US Army Corps of Engineers®

ATTACHMENT 1

PERFORMANCRE WORK STATEMENT AND WORK PLAN

FOR

INTEGRATED REFRACTION TOMOGRAPHY

PR-79, FOSTER RI

Prepared

by

Concord MA

Revised 4 May 16

TABLE OF CONTENTS

TABLE OF CONTENTS I

LIST OF FIGURES III

LIST OF TABLES III

LIST OF ACRONYMS IV

1.0 PROJECT SCOPE AND SCHEDULE 1
- 1.1 Scope 1
- 1.2 Schedule 1
- 1.3 Security 3
- 1.4 Contractor Conduct 3
- 1.5 Payment 3

2.0 PROJECT BACKGROUND 4
- 2.1 Regulatory Background 4
- 2.2 Site History and Contaminants 4
- 2.3 Site Geology and Hydrogeology 5
  - 2.3.1 Overburden Deposits 5
  - 2.3.2 Bedrock Geology 5
  - 2.3.3 Nature of the Weathered Rock 7
  - 2.3.4 Bedrock Structure 8
  - 2.3.5 Joint Systems 10
  - 2.3.6 Hydrogeology 10
  - 2.3.7 Previous Surveying, Surface Geophysics, and Borehole Geophysics Results 12

3.0 GENERAL REQUIREMENTS 17
- 3.1 Summary 17
- 3.2 Existing Conditions 17
- 3.3 Requests for Information 17
- 3.4 Submittals 17
- 3.5 Clean Up 17
- 3.6 Government Resources 17
- 3.7 Omissions 17
- 3.8 Environmental Protection 17
- 3.9 Quality Assurance 18
- 3.10 Damage to Government or Private Property 18
- 3.11 Other Contracts 18
- 3.12 Receiving and Storing Materials and Equipment 18

4.0 SEISMIC DATA REPROCESSING REQUIREMENTS AND OBJECTIVES 19
- 4.1 General Requirements 19
- 4.2 Goals and Objectives 19
- 4.3 Data Quality Objectives, Data Interpretation and Integration 19
- 4.4 Data Quality Objectives 20

5.0 ASSUMPTIONS 22

6.0 DEPTH AND ELEVATION CONTROL 23

7.0 PRE-LOGGING ACTIVITIES 23
7.1 Decontamination 23
7.2 Well Head Inspection 23
7.3 Nike 2 Data Logger 24

8.0 CALIBRATION, STANDARDIZATION, AND REPEAT SECTIONS 24
8.1 Calibration 24
8.2 Standardization or Functions Check 24
8.3 Repeat Sections 25

9.0 VERTICAL SEISMIC PROFILING (CHECK SHOT VARIANT) 25
9.1 Equipment 25
9.2 Setup/Operation 26
9.2.1 Placement of Shot Point 26
9.2.2 Reference (Surface/Land) Geophones 26
9.2.3 Downhole Geophone 27
9.2.4 Cabling 27
9.3 Recording 27
9.4 Processing/Development of check shot profile: 27
9.5 Processing Notes and Cautions 28

10.0 REFRACTION TOMOGRAPHY 28
10.1 Work Flow 28
10.2 SIPT2 Technique 28
10.3 Seismic Refraction Tomography Technique 29

11.0 INTEGRATION WORKFLOW 29

12.0 DELIVERABLES 30
12.1 General 30
12.3 Proposal 31
12.4 SSHP 31
12.5 Report 31
12.6 Figures 32
12.6.1 Maps 32
12.6.2 Panels 33
12.6.3 Profiles 33

13.0 ELECTRONIC DATA DELIVERABLES 33
13.1 VSP Data 34
13.2 Figures 34

14.0 REFERENCES 35

LIST OF FIGURES

Figure 1. Former PR-79 Control Site showing bedrock residential, Nike wells, and overburden piezometers. 2

Figure 2. Glacial deposits inferred from soil types. See Table 1 for detailed description of units underlying and near PR-79 (NRCS, 2013). 6

Figure 3. Migmatite outcrop located approximately 215 ft south of well NIKE 1 looking west (note wide north-south trending fracture). Likely represents bedrock surface conditions under the NIKE PR-79 Control Site. 7

Figure 4. Ponaganset Gneiss outcrop showing widely spaced near vertical fractures and single near horizontal fracture (AGC, 2015). 8

Figure 5. Outcrop-correlated fracture traces near the NIKE PR-79 Control Site (Army Geospatial Center, 2015). Interpreted width of each fracture trace is approximately 20 ft. Stereoplots are lower hemisphere equal area showing poles of fractures contoured according to Kamb (1959) with a significance level of 3σ and a contour interval of 3σ. Residential wells located down gradient of the study area along outcrop-correlated fracture traces have a high potential for being receptors. During the 2010 offsite residential well sampling event, TCE was detected at DW-39 (0.0001J mg/L (estimated concentration between reporting limit and detection limit) (USAIPH, 2010). 9

Figure 6. Spring-Summer 2013 water level monitoring (AMEC, 2014) (see Figure 5). Note that the bedrock and overburden groundwater systems likely merge during springtime. 11

Figure 7. Location and Seismic refraction tomography profiles showing profiles, shot points, and interpreted fence diagrams (Thompson and Miller, 2002). NOTE-well nomenclature changed (see Figure 2 and Table 2). 12

Figure 8. Seismic refraction profiles, piezometers, soil borings, and bedrock supply wells (all geophysically logged) with correct nomenclature (AMEC, 2014, Thompson and Miller, 2002). See Table 3 for Nike 2 wellhead details and Table 4 for piezometer and soil boring depth data. 14

LIST OF TABLES

Table 1. Inferred glacial geologic units underlying the study area (Natural Resources Conservation Service, 2013). See Figure 2 for a regional map and units. 6

Table 2. Current and former well names and survey data (AMEC, 2014, BSC Group, 2002). Data in red was used for positional control for geophysical profiles. Data in green is to be used for reprocessing positional data control. See Figure 8 for piezometer and profile locations, and corrected bedrock well names. 13

Table 3. Wellhead type, conditions, and geologic considerations for planning and executing VSP at Nike 2 (see Figure 8). 15

Table 4. Direct push piezometer and soil boring location and depth data. All data referenced to RI State Plane NAD83, NAVD88 (feet) (see Figure 8). 16

Table 5. Planning, data integration and interpretation charrette matrix and deliverables. 20

Table 6. The following are in addition to pre-mobilization equipment checkout procedures and manufacturer calibration checks, and instrument maintenance. See probe manufacturer instructions and

Darling (2005), Hearst, Nelson, and Paillet (2000), Daniels (1988), USACE (1995), Schlumberger (1987), Keys and MacCary (1971). 24

LIST OF ACRONYMS

EDDs	Electronic Data Deliverables
EM	Engineer Manual
ft	feet
ft bgs	feet below ground surface
IDW	Investigation Derived Waste
in	inch
LAS	Log ASCII Standard
ms	millisecond
SIPT	Seismic Inversion Processing Technique
SOP	Standard Operating Procedure
SSHP	Site Safety and Health Plan
SWWP	Statement of Performance and Technical Specifications
USACE	United States Army Corps of Engineers
USAIPH	United States Army Institute for Public Health
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	Underground Storage Tank
VSP	Vertical Seismic Profiling

1.0 PROJECT SCOPE AND SCHEDULE

1.1 Scope

This Integrated Refraction Tomography Statement of Work and Work Plan (SWWP) addresses planning, execution, quality assurance/quality control, processing, presenting, and reporting requirements for the PR-79 Former Control Site, Foster, Rhode Island environmental investigation under the Formerly Used Defense Sites Program (Figure 1). Vertical seismic profiling (VSP) shall be collected in Nike 2, and used in conjunction with new positional survey data, to reprocess existing refraction data using a modern, robust software package capable of using VSP data as model starting points. This SWWP augments equipment operation and maintenance instructions, and the hydrogeophysics' contractor standard operating procedures. The SWWP shall be the work plan for this project.

1.2 Schedule

The intent is to complete fieldwork within 30 days of APP/SSHP approval (see below). Final report and electronic data deliverables (EDDs) are due 30 July 2016. The contractor shall include a schedule with their site safety and health plan (SSHP)

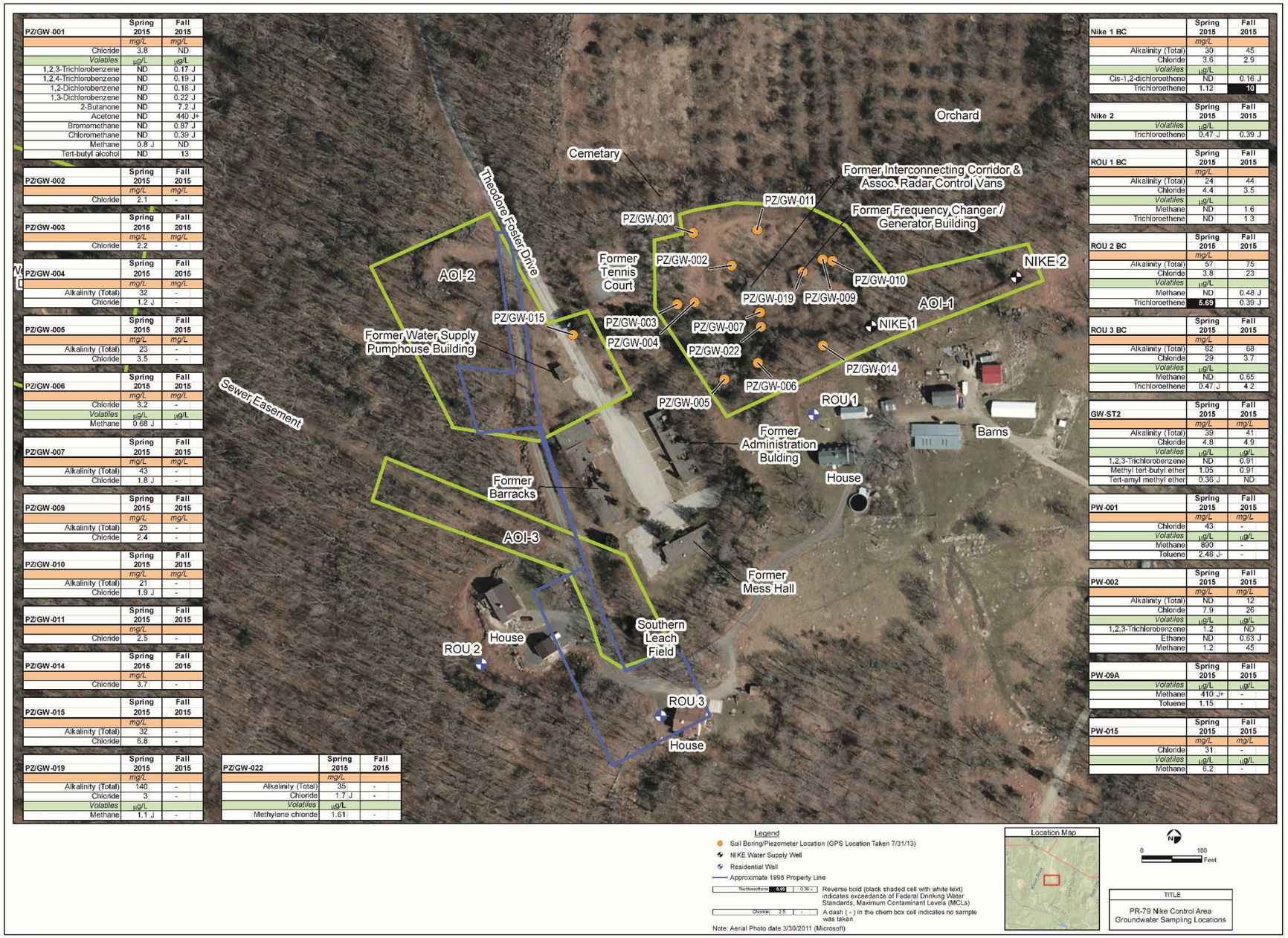
Approximate Days after Notice to Proceed	Task
7	Submit Draft SSHP and Standard Operating Procedures (SOPs) if needed (pre-approved SSHP provided to reduce preparation time)
14	Receive USACE Comments
21	Submit Final HASP, Charrette I Conference Call
28	Mobilize to Foster RI
30	Demobilize from Foster RI
51	Submit draft maps and profiles for USACE review, Charrette II Conference Call/Webinar
58	Receive USACE comments
72	Submit draft report with revised maps and profiles
79	Receive USACE comments
86	Submit final report with log plots and supporting deliverables

The SWWP does not address all of the safety and health requirements associated with the project, which must be addressed in the contractor's project-specific site safety and health plan (SSHP) (USACE, 2014). Two approved safety plans are provided as examples with the data files to minimize time spent preparing the SSHP. The contractor is encouraged to follow and use them in preparing their SSHP.

The SWWP addresses all aspects of a work plan, so the Contractor need not submit a work plan. Where SOPs are used for fieldwork or data processing, these must be submitted as shown in the schedule.

Bidders interested in submitting a proposal can request an electronic copy of project files from the Contracting Officer. These include:

- Approved site health and safety plans (Word and Adobe)
- Original refraction data, field notes, report
- Draft geophysical log plots of all bedrock wells



PZ/GW-001	Spring 2015	Fall 2015
	mg/L	mg/L
Chloride	3.8	ND
Volatiles	µg/L	µg/L
1,2,3-Trichlorobenzene	ND	0.17 J
1,2,4-Trichlorobenzene	ND	0.19 J
1,2-Dichlorobenzene	ND	0.18 J
1,3-Dichlorobenzene	ND	0.22 J
2-Butanone	ND	7.2 J
Acetone	ND	440 J+
Bromomethane	ND	0.87 J
Chloromethane	ND	0.39 J
Methane	0.8 J	ND
Tert-butyl alcohol	ND	13

PZ/GW-002	Spring 2015	Fall 2015
	mg/L	mg/L
Chloride	2.1	-

PZ/GW-003	Spring 2015	Fall 2015
	mg/L	mg/L
Chloride	2.2	-

PZ/GW-004	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	32	-
Chloride	1.2 J	-

PZ/GW-005	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	23	-
Chloride	3.5	-

PZ/GW-006	Spring 2015	Fall 2015
	mg/L	mg/L
Chloride	3.2	-
Volatiles	µg/L	µg/L
Methane	0.68 J	-

PZ/GW-007	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	43	-
Chloride	1.8 J	-

PZ/GW-009	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	25	-
Chloride	2.4	-

PZ/GW-010	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	21	-
Chloride	1.9 J	-

PZ/GW-011	Spring 2015	Fall 2015
	mg/L	
Chloride	2.5	-

PZ/GW-014	Spring 2015	Fall 2015
	mg/L	
Chloride	3.7	-

PZ/GW-015	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	32	-
Chloride	6.8	-

PZ/GW-019	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	140	-
Chloride	3	-
Volatiles	µg/L	
Methane	1.1 J	-

PZ/GW-022	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	35	-
Chloride	1.7 J	-
Volatiles	µg/L	
Methylene chloride	1.61	-

Nike 1 BC	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	30	45
Chloride	3.6	2.9
Volatiles	µg/L	
Cis-1,2-dichloroethene	ND	0.16 J
Trichloroethene	1.12	**10**

Nike 2	Spring 2015	Fall 2015
Volatiles	µg/L	
Trichloroethene	0.47 J	0.39 J

ROU 1 BC	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	24	44
Chloride	4.4	3.5
Volatiles	µg/L	
Methane	ND	1.6
Trichloroethene	ND	1.3

ROU 2 BC	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	57	75
Chloride	3.8	23
Volatiles	µg/L	
Methane	ND	0.48 J
Trichloroethene	**5.69**	0.39 J

ROU 3 BC	Spring 2015	Fall 2015
	mg/L	
Alkalinity (Total)	82	68
Chloride	29	3.7
Volatiles	µg/L	
Methane	ND	0.65
Trichloroethene	0.47 J	**4.2**

GW-ST2	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	39	41
Chloride	4.8	4.9
Volatiles	µg/L	µg/L
1,2,3-Trichlorobenzene	ND	0.91
Methyl tert-butyl ether	1.05	0.91
Tert-amyl methyl ether	0.36 J	ND

PW-001	Spring 2015	Fall 2015
	mg/L	mg/L
Chloride	43	-
Volatiles	µg/L	µg/L
Methane	890	-
Toluene	2.48 J-	-

PW-002	Spring 2015	Fall 2015
	mg/L	mg/L
Alkalinity (Total)	ND	12
Chloride	7.9	26
Volatiles	µg/L	µg/L
1,2,3-Trichlorobenzene	1.2	ND
Ethane	ND	0.63 J
Methane	1.2	45

PW-09A	Spring 2015	Fall 2015
Volatiles	µg/L	µg/L
Methane	410 J+	-
Toluene	1.15	-

PW-015	Spring 2015	Fall 2015
	mg/L	mg/L
Chloride	31	-
Volatiles	µg/L	µg/L
Methane	6.2	-

Figure 1. Former PR-79 Control Site showing bedrock residential, Nike wells, and overburden piezometers.

1.3 Security

The Site has no security restrictions. USACE has secured rights of entry to all abutting properties, access must be coordinated one week in advance.

1.4 Contractor Conduct

Alcohol and firearms are prohibited on project grounds. Contractor and employees must comply with CFR 36 Rules and Regulations.

1.5 Payment

After final inspection and acceptance by the Government, the Contractor must submit an invoice to the Technical Point of Contact. The invoice shall include the invoice date, contract number, dates of service, description of work, and total amount due per line item. For jobs greater than 30 days the contractor may request progress payment. Transmit all invoices to:

Casey.J.Haskell@usace.army.mil (preferred)

Or mailed to:
Casey Haskell
CENAE-EPG
696 Virginia Road
Concord MA 01742

Or faxed to 978-318-8614

2.0 PROJECT BACKGROUND

2.1 Regulatory Background

The United States Army Corps of Engineers (USACE) is conducting a Remedial Investigation/Feasibility Study (RI/FS), residential and supply well, surface water, and shallow groundwater monitoring program at the former PR-79 Nike Control Site in Foster, Rhode Island under the authority of the Defense Environmental Restoration Program for Formerly Used Defense Sites (FUDS) program (Figure 1). The RI is focusing on addressing low-level chlorinated solvent contamination related to former facility operations. The former PR-79 Control Site property currently contains the Foster School District administration building, and its bedrock water supply well, Nike 1. Former bedrock water supply well Nike 2 is disconnected from the water supply system, and is used only for monitoring. The activities documented in this SWWP are intended to be consistent with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act, Rhode Island state law, and USACE regulations and guidance (USACE, 2004a, 1995).

2.2 Site History and Contaminants

The United States Government, under the National Securities Act, obtained the land to build the NIKE missile battery on October 31, 1955. Development of a launch area, control area and line-of-site between the areas was then completed in 1957. In 1964, the Launch and Control Areas were declared excess by the General Services Administration and the former Control Area was given to the Foster School District on July 20, 1965 with the stipulation it be used for education facilities for at least 20 years. Based on information contained in the USACE and CDM documents (USACE, 2003 and CDM, 1994), the town of Foster operated the Fogarty Elementary School in the three main buildings at the Project (former Mess Hall, Barracks, and Administrative buildings) from approximately 1965 to 1987. According to the Site Survey Summary Sheet (USACE, 1992), the Fogarty Elementary School was closed in 1987 and the former Mess Hall and Administration buildings were leased to private companies after 1987. No information was found regarding the activities conducted by these private companies in the former Mess Hall and Administration buildings.

When the property was transferred to the town of Foster in 1965, the buildings were considered fully operational for beneficial reuse by the town. These buildings, and their associated underground storage tanks (USTs) and all associated UST appurtenances, are exempt from the FUDS program. USACE did remove the UST from the former Frequency Changer/Generator Building in June 1994 (USACE, 1993). The Town of Foster demolished the former Barracks, Administration building, and water supply pump house building around 2010. The Town of Foster-Glocester Regional School District, Northwest Special Education Region uses the former Mess Hall for administrative purposes (no classroom activities are conducted on Site). In 2012, the Town of Foster installed a new leach field south of the former Mess Hall building, and repaired/replaced a section of the water line leading from Nike 1 to the former Mess Hall.

NIKE missile sites were constructed throughout the United States during the mid-1950. The missile sites were constructed as defensive rings around major industrial and urban areas and generally consisted of a separate launcher and integrated fire control area (control area) usually located less than two-miles apart. The launcher area was where missiles and warheads were stored, maintained, and if necessary, launched. The control area was where all radar and communication equipment, needed to detect potential targets and guide launch missiles, was maintained and stored. Trichloroethylene (TCE), a volatile organic compound (VOC), was known to be used at both Nike Control and Launcher Areas as a cleaning and

degreasing agent. Based on where TCE may have been used or disposed, the site is divided into five Areas of Interest (AOIs) (Figure 1):

AOI-1. Radar Area
AOI-2. Operations and Maintenance Area
AOI-3. Southern Leach Field
AOI-4. Western Sewage Disposal Area
AOI-5. Western Disposal Area

Surface and subsurface soil sampling has shown no heavy metals above state or federal risk levels, and non-detect to trace VOCs levels (AMEC, 2014). Only bedrock groundwater contains VOCs (Figure 1).

2.3 Site Geology and Hydrogeology

2.3.1 Overburden Deposits

Manmade fill and glacial deposits underlie the study are summarized in Table 1 and Figure 2. Outwash Deposits are present west of the site as terraces bordering streambeds filled with sub-rounded to angular boulders with trace fractions smaller than cobbles. Deposits at the northern end of the Roukous Farm suggest the lowermost deposit is a boulder-rich layer overlying the bedrock. High-resolution LiDAR data suggest some of the unit boundaries west of the Site differ from those shown at the state scale (Sky Research, 2008).

Boring data indicate the PR-79 area is underlain by 0 to 24+ ft of glacial till deposits (AMEC, 2014, Hansen, 1962). South of Winsor Road and Danielson Turnpike, these deposits thicken to 50-100 ft. Soil boring and piezometer re-development data suggest the Lodgement Till underlying the Site is a low hydraulic conductivity unit deposited on a boulder-rich layer overlying the bedrock pavement surface (AMEC, 2014).

2.3.2 Bedrock Geology

Oak Hill is underlain by the South Foster Migmatite (Migmatite) and the intruding Ponaganset Quartz Diorite Gneiss (Ponaganset Gneiss) (Acker, 1950, Frost, 1950). The contact between the two is between Nike 1 and ROU 2, spanning a wide spectrum of partial melt textures with similar compositions.

The Migmatite is a heterogeneous, composite quartz-biotite schist and quartzite unit developed by intrusion from the younger Ponaganset Quartz Diorite Gneiss (Acker, 1950). The schistose member is often intruded along foliation planes with dikes of various composition up to 1.5-ft thick and veins. One exception is the Roukous farm outcrop, where the schist member of the Migmatite is well preserved. Where massive, the quartzite member retains relict bedding and has far fewer intrusions. Frost (1950) described mafic and leucocratic end members based on outcrops along the Danielson Turnpike, driven mostly by potassium feldspar and mafic minerals as seen in thin section.

Table 1. Inferred glacial geologic units underlying the study area (Natural Resources Conservation Service, 2013). See Figure 2 for a regional map and units.

Unit	Extent	Description
Outwash Deposits	West and south of the site, within the Winsor Brook valley. None mapped east of or within the site.	Stratified deposits of sand and gravel deposited by glacial melt-water streams (includes fluviodeltaic deposits).
Ablation Till	Follows LiDAR-measured break in slope on Oak Hill slopes	Unsorted, non-stratified material deposited by glacial ice and consisting of a heterogeneous mixture of clay to boulder size particles. Ablation till is very variable, but tends to be loose and dominantly sandy and may have lenses of firm loamy material.
Lodgement Till (mixed lithology)	Overlies the Oak Hill ridge	Unsorted, non-stratified material deposited by glacial ice and consisting of a heterogeneous mixture of clay to boulder size particles. Lodgement till is usually found on drumlins and till ridges. Lodgement till tends to have a higher percentage of silt and clay than ablation till and is usually very dense.
Ablation Till over Bedrock	Occurs east and south of the site, terminating at US 6.	The soils formed in ablation till (described above) and have ledge or bedrock typically within 6 feet of the surface (mapped in a complex of shallow, moderately deep, and very deep soils).
Human Transported Material	Soils underlying the former Control site and its satellite wastewater treatment and discharge site.	Commonly referred to as fill, human-altered/transported material includes a variety of soil and geologic material deposited by human activity

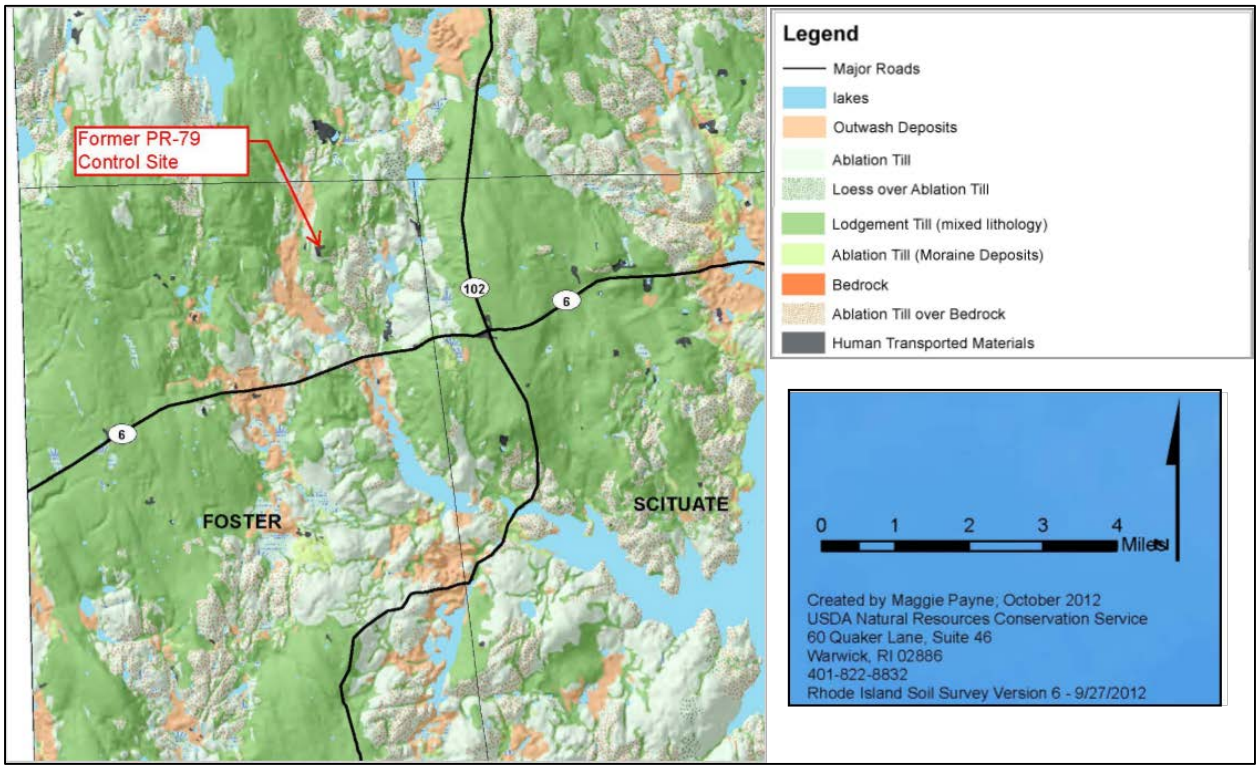


Figure 2. Glacial deposits inferred from soil types. See Table 1 for detailed description of units underlying and near PR-79 (NRCS, 2013).

The Ponaganset Gneiss is a coarse grained, porphyritic, pink to gray, massive to lineated quartz diorite gneiss dominating the western portion of the Clayville Quadrangle. Its average grain size is between 2 and 5 millimeters in diameter with porphyroblasts of plagioclase ranging up to 12 millimeters in length and rectangular Carlsbad-twinned potash feldspar porphyroblasts up to an inch in length. Discontinuous amphibolite zones are present in the western part of the quadrangle, but have not been mapped near the PR-79 Site (Collins, 1997, Quinn, 1971, Nichols, 1961, Frost, 1950). Strong lineation defined by elongate aggregates of quartz and feldspar and trains of biotite and hornblende.

2.3.3 Nature of the Weathered Rock

None of the outcrops in and near the Site show obvious chemical weathering, suggesting glaciation removed this material. Outcrop data indicate the weathered bedrock is characterized by steeply dipping fractures and occasional fracture zones widened by physical weathering processes (freeze-thaw), spaced 4 to 10+ feet apart. Where shallow exposures are present, such as the Roukous farm, these fractures are filled with sediment (Figure 3).

Figure 3. Migmatite outcrop located approximately 215 ft south of well NIKE 1 looking west (note wide north-south trending fracture). Likely represents bedrock surface conditions under the NIKE PR-79 Control Site.

2.3.4 Bedrock Structure

Lineations are present throughout the Clayville Quadrangle (Acker, 1950, Frost, 1950). The northern half of the quadrangle contains lineations plunging up to 10° northern, whereas lineations in the southern half of the quadrangle plunge 10-25° north. Schistosity dip direction is northwest, with anomalous dip directions and steep to vertical dips occurring mostly within the Migmatite. Ponaganset Quartz Diorite Gneiss foliation dip direction is often west.

A regional aeromagnetic survey conducted in 1968 shows a series of narrow, north-south trending anomalies spanning 160-180 nanoteslas, similar to the lineament trend at the site (AGC, 2015, USGS, 1971) (Figure 5). Additional data collection, processing, and regional integration showed similar regional trends following the stream valleys east and west sides of Oak Hill, and correlation with airborne and satellite-mapped features (Frohlich and Fisher, 1985). The 0.5-1.0 miles wide (peak to peak), north-south trending magnetic low features at and west of the Site may be fault or fracture zones within the relatively homogeneous Ponaganset Quartz Diorite Gneiss.

Figure 4. Ponaganset Gneiss outcrop showing widely spaced near vertical fractures and single near horizontal fracture (AGC, 2015).

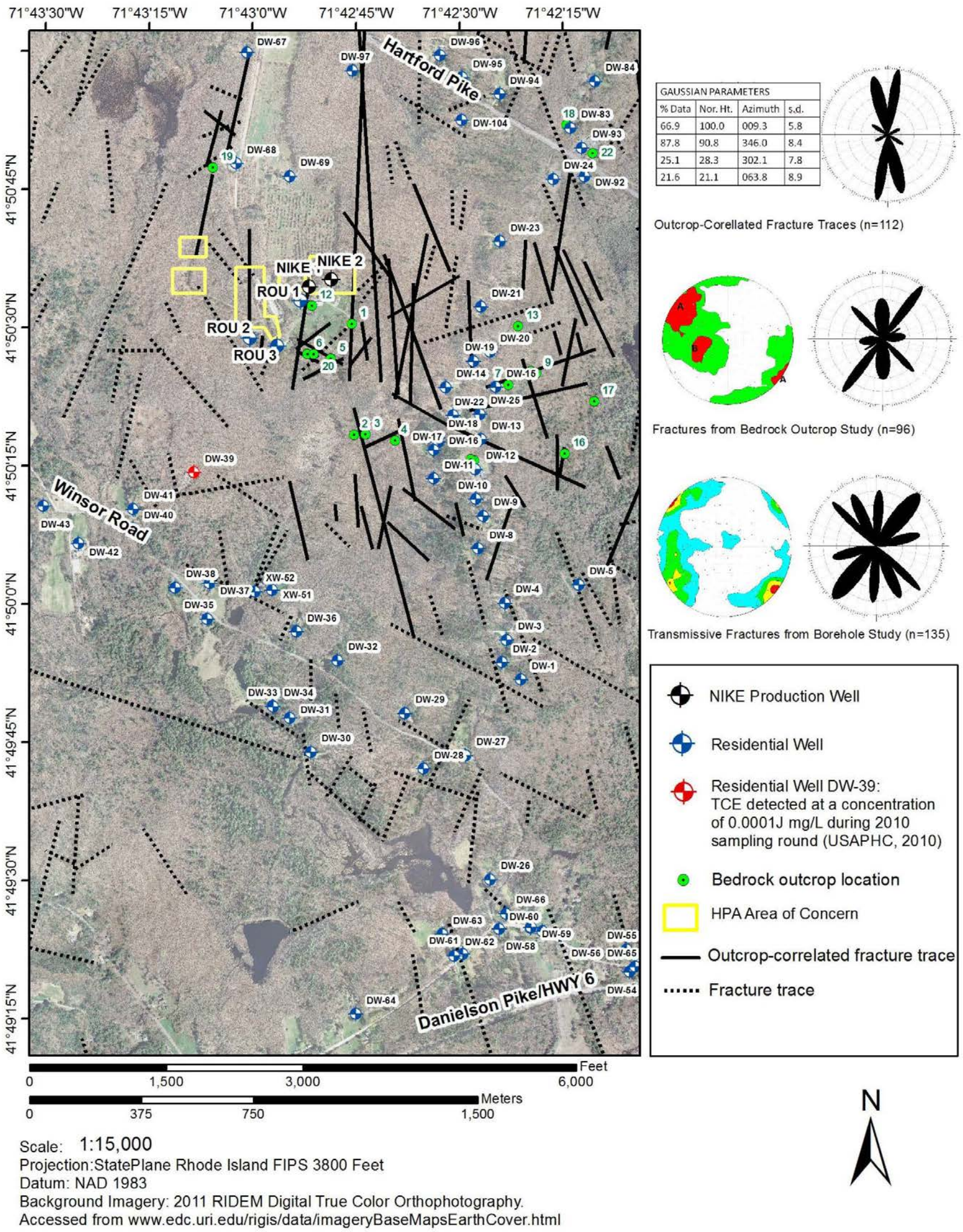


Figure 5. Outcrop-correlated fracture traces near the NIKE PR-79 Control Site (Army Geospatial Center, 2015). Interpreted width of each fracture trace is approximately 20 ft. Stereoplots are lower hemisphere equal area showing poles of fractures contoured according to Kamb (1959) with a significance level of 3σ and a contour interval of 3σ. Residential wells located down gradient of the study area along outcrop-correlated fracture traces have a high potential for being receptors. During the 2010 offsite residential well sampling event, TCE was detected at DW-39 (0.0001J mg/L (estimated concentration between reporting limit and detection limit) (USAIPH, 2010).

2.3.5 Joint Systems

Integrated remote sensing, outcrop, and borehole results show regional fractures trend from northwest (NW) to northeast (NE) (Figure 3). The majority of fractures (59% in outcrop study and 73% in borehole study) were steeply dipping (≥60°), whereas relatively few (3% in outcrop study and 3% in borehole study) were shallowly dipping (≤20°). The Ponaganset Gneiss contains more discrete fracture zones and fractures than the less brittle Migmatite (Figure 3, 4, and 5). Fractures within the Oak Hill area underlying PR-79 show a strong north-south trend.

2.3.6 Hydrogeology

Water level monitoring data in 2013 and 2015 suggest the overburden piezometers are saturated in late winter through late spring. Though the screened intervals have relatively low hydraulic conductivity (0.124 ft/day) and transmissivity (0.679 ft^2/day), they quickly respond to seasonal falling water levels (>0.5 ft per day in May 2015). Overburden groundwater level fell below all piezometers by mid-September 2015. Due to the lack of well screens completed to the bottom of the borehole, it is not known if the overburden groundwater is perched or disappears during late summer/early fall. These data suggest that the overburden was at least partially saturated when the original seismic data was collected.

During springtime, the bedrock groundwater levels at Nike 1/Nike 2/ROU 1 intersect the overburden groundwater (Figure 6). The May-July 2013 water levels in ROU 2 and ROU 3 were 47-65 ft below ground surface, suggesting water levels at the distal western end of the site had little effect on bedrock velocity measurements. Water levels Nike 1 and Nike 2 were likely high enough to affect overburden acoustic velocity.

From at least 2000 to April 2012, a water line leak at the Site caused Nike 1 to over-pump, drawing down the water levels in ROU 1 several times a day. This and the 2013 water level monitoring data indicate one or more bedrock fractures connect ROU 1 and Nike 1, likely along one of the fracture trace trends shown in Figure 5.

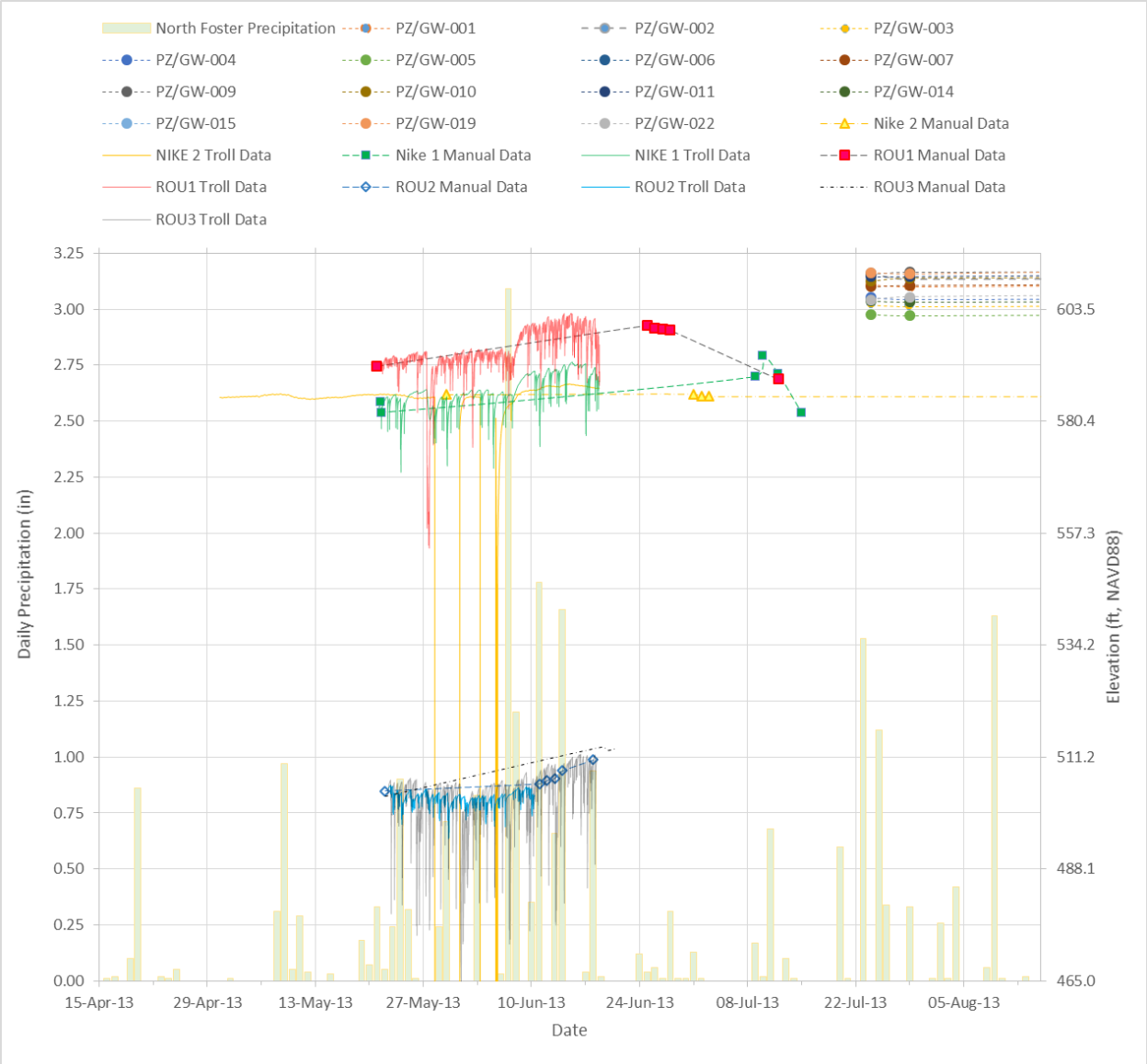


Figure 6. Spring-Summer 2013 water level monitoring (AMEC, 2014) (see Figure 5). Note that the bedrock and overburden groundwater systems likely merge during springtime.

2.3.7 Previous Surveying, Surface Geophysics, and Borehole Geophysics Results

The bedrock topography underlying the site is a key control on shallow groundwater flow, and a major goal for this project. The bedrock surface and possible fracture zones were investigated using the refraction tomography method in 2002 (Thompson and Miller, 2002). The data were processed and modeled using SeisOpt2D, the only available program for this method at the time of the investigation. The data models showed a broad bedrock low trending northeast-southwest, but character within the bedrock could not be resolved. Sometime after completing the refraction tomography work, USACE renamed the wells (Figure 7, Table 2).

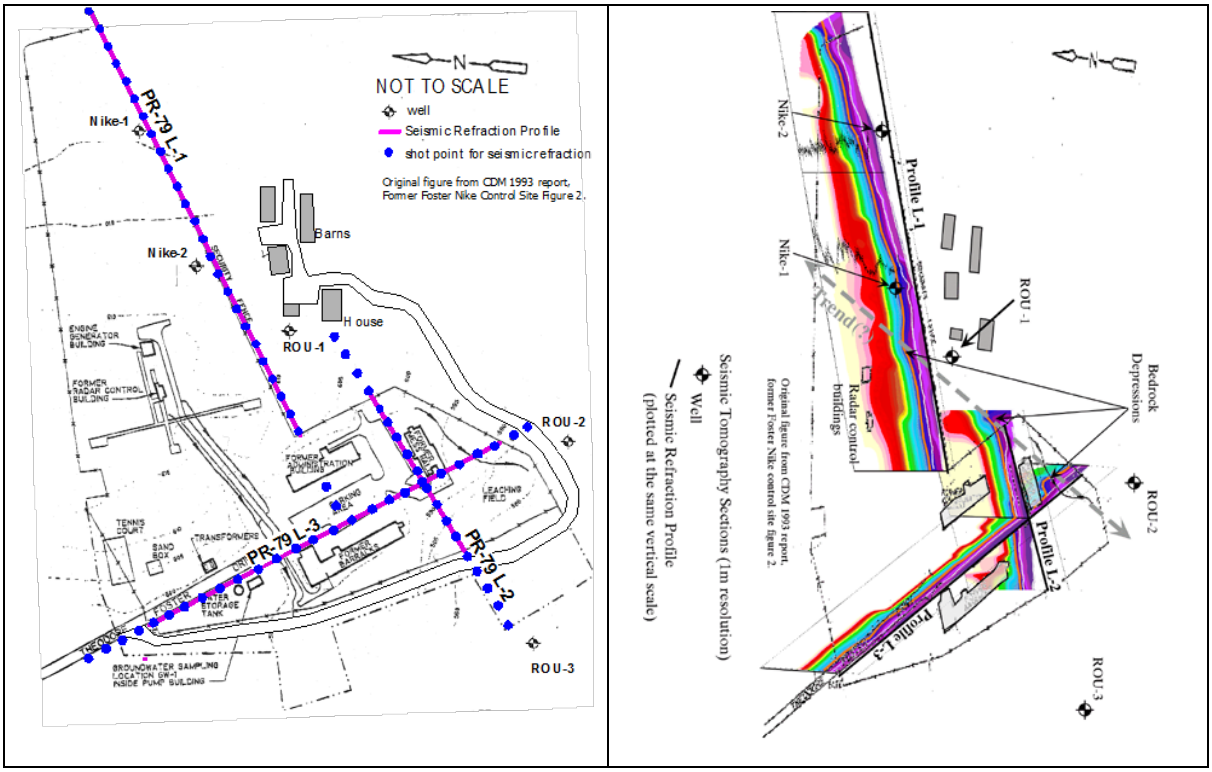


Figure 7. Location and Seismic refraction tomography profiles showing profiles, shot points, and interpreted fence diagrams (Thompson and Miller, 2002). NOTE-well nomenclature changed (see Figure 2 and Table 2).

USACE rehabilitated and redeveloped Nike 2 (formerly named Nike 1) in 2013, removing all obstructions within the well (AMEC, 2014). The top half of the vault was removed, water supply lines capped, casing added, and the area re-graded. A follow-on well survey showed the previous work completed in 2001 had not measured vault top elevations, adding a 3-5 foot vertical error to Nike 1, Nike 2, and ROU-1 well elevations and geophysical profiles tied to these features (Figure 7, Table 2).

A complete suite of borehole geophysics tools was run on all five bedrock wells, including fluid, flow, electric, natural gamma, televiewers, and full waveform sonic logs. Televiewer results showed a fracture frequency and aperture width similar to that shown in Figure 3. Full waveform sonic log Vp suggest the Ponaganset Gneiss may be ~1.3 times faster than the Migmatite.

Table 2. Current and former well names and survey data (AMEC, 2014, BSC Group, 2002). Data in red was used for positional control for geophysical profiles. Data in green is to be used for reprocessing positional data control. See Figure 8 for piezometer and profile locations, and corrected bedrock well names.

Current Name	Nike 1	Nike 2	ROU 1	ROU 2	ROU 3
Names before 2011	Nike 2	Nike 1	ROU-1 Roukous Well	ROU-3 South Well Antonelli Well	ROU-2 West Well Designore Well
Owner	Foster School District	Foster School District	Joe and Fran Roukous	Antonelli Family	Designore Family
Right of Entry Status	Secured	Secured	Secured	Secured	Secured
Schedule Constraints	Pump Must Be Removed	None	Pump Must Be Removed	Pump Must Be Removed	Pump Must Be Removed
Drilling Technique	Unknown	Unknown	Unknown	Air Rotary	Air Rotary
Total Well Depth (ft bgs)	561.9	292.07	378.4	538	659.1
Casing Length (ft bgs)	18	30	18	23	30
Casing Diameter (in)	6	6	6	6	6
Open Hole Diameter (in)	6.1	6.5-9	6.1	6	6
Screened/Open Hole Interval (ft bgs)	543.9	262.07	360.4	515	629.1
Deviation (degrees)	150/1.7	82/1.9	10/1.1	199/4.5	105/3
Depth Reference	Manway Ring, North Side	Casing Top, North Side	Manway Ring, North Side	Casing Top, North Side	Casing Top, North Side
2013 Northing, Easting (RI State Plane, NAD83, ft)	276849.47 269680.51	276931.18 269922.45	276702.28 269586.11	276287.28 269032.68	276200.27 269330.86
2013 Depth Reference Elevation (NAVD88, ft)	612.18 (casing elev. is 606.97)	601.87	607.39	561.04	576.68
2013 Land Elevation	612.18	599.58	611.06	558.41	574.87
Depth Reference	Manway Ring, North Side	Manway Ring, North Side	Manway Ring, North Side	Casing Top, North Side	Casing Top, North Side
2002 Northing, Easting (RI State Plane, NAD83, ft)	276849.8506 269681.4946	276931.6217 269922.9340	276702.3534 269585.6144	276200.5635 269300.8438	276287.5703 269031.9502
2002 Depth Reference Elevation (NAVD88, ft)	606.73	595.65	607.09	576.44	560.70
2002 Land Elevation (NAVD88, ft)	606.73	595.65	607.09	574.64	558.3

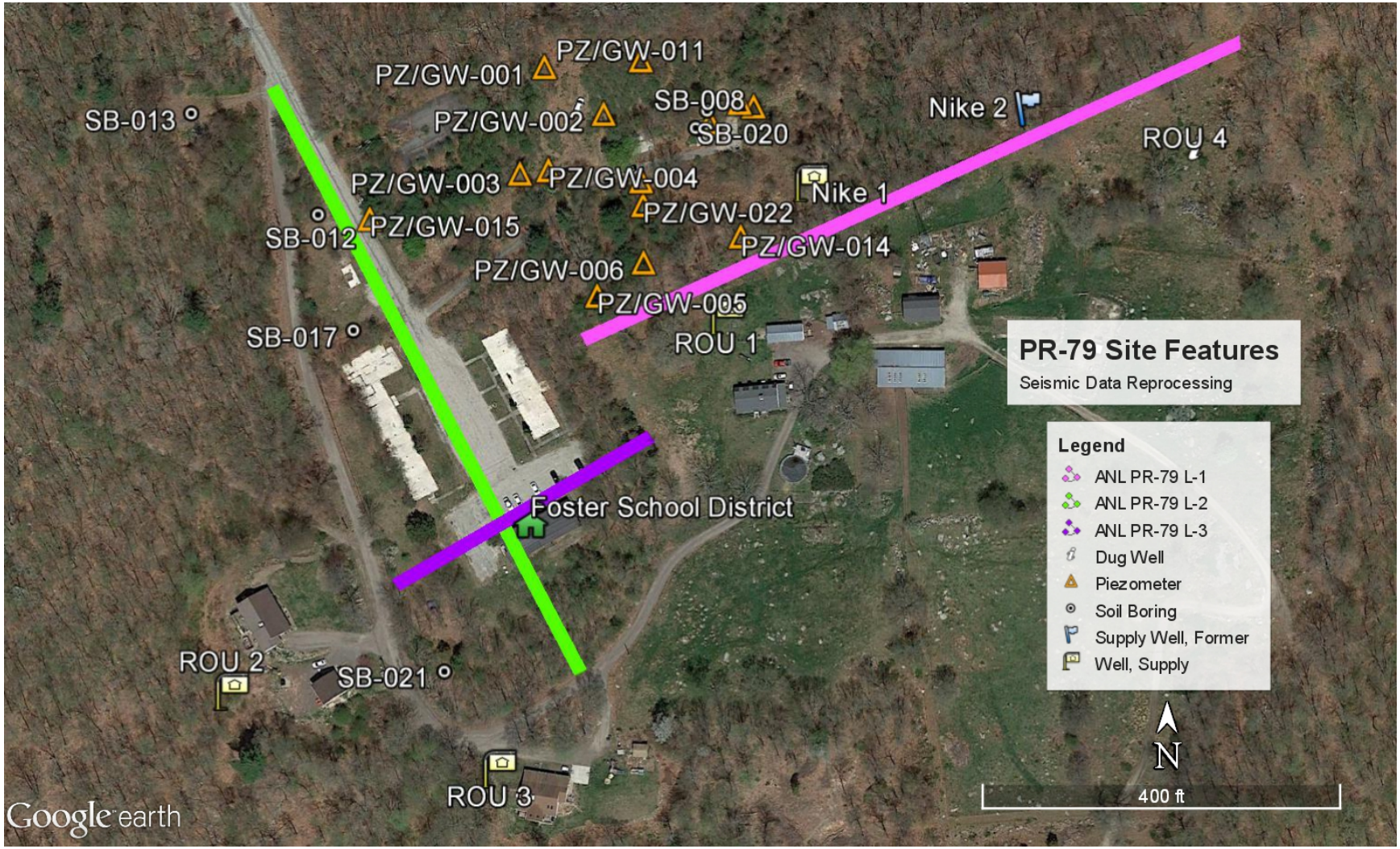


Figure 8. Seismic refraction profiles, piezometers, soil borings, and bedrock supply wells (all geophysically logged) with correct nomenclature (AMEC, 2014, Thompson and Miller, 2002). See Table 3 for Nike 2 wellhead details and Table 4 for piezometer and soil boring depth data.

Table 3. Wellhead type, conditions, and geologic considerations for planning and executing VSP at Nike 2 (see Figure 8).

Well Name	Wellhead Photo	Notes
Nike 2-Before		Nike 2 well vault before demolition
Nike 2-After		Nike 2 wellhead after vault demolition, adding casing (6-in diameter), and redevelopment. Vault floor is still in place. Well cap is not locked. Note blue transducer cable.

Table 4. Direct push piezometer and soil boring location and depth data. All data referenced to RI State Plane NAD83, NAVD88 (feet) (see Figure 8).

Name	Easting (feet)	Northing(feet)	Casing Elevation	Ground Elevation	Refusal Depth* (ft bgs)
PZ/GW-001	269383.64	277000.26	623.12	620.43	16
PZ/GW-002	269449.65	276948.19	622.85	620.11	14
PZ/GW-003	269356.1	276882.16	618.39	615.32	15
PZ/GW-004	269387.88	276885.88	621.48	619.11	19
PZ/GW-005	269441.85	276746.51	615.18	612.88	12
PZ/GW-006	269493.7	276783.23	620.3	617.25	12.5
PZ/GW-007	269491.18	276873.37	620.55	618.12	19.5
PZ/GW-009	269601.31	276960.12	619.89	617.59	13.5
PZ/GW-010	269616.89	276955.94	620.04	617.56	14
PZ/GW-011	269491.23	277007.47	622.55	619.94	24.5
PZ/GW-014	269602.11	276811.88	617.39	614.24	13
PZ/GW-015	269188.44	276832.46	Not Applicable	600.39	8.5
PZ/GW-019	269567.97	276938.45	621.94	618.4	20
PZ/GW-022	269493.35	276846.98	619.92	617.18	17.5
ROU 4	270109.5374	276909.1173	Not Applicable	Not Applicable	11
SB-008	269565.7566	276952.3168	Not Applicable	Not Applicable	8
SB-012	269131.6134	276838.1262	Not Applicable	Not Applicable	12
SB-013	268990.5036	276950.735	Not Applicable	Not Applicable	8
SB-017	269170.7182	276709.731	Not Applicable	Not Applicable	4.5
SB-020	269552.9185	276933.1707	Not Applicable	Not Applicable	20
SB-021	269271.2245	276331.1592	Not Applicable	Not Applicable	12.5
SB-023	268326.1611	276974.658	Not Applicable	Not Applicable	15.5
SB-026	268288.4258	276835.2458	Not Applicable	Not Applicable	24.85

3.0 GENERAL REQUIREMENTS

3.1 Summary

Furnish all materials, equipment, and labor to complete field and office portions of this Integrated Refraction Tomography SWWP:

- SSHP/AHA
- Nike 2 VSP data collection
- Reprocess existing seismic refraction data
- Submit draft and final report, and EDDs

3.2 Existing Conditions

Presented in previous sections.

3.3 Requests for Information

Direct all requests concerning this project to the Technical Point of Contact, Casey Haskell, at 978-318-8398 or Casey.J.Haskell@usace.army.mil.

3.4 Submittals

See Section 12 and 13.

3.5 Clean Up

The Contractor shall practice good housekeeping to maintain a safe job site. The contractor shall keep the work area, including any storage areas, free from the accumulation of waste materials. Upon completing work, the contractor shall remove any tools, equipment, and materials that are not the property of the government. Upon completion of work, the Contractor shall clean up the job site to the satisfaction of the Government. The work site shall be left in the same condition as prior to the start of work to the satisfaction of the technical point of contact.

3.6 Government Resources

The contractor is responsible for providing all materials to complete the project unless otherwise specified in this SWWP and contract.

3.7 Omissions

This contract and SWWP may not cover all specified activities, steps, and procedures required to supply the contract product. In case of omission, the normal industry, state, or federal standards, software requirements, practices, specifications, and/or guides shall prevail. In no instance shall an omission be reason to produce less than an acceptable product.

3.8 Environmental Protection

The contractor shall prevent pollution or damage to the environment resulting from construction during this contract. The contractor will receive no additional payment for environmental protection work. Prevention of pollution and environmental damage is a contractor obligation under current State and

federal Laws and regulations. Assurance of compliance with this section by subcontractors shall be the responsibility of the contractor.

3.9 Quality Assurance

The contractor is responsible for the quality control of the contract work as discussed in the following sections. The government has the right to inspect and test all items called for by the contract, to the extent practicable at all times and at all places during the term of the contract.

3.10 Damage to Government or Private Property

The Contractor shall be responsible for restoring any Government facilities or structures damaged as a result of the firm's operation. The Contractor shall also be responsible for any damage to private property or injury to any person resulting from the firm's operations. The Contractor shall notify the Technical Point of Contact immediately of damage to Government and private property and injury to any person (including employees) resulting from the firms' operation.

3.11 Other Contracts

The Government may undertake or award other contracts for additional work not related to this contract, and the Contractor shall fully cooperate with other Contractors and Government employees. The contractor shall not commit or permit any act, which will interfere with the performance of work by another contractor, or by Government employees.

3.12 Receiving and Storing Materials and Equipment

The contractor is responsible for protecting any stored materials and equipment used for this SWWP. The contractor is responsible for receiving and unloading of delivered goods. Government employees will not receive material or supplies for the contractor and will not be responsible for damage to contractor equipment or material.

4.0 SEISMIC DATA REPROCESSING REQUIREMENTS AND OBJECTIVES

4.1 General Requirements

The contractor shall use the latest versions of all data acquisition, processing, and presentation software used to execute this SWWP to maximize software interoperability. This includes, but is not limited to, log preparation software (e.g., WellCAD, LogPlot), report preparation software (Adobe Professional, Microsoft Office), map preparation software (e.g., ArcGIS/RockWorks/Surfer), and/or any supporting data collection, processing, and interpretation software (e.g., Rayfract, Geotomo/GeoCT, Seismic Pro).

All work shall be done in accordance with the approved site Health and Safety Plans, USACE safety guidance (USACE, 2014), and USACE technical guidance (USACE, 2002, 2001, 1995) except where discussed below. This SWWP and the health and safety plan shall be printed and kept with the geophysical logging team's field documents at all times.

Most of the references used in this SWWP are available at no charge via the Internet, or through the common geophysical societies. The hydrogeophysics team must be familiar with and use the references used in this SWWP.

4.2 Goals and Objectives

The goal of this program is to reprocess existing seismic refraction data using modern software incorporating a priori constraints from downhole seismic data collected in Nike 2. The results will be used to modify top of rock surface maps and identify fracture zone drilling targets (where resolvable), as well as support completing the Remedial Investigation, Feasibility Study, Remedy, and Long Term Monitoring project phases. The Integrated Refraction Tomography program's objectives are:

- Identify vertical extent and lateral changes in lodgment till and outwash deposits
- Define and identify top of weathered bedrock surface
- Define and estimate the top of unweathered bedrock
- Identify location, and horizontal extent of bedrock fracture zones or bedrock depressions where they intersect the seismic profiles

4.3 Data Quality Objectives, Data Interpretation and Integration

Optimize schedule and price by conducting one planning and one draft deliverable charrette (Table 5). A charrette is an intensive planning session where the project team collaborates on project planning, execution, and deliverables. It provides a forum for ideas and offers the unique advantage of giving immediate feedback to all. More importantly, it allows everyone who participates to be a mutual author of the plan and report deliverables.

At a minimum, the contractor's lead geophysicist (field and office) and USACE shall attend the meetings (conference call or webinar unless decided otherwise). These meetings shall be executed in a setting free of office and phone distractions, and convenient to the participants. Where this SWWP cannot be executed due to site conditions and other constraints, these conflicts shall be resolved and alternatives approved by USACE during the planning and initial data collection stages, not during report review.

Table 5. Planning, data integration and interpretation charrette matrix and deliverables.

Charette	Project Drivers	Site Constraints	Site Data Needs	Subsurface Data Trends	Formatting	Deliverables
I –Data Quality Objectives Logistics, Schedule (conference call)	• Goals and Project Objectives understood • DQOs understood • Means and methods agreed upon (tool selection, software)	• Wellhead access • Alternate water supplies • Weekend & weekday operations • Investigation derived waste	• LiDAR map and profiles, • Borehole geophysics • Nike 2 well rehabilitation report • Integrated fracture trace report • Existing HASP	• USACE Top of Rock trend results • USACE Structural Analysis (fractures, folds and faults)	• Plot Layout • Electronic Data Structure	• Project Objective and DQO lists • Standardized log plot formats & track layouts, legends • SWWP Modifications • Schedule update • Bulletized meeting notes
II – Data Interpretation and Trends (email or conference call)	Project Objectives	• Topographic • Modeling • Noise Conditions	Does the contractor require any additional information to complete their tasks?	Cross Section and Map views of surfaces identified in the project objectives	• SWWP items shown on draft plots, cross sections, and figures	• Draft Borehole Plots • Draft Cross Sections • Bulletized Meeting Notes with above graphics

4.4 Data Quality Objectives

The Contractor shall follow and meet the data quality objectives discussed below (United States Environmental Protection Agency, 2006, Theys, 1999). In some cases, the data quality objective will need modification based on field results. In many cases, measurement device specifications and use define these objectives. Where data quality objectives are modified based on field results, the data and evaluation leading to the change shall be fully documented in the report. The Contractor is encouraged to generate and meet additional data quality objectives where they support the project goals and objectives.

A. State the Problem/Identify the Decision

- Depth Precision and Accuracy (e.g., depth of weathered rock top).
- Shots Needed per Interval to Locate Depth of Geologic Boundary.
- Surface Geophone Operation (e.g., vault floor and walls interfere with data collection).
- Data Processing Anomaly Resolution. What process or workflow will be used to verify an anomaly is a fracture zone instead of a data processing artifact?
- Velocity Ranges for Units of Interest. What is the boundary between hard rock, weathered rock, boulder-rich till, and boulder-poor till?
- Seismic Profile Intersection Mismatch. Is it the result of a modeling assumption, positional data error, or other factor?

C. Identify Decision Inputs

- Depth Precision and Accuracy (e.g., depth of weathered rock top). Measured accuracy of depth marks on downhole seismic cable.
- Shots Needed per Interval to Locate Depth of Geologic Boundary. Noise test results.
- Surface Geophone Operation (e.g., vault floor and walls interfere with data collection). Shot records collected after noise test.
- Data Processing Anomaly Resolution. Location of identified lineaments, bedrock structural fabric, existing top of rock trends.
- Velocity Ranges for Units of Interest. Roukous Farm outcrop noise test, Nike 2 VSP data, geophysical well logs, and site data.
- Seismic Profile Intersection Mismatch. What is the vertical difference between the two interpreted surfaces or range of velocities? What were the model input values for each profile? Other factors driving mismatch (e.g., steep topography, software limitations)?

D. Identify the Study Boundaries.

- Depth Precision and Accuracy. Upper 200 feet of the borehole.
- Number of Shots Needed per Interval. Upper 200 feet of the borehole.
- Surface Geophone Operation (e.g., vault floor and walls interfere with data collection). Upper 200 feet of the borehole.
- Data Processing Anomaly Resolution. Location of identified lineaments, bedrock structural fabric, existing top of rock trends, and the model edges.
- Velocity Ranges for Units of Interest. Lateral limits of each profile and bounding bedrock well data sets.
- Seismic Profile Intersection Mismatch. Lateral and lowermost data model boundaries. Internal boundaries may occur within overburden units (where resolvable).

E. Develop Decision Rule/Limits of Decision Errors

- Depth Precision and Accuracy. 0.1 foot (may change depending on borehole deviation correction).
- Number of Shots Needed per Interval. If more than 5 shots are consistently needed per interval, then site acoustic conditions will be evaluated (e.g., wind forecast) and an alternate date for data collection established as long as price does not exceed $25,000.
- Surface Geophone Operation (e.g., vault floor and walls interfere with data collection). Change surface geophone spacing.
- Data Processing Anomaly Resolution. Anomalies potentially representing fracture zones must be twice as large as the horizontal data resolution to be a viable drilling target.
- Velocity Ranges for Units of Interest. If the VSP and outcrop noise test results show the hard rock boundary cannot be resolved, the boundary is not shown on the profiles but discussed in the report. Vertical resolution limits may also be imposed by the data modeling software.
- Seismic Profile Intersection Mismatch. Where land or bedrock topographic changes make models diverge at profile intersections, differences greater than 1 ft in the upper 30 ft necessitate re-running the models to improve internal consistency across all of the data sets.

G. Optimize the Design

- Depth Precision and Accuracy. Alter operating procedures to accommodate site conditions. Fix or replace data cables.
- Number of Shots Needed per Interval. Use noise test conducted on outcrop near ROU1 to establish baseline conditions and measure actual weathered rock velocity.
- Surface Geophone Operation (e.g., vault floor and walls interfere with data collection). Evaluate results from alternate geophone spacing.
- Data Processing Anomaly Resolution. Evaluate supplied LiDAR topographic data, well survey data, and Nike 2 wellhead rehabilitation effects on horizontal interpretation precision and accuracy.
- Velocity Ranges for Units of Interest. Collect a denser VSP data set to better pick the rock-overburden boundary and potentially more subtle changes between weathered and hard rock. Collect a less dense data set from the hard rock section of the borehole.
- Seismic Profile Intersection Mismatch. Evaluate supplied LiDAR topographic data, well survey data, piezometer refusal depths, and Nike 2 wellhead rehabilitation effects on vertical interpretation precision and accuracy, and artifacts introduced by the modeling process.

5.0 ASSUMPTIONS

- Bathroom Facilities. Available at the Foster School District Building.
- Data Provided on NTP. USACE will provide detailed topography, topographic profiles along seismic lines using contractor-provided start-stop coordinates, site plan data in ArcGIS or georeferenced high-resolution image, requested ASCII or LAS borehole geophysics data, borehole deviation plots and data.
- Lyme-bearing ticks and black widow spiders are present on site.
- Offsite Access. Coordination in advance with USACE. All Rights of Entry are secured.
- Onsite Access. No restrictions for Nike 2 or the site.
- Potable Water. Hose-bib at the Foster School District Building. Water is approved for decontamination purposes (runs through two carbon filters).
- Power. None is available near Nike 2.
- Project Datums. Horizontal datum is RI State Plane NAD83. Vertical Datum is NAVD88.
- Schedule. Contractor provides at least two weeks' notice to USACE of actual mobilization date.
- SSHP. Use accompanying plans as a guide. Fourteen days for USACE to review and approve the contractor's SSHP.
- Field Mobilization. About 21 days after approving the SSHP and AHA
- Standards for Field and Functions Checks. Contractor brings all items needed to perform Field and Functions Checks in accordance with this SWWP.
- Subcontractors. USACE encourages use of subcontractors where it optimizes the technical products and minimizes price and schedule problems.
- USACE Partnership. USACE is dedicated to working with the contractor to achieve project success. This includes providing supporting data, coordinating site activities and permissions, limited field oversight, and in depth submittal reviews.
- Work Plan. The SWWP is the work plan. Additional SOPs used by the contractor are referenced in their proposal and submitted with their SSHP.
- Software Names. Does not constitute endorsement or a requirement to use the vendor's product.

All work shall be done in accordance with the approved SSHP, USACE safety guidance (USACE, 2014), and USACE technical guidance (USACE, 2002, 2001, 1995). All personnel shall:

- Have flash-lights available in case of late work hours

- Wear hearing and eye protection appropriate for seismic data collection
- Wear non-steel soled safety boots compatible with electromagnetic geophysical equipment
- Wear Class II or Class III reflective vests
- Wear sunscreen and bug repellant, as necessary

6.0 DEPTH AND ELEVATION CONTROL

Precise and accurate depth is the most important logging parameter. Cable stretch is not a factor for this effort due to the shallow nature of the data collection effort. All depth measurements shall be referenced to the outer casing (north side where measuring points are not labeled). Depth to the sensor shall be measured to the nearest 0.1 ft and for all water levels (before, during, and after logging). The following general procedures are observed for all geophysical probes (Darling, 2005, Hearst, Nelson, and Paillet, 2000, USACE, 1995, Keys and MacCary, 1971).

- Maintain adequate tension between the sensor and depth marker, preventing differential sticking.
- Note Sensor-Probe Top offsets and depth reference
- Briefly describe all problems or any unusual responses during logging. Note depth and response in the logging field notebook and on the log plots.

7.0 PRE-LOGGING ACTIVITIES

7.1 Decontamination

Before logging the first and each successive well, all borehole geophysical probes and cables shall be decontaminated as follows:

a. Wash and rinse cable as it is drawn in or out of the borehole.
b. Remove probes, and dislodge gross contamination (mud, rust flakes) with disposable rags. Remove electrical tape at cable end (if used). Cap the probe and cable ends.
c. Hand-wash the probes, geophone, pulleys, and related equipment thoroughly with potable water mixed with a low phosphate detergent.
d. Remove equipment, place into a second washbasin, and rinse probes with distilled water.
e. Dry equipment.

An alternate method may be used if the method's rinse sample data from other projects indicate it is effective for removing low-level contaminants of concern and is approved by the USACE project chemist before commencing field operations.

Liquid investigation-derived waste (IDW) shall be discharged to the ground where it will not cause erosion or a safety hazard. Solid IDW shall be double-bagged and disposed offsite by the contractor.

7.2 Well Head Inspection

Photo-document the wellhead before logging, and note the following:

- Well name and number
- Height of outer/inner casing above ground surface or vault floor (full description in field notes)
- Water level before, during, and after geophysical logging.

7.3 Nike 2 Data Logger

After collecting a water level and noting the time, the contractor shall remove the data logger and place it into a clean plastic bag for the duration of the logging effort. Once completed, the data logger shall be redeployed, the water level measured, date and time noted. This data will be presented in a table within the contractor's final report.

8.0 CALIBRATION, STANDARDIZATION, AND REPEAT SECTIONS

8.1 Calibration

Calibration procedures are performed on a probe at the vendor, manufacturer, or laboratory before the probe is taken to the field. Physical properties or environmental values of interest are measured in an infinite or semi-infinite model under a controlled environment. Calibration does not guarantee that measurements have a quantitative value in terms of geologic properties, but it does insure that the measurements are consistent and repeatable. This provides a common basis for interpretation, so that measured formations from different areas shall yield the same response for most logging tools and the differential response for different rock or lithology types at the site is quantitatively meaningful (Daniels, 1988). See Table 6 for probe-specific requirements.

Table 6. The following are in addition to pre-mobilization equipment checkout procedures and manufacturer calibration checks, and instrument maintenance. See probe manufacturer instructions and Darling (2005), Hearst, Nelson, and Paillet (2000), Daniels (1988), USACE (1995), Schlumberger (1987), Keys and MacCary (1971).

Probe Name	Field Calibration	Field Standardization	Functions Check
Vertical Seismic Profile	None	Verify instrument repairs have not short or long spliced measurements	• Noise test observations • Steel casing velocity measurement. • Does instrument diameter and arm accommodate borehole/casing conditions? • Per manufacturer's instructions.
Water Level Tape/Meter	None	Verify instrument repairs have not short or long spliced measurements	Per manufacturer's instructions.

8.2 Standardization or Functions Check

Standardization is the process of checking probe responses at the well site before and after logging. This process assesses instrument drift and verifies correct probe and supporting equipment operation. Field portable standards (physical, electrochemical, or radioactive) are not infinite and may not simulate environmental conditions. Two or more standards are used and the results are entered into the data acquisition file created by the logging computer for that probe run (Keys, 1989) and the field journal.

All probes shall undergo field standardization or a functions check before use. In some cases, this shall include field calibration (see Table 6). The borehole hydrogeophysics team shall tabulate the field calibration, field standardization, and functions checks done for each probe at each well, corrections applied. The tabulated information shall be summarized and included with the final report, along with a discussion on how the results affect data quality and measurement uncertainty discussed. Briefly describe all problems or any unusual responses during logging. Note depth and response in the logging field notebook and on the log plots.

This SWWP section does not serve as a substitute for the hydrogeophysics team's internal and equipment-unique checks and field standardization, and vendor specifications.

8.3 Repeat Sections

A repeat sections shall be run to demonstrate probe and depth measurement repeatability. These sections shall encompass a minimum of 10 ft, but not exceed 20%, of the borehole depth. The repeat section shall encompass an interval with fairly consistent geology or geomechanical properties, and a zone of major change (e.g., overburden-weathered bedrock contact).

Repeat sections shall be included as an electronic data deliverable, and shall be included in the report main body or printed appendix only when needed to demonstrate error analysis, corrections applied (e.g., data shift), and/or addressing a project objective. Impacts on data use and interpretation shall be clearly presented in the report, tabulated where convenient.

9.0 VERTICAL SEISMIC PROFILING (CHECK SHOT VARIANT)

Vertical seismic profiles (check shots) are used to measure the in-situ compressional-wave velocity of the sediment and rock penetrated by wells at the site. These data provide confirmatory velocity information for the refraction models; can be used to determine appropriate stacking velocities and travel-time to depth conversions for reflection data, and measure top of bedrock. Equipment used for recording the vertical seismic profile consists of a downhole geophone, three or more surface (land) geophones, impulsive energy source (sledgehammer), cabling, and a seismograph capable of recording at least 10,000 samples per second (0.1-ms sample interval). Hydrophone streamers may be substituted for borehole geophone for cases when the borehole is fluid filled. The data collection interval is determined by the project objectives, smallest feature of interest, and site noise (Barton, 2007, Steeples, 2005).

The general procedure for performing the check shot data consists of placing the surface geophones at a fixed distance from the shot point, and moving the downhole geophone up/down the borehole at a prescribed spacing (dependent on the expected range of velocities). A shot record is gathered for each depth position occupied by the downhole geophone. Some downhole geophones allow changing the output channel number of the downhole geophone, and a single shot record can be built from subsequent measurement points. The first arrival time of the seismic energy is determined for each downhole geophone position. Shot-timing variations, if present, are corrected by using the arrival time information recorded by the surface geophones (should be invariant). The corrected arrival-time data are plotted by depth, and changes in slopes computed from this curve are inversely proportional to the seismic velocity.

9.1 Equipment

- **Surface (land) geophones**: Natural frequency should be within the standard range used for refraction/reflection surveys (14-40 Hz).
- **Downhole phone**: 1-to-3 components. Sidewall locking mechanism. 40 Hz natural frequency is a commonly use receiver element. Can use a hydrophone or hydrophone streamer for fluid filled holes.
- **Energy Source:** Sledgehammer or other impulsive source. Avoid stacking if possible, and stack only when necessary to achieve a good signal-to-noise level. Shot timing is critical (more on this later in processing).

- **Seismograph:** Standard engineering with a high sampling rate (>10,000 samples per second) and good dynamic range (>12-bit A/D). Minimum of 6 channels (3 for surface geophones, 3 for downhole geophone). Most engineering seismographs currently on the market today meet these criteria.

9.2 Setup/Operation

9.2.1 Placement of Shot Point

The velocity of the earth material and the type of well construction used governs the placement of the sledgehammer source. The objective is to record a seismic signal that has been transmitted through the earth, not along the borehole casing and screen. When working in complex settings, the source and surface phone orientation to the borehole should be the same relative to the structural fabric/primary anisotropy direction to achieve results that are more consistent across the site (Barton, 2007). When used to support surface seismic surveys, the source and surface phones should be parallel to the surface seismic line and the difference from the primary anisotropy direction noted in the report, along with potential data limitations.

- **Open Wells:** Shot point can be placed immediately adjacent to the borehole depending on near-surface construction (avoid the cement well pad). The downhole geophone is only placed within the uncased part of the hole, and arrival-time differences within this part of the well can be used to measure the in situ velocity. Refer to the next section for attempting to collect data in the cased part of the well.
- **Cased and partially cased wells:** The shot point will have to be offset from the borehole so that the seismic energy broadsides the well (attempt to shoot through the casing). Steel cased wells are the most problematic, in that the steel casing has a high Q and thus transmits energy quite well. Despite this, the geophysicist may make an initial assumption that the borehole casing is invisible within the range of frequencies used. Offsets of approximately 1/4 to 1/2 of the geophone depth in a cased well should allow recording a direct seismic wave through the casing (e.g. if the geophone was at 25 ft in depth then expect to use offsets of 6-12 ft). Note that too great of a shot offset may yield refracted energy from deeper layers, and skew the resulting time-depth graph. It is best to check the velocities calculated for the cased part of the borehole for unreasonably high values (steel ~25,000 ft/s).

9.2.2 Reference (Surface/Land) Geophones

Placed at a fixed distance from the shot point, and are used to correct for shot-timing variations, if present. Commercial impact triggers can exhibit timing variations ranging from 0.05 to 0.15-ms, depending on their orientation on the sledgehammer handle. If these timing variations are not accounted for, could lead to false unit velocities. For example, a velocity change from 10,000 to 11,200 ft/s could be produced by a 0.05 ms shift in the shot timing (for a 5 ft geophone spacing).

The reference geophones can also be used to estimate the velocities in the near surface, and provide an additional check on the computed velocities if the well construction allows recording near the surface.

Nike 2's vault-style wellhead construction may dictate an alternate approach. Document any modifications or exceptions to this SWWP with photographs, field notes, and in the report.

9.2.3 Downhole Geophone

The vertical spacing used is primarily dependent on expected range of velocities within the subsurface, the desired vertical resolution, and the recording limitations afforded by the seismic gear. Data recorded at a sampling interval of 0.1 ms (10,000 samples per second) theoretically allow discerning arrival time changes as small as 0.2 ms (twice the sampling interval). Note that for material velocities in the range of 10,000 to 25,000 ft/s, a geophone spacing of 5 ft yields theoretical arrival time changes from 0.5 to 0.2 ms.

Where the data quality objective is locating the top of bedrock, the geophone shall be set 30 feet below the bottom of the well casing as determined by electric (induction or resistivity), image, or downhole camera logs backed up by caliper and other logs.

9.2.4 Cabling

The common 3-component downhole geophone usually hooks into the 12-channel, Cannon NK-27-21C connector used by Geometrics, and is wired to record on phones 1-to-3 (or 13, 14, &15 if connected to the 13-24 side). For systems with more than 24 channels, an adaptor cable will likely be required.

9.3 Recording

- Seismograph: Record at the fastest sampling rate allowed. Most of the Geometrics units allow at least a 0.0625 ms sampling rate, and with a record length in the 30- to 100-ms range. Record without analog filters set if possible. Digital filters for display purposes are ok. Wind noise and the ground-coupled airwave should not be a problem, and the reference geophones should be close enough to allow a good S/N ratio.
- Notes: Record the shot offset, position of reference phones, well ID, casing stickup, tool reference point, etc. For each shot, record the depth of the downhole geophone, number of stacks, etc. For the downhole tool, the distance from the tool-bottom-to-sensor should be noted to allow cross checking against the maximum depth penetrated by the well.
- Downhole Geophone Location: The position of the downhole geophone is usually measured using the centerline of the geophone (or geophone cluster). Markers at 5- or 10-ft intervals are located on the downhole cable relative to this centerline. In some cases, the cable reference marks are relative to the “tool head”, and an offset to the geophone centerline must be added to the depth mark. Prior to surveying, the user should verify this with the user manual and by manually checking via tape measure. The user’s manual should specify distance to the geophone center from this point.

9.4 Processing/Development of check shot profile:

- Pick first arrival energy for the downhole and reference geophones;
- Sort the arrival-time data by depth point;
- Compute and apply shot-timing corrections using the arrival time picks obtained from the reference geophones. Develop a mode (most common arrival time) from which to compute timing corrections. If a mode cannot be determined, e.g. either due to a random distribution, then use a median or mean value for correction.
- Compute the average velocity to a receiver station using a straight-line distance assumption from the shot to the receiver and the corrected arrival time (this is not the interval velocity);

- Convert to vertical travel-time using the depth point for the receiver and the computed average velocities (vertical-time=[depth/average velocity]);
- Computed interval velocities by determining the slope (inverse of velocity) between measurement points or sets of measurement points. My preference is to look for significant breaks in the time-depth curve, and use a least-squares fit to fit a line to these segments;
- Compute the average velocity to a receiver station using a straight-line distance assumption from the shot to the receiver and the corrected arrival time (this is not the interval velocity);
- Where available, the data were correlated with the lithologic information and other available borehole geophysical data.

9.5 Processing Notes and Cautions

- For cased wells where the casing precluded recording data, the velocity estimation can only be performed within the uncased part of the well. Only an average velocity can be computed for the cased section, which could gloss over any major velocity changes within the cased section. For example: seismic energy will travel the same amount of time through a 10 ft thick layer of 2500 ft/s, as it will through a 50 ft thick layer at 12,500 ft/s (both require 4 ms).
- Avoid calculating interval velocities directly between measurement points. Small errors in the first-arrival time-pick can produce false variations in velocity. It is generally better to compute an average slope over several measurement points.

10.0 REFRACTION TOMOGRAPHY

Seismic refraction provides acoustic velocity and layer depth information (Redpath, 1973). The refraction method generally depends on an increase in seismic-wave velocity (speed of sound through earth material) with depth, though the newer tomographic codes presently available have the capability of handling a velocity inversion (zones of lower seismic velocity underlying zones of higher velocity). Both a tomographic model and an earth-layer (refractor) profiles shall be prepared as processing outputs from the refraction profiling.

10.1 Work Flow

The processing sequence for the refraction data consists of:

- Update positional data where necessary to reflect the updated site survey
- Pick first arrival times of return energy for each shot
- Assign the array-geometric to the first arrival data
- Invert the first-arrival information for velocity and depth using the Seismic Inversion Processing Technique (SIPT) algorithm (delay-time method)
- Construct a tomographic model of the first-arrival information using the refraction tomography software.

10.2 SIPT2 Technique

The SIPT2 algorithm constructs earth-layer (refractor-interface) models by assuming the subsurface to be comprised of distinct layers, from which the underlying geology is interpreted. Each seismic/earth layer has a discreet velocity (does not vary), and the topography of the interface between layers is computed. The algorithm employs the delay-time method of Pakiser and Black (1957) to calculate depth and position of refraction horizons. A ray-tracing algorithm is then applied, which overcomes difficulties associated

with dipping or undulating horizons and further refines the generated refraction model. Reverse-spread geometry and far offset shot points are used to help constrain the model

Limitations of this method include inability to discern lateral variations in velocity, the inability to see "hidden" layers of lower-velocity at depth, and the inability to handle gradational changes in velocity. The method is also highly dependent on the geophysicist being able to assign travel-time picks to the appropriate seismic layer. Despite these limitations, the application of this technique at other sites has proven highly effective in mapping the topography of fractured bedrock.

10.3 Seismic Refraction Tomography Technique

Tomographic modeling does not require a priori assignment of travel-time picks to individual layers, but constructs a velocity model (cell model) through which the travel-time from a shot point to a particular receiver can be calculated. Modern commercial modeling packages achieve a globally optimized, velocity model using only first arrival travel time data and array geometry as input. For example, GeoCT-II additionally requires a starting velocity model velocity, whereas SeisOpt2D estimates the starting model from the input data.

Software like GeoCT-II inversion code uses the geometry and first-arrival information as a starting point to apply a nonlinear continuum inversion in order to achieve a velocity-depth model. This package also allows providing a priori constraints such as known velocities from downhole surveys, and using earth-layer models as starting points. The processing sequence for the refraction data consisted of the following:

1. Conduct several trial runs, using different cell sizes, smoothing parameters, and starting models to determine which parameters provide the most consistent and stable inversion.
2. Compare the errors between the calculated and measure travel-times, noting whether anomalous features appear or disappear by slightly varying the inversion parameters.
3. Select the data model that best fits the data, local (e.g., Roukous Farm outcrop area) and regional geologic trends, and is consistent with the SIPT results.

Limitations with this method include resolution limits based on geophone spacing, velocity gradients where discreet layers are more applicable, and having a "smoothed" output due to stability needs of the geophysical inversion. The method does allow for both lateral and vertical changes in the velocity field and can be suitable for imaging weak zones (low-velocity) within the bedrock.

11.0 INTEGRATION WORKFLOW

Due to the wide variability of the natural materials' physical, electrical, and acoustic properties, values from one site can rarely be applied to another site. This is further complicated by the large range of potential conditions (formation, borehole, casing, equipment, groundwater) contributing to a probe's response. Consistent log interpretations using site-specific calibrations and geologic framework and hydraulics are achieved using the following steps and done in conjunction with the project geologist (see also Kobr, Mareš, Paillet, 2005, Hearst, Nelson, and Paillet, 2000, 1985, and Keys 1997).

1. Representative or Type Section Borehole. Visually inspect all of the geophysical logs from a single, representative borehole.
2. Assign Qualitative Log Responses. For features supporting the project objectives, their qualitative log response shall be described in the report. Two examples are:

a. Overburden-Weathered Rock Boundary. Expected to 1) be above the casing bottom, 2) minor inflection on the natural gamma log, and 3) moderate to large change in the VSP-measured velocity.
b. Weathered Rock – Hard Rock Boundary. Expected to 1) less than 100 feet below the casing bottom, 2) gradational change in sonic and electric logs, and 3) moderate to gradational change in the VSP-measured velocity, 4) similar velocity range to that measured at the outcrop during noise testing.

3. Boundary Interpretation. Assign a boundary for those depth intervals where the individual log values for the selected borehole are within the range of assigned values. Assess velocity ranges within these boundaries.
4. Verify Boundary Interpretation. Compare assigned lithologies with all project data sets with the best well control (e.g., L-1).
5. Apply Relationships. Construct a final composite lithologic interpretation for the remaining profiles. The final interpretation utilizes multiple well log response and surface seismic results that best characterizes a particular lithology (Cant, 1984). Departures from the final composite geologic interpretation may indicate the presence of fracture zones, alteration zones, previously undescribed rock types, or structural features, which must be interpreted on a profile-by-profile basis (Kobr, Mareš, Paillet, 2005, Mack, 1993, Daniels, 1988), especially in areas of high anisotropy. These departures from the interpretation model should inform the bulk of the formation discussion for the report.

12.0 DELIVERABLES

12.1 General

The Contractor is responsible and accountable for the completeness and quality of their submittals furnished under this contract.

The Contractor shall prepare a transmittal cover letter for all project submittals. The letter shall include a statement that the Contractor has verified that all items required in this SWWP are included in the submittal (unless otherwise agreed to in advance with USACE), performed an internal quality control check on the document as described below (preliminary draft, draft, and final), and all comments have been addressed and incorporated (draft and final). USACE shall <u>not</u> serve as the contractor's technical editor and data interpreter. The letter of transmittal for all submissions shall indicate that the submission meets the following criteria.

a) A geoscience technical writer reviewed the document. This is in addition to the Contractor's standard management review. All text, figures, and tables are internally consistent, and the document was prepared in accordance with the SWWP.
b) Document was reviewed for conflicts, errors, and omissions, and corrected before submittal to USACE.
c) Completeness for each discipline commensurate with the level of effort required for that submission (geology, geophysics)
d) EDDs were reviewed for completeness and data structure compliance with the SWWP prior to submittal to USACE

12.3 Proposal

The contractor's proposal package shall include a succinct two-page summary of how they intend to execute the entire project (workflow, equipment, software, etc.), anticipated subcontractors, (names, roles, and responsibilities); data needed but not already provided, experience, qualifications, technical assumptions, and questions (see Definitive Responsibility Criteria). The proposal shall also include a price summary table with fully burdened price to execute the SWWP broken down as follows:

- SSHP
- Noise test and Nike 2 VSP data collection and processing (labor, mobilization, equipment)
- Refraction tomography data reprocessing, positional data correction, and interpretation
- Integration and reporting

In addition to examining the criteria in FAR 9.104-1 and -2 (a), the Contracting Officer and supporting technical specialists shall evaluate whether the low bidder can meet the Definitive Responsibility Criteria. Bidders are not required to submit criteria documentation beyond that required in this section at the time of bid. The Government will request additional supporting documentation from the bidder anticipated to receive the award.

12.4 SSHP

Draft and final SSHP shall be transmitted electronically as an Adobe file with comment and print permissions granted. Hard copy with signatures shall be with the field vehicle and accessible.

12.5 Report

The report's executive summary shall address the goals and objectives discussed in SWWP Section 3. Findings unique to each profile and the Site shall be summarized, using a table where feasible (e.g., a single table can be used to summarize fracture zones, location, and prioritized drilling targets). A summary figure shall also be included for illustrating site-wide trends (similar to Figure 5 right panel).

The main body shall discuss meeting project goals, data quality objectives, planning, execution/work flow, limitations, effectiveness of the new software (name and version) compared to the original data models, limitations influencing modeling, and interpretations. VSP tool performance and function check results shall be presented and assessed for probe drift and impacts on data quality and usability. Recommendations shall include a tabulated list of drilling target locations on each seismic line (interpreted bedrock fracture zones, bedrock topographic lows), and be presented on a map. References used to help process and interpret the data shall be cited in the text and included in the report's reference list. Additional software used to conduct data collection and processing shall be described (name, version, vendor, workflow and assumptions used).

The report shall include a schematic diagram of the downhole geophone used showing tool length, the sensor's location, depth reference (e.g., tool top), length between depth reference and sensor, length between depth mark and depth reference, and length between depth mark and sensor. The text will discuss any depth shifts (value, direction) made during data collection, processing, and interpretation. The report text or EDD README file shall discuss any depth shifts needed to import processed VSP results into borehole programs like WellCAD or LogPlot (see Section 10.6).

No hard copies of the report are required. The report and its supporting EDDs shall be transmitted electronically via DVD or AMRDEC.

Personnel are encouraged to publish results, but first must submit a written request to the USACE Contracting Officer's Representative (COR) describing what data is needed, where and how it will be used, and for how long. This applies to all uses of the project data beyond project deliverables (e.g., office presentations, marketing efforts, conferences). The USACE has unlimited rights to all documents/material produced under this contract. All documents and materials, including the source codes of any software, produced under this contract shall be USACE-owned and are the property of the USACE with all rights and privileges of ownership/copyright belonging exclusively to the USACE. These documents and materials may not be used or sold by the Contractor without written permission from the USACE. All materials supplied to the USACE shall be the sole property of the USACE and may not be used for any other purpose. This right does not abrogate any other USACE rights under the applicable Data Rights clause(s).

12.6 Figures

All figures, maps, and drawings shall be completed in accordance with USACE (2002a, 2001a), USGS (Hansen, 1996), American Geological Institute (1989), or similar standards (e.g., Compton, 1985 or newer). All figures used in the report shall be exported to a high-resolution graphics file suitable for incorporation into Microsoft Office programs. All figures turned into Adobe PDF files shall use the Press Quality settings for maximum resolution.

12.6.1 Maps

All figures, maps, cross sections, and drawings shall be completed in accordance with USGS (Hanson, 1991), American Geological Institute (2006), or similar standards (e.g., Compton, 1985 or newer). Maps can be produced using any geospatial program (ArcMap, Geosoft Oasis Montaj®, Surfer®, RockWorks®, or other geospatial program. PowerPoint, Visio, Paint, etc., shall not be used as the primary map producing program. Each map shall include the following items:

- Site plan with salient features orienting the reader
- Magnetic and map north arrows
- Property boundaries
- Site boundaries with site-specific project names (e.g., Operable Unit 11, Area of Concern 7)
- Coordinate grid lines and datums
- Graphic scale and representative fraction
- Cultural features (roads, buildings, firing points, range fans, etc.)
- Inset map for geographic reference with survey area outlined or shaded
- Project and company names
- Location of logged wells, showing borehole deviation to map scale
- Location of wells not logged
- When borehole deviation exceeds map symbol size or required by the project objectives, location of task-specific features on the borehole deviation path (e.g., transmissive fractures, fault zones, geologic structures)
- Labeled lines of section or geotechnical profiles
- Any other relevant information affecting interpretation (pumping well location(s), estimated plume boundaries)

- Source references for all data shown

12.6.2 Panels

- SeisOpt2D data model profile from the original report (new models need not be generated)
- Data model profile built using a modern refraction tomography program
- Data model profile showing interpreted overburden units (outwash-boulder till contacts), Top of Weathered Rock, Top of Unweathered Rock, and fracture zones. Overlay salient geophysical and VSP logs onto the profiles.
- Well deviation where resolvable.

Panels shall be exported as *.jpg or similar files (e.g., WMF, EMF) that show maximum resolution. Verify word processing or figure handling program graphics import options have resolution down-sampling turned off before beginning importing.

12.6.3 Profiles

- Have internally and externally consistent interpretation across all available data sets (borehole geophysics, interpreted surface, water level measurements).
- Show vertical and horizontal scales & use the same scales for each intersecting section.
- Define vertical exaggeration.
- Use solid, dashed, dotted, and queried lines to reflect confidence in data interpretations, and define the line types in the panel's legend.
- Label starting and ending compass quadrants for each section.
- Note significant features, such as wells, ground surface topography, and ground features (e.g., utilities, artificial fill, roads, and intersecting lineaments).
- Project wells onto the plane of section along the structural fabric, not the shortest distance between the well and the line of section.
- Show all planar features as they intersect the plane of section (use correct apparent dip angles and reference them to map north, not magnetic north).
- Plot selected geophysical logs to the same scale on all sections (e.g., natural gamma, VSP).
- Plot fracture zones potentially intersecting the seismic profile lines using the correct apparent dip.
- Water level where available

13.0 ELECTRONIC DATA DELIVERABLES

Data files and final deliverables shall be categorized using clearly labeled sub-folders on the submitted DVD. The SWWP, prime to subcontractor statement of work shall also be on the DVD. A README file shall accompany the data, explaining positional data collection method, results, and datums used. A location map in native file and PDF formats shall accompany the data set, showing locations of all investigation activity generating data contained on the DVD. Show scale, datums, north arrow, labeled locations, etc.

Interpreted surfaces, such as top of weathered rock, top of unweathered rock, and resolvable overburden units shall be exported as XYZ Excel-compatible files for each profile, with location and elevation referenced to the project datums (X=northing, Y=easting, Z=elevation). Excel-compatible seismic data model results shall be exported as XYZG Excel-compatible files for each profile with location and elevation referenced to the project datums (X=northing, Y=easting, Z=elevation, G=velocity).

13.1 VSP Data

Data files shall be categorized using clearly labeled sub-folders, with final e-copy report (PDF from original report, not scanned) documenting all phases of data collection, processing, and interpretation, and the SWWP used by the geophysics subcontractor. The DVD accompanying the final report shall contain raw seismogram data files in the SEG-2 standard established by the Society of Exploration Geophysicists (Norris and Falchney, 2002, or Pullan, S.E., 1990) for seismic and radar data files, travel-time arrival picks and shot-receiver geometry information in ASCII format.

13.2 Figures

All maps and drawings shall be submitted in their native file format and a common, high-resolution export (e.g., JPG) on the EDD DVD. Data files shall be categorized using clearly labeled sub-folders by profile or general site data. All raw data (*.dwg, ASCII, GIS shape files with metadata) shall be provided electronically. When used, ARCGIS map documents (MXDs) will be packaged using ESRI's Map Package.

Include the start and stop coordinates for each profile, ground surface elevation, and bottom elevation referenced to the project datums in an Excel-compatible table.

14.0 REFERENCES

Acker, R.C., 1950. The bedrock geology of the northern half of the Clayville Quadrangle, Rhode Island. Master's Thesis. Department of Geology, Brown University, 84 p excluding plates.

AMEC 2012. Draft Remedial Investigation/Feasibility Study Work Plan, Volume I Project Overview for Former Nike PR-79 Control Area, Foster, Rhode Island, March 21, 2012.

AMEC, 2014. Phase I Field Site Investigation Trip Report, Former NIKE PR-79, Foster, Rhode Island, FUDS No.: D01RI0063 02.

Army Geospatial Center, 2015. Integrated Fracture Trace Analysis Former Nike PR-79 Control Area Foster, RI.

Barton, N., 2007. Rock Quality, Seismic Velocity, Attenuation, and Anisotropy. Published by Taylor & Francis, 729 p.

Cant, Douglas J, 1984. Subsurface Facies Analysis. From Walker, R.G., Facies Models. Second Addition. Geological Association of Canada. Pgs 297-310.

Collins, L.G., 1997. Myrmekite and K-Feldspar augen in the Ponaganset Gneiss, Rhode Island, Connecticut and Massachusetts, USA.

Compton, R., 1985. Geology in the Field. Published by John Wiley and Sons.

Daniels, J.J., 1988. Well Logging For Engineering and Environmental Applications: Proceedings of the Symposium on the application of Geophysics to Engineering and Environmental Problems, March 28-31, 1988, Golden, Colorado: The Society of Engineering and Mineral Exploration Geophysicists (invited paper).

Darling, T., 2005. Gulf Drilling Guides - Well Logging and Formation Evaluation. Published by Elsevier through Gulf Professional Publishing.

Frohlich, R.K. and Fisher, J.J., 1985. Geophysical and Remote Sensing Studies of Bedrock Aquifers in Fracture Zones, Report FY-1985 Program. Prepared by the University of Rhode Island for the Rhode Island Water Resources Center.

Frost, R.J., 1950. Bedrock geology of the southern half of the Clayville Quadrangle, Rhode Island. Master's Thesis. Department of Geology, Brown University, 60 p excluding plates.

Hansen, A.J., 1962. Ground-Water Map of the Clayville Quadrangle, Rhode Island. Published by the Rhode Island Water Resources Coordinating Board in Cooperation with the United States Geological Survey.

Hanson, W.R., 1991. Suggestions to Authors of the Reports of the United States Geological Survey, 7th Edition. Published by the U.S. Government Printing Office.

Hearst, J.R., Nelson, P.H., and Paillet, F.L., 2000. Well Logging for Physical Properties – A Handbook for Geophysicists, Geologists, and Engineers. John Wiley and Sons, Ltd., New York.

Keys, W. Scott, 1989. Borehole Geophysics Applied to Ground-Water Investigations. Published by the National Ground Water Association

Keys, W. Scott, 1997. A Practical Guide to Borehole Geophysics in Environmental Investigations. Published by CRC Lewis Publishers, Inc.

Keys, W. Scott, and L.M. MacCary, 1971. Application of Borehole Geophysics to Water-Resources Investigation, Book 2, Chapter E1. Techniques of Water-Resources Investigations of the United States Geological Survey. Department of the Interior US Geological Survey, 134 p.

Kobr, M. Mareš, S., and Paillet, F.L., 2005. Geophysical Well Logging – Borehole Geophysics for Hydrogeological Studies: Principals and Applications, in Rubin, Y. and Hubbard, S.S., Hydrophysics, p. 291-331. Published by Springer, The Netherlands, 523 p.

Natural Resources Conservation Service (NRCS), 2013. Soil Parent Materials of Rhode Island. Available from the United States Department of Agriculture NRCS Rhode Island at http://www.ri.nrcs.usda.gov/technical/soils.html.

Nichols, W.D., 1961. Petrology and Structural Geology of the Bennett Hill Area, Clayville Quadrangle, Rhode Island, 96 p.

Norris, M.W. and Falchney, A.K., 2002. SEG Y rev 1 Data Exchange Format. Prepared by the SEG Technical Standards Committee, Release 1.0, May, 2002.

Pakiser, L.C. and R.A. Black, 1957, Exploring for Ancient Channels with the Refraction Seismograph, Geophysics, v 22 (1), p. 32-47.

Pullan, S.E., 1990. Recommended Standard For Seismic (/Radar) Data Files in the Personal Computer Environment. Geophysics, 55(9), 1260-1271.

Quinn, A., 1971. Bedrock Geology of Rhode Island. US Geological Survey Bulletin 1295.

Redpath, B.B., 1973, Seismic Refraction Exploration for Engineering Site Investigations, Technical Report E-73-4, U.S. Army Waterways Experiment Station, Explosive Excavation Research Laboratory, Livermore, California, 51 p.

Schlumberger, 1987. Log Interpretation Principles/Applications. Schlumberger Educational Services, Houston, Texas.

Sky Research, 2008. Orthophotography and LiDAR Terrain Data Collection, Rhode Island Formerly Used Defense Sites Final Report. Contract No. W9128F-05-D-0015, Delivery Order No. 0004. Prepared by Sky Research, Ashland, Oregon, 11 February.

Steeples, F., 2005. Shallow Seismic Methods, in Rubin, Y. and Hubbard, S.S., Hydrophysics, p. 215-252. Published by Springer, The Netherlands, 523 p.

Theys, P. 1999. Log Data Acquisition and Quality Control, 2nd Edition. Editions Techchip, Paris, 453 pgs.

Thompson, M.D. and Miller S.F., 2002. Seismic Refraction Surveying at Site PR-79 (Former Nike Site), Foster, Rhode Island. Prepared by Center for Environmental Restoration Systems, Energy Systems Division, Argonne National Laboratory, Operated by the University of Chicago for US Department of Energy.

United States Army Corps of Engineers (USACE), 1993. Solicitation – DACA33-93-B-0076 Silo and Tank Closure Nike PR-79, Foster, Rhode Island.

USACE, 1995. EM 1110-1-1802 Geophysical Exploration for Engineering and Environmental Investigations available at http://140.194.76.129/publications/eng-manuals/EM_1110-1-1802/toc.htm.

USACE, 2001. EM 1110-1-1804 Geotechnical Investigations, Engineering and Design available at http://140.194.76.129/publications/eng-manuals/EM_1110-1-1804/toc.htm.

USACE, 2002. ER 1110-1-8157, Engineering and Design Geotechnical Data Quality Management for Hazardous Waste Remedial Activities available at http://140.194.76.129/publications/eng-regs/ER_1110-1-8157/toc.htm.

USACE, 2004. Engineer Regulation (ER) 200-3-1, Formerly Used Defense Sites Program Policy.

USACE, 2014. EM 385-1-1 Safety - Safety and Health Requirements and changes posted at http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_385-1-1.pdf

United States Army Institute for Public Health (USAIPH), Water Supply Management No. 31-0D1R-10, Volatile Organic Chemicals Sampling Event, Nike PR-79 Integrated Fire Control Area, Foster, Rhode Island, 16-19 June 2010.

United States Environmental Protection Agency, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA QA/G-4). Published by the Office of Environmental Information, and available at http://www.epa.gov/quality/qs-docs/g4-final.pdf.

United States Geological Survey, 1971. Aeromagnetic Map of the Clayville Quadrangle, Providence County, Rhode Island. Geophysical Investigations Map GP-788.