Response Action Contract for
Remedial, Enforcement Oversight, and Non-Time Critical
Removal Activities at Sites of Release or Threatened Release of
Hazardous Substances in
EPA Region VIII

U. S. EPA Contract No. 68-W5-0022

Final
Remedial Investigation Report for Bountiful/Woods Cross 5th South PCE Plume (OU2)
Davis County, Utah

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Prepared for:
U. S. Environmental Protection Agency
Region VIII
999 18th Street, Suite 500
Denver, Colorado 80202

Prepared by:
CDM Federal Programs Corporation
1331 17th Street, Suite 1100
Denver, Colorado 80202

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Prepared by:______________________________ Date: ____________
Frank R. Morris, P.G.
Project Manager

Reviewed by:______________________________ Date: ____________
Darwin Nelson, P.E.
Technical Reviewer

Reviewed by:______________________________ Date: ____________
Jeff Montera
RAC VIII QA Coordinator

Approved by:______________________________ Date: ____________
Mario Robles
EPA Region VIII Remedial Project Manager

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Cover: (clockwise from upper left) - BarCads® held for display before installation; sampling set up at MW05; surface completion with sampling manifolds set up for simultaneous purging; and rotosonic drilling operation at MW05.

Tables

Acronyms

amsl	above mean sea level
ASTM	American Society for Testing and Materials
BFC	Bountiful Family Cleaners
bgs	below ground surface
BOR	Bureau of Reclamation
BTEX	benzene, toluene, ethylbenzene, and xylene
CAHs	chlorinated aliphatic hydrocarbons
CCV	continuing calibration verification
CDM	CDM Federal Programs Corporation
CLP	Contract Laboratory Program
CM/DAY	centimeters per day
CM/SEC	centimeters per second
COC	contaminant of concern
CPT	cone penetrometer technology
DEP	David Early Property
DI	deionized
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DPT	direct push technology
DQOs	data quality objectives
Eh	reduction/oxidation potential
EPA	U. S. Environmental Protection Agency
FS	Feasibility Study
ft	feet or foot
ft/day	feet per day
°F	degrees Fahrenheit
gpm	gallons per minute
GPS	global positioning system
HHERA	human health and ecological risk assessment
ICV	initial calibration verification
IDs	identifications
I-15	Interstate Highway 15
in	inches
K	hydraulic conductivity
L	lower aquifer zone
MCL	maximum contaminant level
M	middle aquifer zone
mL	milliliter
mm/yr	millimeters per year
MS/MSD	matrix spike matrix spike duplicate
MTBE	methyl tert-butyl ether
MW	Monitoring Well
NAD	North American Datum

NAPL	non-aqueous phase liquid

NPL	National Priorities List
NTF	Norge Towne Family Cleaners
NVGD	National Vertical Geodetic Datum
OU	operable unit
OU1	Hatchco/Kelly Site
OU2	Unknown Source Plume
PA	preliminary assessment
PCE	tetrachloroethene
PID	photoionization detector
ppb	parts per billion
ppm	parts per million
PRP	potentially responsible party
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RAC	Response Action Contract
RES	residential target zone
RI	remedial investigation
SA	study area
SAP	sampling and analysis plan
Site	Bountiful/Woods Cross Operable Unit 2 Superfund Site
START	Superfund Technical and Response Team
TCE	trichloroethene
TOC	top of casing
U	upper aquifer zone
UDEQ	State of Utah Department of Environmental Quality
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
VOC	volatile organic compound
%R	percent recovery
±	plus/minus

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Section 1
Introduction

This remedial investigation (RI) report serves to document the Phase 2 field investigation effort at the Bountiful/Woods Cross Operable Unit (OU) 2 Superfund Site (Site) and incorporate salient information from the Phase 1 field investigation, which identified the Bountiful Family Cleaners (BFC) and David Early Property (DEP) source areas and delineated shallow groundwater contamination. However, this document does not replace details included in the Phase 1 data analysis report (CDM 2002a), and both reports should be used in conjunction with one another. A description of the Phase 1 field effort is included in Section 1.2.3.

All RI activities were conducted under the Response Action Contract (RAC) No. 68-W5-0022 which provides support to the U.S. Environmental Protection Agency (EPA) under work assignment No. 114-RICO-088G. This report specifically documents the results of the field effort outlined in the sampling and analysis plan (SAP) addendum for Phase 2 (CDM 2002b), and summarizes the conclusions postulated to describe the nature and extent of the tetrachloroethene (PCE)/trichloroethene (TCE) contamination within OU2.

1.1 Purpose and Organization of the Report

The purpose of this RI is to 1) describe the nature of the PCE/TCE groundwater contamination previously documented within OU2, and 2) delineate the vertical and horizontal extents of the plume(s). The compiled data will be used in combination with information from other potentially responsible party (PRP) reports, as a basis for the feasibility study (FS) to follow.

The objectives of the Phase 2 investigation were specifically designed to address data gaps identified during Phase 1 reporting and delineate the PCE/TCE plume within OU2. The data gaps relate to specific areas on site with the following objectives:

- Downgradient of BFC/DEP – Determine if the deeper contamination detected in numerous domestic wells in the vicinity of 1100 West is originating from the suspected source area identified during Phase 1.

- Upgradient of BFC/DEP – Determine if a second source exists for the previously identified upgradient soil gas anomalies in the vicinity of Norge Towne Family (NTF) Cleaners . Sampling attempts during Phase 1 using direct-push technology (DPT) resulted in equipment problems due to deeper target depths of 100 feet (or greater) and difficult geological conditions. The potential for groundwater flow reversals due to drawdown from nearby municipal drinking water wells reportedly pumping at over 1000 gallons per minute [gpm] needs to be verified. This drawdown effect has also been predicted by well head modeling simulations reported in local drinking water source protection plans developed by the City of Bountiful and the Weber Basin Water Conservancy. Long term pumping could potentially cause migration of contamination to the southeast from BFC/DEP.

- 950 West – Determine whether another source of chlorinated aliphatic hydrocarbons (CAH) is likely downgradient of the Hatchco/Kelly (OU1) site in the vicinity of 950 West.

The Phase 2 sampling was ultimately designed to determine the vertical extent of the PCE contamination and to see if the contamination from the upslope target zone (i.e., BFC) near 500 West Street could logically be tied to the downslope deeper domestic well contamination detected in the vicinity of 1100 West Street. Before the Phase 2 field investigation began, the owners of the BFC were identified as a PRP. Under an Administrative Order on Consent (U.S. EPA Docket No. CERCLA-0803002-0002) the BFC PRP conducted a source area investigation on their property (Bowen Collins & Associates 2004).

This portion of the RI report provides documentation of field activities associated with the Phase 2 investigation and ties in a discussion of both Phase 1 and 2 results. Section 1 of the report contains a brief summary of information on site background and previous response actions implemented by EPA and the Utah Department of Environmental Quality (UDEQ) over the past several years (including Phase 1). Section 2 presents the technical approach for the Phase 2 field activities performed at the Site. Section 3 describes the environmental setting of the Site and a conceptual model. Section 4 includes the analytical results, quality assurance (QA) and quality control (QC) issues, data validation/evaluation, and the data quality assessment. Section 5 describes the nature and extent of contamination. Section 6 discusses the fate and transport mechanisms relating to the Site. Section 7 summarizes the baseline risk assessment (Syracuse Research Center [SRC] 2004), conclusions reached at the end of the Phase 2 investigation, and other observations/recommendations. Section 8 provides the references cited in this report.

1.2 Background Information

1.2.1 Site Location and Description

The Bountiful/Woods Cross 5th South PCE Plume Superfund Site (Site) is located in southern Davis County, Utah, approximately 10 miles north of Salt Lake City (Figure 1-1). Specifically, the boundaries inclusive of OU1 and OU2 are approximately 750 South to 300 North and 500 West to 1400 West in the cities of Bountiful, West Bountiful, and Woods Cross, Utah (Figure 1-2). The Site and surrounding areas have been subdivided into separate study areas (Phase 2) as depicted in Figure 1-3. These areas were outlined to address different aspects of the RI broadly defining potential source areas and separating OU2 into upgradient and downgradient portions of the PCE plume.

Previous investigations indicate that groundwater below the Site is contaminated with CAHs, specifically PCE and some associated TCE and other degradation compounds (CDM 2002a). A discussion of historical investigations and response actions, in addition to a Phase 1 summary follow.

1.2.2 History and Response Actions

Detections of PCE and TCE in groundwater at the Site were first noted in 1984. Golder Associates conducted an investigation in May 1987 at the Woods Cross (former Phillips 66) Refinery to identify potential sources of PCE detected in shallow groundwater. PCE was detected in the parts per billion (ppb) range in groundwater both upgradient and downgradient of the refinery (Golder Associates 1987), however no source was identified.

In 1996, EPA's Superfund Technical and Response Team (START) contractor sampled residential wells downgradient and crossgradient of the former Phillips 66 Refinery (now owned by Holly Refining & Marketing Company). Tap water sampled from four homes along 1100 West contained PCE contamination above 5 micrograms per liter (µg/L), which is the PCE maximum contaminant level (MCL) for drinking water (CDM 2002a). Initially, these households were given bottled drinking water, and eventually, two of the four homes were connected to the municipal water supply. A list of all domestic wells sampled during this investigation is included in Table 1-1 along with its corresponding highest PCE concentration.

In 1996, UDEQ conducted a preliminary assessment (PA). Groundwater was identified as the primary exposure pathway. The PA identified the oil refinery, several dry cleaners, and various automotive maintenance facilities as potential sources of the PCE contamination in groundwater.

In 1997, a Geoprobe® investigation at the Hatchco/Kelly property (located directly south of the refinery's petroleum trucking terminal) detected concentrations of CAHs (primarily TCE) as high as 3,750 ppb in shallow groundwater (UDEQ 1999).

In the fall of 1998, UDEQ collected five groundwater samples by cone penetrometer on the east side of Interstate Highway 15 (I-15). One sample, collected downgradient of the BFC, contained PCE at 8 ppb. A definitive PCE source/facility was not identified as part of the investigation (UDEQ 1999).

Annual sampling conducted by Phillips Petroleum Company during the late 1990s has shown elevated PCE, TCE, and vinyl chloride concentrations in three downgradient monitoring wells (MWs) on the western side of the refinery (MW02S, -2D, and -3S). Additionally, samples collected by EPA in 2000 confirmed the presence of PCE and minor amounts of TCE in various domestic wells in the local area.

EPA conducted a passive soil gas survey in March and September 2001 and identified several potential PCE source areas between 200 West and I-15 in West Bountiful and Bountiful, Utah.

Regional municipal drinking water wells exist within a 4-mile radius of the Site. At present, the only known municipal drinking water wells contaminated by CAHs are the Woods Cross #1 and #2, which are off-line and have been out of the system since 1999. However, the contamination associated with these wells is reportedly related to the Bountiful 5-Points PCE Plume located approximately one mile southeast of the Site, opposite the Intermountain Waste Oil Superfund site (UDEQ 2004). The Bountiful Shop Well (closest to the BFC/DEP source) has not been sampled since August 23, 2001 (Bountiful City 2004). In addition, several domestic and irrigation wells have been impacted over recent years.

EPA placed the Site on the National Priorities List (NPL) in October 2001 (see Section 2.2.4). Following the listing, the Site was subdivided into two OUs (OU1 and OU2). Formerly, the OU1 area was called the "Woods Cross 800 West Plume," and OU2 was the 5th South PCE Plume with an unknown source, or the "Unknown Source Plume."

The PRP for OU1 (Hatchco/Kelly) has recently completed a RI for onsite and offsite contaminant plumes of CAHs (HDR 2003a). In addition, a draft focused FS is under review by EPA (HDR 2003b).

1.2.3 Phase 1 Field Investigation

Phase 1 of the RI for the Bountiful/Woods Cross OU2 Site was conducted by CDM Federal Programs Corporation (CDM) during June and July of 2002 to determine the source area(s) for PCE/TCE groundwater contamination indicated by previous investigations. Phase 1 sampling focused on collecting shallow groundwater/ subsurface soil samples and profiling stratigraphy from six target zones established over the Site. Five target zones were identified based on sample results from previous investigations as potential source areas of PCE/TCE contamination. A sixth target zone was added during the Phase 1 investigation to incorporate the western portion of the former Phillips 66 Refinery. The six target zones included:

- West portion of the former Phillips 66 Refinery (WPH)
- East portion of the former Phillips 66 Refinery (EPH)
- Bountiful Family Cleaners at 344 South 500 West Street (BFC)
- Utility corridor along 500 West Street (UTC)
- Residential area near 400 South and 350 West Street (RES)
- Norge Town Family Cleaners between 200 and 285 West Street near 300 South (NTF)

A total of three borings were placed in each target zone using a triangular pattern (upgradient, downgradient and crossgradient of regional groundwater flow). Grab samples of groundwater were collected from each boring using a stainless steel mini-bailer and were analyzed at a mobile laboratory for VOCs using a modified method of SW-846 8021B. Confirmation analysis of the mobile laboratory results was conducted for two soil samples and eight groundwater samples (10% of mobile laboratory analyses). If initial sample results indicated a suspected contaminant source, then additional borings were placed within each target zone and additional groundwater and soil samples were collected to bracket the source area and to establish migration trends. Additional samples were collected and analyzed using the same methods described above.

Private residential and irrigation wells located on the west downgradient portion of the site were also sampled during the Phase 1 investigation by UDEQ. The precise depth of wells was not investigated, but most were completed in the shallow East Shore Aquifer at depths ranging from 145 to 265 feet below ground surface (bgs) (as reported by the property owners). Groundwater samples were analyzed for VOCs by the mobile laboratory.

A total of 71 groundwater samples were collected during the Phase 1 investigation, including 57 grab samples from onsite temporary MWs or soil borings and 14 grab samples from private wells located either at the western edge of the Site or downgradient of the western portion of the Site. PCE, TCE, and a series of associated degradation products were detected in various zones of the shallow aquifer. Concentrations in many of these samples exceeded MCLs. The highest PCE concentrations in the shallow aquifer were observed centered on the BFC/DEP ranging from 164 to 400 ug/L. A significant reduction in contaminant levels occurs moving away from these two properties. (Figure 5-1).

However, another source of CAH contamination in the shallow aquifer is suspected south of 500 South due to the high TCE and degradation compounds (including vinyl chloride) at station WPH10 and the suspected direction of groundwater flow. PCE contamination was observed here at relatively low concentrations. Methyl tert-butyl ether (MTBE) was also identified in the shallow groundwater samples collected from the southern portion of the Site at low levels (stations WPH01, EPH17, WPH10) and at high levels (WPH09, WPH08). These areas are considered as separate plumes and are discussed in further detail in Sections 1.3 and 4.1.

Lower portions of the shallow East Shore Aquifer are also impacted with PCE concentrations above the MCL in domestic wells on the western portion of the Site and downgradient of the Site that are reportedly completed to depths of 150 to over 250 feet bgs. The source of the deeper contamination could not be determined with data from Phase 1.

In summary, the Phase 1 investigation identified a shallow PCE groundwater plume (with only minimal concentrations of other CAHs). The source area was determined to be in the vicinity of the BFC/DEP. During the same time frame, UDEQ sampling also reconfirmed a deeper PCE plume (with little to no other CAHs) west of the refinery. Questions remained at that point whether a connection existed between the deeper PCE contamination detected in the domestic wells and the presumed upgradient source area associated with BFC/DEP. Phase 1 results are detailed in the data analysis report issued October 2002 (CDM 2002a).

1.3 Chemicals of Potential Concern

A baseline human health and ecological risk assessment was prepared by SRC and is summarized in Section 7. This assessment provided a list of chemicals of potential concern (COPCs) for current/future residents and workers (i.e., human receptors) and aquatic ecological receptors. These COPCs were associated with the specific plumes related to the Site and are included in Table 1-2. The two COPCs common to all plumes and both receptors are:

- PCE
- TCE

PCE (also known industrially as perchloroethene) is a solvent used to clean machinery, electronic parts, and clothing. PCE and TCE (a degradation product of PCE) are suspected carcinogens and ubiquitous environmental pollutants (along with other CAHs) in groundwaters of the United States. PCE and TCE were the primary focus of the RI. Both compounds were detected in at least three distinct plumes (i.e., OU2 PCE, MTBE, and an extension of the OU1 Hatchco plumes) at the Site. In some groundwater regimes, these compounds undergo reductive dechlorination, catalyzed by anaerobic bacteria, that yields vinyl chloride (known human carcinogen) and other degradation compounds. This degradation pathway for PCE is presented in a simplified format as Figure 1-4.

Several other human receptor COPCs are PCE/TCE degradation products. These degradation products include *trans*-1, 2-dichloroethene (common to all three plumes), *cis*-1, 2-dichloroethene (in both the OU2 PCE and MTBE plume), and vinyl chloride (detected in the co-mingled MTBE and extended Hatchco plume). The only other COPC that is addressed independently in this RI report is MTBE which is only identified in the MTBE plume and is related to a different source than most of the other COPCs. MTBE is discussed in more detail in Section 4.3. There are seven other human receptor COPCs as listed in Table 1-2 that occur sporadically across the Site.

For aquatic ecological receptors, the only COPCs besides PCE and TCE are benzene, naphthalene, and carbon disulfide as noted in Table 1-2.

Section 2
Phase 2 Field Investigation

2.1 Technical Approach

The Phase 2 field investigation involved collecting environmental samples and other information from three study areas (SAs) within the Site boundaries to satisfy the revised RI data quality objectives (DQOs) specified in Attachment B in the SAP addendum. Each SA boundary, with corresponding boring locations, is illustrated in Figure 2-1. The boring identifications (IDs) tie all associated groundwater, soil, and geotechnical data to one specific location (e.g., "MW01" in the sample identification number or on a well log relates the information back to that specific location shown on the map).

2.1.1 Investigation Objectives

A SAP addendum (CDM 2002b) was produced detailing the field activities scoped for the Phase 2 investigation. The scope of work was designed to address specific data gaps resulting from the Phase 1 field investigation evaluation, determine the full vertical and horizontal extent of PCE/TCE plume, and to gather quarterly water quality data. The first objective was primarily concerned with the characterization of deeper portions of the shallow East Shore Aquifer. Vertical profile data were required over and beyond the lateral extent of the shallow groundwater plume (especially within SA-1). To address the extent of the PCE/TCE plumes, five strategically located borings (MW01 through MW05) were installed with three BarCad® samplers at various depths (up to 250 feet) targeting different saturated zones (Figure 2-1). These 15 samplers were used to collect groundwater quality data on a three dimensional scale. Placement of these borings was based on the delineation of the upper groundwater PCE plume (CDM 2002a) and spaced so that groundwater flow direction could be evaluated between the shallow and deep contamination across the entire area.

The Phase 1 investigation identified low levels of PCE (i.e., soil gas anomalies and two shallow DPT groundwater samples [RES01 and RES02]) regionally upgradient from the identified source area (Figures 1-3 and 1-5, respectively). It was suspected that a nearby high capacity municipal drinking water well (i.e., Bountiful Shop Well) could be affecting movement of the plume due to intermittent pumping (i.e., fluctuating cone of depression). However, another potential PCE source to the east (i.e., NTF Cleaners) had not been evaluated due to depth limitations of the DPT sampling methods used during Phase 1. Two upgradient wells (MW06 and MW07) were completed into the shallow aquifer (maximum 150 ft) at SA-2. Location MW06 was the only well installed to address potential contamination issues surrounding the NTF Cleaners. Its location is immediately downgradient of the dry cleaner. MW07 and the existing BK01 were planned for monitoring any upgradient migration of PCE towards the Bountiful Shop Well.

Unrelated to the Phase 1 investigation, SA-3 addresses another potential source area downgradient of the OU1 Hatcho plume.

This portion of the investigation was designed to help determine if the CAH detections near 950 West are connected to the OU1 source or can be considered a co-mingled plume with another source area identified. The RI at the Hatchco/Kelly property (OU1) has delineated a shallow CAH plume(s) in the area tracking from the subject property to the west-northwest. A decrease in total concentrations of CAHs, primarily TCE, was noted immediately downgradient, with an anomalous increase noted in the vicinity of 950 West. This one anomalous groundwater concentration was postulated by the Hatchco/Kelly RI to be emanating from another offsite source (HDR 2003a). However, the anomaly could also be the result of sampling from a zone of preferential flow within the OU1 plume. In summary, total CAH concentrations over 1,000 ppb of primarily TCE and degradation compounds were identified in an area south of the Holly Refinery near an automotive repair facility and former asphalt plant (SA-3). As a result, the investigation was planned to include shallow soil sampling on 50-ft grid centers surrounding the auto repair building in an attempt to locate any contaminated vadose zone soils. Additional groundwater grab samples were also proposed to fill in data gaps between and around the recently installed Hatchco/Kelly offsite MWs.

The BFC/DEP source area required additional soil and groundwater sampling to the source (e.g., contaminated soils resulting from breached sewer lines, sumps, leaking underground storage tanks, or spills) to identify and delineate the source of PCE contamination. The BFC property owner, now an identified PRP, conducted a separate investigation. Draft results provided by the PRP used and evaluated in this report, however they address only a portion of SA-4. Detailed results of the investigation are provided in the Bountiful/Woods Cross 5th South PCE Plume, Operable Unit 2 (RI Bowen Collins and Associates 2004).

2.2 Field Investigation Tasks

2.2.1 Study Area 1 - Vertical and Horizontal Extent of PCE Contamination Downgradient of BFC/DEP

2.2.1.1 Rotosonic Drilling

The first objective of the Phase 2 field investigation, to evaluate and determine the vertical and horizontal extent of the PCE groundwater contamination, involved installation and sampling of multi-port (BarCad®) MWs. A Sonic/1513-4599 drill rig was used to complete the five borings (minimum 6-inch diameter) to a maximum depth of 250 ft (MW01 to MW05). Rotosonic drilling methods were required because of difficult subsurface conditions (e.g., compacted gravel to cobble size zones) and the objective to retrieve full cores for geological inspection and geotechnical analysis. However, the sonic drilling method produces a substantial amount of heat and core sediments. These sediment were therefore generally hot, often with steam rising. As a result, it was suspected that most of the dissolved-phase VOCs would have volatilized. No chemical analyses were run on the core samples. This drilling method had the advantage of maintaining an open hole with temporary casing and retracting it during completion of the multi-port sampling units. Most of the multi-port systems were telescoped in with an 8-inch diameter boring down to approximately 100 feet and then a 6-inch diameter boring to total depth. The larger diameter boring in the upper portion was sufficient to accommodate the upper BarCad® unit (set above 100 ft) with the other two riser sections completed at the surface. Lithologic and completion logs are included in Appendix A.

2.2.1.2 Geotechnical Soil Sampling

Twenty-five subsurface soils were collected as described in Section 3 and shipped to Maxim Technologies, Inc. for sieve/hydrometer analysis and visual soil classification. The soils were analyzed by American Society for Testing and Materials (ASTM) methods (i.e., D1140, D422, and D2488). The soil samples were collected primarily from the completion intervals where well screens and/or BarCads® were installed. The particle size distribution was then entered into a software program (SOILPROP Version 2.1) to estimate hydraulic properties of the aquifer. The program uses Van Genuchten and Brooks-Cory retention parameters to yield hydraulic conductivity (K) values in centimeters per day (cm/day). All data and calculations are included in Appendix B.

2.2.1.3 Multi-Port Well (BarCad®) Installations

The BarCad® systems are an economical way to test and monitor several vertical portions of the aquifer by drilling just one borehole in a zone of interest. After lithologic logging and photoionization detector (PID) screening of the continuous core were complete, well completion intervals were selected. A set of three BarCad® units (individual completions) were installed at different depths equivalent to a lower, middle, and upper (i.e., L, M, and U, respectively) zone using the manufacturer's standard operating procedures (SOPs) (BESST 2002). Well completion materials consisted of 1-inch diameter Schedule 80 polyvinyl chloride (PVC) riser pipe, Teflon® tubing, stainless steel tube weights, lifting bail subs, ⅜-inch bentonite chips, #60 silica sand filter pack, and a funnel for slurry delivery. A BarCad® representative was on site for the first completion to ensure proper installation methods and to coordinate well completion efforts. When artesian conditions were encountered (as in the two most downgradient borings, MW01 and MW02), a BarCad® manifold, sample discharge control valve, and fluid pressure gauge were required for final completion. Borings MW01 to MW05 were placed between the deep PCE contamination detected in the domestic wells along 1100 West and the suspected source area at BFC/DEP (Figure 2-1).

Twenty-four geotechnical samples, representative of each potential and actual completion zone, were collected for grain size analysis and visual classification. The shallow BarCad® units were installed in the uppermost saturated zone (U). The intermediate BarCad® units were placed in a mid-depth saturated zone (M) as directed by the onsite hydrogeologist, after evaluating the stratigraphy of the entire boring. The deep BarCad® units were positioned in a lower saturated zone (L) of the shallow aquifer. Both M and L zones are comparable to the aquifer materials screened by many of the domestic wells (UDEQ personal communication) located in the vicinity of 1100 West.

Each set of BarCad® units were located so that the measured water quality could be related to the shallow contaminant plume defined during the Phase 1 field investigation. These multi-completion borings are also offset from one another for the purpose of comparing hydraulic gradients and groundwater flow directions. Independent hydrostatic head was measured in each unit with either a water level indicator (i.e., M-Scope) or a pressure gauge attached to a manifold (artesian wells).

2.2.1.4 Well Sampling

The conventional MWs were sampled using low flow techniques (CDM 2002b) and a compressed nitrogen-driven bladder pump system with disposable Teflon® bladders. The BarCad® wells were sampled by releasing compressed nitrogen into the wellhead adapter and returning groundwater to the surface through a Teflon® line. Sample recovery flow is controlled by the two-way valve which restricts the nitrogen from entering the BarCad® unit resulting in a high quality sample (Figure 2-2). All Phase 2 groundwater samples were analyzed for VOCs using the EPA Contract Laboratory Program (CLP) low-level method (OLC03.2).

During each quarterly round of sampling, a minimum of eight groundwater samples (a total of 33 representative of each aquifer zone across the site) were split and also analyzed for natural attenuation parameters (i.e., alkalinity, conductivity, total iron and manganese, nitrate/nitrite, pH, oxidation/reduction potential, sulfate, chloride, and dissolved oxygen). These samples were analyzed through an independent subcontract laboratory and ferrous iron was measured directly in the field using Hach™ kits (Section 6.4).

2.2.2 Study Area 2 - Source Area Identification for PCE Contamination Upgradient of BFC/DEP

The second objective of the Phase 2 investigation was to determine the source of soil gas anomalies and low-level PCE contamination upgradient of BFC/DEP. Other potential sources were evaluated and localized groundwater flow variations due to drawdown from the nearby municipal Bountiful Shop Well were monitored. The other potential point sources of PCE upgradient of the BFC/DEP area included one current and one former dry cleaner location. To make this determination, two shallow aquifer wells (MW06 and MW07) were installed upgradient of BFC/DEP (Figure 3-2). MW06 was strategically placed immediately downgradient from NTF Cleaners. MW07 was installed immediately downgradient of a former dry cleaning establishment located in the shopping plaza at the southwest quadrant of the intersection 200 West and 500 South. This location is approximately in line between the Phase 1 detections and the Bountiful Shop Well. The pre-existing background well (BK01), installed by URS during May 2000, was also used as a third upgradient well within the monitoring network.

Rotosonic drilling methods were used to retrieve full cores for geological inspection and geotechnical analysis. One geotechnical sample from boring MW07 was collected for grain size analysis and visual soil classification from the screened interval.

Conventional 2-inch diameter PVC MWs were installed at these upgradient locations in accordance with the SAP addendum (CDM 2002b).

The new Phase 2 wells, along with the pre-existing (May 2000) background well (BK01), were sampled and analyzed for VOCs by an EPA CLP laboratory using the low-level method (OLC03.2). In addition, the upgradient groundwater samples from the background MW (BK01U) were analyzed for natural attenuation parameters to determine shallow aquifer conditions in an uncontaminated portion of the aquifer. Since the upgradient wells were the only conventional MWs sampled on site, they were also planned for slug testing to determine hydraulic conductivities.

Analytical results, especially if nondetect, from these upgradient wells are not likely to provide enough information alone to determine the origin of the shallow low-level PCE contamination discovered during the Phase 1 investigation. However, the water levels collected from temporary wells during Phase 1 indicated an anomalous flow gradient to the southeast from the BFC target zone. Therefore, during the Phase 2 sampling effort, In-Situ™ transducer/data loggers were placed in all three upgradient wells to continuously monitor water levels that may be affected by seasonal fluctuation and/or variable pumping rates from the nearby Bountiful Shop Well. Hydrographs were produced for each well from May to December 2003 and compared to each other for potential response to variations in the Bountiful Shop Well pumping rates, as well as, precipitation events for the year 2003 (see Section 3.1.3).

All MWs were surveyed by a licensed Utah surveyor to the nearest 0.01 foot vertical National Vertical Geodetic Datum (NVGD) and 0.1 foot horizontal in Utah State Plane Coordinates (Utah North Zone, North American Datum [NAD] 83). Both top of casing and ground surface elevations were measured and are reported in Appendix A.

2.2.3 Study Area 3 – Source Area Identification for Shallow CAH Contamination Downgradient of OU1

Phase 2 included efforts to determine the source area of the CAH contamination detected in several shallow wells downgradient of the Hatchco/Kelly site. The data were turned around quickly to supplement decisions concerning the Hatchco/Kelly RI/FS. A total of 53 vadose zone soils and groundwater samples (including QC) were collected in SA-3 (950 West). The soil samples were located using six north to south transects. Samples were collected using a DPT macrocore tool along transects at approximately 50-ft intervals surrounding the target location, an operating automotive repair facility (Figure 2-1).

Of the 53 total samples, including QC, 25 were soil and 19 were groundwater grab samples. The groundwater samples were collected using DPT methods, PVC slotted screen, and a peristaltic pump. Groundwater samples were collected at a larger (>100-ft) spacing to fill in gaps where the Hactchco/Kelly data were sparse. Another possible source of VOC contamination in this area was centered around a former asphalt plant on the west side of 950 West. Only one soil and one groundwater sample were collected from the estimated center of the former plant location (DP25) to determine if any associated contamination from asphalt operations was present.

Samples were analyzed for VOCs. All surface locations were surveyed with a handheld differential global positioning system (GPS).

2.2.4 Quarterly Groundwater Sampling

All 15 Phase 2 BarCad® Multiport wells (MW01 U-M-L to MW05 U-M-L), 2 conventional wells (MW06U and MW07U), plus the previously existing site background well (BKG01U) were first sampled during March 2003. After evaluation of the March 2003 data, a network, including all of the above MW and a select, but changing number of nearby domestic wells, was established for the quarterly sampling effort through the remainder of 2003 (Figure 2-1). UDEQ was tasked by EPA to conduct the domestic well sampling. However, these domestic well samples were tracked, labeled, and submitted with the CDM-collected quarterly MW samples to a CLP laboratory for analysis. The network of MWs and UDEQ-selected domestic wells were sampled for three successive quarters (i.e., four sets of groundwater samples). All samples were analyzed for VOCs. A select number of groundwater samples, representative of various aquifer zones and lateral extent, were split and sent to an independent subcontract laboratory for determination of natural attenuation parameters (see Section 6.4 and Table 6-1).

2.3 Chemical Analysis and Analytical Methods

All Phase 2 soil and groundwater samples were sent to CLP laboratories for VOC analysis. The soil samples and associated QA/QC samples were analyzed using method OLM04.2, while all groundwater samples and their associated QA/QC samples were analyzed using method OLC03.2 (low-low)(Table 2-1). Selected groundwater samples were also sent to an independent subcontract laboratory for analyses of natural attenuation parameters not determined in the field (Table 2-1).

Section 3
Site Characteristics

3.1 Environmental Setting

3.1.1 Geology

The geology discussion presented below was paraphrased from literature sources. Subsurface field data were found to be very consistent with the descriptions of subsurface conditions. The Site is located in the Basin and Range physiographic province on the southern portion of the East Shore Aquifer (Clark 1990). Basin fill deposits comprising the East Shore Aquifer system were eroded from the mountains and deposited in an elongated graben formed between the Wasatch Front and the Great Salt Lake during Pleistocene Lake Bonneville and pre-Lake Bonneville time. The basin fill is composed of unconsolidated and semiconsolidated sediments in a series of interbedded alluvial and lacustrine deposits. Most of the sediments are coarse-grained near the mountains where delta, alluvial fan, and mudflow deposits predominate. Fine-grained sediments predominate near the west side of the graben where most of the deposits are lacustrine. The thickness of the basin fill in the Bountiful area is unknown. However, the deepest well in the area was completed in unconsolidated material to a depth of 1,985 ft. The thickness of the basin-fill deposits decreases substantially toward the western edge of the graben (Clark 1990). Estimates from gravity data indicate thickness in the range of 6,000 to 9,000 ft (Dames & Moore 1991). The lowermost basin fill unit is the poorly consolidated Salt Lake Formation (Pliocene) consisting of fanglomerates, oolitic limestone, and volcanic ash/tuff with an aggregate thickness of 2,000 ft. Overlying the Salt Lake Formation is the non-indurated alluvial and fluvial deposits estimated to be of Pliocene and Pleistocene age termed pre-Bonneville Alluvium (Thomas 1948). These deposits can be divided into general stratigraphic packages (or zones) based on relative grain size. The logical provenance of the coarse deposits can be attributed to the bedrock of the Wasatch Mountains brought in by alluvial fan deposition. Correlation of pre-Bonneville alluvial deposits between adjacent boring locations is difficult given the fluvial and colluvial origin of the deposits. Significant lateral discontinuity and heterogeneity exists as indicated by the lenticular and discontinuous character of individual beds.

Overlying the pre-Bonneville Alluvium are deposits of the Lake Bonneville Group. Below the Site, the Bonneville Group sediments are a mixture of lake bottom and low to high energy alluvial deposits (Thomas 1948). These sediments comprise much of the bench terraces; however, Mill Creek alluvial deposits may be laterally continuous with the Lake Bonneville Group sediments as is suggested by the higher hydraulic potential observed in sand and gravel beds encountered in many test borings drilled. Below the Holly Refinery, a relatively continuous clay and silt unit is found in the uppermost 15 feet of lake-bottom deposits. This unit reportedly contains fresh water mollusks associated with stagnant lakes. The depth of the Lake Bonneville Group is estimated at a depth of about 80 feet below the refinery (Dames & Moore 1991). A schematic block diagram depicting the site conceptual model of the stratigraphic and hydrogeologic regime described above and confirmed by the Phase 1 and 2 RI is presented in Figure 3-1.

Two significant geologic structures exist in the vicinity of Bountiful and West Bountiful (the Wasatch Fault system and the Warm Springs Fault component). The Wasatch Fault system is the major structural boundary between the Basin and Range and Colorado Plateau physiographic provinces and is composed of 12 zone segments. Slip rates along the Weber segment, closest to the Site, are reported between 1.1 and 1.7 millimeters per year (mm/yr) for the early and middle Holocene and between 0.8 and 1.2 mm/yr for the late Holocene. The faults are manifested as nearly continuous scarps which disrupt the alluvial fan and debris flow bench deposits all along the Wasatch front (Dames & Moore 1991).

The Warm Springs Fault is the westernmost displacement observed along the Wasatch system; the fault also runs through the west-central portion of the Site. The northeast to southwest trending fault is reported to have approximately 20 feet of displacement in the upper Lake Bonneville Group sediments in the vicinity of West Bountiful. The fault plane dips approximately 70 degrees to the west (Thomas 1948). Numerous natural springs and seeps are noted along the trace of the fault extending through the western portion of the Holly Refinery (Figure 3-2). A plan view of section lines for cross-sections A to A′ and B to B′ is also presented in Figure 3-2. Cross-sections of the geologic framework for defining the upper, middle, and lower (U, M, and L) aquifer zones interpreted across the Site can be seen in Figures 3-3 and 3-4.

A fence diagram using a lithoblending algorithm in the Rockworks™ software package is presented as an auto correlation technique for tying all nine newly-installed MWs currently in OU2 (Figure 3-5). This diagram shows relative zones of high permeability, moderate permeability, and low permeability units (i.e., sand/gravel, fine sand/silts, and clays, respectively). Discontinuities are easily seen, as well as, continuous sands where they apply. As shown in the figures, the gray shaded area at the bottom of the upgradient wells is related to mudflow or debris deposits with a high percent clay containing some cobbles and poorly sorted sand and silt. In contrast, the bright yellow zones seen in MW02 are fluvial channel sands and gravels forming two distinct highly permeable units.

3.1.2 Hydrogeology

In general, the East Shore Aquifer system is confined or semiconfined, with some unconfined areas along the mountain front located to the east and in floodplain deposits along stream channels. A potential also exists for isolated perched zones along the benches and in valley lowland areas. The consolidated rocks in the mountains to the east are considered to be the primary recharge source for the East Shore Aquifer system. The Site extends from some of the areas with recharge zones (i.e., in the east with thick sand and gravel sequences) to discharge areas (i.e., in the west as evidenced by numerous artesian wells and confining silt/clay sequences). Section 3.3 provides more detail on the site conceptual model.

The East Shore Aquifer system in the Bountiful area has been described as containing shallow, intermediate, and deep artesian aquifers. Wells believed to be completed within the shallow artesian aquifer system have completion depths of 60 to 250 ft below ground surface (bgs). Wells completed within the intermediate artesian aquifer system have completion depths of 250 to 500 ft bgs, and the deep artesian aquifer system wells are completed at 500 ft bgs and greater. Little work has been done in defining the boundaries between the aquifers since there are no substantial lithologic differences or large vertical head differences (UDEQ 1996). Groundwater flow is generally from the east-southeast towards the west, following the local topography toward the Great Salt Lake (Anderson et al. 1994).

The finer-grained nature of some of the shallow aquifer sediments over the middle and western portion of the Site tends to impede groundwater flow and reduce the permeability. In addition, enhanced adsorption of contaminants by the finer-grained sediments may occur. However, a report compiled for Phillips Petroleum regarding contaminant sources indicates a shallow sand layer located from approximately 20 to 50 ft bgs may be a preferred pathway for contaminant migration immediately east of the refinery (Golder Associates 1987). Higher levels of PCE were strongly associated with this zone, and well logs show increasing proportions of sand and gravel at these depths.

Historically, the shallow East Shore Aquifer has been and continues to be used for industrial applications and irrigation purposes in the area. However, emerging information available about the residential wells in the West Bountiful area indicates that the majority of the wells are completed to depths between 150 and 300 ft, which would indicate that the shallow part of the East Shore Aquifer is used also for drinking water purposes. The shallow, intermediate, and deep portions of the East Shore Aquifer may also be hydraulically connected with one another (Anderson et al. 1994).

The aquifer system underlying the Site is composed primarily of sediments consisting of alternating layers of fluvial gravels, sand, poorly sorted mudflow deposits, discontinuous clays to the east (upgradient), and finer lake bottom sand, silts, and clays to the west (downgradient). Static groundwater elevations vary about 28 ft over the 400 acre site and range from approximately 4,270 ft above mean sea level (amsl) to 4242 ft amsl. In general, a very shallow to flat horizontal gradient exists in the eastern portion of the Site with wide fluctuations apparent during periods of heavy municipal pumping and drought. These fluctuations result in local reversals of flow direction from the presumed regional flow direction (west-northwest). Based on 2003 water level measurements, the lowest water levels were measured between September through November 2003, and the highest water levels were measured between March and May 2003. Table 3-1 summarizes the water level data for the four quarterly events. Table 3-2 includes the most recent water level data for MW08 and surrounding wells collected April 15, 2004. Figures 3-6 through 3-9 present the groundwater potentiometric maps for each zone (U, M and L) during each of the sampling events. Contours in red represent the static water level for the U completions, blue represents the M completions, and green represents the L completions. The regional groundwater flow along the Wasatch Front is generally toward the Great Salt Lake, and in a west-northwest direction at the Site. However, it is apparent that water levels have dropped sharply during the summer and fall months in the upgradient (eastern) unconfined or semiconfined portions of the aquifer. These drops coincide with heavy municipal well pumping, and flow reversals become dominant features (Figure 3-9). However, the area just west of I-15 shows much less of a decline in the upper water-bearing zone during this period and, therefore, is somewhat anomalous and accentuates the flow reversals. A couple of explanations may be that the areas are being recharged by infiltrating irrigation waters from the field between the interstate and the refinery and/or by leakage of the Mill Creek retention pond or drainage ditch. This mounding effect may be accentuated by retention of perched water on a clay lens that becomes fairly continuous in this area within the upper portion of the aquifer.

The horizontal hydraulic gradient at the Site over the RI investigation period ranged from 0.0015 to 0.0053 ft/ft. The greatest range in hydraulic gradient was observed in the upper portion of the aquifer and in the vicinity of the apparent mounding around the Hatchco/Kelly site extending north to MW04U (Figure 3-9). Where the middle and lower zones of the aquifer were tested, the horizontal gradient ranged on the order of 0.001 to 0.002 ft/ft. The hydraulic gradient was calculated using:

$$dH/dL = (h_1 - h_2) / L$$

Where:

dH/dL = hydraulic gradient
$h_1 - h_2$ = difference in hydraulic head
L = distance along the flow path

Vertical hydraulic gradients from each of the multi-port BarCad® MWs were also calculated and reported for each sampling event (Table 3-3). A significant amount of variation was evident across the Site, from upgradient unconfined to confined artesian conditions, and over the seasonal sampling periods. The head difference between the upper and middle zones generally showed the greatest separations ranging from an upward -11.33 feet (artesian) to a downward 3.12 ft (recharge). Corresponding vertical gradients ranged from an upward -0.15 ft/ft to a downward 0.11 ft/ft. The middle to lower zone yielded vertical gradients from -0.03 to 0.01 ft/ft. Seasonal fluctuations in some cases indicated reversal of the vertical flow directions during drops in water levels (MW02).

An aquifer slug test was conducted on BK01U during the last Phase 2 field effort (January 2004). The two other upgradient conventional MWs were not analyzed due to inaccessible conditions (i.e., snow and ice during the sampling event). The K measurement for BK01 (rising head slug test) at 1.99×10^{-2} centimeters per second (cm/sec) was determined by using Aquifer Win32 analytical solution and the theoretical log-linear relationship predicted by Bouwer and Rice 1976 (Appendix B). The K values in literature for a mixture of gravel, sand, and silt, range from 10^{-3} to 10^{-1} cm/sec (Fetter 1988). Additional analyses of hydraulic conductivities were conducted using the grain size analyses from the geotechnical samples collected during rotosonic drilling operations from most of the BarCad® completion zones, or adjacent transmissive units. These data were entered into the software package, SOILPROP™ Version 2.1, which estimates hydraulic properties from particle size distribution. These data are also included in Appendix B. From the 25 geotechnical samples representing saturated permeable aquifer zones, the average K value calculated was 5.97×10^{-1} cm/sec. These hydraulic conductivities represent the most permeable (preferential flow) units within a vertical sequence containing abundant interbedded silt, clay, and poorly sorted debris deposits, having a much lower permeability.

Using the moderately high K value of 1.99×10^{-2} cm/sec from the slug test and nearby municipal well pump test data, and assuming an effective porosity ranging from 0.1 to 0.25 based on literature values for a mixture of gravel, sand, and silt, the average linear groundwater velocity ranges were calculated. Results ranged from 0.34 to 2.98 feet per day (ft/day) for the variations observed in horizontal gradients and flow directions across the Site (Figures 3-6 through 3-9).

The average linear velocity was calculated using:

$$v_x = K\,(dH/dL)/n_e$$

Where:

v_x = average linear groundwater velocity parallel to groundwater flow
K = hydraulic conductivity
n_e = effective porosity
dH/dL = horizontal hydraulic gradient

3.1.3 Meteorology and Climate

Mean annual precipitation in Bountiful is 23.57 inches (in). The months having the highest and lowest average precipitation are May and July, with 3.22 in and 0.96 in, respectively. Average ambient temperatures in Bountiful range from 88.1 degrees Fahrenheit (°F) in July to 22.3°F in January. Climatological data were obtained from the Western Regional Climate Center (2002).

Although the period of the RI has been over a general drought, water levels have shown fluctuations that may be related to spring recharge events and low precipitation. However, sharp declines in water levels are very apparent when nearby municipal wells are brought online or pumping rates increase to supplement the water supply. Figure 3-10 shows a correlation of municipal (Bountiful Shop Well) pumping events with hydrographs produced from continuous water level data collected in the upgradient wells, MW06, MW07, and BK01U. In-Situ™ (miniTroll) transducer/data loggers were installed in each of these wells during the collection of

May 2003 synoptic round water level data and have collected readings on an hourly basis since installation. The most dramatic drop in water level occurred shortly after the Bountiful Shop Well came online after being shut down for the winter and spring months. Potentiometric maps for the upper aquifer zone also show the areal affects of this phenomenon through December 2003 (Figures 3-6 to 3-9). The actual water level contours mimic the area of influence delineated by the Zone 3 simulation (see Appendix G) of the Bountiful Shop Well (Bountiful City 1995). More impacts on the effects of municipal well pumping are discussed in Section 5.1.

Wind patterns for the Salt Lake area are in a north-northwest to south-southeast line, parallel to the Wasatch Range, with roughly equal frequencies from both directions (UDEQ 1997). However, outdoor air monitoring has not been identified a concern at this Site.

3.2 Demographics and Land Use

The Site is bounded by private residences and agricultural land on the west, commercial properties and residences to the south, residential properties to the north, and mostly commercial/residential properties progressively further east. Industrial sites, largely defined by the Holly Refinery, railroad tracks, and I-15 constitute the central portion of the Site (Figure 1-2).

3.3 Site Conceptual Model

A conceptual model of the Site is depicted in a schematic three-dimensional representation (Figure 3-1). The study area contains two distinct physiographic units. The eastern unit is composed of the oldest exposed bench (or terrace) formed by Pleistocene Lake Bonneville and occupies the highest topographic portion of the model. The second unit is a valley-lowland plain with minor topographic relief that extends from the edge of the bench to the shores of Great Salt Lake. The creek depicted in the figure is actually Mill Creek, which drains the bench area just south of the BFC/DEP study area (SA-4) and then is diverted north around the petroleum refinery as it enters the lowland plain. In general, these mountain-front streams are sources of recharge (losing streams) over the bench areas and at some point become discharge points (gaining streams) in the lowland plain. Mill Creek is concrete-lined in long sections and contains various flow control structures along and outside the study area (i.e., retention pond where it passes under the interstate highway). Some evidence indicates that there may be leakage from these structures where creek water is recharging the shallow aquifer just west of I-15 as indicated by the mounding effect. Irrigation of a large alfalfa field between the refinery and I-15 may also contribute to the mounding effect.

Below the benches, the aquifer system is composed of either poorly sorted and only slightly permeable mudflow deposits or coarse-grained and more permeable stream channel deposits. Further from the mountain front and over the lowland plain, the sediments consist of alternating layers of gravel, sand, and clay. Unconfined parts of the aquifer system are generally present as lateral extensions of the confined aquifers upgradient, where confining clays are thin or absent (Clark et al. 1990). Stratigraphic correlations conducted from the deeper Phase 2 borings support this statement (Figures 3-3 and 3-4). Where water table conditions exist in unconfined portions of the aquifer, a significant cone of depression is likely to exist around pumping municipal drinking water wells located upgradient.

The Warm Springs Fault runs through the west-central portion of the Site where the shallow aquifer zones are offset, and consequently where numerous springs and seeps occur at the surface. Near the fault and west towards the Great Salt Lake, the shallow aquifer is under sufficient confining pressures to reverse the downward vertical gradient; wells completed in the shallow aquifer including those in the first groundwater zone are artesian.

To date, the field investigation has gathered limited stratigraphic information from eight borings including six which reach close to the base of the shallow East Shore Aquifer). PCE concentrations from the multi-port MWs can be used in conjunction with the inferred depths of the domestic wells to delineate the extent of the plume with some degree of confidence (Section 5).

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Section 4
Analytical Results and QA/QC Requirements

This section provides an overview of the samples collected and analytical results. It also includes an explanation of the QA/QC field samples, various laboratory programs, a summary of the data validation/evaluation, and achievement of the data quality objectives. All custody and documentation for field and CLP laboratory work was conducted in accordance with the final SAP addendum (CDM 2002b) using Forms II Lite software and tracking forms.

Appendix C includes analytical data summary tables for each of the four quarterly groundwater sampling events and the 950 West investigation, along with associated water level measurements (if applicable). Appendix D includes the data validation reports for all CLP analyses and the evaluation forms, including the qualified Form-1 summaries. Appendix E contains the chain-of-custody forms and Appendix F contains a copy of the field data sheets.

4.1 Study Area 1 – Downgradient of BFC/DEP Source

The portion of the Site centered on BFC/DEP had the highest PCE concentrations (264 μg/L for mobile laboratory analysis and 400 μg/L for a split sample sent to a CLP laboratory) in shallow groundwater during the 2002 Phase 1 investigation. Although reductions in PCE concentrations were observed in groundwater samples immediately surrounding the BFC/DEP source area, PCE concentrations above 5 μg/L, the federal MCL, were still detected in shallow groundwater samples and a few deep domestic wells at least one mile downgradient of the source. Downgradient detections of PCE correspond to the west-northwest direction of regional groundwater flow (Section 5). Because the source(s) for this deeper zone of primarily PCE contamination could not be confirmed from the Phase 1 data, an important focus of the Phase 2 RI was to profile deeper portions of the aquifer along the regional groundwater flow path.

The aquifer zones downgradient of the BCF/DEP source area that were evaluated during Phase 2 include the U, M, and L zones within the shallow East Shore Aquifer. The RI maps included herein that present analytical results are color coded to represent each zone. All U zones are coded with red. Blue is used to represent the M zone, and green is used to represent the L zone (Figures 4-1 through 4-9).

Four quarterly groundwater sampling events were completed during Phase 2 of the RI. The primary contaminant detected was PCE, with minor occurrences of TCE and cis-1,2-dichloroethene (cis-1,2 DCE). The first synoptic water level measurements were collected in May 2003 after completion of the well program surveying. Synoptic water levels were subsequently collected during each of the remaining quarterly sampling events. Figures 4-1 through 4-5 show the variation in the PCE concentration and static groundwater elevation for each round of sampling (depicting each of the three BarCad® completion zones in color code). Each figure represents one multi-port MW location. It should be noted that the first round of data represent different time periods (i.e., March for groundwater sampling and May for water levels). Table 4-1 is a summary of PCE concentrations and its degradation compounds in groundwater from all MWs and domestic wells sampled in SA-1.

A significant decrease in PCE concentrations was observed during June 2003 in all wells with detections above 10 μg/L observed during March 2003. The decrease in concentrations occurred during a period where there was a marked drop in water levels. When water levels stabilized, even though still at lower levels, the concentrations of PCE generally increased as observed in September 2003 and December 2003. It can also be seen that the higher concentrations of PCE migrate downward from the upper (red) zone to the middle (blue) and lower (green) zones along the regional flow trend to the west from MW05 to MW01 (Figure 4-6). PCE and degradation compound concentrations for the three subsequent quarterly events are depicted in Figures 4-7 through 4-9.

4.2 Study Area 2 – Upgradient of BFC/DEP Source

Two conventional wells, MW06 and MW07, were installed upgradient of the BFC/DEP source area as part of the Phase 2 investigation. MW06 was drilled adjacent to and immediately downgradient of the NTF Cleaners to test for any potential source of PCE contamination reaching the groundwater. This MW was completed in the upper portion of the shallow aquifer with a screen interval between 120 and 140 ft bgs. MW07 was drilled between low level PCE contamination detected upgradient of the BFC/DEP source area and the nearby Bountiful Shop Well, which is used as a municipal drinking water supply. MW07 was completed with a screen interval between 112 and 122 ft bgs (Appendix A). These two MWs, and site background well BK01U were retrofitted with data loggers to monitor water levels on a continuous basis. These water levels were compared to pumping rates from the Bountiful Shop Well. Groundwater flow reversals have been apparent in this area resulting from cones of depression developed from heavy pumping of municipal water supply wells.

Figure 3-10 shows the rapid drop in water levels about mid-June 2003. This distinct decline in the water table coincides with records from the Bountiful Shop Well that report that during June 2003, the municipal well came back online. The Bountiful Shop Well had been down January through May 2003. June discharge from the Bountiful Shop Well was approximately 18,000,000 gallons (317 hours run at an average of 950 gpm). For the remainder of the summer and fall months, the discharge was approximately 30.5 million gallons, until December 2003 when the well was taken offline. Pumping in the Bountiful Shop Well resumed again in March 2004 at a rate of 1,027 gpm. The potentiometric maps for the upper aquifer zone (Figures 3-6 to 3-9) also demonstrate the local effects of this pumping by the flow reversals and increasing gradients developing over time.

Table 4-2 presents the results of PCE and other CAHs in the upgradient MWs within SA-2. Samples from all three MWs contained nondetectable concentrations of PCE during March, June, and December 2003. Very low concentrations of PCE, TCE, and cis-1,2- DCE, all below MCLs, were detected during September 2003. These results occurred when the lowest water levels were measured and flow reversals were apparent. It should be noted that method blank PCE contamination was also associated with these samples and the reported PCE concentrations (2.1µg/L [B_ J] and 0.035Jµg/L) for MW06U were qualified as estimated. However, the data were not rejected.

Figures 4-6 through 4-9 summarize all PCE and degradation compounds detected in each quarterly groundwater sampling round both upgradient and downgradient from the BFC/DEP.

4.3 Study Area 3 – 950 West

SA-3 was the only sampling that involved collecting and analyzing soils during the Phase 2 investigation. Appendix C contains a summary table detailing all of the analytical results for groundwater and soil samples with detected VOCs highlighted.

The analytical results from SA-3 (see Figures 4-10 through 4-13) were evaluated to determine if existing soil and groundwater contamination detected in the 950 West area is related to another plume separate from the OU1 Hatcho plume. TCE was the dominant contaminant with an abundance of degradation compounds including vinyl chloride. The specific media under investigation was the shallow upper groundwater approximately 20 ft bgs downgradient of the Hatchco/Kelly property and crossgradient to OU2. In addition to the Hatcho/Kelly source area, there is evidence that another source may exist in the vicinity of the Jensen Automotive auto body shop located at 500 South and 950 West. The data show continuity of CAH contamination from Hatchco/Kelly through SA-3. However, an order of magnitude increase in TCE concentrations was observed surrounding the auto shop. The highest concentration of total CAHs, 1,693 µg/L, was detected immediately west (downgradient) of the building. Further, high concentrations of total CAHs surround the building. Conversely, results from vadose zone soil sampling conducted on 50-ft centers on and adjacent to the property were predominately nondetect for TCE. The single exception was one location on the northwest side of the auto shop building, DP14, that had a very low TCE detection of 0.9 µg/Kg in the shallow soil. The most probable location of any source of CAHs is directly under the building; however, this has not been substantiated.

Figure 4-10 presents all shallow DPT vadose zone grab sample locations with TCE detections. Figure 4-11 shows a similar base map with each of the groundwater DPT sample locations with color coded results. Figures 4-12 and 4-13 break out the degradation compounds associated with TCE groundwater contamination and total CAHs, respectively.

Based on documented or known groundwater flow directions, supported by the Hatchco/Kelly RI report, this contaminant plume appears to be contributing to persistent detections of TCE and other CAHs as measured in the shallow refinery MWs 2S/2D and 3S during earlier stages of the investigation by UDEQ (UDEQ 1999).

In addition to CAHs in groundwater, methyl tert-butyl ether (MTBE) was detected at 1 to 13 milligrams per liter (mg/L) from MW03U and SA-3 (DP27, 34, and 40) in the shallow groundwater. MTBE concentrations were so high that numerous dilutions were required for samples from MW03U which resulted in masking of the CAHs due to biased low concentrations, as noted in the March 2003 results (Appendix D). The MTBE contamination is also co-mingled with the Hatchco OU1 groundwater contaminant plume and was identified along the southern boundary of the Holly Refinery in WPH01, 08, 09, 10, and 17 during the Phase 1 investigation (CDM 2002a). The MTBE occurrence is also mentioned in the Hatchco/Kelly RI report (HDR 2003a). Figure 4-14 shows all locations where MTBE was detected along with concentrations, if known.

4.4 MW08 and Bureau of Reclamation Sampling

During the week of April 12, 2004, field work in support of the OU2 RI continued with additional sampling efforts by CDM and the Bureau of Reclamation (BOR). The sampling effort was designed to help close some data gaps along the southern extent of the Site. Due to potentiometric maps indicating a local groundwater mound in the vicinity of the Hatcho site and Mill Creek west of I-15, questions remained concerning the limits of CAH contamination to the south and east of the Hatcho OU1 plume. The BOR was scoped by EPA to test the shallow groundwater aquifer underlying the residential area along 770 South using cone penetrometer technology (CPT). CDM collected the groundwater grab samples accessed by CPT and shipped them for CLP analysis along with MW08 samples. Results are reported in Appendix C. The shallow groundwater samples yielded very little, if any, CAH contamination and helped verify previously established plume boundaries.

MW08 results also yielded important information for establishing the southern boundary of the OU2 PCE plume. The only concentration above MCLs for PCE was the sample collected from the middle zone, 04B-SA01-MW08M-GW-001, measuring 8.8 μg/L.

Water levels were measured in all aquifer zones of MW08 and surrounding MWs (Table 3-3). A three-point slope analysis for wells MW08M, MW05M, and MW04M yielded a horizontal gradient of 0.0015 ft/ft in a southwest direction which fits previous potentiometric surface maps.

The BOR travel report detailing the sampling event as well as the CPT stratigraphy logs are included in Appendix H. Locations for the sampling points are shown in Figure 4-14.

4.5 QA/QC Samples

Three types of QA/QC samples were collected: duplicate samples, equipment rinsate blanks, and trip blanks. Duplicate samples were to be collected at a frequency of one per 10 (10%) and equipment rinsate collection frequencies were planned a rate of at least one per 20 samples (5%). Trip blanks were planned at rate of one per cooler that contained samples requiring VOC analyses.

4.5.1 Duplicate Samples

Field precision objectives were assessed through the collection and analysis of field duplicate samples, which were submitted to the laboratory. A total of 97 groundwater samples (not including QA/QC samples) were collected by CDM during this investigation. Groundwater samples were also collected by state personnel and analyzed with the CDM-collected samples but these are not included in this evaluation. Of the 97 samples collected by CDM, all were analyzed for VOCs and 29 were analyzed for natural attenuation parameters. Fourteen duplicates were analyzed for VOCs and four duplicates were analyzed for natural attenuation parameters. This resulted in a duplicate collection frequency of 14.4% for VOCs and 13.8% for natural attenuation parameters. This increased frequency (75%) was necessary to provide adequate assessment of precision for each sampling event.

When comparing duplicate sample results, the first step was to determine if either sample result was nondetect (i.e., not detected at a concentration above the reporting limit [RL]). If either sample result was nondetect for an analyte, no further evaluation could be conducted for that analyte in that set of paired sample results because at least one of the results had no value and, therefore, comparability could not be determined. Also, if a sample result was rejected for an analyte during data validation, the result for that analyte in that sample would have no value and, therefore, no further evaluation was conducted.

If both results had values for an analyte (i.e., neither was nondetect or rejected), the next step was to employ one of two calculations. These two calculations were to determine the difference between the results and/or the relative percent difference (RPD). For these types of criteria, guidance was taken from the SAP and SAP addendum for this investigation (CDM 2002c and 2002b, respectively). If an analyte was detected in both of the paired samples and either result was less than five times the RL, the absolute difference between the samples was calculated. If the absolute difference was greater than twice the lowest RL, four times for soils, the samples were considered not comparable and were flagged “A”.

If both sample results were greater than five times the RL or if the reporting limit was not provided by the laboratory, the RPD was calculated. The RPD was calculated using the following equation:

$$RPD = \frac{|S - D|}{(S + D) \div 2} \ *100$$

Where S = first sample value (original value)
D = second sample value (duplicate value)

Based on requirements specified in the approved SAP and SAP addendum, if calculated, the RPD should have a value of less than or equal to 35 % (50 % for soils) for the results to be considered comparable. If an RPD exceeded this value, the results were considered not comparable and were flagged “P“.

There were a total of 926 paired sample results evaluated. Of these 926 paired results, 829 (i.e., approximately 90%) had at least one of the results reported as nondetect. Nine of the paired sample results were flagged based on the above criteria (no soil paired results exceeded criteria). Therefore, out of all the paired sample results, approximately 1% were flagged (i.e., not comparable). The results of the nine paired samples, as indicated in the table, are determined to be incomparable and, therefore, should be considered estimated. Of those 9 paired samples, 5 were flagged based on calculations that yielded an RPD value greater than 35 percent. The remaining 4 samples were flagged because the absolute difference was greater than twice the lowest reporting limit.

It should be noted that one of the sample results in three of the paired samples was qualified with an “E” by the laboratory. This qualifier indicates that those results were outside the calibration range and, therefore, should not be used at face value but should be an indicator of a high concentration for RPD. Since at least one of the results for each of these three pairs is considered an estimated value (i.e., the value not qualified with an “E” should be used), it is not important that these pairs of results were considered not comparable. Minimal numbers of paired results considered not comparable (i.e., approximately 1%) resulted in, the achievement of the data quality objectives because the data flagged during the duplicate comparison are considered usable.

4.5.2 Blank Samples

Two equipment rinsate blanks were collected for the 160 groundwater samples. The low number was due to most of the groundwater sample equipment being either disposable or dedicated. Specifically, dedicated sampling equipment was employed for the quarterly groundwater sampling and Phase 2 sampling in SA-1 and SA-2. In addition to the two equipment rinsate blanks being collected for groundwater samples, two equipment rinsate blanks were collected for the 33 soil samples.

A total of 21 trip blanks were collected for 22 coolers shipped off site to analytical laboratories. As noted in the SAP modification section (Section 4.6), trip blanks were not collected for the soil samples at SA-3. This lack of collection occurred because only a CLP laboratory for soil samples analysis was provided. Therefore, there was no CLP laboratory for water analysis (i.e., trip blanks are aqueous).

During the data validation/evaluation process, the detections in these blanks were used to qualify associated data, if applicable. Sample results may have been qualified as estimated (J/UJ) based on trip blank results or nondetect (U) based on rinsate blank results. Because minimal detections were observed in either type of blanks, very few sample results were qualified based on these two field blank types. For further detail regarding the blank results, Appendix D includes all the data validation/evaluation reports.

4.6 Data Validation/Evaluation

In accordance with the procedures outlined in the approved SAP and SAP addendum for these sampling events, at least 10 percent of all VOC data were validated. Also, the remaining samples in several data packages were evaluated (i.e., partial validation). The natural attenuation data were not validated or evaluated for usability but the data packages were reviewed for completeness. The data validation and evaluation reports are provided in Appendix D. Included with these reports are copies of the original data with validation/evaluation qualifiers. Table 4-4 provides a list of sample delivery groups (SDGs) that were validated/evaluated.

Data validation was performed in accordance with the *USEPA Contract Laboratory Program National Functional Guidelines for Low Concentration Organic Data Review* dated June 2001, or *USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review* dated October 1999, whichever was applicable. Evaluation of data also used guidance from these documents.

Data evaluation was a partial validation which only reviewed:

- Holding times
- Preservation
- Matrix Spike/matrix spike duplicates
- Surrogates (i.e., system and deuterated monitoring compounds)
- Blanks

An approved CDM data validator performed all sample validation/evaluation. A summary of all validation/evaluation actions (i.e., qualifications) are presented in Table 4-5.

Laboratory data were qualified during the data validation/evaluation process using a standardized set of qualifiers:

Data Qualifier	Description
U	The material was analyzed for but not detected above the level of the associated value. The associated value is either the sample quantification limit or the sample detection limit.
UJ	The material was analyzed for but not detected. The associated value is an estimate and may be inaccurate or imprecise.
J	The associated value was an estimated quantity.
R	The data were rejected.

Analytical data quality was assessed through the data validation/evaluation process. All data that were not rejected were determined usable for their intended purpose. The only results that were rejected were several acetone, 2-butanone, and methyl acetate results for groundwater. These results are, therefore, unusable. These results were rejected based on initial calibration, continuing calibration, and/or deuterated monitoring compounds results that were not acceptable. Because acetone, 2-butanone, and methyl acetate are not primary analytes of interest at the Site, and there were minimal rejections based on the overall number of results, the data set is determined to be complete.

Several results were also qualified as nondetect "U" during validation/evaluation. These analytes are listed in Table 4-5. Again, most of these analytes are not considered COPCs or degradation products of PCE. There were TCE and PCE results that were determined nondetect but the concentrations noted were below reporting limits and, therefore, do not affect the outcome of the investigation. Numerous sample results for both aqueous and soil samples were qualified as estimated (J/UJ) due to initial and continuing calibration criteria, deuterated monitoring compounds, and/or internal standards. A summary of these analytes and qualifications are listed in Table 4-5.

In conclusion, the data set for this investigation is usable for the intended purpose except for the few results that were rejected. This data set has also met the completeness goal for this project and provides the information necessary to achieve the data quality objectives.

4.7 Modifications to the SAP Addendum – Phase 2

The following modifications to the SAP addendum – Phase 2 (CDM 2002b) resulted in the changes listed below:

- Sulfate and chloride analysis (SAP addendum Table 4-1) - The subcontracted analytical laboratory for natural attenuation parameter analyses requested minor changes in the analytical methods listed in the SAP addendum. One method change was for sulfate and chloride from EPA method 300.0 to standard method SM 4500. The project chemist granted the change to the turbidimetric method after a determination that there was no detrimental impact to the data quality. EPA was notified of the modification.

- Sulfate analysis (SAP addendum – Phase 2 Table 4-1) - One set of samples (December 2003) was not analyzed for sulfate. This oversight occurred because the Forms II Lite chain-of-custody (COC) left out the definition of wet chemistry analyses required in the delivery order (DO) and the laboratory did not back reference the DO. Because the impact was determined to be minimal, no further corrective action was taken.

- Shelby tubes (SAP addendum – Phase 2 Table 4-1) - Shelby tubes were to be used in sampling for triaxial permeability and porosity determination (EPA 9100 and ASTM D5084). The geological conditions did not allow for effective use of these thin-walled samplers. Each time samples were attempted to be collected from potential completion intervals, the Shelby tubes crumpled and undisturbed samples were not able to be obtained. The two proposed geotechnical methods noted above were deleted from the analytical protocol at the decision of the project manager with no detrimental project impacts. Instead, the samples for grain size analyses were obtained from the rotosonic core at representative completion intervals. These samples were evaluated for particle size distribution and the data entered into SOILPROP™ software for estimation of hydraulic conductivity (Appendix B).

- Slug tests (SAP addendum – Phase 2 Section 4.7) - BK01U was the only upgradient MW that was accessible for slug testing during January 2004. MW06U and MW07 were initially planned, but both were located on asphalt covered with ice and snow. Because testing would require an additional mobilization and supplies would have to be reacquired, a determination was made by the project manager to cancel the tests. Data quality and achievement of data quality objectives was not affected by the decision.

- Equipment rinsate blanks (SAP Section 6.5.1.2) - ASTM Type I water was used to prepare all equipment rinsate blanks instead of Type II. This type of water is run through activated carbon prior to attainment as opposed to Type II water specified in the SAP. The chemical supply house recommended that this deionized (DI) water be used because it would have potentially fewer organic contaminants. This modification was discussed with and approved by EPA prior to implementation.

- Trip blanks (SAP Section 6.5.1.3) - Trip blanks were prepared using the same DI water as described above and were preserved with hydrochloric acid. Trip blanks were only used for aqueous CLP samples (i.e., shipped in each cooler containing samples for VOC analysis), instead of both aqueous and solid media samples.

4.8 Achievement of Data Quality Objectives

Table 4-6 presents a summary of the DQO from the SAP Addendum – Phase 2 (CDM

2002b) and includes text describing how and if DQOs were achieved.

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Section 5
Nature and Extent of Contamination

5.1 OU2 Plume Delineation

The stratigraphic correlations and hydraulic vertical gradients discussed in Section 3 support the premise that dense non-aqueous phase liquid (DNAPL) contaminants released to the environment below the BFC/DEP source area have a pathway to reach significantly lower portions of the East Shore Aquifer downgradient of the source. Under the BFC/DEP source area, the aquifer system is composed of discontinuous clay lenses, mudflow deposits (poorly sorted and only slightly permeable), and stream channel deposits (coarse-grained and highly permeable). Further to the west, over the lowland plain, the subsurface strata consist of alternating layers of gravel, sand, and clay. Unconfined portions of the aquifer system, especially where Mill Creek alluvium is present, are generally lateral extensions of the confined aquifers upgradient. Here, downward migrating contaminants, due to either specific gravity or recharge dominated hydraulic components can then potentially migrate laterally to the confined aquifer units and be picked up by domestic wells.

In general, the PCE contamination in the upper zone of the aquifer is well delineated by the earlier Phase 1 investigation (CDM 2002a). Figure 5-1 depicts the shallow (upper zone) PCE plume clearly indicating the highest levels of contamination (>100 ug/L) centered on the BFC/DEP. Analytical results from the Phase 2 multi-port BarCad® MWs constructed along the general east-west axis of the shallow plume support the Phase 1 shallow PCE contaminant levels as described in Section 4.2. In addition, these data points confirm decreasing levels of PCE in the upper portion of the shallow aquifer from east to west away from the BFC/DEP source area. The PCE contamination is virtually absent in the upper zone from the Warm Springs Fault west. The middle and lower portions of the shallow aquifer, on the other hand, demonstrate increasing concentrations of PCE to the west as the contaminant migrates vertically where it then moves laterally within the middle and lower confined artesian aquifer zones as evidenced in numerous domestic wells in the vicinity of 1100 West.

Figure 5-1 shows lines of isoconcentration values for PCE in each of the three zones by color code (U- red, M – blue, and L – green). The outer boundary of each plume level is depicted by an isoconcentration contour of 1 µg/L. The second isoconcentration contour represents the MCL concentration for PCE (5 µg/L). Additional isoconcentration contours represent the 50 µg/L, 100 µg/L, and 200 µg/L observed in the shallowest portion of the aquifer at the BFC/DEP. Although PCE is the focus of the contaminant plume, TCE and other degradation compounds were detected in shallow groundwater at significant levels above MCLs at two locations, BFC05 and BFC17. These locations are centered on the BFC/DEP source area and have also detected levels of BTEX compounds in the soil and groundwater. The localized TCE results may be due to a small cell of hydrocarbon (BTEX) electron donor in the soil and groundwater, initiating a PCE degradation pathway. Very little, if any, migration of the degradation compounds has been observed in combination with the OU2 PCE plume. This is likely due to dilution of these compounds outside of the hydrocarbon (election donor) source area.

The extent of the PCE plume is also fairly well defined in the lower zone by analyses at domestic wells DW01, DW07, DW15, and DW24. However, the potential still exists that the contaminated middle zone may extend further to the west and is thus inferred by using a dashed line on the plume map. The extent of the plume as defined by the furthest detected value of PCE, is approximately 1.6 miles west-northwest from the BFC/DEP source. This direction matches the regional groundwater flow. Using an average flow rate of 1.66 ft/day, based on average linear velocities calculated in Section 3, advection travel times would take a minimum of 14.3 years to reach this point, discounting mobility and retardation factors and seasonal groundwater gradient changes that would increased the overall travel time.

As can be seen in Figure 5-1, the southern boundary of the plume has not been clearly defined. This data gap has been partially addressed by the installation of another BarCad® well system MW08U-M-L located southwest of the I-15 and 500 South interchange. This location is directly between the OU1 Hatchco/Kelly property and the BFC/DEP. Analytical data from this BarCad® well system sampled on April 15, 2004 provides important hydraulic gradient and chemical data from each aquifer zone. The data more accurately define the southern boundary of the PCE plume and indicate that influence from the Bountiful Well pumping has limited effects in this area to draw contamination to the south and east. Currently, no groundwater modeling has been planned for this phase of the RI/FS.

Secondary to delineating the OU2 PCE plume, elevated levels of MTBE (maximum 13,000 μg/L in MW03U) were observed in MWs and groundwater grab samples collected along the southern boundary of the Site (SA-1 and SA-3). Figure 4-14 shows the affected wells and/or sample locations. The UDEQ Division of Water Quality, which has access to these data, is currently requesting Holly to conduct a "contaminant investigation" of its Light Oil Dock property. Although MTBE is not the focus of this investigation, a distinct plume extends along the direction of groundwater flow and apparently is slightly north of but co-mingled with the Hatchco CAH plume and extending into SA-3 (See Figure 5-1).

5.2 Additional Sampling – PRP Source Delineation

Releases from the BFC/DEP source area are assumed to have occurred prior to 1980 when recycling disposal practices were not as aggressively employed. However, data to support the time frame for the release were not available for this RI report. Data from MW01 installed by the PRP were incorporated into this RI under the ID of BC01U to match database constraints. This well will be useful for any future monitoring requirements at the Site. However, this well was the only MW installed and sampled for the PRP's source area investigation. The screened portion of the well straddles the uppermost saturated zone; lower sections of the shallow aquifer remain untested. PCE and cis-1,2-DCE were the only detections in BCO1U at concentrations of 88 µg/L and 8.5 µg/L, respectively. The PRP's SAP included two of the CDM Phase 1 temporary 1-inch PVC wells installed by DPT methods. However, the wells were dry because water levels had dropped significantly. These temporary wells were designed for initial screening purposes and were not adequately constructed for groundwater monitoring purposes.

Other samples collected and analyzed by the PRP included shallow soils from 12 borings with a maximum depth of 30 ft. PCE levels of up to 63 micrograms per kilogram (µg/kg) were detected under the BFC building. However, only three such borings were hand-augered to a maximum depth of 11 ft, and one of the major sump areas was not evaluated. At these shallow depths, no DNAPLs were encountered. Further investigation is recommended for determining the nature and extent within the source area (Section 7).

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Section 6
Contaminant Fate and Transport

Fate and transport properties are important for understanding the behavior of COCs at the Site. This section describes the subsurface fate and the mobility of PCE. TCE and *cis*-1,2-DCE are also discussed in this section only as biodegradation byproducts of PCE. An understanding of the fate and transport of PCE is necessary to evaluate future potential exposure risks and to evaluate remedial technologies at the FS stage.

6.1 Contaminant Occurrence

Organic constituents may exist in groundwater as dissolved molecular or ionic species or as non-aqueous phase liquids (NAPLs). Typically, the contaminant (e.g., PCE) at the facility originally existed and was used as a NAPL. The contamination could reach the groundwater by two mechanisms:

- Some of the contaminants can dissolve into infiltrating water that contact the NAPL in the vadose zone.

- Continued disposal/release can result in enough NAPL to exceed the capillary forces and specific retention capacity of the soil and move into the saturated zone as NAPL. At the saturated zone, the contaminants start to dissolve into the groundwater. The NAPL would continue to move downward or would float on the water depending on soil characteristics and density and quantity of the NAPL.

DNAPLs exist in the soil/aquifer matrix as dissolved, free phase, and/or residual DNAPL. Free phase DNAPL continues to move downward through the soil under the force of gravity or laterally at the interface of high permeability zones underlain by low permeability zones (e.g., gravelly sand over clay beds/lenses) based on capillary pressure. As the free-phase DNAPL moves, some of the DNAPL is trapped in pores and/or fractures by interfacial tension. The DNAPL that remains is termed the residual DNAPL.

The more mobile forms of DNAPLs are the aqueous phases, since they may travel at nearly the same velocity as the groundwater, except as noted in Section 6.3.3. In addition, the aqueous constituents exist as molecular species rather than ionic, since PCE does not have a functional group capable of forming an ionic species. PCE is likely present at the Site both in dissolved and free phase states as a source in subsurface soils, although not yet identified, and in the groundwater plume.

Site investigations designed to find DNAPL are generally impractical and ineffective. The presence of DNAPL should be suspected at sites where chlorinated solvents were typically used and disposed of as immiscible phase, unless historical records can account for waste solvent volume (e.g., recycling, offsite treatment/disposal). Visual observation of DNAPL during the investigation is not required to infer DNAPL presence. As a general rule, detecting chlorinated solvents in groundwater at concentrations exceeding 1% of their solubility (i.e., 1.5 mg/L for PCE) suggests the presence of DNAPL or residuals (Pankow and Cherry 1996). Although these levels have not been identified in the suspected source area to date, only preliminary data are available and the investigation has not been completed (Bowen Collins & Associates 2004).

6.2 Contaminant Transport

Contaminant transport pathways provide the mechanisms for contamination to travel from its area of deposition and to potentially leave the site. Potential contaminant transport pathways include:

- Volatilization of VOCs into the air
- Groundwater flow off site
- Vertical infiltration of free phase chemicals into the unconfined and/or semiconfined aquifer(s)
- Discharge of contaminated groundwater to downgradient surface water bodies
- Rainwater flow through contaminated soils with subsequent flushing and dissolution into the deeper vadose zone and aquifer matrix

Factors such as topography, geology, hydrogeology, and groundwater flow influence the movement of contaminants in the subsurface, as contaminants migrate through the vadose zone into and with the groundwater. These contaminant transport pathways are described further in the site conceptual model presented in Section 3.3. Solute and immiscible contaminant transport is discussed in this section and volatilization is detailed in Section 6.3.2. Several physical processes control contaminant movement in a dissolved state within the groundwater. Processes that impact contaminant concentration include advection/dispersion and dilution, as described in the paragraphs below.

Advection

Advection is the transport of solute at an average groundwater velocity. The average linear velocity of groundwater through a porous aquifer is determined by the hydraulic conductivity, effective porosity of the aquifer formation, and hydraulic gradient (Freeze and Cherry 1979). The velocity of a contaminant in the groundwater can be decreased if there is precipitation/dissolution or partitioning of the contaminant into other media (e.g., adsorption, volatilization). These physio-chemical processes are discussed in Section 6.3. The topography of the Site, in addition to the complex groundwater flow paths, also impact groundwater velocity and gradients.

Dispersion

The study of dispersion at a site is important to determine the concentration of a contaminant and the time it will take to reach a specific location (e.g., a drinking water well). In other words, dispersion of a contaminant affects the velocity and spatial distribution of a contaminant. Although the above discussion implies one-dimensional dispersion, in actuality, dispersion is three dimensional (i.e., longitudinal, transverse, and vertical). The longitudinal and transverse dispersion coefficient are affected primarily by aquifer heterogeneity, whereas, the vertical dispersion is also affected by the density of the contaminant. Because PCE is denser than water, it has a tendency to migrate vertically faster than many other contaminants.

Dilution

Dilution is an effect of dispersion. When contaminants come in contact with uncontaminated groundwater, mixing occurs, resulting in a decrease in contaminant concentration. Rainwater precipitation can also cause dilution of contaminant concentrations.

6.2.1 Transport of Contaminants in the Vadose Zone

The vadose zone is that portion of the soil between the ground surface and the water table and includes the capillary fringe. Because it is part of the overall flow path, this zone can be very important regarding the migration of contaminants. The vadose zone often contains greater amounts of organic substances (e.g., organic carbon) and metal oxides than the saturated zone. Contaminants can adsorb onto these materials, making their rate of movement substantially less than in the saturated zone. Also, contaminants adhering to materials in the vadose zone may act as future sources of groundwater contamination, even after remediation of groundwater. Finally, the unsaturated zone may be a pathway for volatilized organic compounds (discussed in Section 6.3.1).

PCE can be transported in the vadose zone by two major mechanisms:

- Infiltration (either as DNAPL or dissolved within percolating water)
- Vapor diffusion

The rate of PCE vadose zone transport via either of these mechanisms is highly dependent on the characteristics of the vadose zone matrix (e.g., organic carbon content, permeability, moisture content).

Infiltration

During and after rainwater precipitation, uncontaminated water can infiltrate through the vadose zone and interact with contaminated source soils and dissolve PCE into the infiltrating water. This infiltration allows the PCE to migrate with the rainwater to the water table to add to the groundwater contamination. PCE may also be transported in a free phase. The three major forces that affect free phase transport in the vadose zone include pressure due to gravity, capillary pressure, and hydrodynamic pressure. Gravity forces promote the downward migration of PCE. The fluid pressure exerted at the base of a DNAPL body due to gravity is proportional to the absolute DNAPL (e.g., PCE) density in the vadose zone and the DNAPL body height. The gravity force that drives DNAPL flow is greater in the vadose zone than in the saturated zone and increases with depth within a DNAPL body. Capillary force, however, resists the migration of free phase DNAPL from larger to smaller pore space, inhibiting the downward migration of PCE. Therefore, PCE migration occurs where driving forces such as gravity exceed the restricting forces such as capillary pressure. In most instances, gravity causes PCE to migrate downward through the vadose zone accompanied by lateral spreading of the PCE due to the effects of capillary forces causing preferential flow paths along zones of higher porosity.

Vapor Diffusion

PCE, either adsorbed to the soil particles or dissolved within the interstitial water, will partition into the open pore space (i.e., the pore space not filled with interstitial water) as a vapor. The gaseous PCE will then move through the vadose zone due to PCE vapor concentration gradients between the source region and adjacent regions. This movement is due to diffusion, as described by Fick's Law, and barometric pumping, atmospheric air movement into and out of the vadose zone due to barometric pressure changes.

6.3 Contaminant Fate

The fate of organic chemicals in the subsurface environment is affected by a variety of physico-chemical and biological processes. These processes or mechanisms include hydrolysis, oxidation, photolysis, volatilization, sorption, and biodegradation.

6.3.1 Significance of Environmental Fate

The type and importance of various processes affecting the environmental fate of chemicals in groundwater depend upon the specific chemicals and site conditions. The importance of each process specific to PCE at the site is summarized in general terms in the following table:

Significance of Environmental Fate for PCE at the Site

Process	Not Important	Probably Not Important	May Be Important Depending Upon Site Conditions	Should be Considered as Important
Hydrolysis		X		
Oxidation		X		

Process	Not Important	Probably Not Important	May Be Important Depending Upon Site Conditions	Should be Considered as Important
Photolysis	X			
Volatilization			X	
Adsorption				X
Biodegradation			X	

Based on the above evaluation, adsorption and biodegradation of PCE are the most important environmental fate processes at the Site. In the sections which follow, each of the three most important environmental fate processes are identified and discussed as applicable to the Site.

6.3.2 Volatilization

Volatilization is the process by which a chemical is transferred from soil or water into the air. For this discussion, the COCs are typically at low concentrations (i.e., below saturation) and exist dissolved in the water phase (i.e., minimal free phase liquids). The COCs in the air will exist as gaseous molecules. Depending upon the nature of the chemical and soil, the chemical may also be adsorbed to the soil. Given these environmental conditions, the concentrations of the organic chemical in the soil, water, and air compartments are controlled by the equilibrium processes shown in Figure 6-1. Figure 6-1 depicts two phases in the vadose zone; solid phase and vapor phase. In actuality, the vadose zone consists of three phases; solid, vapor, and aqueous phases. The K_p equation in Figure 6-1 does not take into account the role of the aqueous phase in the vadose zone: The aqueous phase in the vadose zone varies considerably over time in response to infiltration events.

When contamination occurs primarily as dissolved phase in the groundwater, only volatilization at the water table is a significant fate process. The relation between the concentrations in the air and in the free water at equilibrium is described by Henry's law, which states that the concentration of a chemical species in the gas phase is directly proportional to the concentration in the aqueous phase. Henry's law constants are a good measure of a compound's volatility - the higher the Henry's law constant the greater the volatility of the compound. Typically, chemicals with a Henry's law constant greater than 0.005 atmosphere cubic meters (atm-m^3) mole (0.2 dimensionless) partition mostly into air. The Henry's law constant for PCE is 0.01 atm-m^3/mole, which indicates that PCE partitions more into the air than water.

Volatilization of PCE at the Site

In regards to groundwater at the Site, volatilization occurs near the top of the water table. Although volatile, PCE is a DNAPL and, therefore, will be more prone to be near the bottom of the aquifer matrix if it has reached groundwater. Volatilization would be considered minimal except in the dissolved phase at the water table and during migration through the vadose zone. Overall, the process of volatilization occurs at a more rapid rate than hydrolysis or oxidation and may be a major fate process for PCE, especially in the vadose zone. However, in groundwater systems, volatilization is not a significant fate process except near the water table. Volatilization is certainly not a concern where the dissolved phase is in the confined aquifer downgradient.

6.3.3 Adsorption

One of the most important geochemical processes affecting the rate of migration of chemicals dissolved in groundwater is adsorption to and desorption from the solid matrix. If the organic chemical is strongly adsorbed to the solid matrix (i.e., the aquifer material), the chemical is relatively immobile and will not be leached or transported from the source. If the organic chemical is weakly adsorbed, the chemical can be transported large distances from the source, contaminating large quantities of groundwater. The degree of adsorption also affects other transformation reactions such as volatilization, hydrolysis, and biodegradation since these reactions require the chemical to be in the dissolved phase.

The distribution of chemicals between water and the adjoining solid matrix is often described by the soil/water distribution coefficient, K_d. For dissolved chemicals at environmental concentrations, the distribution coefficient is usually defined as the ratio of concentrations in the solid and water phase (Freeze and Cherry 1979). K_d has been shown to be proportional to the fraction of natural organic carbon in the solid matrix, the solubility of the chemical in the aqueous phase and the n-octanol/water partition coefficient (K_{ow}). Classification of a variety of chemicals by K_d is illustrated in Figure 6-2. Retardation factors, described below, and K_d values are site specific. The retardation factor and K_d values shown in Figure 6-2 are intended only to represent the relative mobility of different chemical classes.

A convenient way to express chemical mobility is by use of the retardation factor (R), which is a function of the average velocity of the retarded constituent, velocity of the groundwater, soil bulk density, and total porosity. If $K_d = 0$, the chemical species of concern is not affected by physico-chemical reactions and migrates at the same velocity as the water based on convective-dispersive mechanisms. If $K_d > 0$, the chemical species will be retarded. More accurately, the retardation factor is the average linear velocity of the groundwater divided by the velocity of the contaminant chemical at the point when the chemical concentration is one-half the concentration of the chemical at its source. When K_d equals zero (no adsorption), R equals one (i.e., the chemical and water move at the same velocity). If R equals ten, the contaminant chemicals move at one tenth the velocity of the groundwater. The mobility of chemicals can be classified based on their R value. Typical classifications are illustrated in Figure 6-2.

Overall, adsorption appears to be a major mechanism governing the fate and movement of organics in groundwater.

Adsorption of PCE at the Site

Adsorption of PCE at the Site may be an important process in groundwater. The importance of adsorption depends significantly upon the characteristics of the aquifer matrix material, which acts as the adsorbing medium. In particular, adsorption of hydrophobic organic compounds has been shown to be a function of the amount of natural organic carbon in the aquifer matrix. The COPCs at the Site have a Kd>0 and, therefore, will be adsorbed/retarded to a degree. But, because several factors (eg., organic carbon in aquifer material) are unknown, the actual amount of adsorption/retardation that will occur at the Site cannot be accurately estimated.

6.3.4 Biodegradation and Biotransformation

Degradation or transformation of organic chemicals in the subsurface environment can occur through the action of microorganisms that may be attached to the soil or contained in the void space. Active microbial populations are found in most typical subsurface conditions. Even in low numbers, subsurface microbes possess adequate metabolic activity to reduce the levels of organic compounds migrating through the subsurface soil profiles.

Biodegradation of organic chemicals by microorganisms ultimately produces microbial cells, water, and carbon dioxide (i.e., complete "mineralization"). The enzymes produced by the microorganisms are essentially responsible for the degradation of the organic chemicals. Whether or not a chemical is transformed depends on the microbial population present and the types of enzymes they express.

Typically, biodegradation rates are found to be proportional based on the substrate and microbial numbers. The substrate is defined as the organic compound that provides the bacteria with carbon and energy. However, some organics, termed secondary substrates, do not provide sufficient energy to support growth of the microbial biomass. In this case, a primary substrate must be present. In some cases, the enzymes produced for degradation of the primary substrate also serve to degrade the secondary substrate; this process is termed co-metabolism.

Microbes can facilitate both oxidation and reduction of organics under oxic (i.e., aerobic) or anoxic (i.e., anaerobic) conditions, respectively. A compound is oxidized by losing electrons and is reduced by gaining electrons. Oxidation and reduction reactions are coupled. Two compounds must be present to carry out the reaction. One compound donates electrons (i.e., the electron donor is often referred to as the substrate) and is oxidized and the other compound accepts the electrons (i.e., the electron acceptor) donated by the first and is reduced. Normally, the electron acceptor is an inorganic chemical (e.g., oxygen, nitrate, sulfate, carbon dioxide, etc.) and is not

the primary contaminant. Microorganisms carry out the transfer of electrons from one compound to the other as they break down chemicals for energy and carbon.

Biodegradation of PCE

Research demonstrates that PCE can be biodegraded or biotransformed under specific environmental conditions in the subsurface. The biodegradation of PCE occurs primarily via co-metabolism. For this discussion, co-metabolism is defined as the transformation of a non-growth substrate by growing cells in the presence of a growth substrate, by resting cells in the absence of a growth substrate, or by resting cells in the presence of an energy substrate. This process can occur under both aerobic and anaerobic conditions. Under aerobic conditions, PCE is oxidized and under anaerobic conditions, PCE is used as an electron acceptor and is reduced. The anaerobic reduction is often termed "reductive dechlorination." Reductive dechlorination is not always a co-metabolic process. Recent research has demonstrated that there are also microbes that can actually use PCE as an energy source for growth, which may play an important role in conjunction with the microorganisms that degrade PCE via co-metabolism.

For thermodynamic reasons, microorganisms preferentially utilize those electron acceptors that provide the greatest amount of free energy during respiration (i.e., in order of greatest to least: oxygen, ferric iron, nitrate, sulfate, and carbon dioxide). During biodegradation, microorganisms will facilitate only those redox reactions that yield energy. These redox reactions do not spontaneously occur in groundwater in a relevant timeframe because the initial activation energy requirement is lowered through the use of a catalyst such as a microorganism.

Aerobic Biodegradation of PCE

Numerous microorganism are capable of co-metabolizing PCE under aerobic conditions. Primary substrates such as phenol, toluene, methane, propane, or ammonia must also be present for aerobic co-metabolism, depending on the type of bacteria.

Anaerobic Dechlorination of PCE

While many chlorinated solvents can be degraded aerobically, the anaerobic degradation pathway is much more common in the environment . The anaerobic reductive dechlorination of PCE can be accomplished using numerous electron donors, which are not required to induce certain activity in the microorganisms. The extent to which PCE can be anaerobically transformed to less chlorinated alkenes is highly dependent upon site-specific conditions. The following paragraph briefly explains the complexities of anaerobic reductive dechlorination of chlorinated alkenes.

The anaerobic biotransformation of PCE occurs through a microbially-mediated, sequential dehalogenation process as follows:

PCE → TCE → *cis*-1,2-DCE → vinyl chloride → ethene → ethane

The degree to which this sequence proceeds depends on three factors:

1. The presence of dechlorinating microorganisms
2. The presence of suitable electron donors
3. The presence of competing electron acceptors

The importance of each of these processes is explained in the following paragraphs.

The Role of Microorganisms in Anaerobic Dechlorination of PCE

The microorganisms that carry out anaerobic reductive dechlorination of PCE can be classified into two major groups: (a) methanogens and other anaerobes that incidentally perform dechlorination but derive no benefit from the process, and (b) direct dechlorinators that utilize chlorinated hydrocarbons as electron acceptors in their energy metabolism, a process termed dehalorespiration (Gossett and Zinder 1996). Microorganisms that dechlorinate hydrocarbons incidentally, but do not obtain energy from the process, are ubiquitous. Direct dechlorinators that transform PCE to TCE to *cis*-1, 2-DCE appear to be relatively widespread. However, direct dechlorinators capable of transforming PCE past *cis*-1, 2-DCE seem to be much less common (Gossett and Zinder 1996). Their scarcity or complete absence at a site could mean that complete degradation of PCE would be problematic and that *cis*-1, 2-DCE would accumulate.

Both groups require highly reducing conditions, at least to the level of sulfate reduction. Furthermore, the environment must be progressively more reducing (i.e., lower redox potential) to remove each successive chlorine atom. For example, *cis*-1, 2-DCE cannot be used as an electron acceptor in the redox environment characterized by sulfate reduction (McCarty 1996), and thus the dehalogenation sequence stops at *cis*-1, 2-DCE.

Often the reduction of vinyl chloride to ethene has also been a limiting step, leaving a surplus of vinyl chloride. When this last step does not occur (i.e., vinyl chloride is not reduced to ethane), the vinyl chloride concentration increases and, in itself, becomes a problem (i.e., vinyl chloride becomes a risk driver). Recently, the identification of dehalorespiring organisms such as *Dehalococcoides* that can facilitate complete detoxification has been observed. These dehalorespiring organisms are very efficient dechlorinators, and to date, are the only known organisms that are capable of reductively dechlorinating PCE and its metabolic byproducts (e.g., *cis*-1,2-DCE and vinyl chloride) to innocuous end products, ethene/ethane. With this discovery, the prospect of complete biodegradation is promising.

The Role of Electron Donors

Not only must the necessary microorganisms be present in the subsurface, they must also have the required carbon source, and for some microorganisms, an energy source. This source of carbon and energy is the electron donor. If a suitable electron donor is not available, neither dechlorination nor any other type of energy metabolism will occur.

Typical electron donors in aquifers are naturally occurring organic, carbon-containing, compounds such as humic acid or contaminants such as petroleum hydrocarbons or domestic sewage. Certain inorganic compounds can also serve as electron donors. Under aerobic conditions, ammonium, nitrite, ferrous iron, and sulfide ions can donate electrons, and under anaerobic conditions, molecular hydrogen is an important electron donor. Both the quantity and quality of the electron donor available for any site must be considered.

The Role of Electron Acceptors

A relatively small number of compounds can serve as electron acceptors, but some, if not all of them, are available at most sites. Since the reaction in which these compounds accept electrons involves the release of energy, electron acceptors are used in a sequence according to the amount of energy provided to the cell. The order in which common electron acceptors are used is: oxygen, nitrate, ferric iron, sulfate, and finally carbon dioxide. As each of these is used in turn, the local environment becomes more reducing (i.e., lower redox potential).

Biotransformation of PCE is a multiple step reaction. Each step has different reaction kinetics. The later reactions from *cis*-1, 2-DCE to vinyl chloride to ethene require more highly reducing conditions and will most likely occur under methanogenic conditions whereas the initial steps could occur under iron and sulfate reducing conditions. The rate at which the later steps occur is much slower than the initial reactions.

Since the chlorinated alkene acts as the electron acceptor during biotransformation of the molecule, the dechlorination process may be limited by competitive inhibition. Aerobic metabolism provides the greatest energy to microorganisms in the subsurface and would be the preferential metabolic mode where oxygen is available (i.e., where dissolved oxygen > 1.0 mg/L). Under anaerobic conditions, denitrification is the most preferable metabolic mode.

Actual electron acceptor utilization in the environment is dependent on their concentrations. The specific influence on alternate electron acceptors cannot be generalized. Different microbial systems and groundwater conditions can cause different shifts in thermodynamic equilibrium. Dehalogenation of PCE does not even initiate until sulfate concentration is reduced to less than 200 mg/L (as in all cases of CDM sampling at the site). Since *cis*-1, 2-DCE cannot be used as an electron acceptor in the redox environment characterized by sulfate reduction (McCarty 1996), the dehalogenation sequence stops at *cis*-1, 2-DCE.

Biodegradation of PCE at the Site

Several factors indicate that anaerobic reductive degradation is occurring minimally, or only in specific areas, at the Site. The most important factor, as an indication of anaerobic reductive dechlorination, is the presence of reductive dechlorination byproducts. Both *cis*-1, 2-DCE and vinyl chloride are byproducts of the reductive dechlorination of PCE and are only found sporadically at the Site and at low concentrations, indicating occurrence but not a major role. The fact that by-products are not found throughout the Site and that no vinyl chloride was detected in the OU2 plume suggests that anaerobic degradation of PCE/TCE is only occurring in specific areas. Another factor demonstrating minimal anaerobic reductive degradation at the Site is that ferrous iron detections are sporadic and concentrations are low at the Site.

6.4 Monitored Natural Attenuation

As part of this investigation, groundwater samples from six non-background wells (i.e., in the upper, middle, and/or lower part of the aquifer) and one background well were analyzed for natural attenuation parameters to provide initial information to determine the potential for biodegradation at the Site. The groundwater samples were analyzed for TDS, chloride, nitrate/nitrite, sulfate, alkalinity, TOC, temperature, pH, DO, ORP, ferrous iron, total manganese, and total iron, in addition to VOCs (see Table 6-1). Although these analyses provide information to initially assess monitored natural attenuation (MNA) as a remedial alternative, more information may be needed to completely evaluate MNA at the site.

The pH, conductivity, temperature, and alkalinity are typical of aquifer systems that support natural attenuation. Of particular importance as indicators for the natural reductive dechlorination of PCE is the availability of electron acceptors and organic carbon. The presence of any metabolic byproducts from electron acceptor utilization (e.g. methane and ferrous iron) and byproducts of the dechlorination process (e.g., vinyl chloride) are also important indicators. As identified in the Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water (EPA 1998), other parameters that may need to be determined to assess natural attenuation potential include nitrate, sulfide, methane, carbon dioxide, hydrogen, volatile fatty acids, and ethene/ethane.

- **Redox potential:** The measured redox potential can describe the type of conditions that exist in the subsurface. The measured redox potential of the non-background upper, middle, and lower aquifer conditions range from -42 to 148 mV,

-16 to 180 mV, and -152 to 118 mV, respectively. High redox measurements indicate that the aquifer has oxidizing conditions. Low redox measurements indicate that the conditions are reducing, which are the most conducive to anaerobic reductive dechlorination.

The redox data indicate that the aquifer is predominantly oxidizing with the lower aquifer having the least oxidizing conditions. However, measured redox values may not reflect the actual oxidation-reduction condition of the aquifer and are sensitive to sampling technique. The values are not an absolute measure of the type of conditions that exist and should be evaluated in conjunction with inorganic concentrations (i.e., redox pairs) for a more accurate description of the subsurface redox conditions.

- **Dissolved oxygen:** The aquifer groundwater must be anaerobic (i.e., dissolved oxygen concentrations less than 1.0 mg/L) for reductive dechlorination to occur. The DO concentrations in the non-background upper, middle, and lower part of the aquifer range from 4.60 to 13.08 mg/L, 8.4 to 13.97 mg/L, and 7.56 to 13.7 mg/L, respectively. None of the wells contain DO equal to or less than 1.0 mg/L.

  From the dissolved oxygen concentrations, the aquifer conditions are aerobic (i.e., DO > 1.0 mg/L). However, DO is also an aquifer characteristic that is difficult to accurately measure (e.g., water can oxidize quickly when taken out of its original environment and put into an oxidizing atmosphere). Therefore, the majority of oxygen in the aquifer has not been depleted and significant anaerobic degradation of any site contaminants is unlikely unless conditions are changed.

- **Nitrate:** The presence of nitrate can inhibit the degradation of the more highly chlorinated ethenes. Because nitrate and nitrite were measured as a whole, nitrate values at the Site are not known. As a result, this parameter would need to be measured in order to determine if site conditions are optimal for anaerobic dechlorination.

- **Ferrous iron:** Non-aqueous ferric iron (Fe^{3+}) may be present in the subsurface in solid phases such as hematite, ferric oxyhydroxide, and goethite. Ferric iron may be reduced to ferrous iron (Fe^{2+}), which may be soluble in water. The presence of ferrous iron in groundwater can be an indication that ferric iron is used as an electron acceptor. Ferric iron reducing conditions are conducive to PCE and TCE degradation but can inhibit the degradation of *cis*-1, 2-DCE. The measured ferrous iron concentration in groundwater may be lower than actual available ferrous iron due to precipitation in the subsurface as sulfides or carbonates. Ferrous iron concentrations in the non-background wells range from nondetect to 2.8 mg/L. Three out of the four ferrous iron detections were in the lower aquifer, again indicating that the lower aquifer may be more suitable for reductive dechlorination.

- **Sulfate:** High concentrations of sulfate can inhibit the degradation of *cis*-1, 2-DCE and potentially PCE. Although samples collected in December 2003 were not analyzed for sulfate, the previous sampling events had sulfate concentrations ranging from nondetect (only one sample) to 180 mg/L. High concentrations of sulfate in the groundwater have led to the inhibition of anaerobic dechlorination except in areas where additional carbon sources are present.

- ***cis*-1,2-DCE and Vinyl Chloride**: The minimal amount of cis-1,2-DCE detected at the site and the absence of VC indicates that no significant reductive dechlorination is presently occurring at the OU2 portion of the Site.

- **TOC:** Bioavailable organic carbon is the most important parameter for the anaerobic reductive dechlorination of chlorinated solvents. The organic carbon is required as an electron donor to create the most favorable conditions for reductive dechlorination. If sulfate levels are too high and are inhibiting dechlorination, the addition of organic carbon will stimulate sulfate use as an electron acceptor until it is depleted, and then the next preferred electron acceptor will be used until the electron donor, available organic carbon, is depleted. Once the electron donor is depleted, the dechlorination process will stop until more donors are made available. Other compounds, such as hydrogen, can also be used as an electron donor for anaerobic reductive dechlorination, in addition to BTEX and other organic carbon. As an example of organic carbon requirements for the utilization of sulfate, the removal of 100 mg/L of sulfate would require 22 mg/L of benzene-equivalent organic carbon.

  TOC was not detected in any the samples except one from the lower aquifer in the March 2003 sampling event (4.1 mg/L) and one from the upper aquifer in the December 2003 sampling event (6.5 mg/L). According to the EPA screening criteria, insufficient TOC exists at the Site to sustain complete anaerobic reductive dechlorination. However, the laboratory analysis for TOC may not account for all the anthropogenic carbon. The overall site does not have sufficient bioavailable carbon, including petroleum contaminants to deplete sulfate as a competing electron acceptor and provide for complete reductive dechlorination.

  In general, current conditions at the Site are not conducive to reductive dechlorination. Also, it appears that very little dechlorination has occurred in the recent past. To conclude, reductive dechlorination would only be an option for remediation if changes are made to the aquifer environment.

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Section 7
OU2 Risk Assessment

Analytical results from the groundwater media for both investigations were supplied to SRC to conduct the preliminary human health and ecological risk assessment (HHERA).

7.1 Risk Assessment Summary

A baseline human health and ecological risk assessment was conducted by SRC for the Bountiful/Woods Cross OU2 to supplement this RI. The medium assessed was groundwater and the primary contaminants reviewed were VOCs. It was noted in the risk assessment that the human health risks were assessed in accordance with current EPA guidelines for Superfund Sites. This section summarizes this risk assessment. For more details, the reader is referred to SRC's risk assessment document (2004)

7.1.1 Exposure

The residential wells in the area are used primarily for irrigation but could be used for drinking water or other indoor uses. The shallow aquifer is classified as Class II. For this reason, the groundwater was assessed for possible risks to human health. Because the possibility of groundwater discharge to surface water exists, ecological receptors were also considered. As a result, the four major exposure pathways at the Site are:

- **Human**

  Ingestion of groundwater as drinking water
  Inhalation of contaminant released from indoor water use to indoor air
  Inhalation of contaminant released directly from groundwater into indoor air

- **Ecological**

  Direct contact with groundwater released to the surface (e.g., wetlands or ponds)

For this risk assessment, COPCs were defined as any contaminant that meets all of the following criteria: 1) has one or more toxicity values, 2) was detected in at least one sample of groundwater, 3) is not associated with laboratory blanks, and 4) has a maximum concentration which exceeds a conservative risk-based concentration. Table 1-2 presents the COPCs including which plume they are associated with and what type of receptor. Section 1.3 of this RI also discusses the COPCs in more detail.

The exposure points evaluated during this risk assessment were on a well-by-well basis for human health since the concentration exposed to by a human is based on their use of a single well and its location (i.e., distance from the source). Since there are no known locations where contaminated groundwater is being discharged to the surface, ecological risk calculations were conducted as if groundwater from the upper aquifer were being discharged to the surface. Because the number of samples at the Site was relatively low (i.e., statistically valid estimates of the 95% upper control limit could not be calculated), the maximum detected value was used to determine risk at the Site. If the chemical was never detected, ½ the average detection limit was used. To estimate the concentration in indoor air from indoor use of groundwater, the transfer factor approach was used. For concentrations via soil gas, the Johnson and Ettinger model was employed (SRC 2004).

Other variables affect human exposure such as body weight, intake rate, and exposure duration. Because these specifics can not be determined for a general risk assessment, default values for central tendency exposure (CTE) and reasonable maximum exposure (RME) recommended by the EPA were used.

7.1.2 Toxicity Assessment

For human health, the chemical- and route-specific toxicity values developed by the EPA (i.e., Integrated Risk Information System or Superfund Technical Support Center) were applied. Because the values for TCE are in controversy, a range of different alternative values were used for the risk assessment. Values used for toxicity assessment of ecological receptors were taken from EPA's Ambient Water Quality Initiative, EPA Region IV, or the Canadian Council of Minister of the Environment.

7.1.3 Risk Characterization

7.1.3.1 Human Receptors

The hazard quotient (HQ) was calculated by dividing the chronic daily intake (CDI) the reference dose (RfD). If the result was less than or equal to one, it is considered that there is no noncancer health risk to a human (and visa versa if the HQ is greater than one). Cancer risk to humans is estimated in terms of probability that an individual will develop cancer by age 70 through exposure to a chemical. Cancer risk for each chemical was determined using lifetime average chronic daily intake of the chemical for the Site and the slope factor for the chemical. All excess cancer risks are then summed across all chemicals and exposure pathways. In general, EPA considers cancer risks of one in one million to be negligible and cancer risks above one in ten thousand to require remediation of a site. Values between these end points are evaluated on a case-by-case basis.

The following human health conclusions for the Site were presented in the risk assessment executive summary:

- The only noncancer risk above one is at one well near the southern edge of the site. This concern is due to MTBE being released to air during indoor use of groundwater.

- Cancer risk exceeded the EPA's target range of 1 in 10,000 at 62 locations for residents and 41 locations for workers. In most cases, the primary sources of cancer risk were from PCE and TCE with minor influence from vinyl chloride, benzene, and MTBE.

Where PCE is the major concern, the primary exposure pathway is ingestion of groundwater with less contribution from inhalation. Where TCE is the main concern, the relative contribution of the two exposure pathways depends on the slope factor used to calculate the risk. Comparing the two inhalation pathways, the most important pathway is from release to air from indoor use of groundwater.

7.1.3.2 Aquatic Ecological Receptors

These ecological risks were also determined by reviewing the HQ. A few locations were identified where the HQ was greater than 1 (i.e., posed a noncancer risk). However, it should be noted that 1) the concentration at surface is assumed to be equal to groundwater concentration, which is probably a high estimate, and 2) no known locations were identified where the groundwater is currently being discharged to the surface. The majority of these potential risks are from PCE and TCE.

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Section 8
Summary and Conclusions

The goal of this RI report is to combine the results of the Phase 1 field investigation and the Phase 2 investigation to determine the full nature and extent of PCE/TCE contamination at Bountiful/Woods Cross 5th South PCE Plume OU2. All data gaps resulting from the Phase 1 investigation (CDM 2002a) were addressed in the Phase 2 field investigation.

8.1 Phase 1

The Phase 1 field investigation conclusively determined that BFC/DEP is the source of shallow PCE/TCE contamination in groundwater for the OU2 Unknown Source Plume. The Phase 1 investigation also provided preliminary evidence of at least two separate sources contributing contamination to the domestic wells along 1100 West and the former Phillips 66 (now Holly Refinery) MWs. However, conclusive evidence of the BFC/DEP impact to the domestic wells could not be determined with only the shallow groundwater data available. The Phase 1 investigation helped distinguish separate and distinct plumes within the Site. An extension of the Hatchco/Kelly (OU1) plume is characterized by primarily TCE with degradation compounds (including VC) that can be tracked from their property to the west-northwest onto the southwestern portion of the Holly Refinery (Figure 5-1). This plume extension is substantiated by the previous analytical results confirmed in the Holly Refinery MWs (2S, 2D, and 3S) by UDEQ and CDM's groundwater grab samples from (WPH01 and WPH10). The shallow PCE plume (OU2) mapped during Phase 1 also tracks to the west-northwest. This PCE plume is shown in Figure 5-1 by red isoconcentration lines and ends in the vicinity of the inferred Warm Springs Fault. Analytical results of tap water from a limited number of downgradient domestic wells are also contaminated with primarily PCE and trace hits of TCE/cis-DCE. However, the groundwater in the domestic wells is from a deeper 150 feet or greater portion of the aquifer which is under artesian conditions. No vinyl chloride, as seen in the Hatchco plume extension, was detected in the domestic well samples.

8.2 Phase 2

The primary tasks for Phase 2 of the RI were to: (1) delineate the vertical and horizontal extent of the OU2 PCE/TCE plume, (2) quantify contamination levels in the groundwater for support of risk assessment studies, and 3) conduct quarterly monitoring of the identified COPC, from existing and newly installed permanent MWs for detecting any seasonal influences.

The specific objectives for Phase 2 of the investigation resulted in defining certain areas (SA-1 through -4) of the Site which required different field methods and data sets for making decisions. Conclusions are reported for each SA where work was conducted, exclusive of SA-4 which is now PRP driven. Any remaining data gaps are also addressed below.

SA-1 (Downgradient of BFC/DEP)

- The conceptual hydrogeological model of the Site was enhanced by data from five new soil borings downgradient of the BFC/DEP along the trend of the shallow groundwater PCE plume to depths up to 250 ft. Continuous cores were obtained to confirm stratigraphic relationships of the aquifer and confining units across the Site, and to document the potential pathway for DNAPL contaminants to disperse and migrate to downgradient domestic wells in the vicinity of 1100 West (Section 3).

- Groundwater was sampled on a quarterly basis and results were analyzed to determine contaminant levels for each portion of the aquifer (U, M and L). Results from the new U wells were consistent with observed concentrations from the Phase 1 shallow groundwater plume delineation.

- Synoptic water level data were collected during each round of groundwater sampling and were used to calculate both horizontal and vertical gradients and determine flow directions. The upper to middle vertical gradient is consistently strong downward in the vicinity of MW03, MW04, and MW05. The area just west of I-15 is where the contamination is moving from the upper to the middle zone. The downward gradient direction transitions to an upward vertical gradient from the central portion of the Site (underlying the Holly Refinery) to the west. Here confining units become more significant and even artesian conditions are noted (MW01 and MW02).

- Concentrations of PCE measured during each quarterly groundwater sampling event consistently demonstrate a reduction within the upper zone from east to west and conversely an increase in PCE concentration in the middle/lower zones. However, not enough data have been collected to date to see distinct trends versus time.

- No other potential source areas of PCE were identified between the BFC/DEP and the domestic wells.

- Changing horizontal gradient directions, especially in the upper zone (Figures 3-6 through 3-9), over four quarterly sampling events created uncertainty concerning flow and contaminant transport along the southern boundary of the PCE plume (Figure 5-1). A data gap was immediately recognized in the area to the east of Hatchco/Kelly and southwest of the BFC/DEP source. A new multi-level BarCad® system, similar to the others on site, was installed in January 2004. Sampling was conducted during mid-April 2004. Results were used to revise the southern boundary of the existing PCE plume where data were previously lacking (Figure 5-1).

- Selected domestic wells in the vicinity of 1100 West and beyond were sampled by UDEQ personnel for three of the quarterly rounds. The tap water samples were included in shipments sent to the CLP laboratories for VOC analyses (OLC03.2). Results from the domestic well samples show that PCE is the only significant VOC contaminant detected, which is consistent with the analytical results from MW01M-L located in the same area.

In conclusion, after comparing all multi-level MWs, there is a clear pathway and high probability that contaminants from the BFC/DEP are reaching the domestic wells completed in the artesian M and L zones of the aquifer to the west of the Holly Refinery. Using average aquifer hydraulic parameters, calculated and reported above, the contamination could reasonably reach these domestic wells within the period of time since suspected source area release(s) during the decades before 1980. However, not enough data have been collected consistently over time to state whether the plume has reached a steady state of equilibrium or is still expanding. This lack of consistent data (concentration vs. time) is identified as a data gap.

SA-2 (Upgradient of BFC/DEP)

- The only data gap resulting from incomplete analysis of the Phase 1 field investigation was in the eastern most target zone, related to the dry cleaners (NTF) in that area (CDM 2002a). Since DPT drilling methods were unable to reach groundwater and characterize the potential source area, a conventional MW (MW06U) was completed during Phase 2 immediately downgradient of the dry cleaner's business. No CAH were detected in samples collected during the March 2003 sampling event, the first sampling after development of MW06U. Subsequent events resulted in either nondetect or a low estimated value with method blank contamination.

- Other upgradient low-level PCE contamination (i.e., maximum 1.3 µg/L) was detected during Phase 1 in the residential (RES) target zone (CDM 2002a). MW07U was installed as another upgradient conventional well to monitor water quality between this low-level contamination and the Bountiful Shop Well, which is used as a source for municipal drinking water supply. No CAH were detected in samples collected during the March 2003 sampling event, the first sampling after development of the MW.

- Slightly anomalous water levels from temporary wells installed during Phase 1 in July 2002 indicated a slight groundwater flow reversal to the southeast. The reversal was believed to be caused by drawdown from the heavy pumping at the Bountiful Shop Well, which is located approximately 2,000 ft southeast of the BFC/DEP. Phase 2 water level data also indicate variable fluctuations within seasonal highs and lows and potentiometric maps show greater drawdown near municipal wells.

- In Situ™ data loggers (mini-Troll) units were installed as part of Phase 2 in all of the upgradient wells to monitor water levels on a continuous, hourly, basis. Hydrographs (Figure 3-10) produced from these data revealed a sharp decline in water levels in June 2003, which correlated closely with the city bringing the Bountiful Shop Well back online, after being shut down for the preceding winter months. Abundant evidence exists, including well head protection modeling conducted by the city, that indicates that the surrounding municipal wells have significant impacts on groundwater movement in the shallow East Shore Aquifer. Wellhead protection area (WHPA) zones for the Shop Well were delineated by the City in 1995 (Appendix G). A semi-analytical model was used to simulate time-related capture zones while accounting for potential interferences from other nearby pumping wells. The simulated 15-year time of travel capture zone extends 4,600 ft. and includes the BFC/DEP source area.

Low-level PCE and degradation compounds were detected in all upgradient MWs (i.e., MW06U, MW07U, and BK01U) during the September 2003 quarterly sampling event. This low level of contamination is further evidence that flow reversals are occurring and there could be a smearing effect on the spread of contamination. As discharge at the Bountiful Shop Well decreased in the late fall, the December 2003 water levels were observed to be rising and all upgradient MWs were nondetect for PCE. Information from lower portions of the shallow East Shore Aquifer is completely lacking upgradient of the BFC/DEP source area. This lack of information and means to monitor lower portions of the shallow aquifer between the source area and the municipal wells is considered a data gap.

SA-3 (950 West - Source Area Investigation)

- SA-3 was added to the field investigation effort to evaluate the potential for co-mingling of OU1 and OU2 contaminant plumes. SA-3 is downgradient of OU1 and crossgradient to OU2 and may contain another potential source area (Jensen Automotive) near 950 West and 500 South. This area and the associated groundwater contamination (i.e., TCE, cis-1,2 DCE, and vinyl chloride) are believed to be unrelated to the OU2 PCE plume; however, it is a portion of the Site where the OU1 investigation ended. The Hatchco/Kelly plume identified anomalously high TCE and other CAH hits in their furthest downgradient MW-14 installed off site. Their claim is that another source must be contributing to the OU1 plume. The CAH compounds detected in the downgradient plume are exactly the same, but their relative abundances vary. TCE concentrations in this area increased to levels that approached those detected in their onsite MWs. Soil and groundwater grab samples were collected during Phase 2 to fill data gaps with regard to the Hatchco/Kelly claim and answer the question whether they were the only source of the shallow CAH plume associated with 950 West.

- The analytical results for the groundwater grab samples support the conclusion that another source could be present in the area. TCE and other degradation compounds had concentrations at least an order of magnitude higher in samples surrounding the Jensen Automotive property, especially just downgradient on the west side of building, [DP39], than in samples just to the east between the two areas.

- The analytical results for the soils at SA-3 are not as definitive as the groundwater samples. Although vadose zone soils were collected, screened, and analyzed on 50-ft centers around the automotive shop, nearly all soil sample results for TCE were nondetect. However, one sample, DP 14 on the northwest corner of had a trace detection of TCE and several other samples, DP2 and DP3 to the west and north of the building had elevated detections of cis-1,2 DCE and other CAH compounds. Although attempts were made to collect soils above the saturated zone, many of the samples could be close to the capillary fringe and, therefore, be reflecting some of the groundwater contamination.

In conclusion, evidence supports the Hatchco/Kelly claim that another potential source of CAH contamination is present directly downgradient of the Hatcho site. However, not enough evidence is available to state with certainty that the contamination is not related to OU1. More definitive evidence (historical records, sump/tank/drain inspections, assessment of preferential pathways, and confirmation sampling) is needed to identify the Jensen Automotive property as another source area.

8.3 BFC/DEP Source Area

Although CDM did not conduct the field investigation within SA-4, support will be provided to EPA for the supplemental source area (BFC/DEP) investigation. The conclusions reached in the draft RI report (Bowen Collins & Associates 2004) were based on an incomplete data set utilizing one sample event from only one onsite well and several shallow soil samples. Borings beneath the dry cleaner building were only dug to 11 ft and did not address several sumps and/or drain noted on site plans. Soil contamination was attributed to partitioning from volatilization of compounds in the groundwater plume. At a minimum, the evaluation should be expanded to provide geochemical data and an equilibrium model to support this theory. A discussion should be included on how vapors migrating from 77+ ft bgs accumulate in localized areas under the building and not below the asphalt parking lot.

To assist remedy evaluation and selection, further sampling efforts surrounding the BFC/DEP have been recommended as part of a Phase 3 investigation. A program of sub-slab soil vapor analysis and a membrane interface probe (MIP) study could potentially map the location and extent of the source material in the saturated or unsaturated medium. The other potential release site associated with the BFC/DEP is along the sewer main leading north from the lateral off the property. This northern extension of the area was initially proposed for further investigation (SA-4) (CDM 2002b). Follow up soil and groundwater confirmation sampling should also include a suite of analytes for fully evaluating the geochemistry of the vadose and saturated zone.

Nevertheless, the OU2 PCE plume is adequately defined at this point to move forward with the FS. Further recommendations for pilot testing (etc.) in the source area can be considered either during the FS stage or even postponed to the remedial design phase.

8.4 Risk Assessment Conclusions

The risk assessment states that a few locations exist where there may be risk to human receptors (i.e., noncancer risk due to MTBE at one well and cancer risk from primarily PCE and TCE at several other wells). For ecological receptors, several locations may pose a risk if groundwater were discharged to the surface and the concentrations in the discharged water remained as high as the concentrations in the groundwater at these locations. The risk assessment notes that a few locations exist where there may be risk to human receptors (i.e., noncancer risk due to MTBE at one well [MW03U] and cancer risk from primarily PCE and TCE at several other wells). For ecological receptors, several locations may pose a risk if groundwater were discharged to the surface and the concentrations in the discharged water remained as high as the concentrations in the groundwater at these locations.

Section 9
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Appendix A
Lithologic and Well Completion Logs

Appendix B
Slug Test Data and Grain Size Distribution Analysis

Appendix C
Summary of Analytical Results and Water Level Measurements

CDM

Appendix D
Data Validation Reports and CLP Form-1 Summary Sheets

Appendix E
Chain-of-Custody Forms

Appendix F
Field Data Sheets

Appendix G
Shop Well – Drinking Water Source Protection Plan

CDM

Appendix H
BOR CPT Information