APPENDIX L – GEOPHYSICAL SURVEYS

FINAL REMEDIAL INVESTIGATION REPORT
CASMALIA RESOURCES SUPERFUND SITE
CASMALIA, CALIFORNIA

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

LIST OF ACRONYMS

2-D	two-dimensional
amsl	above mean sea level
ARAR	Applicable or relevant and appropriate requirement
ARCH	air-rotary casing hammer
ATV	all-terrain vehicle
bgs	below ground surface
BTA	Burial Trench Area
btoc	below top of casing
CD	compact disk
COC	chemical of concern
CPT	Cone Penetrometer Testing
CSC	Casmalia Steering Committee
DNAPL	Dense nonaqueous-phase liquid
DQO	data quality objective
ERM	Environmental Resources Management
ET	evapotranspiration
fps	feet per second
FS	Feasibility Study
ft/yr	feet per year
g/cc	grams per cubic centimeter
GPS	global positioning system
HCSM	Hydrogeologic Conceptual Site Model
HSU	Hydrostratigraphic Unit
Hz	Hertz
IPR	Interim Progress Report
lb	pound
LHSU	Lower Hydrostratigraphic Unit
LNAPL	light nonaqueous-phase liquid
MACTEC	MACTEC Engineering and Consulting, Inc.
NAPL	nonaqueous-phase liquid
NE	non-equilibrium
NMD	Normal Move Out
NORCAL	NORCAL Geophysical Consultants, Inc.
P/S Landfill	Pesticide/Solvent Landfill
PSCT	Perimeter source collection trench
RGMEW	Regional Groundwater Monitoring Element of Work
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
Site	Casmalia Resources Superfund Site
SA	Semiannual
SAP	sampling analysis plan
SOP	Standard Operating Procedure
SOW	Scope of Work
TI	technical impracticability
TM	Technical Memorandum
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOCs	volatile organic compounds

1.0 INTRODUCTION

The Casmalia Steering Committee (CSC) conducted geophysical investigations at Casmalia Resources Superfund Site (Site) to investigate potential closed low areas or depressions in the surface of the Lower Hydrostratigrqaphic Unit (HSU). Across much of the Site, the surface of the Lower HSU exists as the contact between the weathered and unweathered Todos Santos claystone. Within the P/S Landfill, this surface exists as the contact between the unweathered claystone, and overlying buried waste and fill material. Possible depressions in the surface of the Lower HSU are of interest because they represent locations where Dense Non-Aqueous Phase Liquids (DNAPLs) may accumulate in the subsurface. Geophysical investigation techniques provide a means to measure physical contrast between elements within the subsurface. The processing of raw geophysical data often allows for accurate locating of boundaries between contiguous bodies that have markedly different physical properties, such as density, seismic velocity (compaction), and electrical and magnetic conductivity, among others. The geophysical investigation was performed in accordance with the June 2004 *RI/FS Work Plan* and the August 2005 *Phase II RI/FS Work Plan Supplement, Revised Draft, Geophysical Survey Plan,* which were submitted to and approved by the United States Environmental Protection Agency (USEPA).

The investigation consisted of three parts:

- A Pilot Study (detailed in the Geophysical Plan),
- A Phase I Production Survey (detailed in the Geophysical Plan), and
- A Phase II Production Survey (designed by the USEPA and CSC after the Pilot Study results were evaluated).

For the Pilot Study, the CSC tested the applicability of the seismic refraction, seismic reflection, and micro-gravity methods to resolve subsurface contrasts along two 1,200-foot lines crossing the Pesticide/Solvent (P/S) Landfill (Figure L-1). For the Phase I Production Survey, the CSC collected seismic refraction data along 16 lines totaling 22,000 feet in length through the Burial Trench Area (BTA), Central Drainage Area, and selected areas south of the Perimeter Source Control Trench (PSCT, Figure L-8). For the Phase II Production Survey, seismic refraction data were obtained over a grid of fourteen 960-foot lines centered on the toe of the P/S Landfill (Figure L-25). After the Phase I Production Survey was completed, an intrusive confirmation follow-up survey was performed using Cone Penetrometer Testing (CPT) borings to investigate a potential low spot suggested by the Phase I results. Similarly, after the Phase II Production Survey was completed, an intrusive confirmation follow-up survey was performed using CPTs and piezometers to investigate potential low spots suggested by the Phase II results.

The Pilot Study and Phase I Production Survey field work was performed from July 26 to August 13, 2004 by geophysicists from MACTEC Engineering and Consulting, Inc. (MACTEC) and NORCAL Geophysical Consultants, Inc. (NORCAL). Rick Miller of the Kansas Geological Survey, working under contract to NORCAL, directed the seismic reflection portion of the Pilot Study work. The Phase II Production Survey was performed from October 10 to 27, 2005, again by geophysicists from MACTEC and NORCAL. The Phase I intrusive follow-up work was performed during September 2004. The Phase II follow-up work was performed during August and September 2007.

It should be noted that the USEPA did not perform a detailed review of the Phase I survey results. Additionally, the USEPA had numerous comments on the CSC's Phase II field data acquisition plan and on the CSC's analysis of the field data. The USEPA prepared an alternate interpretation of the Phase II refraction results. The USEPA's final comments are discussed below in Sections 1.3, and 3.4, and were presented in a letter dated May 4, 2007 (Attachment L-5).

1.1 Pilot Study

The CSC selected seismic refraction as the primary geophysical investigation method because previous geophysical surveys along the Site perimeter (*RI/FS Work Plan [CSC, 2004a] and Section 5.2.10 and Appendix A.4, WCC, 1988a*) have demonstrated that the contact between the weathered and unweathered claystone can be detected with refraction. Although it was expected that refraction could delineate the contact across much of the Site, the CSC was concerned that seismic refraction (or any other surface geophysical method for that matter) could not effectively assess subsurface conditions at the P/S Landfill due to the heterogeneous nature of the fill material contained therein, which includes both crushed and intact drums of refuse. Because a basic assumption of the seismic refraction method is that the subsurface comprises homogeneous and laterally continuous layers, the CSC was concerned that the heterogeneous fill material in the landfill would disrupt the seismic raypaths and result in inaccurate velocity layer models, which could lead to an inaccurate representation of the contact. To address these concerns, the USEPA and CSC designed a Pilot Study to test the performance of the seismic refraction, seismic reflection, and micro-gravity methods on the Pesticide/Solvent (P/S) Landfill.

As previously stated, seismic refraction was included in the Pilot Study because previous work along the Site perimeter demonstrated that the contact between weathered and unweathered claystone could be detected with refraction. Seismic reflection was included in the Pilot Study because it methodically allows for high resolution imaging and might have proved effective for delineating more subtle depressions in the unweathered claystone surface beneath buried waste. Additionally, because seismic reflection requires a shorter surface array length than refraction (for a given investigation depth) a reflection survey could be focused more directly within the toe of the P/S Landfill. However, within areas of shallow depth surface irregularities and near surface velocity contrast, seismic reflection data imaging can be difficult due to variability in actual physical properties and representative processing parameters. Finally, micro-gravity was included in the Pilot Study because low areas might potentially have been revealed through density contrasts between the unweathered claystone and buried waste.

After analysis of the Pilot Study results, the CSC and USEPA agreed that seismic refraction was the only method that could meet the objective of delineating the claystone contact. Accordingly, seismic refraction was selected as the method for a Phase II Production Survey to investigate the existence of the reported low spot within the toe of the P/S Landfill.

1.1.1 Scope of Pilot Study

The Pilot Study was performed along co-located seismic and micro-gravity lines so the results from the different geophysical methods could be directly compared. The Pilot Study lines are designated PS-1 and PS-2. PS-1 was positioned in an east-west direction across the toe of the P/S Landfill near Bench 1. PS-2 was positioned in a north-south direction along the landfill axis and intersected PS-1 near its midpoint (Figure L-1). To the extent possible, the test lines were placed near ground truth locations (boreholes) where the depth of the contact between the

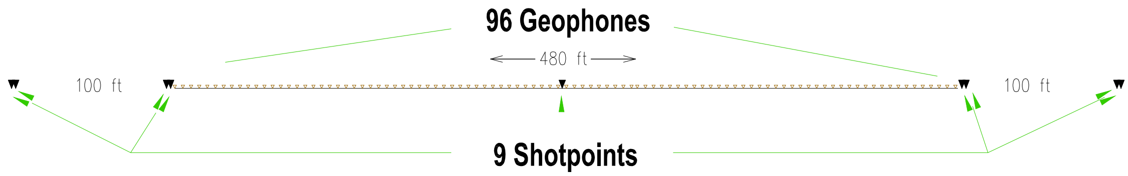
Upper and Lower HSU was known. As shown in Figure L-1, ground truth locations along PS-1 included wells RP-20B, CPT-LA-01, TP-4 and WD-8. Ground truth locations along PS-2 were limited to the Gallery Well and CPT-LA-01.

1.1.1.1 Seismic Reflection

The seismic reflection survey portion of the Pilot Study proceeded as a pair of walk-away tests directed by Mr. Rick Miller of the Kansas Geological Survey. In general, walk-away tests are performed prior to a reflection survey to assess the viability of the reflection method at a given site and to optimize survey parameters for data processing. Walk-away tests were performed along the central portions of lines PS-1 and PS-2 (Figure L-1) using an array of 96 geophones spaced 5 feet apart for a total geophone array length of 480 feet. Shotpoints were positioned nominally 5.0- and 100-feet off each end of the array and in the array center. Additional shotpoints were positioned 2.5- and 97.5-feet off-end for a total of 9 shotpoints per line. The purpose of the additional shotpoints (offset 2.5 feet from the adjacent shotpoint) was to emulate a 2.5-foot spaced geophone array and produce pseudo 192-channel shot gathers. This procedure enhances event coherency and improves discrimination of any special aliasing. Seismic energy was generated using a Digipulse AWD-100 100-pound (lb) accelerated weight drop system mounted to the rear of a “Gator” style all-terrain vehicle (ATV). Multiple hammer blows were struck at each shotpoint location. The data from each blow were first recorded separately; then, data from successive blows were stacked and then recorded. Additional tests were performed using a hammer-and-plate seismic source. Using a laptop computer display, all seismic traces were monitored for noise during data acquisition and the data quality from each hammer blow were assessed before the data were recorded.

As suggested by Mr. Miller, 9 walk-away shotpoints were used instead of the 5 walk-away shotpoints originally described in the Experimental Plan. As described above, the additional shotpoints were used to enhance event coherency (by increasing data density) and make potential reflection events easier to identify. Additionally, the farthest off-end set shotpoints were moved closer to the geophone spread than originally planned because, in the opinion of Mr. Miller, the extremely wide-angle seismic ray-paths from the far-offset shotpoints would not produce useful data. Finally, off-end shotpoints were placed on both sides of the geophone spread instead of off just one end as originally planned. Placing off-end shotpoints on both sides of the spreads was done to test the seismic response over a greater variety of site conditions and, particularly, to test the response when seismic energy travels across the landfill cell boundary.

The walk-away test data were written to a laptop computer as the survey progressed. The raw field data were copied to a compact disc (CD) that was provided to the USEPA after the walk-away test field work was completed. A licensed land surveyor obtained positioning and ground surface elevation data along the Pilot Study lines after the walk-away test was completed. All data were returned to the office where they were processed and analyzed by Mr. Miller, who used the programs WinSeis and SurfSeis, commercial seismic software available from the Kansas Geological Survey. Mr. Miller has prepared a report presenting his processing results and his interpretation, which is included in Appendix L as Attachment L-1.



Schematic of Seismic Reflection Spread for Walk-Away Test

1.1.1.2 Seismic Refraction

The seismic refraction survey portion of the Pilot Study was performed along lines PS-1 and PS-2 using an array of 96 geophones spaced 12.5 feet apart for a total geophone array length of 1,200 feet (Figure L-1). Shotpoints were positioned nominally 6.25- and 200-feet off each end of the array for a total seismic spread length of 1,600 feet. Interior shotpoints were placed every 100 feet within the east-west array for a total of 15 shotpoints along PS-1. Due to difficulties maneuvering the ATV on the steep slope and loose soil along the north-south array, shotpoints were restricted to the benches, resulting in a spacing of approximately 140 feet for a total of 11 shotpoints along PS-2. Seismic energy was generated using a Digipulse AWD-100 100-lb accelerated weight drop system. Multiple hammer blows were struck (stacked) at each shotpoint location to enhance the appearance of the refracted arrivals and improve signal quality. Additional tests were performed using a hammer-and-plate seismic source. Using a laptop computer display, all seismic traces were monitored for noise during data acquisition and the data quality from each hammer blow were assessed before the data were recorded.

The seismic refraction survey was modified from that outlined in the Experimental Plan. At the direction of the USEPA representative, geophones were installed at 5-foot intervals instead of 12.5-foot intervals as described in the Experimental Plan, resulting in a geophone array length of 480 feet instead of 1,200 feet. Moreover, also at the direction of the USEPA representative, shotpoints were placed at 100-foot intervals instead of 150 feet intervals. After discussions between the USEPA and CSC, the geophone spacing was restored to 12.5 feet as originally planned; however the shotpoint spacing was kept at 100 feet along the east-west line (PS-1).

The refraction data were written to a laptop computer as the survey progressed. The raw field data were copied to a CD that was given to the USEPA after refraction pilot study field work was completed. A licensed land surveyor obtained positioning and ground surface elevation data along the Pilot Study lines after the walk-away test was completed. The raw data were returned to the office for processing and analysis using the program SeisImager by Geometrics, Inc. The raw and processed data have been copied to a CD that was provided to the USEPA in February 2005 as part of Appendix L of the Interim Progress Report (IPR).

1.1.1.3 Micro-gravity

The micro-gravity survey portion of the Pilot Study was performed along lines PS-1 and PS-2. Prior to gravity data acquisition, the gravity measurement stations were marked in the field with wood survey hubs. Gravity readings were obtained at 10-foot intervals (stations) along a 750-foot central section of east-west line PS-1 and the southern 600 feet of north-south line PS-2. Because of the time-consuming nature of micro-gravity data acquisition, station spacings were expanded to 20 feet for the remainder of the 1,200-foot-long Pilot Study lines to achieve greater site coverage while keeping within the more limited scope of a Pilot Study. Gravity readings were obtained at a local base station that was established at an aerial photograph survey registration cross north of the P/S Landfill. Gravity readings were also obtained at USGS benchmark BM X533 located approximately 3 miles from the site. In total, gravity measurements were obtained at 209 individual locations.

The micro-gravity scope of work entailed "looping"— moving back to previously surveyed stations to obtain repeat readings for quality control and to measure instrument-related drift in the gravity measurements. Three types of survey loops were performed:

1. Short loops back to previously surveyed stations along the survey lines to obtain repeat readings for quality control;
2. Loops out to the local, onsite base station for repeat readings to assess instrument drift; and
3. A loop offsite to obtain a gravity reading at the USGS benchmark, a procedure that enabled the local Casmalia gravity survey to be tied to USGS to gravity data.

Counting the resurveying loops, 280 gravity readings were obtained.

The gravity measurements were recorded by the gravity survey instrument's computer memory as the survey progressed. Additionally, the readings were hand written in the geophysicist's field logbook. A the end of each field day the data were downloaded to a laptop computer and copied to a CD that was given to the USEPA along with a copy of the geophysicist field log. A licensed land surveyor obtained the positions and elevations of the gravity measurement stations after all gravity readings were obtained. Upon completion of the microgravity field work, the data were returned to the office for data reduction and analysis. Data reduction included correcting the raw data for instrument drift, tide, local, and regional terrain variation, latitude, free air, Bouguer Anomaly, and Complete Bouguer Anomaly. Data analysis entailed forward and inverse modeling. The raw and processed data and computer models were copied to a CD that was provided to the USEPA in February 2005 as part of Appendix L of the IPR.

1.2 Phase I Seismic Refraction Survey

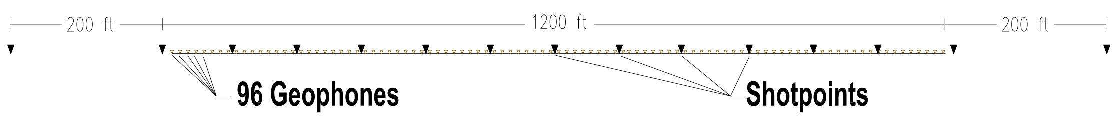
Immediately following the Pilot Study field work, the CSC performed a Phase I Seismic Refraction Production survey. The purpose of the Phase I refraction work was to investigate suspected areas beyond the P/S Landfill for potential low spots in the unweathered claystone surface where DNAPL could accumulate. The Phase I survey area covered the BTA, Central Drainage Area, and selected areas south of the PSCT (Figure L-8). These areas were chosen on the basis of previous site usage and the potential for the existence of DNAPL in the subsurface. The Phase I survey was performed immediately after the Pilot Study to take advantage of the seismic field crew and equipment that were already mobilized to the site; and, because the Phase I refraction work covered areas outside the P/S Landfill, there were no concerns that buried refuse would degrade the accuracy of the results.

The Phase I refraction survey was augmented by follow-up CPT borings at locations where the refraction data indicated that low spots may be present; however, the CPT work did not identify any low areas warranting the installation of piezometers to assess potential DNAPL accumulations. The Phase I refraction results and follow up CPT borings are discussed below in Section 3.3. It should be noted that the USEPA did not perform a detailed review of the Phase I refraction results.

1.2.1 Scope of Phase I Seismic Refraction Production Survey

The Phase I Refraction Survey comprised 16 seismic refraction lines ranging in length from 737.5 feet to 1,200 feet (60 to 96 channels). Including the off-end shotpoints, the Production Survey line lengths totaled approximately 22,000 feet. Geophone arrays were installed with a 12.5-foot geophone spacing. As dictated by site conditions, geophone array lengths ranged from 737.5 feet to 1,200 feet. Shotpoints were positioned 6.25 feet and nominally 200 feet off each end of the array for total seismic spread lengths of up to 1,600 feet. Interior shotpoints were placed every 100 feet within the shorter geophone arrays and 150 feet for the 1,200-foot arrays. A full 96-channel, 10 shotpoint seismic spread produced 960 individual seismic traces. In total, the Phase I Production Survey produced approximately 12,500 seismic traces.

Seismic energy was generated using a Digipulse AWD-100 100-lb accelerated weight drop system mounted to the rear of a “quad” style ATV. Multiple hammer blows were struck (stacked) at each shotpoint location to enhance the appearance of the refracted arrivals and improve signal quality. Using a laptop computer display, all seismic traces were monitored for noise during data acquisition and the data quality from each hammer blow were assessed before the data were recorded.



Schematic of a Typical Phase I Production Survey Refraction Spread

The Phase I survey was modified from the outline presented in the Experimental Plan. At the direction of the USEPA representative, shotpoints were placed at 100-foot intervals instead of 200- to 300-foot intervals. This modification roughly doubled the amount of data that was collected.

The refraction data were written to a laptop computer as the survey progressed. The raw data were copied to a CD that was provided to the USEPA the end of each field day along with a copy of the geophysicist’s field log. The raw data was returned to the office for processing and analysis, using the program SeisImager by Geometrics, Inc. The raw and processed data were copied to a CD that was submitted to the USEPA in February 2005 as part of Appendix L of the IPR.

1.3 Phase II Seismic Refraction Production Survey

The Phase II Production Survey was designed by the USEPA and CSC on the basis of the Pilot Study results, which indicated that seismic refraction could delineate the unweathered clay contact beneath the P/S Landfill. Briefly, because the Pilot Study refraction data yielded velocity layer models that showed the general form of the unweathered claystone surface and even the refuse in the P/S Landfill, a Phase II Survey to obtain additional seismic refraction data was considered warranted.

The Phase II objective was to obtain refraction data along 14 lines arranged in a grid pattern focused on the toe of the P/S Landfill, with the ultimate goal of developing a three-dimensional picture of the unweathered claystone contact beneath the P/S Landfill from which potential low spots could be identified. In addition, the RI/FS Work Plan stated that the CSC would complete CPT borings at any potential low areas indicated by the Phase II refraction results to confirm the presence of a depression. If low areas were confirmed, the CSC would then install a piezometer in the low area to determine if any DNAPL was present.

1.3.1 Development of Phase II Work Plan- Scope and Methodology

The Phase II Geophysical Survey Plan was developed using the Draft-and-Review process and was also facilitated by numerous discussions between the USEPA and CSC. The discussions focused primarily on the number of seismic lines and on shotpoint spacing along the seismic lines. The USEPA originally proposed a Phase II survey with 24 lines and 40-foot shotpoint spacing. The CSC contended that fewer lines were needed because the survey objective was to verify the presence or absence of the unconfirmed low spot, the approximate location of which was suspected on the basis of a 1988 contour map prepared by Canonie and Associates. The CSC also believed that an 80-foot shotpoint spacing would provide sufficient resolution, given that the survey would be performed using a 96-channel seismic system with a 10-foot geophone spacing. Eventually, an agreement was reached such that a 14-line survey would meet objectives. Seven lines were to be oriented north-south and seven east-west. The lines were to be spaced 50 feet apart, with shotpoints spaced 40 feet apart in the landfill toe to help increase resolution over the most likely low spot location, and 80 feet apart towards the ends of the lines in the areas beyond the landfill. It is worth noting that both parties readily agreed to use a 10-foot geophone spacing. The Phase II Work Plan also stipulated that the field data be provided electronically on a daily basis for quality control and to facilitate the USEPA's separate and independent analysis.

As a final step, the CSC sent the USEPA a digital, geo-referenced map showing the final agreed-upon seismic line and shotpoint locations and, after the map was approved by the USEPA, the CSC extracted geographic coordinates for the line locations, which were uploaded into a Global Positioning System (GPS) to facilitate locating the lines in the field. The geophysics field crew used the GPS to navigate to the line locations and place wooden survey stakes in a "line-of-sight" fashion along the planned seismic lines.

The Phase II seismic field work was performed from October 10 to 27, 2005 by geophysicists from MACTEC and NORCAL Geophysical. Follow-up CPT work and piezometer installation was performed during August and September 2007, when the CSC installed multiple CPTs and piezometers to gauge the presence of DNAPL at suspected low spots beneath the P/S Landfill. Please see Section 2.3 for details about seismic survey implementation. The procedures for piezometer installation and preliminarily measured liquid levels are presented in Appendices E (Well and Piezometer Drilling) and F (Groundwater Flow). The final approved Work Plan for the Phase II Seismic Refraction Production Survey is included in Attachment L-6 to this Appendix.

The CSC and USEPA performed separate data processing and interpretation, which resulted in different tomographic velocity models and different interpreted contact surfaces. The USEPA and CSC did not necessarily agree with the conclusions regarding potential low spots in the Lower HSU claystone contact, but did agree on a Follow-up CPT and Piezometer Installation Plan (CSC, 2007) based on the results of the USEPA's analysis and interpretation of the tomographic velocity models.

2.0 FIELD PROCEDURES

2.1 Pilot Study

The Pilot Study data were obtained using three different geophysical methods. In general, seismic reflection and seismic refraction surveys were similar in that they entailed the laying out of an array of geophones along two pre-marked alignments, striking the ground surface with a hammer at various locations, and recording the resulting ground motion using geophones and a laptop computer. The micro-gravity survey work entailed hand-carrying the gravity instrument (gravimeter) to pre-marked measurement stations and taking a reading. A significant aspect of the micro-gravity survey work was looping back to obtain repeat readings at previously occupied measurement stations. This procedure was performed to verify data quality and facilitate removal of instrument-related drift in gravity readings. The Pilot Study data were digitally recorded as the surveys progressed and were copied to CDs at the end of each field day. Upon completion of the geophysical data acquisition, position and elevation data, particularly at the micro-gravity measurement stations, were obtained by a licensed land surveyor. The following sections provide more detail regarding the Pilot Study field procedures.

2.1.1 Seismic Reflection

The geophysics crew chief first marked the Pilot Study walk-away test line locations in the field using tall staking lath. The lines were field-located according to Figure EP-2 in the Experimental Plan (Attachment L-3) by using a fiberglass tape measure to reference the line locations to existing wells and roadways. Next, the geophysics field crew installed a 96-channel geophone array along the east-west alignment (line PS-1). The array comprised single Geospace 40-Hz geophones spaced 5 feet apart for a total array length of 480 feet. Geophones were placed after loose soil and vegetation had been scraped away. The geophone array was then connected to a laptop computer through four Geometrics Geodes, each powered by a conventional 12-volt battery. Data acquisition and functional checks of the geophone array were accomplished using Geometrics Geode software installed on the laptop computer.

After the functional checks were completed, the accelerated weight drop system was maneuvered to the first shotpoint location, 5 feet off the end of the geophone array. Using the laptop computer display, the geophysical crew chief monitored the array for seismic noise and signaled for a hammer blow when the noise was acceptably low. The crew chief reviewed the resulting record before it was recorded. At the crew chief's direction, the hammer operator moved to the next shotpoint, 2.5 feet from the array. Two-way radios were used for communication between the crew chief and hammer operator. Subsequent shotpoints were placed 100- and 97.5-feet off-end, respectively, in the array center, and 5.0-, 2.5-, 100-, and 97.5-feet off the opposite end of the array for a total of 9 shotpoints per walk-away test line. At each shotpoint, three individually-recorded hammer blows were struck, and stacked into a single record. Each shot record was recorded for one second using a ¼ millisecond sampling rate. A hammer-and-plate seismic source was tested on east-end of the PS-1 walk-away spread.

Upon completion of the walk-away test data acquisition along PS-1 the geophone array was picked up and moved to the north-south alignment (PS-2) and the entire process was repeated. The walk-away test data were written to a laptop computer as the survey progressed. The crew chief maintained a field log that contained information about shotpoint locations and digital filenames for the walk-away test data. The raw data were copied to a CD that was given to the

USEPA, along with a copy of the field log, after the walk-away test field work was completed. The reflection Pilot Study field work was completed in one day.

2.1.2 Seismic Refraction

The geophysics crew chief first marked the Pilot Study seismic refraction line locations in the field using tall wooden stakes. The lines were field-located according to Figure EP-3 of the Geophysics Experimental Plan (Attachment L-3) by using a fiberglass tape measure to reference the line locations to existing wells and roadways. Next, the geophysics field crew installed a 96-channel geophone array along the east-west alignment (line PS-1). The array comprised Geospace 8-Hz geophones spaced 12.5 feet apart for a total array length of 1,200 feet. Geophones were placed after loose soil and vegetation had been scraped away. The geophone array was then connected to a laptop computer through four Geometrics Geodes, each powered by a conventional 12-volt battery. Data acquisition and functional checks of the geophone array were accomplished using Geometrics Geode software installed on the laptop computer.

After the functional checks were completed, the accelerated weight drop system was maneuvered to the first shotpoint location, 6.25 feet off the end of the geophone array. Using the laptop computer display, the geophysical crew chief monitored the array for seismic noise and signaled for a hammer blow when the noise was acceptably low. The crew chief reviewed the resulting record before it was recorded. Multiple hammer blows were struck (stacked) at each shotpoint location to enhance the appearance of the refracted arrivals and improve signal quality. Up to 20 hammer blows were stacked. At the crew chief's direction, the hammer operator moved to the next shotpoint, 200 feet from the array. Two-way radios were used for communication between the crew chief and hammer operator. Subsequent shotpoints were placed every 100 feet within the seismic array and 6.25 and 200 feet off the opposite end of the array. Each shot record was recorded for one second using a ¼ millisecond sampling rate. The crew chief maintained a field log that contained information about shotpoint locations and digital filenames for the Pilot Study refraction data.

Upon completion of the Pilot Study refraction survey data acquisition along PS-1, the geophone array was picked up and moved to PS-2 and the entire process was repeated. The refraction data were written to a laptop computer as the survey progressed. The raw data were copied to a CD that was given to the USEPA, along with a copy of the field log, after the refraction field work was completed. The refraction Pilot Study field work was completed in one day.

2.1.3 Micro-Gravity

The micro-gravity survey geophysicist first marked the Pilot Study micro-gravity measurement station with wood survey hubs The stations were field-located according to Figure EP-2 of the Geophysics Experimental Plan (Attachment L-3) by using a fiberglass tape measure to reference the micro-gravity survey lines to existing wells and roadways. Next, the geophysicist designated a local base station at an aerial photograph survey registration cross north of the P/S Landfill. Then, the geophysicist input base station attributes (e.g., approximate position and elevation) into the gravity survey instrument, a Lacoste & Romberg Graviton gravimeter. The approximate position and elevation of the local base station were obtained using a Trimble Pro-XRS global positioning system (GPS) with real-time differential correction capability. The geophysicist then occupied the base station and obtained an initial gravity measurement.

After the initial base station reading was obtained, the geophysicist placed the gravimeter into a field vehicle and drove to the first gravity measurement station at the western end of Pilot Study line PS-1. The gravimeter was hand-carried to the first station and placed on the ground such that the base of the instrument was referenced to a 12- by 18-inch wood board placed on the top of the survey hub. Gravity measurements were obtained approximately every 6 minutes, after the Graviton's self-leveling cycle was completed and the instrument was allowed to settle at the measurement station. Raw observed gravity readings were written to the Graviton's computer memory and were also recorded by hand on the geophysicist's field log. Survey progress was tracked by leapfrogging a pair of boards along the line of measurement stations. The boards provided a clean, stable, and relatively level surface on which to place the instrument, and they marked the next station to be occupied after loops to repeat stations or to the base station so the geophysicist would not inadvertently survey the same station twice. Repeat station loops were performed every 4 to 6 stations, and the local base station was reoccupied approximately once every hour. A reading at the U.S. Geological Survey (USGS) benchmark BM-X533 was obtained after the all of the micro-gravity survey stations were occupied so that the micro-gravity survey data could be tied to the known gravity value from that location.

At the end of each field day, the gravity data were downloaded to a laptop computer and copied to a CD that was given to the USEPA along with a copy of the geophysicist field log. The micro-gravity field work was completed in 6 days. After all gravity readings were obtained a licensed land surveyor obtained position and elevation data for the micro-gravity survey stations.

2.2 Phase I Seismic Refraction Production Survey

The Phase I Production Survey field procedures were similar to those of the seismic refraction portion of the Pilot Study. The geophysics crew chief first marked a Production Survey line location in the field using tall wooden stakes. The line was field-located according to Figure EP-3 of the Geophysics Experimental Plan (Attachment L-3) by referencing its location to existing wells and roadways. Next, the geophysics field crew installed the geophone array. The array comprised Geospace 8-Hz geophones spaced 12.5 feet apart. Geophones were placed after loose soil and vegetation had been scraped away. The geophone array was then connected to a laptop computer through four Geometrics Geodes, each powered by a conventional 12-volt battery. Data acquisition and functional checks of the geophone array were accomplished using Geometrics Geode software installed on the laptop computer.

After the functional checks were completed, and any revealed problems (usually a noisy geophone) rectified, the accelerated weight drop system was maneuvered to the first shotpoint location, 6.25 feet off the end of the geophone array. Using the laptop computer display, the geophysical crew chief monitored the array for seismic noise and signaled for a hammer blow when the noise was acceptably low. Two-way radios were used for communication between the seismic crew chief and the shotpoint crew. Seismic noise was considerable at times due to wind and site activities that included drilling, CPT work, and grading. Accordingly, the crew chief monitored noise levels closely and reviewed the resulting records carefully before they were recorded. Data acquisitions were suspended on occasion until noise dropped to acceptable levels. Multiple hammer blows were struck (stacked) at each shotpoint location to enhance the appearance of the refracted arrivals and improve signal quality. Up to 20 hammer blows were stacked. At the crew chief's signal, the hammer operator moved to the next shotpoint. The crew chief maintained a field log that contained information about shotpoint locations and digital filenames for the Production Survey data.

Geophone array lengths ranged from 737.5 feet to 1,200 feet. Depending on the array length, shotpoints were placed every 100 feet or 150 feet within the seismic array, and 6.25 and 200 feet off each end of the array. Each shot record was recorded for one second using a ¼ millisecond sampling rate. Upon completion of data acquisition along the first refraction line the geophone array was picked up and moved to the next line and the entire process was repeated for each of the sixteen Production Survey lines, designated SL-1 through SL-16 (Figure L-8). The refraction data were written to a laptop computer as the survey progressed. The data were copied to a CD that was given to the USEPA, along with a copy of the field log, at the end of each field day. The Phase I Production Survey lines were mapped using a Trimble Pro-XRS GPS with real-time differential correction capability. The Production Survey field work was completed in 10 days.

2.3 Phase II Seismic Refraction Production Survey

The Phase II Production Survey work was conducted in a fashion similar to that of the Phase I Production Survey, with the main difference being that the Phase II survey used more closely-spaced geophones and shotpoints. All Phase II geophone arrays used 96 channels and 10-foot geophone spacing. Shotpoints were placed 5 feet off each end of the line and interior shotpoints were placed every 40 feet within the central portion of the lines for increased resolution over the most likely low spot location, and at 80-foot intervals towards the line ends. Approximately 20 shotpoints were used for each line.

To install the Phase II seismic lines, the geophysics crew chief first used tall wooden stakes to mark the ends and two interior points along each line. The line marking locations were established using geographic coordinates uploaded to a Trimble Pro-XRS mapping-grade (sub-meter accuracy) GPS, which was used in the field to navigate to each mark location. The coordinates were extracted from an AutoCAD drawing file containing the Phase II line locations that the USEPA and CSC agreed upon in teleconferences during the summer of 2005.

Next, the seismic array was installed along the first line. The geophysics field crew deployed geophone cables and installed the geophones, back-sighting between the tall staking laths to maintain alignment. Additionally, a tape measure was extended along the line to facilitate mapping site features that could affect data quality (e.g., buildings, pavement, and steep slopes). The tape measure was also used to establish and check the shotpoint locations as data acquisition progressed. The seismic array comprised Geospace 8-Hz geophones spaced 10 feet apart. The geophones were usually buried a few inches beneath the ground surface to help minimize wind noise. On paved surfaces, a roto-hammer was used to drill small holes into which the geophone spikes were placed; these geophones were covered with sand bags to further minimize wind noise. The geophone array was then connected to a laptop computer through four Geometrics Geodes, each powered by a conventional 12-volt battery. After the array was installed the crew chief walked the line to check connections and map significant site features. Data acquisition and functional checks of the geophone array were accomplished using Geometrics Geode software installed on the laptop computer.

After the functional checks were completed, and any revealed problems (usually a noisy geophone) rectified, the ATV with the accelerated weight drop system was maneuvered to the first shotpoint location, 5 feet off the end of the geophone array. Using the laptop computer display, the geophysical crew chief monitored the array for seismic noise and signaled for a hammer blow when the noise was acceptably low. Two-way radios were used for communication between the seismic crew chief and the shotpoint crew. Seismic noise was considerable at times due to wind and site activities. Accordingly, the crew chief monitored noise levels closely and reviewed the resulting records carefully before they were saved to a data file. When deemed necessary by the crew chief, data acquisition was suspended until noise dropped to acceptable levels. On the occasion that pumps and other equipment produced unacceptably high noise levels (e.g., near the Gallery Well), the noise source was shut down for a time so the seismic survey could proceed.

Multiple hammer blows were added (stacked) at each shotpoint location to enhance the appearance of the refracted arrivals and improve signal quality. In general, approximately 20 and sometimes up to 50 hammer blows were stacked at each shotpoint. It should be noted that the Geode data acquisition system allowed for a large number of stacks, which greatly enhanced the first break amplitude, without a noticeable increase in the overall noise level on the seismic trace. To document the improvement in data quality over the large number of the stacks, separate data files were written after every fifth hammer blow, in addition to the single data file containing the full stack of all hammer blows at each shotpoint. Each shot record was recorded for one second using a ¼ millisecond sampling rate.

When the crew chief's signaled that data acquisition was completed at a given shotpoint, the weight-drop system was driven to the next shotpoint along the line. To avoid confusion, the crew chief pre-marked the shotpoint locations with fluorescent spray paint. After data acquisition, shotpoints were marked with grade stakes so their locations could be surveyed, first by the geophysics field crew to expedite preliminary data analysis, and later by a licensed land surveyor. After data acquisition was completed along the first seismic line the geophone array was picked up and moved to the next line and the entire process was repeated for each of the 14 Phase II lines, designated P2SL-1 through P2SL-14 (Figure L-25).

The crew chief maintained a field log that contained information about each shotpoint, such as its position along the line, the ground surface conditions, surrounding terrain and nearby surface features, and the corresponding digital filename and the number of hammer blows stacked for each file. The refraction data were written to a laptop computer as the survey progressed. At the end of each field day, the day's data were copied from the field computer to a CD that was given to the USEPA, along with a copy of the day's field log. Every 2 or 3 days, the geophysical crew chief used the GPS to map the locations of shotpoints occupied thus far and update a site-map tracking survey progress. Upon completion of the geophysical survey, ground surface elevations along the production lines were surveyed by Canon Associates, a California Licensed Land Surveyor. A copy of their Survey Report is included (Attachment L-2).

The Phase II field work was completed in 14 days from October 10 to 27, 2005. The topographic land survey work was performed on March 6, 2007. The delay in performing the land survey work was caused by contracting issues related to the purchase of Pacific Engineering, the land survey company of record for the Site, by Cannon Associates. In anticipation of the topographic survey the geophysics field crew marked each shotpoint location with wood stakes and/or paint (on the bench roads) as the seismic survey progressed. The day before Cannon's topographic survey, two members of the original geophysics field crew returned to the Site to locate and freshen (with orange spray paint) the shotpoint markers. Original markers were found for 215 of the 266 total shotpoints. Most of the stakes in the fill soil of the cap were found in place (i.e., still hammered into the soil, albeit many were hidden in the tall grass). Although the stakes on the hard bench roads were lying down, the spray paint marking their original locations were still visible. Where stakes were lying down or where no markers were found, the crew used a fiberglass tape measure pulled between the two adjacent intact markers to re-establish the shotpoint location. The geophysicists also guided the Cannon Associates surveyor to each shotpoint marker to facilitate the topographic survey.

Because the numerous found shotpoint markers appeared to be in an undisturbed condition, it is the CSC's opinion that no significant change in the ground surface topography had occurred; hence, the delay in the performing the topographic survey did not affect the tomographic models produced from the refraction data. The CSC believes that the missing shotpoint markers were relocated accurately, as the vast majority of the original shotpoint marks were found, which provided unmistakable line orientations and numerous known control points to measure from. In addition, the change from 40-foot and 80-foot shotpoint separation distances provided another reference point with which to check locations along each seismic line. As with shotpoint locating during the original survey, re-locating the shotpoints with missing markers was performed using a tape measure.

The CSC believes that the uncertainty introduced into the tomographic inversion models due to possible errors in relocating shotpoint/receiver locations is trivial, given the apparent degree of error (i.e. less than 1 foot) at any on location; and in light of other parameters. That is, given the overall slowness of the media, the depth of the target, and shotpoint/receiver offset distance, the travel time difference of a P-wave traveling 300 feet vs. 301 feet (for example) is not considered significant and is also compensated for to some degree in the data processing algorithms.

3.0 INVESTIGATION RESULTS

3.1 Investigation Results Summary

The Pilot Study demonstrated that subsurface information could be obtained at the P/S Landfill using seismic refraction; however, the Pilot Study also showed that seismic reflection and microgravity would not provide useful information there. Accordingly, the investigation results are based on the analysis of the seismic refraction data obtained for the Pilot Study, Phase I Production Survey, and Phase II Production Survey.

In general, the seismic refraction data were analyzed by preparing tomographic models depicting the velocity layering along each of the seismic lines and then correlating the velocity layers to geologic layers. Tomographic models from the widely-spaced Phase I refraction lines were interpreted in a qualitative fashion; they showed depressions in velocity layering indicative of potential low spots in three areas; however, CPT work did not confirm the presence of a depression. It should be noted that the USEPA did not perform a detailed review of the CSC's analysis of the Phase I data. The greater data density afforded by the grid of seismic lines collected for the Phase II survey allowed for more detailed processing and analysis, the results of which are summarized below and presented with more detail Section 3.4.

The CSC and USEPA each processed the Phase II data independently and prepared separate sets of tomographic models which ultimately resulted in independent interpretations. In general, interpretation is based on the correlation of modeled velocity layers to actual subsurface conditions. For the P/S Landfill investigation, the key step of the interpretation was to establish a specific velocity "signature" for the unweathered claystone. Once established, a contour map of this "iso-velocity surface" representing the contact with the unweathered claystone could be prepared and then inspected for closed topographic lows, which would indicate areas where "free-phase" DNAPL could potentially accumulate.

To determine the best iso-velocity surface for representing the top of unweathered claystone, the CSC annotated its tomographic models with "ground truth," i.e., the position (depth) of the claystone contact as interpreted from boreholes and CPTs, including the CPTs completed during the Summer 2007 (Figures L-26 through L-29). 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 Table L-3). Accordingly, a representative velocity for unweathered claystone immediately below the HSU surface is ill-defined. As such, 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, it is the CSC's belief that the contact does not conform to a single iso-velocity contour model, therefore, an accurate 3-dimensional representation of the contact surface cannot be determined with certainty from the refraction data. Regardless, the CSC prepared a preliminary contour map of the 5,400 fps iso-velocity surface to see if any conclusions could be drawn by assessing its general form.

As part of their analysis of the Phase II data, the USEPA performed data processing, which included re-running the tomographic inversion process for up to 50 iterations and using special three-dimensional kriging algorithms on the model output to prepare contour maps of iso-velocity surfaces for 5,200, 5,400 and 5,600 fps. The CSC understands that the USEPA believes these maps show potential low spots north of Bench Road 1, north of Bench Road 2, and west of the Gallery Well; however, we do not necessarily agree that these maps accurately represent the claystone surface. In particular, the CSC notes that the "low spots" are created (closed) by 5- to 10-foot tall iso-velocity "ridges" that align with the roadways spanning the P/S Landfill. As was discussed with the USEPA at the time, the CSC suspects that the ridges may be artifacts of near-surface velocity anomalies associated with compacted road fill and are not actually present in the claystone surface, in which case there is no topographic closure (i.e. depression) in those areas.

3.2 Pilot Study Results

The pilot study demonstrated that subsurface information could be obtained at the P/S Landfill using seismic refraction; however, testing with seismic reflection and microgravity did not provide interpretable data of the resolution necessary to infer site features. The seismic refraction survey delineated velocity layers that may represent refuse and unweathered claystone, when calibrated with borehole and CPT information. The seismic reflection walk-away test did show possible reflections on a few shot gathers; however, the cause of the possible reflections is not well understood, and the possible reflections appear to be significantly shallower than any other interpretations of the depths of the clay contact. Moreover, even if true reflections are present in the data, the reflecting surface cannot be reliably mapped due to the extremely low seismic velocity exhibited and the difficult reflection ray-path geometry produced by the steep-walled, refuse-filled canyon at the P/S Landfill site.

Finally, analysis of data from the micro-gravity survey did not produce useful subsurface information. Although inverse models produced from the gravity data showed a gross similarity to known subsurface conditions, they were highly unrealistic in terms of calculated layer thickness and material density. Moreover, forward modeling, using more reasonable parameters (i.e., known layer thickness from borehole and CPT data and refuse densities from geotechnical studies), indicates that the gravity method lacks the sensitivity and resolution necessary to assess small yet potentially significant variations of the unweathered claystone surface. Pilot Study results are presented in detail in the following sections.

3.2.1 Seismic Reflection Pilot Results

The seismic reflection data were processed and analyzed by Mr. Miller, under contract to NORCAL Geophysical Consultants, Inc. Mr. Miller processed the data using WinSeis and SurfSeis, commercial seismic software available from the Kansas Geological Survey. Mr. Miller has prepared a report that details the seismic reflection survey results. In particular, his report presents suites of images showing the results of various types of processing on the raw shot gathers. Mr. Miller's report is presented in Attachment L-1, and his findings and conclusions are summarized below. Additionally, the shot gathers referred to in the following summary are presented on Figures L-2 and L-3.

- The useable reflection frequencies obtained with the weight drop source ranged from about 50 Hertz (Hz) to just over 125 Hz;
- The accelerated weight drop system is the better non-invasive source by virtue of the greater power it produces; however, the first hammer impact should be used only to seat the plate and any data produced from the first impact should be discarded;
- Most of the processed shot gathers did not show any indication of reflection events;
- The gathers should be interpreted with caution because the extreme processing used to suppress the various types of seismic noise likely produced artifacts that could be mistaken for reflections;
- Raw shot gathers possess pronounced ground roll, guided waves, and first arrivals. Extreme processing was used to suppress the various types of noise. In general, digital

bandpass filtering decreased surface wave amplitude and enhanced body wave energy. Spectral balancing produced mixed results, reducing high-frequency background noise but boosting surface wave amplitude relative to the body wave. F/k filtering helped suppress ground roll and high-velocity guided waves and refractions;

- The processed shot gathers from Stations 1042 and 1235 along SL-1 exhibit possible reflections, which appear as linear events with a flat-to-negative slope that suggests they may be reflections from the buried canyon wall; however, considering their extremely low velocity it would not be possible to estimate the Normal Move Out (NMO) and stack these events. With the extreme dips of (the canyon walls), the exact placement of the reflecting point cannot be made. Hence, any reflecting surface (e.g., the top of claystone) cannot be reliably mapped; and
- Possible wide-angle reflection events are apparent on gathers from the north end of SL-2; however, it would not be advisable to interpret geology from such events, if processed, because many of the assumptions necessary to process reflection data are based on near-vertical reflection pathways and are not valid for wide angle reflection events.

3.2.2 Seismic Refraction Pilot Results

The seismic refraction pilot study showed that useable seismic refraction data could be obtained at the P/S Landfill. The pilot study survey delineated velocity contrasts that roughly corresponded to contrast between refuse and unweathered claystone, as determined from borehole data. As such, the CSC believed that the seismic refraction method was capable of obtaining useful subsurface information at the P/S Landfill.

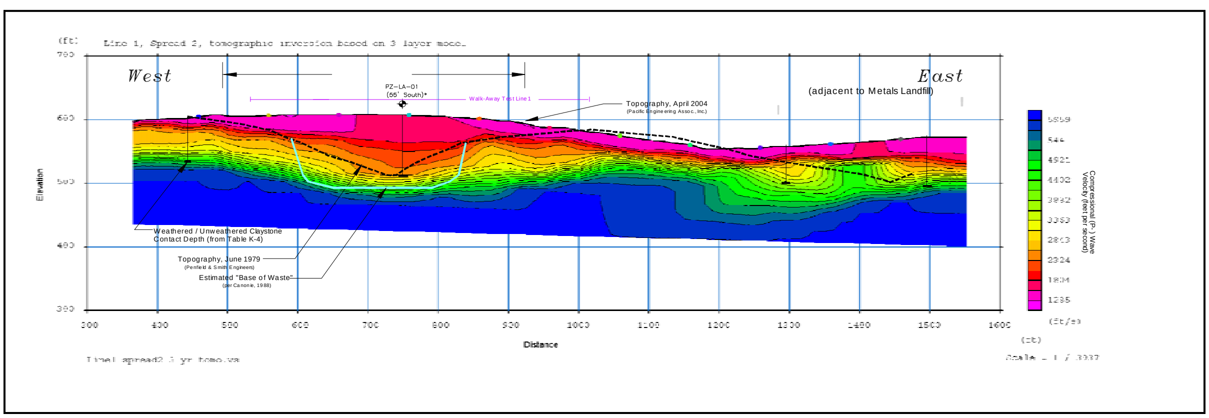
Seismic refraction Pilot Study data were processed using the software package SeisImager (version 3.0) by Geometrics. Additional details on the inversion parameters and process is included as Attachment L-4. SeisImager consists of two programs titled Pickwin (version 2.84) and Plotrefa (version 2.66). Pickwin was used to make first-break picks, and Plotrefa is used to process the seismic refraction data using either the "time-term", "reciprocal", or "tomographic" methods. The data reduction procedure was to compute a preliminary three-layer model using the time-term inversion method. The resulting two-dimensional (2-D) model was then used as the initial model for the iterative, ray-tracing, tomographic inversion. Un-annotated images of the resulting 2-D profiles were output as Adobe Acrobat "pdf" files.

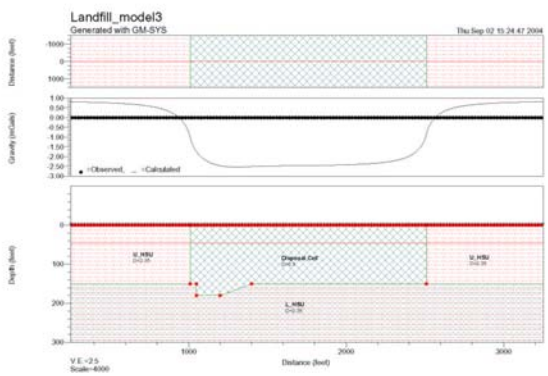
For reporting purposes, the refraction pilot study results are presented as tomographic models that can be considered as subsurface profiles depicting variations in the compressional (P-) wave velocity of subsurface materials along the two Pilot Study test lines (Figures L-4 and L-5). The models are color coded such that hot colors (reds) correspond to low-velocity material (less than 3,000 fps) and cool colors (blues) correspond to high-velocity material (greater than 5,000 fps). Intermediate velocity material is shown in yellow and green. The velocity variations correspond to different subsurface materials. Available borehole information has been placed on the models to help ground truth the survey results.

It should be noted that water has a P-wave velocity of about 5,000 fps, and the water table typically forms the first refracting surface in many seismic refraction surveys. At velocities less than 5,000 fps, media are usually considered to be part of the Low Velocity Layer (LVL) that typically consists of unconsolidated media (i.e. refuse or weathered sediment). A velocity of about 5,200 to 6,000 fps would generally be considered representative of consolidated claystone. Data processing and interpretation of features within an LVL are considered problematic for the following reasons. Due to the irregular and heterogeneous nature of surficial sediments, the LVL is typically of variable thickness which yields variable wave travel times, and both horizontal and vertical velocities within the layer can change rapidly and erratically. Further, the large velocity contrast with the underlying layer bends raypaths significantly such that rays traveling through the LVL are nearly vertical, regardless of the ray's angle in the layer below. The LVL also acts a variable low pass filter affecting wave form shapes (Sheriff, 1978).

In general, both models show an approximately 50- to 60-foot thick section of low-velocity material underlain by high-velocity basement. The low velocity exhibited by the upper seismic layer is indicative of soil or refuse material, while the high velocity of the basement material is indicative of unweathered bedrock. The intermediate velocity is indicative of compacted fill and alluvium. The east-west profile (PS-1) shows a continuous low-velocity layer that is thickest at the landfill axis and becomes thinner toward the east and west, away from the landfill (Figure L-4). Accordingly, the low-velocity layer comprises both landfill refuse and soil material on either side of the P/S Landfill. The north-south profile (PS-2) shows a thick section of low-velocity material along its entire length (Figure L-5).

Weathered/unweathered contact depths from borings RP-20B, WD-8 along PS-1, and the Gallery Well along PS-2 correlate well with the seismic data and show that the contact approximately corresponds to the 5,400 fps P-wave velocity contour in the non-refuse areas. However, CPT-LA-01 and TP-04 show the contact to be in seismically slower material that is shallower than the 5,400 fps contour. The CSC believes that this discrepancy at TP-04 is caused by a localized near-surface seismic anomaly, probably associated with road and concrete gutter in place between TP-4 and WD-8. Such an anomaly is indicated by the unnaturally abrupt downturn in velocity layering at Station 1200 and by the fact that the pronounced notch in the high-velocity layer near TP-4 does not appear on a nearby production survey line, SL-2. The discrepancy at CPT-LA-01 may be caused by velocity anomalies associated with buried refuse.





Forward gravity model using known subsurface conditions predicts no gravity response from assumed low spot

The velocity profiles were produced using SeisImager's tomographic modeling routine. The tomographic modeling was selected over other modeling routines (e.g., time-term, GRM) because it can take full advantage of the dense dataset generated from the numerous closely spaced shotpoints used along the production survey seismic lines. Tomographic modeling can show both lateral velocity variations within seismic layers and gradational velocity transitions between and within seismic layers. Briefly, tomographic modeling divides a subsurface profile into a grid of rectangular cells and calculates a velocity solution for each cell that is based on the field data. The CSC believes that the complex velocity variations likely to be present within the P/S Landfill refuse are best handled with the tomographic modeling.

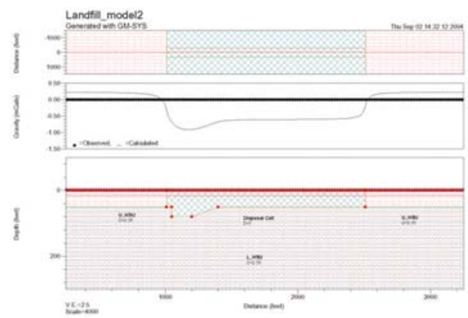
3.2.3 Micro-Gravity Pilot Results

The raw gravity readings obtained in the field were reduced using GEOSOFT's OASIS montaj Gravity and Terrain Correction software. The reduction process consisted of correcting the raw measured gravity readings for instrument drift and for tidal effects, calculating the theoretical gravity reading at each measurement station, and then calculating the Complete Bouguer Anomaly as the difference between corrected measured gravity value and the calculated theoretical gravity value. Profiles showing corrected gravity readings and the Complete Bouguer Anomaly values are presented on Figures L-6 and L-7, for lines PS-1 and PS-2, respectively. The gravity data, raw and corrected, have also been copied in ASCII format to a data disk that is included with this report.

On the basis of the repeat station readings, the micro-gravity survey achieved resolution of approximately 20 micro gals. Plotted in profile format, the gravity data form smooth, gently sloping curves that mirror the ground surface topography. In other words, the higher gravity readings were obtained in the topographically lower areas and lower gravity readings were obtained in the topographically higher areas. Upon closer inspection of the profiles, it appears that the corrected gravity data exhibit the effects of small-scale topographic features, particularly the flat benches along PS-2.

The gravity data were analyzed using inversion modeling to assess what subsurface conditions might produce the observed gravity readings. GEOSOFT's OASIS montaj GM-SYS modeling software was used to perform the modeling. Briefly, inversion modeling entails using a CAD-like drawing utility to create a starting model comprised of series of layers and blocks representing the known subsurface as determined from geologic maps and borehole data. When the inversion process is launched the software first calculates synthetic data based on the initial model and then adjusts various user-selected model parameters (e.g., density, layer thickness) to achieve a better fit between the synthetic data and the actual data collected in the field. The inversion process is usually allowed to run until the synthetic data closely match the field data, at which point the associated model can be taken to represent the subsurface more accurately than the initial starting model.

However, inverting the Pilot Study gravity data produced models with excessive refuse thickness (greater than 200 feet in places) and unrealistic material densities (0.2 grams per cubic centimeter [g/cc]) even when good matches between synthetic and observed data were achieved (Figures L-6 and L-7). Geologically unreasonable models are common products of the inversion process and it is the geophysical analysts' role to assess the validity of modeling output. Pilot Study gravity modeling suggests that unknown factors, possibly relating to the heterogeneous nature of the P/S Landfill refuse, influence the observed gravity measurements. Therefore, confidence in the accuracy of modeling results is greatly reduced.



Forward gravity model, "best case", with shallow low spot (40 ft bgs) and large density contrast, predicts 0.35 mGal low spot anomaly

Forward modeling was also performed to test the sensitivity of the gravity method to variations in low spot burial depth and variation in the density contrast between refuse and the surrounding claystone. Briefly, forward modeling involves creating a hypothetical geologic model and calculating the gravity response to that model. To help assess the micro-gravity survey results, several models were prepared with different refuse thickness, refuse density, claystone density, and low spot depth. The low spot relief was kept at 20 feet. Additionally, estimates of refuse density were obtained from geotechnical research papers, where refuse densities were shown to generally range from 0.6 to 1.2 g/cc. Forward modeling suggests that a 300-foot-wide, 20-foot-deep low spot beneath 140 feet of refuse, even when exhibiting an extreme density contrast of 0.5 g/cc (refuse) versus 2.35 g/cc (for claystone), would not produce a perceptible anomaly. Variations in gravity measurements using this model are most sensitive to low spot burial depth, as anomalies on the order of 0.35 milligals are indicated if the low spot were to occur beneath only 40 feet of refuse.

3.3 Phase I Seismic Refraction Production Survey Results

The seismic refraction survey delineated velocity layers corresponding to weathered and unweathered claystone as determined from borehole data. Accordingly, the refraction results were used to identify potential low spots in the contact between weathered and unweathered claystone.

On the basis of depressions in velocity layering observed on the tomographic models, three potential low spots were identified and designated LOW-1 through LOW-3. However, subsequent CPT borings advanced in the LOW-1 area refuted the existence of a depression in the unweathered claystone surface, and therefore, LOW-2 and LOW-3 were not investigated further. The potential low spot locations are shown on Figures L-9, L-18, and L-24 and are summarized in Table L-1.

In addition to the potential low spots presented in Table L-1, Line SL-8 (Figure L17) exhibits strong undulations in velocity layering between Stations 150 and 450. These undulations correspond to drainage alignments and the former canyon that is now the P/S Landfill, the CSC believes these undulations are associated with colluvium and/or fill material in the filled former canyon and are not caused by depressions in the weathered/unweathered claystone contact. It should be noted that the USEPA did not perform a detailed review of the CSC's analysis of the Phase I refraction data.

3.3.1 Data Processing and Discussion of Phase I Results

Phase I Production Survey refraction data were processed using the software package SeisImager (version 3.0) by Geometrics. SeisImager consists of two programs titled Pickwin (version 2.84) and Plotrefa (version 2.66). Pickwin was used to make first-break picks, and Plotrefa is used to process the seismic refraction data using either the time-term, reciprocal, or tomographic methods. The data reduction procedure was to compute a preliminary three-layer model using the time-term inversion method. The resulting 2-D model was then used as the initial model for the iterative, ray-tracing, tomographic inversion. Un-annotated images of the resulting 2-D profiles were output as Adobe Acrobat "pdf" files.

The final velocity profiles were produced using the SeisImager's tomographic modeling routine. The tomographic modeling was selected over other modeling routines (e.g., time-term, GRM) because it can take full advantage of the dense dataset generated from the numerous closely spaced shotpoints used along the production survey seismic lines. Tomographic modeling can show both lateral velocity variations within seismic layers and gradational velocity transitions between seismic layers. In particular, the CSC believes that gradational velocity variation with depth presents a more realistic portrayal of the transition from weathered to unweathered rock. Additionally, by accounting for lateral velocity variations tomographic modeling will minimize layer distortions that could produce apparent low spots that do not exist.

The refraction results are presented as a series of tomographic models that depict variations in the compressional (P-) wave velocity of subsurface materials along each of the sixteen production survey seismic line (Figures L-9 through L-24). The models are color coded such that hot colors (reds) correspond to lower velocity material (less than 3,000 fps) and cool colors (blues) correspond to higher velocity material (greater than 5,000 fps). Changing velocity corresponds to changing geologic materials or changes in material properties such as compaction, saturation, fracturing, etc. Available borehole information has been placed on the profiles to help ground truth the refraction survey results.

In general, the Phase I models show that the weathered/unweathered claystone contact mimics the ground surface topography and occurs at depths ranging from approximately 20 to 80 feet below ground surface (bgs). Subtle undulations in velocity layering are apparent along most profiles. Most of the layer undulations are likely caused by velocity variations associated with changes in the surface and near-surface material along the seismic lines. Depending on their location, the lines are situated on pavement and varying thickness of soil, alluvium, and/or fill material. Additionally, pronounced depressions in the velocity layering are apparent, particularly along SL-1, SL-5, SL-8, and SL-10 (Figures L-9, L-13, L-17, and L-19, respectively). The depression along SL-10 (Figure L-19) is also present on the intersecting line SL-16 (Figure L-24).

On the basis of the depressions in velocity layering observed on the tomographic models, three potential low spots were identified and designated LOW-1 through LOW-3. CPT borings RICPT-07, -09, and -10 were subsequently advanced within the LOW-1 area and the logs were evaluated to determine the depth to the unweathered claystone contact at each location. The tomographic model suggests the contact in this area dips to approximately 50 feet bgs. According to the CPT logs, however, the contact occurs between 30 and 35 feet bgs. As such, the depressions in velocity layering were attributed to localized variations in the properties of the soil or in the weathered claystone, further calling into question the reliability of using refraction to identify low spots in claystone contact. The CPT information is included on Figures L-18 and L-24 for comparison with the model, and the CPT logs are included in Attachment L-7.

The following provides more detail about the velocity profiles. Although the profiles show gradational velocity variation with depth, for discussion purposes the velocity distribution can be grouped into three main layers, designated V_1, V_2, and V_3. Layer V_1 is the uppermost layer, which ranges in thickness from approximately 5 feet to greater than 60 feet. Shown in red to orange colors, V_1 velocity ranges from approximately 500 to 2,000 fps. Layer V_1 is interpreted to represent soil, fill, and loosely compacted alluvium. Layer V_1 is thickest in the northeast portion of the survey area (SL-2, -3, -7, and -8), where alluvium and fill material predominate, and thinnest in the southern portion of the survey area where it appears that recent grading has removed most of the soil cover and left claystone at or near the surface. The middle layer (V_2) ranges from less than 10 to approximately 35 feet in thickness and exhibits velocities from 2,000 to 5,400 fps. Shown in yellow to light green colors, Layer V_2 is interpreted to be weathered claystone, although it may include compacted fill and alluvium in places. Layer V_2 appears thickest in the northwest portion of the survey area (SL-1, -4, -5, -6, -8, and -12) and thinnest in the southwest. The lowest layer (V_3) occurs at depths ranging from approximately 10 to 80 feet bgs and exhibits velocities from 5,400 to 6,200 fps. Shown in dark green to blue colors, Layer V_3 corresponds to unweathered claystone. The boundary between V_2 and V_3 is interpreted to be the contact between weathered and unweathered claystone.

The velocity layer models show an overall good correlation with weathered/unweathered contact depth information obtained from borings along the seismic lines. Discrepancies are on the order of a few feet can be attributed to the contact’s gradational nature, as described on many boring logs.

3.3.2 Comparison of Phase I Production Survey Results with Ground Truth

The results of the seismic refraction production survey were compared with the Upper/Lower HSU Contact surface interpreted from borehole and CPT data. To facilitate this comparison, the contact picks were placed on the tomographic models (Figures L-9 through L-24). This information is also summarized Table L-2. The comparison shows good correlation between contact picks and velocity layering across many of the profiles. The comparison also shows good agreement between the seismic and borehole data with regard to local structural trends of the contact surface. For example, the three contact picks along seismic line SL-1 (Figure L-9) indicate that the contact corresponds to the onset of material exhibiting a seismic velocity of approximately 5,200 fps. Both the borehole and seismic data along SL-1 also show that the contact dips slightly to the east. Line SL-4 (Figure L-12) includes two contact picks that also correspond to 5,200 fps. Other profiles show the same type of internal consistency with respect to contact position; however, seismic velocity at the contact position is slightly different. For example, both seismic and borehole data along SL-10 (Figure L-18) show the contact dipping to the east, however, the contact occurs at approximately 4,500 fps. Along line SL-11 (Figure L-19), the contact occurs at approximately 5,500 fps.

Overall, the comparison suggests that the contact does not correspond to a single discrete seismic velocity contour throughout the entire survey area but that it occurs within a range of velocities between 4,500 to 5,500 fps. The variation in the velocity signature of the contact is attributed primarily to variations in the near-surface material along the seismic lines. Depending on their location, the seismic lines may cross over thick fill and soil in the Central Drainage Area, thin or absent soil in the freshly graded areas to the west, and/or pavement and hard compacted soil and fill along the roadways. In fact, many of the seismic lines include more than one type of near-surface condition. Additionally, it is likely that the natural geologic variation within the claystone itself and the transitional nature of the weathering process also contribute to the variation of the contact's velocity signature. The borehole and CPT data provide a means of establishing a velocity signature for the Upper/Lower HSU Contact surface, while the velocity profiles themselves show the configuration of the contact surface in the areas between the borehole and CPT points.

It should be noted that a small percentage of borehole contact picks along a few of the velocity profiles do not conform perfectly to the velocity layering. In particular, one of the four picks along SL-8 (Figure L-16) occurs in 3,000 fps material while a second occurs in material over 5,500 fps. However, these picks are from offline borings where topographic variation and lateral changes in soil and claystone properties may have contributed to the discrepancy. It should also be noted that the two other contact picks conform well with SL-8 velocity layering and to the seismic survey as a whole.

Borehole data from the western portion of SL-9 show the contact to be shallower (i.e., in seismically slower material) than expected on the basis of the seismic survey, while the borehole data from the eastern portion of SL-9 conform well with SL-9 velocity layering and with the seismic survey as a whole. It appears, therefore, that a localized condition is affecting claystone velocity in the western portion of SL-9. Field observations indicate that the western area of SL-9 has been used for a borrow source for fill material, and it is thought that the removal of overburden may have lowered the seismic velocity of the claystone in that area. It is also possible that the discrepancy is indicative of a natural geologic variation in claystone properties.

Finally, the CPT data obtained along SL-16, at the potential low spot LOW-1, did not show any indication of a depression in the contact surface (Figure L-24), further calling into question the reliability of using refraction to identify low spots in claystone contact. It appears that the depression in velocity layering is the result of a velocity anomaly that may be caused by localized changes in the properties of the soil or the weathered claystone.

3.4 Phase II Seismic Refraction Survey Results

3.4.1 Overview

The Phase II refraction survey results are presented as tomographic models of subsurface velocity layering along each of the seismic lines (Figures L-26 through L-39). In general, the models show an upper 20- to 130-foot-thick section of low-velocity material underlain by higher-velocity basement. As expected, the low-velocity zone is thickest near the P/S Landfill axis, where the refuse is thickest, and thinner towards the east, west, and south, beyond the landfill boundary, where the low-velocity zone mimics the ground-surface topography. The low-velocity exhibited by the upper section is indicative of soil and refuse material, while the higher velocity basement material is indicative of unweathered bedrock. A lateral transition within the upper low-velocity upper section is not evident across the landfill boundary, indicating that the weathered claystone exhibits a velocity similar to that of landfill refuse. A surprising result is that, as interpreted from seismic refraction data, the P/S Landfill axis in the northern portion of the survey area (and presumed center of the former ravine) diverges from the ravine axis as shown on the 1979 topographic contour map.

With respect to mapping the unweathered clay contact, it was not definitively identified on the tomographic models owing to the wide range of velocities exhibited at the modeled contact location (depth/elevation) where ground truth was applied. The ground truth indicates that the contact does not conform to a single iso-velocity value. Regardless, the CSC prepared a preliminary contour map of the 5,400 iso-velocity surface to see if any conclusions could be drawn by assessing its general form. It was this map that showed the divergence between the landfill axis and the former ravine axis noted above.

The USEPA processed the seismic and land survey data to prepare its own tomographic models and iso-velocity contour maps using the 5,200, 5,400, and 5,600 iso-velocity surfaces. From the USEPA's independent analysis, USEPA identified three potential low spots that were investigated with CPTs and piezometrers in 2007. Ground truthing from the 2007 work indicated that the 4,500 iso-velocity surface correlated better to the contact observed in CPTs, than the depth predicted by higher iso-velocity surfaces that represented unweathered claystone. Deferring to the USEPA's analysis, and in consideration of the fact that the 4,500 iso-velocity surface likely corresponds to areas where fill or weathered claystone can reasonably be expected to exist, the CSC has not reprocessed the seismic refraction data to incorporate the most recent land survey or USEPA comments dated May 4, 2007.

3.4.2 Identifying the Clay Contact on Tomographic Models Using Ground Truth

The key objective of seismic interpretation was to identify the unweathered claystone contact on the tomographic models. If the contact could be correlated to a specific and unique velocity signature, or to a narrow velocity range, then the contact configuration could be mapped in three dimensions by following its associated "iso-velocity" contour through the grid of 16 intersecting tomographic models (14 Phase II models plus the two from the Pilot Study).

To determine what iso-velocity surface best represents the top of unweathered claystone, the CSC annotated its tomographic models with "ground truth", i.e., the position (depth) of the claystone contact as interpreted from boreholes and CPTs. Depth annotating of the tomographic models was performed during the winter of 2005/2006 using the ground truth information available at that time. Later, additional ground truth was added using information from the piezometers completed during the summer of 2007.

The 2005/2006 ground truth was provided by contact depths picked from 10 borings and CPTs that had been completed in advance of the Phase II survey. Five such "pre-survey" ground truth points were located within the Landfill; they included the Gallery Well and PZ-LA-01, CPT-LA-01, CPT-LA-02, CPT-LA-03. Four pre-survey ground truth points were located outside of the landfill to the south; they included SW-18, RIPZ-5B, RIPZ-8, and Sump-9B. One pre-survey ground truth point, RP-20B, was found west of the Landfill.

The 2007 ground truth became available after the Phase II refraction field work was completed and tomographic models were prepared and analyzed. The 2007 ground truth consists of four points-- RIPZ-13, RIPZ-27, RIPZ-38, and RIPZ-39, which were completed in the summer of 2007 (a fifth 2007 boring, RIPZ-14, was advanced in the P/S Landfill but it was located north of the refraction survey area and its ground truth information could not be used to help analyze the tomographic models). The locations of these 2007 piezometers were selected largely on the basis of the USEPA's analysis of the Phase II refraction survey data. Accordingly, the 2007 ground truth points provide a check on the accuracy of the model interpretation and also a means to refine the interpretation.

Ground truth locations are shown on Figure L-25 and the associated contact depths are shown on the tomographic models (Figures L-26 through L-39), although it is worth noting that only 8 of the 14 Phase II lines (P2SL-2, -4 -5, -6, -9, -12, -13, and -14) include ground truth information. Ground truth information is also summarized in Table L-3.

3.4.3 Results of Ground Truth Analysis of Tomographic Models

When the contact depths were plotted on the tomographic models, it was observed that the velocity at the contact ranged from a low of approximately 3,200 fps to a high of 6,000 fps (see Table L-3). This broad velocity range exhibited at the various ground truth locations suggests that the contact does not conform to a single iso-velocity contour, and that the seismic `models developed have poor correlation with real world conditions beyond calibration points. The broad velocity range also made the quantitative identification of the contact based on the models problematic, so the iso-velocity surface representing the claystone contact could not be established with confidence.

In an effort to establish a useable iso-velocity surface, the CSC considered that if the 3,200 and 3,700 fps values associated with RIPZ-13 and PZ-LA-01, respectively, were disregarded, the ground-truth velocities generally cluster around 5,450 fps. Velocities of this magnitude are commonly representative of lithological horizons and could potentially represent a useable iso-velocity signature for the contact. Further, contact velocities exhibited by the 16 Phase I Tomographic Profiles (located entirely outside the P/S Landfill) ranged from 3,000 to 5,500 fps, and cluster between 4,500 and 5,500 fps if a 3,000 fps outlier value is disregarded. The 2007 CPT work, however, indicates that the 4,500 fps iso-velocity surface may be a better fit for the claystone contact.

3.4.4 Results from 2007 CPT Work and Comparison with Tomographic Models

Contact depths from the 2007 CPTs were compared with the Phase II tomographic models. The following contact depths and elevations were measured at these P/S Landfill piezometer locations, which are listed from south to north:

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

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

RIPZ-13 (on Bench 1 Road): RIPZ-13 was installed in 2007 approximately 180 feet north-northwest of the Gallery Well on the Bench 1 access road. The HSU contact was encountered at a depth of 97.00 feet bgs (elevation 498.75 feet amsl). This elevation is higher than the HSU Contact Elevation predicted by the CSC model but lower than that predicted by the USEPA model. Subsequent to the installation of piezometer RIPZ-13, the depth counter on the CPT rig was determined to be inaccurate during the first CPT attempt at proposed piezometer location RIPZ-39. Once the problem with the depth counter was corrected, a second CPT boring was advanced adjacent to RIPZ-13 to confirm that the piezometer was installed at the HSU contact. CPT RIPZ-13a was advanced to a total depth of 97.6, which indicated that depth measurements during the original CPT RIPZ-13 were most likely inaccurate (the total depth was recorded as 105.3 feet), but that the installed depth of the piezometer was correct. Liquid level measurements obtained from the piezometer indicate that the DNAPL thickness had remained stable following well development at approximately 14-feet from December 2007, until March 2009. In March and April 2009, URS performed an eight day purge and recovery test in the well to determine the rate and amount DNAPL recharge surrounding the well. Approximately 42-gallons of DNAPL were pumped from the well during the test period. The DNAPL thickness upon completion of the pumping portion of the recovery test was 2.55-feet, which represented a drawdown of 11.05-feet from the 13.6-feet pre-pumping thickness. The DNAPL thickness in RIPZ-13 subsequently recovered to 7.21-feet in a two month period following completion of the DNAPL purging.

RIPZ-39 was installed in 2007 approximately 350 feet north-northwest of the Gallery Well on the Bench 2 access road. The HSU contact was encountered at a depth of 123.00 feet bgs (elevation 512.11 feet amsl), which corresponds with a sharp increase in CPT tip resistance and pore pressure, and CPT refusal at that depth (CPT RIPZ-39a). This elevation is higher than the HSU contact elevations determined at this location by both the CSC and EPA geophysical models. The contact depth at this location was determined during the advancement of a second CPT boring (RIPZ-39a). Although RIPZ-39 was advanced to a measured total depth of 132.9 feet, it was determined by the number of push rods used that the actual total depth was 123-feet. An electrical malfunction of the depth counter was determined to be responsible and immediately repaired. Liquid level measurements obtained during and after piezometer development have not indicated the presence of DNAPL in RIPZ-39.

RIPZ-14 was installed in 2006 approximately 680 feet north-northwest of the Gallery Well on the Bench 2 access road. The HSU contact was encountered at a depth of 156.00 feet bgs (elevation 552.07 feet amsl), which corresponds to the CPT refusal depth. Liquid level measurements obtained during and after piezometer development have not indicated the presence of DNAPL in RIPZ-14.

Additional discussion of the occurrence and distribution DNAPL beneath and downgradient of the P/S Landfill is contained in Appendix F.

3.4.5 Uncertainty of CPT-Derived Contact Depths Used For Ground Truth

The depth to the unweathered claystone contact is determined with the greatest certainty from boring logs, where unweathered claystone is distinctive as "massive…with a greenish-gray to bluish gray color" (Appendix K). Also, the contact depth can be identified from CPT borings, where it is characterized by a "sharp increase in both tip resistance and dynamic pore pressure." However, because it is an indirect method for soil lithology determination "some uncertainty" exists with the CPT method. To minimize this uncertainty, the CSC performed tests to compare contact depths as determined logged core samples to those determined from co-located CPT borings to see if the contact could be accurately identified. It was observed that two key factors affecting the CPT/boring log agreement are the thickness of the transition zone between weathered and unweathered claystone (which ranged from 0 to 3 feet) and the density of the weathered zone. The comparison study found that the most accurate CPT contact depths are obtained in areas with deeply weathered claystone and a thin transition zone. It should be noted that the CTP/boring log comparison was not performed in the P/S Landfill, where it is believed that weathered claystone was bulldozed away to increase landfill capacity, a process that could increase the accuracy of CPT-derived contact depth information. Figure K-2 of Appendix K illustrates that the agreement between contact depths derived from CPT borings and those derived from boring logs ranged between one and five feet.

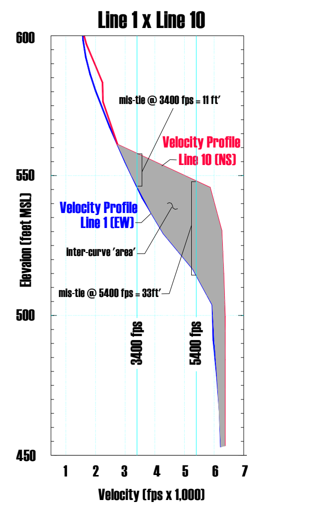
During previous investigations, the CSC used CPT borings to evaluate the depth of the native claystone underlying waste and/or alluvium materials. At that time, the CSC reviewed tip resistance data or responses from previous on-site CPT activities with the USEPA's contractor (Mark Wuttig of CH2M Hill) and generally agreed that an increase in tip resistance (Qc) to 200 tons per square foot (tsf) (over a several foot increment) and positive pore pressure (P_w)

represented reaching the contact between the base of the waste and the top of the unweathered claystone. To further test the CPT methodology, the CSC evaluated CPT signatures in conjunction with lithologic logs from co-located boreholes completed during the Phase I RI activities. The Phase I investigations included pushing 18 CPTs co-located with existing boreholes for which good quality lithologic data on HSU contact depths were available. The validity of the CPT method was confirmed based on calibration of the observed CPT response with known lithologic conditions at the adjacent recently installed and cored confirmation boreholes. The comparison indicates that CPT technology will reliably indicate the depth of the unweathered claystone contact to within zero to five feet of the contact as picked from boring logs. Given the generally accepted depth uncertainties inherent in the refraction method (+/- 10%), the CSC believes that CPT data, in conjunction with borehole data, provide good information with which to ground truth the tomographic models. The CSC acknowledges that a depth counter malfunction caused some uncertainty at two of the 2007 CPT locations, but the malfunction was identified and fixed, and a second CPT, RIPZ-13A, was advanced in place of RIPZ-13 to insure accurate contact depth information was obtained.

3.4.6 Tie Point Analysis

In a further effort to assess the accuracy of the tomographic models, the CSC compared the tomographic models at seismic line intersections to assess how well the velocity layering matches, or ties, at the model intersections. Because a single velocity signature for the contact is not established, the CSC selected two velocity horizons, designated H1 and H2, for the comparison. H1 was picked at 3,400 fps. This velocity contour was selected because it appears as a smooth, narrow, easy to follow band of tightly bunched velocity contours. The tightly bunched contours represent a large velocity change within a relatively thin section of the subsurface. As such, the H1 zone represents the most substantial layer boundary on the models, although it does occur shallower than the expected contact depth. Even though it exhibits sharp, angular, and geologically unreasonable bends in several places, the 5,400 fps contour was selected for horizon H2 because its depth most closely matches the available ground truth information. It is the CSC's opinion that the two velocity horizons bracket the contact and that the contact generally conforms to the horizons' configuration. This conclusion is supported by the results of the 2007 CPT work, which indicate that, within the P/S Landfill, the best iso-velocity surface for the contact may be closer to 4,500 fps.

The CSC completed a tie point analysis or comparison using the digital results (i.e., the tomographic models) by extracting from the tomographic models a velocity profile at each intersection point of the N-S and E-W lines (see illustration, right). The tie point agreement was assessed by superimposing the two profiles and comparing the velocity profiles' projected elevations at 3,400 fps and 5,400 fps. An additional assessment of the overall agreement between the two velocity profiles was made by calculating the area between the two profile curves. The mis-ties (or delta between the projected depth of the same velocity point on the N-S and E-W line) ranged from 0 feet (which would indicate agreement) to over 50 feet, with the largest mis-ties occurring towards the northwest along the buried canyon wall. In general, the north-south lines exhibited shallower velocity layering and overall higher velocity.



Tie Point Comparison Parameters

The results of the velocity horizon comparison are summarized in Tables L-4a and L-4b. A graph showing the distribution of mis-tie distances (in vertical feet) is presented on Figure L-40. For clarity, horizon tie discrepancies are shown in six groups: 0 to 5 feet, 5 to 10 feet, 10 to 15 feet, 15 to 20 feet, 20 to 25 feet, and greater than 25 feet. Figure L-40 indicates that shallower H1 horizon generally ties within 15 feet or less, although a substantial number of the H1 model tie points (26) do exhibit discrepancies of 10 feet or greater. The deeper H2 horizon ties less well— exhibiting a relatively even distribution across all mis-tie distance groups, including 13 mis-ties of 25 feet or greater (compared with only 3 feet for H1 in that category).

The poor H2 model ties are problematic for the objective of mapping the contact because, as noted above, the depth of the 5,400 fps iso-velocity surface matches the contact depth in the ground truth borings. Please note that as stated previously, the 5,400 fps surface also exhibits distorted and geologically unreasonable bends, which contribute to the poor matches at line intersections. This result may be caused by three dimensional “off-line” effects of the steep former canyon walls and/or by the heterogeneous refuse material, which are not adequately accounted for by the modeling process. Additionally, the severe bending of velocity contours, particularly at depth, may be an artifact of the grid used for the tomographic modeling process.

The CSC believes that the individual tomographic models depict gross landfill features and the broad configuration of the weathered/unweathered claystone contact and the refuse/claystone contact. They clearly show the axis of the former ravine but they cannot be used to construct a three dimensional picture of the contact configuration with enough accuracy to image more subtle topographic features. The horizon discrepancies catalogued during the tie analysis of the tomographic models suggest that the seismic refraction survey can provide subsurface information with a depth accuracy no better than this 10 to 15 feet. Additionally, the CSC is concerned about the possible effects of near-surface velocity anomalies on the modeled contact configuration. The apparent “ridges” in the 5,400 fps iso-velocity surface map prepared by the USEPA appear to be caused by near-surface velocity anomalies associated with the bench roads spanning the P/S Landfill. Such a near-surface effect further degrades the accuracy of any buried surface mapped from the refraction data.

4.0 EVALUATION OF ADDITIONAL DATA NEEDS

The geophysical data obtained during this Remedial Investigation (RI), along with lithologic and liquid level data generated during the RI borehole investigations, were evaluated with respect to the groundwater Data Quality Objectives (DQOs) identified in the RI/FS Work Plan. Work Plan Sections 4.3 through 4.6 identify specific decisions and decision rules for issues related to this Task, including those related to contaminant fate extent and transport, groundwater modeling, and TI and FS evaluations. Table 5.1 identifies all of the RI/FS DQO decisions and provides an evaluation of additional data needs associated with each, and the decisions specific to the geophysical investigations are listed below. Note some of these groundwater decisions are also addressed in Appendix E (Well and Piezometer Installation), and Appendix F (Groundwater Levels).

4.1 DQO Decisions Related to Groundwater Contaminant Fate and Transport and Modeling

The specific decisions and decision rules for issues related to groundwater contaminant fate extent and transport and for groundwater modeling are as follows:

- What are the rates and directions of groundwater flow?
- Are subsurface flow and transport pathways identified?

The data collected as a part of these RI investigations are adequate for evaluating groundwater flow and modeling DQO Decisions. Specifically, the HSU contact surface inferred from the geophysical surveys is consistent with the interpretation provided by interpolation of borehole contact data, and is adequate for identifying groundwater flow pathways, rates and directions within the production survey area

The CSC recognizes the importance of addressing the potential presence or absence of low spots in the claystone surface or contact under the P/S Landfill (Bench 1). the CSC believes that the Pilot Study and Phase II seismic refraction data, which the CSC obtained along sixteen 960-foot lines situated on a 50- by 50-foot survey grid centered on the toe of the P/S Landfill, provide adequate data coverage, especially when the survey parameters (i.e., 10-foot geophone and 40-foot shotpoint spacing) are considered. Accordingly, the CSC believes no additional refraction data are needed. The CSC also believes that analysis of the Pilot Study and Phase II seismic refraction data provides an adequate representation of the claystone contact, given the site conditions and the resolution limitations inherent in the refraction method. The CSC acknowledges the USEPA's independent processing efforts, which included three dimensional kriging of the tomographic modeling output and renderings of a 5,400 fps iso-velocity surface. The USEPA renderings suggest potential low spots north of the Gallery Well, the Bench 1 Road, and the Bench 2 Road; however, the CSC does not necessarily agree that the renderings accurately represent the claystone surface. In particular, it is noted that the potential low spots are suggested by 5- to 10-foot-tall iso-velocity ridges that align with the roadways spanning the P/S Landfill. The ridges are suspected to be artifacts of near-surface velocity anomalies associated with compacted road fill, in which case the renderings help illustrate the effect of changes in the overlying material on the modeled configuration of the unweathered claystone surface. As such, they also illustrate the resolution limits of the refraction survey and subsequent processing efforts.

4.1.1 DQO Decisions Related to Feasibility Study Evaluations for Groundwater

The specific decisions and decision rules for issues related to the Feasibility Study (FS) evaluations for groundwater are as follows:

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

Geophysical data collected as a part of these RI investigations are adequate for conducting FS evaluations for groundwater. The HSU Contact distributions, along with aquifer physical property data are sufficient for FS evaluations.

5.0 REFERENCES

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