Long-Term Monitoring Network Optimization Evaluation

for

Operable Unit 2
Bunker Hill Mining and Metallurgical Complex Superfund Site
Idaho

January 2006

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FINAL

LONG-TERM MONITORING NETWORK

OPTIMIZATION EVALUATION

FOR

OPERABLE UNIT 2
BUNKER HILL MINING AND METALLURGICAL COMPLEX
SUPERFUND SITE
IDAHO

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LIST OF ACRONYMS

AWQC	ambient water quality criteria
bgs	below ground surface
Bunker Hill	Bunker Hill Mining and Metallurgical Complex Superfund Site
CIA	Central Impoundment Area
CLP	Contract Laboratory Program
COC	contaminant of concern
COV	coefficient of variation
CSM	conceptual site model
EMP	Environmental Monitoring Plan
ESRI	Environmental Systems Research Institute, Inc.
ft/day	foot per day
ft/ft	foot per foot
GIS	geographical information system
HU	hydrostratigraphic unit
LTM	long-term monitoring
LTMO	long-term monitoring optimization
µg/L	microgram(s) per liter
MCL	maximum contaminant level
MNO	monitoring network optimization
ND	not detected
OU	Operable Unit
PQL	practical quantitation limit
RAO	remedial action objective
ROD	Record of Decision
SCA	Smelter Closure Area
SFCDR	South Fork Coeur d'Alene River
USEPA	United States Environmental Protection Agency

SECTION 1

INTRODUCTION

Groundwater monitoring programs typically have two primary objectives (U.S. Environmental Protection Agency [USEPA], 1994; Gibbons, 1994):

1. Evaluate long-term temporal trends in contaminant concentrations at one or more points within or outside the remediation zone as a means of monitoring the performance of the remedial measure (*temporal objective*) and

2. Evaluate the extent to which contaminant migration is occurring, particularly if a potential exposure point for a susceptible receptor exists (*spatial objective*).

The relative success of any remediation system and its components (including the monitoring network) must be judged based on the degree to which it achieves the stated objectives of the system. Designing an effective groundwater monitoring program involves locating monitoring points and developing a site-specific strategy for groundwater sampling and analysis to maximize the amount of relevant information that can be obtained while minimizing incremental costs. Relevant information is that required to effectively address the temporal and spatial objectives of monitoring. The effectiveness of a monitoring network in achieving these two primary objectives can be evaluated quantitatively using statistical techniques. In addition, there may be other important considerations associated with a particular monitoring network that are most appropriately addressed through a qualitative assessment of the network. The qualitative evaluation may consider such factors as hydrostratigraphy, locations of potential receptor exposure points with respect to a dissolved contaminant plume, and the direction(s) and rate(s) of contaminant migration.

This report presents a description and evaluation of the groundwater and surface water monitoring program associated with the Bunker Hill Mining and Metallurgical Complex Superfund Site (Bunker Hill) Operable Unit (OU) 2. A monitoring network consisting of 77 groundwater monitoring wells and 18 surface water stations was evaluated to assess its overall effectiveness at achieving the OU2-specific monitoring objectives, and to (1) identify potential opportunities to streamline monitoring activities while still maintaining an effective monitoring program, and (2) identify data gaps that may require the addition of additional monitoring points. A three-tiered approach, consisting of a qualitative evaluation, a statistical evaluation of temporal trends in contaminant concentrations, and a spatial statistical analysis (groundwater only), assessed the degree to which the monitoring network addresses the objectives of the monitoring program, as well as other important considerations. The results of the three evaluations were combined and used to assess the optimal frequency of monitoring and the spatial distribution of the components of the monitoring network. The results of the analysis were then used to develop recommendations for optimizing the monitoring program at OU2.

SECTION 2

SITE BACKGROUND INFORMATION

The location, operational history, environmental setting (*i.e.*, geology, hydrogeology, and surface water hydrology), and remediation history of OU2 are briefly summarized in the following subsections. These topics are discussed in detail in the draft OU2 conceptual site model (CSM) report (CH2M Hill, 2005a), which is the primary source of the information presented below.

2.1 SITE LOCATION AND OPERATIONAL HISTORY

Bunker Hill Mining and Metallurgical Complex Superfund Site is within one of the largest historical mining districts in the world. Commercial mining for lead, zinc, silver, and other metals began in this portion of the Coeur d'Alene River Basin (known as the "Silver Valley") in 1883. Heavy metals contamination in soil, sediment, surface water, and groundwater from over 100 years of commercial mining, milling, smelting and associated modes of transportation has impacted both human health and environmental resources in many areas throughout the site.

The Bunker Hill Superfund Site was listed on the National Priorities List in 1983. The Site includes mining-contaminated areas in the Coeur d'Alene River corridor, adjacent floodplains, downstream water bodies, tributaries, and fill areas, as well as the 21-square mile Bunker Hill "Box" located in the area surrounding the historic smelting operations. The USEPA has designated three OUs for the Site:

- The populated areas of the Bunker Hill Box (OU1),
- The non-populated areas of the Bunker Hill Box (OU2), and
- Mining-related contamination in the broader Coeur d'Alene Basin (OU3).

OU2 of the Bunker Hill Mining and Metallurgical Complex Superfund Site is the focus of this report and consists of the non-populated areas of a rectangular 7-mile by 3-mile area known as the Bunker Hill "Box" with the exception of the South Fork Coeur d'Alene River (SFCDR) and the Pine Creek drainage (see Figure 2.1 of this report and Figures 2-1 and 2-2 of the draft CSM report [CH2M Hill, 2005a] which are included in Appendix A). The populated areas of the Bunker Hill Box and the SFCDR/Pine Creek drainage are included in OU1 and OU3, respectively.

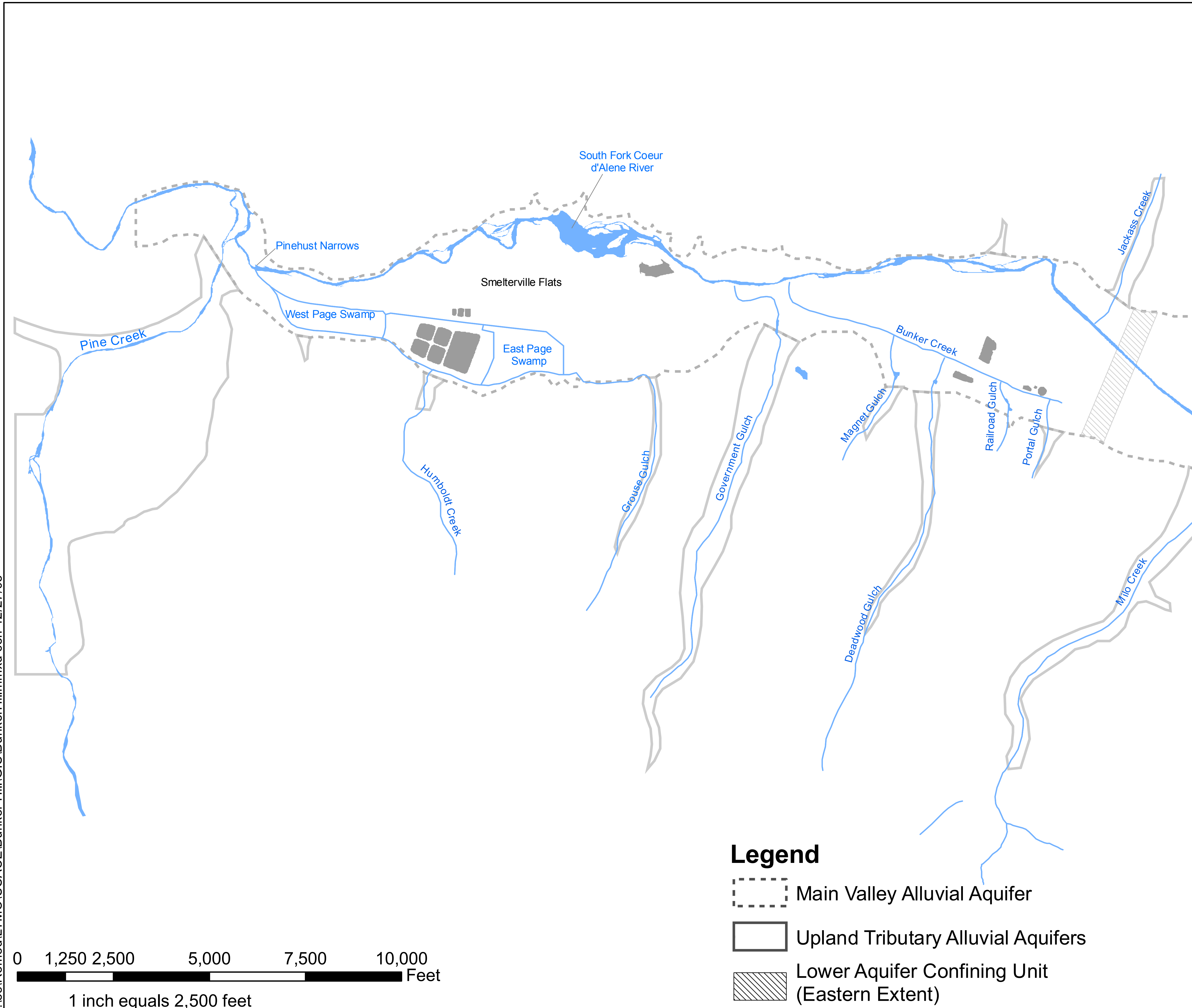

FIGURE 2.1

OU2 SITE FEATURES

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

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Fifty-two mines and mine-related sites were identified within OU2. The primary ores mined during the early stages of mining activity were galena (a source of lead and silver) and tetrahedrite (a source of silver). Later stages of mining activity also targeted sphalerite (a source of zinc that also contained manganese, cadmium, and other metals). Mining activities began in 1885 and large-scale mining operations within OU2 ceased in 1991. Small-scale operations are still ongoing at the Bunker Hill Mine and several other mines are still in operation upstream of OU2.

The draft CSM report (CH2M Hill, 2005a) states that "the long history of mining activities within and upstream of the Bunker Hill site, combined with the dynamic and complex hydrologic system and anthropogenic effects to that system, have resulted in widespread and commingled sources of contamination." For example, mine tailings generated in OU2 were, for many years, deposited directly to the SFCDR, its tributaries, and their associated floodplains, resulting in wide dispersal of tailings throughout the valley floor within OU2. Anthropogenic and natural processes have resulted in the mixing of the tailings with the underlying natural alluvium (*e.g.*, to depths of up to 15 feet in portions of Smelterville Flats). According to the draft CSM report (CH2M Hill, 2005a), historical events left a layer of tailings mixed with alluvium generally 4 to 7 feet thick across the majority of OU2. In addition, tailings, tailings mixtures, and mine waste rock were used as fill in construction projects throughout OU2 over time (*e.g.*, towns, industrial facilities, railroad grades, and road grades).

The OU2 Record of Decision (ROD) issued in 1992 set forth priority cleanup actions to protect human health and the environment. Cleanup actions included a series of source removals, surface capping, reconstruction of surface water creeks, demolition of abandoned milling and processing facilities, engineered closures for waste consolidated onsite, revegetation efforts, and treatment of contaminated water collected from various site sources.

In 1995, with the bankruptcy of the Site's major Potentially Responsible Party, the USEPA and the State of Idaho defined a path forward for phased remedy implementation in OU2. Phase I of remedy implementation includes extensive source removal and stabilization efforts, all demolition activities, all community development initiatives, development and initiation of an institutional controls plan, future land use development support, and public health response actions. Also included in Phase I are additional investigations to provide the necessary information to resolve long-term water quality issues, including technology assessments and pilot studies, evaluation of the success of source control efforts, development of site-specific water quality and effluent-limiting performance standards, and development of a defined operation and maintenance plan and implementation schedule. Interim control and treatment of contaminated water and acid mine drainage is also included in Phase I of remedy implementation. Phase I remediation began in 1995, and source control and removal activities are near completion.

Phase II of the OU2 remedy will be implemented following completion of source control and removal activities and evaluation of the impacts of these activities on meeting water quality improvement objectives. Phase II will consider any shortcomings encountered in implementing Phase I and will specifically address long-term water quality and environmental management issues. The evaluation of the effectiveness of the

Phase I source control and removal activities at meeting the water quality improvement objectives outlined in the 1992 OU2 ROD will be used to determine appropriate Phase II implementation strategies and actions.

2.2 ENVIRONMENTAL SETTING

2.2.1 Geology

This brief summary focuses on the thick sequence of unconsolidated deposits overlying bedrock within OU2, given that all of the groundwater monitoring wells evaluated are screened within these deposits. An east-west-oriented longitudinal geologic cross-section, shown on Figure 3-8 of the draft CSM report (CH2M Hill, 2005a), aids in the visualization of the stratigraphic units described in this subsection. The location of this cross-section is depicted on Figure 3-7 of the CSM report; both figures are included in Appendix A.

The primary stratigraphic units that are relevant to this monitoring network optimization (MNO) evaluation include an upper alluvial sand and gravel unit, a lacustrine silt/clay unit that underlies the upper sand and gravel, and lower sand and gravel unit that underlies the silt/clay. The lacustrine silt/clay that separates the upper and lower sand and gravel units is present throughout the central and western portions of OU2; this unit thins to the east and is not present in the eastern portion of OU2, most likely starting between Milo and Portal Gulches (see Figure 2.1).

Sedimentary deposits in the upland tributary gulches are highly variable in composition and consist of coarse-grained deposits (*i.e.*, sand and gravel) that were deposited in higher-energy depositional environments and a heterogeneous mixture of fine- to coarse-grained colluvium and slope-wash materials. Transitional depositional environments are found predominantly near the mouths of gulches and along the main valley/hillside interface. These transitional deposits consist of a mixture of colluvial and slopewash materials intermixed with main valley alluvial sediments.

2.2.2 Hydrogeology

The primary groundwater-bearing units of concern in the MNO evaluation include the upper and lower alluvial sand and gravel units present beneath the main SFCDR valley and the upland tributary colluvial/alluvial unit that is associated with the hillsides and gulches that discharge to the main SFCDR valley groundwater system. The upper alluvial sand and gravel aquifer is mostly unconfined and is perched on top of the lacustrine silt/clay unit, which acts as an aquitard. However, the upper aquifer may be locally confined where it is overlain by a relatively fine-grained mixture of alluvium and tailings. The thickness of this upper aquifer ranges from less than 10 feet near the valley walls to nearly 40 feet. The lower alluvial sand and gravel aquifer is confined by the overlying lacustrine silt/clay aquitard, and ranges from 20 to 40 feet in thickness. In the eastern portion of OU2, where the aquitard is not present, the upper and lower sand and gravel units are combined into a single thick (up to 60 feet) unconfined alluvial aquifer.

The depth to the water table generally ranges from approximately 8 to 10 feet below ground surface (bgs) in the eastern portion of OU2 to approximately 10 to 25 feet bgs in the central and western portions; however some variability exists. Water table elevations fluctuate seasonally due to temporal variations in precipitation and snowmelt.

As indicated on Figures 3-37 through 3-40 of the draft CSM report (CH2M Hill, 2005a) (Appendix A)**,** regional groundwater flow in the main SFCDR valley is generally from east to west, although local variations in flow direction (*e.g.*, either toward or away from major surface water drainages due to the presence of gaining and losing reaches) exist. The geometric mean hydraulic conductivity values for the upper and lower alluvial sand and gravel aquifers beneath the SFCDR valley, derived from single-well aquifer tests performed by CH2M Hill and reported in 'Single Well Pumping Test Methods and Results (CH2M Hill, 2004), are 103 feet per day (ft/day) and 117 ft/day, respectively. The geometric mean hydraulic conductivity value for the upland tributary aquifer is 5.6 ft/day. The average hydraulic gradient in the upper and lower alluvial sand and gravel aquifers, measured across the Bunker Hill Box, is 0.0046 foot per foot (ft/ft) (CH2M Hill, 2005a). Government Gulch is the only upland tributary aquifer with sufficient monitoring wells to allow calculation of a hydraulic gradient. The measured average hydraulic gradient in the upland aquifer along the length of Government Gulch, derived from groundwater elevation maps contained in the draft CSM report (CH2M Hill, 2005a, see Appendix A), is 0.054 ft/ft. Using the above-described hydraulic conductivity and hydraulic gradient values and estimated values for effective porosity of 0.25 for the main upper and lower alluvial sand and gravel aquifers and 0.20 for the upland aquifer, the average groundwater seepage velocity in OU2 was calculated to range from 1.5 ft/day in the Government Gulch upland aquifer to 2 ft/day in the main valley alluvial aquifers.

With a few exceptions, vertical hydraulic gradients are generally downward in the eastern portion of OU2 and upward in the western portion of OU2 downgradient of the Government Gulch vicinity. Vertical gradients do not appear to be seasonally variable.

2.2.3 Surface Water Hydrology

The main surface water body within OU2 is the SFCDR, which is depicted along with its tributaries on Figure 2.1. The draft CSM report states that the interaction of groundwater and surface water is a significant factor affecting contaminant fate and transport within OU2, and the potential exposure of human and ecological receptors to contaminants of concern (COCs) (CH2M Hill, 2005).

The approximate locations of gaining and losing reaches of the SFCDR within OU2 are shown on Figure 3-41 of the draft CSM report (Appendix A). The gaining and losing conditions were observed under base flow conditions, in which flow in the SFCDR is composed primarily of groundwater discharge. The interaction between surface water and groundwater under different hydrologic conditions is not well-defined.

2.3 NATURE AND EXTENT OF CONTAMINATION

The primary COCs at OU2 are arsenic, cadmium, lead, and zinc, given their elevated concentrations in OU2 groundwater, surface water, soil, and sediment; their potential to have significant negative impacts on potential receptors; or both. Within OU2, arsenic is present in surface water at concentrations toxic to aquatic organisms and other wildlife. Cadmium is widely distributed within OU2, and is relatively mobile in aquatic environments. Lead is present within OU2 at concentrations toxic to waterfowl and other wildlife via ingestion of contaminated soil or sediment. Ambient water quality criteria (AWQC) for zinc are exceeded throughout OU2, generally at levels toxic to aquatic organisms. Zinc is one of the most mobile of the heavy metals and is readily transported in most natural waters. Of these four COCs, cadmium and zinc are, by far, the metals that have the most widespread distribution and highest magnitude of exceedances of cleanup goals in OU2 groundwater.

The primary source for dissolved metals in groundwater within OU2 is metal-rich sediment within the vadose zone. The two release and transport mechanisms for metals from this source are unsaturated flow downward through the vadose zone and the seasonal rise and fall of the water table. The magnitude of dissolved metal release by these mechanisms is related to the magnitude of the hydrologic event. Major hydrologic events, such as occurred in 1996 to 1997, can result in a relatively large influx of metals into the groundwater system due to enhanced flushing of metals out of the vadose zone.

The upper portion of the SFCDR valley essentially constitutes one large source area, preventing delineation of discrete contaminant plumes in OU2 groundwater. Rather, elevated metal concentrations are found in groundwater and surface water throughout OU2. Given the near-surface locations of contaminant sources (*e.g.*, mine tailings), elevated metal concentrations are more prevalent in the surficial aquifers than at deeper depths. Specifically, the upper alluvial sand and gravel aquifer beneath the SFCDR valley and the upland aquifer present in Government Gulch (and perhaps other tributary valleys north and south of the SFCDR valley) tend to have relatively high metal concentrations. In contrast, elevated metal concentrations are less prevalent in the lower alluvial sand and gravel aquifer beneath the lacustrine silt/clay aquitard. This indicates that the silt/clay aquitard has minimized downward migration of metals to the lower alluvial aquifer, despite the presence of a downward vertical hydraulic gradient throughout a sizable portion of OU2.

SECTION 3

LONG-TERM MONITORING PROGRAM AT OU2

The existing groundwater and surface water monitoring program at OU2 was examined to to assess its overall effectiveness at achieving the OU2-specific monitoring objectives, and to (1) identify potential opportunities to streamline monitoring activities while still maintaining an effective monitoring program, and (2) identify data gaps that may required the addition of additional monitoring points. The monitoring program at OU2 is reviewed in the following subsections.

3.1 DESCRIPTION OF MONITORING PROGRAM

The OU2 monitoring program examined during this long-term monitoring optimization (LTMO) evaluation consists of 77 groundwater monitoring wells and 18 surface water monitoring stations. The wells and surface water stations included in this analysis are listed in Tables 3.1 and 3.2, respectively. The groundwater wells are shown on Figure 3.1 classified by hydrostratigraphic unit (HU), and the 18 surface-water monitoring stations are shown on Figure 3.2. These wells and stations were included in the LTMO analysis based on their "Active" status in the draft Environmental Monitoring Plan (EMP) (CH2M Hill, 2005b) and discussions with Bunker Hill site personnel. This evaluation did not include new wells proposed in the EMP or surface water monitoring stations associated with treatment plant outfalls. Monitoring point information listed in Tables 3.1 and 3.2 includes "basecase" sampling frequency (generally quarterly), first used and most recent sampling events, HU for groundwater wells, and location for surface water stations.

The objectives of the groundwater monitoring program at OU2 are outlined in the draft OU2 EMP (CH2M Hill, 2005b) and listed below:

1. Evaluate groundwater within OU2 for compliance with federal maximum contaminant levels (MCLs);

2. Evaluate the nature of groundwater/surface water interaction and the impact of groundwater discharge on surface water quality;

3. Evaluate the cumulative effects of Phase I remedial actions;

4. Provide data for five-year reviews of remedy implementation as required by CERCLA; and

TABLE 3.1
BASECASE GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrogeologic Unit	Current Sampling Frequency	Earliest Sampling Data Used	Most Recent Data Used
Deadwood Gulch Upland Aquifer				
BH-DW-GW-0001	Upland	Quarterly	3/16/2000	4/7/2004
Government Gulch Upland Aquifer				
BH-GG-GW-0001	Upland	Quarterly	4/17/2000	10/19/2004
BH-GG-GW-0002	Upland	Quarterly	4/17/2000	10/19/2004
BH-GG-GW-0003	Upland	Quarterly	4/17/2000	10/19/2004
BH-GG-GW-0004	Upland	Quarterly	4/17/2000	10/19/2004
BH-GG-GW-0005	Upland	Quarterly	2/24/2000	10/19/2004
BH-GG-GW-0006	Upland	Quarterly	2/24/2000	10/19/2004
BH-GG-GW-0007	Upland	Quarterly	4/4/2003	10/14/2004
BH-GG-GW-0008	Upland	Quarterly	4/4/2003	10/18/2004
Upland Aquifer between Deadwood and Railroad Gulches				
BH-ILF-GW-0001	Upland	Quarterly	4/25/2001	1/15/2003
Upland Aquifer at the Smelter Closure Area				
BH-SCA-GW-0001	SCA	Quarterly	2/23/2000	10/13/2004
BH-SCA-GW-0002	SCA	Quarterly	2/23/2000	10/12/2004
BH-SCA-GW-0005	SCA	Quarterly	2/23/2000	10/18/2004
BH-SCA-GW-0006	SCA	Quarterly	2/23/2000	10/18/2004
BH-SCA-GW-0007	SCA	Quarterly	2/23/2000	10/12/2004
Transect 1				
BH-SF-E-0001	Single	Quarterly	3/31/2003	10/11/2004
BH-SF-E-0002	Single	Quarterly	4/1/2003	10/11/2004
BH-SF-E-0003	Single	Quarterly	4/1/2003	10/11/2004
Transect 1 to Transect 2				
BH-SF-E-0101	Single	Quarterly	4/15/2000	10/11/2004
BH-SF-E-0201	Single	Quarterly	4/21/2000	10/11/2004
Transect 2				
BH-SF-E-0301-U	Upper	Quarterly	4/15/2000	10/12/2004
BH-SF-E-0302-L	Lower	Quarterly	4/15/2000	10/12/2004
BH-SF-E-0305-U	Upper	Quarterly	4/2/2003	7/14/2004
BH-SF-E-0306-L	Lower	Quarterly	4/2/2003	10/11/2004
BH-SF-E-0309-U	Upper	Quarterly	4/1/2003	10/12/2004
BH-SF-E-0310-L	Lower	Quarterly	4/1/2003	4/7/2004
BH-SF-E-0311-U	Upper	Quarterly	4/2/2003	10/12/2004
Transect 2 to Transect 3				
BH-SF-E-0314-U	Upper	Quarterly	10/20/2000	10/26/2004
BH-SF-E-0315-U	Upper	Quarterly	10/20/2000	10/26/2004
BH-SF-E-0316-U	Upper	Quarterly	10/23/2000	10/13/2004
BH-SF-E-0317-U	Upper	Quarterly	4/15/2000	10/26/2004
BH-SF-E-0318-U	Upper	Quarterly	10/24/2000	10/13/2004
BH-SF-E-0320-U	Upper	Quarterly	4/15/2000	7/19/2004
BH-SF-E-0321-U	Upper	Quarterly	4/15/2000	10/26/2004

TABLE 3.1 (Continued)
BASECASE GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrogeologic Unit	Current Sampling Frequency	Earliest Sampling Data Used	Most Recent Data Used
BH-SF-E-0322-U	Upper	Quarterly	5/1/2003	10/13/2004
BH-SF-E-0402-U	Upper	Quarterly	4/15/2000	10/26/2004
BH-SF-E-0403-U	Upper	Quarterly	4/15/2000	10/26/2004
BH-SF-E-0407-U	Upper	Quarterly	5/1/2003	10/13/2004
BH-SF-E-0408-U	Upper	Quarterly	10/24/2000	10/13/2004
BH-SF-E-0409-U	Upper	Quarterly	10/24/2000	10/13/2004
BH-SF-E-0410-U	Upper	Quarterly	2/23/2000	10/12/2004
Transect 3				
BH-SF-E-0423-U	Upper	Quarterly	4/15/2000	10/26/2004
BH-SF-E-0424-L	Lower	Quarterly	4/7/2003	10/26/2004
BH-SF-E-0425-U	Upper	Quarterly	4/7/2003	10/12/2004
BH-SF-E-0426-L	Lower	Quarterly	4/7/2003	10/12/2004
BH-SF-E-0427-U	Upper	Quarterly	2/23/2000	10/12/2004
BH-SF-E-0428-L	Lower	Quarterly	4/7/2003	10/12/2004
Transect 3 to Transect 5				
BH-SF-E-0429-U	Upper	Quarterly	2/24/2000	10/26/2004
BH-SF-E-0501-U	Upper	Quarterly	2/23/2000	10/18/2004
BH-SF-E-0502-U	Upper	Quarterly	4/19/2000	10/20/2004
BH-SF-E-0503-U	Upper	Quarterly	1/18/2001	10/26/2004
BH-SF-E-0504-U	Upper	Quarterly	1/18/2001	10/26/2004
Transect 5				
BH-SF-W-0001-U	Upper	Quarterly	4/8/2003	10/19/2004
BH-SF-W-0002-L	Lower	Quarterly	4/8/2003	10/19/2004
BH-SF-W-0003-U	Upper	Quarterly	4/9/2003	10/18/2004
BH-SF-W-0004-L	Lower	Quarterly	4/9/2003	10/18/2004
BH-SF-W-0005-U	Upper	Quarterly	4/18/2000	10/25/2004
BH-SF-W-0006-L	Lower	Quarterly	4/9/2003	10/25/2004
BH-SF-W-0007-U	Upper	Quarterly	4/18/2000	10/25/2004
Transect 5 to Transect 6				
BH-SF-W-0008-U	Upper	Quarterly	4/19/2000	7/27/2004
BH-SF-W-0009-U	Upper	Quarterly	4/19/2000	10/20/2004
BH-SF-W-0010-U	Upper	Quarterly	4/18/2000	10/25/2004
BH-SF-W-0011-L	Lower	Quarterly	4/18/2000	10/25/2004
BH-SF-W-0019-U	Upper	Quarterly	4/18/2000	10/26/2004
BH-SF-W-0018-U	Upper	Quarterly	4/19/2000	10/20/2004
BH-SF-W-0020-U	Upper	Quarterly	4/18/2000	10/26/2004
BH-SF-W-0104-U	Upper	Quarterly	4/19/2000	10/20/2004
BH-SF-W-0111-U	Upper	Quarterly	4/20/2000	10/20/2004
BH-SF-W-0118-U	Upper	Quarterly	2/22/2002	10/20/2004
BH-SF-W-0119-U	Upper	Quarterly	2/22/2002	10/25/2004
BH-SF-W-0121-U	Upper	Quarterly	4/20/2000	10/20/2004
BH-SF-W-0122-L	Lower	Quarterly	4/20/2000	10/20/2004

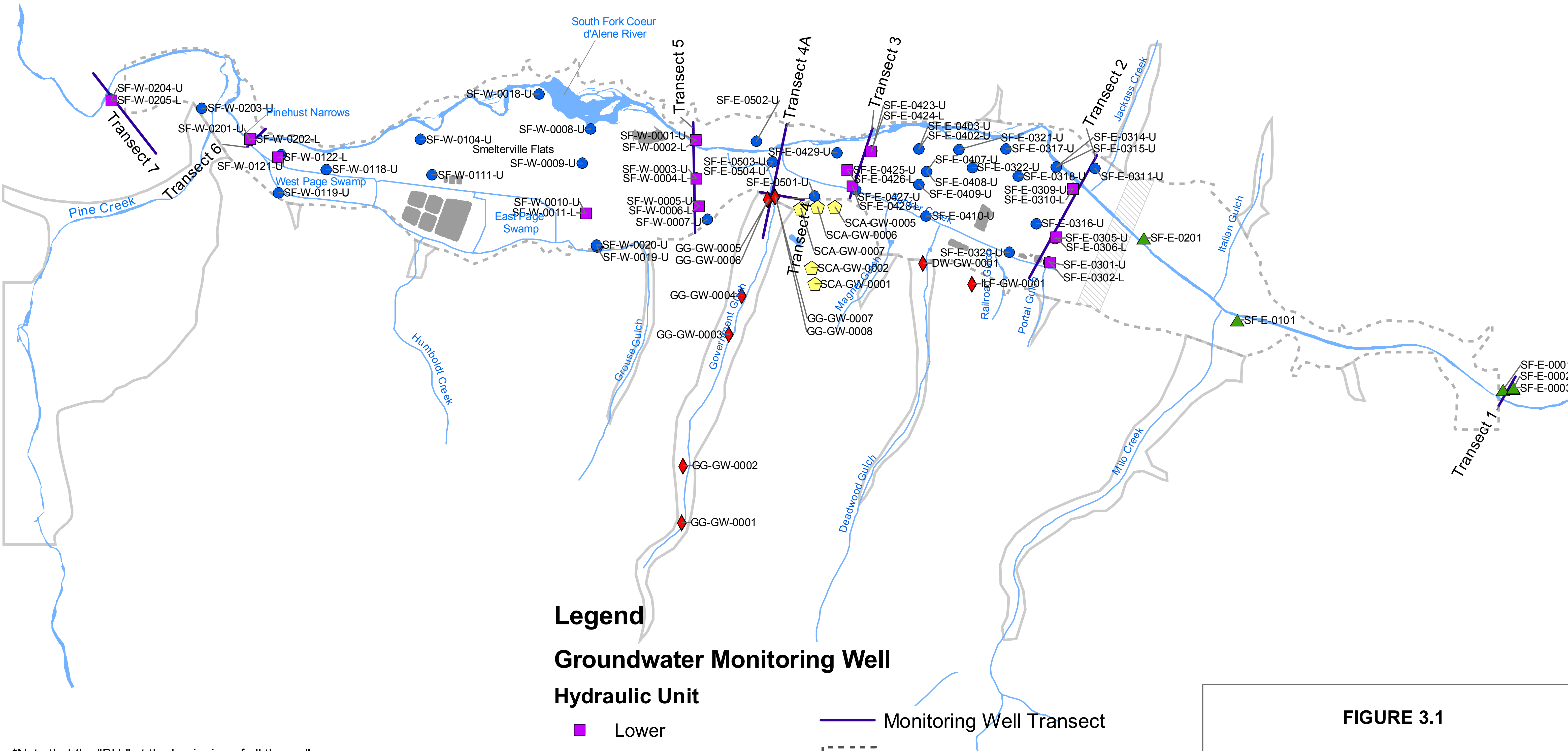
TABLE 3.1 (Continued)
BASECASE GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrogeologic Unit	Current Sampling Frequency	Earliest Sampling Data Used	Most Recent Data Used
Transect 6				
BH-SF-W-0201-U	Upper	Quarterly	4/8/2003	10/20/2004
BH-SF-W-0202-L	Lower	Quarterly	4/3/2003	10/20/2004
Transect 6 to Transect 7				
BH-SF-W-0203-U	Upper	Quarterly	4/21/2000	10/25/2004
Transect 7				
BH-SF-W-0204-U	Upper	Quarterly	4/8/2003	10/25/2004
BH-SF-W-0205-L	Lower	Quarterly	4/8/2003	10/25/2004

TABLE 3.2
BASECASE SURFACE WATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Surface Water Station Name	Location	Current Sampling Frequency	Earliest Sampling Data Used	Most Recent Data Used
BH-BC-0001	Bunker Creek	Quarterly	2/17/00	10/29/04
BH-CS-0001	Seeps North of CIA	Quarterly	3/17/00	10/28/04
BH-DW-0001	Magnet Gulch	Quarterly	4/25/00	10/29/04
BH-GC-0001	Grouse Creek	Quarterly	11/14/01	10/28/04
BH-GG-0001	Gov't Creek at Gulch Mouth	Quarterly	4/25/00	10/28/04
BH-HC-0001	Humboldt Creek	Quarterly	3/22/03	10/28/04
BH-IG-0001	Italian Gulch	Quarterly	3/22/03	4/10/03
BH-JC-0001	Jackass Creek	Quarterly	3/22/03	4/22/04
BH-MC-0001	Old Milo Creek Outfall	Quarterly	5/1/02	10/29/04
BH-MC-0002	New Milo Creek Outfall	Quarterly	2/17/00	10/29/04
BH-MG-0001	Deadwood Gulch	Quarterly	4/25/00	10/29/04
BH-PG-0001	Portal Gulch	Annual[a/]	4/24/00	2/20/02
BH-RR-0001	Railroad Gulch	Annual[a/]	3/22/03	3/22/03
BH-WP-0001	West Page Swamp Outfall	Quarterly	4/24/00	10/28/04
PC-339	Pine Creek below Amy Gulch	Quarterly	4/24/00	4/20/04
SF-268	SFCDR at Elizabeth Park	Quarterly	4/25/00	4/22/04
SF-270	SFCDR at Smelterville	Quarterly	4/21/04	4/21/04
SF-271	SFCDR at Pinehurst	Quarterly	4/24/00	4/20/04

[a/] Station sampled during high-flow events.



Legend

Groundwater Monitoring Well

Hydraulic Unit

- Lower
- SCA
- Single Unconfined
- Upland
- Upper

- Monitoring Well Transect
- Main Valley Alluvial Aquifer
- Upland Tributary Alluvial Aquifers
- Lower Aquifer Confining Unit (Eastern Extent)

*Note that the "BH-" at the beginning of all the wells has been omitted from the labels on this figure.

0 1,250 2,500 5,000 7,500 10,000 Feet

1 inch equals 2,500 feet

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FIGURE 3.1

GROUNDWATER MONITORING WELLS

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

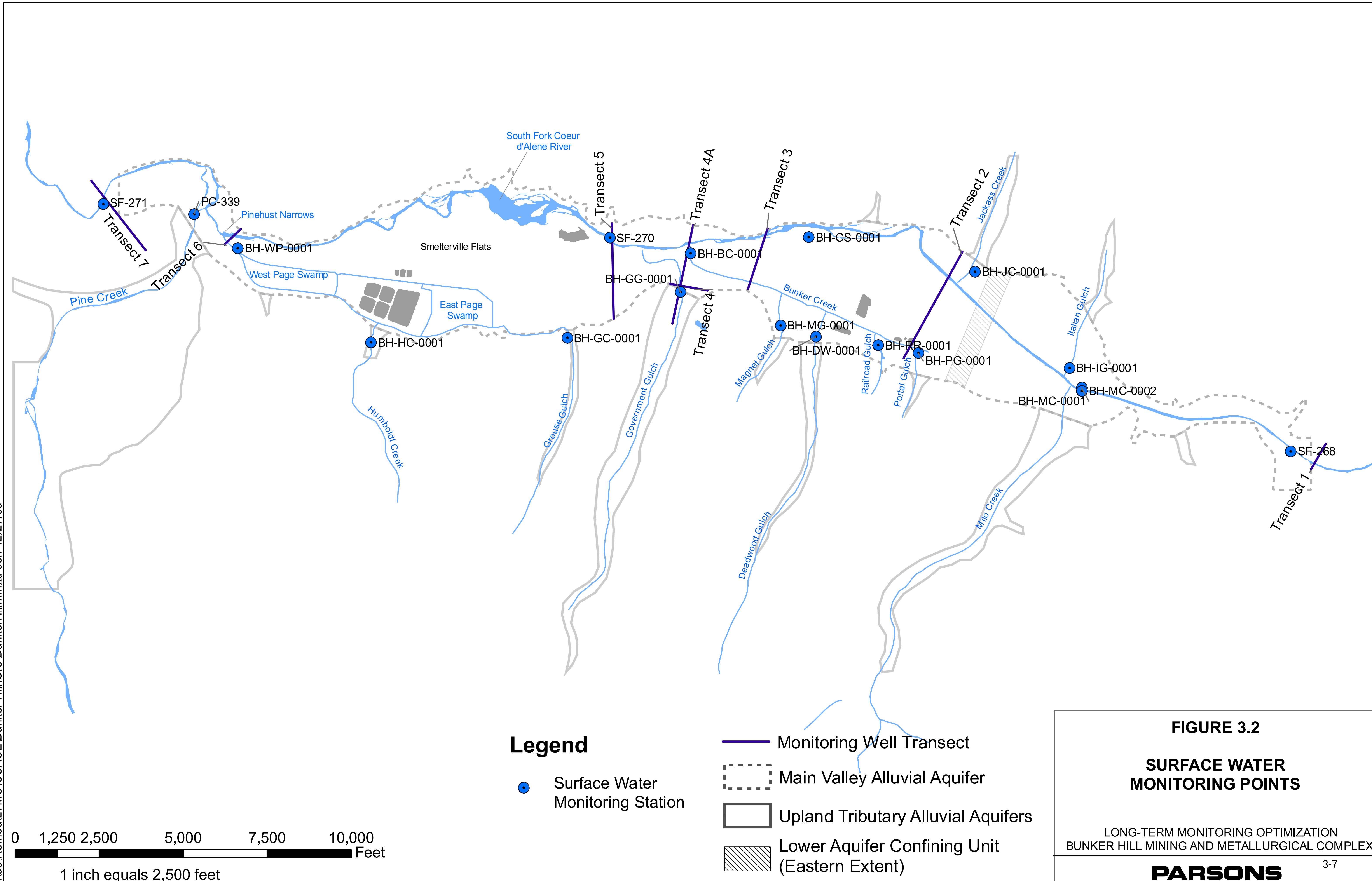


FIGURE 3.2

SURFACE WATER MONITORING POINTS

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

5. Improve understanding of processes and variability within OU2 to assist in Phase I remedial action evaluations and Phase II remedial design and implementation.

The objectives of the surface water monitoring program are also outlined in the draft OU2 EMP (CH2M Hill, 2005b) and listed below:

1. Evaluate tributaries to the SFCDR within OU2 with respect to compliance with the AWQC;

2. Evaluate potential impacts to SFCDR water quality from tributaries and groundwater within OU2; and

3. Evaluate the cumulative effects of Phase I remedial actions with respect to water quality goals and objectives.

Four of the surface water monitoring stations listed in Table 3.2 (PC-339, SF-268, SF-270, and SF-271) are sampled as part of the environmental monitoring plan for OU3 (Coeur d'Alene Basin). However, results generated from sampling of these stations are also used during the analysis and evaluation of OU2 monitoring results. Consequently, OU2 surface water data needs were considered when the OU3 monitoring plan was developed.

3.2 SUMMARY OF ANALYTICAL DATA

The monitoring program for OU2 groundwater and surface water stations were evaluated using results for sampling events performed from February 2000 through October 2004 to represent the time period after Phase I remedial actions were implemented. The Phase I remedial actions resulted in substantial changes to site conditions that were expected to impact groundwater and surface water quality. Therefore, use of data collected prior to Phase I remediation could potentially have resulted in misleading trends that are not representative of recent site conditions. The database was processed to remove duplicate data by retaining the "normal" result for each duplicate sample pair (*i.e.*, excluding the duplicate value). As discussed in Section 2.3, the COCs identified for OU2 include zinc, cadmium, arsenic, and lead (both total and dissolved for surface water stations). Tables 3.3 and 3.4 present summaries of the occurrence of potential COCs based on the data collected from OU2 monitoring points for groundwater and surface water, respectively. Tables 3.3 and 3.4 show that although arsenic and lead have high percentages of detections, cadmium and zinc are more significant COCs at the site based on their widespread and relatively high concentrations compared to their respective MCLs or AWQCs.

Figures 3.3 through 3.6 display the **most recent** (typically October 2004, but the most recent event for wells BH-DW-GW-0001 and BH-SF-E-0310-L [April 2004]; BH-ILF-GW-0001 [Jan 2003]; and BH-SF-E-0305-U, BH-SF-E-0320-U, and BH-SF-W-0008-U [July 2004] occurred prior to October 2004) concentrations of arsenic, cadmium, lead, and zinc respectively for the groundwater monitoring wells classified by MCL exceedance ratio. Table 3.5 presents the corresponding most recent COC concentrations for each monitoring well and associated sampling date. The most recent samples from 51

TABLE 3.3
SUMMARY OF OCCURRENCE OF GROUNDWATER CONTAMINANTS OF CONCERN
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Parameter	Total Samples[a/]	Range of Detects (mg/L)[b/]			Number of Detects	Percentage of Detects	Percentage of Samples with MCL Exceedances	MCL (mg/L)	Number of Wells with Results[c/]	Number of Wells with Detections	Number of Wells with MCL Exceedances
Dissolved Arsenic	1330	0.00004	-	0.119	389	29.2%	17.1%	0.01[d/]	77	74	40
Dissolved Cadmium	1330	0.00001	-	2.13	1003	75.4%	66.2%	0.005	77	77	60
Dissolved Lead	1330	0	-	0.54	372	28.0%	9.5%	0.015	77	72	15
Dissolved Zinc	1327	0.002	-	60.5	1268	95.6%	50.6%	5[e/]	77	77	44

[a/] Analytical data analyzed includes sampling results from February 2000 through October 2004.

[b/] mg/L = milligrams per liter.

[c/] Data includes 77 sampling points shown on Table 3.1

[d/] Arsenic MCL based on new EPA standard that became effective on February 22, 2002. (Compliance January 23, 2006)

TABLE 3.4
SUMMARY OF OCCURRENCE OF SURFACE WATER CONTAMINANTS OF CONCERN
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

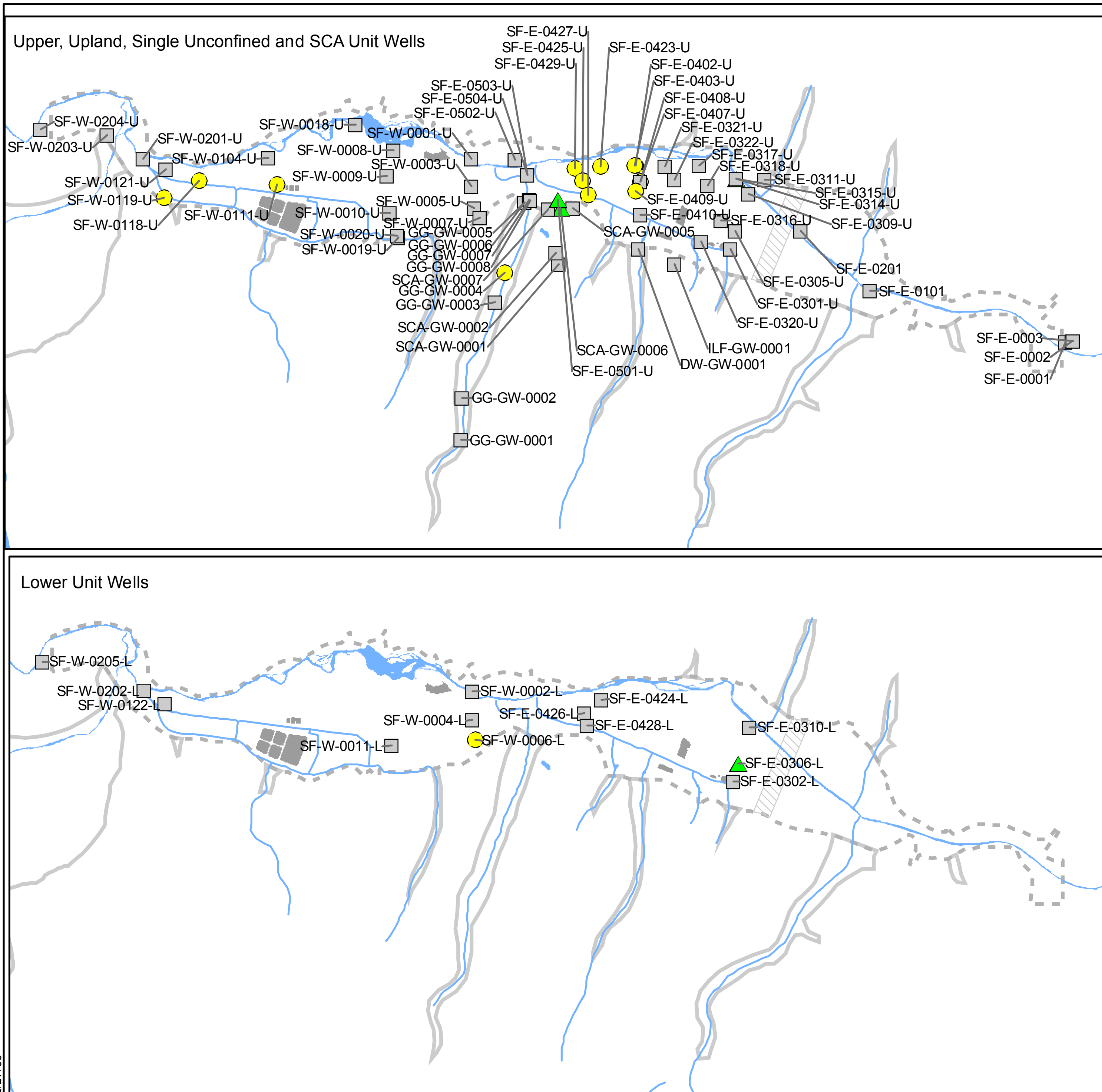
Parameter	Total Samples[a/]	Range of Detects (mg/L)[b/]			Number of Detects	Percentage of Detects	Percentage of Samples with AWQC Exceedances	AWQC[c/] (mg/L)	Number of Stations with Results[c/]	Number of Stations with Detections	Number of Stations with AWQC Exceedances
Arsenic	230	8E-05	-	0.1	134	58.3%	58.3%	0.000018	17	15	15
Dissolved Arsenic	245	0.0001	-	0.11	132	53.9%	53.9%	0.000018	18	16	16
Cadmium	230	5E-05	-	1.04	177	77.0%	72.2%	0.001	17	16	13
Dissolved Cadmium	252	5E-05	-	0.26	192	76.2%	68.7%	0.001	18	17	14
Lead	230	0.0003	-	3.18	185	80.4%	69.6%	0.0025	17	17	14
Dissolved Lead	245	6E-05	-	0.79	151	61.6%	44.9%	0.0025	18	18	15
Zinc	230	0.0024	-	34.8	228	99.1%	90.9%	0.105	17	17	15
Dissolved Zinc	252	0.0041	-	34.5	250	99.2%	87.3%	0.105	18	18	16

[a/] Analytical data analyzed includes sampling results from February 2000 through October 2004.

[b/] mg/L = milligrams per liter.

[c/]AWQCs are hardness dependant. AWQCs shown assume a hardness of 100 mg/L

[c/] Data includes 18 sampling points shown on Table 3.2



Note: Majority of wells "most recent" sampling event occured in October 2004; wells BH-DW-GW-0001, BH-SF-E-0310-L [April 2004], BH-SF-E-0305-U, BH-SF-E-0320-U, BH-SF-W-0008-U [July 2004], and BH-ILF-GW-0001 [Jan 2003], most recent sampling event occurred previously.

Specific concentrations and sampling dates shown in Table 3.5

Legend

Arsenic Concentrations (MCL = 0.01mg/L)

- Non-Detect
- <MCL
- 1 to 10 times MCL

0 1,250 2,500 5,000 7,500 10,000 Feet

FIGURE 3.3

MOST RECENT DISSOLVED ARSENIC CONCENTRATIONS IN GROUNDWATER

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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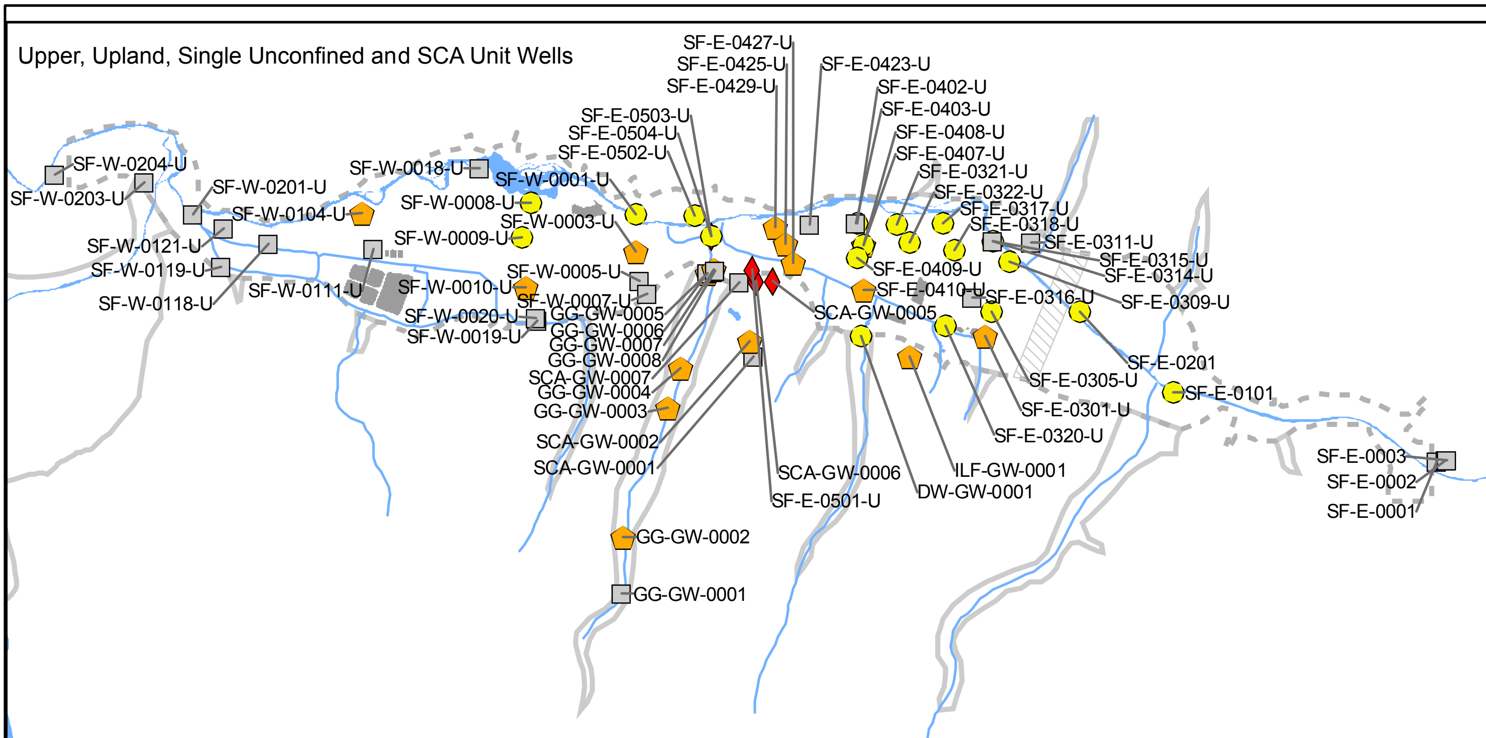

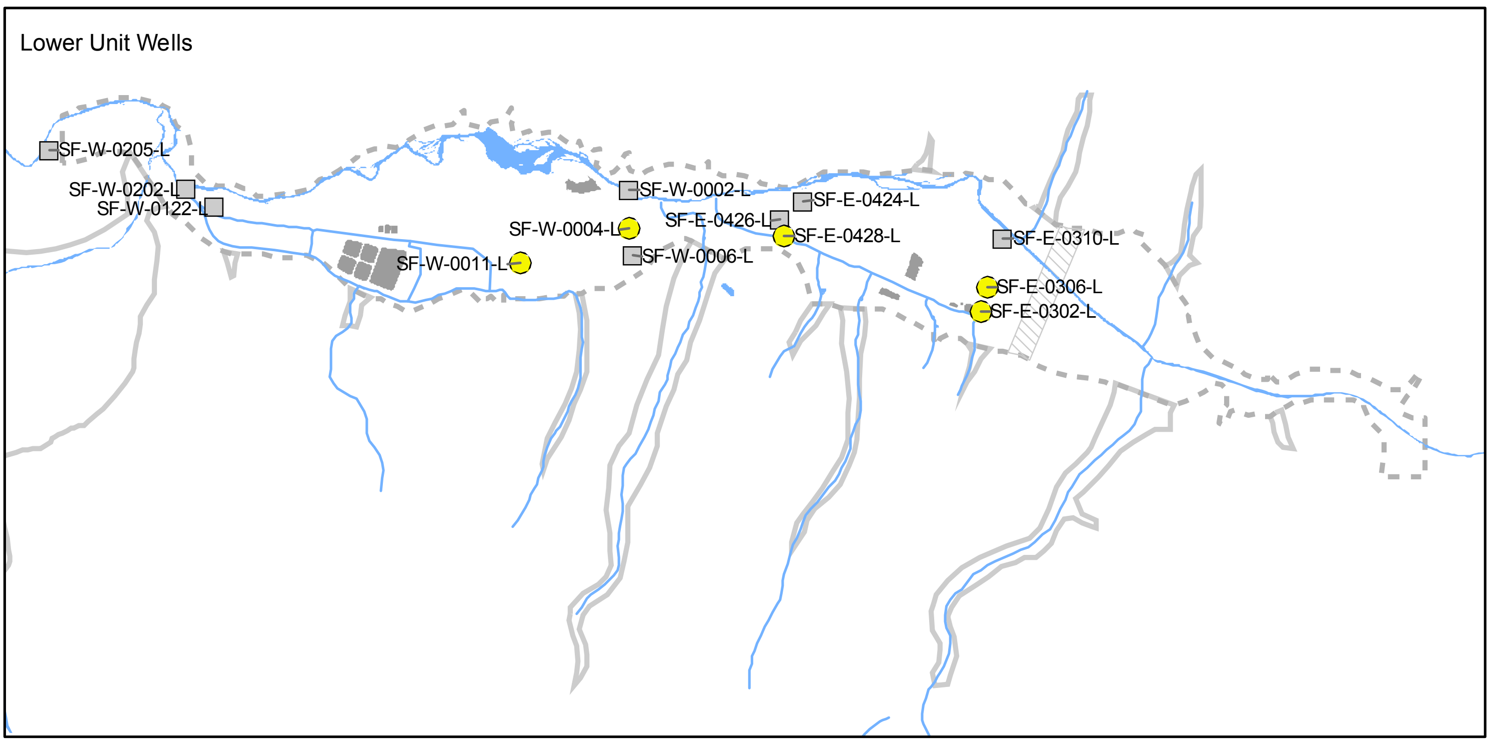

Note: Majority of wells "most recent" sampling event occured in October 2004; wells BH-DW-GW-0001, BH-SF-E-0310-L [April 2004], BH-SF-E-0305-U, BH-SF-E-0320-U, BH-SF-W-0008-U [July 2004], and BH-ILF-GW-0001 [Jan 2003], most recent sampling event occurred previously.

Legend

Cadmium Concentration (MCL=0.005mg/L)

- Non-Detect
- <MCL
- 1-10 times MCL
- 10-100 times MCL
- >100 times MCL

Specific concentrations and sampling dates shown in Table 3.5

0 1,250 2,500 5,000 7,500 10,000 Feet

FIGURE 3.4

MOST RECENT DISSOLVED CADMIUM CONCENTRATIONS IN GROUNDWATER

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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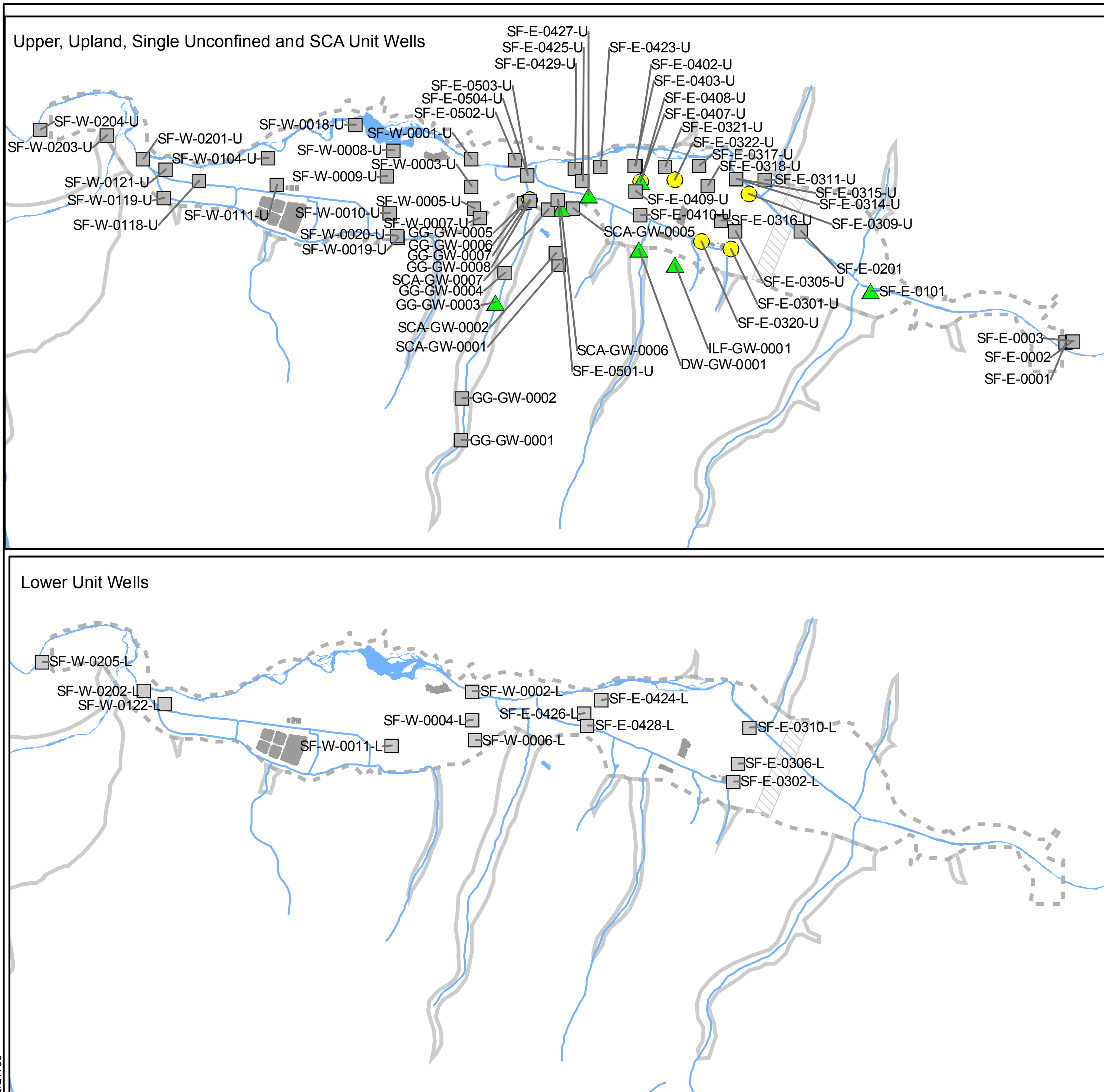

Note: Majority of wells "most recent" sampling event occured in October 2004; wells BH-DW-GW-0001, BH-SF-E-0310-L [April 2004], BH-SF-E-0305-U, BH-SF-E-0320-U, BH-SF-W-0008-U [July 2004], and BH-ILF-GW-0001 [Jan 2003], most recent sampling event occurred previously.

Specific concentrations and sampling dates shown in Table 3.5

Legend

Lead Concentration (MCL=0.015mg/L)

- ■ Non-Detect
- ▲ <MCL
- ● 1 to 10 times MCL

0 1,250 2,500 5,000 7,500 10,000 Feet

FIGURE 3.5

MOST RECENT DISSOLVED LEAD CONCENTRATIONS IN GROUNDWATER

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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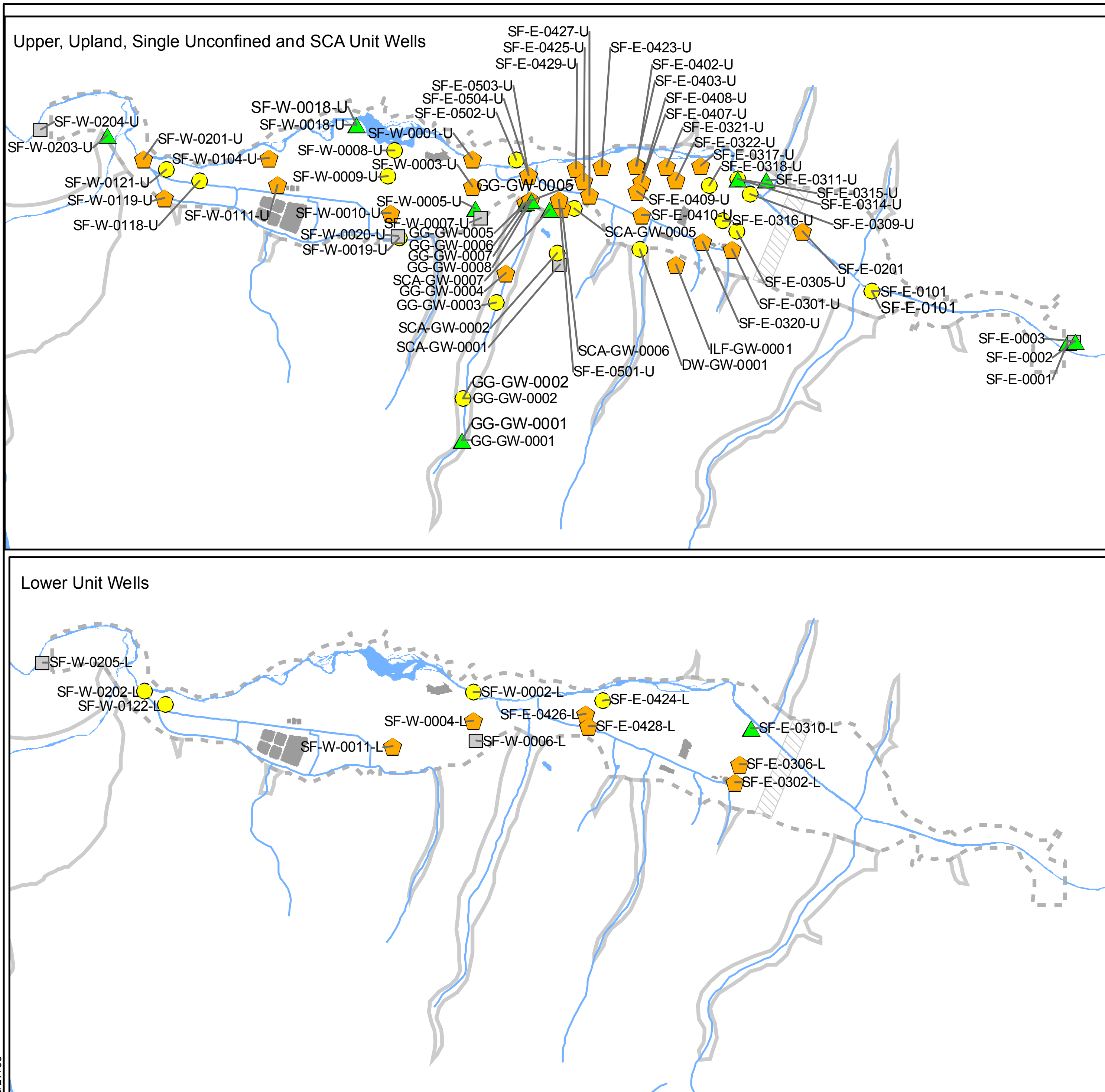

Note: Majority of wells "most recent" sampling event occured in October 2004; wells BH-DW-GW-0001, BH-SF-E-0310-L [April 2004], BH-SF-E-0305-U, BH-SF-E-0320-U, BH-SF-W-0008-U [July 2004], and BH-ILF-GW-0001 [Jan 2003], most recent sampling event occurred previously.

Specific concentrations and sampling dates shown in Table 3.5

Legend

Zinc Concentrations (MCL=5mg/L)

- Non-Detect
- <MCL
- 1 to 10 times MCL
- >10 times MCL

0 1,250 2,500 5,000 7,500 10,000 Feet

FIGURE 3.6

MOST RECENT DISSOLVED ZINC CONCENTRATIONS IN GROUNDWATER

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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TABLE 3.5
MOST RECENT GROUNDWATER COC CONCENTRATIONS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Most Recent Sampling Event	Dissolved Arsenic	Dissolved Cadmium	Dissolved Lead	Dissolved Zinc
		MCL=10µg/L	MCL=5µg/L	MCL=15µg/L	MCL=5000µg/L
BH-DW-GW-0001	4/7/04	ND[a/]	13.5[b/]	0.19	844
BH-GG-GW-0001	10/19/04	ND	ND	ND	233
BH-GG-GW-0002	10/19/04	ND	108	ND	2,120
BH-GG-GW-0003	10/19/04	ND	122	11	5,000
BH-GG-GW-0004	10/19/04	12.6	359	ND	21,700
BH-GG-GW-0005	10/19/04	ND	113	63.1	6,250
BH-GG-GW-0006	10/19/04	ND	ND	ND	182
BH-GG-GW-0007	10/14/04	ND	350	18.7	7,210
BH-GG-GW-0008	10/18/04	ND	ND	ND	333
BH-ILF-GW-0001	1/15/03	ND	249	1	12,300
BH-SCA-GW-0001	10/13/04	ND	ND	ND	ND
BH-SCA-GW-0002	10/12/04	ND	455	ND	2,740
BH-SCA-GW-0005	10/18/04	ND	837	ND	824
BH-SCA-GW-0006	10/18/04	3.8	1420	6.6	14,900
BH-SCA-GW-0007	10/12/04	ND	ND	ND	209
BH-SF-E-0001	10/11/04	ND	ND	ND	190
BH-SF-E-0002	10/11/04	ND	ND	ND	ND
BH-SF-E-0003	10/11/04	ND	ND	ND	155
BH-SF-E-0101	10/11/04	ND	18.4	4.6	3,520
BH-SF-E-0201	10/11/04	ND	36.7	ND	6,430
BH-SF-E-0301-U	10/12/04	ND	101	30.6	21,700
BH-SF-E-0302-L	10/12/04	ND	37	ND	10,400
BH-SF-E-0305-U	7/14/04	ND	21.8	ND	4,640
BH-SF-E-0306-L	10/11/04	2.6	40.6	ND	8,560
BH-SF-E-0309-U	10/12/04	ND	11.7	18	1,640
BH-SF-E-0310-L	4/7/04	ND	ND	ND	291
BH-SF-E-0311-U	10/12/04	ND	ND	ND	77
BH-SF-E-0314-U	10/26/04	4.7	6.7	ND	972
BH-SF-E-0315-U	10/26/04	ND	ND	ND	70
BH-SF-E-0316-U	10/13/04	ND	ND	ND	947
BH-SF-E-0317-U	10/26/04	ND	20.6	ND	7,070
BH-SF-E-0318-U	10/13/04	ND	9.9	ND	1,560
BH-SF-E-0320-U	7/19/04	ND	30	17.2	8,970
BH-SF-E-0321-U	10/26/04	ND	24.8	ND	7,120
BH-SF-E-0322-U	10/13/04	ND	17.5	114	5,860
BH-SF-E-0402-U	10/26/04	39.3	30.9	ND	25,900
BH-SF-E-0403-U	10/26/04	59	ND	ND	12,200
BH-SF-E-0407-U	10/13/04	19.5	321	22.4	11,100
BH-SF-E-0408-U	10/13/04	ND	6.2	7.8	11,200
BH-SF-E-0409-U	10/13/04	44.4	23	ND	20,800
BH-SF-E-0410-U	10/12/04	ND	217	ND	18,700
BH-SF-E-0423-U	10/26/04	57.7	ND	ND	17,100

TABLE 3.5 (Continued)
MOST RECENT GROUNDWATER COC CONCENTRATIONS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Most Recent Sampling Event	Dissolved Arsenic	Dissolved Cadmium	Dissolved Lead	Dissolved Zinc
		MCL=10µg/L	MCL=5µg/L	MCL=15µg/L	MCL=5000µg/L
BH-DW-GW-0001	4/7/04	ND[a/]	13.5[b/]	0.19	844
BH-GG-GW-0001	10/19/04	ND	ND	ND	233
BH-GG-GW-0002	10/19/04	ND	108	ND	2,120
BH-GG-GW-0003	10/19/04	ND	122	11	5,000
BH-GG-GW-0004	10/19/04	12.6	359	ND	21,700
BH-GG-GW-0005	10/19/04	ND	113	63.1	6,250
BH-GG-GW-0006	10/19/04	ND	ND	ND	182
BH-GG-GW-0007	10/14/04	ND	350	18.7	7,210
BH-GG-GW-0008	10/18/04	ND	ND	ND	333
BH-ILF-GW-0001	1/15/03	ND	249	1	12,300
BH-SCA-GW-0001	10/13/04	ND	ND	ND	ND
BH-SCA-GW-0002	10/12/04	ND	455	ND	2,740
BH-SCA-GW-0005	10/18/04	ND	837	ND	824
BH-SCA-GW-0006	10/18/04	3.8	1420	6.6	14,900
BH-SCA-GW-0007	10/12/04	ND	ND	ND	209
BH-SF-E-0001	10/11/04	ND	ND	ND	190
BH-SF-E-0002	10/11/04	ND	ND	ND	ND
BH-SF-E-0003	10/11/04	ND	ND	ND	155
BH-SF-E-0101	10/11/04	ND	18.4	4.6	3,520
BH-SF-E-0201	10/11/04	ND	36.7	ND	6,430
BH-SF-E-0301-U	10/12/04	ND	101	30.6	21,700
BH-SF-E-0302-L	10/12/04	ND	37	ND	10,400
BH-SF-E-0305-U	7/14/04	ND	21.8	ND	4,640
BH-SF-E-0306-L	10/11/04	2.6	40.6	ND	8,560
BH-SF-E-0309-U	10/12/04	ND	11.7	18	1,640
BH-SF-E-0310-L	4/7/04	ND	ND	ND	291
BH-SF-E-0311-U	10/12/04	ND	ND	ND	77
BH-SF-E-0314-U	10/26/04	4.7	6.7	ND	972
BH-SF-E-0315-U	10/26/04	ND	ND	ND	70
BH-SF-E-0316-U	10/13/04	ND	ND	ND	947
BH-SF-E-0317-U	10/26/04	ND	20.6	ND	7,070
BH-SF-E-0318-U	10/13/04	ND	9.9	ND	1,560
BH-SF-E-0320-U	7/19/04	ND	30	17.2	8,970
BH-SF-E-0321-U	10/26/04	ND	24.8	ND	7,120
BH-SF-E-0322-U	10/13/04	ND	17.5	114	5,860
BH-SF-E-0402-U	10/26/04	39.3	30.9	ND	25,900
BH-SF-E-0403-U	10/26/04	59	ND	ND	12,200
BH-SF-E-0407-U	10/13/04	19.5	321	22.4	11,100
BH-SF-E-0408-U	10/13/04	ND	6.2	7.8	11,200
BH-SF-E-0409-U	10/13/04	44.4	23	ND	20,800
BH-SF-E-0410-U	10/12/04	ND	217	ND	18,700
BH-SF-E-0423-U	10/26/04	57.7	ND	ND	17,100

of the 77 monitoring wells (66%) had at least one COC that exceeded MCLs. Likewise, Table 3.6 presents the **most recent** (typically October 2004, but the most recent event for surface water stations BH-IG-0001 [April 2003]; BH-JC-0001, PC-339, SF-268, SF-270, and SF-271 [April 2004]; BH-PG-0001 [Feb 2002]; and BH-RR-0001 [Mar 2003] occurred prior to October 2004) COC concentrations for each surface water monitoring station for both total and dissolved COCs. Figures 3.7 through 3.10 display the most recent total and dissolved concentrations of arsenic, cadmium, lead and zinc, respectively. The most recent samples from 15 of the 18 surface water monitoring stations (83%) had at least one COC that exceeded an AWQC.

TABLE 3.6
MOST RECENT SURFACE WATER COC CONCENTRATIONS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Surface Water Station Name	Location	Most Recent Sampling Event	Arsenic	Dissolved Arsenic	Cadmium	Dissolved Cadmium	Lead	Dissolved Lead	Zinc	Dissolved Zinc
			AWQC= 0.018µg/L		AWQC= 1µg/L		AWQC= 2.5µg/L		AWQC= 105µg/L	
BH-BC-0001	Bunker Creek	10/29/04	2.8[a/]	2.9	32.1	32.3	2.8	1.4	1690	1730
BH-CS-0001	Seeps North of CIA	10/28/04	40.5	41	10.3	10.5	0.64	0.06	11900	12400
BH-DW-0001	Magnet Gulch	10/29/04	0.39	0.36	4.4	4.5	8.1	4.8	570	585
BH-GC-0001	Grouse Creek	10/28/04	0.99	0.48	1	0.91	5.3	0.11	199	157
BH-GG-0001	Gov't Creek at Gulch Mouth	10/28/04	0.36	0.61	189	191	22.4	8.8	6480	6510
BH-HC-0001	Humboldt Creek	10/28/04	0.44	0.43	4.3	4.7	5.3	1.7	1040	1100
BH-IG-0001	Italian Gulch	4/10/03	ND[b/]	0.18	0.18	0.14	0.6	0.26	36.4	18
BH-JC-0001	Jackass Creek	4/22/04	ND	ND	ND	ND	0.47	0.15	3.3	5.9
BH-MC-0001	Old Milo Creek Outfall	10/29/04	0.53	0.58	0.5	0.37	3	1.3	125	122
BH-MC-0002	New Milo Creek Outfall	10/29/04	0.54	0.4	4.4	4.4	250	219	1230	1250
BH-MG-0001	Deadwood Gulch	10/29/04	13.5	13.2	84	85.5	5.3	4.9	2560	2610
BH-PG-0001	Portal Gulch	2/20/02	ND	ND	ND	ND	16	10	292	288
BH-RR-0001	Railroad Gulch	3/22/03	NS[c/]	0.11	NS	76.9	NS	4.4	NS	2820
BH-WP-0001	West Page Swamp Outfall	10/28/04	0.63	0.8	ND	ND	4.6	1.3	53.6	47.9
PC-339	Pine Creek below Amy Gulch	4/20/04	ND	ND	0.32	0.2	0.45	0.21	63.3	47.7
SF-268	SFCDR at Elizabeth Park	4/22/04	0.35	0.28	3.6	3.1	7.4	2.9	485	429
SF-270	SFCDR at Smelterville	4/21/04	0.43	0.34	4.6	4	12	4.8	675	609
SF-271	SFCDR at Pinehurst	4/20/04	0.36	0.25	3.6	3.1	9	3	560	492

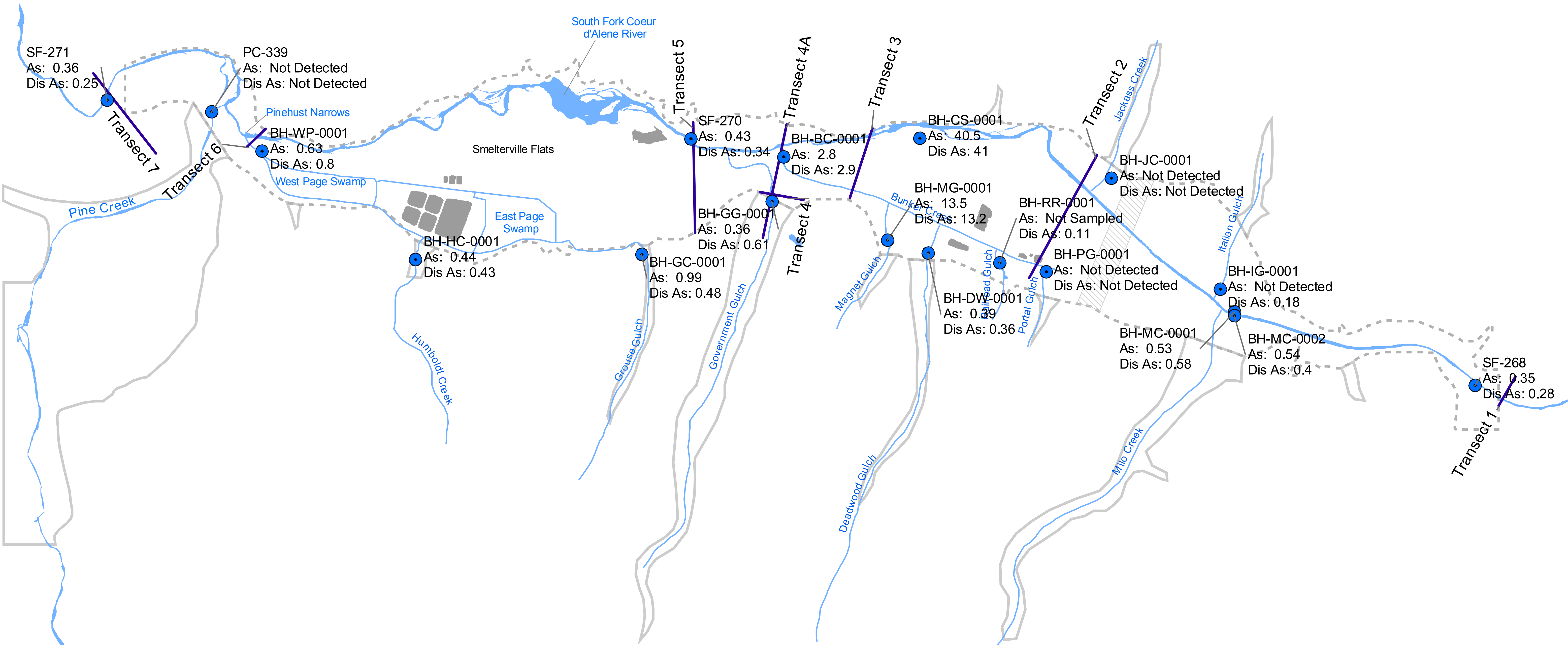
[a/] results in µg/L

[b/] ND = analyte not detected

[c/] NS = not sampled

AWQC exceedances highlighted in yellow

Most recent sampling dates earlier than 10/04 highlighted in grey.



Note: Majority of wells "most recent" sampling event occurred in October 2004, but surface water stations BH-IG-0001 [April 2003], BH-JC-0001, PC-339, SF-268, SF-270, SF-271 [April 2004], BH-PG-0001 [Feb 2002], and BH-RR-0001 [Mar 2003] most recent sampling events occurred previously.

0 1,250 2,500 5,000 7,500 10,000 Feet

1 inch equals 2,500 feet

Legend

- Surface Water Monitoring Station
- Monitoring Well Transect
- Main Valley Alluvial Aquifer
- Upland Tributary Alluvial Aquifers
- Lower Aquifer Confining Unit (Eastern Extent)

FIGURE 3.7

MOST RECENT TOTAL AND DISSOLVED ARSENIC IN SURFACE WATER

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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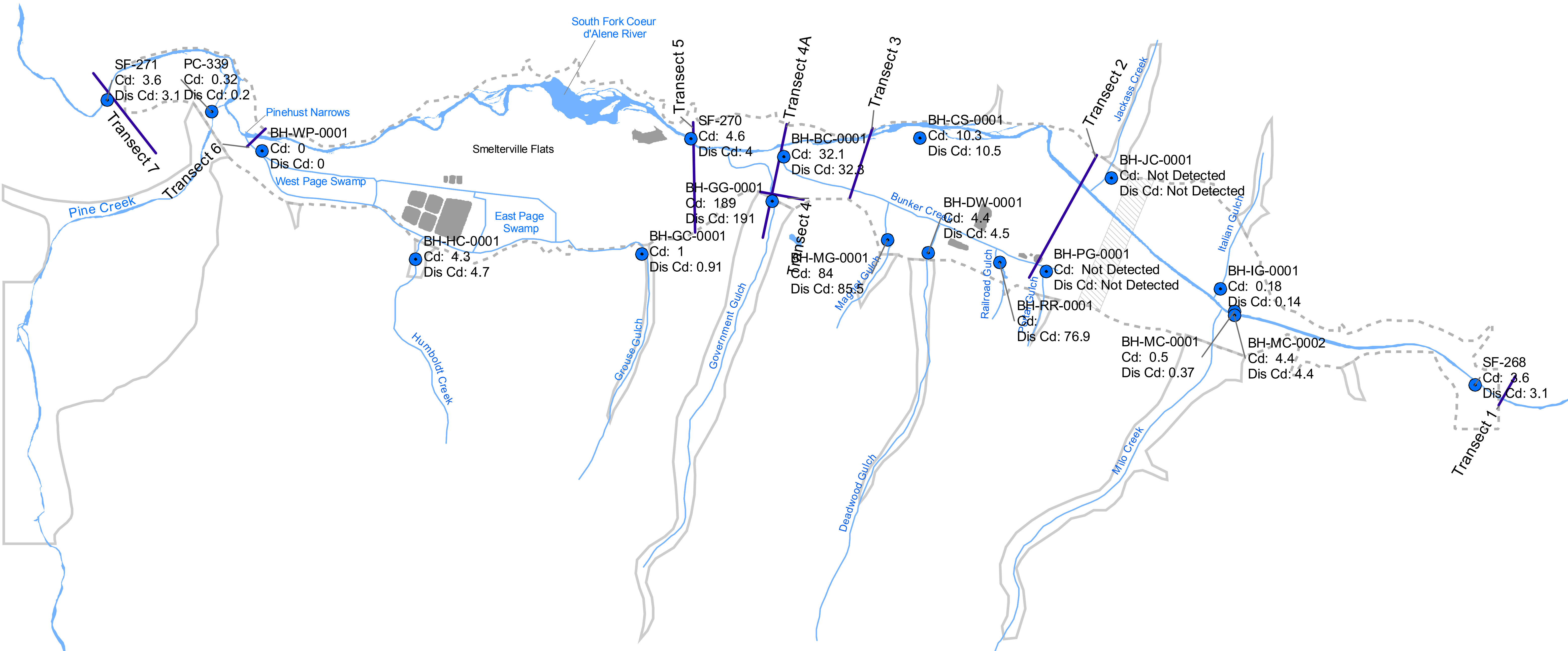

Note: Majority of wells "most recent" sampling event occurred in October 2004, but surface water stations BH-IG-0001 [April 2003], BH-JC-0001, PC-339, SF-268, SF-270, SF-271 [April 2004], BH-PG-0001 [Feb 2002], and BH-RR-0001 [Mar 2003] most recent sampling events occurred previously.

Legend

- Surface Water Monitoring Station
- Monitoring Well Transect
- Main Valley Alluvial Aquifer
- Upland Tributary Alluvial Aquifers
- Lower Aquifer Confining Unit (Eastern Extent)

0 1,250 2,500 5,000 7,500 10,000 Feet

1 inch equals 2,500 feet

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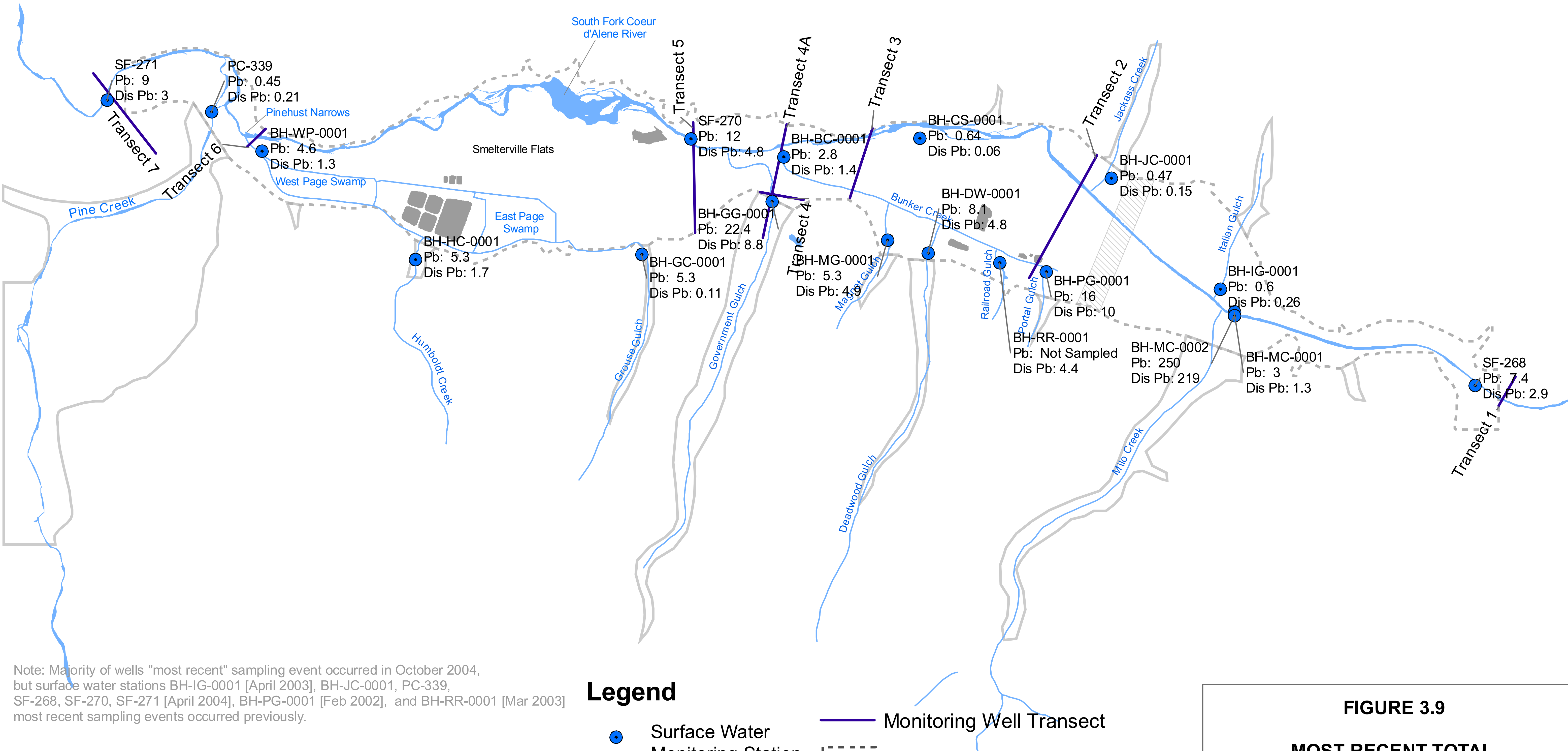
FIGURE 3.8

MOST RECENT TOTAL AND DISSOLVED CADMUM IN SURFACE WATER

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS



Note: Majority of wells "most recent" sampling event occurred in October 2004, but surface water stations BH-IG-0001 [April 2003], BH-JC-0001, PC-339, SF-268, SF-270, SF-271 [April 2004], BH-PG-0001 [Feb 2002], and BH-RR-0001 [Mar 2003] most recent sampling events occurred previously.

0 1,250 2,500 5,000 7,500 10,000 Feet

1 inch equals 2,500 feet

Legend

- Surface Water Monitoring Station
- Monitoring Well Transect
- Main Valley Alluvial Aquifer
- Upland Tributary Alluvial Aquifers
- Lower Aquifer Confining Unit (Eastern Extent)

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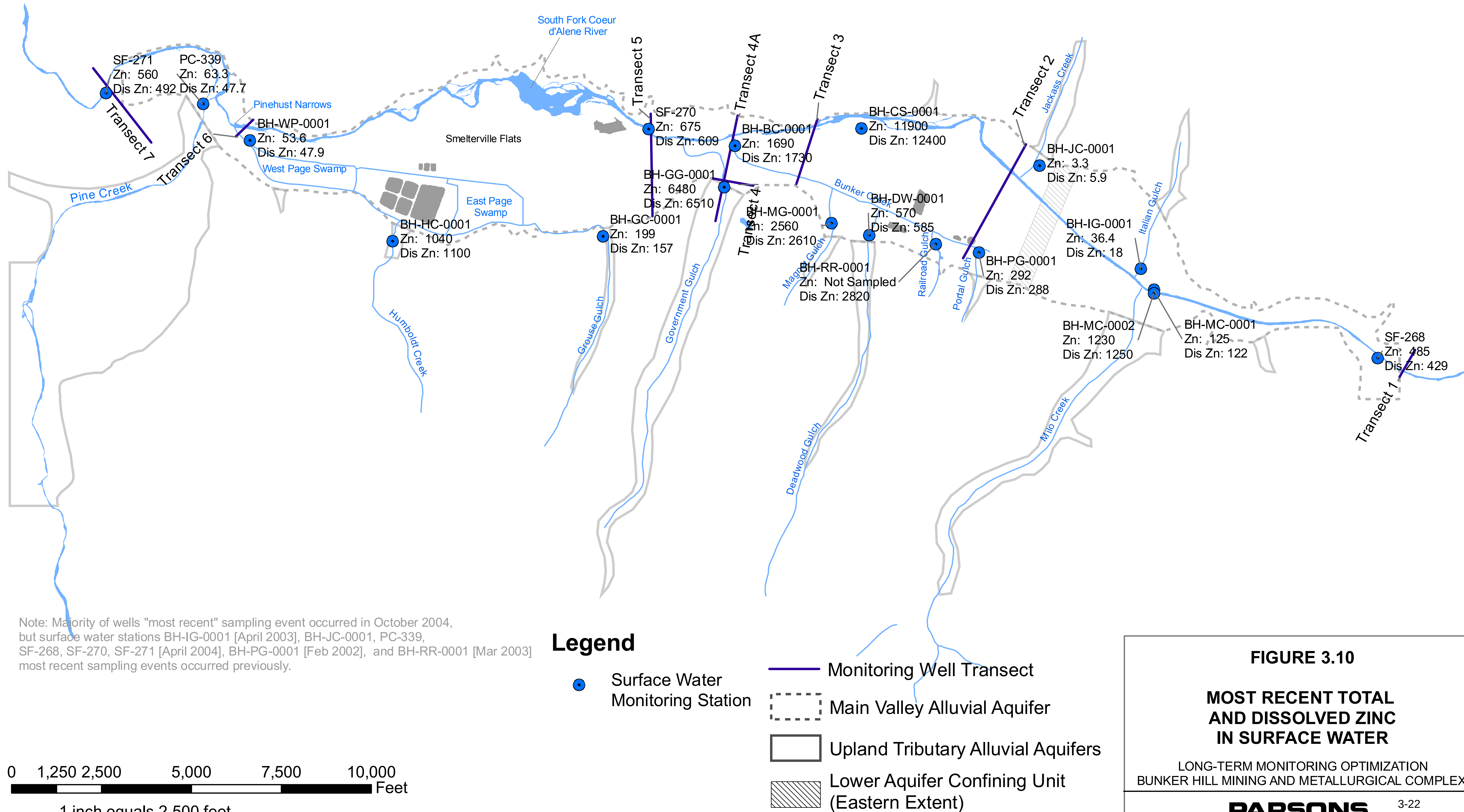
FIGURE 3.9

MOST RECENT TOTAL AND DISSOLVED LEAD IN SURFACE WATER

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS



Note: Majority of wells "most recent" sampling event occurred in October 2004, but surface water stations BH-IG-0001 [April 2003], BH-JC-0001, PC-339, SF-268, SF-270, SF-271 [April 2004], BH-PG-0001 [Feb 2002], and BH-RR-0001 [Mar 2003] most recent sampling events occurred previously.

Legend

- Surface Water Monitoring Station
- Monitoring Well Transect
- Main Valley Alluvial Aquifer
- Upland Tributary Alluvial Aquifers
- Lower Aquifer Confining Unit (Eastern Extent)

FIGURE 3.10

MOST RECENT TOTAL AND DISSOLVED ZINC IN SURFACE WATER

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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SECTION 4

QUALITATIVE LTMO EVALUATION

An effective groundwater monitoring program will provide information regarding contaminant plume migration and changes in chemical concentrations through time at appropriate locations, enabling decision-makers to verify that contaminants are not endangering potential receptors, and that remediation is occurring at rates sufficient to achieve remedial action objectives (RAOs) within a reasonable time. The design of the monitoring program should therefore include consideration of existing receptor exposure pathways as well as exposure pathways arising from potential future use of the groundwater.

Performance monitoring wells located within and downgradient from a contaminated area provide a means of evaluating the effectiveness of a groundwater remedy relative to performance criteria. Long-term monitoring (LTM) of these wells also provides information about migration of the contamination and temporal trends in chemical concentrations. Groundwater monitoring wells located downgradient from the leading edge of a contaminated area (*i.e.*, sentry wells) are used to evaluate possible changes in the extent of the plume and, if warranted, to trigger a contingency response action if contaminants are detected.

Primary factors to consider when developing a groundwater monitoring program include at a minimum:

- Aquifer heterogeneity,
- Types of contaminants,
- Distance to potential receptor exposure points,
- Groundwater seepage velocity and flow direction(s),
- Potential surface-water impacts, and
- The effects of the remediation system.

These factors will influence the locations and spacing of monitoring points and the sampling frequency. Typically, the greater the seepage velocity and the shorter the distance to receptor exposure points, the more frequently groundwater sampling should be conducted.

One of the most important purposes of LTM is to confirm that the contaminant plume is behaving as predicted. Graphical and statistical tests can be used to evaluate plume stability. If a groundwater remediation system or strategy is effective, then over the long term, groundwater-monitoring data should demonstrate a clear and meaningful decreasing trend in concentrations at appropriate monitoring points. The groundwater and surface water monitoring programs at OU2 were evaluated to identify potential opportunities for streamlining monitoring activities while still maintaining an effective performance and compliance monitoring program.

4.1 METHOD FOR QUALITATIVE EVALUATION OF MONITORING NETWORK

The LTMO evaluation included 77 groundwater wells and 18 surface water sampling stations located in OU2. These sampling points, their associated HUs (for groundwater wells), their basecase monitoring frequencies, and the earliest and most recent sampling data used in the LTMO analysis are listed in Tables 3.1 and 3.2; their locations are depicted on Figures 3.1 and 3.2.

Multiple factors were considered in developing recommendations for continuation or cessation of groundwater monitoring at each well. In some cases, a recommendation was made to continue monitoring a particular well, but at a reduced frequency. A recommendation to discontinue monitoring at a particular well based on the information reviewed does not necessarily constitute a recommendation to physically abandon the well. A change in site conditions might warrant resumption of monitoring at some time in the future at wells that are not currently recommended for continued sampling. Typical factors considered in developing recommendations to retain a well in, or remove a well from, an LTM program are summarized in Table 4.1. Typical factors considered in developing recommendations for monitoring frequency are summarized in Table 4.2.

TABLE 4.1
MONITORING NETWORK OPTIMIZATION DECISION LOGIC
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Reasons for Retaining a Well in Monitoring Network	Reasons for Removing a Well from Monitoring Network
Well is needed to further characterize the site or monitor changes in contaminant concentrations through time	Well provides spatially redundant information with a neighboring well (*e.g.*, same constituents, and/or short distance between wells)
Well is important for defining the lateral or vertical extent of contaminants.	Well has been dry for more than two years[a/]
Well is needed to monitor water quality at compliance point or receptor exposure point (*e.g.*, water supply well)	Contaminant concentrations are consistently below laboratory detection limits or cleanup goals
Well is important for defining background water quality	Well is completed in same water-bearing zone as nearby well(s)

a/ Periodic water-level monitoring should be performed in dry wells to confirm that the upper boundary of the saturated zone remains below the well screen. If the well becomes re-wetted, then its inclusion in the monitoring program should be evaluated.

TABLE 4.2
MONITORING FREQUENCY DECISION LOGIC
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Reasons for Increasing Sampling Frequency	Reasons for Decreasing Sampling Frequency
Groundwater velocity is high	Groundwater velocity is low
Change in contaminant concentration would significantly alter a decision or course of action	Change in contaminant concentration would not significantly alter a decision or course of action
Well is necessary to monitor source area or operating remedial system	Well is distal from source area and remedial system
Cannot predict if concentrations will change significantly over time, or recent significant increasing trend in contaminant concentrations is resulting in concentrations approaching or exceeding a cleanup goal, possibly indicating plume expansion	Concentrations are not expected to change significantly over time, or contaminant levels have been below groundwater cleanup objectives for some prescribed period of time

4.2 RESULTS OF QUALITATIVE LTMO EVALUATION FOR GROUNDWATER

The results of the qualitative evaluation of monitoring wells in OU2 are described in this subsection. The evaluation included the 77 groundwater monitoring wells listed in Table 3.1. The qualitative LTMO evaluation for groundwater considered historical analytical results for the four primary COCs (arsenic, cadmium, lead, and zinc) and whether continued monitoring of each well was desirable in light of the OU2 groundwater monitoring goals listed in Section 3.1.

Table 4.3 includes recommendations for retaining or removing each well, the recommended sampling frequency, and the rationale for the recommendations. The draft CSM report (CH2M Hill, 2005a) discusses contaminant fate and transport by monitoring well transect or inter-transect area, beginning at the upgradient (east) end of the site and progressing in the downgradient (westerly) direction. Similarly, the wells in Table 4.3 are listed in general order from upgradient to downgradient according to the transect or inter-transect area in which they are located. The qualitative analysis results are depicted on Figure 4.1 and are summarized by aquifer in the following subsections.

4.2.1 Single Unconfined Aquifer

Wells located along Transect 1 and between Transects 1 and 2 are screened in the single unconfined aquifer, which is located in the easternmost portion of OU2 hydraulically upgradient of the eastern limit of the lacustrine silt/clay aquitard. As shown in Table 4.3, two of the three wells located at Transect 1 are recommended for retention in the LTM program because they provide background groundwater quality data in the upper and lower portions of the aquifer. Collection of background data is useful because it helps define the impact of contaminant sources and temporal variations in the frequency and magnitude of precipitation events within OU2 on groundwater quality. In addition, the qualitative evaluation judged wells located on defined transects to be

TABLE 4.3
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

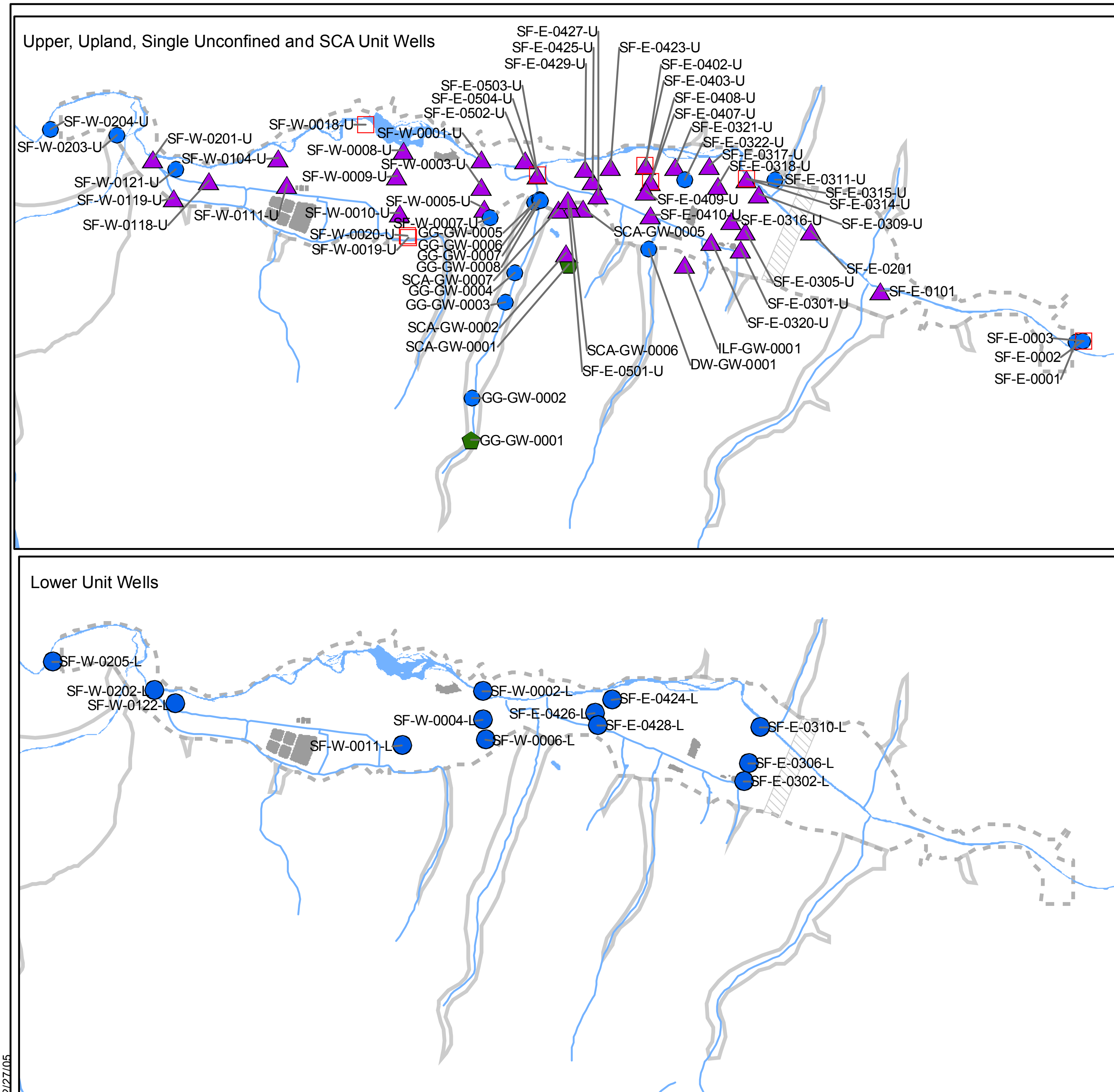
Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
Deadwood Gulch Upland Aquifer						
BH-DW-GW-0001	Upland	Quarterly		x	annual	Monitors effectiveness of Phase I removal actions in Deadwood Gulch and quality of GW emerging from the gulch; decreasing Cd concentrations justify lower frequency; other COCs are < MCL and exhibit stable concentrations
Government Gulch Upland Aquifer						
BH-GG-GW-0001	Upland	Quarterly		x	biennial	Monitors background GW quality in Gov't Gulch; reduced frequency justified by non-detect or very low magnitude COC concentrations over 15 events from 4/00 to 10/04; more frequent delineation of background GW quality unnecessary unless upgradient conditions change.
BH-GG-GW-0002	Upland	Quarterly		x	annual	Monitors elevated metal concentrations in upland aquifer and Phase I remedial effectiveness at achieving MCLs; decreasing Cd and Zn trends (approaching or below MCLs) justify lower frequency; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
BH-GG-GW-0003	Upland	Quarterly		x	annual	Monitors elevated metal concentrations in upland aquifer and Phase I remedial effectiveness at achieving MCLs; decreasing Cd and Zn trends (approaching or below MCLs) justify lower frequency; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
BH-GG-GW-0004	Upland	Quarterly		x	annual	Monitors elevated metal concentrations in upland aquifer and Phase I remedial effectiveness at achieving MCLs; decreasing Cd and Zn trends (approaching or below MCLs) and low magnitude of As levels (near new MCL) justify lower frequency; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
BH-GG-GW-0005	Upland	Quarterly		x	annual	Monitors net effect of Phase I remedial measures on alluvial GW quality in Gov't Gulch; decreasing COC concentrations justifies lower frequency; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
BH-GG-GW-0006	Upland	Quarterly		x	annual	Single, v. slight MCL exceedance (Cd) in Apr 02; perform low-frequency monitoring to assess potential increasing trend for Cd over time; low magnitude of metal concentrations does not justify more frequent sampling; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
BH-GG-GW-0007	Upland	Quarterly		x	annual	Monitors net effect of Phase I remedial measures on alluvial GW quality in Gov't Gulch; lack of temporal trends justifies lower frequency; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
BH-GG-GW-0008	Upland	Quarterly		x	annual	No MCL exceedances; perform low-frequency monitoring to assess potential increasing Zn trend over time; low magnitude of metal concentrations does not justify more frequent sampling; see text in Section 4.2.4 for additional details regarding recommended monitoring frequency
Upland Aquifer between Deadwood and Railroad Gulches						
BH-ILF-GW-0001	Upland	Quarterly		x	semiannual	Well appears to be monitoring effectiveness of Phase I removal and capping actions at two upslope industrial landfills; insufficient data to determine temporal trends for all COCs; perform semiannual sampling to support trend determinations, then reassess frequency. Consider annual frequency if COCs are decreasing
Upland Aquifer at the Smelter Closure Area						
BH-SCA-GW-0001	Upper	Quarterly		x	biennial	Background well for the SCA; more frequent definition of upgradient GW quality not necessary due to concentration stability and lack of increasing trends
BH-SCA-GW-0002	Upper	Quarterly		x	semiannual	At upgradient edge of SCA; increasing metal concentrations justifies higher frequency to support remedial decision-making
BH-SCA-GW-0005	Upper	Quarterly		x	semiannual	Monitors for seepage from SCA waste cell; retain at higher frequency to support remedial decision-making and more rapid response in the event of waste cell seepage
BH-SCA-GW-0006	Upper	Quarterly		x	semiannual	Monitors for seepage from SCA waste cell; retain at higher frequency to support remedial decision-making and more rapid response in the event of waste cell seepage
BH-SCA-GW-0007	Upper	Quarterly		x	semiannual	Monitors for seepage from SCA waste cell; retain at higher frequency to support remedial decision-making and more rapid response in the event of waste cell seepage
Transect 1						
BH-SF-E-0001	Single Unconfined	Quarterly		x	annual	On Transect 1; provides background data in lower portion of alluvial aquifer; upgradient location and lack of MCL exceedances over 1st 2 yr of quarterly sampling justifies relatively low frequency
BH-SF-E-0002	Single Unconfined	Quarterly		x	annual	On Transect 1; provides background data in lower portion of alluvial aquifer; upgradient location and lack of MCL exceedances over 1st 2 yr of quarterly sampling justify relatively low frequency
BH-SF-E-0003	Single Unconfined	Quarterly	x		exclude	Redundant with and typically similar to lower concentrations than BH-SF-E-0001, which exhibits similar trends
Transect 1 to Transect 2						
BH-SF-E-0101	Single Unconfined	Quarterly		x	semiannual	Monitors elevated Cd concentrations in alluvial aquifer in area with low well density; upgradient of Milo Creek channel restoration so indicates impact of restoration on GW quality further downgradient; potentially indicative of surface water impacts on GW quality
BH-SF-E-0201	Single Unconfined	Quarterly		x	semiannual	Monitors elevated Cd and Zn concentrations in alluvial aquifer in area with low well density; indicative of Phase 1 remediation effectiveness (channel restoration at Milo Ck).
Transect 2						
BH-SF-E-0301-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations at Transect 2 near preferential flowpath (pre-1900 river channel) and near area of contaminated fill south of Bunker Ck
BH-SF-E-0302-L	Lower	Quarterly		x	annual	same as BH-SF-E-0301-U; lower aquifer completion interval and lack of increasing trends justify lower frequency
BH-SF-E-0305-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper alluvial aquifer at Transect 2
BH-SF-E-0306-L	Lower	Quarterly		x	annual	Monitors elevated metal concentrations at Transect 2; lower aquifer completion interval and lack of increasing trends justify lower frequency
BH-SF-E-0309-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper alluvial aquifer at Transect 2
BH-SF-E-0310-L	Lower	Quarterly		x	annual	Monitors lower aquifer at Transect 2; lower aquifer completion interval, lack of MCL exceedances, and lack of increasing trends justify removal from LTM program; however, retain at lower frequency to support annual mass flux calculations
BH-SF-E-0311-U	Upper	Quarterly		x	annual	Retain to evaluate contaminant flux across Transect 2 and relationship between the SFCDR and the upper aquifer north of the river (in terms of water quality and head difference). Relatively low sampling frequency justified by lack of MCL exceedances during 8 events over 1.5 years. Well appears to be screened in lower-K unit that is not fully representative of the upper aquifer; consider further frequency reduction to biennial at a later date.

TABLE 4.3 (continued)
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
Transect 2 to Transect 3						
BH-SF-E-0314-U	Upper	Quarterly		x	semiannual	Monitors elevated Cd concentrations in upper aquifer at upgradient perimeter of CIA; retain at relatively high frequency to evaluate effectiveness of Phase I remedial actions and facilitate remedial decision-making
BH-SF-E-0315-U	Upper	Quarterly	x		exclude	Redundant with and consistently lower Cd and Zn concentrations than BH-SF-E-0314-U
BH-SF-E-0316-U	Upper	Quarterly		x	semiannual	Monitors elevated Cd concentrations in upper aquifer within/beneath CIA; retain at relatively high frequency to detect potential migration of metals from CIA and facilitate timely response and remedial decision-making
BH-SF-E-0317-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at perimeter of CIA; retain at relatively high frequency to detect potential migration of metals from CIA and facilitate timely response and remedial decision-making
BH-SF-E-0318-U	Upper	Quarterly		x	semiannual	Monitors elevated Cd concentrations in upper aquifer within/beneath CIA; retain at relatively high frequency to detect potential migration of metals from CIA and facilitate timely response and remedial decision-making
BH-SF-E-0320-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at perimeter of CIA and downgradient of holding ponds; retain at relatively high frequency to detect potential migration of metals from CIA and holding ponds and facilitate timely response and remedial decision-making
BH-SF-E-0321-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at perimeter of CIA; retain at relatively high frequency to detect potential migration of metals from CIA and facilitate timely response and remedial decision-making
BH-SF-E-0322-U	Upper	Quarterly		x	annual	Well is screened in impounded waste material; retain to provide indication of waste toxicity over time, but at reduced frequency because well does not serve a sentry purpose.
BH-SF-E-0402-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at perimeter of CIA; retain at relatively high frequency to detect potential migration of metals from CIA and facilitate timely response and remedial decision-making
BH-SF-E-0403-U	Upper	Quarterly	x		exclude	Redundant with and consistently has similar or lower Cd and Zn concentrations than BH-SF-E-0402-U
BH-SF-E-0407-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer within/beneath CIA; retain at relatively high frequency to facilitate evaluation of effectiveness of Phase I remedial actions and support remedial decision-making
BH-SF-E-0408-U	Upper	Quarterly	x		exclude	Redundant with and consistently has lower Cd and Zn concentrations than BH-SF-E-0407-U
BH-SF-E-0409-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer within/beneath CIA; retain at relatively high frequency to facilitate evaluation of effectiveness of Phase I remedial actions and support remedial decision-making
BH-SF-E-0410-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at perimeter of CIA; retain at relatively high frequency to detect potential migration of metals from CIA and facilitate timely response and remedial decision-making
Transect 3						
BH-SF-E-0423-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer downgradient of CIA at Transect 3; increasing As trend; retain to support mass flux calculation
BH-SF-E-0424-L	Lower	Quarterly		x	annual	Monitors lower aquifer downgradient of CIA at Transect 3; lower aquifer completion interval, lack of increasing trends, and lack of MCL exceedances justify lower frequency; consider reducing to biennial frequency if 5 years of below-MCL results are obtained.
BH-SF-E-0425-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer downgradient of CIA at Transect 3; retain to support mass flux calculation
BH-SF-E-0426-L	Lower	Quarterly		x	annual	Monitors elevated metal concentrations in lower aquifer downgradient of CIA at Transect 3; lower aquifer completion interval, lack of increasing trends, and low contaminant load relative to paired shallow well justify lower frequency
BH-SF-E-0427-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer downgradient of CIA at Transect 3; near preferential flowpath (pre-1900 river channel); retain to support mass flux calculation
BH-SF-E-0428-L	Lower	Quarterly		x	annual	Monitors elevated metal concentrations in lower aquifer downgradient of CIA at Transect 3; lower aquifer completion interval, lack of increasing trends, and low contaminant load relative to paired shallow well justify lower frequency
Transect 3 to Transect 5						
BH-SF-E-0429-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer downgradient of CIA and Slag Pile Area
BH-SF-E-0501-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations and increasing As concentrations in upper aquifer downgradient of SCA
BH-SF-E-0502-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer in area of low well density north of SFCDR
BH-SF-E-0503-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer downgradient of Slag Pile Area
BH-SF-E-0504-U	Upper	Quarterly	x		exclude	Redundant with and tends to have similar or lower Cd and Zn concentrations than BH-SF-E-0503-U
Transect 5						
BH-SF-W-0001-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at Transect 5 near preferential flowpath (pre-1900 river channel)
BH-SF-W-0002-L	Lower	Quarterly		x	annual	Retain to facilitate mass flux calculations; lower aquifer completion interval, lack of MCL exceedances, and lack of increasing trends justify lower frequency; consider reducing to biennial frequency if 5 years of below-MCL results are obtained.
BH-SF-W-0003-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at Transect 5
BH-SF-W-0004-L	Lower	Quarterly		x	annual	Monitors elevated metal concentrations in lower aquifer at Transect 6; lower aquifer completion interval and lack of increasing trends justify lower frequency
BH-SF-W-0005-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer at Transect 5
BH-SF-W-0006-L	Lower	Quarterly		x	annual	Slight exceedances of future As MCL (0.01 mg/L); lower aquifer completion interval, relatively low metal concentrations, and lack of increasing trends justify lower frequency; consider reducing to biennial if 5 years of results indicate continued low-magnitude, stable results
BH-SF-W-0007-U	Upper	Quarterly		x	annual	Only 1 slight MCL exceedance in 18 events; additional delineation of GW quality at edge of alluvial valley unnecessary, but retain at low frequency to facilitate mass flux calculations at Transect 5; consider reducing to biennial frequency if 5th year of data indicate continued low, stable trends.
Transect 5 to Transect 6						
BH-SF-W-0008-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer in Smelterville Flats area (Phase I removal and capping)
BH-SF-W-0009-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer in Smelterville Flats area (Phase I removal and capping)
BH-SF-W-0010-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer in Smelterville area

TABLE 4.3 (continued)
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
BH-SF-W-0011-L	Lower	Quarterly		x	annual	Monitors elevated metal concentrations in lower aquifer in Smelterville area
BH-SF-W-0019-U	Upper	Quarterly	x		exclude	One slight MCL exceedance (Cd in Apr 02) in 20 events; further delineation of this relatively uncontaminated area is unncessary.
BH-SF-W-0018-U	Upper	Quarterly	x		exclude	No MCL exceedances since Oct 01 (13 events); further delineation of this relatively uncontaminated area is unnecessary
BH-SF-W-0020-U	Upper	Quarterly	x		exclude	No MCL exceedances over 17 events from April 00 to Oct 04; further delineation of this uncontaminated area is unnecessary
BH-SF-W-0104-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations in upper aquifer in Smelterville Flats area; near preferential flowpath (pre-1900 river channel) and in Phase I removal/capping area
BH-SF-W-0111-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations (including potentially increasing As levels) near Page WWTP and downgradient of holding ponds
BH-SF-W-0118-U	Upper	Quarterly		x	semiannual	Monitors potentially increasing As concentrations in Upper Aquifer adjacent to West Page Swamp and downgradient from Page WWTP and Smelterville Flats
BH-SF-W-0119-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations (including potentially increasing As levels) near West Page Swamp
BH-SF-W-0121-U	Upper	Quarterly		x	annual	Downgradient of increasing As levels in upper aquifer; relatively low metal concentrations justifies reduced sampling frequency
BH-SF-W-0122-L	Lower	Quarterly		x	annual	Retain to monitor lower aquifer GW quality in area with very low density of lower aquifer wells; downgradient of increasing As levels in upper aquifer; relatively low metals concentrations and lower aquifer completion interval justifies lower sampling frequency
Transect 6						
BH-SF-W-0201-U	Upper	Quarterly		x	semiannual	Monitors elevated metal concentrations at Transect 6 near current and pre-1900 river channels (potential preferential flow paths)
BH-SF-W-0202-L	Lower	Quarterly		x	annual	Monitors lower aquifer GW quality near downgradient edge of "Box"; lower aquifer completion interval and historic lack of MCL exceedances justify lower sampling frequency
Transect 6 to Transect 7						
BH-SF-W-0203-U	Upper	Quarterly		x	annual	Monitors upper aquifer GW quality downgradient of Pine Creek (losing reach) in area of low well density; single slight MCL exceedance (CD, Apr 02) in 16 events justifies reduced frequency
Transect 7						
BH-SF-W-0204-U	Upper	Quarterly		x	annual	Downgradient sentry well permits evaluation of upper aquifer GW quality leaving "Box"; history of relatively low metal concentrations (no MCL exceedances and COCs mostly non-detect) justify reduced frequency; delete from LTM program if 5 yr of low, stable results are obtained
BH-SF-W-0205-L	Lower	Quarterly		x	annual	Downgradient sentry well permits evaluation of lower aquifer GW quality leaving "Box"; relatively low metal concentrations and lower aquifer completion interval justify reduced sampling frequency; delete from LTM program if 5 years of low, stable results are obtained



Legend

Qualitative Evaluation

Sampling Frequency Recommendation

- Biennial
- Annual
- Semiannual
- Exclude

0 1,250 2,500 5,000 7,500 10,000 Feet

FIGURE 4.1

QUALITATIVE EVALUATION SAMPLING FREQUENCY RECOMMENDATIONS FOR GROUNDWATER WELLS

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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particularly useful because they can be used to periodically estimate the mass flux of selected metals migrating across the vertical plane of the transect. Periodic (*e.g.*, annual) estimates of the mass flux of metals across the transects would be a useful way to evaluate the net impact of the various factors influencing groundwater quality throughout OU2 (*i.e.*, the Phase I remedial actions; inputs to and outflows from the groundwater system such as contributions from sources, gains from and losses to surface water, and the influence of fate and transport properties such as metals precipitation and sorption). For this reason, relatively detailed definition of contaminant and hydraulic characteristics along the defined transects was considered to be relatively important during the qualitative analysis. Although a substantial degree of uncertainty may be associated with the magnitudes of calculated mass fluxes given the uncertainty in estimation of representative hydraulic conductivity values, relative changes in mass flux could be determined if the same hydraulic information and wells are used in the calculations from year to year. These relative changes could be useful indicators of remedial effectiveness and the effects of significant hydrologic (e.g., precipitation and snowmelt) events.

The background groundwater quality data collected to date indicate that groundwater at Transect 1 is relatively uncontaminated compared to more downgradient locations. Given the relatively low magnitude and stable nature of metal concentrations in groundwater at Transect 1, indicated by the first two years of quarterly monitoring, a relatively infrequent (*i.e.*, annual) monitoring frequency is recommended for the two Transect 1 wells recommended for retention. Annual sampling should be performed at a time of year when metal concentrations in groundwater are typically relatively elevated based on historical data. The third Transect 1 well, BH-SF-E-0003, is recommended for deletion from the LTM program because it is nearly co-located (both horizontally and vertically) with BH-SF-E-0001 and exhibits similar trends, with generally similar or lower metal concentrations than that well. BH-SF-E-0003 and BH-SF-E-0001 are screened from 41 to 61 feet bgs and 46 to 59 feet bgs, respectively, and thus are monitoring similar portions of the single unconfined aquifer.

The two wells screened in the single unconfined aquifer between Transects 1 and 2 are recommended for continued sampling primarily because they monitor elevated metal concentrations in an area that does not contain any other wells screened in the single unconfined aquifer. Therefore, they appear to be spatially important. In addition, they can be used to indicate the impact of Phase I remedial actions performed in the eastern portion of OU2 on groundwater quality (*e.g.*, channel restoration in the Milo Creek drainage). Data from these wells (especially BH-SF-E-0101, which is screened near the water table) also can be used to assess the impact of surface water infiltration to the groundwater system, given that surface water flow measurements indicate that the SFCDR is losing in this area.

A semiannual monitoring frequency is recommended for wells BH-SF-E-0101 and -0201. Semiannual is the highest frequency recommended in this analysis. Continuation of quarterly monitoring of OU2 wells is not considered appropriate or necessary for the following reasons:

- The quarterly monitoring performed to date is sufficient to qualitatively indicate seasonal changes in COC concentrations (however, the historical data are not necessarily adequate to determine seasonality in a statistical sense in order to perform statistical corrections for seasonality using the Mann-Kendall test for trend).

- Given the very large size of OU2 relative to the estimated advective groundwater velocity, significant changes in groundwater quality resulting from the Phase I remedial actions are not anticipated to be recognizable from one quarter to the next; therefore, quarterly sampling is not necessary to achieve monitoring goals 1 and 3 listed above in Section 4.2, and semiannual sampling is judged to be sufficient to achieve all of the monitoring goals.

- The quarterly monitoring performed to date supports the observation that rapid and substantial changes in groundwater quality are generally not occurring from one quarter to the next. Therefore, semiannual monitoring should be adequate to identify longer-term trends in groundwater quality.

The primary objective of recommending a semiannual monitoring frequency is to provide sufficient data on temporal trends in COC concentrations (especially recent trends) to facilitate making decisions regarding the need for, and scope of, Phase II remedial actions. Once these decisions are made, a further decrease in the groundwater monitoring frequency for wells screened in the single unconfined aquifer and upper alluvial sand and gravel aquifer (Section 4.2.2) to annual is recommended. This is justified given that 1) MCL exceedances are widespread throughout the unconfined aquifers, 2) monitoring data obtained to date indicate that rapid changes in contaminant concentrations are generally not occurring, and 3) the localized nature of remedial actions relative to the large size of OU2 suggest that achieving MCLs in groundwater will be a long process that can be adequately tracked with annual groundwater sampling. In summary, the semiannual monitoring period is recommended to be relatively short (*e.g.*, two to three years) and transitional to a less frequent (*i.e.*, annual) monitoring approach. Annual sampling should be performed at a time of year when metal concentrations in groundwater are typically relatively elevated based on historical data. As stated in Section 4.6, a temporary increase in the frequency of groundwater monitoring in the event of an unusually large hydrologic event should be considered to capture potential effects of dissolved metals releases from the vadose zone.

4.2.2 Upper Alluvial Sand and Gravel Aquifer

Most of the wells completed in the upper alluvial sand and gravel aquifer that underlies the SFCDR valley are recommended for retention in the LTM program because this aquifer has been and continues to be substantially impacted by historic mining-related activities, and detections of COCs at concentrations that are substantially greater than MCLs are widespread. Given that this aquifer is the uppermost water-bearing zone in the SFCDR valley and receives discharge from groundwater underlying the hill slopes and tributary valleys bordering the main valley, groundwater quality in this aquifer is expected to be the primary indicator of the effectiveness of prior (Phase I) and future (Phase II) remedial actions as well as of the effects of precipitation events that result in leaching of contaminants from the vadose zone. In addition, this aquifer is in hydraulic communication with surface water drainages that traverse the Bunker Hill Box. Therefore, monitoring of wells screened in this aquifer is consistent with each of the five groundwater monitoring goals listed above in Section 4.2. Given that only 44 wells are scattered throughout the shallow alluvial aquifer in OU2, which has an average length and width of approximately 29,000 feet and 3,000 feet, respectively, there are few redundancies in terms of spatial location.

A semiannual monitoring frequency for most wells completed in this aquifer is recommended for the same reasons stated for the single unconfined aquifer in Section 4.2.1. However, as is also stated in Section 4.2.1, the semiannual monitoring period should not last longer than needed to support Phase II remedial action decisions, and should be considered to be a short-term (*i.e.*, two to three years) transitional period to a less-frequent (annual) monitoring frequency that is maintained for a longer period of time.

Exceptions to the above-described monitoring strategy for the upper alluvial sand and gravel aquifer are discussed below and in Table 4.3.

Four wells screened in this aquifer are recommended for removal from the LTM program because they are co-located with other wells that exhibit similar temporal trends and that historically have had COC concentrations that are generally similar to or higher than the well recommended for removal. Therefore, continued monitoring of the co-located well should be sufficient to track temporal trends in COC concentrations in the upper aquifer at these locations over time. The wells recommended for removal for these reasons include

- BH-SF-E-0315-U at the northeastern edge of the Central Impoundment Area (CIA) (co-located with BH-SF-E-0314-U),
- BH-SF-E-0403-U at the northern edge of the CIA (co-located with BH-SF-E-0402-U),
- BH-SF-E-0408-U in the interior of the CIA footprint (co-located with BH-SF-E-0407-U), and
- BH-SF-E-0504-U located between Transects 3 and 5 (co-located with BH-SF-E-0503-U).

Three wells are recommended for removal from the LTM program because they appear to be monitoring relatively uncontaminated portions of the upper alluvial sand and gravel aquifer. Continued monitoring of zones that have repeatedly been shown to be relatively unimpacted by historic mining activities does not provide any useful information; it is reasonable to assume that if these areas have not been impacted to date, they will remain unimpacted in the future unless hydraulic conditions undergo a significant change (*e.g.*, installation of a pump and treat system). The wells recommended for removal for this reason are described below

- BH-SF-W-0019-U and BH-SF-W-0020-U are both located at the southern edge of the SFCDR alluvial valley in Smelterville. The former well has had only one very slight MCL exceedance (cadmium in April 2002) in 20 events spanning 4.5 years, and the latter well has not had any MCL exceedances in 17 events spanning 4.5 years).

- BH-SF-W-0018-U is located adjacent to the SFCDR at the north edge of Smelterville Flats. This well has not had any MCL exceedances in 13 monitoring events since October 2001, and the prior MCL exceedances (for cadmium) were very slight (maximum exceedance of 0.003 micrograms per liter [µg/L]). It is possible that groundwater quality at this location is influenced by recharge from relatively clean surface water in the SFCDR.

Well BH-SF-E-0311-U could also potentially be included in this category and removed from the LTM program. However, it was recommended for retention at a relatively low sampling frequency as described in Table 4.3.

Four upper aquifer wells are recommended to be sampled at a lower (annual to biennial) frequency as described below:

- BH-SCA-GW-0001 provides useful background groundwater quality information due to its location upgradient of the Smelter Closure Area (SCA). However, it has exhibited relatively stable metal concentrations over a nearly five-year time frame, and more frequent definition of background conditions is not necessary unless there is reason to believe that conditions at or upgradient of this well will change in the future.

- BH-SF-W-0121-U provides useful information because it is located downgradient of an area exhibiting potentially increasing arsenic concentrations in groundwater (well BH-SF-W-0018-U). Well BH-SF-W-0121-U has exhibited two slight exceedances of the cadmium MCL and one slight exceedance of the lead MCL in 21 sampling events spanning 4.5 years. Annual monitoring of this relatively uncontaminated zone is recommended; more frequent monitoring is not necessary to achieve any of the monitoring goals listed in Section 3.1.

- Wells BH-SF-W-0203-U and -0204-U are located near the downgradient (western) edge of the Bunker Hill Box. They are useful because they monitor upper aquifer groundwater quality leaving the Box. An annual sampling frequency for these wells is recommended, given their history of relatively low and stable metal concentrations, indicating they are monitoring relatively clean groundwater. Groundwater quality at these locations should improve over time due to the effects of prior (Phase I) and future (Phase II) remedial actions (although variation in the magnitude and frequency of precipitation events will likely result in some temporal variation in metal concentrations in OU2 groundwater). Annual sampling of BH-SF-W-0204-U will facilitate annual mass flux calculations for Transect 7.

4.2.3 Lower Alluvial Sand and Gravel Aquifer

There are only 13 lower aquifer wells included in the group of 77 wells evaluated. The relatively low number of lower aquifer wells is likely because this aquifer tends to be much less contaminated than the overlying upper alluvial aquifer as a result of the shallow nature of the contaminant sources and the presence of the lacustrine silt/clay aquitard. All 13 lower aquifer wells are recommended for retention at an annual sampling frequency. The lower sampling frequency (relative to the upper aquifer) is justified by the relatively uncontaminated nature of this aquifer and the fact that is it somewhat hydraulically isolated from the upper aquifer by the aquitard. Annual sampling should be performed at a time of year when metal concentrations in groundwater are typically relatively elevated based on historical data. Reasons for retaining these wells for continued monitoring include:

- 11 of the 13 lower aquifer wells are located along defined transects across the alluvial valley, and periodic sampling of these wells will permit evaluation of metal concentrations in lower aquifer groundwater migrating across the transect lines, thereby supporting evaluation of the impact of Phase I/II remedial actions on groundwater quality in the lower aquifer. Some of these 11 wells contain elevated concentrations of one or more COCs.

- Lower aquifer well BH-SF-W-0122-L is not located on a defined transect, but is located downgradient of a large area between Transects 5 and 6 that contains only one lower aquifer well (BH-SF-W-0011-L). Therefore, groundwater quality in the lower aquifer throughout this large area is not well characterized. This well is centrally located in a relatively narrow portion of the alluvial aquifer, where groundwater from the large, uncharacterized area further to the east funnels through a fairly narrow "neck" near Transect 6. Therefore, continued sampling of this well will provide useful information on lower aquifer groundwater quality funneling out of a fairly large uncharacterized area near the downgradient end of the Bunker Hill Box.

- Lower aquifer well BH-SF-W-0011-L is also not located on a defined transect, but is useful because it monitors elevated metal concentrations in the Smelterville area. This well is the only lower aquifer well in the large, relatively poorly characterized (in terms of the lower aquifer) area mentioned above.

It may be reasonable to further reduce the sampling frequency of some of the lower aquifer wells, or remove them from the sampling program entirely, in the future based on temporal trend criteria described in Section 5. Specifically, these criteria include 1) wells that are continually non-detect for COCs or that have COC concentrations that are less than the MCLs, 2) wells that exhibit decreasing COC concentrations, and 3) wells that exhibit stable concentrations. An example of a well which could be a candidate for additional frequency reduction in the future is BH-SF-E-0310-L, located at Transect 2, given its historic lack of MCL exceedances and stable COC concentrations.

4.2.4 Upland Aquifer

Ten monitoring wells screened in the upland aquifer were evaluated. Eight of the 10 wells are located in or at the mouth of Government Gulch, one well is located at the mouth of Deadwood Gulch, and the remaining well is located near the southern boundary of the SFCDR alluvial valley between Railroad and Deadwood Gulches. Based on the qualitative evaluation, each of these 10 wells is recommended for continued monitoring at varying frequencies as described in the following paragraphs.

Government Gulch was the subject of Phase I removal and capping and channel restoration actions that appear to be having a positive effect on metal concentrations in groundwater in the upland aquifer. Elevated concentrations of COCs detected at wells BH-GG-GW-0002, -0003, -0004, and -0005 appear to be decreasing over time and, in some cases, no longer exceed the MCL. However, the degree to which the decreasing trends are due to the Phase I remedial actions as opposed to other environmental variables such as temporal variation in the frequency and magnitude of precipitation events that result in leaching of contaminants from the vadose zone is not known. Despite the continued presence of elevated COC concentrations at Government Gulch, a relatively infrequent (annual to biennial, see Table 4.3) sampling frequency is recommended by the qualitative analysis based on the assumption that additional (Phase II) remedial actions are not required and will not be performed (*i.e.*, more frequent monitoring of wells associated with Government Gulch is not required in the near term to support Phase II remedial decision-making). If this assumption is incorrect, then a semi-annual sampling frequency is recommended for Government Gulch wells to support Phase II remedial decisions, followed by a reduction to annual sampling. Annual to biennial sampling should be performed at a time of year when metal concentrations in groundwater are typically relatively elevated based on historical data.

Upland aquifer well BH-DW-GW-0001 is recommended for retention because it monitors the effectiveness of Phase I removal actions performed further upstream in Deadwood Gulch at reducing elevated metal concentrations in groundwater. Cadmium is the only COC in groundwater at this location, and, similar to the Government Gulch wells described above, concentrations of this metal are decreasing. Concentrations of arsenic, lead, and zinc are below their respective MCLs and exhibit relatively stable trends. For these reasons, a relatively low (annual) sampling frequency is recommended for this well.

Upland aquifer well BH-ILF-GW-0001 is recommended for retention at a semiannual frequency because it appears to be monitoring the effectiveness of Phase I removal and capping actions at two upslope industrial landfills. This well was installed in 2000 but has only been sampled twice (April 2001 and January 2003) because it has been dry or (once) could not be accessed due to snow. On October 24, 2005 there was approximately 1.8 feet of water in the well. As a result, there are insufficient data for this well to determine temporal trends for all COCs; collection of additional data will support statistical trend determinations, which will in turn help determine the proper future monitoring frequency for this well. If insufficient water is present to collect samples using a dedicated low-flow pump, then sample collection using another feasible method (e.g., non-dedicated peristaltic pump) is recommended.

4.3 RESULTS OF QUALITATIVE LTMO EVALUATION FOR SURFACE WATER

The results of the qualitative evaluation of surface water monitoring stations in OU2 are described in this subsection. The evaluation included the 18 surface water monitoring stations listed in Table 3.2 (the treatment plant outfalls and proposed new stations were excluded). The qualitative LTMO evaluation for surface water considered historical analytical results for the four primary COCs (arsenic, cadmium, lead, and zinc) and whether continued monitoring of each location was desirable in light of the OU2 surface water monitoring goals listed in Section 3.1. Table 4.4 includes recommendations for

TABLE 4.4
QUALITATIVE EVALUATION OF SURFACE WATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Surface Water Station Name	Location	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
BH-BC-0001	Bunker Creek	Quarterly		x	Semiannaual	Monitors elevated metals load discharging to SFCDR from Bunker Creek
BH-CS-0001	Seeps North of CIA	Quarterly		x	Semiannaual	Indicative of metal concentrations in groundwater discharging to SFCDR adjacent to CIA. Monitoring of surface water quality in SFCDR (OU3) upstream and downstream of CIA should be sufficient to measure increase in metal load due to groundwater discharge; repeated measurement of localized seep(s) along this long stretch of river adjacent to CIA for the purpose of gauging the impact of groundwater discharge on surface water quality does not seem especially useful; however, continued sampling would serve to indicate how groundwater quality in this portion of the CIA is changing over time in response to Phase I remedial actions; retain at semiannual frequency to support Phase II remedial decision-making, then reduce to annual
BH-DW-0001	Magnet Gulch	Quarterly		x	Semiannaual	Monitors elevated metals load discharging to Bunker Creek from Magnet Gulch
BH-GC-0001	Grouse Creek	Quarterly		x	Semiannaual	Monitors elevated metals load discharging from Grouse Creek and flowing toward SFCDR
BH-GG-0001	Gov't Creek at Gulch Mouth	Quarterly		x	Semiannaual	Monitors elevated metals load entering SFCDR valley from Gov't Creek and allows quantification of metals load entering groundwater along losing stretch between gulch mouth and SFCDR
BH-HC-0001	Humboldt Creek	Quarterly		x	Semiannaual	Monitors elevated metals load discharging from Humboldt Creek and flowing toward SFCDR
BH-IG-0001	Italian Gulch	Quarterly		x	Semiannaual	Monitors relatively low metals load discharging to SFCDR from Italian Gulch. Only dissolved arsenic exceeds the AWQC based on results from 2 samples. Evaluate whether As concentrations are representative of background levels and reduce to annual frequency if results are not indicative of contamination and stable trend is indicated.
BH-JC-0001	Jackass Creek	Quarterly		x	Semiannaual	Monitors relatively low metals load discharging to SFCDR from Jackass Creek. Only arsenic exceeds the AWQC based on results from 4 samples. Evaluate whether As concentrations are representative of background levels and reduce to annual frequency if results are not indicative of contamination and stable trend is indicated.
BH-MC-0001	Old Milo Creek Outfall	Quarterly		x	Semiannaual	Monitors water that is infiltrating into the old piping system (different water than new Milo Creek outfall); retain to facilitate surface water mass balance calculations.
BH-MC-0002	New Milo Creek Outfall	Quarterly		x	Semiannaual	Monitors elevated metals load discharging to SFCDR from Milo Creek; consistently higher metal concentrations than co-located station BH-MC-0001
BH-MG-0001	Deadwood Gulch	Quarterly		x	Semiannaual	Monitors elevated metals load discharging to Bunker Creek from Deadwood Gulch
BH-PG-0001	Portal Gulch	Annual[a/]		x	Semiannaual	Monitors elevated metals load discharging to Bunker Creek from Portal Gulch
BH-RR-0001	Railroad Gulch	Annual[a/]		x	Semiannaual	Monitors elevated metals load discharging to Bunker Creek from Railroad Gulch
BH-WP-0001	West Page Swamp Outfall	Quarterly		x	Semiannaual	Monitors elevated metals load discharging to SFCDR and net contribution of metals from upstream sources (Grouse and Humboldt Creeks, page WWTP, and East and West Page Swamps)
PC-339	Pine Creek below Amy Gulch	Quarterly		x	Semiannaual	Monitors discharge of metals from Pine Creek to the SFCDR; relatively low metal concentrations; most recent results reviewed were all less than AWQC
SF-268	SFCDR at Elizabeth Park	Quarterly		x	Semiannaual	Measures upstream, background surface water quality
SF-270	SFCDR at Smelterville	Quarterly		x	Semiannaual	Facilitates definition of metals load in SFCDR and spatial changes in that load due to inputs and outflows
SF-271	SFCDR at Pinehurst	Quarterly		x	Semiannaual	Most downstream station in Bunker Hill Box; monitors net outflow of COCs from OU2

[a/] Station sampled during high-flow events.

retaining or removing each monitoring station, the recommended sampling frequency, and the rationale for the recommendations.

The OU2 surface water monitoring program focuses on measuring influxes of COCs to the SFCDR due to the fact that the portion of the SFCDR that passes through OU2 is part of OU3. Therefore, monitoring of the SFCDR itself is primarily performed under the OU3 monitoring program. Only three SFCDR monitoring stations are included in the data set used for this LTMO evaluation (*i.e.*, SFCDR at Elizabeth Park, Smelterville, and Pinehurst). As described in Section 3.1, these three stations (and PC-339 [Pine Creek below Amy Gulch]) are sampled as part of the OU3 monitoring program, but the data are used for both OUs 2 and 3. Fourteen of the remaining 15 monitoring locations are located in tributary drainages just upstream of their confluence with Bunker Creek or the SFCDR. The remaining monitoring station was established to sample groundwater seeps adjacent to the SFCDR just north of the CIA.

Surface water drainages provide a means for metals contamination sourced in OU2 to be transported out of upland areas to the SFCDR and then off site to the west. Therefore, these drainages provide a means by which human and/or ecological receptors both within and downstream of OU2 may be impacted. As stated in the draft CSM report (CH2M Hill, 2005a), 52 mines and mine-related sites have been identified within OU2, most of which are scattered throughout the upland area south of the SFCDR valley. As a result, tributaries to the SFCDR that drain these upland areas can be contaminated with elevated concentrations of metals, an observation supported by the surface water monitoring results reviewed for this qualitative evaluation. Therefore, monitoring of surface water quality in these tributaries is an important component of 1) developing an adequate understanding of the locations of significant contaminant source areas that impact surface water quality, 2) monitoring the effects of Phase I remedial activities on surface water quality, 3) monitoring the effects of temporal variations in the frequency and magnitude of precipitation events on surface water quality, and 4) evaluating the need for Phase II remedial actions. None of the surface water monitoring stations listed in Table 4.4 are recommended for immediate removal from the monitoring program. However, future removal of selected stations may be justifiable as described in the following paragraphs.

The surface water monitoring network depicted on Figure 3.2 of this report and Figure 4-1 of the draft EMP (CH2M Hill, 2005b) appears to be reasonably comprehensive in that input from each of the primary tributaries that flow into the SFCDR is measured. However, some inputs are more significant than others. For example, results of the high-flow monitoring event performed in March 2003 (see Table 5-10 of the draft CSM report [CH2M Hill, 2005a]) indicate that 93 percent of the total cadmium load was measured at two locations (BH-GG-0001 and HB-BC-0001). Similarly, 92 percent of the total lead load was measured at two locations (BH-MC-0002 and BH-BC-0001), and 91 percent of the total zinc load was measured at three locations (BH-MC-0002, BH-GG-0001, and BH-BC-0001). In contrast, high-flow results for Italian Gulch (station BH-IG-0001) indicate that only 0.008 percent of the total cadmium load, 0.2 percent of the total lead load, and 0.03 percent of the total zinc load were discharged by this drainage. Therefore, it may be possible to either remove selected sampling locations such as BH-IG-0001 from the surface water monitoring program or reduce their sampling frequency without introducing significant error into measurement of the total metals load entering the SFCDR.

Table 5-9 of the draft CSM report (CH2M Hill, 2005a) indicates that there were no exceedances of the AWQC for zinc, cadmium, lead, or antimony measured at the mouths of Italian Gulch and Jackass Creek (BH-IG-0001 and BH-JC-0001); however, there was at least one order-of-magnitude exceedance of the AWQC for arsenic at each location. These observations are based on the results of only one to three samples. These two drainages are located north of the SFCDR in an area containing relatively few historic mines. If an additional two years of monitoring indicates continued low metal concentrations in these two creeks, and Phase II remedial actions are not planned, then consideration should be given to removing these stations from the monitoring program or reducing the sampling frequency to biennial (during high-flow conditions). The degree to which the arsenic concentrations detected in these two creeks are representative of background levels should also be assessed. Similar types of analyses should be performed as additional data are obtained to rank the metals loads of the various tributaries to facilitate assessment of the importance of continued monitoring on a semiannual basis.

A semiannual monitoring frequency for surface water in OU2 is judged to be appropriate at this time because these events can be approximately timed to coincide with high- and low-flow conditions, providing data that should be reasonably representative of the range of metal concentrations present in surface water and supporting Phase II remedial decisions. Higher-frequency monitoring results obtained to date can be used to assess the optimal timing of the semiannual events Reduction of the sampling frequency for the seeps north of the CIA to annual after Phase II remedial decisions have been made should be considered, similar to the upper aquifer wells discussed in Section 4.2. Additional recommendations regarding sampling frequency are made as part of the temporal statistical analysis (Section 5), and final recommendations are made in Section 7.

4.4 LABORATORY ANALYTICAL PROGRAM

Groundwater samples are analyzed for dissolved concentrations of a short-list of seven metals using USEPA Contract Laboratory Program (CLP) method ILM05.2. It is assumed that use of a CLP method is required at this site, given its regulatory status.

Surface water samples are analyzed for both total and dissolved concentrations of a short-list of seven metals using the same CLP method referenced above for groundwater. Two additional analytes (calcium and magnesium) are targeted for hardness calculations using the same method. Total and dissolved metal concentrations are each measured annually during the high-flow and low-flow sampling events, respectively. This is reasonable because the suspended sediment load during high-flow conditions is expected to be relatively large, and total concentrations would be indicative of the total metals load being carried by the river/creek. In contrast, the suspended sediment load during low-flow conditions is expected to be relatively small, given that flow is primarily representative of groundwater discharge.

This analytical program appears to be reasonably optimized, and no changes are recommended. It is assumed that pH, specific conductance, turbidity, and depth to water are being measured during well purging; measurement of pH is recommended given its effect on the mobility of selected metals. Measurement of dissolved oxygen and oxidation-reduction potential during purging is recommended for the same reason. These are simple field measurements that can provide further insight into metals fate and transport.

4.5 DATA GAPS

No data gaps in the OU2 surface water monitoring network were observed during the qualitative evaluation. Measurement of inputs to the SFCDR via tributary surface water drainages appears to be adequate for the intended purpose.

Specific data gaps in the groundwater monitoring network were assessed during performance of the qualitative evaluation. Section 7.0 of the draft CSM report (CH2M Hill, 2005a) summarizes general data gaps in a relatively "broad-brush" manner (*e.g.*, general topics that would benefit from an improved understanding are identified), but specific actions to fill these gaps (*e.g.*, installation of five borings in these specific locations) are not identified. The discussion in this subsection is limited to data gaps associated with the groundwater monitoring network, rather than all site-characterization-related data gaps. However, implementation of these recommendations would assist in filling some of the more general characterization-related data gaps outlined in the draft CSM report. A number of the recommendations focus on enhancing the groundwater monitoring networks at existing transect locations to more accurately estimate the mass flux of metals in groundwater across these transect lines, as described above in Section 4.2.1. Periodic mass flux estimates are a potentially useful way to semi-quantitatively measure the effectiveness of Phase I remedial actions. Installation of 22 new monitoring wells should be considered as described below and in Table 4.3.

1. The density of monitoring wells between Transects 1 and 2 is relatively low, and groundwater quality within large areas is not monitored. Subsurface conditions in this area could be better characterized by implementing one or both of the following two approaches:

    a. Installation of at least two additional monitoring well pairs in the single unconfined aquifer north and south of BH-SF-E-0201 to help refine groundwater hydraulic and contaminant characteristics and provide for more timely and comprehensive monitoring of the effects of Phase I remedial actions performed along Milo Creek. Installation of well pairs is recommended due to the prevalence of downward vertical hydraulic gradients in the eastern portion of OU2 and the lack of an aquitard to limit the downward migration of contaminants in the alluvial aquifer. The shallow wells should be screened near the water table and the deep wells in the lower third of the single unconfined alluvial aquifer.

    b. Installation of one monitoring well pair at Transect 2 (between BH-SF-E-0305-U and BH-SF-E-0309-U) to better define the mass flux of metals upgradient of an area that underwent substantial Phase I remedial actions. The pair should consist of both an upper and lower aquifer well. This would be a more cost-effective means of assessing water quality migrating through the single unconfined aquifer to the east, given the well control that already exists at Transect 2; however, approach 1(a) above is recommended if more timely data for the upgradient area are needed for remedial decision-making purposes. Implementation of recommendation 1(b) is still recommended even if 1(a) is also implemented.

2. Installation of one monitoring well pair (upper and lower aquifer wells) in the area between Transects 3 and 5 between existing wells BH-SF-E-0501-U and BH-SF-E-0503-U would help create another north-south transect of wells stretching from BH-SF-E-0502-U in the north to BH-SF-E-0501-U in the south. Groundwater quality in the nearly 1,400-foot wide area between these two existing wells and downgradient of the slag pile area is uncharacterized.

3. Installation of one monitoring well pair at Transect 5 (between BH-SF-E-0003-U and BH-SF-E-0001-U) is recommended to better define the mass flux of metals in the alluvial aquifer along this north-south transect. The two existing wells listed above are nearly 1,000 feet apart.

4. Installation of at least four new well pairs at Smelterville Flats, each consisting of an upper and lower aquifer well (eight wells total), is recommended given the large size of this area and the relatively low number of wells currently present as a result of the removal action that was performed.

5. Installation of at least one monitoring well pair at Transect 6 approximately midway between the SFCDR and the southern perimeter of the main valley alluvial aquifer is recommended to better define the mass flux of metals in the alluvial aquifer along this north-south transect. There is no well control in the approximately 700-foot span between existing well BH-SF-W-0201-U and the edge of the alluvial aquifer. Installation of a well pair along Transect 6 between the SFCDR and the northern limit of the main valley alluvial aquifer also should be considered to obtain more detailed groundwater quality data. Transect 6 is located hydraulically downgradient of the westernmost Phase I remedial action in an area where the alluvial aquifer is inferred to be relatively constricted. Therefore, collection of more detailed groundwater quality data along this transect would be useful in evaluating the effectiveness of Phase I remedial actions and groundwater quality near the western edge of the Bunker Hill Box.

6. Groundwater quality in the western portion of OU2 between Transects 6 and 7 (and along Transect 7) is relatively poorly characterized. Metal concentrations that exceed MCLs (but not by much) have been detected at upper aquifer well BH-SF-W-0201 (Transect 6), and wells further to the west have had few to no MCL exceedances. The draft CSM report (CH2M Hill, 2005a) states that the relatively low magnitude of the metals concentrations measured in alluvial aquifer groundwater at the western end OU2 is not understood. The western extent of elevated metal concentrations in groundwater is not well characterized, and the lateral extent of the main valley alluvial aquifer at Transect 7 does not appear to be well defined. The SFCDR is gaining between Transects 6 and 7, while Pine Creek appears to be losing. It is likely that at least some of the groundwater containing metal concentrations in excess of MCLs at Transect 6 discharges to the SFCDR near and/or west of this transect. Further evaluation of groundwater quality west of Transect 6 would appear to be justified, given the results obtained

at Transect 6. This could potentially be performed in a relatively inexpensive manner by installing and sampling temporary wells and/or by collecting groundwater grab samples using direct push methods, followed by the installation of a relatively small number of permanent monitoring wells at select key locations based on the data obtained.

4.6 LTM PROGRAM FLEXIBILITY

The LTM program recommendations summarized in Tables 4.3 and 4.4 are based on available data regarding current (and expected future) site conditions. Changing site conditions (*e.g.*, periods of drought or excessive rainfall or introduction of hydraulic stresses such as pumping wells) could affect contaminant fate and transport. Therefore, the LTM program should be reviewed if hydraulic conditions change significantly, and revised as necessary to adequately track changes in the magnitude and extent of COCs in environmental media over time. For example, a temporary increase in the frequency of surface water and groundwater monitoring in the event of an unusually large hydrologic event should be considered to capture potential effects of dissolved metals releases from the vadose zone.

SECTION 5

TEMPORAL STATISTICAL EVALUATION

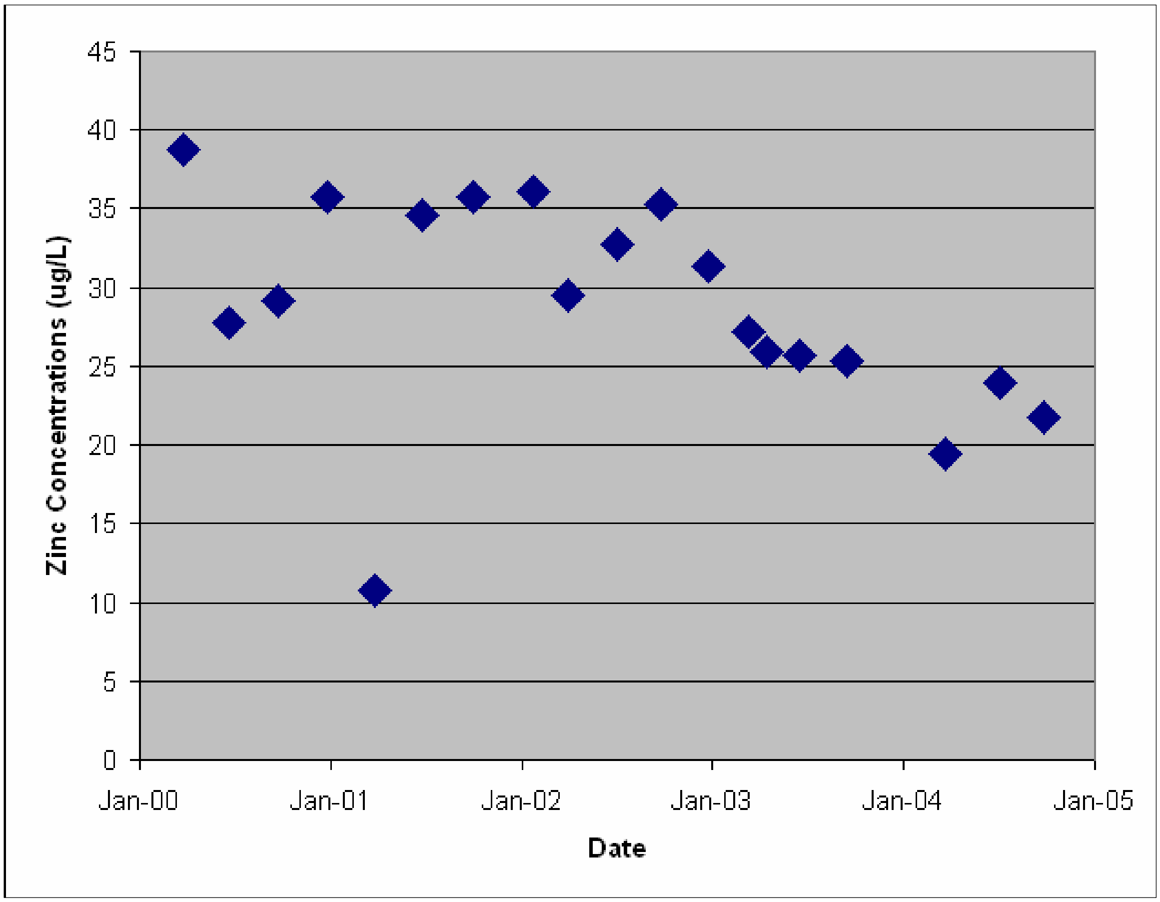
Chemical concentrations measured at different points in time (temporal data) can be examined graphically or using statistical tests to evaluate temporal trends. In general, if removal if contaminant mass is occurring in the subsurface as a consequence attenuation processes (*e.g*., metals precipitation) or remedial actions (*e.g.*, source removal), mass removal will be indicated by a decrease in analyte concentrations through time at a particular sampling location, as a decrease in analyte concentrations with increasing distance from source areas, and/or as a change in the suite of analytes detected through time or with increasing migration distance.

5.1 METHODOLOGY FOR TEMPORAL TREND ANALYSIS OF CONTAMINANT CONCENTRATIONS

Temporal chemical-concentration data can be evaluated for trends by plotting contaminant concentrations through time for individual monitoring wells (*e.g.*, Figure 5.1), or by plotting contaminant concentrations versus downgradient distance from the contaminant source for several wells along the groundwater flowpath over several monitoring events. Plotting temporal concentration data is recommended for any analysis of plume stability (Wiedemeier and Haas, 2000); however, visual identification of trends in plotted data may be a subjective process, particularly if (as is likely) the concentration data do not exhibit a uniform trend, but are variable through time (Figure 5.2).

The possibility of arriving at incorrect conclusions regarding the fate and transport of dissolved contaminants on the basis of visual examination of temporal concentration data can be reduced by examining temporal trends in chemical concentrations using various statistical procedures, including regression analyses and the Mann-Kendall test for trends. The Mann-Kendall nonparametric test (Gibbons, 1994) is well-suited for evaluation of environmental data because the sample size can be small (as few as four data points), no assumptions are made regarding the underlying statistical distribution of the data, and the test can be adapted to account for seasonal variations in the data; however seasonal correction was not appropriate or conducted for this OU2 analysis. The Mann-Kendall test statistic can be evaluated to determine, at a specified level of confidence, whether a statistically significant temporal trend is exhibited by contaminant concentrations detected through time in samples from an individual well. A negative slope (indicating decreasing contaminant concentrations through time) or a positive slope (increasing concentrations through time) provides statistical confirmation of temporal trends that may have been identified visually from plotted data (Figure 5.2). In this analysis, a 90% confidence level is used to define a statistically significant trend.

FIGURE 5.1
ZINC CONCENTRATIONS THROUGH TIME
AT WELL BH-GG-GW-0004
LONG-TERM MONITORING NETWORK OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE



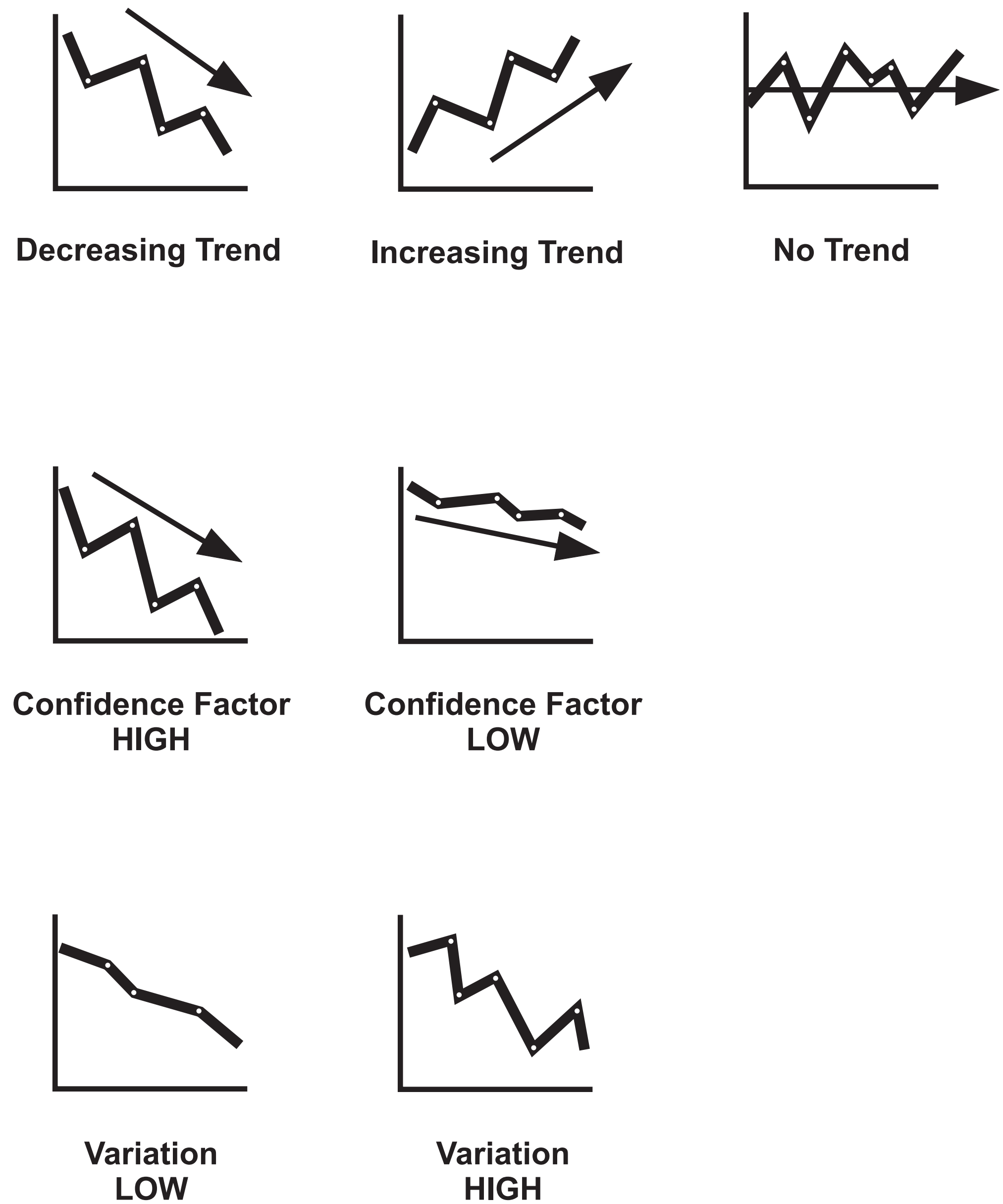


FIGURE 5.2

CONCEPTUAL REPRESENTATION OF TEMPORAL TRENDS AND TEMPORAL VARIATIONS IN CONCENTRATIONS

Long-Term Monitoring Optimization
Bunker Hill Mining and Metallurgical Complex

The relative value of information obtained from periodic monitoring at a particular monitoring well can be evaluated by considering the location of the well with respect to the dissolved contaminant distribution and potential receptor exposure points, and the presence or absence of temporal trends in contaminant concentrations in samples collected from the well. The degree to which the amount and quality of information that can be obtained at a particular monitoring point serves the two primary (*i.e.*, temporal and spatial) objectives of monitoring (Section 1) must be considered in this evaluation. For example, the continued non-detection of a target contaminant in groundwater at a particular monitoring location provides no information about temporal trends in contaminant concentrations at that location, or about the extent to which contaminant migration is occurring, unless the monitoring location lies along a groundwater flowpath between a contaminant source and a potential receptor exposure point (*e.g.*, downgradient of a known body of contaminated groundwater). Therefore, a monitoring well having a history of contaminant concentrations below detection limits may be providing little or no useful information, depending on its location.

A trend of increasing contaminant concentrations in groundwater at a location upgradient of a contaminant source or between a contaminant source and a potential receptor exposure point may represent information critical in evaluating whether contaminants are migrating to the exposure point, thereby completing an exposure pathway. Identification of a trend of decreasing contaminant concentrations at the same location may be useful in evaluating decreases in the areal extent of dissolved contaminants, but does not represent information that is critical to the protection of a potential receptor. Similarly, a trend of decreasing contaminant concentrations in groundwater near a contaminant source may represent important information regarding the progress of remediation near, and downgradient from, the source. By contrast, the absence of a statistically significant (as defined by the Mann-Kendall test with a 90% confidence level) temporal trend in contaminant concentrations at a particular location within, upgradient or downgradient from a plume indicates that virtually no additional information can be obtained by frequent monitoring of groundwater at that location, in that the results of continued monitoring through time are likely to fall within the historic range of concentrations that have already been detected (Figure 5.3). Continued monitoring at locations where no temporal trend in contaminant concentrations is present serves merely to confirm the results of previous monitoring activities at that location.

The temporal trends and relative locations of wells can be weighed to determine if a well should be retained, excluded, or retained with a reduced sampling frequency. Figure 5.4 presents a flowchart demonstrating the method for using trend results to draw these conclusions.

5.2 TEMPORAL EVALUATION RESULTS FOR GROUNDWATER WELLS

The analytical data for groundwater samples collected from the 77 groundwater monitoring wells and 18 surface sampling points in the OU2 LTM program from February 2000 through October 2004 were examined for temporal trends using the Mann-Kendall test. The objective of the evaluation was to identify those wells having increasing or decreasing concentration trends for each COC, and to consider the quality of information represented by the existence or absence of concentration trends in terms of the location of each monitoring point. Increasing or decreasing trends are those identified

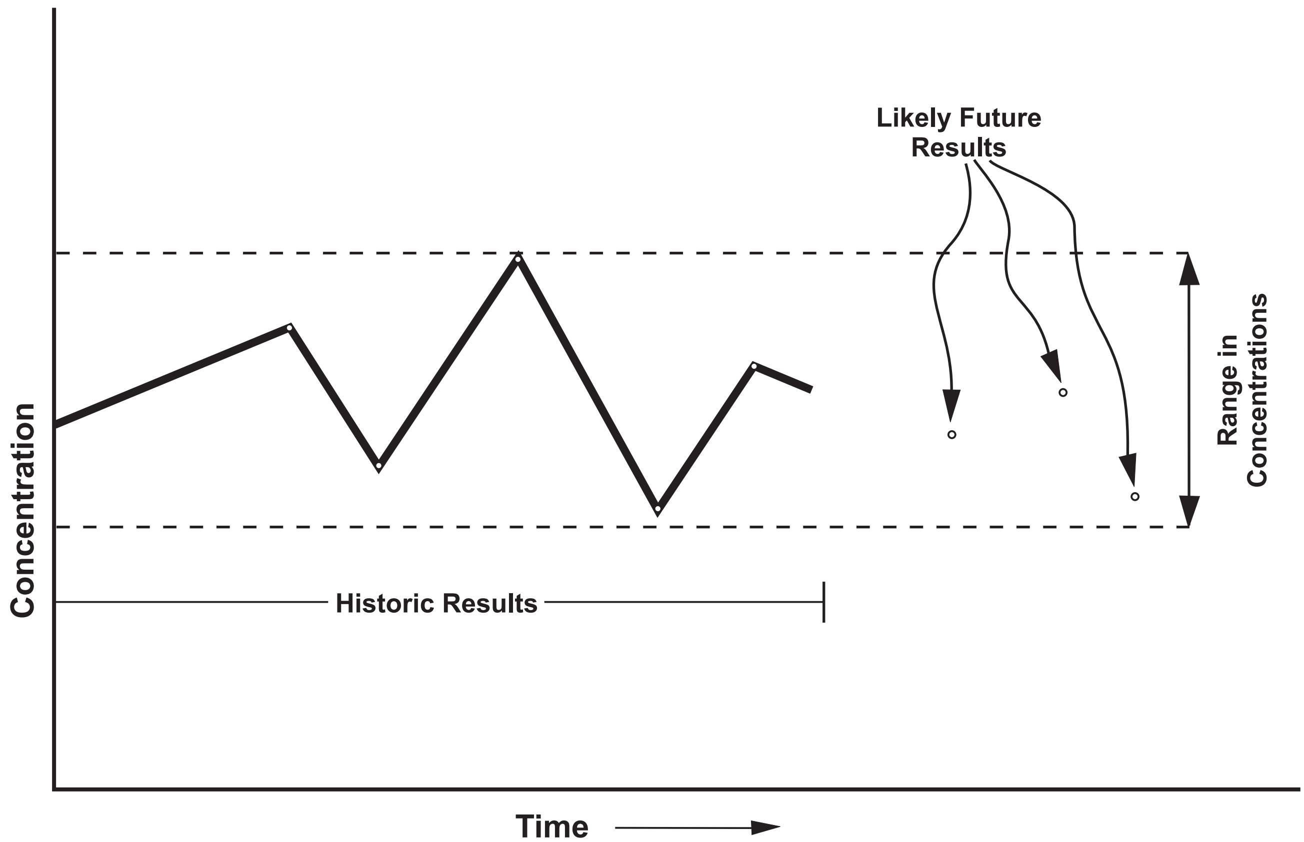
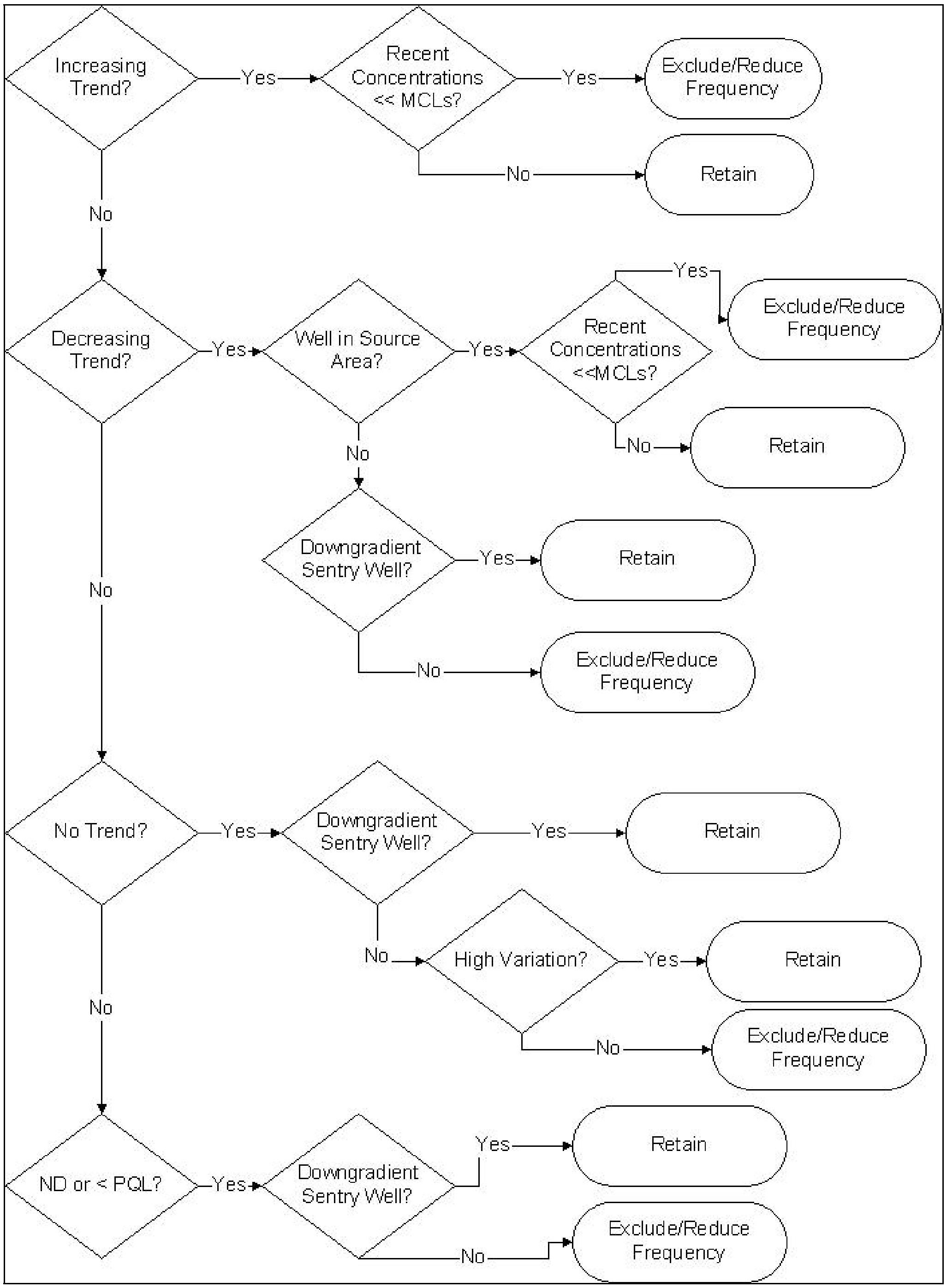


FIGURE 5.3
CONCEPTUAL REPRESENTATION OF CONTINUED MONITORING AT LOCATION WHERE NO TEMPORAL TREND IN CONCENTRATIONS IS PRESENT

Long-Term Monitoring Optimization
Bunker Hill Mining and Metallurgical Complex

draw\739732\diffusion\williamsA.cdr pg2 nap 4/3/02

FIGURE 5.4
TEMPORAL TREND DECISION RATIONALE FLOWCHART
LONG-TERM MONITORING NETWORK OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE



as having positive or negative slopes, respectively, by the Mann-Kendall trend analysis with a confidence level of 95%; "probably" increasing or decreasing trends are those identified with a confidence level of 90-95%.

Summary results of Mann-Kendall temporal trend analyses for COCs in groundwater samples from OU2 are presented in Table 5.1. Table 5.1 also contains the relative location designation assigned to each well. In general, upper HU wells were designated as "source" wells, unless they have had no MCL exceedances, in which case they were designated as "downgradient." Lower wells were also considered to be downgradient due to their vertical separation from contaminant source areas. Trends for four COCs (dissolved arsenic, cadmium, lead, and zinc) were evaluated to assess the value of temporal information provided by each well. As implemented, the algorithm used to evaluate concentration trends assigned a value of "ND" (not detected) to those wells with sampling results that were consistently below analytical detection limits through time, rather than assigning a surrogate value corresponding to the detection limit – a procedure that could generate potentially misleading and anomalous "trends" in concentrations. In addition, a value of "<PQL" was assigned to those constituents for which no values were measured above the practical quantitation limit (PQL), *i.e.*, all sample results were either ND or trace.

For example, arsenic results for groundwater samples from well BH-SCA-GW-0006 include two trace detections of 0.0005 mg/L and 0.0038 mg/L on 4/2/03 and 10/18/04, respectively, and 39 measurements in which arsenic was not detected. In the absence of the "<PQL" classification category, the results of trend analysis would indicate an "Increasing" result for arsenic in these samples, which is primarily an artifact of the analytical procedures, and could generate false conclusions regarding concentration trends. The color-coding of Table 5.1 entries denotes the presence or absence of temporal trends, and allows those monitoring points having nondetectable concentrations, decreasing or increasing concentrations, or no discernible trend in concentrations to be readily identified. Those trends that have confidence levels between 90 and 95% are indicated by the "probably increasing" or "probably decreasing" classifications ("increasing" and "decreasing" classifications correspond to confidence levels of more than 95%). Trend results with bold borders indicate the analytical data sets that contain over 50% non-detects. Although these trends are not deserving of the "ND" classification and resulting LTMO decisions, decisions made based on these trends should take the high number of non-detects into consideration.

Table 5.1 also shows the number of sampling results used in the trend analysis. The five sampling stations that had fewer than six analytical results for each of the COCs were not evaluated using the Mann-Kendall trend analysis, and have a "<6Meas" designation. The Mann-Kendall statistical test requires at least four sampling results; however, to be conservative, six results was used as the minimum threshold in this analysis. This decision was based on the "Roadmap to Long-Term Monitoring Optimization" (USEPA, 2005), which states that at least four to six separate sampling events are required to support the temporal evaluation.

Figures 5.5 and 5.6 display the Mann-Kendall results for cadmium and zinc thematically by well, respectively. The basis for the decision to exclude, reduce the sampling frequency, or retain a well in the monitoring program based on the value of its

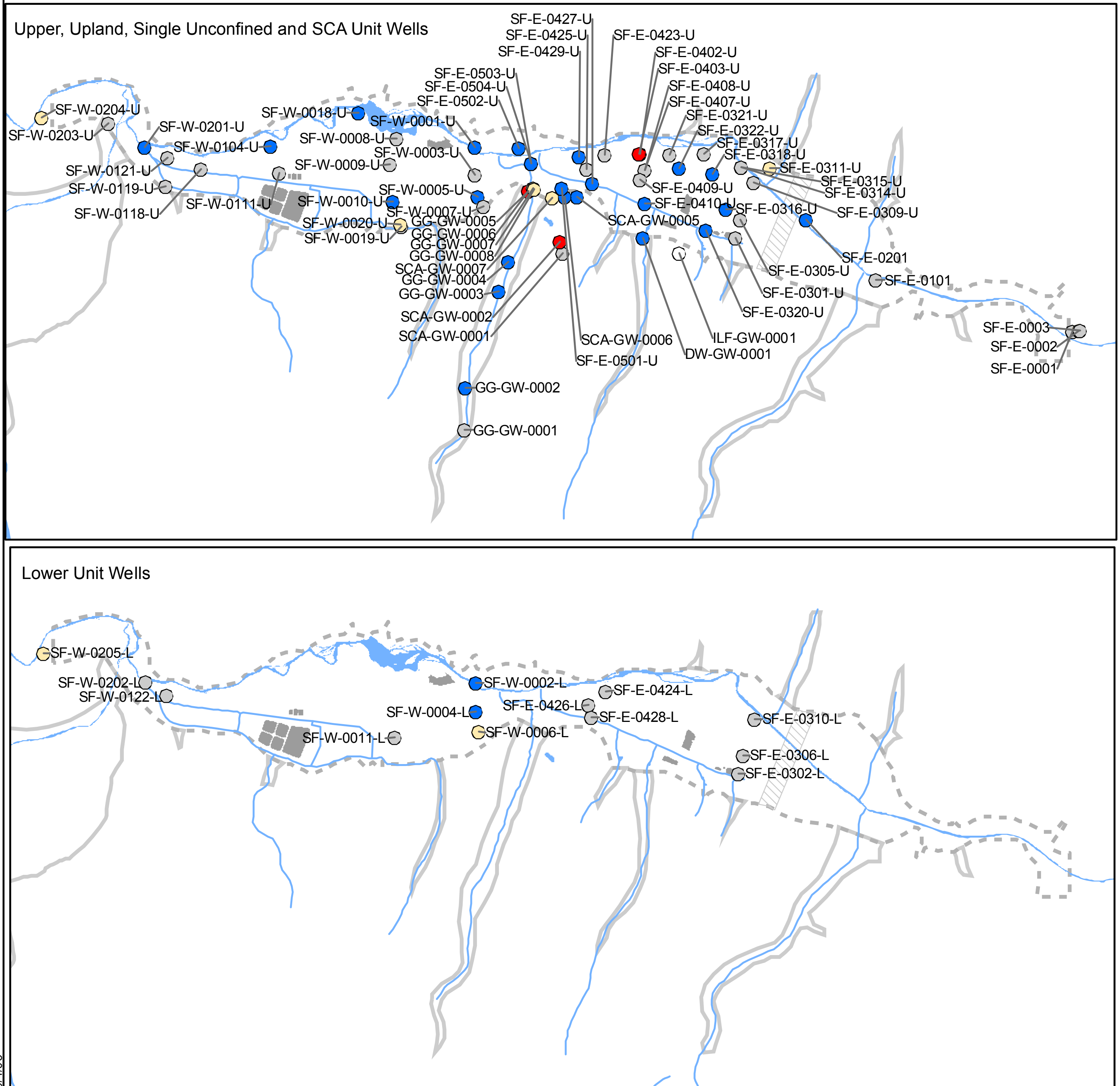
TABLE 5.1
TEMPORAL TREND ANALYSIS OF GROUNDWATER MONITORING RESULTS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydraulic Unit	Relative Location	Number of Sampling Results	Dissolved Arsenic	Dissolved Cadmium	Dissolved Lead	Dissolved Zinc	Exclude/ Reduce	Retain	Rationale
BH-DW-GW-0001	Upland	Downgradient	20	<PQL	Prob. Decreasing	No Trend	Decreasing	X		Cd > MCL, Zn < MCL, decreasing downgradient
BH-GG-GW-0001	Upland	Upgradient	15	<PQL	No Trend	<PQL	Prob. Decreasing	X		Zinc << MCL, decreasing/no trend upgradient
BH-GG-GW-0002	Upland	Source	18	<PQL	Decreasing	No Trend	Decreasing		X	Decreasing CD in source area > MCL
BH-GG-GW-0003	Upland	Source	21	<PQL	Decreasing	Prob. Decreasing	Decreasing		X	Decreasing COCs in source area > MCLs
BH-GG-GW-0004	Upland	Source	19	No Trend	Decreasing	No Trend	Decreasing		X	Decreasing COCs in source area > MCLs
BH-GG-GW-0005	Upland	Source	45	<PQL	Decreasing	Decreasing	Decreasing		X	Decreasing COCs in source area > MCLs
BH-GG-GW-0006	Upland	Downgradient	43	<PQL	Increasing	No Trend	Decreasing	X		Increasing CD <MCL, TR values; Zn <<MCL downgradient
BH-GG-GW-0007	Upland	Source	8	<PQL	No Trend	No Trend	No Trend	X		No trend with low COV in source area
BH-GG-GW-0008	Upland	Downgradient	8	No Trend	<PQL	<PQL	Increasing	X		Increasing Zn downgradient << MCL
BH-ILF-GW-0001	Upland	Downgradient	3	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-SCA-GW-0001	Upper	Upgradient	29	<PQL	No Trend	ND	No Trend	X		Primarily ND, TR or <<MCL upgradient
BH-SCA-GW-0002	Upper	Source	38	No Trend	Increasing	No Trend	Increasing		X	Increasing CD > MCL
BH-SCA-GW-0005	Upper	Source	40	<PQL	Decreasing	<PQL	Decreasing		X	Deceasing CD in source area > MCL
BH-SCA-GW-0006	Upper	Source	41	<PQL	Decreasing	Decreasing	Decreasing		X	Decreasing COCs in source area > MCLs
BH-SCA-GW-0007	Upper	Downgradient	27	No Trend	<PQL	No Trend	Decreasing	X		As and Pb primarily ND or TR. Decreasing/No Trend downgradient
BH-SF-E-0001	Single Unconfined	Upgradient	8	<PQL	No Trend	<PQL	No Trend	X		CD << MCL; Zn low COV; No Trend or < PQL upgradient
BH-SF-E-0002	Single Unconfined	Upgradient	8	<PQL	<PQL	<PQL	No Trend	X		Zn << MCL; No Trend or <PQL upgradient
BH-SF-E-0003	Single Unconfined	Upgradient	8	<PQL	No Trend	<PQL	No Trend	X		CD << MCL; Zn low COV; No Trend or < PQL upgradient
BH-SF-E-0101	Single Unconfined	Source	20	<PQL	No Trend	No Trend	No Trend	X		COCs low COVs; No Trend in source area
BH-SF-E-0201	Single Unconfined	Source	20	<PQL	Decreasing	<PQL	Decreasing		X	Decreasing COCs in source area > MCLs
BH-SF-E-0301-U	Upper	Source	22	No Trend	No Trend	No Trend	No Trend	X		COCs low COVs; No Trend in source area
BH-SF-E-0302-L	Lower	Downgradient	19	<PQL	No Trend	No Trend	Decreasing	X		One detect of Pb << MCL; decreasing or no trend (low COV) downgradient
BH-SF-E-0305-U	Upper	Source	7	<PQL	No Trend	Decreasing	No Trend	X		Most recent Pb ND; low COV no trend in source area
BH-SF-E-0306-L	Lower	Downgradient	8	<PQL	No Trend	<PQL	No Trend	X		No trend with low COV downgradient
BH-SF-E-0309-U	Upper	Source	6	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-SF-E-0310-L	Lower	Downgradient	6	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-SF-E-0311-U	Upper	Downgradient	8	<PQL	<PQL	<PQL	No Trend	X		No trend with low COV downgradient
BH-SF-E-0314-U	Upper	Source	20	<PQL	No Trend	No Trend	No Trend	X		Recent NDs Pb; No trend with low COV in source area
BH-SF-E-0315-U	Upper	Source	18	<PQL	No Trend	No Trend	Decreasing	X		Zn << MCL; no trend/decreasing in source area
BH-SF-E-0316-U	Upper	Source	9	<PQL	Decreasing	<PQL	No Trend		X	Decreasing CD around MCL; No trend with low COV in source area.
BH-SF-E-0317-U	Upper	Source	22	<PQL	No Trend	<PQL	No Trend		X	No Trend in source area (high variation)
BH-SF-E-0318-U	Upper	Source	9	<PQL	Decreasing	No Trend	Decreasing		X	Decreasing CD in source area > MCL
BH-SF-E-0320-U	Upper	Source	20	No Trend	Decreasing	No Trend	Decreasing		X	Decreasing COCs in source area > MCL
BH-SF-E-0321-U	Upper	Source	22	No Trend	No Trend	<PQL	Increasing		X	Increasing Zn in source area >MCL
BH-SF-E-0322-U	Upper	Source	7	No Trend	Decreasing	Decreasing	Decreasing		X	Decreasing COCs in source area > MCL
BH-SF-E-0402-U	Upper	Source	22	Prob. Decreasing	Prob. Increasing	<PQL	Prob. Increasing		X	Probably increasing COCs in source area > MCL
BH-SF-E-0403-U	Upper	Source	22	No Trend	Increasing	<PQL	No Trend		X	Increasing Cd in source area around MCL
BH-SF-E-0407-U	Upper	Source	7	Prob. Decreasing	No Trend	Decreasing	Decreasing		X	Decreasing COCs in source area > MCL
BH-SF-E-0408-U	Upper	Source	4	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-SF-E-0409-U	Upper	Source	9	Decreasing	No Trend	No Trend	No Trend		X	Decreasing As in source area >MCL
BH-SF-E-0410-U	Upper	Source	33	No Trend	Decreasing	<PQL	Decreasing		X	Decreasing COCs in source area > MCL
BH-SF-E-0423-U	Upper	Source	21	Prob. Increasing	No Trend	<PQL	Decreasing		X	Probably increasing As > MCL in source area
BH-SF-E-0424-L	Lower	Downgradient	8	<PQL	No Trend	<PQL	No Trend	X		CD < MCL; Zn No Trend low COV downgradient
BH-SF-E-0425-U	Upper	Source	7	No Trend	No Trend	No Trend	No Trend	X		Pb < MCL; no trend in source area
BH-SF-E-0426-L	Lower	Downgradient	8	<PQL	No Trend	<PQL	No Trend	X		No trend with low COV downgradient
BH-SF-E-0427-U	Upper	Source	35	No Trend	Decreasing	Decreasing	No Trend		X	Decreasing Cd trend in source area >MCL
BH-SF-E-0428-L	Lower	Downgradient	4	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-SF-E-0429-U	Upper	Source	44	No Trend	Decreasing	No Trend	Decreasing		X	Increasing As > MCL in source area
BH-SF-E-0501-U	Upper	Source	43	Prob. Increasing	Decreasing	No Trend	Decreasing		X	Decreasing Zn and Cd >MCL in source area
BH-SF-E-0502-U	Upper	Source	22	<PQL	Decreasing	<PQL	Prob. Decreasing		X	Decreasing COCs in source area < MCL
BH-SF-E-0503-U	Upper	Source	17	No Trend	No Trend	<PQL	Decreasing		X	Decreasing Zn in source area >MCL
BH-SF-E-0504-U	Upper	Source	17	No Trend	Decreasing	<PQL	Decreasing		X	Decreasing COCs in source area > MCLs
BH-SF-W-0001-U	Upper	Source	8	No Trend	Prob. Decreasing	<PQL	Decreasing		X	Decreasing COCs in source area > MCLs
BH-SF-W-0002-L	Lower	Downgradient	8	<PQL	Decreasing	<PQL	No Trend	X		Decreasing (Cd recent ND) or No Trend low COVs downgradient
BH-SF-W-0003-U	Upper	Source	8	<PQL	No Trend	<PQL	No Trend	X		No trend with low COV in source area
BH-SF-W-0004-L	Lower	Downgradient	8	<PQL	Decreasing	<PQL	Prob. Decreasing	X		Decreasing trends downgradient (Zn >MCL)

TABLE 5.1 (Continued)
TEMPORAL TREND ANALYSIS OF GROUNDWATER MONITORING RESULTS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydraulic Unit	Relative Location	Number of Sampling Results	Dissolved Arsenic	Dissolved Cadmium	Dissolved Lead	Dissolved Zinc	Exclude/ Reduce	Retain	Rationale
BH-SF-W-0005-U	Upper	Source	20	<PQL	Decreasing	<PQL	Decreasing	X		Decreasing trends in source area (COCs < MCLs)
BH-SF-W-0006-L	Lower	Downgradient	8	No Trend	<PQL	<PQL	No Trend	X		<PQL or No Trend As low COV, Zn << MCL downgradient
BH-SF-W-0007-U	Upper	Source	18	No Trend	No Trend	ND	No Trend	X		No Trend in source area all COCs recent NDs
BH-SF-W-0008-U	Upper	Source	21	No Trend	No Trend	<PQL	Decreasing		X	As recent NDs, Cd low COV, Zn < MCLs in source area
BH-SF-W-0009-U	Upper	Source	22	<PQL	No Trend	No Trend	No Trend	X		Cd, Zn low COVs, Pb recent NDs; No Trend in source area
BH-SF-W-0010-U	Upper	Source	22	<PQL	Decreasing	<PQL	Decreasing		X	Decreasing COCs in source area > MCLs
BH-SF-W-0011-L	Lower	Downgradient	20	<PQL	No Trend	ND	Decreasing	X		Cd low COV, Decreasing or <PQL/ND downgradient
BH-SF-W-0018-U	Upper	Source	20	No Trend	No Trend	<PQL	Decreasing	X		Decreasing in source area; CD recent ND, ZN<<MCL
BH-SF-W-0019-U	Upper	Downgradient	20	<PQL	Prob. Decreasing	<PQL	Decreasing	X		As, Cd, Pb recent ND, Zn decreasing <MCL downgradient
BH-SF-W-0020-U	Upper	Downgradient	17	<PQL	<PQL	<PQL	No Trend	X		Zinc << MCL, No Trend/<PQL downgradient
BH-SF-W-0104-U	Upper	Source	19	<PQL	Decreasing	<PQL	Decreasing		X	Decreasing COCs in source area > MCLs
BH-SF-W-0111-U	Upper	Source	21	Prob. Increasing	No Trend	No Trend	No Trend		X	As increasing in source area >MCL
BH-SF-W-0118-U	Upper	Source	10	No Trend	No Trend	<PQL	No Trend		X	No Trend upgradient (As high COV, recent MCL exceedance)
BH-SF-W-0119-U	Upper	Source	10	Increasing	No Trend	ND	No Trend		X	As increasing in source area >MCL
BH-SF-W-0121-U	Upper	Downgradient	21	<PQL	No Trend	No Trend	No Trend	X		Cd and Pb recent NDs, Zn No Trend low COV downgradient
BH-SF-W-0122-L	Lower	Downgradient	18	<PQL	No Trend	ND	Decreasing	X		CD recent NDs; decreasing downgradient
BH-SF-W-0201-U	Upper	Source	8	<PQL	Prob. Decreasing	<PQL	No Trend	X		Cd recent NDs; Zn no trend low COV in source area
BH-SF-W-0202-L	Lower	Downgradient	8	ND	No Trend	<PQL	No Trend	X		Cd recent NDs; Zn no trend low COV downgradient
BH-SF-W-0203-U	Upper	Downgradient	16	No Trend	No Trend	<PQL	No Trend		X	Zn no trend high variation downgradient (<MCLs)
BH-SF-W-0204-U	Upper	Downgradient	7	<PQL	<PQL	<PQL	No Trend		X	Zn << MCL; <PQL or No Trend sentry well
BH-SF-W-0205-L	Lower	Downgradient	7	<PQL	No Trend	<PQL	No Trend		X	Zn << MCL; <PQL or No Trend sentry well

ND	= Constituent has not been detected during history of monitoring at inidcated well.
No Trend	= No statistically significant temporal trend in concentrations.
Increasing	= Statistically significant (>95% confidence) increasing trend in concentrations.
Probably Increasing	= Statistically significant (90-95% confidence) increasing trend in concentrations.
Decreasing	= Statistically significant (>95% confidence) decreasing trend in concentrations.
Probably Decreasing	= Statistically significant (90-95% confidence) decreasing trend in concentrations.
<6Meas	= Fewer than 6 measurements for COC.
(bold box)	Analytical results contain greater than 50% Non-detects



Legend

Cadmium Mann-Kendall

Trend Result

- Decreasing
- Increasing
- No Trend
- <PQL
- <4 Measurements

0 1,250 2,500 5,000 7,500 10,000 Feet

FIGURE 5.5

TEMPORAL TREND RESULTS FOR CADMIUM IN GROUNDWATER

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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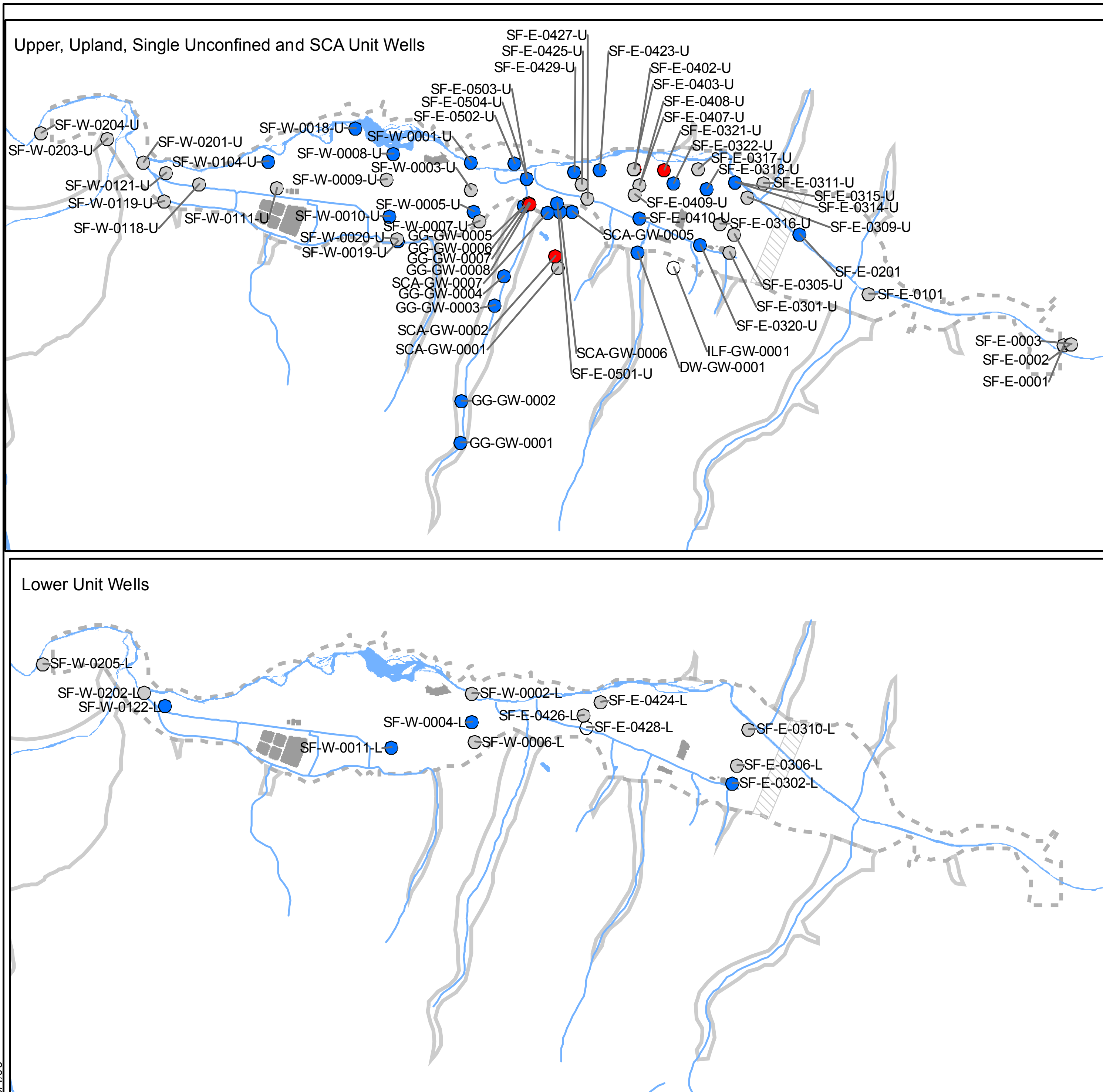

Legend

Zinc Mann-Kendall

Trend Result

- Decreasing
- Increasing
- No Trend
- <4 Measurements

0 2,500 5,000 7,500 10,000 Feet

FIGURE 5.6

TEMPORAL TREND RESULTS FOR ZINC IN GROUNDWATER

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

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temporal information is described in the "Rationale" column of Table 5.1, and a flow chart of the decision logic applied to the temporal trend analysis results is presented on Figure 5.4. Trend results for zinc and cadmium were given more weight than those for the other COCs, given their relatively higher impact; however, the most conservative trend was used in all cases (*e.g.*, if an arsenic or lead trend resulted in a recommendation to retain a well, that well would be recommended for retention.)

Wells that have decreasing trends in a source area in which concentrations are above MCLs (*e.g.*, BH-GG-GW-0002, BH-SF-E-0320-U, and BH-SF-W-0005-U) are valuable because they provide information on the effectiveness of the remedial actions performed to date and the effects of significant hydrologic (i.e., precipitation and snowmelt) events and are thus recommended for retention in the monitoring system. Conversely, wells located downgradient of the source area that have either decreasing concentrations or source area wells with a recent history of concentrations significantly below MCLs (*e.g.*, BH-SF-W-0004-L, BH-SF-W-0122-L, and BH-SF-W-0201-U) will provide limited valuable temporal information in the future and are recommended for exclusion or reduced sampling. Wells with increasing COC concentration trends in the source area (*e.g.*, BH-SF-E-0321-U, BH-SF-E-0402-U, and BH-SF-W-0118-U) provide valuable information about the effectiveness of the remediation system and the effects of significant hydrologic events and areas that should potentially be targeted for Phase II remediation, and should be retained. Wells with stable (low coefficient of variation), 'no trend' results (*e.g.*, BH-SF-E-0426-L, BH-SF-W-0121-U, and BH-SF-E-0425-U) were recommended for exclusion or monitoring reduction because continued frequent sampling would not likely yield new information, while wells with highly variable COC concentrations (*e.g.*, wells BH-SF-W-0118-U, BH-SF-W-0203-U) were recommended for retention.

Table 5.1 summarizes recommendations to retain 36 and exclude or reduce the frequency for 36 of the 72 wells analyzed in the temporal evaluation (not including the well with fewer than six measurements). The recommendations provided in Table 5.1 are based on the evaluation of ***temporal statistical results only***, and must be used in conjunction with the results of the qualitative and spatial evaluations to generate final recommendations regarding retention of monitoring points in the LTM program, and the frequency of monitoring at particular locations in OU2.

5.3 TEMPORAL EVALUATION RESULTS FOR SURFACE WATER STATIONS

Surface water Mann-Kendall trend results are shown in Table 5.2 for both total and dissolved COC concentrations. Limited data (six or fewer measurements) were available for surface water stations BH-IG-0001, BH-JC-0001, BH-PG-001, BH-RR-0001 and SF-270. Only dissolved COCs results were available for BH-JC-0001. Although the temporal trend decision rationale shown on Figure 5.4 was developed for application to a groundwater monitoring network, in this case it was used for the surface water stations by considering each station as a "downgradient" well, since the stations are mostly located at the mouths of the tributaries feeding into Bunker Creek or the SFCDR. As a result, several stations with increasing concentrations above AWQCs were recommended for retention (*e.g.,* BH-CS-0001, and BH-DW-0001), while those with decreasing concentrations and/or low temporal variation and no trends were recommended for

TABLE 5.2
TEMPORAL TREND ANALYSIS OF SURFACE WATER MONITORING RESULTS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Surface Water Station Name	Sampling Results	Arsenic	Dissolved Arsenic	Cadmium	Dissolved Cadmium	Lead	Dissolved Lead	Zinc	Dissolved Zinc	Exclude/ Reduce	Retain	Rationale
BH-BC-0001	39	Decreasing	Decreasing	No Trend	No Trend	Decreasing	Decreasing	Probably Decreasing	No Trend	X		Decreasing or low COV no trend
BH-CS-0001	35	No Trend	No Trend	Increasing	Increasing	Probably Increasing	Increasing	No Trend	No Trend		X	Increasing COCs > standards
BH-DW-0001	16	No Trend	Increasing	No Trend	Increasing	Decreasing	No Trend	No Trend	No Trend		X	Increasing dissolved cadmium above standard
BH-GC-0001	14	No Trend	Increasing	No Trend	Increasing	No Trend	Increasing	No Trend	No Trend		X	Highly variable cadmium and arsenic; Increasing dissolved arsenic > standard
BH-GG-0001	18	Increasing	Increasing	No Trend	No Trend	Probably Increasing	Probably Increasing	No Trend	No Trend		X	Increasing dissolved cadmium and arsenic > standards
BH-HC-0001	7	<PQL	No Trend	No Trend	No Trend	No Trend	Probably Decreasing	No Trend	No Trend	X		Decreasing or low COV no trend
BH-IG-0001	2	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-JC-0001	4	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-MC-0001	8	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	Probably Decreasing	No Trend	X		High number of ND or low COV no trend
BH-MC-0002	40	No Trend	Decreasing	Decreasing	Decreasing	Increasing	Increasing	Decreasing	Decreasing		X	Increasing lead and dissolved lead > standards
BH-MG-0001	14	No Trend	No Trend	No Trend	No Trend	No Trend	Increasing	No Trend	No Trend		X	Increasing dissolved lead > standards, other COCs low COV no trend
BH-PG-0001	3	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-RR-0001	1	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas	<6meas			No recommendation. Fewer than 6 measurements.
BH-WP-0001	11	<PQL	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	No Trend	X		High number of ND or low COV no trend
PC-339	13	No Trend	ND	<PQL	<PQL	<PQL	<PQL	No Trend	No Trend	X		ND or <PQL; Zinc << standards
SF-268	13	No Trend	No Trend	No Trend	No Trend	Decreasing	No Trend	No Trend	No Trend	X		High number of ND or low COV no trend
SF-270	1	<4meas	<4meas	<4meas	<4meas	<4meas	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
SF-271	13	No Trend	No Trend	No Trend	No Trend	Probably Decreasing	No Trend	No Trend	No Trend	X		High number of ND or low COV no trend

ND	= Constituent has not been detected during history of monitoring at inidcated well.
No Trend	= No statistically significant temporal trend in concentrations.
Increasing	= Statistically significant (>95% confidence) increasing trend in concentrations.
Probably Increasin	= Statistically significant (90-95% confidence) increasing trend in concentrations.
Decreasing	= Statistically significant (>95% confidence) decreasing trend in concentrations.
robably Decreasin	= Statistically significant (90-95% confidence) decreasing trend in concentrations.
<6Meas	= Fewer than 6 measurements for COC.
	Analytical results contain greater than 50% Non-detects

exclusion or reduction from the monitoring program (*e.g.*, BH-WP-0001 and BH-BC-0001). As with the groundwater well temporal trend results, the recommendations in Table 5.2 are based on the evaluation of ***temporal statistical results only***, and must be used in conjunction with the results of the qualitative evaluation to generate final recommendations regarding retention and sampling frequency of surface water monitoring stations in the LTM program.

SECTION 6

SPATIAL STATISTICAL EVALUATION

Spatial statistical techniques also can be applied to the design and evaluation of groundwater monitoring programs to assess the quality of information generated during monitoring and to evaluate monitoring networks. Geostatistics, or the theory of regionalized variables (Clark, 1987; Rock, 1988; American Society of Civil Engineers Task Committee on Geostatistical Techniques in Hydrology, 1990a and 1990b), is concerned with variables having values dependent on location, and which are continuous in space but vary in a manner too complex for simple mathematical description. Geostatistics is based on the premise that the differences in values of a spatial variable depend only on the distances between sampling locations, and the relative orientations of sampling locations – that is, the values of a variable (*e.g.*, chemical concentration) measured at two locations that are spatially close together – will be more similar than values of that variable measured at two locations that are far apart.

6.1 GEOSTATISTICAL METHODS FOR EVALUATING MONITORING networks

Ideally, application of geostatistical methods to the results of the groundwater monitoring program at OU2 could be used to estimate COC concentrations at every point within the distribution of dissolved contaminants, and also could be used to generate estimates of the “error,” or uncertainty, associated with each estimated concentration value. Thus, the monitoring program could be optimized by using available information to identify those areas having the greatest uncertainty associated with the estimated plume extent and configuration. Conversely, sampling points could be successively eliminated from simulations, and the resulting uncertainty examined, to evaluate if significant loss of information (represented by increasing error or uncertainty in estimated chemical concentrations) occurs as the number of sampling locations is reduced. Repeated application of geostatistical estimating techniques, using tentatively identified sampling locations, then could be used to generate a sampling program that would provide an acceptable level of uncertainty regarding the distribution of COCs with the minimum possible number of samples collected. Furthermore, application of geostatistical methods can provide unbiased representations of the distribution of COCs at different locations in the subsurface, enabling the extent of COCs to be evaluated more precisely.

Fundamental to geostatistics is the concept of semivariance [$\gamma(h)$], which is a measure of the spatial dependence between sample variables (*e.g.*, chemical concentrations) in a specified direction. Semivariance is defined for a constant spacing between samples (h) by:

$$\gamma(h) = \frac{1}{2n} \sum [g(x) - g(x + h)]^2 \qquad \textit{Equation 6-1}$$

Where:

$\gamma(h)$ = semivariance calculated for all samples at a distance h from each other;

$g(x)$ = value of the variable in sample at location x;

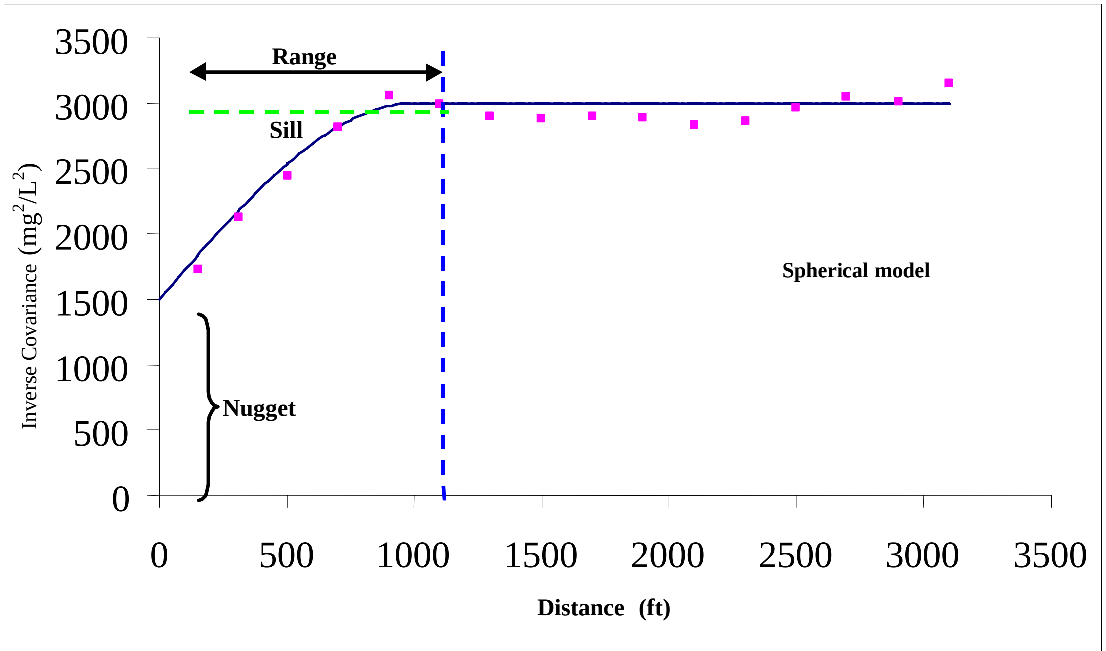
$g(x + h)$ = value of the variable in sample at a distance h from sample at location x; and

n = number of samples in which the variable has been determined.

Semivariograms (plots of $\gamma(h)$ versus h) are a means of depicting graphically the range of distances over which, and the degree to which, sample values at a given point are related to sample values at adjacent, or nearby, points, and conversely, indicate how close together sample points must be for a value determined at one point to be useful in predicting unknown values at other points. For $h = 0$, for example, a sample is being compared with itself, so normally $\gamma(0) = 0$ (the semivariance at a spacing of zero, is zero), except where a so-called nugget effect is present (Figure 6.1), which implies that sample values are highly variable at distances less than the sampling interval. Analytical variability and sampling error can contribute to the nugget. As the distance between samples increases, sample values become less and less closely related, and the semivariance therefore increases, until a “sill” is eventually reached, where $\gamma(h)$ equals the overall variance (*i.e.*, the variance around the average value). The sill is reached at a sample spacing called the “range of influence,” beyond which sample values are not related. Only values between points at spacings less than the range of influence can be predicted; but within that distance, the semivariogram provides the proper weightings, which apply to sample values separated by different distances.

When a semivariogram is calculated for a variable over an area (*e.g.*, concentrations of lead in OU2 groundwater), an irregular spread of points across the semivariogram plot is the usual result (Rock, 1988). One of the most subjective tasks of geostatistical analysis is to identify a continuous, theoretical semivariogram model that most closely follows the real data. Fitting a theoretical model to calculated semivariance points is accomplished by trial-and-error, rather than by a formal statistical procedure (Clark, 1987; Rock, 1988). If a "good" model fit results, then $\gamma(h)$ (the semivariance) can be confidently estimated for any value of h, and not only at the sampled points.

FIGURE 6.1
IDEALIZED SEMIVARIOGRAM MODEL
LONG-TERM MONITORING NETWORK OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX



6.2 SPATIAL EVALUATION OF THE MONITORING NETWORK AT OU2

Cadmium and zinc concentrations were used as the indicator chemicals for the spatial evaluation of the groundwater monitoring network in the OU2 upper HU, and zinc was used for the lower HU. These COCs were selected because of their relative prevalence and spatial distribution in the upper and lower HUs in groundwater at OU2. The kriging evaluation examines a two-dimensional spatial "snapshot" of the data. Therefore, the most recent (typically 2004) analytical data available at the start of this LTMO evaluation were used in the kriging evaluation. Two separate kriging analyses were conducted for the 44 upper HU wells (cadmium and zinc) and one kriging analysis was conducted for the 14 lower HU wells (zinc). Note that single unconfined well BH-SF-E-0201 was included as a lower aquifer well in this analysis because it is screened at a similar depth to the other lower aquifer wells. The spatial evaluation has a lower limit of 11 wells; thus, the upland and single unconfined aquifer well groups did not have adequate spatial coverage for analysis. A spatial evaluation for the surface water points was not appropriate because each monitoring station measures water quality at the mouth of a separate tributary in the drainage system, and thus the points are not spatially correlated.

The commercially available geostatistical software package Geostatistical Analyst™ (an extension to the ArcView® geographic information system [GIS] software package) (Environmental Systems Research Institute, Inc. [ESRI], 2001) was used to develop semivariogram models depicting the spatial variation in the upper HU for cadmium and zinc and in the lower HU for zinc concentrations in groundwater.

As semivariogram models were calculated for each scenario (Equation 6-1), considerable scatter of the data was apparent during fitting of the models. Several data transformations (including a log transformation) were attempted to obtain a representative semivariogram model. Ultimately, the concentration data were transformed to "rank statistics," in which, for example, the 14 wells in the lower HU were ranked from 1 (lowest concentration) to 14 (highest concentration) according to their most recent zinc concentration. Tie values were assigned the median rank of the set of ranked values; for example, if five wells had non-detected concentrations, they would each be ranked "3", the median of the set of ranks: [1,2,3,4,5]. Transformations of this type can be less sensitive to outliers, skewed distributions, or clustered data than semivariograms based on raw concentration values, and thus may enable recognition and description of the underlying spatial structure of the data in cases where ordinary data are too "noisy."

The rank statistics were used to develop semivariograms that most accurately modeled the spatial distribution of the data in the three scenarios. Anisotropy was incorporated into the models to adjust for the directional influence of groundwater flow to the west. Note that the minor ranges used in these variogram models are not intended to be considered for well spacing between the transects. The parameters for best-fit semivariograms for the three spatial evaluations are listed in Table 6.1.

TABLE 6.1
BEST-FIT SEMIVARIOGRAM MODEL PARAMETERS
LONG-TERM MONITORING NETWORK OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

Parameter	Upper HU Zinc	Upper HU Cadmium	Lower HU Zinc
Model	Spherical	Circular	Exponential
Range (ft)	5500	8500	5500
Sill	194	115	18
Nugget	41	105	1.1
Minor Range (ft)	3500	3500	3000
Direction (°)	272	272	272

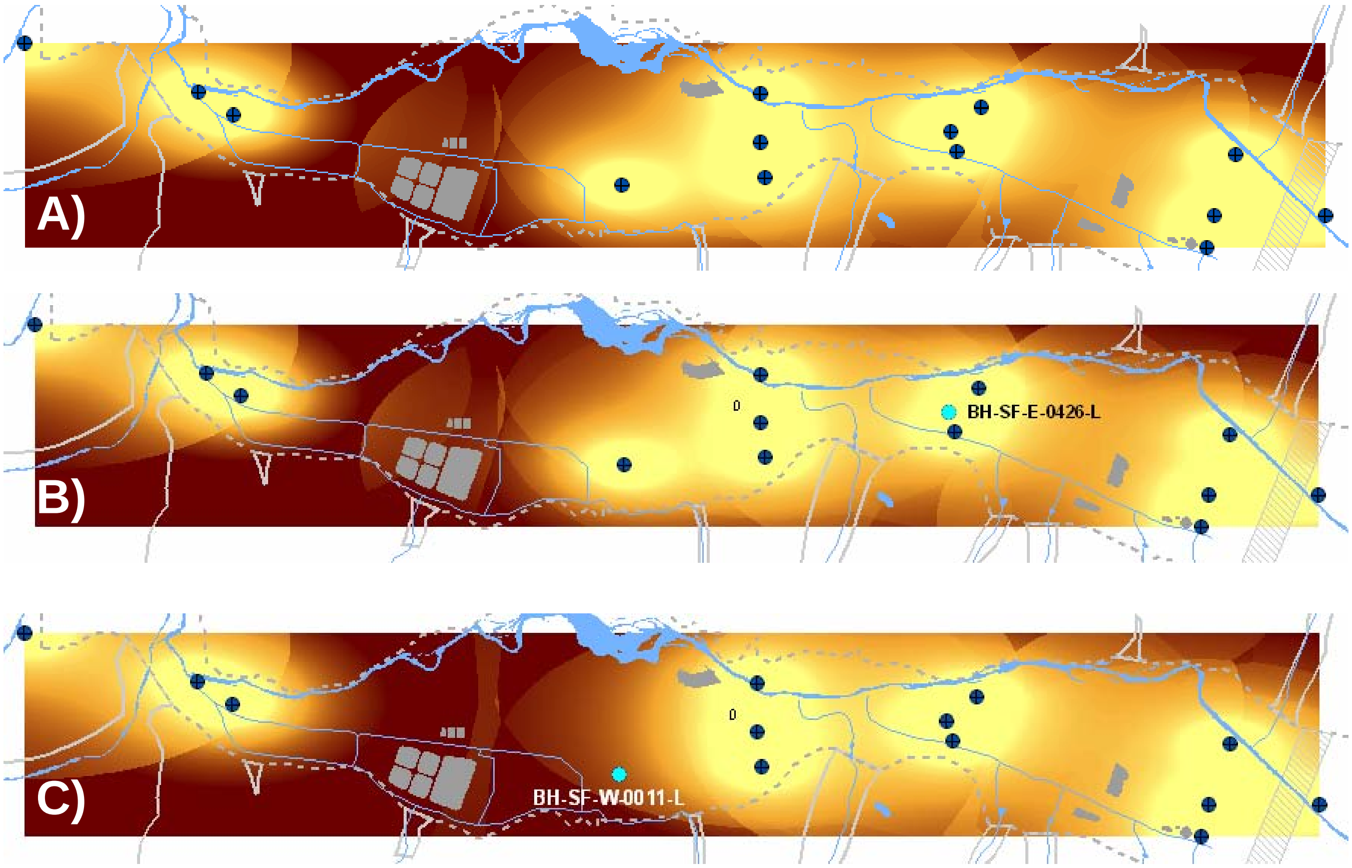
After the semivariogram models were developed, they were used in the kriging system implemented by the Geostatistical Analyst™ software package (ESRI, 2001) to develop two-dimensional kriging realizations (estimates of the spatial distribution of zinc or cadmium in groundwater at OU2), and to calculate the associated kriging prediction standard errors. The median kriging standard deviation was obtained from the standard errors calculated using the entire monitoring network for each scenario (*e.g.*, the 14 wells in the lower HU). Next, each of the wells was sequentially removed from the network, and for each resulting well network configuration, a kriging realization was completed using the COC concentration rankings from the remaining wells. The "missing-well" monitoring network realizations were used to calculate prediction standard errors, and the median kriging standard deviations were obtained for each "missing-well" realization and compared with the median kriging standard deviation for the "base-case" realization (obtained using the complete monitoring network), as a means of evaluating the amount of information loss (as indicated by increases in kriging error) resulting from the use of fewer monitoring points.

Figure 6.2 illustrates an example of the spatial-evaluation procedure by showing kriging prediction standard-error maps for three kriging realizations for the lower HU wells. Note that maps A through C in Figure 6.2 are not a representation of COC distribution, but **standard-error,** which show the error associated with the kriging predicted distribution. Each map shows the predicted standard error associated with a given group of wells based on the semivariogram parameters discussed above. Lighter colors represent areas with lower spatial uncertainty, and darker colors represent areas with higher uncertainty; regions in the vicinity of wells (*i.e.*, data points) have the lowest associated uncertainty. Map A on Figure 6.2 shows the predicted standard error map for the "base-case" realization in which all 14 wells are included. Map B shows the realization in which well BH-SF-E-0426-L was removed from the monitoring network, and Map C shows the realization in which well BH-SF-W-011-L was removed. Figure 6.2 shows that when a well is removed from the network, the predicted standard error in the vicinity of the missing well increases (as indicated by a darkening of the shading in the vicinity of that well). If a "removed" (missing) well is in an area with several other wells (*e.g.*, well BH-SF-E-0426-L; Map B on Figure 6.2), the predicted standard error may not increase as much as if a well (*e.g.*, BH-SF-W-0011-L; Map C) is removed from an area with fewer surrounding wells.

Based on the kriging evaluation, each well received a relative value of spatial information "test statistic" calculated from the ratio of the median "missing well" error to median "basecase" error. If removal of a particular well from the monitoring network caused very little change in the resulting median kriging standard deviation, the test statistic equals one, and that well was regarded as contributing only a limited amount of information to the LTM program. Likewise, if removal of a well from the monitoring network produced larger increases in the kriging standard deviation (more than 1 percent), this was regarded as an indication that the well contributes a relatively greater amount of information and is relatively more important to the monitoring network. At the conclusion of the kriging realizations, each well was ranked from 1 (providing the least information) to the number of wells included in the zone analysis (providing the most information), based on the amount of information (as measured by changes in median kriging standard deviation) the well contributed toward describing the spatial distribution of COCs, as shown in Tables 6.2 to 6.4. Wells providing the least amount of information represent possible candidates for exclusion from the monitoring network at OU2.

6.3 SPATIAL STATISTICAL EVALUATION RESULTS

Figures 6.3 through 6.5 and Tables 6.2 to 6.4 present the test statistics and associated rankings of the evaluated subsets of monitoring locations (zinc in the upper HU, cadmium in the upper HU, and zinc in the lower HU, respectively). The wells are ranked from least to most spatially relevant based on the relative value of the associated recent COC information provided by each well, as calculated based on the kriging realizations. Examination of these results indicate that monitoring wells in close proximity to several



A) Basecase (all wells)
B) Missing well BH-SF-E-0426-L: relative small change in spatial uncertainty
C) Missing well BH-SF-W-011-L: relative large change in spatial uncertainty

Legend

Well missing from kriging realization

Predicted Standard Error Map

Less spatial uncertainty

Greater spatial uncertainty

FIGURE 6.2

IMPACT OF MISSING WELLS ON PREDICTED STANDARD ERROR

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

TABLE 6.2

RESULTS OF GEOSTATISTICAL EVALUATION RANKING OF WELLS BY RELATIVE VALUE OF ZINC IN THE UPPER HU

LONG-TERM MONITORING OPTIMIZATION

BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name [a]	Kriging Metric	Kriging Ranking [b]	Exclude	Retain
BH-SF-E-0407-U	0.99992	1.5[c]	X	
BH-SF-E-0408-U	0.99992	1.5	X	
BH-SF-E-0425-U	0.99994	3	X	
BH-SF-E-0503-U	0.99997	4.5	X	
BH-SF-E-0504-U	0.99997	4.5	X	
BH-SF-E-0501-U	0.99998	6	X	
BH-SF-E-0318-U	0.99999	7.5	X	
BH-SF-E-0322-U	0.99999	7.5	X	
BH-SF-E-0409-U	1.00000	9	X	
BH-SF-E-0427-U	1.00012	10	X	
BH-SF-E-0314-U	1.00016	11.5	X	
BH-SF-E-0315-U	1.00016	11.5	X	
BH-SF-E-0316-U	1.00017	13	X	
BH-SF-E-0402-U	1.00035	14.5	X	
BH-SF-E-0403-U	1.00035	14.5	X	
BH-SF-W-0003-U	1.00054	16	--[d]	--
BH-SF-W-0005-U	1.00084	17	--	--
BH-SF-E-0309-U	1.00086	18	--	--
BH-SF-E-0321-U	1.00121	19	--	--
BH-SF-E-0423-U	1.00129	20	--	--
BH-SF-W-0020-U	1.00155	21	--	--
BH-SF-E-0311-U	1.00156	22	--	--
BH-SF-E-0429-U	1.00172	23	--	--
BH-SF-E-0305-U	1.00177	24	--	--
BH-SF-W-0012-U	1.00209	25	--	--
BH-SF-W-0121-U	1.00233	26	--	--
BH-SF-E-0317-U	1.00313	27	--	--
BH-SF-E-0502-U	1.00371	28	--	--
BH-SF-E-0301-U	1.00445	29	--	--
BH-SF-E-0320-U	1.00621	30		X
BH-SF-W-0007-U	1.00634	31		X
BH-SF-W-0201-U	1.00642	32		X
BH-SF-W-0204-U	1.00703	33		X
BH-SF-W-0119-U	1.00900	34		X
BH-SF-W-0010-U	1.00961	35		X
BH-SF-W-0001-U	1.00966	36		X
BH-SF-E-0410-U	1.01043	37		X
BH-SF-W-0018-U	1.01092	38		X
BH-SF-W-0118-U	1.01270	39		X
BH-SF-W-0008-U	1.01285	40		X
BH-SF-W-0009-U	1.01360	41		X
BH-SF-W-0203-U	1.01385	42		X
BH-SF-W-0104-U	1.01443	43		X
BH-SF-W-0111-U	1.01444	44		X

[a] Well set includes upper aquifer wells designated in Table 3.1.
[b] 1= least relative amount of information; 44= most relative amount of information
[c] Tie values receive the median ranking of the set.
[d] Well in the "intermediate" range; received no recommendation for excludsion or retention (see Section 6.2).

TABLE 6.3

RESULTS OF GEOSTATISTICAL EVALUATION RANKING OF WELLS BY RELATIVE VALUE OF CADMIUM IN THE UPPER HU

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name [a]	Kriging Metric	Kriging Ranking [b]	Exclude	Retain
BH-SF-E-0407-U	0.99996	1.5[c]	X	
BH-SF-E-0408-U	0.99996	1.5	X	
BH-SF-E-0427-U	0.99998	3.5	X	
BH-SF-E-0501-U	0.99998	3.5	X	
BH-SF-E-0318-U	0.99999	5	X	
BH-SF-E-0322-U	1.00000	6.5	X	
BH-SF-E-0425-U	1.00000	6.5	X	
BH-SF-E-0409-U	1.00001	8	X	
BH-SF-E-0503-U	1.00007	9.5	X	
BH-SF-E-0504-U	1.00007	9.5	X	
BH-SF-E-0314-U	1.00013	11.5	X	
BH-SF-E-0315-U	1.00013	11.5	X	
BH-SF-W-0003-U	1.00017	13	X	
BH-SF-E-0309-U	1.00019	15	X	
BH-SF-E-0402-U	1.00019	15	X	
BH-SF-E-0403-U	1.00019	15	X	
BH-SF-E-0321-U	1.00026	17	--[d]	--
BH-SF-E-0423-U	1.00028	18.5	--	--
BH-SF-E-0429-U	1.00028	18.5	--	--
BH-SF-W-0005-U	1.00029	20	--	--
BH-SF-E-0311-U	1.00033	21	--	--
BH-SF-E-0316-U	1.00044	22	--	--
BH-SF-E-0317-U	1.00050	23	--	--
BH-SF-E-0410-U	1.00085	24	--	--
BH-SF-E-0305-U	1.00091	25	--	--
BH-SF-W-0007-U	1.00095	26	--	--
BH-SF-E-0502-U	1.00098	27	--	--
BH-SF-E-0301-U	1.00166	28	--	--
BH-SF-W-0001-U	1.00170	29	--	--
BH-SF-E-0320-U	1.00175	30		X
BH-SF-W-0204-U	1.00180	31		X
BH-SF-W-0020-U	1.00205	32		X
BH-SF-W-0012-U	1.00207	33		X
BH-SF-W-0121-U	1.00209	34		X
BH-SF-W-0119-U	1.00251	35		X
BH-SF-W-0203-U	1.00265	36		X
BH-SF-W-0118-U	1.00293	37		X
BH-SF-W-0010-U	1.00360	38		X
BH-SF-W-0201-U	1.00373	39		X
BH-SF-W-0018-U	1.00384	40		X
BH-SF-W-0008-U	1.00548	41		X
BH-SF-W-0009-U	1.00633	42		X
BH-SF-W-0104-U	1.00763	43		X
BH-SF-W-0111-U	1.00774	44		X

[a] Well set includes upper aquifer wells designated in Table 3.1.
[b] 1= least relative amount of information; 44= most relative amount of information.
[c] Tie values receive the median ranking of the set.
[d] Well in the “intermediate” range; received no recommendation for excludsion or retention.
(see Section 6.2).

TABLE 6.4

RESULTS OF GEOSTATISTICAL EVALUATION RANKING OF WELLS BY RELATIVE VALUE OF ZINC IN THE LOWER HU

LONG-TERM MONITORING OPTIMIZATION

BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name [a/]	Kriging Metric	Kriging Ranking [b/]	Exclude	Retain
BH-SF-E-0426-L	0.99715	1	X	
BH-SF-E-0306-L	1.00072	2	X	
BH-SF-W-0004-L	1.00140	3	X	
BH-SF-E-0302-L	1.00183	4	X	
BH-SF-E-0201	1.00258	5	X	
BH-SF-E-0428-L	1.00520	6	--[c/]	--
BH-SF-W-0006-L	1.00947	7	--	--
BH-SF-E-0424-L	1.00954	8	--	--
BH-SF-W-0122-L	1.00986	9	--	--
BH-SF-W-0202-L	1.01029	10		X
BH-SF-W-0205-L	1.01660	11		X
BH-SF-W-0002-L	1.01831	12		X
BH-SF-E-0310-L	1.02064	13		X
BH-SF-W-0011-L	1.02835	14		X

[a/] Well set includes lower aquifer wells designated in Table 3.1,
and single unconfined aquifer well BH-SF-E-0201.

[b/] 1= least relative amount of information; 14= most relative amount of information.

[c/] Well in the “intermediate” range; received no recommendation for excludsion or retention.
(see Section 6.2).

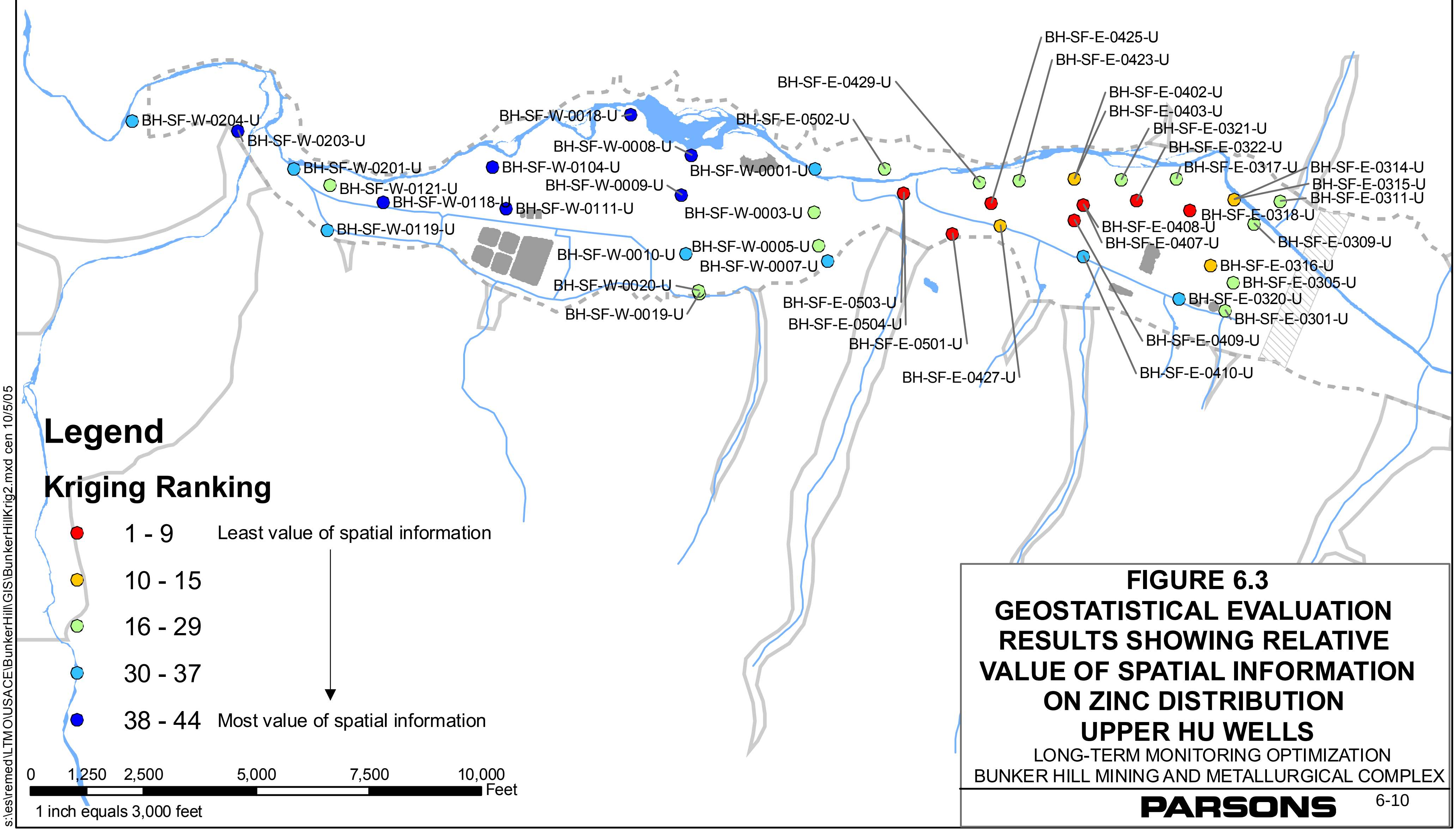


FIGURE 6.3
GEOSTATISTICAL EVALUATION RESULTS SHOWING RELATIVE VALUE OF SPATIAL INFORMATION ON ZINC DISTRIBUTION UPPER HU WELLS

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

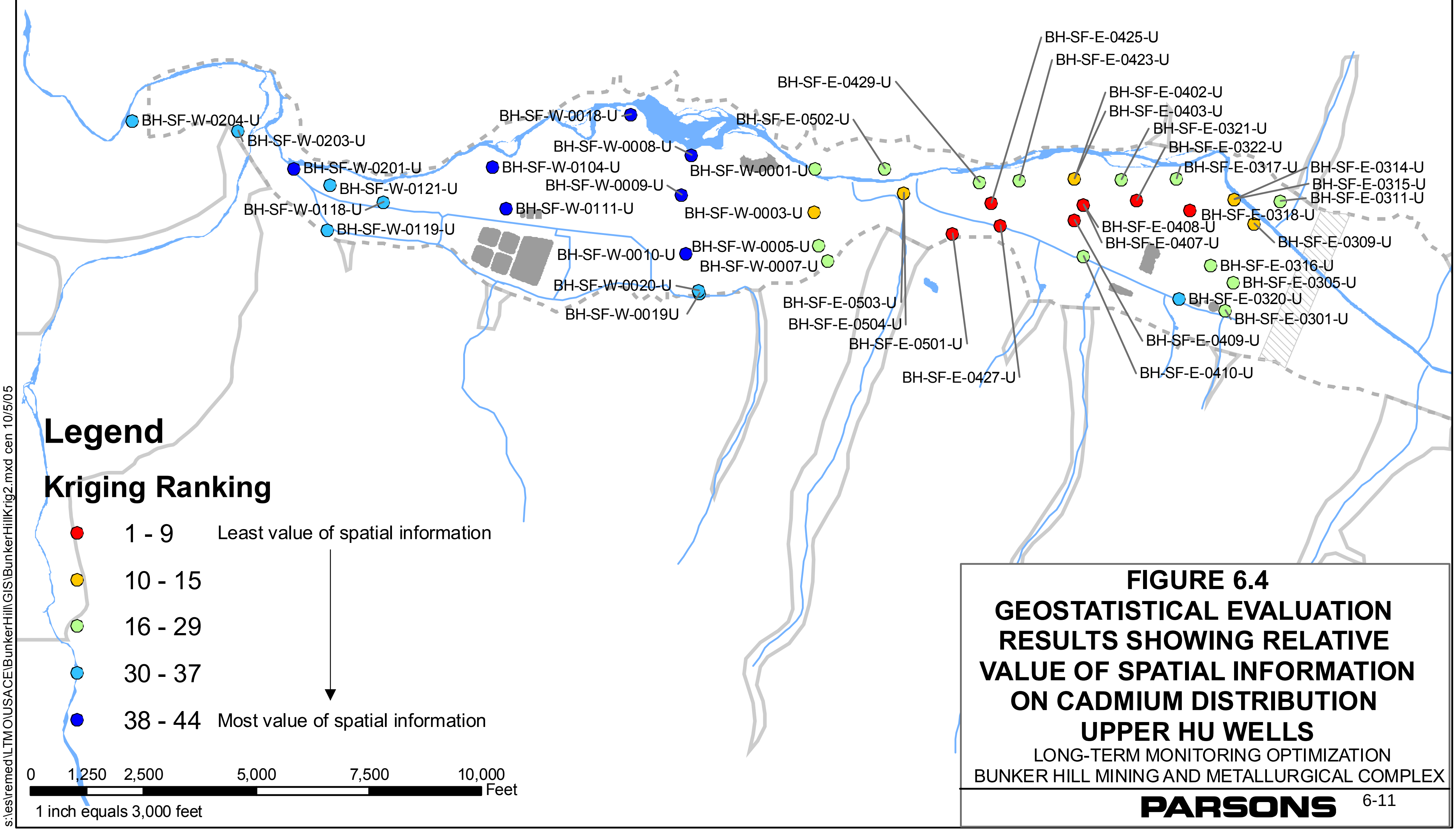


FIGURE 6.4
GEOSTATISTICAL EVALUATION RESULTS SHOWING RELATIVE VALUE OF SPATIAL INFORMATION ON CADMIUM DISTRIBUTION UPPER HU WELLS

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

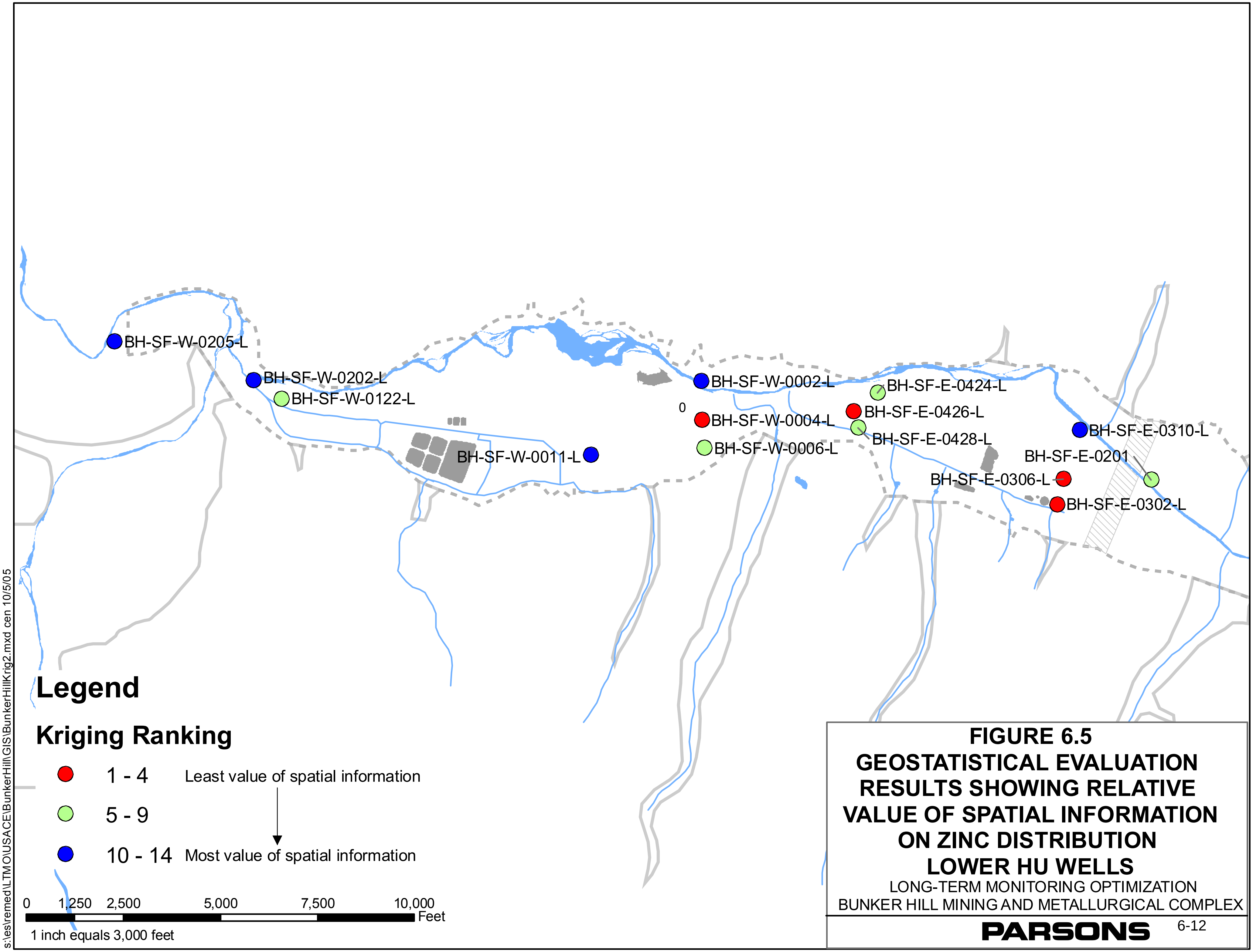


FIGURE 6.5
GEOSTATISTICAL EVALUATION RESULTS SHOWING RELATIVE VALUE OF SPATIAL INFORMATION ON ZINC DISTRIBUTION LOWER HU WELLS

LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

other monitoring wells (*e.g.*, red color coding on Figures 6.3 to 6.5) generally provide relatively lesser amounts of information than do wells at greater distances from other wells or wells located in areas having limited numbers of monitoring points (*e.g.*, blue color coding on Figures 6.3 to 6.5). This is intuitively obvious, but the analysis allows the most valuable and least valuable wells to be identified quantitatively. For example, Table 6.2 identifies the wells ranked below 15 that provide the relative least amount of information, and the wells ranked at or above 30 that provide the greatest amount of relative information regarding the occurrence and distribution of zinc in groundwater among those wells in the upper HU. The lowest-ranked wells are potential candidates for exclusion from the OU2 groundwater monitoring program, and the highest-ranked wells are candidates for retention in the monitoring program; intermediate-ranked wells receive no recommendation for removal or retention in the monitoring program based on the spatial analysis. Note that these recommendations are based only on the statistical evaluation and must be used in conjunction with the results of the qualitative and temporal evaluations to generate final recommendations regarding retention and sampling frequency of monitoring stations in the LTM program. Table 6.5 summarizes the ranking and recommendations for the spatial evaluation of both metals analyzed in the upper HU. In the situations where a upper HU well was recommended for removal or retention in both analyses, it received a classification of “ZC” in the appropriate column. If a well was recommended for removal or retention in just the zinc or the cadmium analysis, it received a “Z” or a “C,’ respectively. The spatial results for the metals were consistent in that no well was recommended for removal based on one metal and retention based on the other.

TABLE 6.5

SUMMARY RESULTS OF GEOSTATISTICAL EVALUATION RANKING OF WELLS BY RELATIVE VALUE OF CADMIUM AND ZINC IN THE UPPER HU

LONG-TERM MONITORING OPTIMIZATION

BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Zinc			Cadmium			Summary	
	Kriging Ranking	Exclude	Retain	Kriging Ranking	Exclude	Retain	Exclude	Retain
BH-SF-E-0301-U	29	--	--	28	--	--	--	--
BH-SF-E-0305-U	24	--	--	25	--	--	--	--
BH-SF-E-0309-U	18	--	--	15	X		C[a/]	
BH-SF-E-0311-U	22	--	--	21	--	--	--	--
BH-SF-E-0314-U	11.5	X		11.5	X		ZC	
BH-SF-E-0315-U	11.5	X		11.5	X		ZC[b/]	
BH-SF-E-0316-U	13	X		22	--	--	Z[c/]	
BH-SF-E-0317-U	27	--	--	23	--	--	--	--
BH-SF-E-0318-U	7.5	X		5	X		ZC	
BH-SF-E-0320-U	30		X	30		X		ZC
BH-SF-E-0321-U	19	--	--	17	--	--	--	--
BH-SF-E-0322-U	7.5	X		6.5	X		ZC	
BH-SF-E-0402-U	14.5	X		15	X		ZC	
BH-SF-E-0403-U	14.5	X		15	X		ZC	
BH-SF-E-0407-U	1.5	X		1.5	X		ZC	
BH-SF-E-0408-U	1.5	X		1.5	X		ZC	
BH-SF-E-0409-U	9	X		8	X		ZC	
BH-SF-E-0410-U	37		X	24	--	--		Z
BH-SF-E-0423-U	20	--	--	18.5	--	--	--	--
BH-SF-E-0425-U	3	X		6.5	X		ZC	
BH-SF-E-0427-U	10	X		3.5	X		ZC	
BH-SF-E-0429-U	23	--	--	18.5	--	--	--	--
BH-SF-E-0501-U	6	X		3.5	X		ZC	
BH-SF-E-0502-U	28	--	--	27	--	--	--	--
BH-SF-E-0503-U	4.5	X		9.5	X		ZC	
BH-SF-E-0504-U	4.5	X		9.5	X		ZC	
BH-SF-W-0001-U	36		X	29	--	--		Z
BH-SF-W-0003-U	16	--	--	13	X		C	
BH-SF-W-0005-U	17	--	--	20	--	--	--	--
BH-SF-W-0007-U	31		X	26	--	--		Z
BH-SF-W-0008-U	40		X	41		X		ZC
BH-SF-W-0009-U	41		X	42		X		ZC
BH-SF-W-0010-U	35		X	38		X		ZC
BH-SF-W-0012-U	25	--	--	33		X		C
BH-SF-W-0018-U	38		X	40		X		ZC
BH-SF-W-0020-U	21	--	--	32		X		C
BH-SF-W-0104-U	43		X	43		X		ZC
BH-SF-W-0111-U	44		X	44		X		ZC
BH-SF-W-0118-U	39		X	37		X		ZC
BH-SF-W-0119-U	34		X	35		X		ZC
BH-SF-W-0121-U	26	--	--	34		X		C
BH-SF-W-0201-U	32		X	39		X		ZC
BH-SF-W-0203-U	42		X	36		X		ZC
BH-SF-W-0204-U	33		X	31		X		ZC

[a/] C = well identified for exclusion or retention in cadmium analysis only.
[b/] ZC = well identified for exclusion or retention in both cadmium and zinc analyses.
[c/] C = well identified for exclusion or retention in zinc analysis only.

SECTION 7

SUMMARY OF LONG-TERM MONITORING OPTIMIZATION EVALUATION

Seventy-seven groundwater monitoring wells and 18 surface water stations at OU2 were evaluated qualitatively using hydrogeologic, hydrologic, and contaminant information, and quantitatively using temporal and spatial statistical techniques. As each tier of the evaluation was performed, monitoring points that provide relatively greater amounts of information regarding the occurrence and distribution of COCs in groundwater and surface water were identified, and were distinguished from those monitoring points that provide relatively lesser amounts of information. In this section, the results of the evaluations are combined to generate a refined monitoring program that potentially could provide information sufficient to address the primary objectives of monitoring, at reduced cost. Monitoring points not retained in the refined monitoring network could be removed from the monitoring program with relatively little loss of information and without sacrificing achievement of monitoring objectives.

7.1 GROUNDWATER MONITORING NETWORK SUMMARY

The results of the qualitative, temporal, and spatial evaluations for the groundwater monitoring wells are summarized in Table 7.1, along with the final recommendations for sampling point retention or exclusion and sampling frequency. These final recommendations are also shown on Figure 7.1. The results of the evaluations were combined and summarized in accordance with the decision logic shown on Figure 7.2 and described below.

1. Each well retained in the monitoring network on the basis of the qualitative hydrogeologic evaluation was recommended to be retained in the refined monitoring program.

2. Those wells recommended for exclusion from the monitoring program on the basis of all three evaluations, or on the basis of the qualitative and temporal evaluations (with no recommendation resulting from the spatial evaluation) were recommended for removal from the monitoring program.

3. If a well was recommended for removal based on the qualitative evaluation and recommended for retention based on the temporal and/or spatial evaluation, the final recommendation was based on a case-by-case review of well information.

TABLE 7.1
SUMMARY OF LONG TERM MONITORING OPTIMIZATION EVALUATION OF THE OU2 GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
			Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Exclude	Retain	Recommended Monitoring Frequency	
Deadwood Gulch Upland Aquifer													
BH-DW-GW-0001	Upland	Quarterly		x	annual	X		Not included			X	Annual	Temporal statistics confirm qualitative analysis.
Government Gulch Upland Aquifer													
BH-GG-GW-0001	Upland	Quarterly		x	biennial	X		Not included			X	Biennial	Temporal statistics confirm qualitative analysis.
BH-GG-GW-0002	Upland	Quarterly		x	annual		X	Not included			X	Annual	Qualitative factor overrides statistics recommendations. Phase I remediation established well enough to justify lower frequency.
BH-GG-GW-0003	Upland	Quarterly		x	annual		X	Not included			X	Annual	Qualitative factor overrides statistics recommendations. Phase I remediation established well enough to justify lower frequency.
BH-GG-GW-0004	Upland	Quarterly		x	annual		X	Not included			X	Annual	Qualitative factor overrides statistics recommendations. Phase I remediation established well enough to justify lower frequency.
BH-GG-GW-0005	Upland	Quarterly		x	annual		X	Not included			X	Annual	Qualitative factor overrides statistics recommendations. Phase I remediation established well enough to justify lower frequency.
BH-GG-GW-0006	Upland	Quarterly		x	annual	X		Not included			X	Annual	Temporal statistics confirm qualitative analysis.
BH-GG-GW-0007	Upland	Quarterly		x	annual	X		Not included			X	Annual	Temporal statistics confirm qualitative analysis.
BH-GG-GW-0008	Upland	Quarterly		x	annual	X		Not included			X	Annual	Temporal statistics confirm qualitative analysis.
Upland Aquifer between Deadwood and Railroad Gulches													
BH-ILF-GW-0001	Upland	Quarterly		x	semiannual	Not Analyzed		Not included			X	Semiannual	Reevaluate for temporal trends once more data has been obtained.
Upland Aquifer at the Smelter Closure Area													
BH-SCA-GW-0001	Upper	Quarterly		x	biennial	X		Not included			X	Biennial	Temporal statistics confirm qualitative analysis.
BH-SCA-GW-0002	Upper	Quarterly		x	semiannual		X	Not included			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SCA-GW-0005	Upper	Quarterly		x	semiannual		X	Not included			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SCA-GW-0006	Upper	Quarterly		x	semiannual		X	Not included			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SCA-GW-0007	Upper	Quarterly		x	semiannual	X		Not included			X	Semiannual	Well is serving as downgradient sentry well for SCA. Qualitative factor overrides statistics recommendations.
Transect 1													
BH-SF-E-0001	Single Unconfined	Quarterly		x	annual	X		Not included			X	Annual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0002	Single Unconfined	Quarterly		x	annual	X		Not included			X	Annual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0003	Single Unconfined	Quarterly	x		exclude	X		Not included		X		Exclude	Temporal statistics confirm qualitative analysis.
Transect 1 to Transect 2													
BH-SF-E-0101	Single Unconfined	Quarterly		x	semiannual	X		Not included			X	Semiannual	Well is spatially important. Qualitative factor overrides temporal statistics.
BH-SF-E-0201	Single Unconfined	Quarterly		x	semiannual		X	X			X	Semiannual	Temporal statistics confirm qualitative analysis.
Transect 2													
BH-SF-E-0301-U	Upper	Quarterly		x	semiannual	X		--	--		X	Semiannual	Qualitative factor (Phase II remediation) overrides statistics recommendations.
BH-SF-E-0302-L	Lower	Quarterly		x	annual	X		X			X	Annual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0305-U	Upper	Quarterly		x	semiannual	X		--	--		X	Semiannual	Qualitative factor (Phase II remediation) overrides statistics recommendations.
BH-SF-E-0306-L	Lower	Quarterly		x	annual	X		X			X	Annual	Statistics confirm qualitative analysis.
BH-SF-E-0309-U	Upper	Quarterly		x	semiannual	Not Analyzed		C[a/]			X	Semiannual	Qualitative factor overrides spatial statistics recommendations.
BH-SF-E-0310-L	Lower	Quarterly		x	annual	Not Analyzed			X		X	Annual	Spatial statistics confirm qualitative analysis.
BH-SF-E-0311-U	Upper	Quarterly		x	annual	X		--	--		X	Annual	Temporal statistics confirm qualitative analysis.
Transect 2 to Transect 3													
BH-SF-E-0314-U	Upper	Quarterly		x	semiannual	X		ZC			X	Semiannual	Additional considerations in qualitative evaluation override temporal statistics
BH-SF-E-0315-U	Upper	Quarterly	x		exclude	X		ZC[b/]		X		Exclude	Statistics confirm qualitative analysis.
BH-SF-E-0316-U	Upper	Quarterly		x	semiannual		X	Z[c/]			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0317-U	Upper	Quarterly		x	semiannual		X	--	--		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0318-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0320-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.

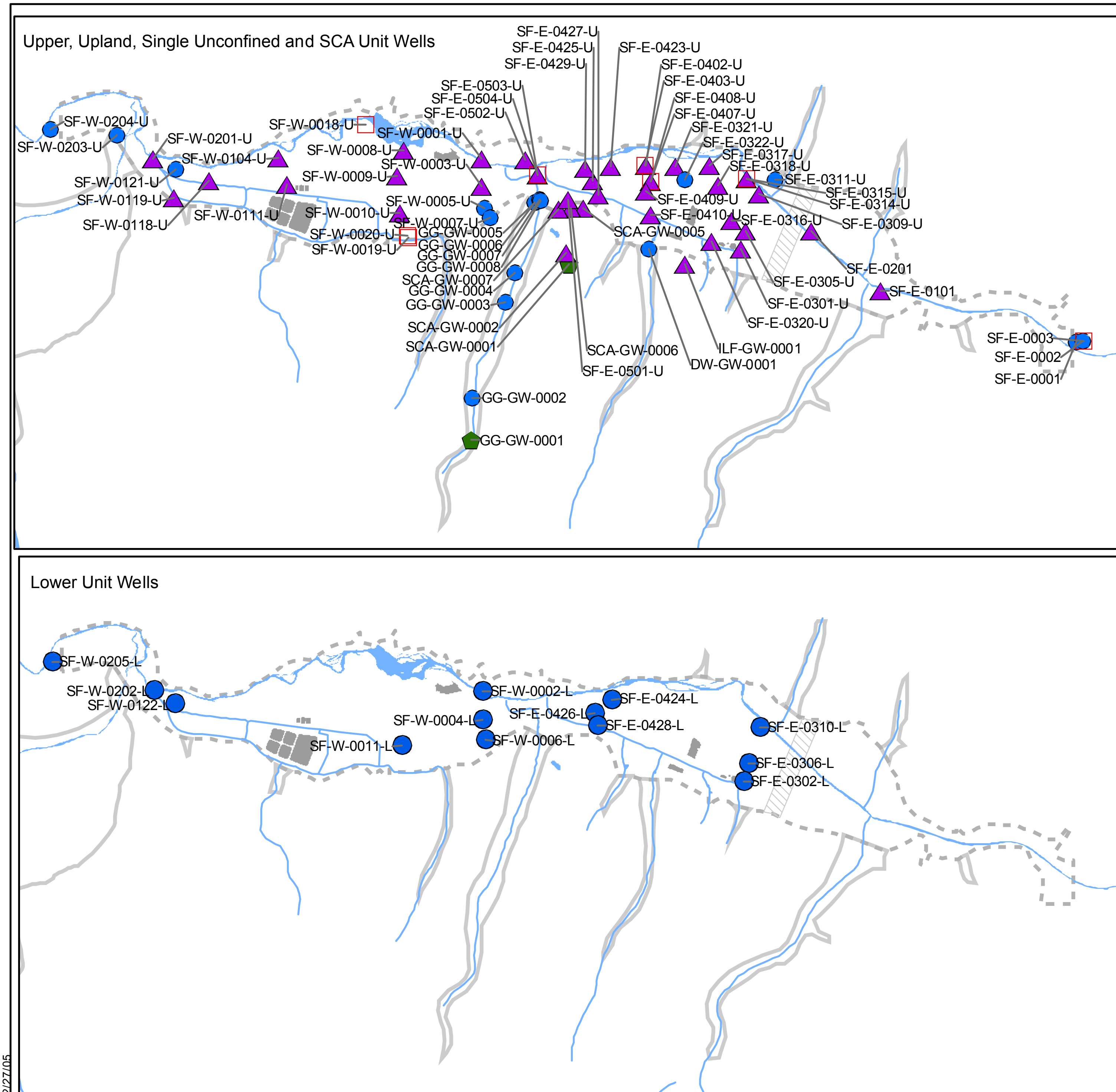
TABLE 7.1 (Continued)
SUMMARY OF LONG TERM MONITORING OPTIMIZATION EVALUATION OF THE OU2 GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
			Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Exclude	Retain	Recommended Monitoring Frequency	
BH-SF-E-0321-U	Upper	Quarterly		x	semiannual		X	--	--		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0322-U	Upper	Quarterly		x	annual		X	ZC			X	Annual	Spatial statistics confirm qualitative analysis. Qualitative factor overrides temporal statistics recommendations.
BH-SF-E-0402-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0403-U	Upper	Quarterly	x		exclude		X	ZC		X		Exclude	Same trends in BH-SF-402-U. Qualitative factor override temporal statistics recommendation.
BH-SF-E-0407-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0408-U	Upper	Quarterly	x		exclude	Not Analyzed		ZC		X		Exclude	Spatial statistics confirm qualitative analysis.
BH-SF-E-0409-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0410-U	Upper	Quarterly		x	semiannual		X		Z		X	Semiannual	Statistics confirm qualitative analysis.
Transect 3													
BH-SF-E-0423-U	Upper	Quarterly		x	semiannual		X	--	--		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0424-L	Lower	Quarterly		x	annual	X		--	--		X	Annual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0425-U	Upper	Quarterly		x	semiannual	X		ZC			X	Semiannual	Qualitative factor (Phase II remediation) overrides temporal statistics recommendations.
BH-SF-E-0426-L	Lower	Quarterly		x	annual	X		X			X	Annual	Statistics confirm qualitative analysis.
BH-SF-E-0427-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0428-L	Lower	Quarterly		x	annual	Not Analyzed		--	--		X	Annual	Temporal statistics confirm qualitative analysis.
Transect 3 to Transect 5													
BH-SF-E-0429-U	Upper	Quarterly		x	semiannual		X	--	--		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0501-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0502-U	Upper	Quarterly		x	semiannual		X	--	--		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0503-U	Upper	Quarterly		x	semiannual		X	ZC			X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-SF-E-0504-U	Upper	Quarterly	x		exclude		X	ZC		X		Exclude	Same trends in BH-SF-402-U. Qualitative factor override temporal statistics recommendation.
Transect 5													
BH-SF-W-0001-U	Upper	Quarterly		x	semiannual		X		Z		X	Semiannual	Statistics confirm qualitative analysis.
BH-SF-W-0002-L	Lower	Quarterly		x	annual	X			X		X	Annual	Statistics confirm qualitative analysis.
BH-SF-W-0003-U	Upper	Quarterly		x	semiannual	X		C			X	Semiannual	Qualitative factor (Phase II remediation) overrides temporal statistics recommendations.
BH-SF-W-0004-L	Lower	Quarterly		x	annual	X		X			X	Annual	Statistics confirm qualitative analysis.
BH-SF-W-0005-U	Upper	Quarterly		x	semiannual	X	0	--	--		X	Annual	Temporal statistics justify reduced monitoring frequency
BH-SF-W-0006-L	Lower	Quarterly		x	annual	X		--	--		X	Annual	Temporal statistics confirm qualitative analysis.
BH-SF-W-0007-U	Upper	Quarterly		x	annual	X			Z		X	Annual	Temporal statistics confirm qualitative analysis; qualitative factors override spatial statistics.
Transect 5 to Transect 6													
BH-SF-W-0008-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.
BH-SF-W-0009-U	Upper	Quarterly		x	semiannual	X			ZC		X	Semiannual	Spatial statistics confirm qualitative analysis. Phase II considerations override temporal statistics.
BH-SF-W-0010-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.
BH-SF-W-0011-L	Lower	Quarterly		x	annual	X			X		X	Annual	Statistics confirm qualitative analysis.
BH-SF-W-0019-U	Upper	Quarterly	x		exclude	X			C	X		Exclude	Temporal statistics confirm qualitative analysis; qualitative factors override spatial statistics.
BH-SF-W-0018-U	Upper	Quarterly	x		exclude	X			ZC	X		Exclude	Temporal statistics confirm qualitative analysis; qualitative factors override spatial statistics.
BH-SF-W-0020-U	Upper	Quarterly	x		exclude	X			C	X		Exclude	Temporal statistics confirm qualitative analysis; qualitative factors override spatial statistics.
BH-SF-W-0104-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.
BH-SF-W-0111-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.
BH-SF-W-0118-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.
BH-SF-W-0119-U	Upper	Quarterly		x	semiannual		X		ZC		X	Semiannual	Statistics confirm qualitative analysis.

TABLE 7.1 (Continued)
SUMMARY OF LONG TERM MONITORING OPTIMIZATION EVALUATION OF THE OU2 GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
			Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Exclude	Retain	Recommended Monitoring Frequency	
BH-SF-W-0121-U	Upper	Quarterly		x	annual	X			C		X	Annual	Statistics confirm qualitative analysis.
BH-SF-W-0122-L	Lower	Quarterly		x	annual	X		--	--		X	Annual	Temporal statistics confirm qualitative analysis.
Transect 6													
BH-SF-W-0201-U	Upper	Quarterly		x	semiannual	X			ZC		X	Semiannual	Spatial statistics confirm qualitative analysis. Phase II considerations override temporal statistics.
BH-SF-W-0202-L	Lower	Quarterly		x	annual	X			X		X	Annual	Statistics confirm qualitative analysis.
Transect 6 to Transect 7													
BH-SF-W-0203-U	Upper	Quarterly		x	annual	X			ZC		X	Annual	Statistics confirm qualitative analysis.
Transect 7													
BH-SF-W-0204-U	Upper	Quarterly		x	annual		X		ZC		X	Annual	Statistics confirm qualitative analysis.
BH-SF-W-0205-L	Lower	Quarterly		x	annual	0	X		X		X	Annual	Statistics confirm qualitative analysis.
New Wells (Recommended for Installation)				**Add**									
Single Unconfined #1	Single Unconfined	NA[d]		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Single Unconfined #2	Single Unconfined	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Single Unconfined #3	Single Unconfined	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Single Unconfined #4	Single Unconfined	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 2 #1	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 2 #2	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 3-5 #1	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 3-5 #2	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 5 #1	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 5 #2	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 6 #1	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 6 #2	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 6 #3	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Transect 6 #4	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #1	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #2	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #3	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #4	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #5	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #6	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #7	Upper	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.
Smelterfille Flats #8	Lower	NA		x	semiannual						x	Semiannual	New well recommended for addition to monitoring program.

[a/] C = well identified for exclusion or retention in cadmium analysis only.
[b/] ZC = well identified for exclusion or retention in both cadmium and zinc analyses.
[c/] C = well identified for exclusion or retention in zinc analysis only.
[d/] NA=not applicable.



Legend

Combined Evaluation

Sampling Frequency Recommendation

- Biennial
- Annual
- Semiannual
- Exclude

0 1,250 2,500 5,000 7,500 10,000 Feet

s:\es\remed\LTMO\USACE\BunkerHill\GIS\BunkerHillCOCs.mxd cen 12/27/05

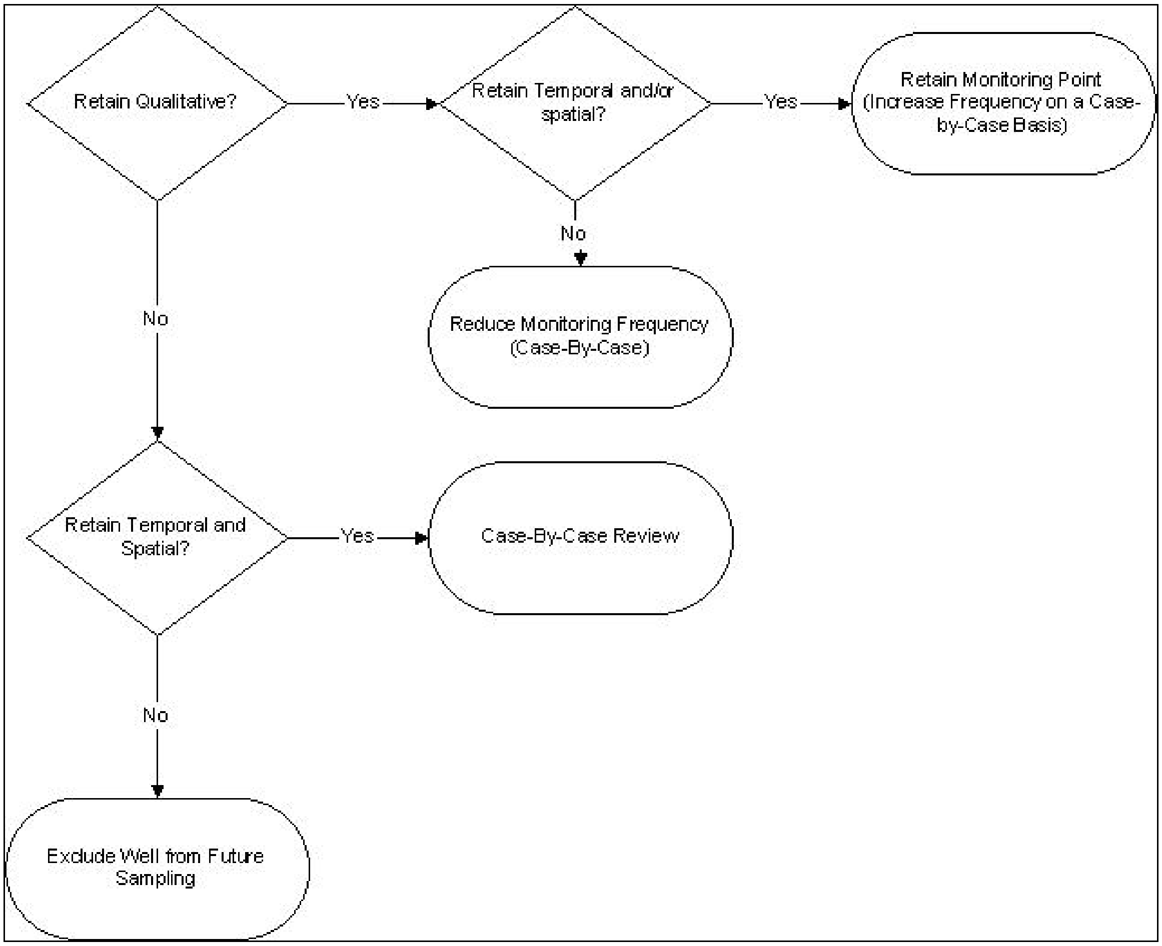
FIGURE 7.1

COMBINED EVALUATION SAMPLING FREQUENCY RECOMMENDATIONS FOR GROUNDWATER WELLS

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX

PARSONS

FIGURE 7.2
COMBINED EVALUTION SUMMARY DECISION LOGIC
LONG-TERM MONITORING NETWORK OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX



4. If a well was recommended for retention based on the qualitative evaluation and recommended for removal based on the temporal and/or spatial evaluation, the well was recommended to be retained, but the possibility of reducing the sampling frequency was evaluated based on a case-by-case review of well information.

It should be noted, as stated in number four above, that the final recommended monitoring frequencies that resulted from the combined analysis are not, in all cases, the same as those recommended as a result of the qualitative evaluation. The justifications for the final recommendations are provided in the "Rationale" column in Table 7.1, and fall into the following general categories:

- *Temporal and/or spatial statistical results confirm the sampling frequency recommendations from the qualitative evaluation.* For example, well BH-SF-E-0315-U is recommended for exclusion from the network or for sampling frequency reduction by both the temporal and spatial statistical results; thus, the statistics confirm the qualitative recommendation to exclude the well. Similarly, well BH-SF-E-0306-L is recommended for exclusion or reduction by the temporal and spatial statistical results; thus the statistics confirm the relatively low (annual) sampling frequency recommended by the qualitative evaluation. Likewise, well BH-SF-E-0410-U is recommended for retention based on the statistical evaluations, which confirm the relatively higher (semiannual) sampling frequency recommendation stemming from the qualitative evaluation.

- *Decrease sampling frequency due to statistics results.* For example, well BH-SF-W-0005-U is recommended for semiannual sampling in the qualitative evaluation. However, the well was recommended for exclusion or reduction in the temporal evaluation because the cadmium and zinc levels are below their respective MCLs; therefore, continued high frequency sampling would yield little additional information. The temporal statistical evaluation results for multiple other wells (*e.g.,* BH-SF-E-0301-U, BH-SF-E-0305-U, and BH-SF-E-0425-U) would also justify reduced sampling frequencies in typical LTMOs in which remediation is complete or well-established. At OU2 however, the qualitative Phase II remediation considerations overrode the statistics as described in Section 4.2.1. As indicated by the temporal recommendation in Table 7.1, in these cases, a reduction in the monitoring frequency may be appropriate once a Phase II remediation plan is in place.

- *Qualitative factor overrides statistics recommendations.* For example, although well BH-SCA-GW-0007 is recommended for exclusion or reduction based on the limited value of its temporal trend information, the qualitative evaluation classified this well as a downgradient sentry well for the SCA; thus, it is recommended for semiannual monitoring. Additionally, although well BH-SF-E-0403-U is recommended for retention by the temporal statistical analysis based on its increasing cadmium concentrations, it is ultimately recommended for exclusion from the monitoring program because the qualitative evaluation points out that it exhibits the same trends and similar or lower COC concentrations than nearby well BH-SF-E-0402-U.

Table 7.2 presents a summary of the revised groundwater monitoring network as compared to the basecase network (number shown in parentheses) classified by HU. For the OU2 groundwater monitoring wells, the LTMO results indicate that a refined monitoring program consisting of 69 of the 77 original wells sampled less frequently (two wells sampled biennially, 30 sampled annually, and 37 sampled semiannually) and 22 additional monitoring wells sampled semiannually would be adequate to address the two primary objectives of monitoring listed in Section 1 and the OU2-specific objectives listed in Section 3.1. This refined monitoring network would result in an average of 149 well-sampling events per year, compared to 308 per year under the current quarterly monitoring program. A well sampling event is defined as a single sampling of a single well. ***Implementing these recommendations for optimizing the LTM monitoring program at OU2 would reduce the number of groundwater well-sampling events per year by approximately 52% percent***.

An approximate total cost per well-sampling event of $315 was derived based on historic cost information provided by the USEPA. This cost includes field work, laboratory analytical, and data transfer; it was assumed that significant savings in overall data management costs would not be realized. Using this cost, eliminating 159 well-sampling events per year would result in an annual savings of approximately $50,000. Because eight existing wells were recommended for exclusion from the monitoring program, and 22 new wells were recommended for addition to the monitoring program, the revised program consists of 91 total wells (compared to 77 in the original program). Thus, all of the cost savings were derived from the recommended monitoring frequency reductions from quarterly to semiannual, annual, or biennial.

TABLE 7.2
SUMMARY OF REVISED AND BASECASE MONITORING PROGRAMS
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

HU	Monitoring Frequency					Total Sampling Points
	Exclude	**Biennial**	**Annual**	**Semiannual**	**Quarterly**	
Lower			13	9	(13)[a/]	22 (13)
SCA		1		4	(5)	5 (5)
Single Unconfined	1		2	6	(5)	8 (5)
Upland		1	8	1	(10)	10 (10)
Upper	7		7	39	(44)	46 (44)
Total Wells	**8**	**2**	**30**	**59**	**(77)**	**91 (77)**

[a/] Basecase sampling frequency corresponding to Table 3.1 shown in parentheses.

7.2 SURFACE WATER MONITORING NETWORK SUMMARY

The results of the qualitative and temporal evaluations for surface water monitoring stations are summarized in Table 7.3, along with the final recommendations for sampling station retention or exclusion and sampling frequency. A spatial statistical analysis of the surface water stations was determined to be inappropriate and was not performed. The results of the evaluations were combined and summarized in accordance with the decision logic shown on Figure 7.2 and described for groundwater monitoring wells in Section 7.1.

All 18 surface water monitoring stations evaluated were recommended for continued sampling at a semiannual frequency as a result of the qualitative assessment. However, as described in Section 4.3, it may be possible to either remove at least two monitoring stations (BH-IG-0001 and BH-JC-0001) from the sampling program in the future, or to reduce their sampling frequency, without introducing significant error into measurement of the total metals load entering the SFCDR. This decision could potentially be made following collection of two additional years of data.

In several cases, the temporal trend results were overridden by qualitative considerations. In general, semiannual monitoring of surface water stations during high- and low-flow conditions is recommended to support the Phase II remedial decisions, at

TABLE 7.3
SUMMARY OF LONG-TERM MONITORING OPTIMIZATION EVALUATION OF SURFACE WATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX SUPERFUND SITE

Surface Water Station Name	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Summary			Rationale
		Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Recommended Monitoring Frequency	
BH-BC-0001	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics; monitor semiannually to support Phase II remedial decision making, then consider reduction to annual during high-flow conditions if most recent data indicate that similar trends persist.
BH-CS-0001	Quarterly		x	Semiannaual		X		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-DW-0001	Quarterly		x	Semiannaual		X		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-GC-0001	Quarterly		x	Semiannaual		X		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-GG-0001	Quarterly		x	Semiannaual		X		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-HC-0001	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics; monitor semiannually to support Phase II remedial decision making, then consider reduction to annual during high-flow conditions if most recent data indicate that similar trends persist.
BH-IG-0001	Quarterly		x	Semiannaual	Not analyzed			X	Semiannual	Reevaluate for temporal trends once more data have been obtained.
BH-JC-0001	Quarterly		x	Semiannaual	Not analyzed			X	Semiannual	Reevaluate for temporal trends once more data have been obtained.
BH-MC-0001	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics; monitor semiannually to support Phase II remedial decision making, then consider reduction to annual during high-flow conditions if most recent data indicate that similar trends persist.
BH-MC-0002	Quarterly		x	Semiannaual		X		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-MG-0001	Quarterly		x	Semiannaual		X		X	Semiannual	Temporal statistics confirm qualitative analysis.
BH-PG-0001	Annual		x	Semiannaual	Not analyzed			X	Semiannual	Reevaluate for temporal trends once more data have been obtained.
BH-RR-0001	Annual		x	Semiannaual	Not analyzed			X	Semiannual	Reevaluate for temporal trends once more data have been obtained.
BH-WP-0001	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics; monitor semiannually to support Phase II remedial decision making, then consider reduction to annual during high-flow conditions if most recent data indicate that similar trends persist.
PC-339	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics; monitor semiannually to support Phase II remedial decision making, then consider reduction to annual or biennial if continued low-magnitude and lack of trends.
SF-268	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics; station indicates background levels.
SF-270	Quarterly		x	Semiannaual	Not analyzed			X	Semiannual	Reevaluate for temporal trends once more data have been obtained.
SF-271	Quarterly		x	Semiannaual	X			X	Semiannual	Qualitative factor overrides temporal statistics due to station's downstream "sentry" location.

least until these decisions are made. After that time, annual sampling of several stations during high-flow conditions could be considered (*e.g.*, BH-BC-0001, BH-HC-0001, BH-WP-0001, and PC-339), assuming that the historical trends (decreasing and/or "no trend" accompanied by a low coefficient of variation [COV]) shown in Table 5.2 persist and no significant changes in upstream conditions (*e.g.*, Phase II remedial actions) occur.

For OU2 surface water, the LTMO results indicate that a refined monitoring program consisting of 18 stations sampled semiannually would be adequate to address the primary objectives of monitoring listed in Section 3.1. This refined monitoring network would result in an average of 36 surface water station-sampling events per year, compared to 66 per year under the current monitoring program (16 stations sampled quarterly and 2 sampled annually). ***Implementing these recommendations for optimizing the LTM monitoring program at OU2 would reduce the number of surface water station-sampling events per year by approximately 45% percent.***

An approximate total cost for each sampling of a surface water station of $337 was derived based on historic cost information provided by the USEPA. This cost includes field work, laboratory analytical, and data transfer; it was assumed that significant savings in overall data management costs would not be realized. Using this cost, eliminating 30 surface water station-sampling events per year would result in an annual savings of approximately $10,000.

SECTION 8

REFERENCES

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APPENDIX A
SELECTED FIGURES FROM THE DRAFT CONCEPTUAL SITE MODEL REPORT (CH2M HILL, 2005A)

APPENDIX B
COMMENTS AND RESPONSES ON THE DRAFT REPORT

Note: All comment responses prepared by Parsons and submitted to project team on 12/2/05

CH2M HILL Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site

General Comment:

This is a well-written and thought out document that follows a logical pathway to evaluate long-term groundwater monitoring network. The applicability to the evaluation of surface water monitoring networks is not as clear and does not fit well with the methods used. This may be an area for further exploration by the Long-Term Monitoring Optimization group.

Response: Agree. The LTMO tools applied for OU2 are best suited to groundwater monitoring networks. As a result, the qualitative evaluation of the surface water monitoring network carried the most weight for this site.

Specific Comments:

Item No.	Section/Page	Line(s)	Comment	Response
1.	Title		It would alleviate a potential source of confusion to add Operable Unit 2 to the title.	Done.
2.	Figure 2.1		The confining unit box shown in this figure and others within the report should be identified as the approximate eastern extent of the confining unit.	Done.
3.	Page 2-1	20	Large-scale mining operations within OU2 ceased in 1991. Small-scale operations are still operating at the Bunker Hill Mine and several other mines are still in operation upstream of OU2.	The sentence will be revised to incorporate the information presented in the comment.
4.	Page 2-6	14-15	It should be noted that the upper portion of the SFCDR valley alluvium is one large source area which prevents the delineation of plumes. Numerous source areas imply that all of the sources of contamination within OU2 can be delineated and defined.	The sentence will be revised to read: "*The upper portion of the SFCDR valley essentially constitutes one large source area, preventing delineation of discrete contaminant plumes in OU2 groundwater*."
5.	Page 3-8	18	"for this plume" is not an accurate depiction of conditions within OU2. Suggest "for OU2 groundwater and surface water"	Revised to reflect suggested text.
6.	Table 3.3		Need a footnote to indicate that the zinc MCL is a secondary MCL.	Done.

Item No.	Section/Page	Line(s)	Comment	Response
7.	Table 3.4		Need to indicate that the AWQC shown in Table 3.4 are hardness dependant. It appears that the AWQC shown are those from the Statistical Analysis Report which assumed a hardness of 100 mg/L.	Done.
8.	Table 3.5		Five of the groundwater monitoring well results shown on the table are for different time periods (other than October 2004). This should be called out and noted. This comment also applies to Table 3.6 and figures generated using this data.	Tables 3.5 and 3.6 and figures modified to note different time periods.
9.	Page 3-9		Groundwater monitoring wells classified by MCL exceedence ratio. This is interesting to see, and appropriate as a summary of the data and the level of decision seems appropriate. However, there appears to be limited value in this approach which may confuse the reader regarding the statistical significance of the information. Also, some statistical information regarding the ratio should be included such as how often the MCL is exceeded at the ratio given. Is this a measurement weighted average or is it based on a single result or sampling event which may or may not be indicative of contaminant concentrations over time at a specific location?	The MCL exceedance ratio data is for the most recent concentration only, and, as suggested in the comment, intended as a higher level summary of the data. The text is updated to emphasize the “most recent” one data point approach, and the figures are updated to clarify date of sampling, per comment #8.
10.	Table 4.3		The rationale given for the BH-SCA series wells should be “seepage” versus “leakage”	Wording changed in table.

Item No.	Section/Page	Line(s)	Comment	Response
11.	Page 4-10	5&6, First Bullet	This bullet states that quarterly monitoring performed to date is sufficient to indicate seasonal changes in COC concentrations. It needs to be stated that the term seasonality as used in this bullet is not the same as seasonality as used statistically for statistical corrections using the Mann-Kendall test for trend. This has been a point of contention recently regarding the statistical analysis of water quality data using the Mann-Kendall test for trend within the group. In general, the current data set is not sufficient to determine or provide a seasonal statistical correction to the evaluation and this statement about seasonality may add to this confusion. While there appears to be seasonal changes (not statistical seasonality) in the data set in response to snowmelt or precipitation events, I do not see that these changes occur on a predictable and consistent time interval that would be required to provide a statistical correction for Mann-Kendall analysis. It would appear that the authors reached the same conclusion as a seasonal correction is not discussed in this report. Some clarification may need to be provided in this report that states whether the data set was sufficient to indicate the presence or lack of statistical seasonality.	The first bullet will be revised to read: "*The quarterly monitoring performed to date is sufficient to qualitatively indicate seasonal changes in COC concentrations (however, the historical data are not necessarily adequate to determine seasonality in a statistical sense in order to perform statistical corrections for seasonality using the Mann-Kendall test for trend).*"
12.	Page 4-10	13-16, Third Bullet	Here the statement that quarterly monitoring performed support the observation that…. This language suggests that the first bullet is indicating that a statistical seasonality is present. If this is the case, the first bullet should be refined to indicate that statistical seasonality is present in the data set and the authors should consider adjusting the data and performing the analysis on the adjusted data set. Again, we did not see statistical seasonality in the data set and would be interested in reviewing this with the authors if they did detect this.	The intent of the third bullet is not to suggest that statistical seasonality is present. The correction made to the first bullet (see response to comment #11) should make this sufficiently clear.

Item No.	Section/Page	Line(s)	Comment	Response
13.	Page 4-11	1-2 and 21-25	While we agree with the recommendation to reduce monitoring frequency further following a two-year period of semi-annual monitoring, the authors recommendation for when annual monitoring should be included. We believe that annual groundwater monitoring in conjunction with low-flow surface water condition is appropriate given the need to evaluate conditions when groundwater is having a greater potential impact on surface water quality.	The referenced text recommends an approximately 2 to 3 year semiannual monitoring period followed by annual monitoring. A more definite time frame for implementing annual monitoring was not included because we did not know the time frame for finalizing Phase II remedial decisions. The text in lines 22-23 states that once the need to collect more frequent data to support Phase II remedial decisions is past the monitoring frequency could be reduced. It would be difficult for us to be more specific at this time.
14.	Page 4-12	1-11	Monitoring wells collocated with other wells on the northern edge of the CIA may appear to be redundant. However, given public interest in the CIA and belief by some that the CIA is a water and contamination source in this area may require the need to retain the two monitoring wells called out in the first two bullets as part of Phase I remedial action effectiveness monitoring. The monitoring wells in questions are screened slightly above/below each other and provide some information on water quality stratification in this area that can be used to indicate the significance of the CIA as a water/contaminant source in this area. In addition, they also provide some information with regard to water quality for water lost from the SFCDR as it infiltrates through the upper aquifer and groundwater quality as it approaches and eventually discharges to the SFCDR.	The two wells recommended in the comment for retention (BH-SF-E-0315-U and BH-SF-E-0403-U) exhibit similar temporal trends as the paired shallower well, but often exhibit lower concentrations. Comparison of water quality results for zinc and cadmium for these two well pairs indicates that the deeper wells consistently have concentrations that are lower than or similar to the shallower wells. It seems as though the stated goal of indicating the significance of the CIA as a water/contaminant source would be best served by monitoring wells located along the downgradient edge of the CIA and monitoring the reach of the SFCDR that is adjacent to and immediately downstream of the CIA, rather than these two wells that are in the interior of the CIA. The goal of assessing the impact of groundwater quality on the SFCDR is best served by monitoring surface water quality in gaining reaches of the SFCDR rather than individual, isolated wells. Continuing to monitor these two wells to assess the impact of surface water discharge on groundwater quality is of questionable utility (especially when the two shallower paired wells will continue to be monitored). In summary, Parsons questions whether sufficient useful and important data are gathered from these two wells to justify their

Item No.	Section/Page	Line(s)	Comment	Response
				retention. If they are retained, then a lower sampling frequency may be appropriate (e.g., annual for 2-3 years then transitioning to biennial). Our intention is to continue to recommend that these wells be deleted from the LTM program purely on technical grounds. However, the USEPA/State/CH2M Hill are free to continue to monitor these wells if they disagree with this recommendation.
15.	Page 4-12	Last Bullet on page	BH-SF-E-0311-U is one of the few monitoring wells located on the north side of the SFCDR. While water quality information from this monitoring well may indicate relatively little contamination in this area, we believe that information from this monitoring well is critical for evaluation of contaminant flux across Transect 2 (as recommended on page 4-4) and also in evaluation of the relationship between north of SFCDR groundwater and the SFCDR (head difference and water quality).	The qualitative evaluation will be revised to recommend retention of this well at a reduced (annual) sampling frequency to support the objectives outlined in the comment. Sampling this well at a reduced frequency is justified given that the well represents a relatively small portion of Transect 2 and has metal concentrations (Cd and Zn) that are 1 to 2 orders of magnitude lower than detected further south along this transect (wells 0309-U and 0305-U). Therefore, mass flux calculations will be dominated by the larger concentrations detected south of the SFCDR. The report will state that additional reduction of the sampling frequency of 0311-U to biennial further into the future should be considered.

Item No.	Section/Page	Line(s)	Comment	Response
16.	Page 4-13	14-19	We agree with the statements regarding water quality in well BH-SF-W-0018-U and the potential influence of the SFCDR on this monitoring location. Given the proximity of this monitoring well with the SFCDR in a losing reach, this monitoring well provides information regarding the impact of potential contaminant sources near this well on relatively clean SFCDR water that is lost to the aquifer in this area. This monitoring well plays a key role in the evaluation of the SFCDR/upper aquifer groundwater relationship.	Comparison of dissolved cadmium and zinc concentrations in well 0018-U with dissolved concentrations of these metals detected in the SFCDR at station SF-270 in April 2004 indicates that they are similar. The dissolved lead concentration at SF270 was higher than typically detected in groundwater at 0018-U. Therefore, it is not clear from these data that the SFCDR water is significantly more clean than the groundwater at well 0018-U. Is it necessary to continually assess the impact of potential contaminant sources near this well on SFCDR water that is lost to the aquifer in this area when the impact results in groundwater COC concentrations that do not exceed cleanup goals (based on results from 20 sampling events performed over 4.5 years)? Our intention is to continue to recommend that this well be deleted from the LTM program purely on technical grounds. However, the USEPA/State/CH2M Hill are free to continue to monitor this well if they disagree with this recommendation. If so, a relatively low monitoring frequency should be considered.
17.	Table 4.4		BH-MC-0001 – The old Milo Creek outfall is not connected to the new outfall and represents water that is infiltrating and finding its way to the old piping system. We feel that this location should be retained in order to complete surface water mass balances.	The report will be revised to retain the old Milo Creek outfall for the reason stated in the comment.
18.	Page 5-2	10-11	See comment above regarding seasonal correction.	Text revised to clarify that MK seasonal correction was not conducted or appropriate for this analysis.

Item No.	Section/Page	Line(s)	Comment	Response
19.	Section 5		We compared the CH2M HILL statistical analysis with that in Section 5. While both evaluations use the Mann-Kendall test for trend, there were differences in the confidences and assumptions underlying the trend test. The LTMO test uses a 90% confidence level and uses data with 4 or more detections in the data set, while the CH2M HILL analysis used a 95% confidence level and was limited to 11 or more samples with greater that 50% detected concentrations at a given location. A comparison of the trends between the two studies indicates that the LTMO study results in far more trends than the CH2M HILL analysis. Given that both documents are now out there, the rationale for selection of confidence level (90%) and the number of samples required (4 or more) should probably be discussed. Using a lower confidence level and a less restrictive data population could result in increased incidence of false trends in addition to additional trends due to more wells meeting the criteria for determining a trend. We observed this in the CH2M HILL statistical analysis when the full period of record data set for each location was evaluated with the same confidence interval but no qualifications for number of samples and detected concentrations. Some discussion comparing methods and results would be helpful since both used the same trend determination methodology (Mann-Kendall).	Table 5.1 and Section 5 text were modified to clarify the MK trend parameters and results to allow for more transparent comparison to the CH2M Hill Analysis. Specifically, the following were added: 1) a column showing the number of sampling results; 2) trends changed to “probably” increasing/decreasing in those cases where the confidence level was between 90 and 95%; 3) identification of those trends in which >50% of the sampling results were ND. Using a 90% confidence interval allows for the identification of more “potential” trends, and is more conservative (e.g., identifying the probably increasing trends in BH-SF-E-0402-U). Using 4 or more results is consistent with other LTMO analyses (i.e. MAROS) and guidance (see [added] USEPA/USACE LTMO Roadmap reference and response to Lorraine Edmond comment #10); the majority of wells had >6 results. Trend recommendations for those wells with fewer than 6 results were revised to “no recommendation”. Text was added to highlight that trends based on less sampling data and/or with >50% ND should be given less relative weight in decision making. Note that no revisions to the trends affected the final well retention/frequency recommendations.
20.	Section 6		The evaluation of the spatial distribution of the monitoring locations within the site (without taking into account the spatial boundary conditions of the site) could be confused with a statistical evaluation of COC distribution. Given the conditions at the site (highly heterogeneous with widespread sampling locations) the significance of this section with respect to the evaluation should be reduced reflecting the applicability of the results on the final selection criteria for wells to retain or be	Text added to clarify that the statistical evaluation (specifically Figure 6.2) was based on the standard error and not the COC distribution. Agree that the heterogeneous conditions make statistical evaluation difficult. Text added to discuss this and to clarify that the statistical evaluation results were not given as high of a weighting in the combined evaluation as a result.

Item No.	Section/Page	Line(s)	Comment	Response
			excluded from the program.	
21.	Section 7		Cost savings. It would be helpful to understand how much of the reduction in cost is associated with the exclusion of monitoring locations and how much of the reduction is associated with the reduction in frequency. This would be a very helpful tool to assist in making further adaptive management changes to the long-term monitoring program.	Text was added to Section 7 to describe the specific cost savings due to monitoring exclusion and reduction.

HTRW Center of Expertise - Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site

General Comment.

An excellent job on a complex project. I agree with the overall recommendations, but defer to the project team for Bunker Hill for a detailed assessment of the recommendations in light of their site conceptual model.

Item No.	Page	Section	Comment	Response
1.	Page 2-5	Sec. 2.2.2	Please indicate if groundwater is used for any purpose within the study area.	Text will be added to state that groundwater is not used for any purpose within the study area.
2.	Page 3-12	Figure 3.3	Please use different symbols in addition to colors in case people only have a black-and-white copy.	Symbols modified in maps to allow for differentiation in black and white.
3.	Page 3-19	Figure 3.7 and subsequent figures	Some of the posted values are the same for several sampling points. Please verify the values. Are these detection limits?	The figures were revised to display non-detects as “ND” and to post the correct COC data (corresponding to Table 3.6).
4.	Page 4-3	Table 4.2	I would like to see one modification to the decision logic used in the qualitative assessment (and in the overall assessment logic). The sampling frequency should probably increase if there has been a recent significant upward trend in the data toward or exceeding a standard at locations suggesting plume expansion.	This modification will be made.
5.	Page 5-2	sec. 5.1	Please revise second to last sentence to read “The Mann-Kendall test statistic can be evaluated to determine, at a specified level of confidence, whether a statistically significant temporal trend…”	Text revised.
6.	Page 5-5	sec. 5.2	May want to separately identify upgradient wells, too.	Upgradient description added to text.
7.	Page 6-5	Table 6.1	a) The minor ranges identified here are significantly larger than the spacing along the transects after the addition of the added wells recommended in the qualitative analysis. I agree with the addition of wells, but I would suggest adding a few sentences cautioning using these ranges as a basis for well spacing in a heterogeneous site such as this. I suspect the anisotropic ranges are poorly constrained. b) For the Upper HU Cd column, verify the sill and nugget values. The sill should not be lower than the nugget, though I am not very familiar with the circular model.	a) Text was added to clarify that the minor range used for the variogram model should not be considered for well spacing along the transects. b) The nugget and sill values were transposed and corrected.

Item No.	Page	Section	Comment	Response
8.	Page 6-6	sec. 6.2	I would like some additional discussion of the impact of the use of ranks in the geostatistical analysis on the sensitivity of the analysis to the edges of the plumes relative to the high concentrations. Are the higher numbers for the ranks assigned to the lower concentrations?	Text was added to clarify that the wells are ranked from lowest concentration (1) to highest concentration (# of wells in set).
9.	Page 6-9	Table 6.2	This table has erroneous page numbers – they should have the prefix of 6-, not 5-.	Page numbers corrected.
10.	Page 6-12	Table 6.5	Please add a footnote to the table explaining the Z, C, and ZC entries. I know its explained in the text, but it should be explained in the footnote, too.	Footnote added to table.
11.	Page 7-2	Table 7.1	Please show the recommended additional wells in this table.	New wells added to summary table.
12.	Page 7-6	Figure 7.2	Again, please indicate the potential to increase sampling frequency for increasing trends in downgradient wells if the current frequency is not adequate.	Increase frequency option added to flow chart.
13.	Page 7-10	sec. 7.1	Would it not be appropriate to sample the new wells at least semi-annually for a couple of years?	Agree, the lower aquifer wells recommended for annual sampling will be recommended for two years of semiannual sampling to establish a better baseline of data followed by annual sampling unless the semiannual sampling results indicate a need for continuing with a higher frequency.

United States Environmental Protection Agency, Region 10 – Office of Environmental Assessment Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site

General Comments. **Lorraine Edmond**

Item No.	Comment	Response
1.	I found the report to be clear, well-organized, and efficient at making use of the abundant site data and the existing Conceptual Site Model. The recommendations for the frequency of sampling make sense, and are tied to the decision-making process, with further modifications that can be made after decisions on Phase II remediation are made. The clear decision logic and recommendations for specific analyses for future decisions makes the LTMO analysis useful both now and in the future.	Noted.
2.	It is hard to say how easily this project will work as a national example, since the site is atypical in so many ways, but the report does a good job of evaluating potential efficiencies in monitoring for Bunker Hill OU2. Some of my comments below reflect the fact that this report will be used as an example for the LTMO process in general.	Noted.
3.	The optimization principles and the decision logic are clearly explained and are consistently tied to the project monitoring objectives. These aspects of the report would be applicable to any project.	Noted.
	Addition of monitoring wells	
4.	I agree that wells should be added to increase density in the transects. The transects are the only places we have that even approach having a reasonable density of wells relative to the rest of the site. Even though considerable uncertainty regarding the absolute value of the metals flux though the transects will remain, I agree that they will continue to be useful for evaluating temporal changes and relative down-valley changes in flux, and additional wells will aid in that evaluation.	Noted
5.	I also agree with the State's comment that additional wells in the Smelterville Flats area are important. It is a large area with a very low density of wells, and a significant amount of remedial effort was expended there. Evaluation of the current groundwater conditions and of the effectiveness of the remedial actions could be significantly aided by the addition of monitoring wells.	Additional wells will be recommended for installation per the response to TerraGraphics comment #29.
	Reduction in monitoring wells	
6.	With regard to specific recommendations to retain certain wells, I defer to the comments by CH2MHill and the State of Idaho, who have much more well-specific knowledge. I agree that the wells evaluating the CIA are important, even though they may appear to be spatially redundant.	Noted

Item No.	Comment	Response
	Reduction in monitoring frequency	
7.	The proposed reductions in monitoring frequency make sense given the amount of data that we have for OU2 already and the rate of change in groundwater quality we are likely to see. I would be much more cautious about decreasing monitoring frequency based on only 4 rounds of sampling, however, which is the threshold the LTMO uses for determining trends. At most sites, this would mean making long-term monitoring decisions based on only the first year's worth of data, which might or might not be representative of a longer time period.	Wells with fewer than 6 results were excluded from the temporal analysis to include the conservative number of sampling points recommended in the USEPA/USACE "Roadmap to LTMO" guidance. In addition, text was added to highlight that trends based on less sampling data should be given less relative weight in decision making.
	Trend Analysis	
8.	The comparison with CH2MHill trend results is worth discussing, since they use almost the same dataset and both will be publicly available. Differences in the number of samples required for testing and in the confidence interval used to determine significance inevitably results in different conclusions regarding trends.	Agreed. Please see response to similar CH2M Hill comment #19 on page 6.
9.	While the threshold used by CH2MHill of 11 samples required before testing for trends is a high one, it is probably appropriate for the OU2 dataset. Other sites may not have this abundance of data, however. The selection of the 90th % confidence interval should also be discussed, as this is also a relatively low threshold for determining that a trend exists. How different would the final conclusions be if a 95% confidence interval had been used?	See response to comment #7 re the number of sampling points relevant for trends. "Probably" increasing/decreasing trend classifications were added to differentiate between the 90% and 95% confidence levels. Using a lower confidence level allows for the earlier identification of trends, and is thus more conservative.
10.	As a general recommendation for other sites, waiting to have 11 sample rounds before analyzing trends may not be realistic. However, as mentioned above, the threshold of 4 data points seems too low. What might prove useful is to show the results of the two analyses side-by-side, along with some discussion of whether or not the resulting recommendations would differ had the LTMO used a higher threshold of sample numbers and of statistical confidence. Showing at least some of the trends graphically would be helpful to the reader.	Agreed that the more information, the better; however, useful information can be determined from fewer than 11 rounds of sampling data (4-6 sampling points is the minimum recommended in USEPA/USACE "Roadmap to LTMO" guidance) and was thus included in this analysis. A column with the number of sampling results used in the analysis was added to Table 5.1 to make the data more transparent. An example graphical trend is shown in Figure 5.1; however, statistical trends are used precisely because it is difficult to quantitatively judge trends based on graphical interpretation.

Item No.	Comment	Response
11.	On the other hand, it may be that the low threshold for trend detection is actually environmentally conservative in the context of an LTMO, if I understand the report correctly. Section 5.1 explains that the "no trend" conclusion results in a recommendation to reduce sampling, since it indicates that no additional information will be obtained by frequent sampling. Detection of a trend, on the other hand may require more frequent monitoring, depending upon the location of the monitoring point. In a sensitive location, then, detection of a trend would mean that additional data would be collected and uncertainty reduced. It would help if the report could discuss the pros and cons of the different approaches to setting the thresholds for trend determination.	Agreed that identifying trends can potentially be more conservative (e.g., increasing or decreasing trends in a source area, as almost all Bunker Hill wells are classified) results in a "retain" recommendation. Text was added to clarify the temporal trend parameters, and a reference was provided (USEPA/USACE's Roadmap to LTMO) that discusses different LTMO approaches and considerations.
12.	However, according to p 5-13, a downgradient well with a decreasing trend might be excluded or have sampling frequency reduced. It seems we would want to reduce uncertainty in these cases as well, depending upon the number and location of such wells. This may simply be an example be where the qualitative analysis comes back in and outweighs the statistical evaluation, particularly if a decision point regarding compliance were approaching, for example.	Agree that the qualitative and/or spatial evaluations would provide additional lines of evidence to reduce uncertainty. Text was highlighted to emphasize that the temporal evaluation related ONLY to the value of temporal data, and that final recommendations are based on a combination of all three evaluations.
13.	Similarly, it would be worth distinguishing between being willing to run a test with 4 samples, and actually recommending beginning the LTMO process with only one year's worth of quarterly samples. I think the report is doing the first, and not the second, but some discussion would be helpful, especially with regard to my earlier comment about the report being used as an example.	Text added to clarify the decision to include >6 sampling points per USEPA/USACE Roadmap to LTMO guidance.

Specific Comments

Item No.	Table/Figure	Comment	Response
1.	Table 3-5 and the associated figures	use "most recent" data to describe current conditions, which is logical. Although most of the most recent sample data were from October 2004, for some locations, data from winter, spring, or summer samples are used. It might be worth acknowledging that, taking a look at those locations, and determining whether using only fall data, for example, would make any difference. (With this dataset it might not, but I can imagine other cases where the seasonality makes the difference between exceeding a standard and not exceeding it.)	Discussion added to the text to describe selection of "most recent" data and appropriateness of including wells with different sampling dates.
2.	Figure 5.4	What is the criterion for the box labeled "high variation"?	High variation = coefficient of variation > 1 (consistent with MAROS). Footnote added to table and explanation added to text.

United States Environmental Protection Agency, Region 10 Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site

General Comments. **Anne Dailey**

Item No.	Comment	Response
1.	The graphics should be readily copied in black and white. Most of document is already copiable in black/white – but a few figures need some symbol adjustments (e.g., Fig. 3.3 and 3.4).	Figures adjusted to display symbology in black and white.
2.	Several of the Bunker Hill OU2 documents cited are draft documents (e.g., the OU2 Environmental Monitoring Plan, updated Conceptual Site Model, and Statistical Trend Analysis). The documents are all still under revision but will be finalized in early 2006 – in part pending integration of the result of the LTMO study. It would be good to be clear about this in the text and in the references in Section 8 should note that these are draft documents.	Text will be revised accordingly.
3.	Several other commenters noted the 90th%ile confidence interval that the LTMO review uses versus the 95th%ile confidence interval used by CH2M Hill in their analysis of the data for EPA Region 10. Given the high degree of scrutiny that this site continues to get (National Academy of Sciences final report on the site due to be release in late December, litigation, high degree of community interest), the report should expand on the selection of 90th%ile vs. 95th%ile confidence interval. How different would the results be? Could you run some of the calculations using the 95%ile confidence interval? If appropriate, perhaps we should schedule a conference call to discuss.	"Probably Increasing" and "Probably Decreasing" trends added to differentiate between 90% and 95% confidence trend results. A 90% confidence interval allows a great amount of trends to be identified. Ultimately, the 90% vs. 95% confidence limits did not affect the LTMO summary recommendations.

Specific Comments

Item No.	Section/Page	Line/para	Comment	Response
1.	Sect. 2.1		Especially for readers unfamiliar with the site, it would be helpful to provide a bit of additional context regarding OU2 in the overall Bunker Hill Mining and Metallurgical Complex Superfund Site. (If you would like, I'd be happy to provide a paragraph or two). This is important in part because there is an extensive environmental monitoring program already in place for Operable Unit 3 (Coeur d'Alene Basin) which is intended to dove-tail with the OU2 EMP. As noted below, several of the surface water stations are sampled routinely as part of the Basin Environmental Monitoring Plan (BEMP) but the results are also used in the OU2 EMP. The following surface water monitoring stations are funded and sampled as part of the BEMP:	The Section 2.1 text will be revised as requested. We will also add information about the dovetailing of the OUs 2 and 3 monitoring programs to Sections 2.1 and 4.3. Please either provide some recommended text to add or direct us to text in existing documents that we should use.

Item No.	Section/Page	Line/para	Comment	Response
			- PC-339 – Pine Creek below Amy Gulch	
			- SF-268 – SFCDR at Elizabeth Park	
			- SF-270 – SFCDR at Smelterville	
			- SF-271 – SFCDR at Pinehurst	
			It should also be noted that consideration of OU2 surface water data needs was considered when we developed the OU3 BEMP.	We will add information about this issue to Sections 3.1 and 4.3
2.	Sect. 2.2		Given that readers unfamiliar with the Bunker Hill Superfund Site will be looking at this report, it might be helpful to include several of the CSM figures cited in this section (e.g., Fig. 3-8 of the CSM).	The CSM figures referenced in Section 2.2 will be added as Appendix A. We will need to solicit clean copies of some of these figures from CH2M Hill because our copies of some of them are marked up.
3.	Sect. 2.3		For readers unfamiliar with the site, it may be helpful to provide a bit more background on the cleanup actions taken to date and potential future Phase II cleanup actions. Please advise if you would think this would be a good addition and would like assistance on preparing such text.	The LTMO report is not meant to be stand-alone, but is an addition to previously-prepared site reports. It is assumed that readers using the LTMO report would also have access to documents such as the CSM. The discussion of cleanup actions performed to date contained in the CSM report encompasses 15 pages. If a summary of these topics is desired, Parsons would appreciate assistance on preparing this text, especially given that we are not familiar with the scope of potential Phase II cleanup actions.
4.	Sect. 3.2	1st line	"plume" is probably an inadequate description for the extent of the groundwater contamination at this site. As you know this site does not a have a classical plume with a point source ….at Bunker Hill the groundwater contamination is extensive and widespread throughout the upper aquifer.	The words "this plume" will be replaced by "OU2".
5.	p. 4-17	2nd full para	As noted above in the comment on Sect. 2.1, 4 surface water stations from the OU3 BEMP contribute information to the OU2 monitoring program.	See response to specific comment #1.
6.	Table 7-1		It would be very helpful to include the recommended additional wells in this table.	New wells added to summary table.

Item No.	Section/Page	Line/para	Comment	Response
7.	Sect. 7		EPA R10's main objective in updating the OU2 monitoring program and engaging in the LTMO process is to ensure that we are collecting the right data on which to base decisions about potential Phase II remedial actions (likely costing 10s of millions of dollars). In addition, we need to ensure that we will be able to evaluate the effectiveness of those remedial actions. While we are aiming to make the program as efficient and effective as possible, the data integrity question is the primary reason for the Region to conduct the LTMO analysis. Cost savings on the monitoring program is an important but definitely a secondary objective. I believe that the report emphasizes the first objective (data integrity) but with the closing paragraphs of the report focusing on cost savings, I wonder there isn't undue emphasis on the cost saving aspect?	The cost-related text is about as minimal as it can be, and comprises only a very tiny fraction of the report. However, we are open to specific suggestions as to how to further minimize the emphasis on this topic. Retaining some cost discussion seems appropriate given that it is a secondary objective.
8.			- It would also be helpful to break out the cost savings due to reduction in frequency and elimination of sampling locations.	Text was added to Section 7 to describe the specific cost savings due to monitoring exclusion and reduction.
9.	p. 2-5	mid 1st para	0.54 ft/ft should be ft/day	ft/ft is correct given that it is referring to a hydraulic gradient.

United States Environmental Protection Agency, Region 10 Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site

General Comments. **Bernie Zavala**

Item No.	Comment	Response
	I have reviewed the above-mentioned document and would like to offer the following comments from a general perspective or from an overall approach to optimizing the long-term monitoring networks. I found the document to be logical and a good mix of qualitative and quantitative assessments tools which were used to make insightful recommendations on the monitoring network at Bunker Hill Superfund OU 2. I didn't provide specific comments to the monitoring locations because I lack intimate working knowledge of the site. I did provide specific comments on the approach.	Noted.
	Overall, the evaluation was good and will be useful for the cleanup. Once the comments have been addressed, the document should be finalized and recommendations implemented.	Noted.

Specific Comments

Item No.	Section	Page	Line/Para	Comment	Response
1.	Section 1.0, Introduction	Page 1-2	second sentence, line (3)	Minor comment, but important, this evaluation (LTMO) is to determine the **overall effectiveness of the monitoring program** and then will optimize the existing program which may include additional monitoring locations or opportunities to streamline the monitoring activities. Please include language in the introduction to emphasis that the LTMO process evaluates the overall effectiveness of the monitoring program first.	The text starting on page 1-2, line 3 will be revised to read: "*A monitoring network consisting of 77 groundwater monitoring wells and 18 surface water stations was evaluated to assess its overall effectiveness at achieving the OU2- specific monitoring objectives, and to (1) identify potential opportunities to streamline monitoring activities while still maintaining an effective monitoring program, and (2) identify data gaps that may require addition of additional monitoring points*."
2.	Section 2.2.1 Geology	Page 2-3	first paragraph, line (15)	It would be useful to include the geologic cross-section to aid the reviewer of this report but it is also understood that information was referenced in the CSM report (CH2M Hill, 2005a). It is suggested that a generalized cross-section could be produced similar to the verbal description that was included in the last two paragraphs in section 2.2.1.	See response to Anne Dailey's specific comment #2 above.

Item No.	Section	Page	Line/Para	Comment	Response
3.				An additional section is needed in Section 2 Site Background Information. It should be Section 2.4 Summary of Remedial Action. What was the history of the remedial actions within the "Box?" Section 3.0 listed that one of the objectives of the groundwater monitoring program for OU 2 was to evaluate the cumulative effects of the remedial action in Phase 1. Please include that summary in Section 2.4.	See response to Anne Dailey's specific comment #3 above.
4.	Section 3 Long-Term Monitoring Program	Page 3-1	lines (4-7)	Similar to the above comment #1, the monitoring network optimization (MNO) first must determine the effectiveness of the network in terms of the monitoring objectives then make the appropriate optimization changes whether its streamline or additions/increases to the monitoring program.	The referenced text will be revised to read: "*The existing groundwater and surface water monitoring program at OU2 was examined to assess its overall effectiveness at achieving the OU2- specific monitoring objectives, and to (1) identify potential opportunities to streamline monitoring activities while still maintaining an effective monitoring program, and (2) identify data gaps that may require addition of additional monitoring points*."
5.	Section 3.1 Description of Monitoring Program	Page 3-8	line (1)	Not sure how this monitoring program will address the second objective, *evaluate the nature of groundwater/surface water interaction and the impact of groundwater discharge on surface water quality*. This comment can't be addressed by the LTMO process but this comment should be addressed by the site team. There is no monitoring program in the groundwater transition zone with surface water.	The nature of groundwater/surface water interaction is addressed at least partially by streamflow measurements that indicate gaining and losing reaches of the various surface water drainages. The impact of groundwater discharge on surface water quality is addressed by measuring surface water quality upstream and downstream of gaining reaches. It is our understanding that groundwater samples have been collected from below the bed of the SFCDR to facilitate assessment of this issue; however, we are unclear whether this is a regular occurrence or a one-time event. This comment does not appear to be requesting specific changes in the LTMO report, and none are proposed at this time.
6.		Page 3-8	line(13)	This comment is similar to the above comment, how will this objective be answered without data from the groundwater transition zone?	See response to specific comment #5 above.

Item No.	Section	Page	Line/Para	Comment	Response
7.		Page 4-5	Table 4.3	Typo, first column of the table Training 2 should be Transect 2.	Text fixed in table.
8.	Section 4.4 Laboratory Analytical Program	Page 4-21	line (20)	I concur with the recommendations of collecting and reporting the results of the water quality field parameters during the purging and sampling of the monitoring wells. The parameters that should be collected are dissolved oxygen, pH, oxidation-reduction potential, specific conductance, turbidity and groundwater elevations. Also, why are dissolved metals collected instead of total for groundwater water quality?	Line 20 will be revised to read: "*It is assumed that pH, specific conductance, turbidity, and depth to water are being measured during well purging….Measurement of dissolved oxygen and oxidation-reduction potential during purging is recommended for the same reason. These are simple field measurements*…." Given that total metal concentrations can be heavily influenced by sample turbidity, they may not be an accurate reflection of what is actually migrating in the groundwater. Dissolved metals probably provide a more accurate measurement of the concentrations of metals dissolved in and migrating with the groundwater.
9.	Section 5.1 Methodology for Temporal Trend Analysis of Contaminant Concentrations	Page 5-2&3	line (9& 2)	Four data points can be used to determine a trend but that it would be better to recommend in this report a minimum of eight data point or two years of quarterly data. Also, why was a 90% confidence level used to define *statistically significant trend* instead of 95% confidence level?	Text added to clarify the decision to include >6 sampling points per LTMO guidance recommendations. "Probably" increasing/decreasing trend classifications were added to differentiate between the 90% and 95% confidence levels. Using a lower confidence level allows for the earlier identification of trends.
10.	Section 7 Summary of Long-Term Monitoring Optimization Evaluation	Page 7-1	line (16)	This paragraph does imply that the existing monitoring network is effective to monitor the remedial action from Phase 1 but I believe a statement is needed in this paragraph to state that fact. Also, it would be good to add to the last sentence that with theses changes or refinements to the groundwater monitoring network it will still meet the remedial action objectives for the site cleanup within an appropriate time frame.	The following text will be added to the end of line 16: " *and without sacrificing achievement of monitoring objectives*."

TerraGraphics Environmental Engineering Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site

General Comments. **Nick Zilka**

Item No.	Comment	Response
1.	Overall the document is well written, the procedures used are clearly described, and the conclusions well reasoned. We commend the authors on their efforts to analyze a large amount of information and distill it into monitoring recommendations.	Noted.
2.	The primary source for dissolved metals in groundwater within OU2 is metal-rich sediment within the vadose zone. The two release and transport mechanisms for metals from this source are unsaturated flow downward through the vadose zone and the annual rise and fall of the water table. The magnitude of dissolved metal release by these mechanisms is related to the magnitude of the hydrologic event. **The LTMO report does not deal with the primary metal source, the release and transport mechanisms and the importance of major hydrologic events. This topic is important and should be addressed in the document.**	Detailed analysis of metals fate and transport in the vadose zone is beyond the scope of this LTMO task. However, by virtue of the fact that groundwater quality data are used as the basis for the LTMO evaluation, the LTMO assessment is influenced by source zone release and transport mechanisms and hydrologic events to the extent that these affect groundwater quality. The following new paragraph will be added between the first and second paragraphs in Section 2.3: "*The primary source for dissolved metals in groundwater within OU2 is metal-rich sediment within the vadose zone. The two release and transport mechanisms for metals from this source are unsaturated flow downward through the vadose zone and the seasonal rise and fall of the water table. The magnitude of dissolved metal release by these mechanisms is related to the magnitude of the hydrologic event. Major hydrologic events, such as occurred in 1996 to 1997, can result in a relatively large influx of metals into the groundwater system due to enhanced flushing of metals out of the vadose zone.*"
3.	The LTMO report includes analysis of surface and groundwater data collected during the period of February 2000 through October 2004. This time period does not include the major hydrologic event that occurred in the basin in 1996-1997. Peak flows on the South Fork of the Coeur d'Alene River (SFCDR) in February 1996 at the Elizabeth Park gage (7,400 cfs) are slightly less than the 50-year recurrence interval flow (7,778 cfs) as presented in Table 3-3 in the Conceptual Site Model Report (CH2M HILL 2005). The average annual flow of the SFCDR during the 1997 water year (564 cfs) was considerably higher than the average for the 1987-2003 period of record	The 2000-2004 data were used to correspond with the period of time after the Phase I remedial activities occurred, as including data from before these actions could result in misleading trends. Because of the frequent sampling, the 2000-2004 time frame provides a large amount of data appropriate for a statistical evaluation.

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	(327 cfs) (CH2M HILL 2005, p.3-10). Groundwater levels peaked in many wells during this period with associated metal release from the two mechanisms described under the previous general comment. **The 2000-2004 database included in the LTMO analysis does not include this high flow event, the associated metal loading to groundwater and the possible impacts on spatial statistical analysis of contaminant concentrations and statistical analysis of temporal trends in contaminant concentrations. These topics are important and should be addressed in the document.**	Recommendations were added to Section 4 to temporarily increase the frequency of surface water and groundwater monitoring in the event of an unusually large hydrologic event to capture potential effects of dissolved metal releases.
4.	Throughout the analysis the authors seem to attribute changes in COC concentrations to remedial actions only. This is probably an invalid assumption. There are many environmental variables that could impact the COC concentrations. This then calls into questions what the trends tell you. If you do not understand the factors influencing the variability in the COC you can not attribute the trends to the Phase 1 remedial action.	Text will be reviewed and revised as appropriate in light of this comment.
5.	Does the shift to a reduced frequency of sampling negatively impact the statistical analyses in any way?	Any future sampling will only serve to add to and enhance the large amount of concentration trend information already available for the site.

TerraGraphics Environmental Engineering Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation for Bunker Hill Mining and Metallurgical Complex Superfund Site (Continued)

Specific comments

Item No.	Section/Page	Line	Comment	Response
1.	Title		OU2 should appear in the title.	Done.
2.	Page 2-3	line 24	needs a period at the end of the sentence.	Done.
3.	P.2-4	lines 17-19	We're not sure the blanket statement that depth to groundwater is 8-10 feet (east) and 10-25 feet (west and central) is correct, e.g. Kellogg well values are greater than 10 feet.	This information came from Section 3.4.2.1 of the CSM report. The word "*generally*" will be inserted in line 17 between "*table*" and "*ranges*" to indicate that this there is some variability. In addition, the end of this sentence will be revised to read: "…*western portions; however, some variability exists*."
4.	Table 3.2		Table indicates that BH-RR-0001 is sampled quarterly. In fact, it is only sampled during the high flow sampling events. The same is true for Portal Gulch.	Sampling frequencies changed in table.
5.	Page 3-8	line 18	Is "plume" the best word for the widespread contamination in the BHSS?	Text modified.
6.	P.3-8	line 21	Several RAs were not "designed" to impact water quality but it was anticipated they would. Suggest "expected".	Text changed to "expected".
7.	Table 3.4		"wells" should be taken out of the title of the last 3 columns since this is a surface water table. Same with the first column in Table 3.6.	"Wells" changed to "Surface Water Stations".
8.	Table 3.6		Table compares the surface water concentrations to the AWQC. The AWQC is for total metals not dissolved so the comparison to the dissolved fraction is in error.	The AWQC was used for both total and dissolved metals to be consistent with CSM Table 5-9.
9.			The concepts of performance and sentry wells mentioned on page 4-1 do not fit well with the Bunker Hill site.	Disagree; most wells screened in the upper aquifer at the site can be termed "performance" wells given that they are located within contaminated areas. Wells installed at the far western edge of OU2 can be considered sentry wells.
10.	Page 4-3	Tables 4.1 and 4.2	Excellent.	Noted.

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11.	Page 4-4		The mass flux justification in section 4.2.1 for sampling the transect wells is not valid. The mass flux estimates from these wells have a high range of potential error because of uncertainty in estimation of a representative hydraulic conductivity value.	Agree that this is the case. However, if the same hydraulic information and the same wells are used in mass flux calculations from year to year, relative changes in mass flux can be determined, which could be useful indicators of remedial effectiveness. The text in Section 4.2.1 will be revised per this comment and the response.
12.	P.4-5	Table 4.3	Rationale for BH-GG-GW-0007 recommends a higher sampling frequency but lists a reduced frequency.	The rationale given for use of a higher sampling frequency is not entirely correct. The sampling frequency will be retained as annual and the rationale will be revised.
13.	P.4-5	Table 4.3	Interesting. In the past we have done monthly and quarterly sampling and now semiannual is considered frequent.	It is our experience that semiannual monitoring is considered relatively frequent in the context of a **long-term** monitoring program (i.e., beyond the characterization stage).
14.			We are surprised that all four of the wells at the mouth of Government Gulch are included in Table 4-3 (GG-GW-0005, 6, 7 and 8). One of the well pairs could be excluded from the list with little data loss.	Agree that these well pairs are in relatively close proximity to each other and may be providing some redundant information. GW-0006 and 0008 were retained to further assess potential increasing trends in metal concentrations (Cd in 0006 and Zn in 0008). Of the shallow wells, GW-0007 has consistently higher cadmium and zinc concentrations than 0005, but consistently lower lead concentrations. The lead concentrations in 0005 consistently exceed the MCL. We recommend continued low-frequency sampling of each of these wells for the time being to get the "full story" regarding groundwater quality at the mouth of Government Gulch.
15.	Page 4-10		The three bullets on page 4-10 raise several questions. Do we need quarterly or even monthly sampling on a minimum number of wells to gain an understanding of the seasonal changes to the groundwater system? Rapid changes in water quality are present in the data set prior to 2000, at least some of which are related to the extreme hydrologic event. Second, does the change from quarterly to semiannual and annual sampling impact the future statistical analysis of the database? Finally, we need to select a time of year	From February 2000 to October 2004, a total of 66 wells had been sampled at least 8 times (59 of which were sampled quarterly), and 32 wells had been sampled quarterly at least 20 times. The maximum number of sampling events performed on wells reviewed for this LTMO evaluation during this approximately 4.5-year period is 45. It is our opinion that continuation of monthly to quarterly monitoring is

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			for sampling the upper aquifer wells that will now go to annual measurements.	not necessary. At this point, the money would be better spent on remedial activities. However, as noted in the response to General Comment #3, recommendations were added to Section 4 to temporarily increase the frequency of surface water and groundwater monitoring in the event of an unusually large hydrologic event to capture potential effects of dissolved metal releases. Collection of additional data (even at a reduced frequency) will enlarge the data set and aid the statistical analysis of the database. Parsons has not performed sufficient analysis of the historical data to recommend a specific time of year for annual measurements. However, it makes sense to perform annual sampling at a time of year when metal concentrations have historically been relatively elevated.
16.			When the recommendation is to go to annual monitoring the authors do not discuss the time of year to perform this monitoring. We are left to assume that it is during the late summer early fall low flow period.	A recommendation to perform the annual sampling at a time of year when metal concentrations in groundwater are typically relatively elevated will be added to the text.
17.	Page 4-12	first bullet	do those well names need "-U" at the end?	Well names fixed in text.
18.	P.4-12	lines 8,10,12, 14	Are these pairs truly co-locations? For example, 402 and 403 are near each other but don't behave the same.	These pairs are co-located in an areal sense but are not screened over the same depth interval vertically. We feel that continued monitoring of both wells that comprise each pair is unnecessary for the reasons given in the text of the report. While trends exhibited by 403 are not a carbon copy of the 402 trends they are generally similar and 403 concentrations from 4/00 to 10/04 were always lower than 402 concentrations.
19.	Page 4-14	line 3	says well BH-SF-W-0018-U has had exceedances of cadmium and lead, but page 4-13 says there have been no exceedances at this well.	Text modified to clarify that the exceedances discussed refer to well BH-SF-W-0121-U.
20.	.		The statement on lines 15 and 16 in section 4.2.4 on page 4-16 that no Phase II remedial actions will be done in Government Gulch probably is incorrect and should be removed.	The following text will be added to the end of line 17: "*If this assumption is incorrect, then a semi-annual sampling frequency is recommended to support Phase*

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				II remedial decisions, followed by a reduction to annual sampling." Table 4.3 will be modified accordingly.
21.	P. 4-16		We are not sure we understand Government Gulch as well as the text implies. We don't know where gaining and losing reaches occur and why the water quality changes are occurring.	Noted; see response to specific comment #20.
22.	Page 4-16	last paragraph starting on that page	Well BH-ILF-GW-0001 was installed in 2000, but has only been sampled twice (4/25/01 and 1/15/03) because it has been dry every other quarter (and once could not be accessed due to snow). We checked again on 10/24/05, and the depth to bottom was 18.98', and the depth to water was 17.21', indicating only 1.77' of water. A low-flow pump was not ordered for this well. This well has not been included in the monitoring program since the change to the low-flow method in April, 2003.	Noted; this information will be added to the text on page 4-16. The text will also be amended to recommend that this well be sampled when possible using another feasible method given the small thickness of the water column (e.g., non-dedicated peristaltic pump). If a sample can be obtained, it would be better to obtain data for this well using an alternate method rather than not sample it because it does not contain a dedicated low-flow pump.
23.	Page 4-17	line 13	Should not say "well" since this is discussing surface water locations.	The term "*monitoring station*" will be used instead.
24.	P. 4-18	Table 4.4	The Milo outfalls are not redundant – one drains the old stormwater system and the other the new. Also, retain seeps for technical and public relations issues.	Both Milo outfalls will be retained.
25.			There is more going on here than just groundwater discharge. There is speculation that an old CIA dividing dike is acting as a preferential route, the Transportation Department used to have to resurface the highway periodically due to subsidence, and the RI identified the seeps as the largest loader to the river.	If the primary reason for sampling the seeps is to determine metals loading to the river, it seems best to determine the net impact of metals loading from the CIA by sampling the river directly at the upstream and downstream ends of the CIA (and perhaps also at intermediate locations adjacent to the CIA depending on the level of detail desired). The seeps only indicate metals discharge at one point along a gaining reach of the river adjacent to the CIA that is estimated to extend for nearly 7000 feet (per Figure 3-41 of the CSM report). However, continued sampling of the seeps would serve to indicate how groundwater quality in this portion of the CIA is changing over time in response to the Phase I remedial actions that were performed. We are not familiar with the public relations issues alluded to in comment #24. Sampling

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				of the seeps at a semiannual frequency will be recommended in the final report.
26.	Page 4-19	line 4	should "groundwater" instead be "surface water"?	Text changed to "surface water".
27.	P. 4-20	lines 11-25	See comment above for page 4-18.	Text refers to surface water.
28.	Page 4-21	last paragraph	Both pH and ORP are measured.	Noted.
29.	P. 4-23		We are surprised no well additions are proposed for Smelterville Flats. There are very few wells out there due to the removal action.	Agree. A recommendation for installation of at least 8 additional wells in the Smelterville Flats area (4 upper aquifer and 4 lower aquifer) will be added to the report.
30.	Page 4-23	lines 22 and 23	do these well names really need the "-U" ?	U removed from well name.
31.	Page 4-24	line 14	Doesn't this well name need the "-U" at the end?	U added to well name.
32.			The word "well" is included in the text in section 4.3 and on Table 4.4 and should be removed.	Changed from "well" to "surface water station".
33.			We question the value of the transect flux calculations mentioned in section 4.5 and the addition of monitor wells to several transects to help in flux calculations. However, these wells would be helpful in better understanding subsurface sources and metal transport.	See response to specific comment #11.
34.			The introductory paragraph of section 5 on page 5-1 does not fit well with the conceptual model of where and how metal sources exist within the Box and how and where metals are introduced into groundwater and surface water systems.	The referenced paragraph will be revised to read as follows: *"Target analyte concentrations measured at different points in time (temporal data) can be examined graphically or using statistical tests to evaluate temporal trends. In general, if removal of contaminant mass is occurring in the subsurface as a consequence of attenuation processes (e.g., metals precipitation) or remedial actions (e.g., source removal), mass removal will be indicated by a decrease in analyte concentrations through time at a particular sampling location, as a decrease in analyte concentrations with increasing distance from source areas, and/or as a change in the suite of analytes detected through time or with increasing migration distance.*

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				Temporal analysis of analyte concentrations for OU2 media is complicated by the fact that metal-rich sediment is present in the vadose zone throughout the SFCDR valley floor. In addition, the annual loading of dissolved metals to groundwater can vary widely with hydrologic conditions. Significant increases in the rate of metal loading to groundwater can occur following unusually high-magnitude rainfall or snowmelt events. Therefore, the conclusions derived from the temporal analysis should consider the potential impacts of time-varying hydrologic conditions."
35.			Metal-rich sediment is present in the vadose zone throughout the valley floor.	Noted. See response to comment #34.
36.			Dissolved metals are introduced into the groundwater seasonally by water movement through the vadose zone and/or by seasonal saturation of the lower portion of the vadose zone by water-level changes.	Noted. See response to comment #34.
37.			Remedial actions have resulted in significant removal of the metal-rich sediment in only a portion of OU2 (dominantly the Smelterville Flats with partial removals in other areas).	Noted.
38.			The annual loading of dissolved metals to groundwater varies widely dependent on hydrologic conditions. The 2000-2004 period of data represents conditions after a significant hydrologic event.	Please see response for General Comment #3 and Specific Comment #34.
39.			The temporal statistical analysis must consider the database in light of long-term hydrologic conditions.	Noted. See response to comment #34. The temporal analysis results will be reviewed in light of this comment and the accompanying text will be revised as appropriate.
40.			The concept of "source wells" and "downgradient wells" in section 5.2 on page 5-5 is confusing. One would presume that wells downgradient from metal source areas could have metal concentrations above MCL levels.	We agree that designation of source and downgradient wells for this site is more difficult and confusing than for a typical site that has a defined contaminant plume. However, we believe that the way the OU2 wells were designated as source or downgradient is appropriate for the Bunker Hill LTMO analysis. Most upper aquifer wells were designated as source wells given the widespread distribution of source material throughout

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				the area. However, if a well did not exhibit MCL exceedances then it seems reasonable to assume that it is not installed in a source area—hence the downgradient designation. It is our understanding that source material is not present in the lower aquifer (beneath the bounding aquitard); therefore, these wells were classified as being downgradient (in a vertical sense) from source areas. In reality, some lower aquifer wells may actually be cross-gradient or upgradient (again, in a vertical sense) from source areas but as long as they are not considered sentry wells they are treated the same on Figure 5.4 (e.g., if a lower aquifer well does not exhibit a temporal trend, and is not a downgradient sentry well, then it follows the same route on the flowchart regardless of whether it is downgradient, cross-gradient, or upgradient).
41.	Figure 5.4		Interesting but does not fit the OU2 area because metal sources exist over most of the area.	Although the Bunker Hill site does not fit the typical mold of a groundwater monitoring site, the temporal trend flow chart still is applicable because (as indicated in the comment) most wells were classified as “source wells” (as shown in Table 5.1) and temporal recommendations were made on that basis.
42.			The utility of Table 5.1 is limited because the database does not represent the range of hydrologic conditions that can and will occur within the area.	The 2000-2004 data selection was appropriate for the LTMO analysis. Please see response for comment General #3.
43.	P. 5-8	Table 5.1	It would be good to differentiate between “exclude” and “reduce”.	Table 5.1 presents only the results from 1 of 3 lines of evidence in the evaluation. The decision whether to reduce or exclude is based on the combined temporal, spatial and qualitative evaluation and is presented in Table 7.1.
44.	P. 5-8	Table 5.1	Reduce vs. exclude seems to rely heavily on the presence of a trend. Lack of a trend may be good data to understand system or point out a lack of understanding. Water quality is not changing – why?	As stated in Section 5.1, continued sampling of ‘no-trend’ wells with low temporal variation provides limited information in terms of temporal trend evaluation (i.e., you’re not likely to learn anything new in the future). The qualitative and/or spatial evaluation may identify other reasons that a well with

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				no temporal trend may be important.
45.	Table 6.2 and 6.3		page numbers say 5-9 and 5-10 instead of 6-9 and 6-10.	Fixed.
46.	Tables 6.2, 6.3, and 6.4		Do not have footnotes.	Footnotes added to tables.
47.			Within the constraints of the database selection, section 7 presents a good comparison of the qualitative and quantitative approaches to the evaluation of the monitoring network.	Noted.
48.	P. 7-3	Table 7.1	Retain 403 and sample semiannually; Qualitative – not a duplication of depth, 14 vs. 22. Spatial – in a high density well area, true, but is at CIA seeps. Temporal – 402 and 403 often don't behave the same way in term of metal concentrations	See response to CH2M Hill comment #14. Graphical analysis of historical (2000-2004) data for wells 0402-U and 0403-U indicates that sampling of 0402-U will allow the maximum metal concentrations present in groundwater at this location to be tracked over time (concentrations decrease with depth in the upper aquifer at this location).
49.	P. 7-4	Table 7-2	Take surface samples at mouths of Grouse, Government, and Deadwood quarterly to pair up with hillsides monitoring (turbidity).	The rationale for this recommendation is unclear. We are not familiar with hillside monitoring being performed in association with Grouse and Deadwood gulches. In addition, the LTMO evaluation does not recommend quarterly monitoring of Government Gulch wells. The role of turbidity in supporting this recommendation is not clear to us. No changes to the LTMO report due to this comment are proposed at this time; further clarification would be required.
50.	Page 7-8	line 21	add a space between "evaluation" and "of" at the end of the line.	Done.