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Remedial Investigation Report For the Westinghouse Hematite Site

Rev 1, Volume 1: Text

Prepared for:

Westinghouse Electric Company
Hematite Facility
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Festus, MO 63028

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January 2007

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contributed to the preparation of this document and should not be considered an eligible contractor for its review.

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ACRONYMS

ABB	Asea Brown Boveri
AMSL	above mean sea level
AOC	area of concern
^{241}Am	americium-241
BGS	below ground surface
BNA	base-neutral-acid extractable organic
CCOPC	chemical contaminant of potential concern
CE	Combustion Engineering Inc.
COC	chain-of-custody
CSM	conceptual site model
DCE	dichloroethylene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
DOE	U.S. Department of Energy
DPT	direct-push technology
DSCC	deeper silty clay/clay
ECD	electron capture detector
EM	electromagnetic
EPA	U.S. Environmental Protection Agency
F&T	fate and transport
FID	flame ionization detector
FS	feasibility study
GAC	General Atomic Company
Gulf	Gulf Oil Corporation
GM	Geiger-Mueller
gpd	gallons per day
gpm	gallons per minute
HDPE	high-density polyethylene
HSA	hollow-stem auger
HSU	hydrostratigraphic unit
ID	inside diameter
IDW	investigation-derived waste
KOH	potassium hydroxide
LBG	Leggette, Brashears & Graham, Inc.
MDC	minimum detectable concentration
MDL	method detection limit
MDNR	Missouri Department of Natural Resources
MIP	membrane interface probe
mL/min	milliliters per minute
MS	matrix spike
MSD	matrix spike duplicate
NaI	sodium iodide
^{237}Np	neptunium-237
NPDES	National Pollutant Discharge Elimination System
NSSSC	near surface silt/silty clay
NTU	nephelometric turbidity unit
O.D.	outer diameter
ORP	oxidation-reduction potential

PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	perchloroethylene
pCi/g	picoCuries per gram
pCi/L	picoCuries per liter
PGDP	Paducah Gaseous Diffusion Plant
PID	photoionization detector
ppb	parts per billion
ppm	parts per million
PRG	preliminary remediation goal
^{238}Pu	plutonium-238
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QC	quality control
^{226}Ra	radium-226
RI	remedial investigation
RCOPC	radiological contaminant of potential concern
SAIC	Science Applications International Corporation
s.u.	standard unit
SVOC	semivolatile organic compound
^{99}Tc	technetium-99
TCE	trichloroethylene
^{232}Th	thorium-232
TSWP	task-specific work plan
UF_6	uranium hexafluoride
UNC	United Nuclear Corporation
USCS	Unified Soil Classification System
USGS	U.S. Geological Survey
UTL	upper threshold limit
VOC	volatile organic compound
WEC	Westinghouse Electric Company, LLC

EXECUTIVE SUMMARY

INTRODUCTION

This Report presents the results of the remedial investigation (RI) conducted at a former fuel cycle facility that is located within 228 acres of property in Hematite, Missouri, and is currently owned by the Westinghouse Electric Company, LLC (WEC). WEC ceased facility operations in June 2001 and is proceeding with Site characterization, remediation, and facility decommissioning. This Report was prepared by Science Applications International Corporation (SAIC) under contract to WEC.

As used throughout this document, the "Hematite Facility" refers to the central portion of the property, encompassing the historic primary operations area, Site Pond and burial pits area (approximately 18 acres) s, while the "Hematite Site" refers to the "Hematite Facility," and other areas which were the focus of this investigation based on potential impacts by previous Facility operations. The term "Property" refers to the entire 228 acres of land owned by Westinghouse.

The objective of this RI is to establish an understanding of the geology, hydrology, and the nature and extent of contamination in surface water, soils, sediment, and groundwater for the Hematite Site. Characterization data collected during the RI are being used in risk assessment studies that will quantify the impact of contamination associated with previous operations on human health and the ecological environment. The results of the baseline risk assessment will be covered under a separate report. Data obtained during this investigation will be used to facilitate development of feasibility studies for selection of appropriate alternatives for remediation. Coupled with process knowledge for the Hematite Facility and known potential source areas for contaminants, this evaluation has led to the development of a conceptual site model (CSM) from which the fate and transport of contaminants in groundwater have been assessed. Finally, the CSM has become the basis from which a groundwater flow and transport model has been constructed and calibrated against empirical data.

The Hematite Facility was originally constructed as the Mallinckrodt Chemical Works in 1955. The Facility became operational in July 1956, producing uranium metals for the nuclear fuel program of the U.S. Navy. Throughout its history, the manufacture of uranium metal and compounds from natural and enriched uranium was the primary activity at the Facility. Operations included the conversion of uranium hexafluoride gas of various ^{235}U enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. Although uranium material production was the primary function at the Hematite Facility, records indicate secondary activities such as uranium scrap recovery and a limited amount of work with thorium compounds as part of early research into the use of thorium in the fuel cycle. In addition to the nuclear materials processed at the Hematite Facility, there was a variety of non-nuclear chemical products stored on-Site and used in many of the processes. Those with the greatest potential for contaminating surface water, soils, and groundwater at the Hematite Facility because of leaks (from storage tanks or process pipelines) or waste disposal activities (e.g., Evaporation Ponds and the Burial Pits) include strong mineral acids (hydrochloric, hydrofluoric, and nitric) and chlorinated organic solvents [perchloroethylene (PCE) and trichloroethylene (TCE)]. A number of potential "areas of concern" have been identified at the Hematite Site and include those locations where these (and other) potential contaminants were stored, used, and/or disposed.

SUMMARY OF GEOLOGIC AND HYDROLOGIC CONDITIONS

The geologic framework of the Hematite Site is dominated by two key bedrock formations, the Jefferson City-Cotter Dolomite and the Roubidoux Formation (sandy dolostone and sandstone) that underlie the Hematite Site. These formations dip gently toward the northeast. The regional landscape is highly dissected by streams yielding topographic relief in excess of 150 ft locally. The Hematite Facility is built upon terrace/alluvial flood plain sediments overlying bedrock within the valley carved by Joachim Creek, which is located approximately 1000 ft south of the Facility. These sediments include 10 to 20 ft of fine-grain material underlain by 5 to 20 ft of coarser-grain sands and gravels.

In the unconsolidated terrace/alluvial flood plain sediments (herein referred to as the overburden), groundwater flow is chiefly confined to the basal, coarse-grain unit and is in a southeastward direction from the Hematite Facility toward Joachim Creek where it discharges. A groundwater mound is associated with the northeast corner of the Hematite Facility and has a significant impact on the potentiometric surface. Groundwater flow in the upper Jefferson City-Cotter Dolomite appears to be affected by the mounding, and components of flow radiate from the Hematite Facility toward the northeast (along bedding planes) and toward the southeast (in a transmissive zone) within this bedrock unit. Below the Jefferson City-Cotter Dolomite, the current direction of groundwater flow appears to reflect a northeasterly direction, which is consistent with the regional groundwater flow direction in the Roubidoux Formation.

In this RI report, several hydrostratigraphic units (HSUs) in bedrock have been defined. In descending order of depth, these are the Jefferson City-Cotter, Jefferson City-Roubidoux contact zone, and Roubidoux HSUs, respectively.

Vertical head gradients are downward from the shallow to deep overburden. Between the deep overburden, and Jefferson City-Cotter HSU, gradients are downward in the vicinity of the Hematite Facility and generally upward near Joachim Creek. Vertical gradients tend to be upward from the Jefferson City-Cotter HSU and deeper HSUs. However, until approximately mid-2004, this gradient was reversed (i.e., downward) as a result of the significant lowering of heads in the Roubidoux Formation. A possible reason for lower heads in the deeper HSUs was the pumping of groundwater from the Roubidoux Formation by water supply wells in the city of Festus.

SUMMARY OF CONTAMINATION AT THE HEMATITE SITE

Most constituents (radionuclides, metals, and organics) at the Hematite Site are closely associated with the footprint of the Hematite Facility and disposal sites within the Hematite Facility.

Inorganic constituents were elevated in surface soil, soil and groundwater at known waste areas/areas of concern within the Hematite Site. These include: the Evaporation Ponds, Deul's Mountain, soils under the buildings, outdoor areas adjacent to buildings, the Burial Pits and the Site Pond. Because the elevated metals concentrations in the groundwater are localized, this suggests that groundwater migration of inorganics is limited and not as extensive as that of chlorinated solvents. There was no indication of metals contamination in the bedrock groundwater.

Sediment data indicate the presence of some inorganics in the Site Pond, Site Creek and Northeast Site Creek. However, the inorganics were generally not detected in the surface water samples from the Site, suggesting that migration of inorganics through surface water is limited or does not occur.

Technetium-99 (^{99}Tc) and, to a lesser extent, uranium is evident in soils, but contamination is also associated with known waste disposal areas (the Evaporation Ponds, Deul's Mountain, Site Pond, Burial

Pits) and soil underneath process buildings, and even where migration to the subsurface has occurred, there is little or no evidence of lateral migration away from these areas. Comparison of the uranium and ^{99}Tc groundwater data with chlorinated volatile organic compound (VOC) results indicates that the radionuclides have not migrated as extensively as the VOCs.

Several sediment samples from Site Pond were found to contain significant contamination with uranium and ^{99}Tc. However, ^{99}Tc was not detected in any of the surface water samples from the Site. Furthermore, uranium activities in surface water are elevated in the Site Pond but decrease significantly in the Site Creek downstream of the Site Pond dam. These data suggest that there is no to minimal migration of these radionuclides via surface water.

The principal organic contaminants in sediment and soil are PCE and TCE. The distribution of PCE and TCE in the groundwater and soil samples appear to reflect one or more source areas associated with the Hematite Facility and nearby disposal areas, although contaminated soils extend southeastward from the Hematite Facility toward Joachim Creek and probably reflect migration of contaminated groundwater from which sorption to soil organic matter has occurred. Dense, nonaqueous-phase liquid (DNAPL) was confirmed at one location under a building at the Hematite Facility based on elevated concentrations of PCE.

Contamination of groundwater with VOCs is widespread. PCE, TCE, and their degradation products are commonly observed. A number of locations have sufficiently elevated PCE or TCE concentrations to suggest the nearby presence of DNAPL. PCE and TCE plumes in the overburden originate at the Hematite Facility and extend southeastward toward Joachim Creek. One component of contamination in the Jefferson City-Cotter HSU has migrated in a southeasterly direction beneath Joachim Creek; a second component has migrated down dip from the Hematite Facility towards the northeast. Deeper contamination in bedrock only has been confirmed in association with private wells PW-19, PW-16, and PW-06 in a residential community to the southeast of the Hematite Facility across Joachim Creek and with PW-03 located east-northeast of the Hematite Facility. PW-06, PW-16, and PW-19 are no longer used as domestic water supply wells and have been converted to dual-completion groundwater monitoring wells as part of this RI.

Polycyclic aromatic hydrocarbons also are commonly found in surface and subsurface soil samples from on-Site locations. They are common products of combustion of coal and other fuels, and also frequently are associated with asphalt-paving material. Their presence is likely from one or a combination of these sources. Localized occurrences of dioxin, polychlorinated biphenyls, and petroleum contamination also were observed.

The presence of organic constituents in surface water is rarely encountered except for several low-level detections of PCE and TCE downstream from the Hematite Facility. Methylene chloride was also detected in a number of surface water samples but these detections were associated with method blanks, suggesting that the results represent common laboratory contaminants rather than Site conditions.

Biological degradation of PCE and TCE is occurring at the Hematite Site, but appears not to have proceeded past the production of 1,1-dichloroethylene (DCE); *cis*-1,2-DCE; and *trans*-1,2-DCE, except in relatively few samples.

CONCEPTUAL SITE MODEL AND NUMERICAL MODELING

The CSM that was developed for this RI focuses on the following key conclusions:

- Flow and transport in a southeasterly direction within the overburden is facilitated by a hydraulic gradient caused by groundwater mounding under the Hematite Facility and discharge to the surface in Joachim Creek

- With increasing depth below the surface, flow/transport directions gradually shift from southeasterly (overburden), to a blend of southeasterly and a regionally imposed northeasterly component (Jefferson City-Cotter HSU), and finally to a regional northeasterly direction (Jefferson City-Roubidoux contact zone and Roubidoux HSUs)

- Contaminant transport in all geologic units projects back to the footprint of the Hematite Facility (and associated disposal areas) as the ultimate source area

Flow and contaminant migration in bedrock at the Hematite Site may have been potentially impacted by pumping in deep production wells operated by the city of Festus. These wells were operational until the summer of 2003 and caused regionally extensive drawdown in the Roubidoux Formation of up to 50 ft in the vicinity of the Hematite Site. In August 2003, the Jefferson County Water Authority brought online a new production facility that draws water from the sediments marginal to and underlying the Mississippi River using horizontal wells and now provides nearly all of the water needs for the city of Festus and other surrounding communities. Startup of this well permitted Festus to place its four production wells located on the west side of the city on standby. These wells had been pumping approximately 1 million gpd from the lower Roubidoux Formation. Currently, they are used only during periods of peak demand in mid- to late summer, or when the collector well is off-line. When supplementing production from the collector well, the pumping rate on these wells is much less than before August 2003.

In the residential community southeast of the Hematite Facility, a number of private wells were completed open hole, which provided a hydraulic connection between the Jefferson City Dolomite and Roubidoux Formation. Full-capacity pumping of the Festus production wells before the new water facility was brought on line in August 2003 probably impacted contaminant distribution at the Hematite Site in several ways. First, hydraulic stresses in the Roubidoux Formation were transferred to the upper Jefferson City-Cotter Dolomite through these wells (e.g., PW-06, PW-16, and PW-19) and facilitated flow and contaminant migration in the Jefferson City-Cotter HSU from the Hematite Facility to the location of the wells. Secondly, downward flow of groundwater and contaminants in these wells spread contaminants to deeper zones at lower heads imposed by pumping of the Festus production wells. A similar mechanism is responsible for vertical migration of contaminants at PW-03.

Once the Festus wells were placed on stand by, rebound of water levels in the Roubidoux Formation progressed rapidly and the potential for downward flow through the private wells declined. The changes in the hydrologic regime since the Festus production wells were no longer pumping at full capacity will likely eventually eliminate future downward vertical migration of contamination once water levels stabilize in the Roubidoux Formation.

A numerical model was constructed for the Hematite Site by: (1) using the CSM to identify hydraulic boundaries, (2) defining a suite of five layers corresponding to the shallow and deep overburden and the three HSUs in bedrock, and (3) establishing the geometric (e.g., thickness and orientation) and

hydraulic properties for each layer. The flow model was calibrated against water level data obtained during the RI (i.e., following shutdown of both the private residential and Festus city wells). The principal conclusions from the modeling investigation include:

- The shallow groundwater mound in a localized area (northeastern corner) of the Hematite Facility plays a major role in flow/transport in both layers of the overburden as well as in the Jefferson City-Cotter HSU.

- The assignment of reasonable downhole flow rates to the open boreholes in the vicinity of PW-19 is essential for creating the observed transport to the southeast in the Jefferson City-Cotter HSU and is supportive of the CSM.

- Particle tracking suggests that contaminant transport directions for layers responding to either the locally imposed or regional flow systems can be rationalized with observed contaminant distribution patterns. Backward particle tracking from contaminated bedrock wells (BR-08-JC, BR-09-JC, and BR-04-JC) suggest that the Burial Pits are the source of contamination in these wells. Particle travel times vary depending on the location of their release points within the Hematite Facility. Particles "released" within the southwestern part of the Hematite Facility (i.e., the process buildings) tend to have longer travel times towards their discharge point (Joachim Creek) when compared to particles "released" within the northeastern part of the Hematite Facility (i.e., the Burial Pits). This is due to the mounding in the northeastern corner of the Hematite Facility that causes downward migration in this area to the transmissive bedrock formations that are conductive and were assumed to have lower porosities than the overburden.

- Contaminant transport modeling of PCE and TCE in groundwater indicates that sorption and degradation can significantly attenuate contaminant migration such that organic contamination levels can decrease by one to two orders of magnitude within close proximity of the source areas.

- Contaminant transport modeling of uranium in groundwater indicates very limited spreading of contamination from source areas, consistent with what was observed in groundwater sample data. The site-specific partition coefficient for uranium is two orders of magnitude higher than the sorption coefficient for organics, resulting in significantly less migration for uranium in groundwater at the Hematite Site when compared to PCE and TCE.

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1. INTRODUCTION

This Report presents the results of the remedial investigation (RI) conducted at a former fuel cycle facility that is located within 228 acres of property in Hematite, Missouri, and is currently owned by the Westinghouse Electric Company, LLC (WEC). WEC ceased facility operations in June 2001 and is proceeding with Site characterization, remediation, and facility decommissioning. This Report was prepared by Science Applications International Corporation (SAIC) under contract to WEC.

As used throughout this document, the "Hematite Facility" refers to the central portion of the property, encompassing the historic primary operations area, Site Pond and burial pits, while the "Hematite Site" refers to the "Hematite Facility," and other areas that were the focus of this investigation based on potential impacts by previous Facility operations. "Property" refers to the 228 acres of land owned by Westinghouse.

1.1 GOALS AND OBJECTIVES OF THE REMEDIAL INVESTIGATION

The overall goals of the RI are to characterize the nature and extent of contamination resulting from previous operations at the Hematite Facility and to reasonably predict contaminant fate and transport (F&T) in the surface and subsurface environment. Characterization data collected during the RI are being used in risk assessment studies that will quantify the impact of contamination associated with previous operations on human health and the ecological environment. The results of the RI will also be used in subsequent feasibility studies (FSs) to determine suitable remedial alternatives for the Hematite Site.

To achieve the goals of the RI, characterization and modeling activities were designed with the following specific objectives:

- To establish a conceptual model for hydrogeologic conditions at the Hematite Site that will be used as a framework for assessing contaminant migration pathways.
- To obtain information necessary for developing a conceptual site model (CSM), including lithologic characteristics and hydraulic conductivities for the overburden and bedrock formations, potentiometric surfaces in the overburden and bedrock groundwater, hydraulic gradients between hydrogeologic units, and interactions between groundwater and surface water features at the Hematite Site.
- To determine whether historic operations have impacted surface water and sediment, and whether contaminants are migrating off-Site through surface water and sediment migration pathways.
- To assess the impact of historic operations on surface and subsurface soils, including the identification of potential sources for groundwater and surface water contamination.
- To define the sources of contamination and characteristics of these source areas that are important to the evaluation of remedial alternatives.
- To assess the nature and extent of contamination in the shallow (i.e., overburden) groundwater, and to determine potential contaminant migration pathways from possible source areas within the Hematite Facility to surface water and deeper (i.e., bedrock) groundwater.
- To assess the nature and determine the horizontal and vertical extent of contamination in bedrock formations where contaminants have been detected during previous investigations.

- To develop a groundwater and contaminant transport model for the Hematite Site that can be used to predict long-term fate of contaminants, to guide future sampling programs, and to evaluate remedial alternatives.

- To address data gaps identified during previous investigations.

A technical approach for achieving the goals and objectives of the RI was presented in a RI/FS Work Plan (LBG 2003) submitted by WEC to the Missouri Department of Natural Resources (MDNR) in May 2003. In response to the conditional approval of the RI/FS Work Plan (MDNR 2003), a series of task-specific work plans (TSWPs) were prepared and submitted to MDNR. The TSWPs, which were reviewed but not formally approved by MDNR, were aligned with the aforementioned RI objectives and provided additional details regarding the following field activities:

- Sampling and analysis of Site and upstream (background) surface water and sediment for radiological contaminants of potential concern (RCOPCs) and chemical contaminants of potential concern (CCOPCs), including the installation of surface water gauging stations (SAIC 2004a).

- Sampling and analysis of surface soil for RCOPCs and CCOPCs (SAIC 2004b).

- Sampling and analysis of subsurface overburden soil, including the installation of temporary monitoring wells that enabled sampling and analysis of overburden groundwater for volatile organic compound (VOC) and radiological contamination detected during previous investigations (SAIC 2004c).

- Drilling and installation of bedrock wells to supplement the pre-RI monitoring network, including (1) discrete interval sampling and analysis of groundwater for VOCs in the new bedrock boreholes and select domestic supply wells, and (2) slug testing at selected wells to measure hydraulic conductivities of the overburden and bedrock formations (SAIC 2004d).

- Sampling and analysis of surface and near-surface soil for RCOPCs and CCOPCs in locations remote from the Hematite Site (SAIC 2004e) to obtain characteristics of soil not likely to have been impacted by previous operations (i.e., local background).

- Baseline groundwater sampling and analysis for RCOPCs, CCOPCs, and basic water quality parameters at pre-RI, newly installed bedrock and temporary overburden groundwater monitoring wells at the Hematite Site, including groundwater level measurements at these wells (SAIC 2004f).

As a result of a detailed review of the RI/FS Work Plan, modifications were made to the original technical approach. These modifications and the technical basis for making these changes were presented in the TSWPs and were based on input from the RI Contractor (SAIC and its subcontractors), WEC, and MDNR.

1.2 SCOPE AND ORGANIZATION OF THE REPORT

This Report presents the results of RI field activities performed from April 2004 through January 2005 in accordance with the aforementioned RI/FS Work Plan and TSWPs. It also provides a summary of the results of the gamma survey conducted in April 2003 and sampling and analyses conducted in December 2003 of soils underneath buildings at the Hematite Facility (SAIC 2003a).

Following the RI field activities, the data were integrated with available information from previous investigations to develop:

- a CSM,
- an evaluation of the nature and extent of environmental contamination associated with historical operations, and
- an assessment and prediction of contaminant F&T in the vicinity of the Hematite Site.

The Report is organized as follows:

- The remainder of Chapter 1 contains a history of operations at the Hematite Facility, descriptions of the various buildings and areas on the Hematite Facility, a summary of previous investigations conducted at the Hematite Site, and the areas of concern (AOCs) identified during these previous studies.
- Chapter 2 describes Site characterization activities performed during the RI.
- Chapter 3 presents the physical characteristics of the Hematite Site, including geology and hydrogeology.
- Chapter 4 discusses the chemical characteristics of the Hematite Site, including nature and extent of contamination.
- Chapter 5 describes likely sources of contamination, possible mechanisms for migration of contaminants, a summary of groundwater and contaminant transport modeling results, and a screening level assessment of monitored natural attenuation.
- Chapter 6 concludes the Report with a summary of major RI findings relevant to future feasibility studies, remedial design and implementation, as well as long-term monitoring of surface water and groundwater conditions in and around the Hematite Site.
- Appendices A through L provide supplemental and supporting information.

The groundwater and contaminant transport modeling conducted as part of the RI is described in more detail in a separate report entitled *Groundwater and Contaminant Transport Modeling for the WEC Hematite Site* (SAIC 2007); the full report is included in Appendix A of this report. Baseline health and ecological risk assessment studies also will be covered in a separate document not included in this report.

1.3 FACILITY LOCATION AND HISTORY OF OPERATIONS

The Hematite Facility is located at 3300 Missouri State Road P in Jefferson County, Missouri, near the town of Hematite (Fig. 1.1). The Westinghouse Hematite Property consists of 228 acres of land with primary operations historically being conducted within the central portion of the property. Figure 1.2 shows the approximate boundary of the Hematite Facility, encompassing the historic primary operations area, Site Pond and burial pits.

Nuclear-related operations at the Hematite Facility began with the purchase of the Property (then consisting of farmlands) by Mallinckrodt Chemical Works in 1955. The Hematite Facility became operational in July 1956, producing uranium metals for the nuclear fuel program of the U.S. Navy.

Mallinckrodt Chemical Works and related entities operated the Hematite Facility until 1961, when ownership was transferred to a joint venture called United Nuclear Corporation (UNC). UNC continued to produce uranium products for the Federal government. In 1971, UNC and Gulf Oil Corporation (Gulf) entered into a joint venture forming the Gulf United Nuclear Fuels Corporation, which owned and managed the Hematite Facility until January 1974. General Atomic Company (GAC), a partnership involving Gulf, owned the Hematite Facility from January 1974 through May 1974, when Combustion Engineering Inc. (CE) purchased the Hematite Facility from GAC. Asea Brown Boveri (ABB) purchased the stock of CE in 1989, and CE began operating the Hematite Facility as ABB Combustion Engineering. In April of 2000, WEC purchased the nuclear operations of ABB, which included the Hematite Facility. WEC ceased operations in June 2001 and is proceeding with Site investigation activities in preparation for Site remediation, including decommissioning.

Throughout its history, the manufacture of uranium metal and compounds from natural and enriched uranium was the primary activity at the Hematite Facility (Section 2.2, page 4 of LBG 2003). Operations included the conversion of uranium hexafluoride (UF_6) gas of various ^{235}U enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. During the period prior to the purchase of the Property in 1971 by Gulf United Nuclear Fuels Corporation, classified government projects dominated Hematite Facility operations. As such, specific details regarding the exact nature of production processes prior to 1974 are not known. The following are examples of known projects during this time (Section 2.2, page 4 of LBG 2003):

- production of uranium metal for use in the U.S. Navy's nuclear-powered submarines and destroyers;
- production of specialized uranium oxides for use in the U.S. Army's Army Package Power Reactor;
- production of highly enriched uranium oxides for a General Atomics gas-cooled reactor;
- production of highly enriched uranium metal for materials test reactors utilized by the U.S. Navy;
- production of uranium-beryllium pellets for use in the SL-1, an experimental U.S. military nuclear power reactor that was part of the Army Nuclear Power Program;
- production of high-enrichment uranium zirconia pellets for a naval reactor; and
- production of highly enriched oxides for use in General Atomics nuclear rocket projects.

Although uranium material production was the primary function at the Hematite Facility, records indicate secondary activities such as uranium scrap recovery and a limited amount of work with thorium compounds as part of early research into the use of thorium in the fuel cycle.

A detailed list of radioactive feed materials historically used for production is not available. However, previous investigators have compiled a list of chemicals (Table 1.1) used at the Hematite Facility during active operations (Section 3.2.6.2, page 26-27 of LBG 2003).

1.4 DESCRIPTION OF THE WESTINGHOUSE HEMATITE FACILITY AND SITE

The Hematite Site and Facility contain features shown on Figs 1.2 and 1.3, respectively, and briefly described below (based on Section 3.2, pages 20-31 of LBG 2003). The "fence line" as used in this Report refers to the "old" fence line, and not the new security fence installed in 2004. The old fence line is shown on all the figures in this report.

- **Buildings.** Several buildings were used for various production operations and material storage. Brief descriptions of the buildings, including historical and current use (as of the date this Report was published), are given in Table 1.2, while building locations are shown on Fig. 1.3. In September 2004, WEC prepared an Engineering Evaluation/Cost Analysis (EE/CA, WEC 2004a) to evaluate potential removal action alternatives for buildings and equipment at the Hematite Facility. The focus of this EE/CA was on buildings that are radioactively contaminated or that can interfere with the future characterization and, if necessary, remediation of impacted soil and/or groundwater beneath the buildings.A Non-Time Critical Action Memorandum was issued in October 2005 documenting the selection of equipement removal and building demplition as the preferred alternative for remediation.

  In advance of building demolition, the former process and storage buildings have been emptied of equipment and materials involved in nuclear fuel production. The removed equipment and materials have been packaged for shipment and sent off-Site for disposal or for metals reclamation. At the conclusion of the equipment removal operations, Westinghouse conducted a final cleaning of the buildings as needed to remove loose dust, dirt, and debris. This cleaning was performed by vacuuming with units fitted with HEPA filtration systems. Following the cleaning, building surfaces were surveyed and, a chemical fixative ("lock down" agent) was applied to the interior surfaces of the radioactively contaminated buildings.

- **Spent Limestone Pile and Fill Areas.** Hydrogen fluoride gas, a byproduct in the UF_6 conversion process, was captured in limestone scrubbers during part of the plant history. Spent limestone was generated from 1968 through 1998, when the limestone scrubbers were replaced with a more efficient wet absorber system. Currently, the spent limestone is stored in surface piles within the fenced area of the Hematite Facility. The spent limestone was also used as fill in at least two areas, one near the Site Spring and the other northeast of the Burial Pits. The spent limestone was also used historically as fill for building and road foundations. Figure 1.3 shows known locations of spent limestone pile and fill areas.

- **Deul's Mountain.** An outdoor pile of potentially radiologically contaminated soil was located southeast of Building 256 (Fig. 1.3). The pile of soil, referred to as Deul's Mountain, came from excavations during construction of Building 256. An EE/CA for removal alternatives was prepared for this material in August 2004 (WEC 2004b) and approved by MDNR in January 2005. A Non-Time Critical Action Memorandum approving excavation and off-Site disposal was signed in June 2005, and the material has been removed from the Facility.

- **"Red Room" Roof Burial Area.** The roof of the "Red Room" of Building 240 was buried in an area located south of Building 101 (the Tile Barn, Fig. 1.3). As noted in Table 1.2, Building 240 was used for UF_6 conversion and the "Red Room" within this building was used for processing highly enriched uranium. Soil contamination was discovered in 1993 during renovations to the Tile Barn and was thought to be from use of this area for temporary scrap storage (Section 3.2.8, page 29 of LBG 2003). Results of a geophysical survey performed in February 2005 detected magnetic and conductivity anomalies in this area, indicative of a trenched or filled area. Details of the investigation can be found in the document *Geophysical Survey at the Westinghouse Hematite Facility, Festus, MO* (Geophex 2005), and the results are summarized in Sect. 2.8 of this RI report.

- **Cistern Burn Pit Area.** The Cistern Burn Pit Area, also located south of Building 101 (Fig. 1.3), was historically used to burn contaminated wood and pallets. Radiological contamination within the cistern was reportedly removed in 1993 (Section 3.2.15, page 31 of LBG 2003) to less than 30 pCi/g of uranium.

- **Burial Pit Area.** The Burial Pit Area is located to the east-northeast of the Hematite Facility (Figs. 1.2 and 1.3). Unlined pits were actively used by previous owners from 1965 to 1970 for disposal of uranium-contaminated materials and other wastes. Other undocumented excavations prior to 1965 may exist. Burial pit logbooks contain entries recorded during the operational period from July 16, 1965 to August 24, 1970 (Section 1.3, page 8 of WEC 2006). According to the logbook, 40 pits were created and filled between 1965 and 1970. The primary waste types disposed of on-site included various solids such as trash, empty bottles, floor tile, rags, drums, bottles, glass wool, lab glassware, acid insolubles, and filters. Chemical wastes were also disposed of in the pits including hydrochloric acid, hydrofluoric acid, potassium hydroxide (KOH), trichloroethene (TCE), alcohols, oils, and wastewater. Based upon the logbook, the mass of uranium disposed in each pit varied, ranging from 178.08 grams to 801.8 grams.

- **Evaporation Ponds.** The Evaporation Ponds are located on the southeast side of the Hematite Facility, south of the process buildings and directly adjacent to and west of the Limestone Storage Pile within the security area on the Site (Fig. 1.3). The ponds were historically used for the disposal of water from cylinder washing potentially contaminated with TCE and technetium-99 (^{99}Tc) (Section 2.6.2, page 15 of LBG 2003). These ponds also received effluent streams for the wet conversion processes being performed in Building 240 (Section 3.2.6.1, page 23 of LBG 2003). Based on aerial photography review, the Evaporation Ponds were constructed sometime after 1966 and before 1971. In 1992, soil was removed from the Evaporation Pond Area as described in Sect. 1.5.3.

- **Sanitary Sewage and Stormwater Systems, including the Former Leach Field.** The current sanitary system (Fig. 1.3) consists of drain lines from buildings, a sewage treatment plant, and a pipeline that carries treated water from the sewage treatment plant to a permitted discharge point into the Site Creek immediately below the Site Pond (Outfall No. 1, Fig. 1.3). The discharge is authorized under a National Pollutant Discharge Elimination System (NPDES) permit issued by MDNR. Sewage sludge is routinely dewatered and disposed of at the Envirocare of Utah low-level waste disposal facility. Due to reduced operations at the Facility, sewage sludge has not accumulated significantly and removal has not been necessary for quite some time. The sanitary system receives water from sinks, toilets, showers, and drinking fountains. It also received pre-treated laundry water, wastewater from a process water demineralization system, and water from laboratory sinks when the Facility was operating. Prior to 1977, wastewater from the sewer pipelines drained into a septic tank and leach field (see Fig. 1.3 for location); the latter is no longer in use since the new sanitary treatment plant was installed. The stormwater system consists of lines that collect water from the roof and ground surface drains and then channel the collected water to a NPDES-permitted discharge point upstream of the Site Pond dam (Outfall No. 3, Fig. 1.3). The Site Pond dam is considered as Outfall No. 2 in the Hematite Facility's NPDES permit.

- **Site Pond and Site Creek.** The Site Pond and Site Creek are located west and southwest of the Hematite Facility and receive NPDES-permitted discharge water from sanitary sewage and storm-water systems (Fig. 1.3). The Site Pond is also fed by a natural spring located on the north tip of the Site Pond (Fig. 1.2). The Site Creek merges with the Lake Virginia tributary, and the combined stream discharges to Joachim Creek (Fig. 1.3).

- **Northeast Site Creek.** This is an intermittent stream that runs parallel to the northeast boundary of the Hematite Facility (Fig. 1.2).

- **Former Gas Station.** This abandoned gas station is within the Hematite Site Property boundary located approximately 1500 ft east of the Hematite Facility along Missouri State Road P (see Fig. 1.2). A 550-gallon single-walled steel underground storage tank was removed in May 2003 (Civil and

Environmental Consultants, Inc. 2003). No associated soil removal was required based on analytical results being below MDNR cleanup guidelines for benzene, toluene, xylene, methyl-t-butyl ether, and total petroleum hydrocarbons. No groundwater was encountered during excavation.

- **Railroad and Gas Pipeline.** Railroad tracks and a high-pressure gas pipeline (approximately 4 to 5 ft deep) cut through the Hematite Site southeast of the Hematite Facility. It has been suggested that the pipeline may be acting as a conduit for contamination transport in the subsurface. During the RI field investigation, excavations to expose the pipeline indicated that the pipeline was not buried in a gravel bed. The materials surrounding the pipeline consisted of native soil. The pipeline depth ranged for 3 to 5 ft below ground surface (BGS).

- **Joachim Creek and Bridge.** This perennial stream runs approximately 800 ft southeast of the Hematite Facility (Figs. 1.1 and 1.2) and eventually discharges into the Mississippi River near the city of Herculaneum, approximately 9 to 10 miles from the Hematite Facility. There were verbal reports of third-party waste disposal activities in the vicinity of Joachim Creek Bridge (Section 3.2.16, page 31 of LBG 2003).

1.5 PREVIOUS ENVIRONMENTAL INVESTIGATIONS AND ONGOING MONITORING PROGRAMS

Brief descriptions of previous investigations are given below, while more details can be found in the referenced reports. Note that additional investigations may have been conducted previously at the Hematite Site. However, reports are only available for the investigations described in the following sections. Comparisons are made between the results of these previous studies and the RI in Chaps. 3 through 5 of this report.

1.5.1 Radiological Survey of the Combustion Engineering Burial Site, July 1983

Radiation Management Corporation, under contract to the Nuclear Regulatory Commission, conducted a radiological survey of the Burial Pits in the spring and summer of 1982 (RMC 1983). External radiation levels were measured and samples were collected to determine radionuclide concentrations in air, groundwater, and surface water. Results of the external radiation surveys indicated detectable levels above background in the northwest corner of the Burial Pit Area adjacent to the old security fence. It was determined that these levels were due to containers of UF_6 routinely stored in an area next to the fence line rather than buried material. Results of surface soil sampling indicated low-level surface contamination that may have resulted from past burial activities or from airborne (i.e., stack) releases. Activities for ^{234}U ranged from 2 to 47 pCi/g, as estimated from ^{238}U activity that ranged from 1.7 to 4.9 pCi/g, and assuming an activity ratio of 10. The activity ratio was estimated from a 4% average enrichment in five samples that were analyzed for isotopic uranium using alpha spectroscopy. Results of subsurface soil sampling (deepest sample at 13 ft) showed the highest ^{234}U activity in the Burial Pits was approximately 400 pCi/g, as estimated from measured ^{238}U activity of 38 pCi/g and a $^{234}U/^{238}U$ activity ratio of 10. In the groundwater and surface water samples, only one groundwater sample collected from a borehole showed gross alpha activity exceeding 15 pCi/L (the drinking water limit at the time). Gross beta activity exceeding 50 pCi/L was found in 5 of the 22 samples, 3 of which came from a borehole near the Evaporation Ponds. High volume air samples collected in the vicinity of the Burial Pits showed no unusual or elevated levels.

1.5.2 Preliminary Assessment Hematite Radioactive Site, Hematite, Jefferson County, Missouri, Ecology and Environment, Inc., April 1990

Ecology and Environment, Inc. prepared a report for Region 7 of the U.S. Environmental Protection Agency (EPA) that discusses the Hematite Site's physical characteristics, potential waste sources, surrounding residential areas and water sources, and groundwater and surface water characteristics (Ecology and Environment 1990). The groundwater assessment was based on regional data and no new field studies were conducted in preparation of this report.

1.5.3 Removal Action: Former Evaporation Ponds

Quadrex performed a radiological characterization of the former Evaporation Ponds in 1992 (Bicehouse 1992). Information gathered from this study was used to develop a source term for risk evaluation. Because of the residual contamination present in the ponds, CE decided to remove soil from the Evaporation Pond area. The material from the retention ponds was disposed at a low-level waste disposal facility.

1.5.4 Investigation to Determine the Source of Technetium-99 in Groundwater Monitoring Wells WS-17 and WS-17B, September 1996

Gateway Environmental Associates, Inc. conducted an investigation to determine the source of ^{99}Tc in overburden monitoring wells WS-17 and WS-17B (GEA 1996). Prior to this investigation, WS-17 had been abandoned due to concerns that the well had a poor surface seal. WS-17B was installed in its place, and subsequent groundwater sampling showed ^{99}Tc activities to be consistent with activities measured in WS-17.

A previous assessment had identified the Evaporation Ponds as a potential source of ^{99}Tc contamination in WS-17 and WS-17B. However, updated groundwater contour maps showed groundwater flow directions that were inconsistent with this hypothesis, and that the more likely source would be located north of WS-17 and WS-17B. Potential sources in this area were the spent limestone pile, the uranium recovery area, and a former ring storage area (located immediately east-northeast of Building 252, refer to Fig. 1.3). Twelve probe holes were drilled to approximately 15 ft deep in the vicinity of these suspected sources. Subsurface soil samples from the probe holes and co-located surface samples were analyzed for gross beta activity. Temporary groundwater monitoring wells were installed in the probe holes, which enabled groundwater level measurements and the collection of groundwater samples for gross beta and ^{99}Tc analysis via liquid scintillation counting. These monitoring wells were abandoned upon completion of the field investigation. Slug tests were conducted in WS-7 and WS-17B to measure hydraulic conductivities.

Soil encountered in all the boreholes (approximately 15 ft deep) consisted of clayey silt overlying silty clay. A highly plastic clay was encountered at the bottom of a few of the boreholes. Hydraulic conductivities were measured at 0.33 ft/day (11.5×10^{-5} cm/sec) in WS-17B, and 0.06 ft/day (2.2×10^{-5} cm/sec) in WS-7. The field hydrogeologist performing the slug test noted the presence of a more conductive discrete zone within WS-17B at 8 to 10 ft BGS.

Based on the groundwater contour map constructed from water levels in the temporary wells, Gateway Environmental Associates concluded that the ^{99}Tc may have entered the groundwater system within the former ring storage area and traveled downgradient toward WS-17/WS-17B. The distribution of gross beta activity in the temporary wells generally supported this hypothesis, with gross beta activity being highest directly underneath the former ring storage area. Gross beta activity in a few surface soil samples from this area were also elevated; however, gross beta activity in the subsurface soil samples

could not be distinguished from the established background. The spent limestone pile and uranium recovery area (area where uranium was extracted from cuno filters; exact location not clear from the report) were deemed to be unlikely sources of ^{99}Tc.

1.5.5 Exploratory Probe-hole Investigation for the Evaporation Ponds at the ABB Combustion Engineering Hematite Facility, April 1997

Gateway Environmental Associates, Inc. conducted a probe-hole investigation in the Evaporation Pond Area (GEA 1997). Seven shallow probe holes (4 ft deep) were advanced within the berm area of the ponds primarily to determine the thickness of the gravel/crushed limestone surface layer. Four deeper probe holes (20 ft deep) were drilled immediately adjacent to the Evaporation Ponds to determine gross alpha and total uranium levels in soil. Soil encountered was generally clayey silt overlying silty clay. A sandy silt layer was encountered at the bottom of one of the probe holes. A gravel layer was encountered in only two of the seven boreholes and was less than 1 ft thick.

Gross alpha activities, which were elevated relative to background, were detected in some of the samples, ranging from 90 to 744 pCi/g. All the samples with elevated gross alpha activities were taken at depths of 5 ft BGS or less. Total uranium activity was detected in some of the samples, ranging from 5 to 534 pCi/g. As in the gross alpha measurements, all the samples with detectable total uranium activity were from depths less than 5 ft BGS.

1.5.6 Hydrogeologic Investigation and Groundwater, Soil and Stream Characterization, March 1999

Leggette, Brashears & Graham, Inc. (LBG), under contract to CE, conducted a hydrogeologic investigation at the Hematite Site in 1998 (LBG 1999). Specific activities included: (1) a geophysical study to delineate the areal extent of the Burial Pit Area; (2) drilling of 17 borings, which were subsequently completed as monitoring wells or piezometers (see Fig. 1.2 for locations of monitoring wells completed as part of this LBG study); (3) physical and chemical analyses of soil and groundwater samples collected from the boreholes and monitoring wells, respectively; and (4) slug testing in selected wells. All of the wells installed during this investigation were located within the vicinity of Hematite Facility (Fig. 1.2). Most were completed in the overburden, while two piezometers and two monitoring wells were installed in bedrock (60 ft BGS depth).

The geophysical study showed numerous disposal trenches detected as anomalies in the geophysical data. The study also indicated that all disposal trenches detected by the instruments contained ferrous materials. Areas where no anomalies were detected could indicate the absence of disposal trenches, or that the geophysical instruments used could not distinguish between the buried materials in these areas and the surrounding soil. A high percentage of the buried ferrous material is present within 10 ft of the surface.

LBG identified five hydrostratigraphic units (HSU) based on the borehole logs and physical tests on soil samples. These units were: (1) a near surface silt/silty clay (NSSSC), which consisted of a brown/gray firm and friable silt that typically graded to a moderate yellowish-brown silty clay; (2) a fat clay, which consisted of a firm to very firm, gray/olive-gray plastic soil; (3) a deeper silty clay/clay (DSCC), which consisted of a slightly firm, slightly plastic, olive gray/gray soil; (4) a clayey/silty/sandy gravel; and (5) the Jefferson City Formation (the first bedrock formation encountered at the Site, refer to Chapter 3 for more detailed discussion of Site geology). The fat clay layer (6 to 10 ft thick) separated the near-surface and deeper silty clay layers but appeared discontinuous because it was not encountered in all the boreholes drilled for this investigation. Atterberg Limit tests confirmed the high plasticity of the fat clay layer; however, tests on some of the samples from the deeper silty clay also indicated high plasticity. These results suggest the gradation between the fat clay layer into the deeper silty clay layer may be

gradual, or the potential presence of fat clay lenses in the deeper silty clay layer. LBG concluded that the fat clay layer could not be considered an aquitard because of its discontinuous nature. The clayey/silty/sandy gravel unit was encountered (thickness ranging from 4 to 6 ft) in all boreholes that were drilled to refusal or auger-drilled to bedrock. Note that all of these boreholes were drilled outside the old fenced area of the Hematite Facility (see Fig. 1.2). Visual examination of the core from one of the boreholes (WS-31, see Fig. 1.2 for location) drilled through shallow bedrock showed gray/tan, fine-grained dolomite. No vertical fractures or joints were intersected by this borehole and bedding planes appeared to be well-sealed. LBG concluded that storativity and transmissivity of the dolomite was from bedding planes and fractures rather than the matrix. A potentiometric surface constructed for the deeper silty clay/sandy-gravel layer indicated a groundwater flow direction generally toward Joachim Creek. A separate potentiometric surface was developed for the near-surface silty clay layer, which indicated multiple groundwater flow directions depending on location within the Hematite Facility.

Average hydraulic conductivities measured in the different HSUs were: (1) 3×10^{-5} cm/sec for the near-surface silty clay, (2) 80×10^{-5} cm/sec for the deeper silty clay layer, (3) 600×10^{-5} cm/sec for the sandy gravel layer (result from one well), (4) 1×10^{-5} cm/sec for unfractured bedrock, and (5) 80×10^{-5} cm/sec for fractured bedrock.

With the exception of one blind duplicate sample, results of VOC analyses in soil samples showed concentrations of perchloroethylene (PCE) that were near the detection limit (5 μg/kg). TCE was not detected in any of the soil samples. The inconsistency between the duplicate samples (the blind duplicate exhibited elevated levels of TCE and PCE) was attributed to sample heterogeneity or laboratory error. In groundwater, TCE and PCE were detected at levels above 50 μg/L in one bedrock well (WS-30, 430 and 350 μg/L, respectively; the piezometer wells were not sampled), and in one well screened within the deeper silty clay and sandy gravel layers (WS-32, 20,000 and 4,400 μg/L, respectively). TCE and PCE in the rest of the groundwater samples were either below the detection limit of 5 μg/L or were less than 50 μg/L. The measured radiological activities were deemed to be approximately at background levels, although a statistical analysis of the data was not conducted. VOCs were below the quantitation limit (4 μg/kg) and radionuclide activity was not detected at levels above background in stream sediment samples collected from two locations (one from the Site Creek downstream of the Site Pond dam and the other from the Northeast Site Creek). PCE was detected near the detection limit (5 μg/L) in the surface water sample collected from the Site Creek. VOCs were not detected in the other surface water samples collected from Joachim Creek and the Northeast Site Creek. Polychlorinated biphenyls (PCBs) were not detected in any of the surface water samples. The surface water samples did not exhibit levels of alpha, beta, or gamma activities above background.

1.5.7 Interim Hydrogeologic Investigation to Support the Engineering Evaluation and Cost Analysis for Response Actions for Off-Site Groundwater Quality, November 2002

In the summer of 2002, WEC retained LBG to perform an interim hydrogeologic investigation (LBG 2002b) to address the detection of VOCs in a number of private water wells near the Hematite Site. Contamination in these private wells was detected in December 2001, when the Missouri Department of Health and Senior Services, upon request from MDNR, added VOCs to the suite of radiological analytes that were normally included in their annual radiological monitoring program. The purpose of the interim hydrogeologic investigation was to evaluate the extent and degree of impacted groundwater on an expedited basis. The results of the study were used to evaluate and, ultimately, select a time-critical removal action to address the detection of VOCs in nearby private domestic water supply wells. The investigation also addressed monitoring for future off-Site and vertical contaminant migration by installing sentry wells.

Bedrock cores were collected from the formations underlying the Hematite Site including the Jefferson City-Cotter Formation, the Roubidoux Formation, and the top of the Gasconade Formation (in order of increasing depth, more details regarding Site geology are presented in Chapter 3). The bedrock borehole locations (BR-01 through BR-04) are shown in Fig. 1.2. The geology and hydrogeologic properties of the bedrock underlying the Site were evaluated through various geophysical tests and video-logging. Vertical profiling of groundwater quality was accomplished by collecting discrete groundwater samples from packer-isolated intervals within the bedrock boreholes. In addition, two overburden boreholes were drilled at two locations along the natural gas pipeline (OB-01 and OB-02) to address concerns that this pipeline was acting as a conduit for off-Site contaminant migration. Monitoring wells were installed in the overburden borehole locations (OB-01 and OB-02) and in BR-03, where analysis by a mobile laboratory indicated the presence of PCE in an overburden soil sample from this location. Wells screened in the Jefferson City-Cotter and the Roubidoux Formations were installed in the bedrock borehole locations; bedrock wells were not installed in the Gasconade Formation because contamination was not detected in any of the groundwater samples collected during sampling of packer-isolated intervals. Bedrock monitoring wells were installed in the Jefferson City-Cotter Formation at BR-01, BR-02, and BR-04. Bedrock monitoring wells were installed in the Roubidoux Formation at BR-01 through BR-04 (see Appendix D for well construction data for all wells installed at the site). Potentiometric maps were prepared from water level measurements in the newly installed bedrock wells.

The geologic character of the overburden was consistent with the previous investigation (Section 4.2, pages 9-13 of LBG 1999). An anomalously deep overburden/bedrock interface was noted in BR-04 (~50-ft depth, compared to 30 to 35 ft within the Hematite Facility). Rock quality and permeability showed a wide range of results even within the same formation; no consistent trends or patterns were noted. Based on potentiometric maps developed for the Jefferson City and Roubidoux Formations, groundwater flow was predominantly to the east. Calculated hydraulic conductivities from the slug tests were reported, although some of these values are suspect due to problems with the drawdown analysis or with the drawdown data (see Chapter 3).

VOC analyses by a mobile laboratory indicated low levels (approximately 4 μg/L of TCE, approximately 12 μg/L of PCE) in groundwater from the overburden well at BR-03. TCE and PCE were not detected in the other overburden wells (OB-01 and OB-02) and in an overburden groundwater sample collected from BR-04. During groundwater sampling from packer-isolated intervals in bedrock at BR-01 through BR-04, VOC contamination was only detected in BR-04 at the 95- to 105-ft-BGS depth interval (within the Jefferson City-Cotter Formation). This was confirmed by analysis of a groundwater sample collected from the bedrock monitoring well subsequently installed and screened within this interval. Contamination in the deeper Roubidoux and Gasconade Formations was not detected in any of the bedrock borehole locations during this study.

Gross alpha and gross beta activities were measured in soil samples collected from the overburden. The data were presented but not discussed due to the lack of information regarding background activities. Gross alpha, gross beta, total U, and ^{99}Tc activities were measured in groundwater samples from the overburden and bedrock. Technetium-99 was below detection limits (approximately 2 pCi/L) in all groundwater samples. Maximum gross alpha, gross beta, and total uranium activities in filtered groundwater samples were 64.7, 118, and 28.7 pCi/L, respectively.

1.5.8 Gamma Walkover Survey, April 2003

A gamma walkover survey (SAIC 2003a) over the entire Hematite Facility and large areas within the Hematite Site was conducted in April 2003 by SAIC. Areas with elevated gamma count rates were consistent with AOCs that had been previously identified (Section 3.2, pages 20-31 in LBG 2003, and Sect. 1.6 of this report). Thus, the survey did not reveal any new surficial sources of radiological contamination. The gamma

walkover survey results were used to locate surface sample locations for the RI; a comparison between the areas with elevated gamma count rates and radiological analyses of surface samples is presented in Chapter 4 of this RI report.

1.5.9 Determination of Distribution Coefficients for Radionuclides of Concern at the Westinghouse Hematite Facility, July 2003

In July 2003, SAIC conducted a study to measure site-specific distribution coefficients for uranium and ^{99}Tc using soil collected from the Hematite Site (SAIC 2003c). A total of 18 soil samples were collected from 6 borings that were advanced to refusal (assumed to be bedrock). Soil physical properties, as well as isotopic uranium and ^{99}Tc activities, were measured in the soil samples prior to conducting the distribution coefficient tests. The soil samples tested in the laboratory were representative of the brown silty clay typically found in the shallow overburden at the Hematite Site. Uranium activities were detected at elevated levels in samples from the restricted areas adjacent to the process buildings (>200 pCi/g total uranium) and the shallowest sample collected from the Tile Barn/Cistern Burn Area (>34 pCi/g total uranium). Except for one sample from the restricted areas, ^{99}Tc was not detected at concentrations greater than the laboratory reporting limits in the samples collected for the study. Results of this investigation are described in *Determination of Distribution Coefficients for Radionuclides of Concern at the Westinghouse Hematite Facility* (SAIC 2003c).

1.5.10 Wetlands and Surface Water Assessment

In preparation for the RI, a wetland and surface water assessment was conducted in November 2003 to delineate and classify potentially jurisdictional wetlands and surface water bodies at the Hematite Site (SAIC 2004a). The assessment was conducted to identify potential impacts of Site investigation activities (i.e., well installation and road building) with regard to compliance with requirements of Sects. 401/404 of the Clean Water Act. The single potential wetland identified at the Hematite Facility is located in a small depression south of the Hematite Facility between the railroad berm and a gravel road that goes from the vicinity of the Hematite Facility to the south towards Joachim Creek. The wetland is a small isolated forested/scrub shrub wetland that is confined to the south and southwest by the gravel road and to the north by the railroad berm. There were no inputs or outputs at the wetland and hydrology appears to be the result of precipitation, which ponds between the road and railroad. A field survey of surface water bodies within the Property was also conducted, and detailed descriptions of the intermittent streams were performed. Based on the wetland and surface water survey, it was concluded that Site investigation activities can be implemented without significant impact to wetlands and surface water bodies.

1.5.11 Ongoing Environmental Monitoring Programs

Since 2002, quarterly groundwater monitoring samples have been collected from bedrock wells BR-01-RB, BR-02-RB, BR-03-RB, BR-04-RB, and BR-04-JC (see Fig. 1.2 for well locations) and analyzed for VOCs and radiological contaminants. Groundwater samples have also been collected periodically at private wells near the Hematite Facility; these private wells are shown in Figure 1.2 (labels begin with "PW"). A discussion of these monitoring results is provided in Chapter 4 of this RI report.

As mentioned previously, the stormwater and sewer water outfalls that discharge into the Site Pond and Site Creek, respectively (Outfalls 1 and 3, see Fig. 1.3), are permitted under NPDES. As part of permitting requirements, both of these outfalls and the surface water at Site Pond Dam (Outfall No. 2, see Fig. 1.3) are monitored regularly for parameters required under the NPDES permit.

The Hematite Facility operates under a Special Nuclear Materials (SNM-33) license from the Nuclear Regulatory Committee (NRC). Following NRC license requirements, samples are routinely

collected for groundwater (nine wells), surface water (four locations), sediment (one location), surface soils (seven locations), vegetation (four locations), and air (from three stack emissions) for gross alpha/gross beta analysis (air samples are analyzed for gross alpha only). The license sampling also includes the effluent sampling conducted under the NPDES permit.

1.6 AREAS OF CONCERN AND POTENTIAL CONTAMINANTS OF CONCERN

Records of historical operations at the Hematite Facility and results of previous investigations were used to develop the following list of AOCs and associated RCOPCs and CCOPCs (Tables 1 and 2 of LBG 2003, see Fig. 1.4 for map of AOCs):

- AOC #1 Groundwater (PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, and ^{99}Tc),
- AOC #2 Surface Water Features (PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, ^{99}Tc, and ^{232}Th),
- AOC #3 Burial Pits (PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, ^{99}Tc, and ^{232}Th),
- AOC #4 Evaporation Ponds (PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, ^{99}Tc, and ^{232}Th),
- AOC #5 Former Leach Field/Sanitary Sewer System (^{232}Th, PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, and ^{99}Tc),
- AOC #6 Soil Beneath Buildings (PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, ^{99}Tc, and ^{232}Th),
- AOC #7 Limestone Storage and Limestone Fill Areas (^{238}U, ^{235}U, ^{234}U, ^{99}Tc, ^{232}Th, and fluoride),
- AOC #8 Outdoor and Shallow Surface Area (PCE, TCE and associated degradation products, fluoride, ^{238}U, ^{235}U, ^{234}U, ^{99}Tc, and ^{232}Th),
- AOC #9 Former Gas Station [PCE, TCE and associated degradation products, semivolatile organic compounds (SVOCs), total petroleum hydrocarbons, and metals],
- AOC #10 Gas Pipeline (PCE, TCE and associated degradation products, fluoride, ^{99}Tc, and ^{232}Th),
- AOC #11 Red Room Roof Burial Area (^{238}U, ^{235}U, ^{234}U, ^{232}Th, and fluoride),
- AOC #12 Domestic Well #3 (PCE and TCE and associated degradation products),
- AOC #13 Deul's Mountain (^{238}U, ^{235}U, ^{234}U, ^{232}Th, and fluoride),
- AOC #14 Cistern Burn Pit Area (PCE, TCE and associated degradation products, SVOCs, metals, dioxin, fluoride, ^{238}U, ^{235}U, ^{234}U, and ^{232}Th), and

- AOC #15 Joachim Creek Bridge. This area was included as an AOC to investigate if materials were buried at this location. No sampling was planned for this AOC (LBG 2003). A geophysical survey was conducted to investigate the AOC (Geophex 2005, also summarized in Sect. 2.8).

The AOCs generally align with the Hematite Site features that are described in Sect. 1.4 of this RI report. With the exception of Joachim Creek Bridge, which was addressed through a geophysical survey (Geophex 2005), the RI field activities were conducted such that soil, sediment and/or groundwater samples were collected from each of the AOCs.

CHAPTER 1 FIGURES

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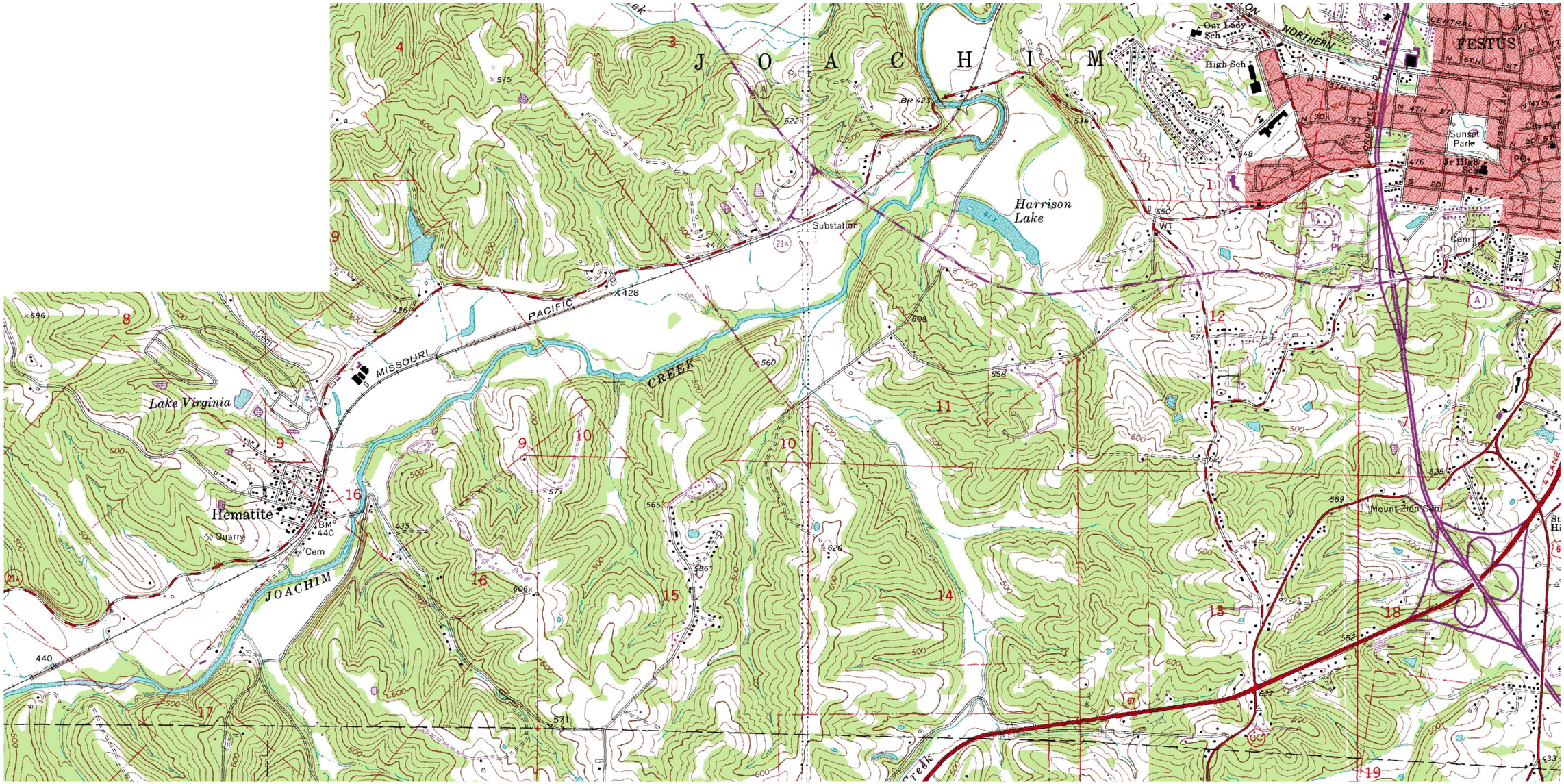

Fig. 1.1. Location of Hematite Site.

AOC	Description
#1	Site Groundwater
#2	Site Pond, Site Creek, and Northeast Creek
#3	Burial Pits
#4	Evaporation Ponds
#5	Former Leachfield/Sanitary Sewer
#6	Soils Beneath Buildings
#7	Limestone Storage and Fill
#8	Outdoor and Shallow Surface Area
#9	Former Gas Station
#10	Natural Gas Pipeline
#11	Red Room Roof Burial Area
#12	Domestic Well #3
#13	Deul's Mountain
#14	Cistern/Burn Pit
#15	Joachim Creek Bridge

TO HEMATITE

Fig. 1.4. Areas of concern at the Hematite Site.

CHAPTER 1 TABLES

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Table 1.1. Chemicals used at the Hematite Facility (adapted from LBG 2003)

Chemical	Use and known storage volumes
Anhydrous ammonia	– less than 750,000 lbs/year used as a reducing gas (cracked ammonia) in the production of UO_2, powder, pellets, and in preparation of material for recycle. Typically stored on-site in 16,000-gal tanks. Typical quantity stored on-site was 47,000 lbs.
Potassium hydroxide (KOH)	– approximately 4,000 lbs/year. Mixed with process water and used as wet-scrubber liquor to remove hydrofluoric acid from the recycle pyrohydrolysis-process effluent. Typical quantity stored on-site: <4,000 lbs.
Liquid nitrogen	– approximately 10,000 L/year were delivered by tanker or generated on-site for use with ammonia to provide air vent cover gas in the conversion process and the pellet furnaces. Typical quantity stored on-site: <8,000 gal. 66,000 lbs typical storage.
Hydrochloric acid	– approximately 900 lbs/year used in cleaning heat-exchanger tubes in the steam boiler and demineralizer regeneration. Typical quantity stored on-site: <1,000 lbs.
Nitric acid	– less than 15,000 lbs/year used to dissolve the U_3O_8 wet-recovery process feed material. Typical quantity stored on-site: <5,000 lbs.
Hydrogen peroxide	– approximately 20,000 lbs/year used to provide a source of oxygen in the wet-recovery process. Typical quantity stored on-site: <7,000 lbs.
Isopropyl alcohol	– approximately 5,000 lbs/year used in cleaning. Typical quantity stored on-site: <3,000 lbs.
Hydrogen fluoride (HF)	– from 1998 until 2001, approximately 980,000 lbs of 35% hydrofluoric acid was generated as a byproduct of UF_6 to UO_2 conversion. Typical quantity stored on-site: <60,000 lbs.
Trichloroethylene (TCE)	– TCE was a thinner for a binding agent used in pellet manufacturing. Records indicate that one drum of TCE was buried in the Burial Pits. TCE was used as a manufacturing aid until the late 1980's and for miscellaneous uses within the plant until the early 1990's.
Perchloroethylene (PCE)	– PCE was used from 1962 to 1972 for fuel refinement for the U.S. Navy, and the Facility used PCE in a pilot fuel process in 1964 and 1965 (Building 255). PCE was used as a process catalyst until the early 1970s and was used at the Hematite Facility in a historic uranium-processing operation. Specific beginning and end dates for the use of this chemical are unknown.

Table 1.2. Historical and current use of buildings within the Hematite Facility (Adapted from LBG 2003; refer to Fig. 1.3 for locations within the Hematite Facility.)

Building number or area designation	Description
Building 101 Tile Barn	The Tile Barn was most recently used as the emergency operations center. Historically, clean and radiological-contaminated equipment had been stored in this building. During construction of the emergency operations center, residual radiological contamination was detected at low activities.
Building 110 Office Building	This building houses the security office and general office space. Radioactive work has never been performed in this building.
Building 115 Diesel Generator – Fire Pump Building	This building housed a diesel-powered emergency generator and a diesel-powered firewater pump. The diesel generator provides backup emergency power to maintain critical loads. No work with radioactive material is known to have been performed in this building.
Building 120 Wood Barn	The Wood Barn has a dirt floor and had historically been used to store both clean and radiological-contaminated equipment. The dirt floor may contain low levels of radioactive contamination.
Building 230 Rod Loading	This building was built around 1992 and was used for loading finished pellets (standard, erbium, and gadolinium) into fuel rods and assemblies in preparation for shipment off-site. No appreciable amounts of chemicals were used in this building. This building currently houses general offices and equipment storage.
Building 231 Warehouse	This building was used for storage of shipping containers. Some refurbishment of shipping containers was conducted in this building. This building is currently used for shipping/receiving and material storage.
Building 235 West Vault	The building was used to store depleted and natural uranium.
Building 240 Red Room, Green Room	This building contained laboratory and maintenance areas, a recycle recovery area, a waste incineration area, and the Health Physics laboratory. Historically, this building housed operations for the conversion of uranium hexafluoride into compounds, solutions, and metal. Building 240 was further divided into two areas: the "Red Room" used for high-enrichment conversion processes and the "Green Room" used for low-enrichment conversion processes and high-enrichment scrap processing. Effluent streams for the wet-conversion processes were piped to the Evaporation Ponds for settling and evaporation. During the plants operation, spills and leaks occurred in these areas and parts of the slab have been subsequently re-poured over the existing contaminated flooring.
Building 252 South Vault	The building was used for storage of oil, chemicals, and source and special nuclear material of various enrichments.
Building 253 Office Building	This building contained offices, various site utilities, uranium storage areas, processing areas, and decontamination facilities. Within Building 253 is an inner building (Building 250) that was formerly a stand-alone structure that housed a boiler, cooling tower pumps, a recycle hopper, and storage areas. Sub-slab contamination was found during the construction of Building 253 in 1989.
Building 254 Pellet Plant	This building was constructed in 1989 and housed equipment and operations for producing fuel pellets from granules of UO_2 or U_3O_8.
Building 255 Erbia Plant	This building was used for the fabrication of uranium compounds into physical shapes. It contained equipment and operations for production of uranium-erbium pellets until 1989 when Building 254 was constructed and pelletizing operations were moved to the new building.
Building 256 Pellet Drying and Warehouse	This structure was for drying of pellets in electric ovens. The structure was also used as a main warehouse for shipping pellets and powder, and for receiving site supplies.
Building 260 Oxide and Oxide Loading Dock	This building, which was built in 1968, housed equipment and operations for the conversion of UF_6 into uranium oxide granules. Other chemicals used or generated in this area include: UO_2, UO_2F_2, U_3O_8, NH_3, N_2, dissociated ammonia, limestone, and CaF_2.

2. SITE CHARACTERIZATION ACTIVITIES

This chapter presents a description of the Site characterization activities performed during the RI in accordance with EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1992), *Superfund Program Representative Sampling Guidance* (EPA 1995), the RI/FS work plans and TSWPs. These activities include:

- sampling and analysis of surface water and sediment from surface water bodies, (Sect. 2.1);
- sampling and analysis of surface soils, (Sect. 2.2);
- sampling and analysis of subsurface soils and installation of temporary overburden monitoring wells (Sect. 2.3);
- bedrock coring, discrete interval sampling, installation of bedrock monitoring wells, discrete interval sampling in select domestic wells, diffusion bag groundwater sampling and analysis, and conversion of select domestic wells to dual-completion monitoring wells (Sect. 2.4);
- in situ hydraulic conductivity testing (Sect. 2.5);
- site-wide baseline sampling of groundwater monitoring wells, including inspection and redevelopment of pre-RI monitoring wells and development of newly installed wells (Sect. 2.6);
- sampling of surface and near-surface soils from off-Site locations (i.e., background sampling) (Sect. 2.7); and
- geophysical survey to locate any buried metals and to assist in the identification of unknown "disturbed areas" (Sect. 2.8).

Overall, the intent of this investigation was to implement a phased approach to sampling. Surface soil sampling locations were selected based on the results of the gamma survey (SAIC 2003a). Subsurface soil sampling locations were based on the need to obtain representative data in all AOCs. Available surface soil analysis results, qualitative VOC depth profiles obtained at multiple locations using a membrane interface probe (MIP), and plume delineation models generated during previous investigations (Plates 3 and 5 of LBG 2002b) were also considered in locating subsurface soil samples. Groundwater target constituents for laboratory analyses were selected based on surface and subsurface soil analytical data from previous studies and quick-turnaround field-screening data obtained from the on-going RI.

2.1 SURFACE WATER AND SEDIMENT SAMPLING

The surface water bodies in the vicinity of the Hematite Site which may have been impacted by historical Site operations are the Site Pond, the Site Creek, Joachim Creek, and the Northeast Site Creek (see Fig. 1.3). The Site Pond and Site Creek receive NPDES-permitted discharge water from sanitary sewage and stormwater systems at Outfalls #1 and #3. The Site Pond is also fed by a natural spring located on the north tip of the Site Pond. The Site Creek merges with the Lake Virginia tributary, and the combined stream discharges to Joachim Creek. The Northeast Site Creek does not directly receive wastewater discharge from the Hematite Facility, but it may have been impacted by surface water runoff and groundwater discharge from the Burial Pit Area. Joachim Creek maybe have been impacted by historical Site operations through surface water flow from the Site Creek and the Northeast Site Creek, as

well as shallow groundwater flowing downgradient from the Hematite Site and discharging into Joachim Creek, surface water runoff from impacted Site soils, and flooding. Some discharge of contaminants is allowed by the NPDES permit for the Facility, and has been monitored according to NPDES permit requirements.

The TSWP *Surface Water and Sediment Investigation* (SAIC 2004a) served as guidance for this portion of the field investigation, along with EPA guidance document *Superfund Program Representative Sampling Guidance Volume 5: Water and Sediment* (EPA 1995).

2.1.1 Surface Water Level Measurements

Staff gauges were installed at the Site Pond, Site Creek, Joachim Creek, Northeast Site Creek, and East Lake; specific locations are shown on Fig. 2.1. Elevations of the staff gauges were surveyed by a professional land surveyor. Surface water levels were measured monthly from June 2004 through January 2005 to assess the hydraulic relationship between these surface water bodies and local groundwater.

2.1.2 Surface Water Sampling

Surface water samples (Fig. 2.2) were collected from the Site Pond (US-03-SW and SW-01-SW), Northeast Site Creek (US-01-SW and SW-09-SW), East Lake Tributary (US-04-SW), and Joachim Creek (US-05-SW, SW-16-SW, SW-08-SW, SW-14-SW, SW-02-SW, SW-15-SW) (Fig. 2.2). One upstream surface water sample (US-02-SW, Fig. 2.2) was also collected from the Lake Virginia Tributary, which merges with the waters of Site Creek prior to discharging to Joachim Creek. Samples from the creeks were collected as grab samples at mid-depth in moving water at the main flow line of the creeks and were considered to represent the entire creek cross-section. Surface water samples collected from Site Pond (SW-01-SW) and an upstream spring location (US-03-SW) were vertical composites from the deepest points in the pond, except for the samples for VOC analyses which were collected as grab samples.

Prior to sample collection, field parameters [i.e., dissolved oxygen (DO), pH, temperature, and specific conductivity] were measured using a water quality meter at each surface water sampling location (SAIC FTP-880). Surface water samples from the Site Creek and Northeast Site Creek were collected using a dipper (SAIC FTP-577), while Joachim Creek and Site Pond were sampled with a bomb sampler due to the deeper water profiles. Downstream samples were collected first, then the remaining samples were collected in an upstream direction to minimize disturbance. Samples for VOC analysis were collected first, with special attention to minimize headspace, followed by the collection of samples for any remaining constituents. At locations where water and sediment samples were collocated, water samples were collected before the sediment samples, and upstream from any imprint made in the streambed. Sampling equipment and tools were decontaminated between sampling locations (SAIC FTP-405). Immediately upon collection, the samples were containerized, labeled, and placed on ice. Surface water samples were shipped to an off-site laboratory and analyzed for RCOPCs and CCOPCs using methods shown in Table 2.1. Quality control (QC) samples [i.e., field duplicates, matrix spikes (MSs), and matrix spike duplicates (MSDs)] were collected at a rate of 1 for every 12 sample locations. Rinsate blanks were collected daily from the decontaminated sampling equipment and analyzed for the full suite of constituents sampled that day. Trip blanks for VOC analysis and temperature blanks were included in each shipping container. A summary of analytical results for the surface water samples are presented and discussed in Chapter 4 of this report.

2.1.3 Sediment Sampling

Sediment (streambed) samples from the Site Creek/Lake Virginia Tributary (SW-04-SS and SW-03-SS), Site Pond (SW-05-SS, SW-07-SS, SW-06-SS, SW-01-SS), Northeast Site Creek/East Lake Tributary

(SW-11-SS, SW-12-SS, SW-13-SS, SW-10-SS, US-04-SS), and Joachim Creek (US-05-SW, SW-16-SS, SW-08-SS, SW-14-SS, SW-02-SS, SW-15-SS) were collected as grab samples (Fig. 2.3). The samples were collected in depositional areas along the main flow line of the water body because particle-reactive contaminants tend to concentrate in the fine-grained sediments in depositional zones. Sediment samples from the Site Pond were collected at the deepest points in the pond at the upper and lower ends.

Streambed and pond sediment samples were collected using stainless steel trowels, shovels, and augers depending on field conditions at the time of sampling. Upon collection, the sample was extracted from the sampling device and placed immediately in appropriate laboratory containers. Samples for VOC analysis were collected first, with special attention to minimize headspace, followed by the collection of samples for any remaining constituents. Sample containers were labeled and placed on ice (SAIC FTP-650). Sediment samples were shipped to an off-site laboratory and analyzed for RCOPCs and CCOPCs (Table 2.2). QC samples (i.e., field duplicates, MSs, and MSDs) were collected at a rate of 1 per 17 sample locations. Sampling equipment was decontaminated between sampling locations (SAIC FTP-405). Rinsate blanks were collected daily from the decontaminated sampling equipment and analyzed for the full suite of constituents sampled that day. Trip blanks for VOC analysis and temperature blanks were included in each shipping container. A summary of analytical results for the sediment samples are presented and discussed in Chapter 4 of this report.

2.2 SURFACE SOIL SAMPLING

Surface soil samples were collected at 12 AOCs (note that some of the AOCs do not include surface soil media, e.g., AOC #1 Groundwater), at other sampling locations identified during the gamma survey (SAIC 2003a), and along east-west and north-south transect lines across the Hematite Site to aid in the evaluation of potential impacts due to deposition from air emissions or contamination from surface activities. Surface soil samples were collected at 115 locations (Figs. 2.4a and b). The *Surface Soil Investigation* TSWP (SAIC 2004b), as well as the EPA document *Superfund Program: Representative Sampling Guidance, Volume 1: Soil* (EPA 1995), served as guidance for this portion of the field investigation. Sample locations and frequencies varied from the initial location/frequencies detailed in the RI/FS Work Plan (LBG 2003) based on data gathered during the gamma survey (SAIC 2003a).

Soil samples were collected from a depth of 0 to 0.5 ft below ground surface (BGS) using stainless steel spades or trowels (SAIC FTP-550). Sample locations covered by asphalt or concrete were relocated to the nearest unpaved area. After collection, samples were placed in stainless steel bowls for radiological screening and classification by a field geologist according to the Unified Soil Classification System (USCS).

Surface soil samples were screened for beta-gamma activity using portable radiation monitoring equipment: Geiger-Mueller (GM) for beta/gamma and a sodium iodide (NaI) for gamma activity (SAIC FTP 451). Relative background count rates (in air) were obtained at each sampling location prior to screening samples. The relative background count rates were used for comparison with count rates from screening the soil core as an indication of the soil core's activity. In addition, prior to final selection of each surface soil sampling location, the general area surrounding the planned location was scanned with a 2 × 2-in. NaI gamma radiation detector. If activities within an area around the planned sampling location did not exhibit elevated activity, then the sample was collected at the planned location. If an area of elevated activity was located during the general area scan, then the location with elevated activity was selected for sampling.

After the soil samples were logged and surveyed, they were containerized, labeled, placed on ice, and shipped to an off-site laboratory (SAIC FTP-650) for radiological and chemical analysis (Table 2.3). Samples

for VOC analyses were collected first, with special attention to minimize headspace. The remaining soils were homogenized in stainless steel bowls. QC samples were collected at a rate of 1 per 19 for field duplicates and 1 per 29 for MS/MSD samples. Rinsate blanks were collected daily and analyzed for the full suite of constituents sampled that day. Trip blanks for VOC analysis and temperature blanks were included in each shipping container. Analytical results for the surface soil samples are presented and discussed in Chapter 4 of this report.

Samples of the spent limestone were collected from approximately ten locations within each of the three limestone storage/fill areas (Figure 1.3) and composited for laboratory analysis. Approximately 50% of the samples within each limestone pile/area were collected at the surface (i.e., within the top 6 inches) and the remaining samples were collected at various depths. The ten samples from each limestone pile/area were then composited in accordance with SAIC FTP-691, Composite Procedures, and sent to the analytical laboratory for the same analyses performed for surface soil samples (see Table 2.3) with the exception of isotopic uranium and thorium analyses. Analytical results for the limestone pile composite samples (LS-01 through LS-03, see Figure 2.4b) are analyzed together with the rest of the surface soil sample results in Chapter 4 of this report.

2.3 SUBSURFACE SOIL SAMPLING AND INSTALLATION OF OVERBURDEN MONITORING WELLS

The Hematite RI TSWP, *Subsurface Soil Investigation and Overburden Monitoring Well Installation and Development* (SAIC 2004c), and associated field changes served as guidance for this portion of the field investigation. Potential soil sampling locations were initially screened using a MIP advanced through the subsurface to bedrock or refusal using direct-push technology (DPT). The focus of the MIP and DPT investigations was VOC detection and plume delineation. These locations were selected in accordance with the AOCs (Sect. 1.6); in many instances, locations were also selected due to elevated radiological activity detected during the gamma survey (SAIC 2003a). If real-time screening data provided by the MIP indicated the presence of VOCs, soil samples were then collected at the same location for VOC analysis. Rotary drilling was used to obtain overburden soil samples in locations where bedrock coring was performed. Details regarding subsurface soil screening, soil sampling, and installation of temporary monitoring wells in the DPT boreholes are described in the following subsections.

2.3.1 Field Screening Using the MIP

The MIP is a recently developed field-screening tool that enables rapid assessment at depth where VOC contamination is likely to be found. As the probe is advanced into the subsurface, VOCs diffuse through a membrane into the heated probe and are swept into gas-phase detectors located on the ground surface. The MIP detectors include a flame ionization detector (FID), an electron capture detector (ECD), and a photoionization detector (PID). Elevated responses from these detectors for a given probe depth indicate the potential presence of VOCs. The MIP is also equipped with instruments that measure soil conductivity, probe depth, and temperature.

If the MIP detector logs indicated the presence of VOCs, a separate borehole for soil sampling was advanced within close proximity of the MIP hole. The MIP logs (i.e., detector response versus depth) were used to select depth intervals within a soil core for qualitative headspace screening and quantitative VOC analysis (Sect. 2.3.2). In some cases, the MIP was used to verify clean soil to verify VOC plume boundaries in subsurface soil. A total of 93 locations were investigated with the MIP; MIP logs can be found in Appendix B.

2.3.2 Subsurface Soil Sampling via Direct-Push Technology

DPT using hydraulic pressure was used to advance Macro-Core® samplers to obtain soil cores. When necessary, a vibratory hammer was used in combination with hydraulics to reach the target depth. Upon setup, 1-min fixed radiological measurements were taken at the sampling locations. The boreholes were advanced to refusal, which was assumed to correspond to bedrock depth. The soil was sampled continuously using 4-ft-long Macro-Core® samplers fitted with acetate liners. This approach allowed for logging of the entire soil profile. Upon removal of the liner from the sampling equipment, it was cut open and representative sections were immediately placed in sealable plastic bags for headspace analysis and labeled with the corresponding depths. The remaining soil cores were scanned for radiological contamination with NaI (gamma) and GM (beta/gamma) hand-held meters (SAIC FTP 451). A 1-min fixed-point measurement was performed at the core section, which exhibited the highest reading noted during the scan. If no elevated scan readings were identified, the fixed reading was performed at the approximate mid-point of the sampling interval. The zone within each sampling interval having the highest readings was selected for radiological sample collection and laboratory analysis. If elevated radiological readings were not detected along the soil core, soil samples for radiological analyses were collected within the same zones as those for the chemical constituents.

Immediately after being scanned and logged, up to 2-ft segments of soil core were placed in separate plastic bags. After a period of 10 min, a headspace analysis was performed by inserting the tip of a hand-held PID inside the bag to measure VOC vapor concentrations (SAIC FTP-750). Field measurements are recorded in the boring logs (Appendix C). Sample locations were selected based on the intervals having the highest headspace readings and a comparison to the MIP logs. If the readings were essentially homogeneous across the entire length of the boring, samples were collected within the approximate center of each lithologic unit with the samples representative of a maximum 10-ft interval. If the soil core was homogeneous with respect to headspace readings but a depth of concern was identified with the MIP, that area of the soil core was selected for sampling. In general, at least three samples were collected for each boring: above the water table, at the top of the saturated zone, and at the bottom of the boring. Additional samples, if collected, were selected due to notable lithologic changes. After the headspace analysis was completed, the selected samples were containerized, labeled, packed on ice, and shipped to an off-site laboratory (SAIC FTP-650) for radiological and chemical analysis (Table 2.4). Soil-sampling equipment was decontaminated between soil-sample intervals and locations (SAIC FTP-400 and FTP-405).

A total of 381 subsurface soil samples were collected from 109 sampling locations (Figs. 2.5a and b) and analyzed for contaminants of concern (Table 2.4). QC samples were collected at a rate of 1 per 16 for field duplicates and 1 per 29 for MS/MSD samples. Rinsate blanks were collected daily and analyzed for the full suite of constituents sampled that day. Trip blanks for VOC analysis and temperature blanks were included in each shipping container.

Boring logs for the overburden boreholes can be found in Appendix C, and are discussed in Chapter 3. A summary of analytical results for the soil samples are presented and discussed in Chaps. 4 and 5.

2.3.3 Installation of Temporary Groundwater Monitoring Wells in Direct-Push Technology Boreholes

Based on information gathered through the MIP detector logs (Sect. 2.3.1, Appendix B) and headspace VOC screening (Sect. 2.3.2), temporary monitoring wells were installed at selected DPT boring locations. Temporary groundwater monitoring well locations are shown on Figs. 2.6a and b, while logs and well construction data can be found in Appendices C and D, respectively. Boreholes not completed as temporary wells were backfilled with a tremied bentonite slurry.

The temporary monitoring wells were installed as follows in accordance with MDNR Well Construction Rules, 10 CSR 23-4.060, *Construction Standards for Monitoring Wells*. Upon completion of soil sampling (Sect. 2.3.2), a 3-in. outer diameter (O.D.) steel casing was driven into the open hole to the desired well screen depth. In general, the well screen depth was selected such that the screen bottom was approximately at the overburden/bedrock interface. At four locations where perched water is suspected (Fig. 2.5b, BP-20, EP-18, BP-22, and NB-57), a second monitoring well was installed and screened at least 10 ft above the overburden/bedrock interface. A well assembly composed of 1-in. inner diameter Schedule 40 polyvinyl chloride (PVC) pipe fitted with a 2.5-in. O.D. pre-packed well screen was then lowered into the 3-in. casing. Once the well assembly was in place, the 3-in. casing was retracted to a point situated just above the screen. A 1- to 2-ft sand barrier was then installed directly above the well screen through a tremie pipe that delivered sand to the desired depth and was advanced upward as the borehole annulus was filled with sand. The secondary filter pack serves as a barrier that prevents the bentonite slurry used for an annular seal from entering the screen interval. After installing the secondary filter pack, the annular region between the well and the borehole was grouted up to the ground surface with a high solids bentonite slurry grout (at least 20% solids) delivered via the tremie method. The annular seal was installed in one continuous operation. Upon grouting the annulus to ground surface, the 3-in casing was removed and additional slurry added to restore the grout level to ground surface, if necessary. The use of a bentonite slurry grout as opposed to chipped or pelletized bentonite will aid in the abandonment process. Screen lengths and depths were selected based on lithologic units, the appearance of saturated soils, static water levels, and field screening measurements (MIP and DPT data). In some cases, if transmissive zones were separated by less to non-transmissive zones of minimal thickness, the wells were designed to capture both transmissive zones.

Temporary monitoring wells were not developed after installation due to the nature of the pre-pack construction. However, three well volumes were removed prior to sampling activities. Groundwater samples for the site-wide groundwater monitoring event were not collected until 2 weeks after completion of the temporary wells to ensure that a return to stable conditions had occurred.

Preliminary groundwater samples were collected after installation of temporary wells to aid in determining the extent of groundwater contamination in the overburden and to ensure that sufficient wells were installed prior to demobilization. These groundwater samples were analyzed at an on-site analytical laboratory for VOCs only (EPA SW-846 8260M); results for the on-site analysis are presented in Chapter 4. Based on the on-site mobile laboratory analyses, a subset of these temporary groundwater monitoring wells was selected for inclusion in the site-wide baseline groundwater sampling event (Sect. 2.6). Additionally, several samples were collected from select wells installed around the Evaporation Ponds and submitted to the off-site laboratory for isotopic uranium, isotopic thorium, and ^{99}Tc analysis. Analytical results from on-site and off-site analyses can be found in Appendix I; off-site analyses are also tabulated in Appendix H.

Surface protection was not installed for any temporary well immediately after installation. Some of these monitoring wells will be converted to permanent monitoring wells with the installation of surface protection, while the rest of the wells will be abandoned following MDNR Well Construction Rules, 10 CSR 23-4.080, *Plugging of Monitoring Wells*.

2.3.4 Subsurface Soil Sampling via Rotary Drilling

In locations associated with planned bedrock monitoring wells near Joachim Creek [NB-62 (BR-06-OB), NB-29 (BR-08-OB), and NB-76 (BR-10-OB); Fig. 2.5a), subsurface soil sampling and installation of overburden monitoring wells (Sect. 2.3.5 below) were performed using rotary drilling in anticipation of large, gravel-size particles in the overburden materials located in Joachim Creek's flood plain. Subsurface soil samples were collected at 2-ft intervals by advancing a 3-in. diameter split spoon. After each 2-ft

sample interval, 3.75-in. inside diameter (ID) hollow-stem augers (HSAs) were advanced to the bottom of the sample interval. The augers were flooded with water once below the water table, and a center-bit was used to prevent or minimize heaving sands. Upon removal, the soil cores/samples were placed on a table, and representative sections were immediately placed in sealable plastic bags for headspace analysis and labeled with the corresponding depths. The remainder of the core was scanned with portable radiological instrumentation, and logged by a field geologist, as previously described (Sect. 2.3.2). After a minimum period of 10 min had passed, the bagged samples were subjected to headspace analysis and intervals selected based on this analysis were containerized as previously described (Sect. 2.3.2). Field measurements are shown in the boring logs (Appendix C). Soil samples were sent to an off-site laboratory for analysis using methods shown in Table 2.4.

2.3.5 Installation and Development of Permanent Overburden Monitoring Wells in Rotary Drilled Boreholes

At NB-62 (BR-06-OB), NB-29 (BR-08-OB), and NB-76 (BR-10-OB), permanent overburden monitoring wells were installed as follows in accordance with MDNR Well Construction Rules, 10 CSR 23-4.060, *Construction Standards for Monitoring Wells*. A 4.25-in. ID HSA with wooden knockout plugs (to prevent soil from entering the augers) was advanced to refusal (assumed to be bedrock). Upon reaching the bottom depth, the plug was removed, and a 2-in nominal diameter PVC riser with a 10-ft PVC screen (0.010-in. slot) was lowered through the augers to the bottom of the boring. Screen lengths were selected based on lithologic units (coarse sands and gravels) and placed at the top of bedrock.

Once the screen and riser materials were lowered to the bottom of the auger string, primary filter pack material (10/20-mesh sand) was placed inside the augers around the well screen. When possible, the placement of the sand and removal of the augers was performed simultaneously to prevent excess backfill materials from building up inside the augers, and to prevent the collapse of the natural formation around the screen interval. The primary filter pack was extended 1.7 to 2.5 ft above the screen and covered by a 1- to 2-ft-thick secondary filter pack composed of 100-mesh sand. Both filter packs were tremied in place to prevent bridging. An approximate 3-ft-thick bentonite seal of 0.25-in. coated bentonite pellets was placed above the secondary filter pack by gravity methods and allowed to hydrate for a minimum of 1 hour. The remainder of the borehole was tremied with a bentonite grout (minimum 20% solids) to ground surface inside the augers in one event. Once the grout reached the surface, the augers were removed and additional bentonite grout added to account for the volume of the augers. Prior to completion of the surface protection, additional grout was added to make up for any settling that may have occurred.

Surface protection was completed by the installation of a 4-in. square aluminum protective casing and a 2- × 2-ft concrete pad sloped to shed water. Steel bollards were installed around the well locations to provide added protection. Metallic tags stamped with the well numbers were permanently affixed to the protective casings. Well construction details are given in Appendix D, while completion diagrams are located in Appendix E.

Permanent overburden monitoring wells (BR-06-OB, BR-08-OB, and BR-10-OB) were developed using 0.75-in. high-density polyethylene (HDPE) tubing with a foot valve and surge block manipulated by mechanical means in 1- to 2-ft increments while pumping until stable water quality parameters (pH, temperature, specific conductivity, and turbidity) were achieved. Initially, the uppermost part of the well screen was surged while the water quality parameters were stabilized. The tubing and surge block were then lowered to the bottom of the well and held stationary until the water quality parameters stabilized. The tubing and surge block were then raised to the bottom of the previously surged zone and the process repeated until the entire screen interval was developed.

After a minimum of three well volumes was removed, water quality parameters were measured in 5-min increments until stable in three successive readings. The criteria for stability were: (1) pH varied less than or equal to 0.1 standard unit (s.u.), (2) temperature varied less than or equal to 0.5°C, (3) conductivity varied less than or equal to 3%, and (4) turbidity less than or equal to 10 nephelometric turbidity units (NTUs). Although a goal of 10 NTU was set for turbidity, in certain instances that goal could not be met due to the natural characteristics of the groundwater. If 10 NTU could not be reached in three attempts, development was considered complete when the water was clear to the unaided eye and the turbidity varied by less than or equal to 10%. It should be noted that natural turbidity levels in groundwater may exceed 10 NTUs and that turbidity is always the last indicator parameter to stabilize (USACE 1998).

All three permanent overburden monitoring wells collocated with bedrock monitoring wells (BR-06-OB, BR-08-OB, and BR-10-OB) were included in the site-wide baseline groundwater sampling event (Sect. 2.6).

Overburden monitoring wells were not installed in all the bedrock monitoring locations for the following reasons: (1) BR-05, BR-09, BR-11, and BR-12 were beyond the extent of overburden contamination delineated by MIP and field analysis of groundwater samples from temporary monitoring wells installed via DPT (Sect. 2.3.3); and (2) only 3 ft of overburden was present at BR-07.

2.4 BEDROCK CORING, DISCRETE INTERVAL GROUNDWATER SAMPLING, AND INSTALLATION OF BEDROCK MONITORING WELLS

One of the objectives of this RI is to assess the nature and determine the horizontal and vertical extent of contamination in bedrock formations where contaminants have been detected during previous investigations. To achieve this objective, bedrock monitoring wells were installed as part of this RI in eight locations (BR-05, BR-06, BR-07, BR-08, BR-09, BR-10, BR-11, and BR-12) (Fig. 2.6a). In addition, a monitoring well screened in the shallower Jefferson City-Cotter formation was installed at BR-03 where bedrock coring and a groundwater monitoring well screened within the Roubidoux formation (BR-03-RB) had been installed during previous investigations (LBG 2002b). The WEC-Hematite RI TSWP, *Subsurface Soil Investigation and Packer Isolation and Discrete Groundwater Sampling and Bedrock Monitoring Well Installation and Development* (SAIC 2004d), and associated field changes served as guidance for this portion of the field investigation. This effort consisted of bedrock coring and associated discrete interval groundwater sampling and monitoring well installations.

2.4.1 Bedrock Coring, Discrete Interval Sampling, and Diffusion Bag Sampling

Bedrock coring at locations shown on Fig. 2.6a (BR-05 through BR-12) proceeded as follows. A 3.75-in. ID HSA was advanced through the overburden to refusal (presumed to be bedrock). The first ~20-ft of bedrock was cored with an NQ-size wireline system. The rock core was boxed and logged by a field geologist. The 3.75-in. ID HSA was then removed and a 10.25-in. ID HSA was drilled to refusal. A 10-in. air rotary bit was advanced to the bottom of the cored interval and a 6-in. steel isolation casing set and tremie-grouted in place. The depth of the isolation casing was determined based on the depth of competent bedrock as observed in rock cores taken from the first 20-ft of bedrock. This isolation casing was installed to prevent the potential downward migration of contaminants from the overburden through the coreholes to the bedrock. After the cement grout around the isolation casing was allowed to harden, coring was continued using an NQ-wireline system at 5- to 10-ft intervals. Boring logs for these bedrock boreholes can be found in Appendix C, and are discussed in Chapter 3.

Discrete interval groundwater sampling was performed as the coring was advanced through the bedrock. Upon completion of a core interval, the core rod string was raised approximately 2 ft above the cored interval. The cored interval was then isolated by lowering a single-stage inflatable packer to the bottom of the core rod string; the bottom of the corehole was used as the lower barrier. A bladder pump was positioned below the packers and adjusted so that it was in the vertical center of the isolated interval.

Following inflation of the single-stage packer with compressed gas, the isolated interval was purged by removing a minimum of three volumes of the isolated interval prior to monitoring for water quality parameters. Stabilization was considered to have been achieved when the water quality parameters were stable for a minimum of three successive readings at 5-min intervals at a purge rate not exceeding 300 milliliters per minute (mL/min). The criteria for stability were: (1) pH varied less than or equal to 0.1 s.u., (2) temperature varied less than or equal to 0.5°C, and (3) conductivity varied less than or equal to 3%. Once these criteria were met, the purge rate was reduced to 100 mL/min for collection of a sample of groundwater for VOC analysis. Immediately upon collection, the groundwater samples were labeled, packed on ice, and transported, along with completed chain-of-custody (COC) forms, to the on-site analytical laboratory for expedited analysis via EPA SW-846 8260M. Purging continued until an additional three volumes had been removed or until the on-site laboratory analytical results were returned. At this time, water quality parameters were monitored and stabilized as above, and another groundwater sample for VOC analysis was collected to verify the results of the initial sample. Duplicate groundwater samples were collected at a rate of 1 in 20 and analyzed at either the on- or off-site laboratory. Results from on-site and off-site analyses can be found in Appendix I; off-site analyses results are also tabulated in Appendix H.

An attempt was made to determine the importance of removing three well volumes prior to testing for parameter stability by collecting and analyzing samples after one and two volumes had been removed. However, due to the absence of contaminated zones encountered after the implementation of this study, the results were inconclusive.

It was not uncommon for non-transmissive zones to be encountered during discrete interval sampling. Non-transmissive zones were indicated by purge flow rates that substantially decreased or dropped to zero, likely because groundwater flow into the isolated interval could not keep up with the purge flow rate. Field checks were made to verify the non-transmissive conditions by releasing the air from the packers and monitoring the purge flow rate as the column of water standing above the packer was allowed to drain into the previously isolated interval. In all cases, after the packers were released, the purge flow rate returned to maximum capacity. This process, involving releasing and re-inflating the packers, was repeated approximately three times to verify the isolated interval was non-transmissive. In these cases, no groundwater sample was collected and coring continued and the next interval was isolated and tested.

During bedrock coring, precautionary measures were implemented to prevent vertical cross-contamination within a borehole. At BR-09 and BR-10, coring was terminated when contamination was detected in discrete interval samples at concentrations greater than a screening level [e.g., drinking water standards (i.e., 5 ppb for TCE)]. After coring was terminated, these boreholes were reamed using a 5.625-in rotary bit, and wells screened within the contaminated intervals were subsequently installed (BR-09-JC, BR-10-JC, see Sect. 2.4.2 on procedures for well installation). At BR-08, coring was suspended when a contaminated depth interval was first encountered, and an isolation casing was installed in the borehole to prevent downward contaminant migration into deeper bedrock when coring resumed. After installation of the isolation casing, coring and packer testing continued until a positive identification of the Roubidoux formation was made. The borehole was then reamed using a 5.625-in rotary bit and a bedrock monitoring well was installed. A second borehole located within a few feet of the first borehole was then drilled to install a monitoring well (BR-08-JC) screened within the contaminated

depth interval identified during the discrete interval sampling at the first borehole. The second borehole was drilled using a 10.25-in HSA through the overburden to refusal, followed by NQ-size wireline coring through the first 20-ft of bedrock. The depth of competent bedrock was determined from the 20-ft rock core, after which a 10-in air rotary bit was drilled to this depth. A 6-in isolation casing was then lowered into the hole and set in place via tremie grouting. Coring and discrete interval sampling was conducted following the same procedure used in the first borehole. Coring in the second borehole was terminated when VOCs were detected in the discrete interval samples. The borehole was then reamed using a 5.25-in air rotary bit prior to installation of BR-08-JC.

At BR-05, BR-06, BR-07, BR-11 and BR-12, coring and packer testing were continued until a positive identification of the Roubidoux formation was made. No VOC levels were detected above 5 ppb during packer testing at these locations.

Core water was recirculated to the maximum extent possible to reduce the amount of investigation-derived waste (IDW) generated. Clean water was added on occasion to remove accumulated sediments inside the core rod string and barrel. Although no quantitative measurements were made regarding the volumes of core water used and lost during the coring process, visual estimations were made. Factors other than loss into the formation were deemed to play major roles in this determination (i.e., loss around augers prior to casing installation and pump and piping leakages); therefore, it is concluded that water loss to the formation did not appreciably dilute collected discrete groundwater samples.

Diffusion bag sampling was performed in BR-05 to confirm the results of the discrete interval sampling. Polyethylene bags were filled with deionized water, sealed, and suspended within the open borehole on 20-ft centers throughout the water column and left in place for a minimum of 2 weeks. The bags were then removed and samples collected for VOC analysis at the on-site laboratory. On-site analysis results for the diffusion bag samples can be found in Appendix I.

2.4.2 Bedrock Monitoring Well Installation

Bedrock monitoring wells (2-in diameter) were installed in accordance with MDNR Well Construction Rules, 10 CSR 23-4.060, *Construction Standards for Monitoring Wells*. The wells were installed either in boreholes drilled for coring and discrete interval sampling (drilling procedures described previously in Sect. 2.4.1), or boreholes that were drilled solely for well installation. For monitoring wells installed in the boreholes that had been used for coring and discrete interval sampling, the boreholes were reamed with a 5.25-in air rotary bit to the desired well depth prior to well installation. For wells installed in new borings (e.g., in locations where wells at two depths were installed, such as BR-05, BR-07, BR-08, BR-10, and BR-12), 10.25-in. ID HSAs were advanced through the overburden to refusal. The first ~20-ft of bedrock was cored with an NQ-size wireline system. A 10-in. air rotary bit was then advanced to a depth corresponding to competent bedrock based on the 20-ft rock core, and a 6-in. steel isolation casing set and tremie-grouted in place. This isolation casing was installed to prevent the downward migration of contaminants from the overburden through the coreholes to the bedrock. A 5.625-in. air rotary bit was then used to drill through the isolation casing down to the desired depth of the well.

After the borehole had been drilled or reamed to the desired well depth, the well string was lowered to the bottom of the borehole. The primary filter pack was installed by tremie method to a position 2 to 5 ft above the screen. A secondary filter pack consisting of clean fine sand was placed by tremie method 1 to 2 ft above the primary filter pack. The purpose of the secondary filter pack was to ensure that grout used for the annular seal did not infiltrate into the primary filter pack. A 3- to 5-ft-thick bentonite seal of pelletized bentonite designed to fall through water without hydrating was placed above the secondary filter pack and allowed to hydrate for 1 hr.

Upon completion of the bentonite seal, the annular seal was installed by emplacing a bentonite slurry grout to a position equivalent to the proposed location of the base of the protective cover. The high solids sodium bentonite slurry, at least 20 % by weight solids, was tremie-grouted from the bottom to the top of the annular space in one continual operation. The grout was allowed to cure for a minimum of 24 hours. After this time, additional grout was added to rectify any settling that may have occurred to restore the grout level to the desired depth.

After completion of the annular seal, a protective cover was installed around the riser pipe and completed per the above-referenced MDNR Well Construction Rules. A concrete pad approximately 2×2 ft was constructed around the protective cover and sloped to drain to prevent ponding around the well. Bollards were also installed around bedrock wells to protect the wellhead from damage by vehicles. Metallic tags stamped with the well numbers were permanently affixed to the protective casings. Well construction data are provided in Appendix D, while well completion diagrams are located in Appendix E. Well construction details can also be found in Appendix C, where they are shown in the associated borings logs.

2.4.3 Video logging and Discrete Interval Groundwater Sampling in Domestic Wells

A number of residential wells southeast of the Facility across Joachim Creek were video-logged to verify the characteristics of the wells in public records (e.g., depth of casing, total depth, etc.). The information obtained from the video logging is provided in Appendix B.

Based on the historical knowledge that VOCs were present in a number of residential wells to the east and southeast of the site, discrete interval sampling was performed on residential wells PW-3 and PW-19 (Fig. 1.2 for domestic well locations).

A dual-stage packer system attached to 2-in. nominal diameter steel pipe capable of isolating zones up to 40 ft was lowered into the open domestic well. A variable-speed submersible pump was positioned inside the steel pipe near the bottom of the isolated zone. Packer-isolation intervals were maintained at 40 ft throughout the initial investigation of PW-19 until the entire well was sampled. At this time, the isolation intervals were reduced to 10 or 20 ft for more specific determination of the vertical extent of contamination. Intervals were maintained at 20 ft throughout the entire investigation of PW-3.

Purging began at 5 gpm or the maximum obtainable pumping rate, whichever was less, with the intent of determining general hydraulic characteristics of the isolated portion of the aquifer. During purging, water levels were monitored inside and outside of the drop pipe. If the interval was not pumped dry prior to the removal of three volumes, the depth to water inside the drop pipe was recorded upon removal of each volume, and the parameter stabilization and sample process initiated (Sect. 2.4.1).

If the interval was pumped dry prior to the removal of three volumes, pumping was stopped and the water level allowed to recover to the approximate midpoint of the isolated interval. Water levels inside the drop pipe were again measured periodically and recorded with elapsed time to determine recovery rates. Once the water level had reached the midpoint of the isolated interval, pumping was resumed with the attempt to equalize the pumping rate to the recharge rate of the aquifer followed by parameter stabilization and sample collection. If the interval did not recharge to the midpoint within 90 min, a sufficient volume of water was allowed to accumulate within the isolated zone and low-flow sampling was initiated without parameter stabilization. This approach was implemented to obtain a basic understanding of, the hydraulic properties of the aquifers. Duplicate samples were collected at the rate of 1 in 20 and analyzed at the on-site laboratory. Select samples were also sent to the off-site laboratory for VOC analysis. A comparison of the on- and off-site laboratory data can be found in Chapter 4. Analytical results from the on-site laboratory can be found in Appendix I.

2.4.4 Diffusion Bag Sampling and Analysis in Domestic Wells

Diffusion bag sampling was performed at PW-19 to validate packer test results prior to installation of the wells, and at PW-16 in place of packer testing. Analytical results from the on-site laboratory can be found in Appendix I. Polyethylene bags were filled with deionized water, sealed, and suspended within the open boreholes on 20-ft centers throughout the water column and left in place for a minimum of 2 weeks. The bags were then removed and samples collected for VOC analysis at the on-site laboratory. Further discussion of the results and comparison to packer test data can be found in Chapter 5.

2.4.5 Conversion of Domestic Wells to Dual-Completion Monitoring Wells

As part of the investigation of the extent of groundwater contamination outside the Facility, domestic wells PW-06, PW-16, and PW-19 (Fig. 2.6a) were converted to dual-completion monitoring wells. These wells were reamed with a tri-cone roller bit to their existing total depth and chlorinated to eliminate any potential bacterial populations. Within the same borehole, two 2-in. PVC monitoring wells were installed: one in the Roubidoux formation and a second within the Jefferson City-Cotter formation. Screened intervals in the Jefferson City-Cotter formation were selected based on results obtained during discrete interval groundwater sampling and diffusion bag sampling (PW-16 and PW-19). The contaminated zones at BR-08, BR-09, and BR-10 appeared to be on a plane with strike and dip directions that are consistent with the known bedding plane orientation at the Hematite Site. The screened intervals at PW-16, PW-19, and PW-06 within the Jefferson City-Cotter Formation were also roughly on the same plane as the contaminated zones identified during packer testing of BR-08, BR-09, and BR-10. The bottom of the screened intervals in the Roubidoux Formation were set at or within 5 ft of the bottom of the original well boreholes.

The dual-completion monitoring wells were installed as described in Sect. 2.3.3, with the exception that bentonite grout was placed above the Roubidoux and below the Jefferson City-Cotter wells. Upon completion of the Roubidoux well, a portion of the borehole was grouted with high-solids bentonite grout to a position near the proposed location of the Jefferson City well and allowed to cure. If necessary, the remainder of the borehole was filled with chipped or pelletized bentonite to the desired location for the Jefferson City well. The upper well was then completed. To ensure that a competent seal was formed between the wells, pumping tests were performed on the Roubidoux well while monitoring the water levels within the Jefferson City well. The pump test results provided by the well installers can be found in Appendix I. Wells were installed in accordance with MDNR Well Construction Rules, 10 CSR 23-4.060, *Construction Standards for Monitoring Wells*. Well construction details are provided in Appendix D, while completion diagrams are located in Appendix E.

2.5 IN-SITU HYDRAULIC CONDUCTIVITY TESTING

In situ hydraulic conductivity tests (slug tests) were performed on selected overburden wells (BR-06-OB, BR-08-OB, BR-10-OB, NB-73, and NB-84), and in the following bedrock wells (BR-07-JC, BR-08-JC, BR-10-JC, BR-11-JC, BR-12-JC, PW-06-JC, PW-19-JC, PZ-03, PZ-04, WS-30, WS-31, BR-01-RB, BR-02-RB, BR-06-RB, BR-07-RB, BR-08-RB, BR-10-RB, BR-12-RB, and PW-06-RB) to supplement data from previous investigations. Testing was performed in accordance with SAIC FTP-376, *Aquifer Analysis by Slug Test Method*, and other approved industry standards. The overburden locations were chosen to provide representative hydraulic conductivities of the overburden near the Facility (terrace deposits) and near Joachim Creek (floodplain deposits; detailed discussion of overburden lithology is presented in Chapter 3). The bedrock locations were selected to provide representative hydraulic conductivities of the Jefferson City–Cotter Formation and Roubidoux Formation across the entire Hematite Site.

The slug tests were performed using a standard technique of pressurizing the well casing with air (a pneumatic slug), which displaces water out of the well thus releasing the pressure, then monitoring the recovery of the water level in the well. During the slug tests, water levels were measured using a pressure transducer that was connected to a data logger capable of recording data every 1 sec. The pneumatic slug assembly was positioned on top of the well casing, all gauges zeroed and all relief valves closed. Prior to insertion into the well, the pressure transducer was programmed with specific well information, and the static water level and total depth were manually recorded. The transducer was then lowered into the well through the pneumatic slug assembly to a position approximately 10 to 15 ft below the static water level, and an airtight fitting was tightened around the transducer cable to seal the connection. Air was introduced into the well via a small portable air compressor until the desired displacement had been achieved. At that point, the relief valve was opened and the test performed as a "rising head" test. A data logger was used to record pressure transducer response from the beginning of pressurization through complete recovery to the static water level. Due to the need to set recording times at such a short interval (every 1 sec), direct observation of the data was not possible in some of the wells tested. After a period of approximately 5 min, the transducer was stopped and the data reviewed to ensure static conditions had been achieved. Additional tests were run routinely to provide replicate recovery data for a given well.

Due to the low conductivities experienced in BR-7-JC, a sufficient water displacement using a pneumatic slug in the well was difficult to achieve. Thus, a traditional "slug" constructed of PVC pipe was used to create displacement and a "falling head" conductivity test was performed. Direct reading of the pressure transducer allowed for the correction of an error common to pneumatic slug testing in aquifers with lower conductivities. In these instances, the transducer reads the pressure inside the well and not the displacement of the water column. By using the direct-read function of the transducer, air was continually applied, thus resulting in a "rise" in the water level. This was monitored until the level had returned to static. At this time, the relief valve was opened and a subsequent lowering of the water level occurred, and the levels routinely monitored until true static conditions were achieved.

2.6 SITE-WIDE GROUNDWATER INVESTIGATION

The purpose of this investigation was to determine baseline groundwater conditions and to assess the presence and/or extent of groundwater contamination for applicable RCOPCs and CCOPCs. This investigation included inspection of the existing (i.e., pre-RI) groundwater monitoring network (Sect. 2.6.1), redevelopment of some of the pre-RI monitoring wells (Sect. 2.6.2,) and sampling of the existing monitoring well network and a select number of wells that were installed as part of the RI (Sect. 2.6.3). The WEC-Hematite RI TSWP, *Site-Wide Groundwater Well Assessment and Baseline Sampling* (SAIC 2004f), served as guidance for this portion of the field investigation.

2.6.1 Monitoring Well Inspection/Assessment

Existing monitoring wells and piezometers (prior to those installed as part of the RI) were visually inspected for compliance with current MDNR Well Construction Rules (MDNR 1996) to determine whether rehabilitation or maintenance was required. Criteria for the assessment included the following:

- Proximity to other sample points.
- Construction methods/materials.
- Availability of construction information (i.e., well installation diagrams).
- Existing conditions:
  - Surface seal.
  - Riser diameter.

- Screen length and interval.
- Recharge rate.

Existing wells selected for sampling with unknown construction details (WS-07, WS-08, WS-09, WS-14, WS-15, and WS-16) were subjected to video examination to determine screen lengths. All wells had static water levels and total depths recorded manually in accordance with established field protocols (SAIC FTP-370). Visual inspection also included a description of the condition of the surface protection, the condition of the visible portion of the well, and the protective casing and riser height above ground surface, if applicable.

Downhole video camera inspections were performed with a 2-in. downhole view or 4-in. dual-view camera run from the top to the bottom of the monitoring well to record structural and/or mechanical damage and the presence of screen plugging and/or biofouling. Continuous footage of the inspection was recorded on a vertical helical scan tape. Overall, it was found that the monitoring wells inspected were in good condition; due to their age, the wells installed prior to LBG 2002b were subjected to redevelopment (next subsection). The results of the well assessment were summarized in *Baseline Groundwater Well Assessment Well Inspection Report* (SAIC 2004g) which is included in Appendix F of this report.

2.6.2 Monitoring Well Redevelopment

Redevelopment of monitoring wells that were installed prior to 2002 (LBG 2002b) was performed with the use of a surge block affixed to 0.75-in. HDPE tubing. In addition to creating a surging effect, the tubing was fitted with a foot valve used to pump the well while surging. The tubing was raised and lowered in approximately 1-ft increments beginning at the bottom of the screen and proceeding upward until the entire screen was surged and pumped.

Redevelopment was considered to have been achieved when the water quality parameters (pH, temperature, specific conductivity, and turbidity) were stable for a minimum of three readings at 5-min intervals.

2.6.3 Groundwater Sampling

Groundwater sampling was conducted following established protocols (WEC-FTP-01, WEC-FTP-02). Details regarding the sampling equipment and depth are as follows:

- Sampling pumps: Permanent monitoring wells and piezometers were sampled using dedicated sampling tubes attached to non-dedicated bladder pumps. Temporary monitoring wells were sampled using dedicated sampling tubes attached to a peristaltic pump. The peristaltic pumps were equipped with an in-line sampling trap when collecting water samples for VOC analysis. Use of the in-line trap allowed sample collection prior to entry into the pump head to minimize VOC volatilization.

- Pump intake depth: For wells installed prior to the RI, the pump intake depth was generally set at the approximate middle of the screened interval. However, deeper pump intake depths were used in wells for which historical data indicated water levels were below the screen mid-point. For overburden wells installed during the RI, the pump intake depth was set at the middle of the screens. For bedrock wells installed during the RI, the pump intake depth was set at the zone of highest contamination based on initial packer test sampling. For bedrock wells with screened intervals that did not exhibit any contamination during the packer testing, the pump intake depth was set at the middle of the screen length.

Groundwater sampling proceeded as follows. After setting up the sampling pump, purging was initiated by adjusting the flow rate to 300 mL/min or less and allowing at least 300 mL to flow through the sampling port. Purge water was allowed to run through the water quality meter to remove any trapped air pockets. Upon removal of the calculated purge volume required for micropurging (low-flow purging and sampling, Puls 1996), field parameters (i.e., specific conductivity, pH, temperature, and turbidity) measurements were recorded. Purging continued and a minimum of two additional parameter measurements were taken in successive 5-min intervals until stability was reached. The criteria for stability were the same as those used in discrete interval sampling from the bedrock boreholes (Sect. 2.4.1). Water levels were monitored periodically during purging to observe any drawdown. The pumping rate was reduced or halted if the water level in the well approached the top of the screened interval. Wells in which drawdown to the top of the screened interval occurred while purging at a rate of 80 mL/min or less were assumed to pump dry. Aside from providing more representative groundwater samples (Puls 1996), the low-flow purging and sampling technique resulted in a reduction of IDW generated during the site-wide sampling event.

Upon stabilization of the water quality parameters, purging was suspended by turning off the pump control box, the discharge tubing was removed from the flow-through cell, and sample collection was initiated. In accordance with EPA recommendations for the order of sample collection (EPA 1992), VOC samples were collected first at a flow rate of 100 mL/min or less. After VOC sample collection was complete, the flow rate was increased up to 300 mL/min, or the maximum allowable pumping rate to correspond to slower recharge rates, whichever was less.

Wells that were pumped dry after parameter stabilization and prior to the completion of sample collection were allowed to remain undisturbed for a minimum of 24 hours and sample collection was then resumed without parameter stabilization. Due to poor recharge, the complete set of analyses intended for the groundwater samples was not collected at BD-22B (no filtered parameters) and BD-07 (no radiologic parameters). Monitoring wells BD-15, EP-14, EP-18A, EP-18B, and WS-09 were not sampled due to poor recharge. The inability to sample from these wells did not impact the assessment of groundwater contamination at the Site since there was still a sufficient number of surrounding wells that provided adequate areal coverage at the Site (refer to Chapter 4 for a complete assessment of groundwater data).

After collection, all samples requiring storage at 4° C were placed in a cooler with ice. COC forms were completed and the samples and appropriate COC forms submitted for shipment to an off-site laboratory. QC samples were collected at a rate of 1 per 16 for field duplicates and 1 per 57 for MS/MSD samples. Rinsate blanks were collected daily from each non-dedicated sampling device and analyzed for the full suite of constituents sampled that day. Trip blanks for VOC analysis and temperature blanks were included in each shipping container.

With the exception of BD-22B, BD-07, PW-06, PW-16 and PW-19, groundwater samples from all monitoring wells were analyzed for gross alpha/beta, isotopic uranium, isotopic thorium, ^{99}Tc, VOCs, metals, chloride, nitrate, and sulfate. As mentioned previously, filtered groundwater samples were not collected from BD-22B, radiological parameters were not collected at BD-07, and groundwater samples from the dual-completion wells (PW-06, PW-16, and PW-19) were sampled for VOCs alone based on historical data that had been collected from the private wells.

Groundwater samples for transuranic [americium-241 (^{241}Am), Neptunium-237 (^{237}Np) and plutonium isotopes] analysis were collected from 30 monitoring wells, 20 of which were selected randomly while the remaining 10 were selected to ensure that the sample set adequately represented AOCs. Groundwater samples for SVOC analysis were collected from wells in the vicinity of paved areas, based on low levels of SVOCs detected in surface and subsurface soil samples generally located near asphalt parking areas or driveways. The presence of dioxins was noted in soil samples from the

Cistern/Burn Pit (Chapter 4). For this reason, dioxin analysis was performed on a groundwater sample from monitoring well CB-02. Groundwater samples from eight monitoring wells located along a north/south transect and eight monitoring wells located along an east/west transect were analyzed for isotopic radium, pesticides, and PCBs. At these 16 transect monitoring well locations, both filtered (0.45 μm) and unfiltered samples were collected for metals and radiological parameters. Fluoride analysis was not performed on groundwater samples due to results in subsurface soil samples that were generally below the reporting limit (~7 mg/kg) except for a few locations within the Evaporation Ponds, under the buildings, and near Deul's Mountain. However, even the highest fluoride level (190 mg/kg in EP-13-06-SL, see Sect. 4.2.5.2) in the subsurface soil is below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984). At all other well locations, only unfiltered samples were collected for metals and radiological parameters. Analysis methods used to determine the target analytes are shown in Table 2.5.

Water quality parameters were measured using field techniques in all the groundwater samples. The water quality parameters include pH, alkalinity, specific conductance, turbidity, DO, oxidation-reduction potential (ORP), sulfide, iron, and temperature. pH, specific conductance, DO, ORP, and temperature were measured using parameter-specific probes or instruments, while alkalinity, sulfide, and iron were measured using colorimetric test kits.

A list of the monitoring wells included in the site-wide sampling event can be found in Appendix D, while the results of the groundwater sample analyses are presented in Chapter 4 of this report.

To assess groundwater potentiometric conditions at the Hematite Site, water levels were measured in 1 day (December 3, 2004) at all monitoring wells included in the site-wide groundwater sampling event. Potentiometric surfaces based on this round of water level measurements are presented in Chapter 3.

2.7 OFF-SITE/BACKGROUND SAMPLING

The purpose of this investigation was to measure off-site/background concentrations of applicable RCOPCs and CCOPCs in surface and subsurface soil, surface water, groundwater and sediment to be used for evaluating contaminant analysis results relative to background conditions (Chapter 4). The Hematite RI TSWP, *Background Sampling* (SAIC 2004e), the *Multi-Agency Radiation Survey and Site Investigation Manual*, Revision 1, August (EPA 2000) and *Establishing Background Levels*, EPA/540/F-94/030, (EPA 1995) served as guidance for this portion of the field investigation. The collection of surface water and sediment samples at locations upgradient of the Hematite Site are discussed in Sect. 2.1. The collection of off-Site soil samples is described in the following paragraphs.

Thirty soil samples were collected from two off-Site locations, split between terrace and alluvial strata (Chapter 3 contains a description of these strata and their distribution in and around the Hematite Site). The terrace strata samples were collected approximately 2.5 miles west of the Hematite Site along Highway P. The alluvial strata samples were collected at the U.S. National Guard Armory Site, located approximately 1 mile to the northeast of the Hematite Site near the junction of State Road P and State Road A (see Fig. 2.7). The soil samples were collected from 0 to 0.5 ft BGS (discrete) and 1 to 4 ft BGS (composite) at each location (EPA 2000). The VOC sample collected from 1 to 4 ft BGS was a discrete sample. Consistent with sampling in impacted areas of the Hematite Site, the soil samples were scanned with GM and NaI detectors to provide background count rate information (SAIC FTP-451). Samples were collected regardless of scanning results so that background radionuclide concentrations were not biased to elevated readings. Soil samples were collected using stainless steel trowels or hand augers in accordance with established field protocols (SAIC FTP-525 and FTP-550). The soils were logged by a field geologist according to the USCS.

After the soil samples were logged and surveyed, they were containerized, labeled, placed on ice, and shipped to an off-site laboratory for radiological and chemical analysis (Table 2.6). QC samples (i.e., field duplicates, MSs, MSDs) were collected at a rate of 1 per 15 samples. Rinsate blanks were collected daily and analyzed for the full suite of constituents sampled that day. Trip blanks for VOC analysis and temperature blanks were included in each shipping container. Results of the off-Site sampling are given in Chapter 4 of this report. Additional information relative to calculations of appropriate background concentrations and analyte screening are provided in Appendix J.

2.8 GEOPHYSICAL SURVEY

A geophysical survey was conducted by Geophex, Ltd (Geophex, 2005) to collect surface magnetic data to assist in the identification of unknown "disturbed areas," which were originally presented on Plate 25 of the RI/FS WP (LBG 2003). These areas encompass locations adjacent to Site Pond and the Tile Barn, southwest of the railroad tracks, north and south of the Joachim Creek Bridge AOC, east of the Burial Pits AOC, and a few locations in the floodplain area. The scope of this geophysical survey did not encompass the Burial Pits AOC, as geophysical surveys have been conducted previously within that portion of the Facility (LBG 1999). Electromagnetic (EM) data was also collected to confirm any anomalies identified with the magnetic data. This EM data provided information about soil electrical conductivity and assisted in the identification of any areas that may have been trenched or filled with non-ferrous items.

Fieldwork was conducted from January 31 to February 4, 2005, within 13 grid areas totaling 5.76 acres. A Geometrics G-858 vertical gradient magnetometer and a Geophex GEM-2 EM induction sensor were walked over tracklines spaced at 5-ft intervals. All data were rectified using differentially corrected GPS to Missouri East State Plane coordinates and placed on Facility drawings.

Geophysical data found that most of the grid areas contained no evidence of buried metallic objects. Only one grid near the dairy barn highlights a number of magnetic anomalies and what appears on the EM data to be rectangular conductivity anomalies. Note that this area corresponds to the Red Room Roof AOC. Other than the Burial Pits, this is the only area where there is evidence of subsurface excavation or burial of objects that may have been trenched and/or filled at some time. Another anomaly rich area exists immediately north and south of the bridge over Joachim Creek. However, the majority of these anomalies are visible surface metal scrap and it is not suspected that any of the buried anomalies infer any organized trenched and/or filled area. These areas appear as ad hoc household dumping areas.

2.9 DATA QUALITY AND DATA VALIDATION

Laboratory analyses of samples collected for the RI were performed in accordance with the *Quality Assurance Project Plan, Hematite Remedial Investigation/Feasibility Study, Final Draft, Revision 1.1,* (QAPP, Appendix A of LBG 2003). The QAPP identified laboratory methods that represent the current state of practice for analysis of samples to measure identified parameters. Quality Control samples were used by the laboratory during the analyses according to the appropriate methodology. These samples included calibration verification samples, calibration blanks, laboratory control samples (LCS), and laboratory method blanks. Quality Assessment samples were also collected to confirm the quality of the data. These samples included field duplicates, matrix spikes (MS), matrix spike duplicates (MSD), trip blanks, and equipment rinsate blanks. Additionally, the laboratory methodology included the analysis of samples to which known concentrations of compounds (surrogates) have been added (spiked) to assess the performance (i.e. recovery) of the analyses.

Level IV data packages were provided by the laboratory. These data packages included the raw data and data summary forms for the primary field samples as well as all supporting QA/QC samples. The RI data were reported to the method detection limit (MDL), in that if a compound was identified below the reporting limit (RL) it was assigned a "J" qualifier to indicate that the concentration is estimated. The laboratory data generated during the RI are tabulated in Appendix H and also provided as electronic files in Appendix I. A data validation technical review was performed on 10% of the laboratory data. This review was performed in accordance with the *EPA Contract Laboratory Program National Functional Guidelines for Organic Data Review, EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review,* and the *Laboratory Data Validation Guidelines for Evaluating Radionuclide Analyses and Radiochemical Data Verification and Validation.* The analyses were evaluated against criteria established in the related analytical procedures and the Westinghouse data quality requirements. Sixty-nine samples with a total of 9,897 data points were validated. None of the data subjected to validation were rejected. Detailed results of the data validation technical review are presented in the Data Validation Report in Appendix H, while data quality as indicated by analysis of quality control and quality assessment samples are summarized below.

Field Duplicates. Field duplicates are collected concurrently with the primary environmental samples and equally represent the medium at a given time and location. Comparison of the primary sample results with the field duplicate results indicated acceptable precision. Review of the results from the analysis of field duplicates did not identify any significant data quality issues with regard to the RI data.

Matrix Spikes and Matrix Spike Duplicates. The MS/MSD samples are laboratory control samples that are collected from the various media at the Site to allow evaluation of potential interferences that may arise from within the media itself. These samples are "spiked" with a known concentration of a compound in the laboratory and submitted for laboratory analysis. The samples are run in duplicate to assess the reproducibility of the results. Evaluation of the results from the sample (MS/MSD) analysis can point to a bias (either high or low) in the data, and this bias should be taken into account when evaluating the data. Approximately 1 MS/MSD sample pair was collected for every 20 samples collected during surface and subsurface soil sampling. During groundwater sampling, the frequency of MS/MSD samples collected was less than 1 in 20 due to low yield of many of the DPT-installed monitoring wells. There is no evidence that collection of additional MS/MSD samples during groundwater sampling would have materially affected the conclusions regarding the data quality. Five (5) MS/MSD samples were collected and analyzed for groundwater during the overall groundwater sampling event. The data from analysis of those samples did not indicate a data bias (high or low), thus those results were not used to qualify the data. Matrix interferences may affect the ability of the analytical instrument to detect concentrations of a contaminant, particularly near the detection limit. In those cases where the detection limit is close to a screening value (i.e. potential cleanup criteria), this limitation could result in the low concentration of that compound not being detected. This issue is typically not a problem where a relatively higher concentration of a compound is reported, since that compound will typically drive the risk and associated remedial measures.

Surrogates. Surrogate compounds are typically similar in chemical composition to the target compounds, so that the recovery of these compounds can be measured and reported as percentage of the added (known) concentration. The surrogate recoveries are evaluated, such that the sample analysis (or batch) is acceptable if the recoveries fall within a specified range. If the recoveries fall outside of the acceptable range, the results are evaluated by the laboratory to determine if the issue materially affects the sample results. As part of the validation effort (Appendix H), only one sample, CB-01-00-SL-FD, was identified with low surrogate recovery in the PCB analysis. This low recovery did not affect analysis for other compounds (i.e. volatile organic compounds) and does not appear to indicate an overall problem with the data, thus the data was determined to be useable for the RI. Given the substantial amount of sample analysis performed and data generated to support the RI, it is not unusual that there were some instances

where the surrogate recoveries were outside the specified range and qualifiers were applied to the data by the laboratory.

Blanks. Trip blank samples consist of containers of organic-free reagent grade water that are kept with the field sample containers from the time these leave the laboratory until they are returned for analysis. The purpose of trip blanks is to determine whether samples are being contaminated from VOCs during transit or sample collection. One trip blank was placed into each cooler used to store and ship samples designated for volatile organic analysis. Equipment rinsate blanks were collected from the water rinsate collected from equipment decontamination activities. They were comprised of samples of analyte-free reagent grade water, which was rinsed over decontaminated sampling equipment. Equipment rinsate blanks are employed to assess the effectiveness of the decontamination process, the potential for cross contamination between sampling locations and incidental field contamination. Laboratory method blanks are non-contaminated samples of the matrix of interest (usually reagent grade water or silica sand) that is subjected to all of the sample preparation (i.e., digestion, distillation, extraction) and analytical methodology applied to the samples. The purpose of the method blank is to check for contamination from within the laboratory that might be introduced during sample preparation and analysis that would adversely affect analytical results. Qualifiers were applied to the primary sample results by the laboratory when compounds were detected in an associated blank. Blank contamination could potentially cause sample results to be biased high (a conservative situation). It should be noted that the first tier of screening within the Baseline Human Health Risk Assessment evaluated potential constituents of concern based on a comparison of the maximum detected concentration to the corresponding regulatory limit. If sample results were reported at levels higher than the regulatory limit (i.e, maximum contaminant level or MCL) a conservative bias would be inherent in the risk assessment process.

Tentatively Identified Compounds. The data validation process and associated report (Appendix H) does not address tentatively identified compounds (TICs). The QAPP (Appendix A of LBG 2003) and Work Plans anticipated use of Level III data, which do not typically include TICs. During execution of the RI, a decision was made by WEC to have sample analysis for the RI performed using Level IV protocols. The Level IV data is reported in a data quality package that can be validated, where Level III data is not. Standard Level IV protocols do not include reporting and evaluation of TICs. Since there was no commitment to identify TICs, the laboratory was not asked to report them, and this information was not included in the data reports that were prepared in support of the RI at this Site. It should be noted that if TICs are identified, the laboratory typically performs a library search to try to identify the compound and estimates the quantity by the analytical methodology. Since the TICs are not included on a target compound list, where the methodology is established, the identification and quantification are less certain than that of the known compounds. Furthermore, the TICs when identified are typically organic compounds that are not associated with a known risk and would not typically be a factor in a risk assessment. As discussed in Sections 4 and 5 of this report, the most predominant organic compounds measured in the RI samples were PCE and TCE, consistent with historical use of these chemicals at the Facility. It is therefore extremely unlikely that TICs, if present, would materially impact decisions regarding remediation at the Site. Furthermore, the Historical Site Assessment (HSA) did not identify a significant potential for the presence of compounds other than those already on the established target compound lists that were identified for the different groups of analytes that were assessed as part of the RI.

Laboratory Review. Laboratory data review typically includes assessment of other laboratory QC measures (i.e. calibration verification recoveries, calibration blanks, LCS recoveries, and laboratory method blanks). If the laboratory identifies issues with the data, it either applies data qualifiers or re-runs the sample, according to the laboratory methodology. These laboratory qualifiers are included in the tabulated data (Appendix H) and electronic data files (Appendix I).

In summary, the impacts of identified potential quality issues (i.e. low surrogate recovery or contaminated method blank) are minimal in that they only occurred in relatively few of the analysis performed as part of the overall data set. In that the data were provided as a result of analysis by different independent methods, one potential issue, such as that with the low PCB surrogate recovery, does not affect the other data obtained through other analysis methods. Overall, these issues did not indicate a systematic error and the data should be considered useable for unrestricted use.

CHAPTER 2 FIGURES

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PROPERTY BOUNDARY

Fig. 2.1. Surface water gauging stations.

PROPERTY BOUNDARY

Fig. 2.2. Surface water sampling locations.

PROPERTY BOUNDARY

Fig. 2.3. Sediment sampling locations.

PROPERTY BOUNDARY

Fig. 2.4a. Surface soil sampling locations.

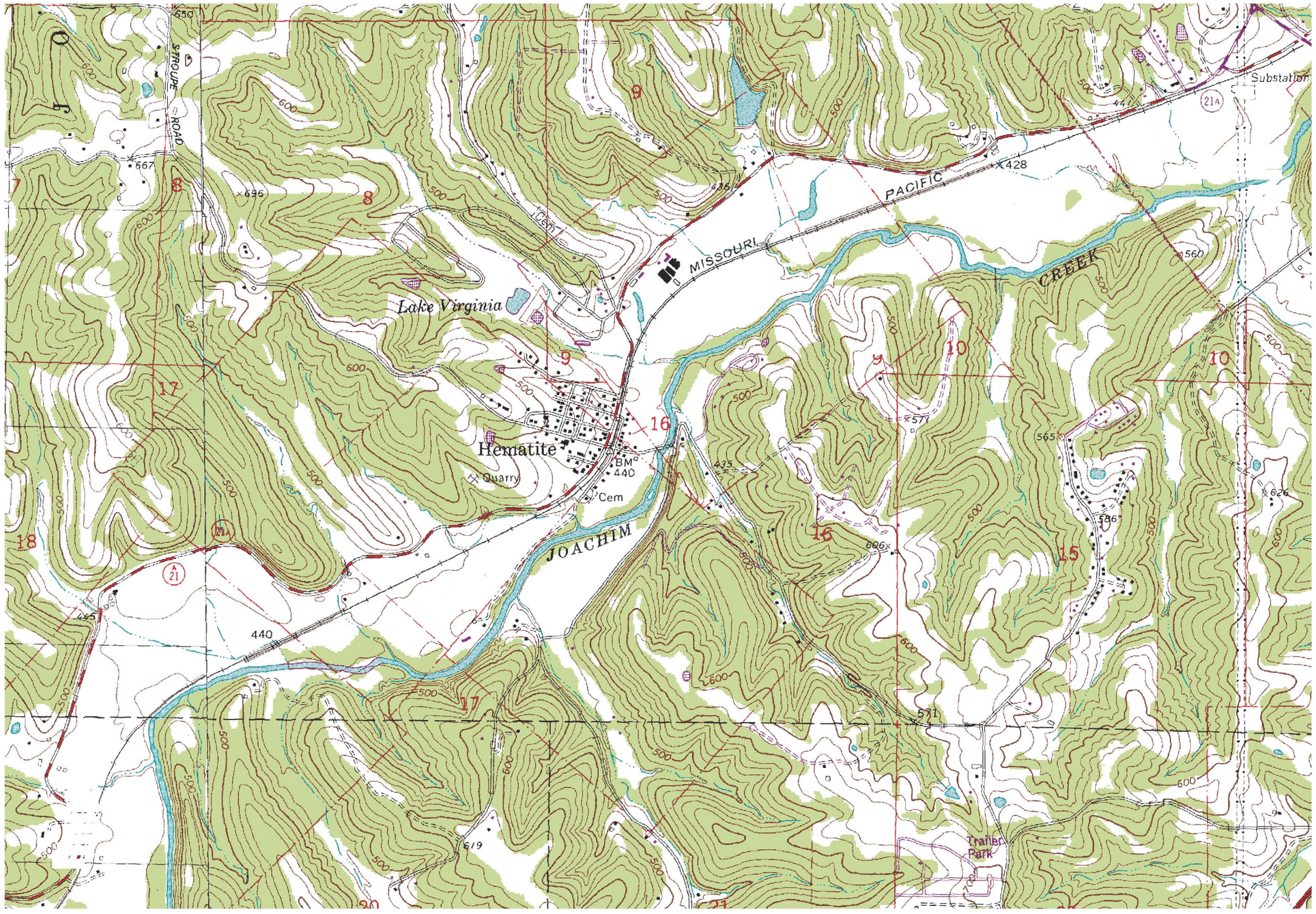
PROPERTY BOUNDARY

Fig. 2.5a. Subsurface soil sampling locations.

PROPERTY BOUNDARY

Fig. 2.5b. Subsurface soil sampling locations, Detail A.

Fig. 2.6b. Groundwater monitoring wells, Detail A.


Lake Virginia
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Quarry
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CHAPTER 2 TABLES

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Table 2.1. Analysis methods for surface water samples

Analysis	Analysis method
Gross alpha and beta	EPA 900: Gas-flow proportional counting.
^{228}Th, ^{230}Th, ^{232}Th	ASTM D3972-90M: Alpha spectrometry.
^{234}U, ^{235}U, ^{238}U	ASTM D3972-90M: Alpha spectrometry.
^{99}Tc	DOE RP 550: Liquid scintillation counting (analogous to ASTM C1387-98, which is a method for solid samples).
Volatile organic compounds	EPA SW-846 8260B: GC/MS.
Semivolatile organic compounds	GC/MS. EPA SW-846 8270C: GC/MS.
Organochlorine pesticides and PCBs	EPA SW-846 8081A: Gas chromatography/electron capture detection. EPA SW-846 8082: Gas chromatography/electron capture detection.
Fluoride	EPA 9214: Potentiometric determination with an ion-selective electrode.
Metals	EPA 6010B: Inductively coupled plasma-atomic emission spectrometry.
Mercury	EPA 7470A: Manual cold-vapor technique.
Total cyanide	EPA 9014: Titrimetric and manual spectrophotometry. (spectrophotometric method was used)

ASTM = American Society for Testing and Materials.
DOE = U.S. Department of Energy
EPA = U.S. Environmental Protection Agency.
GC = gas chromatography.
MS = mass spectrometry.
PCB = polychlorinated biphenyl.
Tc = technetium.
Th = thorium.
U = uranium.

Table 2.2. Analysis methods for sediment samples

Analysis	Analysis method
Gamma-emitting radionuclides	EPA 901.1M: Gamma spectrometry.
^{228}Th, ^{230}Th, ^{232}Th[a]	ASTM D3972-90M: Alpha spectrometry.
^{234}U, ^{235}U, ^{238}U	ASTM D3972-90M: Alpha spectrometry.
Transuranics (Neptunium-237 (^{237}Np), Isotopic Plutonium (Pu))	ASTM D3972-90M: Alpha spectrometry.
^{99}Tc	ASTM C1387-98: Liquid scintillation counting.
VOCs	EPA SW-846 8260B: VOCs by GC/MS.
SVOCs	EPA SW-846 8270C: SVOCs by GC/MS.
Organochlorine pesticides and PCBs	EPA SW-846 8081A: Organochlorine pesticides by GC. EPA SW-846 8082: PCBs by GC.
Fluoride	EPA 9214: Potentiometric determination of fluoride in aqueous samples with ion-selective electrode (used on sediment extract).
Metals	EPA 6010B: Inductively coupled plasma-atomic emission spectrometry.
Mercury	EPA 7471A: Mercury in solid and semi-solid wastes (manual cold-vapor technique).
Total cyanide	EPA 9014: Titrimetric and manual spectrophotometric determinative methods for cyanide (spectrophotometric method was used)

[a]20% and 24% of sampling locations were selected for isotopic thorium and transuranics analysis (^{239}Pu, ^{240}Pu, and ^{237}Np, respectively).

ASTM = American Society for Testing and Materials.
EPA = U.S. Environmental Protection Agency.
GC = gas chromatography.
MS = mass spectrometry.
PCB = polychlorinated biphenyl.
SVOC = semivolatile organic compound.
Tc = technetium.
Th = thorium.
U = uranium.
VOC = volatile organic compound.

Table 2.3. Analysis methods for surface soil samples

Analysis	Analysis method
Gamma-emitting radionuclides	EPA 901.1M: Gamma spectrometry.
^{228}Th, ^{230}Th, ^{232}Th[a]	ASTM D3972-90M: Alpha spectrometry.
^{234}U, ^{235}U, ^{238}U[b]	ASTM D3972-90M: Alpha spectrometry.
^{99}Tc	ASTM C1387-98: Liquid scintillation counting.
Transuranics (^{237}N and Pu)[c]	ASTM D3972-90M: Alpha spectrometry.
Volatile organic compounds	EPA SW-846 8260B: GC/MS.
Semivolatile organic compounds	EPA SW-846 8270C: GC/MS.
Organochlorine pesticides and PCBs	EPA SW-846 8081A: GC/electron capture detection. EPA SW-846 8082: GC/electron capture detection.
Fluoride	EPA 9214: Potentiometric determination with an ion-selective electrode.
Metals	EPA 6010B: Inductively coupled plasma-atomic emission spectrometry.
Mercury	EPA 7471A: Manual cold-vapor technique.
Total cyanide	EPA 9014: Titrimetric and manual spectrophotometry.
Total petroleum hydrocarbons[d]	EPA 8015B: GC/flame ionization detection.
Dioxin[e]	EPA 8290: High-resolution GC/high-resolution MS.

[a]Isotopic thorium analysis was performed on 5% of the samples collected from areas of concern (AOCs) where Th-232 is a RCOPC.

[b]Isotopic uranium analysis was conducted on 5% of the samples.

[c]26% of samples were selected for transuranics analysis. Locations were randomly selected from samples greater than the minimum detectable concentrations but less than the derived concentration guidance levels and to ensure that AOCs were adequately represented.

[d]Conducted on samples collected at the Former Gasoline Station (AOC #10).

[e]Conducted on samples collected at the Cistern Burn Pit (AOC #14).

ASTM = American Society for Testing and Materials.
EPA = U.S. Environmental Protection Agency.
GC = gas chromatography.
MS = mass spectrometry.
Np = neptunium.
PCB = polychlorinated biphenyl.
Pu = plutonium.
Tc = technetium.
Th = thorium.
U = uranium.

Table 2.4. Analysis methods for subsurface soil samples

Analysis	Analysis method
Gamma-emitting radionuclides	EPA 901.1M: Gamma spectrometry.
^{228}Th, ^{230}Th, ^{232}Th[a]	ASTM D3972-90M: Alpha spectrometry.
^{234}U, ^{235}U, ^{238}U [b]	ASTM D3972-90M: Alpha spectrometry.
^{99}Tc	ASTM C1387-98: Liquid scintillation counting.
Transuranics (^{241}Am, ^{237}Np, ^{238}Pu, $^{239/240}$Pu)	ASTM D3972-90M: Alpha spectrometry.
Volatile organic compounds	EPA SW-846 8260B: GC/MS.
Semivolatile organic compounds	EPA SW-846 8270C: GC/MS.
Organochlorine pesticides and PCBs	EPA SW-846 8081A: GC/electron capture detection. EPA SW-846 8082: GC/electron capture detection.
Fluoride	EPA 9214: Potentiometric determination with an ion-selective electrode (used on sediment extract).
Metals	EPA 6010B: Inductively coupled plasma-atomic emission spectrometry.
Mercury	EPA 7471A: Manual cold-vapor technique.
Total cyanide	EPA 9014: Titrimetric and manual spectrophotometry.
Total petroleum hydrocarbons[c]	EPA 8105B: GC/flame ionization detection.
Dioxin[d]	EPA 8290: High-resolution GC/high-resolution MS.

[a]Isotopic thorium analysis was conducted on 5% of the samples collected from areas of concern (AOCs) where Th-232 is a radiological contaminant of potential concern.
[b]Isotopic uranium analysis was conducted on 5% of the samples.
[c]Total petroleum hydrocarbon analysis was conducted on samples collected at the Former Gasoline Station (AOC #10).
[d]Dioxin analysis was conducted on samples collected at the Cistern Burn Pit (AOC #14).
Am = americium.
ASTM = American Society for Testing and Materials.
EPA = U.S. Environmental Protection Agency.
GC = gas chromatography.
MS = mass spectrometry.
PCB = polychlorinated biphenyl.
Pu = plutonium
Tc = technetium.
Th = thorium.
U = uranium.

Table 2.5. Analysis methods for baseline groundwater samples

Analysis	Analysis method
Gross alpha and beta	EPA 900: Gas-flow proportional counting.
^{228}Th, ^{230}Th, ^{232}Th	ASTM D3972-90M: Alpha spectrometry.
^{234}U, ^{235}U, ^{238}U	ASTM D3972-90M: Alpha spectrometry.
Transuranics (^{241}Am, ^{237}Np, ^{238}Pu, $^{239/240}$Pu)[a]	ASTM D3972-90M: Alpha spectrometry.
^{99}Tc	DOE RP 550: Liquid scintillation counting (analogous to ASTM C1387-98 which is a method for solid samples).
Volatile organic compounds	EPA SW-846 8260B: GC/MS.
Semivolatile organic compounds[b]	EPA SW-846 8270C: GC/MS.
Organochlorine pesticides and PCB[c]	EPA SW-846 8081A: GC/electron capture detection. EPA SW-846 8082: GC.
^{226}Ra, ^{228}Ra[c]	EPA 903.1: Radon emanation technique.
Metals	EPA 6010B: Inductively coupled plasma-atomic emission spectrometry.
Mercury	EPA 7470A: Mercury in liquid waste (manual cold-vapor technique).
Nitrate, sulfate, and chloride	EPA 300.0: Determination of inorganic anions by ion chromatography.

[a]Conducted on samples from 30 monitoring wells, 20 of which were selected randomly while the remaining 10 were selected to ensure that the sample set adequately represented areas of concern.

[b]Conducted on groundwater samples collected from wells that are in the vicinity of paved areas. Semivolatile organic compounds were detected in surface and subsurface soil samples collected from this area (Chapter 4).

[c]Conducted on groundwater samples from eight monitoring wells located along a north/south transect and eight monitoring wells located along an east/west transect.

Note: Radiological constituents and metals were collected as filtered and unfiltered samples.

Am = americium.
ASTM = American Society for Testing and Materials.
DOE = U.S. Department of Energy
EPA = U.S. Environmental Protection Agency.
GC = gas chromatography.
MS = mass spectrometry.
Np = neptunium.
PCB = polychlorinated biphenyl.
Pu = plutonium
R = radium.
Tc = technetium.
Th = thorium.
U = uranium.

Table 2.6. Analysis methods of off-Site soil samples

Analysis	Analysis method
Gamma-emitting radionuclides	EPA 901.1M: Gamma spectrometry.
^{228}Th, ^{230}Th, ^{232}Th	ASTM D3972-90M: Alpha spectrometry.
^{234}U, ^{235}U, ^{238}U	ASTM D3972-90M: Alpha spectrometry.
Transuranics (^{241}Am, ^{237}N, ^{238}Pu, $^{239/240}$Pu)	ASTM D3972-90M: Alpha spectrometry.
Volatile organic compounds	EPA SW-846 8260B: GC/MS.
Metals	EPA 6010B: Inductively coupled plasma-atomic emission spectrometry.
Mercury	EPA 7471A: Manual cold-vapor technique.

Am = americium.
ASTM = American Society for Testing and Materials.
EPA = U.S. Environmental Protection Agency.
GC = gas chromatography.
MS = mass spectrometry.
Np = neptunium.
Pu = plutonium
Th = thorium.
U = uranium.

3. CHARACTERIZATION OF STUDY AREA

The following subsections discuss the meteorology, geology, soils, and hydrogeology in the region of the Site, and, in detail, the characteristics of the site-specific geology and hydrogeology beneath the Hematite Site.

3.1 METEOROLOGY

Jefferson County, Missouri, where the Site is located, is characterized by a humid and temperate climate. The annual temperature averages 55°F in Jefferson County, Missouri (USDA 2003). Winters are generally cold to moderate, with temperatures averaging 33°F; however, short periods of cold weather occur during which temperatures frequently drop below 20°F. The coldest weather usually occurs in January with average lows of 15°F. In calendar year 2004, there were 17 days with a maximum temperature of 32°F or below. Summers are moderate to hot, with temperatures averaging 78°F. July is usually the warmest month of the year with average highs of 88°F. In calendar year 2004, there were 19 days with a maximum temperature of 90° or above (NOAA 2005).

USDA (2003) reports that the average annual precipitation in Jefferson County is approximately 38 in. with 45% of this average falling in April through September (data from 1961 to 1976). This is consistent with the value (40 in. per year) reported by Imes and Emmet (1994) for the region around the Hematite Site. Precipitation is generally evenly distributed throughout the year, with the heaviest precipitation commonly occurring in association with spring and summer thunderstorms, most occurring between May and August. In addition, an average of approximately 19 in. of snow accumulates annually. On the average, 18 days of the year have at least 1 in. of snow on the ground (USDA 2003).

3.2 GEOLOGY

The regional geology and physiography are described in Sects. 3.2.1, 3.2.2, and 3.2.3, while the site-specific geology based on data from the RI and previous investigations is presented in Sect. 3.2.4.

3.2.1 Regional Geology and Physiography

The Hematite Site is located within the Ozarks Plateaus Physiographic Province (Fig. 3.1a). The Ozark Plateaus province is a geologic uplift, covering approximately 50,000 miles^2 and is bounded to the north by the Missouri River, to the east by the Mississippi River, to the south by the Arkansas River, and to the west by the Grand and Neosho Rivers. Precambrian igneous and metamorphic rocks that outcrop at the Saint Francois Mountains (Fig. 3.1a) form the basal crust of the entire region and are overlain by Paleozoic sedimentary rocks that range in thickness from 0 around the periphery of the Saint Francois Mountains, to 6000 ft (Imes and Emmet 1994).

The Ozark Plateaus consist of three sections: the Springfield Plateau, the Salem Plateau, and the Boston Mountains. Topography is mostly gently rolling, except in the Boston Mountains, along the escarpments separating the Springfield and Salem Plateaus, and the Saint Francois Range where it is rugged. Karst features such springs, sinkholes, and caves are common in the limestones of the Springfield Plateau and abundant in the dolomite bedrock of the Salem Plateau and Boston Mountains. The Missouri Environmental Geology Atlas (MDNR 2004) did not indicate a significant number of karst features in the vicinity of the Hematite Site.

The Hematite Site is within the Salem Plateau (Fig. 3.1a), which is underlain by flat-lying to gentle northeasterly dipping Cambrian to Lower Ordovician strata that are mostly dolomitic. The Paleozoic rocks are overlain by unconsolidated surficial deposits of Tertiary to Quaternary age. Within the Festus quadrangle where Hematite is located (Whitfield and Middendorf 1992), Ordovician-age Cotter Dolomite outcrops almost entirely throughout the region (Fig. 3.1b). The Ordovician- and Cambrian-age stratigraphic units underlying the Salem Plateau in the vicinity of the Hematite Site include (from youngest to oldest, Imes and Emmet 1994):

- the Cotter Dolomite; the Jefferson City Dolomite; the Roubidoux Formation; the Gasconade Dolomite, which contains a well-defined basal sandstone member called the Gunter Sandstone member; the Eminence Dolomite; and the Potosi Dolomite (these make up the Ozark Aquifer in the area, which is further discussed in Sect. 3.3.1); and

- the Doe Run Dolomite, the Derby Dolomite, the Davis Formation, the Bonneterre Dolomite, the Reagan Sandstone, and the Lamotte Sandstone (these make up the St. Francois confining unit and the St. Francois aquifer).

Numerous fault and fracture zones that exhibit preferential orientations to the northwest-southeast and northeast-southwest have been mapped in the Ozark Plateaus (Imes and Emmet 1994, MDNR MEGA 2004). The northwest-southeast-trending Eureka-House Springs Fault Complex and the St. Genevieve fault zones intersect the northeast and southwest tips of Jefferson County, respectively (McCracken 1966). However, these fault zones are several miles away from the Hematite Site and do not appear to have any influence on the geology or hydrogeology of the area.

Whitfield and Middendorf (1992) map several north-northwesterly trending monoclines on the Festus and DeSoto quadrangles, but nothing in the immediate vicinity of the Hematite Site. Pike (1929) prepared the first geologic map for the Crystal City 15' quadrangle and identified a northeast-southwest-trending structural feature parallel to Joachim Creek (offset slightly to the south of the creek) that was termed the Crystal City Anticline. Later mapping by Schmitz (1965) also shows this anticline, but more nearly coincident with the creek. McCracken (1966) includes the Crystal City Anticline in her survey of Missouri's structural features. Whitfield and Middendorf (1992) do not include it on their map of the area, although the feature is still identified in Missouri's recently published geographic information systems-based geologic atlas (MDNR MEGA 2004).

3.2.2 Bedrock

The Jefferson City Formation and the Cotter Formation are described in Martin et. al. (1961, as referenced in Section 2.4.1, page 9 of LBG 2003) as mostly light-brown to medium-brown, medium to finely crystalline dolomite, and argillaceous dolomite. Chert, which is not abundant, typically is oolitic, banded, mottled, or sandy. Lithologic succession within the formation is complex and varies among locations. Because the two formations are difficult to differentiate without the aid of insoluble residue testing, they are often designated as a combined unit, the Jefferson City-Cotter Dolomite. These two dolomite units average 400 ft thick state-wide and are bounded beneath by the Roubidoux Formation. Imes and Emmett (1994) describe the Roubidoux Formation within the Ozark aquifer system as "…a loosely to well-cemented sandstone or a sandy to cherty dolostone containing several distinct sandstone bodies." The sedimentary rocks in this area dip gently and uniformly to the northeast.

3.2.3 Unconsolidated Deposits

The Festus quadrangle geologic map (Whitfield and Middendorf 1992) shows Quaternary (Holocene) alluvium and terrace deposits to be closely associated with Joachim Creek and its tributaries

in the vicinity of Joachim Creek (Fig. 3.1b). The map also shows that the extent of alluvium and terrace deposits across Joachim Creek (in the vicinity of the private wells, e.g., PW-19) is very limited, consistent with the thin overburden thickness (~3ft) that was encountered in that area (at BR-07, refer to Sect. 3.2.4 and Fig. 3.11).

Whitfield and Middendorf (1992) describe the Holocene alluvium as clay, silt, sand, and gravel chiefly derived from local loess and colluvium. Colluvium is described as a mixture of residuum, from fines to cobbles, and loess that is moving down slope as a result of slope wash and gravity. Colluvium accumulates at the base of valley slopes and in large valleys washes onto the floodplain, blending with the alluvium. Terraces typically contain lenticular beds of sand and gravel interbedded with silt and clay (Section 2.4.2, page 10 of LBG 2003).

The soil survey for Jefferson County conducted by the United States Department of Agriculture (USDA) indicates the presence of seven soil types within the Hematite Site area: (1) the Horsecreek silt loam directly under the Facility and BR-11 area, (2) the Haymond silt loam comprising the terrace deposits between theFacility and Joachim Creek, (3) the Kaintuck fine sandy loam along the immediate flood plain of Joachim Creek (BR-06, BR-08, and BR-10), (4) the Moko-Rock outcrop complex in the vicinity of the Tile Barn, (5) the Freeburg silt loam in the pasture area of BR-05, (6) the Bloomsdale silt loam in the areas of BR-09 and BR-12, and (7) the Useful silt loam in the area of BR-07 (USDA 2003).

Background surface and near-surface soil samples were collected from two locations (Fig. 2.7). The USDA soil survey for Jefferson County indicates that background soil samples collected from the location to the east of the Hematite Site (south of the National Guard Armory – Fig. 2.7) are linked to the occurrence of the Kaintuck, Horsecreek, and, possibly, the Wilbur soil series. These soils are coarse to silty alluvium associated with terrace and flood plain deposits. Although Wilbur soils are not found within the Hematite Site, they are similar to the Kaintuck, Horsecreek, and other terrace flood plain soils mapped on the Hematite Site.

Off-Site surface soil samples also were collected approximately 3 miles southwest of the Hematite Site adjacent to Highway P (Fig. 2.7). Soils in this area belong to the Useful and Freeburg soil series, both of which are found on the Hematite Site.

From this brief assessment, it is apparent that surface soil samples from both background locations are from a group of soil series also found on the Hematite Site or, in the case of Wilbur soils, closely related to soils found on the Hematite Site. Therefore, analytical results for contaminants in background soils should provide a valid basis for comparison with similar data obtained from Hematite Site soils.

3.2.4 Site-Specific Geology

As noted in Sect. 3.2.1, the Hematite Site lies in the northeastern portion of the Salem Plateau. The Ozark uplift took place in the early Paleozoic during a time associated with deposition of a thick sequence of strata that included the Roubidoux Formation and Jefferson City-Cotter Dolomite. As a result of the uplift (locally associated with the St. Francois Mountains to the south-southwest of the Hematite Site, Fig. 3.1a) and subsequent erosion, these sedimentary formations both dip gently and thicken in a northeasterly direction. The approximate strike and dip of the Jefferson City-Cotter strata are N45W and 2 to 5° northeast, respectively, at points closest to the Hematite Site, as indicated on field copies of the Festus quadrangle used by Whitfield and Middendorf (1992) to prepare the most recent geologic map of the area. However, notations on this map indicate that both the strike and dip of these strata are somewhat variable in the region.

The topography in the region of the Hematite Site is relatively deeply dissected by streams (refer to Fig. 1.1 for a topographic map). Downward cutting of Joachim Creek and other streams in the area (or their predecessors) was in response to the Ozark uplift. In the immediate vicinity of the Hematite Site, Joachim Creek is at an elevation of approximately 412 ft above mean sea level (AMSL) and occupies a relatively narrow valley (approximately 2000 ft wide) that generally trends east-northeastward. The valley is bounded both to the north and south by uplands that reach elevations in excess of 600 ft AMSL. A number of intermittent streams are tributaries to Joachim Creek in the area and also are incised resulting in the distinctive dissected topography characteristic of this region. These tributaries flow generally southeastward or northwestward from the highlands to their points of confluence with Joachim Creek.

Figure 3.1b is a portion of the geologic map encompassing the Hematite Site (Whitfield and Middendorf 1992). The shallowest and most relevant components of the bedrock geology in the vicinity of the Facility are dominated by (in descending stratigraphic order) the Cotter Dolomite, Jefferson City Dolomite, and Roubidoux Formations. Figure 3.1b shows that the upland regions to the north and south of Joachim Creek are underlain by the Cotter Dolomite. The Jefferson City Dolomite is exposed in the valley walls of the tributaries to Joachim Creek. The nearest outcropping of the Roubidoux Formation is in the city of Desoto, Missouri, approximately 6 miles to the southwest of the Hematite Site.

The regional characteristics of the bedrock units were described in Sect. 3.2.2. Lithologic descriptions provided in Whitfield and Middendorf (1992) and examination of core materials and core logs obtained during the RI and previous investigations indicate that in the vicinity of the Hematite Site the Jefferson City-Cotter Dolomite is composed of dolostone and sandy dolostone with minor interbedded sandstone and cherty intervals. The Roubidoux Formation is composed of dolostone with chert intervals and relatively common sandstone interbeds. The Jefferson City Dolomite-Roubidoux Formation contact reportedly occurs approximately 10 to 15 ft above a recognizable sandstone layer in the upper Roubidoux Formation. Although this sandstone is not always present, many of the bedrock logs from the Hematite Site appear to confirm its presence. Therefore, this sandstone will be used as a basis for recognizing the Jefferson City-Roubidoux contact in this report.

The stream valleys in this region are characterized by deposits of alluvium that have their origin through local erosion in the upland regions and subsequent deposition in the relatively gently sloping valleys. The valley occupied by Joachim Creek has a zone of alluvium as much as 30 to 35 ft thick underlying and immediately adjacent to the creek that rests on top of the Jefferson City-Cotter bedrock surface. The soil cover in the upland regions is much thinner and observations made at BR-07 (borehole drilled in the upland region southeast of Joachim Creek, refer to Fig. 2.6a for location) indicate a thickness of only several ft.

It is apparent that Joachim Creek has responded to several episodes of uplift in the region evidenced by several different phases of alluvial deposition. For example, Whitfield and Middendorf (1992) mapped a terrace deposit in the valley of Joachim Creek that is found in discontinuous, narrow strips near the margins of the valley or as small, isolated pockets within the valley. The Hematite Site lies on terrace deposits that extend along the northern boundary of the Joachim Creek valley.

3.2.4.1 Overburden

The overall thickness of alluvium/terrace deposits underlying the Joachim Creek valley near the Facility varies from 20 to 35 ft and is comprised primarily of upper fine-grain silts and clay that overlie coarser-grain material (sands and gravels with some cobbles) near the bedrock surface. The thickness of the coarse-grain units is highly variable in this region and ranges from 0 to greater than 20 ft.

The details of the local subsurface geology can be described by a series of geologic cross-sections based on drilling logs obtained from cores associated with this RI, as well as from a number of logs from earlier investigations (LBG 1999, 2002b). Figures 2.5 (a and b) are maps showing the location of borings in the overburden obtained during this investigation. Boring logs were compiled for these locations and a complete inventory of these logs is included in Appendix C.

Three cross-sections were assembled to examine the overburden underlying and proximal to the Hematite Facility. The layout of these cross-sections is provided on Fig. 3.2. Cross-sections B-B' and C-C' are oriented approximately parallel to Joachim Creek. Cross-section A-A' is roughly perpendicular to both B-B' and C-C'. Figure 3.3 is the legend for the geologic units encountered in both the overburden and bedrock in this investigation.

Cross-section A-A' (Fig. 3.4) reveals a bedrock surface that is relatively flat, but slopes gently toward Joachim Creek. The bedrock surface illustrated in cross-sections B-B' and C-C' (Figs. 3.5 and 3.6, respectively) also is relatively flat with no indication of significant relief. The density of the borings represented on Fig. 2.5a supports this inference.

The correlation of lithologic units on Figs. 3.4 to 3.6 focus on the distinction between fine-grain and coarse-grain units. Alluvial depositional environments tend to be rather complex and heterogeneous with numerous examples of abrupt variations in lithologies from coarse to fine representing the complicated interplay between episodes of erosion and deposition as the stream channel migrates laterally within its flood plain. Detailed lithologic correlations can be difficult to make, but the interpretations illustrated in these cross-sections honor the boring logs and are realistic of what might be found in an alluvial depositional setting.

One notable feature revealed by cross-section A-A' (Fig. 3.4) is the change that occurs at the terrace-alluvium boundary that is manifested by a thickening of coarse-grain lithologies from less than 5 ft in the terrace deposits to more than 15 ft in the vicinity of Joachim Creek. The sediment in this area is associated with the most recent episodes of deposition from the stream. Underlying the terrace, there is evidence of variable thickness of coarse-grain materials, but nowhere are these zones as thick as those found in the alluvium. Examination of core material indicates that the pebbles and cobbles of the coarse-grain unit are angular to sub-rounded, suggestive of a local origin and little transportation prior to deposition.

The common occurrence of the coarse-grain material in the lower part of the overburden is significant because it is relatively permeable and appears to be a principal pathway for contaminant migration by groundwater in the overburden (see discussion in Chapter 5). The thickness of this zone has been mapped in the vicinity of the Hematite Site based on the core logs available in Appendix C and from earlier studies (LBG 1999, 2002b) by focusing on the subset of logs that demonstrably intersected the overburden-bedrock interface. These logs yield a reliable estimate of thickness for the coarse-grain units.

Figure 3.7 is an isopach map for the coarse-grain material in this area. Although some interpretation is required in constructing this map, the general configuration of the coarse deposits appears to define several thick, lenticular zones parallel to the stream that may represent old channel lag deposits.

Consistent with information in cross-section A-A' (Fig. 3.4), the subsurface interface between the terrace and alluvial deposits appears to be the zone where significant thickening of sands and gravels occurs near Joachim Creek. In the vicinity of BR-02 (refer to Fig. 2.6a for location), the thickness of the coarse alluvial zone is much less. This area corresponds to the outside of a meander loop of Joachim Creek, which represents a zone of northward, lateral migration and erosion. Recent erosional activity associated with Joachim Creek may have removed much of the coarse-grain material that had been present in this region.

3.2.4.2 Bedrock

Figure 3.8 illustrates the location of three cross-sections that focus on the bedrock underlying the Hematite Site. The cross-sections are presented on Figs. 3.9, 3.10, and 3.11. Overburden detail is purposely omitted, as it is not relevant to a discussion of bedrock. Cross-sections D-D' and E-E' are oriented approximately normal to the regional strike (N45W). Cross-section F-F' is oriented approximately strike-parallel.

The bedrock core logs (Appendix C) obtained during the RI contain few distinctive marker beds that can be used as an indication of location within the stratigraphic section. However, a thin (5 to 10 ft thick) and apparently laterally continuous sandstone interbed mentioned previously (introduction to Sect. 3.2.4) appears to represent a unit that has been described as occurring approximately 10 to 15 ft below the top of the Roubidoux Formation. Cross-section D-D' (Fig. 3.9) shows a correlation based on this marker bed. Because of the strike-normal orientation of the cross-section, this bed yields information about the dip of these strata. The dip represented by this sandstone bed ranges from 1.4 to 2.9° in this cross-section, a value consistent with results from field mapping of surface outcrops (Whitfield and Middendorf, 1992) and from regional studies of these strata. Note that boreholes BR-01-RB and BR-04-RB were drilled by LBG (2002b) and contain the interpreted contact between the Jefferson City Dolomite and the Roubidoux Formation.

Stratigraphic correlation on what is believed to be the same sandstone bed also is illustrated in cross-section E-E' for boreholes BR-06, BR-03, and BR-10 (Fig. 3.10). The location of the marker bed in BR-03 is based on an evaluation of the core from BR-06 and the conclusion that the interpreted contact between the Jefferson City Dolomite and Roubidoux Formation in BR-03-RB (LBG 2002b) appears to be too deep by approximately 50 ft. The original location of the contact may have been based on the incorrect sandstone bed. Shifting the contact upward by this amount puts it in association with the sandstone bed illustrated in the cross-section.

The projection of the sandstone marker bed to BR-02 is problematic because the core log for this borehole shows the presence of only several very thin (~ 1 ft thick) sandstone interbeds within 20 ft of the Jefferson City-Roubidoux contact. Assuming that the contact is properly identified, these thin interbeds are interpreted to be correlative with the more prominent sandstone marker bed observed in the other boreholes. Therefore, the marker bed is projected to a position approximately 15 to 20 ft below this contact in BR-02. The resultant apparent dip of the marker bed in this cross-section is about 3°, comparable to that observed on Fig. 3.9 and within the range of measured values provided by Whitfield and Middendorf (1992).

3.2.4.3 Local structural features

Cross-section F-F' is shown on Fig. 3.11. Based on a correlation of the same sandstone marker bed observed in D-D' and E-E', this bed appears to define a subtle warp in the strata, the axis of which is located close to Joachim Creek. This may be a depositional feature, but probably is not tectonic in origin. The limbs of this warp have an apparent dip on the order of 1 to 2°. As mentioned in Sect. 3.2.1, older geologic maps showed the Crystal City Anticline (Pike 1929, Schmitz 1965, McCracken 1966) passing through this area. More recent maps do not have this feature (Whitfield and Middendorf 1992).

The structural interpretation of bedrock for the Hematite Site based on cross-sections D-D', E-E', and F-F' and discussed above can be integrated into a consistent geologic framework for the area. Figure 3.12 is a cross-section that is coincident with cross-section E-E' and is oriented approximately perpendicular to the regional geologic strike. In this cross section, however, all boreholes associated with the RI and earlier studies (LBG 2002b) that penetrated the sandstone marker bed (and, by inference, the Jefferson City-

Roubidoux contact) have been included. Each borehole has been projected into the plane of the cross-section by correcting for the dip associated with the anticlinal-like structure (cross-section F-F' on Fig. 3.11). Therefore, the logs for boreholes located distant from the cross-section must be moved upward an amount equal to the distance from the plane multiplied by the tangent of the dip angle of the strata obtained from Fig. 3.11. This process has the effect of unfolding the structure into a planar feature, while faithfully retaining information about the regional northeasterly dip of bedding (Figs. 3.9 and 3.10). Because of the vertical adjustment of boreholes not lying in the plane of the cross-section, the vertical scale represents relative elevation.

The results of applying these corrections to the vertical orientation of boreholes (Fig. 3.12) demonstrates that the relative location of the sandstone marker bed identified in all of the cores defines an inclined plane dipping to the northeast at approximately 2.7°. The excellent alignment of the marker bed and the consistency of the apparent dip of this planar feature to the known regional dip of bedrock in this area provide strong support to the structural interpretations presented in this report.

Information regarding the identification of prominent bedrock fracture sets in outcrop or cores is limited, although the logs that describe core material obtained during the RI do mention the presence of fractures when observed. The LBG (2002b) investigation included construction of boreholes BR-01, BR-02, BR-03, and BR-04. Detailed core descriptions and a number of geophysical and hydrologic logging studies were associated with borehole construction. LBG (Section 5.2.1, page 21, and Section 5.3.1, page 26 of LBG 2002b) reports that the fracture density for the Jefferson City-Cotter Dolomite and Roubidoux Formation lies within the ranges of 0.5 to 3.4 and 0.7 to 4 fractures per ft, respectively. Furthermore, they indicate that fractures, joints, and bedding planes in the Roubidoux core appear to be widened by dissolution, whereas it is less apparent in the Jefferson City-Cotter core material. If such observations are generally true for the Hematite Site, they can have an impact on groundwater flow and contaminant transport. However, data obtained during this RI do not provide definitive information related to these earlier observations.

3.3 HYDROGEOLOGY AND HYDROLOGY

Regional hydrogeology is described in Sect. 3.3.1, while site-specific hydrology and hydrogeology based on data collected during the RI are presented in Sects. 3.3.2 and 3.3.3, respectively.

3.3.1 Regional Hydrogeology

As mentioned previously, the Hematite Site is located within the Salem Plateau of the Ozarks Physiographic Province. The Salem Plateau (Fig. 3.1a) roughly coincides with the outcrop area of the Ozark Aquifer, one of the major hydrogeologic units within the Ozark Plateaus Aquifer System (Imes and Emmet 1994). The aquifer consists of dolostone, limestone, and sandstone formations ranging in age from Late Cambrian to Middle Devonian, and is separated from the deeper, more-permeable St. Francois Aquifer by the St. Francois Confining Unit (refer to Sect. 3.2.1 for a list of stratigraphic units). Within the Salem Plateau, the younger formations of the Ozark Aquifer are not present and the outcrop area consists of Ordovician Gasconade, Roubidoux, and Jefferson City Dolomite. The surface of these carbonate rocks has been deeply eroded and dissected by surface drainage systems, forming a rugged topography that is clearly seen in the hills that bound Joachim Creek valley at the Hematite Site. The aquifer's permeability was developed by dissolution of the carbonate rocks along fractures and bedding planes, including karst development, although the latter does not appear to be significant in the region surrounding the Hematite Site (MDNR MEGA 2004). Sandstone is present as massive, clean, well-sorted bodies in some formations and, therefore, is relatively permeable where it is not cemented.

The stratigraphic units making up the Ozark Aquifer in the area are listed in Sect. 3.2.1. The basal formation is the Potosi Dolomite, which is the most permeable formation for this aquifer within the Salem Plateau region and is the most reliable source of groundwater for large-capacity wells. The overlying Eminence Dolomite has less secondary porosity and permeability. The Gasconade Dolomite and Roubidoux Formations are also important water-producing units in the region. The Gasconade Dolomite contains the permeable Gunter Sandstone Member, which is a loosely cemented sandstone along a line that extends from Cooper County, Missouri (approximately 140 miles west-northwest of Jefferson County), south into Boone County, Arkansas. The Roubidoux Formation overlies the Gasconade Dolomite. The Jefferson City and Cotter Dolomite, which serve as the top formations for the aquifer within the Festus quadrangle, consists predominantly of dolostone with small quantities of shale, chert, and sandstone; it is less permeable regionally than the stratigraphically lower rocks of the Ozark aquifer.

The estimated hydraulic conductivity of the Ozark aquifer varies from more than 1.0×10^{-3} ft/second (86 ft/day) to less than 1.0×10^{-8} ft/second (1×10^{-3} ft/day). The hydraulic conductivity north of the northernmost regional groundwater divide varies from about 1.0×10^{-5} ft/second (1 ft/day) to about 1.0×10^{-3} ft/second (86 ft/day). The regional groundwater divide trends east-west through St. Francois County, immediately south of Jefferson County, approximately 35 miles south of the town of Hematite.

Imes and Emmett (1994) report that the Ozark aquifer is unconfined within the Salem Plateau region, with regional and local groundwater movement strongly influenced by surface topography. Groundwater flows from the upland areas toward the valleys where water discharges as stream base flow. Regional flow is controlled by the larger rivers (e.g., Mississippi and Missouri rivers) and regional topography, while local shallower flow is controlled by smaller streams and local topography. Along the northern and eastern boundaries of the Salem Plateau, the aquifer is incised by the Missouri and Mississippi Rivers. The rivers are major discharge areas for groundwater moving north and east from the Salem Plateau.

In the vicinity of the Hematite Site, groundwater within the shallower bedrock units (e.g., Jefferson City – Cotter) appears to be unconfined. However, as discussed in Sect. 3.3.3, observations based on results of a variety of hydraulic testing and potentiometric measurements for the deeper, Roubidoux Formation suggest that in this region this aquifer is confined.

3.3.2 Site-Specific Hydrology

3.3.2.1 Stream characteristics

As noted previously, Jefferson County is characterized by an average of 38 in. of precipitation per year (USDA 2003). The majority of the precipitation will run off from the surface or return to the atmosphere as a result of evapotranspiration, whereas the remainder will infiltrate into the subsurface. Most of the infiltration will follow short, subsurface flow paths in soils and alluvial sediments and discharge into local streams. The remaining flow will enter the bedrock and recharge bedrock aquifers. Shallow groundwater in bedrock formations is influenced by local topography with short flow paths followed by discharge into seeps and springs or alluvium.

The *Missouri Water Atlas* (MDNR 1986) shows that Joachim Creek, located south of the Hematite Facility, is a permanent flowing stream. There are several other surface water features present on the Hematite Site, including a spring, intermittent perennial and ephemeral streams, a lake, and ponds (refer to Figs. 1.2 and 1.3 for the location of these features). Descriptions of these surface water features are summarized below (based on Section 2.5.2, pages 12 to 14 of LBG 2003).

- The Site Spring flows an estimated 1 to 10 gpm most of the year. The spring is likely a result of fracture flow in the Jefferson City-Cotter Dolomite, which receives its source water in the hills northwest of the Hematite Site.

- The Site Pond is a small concrete dam impoundment southwest of the Plant. It receives flow from the Site Spring and the stormwater runoff from the area of the Hematite Facility (see Fig. 1.2 for the outfall location).

- The Site Creek is the effluent from below the dam of the Site Pond. It receives discharge from the Hematite Facility's sanitary water system (see Fig. 1.2 for the outfall location). It flows through a culvert beneath the railroad track and joins the effluent from the Lake Virginia drainage basin.

- The combined Lake Virginia/Site Creek tributary flows east to Joachim Creek.

- The Northeast Site Creek east of the Burial Pits flows southeast, then east to its confluence with the effluent of East Lake tributary, and then to Joachim Creek.

- East Lake, located east of the Hematite Facility, is an earth impoundment lake used as a water supply for cattle. It is reported to never have been used in conjunction with Hematite Facility operations.

- North Lake Tributary is the effluent drainage from North Lake and North Tributary. This tributary crosses the terrace, west of East Lake.

- North Tributary is an intermittent stream west of North Lake.

MDNR (1970) estimated the base flow recession, which is the amount of water that will flow in a stream after a 30-day rainless period. The base flow recession from 1961 through 1965 on the Joachim Creek is 0.2 ft^3/second. These data indicate that Joachim Creek is a gaining stream, and therefore, a recipient of shallow groundwater discharge (LBG 1999). This observation is consistent with the discussion in Chapter 5 that suggests that groundwater in the overburden at the Hematite Site migrates from the vicinity of the Hematite Facility toward Joachim Creek where it discharges.

Water levels at the surface water gauging stations (refer Fig. 2.1 for locations) were measured monthly from June 2004 through January 2005 (Table 3.1). Average, minimum and maximum water levels for this measurement period are shown in the following table:

Gauging Station	**Surface Water Elevation[a] (ft AMSL)**		
	Average	**Min**	**Max**
Site Pond	424.9	424.7	425.1
Site Pond Creek	423.0	422.7	423.6
Northeast Site Creek	427.6	dry	429.0
East Lake	428.5	427.7	429.7
Joachim Creek (at bridge)	412.7	412.5	413.2[b]

[a] Statistics for surface water elevation measurements taken monthly from June 2004 through January 2005.

[b] Water level at the Joachim Creek gauging station was above the surface water gauge in January 2005. The maximum water level elevation shown is the highest measured value when the surface water gauge was not flooded.

The water levels at all the surface water gauging stations (Table 3.1) exhibited similar seasonal trends, with water levels decreasing in the summer (July through September 2004) and increasing in the winter (November through January 2005). Immediately before the measurement event in January 2005, significant precipitation occurred which resulted in elevated water levels at all the surface water gauging stations (Joachim Creek was flooded). The surface water data also shows that the Northeast Site Creek is an intermittent stream, based on observed dry bed conditions in July, September and October 2004.

Surface water levels were also measured through survey methods at points along Joachim Creek downstream of the bridge and closer to the Hematite Site. These surface water measurements were made in conjunction with water level measurements at nearby wells to determine whether groundwater discharges into Joachim Creek. These surveyed surface water measurements are presented and discussed in Sect. 3.3.3.2.

3.3.2.2 Water supply

There are no public water supply intakes on Joachim Creek. According to an early report regarding the Hematite Site prepared for EPA (Ecology and Environment 1990), most of the residents of Hematite receive their drinking water from a public water supply well (in Public Water Supply District #5) located approximately 2.5 miles south-southeast of the town (near the intersection of Sunnyside and Carron roads). Previous reports also state that surface water is not used for drinking within a 4-mile radius of the Hematite Site (Section 2.5.3, page 14 of LBG 2003).

An industrial high-capacity well (125 gallon per minute capacity) is located within the Hematite Facility (LBG 2002a). The well has a total depth of 600 ft BGS (Plate 6 of LBG 2002b), and is open from the Roubidoux Formation through the Eminence Dolomite Formation (refer to Sect. 3.2.1 for bedrock formations underlying the Hematite Site).

Domestic and industrial water wells in the regional area produce water from the Powell-Gasconade aquifer group of the Ozark Aquifer, which includes the Jefferson City and the Roubidoux Formations (MDNR 1974). Note that the Powell Dolomite stratigraphically overlies the Cotter Dolomite, but is absent within the immediate area surrounding the Hematite Site (Whitfield and Middendorf 1992). LBG (2002a) conducted a survey of water-producing wells within a 2-mile radius of the Hematite Facility. A majority of the wells surveyed were open boreholes with casing depths 80 ft or greater, although the older wells tended to have shallower casings (e.g., 40 ft). Out of more than 200 mostly private wells included in the survey, only 6 wells penetrated the deeper Gasconade and Eminence Dolomite. Although the Jefferson City Dolomite is generally not capable of sustained water production because of its low storage capacity and is subject to failure during drought or sustained pumping (MDNR 1974), it appears to be adequate for individual/private-use wells, several of which were completed in this formation (LBG 2002a). However, most of the wells included in the survey intersected both the Jefferson City and the Roubidoux Formations.

3.3.3 Site-Specific Hydrogeology

The components of the hydrogeologic system near the Hematite Site that are relevant to this RI include the following:

- Overburden (see Sect. 3.2.4.1)
- Jefferson City-Cotter Formation (see Sect. 3.2.4.2)
- Roubidoux Formation (see Sect. 3.2.4.2)

Flow within the overburden generally is from areas of high elevation toward lower elevation, with local streams being the zone of discharge. Within this general framework, the principal groundwater flow paths in overburden are dictated by the occurrence of porous and permeable lithologies such as sands and gravels. For this reason, the basal coarse-grain unit in the overburden (occurring in both the terrace and alluvial zones; refer to Fig. 3.4) is expected to be an important pathway for groundwater flow and transport of dissolved contaminants.

Surface topography also appears to be a strong driver that influences groundwater flow directions in the shallow bedrock on the Salem Plateau (refer to Sect. 3.3.1). The impact of topography on flow direction tends to decrease with increasing depth where the influence of regional flow patterns dominated by major rivers to the north and east is the controlling factor. In this region of the Salem Plateau, deep groundwater in these formations generally flows to the northeast (Imes and Emmett 1994).

3.3.3.1 Identification of HSUs in bedrock

Before proceeding with construction of potentiometric maps for bedrock or an assessment of groundwater flow directions, it is important to determine how the screened intervals in the bedrock wells are related to one another. The goal is to identify the HSUs present at the Site and those wells that intercept each one. The cross-section illustrated on Fig. 3.12 forms the basis for this analysis.

Figure 3.13 is an expansion of Fig. 3.12 that includes all bedrock boreholes at the Hematite Site and illustrates the screened intervals in each (or the open intervals for the private wells, portrayed by dashed lines). Although the wells were labeled as either "Jefferson City (JC)" or "Roubidoux (RB)," it is apparent that some completion zones probably were not in the designated formation. The patterned zones delineate three tentatively identified HSUs: Jefferson City-Cotter, Jefferson City-Roubidoux contact zone, and Roubidoux Formation. These HSUs were selected based on geology (e.g., they are strata-bound and parallel to the regional dip). The identification of these HSUs is based on historical and RI data, and should be considered as a working conceptual model that honors available data.

Additional insight into the hydrologic properties of these HSUs is available through estimates of hydraulic conductivity from slug testing conducted during previous investigations (GEA 1996, LGB 1998 and 2002b) and as part of this RI (see Sect. 2.5 for a description of the test method; analyses of the slug test data are in Appendix G of this report). In addition, injection tests were conducted by LBG (2002b, Section 4.2, page 10), which provided estimates of relative transmissivity. Table 3.2 gives the results of the slug tests from a number of well locations in the overburden, Jefferson City-Cotter Dolomite, and Roubidoux Formation obtained during the RI. A re-examination of the LBG 1999 and 2002b data yields results comparable to those obtained in Table 3.2 for the same tested intervals.

As seen in Table 3.2, the K_h values are variable in each formation, but are generally higher in the overburden (3.8 to >155 ft/day) and the Jefferson City-Cotter (<0.2 to 103.9 ft/day) than in the Roubidoux Formation (0.8 to >15 ft/day).

LBG (2002b, Section 4.2, page 10, and associated boring logs) also reported some additional borehole testing information that they refer to as "Permeability Test" data. This information is related to the maximum rate of water injection that could be achieved from isolated 20-ft intervals in boreholes BR-01, BR-02, BR-03, and BR-04 along most of their length. The results are reported in units of "gpm" and are assumed to represent a qualitative measure of permeability; details of the injection test protocol can be found in Section 4.2 (page 10) of LBG 2002b.

Figure 3.14 shows all of the K_h results on cross-section G-G' (refer to Fig. 3.8 for the cross-section location). The injection test results are presented on Fig. 3.15, in which each borehole is represented in its

proper orientation relative to the sandstone below the Jefferson City-Roubidoux contact identified in lithologic cross-sections (i.e., Figs. 3.9 through 3.13). The vertical blue line segments on Fig. 3.15 represent the location in each borehole of those zones with high injection rates (i.e., apparent transmissivity). These boreholes were originally drilled into the Gasconade Formation that underlies the Roubidoux Formation. The injection tests were performed before these boreholes were grouted back to their current completion depths, which account for the length of the test records.

The hydraulic conductivity results on Figs. 3.14 and 3.15 are combined on Fig. 3.16. The patterned areas identify those zones with relatively high conductivity and/or transmissivity. By comparing Fig. 3.16 with Fig. 3.13, where three HSUs have tentatively been identified, the following conclusions can be reached:

- There is an upper transmissive zone that lies within the Jefferson City-Cotter HSU and appears to be most closely associated with those boreholes completed within about 50 ft of the overburden-Jefferson City-Cotter interface (e.g., PZ-03, PZ-04, WS-31, BR-08-JC, and BR-10-JC).

- The Jefferson City-Roubidoux contact zone is a region of variable, but typically low, transmissivity.

- There is a deeper, second zone of high transmissivity (Roubidoux HSU) defined by the injection test results of LBG (2002b, data shown in associated boring logs) that lies immediately below the relatively low transmissivity Jefferson City-Roubidoux contact zone.

In summary, it is reasonable to conclude that observations regarding hydraulic conductivity measurements of the Jefferson City-Cotter and Roubidoux Formations that have emerged from this RI are of local significance and particularly important for understanding the fate and transport of contaminants in bedrock associated with the Hematite Facility. However, the observations may incorrectly suggest hydraulic properties that are regional in scope and apply to the entire thicknesses of these formations. For example, regionally transmissive stratigraphic intervals in the lower part of the Roubidoux Formation are known to support very productive, community-scale water wells. The completion intervals in the upper part of the Roubidoux for the deep wells included in this RI typically are not highly transmissive in comparison to the deeper, more productive units in the formation. Furthermore, the hydraulic conductivity values measured in the upper Roubidoux Formation generally are lower than what was observed in many wells completed in the Jefferson City-Cotter (Table 3.2). However, the high conductivity zone identified within the Jefferson City-Cotter appears to be locally limited to a region extending southeast from the Hematite Facility and probably corresponds to a specific stratigraphic interval in the formation, but is not representative of the formation as a whole.

3.3.3.2 Potentiometric surface

Figures 3.17 through 3.21 illustrate the potentiometric surfaces for the major HSUs defined in this investigation based on water level measurements made during December 2004 (data tabulated in Appendix D). Figure 3.17 shows a number of wells in the immediate vicinity of the Hematite Facility that are completed in the fine-grain sediments in the shallow overburden. These wells typically are screened from 5 to 15 ft BGS, approximately 10 to 15 ft above the overburden-bedrock interface. Although the number of data points is not large, it is apparent that under the main part of the Hematite Facility, head elevations are greater than 430 ft AMSL, whereas heads are 4 to 10 ft lower further to the east and all are less than 430 ft AMSL. The cause of this lateral decline in heads may reflect a shallow flow pathway leading to discharge into the Northeast Site Creek that flows intermittently through this region. Alternatively, it is possible that the Burial Pits on the eastern side of the Hematite Facility (Fig. 1.3)

influence shallow groundwater flow. The burial trenches were excavated to a depth of about 12 ft (LBG 1999) and are expected to contain relatively more permeable fill material than the native sediments. It is possible that a hydraulic connection exists between the Burial Pits and the permeable lower sands and gravels such that shallow groundwater entering the trench area is able to migrate downward to the deep overburden. Figure 3.17 is similar to the potentiometric surface for the NSSSC as defined and reported by LBG (1999, Section 5.2.5, page 21), which suggests that hydrologic conditions in this shallow unit have not changed significantly since 1999.

Figure 3.18 is a potentiometric surface map based on those wells completed in the lower part of the overburden. Many of these wells were installed by DPT to the depth of refusal and some of them may not have fully penetrated the overburden if large cobbles were encountered in the coarse material. Nearly all of these wells are screened at a depth that includes some of the coarse-grain material, but many also incorporate some finer-grain units in the screened interval. However, the wells appear to be hydraulically connected to the coarse-grain basal layer. The potentiometric surface defined by these wells on Fig. 3.18 clearly defines a southeasterly groundwater flow direction toward Joachim Creek. The region of highest hydraulic heads on this map corresponds to the location of the Hematite Facility.

LBG (1999, Section 5.2.5, pages 21-22) also presented a potentiometric map for the DSCC, a unit they identified that lies below the NSSSC and above the coarse-grain material at the base of the overburden. The map was limited in extent to the immediate vicinity of the Hematite Facility. During fieldwork for the RI, geologists were unable to distinguish this subunit in core material. As a consequence, this Report combines water level and contaminant data for the DSCC wells of LBG (1999) and the deep overburden wells of the RI. The water level results illustrated in Fig. 3.18 and related discussion of contaminant distributions in the deeper overburden (Chaps. 4 and 5) suggest that this approach is valid.

In Sect. 3.3.2.1 it was noted that Joachim Creek is a gaining stream in the vicinity of the Hematite Site. Additional information is available that supports this interpretation. As part of the RI, water levels were measured for Joachim Creek at several points near the Facility in association with water level determinations in neighboring overburden monitoring wells in February 2005. The results are summarized as follows (refer to Fig. 3.18 for well locations):

Location	Water Level (ft AMSL)
BR-06-OB	409.7
Joachim Creek near BR-06	409.7
BR-10-OB	408.1
Joachim Creek near BR-10	407.4

These measurements, coupled with the observed hydraulic gradient in the direction of Joachim Creek as illustrated on Fig. 3.18, suggest discharge from the overburden into the stream. During periods of flooding of the stream, there may be temporary reversal of flow proximal to Joachim Creek, but this condition will not persist once the stream water level returns to normal.

Comparison of the hydraulic heads in shallow (Fig. 3.17) and deep (Fig. 3.18) overburden underlying the Hematite Facility illustrates a downward vertical gradient (details are discussed in Sect. 3.3.3.3). Head differences of 10 ft or more are common in the region of the Facility. This fact suggests that the shallow groundwater represents a perched water table. The fact that the hydraulic heads are highest in the vicinity of the Hematite Facility may result from several different mechanisms. For example, a possible source of increased recharge in this area may be related to operation of the Facility. Leaks in stormwater, domestic and process water, and waste transfer piping could be a factor in these

observations. Alternatively, shallow subsurface groundwater flow from the topographically elevated region northwest of the Facility may be important. Likewise, storm runoff from the adjacent Highway P could contribute to this observation.

The potentiometric surface maps for bedrock are presented as a sequence of separate illustrations based on the three HSUs defined in the previous section. Figure 3.19 represents the potentiometric surface for the Jefferson City-Cotter HSU. In general, the potentiometric surface on Fig. 3.19 appears to define a zone of high heads in bedrock under the Hematite Facility. The region of high heads roughly corresponds to similar regions observed in both the shallow and deep overburden wells (Figs. 3.17 and 3.18, respectively) and suggests that the overburden and shallow Jefferson City-Cotter HSU may be hydraulically interconnected.

There is evidence for declining heads in the direction of Joachim Creek, as defined by wells close to the Hematite Facility (i.e., PZ-04, PZ-03, WS-30, and WS-31) and those located further toward the southeast (i.e., BR-08, BR-10, and BR-03). All of these wells are screened in a shallow zone within approximately 50 ft of the overburden-bedrock interface. Evidence, to be presented in Chapter 5, based on contaminant distributions in the Jefferson City-Cotter Dolomite supports an interpretation of flow and transport toward the southeast. Other wells to the north of Joachim Creek and lying on its flood plain (i.e., BR-04, BR-05, BR-09, BR-11, and BR-02) appear to define a potentiometrically flat surface, suggesting little potential for lateral groundwater flow except in close proximity to the Hematite Facility. Contaminant data discussed in Chapter 5 will help refine the details of groundwater flow in this region.

The cluster of wells on the topographically elevated region to the south of Joachim Creek also appears to define a region of high heads, and contours have been drawn in a way that may reflect a topographic influence, with heads declining northwestward in the direction of Joachim Creek. This gradient suggests a zone of groundwater convergence or discharge from the Jefferson City-Cotter HSU to the overburden near to the location of the creek. This inference is consistent with the vertical groundwater gradients observed between the overburden and Jefferson City-Cotter in this area (Sect. 3.3.3.3). However, the water levels measured in PW-19 and PW-06 on December 3, 2004 (Fig. 3.19) appear to be low in comparison to their nearest neighbors and relative to another set of water levels that were obtained less than 2 weeks later. This latter data set was obtained in association with site-wide groundwater sample collection (described in Sect. 2.6) that occurred in late December 2004 and early January 2005. The differences between these two data sets may be associated with slow re-equilibration of water levels in the Jefferson City-Cotter HSU following conversion of PW-06, PW-16, and PW-19 from open holes to dual completion wells in mid-November 2004.

There also is uncertainty in attributing water levels observed in PW-05, PW-10, PW-24, and PW-25 to the Jefferson City-Cotter HSU. These private wells are all completed as open holes (refer to Fig. 3.19 for well locations and Fig. 3.13 for open depth intervals): PW-24 and PW-25 wells are completed in the Jefferson City-Cotter Dolomite and the others reach the Jefferson City-Roubidoux contact zone. It is not possible, given existing information regarding these private wells, to identify which hydrologic zone intersected by these open boreholes has a controlling influence on the observed heads. Thus, it is questionable that they are representative of the Jefferson City-Cotter HSU, as defined by other wells that are isolated within this zone (e.g., PW-06-JC, PW-16-JC, and PW-19-JC). For that reason, water levels for these wells are not included in the potentiometric map in Fig. 3.19.

Figure 3.20 shows a potentiometric surface for the Jefferson City-Roubidoux contact zone HSU that differs significantly from that for the Jefferson City-Cotter HSU that was illustrated in Fig. 3.19. Borehole BR-12-JC has a head value that is elevated with respect to the others, but the more dominant feature is the indication of a significant northeasterly component to the gradient (and to groundwater flow). As already noted, the regional potentiometric gradient declines towards the northeast and Fig. 3.20 appears to be part

of this regional hydraulic regime. As for Fig. 3.19, water levels for the open boreholes/private wells to the south of Joachim Creek have not been included in drawing the potentiometric surface shown on Fig. 3.20 because it is not possible to determine what HSU controls the water levels.

Water levels were measured in BR-12-RB on December 3, 2004 (427.31 ft AMSL) and again on December 8, 2004 (417.9 ft AMSL). The latter measurement was associated with a groundwater sample collection activity (Sect. 2.6). Well BR-12-RB is the only well that showed this magnitude of difference between water levels measured only five days apart and a measurement error is suspected. Other water level measurements in BR-12-RB made during 2005 suggest that the 417.9 ft AMSL value is more likely to be correct and, consequently, this value is used in Fig. 3.20.

Water levels for wells in the Roubidoux HSU (Fig. 3.21) define a potentiometric surface roughly similar to that observed on Fig. 3.20, and appear to reflect the regional influences (i.e., a northeasterly trending gradient). Artesian conditions in BR-03-RB prevented an accurate determination of the head on December 3, 2004, and an additional riser was added to the well before December 9, 2004. The water level in BR-03-RB was re-measured on December 9 as part of groundwater sampling and an elevation of 423.1 ft AMSL was obtained.

The HSUs illustrated in Fig. 3.13 were defined primarily from compelling stratigraphic and structural lines of evidence. The HSUs represent narrow stratigraphic windows, approximately 20-30 ft thick, that are inclined at an angle similar to the regional dip (~2.7º; Fig. 3.12). The wells shown in Fig. 3.13 all are projected into a cross section that represents the axial plane of the subtle warp shown in Fig. 3.11. The relative vertical positions of the wells have been adjusted to compensate for the dipping strata on the flanks of the warp feature (1-2º). Given the thin package of strata that define a HSU it is reasonable to acknowledge that hydraulic integration probably exists within that geologic interval. Therefore, the HSU becomes the key unit from which to construct potentiometric maps for the region and overlay groundwater geochemical relationships.

As illustrated in Fig. 3.13, the stratigraphic window represented by the Jefferson City-Cotter HSU is approximately 20-25 ft thick and encompasses the screened intervals of 16 wells located in the vicinity of the Hematite site. Therefore, this HSU is a data-rich resource and the resulting potentiometric surface (Fig. 3.19) is a convincing representation of integrated water level information and not a random collection of data that bear no relationship to one another. Each of the other HSUs yield unique potentiometric surface maps that emphasize the progressive change in the potentiometric environment from shallow groundwater that is impacted by near surface factors to deeper HSUs where regional potentiometric properties dominate. There is essentially no evidence suggesting the existence of natural hydraulic linkages between vertically adjacent HSUs.

It is possible to combine information from potentiometric surface maps (Figs. 3.17 through 3.21) and slug test results (Table 3.2) to compute estimates of groundwater flow velocities based on Darcy's Law:

$$\text{Linear Velocity} = - K_h \, (dh/dl)/\rho \text{ (where } \rho = \text{porosity).}$$

However, one must assume that the two points used to calculate velocity actually lie on a flow path. Estimates have been made of Darcy flow velocities for a variety of potential flow paths, and the results obtained for overburden range between approximately 20 and 300 ft/year; estimated velocity values in bedrock range from 2 to >300 ft/year. These results, and other estimates based on the assumed rate of advance of contaminant plumes, are discussed in more detail in the groundwater modeling report (Appendix A of this Report and SAIC 2005).

In unconsolidated porous media such as the overburden, there is a reasonable level of confidence that the potentiometric surface provides a good indication of the direction of groundwater flow and contaminant transport. This inference is testable by referring to the distribution of contaminants in overburden groundwater and will be discussed in Chapter 5. In contrast, the relationship between groundwater flow and contaminant transport and the configuration of the potentiometric surface for bedrock formations is more difficult to interpret. Groundwater flow directions in fractured media are dependent on the orientation of transmissive fracture sets. The transmissivity of individual fractures depends on the interconnectivity of a network of fractures. Lithologic features, such as the presence of transmissive interbeds, also will influence flow directions.

Both the Jefferson City-Cotter Dolomite and the Roubidoux Formation are dominated by dolostone, although sandstone interbeds are known to occur in the geologic section underlying this area (see Figs. 3.9 through 3.11). Groundwater flow in the dolostone primarily should follow laterally continuous, permeable interbeds, such as sandstone, and fractures, some of which may have been widened by dissolution. The core logs reveal the presence of the interbeds. The drilling log entries also note that fractures were occasionally encountered in recovered core, but details about the role of fractures in groundwater flow in the vicinity of the Hematite Site are not available because comprehensive information on fracture frequency, orientation, and apertures are not available. As noted in Sect. 3.2.4.3, there is no information on the dominant fracture sets and their orientation in this region.

Preferential flow in bedrock also may be associated with zones of weathering that widen fractures and increase permeability. Some parts of the Jefferson City-Cotter Dolomite near the overburden-bedrock interface in the valley of Joachim Creek may be an example of this process. Consequently, the potentiometric surfaces for the Jefferson City-Cotter Dolomite and Roubidoux Formation should be regarded only as providing information on the potential directions of groundwater flow. A better understanding of the connection between head gradients and groundwater flow will emerge in Chapter 5 when the distribution of contaminants in groundwater from these formations is considered.

3.3.3.3 Vertical head gradients

Whereas the previous discussion examines the potential for lateral groundwater flow (and contaminant transport), it is also important to understand the evidence relating to the potential for vertical groundwater flow at the Hematite Site. Figures 3.22 through 3.24 present vertical gradient results between the shallow and deep overburden, the deep overburden and Jefferson City-Cotter Dolomite, and the Jefferson City-Cotter Dolomite and Roubidoux Formation, respectively. Note that these gradients were calculated based on water level measurements made in December 2004. The vertical gradient is defined as follows:

Vertical Gradient = - dh/dZ = - (shallow head – deep head)/vertical separation of monitored zones
(negative values of –dh/dZ indicate a downward gradient)

Figure 3.22 shows that the vertical gradient between the shallow and deep overburden layers underlying the Hematite Facility is strongly downward, except at WS-26/WS-27 next to Northeast Site Creek where an upward gradient is observed. The general observation of a downward head gradient in this area is consistent with the earlier discussion related to Figs. 3.17 and 3.18. A region of downward gradients under the Hematite Facility also is observed when water levels in the deep overburden are compared to the Jefferson City-Cotter Dolomite, as illustrated on Fig. 3.23. However, the magnitude of the gradient is less than that on Fig. 3.22. The overburden-Jefferson City-Cotter gradient near Joachim Creek is upward, which coincides with the interpretation of this region as a zone of groundwater convergence (i.e., discharge), as seen on Fig. 3.19. As illustrated on Fig. 3.2.4, the gradient between the Jefferson City and Roubidoux Formation is upward throughout most of the area, except to the east for wells BR-02 and BR-05 where the gradient is slightly downward.

3.3.3.4 Interconnectivity of geologic units: time series water level measurements

It is important to assess the degree of interconnectivity of the main hydrologic units in the vicinity of the Hematite Site, because this information will help explain the vertical distribution of contaminants. Furthermore, it is an essential piece of information for the CSM that will support numerical modeling and the F&T evaluation in Chapter 5.

Figures 3.25 through 3.27 are time-series plots of water levels in selected wells with at least quarterly measurements that extend over a period of from one to several years. Comparison of these water level results focuses on the relative shapes of the time-series patterns and not on absolute values of water level elevations. The data show that for the common period of water level records (March to December 2004) the overburden and shallow Jefferson City-Cotter HSU (Fig. 3.25) well hydrographs appear to be very similar. In addition, from August 2004 to August 2005 the hydrographs for BR-04-JC (Jefferson City-Cotter HSU) and BR-08-RB (Jefferson City-Roubidoux Contact Zone HSU) also mimic one another (Fig. 3.26). One possible explanation for these observations is that these geologic units are hydraulically interconnected. Alternatively, the similar hydrographs may reflect the fact that the Jefferson City-Cotter Dolomite outcrops in the vicinity of the Hematite Site and water levels are responding independently to seasonal changes in precipitation and recharge (i.e., elevated water levels in winter-spring and lower during the drier summer months). The Jefferson City-Cotter well shown on Fig. 3.26 is BR-04-JC, which is located northeast of the Facility and completed at a depth of approximately 100 ft BGS. BR-08-RB is located southeast of the Facility and screened at a depth of approximately 110-150 ft BGS.

The discussion in Chapter 5 establishes that VOC contamination originating at the Hematite Facility has migrated downward into parts of the Jefferson City-Cotter HSU. This observation supports the inference of a hydraulic connection between the overburden and shallow bedrock in at least some parts of the Site. In contrast, no VOC contamination exists in the Jefferson City-Roubidoux Contact Zone HSU on the Hematite Site. In addition, information presented in Sect. 3.3.3.1 tends not to support an intimate hydraulic connection between the Jefferson City-Cotter and Jefferson City-Roubidoux Contact Zone HSUs.

Water level data for Roubidoux HSU wells (Fig. 3.27, this figure has the same vertical scale as Fig. 3.26) suggest a somewhat different response over time. The most significant difference is that these wells have experienced an overall rapid rise in water levels that appears to have begun in 2003. Head increases of 30 to 40 ft have taken place by the end of 2004. The magnitude of the increase appears to increase with increasing distance from the Hematite Site, such that BR-02 has the greatest head rise and BR-01 the least over the same period of time. There are two events that most likely have contributed either individually or in concert with one another to cause this dramatic rise.

First, in late summer 2003, the city of Festus, located approximately 5 miles to the east of the Hematite Site (refer to Fig. 1.1 for the location of Festus relative to the Site), brought online a new water-production facility located on the floodplain of the Mississippi River about 1 mile from the river. This “collector” well draws water from the sediments marginal to and underlying the Mississippi River using horizontal wells and now provides nearly all of the water needs for the area. Startup of this well permitted the city to place its four production wells located on the west side of Festus (i.e., closer to the Hematite Site) on standby. These wells had been pumping approximately 1 gpd from the lower Roubidoux Formation. Currently, they are used only during periods of peak demand in mid- to late summer, or when the collector well is off-line. When supplementing production from the collector well, the pumping rate on these wells is much less than before August 2003.

Secondly, once contamination was discovered in private wells located southeast of the Hematite Site across Joachim Creek, the local public water supply system was extended to the residents and all wells in

this area were shut down (between November 2003 and March 2004). The U.S. Geological Survey (USGS) reports that in Missouri, residential, self-supplied water usage is approximately 65 gpd/person (http://water.usgs.gov/pubs/circ/2004/circ1268/htdocs/table06.html). Therefore, the total daily withdrawal of groundwater by the more than 20 families in this area probably was on the order of 5000 GPD. Although this amount is much less than for the city of Festus, there may have been a local impact on drawdown in the Roubidoux Formation until these wells were shut down.

Both of these events relieved a source of hydraulic stress to the Roubidoux Formation. The magnitude of the impact of the shut down of the Festus production wells is regional in scale, while the impact of the shut down of the private wells was probably only of local extent.

Further support for the magnitude of regional impact of the Festus production wells comes from a well located within 1 mile of one of the original Festus production wells that is monitored by USGS and has continuous water level data over the time period of interest (USGS 2005). This USGS well is located ~3 miles northeast of the Hematite Facility, is 1048 ft deep, and is completed in the lower Roubidoux/Potosi Formation. Since mid-2003, this well has experienced a rise in water level of approximately 150 ft (Fig. 3.28).

On July 6, 2005, the city of Festus temporarily resumed pumping three of its deep production wells. Coincident with this event, the water levels in the USGS monitoring well and wells BR-02-RB and BR-03-RB began to decline rapidly. This result adds support to the proposed cause and effect relationship between large-scale pumping (or shutdown) of the Festus wells and observed changes in water levels in monitoring wells penetrating into the Roubidoux HSU on the Hematite Site.

In addition to the overall rise in water levels throughout 2004 in Roubidoux HSU wells located near the Hematite Site, comparison of the shapes of the hydrograph trends for Roubidoux, Jefferson City-Cotter, and overburden wells (Figs. 3.25 through 3.27) shows general similarity over the past 1 to 2 years. However, the amplitude of changes in the Roubidoux water level data appears to be damped in comparison to the other wells. The fine structure to the water level curves on Figs. 3.25 through 3.27 appears to be persistent among wells completed in the three geologic units and, as noted above, probably represents a response to seasonal changes in the amount of precipitation and recharge. The water level records are too short to provide a detailed comparison to local precipitation records.

Whereas information discussed earlier in this section suggests hydraulic interconnection between overburden and at least parts of the Jefferson City-Cotter HSU, deeper bedrock units appear to be more isolated from one another. The contrast between hydrographs for the Jefferson City-Cotter and Roubidoux wells since mid-2002 (Figs. 3.26 and 3.27) suggests that significant hydraulic interconnections do not occur between these two geologic units. This observation supports an interpretation that contamination of the Roubidoux Formation by downward migration of groundwater is unlikely (discussed further in Chapter 5). Rebound of water levels of 20 to 40 ft in the Roubidoux wells (especially BR-04-RB) during this period of time is not reflected to any significant degree in the hydrograph of BR-04-JC. It is more likely that the superficial similarities of the fine structure of these hydrographs are related to their response to seasonal precipitation and recharge factors transmitted to the formations from areas of surface outcrops on a regional scale.

Another example of information supporting the lack of hydraulic interconnectivity between the Jefferson City-Cotter Dolomite and Roubidoux Formation is illustrated by the results of integrity testing in wells PW-06, PW-16, and PW-19. Following their shut down, these private wells were reconfigured as dual-completion monitoring wells with deep and shallow screened intervals isolated by a thick grouted zone. In November 2004, the lower intervals in these wells were pumped at a sustained rate of 2 to 4 gpm for 1 hour, as water levels in the upper zones were monitored. The purpose of the testing was to confirm

the integrity of the grout seal. The shallow zones in PW-06 and PW-19 showed no changes in water level during the test. Not only do these results establish that the grout seal is intact, but they also show that the lower and upper screened intervals of bedrock are not significant in hydraulic communication. Water levels in the upper zone at PW-16 rose slightly (1.09 ft) during the pumping of the deep zone, an observation that is difficult to reconcile with the nature of the testing.

The rebound in water levels observed in the Roubidoux wells on Fig. 3.27 is significant for another important reason. Prior to the shut down of the Festus production wells in 2003 and the private wells near the Hematite Site in 2004, water levels within these Roubidoux wells were 20 to 40 ft lower than results from the most recent measurements made in December 2004. The potentiometric surface for the Roubidoux Formation (Fig. 3.21) and the vertical gradients between this formation and the Jefferson City-Cotter Dolomite (Fig. 3.24) for this RI were measured after a significant period of recovery had occurred and apparently are approaching a new, higher, static potentiometric level. Had similar data been obtained prior to 2003 for all of the new wells shown in these figures, the resultant patterns of head distributions would have been dramatically different. Specifically, there would have been a strong easterly gradient in the Roubidoux Formation (i.e., greater drawdown for wells closer to the city of Festus production wells), and the vertical gradients between the Jefferson City-Cotter Dolomite and Roubidoux Formation would have been consistently downward rather than upward. A potentiometric map for the Roubidoux Formation based on water level data obtained from four wells in August 2002 emphasizes some of these relationships and is presented in Fig. 5.20 with a related discussion.

This observation is critically important because groundwater flow and contaminant migration in the vicinity of the Hematite Facility probably occurred over a period of years prior to 2003 during which hydraulic conditions (at least for the Roubidoux Formation) were very different than today. The distribution of contamination currently observed in the Roubidoux Formation in the private wells southeast of the Facility appears to be related to the lower heads prevailing in that formation prior to 2003. F&T modeling accounts for these recent changes in water levels in the Roubidoux Formation and addresses how the changes will impact future contaminant migration patterns (Chapter 5).

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CHAPTER 3 FIGURES

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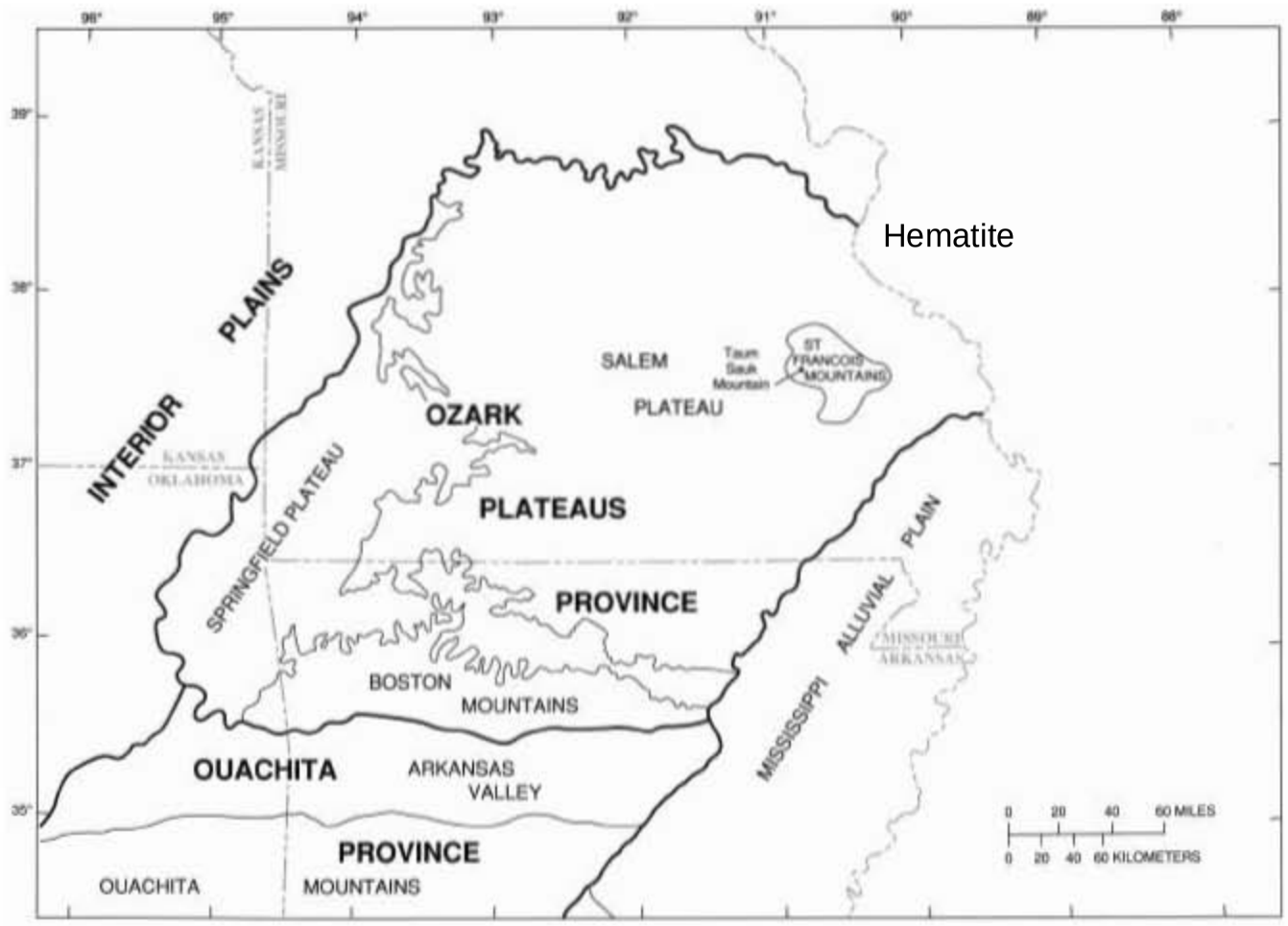


Fig. 3.1a. Location of Hematite in Salem Plateau, Ozarks Plateaus Physiographic Province.

Fig. 3.1b. Geologic map of Hematite Site area.

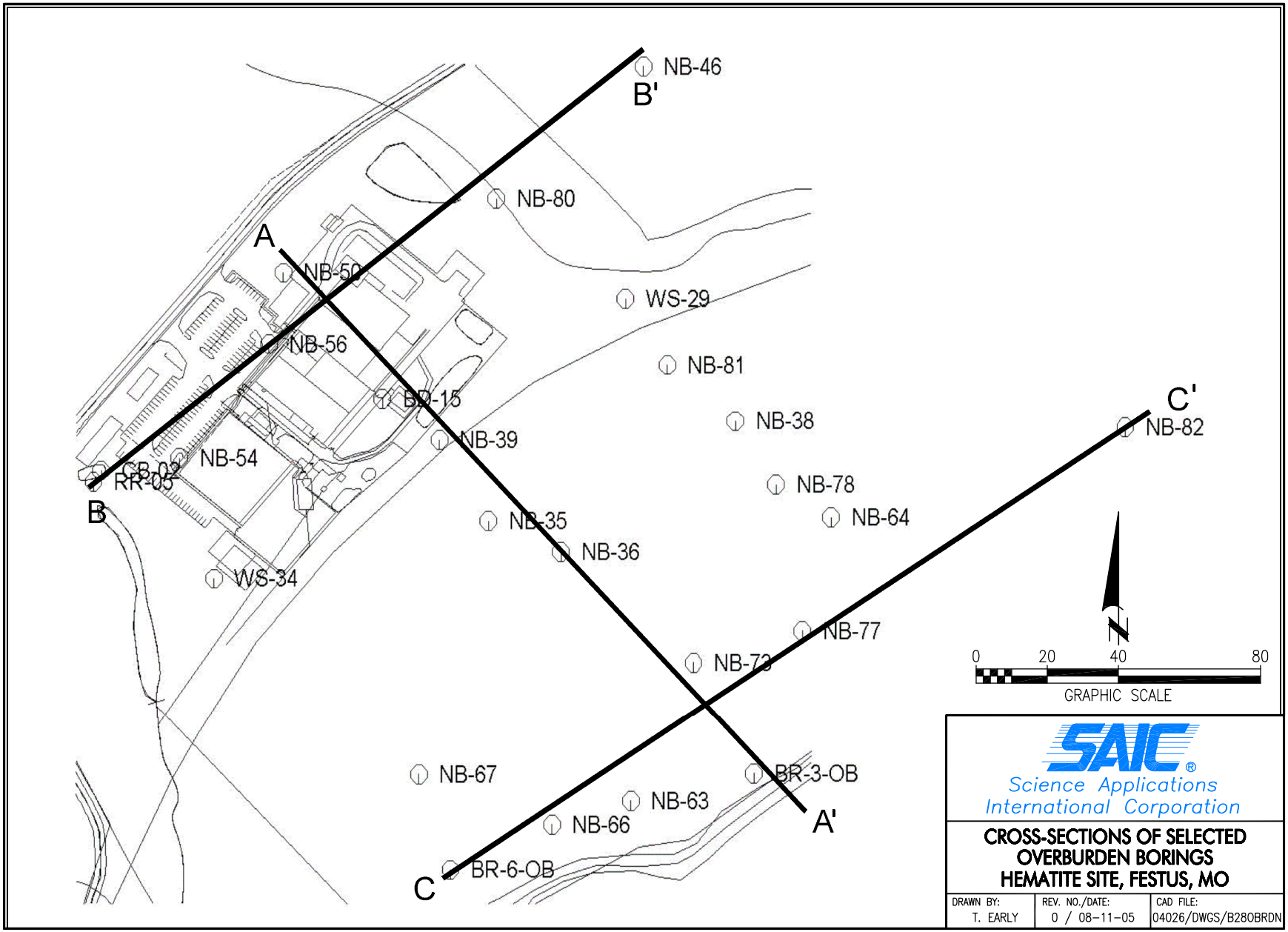


Fig. 3.2. Cross-sections of selected overburden borings.

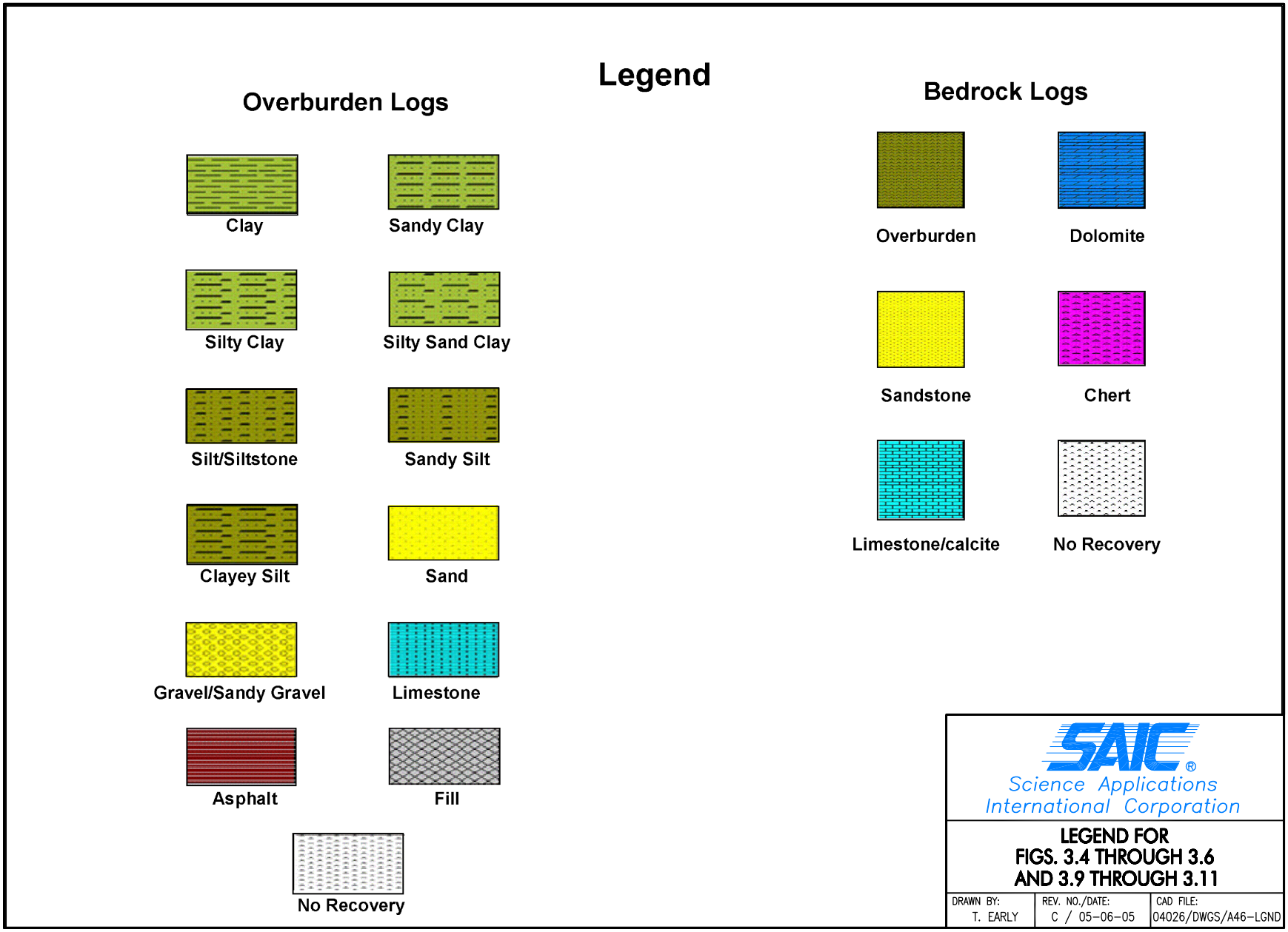


Fig. 3.3. Legend for Figs. 3.4 through 3.6 and 3.9 through 3.11.

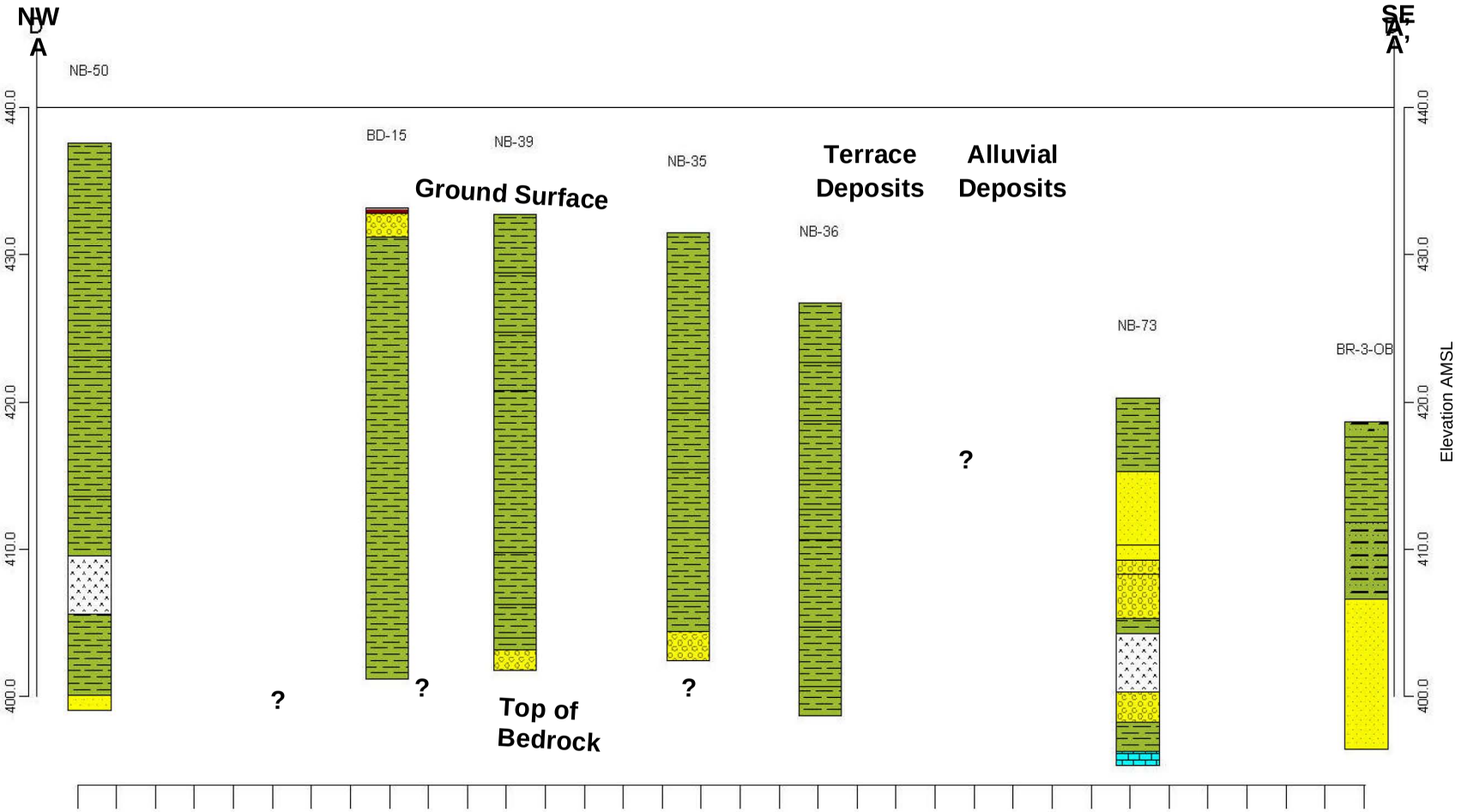


Fig. 3.4. Cross-section A-A'; overburden wells.

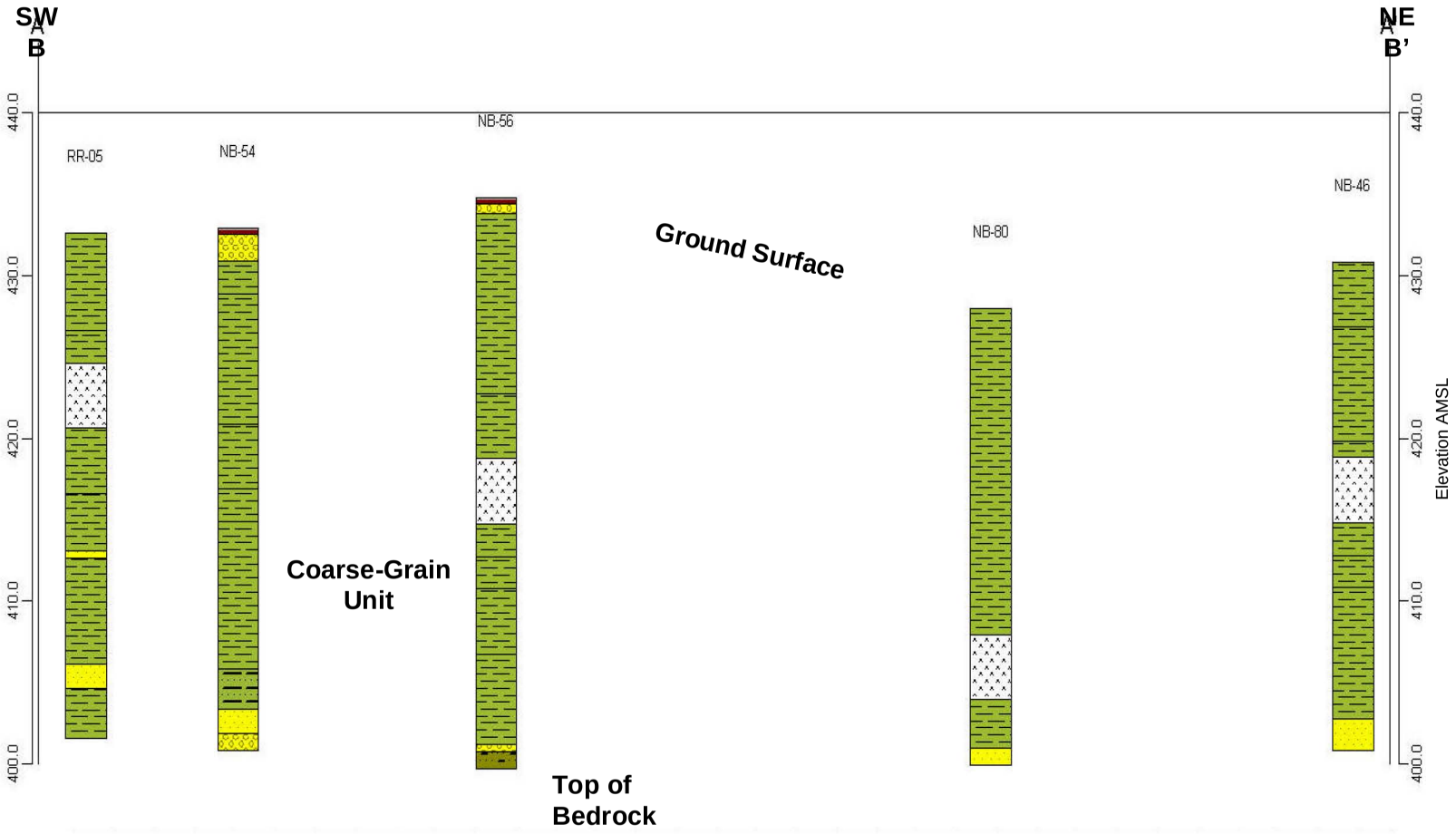


Fig. 3.5. Cross-section B-B'; overburden wells.

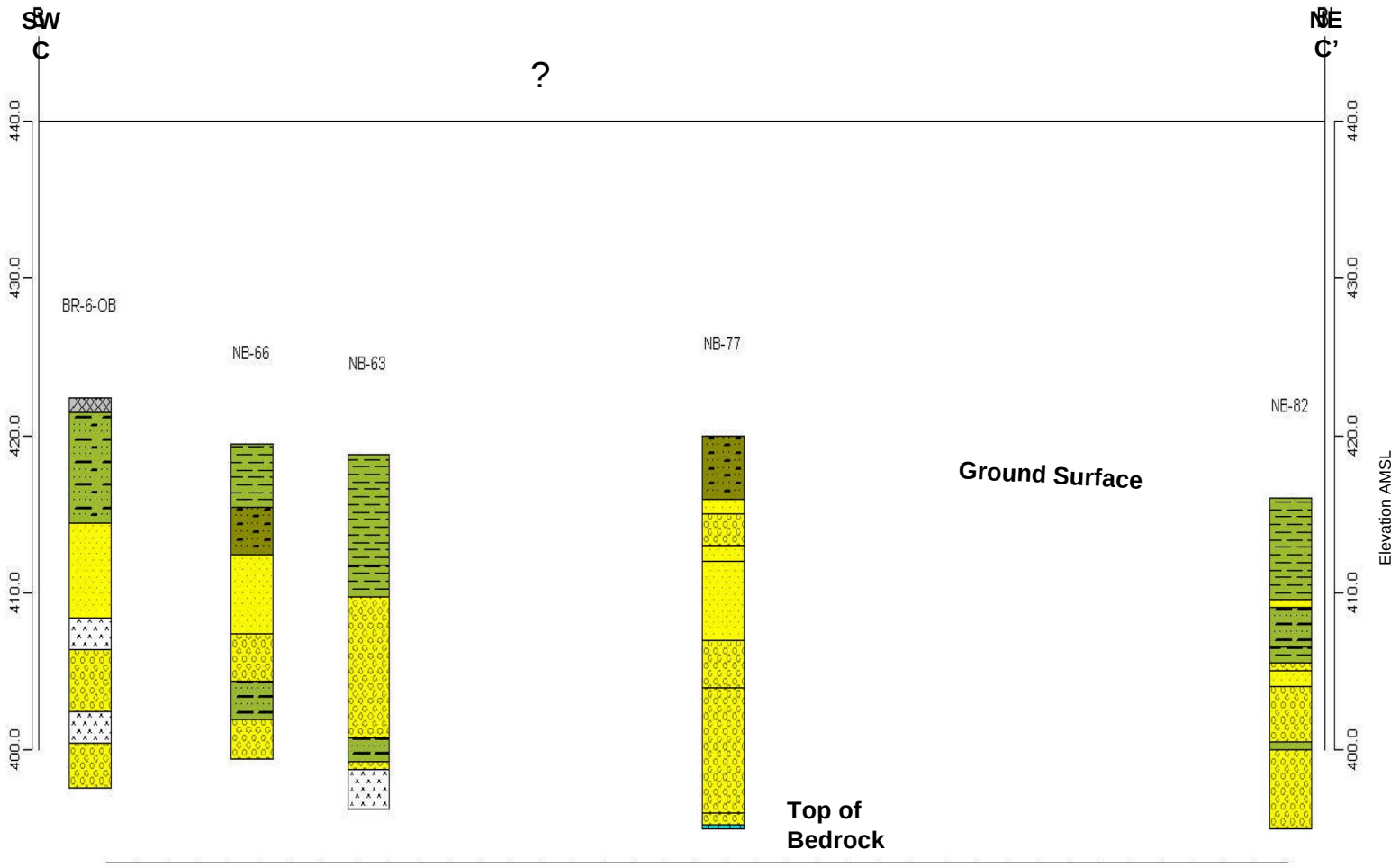


Fig. 3.6. Cross-section C-C'; overburden wells.

Fig. 3.7. Isopach map of coarse-grain-based deposits.

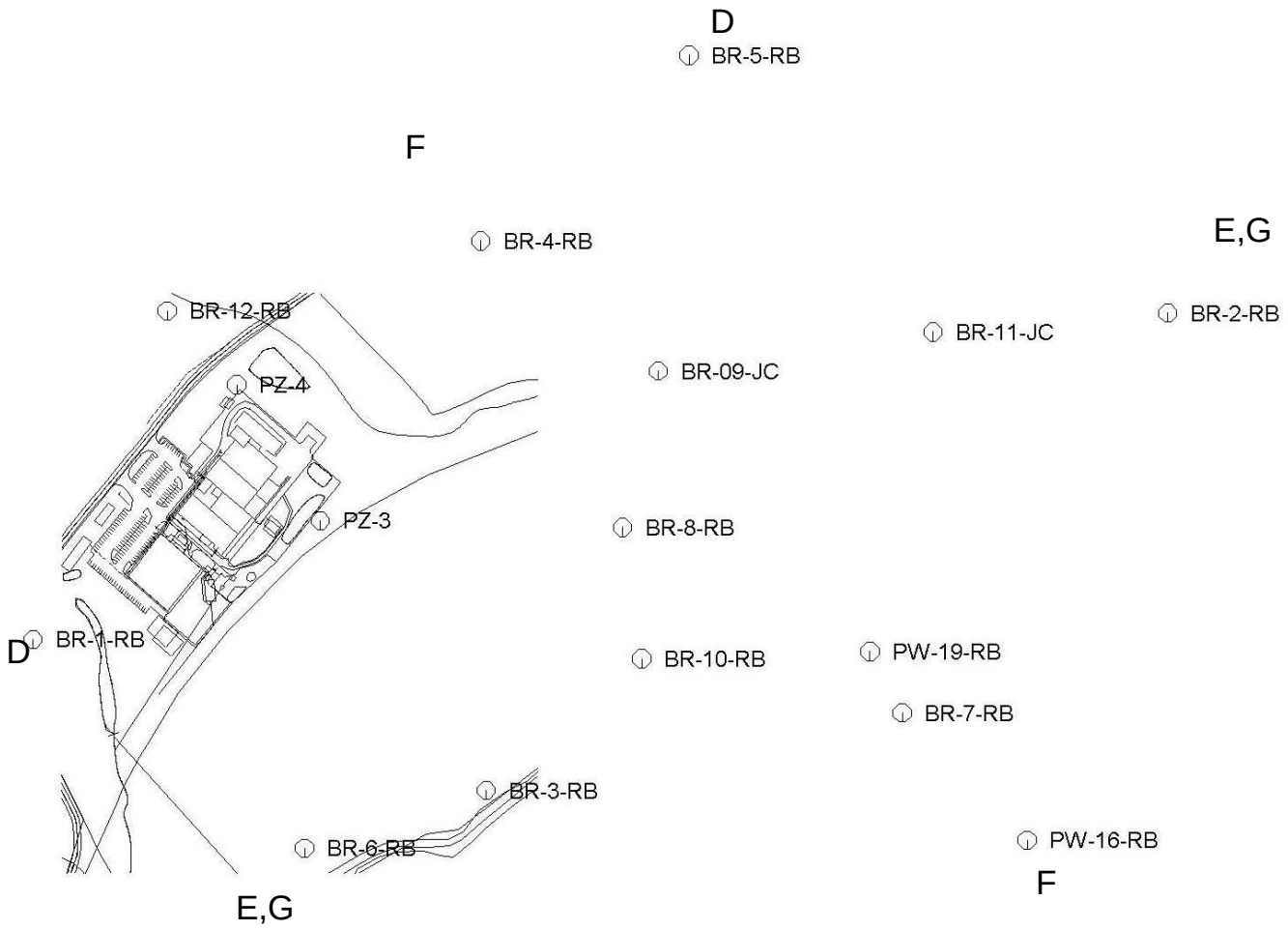


Fig. 3.8. Cross-sections of bedrock wells.

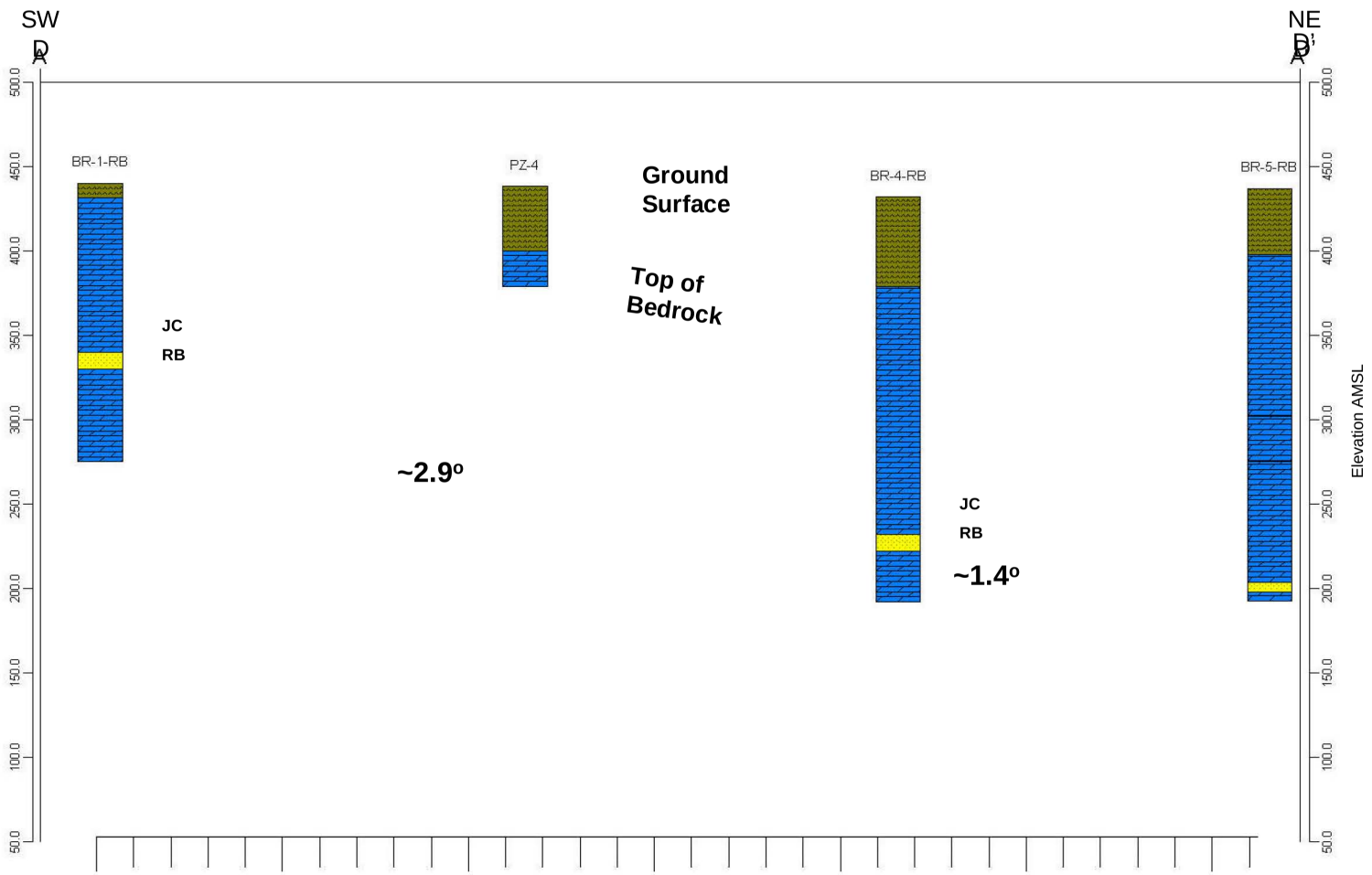


Figure 3.9. Cross-section D-D'; bedrock wells.

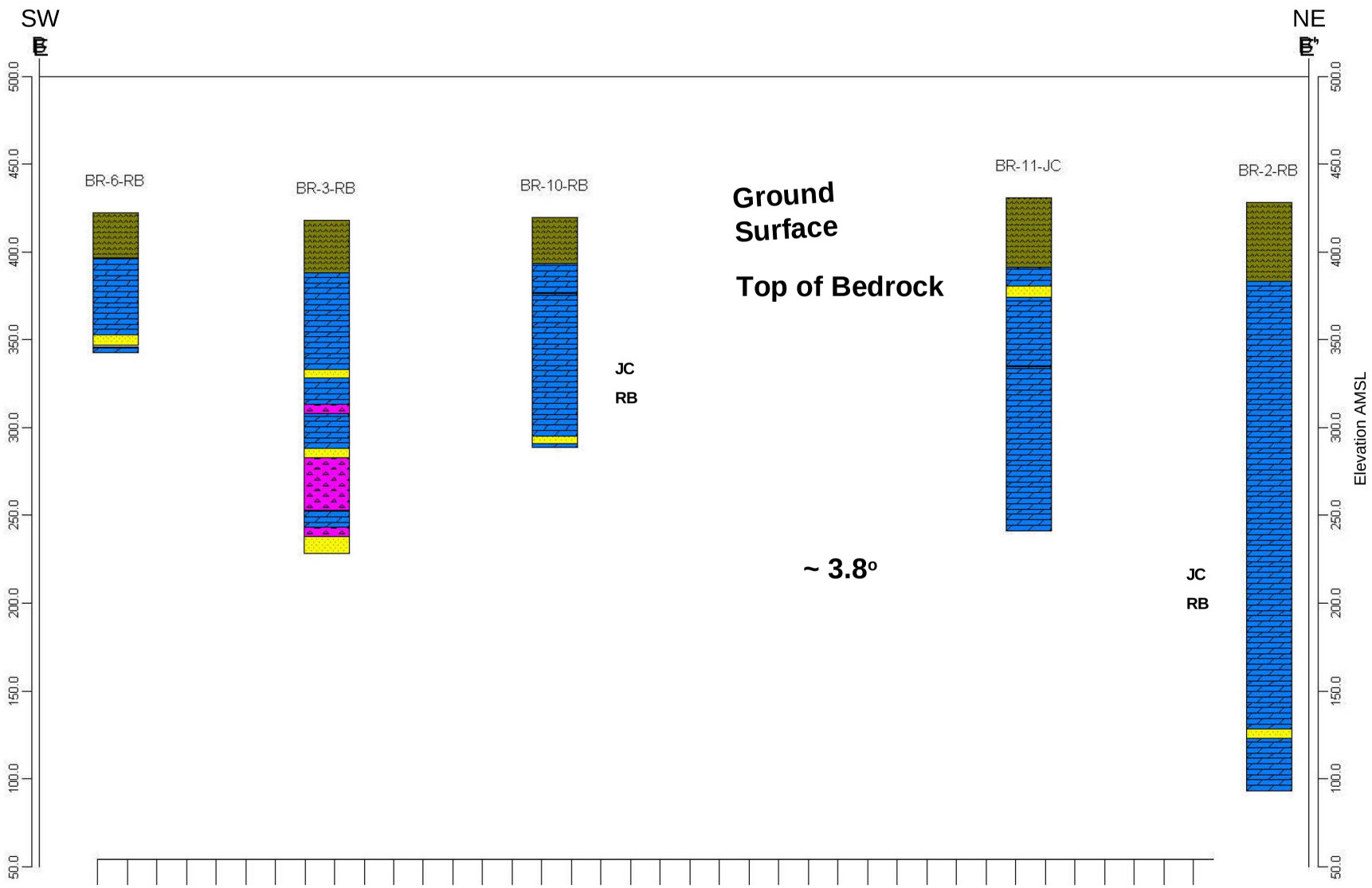


Fig. 3.10. Cross-section E-E'; bedrock wells.

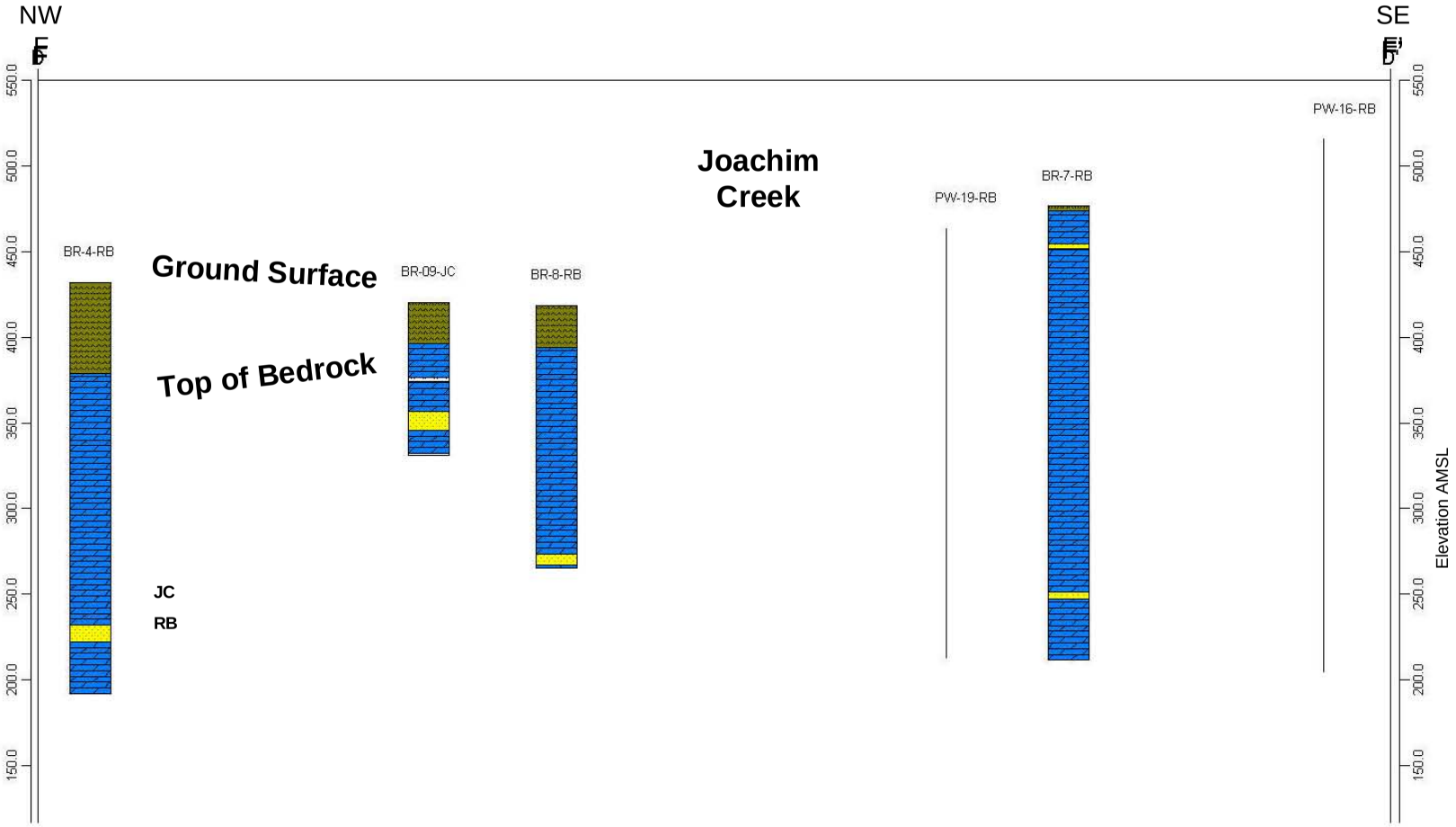


Fig. 3.11. Cross-section F-F'; bedrock wells.

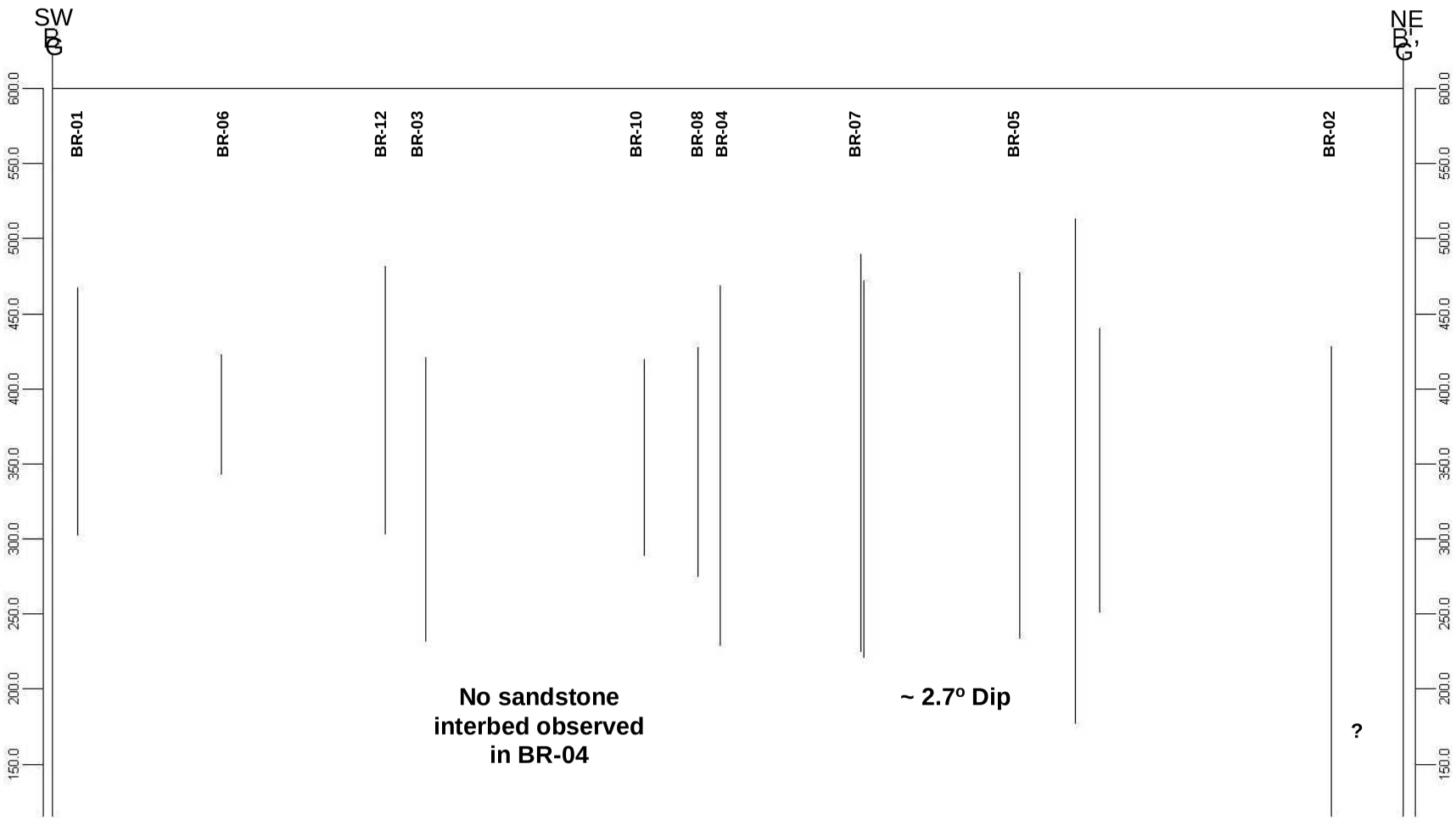
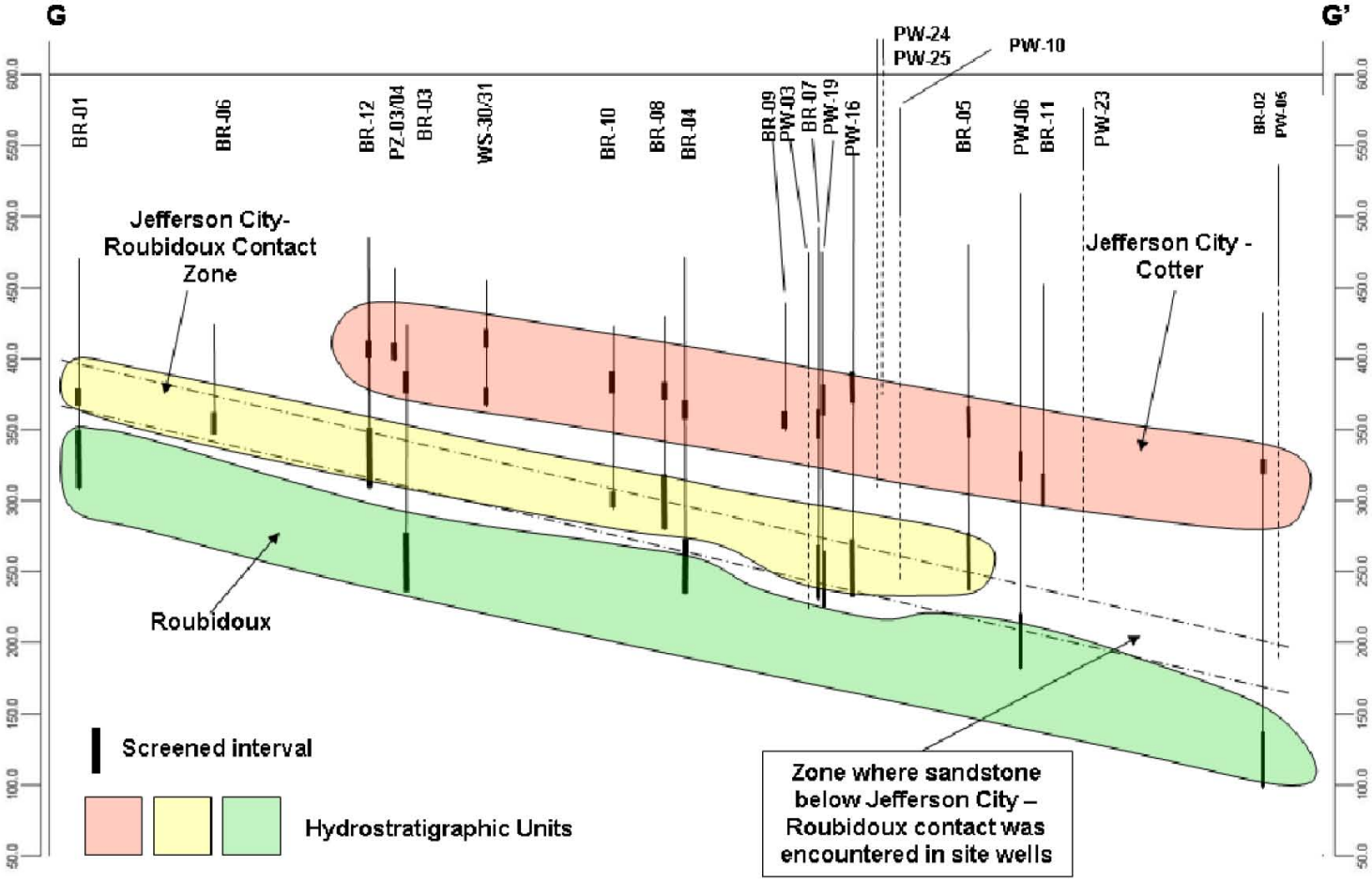


Fig. 3.12. Cross-section G-G'; bedrock wells corrected for geologic dip.


G
G'
PW-24
PW-25
PW-10
BR-01
BR-06
BR-12
PZ-03/04
BR-03
WS-30/31
BR-10
BR-08
BR-04
BR-09
PW-03
BR-07
PW-19
PW-16
BR-05
PW-06
BR-11
PW-23
BR-02
PW-05
Jefferson City-
Roubidoux Contact
Zone
Jefferson City -
Cotter
Roubidoux
Screened interval
Hydrostratigraphic Units
Zone where sandstone
below Jefferson City –
Roubidoux contact was
encountered in site wells
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0

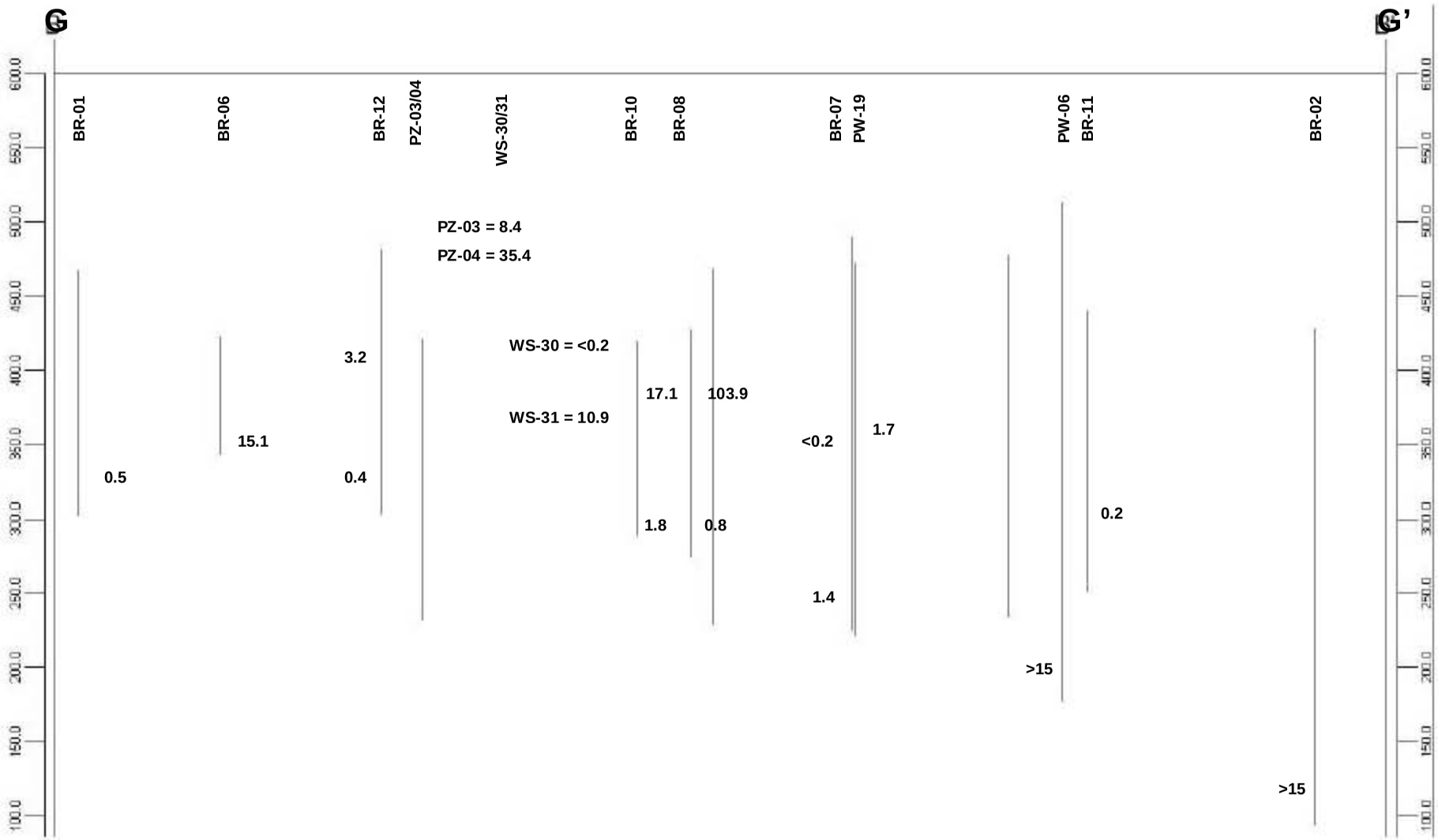


Fig. 3.14. Hydraulic conductivity from slug tests.

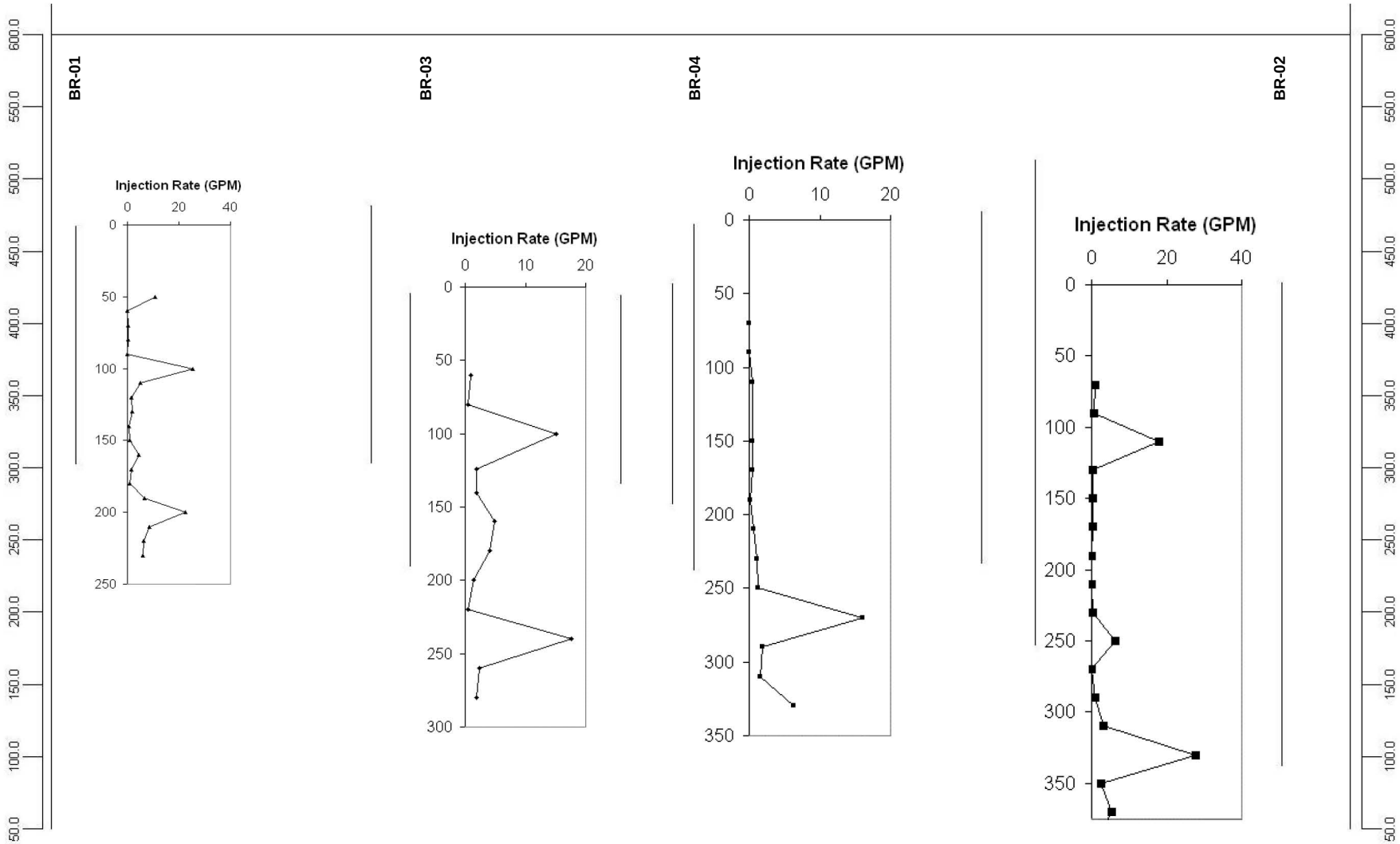


Fig. 3.15. Injection test data.

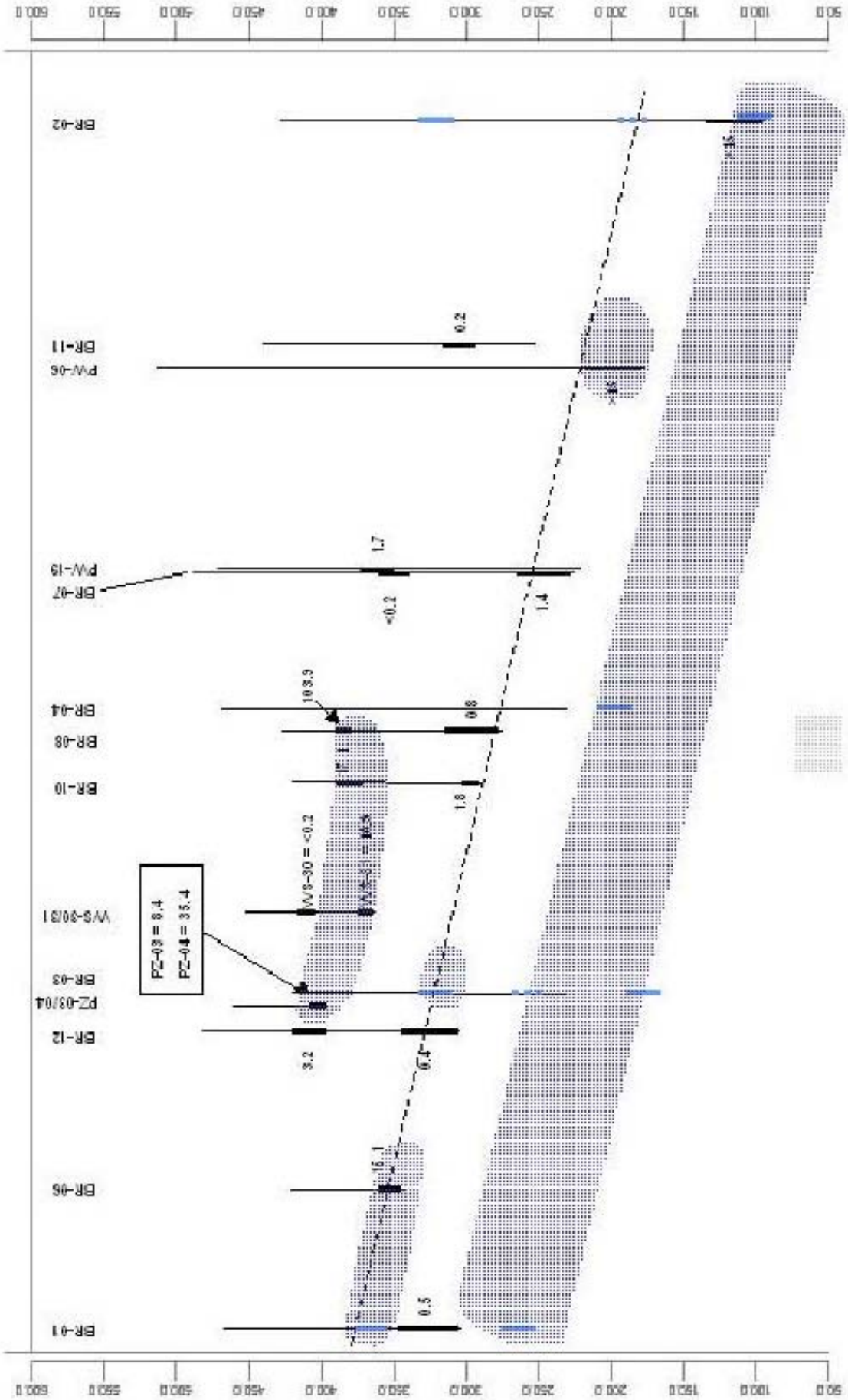


Fig. 3.16. Hydraulic summary.

PROPERTY BOUNDARY

<430 FT

>430 FT

Fig. 3.17. Potentiometric surface of shallow (fine-grained) overburden wells (December 2004).

Fig. 3.18. Potentiometric surface of deeper overburden wells (December 2004).

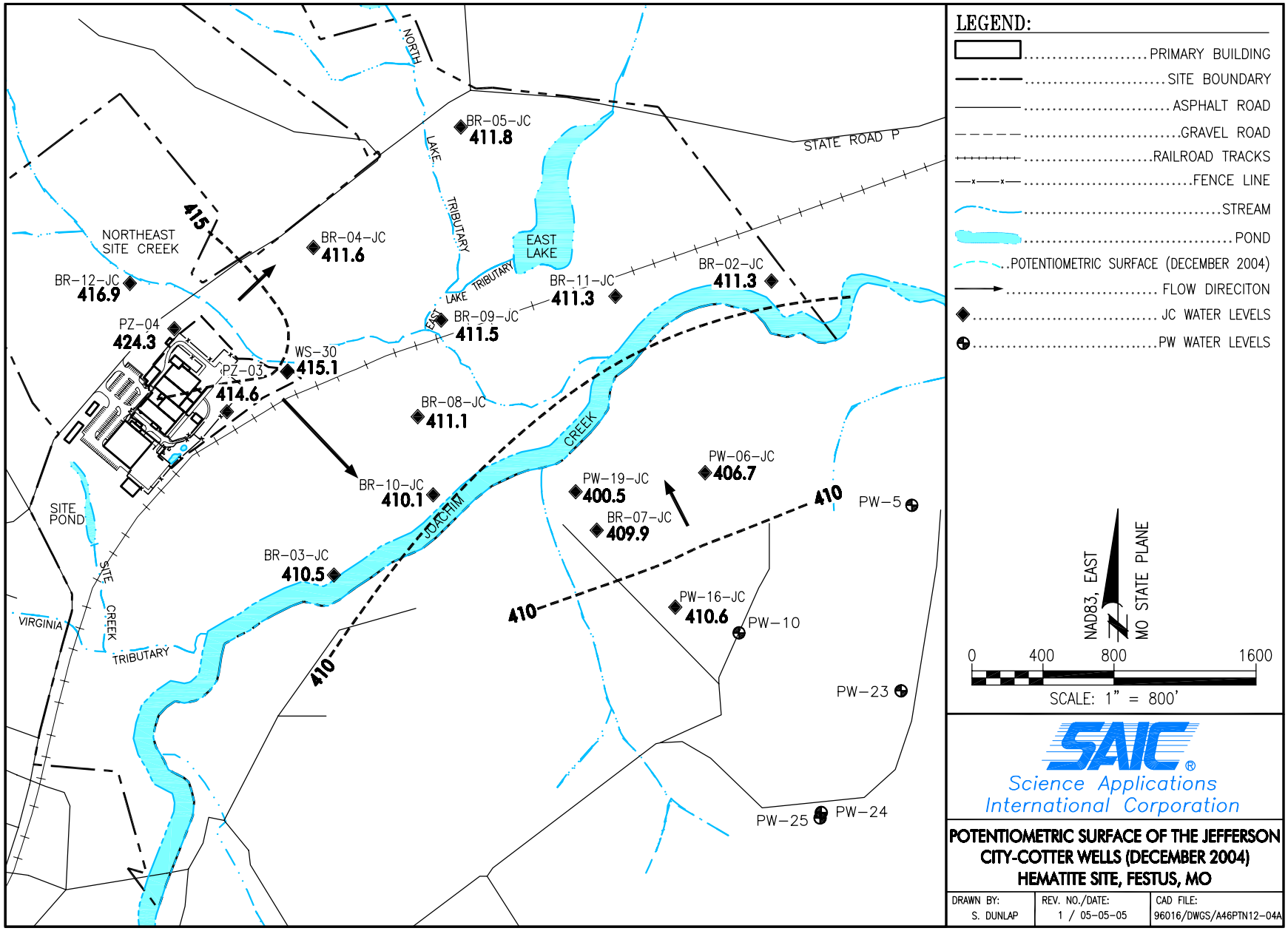


Fig. 3.19. Potentiometric surface of the Jefferson City-Cotter wells (December 2004).

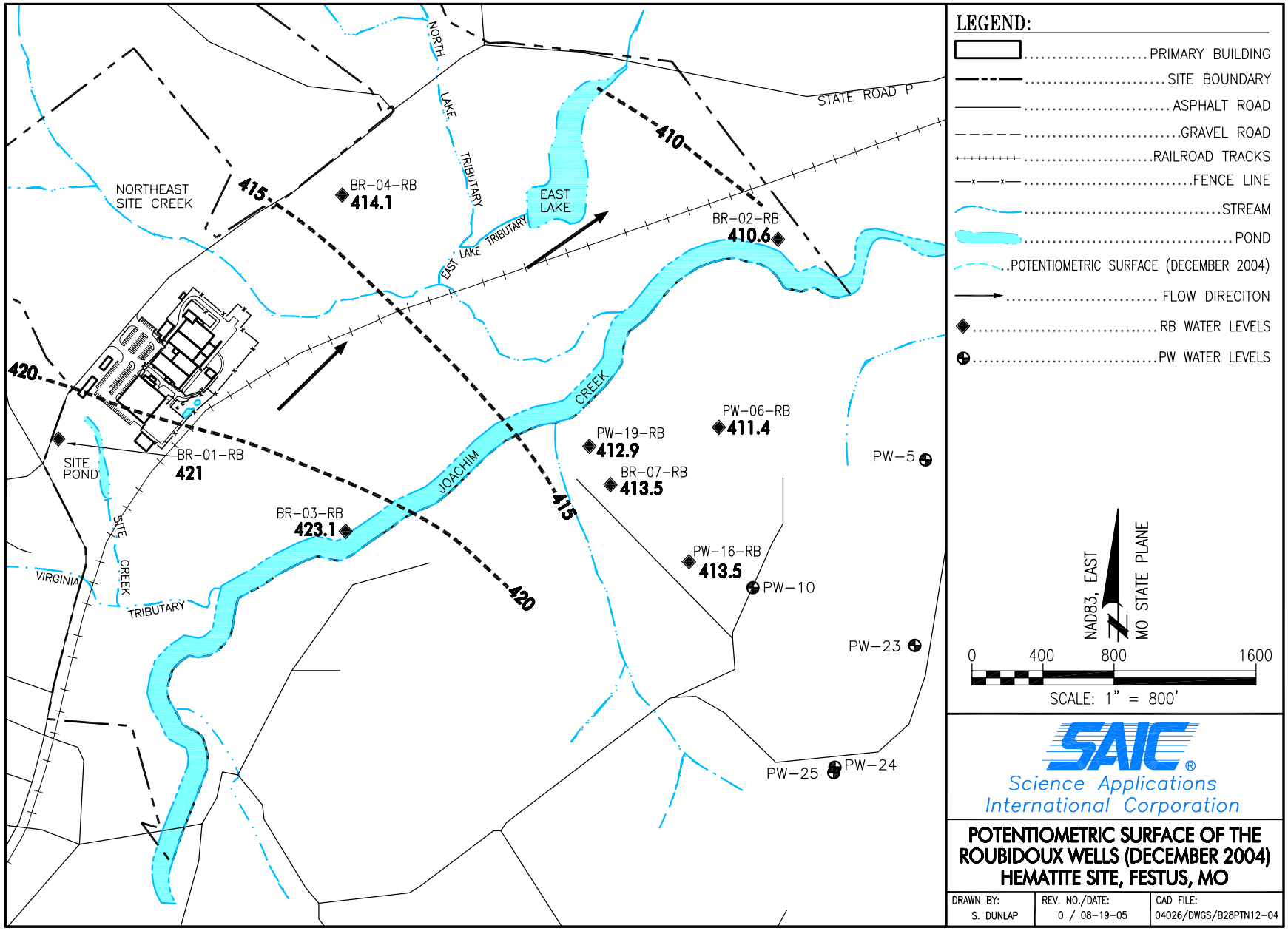


Fig. 3.21. Potentiometric surface of the Roubidoux sells (December 2004).

PROPERTY BOUNDARY

Fig. 3.22. Hydraulic gradient (-dh/dz) between shallow and deep overburden wells (December 2004).

PROPERTY BOUNDARY

Fig. 3.23. Hydraulic gradient (-dh/dz) between deep overburden and Jefferson City wells (December 2004).

PROPERTY BOUNDARY

Fig. 3.24. Hydraulic gradient (-dh/dz) between Jefferson City and Roubidoux wells (December 2004).

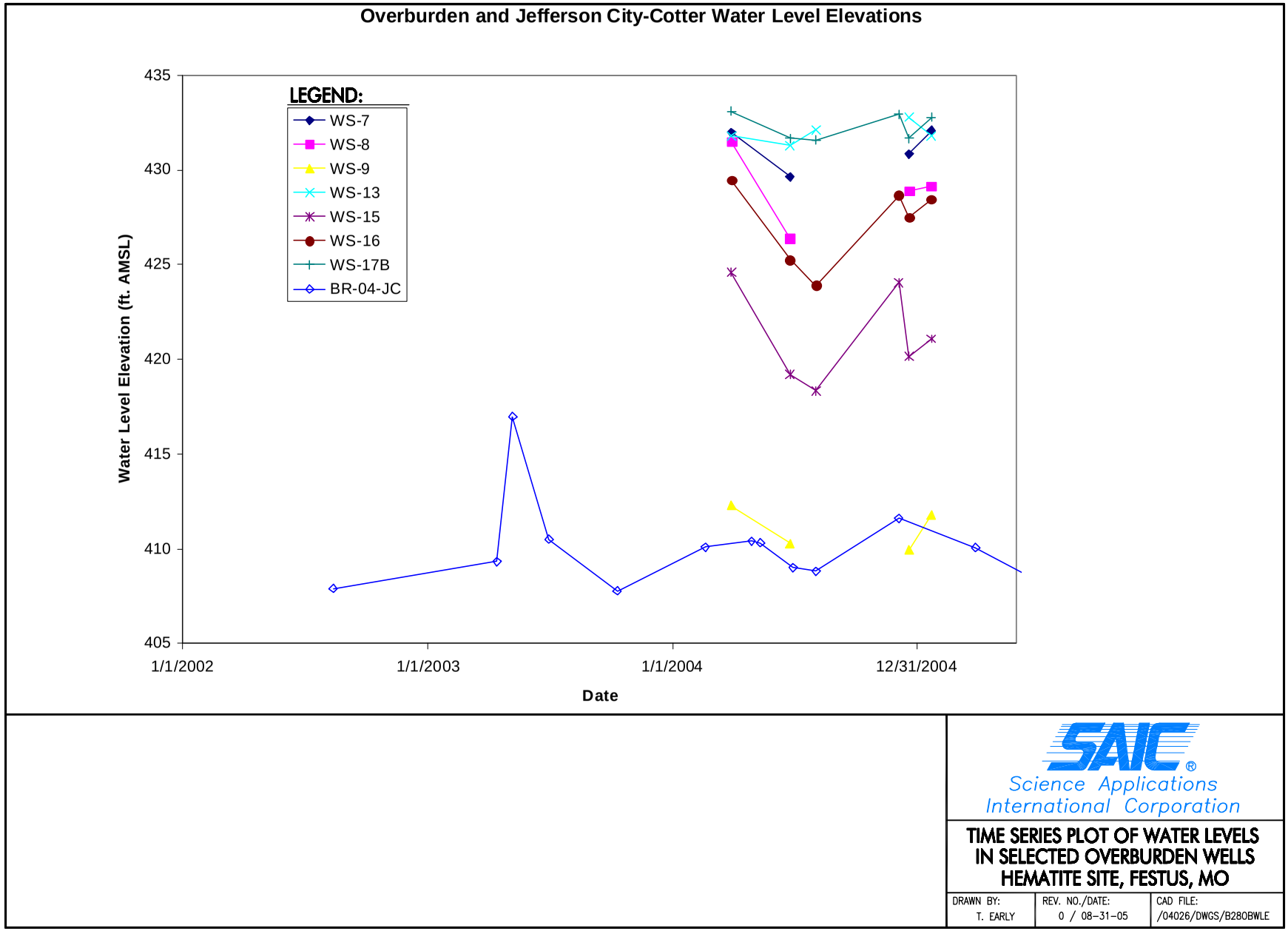
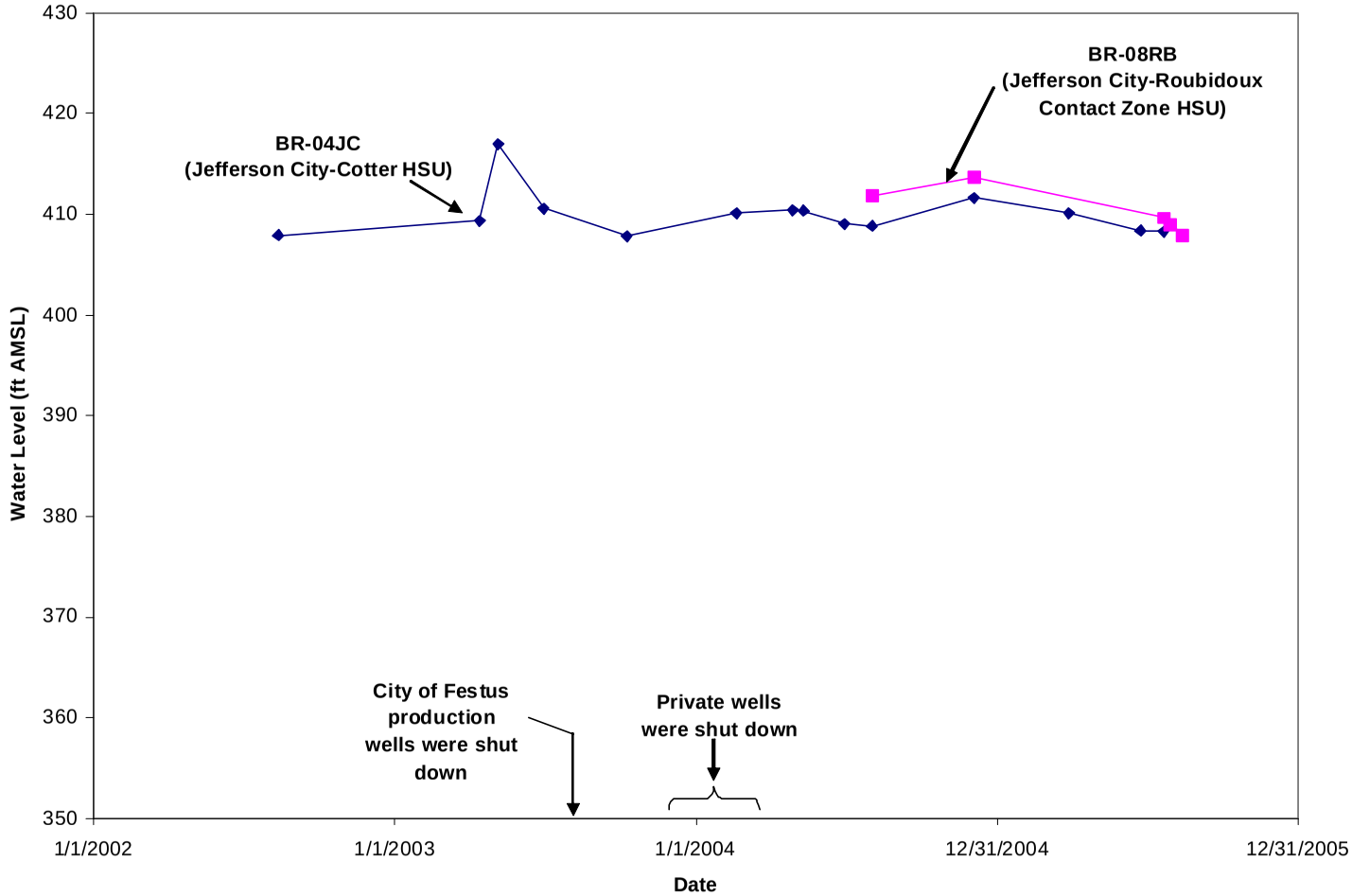


Fig. 3.25. Time series plot of water levels in selected overburden and Jefferson City-Cotter wells.

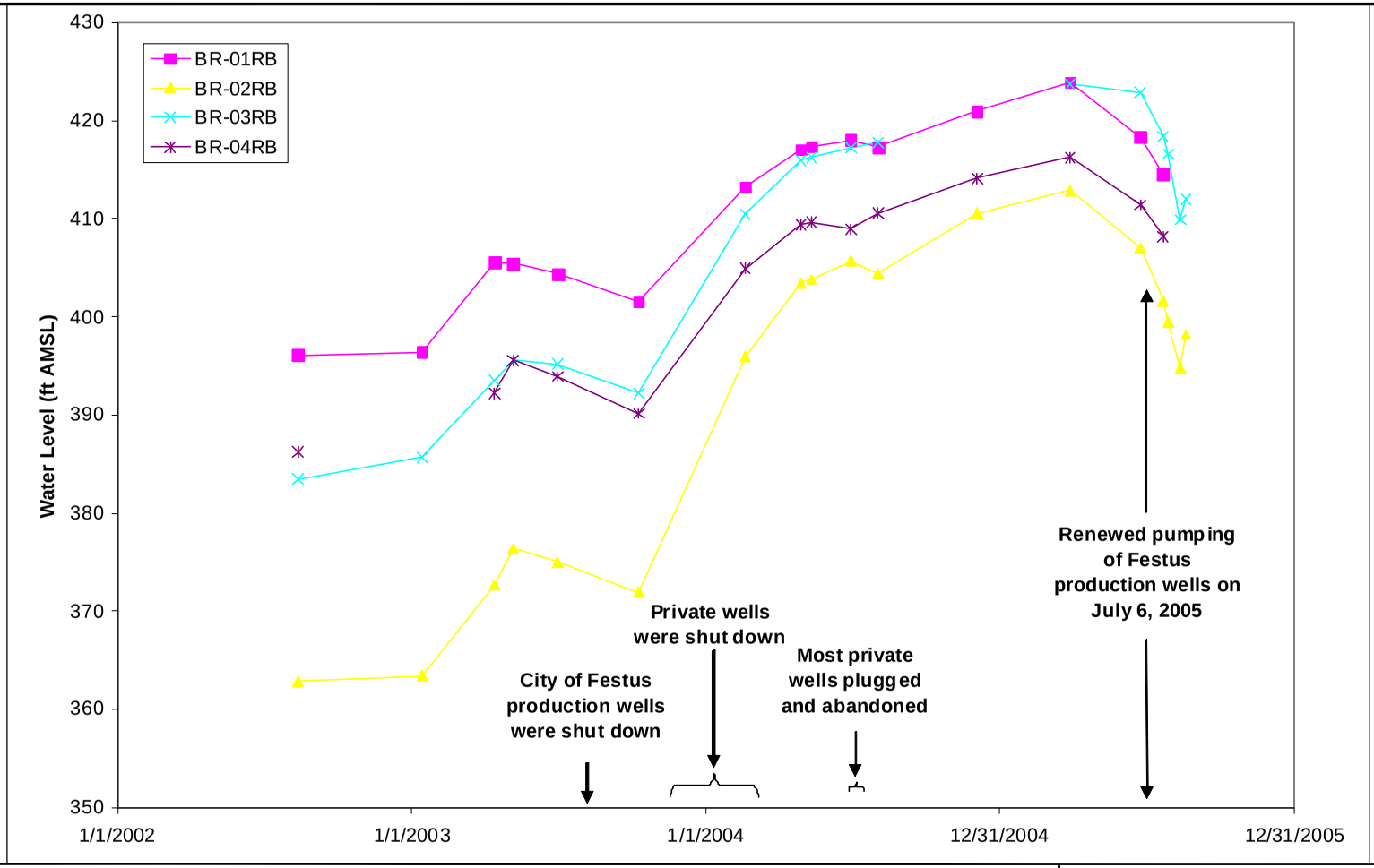


Science Applications International Corporation

TIME SERIES PLOT OF WATER LEVELS IN SELECTED JEFFERSON CITY WELLS HEMATITE SITE, FESTUS, MO

DRAWN BY:	REV. NO./DATE:	CAD FILE:
T. EARLY	0 / 08-31-05	/04026/DWGS/B28JCWLE

Fig. 3.26. Time series plot of water levels in selected Jefferson City-Cotter wells.
Note: The data for BR-04-JC are also shown in Fig. 3.25 but on a different scale for the y-axis.



Science Applications International Corporation

TIME SERIES PLOT OF WATER LEVELS IN SELECTED ROUBIDOUX WELLS HEMATITE SITE, FESTUS, MO

DRAWN BY:	REV. NO./DATE:	CAD FILE:
T. EARLY	1 / 10-11-05	/04026/DWGS/B28RBWLE

Fig. 3.27. Time series plot of water levels in selected Roubidoux wells.

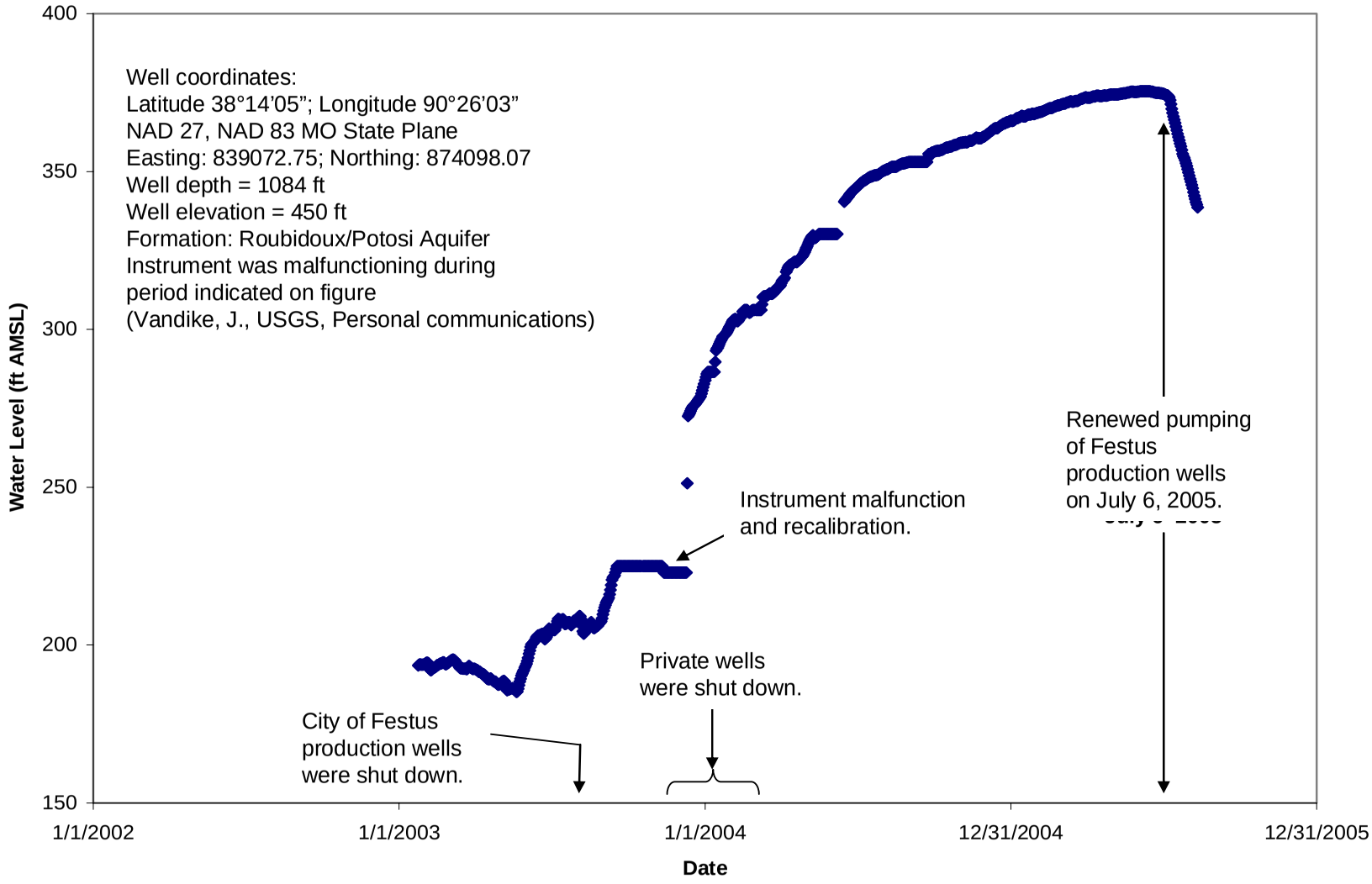


Fig. 3.28. Water level versus time data from USGS well 381405090260301 in Festus, MO.

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CHAPTER 3 TABLE

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Table 3.1. Surface water level measurements

Date	Site Pond		Site Pond Creek		Northeast Site Creek		East Lake		Joachim Creek (at bridge)	
	Gauge Reading of Water Level (ft)	Water Level Elevation (ft AMSL)	Gauge Reading of Water Level (ft)	Water Level Elevation (ft AMSL)	Gauge Reading of Water Level (ft)	Water Level Elevation (ft AMSL)	Gauge Reading of Water Level (ft)l	Water Level Elevation (ft AMSL)	Gauge Reading of Water Level (ft)	Water Level Elevation (ft AMSL)
5/27/2004	--	--	--	--	--	--	--	--	>>6.66	>>416.18
6/1/2004	--	--	--	--	--	--	--	--	3.50	413.02
6/4/2004	1.93	424.98	2.04	423.18	1.30	427.29	1.36	428.65	3.07	412.59
7/2/2004	1.68	424.73	1.55	422.69	dry bed		1.01	428.30	3.03	412.55
8/2/2004	1.75	424.80	1.70	422.84	1.03	427.02	1.16	428.45	3.1	412.62
9/7/2004	1.68	424.73	1.56	422.70	dry bed		0.84	428.13	3.02	412.54
10/14/2004	1.74	424.79	1.70	422.84	dry bed		0.38	427.67	3.26	412.78
11/23/2004	1.80	424.85	1.79	422.93	1.42	427.41	1.31	428.60	3.30	412.82
12/3/2004	1.96	425.01	2.10	423.24	1.46	427.45	1.46	428.75	3.64	413.16
1/5/2005	2.08	425.13	2.42	423.56	3.00	428.99	2.42	429.71	Flooding Condition	

Table 3.2. Summary of Slug Tests, December 2004

Well ID	Formation	Test Date	Description of Recovery Curve on Log Plot	K (ft/s) Rep 1	K (ft/s) Rep 1	K (ft/s) Rep 1	K (ft/s) Rep 1	Average (ft/sec)	Average K (ft/day)
BR-08-OB	COB	12/7/2004	Linear	1.232E-03	1.058E-03			1.145E-03	**98.9**
BR-10-OB	COB	12/6/2004	Linear	2.268E-03	1.315E-03			1.791E-03	**154.8**
BR-06-OB	COB	12/7/2004	Underdamped/Oscillating						**>155**
NB-73	COB	12/8/2004	Slightly underdamped/Oscillating	2.449E-04	2.795E-04			2.622E-04	**22.7**
NB-84	COB	12/14/2004	Linear w/ Slight oscillation	4.451E-05	4.434E-05			4.443E-05	**3.8**
BR-08-JC	JC	12/7/2004	Underdamped/Oscillating	1.363E-03	1.042E-03			1.203E-03	**103.9**
BR-10-JC	JC	12/7/2004	Slight underdamping/Oscillation	1.917E-04	2.030E-04			1.974E-04	**17.1**
BR-11-JC	JC	12/9/2004	Linear	2.045E-06	1.824E-06			1.935E-06	**0.2**
BR-12-JC	JC	12/9/2004	Linear	3.831E-05	3.548E-05			3.689E-05	**3.2**
PZ-04	JC	12/14/2004	Underdamped/Oscillating	4.078E-04	4.108E-04			4.093E-04	**35.4**
BR-07-JC	JC	12/14/2004	Very slow response to intro of slug, did not return to levels before intro of slug in 4 hours.						**<0.2**
PW-19-JC	JC	12/15/2004	Linear w/ Slight curvature	1.836E-05	2.128E-05			1.982E-05	**1.7**
WS-31	JC	12/15/2004	Linear	1.322E-04	1.211E-04			1.267E-04	**10.9**
PZ-03	JC	12/16/2004	Linear w/ Slight curvature	1.174E-04	7.790E-05			9.765E-05	**8.4**
WS-30	JC	12/16/2004	Very slow response to intro of slug, took 1 hour for transducer to drop 2 inches after slug intro						**<0.2**
BR-08-RB	RB	12/7/2004 a	l Concave up	1.261E-05	1.009E-05		5.950E-06	9.550E-06	**0.8**
BR-10-RB	RB	12/7/2004	Concave up	2.659E-05	3.994E-05	1.129E-05	6.030E-06	2.096E-05	**1.8**
BR-06-RB	RB	12/8/2004	Linear	1.748E-04				1.748E-04	**15.1**
BR-12-RB	RB	12/9/2004	Slightly Concave up	5.329E-06	4.765E-06	2.792E-06	4.440E-06	4.332E-06	**0.4**
BR-02-RB	RB	12/10/2004	Underdamped/Oscillating						**>15**
BR-01-RB	RB	12/13/2004	Linear	6.024E-06				6.024E-06	**0.5**
BR-07-RB	RB	12/13/2004	Concave up	too coarse	too coarse	1.582E-05		1.582E-05	**1.4**
PW-06-RB	RB	12/13/2004	Underdamped/Oscillating						**>15**

* The value set for the underdamped wells corresponds to the maximum measured hydraulic conductivity in the other wells within the same formation. For example, the maximum K measured in the RB wells is 15 ft/day in BR-06-RB The slug test data was well behaved for this well (monotonically change in water levels after release of slug). Thus, it is assumed that the lower limit for oscillatory response is 15 ft/day. A similar approach is used for setting the upper limit for slowly responding wells in very tight formation (e.g., wells in the JC and COB formations).

4. CONTAMINANT DISTRIBUTION

This chapter presents the significant findings in the contaminant analyses on surface water, sediment, surface soils, subsurface soils, groundwater, and off-Site soil samples collected as part of the RI. A summary of analytical results is provided in Appendix H (in tabular format), along with the Data Validation Report. The complete set of analytical results is provided in Appendix I (as spreadsheet files on a compact disc).

This chapter is organized as follows:

- Water quality parameters in groundwater (Sect. 4.1);
- Non-radioactive inorganics, including metals, fluoride, cyanide, nitrate, chloride, and sulfate (Sect. 4.2);
- Radionuclides, including uranium, technetium-99 thorium, radium, neptunium, and plutonium (Sect. 4.3); and
- Organics, including VOCs, SVOCs, petroleum, pesticides, PCBs, and dioxins. (Sect. 4.4).

Each section is further subdivided into discussions regarding the contaminant analysis results in each type of environmental media sampled (i.e., surface water, sediment, etc.). Section 4.5 contains discussion of analytical findings with respect to each of the AOCs (listed in Sect. 1.6). It shoud be noted that samples of the waste material in the burial pits were not collected as part of this investigation due to various administrative and technical issues, therefore the description of pit contents presented in this Report is based on available contemporaneous information (i.e. the burial pit log books) and inferred from other information including data obtained from analysis of soil and overburden groundwater samples in the vicinity of the pits. This data is sufficient to define the nature and extent of contamination from this identified source area as presented in this RI Report.

The rationale behind the selection of target RCOPCs and CCOPCs for each environmental medium can be found in the RI/FS WP (Section 4 of LBG 2003), TSWP (SAIC 2004 (a through g) methods, and in Chapter 1 of this report. Details regarding sample collection and analysis methods were presented in Chapter 2. This section focuses on contaminant distributions based on the sample analytical results, while the integration of these contaminant distributions with the Site physical characteristics (presented in Chapter 3) to arrive at past and future mechanisms for transport are presented in Chapter 5. VOC contaminant distribution in subsurface soils and groundwater is presented and discussed in Chapter 5, because the distribution of VOCs was crucial in developing a conceptual model for contaminant transport at the Hematite Site.

The following should be noted regarding the use of minimum detection limits (MDL) and reporting limits in the analytical data reported by the laboratory that conducted all the laboratory analyses for this RI:

- The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured with 99% confidence that the analyte concentration is greater than zero (40 Code of Federal Regulations, Part 136, Appendix B). The laboratory followed prescribed procedures for establishing MDLs.
- The reporting limit (RL) is the lowest concentration that can be reliably quantified under routine laboratory operating conditions. The laboratory determines this using the lowest calibration standard that can be used such that the RL is higher than the MDL.

- In the data package, the laboratory provided MDLs for the radionuclides, and RLs for the rest of the analytes as part of the data package.

- For the organic and inorganic analytes, results that fall below the RL are flagged as "U" unless the analyte can be "J" qualified (i.e., the analyte level is above the MDL).

- For radionuclides, results that fall below the MDL are flagged as "U."

The laboratory also provided measurement errors associated with each radionuclide measurement. Uncertainties need to be evaluated when using the analytical results for quantitative calculations (e.g., baseline risk assessment). On the other hand, the qualitative assessment provided in this RI Report is not expected to be sensitive to these measurement errors; samples with "elevated activities" usually have activities that are sufficiently high such that the measurement error is only a small fraction of the measurement result.

4.1 WATER QUALITY PARAMETERS IN GROUNDWATER

Field parameters were measured in groundwater samples from wells in the overburden, Jefferson City, and Roubidoux Formations during the December 2004 round of sampling (Appendix H.1). Parameters included in this data set are:

- turbidity,
- specific conductance,
- pH,
- temperature,
- dissolved oxygen (DO),
- ORP,
- iron,
- sulfide, and
- alkalinity.

The following subsections describe the ranges of results for field parameters obtained from groundwater samples from overburden and bedrock. The discussions below categorize the analytical results in bedrock groundwater according to geologic formation (i.e., Jefferson City-Cotter and Roubidoux) rather than the HSUs presented in Sect. 3.3.3 (i.e., Jefferson City-Cotter, Jefferson City-Cotter/Roubidoux Contact Zone, Roubidoux). Most of the field parameters are not likely to be sensitive to a specific HSU but are more likely to be a function of the chemical characteristics of a geologic formation (e.g., pH and alkalinity).

4.1.1 Turbidity

Turbidity results for groundwater from the overburden and bedrock units at the Hematite Site are shown in the histogram on Fig. 4.1. Although most groundwater samples have a turbidity of less than 100 NTU, samples from overburden exhibit a much wider range of values. Overburden lithologies range from coarse to fine-grained and the presence of clay-size particulates entrained in groundwater is a reasonable expectation in this environment. The presence of clay particulates in the groundwater is also indicated by higher aluminum analysis results in unfiltered samples when compared to co-located filtered samples (Sect. 4.2.2.2). Turbidity also can be caused by oxidation and precipitation of some metals (e.g., iron and manganese) if samples are exposed to atmospheric oxygen either in the aquifer or prior to

stabilization during sample collection. Groundwater from bedrock typically is expected to have lower turbidity because the presence of unattached clay-size material in fractures is less likely and particulates gradually are filtered out with increasing flow distance through bedrock.

In Sect. 4.2.2.2, the impact of suspended solids is evaluated through a comparison of metals analysis results in filtered and unfiltered samples.

4.1.2 Specific Conductance

As for many chemical parameters at the Hematite Site, specific conductance values for groundwater from the bedrock units lie within a very restricted range when compared to specific conductance in the overburden wells (Fig. 4.2). Specific conductance is a measure of the quantity of dissolved ionic species in water, with higher values corresponding to a greater concentration of ions. Because the dolomite in bedrock exerts such a strong chemical buffering on groundwater, a relatively narrow range of specific conductance values is expected. In contrast, the overburden is subject to much less buffering and is more likely to reflect the impact of the addition of contaminants from the Hematite Facility, many of which will contribute ions in solution (e.g., strong acids, KOH, etc.) or will produce ions from biodegradation (e.g., chloride released from the breakdown of PCE and TCE). The contribution of chloride ions from the breakdown of chlorinated solvents can be significant where very high levels of dissolved chlorinated organics are associated with the presence of non-aqueous phase liquids.

4.1.3 pH

Measurement of pH values accompanied all field sampling activities for groundwater obtained in the vicinity of the Hematite Site. The principal objective of these measurements was to ensure that well purging had been adequate to allow the collection of representative groundwater samples, as evidenced by stable pH values. Two different approaches were used depending on the preference of the field team involved. One team used a pH meter that was calibrated to a single buffer solution (one point calibration). This procedure is effective for evaluating the stability of pH in purge water, but the measured values are accurate only if they are close to that of the buffer. This approach was used during this investigation for sampling all newly constructed wells.

Field measurements of pH in existing, older monitoring wells was done by a field team using a pH meter that had been calibrated against three buffer solutions (three point calibration), bracketing the anticipated range of pHs likely to be encountered in groundwater samples (pH =4, 7, and 10). This approach ensures accurate pH readings across this wide range of values and permits assessment of what factor(s) might account for the observed values of groundwater pH and how they might be impacted by activities associated with the Facility and its disposal sites. Fig. 4.3 shows a histogram of groundwater pH values in samples obtained from the three geologic units at the Hematite Site by this second approach.

Nearly all of the overburden wells represented in Fig. 4.3 are geographically proximal to the Facility and are located in association with various sites on the southern (Former Leach Field, Evaporation Ponds, Limestone Storage Area) and eastern (Burial Pits) sides of the Facility. Therefore, the pH in shallow groundwater in these wells may be affected by several factors. For example, shallow groundwater typically originates from recently recharged precipitation that has absorbed atmospheric CO_2. This process can depress pH values significantly below 7.0, although chemical interaction between newly recharged groundwater and soil will tend to change pH values in the opposite direction. In addition, the impact on pH (and water chemistry) of infiltrating precipitation migrating through the sites that involved surface and subsurface waste disposal might be significant.

In Fig. 4.3 it is possible to distinguish among groundwater from different geologic units based on their pH values. For example, over 80% of the groundwater samples from overburden have pH values less than 7.0 and nearly 30% have pH's below 6.0. It is assumed that the factors mentioned above probably are responsible for the low pH values. In contrast, although the Jefferson City-Cotter groundwater samples in Fig. 4.3 also typically come from the same geographic area as the overburden wells, all but one sample has pHs between 6.8 and 7.5. The outlying sample has an unusually high pH (9.3) with no definitive reason for its occurrence. However, this well is shallow and located close to the Burial Pits that is known to be significantly contaminated with chlorinated VOCs based on previous field investigations and data from the current RI (Sect. 4.4.5.6). The Roubidoux groundwaters illustrated in the histogram are more widely distributed geographically, but the pH range is very narrow (7.1 – 7.31). It is likely that the common, narrow range of pH values for most of the groundwater samples from the Jefferson City-Cotter and Roubidoux formations probably reflects: (1) a greater residence time in bedrock so that chemical reactions are more likely to reach equilibrium (i.e., a greater distance from the surface and sources of contamination to the screened intervals in the wells), and (2) strong chemical buffering of pH due to the interaction with the host carbonate bedrock.

4.1.4 Temperature

All groundwater temperatures measured in the overburden and bedrock wells at the Hematite Site are less than 20°C. These measurements were made in December 2004, with a few measurements associated with field sampling activities in August 2004 and January 2005. With rare exception, groundwater from the Jefferson City and Roubidoux wells exhibited a temperature range from 10 to 14°C. For groundwater from overburden the temperature range was considerably wider (approximately 3 to 19ºC). Temperature measurements are made while groundwater purging is done prior to sample collection. Low flow purging methods are used and generally only a relatively small volume of water passes through the sampling tubing and measurement cell. Therefore, measured temperatures typically are not representative of thermal conditions prevailing in the aquifer. Temperatures associated with that of ambient groundwater, the initial conditions of the sample tubing and measurement cell, and ambient air all are factors that can affect measured temperatures during purging. The cumulative impact of the extraneous thermal factors tends to be more pronounced in shallow wells which probably accounts for the much wider range of temperatures encountered with overburden wells.

4.1.5 Oxidation Reduction Potential and Dissolved Oxygen

The oxidation-reduction (redox) state of aquifer systems is an important property that can help in gaining an understanding of the F&T of chemical species capable of being oxidized or reduced. Many inorganic and biochemical reactions (e.g., precipitation and/or sorption of radionuclide and metals; anaerobic degradation of many organic contaminants) can be affected by these conditions. For example, both uranium and technetium are much less soluble under reducing conditions. Reductive dechlorination of PCE and TCE also requires reducing conditions. In principle, the oxidation-reduction potential of water samples can be measured in the field with a platinum electrode in combination with a standard reference electrode. The measured potential (in millivolts) usually is referred to as the ORP and is meant to assess the state of equilibrium between oxidized and reduced species coexisting in solution. In practice, however, many uncertainties are associated with ORP measurements. For example:

- The solution contains a complex mixture of oxidants and reductants that are not all equally well sensed by the platinum electrode; in general, it is not known to what species the electrode is responding

- Not all redox couples [e.g., Tc(VII)-Tc(IV)] will be in equilibrium

- Some species in groundwater (e.g., S^{2-}) can coat the platinum electrode and interfere with measurements

An alternative (or complementary) approach to determining the redox state of groundwater is to measure directly various couples or indicators of redox conditions (e.g., Fe^{2+} - Fe^{3+}, S^{2-} - SO_4^{2-}, dissolved oxygen). The following sections (Sects. 4.1.6, 4.1.7, and 4.1.8) provide some information for the Hematite Site related to this approach.

Regardless of the limitations of field measurement of ORP, it is common practice to obtain this information and, in combination with other results, use it to provide insight into the redox state of the water.

Figure 4.4 presents results for ORP measurements obtained from groundwater samples from the three major geologic units at the Hematite Site. The ORP values were obtained using an Ag-AgCl reference electrode. The ORP measurements range from a low of -200 to +250mV, with only a few samples showing higher values. The range of values is somewhat wider for groundwater from overburden than from bedrock. If these measurements represent equilibrium values, then from an assessment of the appropriate Eh-pH diagrams for these elements one would expect Fe^{2+} to predominate over Fe^{3+}, and SO_4^{2-} to exceed S^{2-} in solution (e.g., Stumm and Morgan 1981). A similar evaluation could be performed for other redox couples and would show that the predominant species present (oxidized or reduced) is couple-dependant. That is, a positive value of ORP does not necessarily mean that conditions are oxidizing for all redox couples.

Figure 4.5 presents the DO measurements for groundwater samples obtained from the Hematite Site. DO is one of the redox-sensitive species in Hematite Site groundwater. The other redox-sensitive species include iron (Sect. 4.1.6), and sulfide (Sect. 4.1.7). The DO values in the Jefferson City and Roubidoux tend to cluster within a rather narrow range from 1.5 to 3 mg/L, whereas in the overburden, the trend is toward a much wider range of values varying from 0 to 9.76 mg/L. Air-saturated water will support a DO of about 8 mg/L. It is reasonable that shallow, recently recharged groundwater will have elevated DO values. Consumption of DO with increasing residence time in the subsurface occurs where reducing conditions prevail. However, preventing contamination from atmospheric oxygen during field measurement is very difficult and is usually encountered to some extent in any large field sampling program. It is generally safe to say that any errors in readings provide values that are biased high. Nevertheless, the DO results suggest a reducing environment for most samples from each unit.

4.1.6 Iron

A histogram of ferrous (Fe^{2+}) iron concentrations measured in the field is shown on Fig. 4.6. There is a wide range of ferrous iron concentrations in the overburden, with ferrous iron concentrations greater than 10 mg/L in nine groundwater samples. The bedrock groundwater exhibited much lower ferrous iron levels, which reflects the predominantly dolomitic nature of the bedrock (Chapter 3). The ferrous iron field measurements are compared to total iron laboratory measurements in Sect. 4.2.2. The latter comparison is useful in assessing the nature of particulates found in the groundwater samples. In general, the conclusion from Fig. 4.6 and the discussion in Sect. 4.2.2.2 is that total iron equals dissolved iron (present as ferrous iron). This supports the inference that at least moderately reducing conditions exist in the groundwater.

4.1.7 Sulfide

Only four groundwater samples have a measurable amount of sulfide (BR-03-JC, BR-03-RB, BD-01, and DM-02); all other samples have a reported concentration of “0 ppm” by the field analytical method

used. None of the samples with detectable sulfide had a concentration exceeding 0.5 ppm. Sulfide concentrations similar to those observed in the four samples also support reducing conditions at these locations.

4.1.8 Alkalinity

A histogram of the alkalinity values for groundwater from the three geologic units at the Hematite Site is presented on Fig. 4.7. The alkalinity values for groundwater from the overburden range from less than 50 to nearly 300 mg/L.

In contrast, most Jefferson City-Cotter and Roubidoux groundwater samples tend to have higher alkalinity values that primarily are in a narrow range from 150 to 250 mg/L. This latter observation is consistent with the chemical buffering effect of dolomite on the dissolved inorganic carbon species and the narrow range of pHs of the bedrock groundwater illustrated on Fig. 4.3.

4.2 NON-RADIOACTIVE INORGANICS

The following subsections present contaminant assessments of inorganics in surface water (Sect. 4.2.1), groundwater (Sect. 4.2.2), sediment (Sect. 4.2.3), surface soils (Sect. 4.2.4), and subsurface soils (Sect. 4.2.5). Where appropriate, comparisons are made with off-Site sample results. Details regarding sample collection and analysis methods were given in Chapter 2, while the complete data set of inorganics can be found in Appendix H.

4.2.1 Non-radioactive Inorganics in Surface Water

This section reviews surface water data for the presence and distribution of inorganic species. The complete data set for inorganics in surface water can be found in Appendix H.2. In general, except for common ions such as sodium and potassium, the review process involved an examination of measured concentrations with respect to Site geochemical conditions (presented in Sect. 4.1) and to water quality standards (e.g., drinking water standards) where they exist. Overall, the conclusions of this section are consistent with the previous investigations (summarized in Sect. 1.5), which indicated no significant contamination with non-radioactive inorganics.

Twelve surface water samples were collected at the locations shown on Fig. 2.2. Samples labeled “US” were collected upstream to evaluate background conditions. Background values for the following inorganics in surface water were developed: aluminum (0.98 mg/L), barium (0.14 mg/L), iron (1 mg/L), and manganese (0.38 mg/L). The development of these background values is discussed in Appendix J. Several of the analytes were not detected in any of the samples:

- antimony (all less than the RL of ~0.02 mg/L),
- beryllium (all less than the RL of ~0.0026 mg/L),
- cadmium (all less than the RL of ~0.002 mg/L),
- selenium (all less than the RL of ~0.005 mg/L),
- silver (all less than the RL of ~0.01 mg/L),
- thallium (all less than the RL of ~0.01 mg/L),
- cyanide (all less than the RL of ~0.01 mg/L), and
- mercury (all less than the RL of ~0.0002 mg/L).

Aluminum, barium, calcium, iron, magnesium, manganese, potassium, and sodium were detected in the upstream (“US”) samples. The only Site surface water sample ("SW") suggesting contamination was

SW-01-SW (collected from the Site Pond; refer to Fig. 2.2 for the location), based on metals concentrations that are elevated relative to the other "US" and "SW" surface water samples. For example, vanadium was measured at 0.045 mg/L in SW-01-SW, whereas it was not detected above the RL (~0.01 mg/L) in the other surface water samples. However, even where detected, the measured element concentrations are below drinking water standards.

It is doubtful whether element concentrations in SW-01-SW represent dissolved species based on the elevated concentrations of aluminum (19 mg/L), iron (23 mg/L), and manganese (1.3 mg/L). The latter two elements only dissolve in high concentrations in surface water under acidic conditions such as acid mine drainage, whereas the pH of this sample was near neutral (6.9). Similarly, aluminum is an amphoteric element being soluble at a pH <6 and >8.5, but essentially insoluble in the pH range of 6.5 to 8.5 (Srinivasan et al. 1999). Furthermore, aluminum readily precipitates as $Al(OH)_3$. For this to occur, 0.5 mg/L of alkalinity (expressed as $CaCO_3$) must be consumed for every 1 mg/L of $Al_2(SO_4)$ (Srinivasan et al. 1999). Although not measured on this sample, an alkalinity too low to precipitate aluminum in the local environment would be remarkable.

The elements aluminum, iron, and manganese are particularly susceptible to measurements that are biased high because of the turbidity of a water sample. These elements are abundant in native rocks and soils. Similarly, many elements (e.g., arsenic, uranium, chromium, copper, nickel, etc.) are often reported in conjunction with high concentrations of aluminum, iron, and manganese because the hydrous oxides of the latter elements are highly efficient sorbents for other species.

Fluoride was only detected above the RL (0.5 mg/L) in SW-09-SW, which was collected from the Northeast Site Creek downstream of the Burial Pits (see Fig. 2.2 for location). All other elements in this sample were comparable to the "US" samples.

Measured concentrations in the Site surface water samples can be summarized as follows:

- aluminum, 19 mg/L in SW-01, all other samples 0.98 mg/L (Site background) or less;
- arsenic, 0.011 mg/L in SW-01, all other samples < RL 0.01 mg/L;
- barium, 0.63 mg/L in SW-01, all other samples 0.14 mg/L (Site background) or less;
- chromium, 0.026 mg/L in SW-01, all other samples < RL of 0.004 mg/L;
- fluoride, 0.67 mg/L in SW-09, all other samples <RL of 0. 5 mg/L;
- iron, 23 mg/L in SW-01, all other samples 1 mg/L (Site background) or less;
- lead, 0.068 mg/L in SW-01, all other samples <RL of 0.003 mg/L;
- manganese, 1.3 mg/L in SW-01, 0.38 mg/L (Site background) in US-04, all other samples 0.11 mg/L or less;
- nickel, 0.031 mg/L in SW-01, all other samples < RL of 0.005 mg/L;
- vanadium, 0.045 mg/L in SW-01, all other samples <RL of 0.01 mg/L; and
- zinc, 0.35 mg/L in SW-01, 0.012 mg/L in SW-08, 0.017 mg/L SW-02, all other samples <RL of 0.006 mg/L.

4.2.2 Non-radioactive Inorganics in Groundwater

Groundwater samples were collected site-wide during December 2004 (see Sect. 2.6 for a description of sampling and analysis). Groundwater sampling locations are shown on Figs. 2.6a and 2.6b, and the complete data set for this sampling effort is presented in Appendix H.3. Similar to surface water data, the review process for groundwater data involved an examination of measured constituent concentrations except for common ions such as sodium and potassium. Measured concentrations were evaluated with respect to Site geochemical conditions (presented in Sect. 4.1), Site background conditions (presented in Appendix J), and to water quality standards where they exist.

As will be shown in the discussions below, nitrate detections under the Evaporation Ponds and buildings suggest groundwater contamination from Site operations. No other significant contamination from inorganics is indicated.

4.2.2.1 General observations regarding major cations and anions in groundwater

Inorganics in groundwater include constituents that are recognized as being of environmental concern (e.g., arsenic, lead), as well as some that are generally considered to be either non-toxic (e.g., sodium and calcium) or of secondary importance (sulfate and chloride). The more benign constituents comprise the major cations (sodium, potassium, calcium, and magnesium) and anions (chloride, sulfate, and carbonate species) dissolved in groundwater, and are discussed in this subsection. The rest of the inorganics (e.g., metals other than sodium, potassium, calcium and magnesium) are discussed element by element in Sect. 4.2.2.3.

The distribution of elevated amounts of some of the benign constituents in a number of the groundwater samples may be related to activities at the Hematite Facility. They also can provide useful information about geochemical processes taking place as a result of soil–water or rock–water interactions. Overburden wells show the most frequent occurrences of elevated concentrations of these constituents and most of the impacted wells are located immediately around or under the Hematite Facility. Elevated values of sodium, calcium, magnesium, and chloride (in comparison to what was measured in most other wells) are observed in most of the wells located within and next to the buildings ("BD"-labeled wells, refer to Fig. 2.6b for well locations). Other wells with elevated concentrations of common cations and/or anions clusters at various points around the Facility are mainly associated with AOCs (e.g., Evaporation Ponds and the Burial Pit).

There are many potential mechanisms by which groundwater at the Hematite Site might develop elevated concentrations of these constituents. Some occurrences can reasonably be attributed to processes occurring at the Hematite Facility and the chemicals that were used in them (e.g., Table 1.1). For example, releases of nitric and hydrochloric acids at the Hematite Facility will lead to elevated chloride and nitrate concentrations (and lower pH). Reaction between the acids and any dolomite ($CaMgCO_3$) fragments contained in the overburden soil will result in elevated values of calcium and magnesium. Microbial degradation of TCE and PCE will release chloride to groundwater but in quantities that are unlikely to cause a significant increase relative to natural chloride levels.

The occurrence of elevated concentrations of major cations and anions within groundwater in bedrock is significantly more limited than in overburden. None of the Roubidoux wells, and only two of the Jefferson City-Cotter wells (WS-30 and PZ-03), have elevated concentrations for any of these constituents relative to the levels measured in the other bedrock groundwater samples. For example, in comparison to all other groundwater samples from the Hematite Site, groundwater from WS-30 has an unusually high concentration of potassium (69 mg/L). It is interesting to note that this well also has a very high pH (9.3, Sect. 4.1.3).

The fact that groundwater from bedrock wells does not exhibit elevated concentrations of the major cations and anions is attributed to the following factors:

- If the constituents of concern were released in the overburden, these constituents can interact with the overburden soils (e.g., adsorption or precipitation) resulting in attenuation before the groundwater reaches the bedrock.

- The primary bedrock mineral (dolomite) is relatively soluble and has a strong chemical buffering effect on groundwater pH and the dissolved concentrations of calcium and magnesium (additional examples of buffering are described in Sect. 4.1.3).

4.2.2.2 Comparison of unfiltered (total) versus filtered (dissolved) metals concentrations

The role of particulates in influencing measured metals concentrations in groundwater at the Hematite Site can be assessed by comparing metals concentrations in co-located filtered and unfiltered samples (Figs. 4.8a through 4.8d). As mentioned in Chapter 2, groundwater samples collected from all the wells were unfiltered prior to analyses, but filtered groundwater samples were also collected from a subset of wells. Figure 4.9 clearly shows that aluminum tends to be higher in the unfiltered samples, indicating the presence of clay particulates (aluminum is an element found in common clay minerals) that were filtered out by the 0.45-μm filter. High turbidity was measured in some of the samples that had elevated levels of aluminum (Fig. 4.8a); however, there were some groundwater samples where turbidity was low despite high aluminum concentrations (e.g., sample from well NB-54). Iron and manganese concentrations are comparable between unfiltered and filtered samples (Figs. 4.8b and 4.8c). Zinc appears to also be higher in unfiltered samples (Fig. 4.8d), suggesting that zinc is either associated with the clay particles, or is present in particulates larger than the filter size (0.45 μm). This observation indicates that iron and manganese oxyhydroxide particulates were not present in the groundwater samples selected for filtered/unfiltered sampling, or that these particulates are fine enough to pass through 0.45-μm filters.

The presence of iron oxyhydroxide particulates in groundwater at the Hematite Site cannot be completely ruled out for some samples, based on a comparison of total iron measured in the laboratory on unfiltered samples, and ferrous iron measured in the field (Sect. 4.1.6). Note that the total versus ferrous iron comparison can be made on more than 100 samples collected during the site-wide sampling event, in contrast to 16 unfiltered versus filtered comparisons shown on Fig. 4.8a through 4.8d. Fig. 4.8e shows that total iron tends to be higher than ferrous (dissolved) iron for some samples, indicating the possible presence of iron oxyhydroxide particulates in the groundwater. However, there is considerable scatter of data points around the total iron = ferrous iron line suggesting that for many samples most of the dissolved iron is in the ferrous state.

4.2.2.3 Element-by-element discussion of key inorganic constituents in groundwater

Two considerations are important in evaluating the groundwater data. First, all of the samples were not filtered per EPA protocol (Puls et. al 1996) (filtered samples were also collected from a subset of wells; see the discussion in the previous subsection) and some had high turbidity (refer to Sect. 4.1.1, see Appendix H.1 for the complete set of field parameter values). The elements aluminum, iron, and manganese are particularly susceptible to forming particulates that are collected as part of a water sample because they are so abundant in native rocks and soils. Similarly, many elements (e.g., arsenic, uranium, chromium, copper, nickel, etc.) are often detected in conjunction with high concentrations of iron and manganese because the hydrous oxides of the latter elements are highly efficient sorbents for inorganic species.

In evaluating the groundwater data, the measured concentrations are compared against Site background criteria (presented in Appendix J) and drinking water standards primarily for reference. Groundwater from the overburden is not a drinking water source and, as such, comparing groundwater Site data with drinking water standards as a qualitative approach to evaluating environmental impact is likely conservative. A quantitative assessment of risk associated with these groundwater constituents is being performed in a baseline risk assessment and will be documented in a separate report.

The groundwater data are described below on an element-by-element basis.

Aluminum—This element, a major constituent in geologic materials, was present in a number of groundwater samples at mg/L levels (e.g., BD-03 = 3.5 mg/L, LF-08 = 5.6 mg/L, BD-13 = 6.8 mg/L, BD-02 = 6.8 mg/L, and WS-23 = 16 mg/L). The background level developed for aluminum in overburden groundwater was 1.1 mg/L. As described for surface water samples in Sect. 4.2.1, aluminum detections in groundwater are almost certainly derived from the collection of soil particulates as part of the groundwater samples. This is supported by the aluminum concentrations being higher in unfiltered samples when compared to filtered samples (Fig. 4.8a; Sect. 4.2.2.2).

Antimony—This element was not detected above the RL of ~0.02 mg/L in any of the samples. For reference, the drinking water standard for antimony is 0.006 mg/L.

Arsenic—This element was not detected above the RL in most of the samples, with the RL of ~0.01 mg/L (Table 4.1). The drinking water standard for arsenic (0.05 mg/L) is exceeded in samples from deep overburden wells WS-23 and WS-25. The wells are in close proximity northeast of the buildings (see Fig. 2.6b for well locations), but are not located near surface soil samples containing elevated arsenic (see Sect. 4.2.4). Moreover, none of the subsurface soil samples contained elevated arsenic (see Sect. 4.2.5).

The elevated arsenic concentrations in these samples are associated with mg/L levels of iron (see iron concentrations in Appendix H.3). These data suggest the arsenic may be naturally occurring. The phenomenon of arsenic occurring in reducing groundwater zones, often in conjunction with iron-bearing zones, has been demonstrated elsewhere in Missouri and throughout the Midwestern United States. (Aggett and Kriegman 1988, Holm and Curtiss 1988, Korte 1991, Korte and Fernando 1991). An additional possibility is that colloidal iron oxide particles were collected as part of the water sample. The latter is supported by the comparison of total iron and ferrous iron discussed in Sect. 4.2.2.2. As described in the surface water section above, this phenomenon commonly results in detections of other naturally occurring elements.

Barium—This element is abundant naturally and was detected in every sample (range from 0.1 to 0.54 mg/L), with the highest results coinciding with the samples high in aluminum and iron. Thus, association with iron- and aluminum-based particulates is possible. The background values developed for barium in the groundwater of the overburden and the Jefferson City Formation were 0.39 mg/L and 0.54 mg/L, respectively. For reference, the drinking water standard for barium is 2 mg/L, which is not exceeded in any of the wells sampled.

Beryllium—This element was not detected above the RL (~0.0026 mg/L) in any of the samples. For reference, the drinking water standard for beryllium is 0.004 mg/L.

Cadmium—This element was only detected above the RL (~0.002 mg/L) in the groundwater sample from BD-02 (0.0035 mg/L). For reference, the drinking water standard for cadmium is 0.005 mg/L.

Calcium—This element is abundant naturally, especially at the Hematite Site where the underlying bedrock is dolomitic. Results varied from <10 to 260 mg/L. Several wells exceeded 100 mg/L

(BD-02 = 260 mg/L, BD-03 = 120 mg/L, BD-06 = 130 mg/L, BD-08 = 110 mg/L, BP-17 = 160 mg/L, CB-02 = 110 mg/L, DM-02 = 140 mg/L, EP-20 = 140 mg/L, OB-01 = 170 mg/L, WS-24 = 140 mg/L, and WS-27 = 110 mg/L).

Chromium—Most of the samples did not contain chromium above the RL of ~0.004 mg/L, except for the samples shown in Table 4.2. All of the results are from wells in the overburden. The samples with detectable chromium concentrations have mg/L concentrations of iron and/or aluminum, which in turn may be indicative of particulates present in the groundwater samples. As mentioned previously, naturally occurring elements tend to be detected in groundwater samples with suspended or colloidal particulates. For reference, the drinking water standard for chromium is 0.1 mg/L, which is not exceeded in any of samples in Table 4.2.

Cobalt—The maximum value reported for cobalt was 0.042 mg/L from GW-BD-03. The majority of the remaining samples were reported either as not detected (RL ~0.002 mg/L), or near the RL. The background values developed for cobalt in the groundwater of the overburden and the Jefferson City Formation were 0.0024 mg/L and 0.0022 mg/L, respectively. Well BD-03, located inside Building 240, contains 15 mg/L of iron and 3.5 mg/L of aluminum. Hence, colloidal soil particles may be a source of cobalt, a naturally occurring element in soil.

Copper—Most of the samples did not contain copper above the RL (~0.01 mg/L) (Table 4.3). All of the measured concentrations are in the overburden. The background value developed for copper in the overburden groundwater was 0.02 mg/L. For reference, the drinking water standard for copper is 1300 mg/L, which is not exceeded by any of the samples in Table 4.3. As with several other elements, all of the copper concentrations above the RL are associated with mg/L levels of iron.

Iron—Iron is not a toxic element, although there is a secondary drinking water standard for water supply systems (0.3 mg/L) because of its effects on color and taste. Iron is included here for specific discussion because of its implications regarding co-precipitation and/or sorption of elements and the redox status of the aquifer. Iron detections in Hematite Site groundwater are shown in Table 4.4. Except under acid conditions, iron is not soluble in oxidized water hence; the data in Table 4.4 indicate reducing conditions in groundwater or the collection of particulates as part of the water sample.

Lead—Most of the samples did not contain lead above the RL of ~ 0.003 mg/L (Table 4.5). The highest results (BD-02, BD-03, BD-13, WS-23, and WS-25) are once again associated with high iron results. Most of the anomalous lead in soil samples was associated with the Evaporation Ponds (Sects. 4.2.4 and 4.2.5), but monitoring wells WS-23 and WS-25 are located northeast of the plant near the Burial Pits. Thus, there is no logical connection between elevated lead in soil and in groundwater. For these reasons, the lead may be associated with iron oxyhydroxides naturally present in the soil and collected as part of the groundwater sample. In the unfiltered/filtered water samples, lead was only detected in the unfiltered sample from BP-20A (0.0043 mg/L); the associated filtered sample did not have lead above the RL; this is consistent with its possible association with particulates. The background value developed for lead in the overburden groundwater was 0.0082 mg/L. For reference, the drinking water action level for lead is 0.015 mg/L.

Manganese— Every groundwater sample had detectable manganese, with the highest value of 13 mg/L (BD-02) and many other results exceeding 1 mg/L. These data are consistent with the high iron values and indicate reducing conditions in the aquifer or the collection of particulates as part of the water sample. The background value developed for manganese in the overburden groundwater was 3.3 mg/L. For reference, there is no primary drinking water standard for manganese, although there is a secondary standard (for aesthetics and taste) of 0.05 mg/L.

Mercury—This element was not detected above the RL (~0.0002 mg/L) in any of the samples. For reference, the drinking water standard for mercury (inorganic) is 0.002 mg/L.

Nickel—This element was detected above the RL (~0.005 mg/L) in most samples, but only five reported concentrations exceeded 0.05 mg/L (Table 4.6). Wells with the highest nickel concentrations each contain mg/L levels of iron. The highest concentration of nickel was measured in BD-08 (0.15 mg/L), a well that is located inside a building (Fig. 2.6a for location). The background value developed for nickel in the overburden groundwater was 0.031 mg/L. There is no drinking water standard for nickel.

Nitrate—Many of the samples had detectable nitrate. Table 4.7 presents those samples with nitrate >1 mg/L. For reference, the drinking water standard for nitrate is 10 mg/L. This is only exceeded in samples from EP-20 and BD-02, associated with the Evaporation Ponds and soils under the buildings. Nitric acid was used at the Hematite Facility (see Table 1.3) and is a very mobile but highly biodegradable contaminant. Hence, the result at EP-20 and in wells in the Buildings (e.g., BD-02) is likely a result of Hematite Facility operations.

Selenium—Most of the samples did not contain selenium above the RL of ~0.005 mg/L (Table 4.8). For reference, the drinking water standard for selenium is 50 mg/L, which is not exceeded by any of the measured concentrations.

Silver—This element was not detected above the RL (~0.01 mg/L) in any of the samples. For reference, there is no primary drinking water standard for silver, but the secondary drinking water standard (for aesthetics and taste) is 0.1 mg/L, which is not exceeded in any groundwater samples from the Hematite Site.

Sulfate—Most of the results for sulfate were in the range of 20 to 60 mg/L, with the highest reported result at 170 mg/L. These results and the observed variability are not uncommon for natural waters and do not indicate contamination. For reference, there is no primary drinking water standard for sulfate, although there is a secondary drinking water standard of 250 mg/L. All the sulfate levels at the Hematite Site are below the secondary standard.

Thallium—Three groundwater samples (Table 4.9) exceeded the thallium RL of ~0.01 mg/L. For reference, the drinking water standard for thallium is 0.002 mg/L. Thallium was detected in two groundwater samples collected underneath buildings and from the Burial Pits.

Vanadium—Most of the samples did not contain vanadium above the RL of ~0.01 mg/L (Table 4.10). There is no drinking water standard for vanadium. It was not implicated as a soil contaminant (see Sects. 4.2.4 and 4.2.5) and is relatively abundant naturally. Each of the samples in Table 4.10 also contains high aluminum and iron, which suggests these measured concentrations are naturally occurring, as described previously.

Zinc—This element is naturally abundant and has a host of anthropogenic sources. Hence, it was detected in many of the groundwater samples. The background values developed for zinc in the groundwater of the overburden and the Jefferson City Formation were 0.210 mg/L and 0.069 mg/L, respectively. For reference, there is no drinking water standard for zinc although there is a secondary (for aesthetics and taste) drinking water standard (5 mg/L). None of the samples exceeded the secondary standard. Those samples with concentrations greater than 0.05 mg/L are shown in Table 4.11. NB-54 is located at the southwest corner of the buildings, in BD-03 in the center of the buildings, and in NB-32 east of the Evaporation Pond area. The two highest values, in WS-23 and WS-25, are located northwest of the Hematite Facility next to the Burial Pits. As with the other elements, zinc correlates more with high

iron than it does with known contamination sources. It was also higher in the unfiltered samples when compared to the filtered samples (see Sect. 4.2.2.2).

4.2.3 Non-radioactive Inorganics in Sediments

This section reviews sediment data for inorganic, non-radioactive species. Details of sediment sampling are presented in Sect. 2.1. Sampling locations for sediment were shown on Fig. 2.3. Sediment data for selected elements are presented in Table 4.12; the complete data set for inorganics in sediments can be found in Appendix H.4. Cyanide is not included in Table 4.12 because all results were below the RL of 0.96 mg/kg. Antimony is not included in the table because it was only detected in one sample (SW-07-SS, 1.9 mg/kg) at a concentration that was slightly greater than the reporting limit of 1.5 mg/kg.

Concentrations in the Site sediment samples are compared to levels measured in two upstream sediment samples, and to site-specific background concentrations determined from off-Site subsurface soil samples (Appendix J). The results in Table 4.12 show that some of the metals are elevated in a number of sediment samples from the Site Pond, Site Creek, and Northeast Site Creek. Highest concentrations were measured in SW-06-SS from the Site Pond. For example, this sample contained the highest mercury result (1.1 mg/kg); this sample also has the highest aluminum result (13,000 mg/kg) and is one of the two highest samples in iron and manganese (latter data not shown in Table 4.12, but can be found in Appendix H). These data suggest either an accumulation zone where oxyhydroxides of aluminum, iron, and manganese have scavenged metals from the surface water or where some metal scrap may be present.

With the exception of SW-15-SS, which was collected near the bridge on Joachim Creek (see Fig. 2.3), concentrations of inorganics in sediment samples from Joachim Creek are comparable to the upstream and site-specific background concentrations (Table 4.12). As mentioned in Sect. 2.8, anomalies were detected during a geophysical survey at the bridge across Joachim Creek, but the majority of the anomalies were due to visible surface metals scrap from use of the area as an adhoc household dumping site. The elevated metals in SW-15-SS may be due to the presence of the scrap metal.

4.2.4 Non-radioactive Inorganics in Surface Soil

This section reviews surface soil data for inorganic, non-radioactive species. Details of surface soil sampling are presented in Sect. 2.2, while the complete data set can be found in Appendix H.5. The primary conclusion of this section is that elevated data are localized and tend to be associated with previously identified AOCs (e.g., the Burial Pits, the Evaporation Ponds, process buildings, and the Site Pond sediments at the Hematite Site). The same conclusion was reached in the analysis of sediment (Sect. 4.2.3 above) and subsurface soils (Sect. 4.2.5).

4.2.4.1 Review process for surface soil inorganics data

The review process for the surface soil and subsurface soil data was performed in the following steps.

- The distributions of the on-Site data were examined to determine whether multiple populations were present. This approach is commonly used as a means of separating results representing the naturally occurring population from that comprised by contaminants (Fleischhauer and Korte 1990, EPA 2002; Appendix J). The presence of multiple populations, however, does not automatically indicate contamination. Naturally occurring elements will have multiple populations when different soil or rock types are sampled or because of the presence of fill or urban particulates (atmospheric deposition). Hence, professional judgment remains part of the review process.

- Each population identified in the previous step was assessed by comparison to regional and international averages in the published literature, as well as to data from nearby sites. When Site characterization data are within the range of regional and international data compilations; it is unlikely to represent contamination. In this case, on-Site results were also compared to data from 15 off-Site soil locations (refer to Fig. 2.7 for locations, Appendix H.5a). Eight off-Site soil sampling locations representative of the terrace strata were located along Highway P, approximately 2.5 miles west of the Hematite Site. Seven soil sampling locations representative of the alluvial strata were located at the U.S. National Guard Armory Site, located east and north of the Hematite Site near the junction of State Road P and State Road A (Fig. 2.7). No distinction was made between terrace and alluvial samples in the following discussion because little if any contamination is indicated on-site. Site background concentrations were calculated (Appendix J); however, the Site background was just one of the factors considered when evaluating the data for contamination. Additional details of the off-Site sampling program, the background soil sampling locations, and data are presented in Appendix J.

- Analysis for inorganic constituents are subject to interferences. Thus, concentrations of metals are evaluated as a group because contamination with a single inorganic species rarely occurs unless a specific process producing only that contaminant has been identified. A sampling location where one element is elevated with no clearly identified cause usually indicates a sampling or analytical artifact.

- The analytical results for the Site samples are also compared with local, regional, and international data.

The review process is demonstrated for arsenic at the Hematite Site. Figure 4.9 shows a cumulative frequency plot of the arsenic results in surface soils. An examination of the figure demonstrates there are two distinct populations with the upper and lower ends of the two populations meeting at approximately 25 mg/kg. Local, regional, and international data and measurements in urban dust and house dust, as described below, indicate the upper range of background for arsenic from these sources ranges from approximately 10 to 50 mg/kg. Because the second population contains values exceeding 10 to 50 mg/kg, this group of results requires examination as potential Site contamination. Indeed, virtually all samples in this group are either associated with known disposal sites (e.g., Burial Pits) or were collected adjacent to buildings.

Figure 4.10 presents data for arsenic in subsurface soils (data discussed in Sect. 4.2.5). Once again, two distinct populations are present. However, in contrast to the surface soil data, the highest results in the second population are approximately equal to the upper range for arsenic reported as background in regional and international soils data. The three highest values (24, 20, and 17 mg/kg) are associated with the Burial Pits, the limestone storage area, and the Evaporation Ponds, respectively. Hence, although within many background averages, these data are probably evidence of impact from Site activities.

4.2.4.2 General observations regarding inorganics in surface soils

Sampling locations for surface soils (including composite samples from the limestone storage/pile areas) are shown on Figs. 2.4a and 2.4b. The ten highest results are presented in Table 4.13. Table 4.13 does not include the elements generally considered to be non-hazardous major soil components such as aluminum, calcium, and iron, or elements such as barium and vanadium where results were comparable to the off-Site and regional values (Table 4.14).

Not all results in Table 4.13 are suggestive of contamination. For example, most of the cobalt results cannot be distinguished from background, as shown by the cumulative frequency plot in Appendix J. Similarly, selenium results up to approximately 2 mg/kg in Table 4.13 are probably part of a background

distribution with a greater range because the on-Site sample population size is ten times larger than the off-Site sample population. Finally, more than ten results are elevated for the metals mercury, thallium, and zinc, although results not shown on Table 4.13 are within regional and international background ranges, as shown in Table 4.14.

Descriptive statistics for the entire surface soil data set are compared to local, regional, and international averages, as well as to common urban values in Table 4.14. (Cyanide results are not included because none were detected above the RL (0.7 mg/kg) in surface soils.) The Illinois data (IEPA 1994) used in Table 4.14 are from a program to determine state-wide background concentrations and represent a comprehensive regional data set. The data for shale, clay, sandstone, sand, carbonates, soil, and loess are from a comprehensive program performed by the USGS (Connor and Shacklette 1975) and were listed as "Missouri region" in the original text. The regional Illinois data set is included in this evaluation because it is more recent and is based on more up-to-date methods when compared to the USGS Missouri regional data. The Missouri data from Tidball (1984) may include some of the USGS Missouri data. The compilation by Lindsay (1973) is another classical accumulation of soils data. Finally, the results for urban road dust and house dust (Fergusson and Kim 1991) provide perspective regarding the ubiquity of metals in the environment.

The utility of including surface soil comparisons with urban road dust and house dust is demonstrated by reviewing the data for cobalt and zinc. Cobalt is not commonly used in industrial activities. Hence, little enrichment in road and house dust is expected. In such instances, the Hematite Site mean and the means for regional and international studies and for urban and house dusts should be similar because the primary source of cobalt in each case is soil. Indeed, the means for each of the data sets are quite similar. In contrast, zinc is added to the environment from many sources, including tire wear and roofing materials. Thus, the means for road and house dusts should be and are much higher than for background samples as reported by Lindsay (1973), the state of Illinois (1995) and USGS (Connor and Shacklett 1975).

4.2.4.3 Element-by-element discussion of elevated surface soil results

Figure 4.11 shows a map of surface soils with elevated inorganic concentrations, based on the review process described earlier in Sect. 4.2.4.1. The following is an element-by-element discussion of the anomalous surface soil concentrations on Fig. 4.11, and the results shown in Table 4.13. Site background values developed for inorganics in surface soils are presented in Table 4.13 and Appendix J.

Arsenic—Elevated levels were identified by considering the cumulative frequency plot (presented in Fig. 4.9) for arsenic in surface soils and the regional data in Table 4.14. The highest arsenic values are clustered near the Evaporation Ponds (locations shown on Fig. 4.11, "EP"-labeled samples). Other elevated concentrations were mostly from samples collected near buildings (Fig. 4.11, data shown in Table 4.13, "BD"-labeled samples Operations at the Hematite plant involved the handling (e.g., cleaning, machining) of specialty alloys. The presence of heavy metals (e.g., arsenic, chromium, copper, and nickel) could indicate site-related releases from cleaning of specialty alloy metal parts.

Antimony—The elevated antimony values are clustered near the Evaporation Ponds (locations shown on Fig. 4.11, "EP"-labeled samples).

Beryllium—The elevated beryllium values are from samples collected near the Evaporation Ponds (locations shown on Fig. 4.11, data shown in Table 4.13, "EP"-labeled samples).

Cadmium—The elevated cadmium values are from samples collected near the Evaporation Ponds (locations shown on Fig. 4.11, data shown in Table 4.13, "EP"-labeled samples).

Chromium—The highest result (280 mg/kg, BD-10) is outside of common ranges for background and road and house dust, as shown in Table 4.14. Three of the samples listed in Table 4.13 are clustered near the Evaporation Ponds. The other high sample is from OA-08, a location next to a building in the middle of the Hematite Facility area with other elevated metal results.

Cobalt—The highest cobalt result (300 mg/kg, OA-23) is more than approximately ten times the common soil averages (see Table 4.14). The latter sample contains no other metal contaminants and is probably a sampling or analysis artifact. The few elevated results and their sporadic distribution do not indicate a cobalt contamination issue.

Copper—Only one copper result (1800 mg/kg, EP-02) is significantly elevated. Four of the highest reported values are associated with the Evaporation Ponds (Table 4.13). The other location, OA-08, contains other elevated elements (see chromium above).

Fluoride—The highest fluoride levels in the surface soil samples were measured in samples from the Evaporation Ponds area, Deul's Mountain area, next to the buildings and adjacent outdoor areas (EP, DM, BD, and OA-labeled samples in Appendix H.5). The highest fluoride result (170 mg/kg) is still below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984).

Lead—Five of the highest six lead values (Table 4.13) are from samples that had no other anomalous metals. All the anomalous results, however, are near buildings or the Evaporation Ponds.

Mercury— Elevated mercury concentrations in some surface soils closely associated with the Evaporation Ponds ("EP"-labeled samples; Table 4.13, Fig. 4.11). Other samples with elevated results were collected north of the plant (OA-11 and OA-13) near the limestone storage area or next to Building 240 (BD-11). These samples also have elevated levels of otherwise contaminated with other metals and radionuclides.

Nickel—All of the elevated values are associated with the Evaporation Pond area.

Selenium—The highest selenium values are associated with Evaporation Pond samples contaminated with a variety of metals and solvents.

Silver—Silver results are only slightly elevated, with the two highest values (Table 4.13) reported near the Evaporation Ponds.

Thallium—The highest thallium values are associated with samples that contain other metals. These areas are contaminated with a variety of solvents as well.

Zinc—All of the high results except for NB-23 are clustered next to the Evaporation Ponds. NB-23 is east of the plant. Most zinc sources (automobiles, tire wear, and roofing materials) are sources of other metals. Because there are no other metals associated with NB-23, this result is probably a sampling or analysis artifact.

4.2.5 Non-radioactive Inorganics in Subsurface Soils

Sampling locations of subsurface soils were shown on Figs. 2.5a and 2.5b, while sampling and analysis methods were described in Sect. 2.3. The analytical data were reviewed according to the same process conducted on the surface soil sample results, as described in Sect. 4.2.4.1.

4.2.5.1 General observations regarding inorganics in subsurface soils

The ten highest results for subsurface soil samples and selected elements are shown in Table 4.15, and elevated data are presented on Fig. 4.12. Moreover, for some elements, all results were less than the site-specific background concentration and were not included in Table 4.15. These elements were: aluminum, barium, calcium, iron, magnesium, manganese, potassium, silver, sodium, and vanadium. All of the analytical results are provided in Appendix H.6, and descriptive statistics for all of the elements and data are presented in Table 4.16. (Cyanide results are not included because none were detected above the RL of ~0. 96 mg/kg in subsurface soils.)

4.2.5.2 Element-by-element discussion of anomalous subsurface soil results

The element-by-element discussions under surface soils (Sect. 4.2.4.3) can be reviewed for brief mention of potential sources of inorganic/metal constituents. These are not repeated here because of the few elevated subsurface soil trace element results. The element-by-element descriptions provided below are guided in part by the cumulative frequency plots in Appendix J. Site background values developed for inorganics in subsurface soils are presented in Table 4.15 and Appendix J. Indications of contamination appear to be highly localized (e.g., SW-02 and BD-05 samples collected from boreholes near the Site Pond, and under Bldg. 240, respectively) and low-level. Fig. 4.12 shows the locations of samples with anomalous concentrations (refer to Figs. 2.5a and 2.5b for locations of all boreholes from which subsurface samples were collected).

Arsenic—The highest arsenic value in the subsurface was 24 mg/kg. Moreover, there is no apparent correlation among locations or multiple indications of contamination in a single borehole. For example, BP-18, from which the 24-mg/kg sample was collected, had four other arsenic samples that were collected above and below the sample having the elevated concentration and all other samples had concentrations that were <10 mg/kg. Consequently, the highest arsenic values in subsurface soils are most likely natural occurrences.

Beryllium—The highest beryllium values are mostly SW samples (collected near the Site Pond), particularly samples collected from borehole SW-02 (2.8 mg/kg at a depth of 1 ft), which accounts for three of the highest values. The cumulative frequency plot (Appendix J), however, indicates that only two of the results are truly elevated.

Antimony—The highest antimony values are sporadically distributed and low-level (<2 mg/kg).

Cadmium—Three of the highest cadmium values were measured in samples collected from borehole SW-02, thus suggesting low-level contamination with metals at this location. The measured cadmium levels in the subsurface soil samples are all significantly less than the CALM standard of 110 mg/kg. This indicates there is not a contamination problem with cadmium.

Chromium—The highest chromium result (49 mg/kg) is from borehole BD-05—a location that accounts for several of the high values from subsurface soils. Nevertheless, the majority of the data does not correlate to specific locations, thus indicating there is not a significant contamination problem with chromium.

Cobalt—Most of the highest cobalt results are "BD" samples (collected under or near buildings), thus suggesting that elevated levels are from Site operations in these areas. As noted previously, there are no suspected cobalt sources at the Site.

Copper—The highest copper result (38 mg/kg) is from BD-05, which is a location responsible for several other of the highest values reported in subsurface soils.

Fluoride —The highest fluoride results were measured in the Evaporation Ponds, under the buildings and near Deul's Mountain (EP, BD, BLD, and DM-labeled samples in Appendix H.6). However, even the highest fluoride level (190 mg/kg in EP-13-06-SL) is below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984).

Lead—Only one lead result (680 mg/kg, NB-75 at 19 ft) is elevated with respect to background, as can be observed from the cumulative frequency plot (Appendix J). This location and depth do not correlate to other contamination. Hence, there is no evidence of a significant contamination problem with lead and this result is probably an analytical or sampling artifact.

Mercury—SW-02 and EP-18 are the locations with the highest values for mercury. SW-02 has already been identified as having low-level metal contamination (e.g., berryllium, see preceding discussion in this subsection) and the Evaporation Ponds area has already been identified as a significant contamination source based on elevated metals concentrations in surface soil samples (refer to Sect. 4.2.4).

Nickel—The highest nickel result is 97 mg/kg, NB-85, which is outside of regional and international ranges. Another of the high samples is from BD-05, again implicating the latter location with low-level contamination. Nonetheless, the high results are sporadically distributed and relatively low level, thus indicating there is not a significant contamination problem with nickel.

Selenium—The highest selenium values are not significantly elevated (all <3 mg/kg) and are sporadically distributed. The cumulative frequency plot (Appendix J) suggests two distinct populations of roughly equal size. Hence, the higher values are most likely a consequence of two natural populations.

Silver—Silver data are not provided in Table 4.15 because only one result (0.85 mg/kg) appeared to be elevated with respect to background. This highest result, however, is from SW-02, the same location where several other metals are somewhat elevated.

Thallium—Thallium results, much like selenium, are separated into two large, distinct populations, thus indicating most of the higher values are naturally occurring. The highest result, however, is from BD-05, which is a location already implicated with low-level metal contamination.

Zinc—Zinc is relatively abundant naturally. Thus, only a few of the highest results suggest contamination. The locations for the highest zinc results, however, are sporadically distributed, thus indicating there is not a significant contamination problem.

In summary, locations SW-02 and BD-05 appear to have low-level element contamination in the subsurface. Most of the remainder of the highest results was sporadically distributed and not indicative of significant contamination. For example, the following locations had multiple occurrences of the higher results: NB-36-15-SL, cobalt = 54 mg/kg and nickel = 60 mg/kg; NB-42-05-SL, lead = 98 mg/kg and zinc = 380 mg/kg; NB-63-05-SL lead = 120 mg/kg and zinc = 850 mg/kg. However, overlying surface soil samples in these areas are not contaminated with these elements, nor are water samples from these or adjacent wells (refer to Sect. 4.2.2.3 for discussion of groundwater data). Thus, although there is no ready explanation for the latter results, all facts taken together, Site evidence indicates the contamination is both low-level and highly localized. Indeed, several of the higher results may represent natural outliers (considering the small % of elevated results).

4.3 RADIONUCLIDES

Information from the historical Site assessment and previous investigations indicated ^{234}U, ^{235}U, ^{238}U, ^{99}Tc, ^{232}Th and progeny were the most likely radioactive contaminants at the Hematite Site (Sect. 1.5). Radioactive contamination had been investigated as early as 1982 (RMC 1982). Subsequently, certain contaminated locations were identified. For example, a partial removal of contaminated soils and sediments from the Evaporation Ponds occurred in 1992 (Sect. 1.5.3). Similarly, groundwater contamination with ^{99}Tc in the central Hematite Facility area—between the limestone storage area near Deul's Mountain and the Hematite Facility buildings was documented in 1996 (GEA 1996, summarized in Sect. 1.5). In addition, groundwater contamination with ^{99}Tc in six deep (to 20 ft) and seven shallow boreholes in the Evaporation Ponds demonstrated radioactive contamination in soil (GEA 1997, also summarized in Sect. 1.5). Subsequent studies confirmed the ^{99}Tc groundwater contamination, thus suggesting that its extent was localized to a few previously identified areas (summarized in Sect. 1.5).

Isotopic uranium analyses were performed in the current study because the uranium used may have varied from depleted- to natural- to highly enriched. Thorium-232 analyses were performed because it was used in limited investigations regarding possible involvement in the fuel cycle.

The potential for transuranics and ^{99}Tc (contaminants in uranium reprocessed from spent fuel) to be present at the Hematite Site was also examined. According to the U.S. Department of Energy (DOE) (Project Overview and Field Site Reports entitled "A Preliminary Review of the Flow and Characteristics of Recycled Uranium throughout the DOE Complex 1951-1999"), most of the fission products and transuranic isotopes were disposed of as high-level waste during reprocessing by fuel recycling facilities (fuel recycling was not performed at the Hematite Facility; Sect. 1.3). However, traces of transuranics and ^{99}Tc remained with recovered uranium. DOE indicated ^{99}Tc would be the predominant recycled uranium contaminant followed by ^{241}Am and ^{237}Np at significantly lower concentrations. ^{237}Np is a potential contaminant due to its presence in UF_6 feedstock that was historically sent to the Facility.

4.3.1 Radionuclides in Surface Water

Details of surface water sampling are presented in Sect. 2.1.2 and the complete data set is presented in Appendix H.7.

Surface water samples were submitted for determination of isotopic uranium, isotopic thorium, and ^{99}Tc. Neither thorium isotopes nor ^{99}Tc were detected in any of the samples. Data for uranium are presented in Table 4.17, which also includes uranium activities in surface water samples from locations upstream of the Facility ("US" samples). Background levels for uranium radionuclides are developed in Appendix J. These background levels in surface water are as follows: ^{234}U = 0.76 pCi/L, ^{235}U = 0.10 pCi/L, and ^{238}U = 0.82 pCi/L.

SW-01-SW (collected from the Site Pond, refer to Fig. 2.2 for location) has the highest uranium activities (^{234}U = 29.6 ± 4.7 pCi/L; ^{235}U = 1.24 ± 0.273 pCi/L; ^{238}U = 4.77 ± 0.821 pCi/L). Clearly, uranium activities in SW-01-SW are elevated relative to the upstream sample (US-03-SW). Some or all of the uranium is likely sorbed to particulates (recall the elevated aluminum concentration (19.1 mg/L) in this surface water sample; refer to Sect. 4.2.1) and not migrating as a dissolved species. Activities in SW-02-SW (from the Site Creek) are lower relative to the Site Pond, but are still elevated relative to the relevant upstream sample (SW-15-SW). Sample SW-09-SW collected from the Northeast Site Creek also has slightly elevated activities relative to the upstream sample, although the difference is not significantly larger than the measurement errors (~0.5 pCi/L for ^{234}U). Note that the activities in the upstream samples are relatively low and measurement errors are a large percentage of the actual results in these samples. Thus, there is some uncertainty when a Site sample is deemed to be comparable to upstream samples.

However, in the samples with high levels of uranium (e.g., SW-01-SW), the measurement errors in the results for this sample should not affect the inference that this sample contains uranium at levels higher than upstream values.

Samples in secular equilibrium would have a $^{234}U/^{238}U$ ratio near 1. The $^{234}U/^{238}U$ ratio for SW-01 is approximately 6 and sufficiently out of secular equilibrium that some of the measured uranium probably originated from the Hematite Facility operations. This is not surprising given that some release of radiologic compounds is allowed by the NPDES permit for the outfalls that discharge into the Site Pond.

In summary, the surface water data indicate the presence of radioactive contaminants at concentrations above upstream surface water. However, combined with the data for metals and other inorganic constituents, it is possible that some of the uranium measured in the samples indicating contamination from Hematite Site processes is associated with particulates.

4.3.2 Radionuclides in Groundwater

Groundwater samples were collected for radionuclide analysis during the site-wide sampling program performed in December 2004. Sampling and analysis methods were presented in Sect. 2.6 of this report. Locations of groundwater monitoring wells sampled during this event are shown on Figs. 2.6a and 2.6b. All groundwater samples collected were analyzed for isotopic uranium and thorium, ^{99}Tc, gross alpha, and gross beta. A select number of wells was also sampled for transuranic analyses (^{241}Am, ^{237}Np, and isotopic plutonium). Twenty of the locations analyzed for transuranics were generated randomly and the remaining ten were selected to ensure that known source areas were adequately represented in the data set. The radionuclide-specific analyses are discussed in the following sections while the gross alpha and beta measurements can be found in Appendix H.8, which is a complete listing of all the groundwater radionuclide data collected during the RI. Since the sources for alpha and beta emissions at the Site are reasonably well established (i.e., uranium and technetium, respectively), it was deemed more appropriate to do a thorough evaluation of the analyte-specific data and to use the gross emissions measurements as a supplementary data set.

In summary, the radionuclide data indicates only ^{99}Tc has entered the groundwater at numerous locations (Sect. 4.3.2.4). Uranium contamination may also be present (Sect. 4.3.2.1), but the extent is limited. In general, the conclusions of this section are consistent with the previous investigations (summarized in Sect. 1.5) that indicated limited contamination with uranium, and somewhat more, although still localized, contamination with ^{99}Tc. For example, groundwater contamination with ^{99}Tc in the central Hematite Facility area, between the limestone storage area and the main buildings, was documented in 1996 (GEA 1996) and subsequently confirmed with the suggestion that extent was localized to these areas (LBG 1999).

4.3.2.1 Uranium in groundwater

Uranium detected in groundwater by alpha spectrometry is shown in Table 4.18. Uranium in groundwater can be evaluated by comparing the results to the 30-μg/L EPA drinking water standard for uranium. The uranium mass concentration in each groundwater sample was estimated as the sum of ^{234}U, ^{235}U, and ^{238}U mass concentrations which were, in turn, calculated from the measured activities (e.g., data in Table 4.18) using published specific activities (^{234}U: 6.1906×10^{-3} Ci/g, ^{235}U: 2.1616×10^{-6} Ci/g, ^{238}U: 3.362×10^{-7} Ci/g). The EPA standard is exceeded in DM-02 (175 μg/L; a deep overburden well next to Deul's Mountain), WS-24 (82.6 μg/L; a shallow overburden well in the Burial Pits area), and WS-26 (32.7 μg/L; a shallow overburden well in the Burial Pits area). Uranium concentrations in WS-07 (a shallow overburden well near the evaporation ponds), BD-03 and BD-16 (deep overburden wells near the buildings) are 6, 6.5 and 23.6 μg/L, respectively. Uranium mass concentrations in the rest of the

groundwater samples from the overburden and bedrock wells were less than 5 μg/L. Measurement errors in the samples with elevated uranium activities (e.g., DM-02) are a relatively small fraction of the actual result. As such, these measurement errors are not expected to affect the mass concentration calculations and subsequent comparison with drinking water standards.

The sample from BD-03 also contained 15 mg/L of iron and 3.5 mg/L of aluminum, hence the uranium in this sample may be explained as natural and/or sorbed to particulates, although the location of the well in the central Hematite Facility area near a location contaminated with chlorinated solvents (Sect. 4.4) suggests contamination from Hematite Facility operations is also possible. In contrast, the other wells containing uranium over the groundwater standard have low levels of iron and manganese indicating a greater probability the uranium is dissolved. The latter is also indicated on Figs. 4.13 and 4.14, which show virtually no difference between ^{234}U and ^{238}U activities in filtered (<0.45 μm) and unfiltered samples. A similar comparison for ^{235}U is not shown because most of the samples in the subset of filtered/unfiltered samples had non-detectable ^{235}U activities. Uranium associated with iron oxyhydroxide particulates cannot be completely ruled out based on the presence of these particles inferred from a comparison of total and ferrous iron in more than 100 samples (Sect. 4.2.2.2 and Fig. 4.8e). Figs. 4.13 and 4.14 were based on a much smaller number of co-located filtered and unfiltered samples. Natural occurrences of uranium should also be considered. For example, uranium and its daughter products are associated with some dolomitic and limestone formations in the Midwest (Gilkeston et al. 1983, Sasman et al. 1982, Luczaj 1998).

The groundwater sample from BR-12-RB collected as part of the site-wide groundwater sampling event contained an isotopic activity of ^{234}U (12.5 pCi/L) that appeared to be elevated with respect to other bedrock wells. A groundwater sample was collected from BR-12-RB in June 2005, and the measured ^{234}U activity in this sample is comparable to ^{234}U activities measured in the other bedrock wells (refer Table 4.18) The elevated ^{234}U isotopic activity in BR-12-RB sample collected in December 2004 as part of the RI is inconsistent with the overall observation that elevated uranium concentrations in groundwater is limited to the immediate vicinity of known waste areas (e.g., the Burial Pits, the Evaporation Ponds, and under buildings). Other than the December 2004 groundwater sample from BR-12-RB, there is no indication of uranium contamination in the bedrock groundwater. Contaminant transport modeling using a site-specific Kd factor supported the limited mobility of uranium at the Hematite Site (Sect. 5.6). On the other hand, PCE and TCE have spread into the underlying shallow bedrock, and have been detected in a number of the bedrock wells (Sect. 4.4). Thus, uranium contamination without PCE or TCE contamination in the December 2004 sample from BR-12-RB is difficult to reconcile with (1) the more widespread contamination from PCE and TCE, and (2) other evidence for the limited mobility of uranium when compared to PCE and TCE at the Hematite Site. The June 2005 groundwater sample from BR-12-RB is more consistent with previously measured isotopic activities in the other bedrock groundwater samples. It is likely that the elevated ^{234}U activity in the December 2004 sample is due to sampling or analytical errors.

4.3.2.2 Thorium in groundwater

Isotopic thorium data are shown in Table 4.19. The values for thorium isotopes are all relatively low, with only four samples (BD-02, BD-03, BD-16, and BR-01-JC) exceeding total isotopic thorium of 1 pCi/L. Moreover, each of these samples contains mg/L levels of iron. A filtered and unfiltered sample were collected and analyzed for BR-01-JC, and thorium isotopes were not detected in the filtered sample. Detection limits of 0.132, 0.149, and 0.018 pCi/L for ^{228}Th, ^{230}Th, and ^{232}Th, respectively, were recorded. Thus, it is clear that the thorium detected in BR-01-JC is a result of particulates collected as part of the groundwater sample; this is also probable in BD-02 and BD-03. Appendix K contains a report on thorium (and radium) isotopes at the Hematite Site.

4.3.2.3 Radium in groundwater

Three samples contained ^{226}Ra above the MDL (~0.5 pCi/L): BR-12-JC (1.38 pCi/L), BR-01-JC (1.03 pCi/L), and BR-09-JC (1.62 pCi/L); for reference, the drinking water standard ^{226}Ra of 5 pCi/L. Radium-228 was reported above the MDL (~0.5 pCi/L) in BR-09-JC (1.29 pCi/L). All of these samples are from the Jefferson City Dolomite. In a national survey of 96 groundwater public water supply systems, a USGS study (Focazio et al. 2001) found that 30, 33, and 26% of the samples collected were reported above the MDL of 1 pCi/L [the contractual minimal detectable concentration (MDC)] for ^{224}Ra, ^{226}Ra, and ^{228}Ra, respectively. Thus, the radium activities detected in the Jefferson City wells are not unusual and probably represent natural occurrences. In addition, uranium and its daughter products (i.e., ^{226}Ra) are associated with some dolomitic and limestone formations in the Midwest (Gilkeston et al. 1983, Sasman et al. 1982, Luczaj 1998). Appendix K contains a report on radium (and thorium) isotopes at the Hematite Site.

4.3.2.4 Technetium-99 in groundwater

Data for ^{99}Tc are shown in Table 4.20. Clearly, measurable ^{99}Tc activity is more areally extensive compared to any other inorganic or radiochemical species, but is still limited compared to the extent of VOC migration (refer to Sect. 4.4.5.6 and Chapter 5). Figure 4.15 demonstrates ^{99}Tc's association with previously identified contamination sources, such as the process buildings and the Evaporation Ponds, and that detectable ^{99}Tc activity (MDL ~10 pCi/L) is limited to within the Hematite Facility. For reference, the drinking water standard for beta emitters is 4 mrem/yr, which is equal to ~500 pCi/L of ^{99}Tc. ^{99}Tc activities are greater than this reference standard in several of the wells shown in Table 4.20.

4.3.2.5 Transuranics in groundwater

Plutonium isotopes were not detected in any groundwater samples. One sample, NB-64 (south-southeast of the Hematite Facility towards Joachim Creek) reportedly contained ^{241}Am (0.0294 pCi/L), but the result was qualified with "LT" [result was below the requested MDC but higher than the sample-specific MDC]. One sample (BD-16, near buildings) reportedly contained ^{237}Np at 0.0175 pCi/L, but it was also qualified with an "LT." DOE has established derived concentration guides (DCG) for ^{241}Am and ^{237}Np of 30 pCi/L. The reported values are well below the DOE-DCG (DOE 1991).

4.3.2.6 Gross Alpha and Gross Beta in Groundwater

Gross alpha and beta activities in groundwater can be found in Table H.8 of Appendix H. Elevated gross alpha activities were measured in DM-02 (301 pCi/L) WS-24 (132 pCi/L), BD-16 (47.1 pCi/L), BD-02 (26.9 pCi/L), BR-07-RB (19 pCi/L), BD-03 (18.1 pCi/L), WS-26 (18 pCi/L) and BR-10-RB (15.7 pCi/L). The rest of the groundwater samples have gross alpha activities less than 15 pCi/L. For reference, the drinking water standard for gross alpha excluding uranium and radium is 15 pCi/L. The total isotopic uranium activities for the aforementioned samples are: DM-02: 387.8 pCi/L, WS-24: 206.2 pCi/L, BD-16: 19.5 pCi/L, BD-02: 10.0 pCi/L, BR-07-RB: 5.7 pCi/L, BD-03: 16.3 pCi/L, WS-26: 30.6 pCi/L, BR-10-RB: 4.8 pCi/L. After the gross alpha activities are corrected for the U activities, only groundwater samples from BD-16 and BD-02 slightly exceed the drinking water standard.

Gross beta activities were very well correlated with ^{99}Tc activities in the groundwater samples (i.e., plot for gross beta versus ^{99}Tc activity results in a straight line, graph not shown). For reference the drinking water standard for beta emitters is 4 mrem/yr, which for ^{99}Tc is approximately 500 pCi/L.

4.3.3 Radionuclides in Sediments

Sediment samples were collected from several locations around the Hematite Site (see Fig. 2.3) and were analyzed for radionuclides, as described in Sect. 2.1.3. Major findings and discussions of the results are presented in this subsection, while the complete data set can be found in Appendix H.9. The review process is essentially the same as that described previously for inorganics (Sect. 4.1.3). An evaluation of disequilibrium was included for samples with anomalous uranium activities.

4.3.3.1 Uranium in sediments

Off-site/background soil samples collected near the Hematite Site (refer to Fig. 2.7 for locations) yielded background values of 0.92 pCi/g for ^{234}U, a mean of 0.99 pCi/g for ^{238}U, and a mean of 0.08 pCi/g for ^{235}U. Development of these background values is discussed in Appendix J. In uranium that is neither enriched nor depleted, the activity of ^{234}U and ^{238}U are roughly equal and the activity of ^{235}U is roughly 5% of the others. These activity ratios are within experimental error of those found in the off-Site samples.

Hence, the activity ratios in conjunction with the off-Site values are useful for examining the origin of uranium at the Hematite Site. Additional perspective may be gained by comparison to regional data. Using the 690-pCi/mg conversion factor described previously, Tidball (1984) reports a geometric mean of 2.6 pCi/g with a range of 0.759 to 10 pCi/g. Hence, locally determined off-Site values are at the lower end of the range reported for Missouri soils.

In addition, to provide further perspective on uranium activities in sediment and soil samples from the Hematite Site, these may be compared to background values used at the Paducah Gaseous Diffusion Plant (PGDP) (DOE 1997). The Paducah site is a reprocessing facility for uranium located approximately 200 miles southeast of the Hematite Site. Background values for isotopic uranium at Paducah are: ^{234}U = 2.5 pCi/g, ^{235}U = 0.14 pCi/g, and, ^{238}U = 1.2 pCi/g (DOE 1997).

Reviewing the data in Table 4.21 in comparison with the off-Site data and activity ratios described above indicates that samples SW-01-SS through SW-07-SS, and possibly SW-11-SS and SW-12-SS, can be distinguished from background based on total activity. SW-01 through SW-07 are located in the Site Pond or the Site Creek (see Fig. 2.3 for locations). SW-11-SS and SW-12-SS are adjacent to the Burial Pit area. Hence, all of these samples are from known contaminated areas where solvents and other radiological contaminants were found. Uranium activities in sediment samples taken directly from Joachim Creek (SW-15, SW-14, SW-08 and SW-16) are comparable to background.

4.3.3.2 Technetium-99 in sediments

Technetium-99 is a man-made isotope that would only be present as a result of human activity (e.g., Hematite Facility operations). Table 4.22 shows that sediment sampling locations SW-01-SS, SW-06-SS, and SW-07-SS (refer to Fig. 2.3 for locations), as with uranium, have measurable ^{99}Tc activities. These samples were collected from the Site Pond. A smaller amount of ^{99}Tc was reported from SW-12-SS, which was collected next to the Burial Pits.

4.3.3.3 Thorium in sediments

Following the same approach used for uranium (Sect. 4.3.3.1), thorium activities in sediment samples were evaluated through a comparison with activities measured in the off-Site samples collected as part of this RI (see Fig. 2.7 for locations), and with background values from PGDP (DOE 1997). The background values developed from off-Site soil samples for ^{228}Th was 1.33 pCi/g, ^{230}Th was 1.30 pCi/g,

and ^{232}Th was 1.32 pCi/g. Development of these background values is discussed in Appendix J. For additional perspective, background values used at PDGP for isotopic thorium were: ^{228}Th = 1.6 pCi/g, ^{230}Th = 1.5 pCi/g, and ^{232}Th = 1.5 pCi/g (DOE 1997).

Thorium was analyzed in sediment samples SW-02-SS through SW-06-SS (refer to Fig. 2.3 for sample locations). Only SW-06-SS shows elevated thorium with respect to the off-Site and PGDP activities, with ^{228}Th and ^{232}Th activities both at approximately 5 pCi/g and ^{230}Th approximately 3 pCi/g. SW-06-SS (collected in the Site Pond, Fig. 2.3) also contained the highest value for uranium (Table 4.21) and ^{99}Tc (Table 4.22) in sediments. Note that ^{230}Th comes from ^{238}U decay chain whereas ^{228}Th and ^{232}Th come from the ^{232}Th decay chain.

4.3.3.4 Transuranics in sediments

^{237}Np, ^{238}Pu, and $^{239/240}$Pu were not detected above their MDLs in the four samples that were selected for transuranics analysis (SW-01, SW-02, SW-07, and SW-13, refer to Fig. 2.3 for sediment sample locations).

4.3.4 Radionuclides in Surface Soils

Surface soils samples were collected from locations around the Hematite Site (see Figs. 2.4a and 2.4b), and were analyzed for radionuclides as described in Sect. 2.2. Major findings and discussions of the results are presented in this subsection, while the complete data set can be found in Appendix H.10. The review process is essentially the same as that for inorganics (Sect. 4.2.4.1). An evaluation of disequilibrium was included for samples with anomalous uranium activities.

4.3.4.1 Uranium in surface soils

A gamma survey (SAIC 2003a) performed in 2003 was used to guide the selection of surface soil sampling locations. The coincidence of gamma survey anomalies and surface soil samples potentially containing elevated uranium, as described below, is shown on Fig. 4.16.

Following the approach used for uranium in sediments (Sect. 4.3.3.1), the uranium activities in surface soils are evaluated relative to the measured activities in the off-Site samples collected from locations shown in Fig. 2.7. The background criteria developed from off-Site surface soil sample results are: 0.97 pCi/g for ^{234}U, 1 pCi/g for ^{238}U, and 0.07 pCi/g for ^{235}U. To provide additional perspective, the measured activities in the surface soils are also compared with the background values used for isotopic uranium at PGDP (DOE 1997): ^{234}U = 2.5 pCi/g, ^{235}U = 0.14 pCi/g, and ^{238}U = 1.2 pCi/g (DOE 1997).

Isotopic uranium activities from alpha spectroscopy analysis show that OA-08 (in the center of the Facility area), EP-11 (near the Evaporation Ponds), and NB-14 (in or near the drainage from the Site Pond) are contaminated, with ^{234}U activities of 472, 103, and 52.3 pCi/g, respectively (other isotopes are shown in Table 4.23). Note that these activities are more than an order of magnitude higher than the background ^{234}U of 2.5-pCi/g activity used at PGDP. Using a ^{235}U activity of 0.14 pCi/g, which is the background activity used in PGDP, other data from alpha spectrometry and gamma spectroscopy show a majority of the samples in Table 4.23 are contaminated with uranium. Almost all the potentially contaminated surface samples were collected from areas that were previously suspected of uranium contamination, including the Burial Pits, the Evaporation Ponds, Deul's Mountain, and process buildings.

4.3.4.2 Technetium-99 in surface soil

Technetium-99 is a man-made isotope that could only be present in significant quantities from Hematite Site operations. Table 4.24 shows the ^{99}Tc detections (MDL ~1 pCi/g) in surface soil samples, while sample locations with detected ^{99}Tc activities are shown on Fig. 4.17. Several samples collected adjacent to buildings are elevated, most notably at BD-12 (574 pCi/g). However, the samples with the highest ^{99}Tc activities were collected near the Evaporation Ponds where sample EP-10 exceeded 17,000 pCi/g and EP-08 exceeded 3,000 pCi/g. ^{99}Tc activities in the composite samples from limestone storage/fill areas ranged were 23 to 94 pCi/g. However, OA-21, adjacent to the limestone storage area, and OA-22, between the limestone storage area and the buildings, both exceeded 600 pCi/g.

4.3.4.3 Thorium in surface soils

Thorium detections in surface soils are presented in Table 4.25. None of the surface soil sample results exceed the background values for the Hematite Site (1.35 pCi/g for ^{228}Th, 1.39 pCi/g for ^{230}Th, and 1.32 pCi/g for ^{232}Th). In addition, none of the results exceed the background values from Paducah [^{228Th} = 1.6 pCi/g, ^{230}Th = 1.5 pCi/g, and ^{232}Th = 1.5 pCi/g (DOE 1997)]. Hence, the use of ^{232}Th at the Hematite Facility has apparently not resulted in impacts above background levels in sediments and soils. As mentioned previously, ^{230}Th comes from ^{238}U decay chain whereas ^{228}Th and ^{232}Th come from the ^{232}Th decay chain.

4.3.4.4 Neptunium-237 in surface soils

Samples collected as part of the off-Site background data set were all reported as not detected except for the following results: BG-06-00-SL at 0.0134LT pCi/g and BG-07-03-SL at 0.00923LT pCi/g (refer to Appendix H10a for off-Site radionuclide data set). The background value for ^{237}Np developed from off-Site surface soil sample results was 0.01 pCi/g.

Several on-Site Hematite samples reportedly contained ^{237}Np, but most of the data were qualified and only two results are distinguishable from the 0.1 pCi/g used at Paducah and both are surface soils from areas already identified as highly contaminated: EP-02 (0.584 pCi/g) and EP-01 (0.44 pCi/g).

4.3.4.5 Americium-241 in surface soils

Americium-241 was reported only as qualified data in a few samples. The only results exceeding 0.01 pCi/g are the surface soil samples shown in Table 4.26. All results in Table 4.26 are qualified as having both a significant density difference from the laboratory control sample (G) and as having an uncertain identification (TI).

Other reasons to question the values in Table 4.26 are the lack of results intermediate between these and background (<0.01 pCi/g, DOE 1980) and the lack (or low-levels) of ^{237}Np, which co-occurs with ^{241}Am. These and the qualifiers suggest these results cannot be considered as confirmed concentrations.

The sample locations in Table 4.26 were reviewed as a further check regarding the value of the data. The Deul's Mountain samples are surface soils collected adjacent to Deul's Mountain. These same Deul's Mountain samples contained elevated ^{99}Tc and uranium. Similarly, the Evaporation Ponds samples also contained elevated ^{99}Tc and uranium. Hence, the uncertainty regarding the ^{241}Am content of these samples is not an issue because there are other important risk drivers that will require further consideration of these locations.

4.3.4.6 Plutonium-238 and plutonium-239/plutonium-240 in surface soils

The background criterion developed from off-Site surface soils results is 0.02 pCi/g for ^{240}Pu. A relevant background value for ^{238}Pu is 0.073 pCi/g and for ^{239}Pu is 0.025 pCi/g (DOE 1997). These values were determined at the Paducah Plant where uranium enrichment was performed and is consistent with the two reported values (both qualified) from the off-Site samples (0.0224 pCi/g LT and 0.0181 pCi/g LT). Only one on-Site ^{238}Pu result is within an order of magnitude of the Paducah values and that is the surface soil at EP-02 (0.0222 pCi/g). The value is qualified LT and the location is already known to be highly contaminated. Several on-Site samples reportedly contained ^{239}Pu near the background values (Table 4.27), but all were qualified LT (LT = result is < than MDC but > than sample-specific MDC). Moreover, irrespective of the qualifiers, none of the surface results are distinguishable from the background value determined at Paducah.

4.3.5 Radionuclides in Subsurface Soils

Subsurface soil samples were collected from locations around the Hematite Site (see Fig. 2.5a and 2.5b), and were analyzed for radionuclides as described in Sect. 2.3. Major findings and discussions of the results are presented in this subsection, while the complete data set can be found in Appendix H.11. The review process is essentially as that for inorganics (Sect. 4.2.4.1). An evaluation of disequilibrium was included for samples with anomalous uranium activities.

Uranium, technetium, thorium, and plutonium data in subsurface soil samples are presented and discussed in Sects. 4.3.5.1, 4.3.5.2, 4.3.5.3, and 4.3.5.4, respectively.

4.3.5.1 Uranium in subsurface soils

Following the approach used for surface soils, the activities measured in the subsurface soils were evaluated relative to the measured activities in the off-Site samples collected from locations shown in Fig. 2.7. The background criteria developed from the off-Site subsurface soil sample results are: 0.92 pCi/g for ^{234}U, 0.99 pCi/g for ^{238}U, and 0.08 for ^{235}U. To provide additional perspective, the measured activities in the surface soils are also compared with the background values used for isotopic uranium at Paducah (DOE 1997): ^{234}U = 2.5 pCi/g, ^{235}U = 0.14 pCi/g, and ^{238}U = 1.2 pCi/g (DOE 1997).

Subsurface soil data (Table 4.28) indicate that shallow samples associated with the process buildings ("BD"- labeled samples) are contaminated. Likewise, SW-02, located in a low-lying area where drainage from the Hematite Facility collects, and DM-02 collected at Deul's Mountain show significant uranium contamination. A few other samples are potentially elevated above background (BD-16, CB-02, EP-16, EP-17, LF-06, NB-71, and PL-04), but are not significantly contaminated. Except for DM-02-22 (sample collected from 22 ft BGS) the elevated results are from the top 5 ft or less. Moreover, these results coincide with the already-identified contaminated areas. Figure 4.18 shows the subsurface sample locations in Table 4.28.

4.3.5.2 Technetium-99 in subsurface soils

Table 4.29 shows that ^{99}Tc activities detected in a number of subsurface soils were generally lower than concentrations found in surface soils (Table 4.24). EP-13-30 (30 ft depth, Evaporation Ponds) contained 131 pCi/g of ^{99}Tc; the rest of the activities were below 30 pCi/g. There are a number of samples containing approximately 10-30 pCi/g and these are all associated with either the Evaporation Ponds or Deul's Mountain. The significantly lower concentrations in the subsurface suggest that although downward migration of ^{99}Tc is occurring, most of the mass is retained in the surface soils. This is

consistent with the distribution coefficient (K_d) measured on samples collected from the Hematite Site (SAIC 2003c) that was relatively high when compared to published literature values.

4.3.5.3 Thorium in subsurface soils

Thorium detections in subsurface soils are presented in Table 4.30. With the exception of SW-02-01 (collected near the Site Pond at 1 ft BGS), and DM-02-22 (collected near Deul's Mountain at 22 ft BGS), none of the results exceed the background values from Paducah [^{228}Th = 1.6 pCi/g, ^{230}Th = 1.5 pCi/g, and ^{232}Th = 1.5 pCi/g (DOE 1997)]. Hence, the use of ^{232}Th at the Hematite Facility has apparently not cuased widespread impact to sediments and soils.

4.3.5.4 Plutonium-238 and plutonium-239/plutonium-240 in subsurface soils

Following the approach used for surface soils (Sect. 4.3.4.6), the isotopic plutonium activities measured in the subsurface soils are compared to the relevant background value for ^{238}Pu, which is 0.073 pCi/g, and for ^{239}Pu, which is 0.025 pCi/g (DOE 1997). These values are consistent with the two reported values (both qualified) from the off-Site background samples (0.0224 pCi/g LT and 0.0181 pCi/g LT for ^{238}Pu and ^{239}Pu, respectively, Appendix H.10a).

Subsurface results (Table 4.31) are all less than the Paducah background sample by approximately an order of magnitude. Hence, it is concluded that neither ^{238}Pu nor ^{239}Pu are relevant contaminants at the Hematite Site.

4.4 ORGANICS

Samples of surface water, sediments, surface and subsurface soils, and groundwater from the Hematite Site were collected and analyzed for a wide variety of organic contaminants. Sampling and analyses methods were presented in Chapter 2, and the complete data set can be found in Appendices H.12 through H.16. A majority of the organic analytes were not detected above the MDL, or were detected but were below the estimated quantitation limits. Table 4.32 is a similar summary for organic analytes that were detected in at least one sample of sediment, surface, or subsurface soil. Table 4.33 presents a summary of the organic analytes that were detected in at least one sample of surface water and groundwater. The organic analytes are grouped into the following categories: base-neutral-acid extractable organics (BNAs), polynuclear aromatic hydrocarbons (PAHs), dioxins, pesticides, PCBs, petroleum, and VOCs. The BNAs and PAHs comprise the SVOCs that were analyzed using EPA SW-846 8270. Note that not all environmental media samples were analyzed for all the organic compounds; justification for the target analytes selected for each environmental media was described in Chapter 2.

Some of the detections represented in Tables 4.32 and 4.33 are likely to be "false positives." A common cause for false positive results is contamination of samples with common laboratory contaminants during collection, handling, shipping, or analysis. Among the VOCs, methylene chloride, acetone, 2-butanone, and cyclohexane are regarded as laboratory contaminants and frequently are detected in both method blanks and samples alike. For this RI, most of these contaminants were detected in many method blanks and are so noted in the data tables by appropriate validation codes. Among the BNA group of analytes, the common phthalates typically are detected in both samples and blanks. EPA recognizes these analytes as common laboratory contaminants and provides a protocol for screening analyses to avoid reporting false positive results (EPA 1999).

This screening process was not applied in this RI because it requires validation of 100% of the samples. However, it is likely that many of the detections of common laboratory contaminants (e.g., methylene chloride and acetone) in samples from the Hematite Site are false positives.

This RI Report does not include a risk assessment; that evaluation is being provided separately. Consequently, no screening of sediments, soils, surface water, and groundwater analyses for human health or ecological risks related to organic constituents is possible at this time. Rather, Tables 4.32 and 4.33 provide summary level information regarding the analyses for organic analytes and is compared to background results where such information is available. However, it is advantageous to provide a comparison of analytical results against reference concentration values to focus attention on the magnitude and distribution of the more elevated concentrations of constituents observed within any class of compounds. The reference concentrations chosen for this comparison have been extracted from the CALM standards (MDNR 2001) and the preliminary remediation goals (PRGs) from EPA Region 9 (EPA 2004). It is recognized that these are risk-based standards for different media based on potential human health risks alone. However, for the analysis provided in this Report they are simply being applied as reference concentrations to streamline the evaluation of contaminant distributions; no connotation of risk should be associated with this evaluation approach. It is anticipated that once the baseline risk assessment has been completed a more focused risk-based screening can be completed.

The "Scenario A" CALM values or the PRG "Residential Soil" values were used for comparison with the RI sediment and soils data. For water, the CALM standards for "Groundwater" and the PRG entries for "Tap Water" were used as reference concentrations to evaluate the RI surface water and groundwater data. All detects represented in the table were compared against the more conservative of the CALM and PRG levels for each analyte.

The entries in Tables 4.32 and 4.33 are color-coded:

- Gray: media that were not collected and analyzed for a specific group of contaminants.
- Green: analyte not detected above the MDL. Non-detects ("U" qualifier) and "B" qualified results are included in this category.
- White: analyte detected in the sample (no qualifier or "J" qualified results).

For each media and class of constituents listed in Tables 4.32 and 4.33 the number of samples represented in the data set is listed. In addition, for those media/analytes with detectable concentrations the number of samples and maximum concentration observed is provided. The maximum concentration values are in parentheses. All samples with any detectable analytes were then compared to the reference concentrations listed in the tables and this subset of samples form the basis for the discussions of nature and distribution of organic constituents at the Hematite Site. These discussions are organized as follows: organics in surface water (Sect. 4.4.1), organics in sediment (Sect. 4.4.2), organics in surface soils (Sect. 4.4.3), organics in subsurface soils (Sect. 4.4.4), and organics in groundwater (Sect. 4.4.5).

In addition, this section includes other topics related to organic contamination at the Hematite Site. Section 4.4.6 presents a comparison of on- and off-Site laboratory analyses, conducted to validate the on-Site analyses, which was used for measuring VOCs from the discrete interval sampling tests (Sect. 2.4, results presented in Chapter 5). Section 4.4.7 presents a comparison of the MIP screening data with co-located laboratory analysis results. Section 4.4.8 provides a summary of previous studies where organic contamination was detected at the Hematite Site, and compares the results of the RI with these previous studies.

4.4.1 Organics in Surface Water

The surface water sampling locations were shown on Fig. 2.2, while sampling and analysis methods were described in Sect. 2.1.2. Surface water was collected both from on-Site and upstream locations. Upstream samples generally are expected to represent background conditions. A complete set of analyses is found in Appendix H.12.

4.4.1.1 BNAs in surface water

There were no detections for BNAs from either on-Site or upstream locations.

4.4.1.2 PAHs in surface water

There were no detections for PAHs from upstream locations and only one detection for on-Site surface water. One sample (SW-01-SW) from Site Pond had a very low-level detect for fluoranthene, a common contaminant associated with byproducts of combustion.

4.4.1.3 Pesticides in surface water

There were no detections for pesticides from either on-Site or upstream locations.

4.4.1.4 PCBs in surface water

There were no detections for PCBs from either on-Site or upstream locations.

4.4.1.5 VOCs in surface water

One water sample from an upstream location had a detectable level of toluene, although it was not detected in any of the on-Site surface water samples. Three on-Site samples had detectable levels of methylene chloride; however the presence of methylene chloride in method blanks associated with these samples suggests these analysis results are from laboratory contamination and do not represent Site conditions. Several on-Site locations had detectable levels of PCE (SW-01, SW-02, and SW-09) and TCE (SW-09 and SW-16). All five of these samples exceeded the reference concentrations listed in Table 4.33. Two of these locations are closely associated with the Hematite Facility (SW-01, SW-09) while the other two samples (SW-02, SW-16) are from Joachim Creek (see Fig. 2.2 for locations)

4.4.2 Organics in Sediments

The sediment sampling locations were shown on Fig. 2.2, while sampling and analysis methods were described in Sect. 2.1.3 of this report. Sediment was collected both from on-Site and upstream locations. Upstream samples generally are expected to represent background conditions and may include anthropogenic effects. A complete set of analyses is found in Appendix H.13.

4.4.2.1 BNAs in sediments

No BNA analytes were detected above their respective quantitation limits in upstream sediment samples. In contrast, three BNAs were detected at some on-Site sediment locations and include several phthalates (possible laboratory contaminants) and carbazole (a byproduct of combustion of coal and petroleum). All of these constituents were detected at concentrations below the respective reference standards listed in Table 4.32.

4.4.2.2 PAHs in sediments

A variety of PAH compounds were detected in both sediment and soil samples collected for this RI. Most of the PAHs are known to be byproducts of combustion of coal and/or petroleum products. Vehicular traffic on Highway P located on the northern side of the Site, diesel locomotives traveling on the rail line that passes through the Site, and fallout of emissions from any nearby fossil fuel power plants are possible sources for surface deposition of PAHs in the vicinity of the Site.

Six different PAHs were detected in a small number of background sediment samples. The on-Site distribution of PAH analytes is widespread with thirteen compounds being detected in up to ten different sediment sampling locations.

Six different PAHs were observed at concentrations exceeding their respective reference values in as many as nine on-Site sampling sites (Table 4.35, Fig. 4.19). Among these sites, SW-12-SS is located in Northeast Site Creek and all of the remaining samples exceeding reference concentrations came from Site Pond, and Site Creek. No upstream sediment samples exceeded the reference concentrations. The frequent detection of PAHs above the reference values at on-Site locations suggests a localized source(s) that probably was associated with discharges into Site Pond/Site Creek.

4.4.2.3 Pesticides in sediments

One on-Site sediment sample from Site Pond (SW-01-SS) had a low-level detection for the pesticide endrin, but it did not exceed the reference concentration. No other pesticides were detected in any other on-Site or background sediment locations.

4.4.2.4 PCBs in sediments

Two on-Site sediment samples had detectable quantities of PCB-1260, but neither exceeded the reference values for that compound. Both samples (SW-01-SS and SW-07-SS) are from Site Pond. No background samples had detections for PCBs.

4.4.2.5 VOCs in sediments

Acetone (a common laboratory contaminant) and toluene were each detected in one upstream sediment sample. No other VOCs were observed in the background locations. In contrast, eight different VOCs were detected in on-Site sediment samples with acetone being the most frequently observed. Most of the detectable analytes were chlorinated compounds (PCE, TCE, *cis*-1,2-dichloroethylene (DCE), *trans*-1,2-DCE, and vinyl chloride) that are found in subsurface soils and groundwater at the Hematite Site (see Sects. 4.4.4 and 4.4.5). It is reasonable to infer that discharges to on-Site streams from runoff, wastewater outfalls, and groundwater may deliver these VOCs to surface water where subsequently they can become adsorbed onto organic materials associated with the sediments. None of the detected VOC constituents exceeded their respective reference concentrations in any sediment samples.

4.4.3 Organics in Surface Soils

Surface soil samples from the Hematite Site and several off-Site locations were collected and analyzed as part of the RI. Sampling and analysis methods for surface soil samples were described in Chapter 2 of this report. Off-Site locations are shown on Fig. 2.7, whereas on-Site locations are illustrated on Figs. 2.5a and 2.5b. Sect. 3.2.3 describes the soil types associated with the Site (USDA 2003).

The soil survey for Jefferson County indicates that off-Site soil samples collected from the location to the east of the Hematite Site (south of the National Guard armory – Fig. 2.7) are linked to the occurrence of the Kaintuck, Horsecreek, and, possibly, the Wilbur soil series. These soils are well-drained, coarse- to silty-alluvium associated with terrace and flood plain deposits. Although Wilbur soils are not found within the Hematite Site, they are closely similar to the Kaintuck, Horsecreek and other terrace flood plain soils mapped on the Hematite Site.

Off-Site surface soil samples also were collected approximately 3 miles southwest of the Hematite Site adjacent to Highway P (Fig. 2.7). Soils in this area belong to the Useful and Freeburg soil series, both of which are found on the Hematite Site.

From this brief assessment, it is apparent that surface soil samples from both background locations are from a group of soil series also found on the Hematite Site or, in the case of Wilbur soils, closely related to soils found on-site. Therefore, analytical results for contaminants in background soils should provide a valid basis for comparison with similar data obtained from Site soils.

On-Site samples were analyzed for the full suite of analytes whereas VOCs were the only organics for which background samples were analyzed. A complete set of analyses is found in Appendix H.14; analysis results for the off-Site samples are provided in Appendix H.14a.

Surface soil samples from background locations were not analyzed for BNAs, PAHs, pesticides, and petroleum analytes. Consequently, no comparison with results from on-Site surface soil samples is possible for these constituents.

4.4.3.1 BNAs in surface soils

A range of BNA compounds were detected in on-Site surface soil samples. Four phthalates (regarded as common laboratory contaminants) constitute the most frequently detected analytes. In addition, carbazole (a common product of combustion) was detected in about 17% of the samples. With the exception of di-n-octyl-phthalate in one surface soil sample (DM-02-00, near Duel's Mountain: refer to Fig. 2.5b for location), none of the detected BNAs exceeded their respective reference concentrations.

4.4.3.2 Dioxins in surface soils

The process used to compare the measured concentrations of dioxins in samples to a reference concentration follows guidance in EPA (1989). Toxicity Equivalence Factors (TEF) for each dioxin cogener are multiplied by the observed concentrations for the respective cogeners and the results are then summed to produce a Toxicity Equivalent Concentration (TEQ) for the sample. The sample TEQs are compared to the PRG reference values for 2,3,7,8-TCDD for the appropriate media (soil or tap water) to determine any exceedances.

The dioxins 1,2,3,4,6,7,8-HPCDD; 2,3,7,8-TCDF; OCDD; and OCDF were detected at one on-Site location (one sample and one field duplicate) where samples were collected for this analysis (Table 4.36). Location CB-01 is at the Cistern Burn Pit AOC and past activities at this location may account for the presence of low levels of dioxins in surface soil. Dioxin levels (TEQs) in both the sample and duplicate exceed the reference concentration for soil.

4.4.3.3 PAHs in surface soils

Thirteen different PAH compounds were detected in on-Site surface soil samples and some of them (e.g., various anthracenes, pyrenes, fluoranthenes, and chrysene) were found in nearly 80% of samples analyzed.

In comparison to their respective reference concentrations, 41 on-Site samples had exceedances for benzo(*a*)pyrene. Four other PAHs also exceeded their reference concentrations in at least one of these samples (Table 4.37). Samples with PAH contamination above reference level concentrations are illustrated on Figs 4.20a and 4.20b. Most of these locations surround the Hematite Facility and include most AOCs in the immediate vicinity of the buildings. Burning of gasoline (automobiles), diesel fuel (trucks, train locomotives, generators, and residential/commercial heating), wood (home heating and controlled forest burns), and coal (power plants) all produce copious quantities of PAHs that can occur as fallout. Runoff from asphalt pavement (e.g., roads, parking lots) can also be a significant source of PAHs. The location of the Hematite Facility next to a state highway and railroad may point to these sites as likely sources of PAHs, although other local sources may be important as well. Surface soils and stream sediments are most susceptible to contamination because most PAHs have limited solubility.

4.4.3.4 Pesticides in surface soils

All but one of the pesticides listed in Table 4.32 was detected in at least one on-Site surface soil sample. DDT, endrin, and endosulfan II were most frequently observed. It is likely that periodic use of pesticides on or near the Hematite Facility can account for small residues being found in surface soil samples. In addition, prior to construction of the Hematite Facility, the land was farmed. It is possible that some pesticide residues date to that period of time. None of the pesticides were detected at a concentration above the corresponding reference concentration.

4.4.3.5 PCBs in surface soils

No surface soil samples from background locations had detectable quantities of PCBs. However, both PCB-1254 and PCB-1260 were detected in 12% and 22% of the samples collected, respectively. Five surface soil samples (and one field duplicate) had a detection of PCB-1260 above the reference level (Table 4.38). In addition, one of these samples also had PCB-1254 above its reference level. All of these locations surround the Hematite Facility and are associated with recognized AOCs (refer to Figs. 2.4a and 2.4b for sample locations):

- Burial Pit – BP-07,
- Evaporation Ponds – EP-04,
- Limestone Fill Areas – LF-01,
- Outer Area – OA-08 (near the Burial Pit), and
- Red Room Roof Burial Area – RR-01.

4.4.3.6 Petroleum in surface soils

Three of the six samples (collected from the former gas station north-northeast of the Hematite Facility on Highway P, Fig. 2.4a) tested for petroleum had no detectable amounts of either diesel fuel or gasoline. However, gasoline was detected in one sample, but only with an approximate concentration (J qualified). Three samples showed diesel contamination, although those compounds detected were in the heavier end of the retention time window and their pattern did not resemble those expected for common diesel fuel products and may be the result of weathering of the lighter components

through aging (Table 4.39). No samples exhibited petroleum concentrations in excess of a reference level for TPH (200 mg/kg).

4.4.3.7 VOCs in surface soils

The only VOC compounds detected in surface soil samples from background locations were methylene chloride (a common laboratory contaminant) and toluene. Both analytes were frequently observed in these samples. For on-Site surface soil samples, acetone and methylene chloride (both common laboratory contaminants), toluene, PCE, and TCE were detected. Both PCE and TCE probably are related to activities at the Hematite Site. None of the on-Site samples with detectable VOCs exceeded their respective reference concentrations.

4.4.4 Organics in Subsurface Soils

The subsurface soil sampling locations are shown on Figs. 2.5a and 2.5b. All locations are on the Hematite Site and all samples were analyzed for the complete suite of contaminant groups. A complete set of analyses is found in Appendix H.15.

4.4.4.1 BNAs in subsurface soils

Seven different BNA compounds were detected in on-Site subsurface soil samples. The great majority of these detections were for bis(2-ethylhexyl) phthalate and other phthalate analytes. However, phthalates often are associated with laboratory contamination and there presence in the soils may not be significant. None of the BNA constituents detected in these soils exceeded their respective reference concentrations.

4.4.4.2 Dioxins in subsurface soils

Two dioxin compounds, 1,2,3,4,7,8-HxCDD and 1,2,3,6,7,8-HxCDD, were detected in three subsurface soil samples (including one sample and its field duplicate) collected for dioxin analysis (limited to the Cistern Burn Pit Area) (Table 4.40). The samples came from three different depths within boring CB-02, which is located near the Cistern Burn Pit AOC and the detections were observed in samples taken from depths of 5 ft and 15 ft. The TEQs for these samples (and the duplicate) do not exceed the reference concentration for dioxins. Refer to Sect. 4.4.3.2 for a discussion of how the TEQ is determined.

4.4.4.3 PAHs in subsurface soils

Similarities exist between on-Site surface and subsurface soils in regard to the spectrum of PAH compounds detected. For both groups of samples benzo(*a*)anthracene, benzo(*a*)pyrene, benzo(*b*)fluoranthene, and chrysene were most frequently detected, although a range of other PAHs also were observed. A major distinction between surface and subsurface soils is that PAHs were detected in only a small percentage (<10%) of the subsurface samples. The low solubility of PAHs in water probably accounts for their limited subsurface distribution. The likely sources of the PAHs are discussed in Sect. 4.4.3.3.

Ten subsurface soil samples (including one field duplicate) from eight locations (Fig. 4.19; Table 4.41) had detects for at least one PAH [benzo(*a*)pyrene] at concentrations above their respective reference levels. These sample locations are closely associated with the Hematite Facility and include the Limestone Fill and Burial Pit AOCs.

4.4.4.4 Pesticides in subsurface soils

Rare detects of six different pesticides were observed in subsurface soil samples and the sample locations appear to be randomly distributed. No pesticides were detected at concentrations that exceed the reference values.

4.4.4.5 PCBs in subsurface soils

There were no PCB analytes detected above the risk-based screening levels for any subsurface soil samples. However, there were detects for PCB-1254 in one sample and PCB-1260 in two other samples from the Hematite Site. These soil samples are associated with Building 253, the Leach Field, and the Evaporation Ponds.

4.4.4.6 Petroleum in subsurface soils

There were no detects of diesel fuel or gasoline in any subsurface soil samples that were analyzed.

4.4.4.7 VOCs in subsurface soils

A large number of VOC analytes were detected in subsurface soil samples at the Hematite Site. Among these were frequent occurrences of acetone, 2-butanone, and methylene chloride (common laboratory contaminants). However, a wide range of other VOCs were detected, including PCE, TCE, and their common degradation products. Twenty-five to 30% of the samples yielded detectable quantities of PCE and TCE.

Only four VOCs (methylene chloride, PCE, TCE, and 1,1-DCE) had concentrations that exceeded their respective reference levels (Table 4.42). PCE and TCE were detected above their reference concentration levels in 14 and 17 samples, respectively, whereas the other two analytes exceeded their reference levels in only a single sample (including a field duplicate). Locations of subsurface soil samples that exceed reference levels for PCE and TCE are illustrated on Fig. 4.21.

4.4.5 Organics in Groundwater

Groundwater samples were collected from on-Site wells and their locations are shown on Figs. 2.6a and 2.6b, while sample collection and analysis methods are presented in Sect. 2.6. A complete set of analyses is found in Appendix H.16.

4.4.5.1 BNAs in groundwater

Three BNA analytes were detected in groundwater from the Hematite Site, including a phthalate, hexachloroethane, and phenol. Only two analytes (the phthalate and hexachloroethane) exceed their respective reference concentrations (Table 4.43). Bis(2-ethylhexyl)phthalate was observed at four locations and hexachloroethane was found in a single groundwater sample (BD-02) above their reference concentration levels. The phthalates are considered to be common laboratory contaminants and this may be the source of this compound in these samples. All of the locations are in close proximity to the Hematite Facility, so that a local source cannot be ruled out. AOCs encompassing these locations are: under the buildings, the Limestone Fill Areas, the Evaporation Ponds, and the Red Room Roof Burial Area (see Fig. 1.4 for AOCs and Figs. 2.6a and 2.6b for well locations). Note that all these wells are screened in the overburden.

4.4.5.2 Dioxins in groundwater

Dioxins were analyzed in only one groundwater sample (CB-02, from the Cistern Burn Pit) and only 2,3,4,6,7,8-HxCDF was detected. The TEQ for this sample did not exceed the reference concentration for dioxins.

4.4.5.3 PAHs in groundwater

There were no detections of PAHs in any groundwater samples that were analyzed.

4.4.5.4 Pesticides in groundwater

There were no detections of pesticides in any groundwater samples that were analyzed.

4.4.5.5 PCBs in groundwater

There were no detections of PCBs in any groundwater samples that were analyzed.

4.4.5.6 VOCs in groundwater

Twenty VOC analytes were detected in groundwater samples from the Hematite Site. The contaminants fall into two groups. First, there are three constituents that are recognized as common laboratory contaminants:

- Acetone
- Methylene chloride
- 2-butanone

In addition, benzene, toluene, and xylenes were detected in some samples. These three compounds are constituents of fuels (e.g., gasoline) and that may be their source. Low levels of carbon disulfide were detected in four samples.

The second group includes only chlorinated compounds:

- Chloroethane;
- Chloroform;
- Chloromethane;
- 1,1-Dichloroethane;
- 1,2-Dichloroethane;
- 1,1-Dichloroethene;
- *cis*-1,2-DCE;
- *trans*-1,2-DCE;
- PCE;
- 1,1,1-Trichloroethane;
- 1,1,2-trichloroethane;
- TCE; and
- Vinyl chloride.

A total of 80 (including 6 field duplicates) samples contained 1 or more constituents that exceeded reference concentration levels (Table 4.44). The location of these samples is presented and discussed in

Chapter 5, and is associated with a detailed discussion of the principal contaminants and their F&T. With the exception of 2 samples in which methylene chloride is the sole VOC contaminant, the remaining 78 (including 6 field duplicates) samples each contain at least PCE or TCE, and usually both. This is a significant finding because it draws attention to the fact that PCE and TCE are the key chlorinated organic contaminants found in groundwater at the Hematite Site. The most common occurrences of chlorinated VOCs above reference concentrations among the groundwater samples are:

- PCE;
- TCE;
- 1,1-DCE;
- *cis*-1,2-DCE;
- *trans*-1,2-DCE; and
- Vinyl chloride.

The discussion in Chapter 5 provides information suggesting that these six contaminants may have a common origin, with PCE and TCE as parent contaminants widely used at the Hematite Facility, and the other constituents as potential degradation products of them as a result of microbial reductive dechlorination reactions.

Most of the remaining contaminants were detected in only a few samples. Their specific origin or source is more difficult to define because they are not cited as having been used or stored at the Hematite Facility (Table 1.3). More importantly, however, is the fact that their occurrence always coincides with the locations where the primary contaminants in groundwater (i.e., PCE, TCE, etc.) also are found. This coincidence permits the discussion to focus only on these primary contaminants, with the knowledge that these lesser constituents will be addressed simultaneously with them.

4.4.6 Comparison of Volatile Organic Compounds in Groundwater as Determined by Mobile and Off-Site Laboratories

During the summer of 2004, groundwater samples from six wells were analyzed by both an on-Site mobile laboratory and a fixed laboratory located remotely. Confirmation of the on-Site analyses with laboratory analysis was needed to validate on-Site mobile analyses of samples obtained during discrete interval sampling in the bedrock boreholes and domestic wells. The results of the discrete interval sampling are presented and discussed in Chapter 5.

Seven chlorinated VOC analytes were included in the comparison between the on-Site and fixed laboratory, and the results are provided in Table 4.45. In general, the results are comparable: 75% of the concentrations for specific constituents for sample splits from the same well agree within 15% of one another. The poorest agreement was for 1,1-DCE. The samples collected from PW-19 (207-227 ft BGS) account for most of the disagreement in results. The mobile laboratory tended to report lower concentrations than the off-Site laboratory for most analytes where disagreement was observed.

4.4.7 Comparison of MIP Results with Soil and Groundwater Sample Analyses

One of the more important tasks associated with this RI was developing an efficient method for selecting locations for collecting subsurface soil samples and for construction of monitoring wells from which groundwater samples could be obtained. One approach is to collect and analyze subsurface soil samples and to base future decisions on the results. However, the time between sample collection and receipt of analyses can be lengthy. As a result of this concern, a rapid field-based method that uses a MIP was used to facilitate selection of monitoring well locations.

As noted in Sect. 2.3.1, subsurface soil core material was collected by advancing split-spoon samples with a DPT probe. The core was scanned with a hand-held PID and selections were made of several 2-ft intervals of soil core for each location. These samples were sent to an off-Site laboratory for analysis. The results of these analyses are discussed in Sect. 4.4.4 and the results are tabulated in Appendix H.15.

In addition, at nearly all locations where soil and groundwater samples were collected, the Geoprobe™ was used to advance the MIP and to obtain screening-level data for selecting sampling sites and depths. The MIP consists of a membrane inserted in the wall of a tool that is attached to the Geoprobe™. When the membrane is heated electrically, it becomes permeable to volatile compounds in the soil and groundwater next to the probe. The heat helps mobilize the volatiles, which pass through the membrane and are conveyed to three different detectors, as listed below:

- PID,
- FID, and
- ECD.

These detectors respond to somewhat different compounds: the PID and ECD are more sensitive to chlorinated VOCs than the FID.

A complete set of results from the MIP is provided in Appendix B. Figures 4.22, 4.23, and 4.24 are examples of the response of these three detectors as a function of depth at three different sites:

- BD-02: soil highly contaminated with PCE (Fig. 4.22),
- OA-18: soil significantly contaminated with TCE (Fig. 4.23), and
- NB-50: soil with no detectable PCE or TCE (Fig. 4.24).

The detector responses are plotted with the same scale for each sample to simplify a comparison among them. These figures also contain the results of soil and groundwater analyses (where available) performed by the off-Site laboratory that are shown at the proper depth interval from which they were obtained.

Note that the ECD appears to respond best to the regions of known PCE and TCE contamination. The PID has a lesser response and the FID only shows a response in BD-02 (it is unclear if it is detecting PCE or another co-located VOC). Very little response was observed for any detector at NB-50, a result consistent with the absence of contamination. These detectors are not specific for any particular VOC, but the ECD appears to have the most reliable response to regions in the borehole that are known to be contaminated with PCE and TCE.

The results of the comparison of the MIP analysis with those from conventional soil analyses suggest that it is a useful tool for real-time screening of locations for contamination. The combination of detectors permits qualitative assessment of the presence of both chlorinated and non-chlorinated organics.

4.4.8 Organic Contamination Identified in Previous Investigations at the Hematite Site

Three prior investigations provide analyses for sediment, subsurface soil, surface water, and groundwater for selected locations at the Hematite Site (LBG 1999, 2002b). These studies only give results for VOC analytes. Table 4.46 is a summary of the types of media, sample locations, and those samples for which at least one VOC contaminant was detected. Wells were installed as part of these studies, and well locations of the pre-RI wells can be found on Figs. 1.2 and 1.3, but are also included on Figs. 2.6a and 2.6b.

Surface water was collected from four locations:

- Northeast Site Creek 15 ft above the confluence with Joachim Creek (SW-1),
- Lake Virginia/Site Creek Combined Tributary 150 ft south of the railroad bed (SW-3),
- within the banks of Joachim Creek midway between SW-1 and SW-3 (SW-2), and
- beneath the bridge over Joachim Creek in the town of Hematite (SW-4).

Sediment locations SS-1 and SS-2 correspond to surface water locations SW-1 and SW-2, respectively.

In general, the contaminants found in all media from these different investigations are limited to a few, key chlorinated compounds and include the following:

- TCE;
- PCE;
- *cis*-1,2-DCE (and total 1,2-DCE);
- Vinyl chloride; and
- 1,1-dichloroethane.

Most of the soil and groundwater samples included in the LBG (1999) investigations come from locations surrounding the Burial Pit, although several are distributed along the south side of the Hematite Facility. In addition, the LBG (2002b) study primarily focused on locations BR-1, BR-2, BR-3, and BR-4, which are more widely distributed across the site.

Results from the LBG (1999) report cannot be directly correlated with data from this RI, as groundwater from these wells and locations was not analyzed. In addition, wells WS-24 and WS-28 and soils from locations WS-27, WS-29, and WS-32 (LBG 1999) were not sampled during the study.

In general, the results for VOC analyses from these earlier investigations are consistent with contaminant data obtained during the RI. Not only is the areal distribution of contamination similar, but also the specific zone exhibiting contamination in BR-4 (95 to 105 ft BGS) reported by LBG (2002b, Table 5) agrees with results from the current study. Although the concentration of specific contaminants varies somewhat for samples from the same location among the different investigations, there is agreement in the general level of contamination. The major exceptions to this observation are for groundwater samples from WS-29, WS-30, and WS-31 where concentrations for the key VOC contaminants observed during the RI are significantly higher than reported by LBG (1999). Much lower concentrations of the VOCs were observed in groundwater from WS-32 during the RI than reported by LBG (1999). These observations suggest that the details of contaminant migration in groundwater in the vicinity of the Burial Pit may have changed over the past few years.

Detection of contaminants in surface water by LBG (1999) was confined to a very low concentration of PCE at a single location in Joachim Creek (SW-3). No contamination was detected in the upgradient sample, SW-4. During the RI, several low concentration detections of PCE; TCE; and *cis*-1,2-DCE were observed in the Lake Virginia/Site Creek Combined Tributary and Joachim Creek. Sampling of discharges from the wastewater treatment facility to Outfall No. 1 (located immediately downstream of the dam at Site Pond), as part of the NPDES program in 2004, yielded detectable amounts of both PCE and *cis*-1,2-DCE. This may account for some of the contamination observed in surface water samples analyzed as part of the RI.

4.5 SUMMARY OF FINDINGS IN AREAS OF CONCERN

The site-wide distributions of RCOPCs and CCOPCs based on the RI analytical data were presented in the previous subsections, with each subsection devoted to a major class of constituents (e.g., inorganics, radionuclides and organics). In this subsection, the analytical findings for the previously identified constituents of potential concern at each of the AOCs are summarized. As expected, elevated constituent concentrations or activities were present in various locations within the Site, however, the data also shows that some or all of the RCOPCs and/or CCOPCs were either not detected or were present at relatively low levels at a number of the AOCs. Note that a quantitative assessment of risk is being conducted and will be presented in a separate report.

4.5.1 AOC #1 Groundwater

The constituents of potential concern in AOC #1 Groundwater are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium isotopes (^{238}U, ^{235}U, ^{234}U) and ^{99}Tc.

Chlorinated solvents. As mentioned previously (Sect. 4.4.5.6), VOC analyses of groundwater samples indicate that PCE and TCE are the key chlorinated organic contaminants found in groundwater at the Hematite Site (data in Table 4.44 and Appendix H.16f). These two constituents together with their degradation by-products (1,1-DCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and vinyl chloride) are the most commonly occurring VOCs in the Site groundwater. A detailed discussion of PCE and TCE distribution in groundwater is presented in Chapter 5, where plumes in the overburden and bedrock hydrogeologic units are delineated based on the groundwater data. A conceptual model for PCE and TCE transport from the Facility is also presented in Chapter 5.

Fluoride. Subsurface soil samples, collected several months before the groundwater samples, were analyzed for fluoride, which was initially considered as a groundwater CCOPC (see Sect. 1.6). However, fluoride levels in the subsurface soil samples were mostly below or slightly above the reporting limit of ~7 mg/kg with the exception of a few samples from the Evaporation Ponds and under the buildings (Sect. 4.2.5.2). Thus, groundwater samples were not analyzed for fluoride.

Uranium. The RI groundwater data, presented and discussed in Sect. 4.3.2.1 and Table 4.18, suggest that uranium has not migrated to the same extent as the chlorinated VOCs, and the elevated activities are present in the overburden groundwater in localized areas within the Facility. These areas include: Deul's Mountain, the Burial Pits Area, the Evaporation Ponds and under the process buildings. The groundwater data from the bedrock wells do not indicate uranium contamination in the bedrock formations underlying the Hematite Site.

Technetium-99. ^{99}Tc activity was only detected in the overburden groundwater in localized areas in the Facility (Sect. 4.3.2.4 and Table 4.20), and similar to uranium, ^{99}Tc has not migrated in the groundwater to the same extent as the chlorinated solvents.

4.5.2 AOC #2 Surface Water Features

The constituents of potential concern in surface water features within the Hematite Site are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium (^{238}U, ^{235}U, ^{234}U), ^{99}Tc, and ^{232}Th. The surface water features included in this AOC are: the Site Pond and Creek, the Northeast Site Creek, and Joachim Creek. The following is a summary of findings for each of the surface water features that comprise AOC #2.

4.5.2.1 Site Pond and Site Creek.

The Site samples collected from the Site Pond and Creek are: surface water samples SW-01-SW and SW-02-SW, and sediment samples SW-01-SS through SW-07-SS (refer to Figs. 2.2 and 2.3 for sample locations).

Chlorinated solvents. Low levels of PCE and TCE were detected in the Site Pond and Site Creek surface water and sediments (Sects. 4.4.1.5 and 4.4.2.5; Table 4.34, and Appendix H.13e). These data indicate that the elevated levels of chlorinated VOCs in the subsurface soil underneath the Facility (refer to Table 4.42) have had minimal impacts on the Site Pond and Site Creek.

Uranium. Surface water and sediment data from the Site Pond (Sects. 4.3.1 and 4.3.3.1; Tables 4.17 and 4.21) indicate elevated uranium activity relative to upstream values. A limited amount of discharge into the Site Pond from the outfalls is allowed by the NPDES permit (refer to Figure 1.2 for outfall locations). The highest uranium activities in the surface water samples (Table 4.17) were measured in a sample from the Site Pond; this sample also contained a high aluminum concentration (likely from clay particles) suggesting that the uranium in the surface water may be sorbed onto suspended particulates. Uranium activities both in surface water and sediment decrease in the Site Creek downstream of the Site Pond dam.

Technetium-99. ^{99}Tc was not detected in any of the surface water samples from the Site (Sect. 4.3.1). ^{99}Tc was detected in the sediment samples from the Site Pond, but activities decreased significantly in the Site Creek sediments (Sect. 4.3.3.2, Table 4.22).

Thorium. ^{232}Th was not detected in any of the surface water or sediment samples from the Site Pond and Site Creek (it was not detected in any of the surface water and sediment samples from the Site, Table H.7 and H.9).

Fluoride. Fluoride was not detected in any of the surface water samples from the Site Pond and Site Creek (Appendix H.2). It was detected in the sediment samples from the Site Pond (maximum of 28 mg/kg) but was not present in any of the sediment samples from the Site Creek (Appendix H.4).

4.5.2.2 Northeast Site Creek

The Site samples collected from the Northeast Site Creek are surface water sample SW-09-SW and sediment samples SW-10-SS through SW-13-SS (refer to Figs. 2.2 and 2.3 for sample locations).

Chlorinated solvents. PCE and TCE were detected at very low levels (i.e., below report limits of 5 μg/L) in the surface water and sediment samples from the Northeast Site Creek (Table H.12e and H.13e for data). These data suggest that any chlorinated solvents historically disposed of in the Burial Pits (Sect. 1.4) and elevated levels of chlorinated VOCs in subsurface soil underneath the Facility (Table 4.42) have had minimal impact on the Northeast Site Creek.

Uranium. Uranium activities in the surface water and sediment samples from the Northeast Site Creek are slightly elevated relative to the upstream samples (Appendix H.7 and H.9 for data). The data suggests that uranium known to be present in the Burial Pits based on disposal records (Sect. 1.4) has had a minimal impact on the Northeast Site Creek that runs adjacent to the Burial Pits area.

Technitium-99. ^{99}Tc and thorium were not detected in any of the surface water or sediment samples from the Northeast Site Creek (Appendix H.7 and H.9 for data).

Fluoride. Fluoride was detected at a very low level (i.e., 0.67 mg/L slightly above the reporting limit of 0.5 mg/L) in the surface water sample from the Northeast Site Creek. Fluoride was also detected in some of the sediment samples from the Northeast Site Creek (maximum concentration of 10 mg/kg).

4.5.2.3 Joachim Creek

The Site samples collected from Joachim Creek are surface water samples SW-15-SW, SW-14-SW, SW-08-SW and SW-16-SW, and sediment samples SW-15-SS, SW-14-SS, SW-08-SS and SW-16-SS (refer to Figs. 2.2 and 2.3 for sample locations).

Chlorinated solvents. TCE and *cis*-1,2-DCE were detected in one surface water sample from Joachim Creek at a level below the reporting limit of 5 μg/L (data shown in Appendix H.12e).

Uranium and Technetium-99. Uranium activities in surface water and sediment samples from Joachim Creek are comparable to upstream values; ^{99}Tc was not detected in any of the samples (data shown in Appendix H.7 and H.9). These data suggest that uranium and ^{99}Tc known to be present in the Facility have not impacted Joachim Creek.

Fluoride. Fluoride in the surface water and sediment samples from Joachim Creek are comparable to upstream values (data shown in Table H.2 and H.4).

4.5.3 AOC #3 Burial Pits

The constituents of potential concern for soil and groundwater at AOC #3 Burial Pits are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium (^{238}U, ^{235}U, ^{234}U), ^{99}Tc, and ^{232}Th.

Chlorinated solvents. Maximum concentrations of PCE and TCE in soil samples collected from the boreholes within and around the periphery of the Burial Pits area are 170 μg/kg and 45 μg/kg, respectively. However, almost all groundwater samples collected from wells within the Burial Pit Area had detectable concentrations of TCE, PCE and their degradation products (Table 4.44). The Burial Pits area is identified as one of the zones of highest groundwater concentrations of PCE and TCE, and is a potential source zone for groundwater plumes in the overburden and bedrock (see Sect. 5.3).

Uranium, Technitium, and Thorium. The RI groundwater data confirmed the presence of uranium and ^{99}Tc in overburden groundwater directly beneath the Burial Pits (e.g., refer to data for WS-24 and WS-26 in Table 4.18 and 4.20). ^{232}Th was also detected in the groundwater samples from the Burial Pits (Table 4.19).

Fluoride. Fluoride was detected above the reporting limit of ~7 mg/kg in almost all the surface soil samples from and adjacent to the Burial Pits area (BP-labeled samples in Table H.5). The highest fluoride level in the surface soil samples from the Burial Pits (62 mg/kg) is well below the geometric mean of regional values reported by Tidball (1984). A majority of the fluoride results for the subsurface soil sample from this AOC are below the reporting limit (BP-labeled samples in Table H.6). The highest fluoride level in the subsurface soils from this AOC is 18 mg/kg.

4.5.4 AOC #4 Evaporation Ponds

The constituents of potential concern at AOC #4 Evaporation Ponds are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium (^{238}U, ^{235}U, ^{234}U), ^{99}Tc, and ^{232}Th.

Chlorinated Solvents. Similar to the Burial Pits, some of the highest concentrations of PCE and TCE in subsurface soil and groundwater at the Hematite Site were detected in the Evaporation Ponds area (Table 4.42 and 4.44, EP-labeled samples). This area is a potential source zone for PCE and TCE plumes in Site groundwater (discussed in Chapter 5).

Uranium. A number of surface and subsurface soil samples collected from the Evaporation Ponds are potentially contaminated with uranium (Table 4.23 and 4.28, discussion in Sects. 4.3.4.1 and 4.3.5.1). On the other hand, the overburden monitoring wells in the immediate vicinity of the Evaporation Ponds all have low U activities (data shown in Table H.8, EP-labeled samples). The highest ^{234}U activity in the EP wells was 0.108 pCi/L. These data suggest that uranium present in the Evaporation Ponds is not migrating via groundwater away from this area.

Technetium. Several surface soil samples from the Evaporation Ponds had detectable levels of ^{99}Tc (Table 4.24). The highest ^{99}Tc surface soil activity at the Site was measured in a sample from Evaporation Ponds (EP-10-00-SL: 17,100 pCi/g). ^{99}Tc was also detected in the overburden monitoring wells in the immediate vicinity of the Evaporation Ponds. One of the highest ^{99}Tc activities at the Site was measured in monitoring well EP-20 (2080 pCi/L, see Table 4.20 for other ^{99}Tc groundwater activity data). As mentioned previously, elevated ^{99}Tc is present in the overburden groundwater but appears to be localized, and migration away from these localized areas did not occur to the same extent as for PCE and TCE.

Thorium. ^{232}Th was detected in surface soil, subsurface soil and groundwater samples from the immediate vicinity of the Evaporation Ponds (Tables 4.19, 4.25, and 4.30). ^{232}Th in the monitoring well EP-15 was measured at 0.007 pCi/L (Table 4.19).

Fluoride. Some of the highest fluoride levels in the surface and subsurface soil samples at the Site were measured in samples from the Evaporation Ponds area. However, as noted in Sects. 4.2.4.3 and 4.2.5.2, the highest fluoride level in these samples is still below the geometric mean of regional values reported by Tidball (1984).

Metals. Although metals were not included in the list of CCOPCs for the Evaporation Pond area, a number of metals (e.g., arsenic and mercury) were detected at elevated levels relative to Site and regional background values in surface soil samples from the the Evaporation Ponds area (Table 4.13 and Fig. 4.11). Only arsenic was detected above the range of local and regional background values in the subsurface soils (Table 4.15, Table 4.16, Fig. 4.12). Arsenic was not detected in any of the monitoring wells near the Evaporation Ponds (Appendix H.3).

4.5.5 AOC #5 Former Leach Field/Sanitary Sewer System

The potential constituents of concern at AOC #5 are: chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium (^{238}U, ^{235}U, ^{234}U), ^{99}Tc, and ^{232}Th.

Chlorinated Solvents. PCE and TCE were detected in the subsurface soil samples from the Leach Field (maximum values are 80 and 19 μg/kg for PCE and TCE, respectively; Appendix H.15g). The concentrations of PCE and TCE in the LF-monitoring wells are in the upper range of values measured at the Site (e.g., PCE at LF-09 is 14,000 μg/L). The relatively low soil concentration, and high groundwater concentration in the LF-samples suggest that the chlorinated VOCs in the groundwater in the Leach Field area may be a result of migration from upgradient areas (e.g., the process buildings), and not from contaminated subsurface soils in the Leach Field area.

Uranium. None of the surface soils from the Leach Field (labeled "LF") contained ^{235}U above the MDL (~0.5 pCi/g) (data shown in Appendix H.10). Elevated uranium activities were detected in only one

subsurface soil sample (LF-06-05-SL, Table 4.28, data in Appendix H.11); ^{235}U activity was not detected in any of the other subsurface samples from this AOC. Uranium activities in the Leach Field wells were low (i.e., less than 2 pCi/L; data in Appendix H.8).

Technetium and Thorium. ^{99}Tc was detected in one of the Leach Field groundwater wells (LF-08, 246 pCi/L) although none of the surface or subsurface soil samples from the Leach field area had detectable activities of ^{99}Tc. The absence of ^{99}Tc in the subsurface and surface soils and the elevated activity in one of the LF field samples suggests that ^{99}Tc in the Leach Field may be a result of contaminant migration upstream of the Leach Field area (e.g., process buildings). ^{232}Th was 0.097 pCi/L in LF-08.

4.5.6 AOC #6 Soil Beneath Buildings

The potential constituents of concern for AOC #6 Soil Beneath Buildings are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium (^{238}U, ^{235}U, ^{234}U), ^{99}Tc abd ^{232}Th.

Chlorinated solvents. The presence of dense, nonaqueous-phase liquids (DNAPLs) under at least one of the process buildings is indicated by the PCE concentration in a soil sample collected from under Bldg. 253 (6.6×10^6 μg/kg in BLD253-02-21, Table 4.42, see also discussion in Sect. 5.4). PCE and TCE were detected in all the wells under and in the vicinity of the buildings, at concentrations ranging from 2.9 to 200,000 μg/L and 5.8 to 18,000 μg/L for PCE and TCE, respectively ("BD"-labeled samples in Table 4.44). Contaminated PCE and TCE soils underneath the building are the likely source of PCE and TCE plumes in the overburden and shallow groundwater (Chapter 5).

Fluoride. Detectable fluoride levels (RL ~7 mg/kg) in subsurface soil samples from under the buildings ranged from 6.8 to 190 mg/kg; however, fluoride was not detected in a majority of the subsurface soil samples from under the buildings (BD-labeled samples in Table H.6). Also, the highest concentration is lower than the geometric mean of regional values reported by Tidball (1984).

Uranium. Elevated uranium activities relative to the off-site/background samples were measured in shallow (< 5 ft depth) subsurface soil samples from under Bldg. 253 and 255 (e.g., ^{234}U = 604 pCi/g in BLD255-08-01, Table 4.28, see also Sect. 4.3.5.1). ^{234}U activities ranged from 8.0 to 13.8 pCi/L in the overburden monitoring wells installed under and in the vicinity of the process buildings (samples labeled "BD" in Table 4.18).

Technetium-99. ^{99}Tc was detected in two surface soil samples collected adjacent to Bldg. 240 and 255 (86.9 and 540 pCi/g; "BD" labeled samples in Table 4.24, and in two shallow (< 5 ft depth) subsurface soil samples collected underneath buildings (1.6 and 30.2 pCi/g, "BD" and "BLD" labeled samples in Table 4.29). ^{99}Tc activities in the overburden groundwater in and around the buildings ranged from non-detectable (MDL ~10 pCi/L) to 5100 pCi/L (detectable ^{99}Tc activities are shown in Table 4.20, "BD"-labeled samples).

Thorium. ^{232}Th activities above the MDL (~0.1 pCi/L) were measured in some of the overburden monitoring wells under the buildings (0.24 to 0.59 pCi/L; BD-labeled samples in Table 4.19). ^{232}Th was also measured in subsurface soil samples (0.4 to 1.2 pCi/g, BD-labeled samples in Table 4.30) but these activities were within the range of ^{232}Th activities in the off-site/background samples (0.7 to 1.3 pCi/g, Table H.10a).

4.5.7 AOC #7 Limestone Storage and Limestone Fill Areas

The potential constituents of concern for AOC #7 Limestone Storage and Limestone Fill Areas are uranium, (^{238}U, ^{235}U, ^{234}U), ^{99}Tc, ^{232}Th, and fluoride.

Uranium and Technetium. ^{235}U was below the MDL (~1 pCi/g) in surface soil samples collected from the middle and edge of the Limestone Storage Area (OA-24-00-SL and OA-25-00-SL, refer to Fig. 2.4b for sample locations). Of the three samples collected from the limestone storage/fill areas, only the composite sample from the limestone fill in the Burial Pit Area contained detectable ^{235}U activity (see Table 4.23 and Fig. 4.16). ^{99}Tc activities in surface soil samples from the middle and edge of the Limestone Storage Area were measured at 13.1 and 87.5 pCi/g (Table 4.24). ^{99}Tc activities in the limestone storage/fill area samples ranged from 22.7 to 94.1 pCi/g (Table 4.24, Fig. 4.17). ^{235}U and ^{99}Tc activities are higher in surrounding surface soil samples (e.g., see data for OA-23-00-SL in Table 4.23 and 4.24). The presence of uranium and ^{99}Tc in surface soil sample OA-23-00 may be due to the Limestone Storage Area but may also be due to Deul's Mountain or other historical Facility activities in this area [e.g., the ring storage area was located east-northeast of Bldg. 252, as described in (GEA 1996) and summarized in Sect. 1.5.4].

Thorium. ^{232}Th was not measured in the surface soil samples from the Limestone Storage Area. However, ^{232}Th levels measured in surface soil samples from multiple locations within the Facility were within the range measured in the off-site/background samples (see discussion in Sect. 4.3.4.3).

Fluoride. Fluoride was detected above the reporting limit (RL ~7 mg/kg) in several surface soil samples collected in the vicinity of the Limestone Storage area and Deul's Mountain (OA-20-00-SL through OA-27-00-SL, refer to Fig. 2.4b for locations), ranging from 19 through 170 mg/kg (data in Table H.5). Fluoride was not detected in subsurface soil samples downgradient of the Limestone Storage Area (PL-04, N-39, NB-31 samples in Appendix H.6).

4.5.8 AOC #8 Outdoor and Shallow Surface Area

The constituents of potential concern in AOC #8 are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, uranium (^{238}U, ^{235}U, ^{234}U), ^{99}Tc, and ^{232}Th. Surface and subsurface soil samples were collected from outdoor areas within the Facility ("OA"-labeled samples in Fig. 2.4a-b and 2.5a-b). Note that the samples collected in the immediate vicinity of the Limestone Storage Area (OA-24-00-SL and OA-25-00-SL) were discussed previously.

Uranium, Technetium-99, Thorium and Fluoride. The following summary of findings in the outdoor areas is broken down into sub-areas within the Facility:

OA-01 through OA-5 next to Bldg 101 (Tile Barn) and Bldg. 120 (Wood Barn) – The highest ^{235}U and ^{99}Tc activities in these surface soil samples were measured at 12.2 pCi/g and 10.3 pCi/g (Table 4.23 and 4.24). Fluoride was detected above the RL (~7 mg/kg) in one surface soil sample from this sub area (20 mg/kg).

OA-07 through OA-11 next to process buildings (e.g., Bldg 230, 240, 253, 254, etc., Fig. 2.4b for locations) - The highest ^{235}U and ^{99}Tc activities in these surface soil samples were measured at 472 pCi/g (measured using alpha spectroscopy in OA-08-00-SL, Table 4.23) and 58.3 pCi/g (Table 4.24), respectively. One surface soil sample contained 150 mg/kg of fluoride (OA-11-00-SL, data in Appendix H.5). Note that subsurface soil samples collected underneath the buildings contained fluoride in localized areas but fluoride levels were generally below the RL in most of the samples.

OA-12 through OA-16, located east-northeast of Facility fenced area next to Burial Pits (Fig. 2.4b for locations) - The highest ^{235}U and ^{99}Tc activities in these surface soil samples were measured at 3.6 pCi/g and 21.3 pCi/g (Table 4.23 and 4.24). The highest fluoride level in the surface soil samples from this sub-area is 57 mg/kg (Appendix H.5).

OA-20 through OA-27 (surface soil sample locations near Limestone Storage Area and Deul's Mountain), OA-18 and OA-19 (subsurface soil sample locations near Limestone Storage Area and Deul's Mountain) - The highest ^{235}U and ^{99}Tc activities in these surface soil samples were measured at 120 pCi/g (Table 4.23) and 691 pCi/g (Table 4.24), respectively. Only one subsurface soil sample from this sub-area contained detectable ^{235}U (0.747 pCi/g OA-18-03-SL, Table 4.28). ^{99}Tc was not detected in any of the subsurface soil samples from this sub-area. ^{234}U in the groundwater sample from monitoring well OA-19 was 3.04 pCi/L (Table 4.18). As mentioned previously, fluoride was detected above the reporting limit (RL ~7 mg/kg) in several surface soil samples collected in the vicinity of the Limestone Storage area and Deul's Mountain (OA-20-00-SL through OA-27-00-SL, refer to Fig. 2.4b for locations), ranging from 19 through 170 mg/kg (data in Table H.5).

OA-28 through OA-33 (Area north of Facility just outside fence- Fig. 2.4b for location) – ^{235}U and ^{99}Tc were not detected in any of the surface soil samples from this sub-area. The data suggests that Facility activities have not had an impact on this outdoor area.

OA-34 through OA-40 (East of Facility near the Northeast Site Creek, Fig. 2.4a and b for location) - The highest ^{235}U and ^{99}Tc activities in these surface soil samples were measured at 1.9 pCi/g and 1.6 pCi/g, respectively (Table 4.23 and 4.24). ^{232}Th was measured in one surface soil sample from the outdoor areas, and the sample was collected from this sub-area (OA-37-00-SL). The measured ^{232}Th activity in this sample (1.1 pCi/g) is within the range of measured activities in the off-site/background samples.

Chlorinated solvents. TCE was measured at 4,000 µg/kg in a subsurface soil sample from OA-18 (OA-18-33-SL, Table 4.42). Given the depth of this sample (33 ft BGS) and the other OA-labeled samples with TCE (Table 4.42), it is likely that TCE in these boreholes is a result of migration from source areas upgradient of OA-18 and OA-19 (e.g., Bldg 255).

4.5.9 AOC #9 Former Gas Station

The constituents of potential concern in AOC #9 Former Gas Station are chlorinated solvents (PCE, TCE and associated degradation products), semivolatile organic compounds (SVOCs), total petroleum hydrocarbons, and metals.

Chlorinated solvents. PCE and TCE were not detected in any of the subsurface soil samples from this AOC (GS-labeled samples in Appendix H.15g). No VOCs were detected in the surface soils (GS-labeled samples in Appendix H.14g).

Petroleum hydrocarbons. Diesel range organics were detected in the soils from this AOC, ranging in concentration from 15 to 35 mg/kg. (Table H.14f).

SVOCs. Only benzo(*b*)fluoranthene and 4,4'-DDT were detected in the soil samples from this AOC (22J µg/kg, "J" qualified because level is below RL and 2.5 µg/kg, respectively).

Metals. A surface sample from this AOC (GS-04-00-SL) contained one of the highest selenium concentrations in the surface soil samples (1.7 mg/kg) but was comparable to selenium in offsite/background samples (see discussion in Sect. 4.2.4.3).

4.5.10 AOC #10 Gas Pipeline

The potential constituents of concern in AOC #10 Gas Pipeline are chlorinated solvents (PCE, TCE and associated degradation products), fluoride, ^{99}Tc, and ^{232}Th.

During the RI field investigation, excavations to expose the pipeline indicated that the pipeline depth ranged from 3 to 5 ft below ground surface, and was not buried in a gravel bed, but was surrounded by native soil (Sect. 1.4). Thus, the pipeline is buried in the fine-grained overburden layer (Sect. 3.2.4.1) based on the depth and location of the pipeline, the overburden cross-sections in Fig. 3.4 and 3.5, as well as the boring logs for the PL-04, PL-05 and PL-06. It is therefore unlikely that the pipeline is serving as a preferential pathway for any contamination originating from the Facility.

The following is a summary of results for samples collected from the immediate vicinity of the pipeline (PL-labeled samples).

Chlorinated Solvents. PCE and TCE were present in subsurface soil samples collected next to the gas pipeline, but at relatively low levels compared to the concentrations measured within the Facility under the buildings. PCE ranged from 15 to 74 μg/kg in soil samples from PL-06, while TCE was below the reporting limit of ~6 μg/kg (data in Appendix H.15g, "PL"-labeled samples). TCE and PCE were not detected above the reporting limit (~6 μg/kg) in any of the subsurface soil samples from PL-05. PCE and TCE were detected in monitoring well PL-04 (PCE 230 μg/L and TCE 1100 μg/L). PL-04 lies within the groundwater plume that originates from the Burial Pits area (see Chapter 5).

Technetium-99. ^{99}Tc was detected in PL-06 (92.3 pCi/L, Table 4.20), but was below the MDL (10 pCi/g) in all of the subsurface soil samples collected from the pipeline (PL-labeled samples in Appendix H.11).

Thorium. ^{232}Th was not detected (MDL ~0.1 pCi/L) in the monitoring wells in this AOC (data in Appendix H.8, PL-04 and PL-06). ^{232}Th was not measured in the surface soil samples near the pipeline. However, ^{232}Th levels measured in surface soil samples from multiple locations within the Facility were within the range measured in the off-site/background samples (see discussion in Sect. 4.3.4.3). ^{232}Th in subsurface samples from this AOC were also within the range of off-site/background samples (PL-labeled samples in Table 4.30).

4.5.11 AOC #11 Red Room Roof Burial Area

The potential constituents of concern for AOC #11 are uranium (^{238}U, ^{235}U, ^{234}U), fluoride, and ^{232}Th.

Uranium. One of the surface soil samples and one of the subsurface soil samples from the Red Room Roof Burial Area are potentially contaminated with uranium (RR-labeled samples in Table 4.23 and 4.28; discussions in Sects. 4.3.4.1 and 4.3.5.1). Uranium was detected in the overburden monitoring well in this AOC (RR-05) but at levels below the established background in the overburden (^{234}U = 1.68 pCi/L, Appendix J).

Fluoride. Fluoride was detected above the reporting limit of ~7 mg/kg in all 3 surface soil samples from this AOC, with a maximum value of 25 mg/kg (RR-labeled samples in Table H.6). Fluoride levels in the subsurface soil samples from this AOC are either below or slightly above the reporting limit of ~7 mg/kg (RR-labeled samples in Appendix H.6).

Thorium. ^{232}Th activities in subsurface soil samples from this AOC were within the range of off-Site background values (RR-labeled samples in Table 4.30).

4.5.12 AOC #12 Domestic Well #3

The potential constituents of concern in AOC #12 Domestic Well # 3 are chlorinated solvents (PCE and TCE and associated degradation products).

Groundwater samples have been periodically collected from Domestic Well #3 and analyzed for VOCs. PCE and TCE have been detected in this well since sampling began in December 2001, although levels appear to have dropped relative to the historically highest values (340 and 520 μg/L TCE and PCE respectively) to less than 40 μg/L in the sample collected in February 2004 and during the packer testing performed in June 2004 as part of this RI. Monitoring data for Domestic Well #3 are available in a database maintained by Westinghouse.

Bedrock wells BR-05-JC and BR-05-RB were installed northeast of Domestic Well #3 (refer to Fig. 2.6a for location). No VOCs were detected in these wells (data in Table H.16f, reporting limit is 5 μg/L, detection limit is ~1/10th of the RL) in the samples collected as part of this RI.

4.5.13 AOC #13 Deul's Mountain

The constituents of potential concern in AOC #13 Deul's Mountain are uranium (^{238}U, ^{235}U, ^{234}U), ^{232}Th, and fluoride. Note that the pile of soil referred to as Deul's Mountain has been removed from the Facility (Sect. 1.4).

Uranium. The highest uranium activities in groundwater, surface soil and subsurface soil were measured in this AOC (DM-labeled samples in Tables 4.18, 4.23 and 4.28).

Thorium. ^{232}Th was not detected (MDC ~0.1 pCi/L) in the monitoring well in this AOC (DM-02). ^{232}Th in subsurface soil samples from this AOC (DM-labeled samples, Table 4.30) are slightly above the range of ^{232}Th activities measured in the off-Site background samples.

4.5.14 AOC #14 Cistern Burn Pit Area

The constituents of potential concern in AOC #14 are chlorinated solvents (PCE, TCE and associated degradation products), SVOCs, metals, dioxin, fluoride, uranium (^{238}U, ^{235}U, ^{234}U), and ^{232}Th.

Chlorinated solvents. PCE, TCE and its daughter products were not detected in the groundwater sample from the overburden monitoring well in this AOC (CB-02, data in Appendix H.16f).

SVOCs. Benzo(*a*)pyrene was detected above the detection limit but below the reporting limit of ~420 mg/kg in the surface soil sample from this AOC (Table 4.37). No other SVOCs were detected above reference levels in the surface soils (see discussion in Sect. 4.4.3.3). No SVOCs were detected in the monitoring well at this AOC (CB-20, data in Appendix H.15).

Dioxins. Dioxins were reported in surface and subsurface soil samples from this AOC (Tables 4.36 and 4.40). The dioxin results in the subsurface soils are all "B" qualified, i.e., the analyte was also detected in the laboratory blank associated with the sample. Three dioxins were detected in the monitoring well in this AOC but all results were below reporting limits and/or "B" qualified (Appendix H.16b).

Uranium and Technetium. ^{235}U was not detected (MDC ~0.4 pCi/g) in the surface sample from this AOC. One subsurface soil sample from this AOC (CB-02) contains ^{234}U that is at the threshold used to determine contamination (Table 4.23, see also discussion in Sect. 4.3.5.1). The groundwater sample from CB-02 had uranium activities that were very low (<0.1 pCi/L, data in Appendix H.8). ^{99}Tc was not

detected in the groundwater sample from CB-02 (MDC ~10 pCi/L); ^{99}Tc was detected in the surface and subsurface soil samples from this AOC (CB-labeled samples in Table 4.24 and 4.29).

4.5.15 AOC #15 Joachim Creek Bridge.

This area was included as an AOC to investigate if third party materials were buried at this location. No sampling was planned for this AOC (LBG 2003). A geophysical survey was conducted to investigate this AOC (Geophex 2005), the results of which are summarized in Sect. 2.8.

CHAPTER 4 FIGURES

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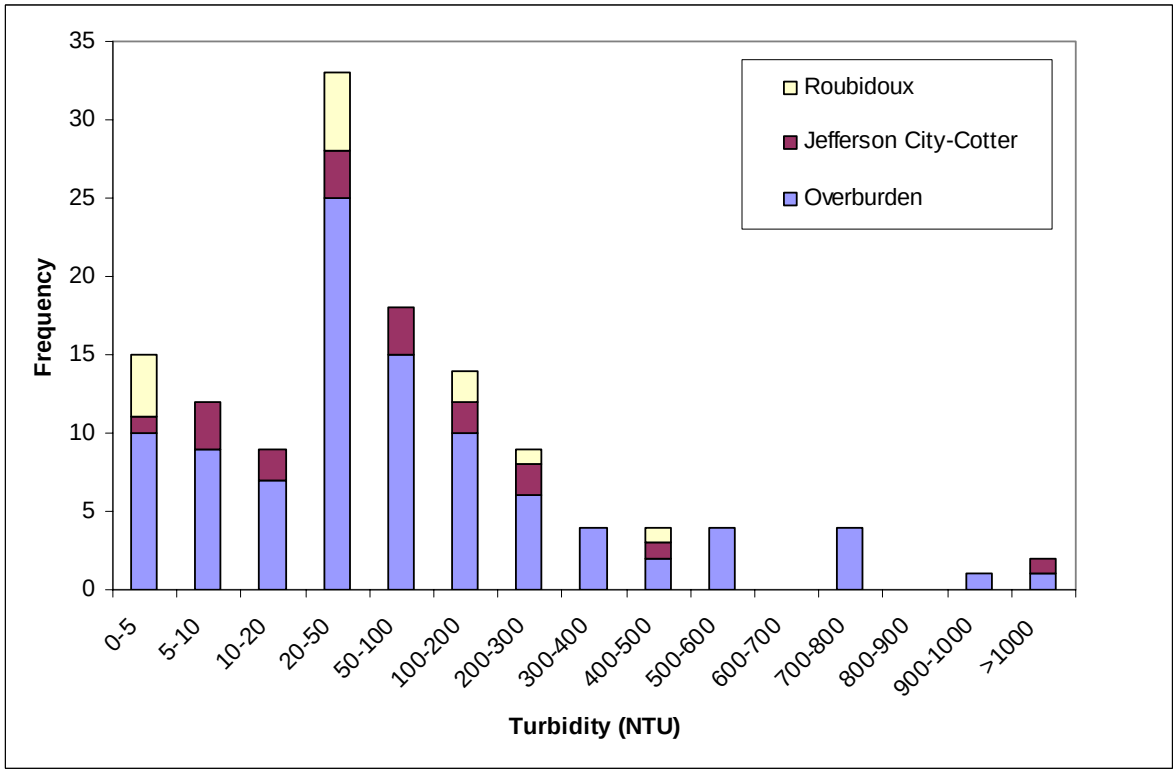

Fig. 4.1. Histogram of turbidity.

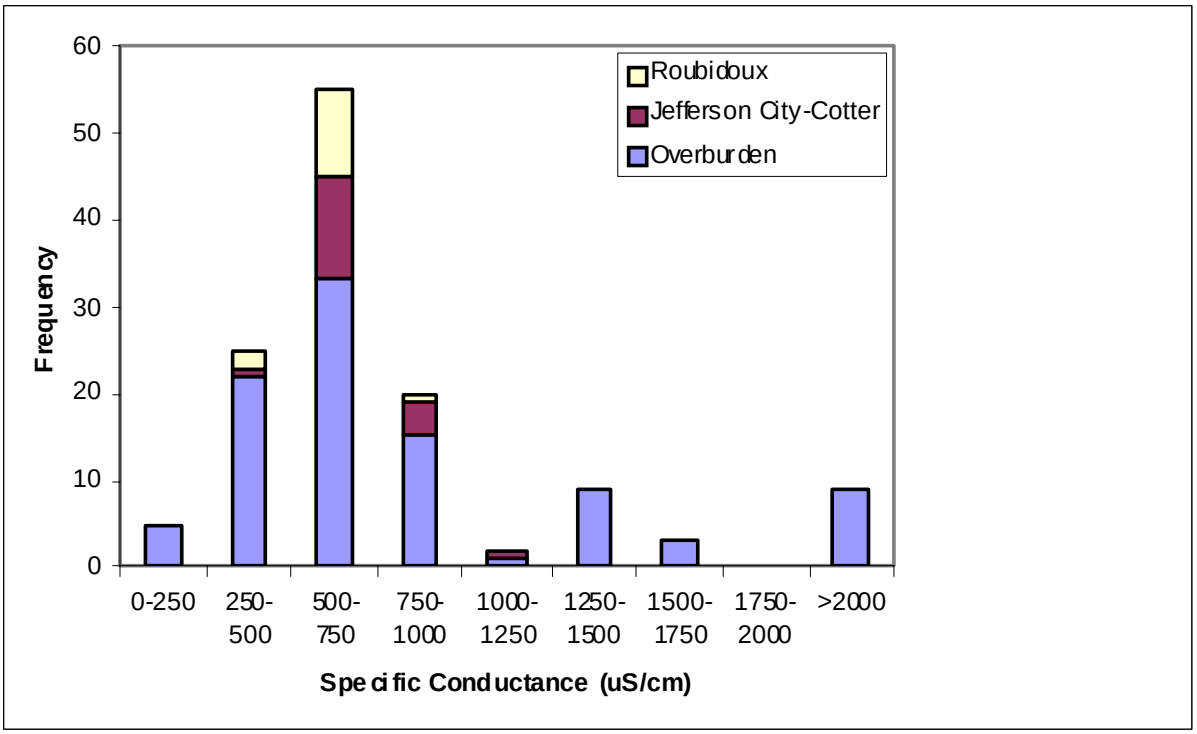

Fig. 4.2. Histogram of specific conductance.

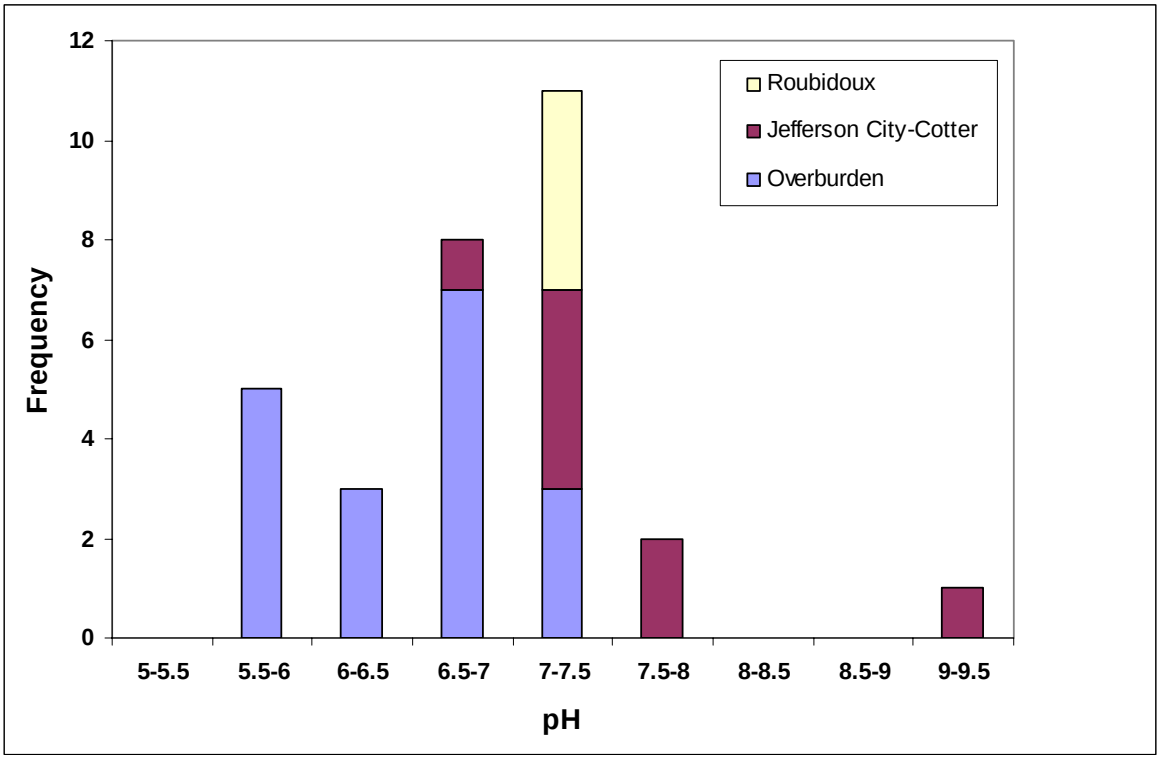

Fig. 4.3. Histogram of groundwater pH.

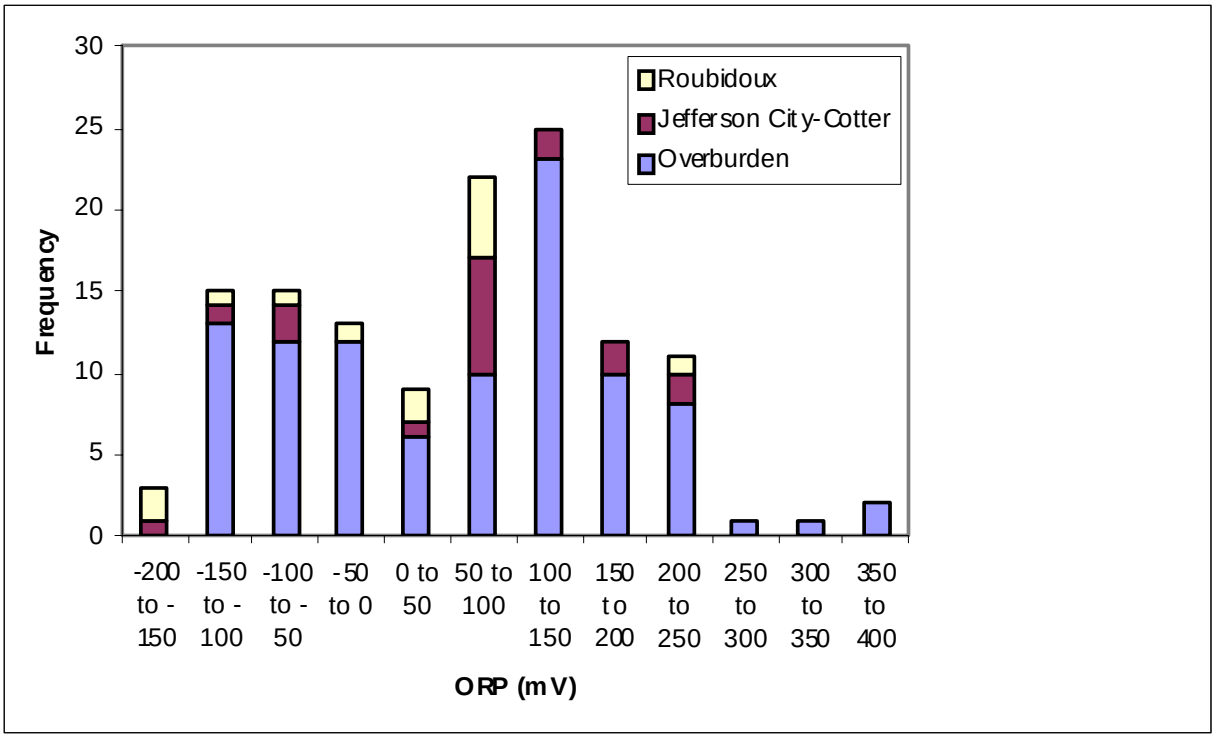

Fig. 4.4. Histogram of groundwater oxidation-reduction potential.

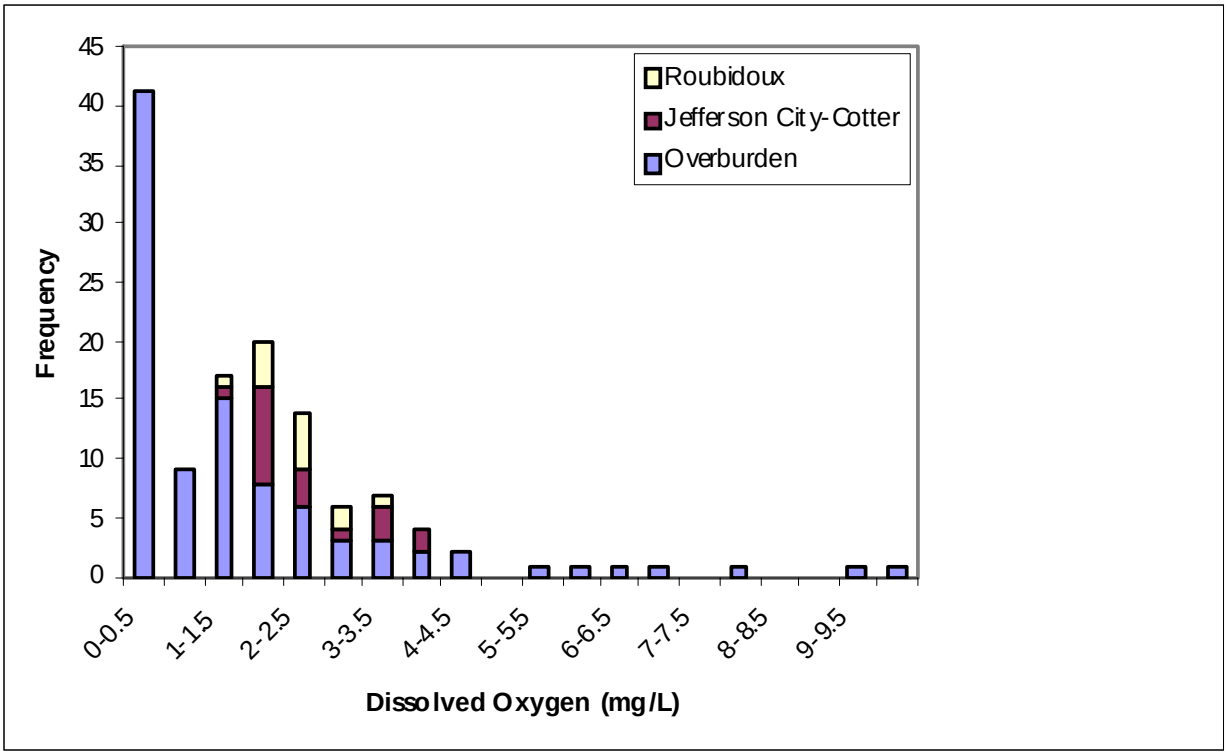

Fig. 4.5. Histogram of groundwater dissolved oxygen.

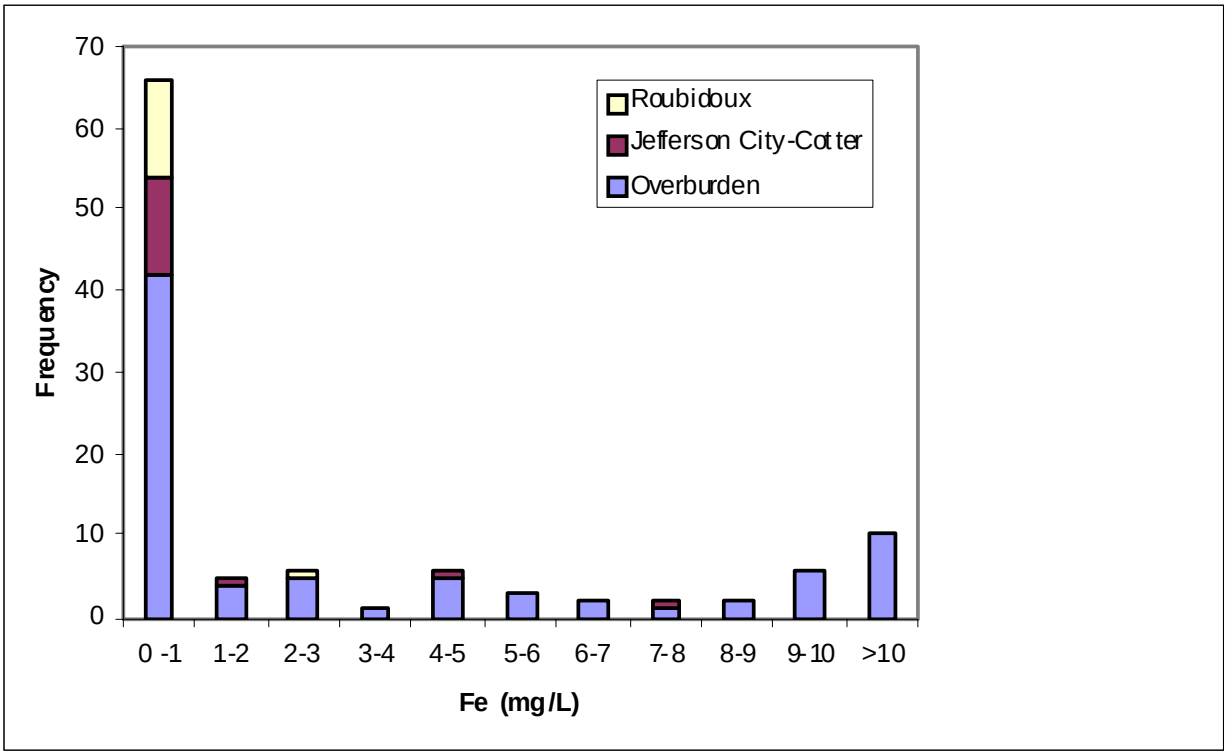

Fig. 4.6. Histogram of ferrous iron concentrations in groundwater.

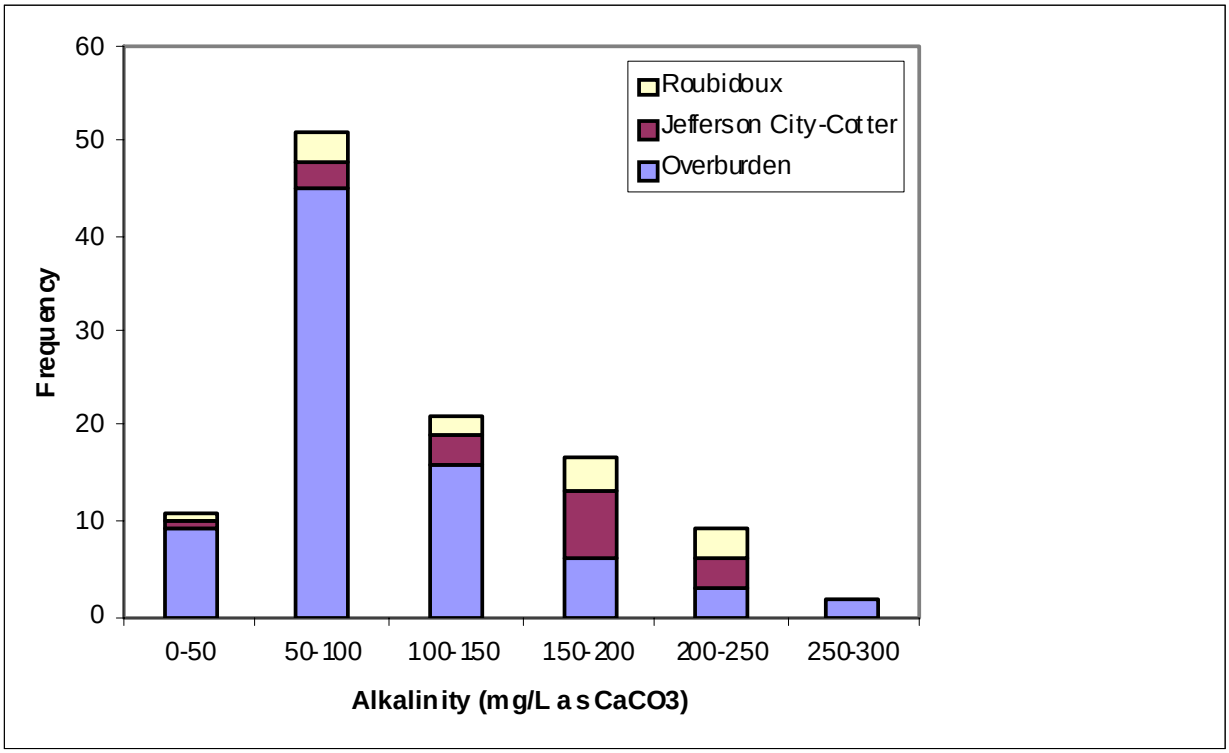

Fig. 4.7. Histogram of groundwater alkalinity.

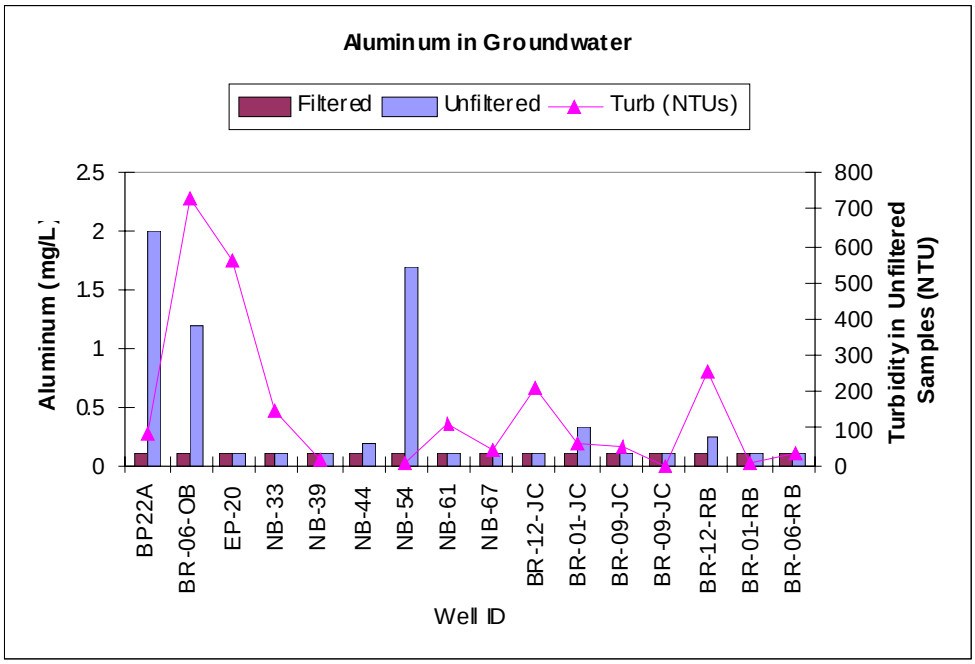

Fig. 4.8a. Comparison of aluminum concentrations in filtered and unfiltered groundwater samples.

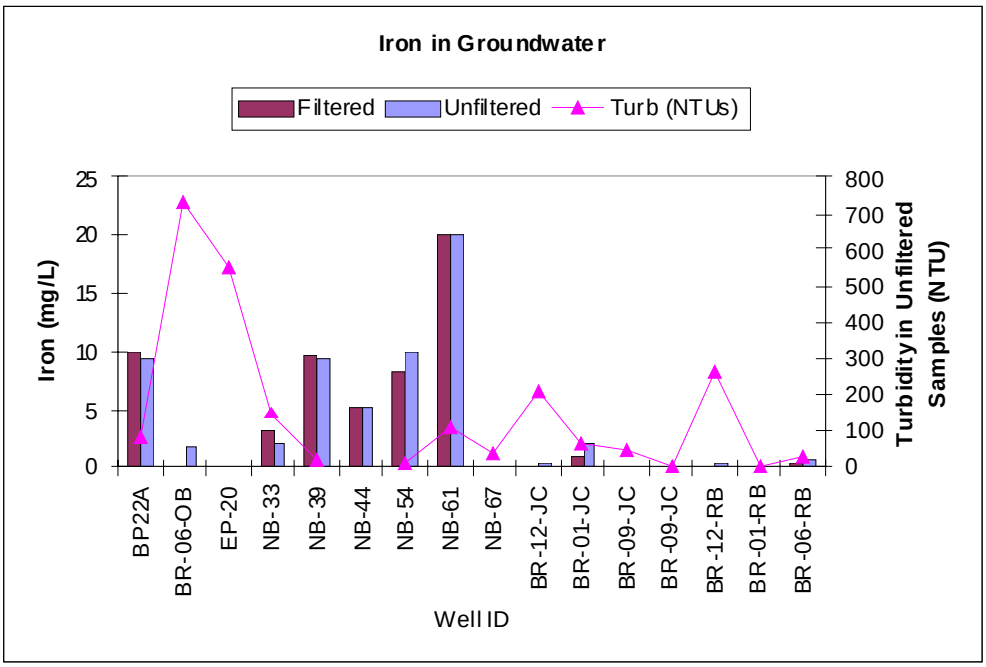

Fig. 4.8b. Comparison of iron concentrations in filtered and unfiltered groundwater samples.

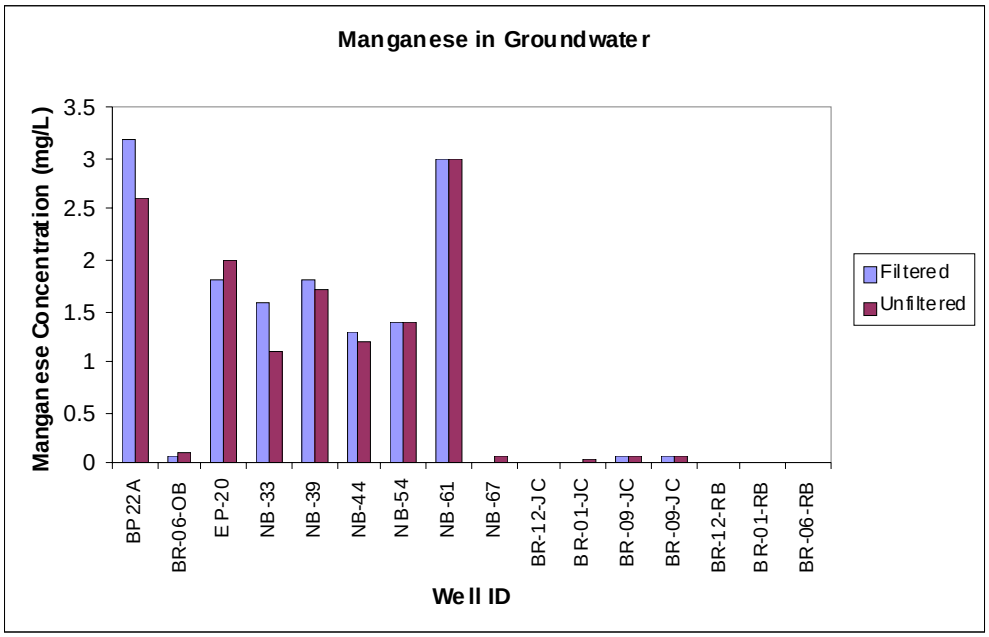

Fig. 4.8c. Comparison of manganese concentrations in filtered and unfiltered groundwater samples.

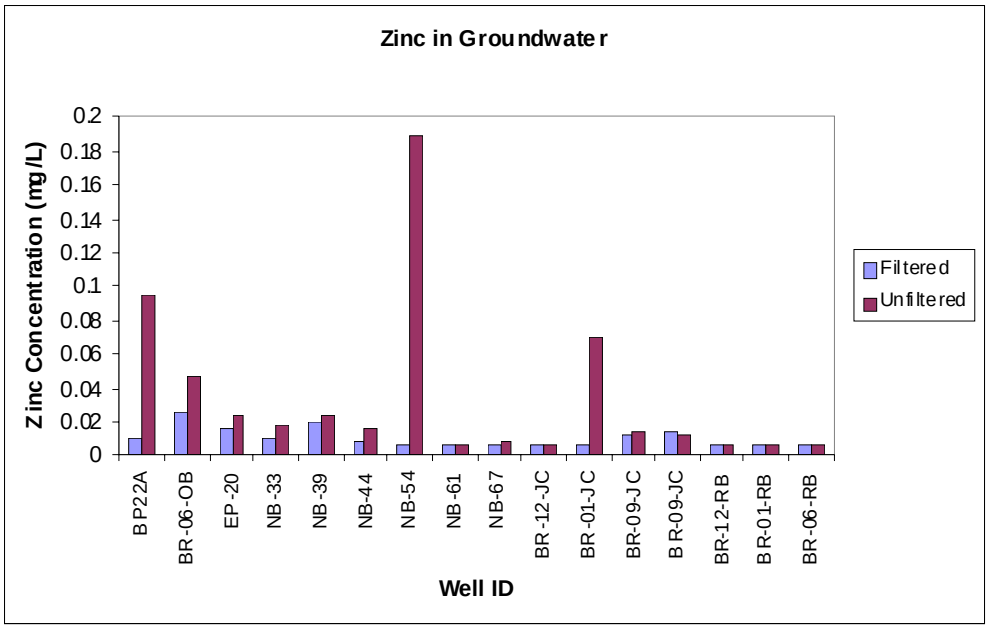

Fig. 4.8d. Comparison of zinc concentrations in filtered and unfiltered groundwater samples.

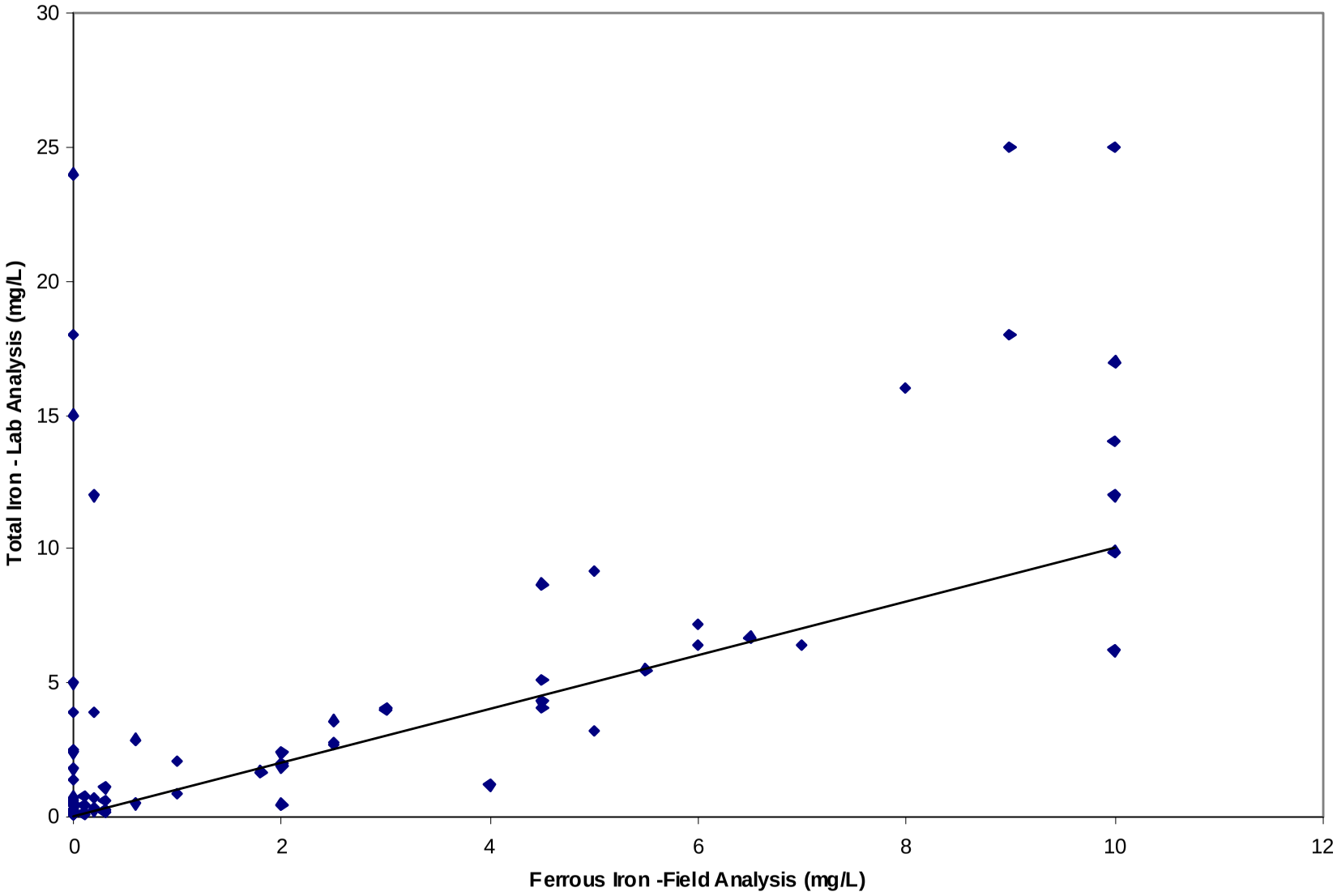

Fig. 4.8e. Comparison of total iron and ferrous iron concentrations in unfiltered groundwater samples. (Total and ferrous iron concentrations were measured in the laboratory and field, respectively.)

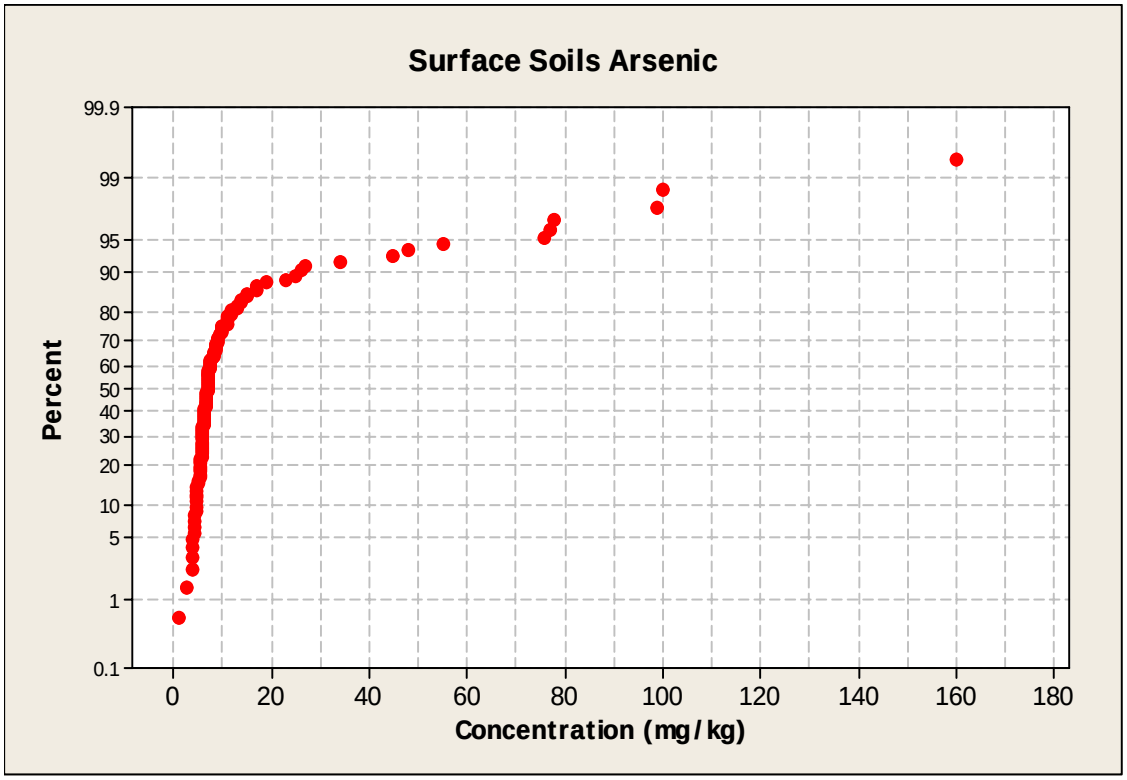

Fig. 4.9. Cumulative frequency plot for arsenic in surface soils.

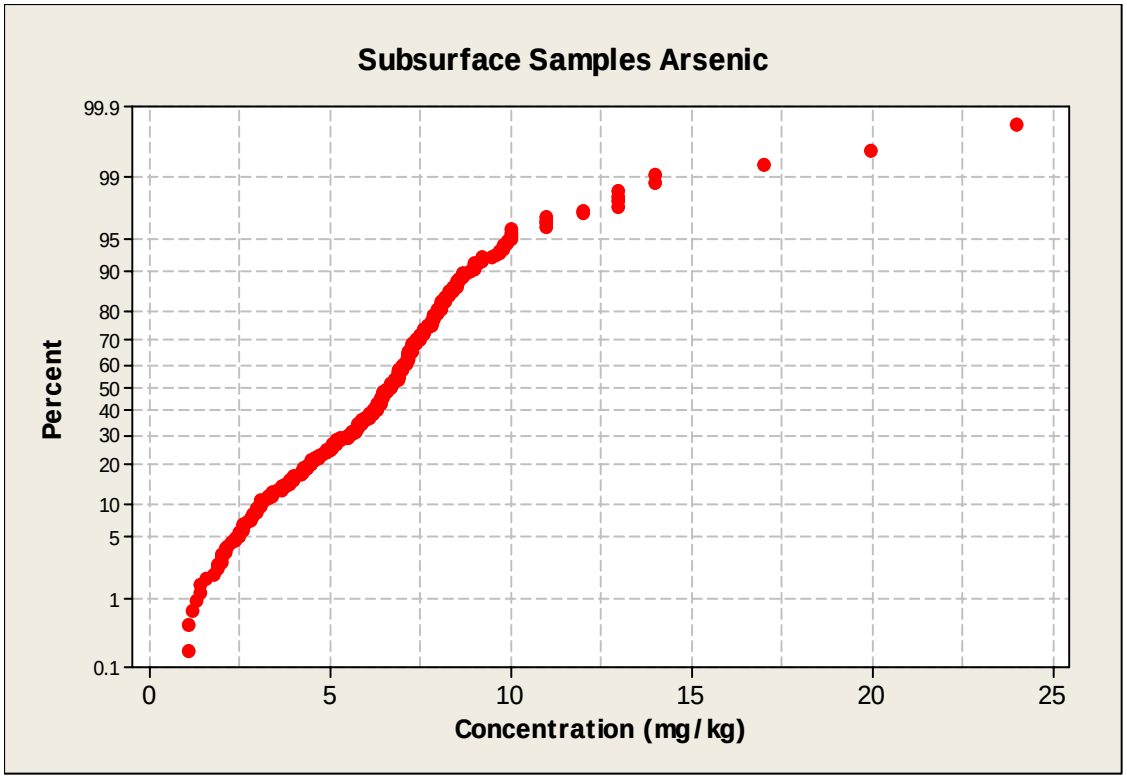

Fig. 4.10. Cumulative frequency plot for arsenic in subsurface soils.

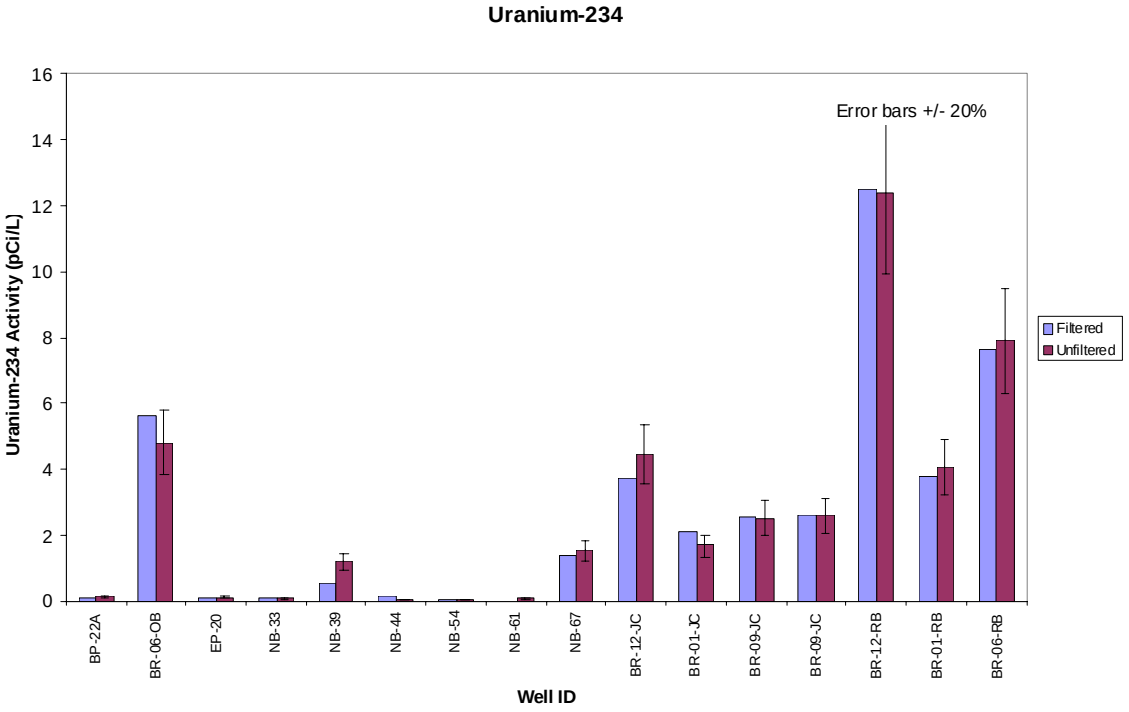

Fig. 4.13. Comparison between ^{234}U activities in filtered (<0.45 mm) and unfiltered groundwater samples. (Error bars correspond to estimated average measurement error reported with analytical results.)

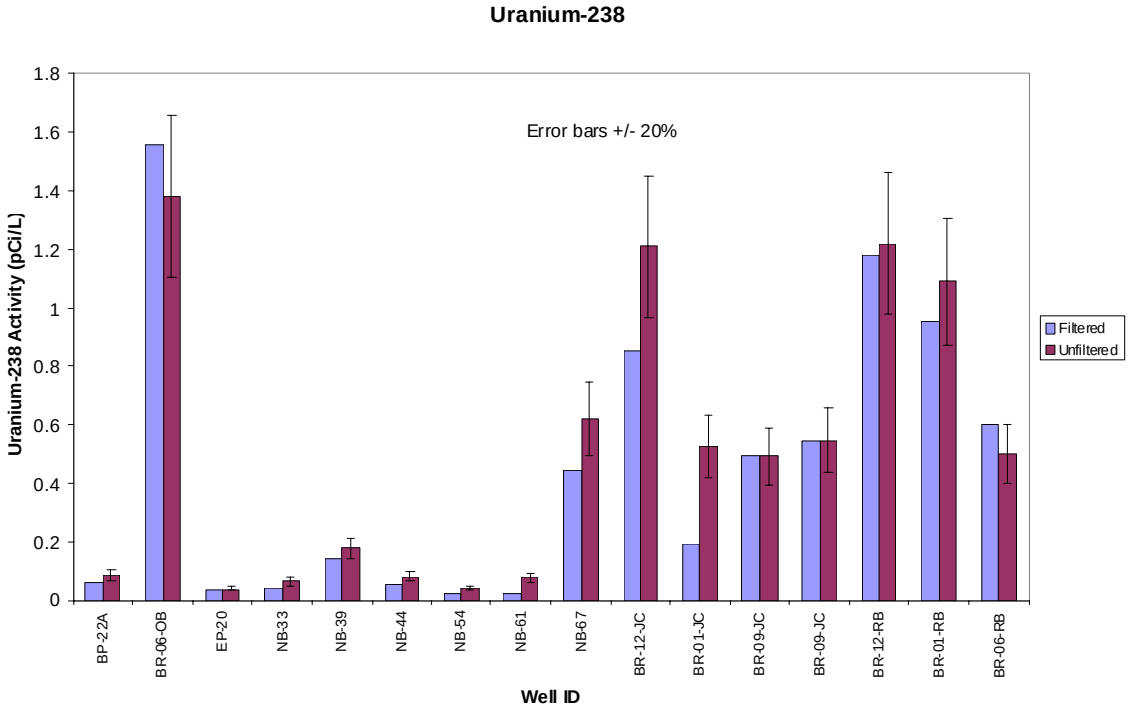

Fig. 4.14. Comparison between ^{238}U activities in filtered (<0.45 mm) and unfiltered groundwater samples. (Error bars correspond to estimated average measurement error reported with analytical results.)

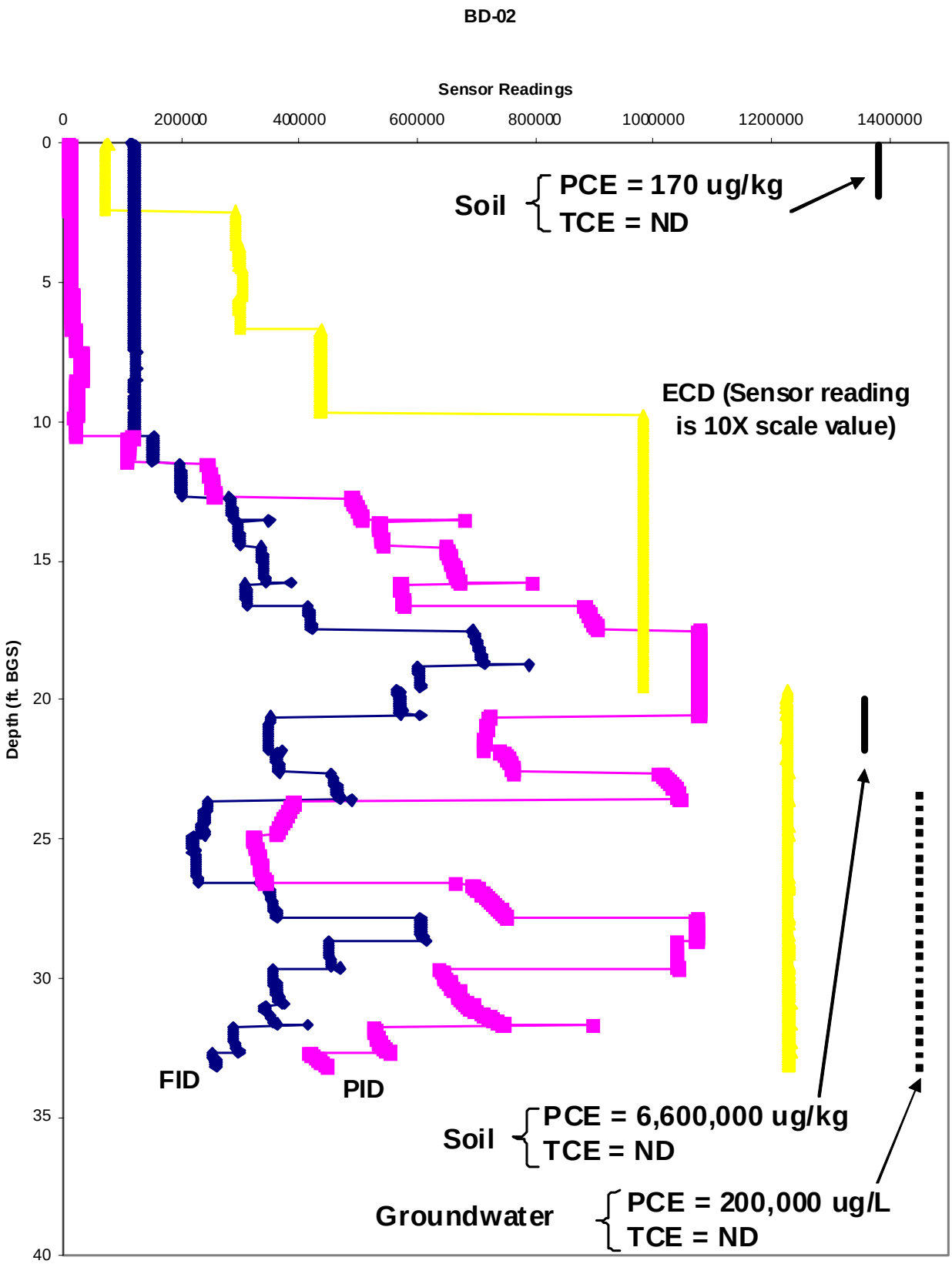

Fig. 4.22. MIP detector response at BD-02.

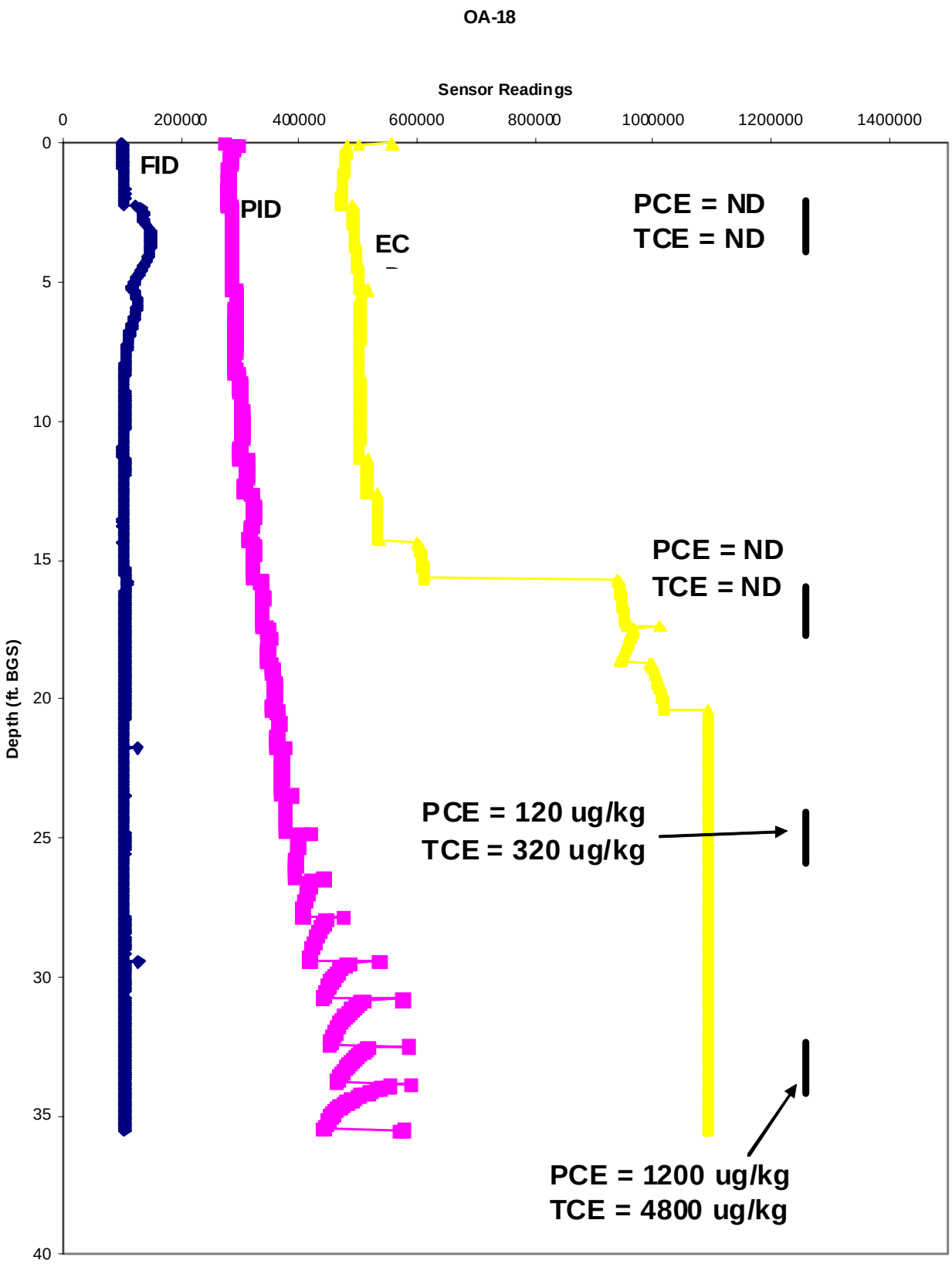

Fig. 4.23. MIP detector response at OA-18.

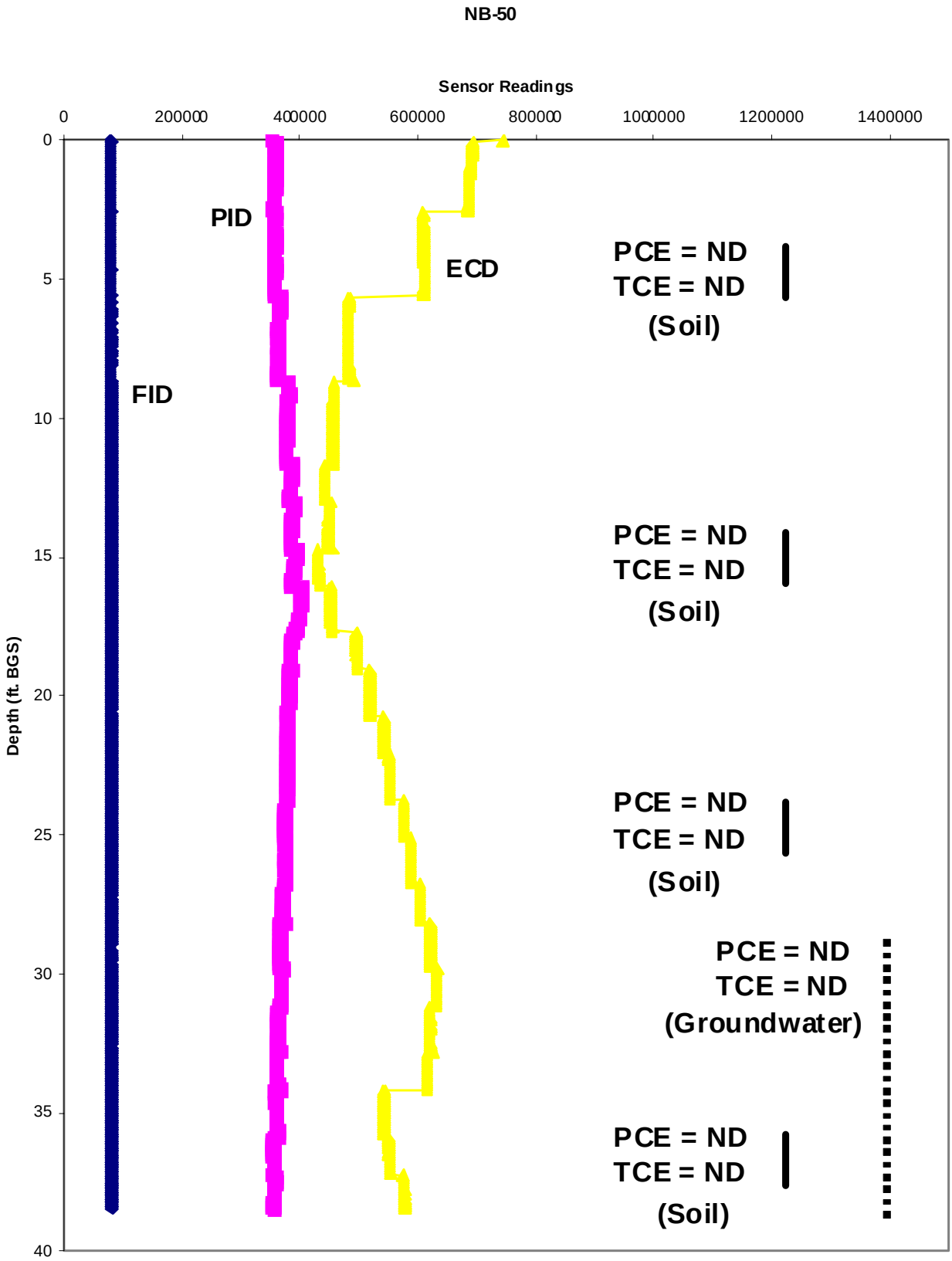

Fig. 4.24. MIP detector response at NB-50.

CHAPTER 4 TABLES

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Table 4.1. Arsenic concentrations in groundwater samples (All other results less than the reporting limit of 0.01 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
BD-02	0.019	Deep overburden	Buildings.
BD-06	0.026	Deep overburden	Buildings.
BD-08	0.019	Deep overburden	Buildings.
BD-13	0.01	Deep overburden	Buildings.
NB-80	0.021	Deep overburden	East of the Burial Pits.
NB-83	0.016	Deep overburden	Between the Hematite Facility and Joachim Creek, towards the east.
WS-23	0.13	Deep overburden	Northeast corner of the Hematite Facility, near the Burial Pits.
WS-25	0.061	Deep overburden	Northern end of the Burial Pits, towards Northeast Site Creek.
WS-29	0.013	Deep overburden	Southern end of the Burial Pits, towards Northeast Site Creek.
BR-08-JC	0.015	Jefferson City-Cotter	Between WEC and Joachim Creek, towards the east.
PZ-03	0.014	Jefferson City-Cotter	Between buildings and Deul's Mountain.
PZ-04	0.023	Jefferson City-Cotter	Northeast corner of the Hematite Facility, near the Burial Pits.
BR-01-RB	0.062	Roubidoux	East of Site Pond.

Table 4.2. Chromium concentrations in groundwater samples (All other concentrations were less than the reporting limit of 0.004 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
WS-16	0.0061	Shallow overburden	Southern end of the Burial Pits.
BD-02	0.021	Deep overburden	Buildings.
BD-13	0.021	Deep overburden	Buildings.
LF-08	0.025	Deep overburden	Former leach field.
OB-02	0.0059	Deep overburden	Between the Hematite Facility and Joachim Creek, towards the east.
WS-23	0.037	Deep overburden	Northeast corner of the Hematite Facility, near the Burial Pits.
WS-25	0.013	Deep overburden	Northern end of the Burial Pits.
WS-32	0.0069	Deep overburden	Between Deul's Mountain and the southeast fence line.

Table 4.3. Copper concentrations in groundwater samples (All other samples less than the reporting limit of 0.01 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
WS-15	0.028	Shallow overburden	Burial Pits.
BD-02	0.039	Deep overburden	Buildings.
BD-03	0.029	Deep overburden	Buildings.
BD-13	0.019	Deep overburden	Buildings.
SW-07	0.02	Deep overburden	Site Pond.
WS-23	0.033	Deep overburden	Northeast corner of the Hematite Facility, near the Burial Pits.

Table 4.4. Iron concentrations in groundwater samples (All other samples less than 1 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
WS-15	2.4	Shallow overburden	Burial Pits.
WS-32	18	Deep overburden	Between Deul's Mountain/Fence Line.
NB-50	2.8	Deep overburden	Between the Hematite Facility and Highway P.
NB-36	12	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-38	8.7	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-44 (duplicate)	5.1	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-44	5.2	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-72	24	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-81	34	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-83	6.4	Deep overburden	Between the Hematite Facility and Joachim Creek, towards East.
BD-02	38	Deep overburden	Buildings.
BD-03	15	Deep overburden	Buildings.
BD-04	2.9	Deep overburden	Buildings.
BD-05	2.5	Deep overburden	Buildings.
BD-06	4.1	Deep overburden	Buildings.
BD-13	17	Deep overburden	Buildings.
BD-14	29	Deep overburden	Buildings.
BD-16	1.9	Deep overburden	Buildings.
NB-54 (duplicate)	8.3	Deep overburden	Buildings, Parking Lot.
NB-54	9.9	Deep overburden	Buildings, Parking Lot.
NB-56	4	Deep overburden	Buildings, Parking Lot.
NB-57A	3.2	Deep overburden	Buildings, Parking Lot.
BP-17	7.4	Deep overburden	Burial Pits.
BP-22A	9.4	Deep overburden	Burial Pits.
BP-22A (duplicate)	10	Deep overburden	Burial Pits.
BP-22B	1.1	Deep overburden	Burial Pits.
NB-61	20	Deep overburden	Burial Pits.
NB-61 (duplicate)	20	Deep overburden	Burial Pits.
NB-79	9.4	Deep overburden	Burial Pits.
NB-80	7.2	Deep overburden	Burial Pits.
WS-25	25	Deep overburden	Burial Pits.
WS-29	18	Deep overburden	Burial Pits.
CB-02	16	Deep overburden	Cistern Burn Pit.
DM-02	1.7	Deep overburden	Deul's Mountain.
OB-02	3.9	Deep overburden	East of the Hematite Site, near Joachim Creek.
NB-46	5.5	Deep overburden	East-northeast of the Hematite Facility, past Northeast Site Creek.
NB-71	6.7	Deep overburden	East-northeast of the Hematite Facility, past Northeast Site Creek.
NB-74	28	Deep overburden	Evaporation Ponds.
LF-08	12	Deep overburden	Former Leach Field.
LF-09	1.1	Deep overburden	Former Leach Field.
LF-09 (duplicate)	1.2	Deep overburden	Former Leach Field.
BR-03-OB	1.4	Deep overburden	Near Joachim Creek.

Table 4.4. Iron concentrations in groundwater samples (All other samples less than 1 mg/L; refer to Fig. 2.6a and b for well locations.) (continued)

Well ID	Result (mg/L)	Formation	Area of concern or general location
BR-06-OB	1.8	Deep overburden	Near Joachim Creek.
BR-10-OB	2.4	Deep overburden	Near Joachim Creek.
NB-66	5	Deep overburden	Near Joachim Creek.
WS-23	25	Deep overburden	Northeast corner of the Hematite Facility, near the Burial Pits.
SW-07	6.2	Deep overburden	Site Pond.
NB-32	3.6	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-33	2	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-33 (duplicate)	3.2	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-35	17	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-39	9.2	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-39 (duplicate)	9.6	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-84	6.4	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
PL-04	21	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
WS-08	2.4	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-85	4.3	Deep overburden	Southwest of the Hematite Facility, towards Site Creek.
NB-86	2.7	Deep overburden	Southwest of the Hematite Facility, towards Site Creek.
WS-34	14	Deep overburden	Southwest of the Hematite Facility, towards Site Creek.
PZ-03	16	Jefferson City	Between buildings and Deul's Mountain.
BR-08-JC	4.1	Jefferson City	Between the Hematite Facility and Joachim Creek.
BR-01-JC	2.1	Jefferson City	East of Site Pond.
PZ-04	3.9	Jefferson City	Northeast corner of the Hematite Facility, near Burial Pits.
BR-02-JC	1.7	Jefferson City	West of the Hematite Site.

Table 4.5. Lead concentrations in groundwater samples (All other samples less than reporting limit of 0.003 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
WS-14	0.0037	Shallow overburden	Burial Pits.
NB-50	0.0033	Deep overburden	Between the Hematite Facility and Highway P.
BD-02	0.0430	Deep overburden	Buildings.
BD-03	0.0340	Deep overburden	Buildings.
BD-06	0.0033	Deep overburden	Buildings.
BD-13	0.0340	Deep overburden	Buildings.
NB-54	0.0170	Deep overburden	Buildings, Parking Lot.
BP-22A	0.0043	Deep overburden	Burial Pits.
WS-25	0.0310	Deep overburden	Burial Pits.
WS-32	0.0075	Deep overburden	Deul's Mountain.
OB-02	0.0057	Deep overburden	East of the Hematite Site, near Joachim Creek.
LF-08	0.0200	Deep overburden	Former Leach Field.
NB-66	0.0082	Deep overburden	Near Joachim Creek.
WS-23	0.0590	Deep overburden	Northeast corner of the Hematite Facility, near Burial Pits.
SW-07	0.0058	Deep overburden	Site Pond.
WS-08	0.0075	Deep overburden	Southeast of the Hematite Facility Fence Line, towards Joachim Creek.
NB-85	0.0045	Deep overburden	Southwest of the Hematite Facility, towards Site Creek.
BR-10-JC	0.0032	Jefferson City	Near Joachim Creek.

Table 4.6. Nickel concentrations in groundwater samples (All other samples less than 0.05 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
BD-02	0.080	Deep Overburden	Buildings.
BD-05	0.097	Deep Overburden	Buildings.
BD-08	0.150	Deep Overburden	Buildings.
NB-72	0.062	Deep Overburden	Between the Hematite Facility and Joachim Creek.
PZ-03	0.067	Jefferson City-Cotter	Between buildings and Deul's Mountain.

Table 4.7. Nitrate (as-N) concentrations in groundwater (All other samples less than 1 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
WS-07	2.2	Shallow overburden	Pipeline, southeast of the Hematite Facility.
WS-17B	3.3	Shallow overburden	Deul's Mountain.
WS-14	1.8	Shallow overburden	Burial Pits.
WS-26	3.1	Shallow overburden	Burial Pits.
WS-28	1.3	Shallow overburden	Burial Pits.
BD-01	67	Deep overburden	Buildings.
BD-02	290	Deep overburden	Buildings.
BD-03	3.8	Deep overburden	Buildings.
BD-04	37	Deep overburden	Buildings.
BD-05	2.6	Deep overburden	Buildings.
BR-08-OB	1.7	Deep overburden	Between the Hematite Facility and Joachim Creek.
EP-20	90	Deep overburden	Evaporation Ponds.
LF-08	1.6	Deep overburden	Former Leach Fields.
NB-34	17	Deep overburden	Southeast of the Hematite Facility towards Joachim Creek.
NB-34 (duplicate)	17	Deep overburden	Southeast of the Hematite Facility towards Joachim Creek.
NB-63	4.5	Deep overburden	Near Joachim Creek.
NB-64	1.7	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-65	2.9	Deep overburden	Near Joachim Creek.
NB-66	2.4	Deep overburden	Near Joachim Creek.
NB-67	2.2	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-73	1.2	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-77	2.2	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-78	2.6	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-82	1.8	Deep overburden	Between the Hematite Facility and Joachim Creek.
PL-06	4.8	Deep overburden	Pipeline, southwest of the Hematite Facility.
BR-08-JC	1.4	Jefferson City-Cotter	Between the Hematite Facility and Joachim Creek.
BR-09-JC	1.1	Jefferson City-Cotter	Between the Hematite Facility and Joachim Creek.
BR-12-RB	1.6	Roubidoux	North-northwest of the Hematite Facility across Highway P.

Table 4.8. Selenium concentrations in groundwater (All other samples below reporting limit of 0.005 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
NB-64	0.0062	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-78	0.0095	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-54	0.0057	Deep overburden	Buildings/Parking Lot.
OB-01	0.0077	Deep overburden	East of Site Pond.
LF-09	0.0065	Deep overburden	Former Leach Field.
NB-65	0.0051	Deep overburden	Near Joachim Creek.
WS-14	0.0073	Shallow overburden	Burial Pits.
WS-26	0.0091	Shallow overburden	Burial Pits.

Table 4.9. Thallium concentrations in groundwater samples (All other samples below reporting limit of 0.01 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
BD-01	0.011	Deep overburden	Buildings.
BD-02	0.026	Deep overburden	Buildings.
BP-17	0.013	Deep overburden	Burial Pits.

Table 4.10. Vanadium concentrations in groundwater (All other samples below reporting limit of 0.01 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
BD-02	0.037	Deep overburden	Buildings.
BD-03	0.034	Deep overburden	Buildings.
BD-13	0.034	Deep overburden	Buildings.
LF-08	0.018	Deep overburden	Former Leach Field.
WS-23	0.044	Deep overburden	Near Burial Pits.
WS-25	0.035	Deep overburden	Burial Pits.

Table 4.11. Zinc concentrations in groundwater (All other samples less than 0.05 mg/L; refer to Fig. 2.6a and b for well locations.)

Well ID	Result (mg/L)	Formation	Area of concern or general location
NB-83	0.050	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-85	0.053	Deep overburden	Between the Hematite Facility and Joachim Creek.
NB-86	0.130	Deep overburden	Between the Hematite Facility and Joachim Creek.
BD-02	0.180	Deep overburden	Buildings.
BD-03	0.170	Deep overburden	Buildings.
BD-13	0.650	Deep overburden	Buildings.
NB-54	0.190	Deep overburden	Buildings/Parking Lot.
BP-22A	0.095	Deep overburden	Burial Pits.
WS-25	0.540	Deep overburden	Burial Pits.
WS-32	0.075	Deep overburden	Deul's Mountain.
WS-23	0.310	Deep overburden	Near Burial Pits.
NB-66	0.054	Deep overburden	Near Joachim Creek.
NB-77	0.085	Deep overburden	Near Joachim Creek.
SW-07	0.210	Deep overburden	Site Pond.
NB-32	0.240	Deep overburden	Southeast of the Hematite Facility.
BR-01-JC	0.069	Jefferson City-Cotter	East of Site Pond.
BR-03-RB	0.150	Roubidoux	Roubidoux.

Table 4.12 Inorganics in Site Sediment (refer to Fig. 2.3 for sample locations)

Sample ID	Aluminum		Arsenic		Bar ium		Beryllium		Cadmium		Chromium		Cobalt		Copper		Fluoride	
	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Site Pond																		
SW-01-SS	9200		4.6		120		0.81		0.76		23		7.7		46		25	
SW-05-SS	5400	J	5.8	=	180	J	0.61	U	0.6	=	10	=	7.7	=	37	=	10	U
SW-06-SS	13000	J	9.1	=	180	J	1.3	=	3.2	=	48	=	14	=	110	=	28	=
SW-07-SS	10000		4.5		150		0.57	U	1.5		31		7.9		66		17	
Site Creek																		
SW-02-SS	4100	J	4.9	=	250	J	0.38	U	0.37	=	8.6	=	6.2	=	9.9	=	6.3	U
SW-03-SS	5300	J	4.9	=	200	J	0.59	U	0.44	=	11	=	8.1	=	13	=	9.9	U
SW-04-SS	6500	J	11	=	940	J	0.86	=	0.64	=	13	=	25	=	38	=	6.7	U
Northeast Site Creek																		
SW-11-SS	7100		6.5		85		0.57		0.28	U	13		8		9.5		7.1	U
SW-12-SS	6100		3.5		47		0.4	U	0.27	U	10		3.8		6.8		8.6	
SW-13-SS	5300		8.9		83		0.51		0.3	U	12		10		7.4		9.8	
SW-10-SS	6300		6		140		0.58		0.31	U	14		8.8		11		10	
Joachim Creek																		
SW-14-SS	660		3		35		0.37	U	0.25	U	8.7		2.3		1	U	6.2	U
SW-15-SS	2200		7.4		110		0.35		0.23	U	24		8		6.5		5.9	U
SW-16-SS	1900		3.2		67		0.37	U	0.25	U	11		3.4		3.4		6.2	U
SW-08-SS	820		3.5		38		0.36	U	0.24	U	8.9		2.1		1.7		6.1	U
SW-08-SS-FD	780		2.2		33		0.35	U	0.24	U	11		2.3		1.4		5.9	U
Upstream Sediment																		
US-04-SS	3000		5.8		58		0.39	U	0.26	U	7.6		5.6		4.3		6.5	UN
US-05-SS	2500		3.5		130		0.37	U	0.25	U	7.2		4.1		4.3		6.2	U
Site-Specific Background in Subsurface Soil																		
Appendix J	17000		9.8		320		0.92		0.72		24		14		13		N.C.	

*Q = data qualifier; J = estimated (below RL but above MDL); U: below MDL; "=": data point was validated

Table 4.12 Inorganics in Site Sediment (refer to Fig. 2.3 for sample locations) (continued)

Sample ID	Iron		Lead		Manganese		Mercury		Nickel		Selenium		Vanadium		Zinc	
	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q	Result	Q
Site Pond																
SW-01-SS	15000		27		400		0.12		29		0.96	U	25		140	
SW-05-SS	14000	J	130	=	890	J	0.074		12	=	1.1	=	20	=	87	=
SW-06-SS	19000	J	71	=	900	J	1.1		48	=	1.8	U	29	=	410	=
SW-07-SS	11000		58		330		0.27		28		0.95	U	29		270	
Site Creek																
SW-02-SS	9500	J	58	=	640	J	0.03		8.6	=	0.85	=	15	=	210	=
SW-03-SS	11000	J	53	=	830	J	0.082		12	=	0.99	U	18	=	150	=
SW-04-SS	23000	J	110	=	5600	J	0.03		27	=	2.6	=	33	=	130	=
Northeast Site Creek																
SW-11-SS	14000		31		600		0.028	U	13		0.71	U	25		44	
SW-12-SS	8200		18		170		0.027	U	7.7		0.96		16		36	
SW-13-SS	16000		26		670		0.03	U	11		1.7		24		66	
SW-10-SS	14000		41		850		0.031	U	13		0.96		24		59	
Joachim Creek																
SW-14-SS	5600		9.8		99		0.025	U	2.9		0.62	U	13		53	
SW-15-SS	17000		41		500		0.026		11		0.77		29		160	
SW-16-SS	5900		29		240		0.025	U	4.4		0.73		11		93	
SW-08-SS	5000		12		77		0.024	U	3.1		0.61	U	9.6		55	
SW-08-SS-FD	4400		30		130		0.024	U	3.3		0.59	U	9.5		61	
Upstream Sediment																
US-04-SS	10000		15		550	*	0.026	U	8.6		0.73		16		23	E
US-05-SS	6200		35		340		0.025	U	4.8		0.62	U	11		140	
Site-Specific Background in Subsurface Soil																
Appendix J	24000		90		960		0.05		17		0.85		40		370	

*Q = data qualifier; J = estimated (below RL but above MDL); U: below MDL; "=": data point was validated

Table 4.13. Ten highest inorganic concentrations (mg/kg) in surface soils

Element	Station ID	Concen-tration (mg/kg)	Element	Station ID	Concen-tration (mg/kg)	Element	Station ID	Concen-tration (mg/kg)	Element	Station ID	Concen-tration (mg/kg)
Antimony	**Site Bkg**	**N.C.**	Arsenic	**Site Bkg**	**9.6**	Beryllium	**Site Bkg**	**0.77**	Cadmium	**Site Bkg**	**0.6**
	EP-11	1.9		EP-02	27		OA-07	1.0		BD-12	1.5
	EP-06	2.2		EP-10	34		EP-03	1.1		OA-01	1.6
	BD-12	2.3		EP-08	45		NB-11	1.1		NB-11	2.2
	DM-02	2.6		BD-11	48		EP-06	1.1		EP-06	2.2
	EP-01	3.2		EP-11	55		SW-01	1.2		EP-04	2.9
	OA-08	3.7N		BD-12	76		BP-07	1.5		EP-03	3.3
	EP-04	5.2		EP-12	77		SW-02	2.6		SW-02	3.5
	EP-02	8.4		EP-04	99		EP-01	3.4		BD-10	4.5
	OA-26	16		EP-09	100		EP-02	4.4		EP-01	4.7
	BD-10	21		EP-06	160		EP-04	5.8		EP-02	11
Element	**Station ID**	**Concen-tration (mg/kg)**	**Element**	**Station ID**	**Concen-tration (mg/kg)**	**Element**	**Station ID**	**Concen-tration (mg/kg)**	**Element**	**Station ID**	**Concen-tration (mg/kg)**
Chromium	**Site Bkg**	**17**	Cobalt	**Site Bkg**	**17**	Copper	**Site Bkg**	**13**	Lead	**Site Bkg**	**81**
	OA-26	35		OA-28	16		EP-11	39		EP-02	230
	LF-01	35		NB-04	16		SW-02	39		NB-05	230
	BD-12	35		SW-02	16		OA-26	43		BD-10	230
	EP-06	37		BD-10	18		EP-01	50		OA-08	270
	BP-07	52		BP-05	21		NB-04	55		OA-01	370
	EP-02	53		EP-06	33		DM-02	60		NB-22	370
	DM-02	55		OA-23	300		OA-08	150		BD-12	430
	EP-04	76		OA-01	13		EP-04	160		NB-04	490
	OA-08	90		BP-01	13		BD-10	180		OA-04	560
	BD-10	280		NB-05	12		EP-02	1800		OA-13	1400

*Site Bkg: Site-specific background concentration for surface soil, as calculated in Appendix J. N.C.: Not calculated, refer to Appendix J.

Table 4.13. Ten highest inorganic concentrations (mg/kg) in surface soils (continued)

Element	Sample ID	Concen-tration (mg/kg)	Element	Sample ID	Concen-tration (mg/kg)	Element	Sample ID	Concen-tration (mg/kg)	Element	Sample ID	Concen-tration (mg/kg)
Mercury	**Site Bkg**	**0.04**	Nickel	**Site Bkg**	**14**	Selenium	**Site Bkg**	**0.97**	Silver	**Site Bkg**	**N.C.**
	OA-23	0.58		OA-26	36		SW-04	1.5		NB-22	0.7
	OA-08	0.62		BD-12	39		GS-04	1.7		SW-02	0.78
	SW-02	0.68		EP-03	39		NB-14	1.7		NB-14	0.82
	EP-03	0.82		EP-06	51		EP-06	1.8		OA-04	1.1
	OA-11	0.84		OA-08	61		BP-05	1.8		DM-02	1.1
	BD-11	0.92		EP-01	90		NB-11	1.8		BD-10	1.1
	OA-13	1.1		BD-11	110		SW-02	2.6		EP-04	1.6
	EP-02	2.6		EP-02	150		EP-08	2.9		EP-02	2
	EP-04	2.8		EP-04	240		BD-10	2.9		EP-11	0.69
	EP-01	3.4		BD-10	300		EP-10	4.1		OA-35	0.69

Element	Sample ID	Concen-tration (mg/kg)	Element	Sample ID	Concen-tration (mg/kg)
Thallium	**Site Bkg**	**Not detected**	Zinc	**Site Bkg**	**310**
	SW-01	2.1		NB-11	380
	OA-08	2.1		NB-10	400
	SW-04	2.1		EP-09	500
	OA-03	2.2		EP-02	520
	EP-02	2.2		BD-10	520
	NB-14	2.6		NB-23	540
	EP-06	2.9		OA-01	610
	OA-12	3.1		EP-06	660
	BD-10	4.7		EP-12	900
	SW-02	5.4		EP-04	1300

*Site Bkg: Site-specific background concentration for surface soil, as calculated in Appendix J. N.C.: Not calculated, refer to Appendix J.

Table 4.14. Comparison of Hematite Site surface soil results with local, regional, and international compilations (mg/kg)

	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium
			Hematite Site samples			
Max	24,000	21	160	1,500	5.8	11
Min	2,000	0.87	1.1	24	0.33	0.22
			Off-Site samples			
Mean	10,444	Not detected	7	192	0.64	0.36
Range	(4,500 to 17,000)	(<~1.2)	(5.1 to 9.6)	(80 to 340)	(<0.36 to 0.92)	(<0.24 to 0.72)
Site Background[a]	17,000.	N.C.	9.6	330.	0.77	0.6
			Tidball (1984)			
Geometric mean	41,000		8.7	580	0.8	<1
Range	(11,000 to 79,000)	-	(2.5 to 72)	(100 to 1,500)	(<1 to 2)	(<1 to 11)
			IEPA 1994			
Mean			6.7			0.97
Range			(0.35 to 24)			(ND to 8.2)
			Connor and Shacklette (1975), Missouri Region geometric mean or range of means (maximum background value)			
Shale/Clay[b]			6.4 to 9 (27)		1.1 to 1.7 (3)	<1 (5)
Sandstone/Sand[b]			1.1 to 4.3 (25)		0.8 (1.5)	----
Carbonates[b]			0.7 to 2.5 (39)		<1 (1)	<1 (12)
Soil[b]			5.5 to 13 (170)		0.8 to 1.3 (2)	<1 (11)
Loess[b]			8.3 (13)		0.95 (1.5)	----
			Lindsay (1973), soil			
Mean	71,000	----	5	430	6	0.06
Range	10,000-300,000		1 to 50	100 to 3,000	0.1 to 40	0.01 to .7
			Fergusson and Kim (1991)			
Urban street dust (range)	15,000-60,000	2 to 10	4 to 15	310	----	0.5 to 4
House dust (mean or range)	25,000	10	16	----	----	5 to 10

[a]Site Background = see Appendix J;

[b]Geometric mean or range of means and maximum background value, Missouri region (Connor and Shacklette 1975).

*Dreher, G.B., and L.R. Follmer 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = not detected.

N.C. = Not calculated, refer to Appendix J for discussion of how elements were selected for Site background calculation.

Table 4.14. Comparison of Hematite Site surface soil results with local, regional, and international compilations (mg/kg) (continued)

Element	Calcium	Chromium	Cobalt	Copper	Fluoride	Iron
			Hematite Site samples			
Max	250,000	280	300	1,800	170	61,000
Min	860	4.9	0.86	5.6	5.7	1,600
			Off-Site samples			
Mean	4,192	13	9	11	---	17,365
Range	(830 to 14,000)	(8 to 24)	(4.8 to 14)	(7.6 to 13)	---	(9,700 to 26,000)
Site Background[a]	N.C.	17	17	13	---	26000
			Tidball (1984)			
Geometric mean	3,300	54	10	13	270	21,000
Range	(>700 to 56,000)	(10 to 150)	(<3 to 30)	(5 to 150)	(10 to 6,400)	(4,900 to 54,000)
			IEPA 1994			
Mean		17.3		19.7		
Range		(<2 to 151)		(1 to 156)		
			Connor and Shacklette 1975, Missouri Region			
			geometric mean or range of means (maximum background value)			
Shale/Clay		95 to 130 (700)		13 (100)		
Sandstone/Sand		2 to 7.4 (100)		1.2 to 8.4 (30)		
Carbonates		2.7 to 16 (70)		0.8 to 5.3 (20)		
Soil		30 to 70 (150)		11 to 23 (150)		
Loess		70 (100)		18 (30)		
			Lindsay 1973, soil			
Mean	13,700	100	8	30		38,000
Range	7,000 to 500,000	1 to 1000	1-40	2 to 100		7,000 to 555,000
			Fergusson and Kim 1991			
Urban street dust (range)	4000 to 120,000	20 to 200	6-9	100 to 300	----	10,000 to 60,000
House dust (mean or range)	15,000	30 to 100	9	200 to 300	----	10,000

[a]Site Background: see Appendix J;

[b]Geometric mean or range of means and maximum background value, Missouri region (Connor and Shacklette 1975).

*Dreher, G.B., and L.R. Follmer 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = not detected.

N.C. = Not calculated, refer to Appendix J for discussion of how elements were selected for Site background calculation.

Table 4.14. Comparison of Hematite Site surface soil results with local, regional, and international compilations (mg/kg) (continued)

Element	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium
			Hematite Site samples			
Max	1,400	53,000	4,400	3.4	300	8,000
Min	3.7	790	41	0.022	5.3	380
			Off-Site samples			
Mean	41	2,528	655	0.03	13	740
Range	(12 to 90)	(1,600 to 5,600)	(240 to 1,100)	(<0.23 to 0.053)	(7.4 to 17)	(460 to 1,100)
Site Background[a]	81	N.C.	1100	.0.04	14	N.C.
			Tidball (1984)			
Geometric mean range	20	2,600	740	0.039	14	4,000
	(10 to 7,000)	(500 to 28,000)	(15 to 3,000)	(<0.1 to 0.8)	(<5 to 70)	(3,300 to 37,000)
			IEPA 1995			
Mean	49.2			0.11	16.8	1,363
Range	(4.7 to 647)			(ND to 1.67)*	(<3 to 135)	270 to 5,820
			Connor and Shacklette 1975, Missouri Region			
			geometric mean or range of means (maximum background value)			
Shale/Clay[b]	11 to 17 (100)		140 to 170 (500)	0.045 (0.19)	21 to 38 (100)	
Sandstone/Sand[b]	17 (150)		29 to 300 (3,000)	0.008 to 0.016 (0.15)	<5 to 18 (150)	
Carbonates[b]	<10 to 4 (7,000)		83 to 830 (7,000)	0.022 to 0.03 (0.17)	<5 to 4.3 (15)	
Soil[b]	18 to 31 (200)		350 to 1,100 (>20,000)	0.03 to 0.16 (1.5)	8.4 to 23 (300)	
Loess[b]	15 (20)		510 (1,000)	0.035 (0.08)	22 (30)	
			Lindsay (1973), soil			
Mean	10	5,000	600	0.03	40	8,300 (400-
Range	2 to -100	600 to 6,000	20 to 3,000	0.01 to 0.3	(5-500)	30,000)
			Fergusson and Kim (1991)			
Urban street dust (range)	500 to 4,000	5,000 to 10,000	300 to 800	0.09	50 to 100	5,000 to 20,000
House dust (mean or range)	300 to 1,000	6,500	200	----	40	13,000

[a]Site Background: see Appendix J;

[b]Geometric mean or range of means and maximum background value, Missouri region (Connor and Shacklette 1975).

*Dreher, G.B., and L.R. Follmer 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = not detected.

N.C. = Not calculated, refer to Appendix J for discussion of how elements were selected for Site background calculation.

Table 4.14. Comparison of Hematite Site surface soil results with local, regional, and international compilations (mg/kg) (continued)

Element	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc
			Hematite Site samples			
Max	4.1	1.1	3,300	2.2	45	1,300
Min	0.54	4.54	120	0.87	5.4	19
			Off-Site samples			
Mean	0.75	ND	141	ND	28	127
Range	(<0.6 to <1.2)		(<120 to 210)		(16 to 36)	(33 to 370)
Site Background[a]	0.97.		N.C.		39	310
			Tidball (1984)			
Mean Range	0.28	<0.7	5,300	-	69	49
	(<0 to 1-2.7)	(<0.7 to 3)	(700 to 12,000)		(15 to 150)	(18 to 640)
			IEPA 1994			
Mean Range	0.5	0.84	216	0.57	25	102.9
	(<.1 to 2.6)	(<0.06 to 5.9)	(14.1 to 7,600)	(0.02 to 2.8)	(<2.5 to 80)	(<5.5 to 798)
			Connor and Shacklette (1975), Missouri Region geometric mean or range of means (maximum background value)			
Shale/Clay[b]						55 to 82 (250)
Sandstone/Sand[b]						5 to 31 (280)
Carbonates[b]						6 to 24 (140)
Soil[b]						30 to 68 (640)
Loess[b]						61 (90)
			Lindsay 1973, soil			
Mean (range)	0.3	0.05	6,300		100	50
	(0.1 to 2)	(0.1 to 5)	(750 to 7,500)		(20 to 500)	(10 to 300)
			Fergusson and Kim 1991			
Urban street dust (range)	1 to 8	0.2 to 1.2	5,000 to 20,000	----	40 to 200	300 to 900
House dust (mean or range)	-----	----	12,000	----	30	800 to 1,600

[a]Site Background: see Appendix J;

[b]Geometric mean or range of means and maximum background value, Missouri region (Connor and Shacklette 1975).

*Dreher, G.B., and L.R. Follmer 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = not detected.

N.C. = Not calculated, refer to Appendix J for discussion of how elements were selected for Site background calculation.

Table 4.15. Ten highest inorganic concentrations (mg/kg) in subsurface soils (Last two digits of Station ID-Depth refers to sample depth in ft.)

	Station ID-depth	Conc. (mg/kg)		Station ID-depth	Conc. (mg/kg)		Station ID-depth	Conc. (mg/kg)		Station ID-depth	Conc. (mg/kg)
	Site Bkg	**9.8**		**Site Bkg**	**N.C.**		**Site Bkg**	**0.92**		**Site Bkg**	**0.72**
Arsenic	NB-47-15	12	Antimony	BD-15-17	1.2	Beryllium	SW-07-23	1.1	Cadmium	NB-86-19	0.93
	BD-16-19	13		DM-03-25	1.2		SW-08-15	1.1		NB-78-18	0.99
	BP-20-27	13		EP-20-25	1.2		CB-02-05	1.1		SW-02-09	1
	EP-13-30	13		NB-38-15	1.2		BP-13-25	1.1		PL-06-29	1.1
	NB-72-19	13		NB-53-13	1.2		SW-02-09	1.1		NB-36-15	1.1
	EP-14-05	14		NB-55-25	1.2		NB-47-15	1.1		NB-51-25	1.2
	OA-18-25	14		NB-65-13	1.2		BD-14-25	1.2		SW-02-15	1.3
	EP-18-09	17		NB-69-22	1.2		SW-02-15	1.2		BD-05-23	1.5
	DM-03-34	20		NB-50-25	1.5		BD-15-17	1.8		NB-32-27	3.7
	BP-18-25	24		NB-39-15	1.8		SW-02-01	2.8		SW-02-01	4.7
	Station ID-depth	**Conc. (mg/kg)**		**Station ID-depth**	**Conc. (mg/kg)**		**Station ID-depth**	**Conc. (mg/kg)**		**Station ID-depth**	**Conc. (mg/kg)**
Chromium	**Site Bkg**	**24**	Cobalt	**Site Bkg**	**14**	Copper	**Site Bkg**	**13**	Lead	**Site Bkg**	**90**
	BP-20-03	26		NB-31-05	17		NB-68-25	29		RR-04-05	51
	NB-29-22	26		GS-07-05	17		SW-08-15	30		NB-42-13	53
	NB-83-23	27		LF-07-15	18		NB-49-25	30		NB-41-05	68
	BD-02-21	28		BD-04-02	19		DM-02-25	30		NB-29-05	86
	NB-82-05	28		NB-46-25	20		OA-19-25	31		BD-13-09	95
	NB-84-33	28		BD-06-01	31		NB-51-25	31		NB-42-05	98
	EP-18-09	29		BD-07-02	32		BP-18-15	31		NB-67-05	110
	NB-83-11	35		BD-08-01	39		NB-47-15	32		NB-82-05	110
	NB-76-24	41		BD-01-01	50		NB-50-25	32		NB-63-05	120
	BD-05-01	49		NB-36-15	54		BD-05-23	38		NB-75-19	680

Site Bkg: Site background, see Appendix J.

N.C. = Not calculated; refer to Appendix J, Background Calculation, regarding selection of elements for background calculations.

Table 4.15. Ten highest inorganic concentrations (mg/kg) in subsurface soils (Last two digits of Station ID-Depth refers to sample depth in ft.) (continued)

	Station ID-depth	Concentration (mg/kg)		Station ID-depth	Concentration (mg/kg)		Station ID-depth	Concentration (mg/kg)
Mercury	**Site Bkg**	**0.05**	Nickel	**Site Bkg**	**17**	Selenium	**Site Bkg**	**0.85**
	OA-18-33	0.055		BP-18-15	37		NB-69-05	2
	BD-05-23	0.056		NB-58-29	38		BD-05-23	2.2
	NB-32-27	0.057		NB-49-25	39		NB-49-25	2.2
	BD-16-25	0.06		SW-08-15	39		NB-50-25	2.2
	NB-47-15	0.061		NB-50-25	40		NB-51-37	2.2
	BD-16-34	0.068		EP-18-09	42		SW-08-25	2.3
	SW-08-15	0.073		NB-47-15	44		NB-37-15	2.4
	EP-18-09	0.19		NB-36-15	60		NB-47-15	2.6
	SW-02-09	0.25		BD-05-23	71		NB-50-15	2.6
	SW-02-01	0.54		NB-85-25	97		NB-47-31	2.9

	Station ID-depth	Concentration (mg/kg)		Station ID-depth	Concentration (mg/kg)
Thallium	**Site Bkg**	**Not detected**	Zinc	**Site Bkg**	**370**
	BD-16-25	2.3		NB-67-05	220
	NB-50-25	2.3		NB-82-05	230
	NB-48-15	2.4		BP-18-31	230
	BD-16-19	2.6		NB-29-05	240
	OA-18-03	2.9		NB-77-24	240
	OA-19-05	3		BD-13-30	240
	BP-18-15	3.2		NB-82-20	300
	NB-36-15	5		NB-42-05	380
	NB-37-15	5.1		NB-76-24	520
	BD-05-23	5.4		NB-63-05	850

Site Bkg: Site background, see Appendix J. N.C. = Not calculated; refer to Appendix J, Background Calculation, regarding selection of elements for background calculations.

Table 4.16. Comparison of Hematite Site subsurface soil results with local, regional, and international compilations (mg/kg)

Element	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium
			Hematite Site samples			
Max	27,000	1.8	24	790	2.8	4.7
Min	680	0.85	1.1	9.6	0.32	0.21
			Off–Site samples			
Mean	10,444	Not detected	7	192	0.64	0.36
Range	(4,500 to 17,000)	(<~1.2)	(5.1 to 9.6)	(80 to 340)	(<0.36 to 0.92)	(<0.24 to 0.72)
Site Background[a]	17,000	N.C.	9.8	320	0.92	0.72
			Tidball (1984)			
Geometric mean	41,000	-	8.7	580	0.8	<1
Range	(11,000 to -79,000)		(2.5 to 72)	(100 to 1,500)	(<1 to 2)	(<1 to 11)
			IEPA 1994			
Mean			6.7			0.97
Range			(0.35 to 24)			(ND to 8.2)
			Connor and Shacklette 1975, Missouri Region			
			geometric mean or range of means (maximum background value)			
Shale/Clay			6.4 to 9 (27)		1.1-1.7 (3)	<1 (5)
Sandstone/Sand			1.1 to 4.3 (25)		0.8 (1.5)	----
Carbonates			0.7 to 2.5 (39)		<1 (1)	<1 (12)
Soil			5.5 to 13 (170)		0.8-1.3 (2)	<1 (11)
Loess			8.3 (13)		0.95 (1.5)	-----
			Lindsay 1973, soil			
Mean	71,000	----	5	430	6	0.06
Range	(10,000 to 300,000)		(1 to 50)	(100 to 3,000)	(0.1 to 40)	(0.01 to .7)

[a]Site Background: see Appendix J;

[b]Dreher, G.B., and L.R. Follmer. 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 μg/kg with a background average of 20 +/- 9 μg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = Not detected.

N.C. = Not calculated, refer to Appendix J for discussion of how elements were selected for Site background calculation.

Table 4.16. Comparison of Hematite Site subsurface soil results with local, regional, and international compilations (mg/kg) (Continued)

Element	Calcium	Chromium	Cobalt	Copper	Fluoride	Iron
			Hematite Site samples			
Max	190,000	49	54	38	190	35,000
Min	300	5.8	1.7	1.5	5.4U	2,100
			Off-Site samples			
Mean	4,192	13	9	11	---	17,365
Range	(830 to 14,000)	(8 to 24)	(4.8 to 14)	(7.6 to 13)	---	(9,700 to 26,000)
Site Background[a]	N.C.	24.	14.	13.	---	24,000.
			Tidball (1984)			
Geometric mean	3,300	54	10	13	270	21,000
Range	(<700 to 56,000)	(10 to 150)	(<3 to 30)	(5 to 150)	(10 to 6400)	(4,900 to 54,000)
			IEPA, 1994			
Mean		17.3		19.7		
Range		(<2-151)		(1-156)		
			Connor and Shacklette 1975, Missouri Region			
			geometric mean or range of means (maximum background value)			
Shale/Clay		95 to 130 (700)		13 (100)		
Sandstone/Sand		2 to 7.4 (100)		1.2 to 8.4 (30)		
Carbonates		2.7 to 16 (70)		0.8 to 5.3 (20)		
Soil		30 to 70 (150)		11 to 23 (150)		
Loess		70 (100)		18 (30)		
			Lindsay 1973, soil			
Mean	13,700	100	8	30		38,000
Range	7,000 to 500,000	1 to 1,000	1 to 40	2 to 100		7,000 to 555,000

[a]Site Background: see Appendix J

.[b]Dreher, G.B., and L.R. Follmer. 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = Not detected.

N.C. = Not calculated, refer to Appendix J for discussion of how elements were selected for Site background calculation

Table 4.16. Comparison of Hematite Site subsurface soil results with local, regional, and international compilations (mg/kg) (Continued)

	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium
			Hematite Site samples			
Max	680	77,000	5,700	0.54	97	4,400
Min	3.8	160	20	0.013	2.7	110
			Off-Site samples			
Mean	41	2528	655	0.03	13	740
Range	(12 to 90)	(1,600 to 5,600)	(240 to 1,100)	(<0.23 to 0.053)	(7.4 to 17)	(460 to 1,100)
Site Background[a]	90	N.C.	960	0.05	17.	N.C.
			Tidball (1984)			
Mean	20	2600	740	0.039	14	14,000
Range	(10 to 7,000)	(500 to 28,000)	(15 to 3,000)	(<0.01 to 0.8)	(<5 to 70)	(3,300 to 37,000)
			IEPA 1994			
Mean	49.2			0.11	16.8	
Range	(4.7 to 647)			(ND to 1.67)[b]	(ND to 135)	
			Connor and Shacklette 1975, Missouri Region geometric mean or range of means (maximum background value)			
Shale/Clay	11 to 17 (100)		140 to 170 (500)		21 to 38 (100)	
Sandstone/Sand	17 (150)		29 to 300 (3,000)		<5 to 18 (150)	
Carbonates	<10 to 4 (7,000)		83 to 830 (7,000)		<5 to 4.3 (15)	
Soil	18 to 31 (200)		350 to 1,100 (>20,000)		8.4 to 23 (300)	
Loess	15 (20)		510 (1,000)		22 (30)	
			Lindsay 1973, soil			
Mean	10	5,000	600	0.03	40	8,300
Range	2 to 100	600 to 6,000	20 to 3,000	0.01 to 0.3	5 to 500	400 to 30,000

[a]Site Background: see Appendix J;

[b]Dreher, G.B., and L.R. Follmer. 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = Not detected.

N.C. = Not calculated; refer to Appendix J, Background Calculation, regarding selection of elements for UTL calculations.

Table 4.16. Comparison of Hematite Site subsurface soil results with local, regional, and international compilations (mg/kg) (Continued)

	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc
			Hematite Site samples			
Max	2.9	0.85	1,600	2.6	56	850
Min	0.53	0.53	110	0.85	8	18
			Off-Site samples			
Mean	0.75	ND	141	ND	28	127
Range	(<0.6 to <1.2)		(<120 to 210)		(16 to 36)	(33 to 370)
Site Background[a]	0.85.		N.C.		40.	370
			Tidball (1984)			
Mean	0.28	<0.7	5,300	-	69	49
Range	(<0.1 to 2.7)	(<0.7 to 3)	(700 to 12,000)		(15 to 150)	(70 to 700)
			IEPA 1994			
Mean						102.9
Range						(ND-798)
			Connor and Shacklette 1975, Missouri Region geometric mean or range of means (maximum background value)			
Shale/Clay						55 to 82 (250)
Sandstone/Sand						5 to 31 (280)
Carbonates						6 to 24 (140)
Soil						30 to 68 (640)
Loess						61 (90)
			Lindsay 1973, Soil			
Mean	0.3	0.05	6,300	-	100	50
Range	1 to 2	0.01 to 5	750 to 7,500		20 to 500	10 to 300

[a]Site Background: see Appendix J

[b]Dreher, G.B., and L.R. Follmer. 2004. Mercury content of Illinois soils. Water, Air, and Soil Pollution. 156:299-315. This study provides a more recent value from 101 cores, 6 samples per core yielding a mean core content of 33 +/- 20 µg/kg with a background average of 20 +/- 9 µg/kg. The higher value was presumed biased by dry deposition from power plants or waste incinerators.

ND = Not detected.

N.C. = Not calculated; refer to Appendix J, Background Calculation, regarding selection of elements for UTL calculations.

Table 4.17. Uranium activities in Hematite Site surface water samples (pCi/L) (Refer to Fig. 2.2 for sampling locations.)

Sample ID	^{234}U	^{235}U	^{238}U	Surface water body sampled
SW-01-SW	29.6	1.24	4.77	Site Pond, near dam.
SW-02-SW	1.49	0.14J	0.418	Lake Virginia Tributary/Site Creek combined stream.
SW-08-SW	0.839	0.0804LT	0.363	Northeast Site Creek/East Lake Tributary combined stream.
SW-09-SW	1.78	0.106LT	0.818	Northeast Site Creek, downstream of Burial Pits
SW-14-SW	0.549	0.0545LT	0.276	Joachim Creek.
SW-15-SW	0.594	0.0641LT	0.321	Joachim Creek.
SW-16-SW	0.483	U	0.152LT	Joachim Creek.
US-01-SW	0.492	0.0306LT	0.281	Northeast Site Creek, upstream of Burial Pits.
US-02-SW	0.678	U	0.74	Lake Virginia Tributary, upstream of Site Creek confluence point.
US-03-SW	0.538	U	0.215	Site Pond, near Site Spring.
US-04-SW	0.516	U	0.329	East Lake Tributary.
US-05-SW	0.439	U	0.221	Joachim Creek.

LT = result is less than requested minimum detectable activity (MDA) but greater than sample MDA.
J = estimated value.
U = below MDA, ~0.05 pCi/L.

Table 4.18. Uranium activity in groundwater by alpha spectrometry (Samples with ^{234}U activity > 2 pCi/L; refer to Figs. 2.6a and 2.6b for well locations.)

Sampling station/ well ID	Formation	Area of concern or general location	^{234}U (pCi/L)	^{235}U (pCi/L)	^{238}U (pCi/L)
BD-01	Deep overburden	Buildings.	8.91	0.383	1.58
BD-02	Deep overburden	Buildings.	8	0.427	1.61
BD-03	Deep overburden	Buildings.	13.8	0.451	2.03
BD-05	Deep overburden	Buildings.	8.8	0.355	1.58
BD-06	Deep overburden	Buildings.	2.33	0.131 J	-
BD-08	Deep overburden	Buildings.	6.17	0.179 LT	-
BD-16	Deep overburden	Buildings.	11.1	0.526	7.84
DM-02	Deep overburden	Deul's Mountain.	315	16.5	56.3
OA-19	Deep overburden	Buildings, Deul's Mountain.	3.04	-	-
WS-07	Shallow overburden	Evaporation Ponds.	12.6	0.532	1.95
WS-15	Shallow overburden	Burial Pits.	-	0.107 LT	-
WS-24	Shallow overburden	Burial Pits.	172	7.57	26.6
WS-26	Shallow overburden	Burial Pits.	19	0.675	10.9
NB-67	Deep overburden	South of Facility, towards Joachim Creek.	-	0.114 LT	0
WS-30	Jefferson City-Cotter	Burial Pits.	6.03	0.161 LT	1.72
BR-01-JC	Jefferson City-Cotter	West of the Hematite Facility.	2.13	-	-
BR-01-RB	Roubidoux	West of the Hematite Facility.	4.08	-	1.09
BR-02-RB	Roubidoux	Southeast of the Hematite Facility.	3.62	-	-
BR-03-JC	Jefferson City-Cotter	South-southeast of the Hematite Facility near Joachim Creek.	3.42	-	-
BR-03-RB	Roubidoux	South-southeast of the Hematite Facility near Joachim Creek.	2.07	-	-
BR-04-JC	Jefferson City-Cotter	East-northeast of the Hematite Site.	3.78	-	-
BR-04-RB	Roubidoux	East-northeast of the Hematite Site.	3.28	-	-
BR-05-RB	Roubidoux	East-northeast of the Hematite Facility.	5.82	-	-
BR-06-OB	Overburden	South of the Hematite Facility near Joachim Creek.	5.65	0.251 LT	1.56
BR-06-RB	Roubidoux	South of the Hematite Facility near Joachim Creek.	7.91	-	-
BR-07-JC	Jefferson City-Cotter	South-southeast of the Hematite Facility, across Joachim Creek.	4.72	-	1.43
BR-07-RB	Roubidoux	South-southeast of the Hematite Facility, across Joachim Creek.	5.22	-	-
BR-08-RB	Roubidoux	South-southeast of the Hematite Facility, towards Joachim Creek.	5.78	-	-
BR-09-JC	Jefferson City-Cotter	East of the Hematite Facility.	2.57	-	-
BR-10-JC	Jefferson City-Cotter	South-southeast of the Hematite Facility, near Joachim Creek.	2.05	-	-
BR-10-RB	Roubidoux	South-southeast of the Hematite Facility, near Joachim Creek.	4.5	-	-
BR-11-JC	Jefferson City-Cotter	East of the Hematite Facility near Joachim Creek.	2.16	-	-
BR-12-JC	Jefferson City-Cotter	North-northwest of the Hematite Facility, across Highway P.	4.45	-	1.21
BR-12-RB*	Roubidoux	North-northwest of the Hematite Facility, across Highway P.	12.5 (5.73)	-	1.22 (0.69)

LT = below the required minimum detectable concentration (MDC) but higher than the sample-specific MDC.
J = estimated value.
"-" = below the sample-specific MDC.
*Numbers in parentheses are activities measured in a groundwater sample collected in June 2005.

Table 4.19. Isotopic thorium in unfiltered groundwater samples (pCi/L)

Sample Station/ Well ID	Formation	Area of concern or general location	$^{228}Th^{a}$	$^{230}Th^{a}$	$^{232}Th^{a,b}$
BD-02	Deep overburden	Buildings.	0.644	0.907	0.586
BD-03	Deep overburden	Buildings.	0.288	0.405	0.265
BD-05	Deep overburden	Buildings.	-	0.25	0.244
BD-06	Deep overburden	Buildings.	0.167 J	-	-
BD-16	Deep overburden	Buildings.	1.1	1	0.834
BR-01-JC[c]	Jefferson City-Cotter	West of the Hematite Facility.	0.997	0.694	0.736
BR-07-RB	Jefferson City-Cotter	South-southeast of the Hematite Facility across creek.	0.141 J	-	-
EP-15	Deep overburden	Evaporation Ponds.	-	-	0.00709
EP-20	Deep overburden	Evaporation Ponds.	-	0.225M3	-
NB-35	Deep overburden	South of the Hematite Facility.	0.228	0.354	0.222
NB-73	Deep overburden	South of the Hematite Facility, towards Joachim Creek.	0.25	0.219	-
OB-2	Deep overburden	East of the Hematite Facility, near Joachim Creek.	0.259	0.306	0.241
WS-14	Shallow overburden	Burial Pits.	-	0.207	-
WS-23	Deep overburden	Near Burial Pits.	-	0.383	0.233
WS-25	Deep overburden	Burial Pits.	-	0.206	-

[a]"-" = not detected; J = estimated; M3 = requested minimum detectable concentration (MDC) not met, activity is greater than the reported MDC.

[b]There are other "detects" for ^{232}Th but all are qualified LT (below the required MDC but above the sample-specific MDC).

[c]Thorium isotopes not detected in filtered BR-01-JC samples; detection limits of 0.132, 0.149, and 0.018 pCi/L for ^{228}Th, ^{230}Th, and ^{232}Th, respectively.

Table 4.20. ^{99}Tc activities in groundwater (pCi/L)

Sample ID	Formation	Area of concern or general location	^{99}Tc
BD-01	Deep overburden	Buildings.	191
BD-02	Deep overburden	Buildings.	5100
BD-04	Deep overburden	Buildings.	298
BD-05	Deep overburden	Buildings.	117
BD-08	Deep overburden	Buildings.	20.5
BP-22B	Shallow overburden	Burial Pits.	70.3
DM-02	Deep overburden	Deul's Mountain.	44.1
EP-15	Deep overburden	Evaporation Ponds.	362
EP-16	Deep overburden	Evaporation Ponds.	675
EP-16 (duplicate)	Deep overburden	Evaporation Ponds.	712
EP-20	Deep overburden	Evaporation Ponds.	2080
LF-08	Deep overburden	Former Leach Fields.	246
NB-31	Deep overburden	South-southeast of the Hematite Facility.	30.6
PL-06	Deep overburden	Pipeline, South of the Hematite Facility.	92.3
WS-14	Shallow overburden	Burial Pits.	138
WS-15	Shallow overburden	Burial Pits.	20.9
WS-16	Shallow overburden	Burial Pits.	24
WS-17B	Shallow overburden	Deul's Mountain.	3610
WS-24	Shallow overburden	Burial Pits.	23.8
WS-28	Shallow overburden	Burial Pits.	20.9
WS-07	Shallow overburden	Evaporation Ponds.	476

Table 4.21. Isotopic uranium activity in sediments (pCi/g) (Refer to Fig. 2.3 for sample locations.)

	Alpha spectroscopy			Gamma spectroscopy
Sample ID	^{234}U (pCi/g)	^{235}U (pCi/g)	^{238}U (pCi/g)	^{235}U (pCi/g)
SW-01-SS	236 M3	10.6	29.5 M3	12.2 G
SW-02-SS	3.99	0.175	1.03	-
SW-03-SS	7.92	0.402	1.39	-
SW-04-SS	2.8	0.093 J	0.952	-
SW-05-SS	19.1	0.78	3.33	-
SW-06-SS	937	41.7	84.6	37.3
SW-07-SS	291	14.1	41.4	14.8 G
SW-08-SS	0.331	-	0.299	-
SW-08-SS-FD	0.32	-	0.283	-
SW-10-SS	0.468	-	0.517	-
SW-11-SS	1.12		0.599	-
SW-12-SS	1.47	0.076 LT	0.566	-
SW-13-SS	0.989	0.0488 LT	0.593	-
SW-14-SS	0.25	0.024 LT	0.244	-
SW-15-SS	0.548	0.0272 LT	0.619	-
SW-16-SS	0.28	-	0.262	-
US-04-SS	0.265	0.0265 LT	0.322	-
US-05-SS	0.229	-	0.262	-

G = sample density differs by more than 15% of LCS density.
J = estimated result.
LT = result is < than the requested minimum detectable concentration (MDC), but > than the sample-specific MDC.
M3 = requested MDC was not met, but the result exceeded the sample-specific MDC.
"-" = below the detection limit.

Table 4.22. ^{99}Tc activity in sediments (pCi/g) (Refer to Fig. 2.3 for sample locations.)

Sample ID	^{99}Tc
SW-01-SS	255
SW-02-SS	1.36 LT
SW-03-SS	2.8 LT
SW-04-SS	1.91 LT
SW-05-SS	16.8
SW-06-SS	284
SW-07-SS	36.3
SW-08-SS	-
SW-10-SS	-
SW-11-SS	-
SW-12-SS	4.36
SW-13-SS	1.54 LT
SW-14-SS	-
SW-15-SS	-
SW-16-SS	-
US-04-SS	-
US-05-SS	-

LT = result is < than the requested minimum detectable concentration (MDC), but > than the sample-specific MDC.
"-" ^{99}Tc was not detected; detection limit of 2 pCi/L.

Table 4.23. Isotopic uranium in surface soils (pCi/g) (Samples analyzed using alpha spectroscopy and samples with detectable ^{235}U activities from gamma spectroscopy analysis are shown in the table; shaded sample results are potentially contaminated using ^{235}U = 0.14 pCi/g as a reference value to distinguish contaminated from uncontaminated soils. Refer to text for discussion of reference value.)

Sample ID	Alpha spectroscopy			Gamma spectroscopy
	^{234}U	^{235}U	^{238}U	^{235}U
BP-12-00-SL	2.35	0.138	1	0.32 U,G
EP-11-00-SL	103	4.26	11.2	2.43 U,G
NB-02-00-SL	0.759	0.026 LT	0.373	0.334 U,G
NB-06-00-SL	0.888	0.0565 LT	0.851	0.3 U,G
NB-12-00-SL	1.45	0.08 LT	0.903	0.155 U,G
NB-14-00-SL	52.3	1.98	3.53	0.606 U,G
NB-17-00-SL	1.09	0.0328 LT	0.801	0.106 U,G
NB-23-00-SL	1.12	0.0843 LT	0.913	0.0327 U,G
OA-08-00-SL	472 M3	19.5 M3	74.3 M3	23.2 U,G
OA-37-00-SL	1.93	0.127	1.08	0.154 U,G
BD-09-00-SL	NA	NA	NA	3.63 G
BD-10-00-SL	NA.	NA	NA	104 G
BD-11-00-SL	NA.	NA	NA	102 G
BD-12-00-SL	NA	NA	NA	20.2 G
BP-03-00-SL	NA	NA	NA	35.3 G
BP-04-00-SL	NA	NA	NA	1.2 G,TI
BP-07-00-SL	NA	NA	NA	53.5 G
CB-01-00-SL	NA	NA	NA	2.87
DM-01-00-SL	NA	NA	NA	308 G
DM-02-00-SL	NA	NA	NA	237 G
EP-01-00-SL	NA	NA	NA	31.2 G
EP-02-00-SL	NA	NA	NA	30.3 G
EP-03-00-SL	NA	NA	NA	6.97 G
EP-04-00-SL	NA	NA	NA	184 G
EP-05-00-SL	NA	NA	NA	18.5 G
EP-06-00-SL	NA	NA	NA	96.5 G
EP-08-00-SL	NA	NA	NA	8.87 G
EP-09-00-SL	NA	NA	NA	4.95 G
EP-10-00-SL	NA	NA	NA	51.4 G
EP-12-00-SL	NA	NA	NA	4.81 G
NB-03-00-SL	NA	NA	NA	0.682 G,TI
NB-11-00-SL	NA	NA	NA	3 G
OA-01-00-SL	NA	NA	NA	4.57
OA-02-00-SL	NA	NA	NA	3.61
OA-04-00-SL	NA	NA	NA	12.2 G
OA-07-00-SL	NA	NA	NA	1.51 G
OA-11-00-SL	NA	NA	NA	2.71 G
OA-13-00-SL	NA	NA	NA	3.6 G
OA-14-00-SL	NA	NA	NA	1.14 G
OA-16-00-SL	NA	NA	NA	1.03 G,TI
OA-21-00-SL	NA	NA	NA	2.88 G
OA-22-00-SL	NA	NA	NA	1.86
OA-23-00-SL	NA	NA	NA	120
OA-26-00-SL	NA	NA	NA	39
PL-01-00-SL	NA	NA	NA	2.43 G
PL-03-00-SL	NA	NA	NA	0.0394
LS-03-00-SL	NA	NA	NA	1.67 G

continued next page

Table 4.23 (continued). Isotopic uranium in surface soils (pCi/g) (Samples analyzed using alpha spectroscopy and samples with detectable ^{235}U activities from gamma spectroscopy analysis are shown in the table; shaded sample results are potentially contaminated using ^{235}U = 0.14 pCi/g as a reference value to distinguish contaminated from uncontaminated soils. Refer to text for discussion of reference value.) (continued)

Sample ID	Alpha spectroscopy			Gamma spectroscopy
	^{234}U	^{235}U	^{238}U	^{235}U
RR-01-00-SL	NA	NA	NA	57.9
SW-01-00-SL	NA	NA	NA	2.86
SW-02-00-SL	NA	NA	NA	11.8

G = sample density differed by more than 15% from the LCS density.

LT= result is < than the requested minimum detectable concentration (MDC), but > than the sample-specific MDC.

NA = not analyzed.

TI = radionuclide identification was tentative.

Table 4.24. ^{99}Tc in surface soil (pCi/g) (Refer to Fig. 4.17 for anomalous sample locations and Figs. 2.4a and 2.4b for locations of all samples analyzed for ^{99}Tc; samples with activities above the MDC (1 pCi/g) are shown below.)

Sample ID	^{99}Tc	Sample ID	^{99}Tc
BD-09-00-SL	86.9	BD-10-00-SL	176 M3
BD-12-00-SL	574	BD-11-00-SL	19 M3
BP-03-00-SL	8.83	BP-02-00-SL	1.13 LT
BP-04-00-SL	68.3	BP-05-00-SL	2.81 LT
BP-06-00-SL	6.36	DM-01-00-SL	35.8 M3
BP-07-00-SL	26.3	DM-02-00-SL	154 M3
CB-01-00-SL	5.15	EP-02-00-SL	219 M3
EP-01-00-SL	183	EP-04-00-SL	189 M3
EP-03-00-SL	17.2	EP-10-00-SL	17100 M3
EP-05-00-SL	5.24	EP-11-00-SL	112 M3
EP-06-00-SL	51	LF-02-00-SL	0.902 LT
EP-07-00-SL	23.5	LF-03-00-SL	1.56 LT
EP-08-00-SL	3420	LF-04-00-SL	2.38 LT
EP-09-00-SL	111	NB-13-00-SL	1.2 LT
EP-12-00-SL	59.9	NB-14-00-SL	7.43 M3
LF-01-00-SL	5.49	NB-15-00-SL	1.81 LT
LF-05-00-SL	12.3	OA-07-00-SL	1.59 LT
NB-11-00-SL	12.7	OA-12-00-SL	1.64 LT
OA-01-00-SL	10.3	OA-26-00-SL	109 M3
OA-02-00-SL	7.39	OA-28-00-SL	0.928 LT
OA-08-00-SL	58.1	OA-29-00-SL	0.907 LT
OA-10-00-SL	20.8	OA-35-00-SL	1.57 LT
OA-11-00-SL	53	OA-36-00-SL	1.39 LT
OA-13-00-SL	5.85	OA-39-00-SL	1.45 LT
OA-14-00-SL	12.4	PL-02-00-SL	1.58 LT
OA-15-00-SL	8.22	PL-03-00-SL	2.96 LT
OA-16-00-SL	21.3	LS-01-00-SL	94.1
OA-20-00-SL	52.6	LS-02-00-SL	93.6
OA-21-00-SL	640	LS-03-00-SL	22.7
OA-22-00-SL	691		
OA-23-00-SL	189		
OA-24-00-SL	13.1		
OA-25-00-SL	87.6		
PL-01-00-SL	37.9		
RR-01-00-SL	14.9		
RR-02-00-SL	1.76		
SW-01-00-SL	22.3		
SW-02-00-SL	18.4		

LT = result is < than the requested minimum detectable concentration (MDC), but > than sample-specific MDC.

M3 = requested MDC was not met, but the sample result exceeds the requested MDC.

Table 4.25. Isotopic thorium activities in surface soils (pCi/g) [Refer to Figs. 2.4a and 2.4b for sample locations; thorium activities were not detected (MDC of 0.1 pCi/g) in the rest of the samples.]

Sample ID	^{228}Th	^{230}Th	^{232}Th
EP-11-00-SL	0.9	1.07	0.939
NB-02-00-SL	0.316	0.415	0.281
NB-06-00-SL	1.06	1.09	0.84
NB-14-00-SL	1.02	1.05	0.774
OA-37-00-SL	1.21	1.2	1.1

Table 4.26. ^{241}Am activity reported in surface soil (pCi/g) [Refer to Figs. 2.4a and 2.4b for sample locations; ^{241}Am not detected in other samples, with a MDC that ranged from 0.3 to 4 pCi/g.]

Sample ID	^{241}Am
DM-01-00-SL	2.3 G,TI
DM-02-00-SL	2.94 G,TI
EP-04-00-SL	3.12 G,TI
EP-06-00-SL	1.04 G,TI

G = sample density differed by more than 15% from the LCS density.

TI indicates the radionuclide identification was tentative.

Table 4.27. ^{239}Pu /^{240}Pu activity in surface soils (pCi/g) [Refer to Figs. 2.4a and b for sample locations; ^{239}Pu/^{240}Pu activities not detected on other samples (MDC ~0.02 pCi/g).]

Sample Location	^{239}Pu/^{240}Pu
BD-12-00-SL	0.00794 LT
EP-02-00-SL	0.0297 LT
NB-03-00-SL	0.0334 LT
NB-06-00-SL	0.0155 LT
BP-03-00-SL	0.00706 LT
OA-37-00-SL	0.00872 LT
OA-01-00-SL	0.0144 LT

LT indicates result is < than the requested minimum detectable concentration (MDC), but > than sample-specific MDC.

Table 4.28. Isotopic uranium in subsurface soils (pCi/g) [Refer to Fig. 4.18 for sampling locations and Figs. 2.5a and 2.5b for all sampling locations; table includes all samples that were analyzed by alpha spectrometry, and samples with gamma activities that were above the detection limit (0.5 to 2 pCi/g).]

	Alpha spectrometry			Gamma spectrometry
Sample ID[a]	^{234}U	^{235}U	^{238}U	^{235}U
BD-13-09-SL	1.08	0.0884 LT	0.892	-0.115 U,G
BD-14-05-SL	1.24	0.081 LT	0.924	0.472 U,G
BD-16-05-SL	1.73	0.0741 LT	0.867	0.309 U,G
BLD253-02-04	172 J	7.74 J	11.1 J	5.9
BLD255-08-01	604 J	23.1 J	13.8 J	13.4
BLD260-06-01	17.8	0.79	5.04	0.87 TI
BP-13-05-SL	0.943	0.0476 LT	0.853	0.319 U,G
CB-02-05-SL	2.48	0.14	1.14	0.0896 U,G
DM-02-05-SL				9.24
DM-02-22-SL	157	6.38	27.2	8.18
DM-02-33-SL				2.91
DM-03-05-SL	0.712	0.0574 LT	0.856	0.0728 U,G
EP-13-03-SL				1.34 J
EP-16-05-SL	2.42	0.154	1.13	-0.153 U,G
EP-17-05-SL	2.67	0.148	1.15	0.442 U,G
EP-18-09-SL				1.61 J
EP-19-05-SL				1.49 J
EP-19-13-SL				1.54 J
LF-06-05-SL	5.62	0.24	1.42	0.356 U,G
NB-30-05-SL	0.917	0.0363 LT	0.884	0.123 U,G
NB-31-15-SL	0.923	0.0356 LT	0.847	0.237 U,G
NB-36-05-SL	0.753	0.0518 LT	0.83	-0.175 U,G
NB-36-15-SL	0.976	0.0268 LT	0.794	0.202 U,G
NB-44-05-SL	0.494	0.0344 LT	0.474	0.0978 U
NB-51-05-SL	0.83	0.0458 LT	0.813	0.189 U,G
NB-55-05-SL	0.836	0.059 LT	0.9	0.119 U,G
NB-63-05-SL	0.738	0.035 LT	0.736	0.162 U,G
NB-71-01-SL	1.7	0.058 LT	0.838	0.184 U,G
NB-78-07-SL	0.736	0.0446 LT	0.689	0.234 U,G
NB-81-09-SL	0.713	0.0228 LT	0.771	0.148 U,G
OA-18-03-SL	0.747	0.0233 LT	0.787	0.0943 U
PL-04-05-SL	4.44	0.25	1.21	0.29 U,G
PL-05-05-SL	1.08	0.111	0.899	-0.179 U,G
RR-04-07-SL	0.751	0.0561 LT	0.76	-0.0326 U,G
RR-05-05-SL	2.8	0.157	1.28	0.571 U,G
SW-02-01-SL	240	12.8	20.1	8.64 G
SW-07-05-SL	0.87	0.0414 LT	0.829	-0.165 U,G

[a] Sample ID, AA-AA-DD-SL, consists of the sampling station AA-AA and sample depth DD in feet. For samples collected from under the buildings, sample ID consists of BLDXXX-AA-DD where XXX is the building number where borehole is located, AA is boring number, sample depth is DD in feet.

G = sample density differed by more than 15% from the LCS density.

J = estimated value.

LT= result is < than the requested minimum detectable concentration (MDC), but > than the sample-specific MDC.

TI = radionuclide identification was tentative.

U = analyte was not detected; note that gamma spectroscopy is not as sensitive as alpha spectroscopy.

Table 4.29. ^{99}Tc in subsurface soils (pCi/g) (Refer to Figs. 2.5a and 2.5b for sample locations.)

Sample ID[a]	^{99}Tc	Sample ID	^{99}Tc
BD-16-05-SL	1.61 LT	EP-17-15-SL	3.74
BLD253-02-04	7.5	EP-17-25-SL	5.21
BLD255-08-01	30.2	EP-18-09-SL	11.7
BP-17-05-SL	4.26	EP-18-29-SL	0.952 UJ
BP-17-15-SL	2.46 LT	EP-19-05-SL	11.4
BP-17-23-SL	1.66 LT	EP-19-13-SL	10.4
CB-02-05-SL	0.785 LT	EP-19-25-SL	4.77
DM-02-05-SL	13.9	EP-19-31-SL	0.708 UJ
DM-02-22-SL	10.9	EP-20-05-SL	3.04
DM-03-05-SL	2.54 LT	EP-20-15-SL	2.74 LT
DM-03-13-SL	5.84	EP-20-25-SL	3.93
DM-03-25-SL	7.04	LF-06-05-SL	4.26
EP-13-03-SL	13.9	LF-08-05-SL	4.37
EP-13-13-SL	8.58	LF-08-37-SL	4.21
EP-13-25-SL	6.39	LF-09-03-SL	1.6 LT
EP-13-30-SL	131	NB-32-27-SL	1.68 LT
EP-14-05-SL	12.8	NB-39-05-SL	2.11 LT
EP-14-13-SL	1.53 J	NB-39-15-SL	2.43 LT
EP-14-25-SL	2.06 J	NB-40-25-SL	0.83 LT
EP-14-31-SL	0.538 UJ	NB-74-05-SL	7.49
EP-15-05-SL	3.42	NB-74-17-SL	2.81 LT
EP-15-13-SL	4.31	NB-74-25-SL	2.45 LT
EP-15-25-SL	11	OA-19-05-SL	1.67 LT
EP-16-05-SL	2.62 LT	PL-04-05-SL	4.54
EP-16-15-SL	17.1	PL-06-33-SL	1.18 LT
EP-16-27-SL	5.24	SW-02-01-SL	2.97 LT
EP-17-05-SL	1.17 LT	SW-02-09-SL	0.907 LT

[a] Sample ID, AA-AA-DD-SL, consists of the sampling station AA-AA and sample depth DD in feet. For samples collected from under the buildings, sample ID consists of BLDXXX-AA-DD where XXX is the building number where borehole is located, AA is boring number, sample depth is DD in feet.

LT = result is < than the requested minimum detectable concentration (MDC), but > than sample-specific MDC.

J = Indicates that the radionuclide was positively identified and the numerical value is approximate.

UJ = Indicates that the analyte was not detected above the sample quantitation limit but the quantitation limit is approximate.

Table 4.30. Isotopic thorium in subsurface soils (pCi/g) (Refer to Figs. 2.5a and 2.5b for sampling locations.)

Sample ID[a]	^{228}Th	^{230}Th	^{232}Th
BD-14-05-SL	1.02	1.13	1.13
BLD240-01-01	1.14 M3	1.06 M3	0.987
BLD240-01-31	0.66 M3	0.792 M3	0.517
BLD240-03-04	1.32 M3	1.22 M3	1.13
BLD240-03-14	1.24 M3	1.14 M3	1.07 M3
BLD240-04-02	1.3 M3	1.01 M3	1.07
BLD240-04-33	0.542 M3	0.756 M3	0.418
BLD253-02-04	1.3 M3	1.3 M3	1.1 J
BLD253-02-21	1.06 M3	1.13 M3	0.876
BLD255-05-01	1.2 3 M3	1.04 M3	1.1
BLD255-05-23	1.55 M3	1.42 M3	1.18 M3
BLD255-07-02	1.29 M3	1.08 M3	1.12
BLD255-07-33	1.33 M3	1.1 M3	1.06
BLD255-08-01	0.988 M3	0.918 M3	0.807
BLD255-08-08	1.25 M3	1.25 M3	1.21
BLD260-06-01	1.11 M3	1.08 M3	1.08
BLD260-06-31	0.685 M3	0.675 M3	0.656
BP-17-05-SL	1.07	1.14	1.16
CB-02-05-SL	0.971	1.01	1.07
DM-02-22-SL	1.54 M3	1.74 M3	1.59
DM-03-05-SL	1.23	1.14	1.15
EP-17-05-SL	1.2	1.2	1.13
NB-30-05-SL	1.15	1.26	1.2
NB-36-05-SL	0.843	0.992	0.804
NB-55-05-SL	1.15	1.14	1.08
NB-71-01-SL	1.23	1.16	1.12
NB-78-07-SL	0.92	0.897	0.854
PL-04-05-SL	1.15	1.15	1.09
PL-05-05-SL	1.28	1.2	0.934
RR-04-07-SL	1.34	1.13	1.29
RR-05-05-SL	1.17	1.24	1.07
SW-02-01-SL	2.39 M3	1.71 M3	2.5

[a] Sample ID, AA-AA-DD-SL, consists of the sampling station AA-AA and sample depth DD in feet. For samples collected from under the buildings, sample ID consists of BLDXXX-AA-DD where XXX is the building number where borehole is located, AA is boring number, sample depth is DD in feet.

M3 = requested minimum detectable concentration (MDC) was not met, but the sample result exceeds the requested MDC.

Table 4.31. ^{239}Pu /^{240}Pu in subsurface soils (pCi/g)

Location[a]	^{239}Pu or ^{240}Pu
BLD255-05-01	0.00556LT
BLD260-06-01	0.00277LT
EP-17-05-SL	0.00479LT
BLD255-08-08	0.00783LT
EP-18-09-SL	0.00715LT
BLD240-03-14	0.00266LT
BLD240-01-31	0.00524LT
BLD255-07-33	0.00402LT

[a] Sample ID, AA-AA-DD-SL, consists of the sampling station AA-AA and sample depth DD in feet. For samples collected from under the buildings, sample ID consists of BLDXXX-AA-DD where XXX is the building number where borehole is located, AA is boring number, sample depth is DD in feet.

LT = result is < than the requested minimum detectable concentration (MDC), but > than the sample-specific MDC.

Table 4.32. Number of sediment and soil samples with organic analyte concentrations above detection limits. Note that sample counts include samples with concentrations below the reporting limit. Maximum concentrations are given in parentheses. Sample results with associated contaminated laboratory blanks were not included in the sample counts. Green shaded cells indicate that none of the samples exceeded detection limits. Grey shaded cells indicate that analytes were not measured.

	Sediment (mg/kg)		Surface Soil (mg/kg)		Subsurface	CALM	PRG
	Upstream	On-site	Background	On-site[a]	Soil (mg/kg)	(mg/kg)	(mg/kg)
BNAs							
Total Number of Samples	**2**	**16**	**0**	**124**	**393**		
Bis(2-Ethylhexyl) phthalate		3 (3.6)		23 (4.7)	28 (2.4)	410	35
Butyl benzyl phthalate				10 (0.22)	3 (1.5)	930	12,000
Di-n-butyl phthalate		1 (2.1)		20 (4.3)	1 (0.28)	2,300	6,100
Di-n-octyl phthalate				2 (.35)[a]	1 (0.093)	0.3	2,400
Carbazole		3 (3.5)		22 (0.91)	5 (0.25)	82	24
Hexachlorobenzene				1 (.04)		0.9	0.3
Hexachloroethane					5 (0.43)	70	35
Isophorone				1 (0.2)		1,700	510
2-Methylphenol					1 (0.034)	3,500	3,100
Phenol						5,200	18,000
Dioxins							
Total number of samples	**0**	**0 0 2 4**					
2,3,7,8-TCDD[b]				2 (16.7E-06)[a]	3 (0.3E-06)[a]		3.90E-06
PAHs							
Total Number of Samples	**2**	**16**	**0**	**124**	**393**		
Acenaphthene		2 (0.58)		19 (.38)	8 (.74)	1,700	3,700
Anthracene		2 (2.4)		21 (1.1)	7 (.42)	8,500	22,000
Benzo(*a*)anthracene	1 (0.041)	9 (21)		85 (6.4)	19 (.63)	1	0.62
Benzo(*a*)pyrene	1 (0.029)	9 (29)		83 (6.6)	15 (.78)	0.2	0.062
Benzo(*b*)fluoranthene	1 (0.039)	9 (57)		90 (7.8)	20 (1.8)	0.9	0.62
Benzo(*k*)fluoranthene		9 (20)		54 (3.2)	11 (.62)	8	6.2
Chrysene	1 (0.033)	9 (29)		83 (8.1)	17 (1.0)	36	62
Dibenzo(*a,h*)anthracene		1 (4.7)		3 (.44)		0.2	0.062
Fluoranthene	1 (0.086)	10 (58)		97 (14)	25 (3.5)	1,600	2,300
Fluorene		2 (0.97)		17 (0.53)	5 (0.5)	1,100	2,700
Indeno(1,2,3-*cd*)pyrene		9 (11)		49 (5)	5 (0.36)	3	0.62
Naphthalene		1 (0.25)		12 (0.1)	1 (0.019)	120	56
Pyrene	1 (0.066)	9 (68)		72 (18)		2,100	2300

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Table 4.32. (continued) Number of sediment and soil samples with organic analyte concentrations above detection limits. Note that sample counts include samples with concentrations below the reporting limit. Maximum concentrations are (mg/kg) given in parentheses. Samples with associated contaminated laboratory blanks were not included in the sample counts. Green shaded cells indicate that none of the samples exceeded detection limits. Grey shaded cells indicate that analytes were not measured.

	Sediment (mg/kg)		Surface Soils (mg/kg)		Subsurface	CALM	PRG
	Upstream	On-site	Background	On-site[a]	Soil (mg/kg)	(mg/kg)	(mg/kg)
Pesticides							
Total Number of Samples	**2**	**16**	**0**	**124**	**393**		
DDD				2 (0.002)		12	2.4
DDE				5 (0.005)	1	8	1.7
DDT				13 (0.025)	2	8	1.7
Dieldrin				3 (0.007)		0.1	0.03
Endosulfan I				2 (0.001)		420	370
Endosulfan II				7 (0.004)	1 (0.0008)		
Endrin		9 (0.003)		11 (.021)	1 (0.0007)	21	18
Heptachlor				2 (.013)		0.3	0.11
Alpha BHC (HCH)				2 (.046)	5 (0.001)	0.3	0.09
Gamma BHC (HCH, Lindane)					2 (0.0002)	1	0.44
PCBs							
Total Number of Samples	**2**	**16**	**32**	**124[a]**	**393**		
PCB-1254				15 (0.54)	2 (.067)	0.6	0.22
PCB-1260		2 (0.059)		27 (0.56)	3 (0.006)	0.6	0.22
Petroleum Hydrocarbons							
Total Number of Samples	**0**	**0 0 6 9**					
Diesel				3 (0.035)		NA	NA
Gasoline				1 (0.0003)		NA	NA

continued next page

Table 4.32 (continued). Number of sediment and soil samples with organic analyte concentrations above detection limits. Note that sample counts include samples with concentrations below the reporting limit. Maximum concentrations (mg/kg) are given in parentheses. Green shaded cells indicate that none of the samples exceeded detection limits. Grey shaded cells indicate that analytes were not measured. (continued)

Analyte	Sediment (mg/kg)		Surface Soil (mg/kg)		Subsurface	CALM	PRG
	Upstream	On-site	Background	On-site	Soil (mg/kg)	(mg/kg)	(mg/kg)
VOCs							
Total Number of Samples	**2**	**16**	**32**	**124[a]**	**393**		
Acetone	1 (0.018)	10 (0.053)		4 (0.0085)	79 (.22)	2,700	14,000
Benzene						6	0.64
Bromodichloromethane						11	0.82
Carbon disulfide					7 (.24)	630	360
Carbon tetrachloride					1 (.045)	2	0.25
Chloroethane					2 (0.029)		3
Chloroform					2 (.012)	0.8	0.22
Chloromethane							47
1,1-Dichloroethane					46 (.62)		510
1,2-Dichloroethane					4 (.0097)	2	0.28
1,1-Dichloroethene					46 (3.6)	0.4	120
cis-1,2-Dichloroethene		3 (0.028)			70 (.39)	1,200	43
trans-1,2-Dichloroethene		1 (0.0072)			6 (.022)	2,900	69
Methylene Chloride			12 (0.025)	1 (.0039)	81 (.019)	51	9.1
MEK (2-Butanone)		1 (0.014)			15 (.046)	7,400	22,000
Tetrachloroethene (PCE)		2 (0.0073)		10 (.034)	127 (6600)	40	0.48
Toluene	1 (0.009)	3 (0.02)	7 (0.0057)	3 (.0093)	17 (.015)	650	520
1,1,1-Trichloroethane					24 (.34)	1,200	1,200
1,2,4-Trichlorobenezene					1 (.0025)	270	62
1,1,2-Trichloroethane						5	0.73
Trichloroethene (TCE)		3 (0.011)		1 (.0013)	97 (4.8)	40	0.053
Vinyl chloride (VC)		1 (0.022)			12 (.015)	0.3	0.079
Xylenes (o, m, p)						418	270

[a]Includes composite samples from limestone storage/fill areas.
[b]Concentration reported as "Total Equivalent Concentration" of 2,3,7,8-TCDD using Toxicity Equivalence Factors from EPA (1989).
BNA = base-neutral-acid extractable organic.
NA = not available.
PAH = polycyclic aromatic hydrocarbon.
PCB = polychlorinated biphenyl.
PRG = preliminary remediation goal.
VOC = volatile organic compound.

Table 4.33. Number of surface water and groundwater samples with organic analyte concentrations above detection limits. Note that sample counts include samples with concentrations below the reporting limit. Maximum concentrations (µg/L) are given in parentheses. Sample results with associated contaminated laboratory blanks were not included in the sample counts. Green shaded cells indicate that none of the samples exceeded detection limits. Grey shaded cells indicate that analytes were not measured.

Analyte	Surface Water (µg/L) Upstream	Surface Water (µg/L) On-site	Groundwater (µg/L)	CALM (µg/L)	PRG (µg/L)
BNAs					
Total number of samples	**5**	**8**	**42**		
Bis(2-Ethylhexyl) phthalate			8 (26)	6	4.8
Butyl benzyl phthalate				3,000	7,300
Di-n-butyl phthalate				2,700	3,600
Di-n-octyl phthalate					1,500
Carbazole					3.4
Hexachlorobenzene				1	0.042
Hexachloroethane			1 (6.5)	1	4.8
Isophorone				100	71
2-Methylphenol					1,800
Phenol			2 (9.8)	4,000	11,000
Dioxins					
Total number of samples	**0**	**0**	**1**		
2,3,7,8-TCDD			1 (0.37E-07)[a]		4.50E-07
PAHs					
Total number of Samples	**5**	**8**	**42**		
Acenaphthene				1,200	370
Anthracene				9,600	1,800
Benzo(*a*)anthracene				0.0044	0.092
Benzo(*a*)pyrene				0.2	0.0092
Benzo(*b*)fluoranthene				0.0044	0.092
Benzo(*k*)fluoranthene				0.0044	0.92
Chrysene				0.0044	9.2
Dibenzo(*a,h*)anthracene				0.0044	0.0092
Fluoranthene		1 (0.97)		300	1,500
Fluorene				1,300	240
Indeno(1,2,3-*cd*)pyrene				0.0044	0.092
Naphthalene				100	6.2
Pyrene				960	180

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Table 4.33. (continued) Number of surface water and groundwater samples with organic analyte concentrations above detection limits. Note that sample counts include samples with concentrations below the reporting limit. Maximum concentrations (µg/L) are given in parentheses. Sample results with associated contaminated laboratory blanks were not included in the sample counts. Green shaded cells indicate that none of the samples exceeded detection limits. Grey shaded cells indicate that analytes were not measured.

Analyte	Surface Water (µg/L) Upstream	Surface Water (µg/L) On-site	Groundwater (µg/L)	CALM (µg/L)	PRG (µg/L)
Pesticides					
Total number of samples	**5**	**8**	**17**		
DDD				2	0.28
DDE				2	0.2
DDT				2	0.2
Dieldrin				0.002	0.0042
Endosulfan					220
Endrin				2	11
Heptachlor				0.4	0.015
Alpha BHC (HCH)				0.0022	0.011
Gamma BHC (HCH, Lindane)				0.2	0.052
PCBs					
Total number of samples	**5**	**8**	**17**		
Arochlor 1254				0.5	0.034
Arochlor 1260				0.5	0.034
Petroleum					
Total number of samples	**0**	**0**	**0**		
Diesel					
Gasoline					
VOCs					
Total number of samples	**5**	**8**	**95**		
Acetone			5 (76)		5,500
Benzene			2 (4.8)	5	0.35
Bromodichloromethane				80	0.18
Carbon Disulfide			4 (8)		1,000
Carbon Tetrachloride				5	0.17
Chloroethane			4 (52)		4.6
Chloroform			5 (6.8)	80	0.17
Chloromethane			1 (1.3)		160
1,1-Dichloroethane			59 (610)		810
1,2-Dichloroethane			8 (8.7)	5	0.12
1,1-Dichloroethene			56 (5100)	7	340

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Table 4.33. (continued) Number of surface water and groundwater samples with organic analyte concentrations above detection limits. Note that sample counts include samples with concentrations below the reporting limit. Maximum concentrations (µg/L) are given in parentheses. Sample results with associated contaminated laboratory blanks were not included in the sample counts. Green shaded cells indicate that none of the samples exceeded detection limits. Grey shaded cells indicate that analytes were not measured.

Analyte	Surface Water (µg/L) Upstream	Surface Water (µg/L) On-site	Groundwater (µg/L)	CALM (µg/L)	PRG (µg/L)
VOCs (continued)					
Total number of samples	**5**	**8**	**95**		
cis-1,2-Dichloroethene		2 (4.4)	70 (19000)	70	61
trans-1,2-Dichloroethene			22 (630)	100	120
Methylene Chloride			20 (1600)	5	4.3
MEK (2-Butanone)			2 (150)		7,000
Tetrachloroethene (PCE)		3 (2.1)	75 (200000)	5	0.1
Toluene	1 (0.85)		6 (3.7)	150	720
1,1,1-Trichloroethane			11 (85)	200	3,200
1,2,4-Trichlorobenezene				70	7.2
1,1,2-Trichloroethane			5 (8.4)	5	0.2
Trichloroethene (TCE)		2 (0.84)	77 (18000)	5	0.028
Vinyl Chloride (VC)			25 (1000)	2	0.02
Xylenes (O, M, P)			1 (3.7)	320	210

[a]Concentration reported as "Total Equivalent Concentration" of 2,3,7,8-TCDD using Toxicity Equivalence Factors from EPA (1989).
BNA = base-neutral-acid extractable organic.
GTARC = Groundwater target concentrations.
PAH = polycyclic aromatic hydrocarbon.
PCB = polychlorinated biphenyl.
PRG = preliminary remediation goal.
VOC = volatile organic compound.

Table 4.34. VOC concentrations in surface water (μg/L) (Refer to Fig. 2.2 for sample locations; only VOCs detected above the reference levels are shown.)

Sample ID	Tetrachloroethylene	Trichloroethene
SW-01-SW	2.1 J	-
SW-02-SW	0.73 J	-
SW-09-SW	0.87 J	0.84 J
SW-16-SW	-	0.64 J

VOC = volatile organic compound.

Table 4.35. PAHs in sediment samples (μg/kg) (Refer to Fig. 2.3 for sampling locations; only PAHs detected above the reference levels are shown.)

Sample ID	Benzo(*a*) anthracene	Benzo(*a*) pyrene	Benzo(*b*) fluoranthene	Benzo(*k*) fluoranthene	Dibenz(*a,h*) anthracene	Indeno(1,2,3-*cd*) pyrene
SW-01-SS	-	260 J	-	-	-	-
SW-02-SS	-	82 J	-	-	-	-
SW-03-SS	-	190 J	-	-	-	-
SW-04-SS	-	71 J	-	-	-	-
SW-05-SS	-	420 J	730	-	-	-
SW-06-SS	-	890 J	1,800	-	-	800 J
SW-07-SS	21,000	29,000	57,000	20,000	4,700	11,000 J
SW-10-SS	-	100 J	-	-	-	-
SW-12-SS	-	110 J	-	-	-	-

*J = estimated, below estimated quantitation limit.
PAH = polycyclic aromatic hydrocarbon.

Table 4.36. Dioxins in surface soil (pg/g) (Refer to Fig. 2.4b for sample location.)

Sample ID	1,2,3,4,6,7,8-HPCDD	OCDD	OCDF
CB-01-00-SL	110 J	5600 J	12 J
CB-01-00-SL-FD	94	4600	11 J

*J = estimated, concentration below quantitation limit.

Table 4.37. PAHs in surface soils (µg/kg) (Refer to Figs. 2.4a and 2.4b for surface soil sampling locations; only PAHs detected above the MDL are shown.)

Sample ID	Benzo(*a*) anthracene	Benzo(*a*) pyrene	Benzo(*b*) fluoranthene	Dibenz(*a,h*) anthracene	Indeno(1,2,3-*cd*) pyrene
BD-09-00-SL	-	630	870	-	-
BD-10-00-SL	6400	6600	7800	-	5000
BD-11-00-SL	-	110 J	-	-	-
BD-12-00-SL	-	400	-	-	-
BP-05-00-SL	-	76 J	-	-	-
CB-01-00-SL	-	63 J	-	-	-
DM-02-00-SL	-	240 J	-	-	-
EP-01-00-SL	710	870	1300	-	-
EP-02-00-SL	-	210 J	740	-	-
EP-04-00-SL	-	200 J	-	-	-
EP-04-00-SL-FD	-	160 J	-	-	-
EP-06-00-SL	-	350 J	-	-	-
LF-01-00-SL	640	900	1100		910
LF-03-00-SL	-	70 J	-	-	-
LF-04-00-SL	-	99 J	-	-	-
NB-04-00-SL	-	360 J	770	-	-
NB-05-00-SL	-	250 J	-	-	-
NB-11-00-SL	-	180 J	-	-	-
NB-14-00-SL	4500	3800	7000	-	2400
NB-15-00-SL	-	100 J	-	-	-
NB-21-00-SL	-	120 J	-	-	-
NB-22-00-SL	-	460 J	1100	-	-
NB-24-00-SL	-	67 J	-	-	-
OA-04-00-SL	-	98 J	-	-	-
OA-05-00-SL	-	270 J	-	-	-
OA-07-00-SL	2500	3200	3800	-	3900
OA-08-00-SL	1400 J	1700	2800	-	1700
OA-09-00-SL	-	220 J	-	-	-
OA-10-00-SL	730	590	920	-	-
OA-11-00-SL	860	920	1300	-	-
OA-12-00-SL	-	130 J	-	-	-
OA-13-00-SL	-	300 J	-	-	-
OA-15-00-SL	3700	4600	7000	440	2800 J
OA-16-00-SL	4700	5300	6800	-	3200 J
OA-23-00-SL	630	610	1000	-	-
OA-26-00-SL	-	590	1100	-	-
OA-28-00-SL	-	76 J	-	-	-
OA-31-00-SL	-	220 J	-	-	-
OA-32-00-SL	-	130 J	-	-	-
OA-33-00-SL	-	160 J	-	-	-
RR-03-00-SL	-	74 J	-	-	-

Table 4.38. PCBs in surface soils (μg/kg) (Refer to Fig. 2.4 for sample locations; only samples with PCBs detected above the risk-based screening levels are shown.)

Sample ID	PCB-1254	PCB-1260
BP-07-00-SL	–	230
EP-04-00-SL	–	300
EP-04-00-SL-FD	–	320
LF-01-00-SL	–	560
OA-08-00-SL	–	400
RR-01-00-SL	540 J	310

*J = estimated, below quantitation limit.
PCB = polychlorinated biphenyl.

Table 4.39. Petroleum in surface soils (mg/kg) [Refer to Fig. 2.4a for sample locations; only samples with detectable diesel fuel and gasoline-range organics detected above the detection limit are shown.]

Sample ID	Diesel fuel	Gasoline
GS-03-00-SL	15 HZ	-
GS-04-00-SL	35 HZ	0.29 J
GS-05-00-SL	26 ZH	-

H = the final pattern was in the heavier end of the retention time window for the analyte.
Z = a significant fraction of the reported result did not resemble the patterns of diesel.

Table 4.40. Dioxins in subsurface soil (pg/g) (Refer to Fig. 2.5b for sample location.)

Sample ID	1,2,3,4,6,7,8-HPCDD	OCDD
CB-02-05-SL	61 B	2200 B
CB-02-05-SL-FD	98 B	4000 B
CB-02-15-SL	15 B	710 B
CB-02-25-SL	4.2 QJB	200 B

B = detected in the method blank.
J = estimated, below quantitation limit.

Table 4.41. PAHs in subsurface soil (μg/kg) (Refer to Figs. 2.5a and 2.5b for sample location.)

Sample ID	Benzo(*a*) anthracene	Benzo(*a*) pyrene	Benzo(*b*) fluoranthene
LF-08-03-SL	-	120 J	-
LF-08-03-SL-FD	-	64 J	-
LF-09-03-SL	-	140 J	-
NB-53-05-SL	-	160 J	-
NB-53-33-SL	630	780	1800
NB-55-13-SL	630	260 J	-
NB-56-05-SL	-	380 J	770
NB-57-34-SL	-	200 J	-
NB-78-18-SL	-	300 J	-
OA-19-05-SL	-	220 J	-

J = estimated, below quantitation limit.
PAH = polycyclic aromatic hydrocarbon.

Table 4.42. VOCs in subsurface soil samples (µg/kg) (Refer to Fig. 4.21 for sample locations and Figs. 2.5a and 2.5b for all locations samples.)

Sample ID[a]	1,1-Dichloro ethene	Methylene chloride	Tetrachloro ethylene	Trichloro ethene
BD-13-09-SL	-	-	830	-
BD-13-15-SL	-	-	8,900	-
BD-13-23-SL	-	-	27,000	-
BD-13-30-SL	-	-	13,000	-
BD-14-31-SL	-	-	-	62
BLD240-01-31	-	-	4,800	-
BLD240-01-31FD	-	-	3,600	-
BLD240-05-23	-	-	-	470
BLD253-02-21	3,600 J	-	6,600,000	-
BLD253-02-21FD	-	54,000 J[b]	800,000	-
BLD255-08-24	-	-	1,600	1,600
BLD260-06-31	-	-	-	350
BP-22-33-SL	-	-	-	170
EP-15-29-SL	-	-	4,600	110
EP-17-30-SL	-	-	18,000	400
EP-20-25-SL	-	-	490	-
NB-31-32-SL	-	-	-	76
NB-40-31-SL	-	-	4,600	410
NB-45-33-SL	-	-	-	54
NB-64-17-SL	-	-	-	76
NB-72-19-SL	-	-	-	280
NB-72-22-SL	-	-	-	310
NB-78-18-SL	-	-	-	260
OA-18-25-SL	-	-	-	320
OA-18-33-SL	-	-	-	4,800
OA-19-33-SL	-	-	-	64

[a] Sample ID AA-XX-YY-SL, refers to the sampling station (AA-XX) shown on Figs. 2.5a and 2.5b and Fig. 4.21, while YY refers to the sample depth in ft BGS. For samples collected from under the buildings, sample ID consists of BLDXXX-AA-DD where XXX is the building number where borehole is located, AA is boring number, sample depth is DD in feet.

[b] J = estimated, below quantitation limit.

B = detected in method blank.

"-" = not detected below the MDL.

Table 4.43. BNAs in groundwater (µg/L) (Refer to Figs. 2.6a and 2.6b for well locations; only samples with detectable BNAs are shown.)

Well ID	Bis(2-ethylhexyl) phthalate	Hexachloroethane
BD-02	-	6.5 J
EP-15	20	-
LF-08	26	-
RR-05	6.3 J	-
SW-07	9 J	-

J = estimated; below quantitation limit.

"-" = below detection limit.

Table 4.44. VOCs in groundwater (μg/L) (Refer to Figs. 2.6a and 2.6b for well locations; only samples with VOCs above reference levels are shown.)

Sample ID	1,1,2-Trichloroethane	1,1-Dichloroethene	1,2-Dichloroethane	Benzene	Chloroethane	Chloroform	*cis*-1,2-Dichloroethene	Methylene chloride	Tetrachloro ethylene	*trans*-1,2-Dichloroethene	Trichloro ethene	Vinyl chloride
GW-BD1-121704	6.7	790	5.3	-	-	6.1	-	-	4,900	-	26	1.5 J
GW-BD13-122804	-	290	-	-	-	-	520	-	900	630	900	-
GW-BD14-122904	-	120 J	-	-	-	-	250	-	2,100	100 J	1,000	-
GW-BD16-122204	-	39	1.1 J	-	-	-	-	-	2.9 J	-	1.2 J	-
GW-BD2-121604	-	5,100 J	-	-	-	-	-	-	200,000	-	-	-
GW-BD3-121704	1.8 J	82		-	-	1.5 J	-	-	3,000	-	16	-
GW-BD4-121704	-	120	-	-	-	-	-	-	1,200	-	130	1.5 J
GW-BD5-121504	-	34	-	-	-	-	100	-	190	-	440	-
GW-BD6-121404	2.7 J	560	7.7	4.8 J	-	6.8	19,000	-	2,100	170 J	18,000	1,000
GW-BD7-121504	-	-	-	-	-	-	-	-	8.7	-	5.8	-
GW-BD8-122804	1.4 J	-	8.7	-	-	2 J	7,200	-	1,400 J	-	12,000	-
GW-BP17-122204	-	11 J	-	-	-	-	340	-	-	-	15 J	7.8 J
GW-BP22A-122804	-	-	-	-	52 J	-	550	-	420	-	990	41 J
GW-BP22B-122804	-	-	-	-	-	-	-	-	270	-	99	-
GW-BR10JC-121304	-	28	-	-	-	-	180	-	160	-	520	16
GW-BR10OB-120804	-	-	-	-	-	-	-	-	110	-	90	-
GW-BR3OB-120804	-	-	-	-	-	-	-	-	20	-	5.8	-
GW-BR4JC-121404	-	26 J	-	-	-	-	-	-	1,700	-	210	-
GW-BR6RB-120704	-	-	-	-	-	-	-	-	-	-	1.9 J	-
GW-BR7JC-121504	-	-	-	-	-	-	-	-	6	-	20	-
GW-BR7RB-121404	-	-	-	-	-	-	-	7.6 B	-	-	1.3 J	-
GW-BR8JC-120604	-	190 J	-	-	-	-	2,400	-	530	-	5,800	180 J
GW-BR8OB-120604	-	-	-	-	-	-	220	-	40	-	190	-
GW-BR9JC-121404	-	100 J	-	-	-	-	1,400	-	1,000	-	2,800	150 J
GW-DM02-122204		27	-	-	-	-	240	-	470	-	270	-
GW-EP16-121304	-	-	-	-	-	-	-	-	7.6	-	1.6 J	-
GW-EP20-121504		-	-	-	-	-	-	-	2,400	-	-	-
NB-34 (dup)	-	180	-	-	-		68 J	74 J	2,000	-	530	-
ED-16 (dup)	-	-	-	-	-	-	-	-	6.1	-	1.2 J	-
BR-09-JC (dup)	-	85 J	-	-	-	-	1,400	-	1,000	-	2,800	150 J
WS-31 (dup)	-	62 J	-	-	-	-	730	-	130	-	1,800	-
BR-10-JC (dup)	-	26	-	-	-	-	180	-	150	-	520	16
LF-09 (dup)	-	-	-	-	-	-	280 J	1,600	14,000	-	1,900	-
GW-LF08-122104	-	-	-	-	-	-	-	-	65	-	5.6	-
GW-LF09-122004	-	-	-	-	-	-	260 J	1,200	14,000	-	1,900	-
GW-NB31-122104	-	33 J	-	-	-	-	280	-	88	-	830	35 J
GW-NB32-122004	-	22 J	-	-	-	-	170	19 J	34	-	360	-
GW-NB33-122104	-	-	-	-	-	-	-	-	23	-	2.1 J	-
GW-NB34-120704	-	210	-	-	-	-	72 J	74 J	2,600	-	620	-
GW-NB35-122104	-	89 J	-	-	-	-	870	-	74 J	-	3,600	-
GW-NB36-122204	-	40 J	-	-	-	-	290	-	38 J	-	810	-
GW-NB39-121504	-	39	-	-	-	-	190	-	-		510	7.5 J
GW-NB44-120604	-	8.9 J	-	-	-	-	-	-	680	-	410	-
GW-NB54-122004	-	-	-	-	-	-	-	-	1,400	-	380	-

Table 4.44. VOCs in groundwater (μg/L) (Refer to Figs. 2.6a and 2.6b for well locations; only samples with VOCs above screening levels are shown.) (continued)

Sample ID	1,1,2-Trichloroethane	1,1-Dichloroethene	1,2-Dichloroethane	Benzene	Chloroethane	Chloroform	*cis*-1,2-Dichloroethene	Methylene chloride	Tetrachloro ethylene	trans-1,2-Dichloroethene	Trichloro ethene	Vinyl chloride
GW-NB56-121604	-	-	-	-	-	-	-	-	6.4	-	-	-
GW-NB61-122204	-	-	-	-	-	-	-	-	1.4 J	-	-	
GW-NB64-122104	-	49	1.1 J	-	-	-	830	-	230 J	-	1,600	1.9 J
GW-NB65-122004	-	-	-	-	-	-	-	12	60	-	15	-
GW-NB67-120704	-	-	-	-	-	-	-	4.3 J	-	-	-	-
GW-NB72-122104	-	380 J	-	-	-	-	3,700	-	-		15,000	-
GW-NB73-122004	-	48 J	-	-	-	-	-	180	1,200	-	240	-
GW-NB74-121304	-	460	3.4 J	1.3 J	-	-	260	-	4,100	-	3,000	11
GW-NB77-122004	-	8.1 J	-	-		-	-	-	260	-	60	-
GW-NB78-122104	-	28	-	-	-	-	870	-	15	-	880	3.9 J
GW-NB80-121704	8.4	-	-	-	-	-	-	-	290	-	2,600	-
GW-NB83-120904	-	-	-	-	-	-	-	4.5	-	-	-	-
GW-NB84-120804	-	-	-	-	-	-	93	-	460	-	240	-
GW-OA19-122104	-	12 J	-	-	-	-	250	-	7.3 J	-	120	-
GW-OB1-121404	-	-	-	-	-	-	-	-	10	-	-	-
GW-OB2-121404	-	-	-	-	-	-	-	-	3.7 J	-	-	-
GW-PL04-122204	-	28 J	-	-	-	-	340	-	230	-	1,100	22 J
GW-PL06-121504	-	-	-	-	-	-	-	-	60	-	4.9 J	-
GW-PW16JC-121604	-	-	-	-	-	-	-	-	7.6	-	66	-
GW-PW16RB-121604	-	-	-	-	-	-	-	-	-	-	15	-
GW-PW19JC-121504	-	42 J	-	-	-	-	460	-	87		710	44 J
GW-PW19RB-121504	-	29	-	-	-	-	350	-	34	-	500	8.5 J
GW-PW6JC-121604	-	-	-	-	-	-	-	-	1.5 J	-	7.6	-
GW-PZ3-121704	-	240 J	3.9 J	-	-	-	1,900	-	1,900	-	7,700	77
GW-PZ4-121304	-	9.1	-	-	-	-	170	-	21	-	250	1.9 J
GW-WS14-121604	-	-	-	-	-	-	800	-	1,400	-	120 J	-
GW-WS16-121604	-	-	-	-	-	-	-	-	120	-	13	-
GW-WS17B-121704	-	-	-	-	-	-	-	-	5 J	-	42	-
GW-WS24-121504	-	-	-	-	-	-	-	-	36	-	14	-
GW-WS27-121504	-	-	-	-	-	-	-	-	3.5 J	-	5.6	-
GW-WS28-121604	-	-	-	-	-	-	-	-	41	-	15	-
GW-WS29-121604	-	-	-	-	-	-	1,100	-	-	-	550	150 J
GW-WS30-121604	-	52 J	-	-	-	-	2,100	-	2,200	-	3,700	-
GW-WS31-121604	-	70 J	-	-	-	-	770	-	150	-	1,900	-
GW-WS32-121704	-	-	-	-	-	-	-	-	21	-	69	-
GW-WS34-121404	-	-	-	-	-	-	-	-	-	-	18	-

VOC = volatile organic compound.

Table 4.45. Mobile versus analytical laboratory results

	TCE			PCE		
	Analytical	**Mobile**	**% Diff**	**Analytical**	**Mobile**	**% Diff**
BW-BR6-65-80-GW-SS	5 U	5 U	---	5 U	5 U	---
BW-BR7-65-75-GW-SS	5 U	0.5 U	---	5 U	0.5 U	---
NB-34-22-32-OL-GW-SS	570 E	559	0.02	2500 E	2399	0.04
PW-03-161-181-GW	25	23.6	0.04	17	14.9	0.12
PW-03-201-221-GW-SS	24	23.8	0.01	15	13.9	0.07
PW-19-207-227-GW-SS	460	212	0.54	78	39	0.5
PW-19-207-227-GW-SS	350 E	212	0.39	63	39	0.38
	1,1-DCA			**1,1-DCE**		
	Analytical	**Mobile**	**% Diff**	**Analytical**	**Mobile**	**% Diff**
BW-BR6-65-80-GW-SS	5 U	5 U	---	10 U	5 U	---
BW-BR7-65-75-GW-SS	5 U	0.5 U	---	5 U	0.5 U	---
NB-34-22-32-OL-GW-SS	48	43	0.1	190	454	0.58
PW-03-161-181-GW	3.8 J	3.8	0	5 U	0.5 U	---
PW-03-201-221-GW-SS	3.4 J	3.6	0.06	0.7 J	1.2	0.42
PW-19-207-227-GW-SS	46	17	0.63	15 J	26	0.42
PW-19-207-227-GW-SS	38	17	0.55	12	26	0.54
	***cis*-1,2-DCE**			***trans*-1,2-DCE**		
	Analytical	**Mobile**	**% Diff**	**Analytical**	**Mobile**	**% Diff**
BW-BR6-65-80-GW-SS	5 U	5 U	---	5 U	5 U	---
BW-BR7-65-75-GW-SS	5 U	0.5 U	---	5 U	0.5 U	---
NB-34-22-32-OL-GW-SS	71	63	0.11	11	13	0.15
PW-03-161-181-GW	14	13.6	0.03	5 U	0.5 U	---
PW-03-201-221-GW-SS	12	11.8	0.02	5 U	0.5 U	---
PW-19-207-227-GW-SS	210	84	0.6	25 U	0.5 U	---
PW-19-207-227-GW-SS	170 E	84	0.5	2.2 J	0.5 U	---
	Vinyl chloride					
	Analytical	**Mobile**	**% Diff**			
BW-BR6-65-80-GW-SS	10 U	5 U	---			
BW-BR7-65-75-GW-SS	10 U	0.5 U	---			
NB-34-22-32-OL-GW-SS	1.9 J	5 U	---			
PW-03-161-181-GW	0.68 J	0.5 U	---			
PW-03-201-221-GW-SS	0.84 J	0.5 U	---			
PW-19-207-227-GW-SS	4 J	0.5 U	---			
PW-19-207-227-GW-SS	3 J	0.5 U	---			

DCA = dichloroethane.
DCE = dichloroethylene.
PCE = perchloroethene.
TCE = trichloroethylene.

Table 4.46. Locations where soil, sediment, surface water, and groundwater samples were obtained and analyzed for VOCs in previous investigations

Location	LBG (1999)	LBG (2002)
Groundwater		
Location 1 (near WS-7)	X	
WS-7	X	
Location 2 (near WS-17)	X	
Location 3 (near WS-14)	X	
WS-14	X	
Location 4 (near WS-16)	X	
WS-16	X	
Location 5 (near WS 15)	X	
WS-15	X	
WS-17B	X	
WS-22	X	
WS-23	X	
WS-24	X	
WS-25	X	
WS-27	X	
WS-28	X	
WS-29	X	
WS-30	X	
WS-31	X	
WS-32	X	
WS-33	X	
WS-34	X	
BR-1*		X
BR-2*		X
BR-3*		X
BR-4*		X
OB-1		X
OB-2		X
Surface Water	X	
SW-1	X	
SW-2	X	
SW-3	X	
SW-4	X	
Soil		
WS-23*	X	
WS-25*	X	
WS--27*	X	
WS-29*	X	
WS-32*	X	
WS-34*	X	
BR-1*		X
BR-2*		X
BR-3*		X
BR-4*		X
OB-1*		X
OB-2*		X
Sediment		
SS-1	X	
SS-2	X	

* Multiple samples were analyzed from different depths.

Locations where at least one VOC was detected (common laboratory contaminants excluded).

VOC = volatile organic compound.

5. CONTAMINANT FATE AND TRANSPORT

In this chapter, the integration of geologic, hydrologic, and geochemical data lead to development of a Conceptual Site Model (CSM) for the Hematite Site. By its very nature, evaluation of empirical data is a look backward in time, and the CSM is an attempt to explain the distribution of contaminants and the apparent direction and rates of their migration (and degradation) in soil and groundwater based on the physical and chemical forces acting on a complex hydrogeologic system over some period of time (e.g., 50 years for the Hematite Facility corresponding to the years of operation). The goal of the CSM is to provide the basis for explaining the current situation at the Hematite Site and a firm technical rationale for projecting the fate of contaminants in the vicinity of the Site into the future through numerical modeling (i.e., a deterministic approach). The complete modeling assessment appears in Appendix A and SAIC (2005) and is summarized in Sect. 5.6.

The approach to developing the CSM used in this Report includes a detailed examination of the distribution of the principal contaminants in soil and groundwater (from Chapter 4), followed by integration of this information with Site geology and hydrology (Chapter 3). The most important contaminants at the Site include PCE; TCE; 1,1-DCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and vinyl chloride, and the following sections will focus on them. However, some soil and groundwater samples contain a limited number of additional contaminants such as uranium, ^{99}Tc, and nitrate. In addition, other geochemical parameters such as pH and the concentrations of several major dissolved species (e.g., chloride, calcium, etc.) will be incorporated into the analysis, as appropriate.

Chapter 5 begins with an evaluation of the inorganic and radionuclide contamination in terms of their fate and potential for transport (Sect. 5.1). Section 5.2 continues with an in-depth analysis of the distribution of the chlorinated VOC contaminants (PCE and TCE) in soil and an analogous discussion for groundwater is presented in Sect. 5.3. The potential for the presence of a dense, nonaqueous-phase liquid (DNAPL) in the subsurface that might represent a long-term source for plume loading is discussed in Sect. 5.4. Section 5.5 develops the CSM for the Hematite Site and the results of numerical modeling based on the CSM are summarized in Sect. 5.6. Finally, in Sect. 5.7, the fate of PCE, TCE, and their degradation products is discussed within the context of natural attenuation processes.

5.1 EVALUATION OF INORGANIC AND RADIONUCLIDE CONTAMINATION

The fate and transport of inorganics and radionuclides are discussed together because of the commonality of the Hematite Site characteristics upon which their mobility depends. Furthermore, at the Hematite Site, contaminants in this group, with the exception of nitrate, do not migrate as easily as volatile organics. It is also important to recognize that the extent of contamination with inorganics and radionuclides was typically limited and localized near the plant and known disposal locations (Chapter 4).

The factors governing transport of inorganics and radionuclides are primarily the pH and redox conditions of the soil and groundwater system and the soil texture. For example, elements that typically migrate as divalent cations, such as lead and copper, are not readily mobile except at extremes of pH such as might be encountered with acid mine drainage. Many of these elements tend to precipitate as hydroxides or oxyhydroxides when the pH is near neutral.

In contrast, at or near neutral pH, ^{99}Tc and uranium are very mobile if redox conditions are sufficiently oxidizing. On the other hand, fine-grained soil texture inhibits mobility both by slowing groundwater flow and by providing a high surface area substrate for sorption of the contaminant. The following is a

discussion of specific Site geochemical characteristics that may influence the F&T of inorganics and radionuclides at the Hematite Site.

5.1.1 pH

Available data for the Hematite Site demonstrate that pH is within the range usually considered "normal" for natural waters, that is, within the range of approximately 5 to 9 (Sect. 4.1.3 and Fig. 4.3). Most water samples lie within the pH range that will inhibit migration of metals such as lead. However, eight groundwater samples from overburden have pH values less than 5 and one sample from the Jefferson City-Cotter HSU has a pH of 9.3. The locations of these samples are discussed in Sect. 4.1.3. These nine samples constitute approximately 7% of the samples analyzed.

5.1.2 Redox Conditions

As discussed in Sects. 4.1.5 through 4.1.8, redox conditions at the Hematite Site can be assessed by multiple means. Field data for ORP and DO suggest moderately reducing to mildly oxidizing conditions (Sect. 4.1.5, Figs. 4.4 and 4.5, respectively). In contrast, the high iron and manganese concentrations reported for groundwater samples (especially from overburden) suggests conditions are more reducing (Fig. 4.6 illustrates results for iron). A comparison of iron and manganese in a number of unfiltered and filtered groundwater samples from all formations suggests that these metals are dissolved rather than in particulate form, supporting the observation of reducing conditions in the groundwater. Other indicators of redox conditions are the soil texture and the appearance of degradation byproducts indicating reduction of TCE and PCE (e.g., *cis*-1,2-DCE). Soils at the Hematite Site, particularly in the area dominated by terrace deposits (Chapter 3), are typically fine-grained, and organic degradation byproducts are definitely present (Sect. 5.3); hence, the overall conditions of the Hematite Site are concluded to be at least mildly reducing.

Consideration of the distribution of nitrate provides additional evidence that conditions are reducing. Because it is an anion, nitrate is repelled by the negative charge on the soil surface. In addition, nitrate is a large ion that does not readily diffuse in and out of soil pores. Thus, nitrate is typically considered a conservative ion, or one that flows at the same rate as groundwater. An exception to this concept is when soil microbes, under reducing conditions, consume nitrate. Nitrate is found in significant concentrations in wells BD-01 and BD-02 in the middle of the plant area (presumably near where it was discharged) and has not migrated much farther. Volatile organics, which exhibit lower rates of microbial degradation than nitrate, have migrated a much greater distance. Therefore, it is concluded that reductive processes occurring in the subsurface have operated as an effective removal mechanism for nitrate.

Under the mildly reducing conditions believed present at the Hematite Site,, the mobility of ^{99}Tc and uranium is expected to be limited. Indeed, a review of the data shows that the bulk of the mass of these contaminants is found principally near the surface and near the Facility, the presumed source(s) of these constituents (Sect. 4.3).

5.1.3 Soil Texture

As discussed in Chapter 3, near-surface soil texture within the terrace deposits underlying the Hematite Facility is generally fine-grained, a fact that will inhibit infiltration and lateral migration. The fine-grained nature of the soil samples was confirmed during the K_d study performed in December 2003 (SAIC 2003c) in which particle size distribution measurements showed the soils to consist of >96% silt- and clay-sized fractions and ~30% clay. That study yielded K_d values for uranium and ^{99}Tc of 175 and 106 mL/g, respectively; values that indicate strong sorption on soil surfaces. Once again, the distribution of inorganics and radionuclides near known source areas supports this observation.

5.2 EVALUATION OF CHLORINATED VOLATILE ORGANIC COMPOUND CONTAMINANTS IN SUBSURFACE SOILS

For the purposes of this discussion, all subsurface unconsolidated sedimentary material is referred to as subsurface soil. This includes surficial soil, as well as the terrace and alluvial materials (i.e., overburden) that were discussed in Chapter 3.

Subsurface soil samples were taken at the locations identified in Figs. 2.5a and 2.5b. Normally, three samples were selected based on a scan of core material for volatile organic constituents by using a hand-held PID (refer to Sect. 2.3 for details regarding subsurface soil sampling). The vertical location of soil samples varied per sampling location, but typically included samples from the top of the water table and the overburden-bedrock contact. In general, one sample was taken from each 10-ft depth interval. For that reason, it is convenient to examine the subsurface soil results in three increments: surface to 10 ft BGS, 10 to 20 ft BGS, and greater than 20 ft BGS.

An evaluation of soil organic data (Sect. 4.4) indicates that the principal contaminants in subsurface soil at the Hematite Site are PCE and TCE. These two constituents represent the most significant contaminants in terms of concentrations, frequency of detection, and lateral and vertical distribution at the site. Three isomers of DCE (1,1-DCE; *cis* 1,2-DCE; and *trans*-1,2-DCE) and vinyl chloride were detected in some soil samples and probably originate through biologically mediated reductive dechlorination reactions (discussed in Sect. 5.5). This is a plausible mechanism for their formation and there is no evidence that any of these constituents was used at the Hematite Facility during its operational period. They occur at relatively low concentrations. Consequently, this section will focus on the distribution of PCE and TCE in soil samples.

Figures 5.1, 5.2, and 5.3 present the results for PCE and Figs. 5.4, 5.5, and 5.6 provide complementary data for TCE for subsurface soil samples from across the Hematite Site. There are several assumptions used in presenting the data in these figures:

- The contours are meant to encompass samples with a range of concentrations (e.g., ND to 10 μg/L; >100 μg/L), but may include samples with non-detect values. The apparent heterogeneity in contaminant distribution is not surprising, given the geologic complexity of the subsurface.

- Contamination is assumed to have entered the subsurface at the Hematite Facility location (i.e., there are no other known disposal areas).

- Soil contamination beyond the Hematite Facility occurred through transport in groundwater or a vapor phase, and subsequent sorption onto natural soil organic matter. Soil contamination will occur only where sufficient soil organic matter exists that can adsorb detectable amounts of the contaminants.

- Soil samples were not collected south of Joachim Creek because the amount of overburden is extremely limited in this area. The steep slope rising to the highlands to the south essentially forms the southern bank of Joachim Creek. Therefore, there is no opportunity for contaminated groundwater in overburden to migrate south of the creek (Sect. 5.3.1).

The general observations from these six figures are:

- The patterns of contaminant distribution in subsurface soil at all depth intervals for both PCE and TCE tend to suggest a close association with the Hematite Facility location as the source area.

- Even for the fine-grain, shallower soils (i.e., 0 to 10 ft depth), it is apparent that PCE and TCE contamination is relatively widely distributed.

- The configuration of the contaminated soil zones appears to correspond to the location of the contaminated groundwater (Sect. 5.3).

- Dashed lines that bound the extent of soil contamination are well constrained by sample data.

Based on information about the Hematite Facility, history and process knowledge obtained during the RI, potential source locations beyond the immediate vicinity of the Hematite Facility have not been identified. Several soil samples in Figs. 5.5 and 5.6 appear to have anomalously high concentrations of TCE in comparison to their location southeast of the presumed source region. However, they occur in an area where groundwater also is highly contaminated with TCE, which could have led to increased partitioning of TCE to soil organic matter.

Shallow, fine-grain soils might not be thought of as a favorable medium for groundwater flow. However, the relatively wide distribution of contaminants in these soils suggests that significant transport has occurred in this unit. For example, vapor migration might be a factor contributing to this observation. Nevertheless, the opportunity for contamination of these soils is significant because their organic content is expected to be relatively high. Indeed, values of organic carbon in excess of 1% are observed in some of these soils. The deepest soil samples (Figs. 5.3 and 5.6) generally include the coarse-grain lithologies where the amount of soil organic matter and the potential for sorption are expected to be lower.

The third observation can be evaluated by comparing the contaminant distribution in soils to the analogous distribution in groundwater as shown in Figs. 5.7 through 5.14 that are introduced in the following section.

5.3 EVALUATION OF THE DISTRIBUTION OF PCE AND TCE IN GROUNDWATER

As discussed in Sect. 4.4.5.6, the most common occurrences of chlorinated VOCs in groundwater at the Hematite Site above their reference concentrations include PCE and TCE and their presumed degradation products: 1,1-DCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and vinyl chloride. A variety of other VOCs were detected in groundwater, but most are only found in a few samples and almost always in association with these six primary contaminants. Furthermore, most of these other VOCs are chlorinated compounds and their chemistry and behavior in groundwater are similar to that of the major chlorinated VOC contaminants. None of these ancillary constituents warrants a separate discussion. Consequently, PCE, TCE and their four principal degradation products will be the focus of the following discussion.

Figures 5.7 through 5.10 illustrate the distribution of PCE in the major hydrogeologic units at the site. These units were described in Chapter 3 and include: (1) the shallow overburden HSU (wells completed at 10 to 15 ft BGS in fine-grain soils), (2) deep overburden HSU (wells completed in the lower part of the overburden to the depth of DPT probe refusal, presumed to correspond to bedrock), (3) the Jefferson City-Cotter HSU, and (4) the Jefferson City-Roubidoux Contact Zone HSU. Wells associated with the Roubidoux HSU are all uncontaminated and no figures for this HSU will be presented. Figures 5.11 to 5.14 represent an equivalent set of illustrations showing the distribution of TCE in these units.

5.3.1 PCE and TCE Distribution in Overburden Groundwater

Figures 5.7, 5.8, 5.11, and 5.12 illustrate the distribution of PCE and TCE in groundwater at two levels within the overburden. In general, shallow overburden groundwater has low to moderate levels of contamination for both of these constituents and the location of affected wells is closely associated with the Burial Pits.

As noted in Figs. 5.7 and 5.11, there are no sample locations northeast of Northeast Site Creek. In fact, several Geoprobe™ holes were placed in this region, but no shallow (i.e., perched) groundwater was encountered. Therefore, it appears that Northeast Site Creek marks the approximate extent of shallow groundwater. Shallow groundwater also appears to be absent in the region southeast of wells WS-17B and BP-22B.

The distribution of PCE and TCE in deep overburden groundwater (Fig. 5.8 and 5.12) is sufficient to define plumes, which suggest generally southeastward migration from source regions underlying the Hematite Facility, a direction compatible with the potentiometric surface for this zone of the overburden (Fig. 3.18). There appears to be an association of the zones of highest concentration of PCE and TCE with the location of the Burial Pits and the Evaporation Ponds (including areas underlying Bldgs. 230 and 240 for PCE). In addition, high concentrations of PCE and TCE (>1000 ug/L) define narrow, elongate plumes that appear to have their sources in the vicinity of the Facility. These latter zones of high concentration probably reflect preferential pathways that originate in the source zones underlying the Hematite Facility and allow groundwater to migrate away from the sources with limited opportunity for dilution. The heterogeneous nature of sedimentation in the terrace/alluvium system could yield such pathways.

A sample from well OB-01 (southwest of Site Pond next to Highway P; Fig. 5.8) had a detectable concentration of PCE (10 μg/L) during the December 2004 round of samples. This result is difficult to understand as there is no indication of contamination in other nearby wells. Information provided by Westinghouse indicates that during 2004, elevated concentrations of PCE were observed at Outfall No. 1 (immediately downstream of Site Pond) due to a damaged vitreous clay pipe and this might be a source of contamination, although no credible pathway from Site Creek to OB-01 has been identified. The damaged pipe is being replaced.

As groundwater in the overburden advances toward Joachim Creek, it must either discharge directly into the stream or migrate in a down-stream direction in the coarse alluvial sediments that overlie bedrock next to the stream and discharge to it more gradually. The configuration of the plume contours in Figs. 5.8 and 5.12 suggests that flow pathways turn toward the east (i.e., in a down-stream direction) as they enter the alluvial material and approach Joachim Creek. Although the flux of groundwater and contaminants discharging to Joachim Creek in the reach of the stream illustrated in these figures is unknown, it has not resulted in significantly elevated concentrations in stream water or sediment. Data presented in Table 4.34 illustrate that PCE and TCE concentrations in Joachim Creek water are less than 1 μg/L.

As noted above, the distribution of PCE and TCE illustrated in Figs. 5.8 and 5.12, respectively, appears to suggest the presence of two potential source zones: one located in the northeastern part of the Hematite Facility (near the Burial Pits) and a second near the Evaporation Ponds and adjacent buildings. Figure 5.15 is an attempt to further resolve information about these different inferred source zones. This figure presents a map of the distribution of molar ratio values of PCE:TCE, defined as follows:

$$\text{Molar Ratio} = \frac{\text{PCE (concentration in } \mu g / L) / 165.8 \text{ (molecular weight of PCE)}}{\text{TCE (concentration in } \mu g / L) / 131.35 \text{ (molecular weight of PCE)}}$$

Groundwater samples with molar ratio values greater than one are said to be PCE-dominant and samples for which the ratio is less than one are TCE-dominant. Figure 5.15 illustrates that the deep overburden groundwater is clearly divisible into two separate populations, one that is PCE-dominant and the other TCE-dominant. The source of PCE-dominant groundwater appears to be associated with the southwestern part of the Hematite Facility. Indeed, one soil sample collected from location BD-02 under Building 240 had a concentration of PCE of 6600 mg/kg. The apparent source for TCE-dominant groundwater is in the northeastern area of the Hematite Facility (Burial Pits). Consequently, it appears that two major source areas and the principal groundwater plumes related to them in overburden have been identified. These presumed source areas are consistent with the patterns of PCE and TCE soil contamination discussed in Sect. 5.2.

The molar ratio of contaminants may be a useful tool for mapping the pathway(s) by which contamination migrates into bedrock where the connection to a specific source is less certain – a hypothesis that is testable. However, both PCE and TCE will degrade microbially under appropriate conditions and the ratio may change with increasing time, dependant on the relative rates of breakdown of these two contaminants.

5.3.2 PCE and TCE Distribution in Bedrock

Figures 5.9, 5.10, 5.13, and 5.14, respectively, illustrate the distribution of PCE and TCE in the Jefferson City-Cotter, Jefferson City-Roubidoux Contact Zone and Roubidoux HSUs. The principal observation from Figs. 5.9 and 5.13 is that the distribution of both PCE and TCE concentrations in groundwater from the Jefferson City-Cotter HSU define a plume that appears to have its source at the Hematite Facility. There are two components of contaminant migration, as shown by the arrows on Figs 5.9 and 5.13. One element of the plume migrates toward the southeast (toward PW-19); a second migrates toward the northeast (toward BR-04 and BR-09). Comparison of these plumes with the associated potentiometric map in Fig. 3.19 shows a direct correspondence between the hydrologic and contaminant data for this HSU. The only region of PCE and TCE contamination in the Jefferson City-Roubidoux contact zone and Roubidoux HSUs is in private wells PW-16 and/or PW-19 located southeast of the Hematite Facility.

A detailed discussion of the distribution of contaminants in these formations is presented in Sect. 5.4 in which the CSM for contaminant transport is developed.

5.4 EVALUATION OF THE POTENTIAL FOR THE OCCURRENCE OF DNAPL AT THE HEMATITE SITE

If PCE and TCE entered the subsurface under, and in the immediate vicinity of, the Hematite Facility due to spills and leaks in process and waste transfer pipelines, releases from the Evaporation Ponds or burial at waste disposal sites (e.g., Burial Pits), then it is appropriate to examine the potential that this contamination currently exists in the form of a DNAPL. It is important to make this assessment because the limited solubility of PCE or TCE from their respective liquid phases can result in a source that persists for decades before it is completely exhausted. Furthermore, the specific gravity of separate phase TCE or PCE is much greater than that of water. Consequently, if sufficient DNAPL was discharged to the subsurface, it has the potential to migrate downward under the influence of gravity (and independent of groundwater flow), thus leaving a trail of residual DNAPL saturation in overburden pore spaces; it may collect in pools on impermeable layers; and it may enter bedrock through pores (if the pore throat

dimensions are sufficiently large) or fractures (if the apertures are wide enough). In addition, DNAPL in bedrock fractures may diffuse into the rock matrix and become an important, long-term, secondary source of TCE or PCE to groundwater plumes.

The potential for the presence of DNAPL at the Hematite Site can be evaluated by estimating if the amount of PCE or TCE soil contamination is sufficient to suggest the presence of residual DNAPL saturation. The concentration of PCE or TCE in soil that is indicative of the presence of DNAPL (C_{sat}) is determined by accounting for the amount associated with pore water (groundwater at the solubility limit fully saturating the pore volume) and with a sorbed component by the following equation:

$$C_{sat} \geq \text{Contaminant in pore water + contaminant sorbed on soil organic matter}$$

It is assumed that soil concentration values in excess of C_{sat} indicate the presence of DNAPL. This approach and specific approaches for evaluating C_{sat} are discussed in ITRC (2004). Calculated values of C_{sat} for TCE range from 230 to 1650 mg/kg and for PCE range from 100 to 750 mg/kg. Soil from boring BD-02 has a PCE concentration of 6600 mg/kg, a clear indication of the presence of DNAPL (see the location in Fig. 5.16). Based on available data, no other soil samples fall within these ranges for either PCE or TCE. Consequently, evidence indicates that DNAPL underlies the Hematite Facility in this location.

It is also possible to infer the presence of DNAPL from the amount of TCE or PCE dissolved in groundwater. A concentration in groundwater greater than 1% of the solubility of the target contaminant frequently is considered to be suggestive of the presence of DNAPL in the vicinity of the sample. However, this method is not a definitive indicator for DNAPL, nor does it yield an estimate of the amount or specific location of DNAPL. Figure 5.16 is a map showing all groundwater data that meet the following criteria:

- TCE concentration greater than 11 mg/L (i.e., 1% of TCE solubility in water = 1100 mg/L) or,
- PCE concentration greater than 2 mg/L (i.e., 1% of PCE solubility in water = 200 mg/L).

Thirteen wells yielded groundwater samples in December 2004 that satisfied one of these criteria. All of these samples are from the overburden and most are underlying or closely associated with the Hematite Facility. The evidence from both soils and groundwater support the likely presence of DNAPL in this area.

The unusually high dissolved concentration of PCE at wells NB-34 and NB-74 and TCE at well NB-72 southeast of the Hematite Facility are not closely associated with the most likely source areas and suggest several alternative explanations. First, these wells may be at locations along particularly transmissive flow paths that convey highly contaminated groundwater rapidly from the source zone and with little dilution. Alternatively, the possibility of DNAPL being in the vicinity of these wells cannot be ruled out. In the absence of information pointing to disposal of waste solvents in these areas in the past, the possibility must be considered that DNAPL was discharged to the subsurface under the Hematite Facility in sufficient quantity that it could have migrated as a mobile, separate phase, possibly along the bedrock interface in the permeable, coarse-grain lithology.

In Chapter 3 it was shown that the bedrock surface underlying the terrace deposits on which the Hematite Facility is located slopes gently toward Joachim Creek (Fig. 3.4). However, this surface has a prominent depression located in the vicinity of BR-04 to the northeast of the Facility that is illustrated in a cross section (Fig. 3.9) and an overburden isopach map (Fig. 3.7). With evidence discussed in this section pointing to the likelihood that organic solvents (i.e. TCE and PCE) exist as free product in soils underlying the Facility, if a sufficient quantity of DNAPL was released to the soil the possibility exists

that it might have been able to migrate down gradient on the overburden-bedrock surface toward the depression. However, there is no evidence from the TCE and PCE concentrations measured in deep overburden soils that such a migration pathway has been active along this projected trajectory (Figs. 5.3 and 5.6). Similarly, groundwater samples obtained from the overburden in the same vicinity do not support this direction for DNAPL transport (Figs. 5.8 and 5.12). Furthermore, groundwater samples that were collected from the overburden and shallow bedrock in association with the construction of BR-04 during the Interim Hydrogeologic Investigation (LBG, 2002b) show no evidence of detectable VOC concentrations. Collectively, these lines of evidence do not support down gradient migration of DNAPL on the overburden-bedrock surface toward the depression near BR-04. Although the conclusion of this analysis is convincing, it does not rule out the possibility of lateral migration of DNAPL in other directions from the source area (as noted above) or vertical migration through overburden and into fractures within the underlying bedrock.

5.5 CONCEPTUAL SITE MODEL

The contoured data for PCE and TCE shown in Figs. 5.9 and 5.13 for the Jefferson City-Cotter HSU define plumes trending east-southeast that appear to have their origin in the northeastern part of the Hematite Facility. Furthermore, these plumes extend eastward across Joachim Creek. It is significant to note that the molar ratios of PCE:TCE for these groundwater samples are all less than one (i.e., TCE-dominant), which supports an inferred source region under the northeastern part of the Hematite Facility. Available data do not support the PCE-dominant region underlying the southwest part of the Facility as a major source of contamination to bedrock.

Figure 5.17 is a cross-section that is oriented to follow the axis of the PCE plume shown in Fig. 5.9. The cross-section focuses on the Jefferson City-Cotter HSU and is oriented approximately parallel to the regional strike of bedrock in this area. Each well and their respective screened intervals are shown, along with the concentrations of PCE from the December 2004 sampling period for both Jefferson City-Cotter and Roubidoux screened intervals. It is possible to contour these data in the vertical plane to complement the contours in the horizontal plane in Fig. 5.9 and emphasize the three-dimensional nature of the plumes. Figure 5.18 is the same cross-section in which TCE data are plotted and referenced to the plume in Fig. 5.13. These cross-sections emphasize that there are plumes for both TCE and PCE that appear to be migrating in the upper 50 ft of the Jefferson City-Cotter Dolomite underlying the area. It is also apparent that this plume extends south of Joachim Creek within the same interval of elevation.

The vertical gradients between the deep overburden (coarse-grain layer) and the Jefferson City-Cotter HSU, as illustrated in Fig. 3.18, indicate downward flow associated with the groundwater mound underlying the Hematite Facility and an upward flow potential closer to Joachim Creek. Therefore, in addition to the dominant lateral flow to the southeast in this HSU (Figs. 5.17 and 5.18), some upward migration of contaminated groundwater into the deep overburden may be occurring near the stream.

South of Joachim Creek, groundwater contamination abruptly appears to spread vertically downward. Packer testing conducted in private well location PW-19 during this investigation (methods described in Sect. 2.4) yielded depth-discrete groundwater samples obtained in 20-ft increments from a depth of 65 ft to the bottom of the well (250 ft), and reveals that VOC contamination extends throughout this entire depth interval (see Figs. 5.17 and 5.18 for results). It is also important to note that the molar ratio of PCE:TCE for groundwater samples from all depths and all wells in this area are TCE-dominant, which establishes the connection between the plume coming from the Hematite Facility in the Jefferson City-Cotter HSU and the contamination observed to the south of Joachim Creek.

Related sampling occurred in PW-16 in which diffusion bag samples were collected along the length of the open borehole. These data show similar information as for the packer testing in PW-19, but this mode of sampling does not yield samples from isolated zones. Vertical flow of groundwater may have occurred in the well bore during the time the diffusion bags were deployed. If true, the observed vertical distribution of contaminants may not reflect the actual vertical distribution within the bedrock as some vertical mixing may have occurred in the well bore. However, if in-well mixing were significant, greater homogenization of TCE and PCE concentrations would be expected. Consequently, PW-19 results (and probably those from PW-16 as well) establish that significant vertical migration of both PCE and TCE occurred in the vicinity of these wells throughout the bedrock to a depth at least as great as the well depths for PW-19 and PW-16. However, little contamination is observed in BR-07 even though it is located nearby. The bedrock is extremely low permeability in this borehole and may have prevented much local migration of PCE and TCE in this area. However, other factors also may be relevant and are discussed in the following paragraphs.

Drawing upon the empirical geologic, hydrologic, and geochemical data obtained during this investigation and discussed in this report, it is possible to develop a CSM for the Hematite Site. First, it has been shown that contamination from the source zone(s) identified under the Hematite Facility has dissolved in groundwater and migrated vertically downward into at least the top 50 ft of the Jefferson City-Cotter Dolomite. Then it appears that lateral flow and transport away from the source towards the southeast occurs in both the deep overburden and the shallow Jefferson City-Cotter HSU. This interpretation is consistent with both the geochemical (soil and groundwater) and hydrologic results for the Hematite Site that establish the source area, potentiometric gradients, and the configuration of resultant contaminant plumes. Furthermore, the northeasterly component to transport in the Jefferson City-Cotter HSU appears to follow bedding planes and is addressed below in more detail.

While the direction of flow and transport within the overburden is driven by a hydraulic gradient influenced by the water level in Joachim Creek (and mounding underlying the Hematite Facility), contaminant migration in the shallow Jefferson City-Cotter HSU was subject to other influences. Figure 3.18 establishes that groundwater mounding in the source area also impacted the shallow Jefferson City-Cotter HSU near the Hematite Facility. Furthermore, evidence suggests that the southeastward migration of contamination in this unit was driven by hydraulic stresses originating near the city of Festus, Missouri.

Section 3.3.3.4 presents a discussion about changes to the water supply system for the city of Festus that occurred in August 2003. Until that time, the city operated five deep production wells that derived water from the Roubidoux Formation in the lower part of the Ozark Aquifer. These wells are located on the west side of Festus approximately 4 miles from the Hematite Site. The average water consumption in the city of Festus water supply system is approximately 1 million gpd (http://www.cityoffestus.org/cityprofile.asp#utilities). In August 2003, a new water production facility was brought on-line to supply water needs for the area. This "collector well" is located near the Mississippi River and draws water from a very shallow depth (~100 ft) from the alluvial sediments of the floodplain, rather than from the Ozark Aquifer system. Once the collector well became operational, the other production wells went on standby and are only expected to be used during periods of peak demand (e.g., July and August) to supplement the output of the collector well or when the collector well is shut down for repairs.

Before August 2003, the extraction of groundwater by Festus was sufficient to cause significant drawdown in the aquifer that threatened to impact neighboring communities that also relied upon deep wells. Drawdown effects were observed in Pevely, Missouri (~5 miles to the north), and the Hematite Site (~4 miles to the southwest). Consequently, the cone of depression and associated hydraulic stress imposed on the Roubidoux Aquifer was significant and of regional extent. Following the August shutdown of the

deep wells, water levels within the Roubidoux Formation have been observed to rise dramatically (20 to 50 ft near the Hematite Facility), as illustrated in Fig. 3.27.

In addition to the impact of the Festus production wells, the residential community that includes homes associated with wells PW-19, PW-16, and others in the area also were pumping until they were shut down over the time period from early November, 2003 through mid-March, 2004. However, the magnitude of the combined pumping by these residences was insignificant relative to the pumping rate in the Festus wells.

Information presented in Sect. 3.3.3.4 and associated figures indicate that little hydraulic interconnection exists between the Jefferson City-Cotter and the Roubidoux HSUs. This observation also is consistent with the presence of the low transmissivity zone (inferred on the basis of a variety of hydraulic test results) that was described also in Sect. 3.3.3.4.

Indirect evidence for hydraulic isolation between the Jefferson City-Cotter and the Jefferson City-Roubidoux Contact Zone HSUs comes from closer examination of Figs. 5.17 and 5.18. If a hydraulic connection exists between these two HSUs, then TCE and PCE contamination in the shallow screened intervals intercepted by wells BR-08 and BR-10 should have been able to migrate downward under the influence of the hydraulic stress on the Roubidoux Formation caused by pumping in the Festus wells. However, the fact that groundwater samples from the deep zones in both BR-08 and BR-10 are uncontaminated suggests that no significant connection exists between these two zones. Packer testing results for these boreholes also confirm this conclusion (Appendix I).

If the bedrock HSUs are not interconnected hydraulically, then the vertical distribution of contamination along the entire length of wells PW-19 and BR-16 requires a different explanation. The answer appears to be related to the open hole construction of these wells and the fact that they previously provided a direct connection among strata of both the Jefferson City Dolomite and Roubidoux Formation.

It is interpreted that hydraulic stresses generated by the Festus wells, while they were operating continuously, created a significant, regionally extensive, downward head gradient from the Jefferson City Dolomite to the Roubidoux Formation. Because of the existence of a non-transmissive interval between them, these two zones are essentially isolated from each other except where open boreholes exist. The private wells in the vicinity of PW-19 created a direct linkage between the Roubidoux Formation and the Jefferson City-Cotter Dolomite that was able to transmit the hydraulic stress in the Roubidoux Formation into the Jefferson City-Cotter. As a result, groundwater at higher heads in the shallower zones (i.e., Jefferson City-Cotter HSU) could move down these well bores and flow into deeper zones (at lower hydraulic head values) intersected by the open borehole. In principle, with sufficient cumulative vertical flow down the well bores within the residential community, lowered hydraulic heads in the Jefferson City-Cotter HSU would be able to establish a potentiometric low that would result in groundwater flow and contaminant transport from the Hematite Site beneath Joachim Creek toward the open boreholes located south of Joachim Creek.

For such a mechanism to be realistic for the Hematite Site, not only must the private wells interconnect the hydraulically isolated zones, but the potential rate of downward flow must be sufficient to significantly impact flow within the Jefferson City-Cotter HSU. Metz and Brendle (1996) investigated vertical flow rates in open boreholes in Florida and measured rates as high as 100 gpm in some wells. Clearly, the magnitude of vertical flow by this mechanism is dependent on the hydraulic properties of the aquifers and the hydraulic head differences involved as well as details about the wells (e.g., diameter). Only some of this information is known for this site. However, the Metz and Brendle (1996) investigation indicates that significant interaquifer flow is possible under favorable conditions.

With multiple wells potentially participating in vertical flow in the residential community near the Hematite Site, the integrated flux of water and its impact on lateral flow in the Jefferson City-Cotter HSU could be very large even if flow rates for individual wells were much lower than those observed by Metz and Brendle (1996). Head differences and transmissivities of the source and receiving zones are important in defining flow rates by this mechanism and would need to be incorporated into a model if a quantitative assessment of the process is required. However, in the modeling component of this RI, the viability of the process is explored by assigning vertical flow rates and observing the resultant impact on the potentiometric surface and contaminant transport (Sect. 5.6 and SAIC 2005).

This mechanism not only helps explain the configuration of the potentiometric surface for the Jefferson City-Cotter HSU (Fig. 3.19), but also accounts for the formation of the well-defined plumes of PCE and TCE migrating toward the southeast from the Hematite Facility (Figs. 5.17 and 5.18). In addition, it provides a credible explanation for how contaminated groundwater has been able to migrate into the Roubidoux Formation in the vicinity of the private wells, but not elsewhere across the Hematite Site where a nontransmissive zone prevents such communication. Contaminated groundwater from the Jefferson City-Cotter HSU enters the open boreholes of the private wells and is then redistributed into any receiving transmissive zones for which the hydraulic heads are lower, thereby spreading contamination throughout the length of these boreholes. Many years of aquifer stress caused by pumping on the wells operated by the city of Festus would have resulted in transfer of an unknown quantity of contaminated groundwater into deeper, transmissive intervals. In effect, these wells became sources of contamination to these deeper intervals that would have been active as long as the hydraulic conditions imposed by pumping of the Festus production wells continued.

During the time when both the private wells and those operated by the city of Festus were in use, the overall flow of contaminated groundwater down the boreholes would be partially offset by periodic pumping on the private wells to meet domestic needs. However, the rate of downward flow would have greatly exceeded the domestic pumping rate so that downward vertical redistribution of contaminants would have been a dominant process. Once the Festus wells were shut down in August 2003, the potential for downward borehole flow and contaminant transport began to dissipate rapidly.

It is possible to explore this model further by examining the concentration of TCE (the most abundant contaminant) observed in groundwater obtained from PW-16 and PW-19 over a nearly 3-year period. Figures 5.19a and 5.19b present the data that include both historical (bulk samples obtained while the private wells were active, open holes) and more recent results from packer tests, diffusion bags, and samples from screened intervals once these wells were reconfigured. Also noted are the dates of shutdown of both the Festus production wells and the private wells.

The most important feature of these figures is that data obtained following shutdown of the Festus production and private wells reveal consistently low concentrations of TCE relative to what had been seen earlier. Even allowing for the time variability of the earlier results, the trend is remarkable. As noted, during the 6 to 7 months following shutdown of the city of Festus wells, water levels in wells completed in the Roubidoux Formation in the general vicinity of the Hematite Site recovered significantly (Fig. 3.27). Therefore, the driving force for continued vertical spreading of contaminants in the private wells greatly declined during this period of time. However, the ultimate fate of contamination that had spread downward through the boreholes over many years prior to this time should be considered. It is probable that this contamination spread laterally in a direction that was dominated by the influence of the regionally extensive head gradient imposed by pumping on the Festus production wells. Following recovery of water levels in the Roubidoux Formation, the northeasterly regional potentiometric gradient was reestablished and flow directions would have shifted accordingly. The influx of uncontaminated groundwater from the southwest would now have the opportunity to greatly dilute and flush

contamination from the area and would lead to reduction in contaminant levels obtained from these wells in a manner consistent to what is observed in Figs. 5.19a and 5.19b.

A better understanding of the changes in flow occurring over time in the vicinity of well PW-19 and others in the residential community can be obtained by examining changes in the potentiometric relationships associated with shutdown of the Festus production wells. In Sect. 3.3.3.2, the potentiometric map for the Roubidoux HSU, based on water level data collected in December 2004, was presented (Fig. 3.21). This map represents conditions after a significant period of recovery of water levels (16 months) and indicates a northeasterly trending head gradient consistent with the known regional gradient. The shape of the recovery curves for wells BR-01 through BR-04 (Fig. 3.27) suggests that recovery is essentially complete. It is possible to examine the potentiometric map for the Roubidoux HSU at a time when continuous pumping of the Festus wells was still occurring. LBG (2003) prepared such a map and Fig. 5.20 illustrates the results for August 13, 2002, the earliest date for which water levels are available for the wells. Although water level data from only four wells are available, they suggest that the Festus wells had the impact of shifting the head gradient to an easterly direction. This is the potentiometric gradient that would have driven the lateral migration of contaminants transported downward in the open boreholes in the years prior to August 2003. Currently, however, the gradient direction has shifted to the northeast and a commensurate change in plume migration in the Roubidoux HSU in this area is anticipated.

Figures 5.17 and 5.18 indicate that borehole BR-07 is located in close proximity to PW-19 and other private wells. The results of groundwater sampling in this well from the discrete intervals shown in the figures and from packer testing (Appendix I) indicate that only very low levels of chlorinated VOC contamination are observed and only in a few depth intervals. Given its location, it is surprising that more extensive contamination is not observed. It has already been noted that most intervals in this borehole appear to have low transmissivity and this may be a contributing factor to what is observed. It is more likely, however, that the explanation is related to the details of how the contaminant plume in the Jefferson City-Cotter HSU responded to the various open hole wells in which vertical flow was occurring. The approaching plume would tend to split apart with different segments migrating preferentially to those wells having vertical flow. In this way, it is possible that BR-07 may be located in a region bypassed by the different plume segments and not be subject to the influx of significant contamination. However, this is an unresolved issue that cannot be answered with available data because it requires more information on the depths of the open holes, when they were constructed, and the vertical distribution of hydraulic properties in them.

This CSM suggests that private wells in the vicinity of PW-19 have had an important role in moving contaminants southeastward from the Hematite Facility in the shallow Jefferson City-Cotter Dolomite. Private wells also exist on the next ridge to the southwest and it is legitimate to question whether they could impact the distribution of contaminants in a similar fashion, as observed in Figs. 5.17 and 5.18. Monitoring well BR-03-JC lies directly between the Hematite Facility and these private wells, and is screened in the same depth interval that exists at WS-30, WS-31, BR-08, and BR-10. In contrast to these wells, however, BR-03-JC is uncontaminated, as are all of the private wells further to the southeast that have been sampled. It must be concluded that the region between these private wells and the Hematite Facility (including BR-03-JC) behaves differently than what is observed in Figs. 5.17 and 5.18. Apparently, contaminant sources at the Hematite Facility do not create a plume in the shallow Jefferson City-Cotter Dolomite that migrates toward BR-03. Additional information on the hydraulic properties of the shallow bedrock in this area coupled with modeling may help to better understand this observation.

There is a second component to this CSM that incorporates data for wells BR-04, BR-09, and PW-03 into an overall understanding for the Hematite Site. Fig. 5.21 is a cross-section similar to Fig. 3.9 that is

oriented approximately parallel to the dip of bedrock in this area. The cross-section includes wells BR-01, PZ-04, BR-04, PW-03, and BR-05. The following information has been incorporated on this cross-section:

- Stratigraphic correlation based on the sandstone layer near the Jefferson City-Roubidoux contact,
- Screened intervals for each well,
- Concentrations for PCE and TCE for isolated zones, and
- Concentration data from packer testing in PW-03.

The principal observations made from this cross-section are:

- The screened intervals in the Jefferson City-Cotter Dolomite in wells PZ-04 and BR-04 align well with the bedding plane dip based on the deeper sandstone layer (i.e., they sample a common stratigraphic level – the Jefferson City-Cotter HSU).

- This stratigraphic level projects upward to the shallow contaminated part of the Jefferson City-Cotter in the vicinity of PZ-04 and the Hematite Facility.

- The Jefferson City-Cotter wells are contaminated as far east as PW-03, but no contamination is observed in BR-05.

- Contamination in PZ-04 and PW-03 is TCE-dominant whereas BR-04 is strongly PCE-dominant.

- Groundwater samples obtained during packer testing at PW-03 show that contamination has spread vertically across the length of this borehole.

It is possible to project BR-09 into the plane of this cross-section. Had this been done, the only zone of contamination in BR-09 would correlate with the contaminated stratigraphic zones in PZ-04 and BR-04. However, contamination in BR-09 is TCE-dominant.

Available evidence appears to suggest that contaminated groundwater has migrated down dip along transmissive bedding plane fractures or a transmissive lithologic unit in the Jefferson City-Cotter Dolomite at least as far as PW-03, but has not yet reached the location of BR-05. The projection of this interval into the zone of contamination underlying the Hematite Facility (e.g., PZ-04) suggests this region as the source zone. However, the distinctive differences in contamination at BR-04 (PCE-dominant) and PZ-04, BR-09, and PW-03 (TCE-dominant) indicate that the specific sources for contamination are different for these two groups of wells. The detailed locations of sources or specific migration pathways that would yield these results cannot be resolved with available data. However, the proposed mechanism for contaminant migration is sound. The hydraulic driver for bedding plane flow and transport is partially associated with groundwater mounding under the northeastern area of the Hematite Facility.

The mechanism for vertical distribution of contaminants observed in PW-03 packer test samples is consistent with what is interpreted to have occurred at PW-16 and PW-19. The impact of the open borehole at PW-03 as a conduit for transferring contamination vertically downward into deeper horizons in the well appears to be of key importance at the Hematite Site. The hydraulic stress imposed on the Roubidoux Formation (and lower Jefferson City-Cotter Dolomite) from pumping in Festus likely contributed significantly to this overall process.

As noted in Chapter 3, hydraulic heads in the Jefferson City-Cotter wells located between the region of BR-09 and Joachim Creek. (i.e., BR-11 and BR-02) are similar to that for BR-05. Based upon the data, it appears that no potential currently exists for down dip flow to these wells and none of them have any contamination. The lack of a driving force, as provided by the groundwater mounding underlying the

northeast part of the Hematite Facility, for wells represented in Figs. 5.19a and 5.19b may account for this observation.

5.6 SUMMARY OF GROUNDWATER AND CONTAMINANT TRANSPORT MODELING

Groundwater flow and contaminant transport modeling was conducted as part of this RI. Specific activities included (1) pre-modeling calculations of hydraulic gradients, groundwater velocities, and sorption coefficients; (2) developing and calibrating a groundwater flow model using historical and more recent RI water level data; (3) particle tracking simulations to infer source zones; (4) simulating chlorinated solvent transport; and (5) simulating radionuclide transport. Details regarding the modeling effort are described in (SAIC 2007) and Appendix A, while highlights of the modeling results are presented here.

The model domain (Fig. 5.22) encompasses a larger region than the Hematite Site so that assumptions at the model boundaries would not significantly impact flow simulations within the area of interest. The HSUs described in Sect. 3.3.3.1 are generally represented in the MODFLOW layer model (Fig. 5.23). BR Zones 1 and 2 in Fig. 5.23 correspond to the Jefferson City-Cotter HSU and BR Zone 3 corresponds to the Jefferson City-Cotter-Roubidoux Contact Zone, while BR Zone 4 corresponds to the Roubidoux HSU. Use of MODFLOW for groundwater modeling implicitly assumes the bedrock formations are suitably modeled as porous media. Geologic features parallel to bedding planes appear to be influencing contaminant transport. These features may include fractures and/or sedimentary interbeds that would suggest somewhat different modeling approaches. However, use of a porous medium assumption is appropriate given that this modeling effort is the first attempted for the Hematite Site.

Initial estimates for hydraulic conductivities of the layers were based on historical and RI slug test results (Sect. 3.3.3.1), but were later adjusted during model calibration. Cells within the top model layer that coincided with Joachim Creek (Fig. 5.24) were "specified head cells." Attempts were made to specify heads at cells in the model that corresponded to the Lake Virginia tributary, Site Creek, and Northeast Site Creek. However, specifying heads to represent these streams was exerting an influence on the simulated hydraulic heads that was not apparent in the monitoring well data. The "river" boundary condition was then used, where the interaction of streams and groundwater is simulated through a streambed with a specified conductance. The streambed conductance had to be set to very low values to match measured water levels. As a result, the influence of these surface streams on the groundwater was ignored in the final calibrated model. The latter assumption is consistent with the fine-grained nature of the shallow soils at the Hematite Site, which probably limits leakage from the surficial (some intermittent) streams to groundwater. With the exception of the bottom two layers of the model (Fig. 5.23), all the boundaries (solid line in Fig. 5.22) were specified as no-flow boundaries. For the bottom two layers of the model (the BR Zone 4 layer and the lower part of BR Zone 3, Fig. 5.23), heads were specified along arc A-D and arc B-C in Fig. 5.24, resulting in a regional northeasterly direction in the deeper layers of the model. This is consistent with the regional flow direction inferred from the water level data after August 2003 (when the city of Festus put the new collector well on-line) in the wells screened within the Roubidoux HSU (Sect. 3.3.3.1).

The model was calibrated using the average of historical water levels from deep overburden wells and the bedrock wells. In the Roubidoux wells where significant water level rebound was observed in 2003 and 2004 (Fig. 3.27), only the water levels from April through December 2004 were included when calculating the average water level for model calibration. Initial attempts at model calibration also included historical data from the pre-RI shallow overburden wells. These initial attempts to simulate the water levels in the shallow overburden wells resulted in unreasonable recharge and high heads in the underlying layers. This might have been due to the perched nature of the groundwater in the shallow

overburden (Sect. 3.3.3.2) trapped over a low-conductivity soil (the "fat clay," as identified by LBG 2002b), which was not explicitly represented in the layer model (Fig. 5.23). Incorporating this low conductivity unit into the model would have required multiple layers to represent the shallow overburden bedrock, which would have increased the number of model grid cells and numerical resources to solve the larger set of equations. Because flow in the shallow overburden bedrock is predominantly downward (Sect. 3.3.3.2), and off-Site contaminant transport is likely from lateral flow through the deep overburden and bedrock, calibration to the shallow overburden wells was discontinued and only the deep overburden and bedrock wells were considered in the final calibrated model.

A comparison between the modeled and calibrated hydraulic heads is shown in Fig. 5.25, where a perfect match is represented by the 1:1 line. The average residual for the final calibrated model is -0.6 ft, with average residuals of -0.02, -1.8, and 0.6 in the deep overburden bedrock, Jefferson City, and Roubidoux wells, respectively. To capture mounding under PZ-04, a high recharge had to be assigned to the northern area of the Burial Pits (0.05 ft/day, compared to 0.0005 to 0.0002 ft/day throughout the rest of the model domain). A higher recharge value over the Burial Pits is plausible since buried objects and use of limestone gravel in the Burial Pits would have resulted in a more permeable layer that is more conductive to percolation of rainfall water to the subsurface. This high recharge alone could not simulate the high heads in the PZ-04 area. To simulate these heads, an injection well flowing at a rate of 2000 ft^3/day (~10.4 gpm) was added as a source in the northeastern end of the plant. This injection well possibly represents a combination of leakage from water distribution pipelines or drainage systems, shallow subsurface groundwater flow from the topographically elevated region northwest of the Facility, or storm runoff from the adjacent Highway P could contribute to this observation.

With the combined high recharge in the Burial Pits and the injection well, the mounding under PZ-04 was reproduced (see potentiometric contour lines in Fig. 5.26). The final hydraulic conductivities of the layers in the calibrated model can be found in SAIC 2005. The relative conductivities of the different layers generally follow what was observed in the slug tests. Furthermore, the hydraulic conductivity for BR Zone 3 representing the Jefferson City-Roubidoux contact zone HSU was set to 0.002 ft/day. This value was arrived at through successive simulations where the conductivity for this layer was lowered until changes in hydraulic heads within the bottom layer (BR Zone 4, Fig. 5.23) did not affect hydraulic heads in the Jefferson City layers (BR Zone 1 and 2, Fig. 5.23). This is consistent with the lack of hydraulic interconnectivity between the Jefferson City and Roubidoux Formations inferred from time-series water level data (Sect. 3.3.3.4). The hydraulic conductivity assigned to BR Zone 3 (0.002 ft/day or 7×10^{-7} cm/second) is within the range of hydraulic conductivities reported for limestone and dolomite (Table 2.2, page 29 of Freeze and Cherry 1979).

MODPATH and the calibrated steady-state flow model were used to gain insight into possible sources of chlorinated solvent contamination detected in bedrock wells BR-08-JC, BR-09-JC, and BR-04-JC (Sect. 4.4). Using the backward tracking capability, MODPATH simulations indicate that particles at these locations all have their sources in the vicinity of the Burial Pit Area (Fig. 5.26). Forward particle tracking indicated that particles at these locations will be advected towards Joachim Creek. Particle pathlines and travel times (Fig. 5.26) vary significantly depending on the release point of the particles within the Hematite Facility. Pathlines originating from source zones towards the southwestern part of the Hematite Facility (e.g., BD-02) are directed towards the southeast, following the hydraulic gradient towards Joachim Creek. Travel time for these particles are three times higher than for some particles that are released within the Burial Pit Area (i.e., ~30 versus ~10 years, respectively, see Fig. 5.26). An elevation view of the pathlines (not shown) reveals that the particles from the Burial Pits Area move down and travel towards Joachim Creek mostly within the transmissive zone in the Jefferson City HSU, resulting in shorter travel times than particles from BD-02, which stay mostly within the layer representing the alluvial/terrace deposits. The hydraulic conductivity for this layer is high near Joachim Creek (e.g., BR-06-OB, Table 3.2), but is an order of magnitude lower near the Hematite Facility

(e.g., NB-84, Table 3.2 and LBG 1999). The pathlines in Fig. 5.26 show a radial pattern from the Burial Pit area, influenced by mounding of groundwater in the vicinity of PZ-04. The model predicts that pathlines directed towards BR-04 turn towards Joachim Creek, as the influence of the mound diminishes. Note that the boundary conditions for the groundwater model implicitly constrain most of the groundwater within the shallow bedrock (e.g., Jefferson City) to discharge into Joachim Creek, and that the regional northeasterly flow exists in the lower (e.g., Roubidoux) layers. However, it is uncertain that groundwater and dissolved contaminants in BR-04-JC (found at a depth of 95 to 105 ft BGS) actually discharge into Joachim Creek, as required by the model. It is possible that at this depth the regional northeasterly flow direction is dominant.

The flow model used for particle tracking includes a simulation of domestic well pumping by specifying well extraction flows at the wells shown in Fig. 5.26 (labeled PW). The domestic well pumping rate was estimated from 2000 USGS water use data (Hutson et al 2005), which stated that for Jefferson County, Missouri, the total population that used self-supplied water was 51.57 x 10^3, and the total groundwater withdrawal from domestic wells was 3.35 x 10^6 gpd, from which the estimated per capita water usage is 65 gpd or 260 gpd (35 ft^3/day) for a household with four members. Although this flow rate was applied to the domestic wells shown in Fig. 5.26 (labeled PW), the pathlines shown in this figure indicate discharge to Joachim Creek. Thus, the numerical modeling suggests that the impact of pumping in the domestic wells (assumed to be equivalent to a steady extraction rate of 35 ft^3/day) was not enough to draw groundwater from the Hematite Facility side of Joachim Creek into the area where the domestic wells are located. On the other hand, if an extraction rate of 2000 ft^3/day (10.4 gpm) is applied to 13 wells in the vicinity of PW-19 to simulate vertical borehole flow, a significant impact on the potentiometric surface is observed, as well as pathlines from BR-08 and BR-09 that now go under Joachim Creek into PW-19 and PW-16 (Fig. 5.27). Note that 10 gpm is the lowest flow rate observed by Metz and Brendle (1996). Because water levels in the Roubidoux have rebounded (Fig. 3.27) and the driving force for this vertical flow rate is no longer present, it is difficult to estimate the actual flow rates that previously existed in the open-borehole domestic wells in the PW-19 area. Nevertheless, the numerical modeling and simulation shown in Fig. 5.27 supports the CSM and the impact of vertical borehole flow described in Sect. 5.5.

Contaminant transport modeling using RT3D was coupled with the flow model for the site, which includes vertical borehole flow to simulate the migration of contaminants from known and suspected source zones at the Hematite Facility. Matching the measured contaminant concentrations with modeled values was not attempted because of the existence of multiple sources and the uncertainty of when these sources were emplaced (e.g., t = 0 for the simulations). As such, the primary purpose of these simulations is to investigate the influence of potential attenuation mechanisms (e.g., sorption and degradation) on the migration of contaminants from known and suspected source zones at the Hematite Facility.

Figures 5.28, 5.29, and 5.30 show simulated PCE concentration contours in the layer corresponding to the deep overburden (Layer 2, Fig. 5.23). The contours emanate from a constant concentration source of 200 mg/L of PCE located at BD-02. Figures 5.28, 5.29, and 5.30 present model results for t = 3,000 days (~8 years); 9,000 days (~25 years); and 15,000 day (~41 years). The sequential degradation (PCE > TCE > *cis*-1,2-DCE > vinyl chloride) model in RT3D's chemical reaction package is used, with degradation parameters taken from the lower range of values reported by Newell and Rifai (2002). Sorption of PCE and its daughter products in the overburden layers was also incorporated, using partition coefficients estimated from natural organic matter measurements (SAIC 2003c, estimation described in SAIC 2005). Two observations can be made from Fig. 5.28 through 5.30: (1) sorption and degradation result in a significant attenuation in PCE levels such that concentrations rapidly drop by one or two orders of magnitude just a short distance from the source (i.e., BD-02), and (2) minimal change between the contour plots at t = 25 years and t = 41 years suggests that a steady-state configuration of the plume is

possible if degradation occurs. The predicted plume also tends to be narrow and is directed towards Joachim Creek.

Figure 5.31 shows another simulation using the same sorption parameters used in Figs. 5.28 through 5.30, but with a 100-mg/L PCE source placed in the northern part of the Burial Pits (see the red square in Fig. 5.31). The degradation parameters were reduced by an order of magnitude to determine whether, even at lower rates, steady-state conditions can be attained within approximately the same time frame as in the previous simulation. Figure 5.31 shows simulated PCE concentrations in the layer corresponding to the transmissive Jefferson City HSU at t = 15,000 (~41 years). The predicted PCE plume is approaching near-steady-state at t = 15,000 days, as shown by a plot of simulated PCE and TCE concentrations versus time at the location corresponding to BR-04-JC (see the insert in Fig. 5.31). The simulation also indicates an elongated PCE plume configuration that is directed towards BR-04, but also encompasses WS-30, WS-31, BR-09, and BR-08. Spreading along the lateral axis of the plume may partially be from the radial flow that is induced by groundwater mounding under the Hematite Site. Lateral spreading is also controlled by the horizontal dispersivity, which was set at 1/5th of the longitudinal dispersivity in the simulation. Figure 5.32 shows still another simulation where the source is located in the southern part of the Burial Pits area and consists of specified PCE and TCE concentrations of 50 mg/L.

The same degradation and sorption parameters are used as in the simulation in Fig. 5.31, but the overall shape of the PCE and TCE plume (shown in Fig. 5.32) is elongated towards the southeast in the direction of Joachim Creek. As in particle tracking, this suggests that contaminant pathways vary depending on the location of the source, even in the relatively small area of the Burial Pits. This is another illustration of how mounding under the Hematite Site near the Burial Pits may have an impact on contaminant migration away from sources within the Hematite Facility. Figure 5.32 also illustrates the movement of TCE towards the PW-19 area under the influence of vertical borehole flow in the open boreholes. Note that the model shows contamination spreading to BR-07, which is not consistent with the packer testing (Appendix I), and sampling from this well location showed minimal to no contamination (Sect. 4.4). The transmissivity of the formation around BR-07 may be lower than PW-19, reflecting smaller-scale heterogeneities that cannot be captured in the model. The transport simulations also indicate vertical spreading of contamination (results not shown) in the bedrock even though the vertical dispersivity was only set to 1/5th of the longitudinal dispersivity. This is in contrast to the relatively narrow (20 to 30 ft) zones of contamination observed during packer testing of the newly drilled boreholes (Appendix I). This discrepancy may be due to use of a porous medium model to simulate a situation where transport is through discrete fractures. The porous medium model was useful in exploring hydraulic and contaminant transport mechanisms that would explain the observed distribution of contaminants in the overburden and bedrock.

Radionuclide transport modeling shows very limited movement of uranium from sources (Fig. 5.33) in the overburden using the partition coefficient measured in the site-specific K_d study (175 mL/g, SAIC 2003c). Sources of uranium (specified concentration of 0.2 mg/L) were placed in Deul's Mountain and the Burial Pits. The K_d factor for uranium is two orders of magnitude higher than the K_d factor for PCE. Thus, it is not surprising that PCE is much more widespread at the Hematite Site than uranium.

5.7 FATE OF PCE AND TCE: EVALUATION OF EVIDENCE SUPPORTING DEGRADATION OF PCE AND TCE BY NATURAL PROCESSES

The most common chlorinated VOC contaminants in groundwater at the Hematite Site include TCE, PCE, and *cis*-1,2-DCE, with less frequent occurrences of 1,1-DCE; *trans*-1,2-DCE; and vinyl chloride. Of these, only PCE and TCE were used at the Hematite Facility, although it is possible that some of the

others were contaminants in the primary solvent materials. An alternate, and more likely explanation, is that the various DCE isomers and vinyl chloride are the result of anaerobic biological degradation of TCE and PCE in the subsurface. The degradation pathway for PCE/TCE under anaerobic conditions is presented in Fig. 5.34. At most sites, *cis*-1,2-DCE is recognized as the principal DCE isomer formed and that is true at the Hematite Site. Only a small number of samples had a quantifiable amount of *trans*-1,2-DCE. An even smaller number of samples had a measurable quantity of vinyl chloride. 1,1-DCE also is frequently observed, but at only relatively low concentrations.

The mix of these chlorinated VOCs found at the Hematite Site represents strong evidence that biologically mediated natural attenuation processes are active in the subsurface. Furthermore, it appears that, for the most part, degradation has stalled at DCE, which is a common occurrence at many sites.

It is prudent to look further at these data to determine if the anaerobic degradation mechanism can be verified for the site. To do this, an index of anaerobic degradation is defined and computed from the molar amounts of the principal contaminants as follows:

Index of Degradation = (PCE+TCE)/*cis*-1,2-DCE

In general, as biodegradation proceeds, the relative amounts of the parent constituents (PCE and TCE) will decrease and the product (*cis*-1,2-DCE) will increase (because further degradation to vinyl chloride does not appear to be important at the Hematite Site). This sequence of events will result in a decline in the index. If biodegradation is a causative factor at the Hematite Site, then it is anticipated that the highest values of the index will occur near the source area, with progressively lower values more distant from the source. Figure 5.35 shows how this ratio varies with location in groundwater from the deep overburden at the Hematite Site. Figure 5.36 presents analogous data for the Jefferson City-Cotter and a few Roubidoux wells.

In Fig. 5.35, it is apparent that the two samples with the highest index values are located beneath the Hematite Facility. This is a reasonable observation as the Hematite Facility is the presumed source of PCE and TCE, and contamination in this area probably was released most recently with less time to undergo degradation. There is a second zone of elevated values of the index that extends outward from the source area toward Joachim Creek, which defines a curved plume. This plume is virtually coincident with the PCE-dominant plume illustrated in Fig. 5.16. Because PCE first degrades to TCE before proceeding to *cis*-1,2-DCE, groundwater that is PCE-dominant should take longer for the index to decline than for TCE-dominant groundwater, where only a single step is required to produce *cis*-1,2-DCE. The remaining samples in the area have index values of less than 5, except for several samples located next to Northeast Site Creek.

Relatively few samples are available from the Jefferson City-Cotter Dolomite and Roubidoux Formation (Fig. 5.36). With one exception, these samples have low values of the index suggesting that they are relatively mature in terms of the degree of reductive dechlorination that has occurred. The single exception (index = 22.09) is for groundwater from the Jefferson City-Cotter Dolomite at BR-04. Groundwater at this location has significant PCE contamination (1700 μg/L) and, coupled with the elevated index value, may suggest rather rapid and extensive contaminant migration from the source zone under the Hematite Facility to this site.

As a general rule, the relative rates of dechlorination reactions for the chlorinated ethenes decrease with the decreasing number of chlorine atoms on the molecule. Thus, the rates might be expected to decline in the following order:

PCE > TCE > *cis*-1,2-DCE > vinyl chloride

This rate sequence also may help explain the limited evidence for production of vinyl chloride in these groundwater samples. However, more likely explanations include either the lack of a consortium of bacteria capable of complete degradation of PCE and TCE to ethane or conditions within the subsurface unfavorable to extensive production of vinyl chloride.

In summary, evidence points to the fact that microbial reductive dechlorination of PCE and TCE is occurring at the Hematite Site. However, there is no information supporting their complete degradation to ethene. In general, it appears that the reductive reactions have essentially stalled following production of DCE, except in a few locations where a detectable amount of vinyl chloride is observed.

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CHAPTER 5 FIGURES

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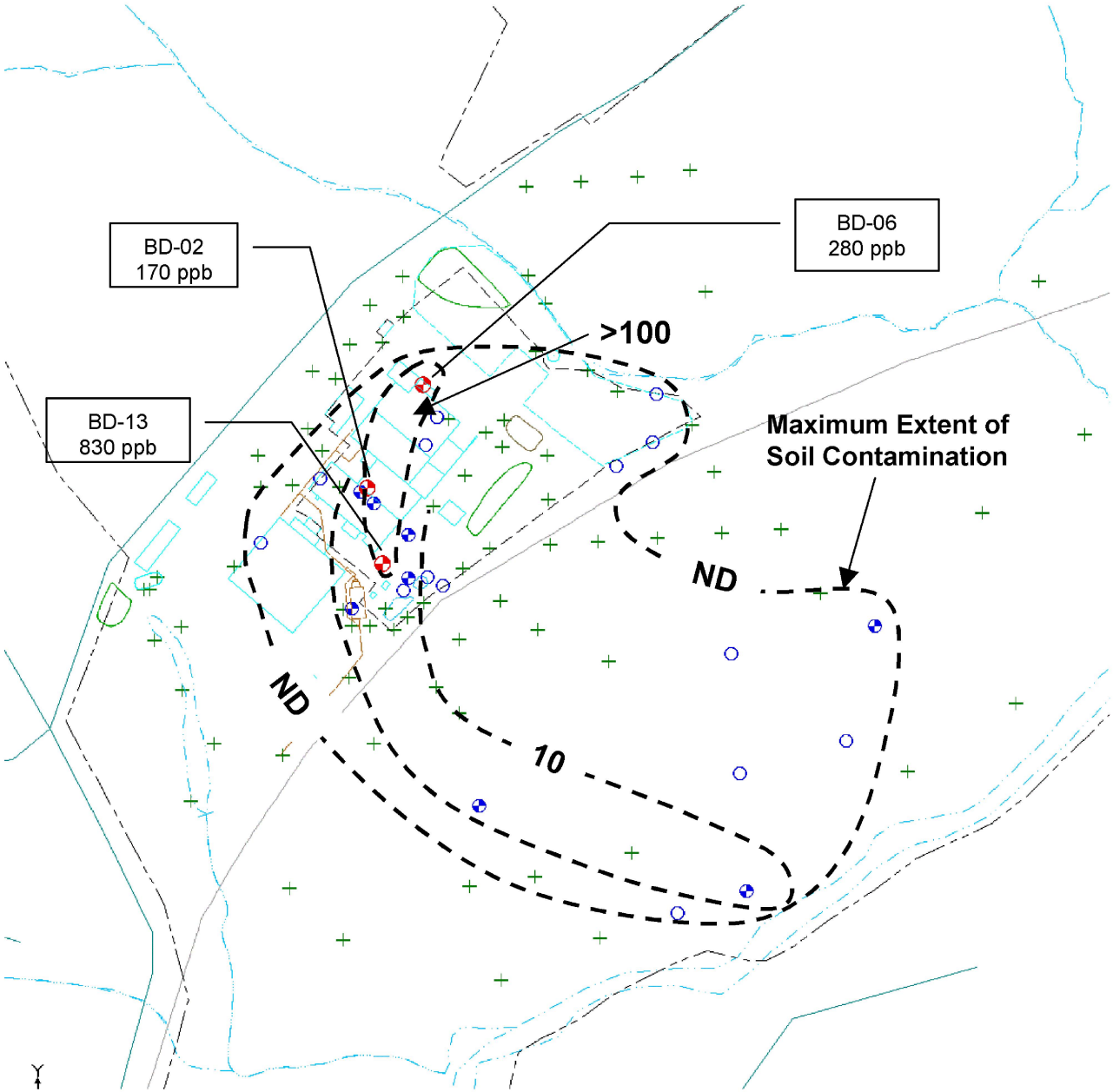


Fig. 5.1. PCE in soil samples collected from 0 to 10 ft BGS.

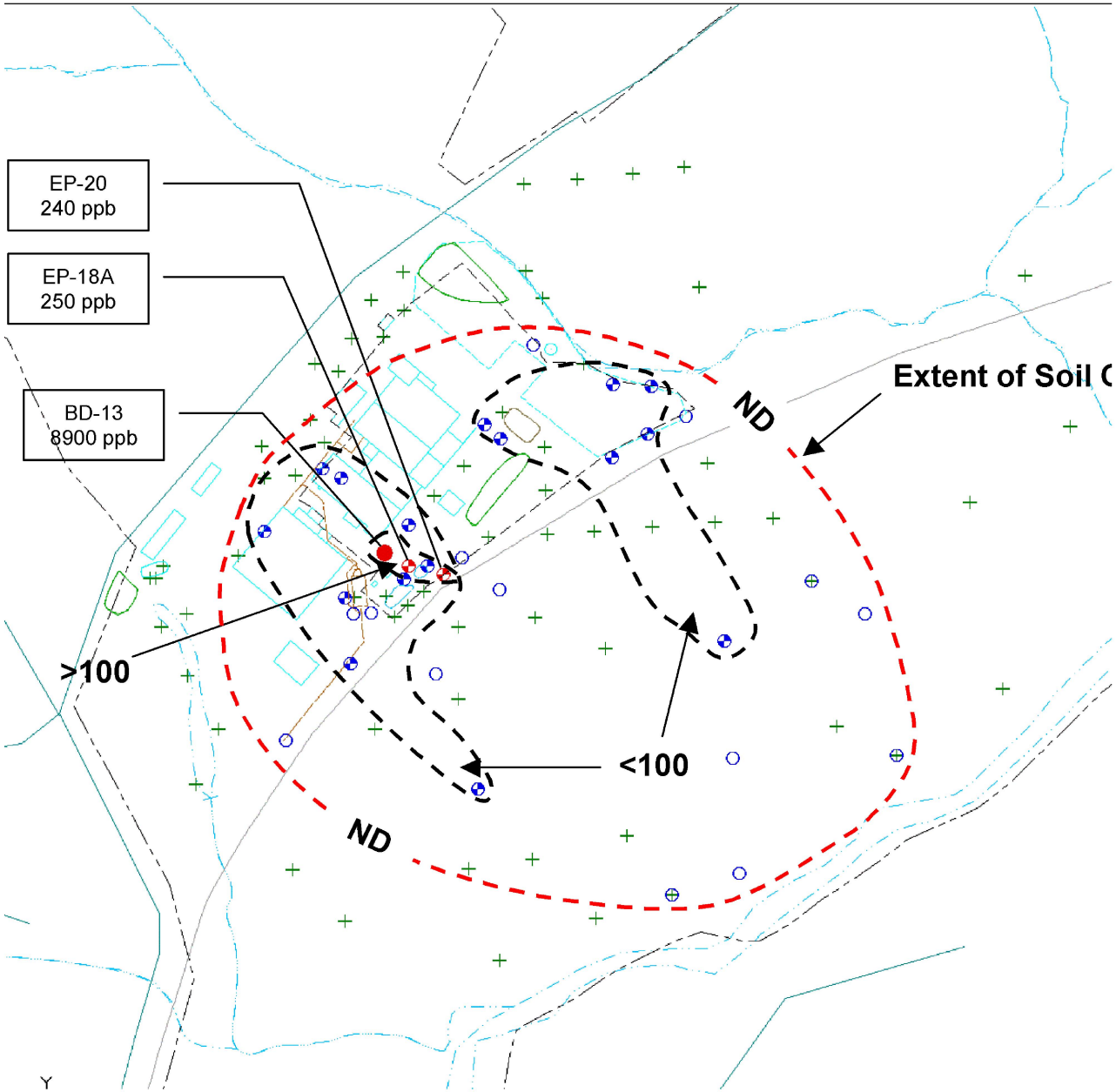


Fig. 5.2. PCE in soil samples collected from 10 to 20 ft BGS.

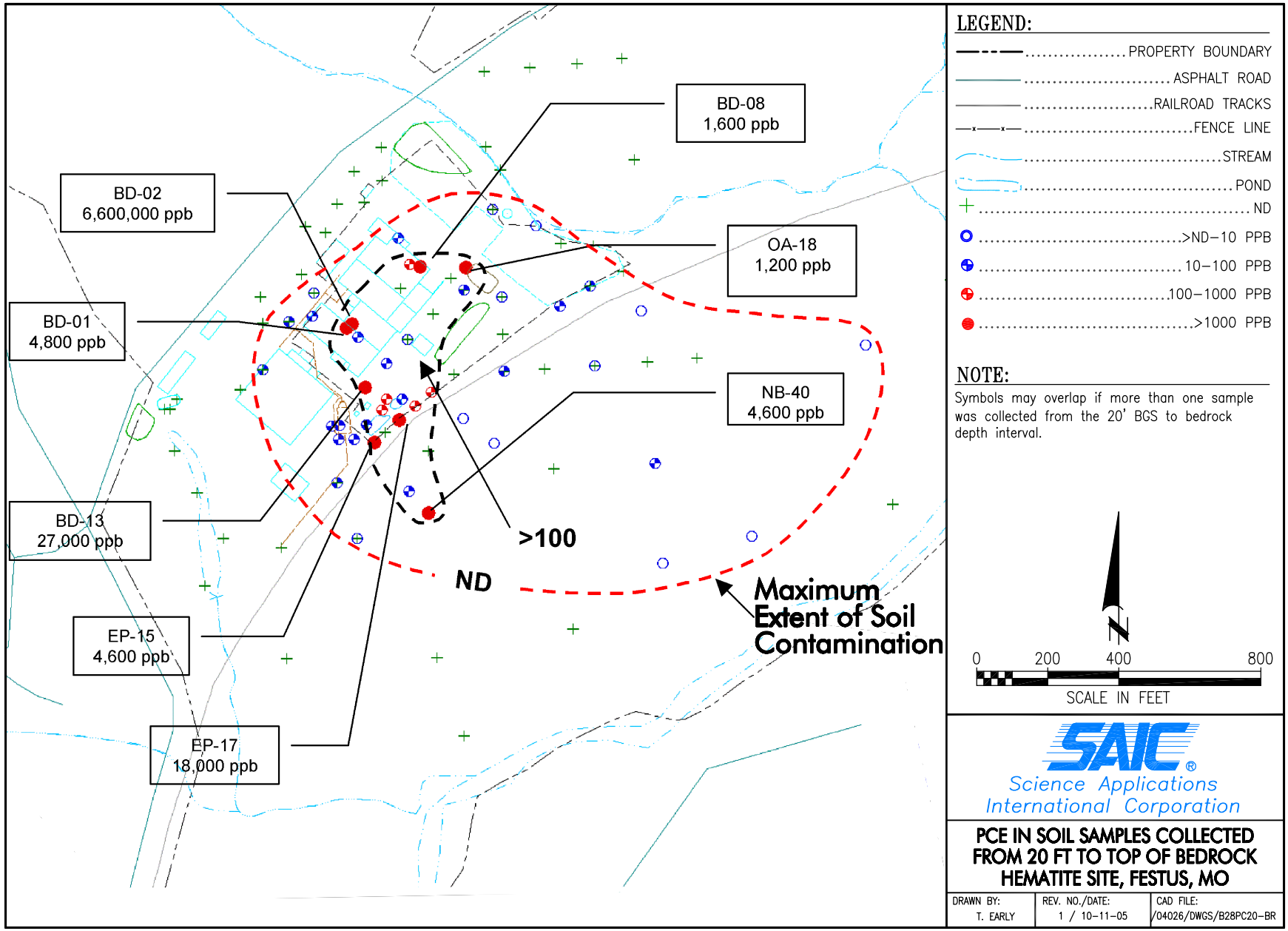


Fig. 5.3. PCE in soil samples collected from 20 ft BGS to top of bedrock.

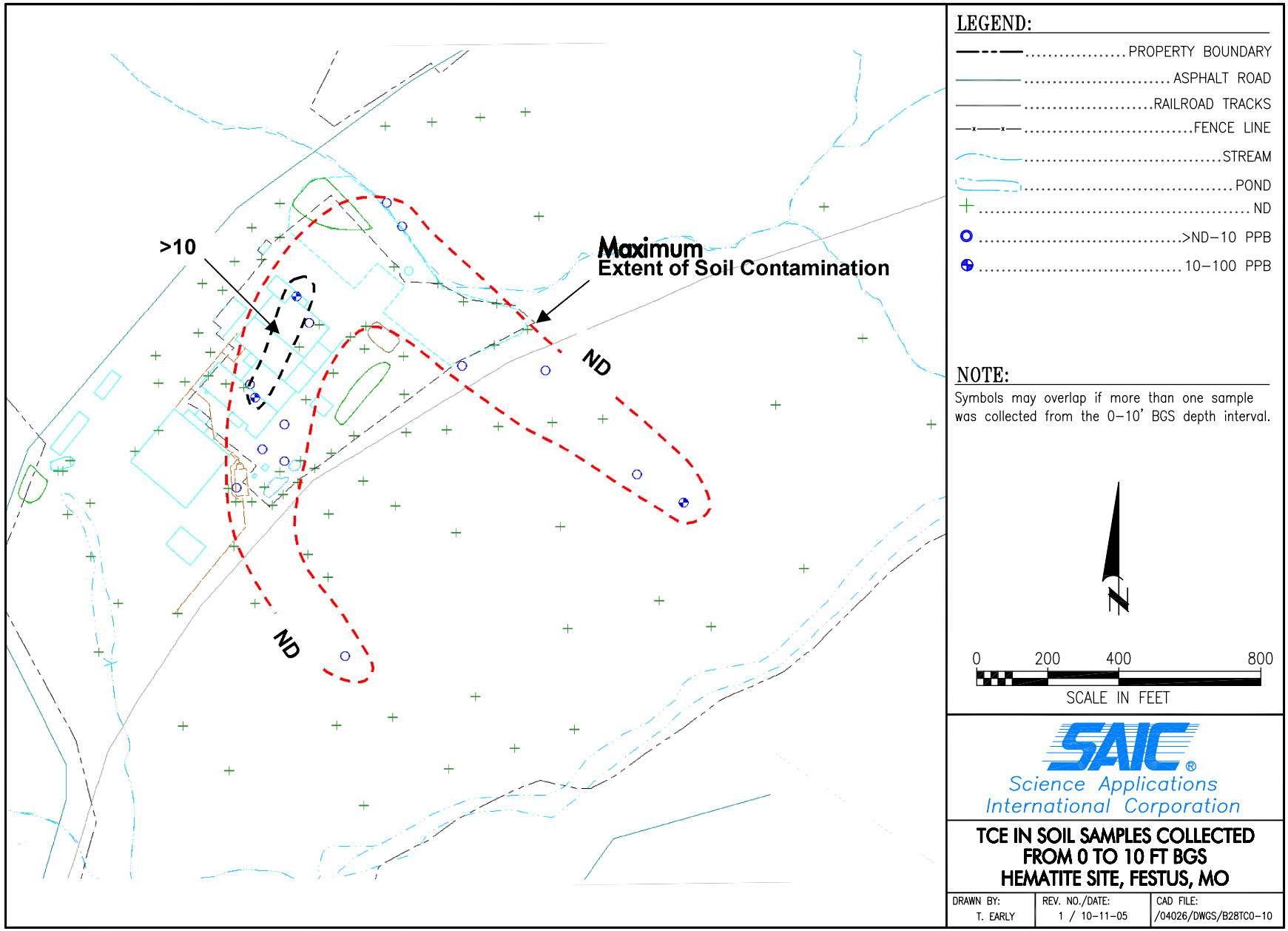


Fig. 5.4. TCE in soil samples collected from 0 to 10 ft BGS.

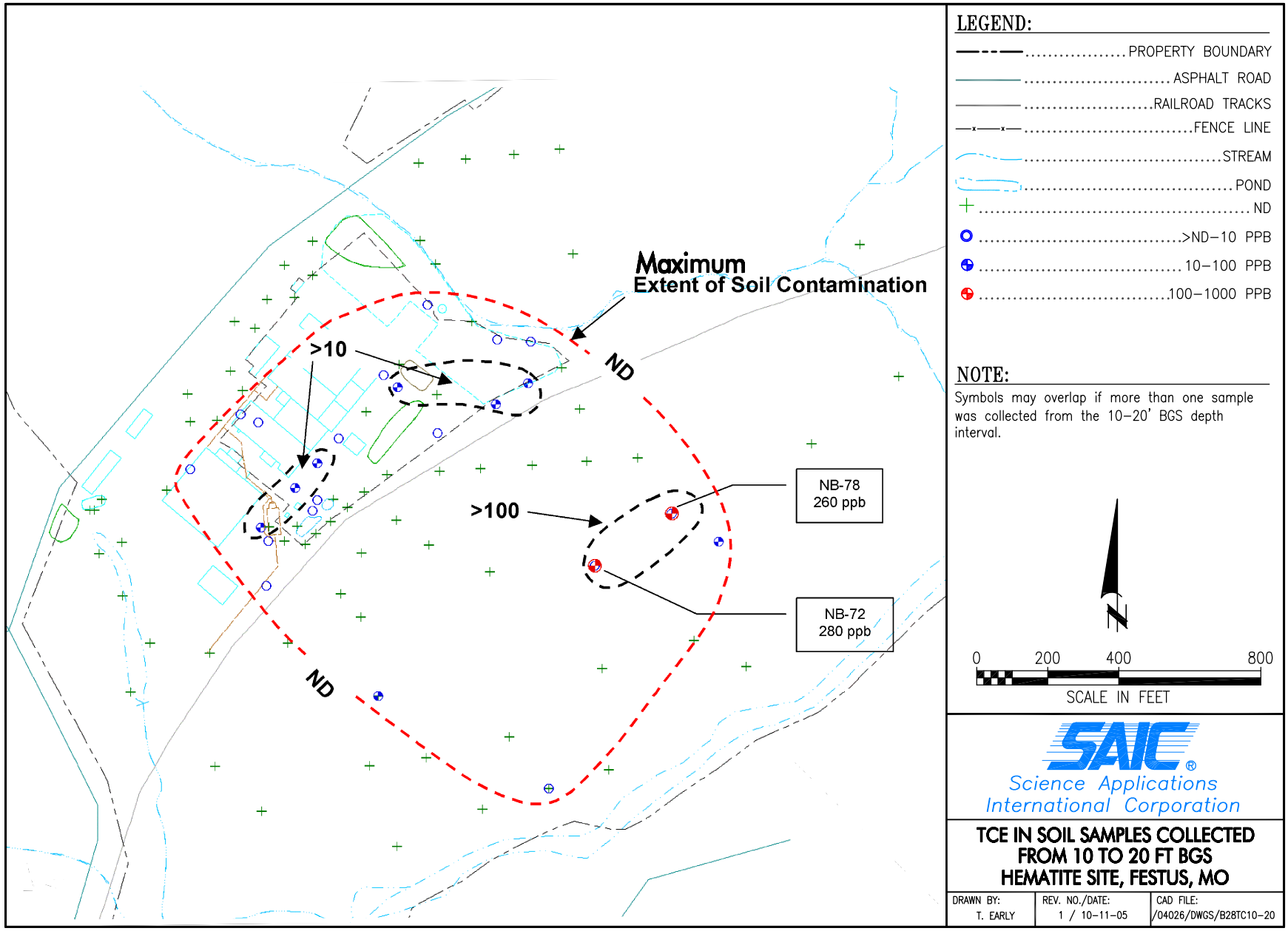


Fig. 5.5. TCE in soil samples collected from 10 to 20 ft BGS.

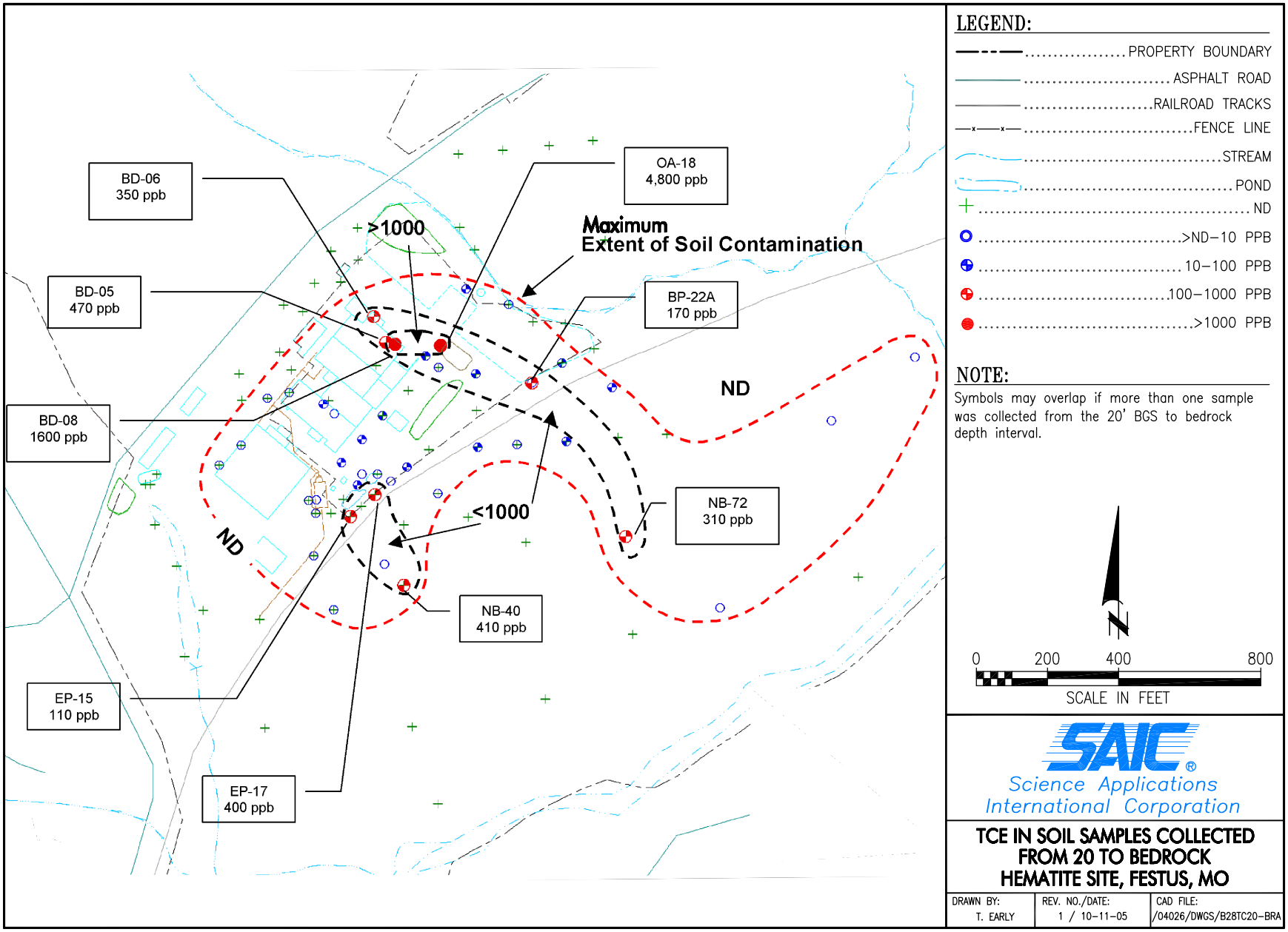


Fig. 5.6. TCE in soil samples collected from 20 ft BGS to top of bedrock.

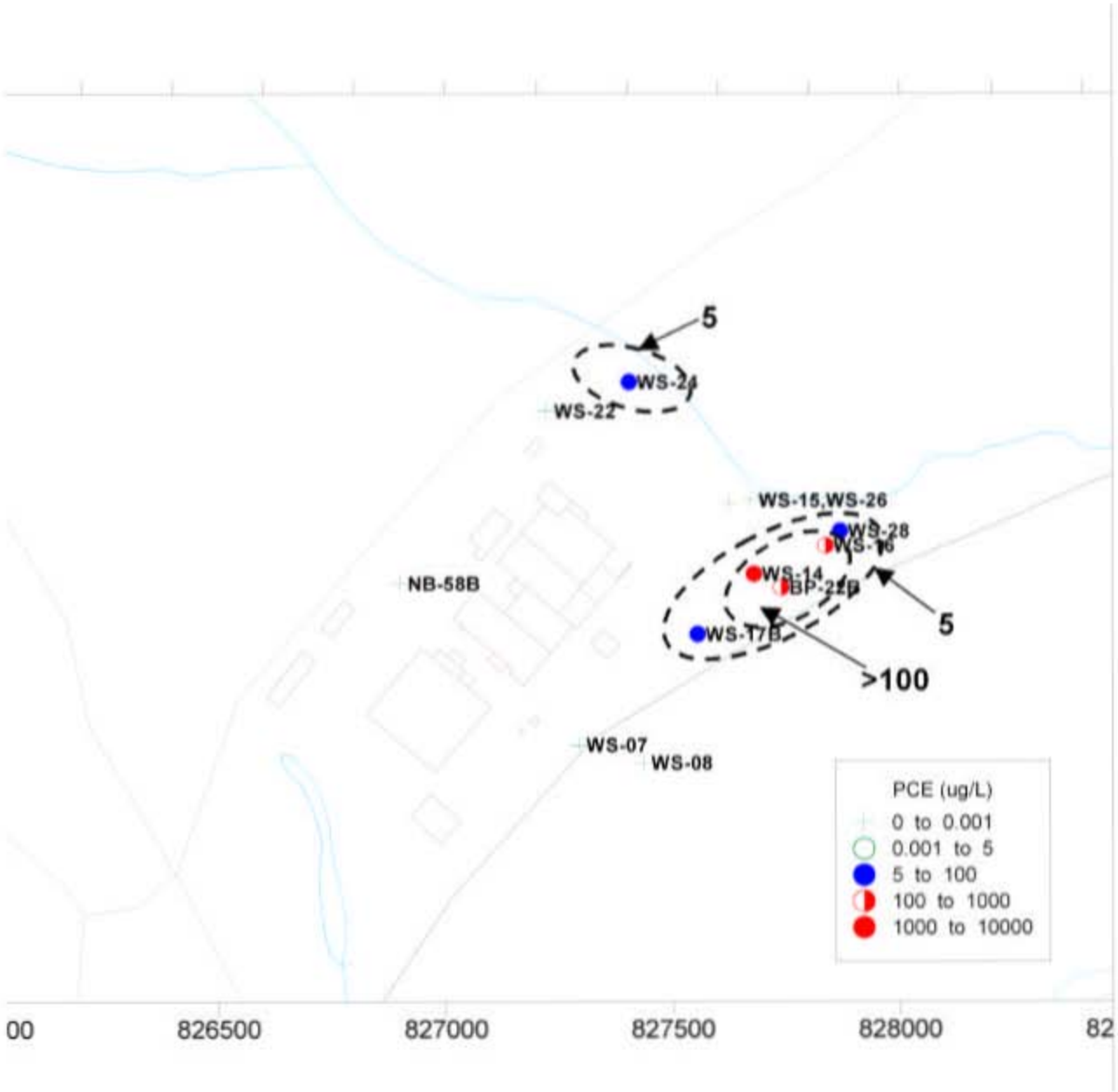


Fig. 5.7. PCE in shallow overburden wells.

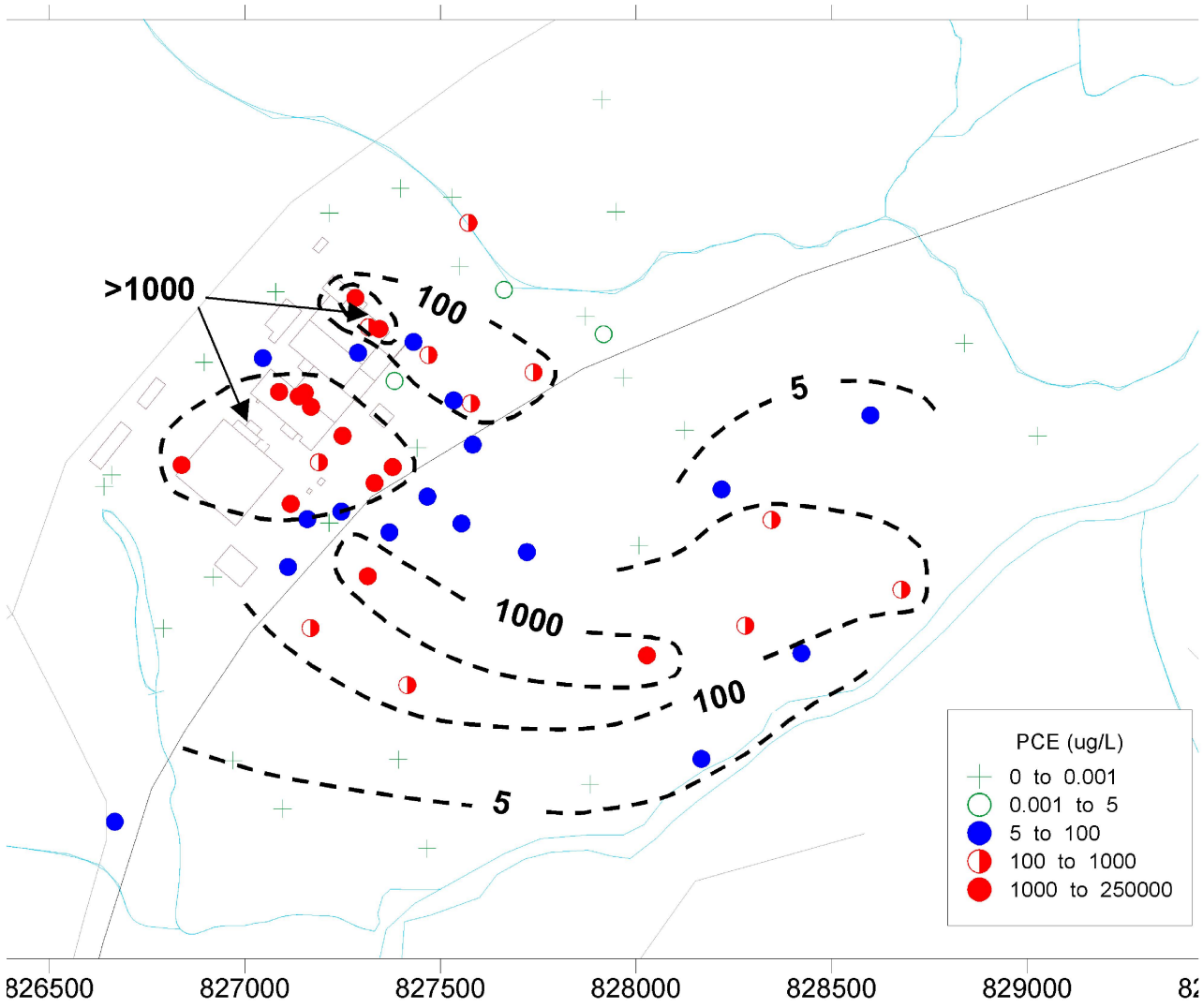


Fig. 5.8. PCE in deep overburden wells.

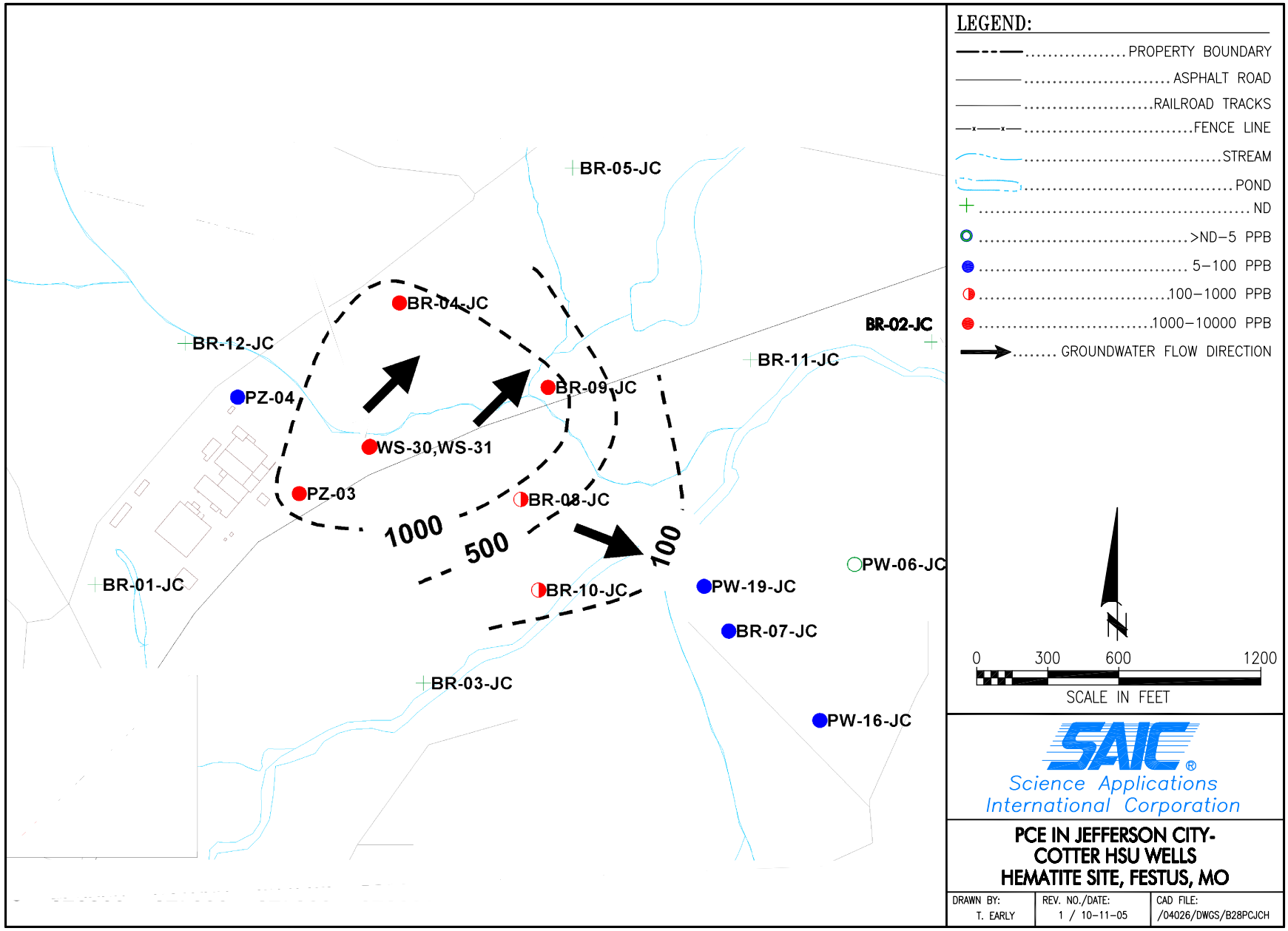


Fig. 5.9. PCE in Jefferson City-Cotter HSU wells.

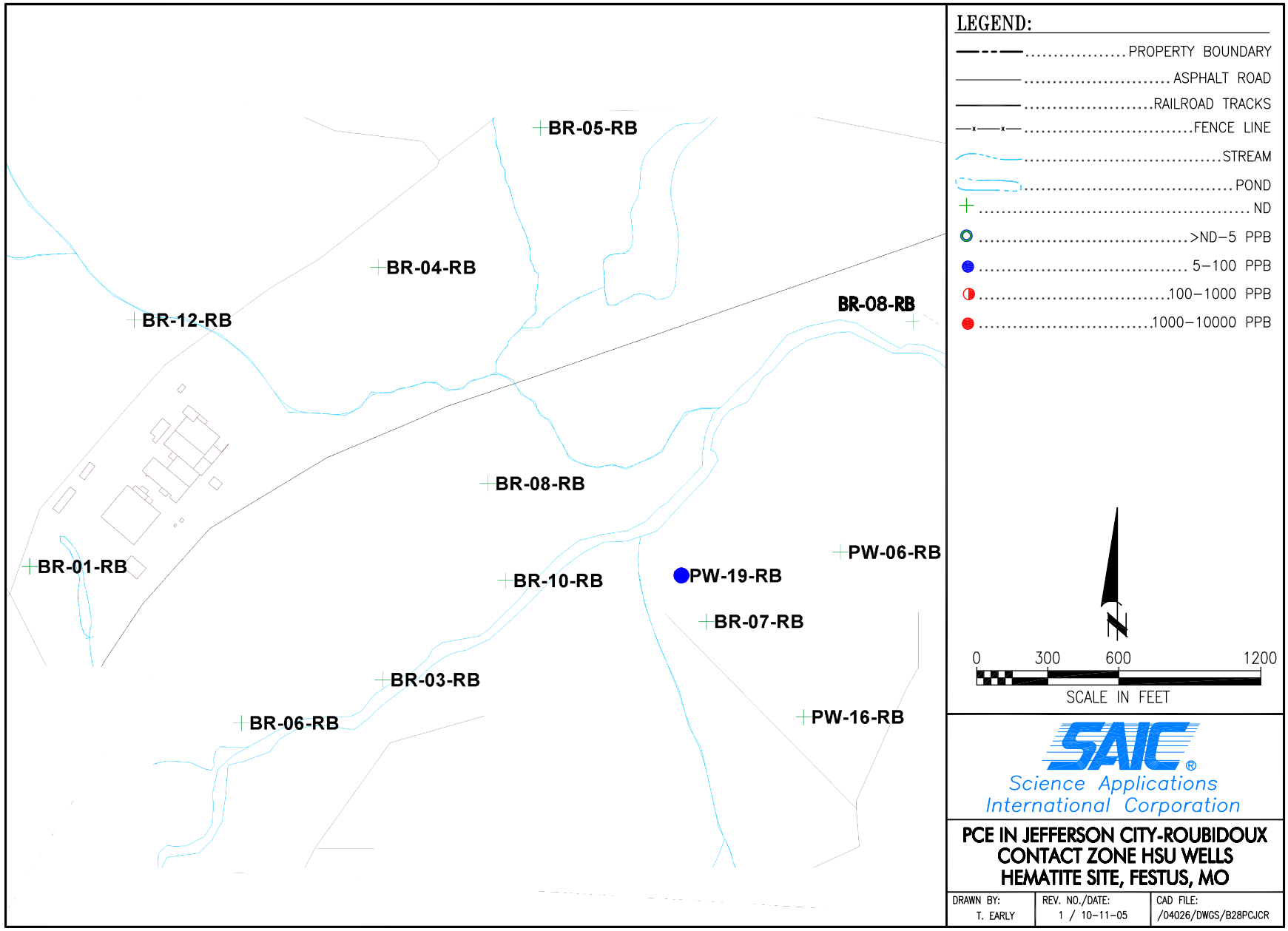


Fig. 5.10. PCE in Jefferson City-Roubidoux contact zone HSU wells.

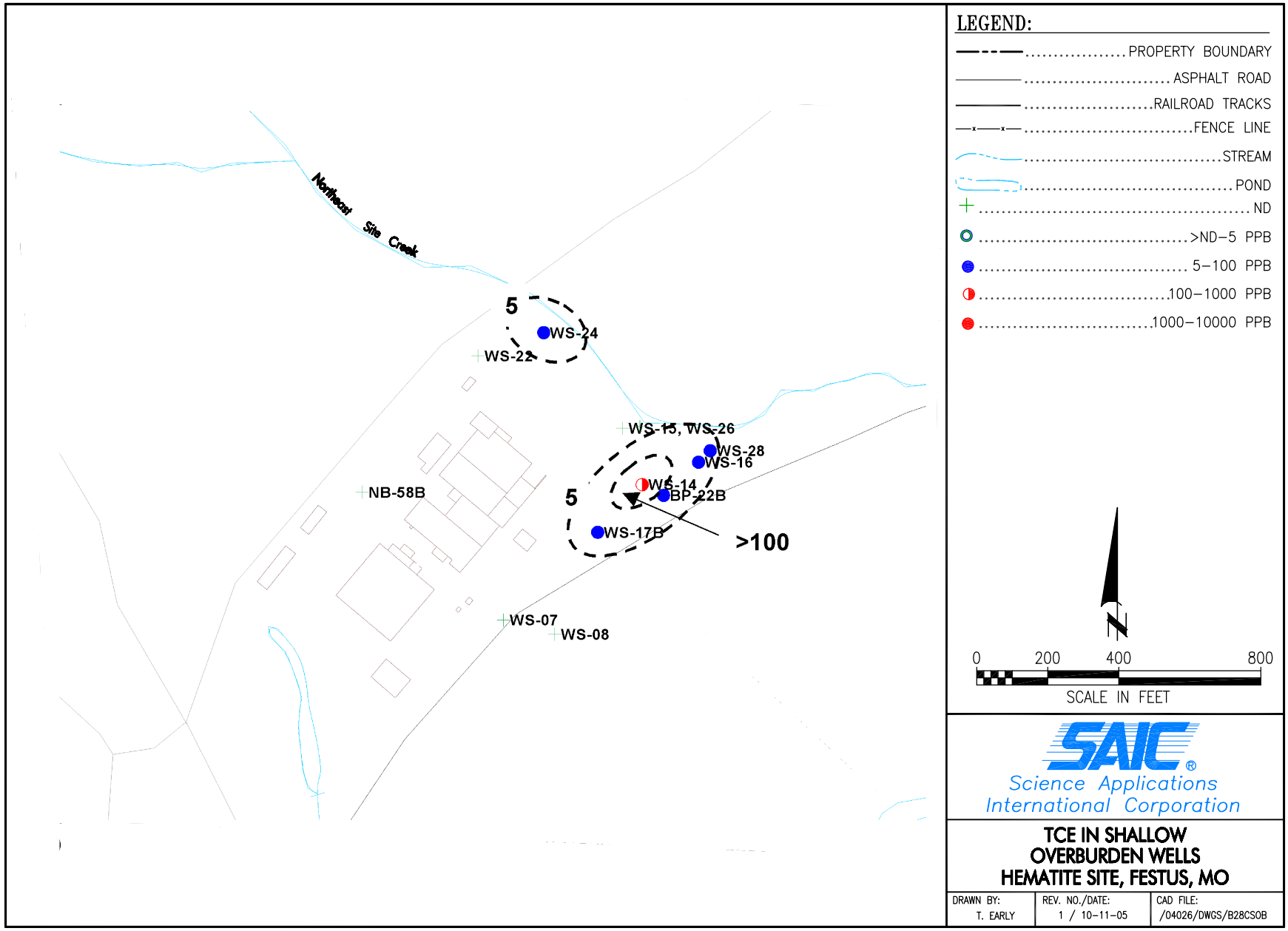


Fig. 5.11. TCE in shallow overburden wells.

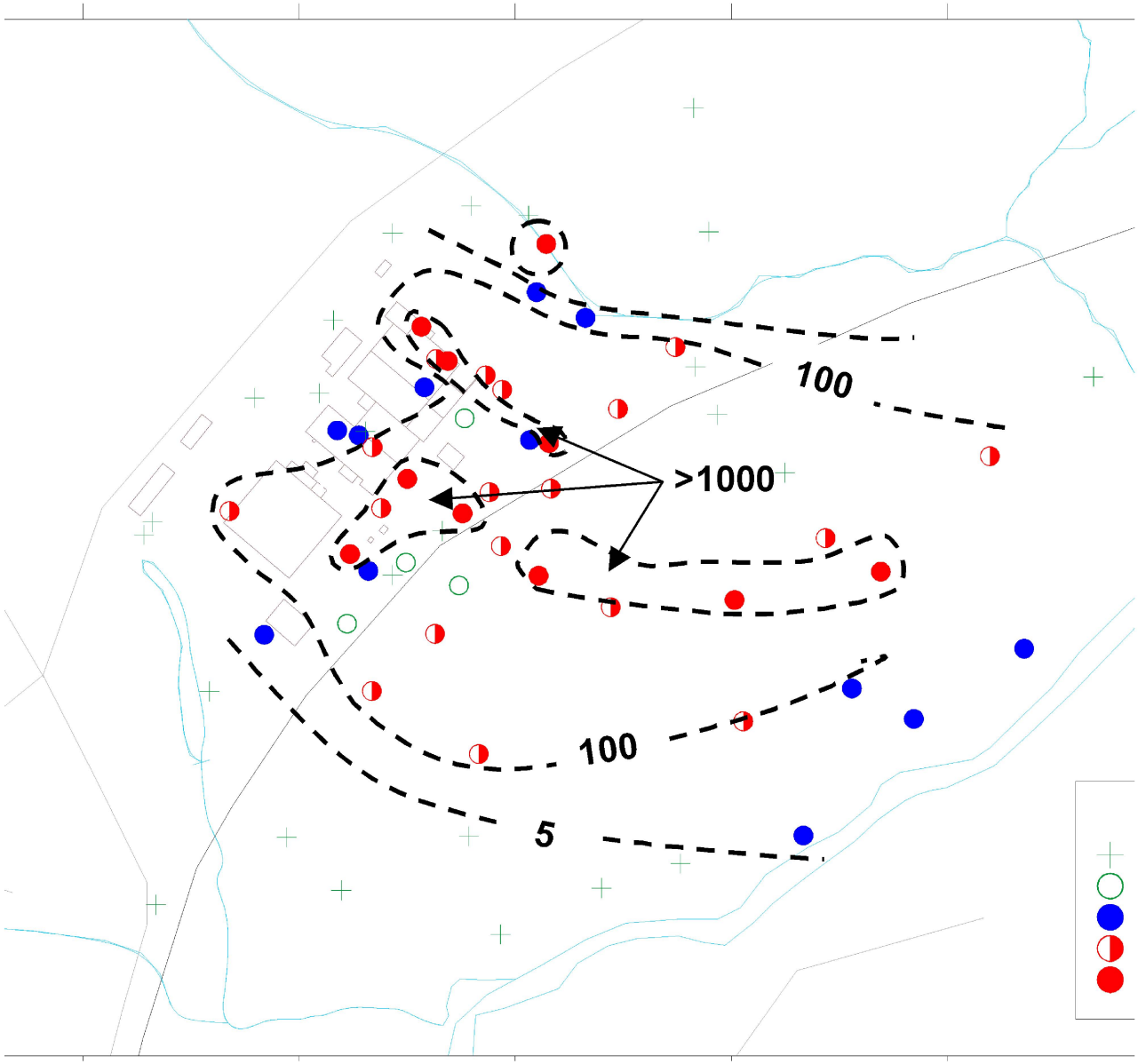


Fig. 5.12. TCE in deep overburden wells.

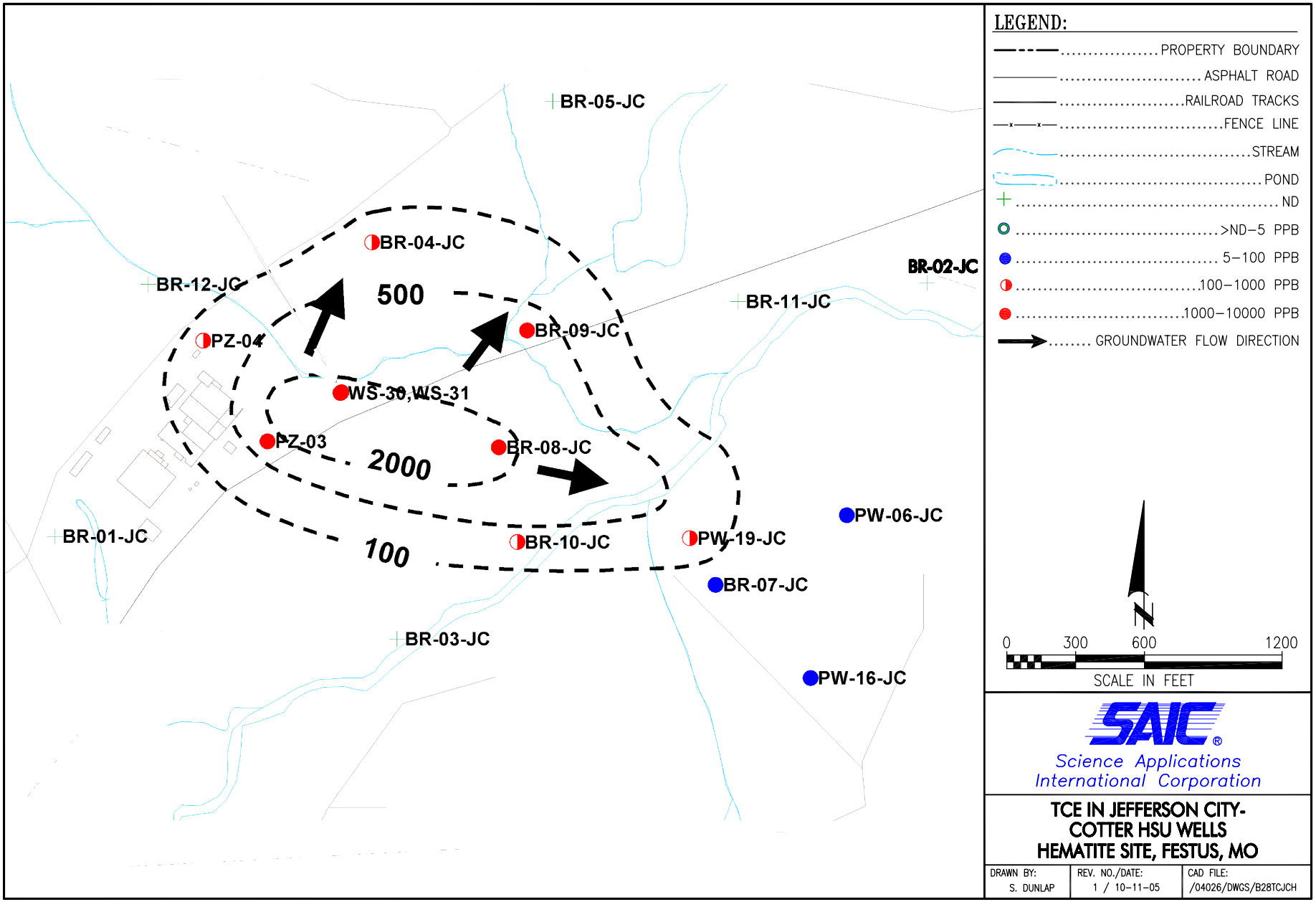


Fig. 5.13. TCE in Jefferson City-Cotter HSU wells.

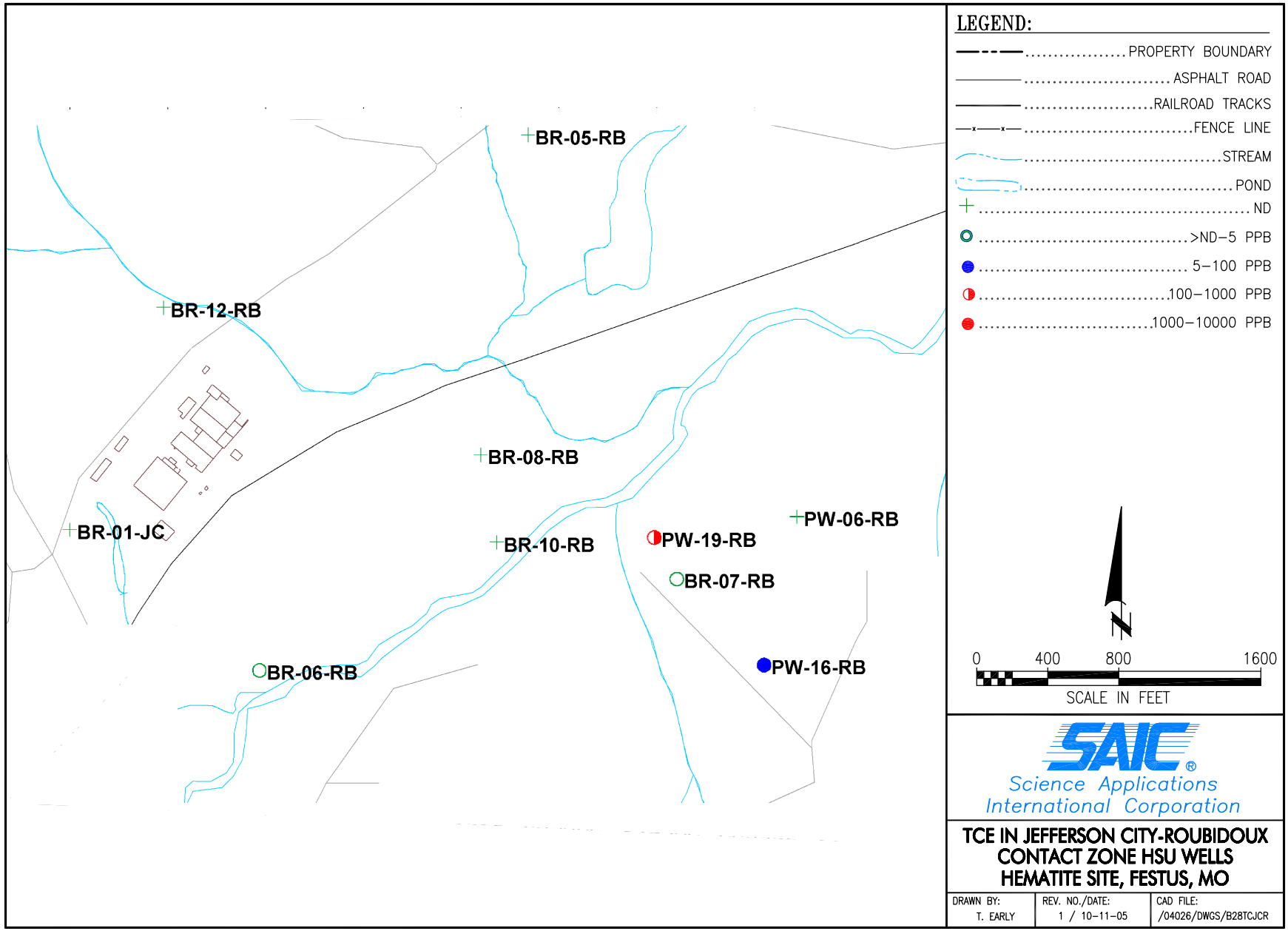


Fig. 5.14. TCE in Jefferson City-Roubidoux contact zone HSU wells.

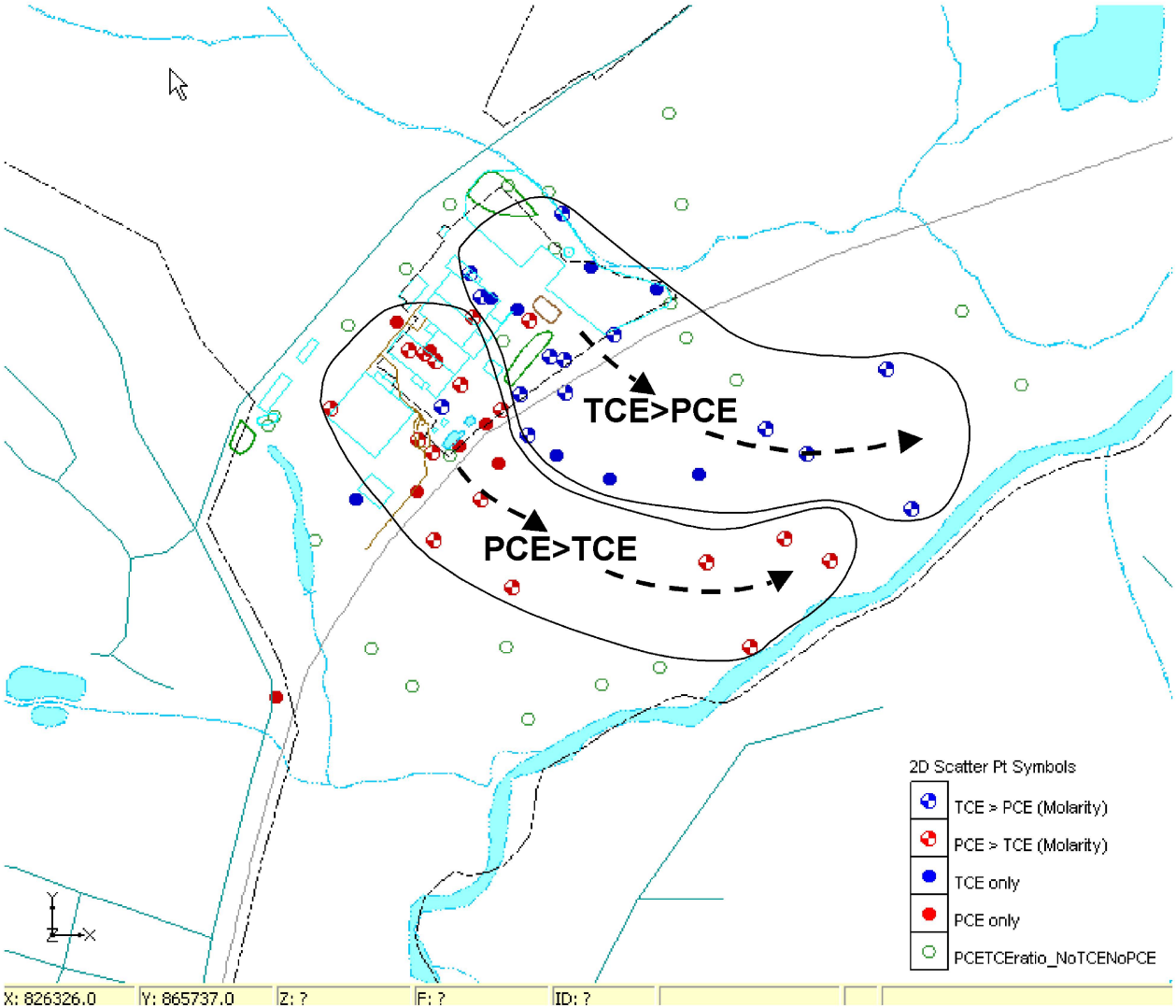


Fig. 5.15. Zones of PCE and TCE domination in coarse-layer overburden groundwater wells based on PCE/TCE (moles/L).

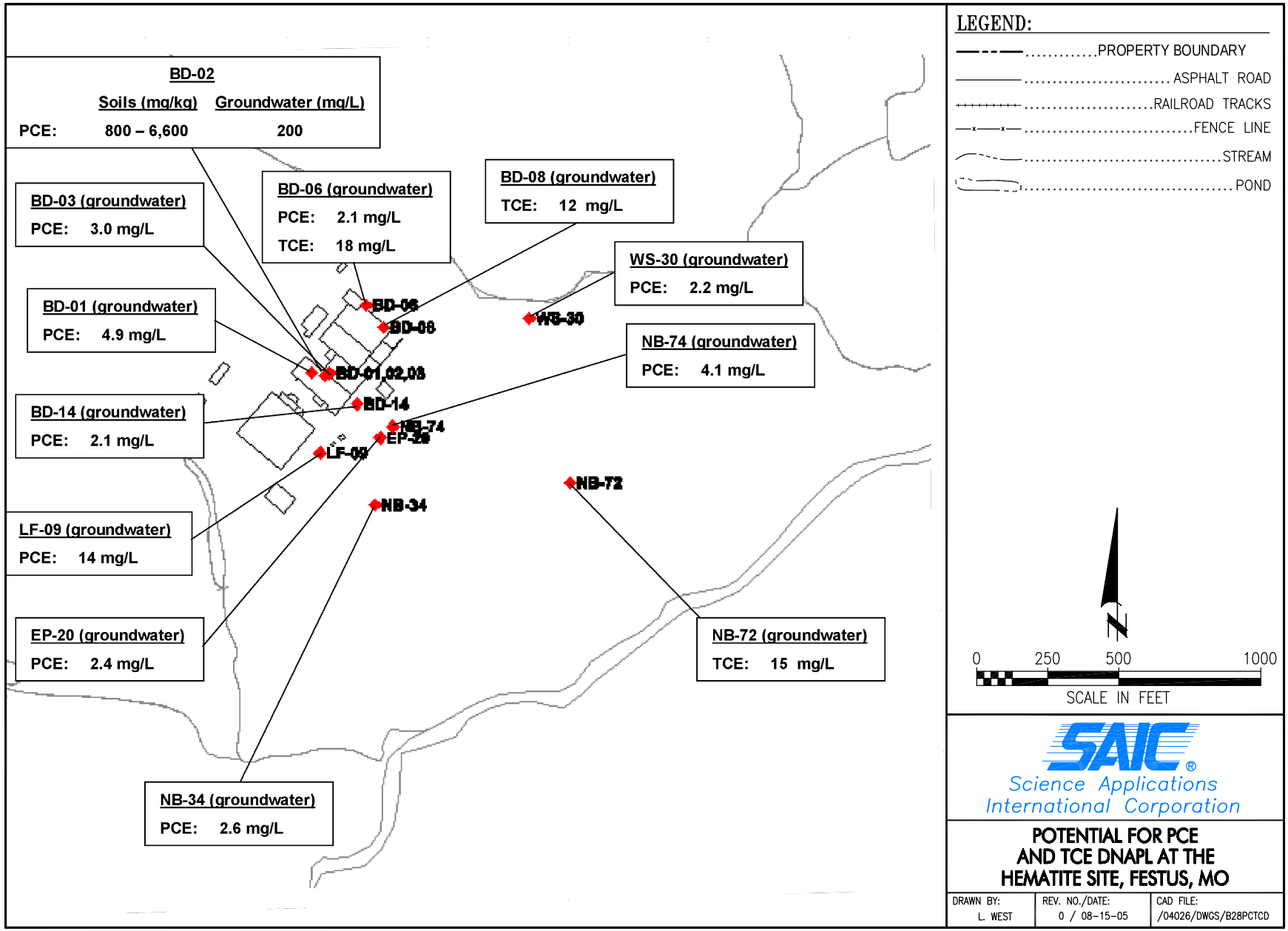


Fig. 5.16. Potential for PCE and TCE DNAPL at the Hematite Site.

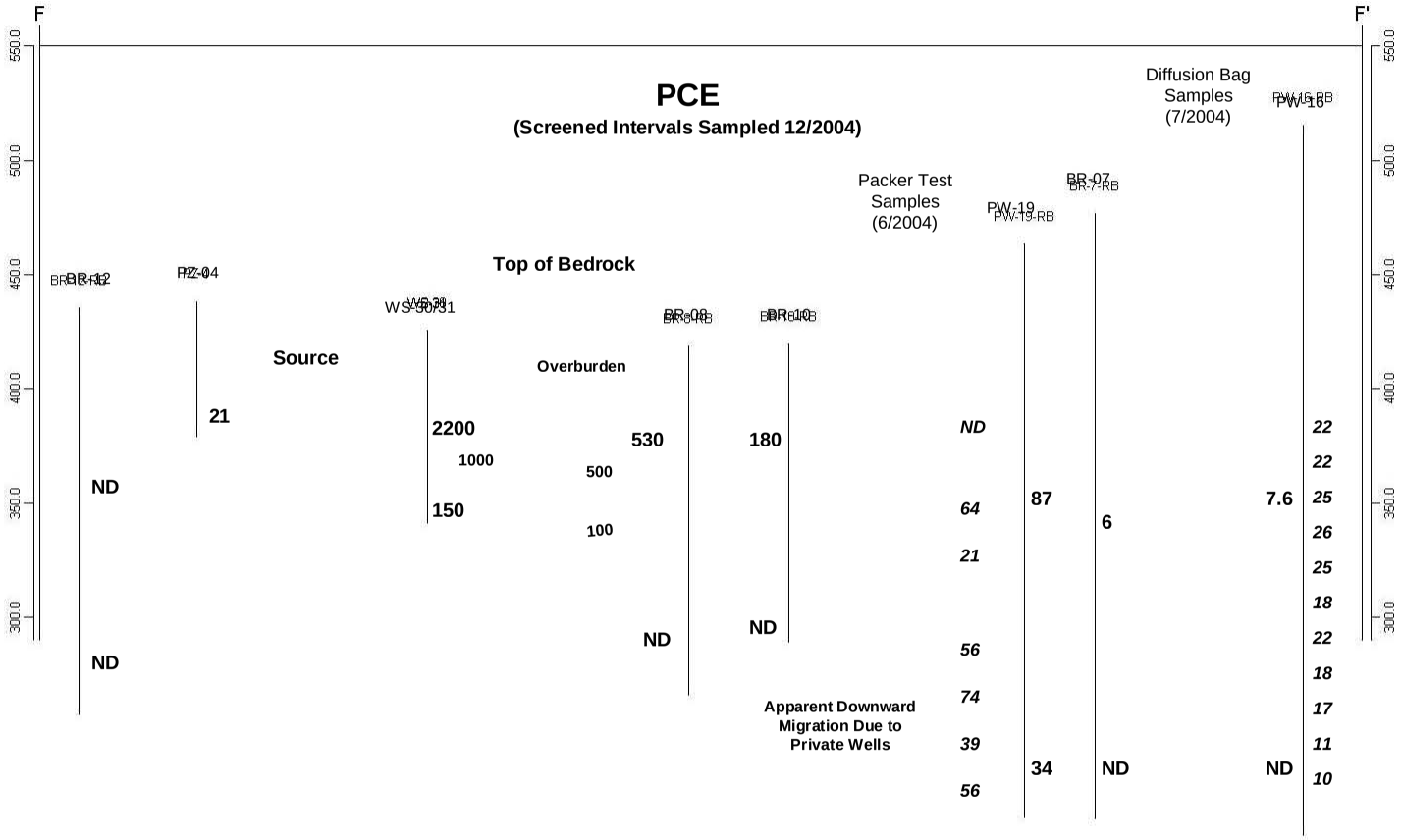


Fig. 5.17. Cross-section F-F'; PCE contamination, Jefferson City-Cotter HSU.

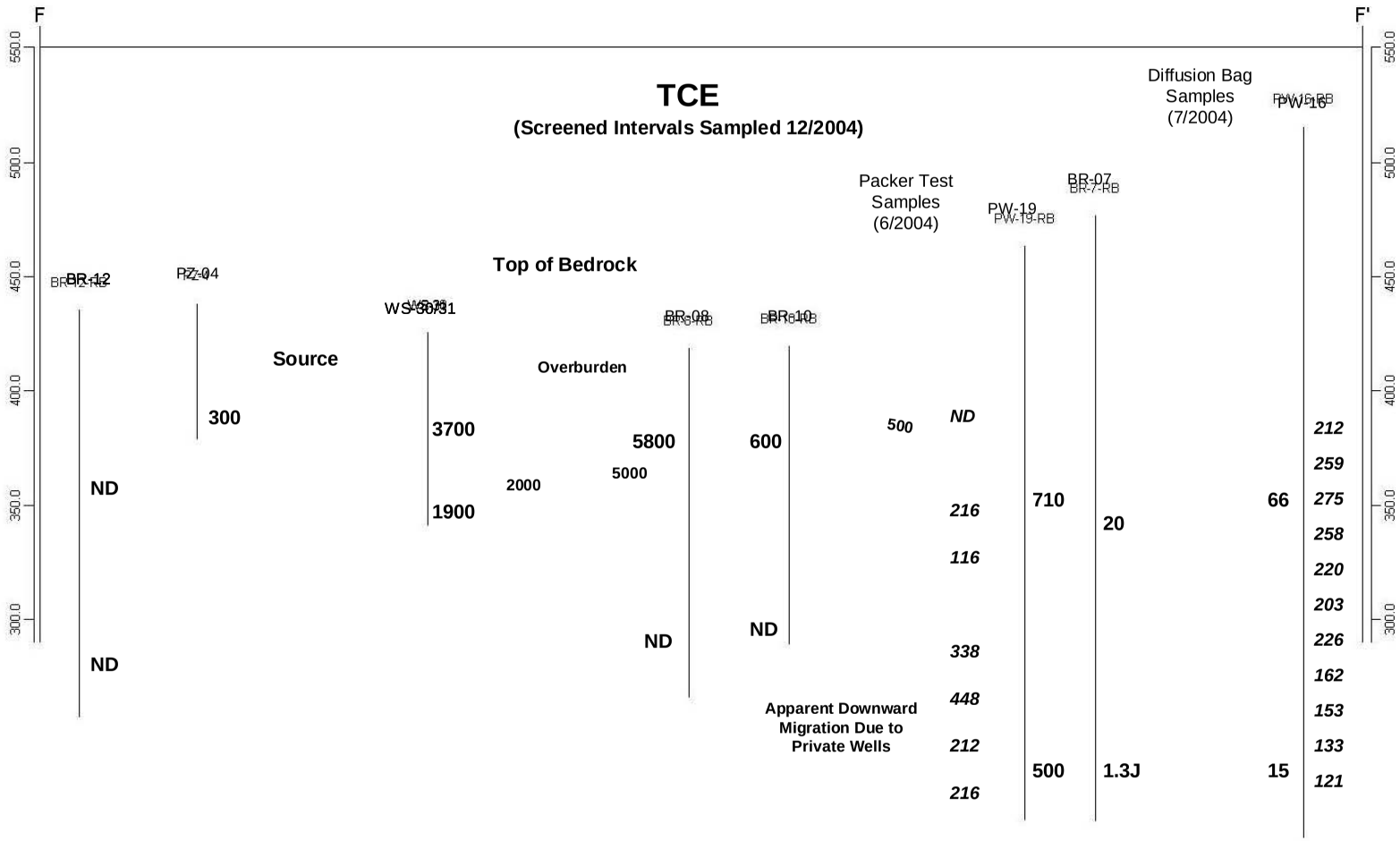


Fig. 5.18. Cross-section F-F'; TCE contamination, Jefferson City-Cotter HSU.

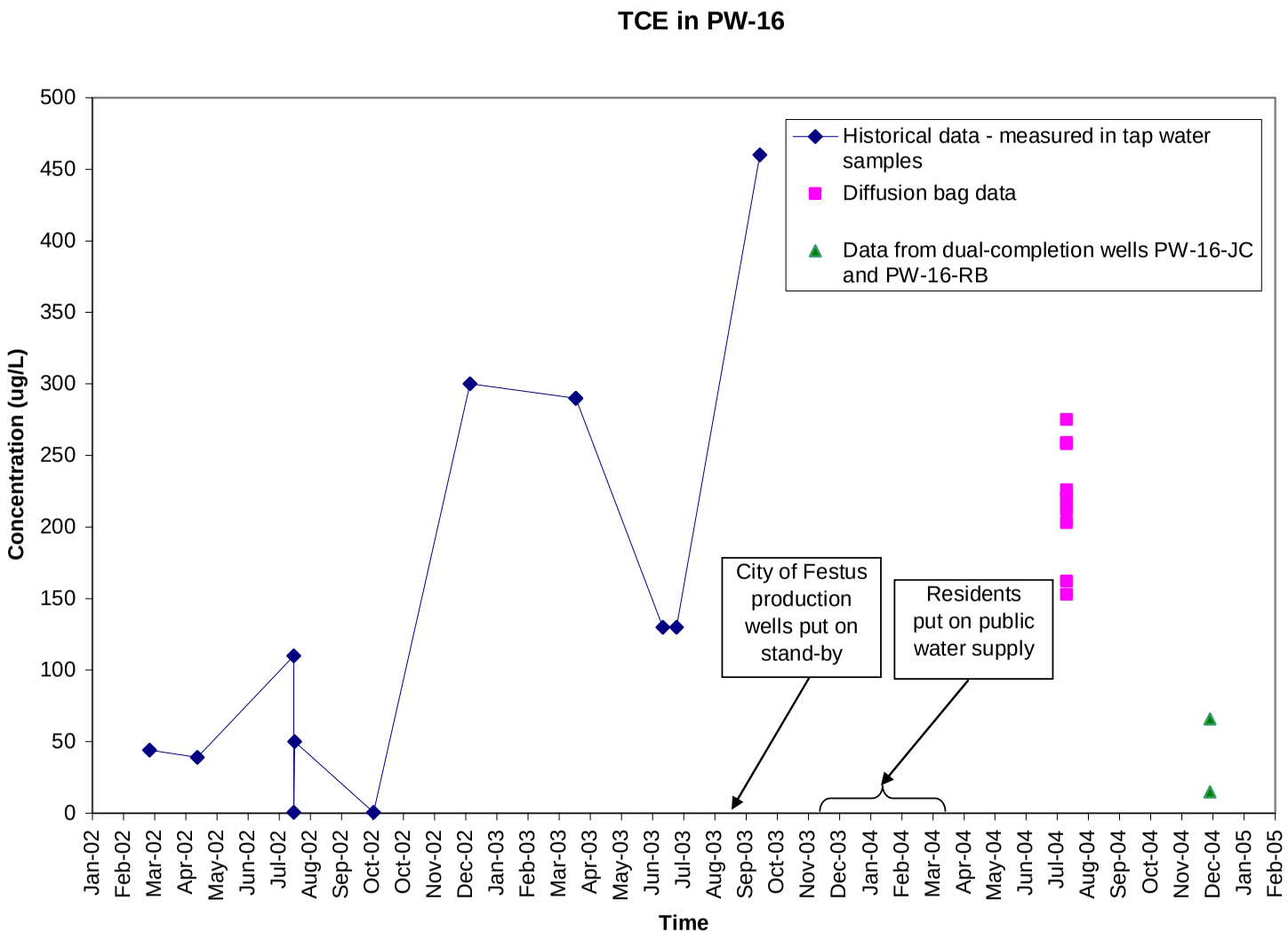


Fig. 5.19a. TCE in PW-16.

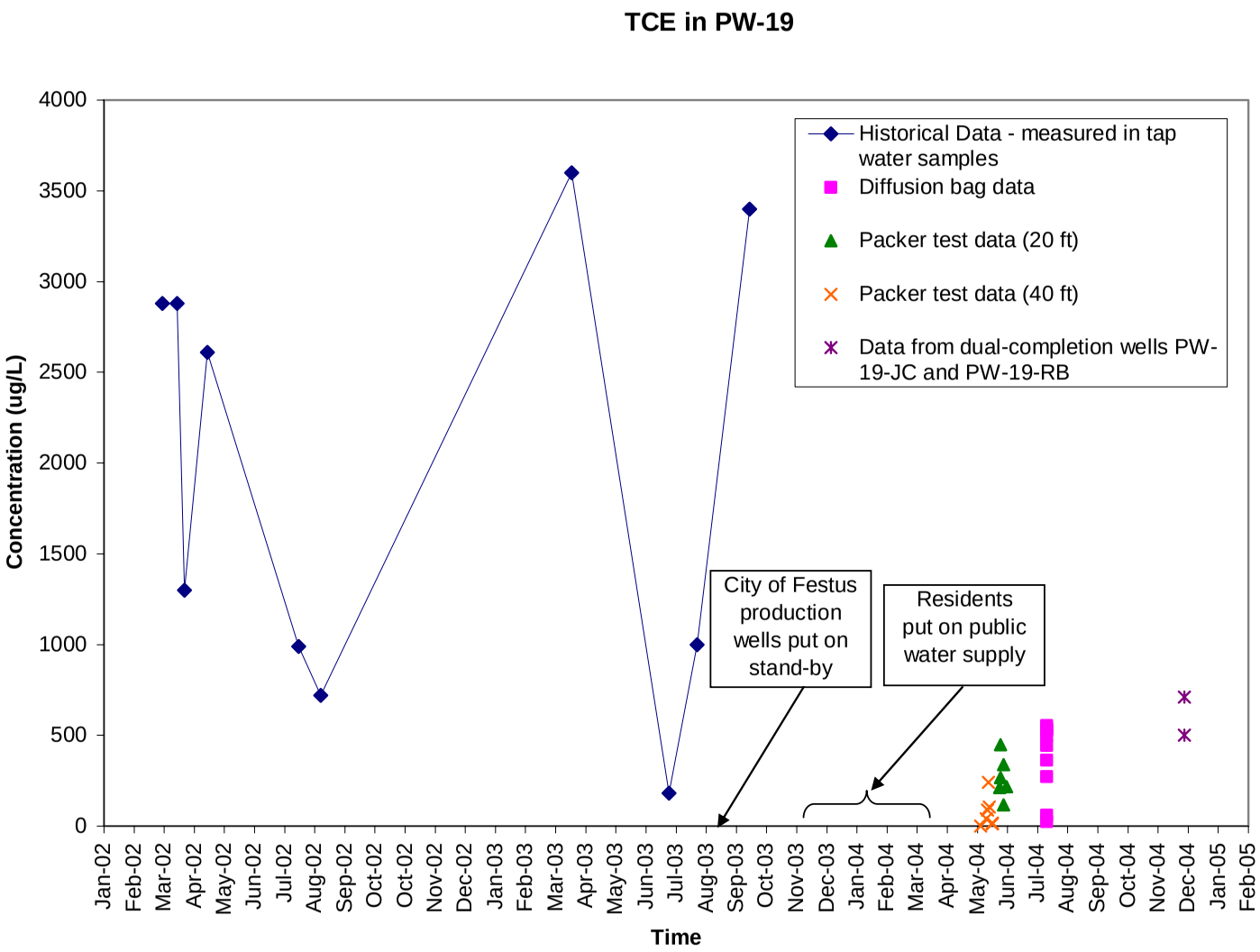


Fig. 5.19b. TCE in PW-19.

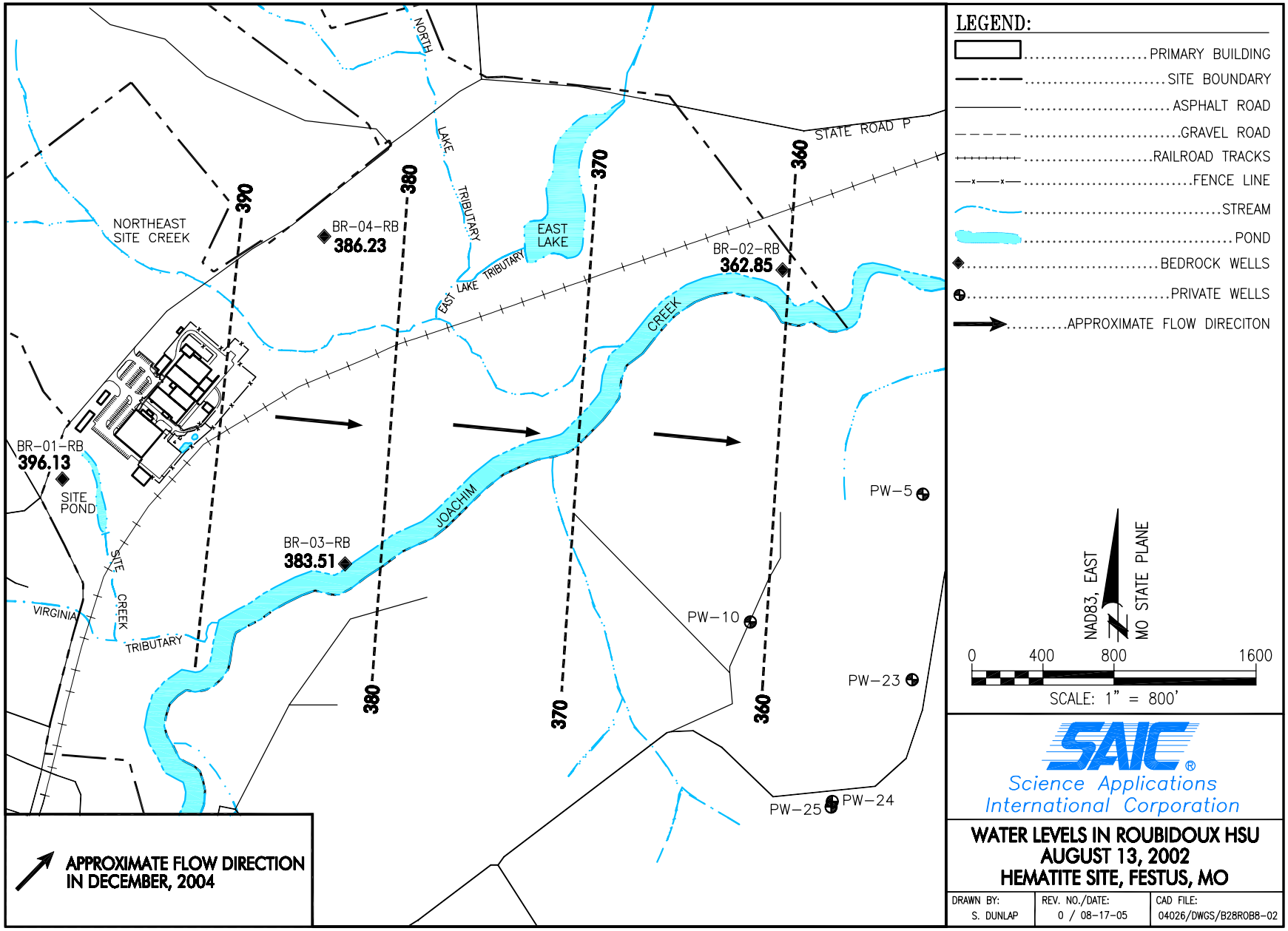


Fig. 5.20. Water levels in Roubidoux HSU: August 13, 2002.

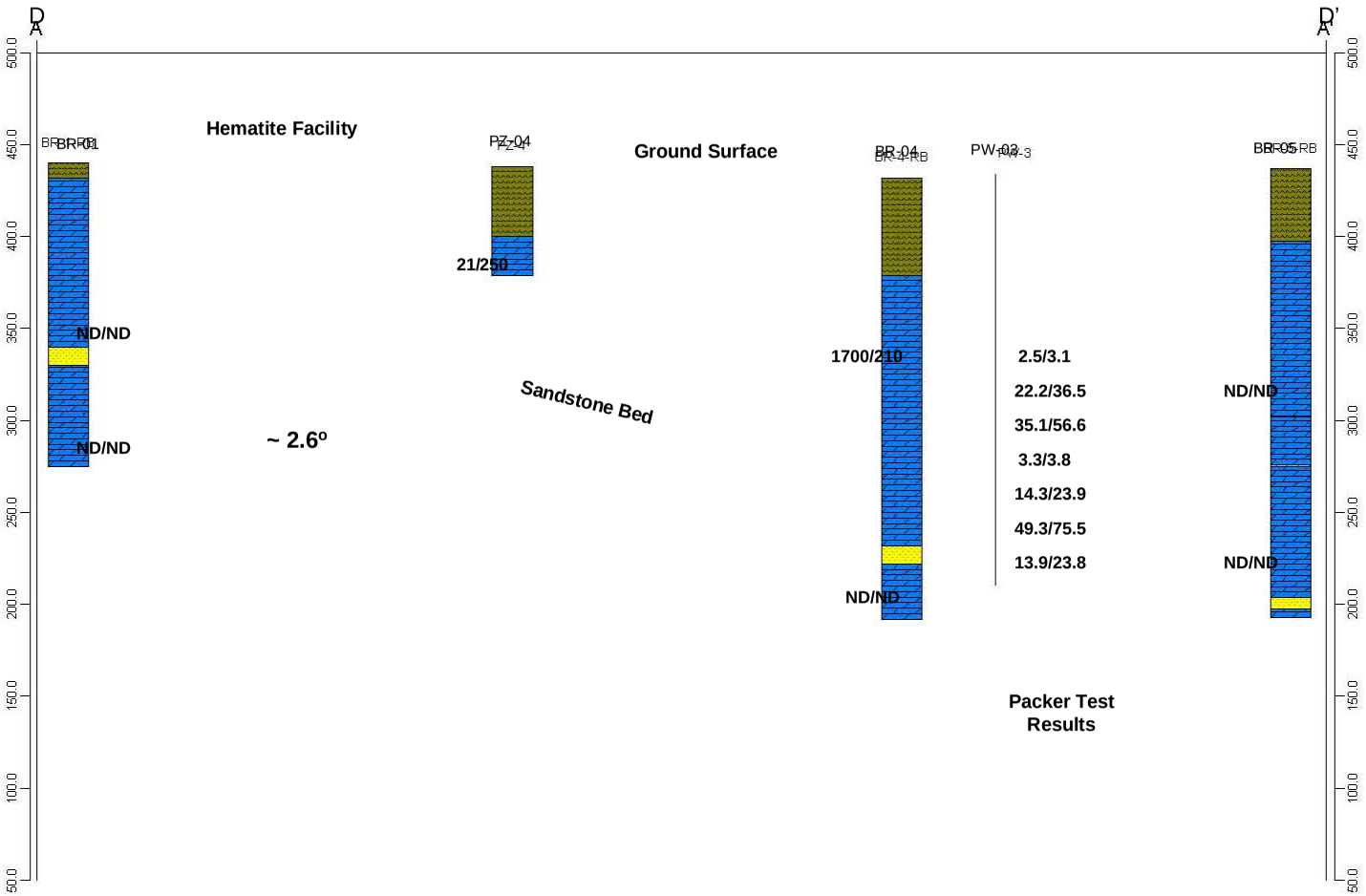


Fig. 5.21. Cross-section D-D'; PCE and TCE concentrations.

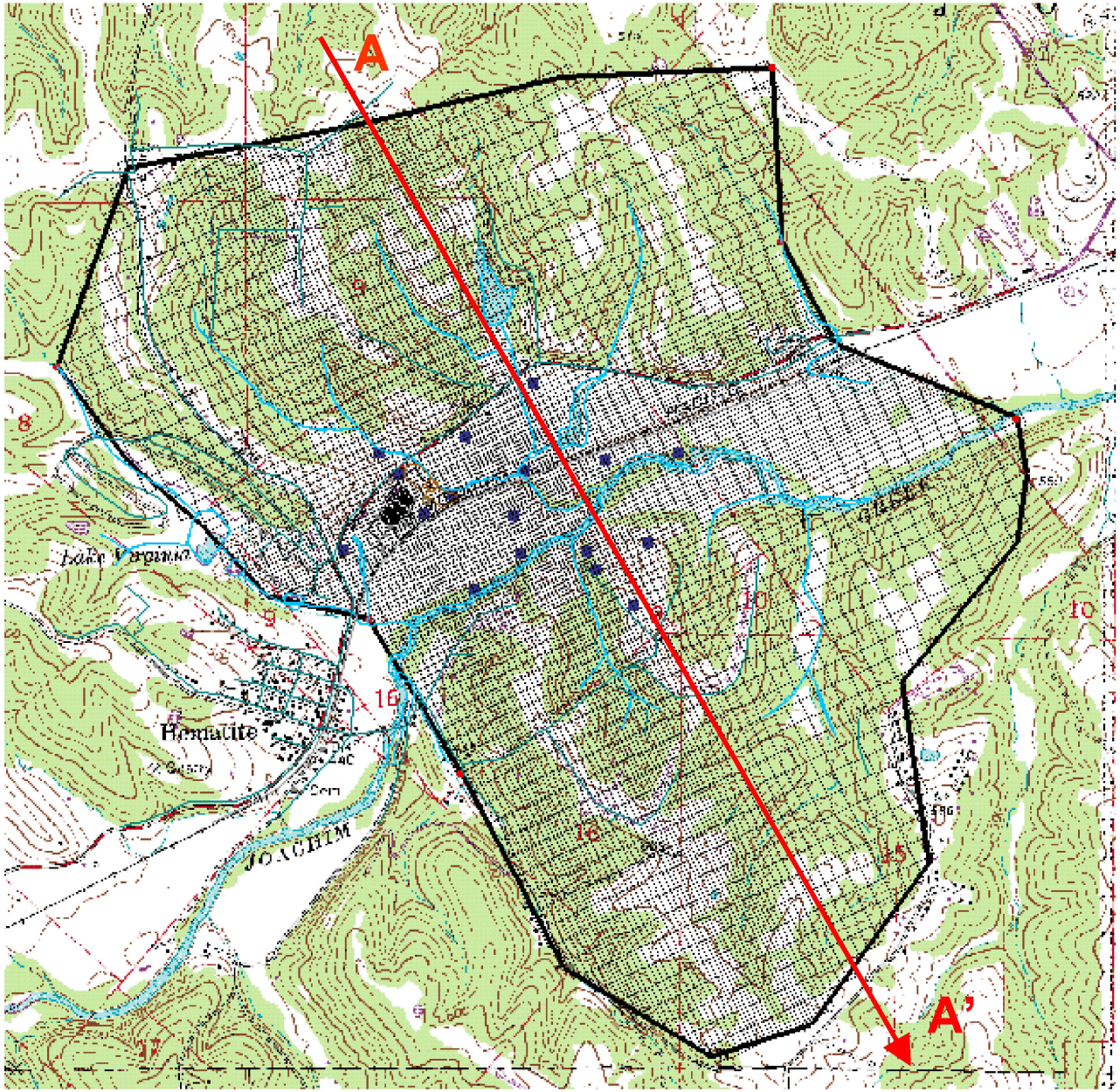


Fig. 5.22. Plan view of MODFLOW/RT3D model domain for the Hematite Site, bounded by solid black line. (Model grid also shown, blue dots correspond to bedrock well locations.)

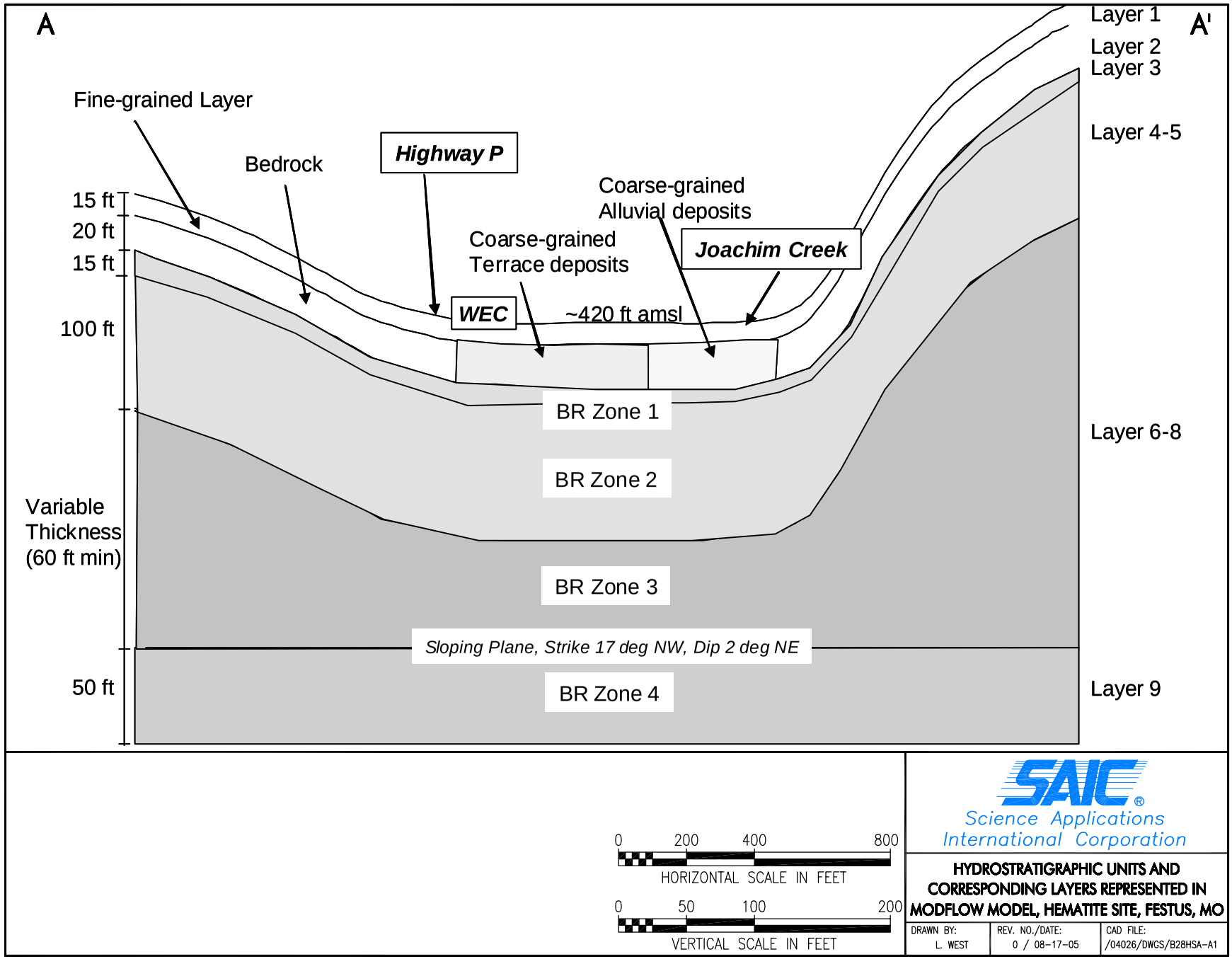


Fig. 5.23. Hydrostratigraphic units and corresponding layers represented in MODFLOW model. (Cross-section A-A' in Fig. 5.21, trending northwest-southeast.)

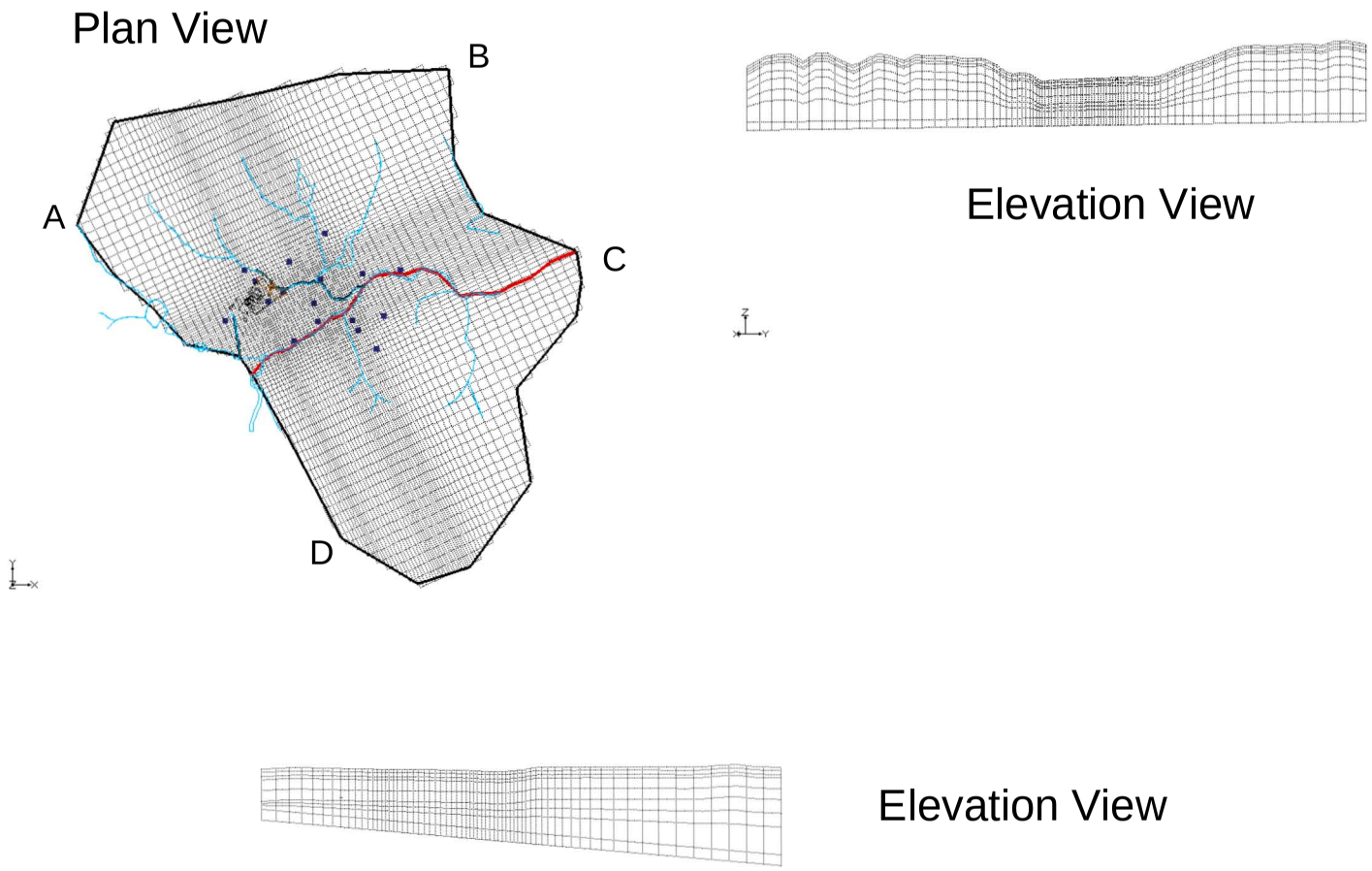


Fig. 5.24. MODFLOW grid in plan and elevation view. [Red line in plan view corresponds to Joachim Creek –cells along this line in the top layer are specified head cells – Arc A-D and Arc B-C are also specified head boundaries in the bottom two layers of the model (refer to Fig. 5.22 for model layers) to produce northeasterly regional groundwater flow.]

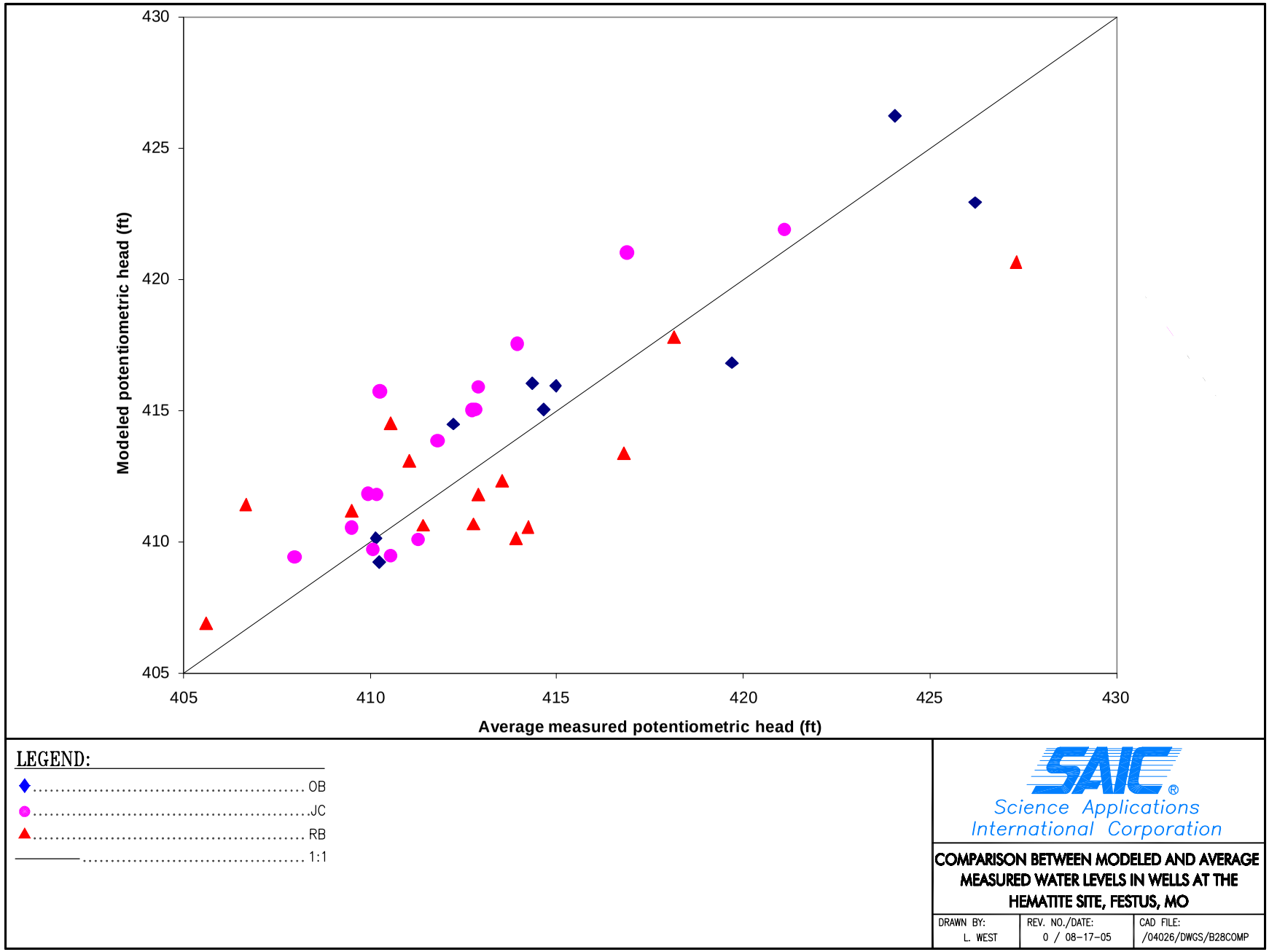


Fig. 5.25. Comparison between modeled and average measured water levels in wells at the Hematite Site. [(Deep) overburden, Jefferson City-Cotter, and Roubidoux wells.]

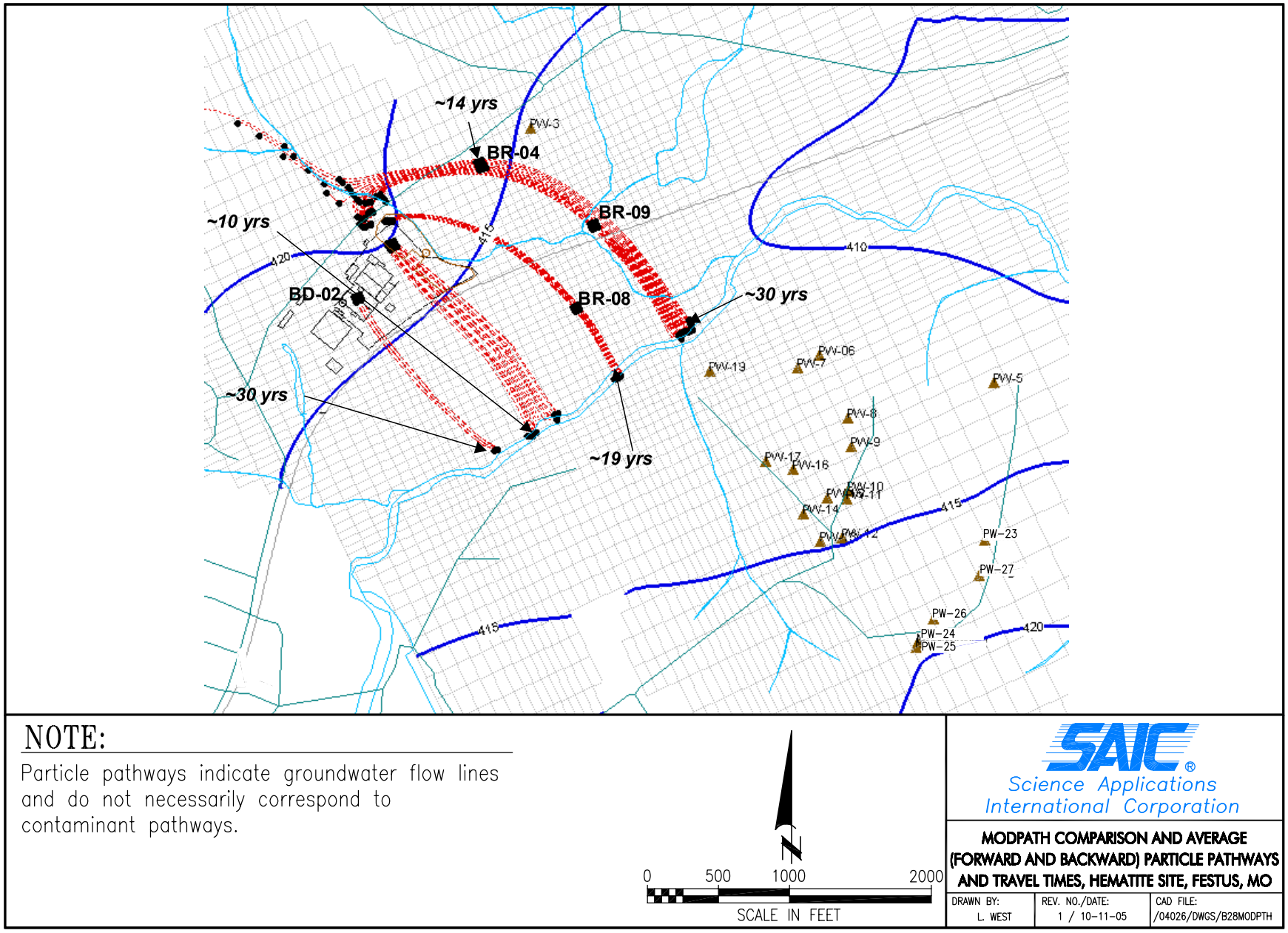
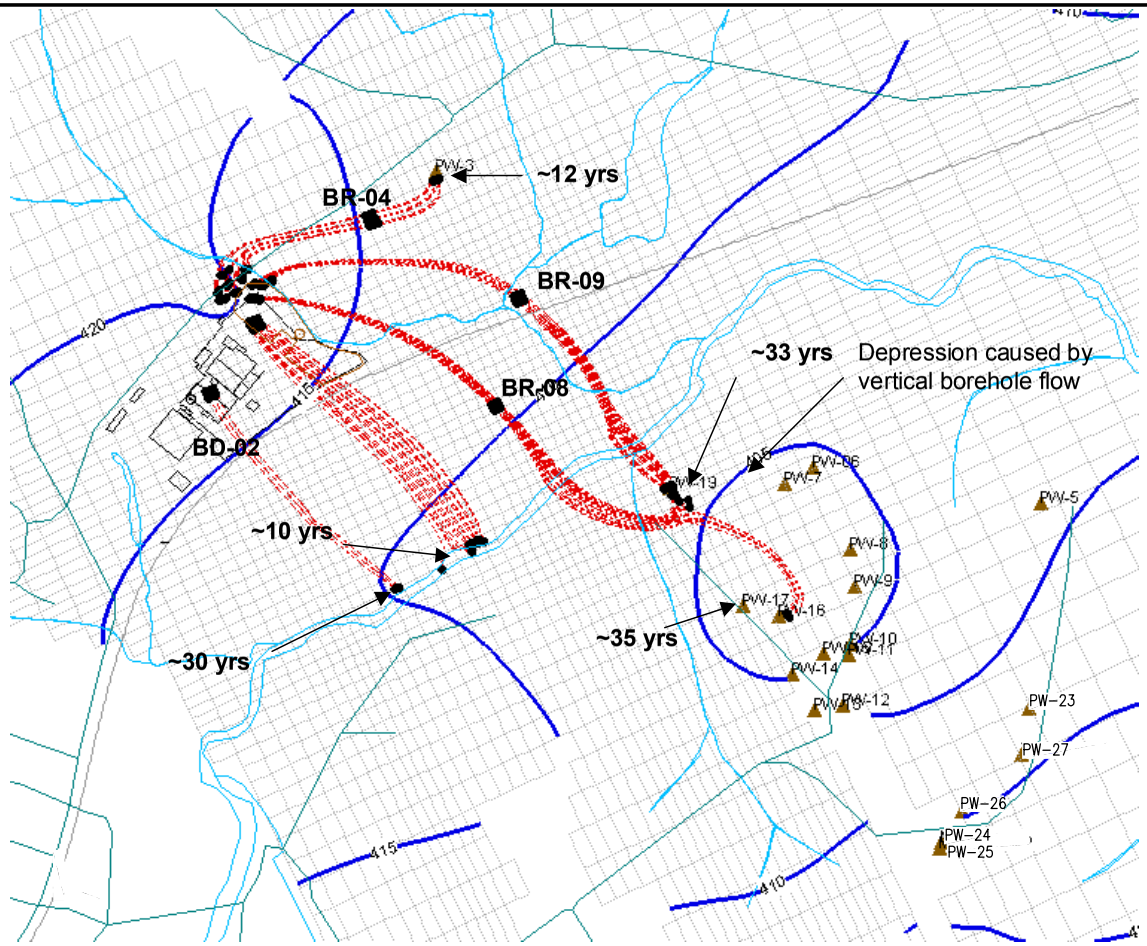


Fig. 5.26. MODPATH-simulated (forward and backward) particle pathways and travel times. [Blue lines are potentiometric contour lines for layers corresponding to transmissive Jefferson City-Cotter HSU; pumping in private wells at household rates (35 ft3/day)]



NOTE:

Particle pathways indicate groundwater flow lines and do not necessarily correspond to contaminant pathways.

N

0 500 1000 2000

SCALE IN FEET

SAIC®
Science Applications International Corporation

MODPATH-SIMULATED (FORWARD AND BACKWARD) PARTICLE PATHWAYS AND TRAVEL TIMES
HEMATITE SITE, FESTUS, MO

DRAWN BY:	REV. NO./DATE:	CAD FILE:
L. WEST	1 / 10-11-05	/04026/DWGS/B28MODPT2

Fig. 5.27. MODPATH-simulated (forward and backward) particle pathways and travel times.
[Blue lines are potentiometric contour lines for layers corresponding to transmissive Jefferson City-Cotter HSU; specified extraction flow rate in private wells at 2000 ft3/day (~10.4 gpm) drawn from Jefferson City-Cotter HSU layer to simulate vertical borehole flow.]

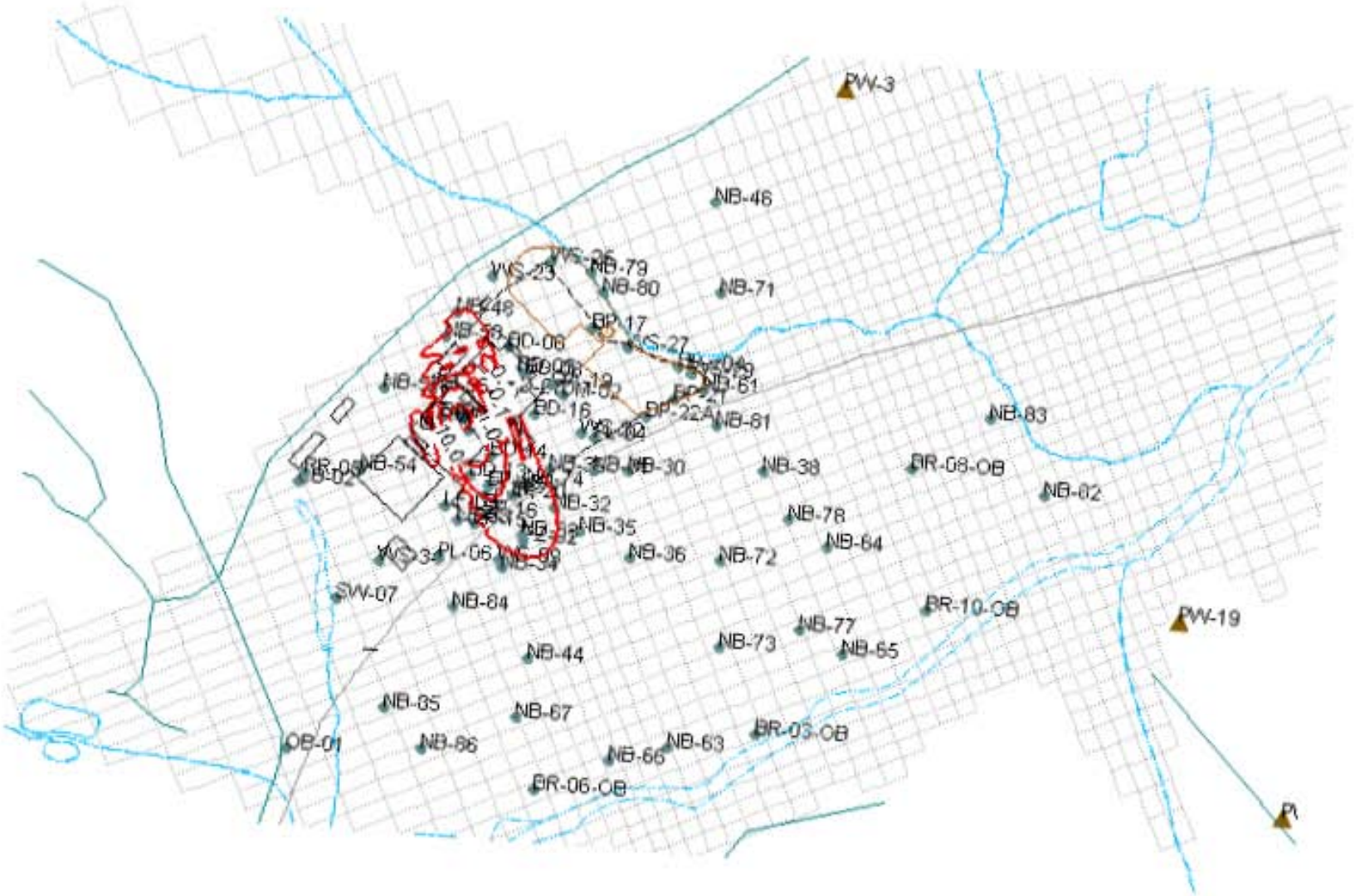


Fig. 5.28. PCE concentration contours (mg/L) in layer corresponding to terrace/alluvial deposits at t = 3000 days (~8 years). (Constant concentration source of 200 mg/L PCE placed in cell corresponding to BD-02; simulated using MODFLOW model with vertical borehole flow and RT3D Sequential Decay chemical reaction package.)

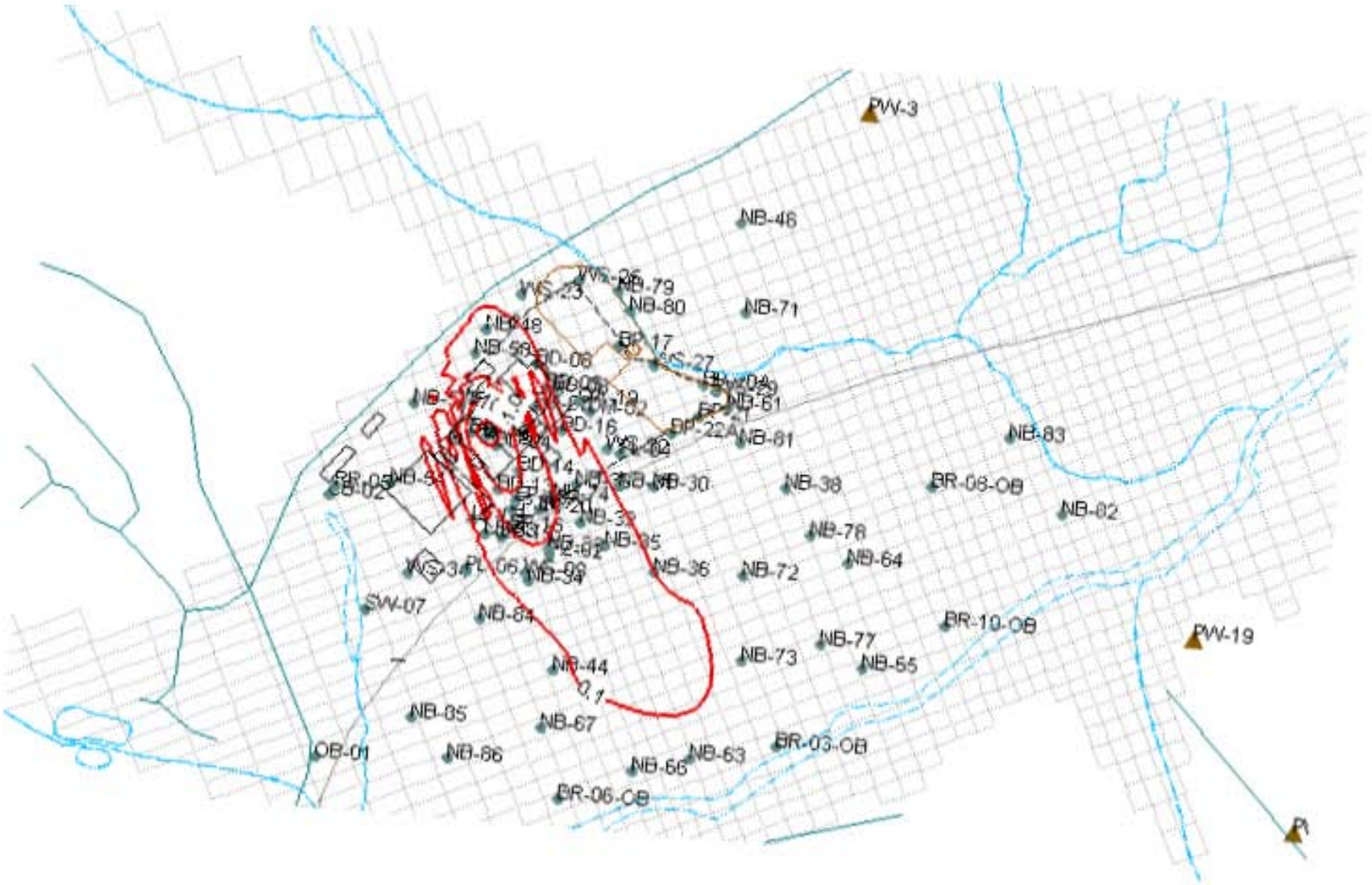


Fig. 5.29. PCE concentration contours (mg/L) in layer corresponding to terrace/alluvial deposits at t = 9000 days (~25 years). (Constant concentration source of 200 mg/L PCE placed in cell corresponding to BD-02; simulated using MODFLOW model with vertical borehole flow and RT3D Sequential Decay chemical reaction package.)

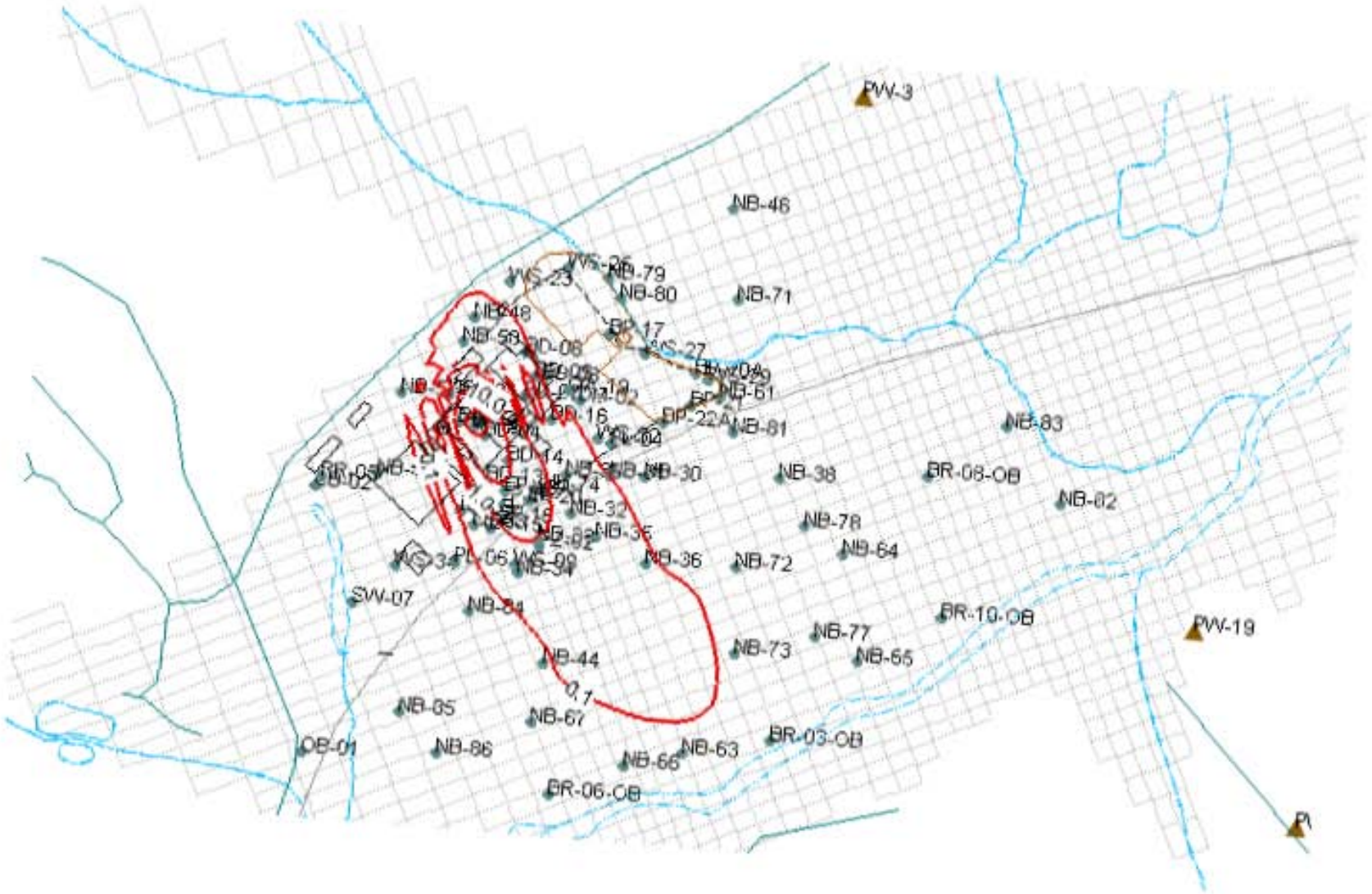


Fig. 5.30. PCE concentration contours (mg/L) in layer corresponding to terrace/alluvial deposits at t = 15,000 days (~41 years). (Constant concentration source of 200 mg/L PCE placed in cell corresponding to BD-02; simulated using MODFLOW model with vertical borehole flow and RT3D Sequential Decay chemical reaction package.)

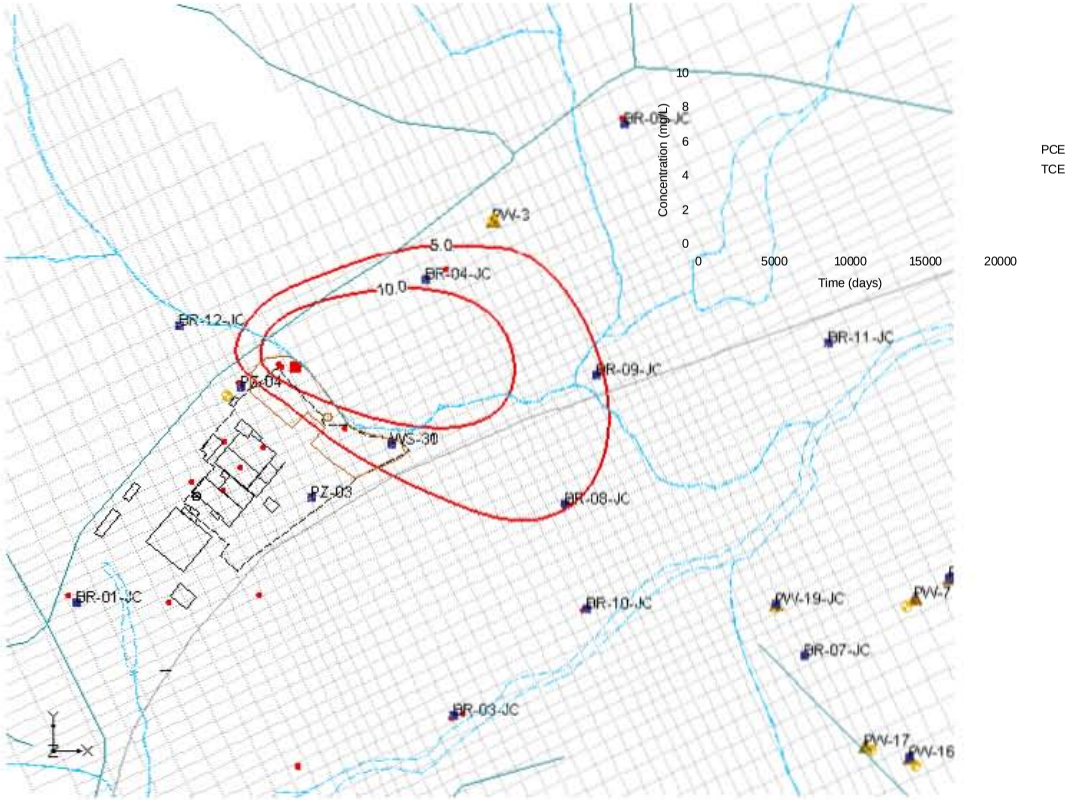


Fig. 5.31. Simulated PCE concentration contours (mg/L) in layer corresponding to transmissive Jefferson City-Cotter Formation at t = 15,000 days (~41 years). [Constant concentration source of 100 mg/L PCE placed in vicinity of Burial Pits (red square); simulated using

Fig. 5.31. Simulated PCE concentration contours (mg/L) in layer corresponding to transmissive Jefferson City-Cotter Formation at t = 15,000 days (~41 years). [Constant concentration source of 100 mg/L PCE placed in vicinity of Burial Pits (red square); simulated using MODFLOW model with vertical borehole flow and RT3D sequential decay chemical reaction package (PCE > TCE > cis-1,2-DCE > vinyl chloride > ethene).]

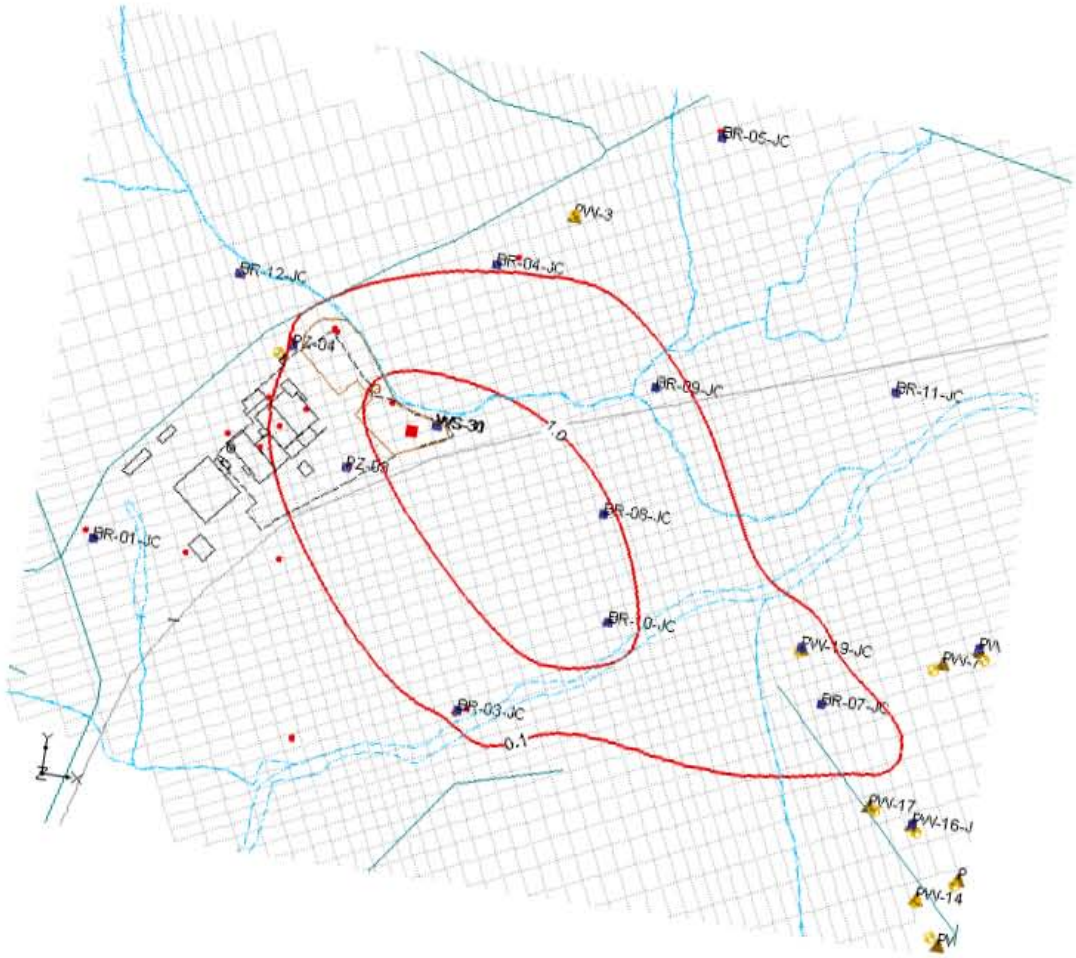


Fig. 5.32. Simulated TCE concentration contours (mg/L) in layer corresponding to transmissive Jefferson City-Cotter Formation at t = 15,000 days (~41 years). [Constant concentration source of 100 mg/L PCE placed in vicinity of Burial Pits (red square); simulated using MODFLOW model with vertical borehole flow and RT3D sequential decay chemical reaction package (PCE > TCE > cis-1,2-DCE > vinyl chloride > ethene); note that TCE shown in figure is from degradation of PCE in source.]

Fig. 5.33. Simulated uranium concentration contours (mg/L) in layer corresponding to deep overburden at t = 74,000 days (~200 years). [Constant concentration source of 0.2 mg/L uranium placed in Burial Pits and Deul's Mountain (red squares); simulated using MODFLOW model with vertical borehole flow and RT3D Tracer Transport package (includes sorption coefficient measured in site-specific study (SAIC 2003c).]

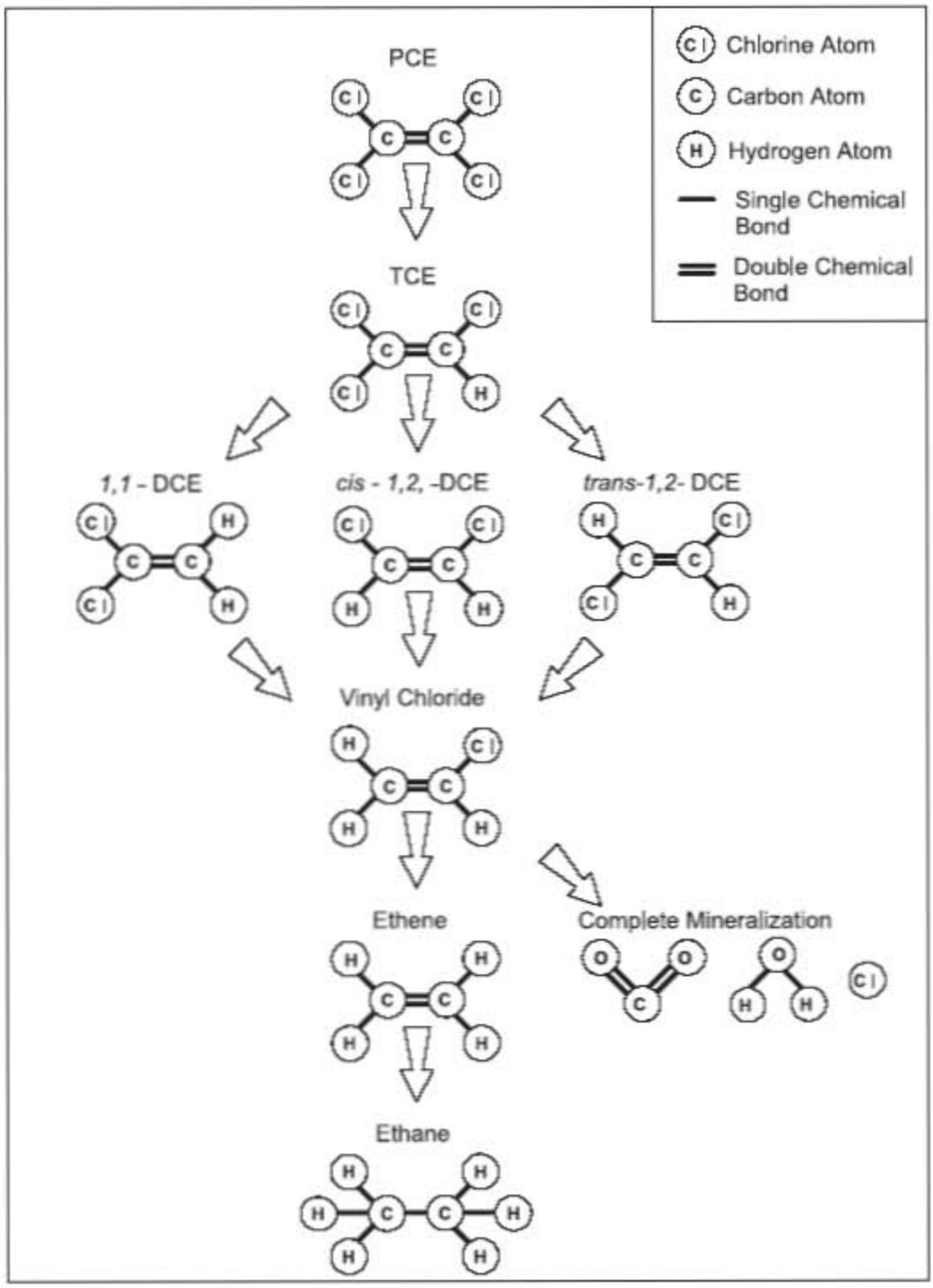


Fig. 5.34. Degradation pathway for PCE/TCE under anaerobic conditions.

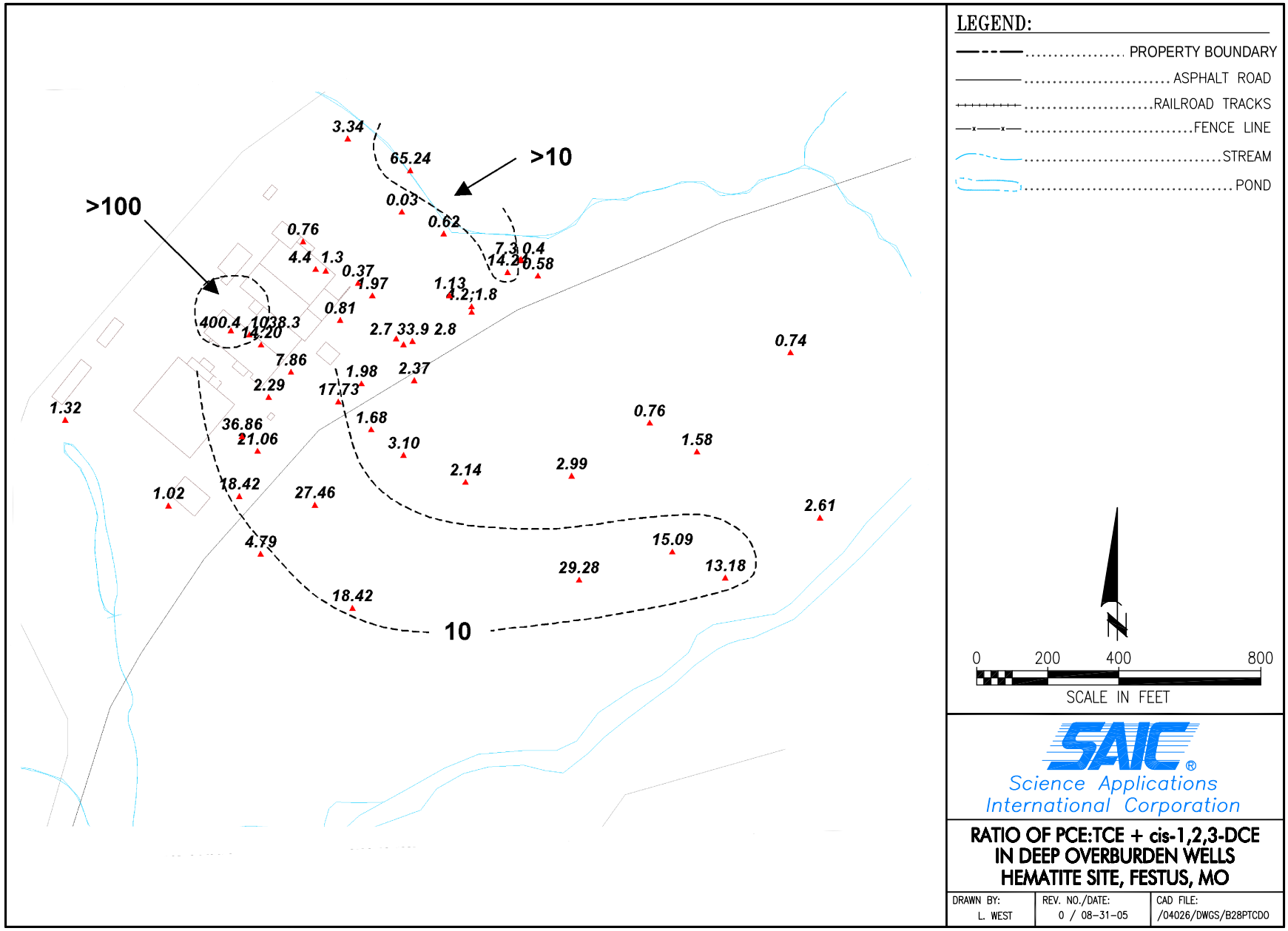


Fig. 5.35. Ratio of PCE:TCE + cis-1,2-DCE in deep overburden wells.

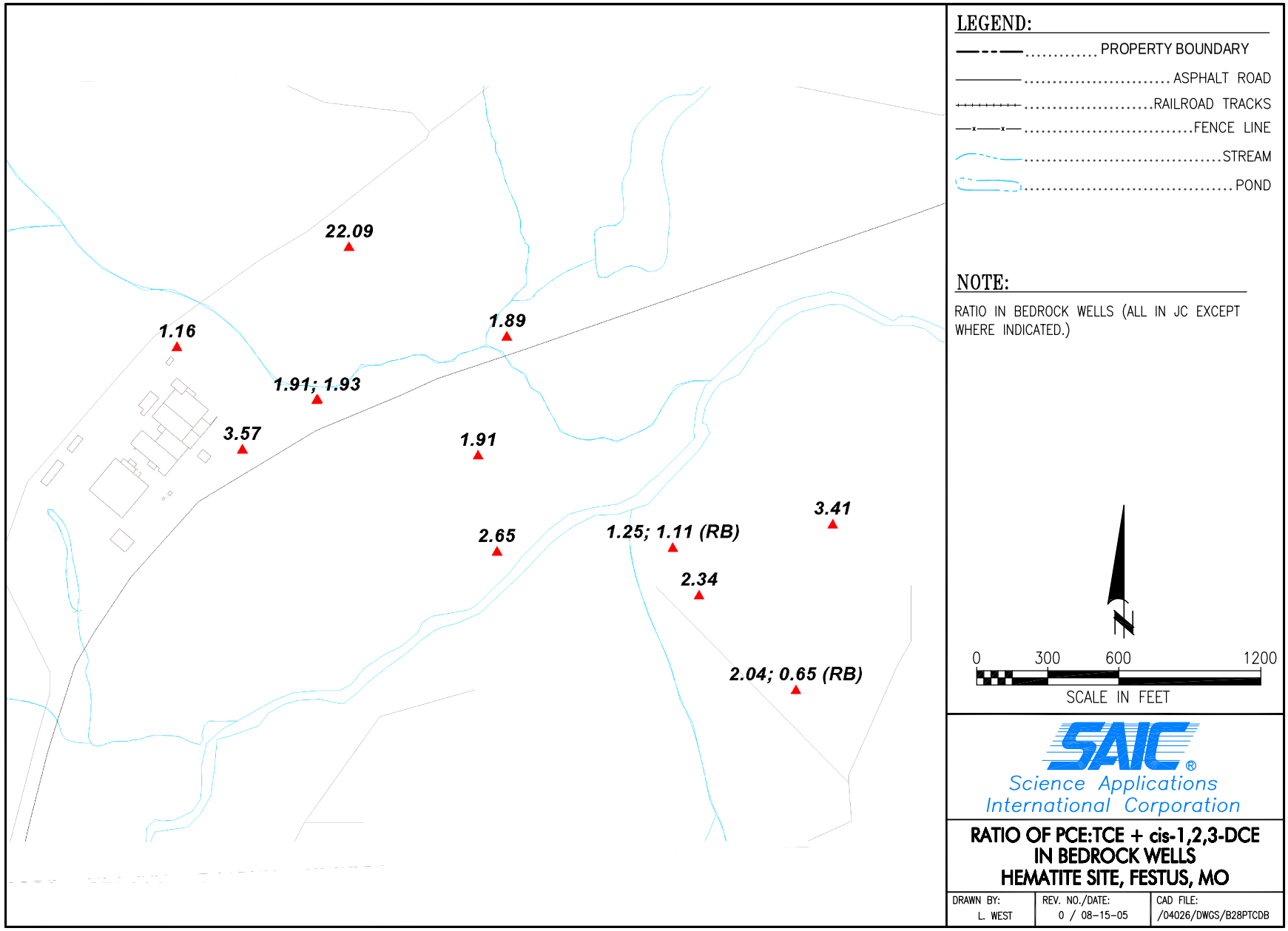


Fig. 5.36. Ratio of PCE:TCE + cis-1,2-DCE in bedrock wells.

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6. SUMMARY AND CONCLUSIONS

The objective of this RI is to establish an understanding of the geology, hydrology, and the nature and extent of contamination in surface water, soils, and groundwater for the Westinghouse Hematite Site, located near the town of Hematite in Jefferson County, Missouri. Data obtained during this investigation will be used to facilitate development of a Feasibility Study for selection of appropriate alternatives for remediation. Coupled with process knowledge for the Hematite Facility and known potential source areas for contaminants, this evaluation has led to the development of a Conceptual Site Model (CMS) from which the fate and transport of contaminants in groundwater have been assessed. Finally, the CSM has become the basis from which a groundwater flow and transport model has been constructed and calibrated against empirical data.

The Hematite Facility was originally constructed as the Mallinckrodt Chemical Works in 1955. The Facility became operational in July 1956, producing uranium metals for the nuclear fuel program of the U.S. Navy. Throughout its history, the manufacture of uranium metal and compounds from natural and enriched uranium was the primary activity at the Ffacility. Operations included the conversion of UF_6 gas of various ^{235}U enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. Although uranium material production was the primary function at the Hematite Facility, records indicate secondary activities such as uranium scrap recovery and a limited amount of work with thorium compounds as part of early research into the use of thorium in the fuel cycle.

In addition to the nuclear materials used at the Hematite Facility, there were a variety of non-nuclear chemical products stored on-Site and used in many of the processes. Those with the greatest potential for contaminating surface water, soils, and groundwater at the Hematite Facility because of leaks (from storage tanks or process pipelines) or waste disposal activities (e.g., the Evaporation Ponds and the Burial Pits) include strong mineral acids (hydrochloric, hydrofluoric, and nitric) and chlorinated organic solvents (PCE and TCE). A number of AOCs have been identified at the Hematite Site and include those locations where these (and other) potential contaminants were stored, used, and/or disposed.

6.1 SUMMARY OF GEOLOGIC AND HYDROLOGIC CONDITIONS

The geologic framework of the Hematite Site is dominated by two key bedrock formations, the Jefferson City-Cotter Dolomite and the Roubidoux Formation that underlie the site. These formations dip gently toward the northeast. The regional landscape is highly dissected by streams yielding topographic relief in excess of 150 ft. The Hematite Facility is built upon terrace/alluvial flood plain sediments overlying bedrock within the valley carved by Joachim Creek. These sediments include 10 to 20 ft of fine-grain material underlain by 5 to 20 ft of coarser-grain sands and gravels.

In the unconsolidated overburden, groundwater flow is chiefly confined to the basal, coarse-grain unit and is in a southeastward direction from the Hematite Facility toward Joachim Creek where it discharges. A groundwater mound is associated with the Hematite Facility and has a significant impact on the potentiometric surface. Groundwater flow in the upper Jefferson City-Cotter Dolomite appears to be affected by the mounding, and components of flow radiate from the Hematite Facility toward the northeast (along bedding planes) and toward the southeast (in a transmissive zone) within this bedrock unit. Below the Jefferson City-Cotter Dolomite, the current direction of groundwater flow appears to reflect a northeasterly trajectory, which is consistent with the regional groundwater flow direction in the Roubidoux Formation. In this RI report, several HSUs in bedrock have been tentatively defined that conform to the orientation of bedding. In descending order of depth, these are the Jefferson City-Cotter, Jefferson City-Roubidoux contact zone, and Roubidoux HSUs, respectively.

Vertical head gradients are downward from the shallow to deep overburden. Between the deep overburden, and Jefferson City-Cotter HSU, gradients are downward in the vicinity of the Hematite Facility and upward near Joachim Creek. Vertical gradients tend to be upward from the Jefferson City-Cotter HSU and deeper HSUs. However, until approximately mid-2004, this gradient was reversed (i.e., downward) as a result of the significant lowering of heads in the Roubidoux Formation. A possible reason for lower heads in the deeper HSUs was the pumping of groundwater from the Roubidoux Formation by water supply wells in the city of Festus.

6.2 SUMMARY OF CONTAMINATION AT THE SITE

Most contamination (radionuclides, metals, and organics) in soil at the Hematite Site is closely associated with the footprint of the Hematite Facility and disposal sites within the Facility. The distribution of contamination in groundwater, however, is significantly different among these potential contaminants. Summary conclusions for all contaminants and media are described in the following subsections.

6.2.1 Inorganics

Cyanide was not detected in any of the surface water, sediment, surface and subsurface and groundwater samples. This is clearly not a constituent of concern at the Site.

Fluoride was detected in one surface water sample collected from the Northeast Site Creek (part of AOC #2). The measured concentration, 0.67 mg/L, was only slightly higher than the reporting limit (0.5 mg/L). Fluoride was not detected in any of the surface water samples from the Site Pond, Site Creek, and Joachim Creek.

The highest fluoride levels in the surface soil samples were measured in samples from the Evaporation Ponds area (AOC #4), Deul's Mountain area (AOC #13), next to the buildings and adjacent outdoor areas (AOC #8). The highest fluoride result (170 mg/kg) is still below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984).

The majority of the subsurface soil samples did not contain fluoride above the reporting limit of ~7 mg/kg. Elevated fluoride concentrations were measured in soil samples in localized areas within the Facility including the Evaporation Ponds (AOC #4), under the buildings (AOC #6) and near Deul's Mountain (AOC #13). However, even the highest fluoride level (190 mg/kg in EP-13-06-SL) is below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984). Note that Deul's Mountain will have been removed and packaged in shipping containers for disposal off-Site by the time this Report is published. Fluoride was not measured in the groundwater because the subsurface soil fluoride data was present in localized areas, suggesting that migration via groundwater is probably minimal.

A number of metals were not detected above reporting limits in the surface water samples. These include antimony, beryllium, cadmium, selenium, silver, thallium, and mercury. The only Site surface water sample which contained metals at levels suggesting contamination was SW-01-SW collected from the Site Pond (AOC #2). Surface water samples from the Northeast Site Creek and Joachim Creek were not contaminated with any of the inorganics.

Some of the inorganics are elevated in a number of sediment samples from the Site Pond, Site Creek, and Northeast Site Creek. Highest concentrations were measured in SW-06-SS from the Site Pond. This sample had the highest mercury result (1.1 mg/kg), highest aluminum result (13,000 mg/kg) and is one of the two highest samples in iron and manganese. These data suggest either an accumulation zone where

oxyhydroxides of aluminum, iron, and manganese have scavenged metals from the surface water or where some metal scrap may be present. With the exception of SW-15-SS, which was collected near the bridge on Joachim Creek, concentrations of inorganics in sediment samples from Joachim Creek are comparable to the upstream and site-specific background concentrations (Table 4.12). The elevated metals concentrations from the sediment sample near the bridge across Joachim Creek may be due to use of this area as an adhoc household dumping site.

Although some metals are present in the Site sediments, the data from the surface water suggests that there is minimal to no migration of inorganics through the surface water at the Site.

A majority of the surface soil samples that had elevated metals concentrations relative to Site and regional background values were collected from the Evaporation Ponds area (AOC #4), and outdoor areas adjacent to buildings (AOC #8).

Data from subsurface soil samples suggest low-level metals contamination in two locations: under one of the process buildings (BD-02, under Bldg. 253, AOC #6) and next to the Site Pond (SW-02). Most of the remainder of the highest results were sporadically distributed and not indicative of significant contamination.

The following metals were not detected above reporting limits in any of the groundwater samples: antimony, beryllium, mercury, and silver. The other metals were detected in groundwater samples mostly from wells installed under the buildings (AOC #6) and Burial Pits (AOC #3). Because the elevated metals concentrations in the groundwater are localized, this suggests that groundwater migration of inorganics is limited and not as extensive as that of chlorinated solvents. There was no indication of metals contamination in the bedrock groundwater.

6.2.2 Radionuclides

Surface water and sediment data from the Site Pond indicate elevated uranium activity relative to upstream values. A limited amount of discharge into the Site Pond from the outfalls is allowed by the NPDES permit (refer to Figure 1.2 for outfall locations). Uranium activities both in surface water and sediment decrease in the Site Creek downstream of the Site Pond dam.

Uranium activities in the surface water and sediment samples from the Northeast Site Creek are slightly elevated relative to the upstream samples (Appendix H.7 and H.9 for data). The data suggests that uranium known to be present in the Burial Pits based on disposal records (Sect. 1.4) has had a minimal impact on the Northeast Site Creek that runs adjacent to the Burial Pits area.

Uranium activities in surface water and sediment samples from Joachim Creek are comparable to upstream values.

The highest uranium activity in surface soil was measured in samples collected from the Deul's Mountain area (AOC #13). In addition, most of the surface soil samples potentially contaminated with uranium were collected from the Evaporation Ponds (AOC #4) and outdoor areas adjacent to buildings (AOC #8), Red Room Roof Burial Area (AOC #11), in the Pipeline area (AOC #10), near the Site Pond (AOC #2), and the Cistern Burn Pit Area (AOC #14).

Subsurface soil data indicate that shallow subsurface soil samples associated with the process buildings (AOC #6), the Site Pond (AOC #2) and a low-lying area where drainage from the Site collects, and DM-02 collected at Deul’s Mountain show significant uranium contamination.

The RI groundwater data suggest that uranium has not migrated to the same extent as the chlorinated VOCs, and the elevated activities are present in the overburden groundwater in localized areas within the Facility. These areas include: Deul's Mountain, the Burial Pits Area, the Evaporation Ponds and under the process buildings. The groundwater data from the bedrock wells do not indicate uranium contamination in the bedrock formations underlying the Hematite Site. The potential for downward migration may exist, but retention in surface soils of uranium by adsorption appears to dominate.

^{99}Tc was not detected in any of the surface water samples from the Site (Sect. 4.3.1).

^{99}Tc was detected in the sediment samples from the Site Pond, but activities decreased significantly in the Site Creek sediments. ^{99}Tc was not detected in any of the surface water or sediment samples from the Northeast Site Creek and Joachim Creek.

The highest ^{99}Tc activities in surface soils were in samples collected near the Evaporation Ponds (AOC #4), outdoor areas adjacent to buildings and the limestone storage area (AOC #6, AOC# 7, AOC #8).

^{99}Tc activities detected in a number of subsurface soils were generally lower than concentrations found in surface soils. The significantly lower concentrations in the subsurface suggest that although downward migration of ^{99}Tc is occurring, most of the mass is retained in the surface soils.

^{99}Tc activity was only detected in the overburden groundwater in localized areas in the Facility including the Evaporation Ponds (AOC #4), under the buildings (AOC #6), in the Leach Field Area (AOC #5), and in outdoor areas adjacent to buildings (AOC #8). Similar to uranium, ^{99}Tc has not migrated in the groundwater to the same extent as the chlorinated solvents.

^{232}Th was not detected in any of the surface water or sediment samples from the Site. The RI also included sample collection and analysis for radium isotopes and for ^{237}Np, ^{241}Am, and for plutonium isotopes. There was no evidence of contamination from these species.

6.2.3 Organics

With the exception of infrequent, low concentrations of PCE and TCE at several locations along Joachim Creek, there is no surface water contamination at the Site.

The only elevated organics in sediment samples above reference levels was observed for a variety of PAHs. A number of PAHs were also commonly found in on-Site surface soil samples. Dioxins, PCBs, and petroleum contamination was found in some samples.

The most significant contamination in subsurface soil is PCE and TCE. Contaminated samples appear to reflect a source area associated with the Hematite Facility and nearby disposal areas, although contaminated soils extend southeastward from the Hematite Facility toward Joachim Creek and probably reflect migration of contaminated groundwater from which sorption to soil organic matter has occurred. DNAPL was confirmed at one location under a building at the Hematite Facility based on elevated levels of PCE concentrations. A few PAHs also are common contaminants; dioxins are occasionally detected above reference concentrations.

Groundwater in the overburden and Jefferson City-Cotter bedrock formation is contaminated with VOCs; there is also contamination in groundwater from the underlying Roubidoux Formation. PCE, TCE, their degradation products, and several additional chlorinated VOCs are commonly observed. A number of locations have sufficiently elevated PCE or TCE concentrations to suggest the nearby presence of

DNAPL. PCE and TCE plumes in overburden originate at the Hematite Facility and extend southeastward toward Joachim Creek. One component of contamination in the Jefferson City-Cotter HSU has migrated in a southeasterly direction beneath Joachim Creek; a second component has migrated down dip from the Hematite Facility to the northeast toward BR-04. Deeper contamination in bedrock only has been observed in association with private wells PW-19, PW-16, and PW-06 in a residential community to the southeast of the Hematite Facility and with PW-03 located near BR-04. PW-06, PW-16, and PW-17 are no longer used as domestic supply wells, and have been converted to dual-completion groundwater monitoring wells as part of this RI.

Biological degradation of PCE and TCE is occurring at the Hematite Site, but appears not to have proceeded past the production of 1,1-DCE; *cis*-1,2-DCE; and *trans*-1,2-DCE, except in relatively few samples.

6.3 CONCEPTUAL SITE MODEL

The CSM that was developed for this RI focuses on the following key conclusions:

- Flow and transport in a southeasterly direction within the overburden is dominated by a hydraulic gradient caused by groundwater mounding under the Hematite Facility and discharge to the surface in Joachim Creek.

- With increasing depth below the surface, flow/transport directions gradually shift from southeasterly (overburden), to a blend of southeasterly and a regionally imposed northeasterly component (Jefferson City-Cotter HSU), and finally to a regional northeasterly direction (Jefferson City-Roubidoux contact zone and Roubidoux HSUs).

- Contaminant transport in all geologic units projects back to the footprint of the Hematite Facility (and surrounding disposal areas) as the ultimate source area.

Flow and contaminant migration in bedrock at the Hematite Site has potentially been impacted by pumping in deep production wells operated by the city of Festus. These wells were operational until August 2003 and caused regionally extensive drawdown in the Roubidoux Formation of up to 50 ft in the vicinity of the Hematite Site. In the residential community southeast of the Hematite Facility, a number of private wells were completed open hole, which provided a hydraulic connection between the Jefferson City Dolomite and Roubidoux Formation. Pumping of the city of Festus wells impacted contaminant distribution at the Hematite Site in several ways. First, hydraulic stresses in the Roubidoux Formation were transferred to the upper Jefferson City-Cotter Dolomite through these wells (e.g., PW-06, PW-16, and PW-19) and facilitated flow and contaminant migration in the Jefferson City-Cotter HSU from the Hematite Facility to the location of the wells. Secondly, downward flow of groundwater and contaminants in these wells spread contaminants to deeper zones at lower heads imposed by pumping of the Festus production wells.

Once the Festus wells were shut down, rebound of water levels in the Roubidoux Formation occurred rapidly and the potential for downward flow through the private wells declined. The changes in the hydrologic regime since shutdown of the Festus production wells eventually will likely eliminate future downward vertical migration of contamination once water levels stabilize in the Roubidoux Formation.

A similar mechanism is responsible for vertical migration of contaminants at PW-03.

6.4 NUMERICAL MODELING

A numerical model was constructed by using the CSM to identify hydraulic boundaries, defining a suite of five layers corresponding to the shallow and deep overburden and the three HSUs in bedrock, and establishing the geometric (e.g., thickness and orientation) and hydraulic properties for each layer. The flow model was calibrated against water level data obtained during the RI (i.e., following shutdown of the Festus wells). The principal conclusions from the modeling investigation include:

- The shallow groundwater mound underlying the Hematite Facility plays a major role in flow/transport in both layers of the overburden, as well as in the Jefferson City-Cotter HSU.

- The assignment of reasonable downhole flow rates to the open boreholes in the vicinity of PW-19 is essential for creating the observed transport to the southeast in the Jefferson City-Cotter HSU and is supportive of the CSM.

- Particle tracking suggests that contaminant transport directions for layers responding to either the locally imposed or regional flow systems can be rationalized with observed contaminant distribution patterns. Backward particle tracking from contaminated bedrock wells (BR-08-JC, BR-09-JC, and BR-04-JC) suggests that the Burial Pits are the source of contamination in these wells. Particle travel times vary depending on the location of their release points within the Hematite Facility. Particles "released" within the southwestern part of the Hematite Facility (i.e., BD-02) tend to have longer travel times towards their discharge point (Joachim Creek) when compared to particles "released" within the northeastern part of the Hematite Facility (i.e., the Burial Pits). This is due to the mounding in the northeastern corner of the Hematite Facility that causes downward migration in this area to transmissive bedrock formations that are conductive, and probably have lower porosities than the overburden.

- Contaminant transport modeling of PCE and TCE in groundwater indicates that sorption and degradation can significantly attenuate contaminant migration such that organic contaminant levels can decrease by one to two orders of magnitude within close proximity of the source areas.

- Contaminant transport modeling of uranium in groundwater indicates very limited spreading of contamination from source areas, consistent with what was observed in groundwater sample data. The site-specific partition coefficient for uranium is two orders of magnitude higher than the sorption coefficient for organics, resulting in significantly less migration for uranium in groundwater at the Hematite Site when compared to PCE and TCE.

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