FINAL
TECHNICAL REPORT FOR THE EVALUATION OF GROUNDWATER DIFFUSION SAMPLERS

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AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE (AFCEE)
TECHNOLOGY TRANSFER DIVISION

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Prepared for

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION

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PREFACE

Parsons Engineering Science, Inc. (Parsons ES) was contracted by the Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division (ERT) to perform a demonstration of groundwater diffusion sampling technology at McClellan Air Force Base (AFB), California. The work was performed for AFCEE/ERT under Contract F11623-94-D0024, Delivery Order RL72.

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SECTION 1

INTRODUCTION

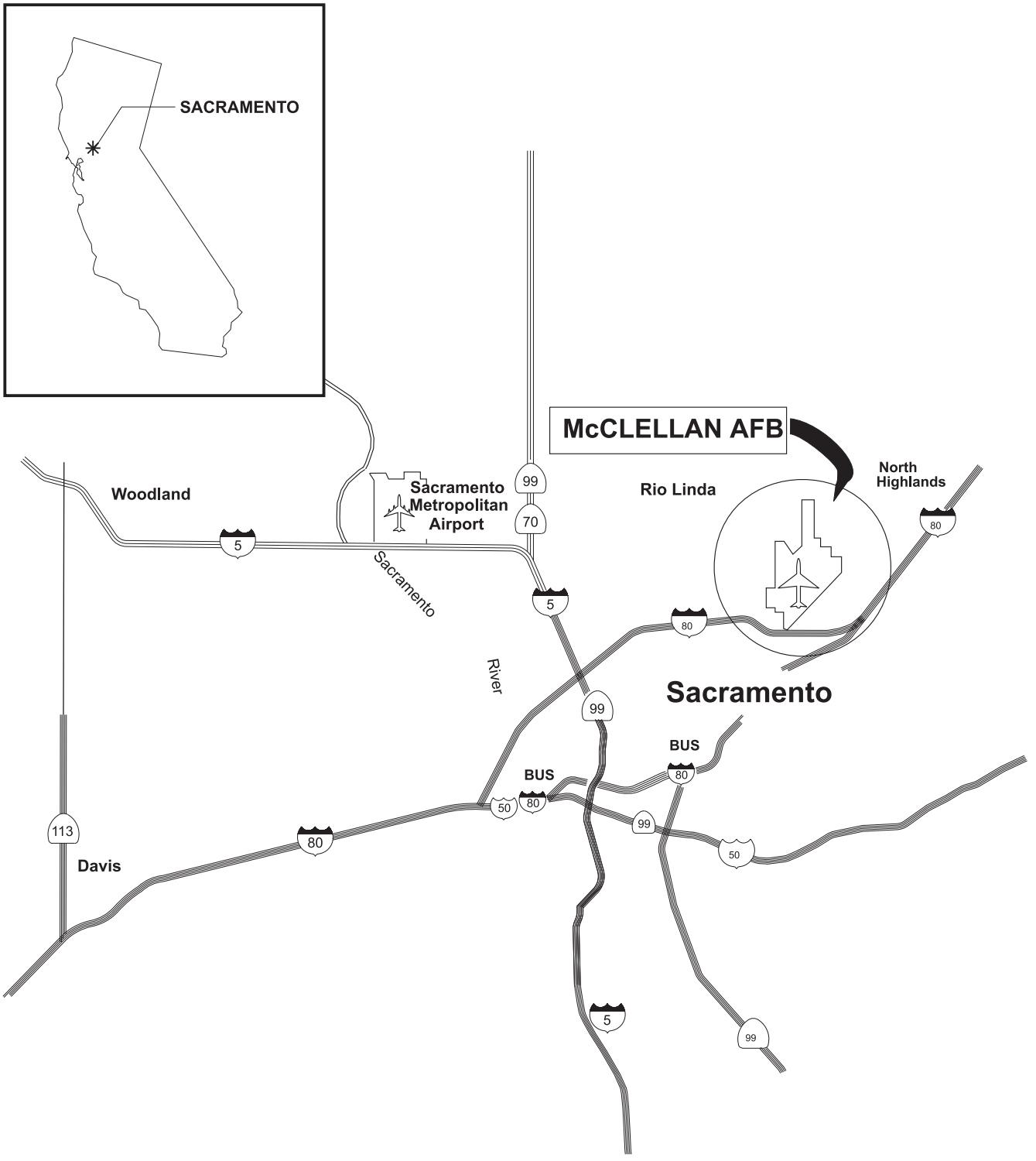
Parsons Engineering Science, Inc. (Parsons ES) was retained by the US Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) to perform an evaluation of passive groundwater diffusion sampling technology. The diffusion sampler evaluation was funded under Contract F11623-94-D0024, Delivery Order RL72, as part of the AFCEE/ERT Remedial Process Optimization (RPO) demonstration project being performed at six Air Force bases (AFBs) nationwide. One of these bases, McClellan AFB, California (Figure 1.1), was selected as the site for evaluation of diffusion samplers.

This report presents results of the groundwater sampling and analysis activities that were performed as part of the diffusion sampler evaluation at Operable Unit D (OUD), McClellan AFB. OUD is located in the northwestern section of McClellan AFB (Figure 1.2). The activities performed and described in this report are in accordance with the *Final Diffusion Sampling and Analysis Work Plan, Operable Unit D, McClellan Air Force Base California* (Parsons ES, 1999).

1.1 OBJECTIVE AND SCOPE OF DEMONSTRATION

The objective of the diffusion sampler evaluation was to evaluate the efficacy of this groundwater sampling methodology in comparison to standard sampling methods. Field sampling was conducted using two types of diffusion samplers to collect groundwater samples from varying depths at selected monitoring wells. One of the diffusion samplers evaluated was the commercially available DMLS™ sampler. The other diffusion sampler evaluated is currently being developed and used by the US Geological Survey (USGS). The standard sampling methods used for comparison to the diffusion sampling results were 1) groundwater sampling following conventional purging of at least three casing-volumes of water and stabilization of water quality parameters (i.e., conventional sampling), and 2) sampling following low-flow/minimal drawdown purging (i.e., micropurging).

McClellan AFB is currently in the process of performing an independent diffusion sampler evaluation to determine the appropriateness of this sampling methodology as a more cost-effective alternative for long-term monitoring of volatile organic compound (VOC) contamination in Base groundwater. The work described in this report generally complies with procedures outlined in the *Final Work Implementation Plan (WIP) for Passive Diffusion Membrane Samplers* (McClellan AFB, 1999), and is intended to supplement the findings of the McClellan AFB evaluation. Results of the diffusion sampler evaluation described herein also may be used in the RPO evaluation of remedial systems at OUD.



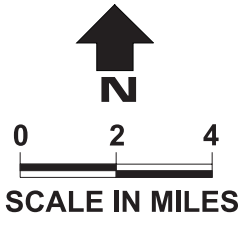


FIGURE 1.1

FACILITY LOCATION MAP

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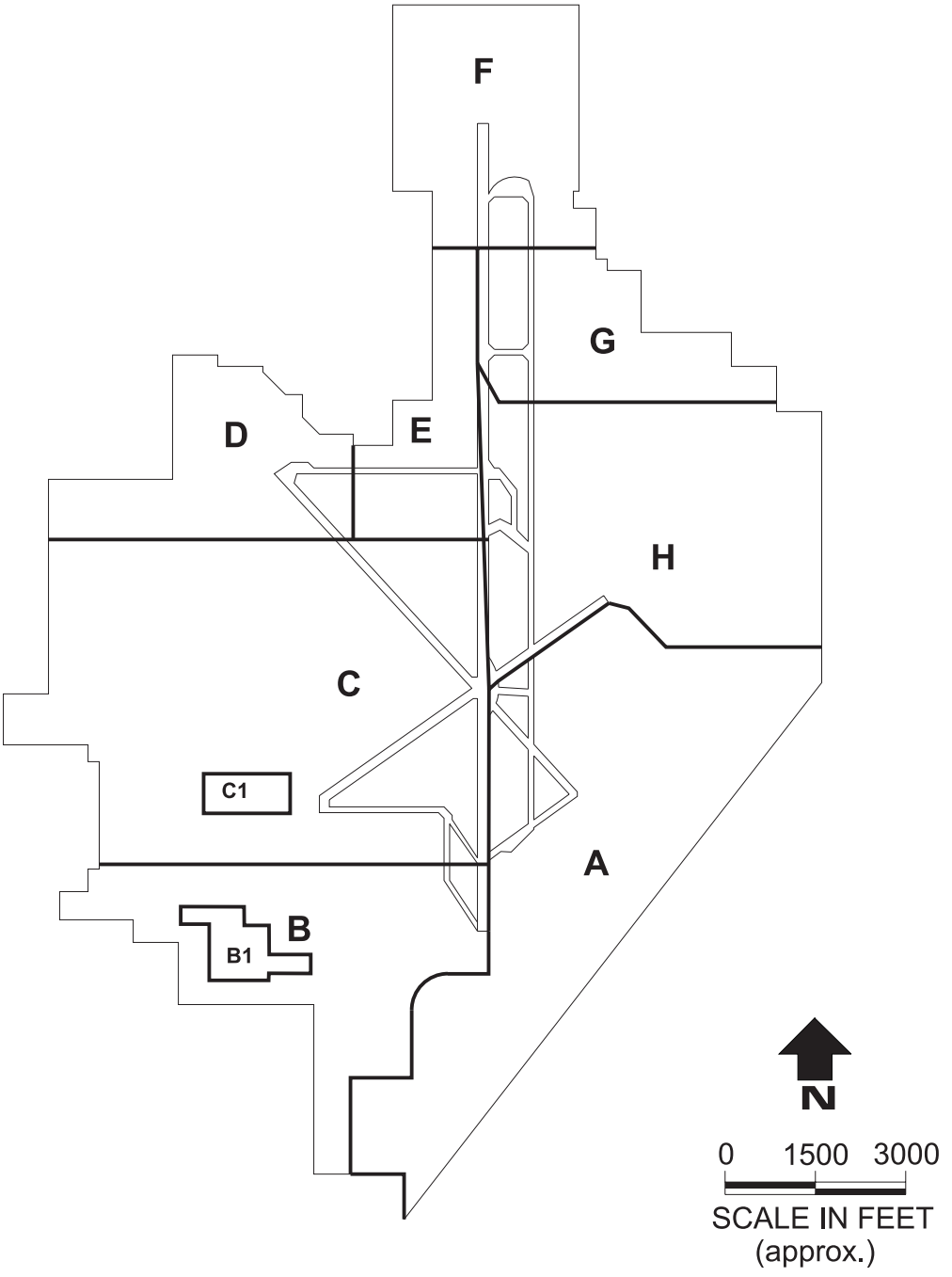

EXPLANATION

BOUNDARIES OF OPERABLE UNITS

McCLELLAN AFB BOUNDARY

FIGURE 1.2

APPROXIMATE BOUNDARIES OF OPERABLE UNITS

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The scope of this project included collecting groundwater samples for VOC analysis from three McClellan AFB monitoring wells using four different sample collection methodologies:

- Following conventional well purging,
- Following micropurge sampling,
- Using USGS passive diffusion groundwater samplers, and
- Using DMLS™ passive diffusion groundwater samplers.

The groundwater samples were analyzed at Quanterra Laboratories of Santa Ana, California (Quanterra) for total VOCs by US Environmental Protection Agency (USEPA) Method SW8260B/5030. Analytical results for samples obtained using the different sampling methods were evaluated for comparability.

1.2 FIELD SCHEDULE

Three field mobilizations to McClellan AFB were required to achieve the objectives described above. During the first mobilization, which occurred on August 3, 1999, the USGS samplers were installed. During the second mobilization, from August 17 to 19, 1999, the USGS samplers were retrieved and sampled, micropurge and conventional samples were collected, and the DMLS™ samplers were installed. During the third and final mobilization from September 2 to 3, 1999, the DMLS™ samplers were retrieved and sampled, and a second round of conventional samples was collected.

1.3 REPORT ORGANIZATION

This report is organized into seven sections, including this introduction, and four appendices. A discussion of the technologies and methods used for sample collection is presented in Section 2. Field activities and deviations from the work plan are summarized in Section 3. Analytical results obtained using the four sampling methods are compared in Section 4. Conclusions and recommendations are presented in Sections 5 and 6, respectively. References cited in the preparation of this report are provided in Section 7. Documentation regarding the diffusion samplers is presented in Appendix A. Field notes and sample collection forms are provided in Appendix B. Laboratory analytical results are included as Appendix C. Details of statistical testing of data comparability are included as Appendix D.

SECTION 2

TECHNOLOGY DESCRIPTIONS

Diffusion sampling is a relatively new technology designed to use passive sampling techniques that eliminate the need for well purging. Specifically, a diffusive-membrane capsule is filled with deionized distilled water, sealed, mounted in a suspension device, and lowered to a specified depth in a monitoring well. Over time (no less than 72 hours), VOCs in the groundwater diffuse across the capsule membrane, and contaminant concentrations in the water inside the sampler attain equilibrium with the ambient groundwater. The sampler is subsequently removed from the well, and the water within the diffusion sampler is transferred to a sample container and submitted for laboratory analysis. The diffusive membranes evaluated in this study are rated for VOCs only. These membranes are not appropriate for monitoring larger or more electrically charged molecules.

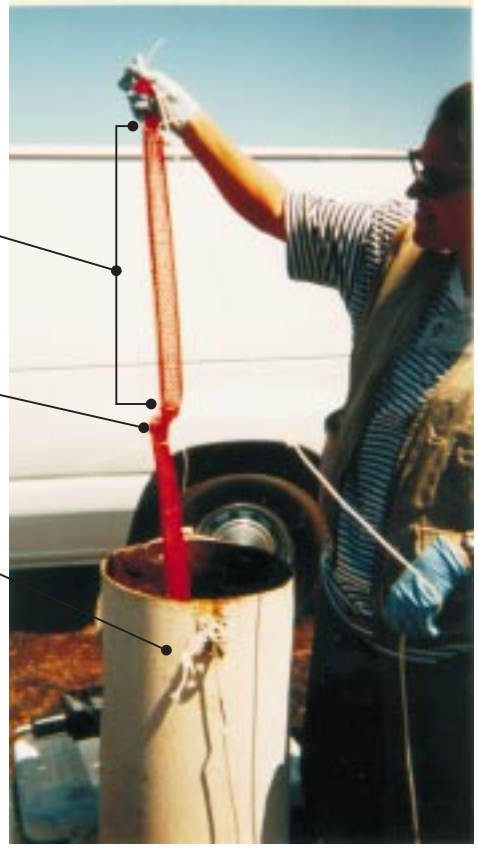
Two types of diffusion samplers were used as part of the evaluation at OUD: the DMLS™ sampler and the USGS sampler. Documentation provided by the manufacturers of the two types of diffusion samplers is provided in Appendix A.

Once the diffusion samplers are placed in the well, they remain undisturbed until equilibrium is achieved between the water in the well casing and the water in the diffusion sampler. Depending on the hydrogeologic characteristics of the aquifer, the diffusion samplers can reach equilibrium within 3 to 4 days (Vroblesky and Campbell, 1999); however, to remain consistent with McClellan AFB test procedures (McClellan AFB, 1999), a 14-day equilibrium period was used during this evaluation. Groundwater samples collected using the diffusion samplers are thought to be representative of water present within the well during the previous 24 to 72 hours.

Brief descriptions of the two diffusion samplers used in this study are presented in the following subsections. The conventional and micropurging sampling techniques used during this study for comparison to the diffusion sampler methods also are described.

2.1 USGS SAMPLER

The standard USGS diffusion sampler consists of water-filled, low-density polyethylene tubing, which acts as a semi-permeable membrane. The USGS sampler typically is constructed of a 1.5-foot long section of 2-inch-diameter, 40-mil polyethylene tubing that is heat-sealed on both ends (Figure 2.1). The sampler holds approximately 300 milliliters (mL) of deionized distilled water. A longer 3-inch-diameter sampler that holds approximately 500 mL of water also is available if larger sample volumes are required. The sampler is placed in “flex-guard” polyethylene mesh tubing for abrasion protection, attached to a weighted rope, and lowered to a predetermined depth within the



Assembled USGS sampler being lowered into monitoring well

USGS sampler prior to sample collection

FIGURE 2.1

USGS DIFFUSION SAMPLER

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screened interval of a well. The rope is weighted to ensure that the sampling devices are positioned at the correct depth and that they do not float upward through the water column. In order to ensure consistency between this investigation and the study being performed by McClellan AFB (1999), multiple USGS samplers were placed end-to-end in the three test monitoring wells to develop vertical contamination profiles.

Upon recovery of the diffusion samplers from the wells, the samplers are cut open, and water samples are transferred into 40-mL volatile organics analysis (VOA) vials. The samples are preserved and submitted to the laboratory for analysis.

For this study, the USGS diffusion samplers were provided by the USGS free of charge. However, the samplers are available commercially from EON Products, Inc. of Lithonia, Georgia at a unit price of approximately $43, which includes a reusable stainless steel weight.

2.2 DMLS™ SAMPLER

The DMLS™ sampler (Figure 2.2) uses dialysis cells as passive collection devices. The dialysis cells are composed of a polypropylene cylinder that holds 38 mL of deionized distilled water. The cells have 0.2-micrometer cellulose acetate filters attached to each end of the cell that serve as the permeable membranes. The cells are mounted in cylindrical holes pre-drilled through a 5-foot polyvinyl chloride (PVC) rod, and are separated by viton spacers, or well seals, that fit the inner diameter of the well (Figure 2.2). The 5-foot rod can accommodate as many as 12 sampling cells (pre-drilled cylindrical hole spacing is 5 inches), and a string of up to 5 rods can be connected together for sampling over long screened well intervals.

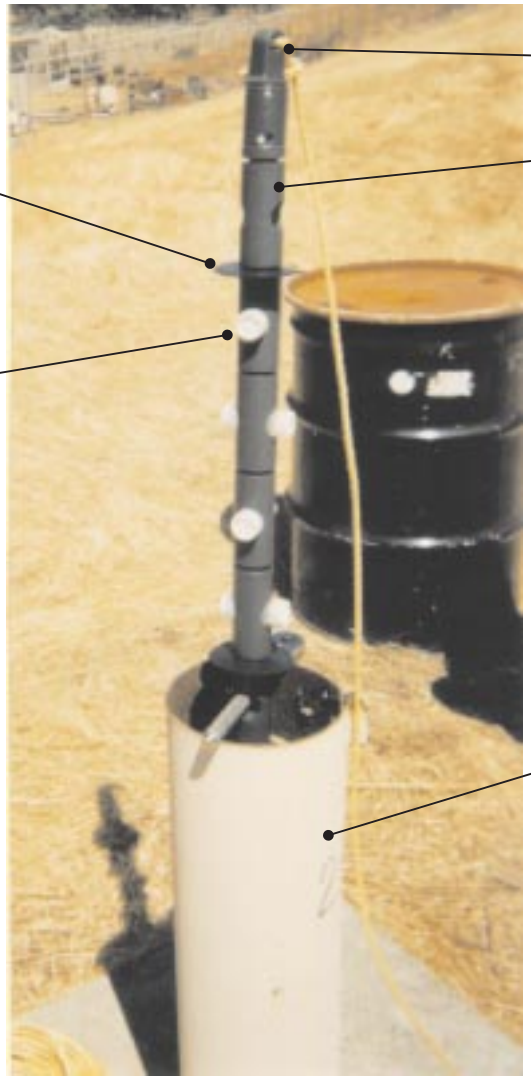
Once loaded with the prepared dialysis cells, the PVC rods are lowered into a well to the desired depth within the screened interval, and are secured with a rope to the top of the well casing. A stainless steel weight is attached to the bottom of the deepest PVC rod to ensure that the samplers are positioned at the correct depth in the well, and that the PVC rods do not float through the water column.

Upon retrieval of the PVC rods, the dialysis cells are removed from the PVC rod, emptied into a decontaminated container for compositing, and then transferred to 40-mL VOA containers. The samples are preserved and sent to a laboratory for analysis.

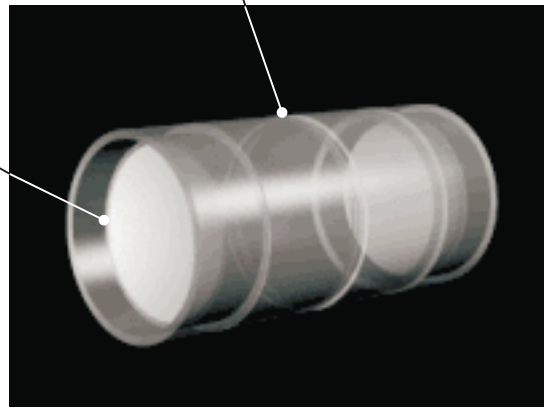
The DMLS™ diffusion samplers were purchased from Johnson Screens of New Brighton, Minnesota at a unit price of approximately $540 ($4,845.82 for nine samplers in August 1999), which includes reusable items as described in Section 4.2.1.

2.3 CONVENTIONAL SAMPLING

Groundwater sampling using conventional well purging involves removing a large volume of water (three to five well casing-volumes) from the well over a short time. The objective of conventional purging is to remove all water present within the well casing, as well as groundwater present in the surrounding well filter pack. Theoretically, by removing this water quickly, the “stagnant” water that resided in the well and filter pack will be replaced with “fresh” groundwater from the surrounding formation with minimal mixing. The “fresh” groundwater that is then sampled is considered to be representative



Assembled DM S sampler
prior to being lowered into
monitoring well



Dialysis cell

FIGURE 2.2

DMLS DIFFUSION SAMPLER

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of the local groundwater. Rapid drawdown of the water level in a well is not uncommon, and often wells are purged dry using this method. Conventional purging is usually performed using a PVC bailer or a high-flow submersible pump (e.g., Grundfos Redi-Flo2 pump).

2.4 MICROPURGING

The objective of micropurging is to remove a small volume of water at a low flow rate from a small portion of the screened interval of a well without mixing water among vertical zones. Ideally, by placing the inflow port of a pump at a prescribed depth within the screened interval of a well, and by withdrawing water at a slow rate, groundwater will be drawn from the aquifer into the well only in the immediate vicinity of the pump. This discrete-depth sampling allows for vertical definition of contamination in the aquifer.

Typically, flexible tubing (e.g., silicon or Tygon) is lowered within a well to the desired screened depth. The upper end of the tubing is then attached to an aboveground peristaltic pump that has a variable speed control. However, when collecting groundwater samples at depths that exceed approximately 25 feet, peristaltic pumps (and frequently the flexible tubing) are not capable of maintaining the necessary suction to draw the groundwater to the surface. In these instances, a submersible pump (e.g., Grundfos Redi-Flo2 pump) or a bladder type pump is required to provide the necessary lifting force to push groundwater to the surface. For these deeper wells, the submersible or bladder pump is typically positioned at the depth that is to be sampled. Regardless of the pumping mechanism used, the pumping rate is adjusted to minimize drawdown. Because micropurging relies on a pumping rate that does not exceed the natural groundwater recharge rate, the water elevation in the well must be constantly monitored to ensure that drawdown does not occur.

SECTION 3

FIELD ACTIVITIES

Using the two types of diffusion samplers as designed, it was necessary to perform the diffusion sampling consecutively, as samples from the two types of diffusion samplers cannot be collected concurrently from the same interval within a well. To evaluate the potential changes in groundwater concentrations over the sampling periods (approximately 14 days between diffusion sampler collection events), conventional groundwater sampling was performed following completion of each diffusion sampling method. If significant differences were reported in groundwater chemistry between the two sampling events, the two sets of conventional groundwater data could be used to normalize the diffusion sampling data.

It also is important to note that during the field activities, the nearby extraction well field was not operated at a "steady-state" condition. This may have affected flowpaths between the tests and ultimately the results.

3.1 DEVIATIONS FROM WORK PLAN

The field activities generally occurred in accordance with the project work plan (Parsons ES, 1999), with one notable deviation. Three monitoring wells (MW-38D, MW-241, and MW-242) were identified for use in collecting groundwater samples during this study (Figure 3.1 and Table 3.1). During the first mobilization, it was determined that monitoring well MW-38D had been compromised due to silt build-up. This well has a documented total depth of 136.03 feet below ground surface (bgs) and is screened over a 10-foot interval from 117.87 to 127.87 feet bgs (Table 3.1). However, during the first field mobilization, the total depth of monitoring well MW-38D was measured as 120.6 feet bgs (Table 3.2). Because only approximately 3 feet of screen remained exposed to the aquifer in this well, it was deemed inappropriate for monitoring in this study. Monitoring well MW-11 was selected as a replacement for MW-38D. Well MW-11 is a 4-inch-diameter well screened across a 10-foot interval from 96.44 to 106.44 feet bgs (Table 3.1), and is located approximately 200 feet north of MW-38D (Figure 3.1).

MW-11 was selected as the replacement well because it had construction details similar to MW-38D, and it had the highest total chlorinated VOC (CVOC) concentration (296.8 micrograms per liter [µg/L]) measured during the first quarter of 1999 (Radian, 1999) of the OUD wells available for this study. Therefore, MW-11 was the well most likely to result in detections of VOCs when groundwater samples were collected and analyzed.

The change in monitoring wells sampled resulted in a second deviation from the work plan. Although three depth intervals were originally identified for sampling via

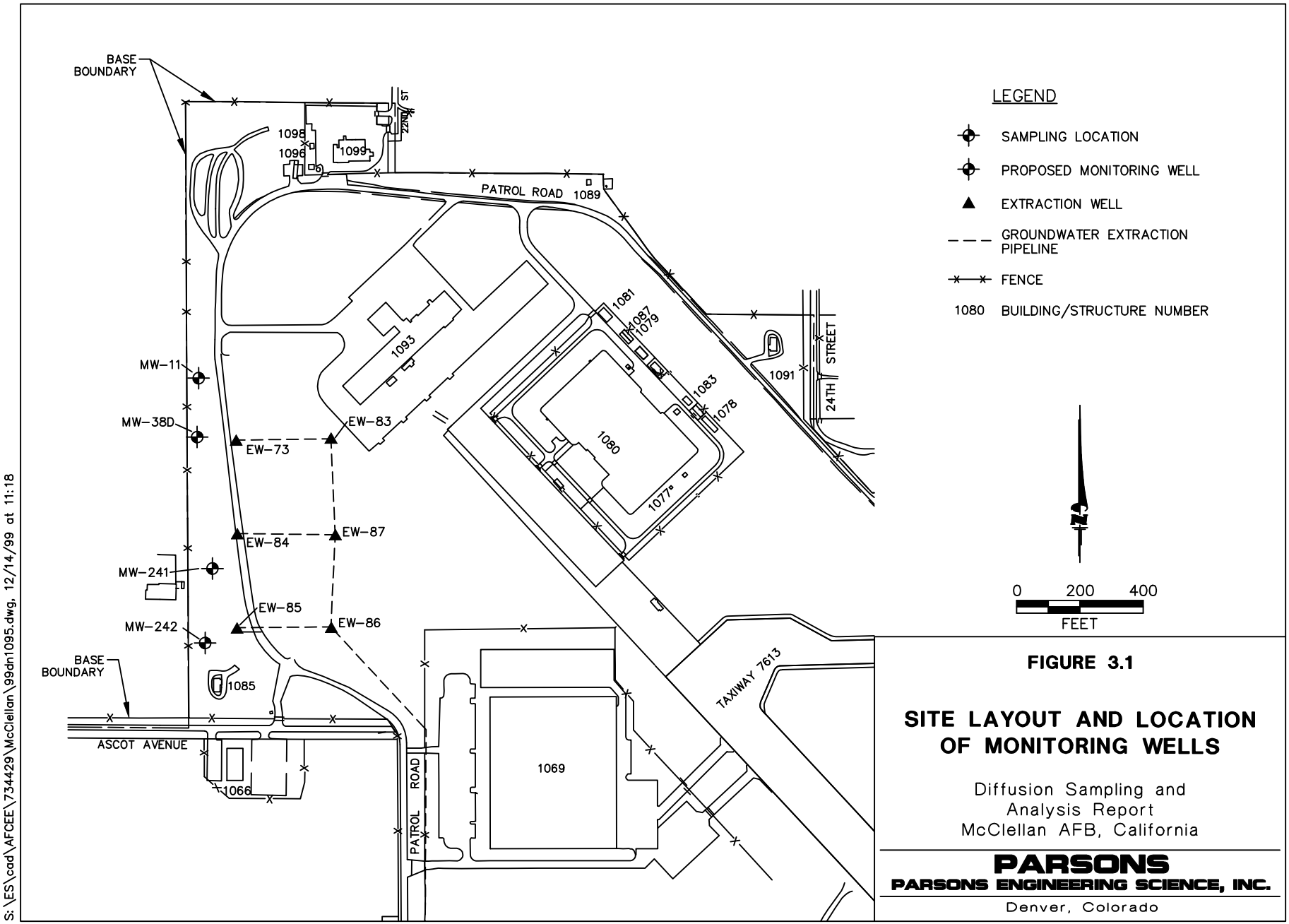

FIGURE 3.1

SITE LAYOUT AND LOCATION OF MONITORING WELLS

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TABLE 3.1
MONITORING WELL CONSTRUCTION DETAILS AND DATA
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

Well	Well Diameter (inches)	Total Depth (feet bgs)[b/]	Beginning Screen Depth (feet bgs)	Ending Screen Depth (feet bgs)	Length of Screen (feet)	First Quarter 1999 Groundwater Data[a/]		
						Groundwater Depth (feet bgs)	Water Level Above Screen Bottom (feet)	Chlorinated VOC Concentration[c/] (µg/L)[d/]
MW-11	4	106.44	96.44	106.44	10.00	100.50	5.94	296.8
MW-38D	4	136.03	117.87	127.87	10.00	NA	25.40[f/]	335.49
MW-241	4	135.50	114.00	134.00	20.00	103.74	30.26	15.17
MW-242	4	138.00	120.00	135.00	15.00	106.81	28.19	12.27

[a/] Source: (Radian, 1999).

[b/] feet bgs = feet below ground surface.

[c/] Includes trichloroethene, 1,1-dichloroethane, 1,1-dichloroethene (1,1-DCE), *cis* -1,2- DCE, *trans* -1,2-DCE, tetrachloroethene, and vinyl chloride.

[d/] µg/L = micrograms per liter.

[e/] NA = not available.

[f/] Datum from the GWOU Phase 2 Work Plan (CH2M Hill, 1997).

TABLE 3.2
SUMMARY OF FIELD-MEASURED DATA
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

Monitoring Well ID	Measurement Date	Sampling Method	Depth Interval (ft bgs)[a/]	Depth to Water (ft bgs)	Total Depth (ft bgs)	Temperature (deg. C)[b/]	Conductivity (µmhos/cm)[c/]	DO[d/] (mg/L)[e/]	pH (units)	ORP[f/] (mV)[g/]
MW-38D	8/3/1999	NA[h/]	NA	98.4	120.6	NM[i/]	NM	NM	NM	NM
MW-11	8/19/1999	micropurge	100.2	98.25	103.00	24.40	416.00	5.83	6.98	127.8
MW-11	8/19/1999	conventional	100.2	98.70	103.00	22.44	390.00	6.48	7.02	139.9
MW-11	9/3/1999	conventional	100.2	98.50	103.00	23.34	395.00	6.70	7.10	125.8
MW-241	8/18/1999	micropurge	116.0	101.12	NM	27.35	313.00	3.01	7.13	69.0
MW-241	8/18/1999	micropurge	124.0	101.03	NM	26.00	311.00	2.78	7.14	83.1
MW-241	8/18/1999	micropurge	132.0	101.04	NM	25.32	306.00	2.80	7.16	51.6
MW-241	8/18/1999	conventional	132.0	101.04	135.10	21.87	286.00	2.98	7.12	76.2
MW-241	9/3/1999	conventional	132.0	101.87	135.10	22.24	286.00	3.11	7.15	80.1
MW-242	8/18/1999	micropurge	121.5	104.40	NM	25.00	215.00	1.70	7.50	47.5
MW-242	8/18/1999	micropurge	127.5	104.60	NM	25.78	222.00	2.07	7.63	78.0
MW-242	8/18/1999	micropurge	133.5	104.35	NM	25.10	223.00	3.01	7.54	37.0
MW-242	8/18/1999	conventional	128.9	104.50	135.70	21.01	194.00	4.71	7.40	50.7
MW-242	9/3/1999	conventional	131.0	105.21	135.70	21.30	198.00	4.67	7.34	100.6

[a/] ft bgs - feet below ground surface.
[b/] deg. C - degrees Celsius.
[c/] µmhos/cm - micromhos per centimeter.
[d/] DO - dissolved oxygen.
[e/] mg/L - milligrams per liter.
[f/] ORP - oxidation/reduction potential.
[g/] mV - millivolts.
[h/] NA - not applicable.
[i/] NM - not measured.

micropurging at MW-38D (Parsons ES, 1999), only one depth interval was sampled via micropurging at MW-11. This adjustment was based on a decision by the field scientist due to the relatively short effective screened interval (the top 5.25 feet of screen were above the water table such that only 4.75 feet of screen were exposed to groundwater) in MW-11 (Table 3.2). One micropurge sample was collected from MW-11 at a depth of approximately 100.2 feet bgs (Tables 3.2 and 3.3).

3.2 SUMMARY OF FIELD ACTIVITIES

As described in Section 1, three field mobilizations were required to achieve the objectives identified for this study. The activities conducted during each mobilization are reviewed in the following subsections.

3.2.1 First Mobilization

The first field mobilization occurred on August 3, 1999. During this mobilization, groundwater elevations and the total depths of the wells to be monitored were measured (Table 3.2). As described in Section 3.1, monitoring well MW-38D was eliminated from the group of wells to be monitored, and MW-11 was selected as its replacement. Following groundwater level measurements, the USGS diffusion samplers were installed in the three wells. USGS diffusion samplers were placed at three depth intervals in each of the three monitoring wells (Table 3.3).

3.2.2 Second Mobilization

The second field mobilization occurred from August 17 through 19, 1999. During this mobilization, the USGS diffusion samplers were recovered from the three monitoring wells, and samples were collected. Also during this mobilization, micropurge and conventional samples were collected from the three wells. Finally, the DMLS™ diffusion samplers were installed in each of the three wells.

Because four of the DMLS™ dialysis cells were composited to obtain adequate sample volumes, the thickness of each monitored interval was approximately 17 inches. For example, four dialysis cells were placed over the following three intervals in MW-241: 115 feet 2 inches bgs to 116 feet 10 inches bgs, 123 feet 2 inches bgs to 124 feet 10 inches bgs, and 131 feet 2 inches bgs to 132 feet 10 inches bgs. Due to the required thickness of the sampling intervals, four 5-foot PVC rods were used in the preceding example.

Micropurge samples were collected from the similar depth intervals that were sampled with the diffusion samplers (Table 3.3).

3.2.3 Third Mobilization

The third and final field mobilization occurred from September 2 to 3, 1999. During this mobilization, the DMLS™ diffusion samplers were recovered from the three wells, and samples were collected for laboratory analysis. Additionally, during this mobilization, a second round of samples was collected using the conventional purging method. During recovery of the DMLS™ samplers, one dialysis cell installed within the intermediate depth interval (100.8 ft bgs) in MW-11 was retrieved uncapped and was therefore excluded from the composited samples for that depth interval.

TABLE 3.3
GROUNDWATER SAMPLING INTERVALS
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

Sampling Method Well	Beginning Screen Depth (feet bgs)[a/]	Ending Screen Depth (feet bgs)	Number of Samplers/ Number of Sampling Intervals[b/]	Mid-Point Sampler Depth/ Mid-Point Pump Depth (ft bgs)[c/]		
				Shallow	Intermediate	Deep
USGS Diffusion Sampling						
MW-11	96.44	106.44	3/3	98.2	100.2	102.2
MW-241	114.00	134.00	3/3	116.0	124.0	132.0
MW-242	120.00	135.00	3/3	121.5	127.5	133.5
DLMS™ Diffusion Sampling						
MW-11	96.44	106.44	12/3	101	103	105
MW-241	114.00	134.00	12/3	115.4-116.6	123.4-124.6	131.4-132.6
MW-242	120.00	135.00	12/3	120.9-122.1	127.7-128.1	133.7-134.1
Micropurge Sampling						
MW-11	96.44	106.44	1/1	-	100.2	-
MW-241	114.00	134.00	1/3	116.0	124.0	132.0
MW-242	120.00	135.00	1/3	121.5	127.5	133.5
Conventional Sampling[d/]						
MW-11	96.44	106.44	1/1 - two events	-	100.2/100.2	-
MW-241	114.00	134.00	1/1 - two events	-	131.0/132.0	-
MW-242	120.00	135.00	1/1 - two events	-	128.9/131.0	-

[a/] feet bgs = feet below ground surface.

[b/] Number of samplers refers to the number of diffusion sampling devices. Because each DMLS™ dialysis cell only contains 38 milliliters of water, it was necessary to collect four dialysis cells per sampling interval to obtain adequate sample volumes for laboratory analysis.

[c/] For DMLS™ diffusion samplers, the sampling interval that was composited during sampling is identified.

[d/] Two conventional sampling events were performed. The first sampling event followed USGS diffusion sample collection and micropurge sample collection. The second sampling event followed DMLS™ diffusion sample collection. Depth of pump installation during each mobilization is separated by a "/".

SECTION 4

FIELD SAMPLING RESULTS AND COMPARISON

4.1 SAMPLING AND ANALYSIS RESULTS

4.1.1 Field Data

Field data collected from each well during this investigation included: depth to groundwater; total well depth; and groundwater pH, conductivity, temperature, dissolved oxygen concentration, and oxidation/reduction potential. Results of these measurements are summarized in Table 3.2. Field notes and sample collection forms are provided in Appendix B. A summary of samples collected, including sampling date, time, method, identification number, depth interval, and type is presented in Table 4.1.

4.1.2 Laboratory Data

A total of 31 primary and 8 quality assurance/quality control (QA/QC) water samples were submitted to Quanterra for analysis of VOCs with USEPA Method SW8260B (Table 4.1). Of the 67 analytes included in the SW8260B analysis, 17 were reported to have detectable concentrations in at least one of the primary samples submitted for analysis (QA/QC samples were not considered in this review). Table 4.2 presents a list of the analytes that had detectable concentrations and the frequency of those detections in the samples submitted for this evaluation. For the purposes of comparing the analytical accuracy or comparability using different sampling methods, only those analytes that were detected in at least ten primary samples were considered in this study. These analytes are identified with an asterisk in Table 4.2 and include: trichloroethene (TCE), *trans*-1,2-dichloroethene (DCE), *cis*-1,2-DCE, 1,1-DCE, 1,1-dichloroethane (DCA), 1,1,2-trichloroethane (TCA), and 1,2-DCA. A summary of analytical results for these analytes is presented in Table 4.3. A complete report of all analytical laboratory results obtained during this study is presented in Appendix C.

4.1.3 Quality Assurance/Quality Control

Groundwater samples were transmitted to Quanterra in two sample delivery groups. Upon receipt from the laboratory, analytical results were validated by Parsons ES using a Level III review that consisted of manually examining data deliverables to assess data quality. Data validation included application of data qualifiers to the analytical results based on adherence to method protocols and project-specific QA/QC limits. Method protocols reviewed included:

TABLE 4.1
GROUNDWATER SAMPLE SUMMARY
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

Sampling Location	Sample Date	Sample Time	Sampling Method	Sample Identification Number	Sampled Interval (ft bgs)[a/]	Sample Type
MW242	8/17/1999	1045	USGS	MW242-121.5'USGS	121.5	Primary
MW242	8/17/1999	1110	USGS	MW242-127.5'USGS	127.5	Primary
MW242	8/17/1999	1125	USGS	MW242-133.5'USGS	133.5	Primary
MW241	8/17/1999	1200	USGS	MW24D-120'USGS	124.0	Duplicate
MW241	8/17/1999	1300	USGS	MW241-116'USGS	116.0	Primary
MW241	8/17/1999	1315	USGS	MW241-124'USGS	124.0	Primary
MW241	8/17/1999	1330	USGS	MW241-132'USGS	132.0	Primary
MW11	8/17/1999	1412	USGS	MW11-101'USGS	98.2	Primary
MW11	8/17/1999	1425	USGS	MW11-103'USGS	100.2	Primary
MW11	8/17/1999	1435	USGS	MW11-105'USGS	102.2	Primary
Spike Sample	8/18/1999	800	Prepared by Lab	MW318	NA	Spike
Spike Sample	8/18/1999	820	Prepared by Lab	MW320	NA	Spike
MW242	8/18/1999	1110	Micropurge	MW242-121.5'µ	121.5	Primary
MW242	8/18/1999	1202	Micropurge	MW242-127.5'µ	127.5	Primary
MW242	8/18/1999	1250	Micropurge	MW242-133.5'µ	133.5	Primary
MW242	8/18/1999	1320	Conventional	MW242-131'C	128.9	Primary
MW241	8/18/1999	1450	Micropurge	MW241-116'µ	116.0	Primary
MW241	8/18/1999	1525	Micropurge	MW241-124'µ	124.0	Primary
MW241	8/18/1999	1550	Micropurge	MW241-132'µ	132.0	Primary
MW241	8/18/1999	1600	Micropurge	MW25D-124'	132.0	Duplicate
MW241	8/18/1999	1630	Conventional	MW241-132'C	131.0	Primary
MW11	8/19/1999	840	Micropurge	MW11-103'µ	100.2	Primary
MW11	8/19/1999	900	Conventional	MW11-103'C	100.2	Primary
Trip Blank	8/19/1999	NA	NA	Trip Blank	NA	Blank
Spike Sample	9/2/1999	800	Prepared by Lab	MW902	NA	Spike
MW242	9/2/1999	1130	DMLS	MW242-121.5'DLMS	120.9-122.1	Primary
MW242	9/2/1999	1140	DMLS	MW242-127.5'DLMS	127.7-128.1	Primary
MW242	9/2/1999	1152	DMLS	MW242-133.5'DLMS	133.7-134.1	Primary
MW241	9/2/1999	1219	DMLS	MW241-116'DLMS	115.4-116.6	Primary
MW241	9/2/1999	1234	DMLS	MW241-124'DLMS	123.4-124.6	Primary
MW241	9/2/1999	1242	DMLS	MW241-132'DLMS	131.4-132.6	Primary
MW11	9/2/1999	1256	DMLS	MW11-101'DLMS	101.0	Primary
MW11	9/2/1999	1300	DMLS	MW11-103'DLMS	103.0	Primary
MW11	9/2/1999	1306	DMLS	MW11-105'DLMS	105.0	Primary
Trip Blank	9/2/1999	NA	NA	Trip Blank	NA	Blank
MW242	9/3/1999	1035	Conventional	MW242-131'C2	131.0	Primary
MW241	9/3/1999	1225	Conventional	MW241-132'C2	132.0	Primary
MW241	9/3/1999	1300	Conventional	MW25D-132'C2	132.0	Duplicate
MW11	9/3/1999	1355	Conventional	MW11-103'C2	100.2	Primary

[a/] ft bgs - Feet below ground surface.

TABLE 4.2
SUMMARY OF ANALYTICAL PARAMETERS DETECTED
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

Analyte	Number of Detects
1,1,1-Trichloroethane	5
1,1,2-Trichloroethane *	18
1,1,2-Trichlorotrifluoroethane	5
1,1-Dichloroethane *	21
1,1-Dichloroethene *	31
1,2-Dichloroethane *	31
Acetone	7
Benzene	5
Chloroform	9
cis-1,2-Dichloroethene *	20
Ethylbenzene	1
Isopropylbenzene	2
m-Xylene & p-Xylene	1
Tetrachloroethene	2
Toluene	1
trans-1,2-Dichloroethene *	10
Trichloroethene *	31

Notes:
- Only primary samples were considered when developing Table 4.2.
- Analytes designated with an asterisk are evaluated further in this study.

TABLE 4.3
SUMMARY OF CVOC ANALYTICAL RESULTS
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

TRICHLOROETHENE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	8	NM	NM	8	NM
MW11-103'	23	24	29	9.6	21
MW11-105'	23	NM	NM	10	NM
MW241-116'	3.8	27	41	32	32
MW241-124'	34	32	NM	33	NM
MW241-132'	40	33	NM	27	NM
MW242-121.5'	6	3.5	NM	5.3	NM
MW242-127.5'	3.5	2.6	NM	3.6	NM
MW242-133.5'	3.4	2.8	4	3.3	3.1

trans-1,2-DICHLOROETHENE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	ND	NM	NM	ND	NM
MW11-103'	ND	ND	ND	ND	ND
MW11-105'	ND	NM	NM	ND	NM
MW241-116'	ND	0.96 J	1	1.4	0.99 J
MW241-124'	1.2	0.9 J	NM	1.1	NM
MW241-132'	1	0.98 J	NM	0.77 J	NM
MW242-121.5'	ND	ND	NM	ND	NM
MW242-127.5'	ND	ND	NM	ND	NM
MW242-133.5'	ND	ND	ND	ND	ND

cis-1,2-DICHLOROETHENE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	0.95 J	NM	NM	1.1	NM
MW11-103'	2.3	3.4	3.8	1.4	3.3
MW11-105'	2.2	NM	NM	1.4	NM
MW241-116'	0.63 J	7.2	7.2	11	6.8
MW241-124'	9.2	6.7	NM	8.1	NM
MW241-132'	7.5	6.5	NM	6	NM
MW242-121.5'	ND	ND	NM	ND	NM
MW242-127.5'	ND	ND	NM	ND	NM
MW242-133.5'	ND	ND	ND	ND	ND

1,1-DICHLOROETHENE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	34	NM	NM	58	NM
MW11-103'	88	170	220	74	170
MW11-105'	89	NM	NM	77	NM
MW241-116'	2.1	17	23	20	18
MW241-124'	20	19	NM	21	NM
MW241-132'	22	15	NM	19	NM
MW242-121.5'	9	6.3	NM	10	NM
MW242-127.5'	4.5	3.8	NM	6.5	NM
MW242-133.5'	4.4	4	5.4	5.2	3.1

TABLE 4.3 (Continued)
SUMMARY OF CVOC ANALYTICAL RESULTS
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

1,1-DICHLOROETHANE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	0.66 J	NM	NM	0.54 J	NM
MW11-103'	1.6	1.6 J	1.7 J	0.67 J	1.5 J
MW11-105'	1.6	NM	NM	0.69 J	NM
MW241-116'	0.36 J	3.5	3.6	4.3	3.4
MW241-124'	4.4	3.6	NM	3.6	NM
MW241-132'	4.2	3.6	NM	2.9	NM
MW242-121.5'	ND	ND	NM	0.22 J	NM
MW242-127.5'	ND	ND	NM	ND	NM
MW242-133.5'	ND	ND	ND	ND	ND

1,1,2-TRICHLOROETHANE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	0.58 J	NM	NM	0.47 J	NM
MW11-103'	1.6	1.3 J	1.6 J	0.64 J	1.5 J
MW11-105'	1.4	NM	NM	0.68 J	NM
MW241-116'	ND	0.23 J	0.32 J	0.24 J	0.27 J
MW241-124'	0.32 J	0.27 J	NM	0.27 J	NM
MW241-132'	ND	0.28 J	NM	0.22 J	NM
MW242-121.5'	ND	ND	NM	ND	NM
MW242-127.5'	ND	ND	NM	ND	NM
MW242-133.5'	ND	ND	ND	ND	ND

1,2-DICHLOROETHANE (concentrations in micrograms per liter)

Sampling Location	Second Mobilization			Third Mobilization	
	USGS	Micropurge	Conventional[a/]	DMLS™	Conventional
MW11-101'	0.95 J	NM	NM	0.74 J	NM
MW11-103'	2.1	2.2 J	2 J	0.83 J	1.9 J
MW11-105'	2.2	NM	NM	0.81 J	NM
MW241-116'	1.8	14	15	15	15
MW241-124'	16	16	NM	14	NM
MW241-132'	16	15	NM	12	NM
MW242-121.5'	0.43 J	0.98 J	NM	0.91 J	NM
MW242-127.5'	1.6	2	NM	0.78 J	NM
MW242-133.5'	1.6	3.5	5.3	1.4	3.6

[a/] Analytical results for conventional purging are presented for the depth at which the pump was installed.

[b/] ND - Not detected.

[c/] NM - not measured.

[d/] J - Estimated value.

- Analytical holding times,
- Method blanks,
- Trip blanks,
- Matrix spikes/matrix spike duplicates,
- Laboratory control samples, and
- Surrogates.

All data were validated using method-applicable guidelines, and in accordance with the *National Functional Guidelines for Organic Data Review* (USEPA, 1994). This review identified detectable quantities of methylene chloride in the method blank samples for both sample delivery groups. Method blank contamination is probably due to laboratory contamination during sample handling, preparation, or analysis. As a result of these detections, any sample with a reported methylene chloride concentration less than 10 times the amount detected in the associated method blank was qualified with a U flag as not detected, indicating the analyte was analyzed for and was not present above the reported sample quantitation limit. Thirty-six methylene chloride values were qualified as not detected as a result of this validation procedure. No other laboratory QA/QC problems were noted during the validation process.

Additional evaluation and validation of the laboratory data were limited to the analytes identified in Table 4.2 as having been detected in a minimum of ten primary samples. For these constituents, the following QA/QC procedures were implemented.

Three duplicate samples were collected and submitted to Quanterra for QA/QC purposes. One duplicate sample each was collected for the USGS diffusion sampling (MW24D-120'USGS), the micropurge sampling (MW25D-124'), and the conventional sampling (MW25D-132'C2) (Table 4.1). Results of the duplicate analyses were compared to the results of the corresponding primary sample using relative percent difference (RPD):

$$RPD = 100\ [abs(P-D)]/[(P+D)/2]$$

where:

abs = absolute value

P = primary sample result

D = duplicate sample result

In no instance did the RPD between primary and duplicate samples exceed 20 percent, demonstrating acceptable accuracy (Table 4.4).

One trip blank was submitted to Quanterra along with each sample delivery group (Table 4.1). These samples were analyzed for the same constituents as the environmental

TABLE 4.4
QA/QC SAMPLE EVALUATION
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

DUPLICATE SAMPLE COMPARISON

USGS Duplicates			
Analyte [a/]	MW241-124'USGS	MW24D-120'USGS	RPD [b/]
1,1,2-TCA (µg/L)	0.32	0.37	14.5
1,1-DCA (µg/L)	4.4	4.4	0
1,1-DCE (µg/L)	20	20	0
1,2-DCA (µg/L)	16	16	0.0
cis-1,2-DCE (µg/L)	9.2	10	8.3
TCE (µg/L)	34	35	2.9
trans-1,2-DCE (µg/L)	1.2	1.3	8.0

Micropurge Duplicates			
Analyte	MW241-132'µ	MW25D-124'	RPD
1,1,2-TCA (µg/L)	0.28	0.28	0
1,1-DCA (µg/L)	3.6	3.5	2.8
1,1-DCE (µg/L)	15	14	6.9
1,2-DCA (µg/L)	15	15	0
cis-1,2-DCE (µg/L)	6.5	6.5	0
TCE (µg/L)	33	32	3.1
trans-1,2-DCE (µg/L)	0.98	0.93	5.2

Conventional Purge Duplicates			
Analyte	MW241-132'C2	MW25D-132'C2	RPD
1,1,2-TCA (µg/L)	0.27	0.24	11.8
1,1-DCA (µg/L)	3.4	3.2	6.1
1,1-DCE (µg/L)	18	15	18
1,2-DCA (µg/L)	15	14	6.9
cis-1,2-DCE (µg/L)	6.8	6.5	4.5
TCE (µg/L)	32	29	9.8
trans-1,2-DCE (µg/L)	0.99	ND [e/]	NA

BLIND SPIKE SAMPLE COMPARISON

Analyte	MW318	Certified Value	Performance Acceptance Limits
1,1,2-TCA (µg/L)	16	16.9	13.5-20.3
1,1-DCA (µg/L)	ND [c/]	-	NA [d/]
1,1-DCE (µg/L)	14	16.1	12.9-19.3
1,2-DCA (µg/L)	17	16.3	13.0-19.6
cis-1,2-DCE (µg/L)	17	16.8	13.4-20.2
TCE (µg/L)	11	11.8	9.44-14.2
trans-1,2-DCE (µg/L)	8.2	9.11	5.47-12.8

Analyte	MW320	Certified Value	Performance Acceptance Limits
1,1,2-TCA (µg/L)	16	16.9	13.5-20.3
1,1-DCA (µg/L)	ND	-	NA
1,1-DCE (µg/L)	14	16.1	12.9-19.3
1,2-DCA (µg/L)	17	16.3	13.0-19.6
cis-1,2-DCE (µg/L)	18	16.8	13.4-20.2
TCE (µg/L)	11	11.8	9.44-14.2
trans-1,2-DCE (µg/L)	8.1	9.11	5.47-12.8

Analyte	MW902	Certified Value	Performance Acceptance Limits
1,1,2-TCA (µg/L)	14	16.9	13.5-20.3
1,1-DCA (µg/L)	ND	-	NA
1,1-DCE (µg/L)	12	16.1	12.9-19.3
1,2-DCA (µg/L)	16	16.3	13.0-19.6
cis-1,2-DCE (µg/L)	15	16.8	13.4-20.2
TCE (µg/L)	9.2	11.8	9.44-14.2
trans-1,2-DCE (µg/L)	7.2	9.11	5.47-12.8

Shaded values indicate deviation from performance acceptance limits.

[α/] µg/L - micrograms per liter; 1,1,2-TCA = 1,1,2-trichloroethane; 1,1-DCA = 1,1-dichloroethane; 1,1-DCE = 1,1-dichloroethene; 1,2-DCA = 1,2-dichloroethane; cis-1,2-DCE = cis-1,2-dichloroethene; TCE = trichloroethene; trans-1,2-DCE = trans-1,2-dichloroethene.

[b/] RPD = relative percent difference.

[c/] ND = not detected.

[d/] NA = not applicable.

[e/] Reporting limit is 1 µg/L

samples. If a detectable concentration of an analyte was detected in one of the blank samples, all primary samples within the same delivery group were qualified as nondetects (U-flagged) if the corresponding analyte was less than 5 times the concentration detected in the blank sample. However, of the analytes reviewed for this process, no detectable concentrations were reported in the blank samples (Appendix C).

Three blind spike samples with known concentrations of specific analytes prepared by an independent laboratory (Environmental Research Associates [ERA] of Arvada, Colorado) were submitted to Quanterra with other groundwater samples collected during this program for precision evaluation. The certified concentrations of various analytes in these samples is provided on the certification sheet provided by ERA (Appendix C). These samples were assigned sample identification numbers of MW318, MW320, and MW902 (Table 4.1) prior to being shipped to Quanterra. Results of the analyses performed on the blind spike samples were compared with the performance acceptance limits provided by ERA. Although analytical results for two of the three blind spike samples were within the performance acceptance limits (Table 4.4), the third (and final) blind spike sample submitted to the laboratory resulted in slightly low-biased differences from the performance acceptance limits for 1,1-DCE, and TCE (Table 4.4). Because the laboratory QC report indicated no concerns with data quality, and because the blind spike samples were transferred directly from ERA to field personnel to Quanterra with no opportunity for sample degradation (adequate preservation, sample holding times met, and no transfer of sample between bottles in the field), these deviations from performance acceptance limits are presumed to be the result of sample preparation error by ERA.

4.2 PERFORMANCE/COMPARISON CRITERIA

The different methods of sample collection were evaluated using the following criteria: cost, accuracy or comparability of data, and other method-specific criteria. These criteria are described in the following sections.

4.2.1 Cost

The following expenses were considered in the development of a cost analysis for each different sampling method: labor, equipment, and disposal or management of investigation-derived waste (IDW). Some of the costs involved in these activities are one-time expenses that are not incurred each time a sample is collected (e.g., PVC rods for use with the DMLS samplers, stainless steel weights, etc.). Furthermore, labor and material costs can vary depending on the scope of the sampling event (e.g., it is less expensive on a unit-cost basis to collect 100 samples than to collect 5 samples). However, in order to present the most accurate estimate of costs associated with this evaluation, only the costs incurred during this field study were considered in the cost analysis. Labor costs were based on actual hours expended as documented in the field notes and the burdened labor rate for a typical field scientist. Equipment costs were taken directly from invoices (when available) or were estimated from vendor quotes. Costs associated with disposal or management of IDW can vary widely depending on the approach used. For this analysis, the only costs considered in the management of IDW are those dealing with containerizing the waste. Additional costs associated with IDW management must be determined on an case-by-case basis, and were not considered in this analysis.

Table 4.5 presents a detailed list of costs incurred for each sampling method during this investigation. The following assumptions were incorporated into Table 4.5 and the cost analysis:

- Field mobilization/demobilization costs were assumed to be equal for all methods with one exception. The micropurge and conventional purge sampling methods required the use of a gas-powered generator and a Grundfos Redi-Flo2 pump, such that a larger field vehicle was required for these sampling methods. Because of this difference, an additional $30 per day was applied to these purge-sampling methods to reflect the vehicle rental rate difference.

- Because the USGS diffusion samplers were provided free of charge for this investigation, costs were obtained from EON Products, Inc. for the USGS samplers.

- Because collection of QA/QC samples would be required regardless of the sample collection procedure used, labor and equipment required for the collection of QA/QC samples were not considered in the cost analysis.

- Because conventional purge sampling occurred on two occasions, only the second round of conventional purge sampling was used for the cost analysis. This approach facilitated breaking out costs associated with conventional purging as opposed to micropurging.

- Many of the common sampling supplies (e.g., nitrile gloves, rope, plastic sheeting, sample containers, etc.) were assumed to be equal in cost regardless of sampling method.

- Sales taxes were not included in the cost analysis.

- Labor estimates included all activities required to collect a sample and decontaminate sampling equipment.

- In instances where supplies or equipment were shared among different sampling methods (i.e., IDW drums, Grundfos Redi-Flo2 pump, generator, meters, etc.), an attempt was made to separate the shared costs into individual method-specific costs that would have been incurred if only one method had been used.

- Laboratory analytical expenses were assumed to be equal regardless of sampling method.

As presented in Table 4.5, the cost per sample using the USGS diffusion sampler was approximately $65, and the cost per sample using the DMLS™ diffusion sampler was approximately $555. The costs per sample for micropurge and conventional purge sampling methods were approximately $308 and $444, respectively. Additionally, a total of approximately 27 gallons of IDW was generated using the micropurge sampling method (Appendix B), and a total of approximately 132 gallons of IDW was generated per sampling event using the conventional purge sampling method (Appendix B). Negligible volumes (less than 5 gallons) of IDW were generated using the two types of diffusive samplers.

TABLE 4.5
COST ANALYSIS
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

CONVENTIONAL PURGE

Unit	Reusable?	Cost per Unit	Number Required	Cost per Event
Field Vehicle Addition[a/]	no	$ 30.00	1	$ 30.00
Pump Rental (day rate)[b/]	no	$ 175.00	1	$ 175.00
Generator Rental (day rate)[b/]	no	$ 75.00	1	$ 75.00
Tubing[b/]	yes	$ 0.52	175	$ 91.00
Meter Rental (day rate)[b/c/]	no	$ 150.00	1	$ 150.00
Drums for IDW[d/]	potentially	$ 50.00	3	$ 150.00
Labor (per person-hour)[d/]	no	$ 60.00	11	$ 660.00
			Total Cost	$ 1,331.00
			Number of Samples Collected	3
			Cost per Sample	**$ 443.67**

MICROPURGE

Unit	Reusable?	Cost per Unit	Number Required	Cost per Event
Field Vehicle Addition[a/]	no	$ 30.00	2	$ 60.00
Pump Rental (day rate)[b/]	no	$ 175.00	2	$ 350.00
Generator Rental (day rate)[b/]	no	$ 75.00	2	$ 150.00
Tubing[b/]	yes	$ 0.52	175	$ 91.00
Meter Rental (day rate)[b/c/]	no	$ 150.00	2	$ 300.00
Drums for IDW[d/]	potentially	$ 50.00	1	$ 50.00
Labor (per person-hour)[d/]	no	$ 60.00	19.2	$ 1,152.00
			Total Cost	$ 2,153.00
			Number of Samples Collected	7
			Cost per Sample	**$ 307.57**

DMLS™ SAMPLER

Unit	Reusable?	Cost per Unit	Number Required	Cost per Event
PVC Rod[e/]	yes	$ 341.00	8	$ 2,728.00
Dialysis Cell (package of 12)[e/]	no	$ 57.00	8	$ 456.00
Well Seal (package of 16)[e/]	no	$ 32.00	8	$ 256.00
PVC Centering Guide[e/]	yes	$ 24.00	8	$ 192.00
Quicklock Connector[e/]	yes	$ 43.00	8	$ 344.00
Hook[e/]	yes	$ 57.50	3	$ 172.50
Weight[e/]	yes	$ 82.00	4	$ 328.00
Labor (per person-hour)[d/]	no	$ 60.00	8.7	$ 522.00
			Total Cost	$ 4,998.50
			Number of Samples Collected	9
			Cost per Sample	**$ 555.39**

USGS SAMPLER

Unit	Reusable?	Cost per Unit	Number Required	Cost per Event
Diffusion Sampler[f/]	no	$ 16.50	9	$ 148.50
Stainless Weight Hanger[f/]	yes	$ 7.50	3	$ 22.50
Stainless Steel Weight[f/]	yes	$ 19.00	3	$ 57.00
Labor (per person-hour)[d/]	no	$ 60.00	6	$ 360.00
			Total Cost	$ 588.00
			Number of Samples Collected	9
			Cost per Sample	**$ 65.33**

[a/] Additional cost for larger vehicle.

[b/] Costs from GeoTech, Inc., Loveland, Colorado.

[c/] Meters include pH, conductivity, dissolved oxygen, oxidation/reduction potential.

[d/] Estimated value.

[e/] Cost from Johnson Screens of New Brighton, Minnesota.

[f/] Cost from EON Products, Inc., Lithonia, Georgia.

As noted, these costs are approximated based on the limited scope of this investigation. If these sampling technologies were applied to large-scale monitoring programs, a reduction in the per-sample cost would probably be realized. Reusable equipment is identified in Table 4.5.

4.2.2 Accuracy/Comparability of Data

For purposes of comparison, the analysis of variance (ANOVA) test was used to compare analytical data collected using the different sampling techniques. ANOVA is a statistical procedure used to compare the means of different groups of observations to determine if there are significant differences among the groups. The one-way parametric ANOVA was used to investigate if differences exist among the analytical results obtained for samples collected using the USGS diffusion sampler, DMLS™ diffusion sampler, and micropurge and conventional purge sampling techniques. The test compares the means of the distributions of analytical results for a given chemical from each sampling technique (Appendix D). This test is designed to determine if the data sets are drawn from the same distribution. If a chemical passes the ANOVA test, it can be concluded that there are no significant differences among the various sampling techniques.

The ANOVA test was run using the Excel™ data analysis toolpack. The software returns an ANOVA “p-value” between zero and one, indicating a “pass” or “fail” condition. A p-value of 0.05 or greater indicates a pass, indicating that the distributions are similar at the 95-percent confidence level. In other words, there is only a one-in-twenty chance of falsely identifying the distributions as similar when they really are not.

Statistical analyses of the data were not included in the original scope of this project. Unfortunately, the limited number of samples available (as few as 3 per sampling method) precluded the use of any linear statistical models in a quantitative manner. Therefore, the ANOVA is used in a qualitative manner to provide a "weight-of-evidence" support for data accuracy and similarity. Furthermore, ANOVA is a parametric test and it is common practice to show that the data set is parametric prior to applying the tests. However, due to the limited number of samples in the data set, no normality tests were performed on the data sets before performing the ANOVA.

In instances where a nondetectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA testing only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well. Only the seven target analytes described in Section 4.1.2 and shown on Table 4.3 were evaluated using the ANOVA test.

Test results are presented in Appendix D and are summarized in Table 4.6. In all instances the p-values calculated for the populations of results for the different sampling methods exceeded 0.05. These ANOVA results indicate that there are no statistically significant differences among analytical results obtained using the four groundwater sampling techniques.

TABLE 4.6
ANOVA p-VALUES
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

Analyte	ANOVA p-Value
1,1,2-trichloroethane	0.74
1,1-dichloroethane	0.99
1,1-dichloroethene	0.47
1,2-dichloroethane	0.88
cis-1,2-dichloroethene	0.96
trichloroethene	0.59
trans-1,2-dichloroethene	0.99

In addition to the evaluation of data comparability using the ANOVA test, further qualitative review of the data was performed. Three peculiarities in the data were noted during this review, and are discussed below.

Analysis of the sample collected using the USGS diffusion sampler in monitoring well MW-241 from the shallowest interval (116 feet) resulted in CVOC concentrations that were consistently biased low compared to the other methods (Table 4.3). Upon further review, it was noted that in all instances, CVOC concentrations in this sample were approximately one-order of magnitude less than other sample results. It is possible that this sample was inadvertently diluted by a factor of 10 at the analytical laboratory. However, this could not be verified.

Analytical results of samples collected using the USGS diffusion sampler in monitoring wells MW-241 and MW-11 were consistently biased low compared to similar samples collected from deeper intervals in the same wells. This trend was not as evident in samples collected using the DMLS samplers, suggesting that a vertical contaminant concentration gradient does not exist in these wells. A potential explanation for this observation may be that a section of the USGS sampler was positioned at an elevation which was greater than the groundwater elevation, thereby exposing the sampler to ambient air during the sampling period. For example, the midpoint of the uppermost USGS sampler installed in MW-11 was 98.2 feet below ground surface (ft bgs) (Table 3.3), while the depth to groundwater was measured to be 98.25 ft bgs (Table 3.2). This suggests that the uppermost USGS sampler in MW-11 may have been at least partially exposed to ambient air during the test. The topmost USGS sampler in MW-241 was installed at 116 ft bgs (Table 3.3) while the groundwater was measured to be at approximately 101 ft bgs (Table 3.2). Although it appears as though this sampler was adequately submerged during the testing, a variation in groundwater elevations could result in low biased contaminants in shallow samplers due to volatilization of the contaminants in shallow groundwater to air.

Analytical results for 1,1-DCE in samples collected with a pump (micropurge and conventional purge) from well MW-11 were substantially higher than those collected using the diffusion samplers (Table 4.3). This occurrence was noted for samples collected during both field mobilizations, suggesting that it may be representative of actual conditions as opposed to sampling or analysis error. This observation is limited to 1,1-DCE in MW-11; in all other instances, minimal differences were noted between the different sampling methods for all analytes. Because 1,1-DCE concentrations in samples collected from wells MW-241 and MW-242 were relatively similar regardless of sampling method, it is unlikely that selective permeability of the diffusion sampler membranes could be the cause of this discrepancy. A possible explanation of this occurrence is that a thin discreet layer (or layers) in the aquifer at MW-11 may contain higher concentrations of 1,1-DCE than the surrounding layers. If the diffusion samplers were not placed at the same depth interval as this layer, this contamination may not be reflected in the analytical results. However, water from a greater percentage of the screened interval can be obtained when using a pump. This is particularly true with conventional purging, and may be possible to a lesser degree with micropurging especially if the pumping rate is slightly greater than the groundwater recharge rate. Samples collected in this way will be representative of groundwater averaged across the interval that was affected by the pump.

4.2.3 Other Method-Specific Criteria

This section presents a qualitative discussion of the advantages and disadvantages associated with implementing the four sampling methods, based on verbal and written evaluations from the sampling personnel, as well as method-specific attributes of the different techniques.

4.2.3.1 USGS Diffusion Sampler

Of the four sampling methods evaluated, the USGS diffusion sampler received the highest ratings from field sampling personnel. Specific advantages inherent in this sampling method and noted by field personnel included the following:

- Requires little to no preparatory work except for measuring rope length for correct sampling depth prior to installation of the device in the well.
- Quick and simple installation and sample collection.
- Minimal decontamination required; only scissors or knife used to open diffusion sampler require decontamination between uses.
- The USGS diffusion samplers produce negligible quantities of IDW.

No disadvantages associated with using this sample collection method were identified by field personnel. However, the following potential drawbacks apply:

- The selectivity of the membrane renders this method inappropriate for the measurement of common charged inorganic natural attenuation parameters (e.g. nitrate, ferrous iron, and sulfate). Additionally, measurement of typical field

parameters (e.g. pH, conductivity, oxidation-reduction potential) is problematic using the diffusion sampler.

- The system is suitable only for collection of samples for VOC analysis.
- Because of the time required for passive diffusion sampling, this method may not be suitable in cases where rapid assessment of groundwater is desired.
- If groundwater elevations vary significantly over time, the USGS diffusion samplers could be exposed to air which might compromise the integrity of the sample.

4.2.3.2 DMLS™ Diffusion Sampler

Of the four sampling methods evaluated, the DMLS™ diffusion sampler received the second highest ratings from field sampling personnel. Specific advantages noted by field personnel included:

- Relatively quick to install and collect sample (although not as quick or simple as the USGS sampler).
- Negligible generation of IDW.
- PVC sampling rods can be reused.

Disadvantages or deficiencies of this sampling method included:

- The system is suitable only for collection of samples for VOC analysis.
- The polyethylene cell volume for the DMLS™ samplers is only 38 mL; therefore, compositing of the samples is necessary to obtain adequate sample volume for laboratory analysis. Compositing can result in loss of VOCs via volatilization during sample mixing and transfer.
- The well seals on the DMLS™ sampler that are used to vertically separate water within the well are ineffective. They do not form a tight fit in the well casing, and therefore well water can mix vertically in the annular space between the well seals and the well casing in response to the predominant vertical hydraulic gradient.
- Because of the time required for passive diffusion sampling, this method may not be suitable in cases where rapid assessment of groundwater is desired.
- Decontamination is necessary if the PVC samplers are re-used, creating a potential for cross-contamination between samples if decontamination procedures are not adequate. Also, decontamination adds labor time to this method, and increases the volume of IDW.
- Similar to the USGS diffusion sampler, the selectivity of the membrane used in this device are inadequate for analysis of common charged inorganic natural attenuation parameters (e.g. nitrate, ferrous iron, and sulfate). Additionally, measurement of

typical field parameters (e.g. pH, conductivity, oxidation-reduction potential) is problematic using the diffusion sampler.

- If groundwater elevations vary significantly over time, the DMLS™ diffusion samplers could be exposed to air which might compromise the integrity of the sample.

4.2.3.3 Conventional Purge Sampling

The conventional purge sampling method was ranked third among the four methods evaluated by field sampling personnel. Advantages specific to this method included:

- Once set up, it is fairly quick and easy to collect groundwater samples using this method.
- Samples for analysis of contaminants other than VOCs can be collected.
- The method is suitable in cases where rapid assessment of groundwater is desired as well as for periodic monitoring.
- Common field parameters (pH, conductivity, temperature, dissolved oxygen, oxidation-reduction potential) can be monitored throughout well purging.
- Dedicated sampling equipment can be installed in each well, eliminating the need for decontamination and minimizing sampling set-up time.
- In theory, sampling using this method would result in ascertaining average concentrations over a large screened interval in a single sample, whereas other methods would result in ascertaining concentrations across discreet depth intervals.
- No opportunity for sample degradation due to potential stagnation of groundwater in well. By purging large volumes of groundwater from a well, one can be confident that sample collected will be from the aquifer formation rather than from the well casing or filter pack.

Noted disadvantages of conventional purging included:

- Long set-up time required.
- Generation of relatively large volumes of IDW.
- Inability to evaluate vertical differences in groundwater chemistry within the same well.
- Not suitable for the collection of all natural attenuation parameters (i.e., dissolved hydrogen).
- Potential to generate highly turbid samples.
- Significant drawdown common with this method may result in poor representation of formation water due to vertical mixing.

- For wells completed in low-permeability aquifers, this method frequently will result in pumping a well dry before sufficient sample volume is collected. In some instances, it may take several hours to days for the well to recharge sufficient groundwater for sample collection.

- With the drawdown that is common with this method, an increased likelihood of volatilization exists due to cascading of groundwater downward through the well filter pack or the well casing.

- Decontamination is necessary if non-dedicated equipment is used, creating a potential for cross-contamination among wells and samples if decontamination procedures are not adequate. Also, decontamination adds sampling labor time, and increases the volume of IDW generated.

4.2.3.4 Micropurge Sampling

Of the four sampling methods evaluated, the micropurge method received the lowest ratings from field sampling personnel. Advantages associated with this method include:

- Ability to collect samples from discrete depth intervals within an aquifer.

- Ability to collect samples for analysis of chemicals other than VOCs.

- Ability to use in cases where rapid assessment of groundwater conditions in required as well as for periodic monitoring.

- Dedicated sampling equipment can be installed in each well eliminating the need for decontamination and minimizing sampling set-up time.

- Ability to monitor all natural attenuation parameters, including dissolved hydrogen.

- Research has indicated that purging at a low flow rate produces lower turbidity and generally higher quality groundwater samples (Puls *et al.*, 1992).

Deficiencies noted for the micropurging method included:

- Micropurging was the most time-consuming method evaluated in this study.

- Although micropurging removes a much smaller volume of purge water than conventional purging, this method still produces more IDW than is generated during use of diffusion samplers.

- Decontamination is necessary if non-dedicated equipment is used, creating a potential for cross-contamination between wells/samples if decontamination procedures are not adequate. Also, decontamination adds labor time and increases IDW.

- Because micropurging relies on minimizing drawdown, a low-flow pump is required. Peristaltic pumps are inadequate for sampling at depths greater than approximately 25 feet bgs. Bladder-type pumps are the preferred pump for micropurging. However, bladder pumps are typically dedicated to a particular well

and no bladder pumps were installed in the wells evaluated in this sampling program. Alternately, a Grundfos Redi-Flo2 pump was used. Using the Grundfos pump for micropurging requires experienced field technicians to regulate the flow rate to minimize drawdown, and therefore vertical mixing of the groundwater. This noted disadvantage is specific to the pump used and not the method.

SECTION 5

CONCLUSIONS

5.1 TECHNOLOGY PERFORMANCE

Each of the four sampling methods was rated in each of the comparison categories described in Section 4.2. Results of this rating are presented in Table 5.1. As the different sampling methods were all considered to be comparable from a data accuracy perspective (see Section 4.2.2), the criteria used to evaluate the four methods were cost and other method-specific criteria (Sections 4.2.2 and 4.2.3). In order to rate method-specific variables, each sampling method was ranked according to four criteria: ease of use, generation of IDW, vertical definition of contamination, and usefulness for natural attenuation monitoring. The results of these rankings were averaged for an overall method-specific ranking. Finally, the rankings obtained for cost per sample and the other method-specific criteria described above were averaged to determine an overall ranking. Results of this rating evaluation are discussed below.

The USGS diffusion sampler method was rated highest of the four methods based on cost, other method-specific criteria, and overall performance (Table 5.1). The micropurge sampling method ranked second in cost and third in other method-specific criteria, such that it was rated second in overall performance. The DMLS™ diffusion sampler was the most expensive of the four methods evaluated, and ranked second in other method-specific criteria, giving it the third ranking in overall performance. Finally, the conventional purge method was ranked third in cost and fourth in other method-specific criteria, such that it was ranked lowest in overall performance.

5.2 LESSONS LEARNED

The following items summarize the lessons learned during this evaluation:

- The USGS diffusion sampler is approximately one-fifth as expensive per sample to implement as the next lowest cost method (micropurging), and nearly one-tenth as expensive as the DMLS™ diffusion sampling. Additionally, it is significantly easier to use than the other methods evaluated.

- The DMLS™ diffusion sampler, although very expensive on a per sample basis for this evaluation, is heavily weighted toward one-time costs. Approximately 75 percent of the total cost of this method represents re-usable equipment (Table 4.4). This suggests that large-scale monitoring programs would result in significantly lower per-sample costs, as reuse of equipment will distribute one-time costs over several sampling events.

TABLE 5.1
METHOD PERFORMANCE RANKING
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

EVALUATION CRITERIA	RANKING FOR EACH METHOD			
	USGS Diffusion Sampler	**Micropurge Sampling**	**DMLS™ Diffusion Sampler**	**Conventional Purge Sampling**
COST PER SAMPLE	1	2	4	3
ACCURACY OF METHOD[a/]	Accuracy acceptable for all methods[a/], no ranking applied			
OTHER METHOD-SPECIFIC CRITERIA[b/]	1.5	2.75	1.75	3.25
-Ease of use	*1*	*4*	*2*	*3*
-Generation of IDW	*1 (tie)*	*3*	*1 (tie)*	*4*
-Verticle definition of contaminants	*1 (tie)*	*3*	*1 (tie)*	*4*
-Natural attenuation monitoring	*3 (tie)*	*1*	*3 (tie)*	*2*
OVERALL PERFORMANCE	**1.25**	**2.375**	**2.875**	**3.125**

[a/] The accuracy of each method is deemed to be acceptable based on the statistical analysis described in Section 4.2.2. However, the available data population is small, and therefore a more rigorous statistical analysis on a larger sample population is recommended.

[b/] Ranking of other method-specific criteria represents average ranking of the four subcategories listed.

- Both diffusion sampling methods evaluated pose difficulties for collecting environmental data needed for natural attenuation studies.

- The DMLS™ sampler would benefit from a redesign of the 38-mL dialysis cells, which provide inadequate sample volume for typical environmental sampling.

- Although occasional variances were observed in the analytical data obtained using the different methods (Table 4.2), the results were determined to be comparable for all four sampling methods.

SECTION 6

RECOMMENDATIONS

The Air Force groundwater diffusion sampler evaluation has demonstrated that diffusive sampling technology can be a cost-effective and accurate method for environmental groundwater monitoring. Of the diffusion sampling technologies evaluated, the USGS sampler is the recommended device based on the evaluation criteria presented herein. Additional comparisons between the different sampling technologies should be performed allowing for a more robust data set from which to make analytical result comparisons. Particularly, varying hydrogeologic settings (e.g. low-permeability to high-permeability aquifers), and increasing the number of wells in the evaluation would allow for a more thorough evaluation of the comparability of the analytical data.

If natural attenuation monitoring is required, the following option should be considered. Frequently, if natural attenuation monitoring is required, it is required at a lower frequency than VOC monitoring (e.g. annually as opposed to quarterly). In this case, annual monitoring of natural attenuation parameters can occur using a traditional sampling method, while quarterly monitoring of VOCs can be accomplished using diffusion sampling technology.

SECTION 7

REFERENCES

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APPENDIX A

DOCUMENTATION AND ILLUSTRATIONS OF DIFFUSION SAMPLING DEVICES

Documentation and Illustrations available upon request from:

Parsons Engineering Science Inc
c/o Pete Guest
1700 Broadway, Suite 900
Denver, CO 80290

APPENDIX B

FIELD NOTES AND SAMPLE COLLECTION FORMS

Field Notes and Sample Collection Forms available upon request from:

Parsons Engineering Science Inc
c/o Pete Guest
1700 Broadway, Suite 900
Denver, CO 80290

APPENDIX C

ANALYTICAL RESULTS

Analytical results available upon request from:

Parsons Engineering Science Inc
c/o Pete Guest
1700 Broadway, Suite 900
Denver, CO 80290

APPENDIX D

ANOVA TESTING

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

TRICHLOROETHENE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	8	24	29	8	21
MW11-103'	23	24	29	9.6	21
MW11-105'	23	24	29	10	21
MW241-116'	3.8	27	41	32	32
MW241-124'	34	32	41	33	32
MW241-132'	40	32	41	27	32
MW242-121.5'	6	3.5	4	5.3	3.1
MW242-127.5'	3.5	2.6	4	3.6	3.1
MW242-133.5'	3.4	2.8	4	3.3	3.1

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9.00	144.70	16.08	203.22
Column 2	9.00	171.90	19.10	156.07
Column 3	9.00	222.00	24.67	267.25
Column 4	9.00	131.80	14.64	152.50
Column 5	9.00	168.30	18.70	159.58

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	531.59	4.00	132.90	0.71	0.59	2.61
Within Groups	7508.94	40.00	187.72			
Total	8040.53	44.00				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

trans-1,2-DICHLOROETHENE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	0.00	0.00	0.00	0.00	0.00
MW11-103'	0.00	0.00	0.00	0.00	0.00
MW11-105'	0.00	0.00	0.00	0.00	0.00
MW241-116'	0.00	0.96	1.00	1.40	0.99
MW241-124'	1.20	0.90	1.00	1.10	0.99
MW241-132'	1.00	0.98	1.00	0.77	0.99
MW242-121.5'	0.00	0.00	0.00	0.00	0.00
MW242-127.5'	0.00	0.00	0.00	0.00	0.00
MW242-133.5'	0.00	0.00	0.00	0.00	0.00

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9.00	2.20	0.24	0.24
Column 2	9.00	2.84	0.32	0.22
Column 3	9.00	3.00	0.33	0.25
Column 4	9.00	3.27	0.36	0.32
Column 5	9.00	2.97	0.33	0.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.07	4.00	0.02	0.07	0.99	2.61
Within Groups	10.23	40.00	0.26			
Total	10.30	44.00				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

cis-1,2-DICHLOROETHENE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	0.95	3.4	3.8	1.1	3.3
MW11-103'	2.3	3.4	3.8	1.4	3.3
MW11-105'	2.2	3.4	3.8	1.4	3.3
MW241-116'	0.63	7.2	7.2	11	6.8
MW241-124'	9.2	6.7	7.2	8.1	6.8
MW241-132'	7.5	6.5	7.2	6	6.8
MW242-121.5'	0	0	0	0	0
MW242-127.5'	0	0	0	0	0
MW242-133.5'	0	0	0	0	0

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	22.78	2.53111	11.83259
Column 2	9	30.6	3.4	8.7025
Column 3	9	33	3.66667	9.73
Column 4	9	29	3.22222	16.78694
Column 5	9	30.3	3.36667	8.6725

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.53844	4	1.63461	0.146669	0.96342	2.606
Within Groups	445.796	40	11.1449			
Total	452.335	44				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

1,1-DICHLOROETHENE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	34	170	220	58	170
MW11-103'	88	170	220	74	170
MW11-105'	89	170	220	77	170
MW241-116'	2.1	17	23	20	18
MW241-124'	20	19	23	21	18
MW241-132'	22	15	23	19	18
MW242-121.5'	9	6.3	5.4	10	3.1
MW242-127.5'	4.5	3.8	5.4	6.5	3.1
MW242-133.5'	4.4	4	5.4	5.2	3.1

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	273	30.3333	1193.628
Column 2	9	575.1	63.9	6362.03
Column 3	9	745.2	82.8	10646.49
Column 4	9	290.7	32.3	843.835
Column 5	9	573.3	63.7	6397.703

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18456.3	4	4614.08	0.906723	0.46928	2.606
Within Groups	203549	40	5088.74			
Total	222006	44				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

1,1-DICHLOROETHANE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	0.66	1.6	1.7	0.54	1.5
MW11-103'	1.6	1.6	1.7	0.67	1.5
MW11-105'	1.6	1.6	1.7	0.69	1.5
MW241-116'	0.36	3.5	3.6	4.3	3.4
MW241-124'	4.4	3.6	3.6	3.6	3.4
MW241-132'	4.2	3.6	3.6	2.9	3.4
MW242-121.5'	0	0	0	0.22	0
MW242-127.5'	0	0	0	0	0
MW242-133.5'	0	0	0	0	0

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	12.82	1.42444	3.052978
Column 2	9	15.5	1.72222	2.394444
Column 3	9	15.9	1.76667	2.4325
Column 4	9	12.92	1.43556	2.822203
Column 5	9	14.7	1.63333	2.1775

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.91463	4	0.22866	0.088767	0.98545	2.606
Within Groups	103.037	40	2.57593			
Total	103.952	44				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

1,1,2-TRICHLOROETHANE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	0.58	1.3	1.6	0.47	1.5
MW11-103'	1.6	1.3	1.6	0.64	1.5
MW11-105'	1.4	1.3	1.6	0.68	1.5
MW241-116'	0	0.23	0.32	0.24	0.27
MW241-124'	0.32	0.27	0.32	0.27	0.27
MW241-132'	0	0.28	0.32	0.22	0.27
MW242-121.5'	0	0	0	0	0
MW242-127.5'	0	0	0	0	0
MW242-133.5'	0	0	0	0	0

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	3.9	0.43333	0.4086
Column 2	9	4.68	0.52	0.355075
Column 3	9	5.76	0.64	0.5376
Column 4	9	2.52	0.28	0.070775
Column 5	9	5.31	0.59	0.479475

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.72608	4	0.18152	0.490191	0.74288	2.606
Within Groups	14.8122	40	0.37031			
Total	15.5383	44				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.

Appendix D
ANOVA TEST
DIFFUSION SAMPLING AND ANALYSIS REPORT
McCLELLAN AIR FORCE BASE, CALIFORNIA

1,2-DICHLOROETHANE (concentrations in micrograms per liter)

	Second Mobilization			Third Mobilization	
Sampling Location	USGS	Micropurge	Conventional	DMLS	Conventional
MW11-101'	0.95	2.2	2	0.74	1.9
MW11-103'	2.1	2.2	2	0.83	1.9
MW11-105'	2.2	2.2	2	0.81	1.9
MW241-116'	1.8	14	15	15	15
MW241-124'	16	16	15	14	15
MW241-132'	16	15	15	12	15
MW242-121.5'	0.43	0.98	5.3	0.91	3.6
MW242-127.5'	1.6	2	5.3	0.78	3.6
MW242-133.5'	1.6	3.5	5.3	1.4	3.6

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	42.68	4.74222	41.03742
Column 2	9	58.08	6.45333	41.7401
Column 3	9	66.9	7.43333	34.2475
Column 4	9	46.47	5.16333	41.29363
Column 5	9	61.5	6.83333	38.0575

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	46.4234	4	11.6058	0.2955	0.87916	2.606
Within Groups	1571.01	40	39.2752			
Total	1617.43	44				

Note: In instances where a non-detectable concentration of an analyte was reported for a sample, a value of zero was assigned for the purposes of the ANOVA analysis only. Additionally, for the conventional purging, each of the three depth intervals evaluated was assigned the same analytical value reported for the one sample collected from that well.