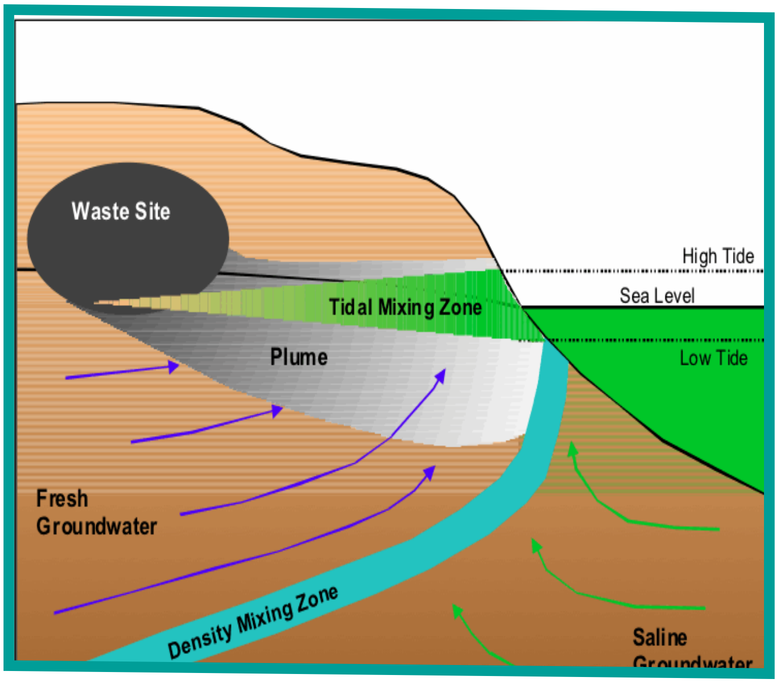
ESTCP
Cost and Performance Report

(ER-0422)



Monitoring of Water and Contaminant Migration at the Groundwater-Surface Water Interface

August 2008

ENVIRONMENTAL SECURITY
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ACRONYMS AND ABBREVIATIONS

AOC 1	Area of Concern 1
ARAR	Applicable or Relevant and Appropriate Requirements
BRAC	Base Realignment and Closure
Cal/EPA	California Environmental Protection Agency
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CoC	contaminant of concern
COTS	commercial off-the-shelf
DCE	dichloroethylene
DLC	data logger/controller unit
DoD	Department of Defense
DPT	direct-push technology
DQOs	data quality objectives
EBS	Environmental Baseline Survey
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FDEP	Florida Department of Environmental Protection
GPS	Global Positioning System
GSI	Groundwater Seepage Incorporated
HSWA	Hazardous and Solid Waste Amendments
IR	Installation Restoration
IRA	Interim Remedial Action
KB2	KB Labs' mobile lab
LCL	lower control limit
MCL	maximum contaminant level
MDL	method detection limit
MNA	monitored natural attenuation
MQO	measurement quality objective
MS	matrix spike
MSD	matrix spike duplicate
NAVFAC	Naval Facilities Engineering Command
ND	not detected
NIST	National Institute of Standards and Technology

ACRONYMS AND ABBREVIATIONS (continued)

NSA	Naval Support Activity
NTC	Naval Training Center
ORP	oxidation reduction potential
OU	Operable Unit
PCE	tetrachloroethene
PI	principal investigator
PQL	practical quantitation limit
QA	quality assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RPD	relative percent difference
RSD	relative standard deviation
SA	study area
SPAWAR	Space and Naval Warfare Command
SWCTL	surface water cleanup target level
TCP	trichloropropane
TDS	total dissolved solids
UCL	upper control limit
VC	vinyl chloride
VOC	volatile organic compound

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Along with the authors, the Panama City demonstration field crew included Joel Guerrero (SSC San Diego), Chris Smith, Ron Paulsen, and Alan Sims (Groundwater Seepage Inc.), and Gregory Jon Groves (Computer Sciences Corporation). In addition to those named above, the NTC Orlando field team also included Kim Paulsen (Groundwater Seepage Inc.). At the Orlando site, site access, boat support, and rock and roll was provided by Dave Peral. Cheryl Kurtz (SSC San Diego) provided assistance in the compilation of this report. Ron George (Oceanscience Group), and John Radford (ZebraTech) have been invaluable partners in the commercialization of this technology.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

The Department of Defense (DoD) and other government and private entities are in the process of identifying, assessing, and remediating a large number of terrestrial hazardous waste sites. Many of these sites are located adjacent to harbors, bays, estuaries, wetlands, and other coastal environments (Chadwick, Kito, Carlson, and Harre, 2003a). There is a general requirement to determine if contaminants from these sites are migrating into marine and surface water systems at levels that could pose a threat to the environment.

Currently, these problems are evaluated by the use of hydraulic head measurement in shoreside wells and numerical models that provide theoretical predictions of flow and contaminant migration. However, these measurements and models are of limited utility in areas adjacent to marine systems where tides, waves, and strong density gradients make it difficult to establish boundary conditions. In addition, current techniques for verifying the model predictions are inadequate.

1.2 DEMONSTRATION OBJECTIVES

The overall objective of this project was to field demonstrate and evaluate the effectiveness of two technologies for characterizing coastal contaminant migration. The specific objectives of this demonstration were to achieve the following:

- Demonstrate that the Trident probe can be used to help delineate areas where groundwater seepage is occurring and contaminant of concern (CoC) concentrations in those areas
- Demonstrate that the UltraSeep system can be used to quantify the flow of groundwater and concentration of contaminants that may be impinging on the surface water system
- Demonstrate the technology to end users to determine the utility of these tools for making decisions at DoD coastal landfills and hazardous waste sites
- Quantify costs associated with the operation of each technology.

1.3 REGULATORY DRIVERS

Concerns over contaminants moving from groundwater to surface water are found at sites being regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). State and federally regulated sites often have to meet levels such as a maximum contaminant level (MCL) at a point of compliance in order to conservatively protect surface water. In many cases, groundwater in shoreline wells must meet surface water applicable or relevant and appropriate requirements (ARAR) due to a lack of information or uncertainty regarding modeled dilution and attenuation factors. By making direct measurements at the point where groundwater enters surface water, decisions can be made based on specific data rather than on uncertain models or a measurement at a conservative point of compliance.

1.4 DEMONSTRATION RESULTS

The first demonstration focused on evaluation of a volatile organic compound (VOC) plume associated with Area of Concern (AOC) 1 at NSA Panama City. The site was adjacent to St. Andrews Bay, and the plume appeared to be migrating toward the bay. At the NSA Panama City site, the Trident probe was used successfully to identify areas of groundwater discharge from the site to the surface waters of St. Andrews Bay. Thirty offshore stations were sampled with the probe sensors and water sampler, and the results were validated with shallow piezometers. The UltraSeep was used successfully at the NSA Panama City site to quantify groundwater discharge rates and VOC discharge concentrations in two discharge zones identified with the Trident probe.

Although groundwater discharge was detected, all target VOC analytes, including dichloroethylene (DCE) in all UltraSeep samples were below the practical quantitation limit (PQL). Results from three shallow piezometers installed adjacent to each UltraSeep station validated the results obtained from the UltraSeep. The utility of the Trident probe and UltraSeep in assessing coastal contaminant migration was successfully demonstrated at the NSA Panama City. No DCE discharge into St. Andrews Bay at levels above the surface water cleanup target level (SWCTL) of 3.2 ug/L was detected. Thus, the results from the study support the selection of monitored natural attenuation (MNA) as a corrective action alternative for the site.

The second demonstration was performed at the former NTC Orlando, Florida. The contaminant of concern at Operable Unit (OU) 4 NTC Orlando was tetrachloroethene (PCE) and its degradation products, which have been detected along the shoreline of Druid Lake. The Trident probe was used successfully to identify areas of groundwater discharge from the site to the surface waters of Druid Lake. Detectable levels of VOC were measured in the subsurface or surface water in the areas of groundwater discharge identified with the Trident probe sensors. The results from shallow piezometers validated the results from the Trident probe.

The UltraSeep was successfully employed to quantify groundwater discharge rates and VOC discharge concentrations in two discharge zones identified with the Trident probe screening. Piezometers were used to validate the UltraSeep sampling and indicated general agreement with the UltraSeep. Overall results for the demonstration show how discharge of VOC to the lake are regulated by the physical pathway and the chemical attenuation that occurs along these pathways, along with the effects of localized mixing in the lake itself.

A cost analysis for the Trident probe and UltraSeep technologies relative to the baseline technologies was developed on the basis of the demonstration, input from the commercial partners, and typical site parameters. The cost analysis assumed a coastal area of interrogation measuring 200 ft by 500 ft with 60 Trident probe sensors, 15 Trident porewater probes, and five UltraSeep sampling points.

The cost analysis indicated that the cost of an integrated Trident probe/UltraSeep survey is expected to be on the order of $120,000, which represents a cost savings of about 42% relative to the estimated cost for the baseline technology of about $210,000. In addition, the demonstration at the NSA Panama City site documented an additional cost avoidance of about $1.25 million based on support for selection of MNA as the corrective action at the site.

1.5 STAKEHOLDER/END-USER ISSUES

The Trident probe and UltraSeep have generally found strong acceptance by stakeholders and end-users. The direct nature of the measurement technology helps to reduce uncertainties that have plagued these sites in the past. The ESTCP demonstrations provided an excellent venue for stakeholder and end-user exposure because both of the site teams integrated the technology into their regulatory programs and used it in the decision-making process. The results were available for review and comment to relevant local, state, and federal regulators and stakeholders. The California (Cal)/EPA will provide formal review and comment on the Trident probe and UltraSeep demonstrations through the Cal/EPA Hazardous Waste Technology Demonstration Program.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The technologies demonstrated included recently commercialized versions of a screening probe for determining where groundwater may be discharging (the Trident probe, Figure 1), and an integrated seepage meter and water sampling system for quantifying discharge rates and chemical loading (the UltraSeep, Figure 2). The commercial versions of the technologies were produced by the Oceanscience Group of Carlsbad, California, in cooperation with Zebra-Tech Ltd., Nelson, New Zealand. Detailed operational manuals for the commercial systems are included in Chadwick and Hawkins, 2004.

The Trident probe is a direct-push, integrated temperature sensor, conductivity sensor, and porewater sampler developed to screen sites for areas where groundwater may be discharging to a surface water body (Chadwick et al., 2003b). Differences in observed conductivity and temperature indicate areas where groundwater discharge is occurring. The integral porewater sampler can rapidly confirm the presence of freshwater or other chemical constituents.

The UltraSeep system is an integrated seepage meter and water sampling system for quantifying discharge rates and chemical loading from groundwater flow to coastal waters. Traditional seepage technology was modified and improved to include automated multiple sample collection and continuous flow detection with ultrasonic flow meters. The resultant instrument, the UltraSeep, makes direct measurements of advective flux and contaminant concentration at a particular location (Chadwick et al., 2003b).

The data produced are time series, over tidal cycles of groundwater flow contaminant concentration, and associated sensor data. These data allow an accurate determination of the presence or absence of groundwater flow and associated contaminant flux from a terrestrial site into a bay or estuary.

There are three primary application areas for the Trident probe and UltraSeep technologies. These include (1) assessment of contaminant discharge to surface water associated with groundwater plumes from terrestrial hazardous waste sites, (2) assessment of contaminant discharge to surface water associated with groundwater leachate from coastal landfills, and (3) assessment of remedy effectiveness for treatment of contaminated groundwater at coastal sites. Other potential applications of the technology include assessment of pore fluid dynamics for contaminated sediments and evaluation of water budgets for water management applications.

2.2 PROCESS DESCRIPTION

A Trident probe survey is conducted by inserting the probe into the seabed (seabed is used here to mean the bottom of the ocean, estuary, or bay) from a small boat. The Trident probe has an integral hydraulic hammer to assist in penetrating harder beds. The resulting survey data are used to develop spatial maps indicating areas where groundwater may be discharging and to determine locations for deployment of the UltraSeep meter for longer term measuring and water sampling.

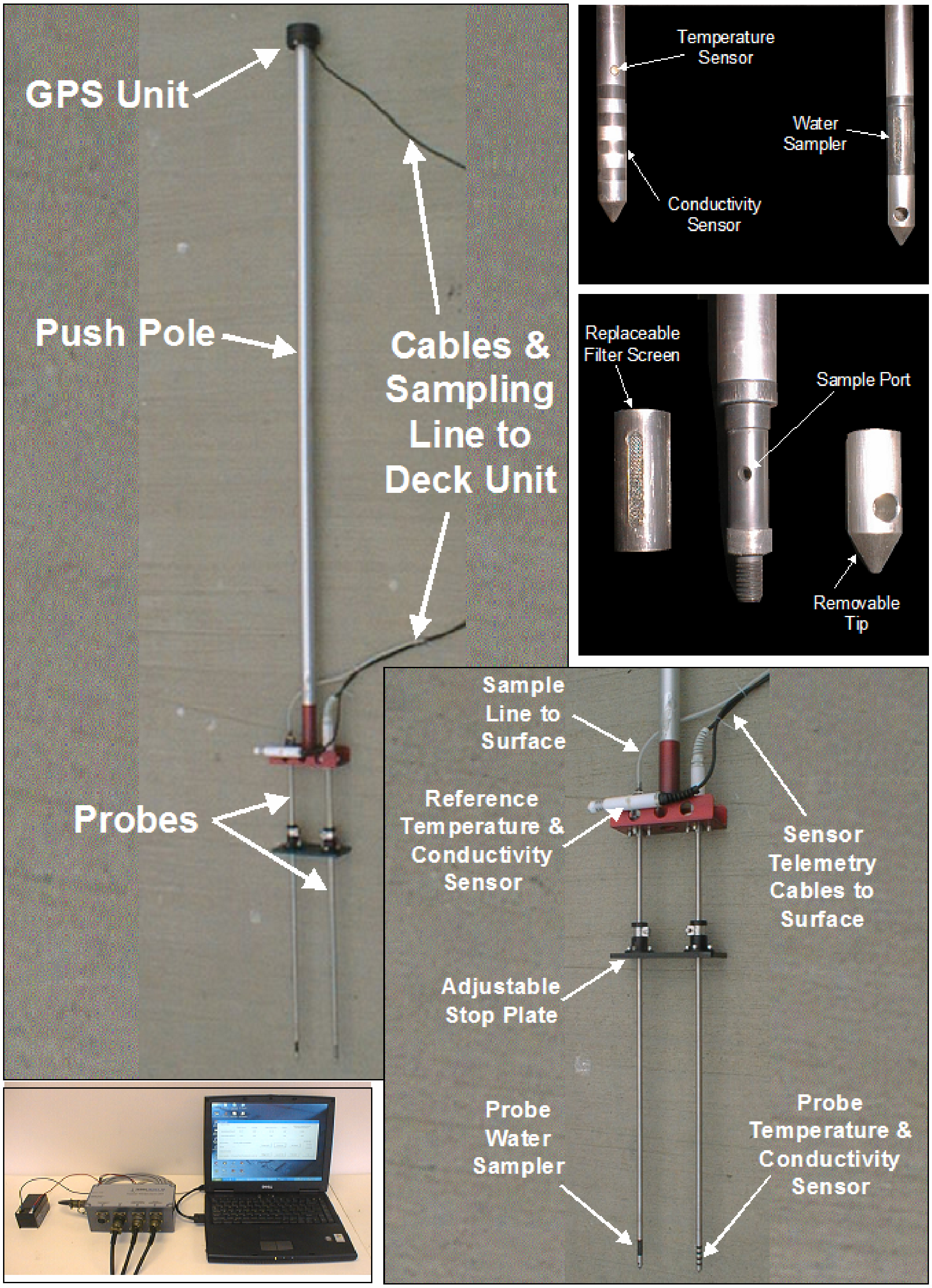

Figure 1. Complete Trident Probe Showing Sensor and Water Sampling Probes, Push Pole, and Global Positioning System (GPS) Unit.

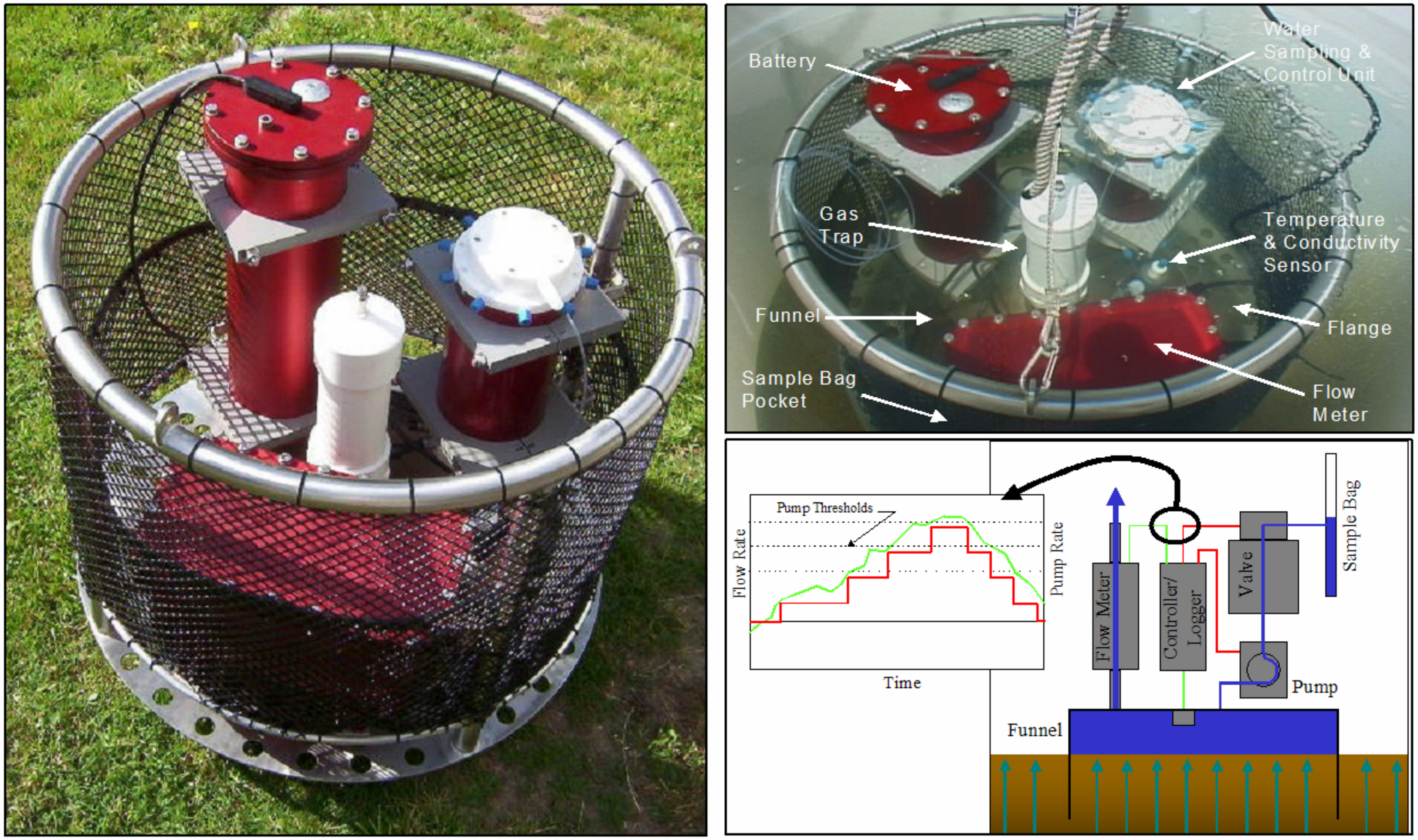

Figure 2. The Oceanscience Group Commercial UltraSeep System.

In operation, Trident probe can be deployed in several ways, depending primarily on the depth of the site. In very shallow water (0 to 1 m), the operator simply walks or wades to the sampling station, and manually pushes the probe to the desired depth, which is the expected method for the NSA Panama City demonstration. Experience has shown that the probe pushes easily by hand to a depth of about 30 cm. An air hammer or a slide hammer can then be used to complete the push, if necessary.

In water of moderate depths (1 to 10 m), the probe is easily deployed from a small boat using the push rod in combination with the air hammer. It is important that the boat be well anchored to minimize lateral loading on the probe during the insertion. In deeper water (>10 m), the probe can be deployed by a diver, or can be attached to a landing frame.

In operation, the UltraSeep meter is lowered to the bottom directly from a boat or by divers using a lift-bag. Once the unit is settled on the bottom, the seal is checked by divers. A period of 2 to 3 hours is generally allowed to ensure that any transient seepage response associated with the deployment activities has dissipated. The data logger/controller (DLC) unit then initiates logging and control functions.

At coastal sites, a typical deployment runs over a 12- to 24-hour period to capture an entire semi-diurnal or diurnal tidal cycle, although the system can be run continuously for up to about 4 days. During this period, the seepage rate is continuously monitored, and up to 10 water samples are collected for chemical analysis. At the end of the deployment, the meter is recovered using a lift line or by driver assistance to the recovery boat.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Prior to the ESTCP demonstration of the commercial systems, the Trident probe and UltraSeep had been tested at five field sites. The five field tests represented a range of potential conditions and applications, including assessment of a terrestrial hazardous waste site, remedy effectiveness for a capping system, and pore fluid dynamics for a contaminated sediment site. The sites were as follows:

1. Anacostia River, Washington, D.C.
2. Eagle Harbor, Washington
3. North Island Naval Air Station, California
4. Pearl Harbor, Hawaii
5. Naval Construction Battalion Center Davisville, Rhode Island

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.4.1 Advantages of the Technology

Initial results from the new Trident probe and UltraSeep meter show that groundwater exchange at coastal sites can be an important process in the transport and fate of dissolved contaminants that emanate from terrestrial waste sites. Advantages of the Trident probe and UltraSeep technologies over traditional technologies include the ability to perform the following:

- Identify the most likely areas of groundwater discharge
- Map these areas rapidly over large spatial areas
- Determine CoC concentrations at the point of exposure
- Collect continuous seepage records to document the dynamics of the groundwater discharge process
- Collect water samples in proportion to the seepage rate, enabling the direct quantification of the chemical loading associated with the groundwater discharge.

2.4.2 Limitations of the Technology

The Trident probe has undergone a series of laboratory and initial field tests, providing confidence that the system will perform well during the demonstration phase (Chadwick et al., 2002). The potential limitations that we anticipate for the Trident probe, based on experience from the initial testing phase, are as follows:

- Potential inability to collect water in fine-grained sediments
- Potential absence of a temperature or conductivity contrast in the impinging groundwater
- Potential breakage of the probes on rocks or debris.

As with the Trident probe, the success of the initial tests for the UltraSeep provide a high level of confidence for success during the ESTCP demonstration phase. The primary technical risks that we anticipate for the UltraSeep include the following:

- Limited chemical detection due to dilution in the seepage funnel
- Confounding effects of chemical diffusion into the funnel that could be interpreted as advection
- Logistical problems associated with site access and leaving equipment deployed on site for a few days.

2.4.3 Alternative Technologies

To our knowledge, there is no comparable alternative technology to the Trident probe, which integrates groundwater detection sensors with water sampling in offshore sediments. The most commonly used technology for this application would be installing a network of temporary mini-wells (or piezometers). Water levels are measured with a pressure manometer and samples are recovered using a peristaltic pump. The most commonly used technologies for assessing seepage are piezometers and a “Lee” meter (Lee, 1977).

Advantages of piezometers include relatively low costs and the ability to resample the same location over time. However, piezometers do not provide a direct measurement of seepage; rather, the flow rate must be inferred from the measured water level difference between the piezometer and the surface water.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Performance objectives for the Trident probe and UltraSeep technologies provide a basis for evaluating the success of the systems during the demonstration. As described in Section 1, the performance of the Trident probe and UltraSeep technologies can be categorized as described in the following subsections.

3.1.1 Trident Probe

The Trident probe can perform the following tasks:

- Mobilize, operate, and demobilize the equipment
- Obtain field measurements within specified measurement quality objectives
- Obtain field and equipment blanks that are free of contamination
- Collect valid water samples of sufficient volume to characterize CoC distributions
- Produce spatial maps of groundwater tracers at the sites of interest
- Identify the presence or absence and areas of potential groundwater CoC discharge to surface water.

3.1.2 UltraSeep

The UltraSeep can perform the following tasks:

- Mobilize, operate, and demobilize the equipment
- Obtain field measurements within specified measurement quality objectives
- Obtain field and equipment blanks that are free of contamination
- Obtain valid, continuous seepage flow records over required time periods
- Obtain valid discharge water samples of sufficient volume to characterize CoC concentrations during periods of positive seepage.

3.2 SELECTING TEST SITES

A number of sites were evaluated as candidate demonstration sites. Sites were selected on the basis of specific requirements and preferable characteristics. In general, the preferred site was adjacent to a surface water body and had an identified contaminated groundwater plume with the following characteristics:

- Easy site accessibility
- Minimal interference with ongoing site operations
- Groundwater discharge rates >1 cm/day
- Significant temperature and/or salinity contrast between groundwater and surface water (>1° C or >1 ppt)
- Groundwater CoC distinctive from background surface water or interstitial water concentrations

- Site manager and regulatory buy-in
- Appropriate timing relative to status of site assessment.

On the basis of the factors listed above, the Panama City site was selected (Figure 3). Final selection for the second demonstration site was completed in December 2004. The site selected for the second demonstration was NTC Orlando, OU 4 (Figure 4). The site was selected based on its compliance with the criteria above and its contrast to the Panama City site used for the first demonstration.

3.3 TEST SITE HISTORY/CHARACTERISTICS

3.3.1 NSA Panama City

Investigation and remediation of contaminated media at Naval Support Activity (formerly Coastal Systems Station) Panama City is being performed under the Corrective Action Program of RCRA and the Hazardous and Solid Waste Amendments (HSWA) (Jordon, 1987; Southern Division Naval Facilities Engineering Command, 2002; Southern Division Naval Facilities Engineering Command, 2004). AOC 1 was the primary site identified where contaminated groundwater could be discharging to the surface water of adjacent St. Andrews Bay (Southern Division Naval Facilities Engineering Command, 2002; Southern Division Naval Facilities Engineering Command, 2004).

For 1,1-dichloroethylene (DCE) at AOC 1, a direct push technology (DPT) investigation in 2001 and monitoring well sampling in 2002 and 2003 showed exceedences near St. Andrews Bay of the Florida Marine SWCTL of 3.2 ug/L. The DPT investigation indicated that 1,1-DCE is completely depleted in the source zone, but it has migrated laterally to the edge of St. Andrews Bay at concentrations slightly above the surface water cleanup target levels (SWCTL). Since there are no wells or DPT locations in the bay, it was unknown where the discharge to surface water would occur.

Theoretically, it was possible that the contaminants would attenuate (through biodegradation, dilution, and dispersion) prior to reaching surface water, especially since the source had been eliminated, and the measured concentrations were close to the SWCTL. Results from the Trident probe and UltraSeep were used to evaluate this hypothesis.

3.3.2 NTC Orlando

NTC Orlando was identified as an installation for closure by the Base and Realignment Commission. OU 4 Study Areas (SA) 12, 13, and 14 were first investigated during a Base Realignment and Closure (BRAC) Environmental Baseline Survey (EBS) in 1994. Water samples collected along the lakeshore contained chlorinated solvents including PCE, TCE, cis-DCE, 1,1-DCE, and vinyl chloride (VC). Lake sediment samples also contained PCE and TCE. A dual recirculation well remediation system was installed in the spring of 1998 as an interim remedial action (IRA) to prevent migration of contaminated groundwater to Lake Druid. The effectiveness of the dual recirculation well system was evaluated in May 2000 as a result of ongoing operational difficulties. The evaluation determined that the dual recirculation well system could not meet the IRA objective of plume containment.

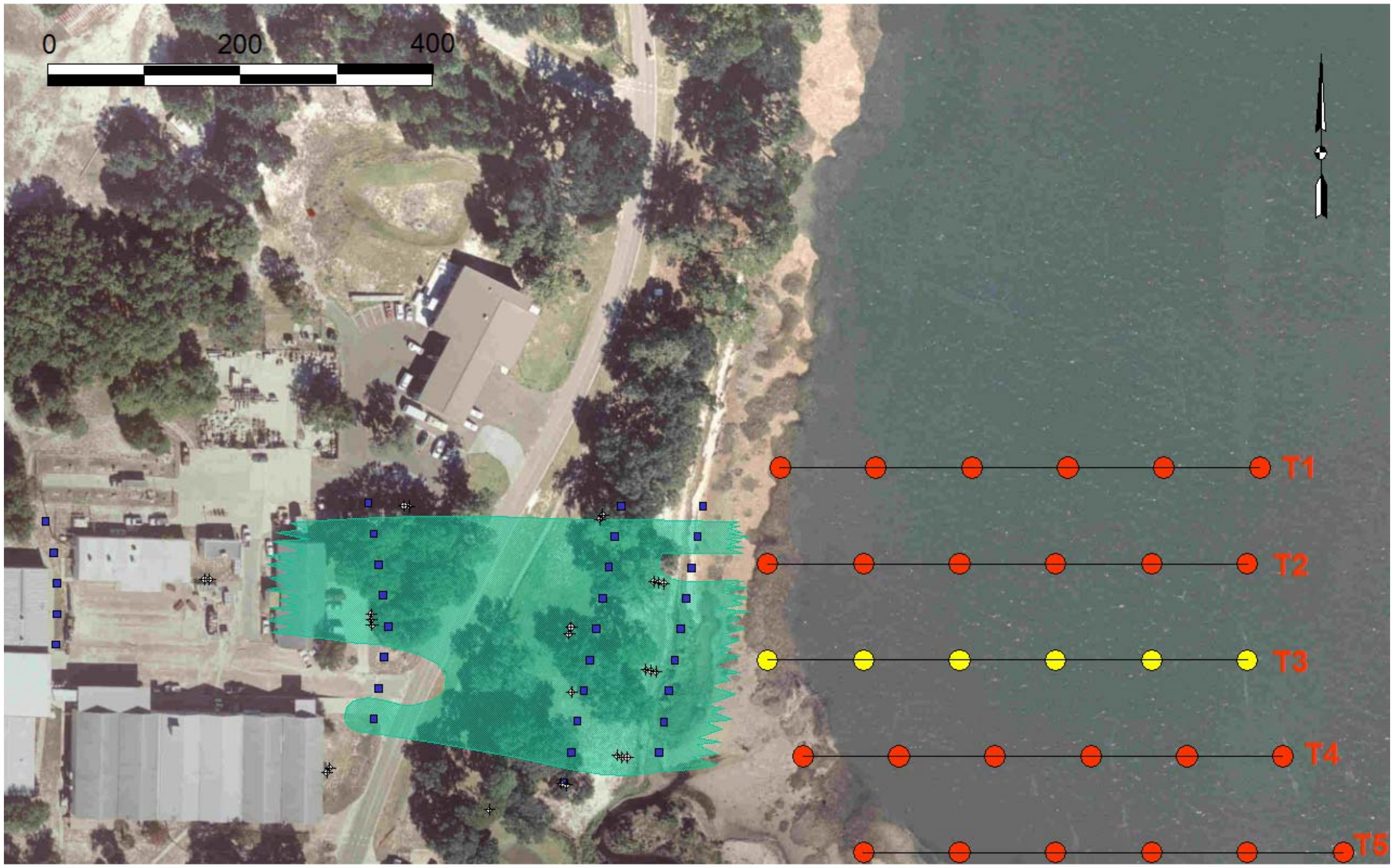

Figure 3. Sampling Design for the Trident Probe Survey at NSA Panama City Showing Historical Monitoring Wells, DPT Locations, Approximate Location of the 1,1-DCE Plume, and Proposed Offshore Transect Locations. (Red circles indicate stations for Trident probe and surface water sampling; yellow circles indicate stations for Trident probe, surface water, and validation.)

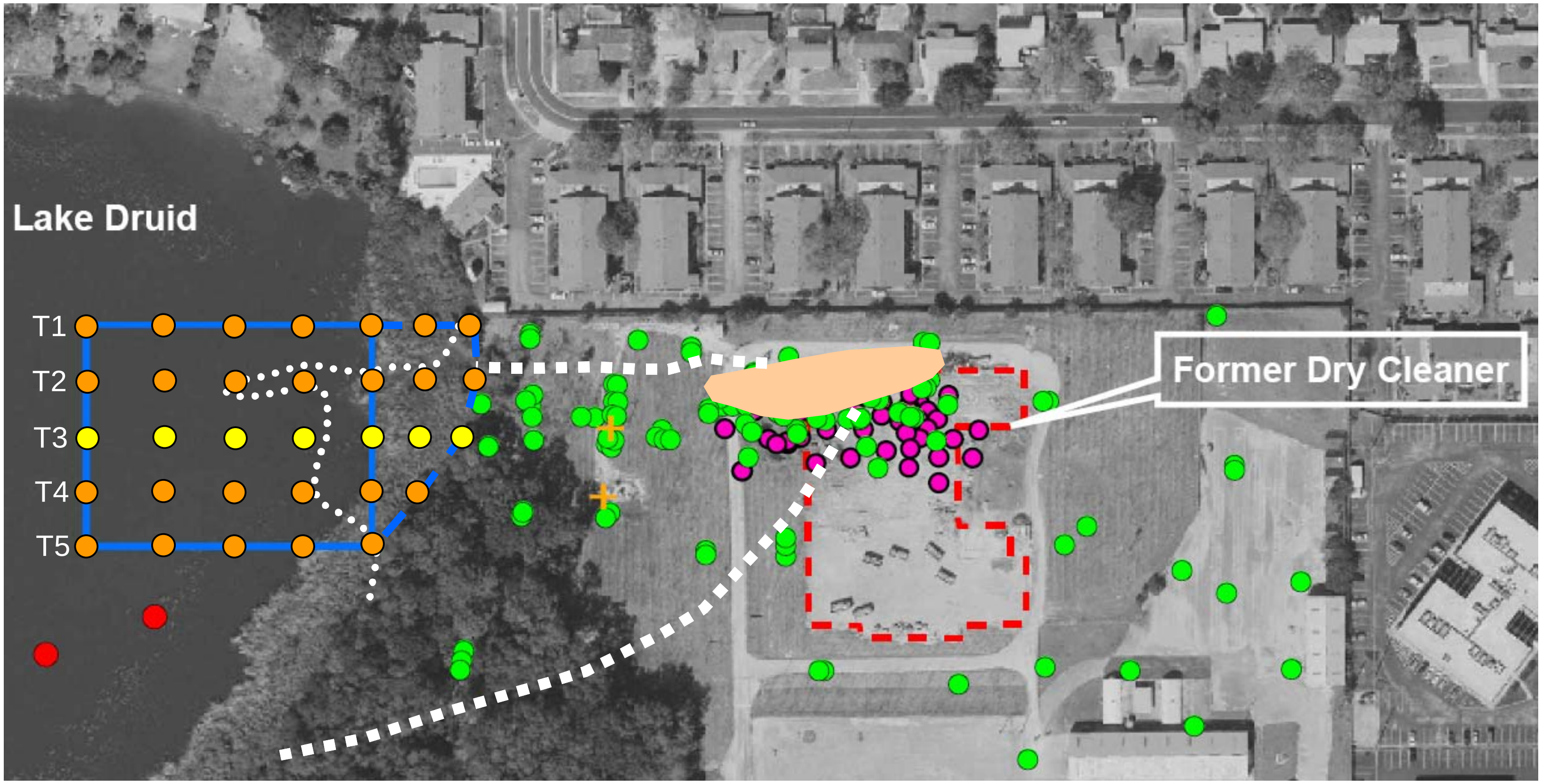

Figure 4. Sampling Design for the NTC Orlando Lake Druid Study Area
(The orange and yellow dots are the proposed Trident sampling stations. The yellow dots indicate transect T3, where the validation piezometers will be installed.)

As a result, the existing facilities were dismantled and the system was modified to operate as a groundwater extraction and treatment system (pump-and-treat system) with ex-situ air stripping prior to discharge to the City of Orlando sanitary sewer system. The working hypothesis for the demonstration was to determine if significant discharge would still occur to Lake Druid with the treatment system shutdown.

3.4 PHYSICAL SETUP AND OPERATION

Demonstration preparation included logistics, sampling system decontamination, and system setup. Logistics included coordinating the demonstration with the Navy site personnel, ensuring that the surface vessel was properly equipped with all necessary equipment (including sampling equipment), and coordinating the schedule of the demonstration with all appropriate personnel and authorities. System decontamination and setup included various tasks to be performed on the Trident probe and UltraSeep prior to deployment as described below. The NSA Panama City Trident probe survey commenced August 9, 2004, and extended to August 15, 2004 (Table 1). The UltraSeep survey commenced August 16, 2004, and extended to August 22, 2004 (Table 2). The NTC Orlando Trident probe survey commenced July 27, 2005, and extended to June 5, 2005 (Table 3). The UltraSeep survey commenced July 3, 2005, and extended to July 11, 2005 (Table 4).

3.5 SAMPLING/MONITORING PROCEDURES

The sampling and monitoring requirements for the demonstration of the Trident probe and UltraSeep technologies at NSA Panama City and NTC Orlando were encompassed in the data quality objectives (DQOs). Sampling procedures associated with these DQOs are described in the demonstration's Quality Assurance Project Plan (Chadwick and Hawkins, 2004; Chadwick and Hawkins, 2005). Basic procedures are summarized below.

3.5.1 Trident Probe

The Trident probe is used in a survey mode of operation. Field operations included wading or small-boat deployment (depending on water depth), direct push of the probe, sensor sampling, water sampling, and cleaning of the water sampler between stations. Field operations generally required the labor of two qualified technicians, the quality assurance (QA) officer, and the principal investigator (PI) for the period of operations.

3.5.2 UltraSeep

The UltraSeep is used in a survey mode of operation. Field operations included wading, diving, and small-boat deployment (depending on water depth), UltraSeep installation, sensor sampling, water sampling, and cleaning of the water sampling system between deployments. Field operations generally required the labor of three qualified technicians (dive certified, if necessary), the QA officer, and the PI for the period of operations.

Table 1. Field Schedule for the Trident Probe Survey, Including Surface Water and Validation Sampling (NSA Panama City).

Trident Task	Day of CY04								
	7-Aug	8-Aug	9-Aug	10-Aug	11-Aug	12-Aug	13-Aug	14-Aug	15-Aug
Stage Trident	■	■							
Stage Trident validation piezometers	■	■							
Install Trident validation piezometers			■						
Conduct Trident survey				■	■	■			
Collect Trident validation samples				■	■	■			
Collect surface water samples				■	■	■			
On-site VOC analysis				■	■	■	■		
On-site data analysis					■	■	■	■	
Select UltraSeep stations								■	
Demobilize Trident								■	■
Demobilize Trident validation equipment								■	■

Table 2. Field Schedule for the UltraSeep Survey Validation Sampling (NSA Panama City).

UltraSeep Task	Day of CY04								
	13-Aug	14-Aug	15-Aug	16-Aug	17-Aug	18-Aug	19-Aug	20-Aug	21-Aug
Stage UltraSeep	■	■							
Stage UltraSeep validation piezometers	■	■							
UltraSeep validation piezometers #1			■	■					
UltraSeep deployment #1			■	■					
UltraSeep validation peizometers #2					■	■			
UltraSeep deployment #2					■	■			
UltraSeep validation piezometers #3							■	■	
UltraSeep deployment #3							■	■	
Ship UltraSeep and validation samples				■		■		■	
Demobilize UltraSeep								■	■
Demobilize UltraSeep validation equipment								■	■

Table 3. Field Schedule for the NTC Orlando Trident Probe Survey, Including Surface Water and Validation Sampling.

Trident Task	Day of CY05								
	27-Jun	28-Jun	29-Jun	30-Jun	1-Jul	2-Jul	3-Jul	4-Jul	5-Jul
Stage Trident									
Stage Trident validation piezometers									
Install Trident validation piezometers									
Conduct Trident survey									
Collect Trident validation samples									
Collect surface water samples									
On-site VOC analysis									
On-site data analysis									
Select UltraSeep stations									
Demobilize Trident									
Demobilize Trident validation equipment									

Table 4. Schedule for the NSA Orlando UltraSeep Survey Validation Sampling.

UltraSeep Task	Day of CY05								
	3-Jul	4-Jul	5-Jul	6-Jul	7-Jul	8-Jul	9-Jul	10-Jul	11-Jul
Stage UltraSeep									
Stage UltraSeep validation piezometers									
UltraSeep validation piezometers #1									
UltraSeep deployment #1									
UltraSeep validation peizometers #2									
UltraSeep deployment #2									
UltraSeep validation piezometers #3									
UltraSeep deployment #3									
Ship UltraSeep and validation samples									
Demobilize UltraSeep									
Demobilize UltraSeep validation equipment									

3.6 ANALYTICAL PROCEDURES

The primary CoC at the NSA Panama City site was 1,1-DCE. The analysis of samples for 1,1-DCE and other target VOCs were analyzed using EPA standard method 8260B (EPA, 1996). The primary CoC at the Orlando site was tetrachloroethene (PCE). Samples of PCE and other target VOC were analyzed using EPA standard method 8260B (EPA, 1996). Other testing methods selected for the study included the Trident Underwater Groundwater Seep Detection System, the UltraSeep Seepage Monitor System, and associated validation testing. Methodologies for these components of the study are described in detail in Chadwick et al. (2003b), Chadwick and Hawkins (2004), Chadwick and Hawkins (2006), and Chadwick and Hawkins (2007).

3.6.1 VOC Analysis

VOC samples from the Trident probe, UltraSeep, surface water, and validation surveys were all analyzed following EPA method 8260B using rapid turnaround at a remote laboratory (NSA Panama City), or using an on-site mobile laboratory (Orlando). Details of the method, analytical instrumentation, matrix considerations, concentration units, statistical procedures and detection limits are all described in EPA (1996).

3.6.2 Water Quality Analysis

Subsamples of the Trident probe, UltraSeep, surface water, and validation samples were analyzed on site using a Myron Model 6b Water Quality Analyzer. The analyzer detects temperature, conductivity, pH, oxidation reduction potential (ORP), and total dissolved solids (TDS). The cell volumes for the measurement are 1.2 ml (pH/ORP) and 5 ml (temperature/conductivity/TDS). Accuracy and precision levels for the meter were in accordance with the manufacturer’s specifications. The meter was calibrated to certified National Institute of Standards and Technology (NIST) standards prior to each survey.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

Performance during the demonstration was assessed based on achieving the performance criteria described in Section 3.2. Performance results are summarized in Tables 5 through Table 8. Confirmation was achieved by meeting the stated criteria for each objective. The confirmation methods used to determine if the performance criteria were met are described for each objective. The PI confirmed these criteria through a process of observation, testing, inspection, analysis, review, best professional judgment, and documentation. For the Trident probe, performance data were collected to demonstrate the ability to perform the following tasks:

- Mobilize, operate, and demobilize the equipment
- Obtain field and equipment blanks that are free of contamination
- Collect valid water samples of sufficient volume to characterize CoC distributions
- Produce spatial maps of groundwater tracers at the sites of interest
- Identify the presence or absence and areas of potential groundwater CoC discharge to surface water.

For the UltraSeep, performance data were collected to demonstrate the ability to perform the following tasks:

- Mobilize, operate, and demobilize the equipment
- Obtain field measurements within specified measurement quality objectives
- Obtain field and equipment blanks that are free of contamination
- Obtain valid, continuous seepage flow records over required time periods
- Obtain valid discharge water samples of sufficient volume to characterize CoC concentrations during periods of positive seepage.

4.2 PERFORMANCE CRITERIA

Performance criteria for the Trident probe and UltraSeep technologies were based on the performance objectives described in the Demonstration Plan. The performance criteria are summarized in Tables 7 and 8, the Trident probe and UltraSeep technologies respectively.

4.2.1 Factors Affecting Technology Performance

4.2.1.1 <u>Trident Probe</u>

The Trident probe has undergone a series of laboratory and initial field tests, providing confidence that the system will perform well during the demonstration phase (Chadwick et al., 2002). The following potential limitations anticipated for the Trident probe are based on experience from the initial testing phase:

Table 5. Matrix Spike, Matrix Spike Duplicate, and Field Duplicate Results for Trident Probe VOC Samples.

Panama City - Trident Matrix Spike/Matrix Spike Duplicates												
Compound	8/12/2004			8/12/2004			8/13/2004			Control Limits		
	MS*	MSD**	RPD***	MS	MSD	RPD	MS	MSD	RPD	Lower	Upper	RPD
PCE	97	97	0	97	97	1	84	97	14	73	131	20
TCE	96	93	3	94	102	8	89	96	7	64	127	20
1,1-DCE	95	86	9	94	100	7	82	94	14	51	143	20
Compound	8/14/2004			8/17/2004			N/A			Control Limits		
	MS	MSD	RPD	MS	MSD	RPD	MS	MSD	RPD	Lower	Upper	RPD
PCE	119	96	**21**	98	99	2	-	-	-	73	131	20
TCE	**132**	97	**30**	102	100	2	-	-	-	64	127	20
1,1-DCE	126	90	**33**	98	91	8	-	-	-	51	143	20
Panama City - Trident Field Duplicates												
Compound	TD-T2-4-SS-A/B			TD-T4-2-SS-A/B			TD-T5-6-SS-A/B			Control Limits		
	1	2	RPD	1	2	RPD	1	2	RPD	RPD		
PCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
TCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
1,1-DCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
Compound	TD-T2-4-S-A/B			TD-T4-2-S-A/B			TD-T5-6-S-A/B			Control Limits		
	1	2	RPD	1	2	RPD	1	2	RPD	RPD		
PCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
TCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
1,1-DCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
Orlando - Trident Matrix Spike/Matrix Spike Duplicates												
Compound	6/30/2005			7/3/2005			7/3/2005			Control Limits		
	MS	MSD	RPD	MS	MSD	RPD	MS	MSD	RPD	Lower	Upper	RPD
PCE	98	90	8	103	108	5	113	104	9	56	138	20
TCE	103	98	5	104	111	7	110	107	3	50	147	20
cis-DCE	113	115	2	113	116	3	120	123	3	59	149	20
trans-DCE	109	105	4	112	116	3	119	121	2	41	157	20
VC	103	94	9	101	104	4	105	104	1	20	187	20
Compound	7/5/2005			7/6/2005			N/A			Control Limits		
	MS	MSD	RPD	MS	MSD	RPD	MS	MSD	RPD	Lower	Upper	RPD
PCE	106	106	0	101	104	3	-	-	-	56	138	20
TCE	113	116	2	116	110	5	-	-	-	50	147	20
cis-DCE	123	129	5	121	116	5	-	-	-	59	149	20
trans-DCE	130	133	3	122	118	3	-	-	-	41	157	20
VC	111	110	1	89	103	14	-	-	-	20	187	20
Orlando - Trident Field Duplicates												
Compound	TD-T3-3-PW			TD-T4-3-PW			TD-T5-1-PW			Control Limits		
	1	2	RPD	1	2	RPD	1	2	RPD	RPD		
PCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
TCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
cis-DCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
trans-DCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
VC	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
Compound	TD-T3-3-SW			TD-T4-3-SW			TD-T5-1-SW			Control Limits		
	1	2	RPD	1	2	RPD	1	2	RPD	RPD		
PCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
TCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
cis-DCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
trans-DCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
VC	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		

*MS = matrix spike **MSD = matrix spike duplicate *** RPD = relative percent difference

Table 6. Matrix Spike, Matrix Spike Duplicate, and Field Duplicate Results for UltraSeep VOC Samples.

Panama City - UltraSeep Matrix Spike/Matrix Spike Duplicates												
	8/17/2004			8/21/2004			N/A			Control Limits		
Compound	MS	MSD	RPD	MS	MSD	RPD	MS	MSD	RPD	Lower	Upper	RPD
PCE	98	99	2	80	84	5	-	-	-	73	131	20
TCE	102	100	2	80	87	8	-	-	-	64	127	20
1,1-DCE	98	91	8	73	76	4	-	-	-	51	143	20
Panama City - UltraSeep Field Duplicates												
Compound	SM-T4-4-B5			N/A			N/A			Control Limits		
	1	2	RPD	1	2	RPD	1	2	RPD	RPD		
PCE	<1.0	<1.0	0	-	-	-	-	-	-	30		
TCE	<1.0	<1.0	0	-	-	-	-	-	-	30		
1,1-DCE	<1.0	<1.0	0	-	-	-	-	-	-	30		
Orlando - UltraSeep Matrix Spike/Matrix Spike Duplicates												
Compound	7/7/2005			7/8/2005			N/A			Control Limits		
	MS	MSD	RPD	MS	MSD	RPD	MS	MSD	RPD	Lower	Upper	RPD
PCE	99	97	3	102	100	2	-	-	-	56	138	20
TCE	108	103	5	105	104	1	-	-	-	50	147	20
cis-DCE	116	111	4	125	129	3	-	-	-	59	149	20
trans-DCE	115	118	3	107	115	7	-	-	-	41	157	20
VC	99	100	1	103	100	3	-	-	-	20	187	20
Orlando - UltraSeep Field Duplicates												
Compound	SM-T3-7-B7			SM-T2-5-B6			SM-T2-3-B3			Control Limits		
	1	2	RPD	1	2	RPD	1	2	RPD	RPD		
PCE	<1.0	<1.0	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
TCE	<10	4.5	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
cis-DCE	470	500	6	6.4	7	9	1.6	1.4	13	30		
trans-DCE	<10	3	0	<1.0	<1.0	0	<1.0	<1.0	0	30		
VC	47	50.1	6	<1.0	<1.0	0	<1.0	<1.0	0	30		

Table 7. Performance Summary for Trident Probe.

Type	Criteria	Expected	Actual - Panama City	Actual - Orlando
Qualitative	Mobilize, operate, and demobilize equipment	As specified in the Demo Plan		
	• Precalibrate sensors	Within specifications	✓ Calibrated within spec prior to shipment	✓ Calibrated within spec prior to shipment
	• Preclean sampler	Based on CoC	✓ Precleaned for VOCs	✓ Precleaned for VOCs
	• Ship to site	Arrive in working order	✓ Arrived in working order	✓ Arrived in working order
Quantitative	Rapidly position, deploy, operate, and reposition the equipment	As specified in the Demo Plan		
	• Cond/Temp/Position	<30 min/station sensor only	NA - sensor recorded during water sampling	Average 13 min/station
	• Including porewater	<60 min/station including water	Average 50 min/station (32 min/station best day)	Average 56 min/station (including storm delays)
Quantitative	Push probe to required/design depth	Target: 60 cm	35 of 35 stations met target	37 of 37 stations met target
Quantitative	Obtain field measurements within specified measurement quality objectives	As specified in the measurement quality objectives (MQOs in the Quality Assurance Project Plan (QAPP)		
	• Conductivity	Accuracy: ≤2% FS Precision: ≤2% mS/cm	Probe Acc: 0.1 - 1.6% Ref Acc: 0.0 - 1.0% Probe Prec: 0.0 - 0.21 mS/cm Ref Prec: 0.0 - 0.12 mS/cm	Probe Acc: 0.1 - 0.8% Ref Acc: 0.1 - 1.3% Probe Prec: 0.0 - 0.42 mS/cm Ref Prec: 0.0 - 0.03 mS/cm
	• Temperature	Accuracy: ≤0.1 C Precision: ≤0.05 C	Probe Acc: 0.0 - 0.01 C Ref Acc: 0.0 - 0.01 C Probe Prec: 0.0 - 0.04 C Ref Prec: 0.03 - 0.05 C	Probe Acc: 0.0 - 0.05 C Ref Acc: 0.0 - 0.01 C Probe Prec: 0.01 - 0.03 C Ref Prec: 0.0 - 0.01 C
	• VOCs - detection limit	PQL: 1-5 ug/L	PQL: 1-5 ug/L	PQL*: 1-20 ug/L Increased PQL due to high DCE concentrations required dilution for 2 Trident samples and 1 piezometer sample
	- analytical performance	Surrogate Spike Recovery within limits	717 of 724 analyses w/i control limits 4>UCL, 3<LCL	540 of 541 analyses w/i control limits 1<LCL (Lab blank)
	- bias	Matrix spike recovery within limits	29 of 30 analyses w/i control limits[1] 1>UCL	50 of 50 analyses w/i control limits[2]
		Lab control spike recovery within limits	24 of 24 analyses w/i control limits[1]	39 of 40 analyses w/i control limits[2] 1>UCL
	- precision	MSDs within limits	12 of 15 analyses w/i control limits[1] 3>RPDL (all in one sample)	25 of 25 analyses w/i control limits[2]
		Field Dups w/i limits	18 of 18 analyses w/i control limits[1]	30 of 30 analyses w/i control limits[2]

Table 7. Performance Summary for Trident Probe. (continued)

Type	Criteria	Expected	Actual - Panama City	Actual - Orlando
Quantitative	Collect valid water samples of sufficient volume to characterize CoC distributions	As specified in the MQOs in the QAPP		
	• VOCs by 8260B	Volume: >80 ml for every station Validation: comparable to shallow piezometer samples	35 of 35 stations sufficient volume Trident and piezometer samples in agreement – not detected (ND) for all target analytes at all validation stations	36 of 37 stations sufficient volume—no sample at 1 station (T3-1) due to high fines content Trident and piezometer samples in agreement—probabilities for 2-sided test using 1/2 PQL All stations: no difference P=0.28 Station T3-6: no difference P=0.57 Station T3-7: no difference P=0.31 cis-DCE: no difference P =0.35 TCE: no difference P=0.18
	• Water quality by UltraMeter	Volume: >40 ml for every station	35 of 35 stations sufficient volume	36 of 37 stations sufficient volume—no sample at 1 station (T3-1) due to high fines content
Quantitative	Obtain trip and equipment blanks that are free of contamination	As specified in the MQOs in the QAPP		
	• Equipment rinsate	ND or comparable to rinse water	15 of 15 analyses ND[1]	30 of 30 analyses ND[2]
	• Trip blank	ND or comparable to pre-trip	15 of 15 analyses ND[1]	NA - analyzed on site
Qualitative	Produce spatial maps of groundwater tracers at the sites of interest	Based on MQOs for completeness as specified in the QAPP	Successfully produced spatial maps for discharge indicators and VOCs	Successfully produced spatial maps for discharge indicators and VOCs
	• Conductivity	Completeness > 95%	Conductivity completeness: 100%	Conductivity completeness: NA (fresh)
	• Temperature	Completeness > 95%	Temperature completeness: 100%	Temperature completeness: 100%
	• VOCs	Completeness > 95%	VOC completeness: 100%	VOC completeness: 97%
Qualitative	Identify the presence or absence and areas of potential groundwater CoC discharge to surface water	If present, isolate discharge areas based on temperature and/or conductivity contrast and/or presence of CoCs	Isolated potential discharge zones based on conductivity contrast. CoCs were attenuated below level of detection	Isolated potential discharge zones primarily based on temperature. CoC distribution corresponded closely to identified discharge zones

[1]For target analytes PCE, TCE, and 1,1-DCE
[2]For target analytes PCE, TCE, cis-DCE, trans-DCE, and VC
*PQL practical quantitation limit
LCL lower control limit
UCL upper control limit

Table 8. Performance Summary for UltraSeep System.

Type	Criteria	Expected	Actual - Panama City	Actual - Orlando
Qualitative	Mobilize, operate, and demobilize equipment	As specified in the Demo Plan		
	• Precalibrate sensors	Within specifications	✓ Calibrated within spec prior to shipment	✓ Calibrated within spec prior to shipment
	• Preclean sampler	Based on CoC	✓ Precleaned for VOCs	✓ Precleaned for VOCs
	• Ship to site	Arrive in working order	✓ Arrived in working order	✓ Arrived in working order
Quantitative	Position, deploy, operate, and reposition the equipment over site-relevant time period	As specified in the Demo Plan		
	• Deployment period	Complete tidal cycle or 24 hours	Completed 25-hour tidal cycle at each target station	Completed 24-hour deployment at each target station
Quantitative	Obtain trip and equipment blanks that are free of contamination	As specified in the MQOs in the QAPP		
	• Equipment rinsate	ND or comparable to rinse water	9 of 9 analyses ND[1]	14 of 15 analyses ND[2] cis-DCE>PQL in 1 blank (1.8 ug/L)
	• Trip blank	ND or comparable to pre-trip	6 of 6 analyses ND[1]	NA—analyzed on site
Quantitative and Qualitative	Obtain valid, continuous seepage flow records over required time periods	Based on MQOs for completeness as specified in the QAPP	Successfully obtained valid, continuous seepage flow records over complete tidal cycle	Successfully obtained valid, continuous seepage flow records over complete tidal cycle
	• Flow	Completeness > 95% Validation: qualitatively comparable to level logging piezometers	Flow completeness: 100% UltraSeep and piezometer samples in general agreement - Both systems indicate discharge at target stations - Mean discharge rates agree within a factor of about 2	Flow completeness: 100% UltraSeep and piezometer samples in general agreement - Both systems indicate discharge at target stations - Mean discharge rates agree within a factor of about 2 - Both systems indicate same spatial trend decreasing with distance from shore

Table 8. Performance Summary for UltraSeep System. (continued)

Type	Criteria	Expected	Actual - Panama City	Actual - Orlando
Quantitative	Obtain valid discharge water samples of sufficient volume to characterize CoC concentrations during periods of positive seepage	As specified in the MQOs in the QAPP		
	• VOCs by 8260B	Volume: > 80 ml Validation: comparable to shallow piezometers	- 17 of 17 samples sufficient volume[3] - UltraSeep and piezometer samples in agreement—ND for all target analytes at all validation stations	- 29 of 29 samples sufficient volume[3] - UltraSeep and piezometer samples in agreement—probabilities for 2-sided test All Stations: no difference P=0.37 Station T2-3: no difference P=0.27 Station T2-5: no difference P=0.36 Station T3-7: no difference P=0.31

[1]For target analytes PCE, TCE, and 1,1-DCE
[2]For target analytes PCE, TCE, cis-DCE, trans-DCE, and VC
[3]Some samples composited to achieve sufficient volume in accordance with Demo Plan

- Potential inability to direct-push the probe to the desired subsurface depth
- Potential inability to collect water in fine-grained sediments
- Potential absence of a temperature or conductivity contrast in the impinging groundwater
- Potential confounding presence of a temperature or conductivity contrast not associated with groundwater discharge
- Potential breakage of the probes on rocks or debris.

4.2.1.2 <u>UltraSeep</u>

As with the Trident probe, the success of the initial tests for the UltraSeep provided a high level of confidence for success during the ESTCP demonstration phase. The primary technical risks anticipated for the UltraSeep included the following:

- Limited chemical detection due to dilution in the seepage funnel
- Inability to collect water samples due to low discharge rates
- Interference of the flow measurements due to gas discharge from the sediments
- Logistical problems associated with site access and leaving equipment deployed on site for a period of a few days.

4.3 DATA ASSESSMENT

4.3.1 Trident Probe Validation Analysis

Validation measurements for comparison with the Trident probe water sample results were developed using piezometers installed at a subset of the Trident probe stations (Figure 1). Water samples were collected synoptically from the Trident probe and the adjacent piezometer. VOC concentrations and water quality characteristics were compared statistically to assess the general level of agreement or disagreement between the Trident probe samples and the validation samples collected with the piezometer.

4.3.2 Trident Probe Survey Results—NSA Panama City

The Trident probe was used to map the surface and subsurface distribution of temperature, conductivity, VOC, and water-quality characteristics at 30 stations (Figure 3). Variability within stations was assessed based on triplicate station deployments at station T3-3. Field sample variability was assessed based on field duplicate samples collected at approximately 10% of the stations. The Trident probe sampling validation was based on piezometers installed to a depth of 2 ft along the T3 transect.

4.3.2.1 <u>Trident Probe Conductivity and Temperature Mapping</u>

Subsurface Trident probe conductivity and temperature measurements were taken at a depth of 2 ft below the sediment surface, and surface water measurements were taken in the overlying surface water within 1 ft of the sediment surface. Each reading represented the average of six to seven individual measurements recorded at the same station. Subsurface conductivity ranged from a low of 5.8 at station T4-4 to a high of 15.3 at station T2-1. Subsurface temperature ranged from a low of 28.6 at station T4-4 to a high of 30.2 at station T2-1.

During the summer, it was expected that areas of groundwater discharge would be characterized by relatively lower conductivity and temperature. Based on the Trident conductivity mapping, three areas were identified as potential regions of groundwater discharge (Figure 3-6). These areas included stations T1-3, T3-3, T4-4, and T5-4. Of the three, T4-4 showed the strongest groundwater signal. Based on the conductivity mapping, the zone of discharge appeared to be limited to a band extending parallel to shore between about 100 to 300 ft offshore.

The low conductivity at these stations was confirmed by water quality analysis of the water samples collected with the Trident probe. In general, the temperature differences across the site proved to be too small to be useful in identifying groundwater discharge zones. The only exception was T4-4, which showed a clearly identifiable lower temperature relative to other areas.

4.3.2.2 Trident Probe VOC Mapping

Subsurface VOC samples were collected at a depth of 2 ft below the sediment surface, and surface water samples were collected within 1 ft above the sediment surface. The primary CoC for AOC 1 was DCE. All VOC analytes, including DCE at all Trident probe stations, were below the PQL. Concentrations above the method detection limit (MDL), but below the PQL, were measured for m,p-Xylene and naphthalene in the surface water at station T1-5, and for naphthalene in the subsurface water at station T5-6. No detectable DCE or other VOC were measured in the subsurface or surface water in the areas of groundwater discharge identified with the Trident probe sensors (Figure 7).

4.3.2.3 Trident Probe Validation Piezometers

Validation of the Trident probe sampling was conducted based on piezometers installed to a depth of 2 ft along the T3 transect (Figure 8). All VOC analytes, including DCE at all Trident validation piezometer stations, were below the PQL and MDL. No detectable DCE or other VOC were measured in the subsurface water in the areas of groundwater discharge identified with the Trident sensors. The results from the piezometers validated the results obtained from the Trident probe.

4.3.3 Trident Probe Survey Results—NTC Orlando

The Trident probe was used to map the surface and subsurface distribution of temperature, conductivity, VOC, and water quality characteristics at 31 stations (Figure 4). Variability within stations was assessed based on triplicate station deployments at station T3-5. Field sample variability was assessed based on field duplicate samples collected at approximately 10% of the stations. Validation of the Trident sampling was conducted based on piezometers installed to a depth of 2 ft along the T3 transect. Results for the Trident probe survey, including conductivity and temperature mapping, are discussed in Sections 4.3.3.1 through 4.3.3.3.

4.3.3.1 Trident Probe Conductivity and Temperature Mapping

Subsurface conductivity was too low to be detected by the Trident probe sensor due to the lake's freshwater characteristics. Subsurface temperature measurements were taken at a depth of 2 ft below the sediment surface, and surface water measurements were taken in the overlying surface water within 1 ft of the sediment surface. Each reading represents the average of six to seven individual measurements recorded at the same station. Standard deviations based on these replicate measurements are also given. Subsurface temperature ranged from a low of 22.6 at station T2-1 to a high of 26.9 at station T5-3.

During the summer, it was expected that areas of groundwater discharge would be characterized by relatively lower temperature. Based on the Trident probe temperature mapping, two areas were identified as potential regions of groundwater discharge (Figure 9). The primary zone appeared to be limited to a band parallel to the shoreline between 50 to 100 ft and extending near-shore. A secondary discharge zone extended 200 to 300 ft offshore, which includes most of the outer transect stations.

The low subsurface temperatures in the inshore zone were considered as more likely due to groundwater discharge, while the offshore zone may have been related to groundwater discharge or to the deeper depth of the lake at these stations.

4.3.3.2 Trident Probe VOC Mapping

Subsurface VOC samples were collected at 2 ft below the sediment surface, and surface water samples were collected within 1 ft above the sediment surface (Figure 10). The primary CoCs for OU 4 were PCE and its breakdown products. At Transect 1 (T1), no detectable PCE or its breakdown products were measured in either the subsurface or surface water in the areas of groundwater discharge identified by the Trident probe sensors. At T2, PCE levels above the PQL were detected in the subsurface water at station T2-5.

Other VOC analytes were detected in the subsurface water at T2 as well. Moderate levels of TCE, cis-DCE, and VC were detected at stations T2-3 and T2-5. At T3, elevated concentrations of cis-DCE were measured at the subsurface and surface water samples at station T3-7. Other VOCs such as TCE and VC were also detected at the subsurface and surface water. In addition, toluene, trans-1,3-dichloropropene, 1,2,3-trichloropropane (TCP), and 1,2–dichloroethane were also present at the subsurface and surface water that were above the PQL.

PCE, cis-DCE, and VC in the subsurface and surface water samples at T4 were detected at stations T4-5 and T4-6. For T5, no detectable PCE and other VOC were measured in either the subsurface or the surface water samples. However, concentrations above the PQL of m,p-xylene, isopropylbenzene, and n-propylbenzene were measured at detectable levels on the surfacewater sample at station T5-4. Trident probe subsurface VOC maps (in µg/L) for DCE are shown in Figure 10.

Generally, the presence of VOC in the subsurface was limited to areas of potential groundwater discharge, as characterized by the Trident probe subsurface temperature mapping. This correspondence indicates that the VOC are potentially by groundwater to the lake interface.

Based on this correspondence of potential groundwater discharge and subsurface VOC detection, three stations, including T3-7, T2-5, and T2-3, were identified as likely candidates for UltraSeep deployment.

4.3.3.3 Trident Probe Validation Piezometers

The Trident probe sampling validation was based on piezometers installed to a depth of 2 ft along the T3 transect. VOC analytes, including PCE from most of the Trident probe validation piezometer stations, were below the PQL and MDL. However, elevated levels of cis-DCE were detected in the subsurface water in the areas of groundwater discharge identified with the Trident probe sensors at station T3-7. TCE and 1,2-dichloroethane (above the PQL) were also identified.

The results from the piezometers compared favorably with the results obtained from the Trident probe (Figure 11). For TCE, both methods showed low-level detections at T3-6, with a slightly lower concentration in the Trident probe compared to the piezometer. At T3-7, the Trident probe TCE result was masked by the large DCE signal but was determined to be <20 µg/L, which was consistent with the detection in the piezometer of 13 µg/L.

The Trident probe and the piezometer indicated “not detected” (ND) at all other validation stations for TCE. For cis-DCE, both methods showed detections of comparable concentration levels at T3-6 and T3-7. Trident probe concentrations were slightly higher than the piezometer results at both stations. Both methods indicated ND for cis-DCE at all other validation stations. PCE and VC were not detected by either method at any of the validation stations.

4.3.4 UltraSeep Validation Analysis

Validation measurements for comparison with the UltraSeep flow and water sample results were developed using piezometers installed adjacent to each of the UltraSeep stations. Calculated flow rates based on water level and hydraulic conductivity measurements in the piezometers were compared to the direct flow measurements from the UltraSeep. The hydraulic conductivity was estimated for each station where a piezometer was installed using an in-situ falling head test at the end of each validation deployment. At each target station, the UltraSeep collected flow-proportional water samples during periods of groundwater discharge from the sediment. The sampler was configured to collect samples over 10 intervals. The UltraSeep water samples were collected from a port in the funnel.

4.3.5 UltraSeep Survey Results—NSA Panama City

Although no VOCs were detected above PQL during the Trident probe survey, it was decided to proceed with the UltraSeep deployments to confirm discharge in the areas that were identified based on conductivity during the Trident probe survey. Based on the results from the Trident probe survey, three stations were selected for deployment of the UltraSeep. The first UltraSeep deployment was carried out successfully at station T4-4 (Figure 12).

Figure 5. Deployment of the Trident Probe in St. Andrews Bay.

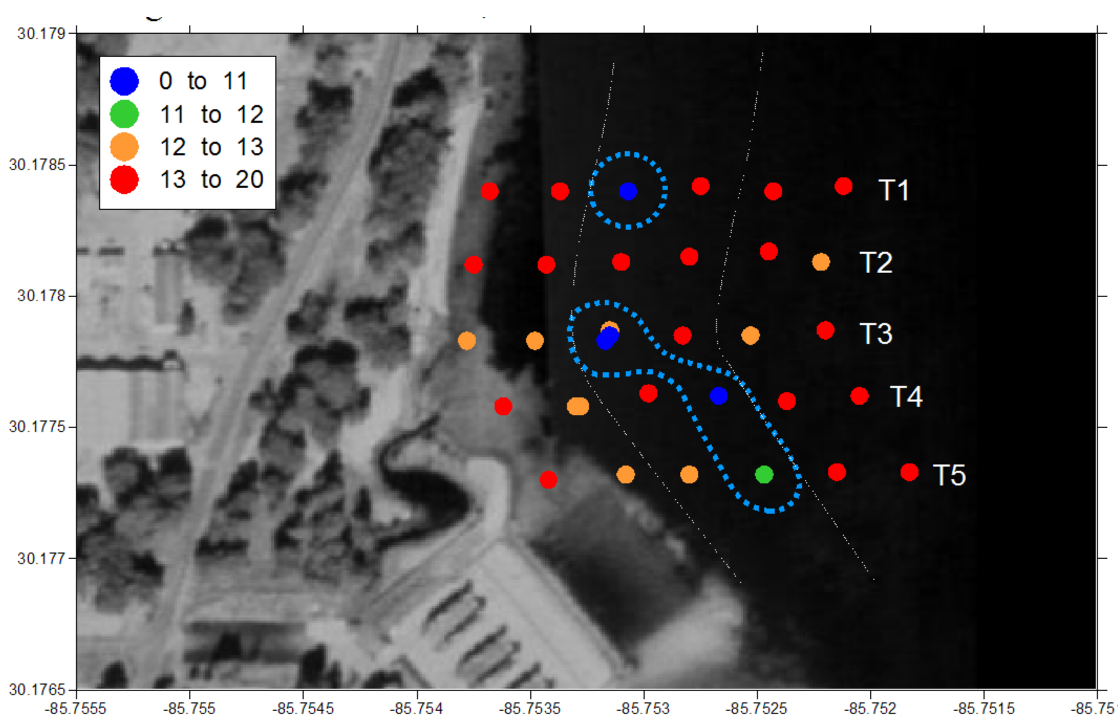

Figure 6. Trident Probe Conductivity Map (mS/cm) for the Area Offshore from AOC 1.

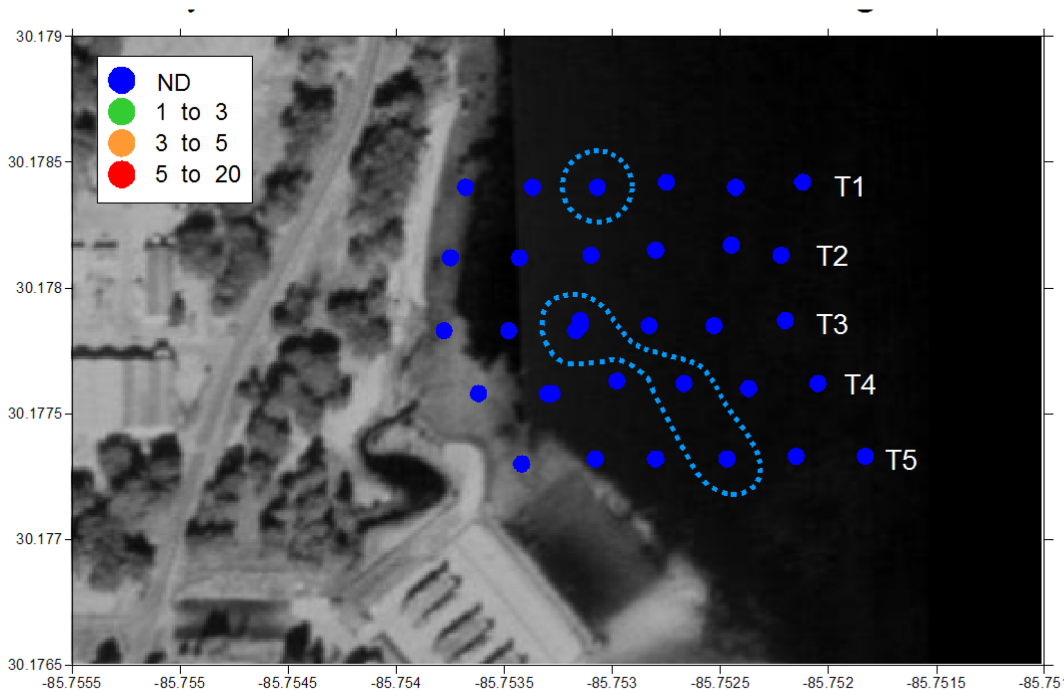

Figure 7. Trident Probe Subsurface 1,1-DCE Map (ug/L) for the Area Offshore from AOC 1.

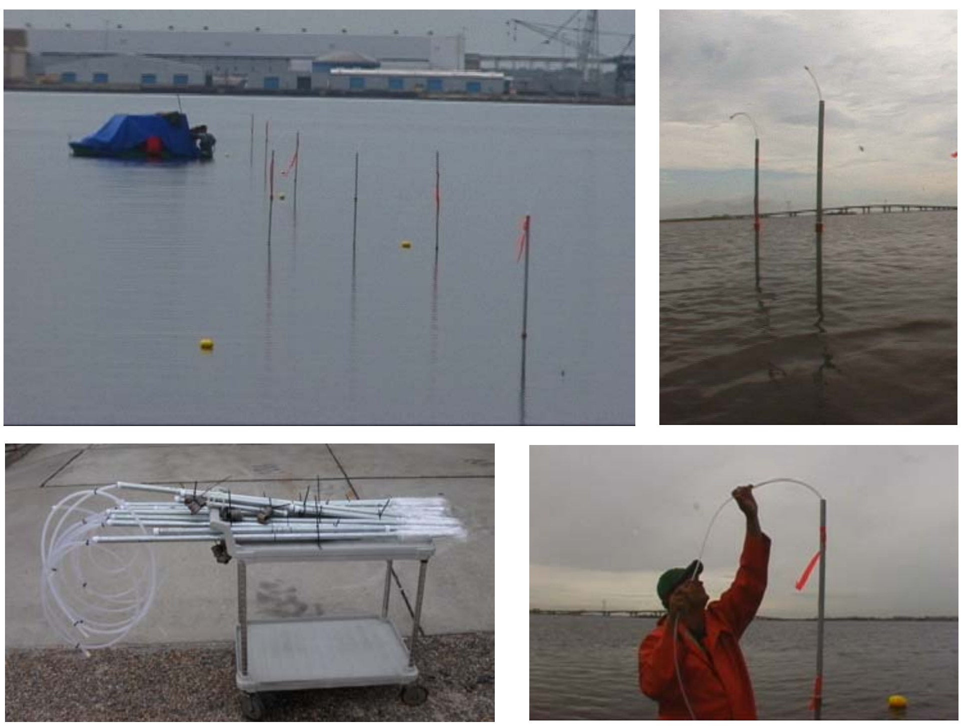

Figure 8. Trident Probe Validation Piezometers at AOC 1.

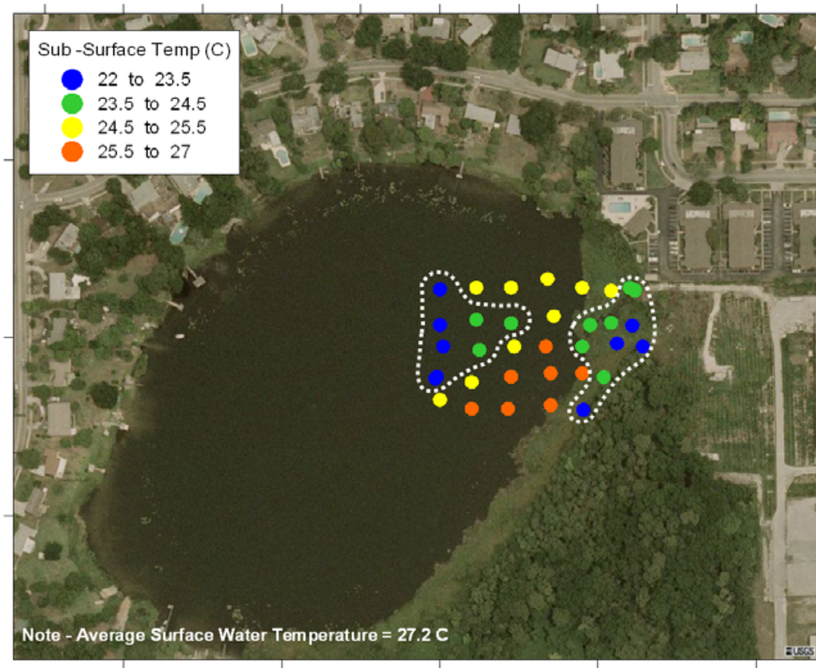

Figure 9. Trident Probe Subsurface Temperature Map (°C) for the Area Offshore of OU 4. (Dotted lines indicate groundwater discharge zones based on subsurface temperature.)

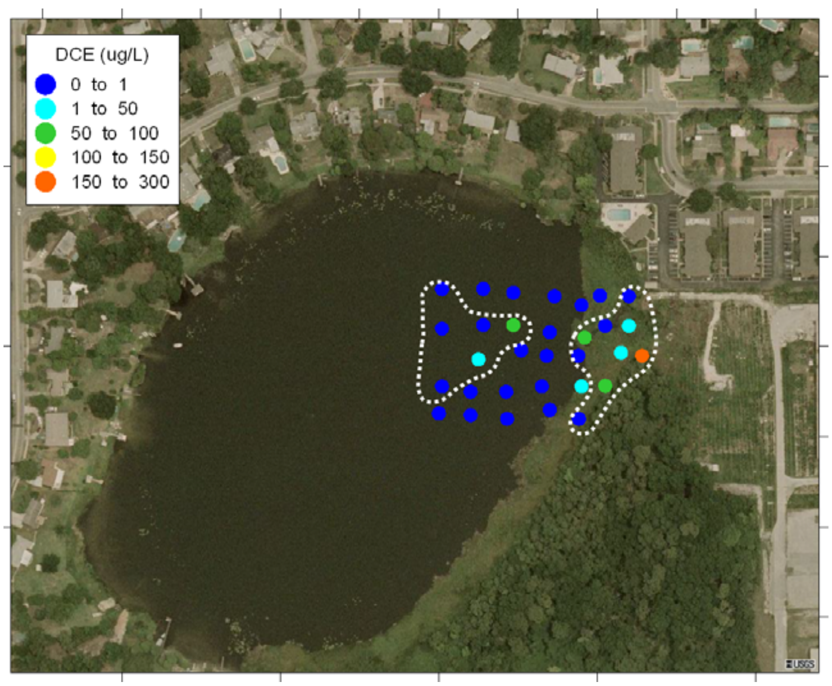

Figure 10. Trident Probe Subsurface DCE Map (µg/L) for the Area Offshore from OU 4. (Dotted lines indicate groundwater discharge zones based on subsurface temperature.)

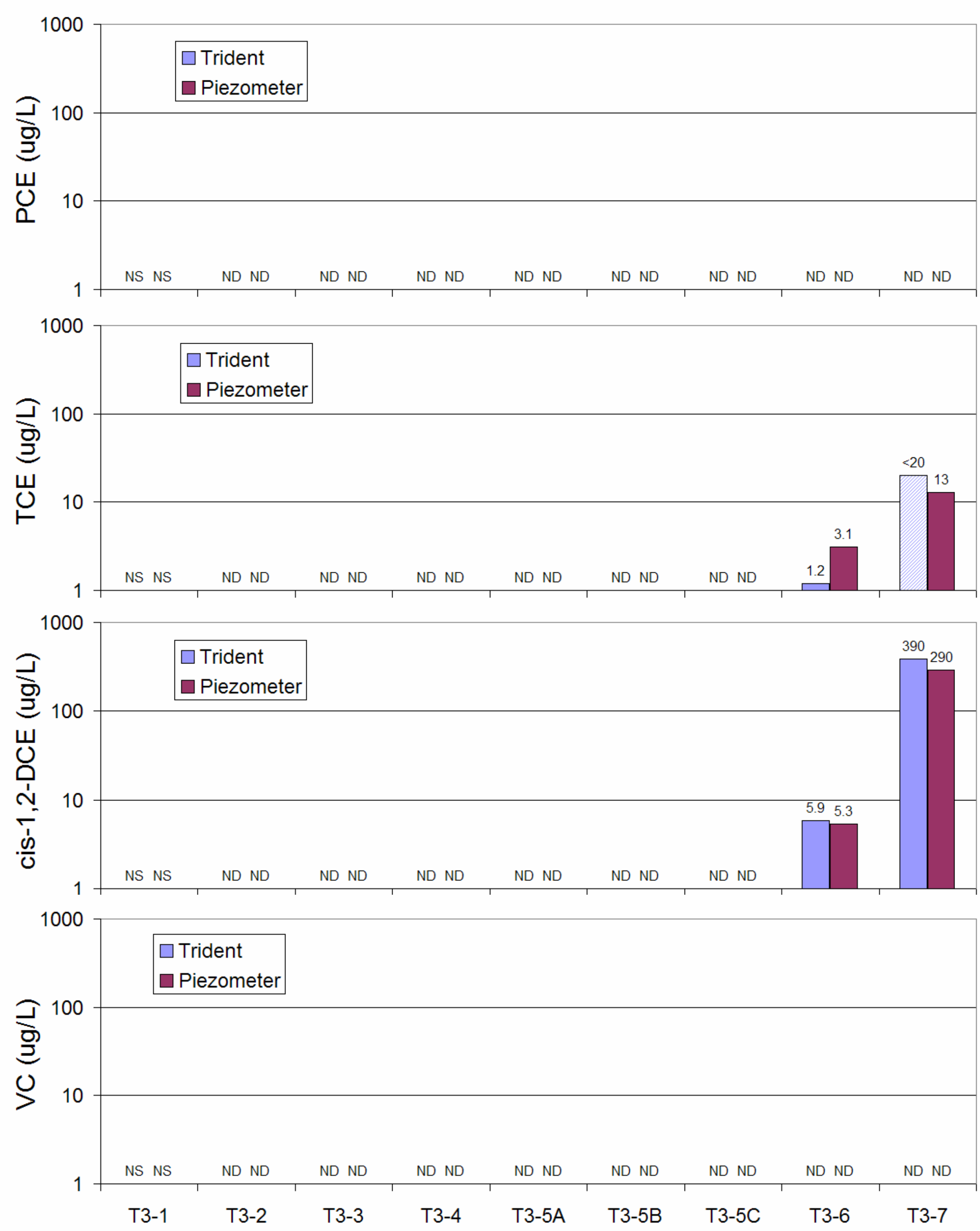

Figure 11. Trident Probe Subsurface VOC Validation Along T3.

Figure 12. The UltraSeep Being Deployed in St. Andrews Bay (bottom left and center); Installed on the Bottom (bottom right); and Viewed from Above, Including the Array of VOC and Level-Logging Piezometers at Station T4-4 (top).

However, during the second deployment at station T3-3, a power system malfunction led to a failure of the system part way through the deployment. The decision was made in the field to resample at T3-3 and abandon the deployment at T1-3 due to restrictions on the survey schedule and cost. The UltraSeep sampling validation was based on piezometers installed to a depth of 1 ft at three replicate locations adjacent to each UltraSeep station. Deployment results at T4-4 and T3-3 are presented in Sections 4.3.5.1 through 4.3.5.3.

4.3.5.1 UltraSeep Groundwater Discharge

Groundwater discharge was quantified over a 25-hour tidal cycle at each of the target stations. Ultrasonic flow data for the UltraSeep was processed to determine specific discharge rates. Specific discharge results for stations T4-4 are shown in Figure 13. At station T4-4, groundwater discharge rates ranged from about 2 to 8 cm/d. Discharge was always positive (out of the sediment), and maximum discharge occurred near the time of high tide. The mean discharge rate for station T4-4 over the 24-hour period extending from 1600 on August 14, 2004, to 1600 on August 15, 2004, was 5.1 cm/d. At station T3-3, groundwater discharge rates ranged from about 1 to 5 cm/d. As with station T4-4, discharge was always positive (out of the sediment), and maximum discharge occurred near the time of high tide. The mean discharge rate for station T3-3 over the 24-hour period extending from 1300 on August 18, 2004 to 1300 on August 19, 2004 was 2.7 cm/d.

4.3.5.2 UltraSeep VOC Discharge

The UltraSeep collected water samples during periods of positive discharge of groundwater from the sediment. The sampler was configured to collect samples over 10 2.5-hour intervals. At station T4-4, sufficient discharge was present during samples 3 through 10 to conduct analysis for VOCs. For samples 1 and 2, the individual sample volume was insufficient, so the two samples were composited to obtain sufficient volume. All VOC analytes, including DCE in all UltraSeep samples at T4-4, were below the PQL, with the exception of toluene in the composite sample T4-4-[B1+B2] (samples 1 and 2), which was detected at the PQL of 1 µg/L. Concentrations above the MDL, but below the PQL, were measured for toluene in samples 3, 5, and 10 (1 replicate of 2 for sample 5). The source of the low-level toluene in these samples is unknown. The equipment blank collected prior to the deployment also showed a low level of toluene (2.6 µg/L), so it is possible that the equipment contributed to the toluene detected in the samples.

At station T3-3, the discharge during samples 7 through 10 was sufficient enough to conduct VOC analysis. For samples 1 through 6, the individual sample volume was insufficient, so samples 1 through 4 were combined into one composite sample (T3-3R-[B1+B2+B3+B4]), and samples 5 and 6 were combined into another composite sample (T3-3R-[B5+B6]). All VOC analytes including DCE in all UltraSeep samples at T4-4, were below the PQL with the exception of toluene. Toluene was detected in all six T3-3 samples, with concentrations ranging from 4.1 to 6.0 µg/L.

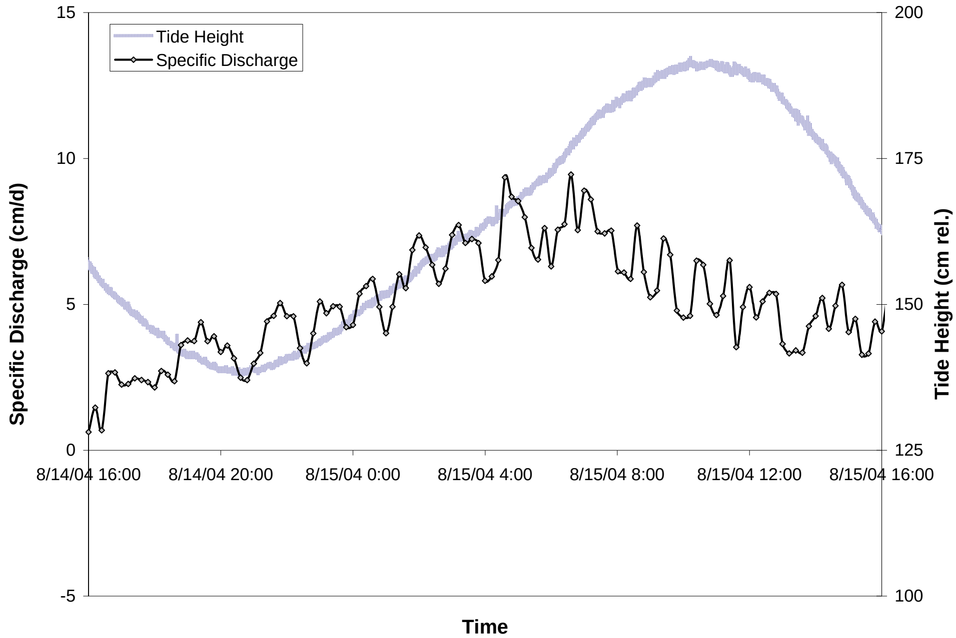

Figure 13. Specific Discharge and Tide Height at the T4-4 Station.

The toluene in these samples is suspected to have been introduced during sample analysis from waterproofing sealants associated with the installation of a new rooftop air conditioner in KB Labs' mobile lab (KB2). Concentrations above the MDL, but below the PQL, were measured for m,p-Xylene in the two composite samples and sample 7 (T3-3R-B7).

4.3.5.3 <u>UltraSeep Validation Piezometers</u>

The UltraSeep sampling validation was based on piezometers installed to a depth of 1 ft at three replicate locations adjacent to each UltraSeep station. All VOC analytes, including DCE at all UltraSeep T4-4 validation piezometer stations, were below the PQL and MDL. All VOC analytes, including DCE at all UltraSeep T3-3 validation piezometer stations, were below the PQL and MDL, with the exception of toluene.

Toluene was detected in all three replicates at the T3-3 UltraSeep station, with concentrations ranging from 3.1 to 4.3 µg/L. The toluene in these samples is suspected to have been introduced during sample analysis from waterproofing sealants associated with the installation of a new rooftop air conditioner in KB2. The results from the piezometers validated the results obtained from the UltraSeep.

Results from the UltraSeep validation piezometer hydraulic conductivity, hydraulic gradient, and specific discharge measurements are shown in Table 9. The UltraSeep flow measurement validation was based on piezometers installed to a depth of 3 ft at three replicate locations adjacent to each UltraSeep station. A surface water stilling well was installed adjacent to each piezometer. The difference in level between the 3-ft piezometer and the stilling well was used to determine the vertical hydraulic gradient. Falling head slug tests on each piezometer were used to determine the hydraulic conductivity. The specific discharge was then estimated based on the methods described in Section 3.4.

Table 9. Panama City UltraSeep Validation Piezometer Results for Hydraulic Conductivity, Vertical Hydraulic Gradient, and Specific Discharge. (Ultraseep-specific discharge results are shown for comparison.)

		Station T3-3				Station T4-4			
	Field Replicate	A	B	C	Overall	A	B	C	Overall
	Hydraulic Conductivity (cm/day)	293	354	389	346	273	170	74	172
Vertical Hydraulic Gradient (cm/m)	Average	1.5	1.1	1.2	1.2	1.5	0.6	2.1	1.4
	Min	0.9	0.3	0.8	0.7	0.6	-0.2	0.7	0.4
	Max	2.0	1.9	1.7	1.8	2.5	2.0	7.3	3.9
	Stdev	0.2	0.4	0.2	0.2	0.4	0.5	1.5	0.8
Piezometer Specific Discharge (cm/day)	Average	4.9	3.5	4.1	4.2	3.6	1.5	3.2	2.7
	Min	3.1	0.9	2.8	2.3	1.5	-0.4	1.1	0.7
	Max	6.6	6.2	5.6	6.2	6.0	4.8	11.0	7.3
	Stdev	0.6	1.2	0.5	0.8	0.9	1.2	2.3	1.5
UltraSeep Specific Discharge (cm/day)	Average				2.7				5.0
	Min				-0.7				0.4
	Max				6.1				10.1
	Stdev				1.5				2.0

Both sites (T3-3 and T4-4) showed a consistently positive vertical hydraulic gradient with average values ranging from 1.1 to 1.5 cm/m for T3-3 and 0.6 to 2.1 cm/m for T4-4. Hydraulic conductivity was generally somewhat higher at station T3-3, ranging from 293 to 389 cm/day compared to T4-4, which ranged from 74 to 273 cm/day. Estimated average specific discharge rates from the piezometers at T3-3 ranged from 3.5 to 4.9 cm/day compared to the average for the UltraSeep of 2.7 cm/day. For station T4-4, the estimated average specific discharge rates from the piezometers ranged from 1.5 to 3.6 cm/day compared to the average for the UltraSeep of 5.0 cm/day.

The fluctuating component of the discharge (mostly attributed to tides) had a similar magnitude for the piezometers and the UltraSeep, generally on the order of 1 to 2 cm/day. A phase difference appears to exist in the tidal response of the piezometers compared to the UltraSeep, which may be attributable to the response time of the piezometers relative to the tidal frequency. Generally, the piezometers showed reasonable agreement with the UltraSeep, given that the piezometer method is an indirect measure of specific discharge and that there are likely to be spatial variations even on the small scales of separation that occurred during these deployments.

4.3.6 UltraSeep Survey Results—NTC Orlando

The Trident probe sensor survey results revealed potential groundwater discharge zones based on temperature contrast and the presence of subsurface VOCs. Based on the results from the Trident probe survey, three stations extending offshore were selected for UltraSeep deployment. These included stations T3-7, T2-5, and T2-3. Station T3-7 was given the highest priority because it had the lowest Trident probe temperature measurement and elevated levels of TCE and DCE. Station T2-5 was given the second priority because it had a moderate Trident probe temperature signal that was clearly lower than the general background. This station also had elevated concentrations of PCE and TCE. Station T2-3 was given the third priority because it too had a moderate Trident probe temperature reading in addition to elevated levels of DCE and VC.

UltraSeep deployments were used to quantify groundwater discharge rates, and VOC discharge concentrations and mass flux at the three target stations. All three UltraSeep station deployments were carried out successfully (Figure 14). The UltraSeep groundwater flow measurement validation was based on level-logging piezometers installed to a depth of 3 ft at three replicate locations adjacent to each UltraSeep station. Paired lake-level stilling wells were installed in conjunction with each piezometer (Figure 14). The UltraSeep VOC discharge measurement validation was based on water sampling piezometers installed to a depth of 1 ft at three replicate locations adjacent to each UltraSeep station. UltraSeep and validation results are summarized in Sections 4.3.6.1 through 4.3.6.4.

4.3.6.1 <u>UltraSeep Groundwater Discharge</u>

Groundwater discharge was quantified over a 24-hour period at each of the target stations. Specific discharge results for station T3-7 are shown in Figure 15. All three stations showed groundwater discharge. Station T3-7 was located near the shoreline, with the vegetated zone on the eastern shore of Lake Druid. Seepage results for station T3-7 are shown in Figure 15.

The measurement period started at 1800 on July 2, 2005, and completed at 1800 on July 3, 2005. Seepage was always positive (discharge), with rates ranging from about 11 to 15 cm/day and a 24-hour mean discharge rate of 12.7 cm/day. The discharge rate remained relatively constant throughout the deployment period, staring at about 15 cm/day and showing a very gradual decrease to about 11 cm/day at about 1300 on July 3, 2005, then increasing back to about 15 cm/day at 1500 on July 3, 2005. The temporal standard deviation over the 24-hour period was about 0.9 cm/day. Station T3-7 had the highest groundwater discharge rate among the three stations. The lake level during the deployment period was gradually increasing from about 3.5 ft (rel) to about 3.7 ft as a result of rainfall.

Station T2-5 was located midway offshore along Transect 2 at the outer extent of the vegetated zone on the eastern shore of Lake Druid. The measurement period started at 1500 on July 4, 2005, and completed at 1500 on July 5, 2005. Seepage was always positive (discharge), with rates ranging from about 1 to 4 cm/day and a 24-hour mean discharge rate of 2.4 cm/day. The discharge rate remained relatively constant throughout the deployment period, with a temporal standard deviation over the 24-hour period of just 0.5 cm/day.

Overall, groundwater discharge at this site was lower than the inshore station T3-7 by about a factor of five, and higher than the offshore station at T2-3 by about a factor of two. The lake level during the deployment period was fairly constant at about 5.5 ft (rel), with the highest level of about 5.6 ft (rel) occurring at about 2200 on July 4, 2006.

Figure 14. Field Deployment and Validation of the UltraSeep at Three Locations Along Druid Lake.

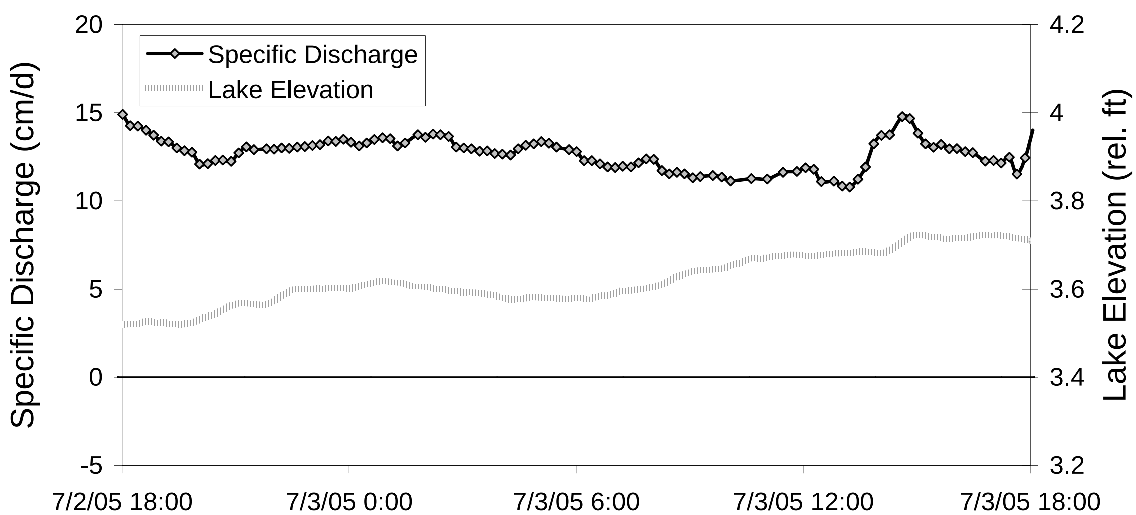

Figure 15. Specific Discharge and Lake Level at the T3-7 Station.

Station T2-3 was located near the offshore end along Transect 2 off the eastern shore of Lake Druid. The measurement period started at 1500 on July 6, 2005, and completed at 1500 on July 7, 2005. Seepage was almost always positive (discharge) with rates ranging from about 0 to 2 cm/day and a 24-hour mean discharge rate of 1.1 cm/day. The discharge rate remained relatively constant throughout the deployment period, with a temporal standard deviation over the 24-hour period of just 0.6 cm/day. Overall, groundwater discharge at this site was the lowest of the three target stations. The lake level during the deployment period was fairly constant at about 11.75 ft (rel), with the highest level of about 11.8 ft (rel) occurring at about 2300 on August 6, 2006.

4.3.6.2 UltraSeep Flow Validation Piezometers

The flow validation piezometer results are summarized in Table 10. The average vertical hydraulic gradient generally decreased with distance from shore, ranging from a minimum of 1.4 cm/m at T2-3 to a maximum of 4.1 cm/m at T3-7. Hydraulic conductivity followed a similar trend, with a maximum average value of 351 cm/day at T3-7 and a minimum of 72 cm/day at T2-3. Station T2-5 had intermediate values of hydraulic gradient and conductivity. Average specific discharge rates for the 24-hour period calculated from the piezometer gradients and hydraulic conductivity ranged from a minimum of 1.0 cm/day at T2-3 to a maximum of 14.3 cm/day at T3-7.

These results were comparable to the average specific discharge rates measured directly by the UltraSeep (Table 10, Figure 16). Direct comparison indicates that the piezometer and UltraSeep results were within about 10% at stations T2-3 and T3-7, but the difference at station T2-5 was considerably higher (60%). The significant variation among the replicate piezometers at this station was possibly a result of its location on the fringe of the shoreline vegetated zone.

Table 10. Ultraseep Validation Piezometer Results for Hydraulic Conductivity, Vertical Hydraulic Gradient, and Specific Discharge. (Ultraseep specific discharge results are shown for comparison.)

		T2-3				T2-5				T3-7			
	Field Replicate	**A**	**B**	**C**	**Overall**	**A**	**B**	**C**	**Overall**	**A**	**B**	**C**	**Overall**
	Hydraulic Conductivity (cm/day)	**120**	**47**	**49**	**72**	**98**	**180**	**213**	**164**	**367**	**335**	**NA**	**351**
Vertical Hydraulic Gradient (cm/m)	Average	1.3	0.7	2.1	1.4	2.7	2.6	4.9	3.4	4.4	3.7	NA	4.1
	Min	0.9	0.3	1.5	0.3	2.3	2.2	4.0	2.2	3.9	3.4	NA	3.4
	Max	1.8	1.4	3.0	3.0	3.1	3.1	5.4	5.4	4.8	4.0	NA	4.8
	Stdev	0.2	0.2	0.3	0.7	0.1	0.2	0.2	1.3	0.2	0.1	NA	0.5
Piezometer Specific Discharge (cm/day)	Average	1.5	0.3	1.0	1.0	2.7	4.6	10.5	5.9	16.2	12.4	NA	14.3
	Min	1.0	0.2	0.7	0.2	2.3	3.9	8.5	2.3	14.4	11.4	NA	11.4
	Max	2.2	0.6	1.4	2.2	3.1	5.7	11.6	11.6	17.8	13.4	NA	17.8
	Stdev	0.2	0.1	0.1	0.6	0.1	0.3	0.4	4.1	0.6	0.4	NA	2.7
UltraSeep Specific Discharge (cm/day)	Average	-	-	-	1.1	-	-	-	2.4	-	-	-	12.7
	Min	-	-	-	-0.5	-	-	-	1.4	-	-	-	10.8
	Max	-	-	-	2.4	-	-	-	3.6	-	-	-	14.9
	Stdev	-	-	-	0.6	-	-	-	0.5	-	-	-	0.9

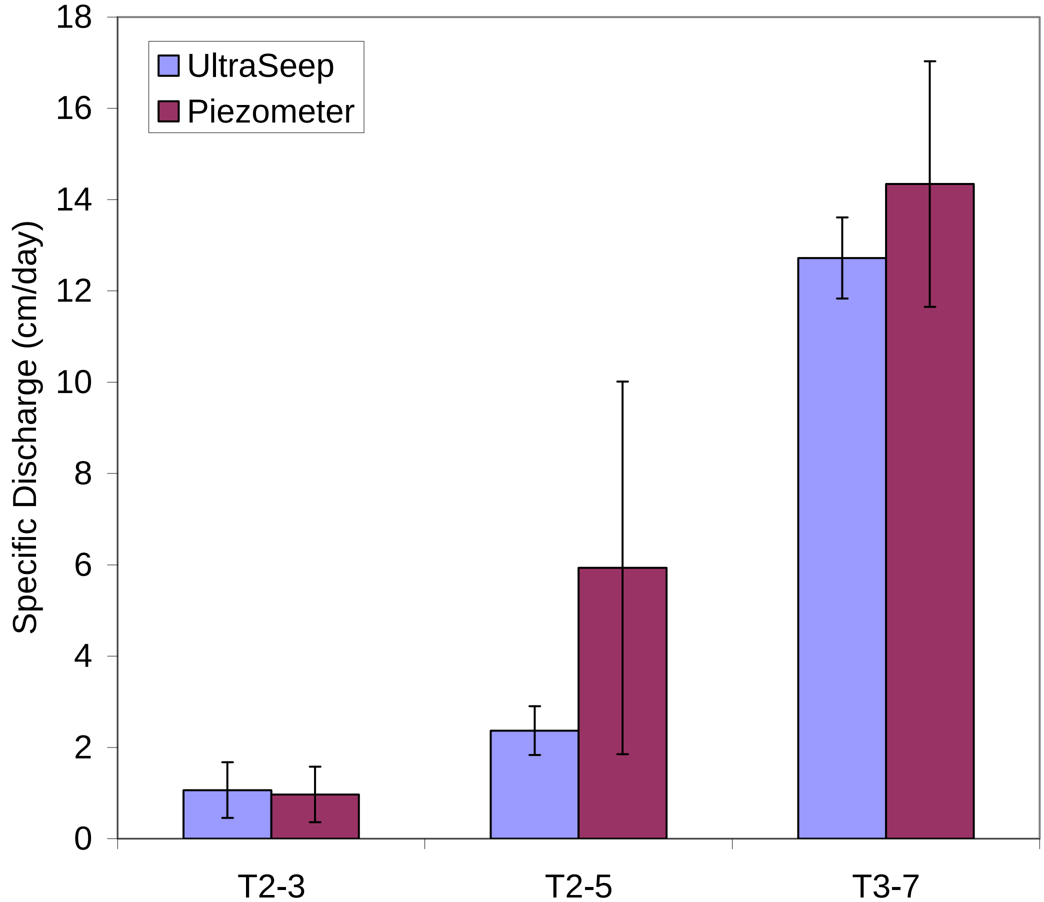

Figure 16. UltraSeep Flow Validation at Each Station.

4.3.6.3 UltraSeep VOC Discharge

At station T3-7, the discharge present during samples 1 through 10 was sufficient enough to conduct VOC analysis, including a replicate taken from sample 7. At station T2-5, the discharge present during samples 1 through 10 was sufficient enough to conduct VOC analysis. For station T2-3, the discharge present during samples 1 through 3 and samples 6 through 10 was sufficient enough to conduct VOC analysis with sample 3 as the replicate. For samples 4 through 5, the individual sample volume was insufficient, so samples 4 through 5 were combined into one composite sample (SM-T2-3-[B4+B5]). At station T3-7, raw sample VOC concentrations above the PQL were detected for TCE, cis-DCE, and VC. Detectable levels of 1,1-dichloroethene, trans-DCE, and toluene were also found at this station. VOC breakdown products were detected at station T2-5, including cis-DCE and VC, along with toluene. Station T2-3 showed low levels of cis-DCE and VC. Toluene was not detected at this station.

To calculate the discharge concentration at each station, the concentration results from samples 8 through 10 were used when the discharge fraction was highest. This method minimizes uncertainty associated with the effects of the starting concentration. For the starting concentration, Space and Naval Warfare Command (SPAWAR) Systems Center (SSC San Diego) personnel used the concentration in the first sample, corrected for the estimated discharge fraction in that sample. This was achieved by iteratively solving for the discharge concentration, correcting the starting concentration, and then recalculating the discharge concentration until the change between subsequent iterations was <1%. The discharge fraction in the first sample ranged from a low of 2% (T2-3) to a high of 21% (T3-7).

Discharge concentrations were calculated for the primary VOC of interest, including PCE, TCE, cis-DCE, and VC, subject to detection. PCE was not detected in the discharge water at any of the three target UltraSeep stations. Station T3-7 had the highest discharge concentrations for TCE, cis-DCE, and VC. TCE was not detected in the discharge waters at stations T2-5 and T2-3, while these stations had comparable discharge concentrations for cis-DCE, and station T2-3 had a slightly higher VC concentration. Variability among replicate calculated discharge concentrations from the last three UltraSeep samples at each site was relatively low, with relative standard deviations (RSD) ranging from <1% to about 25%.

UltraSeep discharge concentrations were used in conjunction with UltraSeep measured discharge rates to quantify the mass flux of VOCs from groundwater to surface water at the three target stations. The mass flux is calculated as the integral over time of the product of discharge rate and concentration, divided by the sampling period. In this case, because the discharge rate is relatively constant, the mass flux was calculated as

$$M = \overline{D} c_D$$

where $\overline{D}$ is the mean discharge rate. The combination of strong discharge rate and high discharge concentrations at station T3-7 lead to a dominant mass flux for VOCs at that station. VOC mass flux at stations T2-5 and T2-3 were comparable for cis-DCE and VC, and nondetect for TCE.

4.3.6.4 UltraSeep VOC Discharge Validation Piezometers

The UltraSeep sampling validation was based on piezometers installed to a depth of 1 ft at three replicate locations in a triangular pattern around each UltraSeep station. The piezometers were generally installed in triplicate within about 3 ft of the UltraSeep. The results indicate general agreement between these shallow piezometer samples and the discharge concentrations determined with the UltraSeep (Figure 17).

At station T2-3, PCE and TCE were both ND, while the mean cis-DCE and VC concentrations were somewhat lower in the UltraSeep discharge but fell within the range of variability of the triplicate piezometers. PCE and TCE were ND in the UltraSeep discharge, with an estimated upper bound of <1.6 µg/L. This upper bound is consistent with the 0.7- µg/L PCE concentration detected in the shallow piezometers (this mean included only one marginal detection) but is lower than the TCE concentration detected in the piezometers. Concentrations of cis-DCE and VC were comparable at this station.

At station T3-7, PCE was ND in the UltraSeep discharge and the piezometers. TCE and cis-DCE had comparable concentrations (within the range of variability). For VC, the discharge concentration was higher than for the piezometer, which was ND, with an upper bound of <10 µg/L. Given that this bias was not observed at other stations, this finding suggests that VC may be forming as a degradation product from DCE very near the interface or even in the surface water at this station.

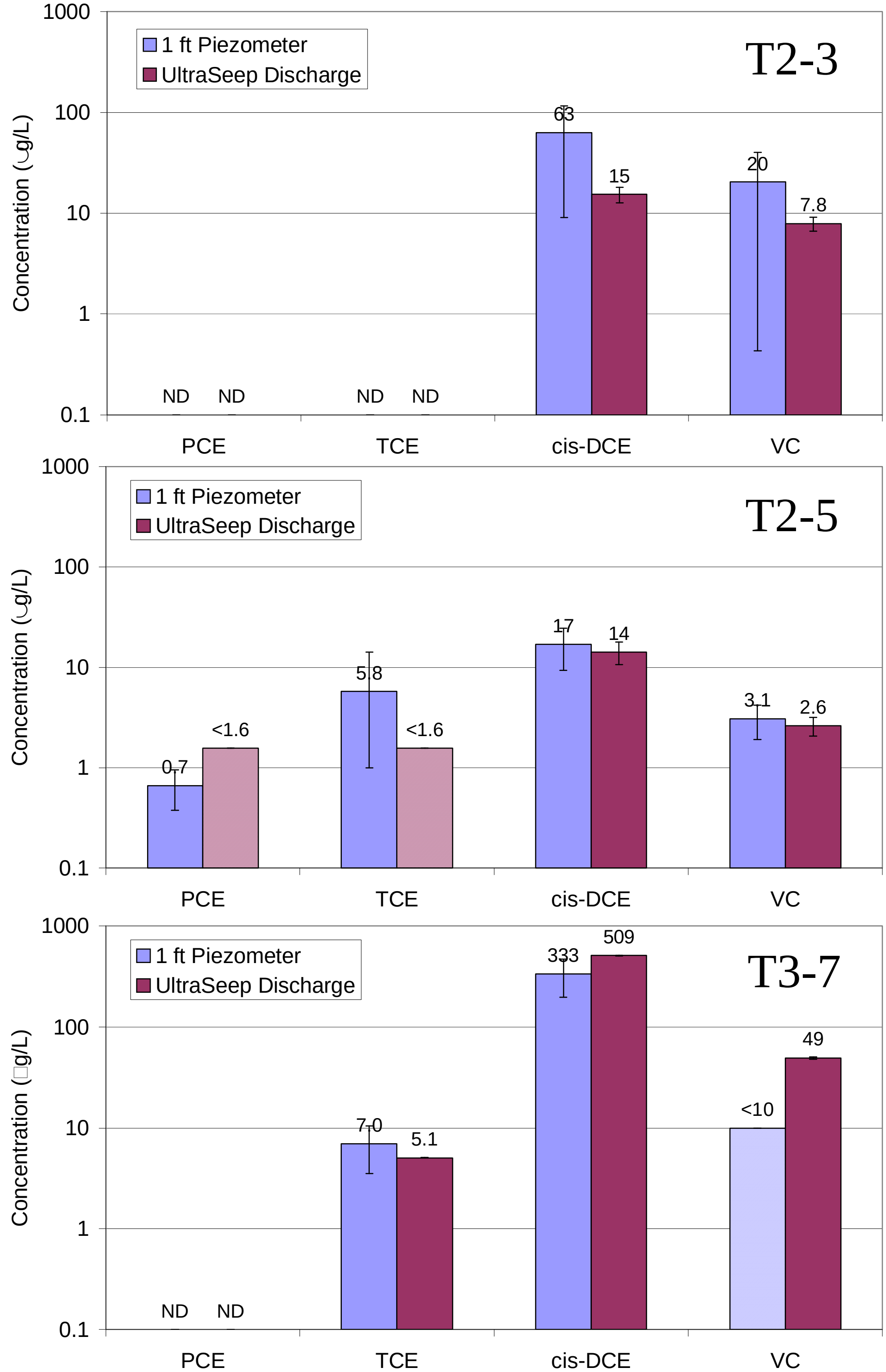

Figure 17. UltraSeep VOC Validation at Each Station.

4.4 TECHNOLOGY COMPARISON

4.4.1 NSA Panama City

A coastal contaminant migration monitoring assessment was conducted at NSA Panama City. The objective of the project was to field demonstrate and evaluate the effectiveness of the Trident probe and UltraSeep for characterizing coastal contaminate migration. The demonstration results were used to evaluate the validity of monitored natural attenuation as a corrective action alternative for AOC 1 at NSA Panama City (Chadwick and Hawkins, 2007).

The Trident probe successfully identified areas of groundwater discharge from the site to the surface waters of St. Andrews Bay. Thirty offshore stations were sampled with the probe sensors and water sampler. The zone of discharge appeared to be limited to a band extending parallel to shore between about 100 to 300 ft offshore. All VOC analytes, including DCE at all Trident probe stations, were below the PQL. No detectable DCE or other VOC were measured in either the subsurface or surface water in groundwater discharge areas identified with the Trident probe sensors. The results from shallow (2-ft) piezometers installed on transect T3 validated the Trident probe survey results.

The UltraSeep successfully quantified groundwater discharge rates and VOC discharge concentrations in two discharge zones identified with the Trident probe. At station T4-4, groundwater discharge was always positive, with rates ranging from about 2 to 8 cm/d, and a 24-hour mean discharge rate of 5.1 cm/d. At station T3-3, groundwater discharge was always positive, with rates ranging from about 1 to 5 cm/d and a 24-hour mean discharge rate of 2.7 cm/d. The positive discharge at these locations was consistent with the results from the Trident probe survey.

Although groundwater discharge was detected at both stations, all VOC analytes, including DCE in all UltraSeep samples, were below the PQL, with the exception of toluene. The source of the low-level toluene in these samples may have originated from the UltraSeep sampling system (T4-4 samples), or from vapors released by roofing sealants at KB Labs during the analysis (T3-3 samples). Results from three shallow piezometers installed adjacent to each UltraSeep station validated the UltraSeep results.

Overall, the project successfully demonstrated the utility of the Trident probe and UltraSeep in assessing coastal contaminant migration. No DCE discharge into St. Andrews Bay at levels above the SWCTL of 3.2 ug/L was detected. Thus, the study results support the selection of monitored natural attenuation as a corrective action alternative for the site.

4.4.2 NTC Orlando

A coastal contaminant migration monitoring assessment was performed at NTC Orlando OU 4 (Chadwick and Hawkins, 2007). The overall project objective was to field demonstrate and evaluate the effectiveness of the Trident probe and UltraSeep System. The demonstration represented a full-scale technology evaluation in the field using the Trident probe and the UltraSeep. The technologies were demonstrated in an offshore area adjacent to a known hazardous waste site where there is documented evidence of potential contaminant migration to the surface water.

The primary contaminant of concern at NTC Orlando OU 4 was PCE and its degradation products, which have been detected at concentrations exceeding the surface water cleanup target level along the shoreline of Druid Lake. An extraction and treatment system had been installed; however, it was unclear whether VOC were continuing to enter the lake and at what rate. The stated objectives of this field effort were as follows:

- Demonstrate that the Trident probe can be used to help identify areas where groundwater seepage is occurring in a freshwater lake environment and to map the lateral extent of any subsurface contamination at the groundwater–surface water interface
- Demonstrate that the UltraSeep system can be used to quantify the flow of groundwater and concentration of contaminants that may be impinging on the surface water system
- Demonstrate the technology to end users to determine the utility of these tools for making decisions at DoD coastal landfills and hazardous waste sites
- Quantify costs associated with the operation of each technology.

The Trident probe successfully identified areas of groundwater discharge from the site to the Lake Druid surface waters. Thirty-one offshore stations were sampled with the probe sensors and water sampler. Two zones of potential groundwater discharge were successfully identified. One near-shore band appeared to be extending parallel to the shoreline about 50 to 100 ft offshore. Another zone that was previously unknown extends 200 to 300 ft offshore.

Most of the VOC analytes detected at the Trident probe stations were above the PQL. Detectable levels of PCE, TCE, DCE, VC, and/or other VOCs were measured in the subsurface or surface water in the groundwater discharge areas identified with the Trident probe sensors. The results from shallow (2-ft) piezometers installed on Transect T3 validated the Trident probe results.

The UltraSeep successfully quantified groundwater discharge rates and VOC discharge concentrations in two discharge zones identified with the Trident probe screening. The strongest discharge was in the near-shore discharge zone at station T3-7. The groundwater discharge was always positive, with rates ranging from about 12 to 16 cm/day, and a 24-hour mean discharge rate of 12.7 cm/day.

At station T2-5, groundwater discharge was always positive, with rates ranging from about 2 to 4 cm/day and a 24-hour mean discharge rate of 2.4 cm/day. The weakest discharge was measured offshore at station T2-3. The groundwater discharge at this site was always positive, with rates ranging from about 0 to 3 cm/day and a 24-hour mean discharge of 1.1 cm/day. The positive discharge at these locations was consistent with the Trident probe survey results. Discharge concentrations were calculated for the primary VOCs of interest, including PCE, TCE, cis-DCE, and VC, subject to detection. PCE was not detected in the discharge water at any of the three target UltraSeep stations. Station T3-7 had the highest discharge concentrations for TCE, cis-DCE, and VC. TCE was not detected in the discharge waters at stations T2-5 and T2-3, while these stations had comparable discharge concentrations for cis-DCE, and station T2-3 had a slightly higher VC concentration. Variability among replicate calculated discharge concentrations from the last three UltraSeep samples at each site was relatively low, with RSDs ranging from <1% to about 25%.

UltraSeep discharge concentrations were used in conjunction with UltraSeep measured discharge rates to quantify the VOC mass flux from groundwater to surface water at the three target stations. The combination of strong discharge rate and high discharge concentrations at station T3-7 lead to a dominant VOC mass flux at that station. VOC mass flux at stations T2-5 and T2-3 were comparable for cis-DCE and VC, and ND for TCE.

The UltraSeep sampling validation was based on piezometers installed to a depth of 1 ft at three replicate locations in a triangular pattern around each UltraSeep station. The results indicate general agreement between these shallow piezometer samples and the discharge concentrations determined with the UltraSeep. At station T2-3, PCE and TCE were both nondetect, while the mean cis-DCE and VC concentrations were somewhat lower in the UltraSeep discharge but fell within the range of variability of the triplicate piezometers.

PCE and TCE were ND in the UltraSeep discharge, with an estimated upper bound of <1.6 µg/L. This upper bound is consistent with the 0.7-µg/L concentration of PCE detected in the shallow piezometers, but is lower than the TCE concentration detected in the piezometers. Concentrations of cis-DCE and VC were comparable at this station.

At station T3-7, PCE was ND in the UltraSeep discharge and the piezometers. TCE and cis-DCE had comparable concentrations (within the range of variability). For VC, the discharge concentration was higher than for the piezometer, which was ND with an upper bound of <10 µg/L. Given that this bias was not observed at other stations, this finding suggests that VC may be forming as a degradation product from DCE very near the interface or even in the surface water at this station.

Overall results for the demonstration are summarized schematically in Figure 18. In the schematic, shoreline concentrations are based on the range reported in shoreline monitoring wells and piezometers, offshore subsurface concentrations are based on the Trident probe samples, offshore discharge concentrations are based on the UltraSeep measurements, and offshore surface water concentrations are based on the surface water samples collected with the Trident probe (Shallow = Station T3-7; Mid-Depth = Station T2-5; Deeper = Station T2-3).

The results show how discharge of VOCs to the lake are regulated by the physical pathway and the chemical attenuation that occurs along these pathways, along with the effects of localized mixing in the lake itself. From the schematic, it is clear that areas close to shore have the strongest discharge and the least attenuation of VOCs, whereas the areas further from shore tend to have lower discharge rates and higher attenuation. Near the shore, the shallow water and low mixing, coupled with the higher discharge rates, lead to higher concentrations in the surface water of the lake, whereas further offshore, the lower discharge and better mixing generally lead to undetectable VOC concentrations in the surface water. Overall, the project successfully demonstrated the utility of the Trident probe and UltraSeep in assessing coastal contaminant migration.

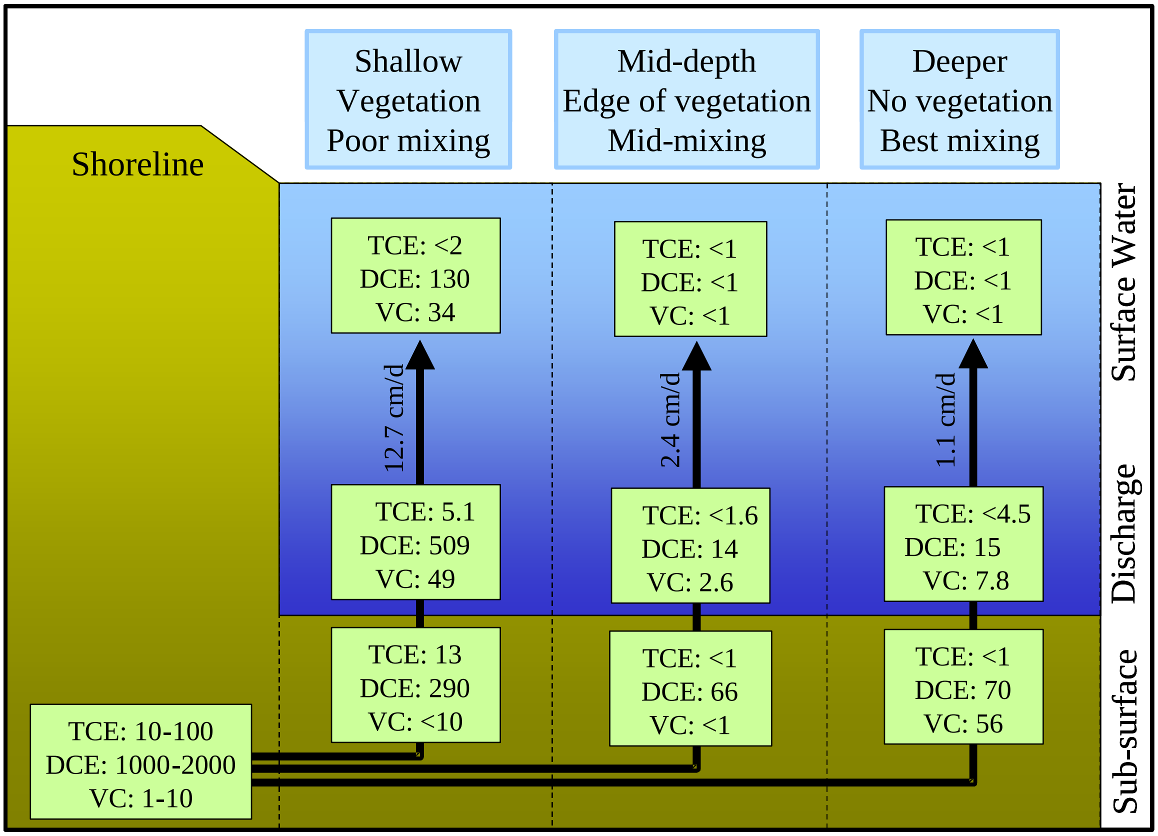

Figure 18. Schematic Representation of the Results from the Trident Probe and UltraSeep Demonstration at Orlando OU 4.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

Cost issues are critical to the evaluation and acceptance of innovative technologies. Along with demonstrating and validating the Trident probe and UltraSeep technologies, an important goal of this project was to develop and validate, to the extent possible, the expected operational costs of the technologies. Relevant costs and related data as described in this section were tracked and documented during the demonstration so that the operational costs of the technology can be estimated with a high degree of veracity.

During the course of the project, commercialization has proceeded in partnership with two commercialization partners. The Oceanscience Group has completed commercialization of the hardware systems, and Groundwater Seepage Incorporated (GSI) has developed a commercial services capability. The costs summarized below are largely based on data provided by these commercial entities through their experience on the demonstration projects and many additional efforts completed during the demonstration project.

5.2 COST ANALYSIS

5.2.1 Cost Basis

The cost basis (e.g., scale of operation) that was used for the future cost analysis was based on an estimated site scale developed from the ESTCP demonstration sites, Y0817 test sites, and other sites that are currently under investigation or considering investigation. The cost basis for the Trident probe and UltraSeep technologies is primarily controlled by the spatial scale of the site and the number of stations and samples that must be generated to adequately satisfy the data quality objectives. The typical site scale and design parameters used for the cost analysis are summarized in Table 11.

5.2.2 Cost Drivers

The expected cost drivers for the Trident probe and UltraSeep technologies are largely driven by labor, analytical laboratory, supplies, transportation, and capital equipment costs associated with planning, mobilizing, operating, demobilizing, data analysis, and reporting. Capital costs for the Trident probe and UltraSeep technologies have been developed by the manufacturer, Oceanscience Group. Purchase, lease, and service cost options are available as the company develops the technology.

For purchase of the equipment, it is expected that capital costs would be amortized over a fairly large number of site evaluations before the purchase of new equipment would be required, and that these costs would be recouped through equipment fees passed on to the customer. Estimated costs for other ancillary capital equipment were documented during the demonstrations. Most of the future engineering, modifications, and upgrades to the equipment are expected to be capitalized by the manufacturer and recouped in the purchase, lease, or service cost for the technology.

Table 11. Site Scale and Design Parameters Used for Cost Analysis.

Parameter	Scale or Design Element
Study driver	Terrestrial groundwater-borne solvent plume migrating toward adjacent surface water body
Survey area	500 ft alongshore × 200 ft offshore
Trident sensor grid	60 stations @ 50 ft alongshore × 50 ft offshore plus 5 contingency and replicates
Trident porewater sampling	15 stations based on sensor results
UltraSeep sampling	5 stations based on Trident sensor and porewater results

Operating costs for the technologies are largely controlled by the labor rates and number of personnel required to field the equipment, analyze the data, and generate the documentation associated with the project. These factors were carefully documented during the demonstrations. Other operating costs include analytical costs, consumables, residuals handling, and system maintenance. Most maintenance functions can be carried out by the operating team.

Mobilization and demobilization costs are largely related to labor and shipping costs. Shipping costs can vary considerably, depending on the distance to the site and the shipment method. Labor costs for mobilization and demobilization should be relatively constant. Mobilization and demobilization costs were documented as part of the demonstration.

5.2.3 Life-Cycle Costs

Estimates of life-cycle costs for the technology were based on the expected working life of the systems (5 to 10 years). Capital cost estimates provided by the manufacturer, along with estimated capital costs for ancillary equipment, were used to develop a life-cycle cost for the technology in collaboration with GSI. The cost analysis incorporates these costs via equipment fees that are passed on to the customer (Table 13). The current rates indicate that the capital investment for the Trident probe and UltraSeep, including ancillary equipment, could be recouped within the expected 5- to 10-year working life, with ~30 uses/year, which is well within the expected market demand for the technology.

5.3 COST COMPARISON

Micro-well networks were used for the Trident probe baseline technology comparison and piezometer networks; Lee meters were used for the UltraSeep baseline technology comparison. However, one should recognize that the Trident probe and UltraSeep technologies represent new technologies that provide capabilities that cannot be achieved through existing technologies, including these baseline technologies. Note that the baseline technologies may be difficult to install at sites with active shipping, whereas the Trident probe and UltraSeep are amenable to these settings.

In addition to direct comparison to other technologies, the demonstrations, particularly at NSA Panama City, indicated how the technologies may lead to significant cost avoidance if they provide sufficiently reliable and convincing technical support to select monitored natural attenuation (MNA) as a final remedy or corrective action instead of a more costly active remedial option. As indicated by the project team at NSA Panama City: “Without direct measurements at the groundwater-surface water interface, the assumed concentration of 1,1-DCE in discharge to surface water would have been based on the monitoring wells closest to St. Andrews Bay. Since the well concentrations exceeded the Florida Department of Environmental Protection (FDEP) Surface Water Cleanup Target Levels, a containment system or barrier would have been required. This project allowed the Navy to avoid an estimated $1.25 million that had been previously budgeted for construction of a barrier."

The cost analysis for the Trident probe and UltraSeep technologies relative to the baseline technologies are summarized in Table 12. Based on typical site parameters, the cost of an integrated Trident probe/UltraSeep survey is expected to be on the order of $120,000. This represents a cost savings of about 42% relative to the estimated cost for the baseline technology of about $210,000. Much of the cost difference stems from the higher labor load associated with installing enough micro-wells to provide comparable spatial resolution to the Trident Underwater Groundwater Seep Detection System. Additional labor load is also associated with the labor-intensive nature of the Lee meters when trying to provide time-resolved seepage measurements and discharge samples, which is critical in tidally influenced coastal environments.

Table 12. Cost Analysis for Trident Probe and UltraSeep Technologies Compared to Baseline Technologies.

Cost Category	Sub Category	Trident/UltraSeep (TU)				Baseline Technology (BT)				Details
Labor Costs		**Rate**	**Units**	**Days**	**Cost ($)**	**Rate**	**Units**	**Days**	**Cost ($)**	
Planning	Preliminary study design	1,000	1	2	2,000	1,000	1	2	2,000	Principal 2 days
	Preliminary budget	1,000	1	2	2,000	1,000	1	2	2,000	Principal 2 days
	Final budget	1,000	1	3	3,000	1,000	1	3	3,000	Principal 3 days
	Contract agreement	1,000	1	3	3,000	1,000	1	3	3,000	Principal 3 days
	Sampling plan	1,000	1	5	5,000	1,000	1	5	5,000	Principal 5 days
	Material orders	600	1	3	1,800	600	1	3	1,800	Technician 3 days
Subtotal					16,800				16,800	
Mobilization Costs	Equipment checkout	600	1	1	600	600	1	1	600	Technician 1 day
	Calibration	600	1	3	1,800	600	1	3	1,800	Technician 3 days
	Preclean	600	1	2	1,200	600	1	2	1,200	Technician 2 days
	Packing	600	1	2	1,200	600	1	2	1,200	Technician 2 days
	Shipping	600	1	2	1,200	600	1	2	1,200	Technician 2 days
Subtotal					6,000				6,000	
Operating Costs	On-site setup/testing	1,000	1	1	1,000	1,000	1	3	3,000	T/U: 1 PI & 2 Technicians @ 1 day
		600	2	1	1,200	600	2	3	3,600	BT: 1 PI & 2 Technicians @ 3 days
	Grid survey and marking	1,000	1	1	1,000	1,000	1	1	1,000	T/U: 1 PI & 2 Technicians @ 1 day
		600	2	1	1,200	600	2	1	1,200	BT: 1 PI & 2 Technicians @ 1 day
	Micro-well installation					1,000	1	6	6,000	60 stations @ 8-10 stations/day
						600	5	6	18,000	BT: 1 PI & 5 Technicians @ 6 days
	Trident C/T sensor survey	1,000	1	3	3,000					60 stations @ 20-25 stations/day
		600	2	3	3,600					T/U: 1 PI & 2 Technicians @ 3 days
	Micro-well C/T sampling					1,000	1	5	5,000	60 stations @ 10-12 stations/day
						600	5	5	15,000	BT: 1 PI & 5 Technicians @ 5 days
	Porewater CoC sampling	1,000	1	3	3,000					15 stations @ 5 stations/day
		600	2	3	3,600					T/U: 1 PI & 2 Technicians @ 3 days
	Level logging PZ install					1,000	1	2	2,000	5 stations + stilling well
						600	2	2	2,400	BT: 1 PI & 2 Technicians @ 4

Table 12. Cost Analysis for Trident Probe and UltraSeep Technologies Compared to Baseline Technologies. (continued)

Cost Category	Sub Category	Trident/UltraSeep (TU)				Baseline Technology (BT)				Details
Labor Costs		**Rate**	**Units**	**Days**	**Cost ($)**	**Rate**	**Units**	**Days**	**Cost ($)**	
										days
	UltraSeep Sampling	1,000	1	4	4,000					5 stations @ 3 stations/day
		600	2	4	4,800					T/U: 1 PI & 2 Technicians @ 4 days
	Lee meter Sampling	1,000	1			1,000	1	4	4,000	5 stations @ 5 stations/2 days
		600	2			600	5	4	12,000	BT: 1 PI & 5 Technicians @ 2 days
	Sample handling and shipping	600	1	2	1,200	600	1	2	1,200	1 Technicians @ 2 days
Subtotal					27,600				74,400	
Demobilization Costs	Demobilize micro-well					1,000	1	2	2,000	BT: 1 PI & 2 Technicians @ 2 days
						600	1	2	1,200	
	Post-clean	1,000	1	0.5	500	1,000	1	0.5	500	1 PI & 1 Technicians @ 0.5 days
		600	1	0.5	300	600	1	0.5	300	
	Packing	1,000	1	1	1,000	1,000	1	1	1,000	1 PI & 1 Technicians @ 1 day
		600	1	1	600	600	1	1	600	
	Shipping	1,000	1	0.5	500	1,000	1	0.5	500	1 PI & 1 Technicians @ 0.5 days
		600	1	0.5	300	600	1	0.5	300	
Subtotal					3,200				6,400	
Analysis and Reporting Costs	Trident/Microwell CoC analysis	120	18	1	2,160	120	18	1	2,160	15 samples + 20% quality control (QC)
	UltraSeep/Lee meter CoC analysis	120	18	1	2,160	120	18	1	2,160	15 samples + 20% QC
	On-site data analysis	1,000	1	1	1,000	1,000	1	1	1,000	Downselect porewater and seepage stations
	Post-survey data analysis	1,000	1	3	3,000	1,000	1	3	3,000	1 PI @ 3 days
	Reporting	1,000	1	10	10,000	1,000	1	10	10,000	1 PI @ 10 days
Subtotal					18,320				18,320	
Project Management		1,000	1	7.4	7,400	1,000	1	9.6	9,600	@ 10% of labor days
Total Labor Costs					**79,320**				**131,520**	

Table 12. Cost Analysis for Trident Probe and UltraSeep Technologies Compared to Baseline Technologies. (continued)

Cost Category	Sub Category	Trident/UltraSeep				Baseline Technology				Details
Non-Labor Costs		**Rate**	**Units**	**Days**	**Cost**	**Rate**	**Units**	**Days**	**Cost**	
Equipment Costs	Trident	150	1	7	1050					Current per day charge by GSI
	Micro-wells					50	60	7	21,000	Estimated from AMS
	Water quality analyzer	50	1	7	350	50	1	7	350	Current per day charge by GSI
	UltraSeep	450	3	4	5,400					Current per day charge by GSI
	Level logging piezometers					50	5	4	1,000	Estimated from Solinst
	Pressure transducers					50	10	4	2,000	Estimated from Solinst
	Lee meters					50	5	4	1,000	Current per day charge by GSI
	Sampling pump	50	1	7	350	50	1	12	600	
	Boat rental	500	1	12	6,000	500	1	12	6,000	Current per day charge by GSI
	Field computer	25	1	12	300	25	1	12	300	Current per day charge by GSI
	Dive gear	65	3	4	780	65	3	12	2,340	Current per day charge by GSI
Subtotal					14,230				34,590	
Material Costs	Calibration standards	10,000	1	1	10,000	12,000	1	1	12,000	BT: Larger due to piezometer materials
	Lines and markers									
	Sand packs									
	Cleaning solutions									
	Sampling bags/containers									
	Log books/sheets									
	Fuel									
	Piezometer standpipes									
	Other misc supplies									
Subtotal					10,000				12,000	
Indirect Activity Costs	Investigation Derived Waste Disposal	100	1	1	100	600	1	1	600	T/U: Minimal due to small purge volumes
										BT: Larger due to purger volumes
Subtotal					100				600	
Travel Costs	Airfare	300	3	1	900	300	6	1	1,800	
	Per diem	150	3	14	6,300	150	5	14	10,500	
	Truck/van	150	1	14	2,100	150	1	14	2,100	
Subtotal					9,300				14,400	
Total Non-Labor Cost					**33,630**				**61,590**	
Project Subtotal					**112,950**				**193,110**	
Fee/Markup @ 8%					**9,036**				**15,449**	
Project Total					**121,986**				**208,559**	

Table 13. Rental Rates for the Trident Probe and UltraSeep Based on Life-Cycle Costs.

Estimate of Initial Cost for Capital and Ancillary Equipment			
Item			**Initial Cost**
Trident Probe			$15,000
Ancillary - Sampling pump			$1,500
Ancillary - Field computer			$1,000
Ancillary - Water quality analyzer			$1,200
		Total Trident	$18,700
UltraSeep			$65,000
Ancillary - Field Computer			$1,000
		Total UltraSeep	$66,000
Equipment Replacement Cost Estimate			
Inflation Rate	*4%*		
	Years of Use		
	0	5	10
Trident & ancillary replacement	$18,700	$22,440	$26,180
UltraSeep & ancillary replacement	$66,000	$79,200	$92,400
Estimated Rental Rate Including Inflation and Maintenance			
Maintenance Rate	*5%*		
		Years of use	
	Uses/year	5	10
Trident & Ancillary	10	$471	$275
	20	$236	$137
	30	$157	$92
	40	$118	$69
	50	$94	$55
		Years of use	
	Uses/year	5	10
UltraSeep & Ancillary	10	$1,663	$970
	20	$832	$485
	30	$554	$323
	40	$416	$243
	50	$333	$194
Current Rental Rates			
Trident Probe			$150
Ancillary - Sampling pump			$50
Ancillary - Field computer			$25
Ancillary - Water quality analyzer			$50
		Total Trident	**$275**
UltraSeep			$450
Ancillary - Field computer			$25
		Total UltraSeep	**$475**

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The key cost drivers for the Trident probe and UltraSeep technologies are labor, analytical laboratory, supplies, transportation, and capital equipment costs associated with planning, mobilizing, operating, demobilizing, data analysis, and reporting. Based on potential charge rates, capital costs for the Trident probe are easily recaptured over the life of the unit. Trident probe capital costs could be reduced if more units are manufactured over time. UltraSeep capital costs are higher and will be more difficult to recapture.

Efforts to reduce the UltraSeep unit cost should continue, which will improve the ability to achieve spatial coverage required to delineate heterogeneous discharge zones. Operating costs for the technologies should decrease (1) as field personnel grow in experience, and become more efficient in executing the projects and (2) as the equipment becomes more widely used and personnel at lower labor rates are available to execute the projects.

6.2 PERFORMANCE OBSERVATIONS

Trident probe and UltraSeep performance was generally in line with expectations. Only minor deviations from the performance criteria occurred. During the NSA Panama City demonstration, the lack of detected contamination limited the ability to assess the correspondence of the technologies compared to the validation endpoints. However, the NTC Orlando demonstration had sufficient chemical gradients present to confirm the validity of both the Trident probe and the UltraSeep over a range of concentrations.

6.3 SCALE-UP

Scale-up for this technology is not a factor because the demonstrations were performed essentially at full scale. Both demonstrations were designed to encompass the range of issues associated with a full-scale groundwater-surface water interaction site. Based on the experience with these sites and others that have been assessed recently using these technologies, the systems are adaptable to a range of scales and requirements. For example, two recent surveys were conducted using only the Trident probe sensor capability with no water sampling and no seepage meter assessment. These screening level assessments were sufficient to satisfy the issue as to whether or not there was significant evidence of groundwater discharge zones. Other sites have focused on porewater sampling or groundwater discharge rates. These efforts indicate that the technologies can be scaled in various ways to meet a given site's specific requirements.

6.4 OTHER SIGNIFICANT OBSERVATIONS

No significant obstacles are anticipated for the implementation of this technology. Commecialization of both the equipment and the service support functions has already occurred, and many independent sites have already been characterized using the technology.

6.5 LESSONS LEARNED

A number of important lessons were learned during the progression of the demonstrations. Many sediment sites are subject to gas bubble ebullition. This process was encountered over the course of the demonstrations, and it was found that gas build-up in the flow meter could lead to measurement failure. A simple gas diverter and discharge loop was developed to eliminate this problem. In areas where fine-grained sediments were present, the Trident probe water sampler often clogged before sufficient water volume could be collected. To alleviate this problem, a simple sand-pack sleeve was developed that slips over the sampler's tip. The sand pack allowed water collection at all target demonstration stations except one.

6.6 END-USER ISSUES

Demonstration results were incorporated into the evaluation of corrective actions for the NSA Panama City AOC 1 assessment and at NTC Orlando for the OU 4 assessment. These results were available for review and comment to relevant local, state, and federal regulators, and stakeholders. In addition, the NSA Panama City site demonstration documented cost avoidance of about $1.25 million based on support for selection of MNA as the corrective action at the site. Regulatory review is currently being conducted by the Cal/EPA Department of Toxic Substances Control. The Cal/EPA will provide formal review and comment on the Trident probe and UltraSeep demonstrations through the Cal/EPA Hazardous Waste Technology Demonstration Program.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

For the NSA Panama City demonstration, end-user and stakeholder buy-in for this technology is significant, as evidenced by the incorporation of the technology into the regulatory program for assessing potential corrective measures at AOC 1. End-user concerns, reservations, and decision-making factors were assessed throughout the demonstrations, and to the extent possible, these issues were addressed through modifications to the technology or methodologies that describe its use.

The demonstration was based on the commercial off-the-shelf (COTS) Trident probe and UltraSeep systems that were produced in collaboration with the Oceanscience Group. Modifications that were incorporated after the Panama City demonstration included installation of a sand pack filter on the Trident probe porewater sampler and installation of a gas bubble deflector and gas trap on the UltraSeep.

For the NTC Orlando demonstration, there was also significant end-user and stakeholder buy-in for this technology, as evidenced by the incorporation of the technology into the regulatory program for assessing potential corrective measures at OU 4. End-user concerns, reservations, and decision-making factors were assessed throughout the demonstrations, and to the extent possible, these issues were addressed through modifications to the technology, or methodologies that describe its use.

The demonstration was based on the COTS Trident probe and UltraSeep systems that were produced in collaboration with the Oceanscience Group. No significant modifications or customization was adopted following the demonstration.

Technology transfer of the migration monitoring technologies to the numerous DoD activities that could use this technology has been accomplished through the publication of articles, the distribution of pamphlets, the presentation of test results at conferences, and Web page and Web tool publication on Navy and EPA public access sites. Articles were submitted to the Navy's environmental magazine, *Currents*, and the Panama City results were cited in the Navy's 5-Year Installation Restoration (IR) Report as a success story. As stated previously, commercial equipment suppliers and service providers have already been identified and are currently applying the technologies at many sites. Together, these efforts should help transition this technology to more DoD activities.

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APPENDIX A

POINTS OF CONTACT

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APPENDIX A

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