APPENDIX F – GROUNDWATER FLOW

FINAL REMEDIAL INVESTIGATION REPORT
CASMALIA RESOURCES SUPERFUND SITE
CASMALIA, CALIFORNIA

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ARAR	Applicable or relevant and appropriate requirement
amsl	above mean sea level
ARCH	air-rotary casing hammer
bgs	below ground surface
BTA	Burial Trench Area
btoc	below top of casing
cm/g	centimeters per gram
COC	chemical of concern
CPT	cone penetrometer testing
CSC	Casmalia Steering Committee
NAPL	non-aqueous phase liquid
DNAPL	dense non-aqueous phase liquid
DQO	data quality objective
Dynes/cm	dynes per centimeter
ERM	Environmental Resources Management
ET	evapotranspiration
ft/yr	feet per year
FS	Feasibility Study
GAC	granular activated carbon
g/cm^3	grams per cubic centimeter
HCSM	Hydrogeologic Conceptual Site Model
HSU	Hydrostratigraphic Unit
LHSU	Lower Hydrostratigraphic Unit
IPR	Interim Progress Report
LNAPL	light non-aqueous phase liquid
MACTEC	MACTEC Engineering and Consulting, Inc.
MIP	membrane interface probe
NE	non-equilibrium
PCT	Perimeter Control Trench
PEST	Parameter Estimation
PS Landfill	Pesticide/Solvent Landfill
PSCT	Perimeter Source Control Trench
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
TI	technical impracticability
USEPA	United States Environmental Protection Agency
UVIF	ultraviolet induced fluorescence
TM	Technical Memorandum
VOC	volatile organic compound
[-]	unit less dimensions

1.0 INTRODUCTION

This appendix to the Final Remedial Investigation (RI) Report documents the groundwater and non-aqueous phase liquid (NAPL) level monitoring and flow evaluation activities conducted at the site pursuant to the requirements set forth in the Remedial Investigation / Feasibility Study (RI/FS) Work Plan. Since 1997, the Casmalia Steering Committed (CSC) has monitored groundwater and NAPL levels on a daily, monthly, or quarterly basis as a part of site operations, the Routine Groundwater Monitoring Element of Work (RGMEW), and the RI/FS. During August and September 2004, the CSC installed and developed new chemical water quality wells and liquid level piezometers to provide additional liquid level data in critical areas as identified in the RI/FS Work Plan (RI/FS Phase I). As a part of Phase II RI/FS investigations conducted between August 2006 and September 2007, the CSC installed and developed additional chemical water quality wells and liquid level piezometers, to address data gaps identified following the 2004 Phase I RI/FS investigation. Appendix E of this RI Report documents the new well and piezometer installation activities for both the 2004 Phase I and 2006/2007 Phase II RI/FS Investigations.

Additional data collection and evaluation activities documented in this Appendix include analysis of horizontal and vertical groundwater flow conditions over time, changes in groundwater storage, NAPL presence and flow potential, construction of a site water budget accounting for known or estimated groundwater inflows and outflows, and construction and calibration of a three-dimensional MODFLOW groundwater flow model.

1.1 Data Collection and Evaluation Objectives

The objectives of installing additional water quality wells and piezometers and measuring liquid levels are to provide data in areas of the site where the United States Environmental Protection Agency (USEPA) had identified potential data gaps, characterize the groundwater flow system including flow rates and directions in space and time, provide hydraulic head data for use in groundwater model calibration, and assess the fate and transport of chemicals of concerns (COCs) in groundwater.

Both dense (D) and light (L) NAPLs are present at the Site. Monitoring was conducted in an effort to identify the nature and extent of these NAPLs in the subsurface and the potential for their migration beneath the site. Additionally, NAPL evaluations were conducted to the extent necessary to complete a technical impracticability (TI) evaluation and for remedial planning during the feasibility study (FS). Assessing the limits of NAPL in the subsurface supports designating specific TI zones. Within these zones it may be impractical to restore groundwater quality back to applicable standards.

The water balance was updated and the three-dimensional MODFLOW groundwater flow model constructed in accordance with the RI/FS Work Plan, and these analyses were used in conjunction with empirical data to assess groundwater flow pathways, and interim extraction system efficacy, and will be used in the FS to evaluate the potential effects of final remedial alternatives.

1.2 Scope of Work

The scope of work for groundwater and NAPL level monitoring and analysis includes the following elements:

- Ongoing monitoring of groundwater and NAPL elevations
- Installation of additional monitoring wells and piezometers in critical site areas
- Mapping and charting of groundwater and NAPL elevations in space and time
- Evaluation of horizontal and vertical hydraulic gradients and changes in groundwater storage
- Analysis of NAPL physical properties and density-driven DNAPL advection
- Construction of a historical site water budget for the combined Zone 1 groundwater and pond system
- Construction of a three-dimensional MODFLOW groundwater flow model and calibration under historical steady-state and transient conditions

Sitewide groundwater and NAPL elevations have been monitored on either a monthly, quarterly, or semiannual basis since 1997. Water levels in monitoring wells and piezometers measured during different historical and recent quarterly periods were tabulated and plotted on water level contour maps and hydrogeologic cross-sections. Monthly liquid level monitoring of selected wells and piezometers, daily monitoring of extraction facilities and associated piezometers, continuous pressure transducer monitoring, and NAPL monitoring were also performed prior to and during the RI investigations.

As documented in Appendix E, during the Phase I RI/FS Investigation performed in 2004, eight new chemical quality wells were installed to provide chemical water quality and hydraulic head data to supplement the existing groundwater monitoring network. Twenty-four new liquid level piezometers were also installed to provide lateral and vertical hydraulic head data to supplement the existing groundwater level monitoring network. An additional Upper Hydrostratigraphic Unit (HSU) replacement well and one additional replacement piezometer were also installed for existing well RG-11B and piezometer RG-PZ-10B, both located north of the pesticide/solvent (P/S) Landfill on the North Ridge. During the Phase I RI/FS investigation performed in 2006 through September 2007, two chemical quality wells, twelve piezometers, one temporary piezometer, and three replacement piezometers were installed to fulfill the objectives described above. Liquid levels in these new wells and piezometers were measured during and after development activities and will continue to be monitored on either a monthly or quarterly, or semiannual basis to further refine characterization of the groundwater flow system.

2.0 METHODOLOGY

2.1 Hydrologic Data Sources

Hydrologic data presented in this Appendix include groundwater and NAPL elevation data from site wells and piezometers, meteorological data including site rainfall and evaporation rates, and other volumetric and rate data including extraction well pumping rates and pond volumes.

Data sources for groundwater elevations include all discrete and continuous groundwater levels measured in wells and piezometers at the site from the period of 1997 through March 2009, and all discrete and continuous NAPL elevations measured through March 2010. Historical groundwater and NAPL level data and previous interpretations of flow conditions were presented in the Groundwater Data Summary Report 1992 through 2000 (Harding Lawson and Associates [HLA], 2000b) and in the 6th, 7th, 9th, Combined 10th and 11th, 12th, Combined 13th and 14th, Combined 15th and 16th, Combined 17th and 18th, Combined 19th and 20th, and the Combined 21st and 22nd Semiannual Reports (HLA, 2000a; Harding ESE, Inc. [Harding], 2001a, c, and 2002; MACTEC Engineering and Consulting, Inc. [MACTEC], 2003a, 2003b, 2004b, 2005a, 2006c, 2007, 2008, and 2009).

The new RI wells and piezometers used to supplement existing monitoring points are shown on Appendix E Figure E-1, and Figures F-1 and F-2 of this Appendix show all of the historical and new well and piezometer locations used for water level and NAPL elevation monitoring in the Upper and Lower HSUs. Water-level hydrographs for all RGMEW and RI/FS wells and piezometers between 1997 and 2009 are included as Attachment F-1.

Hydrologic data including rainfall, estimated runoff and evapotranspiration (ET), and site groundwater and pond storage changes are incorporated in both the site water budget and groundwater flow model. Onsite meteorological data were compared with data from nearby weather stations, and well flow rates and pond stages were measured and documented in Quarterly Site Operations Reports. Figure F-1 shows the locations of the onsite meteorological station, extraction wells and trenches, and five current ponds included in the water budget. Results of the water budget and flow modeling were compared to observed liquid level and volumetric data, and used to further characterize groundwater flow conditions.

2.2 RI and RGMEW Water Level Monitoring

The CSC began a routine water level monitoring program in accordance to the Consent Decree Scope of Work (SOW) in 1997. This monitoring is part of the RGMEW which is conducted on a semi-annual basis. To date, there have been 26 semi-annual (SA) events, which include the following monitoring and reporting activities: quarterly and semiannual water level monitoring at select stations, continuous water level monitoring from selected wells, and frequent water and NAPL level monitoring from liquid control features.

As mentioned above, new piezometers were installed and water and NAPL level data collected in specific site locations identified in the RI/FS Workplan. Liquid levels in these newly constructed piezometers have been included in the RGMEW and site operations monitoring programs. Since February 2000, selected monitoring wells have been constantly monitored using continuously recording pressure transducers. Hydrographs for all RGMEW and RI wells including those with pressure transducers installed are included in Attachment F-1.

Additional historic water level monitoring included daily gauging of extraction wells/sumps and associated piezometers, as well as monthly monitoring of a subset of wells. Water levels also were monitored after development of the new wells and piezometers, as described in Appendix E.

Data collected for the water level portion of the RI was entered into the existing site database. Groundwater elevations in the wells were reviewed and hydrographs of all wells prepared. An assessment of non-equilibrium conditions in low-yielding wells following purging was performed and non-representative data qualified accordingly. Non-equilibrium evaluations for each well monitored included assessment of relative permeability and purge methods and associated likelihood of non-equilibrium, and evaluation of water level trends in purged and background wells before, during, and after purging events. Water level data presentation on tables, maps, cross-sections and hydrographs are qualified and identify obvious and potential non-equilibrium conditions.

Contour maps depicting the Upper and Lower HSU and water table groundwater elevations, saturated thicknesses of the Upper HSU, and HSU head differences at the site were developed for three different periods: March 2001 (high/wet [pre-drought] conditions), March 2004, (low/dry [post-drought] conditions, and December 2008, which includes all Phase 1 and II RI wells and piezometers. Hydrogeologic cross-sections that show water level elevations are presented for December 2008. Tables F-3, F-4, F-5 provide site wide groundwater elevations for December 2008 and vertical head differences and gradients, and estimated changes in storage between 1997 and 2009, respectively. Historical and recent NAPL measurements are tabulated in Table F-6 and charted and in Figure 41. Appendix E of this RI Report documents the well and piezometer installation activities conducted during 2004, 2006, and 2007, and the liquid levels measured during and after development.

March 2001 and March 2004 maps are presented because they represent high/wet (pre-drought), and low/dry (post-drought) conditions, and water levels from these periods were used for calibration of the steady-state MODFLOW groundwater model. Additional groundwater elevation maps by model layer for March 2004 are also presented in Attachment F-3 and were used to assess overall model calibration to horizontal gradients with depth. The December 2008 site-wide groundwater elevation data are presented on contour maps and hydrogeologic cross-sections, as this water level monitoring event best represents current conditions and includes levels from Phase I and Phase II RI wells and piezometers.

The CSC incorporated the historical and new groundwater elevation data into the existing site conceptual model, water budget, and groundwater flow model, which were developed using all available data. The existing and new data collected during the RI/FS were evaluated to assess the following groundwater flow issues:

- Historical water-level trends;
- Horizontal and vertical groundwater flow conditions;
- Temporal changes in hydraulic head distribution and groundwater storage;
- Site water balance;
- Aquifer hydraulic properties; and
- Hydraulic effectiveness of site groundwater control systems.

The results of these evaluations are presented in Section 3.

2.3 NAPL Monitoring and Analysis

The CSC has completed several investigations to assess the presence of NAPLs at the Site. These investigations were completed in accordance with the RI/FS Work Plan. The CSC has also collected information useful in assessing the presence of NAPLs at the site as part of the RGMEW. Both LNAPL and DNAPL are known to exist in the Central Drainage Area. Additional investigations of NAPL distribution in this area, and of the potential presence of NAPL in other areas of the site were performed by installing new wells and piezometers (Appendix E), geologic and geophysical investigations (Appendices E and L), soil investigations for NAPL presence using cone penetrometer testing (CPT) with ultraviolet induced fluorescence (UVIF) and membrane interface probe (MIP) technologies (Appendix M), and analysis of the chemical and physical properties of LNAPL and DNAPL samples (Appendices F and G).

The CSC summarized the preliminary RI findings of the NAPL and other investigations in the Interim Progress Report (IPR) submitted to USEPA in February 2005 (CSC, 2005). In their September 2005 comments on the IPR, USEPA requested that the CSC synthesize the available data specifically regarding the presence of DNAPL in the Lower HSU, assess the potential for migration of site DNAPL, and document that information in a memorandum. A memorandum addressing the elements listed in the USEPA's IPR comments was prepared in February 2006. To facilitate remedial planning for the site, the CSC also evaluated the available LNAPL and select dissolved-phase groundwater data collected for the site. Understanding the link between the NAPL contamination in the source area(s) and the aqueous plume at the site was deemed key to assessing additional data needs and formulating appropriate site groundwater remedies.

As described in Appendices E and L, between 2004 and 2007 the CSC conducted geophysical surveys and piezometer installation investigations in the area of the P/S Landfill to evaluate whether a "low spot(s)" in the surface of the Lower HSU claystone exists, which might contain an accumulation of DNAPL. The CSC's research indicated that during construction of the P/S Landfill, a D7 Caterpillar was used to excavate weathered soils from the claystone to create volume in the landfill. The excavation was limited, however, to only a few feet into the blue claystone as the equipment used could not easily advance the excavation. Photographs taken during construction, and interviews with the equipment operators grading the landfill sub-base, did not indicate any deep closed depression or low spot in the contact. However, a base grade P/S Landfill topographic map prepared by Canonie Environmental in 1979 illustrated a 20-foot-deep depression in the contact surface near the southern edge of the P/S Landfill. Although the CSC could not establish a basis for a possible low spot with site operators, the USEPA requested that CSC confirm the presence or absence of the low spot.

To assess whether the low spot exists, the CSC initially gathered information as part of a "Low Area Investigation" which was completed in 2001 to comply with the Interim Liquids Agreement reached with USEPA at that time. As documented in the final report for those activities, that investigative work did not support the existence of a depression in the clay contact subsurface of the P/S Landfill (Harding ESE, 2001b). During the Low Area Investigation, the CSC advanced five CPT borings to refusal (presumed to be the contact of the unweathered claystone) and installed Piezometer PZ-LA-01 using ¾-inch PVC pre-fabricated well materials that failed within 10 days of the installation. During the investigation, the contact was encountered at elevations much higher than those illustrated on the 1979 Canonie map, and DNAPL was not observed in temporary piezometer PZ-LA-01 prior to its failure. However, USEPA indicated in their comments on the resulting report that the determination to the presence or absence of a low spot depression and potential DNAPL accumulation remained unresolved.

To further investigate potential low spots in critical site areas known or suspected to contain DNAPL, the CSC performed Phase I and Phase II geophysical surveys both on the P/S Landfill and throughout the site. The CSC conducted two phases of seismic refraction to investigate a potential low spot in the southern portion of the P/S Landfill where drummed DNAPL chemicals are known to exist; and as DNAPL is present in the Gallery Well, and due to uncertainties in the pre-and post-construction landfill cell ground surface. During Summer 2004 and Fall 2005, the CSC performed Phase I and Phase II geophysical investigations in accordance with the RI/FS Work Plan, the Geophysical Plan, (MACTEC, 2004a) and the Phase II RI/FS Work Plan Supplement - Geophysical Survey Plan (MACTEC, 2005b), which were submitted to and approved by USEPA. The Phase I geophysical survey investigations included a Pilot Study and a Production Survey. For the Pilot Study, the CSC tested the performance of seismic refraction (along with seismic reflection and micro-gravity methods) on the P/S Landfill. For the Phase I Production Survey, the CSC collected seismic refraction data in the Burial Trench Area (BTA), Central Drainage Area, and selected areas around the Perimeter Source Control Trench (PSCT). The CSC detailed methodologies and results of the Phase I Geophysics in Appendix L of the IPR.

During the Phase II surveys of the P/S Landfill (requested in USEPA's September 26, 2005, comments on the IPR and outlined the Phase II RI/FS Work Plan Supplement, Revised Draft - Geophysical Survey Plan), the CSC performed additional seismic refraction along 14 lines on the southern portion of the P/S Landfill. The Phase II lines were designed to complement the existing two lines previously completed as part of the Phase I RI work at the site and thus bring the total number of seismic refraction lines completed on the P/S Landfill to 16. Phase II seismic investigation procedures and results are described in Appendix L.

Upon completion of the two phases of the geophysical survey, the CSC found that the velocity at the known contact ranged from a low of approximately 3,200 feet per second (fps) to a high of 6,000 fps (see Appendix L Table L-3). The CSC concluded that a representative velocity for unweathered claystone immediately below the HSU surface is ill-defined and an iso-velocity surface representing the claystone surface could not be established with confidence. On the basis of the wide range of velocities associated with the contact, the CSC's believes that the contact does not conform to a single iso-velocity contour model and therefore, an accurate 3-dimensional representation of the contact surface cannot be determined with certainty from the refraction data.

Although the CSC believes that the contact does not conform to a single iso-velocity contour model, the overall tomographic velocity profiles are consistent with the suspected conditions in the P/S Landfill and a potential "low area" in claystone contact at the south half of the P/S Landfill. For example, Seismic Refraction Line P2SL-6 shows a potential "low area" at a velocity of 3,200 to 3,450 fps (yellow color) at the total depth of RIPZ-13 (Figure L-31). Although the total depth of RIPZ-13 is shallower than the Canonie "low area" elevation contour, the EPA believes the seismic refraction data suggests that conditions consistent with a "low area" may occur. However, the seismic velocities in the range of 3,200 to 3,450 fps are typical of unsaturated sediment (Holzer, 2010). Therefore, if unsaturated conditions exist within the potential low spot, then the NAPL movement into fractures below the HSU contact is unlikely due to the complexity of fluid flow within a partially saturated media.

In 2007, Phase II RI/FS Investigation piezometers were installed at four locations at the toe of the P/S Landfill, between Bench Road 2 and the Gallery Well. One Phase II piezometer (RIPZ-13) was located adjacent to failed piezometer PZ-LA-01, and has been observed to contain approximately 14 feet of DNAPL. The installation procedures and as-built specifications of these piezometers are described in Appendix E. NAPL levels in the new piezometers during and after well development are also included in Appendix E and further described in Section 3 of this Appendix.

NAPL monitoring of wells and piezometers has been performed on a routine basis. As a part of the RI investigations and in accordance with the procedures specified in the RI/FS Work Plan and Standard Operating Procedures (SOP), additional NAPL measurements using an interface probe were made in approximately fifty wells and piezometers in May 2005 based on criteria agreed upon between the CSC and the USEPA. In part, these wells were chosen due to the presence of dissolved NAPL within groundwater samples, visual observation of NAPLs during drilling or development, or the wells were located near areas of known or suspected NAPL presence. During this monitoring event, no NAPLs were observed in wells that were not already known to contain NAPLs. Historical and recent NAPL levels measured in existing wells and piezometers were tabulated and plotted to assess trends in NAPL distribution. Additional NAPL measurements during and after new well and piezometer development are included in Appendix E.

Physical properties of LNAPL and DNAPL samples collected from site wells including densities and viscosities were measured. In accordance with USEPA requests the CSC also calculated the vertical hydraulic gradients necessary to offset density-driven DNAPL sinking, and compared the calculated minimum gradients with measured gradients in site areas containing DNAPL in Section 3.2.

2.4 Site Water Budget

As part of the RI, the CSC updated the site water budget (or hydrologic balance) for the combined Zone 1 groundwater and pond system. The water balance was updated in accordance with the RI/FS Work Plan, and was used in conjunction with empirical data and the three-dimensional MODFLOW groundwater flow model to assess groundwater flow pathways, and interim extraction system efficacy.

Hydrologic information necessary to construct the water budget included rates of precipitation, surface water run-off and run-on, pond evaporation and ground evapotranspiration, pond storage, pond dewatering, groundwater storage, groundwater extraction, and estimated rates of groundwater underflow. The different water budget components were quantified using a variety of data sources and estimation methods, including empirical site data, estimated parameter values, rainfall-runoff HELP model results, and groundwater underflow rates estimated using MODFLOW.

A site hydrologic balance for the period 1992-2000 was first presented to USEPA as part of the Groundwater Data Summary Report (Harding Lawson Associates (HLA), 2000b). As described below, the CSC revised and updated the water balance for the period January 1997 through June 2004, corresponding to the period of the transient MODFLOW model, and new information for groundwater underflow and different rates of evapotranspiration and runoff than previously used.

Monthly and cumulative water budgets were developed for Zone 1 as well as two site subareas: north and south of the PSCT. Monthly and cumulative budgets were evaluated to assess system dynamics and potential net system inflow/outflow. Monthly and cumulative "errors" (difference between total inflow, outflow, and change in storage) were calculated to assess potential gain or loss of liquids from the site groundwater system.

Details of water budget construction and results are provided in Attachment F-2, and summarized in Section 3.3.

2.5 Groundwater Flow Modeling

The CSC constructed a site-wide three-dimensional groundwater flow model according to the approach and scope presented in the Work Plan and subsequent model-related meetings and correspondence with USEPA. The CSC used the groundwater flow model (in conjunction with empirical hydrogeologic, flow, and water quality data) to evaluate site-wide and local flow conditions, the hydraulic effectiveness of current liquids extraction, and will use the model as a part of the FS to evaluate potential effectiveness of alternate site remedies. The proposed approach was developed to meet the specific modeling objectives mutually identified by the CSC, USEPA and other agencies, which included:

- Generating a model based on historical flow calibration and simulating current site-wide flow conditions, including simulating site water balance and effects of existing extraction facilities and surface water features; and
- Constructing the model such that it could be used to analyze various remedial alternatives, including landfill capping, groundwater extraction from various existing and potential extraction facilities, pond dewatering, and other potential remedial actions.

The CSC constructed and ran both steady-state and historical transient groundwater flow models and calibrated the models using forward and inverse calibration techniques. The overall features of the groundwater flow models are summarized in below:

- Groundwater flow was simulated using MODFLOW and MODPATH computer programs;
- Steady flow was simulated and calibrated against discreet historical time periods (2001 and 2004);
- Transient flow simulations for the time period 1997-2004 were initially attempted but then abandoned in lieu of performing steady state flow simulations for 2001 and 2004 (wet and dry conditions);
- The model domain encompasses the Zone 1 Area and extends to natural or user-defined boundaries around Zone 1;
- Seven MODFLOW Layers were used to simulate groundwater flow, with the Upper HSU contain three layers (MODFLOW Layers 1-3) and Lower HSU containing 4 layers (Layers 4-7);
- Boundary conditions included specified flow and specified and general heads including a bottom (base of Layer 7) boundary condition
- Heterogeneous horizontal and vertical permeabilities were used for the Upper and Lower HSUs;
- Recharge rates were estimated using the HELP Model computer program;
- Extraction was simulated at the pumping wells and trenches;

- Model calibration was achieved using trial and error approaches and Inverse methods using PEST computer program.

Details of the modeling approach and rationale including model code, construction specifications such as area/domain, layering and depth, boundary conditions, aquifer hydraulic properties, recharge and water balance quantification, surface water (ponds/streams) simulation, pumping stresses, proposed simulation scenarios, calibration criteria and sensitivity analyses, and results are described in Attachment F-3, and summarized in Section 3.4.

3.0 INVESTIGATION RESULTS

3.1 Groundwater Flow Conditions

Groundwater elevation and other hydrologic data presented in this Appendix include continuous water levels collected between 1997 and 2009, and additional presentation and analysis of discrete water levels collected in 2001, 2004, and 2008. Specific tasks of the RI Water Level Monitoring include estimation of horizontal and vertical distribution of hydraulic head and groundwater flow system conditions at the Site, changes in groundwater storage, and hydraulic effectiveness of response systems. This section presents the groundwater elevation data; discussion and interpretation of the data relative to the RI data quality objectives are presented in Section 4.

Figures F-1 and F-2 show the Upper and Lower HSU water level monitoring locations used in the groundwater flow evaluation. Table F-1 presents the well construction details and Table F-2 lists the water level monitoring locations. For completeness and evaluation of transient conditions over multiple water years, groundwater elevations in each well and piezometer measured during the period 1997-2009 were plotted on hydrographs which are presented in Attachment F-1.

Due to the low permeability of the site aquifer materials, water level data for some wells and piezometers have exhibited non-equilibrium conditions for significant periods after well purging or development activities. These non-equilibrium conditions (i.e., an extraordinary slow recovery period as the result of a relatively instantaneous water level reduction following well purging) are illustrated on the hydrographs contained in Attachment F-1. In general, non-equilibrium groundwater elevations have not been used for any historical interpretations (i.e., groundwater elevation contours) of horizontal and vertical gradients or flow conditions as these conditions represent artificially induced depressions locally in the Lower HSU potentiometric surface. Water-level hydrographs for each well were developed for the period January 1997 through March 2009, and trend analyses were performed to identify wells exhibiting slow recovery from initial well development or sample purge events. Wells exhibiting potential or clear non-equilibrium conditions were tabulated, and reported water levels for these wells are clearly identified on the water level tables, maps, and cross-sections contained herein. Unverifiable water levels from the permanently installed wire-line transducer wells are also clearly denoted on the maps and hydrographs.

Groundwater elevations at extraction points in the Gallery Well, Sump 9B, PSCT (PSCT-1 through PSCT-4), Perimeter Control Trench (PCT)-A ([RAP-1A, RAP-2A, and RAP-3A), PCT-B (RAP-1B), and PCT-C (RAP-1C and C-5) are also presented on hydrographs (Attachment F-1). The hydrographs for the Gallery Well and Sump 9B include frequent (daily to quarterly) water level data from 12 nearby piezometers installed adjacent to the extraction facilities. Water level data from these extraction points reflect the dynamics of the pumping systems and seasonal trends. Extraction features and associated piezometers that exhibit fluctuating water levels are listed in tables and depicted on the maps using representative average water levels. The representative water level is the mean of daily water levels measured in the wells during the duration of the particular quarterly water level monitoring event.

Groundwater elevation data collected by the CSC between June 1997 and March 2009 were used to assess horizontal and vertical groundwater flow conditions, temporal changes in hydraulic head distribution and groundwater storage, and the hydraulic effectiveness of Site groundwater control systems.

3.1.1 Horizontal Flow Conditions

Horizontal flow conditions were characterized by constructing potentiometric surface contour maps for the water table (combined Upper and Lower HSU wells) and individual Upper and Lower HSUs. Water level elevation data obtained during the March 2001 (high/wet conditions), March 2004 (low/dry conditions), and December 2008 (recent conditions) are presented on HSU groundwater elevation contour maps, HSU head difference maps, and saturated thickness maps (Figures F-3 through F-16). Saturated thickness of the Upper HSU and regression charts for December 2006 are presented on Figures F-18 through F-21, and December 2008 cross sections are presented on Figures F-22 through F-28. The groundwater elevation contour maps for the water table, Upper HSU, and Lower HSU provide planar views of the horizontal gradients in the different aquifer zones. March 2001 and March 2004 maps are presented because they represent high/wet (pre-drought), and low/dry (post-drought) conditions, and water levels from these periods were used for calibration of the steady-state MODFLOW groundwater model. Additional groundwater elevation maps by model layer for March 2004 are also presented in Attachment F-3 and were used to assess overall model calibration to horizontal gradients with depth. The December 2008 site-wide groundwater elevation data are presented on contour maps and hydrogeologic cross-sections, as this water level monitoring event best represents current conditions and includes levels from Phase I and Phase II RI wells and piezometers. December 2008 water table contours for local areas around the extraction facilities are also presented on Figures F-29 through F-32.

Water table and Upper/Lower HSU groundwater elevation contours were initially created using computerized interpolation software, and then adjusted manually. The manual adjustment took into consideration the local topography, surface water impoundments (ponds), and other natural or manmade features. Figures F-18 through F-21 present regression analysis of December 2008 groundwater elevation versus ground surface elevation data. The groundwater elevations for December 2008 were divided into four depth groups based on well screen depth relative to the Upper/Lower HSU contact at each well location; Figure F-18 shows groundwater elevations in Upper HSU/water table wells versus ground surface elevation, Figure F-19 shows ground surface versus groundwater elevations in Lower HSU wells screened to 25 feet below the contact, Figure F-20 shows ground surface versus groundwater elevations in the Lower HSU 25 to 75 feet below the contact, and Figure F-21 shows ground surface versus groundwater elevations in Lower HSU wells deeper than 75 feet below contact. Note the water table wells correspond to MODFLOW Layers 1, 2, and 3, Lower HSU wells screened to 25 feet below the contact correspond to MODFLOW Layer 4, Lower HSU wells 25 to 75 feet below the contact correspond to MODFLOW Layer 5, and Lower HSU wells deeper than 75 feet below the contact correspond to MODFLOW Layers 6 and 7 (Attachment F-3).

The regression line for the water table during December 2006 (Figure F-18) demonstrates a close relationship between groundwater levels and topography. The correlation is similar to that observed in previous and recent RGMEW monitoring events. This relationship demonstrates that topographic elevation continues to be a useful guide in developing potentiometric surface contours where the data are sparse. Figures F-19 through F-21 for the Lower HSU show deviations from the strong water table versus ground elevation correlation, largely due to the significant vertical hydraulic gradients at the represented locations (Figure F-21). The deeper a well is completed, the greater the deviation is from this relationship, and this has been consistently observed throughout the RGMEW. The Lower HSU is recharged slowly and is generally isolated from the groundwater flow system in the Upper HSU.

3.1.1.1 <u>Water Table Elevations and Saturated Thickness of Upper HSU</u>

Figures F-3, F-8, and F-13 are water table potentiometric surface maps for March 2001, March 2004, and December 2008. Water levels not used for contouring due to non-equilibrium are denoted on the map. These Figures show water table elevation contours only in areas where the Upper HSU is interpreted as being saturated during March 2001, March 2004, and December 2008. A separate contour map was created for the water table because the Upper HSU is absent in several areas (specifically, the hills between the A and B Drainages, between the B and C Drainages, and seasonally along the North Ridge), when the water table occurs in the Lower HSU. The water table contours present a single map of the first water encountered. Figures F-6, F-11, and F-17 show the saturated thicknesses (in feet) of the Upper HSU during these same periods.

The water table potentiometric surface maps for March 2001, March 2004, and December 2008 show the main features of the Site hydrogeology. Relatively few differences in overall hydraulic gradient magnitudes and directions are observed between the different periods. In addition, the 2001, 2004, and 2008 groundwater flow patterns depicted on the contour maps are consistent with those previously observed in the 1980's, as documented by the USEPA (USEPA, 1986) and in the HSIR (WCC and CE, 1989). The site-wide water table maps and inferred horizontal flow conditions for 2001, 2004, and 2008 are essentially unchanged relative to previous monitoring events. During each period, a groundwater flow divide coincides with the topographically elevated North Ridge. Based on the water level elevations and location of the Upper/Lower HSU contact surface, the water table along the North Ridge area occurs in the Lower HSU during most of the year. During December 2008, the water table in the North Ridge area appeared to occur locally below the Upper/Lower HSU contact. Groundwater north of the ridge flows into the North drainage. South of the ridge divide, groundwater flows southward through the Site to the A, B, and C drainages. The contour lines generally follow the topography, as suggested by the correlations shown in Figure F-18.

Based on the water level measurements, local groundwater depressions continue to be observed at PSCT-1, PSCT-2, PSCT-4, and the PCTs, and are inferred at Sump 9B and the Gallery Well. Groundwater is not routinely pumped from extraction point PSCT-3, and, therefore, groundwater depressions are not observed. The extent of the capture zones associated with the extraction features is discussed further in Section 3.5 using more detailed contour maps.

The water table contour map shows that extraction from the PSCT may account for the alignment of the contour lines roughly perpendicular to the PSCT. This indicates that groundwater flow is parallel along much of the PSCT, and the potential for groundwater flow across the PSCT (along the non pumping sections) is minimal. Groundwater gradients generally are steeper in the area north of the PSCT, and the steeper gradients coincide with the steeper topography. South of the PSCT, the groundwater gradients are more gradual, and further reduced by the presence of the onsite ponds.

Groundwater flow across the southern perimeter of the Site appears to be prevented by a reversal in groundwater flow direction immediately south of the Site, apparently associated with the prominent hills that rise just south of the Site boundary. Groundwater in this southern area is channeled toward the heads of the three drainages, where the PCT liquid control features are located.

The overall groundwater flow directions continue to be from the topographically elevated areas in the northern portions of the Site toward the low lying A , B , and C drainages along the southern perimeter of the Site. The groundwater flow system is largely governed by topography and the HSU contact surface, and has remained essentially constant between 1997 and 2009. The lateral groundwater flow directions do not appear to be affected by seasonal recharge.

The saturated thickness of the Upper HSU during 2001, 2004, and 2008 is depicted on Figures F-6, F-11, and F-17. The maps show measured water heights above the Upper/Lower HSU Contact in feet, and isothickness contours including “zero thickness” contours indicating areas where the Upper HSU is unsaturated. As illustrated on the maps, the saturated thickness of the Upper HSU varies in space and time. The saturated thickness of the Upper HSU during wet/high water conditions observed during March 2001 was generally 5 to 10 feet greater than during dry/low water conditions observed during March 2004. These differences are also illustrated in the long-term hydrographs for Upper and Lower HSU wells, which show the declining water levels observed between these two periods. For each time period, saturated thicknesses in Zone 1 exceeding 20 feet were observed in the Central Drainage Area and in the area around the A-Series Pond/RAP-C, and larger saturated thicknesses exceeding 30 feet were observed along the C-Drainage in Zone 2. Conversely, the Upper HSU appears locally unsaturated at the North Ridge and beneath the Hills separating the A, B, and C Drainages.

3.1.1.2 Upper HSU Groundwater Elevations

The Upper HSU potentiometric surface maps for 2001, 2004, and 2008 are (Figures F-4, F-9, and F-14) are very similar to the water table contour map because most of the monitoring locations used for the water table map are completed in the Upper HSU. Upper HSU water level data and contours are not shown in areas where the Upper HSU is unsaturated. The Upper HSU contour maps are generally consistent with those prepared for most of the previous RGMEW monitoring events. This similarity illustrates that the groundwater flow paths remain stable in addition to the general lack of significant seasonal fluctuations.

Topography greatly influences the water table of the HSU, lending to the absence of significant change in the Upper HSU groundwater contour maps between the wet and dry seasons and across years as well as to stable groundwater flow patterns. This observation suggests that groundwater storage may not be as significant a component of the Site water balance as other factors, such as surface runoff, evapotranspiration, and pond storage and evaporation (HLA, 2000b).

3.1.1.3 Lower HSU Groundwater Elevations

The potentiometric surface maps for the Lower HSU during 2001, 2004, and 2008 (Figures F-5, F-10, and F-15) show groundwater flow patterns in the Lower HSU. The Lower HSU water levels not used for contouring are denoted on the maps. Due to previous purging events or recent installation and because the Lower HSU exhibits relatively low permeability, water levels in a number of the Lower HSU wells were not or may not have been in equilibrium during 2001, 2004, or 2008. These data are flagged on the figures and on the hydrogeologic cross-sections. The potentiometric surface of the Lower HSU is similar to that of the Upper HSU and the water table; however, the correlation of topography and groundwater elevation is less pronounced (Figures F-19 through F-21).

The four observed artesian wells are all completed in the Lower HSU. Well MW-2BL is located offsite in the C drainage, and Well RP-6D is in the offsite B drainage. The third artesian well (RP-66C) is in the West Canyon near the Site boundary. The fourth artesian well, RP-16C is located near the north ridge northeast of the P/S Landfill. Artesian conditions in these wells illustrate the major groundwater flow conditions at the Site, which include groundwater recharge prevailing in the topographically elevated portions of the Site and groundwater discharge predominating in the drainages. Historical observations indicate artesian conditions in each of these wells can persist through the wet and dry seasons.

A significant feature of the Lower HSU potentiometric surface is the occurrence of upward hydraulic gradients along the PSCT and the PCTs. For example, during December 2008 upward hydraulic gradients were observed at well pair RG-1B (423.87 feet above mean sea level [amsl])/RG-1C (430.74 feet amsl), near PSCT-1 (409.01 feet amsl) and at well pair RG-4B (552.22 feet amsl)/RG-PZ-4C (553.12 feet amsl) near PSCT-4 (538.45 feet amsl - Table F-4). These gradients appear related to the presence of the PSCT and suggest that groundwater flow pathways may be absent in the unweathered claystone beneath the PSCT.

Many of the Lower HSU wells south of the PCTs have water levels that are higher than the groundwater levels in the PCT extraction wells. Near PCT-A, groundwater elevations during December 2008 in Lower HSU wells MW-15C (411.72 amsl) and RP-101C (418.329 feet amsl) are higher than in extraction well RAP-2A (395.80 feet amsl) located to the north. Similar relationships are observed near PCT-B and PCT-C. These results suggest the presence of inward hydraulic gradients toward the PCTs, and the absence of groundwater flow pathways beneath the PCTs.

3.1.2 Vertical Flow Conditions

Vertical flow conditions were evaluated by tabulating and plotting groundwater elevations in “nested” well pairs within and between the Upper and Lower HSUs, and by constructing hydrogeologic cross-sections showing vertical head conditions. Additional evaluation of vertical gradients and flowpaths was performed as a part of the groundwater modeling, as discussed in Attachment F-3.

Vertical hydraulic gradients are present in several areas including the North Ridge and beneath the capped landfills, PSCT, Ponds, and PCTs. At some locations the magnitude of the vertical hydraulic gradient exceeds that of horizontal gradients.

3.1.2.1 Hydrogeologic Cross-Sections

Six hydrogeologic cross-sections were developed to illustrate the hydraulic gradient field in the vertical plane. They illustrate the construction of the monitoring wells and piezometers, locations of the water table, equipotential lines and location of the Upper/Lower HSU lithologic contact. The cross-sections also display prominent Site features including landfill base elevations. The series of six site-wide sections essentially cover the Zone 1 and Zone 2 areas (see Figure F-22 for locations), and provide a relatively comprehensive view of the hydraulic gradients. December 2008 groundwater elevations are presented on site-wide hydrogeologic cross-sections A-A’ through F-F’ (Figures F-23 through F-28).

The overall groundwater flow directions continue to be from the topographically elevated areas in the northern portions of the Site toward the low lying A, B, and C Drainages along the southern perimeter of the Site. Downward hydraulic gradients are apparent beneath the North Ridge, while upward gradients are observed around some of the extraction features and ponds. The groundwater flow system is largely governed by topography and the HSU contact surface, and has remained essentially constant between 1997 and 2009. The vertical groundwater flow directions do not appear to be affected by seasonal recharge.

3.1.2.2 Nested Well Pairs

Table F-4 presents head differences and vertical gradients for 55 nested well pairs monitored during the June 1997 through March 2009 RGMEW quarterly elevation monitoring events. The vertical gradients indicate a potential for a vertical component of flow. However, because the permeability of the Lower HSU is relatively low, and because some Lower HSU monitoring wells have exhibited extremely low recharge rates after sample purging, some of the Lower HSU wells may not have reached equilibrium with the surrounding potentiometric surface within the Lower HSU since the previous purging/sampling event. The slow recharge rate witnessed in the non-equilibrium wells indicate that either recharge water is limited or that the formation surrounding the wells is of very low hydraulic conductivity. Non-equilibrium data for these wells are noted on Table F-4.

Vertical gradients for the nested well pairs generally remained stable between April 1997 and 2009, and continue to indicate downward flow potential in the topographically elevated recharge areas, and upward flow potential in most of the topographic depressions. Vertical gradients also appear to remain relatively steady over time as illustrated on hydrographs for the nested well groups (Figures P1 through P30, Attachment F-1). In general, groundwater elevations over time in most of the vertical well pairs track closely, and only occasional reversals in gradient directions are observed.

3.1.3 Groundwater Elevation Changes 1997-2009

Hydrographs of site groundwater elevations, between January 1997 and March 2009 are presented in Attachment F-1; historical groundwater elevations prior to 1997 were presented in the Data Summary Report (HLA, 2000b). Each long term hydrograph presents a set of wells grouped by location and HSU. Figures U1 through U44 show the grouped Upper HSU wells, while Figures L1 through L38 show the grouped Lower HSU wells. Tables F1-1 list the Upper and Lower HSU hydrograph well groups by group and by well name. Upper and Lower HSU groundwater elevations over time for the nested well pairs listed in Table A1 are presented on Figures P1 through P30. Extraction facility hydrographs are presented on Figures E1 through E5. On each Upper, Lower,, and Pair hydrograph, non-equilibrium data points between January 1997 and March 2009 are identified using a separate (NE) symbol from those data points determined to be in equilibrium.

Pressure transducers were installed in some Site monitoring wells to provide daily water level data from selected locations. Some of these wells have been continuously monitored since 1997 or 1998 (HLA, 2000b), with the exception of periods of downtime. At the request of the USEPA, several of the transducers were relocated to new wells during the 1st quarter of 2004. Historical graphs of the continuous groundwater elevation data collected since 1997 are presented in Attachment F-1 (Figures T1 through T21).

Historical water levels in these wells have shown several trends and responses to well sampling and seasonal recharge. During 2008-2009 and historically, water level trends for most of the

Upper HSU wells showed relatively rapid response to rainfall events and a quick decline in water levels after rainfall recharge has dissipated.

Water levels in most Upper HSU wells equipped with transducers before and during the 13th SA period indicated either only minor increases or a lack of seasonal water level responses to rainfall during 2003-2004, and median water levels in the Upper HSU and the Lower HSU indicated only small storage increases between December 2003 and March 2004 (Table F-5). Groundwater elevations and associated storage continued to decrease between March through December 2004. Storage increased in both the Upper and Lower HSU between March and May 2005, and December 2005 and March 2006. In addition, storage increased in the Lower HSU between August and December 2005. Groundwater storage decreased in the Upper HSU between March and December 2008, and increased between December 2008 and March 2009. Groundwater storage in the Lower HSU decreased between March and September 2008, and increased between September 2008 and March 2009.

Water levels in the Lower HSU wells equipped with transducers show several trends and responses to sampling, but generally did not exhibit significant responses to recharge during 2001-2002 and 2002-2003, and only minor recharge responses were observed during 2003-2004. Larger recharge responses were measured in Lower HSU wells during the 1st quarter 2005. As with the Upper HSU, the lack of water level response to seasonal rainfall in Lower HSU wells during 2001-2002 and 2002-2003 may be associated with reduced infiltration of rainfall in the recently capped landfill areas, lower rainfall totals as compared with previous years, and/or continued operation of the site extraction facilities. Recharge responses observed in 2004 and 2005 may be associated with above-average rainfall. Recharge response observed between 2005 and 2008 indicates that changes in groundwater elevation and storage are in response to seasonal rainfall.

3.1.4 Groundwater Storage Changes 1997-2009

Table F-5 presents the average water level and storage changes between the quarterly site-wide monitoring events estimated using a set of 326 wells (173 Upper HSU and 153 Lower HSU wells) gauged during the RGMEW monitoring events. Changes in storage were calculated based on the average water level changes in each HSU from one quarter the next, multiplied by the Zone 1 site area (252 acres) and storage/specific yield parameters. The overall Zone 1 storage change between June 1997 and March 2009 was a decrease of approximately 2,900,410 gallons or 8.99 acre-feet (Table F-5). Increases in groundwater storage were calculated for calendar years 1998, 2001, 2005, 2006, 2007, and 2009 (partial year), while decreases in storage were calculated for calendar years 1997 (partial year), 1999, 2000, 2002, 2003, 2004, 2008. The changes in storage are directly related to precipitation (and associated net infiltration). Increases in storage are observed in years with above-average precipitation, while decreases in storage are observed during and following drought years.

3.2 NAPL

This section describes the presence of LNAPL and DNAPL at the site, discusses the distribution of each NAPL phase in the Upper and Lower HSUs, discusses changes in NAPL thickness and distribution over time, and presents analyses of DNAPL flow potential based on subsurface hydraulic properties and NAPL physical properties.

As discussed in the RI/FS Work Plan, groundwater restoration to applicable or relevant and appropriate requirement (ARAR)-based standards can be technically impracticable based upon: (1) geological and hydrogeological constraints; (2) chemical-specific conditions (such as the presence of NAPLs); and/or (3) available treatment technology limitations. In cases where a TI waiver is warranted, the USEPA will approve an alternative remediation strategy that includes source removal or treatment (where practicable), coupled with source migration control and/or containment measures. The geological and hydrogeologic constraints and presence of both LNAPL and DNAPL at the Site are further discussed in Section 10 (TI Evaluation) of this report.

3.2.1 NAPL Distribution

Historical and recent NAPL levels measured in existing wells and piezometers are presented in Table F-6 and illustrated on Figures F-33 through F-39. Figures F-33 through F-35 are maps of LNAPL Distribution in Upper HSU, DNAPL Distribution in Upper HSU, and DNAPL Distribution in Lower HSU, respectively, while Figures F-36 through F-39 are NAPL cross-sections of the Gallery Well area, P/S Landfill and Central Drainage Area, and BTA.

Figures F-40 through F-43 are charts of LNAPL and DNAPL elevations and thicknesses over time in wells and piezometers where NAPL has been observed, and Figures F-44 and F-45 are DNAPL levels over time prior to during and after “shutdown tests” of the Gallery Well performed between August 2004 and Mach 2005. Recovery rates of DNAPL from the extraction systems as gauged in the 6-Pack accumulation tanks are shown on Figure F-46.

3.2.1.1 LNAPL Distribution

LNAPL is currently detected in the following P/S Landfill and Central Drainage Area wells:

- P/S Landfill piezometers RIPZ-13, RIPZ-14, and RIPZ-39;
- Gallery Well, and piezometers GW-PZ-W, GW-PZ-E1, GW-PZ-E2, GW-PZ-E3, RIPZ-23, RIPZ-24, RIPZ-27 and RIPZ-38; and
- Sump 9B, and piezometers Sump 9B-PB, Sump 9B-PC, RGPZ-5B, RIPZ-8, RIPZ-25, and RIPZ-31, and wells Sump 9B-CW and RIMW-3.

Historically, small amounts (less than 0.2 foot) of LNAPL were also observed in RG-3B (Appendix E).

As illustrated on Figure F-33, a continuous separate-phase LNAPL plume occurs beneath the P/S Landfill and Central Drainage Area from RIPZ-14 at the P/S Landfill Bench 5 to south of Sump 9B. Figures F-37 and F-38 illustrate NAPL thicknesses during March 2010 in cross-sections along an east-west line in the Gallery Well area, and a north-south line from the P/S Landfill to the PSCT. During March 2010, the LNAPL thicknesses in the eight Gallery Well piezometers ranged from 0.0 feet (GW-PZ-E3) to 22.39 feet (RIPZ-38). In the Sump 9B area, LNAPL thicknesses during March 2010 ranged from zero (Sump 9B-PA) to 3.342 foot (RIMW-3). During March 2010, the LNAPL thicknesses for piezometers RGPZ-5B and RIPZ-8, located on the bench north of Pad 9B, were 5.52 and 6.92, respectively, and 3.59, 5.02, and 0.60 for P/S Landfill piezometers RIPZ-13, RIPZ-14, RIPZ-39, respectively.

LNAPL presence in the P/S Landfill and Central Drainage Area was confirmed during the UVIF and MIP NAPL investigations documented in Appendix M. The elevated UVIF and MIP responses, in combination with the high concentrations of organic compounds found in soil at the toe of the P/S Landfill and in the portion of the Central Drainage Area between the Gallery Well to PSCT-1, are consistent with the known presence of NAPLs in these site areas.

The NAPL survey within the BTA also exhibited significant UVIF and MIP responses, which are consistent with elevated concentrations of organic compounds found in soil and groundwater in this area. Soil-partitioning calculations indicate the potential presence of LNAPLs in the BTA. This finding is supported by the annotations of suspecting LNAPL documented on drill logs while completing several of the new wells and piezometers in the BTA. However, to date LNAPL has not been measured as a separate phase in any of the BTA wells or piezometers.

3.2.1.2 DNAPL Distribution

DNAPL is currently detected in the following P/S Landfill and Central Drainage Area wells:

- P/S Landfill piezometer RIPZ-13;
- Gallery Well and Gallery Well bench piezometer RIPZ-27;
- RG-PZ-7C; and
- RG-PZ-7D.

Appendix E contains groundwater measurements in the new wells and piezometers during development through March 2009 and NAPL measurements through March 2010. DNAPL has not yet been observed in any of the RI chemical quality wells or piezometers, except RIPZ-13 and RIPZ-27, although DNAPL was observed in Lower HSU fractures in boring RISB-02.

3.2.2 NAPL Thickness Changes 1997-2010

Where present, LNAPL thicknesses in the wells and piezometers have changed over time (Figures F-40 and F-41). For example, in the Gallery Well piezometer GW-P(E3), LNAPL thicknesses decreased from a high of 8.98 in June 2001 to zero by March 2010. LNAPL presence and dynamics around the Gallery Well may be related to release of NAPL from buried drums pierced during the Summer 2000 piezometer installation along Bench Road 1, and subsequent extraction of LNAPL at the Gallery Well.

As illustrated on Figures F-42 and F-43, DNAPL thicknesses in the Gallery Well and RGPZ-7C and -7D have fluctuated over time. Only minor thickness fluctuations have occurred in the Gallery Well and RGPZ-7D since 2003, while the DNAPL thickness in RGPZ-7C has increased from around 9 feet in 2003 to a high of 19.89 feet in March 2008. DNAPL thickness in RIPZ-13 was 9.42 feet following installation of the piezometer in August 2007 and increased to a maximum of 14.19 feet in December 2007; the DNAPL thickness had remained stable at nearly 14 feet through March 2009. In March and April 2009, the CSC performed a DNAPL purge and recovery test to determine the rate and amount of DNAPL recharge in the immediate vicinity of the well (Figure F5-2). During the eight pumping days of the test, approximately 42 gallons of DNAPL were pumped from the well. During the week of March 23, 2009, the CSC began slowly pumping DNAPL from RIPZ-13 using a Watera pump set near the bottom of the piezometer at a rate of approximately 0.5 gallons per hour. DNAPL slowly decreased to a thickness to 8 feet while the pumping rate was slowly increased. The DNAPL then decreased to less than 3 feet as the pumping rate was increased to above 2 gallons per hour. Pumping stopped on April 2, 2009 with a total recovery of 0.1 gallon of LNAPL, 2.8 gallons of water, and 42.3 gallons of DNAPL. The DNAPL thickness upon completion of the pumping portion of the recovery test was 2.55-feet, which represented a DNAPL drawdown of 11.05 feet from the 13.6-feet prepumping thickness (Figure F5-1). The DNAPL thickness in RIPZ-13 recovered to 7.21-feet in a two month period following completion of the purging. The DNAPL level continued to slowly recover over a 1-year period to a thickness of 14.0 feet on June 18, 2010 (Figure F5-1).

3.2.3 NAPL Physical Properties

Physical property testing was performed during the RI for DNAPL and LNAPL samples collected from the Gallery Well, and DNAPL collected from piezometer RGPZ-7C. The physical properties measured and test methods used include:

- Density by test method ASTM D4052;
- Specific gravity by method ASTM D4052.
- Flash point by method ASTM D93.

The results of the physical properties testing for DNAPL and LNAPL samples collected from the Gallery Well and the DNAPL sample collected from piezometer RGPZ-7C were as follows:

Sample	Density (g/cm^3),	Specific Density [-}	Flash Point (°F)
Galley Well (DNAPL)	1.0851	1.0863	31
Galley Well (LNAPL)	0.9905	0.9914	38
RGPZ-&C (DNAPL)	1.0184	1.0194	27

DNAPL samples were also collected from the Gallery Well in 1994 and 1998 and analyzed for density and interfacial tension. The water/DNAPL interfacial tension was determined using two water samples: a groundwater sample from the Gallery Well, and a tap water sample. The results were as follows:

- Density = 1.09 g/cm^3 (1994); 1.1 g/cm^3 (1998)
- Tap water-DNAPL interfacial tension = 7.1 dynes/cm (1998)
- Ground water-DNAPL interfacial tension = 2.8 dynes/cm (1998)
- (average interfacial tension = 4.95 dynes/cm)

The relatively low DNAPL densities are expected due to the mixture of constituents within the DNAPL sample; due to co-solvency effect of the DNAPL mixture, several compounds (i.e., hydrocarbons) have individual a pure phase density of approximately 0.8 g/cm^3. (i.e., are LNAPL) The analytical results from the DNAPL sample collected in 2004 are presented in Appendix G. The data indicate that the chlorinated constituents which account for the largest dissolved concentrations are only minor components of the DNAPL.

The interfacial tension is much lower than that commonly exhibited by DNAPL forming compounds. A commonly cited range for DNAPL compounds is 20 to 60 dynes/cm. The much lower result from the Gallery Well DNAPL is apparently due to the presence of alcohol compounds in the DNAPL mixture. In addition, inorganic surfactants, which lower the interfacial tension even when present at relatively low concentrations, may also be present in the DNAPL.

NAPL sampling was also performed for wells RGPZ-7C and -7D and the Gallery Well in May 2003. Analytical results for NAPL sampling performed during May 2003 and the RI in December 2004 are presented on Table F-10.

3.2.4 DNAPL Flow Analysis

This section presents a summary of DNAPL flow and transport processes and a calculation of density-driven flow potential for vertical DNAPL migration in the area of PSCT-1.

3.2.4.1 DNAPL Flow and Transport Processes

As described in the RI/FS Work Plan and preliminary site conceptual models, the Upper/Lower HSU contact surface and associated permeability contrasts between the two HSUs are known to influence groundwater flow and solute transport. Site investigations indicate that aquifer physical properties differ between the weathered claystone of the Upper HSU and unweathered claystone of the Lower HSU. The measured permeabilities of the Lower HSU beneath the contact are generally much lower than the permeabilities of the Upper HSU (CSC, 2004). DNAPL, if present, can potentially accumulate or pool at the base of the Upper HSU and flow laterally along or vertically through the contact surface. DNAPL accumulation and migration is dependent on: the three-dimensional distribution of physical soil properties (e.g., porosity and permeability); the presence and size of fractures; the subsurface pressures at potential DNAPL depth intervals; and the physical properties of DNAPL (e.g., specific gravity, viscosity, and interfacial tension). Closed depressions (or “low spots”) in the HSU contact surface could allow DNAPL to accumulate and potentially achieve thickness and pressure sufficient to migrate into the Lower HSU.

Potential DNAPL penetration from the fill material into the Upper or Lower HSU requires displacement of the water-saturated porous matrix or fractures. The driving force for DNAPL movement is the additional pressure buildup due to its higher density relative to water. The additional pressure generated by the DNAPL pool is counteracted by pore-scale capillary forces which retain water within pores or fractures. DNAPL is able to displace water only when the DNAPL pool height generates sufficient pressure to overcome the capillary pressures.

Factors that favor DNAPL movement are wider pore radii or fracture apertures, higher DNAPL density and lower interfacial tension. The maximum depth to which a DNAPL penetrates in fracture networks depends on several factors, including fracture aperture, number and type of fracture connections, the physical properties of the DNAPL, and the height of the column of continuous DNAPL above the fractures at the front of the DNAPL zone. According to Pankow and Cherry (*1996*) it is generally not possible to predict the maximum depth of DNAPL penetration at fractured rock sites even when there is exceptionally-detailed information on the geology, groundwater flow, and fracture network properties because the fracture-specific data for such predictions generally cannot be obtained from our limited investigative methods.

Calculation of the required DNAPL pool height for entry into the Lower HSU was previously performed and presented in the Technical Memorandum, Interim Collection/Treatment/Disposal of Contaminated Liquids Component of Work (ICF Kaiser, 1998). Calculations were performed using both the equation based on hydraulic conductivity (McWhorter and Kueper, 1996) and the equation based on fracture aperture openings (McWhorter and Kueper, 1991), along with previous estimates of DNAPL fluid properties including a DNAPL density of 1.09 g/cm^3. Using the hydraulic conductivity equation, the required DNAPL pool heights ranged from 1.1 feet (using the maximum hydraulic conductivity of 2.5 x 10-4 cm/s) to 9.1 feet (using the geometric mean hydraulic conductivity 1.2 x 10^{-6} cm/s). Using the fracture aperture equation, the required pool heights range from 0.09 and 0.23 feet.

These results suggest a potential for DNAPL to initiate entry into the Lower HSU at the Gallery Well. However, the effect of local hydraulic gradients is not accounted for in the above equations; and may be important when considering the DNAPL migration in the vicinity of the Gallery Well. Specifically, upward hydraulic gradients due to the configuration of the P/S landfill and amplified by pumping at the Gallery Well will act to prevent downward migration of DNAPL. Detailed analyses of the impacts of hydraulic gradient on downward DNAPL migration are addressed in the section below.

3.2.4.2 Resistance to Downward DNAPL Migration by Upward Vertical Hydraulic Gradients

To drive DNAPL from a free surface into a porous (subsurface) media, there are three forces that act concurrently including the force due to gravity (or density driving force), the capillary force, and the hydraulic force. The gravitational force will act to settle the denser material to the "bottom" of the containing media; the capillary force (or specifically the capillary action of water) will act to prevent DNAPL invasion due to water being the preferred wetting agent with the surrounding media (i.e., high surface tension); and the flow direction of the groundwater, i.e., the hydraulic gradient. DNAPL migration will occur if the sum of the driving force (gravity and possibly downward hydraulic force) exceeds the restricting force (capillary force and possibly hydraulic force). The hydraulic gradient force can promote or resist DNAPL migration, depending on its principal direction.

In order to evaluate the ability of DNAPL to migrate downward into claystone fractures or pores, the CSC developed and applied a series of mathematical equations using site-specific data. The input parameters used in the equations were derived from actual site measurements where and when such data was available. A summary of the equations and resulting conclusions regarding DNAPL movement is presented in Attachment F-4 of this appendix. Detailed tabulation of the historical data and calculations are also included in Attachment F-4.

As discussed in other sections of this report and presented in Figures F-34 and F-35, DNAPL has been detected in the Upper HSU under the P/S Landfill RIPZ-13 to the Gallery Well and in the lower HSU in the area of RGPZ-7C/7D, and may be potentially present in the area extending from PSCT-1 northward to RIPZ-13. Nested well pairs within this area provide the hydraulic head (pressure) field data for evaluation. Five representative well pairs with relatively complete historical observations are within the area of specific consideration and include:

- 1 pair (RIPZ-23 and GW-PZ-W) in the vicinity of the area from RIPZ-13 to the Gallery Well,
- 3 pairs (RGPZ-6B/6C, RGPZ6C/6D, and RGPZ-7C/7D) downgradient of the Gallery Well and amongst Sump 9, PCST-1, and PSCT-2, and
- 1 pair (RG-1B/1C) adjacent to PCST-1.

It is noted that although piezometers RIPZ-23 and GW-PZ-W, may not be an exact nested well pair, in order to illustrate the flow scenarios near the area between RIPZ-13 and the Gallery Well and to account for the DNAPL presence in RIPZ-13 and the Gallery Well, these wells are used as a well pair as the separation is less than 10 ft. Additionally, three other well pairs outside of the (potential) DNAPL area are also selected for analysis in comparison to the hydraulic scenarios of those five well pairs mentioned above, which include:

- 2 well pairs (RG-4B/4C and RGPZ-3C/3D) adjacent to PSCT-4, and
- 1 well pair (WP-8S/8D) located at the toe of the Heavy Metals Landfill

Table F-8 summarizes the statistical analyses on the historical data sets of observed vertical hydraulic gradients (upward positive) and the calculated upward vertical hydraulic gradients (required to halt DNAPL downward invasion) before and after the year 2001 when capping remedies for P/S landfill and Heavy Metal landfill were completed and the current groundwater extraction features were also put online.

Site-specific analyses on DNAPL migration are discussed below.

At RGPZ-7C/7D between Sump 9B and PSCT-1 (downgradient of the Gallery Well), the pre-2001 observed vertical hydraulic gradients (upward positive) had a range from -2.43 to 0.11 ft/ft with a median value of -1.852 ft/ft, statistically less than the post-2001 observed gradients (with a median value of 0.051 ft/ft). Calculations based on the use of the DNAPL density value of 1.0184 g/cm^3 indicate that only 15% of the 20 pre-2001 observed vertical (upward) hydraulic gradients were sufficient to impede DNAPL invasion and overcome the gravity gradient (0.0184 ft/ft); while this number rose to 82% (of the 67 post-2001 observations) after 2001, likely due to the reduced recharge of rainfall in the capped landfill areas combined with the lowering of the action levels within extraction features such as Sump 9B and PSCT wells. Moreover, the observed vertical hydraulic gradients during January 2003 to December 2006 had a range of 0.0064 to 0.100 ft/ft, all exceeding the associated required upward hydraulic gradients ranging from -0.001 to 0.022 ft/ft and indicating that DNAPL downward migration could have been effectively resisted at RGPZ-7C/D during that time period. However, the most recent observed vertical hydraulic gradients (in a range of -0.11 to 0.0006 ft/ft since March 2007) have been consistently less than the required upward gradients (i.e., 0.005 to 0.024 ft/ft), partially due to the DNAPL thickness increase to 15 ~ 19.98 feet after 2007 from < 15 feet prior to 2007. This DNAPL thickness increase could be the result of DNAPL migration through the limited but potentially interconnected fracture network from potential sources including ponds and pads in the central drainage area and/or the P/S landfill, as discussed in Appendix G or more likely due to the punching of DNAPL containing drums during the 2007 RI investigation activities. Nonetheless, the results suggest a possible on-going DNAPL downward migration from RGPZ-7C to RGPZ-7D within the Lower HSU since March 2007. However, this appears to be a tentative and localized effect and is not widespread throughout the central drainage area. Furthermore, the up-to-date observed DNAPL thickness at RGPZ-7D has been below 3 feet, which is much less than the required DNAPL pool height, so it is unlikely for DNAPL to migrate deeper beyond RGPZ-7D.

At RIPZ-23/GW-PZ-W (in the vicinity of the area from RIPZ-13 to the Gallery Well), no groundwater elevation records were available before 2001. Since December 20, 2004, the observed vertical hydraulic gradients have been consistently exceeding the required upward vertical hydraulic gradients (ranging from 0.0511 to 0.0804 ft/ft based on the DNAPL density from the 2004 Gallery Well sample), clearly indicating that the local vertical hydraulic gradient in response to the configuration of the P/S landfill and amplified by pumping at the Gallery Well is sufficient to prevent and reverse DNAPL entry to the lower HSU in the vicinity area of the Gallery Well directly downgradient from the P/S Landfill.

At the other three well pairs within 200-ft radii of PSCT-1 including RG-1B/1C, RGPZ-6B/6C and RGPZ-6C/6D where DNAPL product has not been detected, the pre-2001 observed vertical hydraulic gradients are generally less than the post-2001 observed vertical hydraulic gradients, likely because of the implementation of the current groundwater extractions and landfill remedies. In particular, over 70% of the post-2001 observed vertical hydraulic gradients at RG-

1B/1C exceeded the required upward vertical hydraulic gradients necessary to halt the DNAPL downward migration (if present), most likely due to the influence of PSCT-1 extraction. Between RGPZ-6B and RGPZ-6C, calculations using the DNAPL density value of the 2004 RGPZ-7C DNAPL sample demonstrate that the observed vertical hydraulic gradients have been generally less than the required upward vertical hydraulic gradients to allow DNAPL downward movement since March 26, 2003 (if DNAPL was present). However, the observed vertical hydraulic gradients between RGPZ-6C and RGPZ-6D are generally sufficient to prevent DNAPL from migrating downward from RGPZ-6C to RGPZ-6D (if DNAPL was present). Noting that piezometers RGPZ-6B/6C/6D are nested in one borehole, we can conclude that limited potential exists for DNAPL (if present) invasion downward at RGPZ-6B/6C/6D.

Away from the area where DNAPL has been detected and is potentially present, observed gradients at three well pairs (i.e., RG-4B/4C, RGPZ-3C/3D, and WP-8S/8D) illustrate that the local flow scenario has been changed since the capping of landfills. At the well pair of WP-8S and WP-8D, located at the toe of the Heavy Metals Landfill, the observed gradient is an example of an upward hydraulic gradient that develops without groundwater extraction but is significantly influenced by the recharge change associated with the 2001 capping over the Heavy Metal Landfill, as indicated by the fact that the pre-2001 observed vertical hydraulic gradients in a range of -0.182 and 0.165 ft/ft with a median value of 0.068 ft/ft, were statistically less than the post-2001 gradients ranging from 0.063 to 0.373 ft/ft with a median value of 0.230 ft/ft. In contrast, such a change in vertical hydraulic gradients has not been observed at RG4B/RGPZ-4C and RPGZ-3C/3D, likely because they are located away from the influence area of the capped landfills.

In summary, the comparative analysis on historical vertical hydraulic gradients and the required upward vertical hydraulic gradients to arrest DNAPL downward migration demonstrates that post-2001 observed vertical hydraulic gradients (upward positive) are generally greater than those of pre-2001 data set, i.e., DNAPL downward movement is restricted due to the placement of landfill caps (and groundwater extraction). Since landfill capping, sporadically, the groundwater gradients were insufficient to prevent downward DNAPL movement but these periods of insufficiency would not drive continuous, long term movement.

3.2.5 Potential NAPL Mobility / Migration

The following section summarizes potential NAPL migration mechanisms within the Central Drainage Area and the Burial Trench Area, which are the primary NAPL areas.

The primary potential sources of NAPLs within the eastern portion of the site are the P/S Landfill and the former ponds and pads located south of the P/S Landfill but within the Central Drainage Area. The P/S Landfill is likely a continuing source of both LNAPLs and DNAPLs. Note that presently LNAPL and DNAPL are both being recovered by liquid extraction conducted in the Gallery Well.

The Gallery Well and associated clay barrier contain and collect DNAPL that migrates laterally along the contact with the Lower HSU under the P/S Landfill, as the containment feature is “keyed” approximately 5 feet into the underlying bedrock contact. The LNAPLs that exist in the P/S Landfill and Central Drainage Area are intercepted by a number of different physical containment features, including:

- The Gallery Well/clay barrier at the toe of the P/S Landfill

- Sump 9B
- The PSCT (collected by extraction well PSCT-1)

In addition to the potential lateral migration along the HSU contact in this area, DNAPL could migrate downward into the underlying fractured bedrock (i.e., Lower HSU) under certain conditions. However, fracture interconnectivity in the relatively ductile unweathered claystone may not be laterally extensive enough to provide the necessary flow path for migration through the Lower HSU from upgradient in the Central Drainage Area (i.e., from the free DNAPL present at the Gallery Well and southern P/S Landfill area). As discussed in Section 4, fracturing in the Lower HSU does not include readily identifiable patterns that would indicate interconnected sets, nor are fractures at depth of sufficient aperture to be substantially transmissive. Clay infilling further reduces fracture porosity in the Lower HSU.

Potential DNAPL penetration into the Lower HSU requires displacement of the water-saturated porous matrix or fractures. The driving force for DNAPL movement is the additional pressure buildup due to its higher density relative to water. Pore-scale capillary forces that retain water within pores or fractures counteract the additional pressure generated by the DNAPL pool. DNAPL is able to displace water only when the DNAPL pool height generates sufficient pressure to overcome the capillary pressures. The densities of the DNAPLs found in this area are relatively low (the Gallery Well DNAPL density has been measured at approximately 1.08 g/cm^3], and piezometer RGPZ-7C DNAPL density is only 1.02 g/cm^3). The low densities of these DNAPLs are due to the mixture of chemicals within them, which include many organic chemicals with individual densities less than water. The interfacial tension (i.e., the surface tension between two liquids) between the DNAPL and ground water is also relatively low, apparently due to the presence of alcohols and/or inorganic surfactants that are present in the DNAPL. While the relatively low densities reduce the potential for DNAPL migration, the low interfacial tension produces the opposite effect, greatly increasing the migration potential.

As noted in the RI/FS Work Plan, previous site conditions could have resulted in downward DNAPL migration based on reasonable assumptions for DNAPL properties (densities and interfacial tensions), DNAPL pooled heights, and fracture apertures. The observation of DNAPLs in piezometers RGPZ-7C and RGPZ-7D suggest that vertical migration of DNAPLs through the limited but potentially interconnected fracture network in the Lower HSU has already occurred within the Central Drainage Area.

Subsurface conditions and DNAPL presence in the Upper and Lower HSUs between the P/S Landfill and PSCT are illustrated on Figure F-38 (see Figure F-36 for the cross-section location). The presence of DNAPL in the Lower HSU (at RGPZ-7C and RGPZ-7D) could be attributable to a number of past conditions at the site and associated factors including but not limited to those listed below:

- Prior to the CSC's tenure at the site, when liquid extraction from the Gallery Well was limited and the action level in the well was significantly higher, the DNAPL pool height behind the clay barrier was reported to be as high as 9 feet, which exceeds the required thickness to effect DNAPL entry into underlying fractures.
- DNAPL reported in RGPZ-7C and RGPZ-7D may have originated from sources in the area other than the P/S Landfill, including Pads 9A and 9B or Pond R. The DNAPL may have migrated through a limited fracture network below these historical sources to the depths of the piezometers.

- The DNAPL noted in the Lower HSU may have entered the Lower HSU and migrated prior to the construction of the containment features of the P/S Landfill.

The potential for continued and significant DNAPL migration deep into the Lower HSU is considered to be relatively low under current site conditions (i.e., with the current extraction systems operating in the P/S Landfill and the PSCT) because of the relatively limited areas where evidence of DNAPL has been found at the site, the low DNAPL pool heights in those areas, the relatively low frequency and small apertures of fractures identified within the Lower HSU, and the absence of an obvious connected fracture network deeper in the Lower HSU. Liquids extraction within the containment features noted above has also created localized upward hydraulic gradients, which tend to minimize the potential for downward contaminant migration.

The CSC has evaluated mobility/migration of NAPLs between the Burial Trench Area and PSCT-4. Three new RI monitoring wells (RIMW-6, RIMW-7, and RIMW-8) were installed within the Burial Trench Area to evaluate ground water chemistry and to identify NAPL presence in that area. Although observations made during the drilling of well RIMW-7 indicated the potential presence of LNAPL, none of the newly installed RI monitoring wells in this area has contained measurable amounts of NAPLs. It should be noted, however, that these wells were intentionally installed outside of the former burial cells, and the CSC has assumed that NAPLs could be present within any of these former waste disposal features. Surface tar seeps in several locations within the Burial Trench Area may be evidence that LNAPLs are present within the former trenches. The absence of NAPLs in the new wells is therefore not definitive evidence that NAPLs do not exist within the study area; rather, it indicates that the NAPLs that may be present are not found outside of their original trench locations. Subsurface conditions between the Burial Trench Area and PSCT-4 are illustrated on a cross-section (see Figure F-39).

There are some potentially significant differences between the potential mobility of NAPLs observed within the Central Drainage Area and those NAPLs that are present within the Burial Trench Area. These potential differences include:

- The volume of wastes within the presumed sources area can affect the lateral and vertical migration of the NAPLs (e.g., increased DNAPL pool heights can increase the potential for downward migration within fractures), and the magnitude of the NAPL sources is likely greater in the Central Drainage Area compared with the Burial Trench Area. The CSC currently believes that the primary source of the NAPLs in the Central Drainage Area is the P/S Landfill, which received large quantities of containerized waste pesticides and solvents. The quantity of wastes within the Burial Trench Area is not as great as that of the P/S Landfill.
- NAPL migration in the Central Drainage Area is likely influenced by the geologic properties of an alluvial canyon. This includes the presence of high hydraulic conductivity alluvium and weathered claystone. The former drainage channel could also act as a geologic depression where DNAPLs could accumulate and migrate down slope. In contrast, the Burial Trench Area was carved out of a ridge of bedrock. No obvious preferential flow paths or low points are known to exist in this area.

Similar to the Central Drainage Area where the CSC extracts DNAPL using the existing well network, the CSC extracts liquids from an extraction point within the PSCT located immediately downgradient from the Burial Trench Area. To date, NAPLs have not been observed within PSCT-4, which is the closest extraction well to the Burial Trench Area. The data collected to date indicate that the NAPLs (if present) beneath the Burial Trench Area have not migrated significantly since they were originally emplaced.

3.3 Site Water Budget

A hydrologic water budget was constructed to aid in estimating fluid fluxes into and out of the Zone 1 aquifer system. Details of each budget component including data sources and parameter quantification, including descriptions of hydrologic sub-models used in the water balance, are included in Attachment F-2.

The mass balance was performed for the period from January 1997 through June 2004 for the combined site surface and groundwater system. Measured or estimated volumes for each identified system inflow, outflow, and storage component were tabulated monthly. The water budget period and temporal discretization correspond to the simulation periods used in the MODFLOW model historical calibration (Attachment F-3).

Measured or estimated volumes for each identified system inflow, outflow, and storage component were tabulated at a monthly frequency. Figure F-47 illustrates the identified site water budget components. Monthly and cumulative budgets were evaluated to assess system dynamics and potential net system inflow/outflow. Sensitivity analyses of the most critical budget components (e.g., evapotranspiration) were also performed.

The Zone 1 hydrologic system consists of the following components:

Inflows	**Outflows**	**Changes in Storage**
Precipitation	Pond Evaporation	Surface Water (Ponds)
Surface Water Run-on	Evapotranspiration	Groundwater
Dust Control (from ponds)	Groundwater Extraction	
Irrigation (from ponds)	Pond Dewatering	
Groundwater Underflow	Surface Water Run-off	
	Groundwater Underflow	

Table F-7 summarizes the cumulative 1997-2004 water budget volumes for the sitewide Zone 1 area, and Figure F-48 shows the sitewide Zone 1 cumulative recharge, discharge, and total budget/error over time. Details of the cumulative recharge, discharge, and total budget/error for the two subareas north and south of the PSCT are included in Attachment F-2.

For the site as a whole and each subarea, the largest recharge component is rainfall recharge and the largest discharge components are evapotranspiration followed by pond evaporation. The cumulative error propagated through time (resulting from bad data, missing data, or an actual discrepancy), as well as the month-to-month error, indicates the relative balance of the surface/groundwater system and the potential capture effectiveness of the pumping systems in removing recharged water. A negative error (more discharge than recharge) was calculated for the entire site as well as for the south of the PSCT subarea. The cumulative negative error for the entire Zone 1 area for the period from January 1997 through June 2004 was around 300 million gallons. Almost all of this error is associated with the south of the PSCT subarea. The cumulative negative error for the north of the PSCT subarea for the period from January 1997 through June 2004 was essentially zero.

Using the monthly water budget approach, it is readily apparent that seasonal precipitation controls when the system error swings from positive to negative. In any given year, most months indicate that more groundwater is being removed from the system than is entering the system (a negative error). Months when the opposite is true include those with high precipitation events. Positive errors are calculated each water year during the wettest winter months. During the El Niño water years (i.e., 1997-98 and 2000-2001), the positive monthly errors are greater than during normal precipitation years.

3.4 Groundwater Flow Modeling

The CSC constructed a site-wide three-dimensional groundwater model according to the approach and scope presented in the RI/FS Work Plan. The CSC evaluated the results of the groundwater flow model (in conjunction with empirical hydrogeological, flow, and water quality data) to evaluate site-wide and local flow conditions, the hydraulic effectiveness of current liquids extraction, and potential effectiveness of alternate site remedies developed during the TI evaluation and FS portions of this project. The groundwater model is not being used to simulate multi-phase or NAPL flow or solute transport, but is used as a tool to assess solute and NAPL transport and containment.

Steady-state and transient calibration simulations have been performed using a seven-layer MODFLOW model (Figure F-49). Analyses of several input parameters have been performed and documented in Technical Memoranda submitted to the USEPA (MACTEC, 2006a and b).

Details of the groundwater flow model development, input parameters, calibration process, and results are included in Attachment F-3. Tables F-7 and F-9 summarize the MODLOW calibration results and MODFLOW water budget, respectively, and Figure F-50 illustrates simulated steady-state groundwater elevations and flowpaths.

With respect to volumetric groundwater flow rates, flowpaths and NAPL migration potential, model simulations indicate the following:

- Simulated on-site groundwater flowpaths are three-dimensional; downward hydraulic gradients and flowpaths are simulated in the northernmost Burial Trench Area with neutral or upward vertical gradients simulated near PSCT-4.
- Vertical flow components are simulated between the toe of the P/S Landfill and PSCT-1; however, these are variable with local upward flow components simulated in the area between the Gallery Well and PSCT-1 (MACTEC, 2006b). Upward flow is induced by extraction at the Gallery Well and Sump 9B, and at the PSCT.
- On a mass-flux basis, most groundwater flow occurs through the Upper HSU and uppermost portions of the Lower HSU; horizontal and vertical volumetric fluxes below 100 feet into the Lower HSU are negligible.
- Preferential pathways in the Upper HSU control lateral flow, especially in the Central Drainage Area. Calibration results confirm high hydraulic conductivity zones in the historical drainages areas, and these preferred pathways appear to be important controls on groundwater flow rates and directions.

The downward hydraulic gradients and simulated vertical flowpaths suggest the possibility of local enhanced downward DNAPL migration beneath the P/S Landfill and near the BTA. However, to date no DNAPL has been detected in the BTA. In the Central Drainage Area, upward vertical flow is induced by extraction at PSCT-1 is simulated in the area of RGPZ-6C/D and RGPZ-7C/D. This condition creates a counterforce against DNAPL migration in this area.

3.5 Hydraulic Effectiveness of Response Systems

The following sections discuss the construction and operation of the Gallery Well, Sump 9B, the PSCT, and the PCTs (PCT-A, PCT-B, and PCT-C), and their hydraulic effectiveness based on the local water level elevation data and groundwater flow modeling results. Further discussion of extraction system effectiveness based on the Groundwater Flow Model is presented in Attachment F-3.

3.5.1 Gallery Well

A subsurface clay barrier was constructed below the toe of the P/S Landfill in 1980. The barrier is approximately 13 feet wide and 50 feet deep at its deepest point and reportedly extends a minimum of 4 feet into the unweathered claystone bedrock. A partially constructed buttress embankment to protect the toe area of the P/S Landfill was built over the clay barrier, and extends approximately 30 feet above the clay barrier. A collection gallery and associated extraction point (the Gallery Well) was installed adjacent to the upgradient face of the clay barrier to facilitate removal of contaminated liquids. The Gallery Well consists of an approximately 5 to 6 foot diameter gravel filled pit adjacent to the upgradient (north) side of the clay barrier with a casing in the center of the pit to allow pumping of contaminated liquids and groundwater. The Gallery Well extends to a depth approximately 75 feet below the top of the buttress embankment. Fluids extracted by the Gallery Well currently are taken to a permitted, offsite disposal facility.

Figure F-29 presents a local potentiometric surface map for the area near the Gallery Well, Sump 9B, and PSCT during December 2008. Fluid levels were measured between December 16 and 29, 2008, the dates of the December 2008 site-wide water level monitoring event. Because of fluctuations in liquid levels due to pumping, the averages of water levels measured two times a day in the pumping facilities and associated piezometers are depicted on the maps and cross-sections. The hydraulic impact of the Gallery Well facility is shown on Figure F-29 where the 500-foot and 520-foot contours reflect the depression cone of the Gallery Well, indicating the Gallery Well is likely producing a capture zone that extends to the south of the clay barrier. As illustrated in cross-section on Figure F-37, liquid extraction from the Gallery Well maintains the liquid levels along the Gallery Well bench below the upper limit of the clay barrier.

MODPATH results (Attachment F-3) indicate the Gallery Well primarily captures groundwater originating from the north ridge area and PCB Landfill area northwest of the Gallery Well.

3.5.2 Sump 9B

Sump 9B is a gravel filled collection trench and associated extraction point installed approximately 200 feet downgradient (south) of the Gallery Well and upgradient of the PSCT. During closure of former Pad 9B, Sump 9B was constructed to address observed contamination (i.e., free product) below the groundwater table. Sump 9B consists of a circular sump, approximately 27 feet deep and 12 feet wide. Extending approximately 100 to 150 feet westward from the sump is a shallow (estimated 8 to 12 feet deep) trench. The sump and trench are filled with gravel to approximately 6 feet below grade and covered with compacted fill material. An extraction point is installed at the deepest portion of the sump. Fluids removed from the sump are currently containerized and delivered to a permitted, offsite disposal facility.

The flat topography near Sump 9B promotes infiltration of rainfall runoff and groundwater recharge with groundwater encountered at only a few feet below ground surface. The shallow water table is evidenced by a seep (the 9B Road Seep) that was observed south of Sump 9B in June 1998. Consequently, in 1998 a collection sump was constructed near the seep, and is designated as the “Road Sump.”

The increased groundwater recharge occurring in the Sump 9B vicinity counteracts the hydraulic impact of groundwater extraction at Sump 9B. The local contour map (Figure F-29) does not reveal the presence of a distinct capture zone associated with extraction at Sump 9B. The water levels shown in Sump 9B and the nearby piezometers are representative median values that take into account the daily fluctuation due to pumping. During current pumping conditions, the water level in Sump 9B is usually maintained between 20 and 23 feet btoc (below top of casing), while the action level is 20 feet btoc. The impact of groundwater extraction at Sump 9B is reflected in the observed drawdown in each of the nearby five shallow piezometers, one monitoring well, the deeper ‘Companion Well’, and inferred convergent flow toward the Sump.

MODPATH results (Attachment F-3) indicate Sump 9B captures groundwater originating from the North Ridge area as well as groundwater recharged within the Central Drainage north of Sump 9B.

3.5.3 PSCT

The PSCT is a continuous collection trench that is approximately 2,650 feet long and nominally 3 feet wide. The PSCT was installed in 1990, on a roughly west to east alignment, across most of the central portion of the Site and is situated downgradient of the five inactive landfill cells and the BTA. The PSCT extends to depths ranging from approximately 13 to 65 feet, depending upon the depth at which unweathered claystone bedrock was encountered during construction. The PSCT is designed to intercept subsurface liquids migrating from north to south across the Site. The major components of the PSCT include a filter fabric placed against the native alluvial or fill soils, a permeable gravel backfill, native soil backfill above the gravel, a low permeability cap to minimize water infiltration, and four collection sumps and associated extraction points. The gravel backfill extends approximately 10 feet above the highest level of groundwater seepage observed during excavation.

The four collection sumps were constructed by excavating pits into unweathered claystone bedrock. The sumps are also filled with gravel with a screened casing to facilitate liquid removal. Liquids collected in the PSCT flow along the bottom of the trench toward the center of each sump, away from engineered flow divides that isolate the individual sumps. When liquid levels exceed the level of the flow divides, liquids flow along the base of the trench to the lowest point in the system, located at extraction point PSCT-1. Currently, liquids are extracted from the PSCT-1, PSCT-2, and PSCT-4 sumps in this barrier system. Action and operating water levels in these three Sumps are currently below the Upper/Lower HSU Contact. PSCT-3 is also equipped with a dedicated extraction pump, although liquid levels in the sump never reach the required action level of 51 feet btoc. Liquids extracted from the PSCT are treated at the PSCT GAC Treatment System and effluent discharged into Pond 18.

In June 1998, four wells were installed to delineate the capture zones downgradient of the PSCT extraction wells. RG-1B and RG-1C are approximately 25 feet south of PSCT 1 and RG-2B and RG-4B are approximately 25 and 50 feet downgradient of PSCT-4, respectively. RG-1C is completed in the Lower HSU and the remaining three wells are in the Upper HSU. Additional piezometers adjacent to the PSCT were installed during 2000, 2004, and 2006.

Figure F-29 shows the impact of groundwater extraction at PSCT-1, PSCT-2, and PSCT-4. Capture zones extend southward in the Upper HSU from the PSCT extraction wells, and convergent flow to the Trench and Sumps is inferred based on water levels in the Sumps and nearby monitoring wells/piezometers. The inward gradients (into the trench) are also evident in the cross-section (Figure F-28).

PSCT-1: During December 2008, the water level in RG-1B (25 feet south of PSCT-1) was approximately 14 feet above that measured in PSCT-1. The water level in adjacent Upper HSU piezometer RIPZ-18, well RIMW-2, and well RG-7B, all farther downgradient than RG-1B, were 0.82, 8.69, and 0.70 feet, respectively, above RG-1B. The water level in adjacent Lower HSU Well, RG-1C, farther downgradient than RG-1B, was approximately 6.87 foot higher than the water level measured in the RG-1B. The differences in well water levels demonstrate the continued presence of a northward groundwater gradient and groundwater capture zone extending downslope of PSCT-1.

PSCT-2: During December 2008, an inward gradient to the extraction well from the south was observed with downgradient piezometers RIPZ-19 and RIPZ-11, where water levels were 12.90 and 1.71 feet higher, respectively, than in PSCT-2. Two additional piezometers located south of PSCT-2 (RIPZ-6 and -7) did not display an inward gradient to the extraction Sump, although RIPZ-6 was not in equilibrium and RIPZ-7 was dry during December 2008. Lithologic observations during drilling and installation of piezometers RIPZ-6 and-7 indicated extremely ”tight” drilling conditions in the area south of PSCT 2, consistent with the ongoing non-equilibrium of water levels in those wells associated with their installation and initial development in 2004.

PSCT-4: At PSCT-4, an inward gradient to the extraction well from the south was observed during December 2008, with downgradient well RG-4B exhibiting a water level of 13.77 feet higher than in PSCT-4. Downgradient well RG-2B was dry during the December 2008 monitoring event. The December 2008 water levels in Piezometers RIPZ-9 and RIPZ-16, both upgradient of the PSCT, indicated an inward gradient to the extraction well (water levels 12.77 and 14.86 feet higher than PSCT-4, respectively). The water level from well RIMW-5 installed downgradient of the PSCT did not indicate an inward gradient to extraction, as the RIMW-5 water level was 4.49 feet lower than PSCT-4. This is consistent with historical data.

MODPATH results (Attachment F-3) indicate PSCT-1 captures groundwater originating from the North Ridge areas north and east of the Metals, C/C, and Acids Landfills, as well as groundwater recharged within the Central Drainage north of PSCT-1. PSCT-2 captures groundwater recharged in the PCB Landfill-BTA area, and areas between the BTA and PSCT northwest of PSCT-2.

3.5.4 Perimeter Control Trenches (PCTs)

The three perimeter PCTs were constructed to intercept groundwater at the Site boundary and prevent offsite migration of groundwater contaminants. The design and construction of the PCTs are described in the Construction Report prepared by Brierly and Lyman (June 1989). In

1990, Brierly and Lyman evaluated the performance of the PCTs (Brierly and Lyman, 1990). An updated analysis of the hydraulic effectiveness of the PCTs was also presented in the Technical Memorandum ™ (ICF Kaiser, 1998), and compared to the Brierly and Lyman study.

PCT-A: In 1981, a subsurface clay core barrier was constructed along the eastern and southern perimeter of former Pond 20. Records of field inspections conducted during construction indicate that the excavation for the clay core of the barrier wall was 15 feet wide and extended into firm claystone bedrock. In 1990, a gravel filled trench (PCT-A) and associated groundwater extraction points (RAP-1A, RAP-2A, and RAP-3A) were installed to collect and pump groundwater at the southeast corner of the facility. These facilities were constructed as an additional means for intercepting groundwater flowing toward the A drainage area (Figure F-30).

Groundwater flow at the southeastern perimeter of the Site is directed into the A drainage due to the presence of a prominent hill south of the Zone 1 boundary. Groundwater recharge through this hill causes a reversal of the flow gradient immediately south of the Site boundary. This topographically induced groundwater divide is complemented by the presence of the PCT-A, which extends eastward across the head of the A-Drainage.

Water levels in all three PCT-A extraction wells are generally maintained between 10 to 30 feet lower than the prevailing water levels immediately downgradient of the PCT. This demonstrates the reversal in groundwater gradients by the operation of PCT-A, and the effective prevention of groundwater movement from the Site into the A drainage.

Much of the extracted groundwater at RAP-2A and RAP-3A likely originates from the nearby RCF Pond and the hill south of PCT-A. The water level in the RCF Pond during December 2008 was approximately 42 feet higher than in RAP-3A, which is less than 200 feet from the southern perimeter of the pond.

Hydrographs of groundwater elevations at the three PCT-A extraction points and nearby observation wells are presented in Appendix F1. As illustrated on Hydrograph E4, measured water levels in the extraction wells indicate seasonal water level variations are minimal between the RGMEW monitoring events from September 1997 to March 2009.

PCT-B: In 1973, a subsurface clay barrier was installed directly downgradient from Pond 13 between the two hills flanking the head of the B drainage. The clay barrier was constructed to restrict groundwater flow entering the B-Drainage area. The barrier is reported to be 8 feet wide and approximately 50 feet deep, extending about 4 feet into unweathered claystone. In addition, a 1-foot wide gravel perimeter trench (PCT-B) and a former extraction point (B-5) were constructed downgradient of the clay barrier to assist in groundwater collection and removal. The pump in Well B-5 has since been removed and there are no current plans to replace it.

The PCT-B perimeter trench contains an extraction well (RAP-1B), which is directly south of Pond 13 in the B drainage. Figure F-31 shows the December 2008 water table surface in the vicinity of PCT-B. During December 2008, the groundwater elevation in RAP-1B was 1.65 feet lower than the groundwater elevation in Well B-5. The lower water level in PCT-B indicates that the facility is effective in preventing offsite groundwater flow. Groundwater flow in the vicinity of PCT-B is further impeded by the reversal in groundwater gradients that occur immediately south of the Site. There are two prominent hills in Zone 2 on either side of the B-Drainage. The topography here rises to an elevation of more than 150 feet above the topographic elevation of the southern perimeter of Zone 1. These topographic highs result in corresponding increases in groundwater elevation on either side of the B-Drainage. The net result is that groundwater gradients are oriented northward towards the Zone 1 Site boundary, or are directed into the B drainage. Thus, the head of the B-Drainage serves as a groundwater divide, preventing groundwater from flowing past PCT-B. The eastern and western edges of PCT-B are keyed in to bedrock and terminated within the adjoining hills.

Hydrographs of groundwater elevations in RAP-1B and nearby observation wells are presented in Appendix F1. As illustrated on Hydrograph E5, measured water levels in the RAP wells indicate seasonal water level variations are minimal between the RGMEW monitoring events from September 1997 to March 2009. Water levels in RAP 1B during the 2008-2009 monitoring periods were similar to historical water levels.

PCT-C: A perimeter control feature consisting of a clay barrier and a separate extraction trench was constructed southwest of the A Series Pond to intercept groundwater migrating southwest from Zone 1 toward the C-Drainage and Casmalia Creek (Figure F-32). The extraction trench is 305 feet long and was constructed at the western end of the clay barrier. One sump and extraction well RAP-1C were constructed within the trench. Liquids are also extracted from nearby Well C-5. The close proximity of PCT-C to the A Series Pond makes it difficult to achieve the target water levels while water levels in the A Series Pond remain high.

December 2008 and historical water levels in PCT-C and adjacent observation wells indicate that, under normal operations, a significant capture zone exists south of PCT-C and horizontal gradients are reversed. At the southeastern end of the clay barrier, groundwater is impeded by a reversal in the groundwater gradient due to the hill between the B and C drainages. Groundwater flow past the western end of the clay barrier is prevented by groundwater extraction from the PCT-C trench. Thus, PCT-C appears to be effectively preventing offsite migration of groundwater in this vicinity.

Hydrographs of groundwater elevations in RAP-1C and C-5, and nearby observation wells are presented in Appendix F1. As illustrated on Hydrograph E5, measured water levels in the RAP-1C and C-5 indicate only minimal seasonal water level variations between the RGMEW monitoring events from September 1997 to December 2006. Water levels in wells RAP-1C and C-5 during the 2007-2008 monitoring periods were similar to, or lower than, historical water levels.

MODPATH results (Attachment F-3) indicate PCT-A captures groundwater originating from areas south of the PSCT, the RCF Pond, and the hills between the A- and B-Drainages. PCT-B captures groundwater originating from areas south of the PSCT, the RCF Pond, B-Drainage, and the hills between the A-, B-, and C-Drainages. PCT-C captures groundwater originating from areas south of the PSCT and the A-Series Pond.

3.6 Groundwater Flow Summary

The following summarizes the major conclusions regarding groundwater flow conditions at the Site:

- The dominant large scale feature influencing groundwater flow at the Site is a pervasive zone of weathering and enhanced secondary fracture conductivity in the Upper HSU.
- The Upper HSU is poorly transmissive, the Lower HSU even less so. Borehole hydraulic tests reported by the USEPA (1986) yielded a maximum hydraulic conductivity of 31 feet per year (ft/yr) in the Upper HSU. The HSCER Report (WCC, 1988a) cites a geometric

mean hydraulic conductivity of 70.4 ft/yr in the Upper HSU, and 1.04 ft/yr in the Lower HSU.

- The Upper/Lower HSU contact surface and associated permeability distribution influences flow conditions in the Upper HSU. Characterization of the contact surface includes borehole and geophysical data collected during summer and fall 2004 and 2006/2007 RI Investigations.
- A high degree of correlation exists between topographic elevation and water table elevation. This allows the topographic data to be used in guiding interpretation of water level data (WCC, 1988a; ICF Kaiser, 1998).
- Groundwater flow through Zone 1 is generally to the south. Groundwater at the southern perimeter of the Site is intercepted by the PCTs, extracted, and discharged to onsite surface impoundments.
- Based on historical and recent groundwater elevation data from wells and piezometers, a groundwater flow divide that separates groundwater flow entering the Site is present along the north ridge, north of the landfills. The water table in this area receives recharge from precipitation and inflow from the higher ground west of the Zone 1 boundary. The flow divide occurs as a result of ground surface and Upper/Lower HSU contact topography, with lateral flow to the north and south away from the topographic divide. The flow divide exists in roughly the same location in both Upper and Lower HSUs, and occurs in roughly the same location throughout the water year.
- Comparison of the elevation of the Upper/Lower HSU contact with groundwater elevations in Upper and Lower HSU wells and piezometers during 2006 and 2007 indicates the Upper HSU beneath the north ridge may be locally saturated after winter recharge events. The saturated thickness appears to vary in space and time with a maximum thickness of about 10 feet.
- Based on historical and recent groundwater elevation data from nested wells and piezometers, vertical gradients vary across the Site and change slightly during the water year. Downward vertical gradients are generally observed in the area between the north ridge and the PSCT, and neutral or upward gradients are indicated near the PCTs. The vertical gradients change over time, with maximum downward gradients generally observed during the summer or fall.
- DNAPL and LNAPL are present at the site. LNAPL is present in the Central Drainage area, in the Upper HSU from under the P/S Landfill to north of PSCT-1. DNAPL is present in the Central Drainage area, in the Upper HSU under the P/S Landfill to the Gallery Well
- DNAPL is present in the Lower HSU in the area of wells RGPZ-6C and D to RGPZ-7C and D, north of PSCT-1.
- DNAPL migration within the HSU occurs, however, capture trenches and the capping of landfills act to restrict DNAPL movement. An analysis of active forces that affect DNAPL migration indicated that since landfill capping the potential for vertical DNAPL migration from the Upper HSU to the Lower HSU is significantly retarded by the vertical hydraulic gradients.
- Water budget analysis indicates the site as a whole exhibits a slight negative error, and more groundwater is being removed from the aquifer system than is recharging it.

- Groundwater flow modeling confirms the overall conclusions regarding groundwater flow paths and the state of the site water balance. MODPATH results indicate curvilinear flow paths downward from the North Ridge recharge area, through the Upper and Lower HSUs, and upward flow and discharge at the extraction features and Ponds.

4.0 EVALUATION OF ADDITIONAL DATA NEEDS

The Phase I and Phase II RI/expanded RGMEW groundwater and NAPL level program met the sampling objectives with respect to essentially complete collection of the groundwater and NAPL levels over time and characterization, to the extent that is technically practical, of the vertical and lateral extent of both LNAPL and DNAPL. Further characterization of DNAPL in the Lower HSU would require the installation of enumerable new deep wells, as no practical number of wells could completely characterize the extent of DNAPL in the Lower HSU due to the irregular distribution of fractures within the claystone that may potentially contain DNAPL. Liquid level monitoring at the site is ongoing, and historical, current, and future data will be used for remedial analyses.

The groundwater and NAPL level data obtained during the Phase I and Phase II RI investigation, along with historical data, were evaluated with respect to the groundwater Data Quality Objectives (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. The RI/FS Work Plan identifies all of the RI/FS DQO decisions and provides an evaluation of additional data needs associated with each, and the decisions specific to groundwater flow are listed below. Note some of these groundwater decisions are also addressed in Appendix E (Well and Piezometer Installation), Appendix G (Groundwater Chemistry), Appendix L (Geophysics), and Appendix M (NAPL Surveys).

4.1 DQO Decisions Related to Groundwater Contaminant Fate and Transport

The specific decisions and decision rules for liquid level 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?

The CSC believes that the groundwater data collected as a part of these RI investigations are adequate for evaluating the contaminant fate extent and transport DQO Decisions noted above. 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 assessed as a part of groundwater model calibration. Flow pathways have been further refined on the basis of the additional HSU contact information generated during this drilling investigation. Groundwater flow analyses are currently being 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 it's extent is delineated from (the absence of NAPL in) perimeter wells and piezometers.

Similarly, groundwater flow pathways, rates and directions have been characterized on the basis of validated subsurface and hydrologic data, the water budget analysis, and groundwater flow modeling.

The CSC intends to evaluate the hydraulic effectiveness of extraction systems on an ongoing basis as a 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.

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 investigations and modeling results 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 was evaluated as a part of groundwater modeling task; 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 TI 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 investigations 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 investigations 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.

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