Non-Invasive Determination of the Location and Distribution of Free-Phase Dense Nonaqueous Phase Liquids (DNAPL) by Seismic Reflection Techniques

Semi-Annual Technical Progress Report

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by

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Abstract

This semi-annual technical progress report is for part of Task 4 (site evaluation), on DOE contact number DE-AR26-98FT40369. The project had planned one additional deployment to another site other than Savannah River Site (SRS) or DOE Hanford.. After the SUBCON midyear review in Albuquerque, NM, it was decided that two additional deployments would be performed. The first deployment is to test the feasibility of using non-invasive seismic reflection and AVO analysis as monitoring to assist in determining the effectiveness of Dynamic Underground Stripping (DUS) in removal of DNAPL.

The Second deployment site is the Department of Defense (DOD) Charleston Navy Weapons Station, Solid Waste Management Unit 12 (SWMU-12) Charleston, SC was selected in consultation with National Energy Technology Laboratory (NETL) and DOD Navy Facilities Engineering Command Southern Division (NAVFAC) personnel. Base upon the review of existing data and due to the shallow target depth the project team has collected three Vertical Seismic Profiles (VSP) and experimental reflection line. At the time of preparing this report VSP data and experimental reflection line data has been collected and has have preliminary processing on the data sets.

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1.0 Introduction

This semi-annual technical progress report outlines the status of Task 4 (site evaluation) under DOE contact DE-AR26-98FT40369. This report pertains only to the experimental data acquisition of Task 4. The new additional site is the SWMU-12 at the Charleston Navy Weapons Station (Figure 1). This site offers some unique technical challenges in that the depth that the seismic is to image is very shallow, less than 20 feet below land surface.

At the SWMU-12 site the greatest concentration of DNAPL is located in the upper 20 feet within the surficial aquifer (Figure 2). In the lower aquifer there appears to be very low concentrations of dissolved chlorinated solvents, so therefore the emphasis is to image the DNAPL in the upper surficial aquifer. At the time of preparing this report the project team had completed a site visit and reviewed all the existing data for this site. Base upon the review of existing data and due to the shallow target depth the project team has collected three Vertical Seismic Profiles (VSP) and experimental reflection line. At the time of preparing this report VSP data and experimental reflection line data have been collected and preliminary processing on the data sets had been completed.

2.0 Executive Summary

This semi-annual technical progress report is part of Task 4 (site evaluation), for DOE contact number DE-AR26-98FT40369. After the SUBCON midyear review in Albuquerque, NM and the peer review it was decided that two additional deployments would be performed. The first deployment is to test the feasibility of using non-invasive seismic reflection and AVO analysis as monitoring to assist in determining the effectiveness of Dynamic Underground Stripping (DUS) in removal of DNAPL. The site selected for this feasibility study is the solvent storage area at M-area Savannah River Site. The second site is to test the concept under a differing set of geologic conditions. The second deployment is to the DOD Charleston Navy Weapons Station, SWMU-12 site, Charleston, SC, which was selected in consultation with NETL and DOD NAVFAC personnel. Tasks 4, 5, and 6 will be performed at the Charleston Navy Weapons Station. This site offers some unique technical challenges in that the depth that the seismic is to image is very shallow, less than 20 feet below land surface.

At the SWMU-12 site the greatest concentration of DNAPL is located in the upper 20 feet within the surficial aquifer (Figure 2). In the lower aquifer there appears to be very low concentrations of dissolved chlorinated solvents, so therefore the emphasis is to image the DNAPL in the surficial aquifer. At the time of preparing this report the project team has completed a site visit and reviewed all the existing data for this site. Base upon the review of existing data and due to the shallow target depth the project team had collected three Vertical Seismic Profiles (VSP) and experimental reflection line. At the time of preparing this report VSP data and experimental reflection line data have been collected and preliminary processing on the data sets had been completed. Very preliminary analysis of the experimental reflection seismic suggests that there are reflections at the shallow depth where the DNAPL is occurring. The next step will be to generated a series of reflection coefficients versus offsets models (AVO) to determine if

DNAPL replaces water in the pore spaces and if there is a change in the amplitude that is sufficient to identify on the seismic data.

3.0 Project Objectives

The research as initially proposed was a 14 month proof of concept study to determine the location and distribution of subsurface DNAPL contamination at the 200 West area, DOE Hanford Site by the use of two and three-dimensional high resolution seismic reflection data and borehole geophysical surveys. The major change in the objectives is now the proof of concept is being applied to the M-area solvent tanks area at Savannah River Site and at the Charleston Navy Weapons Station, Charleston SC. The specific objectives of the research at these sites are:

- Subsurface imaging of geologic sinks where DNAPL can pool.
- Direct detection of DNAPL by use of seismic reflection amplitude versus offset (AVO) method.
- To test the feasibility of using high-resolution seismic techniques and AVO analysis as a monitoring tool in evaluating the effectiveness of DUS technique at the M-area solvent tank area (SRS only).

4.0 Project Accomplishments

Task 4 for the SWMU-12 site at the Charleston Navy Weapons Station (CNWS) commenced in late December. Initial review of existing data was completed in January. After the site visit and review of existing data, Vertical Seismic Profiles (VSP) were completed in three wells and one experimental seismic line acquired on site. Both P and S-wave VSPs were collected from each well. Data from the VSP will provide P-wave and S-wave velocities that will be used in the AVO modeling to determine if free phase trichloroethylene (TCE) or tetrachloroethylene (PCE) have an AVO effect on the surface seismic amplitude.

5.0 Problems Encountered

No problems were encountered during this reporting period.

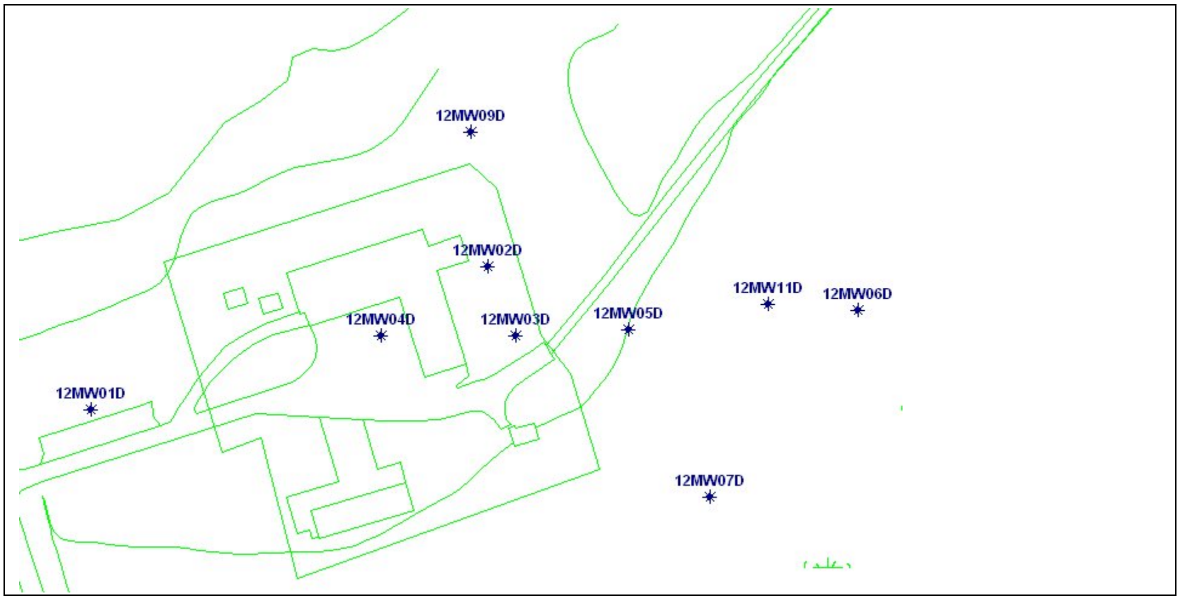


Figure 1. Location map of the Solid Waste Management Unit 12 (SWMU) site at the Charleston Navy Weapons Station.

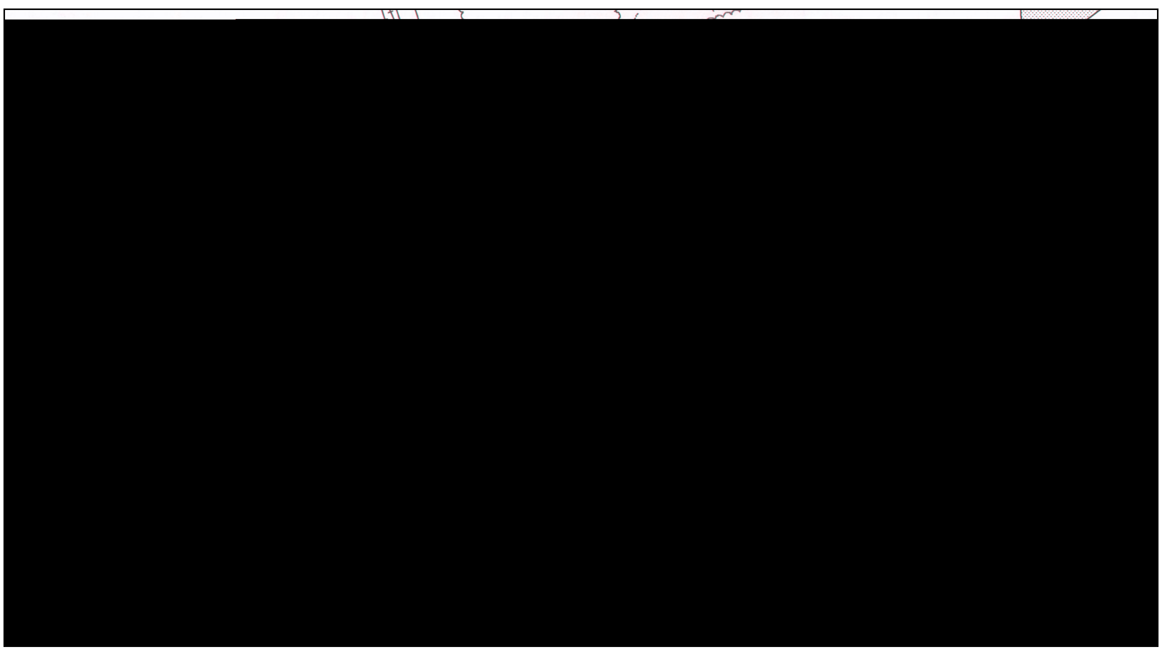


Figure 2. Contour map showing the total chlorinated solvent concentrations in upper surficial aquifer at the SWMU-12 site. The outer dashed contour line is zero concentration and the inner most contour line is 30,000 micrograms per liter.

6.0 Experimental

The SWMU-12 site at the Charleston Navy Weapons Station offers some unique technical problems for applying the AVO technique to directly detect DNAPL. Therefore, we decided to collect Vertical Seismic Profiles (VSP) in three wells and acquire a short experiment seismic reflection line. The site is located in a low swampy area where the water table is almost at land surface. Another technical obstacle is the target zone where the DNAPL is accumulating is between 15 to 20 feet below land surface.

6.1 Seismic Reflection Data

6.1.1 Vertical Seismic Profile (VSP) Data Acquisition

Vertical seismic profiles were collected in boreholes 12MW-01D, 12MW-05D, and 12MW-10S at the Charleston Naval Weapons Station (SWMU-12). These data include both compressional wave (P) (12MW-01D, 12MW-05D, 12MW-10S) and shear wave (S) (12MW-01D) recordings. The VSPs were collected to provide information on the subsurface P and S wave velocity field of the geologic layers at and above the known DNAPL contamination at the Charleston Naval Weapons Station SWMU-12 (Figures 4-7).

The data collected are to be used to construct seismic models to investigate the probable amplitude versus offset (AVO) response that would be recorded by the surface seismic survey. In addition, the subsurface velocity information is needed to perform high-fidelity ties between the surface seismic profiles and the borehole lithology picks. The velocity versus depth information obtained from the VSPs can be used to convert interpretations made on the seismic data to depth.

Seismic recordings were made at 1 meter increments from the bottom of the borehole to approximately 1 meter below land surface using a three geophone (1 vertical, 2 horizontal) Geostuff sonde and an 8 lb. sledgehammer source. For P-wave acquisition a vertical steel cylinder was placed on the ground and struck four to eight times. Each hit was vertically summed to the preceding hits in the seismograph and written to tape as a single record for each level. For S-wave acquisition strike plates were mounted on the ends of an 8 ft horizontal plank and a truck was driven on the plank to couple the plank to the ground. Each end of the plank was struck six to eight times, first from one side of the vehicle and then the other. The summed records for each source orientation were written to disk separately for each level.

Because of the relatively shallow depths of investigation and the critical need to have reliable subsurface velocity information, the P-wave VSPs from boreholes 12MW-01D, and 12MW-05D were logged multiple times with different seismographs and slightly different recording parameters. The recording parameters for each VSP are summarized in the Table 1.

Table 1. Summary of VSP recording parameters.

	12MW-01D	**12MW-05D**	**12MW-10S**	**18CC-Q1**
No. of VSP runs	3 P, 1 S	2 P, 0 S	2 P, 0 S	3 P, 1 S
Recorded depth P wave (m from TOC)	1-12	1-14	1-5	1-31, 1-51,1-15
Recorded depth S wave (m from TOC)	1-12	.	.	1-31
Source offset P wave (m)	2.0-0.55, 2.0-0.55, 2.0	2.0-0.55, 2.0	0.55, 1.0-0.55	2.5-1.5, 2.0,2.0
Source offset S wave (m)	1.82	.	.	2.5
No. of source hits P-wave	4, 8, 8	8	8	8
No. of source hits S-wave	(6,6)	.	.	(8,8)
Depth increment (m)	1	1	1	1
Sample rate P-wave (ms)	0.125, 0.125, .02833	0.125, 0.021	0.125, 0.125	0.125,0.0283,0.02833
Sample rate S-wave (ms)	0.125	.	.	0.125
Record length P-wave (ms)	200	200	200	200
Record length S-wave (ms)	200	.	.	400
Seismograph	Seistronix RAS-24 (P 1, 2 & S) Geometrics Geode (P 3)	Seistronix RAS-24 (P 1) Geometrics Geode (P 2)	Seistronix RAS-24	Seistronix RAS-24 (P 1 & S) Geometrics Geode (P 2, 3)

6.1.2 Vertical Seismic Profile (VSP) Data Processing

The generalized data processing flow for the VSP data appears below (Figure 3). The PC-based VISTA seismic processing software (Seismic Image Software, Ltd.) was used to process the data. In the field some rudimentary data processing was performed for QA/QC purposes using VISTA. The field QA/QC ensured that usable data were recorded. The field data processing also revealed that no usable VSP data could be obtained from borehole 12MW-10S.

First arrival times were picked on the P-wave records and the better of the two channels on the S wave records. These times were corrected for source offset from the borehole to true vertical travel time (TVT), or zero-offset time, using a straight raypath assumption. No correction for reflection normal moveout was made. The velocity profile, average velocity and interval velocity, for each borehole was computed (Figures 4 through 7) using the data presented in Tables 2 through 6. The average velocity (total depth divided by total time) from the surface to the recording depth is used to convert recording time to depth. The interval velocity, or velocity of the material between recording levels, is an approximate indicator of lithologic changes in the borehole.

For correlation to the surface seismic data displays of the up-going wavefield data were shifted to two-way reflection time (twice TVT) and narrow (3-10 trace) front corridor stacks were produced. Because the time-depth relationship for the front corridor stack is known, the depth to the reflectors in the subsurface can be found.

On the following pages appear the data tables and interval velocity curves from the best VSP profiles, P-wave and S-wave, recorded in boreholes 12MW-01D, 12MW-05D. Near the surface the pick times are unreliable because the seismic raypath is not favorably oriented with respect to the geophone. Thus, no velocity information is reported for the upper few meters of the borehole.

In borehole 12MW-05D it was possible to obtain S-wave information by processing first arrival information recorded on the shear wave geophones during the P-wave VSP. The S-wave velocities found were compared to those obtained in 12MW-01D to verify that valid S-wave velocities were computed.

Generalized Vertical Seismic Profile Data Processing Flow

Reformat SEG-2 to SEG-Y
|
Sort field records / Reverse & sum shear wave records
|
Write depth information into trace headers
|
Display / Trace edits / Bandpass filter
|
Pick first breaks
|
Correct times for source offset (TVT) / Calculate velocity profile
|
Time align downward traveling energy / Mean amplitude scaling
|
Wavefield separation (spatial median filter, 5 pt)

(Down-going waves)
|
Spiking deconvolution operator found
|
Bandpass filter/Scaling
|
Display

(Up-going waves)
|
Spiking deconvolution applied

Bandpass filter /Scaling
|
Display
|
Align at two-way reflection time
|
Median filter (5 pt)
|
Display
|
Mute/Front corridor stack
|
Spectral whitening
|
Bandpass filter/Scaling
|
Display

Figure 3. Vertical seismic profile (VSP) data processing flow.

Table 2. P-wave velocity table from Well 12MW-01D

Well 12MW-01D

P-Wave Vertical Seismic Profile

GL = 2.52 m TOC = .60 m

(Offset = 2 m)

Seq. No.	Depth (TOC) (m)	Pick Time (ms)	Depth (GL) (m)	True Vertical Time (ms)	Average Velocity (ft/s)	Interval Velocity (ft/s)	Two-way Time (ms)
13	1	4.46	0.37	0.81	1497	1497	1.62
12	2	4.52	1.37	2.55	1759	1881	5.11
11	3	5.25	2.37	4.01	1938	2251	8.02
10	4	5.90	3.37	5.07	2181	3101	10.14
9	5	6.37	4.37	5.80	2473	4515	11.59
8	6	6.94	5.37	6.50	2710	4657	13.00
7	7	7.73	6.37	7.37	2834	3758	14.75
6	8	8.50	7.37	8.20	2948	3957	16.41
5	9	8.77	8.37	8.53	3219	10023	17.06
4	10	9.06	9.37	8.86	3469	9876	17.73
3	11	9.65	10.37	9.47	3592	5393	18.94
2	12	10.71	11.37	10.55	3537	3052	21.09

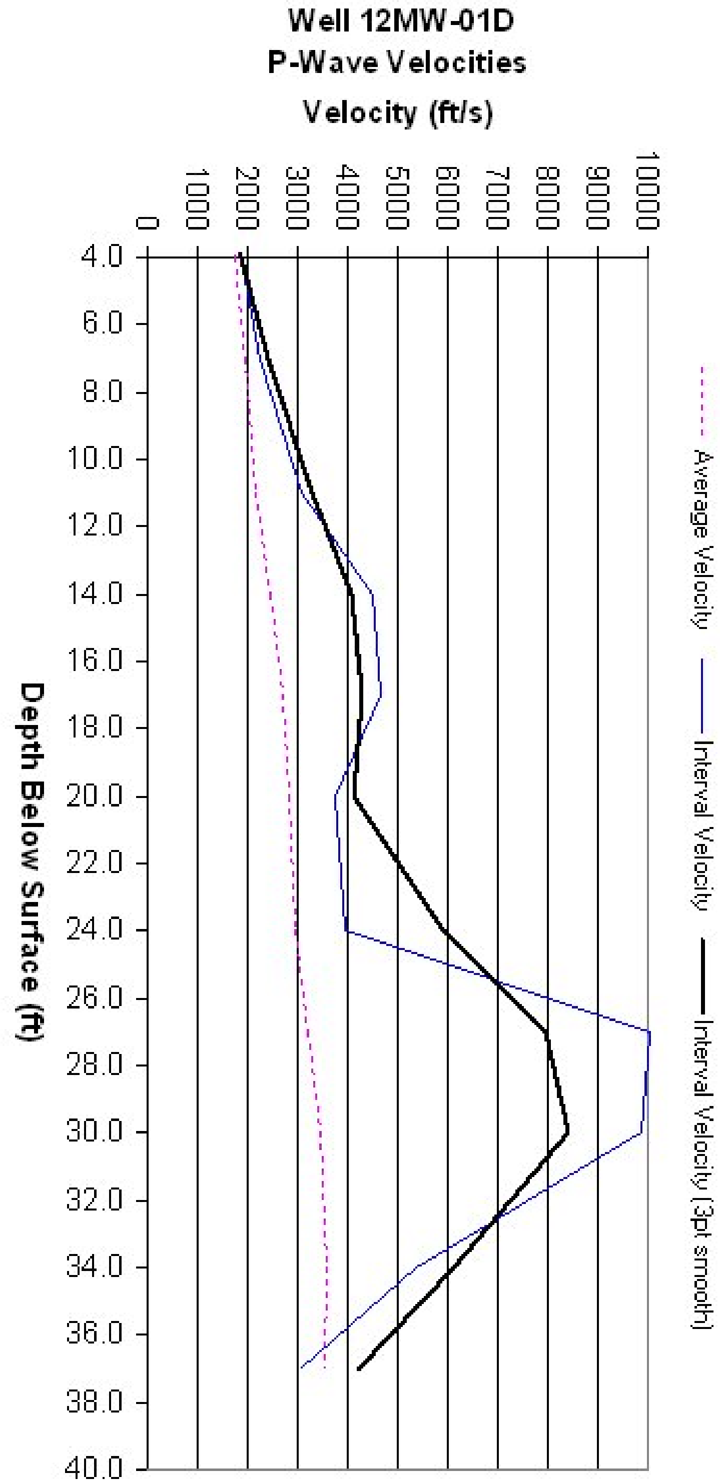


Figure 4. Graph of P-wave interval velocity, smoothed interval velocity and average velocity versus depth in borehole 12MW-01D.

Table 3. S wave velocity table from well 12MW-01D

Well 12MW-01D

S-Wave Vertical Seismic Profile

GL 2.52 m TOC = 0.6 m

(Offset = 1.82 m)

Seq. No.	Depth (TOC) (m)	Pick Time (ms)	Depth (GL) (m)	True Vertical Time (ms)	Average Velocity (ft/s)	Interval Velocity (ft/s)	Two-way Time (ms)
12	1	14.85	0.40	3.19	412	412	6.38
11	2	15.00	1.40	9.15	502	551	18.29
10	3	16.00	2.40	12.75	618	911	25.50
9	4	20.50	3.40	18.07	617	616	36.15
8	5	29.85	4.40	27.58	523	345	55.17
7	6	37.25	5.40	35.30	502	425	70.60
6	7	43.40	6.40	41.74	503	509	83.49
5	8	49.90	7.40	48.46	501	489	96.91
4	9	55.95	8.40	54.68	504	527	109.36
3	10	61.40	9.40	60.28	512	586	120.56
2	11	65.10	10.40	64.13	532	853	128.25
1	12	70.35	11.40	69.47	538	614	138.94

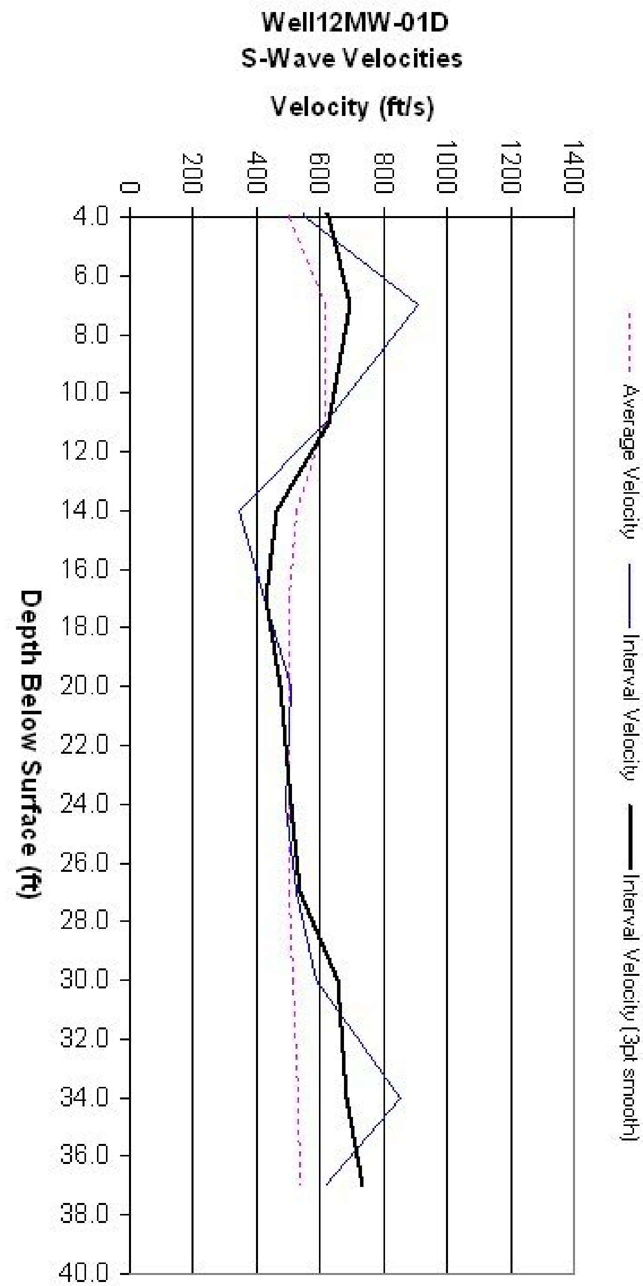


Figure 5. Graph of S-wave interval velocity, smoothed interval velocity and average velocity versus depth in borehole 12MW-01D.

Table 4. P wave velocity table from well 12MW-05D

Well 12MW-05D

P-Wave Vertical Seismic Profile

GL = 1.79 m TOC = 0.43 m

(Offset = 2 m)

Seq. No.	Depth (TOC) (m)	Pick Time (ms)	Depth (GL) (m)	True Vertical Time (ms)	Average Velocity (ft/s)	Interval Velocity (ft/s)	Two-way Time (ms)
10	5	8.750	4.57	8.02	1870	1870	16.03
9	6	9.750	5.57	9.18	1991	2827	18.35
8	7	10.250	6.57	9.81	2198	5213	19.61
7	8	10.630	7.57	10.28	2417	6956	20.55
6	9	11.500	8.57	11.20	2511	3559	22.40
5	10	12.250	9.57	11.99	2618	4143	23.98
4	11	13.130	10.57	12.90	2688	3605	25.80
3	12	13.880	11.57	13.68	2775	4227	27.35
2	13	14.630	12.57	14.45	2854	4255	28.90
1	14	15.130	13.57	14.97	2974	6309	29.94

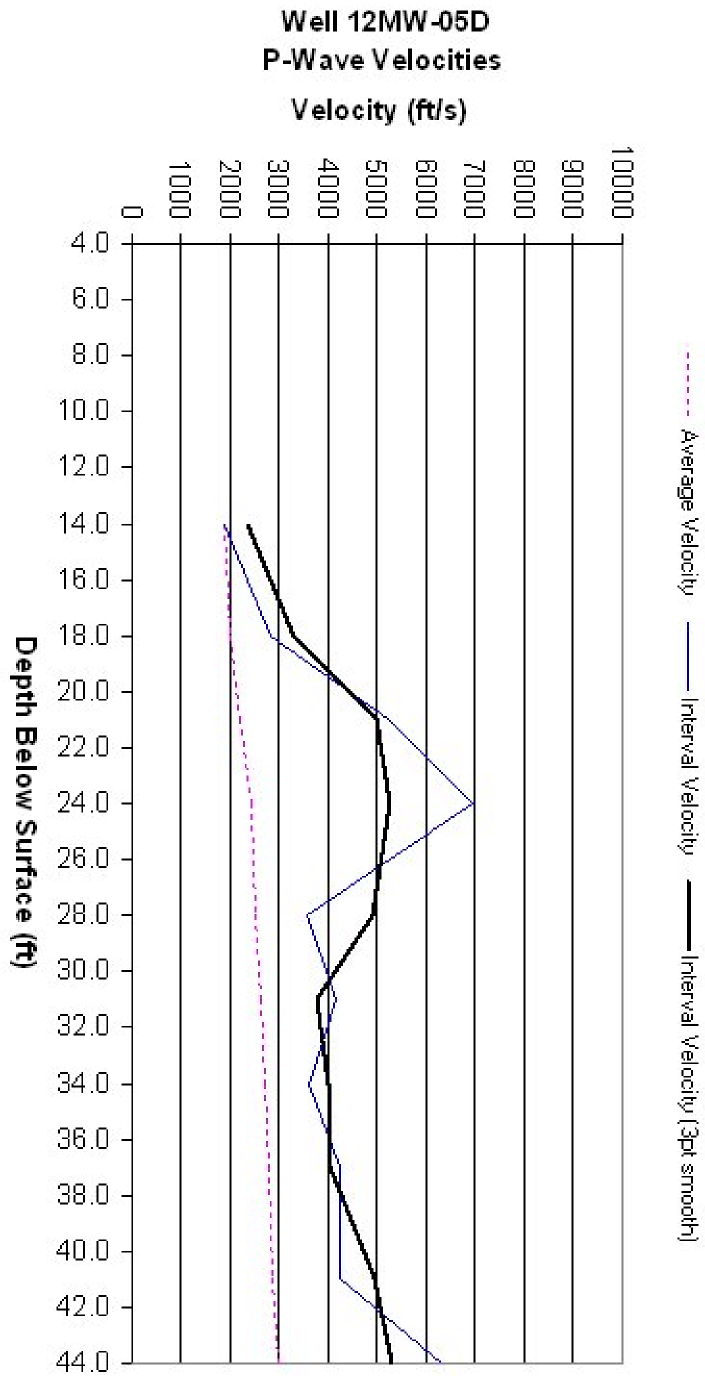


Figure 6. Graph of P-wave interval velocity, smoothed interval velocity and average velocity versus depth in borehole 12MW-05D.

Table 4. S wave velocity table from well 12MW-05D

Well 12MW-05D

S-Wave Vertical Seismic Profile

GL = 1.795 m TOC = 0.43 m

(Offset = 2 m, (5-14 m))
(Offset = 1 m, (3-4 m))
(Offset = 0.55 m, (1-2 m))

Seq. No.	Depth (TOC) (m)	Pick Time (ms)	Depth (GL) (m)	True Vertical Time (ms)	Average Velocity (ft/s)	Interval Velocity (ft/s)	Two-way Time (ms)
14	1	22.71	0.52	5.71	299	299	11.43
13	2	20.31	1.52	12.29	406	499	24.58
12	3	25.08	2.52	19.65	421	446	39.29
11	4	29.99	3.52	26.08	443	510	52.17
10	5	35.92	4.52	32.84	452	485	65.69
9	6	46.10	5.52	43.35	418	312	86.69
8	7	54.85	6.52	52.44	408	361	104.88
7	8	63.27	7.52	61.14	404	377	122.29
6	9	70.42	8.52	68.55	408	443	137.10
5	10	75.04	9.52	73.44	425	672	146.87
4	11	80.48	10.52	79.06	437	583	158.12
3	12	86.42	11.52	85.14	444	540	170.28
2	13	92.75	12.52	91.59	448	509	183.17
1	14	97.48	13.52	96.43	460	678	192.86

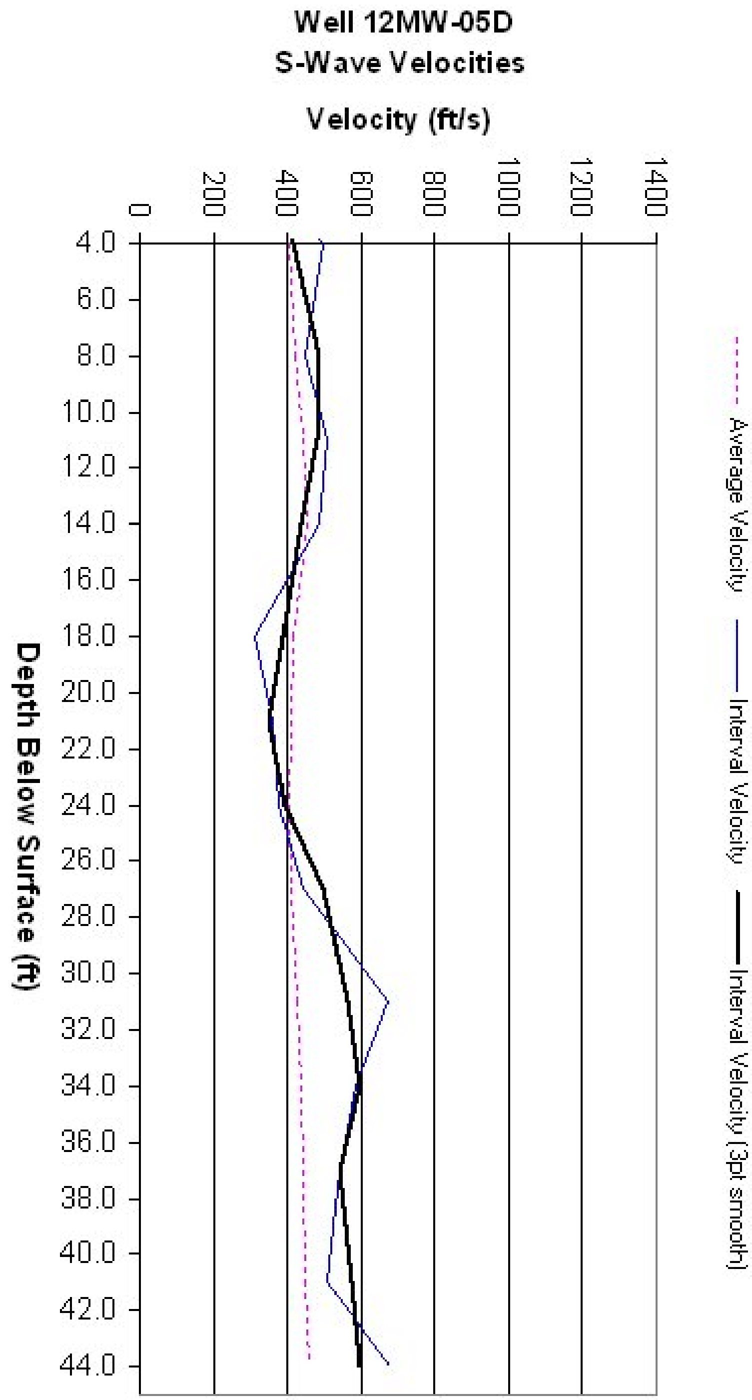


Figure 7. Graph of S-wave interval velocity, smoothed interval velocity and average velocity versus depth in borehole 12MW-05D.

6.2 Seismic Reflection Profiles

6.2.1 Seismic Reflection Acquisition

To evaluate the recording parameters needed to optimally image the target geologic horizons at the Charleston Naval Weapons Station SWMU-12, a test seismic reflection profile was recorded. Because target depths are shallow, 15-40 feet, adequate spatial sampling of the seismic wave field is critical. In addition, high frequency seismic wave energy must be generated and recorded to be able to resolve closely spaced reflectors.

The test line was recorded using a 24 channel recording system utilizing single 100 Hz geophones at two foot station spacing. The recording geometry was offend with a 1 or 2 foot near offset. Source points were positioned at one foot station spacing on the half station so that tests could be done to process the data as either one foot or half foot CMP spacing to evaluate spatial resolution requirements. The line was first recorded using an 8 lb. sledgehammer source, then partly re-recorded using a 4 lb. sledgehammer source. This later test was done because a smaller seismic source can generate higher frequency waves needed for high resolution. A trade-off exists, however, in that the energy generated by a smaller source attenuates more quickly in the subsurface resulting in limited depth imaging. The parameters used to record the test line are listed in the table below.

Table 5. Test seismic reflection profile recording parameters

Type of survey	P-wave seismic reflection
Station interval	2 feet
Source	8 lb. hammer, 4 lb. hammer
Source interval	1 foot on half stations
Record Length	300 milliseconds
Recording instrument	Geometrics Geode 24 bit A/D resolution
Number of channels	24
Instrument Gain	36 dB fixed
Sample interval	0.25 millisecond
Data format	SEG-2
Data redundancy	24 fold max, 12 fold nominal
Geophones	Geospace 100 Hz vertical one per station
Near offset	2 feet, 1 foot alternating
Far offset	48 feet, 47 feet alternating
Cable Geometry (m)	SP------2.0'(1.0')------48.0'(47.0')

6.2.2 Seismic Reflection Data Processing

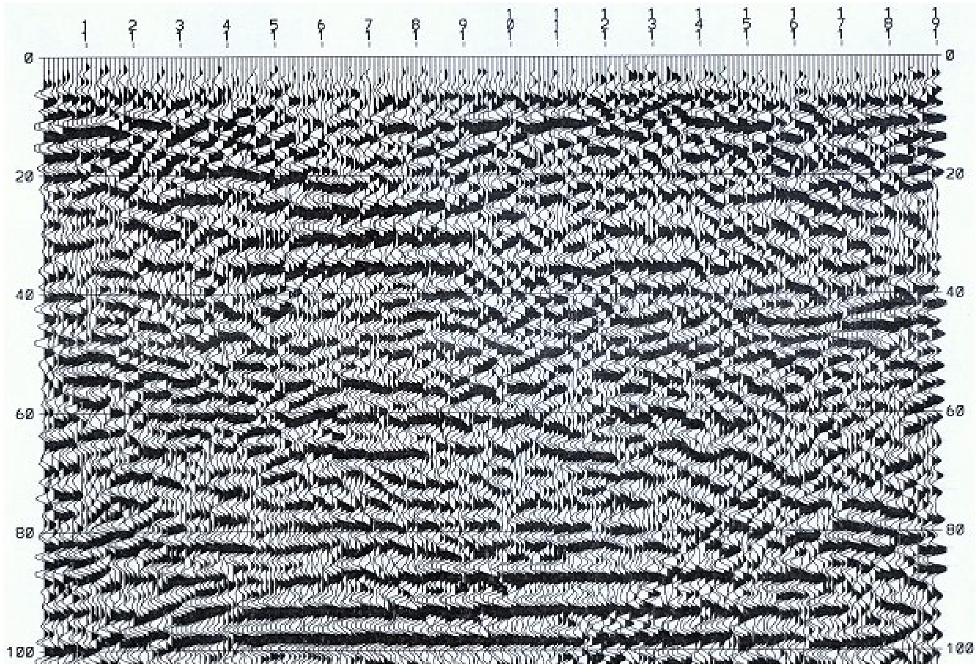
After completion of the field survey extensive detailed seismic data processing was performed at ESRI-USC's Environmental Geophysics Laboratory on the campus of the University of South Carolina. To process the data the Landmark Graphics Corp. state-of-the-art ProMAX software operational on a Sun Microsystems Ultra-60 workstation was used. The generalized flow used to process the data is shown in Figure 8. The finished test reflection profiles appear in Figure 9.

The results of the test profile indicated that quality seismic reflection data could be obtained from the target horizons. Ambient noise is not a problem, however, acoustic echoes were recorded off of buildings and infrastructure. Ground roll is a concern, but can be partly dealt with via two-dimensional filtering techniques. Furthermore, to adequately image the shallow reflectors of interest with sufficient subsurface redundancy for structural mapping and AVO analysis, source and receiver spacing of one foot are indicated. In addition, the smaller 4 lb. hammer yields higher frequency data without loss of imaging the horizons of interest.

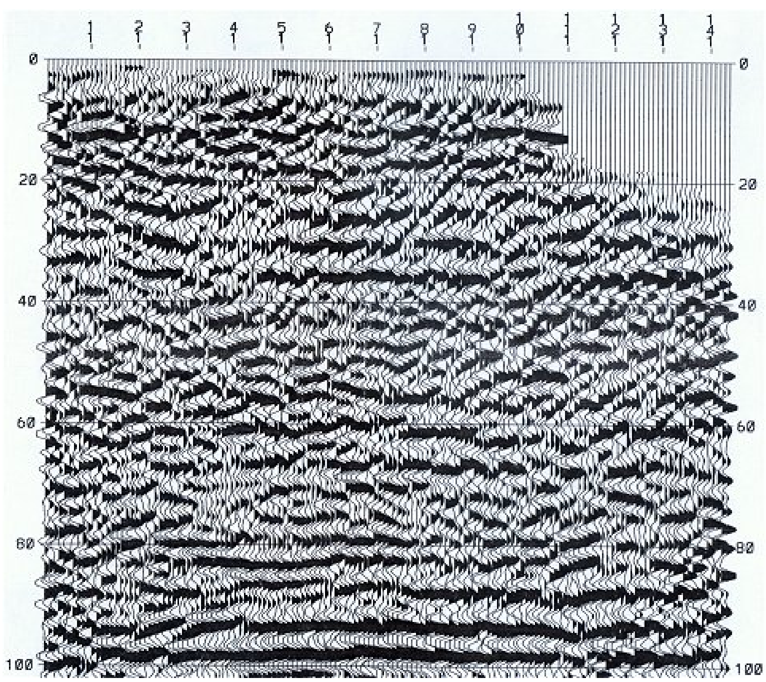
Seismic Data Processing Flow

Reformat field data – SEG-2 to SEG-Y
|
Trace edit/ First break mute
|
Geometry definition & assignment
|
Deconvolution – spiking
|
Spectral whitening
|
CMP sort
|
Velocity analysis (constant velocity stacks)
|
NMO – (NMO datum)/ Bandpass filter/Scaling
|
Stretch mute – 30 percent → CDP stack w/root n scaling for QC
|
Surface consistent residual statics
|
CDP stack w/root n scaling – adjustment to final datum
|
Spectral whitening
|
Trace mix – 3 pt.
|
Bandpass filter
|
Scaling
|
Display

Figure 8. Diagram showing the data processing sequence followed to produce the test seismic sections.



Test reflection profile 8 lb. hammer source



Test reflection profile 4 lb. hammer source

Figure 9. Test reflection profiles. Comparison between 8 lb. hammer (top) and 4 lb. hammer (bottom) seismic source. The reflections of interest occur earlier than 50 ms time. Note higher frequency content of 4 lb. hammer seismic source and better definition of shallow events.

7.0 Results and Discussion

At time of writing this report the data collected so far during Task 4 (site evaluation) have only had preliminary processing done on the VSP data and the test reflection profile and there has been no analysis of data. The only results are that the velocity data from the VSP appear to represent the subsurface and the experimental reflection profiles appear to have reflectors on it.

8.0 Conclusion

The next step is to analyze the velocity data from the VSPs and the experimental reflection profile. Once the project team feels comfortable that the velocity data are valid for the area, the team will proceed with AVO modeling to determine if the presence of DNAPL will alter the seismic amplitudes. If the modeling suggests that there is a change in seismic amplitude due to the presence of DNAPL at the Charleston Navy Weapons Station then the project team will proceed with Tasks 5 and 6.

9.0 References

This report contains no references.