APPENDIX E – WELL AND PIEZOMETER INSTALLATION

FINAL REMEDIAL INVESTIGATION REPORT
CASMALIA RESOURCES SUPERFUND SITE
CASMALIA, CALIFORNIA

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TABLE OF CONTENTS

LIST OF TABLES

Table # **Description**

LIST OF FIGURES

LIST OF ATTACHMENTS

LIST OF ACRONYMS

°C	temperature degree centigrade
amsl	above mean sea level
ARCH	air-rotary casing hammer
ASTM	American Society for Testing and Materials
BC Laboratory	BC Analytical Laboratories
bgs	below ground surface
CD	Compact Disc
COC	chemical of concern
CPT	cone penetrometer testing
CSC	Casmalia Steering Committee
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DQO	data quality objective
Eh	oxidation reduction potential
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
FS	Feasibility Study
GAC	granular activated carbon
GPS	global positioning system
Gregg	Gregg In Situ, Inc.
HCSM	Hydrogeologic Conceptual Site Model
HSA	Hollow stem auger
HSU	Hydrostratigraphic Unit
ID	inside diameter
IPR	Interim Progress Report
LNAPL	light non-aqueous phase liquid
MACTEC	MACTEC Engineering and Consulting, Inc.
mg	milligrams
mg/L	milligrams per liter
mm	millimeters
mV	millivolts
NAPL	non-aqueous phase liquid
NTU	Nephelometric Turbidity Unit
OD	outside diameter
ORP	oxidation-reduction potential (redox)
OVM	organic vapor monitor
PCB	polychlorinated biphenyl
PDF	Portable Document Format
pH	unit of measurement for acid/base properties
PID	photo-ionization detector
PS Landfill	Pesticide/Solvent Landfill
PSCT	Perimeter Source Control Trench
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RGMEW	Routine Groundwater Monitoring Element of Work

RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SA	semiannual
SAP	Sampling Analysis Plan
SOP	Standard Operating Procedures
SOW	Scope of Work
SVOC	semi-volatile organic compound
µmhos/cm	micromhos per centimeter
URS	URS Corporation
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
WDC	Water Development Corporation

1.0 INTRODUCTION

This Appendix to the Final Remedial Investigation Report documents the groundwater monitoring well, piezometer, and hydropunch boring installation activities conducted at the site during two phases of field work. Phase I, was conducted during the Summer and Fall of 2004, pursuant to the requirements set forth in the RI/FS Work Plan; and Phase II was conducted during the Summer and Fall of 2006 and the Winter and Spring of 2006/2007, pursuant to the requirements set forth in the RI/FS Work Plan and the Appendix E – Well and Piezometer Installation Errata Redline. During Phase I, conducted between August and December 2004, the Casmalia Steering Committee (CSC) installed and developed eight new chemical water quality wells, 24 liquid level piezometers, one replacement chemical quality well, one replacement piezometer, and one deep exploratory boring at the site (Figure E-1). The Phase I groundwater monitoring points were installed to provide data in areas of the site where the CSC and Environmental Protection Agency (EPA) had identified potential data gaps. During Phase II, conducted between July 2006 and August 2007, the CSC installed and developed two new chemical water quality wells, sixteen liquid level piezometers, three replacement liquid level piezometers, one temporary liquid level piezometer, one deep exploratory boring, and seven hydropunch borings at the site (Figure E-1). The Phase II groundwater monitoring points were installed to provide data in areas of the site where the CSC and EPA had identified potential data gaps still present following the 2004 Phase I RI/FS.

1.1 Data Collection Objectives

1.1.1 2004 Phase I RI/FS Data Quality Objectives (DQOs)

Chemical water quality wells and piezometers were installed in selected areas of the site where the CSC and EPA identified potential RI/FS data gaps with respect to geologic, groundwater flow, and groundwater quality conditions. The purpose of the chemical quality wells was to provide chemical water quality and liquid level data to augment the existing groundwater quality monitoring network in monitoring the distribution of contaminants at the site and to further refine the Hydrogeologic Conceptual Site Model (HCSM). The purpose of the piezometers was to provide both lateral and vertical hydraulic head data to augment the existing groundwater water level monitoring network and to provide non-aqueous phase liquid (NAPL) wells in selected areas of the Central Drainage.

All chemical quality wells were installed in the Upper Hydrostratigraphic Unit (HSU) and generally screened near the water table, which typically occurs near the contact between the weathered and unweathered claystone units, or within alluvium (in well RIMW-9). All new chemical quality wells were installed in Zone 1 (within the pre-2003 site fenced area). Well RIMW-9 is located just outside the current fenced area as shown on Figure E-1.

Piezometers were located across the site in areas where additional lithologic and liquid level information was required for the RI/FS. Existing wells and piezometers were utilized, supplemented by new piezometers installed as part of this effort, in an attempt to satisfy this objective. These monitoring locations, which provide lithologic and liquid level information at varying depths, were generally located in the vicinity of extraction features, potential groundwater flow divides, the Central Drainage, and/or strategic areas of the site where there was determined by EPA to be insufficient or an absence of hydraulic head and NAPL distribution data.

1.1.2 2006/2007 Phase II RI/FS DQOs

Chemical water quality wells, piezometers, and hydropunch borings were installed during the 2006/2007 Phase II RI/FS to close minor data gaps that remained following the 2004 Phase I RI/FS. The purpose of the chemical quality wells was to determine the extent of Upper HSU Chemicals of Concern (COCs) west of the Burial Trenches area.

The purpose of the piezometers was to determine the light non-aqueous phase liquid (LNAPL) distribution and thickness in the Central Drainage and Burial Cell Area, and to characterize the groundwater in the vicinity of Phase I sampling location RISBON-59.

Five additional piezometers were also installed within the Pesticide Solvent Landfill to identify potential low spots in the Upper/Lower HSU contact and possible presence of dense non-aqueous phase liquid (DNAPL). Tomographic models of the Phase II geophysical surveys of the southern portion of the P/S Landfill were developed by the CSC and EPA. The geophysical survey and CSC modeling results are documented in Appendix L. The 2007 Phase II piezometers were located in potential HSU contact low spots modeled by EPA from the Phase II geophysical survey. Piezometer locations were proposed by the CSC in the July 13, 2007 *Final Plan for RI Follow-up to the P/S Landfill Seismic Refraction Survey* (CSC, 2007). Three of these piezometers were installed as proposed in the RI/FS Work Plan (RIPZ-13, RIPZ-14, and RIPZ-27) and two additional piezometers (RIPZ-38 and RIPZ-39) were installed at the request of EPA based on their analysis of Phase II seismic data.

The purpose of the hydropunch borings was to determine the extent of Upper HSU COCs south of the Perimeter Source Control Trench (PSCT) and to characterize volatile organic compounds (VOCs) present in the vicinity of piezometer RIPZ-37 and NAPL boring RISBON-59. The chemical quality wells and piezometers were installed in the Upper HSU and generally screened near the water table, which typically occurs near the contact between the weathered and unweathered claystone units, or within alluvium, although it occurred within the unweathered claystone in RIMW-11. All Phase II chemical quality wells and piezometers were installed in Zone 1 (within the pre-2003 site fenced area). The hydropunch punch borings were targeted for five-feet below the water table.

1.2 Scope of Work (SOW)

1.2.1 2004 Phase I RI/FS SOW

Chemical quality groundwater monitoring well installation activities included drilling, core-logging and photo-documentation, downhole video logging, downhole geophysical logging, well construction, well development, and surveying. Eight new chemical quality wells and one replacement chemical quality well were installed. Well locations are shown on Figure E-1, and Table E-1 summarizes the well locations and depths. All wells were screened at, or just above, the weathered/unweathered claystone contact, or within the alluvium. All of the new chemical quality groundwater monitoring wells were installed using an Air-Rotary Casing Hammer (ARCH) drill rig.

Piezometer installation activities included drilling, core-logging and photo-documentation, direct push continuous coring, Cone Penetrometer Testing (CPT), piezometer construction, piezometer development, and surveying. Figure E-1 shows the piezometer locations, and Table E-1 summarizes the piezometer locations and depths. The piezometers were field located with an EPA representative prior to work. Twenty four new piezometers and one replacement piezometer were installed. Eighteen shallow piezometers were installed with total depths of between 15 and 85.5 feet below ground surface (bgs), five intermediate piezometers were installed with total depths of between 89 and 160.5 feet bgs, and 1 deep piezometer was installed to a depth of 220.5 feet bgs. The new piezometers were installed using three methods: ARCH drilling, CPT and Direct Push/Geoprobe coring.

One deep exploratory boring (RISB-01) was installed using ARCH methods to a depth of 255 feet bgs. The soil boring included drilling, core-logging and photo-documentation, downhole video logging, and geophysical logging, which provided geologic data.

The scope of these investigations, as developed in the RI/FS Work Plan, was intended to provide the information necessary to address data quality objectives related to groundwater flow and quality. Liquid level and water quality data obtained from the new wells and piezometers will fill data gaps previously identified with respect to groundwater flowpaths and the distribution of COCs and NAPL in groundwater. The lithologic information obtained from the RI boreholes has been evaluated and used to update the HSU contact surface (Figure E-2), known to be an important control on groundwater flow and subsurface transport. Preliminary liquid level information obtained during new well and piezometer development is contained in this Appendix, and groundwater quality sampling results for the new and existing wells and piezometers (see Appendix G) are now available for evaluation. Liquid level and water quality sampling results from these new and existing wells and piezometers are being used to complete the groundwater elements of the RI provide the information necessary to evaluate groundwater remedial alternatives.

1.2.2 2006/2007 Phase II RI/FS SOW

Chemical quality groundwater monitoring well installation activities included drilling, core-logging and photo-documentation, downhole video logging, downhole geophysical logging, well construction, well development, and surveying. Two new chemical quality wells were installed. Well locations are shown on Figure E-1, and Table E-1 summarizes the well locations and depths. One well was screened at, or just above, the weathered/unweathered claystone contact, and the other within the unweathered claystone. Both new chemical quality groundwater monitoring wells were installed using a CME-85 rig converted for air rotary.

Piezometer installation activities included drilling, core-logging and photo-documentation, direct push continuous coring, CPT, piezometer construction, piezometer development, and surveying. Figure E-1 shows the piezometer locations, and Table E-1 summarizes the piezometer locations and depths. The piezometers were field located with an EPA representative prior to work. Nine new piezometers and thee replacement piezometers were installed. All piezometers were installed in the Upper HSU, with total depths of between 18 and 155 feet bgs. The new piezometers were installed using three methods: air rotary drilling, CPT and Direct Push/Geoprobe coring. Two of the three replacement piezometers (RIPZ-31B and -33B) were installed using the CME-85 rig configured for hollow stem auger (HSA) drilling, and the third (RIPZ-34B), was installed using a direct push/Geoprobe coring rig.

The six hydropunch borings installed south of the PSCT during the first week of January 2007 (RIHP-1 through RIHP-6), were installed using a CPT rig similar to the one used to install the pre-fabricated piezometers. The hydropunch boring depths ranged from 30 to 55 feet. A seventh piezometer (RIHP-7) was installed along NTU Road in April 2007 to characterize VOCs present in nearby piezometer RIPZ-37 and in NAPL Boring RISBON-59.

One deep exploratory boring (RISB-02) was installed using air rotary methods to a depth of 252.5 feet bgs. The soil boring included drilling, core-logging and photo-documentation, downhole video logging, and geophysical logging, which provided geologic data.

Five piezometers (RIPZ-13, -14, -27, -38, and -39) were also installed within the P/S Landfill in 2006/2007 to obtain liquid-level data (groundwater and NAPL) in this critical area of the Site. At three of these locations (RIPZ-13, -38, and -39) two separate CPT pushes were performed to verify HSU contact depths at these locations prior to completing piezometers.

The scope of these investigations, as developed in the RI/FS Work Plan, provides the information necessary to address data quality objectives related to groundwater flow and quality. Liquid level and water quality data obtained from the new wells and piezometers fill data gaps previously identified with respect to groundwater flowpaths and the distribution of COCs and NAPL in groundwater. The lithologic information obtained from the RI boreholes has been evaluated and used to update the HSU contact surface (Figure E-2), known to be an important control on groundwater flow and subsurface transport. Preliminary liquid level information obtained during new well and piezometer development is contained in this Appendix, and groundwater quality sampling results for the new and existing wells and piezometers (see Appendix G) is now available for evaluation. Liquid level and water quality sampling results from these new and existing wells and piezometers is being used to complete the groundwater elements of the RI to provide the information necessary to evaluate groundwater remedial alternatives.

2.0 METHODOLOGY

This section of the Appendix documents the procedures used for coring, logging, installation, and development of the soil borings, piezometers and chemical quality wells. Landfill cap liner repair, surveying, and decontamination procedures are also presented in this Section. Additional documentation of these procedures is presented in the Attachments.

All of the well and piezometer installations were conducted in accordance with the procedures described in the RI/FS Work Plan, Sampling Analysis Plan (SAP), and Quality Assurance Project Plan (QAPP), for the 2004 Phase I RI/FS. The 2006 Phase II RI/FS was also conducted in accordance to the Appendix E – Well and Piezometer Installation Errata Redline. Minor deviations from the procedures specified in the Work Plan (i.e., waiver of video requirement for direct push alluvial boreholes, and waiver of installation of piezometer RIPZ-1 and well RIMW-04) were approved by EPA as documented on the RI Change Forms (RICFs; Appendix Q). Any deviations are discussed in Section E2.7 of this Appendix.

2.1 Well and Piezometer Installation Procedures

Well and piezometer installation was accomplished using ARCH drilling (Phase I only), air rotary drilling (Phase II only), CPT (Phase I and II), Direct Push/Geoprobe coring methods (Phase I and II), and HSA (Phase II piezometer replacement only). A summary of the drilling and logging programs, including methods used for each boring, is provided in Tables E-1 through E-3. Specific procedures used during coring and installation of each new well and piezometer are described below.

2.1.1 Contractors and Subcontractors

The CSC contracted MACTEC Engineering and Consulting, Inc. (MACTEC) to oversee the RI groundwater investigations, including the well and piezometer drilling and installation. MACTEC subcontracted with the following companies to complete the well and piezometer installation tasks:

- Field Lining Systems, Avondale, Arizona – landfill cap repair
- Golder Associates, Ontario, Canada – chloride diffusion testing
- Gregg In Situ, Signal Hill, California – direct push and CPT piezometers
- Pacific Engineering, Santa Maria, California – surveying (subsequently re-named Cannon Associates)
- Water Development Corporation, Zamora, California – ARCH and air rotary wells and piezometers
- Welenco, Bakersfield, California – borehole geophysics and video logging.

All of the drilling and coring work was conducted under the direction of a MACTEC California Registered Geologist or California Certified Hydrogeologist.

2.1.2 2004 Phase I RI/FS Coring and Drilling Equipment and Procedures

Several different drilling methods utilizing different equipment and procedures were employed to install the 35 wells, piezometers, and deep soil boring, as described below. During well and piezometer drilling, various subsurface lithologic and structural data were obtained via collection and logging of cuttings, core samples, downhole video, and from various borehole geophysical data. This data is described below, and will be used to further characterize the physical properties of the subsurface during RI/FS evaluations.

Upper HSU piezometers installed using CPT and Direct Push were completed during August and September 2004. ARCH drilling was conducted between October and December 2004.

2.1.2.1 Cone Penetrometer Testing and Direct Push Coring Procedures

Nine ¾ inch (internal diameter) piezometers were drilled and installed using direct push and CPT methods between August 30 and September 9, 2004. Five piezometers (RIPZ-3, -4, -7, -25, and -26) were installed using direct push, and four piezometers (RIPZ-12, and -22 through -24) were installed using CPT. One additional piezometer was attempted at proposed location RIPZ-21, but installation of the piezometer was abandoned due to refusal of the CPT due to hard formation material. The direct push and CPT work was performed by Gregg In Situ, Inc. (Gregg), Signal Hill, California, under the direction of a MACTEC, California Registered Geologist. Direct push and CPT drilled piezometers were installed to total depths of between 15 and 105-feet bgs and installed within the Upper and Lower HSU. Table E-2 lists the piezometers construction specifications. As proposed in RI change form RICH form 008.2 on August 31, 2004 and approved by the EPA on November 19, 2004, downhole video logging of shallow Upper HSU piezometers installed using CPT/Direct Push technologies was not performed, as it was not likely to provide useful information on fracture or water inflow locations.

In order to minimize hazardous waste generation and worker exposure, CPT methodology was used for ¾-inch piezometers that were constructed within landfill footprints and locations in the central drainage known to contain NAPLs. The CPT system incorporates a steel probe that is hydraulically advanced into the formation while measuring tip resistance, unit friction, pore pressure, and sleeve friction. The information was relayed to a data recorder/processor, and the measurements were plotted. The readings were compared with known readings for different formation types to provide classification of each formation type encountered. The data was then reproduced on automated CPT logs which were annotated with the inferred lithologic description, and the equivalent American Society for Testing and Materials (ASTM) D 2488-93 soil type. Portable document format (pdf) files of original CPT logs for the piezometers are included on compact disc (CD) in Attachment E-1.

After the pilot CPT borehole was advanced to the target depth, the CPT drive pipe was removed and an approximately 2.5-inch diameter pipe with a disposable tip was driven through the CPT pilot hole to the target depth. A prefabricated well consisting of ¾-inch well casing, screen, and sand pack was installed within the drive pipe. The top of the prefabricated screen and sand pack was threaded into the bottom of a prefabricated plug installed to keep grout from reaching and damaging the sand pack. The top of the plug was threaded into a section of blank casing wrapped with a prefabricated bentonite seal, which was in turn flush-threaded into stainless steel or Schedule 40-PVC ¾-inch ID blank casing extending to just below or above ground surface. The annular space surrounding the blank flush-threaded pipe was backfilled with bentonite/cement grout or bentonite slurry, poured from the surface through the 2.5-inch diameter push rod.

Stainless steel pre-fabricated well casings were used for piezometers installed within landfill footprints (RIPZ-12 and RIPZ-22). Schedule 40-PVC pre-fabricated well products were used for all remaining CPT drilled piezometers (RIPZ-23 and RIPZ-24).

A direct push Geoprobe Coring System was used to install 5 of the piezometers. All of these piezometers were located outside areas of known significant waste. Core samples from the direct push boreholes were logged for lithological content by a MACTEC, California Registered Geologist. Soil lithologies were logged in accordance with the Unified Soil Classification System (USCS) and standard geologic techniques. Rock samples were described following the format used by the U.S. Department of Interior Bureau of Reclamation (Engineering Geology Field Manual). Soil and rock samples were continuously collected for lithological description using a hydraulically pushed stainless steel core barrel lined with a clear acetate sample tube. After being driven up to the 4-foot length of the core barrel, the rods were removed from the borehole and the acetate sample tube was removed from the core barrel and split apart to expose its contents. The sample tube contents were photographed and are reproduced as pdf files on CD in Attachment E-3. The retained cores were preserved onsite in soil core boxes.

After the direct push borehole was advanced to the target depth, a prefabricated well, consisting of ¾-inch well casing, screen, sand pack, and bentonite seal was installed within the drive pipe. The top of the prefabricated screen and sand pack was threaded into the bottom of a prefabricated plug installed to keep grout from reaching and damaging the sand pack. The top of the plug was threaded into flush threaded Schedule 40-PVC ¾ inch blank casing extending to approximately two feet above ground surface. The annular space surrounding the blank flush-threaded pipe was backfilled with bentonite/cement grout or bentonite slurry, poured from the surface through the 2.5-inch diameter push rod.

Soils generated during direct push coring activities were placed into appropriately labeled core boxes for future reference. Soils were not generated during the CPT investigation. Head space screening was performed using a photo-ionization detector (PID) to assist in the characterization of obvious soil contamination and to assist in personal protection. The PID was equipped with an 11.8 electron-volt lamp, and the PID was calibrated daily in accordance with manufacturer's recommendations. Head-space screening was performed by removing a portion of the formation material and immediately placing it in a heavy duty sealable plastic bag. The bag was allowed to sit for a minimum of five minutes and not more than ten minutes. The bag was then opened slightly and a reading was collected using the PID. The reading was documented on the boring log.

An eight-inch diameter protective lockable steel casing and concrete pad was installed around each piezometer completed with an above grade construction. A Christi box was installed for wells completed with below grade construction (RIPZ-12, and -22, through -24). The protective cover and Christi boxes were secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the well casing was surveyed for elevation, northing and easting coordinates (Table E-8).

2.1.2.2 <u>Air-Rotary Drilling and Coring Procedures</u>

Eight chemical quality wells, one replacement chemical quality well, 15 piezometers, one replacement piezometer, and one soil boring were drilled and installed between September 28 and December 10, 2004 (RIMW-1, -2, -3, -5 through -9, RG-11B-2, RIPZ-2, -5, -6, -8, -9, -10B, -10C, -10D, -11, -15 through -20, RGPZ-10B-2, and RI-SB-1). Proposed chemical quality well

RIMW-4 and piezometer RIPZ-1 were deleted from the program after it was agreed between the CSC and the EPA that RIMW-4 and new piezometer RIPZ-8 were redundant, and RIPZ-8 could be used for chemical quality monitoring in place of RIMW-4, and Upper HSU well B6B, along with new piezometer RIPZ-02 were adequate for PCT-B water level monitoring. A request to delete proposed chemical quality well RIMW-4 was submitted to the EPA in the RI change order form RICH form 014 on December 10, 2004, and approved by the EPA on January 18, 2005. A request to delete proposed piezometer RIPZ-1 was submitted to the EPA in the RI change order form RICH form 008.2 on August 341, 2004, and approved by the EPA on November 19, 2004. The wells, piezometers, and the boring were drilled by Water Development Corporation (WDC), Zamora, California. Chemical quality wells were drilled and installed to total depths of between and 30.5 to 75.5 feet bgs and installed within the Upper HSU. Piezometers were screened at depth intervals ranging from 17 to 160 feet bgs in both the Upper HSU and Lower HSU. Table E-2 lists the well and piezometer construction specifications.

Soils and lithologies observed during each well/piezometer installation and boring advancement were logged by a MACTEC, California Registered Geologist, or a field geologist under the supervision of a California Registered Geologist. Soils encountered were described in accordance with the USCS and standard geologic logging techniques. Rock samples were described following the format used by the U.S. Department of Interior Bureau of Reclamation (Engineering Geology Field Manual). Soil and rock samples were collected for logging using a 94-mm core barrel from intervals detailed in Table A-7 of the RI/FS Work Plan (June 2004). Modifications to this program were made in the field based on conditions encountered through discussions between MACTEC and EPA's onsite representative (CH_2M Hill). Borings RISB-01 and RIPZ-10D were drilled first and drilling and coring methods adjusted to maximize geologic core quality. Individual continuous coring run intervals ranged from approximately one-foot to five-foot lengths based on core recovery. Coring methodologies and results are further described in Section E3.1. The core samples were photographed (Attachment E-3) and preserved onsite in soil core boxes.

Upon completion of coring activities, the drill pipe and coring assembly were removed and the borehole opened to approximately 6.5 inches (piezometers) and approximately 8.5 inches (wells) using an air rotary tri-cone rock bit. The sidewalls for all wells were then flushed with rig water to facilitate easier and more productive geophysical and video logging (RIPZ-10C, -10D, -15, -16 and -17). Flushing of the sidewalls was conducted by circulating rig water through the drill pipe and up through the annular space of the borehole to dislodge formation derived clays and mud that could otherwise obscure the geophysical and video logging. Water generated during flushing activities was containerized within the same roll-off bins as downhole generated fluids and cuttings.

Head space screening was performed using a PID to assist in the characterization of obvious soil contamination. The PID was equipped with an 11.8 electron-volt lamp. The PID was calibrated daily in accordance with manufacturer's recommendations. Head-space screening was performed by removing a portion of formation material from the core barrel and immediately placing it in a heavy duty sealable plastic bag. The plastic bag was allowed to sit for a minimum of five minutes and not more than ten minutes to allow its contents to volatilize. The plastic bag was then opened slightly and a reading was collected using the PID. The reading was documented on the boring log. Head space readings were subsequently used to segregate clean from contaminated drill cuttings during placement of spoils into roll off soil bins.

An approximately eight-inch diameter protective lockable steel casing and concrete pad was installed around each well and piezometer. The protective cover was secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the well casing was surveyed for elevation, northing, and easting coordinates. Elevation information is summarized on Table E8.

2.1.3 2006/2007 Phase II RI/FS Coring and Drilling Equipment and Procedures

Several different drilling methods utilizing different equipment and procedures were employed to install the 13 wells, piezometers, and deep soil boring, as described below. During well and piezometer drilling, various subsurface lithologic and structural data were obtained via collection and logging of cuttings, core samples, downhole video, and from borehole geophysical data from one deep boring. This data is described below, and will be used to further characterize the physical properties of the subsurface during RI/FS evaluations.

Upper HSU piezometers installed using CPT and Direct Push were completed during July and August 2006. Air rotary and HSA drilling was conducted between September and October 2006. One replacement boring (RIPZ-34B) and seven hydropunch borings were installed using CPT/Direct Push in January and May 2007.

2.1.3.1 Cone Penetrometer Testing and Direct Push Coring Procedures

Seven ¾ inch (internal diameter) piezometers were drilled and installed using direct push and CPT methods between July 17 and August 18, 2006. Six piezometers (RIPZ-31 through -35 and -37) were installed using direct push, and five piezometers (RIPZ-14 [2006], and RIPZ-13, -27, -38, and -39 [2007]) were installed using CPT. One replacement piezometer (RIPZ-34B) was also installed using direct push and six hydropunch borings were installed using CPT in January 2007. A seventh hydropunch boring was installed in May 2007. The direct push and CPT work was performed by Gregg under the direction of a MACTEC California Certified Hydrogeologist. Direct push and CPT drilled piezometers were installed to total depths of between 18 and 155-feet bgs and installed within the Upper HSU. Table E-2 lists the piezometers construction specifications.

In order to minimize hazardous waste generation and worker exposure, CPT methodology was used for the ¾-inch piezometers that were constructed within the Pesticide Solvent Landfill footprint. The CPT system incorporates a steel probe that is hydraulically advanced into the formation while measuring tip resistance, unit friction, pore pressure, and sleeve friction. The information was relayed to a data recorder/processor, and the measurements plotted. The readings were compared with known readings for different formation types to provide classification of each formation type encountered. The data was then reproduced on a CPT log which was annotated with the inferred lithologic description, and the equivalent ASTM D 2488-93 soil type. Depths for the 2007 Phase 2 P/S Landfill piezometers were determined using the depth counter on the rig, and verified by measuring the lengths and numbers of CPT rods advanced at each location, and finally by sounding the finished piezometers for total depth.

During the 2007 Phase 2 P/S Landfill piezometer installation, it was necessary to confirm that the depth counter of the CPT rig was accurate after the total depth was reached at proposed piezometer location RIPZ-39, and it was observed that although the depth counter recorded a total depth of 132-feet, the actual depth based on the number and length of push rods was 123 feet. The discrepancy was determined to be due to a problem with the electrical circuitry of the rig and quickly fixed. A second CPT was advanced at proposed piezometer location RIPZ-39, which demonstrated that the depth counter on the rig matched the length and number of push rods. A second CPT was also driven adjacent to piezometer RIPZ-13, installed the previous day, to insure that the installed depth of the piezometer was placed at the HSU contact. No additional depth problems were noted during the remainder of the 2007 CPT investigation. CPT logs for the piezometers are included in Attachment E-1.

A direct push Geoprobe coring system was used to install six of the piezometers and one of the replacement piezometers. All of these piezometers were located outside areas of known significant waste. Core samples from the direct push boreholes were logged by a MACTEC field geologist under the supervision of a California Certified Hydrogeologist. Soil lithologies were logged in accordance with the USCS and standard geologic techniques. Rock samples were described following the format used by the U.S. Department of Interior Bureau of Reclamation (Engineering Geology Field Manual). Soil and rock samples were continuously collected for logging using hydraulically pushed stainless steel core samplers lined with clear acetate liners. After being driven up to the 4-foot length of the liners, the rods were removed from the borehole and the acetate sleeve was removed from the sampling barrel and split apart. The core samples were photographed (Attachment E-3) and preserved onsite in soil core boxes.

Soil and rock core generated during direct push sampling activities were placed into appropriately labeled core boxes for future reference. Core was not generated during the CPT investigation. Head space screening was performed using a PID to assist in the characterization of obvious soil contamination and to assist in personal protection. The PID was equipped with an 11.8 electron-volt lamp. The PID was calibrated daily in accordance with manufacturer's recommendations. Head-space screening was performed by removing a portion of the formation material and immediately placing it in a heavy duty sealable plastic bag. The bag was allowed to sit for a minimum of five minutes and not more than ten minutes. The bag was then opened slightly and a reading was collected using the PID. The reading was documented on the boring log.

An eight-inch diameter protective lockable steel casing and concrete pad was installed around each piezometer completed with an above grade construction. The protective covers for all piezometers, with the exception of temporary piezometer RIPZ-37, were secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the well casing was surveyed for elevation, northing and easting coordinates (Table E-8).

2.1.3.2 Air-Rotary Drilling and Coring Procedures and HSA Drilling

Two chemical quality wells; two piezometers, and one soil boring were drilled and installed using air rotary between September 12 and October 5, 2006 (RIMW-10, -11, RIPZ-29, and -30, and RISB-02). The wells, piezometers, and the boring were drilled by WDC. Chemical quality wells were drilled and installed to total depths of 60 and 55 feet bgs, and installed within the Upper HSU. Piezometers were screened at depth intervals of 24 to 45 and 31 to 56 feet bgs, and installed within the Upper HSU. Two replacement piezometers were drilled by WDC using the CME-85 rig configured for HSA on October 2, 2006. Table E-2 lists the well and piezometer construction specifications.

Soils and lithologies observed during each well/piezometer installation and boring advancement were logged by a MACTEC, California Registered Geologist, or a field geologist under the supervision of a California Registered Geologist. Soils encountered were described in accordance with the USCS and standard geologic logging techniques. Rock samples were described following the format used by the U.S. Department of Interior Bureau of Reclamation (Engineering Geology Field Manual). Soil and rock samples collected during air drilling were obtained for logging using a 94-millimeter (mm) core barrel from the ground surface to the total depth of the boring, or from the bottom of the surface conductor, to the total depth of the boring. Individual continuous coring run intervals ranged from approximately one-foot to five-foot lengths based on core recovery. Coring methods were performed during the 2006 Phase II RI/FS followed the methods that proved to be the most successful during the 2004 Phase I investigation, with modifications as necessary to improve core recovery. Coring methodologies for the 2004 Phase I and 2006 Phase II investigations are described in Section E3.1. The samples were photographed (Attachment E-3) and preserved onsite in core boxes. Replacement piezometers RIPZ-31-B and -33-B were logged via drill cuttings only.

Upon completion of coring activities, the drill pipe and coring assembly were removed and the borehole opened to approximately 6.5 inches (piezometers) and approximately 8.5 inches (wells) using an air rotary tri-cone rock bit. Upon completion of drilling activities using the CME 85 drilling rig configured for HSA, the polyvinyl chloride (PVC) well materials were lowered to the bottom of the boring through the center of the HSA.

Head space screening was performed using a PID to assist in the characterization of obvious soil contamination. The PID was equipped with an 11.8 electron-volt lamp, and was calibrated daily in accordance with manufacturer's recommendations. Head-space screening was performed by removing a portion of formation material from the core barrel and immediately placing it in a heavy duty sealable plastic bag. The plastic bag was allowed to sit for a minimum of five minutes and not more than ten minutes. The plastic bag was then opened slightly and a reading was collected using the PID. The reading was documented on the boring log. Head space readings were subsequently used to segregate clean from contaminated drill cuttings during placement of spoils into roll off soil bins.

An approximately eight-inch diameter protective lockable steel casing and concrete pad was installed around each well and piezometer. The protective cover was secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the well casing was surveyed for elevation, northing, and easting coordinates. Elevation information is summarized on Table E8.

2.1.3.3 Hydropunch Boring Procedures

Six hydropunch borings (RIHP-1 through RIHP-6) were installed on January 4 and 5, 2007. The borings were pushed to obtain reconnaissance Upper HSU groundwater samples in areas south of the PSCT. The boreholes were advanced using a CPT rig to target depths agreed upon in the field between representatives of the CSC and USEPA. Upon removal of the CPT push rods, temporary slotted and blank Schedule 40 PVC casing was placed within the open borehole to insure that the holes remained open while awaiting the inflow of groundwater. Bentonite seals were subsequently placed around the PVC casing at the surface to prevent surface water runoff into the borehole. Five of the six hydropunch borings were sampled for volatile organic compounds (VOCs) by EPA Test Methods 8260 and 504.1 (RIHP-1 through –HP-5) and two locations (RIHP-1 and -5) were also sampled for semi-volatile organic compounds (SVOCs) by EPA Test Method 8270. Insufficient groundwater volume precluded sampling for 8270 from hydropunch locations RIHP-3 through -4, or 8260 from RIHP-6. The temporary casings for hydropunch locations RIHP-1 through -6 were abandoned during the April 2007 semi-annual groundwater monitoring event.

A seventh hydropunch boring (RIHP-7) was installed May 22, 2007. RIHP-7 was advanced using a Rhino direct push rig to a target depth agreed upon in the field between representatives of the CSC and the USEPA. The borehole was continuously cored to the total depth of 40-feet bgs using direct push core barrel lined with a clear acetate sample liner. Temporary slotted and blank Schedule 40 PVC casing was placed within the open borehole to insure that the hole remained open while awaiting the inflow of groundwater and sealed at the surface similar to RIHP-1 through RIHP-6. RIHP-7 was subsequently sampled for VOCs and SVOCs. The temporary casing, with a slotted interval of between 20 and 40-feet bgs, remains in place.

2.1.4 Borehole Geophysical Logging

To assist in characterization and the determination of screened intervals, selected boreholes were logged using video and geophysical instruments by Welenco, of Bakersfield, California upon completion of drilling activities. The purpose of continuous coring, video logging, and geophysical logging was to attempt to identify the locations of lithologic contacts, fracture zones, and zones that produced water. This information was used in determining the well design or the need for further drilling. The downhole geophysical logging methods listed below were used on select boreholes:

- Digital Optical Borehole Televiewer
- Digital Acoustic Borehole Televiewer
- Down hole Side Scan Video
- Natural Gamma Induction

Table E-3 summarizes the coring and geophysical logging program that was performed for both the 2004 Phase I and 2006 Phase II events. The methodology used for selecting which vertical intervals to core and video or log using geophysical instrumentation during the RI/FS, consisted of reading the June 2004, RI/FS Work Plan, Volume 3. As detailed in EPA approved Table E-6: Well and Piezometer Drilling and Logging Program, located in Appendix A, all Upper HSU wells and piezometers drilled during the Phase I event, using the ARCH rig, were continuously cored from ground surface to the total depth, at which point a downhole and side-scan video survey of the open borehole was performed from immediately below the temporary surface conductor casing to the total depth drilled. Wells drilled in areas of fill had the temporary surface conductor placed to deeper depths, as necessary. All wells and piezometers drilled during the 2006 Phase II event using air rotary were also continuously cored from ground surface to the total depth, at which point a downhole and side-scan video survey of the open borehole was performed from immediately below the temporary surface conductor casing to the total depth drilled.

During the 2004 Phase I RI/FS, as detailed in Table E-3, geophysical, optical acoustic televiewer logs, and downhole and side-scan video surveys were also performed in one soil boring (RISB-01), four Lower HSU wells (RIPZ-10B, -10C, 10D, -15, and -16), one Upper HSU replacement well (RG-11B-2), and one Upper HSU replacement piezometer (RGPZ-10B-2). During the 2006 Phase II RI/FS, geophysical, optical acoustic televiewer logs, and downhole and side scan video surveys were also performed in one soil boring (RISB-02). The geophysical, optical acoustic televiewer, and downhole and side-scan surveys for all boreholes, with the exception of RIPZ-15 and -16, were performed from immediately below the temporary surface conductor casing to the total depth drilled. In RIPZ-15 and -16, the temporary conductor casings were installed into the Lower HSU to prevent cross contamination between the Upper and Lower HSU. In these wells, the geophysical and video surveys were performed from below the conductor casings to the total depths.

As detailed in Table E-3, all boreholes receiving geophysical and optical acoustic televiewer surveys were continuously cored from the ground surface to the total depths drilled. Two additional Lower HSU wells (RIPZ-10B and -10C), drilled adjacent to RIPZ-10D, were continuously cored and video logged only at the proposed screen intervals identified during the drilling and subsequent video and geophysical logging of RIPZ-10D.

It should be noted that because of the formation lithology and drilling methods used, there was a significant amount of “cleaning” of the borehole wall that was required from deeper borings prior to obtaining useful information from the downhole geophysical equipment. Borings that required cleaning of the formation were RIPZ-10C, -10D, -15, -16, and -17. Cleaning was not required for deep boring RISB-02, drilled during the 2006 Phase II RI/FS, because the borehole was filled with groundwater, and the geophysical logging was not performed until the solids in the water had settled out.

Geophysical and lithological information generated during logging of piezometer RIPZ-10D was used to help determine coring intervals for adjacent “C” and “B” wells. Down hole and side scan video was performed on all of the chemical quality wells, piezometers, and soil borings RISB-01 and -02. The video was useful in identifying water entry and obvious fractures with water entry.

Pdf files of geophysical logs for the 2004 and 2006 RI/FS are included on a CD and presented in Attachment E-2. The following graphs and tables were prepared by Welenco and are included in Attachment E-2 for each geophysical log:

- DUAL INDUCTION GAMMA RAY LOG
- OPTV BOREHOLE IMAGE LOG
- OPTV INTERPRETED DIPS LOG
- OPTV BEDDING AND FRACTURE DATA TABLE
- FRACTURE ANALYSIS LOG
- FRACTURE ANALYSIS STEROGRAMS
- DIP DATA INTERPRETATION TABLE
- FRACTURE DIP AZIMUTH ROSE DIAGRAM
- DIP DATA STRUCTURAL INTERPRETATION LOG
- DIP DATA STRUCTURAL INTERPRETATION STEREOGRAM
- DIP DATA STRUCTURAL INTERPRETATION TABLE

In response to the September 26, 2005 EPA comments on the Interim Progress Report (IPR), additional rose diagrams of bedding were developed and are included in Attachment E-2.

To resolve potential depth discrepancies identified in the December 20, 2002 Well Inventory Report (MACTEC, 2002) existing wells B-5, RP-47C, and T-3D were also video logged during the 2004 RI drilling program. Existing site wells SW-15, RGPZ-8D, RP-3C, and RP-3D, also identified as wells with potential depth discrepancies, were previously video logged in June 2000. The results of the 2000 and 2004 depth discrepancy investigations are presented in the Final Well Inventory Report (MACTEC, 2006).

2.1.5 2004 Phase I RI/FS Chemical Quality Well Installation Procedures

Decisions regarding screened intervals for chemical quality wells were made in consultation with EPA's onsite representative (CH_2M Hill). A summary of coring, video, and downhole geophysical logging results was provided to EPA's representative for discussion and interpretation prior to finalizing well construction details and completing the well.

All chemical quality monitoring wells were constructed using 4-inch diameter Schedule-40 flush-joint threaded PVC blank and factory-slotted (0.040 inch) pipe inserted with the slotted interval adjacent to the Upper HSU zone to be monitored. Stainless steel centralizers were attached above and below the screened section of the PVC casing in the borehole. The sand pack consisted of Monterey medium aquarium sand placed slowly to prevent bridging. The sand pack extended from the bottom of the borehole to approximately three feet above the top of the well screen. At least three feet of bentonite pellet seal was placed immediately above the sand pack to prevent intrusion of the overlying bentonite-cement grout material into the sand pack. The bentonite seal was allowed to hydrate sufficiently before subsequent placement of grout. A handful of bentonite pellets was placed in a cup and hydrated at the same time the down hole bentonite seal was hydrated to accurately gauge proper hydration of the seal. Well construction details and boring logs are included in Attachment E-9.

A protective lockable steel casing and concrete pad were installed around each well. The protective cover was secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the well casing was surveyed for elevation, northing, and easting coordinates.

2.1.6 2004 Phase I RI/FS Piezometer Installation Procedures (ARCH)

Decisions regarding screened intervals for piezometers were made in consultation with EPA's onsite representative (CH_2M Hill). A summary of coring, video, and downhole geophysical logging results was provided to EPA's representative for discussion and interpretation prior to finalizing well construction details and completing the piezometer.

All piezometers installed using ARCH techniques were constructed using 2-inch diameter Schedule-40 flush-joint threaded PVC blank and factory-slotted (0.040 inch) pipe inserted with the slotted interval adjacent to the Upper HSU zone to be monitored. Stainless steel centralizers were attached above and below the screened section of the PVC casing in the borehole. The sand pack consisted of Monterey medium aquarium sand placed slowly to prevent bridging. Sand was placed using a tremmie pipe in all wells with depths greater than 50 feet. The sand pack extended from the bottom of the borehole to approximately three feet above the top of the well screen. At least three feet of bentonite pellet seal was placed immediately above the sand pack to prevent intrusion of the overlying bentonite-cement grout material into the sand pack. The bentonite seal was allowed to hydrate sufficiently before subsequent placement of grout. A handful of bentonite pellets was placed in a cup and hydrated at the same time the down hole bentonite seal was hydrated to accurately gauge proper hydration of the seal.

A protective lockable steel casing and concrete pad were installed around each piezometer. The protective cover was secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the piezometer casing was surveyed for elevation, northing, and easting coordinates.

Temporary steel drive casing was used at RIPZ-15 and RIPZ-16 to prevent cross contamination of the Lower HSU while drilling through known or suspected contamination of the Upper HSU. These areas were predetermined through discussions with EPA’s onsite contractor. The procedures described below were used during the drilling and installation of these two piezometers:

A pilot borehole was drilled and cored from the ground surface to approximately 10 feet into the unweathered claystone.

The pilot hole was opened with an approximately 9 ½-inch diameter bit and 9 ⅝-inch outside diameter (OD) with an approximately 9-inch inside diameter (ID) temporary drive casing to approximately 13 feet into the unweathered claystone. The temporary casing was advanced until the casing shoe was set a minimum of seven feet below the top of the unweathered claystone leaving three to six feet of 9 ½-inch diameter open hole beneath the casing shoe. Any sloughed material was then subsequently cleaned out of the hole. Teflon tape and environmentally safe Teflon pipe compound was added to all threaded connections to ensure the connections were water tight.

Bentonite chips or pellets were then poured through the temporary drive casing until the open borehole beneath the casing shoe and a minimum of three feet of temporary casing were filled. Water was then added to the bentonite and allowed to sit until hydrated as determined by a control sample monitored at the ground surface.

7 ⅝-inch OD temporary steel drive casing (with 6 ⅝-inch ID) was then placed inside the 9 ⅝-inch OD drive casing after the bentonite had hydrated. Teflon tape and pipe compound were added to the threaded connections. In addition, waterproof pipe wrap was added to the outside of each connection.

The 7 ⅝-inch OD temporary drive casing was then advanced until the shoe was even with the bottom of the bentonite seal (a minimum of three feet below the outer casing shoe).

A pilot boring was then cored through the bottom of the bentonite to the anticipated total depth of the boring once the bentonite was fully hydrated. Coring through the bentonite and to the total depth of the hole followed the procedures previously described.

2.1.7 2004 Phase I ¾-inch Diameter Piezometer Installation Procedures

After the pilot CPT borehole was advanced to the target depth, the CPT drive pipe was removed and approximately 2 ½-inch diameter pipe with a disposable tip was driven through the CPT pilot hole to the target depth. A pre-fabricated well consisting of ¾-inch well casing, screen, and sand pack was installed within the drive pipe. The top of the prefabricated screen and sand pack were threaded into the bottom of a prefabricated plug installed to keep grout from reaching and damaging the sand pack. The top of the plug was threaded into a section of blank casing wrapped with a prefabricated bentonite seal, which was in turn flush-threaded into stainless steel ¾-inch ID blank casing extending to just above ground surface. The annular space surrounding the blank flush-threaded pipe was backfilled with bentonite/cement grout or bentonite slurry, poured from the surface through the 2 ½-inch diameter push rod.

2.1.8 2006 Phase II RI/FS Chemical Quality Well Installation Procedures

Decisions regarding screened intervals for chemical quality wells were made in consultation with EPA's onsite representative (CH_2M Hill). A summary of coring, video, and downhole geophysical logging results was provided to EPA's representative for discussion and interpretation prior to finalizing well construction details and completing the well.

Both chemical quality monitoring wells were constructed using 4-inch diameter Schedule-40 flush-joint threaded PVC blank and factory-slotted (0.050 inch) pipe inserted with the slotted interval adjacent to the Upper HSU zone to be monitored. Stainless steel centralizers were attached above and below the screened section of the PVC casing in the borehole. The sand pack consisted of Monterey medium aquarium sand placed slowly to prevent bridging. The sand pack extended from the bottom of the borehole to approximately three feet above the top of the well screen. At least three feet of bentonite pellet seal was placed immediately above the sand pack to prevent intrusion of the overlying bentonite-cement grout material into the sand pack. The bentonite seal was allowed to hydrate sufficiently before subsequent placement of grout. A handful of bentonite pellets was placed in a cup and hydrated at the same time the down hole bentonite seal was hydrated to accurately gauge proper hydration of the seal. Well construction details and boring logs are presented in Attachment E-9.

A protective lockable steel casing and concrete pad were installed around each well. The protective cover was secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the well casing was surveyed for elevation, northing, and easting coordinates.

2.1.8.1 <u>2006 Phase II RI/FS Piezometer Installation Procedures (ARCH and HSA)</u>

Decisions regarding screened intervals for piezometers were made in consultation with EPA's onsite representative (CH_2M Hill). A summary of coring, video, and downhole geophysical logging results was provided to EPA's representative for discussion and interpretation prior to finalizing well construction details and completing the piezometer.

Both piezometers installed using air rotary techniques were constructed using 2-inch diameter Schedule-40 flush-joint threaded PVC blank and factory-slotted (0.020 inch – RIPZ-29 and 0.050 inch – RIPZ-30) pipe inserted with the slotted interval adjacent to the Upper HSU zone to be monitored. Stainless steel centralizers were attached above and below the screened section of the PVC casing in the borehole. The sand pack consisted of Monterey medium aquarium sand placed slowly to prevent bridging. The sand pack extended from the bottom of the borehole to approximately three feet above the top of the well screen. At least three feet of bentonite pellet seal was placed immediately above the sand pack to prevent intrusion of the overlying bentonite-cement grout material into the sand pack. The bentonite seal was allowed to hydrate sufficiently before subsequent placement of grout. A handful of bentonite pellets was placed in a cup and hydrated at the same time the down hole bentonite seal was hydrated to accurately gauge proper hydration of the seal. The two replacement piezometers installed using the CME-85 rig configured for HSA, was constructed using 2-inch diameter Schedule-40 flush-joint threaded PVC blank and factory-slotted (0.020 inch) pipe inserted through the center of the auger. The sand, bentonite and grout seals were subsequently emplaced, using the center of the auger as a tremmie.

A protective lockable steel casing and concrete pad were installed around each piezometer. The protective cover was secured with a lock keyed with the Site master well key. The protective casing was subsequently painted, stenciled, and the piezometer casing was surveyed for elevation, northing, and easting coordinates.

2.1.9 2006/2007 Phase II ¾-inch Diameter Piezometer Installation Procedures

Piezometer installation procedures for the Phase II ¾-inch piezometers were identical to those used during Phase I ¾-inch piezometers, described in Section 2.1.7. After the pilot CPT borehole was advanced to the target depth, the CPT drive pipe was removed and approximately 2.5-inch diameter pipe with a disposable tip was driven through the CPT pilot hole to the target depth. A prefabricated well consisting of ¾-inch well casing, screen, and sand pack was installed within the drive pipe. The top of the prefabricated screen and sand pack were threaded into the bottom of a pre-fabricated plug installed to keep grout from reaching and damaging the sand pack. The top of the plug was threaded into a section of blank casing wrapped with a pre-fabricated bentonite seal, which was in turn flush-threaded into stainless steel ¾-inch ID blank casing extending to just above ground surface. The annular space surrounding the blank flush-threaded pipe was backfilled with bentonite/cement grout or bentonite slurry, poured from the surface through the 2 ½-inch diameter push rod.

For the Phase II ¾-inch piezometers installed in the Central Drainage using direct push, the borehole was advanced to the target depth, and a pre-fabricated well, consisting of ¾-inch well casing, screen, and sand pack was installed within the drive pipe. The top of the prefabricated screen and sand pack were threaded into the bottom of a prefabricated plug installed to keep grout from reaching and damaging the sand pack. The top of the plug was threaded into a section of blank casing wrapped with a pre-fabricated bentonite seal, which was in turn flush-threaded into Schedule 40-PVC ¾ inch blank casing extending to approximately two feet above ground surface. The annular space surrounding the blank flush-threaded pipe for all piezometers except for RIPZ-37 was backfilled with bentonite/cement grout or bentonite slurry, poured from the surface through the 2 ½-inch diameter push rod. The annular space surrounding the blank flush-threaded pipe for RIPZ-37, which is a temporary piezometer, was backfilled with bentonite chips to facilitate easy abandonment. Well construction details and boring logs for Central Drainage piezometers installed in 2007 are included in Attachment E-9.

2.2 Well/Piezometer Development Procedures

A brief description of the well development procedures for chemical quality wells and piezometers installed during the 2004 and 2006/2007 RI/FS is described below. Liquid levels measured in the wells and piezometers before, during, and after development are listed in Table E-4. A summary of final well and piezometer water quality parameters collected during development is provided in Table E-5.

2.2.1 2004 and 2006 Chemical Quality Well Development

Chemical quality well development was completed using a development rig provided by WDC. The total depth of the well and depth to water were measured to calculate the volume of water in the well casing. The measured total depth was compared to the anticipated total depth documented on the boring log to determine whether sediments had accumulated on the bottom of the casing. When necessary, a stainless steel bailer was used to remove the sediments. After the well was reasonably cleared of sediments a surge block was lowered into the casing, and raised and lowered several times (swabbed), across the entire length of the screened portion of the well.

Purging of the water column within the chemical quality wells continued with a stainless steel bailer once swabbing was completed. Water quality parameters measurements (pH, specific conductance, turbidity, oxidation-reduction potential (ORP), dissolved oxygen (DO), and temperature) were made for each casing volume of water removed and then recorded on a development log. Water quality meters were calibrated each morning and documented onto field notes. Water quality parameters were measured in the following units:

- Temperature — Degrees Centigrade (°C)
- Conductivity — micromhos per centimeter (μmhos/cm)
- pH — hydrogen ion index (-log [H^+])
- Turbidity — nephelometric turbidity units (NTU)
- ORP — millivolts (mV)
- DO — milligrams per liter (mg/l).

Water level readings were also recorded during development and used to gauge presence and recovery rates of water within the well casings (Table E-4). In all wells, with the exception of RIMW-1, installed during the 2004 RI/FS, and RIMW-11, installed during the 2006 RI/FS, the recharge of water in the well casing failed to keep up with drawdown of the water table by the bailer. In these cases, well development consisted of dewatering the casing multiple times over a minimum of three days. Due to the ongoing surging action of the sand pack caused by continual bailing of these well casings, and insufficient water recovery, wells were considered developed even though clear, sediment free water may not have been obtained.

The development rig and all downhole equipment were steam cleaned before use at each location. Water removed from the casing during well development was temporarily stored onsite in a 500-gallon portable storage tank and subsequently treated through the PSCT Granular Activated Carbon Treatment System (GAC). Water derived from wells impacted by NAPL's were transported to the PSCT treatment area and subsequently pumped into site tanks designed to contain Gallery Well and Sump 9B liquids.

2.2.2 2004 and 2006 Air Rotary and HSA Piezometer Development

Piezometer well development was completed using a development rig provided by WDC. The total depth of the piezometer and depth to water were measured to calculate the volume of water in the well casing. The measured total depth was compared to the anticipated total depth documented on the boring log to determine whether sediments had accumulated on the bottom of the casing. When necessary, a stainless steel bailer was used to remove the sediments. After the well was reasonably cleared of sediments, a surge block was lowered into the casing and raised and lowered several times (swabbed) across the entire length of the screened portion of the well.

Purging of the water column within the piezometers continued with a stainless steel bailer once swabbing was completed. Water quality parameters (pH, specific conductance, turbidity, Eh, DO and temperature) measurements were made for each casing volume of water removed and recorded on a development log. Water quality meters were calibrated each morning and documented onto field notes.

Water level readings were also recorded during development and used to gauge draw down of water within the well casing. In most piezometers the recharge of water in the well casing failed to keep up with draw down of the water table by the bailer. In those cases well development continued over a period of a minimum of three days. Due to the ongoing surging action of the sand pack, caused by continual bailing of the well casings and insufficient water recovery, wells were considered developed even though clear, sediment free water may not have been obtained. In no cases was a submersible pump used during the development process of piezometers with low yield rates.

The development rig and all downhole equipment were steam cleaned before use at each location. Water removed from the casing during well development was temporarily stored onsite in a 500-gallon portable storage tank and subsequently treated through the PSCT GAC. Water derived from piezometers impacted by NAPL's were transported to the PSCT treatment area and subsequently pumped into site tanks designed to contain Gallery Well and Sump 9B liquids.

2.2.3 2004 Phase I ¾-inch Diameter Piezometer Well Development Procedures

Well development methods for shallow piezometers consisted primarily of airlift techniques for piezometers located within the landfill footprints or the central drainage, and manual bailing, for wells with non-detectable vapors and not impacted by NAPLs. The airlift technique was designed to minimize exposure of noxious chemicals to the worker and the environment.
Piezometers RIPZ-3 and -4 were developed solely using manual bailers. They were purged over a period of several days using appropriately sized bailers designed for ¾-inch diameter wells. Water quality parameters (pH, specific conductance, turbidity, Eh, DO and temperature) measurements were made for each casing volume of water removed and recorded on a development log. Water quality meters were calibrated each morning and documented onto field notes.

Water level readings were also recorded during development and used to gauge draw down of water within the well casing. In both piezometers, the recharge of water in the well casing failed to keep up with draw down of the water table by the bailer. In those cases well development continued over a period of a minimum of four days. Due to the ongoing surging action of the sand pack, caused by continual bailing of these well casings and insufficient water recovery, piezometers were considered developed even though clear, sediment free water may not have been obtained.

Piezometers RIMW-12, and -22 through -26, were developed using the airlift technique. The airlift technique consisted of the following:

A small-valved recovery head was installed on the top of the 1-inch OD casing. The head was equipped with approximately ⅜-inch tubing which was lowered to the bottom of the well casing. Air was introduced at the bottom of the well using a compressor located downwind of development activities. Development water was airlifted up the annular space of the well casing and through an approximate ½-inch diameter hose affixed to the recovery head. Clean downhole tubing was used for each piezometer. Water was discharged into a graduated tank.

Surging of the well casing was performed by repeatedly raising and lowering the bottom of the downhole air tube across the length of the sand pack. Introduction of air into the well column was stopped once fluids from the well were no longer being brought to the surface. The well was the allowed to recover before development activities continued. Vapors collected in the tank were scrubbed through one 55-gallon vapor carbon drum stored at piezometer locations RIPZ-23 through -26. Airlifting was performed from one to three times per well per day over a period of four days. Water level measurements were not collected from piezometers under development once airlift development activities began. Parameter measurements were not collected in wells installed within the landfill footprints and central drainage in areas of known NAPL. Piezometers RIPZ-12 and -22 were developed using both the airlift and manual bailer method. RIPZ-24 and 26 were subsequently swabbed using an appropriately sized surge block. Water removed from the casing during well development was treated through the PSCT GAC. Water derived from piezometers impacted by NAPL were transported to the PSCT treatment area and subsequently pumped into site tanks designed to contain Gallery Well and Sump 9B liquids.

2.2.4 2006/2007 Phase II ¾-inch Diameter Piezometer Well Development Procedures

Well development methods for ¾-inch diameter piezometers consisted of airlift techniques for all piezometers with the exception of RIPZ-32, which was manually bailed, and RIPZ-13, which was developed by four days of pumping via a Waterra pump and two days of manual bailing. Some manual bailing was also performed for piezometers RIPZ-14, -35, and -37. Although manual bailing was performed for RIPZ-13 and -14, which were impacted by detectable vapors, the bailing was conducted using Level B Health and Safety respiratory protection. The airlift technique and Waterra pump were used to minimize exposure of noxious chemicals to the worker and the environment. Water quality parameters for ¾-inch diameter piezometers installed during the 2006/2007 RI investigation were not measured for either pH, specific conductance, Eh, DO or temperature due to the presence or likely presence of NAPL in groundwater. Turbidity measurements were measured in four piezometers (RIPZ 14, -31, -32, and -33).

Water level readings were also recorded during development and used to gauge draw down of water within the well casing. For piezometer RIPZ-35, which had undergone development via bailing, there was insufficient recharge of water in the well casing to continue bailing past the first day of development. Due to the surging action of the sand pack, caused by bailing of this piezometer, and insufficient water recovery, the piezometer was considered developed even though clear, sediment free water may not have been obtained.

The airlift technique consisted of the following:

A small-valved recovery head was installed on the top of the 1-inch OD casing. The head was equipped with approximately ⅜-inch tubing which was lowered to the bottom of the well casing. Air was introduced at the bottom of the well using a compressor. The compressor was located downwind of development activities. Development water was airlifted up the annular space of the well casing and through an approximate ½-inch diameter hose affixed to the recovery head. Clean downhole tubing was used for each piezometer. Water was discharged into a graduated tank. Surging of the well casing was performed by repeatedly raising and lowering the bottom of the downhole air tube across the length of the sand pack. Introduction of air into the well column was stopped once fluids from the well were no longer being brought to the surface. The well was the allowed to recover before development activities continued. Vapors collected in the tank were scrubbed through one 55-gallon vapor carbon drum temporarily stored in the back of a MACTEC truck. Airlifting was performed from one to six times per well per day over a period of three to four days. Water level measurements were not collected from piezometers under development once airlift development activities began. Replacement piezometer RIPZ-34-B was developed over one day using the airlift technique.

The Waterra pump was used in piezometer RIPZ-13 because multiple attempts at airlifting were unsuccessful and liquid level recharge into the well casing exceeded the rate of liquids removal during two days of manual bailing. Liquids and vapors generated using the Waterra pump in piezometer RIPZ-13 were contained the same as those generated using the airlift technique.

Water removed from the casing during well development was treated through the PSCT GAC. Water derived from piezometers impacted by NAPL were transported to the PSCT treatment area and subsequently pumped into site tanks designed to contain Gallery Well and Sump 9B liquids, or vacuumed out of the temporary storage tank directly during the routine site liquids off-haul.

2.3 Chloride Diffusion Sampling

Four soil core samples were collected for chloride diffusion during chemical quality well and piezometer installation during the 2004 Phase I RI/FS. One sample was collected from alluvium material encountered in each of RIMW-2 (28 feet bgs) and RIPZ-18 (21 feet bgs), one sample was collected from weathered mudstone in RIMW-8 (57 feet bgs), and one sample was collected of unweathered mudstone from RIPZ-10B (57 feet bgs). One sample from each of the weathered and unweathered mudstone formations from proposed well RIMW-4 were never collected due to the cancellation of well from the program. During the 2006 Phase II RI/FS, one sample from each of the weathered and unweathered claystone formation was collected, as replacements for the two samples not collected during the 2004 RI/FS. One sample was collected from the weathered claystone in RIMW-11 (13 feet bgs); and one sample was collected from the unweathered claystone in RIMW-11 (53 feet bgs). Chloride diffusion samples were submitted to Golder Associates, Ontario, Canada. In addition to chloride diffusion, the samples were also run for total organic carbon content, total porosity, specific gravity and density.

2.4 NAPL Observations During Drilling and Development

NAPL presence in the new wells and piezometers was investigated during drilling activities in both the 2004 Phase I and the 2006/2007 Phase II RI/FS. Table E-6 summarizes the NAPL observations. NAPL observations included: inspection of core samples for chemical sheens, discoloration, and odors; organic vapor monitor (OVM) monitoring of volatile chemicals in bagged soil samples; downhole video observation; and gauging of NAPL in open boreholes and completed wells and piezometers. The OVM readings are listed on the new well and piezometer boring logs (Attachment E-9), and NAPL observations during and after development are listed in Table E-4, and on the well development forms and presented as pdf files on CD in Attachment E-4. Additional discussion of DNAPL levels in the Phase II piezometers installed in the P/S Landfill in 2007 is provided in Section 3.2 and in Appendix F.

2.5 Landfill Cap Liner Repair

Landfill cap liners penetrated by the RI boreholes were repaired in accordance with the procedures specified in the RI/FS Work Plan. Table E-7 summarizes the landfill cap liner repair program. Field Lining Systems conducted the repairs in October 2004. The sites repaired were RISB-01, (near the northern edge of the CC Landfill), RIPZ-12 (southern edge of the Metals Landfill), RIPZ-21 (western portion of the Acids Landfill - piezometer not installed), RIPZ-22 (southern edge of the CC Landfill), RIPZ-23 (west of the Gallery Well), and RIPZ-24 (east of the Gallery Well).

Liner repairs for 2006 Phase II piezometer RIPZ-14, installed in the P/S Landfill, was performed by URS site personnel in October 2006. The liner repairs for 2007 Phase II piezometers RIPZ-13, -27, -38, and -39, also installed in the P/S Landfill, was also performed by URS Corporation (URS) in November 2007.

Soil borings drilled under the direction of Environmental Resources Management (ERM) and URS in the southern portions of the P/S Landfill Cap Liner near the Gallery Well also were sealed by Field Lining Systems during October 2004.

The following reports documenting the 2004 and 2007 HDPE liner repairs, signed by California licensed Professional Engineers (PEs), are included in Attachment E-5:

- *HDPE Penetration Repair Documentation Report, Casmalia Hazardous Waste Management Facility, Casmalia, California*, dated February 2, 2005 by MACTEC; and

- 2007 HDPE Penetration Repair Documentation Report, Casmalia Hazardous Waste Management Facility, Casmalia, California, URS Project no. 28906580, dated January 18, 2008.

The 2006 HDPE liner repair in the vicinity of RIPZ-14 is documented in a March 28, 2007 email from Anthony Colera of URS, included in Attachment E-5.

2.6 Surveying

Land surveying of eight new chemical quality wells, 24 new piezometers, replacement wells RG-11B-2 and RGPZ-10B-2, and soil boring RISB-01, installed during the 2004 Phase I RI/FS was performed by Pacific Engineering, Santa Maria, California on December 13, 17, and 22, 2004. Land surveying of two new chemical quality wells, nine new piezometers, replacement piezometers RIPZ-31-B and RIPZ-33-B, and soil boring RISB-02 was performed by Pacific Engineering on October 16 and 17, 2006; and surveying for six hydropunch locations and one replacement piezometer (RIPZ-34-B), was performed by Cannon Associates (formally Pacific Engineering), on March 7 and 8, 2007. All wells and piezometers were measured for northing, easting, casing elevation and ground surface elevations to the nearest 100th of a foot using the historical site datum (Table E-8). Soil borings RISB-01 and RISB-02 were measured for northing, easting, and ground surface elevation. The hydropunch locations were measured for northing, easting, and top of the temporary casing.

The four 2007 Phase 2 P/S Landfill piezometers were surveyed on August 29, 2007. Hydropunch location RIHP-7 was located using global positioning system (GPS) technology by URS.

In addition to the above, seven previously installed monitoring wells were resurveyed in December 2004 by Pacific Engineering to confirm accuracy of prior readings (RG-5B through RG-11B). Coordinates generated during surveying activities for these wells were used to update Figure E-1.

2.7 Deviations from the RI/FS Workplan

All of the well and piezometer installations were conducted in accordance with the procedures described in the RI/FS Work Plan, SAP, and QAPP. Minor deviations from the procedures specified in the Work Plan (i.e., waiver of video requirement for direct push alluvial boreholes, and waiver of installation of piezometer RIPZ-1 and well RIMW-4) were approved by EPA as documented on the RICFs (Appendix Q). Piezometer RIPZ-21 (Acids Landfill) was not completed due to CPT refusal, and piezometer RIPZ-7 (PSCT-2 area) currently is dry.

3.0 INVESTIGATION RESULTS

This section presents the results of the well and piezometer drilling and installation activities conducted during the 2004 and 2006 RI/FS investigation. Included in this section are evaluations of core quality and downhole geophysical results; a summary evaluation of subsurface conditions encountered including lithologies, HSU contact surface elevations, bedding and fracture data; and well and piezometer development performance.

3.1 Drilling and Coring Methods and Core Quality

This section describes the air rotary coring methods used and results achieved. Maximizing core quality was a task objective from the onset of the drilling and coring efforts, in order to obtain the best possible information on subsurface lithologies and fracture distribution. Several different drilling and coring methods were employed during the start of 2004 RI/FS in order to produce core of sufficient quality. The evolution of the different coring methods deployed during drilling of soil boring RISB-01 and piezometer RIPZ-10D are briefly described below. Final drilling and coring procedures utilized for piezometer RIPZ-10D were deemed successful by the EPA, and these specific methods used for the other wells and piezometers installed after RIPZ-10D in 2004. These procedures proved to be less successful during the 2006 drilling program and further adjustments were made during the installation RIMW-10 that were employed during the advancement of subsequent borings. It should be noted that throughout the weathered and unweathered claystone formations, there are random intervals of weaker and fractured materials that do not lend themselves to providing intact and good quality core samples.

3.1.1 Deep Soil Boring RISB-01

Initially, a 94-mm finger bit with a five-foot length solid continuous core barrel was utilized. Individual coring run intervals were from approximately one to five-foot lengths in an attempt to produce good quality core and sufficient recovery. This technique was subsequently abandoned due to the fractured nature of the core recovery.

The first modification to the coring method occurred at a depth of 55-feet bgs. The modification consisted of using a face discharge stratapack bit with a 1.5-inch protrusion. This technique was also subsequently abandoned due to the fractured nature of the core recovery.

Next, a face discharge stratapack bit with a 2½-inch protrusion was used in conjunction with one and two-foot coring runs. This method was abandoned due to poor core recovery.

Next, a stratapack face discharge bit with a 3 piece shoe was attempted using a one foot run. This method was abandoned and the 3 piece shoe was replaced with a solid shoe. This method was attempted with successive one-foot runs, both with and without added water. The core quality using this method showed mechanical breakage but not as bad as previous runs. A source water sample of rig water was collected for analyses and submitted to BC Analytical Laboratories (BC Laboratory), Bakersfield, California.

At 63-feet bgs, a face discharge soil bit with add-on recessed finger bits with a 5-inch OD was then attempted for a one foot run and abandoned. The rock bit was removed and a finger bit with a 4.5-inch protrusion was added. Coring resumed following this method with the occasional addition of rig water. Individual coring runs ranged from two to five foot lengths. The core recovery improved to nearly 100 percent following this method. However, some glazing of the sides of the core was observed.

From 151 to 156-feet bgs, the finger bit was removed and a face discharge strata pack bit with no protrusion on the lead lip shoe was then attempted, as specified in the work plan. No core was recovered during this interval. A face discharge strata pack bit with a five-foot split barrel and a 6.5-inch protrusion was then attempted from 156 to 161-feet bgs. No core was recovered during this interval.

A finger bit with a five-foot split barrel and a 4.5-inch protrusion was then run from 161-feet bgs. This configuration was continued using five foot runs to the total depth of the boring at 255-feet bgs. Different rotation speeds and down hole pressures were attempted. Core recovery was mostly 100 percent with few exceptions. Some glazing was noted.

3.1.2 Deep Piezometer RIPZ-10D

Initially, a 94-mm strata core face discharge bit with a retractable shoe on a spring loaded five-foot length core barrel was utilized. Individual coring run intervals were five-foot lengths. This technique was subsequently abandoned due to core recovery and quality.

A lead lip shoe was added for one coring run from 20 to 25-feet bgs. No core was recovered during this interval. A retractable shoe was added at 25-feet bgs. Drilling resumed to 70-feet bgs using this method for coring runs of 2½ to 5-foot length. Core recovery was 100 percent during this interval. Drilling continued from 70 to 95-feet bgs using a lead lip shoe. Core recovery was moderately good. However, some portions displayed evidence of mechanical breakage.

At 95-feet bgs, drilling continued using a retractable shoe, punch core. Drilling continued to 113-feet bgs with mostly 100 percent core recovery. This method was abandoned after the punch core samplers were damaged. Coring continued from 113-feet bgs using a lead lip shoe. Core recovery using the lead lip shoe was poor. The lead lip shoe was abandoned at 129-feet bgs and another punch core was added. Drilling resumed using the punch core and the addition of rig water to the total depth of 240-feet bgs.

As a consequence, the stratapack bit with the retractable shoe punch core was used throughout the remainder of the 2004 drilling program.

3.1.3 Upper HSU Well RIMW-10

A CME-85 drilling rig equipped for Air-Rotary was employed during the 2006 drilling program, as WDC did not have an ARCH rig available in time to meet the schedule of the investigation. Eight-inch diameter HSAs were initially used as temporary conductor casings, though WDC switched to 10-inch HSAs during the first hole drilled (RIMW-10) to improve circulation.

The stratapack bit with retractable shoe punch coring methodology refined during the 2004 program was initially employed, but this method did not yield acceptable core. New coring equipment was ordered by WDC on September 12, 2006, although it did not arrive at the site until September 14, 2006 due to a fire on California Interstate 5 on September 13, 2006. The first coring method attempt on September 14, 2006 consisted of two 2.5-foot coring runs between 25 and 30-feet bgs using a three piece extended shoe with a step out carbide bit, a 5-foot core barrel, and HQ rods. At 30-feet bgs, WDC experienced circulation problems, so switched back to a stratapack bit and cored between 30 and 43 feet-bgs in six core runs ranging from 1½ to 3-feet in length. They subsequently switched back to the three piece extended shoe bit at 43-feet bgs, and continued drilling with acceptable core results, but continued circulation problems. The circulation problems were ultimately remedied by switching to a larger compressor and replacement of hoses.

The coring for the remainder of the 2006 air rotary drilling investigation was performed using a three piece extended shoe with a step out carbine bit and variations of air flow, regulated by the drillers based on the quality of core at each drilling location. This method produced acceptable core.

3.2 Results of Downhole Geophysical Logging

Downhole and sidescan videos were performed at all air rotary well and piezometer locations during the 2004 and 2006 RI/FS to assist in identifying water entry and obvious fractures with water entry. In an attempt to better identify rock lithology, fractures and bedding and their orientations, an optical-acoustic borehole televiewer was also used in the deeper boreholes RIPZ-10D, RIPZ-15, RIPZ-16, RIPZ-17, RI-SB-1, RG-11B-2, and RGPZ-10B-2, for wells drilled during the 2004 Phase I RI/FS, and RISB-02, during the Phase II RI/FS. In addition, gamma logs were also performed at the deeper boreholes to identify possible changes in rock lithology as indicated in contrasts in natural gamma radiation. Table E-3 summarizes the coring and geophysical logging program that was performed at each of the wells and piezometers. Pdf files of geophysical logs are included on a CD and presented in Attachment E-2.

3.2.1 Downhole Video and Gamma Logging

It should be noted that because of the formation lithology and drilling methods used, there was a significant amount of “cleaning” of the borehole wall that was required prior to obtaining useful information from the downhole geophysical equipment. Borings that required additional drilling (deepening) based on conditions encountered, were subsequently video logged again upon completion of drilling activities.

The geophysical and video results were generally very good. Clear televiewer images were provided which allowed identification of bedding and fracture zones. Interpretations of televiewer output were provided by Welenco and where fractures were identified, notations are made directly on the logs by Welenco (Attachment E-2). Side-scan video of the borehole provided the most useful information regarding water entry to the borehole and fractured areas. Most decisions regarding well and piezometer screened intervals were made based on comparison of core sample fracture data with side-scan video, gamma, and televiewer results. The grouping of fractures and bedding planes shown on the stereonets in Attachment E-2 were manually chosen by Welenco personnel during their analyses of the data. The grouping of fractures and bedding planes was not an automatic function of the program. Welenco used their experience and judgment to choose in the groupings.

Subsequent stereonet analyses of bedding and fracture planes were performed and are discussed in detail below.

Note that information presented on the boring logs include field descriptions of the core, core recovery, drilling conditions (i.e., hard drilling, soft drilling), and well construction details, along with observations of fractures, color changes, evidence of water, and any other relevant observations during the downhole video and optical televiewer surveys. All observations from the geophysical video surveys were noted onto the field copy of the boring log by the field geologist and subsequently entered into the boring log database. No process was employed to over-ride the original core description, as the information from both the core and the video survey was added to the final boring log. The boring logs do not contain information generated by the geophysical logs.

3.3 Subsurface Lithologies and Structure

This Section discusses the subsurface conditions encountered during coring and logging of the new wells and piezometers installed during the 2004 and 2006 Phase I and II RI/FS. Included herein are brief discussions of the lithologies observed and distribution of the Upper/Lower HSU contact surface observed to separate the fill, alluvium, and weathered claystone from the unweathered claystone.

3.3.1 Lithologies

Well completion details and logs of borings for the chemical quality wells and piezometers installed during the 2004 and 2006 RI/FS are provided in Attachment E-9. A summary of well construction details is included in Table E-2.

In the chemical quality wells, brown and grayish brown fill and alluvium, consisting of clayey gravel with sand, sandy lean clay, lean clay with sand, silty sand, clayey sand, and lean clay was encountered in well boreholes from the ground surface to depths varying from 0.5 to 67 feet bgs. Grayish brown and olive brown weathered claystone/mudstone was encountered underlying the fill and alluvium material in all well boreholes with the exception of RIMW-9, which was completed within alluvium. The weathered claystone/mudstone was underlain by unweathered claystone/mudstone in all of the chemical quality wells, with the exception of RIMW-3, which was completed within weathered bedrock, at depths ranging from 8 to 60-feet bgs. A typical 1 to 4-foot transition zone was noted between the weathered claystone/mudstone and the underlying unweathered claystone/mudstone.

Lithologies encountered in the piezometers and replacement well and piezometers included brown, gray, and brownish gray fill and alluvium, consisting of clayey gravel with sand to lean clay, were encountered in all piezometer boreholes with the exception of RIPZ-11, from the ground surface to depths varying from 0.1 to 65 feet bgs. Grayish brown weathered claystone/mudstone was encountered underlying the fill and alluvium material in all piezometer boreholes with the exception of piezometers RIPZ-5, -RIPZ-32, RIPZ-33, RIPZ-33-B, RIPZ-34, RIPZ-35, and IRPZ-37, which were completed within alluvium. The weathered claystone/mudstone was underlain by unweathered claystone/mudstone in all piezometers, with the exception of RIPZ-4, RIPZ-29, RIPZ-31, and RIPZ-31-B, which were completed within weathered bedrock, at depths ranging from 18 to 62-feet bgs. A typical 1 to 4-foot transition zone was noted between the weathered mudstone and the underlying unweathered mudstone.

In soil borings RISB-01 and RISB-02, fill, consisting of pale brown gravelly lean clay, and grayish brown lean clay with sand (in RISB-01) and dark gray lean clay (in RISB-02) was encountered from the ground surface to a depths of 12.3 and 10 feet bgs, respectively. The fill was underlain by weathered claystone/mudstone from 12.3 feet to 41.4 feet bgs in RISB-01, and from 10 feet to 28 feet bgs in RISB-02. A weathered/unweathered transition zone from 41.4 to 54.7 feet bgs was present in RISB-01, which was underlain by unweathered mudstone from 54.7 feet to the total depth of 255 feet bgs. The weathered claystone in RISB-02 was underlain by unweathered claystone from 28 feet to the total depth of 252.5 feet. A four-foot section of grayish brown to olive brown, clayey gravel was encountered within the weathered mudstone in RISB-01 at depths of between 21 to 25 feet bgs. The clayey gravel unit is interpreted as being a zone of increased weathering within the already weathered mudstone.

3.3.2 Interpretation of HSU Contact Depths

Lithologies of the continuous core samples collected from the air-rotary and direct push boreholes and inferred from independent downhole geophysical logs performed in the RI and replacement piezometers and chemical quality wells included the following:

- Brown and gray fill and alluvium, consisting of clayey gravel, clayey and silty sand, sandy clay, and lean clay
- Yellowish to Grayish brown and olive brown weathered claystone
- Dark Gray Unweathered claystone.

The distinction between the weathered and unweathered claystone was apparent with respect to color, presence and concentration of iron oxides, claystone density and degree of consolidation, and degree of fracturing. Typically, a 1 to 4-foot transition zone was noted between the weathered mudstone and the underlying unweathered mudstone. Often, an intermediate color change (from more yellowish brown to darker olive or grayish brown) was observed in this transition zone. These transitions were apparent in both the optical televiewer logs and core samples (Attachments E2 and E3). For logging and characterization purposes, the HSU contact depth/elevation was taken to be base of the transition zone.

For CPT Borings, where core samples were not collected, the HSU contact depth was inferred based on tip resistance signature, as described in detail in the RI/FS Work Plan and IPR Appendices K and M. In these borings, the HSU contact was inferred based on a sharp increase in tip resistance, generally from less than 200 to over 500 tons per square foot over a depth interval of a few feet. Note the HSU contact was not encountered in the five RIPZ piezometer boreholes pushed using CPT or in some of confirmation NAPL investigation CPTs (RISBONs). However, the contact was inferred present at the bottoms of the confirmation CPTs (RICPTs) and good correlation was made with contact depths logged in drilled boreholes adjacent to the confirmation CPTs. At 2007 Phase II piezometer RIPZ-27, the determined contact elevation was within one foot of the adjacent Gallery Well. In addition, during the 2007 Phase II piezometer installations, multiple CPT pushes and similar signatures were obtained at three locations (RIPZ-13, -38, and -39). The contact elevations for the 2007 Phase II piezometers determined by CPT were compared with the Phase II geophysical models developed by the CSC and EPA as discussed in Section 3.3.3.

Note the CPT signatures for RIPZ-13 and RIPZ-13a indicated several buried solvent drums may have been pierced during pushing of each CPT. Sharp tip friction “spikes” were observed at depths of around 50 and 70 feet bgs in RIPZ-13 and at a depth of around 65 feet bgs in RIPZ-13A (Attachment E-1). It is possible non-aqueous phase liquids contained in buried drums may have been released during pushing of these CPTs.

3.3.3 HSU Contact Surface

The structural contact surface separating the Upper and Lower HSUs was refined on the basis of new well and piezometer borehole data along with additional CPT data obtained during the confirmation soil boring and NAPL investigation tasks (Appendices K and M).

3.3.3.1 Sitewide Contact Surface

Figure E-2 presents a contour map showing the elevation of the top of the Upper HSU also known as the Upper HSU/Lower HSU contact. Figure E-2 incorporates new RIPZ, RIMW, and RISBBC, RISBON, RIHP, and RICPT contact elevation data.

Note that separate symbols are used to identify cored versus CPT borings on the map, and each boring is labeled and the contact elevation posted. The elevations of major topographic contours are labeled for comparison with the contact elevations. In cases where a contact elevation point is significantly higher or lower than multiple adjacent control points and for clarity in contouring, the contact elevations logged or inferred in a few historical borings and RISBON and RICPT borings are not used in contouring. These discrepancies are limited to a few boreholes, which are identified with a flag on Figure E-2.

The structural contact surface shown on Figure E-2 is generally similar to RI/FS Work Plan Figure 2-31, with additional contact surface refinement specifically within the North Ridge, Burial Trenches, and Central Drainage areas.

3.3.3.2 Contact Beneath the P/S Landfill

HSU contact depths beneath the P/S Landfill were determined from tip friction signatures in the 2007 Phase II CPTs advanced at five locations. These elevations were compared with the Phase II geophysical models developed by the CSC and EPA from Seismic Refraction surveys completed on the toe of the landfill with respect to potential low spots or depressions in the contact surface. Integration of the borehole contact data with the geophysical investigation results is further discussed in Appendix L. The contact elevations determined from CPT at each piezometer location were within the accepted “margin of error” of the estimated contact elevations determined from the geophysical models.

During the 2007 Phase 2 P/S Landfill piezometer installation, it was necessary to confirm that the depth counter of the CPT rig was accurate after the total depth was reached at proposed piezometer location RIPZ-39, and it was observed that although the depth counter recorded a total depth of 132-feet, the actual depth based on the number and length of push rods was 123 feet. The discrepancy was determined to be due to a problem with the electrical circuitry of the rig and quickly fixed. A second CPT was advanced at proposed piezometer location RIPZ-39, which demonstrated that the depth counter on the rig matched the length and number of push rods. A second CPT was also driven adjacent to piezometer RIPZ-13, installed the previous day, to insure that the installed depth of the piezometer was placed at the HSU contact. No additional depth problems were noted during the remainder of the 2007 CPT investigation.

The following contact depths and elevations were measured at these P/S Landfill piezometer locations, which are listed from South to North:

3.3.3.2.1 RIPZ-27 North of Gallery Well

RIPZ-27 was installed in 2007 approximately nine feet north of the Gallery Well on the access road. The HSU contact was encountered at a depth of 77.65 feet bgs (elevation 481.86 feet above mean sea level [amsl]), which corresponds to an increase in tip resistance; CPT refusal was encountered at a depth of 78.00 feet bgs. This elevation is within one foot of the HSU contact elevation at the adjacent Gallery Well (481.23 feet amsl). This elevation is also close to the HSU contact Elevation determined at this location from the CSC's geophysical modeling, but lower than the elevation determined by EPA from their geophysical model. Liquid level measurements obtained during and after piezometer development had not indicated the presence of DNAPL in RIPZ-27 until September 2009. Since September 2009, the DNAPL thickness has ranged from 2.84 to 6.75 feet in September and December 2009, respectively.

3.3.3.2.2 RIPZ-38 West of Gallery Well

RIPZ-38 was installed in 2007 approximately 52 feet west of the Gallery Well on the access road. This piezometer was located east of an inferred low spot identified by EPA, which occurred farther west along the access road but was identified beneath the western portion of the Gallery Well clay barrier. The actual location investigated was between the Gallery well and the inferred western low spot. The HSU contact at RIPZ-38 was encountered at a depth of 75.5 feet bgs (elevation 487.44 feet amsl), which corresponds with a sharp increase in CPT tip resistance and pore pressure at that depth (CPT RIPZ-38A). This elevation is 6.21 feet higher than the HSU contact elevation at the Gallery Well (481.23 feet amsl), and higher than the HSU contact elevations determined at this location by both the CSC and EPA geophysical models. Liquid level measurements obtained during and after piezometer development have not indicated the presence of DNAPL in RIPZ-38. A second CPT boring (RIPZ-38a) was advanced at this location to confirm the HSU contact depth determined by the first boring. CPT RIPZ-38 was advanced to a depth of 74.6-feet bgs, and RIPZ-38a was advanced to 75.5 feet later that day. The larger diameter pipe used to install the pre-fabricated piezometer was subsequently advanced to 80 feet bgs.

3.3.3.2.3 RIPZ-13 on P/S Landfill Bench 1 Road

RIPZ-13 was installed in 2007 approximately 150 feet north-northwest of the Gallery Well on the Bench 1 access road. The HSU contact was encountered at a depth of 97.00 feet bgs (elevation 497.55 feet amsl), which corresponds with a sharp increase in CPT tip resistance at that depth followed by CPT refusal at 97.6 feet (CPT RIPZ-13A). This elevation is higher than the HSU contact Elevation determined at this location from the CSC's geophysical modeling, but lower than the elevation determined by EPA from their geophysical model. Subsequent to the installation of piezometer RIPZ-13, the depth counter on the CPT rig was determined to be inaccurate during the first CPT attempt at proposed piezometer location RIPZ-39. Once the problem with the depth counter was corrected, a second CPT boring was advanced adjacent to RIPZ-13 to confirm that the piezometer was installed at the HSU contact. CPT RIPZ-13a was advanced to a total depth of 97.6 feet, which indicated that depth measurements during the original CPT RIPZ-13 were most likely inaccurate (the total depth was recorded as 105.3 feet), but that the installed depth of the piezometer was correct.

Liquid level measurements obtained from the piezometer indicate that the DNAPL thickness had remained stable following well development at approximately 14 feet from December 2007, until March 2009. In March and April 2009, URS performed an eight day purge and recovery test in the well to determine the rate and amount DNAPL recharge surrounding the well. Approximately 42-gallons of DNAPL were pumped from the well during the test period. The DNAPL thickness upon completion of the pumping portion of the recovery test was 2.55-feet, which represented a drawdown of 11.05-feet from the 13.6-feet pre-pumping thickness. The DNAPL thickness in RIPZ-13 subsequently recovered to 7.21-feet in a two month period following completion of the DNAPL purging and to 8.47 by March 2010 and continued to rise to pre-test levels of approximately 14 feet over the proceeding months.

3.3.3.2.4 RIPZ-39 on P/S Landfill Bench 2 Road

RIPZ-39 was installed in 2007 approximately 300 feet north-northwest of the Gallery Well on the Bench 2 access road. The HSU contact was encountered at a depth of 123 feet bgs (elevation 512.11 feet amsl), which corresponds with a sharp increase in CPT tip resistance and pore pressure, and CPT refusal at that depth (CPT RIPZ-39a). This elevation is higher than the HSU contact elevations determined at this location by both the CSC and EPA geophysical models. The contact depth at this location was determined during the advancement of a second CPT boring (RIPZ-39a). Although RIPZ-39 was initially advanced to a measured total depth of 132.9 feet, it was determined by the number of push rods used that the actual total depth was 123 feet. An electrical malfunction of the depth counter was determined to be responsible for the discrepancy and immediately repaired. Liquid level measurements obtained during and after piezometer development have not indicated the presence of DNAPL in RIPZ-39.

3.3.3.2.5 RIPZ-14 on P/S Landfill Bench 5 Road

RIPZ-14 was installed in 2006 approximately 680 feet north-northwest of the Gallery Well on the Bench 2 access road. The HSU contact was encountered at a depth of 156 feet bgs (elevation 552.07 feet amsl), which corresponds to the CPT refusal depth. Liquid level measurements obtained during and after piezometer development have not indicated the presence of DNAPL in RIPZ-14.

Additional discussion of the occurrence and distribution DNAPL beneath and downgradient of the P/S Landfill is contained in Section 3.5, below, and in Appendix F, and discussion of the geophysical surveys is contained in Appendix L.

3.3.4 Bedding and Fracture Orientations

Planar attitudes of bedding and fracture features noted in the core samples, geophysical logs, and optical televiewer images were analyzed to determine their orientations. Initial structural analyses of bedding and fractures was performed by Welenco for eight new wells, piezometers, and geologic borings at the site using the geophysical logs and televiewer surveys: RIPZ-17, RIPZ-10D, RGPZ-10B2, RG-11B2, and RISB-01 located along the North Ridge; RIPZ-15 and RIPZ-16 located between the toe of the PCB landfill and the PSCT Trench, and RISB-02 located in the Central Drainage. Fracture and bedding orientations were plotted on Schmidt lower hemisphere stereographic projections and rose diagrams to evaluate trend frequencies by Welenco. All fractures and dip orientations identified by Welenco on the televiewer logs are summarized in Table E-9. Rose diagrams of fracture and bedding dips in each borehole in the Study Area are presented on Figure E-3. Figures E-4 and E-5 present the Structural Interpretation Logs and Fracture Analysis Logs in each borehole.

After review of the Welenco analyses, additional Schmidt and rose diagrams were created from the bedding and fracture data for the purpose of evaluating the orientations collectively, as well as by depth relative to the HSUs. The bedding and structure data sets were also grouped by depth below the HSU contact, at depth intervals corresponding to the depths of the MODFLOW groundwater flow model layers (i.e., 0-25 feet below HSU contact, corresponding to Model Layer 4 – see Appendix F). These additional Schmidt and rose diagrams are shown on Figures E-6 through E-21. In order to evaluate fracture frequency, the cumulative numbers of fractures from the televiewer logs for each deep boring were plotted against depth for each borehole and are presented in Figure E-22. Similar plots of cumulative fractures vs. depth for borings completed during the Summer 2000 drilling program were first presented in the RI/FS Workplan and are republished in this Appendix as Figures E-23 through E-26 for reference.

3.3.4.1 Bedding

Bedding features of both the Upper and Lower HSU units were identified on the basis of lamina and color changes, as observed in the optical televiewer images (Attachment E-2) and core samples (Attachment E-3). Planar attitudes of the bedding features were measured on the basis of the televiewer logs and Illustrated in Figures E-3, E-4, and E-14 through E-17. In the western portion of the North Ridge area (Wells RGPZ-10B-2, RIPZ-10D, RIPZ-17, and RG-11B-2), bedding is characterized by an average dip of 8.6°. In boring RISB-01, on the eastern side of the North Ridge, geophysical logging indicates that the average dip of bedding increases to 17.4°. In the center of the site near the Burial Trenches, wells RIPZ-15 and RIPZ-16 show that bedding angles tend to decrease to an average dip of 7.3°. In the central drainage, bedding within RISB-02 maintained an average dip of 19.4 degrees with the exception of two features at approximately 205 and 206 feet bgs. Though identified as bedding on the televiewer logs, the planes that dip 76 and 79.1 degrees to the north east, respectively, are more likely fractures. Only four bedding planes were identified in the Upper HSU as illustrated in Figures E-14 and E-15; all in RISB-01.

Strike of the Upper and Lower HSU low-angle beds is variable; the Upper HSU bedding exhibits a mean dip direction to the south-southwest, while Lower HSU bedding dips predominantly to the northeast (Figure E-14). Within the Lower HSU, 50 percent of the bedding planes identified occurred between 0 and 75 feet below the HSU contact (model Layers 4 and 5) and 40 percent occurred between 75 and 150 feet below the HSU contact (model Layer 6) as illustrated in Figures E-16 and E-17.

By the very nature of the weathered claystone matrix, groundwater flow through “bedding planes” is likely in the Upper HSU. However, groundwater flow through bedding planes in the Lower HSU is not likely; within this unit, primary bedding is described as lamina indicating primary bedding planes have not been buckled to create flowpaths. Further video logging of boreholes show that where water enters the boreholes, it is generally associated with fracturing and not stratigraphic features (Woodward-Clyde Consultants and Canonie Environmental, 1989).

3.3.4.2 Fractures

3.3.4.2.1 North Ridge Area

Borings RIPZ-17 and RIPZ-10D are located on the North Ridge above the PCB Landfill. Steeply inclined fractures dipping roughly between north and northeast constitute 100 percent of those observed in the Upper HSU at Boring RIPZ-17 as illustrated in Figure E-11. A fracture zone with a mean dip of 65 degrees to the north-northeast and a true thickness of 4.9 feet is identified in the Upper HSU between 15 and 26 feet bgs. Fractures steeply dipping, or near-steeply dipping to the north-northwest constitute 67 percent of those in the Lower HSU. Two subhorizontal fractures were also observed dipping to the west and northeast. At RIPZ-10D, subhorizontal fractures dipping to the south-southeast constitute 77 percent of those observed in the Upper HSU, with a smaller number of moderately inclined fractures (30°-60°) dipping to the north-northeast as illustrated in Figure E-8. Subhorizontal fractures constitute 70 percent of those in the Lower HSU with one moderately inclined and two steeply inclined fractures also observed, all dipping generally to the northeast.

Borings RG-11B-2 and RGPZ-10B-2 are located to the east of RIPZ-17 and RIPZ-10D north of the Pesticide/Solvent Landfill. Subhorizontal fractures dipping approximately east to southeast constitute 52 percent of those observed in the Upper HSU at boring RG-11B-2. A moderately inclined set dipping north-northwest is also present as illustrated on Figure E-7. A fracture zone with a mean dip of 16 degrees southeast and a true thickness of 6.5 feet is identified in the Upper HSU between 18 and 25 feet bgs with. Subhorizontal fractures dipping generally to the northeast constitute 67 percent of those observed in the Lower HSU. Three other moderately and steeply inclined fractures were observed dipping due north and southeast. Subhorizontal fractures dipping between the north and east, or to the southeast constitutes 80 percent of those observed within the Upper HSU at Boring RGPZ-10B-2 as illustrated on Figure E-6. Two fracture zones are identified within the Upper HSU between 16-19 feet and 21-26 feet bgs. The zones have mean dips to the northeast of 12 and 17 degrees, and true thicknesses of 3.4 and 4.6 feet, respectively. Three fractures were observed within the Lower HSU at RGPZ-10-B2; all subhorizontal with a mean dip to east.

RISB-01 is located on the North Ridge, above the Caustic/Cyanide Landfill and near the eastern border of the site. Three fractures were observed in the Upper HSU at boring RISB-01; two subhorizontal dipping southwest and northwest, and one steeply inclined dipping north-northwest as illustrated in Figure E-12. Fractures in the Lower HSU are exclusively steeply inclined and generally dip to the southeast; there was only one measurement to that did follow this trend.

3.3.4.2.2 Burial Trench Area

Borings RIPZ-15 and RIPZ-16 are located in the center of the site near the burial trenches. At RIPZ-15 the Upper HSU extends to 60 feet bgs and the televiewer log begins at 74 feet bgs, providing only Lower HSU data. Steeply inclined fractures constitute 63 percent of those observed, half of which dip to the northwest as illustrated in Figure E-9. One subhorizontal fracture (<30 degrees) was observed dipping to the east-southeast. A fracture zone with a mean dip of 68 degrees to the northwest is identified in the Lower HSU between 156 and 158 feet bgs with a true thickness of 0.7 feet. Boring RIPZ-16 was also cased below the HSU contact and televiewer log provides only Lower HSU data. Two subhorizontal and four moderately to steeply inclined fractures with a mean dip direction to the southeast were observed as illustrated on Figure E-10.

3.3.4.2.3 Central Drainage Area

At RISB-02 in the Central Drainage, the Upper HSU extends to 28 feet bgs and the televiewer log begins at 45 feet providing only Lower HSU data. Subhorizontal fractures constitute 47 percent of those observed as illustrated on Figure E-13. A wide range of moderately and steeply inclined fractures are also present. Dips tend to be to the northwest and southeast, with a mean dip of near horizontal. An open fracture dipping 34 degrees northwest is identified on the televiewer log between 186 and 187 feet bgs with a true thickness of 0.4 feet. DNAPL was observed to actively enter the borehole water column from Lower HSU fractures during downhole video logging and accumulate at the bottom of the 253-foot deep boring to a thickness of approximately 15 feet.

3.3.4.2.4 Fractures by Depth

Figures E-18 and E-19 illustrate all of the fractures observed in the RI boring optical televiewer logs divided by HSU and plotted collectively. The figures illustrate that the weathered Upper HSU contains a greater number of fractures than the unweathered lower, in spite of borings RIPZ-15, RIPZ-16, and RI-SB-02 providing only Lower HSU data. The plots show that subhorizontal fractures and more steeply inclined fractures of varying orientation are common to both the Lower and the Upper HSU. However, the Upper HSU contains a higher proportion of subhorizontal fractures than the Lower HSU. A notable difference between the units is the lack of steeply inclined fractures dipping to the southeast that are present in the Lower HSU, but not the Upper HSU. Much of this disparity owes to the relatively unique fractures observed within the Lower HSU in RISB-01. When plotted on a rose diagram as in Figure E-18, the resultant dip directions for the Upper and Lower HSU are very close at N53E and N57E, respectively.

Figures E-20 and E-21 illustrate fractures observed within groundwater model Layers 4 and 5 (0 to 75 feet below the HSU contact), and 6 and 7 (greater than 75 feet below the HSU contact), respectively. The model layers are defined by depth below the HSU contact; Layer 4 extends 25 below the contact, Layer 5 extends from 25 to 75 feet below the contact, Layer 6 extends from 75 to 150 feet below the contact, and Layer 7 extends from 150 feet to the bottom of the RI borings. The Figures show a decreasing trend in the percentage of subhorizontal fractures with increasing depth below the contact, ranging from 43 percent in Layer 4 to 21 percent in Layer 8. The total number of fractures also displays a decreasing trend with increasing depth below the contact, ranging from 23 and 24 in Layers 4 and 5 respectively, to 14 in Layer 7. The mean dip directions range from northeast and north in Layers 4 and 5, respectively, to south-southeast and east-southeast in Layers 6 and 7, respectively.

Figure E-22 illustrates the cumulative number of fractures noted in the optical televiewer logs for each RI boring plotted against depth. Fracture frequency as indicated by the slope of the curve tends to decrease with depth in these borings, though some fracturing was observed throughout the entire depth of each boring. Similar plots of fractures as observed in core samples, down-hole video, and acoustical (rather than optical) televiewer logs for borings completed during the Summer 2000 drilling program are republished in this Appendix as Figures E-23 through E-26 for reference. These figures illustrate that while fracture frequency decreases with depth in some borings (RGPZ-12D and RGPZ-13D); many others contain significant numbers of fractures throughout the entire depth of the boring. It should be noted that, for multiple reasons, these figures do not necessarily present an accurate accounting of claystone fracturing in the most shallow depth ranges of the borings. Steel conductor casings employed to hold the top of a borehole open during drilling prevent logging the uppermost depths with a televiewer or down-hole video. And in some borings, shallow core was recovered poorly or not at all (RGPZ-3D, RGPZ-4C, RGPZ-16D, RGPZ-6D, and RGPZ-8D) and no fractures were recorded. Although this prevents a clear comparison of relative fracturing between the lower and uppermost reaches within a boring, the figures do illustrate that substantial fracturing is present in some borings to their total depths, which in some cases are greater than 200 feet bgs (RGPZ-11D and RGPZ-16D).

3.3.4.2.5 Summary of Previous Investigations

Woodward-Clyde Consultants performed detailed analyses of the fractures and structural patterns at the site by conducting surface geologic mapping, collecting oriented core samples from vertical and inclined borings, and by mapping and categorizing fractures and bedding exposed in a deep excavation (Woodward-Clyde Consultants, 1988a (HSCER) and 1989 (HSIR)). As part of this RI Report, the CSC conducted the Resource Conservation and Recovery Act (RCRA) Canyon Outcrop Assessment in order to review and affirm the previous work conducted by Woodward-Clyde Consultants. A detailed discussion of the assessment findings is included in Appendix H.

The weathered and unweathered claystone were observed to be massive to faintly bedded, and characterized by low-dipping (3° to 20º) to essentially flat bedding planes with variable strike directions. In general, bedding inclinations were described as steepest in the southern and western areas (5° to 20º) and decreasing to the north (3° to 5º). Though the San Antonio Syncline is mapped roughly paralleling the southwest boundary of the site and the Casmalia Anticline is mapped trending northwest towards the facility (Woodring and Bramlette, 1950), Woodward-Clyde concluded that bedding plane attitudes do not support the presence of either structure in the near-surface beneath the site, and it was noted that the structures may be relatively deep-seated or located adjacent to the site. Stratigraphic correlations based on gamma ray signatures suggest that the site is underlain by broad undulations or low-amplitude flexures with a maximum dip of 3º (Section 5.3.2, Page 5-28, Figure 5.1-1, Woodward-Clyde Consultants, 1988a). Evidence that the weekly expressed horizontal bedding does not provide a pathway for groundwater flow was observed at a seep exposed in an excavation near the caustics landfill. Moisture above the water table was seen traveling vertically through fractures; while the horizontal bedding planes remained dry (Figure 3-5 HSIR, Woodward-Clyde Consultants, 1989). This observation was corroborated by separate dye tracer studies which found that only the most interconnected and open fractures transmitted water during ponding (Appendix A-2, Woodward-Clyde Consultants, 1989).

Core recovery was generally poor in the weathered Upper HSU portions of the boreholes, while core samples from the unweathered Lower HSU showed zones of high and low fracture density. Fracture orientations were plotted on stereographic projections and rose diagrams (Attachment E-7) to evaluate trend frequencies and to compare trends in the weathered and unweathered claystones (Woodward-Clyde Consultants, 1988a). Almost 300 fracture orientations were plotted and indicate more than 75 percent of the fractures have steeply dipping (greater than 60º) to near vertical inclinations. Less than 25 percent of the fractures are subhorizontal (less than 30º). The fractures observed in the weathered claystone showed dominant patterns of northeast to east-northeast trends that steeply dip to the northwest and southeast, and northwest and west-northwest trends that steeply dip to the northeast and southwest. Fracture orientations measured in core obtained from a limited number of vertical borings in the unweathered claystone showed no predominant orientation (Section 5.3.4.8, Page 5-43, Woodward-Clyde Consultants, 1988a).

Fracture density or spacing was measured in borehole core samples, surface exposures, and excavations. The core boring fracture data are summarized graphically in HSCER Figures 5.3-5 through 5.3-7. Fracture spacing estimated from reconstituted core ranged from 1 to 2 inches to 1 foot (Woodward-Clyde Consultants, 1988a). Significantly fewer fractures were observed in core from the unweathered claystone in spite of poor core recovery in some boreholes within the Upper HSU. The cumulative number of fractures observed with depth in the core borings (Attachment E-8) indicates a decreasing trend in some borings (see Woodward-Clyde 1988a, Figure 5.3-9 data for CB-4 and CB-7I), while other borings exhibited similar fracture frequencies in the shallow and deeper core samples (see HSCER Figure 5.3-9 data for CB-5I, CB-6I, and CB-8I). The variability in the fracture density with depth and the range of fracture orientations displayed between adjacent borings do not suggest extensive lateral continuity, or strong interconnectivity between fractures (HSCER Figure 5.3-7). A deep excavation across the weathered/unweathered claystone contact confirmed the trend of decreasing fracture density in the unweathered claystone. Fewer than four prominent fractures were observed in 120 feet of exposed unweathered claystone compared to 16 prominent fractures mapped in 170 feet of weathered claystone. Some vertical fractures in the excavation were observed to extend across the contact from the weathered to the unweathered claystone (Woodward-Clyde Consultants, 1988a).

Fracture apertures were measured in core using a “feeler” gauge. Disturbed core, however, may have biased the measured apertures, and in-situ aperture sizes are likely smaller than those reported due to release of compressive stress and disturbance during drilling and measurement. Fracture aperture in the unweathered claystone ranged from immeasurably small to a maximum of 0.25 mm. Less variation in apertures was noted below a depth of 120 feet in the unweathered zone, and in general, there appeared to be a decrease in density of larger fractures (greater than 0.1 mm) at depths greater than approximately 100 feet (Attachment E-8).

3.3.4.3 <u>Summary</u>

The Todos Santos claystone that underlies the site is massive to faintly bedded. Bedding features within the Upper HSU are largely obscured by extensive subhorizontal and high angle fracturing and are therefore difficult to identify in the optical televiewer logs. Bedding planes identified within the RI borings are nearly all subhorizontal with varying strikes. This is consistent with the 1989 HSIR by Woodward-Clyde Consultants which concluded that the San Antonio Syncline and Casmalia Anticline are not present in the near surface below the site and that structure is generally characterized by gradual, broad, low amplitude flexure. The HSIR further concluded that visual evidence and dye tracer studies show that the weakly expressed bedding planes are not a significant groundwater conduit.

Fractures observed within the claystone tend to be subhorizontal (48 percent) or subvertical. Subvertical fractures are underrepresented within the RI borings due to the vertical nature of the borings/sampling patterns; however, the 1988 HSCER which included surface mapping, trenching and directional borings concluded that 75 percent of the fracturing within the claystone was subvertical and less than 25 percent was subhorizontal. The Upper HSU contains a higher fracture frequency, as well as a greater proportion of subhorizontal fractures; attributed to exfoliation of the claystone due to unloading at shallower depths bgs. Fracture frequency and aperture size tend to decrease with depth, though fracturing occurs in zones and areas of higher fracture frequency have been observed at lower depths. Fracture dip directions exhibit great variability. The average dip direction of fractures within both the Upper and Lower HSU is to the east-northeast to west-northwest. However, mean dip directions between 75 and 150 feet below the HSU contact (model layer 6) and 150 feet below the HSU contact to the total depth of the borings (model layer 7) are south-southeast and east-southeast, respectively. Comparison of fracture density and orientations between adjacent boreholes do not suggest that the fractures maintain extensive laterally continuity or interconnectivity.

3.3.5 Core Sample Physical Properties and Chloride Diffusion Test Results

Golder Associates' Report on Diffusion Testing of Core Samples is included as Attachment E-6. The results of the physical property and chloride diffusion testing of the four core samples collected in 2004 are summarized below:

- Claystone Specific Gravity ranged from 2.51 to 2.62
- Total Porosity ranged from 29.5 to 50.5 percent
- Dry Density ranged from 1.24 to 1.80 megagrams per cubic meter (Mg/m^3)
- Total Organic Carbon Content ranged from 0.09 percent to 2.34 percent
- Chloride Matrix Diffusion Coefficients ranged from 1.0E-07 to 8.0E-06 square centimeters per second.

The results of the physical property and chloride diffusion testing of the two core samples collected in 2006 are summarized below:

- Claystone Specific Gravity ranged from 2.48 to 2.61
- Total Porosity ranged from 46 percent to 49 percent
- Dry Density ranged from 1.21 to 1.41 (Mg/m^3)
- Total Organic Carbon Content ranged from 0.27 percent to 0.88 percent
- Chloride Matrix Diffusion Coefficients ranged from 3.0E-7 to 5.0E-7 square centimeters per second.

Additional testing details including chloride diffusion breakthrough curves are included in Attachment E-6.

3.4 Well/Piezometer Development

3.4.1 2004 Phase I RI/FS

Development of the Phase I water quality wells and piezometers was conducted during November and December 2004. The CSC met all of the Work Plan - Well Development Scope of Work (SOP) standards for casing volumes removed or "development days" performed. Water levels observed during and after development in each well are summarized in Table E-4. Total volumes removed and final water quality parameters measured during or after well development are summarized in Table E-5. Well development forms are included in Attachment E-4.

Because of the presence of NAPL, no water quality parameters were collected from RIMW-3, RIMW-7, RIPZ-8, and RIPZ-23 through RIPZ-26 during development. However, turbidity values were collected from RIMW-7 and RIPZ-8. Turbidity values range from a low of 2.7 NTU in

RIPZ-16 to a high of greater than 1,000 NTU in several wells/piezometers. Measured pH range from 5.93 in RIMW-6 to 8.29 in RIMW-9. DO range from 0.78 mg/L in RIPZ-22 to 35.3 mg/L in RIMW-5. Temperature range from 14.2 degrees °C to 25.5 degrees °C in RIPZ-6 and RIMW-9, respectively. Conductivity values range from 3.07 μmhos/cm in RIMW-8 to 12.39 μmhos/cm in RIMW-1. ORP values range from a low of -146 millivolts (mV) in RIMW-8 and RIPZ-2 to a high of 230 mV in RIPZ-18.

Turbidity remained high (greater than 1,000 NTUs) in 5 of the 8 installed RIMWs and RIPZ-8 (to be sampled in lieu of MW-4). However, developing the Upper HSU wells and piezometers is difficult due to their very low water-level recovery rates and water column heights after purging. Like the existing wells at the site, in most cases the new wells yield very little water, quickly go dry during bailing, and recover very slowly. This limits the rate at which development can occur and prohibits application of some development techniques such as pumping, or swabbing in cases where water in the well screen is limited. Under these conditions, turbidity may never decrease to guidance levels of less than 5 NTUs by bailing dry a limited volume of water.

In addition to the development activities performed in November and December 2004, the Phase I RIMW wells were also bailed dry during water quality sampling conducted over the week of January 17, 2005, and additional well development was conducted during the 15th Semi Annual (SA) monitoring event in an effort to obtain lower NTU values. The additional well development was performed on wells RIMW-2, RIMW-8, and RIMW-9 using a surge block and submersible pump, and wells RIMW-5 and RG-11B-2 were developed using a surge block and bailer. In all wells, with the exception of RIMW-5, the final NTU reading was 85.7 NTU or less. The NTU for well RIMW-5 was still >1,000 at the end of the additional development. RIMW-3 and RIPZ-8 were not sampled until later (March 2005) due to the malfunctioning pump equipment.

3.4.2 2006/2007 Phase II RI/FS

Development of the Phase II water quality wells and piezometers was conducted during August and October 2006, January 2007, and August and September 2007. The CSC met all of the Work Plan - Well Development SOP standards for casing volumes removed or "development days" performed. Water levels observed during and after development in each well are summarized in Table E-4. Total volumes removed and final water quality parameters measured during or after well development are summarized in Table E-5. Well development forms are included in Attachment E-4.

Because of the presence or potential for the presence of NAPL, no water quality parameters were collected from RIPZ-13, RIPZ-14, RIPZ-27, RIPZ-29 through RIPZ-33, RIPZ-35, RIPZ-37, RIPZ-38, RIPZ-39, RIPZ-31-B, RIPZ-33-B, and RIPZ-34-B during development. However, turbidity values were collected from RIPZ-29 through RIPZ-33, RIPZ-31-B, and RIPZ-33-B. Turbidity values ranged from a low of 18.5 NTU in RIMW-11 to a high of greater than 1,000 NTU in RIPZ-31. pH, DO, temperature, conductivity, and ORP, in the two wells measured for the full suite of parameters (RIMW-10 and RIMW-11), was 5.32 and 6.97 for pH, respectively; 5.25 and 3.02 mg/L for DO, respectively; 17.8 and 18.7 °C , for temperature, respectively; 8.01 and 2.98 μmhos/cm, for conductivity, respectively; and 70 and -12 mV, for ORP, respectively.

Turbidity was greater than 1,000 NTUs in 1 of the 9 installed wells and piezometers that had NTU readings taken (RIPZ-31). Of the other 8 piezometers, 4 had NTU measurements in excess of 400 (RIPZ-30, RIPZ-32, RIPZ-33, and RIPZ-31-B). However, developing the new

Upper HSU wells and piezometers is difficult due to their very low water-level recovery rates and water column heights after purging. Like the existing wells at the site, in most cases the new wells yield very little water, quickly go dry during purging, and recover very slowly. This limits the rate at which development can occur and prohibits application of some development techniques such as pumping, or swabbing in cases where water in the well screen is limited. Under these conditions, turbidity may never decrease to guidance levels of less than 5 NTUs by bailing dry or airlifting a limited volume of water.

3.5 NAPL Observations After Development

NAPL or possible NAPL was observed in video logs and core samples from several of the RI/FS wells and piezometers and boring RISB-02, and high OVM concentrations were measured in samples from the same boreholes (Table E-6).

In the Central Drainage Area, NAPL presence is indicated in Wells RIMW-3, RIPZ-8, RIPZ-13, RIPZ-14, RIPZ-23 through RIPZ-27, RIPZ-31, RIPZ-38, RIPZ-39, and boring RISB-02. LNAPL was subsequently gauged in the casings of completed piezometers RIPZ-8, RIPZ-13, RIPZ-14, RIPZ-23, RIPZ-24, RIPZ-25, RIPZ-27, RIPZ-31, RIPZ-38, and RIPZ-39. The NAPL in these wells floating on the water columns, indicating it is lighter than water (LNAPL). Each of these wells or piezometers is completed in the Upper HSU on bench 1, bench 2, and bench 5 of the P/S Landfill, and in the area of the Gallery Well and Sump 9B, which is known to contain LNAPL in nearby existing wells and piezometers. NAPL was also observed in RIPZ-13 and RIPZ-27 beneath the water column indicating it is denser than water (DNAPL); see below.

In the Burial Trench Area, NAPL presence is indicated in wells RIMW-7 and RIPZ-15. NAPL observations in these two borings were made in samples from the Upper HSU, to a depth of around 50 feet bgs in each boring. NAPL was not observed in deeper samples or video of the lower portion of Lower HSU piezometer RIPZ-15, indicating the NAPL at this location is limited to the Upper HSU. New well RIMW-7 and piezometer RIPZ-15 have not exhibited NAPL in the completed well casings to date.

3.5.1 DNAPL in Phase 2 P/S Landfill Piezometers

Since their installation in August 2007, NAPL presence and thickness has been monitored in the five Phase 2 piezometers installed in the P/S Landfill. These piezometers were installed at locations of potential depressions in the HSU contact based on the Phase 2 geophysical surveys. These potential depressions were identified by EPA as likely locations where DNAPL could pool and accumulate. Based on the elevations of the HSU contact inferred from the piezometer CPT signatures (Section 3.3.3), significant depressions in the HSU contact surface were not identified at the locations investigated.

Table E-4 contains the liquid level data for the RI piezometers before during and after development, and additional liquid level data and discussion is included in Appendix F. Water and NAPL levels were gauged during development and daily, weekly, monthly, and quarterly after piezometer development. To date, DNAPL has not been observed in three of the five piezometers installed in the P/S Landfill (RIPZ-14, RIPZ-38, and RIPZ-39). The absence of DNAPL in these piezometers further indicates the HSU contact surface at these locations does not contain closed depressions where DNAPL has accumulated.

DNAPL and LNAPL have been observed in RIPZ-13 on Bench Road 1. The thickness and elevations of LNAPL and DNAPL in RIPZ-13 over time are listed in Table F-6 and illustrated on Figures F-40 through F-43 in Appendix F. The thickness of DNAPL gauged daily during and immediately after development of RIPZ-13 in August 2007 was relatively stable ranging from around 8.5 to 9.5 feet thick. During September and October 2007, daily and weekly measurements indicated DNAPL thickness in RIPZ-13 was between around 7.1 to 9.6 feet, with two intermittent measurements indicating DNAPL thickness of 12 to 14 feet. Since December 2007, the DNAPL thickness had remained stable at approximately 14-feet.

The stable DNAPL thickness in RIPZ-13 indicated that DNAPL was in equilibrium adjacent to the well, although it did not confirm if the presence of the DNAPL was due to DNAPL accumulation in the formation/waste materials adjacent to the piezometer. As noted in Section 3.3.2, it is possible that non-aqueous phase liquids contained in buried drums may have been released during the installation of CPTs RIPZ-13 and RIPZ-13A. DNAPL observed in RIPZ-13 may have originated from drums pierced during CPT installation.

In March and April 2009, The CSC performed a DNAPL purge and recovery test in RIPZ-13 to determine the rate and amount of DNAPL recharge following purging activities in the immediate vicinity of the well. During the eight pumping days of the test, approximately 42-gallons of DNAPL were pumped from the well. The DNAPL thickness upon completion of the pumping portion of the recovery test was 2.55 feet, which represented a drawdown of 11.05 feet from the 13.6 feet pre-pumping thickness. The DNAPL thickness in RIPZ-13 subsequently recovered to 7.21-feet in a two month period following completion of the DNAPL purging and then to 8.47 feet by March 2010 and subsequent return to pre-test level in the following months.

DNAPL and LNAPL have also been observed in RIPZ-27, located just north of the Gallery Well on the access road. The thickness and elevations of LNAPL and DNAPL in RIPZ-27 over time are listed in Table F-6 and illustrated on Figures F-40 through F-43 in Appendix F. DNAPL was not observed within the well until September 2009 and LNAPL was not measured above trace amounts until December 2009.

4.0 EVALUATION OF ADDITIONAL DATA NEEDS

The groundwater data obtained during this RI/FS, along with historical data, were evaluated with respect to the groundwater DQOs identified in the RI/FS Work Plan. RI/FS Work Plan Sections 4.3 through 4.6 identify specific decisions and decision rules for issues related to this Task, including those related to contaminant fate extent and transport, groundwater modeling, and TI and FS evaluations. Table 5.1 of the IPR identifies all of the RI/FS DQO decisions and provides an evaluation of additional data needs associated with each, and the decisions specific to well and piezometer drilling are listed below. Note some of these groundwater decisions are also addressed in Appendix F (Groundwater Levels), Appendix G (Groundwater Chemistry), Appendix L (Geophysics), Appendix M (NAPL Surveys) and Appendix O (Monitored Natural Attenuation Evaluation).

4.1 DQO Decisions Related to Groundwater Contaminant Fate and Transport

The specific decisions and decision rules for issues related to groundwater contaminant fate extent and transport that were included in the DQOs of the RI/FS Work Plan are as follows:

- What is the nature of the former seeps in the Central Drainage Area?
- Is historical physical data adequate for use in groundwater modeling?
- What is the nature and extent of NAPL in the Capped Landfills Area?
- Are there NAPLs present in other areas of the site and what is the character of these NAPLs?
- What are the rates and directions of groundwater flow?
- Are subsurface flow and transport pathways identified?
- What is the hydraulic effectiveness of the interim liquids extraction systems?
- What is the extent(s) of site-related groundwater impacts?
- How have concentrations of different water quality parameters changed over time?
- Based on the observed water quality trends, what are the anticipated future concentration trends?

The CSC believes that the groundwater data collected as a part of the RI/FS are adequate for evaluating the most of the contaminant fate extent and transport DQO Decisions noted above. The CSC has also collected Phase 1 and Phase 2 characterization data for LNAPL distribution and thickness in the Central Drainage, Upper and Lower HSU DNAPL presence distribution and thickness, including the 2007 Phase 2 piezometer installations in the P/S Landfill, and the extent of Upper HSU COCs west of the Burial Trenches area and south of the PSCT. In addition, deep geologic conditions within Zone 1 have been characterized through installation of Phase 1 and 2 soil borings, piezometers and monitoring wells. Specific analyses of these DQO decisions are summarized below.

Hydrologic data collected before and during the RI indicate natural occurrence of springs and seeps as groundwater discharge areas. These data include mapped seeps and springs prior to landfill operations, and historical and recent groundwater elevation data, which indicate shallow water table and local artesian conditions in these areas.

Historical and current hydrologic data are sufficient for groundwater modeling. Aquifer hydraulic properties including hydraulic conductivities and relative permeabilities have been characterized and additional analyses of these properties is included in the groundwater modeling. Flow pathways are based on the permeability distribution, which has been further refined on the basis of the additional HSU contact information generated during this drilling investigation.

Groundwater flow analysis was performed as a part of the groundwater modeling task. Historical and recent water level data are comprehensive in both time and space, and are adequate for transient model calibration and validation.

Sufficient data have been collected to evaluate presence, nature, and extent of NAPL. NAPL distribution has been characterized on the basis of measurements in the existing and new wells and piezometers, and its extent is delineated from (the absence of NAPL) in perimeter wells and piezometers. Five additional shallow piezometers (RIPZ-31 through RIPZ-35) were installed during Phase 2 to verify LNAPL distribution and confirm LNAPL thicknesses in the Central Drainage area. Two other Phase 2 Upper HSU piezometers (RIPZ-29 and RIPZ-30 were installed in the Burial Trench Area, and one Phase 2 Upper HSU piezometer and follow-up hydropunch boring was installed near UVIF/MIP boring RISBON-59, near Former Pond 3.

DNAPL presence beneath the P/S Landfill has been investigated by installing five pushed piezometers (RIPZ-13, -14, and -27 as originally proposed in the Final RI/FS Work Plan, and additional piezometers RIPZ-38 and-39). The locations of these piezometers were optimized based on the results of the Phase 2 geophysical refraction survey.

DNAPL was initially only observed to be present in one of these piezometers (RIPZ-13) at development thicknesses of 7.03 to 9.32 feet. DNAPL was subsequently observed in piezometer RIPZ-27 beginning September 2009.

Groundwater flow pathways, rates and directions have been characterized on the basis of validated subsurface and hydrologic data. The new RI wells and piezometers provide sufficient groundwater elevation data to assess flow pathways and assess extraction system effectiveness. The CSC has been evaluating the hydraulic effectiveness of extraction systems as a part of groundwater modeling task and will continue to do so as part of the Final RI/FS. As we have noted in the past, the historical and recent RI data are sufficient to complete these analyses.

The extent of and trends in groundwater impacts have been characterized. The Routine Groundwater Monitoring Element of Work (RGMEW) groundwater sampling program has provided extensive historical information on the distribution of COCs and temporal variability and the existing data are sufficient to evaluate future water quality trends. The additional groundwater sampling conducted as a part of the RI has provided characterization of the presence and distribution of additional potential COCs and refined delineation of impact areas.

The distribution of COCs observed during the Fall 2004 and Spring 2005 combined RI/RGMEW groundwater sampling and from subsequent RI/FS groundwater quality samples is presented in Appendix G. Sampling results from the existing RGMEW wells and piezometers and new RIMW water quality sampling locations have provided complete lateral definition of the COC plumes, except in the area between the Burial Trenches and PSCT-4. In order to delineate the extent of COCs in groundwater in this area, the CSC installed and sampled two additional Phase 2 Upper HSU monitoring wells (RIMW-10 and RIMW-11) approximately 150 feet west and 200 feet southwest, respectively, of Well RIMW-5.

4.2 DQO Decisions Related to Groundwater Modeling

The specific decisions and decision rules for issues related to groundwater modeling that were included in the DQOs of the RI/FS Work Plan are as follows:

- What are the rates and directions of groundwater flow?
- Are all subsurface flow and transport pathways identified?
- What is the hydraulic effectiveness of the interim liquids extraction systems?
- What is the state of the site water balance?
- Is there any net recharge (that is not removed via extraction or evaporative processes)?

The groundwater data collected as a part of these RI/FSs are adequate for evaluating the groundwater modeling DQO Decisions. As described above, important controls on groundwater flow including distribution of aquifer permeabilities and hydraulic gradients have been adequately characterized on the basis of the existing and new subsurface property and liquid level data. The state of the site water balance and hydraulic effectiveness of extraction systems are evaluated in Appendix F, and historical and recent RI data are sufficient for these analyses.

4.3 DQO Decisions Related to TI Evaluations for Groundwater

The specific decisions and decision rules for issues related to the Technical Impracticability Waiver for groundwater that were included in the DQOs of the RI/FS Work Plan are as follows:

- What is the nature and extent of groundwater contamination? Is DNAPL or LNAPL present or likely to be present?
- What are the site hydrogeologic properties and will these properties preclude effective removal of contamination?

The groundwater data collected as a part of these RI/FSs are adequate for evaluating the TI for groundwater. As described above, the nature and extent of groundwater contamination and NAPL has been characterized or will be characterized on the basis of water quality and liquid level data from existing and new wells. Physical property data collected to date include hydraulic conductivities, porosities, and NAPL density and viscosity, which will be used for TI evaluations.

4.4 DQO Decisions Related to FS Evaluations for Groundwater

The specific decisions and decision rules for issues related to the FS evaluations for groundwater that were included in the DQOs of the RI/FS Work Plan are as follows:

What is the chemical nature and physical extent of the contaminated area requiring remediation?

What are the relevant physical properties of the subsurface vadose zone and/or saturated zone where contamination is present?

Groundwater data collected as a part of these RI/FSs are adequate for conducting FS evaluations for groundwater. The nature and extent of groundwater contamination and NAPL has been characterized or will be characterized on the basis of water quality and liquid level data from existing and new wells. As described above the physical property data collected to date which are necessary to assess FS alternatives are sufficient for these analyses.

5.0 REFERENCES

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