Contract No. 400022-TO-35

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Executive Summary

The Record of Decision and Consent Decree for the Butte Mine Flooding Operable Unit stipulates that the Montana Bureau of Mines and Geology (MBMG) perform the specified monitoring and sampling for the site and annually prepare an update of data collected from the Post Remedial Investigation/Feasibility Study and Consent Decree monitoring program. The report is to incorporate the most recent year's data with previously collected information. This report presents 2011 data, integrated with data collected since 1982, when the Anaconda Company suspended underground mine dewatering and mining in the Berkeley Pit.

Major 2011 observations and developments included:

1. Updating the annual Berkeley Pit model to account for continued diversion of Horseshoe Bend drainage water away from the Pit, discharge of sludge from the treatment plant into the Pit, and diversion of storm water flow from the Butte Hill into the Pit. The projected date when the 5,410-ft water-level elevation would be reached at the Anselmo Mine was modified from February 2023 (2010 Report) to April 2023, a change of -0.16 years (-2 months);
2. Continued West Camp pumping to maintain the groundwater level below the 5,435-ft elevation, stipulated in the 1994 Record of Decision. Upgrades to the pump station occurred between mid-July 2011 and the end of the year, resulting in intermittent pumping. The volume of water pumped in 2011 was within 1 percent of that in 2010 (252.9 vs. 253.5 acre-ft). Although the volume pumped during 2011 was very near that pumped in 2010, water levels in 2011 decreased between 4 ft and 4.25 ft throughout the West Camp underground system; and
3. Observed water-quality variations in East Camp alluvial well LP-16 (sampled once) showed a moderate increase in sulfate, copper, and zinc. Metal concentrations remain elevated in LP-17 (sampled twice); however, concentrations decreased from 2009–2010 levels. Nitrate concentrations in LP-17 decreased by 30 percent in 2011 but remain four times the recommended standard.

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

Monitoring and sampling activities performed during 2011 reflect the long-term program outlined in the 2002 Consent Decree. Since the Consent Decree was implemented, some monitoring sites in the early monitoring program have been dropped, while others have been added. The MBMG has made some minor organizational changes in this year's report in an effort to make it more readable.

Previous mine flooding operable unit reports are:

Report Number	Authors	Year published
MBMG 376	Duaime, Metesh, Kerschen, Dunstan	1998
MBMG 409	Metesh, Duaime	2000
MBMG 410	Duaime, Metesh	2000
MBMG 435	Duaime, Metesh	2001
MBMG 456	Metesh, Duaime	2002
MBMG 473	Duaime, Metesh	2003
MBMG 489	Duaime, Metesh	2004
MBMG 518	Duaime, Metesh	2005
MBMG 527	Duaime, Metesh	2005
MBMG 549	Duaime, Metesh	2006
MBMG 566	Duaime, Tucci	2007
MBMG 577	Duaime, Tucci	2008
MBMG 589	Duaime, Tucci	2009
MBMG 599	Duaime, Tucci	2011
MBMG 609	Duaime, Tucci	2011

List of acronyms used in text

AMC	Anaconda Mining Company
ARCO	Atlantic Richfield Company
BP/ARCO	British Petroleum/Atlantic Richfield Company
BMFOU	Butte Mine Flooding Operable Unit
CD	Consent Decree
CWL	Critical Water Level
DEQ	Montana Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
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
MR	Montana Resources
MSL	Mean Sea Level
ORP	Oxidation-Reduction Potential
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SC	Specific Conductance at 25^{o}C
SMCL	Secondary Maximum Contaminant Level

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SECTION 1.0 SITE BACKGROUND

Butte has a long history of mining, dating back to 1864 with the development of gold placers in Missoula and Dublin gulches and along Silver Bow Creek (Miller, 1978). Placer mining was short-lived and quickly followed in 1866 by the development of silver mines (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 groundwater to central pump stations to improve efficiency (Daly and Berrien, 1923). The Anaconda Copper Mining Company, which would eventually control a majority of the underground mines, began interconnecting selected mine levels for draining groundwater 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 and 1-2). This acidic and highly mineralized water necessitated specialized pumps and piping. 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 Silver Bow Creek. This practice of discharging untreated, acidic, metal-laden water to Silver Bow Creek continued until the late 1950s, at which time the Anaconda Company began adding lime to the water to raise the pH and reduce its mineral content (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 for two reasons: to reduce the amount of water pumped from the underground workings and to lessen the required amount of fresh air brought into the mines for worker safety.

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

5 and 1-6 compare Butte's land-surface topography between 1904 and 2012 through the use of digital elevation models. The impacts of open-pit mining and associated waste facilities is obvious north and northeast of the Berkeley Pit (fig. 1-6).

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

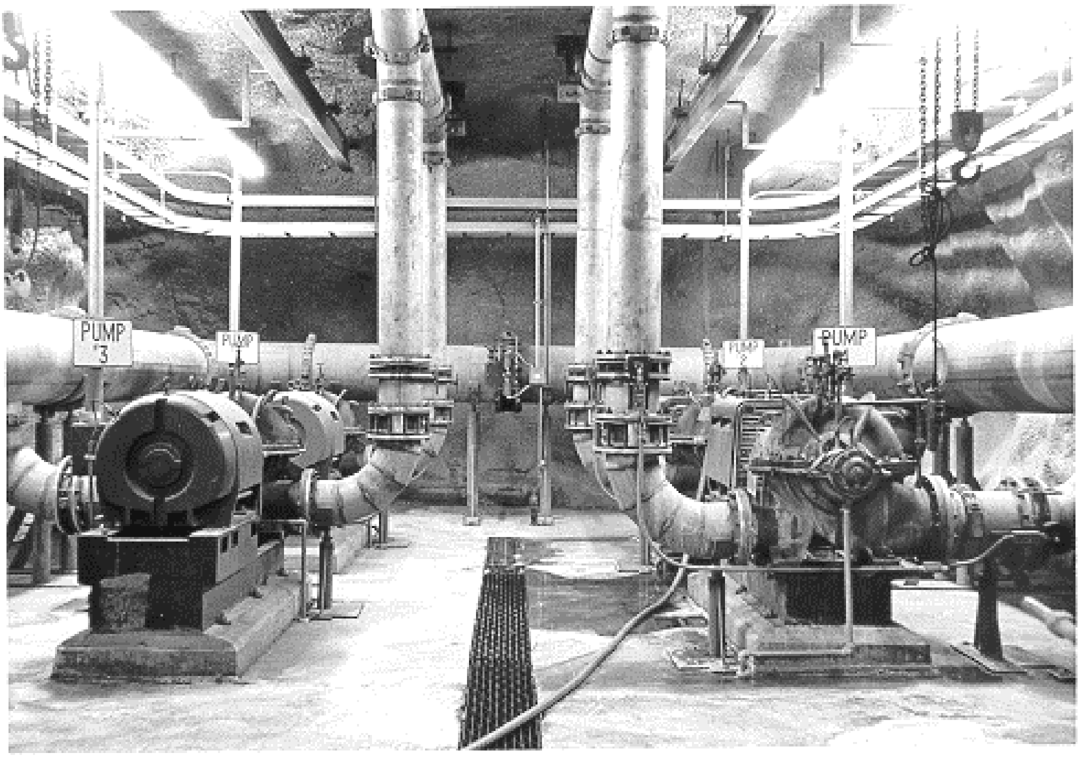


Figure 1-2. Kelley Mine pump station, 3,900-ft level. (Photo courtesy World Museum of Mining, Butte, MT.)

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. Map showing location of some underground mines engulfed by development and expansion of the Berkeley Pit.

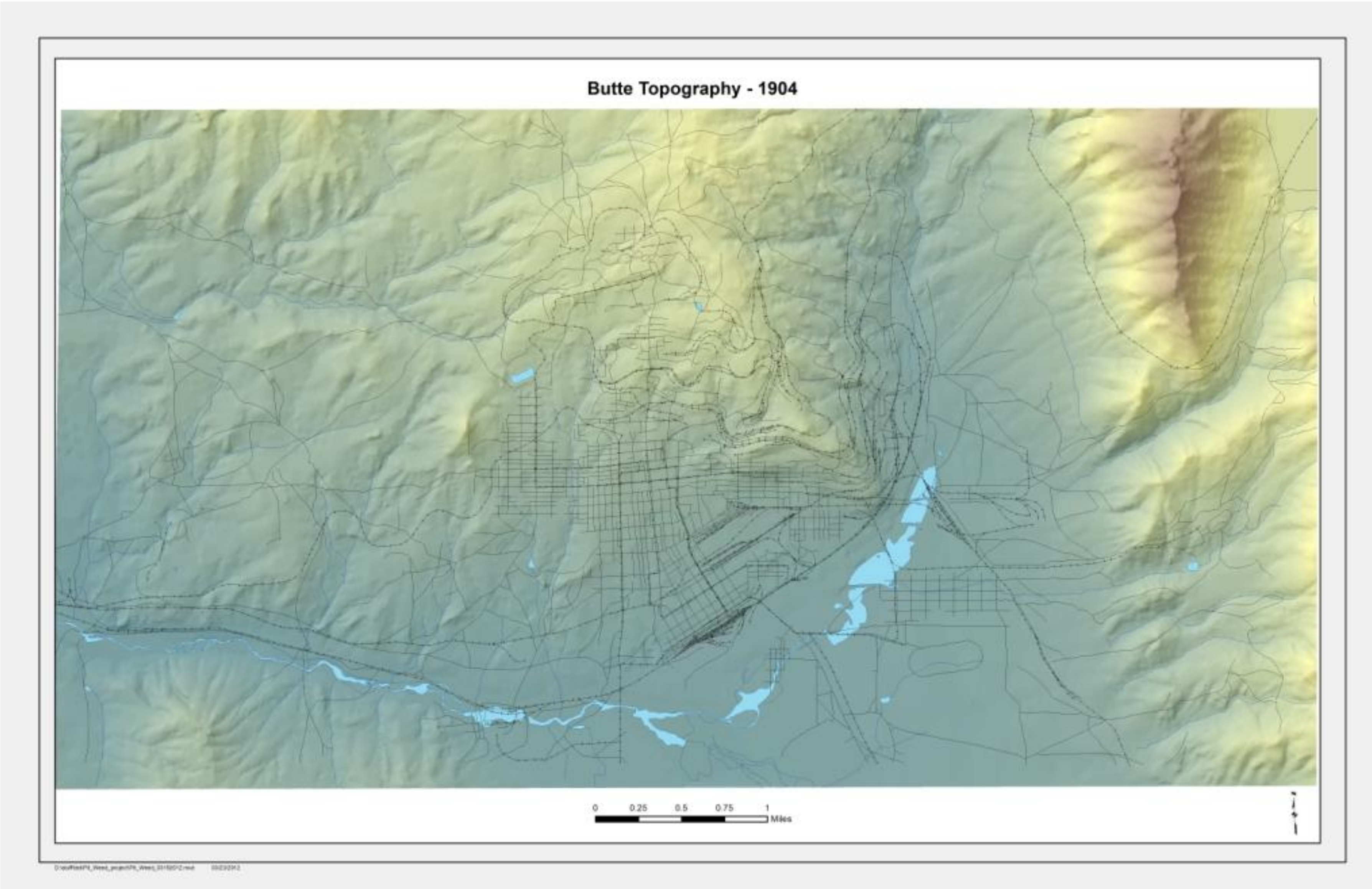


Figure 1-5. Digital elevation model showing Butte land-surface topography, 1904.

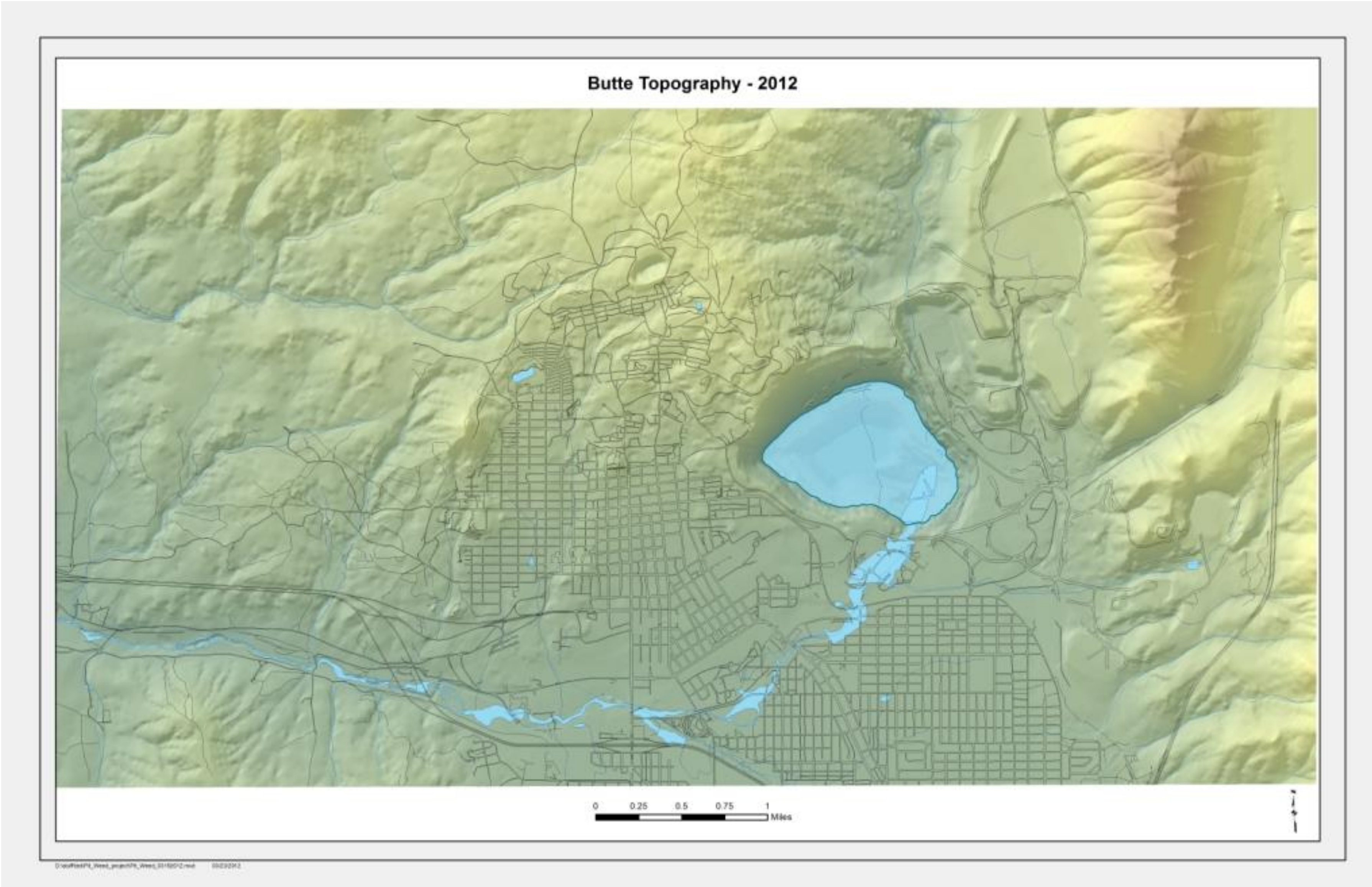


Figure 1-6. Digital elevation model showing Butte land-surface topography, 2012.

Active underground mining continued in the Kelley and Steward Mines until 1975 (Burns, 1994); however, the Anaconda Company continued to operate the underground pumping system, which not only kept the mines dewatered, but also did the same for the Berkeley Pit. When the Anaconda Company discontinued selective underground vein mining in 1977, they eventually allowed the lowermost mine workings to flood up to just below the 3,900-level pump station.

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 continued to operate until shortly after the Anaconda Company's announcement in April 1982 that they were going to shut down the the Kelley Mine pump station, which had been lifting up to 5,000 gallons per minute (gpm) of water to the land surface. 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). Montana Resources 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, including the Berkeley Pit, Continental Pit, Weed Concentrator, cessation of underground mining, and ancillary activities between 1995 and 2004.

Table 1.0.1 Timeline of selected activities related to Butte mining operations, 1955–2004.

Date	Activity
July 1, 1955	Ore production from Berkeley Pit begins.
May 1963	Weed Concentrator came online. Yankee Doodle Tailings Pond put into operation to receive concentrator tailings discharge.
1966–1967	Kelley Mine central pump station (3900 level) constructed, pump station moved from High Ore Mine 3800 level.
1975	Selective vein mining stopped in underground mines.
1977	Underground mine levels below Kelley 3900 level allowed to flood.
January 1, 1980	East Berkeley Pit started. (Renamed Continental Pit in 1986 by Montana Resources.)
April 22, 1982	Kelley Mine central pump station shut down. Flooding of underground workings above 3900 level begins.
May 1982	Mining ceases in Berkeley Pit.
Summer 1982	Horseshoe Bend drainage water diverted to Berkeley Pit.
September 1982	Anaconda Company goes to zero discharge from mining operations. Clean water diverted around mine property via Clear Water Ditch to SBC at Texas Ave.
June 30, 1983	Mining in Continental Pit suspended.
Summer 1983	Leach pad ponds breached and water diverted to Berkeley Pit. Water from Continental Pit and Clear Water Ditch diverted to Berkeley Pit.
December 1985	Anaconda Co. sells Butte Mining District properties to Dennis Washington, who forms Montana Resources (MR).
July 1986	MR begins mining in Continental Pit.
	MR begins leaching operations.
April 1996	Horseshoe Bend drainage water diverted away from Berkeley Pit. Water is pumped to Yankee Doodle Tailings Dam and mixed with concentrator tailings.
1998	MR deactivates leach pads.
August 1998	MR begins pumping of water from Berkeley Pit for copper recovery at precipitation plant.
September 29, 1998	Major landslide along southeast corner of Berkeley Pit results in 1.3 million cubic yards of material entering the pit. Water levels in Berkeley Pit and underground mines rise an additional 2.5 ft as a result.
December 1999	MR lowers intake line for copper recovery process to improve copper recovery.
June 30, 2000	MR suspends mining operations due to high energy costs; Horseshoe Bend drainage water diverted back into Berkeley Pit.
November 2003	MR resumes mining operations.
November 17, 2003	Horseshoe Bend water treatment plant comes online. Horseshoe Bend drainage water diverted away from Berkeley Pit.
January 2004	MR restarts Berkeley Pit copper recovery project.
2004	MR resumes limited leaching operations.

Section 1.1 Introduction

The Anaconda Company announced on April 23, 1982 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, Anaconda 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 water 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, that can be broken down into the following categories:

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 this monitoring network. The current monitoring program includes 63 monitoring wells, 11 mine shafts, and 4 surface-water sites. The Berkeley Pit and Continental Pit, as appropriate, are also part of the monitoring network. The Consent Decree monitoring network can be grouped into the following categories:

1) East Camp bedrock wells—13;
2) East Camp mines—6;
3) East Camp alluvial wells within the active mine area—22;
4) East Camp alluvial wells outside the active mine area—16;
5) Bedrock wells outside active mine area—4;
6) West Camp mines—3;
7) West Camp wells—6;
8) Outer Camp mines—2; and
9) Outer Camp wells—2.

The 1994 ROD and 2002 CD established separate critical maximum water levels (CWLs) for the East Camp and West Camp bedrock systems, while 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), NAVD 29 datum] at any of the eight compliance points, while in the West Camp bedrock system, the maximum water level cannot exceed an elevation of 5,435 ft msl (NAVD 29 datum) at well BMF96-1D. The compliance points in the East Camp consist of the following mine shafts and bedrock monitoring wells:

1) Anselmo
2) Granite Mountain
3) Kelley
4) Pilot Butte
5) Belmont Well #2

6) Bedrock Well A

7) Bedrock Well C

8) Bedrock Well G

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 Significance Differences" document to see the entire scope of activities addressed in the CD and how they differ from items addressed in 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 was included in the CD. The monitoring performed by the MBMG is under the direction of DEQ and EPA.

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. In 2011 more than 85 percent of the underground mine workings are flooded. The upper 12 percent of underground workings will never be flooded, as they are at elevations above the specified CWL; therefore less than <u>3 percent</u> of the underground workings remain to be flooded.

This document is the 16th BMFOU report and summarizes 30 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 Report376 for additional detail and information.

The MBMG continued monitoring activities in 2011 in the East Camp, West Camp, and Outer Camp systems (fig. 1-7). 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 were hydraulically isolated many decades ago. The hydraulic separation has allowed Outer Camp System water levels to return to or approach pre-mining conditions.

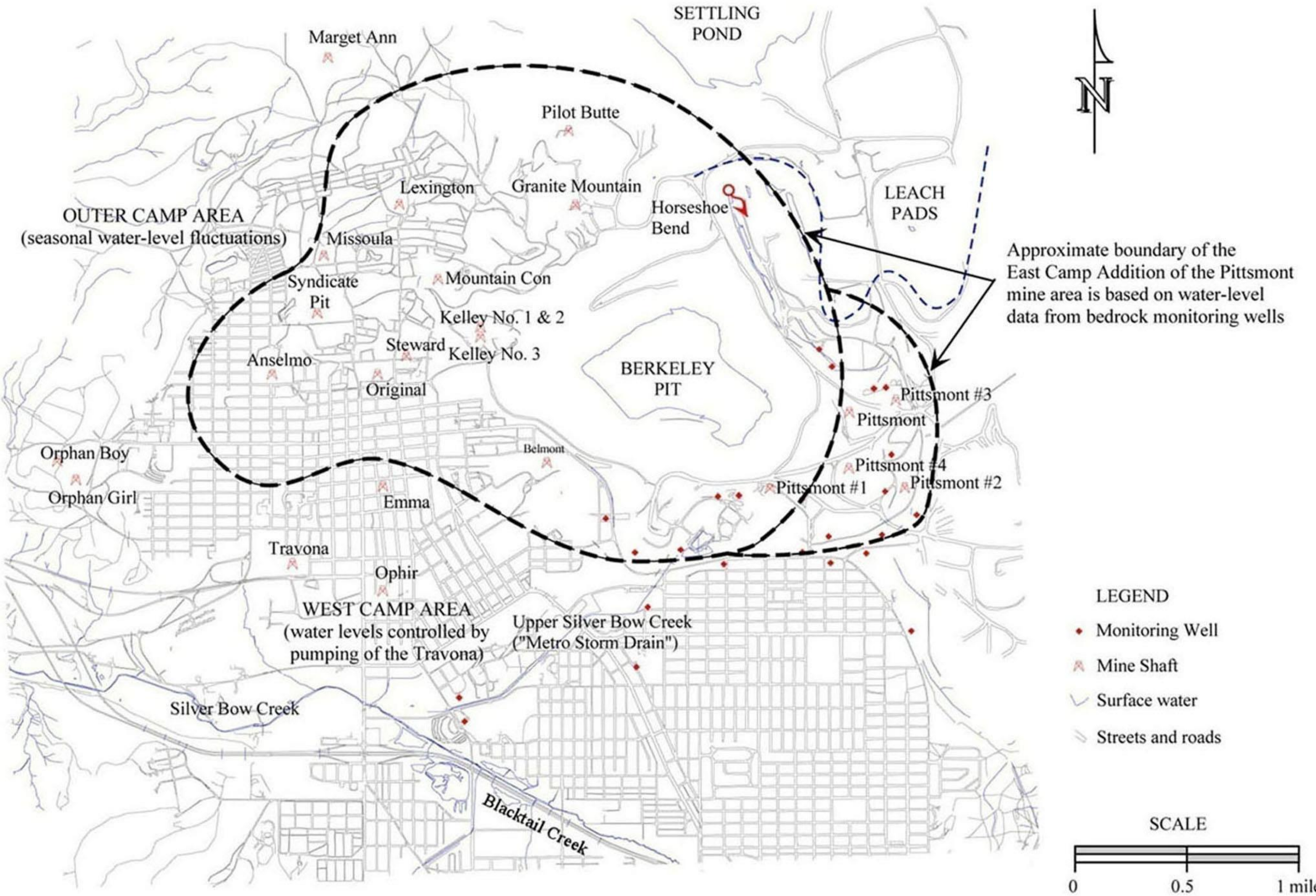


Figure 1-7. The mines of the Butte Hill are currently considered in three groups: the East Camp, which includes the Berkeley Pit and the area to the east; the West Camp to the southwest; and the Outer Camp, which includes the outlying mines.

Section 1.2 Notable 2011 activities and water-level and water-quality observations

For the third consecutive year nothing significant occurred: i.e., earthquake, landslide, or mine exploration activity that impacted water levels or water quality throughout the monitoring network. The main activities and observations for 2011 are listed below:

(1) Montana Resources (MR) continued mining and milling operations throughout 2011.

(2) Water from East Camp alluvial well LP-16 contained modest increases in sulfate, copper, and zinc concentrations when compared to samples collected in prior years.

(3) Water from East Camp alluvial well LP-17 contained decreased concentrations of metals when compared to 2009–2010 values; however, metal concentrations remain considerably higher than pre-2003 levels.

(4) West Camp pumping was intermittent between July and December due to construction upgrades at the pump station as well as the Butte Treatment Lagoons, where West Camp water is sent for treatment. Water levels decreased in West Camp mines.

Section 1.3 Precipitation trends

Total precipitation for 2011 was 12.46 in, compared to 14.86 in in 2010 (16 percent decrease) (NOAA, 1999; AccuWeather.com, 2012). Precipitation totals have been below average for 10 of the past 13 years and 18 of the last 30 years. The 2011 precipitation total was a decrease of two percent below the long-term average of 12.72 in. Table 1.3.1 contains monthly precipitation statistics from 1982 through 2011, while figure 1-8 shows this information graphically in comparison to the long-term annual average. Overall, precipitation totals since flooding of the mines began are very similar to the long-term average (12.59 in vs. 12.72 in). Figure 1-9 shows departure from normal precipitation from 1895 through 2011.

Table 1.3.1 Butte precipitation statistics, 1982–2011.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AVERAGE
Mean	0.46	0.43	0.74	1.10	1.98	2.33	1.35	1.34	0.99	0.78	0.58	0.51	12.59
Std. Dev.	0.32	0.28	0.40	0.68	0.78	1.20	1.05	0.88	0.68	0.55	0.38	0.37	2.90
Maximum	1.40	1.26	1.84	3.20	3.88	4.62	4.18	3.10	2.56	2.21	1.50	1.99	19.96
Minimum	0.09	0.11	0.11	0.00	0.81	0.50	0.00	0.09	0.07	0.00	0.07	0.01	8.32
Number of years precipitation greater than mean													12
Number of years precipitation less than mean													18

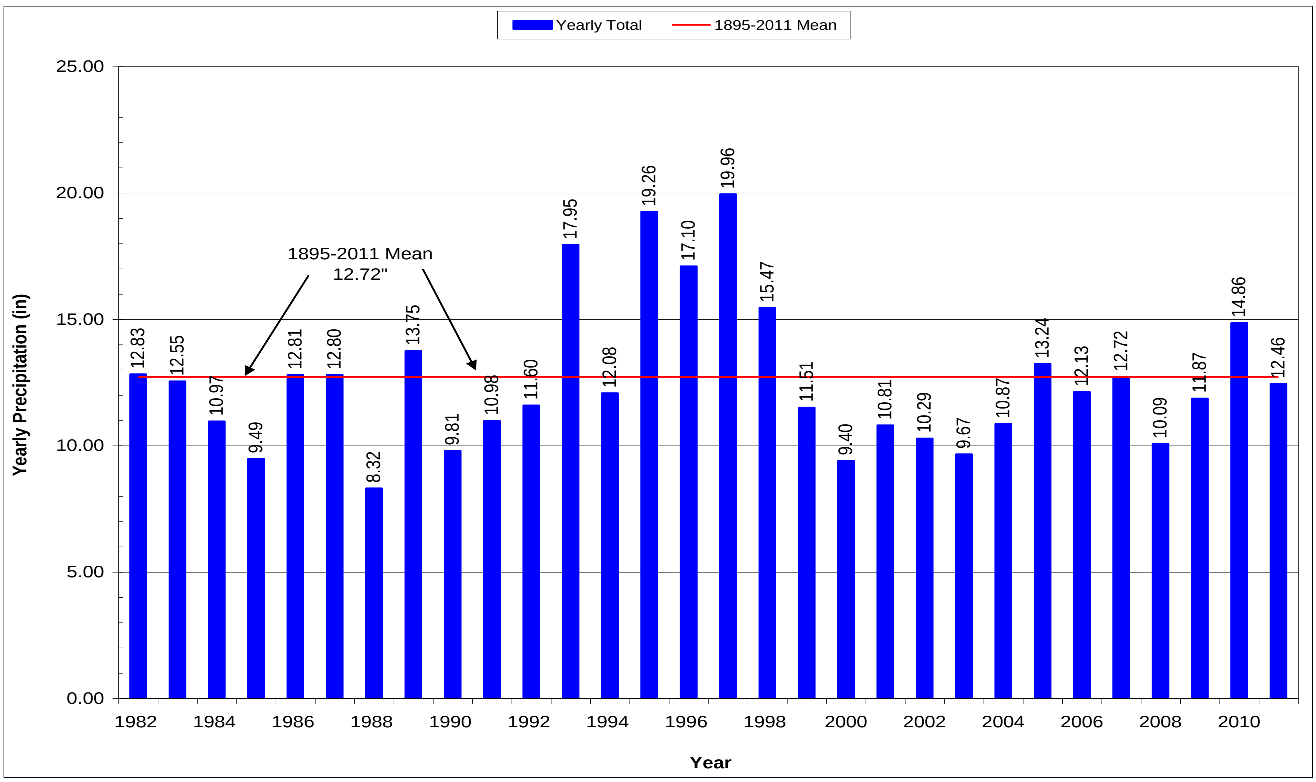


Figure 1-8. Yearly precipitation totals 1982–2011, showing 1895–2011 mean.

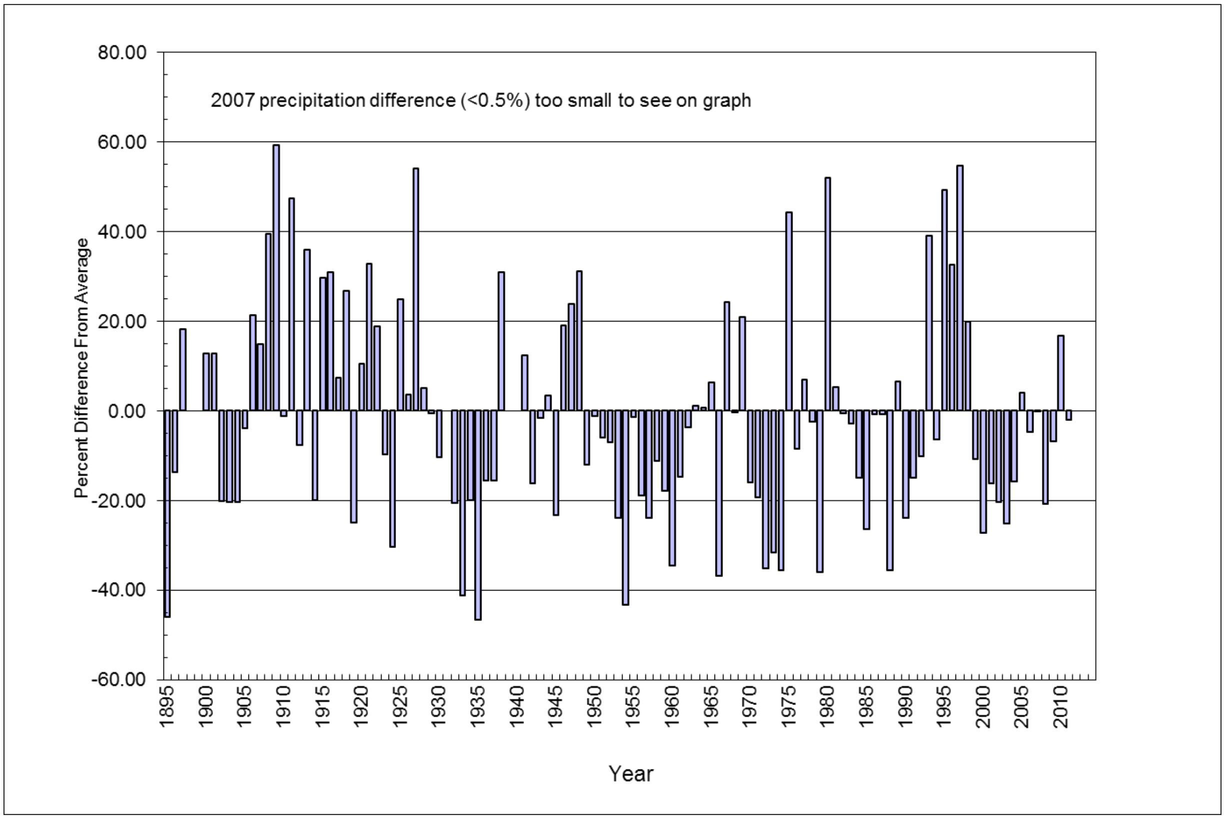


Figure 1-9. Percent precipitation variation from normal, 1895–2011.

SECTION 2.0 EAST CAMP SYSTEM

The East Camp is composed of that portion of the bedrock aquifer affected by underground mine dewatering in 1982 and the overlying shallow alluvial aquifer. The shallow East Camp alluvial system includes the alluvial aquifer within the active mine area and a portion of the alluvial aquifer, primarily south and outside the active mine area (fig. 2-1). 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. 2-2). It also includes the bedrock system adjacent to the East Camp mines and the shallow East Camp alluvial system.

Section 2.1 East Camp Alluvial System

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

For each series discussed below, water-level elevations and monthly precipitation are shown on hydrographs for selected wells. Water-quality results are shown and discussed for any sampled wells, but unlike the water-level monitoring program where monthly data are collected from all wells, water-quality samples are collected one to two times annually at selected wells.

Four new alluvial monitoring wells were installed within the East Camp system during 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 BMF05-series wells are in areas where data gaps existed and are equipped with transducers for increased water-level data collection frequency. The BMF05-series wells are discussed with the GS-series wells. Water-quality samples from BMF05 wells were collected quarterly through 2007 (to help establish baseline conditions) and and have been collected semi-annually since.

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

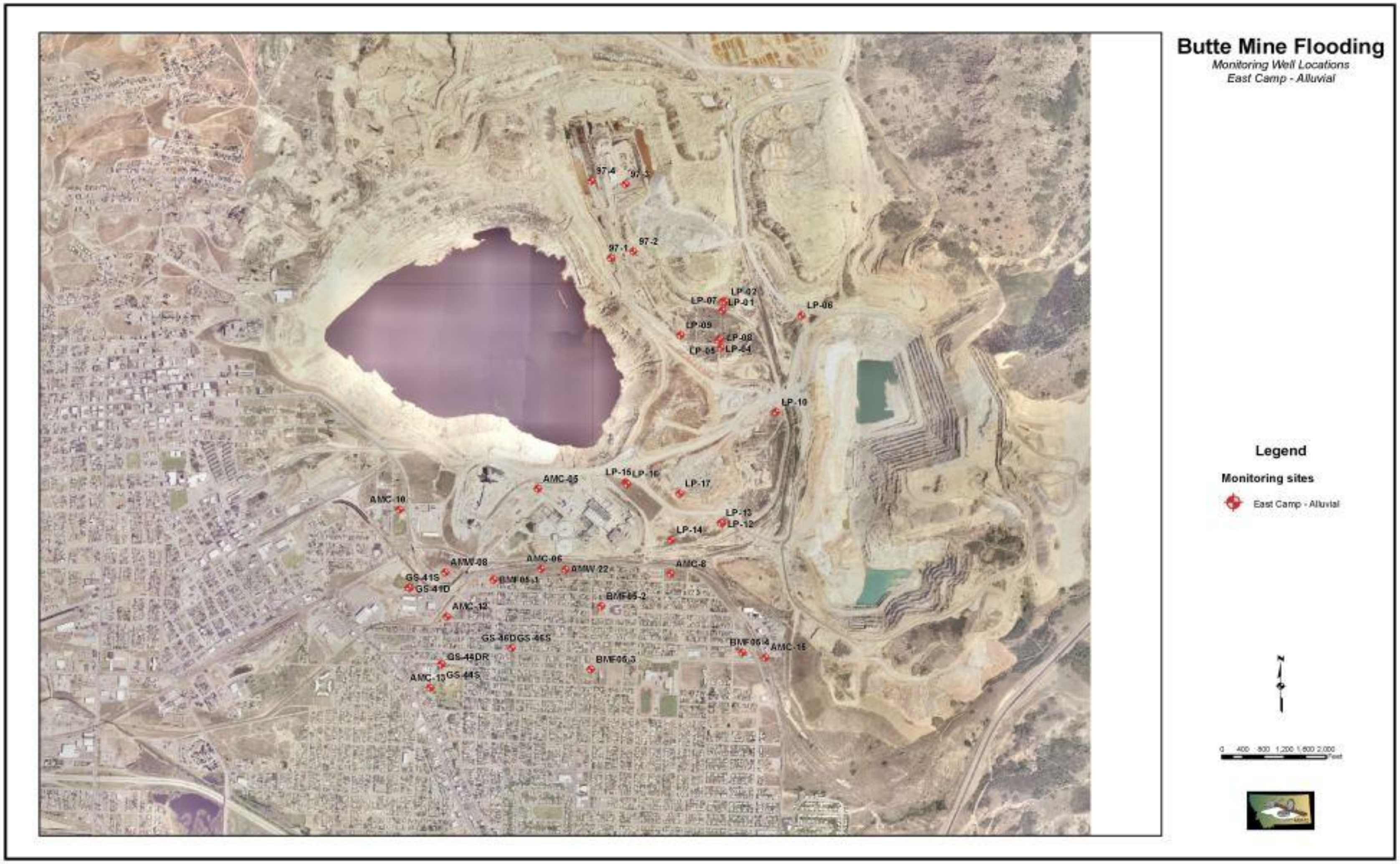


Figure 2-1. East Camp alluvial monitoring wells.

Section 2.1.1 AMC-Series Wells

The locations of the Anaconda Mining Company (AMC) wells are shown in figure 2-3; table 2.1.1.1 lists the annual water-level changes for these sites. Water levels increased in six of seven AMC series wells for 2011, but AMC-10 remained dry, as it has been since its installation in 1983. The general increase in water levels during 2011 continues a trend beginning in 2008. Water levels had a net decline during the first 20 years of monitoring; however, water levels in six of seven of the wells have risen during 7 of the past 9 years. Over the entire record, there are net water-level declines of 2 to more than 25 ft in six wells, with one well dry since its installation.

Well AMC-5 is located within the active mine area; wells AMC-6 and AMC-8 are located south of the active mine area and the Butte Concentrator (fig. 2-3). Well AMC-12 is located southwest of these wells. Hydrographs for wells AMC-5, AMC-12 (fig. 2-4), and AMC-6 and AMC-8 (fig. 2-5) 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. 2-3). The Emergency (Dredge) Pond was reflooded in fall 2003 prior to MR's start-up. The water-level trend in AMC-5 for 2003–2005 shown in figure 2-4 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. The water level in well AMC-5 began to rise in the summer of 2006 following increased precipitation in April and June. The water level continued to rise throughout the remainder of the summer before leveling off in the fall; water levels rose again in early 2007 before stabilizing the remainder of the year. While the initial water-level increases coincide somewhat with early spring precipitation, the overall water-level trends for 2006 through 2011 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.

Figure 2-2. AMC well location map.

Table 2.1.1.1 AMC-series wells. Minus sign (-) indicates a decline (drop) in water level.

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
Change Yrs 21–29	6.68	6.42	9.57	0.00	2.22	1.22	5.99
Net Change	-25.36	-3.89	-3.61	0.00	-2.03	-2.47	-8.72

Figure 2-3. East Camp bedrock monitoring wells.

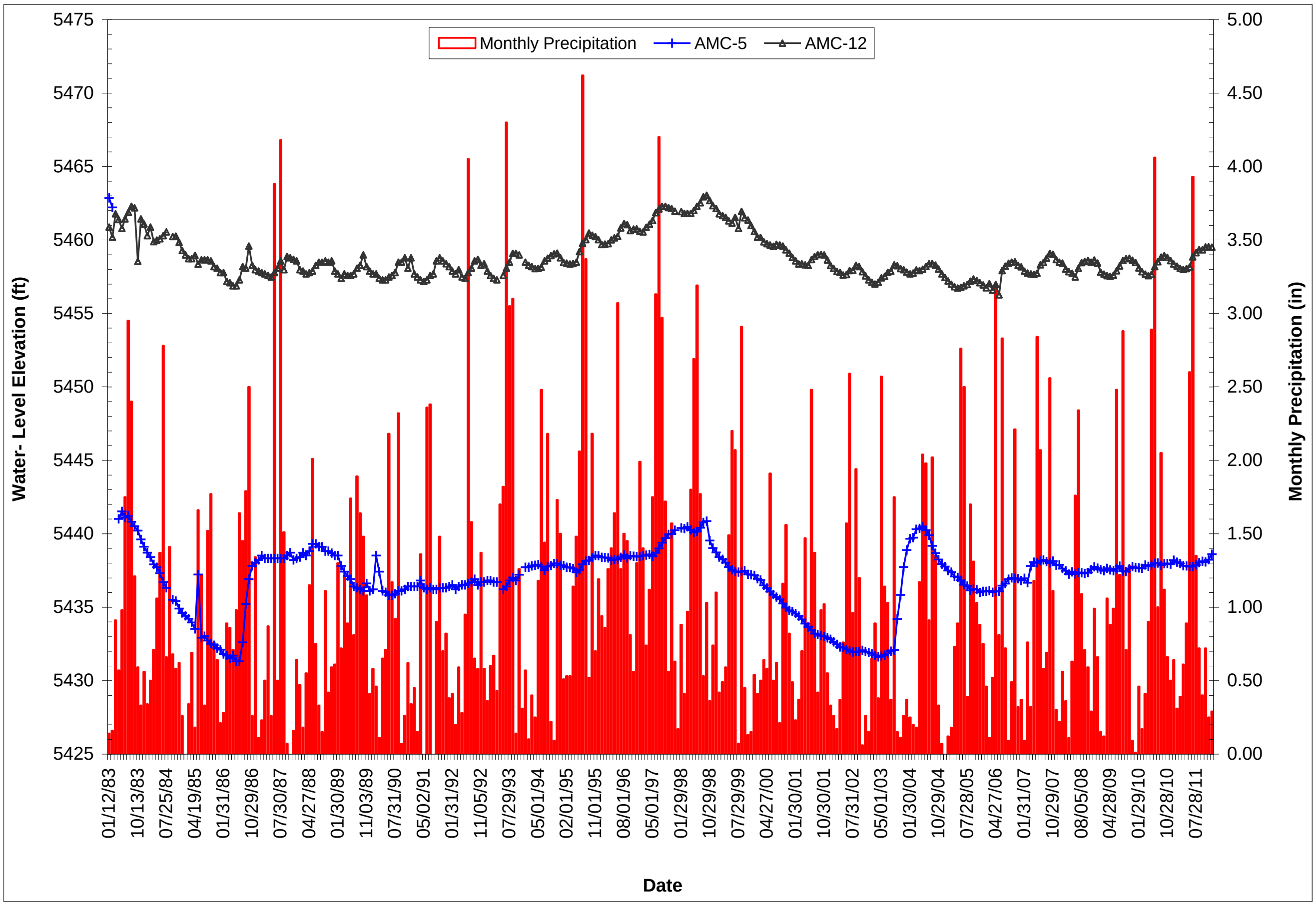


Figure 2-4. Water-level hydrographs for wells AMC-5 and AMC-12.

Well AMC-6 is directly south of the concentrator facility and the Emergency (Dredge) and Ecology ponds. Water-level trends during 2003–2004 were similar to those seen in 1986–1987 following the resumption of mining. However, water levels in 2005 appear to be less influenced by water levels in the Emergency (Dredge) and Ecology ponds. Through the summer of 2005, water levels in this well continued the strong downward trend that began in the fall of 2004. Beginning late spring 2005, minor water-level increases (1 ft or less) occurred that might be in response to precipitation events (fig. 2-5). Beginning in 2006 and continuing through 2010, water levels have risen each spring following precipitation events, and have fallen each autumn. In 2011 water levels continued to rise throughout the entire year (May–December). 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. 2-5) and continuing throughout the remainder of the year. It appears that sediment removal increased pond leakage and potential recharge to the alluvial aquifer. The pond drainage and refilling masked the seasonal water-level decline seen throughout the record. Water-level response in AMC-6 has always been strongly influenced by seasonal precipitation, even though it had a net water-level increase for 2006, 2007, and 2009 and precipitation was below average.

The water-level trend from 2003 through 2005 in well AMC-8 (fig. 2-5) was very similar to that in the 1986–1988 time period, with a period of increase associated with the resumption of mining followed by a water-level decline. While water levels had a net decline for 2005, there was slight upward movement during the late fall–early winter that originally appeared to have been in response to precipitation events; water levels continued to rise throughout almost all of 2006 and 2007, independent of precipitation 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 an upward trend similar to those seen in AMC-6 throughout 2011 with no seasonal variation.

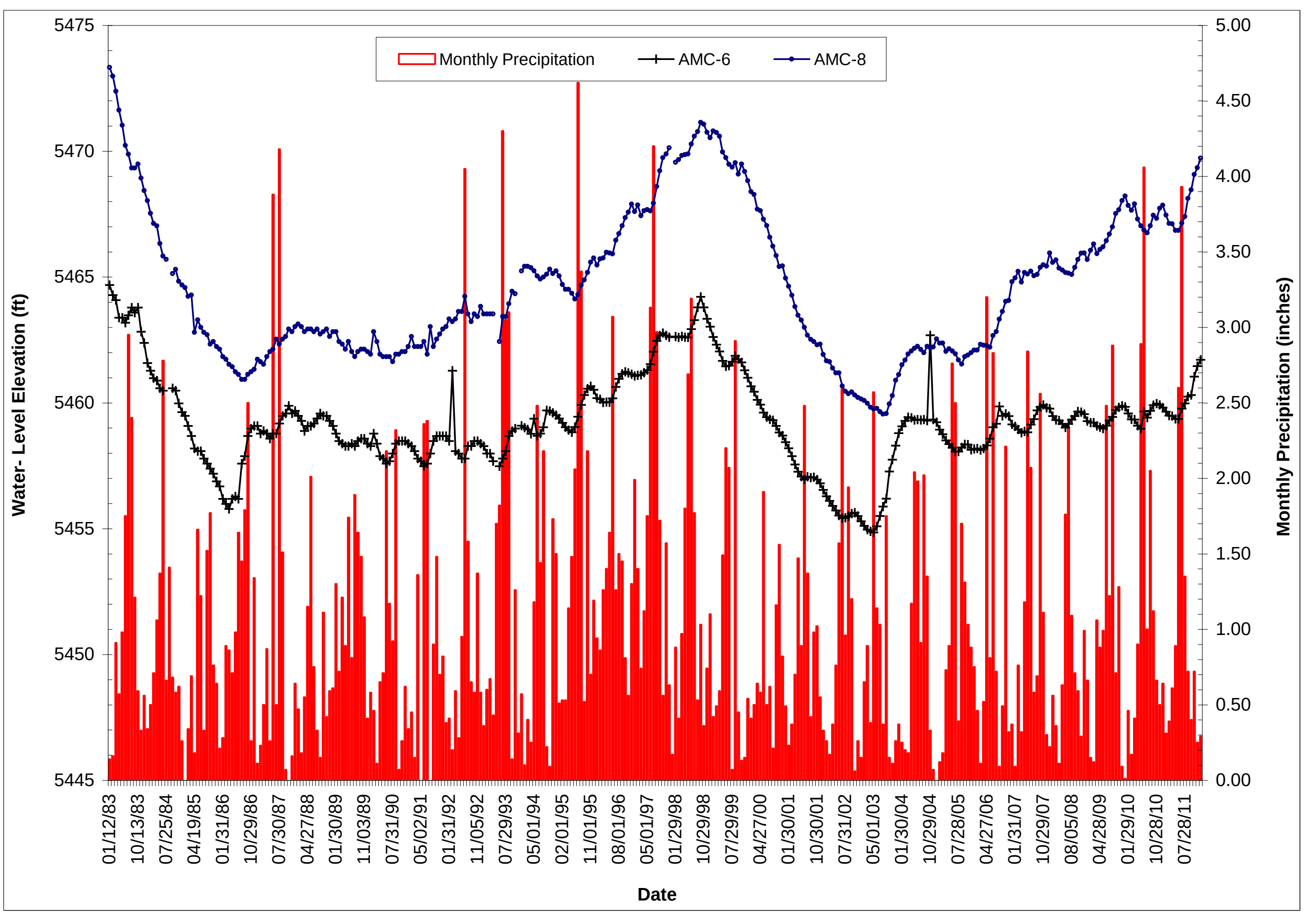


Figure 2-5. Water-level hydrographs for wells AMC-6 and AMC-8.

Well AMC-12 water-level variations during 2006–2007 with a net water-level rise of more than 3.5 ft (fig. 2-4) differed from water levels observed between 2001 and 2005, which generally declined. These water-level changes may be related to the construction completion of the Butte Priority Soils Unit subdrain, which underlies the Silver Bow Creek (SBC) channel above the confluence with Blacktail Creek, and the periodic discharge of clean water the SBC channel. Annual water-level changes were <0.1 ft during 2008–2010; the 2011 change was the largest (1.13 ft) since 2006, which may be related to MR's cleaning of the Ecology Pond. Seasonal changes are noticable on the AMC-12 hydrograph.

Well AMC-13 is located on the west side of Clark Park, south of wells GS-44S and GS-44D (fig. 2-3). This well's hydrograph shows both a response to precipitation events and possibly lawn watering (fig. 2-6a). Water levels begin to rise late each spring, continue to rise throughout the summer, and decline each fall. This pattern is typical of water level patters observed in prior years.

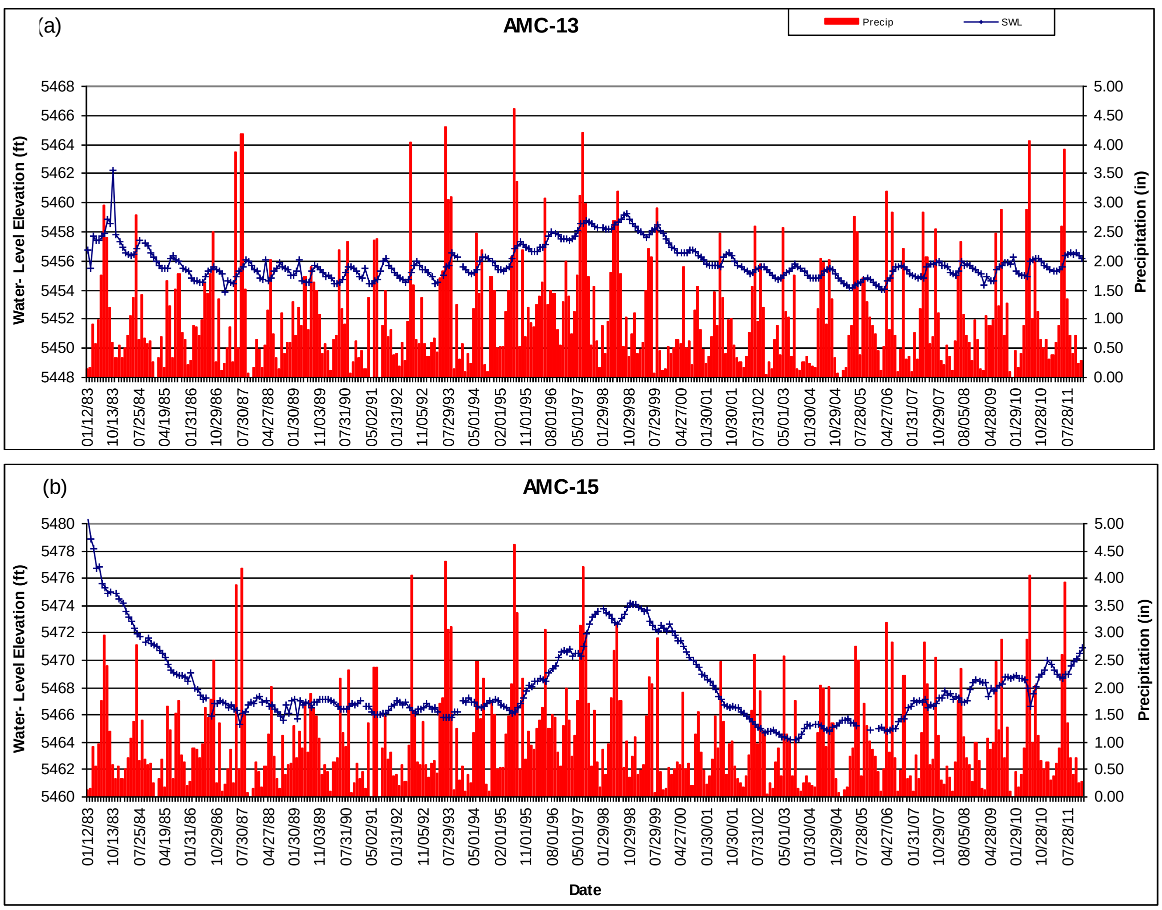


Figure 2-6. Water-level hydrographs for wells AMC-13 (a), and AMC-15 (b).

Well AMC-15 is located on the west side of the Hillcrest waste dump (fig. 2-3) in a reclaimed area. Depth to water in this well is 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. This is reflected in the hydrograph (fig. 2-6b). The influence of below-normal precipitation is shown by the steep decline in water levels beginning in late 1999 (fig. 2-6b), when this well did not show any significant response to precipitation events and water levels fell until mid-2003, when the water level rose almost ½ foot between September and December. These time frames correspond to the 1998 Berkeley Pit landslide and the fall-2003 resumption of mining by MR. Water levels have risen continually through 2011, with apparent seasonal variations. However, peak water levels occur later in the year (November–December) than they do in other alluvial well sites. The waterlevel has risen in 8 of the past 10 years.

Section 2.1.1.1 AMC-Series Water Quality

Concentration exceedances and trends for chemical constituents in the 2011 data collected from the AMC-series wells are summarized in Table 2.1.1.2. Water from AMC-5, just south of the Berkeley Pit, has exceeded a number of maximum containment levels (MCLs) and secondary maximum containment levels (SMCLs) throughout the period of record. The concentrations of most dissolved metals have shown a slight downward trend.

Water from AMC-6 shows continued and consistent decreasing concentrations in nearly all dissolved constituents. Cadmium is the only constituent whose concentration exceeds its drinking water MCL. Sulfate concentrations increased slightly (30 percent) from 175 mg/L in 2004 to 250 mg/L in 2008 (fig. 2-7) but have since dropped back to 2004 levels. Current concentrations are well below historic 1980s levels.

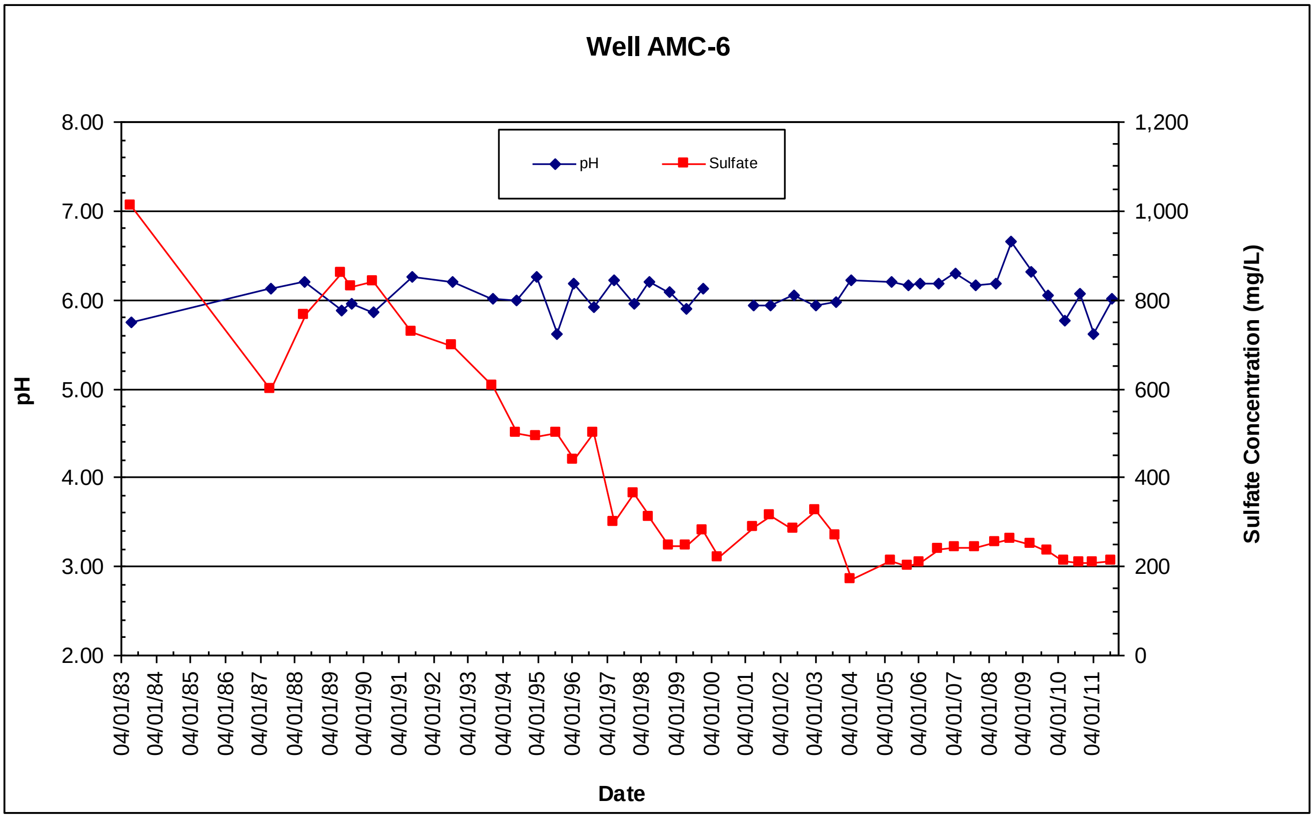
The concentrations of dissolved constituents reported for samples collected in 2011 from AMC-8 are consistent with previous results. Sulfate concentrations continue to increase (fig. 2-7), doubling since the fall of 2006, from 400 mg/L to more than 900 mg/L in November 2011. Cadmium concentrations have increased the past several years and are currently above their MCL.

Table 2.1.1.2 Exceedances and trends for AMC-series wells, 2011.

Well Name	Exceedances	Concentration	Remarks
AMC-5	Y	Variable	High iron, manganese, cadmium, copper, and zinc
AMC-6	Y	Downward	Downward trend continues
AMC-8	Y	Variable	Increasing sulfate and cadmium
AMC-12	Y	Downward	Very high iron, manganese, cadmium, and zinc
AMC-15	N	Variable	Unchanged in recent years, currently only sampled every 2 years

In 2006, access was restored to wells AMC-12 and AMC-15, allowing them to again be sampled. Water from AMC-12 has high-to-very high concentrations of iron, manganese, cadmium, and zinc; this well is located just south of the SBC drainage, which received untreated mine and process water for decades.

As in the recent past, no strong water-quality trends are apparent in most AMC-series wells; however, water from several wells exhibits a slight downward trend in dissolved constituents during the period of record. Overall, metal concentrations in 2011 water samples are little changed from previous years, with the exception being sulfate and cadmium concentrations in well AMC-8, which continue to increase. Wells closest to historic and current mining operations have the highest levels of contamination; well AMC-5 has very high levels of iron, manganese, cadmium, copper, and zinc.



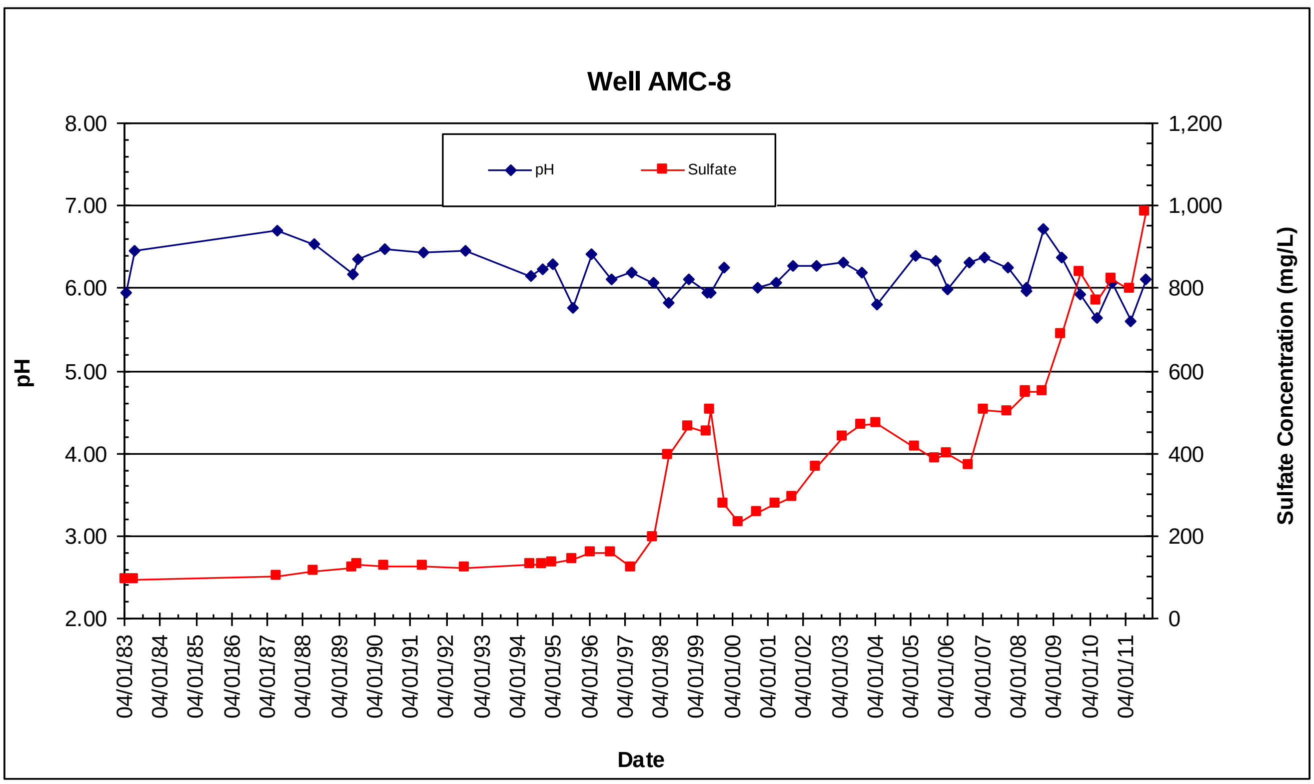


Figure 2-7. Graphs showing pH and sulfate concentration changes over time for wells AMC-6 (top) and AMC-8 (bottom).

Section 2.1.2 LP-Series Wells

The locations of the 17 LP-series monitoring wells are shown in figure 2-8. As discussed in Duaime and others (1998), these wells were installed in 1991 and 1992 as part of the BMFOU RI/FS study. Water-level monitoring and sampling of the LP-series wells continued throughout 2011. Table 2.1.2.1 presents a summary of annual water-level changes. Well LP-11 was plugged and abandoned in 2001; well LP-03 was plugged and abandoned in 2002 to make room for the HSB water-treatment plant. Wells LP-06 and LP-07 had been dry for more than 3 years, before having a water-level rise during 2004; however, they began to decline in 2005 and have been dry since January 2006. Well LP-06 was plugged and abandoned in 2010 to allow for mine expansion. Well LP-08 has been dry since May 2010. Water levels rose in 8 of the remaining 12 wells. Wells LP-04 and LP-10, north of the Pittsmont Waste Dump, had water-level declines varying from 0.34 ft to 1.03 ft. Since monitoring began, water levels have declined, from a minimum of 2.2 ft in LP-10 to a maximum of 43 ft in well LP-08, in 12 of the LP-series wells. Net water-level increases vary between 0.34 ft and 7.8 ft in wells LP-12, 13, 14, 15, and 17 located south of the Pittsmont Waste Dump.

Table 2.1.2.1 Annual water-level change in 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	Dry	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	Dry	Dry	Dry	0.61
Change Years 21-30	**0.22**	**0.05**	P&A*	**-0.34**	**0.03**	**Dry**	**Dry**	**Dry**	**0.61**
Net Change	**-27.08**	**-24.33**	**-31.45**	**-30.94**	**-32.09**	**-4.17**	**-17.43**	**-43.01**	**-33.09**

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

(*) Plugged and abandoned

Table 2.1.2.1 Annual water-level change in LP-series wells (ft). (*cont.*)

Year	LP-10	LP-11	LP-12	LP-13	LP-14	LP-15	LP-16	LP-17
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
Change Years 21-30	**-1.03**	P&A*	**0.78**	**0.94**	1.61	**0.87**	**0.53**	0.16
Net Change	**-2.20**	**-5.38**	**7.28**	**4.84**	7.80	**0.34**	**-3.16**	5.59

(*) Plugged and abandoned

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

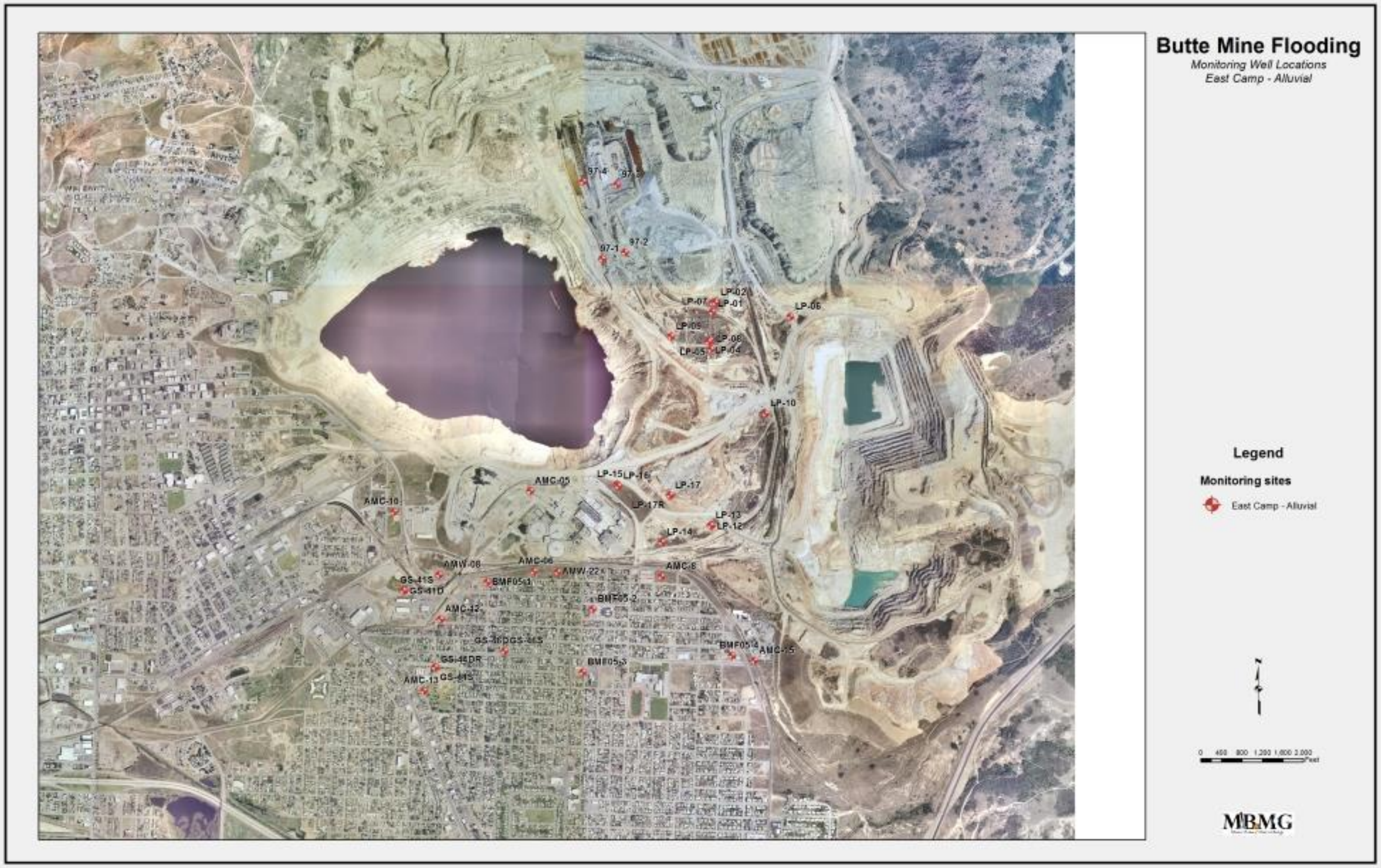


Figure 2-8. LP series and MR97 wells location map.

Water-level rise beginning in 2004 in 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. However, when it resumed mining in 2003, MR 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-10) are located south and downgradient of the leach pads where the leaching resumed. MR again operated limited leaching during 2010–2011 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 five of the LP-series wells, which are located south of the leach pads and north of the Pittsmont Waste Dump.

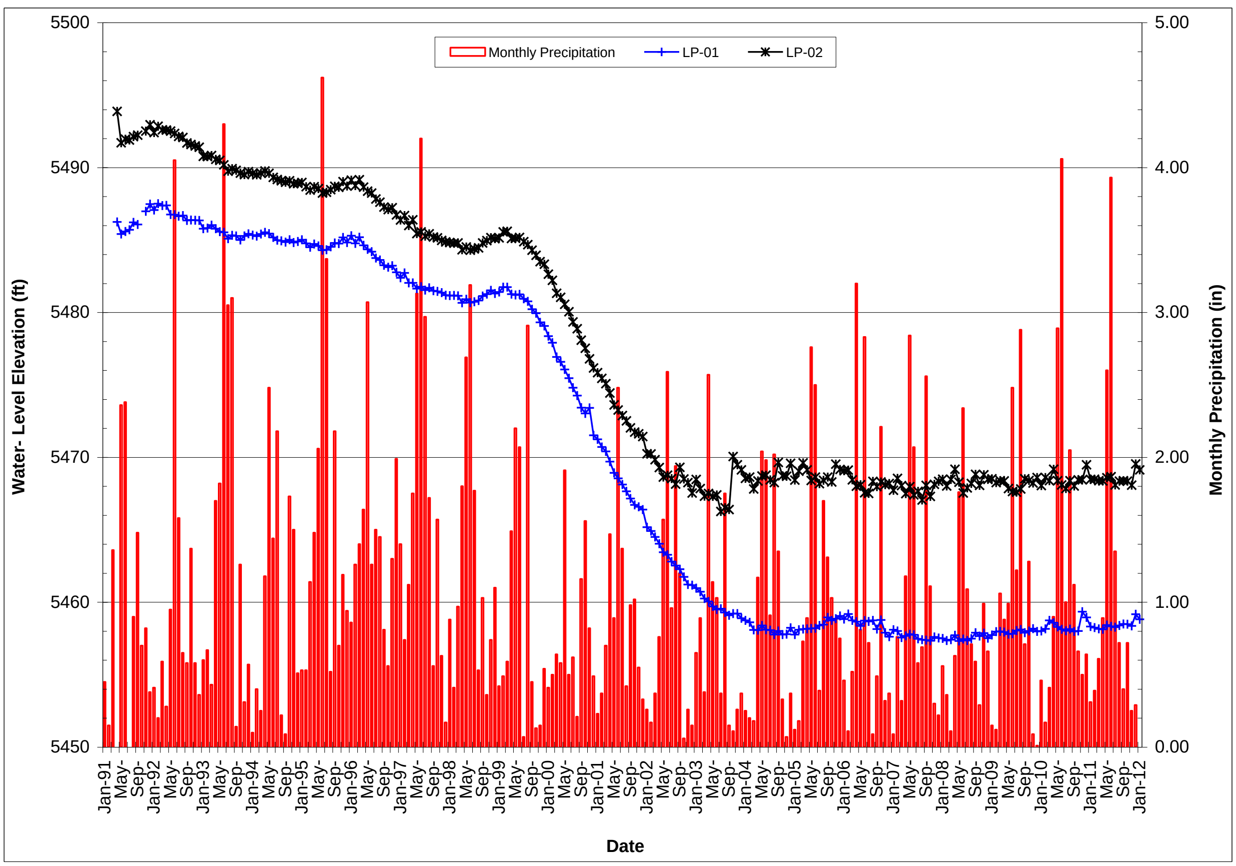


Figure 2-9. Water-level hydrographs for wells LP-01 and LP-02 located north of the Pittsmont Waste Dump and south of the leach pads.

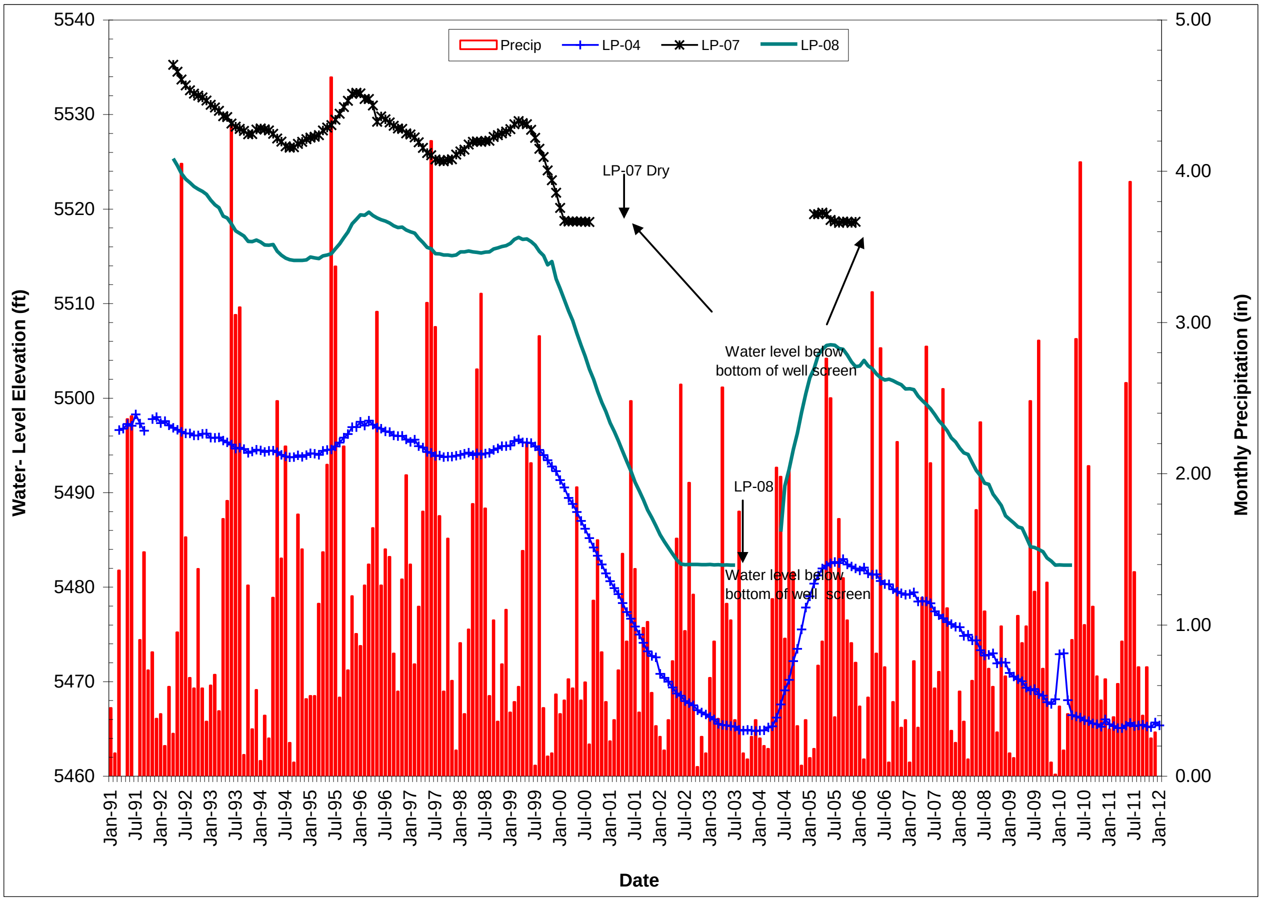


Figure 2-10. Water-level hydrographs for wells LP-04, LP-07, and LP-08 located north of the Pittsmont Waste Dump and south of the leach pads.

Wells LP-01 and LP-02 are located near the base of several leach pads and screened between 129 and 159 ft, and 177 and 197 ft, respectively, in a relatively deep section of the alluvial aquifer. As shown in figure 2-9, water levels steadily declined in well LP-019 between 1991 and 2004. Since 2004, water levels have varied slightly, with periodic increases followed by declines. Water-level fluctuation in LP-01 has been less erratic in recent years than that 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 tight 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 wells LP-04, LP-07, and LP-08, which are located south of wells LP-01 and LP-02 and north of the Pittsmont Waste Dump (fig. 2-8).

Well LP-04 is screened from 125 ft to 145 ft below ground surface, well LP-07 is screened from 90 ft to 95 ft below ground surface, and well LP-08 is screened 81 ft to 96 ft below ground surface. Based upon these well-completion depths, wells LP-07 and LP-08 are completed in the upper section, while well LP-04 is completed in a deep section of the alluvial aquifer. Water-level trends are similar for wells LP-04, LP-07, and LP-08. It is interesting to note that while well LP-08 was dry for a period from mid-2003 through mid-2004, the subsequent water-level movement paralleled that in well LP-04 once water levels rose back above the screen interval. Water-level control in all of these wells depends on whether the leach pads are operating, and that factor has much greater influence on water levels than does weather, as there is very little seasonal variation portrayed in figure 2-10. Well LP-07 has remained dry since late 2000, except for a short period in early 2005. LP-08 has been dry since mid-2010.

Wells LP-14, LP-15, and LP-16 are located southwest of the Pittsmont Waste Dump (fig. 2-8). A consistent increase in water levels occurred in these wells following their installation in 1992, until the Berkeley Pit landslide of 1998 (fig. 2-11). Post-landslide, water levels in all three wells declined until beginning to rise in September 2003. Water-level recovery was minor until May 2006 when rates of water-level rise increased. At the end of 2011, water levels in LP-14 were within 0.5 ft of the water level elevation just prior to the landslide; however, water levels in LP-15 and LP-16 were 10 ft or more below their 1998 pre-landslide levels. Wells LP-15 and LP-16 are located near one another and completed as a nested pair; LP-15 is screened from 215 ft to 235 ft and LP-16 is screened from 100 ft to 120 ft below ground surface. Water-level trends are generally similar in these wells. None of these wells shows any response to seasonal trends, i.e., precipitation events.

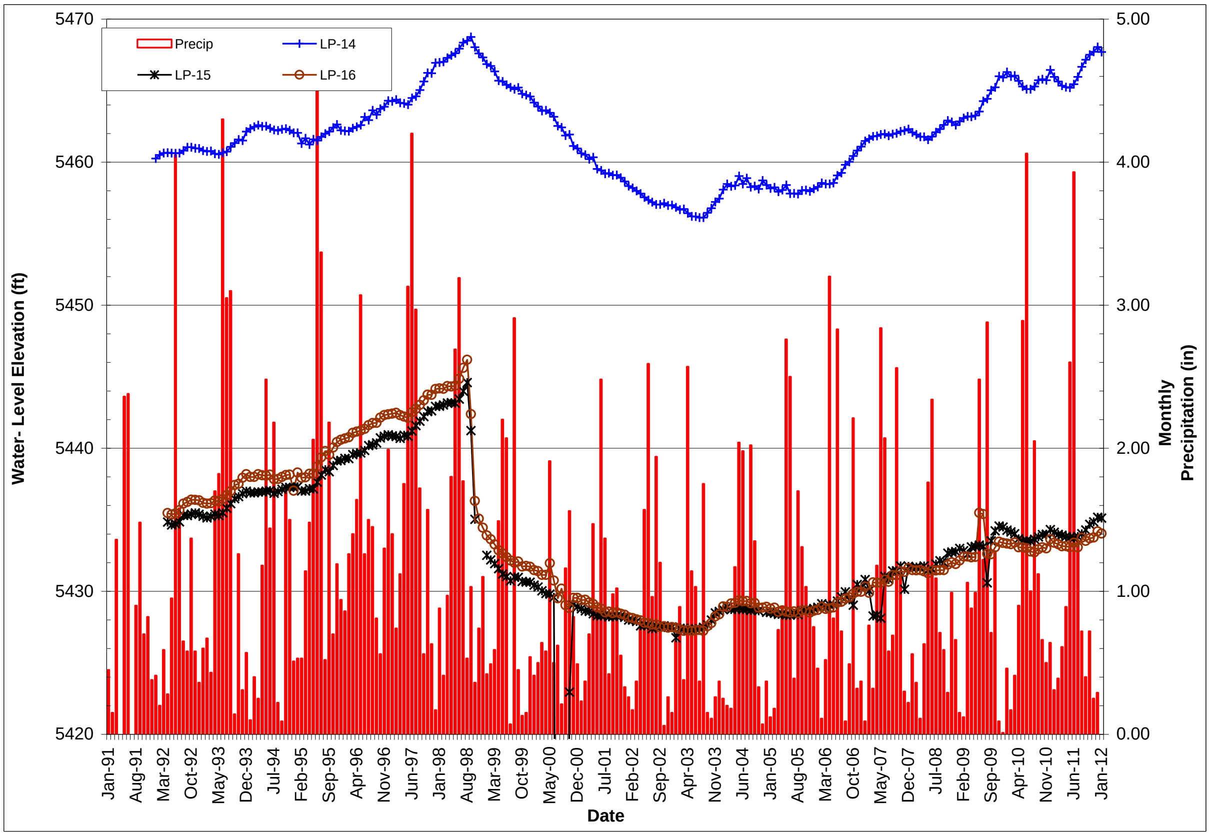


Figure 2-11. Water-level hydrographs for wells LP-14, LP-15, and LP-16.

The general observation made in the last several yearly reports, that wells between the leach pads and Pittsmont Waste Dump were affected by leach pad operations, including the 1999 leach pad dewatering and historic mine dewatering, remains true. Water levels in the LP-series wells are controlled by the operation and subsequent dewatering of the leach pads, operation of the Yankee Doodle Tailings Dam, by depressed water levels in the Berkeley Pit, or a combination of all three. Water-level response in wells adjacent and downgradient of limited leaching operations during 2004–2005 and 2009–2011 clearly demonstrates the relationship of water-level change and leach pad operation. The influence of seasonal precipitation events is minimal, at best, on water levels in these wells.

An alluvial aquifer potentiometric map (fig. 2-12), constructed using December 2011 water levels (BMF monitoring well network sites only), shows that alluvial groundwater flows towards the Berkeley Pit from the east and south. Groundwater in alluvium south of the Berkeley Pit, contaminated by historic mining activities (Metesh and Duaime, 2000), is flowing north towards and into the Berkeley Pit, ensuring that there is no southward migration of contaminated water.

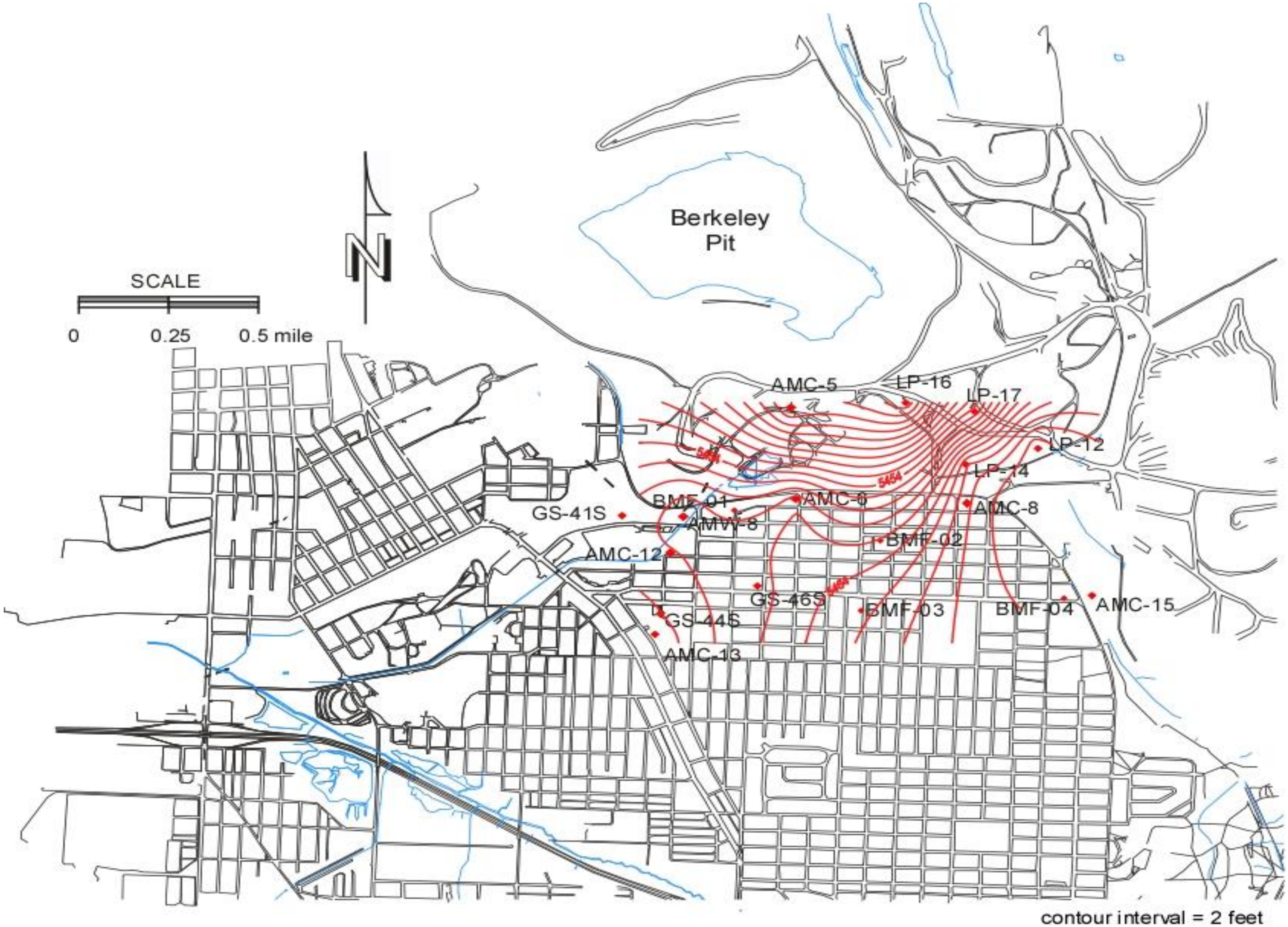


Figure 2-12. Alluvial aquifer potentiometric map for December 2011 (contour interval is 2 ft).

Section 2.1.2.1 LP-Series Wells Water Quality

Current water-quality monitoring of the LP-series wells is restricted primarily to those west and south of the Pittsmont Waste Dump (fig. 2-8), with the exception of three wells (LP-08, LP-09, and LP-10) that are south of the leach pad area and north of the Pittsmont Waste Dump. Water-quality data from samples collected in 2011 showed limited changes in several wells; the changes are summarized in table 2.1.2.2.

Well LP-08 has been sampled each spring between 2005 and 2009 to determine if water-quality changes observed in well LP-09 were occurring further to the southeast. While water produced by LP-08 in recent years is highly contaminated in most cases, concentrations are less than historic levels (i.e., Al 1,710,000 µg/L in 1992 and 1,226,189 µg/L in 2009). However, 2009 concentrations are elevated above 2008 levels. There was insufficient water in the well to support sample collection in 2010 and 2011.

Well LP-09 was sampled six times between its installation in 1992 and 1996; after 1996 it was not resampled until April 2003. Annual samples were collected until 2011, but since then there has been too little water in the well to collect samples. Data review indicates large concentration increases in most dissolved constituents starting in 1994. Data collected in 2010 show that the elevated sulfate and zinc concentrations have been sustained (fig. 2-13). The concentration of cadmium increased from 600 µg/L in 1992 to more than 11,000 µg/L in 2010; zinc concentrations increased from 172,000 µg/L in 1992 to more than 1,700,000 µg/L in 2010. (Zinc concentrations have declined since the 2010 levels, but are still an order of magnitude above 1992–1996 levels.) In general, dissolved metals concentrations increased by nearly an order of magnitude during the past 6 to 10 years, approaching concentrations observed in the ‘pregnant’ solution from the upgradient leach pads.

Water from LP-16 contained moderate increases of sulfate, copper, and zinc in 2010–2011 samples (fig. 2-14). The increases depart from historic downward trends. No other analytes showed increasing trends.

Water from LP-17 changed significantly from previous samples: during 2006–2011 concentrations of cadmium, copper, and zinc decreased by 50 percent from 2003–2005 levels. Nitrate concentrations were extremely high in the 2006–2009 samples, decreasing in 2010–2011 samples. However, current nitrate concentrations are still four times the MCL.

The water-quality trend in other LP-series wells generally remained the same in 2011 as in recent years. A summary of exceedances and trends is presented in table 2.1.2.2.

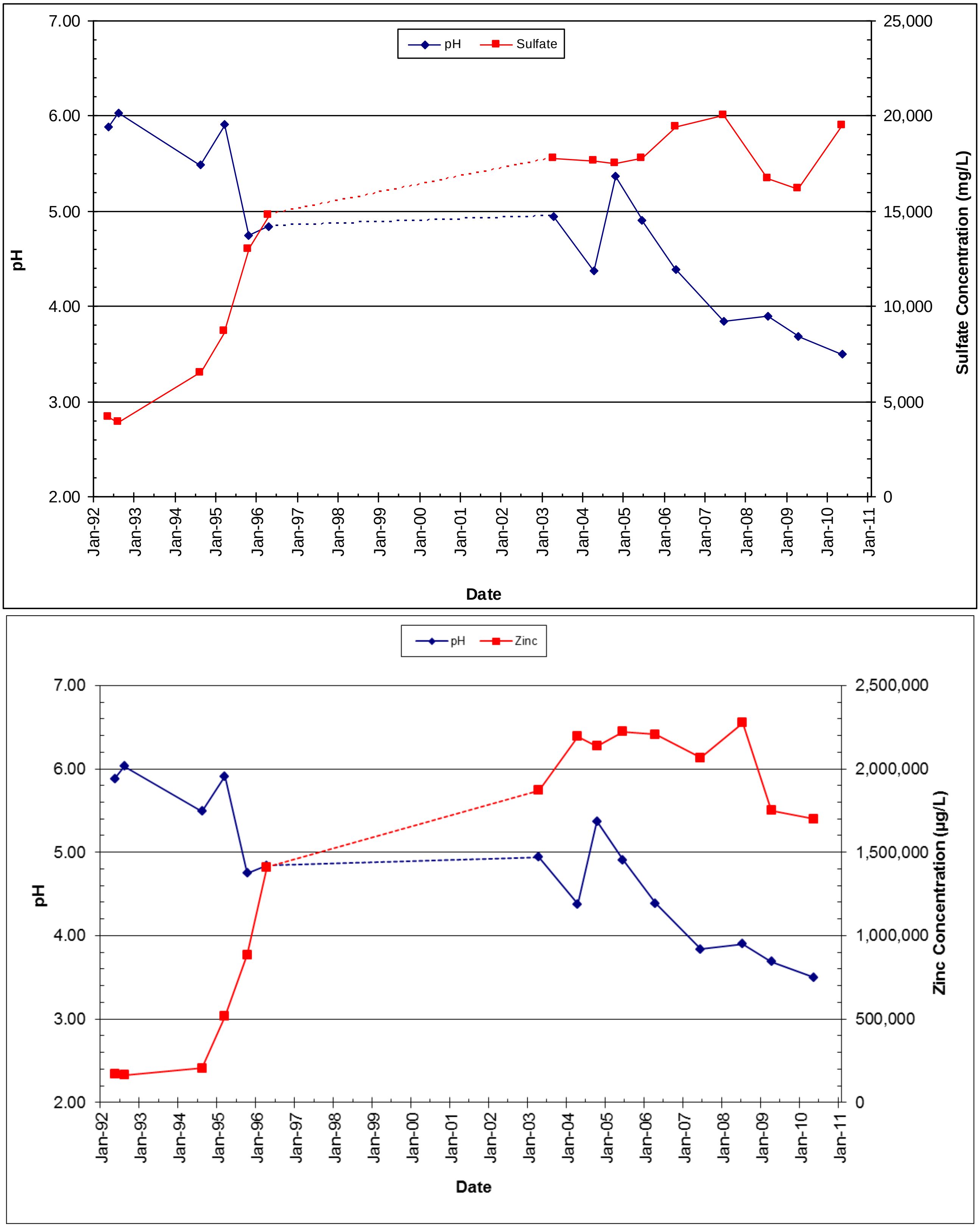


Figure 2-13. Sulfate (top) and zinc (bottom) concentrations vs. pH in well LP-09.

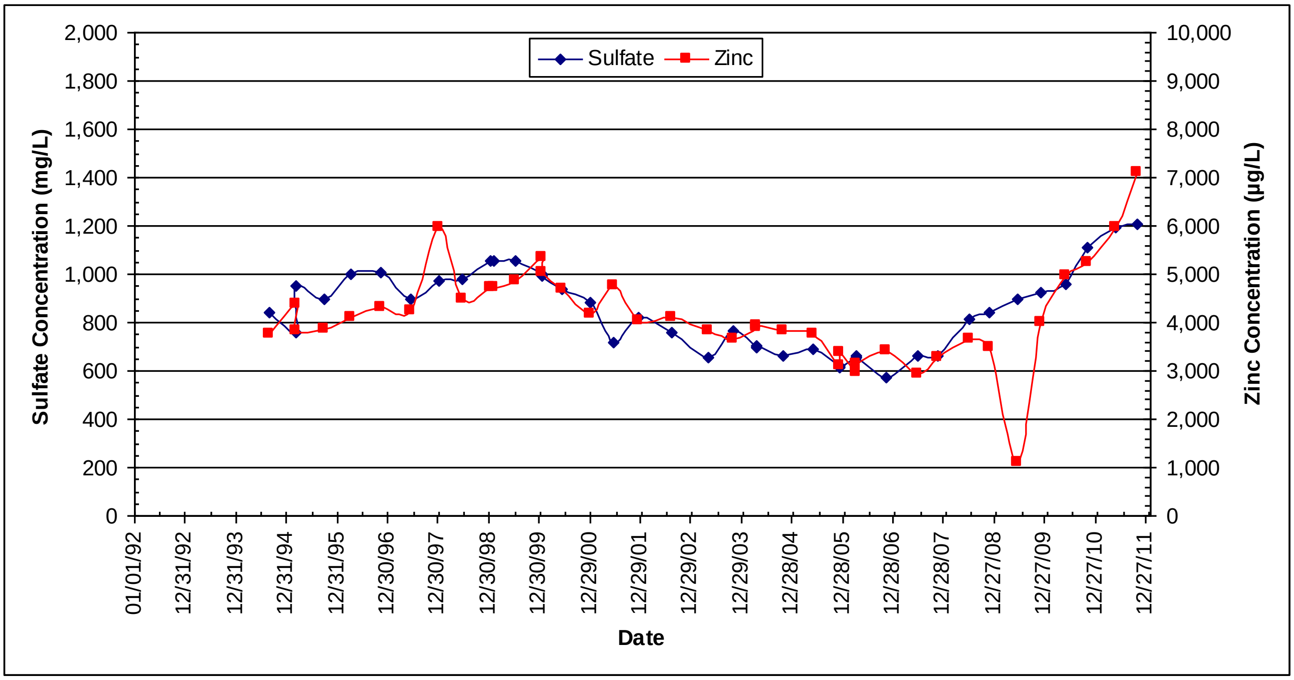


Figure 2-14. Sulfate and zinc concentrations in well LP-16.

Table 2.1.2.2 Exceedances and trends for LP-series wells, 2011.

Well Name	Exceedences (1 or more)	Concentration Trend	Remarks
LP-08	Y	Downward	Very elevated concentrations. No 2011 sample.
LP-09	Y	Upward	Large increases since 1992. No 2011 sample.
LP-10	N	None	No significant changes in 2009, not sampled in 2006–2007, 2010 due to access problems.
LP-12	Y	None	No significant changes in 2011.
LP-13	Y	None	No significant changes in 2011.
LP-14	Y	Variable	No significant changes in 2011.
LP-15	Y	None	Net change is small for most analytes. No 2009–2010 samples due to access issues.
LP-16	Y	Variable	Sulfate trend continues increase seen in 2008, copper and zinc increased 2010–2011.
LP-17	Y	Downward	Nitrate declining; however, still 4 times MCL.

Section 2.1.3 Precipitation Plant Area Wells

Wells MR97-1, MR97-2, MR97-3, and MR97-4 (fig. 2-8, p. 38) are adjacent to various structures (drainage ditches, holding ponds) associated with the leach pads and precipitation plant. Table 2.1.3.1 lists annual and net water-level changes for these wells. Water-level changes appear to correspond to flow in these ditches and water levels in ponds.

Table 2.1.3.1 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
Change Years 11–15	**2.83**	**7.81**	**6.35**	**-2.81**
Net Change	**2.49**	**-0.34**	**-5.41**	**0.09**

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

Within the MR-group wells, water levels in MR97-1 have shown the greatest variation (fig. 2-14) due to numerous changes in nearby mining operations and infrastructure. Water levels initially increased in spring 1999, when MR began to discharge water from their Berkeley Pit copper recovery project into the Pit through a channel adjacent to well MR97-1. This channel had not been used since April 1996, when water from HSB that flowed in the channel was captured to prevent it from flowing into the Pit. Rapid water-level increases recurred at the time of MR's June 2000 mining suspension. 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 through the channel at that time. However, the flow of water was only about one-third the previous flow. Because the flow was decreased, less water would be available for groundwater recharge and water levels were expected to stabilize or drop. Surprisingly, water levels rose before gradually declining over the next year.

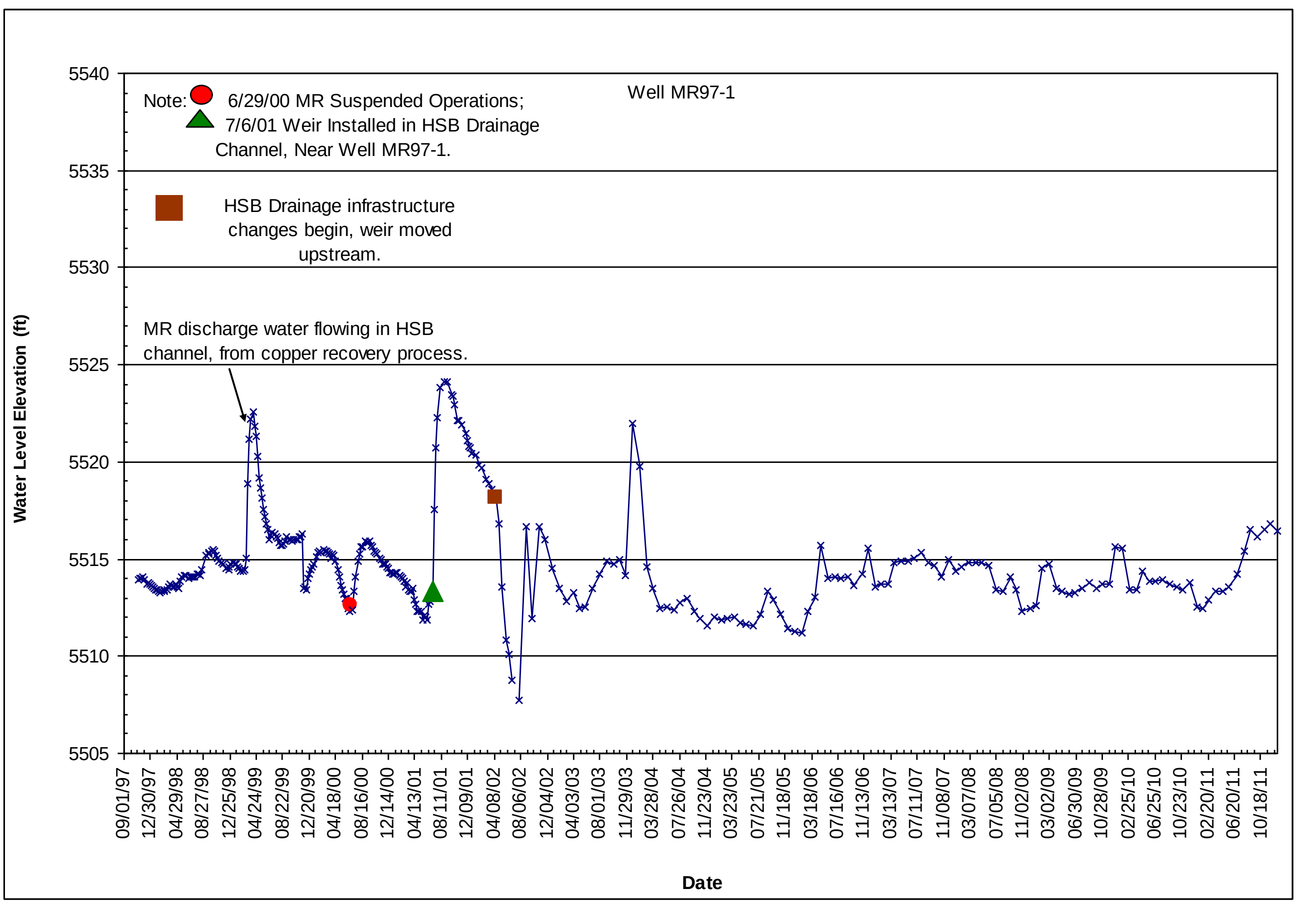


Figure 2-15. Water-level hydrograph for well MR97-1.

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. Water levels showed some minor fluctuations during early 2003, rose several feet mid-year, and leveled off. A substantial December 2003 water-level rise coincides with the resumption of MR's copper recovery project and the resumption of discharge water flow in the drainage ditch. Water levels declined during early 2004 before leveling off for most of the remainder of 2004 and early 2005. Water levels have shown minor periodic variations between 2005 and 2011, with no noticeable upward or downward trends.

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 was reflected as water-level declines in wells MR97-2 and MR97-3 (figs. 2-16 and 2-17). Water-level increases occured in 2009–2011 when limited leaching operations resumed. Water-level increases were also seen in wells MR97-2, MR97-3, and MR97-4 following MR's June 29, 2000 suspension of mining (figs. 2-16, 2-17, and 2-18). The response in water levels in well MR97-2 (fig. 2-16) was very similar to that seen in well MR97-1. A similar increase was seen in well MR97-2 following the 2001 weir installation. Water levels were stable at this site during 2003–2005 through mid-2006 and did not show the same fluctuations as noted in well MR97-1. However, water levels increased during June, July, and November 2006, leveled off before rising during early spring 2007, before leveling off and then decreasing slightly in the latter part of 2007. Water levels gradually increased from 2009 to 2011.

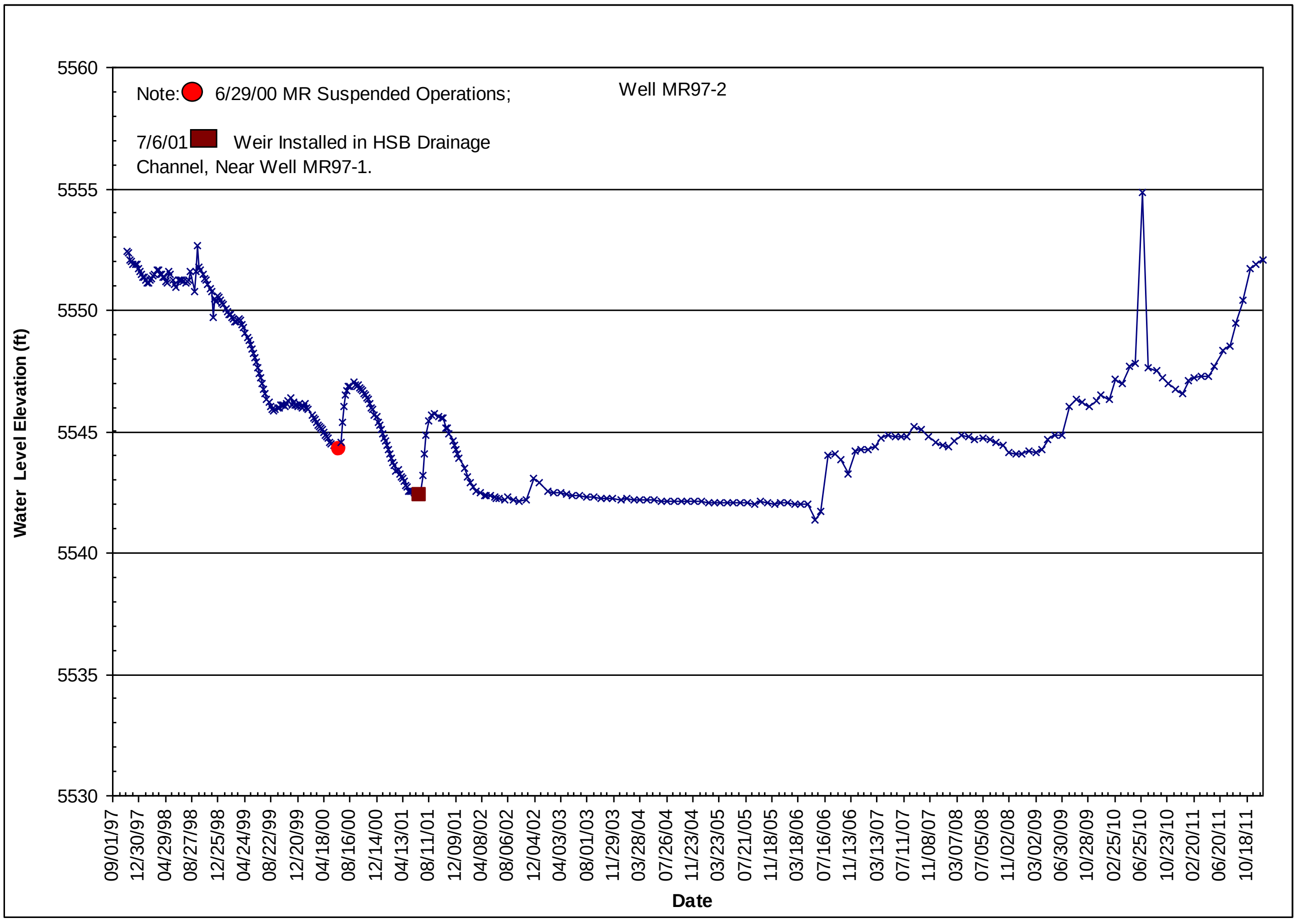


Figure 2-16. Water-level hydrograph for well MR97-2.

The water level in well MR97-3 showed only minor responses during the 2001 and 2002 construction activities (fig. 2-17). With the exception of a brief period early in 2004, water levels continued to drop until spring 2005 when they began a generally upward trend that continued throughout most of 2006 and 2007; the net water-level recovery was about 8 ft by the end of 2008. Water levels varied through each year between 2008 and 2011. This MR-series well is most distant from the HSB drainage channel and appears to be the least responsive MR-series well to operational changes and flows in the channel.

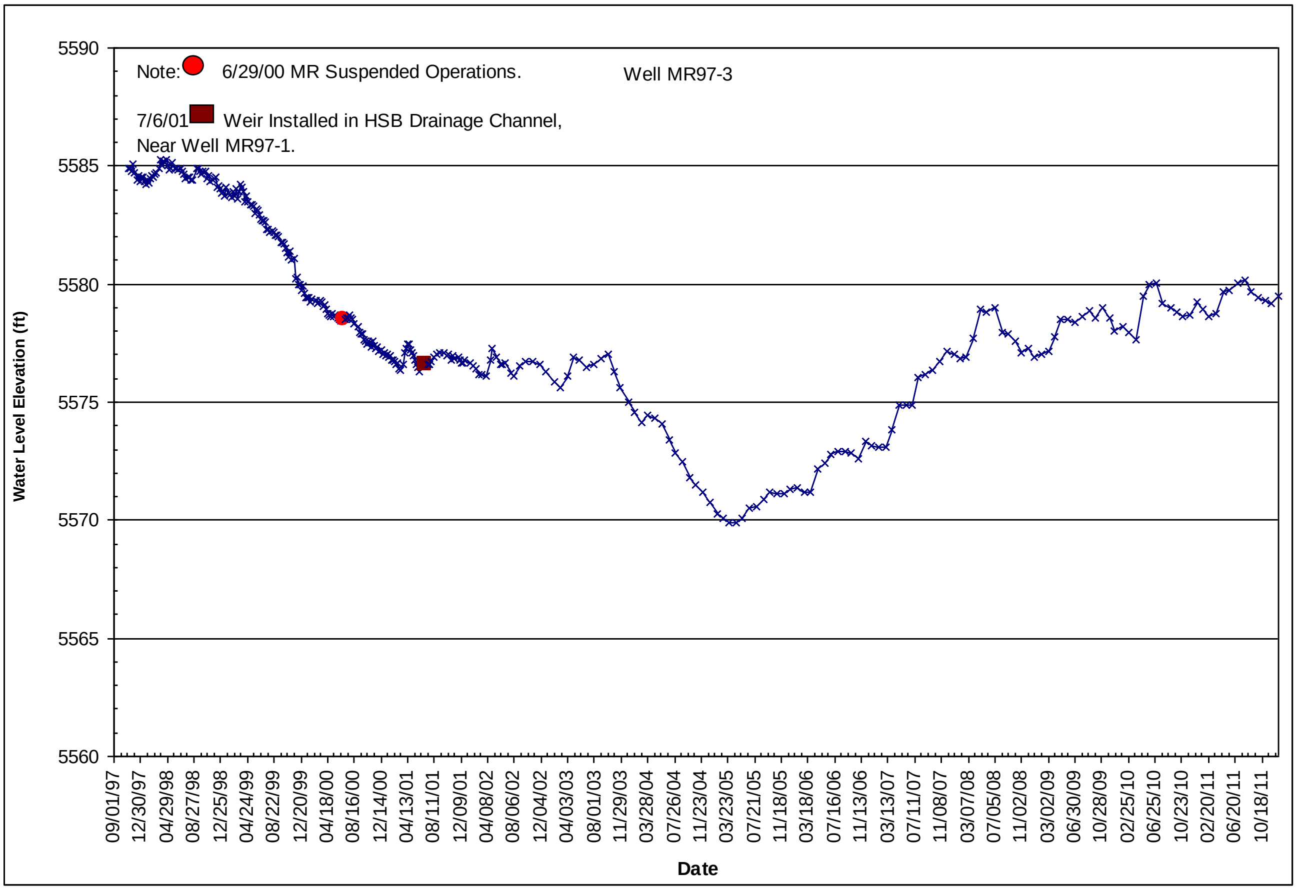


Figure 2-17. Water-level hydrograph for well MR97-3.

Water-level changes in well MR97-4 (fig. 2-18) have shown the least amount of variability. Water levels declined between 2009 and early 2011, with a net decline of almost 2 ft. The net period of record water-level change in this well is less than 0.10 ft.

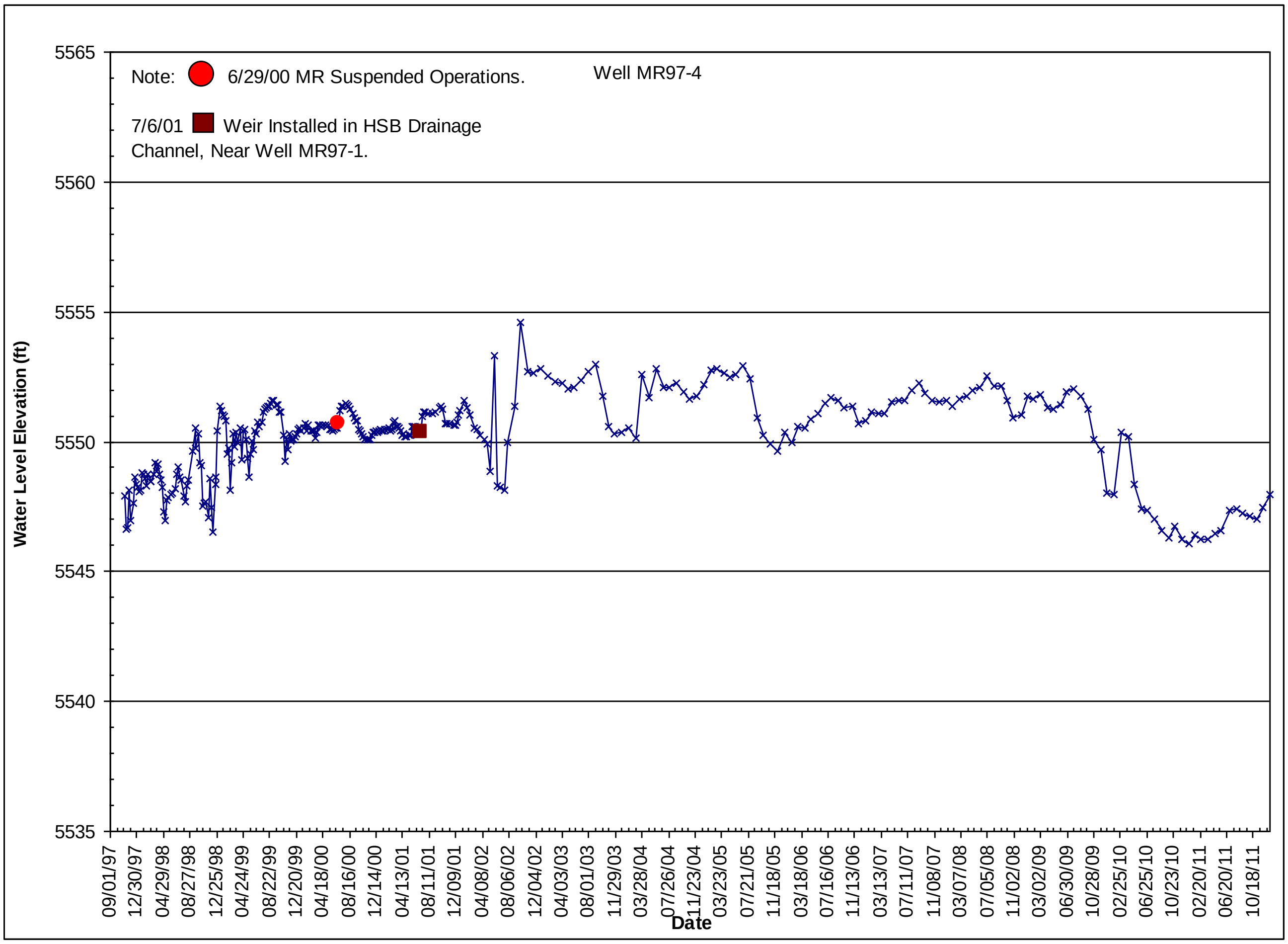


Figure 2-18. Water-level hydrograph for well MR97-4.

Since its installation in 1997, water levels declined 5.25 ft or more in well MR97-3, located nearest the leach pads and ancillary facilities (table 2.1.3.1), but water levels rose between 0.09 and 2.49 ft in more distant wells MR97-4 and MR97-1, respectively. 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 2011. Previous sampling documented the presence of elevated metals; this contamination most likely resulted from leach pad and precipitation plant operations.

Section 2.1.4 GS- and BMF05-Series Wells

Continuous and monthly water-level monitoring of the six GS-series and four BMF05-series wells continued throughout 2011. The locations of these wells are shown in figure 2-19; table 2.1.4.1 contains annual water-level changes. Wells GS-41, GS-44, and GS-46 are ‘nested pairs’; the wells at each site were drilled adjacent to each other, but completed at different depths. The ‘S’ and ‘D’ identify the shallow and deep well in each pair. Water levels had a net decline in three of the six GS-series wells in 2008, which is in contrast to net increases seen in all six wells during 2006 and 2007; however, water levels rose in all wells during 2009. Water levels rose in two wells in 2010 and all four wells in 2011. During most years, water levels change similarly in all the GS-series wells; therefore the mixed signals during 2008 and 2010 are not characteristic. Water levels during the entire period of record in all six GS-series wells have net increases ranging from 1.2 ft to 3 ft.

Figures 2-20 through 2-22 are water-level hydrographs with monthly precipitation totals shown for the three well pairs (GS-41, GS-44, and GS-46). The seasonal water-level variations closely follow annual precipitation seasonality. Water levels gradually rise in the spring as monthly precipitation increases and then decline throughout the fall.

During 2011, water-level changes in wells GS-41S and GS-41D were similar to changes observed since 2006 (fig. 2-20), and the influence of seasonal precipitation appears to dominate the hydrograph. Water levels increased from 0.80 to 0.95 ft in these two wells during 2011.

Net water-level changes in the GS-44 nested pair during 2011 were similar to those seen in the past and those seen in 2011 in the GS-41 wells (fig. 2-21). Water levels in wells GS-44S and GS-44D increased 0.68 ft during 2011.

Overall, water-level trends were similar during 2011 in wells GS-46S and GS-46D (fig. 2-22), and followed similar seasonal trends discussed previously for wells GS-41 and GS-44. Water levels increased 0.99 ft in well GS-46S and 0.98 ft in well GS-46D during 2011. There has been a net water-level rise since monitoring began.

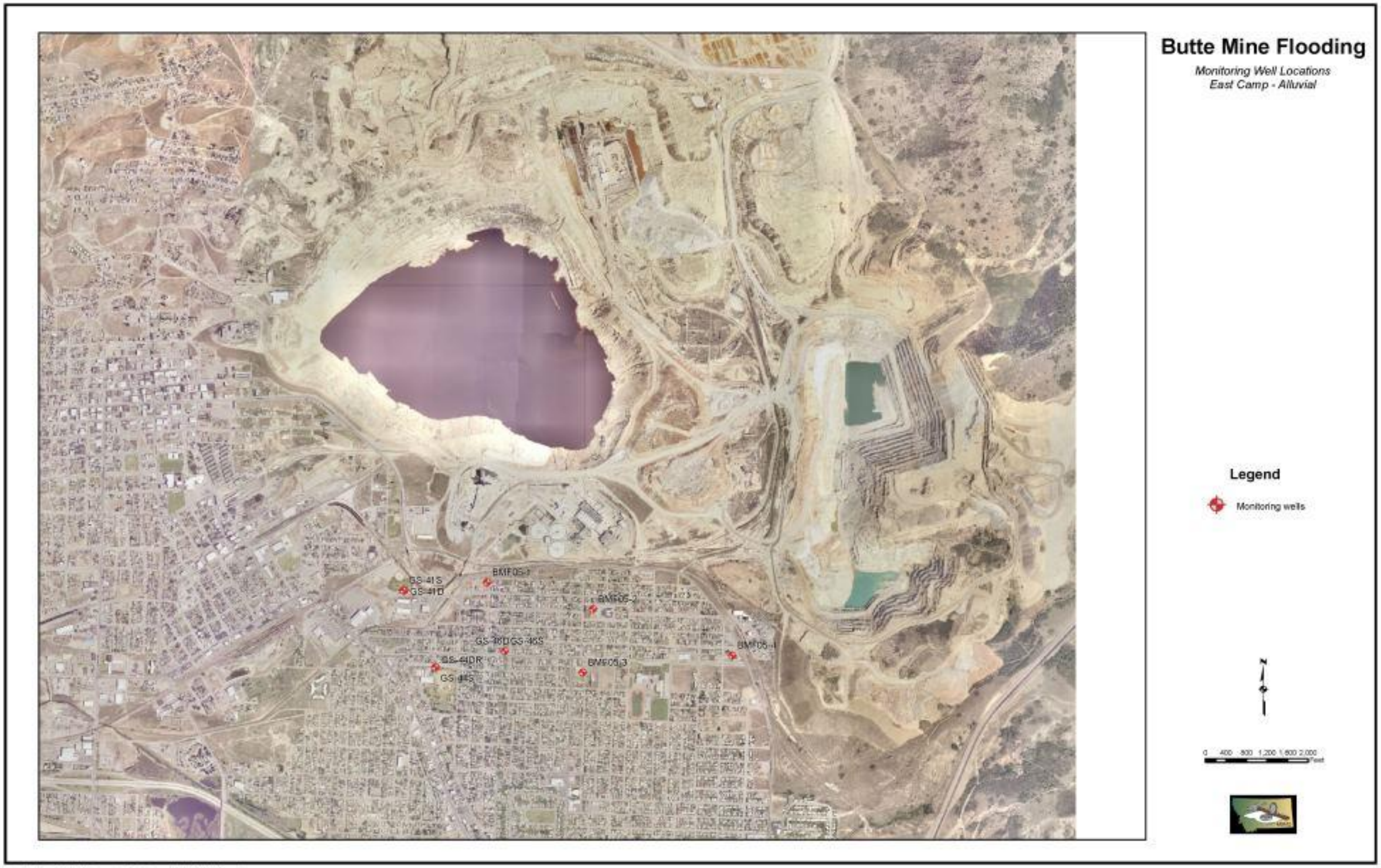


Figure 2-19. GS and BMF wells.

Table 2.1.4.1 Annual water-level changes in GS and BMF05-series wells (ft).

Year	GS-41S	GS-41D	GS-44S	GS-44D	GS-46S	GS-46D	BMF05-1	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
Change Years 11–19	**1.60**	**1.76**	**1.75**	**1.65**	**3.88**	**3.50**	**4.12**	**3.85**	**3.56**	**5.56**
Net Change	**1.22**	**1.33**	**1.53**	**1.48**	**3.04**	**2.62**	**4.12**	**3.85**	**3.56**	**5.56**

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

At the GS-41 and GS-44 sites, water levels in shallow wells are at higher altitudes than those in the deep wells, implying a downward vertical gradient. Water moves downward from the upper part and provides recharge to the lower part of the aquifer. Water levels in wells GS-46S and GS-46D show the opposite, with water levels in well GS-46D at higher elevations than water levels in GS-46S. The vertical gradient implies that water at depth can potentially move upwards and possibly discharge into a surface-water body such as Silver Bow Creek. However, as noted later, the water in well GS-46D is of good quality and would not cause concern.

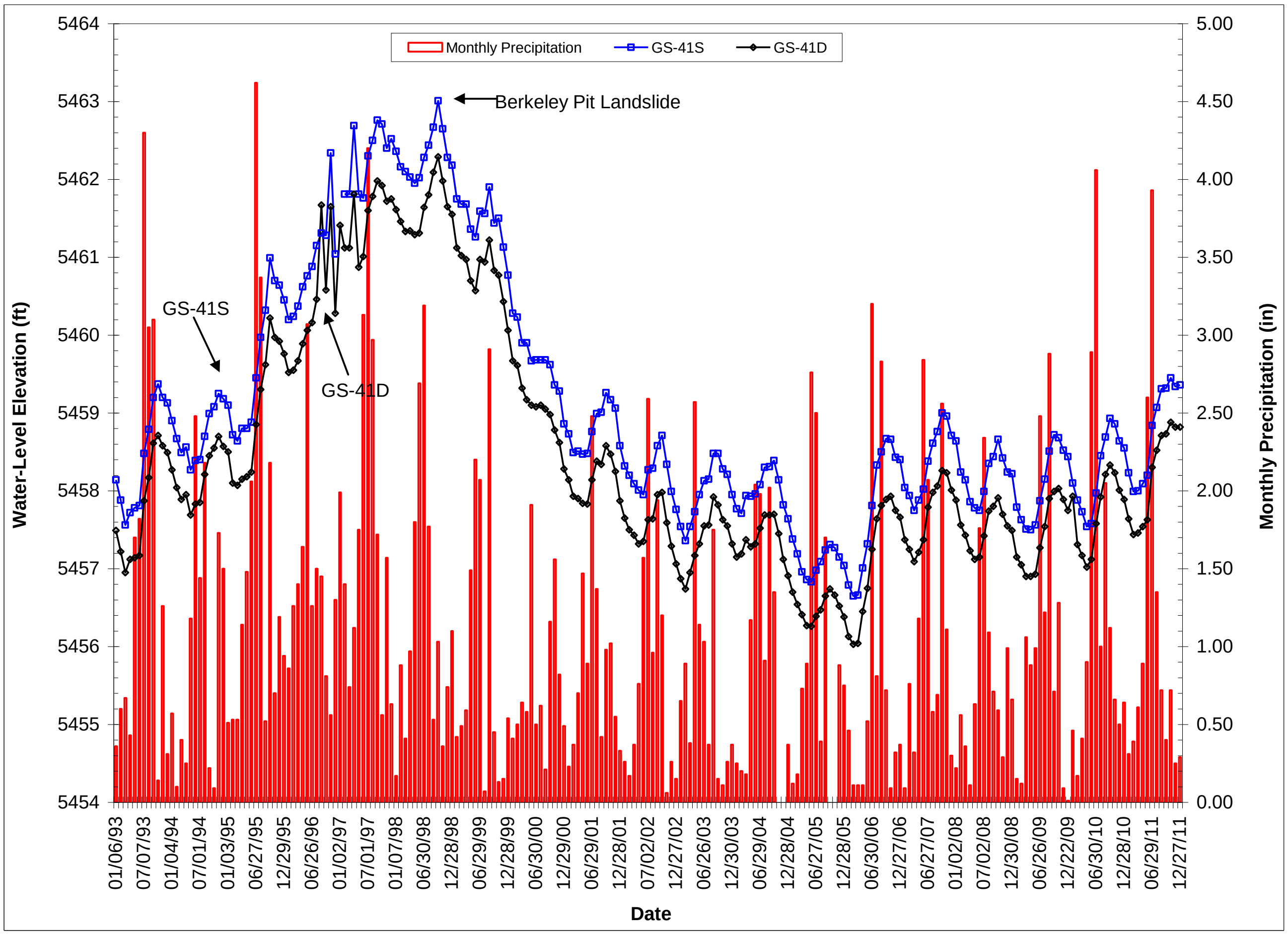


Figure 2-20. Water-level hydrographs for wells GS-41S and GS-41D.

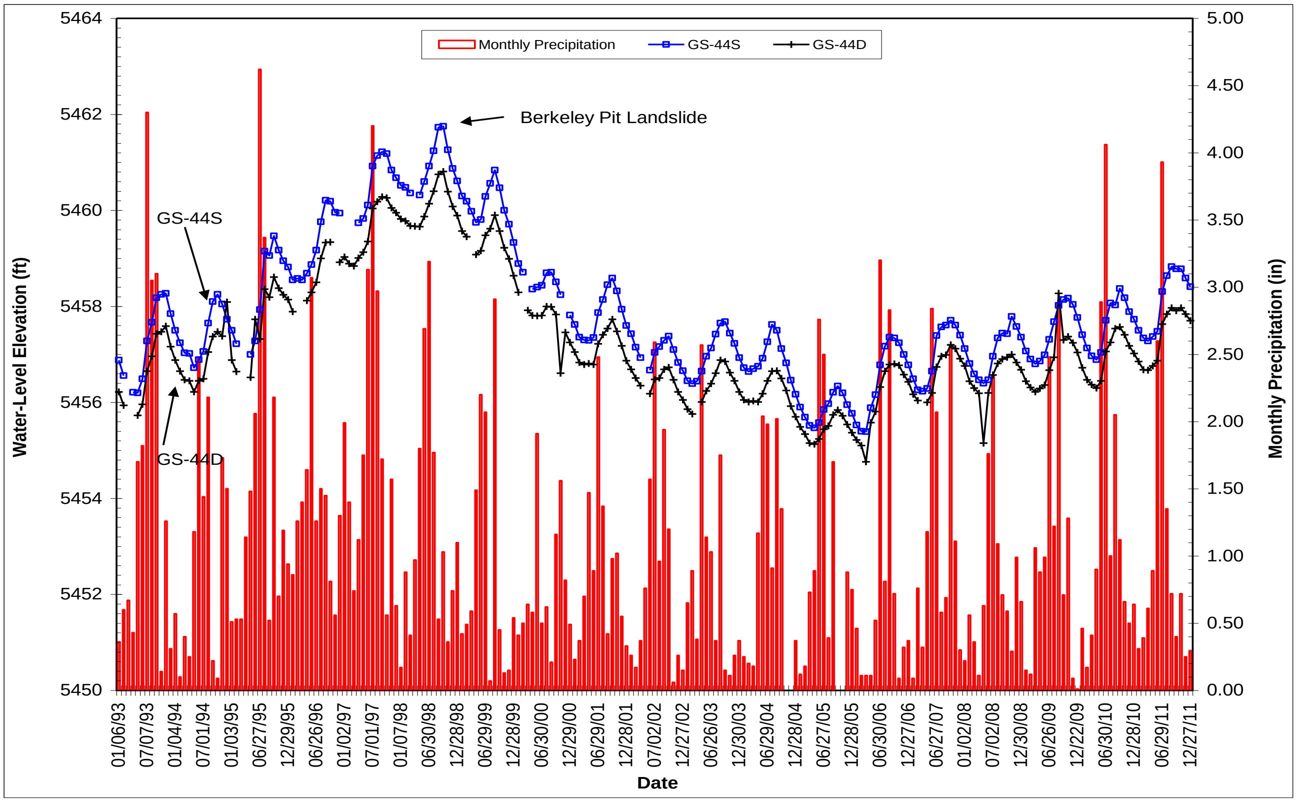


Figure 2-21. Water-level hydrographs for wells GS-44S and GS-44D.

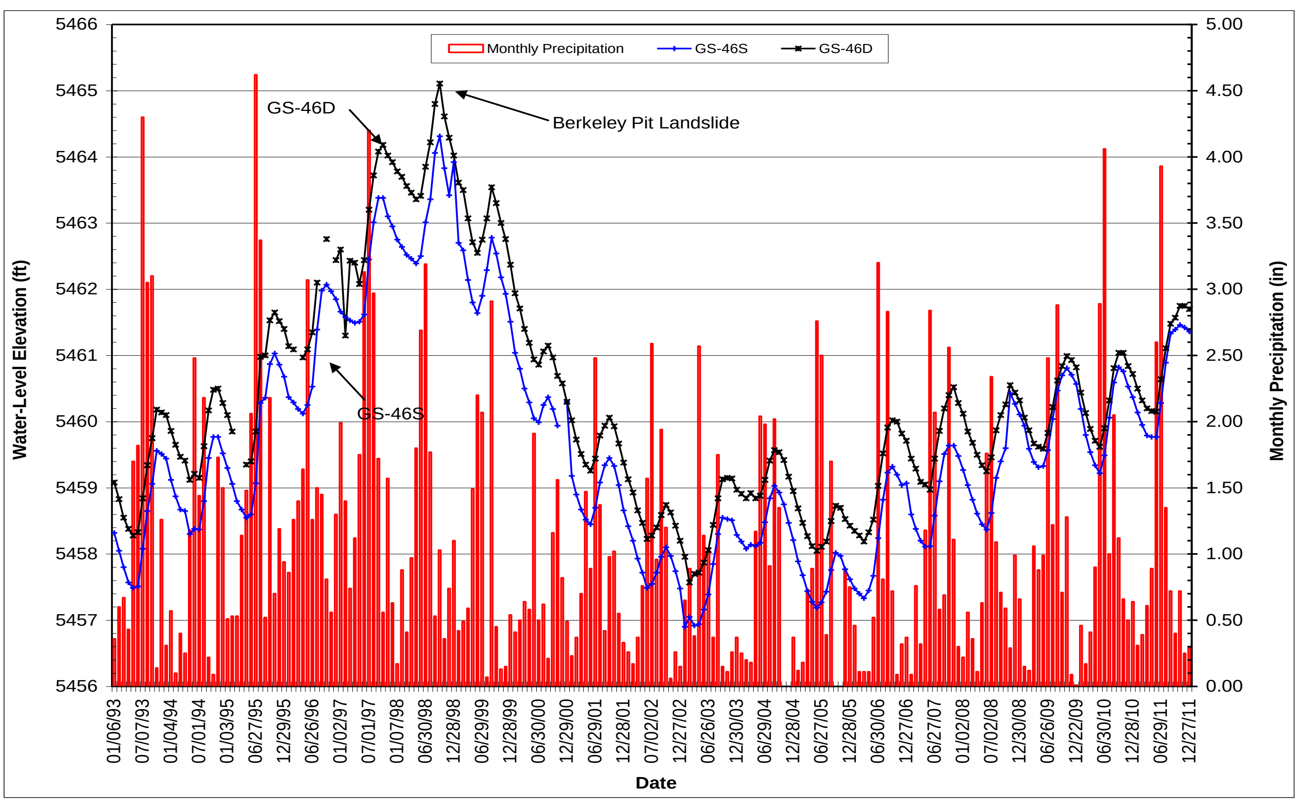


Figure 2-22. Water-level hydrographs for wells GS-46S and GS-46D.

The BMF05-series wells were installed in late 2005 and early 2006 to replace the domestic wells originally part of the post-RI/FS monitoring program. The domestic wells were monitored from 1997 through 2002, but data evaluation determined that dedicated monitoring wells would be more reliable for a long-term monitoring program and not be influenced by household usage. The location of the BMF05-series wells is shown in figure 2-19. The well sites were selected to provide coverage throughout the same area covered by the domestic wells and to provide information for areas south of the Berkeley Pit—active mine area. Monitoring this area is important to better define the groundwater divide between the Butte Mine Flooding alluvial aquifer and the Butte Priority Soils aquifer. Pressure transducers were installed in spring 2006 in each well for continuous water-level monitoring. Water levels have generally risen in all four wells since their installation (table 2.1.4.1).

Figure 2-23 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. Each well has a seasonal upward water-level movement that levels off each fall and early winter, with the exception of well BMF05-4, in which water levels continue to rise throughout the fall and winter. The long-term water-level trend is slightly upward in all of these wells. Well BMF05-1 saw a larger than normal water-level increase during the last quarter of 2011 that correspondes to the refilling of MR's Ecology Pond following maintenance activites. Water-level increases were similar to those in nearby well AMC-6. Figure 2-24 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. Seasonal variability is not as pronounced in the BMF-series alluvial wells as it is in the GS-series wells.

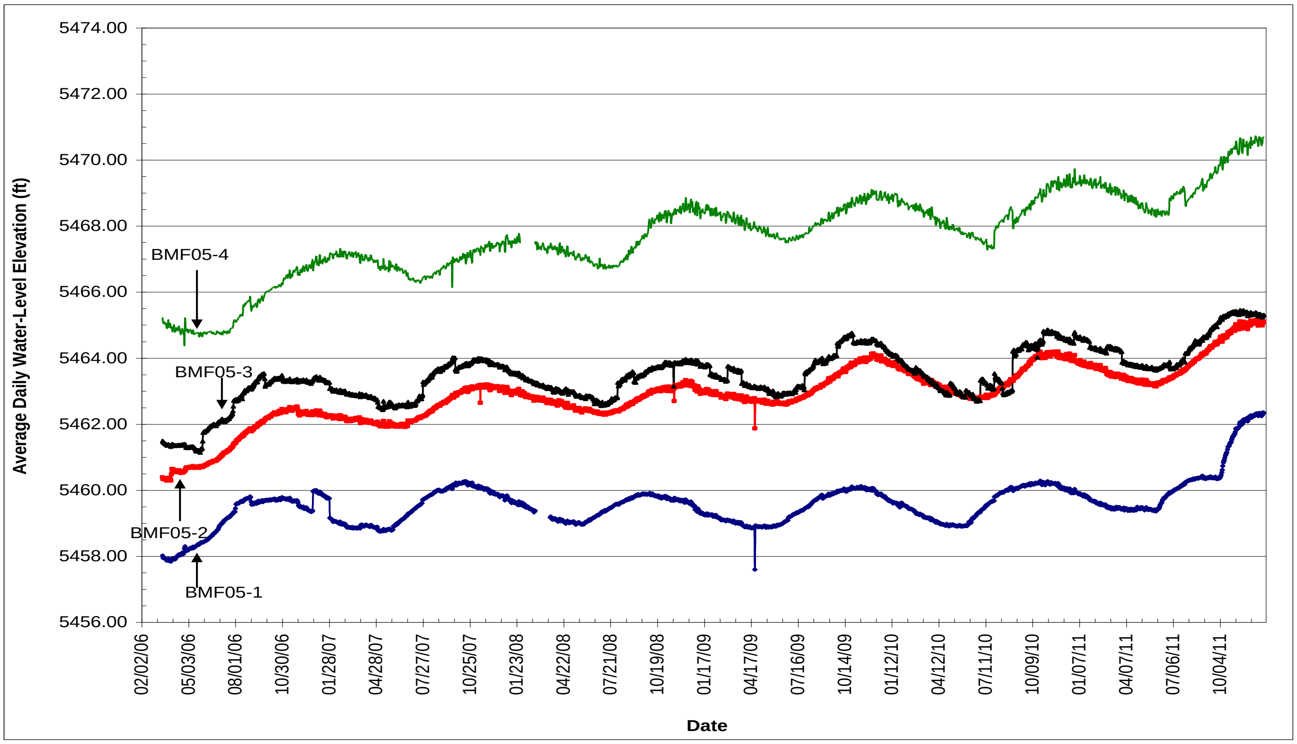


Figure 2-23. Average daily water-levels for BMF05-series wells.

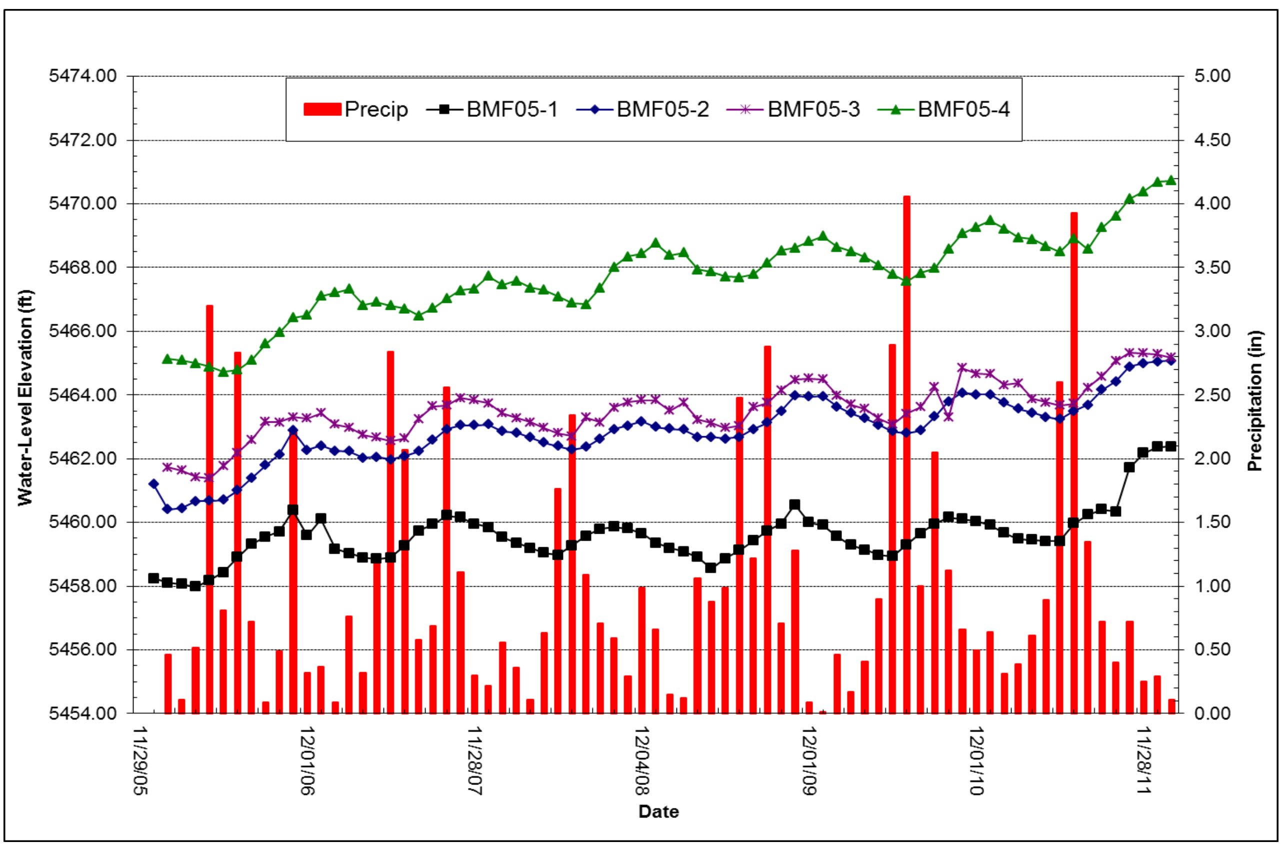


Figure 2-24. Monthly water levels vs. precipitation, BMF05-series wells.

Section 2.1.4.1 GS- and BMF05-Series Wells Water Quality

Water-quality samples were collected during April 2011 from GS-series wells as part of the 2011 BMFOU monitoring. The poor water quality in GS-41S and GS-41D reflects their proximity to the Parrot Tailings area; concentrations of dissolved constituents are extremely high. Data collected in 2011 confirm the large increases noted in many of the dissolved constituents since 2004; however, concentrations were similar to those seen in 2010 data.

Concentrations of several dissolved constituents continue to exceed MCLs in well GS-44S at the north end of Clark Park. Cadmium concentrations continue to exceed the MCL in 2005–2011 samples, after being below the MCL for the previous 3 years. Water from well GS-44D also continues to contain cadmium concentrations greater than the MCL, but cadmium conncentrations have gradually decreased by as much as 50 percent during the period of record. Water from wells GS-46S and GS-46D, northeast of Clark Park, continued to be of good quality in 2011, and constituent concentrations show little upward or downward trends, with the exception of uranium (GS-46S), which exceeds the MCL in the 2005–2009 and 2011 sample results.

Quarterly water-quality samples were collected from the BMF05 wells 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 a pH less than 5.50 and elevated concentrations of iron, manganese, cadmium, copper, and zinc. Table 2.1.4.2 shows the mean values for these constituents and the appropriate MCL or SMCL.

Table 2.1.4.2 Mean concentrations of analytes that exceed water-quality standards, well BMF05-1.

Analyte	Mean Concentration (mg/L)	MCL (mg/L)	SMCL (mg/L)
pH	5.17		6.5–8.5
Iron	8.46		0.30
Manganese	122.		0.05
Aluminum	0.533		0.05–0.2
Cadmium	0.204	0.005	
Copper	3.46		1.3
Zinc	47.5		5
Sulfate	1,554		250

Based upon the location of BMF05-1, adjacent to the 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.

Wells BFM05-2 and BMF05-4 have pH values that are above MCLs.

Section 2.2 East Camp Underground Mines

Monitoring of water levels in the seven East Camp underground mines continued. Their locations are shown in figure 2-25. During 2011, water levels rose between 7.1 and 9.1 ft in the mines, which was 0.1 ft to 2 ft more than 2010's totals. The Berkeley Pit water level rose 7.2 ft, which is 0.12 ft less than in 2010 (table 2.2.1). Figure 2-26 shows the annual water-level changes graphically for these sites. The net 2011 water-level change in the mine shafts and in the Berkeley Pit were comparable. 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 2.2.1 Annual water-level change in East Camp mines (ft).

Year	Berkeley Pit	Anselmo	Kelley	Belmont [1]	Steward	Granite Mountain	Lexington[2]	Pilot Butte
1982			1,304.00	117.00	85.00			
1983			877.00	1,054.00	1,070.00			
1984			262.00	269.00	274.00			
1985			122.00	121.00	123.00			
1986		56.00	96.00	102.00	101.00			
1987		77.00	84.00	77.00	79.00	67.00		
1988		53.00	56.00	53.00	52.00	57.00	8.10	
1989		29.00	31.00	31.00	29.00	31.00		
1990		32.00	33.00	34.00	33.00	34.00		
1991	12.00	29.00	33.00	30.00	29.00	31.00		
Change Years 1-10	***12.00***	***276.00***	***2,898.00***	***1,888.00***	***1,875.00***	***220.00***	***8.10***	
1992	25.00	22.00	24.00	24.00	23.00	25.00		
1993	26.00	24.00	25.00	26.00	25.00	26.00		
1994	27.00	25.00	26.00	25.00	25.00	27.00		
1995	29.00	28.00	27.00	18.00	28.00	30.00		
1996	18.00	16.00	19.00	4.15	18.00	18.00	1.19	3.07
1997	12.00	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**
Net Change*	***300.00***	***539.44***	***3,173.39***	***2,143.98***	***2,149.55***	***504.19***	***158.96***	***159.33***

(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 since February 2003, due to obstruction in shaft at 366 ft below surface.

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

Figure 2-25. East Camp and bedrock wells location map.

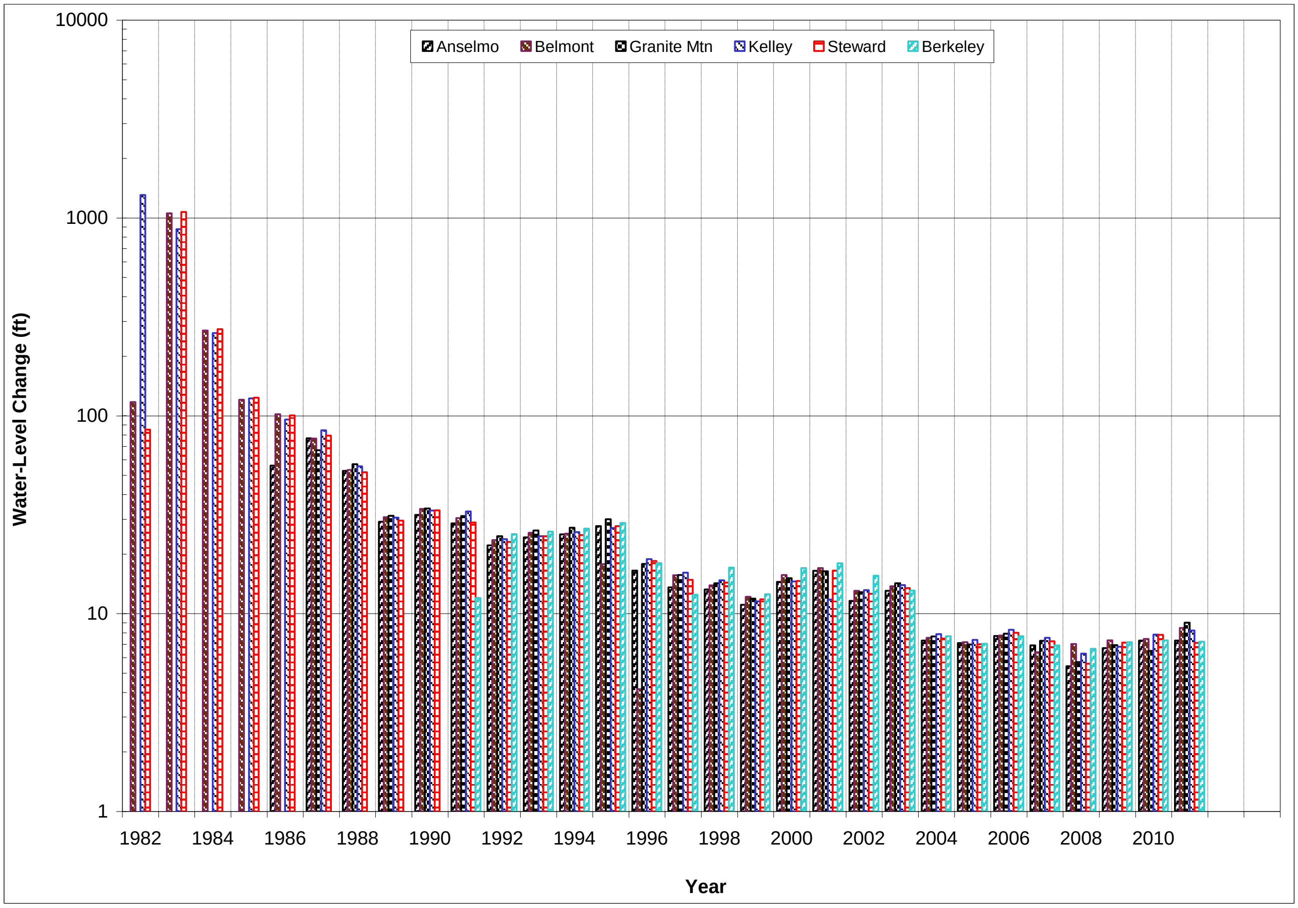


Figure 2-26. East Camp mines annual water-level changes.

Water levels for the Anselmo Mine and Kelley Mine for the period of record are shown in the hydrograph in figure 2-27. Except for the steadily increasing water levels, there are no obvious variations from the upward trend when viewed at this scale; however, when more detailed water levels are plotted from 1995 through 2011, several variations become noticeable (fig. 2-28). The removal of HSB drainage water discharging into the Pit in April 1996 slowed the rate of water-level rise, but the July 2000 addition of the HSB drainage water following MR's suspension of mining resulted in an increased rate of rise. The slope of the line, or rate of rise, shown in figure 2-28 remained constant throughout 2011, 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.

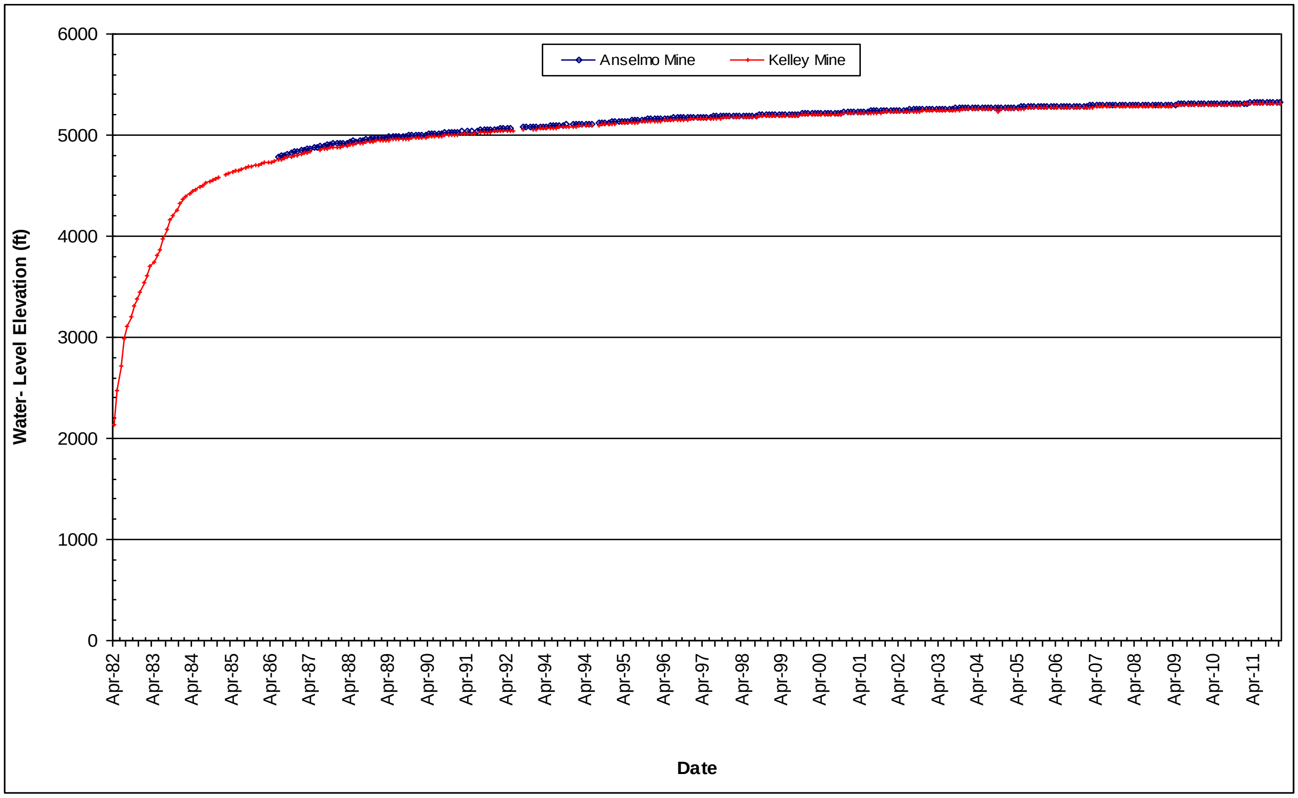


Figure 2-27. Anselmo Mine and Kelley Mine hydrograph, 1983–2011.

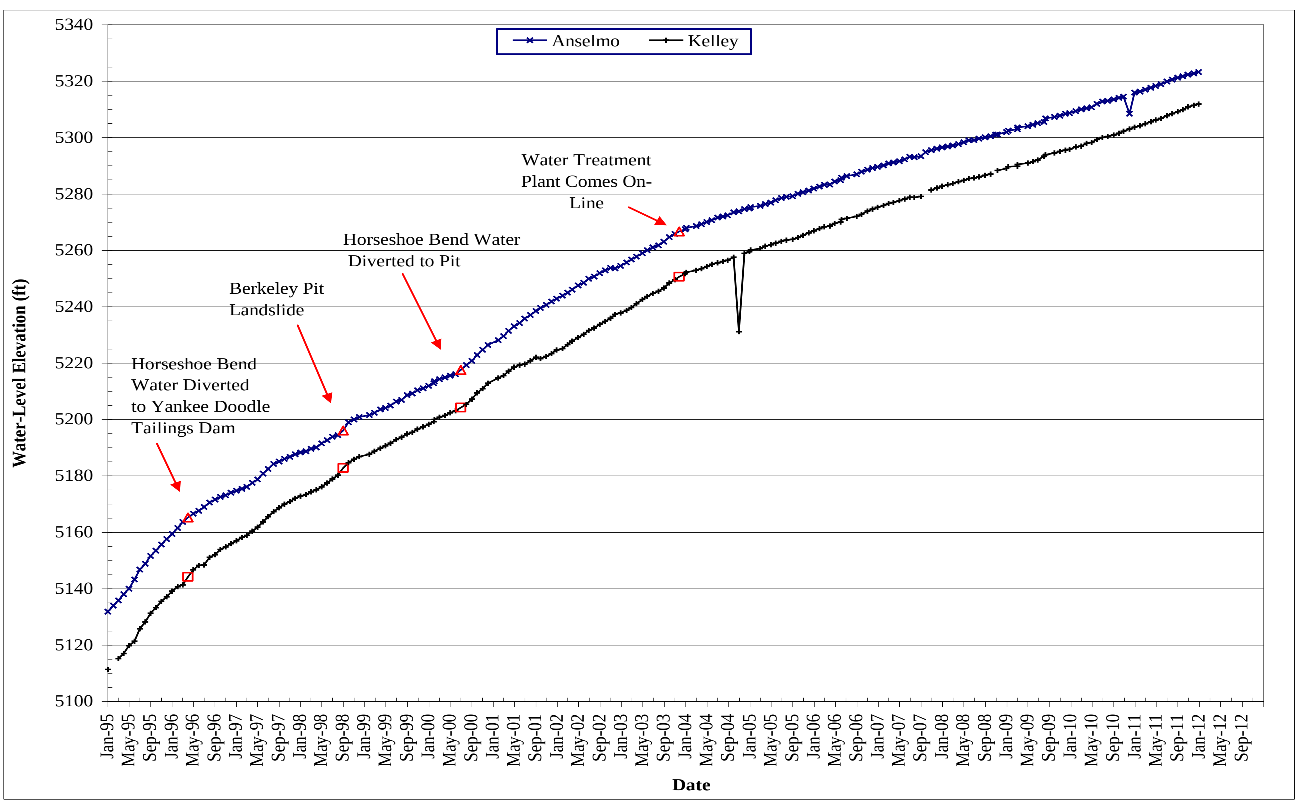


Figure 2-28. Anselmo Mine and Kelley Mine hydrograph, 1995–2011.

Figure 2-29 shows monthly water-level change in the Berkeley Pit from 1991 through 2011. The rate of water-level rise increased beginning in the last 6 months of 2000, following the addition of HSB drainage water, which continued through 2003. However, the rate of rise decreased beginning in 2004 as a result of the HSB treatment plant coming online and decreasing inflow into the Pit.

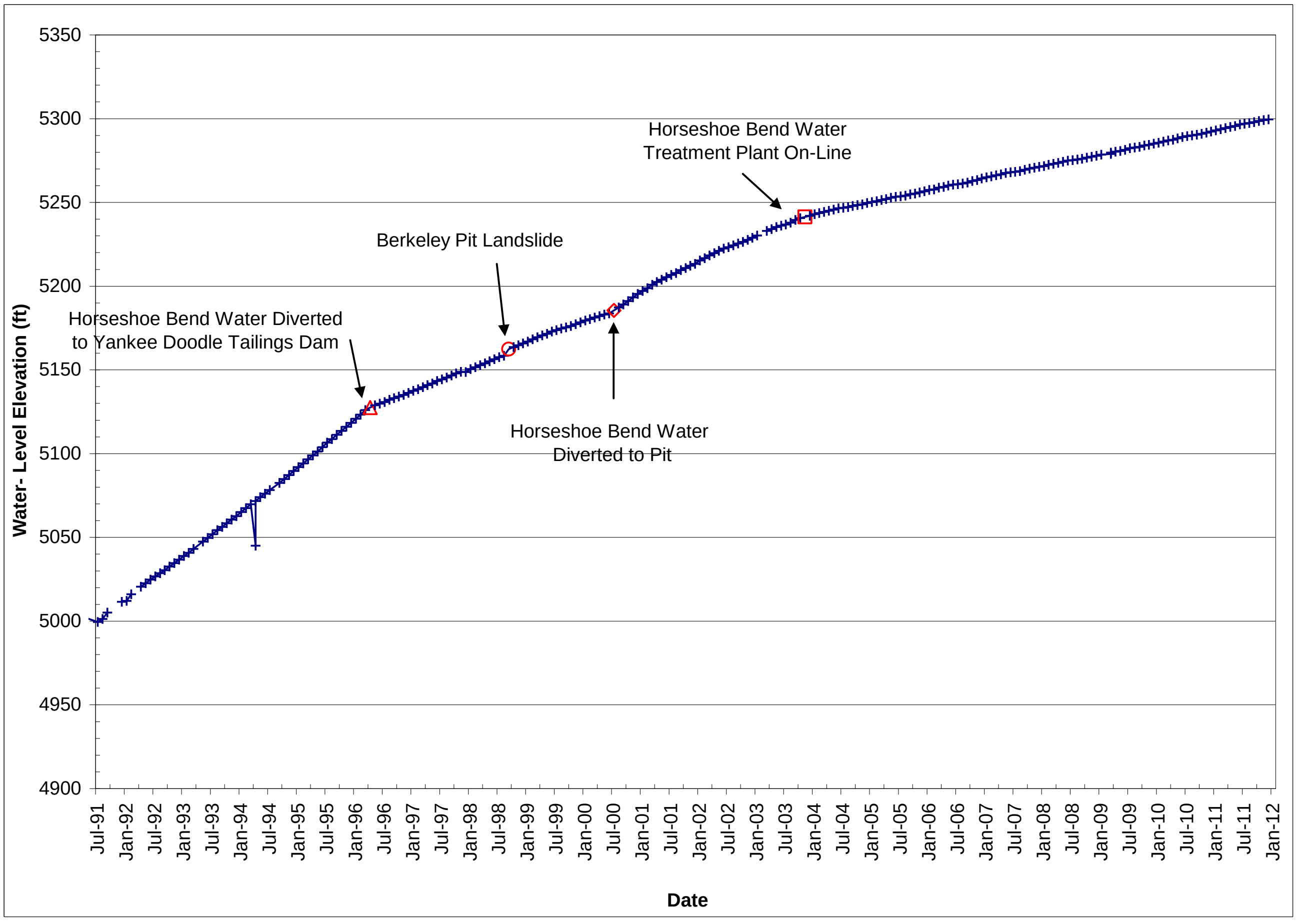


Figure 2-29. Water-level hydrograph for the Berkeley Pit, 1991–2011.

Figure 2-30 is a plot of selected mineshaft water levels and precipitation. There is no apparent influence on water levels in the underground mines from monthly precipitation. 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 the 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 2011 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.

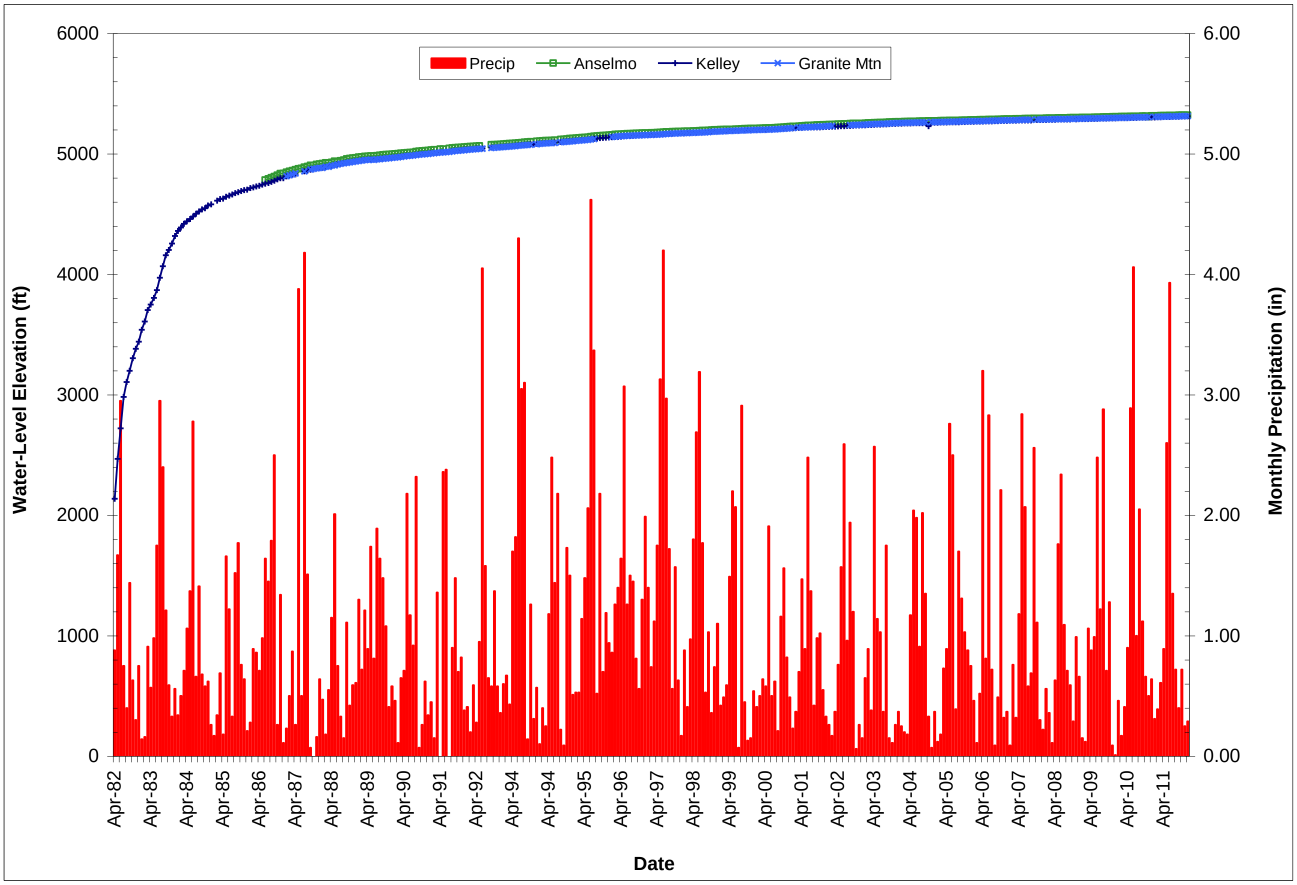


Figure 2-30. Water level hydrograph for selected East Camp mines, with monthly precipitation.

The 1994 ROD and 2002 CD established eight points of compliance (POC) in the East Camp bedrock system, five of which are underground mines. These points of compliance were selected to verify that contaminated water remains contained within the underground mines 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 2011 was the Pilot Butte Mine about 0.5 mi north of the Berkeley Pit (fig. 2-25), at an elevation of 5,326 ft, or 83 ft below the action level. The lowest water level at the end of 2011 was 5,300 ft in the Berkeley Pit, which confirms that groundwater continues to flow towards the Pit.

Section 2.2.1 Water Quality

Earlier reports (see list on page xiii) discussed the lack of appreciable change in water quality within the East Camp mines until 2002, when several of the shafts exhibited significant departure (increases) from previous trends. Data from 2011 indicate that elevated concentrations are sustained for yet another year. Most notable are elevated concentrations of arsenic, iron, manganese, zinc, and sulfate in the Kelley Mine waters. The Kelley and Steward mines were sampled during the spring 2011 sampling event at depths of 100 ft and 500 ft below the water surface. Concentrations varied little with sample depth. (Data shown in figures are from samples collected 100 ft below the water surface.) No depth sample was collected from the Anselmo Mine due to obstructions in the mine shaft.

Kelley: iron, sulfate, arsenic, and aluminum increased to near historic high concentrations in 2003–2004, decreasing gradually between 2005 and 2011. Iron and arsenic concentrations are shown in figure 2-31. Copper concentrations increased in the 2010–2011 samples; however, they remain low (333 to 255 µg/L, respectively).

Anselmo: iron concentrations remain elevated but are less than observed in 2004; arsenic concentrations were similar to those seen in 2004; zinc concentrations remain similar to those seen in 2007 (fig. 2-32). Copper concentrations remain low (<20 µg/L).

Steward: iron and arsenic concentrations remain high, following the 2004 increases. The trend has been downward for zinc and copper (fig. 2-33); however, zinc concentrations remain well above standards.

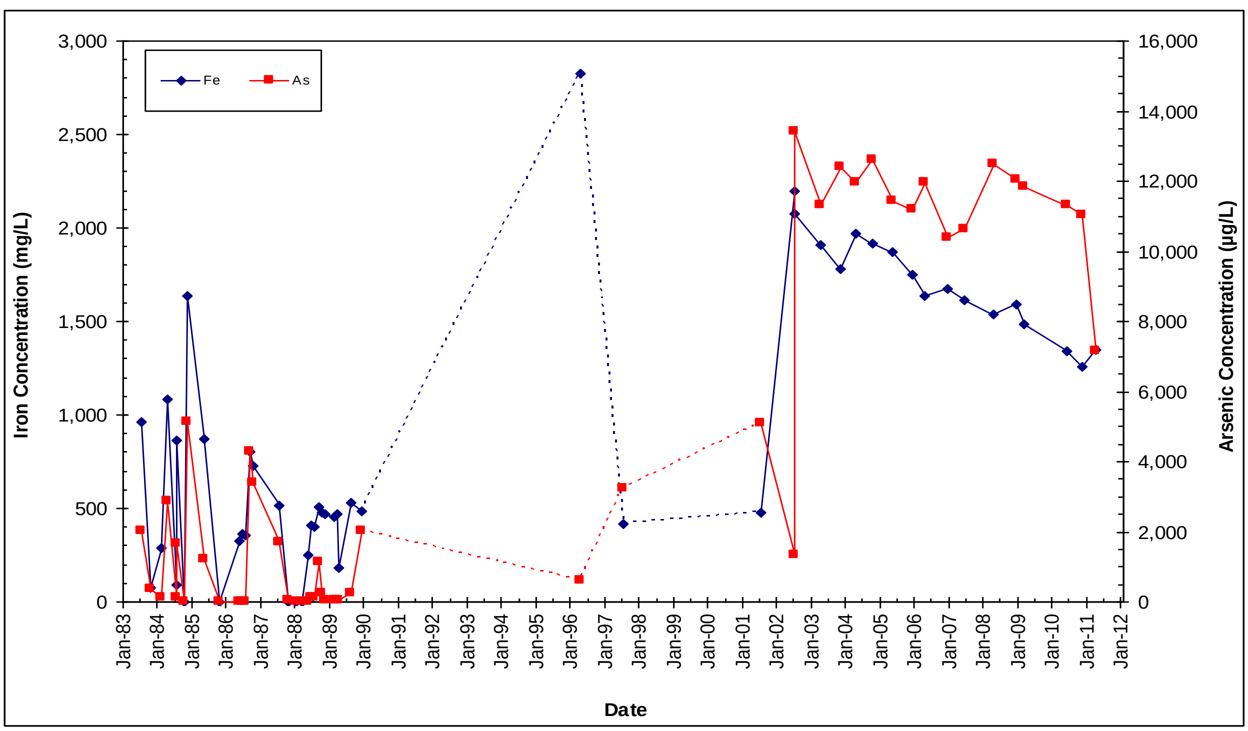
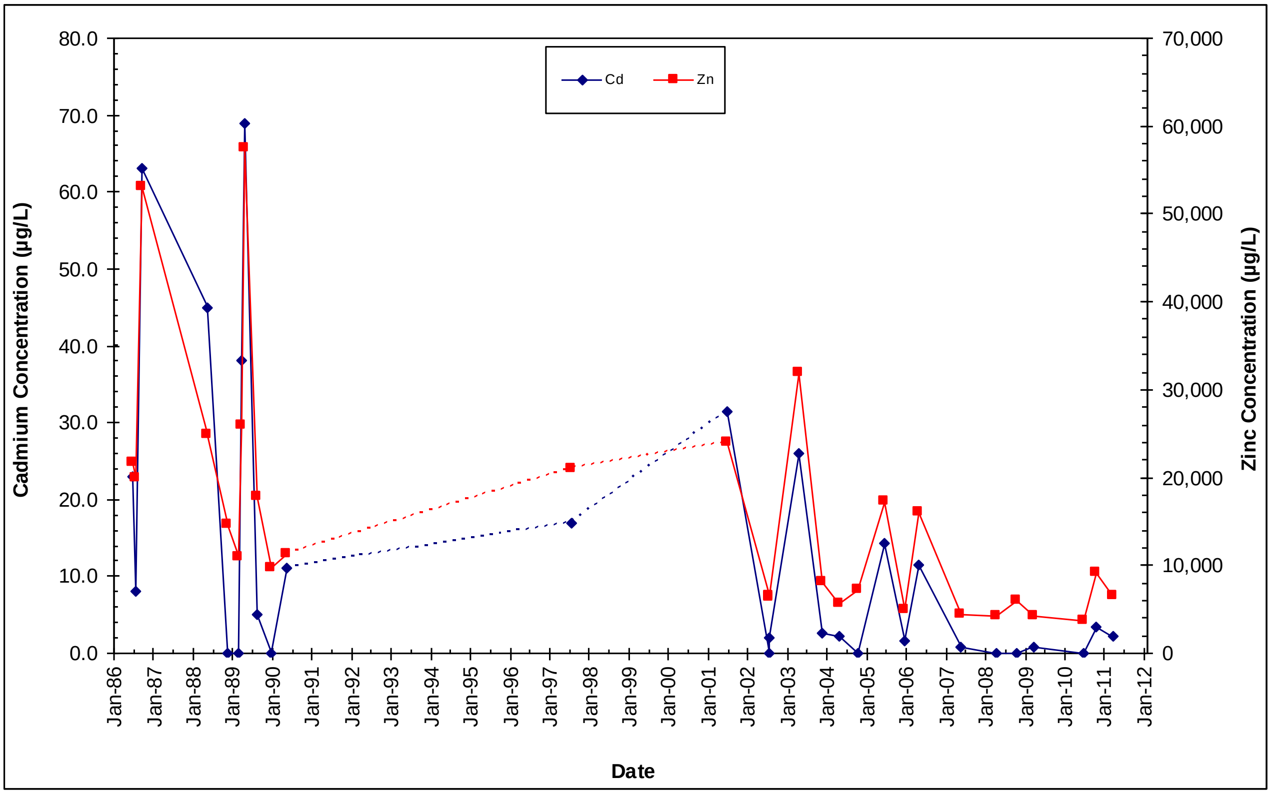


Figure 2-31. Iron and arsenic concentrations over time in the Kelley Mine.



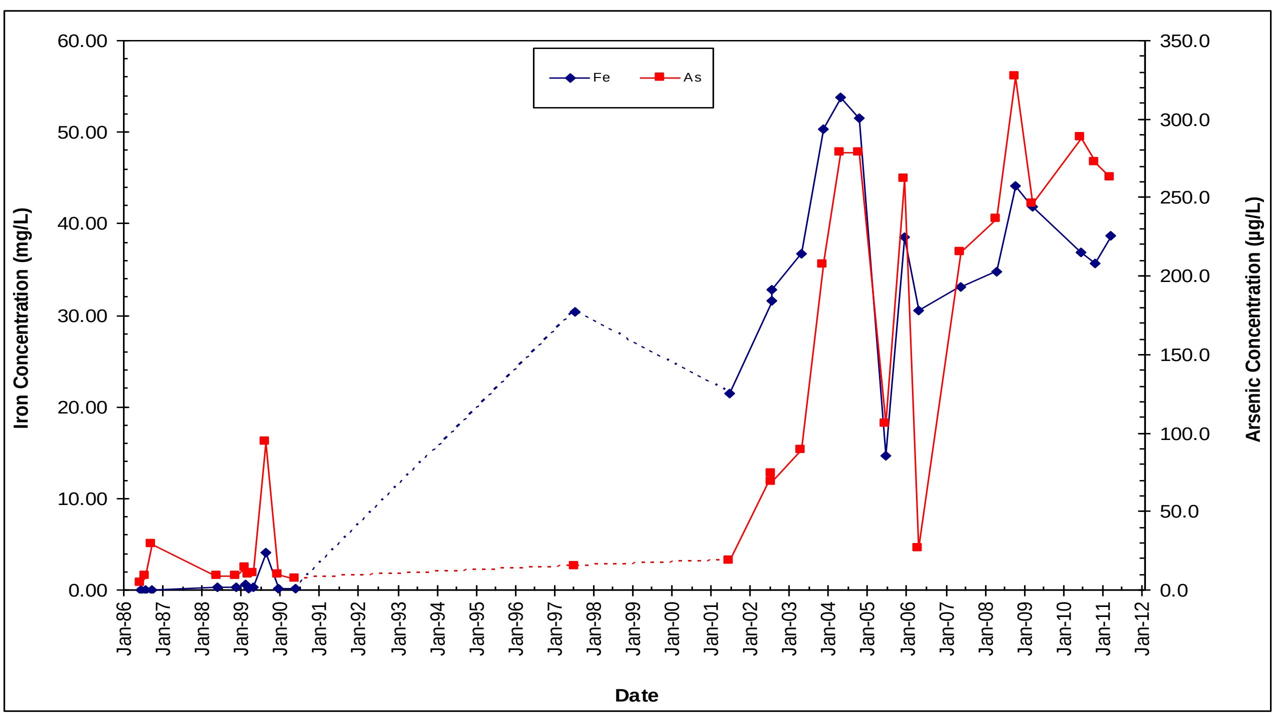
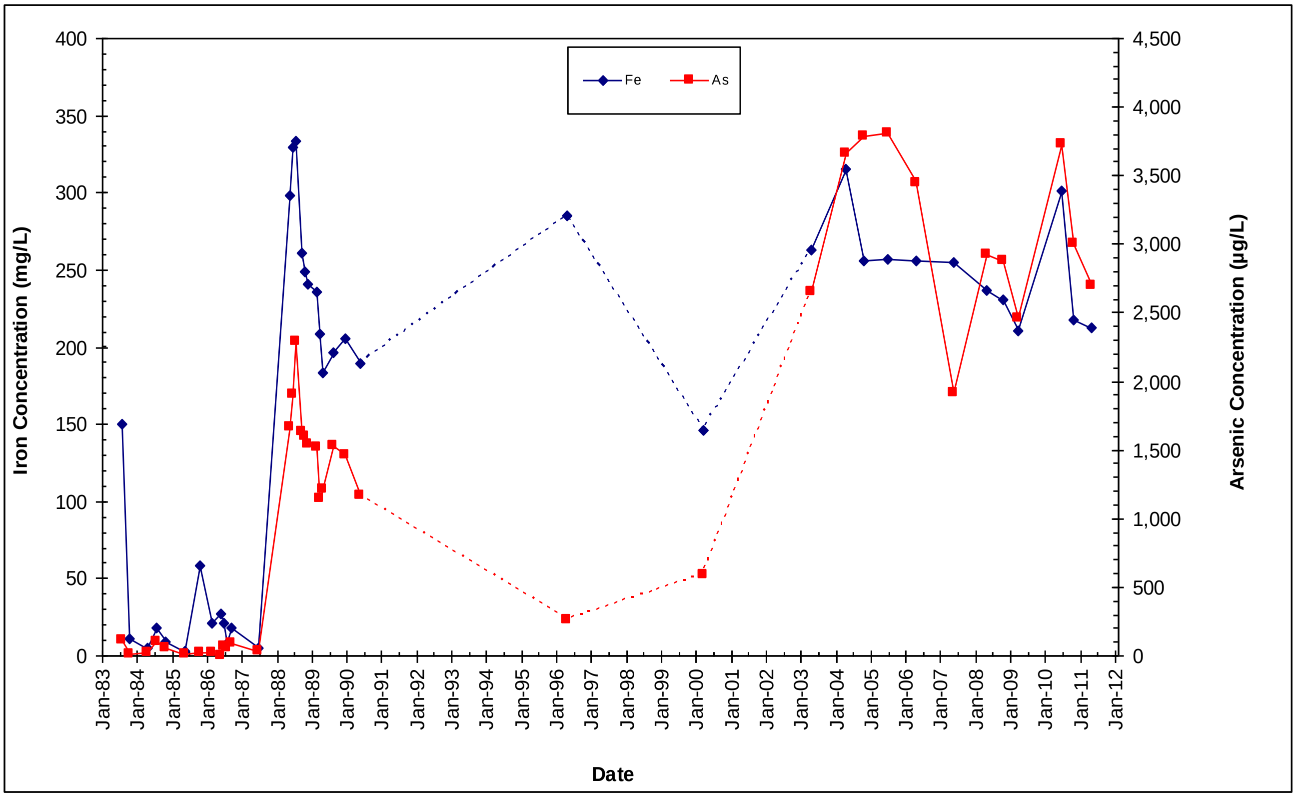


Figure 2-32. Iron and arsenic concentrations (top) and cadmium and zinc concentrations (bottom) over time in the Anselmo Mine.



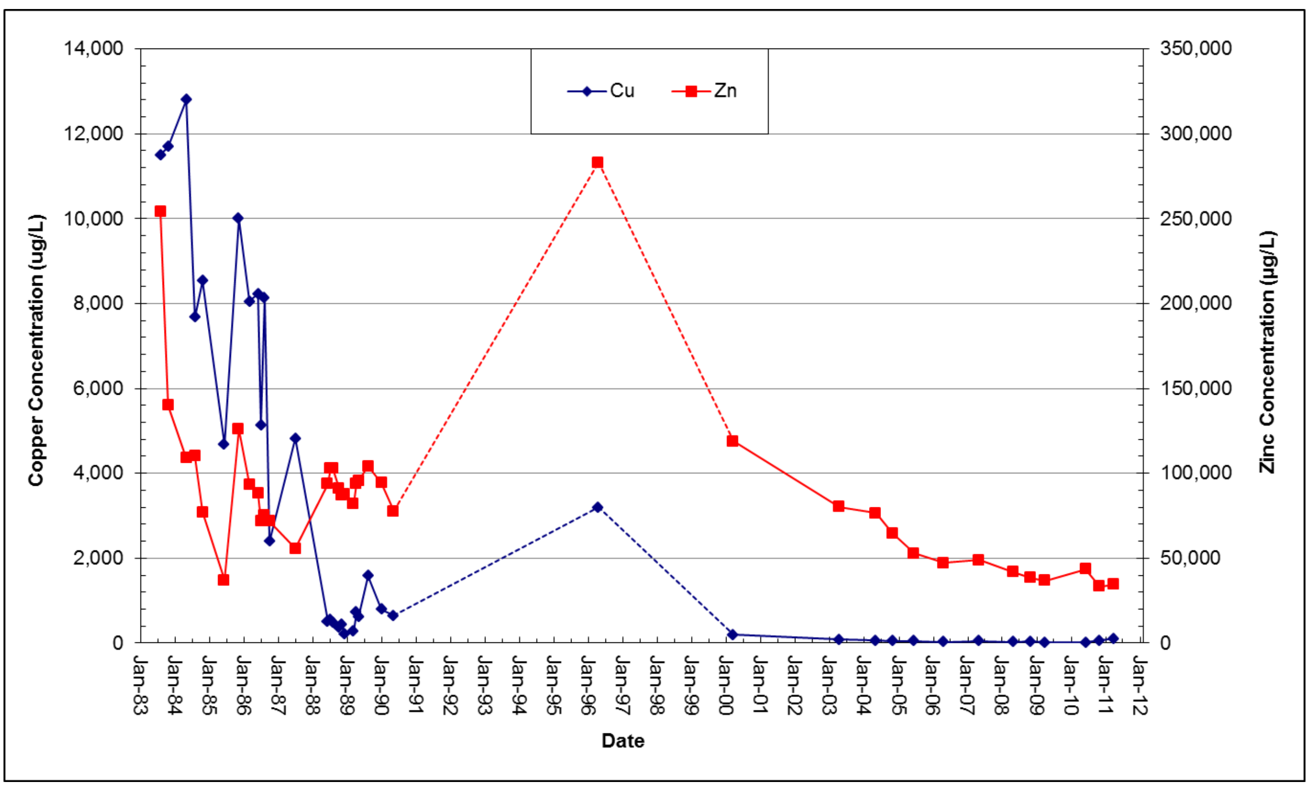


Figure 2-33. Iron and arsenic concentrations (top) and cadmium and zinc concentrations (bottom) over time in the Steward Mine.

Section 2.2.2 RI/FS Bedrock Monitoring Wells

Monitoring of the nine RI/FS and ROD-installed bedrock wells continued. Monitoring-well locations are shown in figure 2-25. Water levels rose in wells A, B, C, D-1, D-2, G, and J at rates similar to those in the East Camp Mine system; water levels in wells E and F increased at lesser rates. Table 2.2.1.1 contains yearly water-level changes, and figure 2-34 shows these changes graphically.

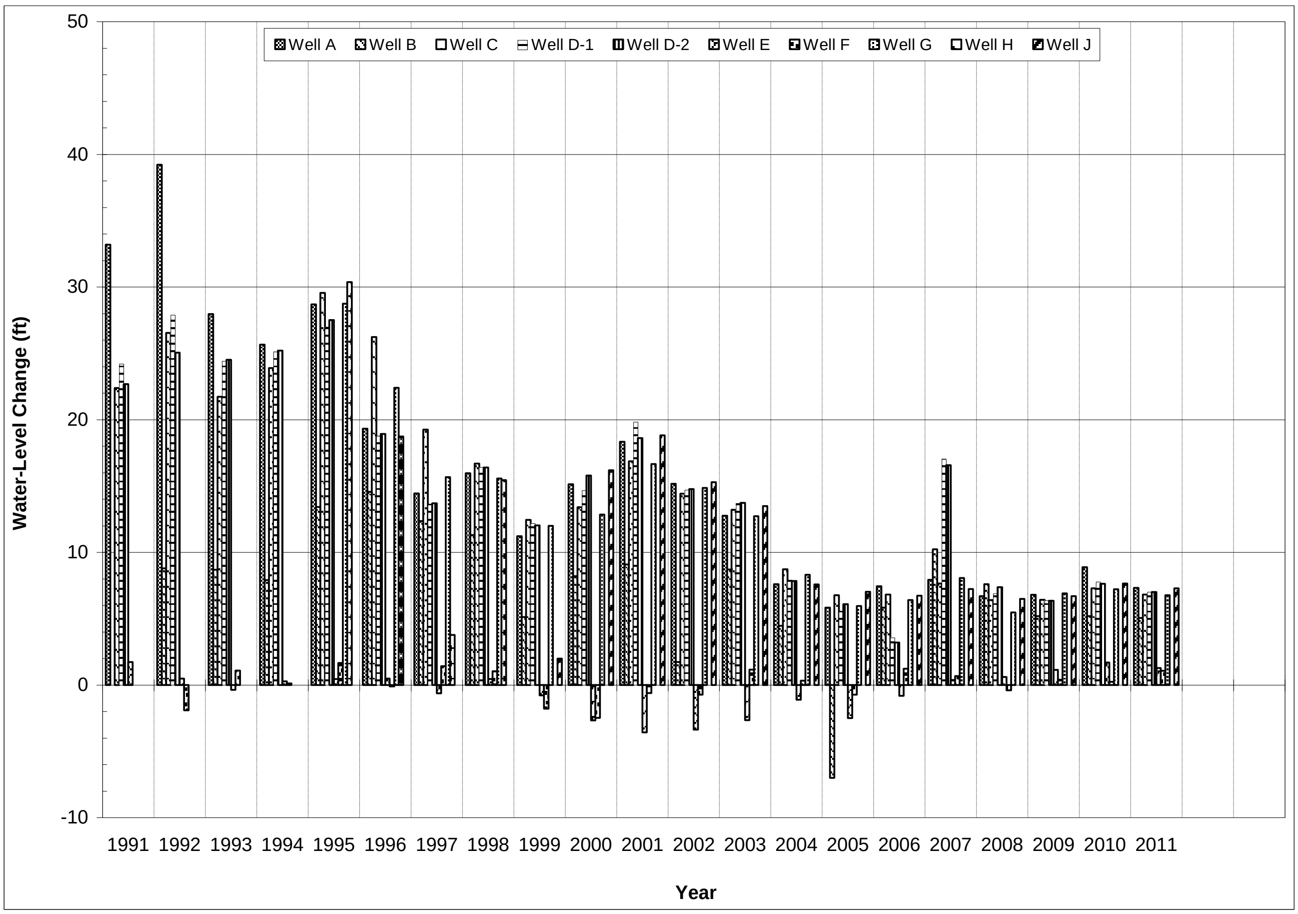


Figure 2-34. RI/FS bedrock wells annual water-level change.

Water levels in the bedrock aquifer, which had been affected by historic underground mine dewatering, are responding to the cessation of pumping and show no apparent relationship to precipitation or seasonal changes through 2011. Instead, 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, are the major influences. Figure 2-35 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 control the annual rate of rise in this system.

Table 2.2.1.1 RI/FS bedrock well annual water-level change (ft).

Year	Well A	Well B	Well C	Well D-1	Well D-2	Well E	Well F	Well G	Well H(1)	Well J(2)
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 2.2.1.1 RI/FS 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
Net Change	**335.44**	**146.31**	**313.35**	**314.52**	**310.83**	**-9.64**	**1.55**	**206.48**	**68.29**	**122.44**

(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 2.2.1.1 RI/FS 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

Table 2.2.1.1 RI/FS bedrock well annual water-level change (ft). (cont.)

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**
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**
Net Change	**338.38**	**346.45**	**276.05**	**240.42**	**417.18**

(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

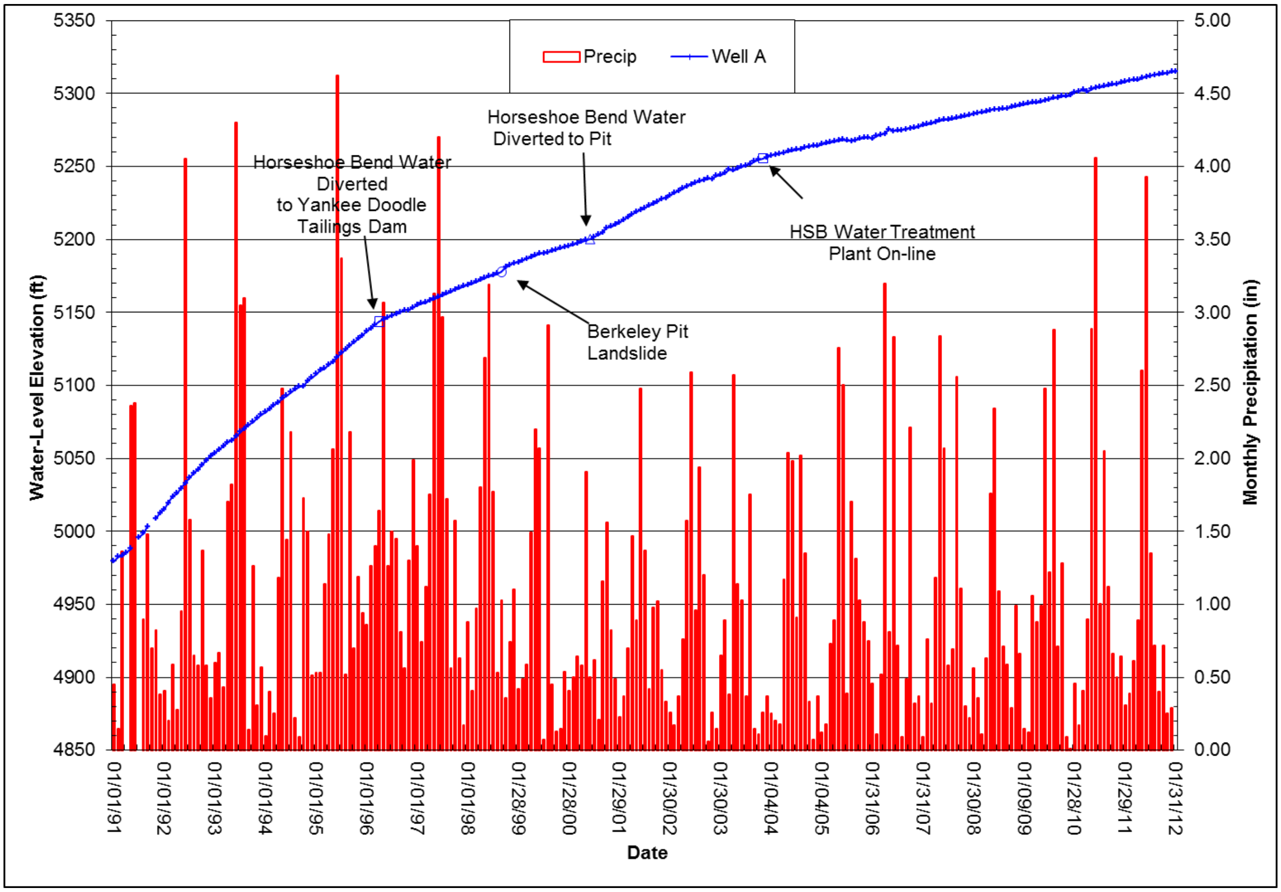


Figure 2-35. Water-level hydrograph for bedrock well A.

The water-level change in well B was about one-half the rate of the other bedrock wells and Berkeley Pit until November 2002. Due to a water-level decline during November and December, the 2002 rate of water-level rise in well B was only 11 percent of that in the Berkeley Pit. The 2003 and 2004 water-level increases were closer to 60 percent of that of the other bedrock wells; however, the apparent influence of the July 2005 Dillon, Montana earthquake and slow recovery from water-quality sampling caused water levels in well B to fall about 7 ft in 2005. 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 2008 water-level increase in well B was only slightly higher than that seen in any of the wells or mines in the East Camp system; the 2009–2011 increases were 1–2 ft less than the other bedrock wells and mine shafts. 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 shown in figure 2-36.

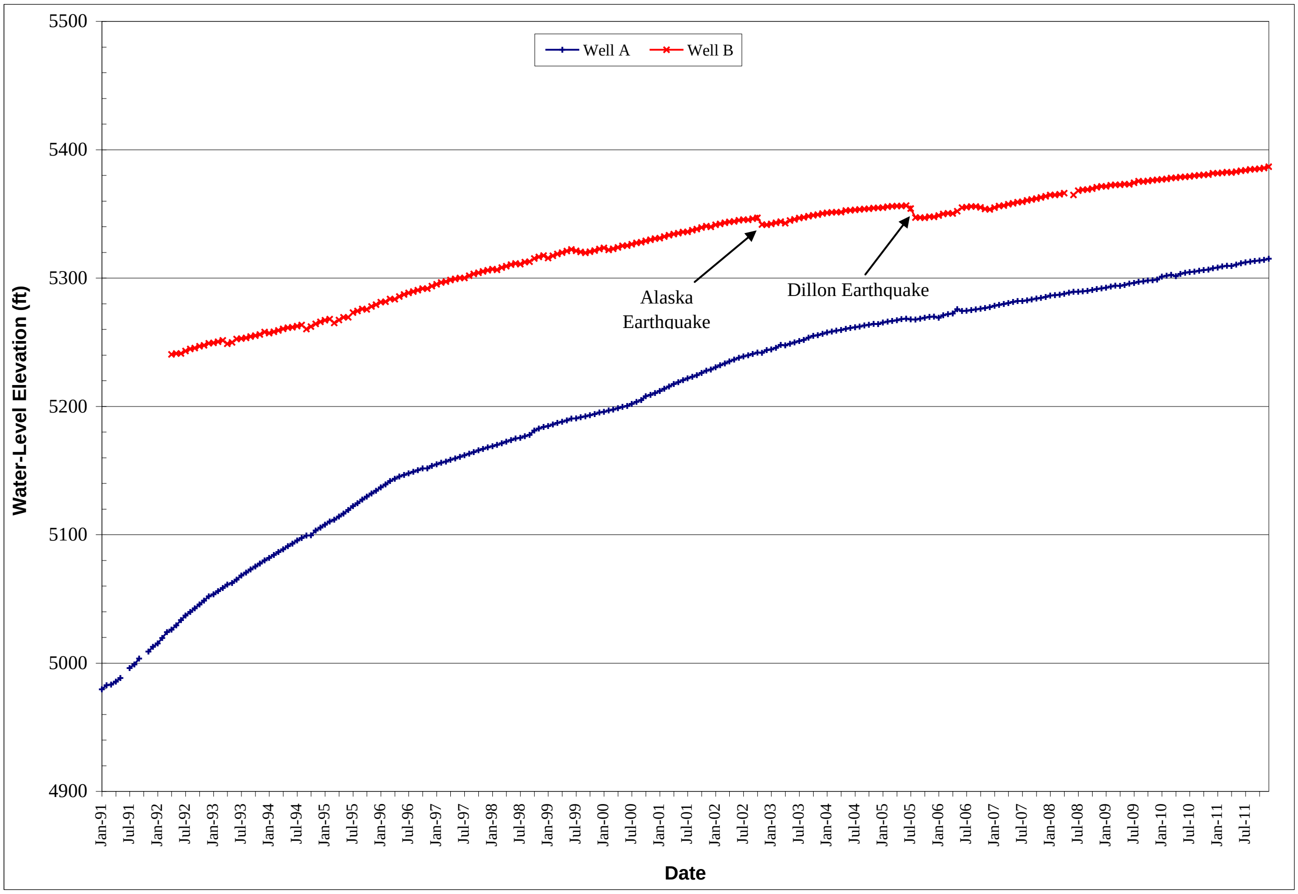


Figure 2-36. Water-level hydrographs for East Camp bedrock wells A and B.

Water levels in wells E and F do not follow the long-term upward patterns observed in the other bedrock wells (fig. 2-37). Water levels in these two wells are considerably higher than those in the other bedrock wells, indicating a lack of interconnection to historic mining activities and impact from dewatering. The water level in well E has a net decline of about 10 ft over time, while well F has a net increase of less than 2 ft.

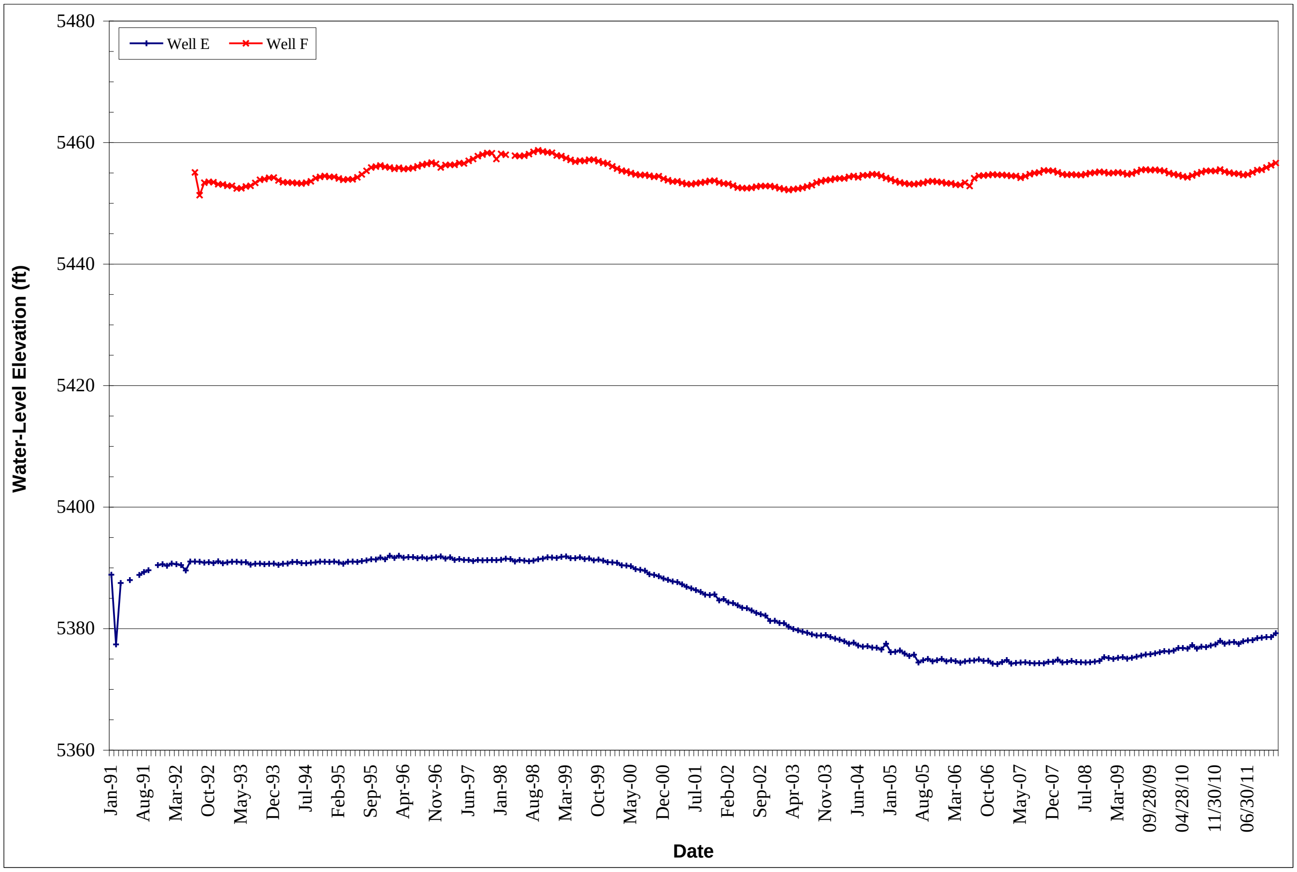


Figure 2-37. Water-level hydrographs for East Camp bedrock wells E and F.

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 2-38. Historic water levels for well H are also shown as well as a linear projection through 2011. Water levels for well J initially plotted very closely to well H projected levels, verifying that well J was completed in the same bedrock zone as well H. However, beginning in April 2004, the water level for well J plots below the projected water level for well H, because the Berkeley Pit filling rate is slowing because of 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 currently be more than 50 ft higher than currently. The diversion of HSB drainage water away from the Pit has had a significant impact, as seen by the slowing Pit filling rate.

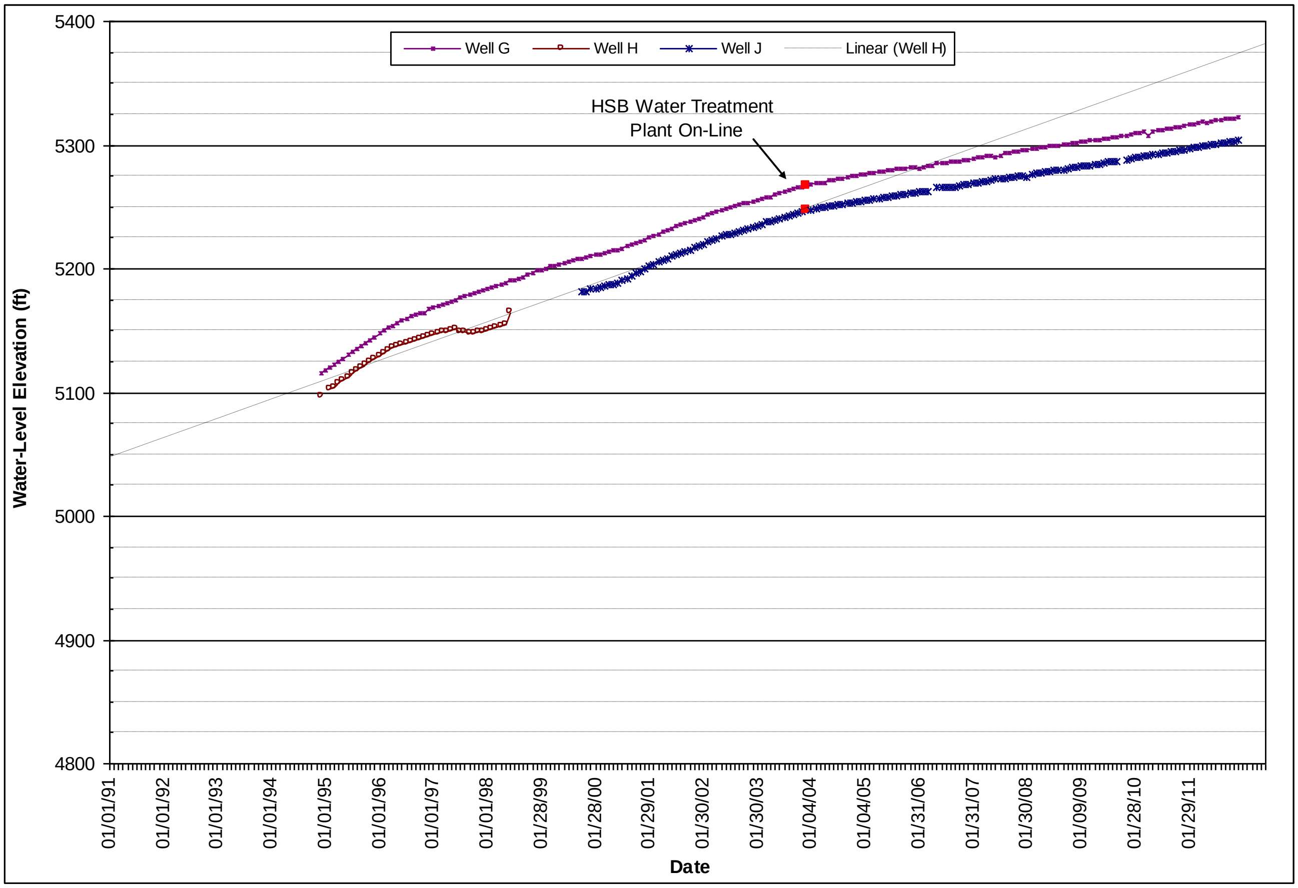
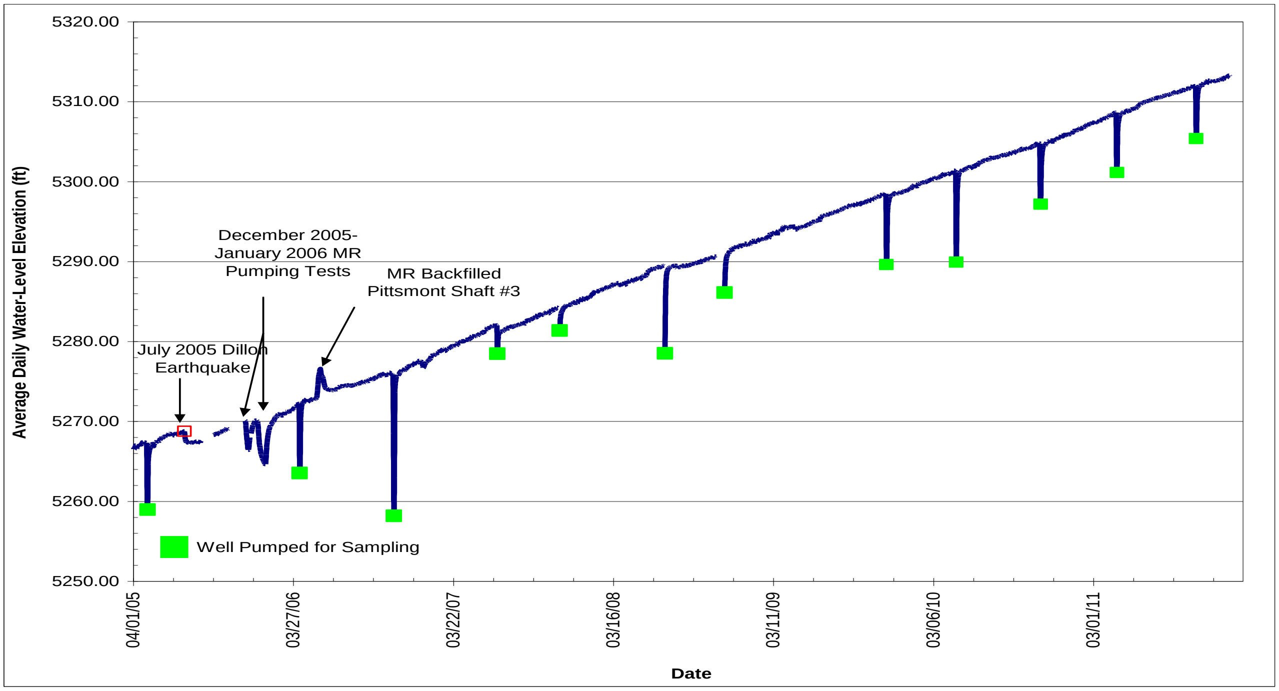


Figure 2-38. Water-level hydrographs for bedrock wells G, H, and J.

The monitoring program mandated in the 2002 CD specified that water levels be monitored continually 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 2-39 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 the level of detail when each different event occurred, while the bottom graph shows the level of detail from monthly water-level measurements. The transducer data allow the time a change occurs to be resolved to a 1-h time interval and a better determination of its magnitude. The increased level of monitoring allows a more accurate interpretation of water-level changes whether they are natural (i.e., earthquakes or slumps) or human-induced (i.e., pumping). Additional bedrock wells, beyond those specified in the 2002 CD, have been equipped with water-level transducers to better track water-level changes in the East Camp bedrock system in response to various mining-related activities, i.e., grouting and back-filling of underground mine workings, and the MERDI/MSE pumping test at the Belmont Mine site. The sites with increased level of monitoring are: D-2, DDH-2, Well J, and Parrott 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. 2-40) for the East Camp bedrock aquifer shows the flow of water from all directions is towards the Pit. While there were short-term influences on water levels in a number of these wells, the overall direction of groundwater flow did not change.



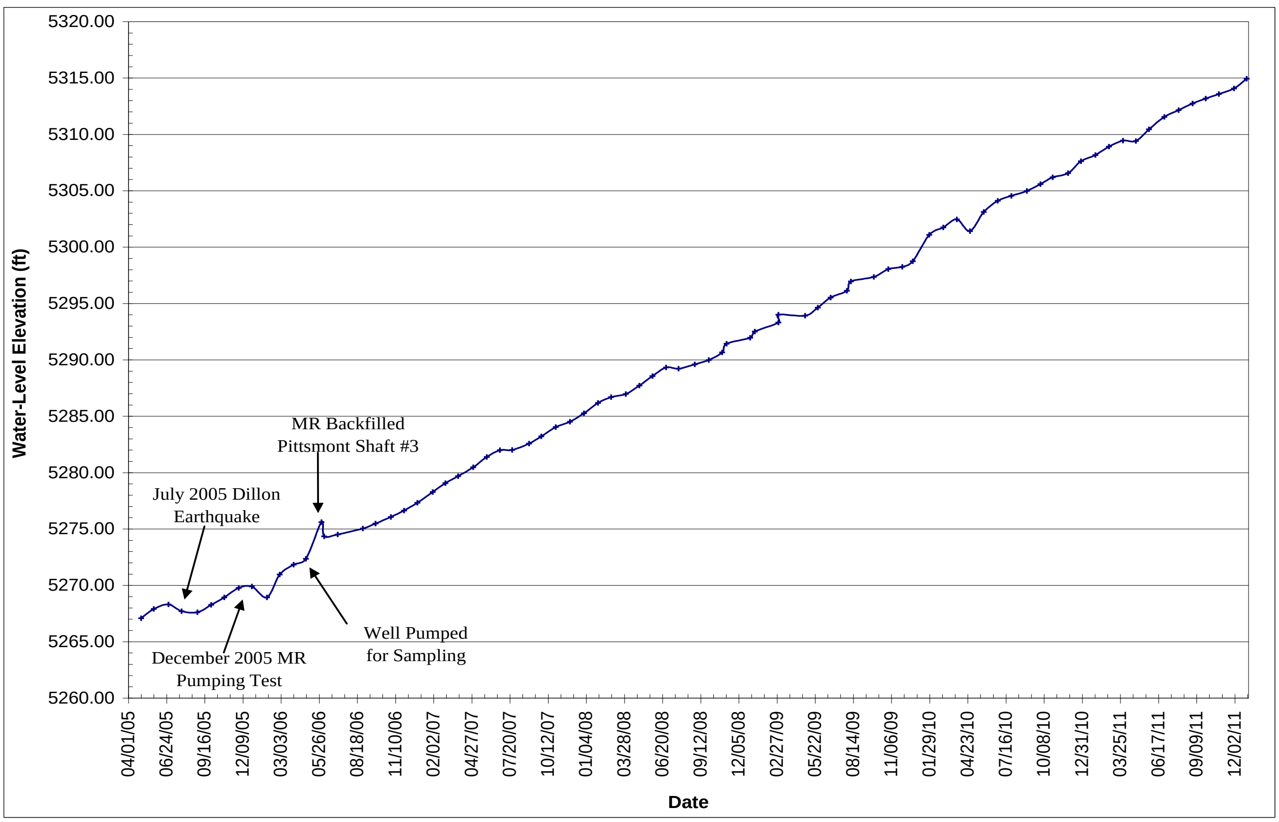


Figure 2-39. Hydrographs for well A comparing daily average water level (top) and monthly water level (bottom) monitoring frequency.

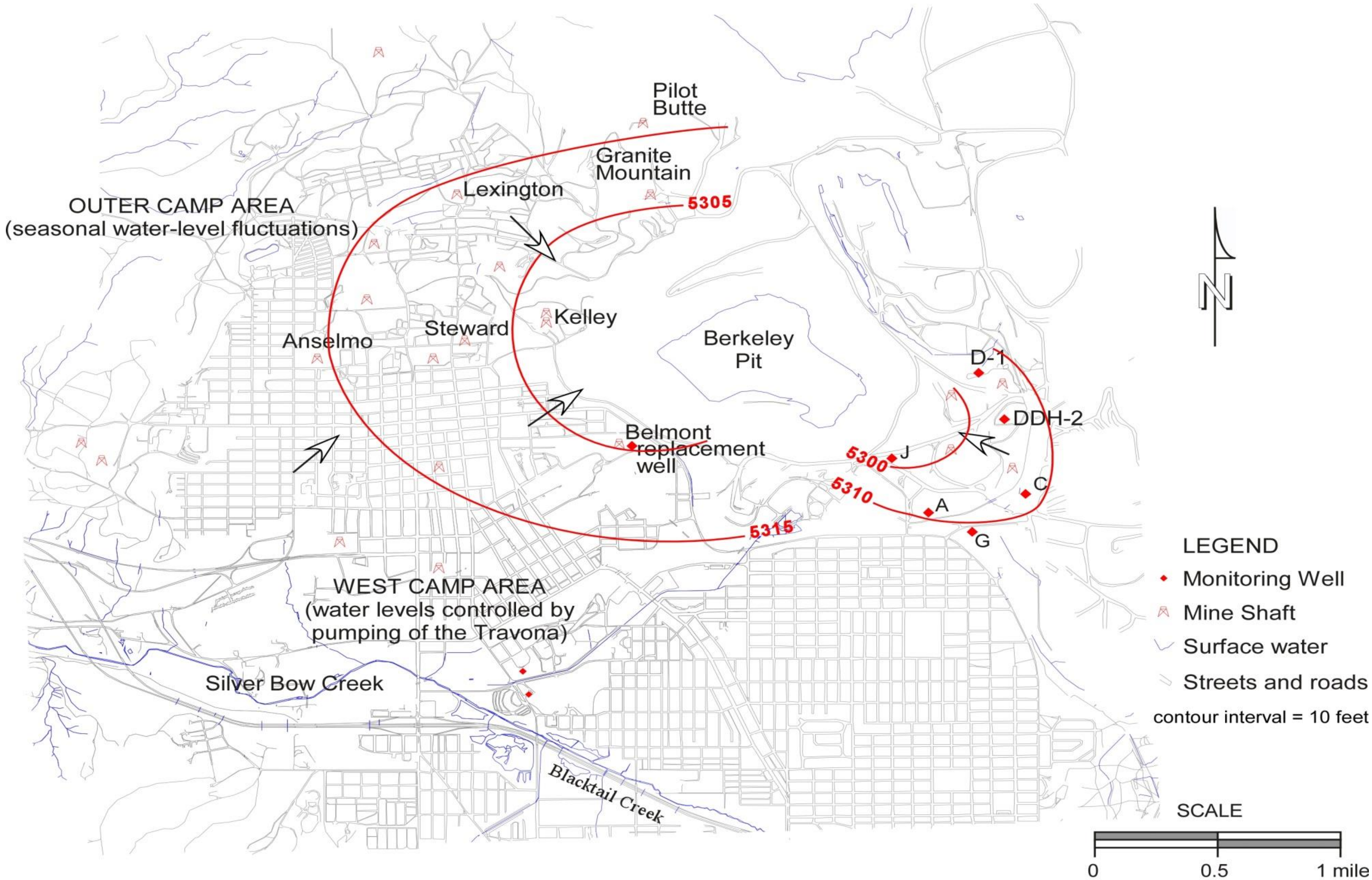


Figure 2-40. Potentiometric map for the East Camp bedrock aquifer, December 2011; arrows indicate direction of groundwater flow (contour interval is 10 ft).

Section 2.2.2.1 RI/FS Bedrock Well Water Quality

Water quality in the East Camp bedrock wells has shown little change in recent years. Data collected in 2011 indicate only slight change for most wells. Table 2.2.1.1.1 summarizes the water-quality trends over the past few years; as noted in previous reports, the status of well B changed with respect to MCLs due to the change in the water-quality standard of arsenic from 18 µg/L to 10 µg/L. In water from most wells, there was little change in the concentration of dissolved constituents. Arsenic was the only MCL exceeded in water from the bedrock wells (excluding well J), while iron, manganese, zinc, and sulfate were the SMCLs most often exceeded. In addition, several wells have pH levels below the recommended limit of 6.5.

While water from the majority of sites exceed one or more secondary standards, the concentrations from different wells can vary considerably. Figure 2-41 shows iron and arsenic concentrations for six of the bedrock wells sampled during the spring of 2011. In figure 2-39, iron concentrations vary from 1 to greater than 400 mg/L; arsenic concentrations vary from 2 to greater than 1,200 µg/L.

Bedrock well J has the greatest number of water-quality exceedances. Water quality in this well has been very poor as expected, considering its close proximity to the Pit and the interconnection of adjacent mine workings to the Pit. The well is completed approximately 40 ft above workings from the Pittsmont Mine that extend to the Pit. Figure 2-42 compares selected trace metal concentrations in water from well A, well J, and the Berkeley Pit sample collected from 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 observations supported by water-level monitoring that bedrock groundwater flow is towards the Pit and no contamination is leaving the site. The extremely high concentrations of copper, cadmium, and zinc in the Pit water and in water from well J show that any flow from these sites away from the Pit would be easily detected in samples from more distant wells.

Table 2.2.1.1.1 Exceedances and recent trends for East Camp bedrock well water quality, 1989 through 2011.

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

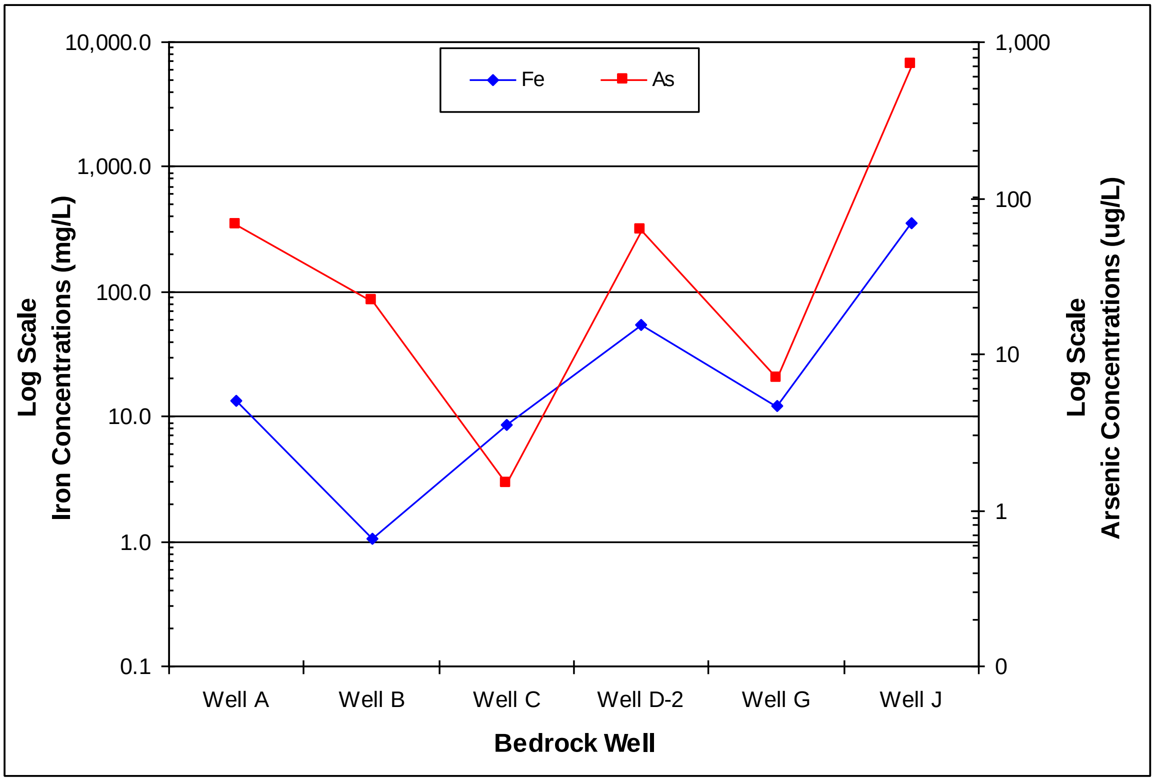


Figure 2-41. Bedrock well iron and arsenic concentration comparisons, spring 2011.

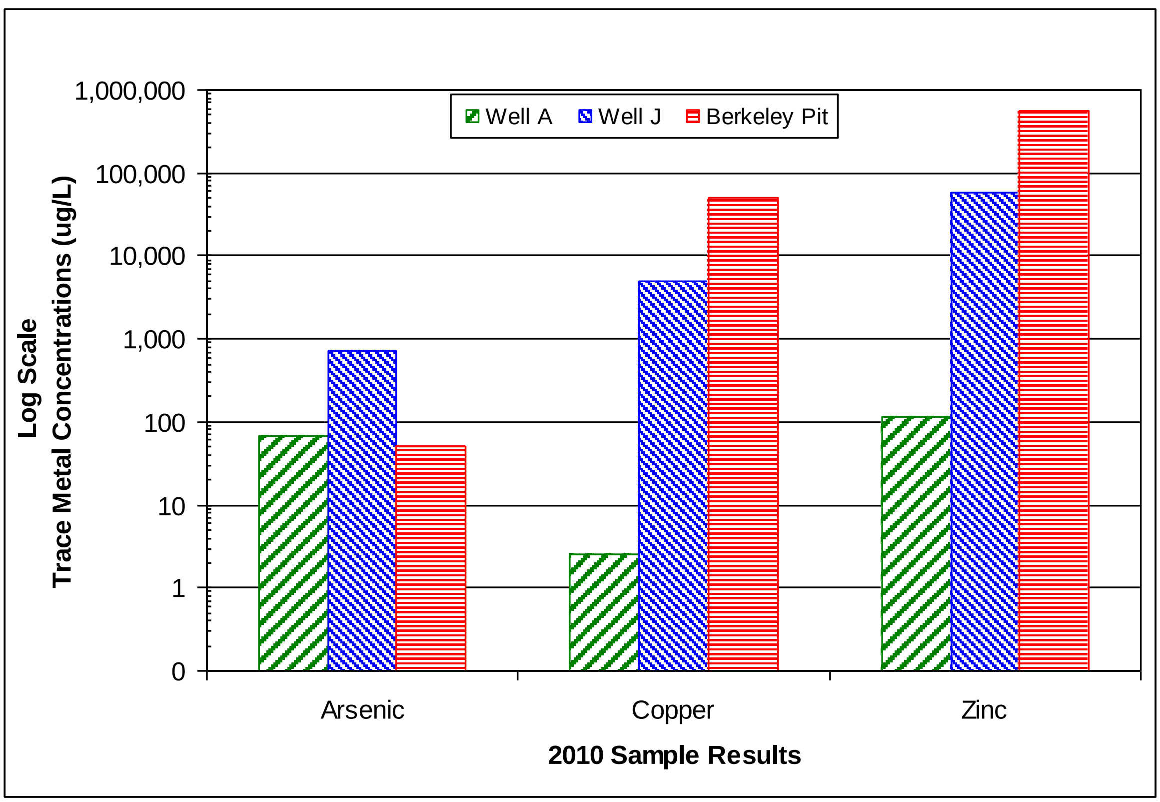


Figure 2-42. Selected trace metal comparisons between bedrock wells A, J, and the Berkeley Pit 1-ft depth sample.

Section 2.2.3 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. Well DDH-1 can no longer be monitored because during site maintenance and cleanup around the concentrator facility in 2007, the well was apparently accidently plugged. For the year 2011, water levels rose 7.44 and 4.93 ft, respectively, in DDH-2 and DDH-8, consistent with water-level rises in the RI/FS bedrock wells and East Camp mine shafts. Figure 2-43 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, with water levels rising more than 52 ft. The increase occurred at a time when 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 unusual 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-08 during 2011 was similar (4.93 ft) to that in the other bedrock wells; however, the water-level elevation is now more than 50 ft higher than that in the other bedrock wells due to the unexplained 2005 increase. It is important to note that 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. Due to completion uncertainties and the drilling techniques, it is not unexpected to have problems occur with these wells. In the past, another 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.

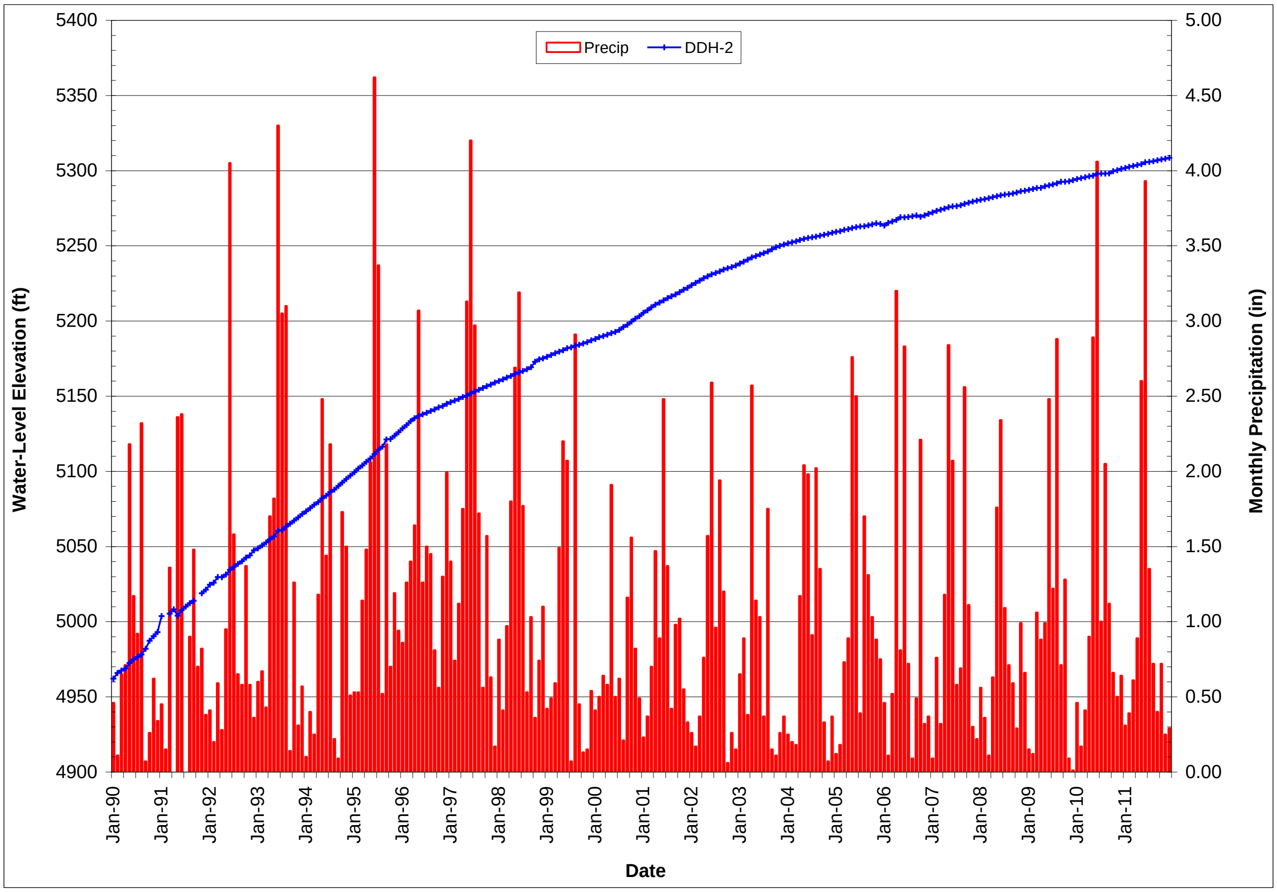


Figure 2-43. Water-level hydrograph for bedrock well DDH-2.

Section 2.3 Berkeley Pit and Horseshoe Bend Drainage

The Berkeley Pit water-level elevation was surveyed each month to coincide with monthly water-level monitoring in wells and mine shafts. The hydrograph in figure 2-44 shows the Pit's water-level rise since 1995.

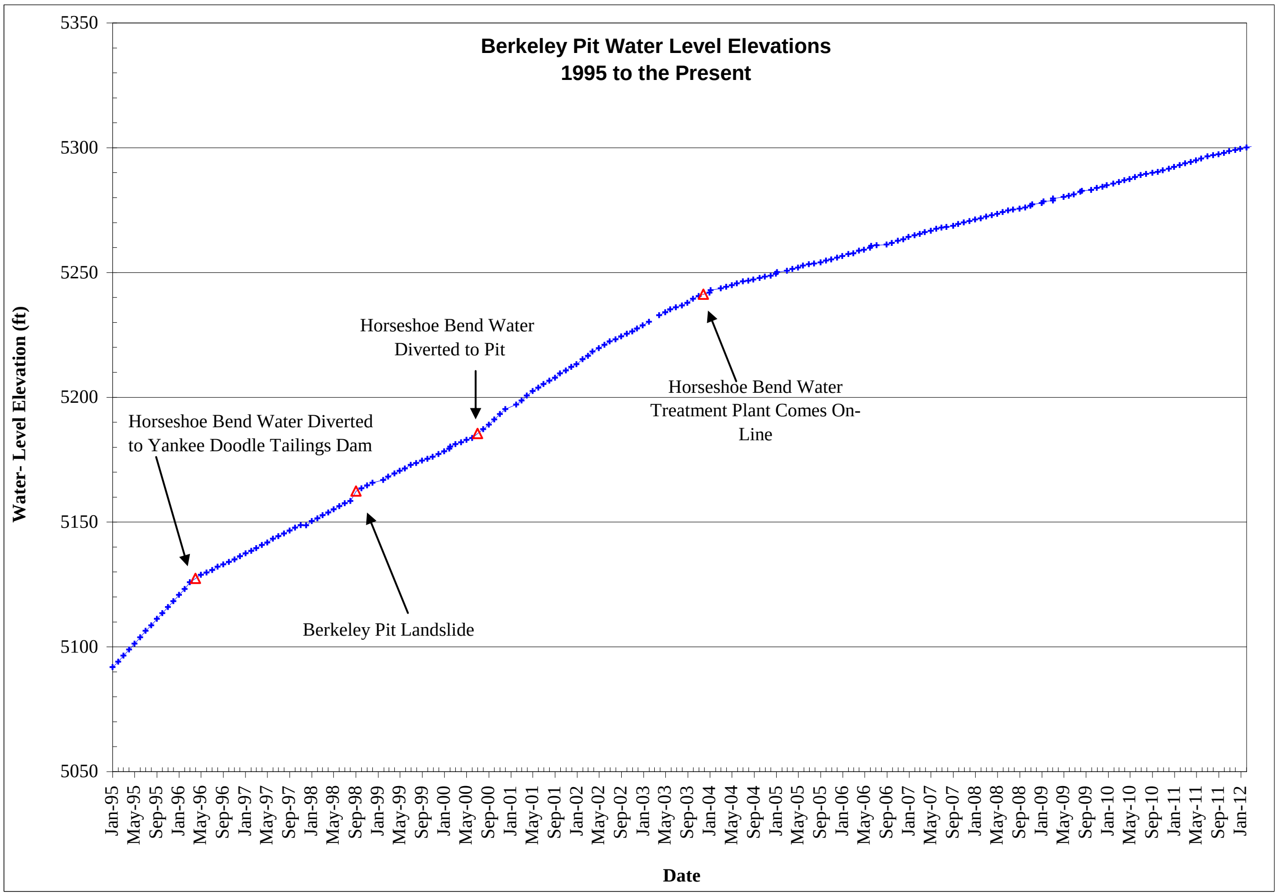


Figure 2-44. Water-level hydrograph of Berkeley Pit, 1995–2011.

The current overall Berkeley Pit water-level elevation trend is similar to that of previous years. Four changes in slope in figure 2-44 show the influence of HSB diversions and a landslide 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 and incorporated into the mining and milling process; 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 to a decreased filling rate 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 2011 was 7.20 ft, compared to 7.32 ft for 2010. Table 2.3.1 summarizes the changes in handling HSB water and other events that influenced changes in Berkeley Pit water-level filling rates.

Table 2.3.1 Summary 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	3-plus ft water-level increase
June 2000	MR suspends mining operations; HSB water diverted to Berkeley Pit. Water from Continental Pit diverted to Berkeley Pit.	Increases Pit water-level filling rate
November 2003	MR resumes operations and HSB water-treatment plant comes online	Slows the Pit filling rate

The 2002 CD contains a stipulation that the water level in the Berkeley Pit must remain below four mines and four bedrock monitoring wells identified as the points of compliance (POCs). The POCs are listed in table 2.3.2 along with December 2011 water-level elevations and December 2011 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 2.3.2. East Camp points of compliance and depth below CWL, December 2011.

Point of Compliance	December 2011 Water-Level Elevation (ft)	Depth Below CWL (ft)
Anselmo Mine	5323.24	86.76
Granite Mountain Mine[1]	5315.29	94.71
Pilot Butte Mine[1]	5326.11	83.89
Kelley Mine	5311.89	98.11
Belmont Well #2	5312.65	97.35
Well A	5314.94	95.06
Well C	5311.72	98.28
Well G	5322.52	87.48
Berkeley Pit (not a compliance point)	5299.50	110.50

[1]November 2011 water-level elevation, no access during December monitoring.

Flow monitoring of the Horseshoe Bend drainage (HSB) continued throughout 2011. Ice build-up on the holding pond and bio-fouling of the transducer used to measure flow were ongoing problems through 2010. However, more frequent site visits to clean the transducer and note gauge height readings have helped to improve data quality. In late 2007, buildup of iron-hydroxide within the inlet pipe periodically caused backwater conditions potentially seen as erroneous high-flow measurements. The 2007 average daily flow rate was 3,297 gpm, an increase of almost 500 gpm over average flows measured in 2006. The 2011 average daily flow rate was 3,464 gpm, an increase of 353 gpm over the 2010 average. A total of 1.81 billion gallons of water flowed through this site in 2011 to be treated by the HSB water treatment plant. Figure 2-45 shows the daily average flow rate from July 2000 through December 2011.

A non-contact radar system (Radar Level Sensor™) was installed at the HSB monitoring station during the fall of 2011 to replace the transducer and collect more reliable flow data. The unit sends radar signals onto the water surface (16 pulses per second) to measure the distance to the water surface during a 25-s interval once each hour. Figure 2-46 is a view of the radar system's installation. A new staff gauge was installed concurrently and sediment that had accumulated over the past 8 years in the pool behind the weir plate was removed.

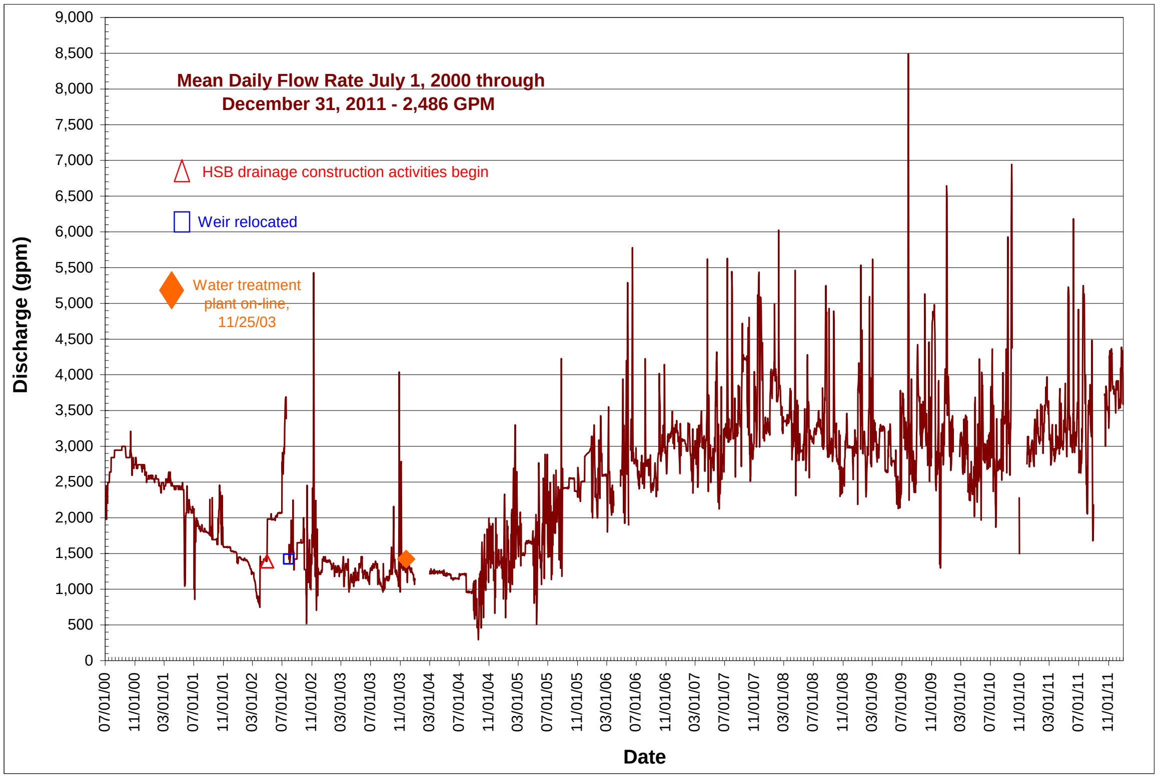


Figure 2-45. Horseshoe Bend Drainage flows: July 2000 through December 2011.

Figure 2-46. Radar system installation at the Horseshoe Bend weir monitoring station.

Flows measured at the HSB Falls flume averaged 177 gpm during 2011, a decrease of 129 gpm (40 percent) from the 2010 average. The flow in 2010–2011 also was considerably less than in prior years, and the historic flow rates of 1,000 gpm or more reported by MR. Figure 2-47 is a hydrograph for the total period of record based on historic flows measured when MR operated the site, and flows 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.

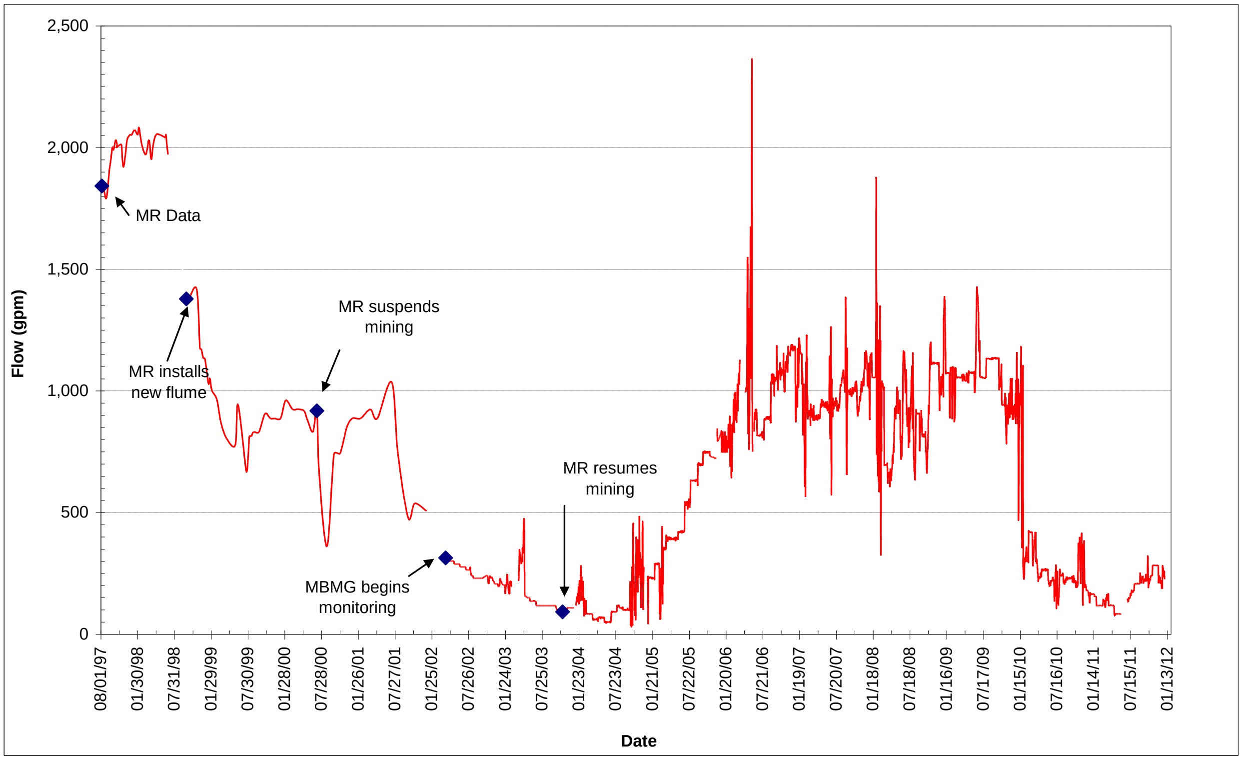


Figure 2-47. Horseshoe Bend Falls long-term daily average flow rates; includes both MR and MBMG data.

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 very important to the flow of water from the HSB drainage.

Section 2.3.1 Berkeley Pit and Horseshoe Bend Drainage Water Quality

Water-quality sampling of the Berkeley Pit occurs each year in late spring and late fall, at a minimum of three depths. In addition to collecting samples for inorganic analysis, a vertical profile of the upper 650 ft of the water column provides *in situ* measurements of: 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 at the weir used for flow monitoring just upstream of the influent pond associated with the water treatment plant. Therefore, water samples represent the water entering the plant.

Section 2.3.1.1 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. 2-48). Sampling in 1986 and 1987 used a helicopter to transport boats to the water surface. 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. Since 1991 samples have 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. MR installed a new boat dock on the south side of the Pit in the summer of 2011 (fig. 2-49) that provides safe access to the boat.

Figure 2-48. 1985 Berkeley Pit sampling event.

Figure 2-49. Newly installed (2011) boat dock, with MR pontoon boat used for Berkeley Pit sampling.

Section 2.3.1.2 Berkeley Pit Water Chemistry

Currently the Berkeley Pit water is approximately 850 ft deep, consisting of roughly 41.6 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 water-quality data. Prior to 2001, water-quality samples were collected when deemed necessary, i.e., during the RI/FS investigation, that produced data from as far back as November 1984. These data are published and can be found on the MBMG Ground Water Information Center (GWIC) website (GWIC, 2011).

Water quality in the Berkeley Pit has been monitored semi-annually since spring 2001, as per terms of the 2002 CD. Data collected prior to 2001, though accurate, are not as consistent as the semi-annual monitoring which began in 2001, and for the most part are excluded. 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 2.3.1.3 Physical Parameters

Physical parameters of pH, specific conductance (SC), oxidation-reduction potential (ORP), and temperature were measured *in situ* between 0 and 600 ft below water surface using Hydrolab multi-parameter sampling equipment during each event. Depth profiles for the 2011 sampling events are presented in figure 2-50, and long-term (2001–2011) changes are shown in figure 2-51.

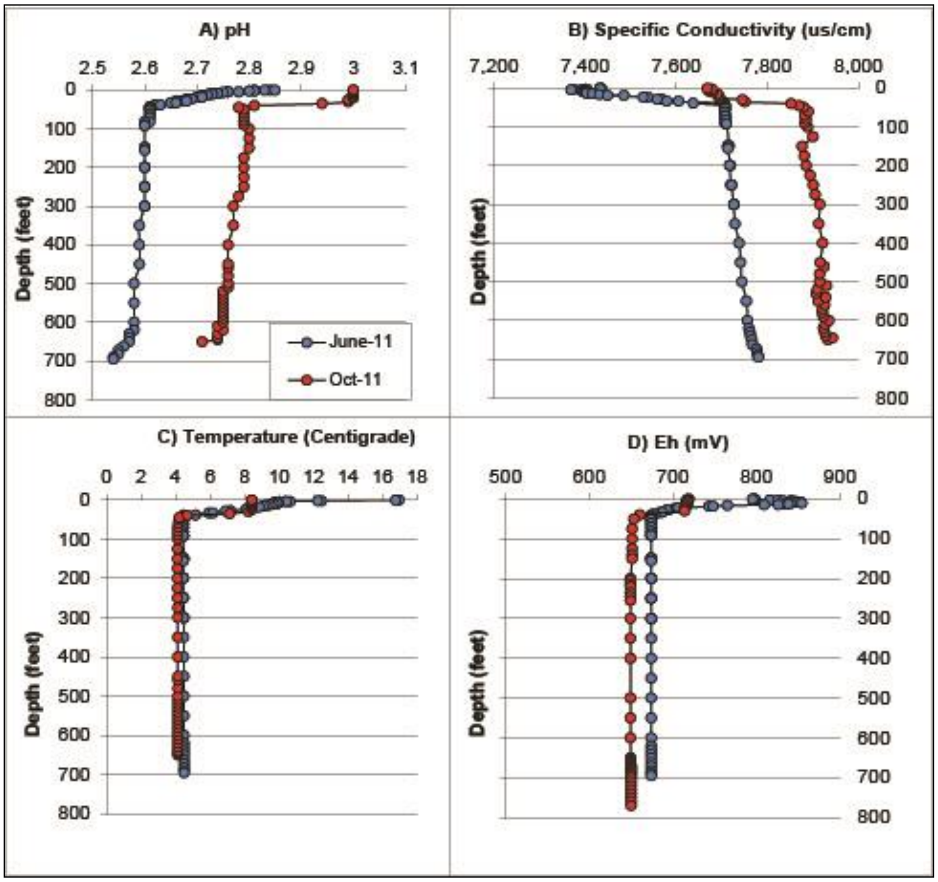


Figure 2-50. 2011 depth profiles for the Berkeley Pit Lake System.

Depth profiles (fig. 2-50) for pH (A), specific conductance (B), temperature (C), and Eh (D) were similar. Other than for changes observed in the upper 50 ft caused by wind-driven effects, temperature gradients, and dissolved oxygen concentrations, Berkeley Pit depth profiles remained consistent below 45 ft. A chemocline was not observed at depth.

Profiles collected each fall are shown for 5 years (along with May 2010 profiles) (2002, 2006, 2007, 2008, 2010, and 2011) in figure 2-51. The profile from 2002 represents a 3-year period when HSB water was being diverted into the Berkeley Pit, and copper recovery operations from the Pit were suspended. In November 2003 the HSB treatment plant came online, capturing and treating HSB water, and in January 2004 Montana Resources began pumping at depth for Cu-recovery operations.

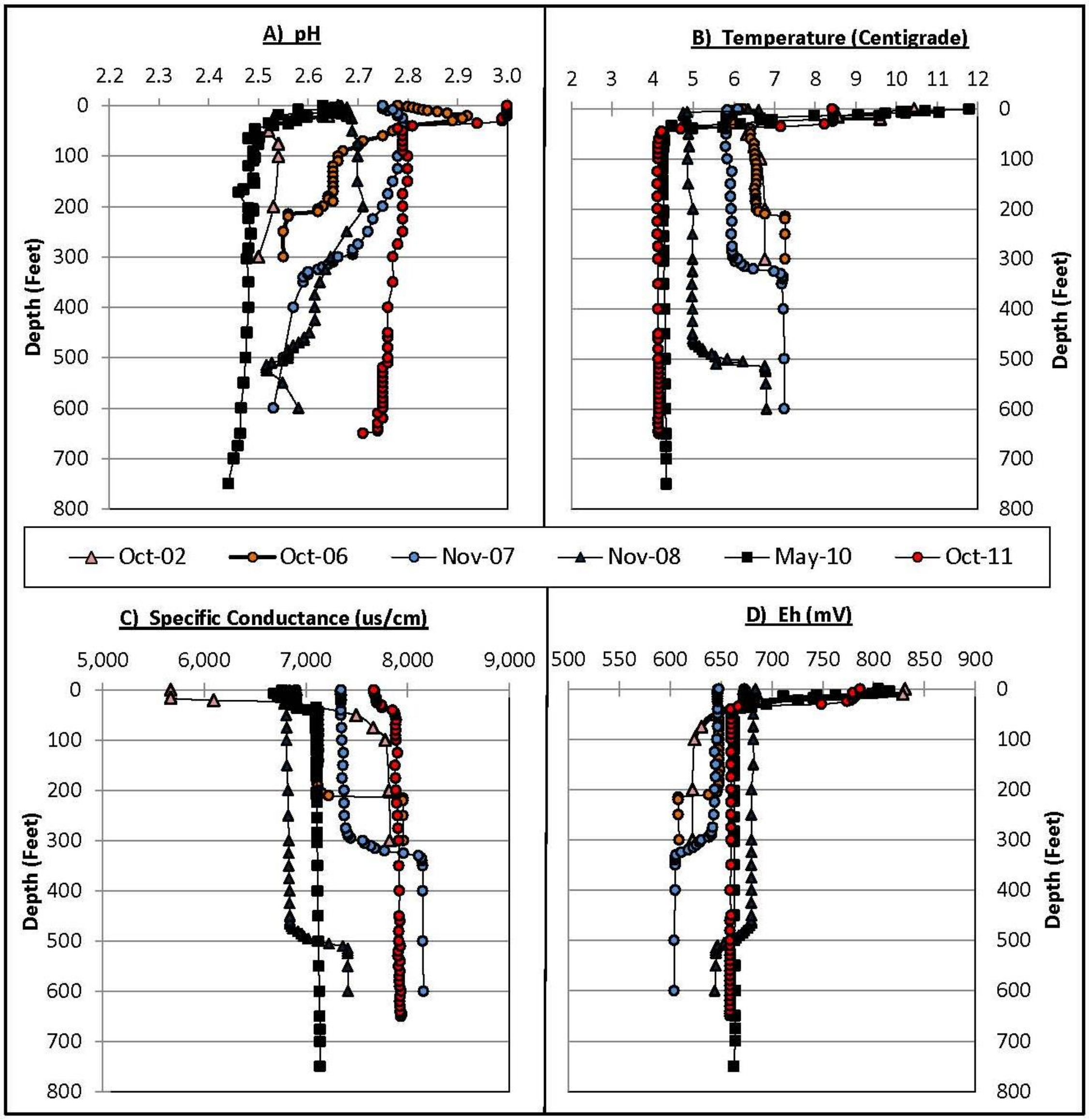


Figure 2-51. Long-term changes in depth profiles for selected parameters in the Berkeley Pit Lake. All data from all years are from fall sampling events, with the excepton of May 2010.

Temperature profiles (fig. 2-51B) suggest that a thermocline exists in the upper 50 ft. During winter, cold air temperatures cool the shallow water to create a seasonal epilimnion. Inversely, warm air temperatures in the summer create thermal stratification with warm water on top of cold. During early spring and late fall, air temperatures create water temperatures in the epilimnion that are consistent with the metalimnion waters, and mixing between the two zones (turnover) is possible.

Prior to fall 2009, a density stratification boundary (chemocline) occured at varying depths in the water column, creating a meromictic lake with different water qualities above and below the chemocline. Water above the chemocline, referred to as the mixolimnion, was distinguished from water below the chemocline (monimolimnion) by higher pH, lower specific conductivity, lower concentrations of dissolved metals, and higher oxidation-reduction potential.

Between 2003 and 2009, the depth to the chemocline increased as a direct result of pumping by the MR Cu-recovery operations (fig. 2-52). Evidence for the increasing depth of the chemocline is noted in all depth profiles, and has been discussed in previous reports (Duaime and Tucci, 2007, 2008, 2009, 2011a, 2011b). The effects of the Cu-cementation process on the chemocline are best observed in the SC profile (fig. 2-51C). Prior to January 2004, the depth of the chemocline, though variable, remained less than 50 ft below water surface. Since then, pumping (>10,000 gpm for 7 years) for the Cu-recovery process has drawn down the chemocline at an average rate of 60 ft per year. The rate of decline has increased, as the diameter of the Pit narrowed with depth (fig. 2-52). As of November 2009, the chemocline was pumped to extinction. Profiles measured in 2011 confirm the lack of a chemocline.

The lack of a chemocline will allow spring and fall lake turnover each year and more consistent water quality with depth. As a result, the Pit has transitioned from a miromictic (no annual turnover) lake to a holomictic (turnover) lake. The frequency and extent of mixing will depend on seasonal effects and wind-driven events, but given the depth to surface area ratio of the Pit, turnover should be temperature-driven and only occur twice a year. Frequent turnover events have caused the water quality of the deep Pit to change because oxygen can now be introduced at depth. Ratios of Fe II/Fe III have decreased at depth, which affects oxidation-reduction potential and the solubility of many metals, including copper. The lack of a chemocline will improve water quality at depth, but decrease the efficiency of MR's Cu-recovery process.

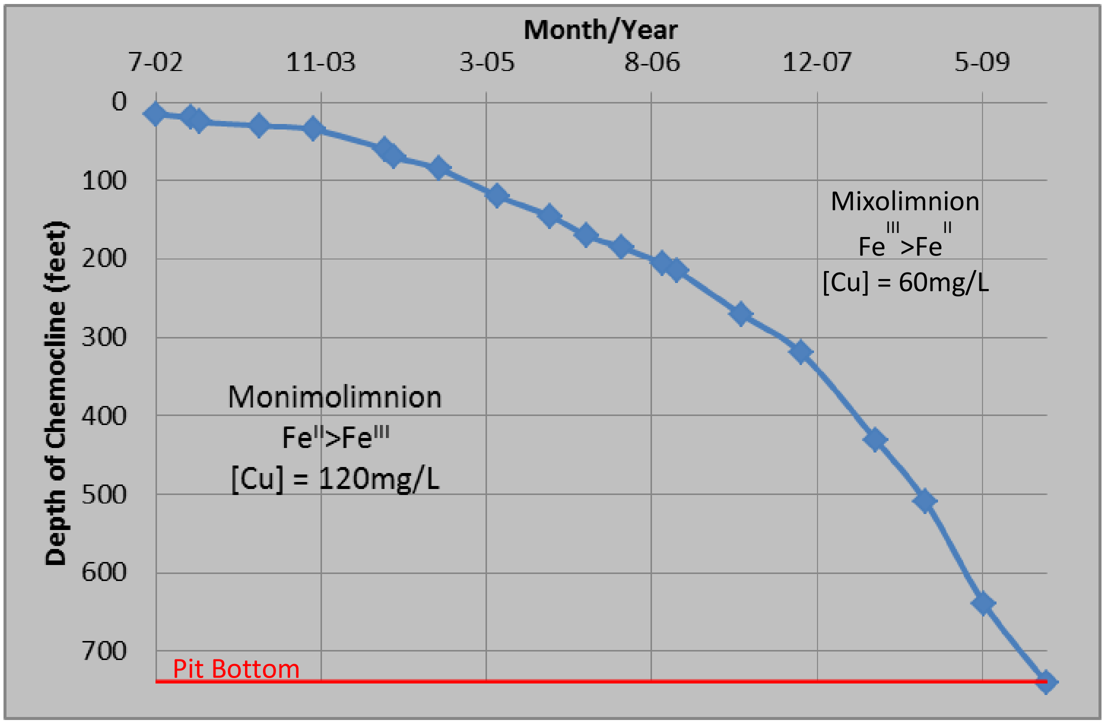


Figure 2-52. Depth of the Berkeley Pit chemocline from water surface over time.

Additionally, depth profiles of SC (fig. 2-51B) and Eh (fig. 2-51D) appear to indicate homogeneous water-quality conditions throughout the water column. Relatively homogeneous physical parameters with respect to depth are indicative that turnover is occurring, creating a well-mixed water column. Without thermal or density stratification, the Berkeley Pit should remain a chemically homogeneous mixture with respect to depth, experiencing one to several turnover events per year.

As a general rule, pH of the Berkeley Pit, at depths below about 50 ft, is between 2.4 and 2.8 and the lake is a well-buffered system. Secondary iron minerals such as schwertmannite and k-jarosite, which are in chemical equilibrium with respect to solid/aqueous concentrations, along with the buffering capacity of aqueous sulfate, are the geochemical processes that have kept the pH constant.

Section 2.3.1.4 Chemical Parameters

Notable changes in the chemistry of the Berkeley Pit have occurred as a result of Cu-recovery activities and the diversion of HSB water away from the Berkeley Pit since November 2003. Water-quality samples have been collected by the MBMG at a minimum of three depths semi-annually, and analytical results have been published on the MBMG GWIC online database (GWIC, 2011). This section discusses some of the recent changes in chemical parameters that have been observed.

The Cu-recovery process currently extracts water at a depth >700 ft below the water surface. This water is then passed over scrap iron where dissolved copper plates onto the iron through a process known as oxidative-reductive ion exchange. Dissolved iron replaces the copper in solution and this iron-rich, low-copper water is discharged to the Pit surface.

The chemical equation for this process is described below:

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$

The chemistry of these waters is illustrated in table 2.3.1.4.1. Influent and effluent samples from the copper precipitation process were taken in 2010, and are shown as precip-in and precip-out, respectively. The influent sample is consistent with the depth from which it was extracted [~700 ft below surface (fbs)] and the effluent sample, as a result of the ion exchange process, is low in copper and high in iron concentrations.

Table 2.3.1.4.1 Water composition that currently represents the Berkeley Pit Lake System.

	pH	SC	Ca	Mg	Na	K	Fe	Mn	Al	Cu	Zn	As	SO_4
Precip-in	2.57	7,400	458	546	75	10	413	255	289	67	606	0.1	8,750
Precip-out	2.71	7,300	455	547	78	11	588	256	280	22	596	0.07	8,327
BP Surface	2.63	6,670	451	530	78	6	428	253	272	59	588	0.08	6,997
BP 700 fbs	2.44	7,140	447	530	78	6	428	251	281	66	591	0.09	7,187

All data shown in this table are from 2010 sampling events. All data are in mg/L except pH (standard units) and SC (µs/cm@25^{0}C).

Currently, the Cu-recovery process is recycling deep Berkeley Pit water to the lake surface at about 11,000 gpm. This process has been in operation since 2004, and has significantly impacted the chemistry of the Pit at all depths. High dissolved iron concentrations in the return water from the Cu-cementation plant has significantly increased formation of secondary iron precipitates throughout the water column. Precipitated schwertmannite ($Fe_8O_8(OH)_6SO_4$) (fig. 2-53) and K-jarosite ($KFe_3(OH)_6(SO4)_2$) is the leading contributor to water-quality change in the Berkeley Pit since 2003. Since the initiation of Cu-recovery in the Berkeley Pit (fall 2003), roughly 150 million pounds of Fe has precipitated as secondary iron minerals. Without the presence of a chemocline since fall 2009, Fe-precipitates do not redissolve during settlement, and permanently remove iron from the lake.

Mining the Berkeley Pit water for copper has had significant positive impacts on water quality. Water quality in Precip Plant influent samples are given in table 2.3.1.4.2. Between 2001 and 2011, significant decreases have been observed for Fe (56 percent), Cu (60 percent), P (88 percent), and As (87 percent).

Figure 2-53. Accumulation of secondary iron precipitates in a sediment trap deployed in the Berkeley Pit for 150 days.

Table 2.3.1.4.2 Water-quality changes to Precipitation Plant influent.

Date	pH	SC µs/cm	TDS mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Fe mg/L	Mn mg/L	Al mg/L	Cu mg/L	Zn mg/L	P mg/L	As µg/L	SO_4 mg/L
8/20/2001	2.55	8,610	12,610	442	499	86	9	932	238	270	167	626	0.8	731	9,160
2/24/2003	2.40	7,645	12,490	460	511	78	8	899	244	262	156	513	0.6	750	9,250
7/8/2005	3.01	7,310	13,567	465	526	82	7	1046	254	238	182	651	0.7	303	9,980
6/25/2010	2.57	7,400	11,633	458	546	75	10	413	255	289	67	606	0.1	96	8,750
Percent Decrease	NC	14	8	NC	NC	NC	NC	56	NC	NC	60	NC	88	87	5

The effects of the Cu-cementation process on dissolved iron are presented in figure 2-54. Between 2010 and 2011, significant decreases in Fe concentrations were observed at all depths, indicating that dissolved Fe concentrations have yet to reach equilibrium, and future changes in the geochemistry of the Berkeley Pit can be expected.

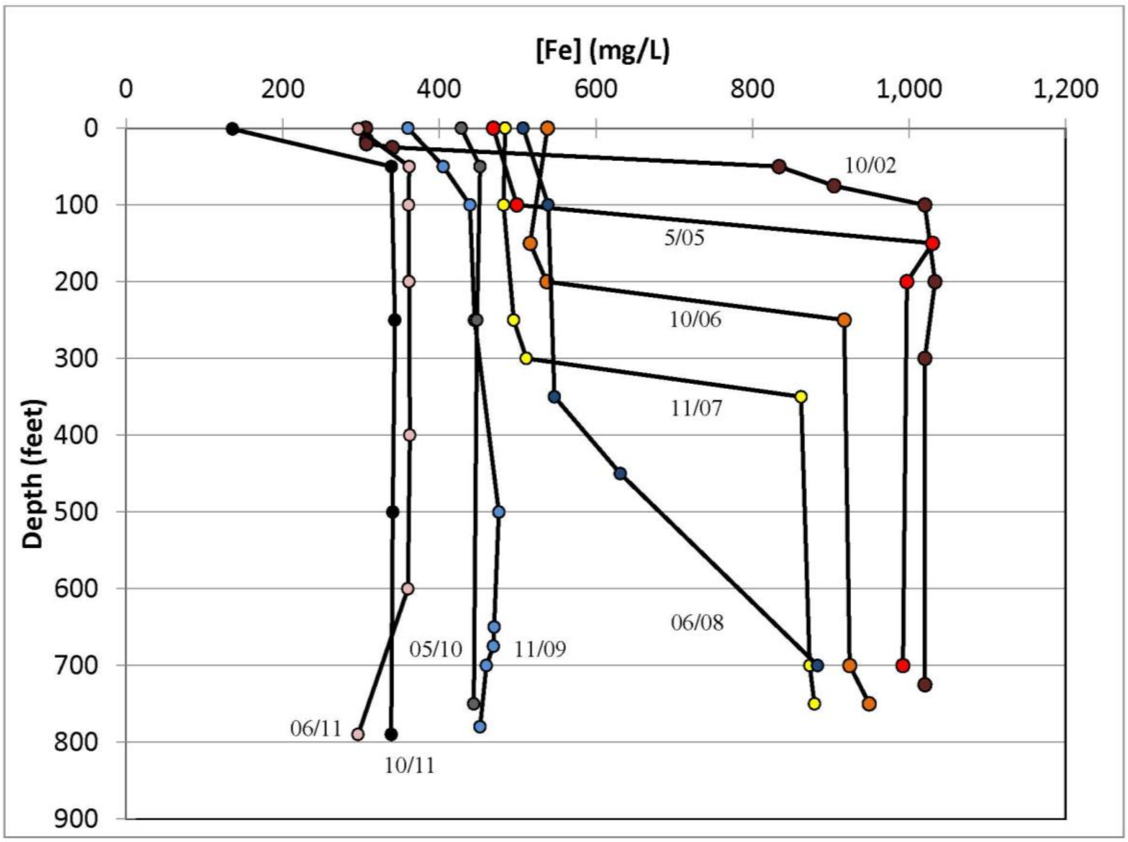


Figure 2-54. Effects of Cu-recovery process on dissolved iron.

Changes in dissolved-iron speciation in the near-surface water and at depth are presented in figure 2-55. Significant decreases in ferrous iron (Fe II) concentrations at depth between 2006 and 2011 do not coincide with ferric iron (Fe III) concentrations at depth that have remained stable. These iron concentrations are consistent with increases in the oxidation-reduction potential (fig. 2-49D) at depth during the same time period. As of November 2009, concentrations of Fe II<Fe III in deep Pit samples are opposite concentrations initially observed in fall 2003 of Fe II>Fe III. Also, since November 2009, concentrations of Fe III have been decreasing in surface-water samples. These Fe speciation trends observed since fall 2009 correlate well with loss of the chemocline.

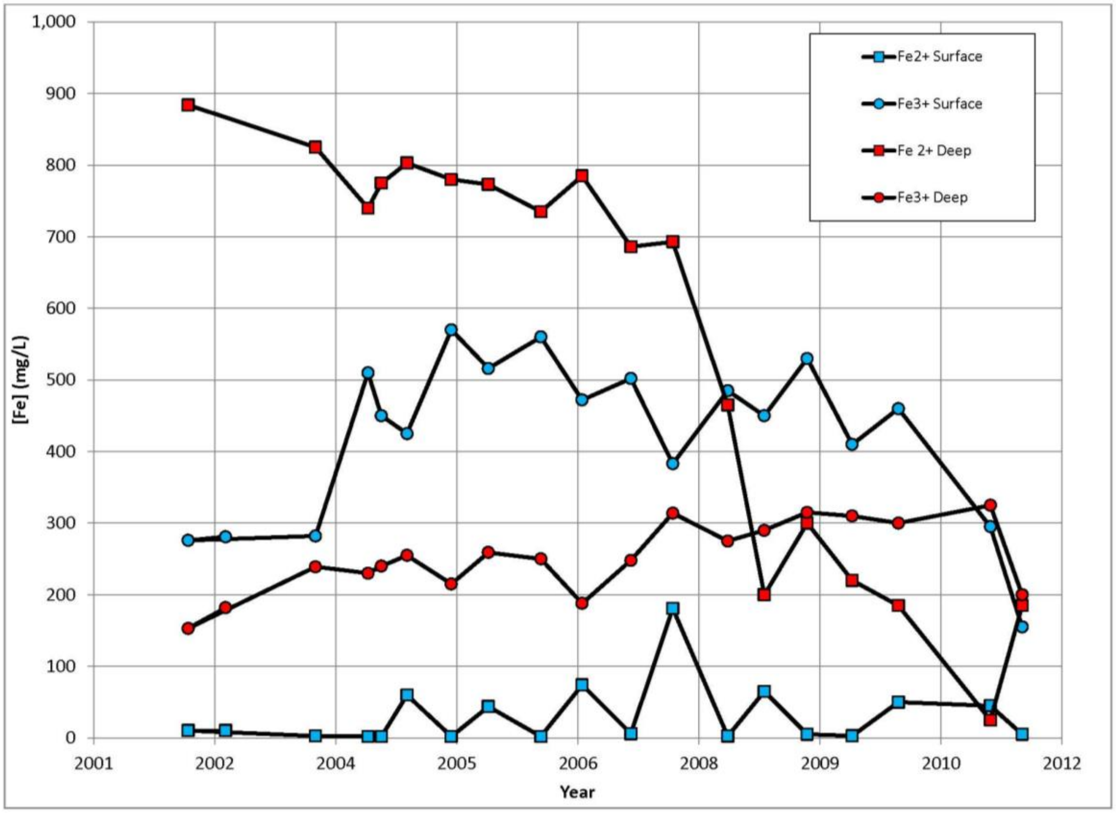


Figure 2-55. Effects of MR Cu-cementation process on Fe speciation.

The effects of the MR Cu-cementation process on dissolved copper are presented in figure 2-56. Decreasing trends were observed at all depths from 2007 to 2009. Most significant decreases were seen at depth. The decrease in Cu is explained by the permanent removal of dissolved Cu by the Cu-recovery process and also the co-precipitation of copper onto secondary iron precipitates. As of November 2009, homogeneous water-quality conditions with respect to Cu are present throughout the water column. Overall, concentration of Cu in the Berkeley Pit decreased 60 percent since 2002.

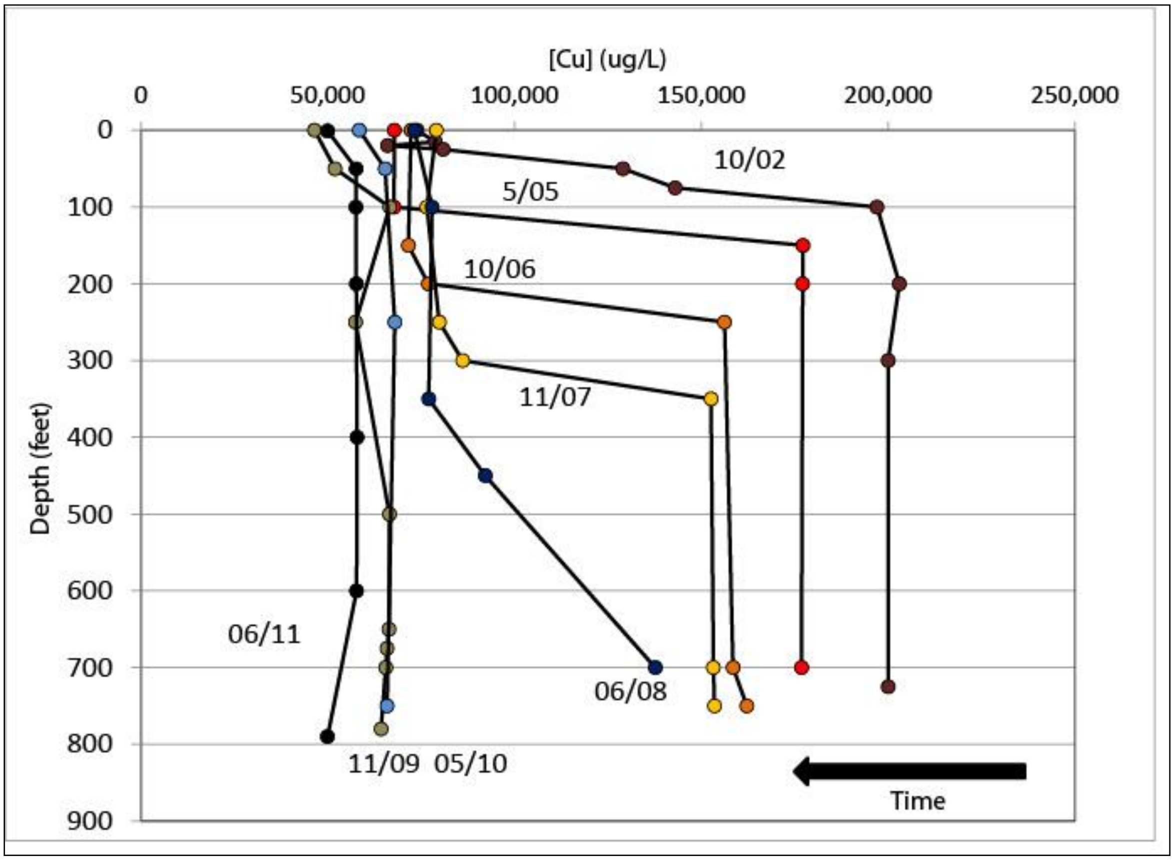


Figure 2-56. Effects of Cu-precipitation process on dissolved copper.

Arsenic concentrations, more than any other dissolved contaminant, have decreased at all depths over time, decreasing by more than an order of magnitude. Figure 2-57 portrays trends in arsenic at all depths since 2002; the significant decrease is explained by the co-precipitation of arsenic onto secondary iron precipitates, and can be directly attributed to the Cu-precipitation process. Mining the copper in the Berkeley Pit has significantly removed a major contaminant of concern. Concentrations of As have appeared to stabilize at all depths since June 2008.

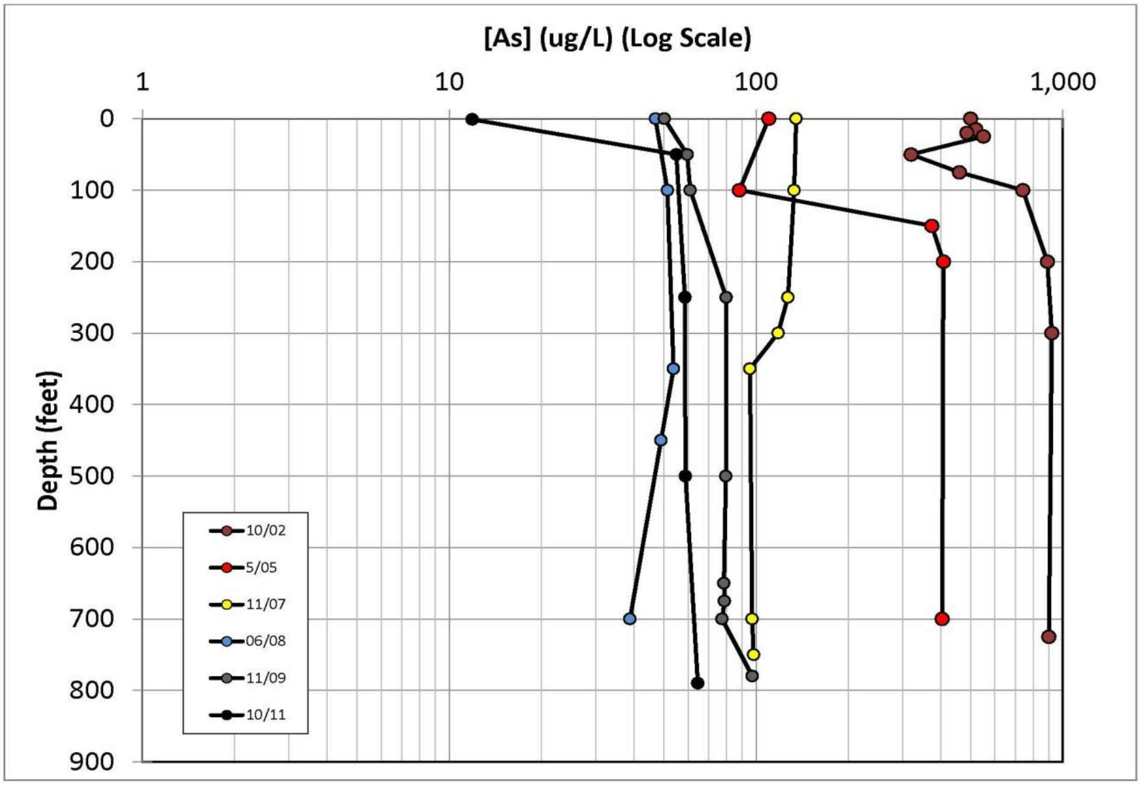


Figure 2-57. Effect of Cu-recovery on dissolved As at all depths.

Arsenic concentrations reached their maximum values during late 2003. Following the resumption of mining and the diversion of HSB water away from the Pit, arsenic concentrations in the surface water began to decrease (2004 sampling event), and further decreases at all depths are shown by later sampling events. Similarly, phosphate concentrations (PO_4) show the same decreasing trends, suggesting PO_4 is co-precipitating as well.

Eight years of Cu recovery by MR have resulted in the elimination of the chemocline, significant decreases in both Cu and Fe concentrations (50 percent reductions), and order of magnitude decreases in dissolved P and As concentrations. Decreases in major trivalent and divalent cations, such as Fe and Cu, have had a positive impact on total acidity of the Berkeley Pit. Total acidity is described below:

$$[H^{+} + HSO_4^{-}] + 2[Fe^{2+} + Cu^{2+} + Zn^{2+} + Mn^{2+}] + 3\,[Fe^{3+} + Al^{3+}]$$

Eight years of Cu-recovery have resulted in a 13 percent decrease in total acidity in the Berkeley Pit. The decrease in total acidity results in a significant cost benefit, as less lime at the Horseshoe Bend Treatment Plant is needed to treat Pit water.

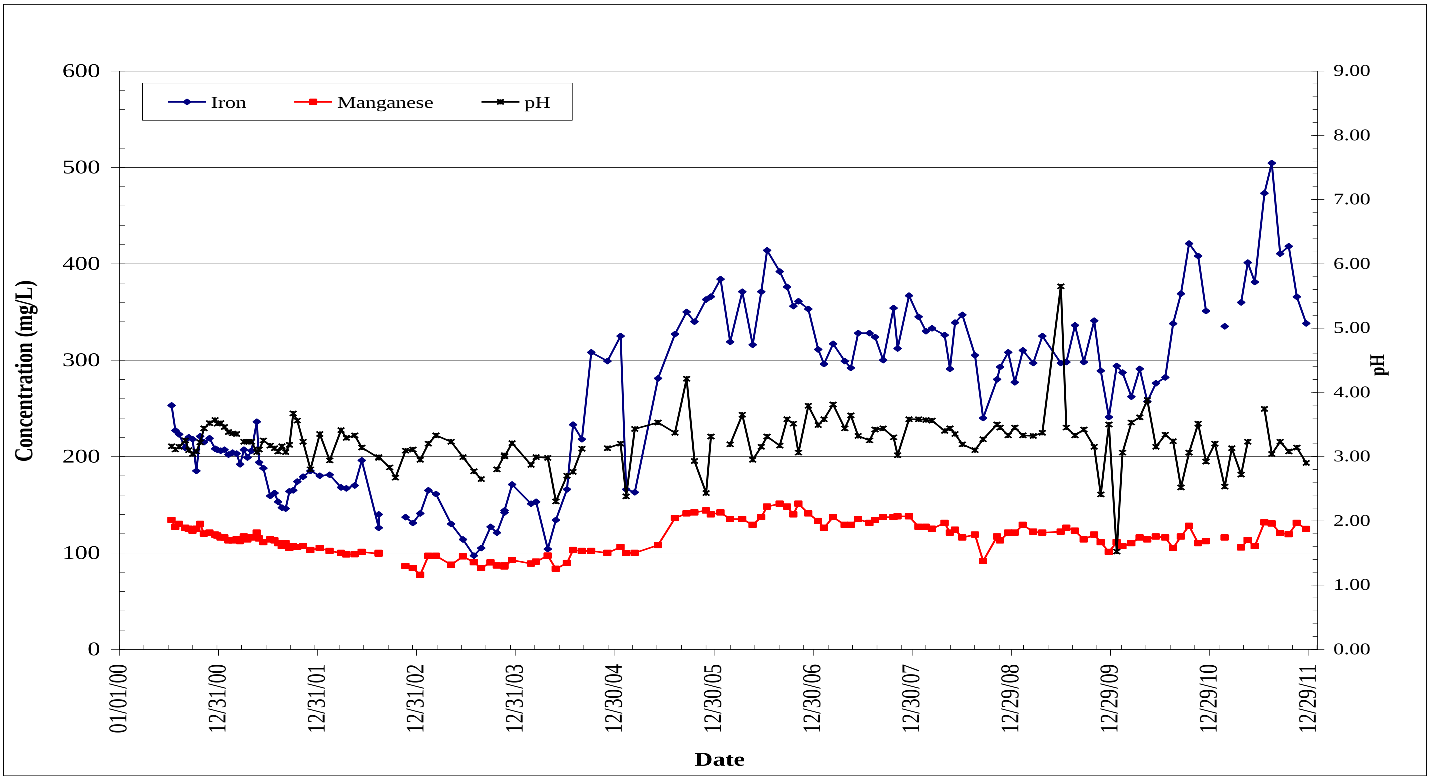
Section 2.3.2 Horseshoe Bend Water Quality

Monitoring of the HSB drainage began in July 2000 following MR's temporary suspension of mining. Similar to the changes seen in flow rates during the period of mine suspension, concentrations of a number of the trace metals decreased also. Metal concentrations began to increase in mid-2004 when flow rates increased (fig. 2-58). Copper and zinc concentrations increased through early and mid-2006, respectively, before declining. Copper concentrations are currently less than one-third those seen in 2000; zinc concentrations are similar to 2000 concentrations.

The water quality of the HSB drainage continues to be slightly better than that of the Berkeley Pit (table 2.3.2.1).

Table 2.3.2.1 Selected chemistry from Berkeley Pit and Horseshoe Bend waters.

Area	Sample Date	pH (S.U.)	SO_4 (mg/L)	Al (µg/L)	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)
Berkeley Surface	6/10/11	2.84	9,909	270,853	49,991	21	550,319
HSB	6/14/11	3.24	7,617	258,999	38,769	2.6	240,699



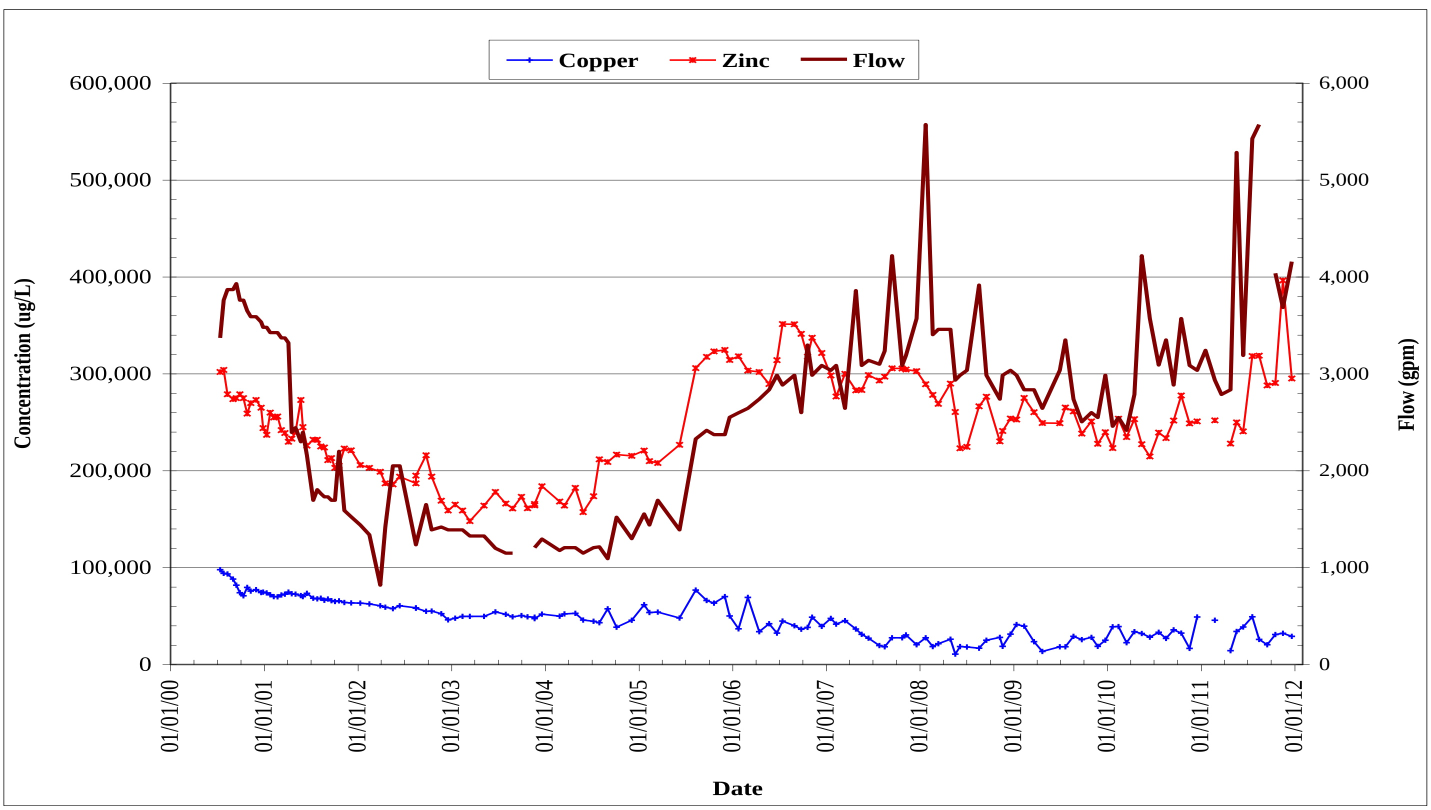


Figure 2-58. Horseshoe Bend water quality: comparisons of selected constituents, 2000–2011.

SECTION 3.0 WEST CAMP SYSTEM

Water-level monitoring continued during 2011 in the three mine shafts and six monitoring wells (fig. 3-1) that constitute the West Camp system. ARCO diverted the water pumped from the West Camp to the Lower Area One wetlands demonstration site (now know as the Butte Treatment Lagoons) during March 2002. Pumping occurred almost continuously through June 2011; pumping was intermittent from mid-July through December 2011 because of construction at the pump station and at the Butte Treatment Lagoons where the water was pumped for treatment and discharge. The volume of water pumped was almost the same as that in 2010; however, water levels decreased throughout the underground mine system. Water levels at the end of 2011 were 17 ft below the West Camp's critical water-level elevation.

Section 3.1 West Camp Underground Mines

Water levels in the West Camp Mine system continue to be controlled by pumping facilities located at the BMF-96-1D and BMF-96-1S site. ARCO constructed the West Camp Pumping Well (WCPW) for dewatering purposes in the fall of 1997 and transferred pumping activities to it 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. The pump station and support system were modified and upgraded by ARCO in late 2011 (figs. 3-2 through 3-5). These upgrades interrupted pumping for longer periods of time than in previous years; however, additional water-level monitoring was implemented to confirm that water levels were maintained at appropriate levels; figure 3-6 shows water levels in the Travona, Ophir, and well BMF96-1D during the period of construction.

The quantity of water pumped (252.9 acre-ft) was similar to that for the past 10 years. Table 3.1.1 shows the annual amount of water pumped in acre-ft, the change in acre-ft from the previous year, and the percent change from 1996 (the first full year of continuous pumping). Figure 3-7 shows the amount of water pumped annually and the percent of average annual precipitation since 1982.

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Figure 3-1. West Camp monitoring sites location map.

Figure 3-2. West Camp pump station 1997–2011.

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

Figure 3-4. West Camp construction of new pump station foundation and infrastructure improvements surrounding pumping well and discharge line.

Figure 3-5. New West Camp pump station, 2011.

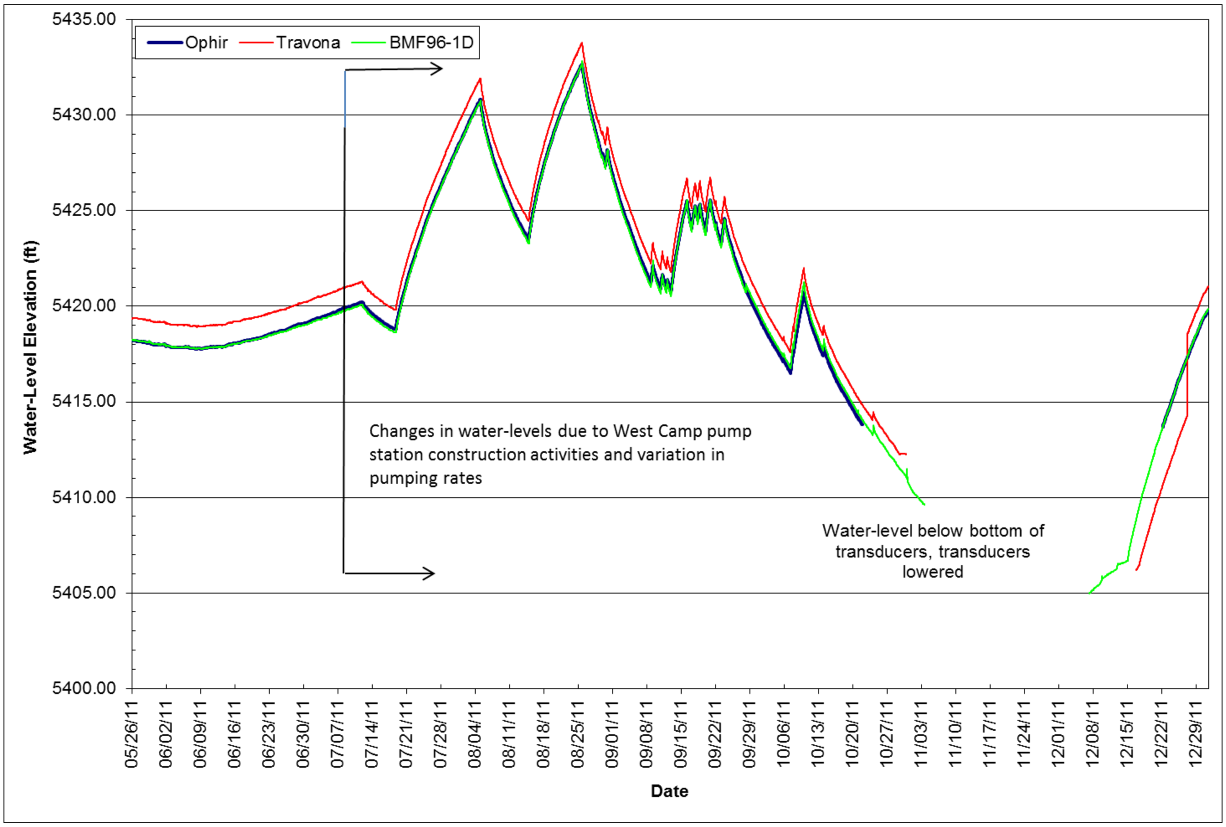


Figure 3-6. Hydrograph showing water levels in the Travona Mine, Ophir Mine, and well BMF96-1D during 2011 construction activites.

Table 3.1.1 Annual quantity of water pumped from the West Camp (acre-ft).

Year	Total Amount Pumped (acre-ft)	Change From Prior Year (acre-ft)	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	118
1998	370.72	+83.02	152
1999	326.56	-44.16	134
2000	270.20	-56.36	110
2001	260.37	-9.83	106
2002	247.66	-12.71	101
2003	231.43	-16.23	95
2004	254.70	+23.26	104
2005	257.82	+3.12	105
2006	290.33	+32.51	119
2007	273.96	-16.37	112
2008	255.16	-18.79	104
2009	247.03	-8.13	101
2010	253.49	6.46	104
2011	252.93	-0.56	103

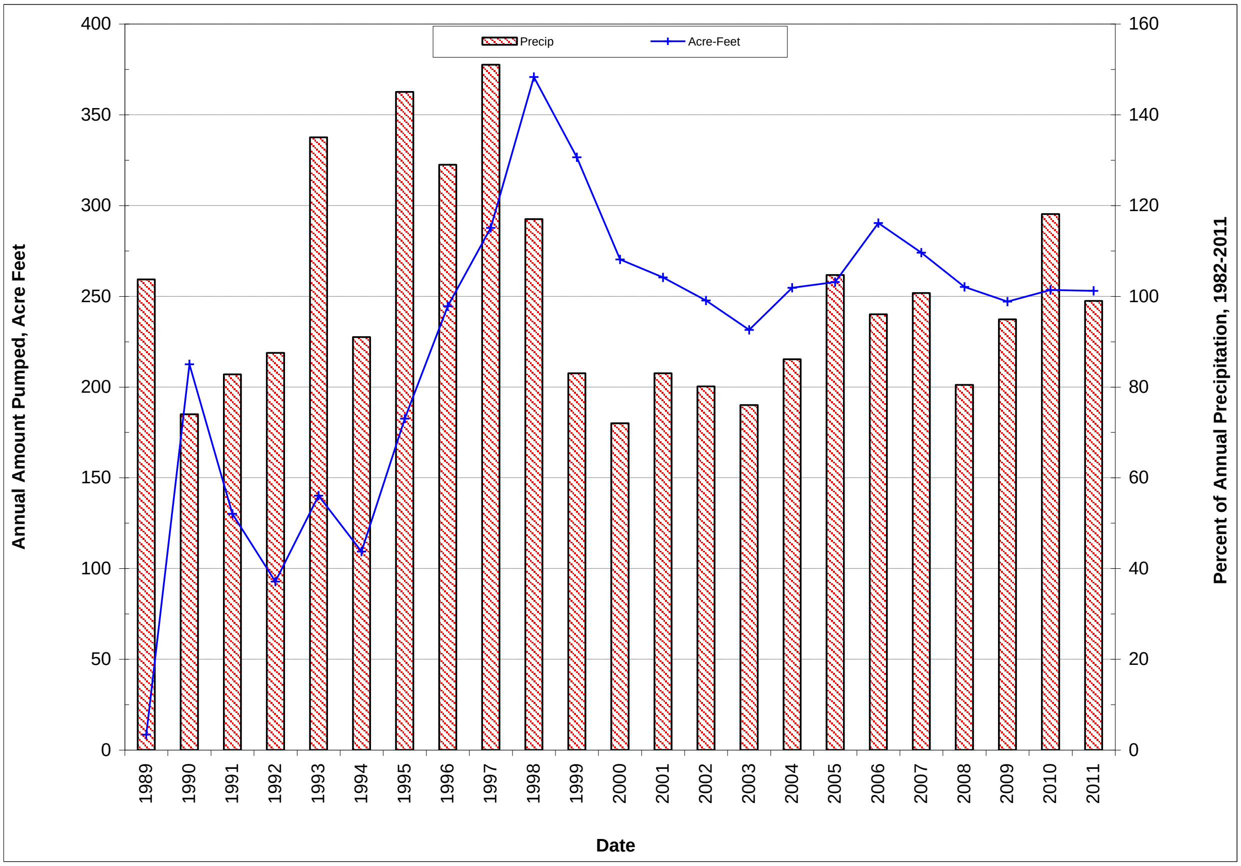


Figure 3-7. Annual amount of water pumped from the West Camp system.

Water-level changes in the West Camp mines reflect changes in pumping rates at the WCPW and precipitation, decreasing between 3.99 and 4.27 ft during 2011. Figure 3-8 shows annual water-level changes for the West Camp sites. Water levels are more than 17 ft below the West Camp action level of 5,435 ft stipulated in the 1994 ROD.

Water-level elevations for the three West Camp mines are shown in figure 3-9. 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.

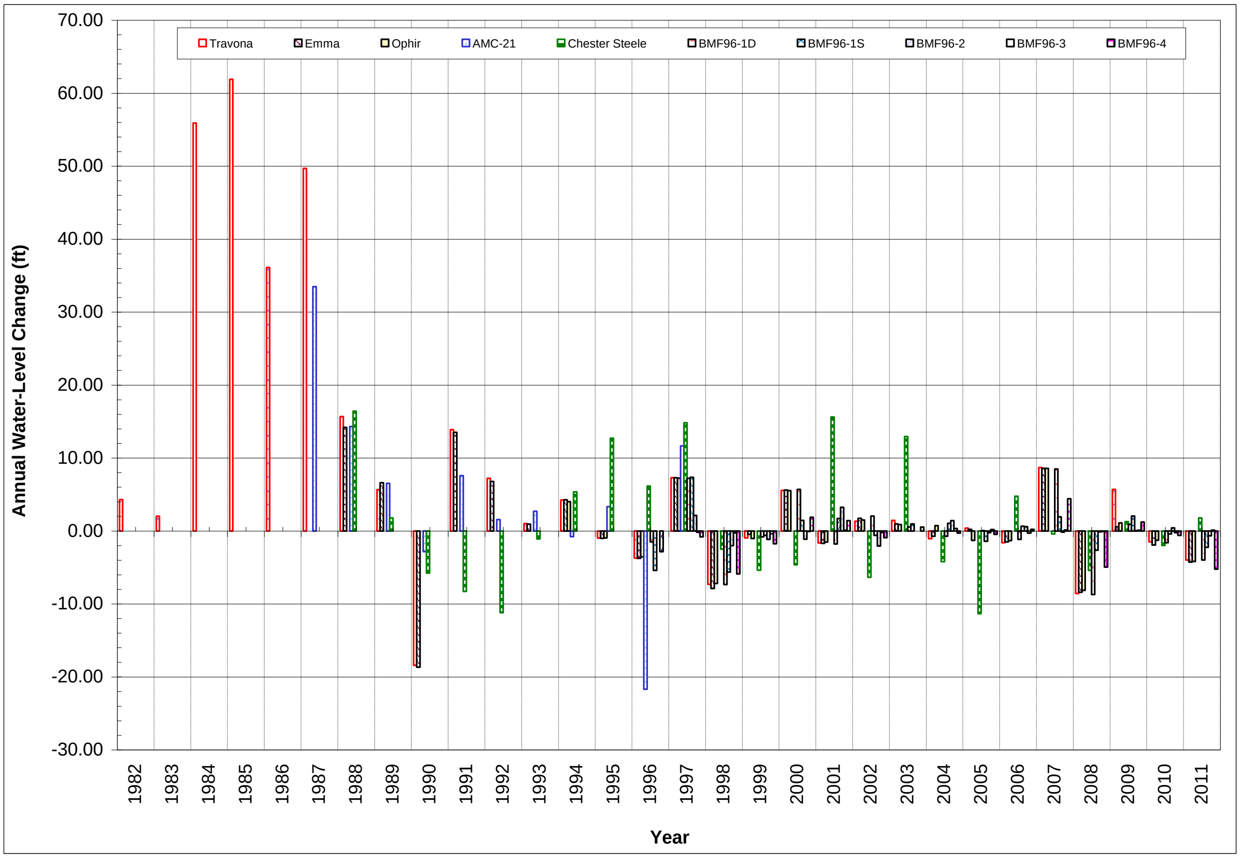


Figure 3-8. Annual water-level changes for West Camp site.

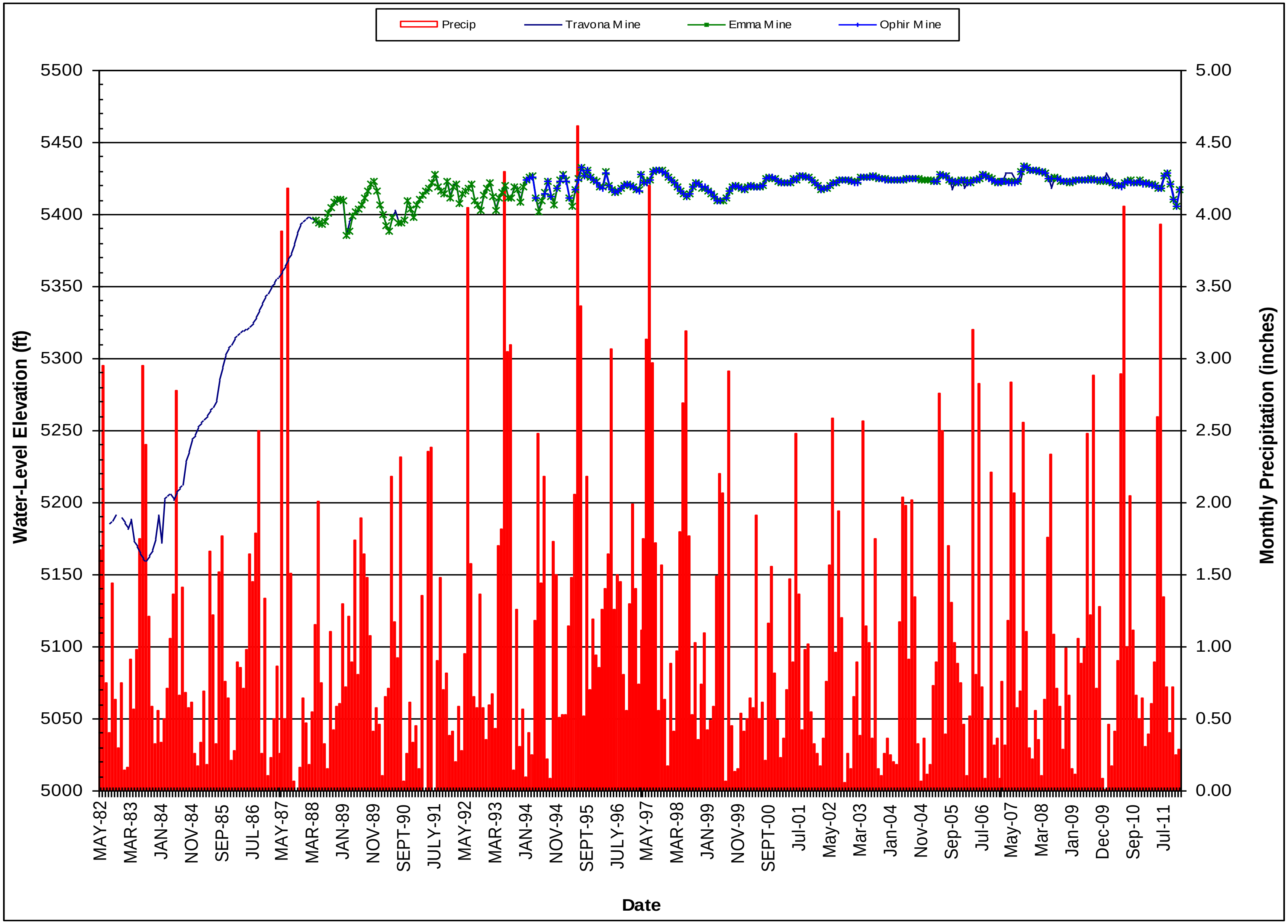


Figure 3-9. Water-level hydrographs for West Camp mines.

Section 3.2 West Camp Monitoring Wells

Water levels decreased in four of the five BMF96 West Camp wells during 2011. Well BMF96-1D, which was completed into the Travona Mine workings, had a water-level change similar to that in the West Camp mines. These changes are shown in table 3.2.1 and figure 3-8.

Figure 3-10 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, reflecting 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 important because well BMF96-4 was not completed instead into bedrock within the area of the historic 1960s flooding problems that led the Anaconda Company to install well AMC-21 to control water levels in the West Camp (fig. 3-11; see Duaime and others, 1998, for in-depth discussion of historic flooding problems in the West Camp System). Well BMF96-1S is located adjacent to well BMF96-1D, but was completed much shallower in weathered bedrock. This well also shows a response to pumping in the WCPW.

Water levels in wells BMF96-2 and BMF96-3 are 20 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. 3-12) 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. However, since 2002, water-level changes in BMF96-2 and BMF96-3 corresponded with the changes seen in the other wells. When hydrographs for BMF96-2 and BMF96-3 are plotted at an expanded scale (fig. 3-13), the detail in water levels becomes apparent and both wells respond quickly to precipitation events. Water-level trends during 2011 were similar to those seen the previous several years. No response was seen due to reduced pumping during the summer and fall of 2011, related to the West Camp upgrades (fig. 3-14). 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 3.2.1 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**
Net Change*	**232.22**	**21.42**	**-1.97**	**26.15**	**-2.71**	**-1.85**	**0.26**	**-3.63**	**-11.32**

(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.

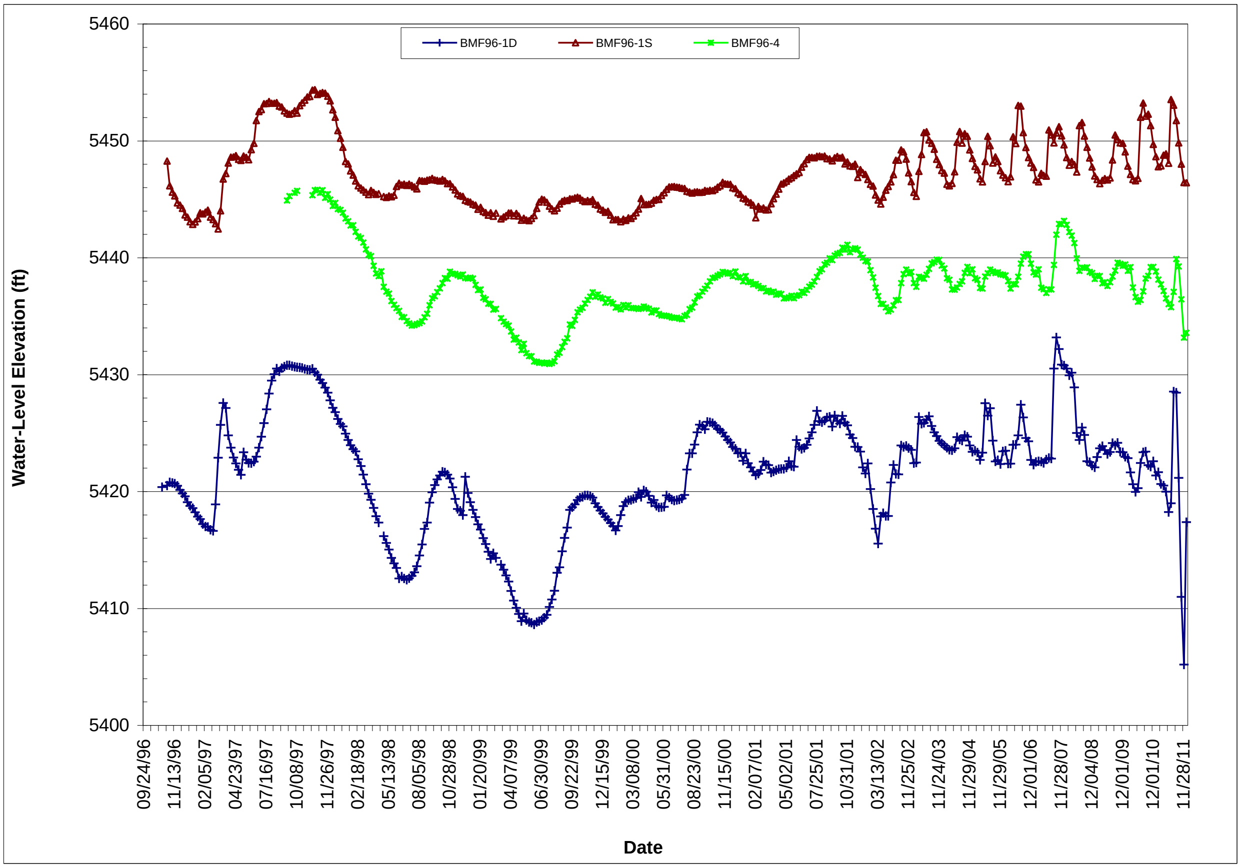


Figure 3-10. Water-level hydrographs for West Camp wells BMF96-1D, BMF96-1S, and BMF96-4.

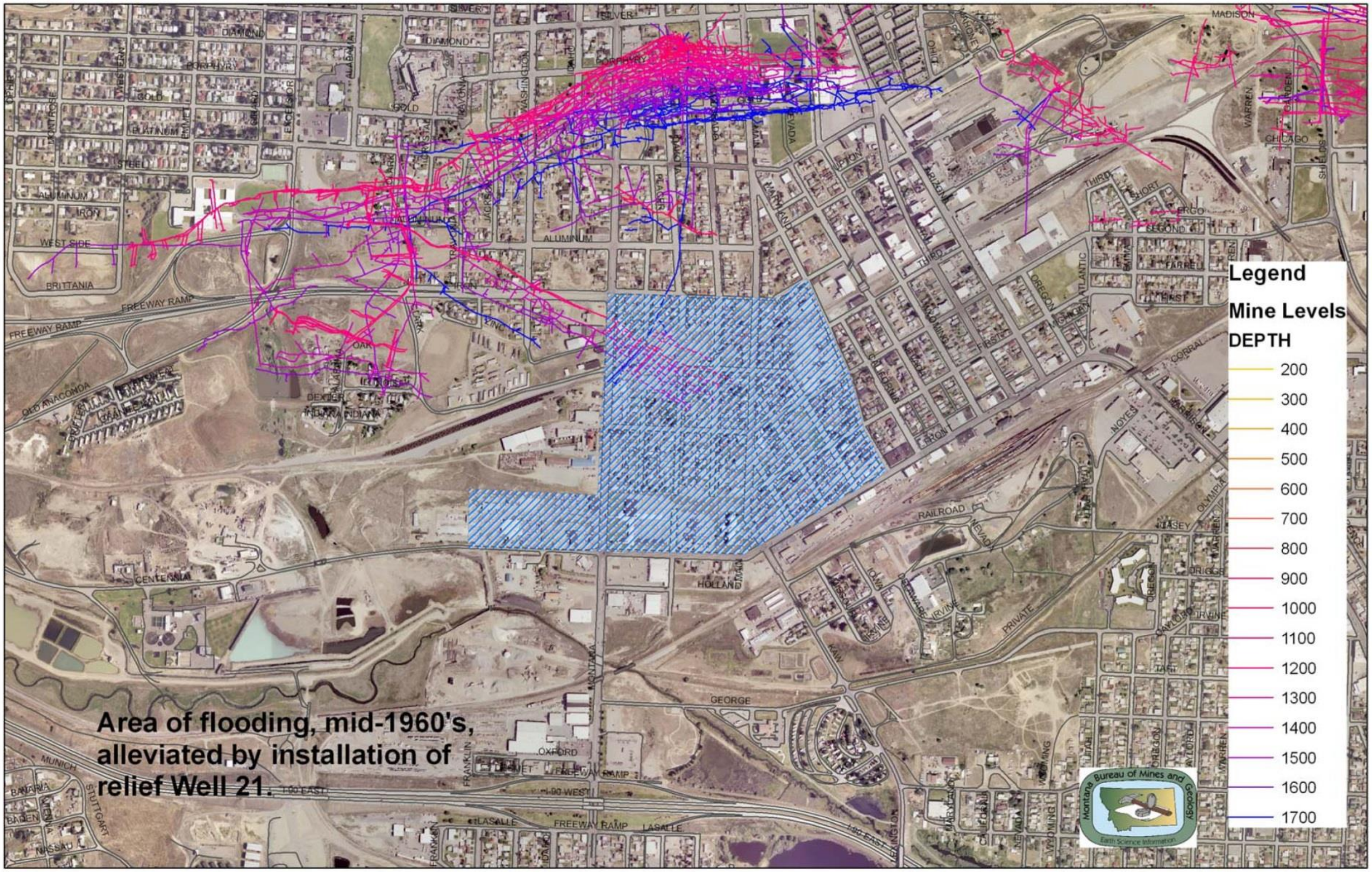


Figure 3-11. Area of the West Camp affected by basement flooding problems, 1960s. Blue hatch pattern outlines the problem area.

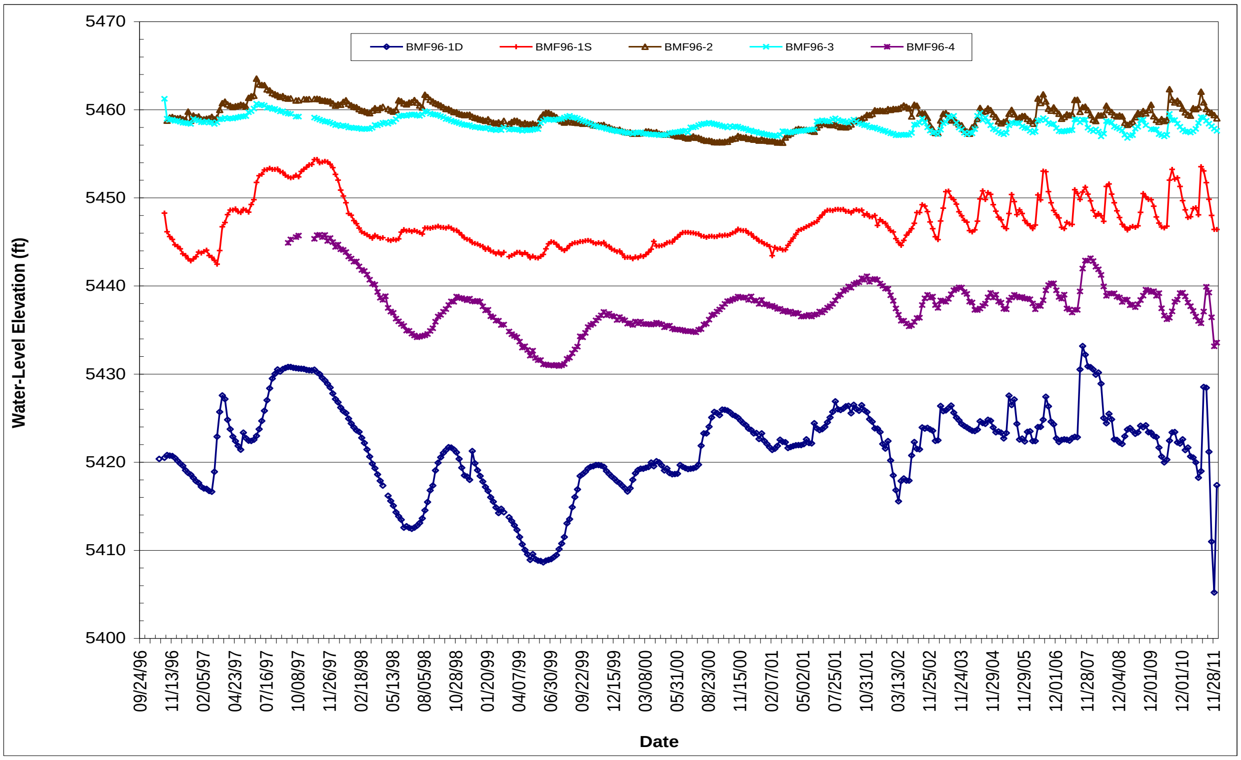


Figure 3-12. Water-level hydrographs for BMF96-series wells.

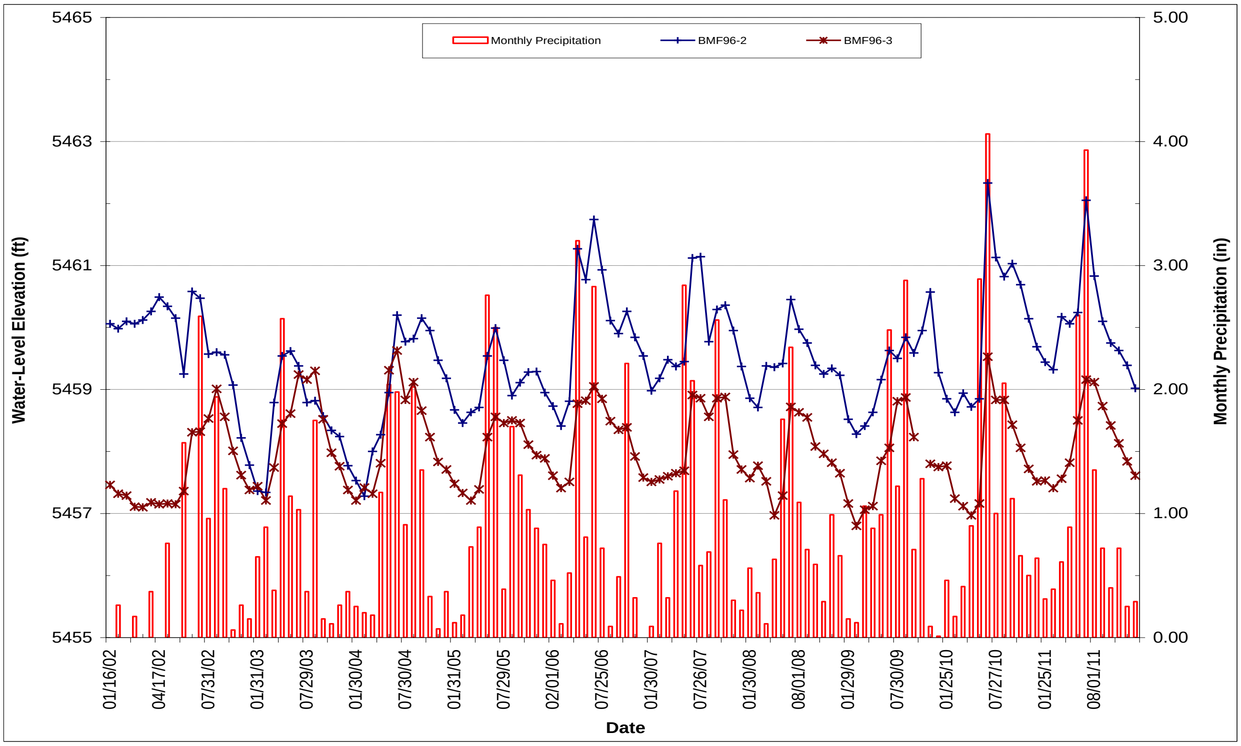


Figure 3-13. Water-level hydrographs for wells BMF96-2 and BMF96-3, 2002–2011.

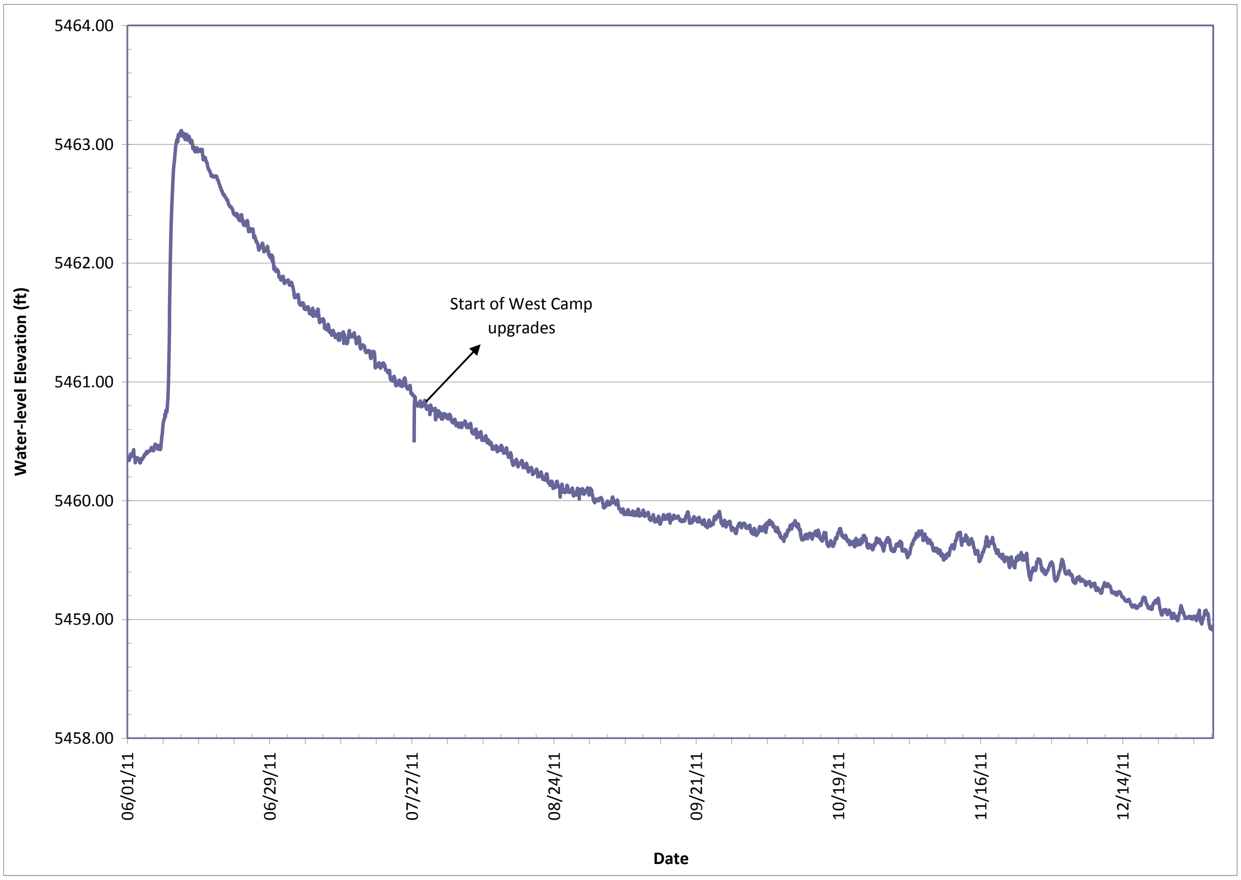
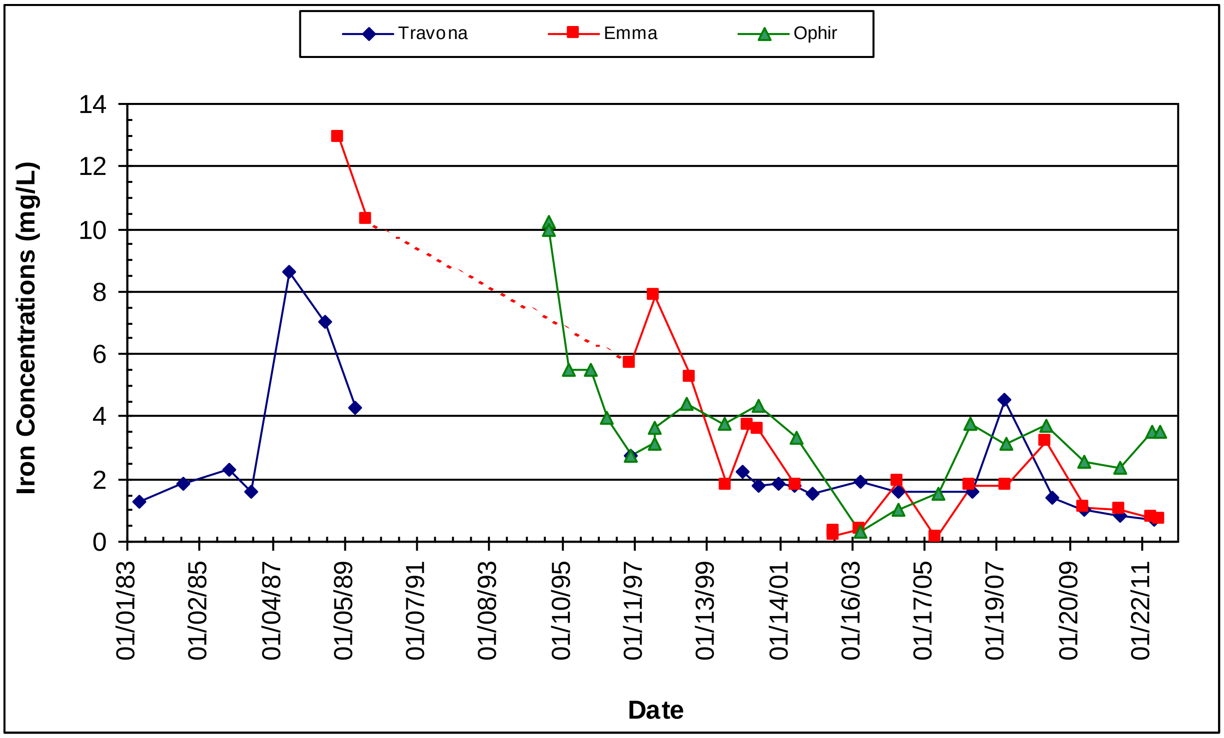


Figure 3-14. Water-level hydrograph for well BMF96-2 showing water-level changes during 2011 West Camp upgrades.

Section 3.2.1 West Camp Mines and Monitoring Wells Water Quality

In 2011 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 (100 µg/L in water from the Travona Mine and about 25 µg/L in water from the Emma Mine), the concentrations of most dissolved constituents in the West Camp water were similar (figs. 3-15 and 3-16). The concentrations of most dissolved metals in water from well BMF96-4 were low and continue to trend downward (fig. 3-17). Concentrations of zinc showed some variation between 2003 and 2007; however, concentrations are well below the SMCL and have returned to pre-2003 levels. Arsenic concentrations continue to range between 3 and 7 µg/L.



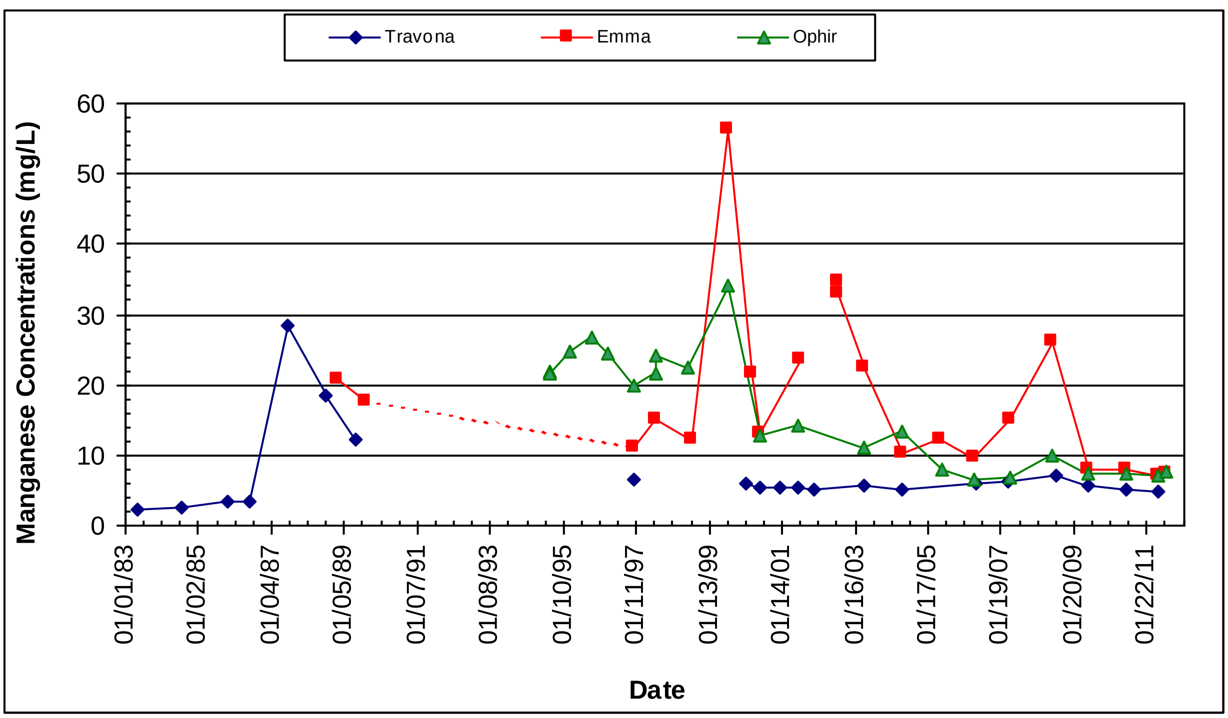
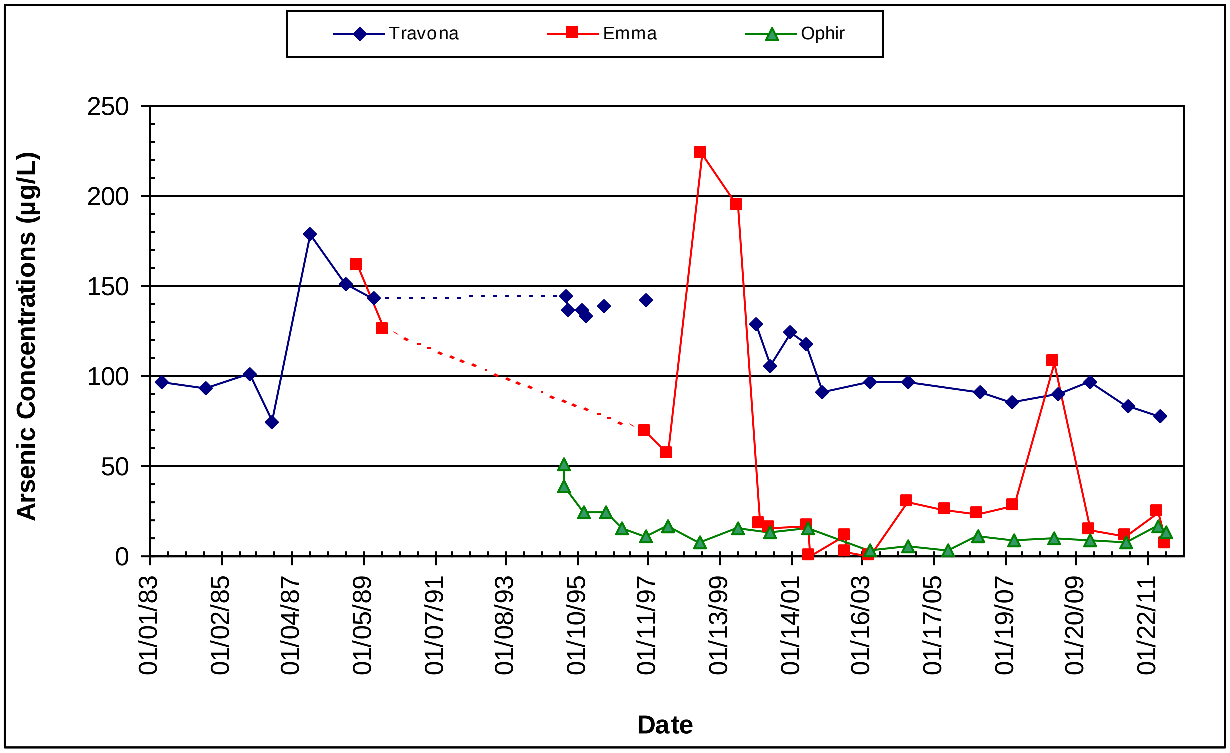


Figure 3-15. Iron and manganese concentrations in the West Camp mines.



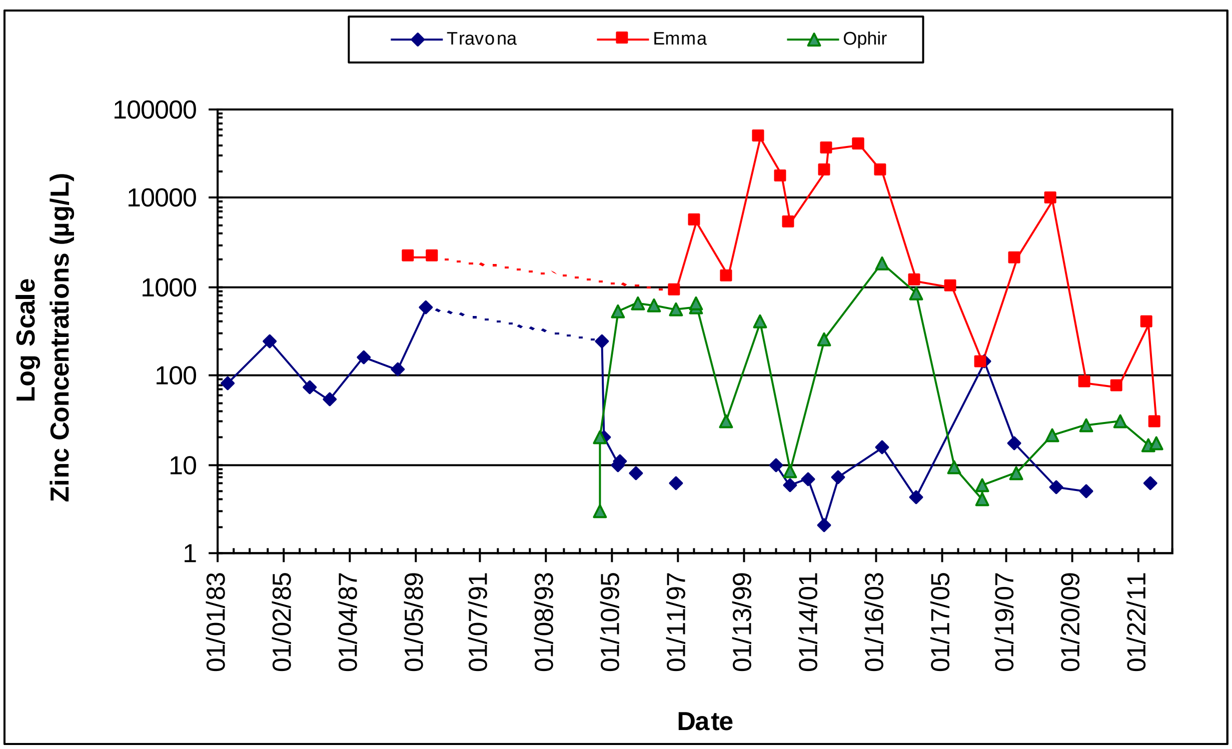
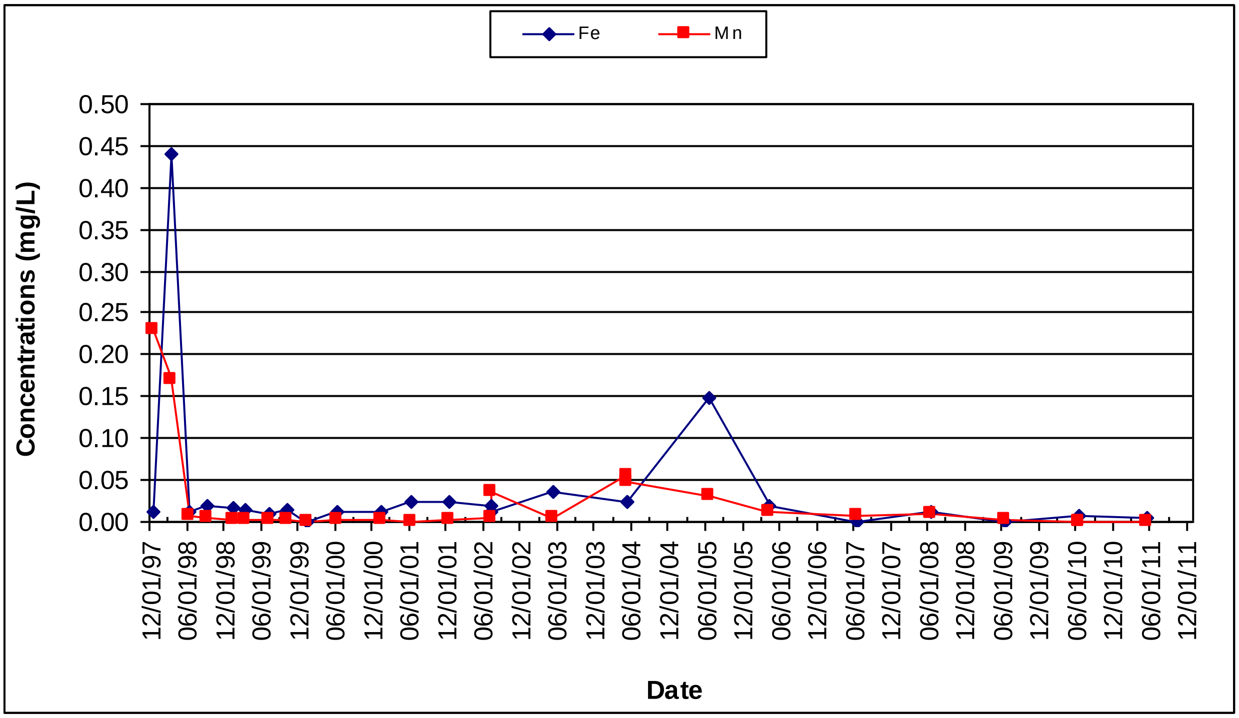


Figure 3-16. Arsenic and zinc concentrations in West Camp mines.



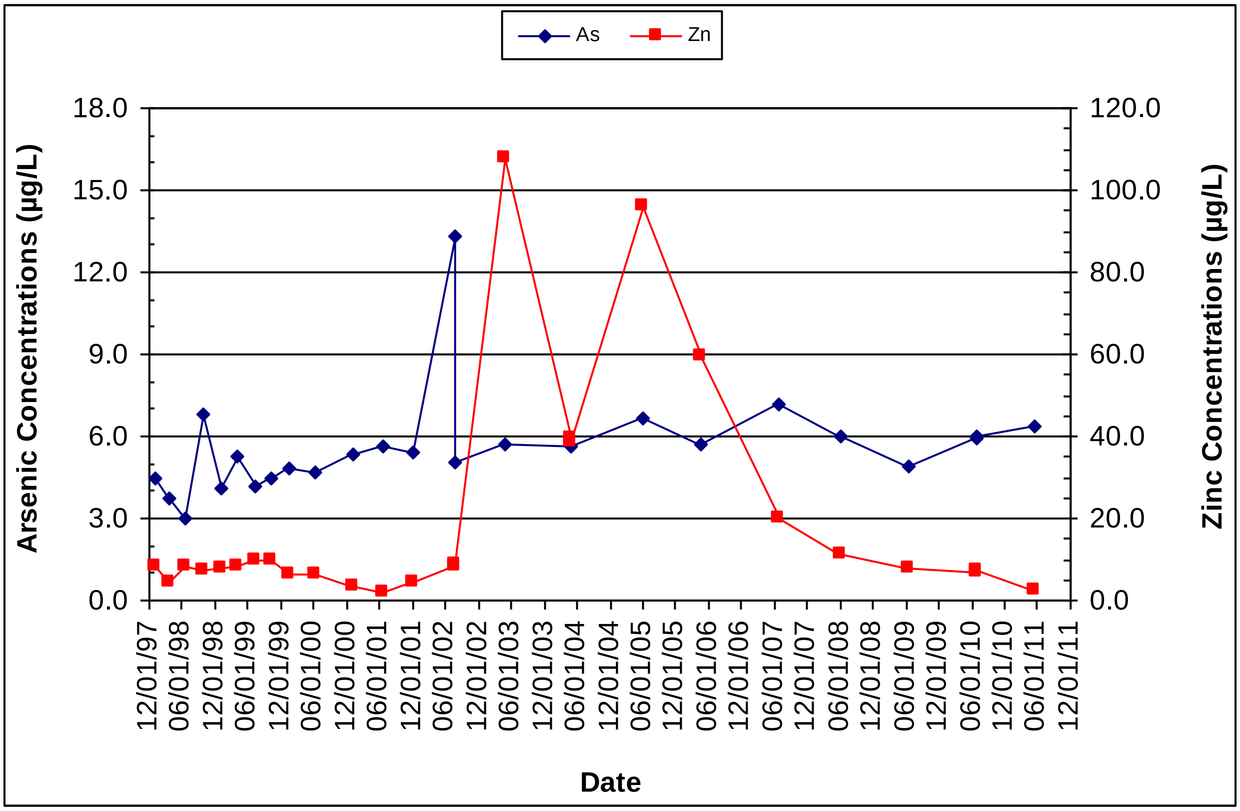


Figure 3-17. Selected water chemistry for West Camp well BMF96-4.

SECTION 4.0 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. 4-1). 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 4.1 Outer Camp System Water Levels

Outer Camp water levels rose in 2003 for the first time in 5 years; however, water levels declined in all but one site during 2004 and at all sites in 2005. This trend reversed in 2006 when water levels rose at all four locations, and continued in 2007 with increases in three of the four sites. However, in 2007 the amount of rise was much less than in 2006. Water levels declined at three of the four Outer Camp sites in 2008, in amounts equal to or greater than the 2007 increases. Since 2009, water levels have increased in at least three of the four sites; table 4.1.1 contains yearly water-level change data, and figure 4-2 shows these changes graphically.

Figure 4-3 shows water levels for the Orphan Boy Mine and the Montana Tech well, along with monthly precipitation. Water levels in the Montana Tech well showed a similar response to seasonal precipitation events from 2001 through 2004, rising each spring and declining throughout the winter. However, the 2005 water-level rise was less than that of the previous 2 years even though annual precipitation amounts were greater than those received in 2004. The spring 2006 water-level response was similar to that of previous years, with water levels beginning to rise in April; however, a corresponding decline in the fall did not occur. Instead, water levels rose into the late fall–early winter before leveling off. Water levels again rose in the spring and summer of 2007, before leveling off during the late fall–early winter. Water-level responses in 2008 and 2009 showed more of a seasonal trend, with seasonal peaks less than those of 2007. Water levels continued their seasonal downward trend through the first half of 2010, followed by a continuous rise through the remainder of the year and through the summer of 2011, before leveling off. Water-level changes in 2011 varied from a rise of 4.28 ft in the Montana Tech well to an increase of 12.08 ft in well S-4.

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

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

Table 4.1.1 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
Change Years 21–30	9.32	13.02	16.84	10.16
Total Change*	36.53	43.22	38.42	18.30

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

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

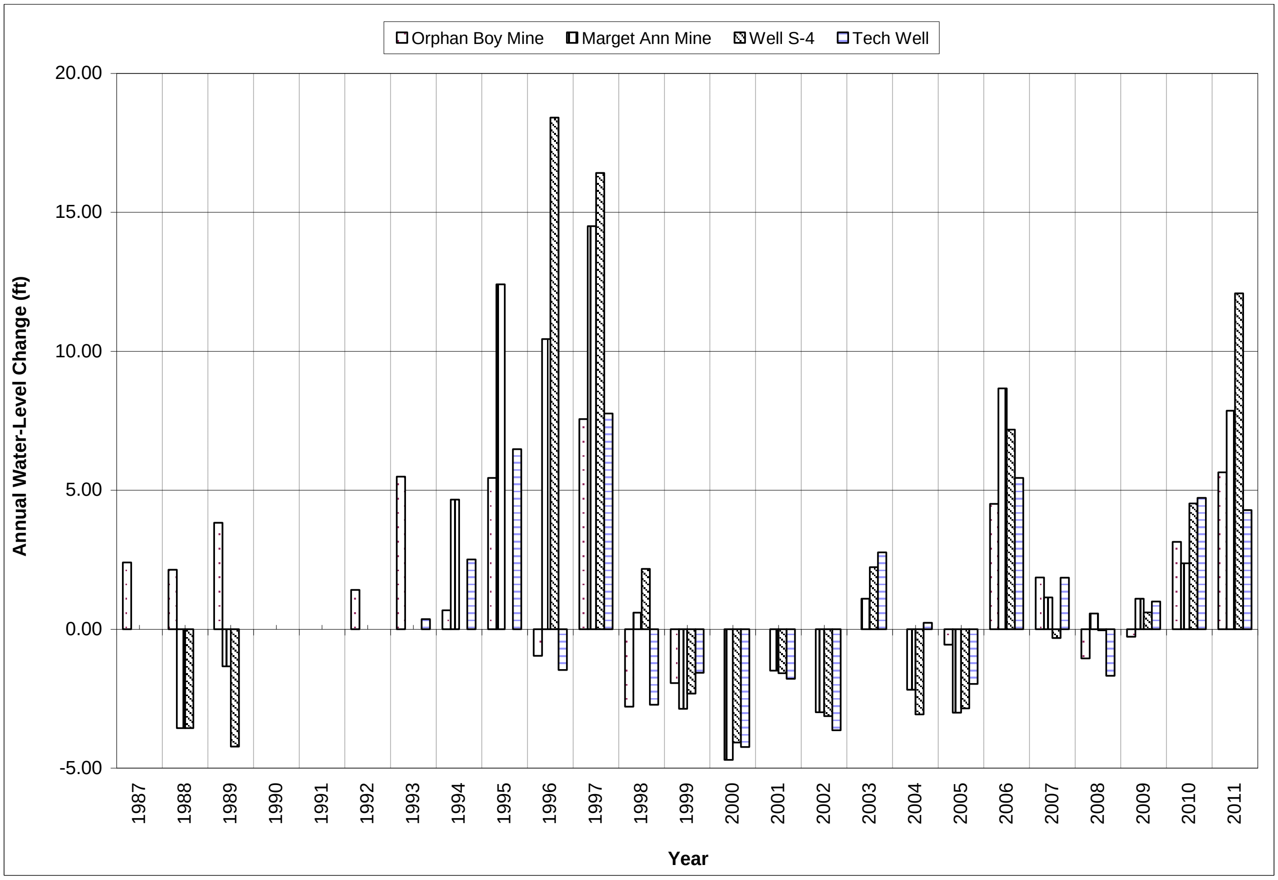


Figure 4-2. Outer Camp sites annual water-level change.

The water level in the Marget Ann Mine rose more than 7.8 ft during 2011; this was the sixth year that it rose and the seventh increase in the past 10 years. The water level in well S-4 rose by 12.08 ft during 2011, the 3rd year of the past 5 that it increased. Figure 4-4 shows water-level hydrographs for these two sites with monthly precipitation. Water levels from 1994 through 1998 showed a consistent increase regardless of precipitation. From 1999 through 2002, water levels declined, with little apparent influence from precipitation. Water levels in the Marget Ann Mine and well S-4 increased throughout 2003. The initial 2003 water-level rise occurred shortly after substantial precipitation in April 2003 and continued for the remainder of the year. During 2004 and 2005, water levels declined steadily regardless of precipitation. This trend reversed in 2006 and continued until 2011, with water levels rising in April before leveling off and declining in the late fall–early winter. The water-level rise at both sites was the largest seen during the period of monitoring. Similar to 2003, considerable precipitation occurred in May and June 2011, which may account for the large water-level increases. The same trend was observed in the Montana Tech well and Orphan Boy Mine, although to a lesser degree.

Water levels in all four of the Outer Camp sites have a net increase since monitoring began. The increase varies from more than 18 ft at the Montana Tech well to more than 43 ft in the Marget Ann Mine.

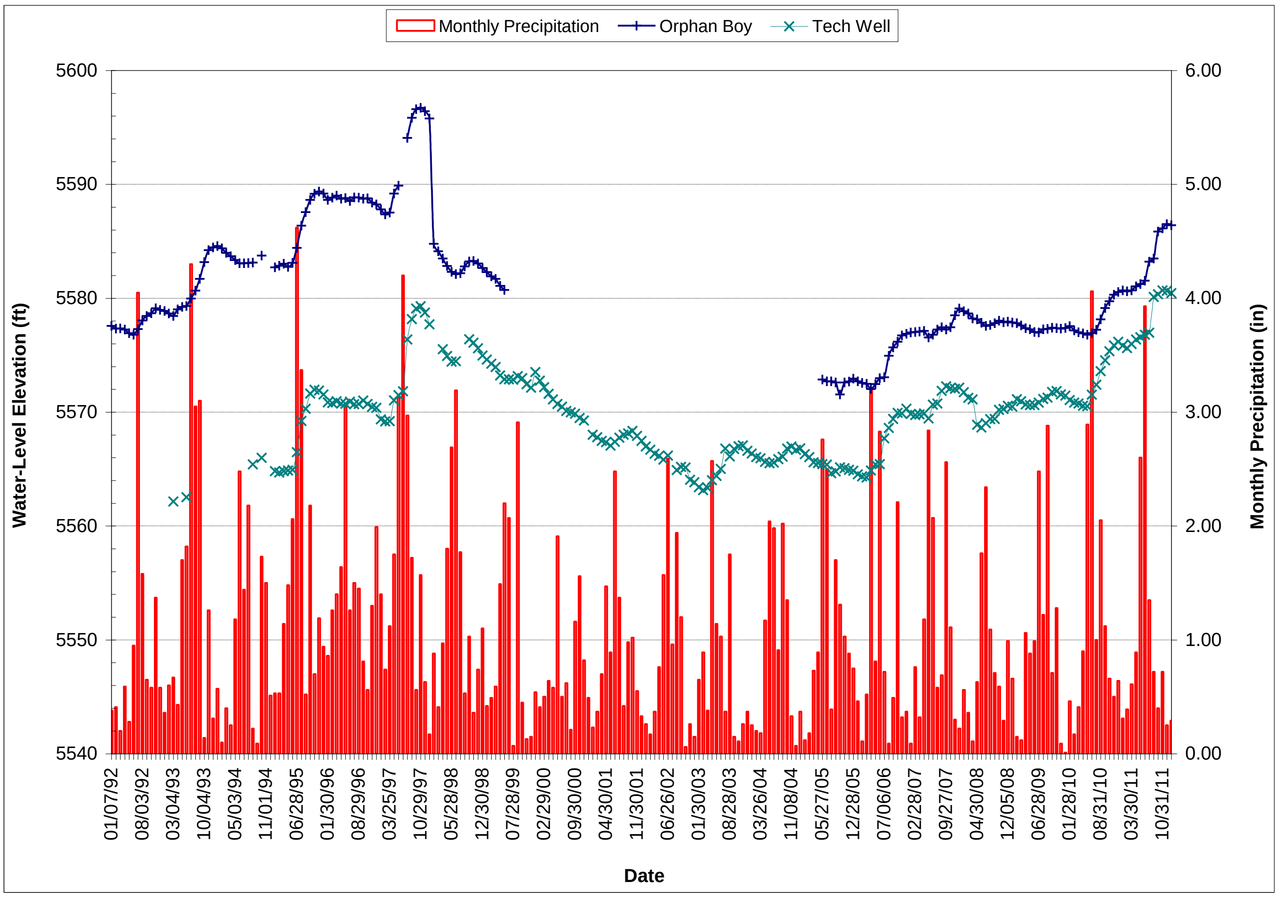


Figure 4-3. Water-level hydrograph for the Orphan Boy Mine and Montana Tech well.

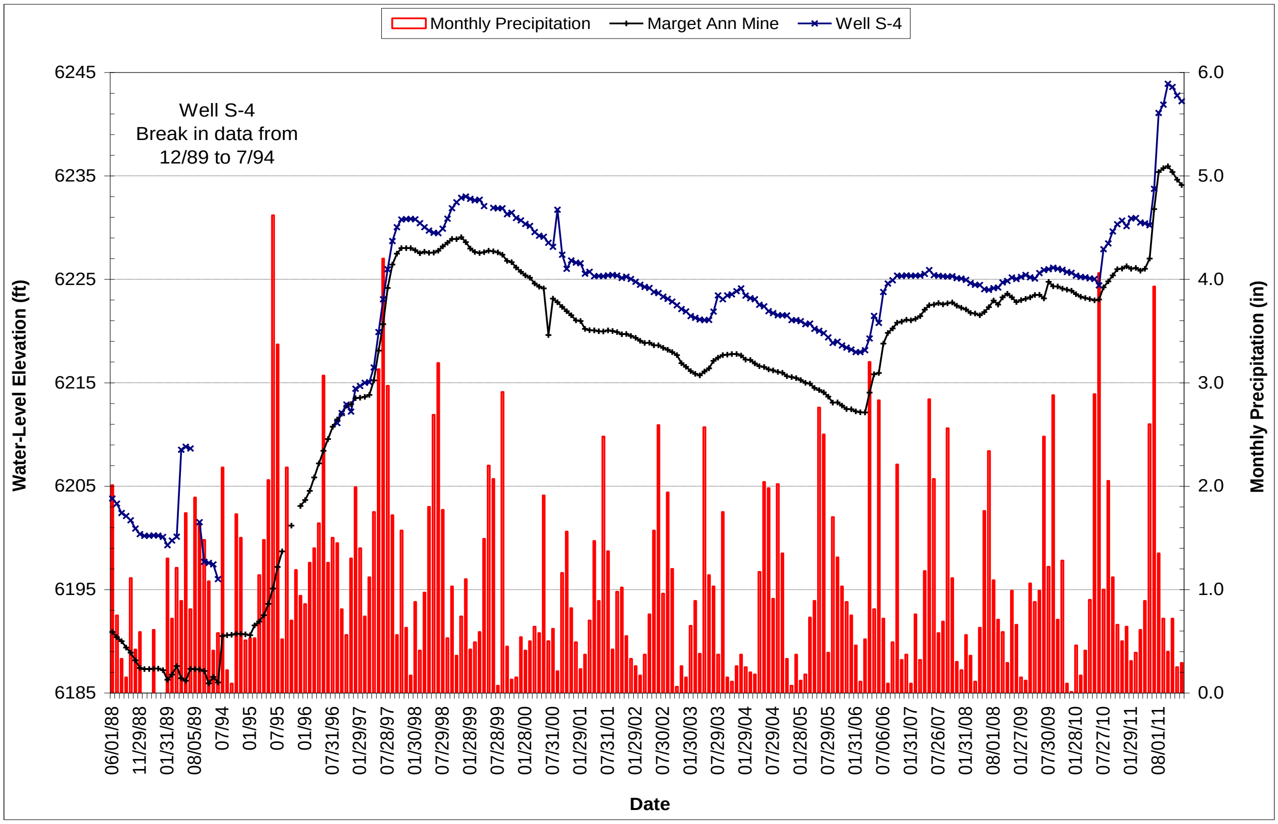


Figure 4-4. Water-level hydrograph for the Marget Ann Mine and well S-4.

Section 4.2 Outer Camp Water Quality

Water-quality samples were collected from all four locations within the Outer Camp System during 2011 (the Marget Ann Mine and MT Tech well are sampled every other year). The Orphan Boy Mine and Green Lake seep were sampled during both the spring and fall sample events. Figures 4-5 and 4-6 show selected water chemistry for the Orphan Boy Mine. Water-quality trends have been downward or unchanged with the exception being zinc, which appears to have increased since 2005. However, the apparent increase coincides with a change in sampling procedures. The 1987 and 1988 samples were collected by bailing a sample 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 equilibrium being reached as a result of the workings in this area being flooded for a longer period of time.

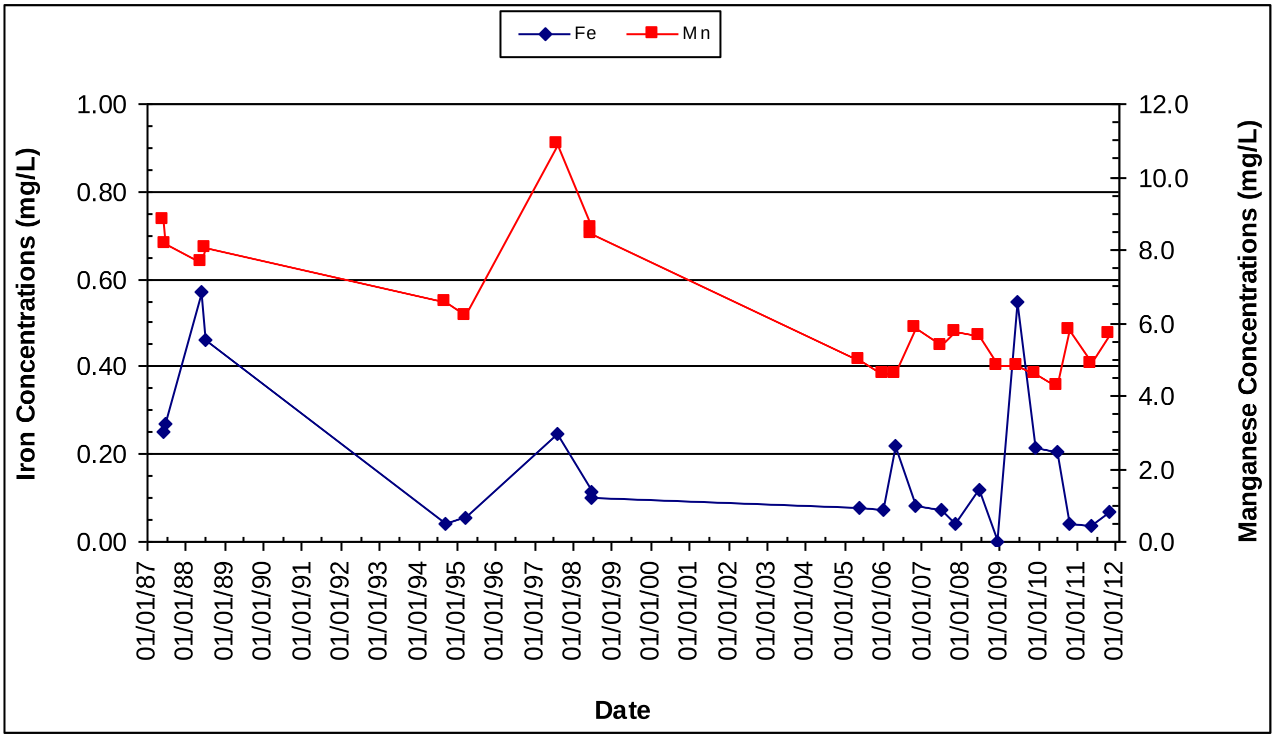


Figure 4-5. Iron and manganese concentrations for the Orphan Boy Mine.

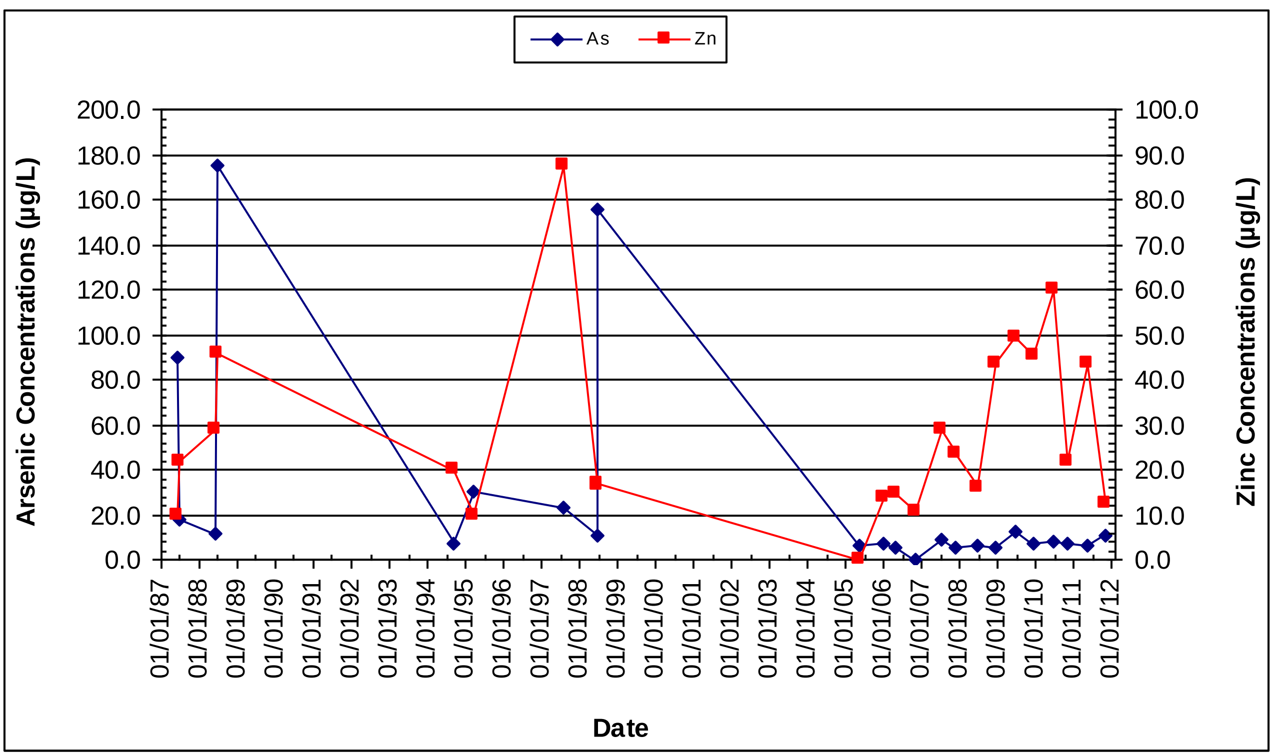


Figure 4-6. Arsenic and zinc concentrations for the Orphan Boy Mine.

SECTION 5.0 PARK WELLS

The locations of the park monitoring wells are shown on figure 5-1. The Hebgen Park and Parrot Park wells are part of the monitoring program specified in the 2002 CD. The Belmont Well #1 has been included because it is a bedrock well located within the East Camp system, and is part of the CD monitoring program.

Section 5.1 Park Wells' Water Levels

Annual water-level changes are listed in Table 5.1.1 and shown on figure 5-2. The yearly water-level changes in Belmont Well #1 since 1997 have 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, water levels have risen between 4 and 10 ft in the Hebgen and Parrot Park wells, but have fallen more than 2 ft in Belmont Well #1.

Table 5.1.1 Annual water-level change for miscellaneous wells, in feet.

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

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

Table 5.1.1 Annual water-level change for miscellaneous wells, in feet. (cont.)

Year	Hebgen(1)	Parrot	Belmont Well #1	Year	Hebgen(1)	Parrot	Belmont Well #1
2003	1.25	3.52	-54.19	2013			
2004	-0.12	-1.12	-39.79	2014			
2005	-2.19	6.76	-5.01	2015			
2006	2.86	6.95	35.07	2016			
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				2022			
Change Years 21-30	1.47	-2.73	16.23				
Net Change* Years 1-29	3.95	10.18	-2.39				

(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.

P&A- well plugged and abandoned.

Annual water-level response during 2011 at the Hebgen Park well (fig. 5-3) 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 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 dropped 0.82 ft during 2011; since monitoring began at this site, water levels have increased 3.9 ft

The water-level hydrograph for the Parrot Park well is shown on figure 5-4, along with monthly precipitation. Water levels declined during most of 2002 before leveling off and rising in December. Water levels and trends in 2003 were similar to those of 2000 and 2001; however 2004 water levels did not show the same response to precipitation. Water levels declined for most of 2004 before rising almost 3.5 ft in November and December. The rise late in 2004 is not related to either precipitation events or lawn irrigation. Water levels continued to rise through 2005 and 2006 regardless of precipitation. Water levels continued to rise during the first two months of 2007 before declining for the next four months. Water levels began to rise again in July before leveling off in October and declining the remainder of the year. Water levels rose steadily throughout 2008 and the first half of 2009 regardless of seasonal climatic conditions. However, beginning in June water-levels began to fall eventually declining almost 27 ft for the year. Water levels continued to decline through July 2010 before rising slightly and then again falling in December; the 2010 water-level decline was more than 7.5 ft The 2011 water-levels appeared to change seasonally; however, the spring increase was several feet greater than that of 2010. Water levels at this site have risen more than 10 ft since monitoring began in 1988.

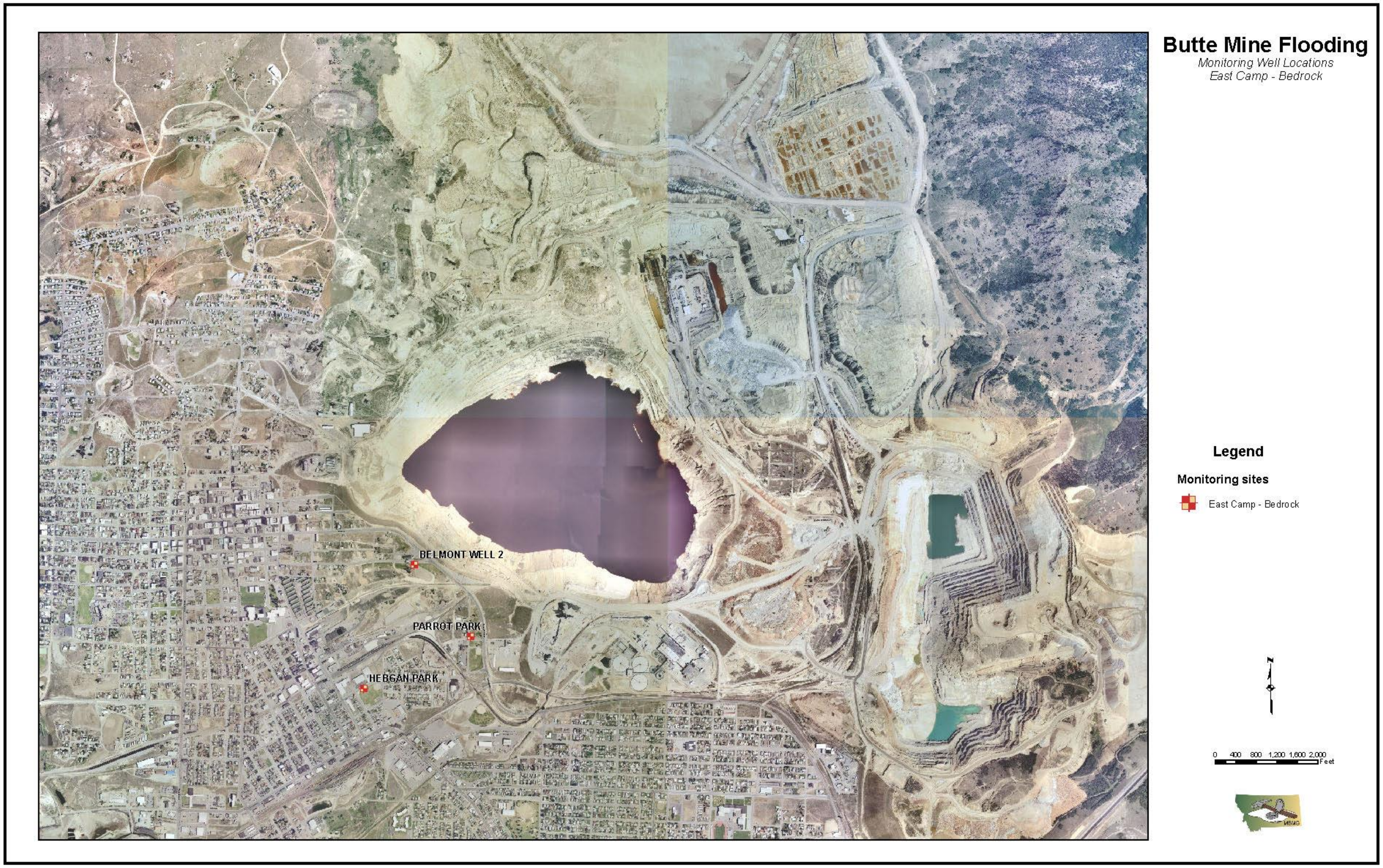


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Figure 5-1. East Camp Park monitoring wells location map.

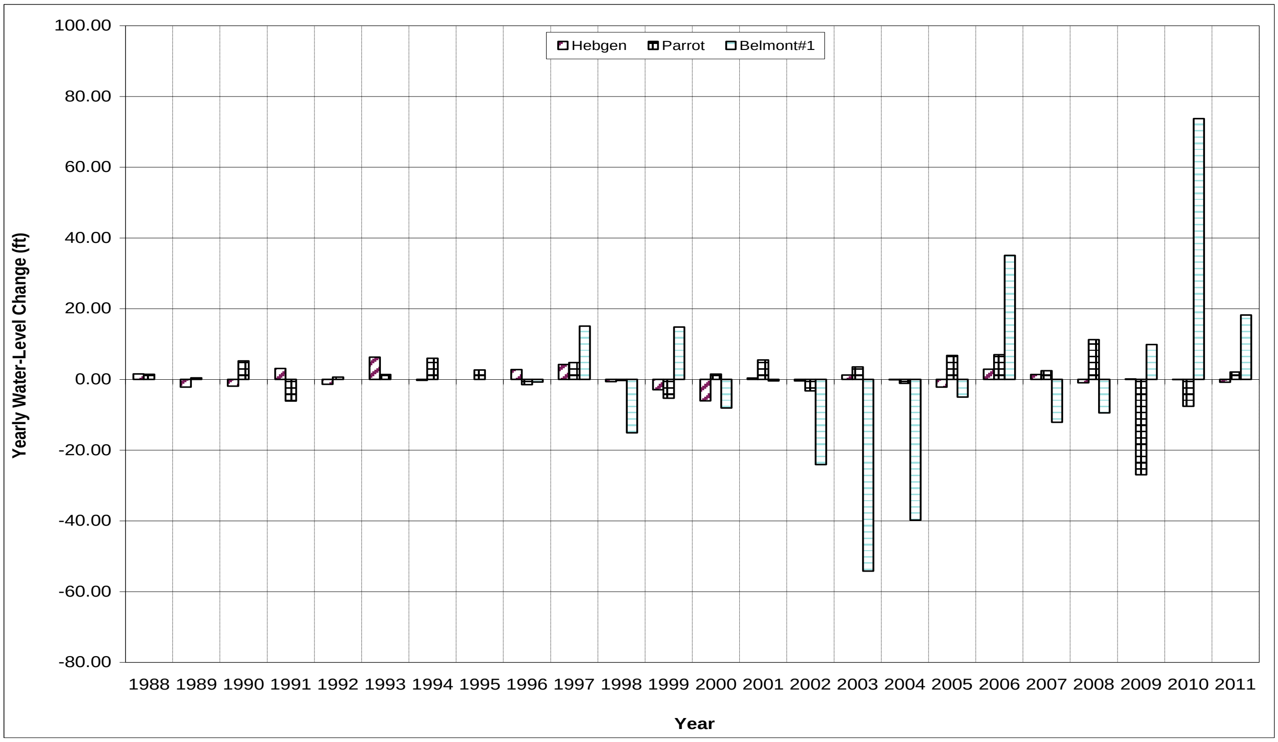

Figure 5-2. Park wells annual water-level changes.

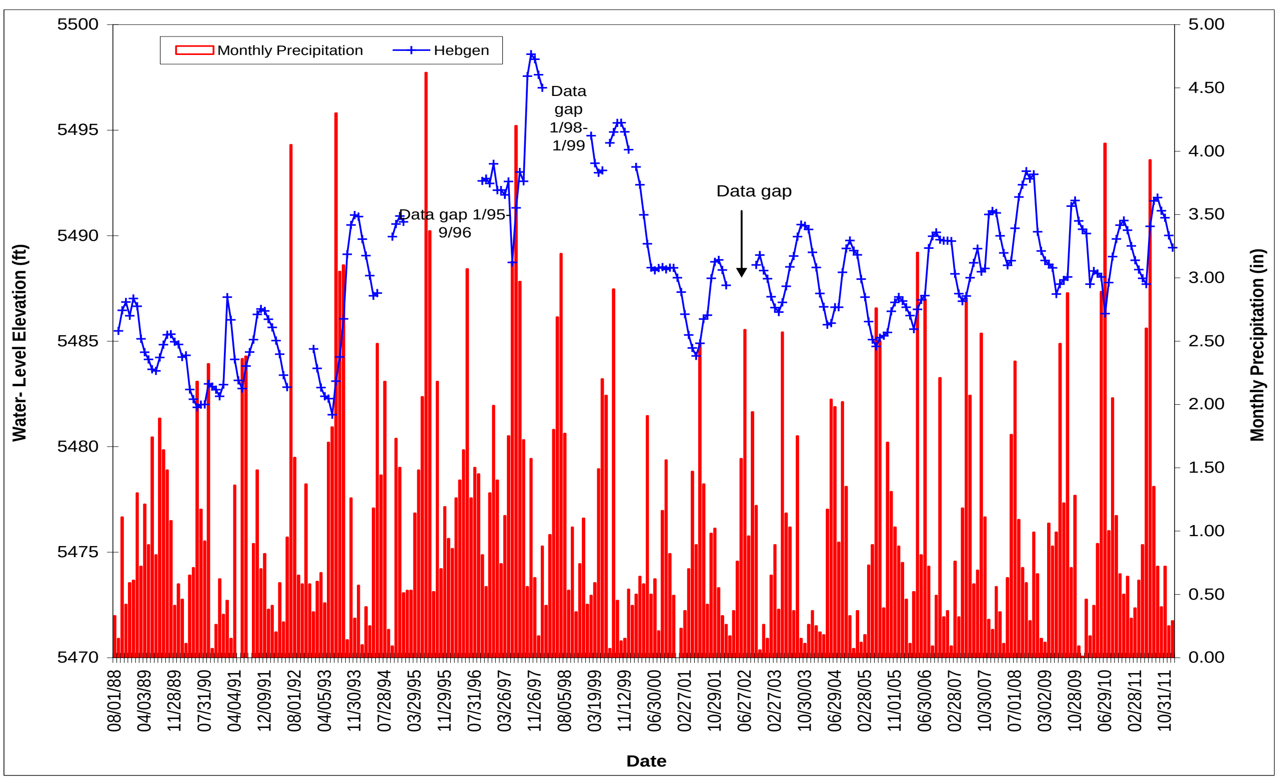

Figure 5-3. Water-level hydrograph for the Hebgen Park well.

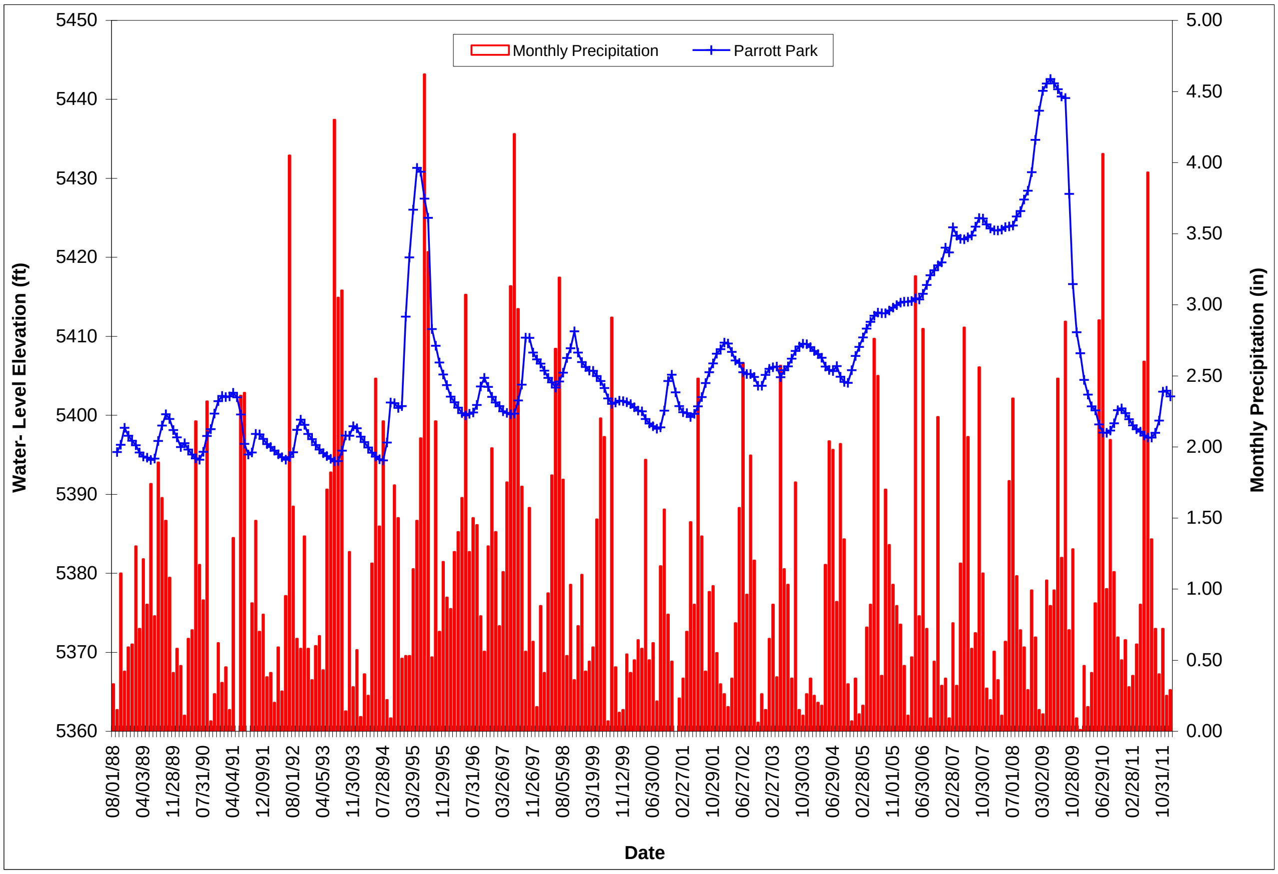

Figure 5-4. Water-level hydrograph for Parrot Park well.

Figure 5-5 is a water-level hydrograph, which shows the recent water-level trends for both the Parrott and Hebgen Park wells. The water-level increases in the Parrot well from 2004 through 2008 did not occur in the Hebgen well, nor is the decline that began in mid 2009 and continued into the middle of 2010. The Hebgen Park well appears to respond to seasonal conditions (snowmelt, precipitation, and lawn irrigation); water levels in the Parrot Park well change less consistently and do not appear to follow climatic variability.

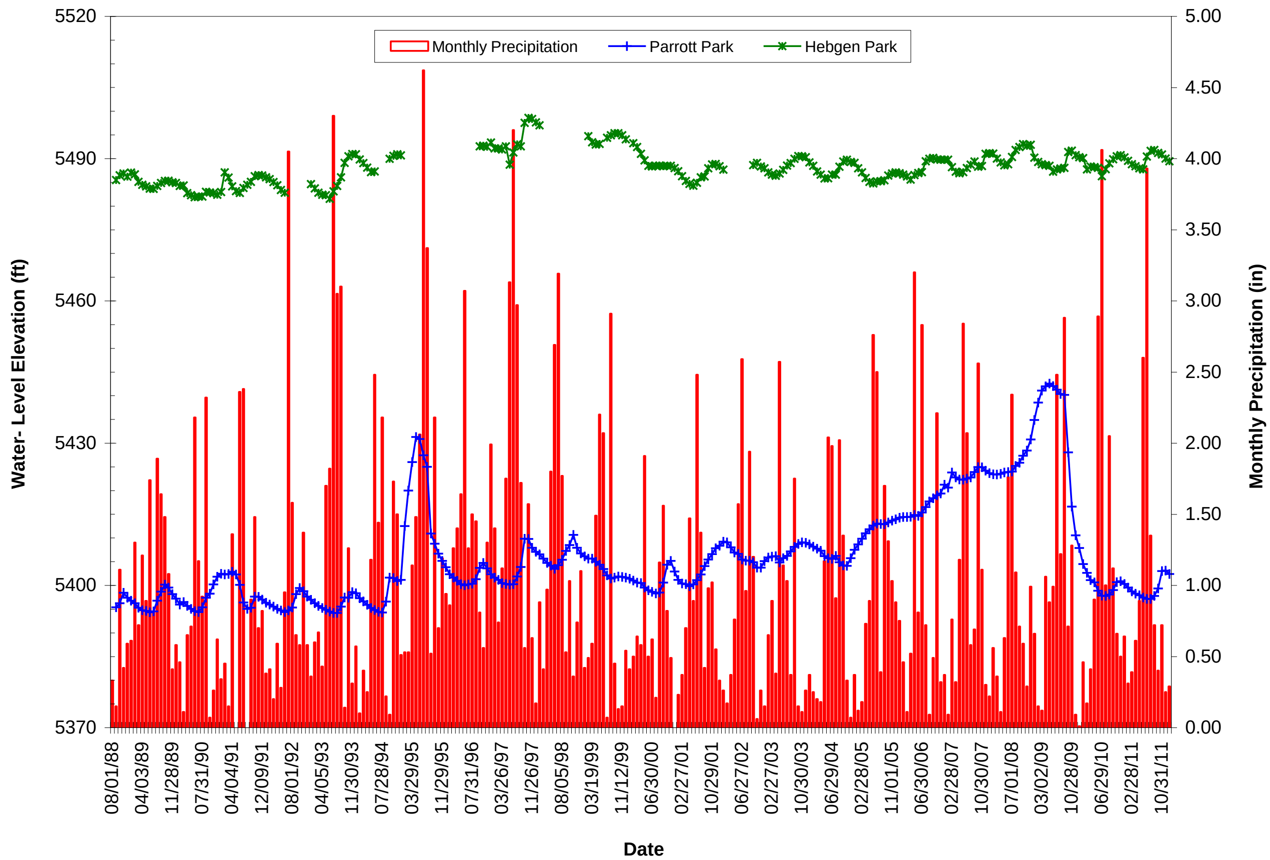

Figure 5-5. Water-level hydrographs for Parrot Park and Hebgen Park wells.

The Belmont Well #1 was drilled as a replacement well for 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 (fig. 5-6). From 2002 through 2005 water levels declined more than 120 ft, before rising 35 ft in 2006. Water levels declined over 12 ft in 2007 and another 9 ft in 2008, but then rose almost 10 ft in 2009. Water levels rose more than 73 ft in 2010 and more than 18 ft in 2011. While the exact reasons and mechanism controlling the rise and fall in water levels is unknown, the maximinum and minimum water-level elevations are similar during each period of change.

The water-level changes between 2003 and 2010 initially appeared to be in response to precipitation and/or lawn irrigation when water levels and precipitation were compared (fig. 5-6); 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 5-7 is a hydrograph for this well from the fall of 2003 through 2011, 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.

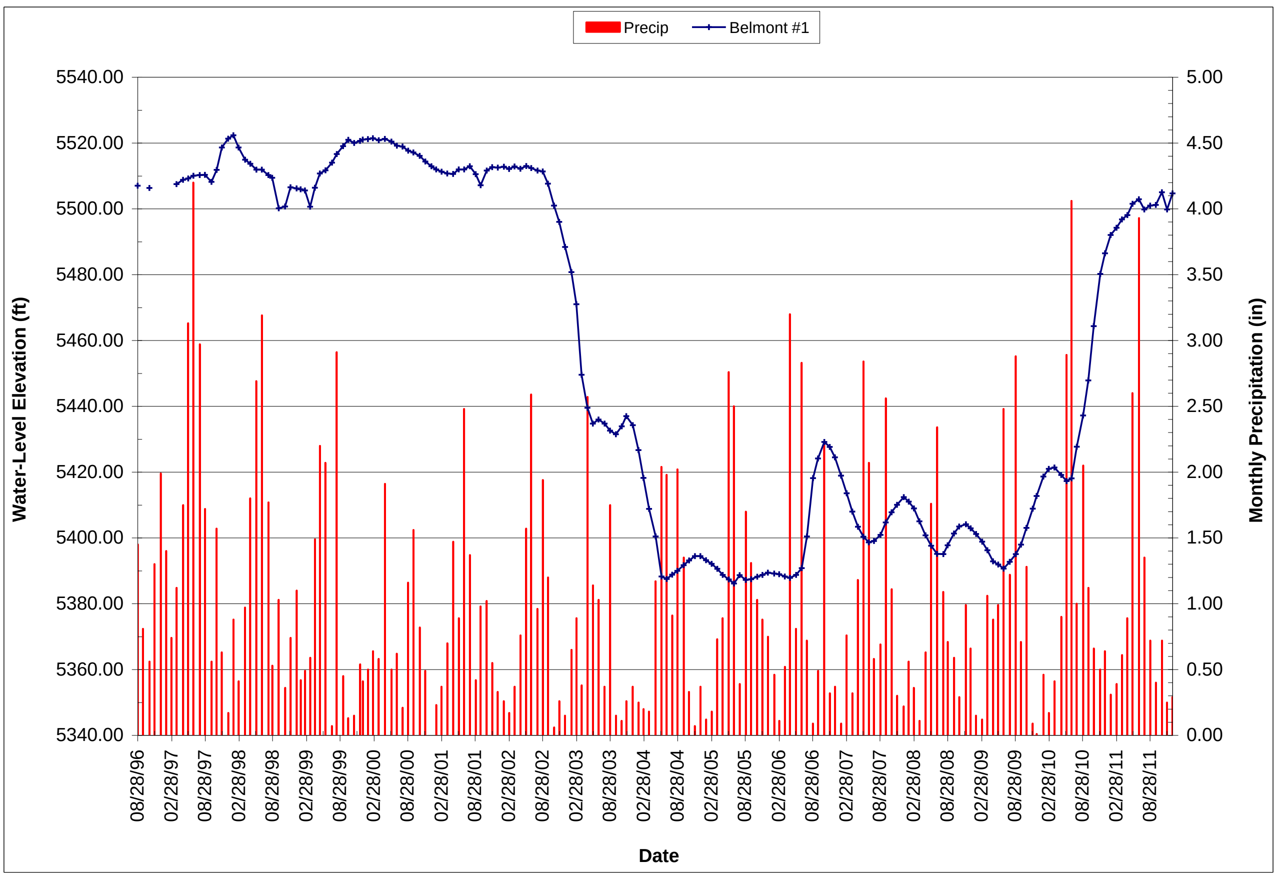

Figure 5-6. Water-level hydrograph for Belmont Well #1.

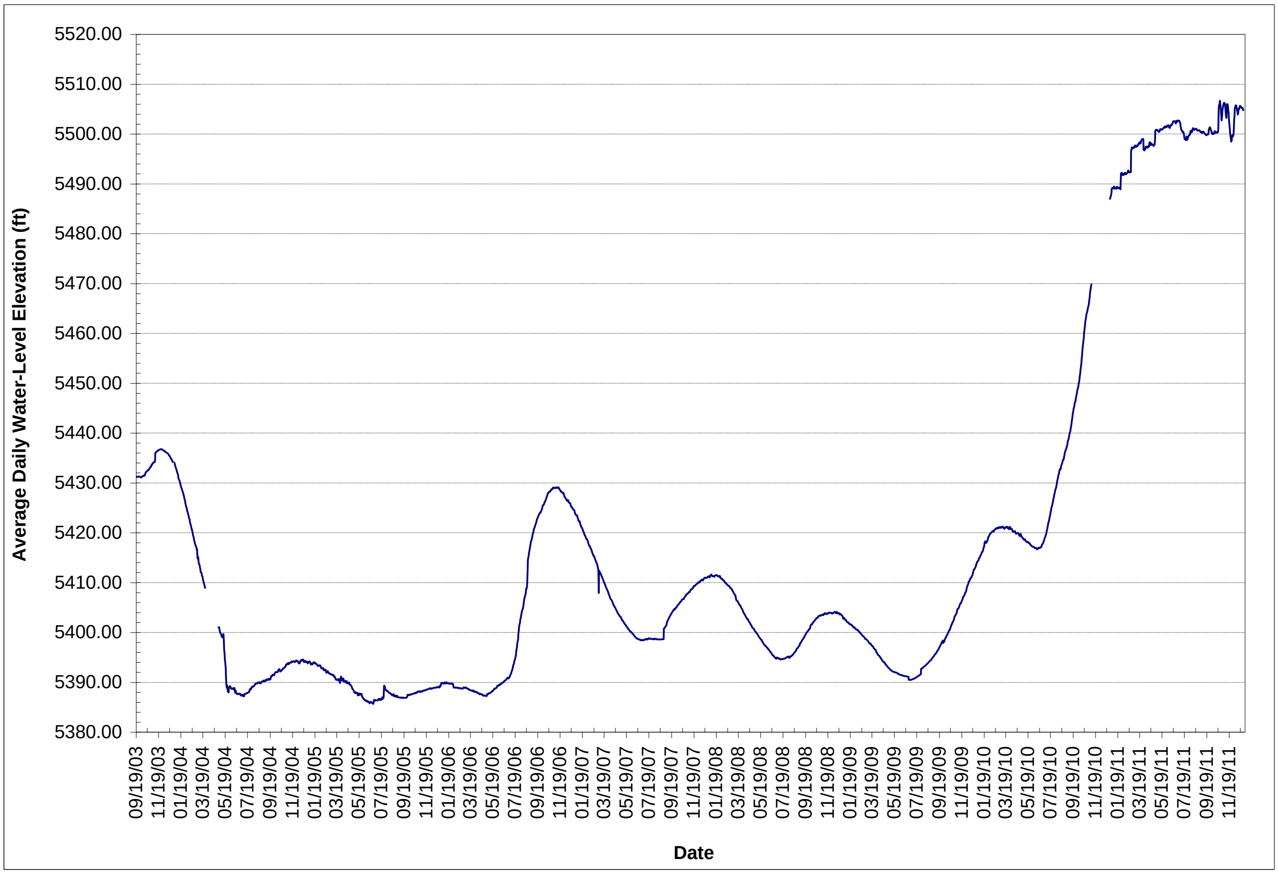

Figure 5-7. Hydrograph showing average daily water-level elevations for Belmont Well #1.

Section 5.2 Park Wells Water Quality

Water-quality samples were collected only from the Parrot Park well during 2011. Figure 5-8 shows concentration trends for cadmium and copper over time, while figure 5-9 shows arsenic and zinc concentration trends. Arsenic and cadmium concentrations in the samples exceed the MCL. Although cadmium concentrations declined in 2008 to levels below the MCL, concentrations in 2009–2011 were above the MCL. In 2011, concentrations increased for arsenic, copper, and cadmium; zinc concentrations remained similar to those of the preceding 3 years (figs. 5-8 and 5-9).

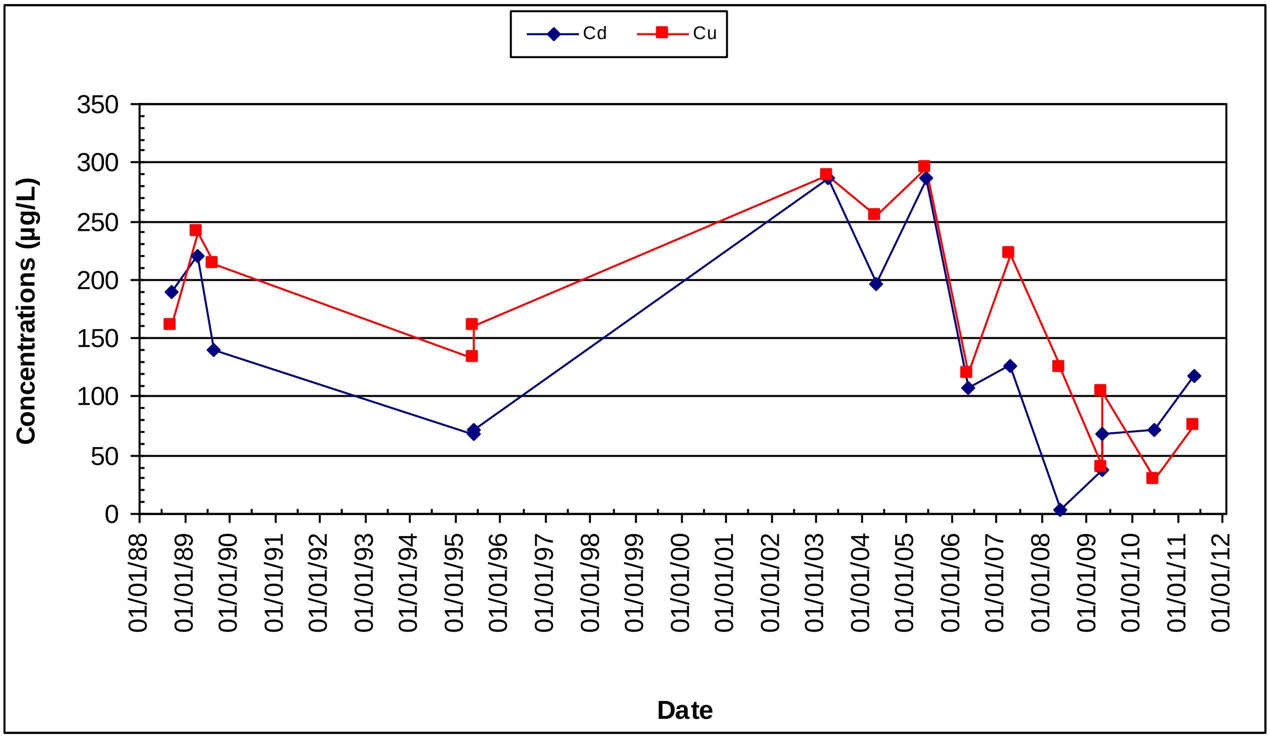

Figure 5-8. Cadmium and copper concentrations for the Parrot Park well.

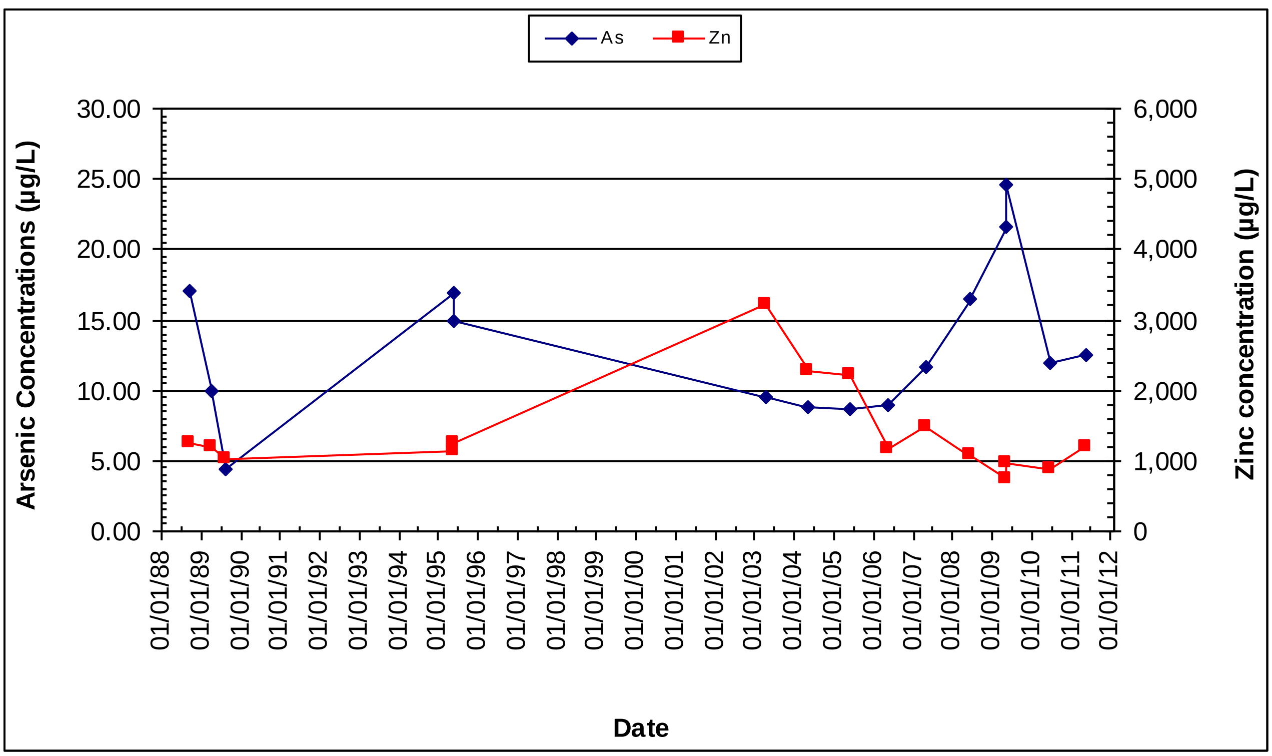

Figure 5-9. Arsenic and zinc concentrations for the Parrot Park well.

SECTION 6.0 REVIEW OF THE BERKELEY PIT MODEL

The Berkeley Pit water-level model was updated based upon actual 2011 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 2011.

Based upon the 2011 model update, the critical water level (CWL) of 5,410 ft is projected to be reached at the Anselmo Mine in **April 2023**, 2 months (0.16 years) later than predicted in the 2010 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's 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 2011; the consistent filling rate and operational activities led to the minor adjustment in filling-rate projection. The Pit contained 41.6 billion gallons of water at the end of 2011, while the projected volume of water in April 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 Butte Mine Flooding Operable Unit (EPA, 1994, 2002). Based upon the current water-level projections, a review of the HSB treatment plant design and operation would begin in April 2019. Any necessary upgrades would have to be completed by April 2021 (fig. 6-1).

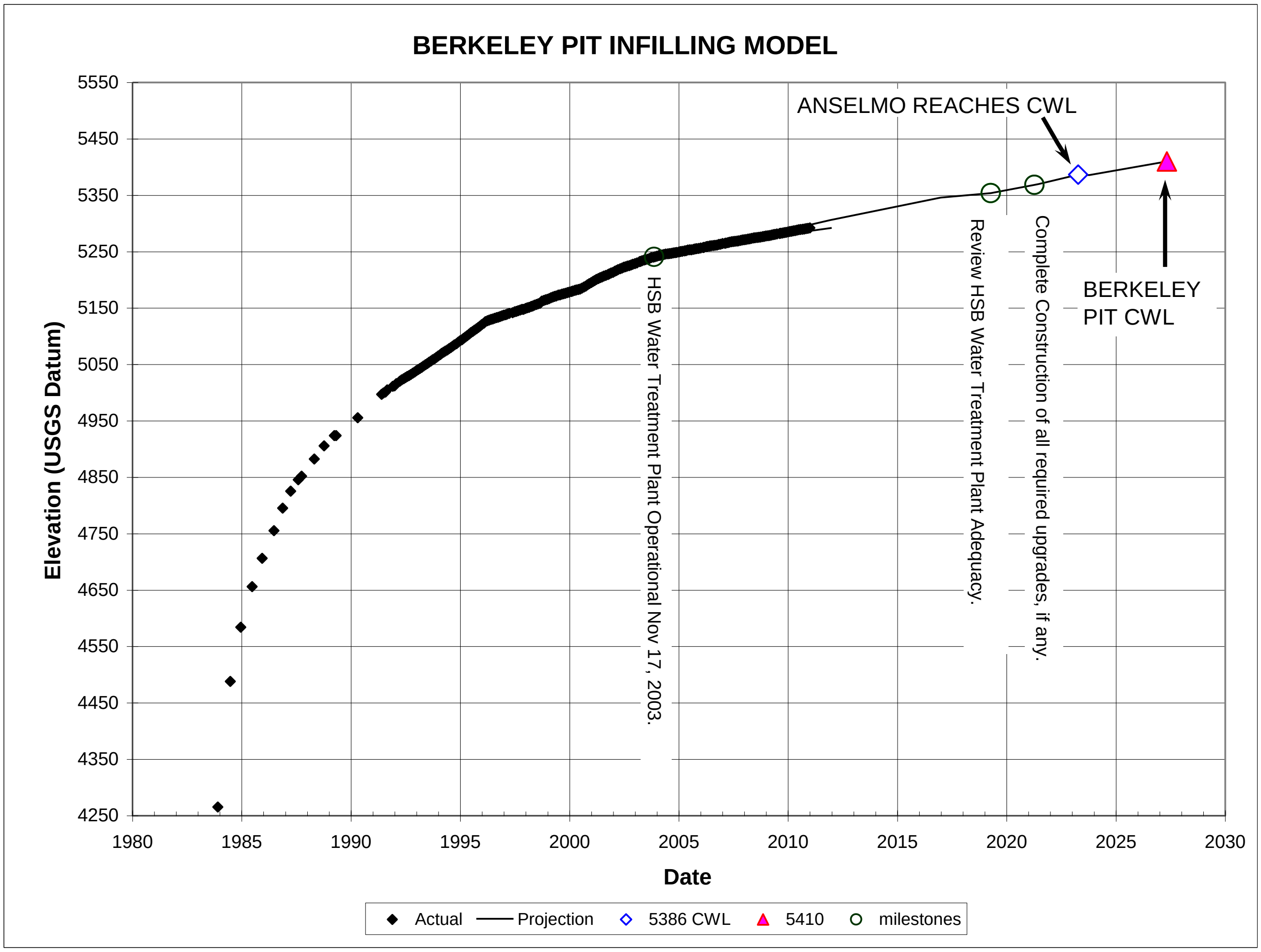

Figure 6-1. Figure showing projected Berkeley Pit filling rate and dates of treatment review and upgrades.

SECTION 7.0 CONCLUSIONS AND SUMMARY

Water-level trends in the alluvial monitoring system within the active mine area were similar to those in 2004–2006, with water levels increasing in a majority of the wells north of the Pittsmont Dump. This reverses the trend observed from 2003 and earlier and from 2007 through 2010 of water levels decreasing in a majority of these wells. Water levels rose in a majority of the wells south of the Pittsmont Dump, continuing the trend that began in 2003.

Seasonal precipitation still had 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 activities than to 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. The decrease in annual precipitation in the Butte Basin since 1999 had been considered a good explanation for water-level decreases in a number of monitoring wells. However, water levels increased in all of the AMC- and GS-series wells in 2003, increased in a majority in 2004, but fell in 2005. The 2003 water-level increase occurred although precipitation was less than that of previous years. The increases were greater in wells nearest the mine site, and water levels there rose most during late summer and the remainder of the year. While this time coincides with MR's mine start-up activities, no direct link was found between start-up activities and water-level changes. However, a relationship between filling of the MR concentrator Emergency (Dredge) Pond and water-level increases in several AMC wells was apparent. A similar water-level response was seen in 2011 in several wells (AMC- and BMF05-series) following MR's cleaning and deepening of the Ecology Pond. The correspondence supports the relationship between operational changes and water-level changes near the active mine area. Water-level increases in 2011 were consistent throughout the alluvial monitoring network, similar to trends observed in 2006–2007and 2009–2010.

The water-level rises in the East Camp bedrock system are independent of precipitation 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, the continued diversion of HSB drainage water away from the Berkeley Pit did influence East Camp bedrock water levels; the water-level rise for 2011 in wells A and G was about 45 percent that of 2002–2003, when HSB water flowed into the Pit.

The date the East Camp System water level is predicted to reach the CWL elevation of 5,410 ft in the Anselmo Mine was changed from February 2023 to April 2023, 2 months later than predicted in 2010. 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 mine system and ensure that all water in the historic underground mine system will continue to flow towards the Berkeley Pit.

The pumping of groundwater in the West Camp System continues to control water levels. Pumping was modified from July through the end of 2011 to allow for upgrades at the West Camp pump station and operational changes at the BTL; however, the volume of water pumped during 2011 was similar to that of 2010. Water-level elevations decreased up to 4 ft throughout this system and are now about 17 ft below the maximum allowable level.

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 a continuation of several dissolved constituents upward; concentrations still remain below values observed during initial flooding. Data from the Emma shaft continue to show departure from recent trends and a notable difference in water quality compared to the Travona Mine.

Results in 2011 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 30 years. Numerous individuals have been responsible for actual data collection. 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 the British Petroleum/Atlantic Richfield Company is greatly appreciated; 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 the new alluvial monitoring wells: Gilman Construction, Continental Public Land Trust, Butte School District #1, and Race Track Volunteer Fire Department.

Special recognition is given to Matt Berzel, Garrett Smith, Paul Thale, and Peggy Delaney, MBMG, for assisting with the preparation of this report.

Errors and omissions remain the authors' responsibility.

REFERENCES

AccuWeather 2012, Online database www.accuweather.com [Accessed February 2012].

Burns, G., 1994, A review of the geology and historic production of the Butte District: Presented at the 100th Annual Northwest mining Association Conference, 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 (1982–1987): 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., 2005a, 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., 2005b, 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., 2011a, 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., 2011b, 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.

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, *in* Mine water and the environment, vol. 25, no. 2, June 2006.

GWIC, 2011, Montana Bureau of Mines and Geology, Ground Water Information Center, Online Database, 2011.

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.

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

Sales, R.H., 1914, Ore deposits at Butte, Montana: American Institute of Mining and Metallurgical Engineers, Transactions, vol. 46, no. 3-106.

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