United States
Environmental Protection
Agency

Office of Research and
Development
Washington, D.C. 20460

EPA/600/R-00/091
October 2000

Environmental Technology Verification Report

Groundwater Sampling Technologies

W. L. Gore and Associates, Inc.

GORE-SORBER® Water Quality Monitoring

Sandia
National
Laboratories

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

EPA

Sandia National Laboratories

ETV JOINT VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**GROUNDWATER SAMPLING TECHNOLOGIES**
APPLICATION:	**VOC-CONTAMINATED WATER SAMPLING**
TECHNOLOGY NAME:	**GORE-SORBER Water Quality Monitoring**
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PROGRAM DESCRIPTION

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification Program (ETV) to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations and stakeholder groups consisting of regulators, buyers, and vendor organizations, with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Site Characterization and Monitoring Technologies Pilot, one of 12 technology areas under ETV, is administered by EPA's National Exposure Research Laboratory. Sandia National Laboratories, a Department of Energy laboratory, is one of the verification testing organizations within the ETV Site Characterization and Monitoring Pilot. Sandia collaborated with personnel from the U.S. Geological Survey to conduct a verification study of groundwater sampling technologies. This verification statement provides a summary of the results from a verification test of GORE-SORBER Water Quality Monitoring technology manufactured by W. L. Gore and Associates, Inc.

DEMONSTRATION DESCRIPTION

In August 1999, the performance of six groundwater sampling technologies was evaluated at the US Geological Survey (USGS) Hydrological Instrumentation Facility at the National Aeronautics and Space Administration Stennis Space Center in southwestern Mississippi. Each technology was independently evaluated in order to assess its performance in the collection of volatile organic compound- (VOC) contaminated water. The verification test design incorporated the use of a 5-inch diameter, 100-foot standpipe at the USGS facility. The standpipe, serving as an "above-ground" well, was filled with tap water spiked with various concentration levels of six target volatile organic compounds. The target compounds (1,2-dichloroethane, 1,1-dichloroethene, trichloroethene, benzene, 1,1,2-trichloroethane, and tetrachloroethene) were chosen to represent the range of VOC volatility likely to be encountered in normal sampler use. Water sampling ports along the exterior of the standpipe were used to collect reference samples over the same time interval that the passive membrane samplers were exposed to the water inside the standpipe. Two trials were carried out at the standpipe. The first trial was a relatively low (~20 µg/L) concentration level mixture of the six target VOCs. The second trial incorporated a slowly changing concentration in the standpipe at higher (~200 µg/L) concentrations. The modules were tested at five depths ranging from 17 to 53 feet.

The standpipe trials were supplemented with additional trials at groundwater monitoring wells in the vicinity of sites with VOC-contaminated groundwater at the NASA Stennis facility. The GORE-SORBER modules were deployed in five 2-inch and 4-inch wells, along with co-located submersible electric gear pumps as reference samplers. The principal contaminant at the onsite monitoring wells was trichloroethene. The onsite monitoring provided an opportunity to observe the operation of the sampling system under typical field-use conditions.

All GORE-SORBER modules were analyzed using a gas chromatograph-mass spectrometer (GC-MS) at the W. L. Gore and Associates, Inc. (Gore) laboratory since the sampler is sold with analysis included. The Gore laboratory uses a modified method derived from EPA Methods SW-846 8260 and 8270. All reference samples were analyzed by two identical field-portable GC-MS systems that were located at the test site during the verification tests. The GC-MS analytical method used for the reference samples was a variation of EPA Method 8260 purge-and-trap GC-MS, incorporating a headspace sampling system in lieu of a purge and trap unit. The overall performance of the groundwater sampling technologies was assessed by evaluating sampler precision and comparability with reference samples. Other logistical aspects of field deployment and potential applications of the technology were also considered in the evaluation.

Details of the demonstration, including an evaluation of the sampler's performance, may be found in the report entitled *Environmental Technology Verification Report: W. L. Gore and Associates, GORE-SORBER Water Quality Monitoring*, EPA/600/R-00/091.

TECHNOLOGY DESCRIPTION

The GORE-SORBER module consists of a water impermeable membrane surrounding an adsorbent material that is used to collect volatile and semi-volatile compounds in water. When placed in the screened, saturated interval of a monitoring well or piezometer, the waterproof, vapor-permeable membrane collector housing allows for the selective movement of volatile and semi-volatile organic compounds across the membrane onto the adsorbent. The hydrophobic nature of the membrane restricts liquid water transfer across the membrane.

A GORE-SORBER module consists of four separate sorber packets combined into a single sampling unit. A typical sorber packet is about 25 mm in length, 3 mm in diameter, and contains 40 mg of a granular adsorbent material that is selected on the basis of the specific compounds to be detected. Proprietary polymeric and carbonaceous resins are used as the sorbent material because of their affinity for a broad range of VOCs and semi-VOCs. The sorber packets are sheathed in the bottom of a length of vapor-permeable insertion and retrieval cord that includes a loop attachment. The four sorber units and associated membrane cord are collectively termed the GORE-SORBER module. Both the retrieval cord and sorbent container are constructed solely of inert, hydrophobic, microporous membrane. Every module has sufficient sorbers such that there is always a minimum of two samples available in each module for use as duplicates or backups as needed. A unique feature of the membrane is that it is hydrophobic, excluding the transfer of liquid water across the membrane, while facilitating vapor transfer. Thus, VOC and SVOC vapors can penetrate the sorbent module freely and collect on the adsorbent material. Depending on the membrane characteristics, liquid water transfer across the membrane will be limited up to a particular depth, and therefore, it is important to know the desired depth of installation. Different membranes can be used for different installation depths, and GORE technical support personnel can help in membrane selection. Standard (STND) and high water entry pressure (HWEP) membranes were evaluated in this verification test.

The sampling modules are compact and completely passive. They are fastened to a string and stainless steel weight, suspended in the well, normally at the mid-screen location, and left in place for 48 hours. Upon retrieval they are placed in airtight containers and overnight shipped to the Gore laboratory. Laboratory analysis options for the sorbent modules include methods for the determination of volatile organic compounds, semi-volatile organic compounds, and polycyclic aromatic hydrocarbons. In addition to these common suites of compounds, the samples can also be analyzed for specific groups of compounds; i.e., fuel hydrocarbons, chlorinated organics, and others. The analyses follow modified EPA SW846 Methods 8260 for VOCs, and 8270 for semi-VOCs. All analytical services on GORE-SORBER modules are performed at the W.L. Gore & Associates, Inc. laboratory in Elkton, MD.

VERIFICATION OF PERFORMANCE

The following performance characteristics of the GORE-SORBER Water Quality Monitoring system were observed:

Precision: The precision of the sampling modules, under stable concentration conditions, was determined by the collection of replicate samples in a standpipe trial in which the target concentration levels were about 20 µg/L at water column depths ranging from 17 to 46 feet. GORE-SORBER STND membrane module precision, represented by the relative standard deviation, for all target VOC compounds at 17- and 28-foot sampling depths ranged from 2 to 28% with a median value of 14%. GORE-SORBER HWEP module relative standard deviations at 17-, 28-, 35- and 46-foot depths ranged from 9 to 35% with a median of 21%. Reference method relative standard deviations, under similar sampling, conditions ranged from 3 to 17% with a median value of 12%.

Comparability with a Reference: GORE-SORBER module results are reported in terms of total mass of VOC collected in the module. In this format, the data are not directly comparable to the concentration data derived from conventional groundwater monitoring. The first deployment of a module is usually accompanied by the collection and analysis of a conventional groundwater sample, which enables comparison of the two data formats. The correlation between GORE-SORBER modules data and conventional groundwater sample data was carried out by deploying GORE-SORBER modules and reference pump in five different wells with known TCE contamination. Trichloroethene concentration in these 5 wells ranged from 5 to 2,000 µg/L. The observed correlation between GORE-SORBER module data and reference sample data was very good. The correlation coefficients for the STND and HWEP modules were 0.997 and 0.998 respectively.

Versatility: The versatility of the GORE-SORBER module in typical field screening and monitoring applications for VOC compounds in groundwater is as follows: The modules have limited versatility in terms of deployment depth since the maximum deployment for which they are rated is a water column depth of 50 feet. The modules have wide versatility in terms of the number of compounds detected since they can sample both VOCs and semi-VOCs. The modules are judged to have limited versatility in terms of application to monitoring for regulatory compliance by virtue of their moderate (15-30% relative standard deviation) precision.

Logistical Requirements: The sampling modules can be easily deployed and retrieved in the field by one person. An hour of training is generally adequate to become proficient in the use of the samplers. The samplers require a 48-hour exposure interval, and thus two trips are required to the well for deployment and retrieval. The modules are completely passive and require no external power for operation. Following retrieval, the samplers are shipped to the Gore analytical laboratory by overnight mail. Refrigeration of the sample during shipment is not required. In order to estimate groundwater concentrations, the GORE-SORBER module must be periodically accompanied by co-located conventional groundwater sampling and analysis. Vendor recommendations are, at the onset of sampling, to deploy the modules and conventional methods in two parallel sampling events to establish the relationship between the two sampling methods. Thereafter, annual parallel sampling events are suggested.

Overall Evaluation: The results of this verification test show that the GORE-SORBER Water Quality Monitoring system can be used to monitor long-term concentration trends of VOCs in monitoring wells. The GORE-SORBER modules are designed and are optimally suited for relatively low-cost VOC concentration trend monitoring and screening. They are well suited for plume edge monitoring to detect general concentration trends. The technology does require the periodic collection and analysis of co-located reference samples in order to interpret the data from GORE-SORBER module in terms of water concentration.

As with any technology selection, the user must determine if this technology is appropriate for the application and the project data quality objectives. For more information on this and other verified technologies visit the ETV web site at http://www.epa.gov/etv.

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GORE-SORBER® Water Quality Monitoring

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Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development (ORD), funded and managed, through Interagency Agreement No. DW66940927 with Sandia National Laboratories, the verification effort described herein. This report has undergone peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use of a specific product.

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Acknowledgments

The authors acknowledge the support of all those who helped in the vendor solicitation, planning, field deployment, and analysis phases of this verification test. In particular, we recognize Steve Gardner (US EPA NERL, Las Vegas) who provided technical assistance and peer reviewed the test plan. We also acknowledge the assistance of Eugene Hays, Bill Davies, and Ed Ford (US Geological Survey) in providing access to the Standpipe Facility at the NASA Stennis Space Center as well as for their administrative and logistical support during the standpipe and groundwater monitoring trials. We also thank Ronald McGee and Jenette Gordon (NASA, Environmental Management) for their willingness to grant us access to the groundwater monitoring wells at the NASA Stennis Space Center. Thanks also to Greg New (Foster Wheeler Environmental Corporation) for his assistance in getting much of the site hydrological and well monitoring data into our hands during the planning phases of this test. Finally, we thank Craig Crume and Mika Greenfield (Field Portable Analytical) for their long hours, care, and diligence in onsite sample analysis during the field trials.

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List of Abbreviations and Acronyms

BFB	Bromofluorobenzene
BNZ	Benzene
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CF	Comparison Factor
DIFF	Difference
EPA	US Environmental Protection Agency
ePTFE	Expanded polytetrafluoroethene
ETV	Environmental Technology Verification Program
GC-MS	Gas chromatograph-mass spectrometer
HIF	Hydrological Instrumentation Facility
HWEP	High water entry pressure (membrane)
MSL	Mean sea level
MW	Monitoring well
NASA	National Aeronautics and Space Administration
ND	Not detected
NERL	National Exposure Research Laboratory
PAH	Polycyclic aromatic hydrocarbon
PCE	Tetrachloroethene
PTFE	Polytetrafluoroethylene
QA	Quality assurance
QC	Quality control
REF	Reference
RSD	Relative standard deviation
SCMT	Site Characterization and Monitoring Technologies Pilot
SNL	Sandia National Laboratories
SP	Sample port
SSC	Stennis Space Center
STND	Standard (membrane)
SVOC	Semi-volatile organic compound
TCE	Trichloroethene
TWA	Time-weighted average
USGS	US Geological Survey
VOA	Volatile organics analysis
VOC	Volatile organic compound
12DCA	1,2-dichloroethane
11DCE	1,1-dichloroethene
112TCA	1,1,2-trichloroethane

Section 1 — Introduction

Background

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification Program (ETV) to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations and stakeholder groups consisting of regulators, buyers, and vendor organizations, with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ETV is a voluntary program that seeks to provide objective performance information to all of the participants in the environmental marketplace and to assist them in making informed technology decisions. ETV does not rank technologies or compare their performance, label or list technologies as acceptable or unacceptable, seek to determine "best available technology," nor approve or disapprove technologies. The program does not evaluate technologies at the bench or pilot scale and does not conduct or support research.

The program now operates 12 pilots covering a broad range of environmental technology areas. ETV has begun with a 5-year pilot phase (1995–2000) to test a wide range of partner and procedural alternatives in various pilot areas, as well as the true market demand for and response to such a program. In these pilots, EPA utilizes the expertise of partner "verification organizations" to design efficient processes for conducting performance tests of innovative technologies. These expert partners are both public and private organizations, including federal laboratories, states, industry consortia, and private sector facilities. Verification organizations oversee and report verification activities based on testing and QA protocols developed with input from all major stakeholder/customer groups associated with the technology area. The demonstration described in this report was administered by the Site Characterization and Monitoring Technologies (SCMT) Pilot. (To learn more about ETV, visit ETV's Web site at http://www.epa.gov/etv.)

The SCMT pilot is administered by EPA's National Exposure Research Laboratory (NERL). Sandia National Laboratories, one of two verification organizations associated with the SCMT pilot, conducted a verification study of groundwater sampling technologies during the summer of 1999. Groundwater sampling technologies are commonly employed at environmental sites for site screening and characterization, remediation assessment, and routine environmental monitoring. Groundwater sampling technologies generally fall into three categories: 1) active pumping systems, 2) discrete level grab systems, and 3) passive diffusional systems. All three types of samplers were evaluated during this verification study.

Demonstration Overview

In August 1999, a demonstration study was conducted to verify the performance of six groundwater sampling systems: Multiprobe 100 (multi-level sampler, Burge Environmental, Tempe, AZ), SamplEase (bladder pump, Clean Environment Equipment, Oakland, CA), Micro-Flo (bladder pump, Geolog Inc., Medina, NY), Well Wizard (bladder pump, QED Environmental, Ann Arbor, MI), Kabis Sampler, (discrete-level grab sampler, Sibak Industries, Solano Beach, CA), and GORE-SORBER Water Quality Monitoring (diffusional sampler, W. L. Gore and Associates Inc., Elkton, MD). This report contains the evaluation of the W. L. Gore and Associates Inc., GORE-SORBER Water Quality Monitoring technology.

It is important to point out that the scope of this technology demonstration was purposely limited to sampler performance parameters such as precision, accuracy, and where applicable, deployment logistics. Several of the systems tested in this study are specifically designed for the low volume purge methods—a relatively new approach to the collection of a representative sample from a groundwater monitoring well. This study was specifically intended to evaluate sampler performance and was not an evaluation of the merits of a low-flow purge and sampling protocol. This protocol has been proposed, published, and tested elsewhere [Puls and Barcelona, 1996] and is beyond the scope of this particular investigation.

The demonstration was conducted in August of 1999 at the National Aeronautic and Space Administration (NASA) Stennis Space Center in southwestern Mississippi. Sandia worked in cooperation with the US Geological Survey, a federal agency resident at the NASA Stennis site, and used a 100-foot, 5-inch diameter standpipe that is one of the testing facilities associated with the USGS Hydrological Instrumentation Facility at this site. The standpipe, serving as an "above-ground" well, was filled with water spiked with various concentration levels of six target volatile organic compounds (VOC). Water sampling ports along the exterior of the pipe permitted the collection of reference samples at the same time that groundwater sampling technologies collected samples from the interior of the pipe.

The standpipe trials were supplemented with additional trials at a number of groundwater monitoring wells at sites with VOC-contaminated groundwater at the NASA Stennis facility. The technologies were deployed in five 2-inch wells along with a co-located reference sampler. The principal contaminant at the site was trichloroethene.

With the exception of the GORE-SORBER Water Quality Monitoring technology, all technology and reference samples were analyzed by the same field-portable gas chromatograph-mass spectrometer system that was located at the test site during the verification tests. In the case of the GORE-SORBER modules, analysis was performed at an offsite W.L. Gore laboratory since purchase of the module normally includes analysis. The overall performance of the groundwater sampling technologies was assessed by evaluating sampler precision as well as comparability with reference samples collected at the same time technology samplers were collected during the various trials. Other aspects of field deployment, such as logistical requirements and potential applications of the technology are also considered in this evaluation.

A brief outline of this report is as follows: Section 2 contains a brief description of the GORE-SORBER module and its capabilities. Section 3 outlines a short description of the test facilities and a summary of the verification test design. Section 4 includes a technical review of the data with an emphasis on assessing overall sampler performance. Section 5 presents an update of the GORE-SORBER Water Quality Monitoring technology and provides examples of representative applications in environmental characterization and monitoring settings. Appendix A includes performance data for the reference pump, and Appendix B includes an assessment of quality control data associated with the analytical method used in this study.

Section 2 — Technology Description: W. L. Gore and Associates Inc. GORE-SORBER Water Quality Monitoring

This section provides a general description and overview of the capabilities of the GORE-SORBER Water Quality Monitoring technology. The information used to prepare this section was provided by W. L. Gore and Associates, Inc.

The GORE-SORBER module consists of an expanded polytetrafluoroethene (ePTFE) membrane surrounding an adsorbent material that is used to collect volatile and semi-volatile compounds in water. When placed in the screened, saturated interval of a monitoring well or piezometer, the waterproof, vapor-permeable membrane collector housing allows for water/air partitioning (in accordance with Henry's Law) of dissolved-phase organic compounds while preventing transfer of liquid water and eliminating impact from suspended solids on the adsorbent.

Module Configuration

A typical GORE-SORBER module consists of four separate "sorbers" as shown in Figure 1. A typical sorber is about 25 mm in length, 3 mm in diameter, and contains 40 mg of a granular adsorbent material that is selected on the basis of the specific compounds to be detected. Typically, polymeric and carbonaceous resins are used because of their affinity for a broad range of VOCs and semi-VOCs (SVOCs). The sorbers are sheathed in the bottom of a length of vapor-permeable insertion and retrieval cord that includes a loop attachment. The four sorber units and associated cord are collectively termed a GORE-SORBER® module. Both the retrieval cord and sorbent container are constructed solely of inert, hydrophobic, microporous membrane. Every module has sufficient sorbers such that there is always a minimum of two samples available in each module (for use as duplicates or backups, if needed).

A unique feature of the membrane is that it is hydrophobic, excluding the transfer of liquid water across the membrane, while facilitating vapor transfer. Thus VOC and SVOC vapors can penetrate the sorbent module freely and collect on the adsorbent material. Depending on the membrane characteristics, liquid water will be excluded to a particular depth, therefore it is important to know the desired depth of installation. Different membranes can be used for different installation depths, and GORE technical support personnel can help in the selection of the best membrane type. This ability to protect the sorbent media from contact with soil and groundwater without retarding gaseous diffusion facilitates the application of Gore's screening methods in both the saturated and unsaturated zones.

Two different membrane types were evaluated in this verification test. This first membrane type termed *standard*, hereafter abbreviated STND, is recommended for deployment in wells in which the depth of the overlying water column does not exceed 30 ft. A second higher density membrane type termed *high water entry pressure*, hereafter abbreviated HWEP, can be deployed in wells with overlying water column depths up to 50 ft.

Sorbent Selection

Sorbent selection is a critical component of any passive sampling system. Selected sorbents must have good sensitivity to a broad range of volatile and semi-volatile organic compounds while exhibiting hydrophobic properties to minimize preferential uptake and competition from water vapor. The sorbents used in the GORE-SORBER modules include carbonaceous and polymeric resins. They are designed to provide good adsorption properties for both the VOC and SVOC components in a mixture while at the same time minimizing the collection of water vapor on the sorbent.

Shipping

The modules are shipped in box containers, and each module is shipped in a separate, pre-labeled glass jar with a corresponding pre-labeled lid. The numbers on the glass jar, the lid and the module will all correspond to each other.

The shipment also contains string and stainless steel weights to secure the module loop and to allow the field personnel to lower the sampler into

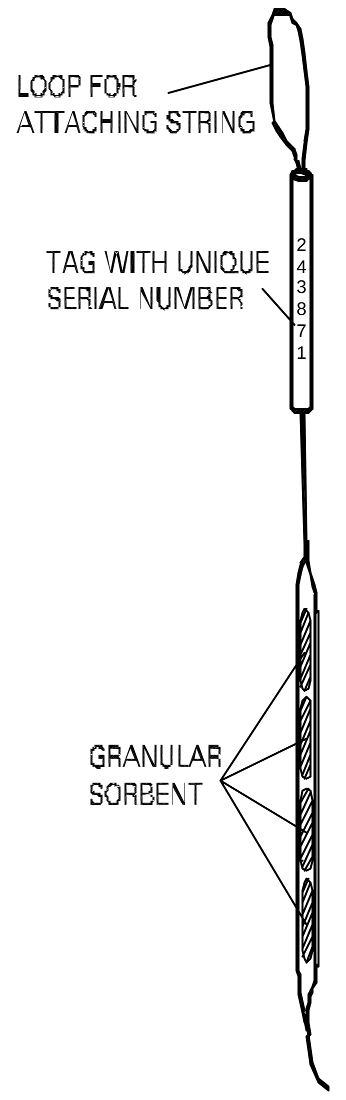

Figure 1. **Schematic diagram of a GORE-SORBER module..**

the saturated zone. A chain of custody and an installation/retrieval form also accompany the shipment.

Prior to deployment in a monitoring well, the containers should be inspected to ensure that the proper number of modules has been received, and that the sorber units have not been damaged in shipping.

Installation and Retrieval

Upon first use at a particular monitoring well, the data collected by the GORE-SORBER module must be calibrated using conventional water sampling and analysis methods as a reference. After at least two parallel sampling events, the GORE-SORBER modules can be installed by themselves (without matrix sampling), but it is advisable to collect groundwater samples by a reference method periodically (e.g., annually) in order to confirm the relationship between these two sampling methods.

Before installation of the GORE-SORBER module into a well, it is necessary to know the depth to water, and the screened interval of the well. The GORE-SORBER module should be placed in the middle of the screened interval. A length of cord supplied with the module is tied to a clean stainless steel weight. The GORE-SORBER module is tied to the cord directly above the weight. The cord is lowered into the well to the appropriate depth and tied off to the wellhead. After an exposure period of approximately 48 hours, the module is pulled out of the well and the sample number is confirmed. The module is then placed into the same numbered glass vial, and placed into the shipping container. Additional modules are shipped as trip blank samples and are provided to document whether the modules are impacted during shipment. Trip blanks are selected by the field team and noted on the insertion/retrieval form. After module installation is complete, the box containing the trip blanks is transported to a secure location for temporary storage until retrieval time. This temporary storage area must be out of direct sunlight, well-ventilated, and free from heat extremes as well as any obvious ambient air contamination. Boxes with field-exposed modules and trip blanks are returned along with the chain-of-custody form to Gore's laboratory in Elkton, MD usually via overnight courier. Under these shipping conditions, refrigeration of the sample is not necessary.

Analytical Methods

Laboratory analysis options for the modules include methods for the determination of volatile organic compounds, semi-volatile organic compounds, and polycyclic aromatic hydrocarbons (PAHs). In addition to these common suites of compounds, the samples can also be analyzed for specific groups of compounds; i.e., fuel hydrocarbons, pesticides, explosives, and chemical agents, among others. The analyses follow modified EPA Methods SW846 8260 for VOCs, and 8270 for SVOCs. All analytical services on GORE-SORBER modules are performed at the W.L. Gore & Associates, Inc. laboratory in Elkton, MD.

Following module receipt and logging at the laboratory, they are removed from the shipping containers and prepared for the analytical process. The sorber packets are removed, inspected, and placed into an automatic thermal desorption unit. During analysis, a heat pulse in the thermal desorption unit is used to volatilize the collected VOCs. The desorbed compounds are then transported via a carrier gas flow into the inlet of a gas chromatograph-mass spectrometer (GC-MS). The compounds are identified and quantified in the GC-MS. When the analyses are complete, an analytical chemist verifies the data and a draft data table is prepared.

Data Analysis

Absolute levels of detected ions in the GC-MS are determined by the ionization efficiency of the target compound. These efficiencies vary by a factor of twenty for typical target analytes, and make inter-compound comparison of ion count data difficult or impossible. Furthermore, detected ion levels can change as MS tuning adjustments are made. They are also dependent on such variables as the cleanliness of the MS source, and the age of the GC column or desorption unit cold trap. For this reason, GORE always includes analyses of sorbers injected with reference standard solution, and reports target data as a mass of analyte, in micrograms (µg) per sorbent module.

Typically, data from groundwater samples are compared against the data from the GORE-SORBER modules, and the relationship is evaluated between concentration in groundwater and mass sorbed on the collector. This relationship is then confirmed in at least one, and preferably two, parallel, sampling events. After two sampling events, the GORE-SORBER modules may be used alone, with periodic (annual) parallel sampling to confirm and enhance the relationship between these sets of data.

Vapor pressure, water solubility, molecular weight, and the Henry's Law partitioning coefficient are important chemical parameters to consider when interpreting analysis data. The Henry's Law coefficient reflects a compound's behavior when partitioned into air and water, which aids in understanding an organic chemical's likely state in the subsurface.

Guidelines for Use

Outlined below are some general guidelines for the use and installation of passive, adsorbent-based GORE-SORBER modules in monitoring wells as a means of qualitatively screening water quality as part of a groundwater monitoring program.

- GORE-SORBER modules can be used to reduce the frequency of groundwater purging and sampling for petroleum and chlorinated organic chemicals, including polycyclic aromatic hydrocarbons.
- An initial round of testing consisting of water sampling and testing by conventional means along with simultaneous sampling with GORE-SORBER modules is recommended. The deployment and retrieval of the GORE-SORBER modules should occur prior to

any purging/sampling of the well for matrix testing purposes. This comparison is done in order to establish a baseline relationship at a particular well between the water concentration data and the sorber mass data. The results are then plotted on a scatter diagram or color contour maps to show the site-specific relationship between groundwater concentration and mass on the GORE-SORBER module.

- Subsequent testing may be performed only using GORE-SORBER modules to monitor trends in water quality at a specific well over time.
- Conventional well purging and groundwater sampling, concurrent with the use of GORE-SORBER modules, is recommended every four to six sampling events. To ensure comparability of the data, these periodic matrix samples must be collected and analyzed in a consistent manner.
- GORE-SORBER modules should be placed within the screened interval in the monitoring well, and not in the headspace of the well or outside the screened interval. Placement of the module in the screened interval where water flow is occurring will avoid stagnation effects that are likely to occur if the module is placed in a section of the well that is not screened.
- Modules should not be placed in direct contact with free product (that is, liquid hydrocarbons or solvents).
- A two-day exposure period is recommended for modules deployed directly in the groundwater. This exposure period has been derived experimentally as part of Gore's product validation efforts.
- GORE-SORBER modules can be used to test for benzene, toluene, ethylbenzene and xylenes (BTEX), petroleum hydrocarbons, chlorinated solvents and many semi-volatile organic compounds, such as polycyclic aromatic hydrocarbons (PAHs). Application for ethers, alcohols, ketones or most other highly water-soluble compounds has not been validated at this time.
- Information relative to the site, the well construction, as well as water sampling and testing procedures being used, will be useful for data interpretation purposes.

Data Interpretation and Use

The data collected from a GORE-SORBER Water Quality Monitoring event along with interpretations are provided in a final report, which contains the following information:

- Chain–of–custody documentation
- A summary of the laboratory procedures used in the analysis of the GORE-SORBER modules
- A tabulation of the data from each module (with accompanying groundwater concentration data (if available) and color contour maps, as necessary)
- Scatter diagrams comparing data from the GORE-SORBER modules with groundwater concentration data (if available)

GORE-SORBER Water Quality Monitoring technology is designed for well screening programs to detect order-of-magnitude changes in groundwater concentrations over time; or, for "sentry" monitoring programs at the leading edge of a migrating plume. Ideally, this technology can be used to compliment an existing water quality monitoring program, thereby reducing the number of aqueous groundwater samples that need to be collected and analyzed. Such an approach can result in considerable cost savings.

Additional information on potential applications of this technology for environmental characterization and monitoring can be found in Section 5–Technology Updates and Applications.

Section 3 — Demonstration Process and Design

Introduction

The principal objective of this demonstration was to conduct an independent evaluation of the capabilities of several groundwater-sampling technologies for VOC-contaminated water. A number of key performance parameters were chosen to evaluate overall sampler performance. In order to ensure data integrity and authenticity of results, data quality control measures were also incorporated into the study design. Personnel at Sandia National Laboratories developed the design with concurrence from the various technology vendors participating in the study. EPA personnel with professional expertise in the area of groundwater sampling also provided technical review of the study design. A complete demonstration plan has previously been published [Sandia, 1999].

Site Description

The John C. Stennis Space Center (SSC) in southwest Mississippi is one of ten NASA field centers in the United States. It is NASA's primary center for testing and flight certifying rocket propulsion systems for the Space Shuttle and future generations of space vehicles. Over the years, SSC has evolved into a multi-agency, multi-disciplinary center for federal, state, academic and private organizations engaged in space, oceans, environmental programs, and national defense. The USGS is a one of the resident agencies at the NASA-Stennis complex and operates a number of testing facilities as a part of its Hydrologic Instrumentation Facility (HIF). This facility supports USGS agency-wide hydrologic data-collection activities through the identification of agency needs, development of technical specifications, and testing and evaluation.

Standpipe Facility – One of the HIF test centers is known as the Standpipe Facility. The facility was designed by Doreen Tai, an HIF chemical engineer, and is housed in a Saturn V rocket storage building at the Stennis complex. A schematic diagram of the standpipe and accessories is shown in Figure 2. The standpipe is an above-ground, 100-foot long, 5-inch diameter, stainless steel pipe with numerous external sampling ports along its length. Two large tanks at the top of the standpipe are used to prepare solutions which can then be drained into the standpipe. The tanks are equipped with motor-driven mixing propellers and floating lids to minimize loss of volatile compounds during solution mixing and transfer. An external standpipe fill line at the bottom of the pipe enables the pipe to be filled from the bottom up, thereby minimizing flow turbulence and VOC losses in the prepared solutions. The external access ports allow reference samples to be taken simultaneously with the collection of technology samples inside the pipe. As shown in Figure 2, the indoor facility has six levels of access, including the ground floor, and a freight elevator services all levels. In this demonstration, the standpipe was used in a series of controlled water sampling trials. Technology vendors sampled VOC-contaminated water solutions from the standpipe while reference samples were simultaneously taken from the external ports.

Site Hydrogeology – The second phase of this technology demonstration involved the collection of groundwater samples from five onsite wells at SSC. The site has about 200 wells that have been used for subsurface plume characterization and routine groundwater monitoring. The shallow, near-surface geology where most of the contaminant plumes are located can be summarized as follows [Foster Wheeler, 1998]: The geology generally consists of a thin veneer of clayey sediments known as Upper Clay, which are found at elevations ranging from 10 to 30 feet above mean sea level (MSL). These overlay a sandy unit named the Upper Sand (at 5 to 15 feet MSL). The Upper Sand is underlain by a second clayey unit named the Lower Clay and a second sandy unit called the Lower Sand (at –35 to 5 feet MSL). Below the Lower Sand another clayey unit is present which represents an unnamed or undifferentiated Pleistocene deposit. This deposit is underlain by a thick zone of interbedded sand and clay deposits that form the Citronelle Formation (at –100 to –40 feet MSL). The VOC contamination is present in the Upper Sand and Lower Sand water bearing zones; and most of the wells selected for use in this test were screened in these zones. Typical sampling depths for the wells selected for study ranged from about 15 to 85 feet below ground level.

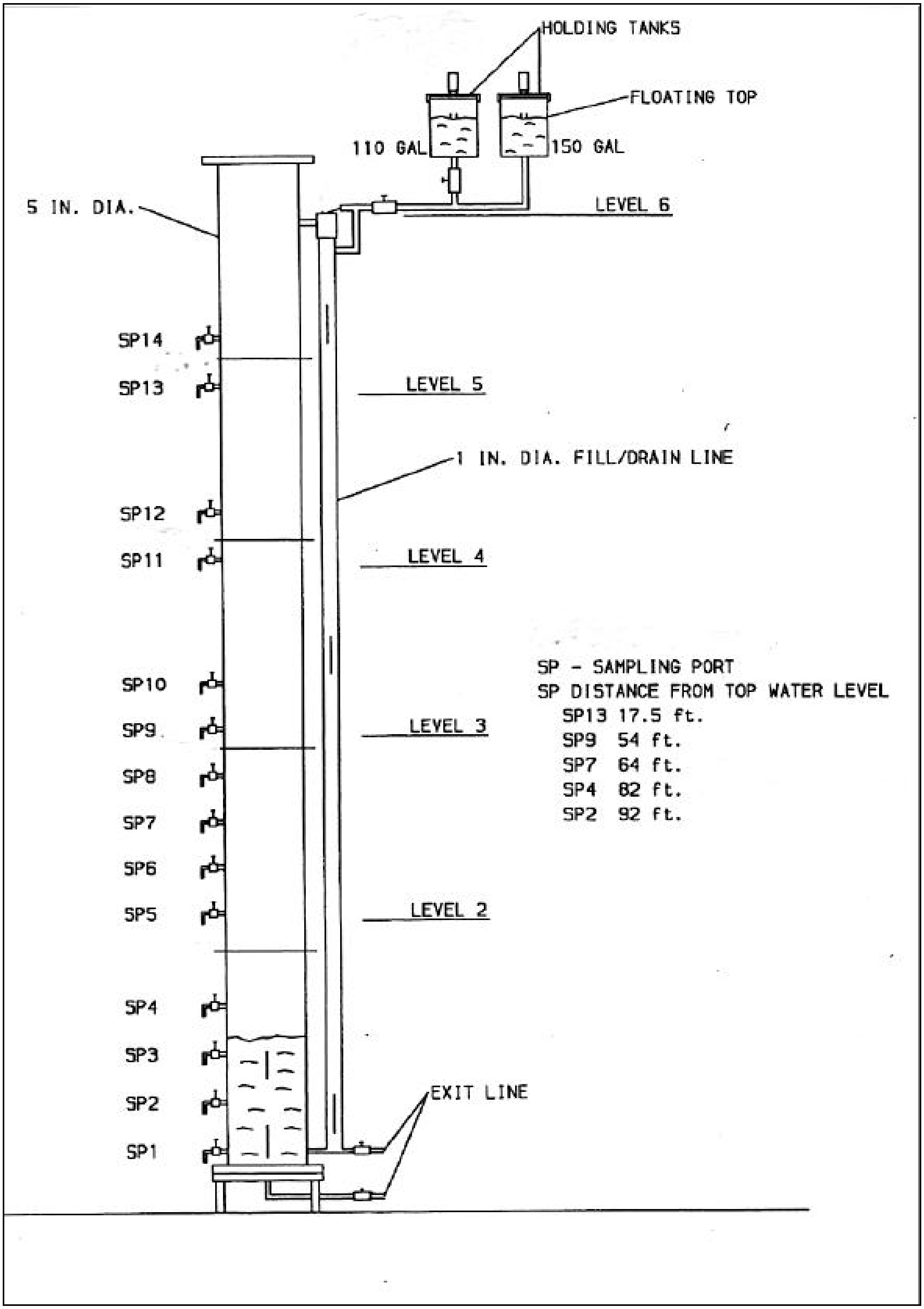

Figure 2. The standpipe at the USGS Hydrological Instrumentation Facility.

Groundwater Monitoring Wells—Construction information for the five wells selected for use in this study is given in Table 1. The wells were constructed with 2-inch-diameter polyvinylchloride (PVC) pipe with a 10-foot PVC screen length. All GORE-SORBER Water Quality Monitoring and reference pump samples were collected at the mid-screen level. Typical water depth above the mid-screen sampling point in the wells selected for study ranged from about 2 to 10 feet.

Verification Test Design Summary

The verification test design for the GORE-SORBER Water Quality monitoring system consisted of two test events. The first was a test conducted under carefully controlled sampling conditions at the standpipe. This trial enabled GORE-SORBER module precision to be systematically evaluated. The second series of tests were conducted a series of groundwater monitoring wells. These field trials presented an opportunity to observe the technology in actual field use under conditions very similar to those that would be encountered in routine use. The field trials also offered an opportunity to compare GORE-SORBER Water Quality Monitoring results to reference sample results. Together, these two study elements provide a data set that is adequate for an overall performance assessment of the GORE-SORBER Water Quality monitoring system in applications involving the sampling of VOC-contaminated groundwater.

Test Design Elements

Additional test design element descriptions are given below. The six participating technologies in this verification test were split into two categories namely, *active sampler*s and *passive samplers*, with differing sampling trials specific to the two sampler categories. The test design element descriptions that follow were those used for evaluation of the GORE-SORBER Water Quality Monitoring system.

Target VOC Compounds—Six target compounds, all regulated under the US EPA Clean Water Act, were selected for testing in this study. The compounds were 1,2-dichloroethane (12DCA), 1,1-dichloroethene (11DCE), trichloroethene (TCE), benzene (BNZ), tetrachloroethene (PCE), and 1,1,2-trichloroethane (112TCA). With the exception of benzene, all of these compounds are chlorinated and have regulatory limits of 5 µg/L in water as presented in the Clean Water Act. The six compounds selected encompass a range of volatility, a parameter that is likely to influence sampler performance. Target compound volatility and other relevant physical data are given in Table 2.

Table 1. Construction Details of Groundwater Monitoring Wells

Well No.	TOC (ft, MSL)	Total Depth (ft)	Screen Elev. (ft, MSL)		Well Dia. (in)	Well Install Date	Depth to Water (ft)	Water Level (ft, MSL)	Water Depth Above Screen Midpoint (ft)
			Top	Bottom					
06-04	28.8	39.0	–1.3	–11.3	2	04/95	24.6	4.2	10.5
06-09	13.0	18.0	4.0	-6.0	2	05/95	8.7	4.3	5.3
12-01	28.5	18.0	13.2	8.7	2	06/92	10.9	17.6	9.4
12-06	28.1	17.0	21.0	11.0	2	05/95	9.7	18.5	2.2
12-09	28.0	18.0	18.0	8.0	2	05/95	10.0	18.0	5.0

Notes: TOC = top of well column; water levels from most recent quarterly well-monitoring data.

Table 2. Target VOC compounds

Compound	Henry's Constant (kg·bar/mole at 298 K)[a]	Boiling Pt. (ºC)
Tetrachloroethene (PCE)	High (17.2)	121
1,1-Dichloroethene (11DCE)	High (29.4)	32
Trichloroethene (TCE)	Mid (10.0)	87
Benzene (BNZ)	Mid (6.25)	80
1,2-Dichloroethane (12DCA)	Low (1.39)	84
1,1,2-Trichloroethane (112TCA)	Low (0.91)	114

[a] Henry's constant data from NIST, 2000

Test Concentrations—Water mixtures containing the six target VOCs in a range of concentration levels were loaded into the standpipe during testing. For the GORE-SORBER Water Quality Monitoring evaluation, the target compound concentration was low (~20 µg/L) and uniform throughout the pipe. Spike solutions of all six target compounds were prepared in methanol from pure compounds. Normally a 5-10 mL volume of the spiking solution was injected into the mixing tank that was pre-filled with tap water. The solution was covered with a floating lid, gently mixed for 5 minutes, and drained into the standpipe. Preliminary studies at the standpipe revealed volatile losses of target compounds during the process of mixing and standpipe filling. Consequently spike concentrations were not used as a reference value in this study. Alternatively, the study design specified the collection of reference samples from standpipe external sampling ports. Reference samples were collected at the same time that each technology sample was collected from the standpipe.

Groundwater Well Reference Samples—The use of five onsite monitoring wells in the second phase required the use of a co-located reference sampler of known performance such that a comparison of reference and GORE-SORBER module data could be compared. A submersible electric gear pump (Fultz, Model SP-300) was chosen as the reference sampling device. Verification studies on the performance of this pump were carried out during the standpipe phase of the experiments to provide technical data substantiating its use as a reference method in the field. A more complete description of the pump along with a summary of these data is given in Appendix A. During field sampling events, the reference pump was co-located with the GORE-SORBER modules at the same depth in the well in order to provide periodic reference samples from the well over the duration that the modules were in the well.

Sampler Performance Parameters

Four performance parameters were evaluated in the overall assessment of each technology. They are briefly outlined in the following paragraphs.

Precision—Sampler precision was computed for the range of sampling conditions included in the test matrix by the incorporation of replicate samples from both the standpipe and the groundwater monitoring wells in the study design. The *relative standard deviation* (RSD) was used as the parameter to estimate precision. The percent relative standard deviation is defined as the sample standard deviation divided by the sample mean times 100, as shown below:

$$RSD(\%) = \frac{\sqrt{\dfrac{\Sigma(X_i - \bar{X})^2}{n-1}}}{\bar{X}} \bullet 100$$

Here, X_i is one observation in a set of n replicate samples where $\bar{X}$ is the average of all observations, and n is the number of observations in the replicate set. Precision data from the GORE-SORBER modules and reference samples are not directly comparable since multiple samples are used to derive a time-weighted average reference concentration. In this study, precision data from a similar test in which replicate reference samples collected at multiple standpipe depths, comparable to those at which the GORE-SORBER modules were tested, are used for qualitative comparison with GORE-SORBER module precision.

Comparability—In each standpipe and groundwater monitoring test a series of reference samples were collected that were used to compute a time-weighted average concentration over the exposure interval of the GORE-SORBER modules. The mathematical expression used to describe the *time weighted average* (TWA) concentration is given below:

$$TWA = \frac{\sum_{i=1}^{6} C_i \bullet T_i}{48}$$

where C_i is the measured concentration in units of μg/L at a given time step, and T_i is the duration of the time step in hours. (Note that for i =1 and 6, a time step duration of 6 hours was used. For all other values of i, a time step value of 12 hours was used.) The GORE-SORBER module data are reported in mass units of VOC collected and thus are not directly comparable to the time-weighted-average concentration determined from the reference sampler. For the groundwater wells, the coefficient of variation (r) as defined by Havlicek and Crain [1988] is used to describe the degree of correlation between the GORE-SORBER module data and the reference data over the range of concentration examined in this study. A value of r that is near 1 indicates a high degree of linear correlation in the two data sets.

Sampler Versatility—The versatility of the GORE-SORBER Water Quality Monitoring technology was determined by evaluation of sampler performance over the volatility and concentration range of the target compounds as well as the range of sampling depths encountered in both the standpipe and the groundwater monitoring well trials. A sampler that is judged to be versatile operates with acceptable precision and comparability with reference samples over the range of experimental conditions included in this study. Those samplers judged to have low versatility may not perform with acceptable precision or comparability for some of the compounds or at some of the sampling depths.

Field Deployment Logistics—This final category refers to the relative ease of deployment of the sampler under its intended scope of application. This is also a less objective category and incorporates field observations such as personnel and training required for use, ancillary equipment requirements, portability, and others.

Sample Analysis

Because the GORE-SORBER modules are only analyzed at Gore laboratories, different analytical methods were used for technology and reference samples. All reference sample analyses were conducted onsite, using analytical services provided by Field Portable Analytical (Fremont, CA). The GORE-SORBER modules were analyzed by the W. L. Gore laboratory using thermal desorption of the sorbent media followed by GC-MS analysis using a modification of EPA SW846 Methods 8260 and 8270 [EPA, 1996]. A brief description of the analytical method for the GORE-SORBER Water Quality Monitoring technology is given in Section 2.

The onsite analytical instrumentation used for reference sample analysis consisted of two identical field portable GC-MS units (Inficon, HAPSITE Syracuse, NY) equipped with the Inficon Headspace Sampling Systems. The analysis method used was a modified Method 8260 (purge-and-trap GC-MS) with headspace sampling replacing the purge-and-trap portion of the method [EPA, 1996]. Sample throughput was on the order of 4 to 6 samples per hour per instrument for a daily throughput of 60-70 samples per instrument. The Inficon field-portable GC-MS system with headspace vapor sampling accessory has previously gone through the ETV verification process. Results from this verification study showed that system accuracy and precision for VOC in water analysis was comparable with a conventional fixed laboratory analysis using purge-and-trap sample handling combined with bench-top GC-MS analytical systems [EPA, 1998].

A brief summary of the analytical method follows: Reference samples were brought to the analysis location in 40-mL volatile organics analysis (VOA) vials and kept at temperatures near 4 °C until they were prepared for instrument analysis. As a result of the relatively high sample throughput and the use of two instruments, sample holding times did not exceed 24 hours in most cases. Consequently, no sample preservatives were used in the study. Immediately prior to analysis, the chilled VOA sample vials were uncapped and immediately transferred to a 50-mL glass syringe. Half (20 mL) of the sample was then transferred to a second 40-mL VOA vial and the vial was immediately capped. A 5-µL solution containing internal standards and surrogate standards was injected through the septum cap of the vial. The vial was then placed in the headspace sampling accessory and held at 60 °C for 15 minutes. (The original vial was again filled with the remainder of the sample, capped, and held under refrigeration as a spare.) Following the temperature equilibration time, a vapor extraction needle was inserted through the vial's septa cap and into the headspace. A pump in the GC-MS then sampled a fixed volume of headspace gas through a heated gas transfer line and into a fixed-volume gas sampling loop in the GC-MS. Under instrument control, the gas sample was then injected onto the capillary column for separation and detection. An integrated data system processed the mass detector data and output results for the six target analytes plus internal and surrogate standards in concentration format. The method used the internal standard method (as outlined in Method 8260) for computation of target compound concentrations. Surrogate standard results were used as measures of instrument data quality, along with other quality control measures outlined below.

Data Processing

The results from chemical analysis of both GORE-SORBER modules and reference samples were compiled into spreadsheets and the arithmetic mean and percent relative standard deviation (as defined in Section 3) were computed for each set of replicate samples from each standpipe and monitoring well trial. All GORE-SORBER module data for the six target compounds were reported in units of micrograms of target VOC collected on the sorbent. All reference data were reported in concentration units of µg/L. Direct trial-by-trial comparisons were then made between technology and reference sample results as outlined below. All the processed data from the verification study have been compiled into data notebooks and are available from the authors by special request.

Data Quality Control

The desirability of credible data in ETV verification tests requires that a number of data quality measures be incorporated into the study design. Additional details on data quality control are provided in the following paragraphs.

Sample Management—All sampling activities were documented by Sandia field technicians using chain-of-custody forms. To save sample handling time and minimize sample labeling errors in the field, redundant portions of the chain-of-custody forms and all sampling labels were pre-printed prior to the field demonstration.

Field Logbooks—Field notes were taken by observers during the standpipe and groundwater well sampling trials. The notes include a written chronology of sampling events, as well as written observations of the performance characteristics of the various technologies tested during the demonstration.

Pre-demo Analytical System Audit—Prior to the actual demonstration, a number of samples containing the six target compounds at various concentration levels were prepared at SNL and sent via overnight express mail to Field Portable Analytical for analysis. The laboratory used the same headspace–GC-MS method intended for use in the final field test during this pre-demo audit. Results from this preliminary audit revealed acceptable performance of the GC-MS system and its accompanying method. The written analytical method that was used during the full demonstration was also reviewed and approved at this time.

Reference Analytical Method—The analytical method was an adaptation of EPA Method 8260B and followed the data quality requirements outlined in the method. Included in the list of data quality measures were: 1) initial calibration criteria in terms of instrument linearity and compound recovery, 2) daily instrument calibration checks at the onset and completion of each 12-hour analysis shift, 3) blank sample instrument performance checks, 4) internal standard recovery criteria, and 5) surrogate standard recovery criteria. A summary of the GC-MS analysis quality control data for the demonstration period is given in Appendix B.

GORE-SORBER Water Quality Monitoring Analysis—The analytical methods employed in the analysis of the GORE-SORBER modules were a modified EPA SW846 Method 8260 for VOCs and 8270 for semi-VOCs. Before each run sequence and after every 30 samples, a sorber containing 5µg bromofluorobenzene (BFB), and a method blank were analyzed. The BFB mass spectra was required to meet acceptance criteria set forth in the analytical method. System cleanliness was verified with no detection of target compounds in the method blanks. Standards containing the selected target compounds at three calibration levels of 5, 20, and 50 µg were analyzed following the initial BFB and method blank checks. The linear calibration curve acceptance criterion for each target compound was relative standard deviation less than 35% . If this criterion was not met for any target compound, non-linear second- or third-order standard curves were generated, as appropriate. A second-source reference standard, at a level of 10 µg per target compound, was analyzed after every ten samples and/or trip blanks and at the end of the run sequence to ensure detectability of each target compound throughout the analysis. All target compounds were detected in each of the second-source reference standards.

Verification Test Plan

The preceding information, as well as that which follows, is summarized from the Groundwater Sampling Technologies Verification Test Plan [Sandia, 1999], which was prepared by SNL in entirety and with concurrence of all participants prior to the field demonstration. The test plan includes a more lengthy description of the site, the role and responsibilities of the test participants, as well as a discussion of the experimental design and data analysis procedures.

Standpipe and GW Well Sampling Matrix

The sampling matrix for the standpipe sampling phase of the demonstration is given in Table 3. In this test, GORE-SORBER modules were deployed at up to four depths in the pipe. Four replicates of two types of modules–standard (STND) and high water entry pressure (HWEP) modules–were positioned at the depths shown in Table 3. The test was conducted with a uniform low concentration (10-20 µg/L) standpipe mixture in the pipe. The cluster of modules at each depth were tied to a weighted nylon cord, lowered into the standpipe, and left in place for a 48-hour period. Periodically, throughout the 48-hour module exposure interval, duplicate reference samples were collected from the adjacent sampling ports. The first duplicate reference sample was collected at the time of module deployment, the last reference sample was collected when the modules were withdrawn from the well, and the other 4 sets of reference sample collections were done at approximate 12-hour intervals between module deployment and retrieval.

Table 3. The GORE-SORBER Module Verification Trial at the Standpipe

VOC Concentration Level	Standpipe Collection Port /Depth	STND Module Replicates	HWEP Module Replicates
Low (~20 µg/L)	SP14 - 17 feet	4	4
	SP12B - 28 feet	4	4
	SP12 - 35 feet	--	4
	SP10B - 46 feet	--	4

Notes: The STND module construction is not recommended for deployment in water column depths in excess of 30 feet. The HWEP module is rated for water column depths up to 50 feet. In each trial, duplicate reference samples were collected from adjacent sampling ports at approximate 12-hour intervals, starting with GORE-SORBER module deployment and ending with GORE-SORBER module retrieval.

The groundwater well sampling matrix is shown in Table 4. The groundwater well trials 1 through 5 were carried out as follows. The GORE-SORBER modules were tied to the pump line directly above the pump intake and within 15 cm of the pump intake. This pump/module configuration was lowered into the well to the mid-point of the well screen, and left in place for 48 hours. Periodic reference samples were collected from the well using the submersible electric pump. Five reference samples were collected at approximate 12-hour intervals over the duration of the 48-hour module exposure interval, beginning with a reference sample collection at the time of module placement and ending with a reference sample collection at the time of module retrieval. The reference pump was left in place in the well during the 48-hour module exposure interval so that the water column was not disturbed by repeated pump placement and withdrawal. Teflon tubing (1/4-inch outside diameter, 3/16-inch internal diameter) was used to transport the water sample from the pump outlet to the collection vial at the wellhead. During each of the five reference sample collection events, the pump was operated at a low (100-200 mL/min) flow rate. A pre-sampling purge volume of about 2 liters was used to flush the pump and tubing volume of the reference pump to ensure that the pump was sampling from the water zone in which the modules were positioned. Following this initial purge, duplicate 40 mL VOA sampling vials were sequentially filled. The results from the five reference samples were then used to calculate a time-weighted average concentration for comparison with the GORE-SORBER module results.

Chronological Summary of Demonstration Activities

The demonstration began on Monday, August 9 and concluded on Tuesday, August 17. The first four days of the demonstration were devoted to testing those technologies designated "active samplers." Included in this group were Burge Environmental (multi-level sampler) Clean Environment Equipment (bladder pump), Geolog (bladder pump), QED Environmental (bladder pump), and Sibak Industries (discrete-level grab sampler). The second half of the demonstration interval was devoted to testing the "passive sampler" category of which W. L. Gore and Associates Inc. (GORE-SORBER module) was the only participant. A short briefing was held on Monday morning for all vendor participants to familiarize them with the standpipe facility and the adjacent groundwater monitoring wells. The passive sampler category tests were begun at the standpipe Thursday, August 12 and were completed on Monday, August 16. The passive samplers were also deployed at a number of onsite monitoring wells simultaneously with standpipe testing.

Table 4. GORE-SORBER Module Verification Trials at the Groundwater Monitoring Wells

Trial	Well	Distance from top of well to screen mid point (feet)	Water Column Depth (feet)	Approximate TCE Conc. (mg/L)	No. of Replicates per technology
1	06-04MW	35.1	9.8	350	4
2	12-09MW	15.0	5.2	5	4
3	12-01MW	19.9	6.8	2000	4
4	06-09MW	14.0	5.4	50	4
5	12-06MW	12.1	2.5	40	4

Notes: Reference samples were collected at 12-hour intervals from a submersible electric sampling pump collocated with the GORE-SORBER modules. Water column depth refers to the depth of water above the sampler placement location at the well screen mid-point. Four replicates were analyzed for each of the two GORE-SORBER modules membrane types (STND and HWEP) that were tested. Five sets of reference samples were also collected in duplicate at 12-hour intervals throughout the module exposure interval in each well.

Reference sample analysis was carried out in a mobile laboratory parked near the standpipe and occurred simultaneously with field-testing. An approximate 24-hour turn around time was encountered between sample collection and chemical analysis completion. As previously noted, GORE-SORBER module analysis was conducted at Gore laboratories and reference sample analysis was carried out onsite. All reference samples were analyzed on the same instrument and usually on the same day. This approach was taken to minimize the possible influence of instrument variability on the analysis results.

GORE-SORBER modules were shipped to the W.L. Gore laboratory in Pennsylvania via overnight mail at the conclusion of the field study and received at the laboratory on August 18. Laboratory analysis of all modules was carried out between August 23 and August 27.

The demonstration technical team observed and recorded the operation of each technology during both standpipe and monitoring well trials to assist in the assessment of logistical requirements and technology ease of use. These observations also were used to document any performance anomalies as well as the technical skills required for operation.

Deviations from the Verification Plan

A listing of the deviations from the test plan during GORE-SORBER Water Quality Monitoring testing that are judged to be important are summarized, along with an assessment of the resulting impact on the verification test data set.

Data collected at other standpipe depths—GORE-SORBER modules were deployed at depths greater than those specified for normal module use. Data from these tests were used only for further product research and development by W. L. Gore personnel.

Data outliers—Two replicate data points from the standpipe Trial 1 data set were obvious outliers caused by membrane leakage of liquid water and were dropped from the data set prior to the analysis of precision and comparability to reference samples. Instances where this occurred along with ramifications for typical sampler use in the field are included in the discussion of results.

Missed 12-hour sampling event—The third sampling event (Deployment time + 24 hours) at well number 12-01 was missed. To make up for this data loss, the previous (+12 hour) and following (+36-hour) sample data were averaged and used in place of the missing data. The impact of this data loss is not important since the well concentration was stable over the entire 48-hour period.

Section 4 — GORE-SORBER Water Quality Monitoring Performance Evaluation

Introduction

This section briefly discusses the results of test data analysis and summarizes sampler performance. Sampler precision, comparability with reference sample data, and overall versatility of the sampler for the characterization of VOC-contaminated water are discussed. Only summary data are given in this report. A complete tabulation of all test data is available from the authors via individual request.

Standpipe Concentration Stability

The stability of the target VOC concentrations in the standpipe over the 48-hour exposure interval in Trial 1 are illustrated with TCE results in Figure 3. Reference concentrations were measured at 17-, 28-, 35-, and 46-foot depths five times (every 12 hours) over the 48-hour exposure interval. Concentrations of the target analytes were stable and within the analytical uncertainty of the reference method. Little change in concentration with depth is observed. The rightmost entry on the graph is the time-weighted average of the five concentration measurements. The other target VOC data show stable concentration trends with time that are similar to that of TCE.

Sampler Precision

The precision for the GORE-SORBER STND and HWEP modules for the steady-state concentration trial is given in Table 5 and Figures 4 and 5. The steady-state concentration trial consisted of a low (~15 µg/L) concentration mixture containing all six target analytes that was essentially uniform throughout the entire length of the standpipe, as discussed in the previous section. GORE-SORBER modules were positioned at 17-, 28-, 35-, and 46-foot depths and exposed for 48 hours. Reference-sample relative standard deviation was not calculated because only duplicate reference samples were collected from each of the sampling

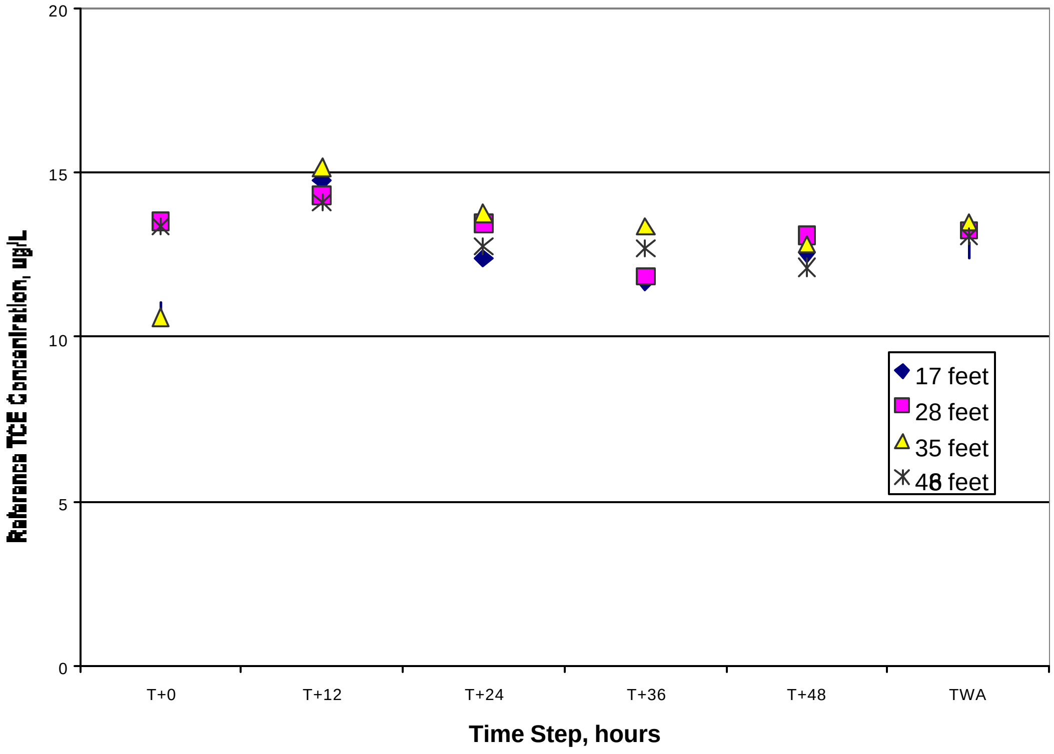

Figure 3. TCE Concentration over the 48-hour exposure interval in the standpipe trial at all sampling levels.

ports over the module exposure interval. However, the precision results from four replicate reference samples collected from a similar multi-level sampling test conducted at the standpipe during the same week are given in Table 5 for a qualitative comparison with Gore module precision results.

In the calculation of precision data, two outlier data points were dropped from the data set. (One result was dropped from the 17-foot level and the other from the 35-foot level.) The rationale for dropping these data was the observation of liquid water penetration through the membrane and into the sorbent region of the module. This was noted during inspection of the modules prior to their analysis at the W. L. Gore laboratory. When water penetrates the membrane, it displaces the VOCs adsorbed on the sorbent material. The result of water leakage through the membrane is a conspicuously low collection mass of the target VOCs on the sorbent material.

Table 5. STND and HWEP Module Precision Summary from the Standpipe Trial

Compound	Depth	Relative Standard Deviation, %		
		STND	HWEP	Reference[A]
11DCE	17	4	26[B]	9
	28	21	35	
	35		9[B]	9
	46		29	
12DCA	17	2	16[B]	11
	28	11	9	
	35		11[B]	17
	46		27	
BNZ	17	13	31[B]	3
	28	20	29	
	35		11[B]	6
	46		21	
TCE	17	10	32[B]	11
	28	19	21	
	35		13[B]	16
	46		18	
112TCA	17	8	12[B]	15
	28	15	20	
	35		11[B]	11
	46		20	
PCE	17	17	25[B]	12
	28	28	23	
	35		13[B]	13
	46		21	
Minimum		2	9	3
Maximum		28	35	17
Median		14	21	12

[A] Reference precision data are taken from a similar multi-level test conducted during the same week in which quadruplicate reference samples were collected at 17- and 35-foot depths.
[B] Relative standard deviation was calculated from three replicate samples instead of the normal four replicates.

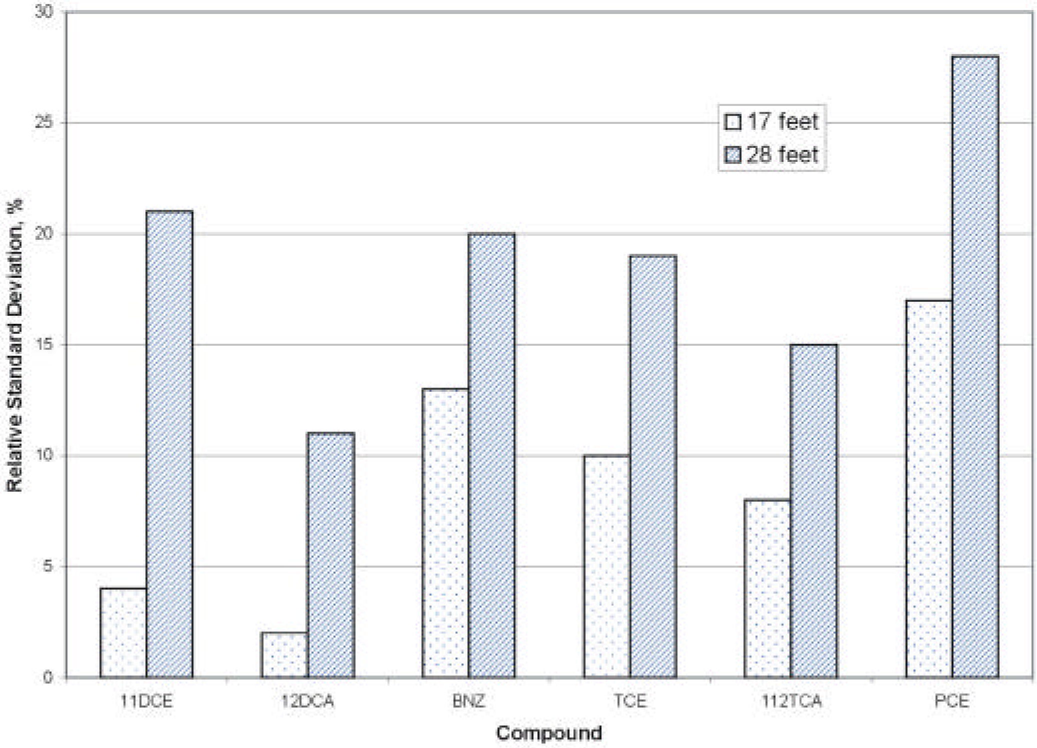

Figure 4. STND module precision in the standpipe trial by depth and target compound.

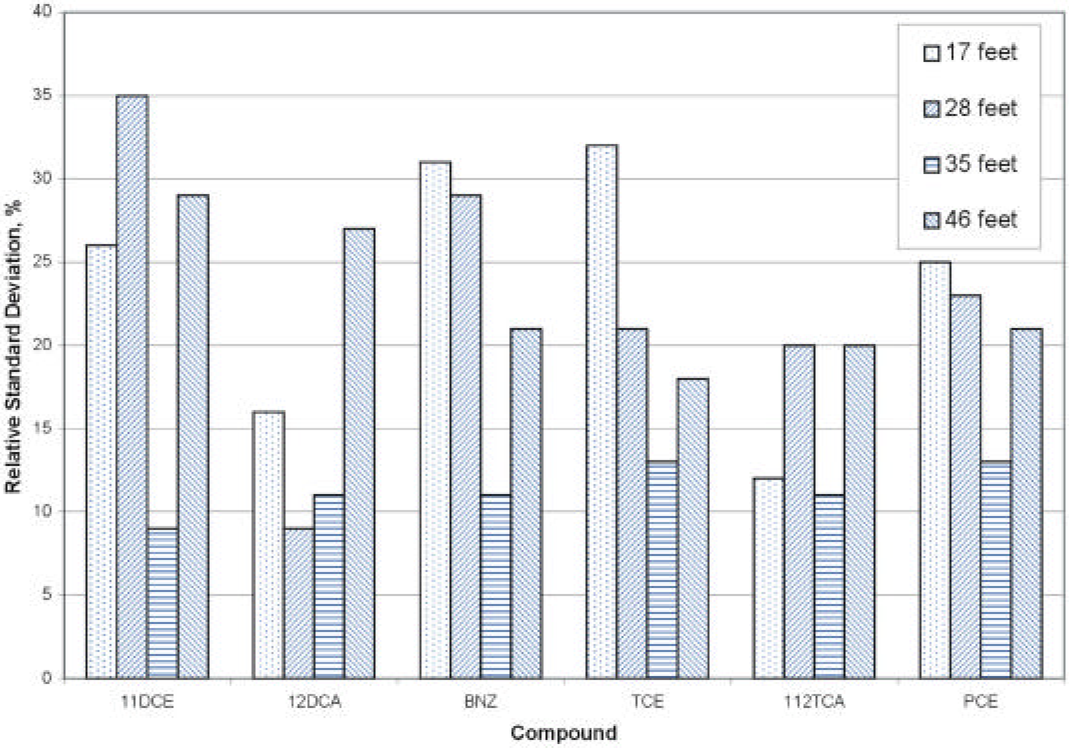

Figure 5. HWEP module precision in the standpipe trial by depth and target compound.

Precision for the STND module decreases with depth for all compounds tested, as shown in Figure 4. The decrease in precision is most likely due to contamination of the sorbent material with water. The vendor recommends that the STND module be deployed at depths less than 30 feet, as water can migrate through the membrane. The relative standard deviations at the 17-foot depth ranged from 2 to 17% for the six test compounds whereas the relative standard deviations at the 35-foot depth ranged from 11 to 28%. The median RSD for the STND modules is 14% when the results from all 6 target compounds are combined. For a comparable reference sample, the median RSD for all 6 compounds is 12%. For depth levels in which direct comparisons can be made between the GORE-SORBER modules and reference measurements, four STND module RSD values were less than the reference method and two were greater than the reference method. Thus, from a qualitative perspective, GORE-SORBER STND module and reference method precisions are comparable.

Precision for the HWEP module shows variability with depth in a generally consistent trend for all target VOCs. The best precision is observed at an intermediate sampling depth. This trend can be seen in Figure 5 which is a bar plot of percent RSD at the tested depths for each of the six target compounds. As an example, TCE has an RSD of 32% at 17 feet and 21% at 28 feet. The minimum RSD, or best precision, is 13% at 35 feet, followed by an RSD increase to 18% at 46 feet. Nearly all of the six compounds tested reveal this trend, showing the best precision in the middle (28- to 35-foot) depth range of this test. The median RSD for the HWEP module was 21% when results from all 6 target compounds are combined. For a comparable reference sample, the median RSD is 12%. A comparison of HWEP module precision with reference sample precision shows that in six cases, the HWEP module was less than or equal to the reference method and in six cases the GORE RSD was greater than the reference method. Thus from a qualitative perspective, GORE-SORBER HWEP module and reference method precision is comparable.

Monitoring Well Results

GORE-SORBER STND and HWEP modules were installed for a 48-hour exposure interval at five different monitoring wells with TCE concentrations ranging from 5 to 2000 µg/L. The samplers were deployed at relatively shallow depths as noted in Table 6, with the shallowest deployment in a water column depth of 2.5 feet and the deepest in a water column depth of 9.8 feet. Reference samples were collected at 12-hour intervals throughout the 48-hour exposure interval using a co-located submersible electric pump that was left in the well over the duration of the module exposure period. The five samples collected with the reference pump were used to compute a time-weighted average TCE concentration in each well. Precision data from the four replicate STND and HWEP modules deployed in each well are given in Table 6 along with the average TCE mass collected in the four replicate modules. The relative standard deviations for the STND and HWEP modules observed in the field tests are greater than the precision data obtained for TCE in the standpipe tests. In the standpipe, STND module precision ranged from 10 to 19%; whereas in the field, precision ranged from 11 to 64%. For the HWEP modules, the standpipe precision for TCE ranged from 13 to 32% in comparison with a field precision range of 10 to 65%.

Table 6. STND and HWEP Module and Reference Results from GW Monitoring Wells

Well No.	Water Depth Above Module (feet)	TCE TWA Well Conc. (µg/L)	STND Module		HWEP Module	
			TCE Mass (µg)	RSD (%)	TCE Mass (µg)	RSD (%)
12-09	5.2	3.9	0.1	19	0.1	27
12-06	2.5	42.5	4.2	11	4.3	28
06-09	5.4	47.8	3.3	29	3.1	33
06-04	9.8	327	28	64	37	65
12-01	6.8	1940	110	22	160	10

A log-log scatter plot of reference sample results versus each of the four replicate module measurements is shown in Figure 6 for the STND modules and Figure 7 for the HWEP modules. The plotted results reveal very good linearity across nearly three orders of magnitude in monitoring well TCE concentrations. The correlation coefficients for the average STND and HWEP results versus the reference TCE concentration at each well is greater than 0.99 in both cases. The observed correlation coefficients very near 1.00 indicate that variations in the well concentration are proportionately observed in the GORE-SORBER module results.

Deployment Logistics

The following observations were made during testing of the GORE-SORBER modules at both the standpipe and groundwater monitoring wells.

- Only one person is required to deploy the GORE-SORBER modules. The collection of reference samples for the determination of a calibration constant at initial module deployment would likely require more than one field technician. Training requirements for deployment of the samplers are minimal with an hour of so of instruction required for a technician to become proficient in routine handling and use of the sampling modules.
- The modules are very compact, self contained, and require no external power for operation.
- The modules are tied to a weighted cord and lowered to the mid-point of the well screen. The cord is then tied off at the wellhead. The time required for deployment of the modules in a well is on the order of minutes.
- Under typical use, well purging is not required. The module is lowered into the well, positioned at the mid-screen level, and retrieved 48 hours later.
- Care must be taken to deploy samplers only within the range of overlying water column depth for which they are rated. Deployment at depths in excess of specifications can result in water leakage across the membrane and erroneous results.
- The analyst must also use caution in interpreting data from single module deployments. During this study, outlier values were noted from two samplers placed at depth but within product specifications. This observation is suggestive of a membrane defect in those two samplers. Each module contains duplicate sorbent packets that can be used to verify the results. However, if membrane leakage occurs, both sorbent packets may be adversely affected by the leakage. To provide additional quality control, two separate modules could be deployed in a sampling event; however, deployment costs would double under such a scheme.

Sampler Versatility

Based on test results, the following comments can be made about the versatility of the GORE-SORBER Water Quality Monitoring technology:

- The modules must be carefully matched to anticipated water column depth above the sampler. The STND module is recommended for deployment in conditions in which the overlying water column depth is less than 30 feet. The HWEP is recommended for deployment in conditions where the overlying water column depth is less than 50 feet.
- The modules collected all of the six target analytes selected for use in this study. The target analytes were selected to represent a wide range of compound volatility and solubility. Thus in this respect the modules are judged to be versatile and can be used for a variety of VOC contaminants in water.
- The GORE-SORBER Water Quality Monitoring technology is probably best suited for screening applications where precision requirements are modest. Its use as a device for monitoring compliance with federal or state groundwater contamination regulations may be limited by its moderate (15-30% RSD) precision as reflected in these tests. In this regard, the modules are judged to have limited versatility.
- The system is designed for trend monitoring in wells and must be calibrated against a conventional sample collected with a low-flow purging and sampling protocol or other accepted method. The units of measurement for the module and conventional groundwater monitoring are not the same so that a cross-comparison is necessary to interpret module data in terms of conventional groundwater VOC concentration units.

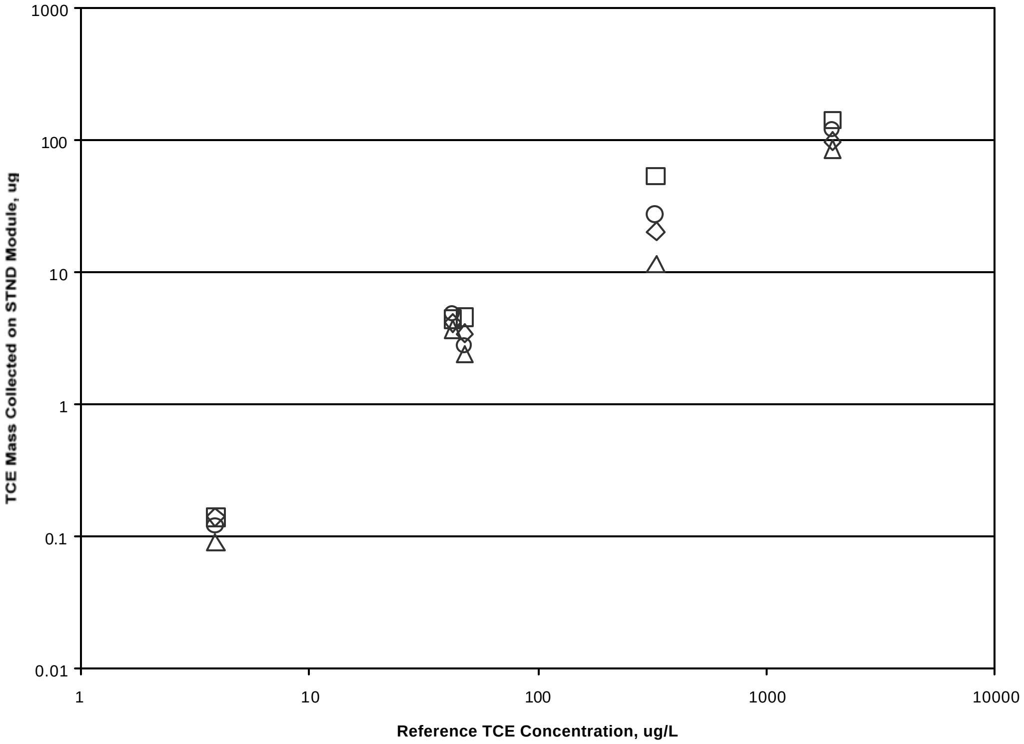

Figure 6. Scatter plot of STND module data vs. reference data for all GW monitoring wells. (Note that each symbol represents a single measurement at each of the four concentration levels)

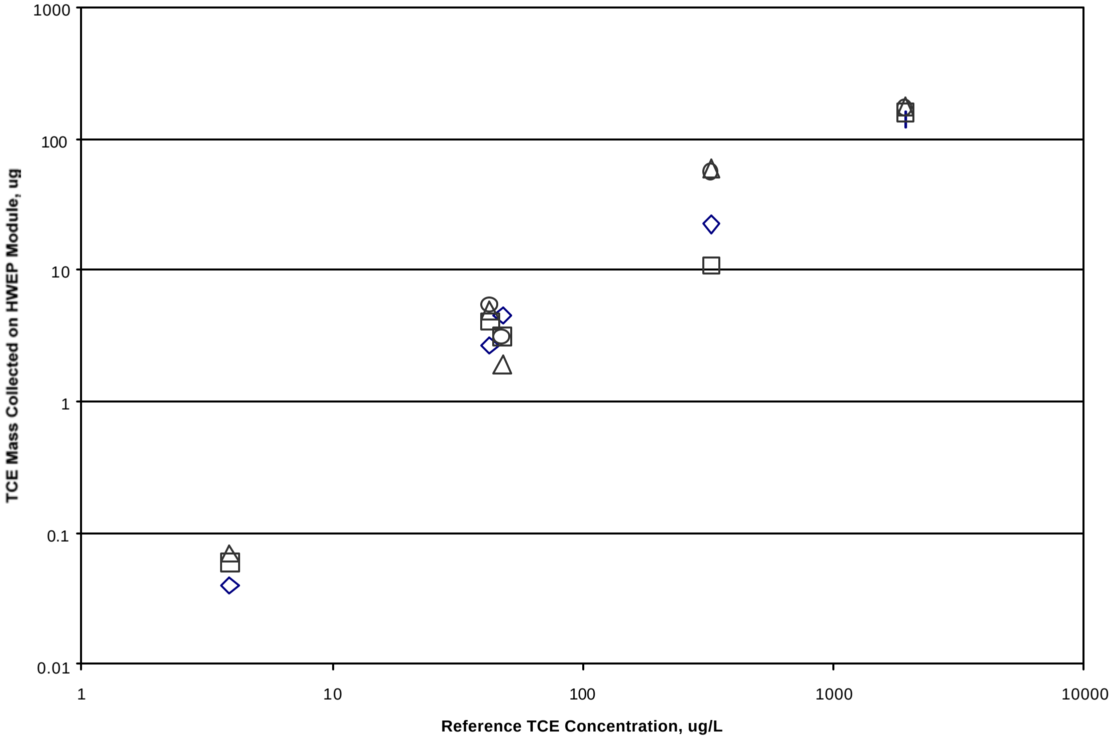

Figure 7. Scatter plot of HWEP module data vs. reference data for all GW monitoring wells. (Note that each symbol represents a single measurement at each of the four concentration levels)

- Following deployment, the sampler units are re-packaged in their original shipping vials and mailed back to the W. L. Gore Laboratory for analysis. The module is sold with analysis costs included. Analysis of the modules is only available through W. L. Gore Laboratory.
- The analytical method used by the W. L. Gore Laboratory can provide a comprehensive screening for both volatile and semi-volatile organic compounds.

Performance Summary

A summary of GORE-SORBER Water Quality Monitoring technology performance is given in Table 7. Summary categories include precision, accuracy, comparability with reference method, versatility, and logistical requirements. Cost and physical characteristics of the equipment are also summarized in the table.

The precision results of this verification test suggest that care must be taken to select the correct sampler membrane type for optimum results. The results of this study show that the STND membrane module is optimized for deployment in water column depths less than 30 feet whereas the HWEP membrane modules are optimized for deployment at depths less than 50 feet.

The moderate precision (15-30% RSD) noted for these modules suggest that they are best used for screening purposes or for concentration trend monitoring. They may also be well suited in plume edge monitoring for gross changes in VOC concentrations in groundwater. The modules are versatile in the sense that they can be used to collect a broad range of both VOC and semi-VOC compounds. This makes them useful for screening groundwater systems that may contain multiple contaminants.

Table 7. GORE-SORBER Module Performance Summary

Performance Parameter	Performance Summary
Precision	For 6 target compounds at a concentrations level of ~20 µg/L, and at sampling depths shown below: STND module (17 and 28 foot depths) RSD range: 2 – 28% Median: 14% HWEP module (17, 28, 35 and 46 foot depths) RSD range: 9 – 35% Median: 21%
Comparability with Reference Samples	At 5 groundwater monitoring wells with TCE concentrations ranging from 5 to 2000 µg/L, the correlation coefficients computed from an average of four replicate modules versus the corresponding time-weighted-average reference concentration over the 48-hour exposure interval was as follows: STND Module: Correlation Coefficient = 0.997 HWEP Module: Correlation Coefficient = 0.998
Sampler versatility	Limited versatility in terms of deployment depth Wide versatility in terms of compounds detected Limited versatility in terms of monitoring for regulatory compliance Limited versatility in terms of deployment at locations different from where reference measurements are taken.

Table 7. GORE-SORBER Module Performance Summary (Continued)

Performance Parameter	Performance Summary
Logistical requirements	Modules can be deployed and retrieved by one person. Technician training requirements are about 1 hour. Modules require comparison with co-located conventional groundwater sample and analysis for data interpretation. Modules are compact and completely passive—no power requirements. Module use requires two trips to the well, one for installation and one for retrieval following a 48-hour exposure interval.
Completeness	Modules were successfully used to collect all of the samples prescribed in the test plan.
Purchase cost	Per module cost ranges from $125 to $240 depending on the number of compounds desired in the analysis. Costs include analysis but do not include manpower for deployment/retrieval or overnight shipping costs to the laboratory following sampler retrieval.
Size and weight	Each membrane module is about 4 inches long x 0.1 inch wide and weighs about 2 ounces.
Other	In order to provide a basis for comparison of Gore-Sorber module data to actual VOC concentrations in a well, a co-located groundwater well sample and analysis by conventional means is required.

Note: Target compounds were: 1,1-dichloroethene, 1,2-dichloroethane, benzene, trichloroethene, 1,1,2- trichloroethane, and tetrachloroethene.

Section 5 — GORE-SORBER Water Quality Monitoring Technology Update and Representative Applications

Note: The following comments were provided by the vendor and have not been verified as a part of this ETV test. They have been edited only for editorial consistency with the rest of the report.

Soil Gas Applications

A similar product from W.L. Gore & Associates, Inc. is the GORE-SORBER Screening Survey, which uses the same principles of passive adsorption to collect a sample of soil gas over an exposure period of 10 - 14 days. This technology has been validated at over 2,000 sites worldwide since it was introduced in the early 1990's. This technology has also been evaluated as part of a separate ETV report entitled "Soil Gas Sampling Technology, W.L. Gore & Associates, Inc., GORE-SORBER Screening Survey", and is available in Portable Document Format (.pdf) at http://www.epa.gov/etv/verifrpt.htm#02.

Water Quality Monitoring

This section describes a recent application of the GORE-SORBER Water Quality Monitoring technology.

Site Description

The technology was applied at a military facility located on the eastern coast of the U. S. The facility conducted munitions testing for approximately 30 years. Numerous wells were installed, in several phases, as part of on-going remedial efforts at various locations at the facility. The site geology consists of unconsolidated alluvial sediment and alluvial deposits of gravel, sand, silt, and clay. Groundwater depth ranges between 5 and 30 feet, with a flow gradient extending from northeast to southwest.

A contaminated groundwater plume was identified and delineated in the primary area of investigation. Elevated concentrations of several chlorinated and non-chlorinated compounds occur in the groundwater. Contaminant compounds included 1,1,2,2-tetrachloroethane, trichloroethene, carbon tetrachloride, chloroform, and toluene. Maximum total VOC levels ranged between 4,000 and 5,000 µg/L. Groundwater monitoring did not reveal the presence of any dense non-aqueous phase liquids. The hydrologic system is believed to discharge into wetlands found farther south of the area, although the contaminant plume has not reached the wetlands. Monitoring well sampling occurs quarterly.

Passive Sampling Events

To date, two passive groundwater sampling events have been undertaken using the GORE-SORBER Water Quality Monitoring system with concurrent groundwater sampling. The first sampling phase occurred in July 1997, where 28 wells were co-sampled. A total of 33 wells were co-sampled in December 1998. The majority of the wells sampled during the first phase were also sampled during the second phase. In most cases, each well was sampled using both the GORE-SORBER modules and traditional groundwater sampling. However, there were a few instances of missing concurrent data.

The collectors were lowered into each well and positioned in the groundwater within the screened interval. Following a two-day exposure, the collectors were retrieved and returned to the laboratory for analysis. Traditional groundwater sampling (matrix sampling) was conducted immediately following the retrieval of the collectors during each sampling phase. Target compounds were chlorinated compounds and xylenes. The analytical methods used for module analysis were a modified SW846 Methods 8260 and 8270. Analytical results were provided for chlorinated compounds as well as petroleum-related compounds.

Results

Target compounds reported in common between both sets of data were examined. Scatter plots were generated to examine the comparability of the two sets of data for trichloroethene, 1,1,2,2-tetrachloroethane, and carbon tetrachloride (Figure 8). The correlation coefficients range from 0.60 to 0.97, respectively.

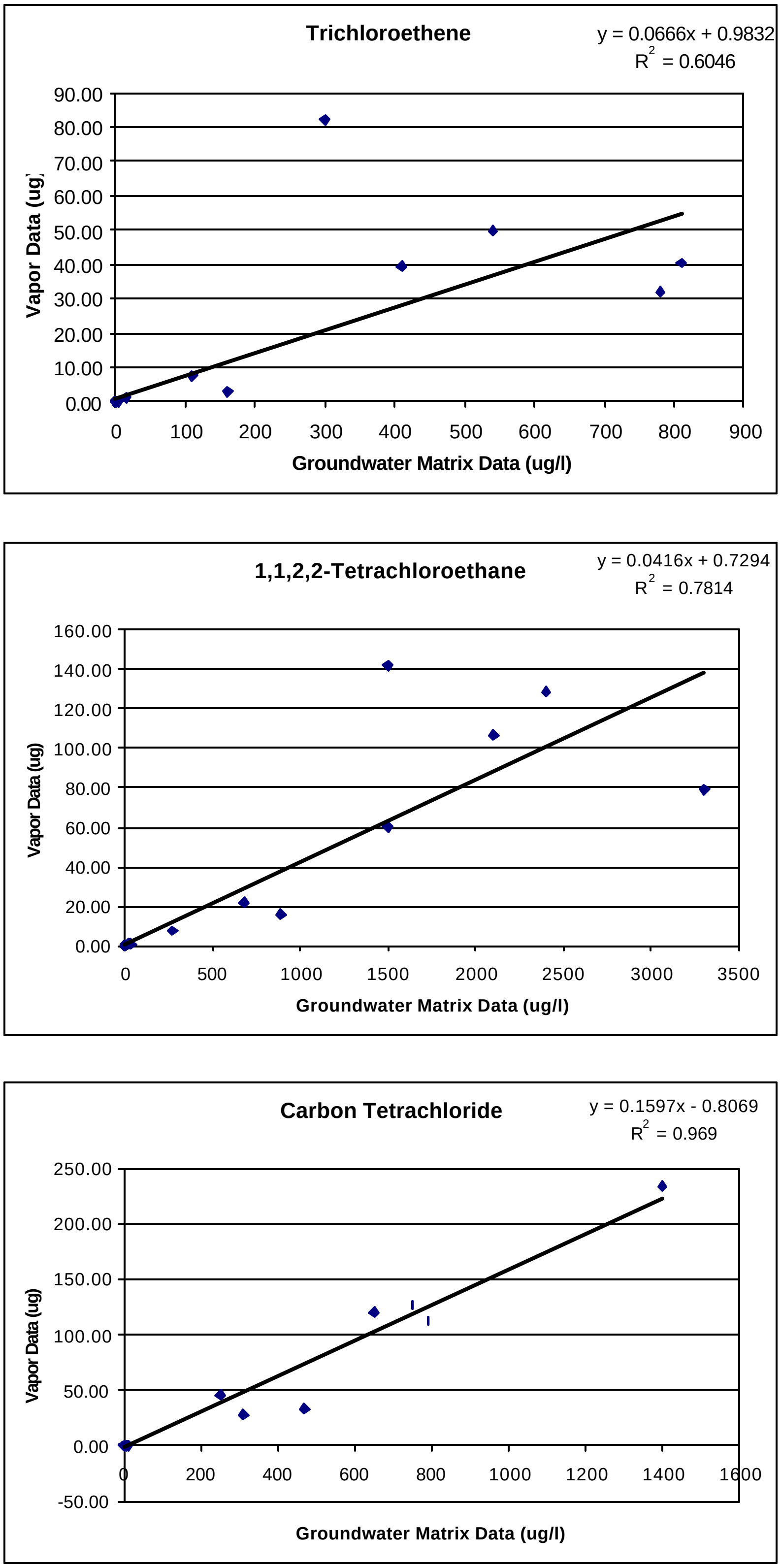

Figure 8. **Statistical Comparisons between groundwater data and module data for TCE, 1,1,2,2-tetrachloroethane, and carbon tetrachloride**

The data from GORE-SORBER modules and the groundwater data were also plotted as contour maps for selected compounds for each sampling phase (copies of these maps are available from W.L. Gore & Associates, Inc.). The spatial distribution of the data indicates that the GORE-SORBER Water Quality Monitoring system is more sensitive to lower concentration levels of compounds in groundwater than is traditional groundwater analysis. Furthermore, the smaller groundwater contaminant plume footprint, based on the matrix sampling, is likely due to higher laboratory quantitation limits. However, the general plume orientation and the location of "hot spots" is consistent when comparing maps from both sets of data. Differences between the two contour surfaces tend to be a function of missing data between phases.

Cost Savings

Though the data collection effort is increased in the early stages of this application, the long-term cost savings are realized in subsequent sampling events when only passive samplers are used. The cost savings comparison realized from this case study is summarized in Table 8 for one round of sampling. The use of GORE-SORBER Water Quality Monitoring technology would lower the sampling costs by approximately 72%. This represents a significant reduction in long-term costs associated with groundwater monitoring.

In general, there is a good correlation between the passive sampler results and the groundwater data results from this study. Apparent discrepancies were a function of missing data within and between sampling phases. The results indicate that the GORE-SORBER modules alone are capable of capturing the quality of the groundwater, and can illustrate concentration changes across an area of interest. As a result of this study, the regulatory agency is reviewing a proposal to perform matrix sampling on a less frequent basis (i.e., annually) thus lowering the project sampling costs by more than $60,000 over the estimated 20-year life of this project.

Table 8. Cost Comparison for One Round of Sampling

Item	Units	Unit Description	Extended Cost
Conventional Sampling/Analysis			
Project Management	42	Hours	$2,145
Field Crew	235	Hours	$12,993
Equipment-pump	1	Lump sum	$1,765
Purge water disposal	0	Dollars	0#
Laboratory costs	50	Samples	$7,452
Total			**$24,355**
GORE-SORBER Water Quality Monitoring Survey			
Project Management	4	Hours	$204
Field Crew	31	Hours	$1,324
Equipment-consumables	1	Lot Charge	$100
Laboratory costs	26	Samples	$5,070
Total			**$6,698**

On-site purge water treatment was available at this site

Section 6 — References

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Appendix A — Reference Pump Performance

Introduction

In addition to the sampling at the standpipe, the verification test design included the collection of vendor samples from onsite groundwater monitoring wells. During monitoring well sampling, a reference pump was co-located in the well with the vendor sampler. Both vendor and reference samples were collected simultaneously to enable a comparison of the results. This appendix summarizes the reference sampler chosen and outlines its performance and acceptability as a reference sampling technique.

System Description

The reference pump selected for use in this verification study was a submersible electric gear pump (positive displacement, low-speed pump, Fultz, Model SP-300, Lewistown, PA). Pump construction materials are stainless steel and polytetrafluoroethylene (PTFE), and pump dimensions are 7.5 inches in length by 1.75 inches in diameter. This pump is a positive displacement device. Water is introduced into the pump through a 60-mesh inlet screen into a stainless steel cavity. Two PTFE gears inside the pump cavity push the water to the surface through 100 feet of ¼-inch outside diameter PTFE tubing. An electronic controller is used to regulate the flow rate of the pump. Nominal sample collection flow rates were in the range of 100–200 mL/min.

Performance Evaluation Method

The gear pump was tested during the standpipe trials in the same manner as the other vendor pumps. Water samples were collected from the interior of the standpipe in four separate trials with both low (~20 µg/L) and high (~200 µg/L) target concentrations at low (17 feet) and high (91 feet) sampling depths (see Section 3 for additional details). Reference samples were collected from external sampling ports simultaneously with the pump samples. In each trial, five replicate pump samples and five replicate port samples were collected. Following collection, all samples were analyzed using the same onsite GC-MS system.

Pump Precision

A summary of pump precision is given in Table A-1. The percent relative standard deviation results for each of the six target compounds in the four standpipe trials (low concentration—shallow, low concentration—deep, and so on) for the gear pump and the external sampling port are given in columns 4 and 5, respectively. The relative standard deviation range for the pump was 3.2 to 16.3%, with a median value of 7.6%. The port precision data ranged from 2.8 to 16.2%, with a median value of 10.1%. The final column in the table gives the value of *p* associated with the F-ratio test (see Section 3 for a description of this test). Values of *p* less than 0.05 may indicate that significant, nonrandom differences exist between the two estimates of precision.

Out of 24 trials, only 2 show values of *p* less than 0.05. These data indicate that pump precision was not statistically different from the precision obtained from the reference samples taken directly from the standpipe external ports.

Table A-1. Precision of Gear Pump and Reference Samples in Standpipe Trials

Compound	Conc. Level	Depth (ft)	Gear Pump Precision (%RSD)	Port Precision (%RSD)	F-Ratio	F-Ratio *p*
11DCE	Low	17	15.7	14.2	1.11	0.46
	Low	91	3.5	14.4	14.7	**0.01**
	High	17	4.0	8.6	4.81	0.08
	High	91	7.6	9.7	1.28	0.41
12DCA	Low	17	15.4	12.5	2.35	0.21
	Low	91	3.2	13.2	14.1	**0.01**
	High	17	5.1	9.0	3.18	0.14
	High	91	6.0	10.4	2.38	0.21
BNZ	Low	17	8.1	11.8	1.71	0.31
	Low	91	7.6	12.9	2.30	0.22
	High	17	3.7	8.4	5.02	0.07
	High	91	6.1	9.4	1.83	0.29
TCE	Low	17	16.3	10.5	2.41	0.21
	Low	91	5.9	12.1	3.12	0.15
	High	17	6.4	2.9	4.82	0.08
	High	91	9.6	8.6	1.55	0.34
112TCA	Low	17	9.4	16.2	3.38	0.13
	Low	91	8.4	15.0	2.81	0.17
	High	17	7.6	3.5	4.76	0.08
	High	91	11.0	6.5	3.43	0.13
PCE	Low	17	12.9	9.6	1.36	0.39
	Low	91	9.0	11.7	1.50	0.35
	High	17	4.5	2.8	2.28	0.22
	High	91	12.7	8.8	2.38	0.21
Minimum			3.2	2.8		
Maximum			16.3	16.2		
Median			7.6	10.1		

Pump Comparability with Reference Samples

Gear pump comparability is expressed as the percent difference relative to the reference sample concentration by subtracting the average reference value from the average gear pump value, dividing the result by the average reference value, and multiplying by 100. The percent differences for each of the 24 trials are given in Table A-2. They range from −13 to 24% with a median value of 7%. A t-test for two sample means was used to evaluate the statistical significance of the differences between the gear pump and reference samples. The tabulated values of *p* give a quantitative measure of the significant of the observed difference in probabilistic terms. Values of *p* less than 0.05 suggest that a statistically significant bias may exist for the trial. With five exceptions, all values of *p* are greater than 0.05, indicating that overall, the differences between the two sampling methods are statistically indistinguishable.

Table A-2. Comparability of the Gear Pump with the Reference Samples in Standpipe Trials

Compound	Conc. Level[a]	Depth (ft)	Difference (%)	t-Test[b] *p*
11DCE	Low	17	–4	0.64
	Low	91	7	0.31
	High	17	–3	0.54
	High	91	13	**0.05**
12DCA	Low	17	24	**0.05**
	Low	91	10	0.13
	High	17	–2	0.71
	High	91	12	0.06
BNZ	Low	17	11	0.13
	Low	91	13	0.11
	High	17	0	0.98
	High	91	14	**0.03**
TCE	Low	17	0	0.99
	Low	91	16	**0.04**
	High	17	0	0.95
	High	91	11	0.10
112TCA	Low	17	–6	0.51
	Low	91	7	0.41
	High	17	1	0.77
	High	91	10	0.15
PCE	Low	17	–13	0.08
	Low	91	6	0.37
	High	17	–6	**0.03**
	High	91	6	0.42
Minimum			-13	
Maximum			24	
Median			6.5	

[a] The low-level concentration was in the range of 10 to 20 µg/L for all 6 target compounds. The high-level concentration was in the range of 175 to 250 µg/L.

[b] The t-test was used to compare differences between the gear pump and reference samples for each compound in each trial. Small values of *p* (<0.05) are shown in bold and are suggestive of a statistically significant difference. See text for further details.

The percent difference data for the gear pump are also shown graphically by target compound in Figure A-1 for each of the four standpipe trials. Fifteen of the 24 percent difference values are in the positive percent difference range, suggesting that many of the samples collected with the gear pump contained higher concentrations than those samples collected from the corresponding external sampling port. An exhaustive evaluation of the data was not performed to characterize this phenomenon; however, it is possible that this was a result of bias in the analytical method, since one would not expect sample losses to be significant in the reference sampling procedure.

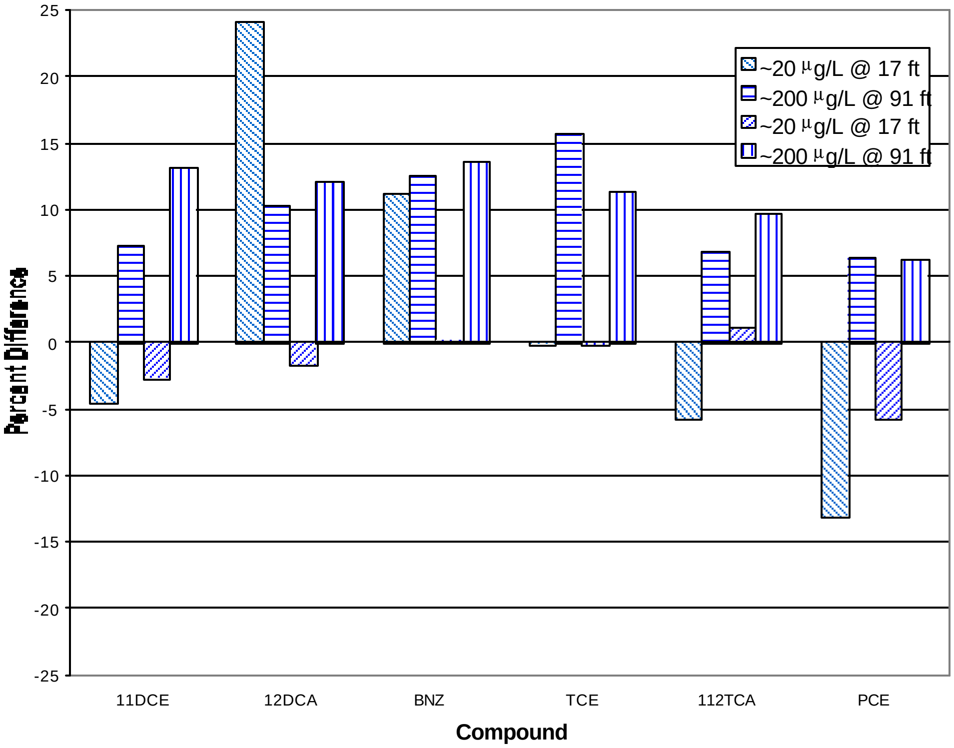

Figure A-1. Percent recoveries of the reference pump by compound for the four standpipe trials.

Reference Pump Performance Summary

The test data for the reference pump reveal considerable variability for PCE and 12DCA. However, the variability and comparability for TCE, the only compound encountered in the field trials, are acceptable. The mean relative standard deviation for TCE at concentration levels ranging from 20 to 200 µg/L was 9.6% and the mean percent difference for TCE in the same concentration range was 7%. The data presented for TCE show that the pump is equivalent to the reference sampling method in terms of both precision and accuracy and is acceptable for use as a reference standard.

Appendix B — Quality Summary for Analytical Method

Introduction

An onsite GC-MS-headspace method was chosen for analysis of all samples in this study. Two identical GC-MS systems were operated by Field Portable Analytical (Folsom, CA) using a modified EPA Method 8260 (for a summary of the method, see Section 3). Data quality measures were incorporated into all onsite analyses consistent with the guidelines in Method 8260. This appendix summarizes those data quality measures, thereby demonstrating the adequacy of the method for this verification study.

Data Quality Measures

A number of data quality measures were used to verify acceptable instrument performance and the adequacy of the final analytical results throughout the course of the study. These measures are summarized in Table B-1. All data quality measures in this table were followed, with the exception of duplicates. Duplicates were not routinely run since all of the samples from the field were in batches of replicates. Earlier pre-field demonstration studies indicated that the field replicates were the same in composition so that they could be treated as analysis duplicates.

Table B-1. Onsite GC-MS-Headspace Method Quality Control Measures

Quality Control Check	Minimum Frequency	Acceptance Criteria	Corrective Action
MS tune check w/ bromofluorobenzene (BFB)	Every 12 hours	Ion abundance criteria as described in EPA Method TO-14	1) Reanalyze BFB 2) Adjust tune until BFB meets criteria
5-Point (Minimum) calibration	Beginning of each day	%RSD ≤ 30%	Rerun levels that do not meet criteria
Continuing calibration check (CCC)	Beginning of each day	± 25% difference of the expected concentration for the CCC compounds	1) Repeat analysis 2) Prepare and run new standard from stock 3) Recalibrate
End calibration checks	End of each day	± 25% RPD of the beginning CCC	1) Repeat analysis 2) If end check is out, flag data for that day
Duplicates	10% of the samples	Relative percent difference ≤ 30%	1) Analyze a third aliquot 2) Flag reported data
Method blanks	After beginning of day CCC	Concentrations for all calibrated compounds < practical quantification level	Rerun blanks until criteria are met

Data Quality Examples

The following data are examples of system performance throughout the course of the study. In the interest of brevity, all quality control data are not shown in this appendix. A complete tabulation of all quality control data is included in the GW SAMPLING DATA NOTEBOOK and is available for viewing through a request to the ETV Site Characterization and Monitoring Technologies Pilot Manager.

Method Blank Check

Method blanks were run at the beginning of each 12-hour analysis session. Concentration levels of the six target compounds were reported as non-detectable (<5 µg/L) for all method blank samples.

Continuing Calibration Check

The method criterion for the continuing calibration checks run at the beginning and end of each analysis cycle was a value within 25% of the expected value. The results of the TCE continuing calibration checks for both of the GC-MS instruments used in the study are shown in Figures B-1 and B-2. Similarly, the results of the PCE continuing calibration check for both instruments are shown in Figures B-3 and B-4. All check compound recoveries fall within the predefined control interval of 70 to 130%. The control interval is specified in EPA Method SW-846, from which this method is adapted. The relative percent differences between the pre- and post-analysis batch calibration check samples are shown in Figure B-5. In two cases, the relative percent difference falls outside the 25% window. Data from these days were not rejected, however, since the ±30% criteria for the calibration check was met.

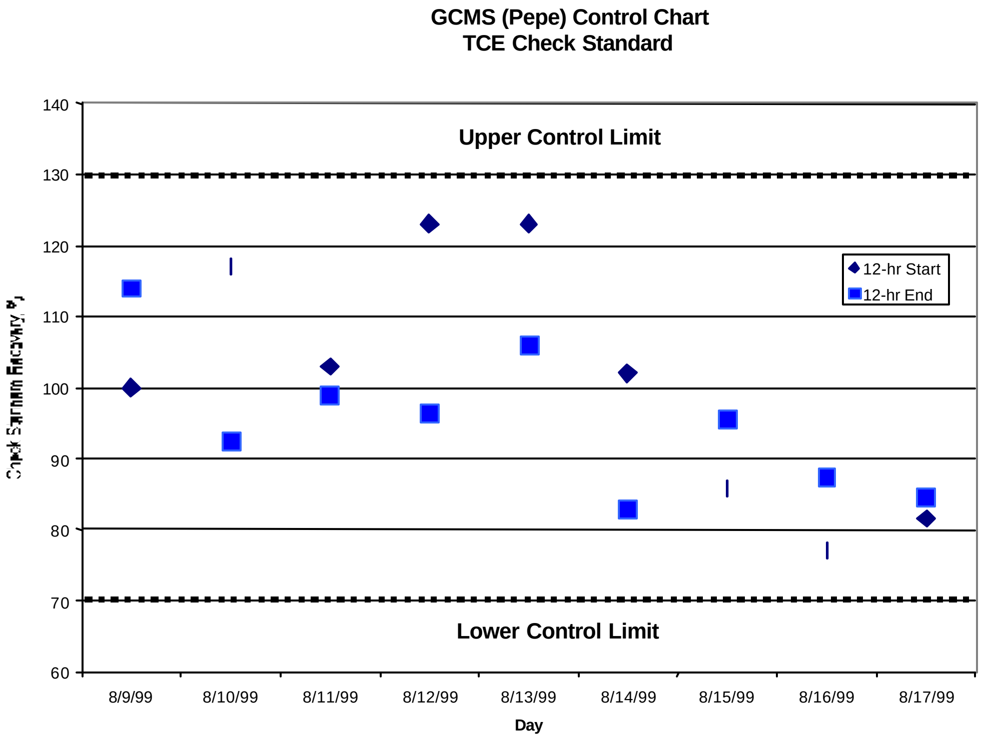

Figure B-1. Calibration check control chart for TCE on GC-MS #1.

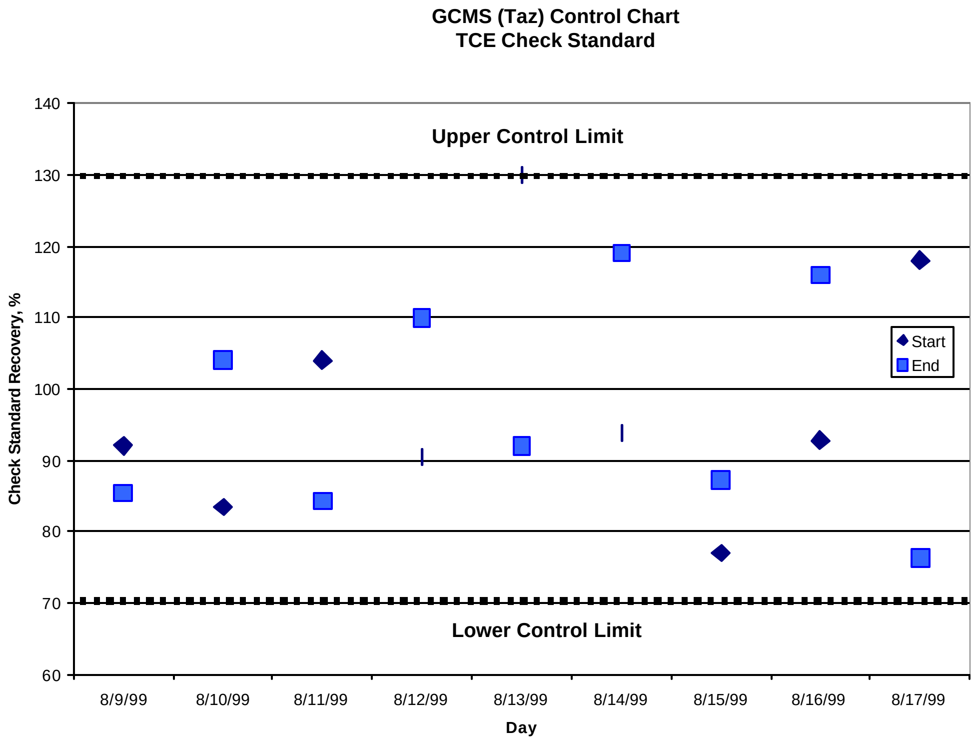

Figure B-2. Calibration check control chart for TCE on GC-MS #2.

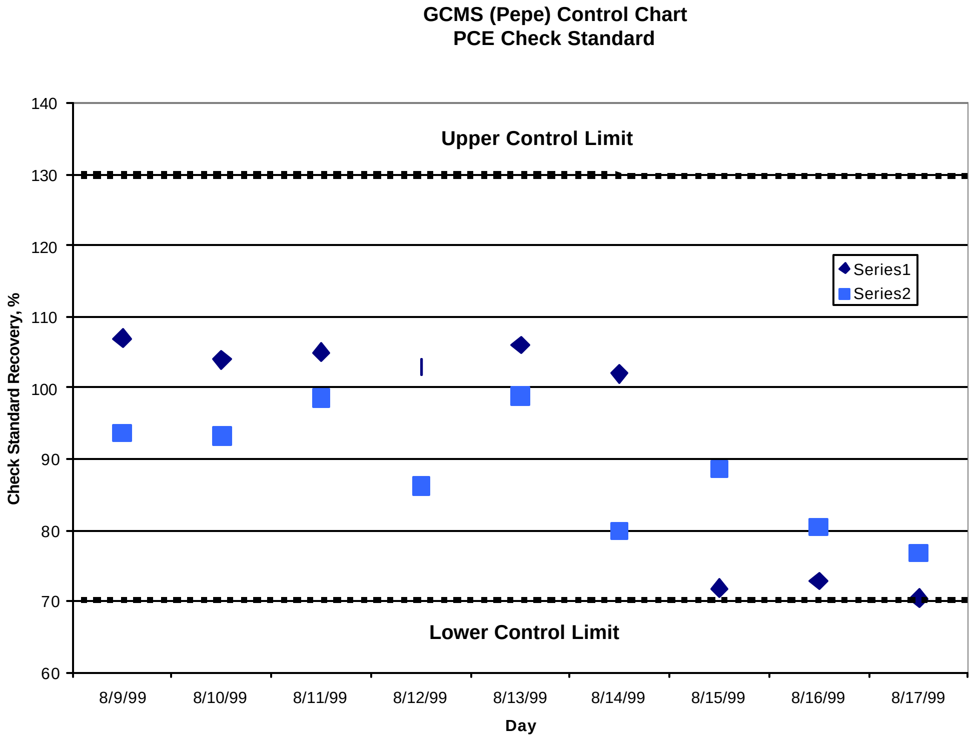

Figure B-3. Calibration check control chart for PCE on GC-MS #1.

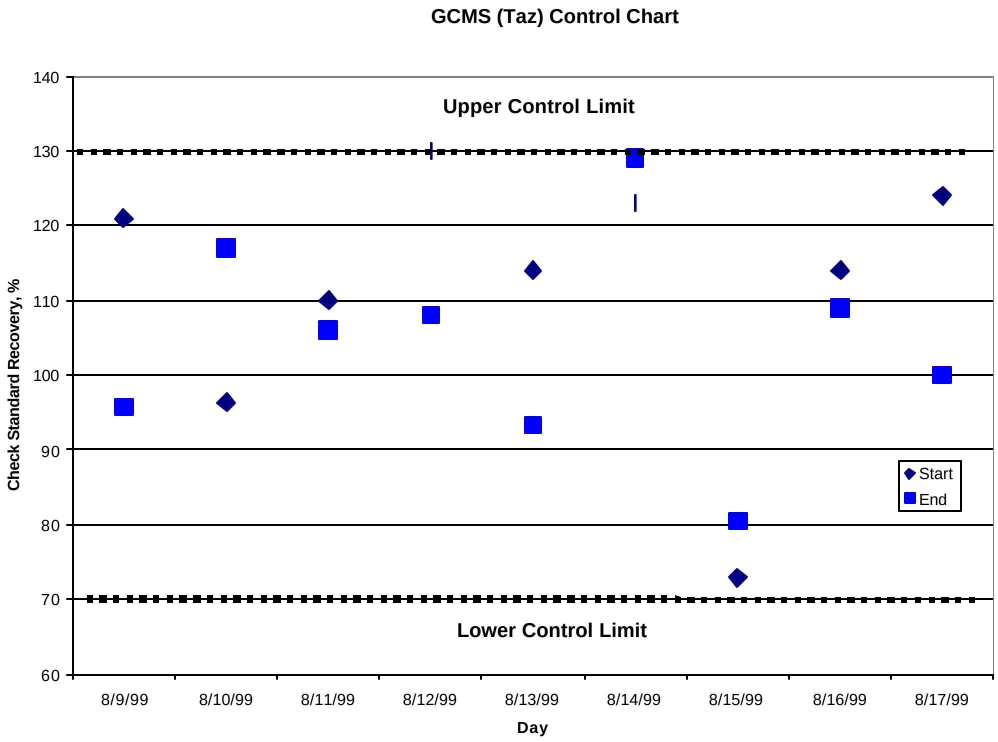

Figure B-4. Calibration check control chart for PCE on GC-MS #2.

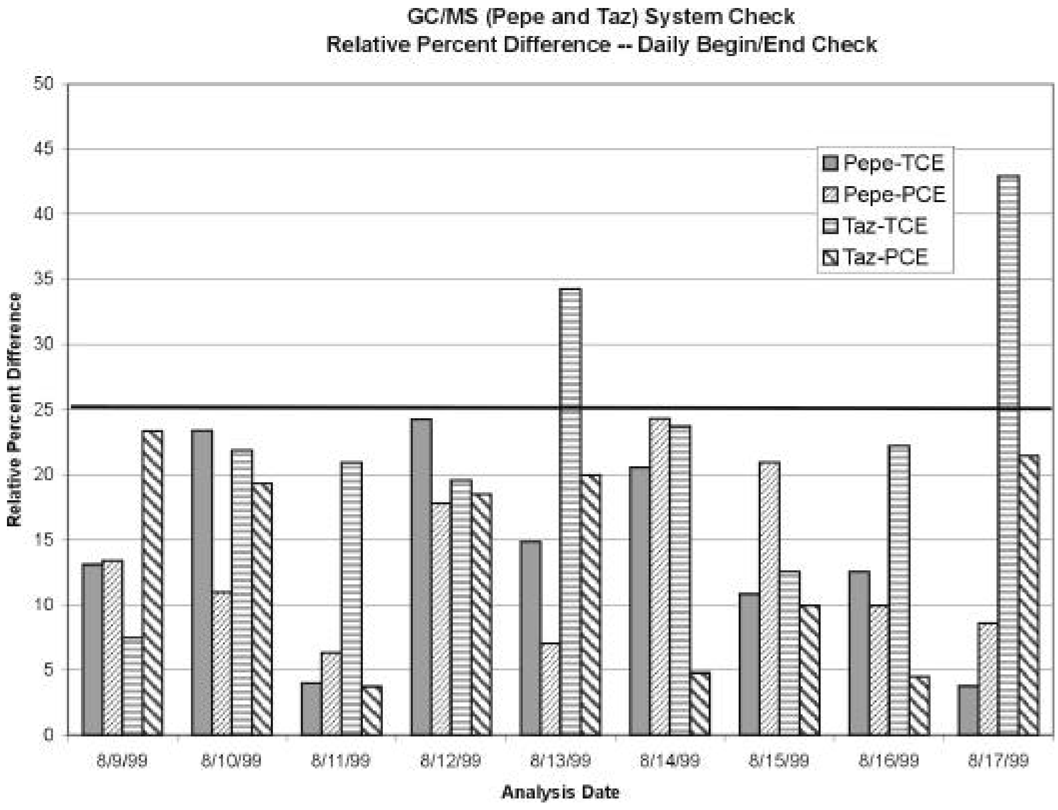

Figure B-5. GC-MS system check relative percent differences.