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Environmental Security Technology Certification Program (ESTCP), Project ER-200921

Demonstration of the AGI Universal Samplers (F.K.A. the GORE® Modules) for Passive Sampling of Groundwater

Louise Parker, Richard Willey, Timothy McHale, William Major,
Tommie Hall, Ron Bailey, Kelsey Gagnon, and Gordon Gooch

March 2014

Cold Regions Research
and Engineering Laboratory

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Final Report

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Under Project ER-200921, “Demonstration/Validation of the GORE Module for Passive Groundwater Sampling”

Abstract

The GORE Module is a passive sampler that was developed to sample air and water for a variety of volatile and semi-volatile organic compounds (VOCs and SVOCs). Recently, Amplified Geochemical Imaging (AGI) LLC (Elkton, MD) has acquired this technology, and the sampler is now known as the AGI Universal Sampler.

The objectives of this project were to determine, when sampling groundwater, if the GORE Modules can provide (1) technically defensible analytical data for VOCs and SVOCs and (2) substantial cost savings when compared with the US Environmental Protection Agency's (US EPA) low-flow purging and sampling method. Sampling was conducted at two sites: the Southern Bush River section of Aberdeen Proving Ground (APG), MD, and the former Pease Air Force Base in Portsmouth, NH. Analytes included chlorinated VOCs and hydrocarbon VOCs and SVOCs. Additional Modules placed in some wells allowed us to examine concentration gradients in those wells with depth both before and after low-flow sampling.

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Preface

Funding for this demonstration was provided by the Environmental Security Technology Certification Program (ESTCP) under Project ER-200921, "Demonstration/Validation of the GORE Module for Passive Groundwater Sampling." The Program Manager was Dr. Andrea Leeson.

The work was performed by Louise Parker, Kelsey Gagnon (student), and Ron Bailey (Biogeochemical Sciences Branch, Dr. Terrence Sobecki, Chief) and Tommie Hall and Gordon Gooch (Engineering Resources Branch, Jared Oren, Chief), US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL); Richard Willey (now retired), US Environmental Protection Agency (EPA) Region 1, Boston, MA; Timothy McHale, Civil Engineer Corps Officer School (CECOS), Naval Education and Training Command (NETC); and William Major (now retired), Engineering and Expeditionary Warfare Center (EXWC), Naval Facilities Engineering Command (NAVFAC). Contact information for the authors can be found in Appendix A.

At the time of publication, Dr. Justin Berman was Chief of the Research and Engineering Division, ERDC-CRREL. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

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dropped out and we had to find a second lab to conduct the analyses. We also want to thank Susan Bigl (formerly with CRREL) for generously donating her time to help the lead author through the trials and tribulations of formatting parts of the draft document in Microsoft Word.

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Acronyms and Abbreviations

%RSD	Percent Relative Standard Deviation
124TMB	1,2,4-trimethylbenzene
135TMB	1,3,5-trimethylbenzene
AFB	Air Force Base
AGI	Amplified Geochemical Imaging LLC
APG	Aberdeen Proving Ground
ASTM	American Society for Testing and Materials (now known as ASTM International)
bgs	Below the Ground Surface
BNZ	Benzene
BP	Bladder Pump
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CCl4	Carbon tetrachloride
cDCE	*cis*-1,2-Dichloroethylene
CECOS	Civil Engineer Corps Officer School
CLB	Chlorobenzene
CLF	Chloroform
CRREL	Cold Regions Research and Engineering Laboratory
DCA	1,2-Dichloroethane
DCB	Dichlorobenzene
DL	Detection Limit
DO	Dissolved Oxygen
DoD	US Department of Defense

DOE	US Department of Energy
DP	Direct Push
EBNZ	Ethylbenzene
EDQW	Environmental Data Quality Workgroup
ELAP	Environmental Laboratory Accreditation Program
EPA	Environmental Protection Agency
ePTFE	Expanded Polytetrafluoroethylene
ERDC	US Army Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EXWC	Engineering and Expeditionary Warfare Center
FAA	Federal Aviation Administration
FLRS	Flight-line Refueling System
GC/MS	Gas Chromatography/Mass Spectrometry
HSE	Health and Safety Executive
HWEP	High Water Entry Pressure
IRP	Installation Restoration Program
ISO/IEC	International Organization for Standardization and International Electrotechnical Commission
ITRC	Interstate Technology and Regulatory Council
K_{AW}	Partitioning Coefficient from Water into the Sorbent
K_{OW}	Octanol-Water Partition Coefficient
LF	Low Flow
LNAPL	Light Non-aqueous Phase Liquid
LTM	Long-Term Monitoring
MCL	Maximum Contaminant Level

MDL	Method Detection Level
MS	Matrix Spike
MSD	Matrix-Spike Duplicate
MTBE	Methyl *tert*-butyl ether
NAPH	Naphthalene
NAVFAC	Naval Facilities Engineering Command
NELAC	National Environmental Laboratory Accreditation Conference
NETC	Naval Education and Training Command
NH AGQS	New Hampshire Ambient Groundwater Quality Standards
NJ DEP	New Jersey Department of Environmental Protection
NR	Not Reported
NS	No Significant Difference
NTU	Nephelometric Turbidity Units
O&M	Operations and Maintenance
OMB	White House's Office of Management and Budget
ORP	Oxidation Reduction Potential
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated biphenyls
PCE	Tetrachloroethylene
PDA	Pease Development Authority
PDB	Polyethylene Diffusion Bag sampler
PH2	Pump House 2
PI	Principal Investigator
PP	Peristaltic Pumps
psig	Pounds (Force) per Square Inch Gauge

QA	Quality Assurance
QC	Quality Control
RDL	Reporting Detection Limit
RM-ANOVA	Repeated-Measures Analysis of Variance
ROD	Record of Decision
RSD	Relative Standard Deviation
SBR	Southern Bush River (area of APG)
Sig	Significant difference
SVOC	Semi-volatile organic compound
TCA	1,1,2-Trichloroethane
TCE	Trichloroethylene
tDCE	*trans*-1,2-dichroloroethylene
TDS	Total Dissolved Solids
TetCA	1,1,2,2-Tetrachloroethane
TOC	Top of Casing
TOL	Toluene
US EPA	US Environmental Protection Agency
UST	Underground Storage Tank
VC	Vinyl Chloride
VOA	Volatile Organic Analyte
VOC	Volatile Organic Compound
XYLs	Total Xylenes

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters
pounds (force) per square inch gauge	6.894757	kilopascals

Executive Summary

The GORE Module is a passive sampler that W. L. Gore & Associates, Inc. (Elkton, MD) developed to sample air and water for a variety of volatile and semi-volatile organic compounds (VOCs and SVOCs). In the past few months, Amplified Geochemical Imaging (AGI) LLC (Elkton, MD) has acquired this technology; and the sampler is now known as the AGI Universal Sampler. However, because this technology was only recently acquired, the text will continue to refer to these samplers as the GORE Modules or simply as the Modules.

The GORE Module consists of a GORE-TEX membrane tube approximately 1 ft in length and 0.25 in. in diameter. This membrane is expanded polytetrafluoroethylene (ePTFE) and is chemically-inert, vapor-permeable, and waterproof. Housed inside the membrane tubing are several packets of hydrophobic sorbents that have an affinity for a broad range of volatile and semi-volatile organic compounds.

The objectives of this project were to determine, when sampling groundwater, if the AGI Universal Samplers can provide (1) technically defensible analytical data for VOCs and SVOCs and (2) substantial cost savings when compared with the US Environmental Protection Agency's (US EPA) low-flow purging and sampling method. For this demonstration, we compared samples collected using the GORE Modules to samples collected using the EPA's low-flow sampling protocol. Sampling was conducted at two sites: the Southern Bush River section of Aberdeen Proving Ground (APG), MD, and the former Pease Air Force Base in Portsmouth, NH.

The GORE Modules were placed in the monitoring wells at the same depth as the inlet to the pump or tubing used to collect the low-flow samples. When the screen length in the wells was long enough, two additional Modules were placed in the well, one halfway between the top and midpoint of the screen and one halfway between the bottom and the midpoint of the screen. This allowed us to profile contamination in the well with depth. We used duplicate field samples to assess the reproducibility of the two methods. Analytes at the APG site included several chlorinated VOCs: tetrachloroethylene (PCE); *cis*-1,2-dichloroethylene (cDCE); trichloroethylene (TCE); 1,1,2,2-tetrachloroethane (TetCA); and chloroform (CLF).

VOCs and SVOCs at the Former Pease site included benzene (BNZ), toluene (TOL), ethylbenzene (EBNZ), and total xylenes (XYLs) (i.e., BTEX compounds); 1,2,4-trimethylbenzene (124TMB); 1,3,5-trimethylbenzene (135TMB); naphthalene (NAPH); isopropylbenzene; and 2-methylnaphathalene. The low-flow samples were analyzed using EPA method 8260B, and the GORE Modules were analyzed by the Gore Laboratory using EPA method 8260C for VOCs or 8270 for SVOCs that have been modified for thermal desorption.

The analyses of field duplicate Modules revealed that there was good agreement between the replicate samples in most instances. At APG, for three of the analytes (TCE, TetCA, and BNZ), 90% of the replicate samples had relative standard deviations (RSDs) that were 20% or less. For the remaining analytes (PCE, cDCE, and CLF), at least 70% of the duplicate pairs had RSDs that were less than 20%. In instances when there was poor reproducibility, we observed that this occurred primarily in a couple of wells that had been purged, were shallow, and where the upper portion of the screen was near the water table.

At the Pease site, reproducibility was very good for most (nine) of the analytes; 80% of the duplicate pairs had RSDs that were 20% or less. For BNZ, EBNZ, and XYLs, at least 60% of these sample pairs had a similar RSD. For TOL, the reproducibility was poorest; only one-third of the replicate samples had RSDs of 20% or less. Once again, we found that the poor reproducibility occurred in a few (three) wells. At this site, this happened when the samplers were left in the well for more than 2 hours and the sampler depth below the water table was 40 ft or more. It may be that leaving the samplers for more than 2 hours is too long a contact time, especially given the sampling depth.

Ten percent of the samplers that were used at the APG site were sent to an independent contract laboratory for analyses. They used the same analytical method that is used by the Gore Laboratory. We found that there was excellent agreement between the analyte concentrations of the replicate samples analyzed by the two different laboratories for all the analytes that were compared.

With respect to the sensitivity of the sampling method, at the Aberdeen site the GORE Modules provided data that was below the action level (i.e., the EPA's maximum contaminant level [MCL] for drinking water). How-

ever, the detection capability of the low-flow method was one-twentieth of that for the GORE Modules. Because of this and because some agencies require or recommend lower quantitation limits (i.e., one-third to one-tenth of the EPA's MCL for drinking water), we recommended to the Gore Laboratory that they try to develop a lower detection capability.

Subsequently at the Pease site, the detection capability of the GORE method was considerably lower and was comparable to that for the low-flow samples for most of the analytes (e.g., BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, and NAPH); that is, the method detection levels (MDLs) were equivalent. Specifically, the detection level was below *one-tenth* of the EPA's MCLs for drinking water for these analytes. This was also true for TCE (although the low-flow samples were not analyzed for this analyte). This demonstrates a much improved sensitivity for this analyte when compared with the capability demonstrated at the previous test site. However, for the remaining analytes (*n*-butylbenzene, *n*-propylbenzene, isopropyltoluene, isopropylbenzene, and 1,2-dibromoethane), the MDLs were higher for the GORE Modules than for the analytical method used for the low-flow samples.

Also at the Pease site, we found that in many instances we were able to detect low concentrations of contaminants by using the GORE Modules but not by using the low-flow sampling. We found good agreement between replicate Module samplers in these instances and that this occurred even though these concentrations were well above the detection capability of the analytical method used for the low-flow samples. This is an issue that we recommend should be studied further.

For both sites, the data for the mid-level samplers and the data for the mean concentrations for the three samplers (at three depths) were compared with the data for the low-flow samples for each of the analytes. At both sites and in all cases (except one), there was a statistically significant linear relationship between the GORE data and the low-flow data; and this relationship was typically one to one. At APG, the slope of the line for PCE, cDCE, and TCE was not significantly different from 1.0. However, the slope was less than 1.0 for TetCA and for the mid-level data for CLF.

At the Pease site, there was a highly significant linear relationship between the pre-purge and post-purge GORE data and the low-flow data. This was true for both the mid-level and the mean data with one exception (the

post-purge mid-level data for BNZ). The slopes of these lines were not significantly different from 1.0 for EBNZ, XYLs, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. The two analytes where the slope was significantly different from 1.0 were BNZ and TOL.

Although there was generally good agreement between the GORE data and the low-flow data at both sites, plots of the Module data with depth showed that there was substantial stratification of some analytes in some of the wells. This was especially true for the wells near a source of contamination. At APG, we even observed pronounced stratification of all the VOCs in a shallow well with a relatively short (5 ft) screen. In this well, analyte concentrations were as much as 50 times higher in the upper Module than in the lower sampler. Low-flow concentrations for PCE, CLF, and TCE were low and agreed best with the mid-level Module in this well. In contrast, the low-flow concentration of TetCA was high and agreed best with the upper level sampler; and the low-flow concentration of cDCE agreed best with an average of the concentrations found with the upper and mid-level Modules.

With respect to where to place passive samplers within the well screen, there was good agreement between the mid-level sampler and the low-flow concentrations for some wells; and thus, placing the sampler at the midpoint of the well screen is advisable in those cases. However in other instances, purging brought water into the well from a zone that was not interrogated by the mid-level sampler; and thus, low-flow analyte concentrations agreed best with the upper or bottom sampler. Thus, the mid-level sampler did not always best represent analyte concentrations obtained by low-flow sampling. However, the opposite is also true; the low-flow samples did not always collect the highest concentrations of contaminants in the wells, and this is often important to regulators.

The differences in contaminant concentrations with depth explain some of the scatter in the data when the GORE data were plotted against the low-flow data. These differences also explain why, for some wells, the mid-level sampler agreed best with the low-flow data while, in other cases, the mean concentration of the samplers (for the three depths) yielded better agreement with the low-flow data.

With respect to the ease of use of the GORE technology, our field crew found that sample collection was quick and easy and did not require any

special training. We also found that this sampling method required very little auxiliary equipment or clean up, and there were fewer concerns with sample handling and safety. Specifically, shipping the Modules was much easier (and less costly) than shipping coolers with water samples and ice. Also, express carriers now require additional measures be taken when shipping these coolers. This is to prevent any leakage from them; and some carriers have mentioned that in the future, they may require additional guarantees about compensation for any damage they cause. Overall, we do not foresee any scale-up constraints that would prevent wide-scale use of this technology.

Using the initial startup costs, annual field sampling costs, annual sample processing and analyses costs, and the estimated operations and maintenance costs over the 10-year period, we determined the 10-year monitoring costs for the two sampling methods at both sites. Based upon those numbers, we determined the estimated cost savings for the GORE sampling method.

For the GORE Modules, we determined that 99.75% of the total 10-year long-term monitoring (LTM) cost is associated with sample collection; 85% of that cost is the price of the samplers, and labor is the other 15%. In contrast, the initial start-up costs, sample processing and analyses costs, and operations and maintenance (O&M) costs are essentially negligible with this method.

For low-flow sampling, sample collection accounts for 45% of the total LTM costs for 10 years; and of that amount, 93% is labor. Laboratory analyses account for approximately another 25% of the total LTM costs. The start-up costs (dedicated pumps, purge equipment, etc.) account for less than 10% of the total LTM costs over 10 years, and the O&M costs are roughly 3% of the total LTM costs. We believe that these figures agree with what most practitioners would say (i.e., that low-flow purging and sampling is labor-intensive and costly and that although dedicated sampling equipment is expensive, it is only a small amount of the total LTM costs).

The GORE Modules provided lower costs than low-flow sampling although the degree of the cost savings depends heavily on the price of the GORE Modules. For the use of these samplers to be desirable from a cost perspective (i.e., they provide cost savings greater than 20%), the price of the Modules needs to be about $190 per sampler (at today's costs). When that

price is used in calculating the cost savings, one can achieve a cost savings of about 30% to 45%, depending upon the size of the field crew used for low-flow sampling.

1 Introduction

1.1 Background

Long-term groundwater sampling programs are needed to assess trends in contaminant concentrations and the possibility of increased risk to human health and to the environment. While these sampling programs are costly, there are ways to reduce the costs of the field work. Passive sampling techniques, such as using passive-diffusion samplers (e.g., the Polyethylene Diffusion Bag [PDB] sampler) and equilibrated-grab samplers (e.g., the Snap Sampler), continue to gain acceptance within the user and regulatory community (e.g., NJ DEP 2005; ITRC 2004, 2006, 2007). Where it is appropriate, passive sampling methods can provide considerable cost savings when compared with conventional low-flow purging and sampling methods. Cost reductions associated with passive sampling methods result from reduced labor during sampling, reduced equipment costs, and a reduced volume of purge water waste. As examples, Parsons (2003, 2005), Imbrigiotta and Trotsky (2010, 2011b), and Parker et al. (2009, 2011a, 2011b) have reported cost savings of 46% to 70% for several types of passive sampling methods.

Passive sampling methods are based on the concept that water within the open interval of a well is continuously refreshed by the continuous natural flow of groundwater through the well screen (Robin and Gillham 1987; Powell and Puls 1993). Several studies (e.g., Vroblesky 2001; Parker and Clark 2004) have shown that the PDB samplers can provide quality data and equivalent analyte concentrations of most volatile organic compounds (VOCs) when compared with the conventional low-flow purging and sampling method. In most instances, findings from other studies conducted using the Snap Sampler (Parker and Mulherin 2007; Parker et al. 2009, 2011a, 2011b) and the regenerated-cellulose membrane (or dialysis membrane) sampler (Imbrigiotta and Trotsky 2010, 2011a, 2011b; Imbrigiotta et al. 2007) also yielded quality data and comparable analyte concentrations to the low-flow sampling method for a variety of inorganic and organic analytes. Where the use of passive sampling is appropriate, data-quality improvements can also include better delineation of contamination with depth within the screened zone, such as shown by Vroblesky and Peters (2000), Vroblesky and Petkewich (2000), and Vroblesky et al. (2003).

Although the improvements and potential cost savings associated with passive sampling are significant, many passive-sampling devices currently being used have limitations. For example, the PDB sampler can be used for only select VOCs; and other devices, such as the Snap Sampler, cannot be used in smaller diameter wells, such as many of the smaller direct-push (DP) wells. Like the PDB Sampler, the GORE Module is easy to use and requires minimal labor to obtain a sample. However, this sampler can be used for a broader range of organic compounds than the PDB sampler and can be used in small diameter wells and piezometers.

Unfortunately, the applicability of the GORE Module technology has not been well demonstrated, especially recently and with respect to sampling groundwater. A favorable independent third-party evaluation would promote acceptance of this presumably cost-saving technology.

Anticipated benefits for the Department of Defense (DoD) and the Department of Energy (DOE) associated with using this sampler could include substantially reduced costs for long-term monitoring and better plume delineation, which could result in more effective and less costly remediation.

1.2 Objectives of the demonstration

The objectives of this ESTCP (Environmental Security Technology Certification Program) demonstration were to determine the utility, sensitivity, comparability, and potential cost savings of using the GORE Modules for passive groundwater sampling of VOCs and semi-volatile organic compounds (SVOCs) when compared with conventional low-flow sampling. Data-quality objectives included reproducible data and equivalent or better plume delineation with the GORE Modules. Qualitative objectives included that the sampler was easy to use, that it was technically robust, and that there were not any scale-up constraints.

To meet these objectives, we conducted sampling at two sites: the Southern Bush River (SBR) Area of the Edgewood Area of Aberdeen Proving Ground (APG), MD, and at the former Pease Air Force Base (AFB), Portsmouth, NH. Using GORE Modules and the US Environmental Protection Agency's (US EPA) low-flow purging and sampling protocol (US EPA Region 1 1996), we collected samples from the same wells. Analytes at the

SBR site included five chlorinated VOCs. The primary contaminants at the former Pease AFB were hydrocarbons, including VOCs and some SVOCs (e.g., naphthalene [NAPH] and methylnaphthalene).

The GORE Modules were deployed at the same depth as the inlet of the pump or tubing used to collect the low-flow samples. Also when possible (i.e., in wells with longer screens), the Modules were deployed half way between the top and the midpoint of the screen and half way between the bottom and the midpoint of the screen. In all the wells, the Modules were deployed prior to low-flow sampling and again after low-flow sampling. This allowed us to observe the contaminant stratification in the well under ambient flow conditions and after purging and sampling the well.

1.3 Regulatory drivers

The most commonly accepted and practiced method for sampling a groundwater monitoring well is to use a low-flow purging and sampling method that was first outlined by Puls and Barcelona (1996) and subsequently formalized by the US EPA Region 1 (1996), Nielsen and Nielsen (2002), the American Society for Testing and Materials (ASTM 2003a), and several others. However, low-flow sampling requires substantial investment in equipment, such as (preferably) dedicated variable-speed pumps, field parameter monitoring equipment, etc. This process is relatively time consuming and thus costly.

Also, alternatives to low-flow sampling are desirable from a data-quality perspective. Typically, low-flow sampling collects a sample that is mixed as a result of flow-weighted averaging of inflow along part or all of the length of the well screen. However, this approach tends to pull samples from the more transmissive parts of the formation, which may not be where the highest concentrations of the analytes are contained. In contrast, passive sampling collects samples under ambient flow conditions and allows vertical profiling of the well and presumably of the formation.

The primary driver for conducting this demonstration has been the lack of third-party verification of the GORE Module technology.

2 Technology

2.1 Technology description

The GORE Module (Fig. 1) was developed by W. L. Gore & Associates, Inc. (Elkton, MD). Amplified Geochemical Imaging (AGI) LLC (Elkton, MD) has acquired this technology, and the sampler is now known as the AGI Universal Sampler. However, because this technology was only recently acquired, this report will continue to refer to these samplers as the GORE Modules or simply as the Modules. This passive sampler was designed to be used to sample a wide variety of volatile and semi-volatile organic compounds. Reportedly, these samplers can be used for a number of analytes, including chlorinated solvents; fuel-related compounds; oxygenates; 1,4-dioxane; and some explosives, chemical warfare agent breakdown compounds, pesticides, and polycyclic aromatic hydrocarbons (PAHs). (A relatively comprehensive listing of the analytes detected by the Module can be found in an Interstate Technology and Regulatory Council [ITRC 2007] document on passive samplers.)



Figure 1. Photos of the GORE Module (courtesy of W. L. Gore & Associates, Inc.).

The Module consists of a GORE-TEX® membrane tube approximately 1 ft in length and 0.25 in. in diameter. This membrane is expanded polytetrafluoroethylene (ePTFE) and is chemically-inert, vapor-permeable, and waterproof. Housed inside the membrane tubing are several packets of hydrophobic sorbents that have an affinity for a broad range of volatile and semi-volatile organic compounds.

Figure 2 depicts how the Module collects analytes from an aqueous solution. The analyte must first partition from solution into the vapor phase. Once in the vapor phase, the molecule can then diffuse through the mem-

brane while liquid water is prevented from passing through the (waterproof) membrane. Once the analyte passes through the membrane, it is then sorbed by the adsorbent contained in the sampler.

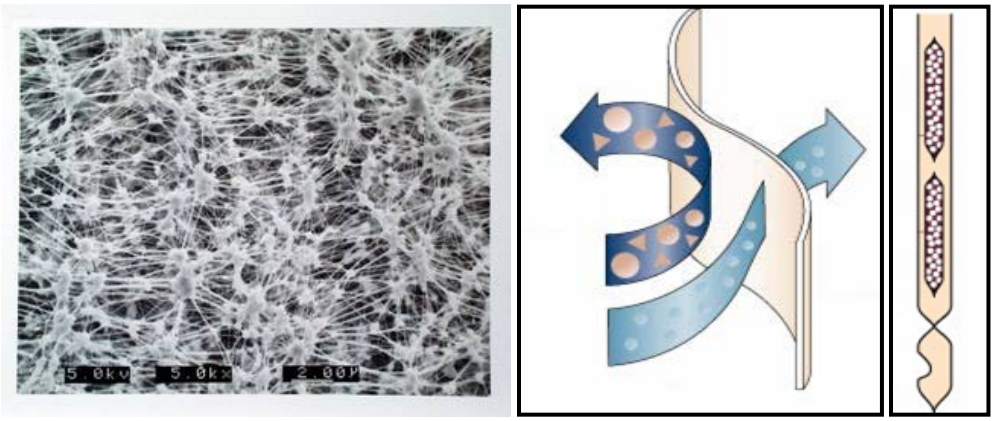


Figure 2. Enlargement of the pores in the GORE-TEX membrane (left) and a schematic representation of vapors diffusing through the membrane (courtesy of W. L. Gore, Inc.).

The sampler can be deployed in unsaturated and saturated soils, sediments, air, and water. In groundwater monitoring wells, the sampler is deployed by tying it to a line of the desired length (for the sampling depth), placing suitable weights on the end of the string, and lowering it into the well. Any well or piezometer with a diameter greater than 0.25 in. can accept this sampler. The sampler immediately begins to collect the analytes, and typical sampling times range from 15 minutes to 4 hours. Depending upon the flow dynamics in the well, high-resolution vertical profiling can be achieved in some cases by simply placing the Modules at multiple sampling depths.

Each Module can be identified by a unique code that is printed on the sampler by the manufacturer. After recovering the Modules from the well, they are returned to their respective coded sample vials and shipped to the manufacturer's laboratory. Analyses are by Gas Chromatography/Mass Spectrometry (GC/MS), using either EPA SW-846 Method 8260C for VOCs or 8270 for SVOCs (US EPA Office of Solid Waste 1996), which were modified for thermal desorption. If desired, the laboratory can calculate the concentration values and will provide those values to the customer in a spreadsheet format. The chemical analyses of the samplers and data computations are included in the purchase price of the Modules.

2.2 Technology development

The GORE Modules have been commercially available for more than 15 years. Whereas the original (and continued) application of this sampler was for soil gas and air sampling for site assessment programs, these samplers are now also used in vapor intrusion investigations, sediment porewater sampling, remediation monitoring, pipeline integrity testing, and surface-water and groundwater sampling.

The US EPA conducted verification studies on the performance of the GORE Module on two occasions. In the first study (Billets 1998), the Modules were used to sample soil gas at two sites with differing geological (soil) characteristics. This study compared the total mass of each of the contaminants to the analyte concentration that was determined using conventional active soil-gas sampling and analyses. The GORE Modules identified the same target compounds observed by the reference method as well as other compounds that were not recovered by the reference method but were known to be present at these sites. Published correlations with the reference method ranged from 0.88 to 0.99.

In the second verification study by the US EPA (Einfeld and Koglin 2000), they examined the performance of the GORE Module for sampling groundwater. They first tested the Modules in a 5 ft diameter, 100 ft tall standpipe containing a test solution of six VOCs. In the first trial, concentrations were relatively low (about 20 μg/L). The second trial tested the samplers in a test solution with higher concentrations (about 200 μg/L) that varied with depth. The samplers were left in place for 48 hours. This study tested two types of Modules: a standard Module with a conventional membrane and a Module with a high water entry pressure (HWEP) membrane. (At the time of this second verification study, Gore recommended the HWEP-membrane Module for depths greater than 30 ft because they had previously found that water migrated through the standard membrane at deeper depths.) Control samples were collected from the sampling ports on the side of the standpipe. At the 14 ft depth, the percent relative standard deviation (RSD) for the target VOCs for the Modules with the standard membrane were comparable to that seen for the control samples (approximately 2% to 17% RSD). At the 28 ft depth, the precision was poorer; and the RSD ranged from approximately 12% to 28%. For the HWEP mem-

brane, the RSD at these two depths was generally larger than that observed with the standard membrane.

Einfeld and Koglin (2000) also deployed these samplers in five monitoring wells containing Trichloroethylene (TCE) contamination. They collected reference samples at 12-hour intervals throughout the 48-hour exposure period by using a co-located (dedicated) submersible pump. (Samples were collected in 12-hour intervals so that a time-weighted average concentration could be determined for the pumped samples.) Plotted results indicated good linearity across nearly three orders of magnitude for the Module data when compared with the pumped data for both Module types. However, the precision for the Modules was poor with RSDs ranging from approximately 10% to 65% (for both Module types). The researchers had previously noted that even with the HWEP membrane, water had penetrated the membrane on two occasions, yielding spurious data. They concluded that the sampler had limited versatility in terms of deployment depths.

Subsequent to this study, the Gore Laboratory shortened the recommended deployment time to between 15 minutes and 4 hours. According to Gore, water intrusion at deeper sampling depths is no longer an issue for the standard membrane with these shorter exposure times; and they have successfully used these samplers to collect samples at 1000–1200 ft below the ground surface (bgs) (with water levels at 550–750 ft bgs). As a result of these research findings, the manufacturer currently only sells the standard membrane.

More recently, Gore developed a physically-based model to calculate groundwater concentrations. This model converts the mass to concentration units using an algorithm that incorporates water temperature, water pressure, and the uptake rate of the analytes from an aqueous solution by the Module (as measured in the Gore Laboratory). This is explained below, but the foundation for this modeling mirrors accepted ASTM methodology used to report concentration values in air taken from passive, sorbent-based samplers (ASTM 2003b, 2008; HSE 1995).

Gore experimentally determined the reference sampling rate for the Module, SR^{O}, under controlled laboratory conditions for each of the analytes. The sampling rate for the Module in a well, SR_{well}, will be affected by the

temperature of the groundwater, velocity of water in the well, and the water pressure above the Module (or depth of the sampler in the water column). Water temperature affects the partitioning of dissolved compounds from the water to the air and thus affects SR_{well}. For example, if the groundwater temperature is less than the reference temperature (21°C), the Henry's Constant will be lower; and thus, the sampling rate will be lower. Both calibration terms are computed from the well information collected during the sampling.

The calibrated sampling rate (L/hr) for each well is

$$SR_{well} = SR^{O} \times Z_p \times Z_t,$$

where Z_p and Z_t are the calibration terms for water pressure and temperature, respectively.

The calculated concentration (in µg/L) can be most simply expressed as

$$\text{Concentration} = \text{mass} / (\text{exposure time} \times SR_{well}).$$

Appendix B provides the calibration data and a more detailed description of this algorithm with a more rigorous regression for calculating concentration values.

Although the developer has dramatically shortened the recommended deployment time to reduce problems with water intrusion of the membrane at deeper sampling depths, there are still instances where this can be an issue for some analytes. When the depth of the Modules below the water table exceeds 32 ft, analytes with higher aqueous solubility and lower Henry's Law constants are biased low (Anderson 2013). In this instance, methyl *tert*-butyl ether (MTBE) is lost entirely and 1,2-dichloroethane (DCA); 1,1,2-trichloroethane (TCA); and 1,1,2,2-tetrachloroethane (TetCA) are biased low by about 40% (Anderson 2013).

2.3 Advantages and limitations of the technology

Reported advantages associated with using the GORE Module include that it can be used to sample for a broad range of VOCs and SVOCs, minimal training is needed to use the sampler, and installation is quick and easy.

The ease of use minimizes the costs associated with collecting a sample. Also, there is no power required to use this sampler, and there is no purge water generated; and this also reduces the logistical burdens and cost of this sampling method. There is no minimum volume constraint associated with the Module other than that the sampler must remain fully submerged during deployment; this is especially an advantage when having to sample wells with low recharge rates. The Module can be used to sample multiple depths within the well, which can provide additional information on contaminant concentrations in the formation with depth. These samplers can be deployed in any well or piezometer with a diameter greater than 0.25 in. They also do not require low-temperature storage during and following sample collection, during shipping, or prior to analyses. This reduces the costs associated with shipping coolers full of ice or blue ice to transport samples to the laboratory.

One limitation associated with using the GORE Module is that, like all no-purge sampling methods, it relies on the assumption that there is continuous natural flow, representative of the aquifer, through the well screen. Another limitation is that the sampler is exposed to other analytes in the water column above the sampling depth during both deployment and retrieval although this exposure is very brief.

However, the primary limitation, especially for some regulators, is that the concentration of contaminants in the groundwater is not measured directly but must be calculated using an experimentally derived algorithm. Also, regulators are concerned that analyte concentrations may not be comparable to that obtained by low-flow purging and sampling methods. It is our plan that this demonstration will address these concerns.

3 Performance Objectives

For the GORE Module, the performance criteria we used for this demonstration focused on the utility, sensitivity, data comparability, and potential cost savings associated with this sampling method when compared with low-flow purging and sampling. Table 1 lists the performance objectives we developed and used for this demonstration, the data requirements, and success criteria.

Table 1. Performance objectives.

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
Equivalent or better plume delineation with GORE Modules vs. low-flow sampling	Concentration data for both sampling methods, with depth for GORE Modules	• Equivalent or lower analyte sensitivity, preferably maximum detection limit (MDL) at $^1/_{10}$ the maximum containment level (MCL) • No statistically significant difference between GORE and low-flow data • Information on contamination with depth
Reproducible data	Replicate samples and analyses by independent laboratory	• RSDs of 20% (or less) • No significant difference in analyte concentrations between Gore and independent lab results
Reduced sampling cost	Records of sampling time, equipment costs, waste disposal, and other costs associated with both sampling methods	• A minimum of a 20% cost savings
Qualitative Performance Objectives		
Ease of use	Feedback from field technician on usability of technology and time required to train an individual in its use	• Samples are easy to collect • Samplers work as described • A single field technician can conduct the sampling • Minimal training required
Technology robustness	Written records during sampling	• No issues with the strength, sampling depth (below water table), or durability of samplers
Scale-up constraints	Observation of issues that would limit or require modification for large scale use	• Lack of significant issues preventing large scale use of the GORE Module

3.1 Comparability of the GORE Modules and low-flow sampling

To determine the comparability of the data, we compared analyte concentrations in samples collected using low-flow sampling and those derived using the GORE Modules. We used standard statistical methods to compare the low-flow data with the GORE data from the same depth and with the mean values for the three depths. The statistical analyses included paired t-tests and Repeated-Measures Analysis of Variance (RM-ANOVA) or their non-parametric equivalents when needed. Linear regression, using a least-squares method, was used to determine if there was a significant relationship between the GORE data and the low-flow data and if the relationship was one to one.

Our requirements for success included that there were no statistically significant differences between the analyte concentrations in samples collected with the GORE Modules and the low-flow samples, that there was a significant one-to-one correlation between the data, and that the sensitivity of the GORE method was similar to or better than low-flow sampling.

Although low-flow purging and sampling is currently the industry standard, it is not known whether that sampling method, or any method, yields results that accurately reflect analyte concentrations in the aquifer. Therefore, it is important to understand the conceptual differences of each sampling technology and the site hydrogeology when interpreting the data from this demonstration or from any similar comparison. Typically, low-flow purging and sampling yields water that is mixed over the length of the well screen; the degree of mixing is a function of the hydrogeology of the formation (especially for the portion of the formation that abuts the well screen), the permeability of the filter pack materials and the mesh size and length of the well screen, and the pumping rate. Purging the well until the purge parameters stabilize is designed to pull water into the well from the aquifer and thus allow collection of a fresh water sample as opposed to collecting water from the stagnant casing.

In contrast, the GORE Module samples the water in the well screen and thus relies on water flowing through the screen to provide fresh water. Flow through the well screen may be horizontal and laminar or there may be mixing in the well bore or screen. Under ambient conditions, the degree of mixing in the well and well bore is a function of the hydrogeology of the

formation where the well screen is located (especially the permeability of any and all zones), well construction (including the size and length of the well screen and filer pack materials), contaminant concentration differences (in water coming from different strata or within the well), and temperature differences (in water coming from different strata or within the well). Therefore, in some instances, the GORE Module data can reflect stratification of contaminants with depth within the well screen whereas the low-flow samples reflect a concentration value that results from the mixing that has occurred with purging.

Therefore, to obtain some measure of the capability of the GORE Modules to delineate contaminant stratification in the wells and to show how the GORE data compared with the low-flow data, plots of the analyte concentrations with depth compare the GORE data (at three depths) with the low-flow data (at one sampling depth).

3.2 Reproducibility of the GORE method

Another primary objective for this demonstration was that the GORE Module technology provides data with good precision, preferably similar to that provided by low-flow sampling. For each analyte with detectable concentrations, we used the following measure of success: for concentrations that were three times the detection limit or more, the RSD for the GORE data should be 20% or less. For each analyte, we then determined the percentage of wells that met this goal.

We collected replicate samples for 10% of the GORE Modules collected at the first site. These samples were sent to an independent contract laboratory for analyses. We used a paired t-test to determine if there was a statistically significant difference between the values determined by the Gore and contract laboratories.

3.3 Cost savings

Another important criterion for this demonstration was that this sampling method be less costly than low-flow sampling. This was determined by assessing the costs associated with each of these methods. The cost comparison included the field crew's salary (time) (which included sample site cleanup and waste disposal), the cost of all equipment associated with both sampling methods, and the cost of analyses (as this cost would not be

the same for the two sampling methods because the price of the analyses of the GORE Modules is included in the purchase price). For the cost models, we assumed that all work on site would be performed by on-site personnel; and so travel costs were not included in the cost comparison. We set a minimum cost savings of 20% as our goal.

3.4 Other subjective measures

Other subjective measures for measuring the success of this sampling method included that it should be easy to use and no major problems should be noted. To determine this, we documented any problems associated with using these samplers, noted user acceptance, and recorded the time needed for training.

The test method should also be sufficiently robust. The sampler should be durable; and it should work as designed, even at depths more than 30 ft below the water table where problems have been encountered in the past.

Finally, there should not be any scale-up constraints that would prevent wide-scale use of this technology.

4 Site Descriptions

4.1 First test site: Aberdeen Proving Ground

4.1.1 Site location and history

For this demonstration, we selected the Southern Bush River (SBR) area in the Edgewood section of Aberdeen Proving Ground, MD (Fig. 3) as our first test site.



Figure 3. Location of the Southern Bush River site on Aberdeen Proving Ground, MD.

APG is located in the headwaters of the Chesapeake Bay near Aberdeen, MD. Its northernmost point is near the mouth of the Susquehanna River, where the river enters the Chesapeake Bay; and on the south, it is bordered by the Gunpowder River. The installation lies on two peninsulas separated by the Bush River. The northeastern section of APG is known as the Aberdeen Area and the southwestern section is referred to as the Edgewood Area (formerly known as the Edgewood Arsenal).

The Edgewood Area covers approximately 13,000 acres and includes Gunpowder Neck, Poole's Island, Carroll Island, and Graces Quarters. Edgewood Arsenal was used for the development and testing of chemical agent munitions. From 1917 to the present, this area has been used to conduct chemical research programs. In the past, this included manufacture, storage, testing, and disposal of chemical agents and other toxic materials. Thus, Edgewood has large areas of land and water and numerous buildings that are contaminated or potentially contaminated, including potentially buried ordnance. Substances disposed of in this area included significant quantities of napalm, white phosphorus, and chemical agents. The surface waters include rivers, streams, and wetlands; and surface-water sampling has found white phosphorus and various pesticides, VOCs, and metals (US EPA 2009). Groundwater sampling has identified various metals, VOCs, and chemical warfare agent degradation products. Soil sampling has found various VOCs, metals, and unexploded ordnance in the surface and subsurface soil.

The Southern Bush River Area is located on a peninsula that is bounded by the Bush River to the east and south and Kings Creek to the southwest (Fig. 3). The US Army has designated the area for industrial land use, and this site is listed as a Superfund site by the US EPA.

The 26th Street Disposal Site consists of two distinct areas separated by 26th Street. The west side of this street consists of a gas-mask canister and charcoal burning area (as shown in Fig. 4). The east side of this street is an area where dumping of miscellaneous debris occurred. A geophysical investigation performed in June 1994 confirmed that the two areas are distinct and determined the thickness of the fill to be approximately 5 ft.

Historical aerial photographs from 1929 indicate activity in the burning area for the mask canisters. Activity at this site continued until the late

1960s to early 1970s. The burning operations on the west side of 26th Street covered an area approximately 300 by 50 ft. The small-scale disposal operation involved the burning of off-specification and unserviceable gas mask canisters. The canisters were burned inside their wooden box packaging. The metal parts residue from this burning were left in place. Visual examination of the area reveals box hinges on the ground surface and canister bodies visible in depressions. A thin cover of soil exists over the burned residue, except in one location where erosion has occurred and has exposed the buried canister bodies.

The 22nd Street Landfill encompasses approximately 8.3 acres east of 22nd Street and northwest of the Toxic-Gas Yard/Rad Yard (Fig. 4). The landfill also occupies an area adjacent to the Bush River, including a former marsh area. Interviews and aerial photography from 1970 indicate the landfill was used during the late 1960s and early 1970s. Currently, the 22nd Street Landfill is an open, grass- and marsh-covered area.

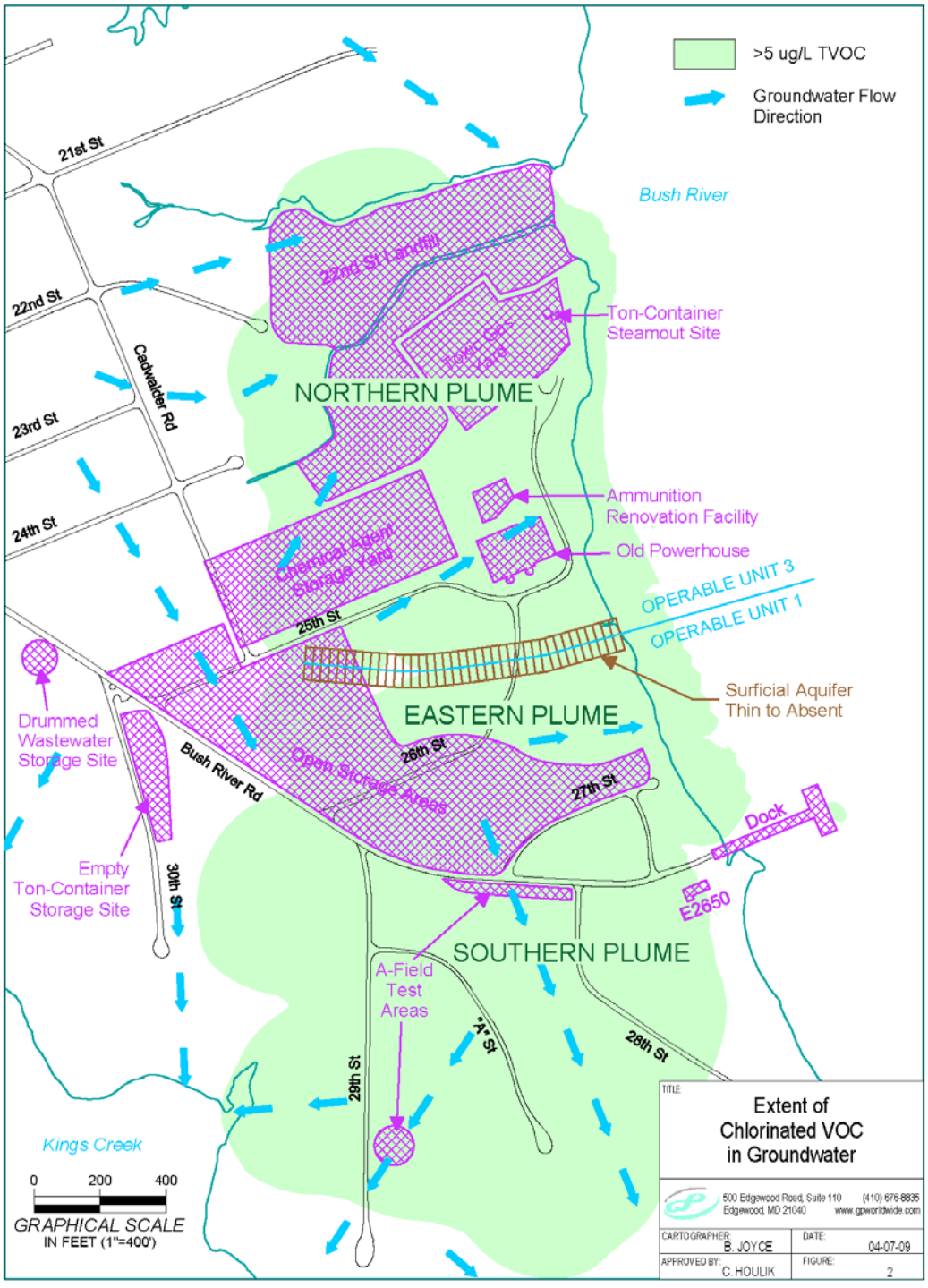


Figure 4. Map of the Southern Bush River Area showing the extent of the contaminant plumes and ground water flow direction (General Physics [2009]).

4.1.2 Site geology/hydrogeology

The following description of this site was taken from Dunbar et al. (2001).

> A regional geologic and geomorphic model was developed for the Aberdeen Proving Ground (APG). Regional geologic information and interpretation of data from over 200 geologic and water well borings indicate that APG is situated upon Pleistocene terraces of the ancestral Susquehanna River, which unconformably overlie Cretaceous deposits. The remnants of at least three and possibly four separate filling cycles, ranging from middle Wisconsin to early Pleistocene in age (youngest to oldest), are present at APG.
>
> From the Fall Line, which is the boundary between the Piedmont and Coastal Plain physiographic provinces northwest of APG, Precambrian basement rocks dip toward the southeast and are overlain by Atlantic Coastal Plain strata of Cretaceous and Pleistocene ages, separated by unconformities. The depth of the Precambrian bedrock surfaces increases from its exposure at the surface at the Fall Line toward the Atlantic Ocean (Richards 1948; Owens 1969); the surface is situated at a depth of well over 1000 m in eastern Maryland. Deposits of sands, silts, clays and gravels overlie the Precambrian rocks. These sediments, which dip and thicken eastward and southeastward, are the evidence of fluvial, deltaic, and near-shore deposits from the late Mesozoic to Cenozoic sea-level changes (USGS 1967; Vroblesky and Fleck 1991), Upper Cretaceous sediments are absent at APG but are present throughout much of the Coastal Plain. Lower Cretaceous beds (Potomac Group) are unconformably overlain by Quaternary sediments that accumulated during the Pleistocene in the highly variable depositional conditions of fluvial and estuarine environments associated with interglacial sea-level changes (Owens 1969; Owens and Denny 1979).

The hydrogeology of the Southern Bush River area is characterized by thick, wedge-shaped deposits of unconsolidated Coastal Plain sediments that dip southeastward while resting over an unconformity of older crystalline rocks of the Piedmont Physiographic Province (Owens 1969; Lorah and Clark 1996) (Fig. 5).

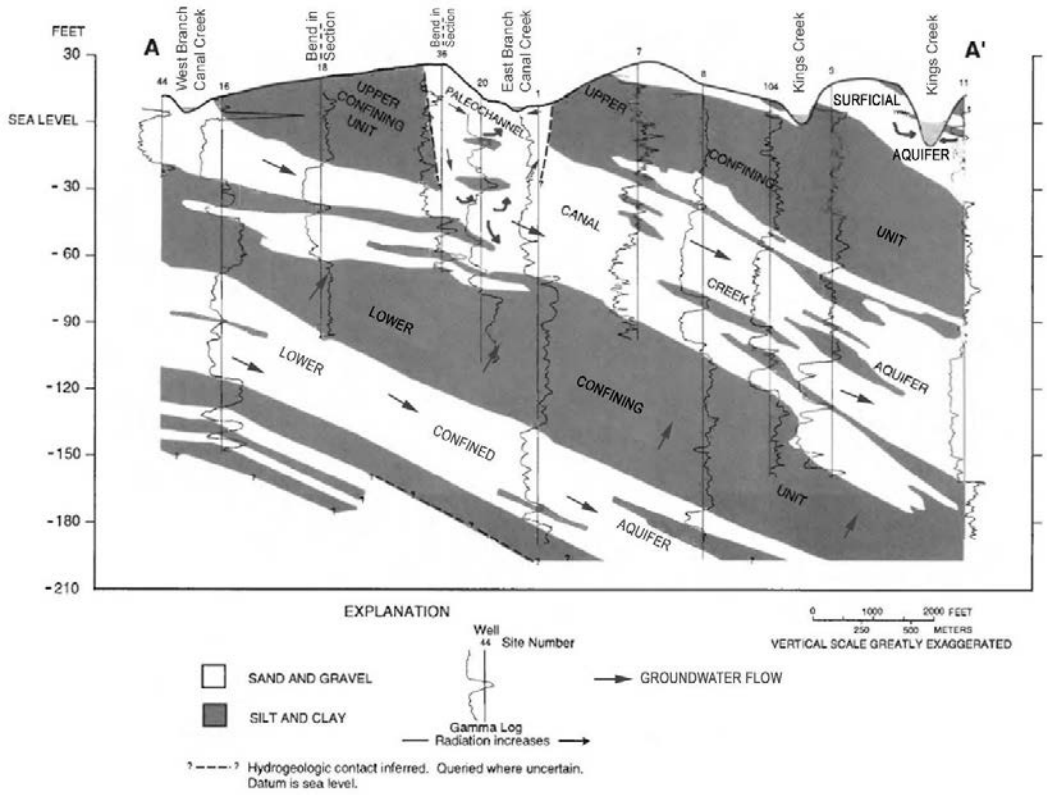


Figure 5. Cross-section of the Southern Bush River Area. (Taken from Oliveros and Vroblesky [1989] as modified by Lorah and Clark [1996].)

The surficial aquifer in the Southern Bush River area consists primarily of sediments of the Talbot Formation. The lithology of this unit consists of both sands and gravels as well as areas of silts and clays and is highly variable due to disturbances from excavation and land-fill activities (Lorah and Clark 1996). Paleochannels of various sizes and orientations have been mapped throughout the Southern Bush River Peninsula (Davies et al. 1995). This unit is discontinuous in the Canal Creek area to the north-northwest of Kings Creek and west of the Southern Bush River area.

The underlying upper confining unit, Canal Creek Aquifer, lower confining unit, and the lower confined aquifer are all composed of Cretaceous Potomac Group sediments (Oliveros and Vroblesky 1989; Lorah and Clark 1996) (Fig. 5). These sediments both dip and generally thicken to the southeast. Both the aquifers and confining units contain laterally non-continuous beds as well as variations in thickness common for fluvial deposits. The upper confining unit outcrops in the western portion of the Bush River study area (Fig. 6). The Canal Creek aquifer ranges from 30 to

70 ft thick in the Canal Creek area (Lorah and Clark 1996). The lower confined aquifer underlies the approximately 60 ft thick lower confining unit.

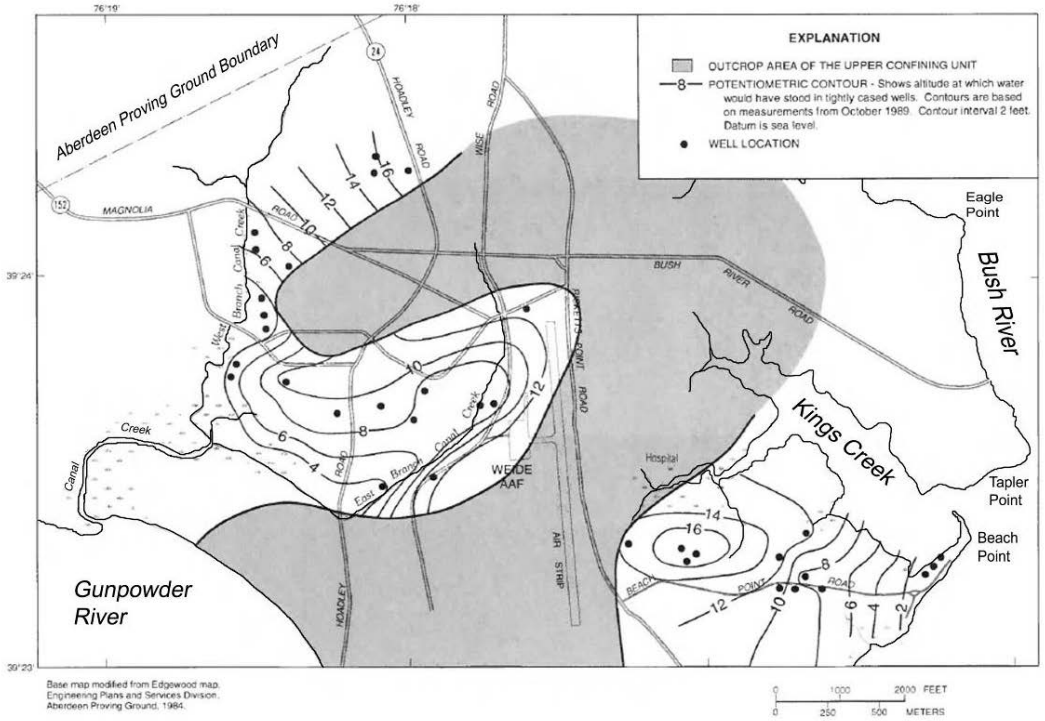


Figure 6. Map showing outcrop area of the upper confining unit (Lorah and Clark [1996]).

The surficial aquifer is recharged from infiltration of both precipitation and surface water as well as from upward flow from the underlying Canal Creek aquifer. The surficial aquifer discharges to surface water, leaky sewers and storm drains, and the underlying Canal Creek aquifer (Lorah and Clark 1996). Groundwater flow in the Canal Creek aquifer is generally from the northwest to southeast.

Generally, groundwater flow directions in the three aquifers do not differ significantly in the study area (Lorah and Clark 1996).

4.1.3 Contaminant distribution

The legacy of the extensive testing and training at the Aberdeen Proving Ground includes at least 25 distinct plumes of groundwater contamination in the APG area (Green 2005). Groundwater contamination in the Canal Creek and Southern Bush River areas is widespread (Lorah and Clark 1996). Chlorinated organic solvents are considered the primary contami-

nants due to their pervasiveness and the relatively high levels present at the site. Some inorganic and other types of organic compounds are also present in the area (Lorah and Clark 1996). Contamination in the Canal Creek area to the west of Southern Bush River area is present in both upper surficial and underlying Canal Creek aquifers where the two aquifers are not hydraulically separated by the upper confining unit.

In 1983 and 1984, the Maryland State Health Department collected water samples from the six standby water supply wells in the Canal Creek Area. VOCs were detected in all wells. The major contaminant was TetCA with a maximum concentration of 2300 µg/L (Lorah and Vroblesky 1989). Other VOCs detected in the groundwater included carbon tetrachloride; tetrachloroethylene (PCE); chloroform (CLF); TCE; *trans*-1,2-dichroloroethylene (tDCE); TCA; DCA; vinyl chloride (VC); benzene (BNZ); Chlorobenzene (CLB); and total xylenes (XYLs). Figure 4 shows the generalized extent of VOC contaminant plumes in this area, and Figure 7 shows the location of two TetCA plumes in the upper surficial aquifer.

In 1977, water column samples were collected from Kings Creek and Bush River (US Army Environmental Hygiene Agency 1977). Along with evidence of nutrient overloading, this study found silver, zinc and mercury concentrations above background levels. Subsequent studies in the area have found VOCs and elevated levels of cyanide, copper, lead, zinc, and beryllium in the surface water samples from the Canal Creek. Arsenic, chromium, lead, pesticides, and polychlorinated biphenyls (PCBs) were also detected in the bottom-sediment samples in both Canal and Kings Creeks (US Army Environmental Hygiene Agency 1977; Lancellotti 1987).

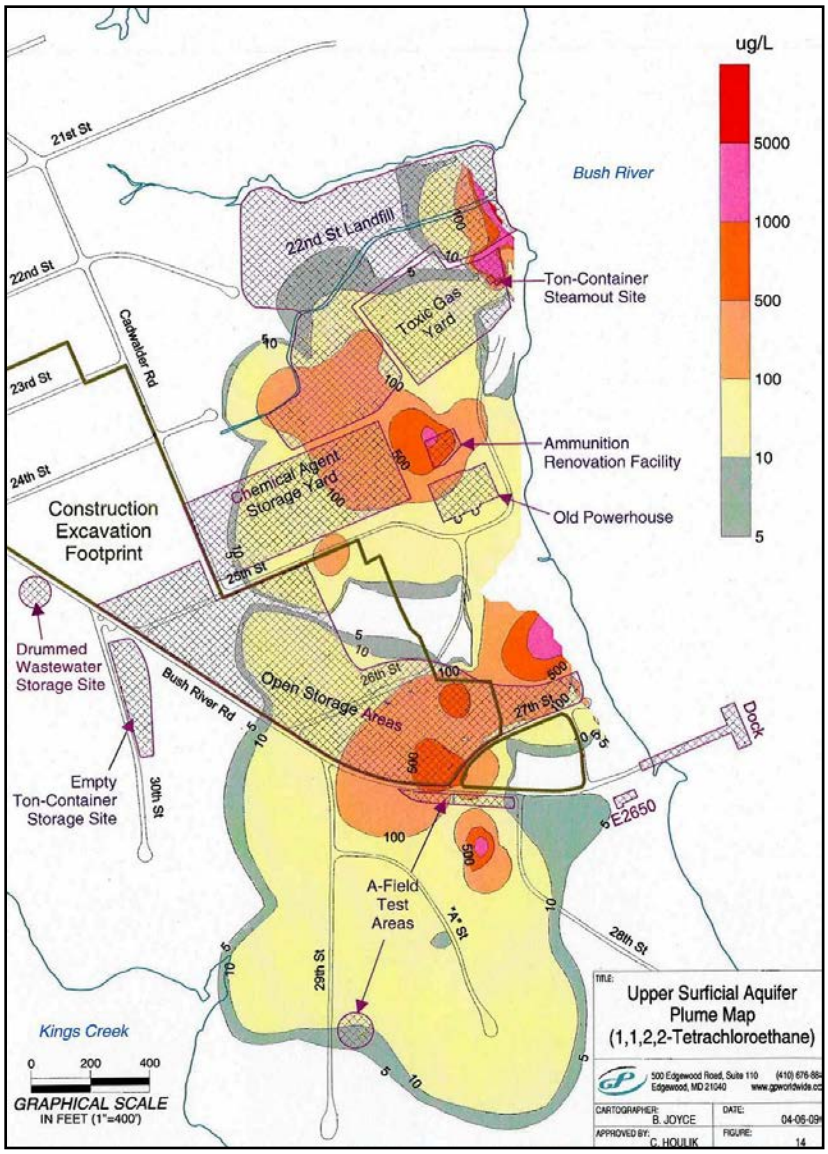


Figure 7. Map showing the location of 1,1,2,2-Tetrachloroethane plumes in the upper surficial aquifer (General Physics [2009]).

4.2 Second test site: former Pease Air Force Base

4.2.1 Site location and history

Acreage for the former Pease AFB spans both the town of Newington and the City of Portsmouth in New Hampshire. The former AFB occupies approximately 4365 acres and is located on a peninsula in southeastern New Hampshire. The peninsula is bounded on the west and southwest by Great Bay, on the northwest by Little Bay, and on the north and northeast by the Piscataqua River (Fig. 8).

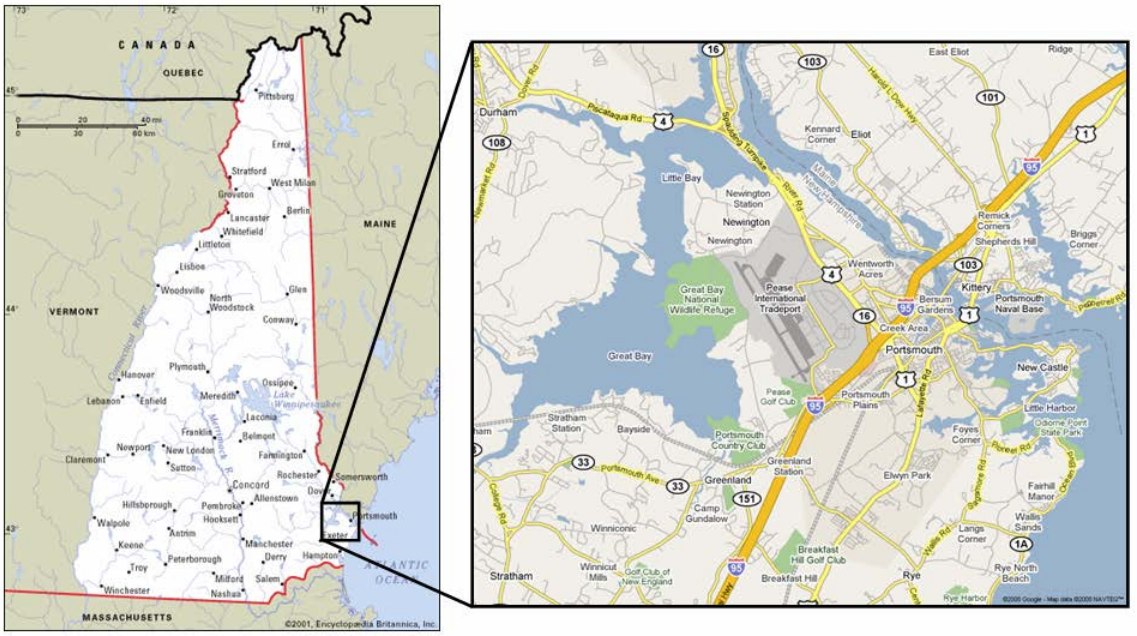


Figure 8. Location of the former Pease AFB.

At the onset of World War II, the US Navy used an airport at this location. The US Air Force assumed control of the site in 1951, and construction of the base was completed in 1956. Over time, various quantities of fuels, oils, lubricants, solvents, and protective coatings were used; and as a result of these activities, contaminants from these substances were released into the environment. Specifically, fuels, organic solvents, PAHs, and metals have been found in soils on the base. Studies have found that the groundwater is contaminated with VOCs, including TCE and PCE. PAHs, pesticides, and heavy metals have been found in the sediments from various discharge ditches.

The base continued to operate until it was closed in 1991 when the Air Force transferred most of the property to the Pease Development Authority (PDA). The airfield is now a commercial airport, and other portions of the PDA property are being used for light commercial and industrial facilities. Another portion of the former base was transferred to the US Department of Interior for use as a national wildlife refuge, and the Air Force retained 229 acres for use by the New Hampshire Air National Guard.

The DoD's Installation Restoration Program (IRP) established eight IRP zones in 1991. Eleven Records of Decision (RODs) (representing all the major Superfund cleanup decisions) were completed between 1993 and

1997, and initial remedial design and construction activities for the base were also completed (MWH Americas, Inc. 2004). Operation and maintenance and long-term monitoring (LTM) activities with modifications to the remedial activities have been on-going.

Sampling occurred in Zone 3, which occupies approximately 440 acres and is located in the central portion of the former AFB. The zone contains numerous buildings with adjacent paved parking areas, a network of roads, and the flight-line area, which is where we collected our samples. The flight-line area includes the runway, aircraft parking apron, and the grassy infield between the parking apron and the runway. The flight-line area is a major feature of the base and makes up nearly one-third of this zone. This zone also contains seven IRP sites that are buildings and three underground-storage-tank sites.

The monitoring wells selected for this demonstration are located in the flight-line area of Zone 3. The US Air Force is currently conducting remedial action activities associated with the Underground Storage Tank (UST) Program on the flight-line. A total of 72 petroleum hydrocarbon plumes have been identified in association with the flight-line refueling system (FLRS). The FLRS was designed to deliver aircraft fuel from large aboveground tanks at the bulk fuel storage area to the pump house USTs along the flight line. The system also included hydrant laterals and pump houses used to collect fuel from aircraft defueling operations.

For this demonstration, we sampled the Pump House 2 (PH2) site, which consists of plumes 6, 7, 8, and 9 and their periphery (Fig. 9): PH2, USTs, a collection storage tank, and hydrant laterals. Previous remediation at this site was conducted in two phases. Phase I consisted of vertical contamination profiling followed by the in situ injection of an organic carbon material. Phase II consisted of a second injection of this material.

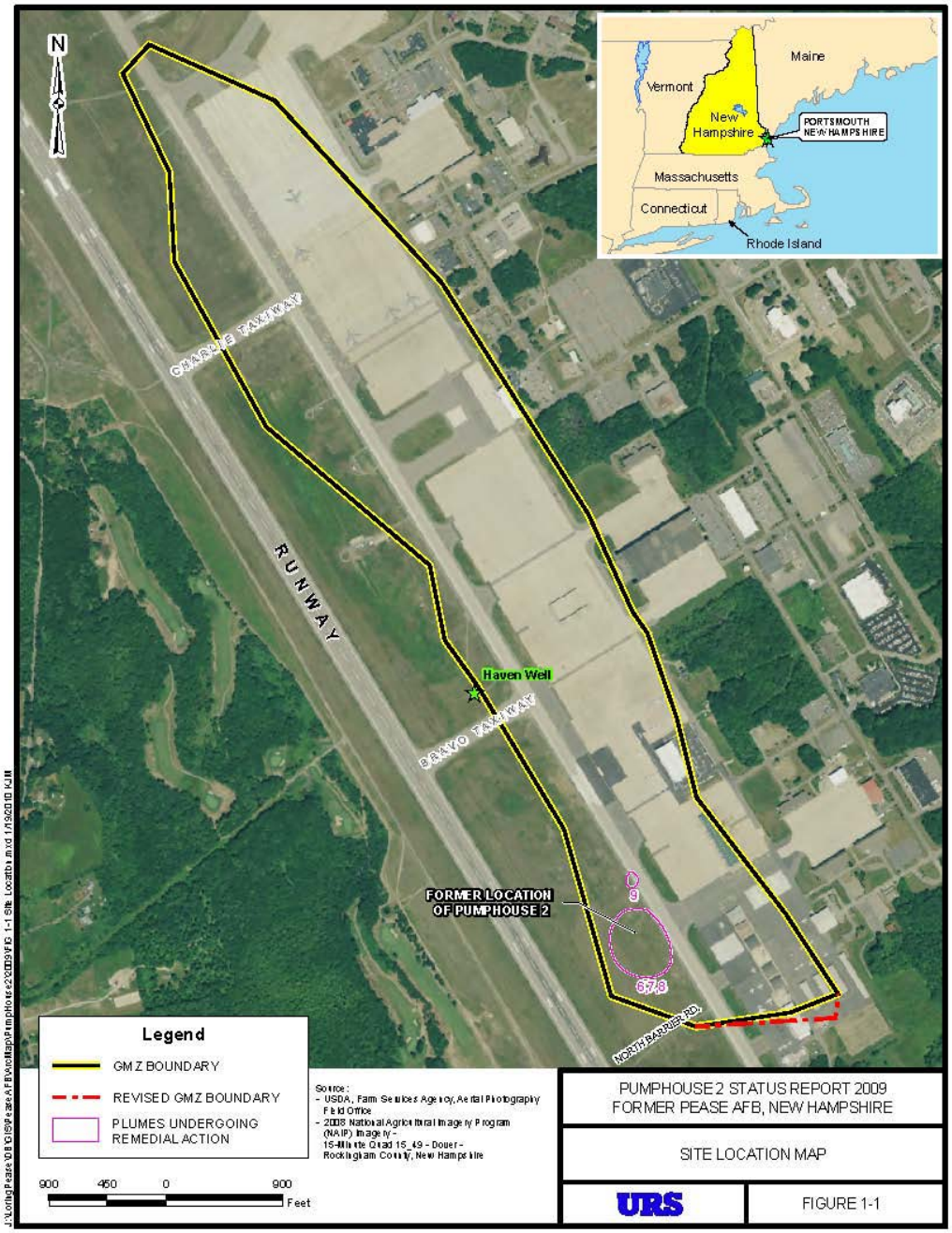


Figure 9. Flight-line area of Zone 3 showing plumes 6, 7, 8, and 9.

4.2.2 Site geology and hydrogeology

The shallow subsurface beneath Zone 3 consists of four unconsolidated lithologic units: upper sand, marine clay and silt, lower sand, and glacial till. The bedrock underlying these lithologic units is either the Kittery or Eliot formation, depending on the specific location within the zone. The

thickness of the overlaying unconsolidated lithologic units varies across the site. The elevation of the bedrock interface is also highly variable, presumably because of the Zone's glacial history. Figures 10 and 11 show cross sections of the geology of Zone 3.

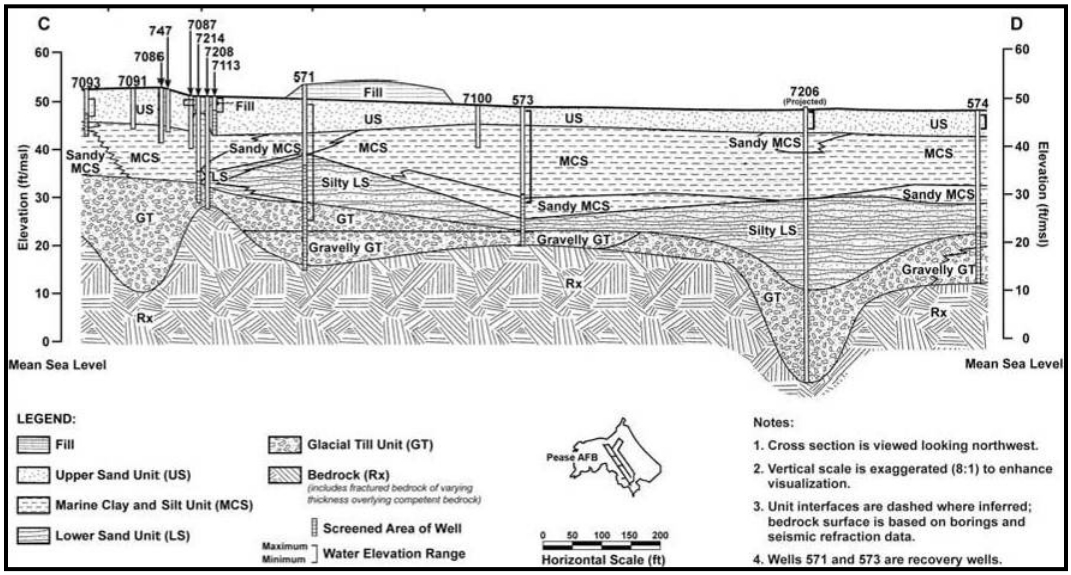


Figure 10. North–south cross section of the hydrogeology of Zone 3 (Roy F. Weston, Inc. 1992).

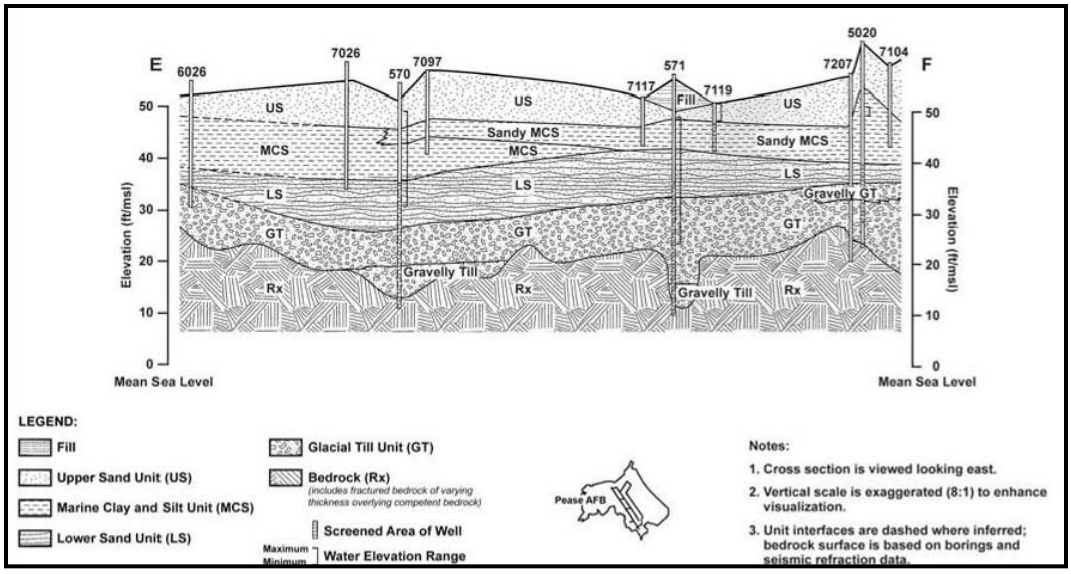


Figure 11. East–west cross section of the hydrogeology of Zone 3 (Roy F. Weston, Inc. 1992).

Groundwater flow in the upper sand, lower sand, and bedrock units of the PH2 site generally ranges from northeast to southeast (URS Group, Inc. 2010).

4.2.3 Contaminant distribution

4.2.3.1 Meter Pit 5

Meter Pit 5 is the most contaminated portion of the PH2 site and is the source of the large, downward-plunging plume of groundwater contamination to the south and west of the meter pit (URS Group, Inc. 2010). The primary source area is approximately 250 ft long, extending west–southwestward from Meter Pit 5.

In 2009, the five lower-sand monitoring wells in the source area exhibited BNZ, toluene (TOL), ethylbenzene (EBNZ), XYLs, NAPH, 124TMB, and 1,2-dibromoethane at concentrations above the New Hampshire Ambient Groundwater Quality Standards (NH AGQS) (URS Group, Inc. 2010). (Table 2 gives the NH AGQS limits for all the analytes found at this site.) In 2009, the upper sand well in the source area (HY2-4467) had no concentrations that exceeded the NH AGQS for any of the contaminants of concern. Residual LNAPL (light non-aqueous phase liquid) still is detected at the Meter Pit 5 area, with three locations showing LNAPL in 2009 (HY2-4472, PH2-4908, and PH2-5336).

Table 2. NH AGQS limits for analytes found at the test site.

Analyte	NH AGQS limits (µg/L)
benzene	5
toluene	1,000
ethylbenzene	700
xylenes (total)	10,000
naphthalene	20
124TMB	330
135TMB	330

Analyte	NH AGQS limits (µg/L)
n-butylbenzene	260
n-propylbenzene	260
p-isopropyltoluene	260
sec-butylbenzene	260
tert-butylbenzene	260
1,2-dibromoethane	0.05
isopropylbenzene	800
MTBE	13

The highly localized presence of residual source material appears to be slowing the rate of remediation, and there does not appear to be any expansion or migration of the plume. The historically flat to neutral horizontal groundwater flow gradients in the lower sand and bedrock units may account for the apparent lack of plume migration.

4.2.3.2 Meter Pit 6

In 2009, in one of the upper sand wells in the Meter Pit 6 source area, BNZ, NAPH, and 124TMB were detected at concentrations that exceeded NH AGQS. NAPH also exceeded NH AGQS in one of the lower sand wells within the source area. Since 1999, there has been no indication of contaminant migration from the Meter Pit 6 source area toward the Meter Pit 5 plume or from the Meter Pit 5 plume toward the Haven Well (URS Group, Inc. 2010).

5 Test Design

5.1 Aberdeen Proving Ground test site

Louise Parker, Tommie Hall, Ron Bailey, and Kelsey Gagnon (summer student from the University of New Hampshire), all with the US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL), conducted the field work at this site.

5.1.1 Conceptual experimental design

The demonstration at this site examined the use of the GORE Module to sample for several VOCs. Contaminants included BNZ, CLF, *cis*-1,2-dichloroethylene (cDCE), TCE, PCE, and TetCA. Specifically, analyte concentrations recovered with the GORE Modules were compared with those in samples taken using the EPA's low-flow purging and sampling protocol (US EPA Region 1 1996). We collected low-flow samples by using a peristaltic pump. Dedicated Teflon-lined polyethylene tubing, which we placed in the well a month earlier, was used to collect the low-flow samples. We deployed three GORE Modules in series on a single line in the screened portion of the well. The deployment depths were the same as the pump inlet (the midpoint of the well screen), the midpoint of the upper half of the well screen, and the midpoint of the lower half of the well screen. After the proper deployment time (about 15 minutes to 2 hours) was complete, we recovered the Modules from the well. We refer to these samples as the "pre-purge samples," and they reflect analyte concentrations that would typically be obtained using this passive sampler technology. After the pre-purge Modules were removed from the well, a water-level/temperature probe was used to determine the depth to water in the well and the water temperature in the well. After recording this information, we decontaminated the meter.

After recovering the first set of GORE Modules from the well, we collected the low-flow samples. After this collection, we deployed another string of three Modules in the well and recovered them after the deployment period was complete. These samples reflect the concentrations of the analytes in the well after purging the well and are referred to as the "post-purge sam-

ples." This allows us to examine analyte concentrations with depth in the wells before and after purging.

5.1.2 Baseline characterization

This site contained mostly conventional 4 in. diameter monitoring wells and a few conventional 2 in. diameter monitoring wells. Contamination at this site was previously characterized using piezometers and DP wells. The location of these wells and piezometers were shown on maps provided by General Physics (2009).

Prior to conducting any field work at the SBR site, we developed a list of tentative conventional and DP wells and piezomenters to sample. Our first task during our first visit to this test site was to locate the wells and piezometers. However, none of the DP wells or piezometers that had been used to characterize the site had been sampled in several years, and we found that most of these wells were either damaged or destroyed or that we could not find them.

For those wells we located, we noted their condition and determined the depth to the bottom of the casing. The team also compared the measured depths of the wells with the construction details to determine the extent of silting in the wells. Based on these findings, we revised the list of wells to be sampled.

For the second site visit, because many of these wells had not been sampled for almost a decade, it was necessary to cut vegetation around the wells so that we could access them more readily.

We then placed in each of the wells tubing for the peristaltic pumps and purged each well at a low flow rate. We slowly increased the flow rate to determine the maximum pumping rate for the well (with a minimum drawdown) and noted the water quality in the well to determine if the well needed to be redeveloped. However, all of the preselected wells were viable. The tubing (for the pumps) remained in the wells for approximately one month prior to our starting the demonstration.

5.1.3 Design and layout of technology components

5.1.3.1 Monitoring wells

Table 3 provides a list of the monitoring wells used in this study, and Figure 12 shows the location of these wells. None of the wells used in this study contained free (undissolved) product.

Table 3. Wells sampled at the Southern Bush River Site.

Well #	Internal Diameter (in.)	Screen Interval (ft bgs)	Screen Length (ft)
23	4	20–30	10
24	4	17–27	10
25	4	5–15	10
26	4	12.3–17.3	5
27	4	9.4–14.4	5
33	4	10–20	10
35 A	4	19–31	12
35B	4	2–9	7
36R	4	10–20	10
37	4	10–13	3
40	4	4–14	10
41	4	13–25	12
44	4	12–15	3
45	4	16–23	7
53 A	4	9–19	10
53 B	4	22–32	10
55	4	8.5–18.5	10
56 A	4	34–44	10
56 B	4	46.5–56.5	10
57	4	23–33	10
58	4	10.5–20.5	10
59	4	5.5–15.5	10
61 A	4	23–33	10
61 B	4	36–46	10
62	4	15.5–25.5	10
63	4	5–15	10
64	4	11.5–18.5	7
90	4	3.8–12.8	9
91	4	4.8–13.8	9
92	4	6.3–15.3	9
111	4	38–58	20
113	2	16–26	10
116	2	52–62	10
118	2	17–27	10
119	2	42–52	10
128	2	8–13	5
130	6	16–36	10
131	2	7–12	5
133	2	8–18	10
134	2	42–52	10
140	2	11.5–16.5	5
142	2	26–36	10
146	2	6–16	10
147	2	28–38	10
148	2	6–16	10

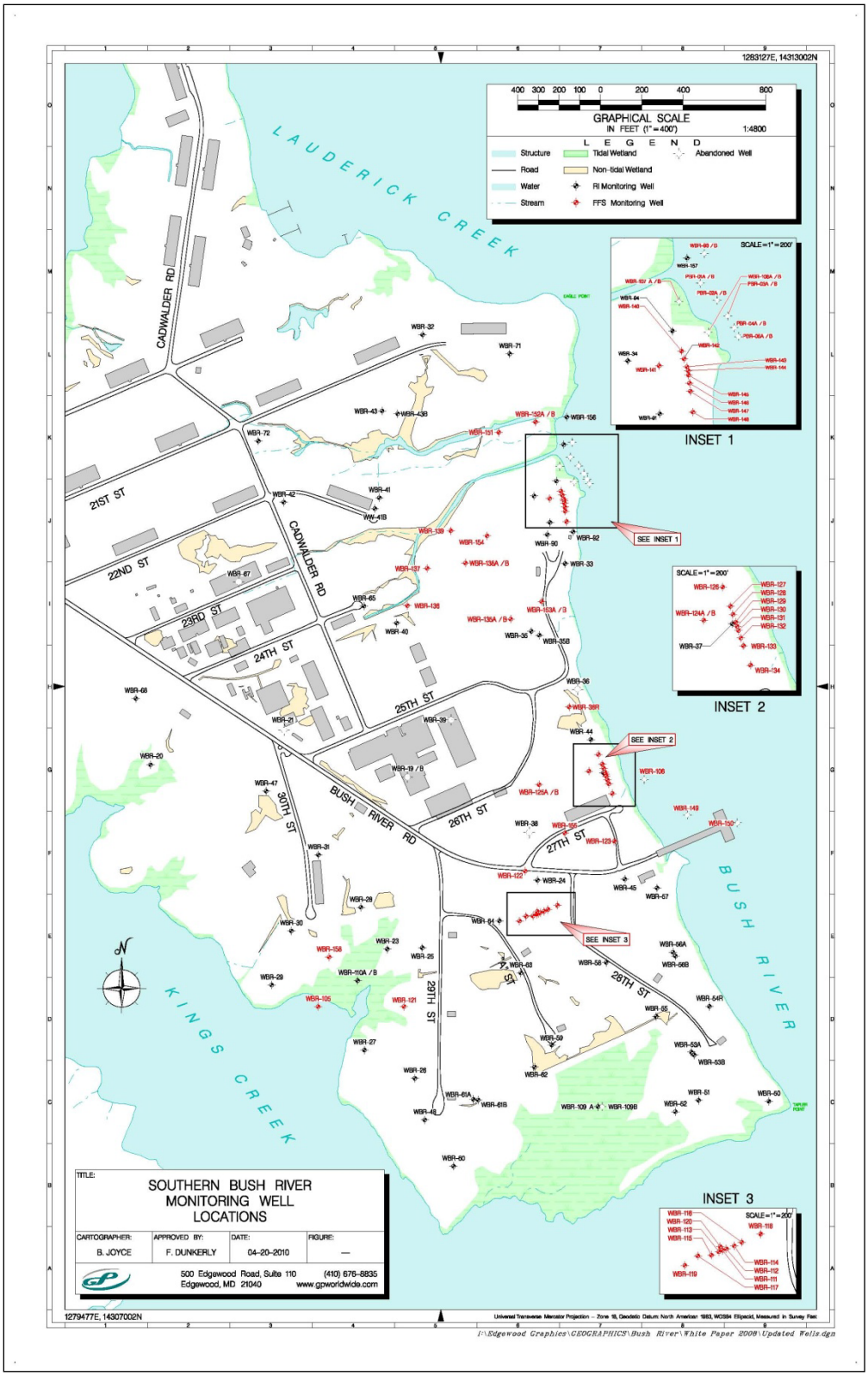


Figure 12. Monitoring wells in the Southern Bush River Area (General Physics [2009]).

5.1.3.2 *Installing the sampling equipment in the wells*

Figure 13 shows a schematic of the sampling equipment deployed in each of the wells. The tubing for the peristaltic pump was placed in each of the wells so that the intake was at the midpoint of the well screen. For each of the wells that had a screen that was 7 ft in length or longer, we deployed in the well three GORE Modules on a single line (in series). One Module was placed at the midpoint of the well (i.e., the pump inlet), one at the mid-point of the upper half of the screen, and one at the midpoint of the lower section of the well screen. Stainless steel weights were tied to the lower end of the assembly, and (uncolored) plastic zip ties were secured to the ends of the Modules so that they remained in a vertical orientation in the well. For the wells with 3 ft screens, only one GORE Module was deployed, monitoring the midpoint of the well screen. Two of the wells with 5 ft screens had samplers placed at all three depths and two of these wells had only mid-level sampler.

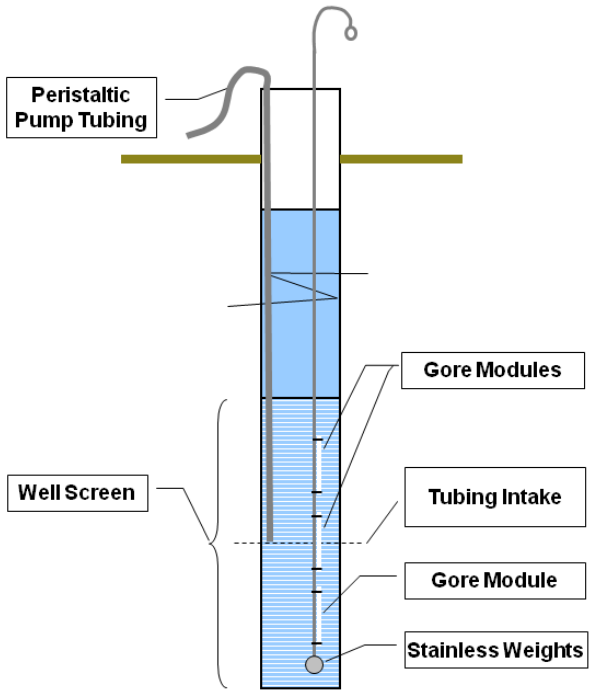


Figure 13. Diagram showing the location of the sampling equipment in each well.

5.1.4 Field testing

At this site, the field work was conducted in four phases (Table 4). The first two phases consisted of the initial and second site visits (as described pre-

viously in Section 5.1.2). After leaving the tubing in the wells for approximately one month, we conducted the field demonstration and then site cleanup. Site cleanup consisted of removing the tubing from the wells and decontaminating equipment. Disposable materials were bagged and disposed of according to directions from the site manager. All purge water and decontamination water were also disposed of according to the directions of the site manager.

Table 4. Schedule for demonstration activities.

	Month			
	1	2	3	4
Initial site visit and revision of the list of wells	X			
Final well selection and deployment of tubing in wells		X		
Field demonstration (testing)			X	X
Site cleanup			X	X

5.1.5 Sampling methods

In all, we sampled 48 wells. From each well that had a screen that was at least 7 ft in length, we collected the following samples: three pre-purge GORE Module samples, three low-flow (replicate) samples, and three post-purge GORE Module samples. The sampling depths for the GORE Modules were at the midpoint of the upper half of the well screen, at the same depth as the tubing inlet, and at the midpoint of the lower half of the well screen. Only the mid-depth Module was deployed in the four wells with the shorter screens (well numbers 128 and 133 with 5 ft screens and well numbers 37 and 44 with 3 ft screens). Table 5 summarizes the type and number of samples.

In addition, we collected standard QA/QC (quality assurance/quality control) samples for both sampling methods. For the low-flow sampling, this included 20% field duplicates, 10% matrix-spike (MS) samples, 10% matrix-spike duplicate (MSD) samples, and trip blanks (one per cooler). The contract laboratory prepared the trip blanks using analyte-free water. Trip blanks and MS and MSD samples were identified on the respective sample vial and chain-of-custody form. However, the field duplicates were identified in a way that prevented the laboratory from knowing that the sample was a duplicate (i.e., they were blind duplicate samples).

Table 5. Summary of the type and number of samples collected at the APG site*.

Samples per Well #	Description	# Wells	# Days	Total # Samples
3	GORE Module pre-purge (3 depths)	44		132
1	GORE Module pre-purge (midpoint only)	4		4
1	Low flow	48		48
3	GORE Module post-purge (3 depths)	44		132
1	GORE Module post-purge (midpoint only)	4		4
	Total GORE Modules			**272**
	Total Low-flow samples			**48**

*Does not include QA/QC samples

QA/QC samples for the GORE Modules included 10% duplicate samplers (which were analyzed by the Gore Laboratory) and trip blanks (one per box of samplers). Because of the nature of the GORE Module sampling mechanism, it is not possible to have spiked (MS and MSD) samples. Therefore, we sent a second set of duplicate samples to an independent laboratory that is knowledgeable with the Gore analytical method. This allowed us to compare the results from a different analytical laboratory with the analyses by the Gore Laboratory. The duplicate samples were not marked as duplicates, so the laboratory analyses were completely blind for both laboratories. We also requested that the Gore Laboratory analyze both sorbent packets in some of the samplers; these are duplicate "analytical" samples. Table 6 gives the number of each of the QA/QC samples.

Table 6. Description and number of QA/QC samples.

Description	Total # Samples
Low-flow field duplicate samples	10
Low-flow MS samples	5
Low-flow MSD samples	5
Low-flow trip blanks	4
Module duplicates, blind samples, analyses by Gore	30
Module duplicates, samples were marked as duplicates, analyses by Gore	6
Module duplicates, blind samples, independent lab analysis	30
Module, trip blanks	4

5.1.5.1 Sample collection

On the sampling day, we lowered the GORE Modules into the wells, left them for the recommended exposure time (about 15 minutes to 2 hours), and then retrieved them. Using a clean paper towel, we wiped all excess liquid water from the Modules. We then returned each Module to its vial with its corresponding serial number and returned the vial to the box it came from. As mentioned previously, these were the pre-purge samples. For each GORE Module, the laboratories received a vial with a serial number on it but with no other means of identification. It was not necessary to keep the Modules refrigerated or on ice during sampling, holding, or shipping.

Each morning (and at other times as needed), prior to low-flow sampling, we calibrated the turbidity meter and Horiba probe. (Appendix C describes this in more detail.)

Upon retrieval of the first set of GORE Modules, low-flow purging began. As outlined by the EPA (US EPA Region 1 1996) we collected samples once the purge parameters stabilized. Monitored purge parameters included turbidity, dissolved oxygen (DO), conductivity, salinity, pH, total dissolved solids (TDS), oxidation reduction potential (ORP), and temperature. These parameters were monitored every three to five minutes (depending upon the flow rate being used) until a minimum of three successive readings did not vary by more than 10%, and (preferably) the turbidity measurements were below 10 NTU (Nephelometric Turbidity Units). We monitored turbidity by using a portable field turbidity meter (LaMotte model 2020). The other purge parameters were monitored using a Horiba (MDL W-22XD) probe and a flow-through cell. To prevent excessive drawdown in the well, we periodically monitored the water level in the well during pumping (using a water-level meter). In the few instances where we observed drawdown that was greater than about 1 ft, we lowered the flow rate; and if drawdown continued beyond the top of the screen, then we collected the samples as quickly as possible.

Low-flow samples were collected in 40 mL VOA (volatile organic analyte) vials. A minimum of three vials were collected from each well (i.e., more vials were collected when additional QA/QC samples were needed). All

low-flow sample vials were placed on ice in a cooler and kept cold until they were shipped on ice to the laboratory for analyses.

After the low-flow samples were collected, we turned off the pump and carefully placed a second set of GORE Modules in the well. These post-purge samples were collected following the same procedures as those outlined for the first set of Modules.

After filling out all chain-of-custody forms, we placed the low-flow samples on fresh ice and shipped them to the laboratory by express next-day delivery. When the box that contained the GORE Modules was full, the box was sent by regular mail back to the Gore Laboratory.

5.1.5.2 Documentation

During the first two field visits, the team recorded well information in a bound field notebook that was dedicated to this project.

During sampling, in the same notebook, we recorded the following information for each of the wells: the well number and sample date, arrival time at the well, and departure time from the well. During low-flow sampling, we recorded the following information: water-level and time initially and during purging, purge rate, purge parameter readings and time for each reading, and the start and finish time for sample collection. For sampling with the GORE Modules, we also recorded in this notebook: the deployment times for the samplers, the serial numbers on the Modules, the depth to groundwater (determined by using a water depth probe, which was determined after collecting the pre-purge samples but before purging the well), the sampling depths of the Modules, the groundwater temperature (determined by using a temperature probe), and the retrieval times.

We used permanent markers on waterproof labels to identify the low-flow samples. These samples were marked with the well number, sampling date and time, and the name of the individual who collected the sample. For the GORE samples, no labeling was necessary because each Module has a unique serial number that is attached to the Module.

For both sampling methods, we recorded the time it took to conduct different aspects of the field sampling procedures. (This information was lat-

er used in the cost analyses.) Also, we noted in the field notebook any other pertinent information and problems for either of the field methods.

5.1.5.3 Analyses

White Water Associates, Inc. (Amasa, MI), analyzed the low-flow samples by using EPA Method 8260B GC/MS (US EPA Office of Solid Waste 1996). They are a NELAC (National Environmental Laboratory Accreditation Conference) and DoD ELAP (Environmental Laboratory Accreditation Program) certified laboratory. Appendix C provides additional information on calibration and other QA/QC requirements for the contract laboratory.

Most of the GORE Modules were analyzed for VOCs at the Gore Laboratory. All the Modules were analyzed using EPA Method 8260C GC/MS that has been modified for thermal desorption. The method for desorption of the individual sorbent packets was proprietary when these analyses were conducted. Ten percent of the GORE Modules collected at this site were replicate samples that were sent to an independent laboratory for analyses, MRIGlobal (Kansas City, MO). This laboratory was familiar with the analyses of the GORE Modules and is a NELAC and ELAP certified laboratory.

5.1.6 Data analyses

To eliminate problems with large amounts of data below the detection limit, we conducted the statistical analyses on only the data from those wells and analytes where the concentrations were above the detection limit. In instances where many of the wells had concentrations that were below the detection limit, comparisons were made only for analytes where at least five wells had concentrations above the detection level. In instances where one of the treatments had a concentration that was below the detection limit, the detection limit was substituted into the data set for the statistical analyses.

All the statistical analyses of the test data were conducted on an analyte-by-analyte basis, and standard statistical analyses were used throughout.

5.1.6.1 Analyses of QA/QC data

We collected replicate samples for 10% of the GORE Modules and low-flow samples. The precision of these sampling methods was determined by cal-

culating the RSD among the replicate samples. We set as our goal that the RSD should not exceed 20%. The percent of the wells that met this criterion out of the total number of wells was then calculated for each of the analytes.

To compare the analyses of the Modules by the two laboratories, we first tested the data for normality. For data that passed this test, we used a paired t-test to determine if there was a statistically significant difference between the values determined by the Gore and contract laboratories. In instances where the data did not pass this test, the data was log-transformed and then a paired t-test was used to determine if there were significant differences between the analyses by the two laboratories. We found that paired t-tests could be used on all of this data, so it was not necessary to use a non-parametric test.

Linear regression analyses using the least-squares method was used to determine if there was a statistically significant linear relationship between the data for the two laboratories and if that relationship was one-to-one (i.e., if the slope was significantly different from 1.0).

5.1.6.2 Analyses of the test data

We used standard statistical analyses to determine if there were significant differences between the three sample types (i.e., the low-flow-samples, the GORE Module pre-purge samples, and the GORE post-purge samples). We compared both of the midpoint data with the low-flow data and the mean data (i.e., mean values for the three sampling depths) with the low-flow data.

We tested the data to determine if they were normally distributed and if the variances were homogenous. Whenever possible, we used conventional parametric analyses of the raw data because these tests are usually more rigorous than non-parametric tests. If the raw data did not prove to be normally distributed, the data were log transformed and tested for normality and homogeneity of the variances. In instances where we could not use conventional parametric tests on either the raw data or the log-transformed data, we used non-parametric tests.

For normally distributed data, we used RM-ANOVA tests to determine if there were statistically significant differences between the analyte concentrations in the three different types of samples (i.e., pre-purge data, post-purge data, and low-flow data). When we found statistically significant differences, we determined whether the differences between the three types of samples were statistically significant by using a Holm-Sidak method for pair-wise multiple comparisons. In cases where non-parametric tests had to be used, we used a Friedman RM-ANOVA test to determine if there was a significant difference between the treatments. In the instances where a significant difference was found, we used a Tukey test to determine which treatments differed from each other significantly. All statistical tests were conducted at the 95% confidence level using SigmaPlot 12 software (by Systat Software, Inc.).

We used linear regression to determine if there was a significant relationship between the GORE data and the low-flow data and if the relationship was one to one (at a 95% confidence level using the data-analysis tools in Excel software).

The analyte recoveries with sampling depth were compared by constructing plots of the contaminant concentrations at the three depths using the GORE Module data (for both the pre-purge and post-purge data) and one depth using low-flow purging and sampling. Also, using the low-flow and GORE data, we constructed site maps to delineate one of the contaminant plumes at this site by using GeoSoft Oasis Montage software.

5.2 Former Pease AFB test site

Because the experimental design, sampling methods, and data analysis were essentially the same, we have only noted instances where there were differences in the procedures.

5.2.1 Conceptual experimental design

Contaminants at this site included BNZ; TOL; EBNZ; XYLs; NAPH; 124TMB; 135TMB; *n*-butylbenzene; *n*-propylbenzene; *sec*-butylbenzene; *tert*-butylbenzene; isopropylbenzene; *p*-isopropyltoluene; and 1,2-dibromoethane.

5.2.2 Baseline characterization

Because the wells at this site have been sampled on a quarterly basis, it was not necessary to conduct substantial field preparation of the site prior to sampling. However, it was necessary to obtain security clearances from the Federal Aviation Administration (FAA) so that we could work on this field site because it was located in the flight-line area. Each time we wanted to move onto, around, or off the field site, we had to have permission from the tower. To be able to do this, we had to take training from the FAA. Training including learning the terminology used to describe all the aspects of the Pease airport; procedures with respect to moving on, off, and around the flight-line area; and how to obtain permissions and talk with the tower.

5.2.3 Design and layout of technology components

5.2.3.1 Monitoring wells

We selected 26 monitoring wells in the PH2 area to sample. Table 7 gives a list of those wells, and Figure 14 shows their location. This table also provides information on the well diameter and screen depth for each of the wells. Most of the wells at this site (16 in all) had shorter screens, either 3 or 5 ft in length (Table 7). The remaining (10) wells had 10 ft screens. While some of the wells were at the epicenter of the plume, none of them contained free product.

Table 7. List of the wells sampled at the former Pease AFB.

Well #	Well Diameter (in.)	Screen		Sampling Depth (ft bgs)				Sampling Time
		Depth (ft bgs)	Screen Length (ft)	Low-flow Sampling	Upper Module	Middle Module	Lower Module	
HY2-4460	1.25	5.6–15.6	10	10.6	8.2	10.2	12.2	15 min
HY2-4467	1.25	5.7–15.6	9.9	11.4	9	11	13	2 hr
HY2-5400	2	29–34	5	31.5	—	31.1	—	30 min
PH1-5321	2	22–32	10	27	24.1	26.6	29.1	2 hr
PH1-6507	4	69–79	10	74	71.1	73.6	76.1	2 hr
PH2-5324	2	46–51	5	48.5	—	48.1	—	30 min
PH2-5341	2	30–33	3	31	—	30.6	—	15 min
PH2-5369	2	36.5–46.5	10	41	38.6	40.6	42.6	15 min
PH2-5388	2	31–34	3	32	—	31.6	—	15 min
PH2-5601	2	40.8–45.8	5	42	—	41.6	—	15 min
PH2-5602	2	31.5–36.5	5	33	—	32.6	—	1 hr
PH2-5603	2	42.5–47.5	5	45	—	44.6	—	2 hr
PH2-5604	2	48–53	5	50	—	49.6	—	2 hr
PH2-5605	2	41–46	5	43	—	42.6	—	2 hr
PH2-5606	2	60–65	5	62	—	61.6	—	15 min
PH2-5607	2	39.9–44.9	5	42.4	—	42	—	15 min
PH2-5608	2	33–38	5	35	—	34.6	—	2 hr
PH2-5627	2	35–40	5	37.2	—	36.8	—	2 hr
PH2-5628	2	46–51	5	48	—	47.6	—	2 hr
PH2-6508	2	55.3–65.3	10	60	57.5	59.6	62	2 hr
PH2-6627	2	56–66	10	60.4	57.5	60	62.5	2 hr
PH2-6628	2	60–70	10	64.6	61.7	64.2	66.7	2 hr
PH2-6657	2	52.3–57.8	5.5	55	—	54.6	—	2 hr
PH2-6658	2	57.5–65.5	8	61.5	—	61.1	—	2 hr
PH2-6659	2	50–60	10	55	52.1	54.6	57.1	2 hr
PH2-6660	2	60.6–70.6	10	68.5	65.6	68.1	70.6	2 hr

For the wells shaded in blue, the low-flow samples were collected by URS.

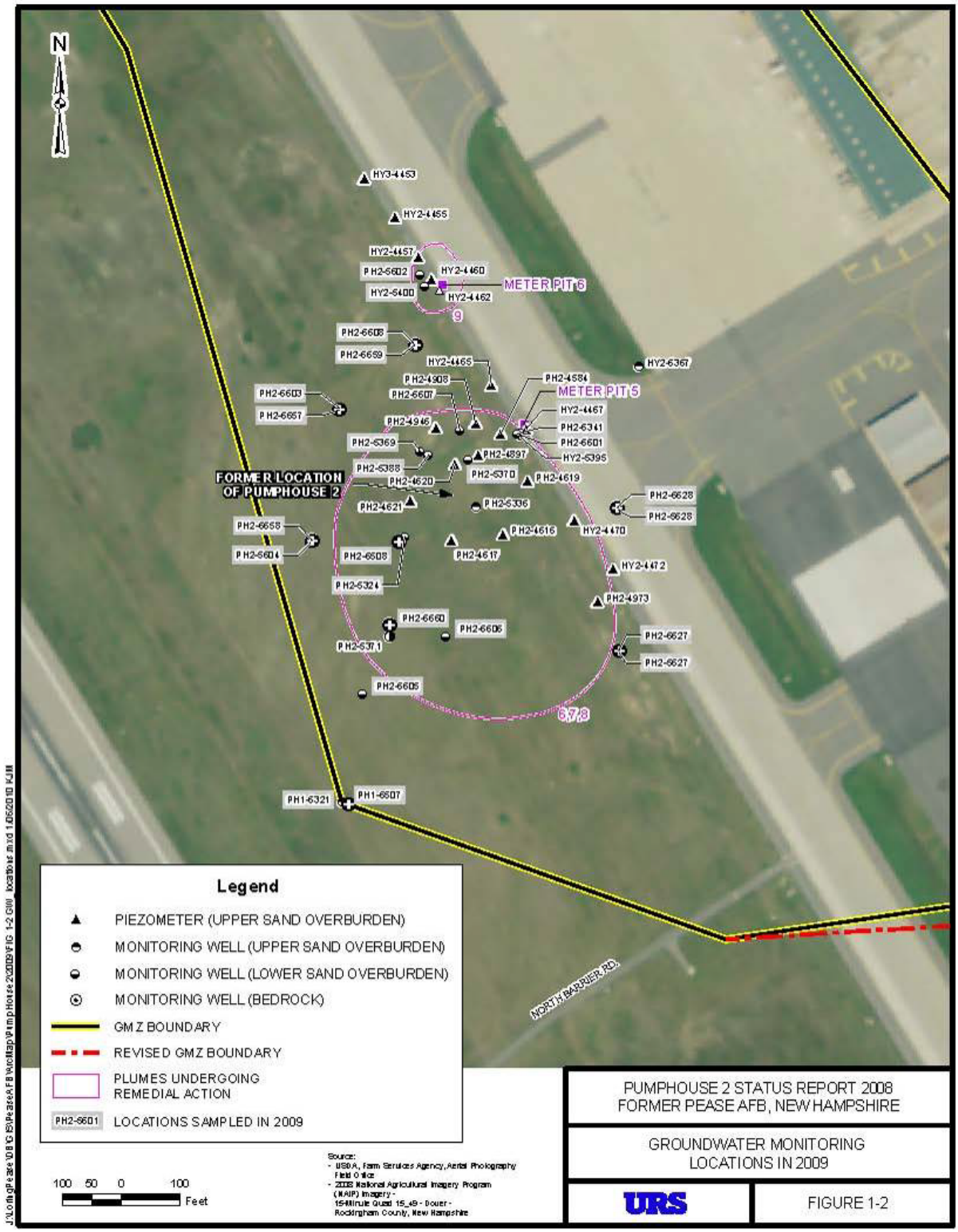


Figure 14. Arial photograph showing the location of the wells in the Pump House 2 area.

5.2.3.2 Installation of the sampling equipment in the wells

For this demonstration, some of the wells that we had selected to sample were sampled by URS as part of their quarterly sampling round. For those wells, the URS personnel used a Grundfos pump with dedicated Teflon tubing to collect the low-flow samples. The Grundfos pumps were only used in wells with similar analyte concentrations and were decontaminated prior to installing them in each of the wells. CRREL personnel sampled the remaining wells. The team used a bladder pump with dedicated tubing to sample all but two of those wells; they used a peristaltic pump and dedicated tubing to sample the two shallowest wells.

Prior to starting any field work, the bladder pumps that were to be used at this site were returned to the manufacturer where they were cleaned; refurbished with new materials, including new bladders; cleaned again; and rinsed with deionized water.

The team installed the clean bladder pumps two weeks before conducting the field tests. At that time, the wells were pumped to make certain all the pumps worked and to allow time for the materials in the pumps and tubing to equilibrate with the analytes in the well water. At the same time, we placed dedicated tubing in the two wells we sampled using peristaltic pumps. We pumped those wells, also.

Figure 15 shows the deployment of the sampling equipment in each well. This figure is similar to that described previously for the APG site except that we deployed the GORE Modules so that they were only attached at the bottom of sampler. This allowed them to float upwards rather than being tethered to the sampling line.

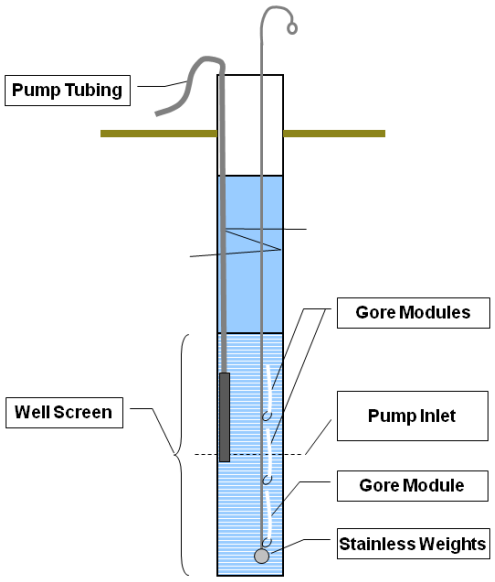


Figure 15. Diagram of the sampling equipment in the well at the Pease site.

5.2.4 Field testing

The low-flow samples that were collected by the URS personnel (in the presence of the CRREL personnel) are shaded in blue on Table 7. For the remaining wells, the CRREL field crew, consisting of Ron Bailey, Gordon Gooch, and Louise Parker, conducted the low-flow sampling. Both the URS and CRREL personnel used low-flow sampling according the protocol given by EPA Region 1 (1996). All sampling with the GORE Modules was conducted by the CRREL field crew.

Immediately after collection, the respective sampling teams placed all the low-flow samples on ice. Towards the end of each sampling day, the respective sampling teams repacked the coolers (placing the samples on fresh ice) and filled out the chain-of-custody forms. The contract laboratory collected both the CRREL and the URS coolers at the end of the URS sampling day. Any low-flow samples that were collected by the CRREL personnel after hours (i.e., after the coolers were picked up by the contract lab) were kept in a hotel refrigerator until the next day when they were repacked on ice (in a cooler) and kept on ice until they were processed for pick up by the laboratory.

Site cleanup consisted of removing the sampling equipment from the wells. The pumps were bagged and returned to CRREL where they were decontaminated. Disposable materials were bagged and disposed of ac-

cording to directions from the site manager. All purge water and decontamination water was disposed of at the end of each sampling day according to the directions of the site manager.

5.2.5 Sampling methods

For each of the wells with the 10 ft screens, we deployed the GORE Modules at the three sampling depths. For the sixteen wells with the shorter length screens (3 ft, 5 ft, and 8 ft), we deployed only the mid-depth Module. Table 8 summarizes the type and number of samples.

Table 8. Summary of the type and number of samples*.

Samples per Well	Description	# Wells	Total # Samples
3	GORE Module pre-purge (3 depths)	10	30
1	GORE Module pre-purge, midpoint only	16	16
1	Low-flow	26	26
3	GORE Module post-purge (3 depths)	10	30
1	GORE Module post-purge, midpoint only	16	16
	Total GORE Modules		**92**
	Total Low-flow samples		**26**

* Does not include QA/QC samples

In addition, standard QA/QC samples were collected for both sampling methods. For the low-flow sampling, this included 20% low-field duplicates, 10% MS samples, 10% MSD samples, and trip blanks (one per cooler). (Trip blanks were prepared by the contract laboratory using analyte-free water and delivered to the field site prior to sampling.)

QA/QC samples for the GORE Modules included 10% duplicate samplers (that were analyzed by the Gore Laboratory) and trip blanks (one per box of samplers). The duplicate samples were not marked as duplicates, and the trip blanks were not labeled as trip blanks; so the laboratory analyses of these samples were completely blind.

5.2.6 Chemical analyses

All of the low-flow samples were analyzed by Katahdin Analytical Services, Scarborough, ME, using EPA Method 8260B GC/MS (US EPA Office of Solid Waste 1996). They are a NELAC and DoD ELAP certified laboratory.

The GORE Modules were analyzed for VOCs at the Gore Laboratory by using EPA Method 8260C GC/MS that has been modified for thermal desorption. Because of time and cost constraints, we were not able to arrange an independent contract laboratory to analyze the GORE Modules for this site.

5.2.7 Data analyses

Data handling and the data analyses were the same as described previously in Section 5.1.6.

6 Sampling Results for APG

6.1 Reproducibility of the sampling methods (replicate samples)

6.1.1 Reproducibility of the GORE Modules

One of the primary objectives of this demonstration was to establish whether the GORE sampling method and analyses yielded good precision. This was determined by comparing the results from co-located field duplicate samples. Most of the replicate samples were "blind samples" in that the laboratory did not know that the two samples were replicates. However, there were also some samples where the Gore Laboratory analyzed two different sorbent packets from the same Module. In those cases, the laboratory was aware that the samples were replicates. All this data can be found in Appendix D.

We set a relatively stringent guideline for precision by requiring that the RSD be 20% or less for those analytes where the concentrations were at least three times the detection level. (This is equivalent to a Relative Percent Difference of 28%.) By way of example, two values that differ by a factor of 1.33 (e.g., 100 and 133) yield a 20% RSD. In contrast, two values that differ by a factor of 1.5 (e.g., 100 and 150) yield a 28% RSD, those that differ by a factor of 2 (e.g., 50 and 100) yield a 47% RSD, and those that differ by an order of magnitude (e.g., 25 and 250) yield a 116% RSD.

Table 9 summarizes the findings for those samples when analyte concentrations were at least three times the detection limit. Appendix Table D9 presents a summary of the findings for all the replicate pairs, regardless of analyte concentrations. Generally, we had excellent agreement between the replicate GORE Modules (Table 9). For TCE, TetCA, CLF, and BNZ, all or almost all (greater than 90%) of the blind replicate pairs met our guideline in that the RSD was 20% or less. For PCE and pentadecane, approximately 60% and 67%, respectively, met the guideline. For cDCE, none of the 3 replicate samples met the 20% guideline; but the RSD for all of them was between 25% and 30%.

Table 9. Summary of the results from the analyses of replicate samples*.

		# Replicate Pairs		<25% RSD		<20% RSD		<10% RSD		~100% RSD	
Analyte	Sample		%RSD	#	Percent	#	Percent	#	Percent	#	Percent
PCE	GORE blind	5	6–115%	3	60%	3	60%	0	0%	2	40%
	LF	4	3–15%	4	100%	4	100%	3	75%		
TCE	GORE blind	13	0.6–91%	12	92.3%	12	92.3%	9	75%	1	7.7%
	GORE not blind	4	1.1–38%	3	75%	3	75%	3	75%	0	0%
	LF	10	0–10.5%	10	100%	10	100%	9	90%	0	0%
TetCA	GORE blind	14	0.1–52%	13	93.8%	13	93.8%	12	85.7%	0	0%
	GORE not blind	5	1.7–5%	5	100%	5	100%	5	100%	0	0%
	LF	9	0–12%	9	100%	9	100%	8	89%	0	0%
cDCE	GORE blind	3	25.9–28.8%	3	100%	0	0%	0	0%	0	0%
	GORE not blind	2	5.8–6.0%	2	100%	2	100%	2	100%	0	0%
	LF	8	0–15.2%	8	100%	8	100%	7	88%	0	0%
CLF	GORE blind	1	18.9%	1	100%	1	100%	0	0%	0	0%
	LF	5	0–11%	5	100%	5	100%	4	80%	0	0%
BNZ	GORE blind	1	14.2%	1	100%	1	100%	0	0%	0	0%
	LF	2	0.8–2.5%	2	100%	2	100%	2	100%	0	0%
pentadecane	GORE blind	3	17.3–25.6%	3	100%	2	66.60%	0	0%	0	0%
	LF	0	Not measured								

*Where analyte concentrations were at least 3 times the detection level

We would expect that the variability would be greatest at the very low concentrations (i.e., near the detection limit). For the replicate samples where the concentrations were just above the detection limit, the precision was actually good and met our guideline (Appendix Table D9). However, there were several instances where the analyte was not detected in one of the replicate samples but was in the other; these instances are highlighted in yellow in Table 10. It is interesting that much of the poor reproducibility occurred in three samples. These samples were the pre-purge samples collected in well number 133 where there were issues with four analytes, the post-purge samples collected in wells 37 and 148 where there were issues with two analytes, and well 35A where there was an issue with PCE. Since most of these samples were collected after the well was purged (i.e., were event numbers 2 or 4), we suspect that purging the well may have contributed to greater variability. This may be because three of these wells (133, 37, and 148) were shallow, and the sampler depth and screened interval were just below the water table (

Table 11).

Table 10. Summary of the wells with GORE Modules that had a high RSD.

Analyte	Well	Event #	Module Depth	Concentration		Std. Dev.	%RSD
				Sampler	Mean		
PCE	37	4	mid only	4.4 U			
	37	4	mid only	182	93.3	125.7	135
	133	1	mid only	97.2			
	133	1	mid only	14.4	55.8	58.57	105
	35A	2	mid	376			
	35A	2	mid	39.4	208	238.2	115
	148	2	top	173			
	148	2	top	4.4U	88.6	119.0	134
TCE	133	1	mid only	1200			
	133	1	mid only	260	729	662.8	91
1122TetCA	133	1	mid only	1610			
	133	1	mid only	738	1170	613.8	52
CLF	37	4	mid only	35.4	19.9	21.94	110
	37	4	mid only	4.4 U			
	133	1	mid only	102	55.3	66.62	120
	133	1	mid only	8.2			
pentadecane	130	2	mid	18.2			
	130	2	mid	4.4 U	11.3	9.776	86
	148	2	bottom	14.4			
	148	2	bottom	4.4 U	9.4	7.092	75
	148	2	top	2176			
	148	2	top	17.1	1100	1527	139
	41B	2	top	4.4 U			
	41B	2	top	21	12.7	11.73	92
	61B	2	mid	4.4 U			
	61B	2	mid	50.9	27.6	32.87	119

Replicate pairs that are highlighted in yellow had one sample with analyte concentrations that were below (or just above) the detection level. Event 1 occurred before purging the well; events 2 and 4 occurred after purging the well.

Table 11. Information on wells with higher RSDs.

Well Number	Depth to Water Table (ft bgs)	Top of Screen (ft bgs)	Depth of Sampler (ft bgs)
35A	5	19	25
37	8	10	11.5
133	15.1	8	17.1
148	6	6	(top sampler) 8.5

Initially, the Gore Laboratory felt that the poor reproducibility for some wells may have been because we secured the top of Modules to the line rather than tethering them only at the bottom, which would have allowed the samplers to float freely in the well. They felt that this may have allowed one of the Modules to be in a more preferential pathway with respect to the inflow of contaminated water in the well. We changed this procedure at our second demonstration site to eliminate this possibility.

The RSD was considerably better (less than 10% in all cases) for the analytical duplicate samples where the Gore Laboratory knew the samples were duplicates (Table 9). These results are not totally surprising given that for these replicate samples, two different sorbent packets within the same sampler were analyzed (as compared with analyzing sorbent packets from two different co-located duplicate samplers).

6.1.2 Agreement between analyses by the Gore and independent laboratories

For 10% of the GORE samples, a replicate sample was collected and sent to an independent laboratory familiar with the analyses of the GORE Modules (i.e., MRIGlobal, Kansas City, MO). These replicate samples were blind in that neither laboratory knew the identity of any of the samples. Figures 16 through 20 give comparisons for the five analytes that were detected at this site (TCE, TetCA, PCE, cDCE, and pentadecane). (Appendix Table F1 provides the raw data.) These figures show that there was generally excellent agreement between the two laboratories for all five of the analytes detected. The statistical analyses (i.e., paired t-tests and a linear least-fit model) confirmed that there was good agreement (Appendix Table F2). There was no statistically significant difference between the results of the two laboratories for the chlorinated solvents, but there was for pentadecane. For pentadecane, analyses using a linear least-fit model de-

termined there was a significant linear relationship between the data for the two laboratories although concentrations were slightly lower for the contract laboratory's data. However, it should be noted that there were not many pairs of data for this comparison; and generally, the analyte concentrations were near the detection level.

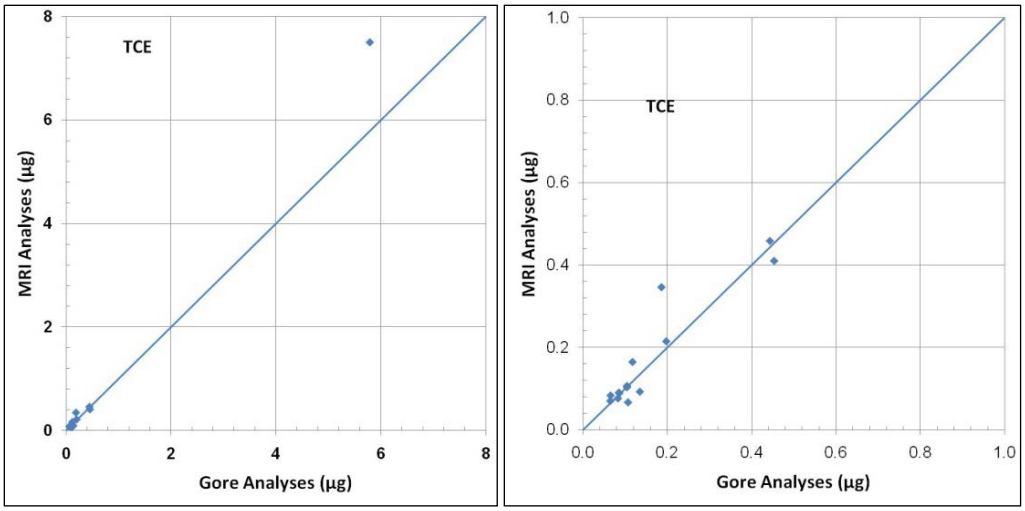


Figure 16. Comparison of the analyses of GORE Modules by the two laboratories for TCE for all analytes (left) and an enlargement for low recoveries of the analyte (right).

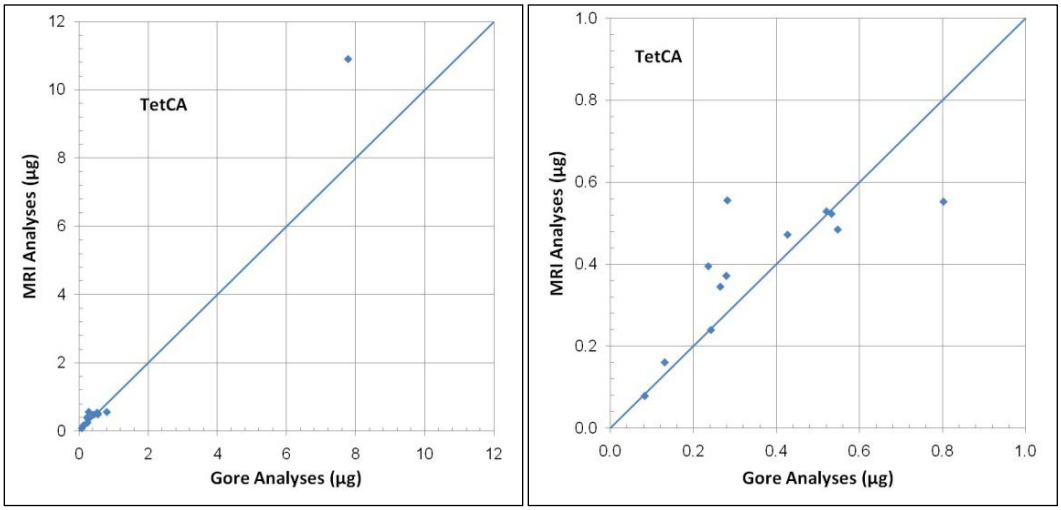


Figure 17. Comparison of the analyses of the GORE Modules by the two laboratories for TetCA for all concentrations (left) and an enlargement for low recoveries of the analyte (right).

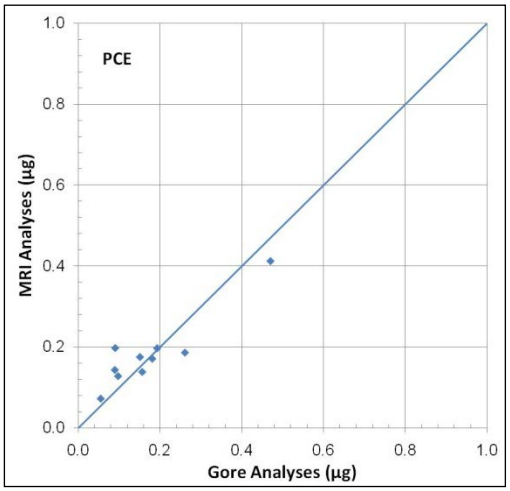


Figure 18. Comparison of the analyses of the GORE Modules by the two labs for PCE.

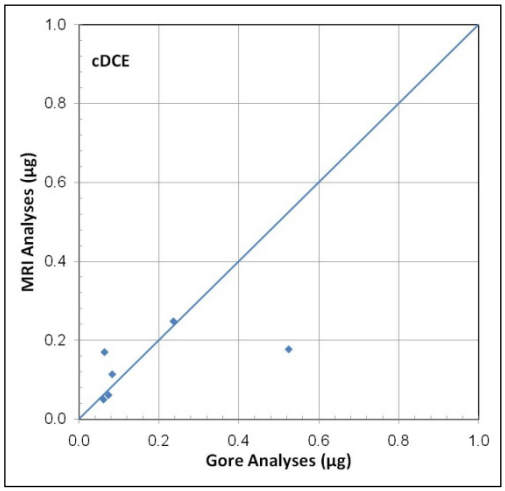


Figure 19. Comparison of the analyses of the GORE Modules by the two labs for cDCE.

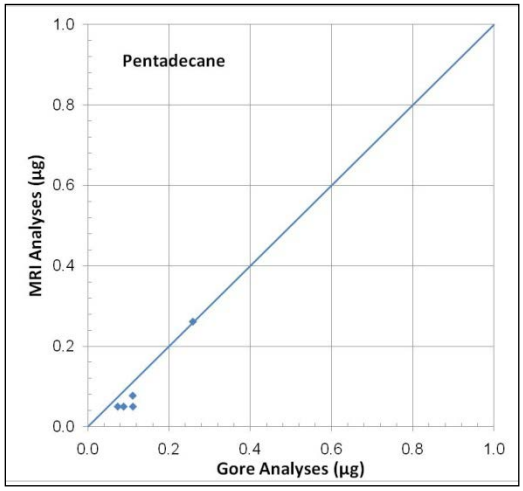


Figure 20. Comparison of the analyses of the GORE Modules by the two laboratories for pentadecane.

6.1.3 Reproducibility of the low-flow samples

Table 9 also presents a summary of the data for the replicate samples for low-flow sampling, and Appendix E provides all the data for the replicate samples. All of the analytes present in the low-flow replicate pairs met our guideline (i.e., the RSD was 20% or less). These results are not surprising given that our replicate samples were taken consecutively without stopping the pump. While this is conventional practice within the sampling community, these samples were not true co-located field duplicate samples. Therefore, these samples are perhaps better defined as subsample

field duplicates (as defined by the US EPA [2005]). For the low-flow samples, pentadecane could not be determined using the standard EPA method for VOCs.

6.2 Agreement between GORE Modules and low-flow data

Appendix G provides the results for the chemical analyses of the pre-purge and post-purge GORE Modules (at the three sampling depths) and low-flow samples for those analytes and wells where analytes were detected. Analytes that were detected in at least some of the wells included PCE, CLF, TetCA, TCE, cDCE, BNZ, CLB, and pentadecane. Pentadecane concentrations were not compared because the low-flow samples were not analyzed for this analyte.

6.2.1 Sensitivity of the two analytical methods

The MDL for the analytical method used for the low-flow samples was approximately one twentieth of the GORE method. That is, for the low-flow samples, the detection limit generally was 0.2 µg/L; and for the GORE Modules, it was 4.4 µg/L. (The quantitation limit for the Modules was generally 5.4 µg/L, and the reporting limit for the low-flow data was 1 µg/L.) Even though the detection level was higher for the GORE Modules, the detection limit was still below the action level for these contaminants (i.e., the EPA's MCL). This would allow the Remediation Program Manager or other interested parties to make decisions based on the action levels. However, a lower detection level is often desired and in some cases required, such as in the EPA's Quality Performance Project Plan Manual (US EPA 2005).

The detection level for the analytical method that was used for these analyses can be lowered by a factor of two by simply doubling the time they are left in the well. Since the time when this demonstration was conducted and prior to our conducting the second demonstration at the next test site, the Gore Laboratory has reported that they have been able to obtain a lower detection capability for most of these analytes (i.e., similar to what was observed for the low-flow samples). We will discuss this in more detail in the section on the Pease site.

6.2.2 Comparison of the mid-depth GORE Module with the low-flow data

We first compared the data for the mid-level GORE Modules with the low-flow data because the mid-level sampler was at the same depth as the intake for the pump used for low-flow sampling. Therefore, we expected that concentrations would be similar.

Figures 21 through 25 show comparisons between the pre-purge and post-purge GORE data compared with the low-flow data for PCE, TetCA, TCE, cDCE, and CLF, respectively. Generally, there was good agreement between the GORE and low-flow data for PCE, TetCA, and TCE. Concentrations of PCE for the GORE Modules agree well with the low-flow data, and there does not appear to be any systematic bias (either positive or negative) associated with this data. While concentrations of TetCA and TCE appear to agree closely with the low-flow concentrations, there appears to be a very slight negative bias associated with the GORE samples (i.e., concentrations are slightly less). There also appears to be slightly more scatter in the data for cDCE and CLF, and again there appears to be a slight negative bias associated with the GORE samples. These conclusions are confirmed by the statistical analyses, which Appendix Tables H1 and H2 summarize.

Specifically for PCE, there were no significant differences between the pre-purge and the low-flow data or between the post-purge and low-flow data. Analyses using a linear least-fit model determined that there was a significant linear relationship between the GORE data and the low-flow data; and in both cases, the slope of the line was not significantly different from 1.0.

The RM-ANOVA test on the TetCA, TCE, cDCE, and CLF revealed that there were statistically significant differences between the pre-purge GORE and low-flow data and between the post-purge GORE and low-flow data. There was a statistically significant linear relationship in all cases. Although the slope of the line appeared different from 1.0 for TCE and cDCE, this difference was not statistically significant. However, the slopes of the lines were less than 1.0 for TetCA and CLF; the slopes were approximately 0.6 and 0.7, respectively.

We might expect that the low-flow data would agree more closely with the post-purge data than with the pre-purge data. Although we found that there was slightly better agreement for two analytes (TCE and CLF), agreement for TetCA was slightly better for the pre-purge samples. Statistical analyses revealed that there were no statistically significant differences between the pre-purge and post-purge GORE data for any of these analytes.

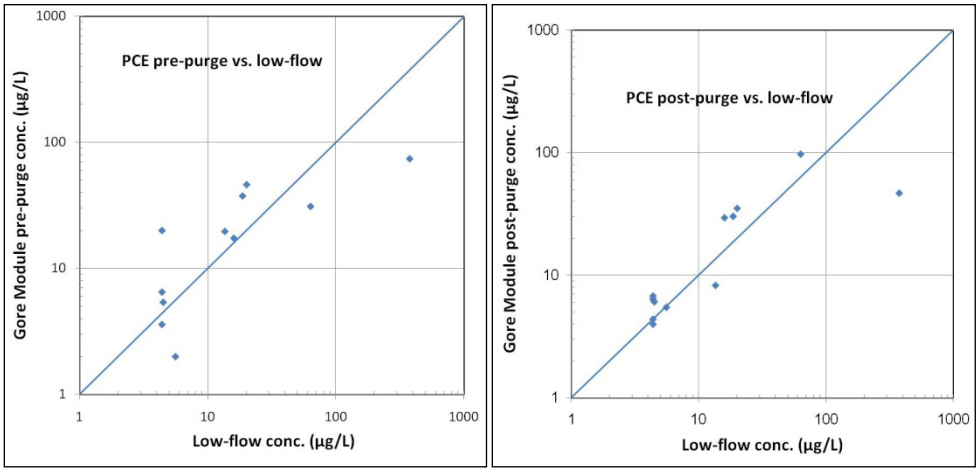


Figure 21. Comparison of the pre-purge (left) and post-purge (right) GORE data for the mid-level samples vs. low-flow data for PCE.

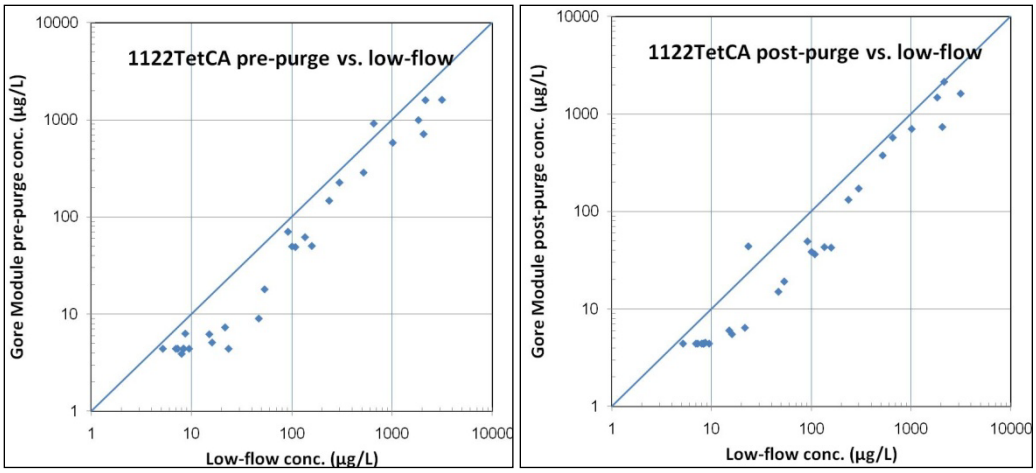


Figure 22. Comparison of the pre-purge (left) and post-purge (right) GORE data for the mid-level samples vs. low-flow data for TetCA.

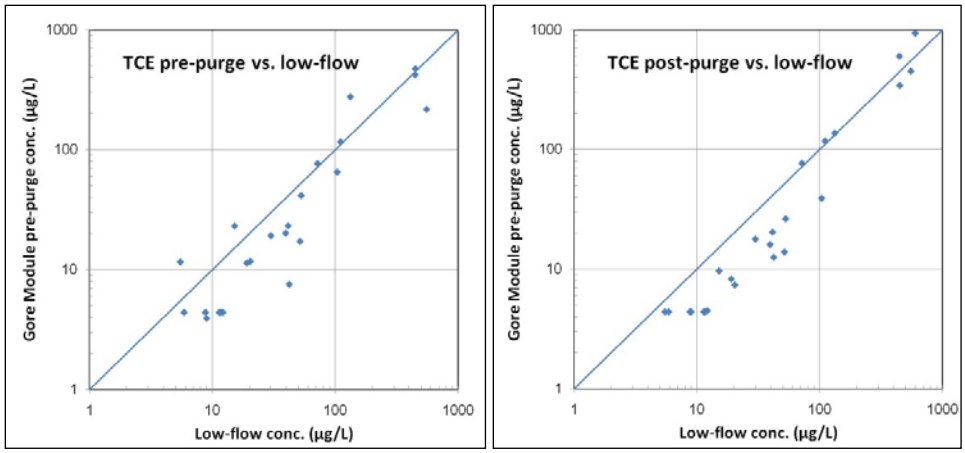


Figure 23. Comparison of the pre-purge (left) and post-purge (right) GORE data for the mid-level samples vs. low-flow data for TCE.

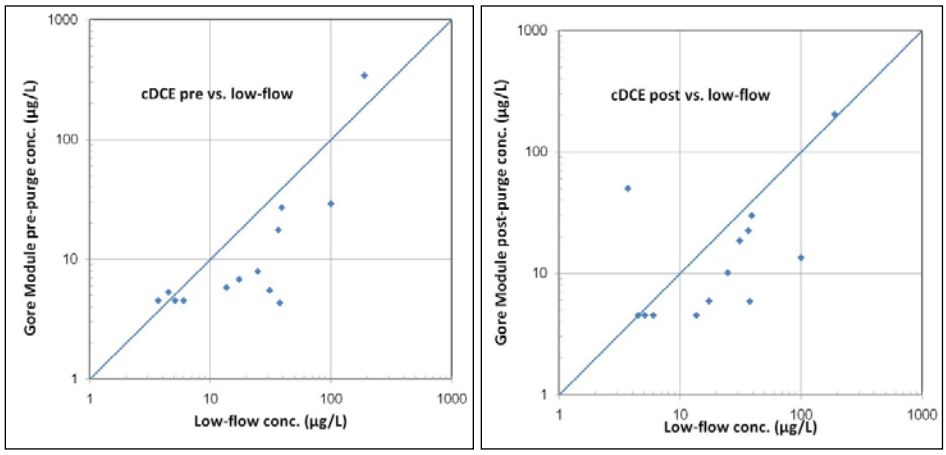


Figure 24. Comparison of the pre-purge (left) and post-purge (right) GORE data for the mid-level samples vs. low-flow data for cDCE.

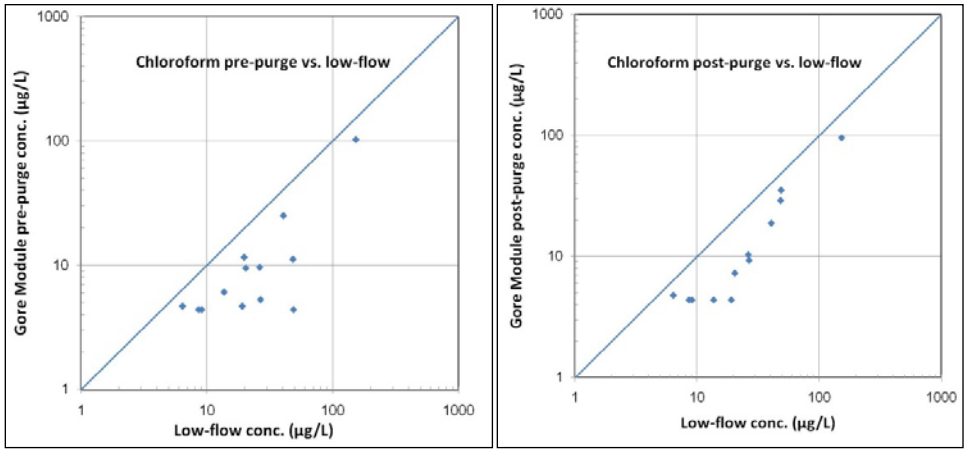


Figure 25. Comparison of the pre-purge (left) and post-purge (right) GORE data for the mid-level samples vs. low-flow data for CLF.

6.2.3 Comparison of the mean GORE data (for the three Modules) with the low-flow data

For the pre-purge and the post-purge GORE data for each well and analyte, we also calculated the mean concentration value for the Modules at the three depths within the well. Since low-flow sampling is reported to provide a flow-weighted average sample of the groundwater pumped from the well, we thought this mean value might agree better with the low-flow samples.

Figures 26 through 30 compare the mean concentrations for the GORE Modules for PCE, TetCA, TCE, cDCE, and CLF to the low-flow sampling results. The left figures compare the data for the pre-purge GORE Modules and the low-flow samples, and the right figures compare the data for the post-purge GORE Modules and the low-flow samples. Again, generally there appears to be good agreement between the GORE data and the low-flow data. The linearity of the data appears to be best for TCE and TetCA although there appears to be a slight negative bias associated with this data, especially for the TetCA data. In contrast, there does not appear to be a negative bias associated with the PCE, cDCE, and pre-purge/low-flow data for CLF although there is a more scatter in this data. The results of the statistical analyses generally agree with these findings, and Appendix Tables I1 and I2 summarize these.

Specifically, there were no statistically significant differences between the pre-purge and low-flow data or between the post-purge and low-flow data for PCE and cDCE. There were significant differences between the concentrations of the pre-purge and low-flow data for TetCA and between the post-purge and low-flow data for TetCA, TCE, and CLF.

When a linear model was used to determine the linearity of these relationships and whether the slope of the lines were significantly different from 1.0, there was a strong, statistically significant linear relationship between the GORE and low-flow data for all the analytes. The slopes of these lines were not significantly different from 1.0 for PCE and cDCE and for the pre-purge/low-flow data for TCE. However, the slope of the line for the post-purge/low-flow data for TCE was significantly less than 1.0 (0.73). The same was true for TetCA for both the pre-purge/low data and the post-purge/low-flow data; the slopes of these lines were about 0.6. We did not

use a linear regression model on the CLF data because there were only a few wells with concentrations that were well above the detection level.

There does not appear to be a consistent trend with respect to whether the post-purge data agrees better with the low-flow data or whether the pre-purge data does. This is borne out by our finding that there was no statistically significant difference between the pre-purge and post-purge GORE data for any of the analytes (Appendix Table I1).

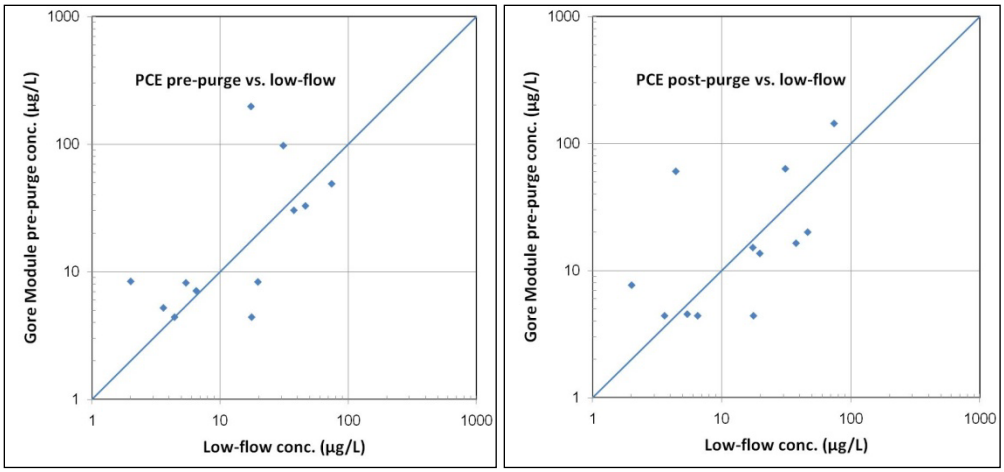


Figure 26. Comparison of the pre-purge (left) and post-purge (right) mean concentrations for the Modules vs. the low-flow concentrations for PCE.

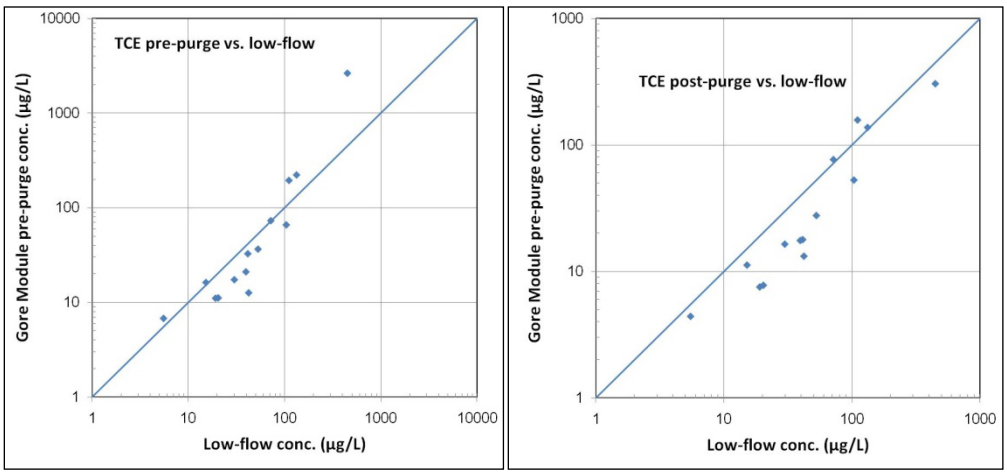


Figure 27. Comparison of the pre-purge (left) and post-purge (right) mean concentrations for the Modules vs. low-flow concentrations for TCE.

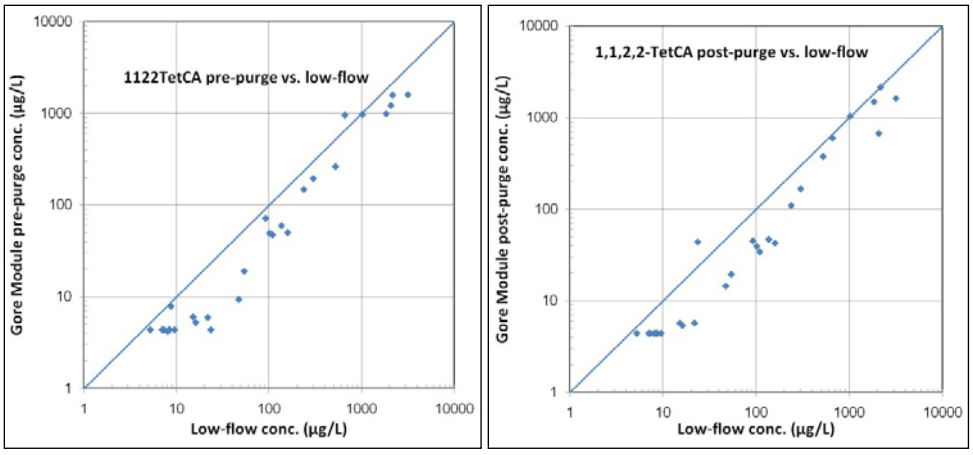


Figure 28. Comparison of the pre-purge (left) and post-purge (right) mean concentrations for the Modules vs. low-flow concentrations for TetCA.

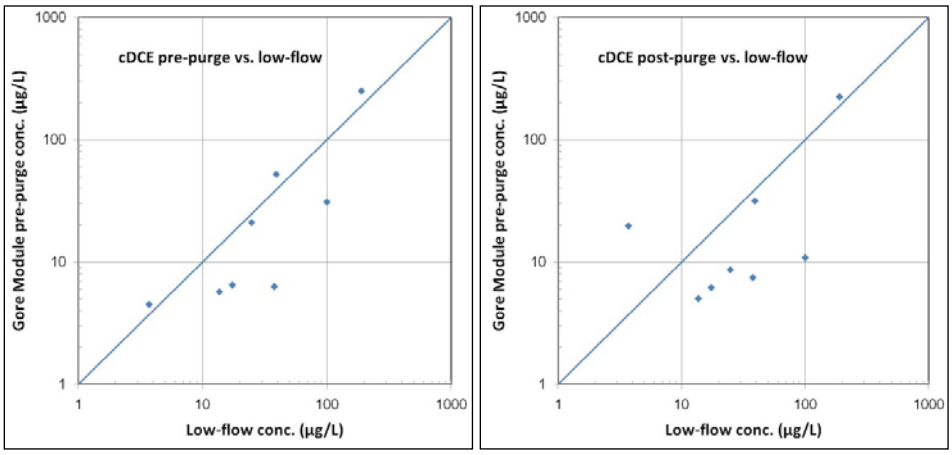


Figure 29. Comparison of the pre-purge (left) and post-purge (right) mean concentrations for the Modules vs. low-flow concentrations for cDCE.

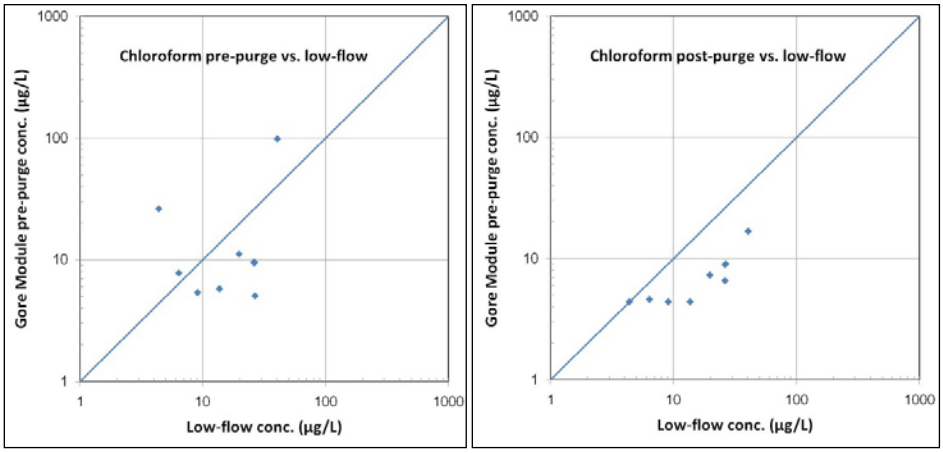


Figure 30. Comparison of the pre-purge (left) and post-purge (right) mean concentrations for the Modules vs. low-flow concentrations for CLF.

6.2.4 Sensitivity of the sampling methods

While there was generally good agreement between the GORE data and the low-flow data, the detection limit for the analytical method used for the low-flow samples was approximately one twentieth of the method used for the GORE Modules. The significance of this difference becomes apparent when the contaminant plumes are delineated on site maps. Figure 31 shows the TCE plumes when delineated by the (a) pre-purge and (b) post-purge GORE Module data. Figure 32 (a) shows the TCE contaminant plumes for the low flow data and (b) shows an overlay between the pre-purge GORE data and the low-flow data.

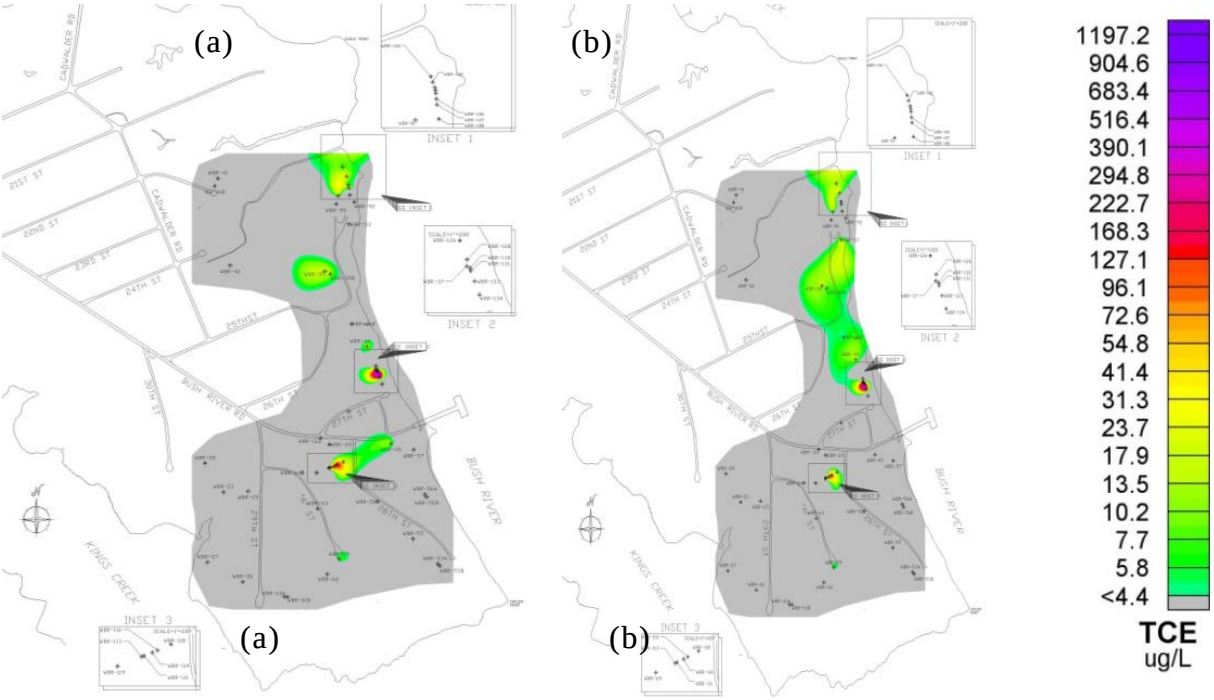


Figure 31. (a) Map of TCE contaminant plumes as delineated by pre-purge GORE Module data. (b) Map of TCE contaminant plumes as delineated by post-purge GORE Module data.

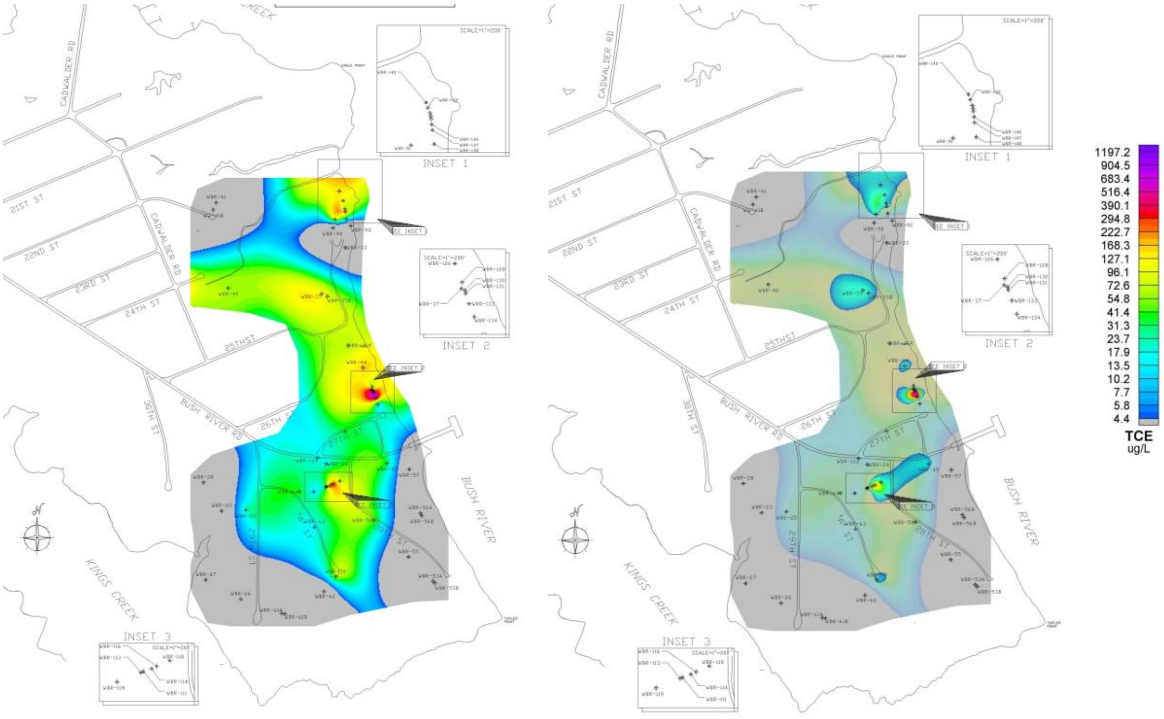


Figure 32. (a) Map of TCE contaminant plumes as delineated by low-flow data. (b) Overlay of pre-purge GORE data on low-flow data for TCE.

It is clear that there is excellent agreement between the two methods although, as we mentioned previously, the analytical method used in conjunction with low-flow sampling provided lower detection capability at the time these tests were performed.

6.3 Profiling contaminant concentrations with depth in the wells

There were approximately fourteen wells where we determined analyte concentrations with depth and found concentrations above the detection level. Generally, the data from the GORE Modules revealed that there was not much difference in concentration with depth in most of the wells. This was true for both the pre-purge and post-purge data. However, there were five wells where there were substantial differences in some of the analyte concentrations with depth. These wells were numbers 111, 114, 116, 131, and 147. Each of these wells was located at the epicenter of their respective contaminant plume.

6.3.1 Well 111

Well 111 was one of the few wells with a 20 ft screen. The Modules were located approximately 30 to 40 ft below the water table. Analytes found in this well included TCE, TetCA, and cDCE. For both the pre-purge and post-purge samples, concentrations were typically highest in the bottom portion of the well and lowest at the mid sampling depth. Concentrations were approximately two times greater at the bottom of the well than in the midsection although there was less of a difference for the post-purge cDCE concentrations (Fig. 33). Generally, low-flow concentrations agreed best with the mid-level data (which was at the same depth as the inlet of the pump that was used for the low-flow samples). These figures indicate that the low-flow sample is drawn from the zone that feeds the midsection of the well under ambient (non-pumped) conditions. We collected duplicate Module samples at the top and bottom of the well screen in this well, and we found that there was good to excellent agreement between the two blind replicate samples for these analytes (Table 12).

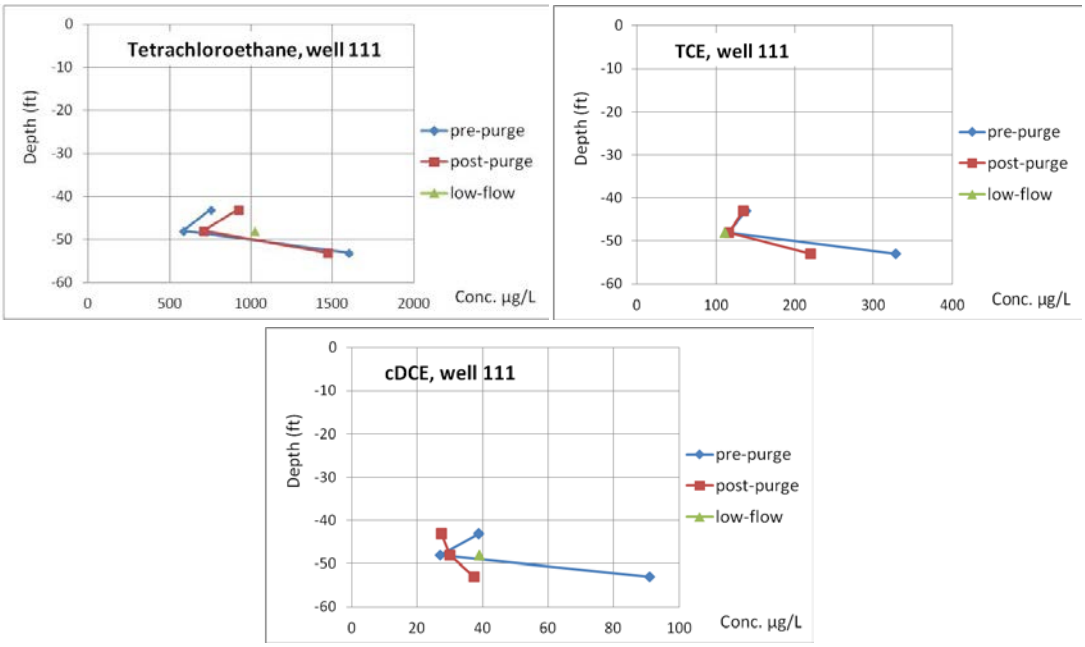


Figure 33. Concentrations of PCE, TCE, and cDCE with depth in well 111.

Table 12. Summary of results for blind replicate samples for profiled wells.

	%RSD for blind replicate samples			
	Well 111		Well 131	Well 147
Sampling level	bottom	top	mid	mid
Analyte				
PCE	1	5	7	9
TCE	3.2	5.6	0.6	12.3
TetCA	2.9	11	1.7	3.2
cDCE	28.8	25.9	4.7	27.5
CLF			18.9	

6.3.2 Well 114

Well 114 is close in proximity to well 111 but is slightly shallower. (The depth of the well screen for this well ranges from 28 to 38 ft bgs vs. 38 to 58 ft bgs for well 111.) The depth of the Modules was well below the water table (about 10 ft). This well also showed some stratification of TCE and TetCA with depth but only after purging (Fig. 35). In both cases, the concentrations were approximately two times greater at the bottom of the well screen than at the top. In most instances, the post-purge data appears to agree best with the low-flow data. For TetCA, agreement is best for the deepest sampler while it was the data from the mid-level sampler that agreed best with the low-flow data for TCE. For CLF, there is very little difference in concentration with depth; but it is clear that the post-purge data agrees better with the low-flow data. For cDCE, concentrations were near the detection level, except for the mid-level post-purge sampler. These figures indicate that low-flow sampling draws water from a zone (or zones) that is more contaminated with TetCA and less contaminated with CLF. It appears that pumping the well pulls water from a lower zone. When we examine the data from the next well (116) we see that data also supports this hypothesis.

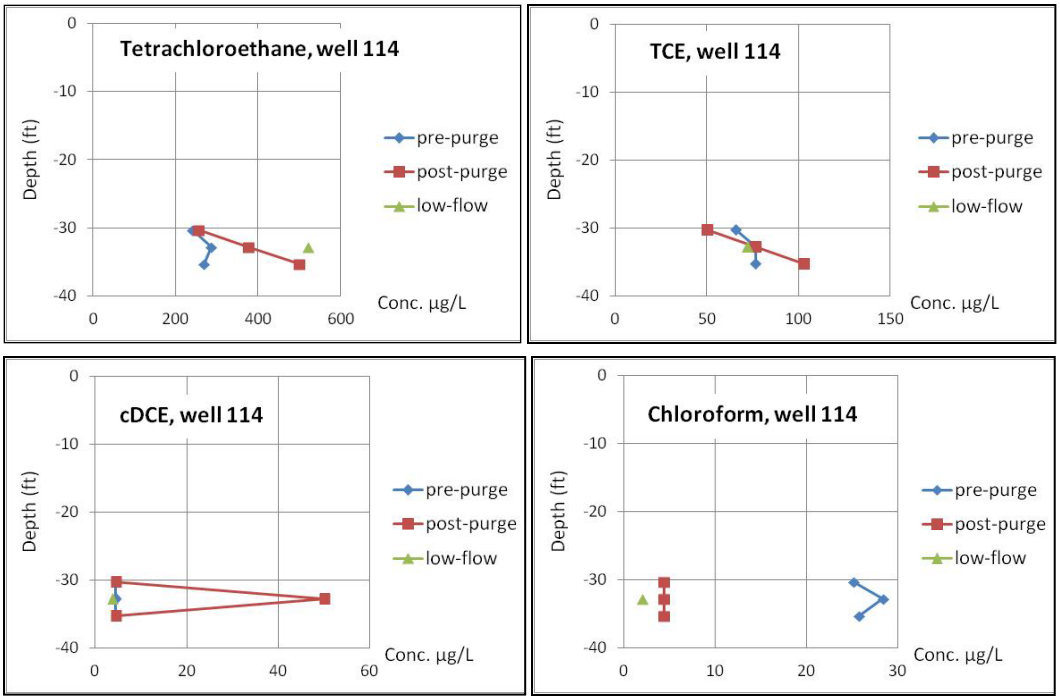


Figure 34. Concentrations of TetCA, TCE, cDCE, and CLF with depth in well 114.

6.3.3 Well 116

Well 116 is located in close proximity to well 111. In contrast to the previous well, the screen for this well overlaps the upper portions of the bottom of well 111 but also goes deeper. (The depth of the well screen for this well ranges from 52 to 62 ft bgs while that for well 111 went as deep 58 ft bgs.) There were very pronounced concentration gradients in this well for the pre-purge samplers for TetCA, TCE, and cDCE (Fig. 35). Concentrations were approximately 1.5 times, 4 times, and 2 orders of magnitude higher (respectively) at the bottom of the screen than at the top. In contrast, the post-purge samples showed little variation in analyte concentrations with depth and agreed best with the low-flow concentrations, indicating that pumping the well resulted in mixing any stratification that was initially present in the well. CLF was not detected in this well.

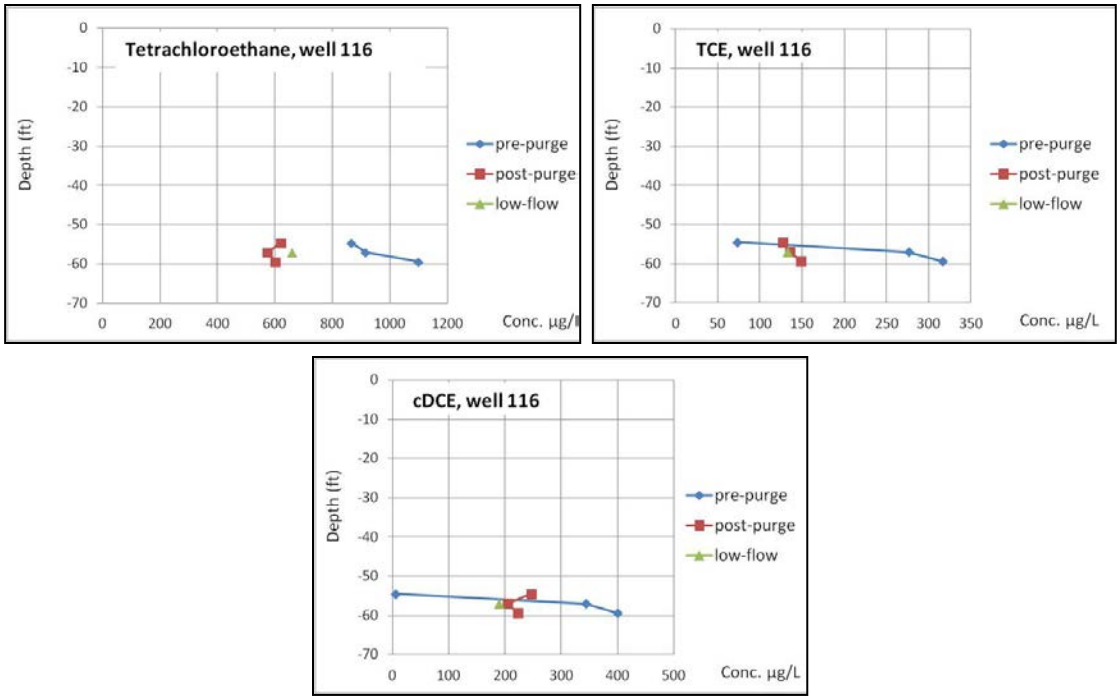


Figure 35. Concentrations of TetCA, TCE, and cDCE with depth in well 116.

6.3.4 Well 131

Well 131 was a relatively shallow well (with a 5 ft screen at 7 to 12 ft bgs). Prior to purging this well, there were very steep gradients in analyte concentrations for all five chlorinated solvents (TCE, TetCA, CLF, cDCE, and PCE) found in this well. Concentrations were generally an order of magnitude higher in the upper portion of the well screen (Fig. 36). The low-flow concentrations of TCE, CLF, and PCE agreed most closely with the mid-level GORE Module data while the low-flow concentration of TetCA agreed most closely with the upper-level (pre-purge) GORE sample, and the low-flow concentration of cDCE agreed most closely with an average of the concentrations reported for the mid-level and top-level (pre-purge) samplers. Generally, low-flow concentrations of these analytes agreed better with the pre-purge samples than with the post-purge samples. For this well, the lower post-purge concentrations may have been caused by partially dewatering the well. This is the reason why there was not a post-purge sample from the upper portion of the well screen. However, if we examine the data for the replicate sample that was collected in this well (Table 12), we see that there was good agreement between the replicates. It is also interesting that there was such a pronounced concentration gradient in this well given that the screen was only 5 ft in length and that con-

centrations were so much higher in the upper portion of the well screen, especially given that this well is relatively shallow. Vroblesky (2001) also observed substantial concentration gradients within a short (3 ft) screened interval.

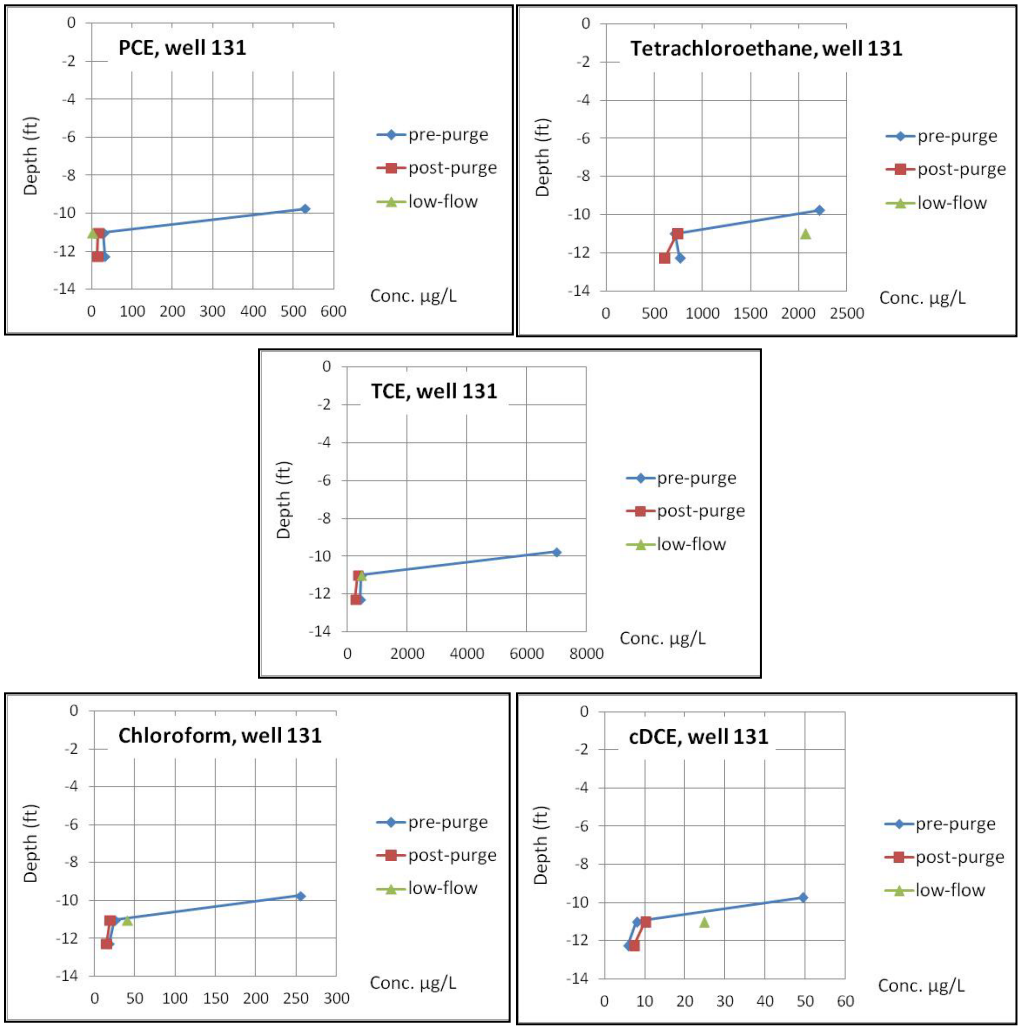


Figure 36. Concentrations of PCE, TetCA, TCE, CLF, and cDCE with depth in well 131.

6.3.5 Well 147

Well 147 had a 10 ft screen, and the Modules were approximately 25 ft below the water table. There also was a gradient in analyte concentrations with depth in this well with concentrations greatest in the upper portion of the well screen and lowest in the bottom section of the well screen (Fig. 37). This was true for the pre-purge samples for all five analytes (TCE, PCE, TetCA, cDCE, and BNZ) found in this well. Analyte concentrations

were approximately 1.5 to 4 times greater in the upper portion of the screened interval than in the bottom section. In almost all cases, the concentrations in the low-flow samples agreed best with the pre-purge samples from the upper portion of the screen. For the post-purge samples, there was a similar concentration gradient for TCE and TetCA. For PCE, cDCE, and BNZ, concentrations in the upper sampler were the same as the mid-level sampler. Also, the highest concentrations of the post-purge samples for PCE, TetCA, and BNZ were only approximately half of the concentration of the low-flow sample. These data are confusing in that if the low-flow pumping had drawn water with high concentrations of these analytes, then one would expect that the post-purge data would be higher than the pre-purge data rather than the opposite. However, when we look at the results for the blind duplicate sample that was collected in this well (Table 12), again we see that there was excellent agreement between the duplicate samples for these analytes. The poorest agreement was with cDCE where the RSD was 27.5%.

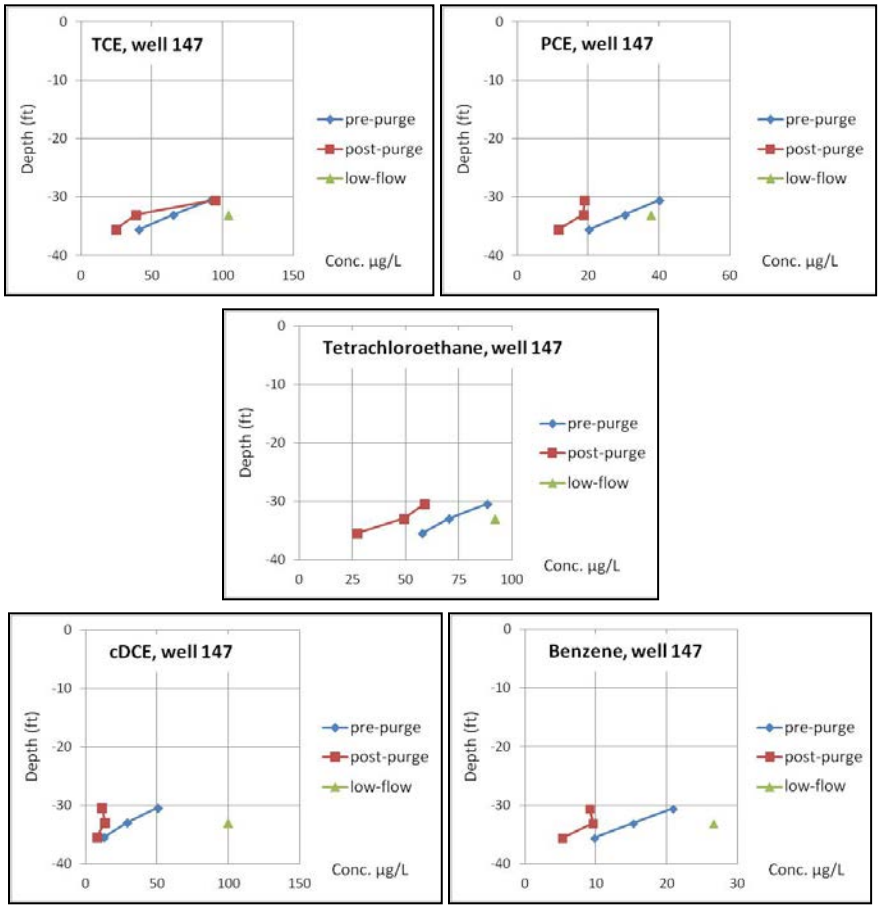


Figure 37. Concentrations of TCE, PCE, TetCA, cDCE, and BNZ with depth in well 147.

In previous sections of this report, we plotted the data from the GORE Modules against the low-flow data for each of the wells. In some instances, there were samples that appeared to be outliers and that better agreement between the two methods could be obtained by eliminating a particular sample. For some wells, the apparent outliers appear to be due to stratification in the well. Figure 27 is an example of this, showing mean pre-purge GORE data compared with the low-flow data for TCE. The apparent outlier in that series was well 131 (Appendix Table E2) where the pre-purge concentration of TCE in the upper portion of the well screen was more than an order of magnitude higher than the midsection. Taking the mean for these three values would yield a considerably higher value than that of the low-flow sample and explains why the mean value appears to be an outlier in Figure 27 (left). In contrast, for example the TCE concentrations for the pre-purge samplers at the bottom and midpoint of the screened interval agreed well with the low-flow value.

Another similar example can be seen by examining the TetCA concentrations in well 131. The concentration of this analyte in the upper section of the screen agreed well with the low-flow concentration while the mid-level GORE data and the mean of all three pre-purge values would have yielded much poorer agreement than using the upper pre-purge value.

6.4 Conclusions for the APG site

The demonstration at this site has shown that the GORE Module is able to provide reproducible results in most instances and that there was very good agreement between the analyses conducted by the Gore Laboratory and an independent contract laboratory. We observed that when there was poor reproducibility between replicate samples, this occurred primarily after purging wells that were shallow and where the upper portion of the screen was near the water table. Under normal use of the GORE Modules, the wells would not be purged; thus there would not be any post-purge samples, and this would not occur.

Given that the Modules are stable for several months and that each sampler contains a duplicate packet of sorbents, samples with questionable results can be rerun without having to go back to the field to collect additional samples. This could provide a cost savings.

The data for the mid-level samplers and the mean values for the Modules at the three depths were compared with the data for the low-flow samples. In all cases, there was a strong, statistically significant linear relationship between the GORE data and the low-flow data for all the analytes (PCE, cDCE, TCE, TetCA, and CLF). For PCE, cDCE, and TCE, this relationship was typically one to one (i.e., the slope of the line for the plotted data was not significantly different from 1.0). Instances where the relationship was less than 1.0 included the following: the pre- and post-purge mid-level and mean data for TetCA, the pre-and post-purge mid-level data for CLF, and the post-purge mean data for TCE.

While the slopes of the lines were significantly less than 1.0 for some analytes, there was a highly significant linear relationship between the low-flow samples and the GORE Modules for all the analytes. Therefore, we believe that revising the algorithm used to calculate concentration values for these analytes could provide better agreement (i.e., a slope closer to 1.0). This is something we recommended that the Gore Laboratory should continue to work on.

Although we thought that perhaps the low-flow data would agree better with the post-purge data than with the pre-purge data, we did not find this to be true.

While there was generally good agreement between the GORE data and the low-flow data, there was stratification in analyte concentrations with depth in some wells. This stratification appears to be greatest at the epicenters of the plumes. The differences in concentrations with depth explain why for some wells the mid-level sampler agreed better with the low-flow data while in other cases the mean concentration of the samplers (for the three depths) yielded better agreement with the low-flow data. This would also explain some of the scatter in the data when the GORE Module data are plotted against the low-flow data.

While it is generally held within the groundwater-sampling community that low-flow sampling collects a sample that is a flow-weighted average for the well, we see instances where the low-flow concentrations agreed best with samples collected from only one portion of the well screen (by the GORE Modules). Presumably, in these instances, low-flow sampling drew its sample from the same zone in the formation that was interrogated

by the GORE Module. In other instances, we see that low-flow sampling did not collect a sample from water that flows into the well under ambient (non-pumped) conditions. These differences point to the question of where to place a passive sampler in a well. Depending upon the data quality objectives for the sampling event, it may desirable to place the sampler where the analyte concentrations agree best with the low-flow sample. In other instances, it may be best to place the sample where one will obtain the highest concentrations and thus obtain a higher estimate of the level of contamination.

With respect to the sensitivity of the GORE method, the Modules were able to provide data that was at the action level. Specifically, the detection level was below the EPA's MCLs for drinking water (US EPA 2011). While detection levels below the MCL are typically the industry standard, currently some agencies require or recommend even lower quantitation limits. An example is the EPA, which recommends in their Quality Assurance Project Plan Manual (US EPA 2005) that the quantitation limit should be no greater than one-third of the action limit and ideally one-tenth of the action limit. Given that the low-flow method was able to show lower concentration values at this site, as shown in Figures 31 and 32, one would assume that most regulators would prefer the low-flow method. Therefore, when we completed the analyses of the data for this field site, we recommended to the Gore Laboratory that they should continue developing lower detection capability for this technology. They report that they have been able to reach these lower levels for most analytes. We will discuss this further at our next field site.

7 Sampling Results for the Former Pease AFB

Contaminants that we detected in at least some of the wells at this site by using both sampling technologies (i.e., the GORE Modules and low-flow sampling) included BNZ; TOL; EBNZ; XYLs; NAPH; 124TMB; 135TMB; isopropylbenzene; *p*-isopropyltoluene; and 1,2-dibromoethane.

7.1 Reproducibility of sampling methods (replicate samples)

7.1.1 Reproducibility of the GORE Modules

Once again, we compared the results from co-located field duplicate samples to determine if this sampling and analytical method yielded good precision. For this demonstration, all of the replicate samples were "blind samples" in that the laboratory did not know that the two samples were replicates. Again, the guideline that we set for reproducibility was that the majority of samples had RSDs of 20% or less.

Appendix Tables J1–J17 provide the results for the analyses of the duplicate GORE Modules for the same sampling depth and contact time. Table 13 summarizes this data for those samplers where concentrations were at least three times the MDL. For most of the analytes, there was good agreement between the duplicate GORE Modules. That is, for a given analyte, more than 80% of the duplicate pairs met our guideline (i.e., the RSD was 20% or less). This was true for 135TMB, NAPH, 2-methylnaphthalene, octane, undecane, *n*-propylbenzene, isopropylbenzene, *n*-butylbenzene, and isopropyltoluene. The exceptions were BNZ, EBNZ, and XYLs where 60% or more of the replicates met the 20% RSD guideline; 124TMB where 73% of the replicates met the guideline; and TOL with the poorest agreement with only 35% of the replicates meeting the guideline.

Table 13. Summary of the results from the analyses of replicate GORE Module samples*.

Analyte	Sample type	# reps.	%RSD range	<50% RSD		<20% RSD	
				#	%	#	%
benzene	LF	2	0–13	2	100%	2	100%
	GORE	15	0–116	10	67%	9	60%
toluene	GORE	17	0–123	10	59%	6	35%
ethylbenzene	LF	1	17	1	100%	1	100%
	GORE	16	0–108	13	81%	10	63%
total xylenes	LF	2	4.7–6.4	2	100%	2	100%
	GORE	15	3.0–107	12	80%	10	67%
undecane	GORE	15	0–21	15	100%	14	93%
1,2,4-trimethylbenzene	LF	2	6.7–19	2	100%	2	100%
	GORE	15	0–76	13	87%	11	73%
1,3,5-trimethylbenzene	LF	1	45	1	100%	0	0%
	GORE	15	0–51	14	93%	12	80%
naphthalene	LF	1	28	1	100%	0	0%
	GORE	15	0–56	14	93%	14	93%
2-methylnaphthalene	GORE	11	0–31	11	100%	10	91%
octane	GORE	14	0–30	14	100%	13	93%
isopropylbenzene	GORE	6	2–8.5	6	100%	6	100%
n-propylbenzene	LF	2	0–5.2	2	100%	2	100%
	GORE	4	0.9–9.6	4	100%	4	100%
isopropyltoluene	GORE	2	5.1–13	2	100%	2	100%
n-butylbenzene	GORE	1	4.8	1	100%	1	100%
tert-butylbenzene	LF	2	0	2	100%	2	100%

*Where analyte concentrations were at least 3x the detection limit

When we examined those analytes where there was the poorest agreement, we see that the poor replication primarily occurred in four wells: PH2-5608, PH2-6508, PH2-6658, and PH2-6660. (The data for the wells with high variability [greater than 30%] are highlighted in brown in Appendix Tables J1, J2, J3, J4, and J6 for BNZ, TOL, EBNZ, XYLs, and 124TMB, respectively.) There were three pairs of duplicate samplers in wells PH2-6508 and PH2-6660; the other wells had only one pair of duplicate samplers. We took the duplicate samples before purging the well in wells PH2-5608 and PH2-6658 and after purging the well in the other two wells. The generally low concentrations of the analytes in wells PH2-5608 and PH2-6508 probably explains the higher variability in those wells. Well PH2-6658 had poor reproducibility for BNZ, TOL, and EBNZ. Well PH2-6660 had the poorest reproducibility overall, especially for BNZ and TOL. Also,

while the Modules placed in the mid and lower portion of the well screen had excellent reproducibility for several of the analytes (e.g., EBNZ, XYLs, and 124TMB), the Module placed in the upper portion of the well screen had the poorest reproducibility.

In all of these wells, the Modules were placed 40 ft or more below the water table. As noted in Section 2.2 (and discussed in more detail in Appendix B1), some analytes are lost from the Modules when the depth below the water table is greater than 32 ft. (This is because the water entry pressure of the membrane is such that water will pass through the membrane and come in contact with the solid sorbent. Sorption then becomes a function of the partitioning coefficient of the analyte by the sorbent [K_{AW}]). Among the analytes found at this site, Gore has found that EBNZ, XYLs, and 124TMB are the most affected by this issue and that BNZ and TOL would be expected to be less affected. However, the analytes that we found to have the poorest reproducibility were not those reported to be most prone to penetrate the membrane. Therefore, we suspect that the depth below the water column per se was not the cause of the poor reproducibility for these analytes in these wells.

However, we also noted that the samplers with the poorest reproducibility had been left in the wells for longer than two hours, especially well PH2-6660 where the samplers were left for 3 hours. It may be that this contact time was too long and that uptake was no longer in the linear portion of the curve, or it may be that for the deeper samplers there is penetration of the membrane with a prolonged contact time. It is also possible that in some wells there were too many samplers too close together, which impeded flow in the well, or that the flow in the well was such that one pair of samplers was in a preferential location with respect to the flow of contaminants into the well. (We had secured the Modules only at the bottom so that they could float relatively freely in the well. This was done to reduce or eliminate any bias from position in the well. However, placing multiple samplers at the same depth may have interfered with the samplers floating freely.)

We see that when the data for the wells with the long contact times (i.e., 2 hours or more) are removed, the agreement between the replicate samples is much better for these analytes (Table 14). Therefore, we conclude that generally there is good repeatability when duplicate samples are taken, ex-

cept in wells where the samplers are below the water by 40 ft or more and left for 2 hours or more. Until this is better understood, we would recommend that the samplers should not be left in the well for longer than 90 minutes, especially if they are deployed more than 32 ft below the water table.

Table 14. Revised summary of the results for the replicate GORE samples*.

Analyte	# reps.	%RSD range	# <20% RSD	% of replicates meeting the guideline
benzene	10	0–34	9	90%
toluene	12	0–95	6	50%
ethylbenzene	9	2–28	7	78%
total xylenes	8	3–51	6	75%
1,2,4-trimethylbenzene	8	0–24	7	88%
1,3,5-trimethylbenzene	8	0–25	7	88%

*Data for samples with contact times greater than 2 hours have been eliminated from consideration (in cases where there was poor agreement initially).

7.1.2 Reproducibility of the low-flow samples

Appendix K gives the raw data for all of the replicate samples. Unfortunately, for most of the replicate low-flow samples, analyte concentrations were below the detection limit. For those samples where the analyte concentrations were greater than 3 times the detection limit, the results were summarized in Table 13. These analytes included BNZ, EBNZ, XYLs, 124TMB, 135TMB, NAPH, *n*-propylbenzene, and *tert*-butylbenzene. For most of these analytes, the replicate samples met the 20% RSD guideline. The exceptions were 135TMB and NAPH where the RSD was 45% and 28%, respectively.

Again, when comparing these results with those for the GORE Modules, it is important to remember that the duplicate low-flow samples are taken sequentially without stopping the pump, and thus these samples are actually subsample field duplicates as defined by the US EPA (2005). Real field duplicate samples, where the pump is stopped and started, would be expected to yield higher RSDs for the low-flow samples. In contrast, the GORE Modules are true field duplicate samples.

7.2 Agreement between GORE Modules and low-flow data

Appendix L presents the results for the analyses of the pre-purge and post-purge GORE Modules (at the three sampling depths) and the low-flow samples for those analytes and wells where we detected analytes. Analytes that were detected in at least some of the wells by using both sampling methods included BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. Also, using both sampling methods, we detected dibromoethane in one well and isopropyltoluene in several wells although the low-flow values were typically J values. (This analyte is not one of the VOCs detected by 8260B.)

In a few instances, PCE and TCE were found using the GORE Modules but were not reported for the low-flow data. This is because these two analytes were not on the list of target analytes for this site, and thus their analyses were not routinely requested and were not requested for this sampling round. Also, detectable levels of undecane, 2-methylnaphthalene, and octane were recorded by the GORE Modules but not by the low-flow data. These analytes are not measured using EPA method 8260B and historically have not been reported for this site. Thus, they also were not on the list of target analytes for this site. Although we do not have results for these analytes in the low-flow samples and thus cannot confirm the concentration values found in these samples, this data does indicate that the GORE Modules are able to provide data on more of the hydrocarbons present at this site than the method currently being used at this site (i.e., analyses only for VOCs by using EPA method 8260B).

7.2.1 Sensitivity of the two analytical methods

Previously at the APG site, the analytical method used for low-flow purging and sampling was able to provide greater sensitivity than the method for the GORE Modules. (In that study, the method detection limit for the low-flow samples for most analytes was 0.2 µg/L while for the GORE Modules it was 4.4 µg/L.) Since that time, the Gore Laboratory has been working on lowering their detection capability so that detection levels are more comparable with the analytical method used for the low-flow samples.

For this site, the Gore Laboratory was able to obtain an equivalent detection capability for most of the analytes (e.g., BNZ, TOL, EBNZ, XYLs,

124TMB, 135TMB, and NAPH) by modifying the currently accredited method. Table 15 provides the MDL for the two analytical methods. For the remaining analytes, the MDLs remain higher with the GORE Modules than with the low-flow samples. Those analytes include *n*-butylbenzene; *n*-propylbenzene; isopropyltoluene; isopropylbenzene; and 1,2-dibromoethane (Table 15). However, the detection capability was below one-tenth of the EPA's MCLs (EPA 2011) (Table 15). We also noted that for TCE (which was not reported for the low-flow samples), the detection capability for the Modules was less than one tenth of the MCL. This is a substantial improvement in the detection capability for this analyte when compared with the results from the previous test site.

Table 15. Detection capability of the two analytical methods.

Analyte	EPA MCL mg/L (µg/L)	Concentration µg/L		
		GORE MDL	Low-flow samples	
			RDL	MDL
benzene	0.005 (5)	0.22	1	0.30
toluene	1 (1000)	0.21	1	0.30
ethylbenzene	0.7 (700)	0.21	1	0.20
xylenes (total)	10 (10,000)	0.21	3	0.20
undecane	—	2.9	NR	NR
1,2,4-trimethylbenzene	—	0.21	1	0.20
1,3,5-trimethylbenzene	—	0.20	1	0.20
naphthalene	—	0.19	1	0.30
octane	—	0.4	NR	NR
n-butylbenzene	—	5.85	1	0.20
n-propylbenzene	—	7.07	1	0.30
4-isopropyltoluene	—	5.94	1	0.20
isopropylbenzene	—	0.66	1	0.20
trichloroethylene	0.005 (5)	0.279	NR	NR
2-methylnaphthalene	—	0.22	NR	NR
1,2-dibromoethane	0.005 (5)	11.7	1	0.20
1,4-dichlorobenzene	0.075 (75)	0.22	NR	NR
carbon tetrachloride	0.005 (5)	0.23	NR	NR
chlorobenzene	0.1 (100)	0.25	NR	NR
methyl *tert*-butyl ether	—	0.36	1	0.40

MCL = EPA's Maximum Contaminant Level allowable in drinking water

RDL = Reporting Detection Limit

MDL = Method Detection Limit

NR = Not reported for this study

7.2.2 Comparison of the mid-level GORE Module data with the low-flow data

Contaminants that were detected by using both sampling methods in enough wells (at least 5) to allow statistical analyses of the data included BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. Figures 38 through 48 show comparisons between the pre-purge and post-purge GORE data (at the mid-depth level) compared with the low-flow data for each of those analytes respectively. Generally, there was very good agreement between the two sampling methods with the exception of instances where concentrations were near the detection level. This was true for TOL, EBNZ, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. For several of these analytes, there are additional figures that show the improved agreement between the methods once the values near the detection limit were removed. Specifically, this is illustrated for TOL in Figures 40, for isopropylbenzene in Figures 47, and for propylbenzene in Figures 49. The analytes that appeared to have the most scatter were BNZ and XYLs.

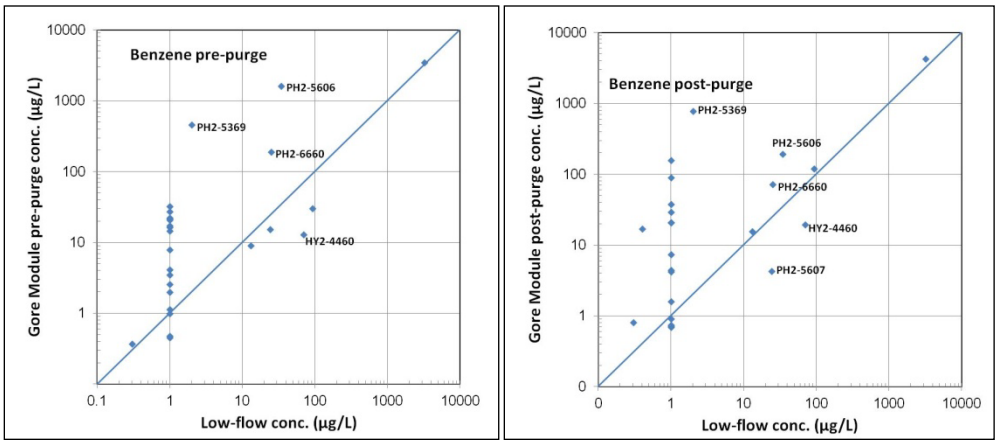


Figure 38. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for benzene.

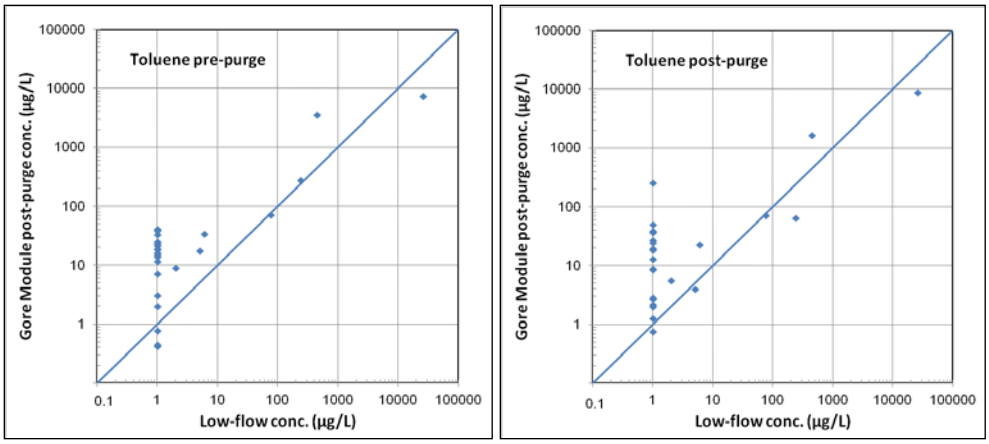


Figure 39. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for toluene.

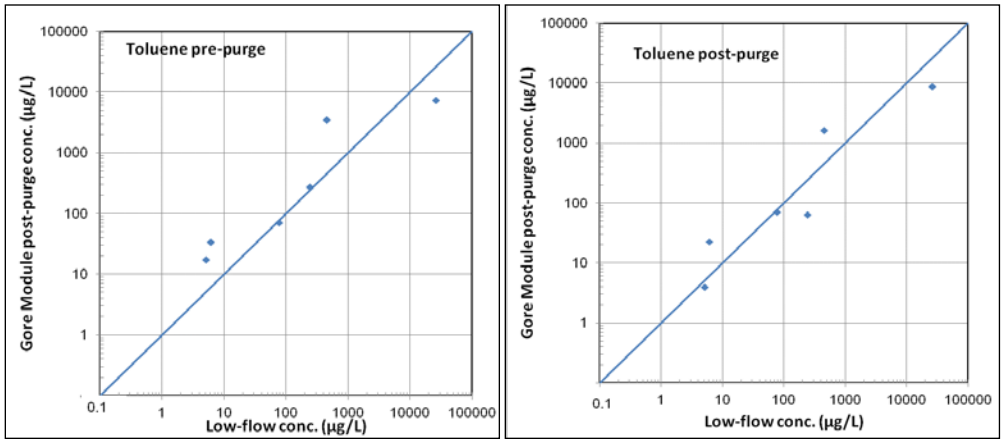


Figure 40. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for toluene with the values near the detection limit removed.

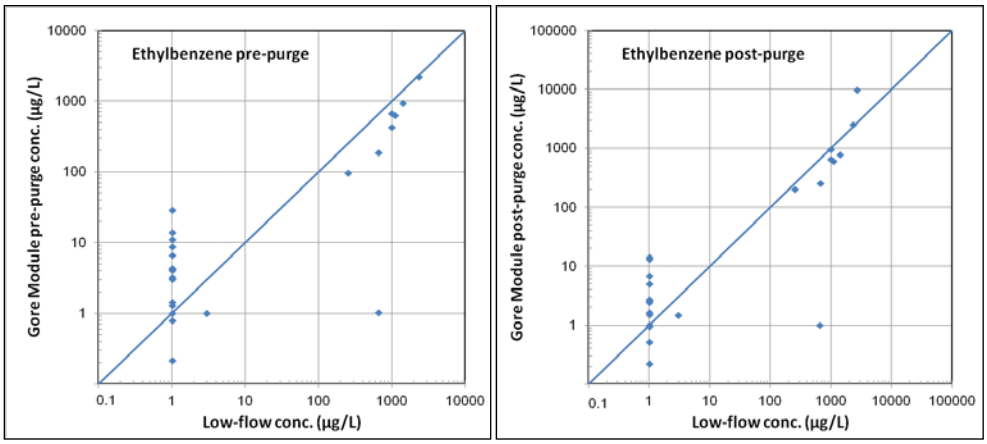


Figure 41. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for ethylbenzene.

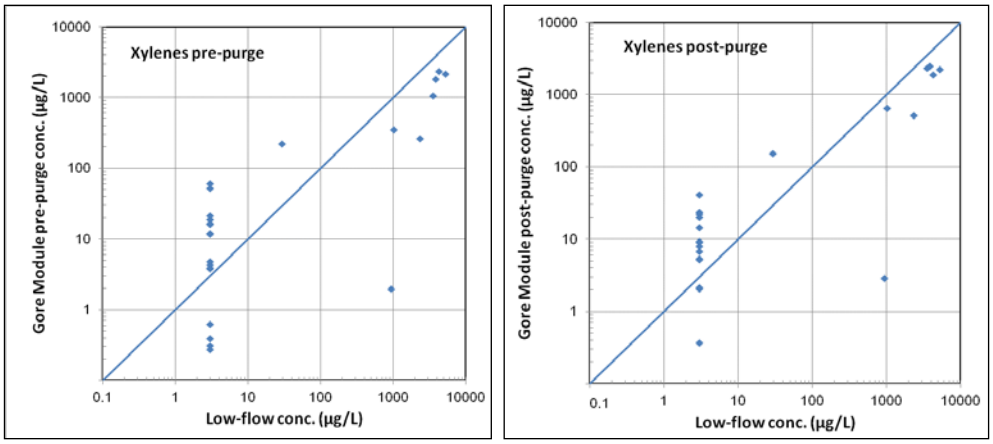


Figure 42. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for total xylenes.

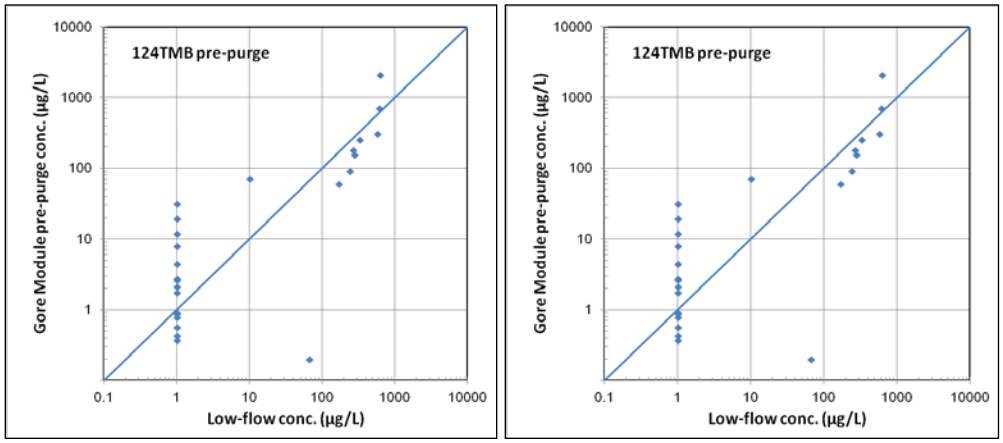


Figure 43. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for 124TMB.

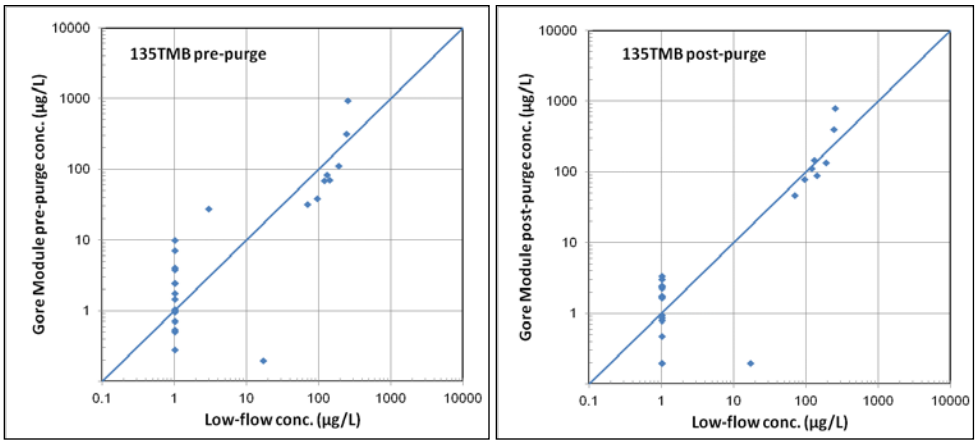


Figure 44. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for 135TMB.

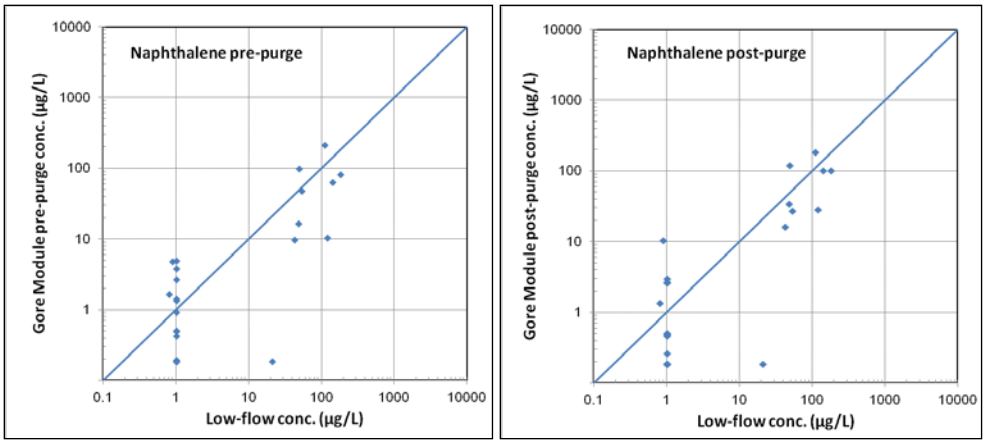


Figure 45. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for naphthalene.

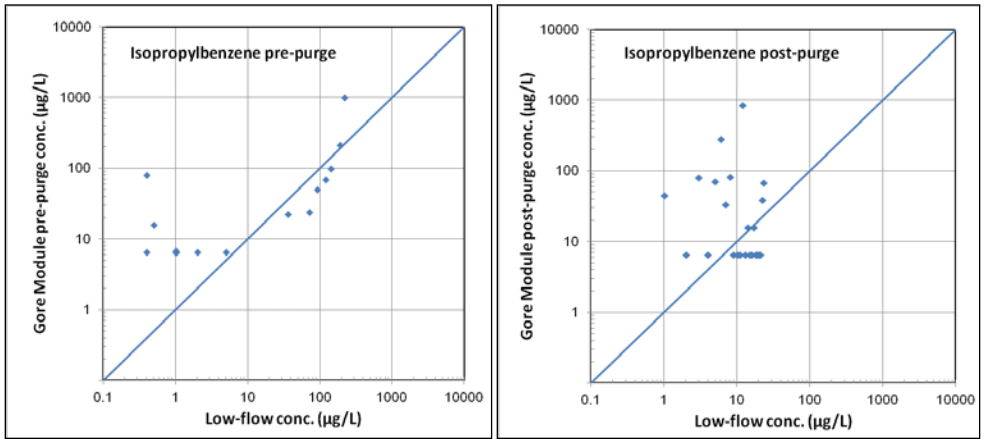


Figure 46. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for isopropylbenzene.

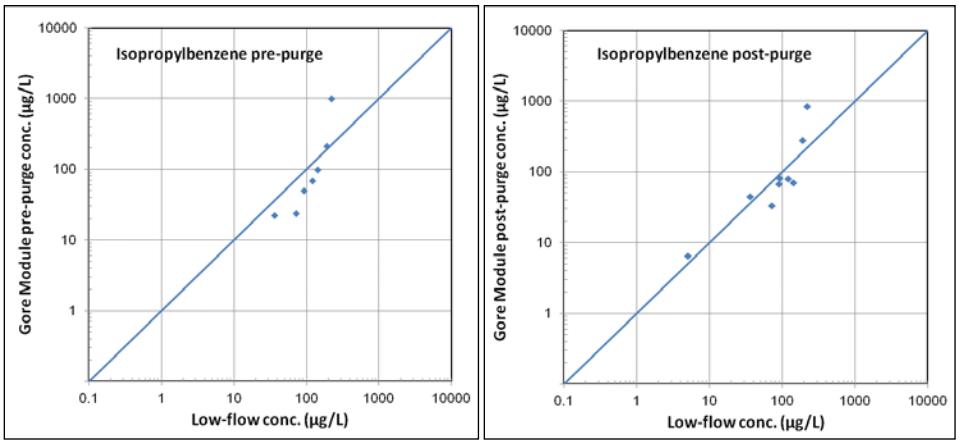


Figure 47. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for isopropylbenzene with the values near the detection limit removed.

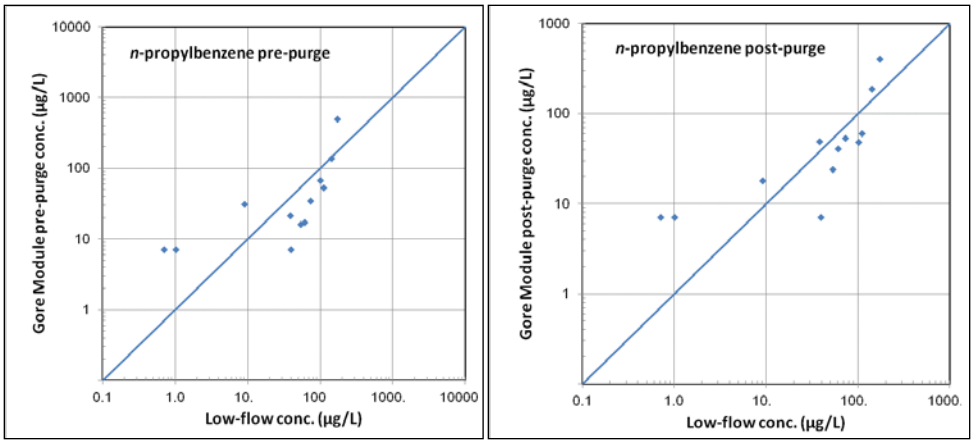


Figure 48. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for *n*-propylbenzene.

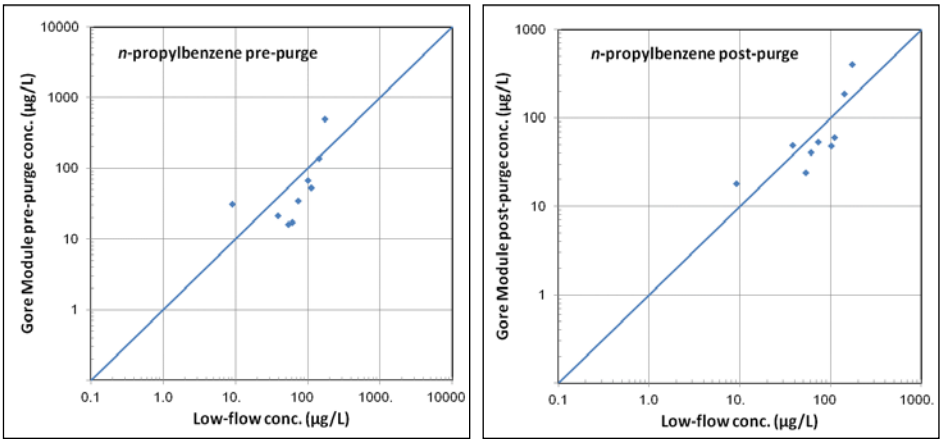


Figure 49. Comparison of the pre-purge (left) and post-purge (right) mid-level GORE data with the low-flow data for propylbenzene with the values near the detection limit removed.

When the data for each of the analytes were analyzed to determine if there was a significant difference between the pre-purge GORE data and the low-flow data or between the post-purge GORE data and low-flow data, there was no significant difference for most of the analytes. This was true for TOL, EBNZ, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. BNZ and XYLs were the only analytes where a statistically significant difference was found. For XYLs, there was only a significant difference between the pre-purge GORE Module data and the low-flow data. For BNZ, concentrations for both the pre-purge and post-purge GORE data were significantly greater than the concentrations for low-flow data. (The Gore chemists have also noticed this with other environmental samples [Anderson 2013] although the cause for this is not clear). Appendix Table M1 summarizes the results of the statistical analyses to determine if

there is a statistically significant difference between the sampling methods.

The analyses of the data using a linear least-fit model confirmed that there was a statistically significant linear relationship between the pre-purge GORE data and the low-flow data for all the analytes and that the slope of the line was not significantly different from 1.0, with the exception of TOL (0.3) (Appendix Table M2). The same was true when the post-purge and low-flow data were compared (with two exceptions: the linear model did not fit the data for BNZ, and the slope of the line was again significantly different from 1.0 for TOL [0.3]) (Appendix Table M2).

Initially, we expected that there would be slightly better agreement between the post-purge and low-flow data than between the pre-purge and low-flow data. This held true for all the analytes except for BNZ (Appendix Table M2). However, there was no statistically significant difference between the pre-purge and post-purge GORE data for any of the analytes (Appendix Table M1).

7.2.3 Comparison of the mean GORE and low-flow data

We compared the mean pre-purge values and the mean post-purge values (for the three sampling depths) to the low-flow data for each of the analytes. Figures 50 through 62 show these comparisons for BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene, respectively. Again, we see that, with the exception of the samples where the concentrations were near the detection limit, there was good agreement between both the mean pre-purge and low-flow data and between the mean post-purge and low-flow data for these analytes. This is illustrated in Figures 51, 53, 58, and 61 for BNZ, TOL, 135TMB, and isopropylbenzene, respectively, which do not include the data for samples where the concentrations were at or near the detection limit. Once again, the analytes with the poorest agreement (i.e., most scatter in these plots) were BNZ and XYLs. The other analyte that showed substantial scatter was *n*-propylbenzene when the pre-purge GORE data was compared with the low-flow data.

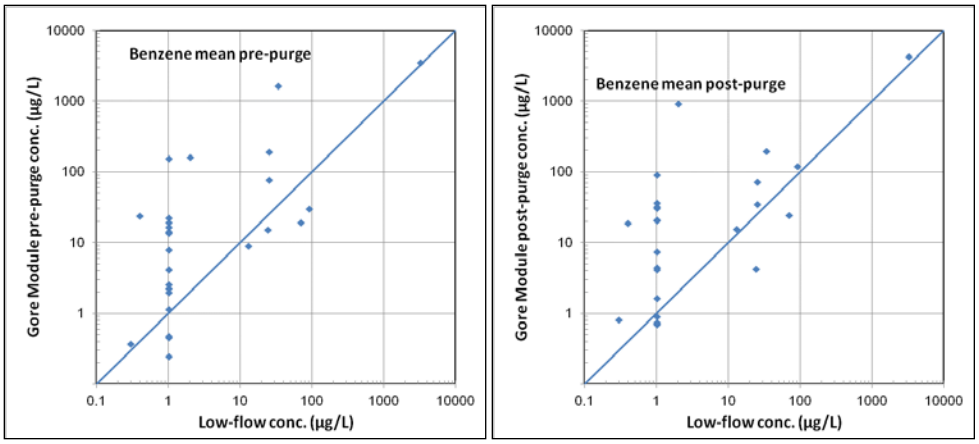


Figure 50. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for benzene.

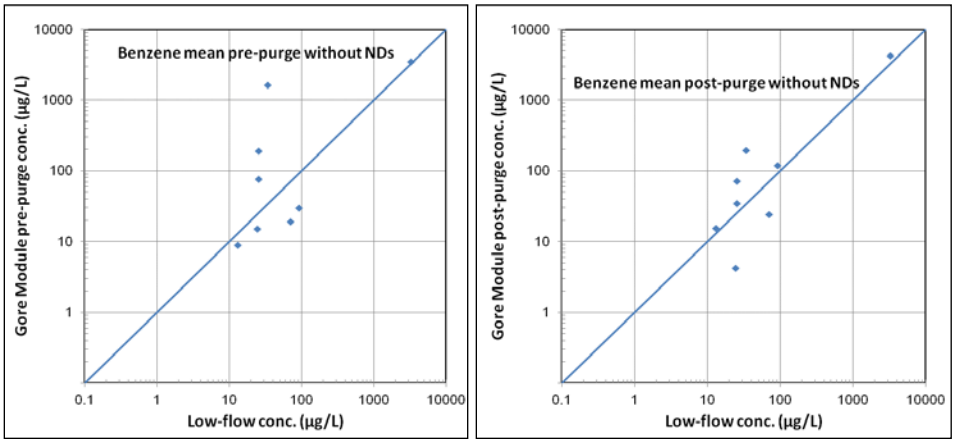


Figure 51. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for benzene with the values near the detection limit removed.

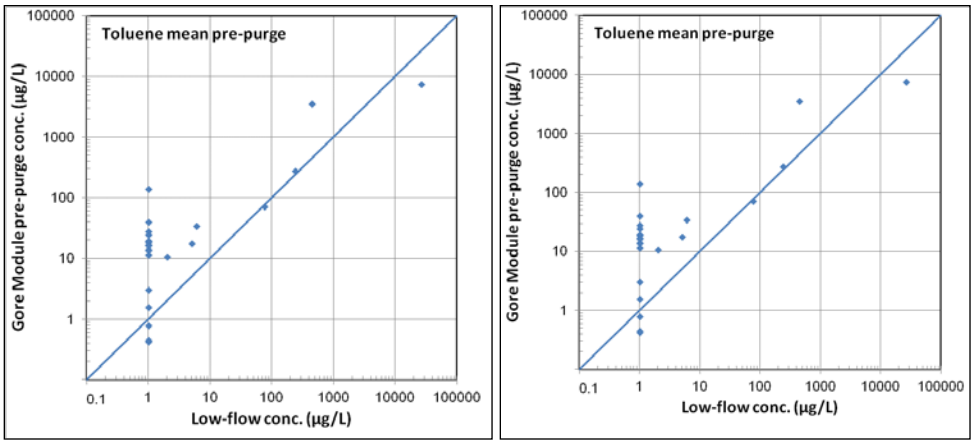


Figure 52. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for toluene.

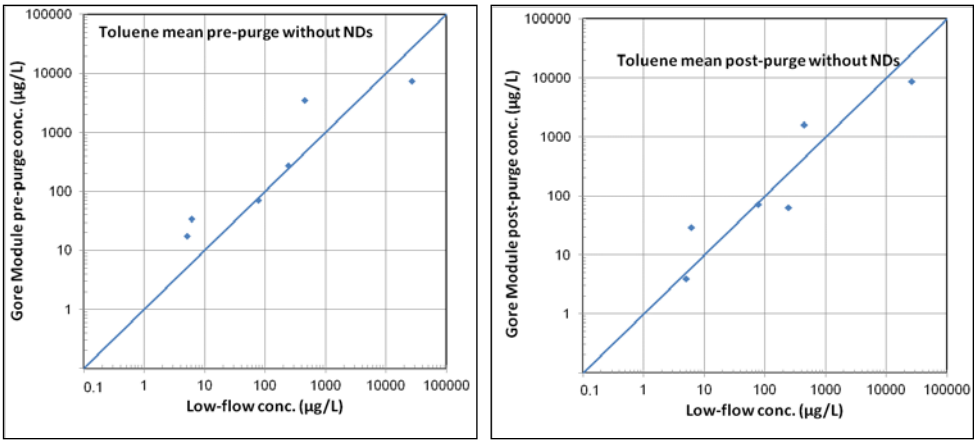


Figure 53. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for toluene with the values near the detection limit removed.

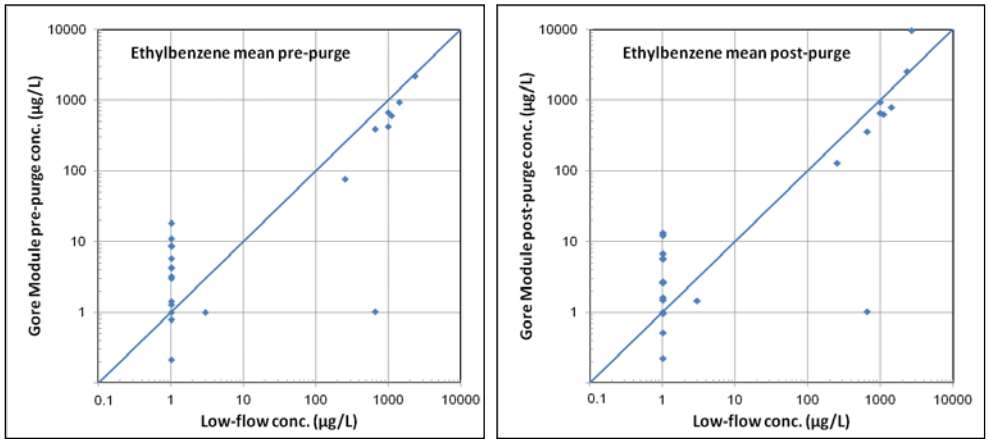


Figure 54. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for ethylbenzene.

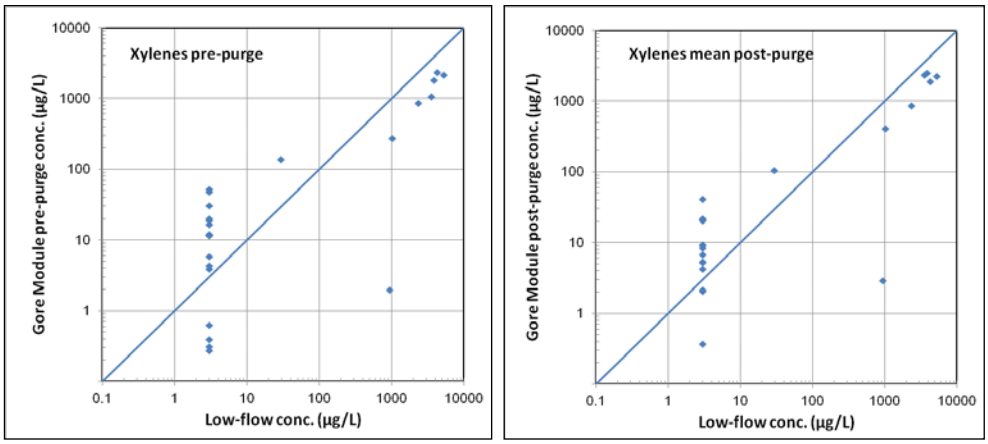


Figure 55. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for total xylenes.

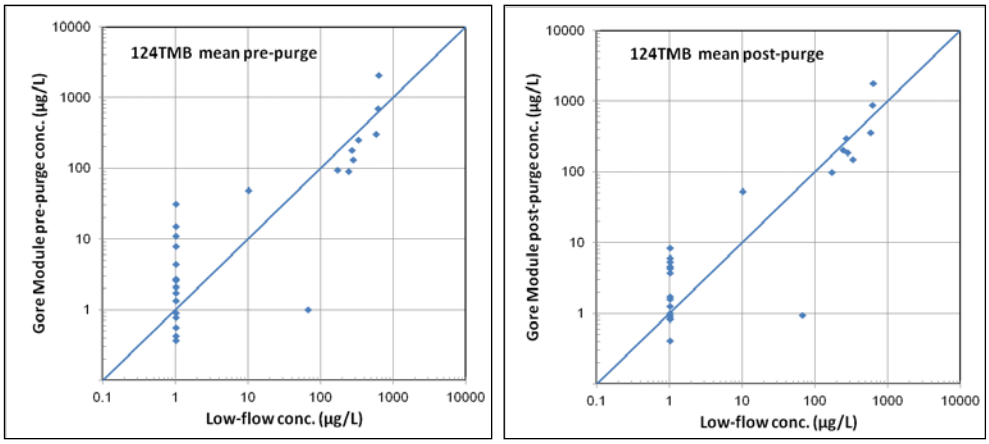


Figure 56. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for 124TMB.

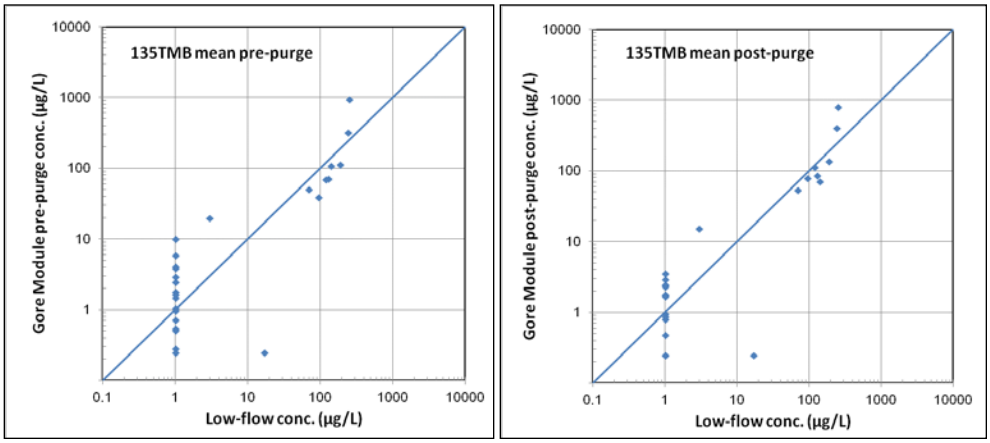


Figure 57. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for 135TMB.

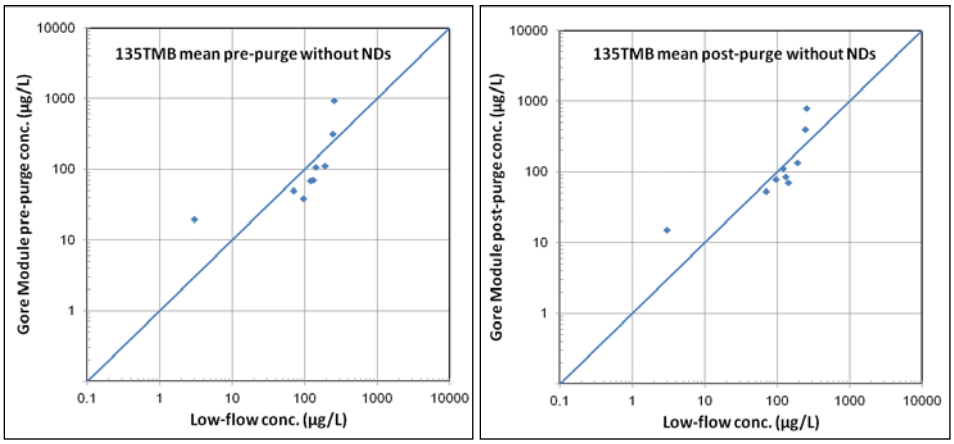


Figure 58. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for 135TMB with the values near the detection limit removed.

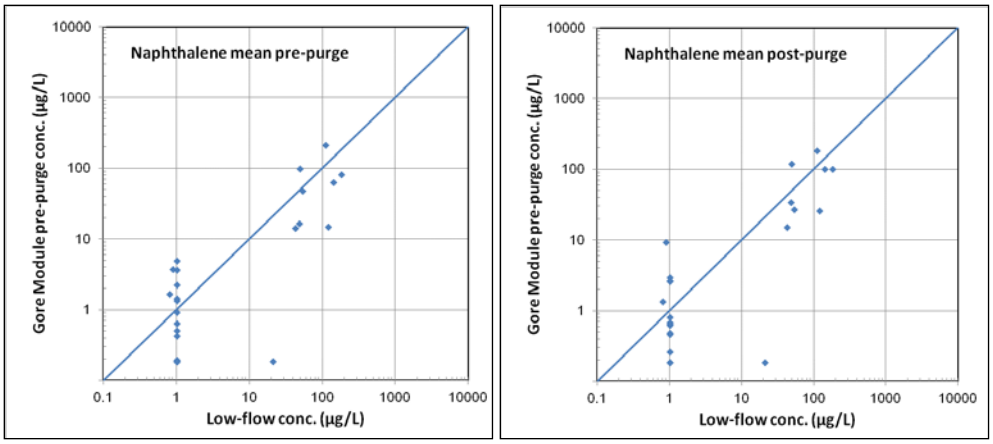


Figure 59. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for naphthalene.

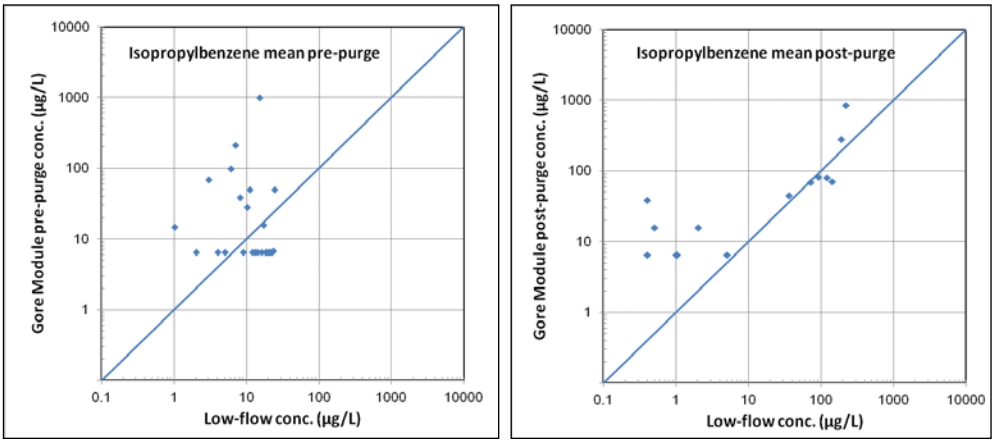


Figure 60. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for isopropylbenzene.

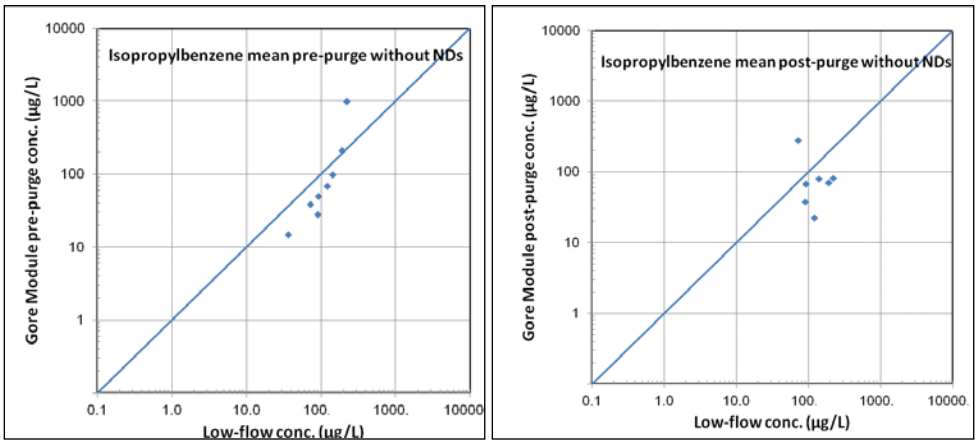


Figure 61. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for isopropylbenzene with the values near the detection limit removed.

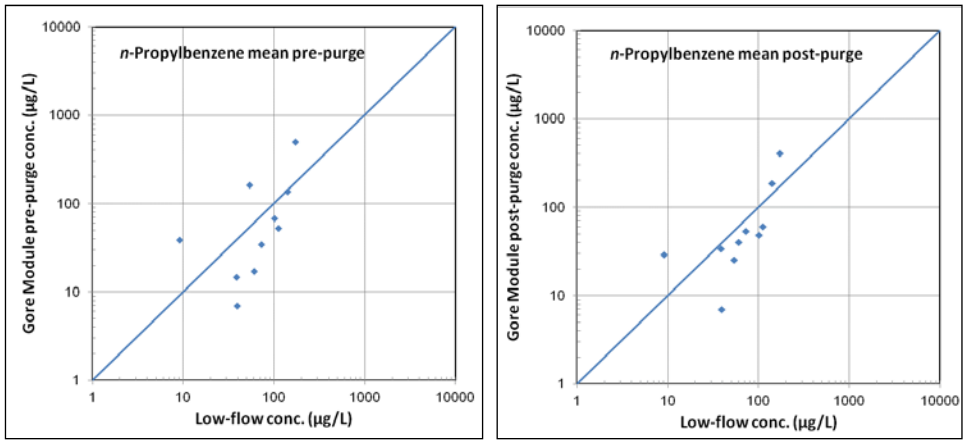


Figure 62. Comparison of the mean pre-purge (left) and post-purge (right) GORE data with the low-flow data for *n*-propylbenzene.

For most of the analytes, there were no statistically significant differences between the mean pre-purge GORE and low-flow data or between the mean post-purge GORE and low-flow data. This was true for EBNZ, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. Statistically significant differences were found for BNZ, TOL, *n*-butylbenzene, and XYLs. For BNZ and *n*-butylbenzene, there was only a statistically significant difference between the post-purge GORE data and the low-flow data. For TOL and XYLs, there only was a significant difference between the pre-purge GORE and low-flow data. Appendix Table N1 summarizes these analyses.)

Analyses using a linear least-fit model confirmed that there was a highly significant linear relationship between the mean pre-purge and post-purge GORE and the low-flow data for all the analytes (significance was less than 0.0225) (Appendix Table N2). The slope of this line was not significantly different from 1.0 for most of the analytes: EBNZ, XYLs, 124TMB, 135TMB, NAPH, isopropylbenzene, and *n*-propylbenzene. The exceptions were the post-purge BNZ data (slope of 1.3) and TOL (slope of 0.3 for both pre-purge and post-purge data). Again, although there was slightly better agreement between the post-purge and low-flow data than between the pre-purge and low-flow data, there were no statistically significant differences between the pre-purge and post-purge GORE data for any of the analytes (Appendix Table N1).

These findings for the analyses of the mean data are similar to those for the analyses of the mid-level data.

7.2.4 Discussion

Although we have seen good agreement between the two sampling methods for both the mid-level GORE data and the mean GORE data, we see that there was considerable scatter along the y-axis at the detection level for the low-flow samples for most of the analytes (e.g., as shown for BNZ in Fig. 38 [left] and for TOL in Fig. 39 [right]). This is primarily due to differences in the way the low-level data was reported. For the low-flow samples, the laboratory used the reporting limit while for the GORE Modules the data was reported at the MDL level. Thus, the GORE data tends to scatter above and below the reporting limit of the low-flow samples. This was true for BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, and NAPH. For *n*-propylbenzene and isopropylbenzene, the MDLs for the GORE Modules were higher than the reporting limits for the low-flow samples, and thus the scatter is about the x axis (e.g., as shown for isopropylbenzene in Fig. 60 [left]).

Using the GORE Modules, for some wells we detected analytes at levels significantly above the reporting limit for the low-flow samples (i.e., ten times greater or more) while the values reported for the low-flow samples were below the detection level. These analytes included BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, and NAPH. We thought that this might have been a function of the depth below the water table. However, we see that this occurred both in wells that were relatively shallow and in those that were very deep (Appendix O). In these instances, the generally good agreement between replicate GORE samples suggests that these analytes were present in the well water and that the GORE samples are not reporting falsely high concentrations.

7.3 Profiling contaminant concentrations with depth in the wells

Most of the wells at this site had relatively short well screens, so there were only ten wells that had long enough screens that would allow us to profile contamination with depth. Only eight of these wells had contaminant concentrations that were above the detection level and could actually be profiled. Most of these wells were associated with the Pit 5 area and included PH1-6507, PH2-5369, PH2-6508, PH2-6627, and PH2-6628. The other two wells were HY2-4460 and PH2-6659, and they were associated with Pit 6. With the exception of the Modules in well HY2-4460, which was a shallow well, all the Modules were at least 30 ft below the water table.

7.3.1 Pit 5

7.3.1.1 Well PH2-5369

Well PH2-5369 is located in the deep overburden at the source of the contamination. For both the pre-purge and post-purge GORE Modules, there was a very pronounced concentration gradient with increasing depth for most analytes. This was true for BNZ, EBNZ, XYLs, 124TMB, 135TMB, NAPH, isopropylbenzene, *n*-propylbenzene, isopropyltoluene, methylnaphthalene, *n*-butylbenzene, and undecane. This trend was most pronounced for the post-purge samples (Fig. 63). This finding is not surprising given that we also found pronounced stratification in the wells at the epicenter of the plumes at the APG site.

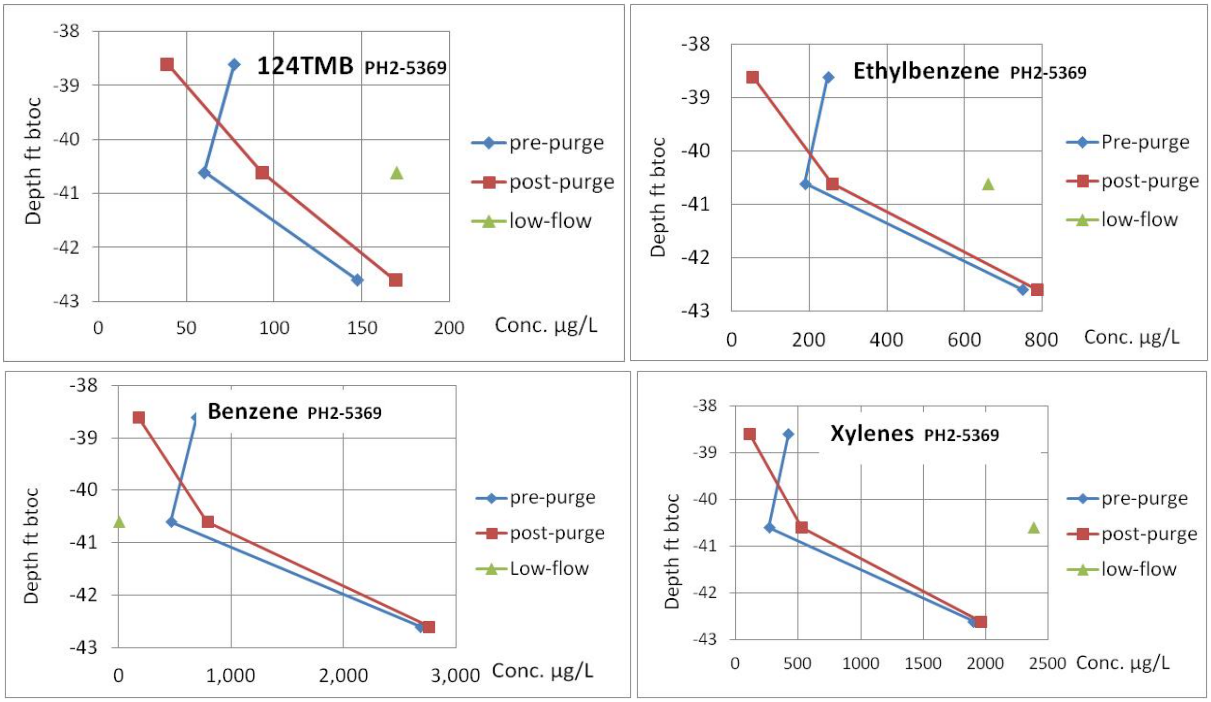


Figure 63. Contaminant profiles for well PH2-5369 for 124TMB, ethylbenzene, benzene, and the xylenes.

When low-flow sampling was used, concentrations of most analytes agreed most closely with the concentrations found in the GORE Modules collected from the deepest part of the screened interval. This was generally true for both the pre-purge and post-purge samples. The poorest agreement was for BNZ where the reported low-flow concentration was near the detection level and two to three orders of magnitude less than that found with the GORE Modules (Fig. 63 [c]). It is not clear to us why the BNZ concentra-

tion was so low in the low-flow sample compared with the high levels found with the GORE Modules. However, the high concentrations of BNZ found with the GORE Modules agree well with what one might expect given the concentrations of the other BTEX compounds in this sample.

Clearly, placing the GORE Modules at the mid-level of the screen in this well did not yield the highest concentrations of most of these analytes or provide the best agreement with low-flow sampling.

7.3.1.2 Well PH2-6660

This well is located in bedrock downgradient of the source in the dissolved plume. There were also pronounced concentration gradients in this well for several analytes. Unlike the previous well where concentrations were highest in the deepest portion of the screened interval, concentrations tended to be highest in the midsection of the screen, especially for the pre-purge samples. For many of the analytes in the post-purge sample, analyte concentrations were almost as high in the lowest section of the screen.

When the low-flow sample is compared with the GORE Modules, we see that concentrations of several analytes agreed best with the samplers collected from the shallowest portion of the well screen (Fig. 64). This was true for BNZ, XYLs, 124TMB, and 135TMB. This was also true for TOL and NAPH (not shown) but only for the pre-purge Module. Generally, analytes that were not detected by one method were not detected using the other method (i.e., low-flow sampling vs. the GORE Modules). The poorest agreement was for EBNZ, which was not detected in the low-flow sample while low concentrations were found with the GORE Modules. These data indicate that purging the well brought in cleaner water that comes from the same location as that sampled in the upper portion of the well screen by the GORE Module. Because this was a downgradient well and we had expected low concentrations of analytes, the GORE Modules were left in the well for a much longer contact time (3 hours). It appears that this longer contact time allowed us to detect low concentrations of EBNZ and TOL that were not detected using the current low-flow sampling and analytical practices

Once again, placing the GORE Modules at the mid-level of the screen did not yield the best agreement with low-flow sampling.

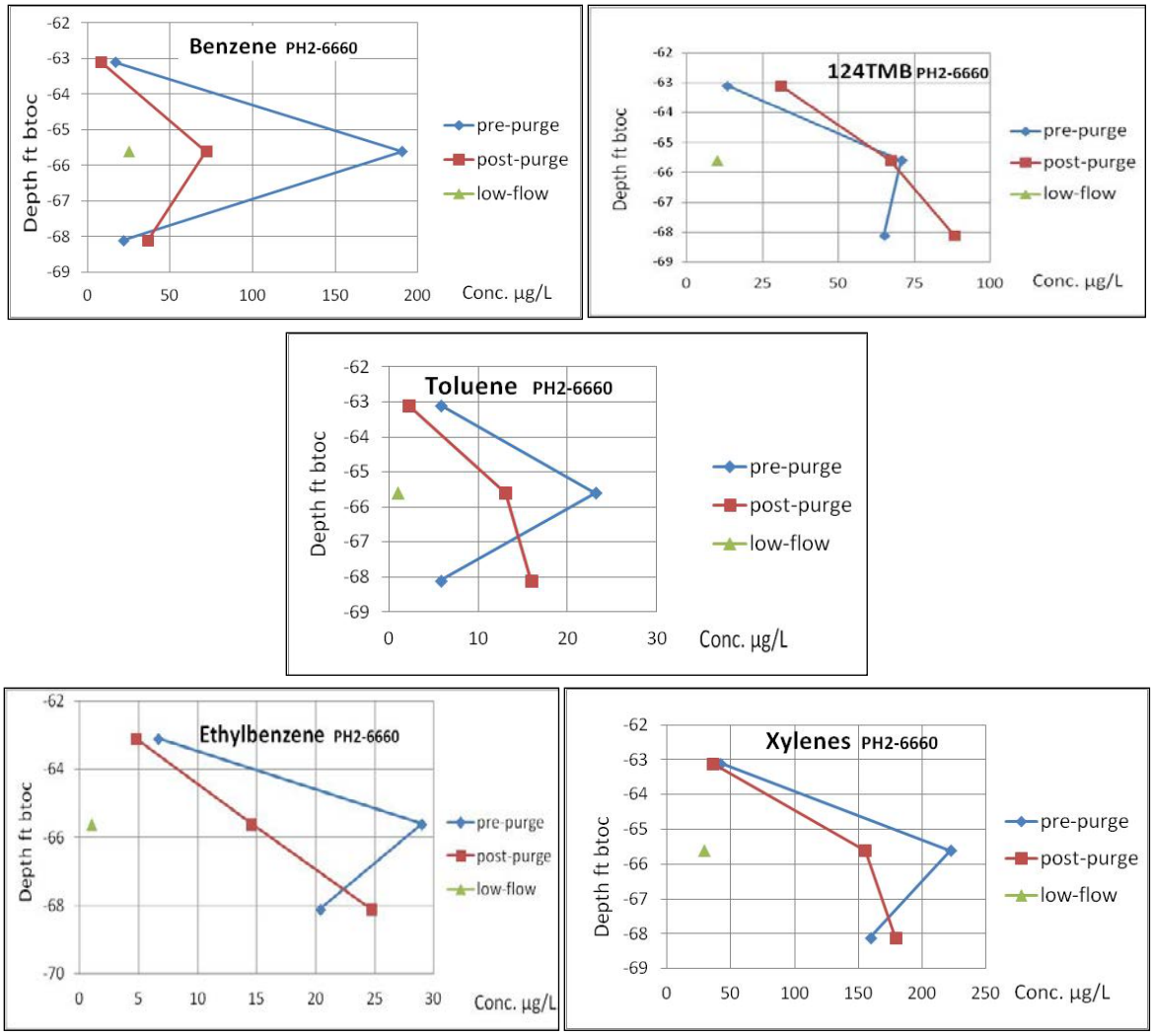


Figure 64. Profile of contaminant concentrations in well PH2-6660 for benzene, 124TMB, toluene, ethylbenzene, and the xylenes.

This was one of the wells where we had previously noted that there was poor reproducibility for some of the replicate Module samples for some of the analytes. For the post-purge duplicate samplers, there was poor reproducibility for all three sampling depths for BNZ and for two of the depths for TOL (Appendix J). In contrast, we found that reproducibility was excellent for 124TMB for all three replicate samples and for EBNZ and XYLs for two of the sampling depths (Appendix J). If the BNZ and TOL data for the replicate samplers had been used, Module concentrations of these analytes would have been even higher (Appendix J). Therefore, given those findings, we believe that the profiles shown for this well were fairly representative of the conditions in the well.

7.3.1.3 Well PH2-6508

Well PH2-6508 is also located downgradient of the source in the dissolved plume in bedrock. Generally, analyte concentrations were low in this well. Concentrations of most analytes were below the reporting limit for the low-flow samples and just slightly above the MDL for the GORE Modules, with BNZ, TOL, and XYLs having the highest concentrations (Fig. 65). There were very slight differences in analyte concentrations with depth in this well; concentrations were slightly higher at the mid-level for the pre-purge samplers.

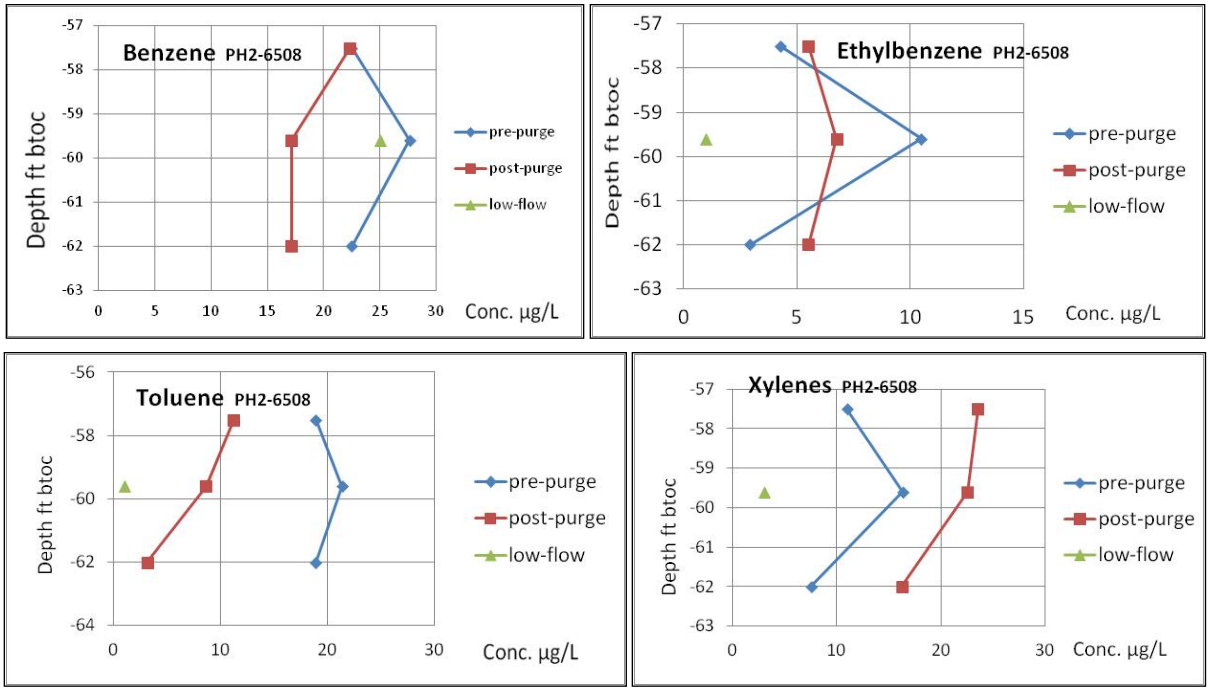


Figure 65. Concentration profiles for contaminants in well PH2-6508 for benzene, ethylbenzene, toluene, and the xylenes.

When the GORE data is compared with the low-flow data, we see that it agrees well for the pre-purge BNZ data. However, for EBNZ and TOL, it appears that either cleaner water was brought into the well with purging or that the detection capability was better with the GORE Modules. Again, because this was a downgradient well and we expected low concentrations of these analytes, the GORE Modules were left in the well for more than 2 hours. It appears that if the Modules are used for longer contact times, low levels of several analytes can be found that are not detected using the current low-flow purging and sampling and analytical methods.

Again, we found poorer reproducibility among some of the three duplicate samples in this well. For most analytes, there was excellent agreement among the two mid-level samplers and poorer agreement between the two upper Modules and between the two lower-level Modules. These samples were taken after purging the well, and this may have impacted flow pattern within the well and thus possibly reproducibility. However, for most of the analytes, concentrations were low; and one would expect poorer agreement closer to the detection level. Again, we see that if we were to replace the post-purge data for this well with the data for the replicate samples, analyte concentrations would not have been lower; and the change in these figures would have shown slightly better agreement between the post-purge and pre-purge samples.

7.3.1.4 Well PH1-6507

PH1-6507 is a downgradient, distal well. For the GORE Modules, there was very little difference in analyte concentrations with depth for any of these analytes prior to purging the well (Fig. 66). However, after the well was purged, concentrations were substantially higher in the deepest section of the well for TOL, BNZ, EBNZ, and XYLs. The same was true for undecane, 124TMB, 135TMB, and NAPH although concentrations were not as high, and the differences were not as pronounced.

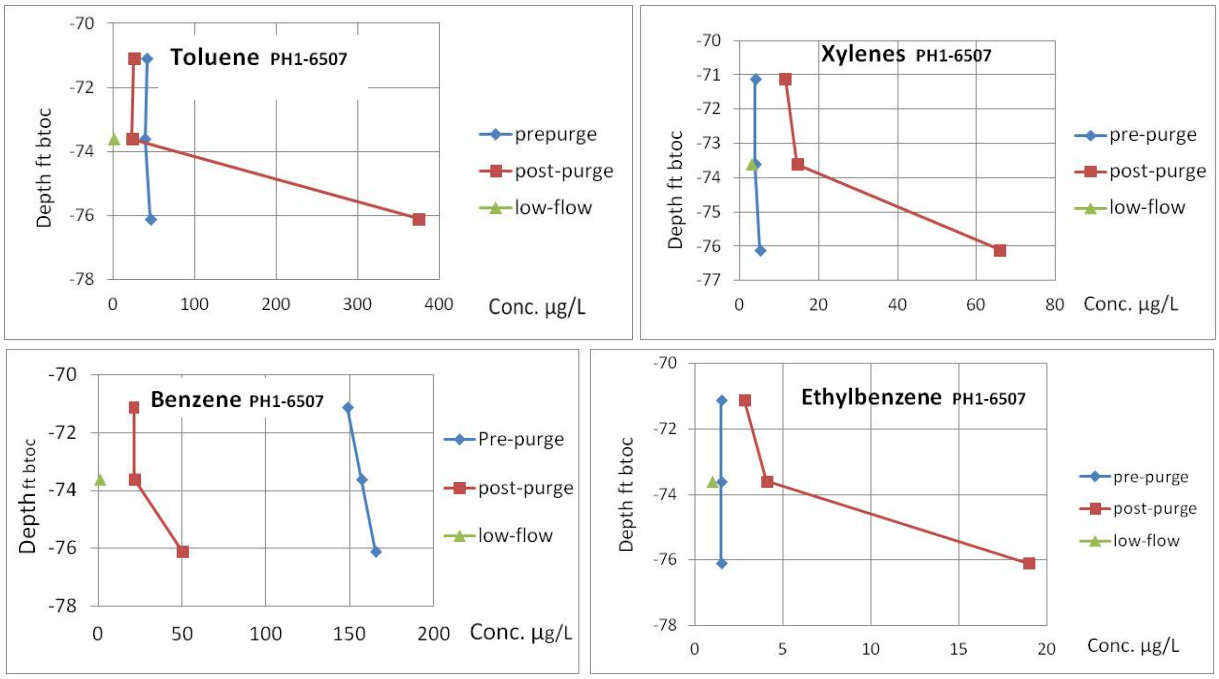


Figure 66. Contaminant profiles in well PH1-6507 for toluene, the xylenes, benzene, and ethylbenzene.

Analyses of the low-flow samples revealed that none of these analytes were found at concentrations that exceeded the detection level. For two analytes (XYLs and EBNZ), low-flow concentrations agreed most closely with concentration values for the pre-purge GORE samples even though it appears that purging the well brought in more highly contaminated water for these two analytes in the lowest portion of the well. (When we checked our sampling log, we found that this is one of the few instances where the post-purge sampling was not conducted until the following morning.) Because this was a downgradient well and we expected low concentrations of these analytes, we left the GORE Modules in the well for 2 hours. Once again, we see that by using a longer contact time for the GORE Modules, we detected low levels of several analytes that were not detected using the current sampling and analytical methods used for the low-flow samples.

7.3.1.5 Wells PH2-6627 and PH2-6628

PH2-6627 and PH2-6628 are located downgradient in the shallow overburden and are considered sentry wells; so once again, we left the GORE Modules in the well for the longer 2-hour period. When low-flow sampling was used, concentrations of TOL, EBNZ, XYLs, 124TMB, and 135TMB were below the detection limit; and the concentration of NAPH was at the detection level. In contrast, the GORE Modules detected these analytes at concentrations well above the detection level. Unlike the previous wells, there was no indication of any substantial contaminant stratification for any of these analytes either before or after purging (Fig. 67). Again, by using a longer contact time for the GORE Modules, we were able to detect several analytes that were not detected when conventional low-flow sampling and analyses were used.

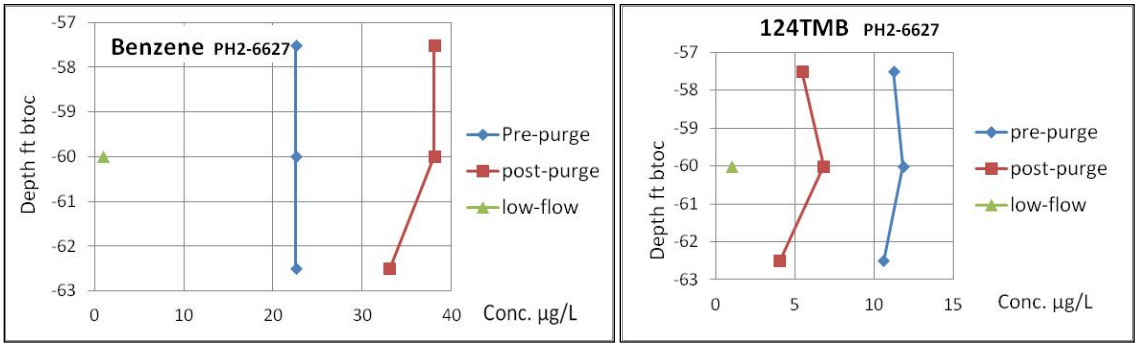


Figure 67. Contaminant profiles in well PH2-6627 for benzene (left) and 124TMB (right).

7.3.2 Pit 6

7.3.2.1 Well HY2-4460

HY2-4460 is a source well that is located in the shallow overburden. As we have seen in other wells near a source, there was a pronounced concentration gradient with depth in this well. Concentrations were considerably lower for the shallowest sampler than for the two deeper samplers (Fig. 68). For the pre-purge samplers, concentrations were generally highest for the bottom-level sampler; this was also true for the post-purge samplers for BNZ and TOL. For the remaining analytes, the mid-level post-purge samplers had the highest concentrations.

Generally, the post-purge GORE data agreed better with the low-flow data than did the pre-purge data. For most of the analytes (EBNZ, XYLs, 124TMB, 135TMB, and *n*-propylbenzene), post-purge concentrations were highest in the mid-level GORE sampler and agreed best with low-flow concentrations. These data indicate that purging the well brought in water with generally higher concentrations, most likely from the same source that is interrogated by the mid-level GORE Module. The exception to this was TOL where low-flow concentration was near the detection limit and agreed best with the shallowest post-purge Module.

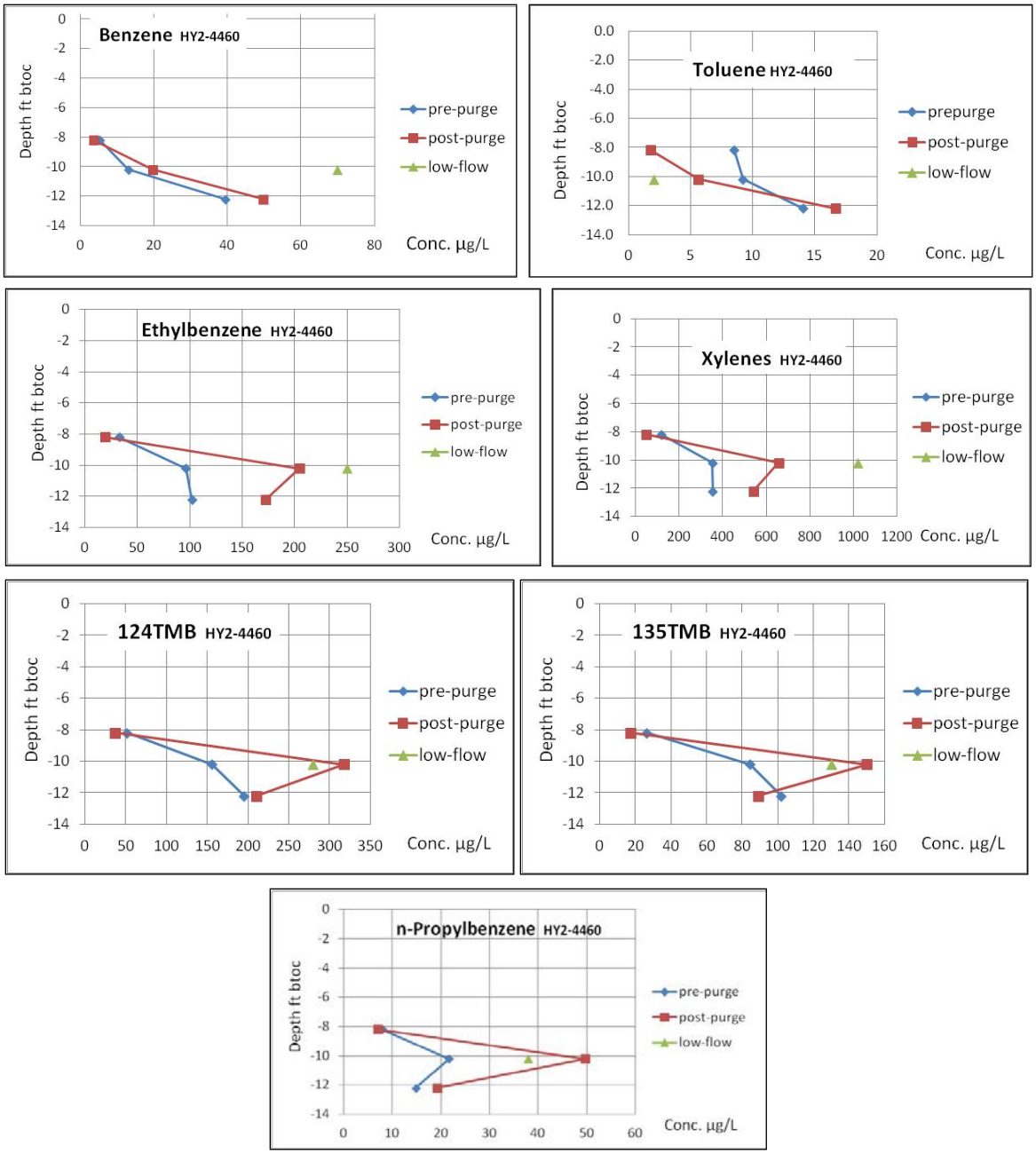


Figure 68. Contaminant concentrations with depth in well HY2-4460 for benzene, toluene, ethylbenzene, the xylenes, 124TMB, 135TMB, and *n*-propylbenzene.

7.3.2.2 Well PH2-6659

PH2-6659 is a downgradient, deep bedrock well. Concentrations of all the analytes were below the detection level when low-flow sampling was used (Fig. 69). However, when the GORE Modules were used, we found concentrations well above the detection level for most analytes (BNZ, TOL, EBNZ,

XYLs, undecane, 124TMB, 135TMB, NAPH, and methylnaphthalene) (Fig. 69). Because this well was also a down-gradient well, these samplers were left in the well for a longer contact time. Once again, with a longer contact time, we see that we are able to detect low levels of contaminants with the Modules that we were not able to detect with the sampling and analytical methods used with low-flow purging and sampling. For this well, the contact time varied between the pre-purge and post-purge samples. The pre-purge samplers were left in the well for 2 hours and the post-purge samplers were left in the well for 1 hour. However, the difference in these two contact times did not seem to consistently bias analyte concentrations in one direction or the other (i.e., some analyte concentrations were sometimes higher in the pre-purge samples while for other analytes, the opposite was true). Before the wells were purged, concentrations were substantially higher in the midsection for TOL, EBNZ, and XYLs. However, after we purged the well, concentrations of these analytes were virtually the same at all three depths. This indicates that purging mixed any stratification that was previously present in the well.

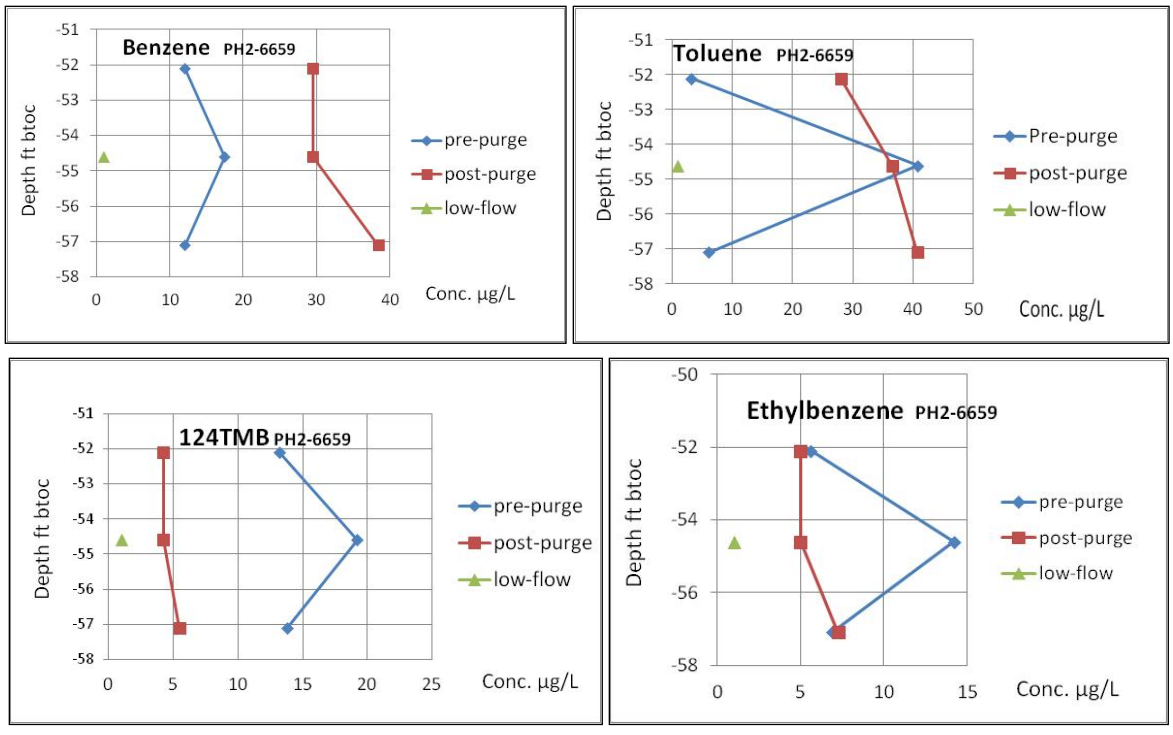


Figure 69. Contaminant concentrations with depth in well PH2-6659 for benzene, toluene, 124TMB, and ethylbenzene.

7.3.2.3 Summary

For both source area wells, there was a pronounced stratification in the wells that was not affected by purging. For some analytes, agreement between concentration values for the GORE Modules and low-flow sampling was best for the deepest Module. For other analytes, agreement was best if the concentration values for the two lowest Modules were averaged. For one of the downgradient, bedrock wells (from Pit 5), there also was a pronounced concentration gradient in the well that was not affected by purging.

For the other source well, located in the shallow overburden, agreement with low-flow sampling was better for the post-purge sample than for the pre-purge sample. For some analytes, agreement with low-flow sampling was best for the mid-level sample while for other analytes, agreement was best for the deepest sampler.

For the remaining downgradient wells, the GORE Modules consistently detected significant concentrations of most of these analytes. For two of these wells there was pronounced stratification prior to purging but not after purging. For another downgradient well there was no stratification prior to purging the well but there was after purging. For two sentry wells (downgradient of Pit 5), there was no stratification in the well either before or after purging. In contrast, none of these analytes were detected using low-flow sampling. This is a significant finding in that by using the GORE Modules there appears to be an enhanced capability to detect low-level contamination when compared with low-flow sampling, even though the MDLs are similar for most analytes (Table 15).

7.4 Conclusions for the former Pease AFB site

Contaminants that we detected in at least some of the wells by using both sampling technologies (i.e., the GORE Modules and low-flow sampling) included VOCs and some SVOCs. These analytes included BNZ; TOL; EBNZ; XYLs; NAPH; 124TMB; 135TMB; isopropylbenzene; *p*-isopropyltoluene; and 1,2-dibromoethane. Also, we were able to detect three analytes with the GORE Modules that could not be detected using the conventional 8260B analyses for VOCs. These analytes included undecane, 2-methylnaphthalene, and octane.

At this site, the detection capability of the GORE method was generally comparable to the analytical method used for the low-flow samples for most of the analytes (e.g., BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, and NAPH) with equivalent MDLs (Table 15). For the remaining analytes (*n*-butylbenzene, *n*-propylbenzene, isopropyltoluene, isopropylbenzene, and 1,2-dibromoethane), the MDLs were higher for the GORE Modules than the analytical method used for the low-flow samples (Table 15).

With one exception (1,2-dibromoethane), the GORE Modules were able to provide data that was well below the action level. Specifically, the detection level was below *one-tenth* of the EPA's MCLs for drinking water (US EPA 2011). This was also true for TCE (although the low-flow samples were not analyzed for TCE), and this demonstrates an improved sensitivity than that found at the previous test site. These lower quantitation limits meets regulatory guidelines such as that of the EPA (2005) who recommend in their *Quality Assurance Project Plan Manual* that the quantitation limit should be no greater than one-third of the action limit and ideally one-tenth of the action limit.

The reproducibility of the replicate samples was good (i.e., met our guideline) for most of the analytes found at this site. We found reproducibility was poorest in three of the wells where the depth below the water table for the samplers was 40 ft or more and the samplers were left in the well for more than 2 hours. It may be that 2 hours was too long a contact time, especially given the sampling depth; that one sampler was in a more preferential pathway with respect to incoming water; or that purging the well changed the flow pattern in the well, which led to poorer reproducibility.

We compared the data for the mid-level samplers and the data for the mean concentrations for the three samplers (at three depths) with the data for the low-flow samples. In all cases but one (mid-level post-purge samplers for BNZ), there was a statistically significant linear relationship between the GORE data and the low-flow data. This relationship was typically one to one, with the exception of TOL (where the slope was about 0.3). This relationship was slightly better for the mean data than for the mid-level data for almost all the analytes (with one exception 135TMB). For many of the analytes, there was slightly better agreement between the post-purge and low-flow data than the pre-purge and low-flow data. However, these differences were not statistically significant.

Although there was generally good agreement between the GORE data and the low-flow data, plots of the GORE Modules with depth showed that there was pronounced stratification of some analytes with depth in some of the wells. This was especially true for the wells near a contaminant source. For those wells, the pattern of stratification was not changed by purging. However, in one of the source wells, purging brought in higher concentrations of contaminants; and therefore, the post-purge data agreed better with the low-flow data. In other wells, purging brought in cleaner water.

With respect to where to place the passive samplers within the well screen, for some wells there was good agreement between the mid-level sampler and the low-flow concentrations; and thus, placement of the sampler at the midpoint of the well screen would be advisable. However, in other instances, purging brought water into the well from a zone that was not interrogated by the mid-level sampler; and thus, low-flow analyte concentrations agreed best with the upper or bottom sampler. Low-flow sampling collects a sample that is a flow-weighted average for the well. The degree of flow weighting depends upon the permeability of the formation, well construction (filter pack, screen size, screen length, etc.), and the presence of concentration or temperature gradients in the water (from different zones) entering the well. Thus, the mid-level sampler did not always best represent analyte concentrations obtained by low-flow sampling. Also, in at least two wells (PH1-6507 and PH2-5369), the mid-level sampler did not provide the highest concentrations of contaminants in the wells, which is important to regulators.

The differences in contaminant concentrations with depth explain some of the scatter in the data when we plotted the GORE data against the low-flow data These differences also explain why for some wells the mid-level sampler agreed better with the low-flow data while in other cases the mean concentration of the samplers (for the three depths) yielded better agreement with the low-flow data.

We also found that in many instances we were able to detect low concentrations of contaminants by using the GORE Modules but not by using the low-flow sampling methods and analyses, even though those concentrations found using the Modules were well above the detection level for the low-flow samples. These differences resulted in considerable scatter in the

plots at the detection level for these two methods. While we realize that in some instances the RSD was greater than the desired 20%, especially for some samples that were left in the wells for 2 hours or more, there is more than enough data to show that this trend is real (i.e., the GORE Modules were able to detect concentrations of analytes below the MDL for the analytical method used for the low-flow samples). However, in these cases, perhaps the uptake was no longer in the linear portion of the uptake curve; and the actual concentrations may be less than were reported.

8 Performance Assessment

The primary success criteria for this demonstration were that the GORE Module could provide equivalent (or better) plume delineation and analyte sensitivity when compared with low-flow purging and sampling, that the method has good reproducibility, and that using this method would result in a substantial cost avoidance or cost savings (preferably at least 20%). Table 16 outlines these criteria, and they are discussed below.

Table 16. Performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Equivalent or better plume delineation with Module vs. low-flow sampling	Low-flow concentration data and GORE concentration data with depth in wells	• Equivalent or better (lower level) analyte sensitivity	APG site: • The MDL for GORE method was below the MCLs. However, it was ~20x greater than the low-flow MCL. Pease site: • For most analytes, equivalent MDLs with low-flow sampling. • GORE MDLs were $^{1}/_{10}$ of the EPA's MCLs. • In many instances, low concentrations were detected with the Modules (with good reproducibly) but not with low-flow sampling.
		• Statistical tests of data (paired t-test, RM-ANOVA, or similar non-parametric tests at 95% confidence level) reveal no significant difference	APG site: • Significant differences for several analytes. Pease site: • Generally no significant differences; poorest agreement was with BNZ and XYLs.
		• Linear least fit model shows linear relationship with a slope that is not significantly different from 1.0	At both sites: • Statistically significant linear relationship between the GORE and low-flow data, typically with a slope of 1.0. • Instances where the slope was not 1.0 were TetCA and CLF at the APG site and TOL at the Pease site. Revision of the algorithm for these analytes may be able to correct this.

Performance Objective	Data Requirements	Success Criteria	Results
		• Vertical profile of wells with GORE Modules	• Vertical profiles revealed. • Pronounced concentration gradients in wells near plume epicenters, even in a well with a 5 ft screen. • Mid-level Modules did not always yield best agreement with low-flow data. • Highest concentrations of contaminants not always found in mid-level sample.
Reproducible data	Replicates	• RSD equivalent to 20%	APG site: • Generally good (70% to 90%) agreement for most analytes (i.e., RSD <20%); agreement poorest in 3 shallow wells. Pease site: • Generally good agreement; agreement poorest for 3 wells where Module depth was more than 40 ft or more below water table and contact time was 2 hours or more.
		• Good agreement between analyses by different laboratories	APG site: • Excellent agreement between labs for all analytes, except possibly pentadecane. No data for Pease site.
Reduced sampling cost	Records of sampling time, equipment costs, waste disposal, and other costs associated with both sampling methods	• A minimum of a 20% cost savings	APG site: • Cost savings of 18% to 35%, depending upon the size of field crew. Pease site: • Cost savings of 10% to 25%, depending on size of field crew. For both sites: • Cost savings heavily dependent upon cost of Modules. • Cost savings of 30% to 40% using newer price quote for Modules.
Qualitative Performance Objectives			
Ease of use	Feedback from field technician on usability of technology and training time needed (required)	• Samples are easy to collect • Samplers work as described • A single field technician can conduct the sampling • Minimal training required	• Samples were easy to collect. • Samplers worked as described. • Only one person was needed to collect these samples. • No special training was needed.

Performance Objective	Data Requirements	Success Criteria	Results
Technology robustness	Written records during sampling	• No issues with the strength, sampling depth (below water table), or durability of samplers	• No issues with strength or durability of samplers. • May be an issue with water intrusion for samplers left in well more than 2 hours when samplers are >30 ft below the water table.
Scale-up constraints	Observation of issues that would limit or require modification for large scale use	• Lack of significant issues preventing large-scale use of GORE Modules	• We did not find any significant issues that would prevent large-scale use of the GORE Modules.

8.1 Equivalent or better plume delineation

8.1.1 Sensitivity of method

For the analyses at the APG site, the MDL for the analytical method used for the low-flow samples was approximately one-twentieth of that of the method used for the GORE Modules. That is, for the low-flow samples, the detection limit generally was 0.2 µg/L; and for the GORE Modules, it was 4.4 µg/L. The detection levels for the Modules were below the action level (i.e., the EPA's MCLs) for these contaminants. However, given that some agencies require or recommend quantitation limits that are one-third to one-tenth lower than the action levels and that the analytical method for the Modules was not able to obtain that low a detection capability, we suggested to the Gore Laboratory that they should continue work to lower detection capability for this technology.

Following our recommendation, the Gore Laboratory continued to work on lowering the detection capability. Subsequently, at the Pease site we found that the detection capability of the GORE method was comparable to the analytical method used for the low-flow samples for most of the analytes (i.e., the MDLs were equivalent). This was true for BNZ, TOL, EBNZ, XYLs, 124TMB, 135TMB, and NAPH. However, for the remaining analytes (*n*-butylbenzene; *n*-propylbenzene; isopropyltoluene; isopropylbenzene; and 1,2-dibromoethane), the MDLs were still higher for the GORE Modules than the analytical method used for the low-flow samples. For those analytes where there was good agreement between the detection capabilities of the two methods, the GORE Modules provided data that was below *one-tenth* of the EPA's MCLs for drinking water. This was also true for TCE, and this demonstrates the improved sensitivity of the analyses of the Modules since the work conducted at the APG test site.

At the Pease site, we also found that in many instances we detected by using the GORE Modules low concentrations of contaminants that were not detected by using low-flow sampling, even though the concentrations were well above the detection levels of the low-flow sampling method. In several instances, these findings were confirmed by replicate sample data. Overall, these differences and differences in the MDLs for the two methods resulted in considerable scatter at the detection levels between these two methods. This is an area that we believe needs additional study.

8.1.2 Agreement between analyte concentrations for the GORE and low-flow data

At both sites, we compared the data for the mid-level samplers and the data for the mean values for the Modules (at the three depths) with the data for the low-flow samples. In most instances, we found that there was good to excellent agreement between the two sampling methods. Specifically, at the APG site there was a strong, statistically significant linear relationship between the GORE data and the low-flow data for all the analytes (i.e., PCE, cDCE, TCE, TetCA, and CLF). For PCE, cDCE, and TCE, this relationship was typically one to one (i.e., the slope of the line for the plotted data was not significantly different from 1.0). For two analytes (TetCA and CLF), we found that the slope of the line was significantly less than 1.0 (about 0.6 and 0.7, respectively). We had thought that perhaps the post-purge data would agree better with the low-flow data than the pre-purge data, but we did not find this to be the case.

For the Pease site, when the data for the mid-level samplers and the data for the mean concentrations were compared to the data for the low-flow samples, in all cases (but one) there were statistically significant linear relationships between the GORE data and the low-flow data; and the slopes of these line were not significantly different from 1.0. These relationships were slightly better for the mean data than the mid-level data. The poorest agreement was for the mid-level BNZ data. The slope of the line for TOL was significantly less than 1.0 (0.3). For many of the analytes, there was slightly better agreement between the post-purge and low-flow data than between the pre-purge and low-flow data. However, these differences were never statistically significant.

8.1.3 Vertical profiles of wells with GORE Modules

While the lack of statistically significant differences and the presence of statistically significant linear agreements between the low-flow sampling data and the GORE data were criteria we used to evaluate the GORE sampling method, it is important to remember the following: although low-flow purging and sampling is the current industry standard, it is not known whether that sampling method or any sampling method yields results that accurately reflect analyte concentrations in the formation. This is not surprising given the disturbance caused during drilling and the relatively large diameter of most wells. Therefore, it is important to understand the conceptual differences of each sampling technology when interpreting the data from this demonstration or at any site where a similar comparison is made.

Typically, low-flow purging and sampling methods yield water that is mixed over the length of the well screen; the degree of mixing is primarily a function of the permeability of the zones in the formation where the screen is located and the pumping rate. Purging the well until the purge parameters stabilize is designed to pull fresh water into the well and thus to provide fresh water from the aquifer (as opposed to collecting water from the stagnant casing).

In contrast, the GORE Module collects a sample in the well screen and relies on water flowing through the well screen to provide fresh water to the sample. Flow through the well screen may be horizontal and laminar, or there may be mixing in the well bore and screen. The degree of mixing in the well and well bore again is a function of the hydrogeology of the formation where the screen is located, well construction (including the length of the well screen, screen size, and filter pack materials), differences in contaminant concentrations (in water coming from different strata in the formation or from within the well), and temperature differences (in water coming from different strata in the formation or from within the well). Therefore, depending upon the flow patterns in the well, the GORE Module data can reflect stratification of contaminants with depth within the well screen. In contrast, the low-flow samples are pulled from the most permeable part of the formation and reflect a concentration value that results from any mixing that has occurred with purging.

Although there was generally good agreement between the GORE data and the low-flow data at both sites, we found that there was pronounced stratification in analyte concentrations with depth in some wells. This stratification was greatest at the epicenters of the plumes and even occurred in a well with a 5 ft screen.

There were instances where the low-flow concentrations agreed best with the mid-level GORE Modules. However, there were other instances where purging brought water into the well from a zone that was not interrogated by the mid-level sampler; and thus, low-flow analyte concentrations agreed best with the upper or bottom sampler. In some cases, either the upper or lower Module had much higher concentrations than the mid-level sampler. Also, the post-purge samples agreed best with the low-flow concentrations in some wells while in other wells, the opposite was true. These findings have implications when selecting a sampling method (i.e., when considering whether to use a passive method or a pumped method and also when trying to decide where to place a passive sampler in the well screen).

8.2 Reproducible data

8.2.1 Reproducibility of the GORE Modules among replicate field samples

Another important objective for this demonstration was that the GORE-Module method could yield good precision. We set as a guideline that the RSD should be 20% or less or equal to (or better than) the %RSD for the low-flow samples.

At the APG site, reproducibility was generally good. For TCE, TetCA, and BNZ, at least 90% of the replicate samples met the guideline; and at least 70% of the replicates for PCE, cDCE, and CLF also met the guideline. It was noted that at this site, most of the poor reproducibility occurred in three of the shallowest wells that had screens near the top of the water table. Since these samples were collected after purging the well, we believe that purging may have lowered the water table sufficiently to affect reproducibility. This would *not* be a concern in the normal use of the GORE Modules because wells are not purged with this sampling method.

At the Pease site, the reproducibility was very good for most (nine) of the analytes where at least 80% of the samples met the guideline. The repro-

ducibility of three other analytes (BNZ, EBNZ, and XYLs) was not quite as good: 60% (or more) of these samples met the guideline. For TOL, the reproducibility was poor; and only 35% of the replicate samples met the guideline. However we noted that, like the Aberdeen site, the poor reproducibility was primarily associated with samples collected from a few of the wells. Three of these wells were very deep wells, and the water table was at least 40 ft above where the Modules were placed. Also, these samplers had been left in the well for more than 2 hours. It is known that water can penetrate the membrane at these depths, and this is accounted for in the model used to calculate analyte concentrations. It may be that when samplers are left in the well for longer periods at these depths, reproducibility is affected; or it may be that the algorithm needs some minor modification.

8.2.2 Agreement in the analyses of the GORE Modules among different laboratories

While we were not able to obtain a contract lab for the independent analyses of the Modules from Pease AFB, we were able to do so at the APG site. At this site, there was good agreement between the analyses conducted by the Gore Laboratory and the contract laboratory for all the analytes found at this site (with the possible exception of pentadecane). Because each GORE Module contains a duplicate packet of sorbents, samples with questionable results can be rerun without having to go back to the field to collect additional samples. Given that the samples can be rerun months later if need be (since the shelf life is three months rather than days), this could be a cost saver.

8.3 Reduced sampling cost

Another primary objective was that this sampling device provides a minimum cost savings of 20% when compared with conventional low-flow purging and sampling. This will be discussed in more detail in the next section. However, using the initial quoted price, cost savings ranged from 18% to 35% at the APG site and from 10% to 25% at the Pease site, depending upon whether the field crew consisted of one or two individuals. Using a more recent price quote from Gore, cost savings would be greatly improved and would range from 30% to 45% at APG and from 30% to 40% at the Pease site.

8.4 Ease of use

Our field crew found that these samplers were easy to use. The project's principal investigator (PI) was amazed to see how many wells could be sampled in a day when the pumping associated with low-flow sampling was eliminated. The only complaint we had was that we had been instructed by the Gore crew that when blotting the samples, to be sure to carefully remove any residual water. We found it hard to remove the residual water from under the tag with the serial number on it.

8.5 Robustness of the technology

The samplers worked as designed although there were some concerns with samplers left for more than 2 hours if they were placed more than 30 ft below the water table.

Because there is very little ancillary equipment associated with this technology, it is robust. Unlike low-flow sampling, there are fewer handling and safety concerns, such as possibly spilling gasoline, keeping the power cord from the generator dry in the rain, keeping the samples cold in the field and during shipping, and packing the coolers to prevent leaking during shipping.

8.6 Scale-up constraints

We do not foresee that there would be any scale-up constraints that would prevent wide-scale use of this technology.

9 Cost Assessment

9.1 Cost model

One of the objectives of this demonstration was to determine the potential cost avoidance or cost savings associated with using the GORE Modules vs. using conventional low-flow purging and sampling methods. The cost models used in these analyses include the initial site work, initial capital costs, sample collection costs, costs associated with sample processing and analyses, and expected long-term operation and maintenance costs. We based the cost estimates for each site on specifics for the site (e.g., the depth of the wells) and information gathered during work at the site (e.g., the average purge time for a well, average set-up time, clean-up time, etc.). We made the following assumptions:

- Each site has 50 monitoring wells.
- The wells are to be sampled quarterly over a period of 10 years.
- The low-flow sampling is conducted with dedicated bladder pumps.
- The average sampling depth for the wells determines the length of the tubing or sampling line needed to sample the site.
- The labor rate for members of the field crew is $50 per hour.
- A day is 8 hours (to avoid overtime charges).
- Travel expenses are not included.
- Low-flow sampling uses a crew of two.

9.1.1 Cost model for the GORE Modules

Table 17 gives the cost model for the GORE Modules. Initial site work for the GORE Modules is relatively minimal and includes labor for purchasing equipment and supplies and for preparing the sampling lines for deployment in the wells. The major initial capital cost is the purchase of a water-level and temperature probe. Other less costly expenses are the sample lines, reusable weights (to keep the Modules at the desired deployment depth), plastic sheeting (for laying out the sampling line to measure it), sprayers for decontaminating and rinsing the water-level probe, and a small drum for holding the wastewater from cleaning the water-level probe.

Table 17. Cost Model for the GORE Modules.

Cost Element	Data Tracked During the Demonstration	Costs	
(1) Initial startup	• Labor: initial planning fieldwork, purchasing equipment and supplies • Labor measuring lines for deployment	Field personnel	$50/ hr
	• Equipment and supplies: one-time purchases (50 wells)	Water-level and temperature meter	$1364/ea
		Sampling line, 225 ft	$3/role
		Stainless weights	$24/50
		Decon buckets	$5/ea
		Sprayer for decon	$9/ea
		Plastic tarp	$13/ea
		Drum for waste water	$40/ea
(2) Quarterly sampling costs	• Samplers	GORE Modules	$190/ea
	• Labor: sampler installation and retrieval, water level and temperature readings, site cleanup	Field personnel	$50/hr/person
(3) Sample processing and analyses	• Shipping	Samplers to lab	$15/ box
	• Analytical costs	Included in purchase price	$0
(4) Operations and maintenance	• Replace equipment and supplies	Sampling line, 225 ft	$3/role
		Water level and temperature meter	$1364/ea
		Sprayer for decon	$9/ea
		Tarp	$13/ea
		Drum for waste water	$40/ea
(5) Long-term monitoring costs	• Total Costs, no inflation	(a) Annual sampling cost	Sum
		(b) Total costs after 1 year	Sum of start-up costs and annual sampling cost
		(c) After 10 years	= #5b + (9 × #5a)
	• Cumulative Costs, using OMB's* 2.25% annual inflation	After 1 year	= #5b
		After 2 years	= #5b + (1.0225 × #5a)
		After 10 years	Cumulative sum based upon compounded interest

*OMB is the White House's Office of Management and Budget

Website: www.whitehouse.gov/omb

Quarterly sampling costs include the cost of the GORE Modules; the labor for one person to take the water level and water temperature measurements, to deploy the samplers in the well, and to decontaminate the water-level meter; and the labor for another person who follows later and retrieves the samplers and cleans up the site. By using two people to sample the wells, the wait time for the deployment period or the time needed to return to the well after the recommended deployment time is essentially eliminated. We believe that this would be the most efficient method to collect these samplers, especially given the typically short deployment times (15 minutes to 1 hour), and thus would increase the number of wells that can be sampled in a day.

The primary sample processing and analyses costs include a small amount of labor to fill out the chain-of-custody forms and to box up the samplers and the cost of shipping the samples via regular mail. No ice is needed to ship the samples; and no special handling for shipping, such as over-night delivery, is needed because the samplers are stable for approximately three months. Also, there is no separate cost associated with the laboratory analyses; this cost is included in the purchase price of the Modules.

Operation and maintenance costs would primarily be for the purchase price of these items. Anticipated replacement items include the sampling lines, plastic waste drums, decontamination equipment, tarps, and eventually replacing the water-level and temperature probe. There would be a small amount of additional labor associated with ordering replacements and measuring out the sample lines.

9.1.2 Cost model for low-flow sampling

Table 18 gives the cost model for low-flow sampling. The labor costs for initial site work include purchasing equipment, setting up a contract for laboratory analyses, and deploying the pumps in the wells and purging them. (Initial purging of the well is advisable; this will allow the field crew to confirm that the pumps are working, and it allows time for the materials in the pumps to equilibrate with analytes in the well water thereby reducing potential losses of analytes due to sorption.)

Table 18. Cost Model for low-flow sampling.

Cost Element	Data Tracked During the Demonstration	Costs	
(1) Initial startup	• Labor: initial planning fieldwork, purchasing equipment and supplies • Labor: installation of equipment in wells	Field personnel	$50/hr/person
	• Major equipment and supplies: one-time purchases (50 wells)	Bladder pump	$684/pump
		Tubing (49 ft roll)	$116/roll
		Generator	$1100/ea
		Air compressor	$180/ea
		Pump controller	$2260/ea
		Water quality meter	$3650
		Turbidity meter	$1100
		Flow-thru cell	$300/ea
		Water-level meter	$575/ea
		Coolers	$100/ea
	• Assorted other smaller equipment and supplies	Purge buckets, decon equipment, gas cans, moisture traps, GFI power strips, rain canopy, table, chairs, waste drum, etc.	Actual costs
(2) Quarterly sampling costs	• Materials and supplies		Actual costs
	• Labor: sampling 50 wells and waste disposal	Field personnel	$50/hr/person
(3) Sample processing and analyses	• Labor: sample preparation	Field personnel	$50/hr/person
	• Express shipping	Per cooler	Actual costs
	• Miscellaneous supplies	Ice, plastic bags	Actual costs
(4) Operations and maintenance	• Labor: purchase, repair, and replace equipment; purge wells with new equipment	Field personnel	$50/hr/person
	• Repair/replace equipment	Meter for purge parameters	$3650/ea
		Turbidity meter	$1100/ea
		Water-level meter	$575/ea
		Generator	$1100/ea
		Compressor	$180/ea
		Bladder pumps	$684/ea
		Pump controller	$2650/ea
		Coolers	$100/ea
		Waste storage drums	$60/ea
		Tubing	$116/roll

Cost Element	Data Tracked During the Demonstration	Costs	
(5) Long-term monitoring costs	• Total Costs, no inflation	(a) Annual sampling cost	= #2 + #3 + (#4/10)
		(b) Total costs after 1 year	= #5a (above) + #1
		(c) Total after 10 years	= #5b + [9 × (#5a)]
	• Cumulative costs, using OMB's 2.25% annual inflation	Year 2 year	= #5b + (1.0225 × #5a)
		After 10 years	Cumulative sum based on compounded interest

With respect to the initial capital costs, there is a considerable amount of equipment that must be purchased for low-flow purging and sampling. This includes dedicated pumps and tubing, generators, controllers, extension cords, air compressors, air hose, purge parameter equipment and initial supplies, decontamination equipment, waste buckets, and storage drums for purge water. The number of each of these items that is needed depends upon the number of sampling crews that are deployed at the same time.

Sampling costs include labor and some supplies. Labor costs include packing up equipment and materials needed for sampling; filling coolers with ice; setting up the needed equipment on site, including calibration of the equipment; purging the well until the purge parameters stabilize; collecting the samples; decontaminating the water-level meter and purge parameter equipment; disposing of decontamination and purge water; and site cleanup. Supplies include gasoline, deionized water for decontamination, purge parameter supplies (standards), ice, detergent, Drierite desiccant, etc.

Analytical costs are the primary cost associated with sample processing and analyses. Other costs include the labor needed to pack the coolers and complete the chain-of-custody forms. The other major cost would be for shipping the coolers and ice. We have found that it is becoming increasing more difficult to use express carriers to ship coolers that contain water samples and loose ice. Typically, these carriers now will only accept the coolers if the water samples and ice is double packed in ziplocked plastic bags. Even with double bagging the samples and ice, one of the carriers told us that in the future they would also require customers to sign a document accepting financial responsibility for any damage caused by coolers that leak.

Operation and maintenance costs include replacing tubing (which would tend to crack with use, especially at the top of the wells); replacing and repairing the pumps, purge-parameter equipment, and water-level meter; and replacing coolers.

9.2 Cost drivers

The major cost drivers are the following:

- The sampling time for low-flow sampling and for the GORE Modules, especially the number and size of the field crews
- Equipment costs for low-flow sampling
- Cost of GORE Modules
- Analytical costs for low-flow sampling

These will be discussed in more detail in the next section (9.3).

9.3 Cost analysis

9.3.1 Cost analysis for sampling at APG

Tables 19 and 20 provide the estimated costs for sampling using the GORE Modules and low-flow sampling, respectively, at a site similar to the SBR site at APG.

Although, the cost analysis for low-flow sampling was based upon the assumption that dedicated bladder pumps would be used in each well, the wells at this site are relatively shallow and could be sampled using a peristaltic pump (with tubing dedicated to each of the wells). Therefore, we also completed a cost analysis assuming that peristaltic pumps with dedicated tubing were used to collects samples at this site. The number of peristaltic pumps needed would vary depending on the number of field crews collecting the samples.

There are areas at this site where there are a lot of wells that are close together, and that would speed up the sampling time especially for low-flow sampling. However, there are other wells that are remote and are located in relatively heavy brush. For those wells, access is more difficult; and more time is needed to sample these wells. Typically, the most common practice in the industry for low-flow sampling is to use a team of two individuals at each well. This assumption was used in determining the cost of

low-flow sampling, provided in Table 20. While using two people to sample a site is the safest procedure (in case of injury) and there are time savings associated with set up and tear down of a site, the time spent purging the well is typically more than a half hour and does not require two individuals. Therefore, we conducted cost analyses based upon a field crew that consisted of two individuals and also based also upon two field crews (of one individual each) that would sample the site simultaneously. Because many laboratories will negotiate on the price of analyses and offer their services at a reduced cost, we also conducted a cost analyses for low-flow sampling assuming that the analytical costs were lowered by 10% (for the APG site) or 15% (for the Pease site). We also calculated what the LTM costs would be if some of the wells had to be redeveloped or rehabilitated.

For the GORE Modules, we determined the LTM costs initially using the most recent price quoted to us. We then conducted additional cost analyses using the original price estimate that we received from W. L. Gore. We also calculated what the LTM costs would be if some or all of the wells had to be redeveloped or rehabilitated, and we determined what the costs would be if the price of the Modules were to be further reduced (from the most recent price quote) as a result of large-scale production of the Modules.

For the GORE Modules (Table 19), we determined that 99.75% of the total 10-year LTM cost is associated with the sample collection phase; and of that cost, the price of the samplers is approximately 85%, and labor (sampler deployment, retrieval, etc.) is the other 15%. In contrast, the initial start-up costs, sample processing and analyses costs, and costs for Operations and Maintenance (O&M) are essentially negligible with this method (i.e., the costs for each of these were less than 0.4%).

Table 19. LTM costs associated with using the GORE Modules at the APG site.

Cost Element	Data Tracked During the Demonstration	Details	Cost ($)
(1) Initial startup	Labor: planning purchases and measuring lines for fieldwork	$50/hr/person, 11 hr total	550
	Sampling equipment and supplies	Water-level and temperature meter	1364
		Line	18
		Stainless weights	98
		Decon equipment, buckets, storage drum, etc.	76
		Equipment subtotal	1556
	Total costs for startup	**Initial startup subtotal**	**2106**
(2) Quarterly sampling	Labor: deploying and retrieving samplers, water-level and temperature measurements, site cleanup	36.6 hr total	1832
	Samplers and supplies	55 samplers and supplies	10,462
	Total costs for sampling	Quarterly sampling subtotal	12,294
		Annual sampling subtotal	**49,176**
(3) Sample processing and analyses	Labor: processing samples	0.33 hr total	16
	Shipping		15
	Analyses		0
	Total costs for sample processing and analyses	Quarterly sample processing and analyses subtotal	31
		Annual cost	**125**
(4) Operations and maintenance	Equipment replacement	Water-level and temperature meter	1364
		Line, tarp, storage drum, sprayer for decon	89
	Total costs	O&M subtotal for 10 years	1453
		Annual O&M subtotal	**145**
(5) Long-term monitoring	Total costs, no inflation	Annual sampling cost	49,301
		Cost after Year 1	51,406
		Cost after Year 10	496,564
	Cumulative costs, assuming OMB's 2.25% annual inflation average	After Year 1	51,406
		After Year 10	**538,911**

In contrast, for low-flow sampling (

Table 20), the start-up costs account for about 7% of the total LTM costs for 10 years; and the sampling equipment (dedicated pumps, purge equipment, etc.) accounts for 87% of that amount. Sample collection accounts for 45% of the total LTM costs; and of that amount, 93% is labor. Laboratory analyses account for another 25% of the total LTM costs, and the O&M costs are only about 3% of the total LTM costs. We believe that these figures agree with what most practitioners believe (i.e., that low-flow purging and sampling is a labor-intensive and costly sampling method and that although dedicated sampling equipment is expensive, it is only a small amount of the total LTM costs. We calculated that the equipment accounts for only 9% of the total LTM costs (which was determined by combining equipment costs for initial start up and for O&M).

Table 21 presents the cost estimates based upon the modifications that we mentioned previously. Table 22 shows the cost avoidance or cost savings that can be achieved with the various scenarios.

By examining Table 22, we see that by using the original (higher) price quote for the Modules and using the conventional team of two individuals to sample the wells, the cost savings is about 35%, which is well above the desired goal of a 20% cost savings. However, if two teams (of one individual each) were used to sample the site using low-flow sampling, the cost savings for the Modules would only be about 18%, which is just slightly below the desired 20%. This indicates that the price of the Module is a critical element for cost savings to occur. Clearly, having to recondition either all or some of the wells would reduce the cost savings below the desired goal.

Table 20. LTM costs associated with using low-flow sampling at the APG site*.

Cost element	Data Tracked During the Demonstration	Details	Cost ($)
(1) Initial startup	Labor: planning purchases and initial fieldwork	One crew of 2 individuals at $50/hr/person, 176.8 hr total	8840
	Dedicated sampling equipment and supplies	Bladder pumps, tubing, cable, controller, etc.	42,540
		Purging equipment	5781
		Gas-powered generator	1100
		Other	11,762
		Equipment subtotal	61,183
	Total costs for startup	**Initial startup subtotal**	**70,023**
(2) Quarterly sample collection	Labor: packing, setting up site, calibrating, purging, sampling, cleaning up site, and disposing of purge water	One crew of 2 individuals at $50/hr/person, 205.9 hr total	10,295
	Supplies	Gasoline, Drierite, standards for purging, etc.	730
	Total costs for sampling	Quarterly sampling subtotal	11,025
		Annual sampling subtotal	**44,100**
(3) Sample processing and analyses	Labor: processing samples	18 hr total	900
	Supplies and shipping		1983
	Analyses		6050
	Total costs for sample processing and analyses	Quarterly sample processing and analyses subtotal	8933
		Annual cost	**35,732**
(4) Operations and maintenance	Equipment replacement	Sampling equipment (pumps, tubing, cable, controller, etc.)	11,203
		Purging equipment	9645
		Gas-powered generator	1650
		Compressor	288
		Coolers, storage drums, etc.	5221
		Equipment subtotal	28,007
	Labor	Purchasing and repairing equipment	800
		Installing replacement equipment, purging wells	1275
		Labor subtotal	2075
	Total costs	O&M subtotal for 10 years	28,007
		Annual O&M subtotal	**2801**
(5) Long-term monitoring	Total costs, no inflation	Annual sampling cost	79,833
		Cost after Year 1	141,016
		Cost after Year 10	892,185
	Cumulative costs, assuming OMB's 2.25% annual inflation average	After Year 1	141,016
		After Year 2	22,645
		After Year 10	**978,102**

*Based upon a field crew of two individuals.

Table 21. Total LTM costs for the APG site based upon different assumptions for sampling at the site.

Sampler	APG 10-year Cost
Original estimate for the GORE Modules	$630,566
Low-flow (LF) sampling, 2 teams using bladder pumps (BPs)	$767,565
LF, 1 team using BPs	$978,102
New estimate for Modules	$538,871
LF, 2 teams using peristaltic pumps (PPs)	$737,563
LF, 1 team using PPs	$939,804
New estimate Modules, recondition *all* wells	$541,814
New estimate Modules, recondition *some* wells	$540,646
Further reduced price for Modules, less 20%	$448,215
LF, 2 teams (BPs), recondition *some* wells	$769,025
LF, 1 team (BPs), recondition *some* wells	$979,562
LF, 2 teams (PPs), with 10% lower analytical cost	$697,256

Table 22. Cost savings for LTM using GORE samplers at the APG site based upon different assumptions about work at the site.

Comparison	% of LTM Cost	% Cost Savings
Original Gore estimate/2 teams (BPs)	82.2	17.8
Original Gore estimate/1 team of 2 (BPs)	64.5	35.5
Original Gore estimate/LF, 1 team peristaltic	67.1	32.9
Original Gore estimate/LF, 2 teams peristaltic	85.5	14.5
New Gore estimate/LF, 2 teams (BPs)	70.2	29.8
New Gore estimate/LF, 1 team (BPs)	55.1	44.9
New Gore estimate/LF, 2 teams (PPs)	73.1	26.9
New Gore/LF, 1 team (PPs)	57.3	42.7
New Gore, recondition *all* wells/LF, 2 teams (BPs)	70.6	29.4
New Gore, recondition *some* wells/LF, 2 teams (BPs)	70.4	29.6
New Gore, recondition *all* wells/LF 1 team (BPs)	55.4	44.6
New Gore, recondition *all* wells/LF, 2 teams (BPs), recondition some wells	70.5	29.5
20% lower Gore/LF, 2 teams (BPs)	58.4	41.6
New Gore/LF, 2 teams (pps), with 10% lower analytical cost	77.3	22.7
LF, 2 teams (BPs)/LF, 1 team of 2 (BPs)	78.5	21.5
LF, 2 teams: peristaltic pumps vs. bladder pumps	96.1	3.9
LF, 1 team: peristaltic pumps vs. bladder pumps	96.1	3.9

If peristaltic pumps were used on the site (instead of bladder pumps) for low-flow sampling of the wells, we see that the cost savings for the Modules are now only 21% and 14% based upon using two and one low-flow team, respectively.

However, when we use the more recent price quote for the Modules, the cost savings are substantially greater, approximately 30% and 45% compared with using two low-flow teams and one low-flow team, respectively. Using peristaltic pumps for low-flow sampling only decreases these cost savings by a few percent. Reconditioning either some or all of the wells with the Modules still provides nearly 30% cost savings, even when compared with the more cost-effective option of using two teams to collect the low-flow samples.

However, it is more likely that at least some of the wells where low-flow sampling is used would also require reconditioning. In this case, the cost savings for the Modules would be about 30% (again assuming that two low-flow teams were used). If the laboratory gave a 10% discount on the price of the analyses for the low-flow samples, the cost savings for the GORE Modules would still be over 20%.

In conclusion, as long as the more recent price provided by W. L. Gore is used in these analyses, this technology can provide a cost savings of 25% to 45% at this site when compared with low-flow sampling.

9.3.2 Cost analysis for sampling at the former Pease AFB

Tables 23 and 24 show the estimated costs for sampling with the GORE Modules and low-flow sampling (using a team of two), respectively, a site with similar conditions to those found at the former Pease AFB. Most of the assumptions made for the cost analyses at the APG site hold for this site as well. However, one of the differences with this site is that most of the wells were too deep to use a peristaltic pump, so we did not conduct any cost analysis that considered peristaltic pumps. For this analysis, we assumed two field crews (each consisting of one person).

Table 23. Cost estimate for LTM using the GORE Modules at the former Pease AFB site.

Cost Element	Data Tracked During the Demonstration	Details	Cost ($)
(1) Initial startup	Labor: planning purchases and measuring lines for fieldwork	$50/hr/person, 11 hr total	550
	Sampling equipment and supplies	Water-level and temperature meter	1364
		Line	36
		Stainless weights	98
		Decon equipment, buckets, storage drum, etc.	86
		Equipment subtotal	1574
	Total costs for startup	**Initial startup subtotal**	**2124**
(2) Quarterly sample collection	Labor: deploying and retrieving sampler, taking water-level and temperature measurements, cleaning up site	34.6 hr totals	1732
	Samplers and supplies	55 samplers and supplies	10,4774
	Total costs for sampling	Quarterly sampling subtotal	12,206
		Annual sampling subtotal	**48,824**
(3) Sample processing and analyses	Labor: processing samples	0.33 hr total	16
	Shipping	Regular mail	15
	Analyses		0
	Total costs for sample processing and analyses	Quarterly sample processing and analyses subtotal	31
		Annual cost	**125**
(4) Operations and maintenance	Equipment replacement	Water-level and temperature meter	1364
		Line, tarp, storage drum, sprayer for decon	107
	Total costs	O&M subtotal for 10 years	1471
		Annual O&M subtotal	**147**
(5) Long-term monitoring	Total costs, no inflation	a) Annual sampling cost	48,949
		b) Cost after Year 1	51,072
		c) Cost after Year 10	493,080
	Cumulative costs, assuming OMB's 2.25% annual inflation average	After Year 1	51,072
		After Year 10	**545,935**

Table 24. Cost Estimate for LTM using low-flow sampling at the former Pease AFB site.

Cost Element	Data Tracked During the Demonstration	Details	Cost ($)
(1) Initial startup	Labor: planning purchases and initial fieldwork	One crew of 2 individuals at $50/hr/person, 211.8 hr total	10,590
	Dedicated sampling equipment and supplies	Bladder pumps, tubing, cable, controller, compressor, etc.	44,910
		Purging equipment	5851
		Gas-powered generator	1100
		Other	3052
		Equipment subtotal	54,913
	Total costs for startup	**Initial startup subtotal**	**65,503**
(2) Quarterly sample collection	Labor: packing, setting up on site, calibrating, purging, sampling, cleaning up site, and disposing of purge water	One crew of 2 individuals at $50/hr/person, 207.4 hr total	10,370
	Supplies	Gasoline, Drierite, calibration standards for purge parameter meter, etc.	730
	Total costs for sampling	Quarterly sampling subtotal	11,100
		Annual sampling subtotal	**44,401**
(3) Sample processing and analyses	Labor: processing samples	16.8 hr total	840
	Supplies and shipping	Ice, plastic bags, shipping, etc.	1354
	Analyses		6050
	Total costs for sample processing and analyses	Quarterly sample processing and analyses subtotal	8244
		Annual cost	**32,975**
(4) Operations and maintenance	Equipment replacement (over 10 years)	Sampling equipment (pumps, tubing, cable, controller, compressor, etc.)	13,251
		Purging equipment	10,100
		Gas-powered generator	1760
		Coolers, storage drums, etc.	3294
		Equipment subtotal	26,645
	Labor (over 10 years)	Purchase/repair equipment, 16 hr	800
		Install replacement equipment, purge wells, 25.5 hr total	1275
		Labor subtotal	2075
	Total costs	O&M subtotal for 10 years	28,720
		Annual O&M subtotal	**2872**
(5) Long-term monitoring	Total costs, no inflation	Annual sampling cost	77,376
		Cost after Year 1	142,879
		Cost after Year 10	867,980
	Cumulative costs, assuming OMB's 2.25% annual inflation average	After Year 1	142,879
		After Year 10	**956,042**

For low-flow sampling, routine costs include labor for sampling and the cost of supplies. Labor includes time for field set up, purge parameter stabilization, sampling time, decontamination of the water-level meter and purge parameter equipment, disposal of decontamination and purge water, reordering supplies, site cleanup, and packing and shipping sample coolers (including chain-of-custody forms). Supply costs will include calibration solutions for purge parameter meters, fuel for the generator, etc.

Table 25 shows the total LTM cost for sampling at this site based upon whether the low-flow field crew consisted of one or two individuals, whether the original or more recent price quote for the Modules is used, whether all of the wells needed to be reconditioned with the GORE Modules, whether some of the wells would also need reconditioning with low-flow sampling, and if the analytical cost for the low-flow samples was reduced by 15% (for example).

Table 25. Total LTM costs for the former Pease AFB based upon differing assumptions.

Sampler	10-Year Cost
Original Gore estimate	$736,341
LF, 2 teams	$820,370
LF, 1 team	$956,042
New estimate for Modules	$581,732
Previous estimate reduced by another 20%	$489,139
New estimate for Modules and reconditioning all wells	$596,380
LF, 2 teams, reconditioning some wells	$839,659
LF, 1 team, reconditioning some wells	$963,342
LF, 1 team, −15% analytical	$915,837
LF, 2 teams, −15% analytical	$787,401

Table 26 presents the cost savings that could be achieved at this site by using the GORE Modules based upon the various scenarios given in Table 25. Based upon the original estimate for the GORE Modules, the cost savings would be slightly more than 20% vs. using a single team of (two individuals) for low-flow sampling. However, if two field crews (of one individual each) are used for low-flow sampling, the cost savings for the GORE Modules is only 10%.

Table 26. Cost savings for LTM using GORE samplers at the Pease site based upon different assumptions about work at the site.

Comparison	% Cost	Cost Savings %
Original estimate Gore/LF, 2 teams	89.8	10.2
Original estimate Gore/LF, 1 team	77.0	23.0
New estimate for Gore/LF, 2 teams	70.9	29.1
New estimate for Gore/LF, 1 team	60.8	39.2
New Gore estimate, recondition *all* wells/LF, 2 teams	72.7	27.3
New Gore estimate, recondition *all* wells/LF, 1 team	62.4	37.6
New Gore estimate, recondition *all* wells/LF, 2 teams recondition *some* wells	71.0	29.0
Lower (by 20%) Gore estimate/LF, 2 teams	59.6	40.4
New Gore estimate/LF, 1 team −15% analytical	63.5	36.5
New Gore estimate /LF, 2 teams −15% analytical	73.9	26.1

When the more recent (newer) price estimate is used for the GORE Modules, the cost savings become 30% and 40% when compared with two and one low-flow sampling teams, respectively. Even if all the wells with the GORE samplers had to be reconditioned, these cost savings would only be a few percent lower, and would be well above the desired 20%. The same is true if the field crew could obtain a 15% cost savings on the analytical costs for low-flow sampling. Also, if the manufacturer were able to reduce the cost of the Modules by, for example, another 20% (as a result of mass production of the Modules), the cost savings would increase from 30% to 40% (based on the assumption that two low-flow teams conducted the sampling at this site).

9.3.3 Summary of cost analyses for both sites

These cost analyses show that for the use of the GORE Modules to be desirable from a cost perspective (i.e., cost savings greater than 20%), the price of the Modules needs to be about $190 per sampler (i.e., the newer price estimate). With that price for the Modules, the field crew can achieve a cost savings of 30% to 45%, depending on the size of the crew used for low-flow sampling. Unlike low-flow sampling where the majority of the cost is associated with labor, the majority of the cost for the GORE technology is associated with the purchase price of this sampler, which also includes the analytical costs.

10 Implementation Issues

Although this demonstration has shown that analyte concentrations of GORE Modules samples generally agree well with low-flow sampling and that this technology can provide substantial cost savings, there are several other issues that we need to address to promote greater acceptance of this technology.

10.1 Regulatory issues

10.1.1 Regulatory issues with passive sampling

A survey sent to the ITRC's state points of contact in 2007 found that at that time, there were some regulatory barriers (i.e., statutes, regulations, or guidance) that either prohibited or impeded the use of passive sampler technologies (ITRC 2007). Of the 16 states responding to the survey, 25% believed their state prohibited the use of passive sampling technologies because they required either three-well-volume purging or low-flow purging and sampling. Other states required that the wells be purged although they do not necessarily specify how or to what extent they must be purged. This also would preclude using passive sampler technologies. However, all the states appeared receptive to passive sampling although they tended to lean towards requiring an on-site demonstration to verify their reliability. New Jersey was the only responding state that has published guidance on using a specific passive sampling technology for groundwater.

To broaden knowledge of passive sampling and to address regulatory concerns, the ITRC Passive/Diffusion Sampling Team published several guidance documents on various passive sampling technologies: two documents on the use of PDB samplers for sampling VOCs (Vroblesky 2001; ITRC 2004); an overview document on fourteen passive sampling technologies, which includes the GORE Modules (ITRC 2006); and a protocol document on the use of five passive samplers, which also includes the GORE Modules (ITRC 2007). All of these documents are available for free on the ITRC website (http://www.itrcweb.org/). The ITRC also provides on their website an archived copy of the free internet training class they offered previously on using these five sampling devices.

More recently, the ASTM D.18.21.04 team (that focuses on sample collection for groundwater monitoring) has developed a standard guide on the selection of passive sampling techniques; this standard has been recently revised and is currently in the balloting process.

10.1.2 Regulatory concerns with the GORE Modules

With respect to the GORE Modules, two of the primary concerns with this technology have been regulatory acceptance of the analytical method and the conversion of the mass data to concentration values. In September 2010, the Gore Laboratory became accredited to ISO/IEC* 17025, DOD ELAP, and NELAC quality standards for EPA Method 8260C (Appendix B). Also, very recently, they were able to add their concentration capabilities to that accreditation. Appendix B provides a list of the analytes this applies to. The Gore chemists are also working with ASTM to develop a standard method of generating concentration data from passive sampling methods.

Our demonstration has shown that the reproducibility of this method is generally good. We found that that there were two situations where the reproducibility was not as good. The first situation was at the APG site when we deployed the samplers in wells after low-flow purging and sampling had been conducted, and the top of the screens in these wells was just below the water table. We suspect that purging the well may have lowered the water table enough that it was just above or below the top of the screen. However, this would not be an issue normally when the Modules are used because the well would not be purged and the water level would be determined prior to deploying the samplers.

The other instances where we encountered poor precision were at the Pease site where the sampler was placed more than 32 ft below the water table and was then left for more than 2 hours. It is not clear what caused the poor precision in these instances. Therefore, until the Gore chemists have had a chance to work further on this issue, we would recommend that the samplers be deployed for no more than 90 minutes in wells where there will be more than 32 ft of head above the sampler.

* ISO/IEC International Organization for Standardization and International Electrotechnical Commission

The final issue that we feel needs to be addressed is how to treat the data that is near the detection limit. Although the MDL for the GORE Method and low-flow sampling were equivalent for most analytes, there were numerous instances (at the Pease site) where the GORE Modules detected concentrations of analytes that were above the MDL but that were not detected by the method used to analyze the low-flow samples. With the data that we have, it is hard to know which sampling method yielded more accurate or truer concentrations at these low-levels. However, in many cases, replicate samplers yielded similar results. This would indicate that the Modules are able to detect lower levels of some analytes. It may be that the concentrations are lower than was reported because the contact time was no longer in the linear uptake portion of the curve.

10.2 End-user concerns

For the most part, the GORE Module sampling method appears to be a reliable, easier, less expensive sampling method than low-flow sampling of VOCs and SVOCs. However, the use of these samplers is limited to those analyte types. Therefore, if a user has a site with other analyte types, they may want to continue to use a low-flow sampling, which has broader analyte capability, or they may want to consider using a passive-equilibrated grab sampler, such as the Snap Sampler.

Also, the Modules cannot be used for all VOCs. According to data presented by W. L. Gore (Appendix B1), analytes that are highly soluble, such as MTBE, tend to be desorbed too rapidly to be accurately quantified. Also, we would recommend working closely with the Gore chemists if using these samplers to detect low concentrations of analytes where the sampler will be more than 32 ft below the water table. We assume that the algorithm will undergo some modifications and improvements with time as more analytes are studied and there is more data to compare. We would recommend that users be careful that they measure the water temperature at the sampling depth in wells rather than near the surface since temperature can affect concentrations values. This would be especially important in wells where the sampling depth is 30 ft or more below the water surface.

One of the concerns with the use of this technology has been whether an independent laboratory can be used for the analyses of the samples. While the analytical method used by the Gore laboratories is EPA 8260C, the

method used for desorption is proprietary at this time. Therefore at this time, any lab wishing to conduct these analyses would have to develop this portion of the method. It is not clear whether this portion of the method will become available in the future. However, if a user wants to have another laboratory conduct the analyses, the manufacturer would have to modify the purchase price of the Modules because the current price includes the analyses; and it would not be economically feasible to pay for another laboratory to analyze the samples when the analyses have already been paid for.

The cost savings associated with this technology depends primarily upon the pricing used for the GORE Modules. Currently, to obtain cost savings of 30% to 45%, the price of the Modules would have to be $190 or less. (This price would be expected to increase with inflation.) Because this method does not use much equipment, the long-term O&M costs are low.

A final concern is whether wells that are sampled with passive samplers will need to be reconditioned more often than wells that undergo active sampling, such as low-flow purging and sampling. While this may be a concern, others in the industry would argue that wells where low-flow sampling is used may actually require more frequent redevelopment because of the fines brought into the well with each sampling event. In either case, our cost analyses show that even if the wells did need to be redeveloped more often with the GORE Modules, it could still be cost effective to use this technology.

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Appendix A: Points of Contact

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Bette Premo	White Water Associates, Inc. 429 River Lane, PO Box 27 Amasa, MI 49903	Voice: 906-822-7889 bette.premo@white-water-associates.com	Analysis of low-flow samples for APG
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Appendix B: Additional Information on Gore Analyses and Certification

The following document was provided by W. L. Gore &Associates, Inc. The only changes to the text were some changes in format and minor editorial changes.

Appendix B1: Summary of sampling rate calibration for GORE SPG-0008 Modules in aqueous phases

Purpose

The purpose of this document is to (1) summarize the test protocol, (2) summarize the methodology for analysis of data, and (3) present general results for generating concentration calibration of the GORE® Module, SPG-0008, in aqueous phase media following Gore's "Standard Practice for Determining the Sampling Rate of Passive Diffusion Samplers in Various Environmental Media": SPG-SOP-0493. The work will be summarized in three parts—Part 1: shallow water, Part 2: deep water, and Part 3: sediment.

Principle of operation of the GORE Module

The GORE® Module is designed with solid adsorbents enclosed inside a tubular microporous PTFE membrane. When placed in water, the pores and hydrophobic nature of the PTFE keep liquid water from entering the membrane until a water head of about 34 ft is reached. The membrane will not keep water vapor from entering, but the adsorbents are very hydrophobic and through testing validated to be unaffected by this moisture vapor. In shallow water, <34 ft, volatile and semi-volatile compounds will partition from the dissolved water into the air phase in the PTFE membrane according to Henry's Law. This partitioning is instantaneous; and within seconds to minutes, the compound is adsorbed by the adsorbent inside the sealed tube. Because the diffusivity in air is about 10,000 times higher than the diffusivity in water, the sampling rate is controlled by the water contact area of the membrane that allows the Henry's Law effect to

occur. This contact area is set by the membrane diameter and length of the sealed tube, which is fixed in Gore's manufacturing process.

Henry's law as well as diffusivity, which are fundamentally incorporated into the sampling rate, are affected by temperature, T, and follow an Arrhenius equation

$$H_T = H_r \times \exp([-E_a/R](1/T_r - 1/T)).$$

Because a 5°C temperature change can make a 15% change in sampling rate, the temperature of the sampled water should be known to get the most precise concentration.

The membrane pore size is also small enough that colloidal particles and microbes cannot pass through the membrane. This keeps the adsorbent from getting contaminated and eliminates any need to add preservative or to chill during storage or transportation.

When the water pressure exceeds the water entry pressure of the membrane, about 34 ft of water, the water comes in contact with the solid adsorbent. Under this condition the compounds in the water will partition from the water into the solid. The partitioning coefficient, K_{AW}, can be approximated by the octanol-water coefficient, K_{OW}, but has been measured more precisely in the lab for Gore's specific solid adsorbent. The sampling rate is the product of the sampling rate at <34 ft of water and the K_{AW}.

In sediment, the sampler measures pore-water concentration, which is generally agreed to be the preferred measurement as it is more indicative of bioavailability. In sediment the volumetric availability of water to the sampler is reduced by the volume fraction solids in the sediment, which typically varies from 0% to 35%, but can be has high at 73% in well packed and broad particle size distribution sediments. As a result, sampling rates in sediment are multiplied by the fraction pore water in the sediment to determine concentration.

Part 1: calibration in shallow water

Part 1 summarizes the work in shallow water generating calibration data, evaluating the physical and chemical factors affecting the sampling rate,

and measurement of the actual sampling rates or regression calibration equations needed to determine concentrations.

Sample generation in water

In this calibration work, solutions of analytes at known concentrations were formulated in clean 4 L smoked glass jugs by injecting micro-liter amounts of environmental standards using a calibrated syringe into pure or deionized water and stirring for a minimum of 2 hours but generally overnight. Headspace in the jugs was minimized and generally less than 1% by volume during the tests. Jugs were temperature controlled by placing them in a water-filled cooler, chilled via a cooper tubing loop in the cooler. Temperature was measured with a certified digital temperature gauge, and an average value used for each temperature experiment.

GORE® Modules were weighted so they would not float and placed in the jugs at time zero. They were removed at various intervals to generate samples along with duplicates that showed mass increasing with exposure time. The Module exposure time was selected to span minutes to hours and was generally reduced for high concentration tests to maintain uptake with time in roughly the linear dynamic range. Modules were removed and dried with a paper towel and returned to their original container for analysis. They were analyzed by GORE 8260C (SPG-WI-318 or SPG-WI-10028) method in duplicate, which is based on EPA SW846 Method 8260C.

Water samples were also taken and measured at an outside accredited lab using EPA SW846 Method 8260B. The concentrations agreed well with the calculated concentrations based on the standard certification, jug volume, and syringe injection. The variability of the outside lab 8260B values were found to be high, so for the sampling rate calculations we used the concentrations based on syringe dosing.

Calibrations were run at five concentrations, nominally at 6, 24, 118, 590, 1420 µg/L and five temperatures nominally at 5°C, 10°C, 15°C, 20°C, and 25°C. Samples were taken at four different exposure times. Samples were run in duplicate. A total of 176 data points were generated using 28 compounds from Gore's standard compounds list. Tridecane and pentadecane were not evaluated due to their very low solubility in water. In addition, another 23 compounds were tested using an 8260 liquid standard at nom-

inal concentrations of 0.5, 1.0, 5.0, 15, 95, and 470 µg/L at a temperature typical of groundwater, 15°C. This is a living calibration; and as additional data are generated, they may be qualified and added to this data set to improve the precision of the sampling rate calibration and broaden the compound list.

Key variable effects

As expected from theory, at short to moderate exposure times, mass will increase roughly linearly proportional to exposure time, as well as proportional to concentration, and exponentially with temperature following Arrhenius law. Temperature affects the Henry's law as well as diffusivity in water. Sampling rate is generally independent of concentration and time at mass values significantly below saturation. In the following sections we have characterized the sampling rate for each compound as affected by temperature and also developed calibrations using regression, which account for the minor impact of time and mass.

Concentration using Simple Sampling Rate Determination

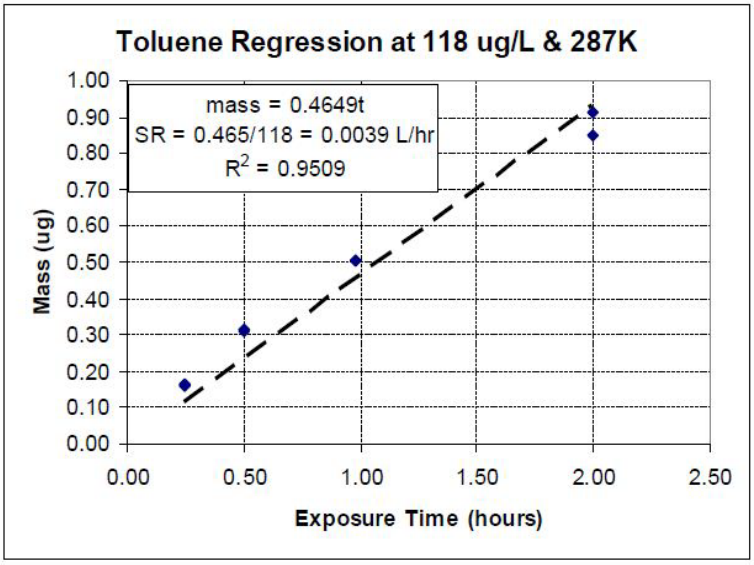
A simple way to determine concentration is to measure mass on the GORE sampler, divide by exposure time, and divide by sampling rate, SR.

$$\text{Conc [ug/L]} = \text{mass/time/SR} \quad (1)$$

The sampling rate can be determined via measurements of mass versus time at a known concentration and temperature according to the following modification of equation (1).

$$\text{SR} = \text{mass/time/concentration} \quad (2)$$

Sampling rates in L/hr were determined by measuring the trend or regression mass uptake versus time and dividing by the concentration. A measurement like this will use eight data points (4 times × 2 samples). Such a sampling rate can be measured at any concentration and temperature.



This figure is a plot of mass versus time for water at 118 ug/L and 287 K. This is actual data from a single run. A slope of 0.465 ug/hr divided by the concentration of 118 ug/L yields a sampling rate, SR, of 0.0039 L/hr.

The SRs typically range from about 0.004 to 0.007 L/hr at 15°C. Table B1 shows SRs measured for our standard compound list at five temperatures.

Rigorous concentration using regression

A preferred method for determining concentration that will yield improved accuracy over a wide range of concentrations, exposure times, and temperatures is to use all data in a regression analysis. This allows adjustments for the minor non-linear influences of mass and time as well as the effects of temperature. This is done by regressing equation (1) or a universal version of equation (1) where

$$\text{Conc} = (\text{mass})^{b} / (\text{time})^{-d} / [-SR_o \times \exp(-Ea/R/T)] \quad (3)$$

The subtle non-linear effects of mass and time will be evident in the deviation of coefficients b and d from 1.0. This regression generates four constants b, d, SRo, and −Ea/R by regressing ln(Conc) versus ln(mass), ln(time), 1/temp. These four constants can be used to determine concentration via the following equation.

$$\text{Conc} = (\text{mass})^{b} / (\text{time})^{-d} / [-SR_o \times \exp(-E_a/R(1/T))] \quad (4)$$

Where conc is in ug/L, mass is in ug, time in hours, T in degrees Kelvin.

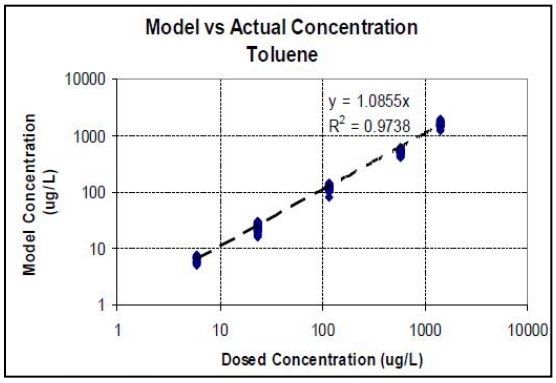
Equation (4) can be also expressed at a reference temperature, Tr, such as 15°C by the following.

$$\text{Conc} = (\text{mass})^{b} / (\text{time})^{-d} / [-\text{SRr} \times \exp(-\text{Ea}/\text{R}(1/\text{T}_r - 1/\text{T}))] \qquad (5)$$

This allows sampling rates, SR_r, at any reference temperature, Tr, and for any analyte to easily be compared. These values of SR_r at 293.14 K can be found in Table B1.

When sampling times are between 0 and 4 hours, using the four-constant equation (5) is preferred. For concentrations from about 5 to 1500 µg/L one hour exposure times generally give the lowest error, typically with average error of 6%–20% and with total error range of 12%–32%.

For low concentrations where sampling times are greater than 4 hours, it is preferred to use equation (1) to avoid unrealistic effects from the coefficient d or to set d to 1.0. In such a case, SR in equation (1) can be substituted with $[SR_r \times \exp(-Ea/R(1/Tr - 1/T))]$ to use an SR representative of the well temperature, T.



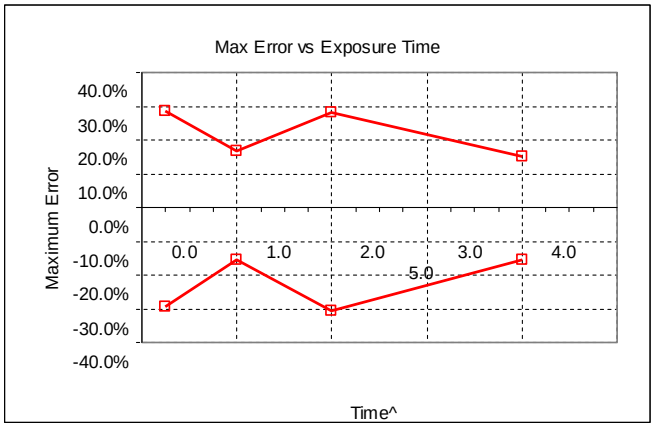
This is a plot of the calculated concentration from the four constant regression compared to the dosed concentration. Agreement is excellent for the 176 data points. There does appear to be a slight high bias of 8.6% over the full range of this data although it is well within acceptable limits of variability.

Table B2 shows the tabulated summary of the four-constant regression (using equation 5) with R_{sq} values and error estimates for the four constants for each analyte. Most regression R_{sq} values are 0.99 or greater for each analyte. In general, $-E_a/R$ is about 2400 +/- 400, b is about 0.9, d is

about −0.75, and SR(15°C) ranges from 0.004 L/hr to 0.007 L/hr, increasing with MW of the compound.

Error estimates

The error in the water concentration values will depend on both the error in mass from the analytical method as well as the error in the concentration calibration. Table B3 shows the error in the mass values from the 8260C low sensitivity method.



The standard error of the regression and standard errors of the constants can be found in Table B2. For each compound we have measured the error between the derived concentration and the actual concentration. The error tends to be lowest at our recommended exposure time of one hour as shown by the example for toluene above.

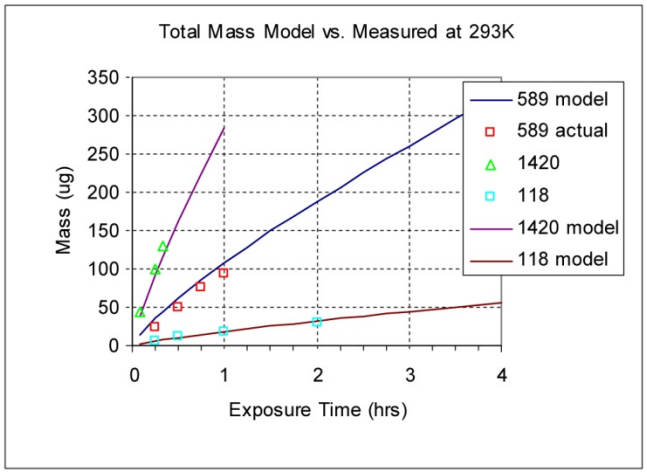
Table B4 shows the total average error in water concentration by compound as well as the low and high error. The average ranges from about 6% to 20%, which is similar to the analytical method errors. The low and high errors range from 12% to 32% and include contribution from measurement errors in both time and temperature.

Sorbent saturation

As the mass increases on a solid sorbent and the sorbent approaches saturation, reverse diffusion can occur, which causes the sampling rate to drop. Eventually, the mass level will reach a maximum steady state value at any concentration. A rate of mass uptake with time that deviates significantly from linear indicates that sorbent saturation could be an issue. When using equation (1), staying in the linear range to avoid the effects of adsor-

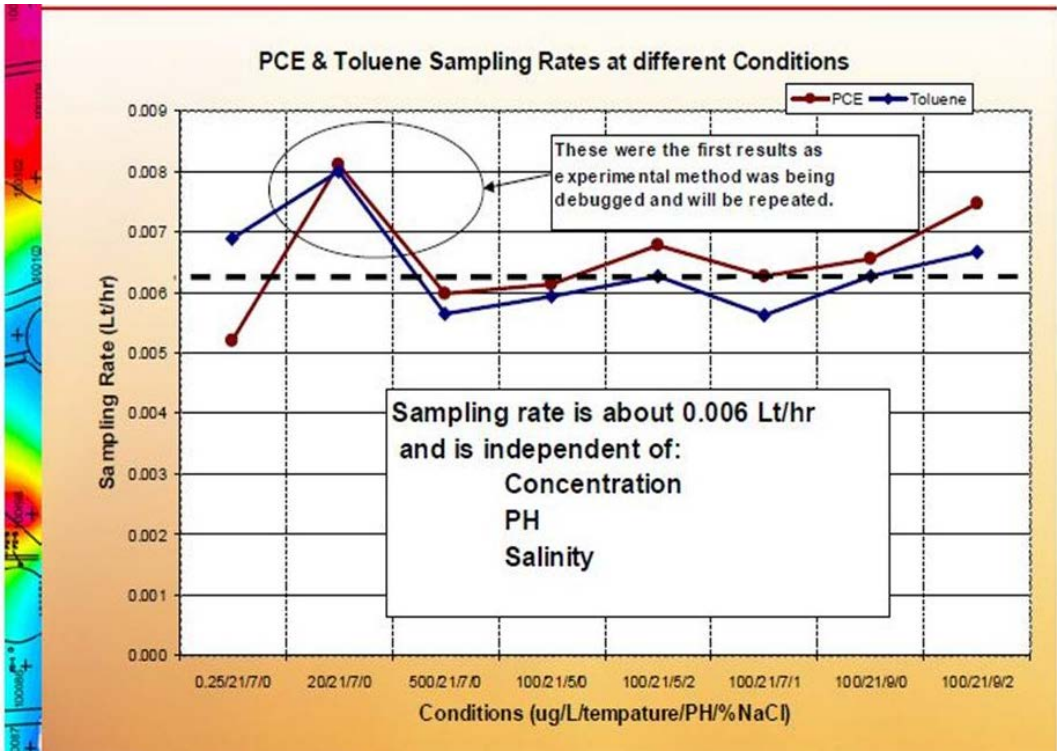
bent saturation is important. We recommend keeping the total mass on the Module below 50 µg or flagging when this is exceeded.

The four-constant regression (eq. 5) accounts for some of the non linearity allowing good accuracy at higher mass levels. From the experimental data we have found this safe range can be extended to 100 µg or higher as shown in the chart below. This chart compares total mass of all compounds (excluding heavy alkanes, which have solubility issues) versus time in comparison to that predicted from the four-constant concentration equation.



Effect of p H and salinity

Because neither pH nor salinity is known to have a significant impact on Henry's law or diffusivity in water, we did not expect them to have a significant impact on sampling rate. To confirm this, experiments were run varying pH from 5 to 9 and NaCl content from 0% to 2%. The chart below shows no significant impact for combinations of pH and NaCl content over this range on the sampling rate of TOL in water at 21°C.



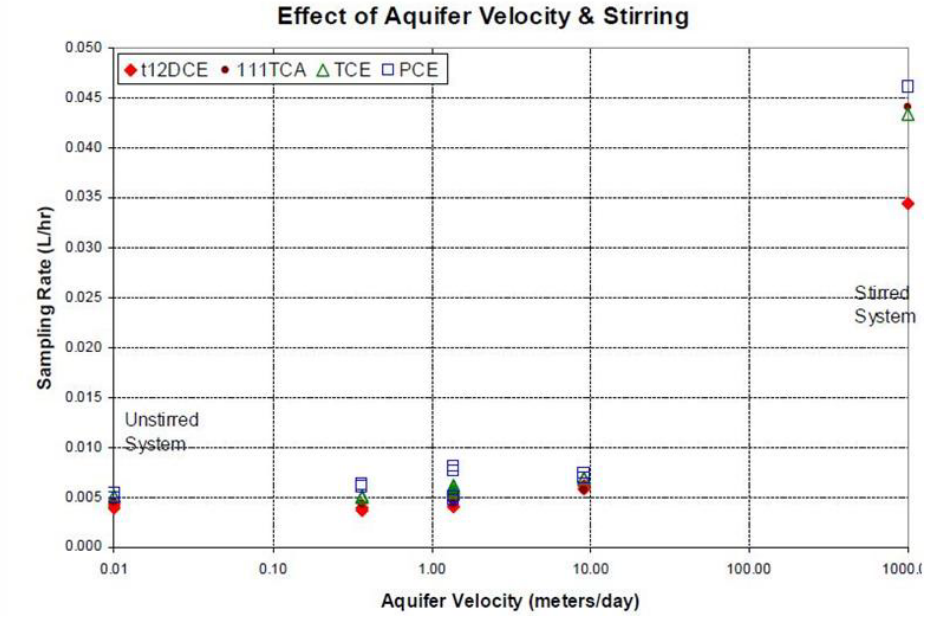
Effect of pH and salinity on sampling rate

Impact of aquifer velocity

The velocity in most aquifers is quite slow, typically a meter per day or less. Occasionally water flow could be much higher such as encountered in karst aquifers, streams, or rivers. Mass transfer coefficients are higher in high flow conditions, which will lead to higher sampling rates. We validated that a highly stirred system had sampling rates about 10 times higher than those that were non-stirred. We decided to evaluate the effect of aquifer velocity.

A test apparatus was built comprising a 3 in. PVC pipe tee filled with clean sand in each of the horizontal straight legs and screened to leave the center open. A test solution was run through this system using a variable flow pump and GORE samplers were placed into the simulated well through the vertical leg of the tee. Tests were run to examine the effect of velocity by varying the pumping rate and hence water velocity.

The chart below shows no significant effect of aquifer velocity up to a speed of about 10 meters/day. At velocities significantly above this, similar to a stirred system, sampling rates are about 10 times higher.

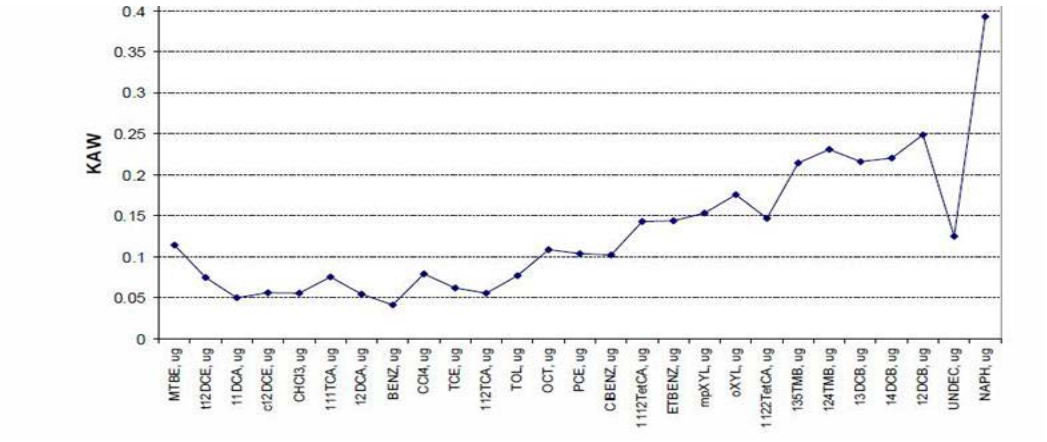


Part 2: calibration in deep (>34 ft) water

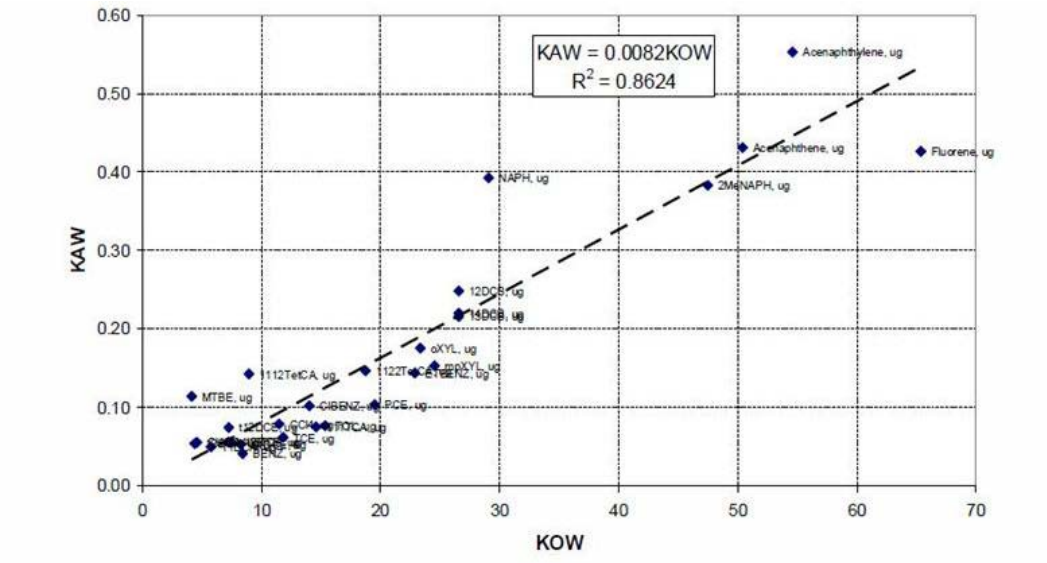
Part 2 describes the effect of deep water on the GORE sampler and summarizes the effects on sampling rate and concentration measurement.

When the water pressure exceeds the water entry pressure of the membrane, at about 34 ft of water, the water comes in direct contact with the solid adsorbent. Under this condition, the compounds in the water will partition from the water into the solid. The portioning coefficient is closely related to the octanol-water partition coefficient, K_{OW}, but has been measured more precisely in the lab for Gore's specific solid adsorbent, K_{AW}. The sampling rate for deep water is the product of the sampling rate at <34 ft of water and the K_{AW}.

Measurement of the K_{AW} was done in a one liter stainless steel vessel pressurized with nitrogen to simulate water heads above 34 ft of water. Pressures of up to 465 psig or 200 ft of water head were used. The sampling rate change was the same at all pressures above 34 ft of water. The K_{AW} was determined as the ratio between the mass or sampling rate above 34 ft of head to the rate at <34 ft of head and is shown in the chart below.



K_{AW} Correction for High Pressure



Relationship between K_{OW} and K_{AW}

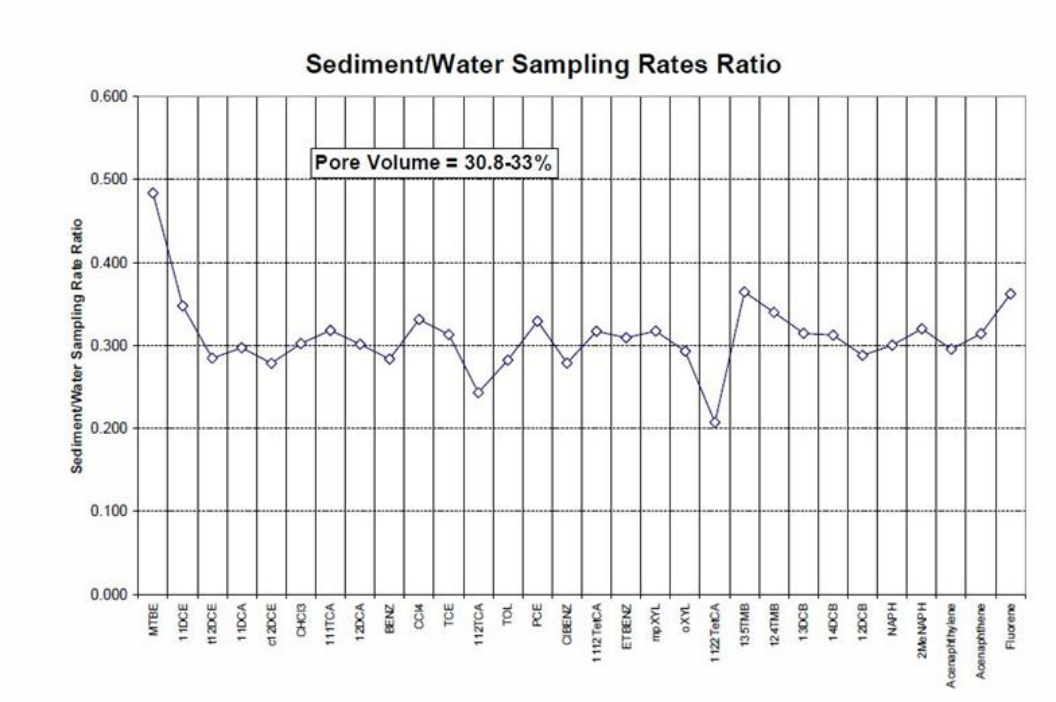
Part 3: calibration in sediment

Part 3 describes the effect of sediment solids or sediment pore volume on the sampling rate and concentration measurement.

In sediment, the sampler measures the pore-water concentration, which is generally the preferred measurement because it is more indicative of bioavailability. In sediment, the volumetric availability of water to the sampler is reduced by the volume fraction of solids in the sediment. As a result, sampling rates in sediment are multiplied by the fraction pore water to determine concentration. The pore-water fraction can range from 1.0 for wa-

ter without sediment to as low as 0.25. Typically, most sediments have pore-water fractions of 0.9 to 0.65.

A sampling rate study was done with water and with water added into a well-packed sorted sand. The pore-water fraction in this test was measured between 30.8% and 33% by volume. Below is a plot of the ratio of sampling rates measured in the sediment to open water. The average ratio is equal to the pore-water fraction, confirming that sampling rate in sediment is on average equal to the product of the pore-water fraction times the sampling rate in water.



Summary

The GORE® Module can be used to determine the concentration of volatile and semi-volatile compounds in a water phase. This requires knowing the exposure time and water temperature. It also requires knowing if the sample is above or below 34 ft of water head and if the water has a velocity above 10 m/day. Regressions of large amounts of data were used to generate a four-constant equation to generate concentration values in water. Potential error in the concentration values is excellent, typically less than 25%.

Table B1. Water sampling rates* standard list.

	SRr 293.14	SR @ 277.54	SR @ 282.44	SR @ 287.84	SR @ 293.24	SR @ 298.94
MTBE	0.0025	0.0014	0.0016	0.0018	0.0022	0.0029
tDCE	0.0043	0.0028	0.0028	0.0027	0.0037	0.0048
11DCA	0.0047	0.0031	0.0033	0.0033	0.0039	0.0052
c12DCE	0.0046	0.0030	0.0031	0.0031	0.0038	0.0051
CHCl3	0.0046	0.0030	0.0031	0.0031	0.0038	0.0051
111TCA	0.0066	0.0043	0.0047	0.0047	0.0056	0.0076
12DCA	0.0045	0.0029	0.0029	0.0030	0.0036	0.0050
BNZ	0.0050	0.0031	0.0034	0.0035	0.0042	0.0056
CCl4	0.0068	0.0044	0.0048	0.0047	0.0058	0.0080
TCE	0.0052	0.0030	0.0034	0.0034	0.0043	0.0058
112TCA	0.0043	0.0027	0.0027	0.0028	0.0034	0.0048
TOL	0.0056	0.0034	0.0039	0.0039	0.0047	0.0062
OCT	0.0064	0.0046	0.0050	0.0040	0.0058	0.0089
PCE	0.0061	0.0036	0.0043	0.0043	0.0051	0.0069
CLB	0.0054	0.0033	0.0039	0.0040	0.0045	0.0059
1112TetCA	0.0061	0.0037	0.0042	0.0044	0.0050	0.0065
EBNZ	0.0060	0.0037	0.0045	0.0044	0.0052	0.0069
mpXYL	0.0064	0.0039	0.0048	0.0046	0.0055	0.0072
oXYL	0.0066	0.0041	0.0050	0.0048	0.0057	0.0074
1122TetCA	0.0044	0.0027	0.0029	0.0031	0.0036	0.0046
135TMB	0.0079	0.0046	0.0059	0.0056	0.0071	0.0093
124TMB	0.0078	0.0046	0.0060	0.0055	0.0071	0.0092
13DCB	0.0072	0.0041	0.0055	0.0053	0.0063	0.0080
14DCB	0.0071	0.0040	0.0054	0.0052	0.0062	0.0079
12DCB	0.0070	0.0040	0.0053	0.0051	0.0060	0.0076
UNDEC		0.0026	0.0024	0.0020	0.0031	0.0029
NAPH		0.0041	0.0056	0.0054	0.0064	0.0081
TRIDEC						
2MeNAPH		0.0043	0.0066	0.0066	0.0080	0.0108
PENTADEC						
Total mass	0.1177	0.0822	0.1339	0.1334	0.1773	0.1981

* Values in L/hr

Total mass does not include UNDEC, TRIDEC, PENTADEC (28 compounds)

Table B2. Constant regression output.

	Adjusted Rsq	Standard Error	ln(SR_0)	b	$-E_a/R$	d	Std Error ln(SR_0)	Std Error b	Std Error −Ea/R	Std Error d
MTBE	0.997	0.0960	−3.217	0.981	2704	−0.709	0.2881	0.0062	83	0.0082
t12DCE	0.992	0.1659	−1.877	0.905	2147	−0.760	0.4971	0.0100	144	0.0138
11DCA	0.995	0.1272	−1.346	0.916	1965	−0.746	0.3809	0.0077	110	0.0106
c12DCE	0.995	0.1299	−1.905	0.911	2137	−0.751	0.3892	0.0078	112	0.0109
CHCl3	0.996	0.1260	−1.841	0.912	2118	−0.748	0.3776	0.0076	109	0.0105
111TCA	0.995	0.1279	−2.684	0.902	2259	−0.761	0.3836	0.0076	111	0.0106
12DCA	0.995	0.1263	−2.161	0.908	2218	−0.746	0.3786	0.0076	109	0.0106
BNZ	0.995	0.1323	−2.207	0.920	2198	−0.754	0.3965	0.0080	114	0.0110
CCl4	0.994	0.1405	−3.121	0.889	2379	−0.776	0.4220	0.0083	122	0.0116
TCE	0.992	0.1655	−3.338	0.900	2522	−0.772	0.4969	0.0099	144	0.0137
112TCA	0.995	0.1264	−2.412	0.896	2302	−0.724	0.3790	0.0075	109	0.0107
TOL	0.994	0.1426	−2.873	0.916	2364	−0.756	0.4281	0.0087	124	0.0119
OCT	0.938	0.4698	−5.984	0.822	3235	−0.827	1.4231	0.0277	412	0.0388
PCE	0.991	0.1773	−3.780	0.877	2601	−0.775	0.5329	0.0103	154	0.0147
CLB	0.994	0.1457	−2.601	0.911	2292	−0.747	0.4370	0.0088	126	0.0122
1112TetCA	0.996	0.1235	−2.676	0.898	2281	−0.725	0.3705	0.0073	107	0.0104
EBNZ	0.993	0.1597	−2.930	0.918	2357	−0.752	0.4794	0.0097	138	0.0134
mpXYL	0.992	0.1678	−3.036	0.909	2372	−0.749	0.5037	0.0101	145	0.0140
oXYL	0.993	0.1555	−2.862	0.911	2312	−0.740	0.4667	0.0094	135	0.0131
1122TetCA	0.996	0.1118	−1.971	0.913	2167	−0.691	0.3351	0.0067	97	0.0096
135TMB	0.988	0.2024	−4.435	0.897	2720	−0.738	0.6093	0.0121	176	0.0170
124TMB	0.989	0.1997	−4.126	0.890	2631	−0.731	0.6009	0.0118	173	0.0169
13DCB	0.991	0.1832	−3.422	0.888	2449	−0.730	0.5503	0.0108	159	0.0155
14DCB	0.991	0.1802	−3.263	0.892	2408	−0.724	0.5413	0.0107	156	0.0153
12DCB	0.992	0.1697	−2.970	0.894	2327	−0.716	0.5092	0.0101	147	0.0144
UNDEC	0.694	0.374	−1.406	0.426	1708	−0.806	1.792	.00.028	517	0.053
NAPH	0.992	0.166	−3.374	0.915	2430	−0.671	0.497	0.010	144	0.014
2MeNAPH	0.984	0.238	−5.498	0.869	2990	−0.689	0.72	0.014	208	0.021
Total mass	0.993	0.1543	−6.111	0.907	2419	−0.732	0.4666	0.0093	134	0.0130

Table B3. 8260C Mass Uncertainty. GORE 8260C Method for Mass using SPG-0008 Modules.

	99% Uncertainty Range +/−	95% Uncertainty Range +/−
MTBE	20%	14%
t12DCE	22%	15%
11DCA	18%	12%
c12DCE	18%	12%
CHCl3	16%	11%
111TCA	18%	12%
12DCA	20%	13%
BNZ	16%	10%
CCl4	19%	12%
TCE	15%	10%
112TCA	18%	12%
TOL	15%	10%
OCT	20%	13%
PCE	16%	11%
CLB	18%	12%
1112TetCA	19%	13%
EBNZ	18%	12%
mpXYL	18%	12%
oXYL	18%	12%
1122TetCA	23%	15%
135TMB	21%	14%
124TMB	20%	14%
13DCB	19%	13%
14DCB	19%	13%
12DCB	20%	14%
NAPH	21%	14%
2MeNAPH	25%	17%

Table B4. Constant water concentration uncertainty. Error in concentration reporting*.

	Average Error	Minimum Error	Maximum Error
MTBE	6%	−12%	12%
t12DCE	11%	−26%	21%
11DCA	8%	−19%	13%
c12DCE	9%	−19%	15%
CHCl3	9%	−20%	14%
111TCA	9%	−19%	23%
12DCA	10%	−19%	17%
BENZ	8%	−18%	13%
CCl4	10%	−23%	22%
TCE	10%	−21%	14%
112TCA	11%	−21%	21%
TOL	7%	−17%	14%
OCT	20%	−41%	42%
PCE	10%	−24%	15%
ClBENZ	7%	−16%	14%
1112TetCA	8%	−17%	18%
EtBENZ	6%	−19%	14%
mpXYL	7%	−22%	13%
oXYL	7%	−19%	13%
1122TetCA	8%	−16%	17%
135TMB	9%	−23%	17%
124TMB	10%	−28%	19%
13DCB	10%	−22%	17%
14DCB	10%	−22%	17%
12DCB	9%	−23%	17%
NAPH	10%	−24%	21%
2MeNAPH	13%	−32%	30%

* For 1 hour exposure, includes error related to mass value from GORE analytical method 8260C

Appendix B2: Certification of the Gore Laboratory

American Association for Laboratory Accreditation

SCOPE OF ACCREDITATION TO ISO/IEC 17025:2005

W.L. GORE AND ASSOCIATES
SURVEY PRODUCTS GROUP LABORATORY
100 Chesapeake Boulevard
Elkton, MD 21921
James Whetzel Phone: (410)-506-4779
jwhetzel@wlgore.com

ENVIRONMENTAL

Valid To: September 30, 2014 Certificate Number: 3062.01

In recognition of the successful completion of the A2LA evaluation process, (including an assessment of the laboratory's compliance with ISO IEC 17025:2005, the 2003 NELAC Chapter 5 Standard, and the requirements of the DoD Environmental Laboratory Accreditation Program (DoD ELAP) as detailed in version 4.2 of the DoD Quality Systems Manual for Environmental Laboratories) accreditation is granted to this laboratory to perform recognized EPA methods using the following testing technologies and in the analyte categories identified below:

Testing Technologies

Gas Chormatography/Mass Spectrophotometry

Parameter/Analyte	Solid Hazardous Waste
Methyl tert-Butyl Ether	EPA 8260C (modified), SPG-WI-0318
Benzene	EPA 8260C (modified), SPG-WI-0318
Toluene	EPA 8260C (modified), SPG-WI-0318
Ethylbenzene	EPA 8260C (modified), SPG-WI-0318
m,p-Xylenes	EPA 8260C (modified), SPG-WI-0318
o-Xylene	EPA 8260C (modified), SPG-WI-0318
BTEX (Combined masses of Benzene, Toluene, Ethylbenzene, and Xylenes)	EPA 8260C (modified), SPG-WI-0318
Octane	EPA 8260C (modified), SPG-WI-0318
1,3,5-Trimethylbenzenes	EPA 8260C (modified), SPG-WI-0318
1,2,4-Trimethylbenzenes	EPA 8260C (modified), SPG-WI-0318
TMBs (Combined masses of 1,3,5-Trimethylbenzene & 1,2,4-Trimethylbenzene	EPA 8260C (modified), SPG-WI-0318
Undecane	EPA 8260C (modified), SPG-WI-0318
Tridecane	EPA 8260C (modified), SPG-WI-0318
Naphthalene	EPA 8260C (modified), SPG-WI-0318

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5301 Buckeystown Pike, Suite 350 | Frederick, Maryland 21704-8373 | Phone: 301 644 3248 | Fax: 301 662 2974 | www.A2LA.org

Parameter/Analyte	Solid Hazardous Waste
2-Methylnaphthalene	EPA 8260C (modified), SPG-WI-0318
Combined masses of Naphthalene and 2-Methylnaphthalene	EPA 8260C (modified), SPG-WI-0318
Tetrachloroethene	EPA 8260C (modified), SPG-WI-0318
Trichloroethene	EPA 8260C (modified), SPG-WI-0318
cis-1,2-Dichloroethene	EPA 8260C (modified), SPG-WI-0318
trans-1,2-Dichloroethene	EPA 8260C (modified), SPG-WI-0318
Combined masses of cis-1,2 Dichloroethane and trans-1,2 Dichloroethane	EPA 8260C (modified), SPG-WI-0318
1,1-Dichloroethane	EPA 8260C (modified), SPG-WI-0318
1,2-Dichloroethane	EPA 8260C (modified), SPG-WI-0318
1,1,1-Trichloroethane	EPA 8260C (modified), SPG-WI-0318
Chloroform	EPA 8260C (modified), SPG-WI-0318
Chlorobenzene	EPA 8260C (modified), SPG-WI-0318, Screening only
1,4-Dichlorobenzene	EPA 8260C (modified), SPG-WI-0318
1,3-Dichlorobenzene	EPA 8260C (modified), SPG-WI-0318
1,2-Dichlorobenzene	EPA 8260C (modified), SPG-WI-0318
1,1,1,2-Tetrachloroethane	EPA 8260C (modified), SPG-WI-0318
1,1,2,2-Tetrachloroethane	EPA 8260C (modified), SPG-WI-0318
1,1,2-Trichloroethane	EPA 8260C (modified), SPG-WI-0318
Carbon Tetrachloride	EPA 8260C (modified), SPG-WI-0318
Sample Preparation	W.L. Gore Method SPG-WI-10006



American Association for Laboratory Accreditation

Accredited Laboratory

A2LA has accredited

W.L. GORE AND ASSOCIATES
SURVEY PRODUCTS GROUP LABORATORY

Elkton, MD

for technical competence in the field of

Environmental Testing

This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2005 *General Requirements for the Competence of Testing and Calibration Laboratories*. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (*refer to joint ISO-ILAC-IAF Communiqué dated 8 January 2009*).

Presented this 17th day of December 2012.

President & CEO
For the Accreditation Council
Certificate Number 3062.01
Valid to September 30, 2014

For the tests to which this accreditation applies, please refer to the laboratory's Environmental Scope of Accreditation.

Appendix C: Additional Quality Assurance/Quality Control Sampling

Equipment blanks

Prior to shipping the pumps to the test site, equipment blanks were collected from two 50 ft lengths of the peristaltic tubing following deployment in deionized water for 10 days. While the GORE Modules are treated during manufacture to remove any ambient contamination, two Modules were selected for blank testing. These samples were shipped directly from our laboratory to the laboratory conducting the analyses.

Low-flow sample handling by the laboratory

To insure data validity, standard laboratory practices for analyses included the following:

- Receiving, log-in, and proper low-temperature storage of the low-flow samples
- Chain-of-custody documentation
- All analyses conducted within the EPA-recommended holding times
- Standards preparation and analysis
- Instrument calibration
- Instrumentation QC
- Standard QA/QC samples

The Matrix-Spike (MS) and Matrix-Spike Duplicate (MSD) samples were identified with the suffixes MS and MSD on the Chain-of-Custody Forms. (These samples help identify matrix effects on the recovery of a known quantity of the analytes of interest.)

Field calibration procedures

The Horiba (MDL W-22XD) probe was calibrated each morning using the Horiba Autocalibration solution. This solution is used to calibrate the meter for pH, conductivity, turbidity, and DO. (The other purge parameters

are calculated based on these measurements.) The meter was also checked approximately 6 weeks prior to going in the field.

Laboratory calibration procedures, quality-control checks, and corrective action

Certified reference samples were used by all the laboratories to ensure proper calibration and thus accuracy of the analyses. One out of 40 samples was a certified reference sample (2.5%). One out of 20 samples was a calibration standard (5%).

All laboratory data was reviewed for completeness, detection and quantitation limits, QA/QC analyses, and the adequacy of the holding times by the laboratory supervisor and the PI.

For the low-flow samples, the analytical laboratory used standard EPA protocols and followed DoD Quality Systems Manual Practices for Environmental Laboratories (DoD EDQW 2003) practices for calibrating the analytical instrumentation, including calibration curves for at least three standards at different concentrations, internal and external standards, testing blanks, and others as the method requires. Any issues were to be reported to the PI immediately. Certified reference samples were used by the laboratory to ensure proper calibration and accuracy of the analyses. All certified reference samples were required to be within 20% of the known values.

Appendix D: Results of the Analyses of Replicate Modules by the Gore Laboratory

Table D1. Results for tetrachloroethlylene.

Well	Duplicates	Event #	Sampling Depth	PCE (µg/L)	Mean	Std. Dev.	%RSD
Blind duplicates							
37		3	only	4.4 U			
37	dup	3	only	4.4 U	4.4	0	0
37		4	only	4.4 U			
37	dup	4	only	182.2	93.3	125.699	135
91		1	bottom	7.9			
91	dup	1	bottom	7.9	7.9	0	0
91		1	mid	6.1			
91	dup	1	mid	6.0	6.1	0.06771	1
91		1	top	10.4			
91	dup	1	top	11.0	10.7	0.40624	4
92		1	mid	6.4			
92	dup	1	mid	4.4 U	5.4	1.41421	26
92		2	top	4.4 U			
92	dup	2	top	4.4 U	4.4	0	0
111		2	bottom	11.4			
111	dup	2	bottom	11.5	11.5	0.07333	1
111		2	top	6.0			
111	dup	2	top	6.5	6.3	0.31286	5
130		2	mid	4.4 U			
130	dup	2	mid	4.4 U	4.4	0	0
131		2	mid	16.0			
131	dup	2	mid	17.7	16.8	1.1659	7
133		1	only	97.2			
133	dup	1	only	14.4	55.8	58.5708	105
147		1	mid	30.3			
147	dup	1	mid	26.8	28.6	2.49016	9
35A		1	mid	46.8			
35A	dup	1	mid	50.6	48.7	2.69886	6
35A		2	mid	376.3			
35A	dup	2	mid	39.4	207.9	238.221	115
148		2	top	172.7			
148	dup	2	top	4.4U	88.6	119.006	134
Known duplicates							
92		1	bottom	4.4U			
92	dup	1	bottom	4.4U	4.4	0	0

Table D2. Results for trichlorethylene.

Well	Duplicate	Event #	Sampling Depth	TCE (µg/L)	Mean	Std. Dev. Dev	%RSD
Blind samples							
24		3	bottom	4.4 U			
24	dup	3	bottom	4.4 U	4.4	0	0
24		3	mid	4.4 U			
24	dup	3	mid	4.4 U	4.4	0	0
24		3	top	4.4 U			
24	dup	3	top	4.4 U	4.4	0	0
37		3	only	422			
37	dup	3	only	404	413	12.7279	3.1
37		4	only	599			
37	dup	4	only	504	552	67.1751	12
58		1	bottom	4.4 U			
58	dup	1	bottom	4.4 U	4.4	0	0.0
58		1	top	4.4 U			
58	dup	1	top	4.4 U	4.4	0	0.0
91		1	bottom	34.8			
91	dup	1	bottom	36.3	35.5	1.0833	3.0
91		1	mid	23.2			
91	dup	1	mid	22.9	23.0	0.20312	0.9
91		1	top	40.2			
91	dup	1	top	44.2	42.2	2.84367	6.7
111		2	bottom	220			
111	dup	2	bottom	230	225	7.2189	3.2
111		2	top	135			
111	dup	2	top	146	140	7.82262	5.6
118		1	bottom	13.2			
118	dup	1	bottom	10.8	12	1.68456	14.1
118		1	top	12.5			
118	dup	1	top	9.5	11	2.15656	19.6
128		1	only	4.4 U			
128	dup	1	only	4.4 U	4	0	0.0
130		2	mid	26.3			
130	dup	2	mid	34.8	30.6	6.06471	19.8
131		2	mid	340			
131	dup	2	mid	343	342	2.05747	0.6
133		1	mid	1200			
133	dup	1	mid	260	729	662.761	91.0
147		1	mid	65.2			
147	dup	1	mid	54.7	59.9	7.39725	12.3
148		1	mid	4.4 U			

Well	Duplicate	Event #	Sampling Depth	TCE (µg/L)	Mean	Std. Dev. Dev	%RSD
148	dup	1	mid	4.4 U	4.4	0	0.0
148		1	top	4.4 U			
148	dup	1	top	4.4 U	4.4	0	0.0
148		2	bottom	4.4 U			
148	dup	2	bottom	4.4 U	4.4	0	0.0
148		2	mid	4.4 U			
148	dup	2	mid	4.4 U	4.4	0	0.0
148	dup	2	top	4.4 U			
148		2	top	4.4 U	4.4	0	0.0
35A		1	mid	20.1			
35A	dup	1	mid	21.9	21.0	1.27005	6.1
35A		2	mid	16.0			
35A	dup	2	mid	18.2	17.1	1.55277	9.1
Known replicates							
24		3	mid	4.4 U			
24		3	mid	4.4 U	4.4	0	0.0
114		1	mid	76.6			
114		1	mid	77.8	77.2	0.88782	1.1
116		1	mid	276			
116		1	mid	267	272	6.70577	2.5
116		2	top	127			
116		2	top	124	126	2.1915	1.7
118		1	mid	23.1			
118		1	mid	13.4	18.2	6.88473	37.8
128		1	only	4.4 U			
128		1	only	4.4 U	4.4	0	0.0

Table D3. Results from analyses of replicate blind GORE Modules for 1,1,2,2-tetrachlorothane.

Well	Duplicate	Event #	Sampling Depth	TetCA (µg/L)	Mean	Std. Dev.	%RSD
Blind samples							
24		3	bottom	4.4 U			
24	dup	3	bottom	4.4 U	4.4	0	0.0
24		3	mid	4.4 U			
24	dup	3	mid	4.4 U	4.4	0	0.0
24		3	top	4.4 U			
24	dup	3	top	4.4 U	4.4	0	0.0
37		3	only	1593			
37	dup	3	only	1685	1639	64.852	4.0
37		4	only	2144			
37	dup	4	only	1902	2023	171.15	8.5
58		1	bottom	19.4			
58	dup	1	bottom	16.4	17.9	2.0661	11.5
58		1	top	19.9			
58	dup	1	top	18.7	19.3	0.8418	4.4
91		1	bottom	5.4 J			
91	dup	1	bottom	5.4 J	5.4	0	0.0
91		1	mid	5.1 J			
91	dup	1	mid	5.2 J	5.2	0.0707	1.4
91		1	top	5.3 J			
91	dup	1	top	5.6	5.4	0.1793	3.3
111		2	bottom	1474			
111	dup	2	bottom	1415	1444	41.655	2.9
111		2	top	920			
111	dup	2	top	788	854	93.634	11.0
118		1	bottom	51.1			
118	dup	1	bottom	43.2	47.1	5.5745	11.8
118		1	top	47.2			
118	dup	1	top	35.9	47.2	8.0078	17.0
128		1		4.4 U			
128	dup	1		4.4 U	4.4	0	0.0
130		2	mid	172			
130	dup	2	mid	198	185	18.270	9.9
131		2	mid	737			
131	dup	2	mid	755	746	12.756	1.7
133		1	mid	1610			
133	dup	1	mid	738	1172	613.78	52
147		1	mid	70.4			
147	dup	1	mid	73.6	72.0	2.2704	3.2
148		1	mid	4.4 U			

Well	Duplicate	Event #	Sampling Depth	TetCA (µg/L)	Mean	Std. Dev.	%RSD
148	dup	1	mid	4.4 U	4.4	0	0.0
148		1	top	4.4 U			
148	dup	1	top	4.4 U	4.4	0	0.0
148		2	bottom	4.4 U			
148	dup	2	bottom	4.4 U	4.4	0	0.0
148		2	mid	4.4 U			
148	dup	2	mid	4.4 U	4.4	0	0.0
148		2	top	4.4 U			
148	dup	2	top	4.4 U	4.4	0	0.0
35A		1	mid	147			
35A	dup	1	mid	147	147	0.1588	0.1
35A		2	mid	132			
35A	dup	2	mid	117	125	10.352	8.3
Known replicates							
24		3	mid	4.4 U			
24	dup	3	mid	4.4 U	4.4	0	0
114		1	mid	286			
114	dup	1	mid	294	290	5.77080	2.0
116		1	mid	915			
116	dup	1	mid	853	884	43.9441	5.0
116		2	top	621			
116	dup	2	top	666	643	31.7037	4.9
118		1	mid	49.7			
118	dup	1	mid	51.0	50.3	0.87890	1.7
128		2	only	43.9			
128	dup	2	only	46.2	45.0	1.605	3.6

Table D4. Results from analyses of replicate blind GORE Modules for *cis*-1,2-dichloroethylene.

Well	Duplicate	Event #	Sampling Depth	c12DCE (µg/L)	Mean	Std. Dev.	%RSD
Blind samples							
37		3	only	4.5			
37	dup	3	only	4.5	4.5	0	0
37		4	only	4.5			
37	dup	4	only	4.5	4.5	0	0
111		2	bottom	37.3			
111	dup	2	bottom	56.4	46.9	13.5	28.8
111		2	top	27.4			
111	dup	2	top	39.6	33.5	8.7	25.9
130		2	mid	4.5			
130	dup	2	mid	4.6	4.6	0.1	1.6
131		2	mid	10.1			
131	dup	2	mid	10.8	10.4	0.5	4.7
133		1	mid	17.6			
133	dup	1	mid	4.5	11.0	9.2	83.7
147		1	mid	29.2			
147	dup	1	mid	19.6	24.4	6.7	27.5
148		1	mid	4.5			
148	dup	1	mid	4.5	4.5	0.0	0.0
148		1	top	4.5			
148	dup	1	top	4.5	4.5	0.0	0.0
148		2	bottom	4.5			
148	dup	2	bottom	4.5	4.5	0.0	0.0
148		2	mid	4.5			
148	dup	2	mid	4.5	4.5	0.0	0.0
35A		1	mid	4.5			
35A	dup	1	mid	4.5	4.5	0.0	0.0
35A		2	mid	4.5			
35A	dup	2	mid	4.5	4.5	0.0	0.0
Known replicate samples							
37		3	only	4.5			
37	dup	3	only	4.5	4.5	0	0
114		1	mid	4.5			
114	dup	1	mid	4.5	4.5	0	0
116		1	mid	344			
116	dup	1	mid	374	359	21.622	6.0
116		2	top	246			
116	dup	2	top	226	236	13.7063	5.8

Table D5. Results of replicate analyses for blind GORE Modules for chloroform.

Well	Duplicate	Event #	Sampling Depth	CHCl3 (µg/L)	Mean (µg/L))	Std. Dev.	%RSD
Blind Samples							
24				12.8	13.2	0.565685	4.3
24	dup			13.6			
37		3	only	4.4	4.4	0	0.0
37	dup	3	only	4.4			
37		4	only	35.4	19.9	21.93511	110.2
37	dup	4	only	4.4 U			
58		1	bottom	5.5	5.0	0.791431	16.0
58	dup	1	bottom	4.4 U			
58		1	top	4.4 U	4.4	0	0.0
58	dup	1	top	4.4 U			
111		2	bottom	4.4 U	7.1	3.869327	54.2
111	dup	2	bottom	9.9			
111		2	top	4.7	5.6	1.257615	22.5
111	dup	2	top	6.5			
131		2	mid	18.9	18.9	18.9	18.9
131	dup	2	mid	18.9			
133		1	mid	102	55.3	66.61606	120.4
133	dup	1	mid	8.2			
35A		1	mid	4.7	5.4	1.042402	19.2
35A	dup	1	mid	6.2			
35A		2	mid	4.4 (U)	4.9	0.636396	13.1
35A	dup	2	mid	5.3			
Known replicates							
37		3	only	4.4 U			
37	dup	3	only	4.4 U	4.4	0	0.0
118		1	mid	11.6			
118	dup	1	mid	11.5	11.5	0.07324	0.6

Table D6. Results from analyses of blind replicate GORE Modules for benzene.

Well	Duplicate	Event #	Sampling Depth	BNZ (µg/L)	Mean	Std. Dev.	%RSD
147		1	mid	15.3			
147	dup	1	mid	12.5	13.9	1.97748	14.2

Table D7. Results for replicate GORE Modules for pentadecane.

Well	Duplicate	Event #	Sampling Depth	PENTADEC (µg/L)	Mean	Std. Dev.	%RSD
Blind samples							
33		1	mid	18.4			
33	dup	1	mid	14.2	16.3	2.99201	18.4
33		2	mid	4.4 U			
33	dup	2	mid	4.4 U	4.4	0	0.0
37		3	only	4.4 U			
37	dup	3	only	4.4 U	4.4	0	0.0
37		4	only	4.4 U			
37	dup	4	only	4.4 U	4.4	0	0.0
130		2	mid	18.2			
130	dup	2	mid	4.4 U	11.3	9.77625	86.4
147		1	mid	30.9			
147	dup	1	mid	44.5	37.7	9.66769	25.6
148		2	bottom	14.4			
148	dup	2	bottom	4.4 U	9.4	7.09229	75.3
148		2	mid	17.7			
148	dup	2	mid	13.8	15.7	2.72517	17.3
148		2	top	2176			
148	dup	2	top	17.1	1097	1526.56	139
41B		2	bottom	4.4 U			
41B	dup	2	bottom	4.4 U	4.4	0	0.0
41B		2	mid	4.4 U			
41B	dup	2	mid	4.4 U	4.4	0	0.0
41B		2	top	4.4 U			
41B	dup	2	top	21.0	12.7	11.7295	92.4
Known replicates							
116		2	top	4.4 U			
116	dup	2	top	4.4 U	4.4	0	0.0
61B		2	mid	4.4 U			
61B	dup	2	mid	50.9	27.6	32.8662	119

Table D8. Results from analyses of blind replicate GORE Modules for Chlorobenzene.

All Replicates were non-detects.

Table D9. Summary of the results from the analyses of replicate samples*.

Analyte	Sample Type	# Reps.	RSD Range	# < 25% RSD	% < 25% RSD	# < 20% RSD	% < 20% RSD
PCE							
	LF	4	3%–15%	4	100%	4	100%
	blind GORE	16	0%–135%	11	69%	11	69%
	GORE reps.	1	0%	1	100%	1	100%
TCE							
	LF	10	0%–10.5%	10	100%	10	100%
	blind GORE	26	0%–91%	25	96%	25	96%
	GORE reps.	6	0%–38%	5	83%	5	83%
1,1,2,2-tetrachloroethane							
	LF	9	0%–12%	9	100%	9	100%
	blind GORE	26	0%–52%	25	96%	25	96%
	GORE reps.	6	0%–5%	6	100%	6	100%
cis-1,2-dichloroethylene							
	LF	11	0%–67%	10	91%	10	91%
	blind GORE	14	0%–84%	10	71%	10	71%
	GORE reps.	4	0%–6%	4	100%	4	100%
benzene							
	LF	2	0.8%–2.5%	2	100%	2	100%
	blind GORE	1	14.2%	1	100%	1	100%
	GORE reps.	0					
pentadecane							
	LF	Not determined					
	blind GORE	12	0%–139%	7	58%	7	58%
	GORE reps.	2	0%–132%	1	50%	1	50%
chlorobenzene*							
	LF	1	4%	1	100%	1	100%
	blind GORE	0					
	GORE reps.	0					
chloroform							
	LF	5	0%–11%	5	100%	5	100%
	blind GORE	10	0%–120%	8	80%	7	70%
	GORE reps.	2	0%–0.6%	2	100%	2	100%

*Where analyte concentrations were above the detection limit.

Appendix E: Replicate Low-Flow Samples

Table E1. Results of analyses of duplicate low-flow samples for tetrachloroethlylene.

Well	Duplicate	PCE (µg/L)	Mean	Std. Dev.	%RSD
37		17.6			
37	dup	20 J	18.8	1.6970563	9
91		5.4			
91	dup	5.6	5.5	0.1414214	3
131		17.4			
131	dup	14 J	15.7	2.4041631	15
147		37.6			
147	dup	42.1	39.9	3.1819805	8

Table E2. Results of analyses of duplicate low-flow samples for trichloroethylene.

Well	Duplicate	TCE (µg/L)	Mean	Std. Dev.	%RSD
24		1.7			
24	dup	1.7	1.7	0	0
37		447			
37	dup	519	483.0	50.91169	10.5
44		51.8			
44	dup	51.5	51.7	0.212132	0.4
58		8.8			
58	dup	8.9	8.9	0.070711	0.8
91		41.4			
91	dup	43	42.2	1.131371	2.7
131		450			
131	dup	390	420.0	42.42641	10.1
140		42.3			
140	dup	40.5	41.4	1.272792	3.1
142		30			
142	dup	29.9	30.0	0.070711	0.2
146		9			
146	dup	9.1	9.1	0.070711	0.8
147		104			
147	dup	109	107	3.535534	3.3

Table E3. Results of analyses of duplicate low-flow samples for 1,1,2,2-tetrachloroethane.

Well	Duplicate	TetCA (µg/L)	Mean	Std Dev.	%RSD
24		8.3			
24	dup	7.9	8.1	0.28284	3.5
44		159			
44	dup	167	163	5.65685	3.5
58		53.8			
58	dup	50.2	52	2.54558	4.9
91		16.1			
91	dup	17.8	17.0	1.20208	7.1
131		2070			
131	dup	2260	2165	134.35029	6.2
140		47			
140	dup	46.8	46.9	0.14142	0.3
142		2.5			
142	dup	2.2	2.35	0.21213	9.0
146		8			
146	dup	8.2	8.1	0.14142	1.7
147		91.9			
147	dup	109	100	12.09153	12.0

Table E4. Results of analyses of duplicate low-flow samples for chlorobenzene.

Well	Duplicate	CLB (µg/L)	Mean	Std. Dev.	%RSD
142		0.87 J			
142	dup	0.92 J	0.90	0.04	4.0

Table E5. Results of analyses of duplicate low-flow samples for chloroform.

Well	Duplicate	CHCl3 (µg/L)	Mean	Std. Dev.	%RSD
24		12.8	13.2	0.56569	4.3
24	dup	13.6			
37		48.9	45.5	4.87904	10.7
37	dup	42			
58		26.7	25.4	1.90919	7.5
58	dup	24			
131		40.6	39.8	1.13137	2.8
131	dup	39			
146		1.3	1.3	0	0.0
146	dup	1.3			

Table E6. Results of analyses of duplicate low-flow samples for *cis*-1,2-dichloroethylene.

Well #	Duplicate	cDCE (µg/L)	Mean	Std. Dev.	%RSD
58		0.56			
58	dup	0.2	0.38	0.254558	67.0
131		24.7			
131	dup	25	24.9	0.212132	0.9
44		6			
44	dup	5.6	5.8	0.282843	4.9
90		0.2			
90	dup	0.2	0.2	0	0.0
91		2.7			
91	dup	2.7	2.7	0	0.0
147		99.6			
147	dup	114	107	10.18234	9.5
146		1.7			
146	dup	1.6	1.65	0.070711	4.3
140		37.6			
140	dup	36.5	37.1	0.777817	2.1
142		17.3			
142	dup	17.3	17.3	0	0.0
24		0.2			
24	dup	0.2	0.2	0	0.0
37		31			
37	dup	25	28.0	4.242641	15.2

Table E7. Results of analyses of duplicate low-flow samples for benzene.

Well	Duplicate	BNZ (µg/L)	Mean	Std. Dev.	%RSD
142		22			
142	dup	22.8	22.4	0.56569	2.5
147		26.6			
147	dup	26.3	26.45	0.21213	0.8

Appendix F: Data Comparing the Analyses of the GORE Modules by the Gore and Contract (MRIGlobal) Laboratories

Table F1. Raw data giving the results of analyses of the GORE Modules by MRIGlobal and Gore laboratories.

		Total Mass Desorbed from One Module (µg)										
Well	Lab	tDCE	cDCE	CHCl3	12DCA	BNZ	CCl4	TCE	112TCA	PCE	TetCA	PENTADEC
58	Gore	0.02 U	0.02 U	0.025 J	0.02 U	0.02 U	0.029	0.02 U	0.02 U	0.02 U	0.083	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.078	0.05 U
	MRI dup	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.079	0.05 U
133	Gore	0.05	0.08	0.50	0.02 U	0.02 U	2.43	5.80	0.08	0.47	7.78	0.02 U
	MRI	0.076	0.11	0.50	0.05 U	0.05 U	2.7*	7.5*	0.073	0.41	10.9 #	0.05 U
	MRI dup	0.080	0.11	0.48	0.05 U	0.05 U	2.6*	7.0*	0.073	0.41	10.4 #	0.05 U
44	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.083	0.02 U	0.02 U	0.24	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.076	0.05 U	0.05 U	0.24	0.05 U
	MRI dup	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.068	0.05 U	0.05 U	0.20	0.05 U
44	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.087	0.025 J	0.02 U	0.265	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.089	0.05 U	0.05 U	0.35	0.05 U
128	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.029	0.02 U
	Gore dup	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.031	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
90	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
90	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
35 A	Gore	0.02 U	0.02 U	0.026	0.050	0.02 U	0.02 U	0.107	0.02 U	0.262	0.803	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.067	0.05 U	0.19	0.55	0.05 U
	Gore	0.02 U	0.02 U	0.025	0.038	0.02 U	0.02 U	0.085	0.02 U	0.182	0.533	0.02 U
35A	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.090	0.05 U	0.17	0.52	0.05 U
90	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U

		Total Mass Desorbed from One Module (µg)										
Well	Lab	tDCE	cDCE	CHCl3	12DCA	BNZ	CCl4	TCE	112TCA	PCE	TetCA	PENTADEC
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
90	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
35 A	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.065	0.02 U	0.157	0.548	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.070	0.05 U	0.14	0.49	0.05 U
35 A	Gore	0.02 U	0.02 U	0.02 U	0.06	0.02 U	0.02 U	0.135	0.02 U	0.152	0.521	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.092	0.05 U	0.18	0.53	0.05 U
33	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.111
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
33	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.088
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
33	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
33	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.074
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
92	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	Gore dup	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
92	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
147	Gore	0.02 U	0.061	0.02 U	0.02 U	0.048	0.02 U	0.198	0.02 U	0.098	0.280	0.259
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.21	0.05 U	0.13	0.37	0.26
147	Gore	0.034	0.236	0.02 U	0.02 U	0.101	0.02 U	0.443	0.026	0.194	0.427	0.111
	MRI	0.065	0.25	0.05 U	0.05 U	0.11	0.05 U	0.46	0.05 U	0.20	0.47	0.077
91	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.105	0.02 U	0.05 J	0.032	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.11	0.05 U	0.05 U	0.05 U	0.05 U
91	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.105	0.02 U	0.028	0.029	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.10	0.05 U	0.05 U	0.05 U	0.05 U
91	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.066	0.02 U	0.02 U	0.02 J	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.083	0.05 U	0.05 U	0.05 U	0.05 U

		Total Mass Desorbed from One Module (µg)										
Well	Lab	tDCE	cDCE	CHCl3	12DCA	BNZ	CCl4	TCE	112TCA	PCE	TetCA	PENTADEC
148	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
92	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
92	Gore	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	MRI	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
147	Gore	0.02 U	0.07	0.02 U	0.02 U	0.026	0.02 U	0.118	0.02 U	0.056	0.131	0.02 U
	MRI	0.05 U	0.061	0.05 U	0.05 U	0.05 U	0.05 U	0.16	0.05 U	0.072	0.16	0.05 U
147	Gore	0.02 U	0.063	0.02 U	0.02 U	0.046	0.02 U	0.19	0.02 U	0.09	0.24	0.02 U
	MRI	0.05 U	0.17	0.05 U	0.05 U	0.090	0.05 U	0.35	0.05 U	0.14	0.40	0.05 U
147	Gore	0.02 U	0.53	0.02 U	0.02 U	0.04	0.02 U	0.45	0.02 U	0.09	0.28	0.02 U
	MRI	0.05 U	0.18	0.05 U	0.05 U	0.11	0.05 U	0.41	0.05 U	0.20	0.56	0.05 U

Table F2. Results of statistical analyses comparing the total mass determined by Gore and MRIGlobal laboratories.

				Linear least-fit model on raw data			
Analyte	Test	Significant difference?	# pairs	r^2	Significance	Slope	Slope sig. dif. from 1.0?
TCE	Paired t on logs	No	15	0.999	2.1 E-20	1.3	No
TetCA	Paired t on logs	No	13	0.996	1.8 E-14	1.4	No
PCE	Paired t on raw	No	10	0.942	2.1 E-06	0.93	Yes
cDCE	Paired t on logs	No	6	0.648	0.0386	0.51	No
pentadecane	Paired t on raw	Yes	5	0.942	0.00395	0.86	Yes

Appendix G: Results for GORE Modules and Low-Flow Samples

These data tables do not contain the results for the wells where all the concentrations were below the detection limit. Also, these tables do not include any of the results for the replicate samples that were given previously.

Table G1. Raw data for tetrachloroethylene.

PCE (µg/L)							
	Pre-purge GORE			Post-purge GORE			
Well #	bottom	mid	top	bottom	mid	top	LF
37		8.3			13.6		19.7
37		4.4 U			4.4 U		17.6
55	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	29.2	0.2 U
59	12.8	4.0 J	4.4 J	4.4 U	4.4 U	4.4 U	6.5
91	7.9	6.1	10.4	4.7 J	4.5 J	4.4 U	5.4
111	13.8	5.5	5.8	11.4	5.6	6.0	0.2 U
130	4.4 U	6.8	4.4 U	4.4 U	4.4 U	4.4 U	3.6
131	31.9	29.5	529	14.4	16.0		17.4
133		97.2			63.4		31.1
147	20.3	30.3	40.1	11.6	18.7	19.0	37.6
35A	58.7	46.8	40.7	28.7	376	27.7	74.2
35B	33.9	35.2	29.2	18.4	20.1	21.7	46.3
148	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	173	0.2 U

Table G2. Raw data for chloroform.

	Concentration chloroform (µg/L)						
	Pre-purge GORE Modules			Post-purge GORE Modules			
Well #	bottom	mid	top	bottom	mid	top	LF
24		5.7			6.1		13.7
37		11.2			29.2		48.4
37		4.4 U			35.4		48.9
58	5.5	5.3 J	4.4 U	7.1	9.3	10.7	26.7
59	7.5	9.5	11.4	5.4 J	7.3	7.0	20.4
63	8.1	9.6	11.1	5.9	10.4	10.5	26.3
111	12.7	4.7 J	5.8	4.4 U	4.8 J	4.7 J	6.4
114	25.7	28.3	25.1	4.4 U	4.4 U	4.4 U	2.0 U
118	10.0	11.6	11.9	7.4	6.9	7.6	19.8
131	17.8	25.1	255	14.6	18.9		40.6
35A	5.8	4.7 J	5.6	4.4 U	4.4 U	4.4 U	9.1

Table G3. Raw data 1,1,2,2-tetrachloroethane.

Well #	Concentration TetCA (µg/L)						
	GORE pre-purge			GORE post-purge			
	bottom	mid	top	bottom	mid	top	LF
24	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	8.4
24	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	8.3
25	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	7.3
37		993			1481		1840
37		1590			2144		2160
40	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	7.0
44		50.3			42.6		159
45	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	1.7
55	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	0.43 J
58	19.4	18	19.9	18.1	19.1	21.2	53.8
59	42.4	49	51.8	30.5	36.4	35.7	109
63	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	5.2
64	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	9.5
91	5.4 J	5.1 J	5.3 J	6.1	5.5	4.4 U	16.1
111	1600	581	750	1470	704	920	1020
113	6.2	6.2	5.7	6.7	6.0	4.4 U	15.1
114	269	286	241	500	376	257	522
116	1100	915	865	601	574	621	659
118	51.1	49.7	47.2	43.2	38.5	35.9	101
119	10.7	6.3	6.8	4.4 U	4.5 J	4.4 U	8.7
128		4.4 U			43.9		23.5
130	225	226	135	201	172	125	300
131	766	713	2220 J	607	737		2070
133		1610			1620		3160
134	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	3.0
140	9.8	9.0	9.4	9.5	15.0	19.0	47.0
142	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	2.5
146	4.4 U	3.9	4.4 U	4.4 U	4.4 U	4.4 U	8.0
147	57.9	70.4	88.5	27.4	49.3	58.9	91.9
148	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	0.54
35A	180	147	120	100	132	95.3	237
35B	55.9	61.9	61.6	45.1	43.1	52.4	136
36R	4.7 J	7.3	5.9	4.4 U	6.4	6.3	21.7

Table G4. Raw data for trichloroethylene.

Well #	Concentration TCE (µg/L)						
	Pre-purge GORE Modules			Post-purge GORE Modules			
	bottom	mid	top	bottom	mid	top	LF
23	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	31.7	0.2 U
24	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	1.9
24	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	122	1.7
25	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	2.8
26	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	84.2	0.2 U
37		217			450		555
37		422			599		447
40	3.8	4.4 U	4.4 U	6.6	4.4 U	4.3	11.4
44		17.2			13.9	51.8	
45	4.4 U	11.6	4.4 U	4.4 U	4.4 U	4.4 U	5.5
55	4.4 U	4.4 U	4.4 U	10.5	4.4 U	4.4 U	0.2 U
57	4.4 U	4.4 U	4.4 U	4.4 U	3.9	4.4 U	0.2 U
58	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 J	8.8
59	9.9	11.4	12	6.8	8.3	7.5	19.1
63	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	1.5
64	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	5.9
91	34.8	23.2	40.2	20.3	20.3	12.8	41.4
111	328	116	138	220	117	135	111
113	4.4 U	4.4 U	6.5	4.4 U	4.4 U	4.4 U	2.4
114	76.6	76.6	65.9	103	76.6	50.3	71.9
116	317	276	72.8	149	136	127	133
118	13.2	23.1	12.5	10.8	13.4	9.5	15.2
119	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	1.1
128		4.4 U			4.4 U		11.7
130	44.7	41.6	23.5	35.9	26.3	20.7	52.9
131	432	474	6980 J	270	340		450
133		1200			932		602
134	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	1.0 J
140	23.4	7.5	7.0	9.2	12.5	17.8	42.3
142	13.8	19.2	19.3	13.4	17.7	18.0	30
146	4.4 U	3.9	4.4 U	4.0	4.4 U	4.4 U	9
147	40.9	65.2	91.8	24.5	38.9	94.7	104
148	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	2.8
35A	24.0	20.1	19.1	11.9	16.0	24.7	39.6
35B	11.9	11.7	9.9	6.8	7.4	9.1	20.4
36R	4.4 U	4.4 U	4.4 U	4.4 U	4.5 J	4.4 J	12.2

Table G5. Raw data for *cis*-1,2-dichloroethylene.

Well #	Concentration cDCE (µg/L)						
	Pre-purge GORE Modules			Post-purge GORE Modules			LF
	bottom	mid	top	bottom	mid	top	
25	4.5 U	5.3 J	4.5 U	4.5 U	4.5 U	4.5 U	4.5 U
37		5.5 J			18.6		29.6
37		4.5 U			4.5 U		31
44		4.5 U			4.5 U		6
111	90.9	27.0	38.7	37.3	30.0	27.4	39
114	4.5 U	4.5 U	4.5 U	4.5 U	50.1	4.5 U	3.7
116	400	344	4.5 U	223	204	246	189
130	6.8	5.8	4.5 U	6.1	4.5 U	4.5 U	13.6
131	5.8	7.9	49.4		7.2	10.1	24.7
133		17.6			22.5		36.6
140	10.1	4.3	4.5 U	7.3	5.9	9.2	37.6
142	4.5 U	6.8	8.2	5.7	5.9	7.0	17.3
147	12.9	29.2	50.4	7.9	13.5	11.3	99.6
35A	4.5 U	4.5 U	4.5 U	4.5 U	4.5 U	4.5 U	5.1

Table G6. Raw data for chlorobenzene.

Well #	Concentration chlorobenzene (µg/L)						
	Pre-purge GORE Modules			Post-purge GORE Modules			LF
	bottom	mid	top	bottom	mid	top	
63	7.9	6.1	5.3 J	7.1	17.2	9.8	18.8
64	140	68.7	51.8	149	71.8	50.6	296

Table G7. Raw data for benzene.

Well #	Concentration benzene (µg/L)						
	Pre-purge GORE Modules			Post-purge GORE Modules			LF
	bottom	mid	top	bottom	mid	top	
142	11.4	15.5	15.8	14.7	11.3	12.9	22.0
147	9.8	15.3	20.9	5.3 J	9.6	9.1	26.6

Table G8. Raw data for pentadecane*.

Well #	Concentration Pentadecane (µg/L)					
	Pre-purge GORE Modules			Post-purge GORE Modules		
	bottom	mid	top	bottom	mid	top
23	16.6	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U
24	21	17.8	4.4 U	4.4 U	4.4 U	4.4 U
25	4.4 U	4.4 U	4.4 U	13	4.4 U	4.4 U
26	140	15.9	4.4 U	4.4 U	17.8	4.4 U
28	14.6	4.4 U	4.4 U	20.6	20.9	15.6
33	25.4	18.4	20.1	4.4 U	4.4 U	15.9
37		13.3			4.4 U	
40	4.4 U	4.4 U	4.4 U	36.5	20.8	18.3
41	21.0	17.5	16.7	4.4 U	4.4 U	4.4 U
57	4.4 U	4.4 U	4.4 U	4.4 U	9.8	22.9
62	4.4 U	16.3	13.5	4.4 U	4.4 U	4.4 U
116	4.4 U	4.4 U	4.4 U	30.0	4.4 U	4.4 U
119	51.2	21.1	17.8	4.4 U	4.4 U	4.4 U
130	19.1	16.9	15.5	4.4 U	18.2	4.4 U
134	14.5	25.3	16.2	24.1	16.9	19.4
146	14.6	16.9	4.4 U	26.3	53.8	40.5
147	53.7	30.9	22.9	4.4 U	4.4 U	4.4 U
148	4.4 U	4.4 U	4.4 U	14.4	17.7	2180
35B	18.6	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U
36R	21.0	24.4	4.4 U	4.4 U	4.4 U	4.4 U
61B	28.8	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U

* The analytical method used for the low-flow samples did not was not able to detect this analyte.

Appendix H: Results of the Statistical Analyses Comparing the Mid-Level GORE Data with Low-Flow Sampling at the APG Site

Table H1. Summary of statistical analyses comparing the mid-level GORE Modules with the low-flow data*.

Analyte	vs. low-flow		Pre- vs. post-purge	Test type	Type of multiple comparison test used
	Pre- purge	Post-purge			
PCE	NS	NS	NS	Friedman RM-ANOVA on ranks	
TetCA	Sig	Sig	NS	RM-ANOVA on logs	Holm-Sidak
TCE	Sig	Sig	NS	RM ANOVA on logs	Holm-Sidak
cDCE	Sig	Sig	NS	RM-ANOVA on logs	Holm-Sidak
CLF	Sig	Sig	NS	RM-ANOVA on raw data	Holm-Sidak

* With non-detects removed from data set.

NS = No significant difference

Sig = Significant difference

Table H2. Linear least-fit model of the mid-level GORE data vs. low-flow sampling.

Analyte	Purge type	R^2	Sig. level	Slope	Sig. different from 1.0?
PCE	Pre-purge	0.61	1.9 E-03	0.9	No
	Post-purge	0.63	1.5 E-03	1.2	No
TetCA	Pre-purge	0.91	1.2 E-15	0.55	**Yes**
	Post-purge	0.89	3.9 E-14	0.63	**Yes**
TCE	Pre-purge	0.765	1.6 E-08	1.15	No
	Post-purge	0.90	4.3 E-13	1.13	No
cDCE	Pre-purge	0.79	3.9 E-04	1.35	No
	Post-purge	0.78	4.9 E-04	0.83	No
CLF	Pre-purge	0.95	4.16 E-05	0.69	**Yes**
	Post-purge	0.98	1.28E-06	0.66	**Yes**

Appendix I: Results of the Statistical Analyses Comparing the Mean GORE Data with Low-Flow Sampling at the APG Site

Table I1. Statistical analyses comparing the mean concentration of the raw data for the three GORE Modules with the low-flow data.

Analyte	vs. low flow		Pre- vs. post-purge	Test type	Multiple comparison test
	Pre-purge	Post-purge			
PCE	NS	NS	NS	RM-ANOVA on raw data	
TetCA	**Yes**	**Yes**	NS	RM-ANOVA on logs	Holm-Sidak
TCE	NS	**Yes**	**Sig[1]/NS[2]**	[1]Friedman RM ANOVA on ranks [2]Wilcoxon Signed Rank test	[1]Tukey
cDCE	NS	NS	NS	RM-ANOVA	
CLF	NS	**Yes**	NS	RM-ANOVA on logs	Holm-Sidak

Table I2. Linear least-fit model of the mean GORE data (for 3 depths) vs. low-flow sampling.

Analyte	Purge type	R^2	Sig. level	Slope	Sig. different from 1.0?
PCE	Pre-purge	0.29	0.039	1.17	No
	Post-purge	0.69	1.6 E-04	1.36	No
TetCA	Pre-purge	0.93	5.0 E-17	0.61	Yes
	Post-purge	0.87	2.1 E-13	0.64	Yes
TCE	Pre-purge*	0.94	4.9 E-09	1.06	No
	Post-purge	0.93	1.4 E-08	0.73	Yes
cDCE	Pre-purge	0.86	6.4 E-04	1.07	No
	Post-purge	0.80	1.9 E-03	0.915	No

*Minus one possible outlier (the upper sample in well 131).

Appendix J: Results from the Analyses of Duplicate GORE Samples at the Pease Site

Table J1. Findings for duplicate GORE samples for benzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft TOC)	Concentration (µg/L) (DL = 0.247)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	0.82			
00675003				0.63	0.73	0.14	18.6
00675056	PH2-5324	0:33	48.1	17.38			
00675060				16.93	17.16	0.32	1.9
00675061	PH2-5324	0:15	48.1	28.18			
00675062				29.01	28.60	0.59	2.1
00675027	PH2-5388	0:15	31.6	7.08			
00675041				6.14	6.61	0.66	10.0
00675034	PH2-5604	2:00	49.6	0.48			
00675037				1.12	0.80	0.45	56.3
00675063	PH2-5604	2:00	49.6	0.92			
00675065				0.92	0.92	0.00	0.0
00675064	PH2-5606	0:15	61.6	1036			
00675066				1363	1199.40	230.86	19.2
00675008	PH2-5608	2:00	34.6	2.58			
00675009				1.57	2.08	0.71	34.3
00675055	PH2-6508	2:28	57.5	23.47			
00675059				19.12	21.30	3.08	14.5
00675054	PH2-6508	2:28	59.6	19.12			
00675058				19.12	19.12	0.00	0.0
00675053	PH2-6508	2:28	62	14.67			
00675057				56.52	35.60	29.59	83.1
00675016	PH2-6627	2:00	57.5	38.08			
00675018				33.05	35.57	3.56	10.0
00675014	PH2-6627	2:00	62.5	33.05			
00675017				27.95	30.50	3.61	11.8
00675031	PH2-6658	2:25	61.1	32.39			
00675032				14.86	23.62	12.40	52.5
00675049	PH2-6660	3:08	63.1	8.28			

Module #	Well #	Contact time (hr:min)	Module depth (ft TOC)	Concentration (µg/L) (DL = 0.247)	Mean conc. (µg/L)	Standard deviation	%RSD
00675051				22.68	15.48	10.18	65.8
00675048	PH2-6660	3:08	65.6	71.77			
00675050				173.99	122.88	72.27	58.8
00675035	PH2-6660	3:08	68.1	36.66			
00675036				372.14	204.40	237.22	116.1

TOC = Top of casing

Table J2. Findings for duplicate GORE samples for toluene

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.21)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	0.76			
00675003				1.11	0.94	0.24	26.0
00675056	PH2-5324	0:33	48.1	23.2			
00675060				22.8	23.0	0.29	1.3
00675061	PH2-5324	0:15	48.1	41.4			
00675062				42.9	42.1	1.05	2.5
00675027	PH2-5388	0:15	31.6	28.1			
00675041				31.9	30.0	2.67	8.9
00675034	PH2-5604	2:00	49.6	0.45			
00675037				2.34	1.40	1.33	95.5
00675063	PH2-5604	2:00	49.6	2.16			
00675065				1.80	1.98	0.26	13.0
00675064	PH2-5606	0:15	61.6	9099			
00675066				11170	10135	1464.86	14.5
00675008	PH2-5608	2:00	34.6	13.87			
00675009				5.24	9.55	6.10	63.9
00675055	PH2-6508	2:28	57.5	38.1			
00675059				18.1	28.1	14.13	50.3
00675054	PH2-6508	2:28	59.6	20.2			
00675058				20.2	20.2	0.00	0.0
00675053	PH2-6508	2:28	62	16.0			
00675057				172	93.8	109.98	117.2
00675016	PH2-6627	2:00	57.5	50.0			
00675018				19.1	34.6	21.86	63.2
00675014	PH2-6627	2:00	62.5	45.4			
00675017				26.5	36.0	13.38	37.2
00675031	PH2-6658	2:25	61.1	40.5			
00675032				7.5	24.0	23.37	97.4
00675049	PH2-6660	3:08	63.1	2.2			
00675051				32.6	17.4	21.52	123.5
00675048	PH2-6660	3:08	65.6	13.1			
00675050				18.1	15.6	3.57	22.9
00675035	PH2-6660	3:08	68.1	15.9			
00675036				34.6	25.3	13.23	52.3

Table J3. Findings for duplicate GORE samples for ethylbenzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.21)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	1.48			
00675003				1.33	1.40	0.11	7.6
00675056	PH2-5324	0:33	48.1	952			
00675060				835	893	82.60	9.2
00675061	PH2-5324	0:15	48.1	1352			
00675062				1401	1377	34.22	2.5
00675027	PH2-5388	0:15	31.6	5.22			
00675041				6.01	5.61	0.56	10.0
00675034	PH2-5604	2:00	49.6	0.22			
00675037				0.42	0.32	0.14	43.5
00675063	PH2-5604	2:00	49.6	0.96			
00675065				0.78	0.87	0.13	14.4
00675064	PH2-5606	0:15	61.6	9663			
00675066				9940	9802	195.53	2.0
00675008	PH2-5608	2:00	34.6	3.05			
00675009				2.04	2.55	0.71	27.9
00675055	PH2-6508	2:28	57.5	3.62			
00675059				1.32	2.47	1.63	65.8
00675054	PH2-6508	2:28	59.6	2.49			
00675058				2.49	2.49	0.00	0.0
00675053	PH2-6508	2:28	62	2.49			
00675057				18.75	10.62	11.49	108.2
00675016	PH2-6627	2:00	57.5	8.14			
00675018				5.61	6.88	1.79	26.0
00675014	PH2-6627	2:00	62.5	5.61			
00675017				4.31	4.96	0.92	18.6
00675031	PH2-6658	2:25	61.1	11.06			
00675032				7.97	9.51	2.18	23.0
00675049	PH2-6660	3:08	63.1	4.73			
00675051				11.3	8.04	4.68	58.2
00675048	PH2-6660	3:08	65.6	14.5			
00675050				15.3	14.91	0.55	3.7
00675035	PH2-6660	3:08	68.1	24.7			
00675036				29.0	26.85	3.03	11.3

Table J4. Findings for duplicate GORE samples for total xylenes.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.21)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	0.37			
00675003				0.37	0.37	0.00	0.0
00675056	PH2-5324	0:33	48.1	2330			
00675060				2076	2203	179.88	8.2
00675061	PH2-5324	0:15	48.1	3485			
00675062				3637	3561	107.48	3.0
00675027	PH2-5388	0:15	31.6	21.03			
00675041				24.54	22.78	2.48	10.9
00675034	PH2-5604	2:00	49.6	0.63			
00675037				1.53	1.08	0.64	59.0
00675063	PH2-5604	2:00	49.6	5.27			
00675065				3.86	4.57	1.00	21.9
00675064	PH2-5606	0:15	61.6	25631			
00675066				27789	26710	1525.40	5.7
00675008	PH2-5608	2:00	34.6	12.24			
00675009				5.73	8.99	4.60	51.2
00675055	PH2-6508	2:28	57.5	14.79			
00675059				6.39	10.59	5.94	56.1
00675054	PH2-6508	2:28	59.6	11.05			
00675058				10.20	10.63	0.60	5.7
00675053	PH2-6508	2:28	62	9.24			
00675057				66.19	37.72	40.27	106.8
00675016	PH2-6627	2:00	57.5	20.76			
00675018				19.68	20.22	0.76	3.8
00675014	PH2-6627	2:00	62.5	19.68			
00675017				16.39	18.04	2.33	12.9
00675031	PH2-6658	2:25	61.1	52.52			
00675032				45.86	49.19	4.71	9.6
00675049	PH2-6660	3:08	63.1	35.41			
00675051				64.5	49.98	20.60	41.2
00675048	PH2-6660	3:08	65.6	155.2			
00675050				156.4	155.79	0.82	0.5
00675035	PH2-6660	3:08	68.1	179.1			
00675036				203.6	191.38	17.29	9.0

Table J5. Findings for duplicate GORE samples for undecane.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 2.9)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	nd			
00675003				4.96	3.93	1.46	37.1
00675056	PH2-5324	0:33	48.1	16.4			
00675060				16.4	16.4	0.00	0.0
00675061	PH2-5324	0:15	48.1	nd			
00675062				nd	3	0.00	0.0
00675027	PH2-5388	0:15	31.6	27.89			
00675041				24.68	26.28	2.27	8.6
00675034	PH2-5604	2:00	49.6	7.94			
00675037				8.58	8.26	0.45	5.5
00675063	PH2-5604	2:00	49.6	8.58			
00675065				8.88	8.73	0.21	2.4
00675064	PH2-5606	0:15	61.6	302			
00675066				nd	153	211.6	139
00675008	PH2-5608	2:00	34.6	8.11			
00675009				7.76	7.93	0.25	3.2
00675055	PH2-6508	2:28	57.5	27.3			
00675059				27.3	27.3	0.00	0.0
00675054	PH2-6508	2:28	59.6	36.6			
00675058				36.6	36.6	0.00	0.0
00675053	PH2-6508	2:28	62	27.3			
00675057				36.6	32.0	6.62	20.7
00675016	PH2-6627	2:00	57.5	70.1			
00675018				55.8	62.9	10.17	16.2
00675014	PH2-6627	2:00	62.5	62.1			
00675017				59.0	60.5	2.15	3.5
00675031	PH2-6658	2:25	61.1	99.2			
00675032				100.2	99.7	0.74	0.7
00675049	PH2-6660	3:08	63.1	52.3			
00675051				53.6	52.9	0.95	1.8
00675048	PH2-6660	3:08	65.6	50.6			
00675050				52.2	51.4	1.07	2.1
00675035	PH2-6660	3:08	68.1	74.9			
00675036				72.7	73.8	1.53	2.1

Table J6. Findings for duplicate GORE samples for 1,2,4-trimethylbenzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.21)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				bdl	0.21	0.00	0.0
00675056	PH2-5324	0:33	48.1	170.5			
00675060				191.3	180.9	14.72	8.1
00675061	PH2-5324	0:15	48.1	317			
00675062				289	303	19.93	6.6
00675027	PH2-5388	0:15	31.6	4.62			
00675041				3.92	4.27	0.49	11.4
00675034	PH2-5604	2:00	49.6	0.57			
00675037				0.57	0.57	0.00	0.0
00675063	PH2-5604	2:00	49.6	4.29			
00675065				6.09	5.19	1.27	24.5
00675064	PH2-5606	0:15	61.6	1863			
00675066				1895	1879	23.00	1.2
00675008	PH2-5608	2:00	34.6	2.32			
00675009				2.61	2.47	0.21	8.4
00675055	PH2-6508	2:28	57.5	1.5			
00675059				4.0	2.7	1.76	64.1
00675054	PH2-6508	2:28	59.6	4.6			
00675058				4.0	4.3	0.41	9.7
00675053	PH2-6508	2:28	62	13.2			
00675057				4.0	8.6	6.49	75.7
00675016	PH2-6627	2:00	57.5	5.4			
00675018				5.4	5.4	0.00	0.0
00675014	PH2-6627	2:00	62.5	4.0			
00675017				4.0	4.0	0.00	0.0
00675031	PH2-6658	2:25	61.1	37.1			
00675032				31.6	34.4	3.88	11.3
00675049	PH2-6660	3:08	63.1	41.9			
00675051				30.9	36.4	7.78	21.4
00675048	PH2-6660	3:08	65.6	66.4			
00675050				67.1	66.8	0.47	0.7
00675035	PH2-6660	3:08	68.1	87.6			
00675036				88.1	87.8	0.33	0.4

Table J7. Findings for duplicate GORE samples for 1,3,5-trimethylbenzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.20)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				0.33	0.26	0.10	37.0
00675056	PH2-5324	0:33	48.1	89.1			
00675060				77.3	83.2	8.35	10.0
00675061	PH2-5324	0:15	48.1	124			
00675062				142	133	12.18	9.2
00675027	PH2-5388	0:15	31.6	3.13			
00675041				3.13	3.13	0.00	0.0
00675034	PH2-5604	2:00	49.6	0.55			
00675037				0.55	0.55	0.00	0.0
00675063	PH2-5604	2:00	49.6	1.75			
00675065				1.46	1.61	0.20	12.7
00675064	PH2-5606	0:15	61.6	835			
00675066				862	848	19.19	2.3
00675008	PH2-5608	2:00	34.6	1.05			
00675009				1.05	1.05	0.00	0.0
00675055	PH2-6508	2:28	57.5	2.21			
00675059				1.54	1.9	0.48	25.4
00675054	PH2-6508	2:28	59.6	2.86			
00675058				2.21	2.5	0.46	18.1
00675053	PH2-6508	2:28	62	2.21			
00675057				4.73	3.5	1.78	51.3
00675016	PH2-6627	2:00	57.5	2.64			
00675018				2.64	2.6	0.00	0.0
00675014	PH2-6627	2:00	62.5	2.64			
00675017				1.83	2.2	0.57	25.4
00675031	PH2-6658	2:25	61.1	10.0			
00675032				11.7	10.9	1.18	10.9
00675049	PH2-6660	3:08	63.1	8.6			
00675051				11.2	9.9	1.87	18.8
00675048	PH2-6660	3:08	65.6	18.0			
00675050				19.3	18.6	0.88	4.7
00675035	PH2-6660	3:08	68.1	26.8			
00675036				24.5	25.7	1.63	6.3

Table J8. Findings for duplicate GORE samples for naphthalene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.19)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				bdl	0.19	0.00	0.0
00675056	PH2-5324	0:33	48.1	33.1			
00675060				29.7	31.4	2.39	7.6
00675061	PH2-5324	0:15	48.1	42			
00675062				50	46	5.48	11.9
00675027	PH2-5388	0:15	31.6	0.76			
00675041				0.76	0.76	0.00	0.0
00675034	PH2-5604	2:00	49.6	0.20			
00675037				0.20	0.20	0.00	0.0
00675063	PH2-5604	2:00	49.6	2.64			
00675065				2.21	2.42	0.30	12.5
00675064	PH2-5606	0:15	61.6	211			
00675066				233	222	15.57	7.0
00675008	PH2-5608	2:00	34.6	1.67			
00675009				1.67	1.67	0.00	0.0
00675055	PH2-6508	2:28	57.5	0.83			
00675059				0.83	0.8	0.00	0.0
00675054	PH2-6508	2:28	59.6	1.21			
00675058				1.21	1.2	0.00	0.0
00675053	PH2-6508	2:28	62	0.83			
00675057				1.93	1.4	0.77	56.0
00675016	PH2-6627	2:00	57.5	3.07			
00675018				3.07	3.1	0.00	0.0
00675014	PH2-6627	2:00	62.5	2.26			
00675017				1.84	2.1	0.29	14.4
00675031	PH2-6658	2:25	61.1	5.0			
00675032				5.0	5.0	0.00	0.0
00675049	PH2-6660	3:08	63.1	7.3			
00675051				8.8	8.0	1.06	13.2
00675048	PH2-6660	3:08	65.6	10.5			
00675050				11.0	10.7	0.35	3.2
00675035	PH2-6660	3:08	68.1	14.5			
00675036				14.8	14.7	0.23	1.6

Table J9. Findings for duplicate samples for 2-methylnaphthalene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.22)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				bdl	0.22	0.00	0.0
00675056	PH2-5324	0:33	48.1	11.5			
00675060				11.8	11.7	0.21	1.8
00675061	PH2-5324	0:15	48.1	15.7			
00675062				20.8	18.3	3.63	19.9
00675027	PH2-5388	0:15	31.6	nd			
00675041				nd	0.22	0.00	0.0
00675034	PH2-5604	2:00	49.6	0.23			
00675037				nd	0.22	0.01	3.3
00675063	PH2-5604	2:00	49.6	2.95			
00675065				2.40	2.68	0.39	14.5
00675064	PH2-5606	0:15	61.6	151			
00675066				179	165	19.56	11.9
00675008	PH2-5608	2:00	34.6	0.24			
00675009				0.24	0.24	0.00	0.0
00675055	PH2-6508	2:28	57.5	0.96			
00675059				0.52	0.7	0.31	41.3
00675054	PH2-6508	2:28	59.6	1.36			
00675058				2.12	1.7	0.54	30.9
00675053	PH2-6508	2:28	62	0.96			
00675057				1.36	1.2	0.29	24.7
00675016	PH2-6627	2:00	57.5	1.13			
00675018				1.13	1.1	0.00	0.0
00675014	PH2-6627	2:00	62.5	1.13			
00675017				0.62	0.9	0.36	41.3
00675031	PH2-6658	2:25	61.1	4.91			
00675032				4.91	4.9	0.00	0.0
00675049	PH2-6660	3:08	63.1	7.35			
00675051				9.01	8.2	1.17	14.3
00675048	PH2-6660	3:08	65.6	9.24			
00675050				9.95	9.6	0.50	5.2
00675035	PH2-6660	3:08	68.1	13.2			
00675036				14.8	14.0	1.12	8.0

Table J10. Findings for duplicate GORE samples for trichloroethylene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.28)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	nd			
00675003				bdl	0.28	0.00	0.0
00675056	PH2-5324	0:33	48.1	nd			
00675060				nd	0.3	0.00	0.0
00675061	PH2-5324	0:15	48.1	nd			
00675062				nd	0.3	0.00	0.0
00675027	PH2-5388	0:15	31.6	nd			
00675041				nd	0.28	0.00	0.0
00675034	PH2-5604	2:00	49.6	0.29			
00675037				nd	0.29	0.01	2.8
00675063	PH2-5604	2:00	49.6	nd			
00675065				nd	0.28	0.00	0.0
00675064	PH2-5606	0:15	61.6	nd			
00675066				nd	0	0.00	0.0
00675008	PH2-5608	2:00	34.6	nd			
00675009				nd	0.28	0.00	0.0
00675055	PH2-6508	2:28	57.5	4.04			
00675059				nd	2.2	2.66	123
00675054	PH2-6508	2:28	59.6	nd			
00675058				nd	0.3	0.00	0.0
00675053	PH2-6508	2:28	62	4.04			
00675057				17.22	10.6	9.32	87.6
00675016	PH2-6627	2:00	57.5	nd			
00675018				nd	0.3	0.00	0.0
00675014	PH2-6627	2:00	62.5	nd			
00675017				nd	0.3	0.00	0.0
00675031	PH2-6658	2:25	61.1	nd			
00675032				nd	0.3	0.00	0.0
00675049	PH2-6660	3:08	63.1	nd			
00675051				nd	0.3	0.00	0.0
00675048	PH2-6660	3:08	65.6	nd			
00675050				nd	0.3	0.00	0.0
00675035	PH2-6660	3:08	68.1	12.47			
00675036				nd	6.4	8.62	135

Table J11. Findings for duplicate GORE samples for octane.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.40)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	0.63			
00675003				0.63	0.63	0.00	0.0
00675056	PH2-5324	0:33	48.1	6.48			
00675060				6.48	6.5	0.00	0.0
00675061	PH2-5324	0:15	48.1	11.15			
00675062				12.44	11.8	0.91	7.8
00675027	PH2-5388	0:15	31.6	8.29			
00675041				8.29	8.29	0.00	0.0
00675034	PH2-5604	2:00	49.6	1.31			
00675037				1.03	1.17	0.19	16.6
00675063	PH2-5604	2:00	49.6	1.03			
00675065				1.03	1.03	0.00	0.0
00675064	PH2-5606	0:15	61.6	480			
00675066				522	501	30.04	6.0
00675008	PH2-5608	2:00	34.6	2.89			
00675009				2.65	2.77	0.17	6.1
00675055	PH2-6508	2:28	57.5	8.11			
00675059				5.81	7.0	1.63	23.3
00675054	PH2-6508	2:28	59.6	5.81			
00675058				5.81	5.8	0.00	0.0
00675053	PH2-6508	2:28	62	5.81			
00675057				10.3	8.0	3.16	39.2
00675016	PH2-6627	2:00	57.5	17.5			
00675018				17.5	17.5	0.00	0.0
00675014	PH2-6627	2:00	62.5	15.0			
00675017				15.0	15.0	0.00	0.0
00675031	PH2-6658	2:25	61.1	14.5			
00675032				20.2	17.4	4.05	23.3
00675049	PH2-6660	3:08	63.1	8.20			
00675051				8.17	8.2	0.02	0.3
00675048	PH2-6660	3:08	65.6	6.45			
00675050				6.45	6.4	0.00	0.0
00675035	PH2-6660	3:08	68.1	11.84			
00675036				11.84	11.8	0.00	0.0

Table J12. Findings for duplicate GORE samples for tetrachloroethylene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 0.28)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	nd			
00675003				nd	0.28	0.00	0.0
00675056	PH2-5324	0:33	48.1	nd			
00675060				nd	0.28	0.00	0.0
00675061	PH2-5324	0:15	48.1	2.57			
00675062				nd	1.4	1.62	114
00675027	PH2-5388	0:15	31.6	22.4			
00675041				nd	11.35	15.66	138
00675034	PH2-5604	2:00	49.6	nd			
00675037				0.53	0.40	0.18	44.3
00675063	PH2-5604	2:00	49.6	nd			
00675065				0.53	0.40	0.18	44.3
00675064	PH2-5606	0:15	61.6	nd			
00675066				nd	0	0.00	0.0
00675008	PH2-5608	2:00	34.6	0.78			
00675009				nd	0.53	0.36	67.4
00675055	PH2-6508	2:28	57.5	nd			
00675059				nd	0.3	0.00	0.0
00675054	PH2-6508	2:28	59.6	4.39			
00675058				nd	2.3	2.91	125
00675053	PH2-6508	2:28	62	nd			
00675057				2.39	1.3	1.50	112
00675016	PH2-6627	2:00	57.5	nd			
00675018				nd	0.3	0.00	0.0
00675014	PH2-6627	2:00	62.5	nd			
00675017				5.27	2.8	3.53	127
00675031	PH2-6658	2:25	61.1	2.42			
00675032				4.45	3.4	1.43	41.7
00675049	PH2-6660	3:08	63.1	nd			
00675051				nd	0.3	0.00	0.0
00675048	PH2-6660	3:08	65.6	nd			
00675050				nd	0.3	0.00	0.0
00675035	PH2-6660	3:08	68.1	nd			
00675036				7.19	3.7	4.89	131

Table J13. Findings for duplicate GORE samples for isopropylbenzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 6.6)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				bdl	6.60	0.00	0.0
00675056	PH2-5324	0:33	48.1	80.0			
00675060				72.0	76.0	5.71	7.5
00675061	PH2-5324	0:15	48.1	112			
00675062				127	120	10.21	8.5
00675027	PH2-5388	0:15	31.6	nd			
00675041				nd	6.60	0.00	0
00675034	PH2-5604	2:00	49.6	nd			
00675037				nd	6.60	0.00	0.0
00675063	PH2-5604	2:00	49.6	bdl			
00675065				bdl	6.60	0.00	0.0
00675064	PH2-5606	0:15	61.6	787			
00675066				820	804	23.17	2.9
00675008	PH2-5608	2:00	34.6	15.9			
00675009				14.9	15.40	0.76	4.9
00675055	PH2-6508	2:28	57.5	bdl			
00675059				nd	6.6	0.00	0.0
00675054	PH2-6508	2:28	59.6	nd			
00675058				nd	6.6	0.00	0
00675053	PH2-6508	2:28	62	nd			
00675057				bdl	6.6	0.00	0
00675016	PH2-6627	2:00	57.5	nd			
00675018				nd	6.6	0.00	0.0
00675014	PH2-6627	2:00	62.5	nd			
00675017				nd	6.6	0.00	0
00675031	PH2-6658	2:25	61.1	bdl			
00675032				bdl	6.6	0.00	0.0
00675049	PH2-6660	3:08	63.1	bdl			
00675051				bdl	6.6	0.00	0.0
00675048	PH2-6660	3:08	65.6	38.9			
00675050				37.8	38.3	0.77	2.0
00675035	PH2-6660	3:08	68.1	50.0			
00675036				48.4	49.2	1.08	2.2

Table J14. Findings for duplicate GORE samples for *n*-propylbenzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 7.07)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				bdl	7.07	0.00	0.0
00675056	PH2-5324	0:33	48.1	56.7			
00675060				49.4	53.0	5.11	9.6
00675061	PH2-5324	0:15	48.1	76.6			
00675062				87.0	82	7.36	9.0
00675027	PH2-5388	0:15	31.6	bdl			
00675041				bdl	7.07	0.00	0
00675034	PH2-5604	2:00	49.6	nd			
00675037				nd	7.07	0.00	0.0
00675063	PH2-5604	2:00	49.6	bdl			
00675065				bdl	7.07	0.00	0.0
00675064	PH2-5606	0:15	61.6	398			
00675066				403	401	3.48	0.9
00675008	PH2-5608	2:00	34.6	bdl			
00675009				bdl	7.07	0.00	0.0
00675055	PH2-6508	2:28	57.5	nd			
00675059				bdl	7.1	0.00	0.0
00675054	PH2-6508	2:28	59.6	bdl			
00675058				bdl	7.1	0.00	0
00675053	PH2-6508	2:28	62	bdl			
00675057				nd	7.1	0.00	0
00675016	PH2-6627	2:00	57.5	bdl			
00675018				bdl	7.1	0.00	0.0
00675014	PH2-6627	2:00	62.5	bdl			
00675017				bdl	7.1	0.00	0
00675031	PH2-6658	2:25	61.1	bdl			
00675032				bdl	7.1	0.00	0.0
00675049	PH2-6660	3:08	63.1	23.2			
00675051				21.3	22.2	1.39	6.2
00675048	PH2-6660	3:08	65.6	18.2			
00675050				bdl	12.6	7.85	62.2
00675035	PH2-6660	3:08	68.1	17.2			
00675036				bdl	12.2	7.19	59.1

Table J15. Findings for duplicate GORE samples for isopropyltoluene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 5.94)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	bdl			
00675003				bdl	5.94	0.00	0.0
00675056	PH2-5324	0:33	48.1	11.0			
00675060				nd	8.5	3.60	42.4
00675061	PH2-5324	0:15	48.1	16.1			
00675062				19.3	18	2.27	12.8
00675027	PH2-5388	0:15	31.6	bdl			
00675041				bdl	5.94	0.00	0
00675034	PH2-5604	2:00	49.6	nd			
00675037				nd	5.94	0.00	0.0
00675063	PH2-5604	2:00	49.6	bdl			
00675065				bdl	5.94	0.00	0.0
00675064	PH2-5606	0:15	61.6	123			
00675066				132	127	6.52	5.1
00675008	PH2-5608	2:00	34.6	bdl			
00675009				bdl	5.94	0.00	0.0
00675055	PH2-6508	2:28	57.5	bdl			
00675059				bdl	5.9	0.00	0.0
00675054	PH2-6508	2:28	59.6	bdl			
00675058				bdl	5.9	0.00	0
00675053	PH2-6508	2:28	62	bdl			
00675057				bdl	5.9	0.00	0
00675016	PH2-6627	2:00	57.5	6.71			
00675018				9.69	8.2	2.11	25.7
00675014	PH2-6627	2:00	62.5	6.10			
00675017				6.10	6.1	0.00	0
00675031	PH2-6658	2:25	61.1	bdl			
00675032				bdl	5.9	0.00	0.0
00675049	PH2-6660	3:08	63.1	bdl			
00675051				bdl	5.9	0.00	0.0
00675048	PH2-6660	3:08	65.6	bdl			
00675050				bdl	5.9	0.00	0.0
00675035	PH2-6660	3:08	68.1	bdl			
00675036				bdl	5.9	0.00	0.0

Table J16. Findings for duplicate GORE samples for *n*-butylbenzene.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	Conc. (µg/L) (DL = 5.85)	Mean conc. (µg/L)	Standard deviation	%RSD
00675002	HY2-4467	2:00	13	nd			
00675003				nd	5.85	0.00	0.0
00675056	PH2-5324	0:33	48.1	bdl			
00675060				nd	5.85	0.00	0.0
00675061	PH2-5324	0:15	48.1	6.16			
00675062				6.72	6.44	0.40	6.2
00675027	PH2-5388	0:15	31.6	nd			
00675041				nd	5.85	0.00	0
00675034	PH2-5604	2:00	49.6	nd			
00675037				nd	5.85	0.00	0.0
00675063	PH2-5604	2:00	49.6	bdl			
00675065				bdl	5.85	0.00	0.0
00675064	PH2-5606	0:15	61.6	66.9			
00675066				71.6	69.3	3.32	4.8
00675008	PH2-5608	2:00	34.6	bdl			
00675009				bdl	5.85	0.00	0.0
00675055	PH2-6508	2:28	57.5	bdl			
00675059				nd	5.85	0.00	0.0
00675054	PH2-6508	2:28	59.6	bdl			
00675058				bdl	5.85	0.00	0
00675053	PH2-6508	2:28	62	bdl			
00675057				bdl	5.85	0.00	0
00675016	PH2-6627	2:00	57.5	nd			
00675018				nd	5.85	0.00	0.0
00675014	PH2-6627	2:00	62.5	nd			
00675017				nd	5.85	0.00	0
00675031	PH2-6658	2:25	61.1	bdl			
00675032				bdl	5.85	0.00	0.0
00675049	PH2-6660	3:08	63.1	bdl			
00675051				bdl	5.85	0.00	0.0
00675048	PH2-6660	3:08	65.6	bdl			
00675050				bdl	5.85	0.00	0.0
00675035	PH2-6660	3:08	68.1	7.40			
00675036				6.83	7.12	0.40	5.6

Table J17. Findings for duplicate GORE samples for other analytes occasionally detected in the study.

Module #	Well #	Contact time (hr:min)	Module depth (ft bgs)	14DCB (DL=0.22)	CCl_4 (DL=0.23)	112TCA (DL=0.35)	1,2-Dibromo-ethane (DL=11.7)	CLB (DL=0.25)
00675002	HY2-4467	2:00	13	nd	nd	nd	nd	nd
00675003				nd	nd	nd	nd	nd
00675056	PH2-5324	0:33	48.1	nd	nd	nd	nd	nd
00675060				nd	nd	nd	nd	nd
00675061	PH2-5324	0:15	48.1	nd	nd	nd	nd	nd
00675062				nd	nd	nd	nd	nd
00675027	PH2-5388	0:15	31.6	nd	nd	nd	nd	nd
00675041				nd	nd	nd	nd	nd
00675034	PH2-5604	2:00	49.6	nd	nd	nd	nd	nd
00675037				nd	nd	nd	nd	nd
00675063	PH2-5604	2:00	49.6	nd	nd	nd	nd	nd
00675065				nd	nd	nd	nd	nd
00675064	PH2-5606	0:15	61.6	nd	nd	nd	nd	nd
00675066				nd	nd	nd	nd	nd
00675008	PH2-5608	2:00	34.6	nd	nd	nd	nd	nd
00675009				nd	nd	nd	nd	nd
00675055	PH2-6508	2:28	57.5	nd	nd	nd	nd	nd
00675059				nd	nd	nd	nd	nd
00675054	PH2-6508	2:28	59.6	nd	nd	nd	nd	nd
00675058				nd	nd	nd	nd	nd
00675053	PH2-6508	2:28	62	nd	nd	nd	nd	nd
00675057				nd	nd	nd	nd	nd
00675016	PH2-6627	2:00	57.5	nd	nd	nd	nd	nd
00675018				nd	nd	nd	nd	nd
00675014	PH2-6627	2:00	62.5	nd	nd	nd	nd	nd
00675017	PH2-6627	2:00	62.5	nd	nd	nd	nd	nd
00675031	PH2-6658	2:25	61.1	nd	nd	nd	nd	nd
00675032				nd	nd	nd	nd	nd
00675049	PH2-6660	3:08	63.1	nd	nd	nd	nd	nd
00675051				nd	nd	nd	nd	nd
00675048	PH2-6660	3:08	65.6	nd	nd	nd	nd	nd
00675050				nd	nd	nd	nd	nd
00675035	PH2-6660	3:08	68.1	nd	nd	nd	nd	nd
00675036				nd	nd	nd	nd	nd

Appendix K: Results for the Low-Flow Duplicate Samples

Table K1. Results for the low-flow duplicate samples.

Analyte	Well	Conc. (µg/L)	Mean Conc. (µg/L)	Std. Dev.	RSD (%)
benzene	HY2-4467	0.3J	0.3	0	0.0
	HY2-4467 DUP	0.3J			
	PH2-5607	24	22	2.828427	12.9
	PH2-5607 DUP	20			
	PH2-6660	**25**	25	0	0.0
	PH2-6660 DUP	**25**			
toluene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	5U	3.5	2.12132	**60.6***
	PH2-5607 DUP	2			
	PH2-6660	1U	1	0	0.0
	PH2-6660 DUP	1U			
ethylbenzene	HY2-4467	3	3.5	0.707107	20.2
	HY2-4467 DUP	4			
	PH2-5607	650 E	580	98.99495	17.1
	PH2-5607 DUP	510			
	PH2-6660	1U	1	0	0.0
	PH2-6660 DUP	1U			
xylenes (Total)	HY2-4467	3U	3	0	0.0
	HY2-4467 DUP	3U			
	PH2-5607	930 E	890	56.56854	6.4
	PH2-5607 DUP	850			
	PH2-6660	29	30	1.414214	4.7
	PH2-6660 DUP	31			
naphthalene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	21	17.5	4.949747	28.3*
	PH2-5607 DUP	14			
	PH2-6660	0.9J	0.9	0	0.0
	PH2-6660 DUP	0.9J			
1,2,4-trimethylbenzene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	67	59	11.31371	19.2
	PH2-5607 DUP	51			
	PH2-6660	10	10.5	0.707107	6.7

Analyte	Well	Conc. (µg/L)	Mean Conc. (µg/L)	Std. Dev.	RSD (%)
	PH2-6660 DUP	11			
1,3,5-trimethylbenzene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	17	25	11.31371	45.3*
	PH2-5607 DUP	33			
	PH2-6660	3	3	0	0
	PH2-6660 DUP	3			
n-butylbenzene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	0.9J	0.95	0.070711	7.4
	PH2-5607 DUP	1J			
	PH2-6660	1U	1	0	0.0
	PH2-6660 DUP	1U			
n-propylbenzene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	39	40.5	2.12132	5.2
	PH2-5607 DUP	42			
	PH2-6660	9	9.0	0	0
	PH2-6660 DUP	9			
isopropylbenzene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	5U	5U	0	0.0
	PH2-5607 DUP	1U	3	2.828427	94.3
	PH2-6660	0.4J	0.4	0	0.0
	PH2-6660 DUP	0.4J			
sec-butylbenzene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	2J	2	0	0.0
	PH2-5607 DUP	2			
	PH2-6660	0.8J	0.8	0	0.0
	PH2-6660 DUP	0.8J			
tert-butylbenzene	HY2-4467	3	3	0	0
	HY2-4467 DUP	3			
	PH2-5607	74	74	0	0
	PH2-5607 DUP	74			
	PH2-6660	15	15	0	0
	PH2-6660 DUP	15			
p-isopropyltoluene	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	5	3	2.8284	94.3
	PH2-5607 DUP	1U			

Analyte	Well	Conc. (µg/L)	Mean Conc. (µg/L)	Std. Dev.	RSD (%)
	PH2-6660	1U	1	0	0.0
	PH2-6660 DUP	1U			
1,2-dibromoethane	HY2-4467	1U	1	0	0.0
	HY2-4467 DUP	1U			
	PH2-5607	3	3	0	0.0
	PH2-5607 DUP	3J			
	PH2-6660	2	2	0.0	0
	PH2-6660 DUP	2			

*Samples where the %RSD exceeded the guideline.

Table K2. Data for replicate low-flow samples.

		Concentration (µg/L)						
Well	Date	BNZ	TOL	EBNZ	XYLs	NAPH	124TMB	135TMB
HY2-4467	10/26/11	0.3J	1U	3	3U	1U	1U	1U
Dup		0.3J	1U	4	3U	1U	1U	1U
	mean	0.3	1	3.5	3	1	1	1
	Std Dev	0	0	0.70711	0	0	0	0
	%RSD	0.0	0.0	20.2	0	0	0	0
PH2-5607	10/25/11	24	5U	650 E	930 E	21	67	17
Dup		20	2	510	850	14	51	33
	mean	22	3.5	580	890	17.5	59	25
	Std Dev	2.8284	2.1213	98.995	56.5685	4.94975	11.314	11.314
	%RSD	12.9	60.6	17.1	6.4	28.3	19.2	45.3
PH2-6660	10/28/11	25	1U	1U	29	0.9J	10	3
Dup		25	1U	1U	31	0.9J	11	3
	mean	25	1	1	30	0.9	10.5	3
	Std Dev	0	0	0	1.41421	0	0.70711	0
	%RSD	0.0	0.0	0.0	4.7	0.0	6.7	0.0
PH2-6508	10/26/11	1U	1U	1U	3U	1U	1U	1U
Dup		0.4J	1	0.9J	3	1	1U	1U
	mean	0.7	1	0.95	3	1	1	1
	Std Dev	0.42426	0	0.07071	0	0	0	0
	%RSD	60.6	0.0	7.4	0.0	0.0	0.0	0.0

Table K2 continued.

		Concentration (µg/L)						
Well	Date	*n*-butyl-benzene	*n*-propyl-benzene	p-isopropyl-toluene	*sec*-butyl-benzene	*tert*-butyl-benzene	1,2-dibromo-ethane	Isopropyl-benzene
HY2-4467	10/26/11	1U	1U	1U	1U	3	1U	1U
Dup		1U	1U	1U	1U	3	1U	1U
	mean	1	1	1	1	3	1	1
	Std Dev	0	0	0	0	0	0	0
	%RSD	0	0	0	0	0	0	0
PH2-5607	10/25/11	0.9J	39	5	2J	74	3	5U
Dup		1J	42	1U	2	74	3J	1U
	mean	0.95	40.5	3	2	74	3	3
	Std Dev	0.07071	2.1213	2.8284	0.00000	0.00000	0.00000	2.8284
	%RSD	7.4	5.2	94.3	0.0	0.0	0.0	94.3
PH2-6660	10/28/11	1U	9	1U	0.8J	15	2	0.4J
Dup		1U	9	1U	0.8J	15	2	0.4J
	mean	1	9	1	0.8	15	2	0.4
	Std Dev	0	0	0	0	0	0	0
	%RSD	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PH2-6508	10/26/11	1U	1U	1U	1U	1U	1U	1U
Dup		1UJ	0.7J	1UJ	0.2J	1U	1U	2
	mean	1	0.85	1	0.6	1	1	1.5
	Std Dev	0	0.21213	0	0.56568	0	0	0.70711
	%RSD	0.0	25.0	0.0	94.3	0.0	0.0	47.1

Values shaded in green were at or near the detection limit and were not used in the summary table (13).

Appendix L: Raw Data for the Pease Site

Table L1. Results for benzene, toluene, ethylbenzene, total xylenes, undecane, and 1,2,4- and 1,3,5-trimethylbenzene.

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	BNZ	TOL	EBNZ	XYLs	UNDEC	124 TMB	135 TMB
00674947	HY2-4460	10/25	8:42	0:15	8.2	5.27	8.49	32.7	117	nd	51.5	26.3
00674946	HY2-4460	10/25	8:42	0:15	10.2	13.0	9.19	96.5	353	82.7	156	84.3
00674948	HY2-4460	10/25	8:42	0:15	12.2	39.4	14.1	102	354	62.2	195	102
00674956	HY2-4460	10/25	10:26	0:15	8.2	3.63	1.78	19.4	48.2	47.0	36.8	17.2
00674955	HY2-4460	10/25	10:26	0:15	10.2	19.6	5.61	204.7	657	nd	317	150
00674954	HY2-4460	10/25	10:26	0:15	12.2	49.8	16.7	172.6	541	55.8	211	89.0
LF	HY2-4460	10/25	10:10		12.4	70	2	250	1,020		280	130.0
00674992	HY2-4467	10/26	11:03	2:30	13	0.37	0.79	bdl	0.3	3.67	0.43	0.3
00675002	HY2-4467	10/26	15:40	2:00	13	0.82	0.76	1.48	0.4	nd	bdl	nd
LF	HY2-4467	10/26	15:22		11.4	0.3J	1U	3	3U		1U	1U
00674949	HY2-5400	10/25	8:47	0:30	31.1	nd	72.2	611	2,158	15.3	307	113.2
00674957	HY2-5400	10/25	10:22	0:30	31.1	4.49	72.2	638	2,264	nd	366	137.1
LF	HY2-5400	10/25	10:15		31	nd	76	1,100	5,200		580	190
00675047	PH1-5321	10/24	14:38	3:01	24.1	1.55	2.13	bdl	0.3	nd	bdl	nd
00675046	PH1-5321	10/24	14:38	3:01	26.6	3.54	2.02	nd	0.3	3.59	bdl	nd
00675045	PH1-5321	10/24	14:38	3:01	29.1	1.68	0.57	bdl	bdl	nd	bdl	0.25
LF*	PH1-5321	4/19			27	nd	1 U		3 U		1 U	
00674953	PH1-6507	10/25	9:44	2:00	71.1	21.6	25.1	2.81	11.5	50.2	3.10	2.47
00674952	PH1-6507	10/25	9:44	2:00	73.6	21.6	22.8	4.08	14.6	53.6	3.78	2.47
00674951	PH1-6507	10/25	9:44	2:00	76.1	50.2	374	19.0	65.9	56.7	6.38	3.91

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	BNZ	TOL	EBNZ	XYLs	UNDEC	124 TMB	135 TMB
00675044	PH1-6507	10/24	14:29	1:59	71.1	148	41.4	1.51	3.9	77.2	0.92	nd
00675043	PH1-6507	10/24	14:29	1:59	73.6	157	39.2	1.51	3.9	77.2	0.92	0.94
00675042	PH1-6507	10/24	14:29	1:59	76.1	165	45.9	1.51	5.1	83.0	0.92	nd
LF	PH1-6507	10/24	17:47		74	nd	1 U	1 U	3 U		1 U	1 U
00674988	PH2-5324	10/26	9:37	0:30	48.1	9.09	34.5	944	2,354	17.7	254	109
00674993	PH2-5324	10/26	11:27	0:30	48.1	15.7	30.2	798	1,895	16.1	152	70.6
LF	PH2-5324	10/26	11:10		48.5	13	6	1,400	4,200		330	140
00674976	PH2-5341	10/26	8:46	0:15	31	3,514	7,455	2,193	7,366	119	701	320
00674989	PH2-5341	10/26	10:25	0:15	31	4,261	8,810	2,581	8,726	298	890	408
LF	PH2-5341	10/26	10:00		31.5	3,200	26,000	2,300	11,000		620	240
00674960	PH2-5369	10/25	10:53	0:15	38.6	691	17.4	248	419	228	77.3	42.5
00674959	PH2-5369	10/25	10:53	0:15	40.6	465	7.18	189	265	187	60.1	32.4
00674958	PH2-5369	10/25	10:53	0:15	42.6	2,678	18.1	750	1,900	162	147	75.4
00674967	PH2-5369	10/25	13:42	0:15	38.6	172	3.80	53.5	111	195	38.8	24.1
00674966	PH2-5369	10/25	13:42	0:15	40.6	788	2.02	258	525	211	92.7	46.9
00674965	PH2-5369	10/25	13:42	0:15	42.6	2,761	8.81	788	1,956	270	169	90.0
LF	PH2-5369	10/25	12:30		41.0	2	0.8 J	660	2,300		170	70
00674961	PH2-5388	10/25	12:00	0:15	31.6	8.00	16.5	4.41	18.9	nd	7.91	3.83
00674968	PH2-5388	10/25	14:10	0:15	31.6	4.23	5.74	1.01	5.4	15.5	0.94	2.42
LF	PH2-5388	10/25	14:05		32.5	nd	1 U	1 U	3 U		1 U	1 U
00674977	PH2-5601	10/26	8:50	0:15	42.0	30.5	18.7	429	1,068	20.0	91.0	39.1
00674990	PH2-5601	10/26	10:25	0:15	42.0	121	18.7	955	2,380	26.9	205	79.7
LF	PH2-5601	10/26	10:05		43.3	92	1 J	1,000	3,500		240	94.0
00674950	PH2-5602	10/25	9:22	1:00	32.6	1.99	278	681	1,843	nd	181	68.9
00674964	PH2-5602	10/25	11:36	0:15	32.6	7.39	64.3	657	2,519	nd	302	113
LF	PH2-5602	10/25	11;25		34		240	990	3,800		270	120

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	BNZ	TOL	EBNZ	XYLs	UNDEC	124 TMB	135 TMB
00674962	PH2-5603	10/25	12:08	2:00	44.6	0.46	0.43	bdl	0.4	3.84	0.37	0.51
00674969	PH2-5603	10/25	15:14	2:00	44.6	1.64	27.5	2.64	9.5	4.56	1.28	0.81
LF	PH2-5603	10/25	15:05		45		1 U	1 U	3 U		1 U	1 U
00675034	PH2-5604	10/28	11:04	2:00	49.6	0.48	0.45	0.22	0.6	7.94	0.57	0.55
00675063	PH2-5604	10/28	15:21	2:00	49.6	0.92	2.16	0.96	5.3	8.58	6.09	1.75
LF	PH2-5604	10/28	15:10		50		1 U	1 U	3 UJ		1 U	1 U
00675023	PH2-5605	10/28	8:23	2:07	42.6	4.16	19.4	3.26	11.9	6.05	2.13	0.96
00675052	PH2-5605	10/28	12:57	2:48	42.6	0.70	2.73	1.65	9.2	5.46	8.44	2.31
LF	PH2-5605	10/28	12:53		43		1 U	1 U	3 U		1 U	1 U
00674991	PH2-5606	10/26	10:22	0:15	61.6	1,631	3560	12,188	32,404	199	2,063	948
00674994	PH2-5606	10/26	12:11	0:15	61.6	195	1656	9,864	25,538	225	1,798	805
LF	PH2-5606	10/26	11:35		61.7	34	440	2,700	11,000		630	250
00674971	PH2-5607	10/25	15:15	0:15	42.4	15.4	17.6	1.02	2.0	46.6	nd	nd
00674972	PH2-5607	10/25	16:48	0:15	42.4	4.30	4.03	1.02	2.9	28.2	0.96	nd
LF	PH2-5607	10/25	16:40		42.4	24	5U	650 E	930 E		67	17
00675008	PH2-5608	10/27	10:07	2:00	34.6	2.58	13.9	3.05	12.2	8.11	2.61	1.05
00675019	PH2-5608	10/27	15:01	2:00	34.6	0.72	1.28	0.23	2.09	6.97	0.41	nd
LF	PH2-5608	10/27	14:45		35		1U	1U	3U		1U	1U
00675004	PH2-5627	10/27	8:20	2:00	36.8	1.14	3.10	0.80	3.92	6.91	2.72	0.72
00675013	PH2-5627	10/27	11:20	3:28	36.8	0.75	2.85	0.53	2.17	4.94	0.83	0.48
LF	PH2-5627	10/27	11:08		37.2		1 U	1 U	3 U		1 U	1 U
00674978	PH2-5628	10/26	9:16	2:16	48.0	14.5	11.6	1.30	4.38	49.8	0.79	1.50
00674999	PH2-5628	10/26	13:51	2:00	48.0	20.8	19.6	2.69	6.89	69.7	0.86	0.88
LF	PH2-5628	10/26	13:34		48.0		1 U	1 U	3 U		1 U	1 U
00674987	PH2-6508	10/26	9:51	2:16	57.5	22.5	18.9	4.26	11.0	32.4	1.76	1.81
00674986	PH2-6508	10/26	9:51	2:00	59.6	27.6	21.4	10.5	16.3	32.4	1.76	1.81

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	BNZ	TOL	EBNZ	XYLs	UNDEC	124 TMB	135 TMB
00674979	PH2-6508	10/26	9:51	2:16	62	22.5	18.9	2.94	7.5	32.4	1.76	1.81
00675001	PH2-6508	10/26	13:30	2:00	57.5	22.3	11.2	5.50	23.5	24.0	1.74	nd
00675000	PH2-6508	10/26	13:30	2:16	59.6	17.1	8.62	6.75	22.5	24.0	1.74	1.79
00674995	PH2-6508	10/26	13:30	2:00	62	17.1	3.15	5.50	16.3	nd	1.74	1.79
LF	PH2-6508	10/26	13:10		60	25	1	1 J	3.0		1 U	1 U
00675007	PH2-6627	10/27	8:31	2:00	57.5	22.6	26.3	4.27	18.3	58.6	11.2	4.13
00675006	PH2-6627	10/27	8:31	2:00	60	22.6	33.4	4.27	21.4	61.7	11.8	4.13
00675005	PH2-6627	10/27	8:31	2:00	62.5	22.6	23.9	4.27	20.5	67.2	10.6	4.13
00675016	PH2-6627	10/27	12:57	2:00	57.5	38.1	50.0	8.14	20.8	70.1	5.43	2.64
00675015	PH2-6627	10/27	12:57	2:00	60	38.1	50.0	6.89	23.9	55.8	6.79	3.41
00675014	PH2-6627	10/27	12:57	2:00	62.5	33.1	45.4	5.61	19.7	62.1	4.02	2.64
LF	PH2-6627	10/27	12:35		60.4		1 U	1 U	3 U		1 U	1 U
00674975	PH2-6628	10/26	8:45	2:00	61.7	16.2	15.3	1.44	5.88	30.8	1.62	1.66
00674974	PH2-6628	10/26	8:45	2:00	64.2	21.0	15.3	1.44	4.87	30.8	0.87	nd
00674973	PH2-6628	10/26	8:45	2:00	66.7	21.0	19.9	1.44	6.99	30.8	1.62	1.66
00674998	PH2-6628	10/26	13:05	2:00	61.7	21.1	24.4	2.74	8.10	36.7	1.63	1.67
00674997	PH2-6628	10/26	13:05	2:00	64.2	21.1	24.4	2.74	8.10	45.6	1.63	1.67
00674996	PH2-6628	10/26	13:05	2:00	66.7	21.1	28.9	2.74	9.17	52.6	1.63	1.67
LF	PH2-6628	10/26	12:22		64.6		1 U	1 U	3 U		1 U	1 U
00674963	PH2-6657	10/25	12:10	2:00	54.6	16.6	25.1	8.88	16.8	37.4	4.45	2.47
00674970	PH2-6657	10/25	15:20	2:00	54.6	90.6	259.4	13.4	41.7	42.2	3.78	2.47
LF	PH2-6657	10/25	15:00		54.3		1 U	1 U	3 U		1 U	1 U
00675031	PH2-6658	10/28	11:49	2:24	61.1	32.4	40.5	11.1	52.5	99.2	31.6	10.0
LF	PH2-6658	10/28	16:23		61.5		1 U	1 U	3 U		1 U	1 U
00675012	PH2-6659	10/27	10:13	2:00	52.1	12.0	3.22	5.61	34.4	43.9	13.2	5.64
00675011	PH2-6659	10/27	10:13	2:00	54.6	17.5	40.8	14.2	60.9	48.3	19.2	7.06

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	BNZ	TOL	EBNZ	XYLs	UNDEC	124 TMB	135 TMB
00675010	PH2-6659	10/27	10:13	2:00	57.1	12.0	6.07	6.89	49.3	48.3	13.8	4.91
00675022	PH2-6659	10/27	16:23	1:00	52.1	29.5	28.0	5.00	18.4	84.5	4.24	3.06
00675021	PH2-6659	10/27	16:23	1:00	54.6	29.5	36.5	5.00	20.4	84.5	4.24	3.06
00675020	PH2-6659	10/27	16:23	1:00	57.1	38.4	40.7	7.26	27.7	97.5	5.47	4.40
LF	PH2-6659	10/27	16:15		55		1 U	1 U	3 U		1 U	1 U
00675026	PH2-6660	10/28	8:18	2:00	63.1	16.8	3.22	6.61	42.0	80.9	13.2	5.38
00675025	PH2-6660	10/28	8:18	2:00	65.6	190.5	40.8	29.0	222	86.4	70.7	28.0
00675024	PH2-6660	10/28	8:18	2:00	68.1	21.9	6.07	20.3	159	80.9	64.9	25.7
00675049	PH2-6660	10/28	12:00	3:08	63.1	8.28	28.0	4.73	35.4	52.3	30.9	8.59
00675048	PH2-6660	10/28	12:00	3:08	65.6	71.8	36.5	14.5	155	50.6	67.1	18.0
00675035	PH2-6660	10/28	12:00	3:08	68.1	26.1	11.4	17.6	128.1 179	52.2 4.9	63.4	19.3
LF	PH2-6660	10/28	11:25		68.5	25	1 U	1U	29.0		10	3
Detection limit for Modules						**0.25**	**0.23**	**0.21**	**0.21**	**2.90**	**0.21**	**0.20**
Detection limit for low-flow samples						**1**	**1**	**1**	**3**	**1**	**1**	**1**
*Historical data because pump did not work.												

Table L2. Results for naphthalene, 2-methylnaphthalene, trichloroethylene, isopropylbenzene, *n*-propylbenzene, 4-isopropyltoluene, and *n*-butylbenzene.

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	NAPH	methyl-NAPH	TCE	isopropyl-benzene	*n*-propyl-benzene	isopropyl-toluene	*n*-butyl-benzene
674947	HY2-4460	10/25	8:42	0:15	8.2	2.82	2.46	nd	7.31	7.91	7.39	6.99
00674946	HY2-4460	10/25	8:42	0:15	10.2	10.5	6.40	nd	22.3	21.7	25.5	22.4
00674948	HY2-4460	10/25	8:42	0:15	12.2	31.9	27.9	nd	15.9	14.9	26.1	19.4
00674956	HY2-4460	10/25	10:26	0:15	8.2	3.83	2.46	nd	bdl	bdl	5.94	bdl
00674955	HY2-4460	10/25	10:26	0:15	10.2	28.6	30	nd	45.4	49.7	53.7	53.3
00674954	HY2-4460	10/25	10:26	0:15	12.2	46.4	29	nd	20.4	19.2	25.1	18.3
LF	HY2-4460	10/25	10:10		12.4	120	NR	NR	36	38.0	17 J	7.0
00674992	HY2-4467	10/26	11:03	2:30	13	nd	nd	0.76	nd	nd	bdl	bdl
00675002	HY2-4467	10/26	15:40	2:00	13	nd	nd	nd	bdl	bdl	bdl	nd
LF	HY2-4467	10/26	15:22		11.4	1U	NR	NR	1U	1U	1U	1U
00674949	HY2-5400	10/25	8:47	0:30	31.1	82.2	59.2	nd	69.3	53.3	24.9	11.4
00674957	HY2-5400	10/25	10:22	0:30	31.1	101.8	77.1	nd	80.8	60.9	32.1	14.2
LF	HY2-5400	10/25	10:15		31	180	NR	NR	120	110	110.0	7.0
00675047	PH1-5321	10/24	14:38	3:01	24.1	nd	nd	nd	nd	nd	bdl	nd
00675046	PH1-5321	10/24	14:38	3:01	26.6	bdl	nd	nd	nd	nd	nd	nd
00675045	PH1-5321	10/24	14:38	3:01	29.1	nd	nd	nd	nd	nd	nd	nd
LF*	PH1-5321	4/19			27	1 U*	NR*	NR*	1 U*	1 U*	1 U*	1 U*
00674953	PH1-6507	10/25	9:44	2:00	71.1	0.49	0.58	nd	nd	nd	bdl	nd
00674952	PH1-6507	10/25	9:44	2:00	73.6	0.49	0.58	4.57	nd	bdl	bdl	bdl
00674951	PH1-6507	10/25	9:44	2:00	76.1	0.92	0.58	91.7	bdl	bdl	bdl	bdl
00675044	PH1-6507	10/24	14:29	1:59	71.1	0.50	nd	nd	nd	nd	nd	nd
00675043	PH1-6507	10/24	14:29	1:59	73.6	0.50	nd	nd	nd	nd	nd	nd
00675042	PH1-6507	10/24	14:29	1:59	76.1	0.94	0.59	nd	nd	nd	nd	nd
LF	PH1-6507	10/24	17:47		74	1 U	NR	NR	1 U	1 U	1 U	1 U

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	NAPH	methyl-NAPH	TCE	isopropyl-benzene	*n*-propyl-benzene	isopropyl-toluene	*n*-butyl-benzene
00674988	PH2-5324	10/26	9:37	0:30	48.1	47.9	19.6	11.1	99.4	68.3	16.5	6.05
00674993	PH2-5324	10/26	11:27	0:30	48.1	27.1	11.0	nd	71.0	48.6	10.9	bdl
LF	PH2-5324	10/26	11:10		48.5	53	NR	NR	140	100	7 J	2 J
00674976	PH2-5341	10/26	8:46	0:15	31	99.2	33.5	nd	213	139	48.8	20.4
00674989	PH2-5341	10/26	10:25	0:15	31	121	49.8	nd	284	188	78.4	50.3
LF	PH2-5341	10/26	10:00		31.5	49 J	NR	NR	190	140	**10 J**	**5 J**
00674960	PH2-5369	10/25	10:53	0:15	38.6	8.73	6.94	nd	29.4	19.2	7.84	bdl
00674959	PH2-5369	10/25	10:53	0:15	40.6	9.79	5.26	nd	24.2	16.3	6.18	bdl
00674958	PH2-5369	10/25	10:53	0:15	42.6	24.3	10.7	nd	63.7	41.1	9.99	bdl
00674967	PH2-5369	10/25	13:42	0:15	38.6	3.78	2.24	nd	12.3	9.71	6.18	bdl
00674966	PH2-5369	10/25	13:42	0:15	40.6	16.5	9.61	nd	33.5	24.3	8.92	6.89
00674965	PH2-5369	10/25	13:42	0:15	42.6	25.8	14.7	nd	69.4	46.8	14.7	9.47
LF	PH2-5369	10/25	12:30		41.0	42	NR	NR	71.0	53	**3 J**	**1 J**
00674961	PH2-5388	10/25	12:00	0:15	31.6	1.44	0.91	nd	nd	bdl	bdl	bdl
00674968	PH2-5388	10/25	14:10	0:15	31.6	nd	nd	nd	nd	nd	bdl	nd
LF	PH2-5388	10/25	14:05		32.5	1 U	NR	NR	1 U	1 U	1 U	1 U
00674977	PH2-5601	10/26	8:50	0:15	42.0	16.8	6.32	nd	28.1	17.3	6.68	bdl
00674990	PH2-5601	10/26	10:25	0:15	42.0	34.5	10.0	nd	67.9	40.7	nd	bdl
LF	PH2-5601	10/26	10:05		43.3	48	NR	NR	89.0	60.0	4 J	2 J
00674950	PH2-5602	10/25	9:22	1:00	32.6	64.4	30.0	nd	51.0	35.0	15.91	6.72
00674964	PH2-5602	10/25	11:36	0:15	32.6	101	57.5	nd	81.6	53.8	29.47	12.4
LF	PH2-5602	10/25	11;25		34	140	NR	NR	91.0	72.0	12 J	5.0
00674962	PH2-5603	10/25	12:08	2:00	44.6	bdl	nd	2.17	bdl	bdl	bdl	nd
00674969	PH2-5603	10/25	15:14	2:00	44.6	bdl	nd	4.96	bdl	bdl	bdl	bdl
LF	PH2-5603	10/25	15:05		45	1 U	NR	NR	0.4 J	1 U	1 U	1 U
00675034	PH2-5604	10/28	11:04	2:00	49.6	0.20	0.23	0.29	nd	nd	nd	nd

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	NAPH	methyl-NAPH	TCE	isopropyl-benzene	*n*-propyl-benzene	isopropyl-toluene	*n*-butyl-benzene
00675063	PH2-5604	10/28	15:21	2:00	49.6	2.64	2.95	nd	bdl	bdl	bdl	bdl
LF	PH2-5604	10/28	15:10		50	1 U	NR	NR	1 U	1 U	1 U	1 U
00675023	PH2-5605	10/28	8:23	2:07	42.6	0.51	bdl	nd	bdl	bdl	bdl	bdl
00675052	PH2-5605	10/28	12:57	2:48	42.6	2.96	3.23	bdl	bdl	bdl	bdl	bdl
LF	PH2-5605	10/28	12:53		43	1 U	NR	NR	1 U	1 U	1 U	1 U
00674991	PH2-5606	10/26	10:22	0:15	61.6	212	124	nd	1,005	502	151	55.2
00674994	PH2-5606	10/26	12:11	0:15	61.6	186	109	nd	847	409	125	52.5
LF	PH2-5606	10/26	11:35		61.7	110	NR	NR	220	170	12 J	6 J
00674971	PH2-5607	10/25	15:15	0:15	42.4	nd	nd	nd	nd	nd	bdl	nd
00674972	PH2-5607	10/25	16:48	0:15	42.4	nd	0.93	nd	nd	nd	bdl	nd
LF	PH2-5607	10/25	16:40		42.4	21	NR	NR	5U	39	5	0.9J
00675008	PH2-5608	10/27	10:07	2:00	34.6	1.67	0.24	nd	15.9	bdl	bdl	bdl
00675019	PH2-5608	10/27	15:01	2:00	34.6	1.36	nd	nd	16.2	bdl	bdl	nd
LF	PH2-5608	10/27	14:45		35	0.8J	NR	NR	0.5J	1U	1U	1U
00675004	PH2-5627	10/27	8:20	2:00	36.8	1.35	1.42	nd	nd	bdl	nd	bdl
00675013	PH2-5627	10/27	11:20	3:28	36.8	0.26	bdl	nd	nd	bdl	bdl	nd
LF	PH2-5627	10/27	11:08		37.2	1 U	NR	NR	1 U	1 U	1 U	1 U
00674978	PH2-5628	10/26	9:16	2:16	48.0	0.43	nd	nd	nd	nd	bdl	nd
00674999	PH2-5628	10/26	13:51	2:00	48.0	0.47	nd	nd	bdl	nd	bdl	nd
LF	PH2-5628	10/26	13:34		48.0	1 U	NR	NR	1 U	1 U	1 U	1 U
00674987	PH2-6508	10/26	9:51	2:16	57.5	nd	nd	nd	bdl	bdl	bdl	nd
00674986	PH2-6508	10/26	9:51	2:00	59.6	nd	nd	nd	bdl	bdl	bdl	nd
00674979	PH2-6508	10/26	9:51	2:16	62	nd	nd	4.78	bdl	bdl	bdl	nd
00675001	PH2-6508	10/26	13:30	2:00	57.5	0.96	0.60	nd	15.2	bdl	bdl	nd
00675000	PH2-6508	10/26	13:30	2:16	59.6	0.51	nd	4.74	16.1	bdl	bdl	nd
00674995	PH2-6508	10/26	13:30	2:00	62	0.51	nd	nd	14.4	bdl	nd	nd

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	NAPH	methyl-NAPH	TCE	isopropyl-benzene	*n*-propyl-benzene	isopropyl-toluene	*n*-butyl-benzene
LF	PH2-6508	10/26	13:10		60	1 U	NR	NR	2	0.7 J	1 UJ	1 UJ
00675007	PH2-6627	10/27	8:31	2:00	57.5	3.83	3.73	8.96	nd	bdl	bdl	bdl
00675006	PH2-6627	10/27	8:31	2:00	60	3.83	3.73	nd	nd	bdl	bdl	bdl
00675005	PH2-6627	10/27	8:31	2:00	62.5	3.44	2.90	8.96	nd	bdl	bdl	bdl
00675016	PH2-6627	10/27	12:57	2:00	57.5	3.07	1.13	nd	nd	bdl	6.71	nd
00675015	PH2-6627	10/27	12:57	2:00	60	2.67	1.13	nd	nd	bdl	bdl	bdl
00675014	PH2-6627	10/27	12:57	2:00	62.5	2.26	1.13	nd	nd	bdl	6.10	nd
LF	PH2-6627	10/27	12:35		60.4	1	NR	NR	1 U	1 U	1 U	1 U
00674975	PH2-6628	10/26	8:45	2:00	61.7	nd	0.56	nd	nd	nd	bdl	nd
00674974	PH2-6628	10/26	8:45	2:00	64.2	nd	0.56	nd	nd	nd	bdl	nd
00674973	PH2-6628	10/26	8:45	2:00	66.7	0.90	0.56	nd	nd	nd	bdl	nd
00674998	PH2-6628	10/26	13:05	2:00	61.7	0.48	0.56	nd	nd	nd	nd	nd
00674997	PH2-6628	10/26	13:05	2:00	64.2	nd	0.56	nd	nd	nd	bdl	nd
00674996	PH2-6628	10/26	13:05	2:00	66.7	0.90	0.56	15.5	nd	nd	nd	nd
LF	PH2-6628	10/26	12:22		64.6	1 U	NR	NR	1 U	1 U	1 U	1 U
00674963	PH2-6657	10/25	12:10	2:00	54.6	0.92	0.58	nd	6.91	bdl	bdl	bdl
00674970	PH2-6657	10/25	15:20	2:00	54.6	0.49	nd	58.5	bdl	bdl	bdl	bdl
LF	PH2-6657	10/25	15:00		54.3	1 U	NR	NR	1 U	1 U	1 U	1 U
00675031	PH2-6658	10/28	11:49	2:24	61.1	4.99	4.91	nd	bdl	bdl	bdl	bdl
LF	PH2-6658	10/28	16:23		61.5	1 U	NR	NR	1 U	1 U	1 U	1 U
00675012	PH2-6659	10/27	10:13	2:00	52.1	2.26	2.06	nd	bdl	bdl	bdl	bdl
00675011	PH2-6659	10/27	10:13	2:00	54.6	2.67	2.94	nd	bdl	bdl	bdl	bdl
00675010	PH2-6659	10/27	10:13	2:00	57.1	1.84	2.06	nd	bdl	bdl	bdl	bdl
00675022	PH2-6659	10/27	16:23	1:00	52.1	0.83	1.00	8.27	bdl	nd	bdl	nd
00675021	PH2-6659	10/27	16:23	1:00	54.6	nd	1.00	nd	bdl	nd	nd	nd
00675020	PH2-6659	10/27	16:23	1:00	57.1	0.83	1.00	15.4	bdl	bdl	nd	nd

				Module		Conc. (µg/L)						
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	NAPH	methyl-NAPH	TCE	isopropyl-benzene	*n*-propyl-benzene	isopropyl-toluene	*n*-butyl-benzene
LF	PH2-6659	10/27	16:15		55	1 U	NR	NR	1 U	1 U	1 U	1 U
00675026	PH2-6660	10/28	8:18	2:00	63.1	1.77	1.07	nd	bdl	bdl	bdl	bdl
00675025	PH2-6660	10/28	8:18	2:00	65.6	4.82	2.79	nd	79.7	31.5	bdl	nd
00675024	PH2-6660	10/28	8:18	2:00	68.1	4.82	3.19	nd	70.2	27.7	bdl	bdl
00675049	PH2-6660	10/28	12:00	3:08	63.1	7.26	7.35	nd	bdl	bdl	bdl	bdl
00675048	PH2-6660	10/28	12:00	3:08	65.6	10.5	9.24	nd	38.9	18.2	bdl	bdl
00675035	PH2-6660	10/28	12:00	3:08	68.1	10.7	9.7	8.8	36.1	16.8	bdl	bdl
LF	PH2-6660	10/28	11:25		68.5	0.9J	NR	NR	0.4J	9	1U	1U
Detection limit for Modules							0.22	0.279		7.07	5.94	
Detection limit for low-flow samples						1	NR	NR	1	1	1	1
*Historical data because pump did not work.												

Table L3. Results for 1,2-dibromoethane, 1,4-dichloroebenzene, carbon tetrachloride, 1,1,2-trichloroethane, and chlorobenzene.

				Module		Conc. (µg/L)				
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	Dibromo-ethane	DCB	CCl_4	112TCA	CLB
674947	HY2-4460	10/25	8:42	0:15	8.2	nd	nd	nd	nd	nd
00674946	HY2-4460	10/25	8:42	0:15	10.2	nd	nd	nd	nd	nd
00674948	HY2-4460	10/25	8:42	0:15	12.2	nd	nd	nd	nd	nd
00674956	HY2-4460	10/25	10:26	0:15	8.2	nd	nd	nd	nd	nd
00674955	HY2-4460	10/25	10:26	0:15	10.2	nd	nd	nd	nd	nd
00674954	HY2-4460	10/25	10:26	0:15	12.2	nd	nd	nd	nd	nd
LF	HY2-4460	10/25	10:10		12.4	1 U				
00674992	HY2-4467	10/26	11:03	2:30	13	nd	nd	nd	nd	nd
00675002	HY2-4467	10/26	15:40	2:00	13	nd	nd	nd	nd	nd
LF	HY2-4467	10/26	15:22		11.4	1U				
00674949	HY2-5400	10/25	8:47	0:30	31.1	nd	nd	nd	nd	nd
00674957	HY2-5400	10/25	10:22	0:30	31.1	nd	nd	nd	nd	nd
LF	HY2-5400	10/25	10:15		31	2 U				
00675047	PH1-5321	10/24	14:38	3:01	24.1	nd	nd	nd	nd	nd
00675046	PH1-5321	10/24	14:38	3:01	26.6	nd	nd	nd	nd	nd
00675045	PH1-5321	10/24	14:38	3:01	29.1	nd	nd	nd	nd	nd
LF*	PH1-5321	4/19			27	1 U*				
00674953	PH1-6507	10/25	9:44	2:00	71.1	nd	1.01	nd	nd	nd
00674952	PH1-6507	10/25	9:44	2:00	73.6	nd	nd	nd	nd	nd
00674951	PH1-6507	10/25	9:44	2:00	76.1	nd	nd	nd	nd	nd
00675044	PH1-6507	10/24	14:29	1:59	71.1	nd	nd	nd	nd	nd
00675043	PH1-6507	10/24	14:29	1:59	73.6	nd	nd	nd	nd	nd
00675042	PH1-6507	10/24	14:29	1:59	76.1	nd	nd	nd	nd	nd
LF	PH1-6507	10/24	17:47		74	1 U				
00674988	PH2-5324	10/26	9:37	0:30	48.1	nd	nd	nd	nd	nd
00674993	PH2-5324	10/26	11:27	0:30	48.1	nd	nd	nd	nd	nd
LF	PH2-5324	10/26	11:10		48.5	1 U				
00674976	PH2-5341	10/26	8:46	0:15	31	24.9	nd	nd	nd	nd

				Module		Conc. (µg/L)				
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	Dibromo-ethane	DCB	CCl_4	1.1.2TCA	CLB
00674989	PH2-5341	10/26	10:25	0:15	31	52.5	nd	nd	nd	nd
LF	PH2-5341	10/26	10:00		31.5	**49**				
00674960	PH2-5369	10/25	10:53	0:15	38.6	nd	nd	nd	nd	nd
00674959	PH2-5369	10/25	10:53	0:15	40.6	nd	nd	nd	nd	nd
00674958	PH2-5369	10/25	10:53	0:15	42.6	nd	nd	nd	nd	nd
00674967	PH2-5369	10/25	13:42	0:15	38.6	nd	nd	nd	nd	nd
00674966	PH2-5369	10/25	13:42	0:15	40.6	nd	nd	nd	nd	nd
00674965	PH2-5369	10/25	13:42	0:15	42.6	nd	nd	nd	nd	nd
LF	PH2-5369	10/25	12:30		41.0	2 U				
00674961	PH2-5388	10/25	12:00	0:15	31.6	nd	nd	nd	nd	nd
00674968	PH2-5388	10/25	14:10	0:15	31.6	nd	nd	nd	nd	nd
LF	PH2-5388	10/25	14:05		32.5	1 U				
00674977	PH2-5601	10/26	8:50	0:15	42.0	nd	nd	nd	nd	nd
00674990	PH2-5601	10/26	10:25	0:15	42.0	nd	nd	nd	nd	nd
LF	PH2-5601	10/26	10:05		43.3	2 U				
00674950	PH2-5602	10/25	9:22	1:00	32.6	nd	nd	nd	nd	nd
00674964	PH2-5602	10/25	11:36	0:15	32.6	nd	nd	nd	nd	nd
LF	PH2-5602	10/25	11;25		34	1 U				
00674962	PH2-5603	10/25	12:08	2:00	44.6	nd	nd	nd	nd	nd
00674969	PH2-5603	10/25	15:14	2:00	44.6	nd	nd	0.41	nd	nd
LF	PH2-5603	10/25	15:05		45	1 U				
00675034	PH2-5604	10/28	11:04	2:00	49.6	nd	nd	nd	nd	nd
00675063	PH2-5604	10/28	15:21	2:00	49.6	nd	nd	nd	nd	nd
LF	PH2-5604	10/28	15:10		50	1 U				
00675023	PH2-5605	10/28	8:23	2:07	42.6	nd	nd	nd	nd	nd
00675052	PH2-5605	10/28	12:57	2:48	42.6	nd	nd	nd	nd	nd
LF	PH2-5605	10/28	12:53		43	1 U				
00674991	PH2-5606	10/26	10:22	0:15	61.6	nd	nd	nd	nd	nd
00674994	PH2-5606	10/26	12:11	0:15	61.6	nd	nd	nd	nd	nd

				Module		Conc. (µg/L)				
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	Dibromo-ethane	DCB	CCl_4	1.1.2TCA	CLB
LF	PH2-5606	10/26	11:35		61.7	5 U				
00674971	PH2-5607	10/25	15:15	0:15	42.4	nd	nd	nd	nd	nd
00674972	PH2-5607	10/25	16:48	0:15	42.4	nd	nd	nd	nd	nd
LF	PH2-5607	10/25	16:40		42.4	3				
00675008	PH2-5608	10/27	10:07	2:00	34.6	nd	nd	nd	nd	nd
00675019	PH2-5608	10/27	15:01	2:00	34.6	nd	nd	nd	nd	nd
LF	PH2-5608	10/27	14:45		35	5				
00675004	PH2-5627	10/27	8:20	2:00	36.8	nd	nd	nd	nd	nd
00675013	PH2-5627	10/27	11:20	3:28	36.8	nd	nd	nd	nd	nd
LF	PH2-5627	10/27	11:08		37.2	1 U				
00674978	PH2-5628	10/26	9:16	2:16	48.0	nd	nd	nd	nd	nd
00674999	PH2-5628	10/26	13:51	2:00	48.0	nd	0.97	nd	nd	nd
LF	PH2-5628	10/26	13:34		48.0	1 U				
00674987	PH2-6508	10/26	9:51	2:16	57.5	nd	nd	nd	nd	nd
00674986	PH2-6508	10/26	9:51	2:00	59.6	nd	nd	nd	nd	nd
00674979	PH2-6508	10/26	9:51	2:16	62	nd	nd	nd	nd	2.56
00675001	PH2-6508	10/26	13:30	2:00	57.5	nd	nd	nd	nd	nd
00675000	PH2-6508	10/26	13:30	2:16	59.6	nd	nd	nd	nd	nd
00674995	PH2-6508	10/26	13:30	2:00	62	nd	nd	nd	nd	nd
LF	PH2-6508	10/26	13:10		60	1 U				
00675007	PH2-6627	10/27	8:31	2:00	57.5	nd	nd	nd	nd	nd
00675006	PH2-6627	10/27	8:31	2:00	60	nd	nd	nd	nd	nd
00675005	PH2-6627	10/27	8:31	2:00	62.5	nd	nd	nd	12.34	nd
00675016	PH2-6627	10/27	12:57	2:00	57.5	nd	nd	nd	nd	nd
00675015	PH2-6627	10/27	12:57	2:00	60	nd	nd	nd	nd	nd
00675014	PH2-6627	10/27	12:57	2:00	62.5	nd	nd	nd	nd	nd
LF	PH2-6627	10/27	12:35		60.4	1 U				
00674975	PH2-6628	10/26	8:45	2:00	61.7	nd	nd	nd	nd	nd
00674974	PH2-6628	10/26	8:45	2:00	64.2	nd	nd	nd	nd	nd

				Module		Conc. (µg/L)				
LF or Module #	Well #	Date	Sampling Time	Contact time (hr:min)	Depth (ft bgs)	Dibromo-ethane	DCB	CCl_4	112TCA	CLB
00674973	PH2-6628	10/26	8:45	2:00	66.7	nd	nd	nd	nd	nd
00674998	PH2-6628	10/26	13:05	2:00	61.7	nd	nd	nd	nd	nd
00674997	PH2-6628	10/26	13:05	2:00	64.2	nd	nd	nd	nd	nd
00674996	PH2-6628	10/26	13:05	2:00	66.7	nd	nd	nd	nd	nd
LF	PH2-6628	10/26	12:22		64.6	1 U				
00674963	PH2-6657	10/25	12:10	2:00	54.6	nd	nd	nd	nd	nd
00674970	PH2-6657	10/25	15:20	2:00	54.6	nd	nd	5.37	nd	nd
LF	PH2-6657	10/25	15:00		54.3	1 U				
00675031	PH2-6658	10/28	11:49	2:24	61.1	nd	nd	nd	nd	nd
LF	PH2-6658	10/28	16:23		61.5	1 U				
00675012	PH2-6659	10/27	10:13	2:00	52.1	nd	nd	nd	nd	nd
00675011	PH2-6659	10/27	10:13	2:00	54.6	nd	nd	nd	nd	nd
00675010	PH2-6659	10/27	10:13	2:00	57.1	nd	nd	nd	nd	nd
00675022	PH2-6659	10/27	16:23	1:00	52.1	nd	nd	nd	nd	nd
00675021	PH2-6659	10/27	16:23	1:00	54.6	nd	nd	nd	nd	nd
00675020	PH2-6659	10/27	16:23	1:00	57.1	nd	nd	nd	nd	nd
LF	PH2-6659	10/27	16:15		55	1 U				
00675026	PH2-6660	10/28	8:18	2:00	63.1	nd	nd	nd	nd	nd
00675025	PH2-6660	10/28	8:18	2:00	65.6	nd	nd	nd	nd	nd
00675024	PH2-6660	10/28	8:18	2:00	68.1	nd	nd	nd	nd	nd
00675049	PH2-6660	10/28	12:00	3:08	63.1	nd	nd	nd	nd	nd
00675048	PH2-6660	10/28	12:00	3:08	65.6	nd	nd	nd	nd	nd
00675035	PH2-6660	10/28	12:00	3:08	68.1	nd	nd	nd	nd	nd
LF	PH2-6660	10/28	11:25		68.5	**2**				
Detection limit for Modules							**0.221**	**0.227**	**0.348**	**0.248**
Detection limit for low-flow samples						**1**	**NR**	**NR**	**NR**	**NR**
*Historical data because pump did not work.										

Appendix M: Results of the Statistical Analyses Comparing the Mid-Level GORE Data with Low-Flow Sampling

Table M1. Results of the statistical analyses of the pre-purge and post-purge mid-level GORE data and the low-flow data*.

			Significant difference?				Mean of log conc.		
Analyte	Significance	Test	Pre-purge vs. LF	Post-purge vs. LF	Pre-purge vs. post-purge	Test type	Pre	Post	LF
toluene	NS	1-way RM-ANOVA on logs							
benzene	Sig	1-way RM-ANOVA on logs	yes <.001	yes <.001	no	Holm-Sidak	1.57	1.67	0.70
124TMB	NS	1-way RM-ANOVA on logs							
135TMB	NS	1-way RM-ANOVA on logs							
xylenes	Sig	Friedman RM-ANOVA on ranks	yes <.005	no	no	Tukey			
ethylbenzene	NS	Friedman RM-ANOVA on ranks							
naphthalene	NS	1-way RM-ANOVA on raw data							
propylbenzene	NS	1-way RM-ANOVA on logs							
isopropylbenzene	NS	1-way RM-ANOVA on logs							

*For data that did not include concentrations that were less than three times the detection limit.

Table M2. Results to determine the fit of a linear least-fit model of the raw mid-level GORE data vs. low-flow sampling*.

	Pre-purge vs. low-flow				Post-purge vs. low-flow			
Analyte	R^2	Significance	Slope Sig. different from 1.0?	Slope	R^2	Significance	Slope Sig. different from 1.0?	Slope
benzene	0.9975	3.42E-05	yes	1.09	0.001	0.934 NS		
toluene	0.827	0.0221668	yes	0.29	0.972	0.00133338	yes	0.34
ethylbenzene	0.587	0.00723	no	2.21	0.670	0.00271061	no	1.96
xylenes	0.617	0.0051601	no	1.47	0.730	0.00115499	no	1.31
124TMB	0.618	0.0087336	no	1.45	0.738	0.00101332	no	1.50
135TMB	0.603	0.0102302	no	1.68	0.751	0.00369449	no	1.74
naphthalene	0.54	0.0285757	no	0.65	0.688	0.00775121	no	0.76
isopropylbenzene	0.569	0.0087048	no	2.08	0.671	0.00491502	no	1.99
*minus data <3x DL								

Appendix N: Results of the Statistical Analyses Comparing the Mean GORE Data with Low-Flow Sampling

Table N1. Results from statistical analyses comparing the mean concentrations for the three GORE Modules with the low-flow data (for data without concentrations near detection limit removed).

			Significant difference?				Mean conc. (µg/L)		
Analyte	Significant difference?	Test	Pre vs. LF	Post vs. LF	Pre vs. Post	Test	Pre	Post	LF
n-butylbenzene	Yes	1- way RM-ANOVA on raw data	No	Yes	No	Holm-Sidak	19.3	27.7	5.3
benzene	Yes	Friedman RM-ANOVA on ranks	No	Yes	No				
toluene	Yes	Friedman RM-ANOVA on ranks	Yes	No	No	Holm-Sidak	1.41	1.35	0.54
ethylbenzene	No	RM-ANOVA on logs							
xylenes, total	Yes	Friedman RM-ANOVA on ranks	Yes	No	No	Tukey			
124TMB	No	Friedman RM-ANOVA on ranks							
135TMB	No	RM-ANOVA on ranks							
naphthalene	No	1-way RM-ANOVA on raw data							
isopropylbenzene	No	RM-ANOVA on ranks							
n-propylbenzene	No	RM-ANOVA on logs							

* only data ≥3x DL

Table N2. Linear least-fit model of the raw mean GORE data (for 3 depths) vs. low-flow sampling (with non-detect data removed, unless marked otherwise with an *).

	pre vs. lf				post vs. lf			
Analyte	R^2	Significance	Slope sig. dif. from 1.0?	Slope	R^2	Significance	Slope sig. dif. from 1.0?	Slope
benzene	0.829	0.001128	no	1.10	0.998	8.34E-10	yes	1.33
toluene	0.827	0.008129	yes	0.289	0.972	0.008129	yes	0.34
ethylbenzene	0.589	0.01164	no	2.22	0.662	0.005459	no	1.94
xylenes	0.621	0.008488	no	1.48	0.725	0.002504	no	1.30
124TMB	0.615	0.005279	no	1.44	0.72	0.001346	no	1.46
135TMB	0.613	0.00922	no	1.7	0.718	0.002743	no	1.68
naphthalene	0.553	0.025876	no	0.66	0.678	0.008561	no	1.75
isopropylbenzene*	0.571	0.022481	no	2.09	0.685	0.007987	no	2.06
n-propylbenzene*	0.634	0.004231	no	1.45	0.741	0.000956	no	1.37

* For all data

Appendix O: Difference in Detections Between the Modules and Low-Flow Sampling

Table O1. Analytes detected with the Modules but not low-flow sampling

Well #	Depth & geology	BNZ	XYLs	EBNZ	TOL	124TMB	135TMB	NAPH
Plumes 6,7,8 pit 5								
source								
HY2-4467	shallow OB		√		√	√	√	√
PH2-4897	shallow OB							
PH2-5341	deep OB							
PH2-5369	deep OB				√			
PH2-5370	deep OB							
PH2-5388	deep OB	√	√	√	√	√	√	√
PH2-5601	deep OB				√			
PH2-5607	lower sand OB							
dissolved plume downgradient								
PH2-5324	deep OB							
PH2-5606	deep OB							
PH2-6508	bedrock		√	√		√	√	√
PH2-6660	bedrock			√	√			
plume boundary								
PH2-5603	deep OB	√	√	√	√	√	√	√
PH2-5604	deep OB	√	√	√	√	√	√	√
PH2-5605	deep OB	√	√	√	√	√	√	√
PH2-6657	bedrock	√	√	√	√	√	√	√
PH2-6658	bedrock	√	√	√	√	√	√	√
downgradient distal								
PH1-5321	shallow OB	√	√	√	√	√	√	√
PH1-6507	bedrock	√	√	√	√	√	√	√
downgradient sentry								
PH2-5627	deep OB	√	√	√	√	√	√	√
PH2-5628	deep OB	√	√	√	√	√	√	√
PH2-6627	shallow BR	√	√	√	√	√	√	√
PH2-6628	shallow BR	√	√	√	√	√	√	√
plume 9 pit 6								
pit 6 source								
HY2-4460	shallow OB							
HY2-5400	deep OB	√						
PH2-5602	deep OB	√						
downgradient								
PH2-5608	deep OB	√	√	√	√	√	√	√
PH2-6659	bedrock	√	√	√	√	√	√	√

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14. ABSTRACT

The GORE Module is a passive sampler that was developed to sample air and water for a variety of volatile and semi-volatile organic compounds (VOCs and SVOCs). Recently, Amplified Geochemical Imaging (AGI) LLC (Elkton, MD) has acquired this technology, and the sampler is now known as the AGI Universal Sampler.

The objectives of this project were to determine, when sampling groundwater, if the GORE Modules can provide (1) technically defensible analytical data for VOCs and SVOCs and (2) substantial cost savings when compared with the US Environmental Protection Agency's (US EPA) low-flow purging and sampling method. Sampling was conducted at two sites: the Southern Bush River section of Aberdeen Proving Ground (APG), MD, and the former Pease Air Force Base in Portsmouth, NH. Analytes included chlorinated VOCs and hydrocarbon VOCs and SVOCs. Additional Modules placed in some wells allowed us to examine concentration gradients in those wells with depth both before and after low-flow sampling.

15. SUBJECT TERMS

AGI Universal Sampler
GORE Module
Integrative sampler
Kinetic sampler
No-purge groundwater sampling
Passive accumulation sampler
Passive groundwater sampling

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