FINAL REPORT

Methods for Minimization and Management of Variability in Long-Term Groundwater Monitoring Results

ESTCP Project ER-201209

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High variability in groundwater monitoring results makes it difficult to accurately evaluate remedy effectiveness and to predict remediation timeframes. In order to determine the effect of sample collection method on monitoring variability, five methods for collecting groundwater samples from monitoring wells were compared at two sites in Texas and California with chlorinated VOC plumes. The five sample collection methods evaluated included three variations of low-flow purge sampling: low-flow with purge to parameter stability ("Low-Flow Standard"), low-flow with fixed small volume purge (3 Liters), and low- flow with fixed large volume purge (18 Liters), and two no purge methods using commercial devices: Active No Purge (HydraSleeve) and Passive No Purge (SNAP samplers). Eight monitoring wells were sampled at each site six times using each sampling method at approximately two month intervals, resulting in a total of 480 groundwater samples. For the dataset as a whole, the five sample methods yielded relatively small differences in VOC concentration (<+/-20%), and with the exception of the Active No Purge (HydraSleeve) method at the California site, only small differences in variability between sample events. For the purge methods tested, results indicate that low flow purge sampling using a fixed purge volume provides results of equal quality compared to

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ACRONYMS

1,1-DCE	1,1-dichloroethene
1,2-DCA	1,2-dichloroethane
bgs	Below ground surface
cis-1,2-DCE	cis-1,2-dichloroethylene
COC	Chemical of concern
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
ft	Foot, feet
LTM	Long term monitoring
NELAC	National Environmental Laboratory Accreditation Conference
PCE	Tetrachloroethylene
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RPD	Relative percent difference
RV	Recreational vehicle
SOP	Standard Operating Procedure
TCE	Trichloroethylene
trans-1,2-DCE	trans-1,2-dichloroethylene
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound
VC	Vinyl chloride

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EXECUTIVE SUMMARY

ABSTRACT

We compared five methods for collecting groundwater samples from monitoring wells in order to evaluate their impact on VOC concentration and variability in monitoring results.

What We Learned

1. The sample method (except Active No Purge) has only a modest impact on monitoring variability and concentration.

2. As a result, monitoring well sampling methods should be selected based on factors such as cost, ease of implementation, and sample volume requirements rather than concerns regarding data quality.

3. Figure A.1 shows results of a semi-quantitative analysis based on field program results depicting sampling methods. Results are based on a ranking system of 1-5 (with 1 being best), evaluated on the basis of variability and cost only. Other factors such as sample volume requirements and regulatory factors should also be taken into consideration when selecting a sample method.

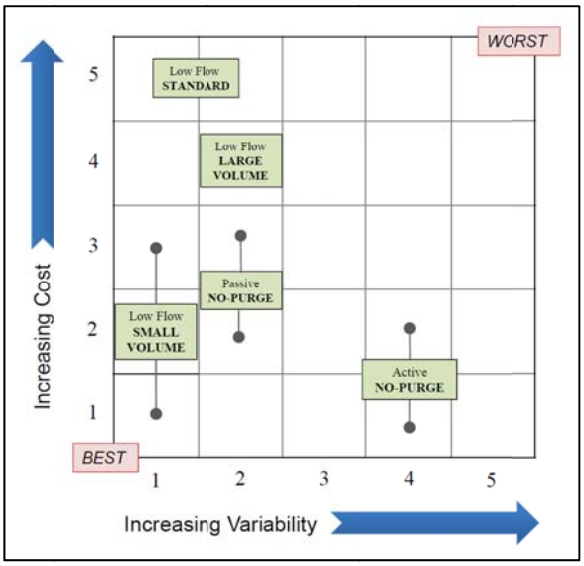


Figure A.1. Semi-Quantitative Analysis of Sampling Methods. *Gray dots indicate range of costs for shallow and deep wells. For a description of the five methods see Figure E.1)*

Key Things to Watch Out For

4. Monitoring purge to parameter stability increases the cost and complexity of sample collection without providing any clear benefits in terms of data quality.

Key Conclusions

5. At both sites, Low Flow Standard (purging to parameter stability) and Low Flow Alternative (Small Volume) showed the lowest variability. The results were consistent between the two sites except for the Active No Purge (HydraSleeve) method which was more variable at the California site than the Texas site.

6. Although Low Flow Alternative (Large Volume) and Passive No Purge (SNAP Samplers) yielded slightly more variable groundwater monitoring results than Low Flow Standard, this increase in variability would have little impact on the number of events needed to characterize the long-term concentration trend. However, the increased variability with the Active No Purge method would increase the number of sampling events required to characterize long-term concentration trend in the well.

7. Although statistically-significant differences in concentration were observed between methods, the average bias was small. This finding is consistent with a number of previous studies on the effect of sample method on contaminant concentration, although some prior studies have suggested a low bias for the Active No Purge method.

E.1 BACKGROUND AND INTRODUCTION

The National Research Council has estimated that annual monitoring costs over $100,000,000 at DoD (Department of Defense) facilities across the country (NRC, 2013). This cost includes on-going monitoring of roughly 40,000 groundwater monitoring wells. A primary purpose of this monitoring is to determine the long-term reduction in contaminant concentrations due to natural attenuation or active remediation. However, short-term variability in contaminant concentrations limits our ability to accurately quantify contaminant attenuation rates, increasing our monitoring costs and limiting our ability to make appropriate site management decisions. The purpose of this project was to: i) validate sample collection methods and procedures that minimize variability in groundwater monitoring results, and ii) validate improved methods to optimize monitoring frequency and assess long-term concentration trends that better account for short-term variability in groundwater monitoring results. The specific goals of the project are as follows:

1. Task 1: Validate the use of alternative field sampling procedures for the collection of groundwater samples in order to minimize variability in groundwater monitoring results.
2. Task 2: Develop and validate an improved method to optimize monitoring frequency based on a site-specific evaluation of the short-term variability and long-term attenuation rate.
3. Task 3: Develop and validate an improved method to identify long-term concentration trends that better account for the potentially confounding effects of short-term variability.

Note that the field program, while very intensive compared to routine groundwater monitoring program, was only conducted at two sites. It is possible that other sites could have different responses to the field sampling procedures relative to these two sites.

E.2 EFFECT OF ALTERNATIVE SAMPLING METHODS ON MONITORING VARIABILITY

The overall objective of the Task 1 demonstration was to validate sample collection procedures that minimize variability in groundwater monitoring results. The demonstration provided a direct comparison of the short-term variability associated with three commonly used sampling methods: i) Low-flow purge, ii) SNAP Sampler (Passive No Purge), and iii) HydraSleeve (Active No Purge) (see Figure E.1).

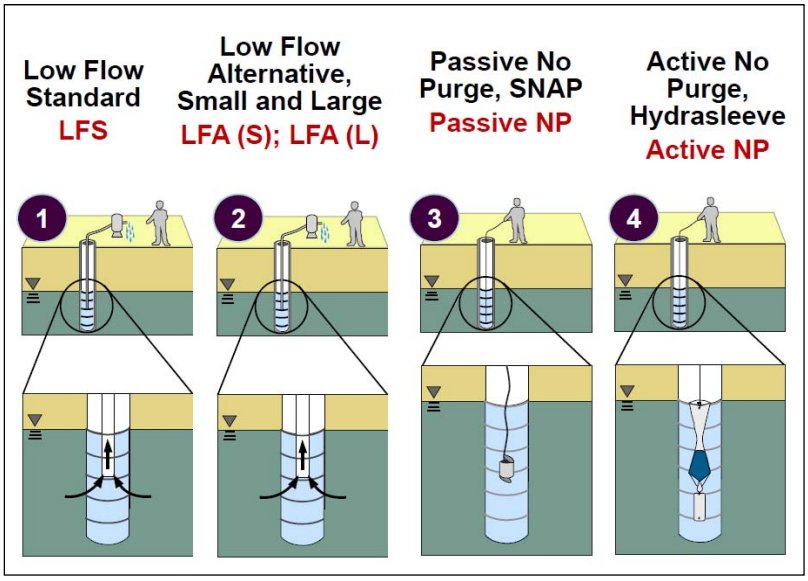


Figure E.1. Sampling Methods Implemented in Demonstration at Two Sites. LFS (purging to parameter stability) is the conventional method used today. LFA is purging a constant volume every time (Small=3 Liters; Large=18 Liters). Passive NP is the SNAP sampler, Active NP is the HydraSleeve.

The objective of the field demonstration was met by:

1) Appling four alternative sampling methods (including two variations of low-flow purge, for a total of five methods) to eight monitoring wells at each of two demonstration sites,
2) Appling low-flow purge to parameter stability using standard procedures as the reference sampling method for each monitoring well,
3) Conducting six rounds of sampling using each sampling method, and
4) Comparing the short-term variability associated with each sampling method.

E.2.1 Field Demonstration Program

We used a field demonstration to determine whether alternative groundwater sampling methods would reduce the short-term variability in groundwater monitoring results. We evaluated five sampling methods (Figure E.1).

The field demonstration was conducted at eight monitoring wells at each of two demonstration sites; one in Texas and one in California. Each sampling method was used six times (Table E.1), with a total of 96 samples per method, 480 total groundwater samples for the demonstration program from both sites.

Table E.1. Field Testing Schedule

Sampling Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Program Week	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
Sample Method/Procedure																								
1) Low-Flow Standard	X				X				X				X				X				X			
2) Low-Flow Alternative Procedure (Small and Large Volumes)		X				X				X				X				X				X		
3) Passive No-Purge (SNAP)			X				X				X				X				X				X	
4) Active No-Purge (HydraSleeve)				X				X				X				X				X				X

Four chemicals were consistently detected in the samples from the Texas site while ten chemicals were consistently detected in the wells from the California site. As a result, the full data set consisted of 3,262 individual concentration measurements.

E.2.2 Field Demonstration Results

The resulting dataset was used to evaluate the effect of sample method on short-term variability in the monitoring results and statistical bias (i.e., difference in concentration between methods).

Effect of Sample Method on Variability: The effect on monitoring variability was evaluated by comparing the consistency in concentration results across the six sample events for each sample method (after correcting for any overall concentration trend over the duration of the field program). At both sites, Low Flow Standard and Low Flow Alternative (Small Volume) showed the lowest variability (Figure E.2). The results were consistent between the two sites except for the Active No Purge (HydraSleeve) method which was more variable at the California site than the Texas site.

> ***Goal:***
> Identify the sample method with *lowest* short-term variability.

California Site **Texas Site**

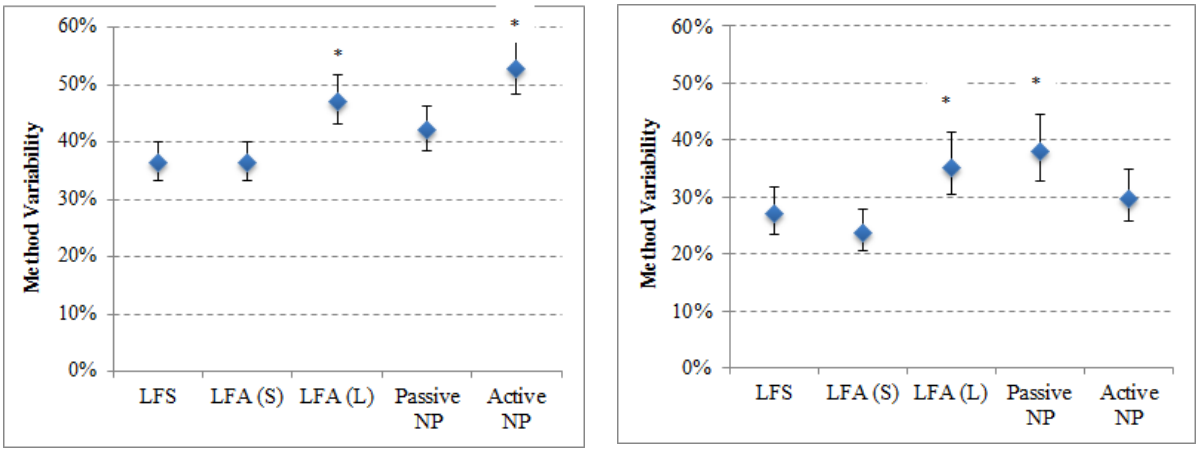


Figure E.2. Short-Term Variability by Sample Method: Results for Individual Sites. The graphs show the standard deviation of the normalized residuals (short-term variability factors) for each sample

method. The error bars show the 95% confidence interval for the standard deviation. * = method variability is significantly higher than Low Flow Standard ($p<0.05$). LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

Although Low Flow Alternative (Large Volume) and Passive No Purge (SNAP Samplers) yielded slightly more variable groundwater monitoring results, this increase in variability would have little impact on the ability to characterize the long-term concentration trend (Table E.2). The variability associated with the Active No Purge (HydraSleeve) method does increase the amount of monitoring required to characterize the long-term trend (by 39%) because the Active No Purge (HydraSleeve) method generated more outliers (i.e., concentration measurements that were very different from the average concentration). The SERDP study ER-1705 also found that the Active No Purge (HydraSleeve) method yielded results that were more variable than those obtained using the Low Flow Standard method.

Table E.2. Effect of Sample Method on Amount of Monitoring Required to Characterize the Long-Term Concentration Trend.

Sampling Method	Short-Term Variability[1]	Quarterly Monitoring Events[2]	Increase Relative to Low Flow Std.[3]
Low Flow Std.	0.45	28	--
Low Flow Alternative Small Vol.	0.47	28	0%
Low Flow Alternative Large Vol.	0.50	30	7%
Passive No Purge (SNAP)	0.52	30	7%
Active No Purge (HydraSleeve)	0.81	39	39%

Notes:

1) Short-term variability factor for Tier 2 Optimization tool built as part of Task 2 of this study, and calculated as the standard deviation of the natural log of the residuals for each monitoring record.
2) Number of quarterly monitoring events required to characterize a long-term concentration trend with medium accuracy for a monitoring well with a true attenuation rate of 0.14 yr^{-1} (half-life of five years) and a short-term variability factor equal to that measured for the specific sampling method.
3) Percent increase in number of monitoring events (relative to Low Flow Std.) required to characterize the long-term concentration trend with the same level of accuracy.

Effect of Sample Method on Concentration: The effect of sample method on the measured contaminant concentration was evaluated by comparing each individual concentration measurement to the average concentration for that chemical in that well (after correcting for temporal trends). Although statistically-significant differences in concentration were observed between methods, the average bias was small (i.e., +/-20%, Figure E.3). This finding is consistent with previous studies of the effect of sample method on contaminant concentration.

Statistical Bias:
If the same method consistently yields concentration results above the trend line for the full data set, then that method is showing high statistical bias relative to the full data set (i.e., the method yields a higher measured concentration compared to other sample methods).

California Site **Texas Site**

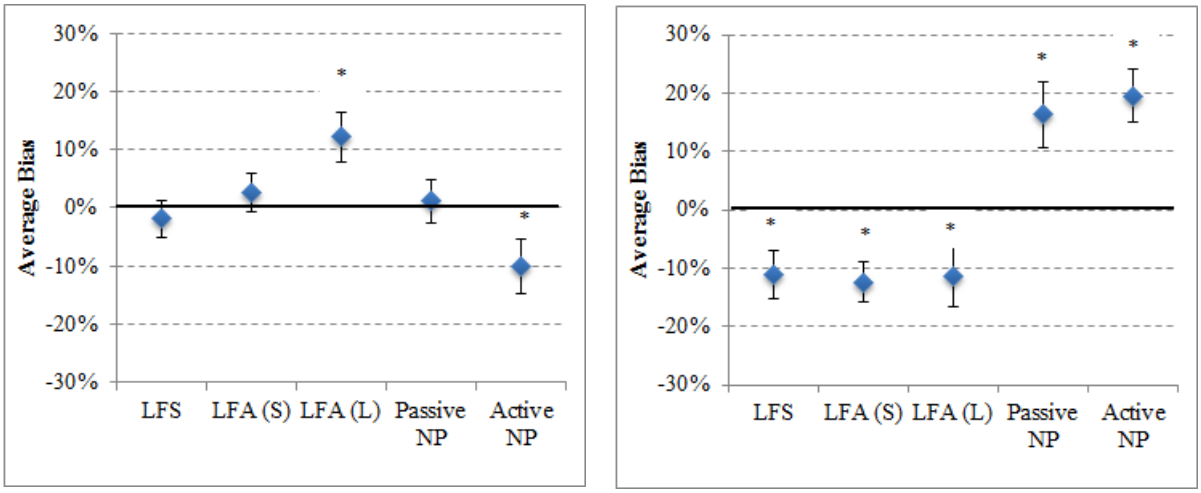


Figure E.3. Statistical Bias in Contaminant Concentration by Sample Method: Results for Individual Sites. The graphs show the average of the normalized residuals (i.e., average statistical bias) for each sample method with the horizontal line at 0% representing no bias relative to the average of all five sampling methods. Positive values indicate higher concentrations and negative values indicated lower concentrations than average. The error bars show the 95% confidence interval for normalized residual. * = method bias is significantly different from zero ($p<0.05$). LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

E.2.3 Cost Evaluation

Incurred costs from the field demonstration program by GSI were used to estimate field program costs at a typical site in which each sample method will exclusively be used. Total monitoring program costs are estimated, as seen in Figure E.4 below and represent total costs for a 10 year semi-annual monitoring program at a site consisting of 15 monitoring wells.

The following represents the total cost from least to most expensive for <u>shallow wells</u>:

i) Low Flow Alternative (Small Volume)
ii) Active No Purge (HydraSleeve)
iii) Passive No Purge (SNAP)
iv) Low Flow Alternative (Large Volume)
v) Low Flow Standard

Additionally, the total cost from least to most expensive for <u>deep wells</u> is as follows:

i) Active No Purge (HydraSleeve)
ii) Passive No Purge (SNAP)
iii) Low Flow Alternative (Small Volume)
iv) Low Flow Alternative (Large Volume)
v) Low Flow Standard

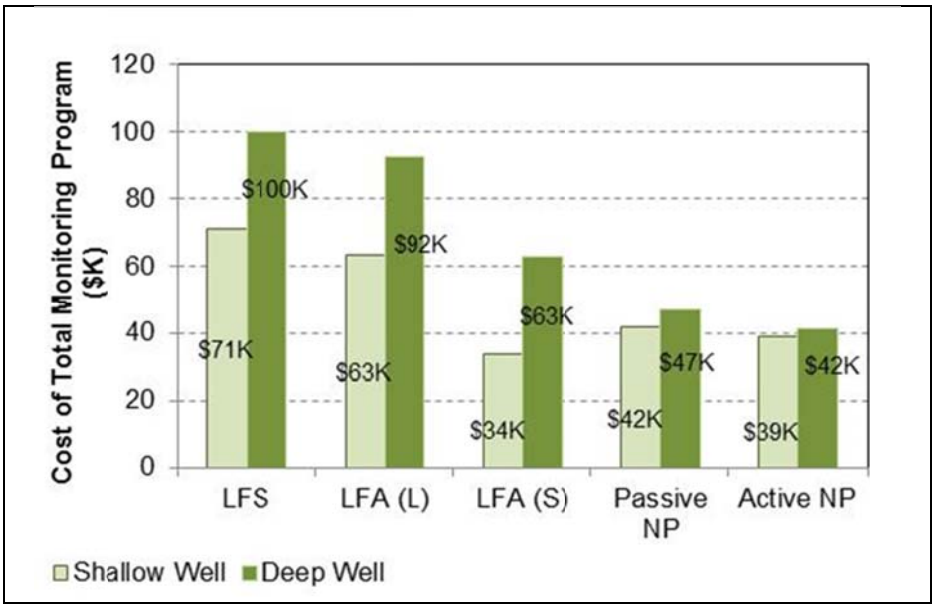


Figure E.4. Cost of Total Monitoring Program (10 years, semi-annual sampling, 15wells, in $K) for Shallow (lighter shade) and Deep (darker shade) Wells. LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

E.2.4 Overall Findings

Our hypothesis was that the alternative sampling methods would decrease short-term variability in groundwater monitoring results. However, the alternative sampling methods (except Active No Purge) yielded monitoring results with similar or slightly higher monitoring variability. At the California site, the Active No Purge method yielded monitoring results with a greater number of outliers (i.e., results that were far off from the average concentration in the well). The comparison of sampling methods supports the following overall conclusions.

Effect of Sample Method on Monitoring Results: The sample method has only a modest impact of monitoring variability and concentration. The difference in concentration between sample methods was small (i.e., less than +/- 20%). With the exception of the Active No Purge method, the differences in monitoring variability between the methods would have little impact on the ability to characterize the long-term concentration trend. As a result, **monitoring well sampling methods should be selected based on factors such as cost and ease of implementation rather than concerns regarding data quality.** For Active No Purge, site-specific multiple-event validation may be warranted to ensure that the sample method does not adversely impact data variability. We used specific sample methods to represent general categories of sample collection methods; we would expect the project results to be applicable to other sample methods within these categories. For example, we would expect the project findings obtained using the SNAP sampler to be comparable to other Passive No Purge methods such as a passive diffusion bag sampler.

Utility of Monitoring Purge Parameters: There were no clear differences in data quality (i.e., concentration and variability) between samples collected using Low Flow Standard (i.e., purge to parameter stability) and the two alternative fixed volume purge methods (i.e., 3L purge and 18L

purge). **The results from this study suggest that monitoring purge parameter stability does not provide any clear benefits in terms of data quality. However, monitoring purge parameter stability increases the cost and complexity of sample collection.**

Conceptual Model for Short-Term Variability: The results from this project and prior SERDP projects on variability in groundwater monitoring results support a conceptual model that short-term variability is mostly attributable to temporal variability in contaminant concentrations entering the monitoring well. This temporal variability can also be thought of as small scale spatial variability in contaminant concentrations within the contaminant plume (see Figure E.5).

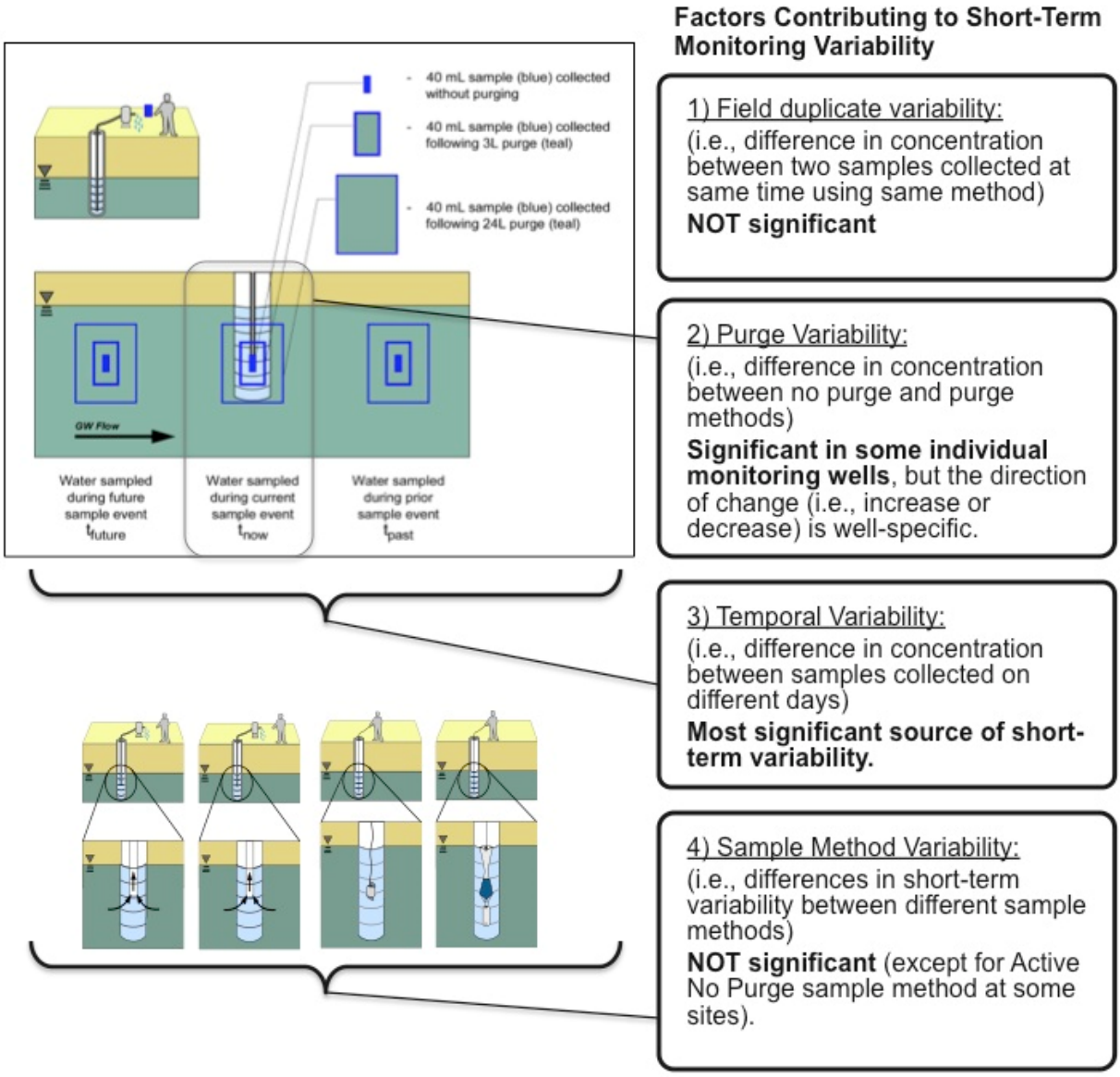


Figure E.5. Conceptual Model for Short-Term Variability in Groundwater Monitoring Results

E.3 IMPROVED METHOD FOR OPTIMIZATION OF MONITORING FREQUENCY

The primary goal of Task 2 was to develop a new method to optimize monitoring frequency based on an understanding of the short-term variability and long-term attenuation rate at a particular site (McHugh et al., 2015a). The optimization method is designed to help a project manager answer two questions:

Question 1: *How much monitoring data do I need to determine a site's long-term source attenuation rate with a defined level of accuracy or confidence?*

Question 2: *What are the trade-offs between monitoring frequency (e.g., quarterly, semi-annually, or annually) vs. the time required for trend identification (the number of years until you get the answer to Question 1)?*

These two questions are not directly addressed by currently available monitoring frequency optimization methods.

The optimization method has been implemented in Excel spreadsheet form. This new optimization method can be used to select an appropriate monitoring frequency as follows:

1. Select the primary goal of long-term monitoring: This optimization method is appropriate when the long-term monitoring data will be used to either:
   i) demonstrate that constituent concentrations are decreasing: the method will determine the amount of monitoring needed to determine the direction of the long-term trend (i.e., increasing or decreasing) with a defined level of confidence; OR

   ii) determine how fast concentrations are decreasing or when concentrations will decrease to a clean-up goal: the method will determine the amount of data needed to estimate the long-term attenuation rate with a defined level of accuracy. The attenuation rate can be used to estimate when concentrations will decrease to a clean-up goal.

2. Identify the timeframe in which the monitoring goal should be met. In other words, how quickly does the demonstration of decreasing concentrations or time to clean-up need to be made?

3. Based on the monitoring goal and the decision timeframe, use the Excel spreadsheet tool to determine the appropriate monitoring frequency.

In order to evaluate typical results, the optimization method has been applied to twenty contaminated groundwater sites: nine benzene sites, eight PCE/TCE sites, and three arsenic sites. For each site, we answered Questions 1 and 2 from above.

Question 1: How much monitoring data do I need to determine a site's long-term source attenuation rate with a defined level of accuracy or confidence (Table E.3)?

Table E.3: Monitoring Data Required to Determine the Long-Term Attenuation Rate

Accuracy/Confidence Goal	Years of Quarterly Monitoring Required		
	Best Site	**Median Site**	**Worst Site**
Medium Confidence: Statistically-significant decreasing concentration trend ($p<0.1$) for 80% of monitoring wells	2.8 years	7.3 years	30 years
Medium Accuracy: Determine the long-term attenuation rate with an accuracy (i.e., 95% confidence interval) of +/- 50% or +/- 0.1 yr^{-1} (whichever is larger) for 80% of monitoring wells.	4 years	7.4 years	14.5 years

Based on application of the Optimization Tool at twenty sites, key findings are:

- It is important for project managers to recognize that apparent trends characterized using too little data can be misleading and may result in inappropriate management decisions.
- When evaluating natural attenuation, there are often situations where the project manager can be confident that contaminant concentrations are decreasing but highly uncertain as to when numerical clean-up goals will be attained.
- For sites with slow attenuation rates, it may be difficult to prove with statistical confidence that contaminant concentrations are decreasing.

Question 2: What are the trade-offs between monitoring frequency (e.g., quarterly, semi-annually, or annually) vs. the time required for trend identification (the number of years until you get the answer to Question 1).

For Question 2, the answer is the same for all sites. Although the time required to characterize the long-term attenuation rate depends on both the short-term variability and the attenuation rate, the trade-off between monitoring frequency and monitoring time is independent of these parameters (McHugh et al., 2015c). The relative trade-off between monitoring frequency and time required to characterize the long-term trend is summarized in Table E.4.

Table E.4 Trade Off Between Monitoring Frequency and Monitoring Time

Monitoring Frequency	Relative Time Required to Characterize Long-Term Trend	Relative Cost to Characterize Long-Term Trend	Relative Value of One Monitoring Event
Weekly	0.40	5.3	0.19
Monthly	0.67	2.0	0.50
Quarterly	**1**	**1**	**1**
Semi-Annual	1.25	0.63	1.6
Annual	1.56	0.39	2.6
Every 2 Yrs	1.95	0.24	4.1
Every 5 Yrs	2.85	0.15	6.7

Note: Relative cost is the same as the relative total number of monitoring events required (i.e., based on the assumption that cost is proportional to number of monitoring events). See Appendix B for derivation of these relationships.

For example, a site that required four years of quarterly monitoring to characterize the long-term attenuation rate would require five years (= 4 x 1.25) of semiannual monitoring to characterize the long-term trend with the same level of accuracy. Four years of quarterly monitoring is 16 total monitoring events while five years of semiannual monitoring is ten total monitoring events. Therefore, the relative cost of the annual monitoring program would be 60% (10/16) of the cost of the quarterly monitoring program (Table E.5). **A project manager can use the trade-off between monitoring frequency and monitoring time to select an optimal monitoring frequency.**

Table E.5 Example of Site With Trade Off Between Monitoring Frequency and Monitoring Time

Monitoring Frequency	Relative Time Required to Characterize Long-Term Trend (Years)	Relative Cost to Characterize Long-Term Trend	Relative Value of One Monitoring Event
Weekly	1.6	5.3	0.19
Monthly	2.7	2.0	0.50
Quarterly	**4.0**	**1**	**1**
Semi-Annual	5.0	0.63	1.6
Annual	6.2	0.39	2.6
Every 2 Yrs	7.8	0.24	4.1
Every 5 Yrs	11.4	0.15	6.7

The full discussion of this optimization method is covered in a separate report (McHugh et al., 2015a):

A New Method to Optimize Monitoring Frequency and Evaluate Long Term Concentration Trends

This report and the Monitoring Optimization and Trend Analysis Toolkit Excel-based tool and User's Guide can be found on the ESTCP web site under ER-201209.

E.4 IMPROVED METHOD FOR EVALUATION OF LONG-TERM MONITORING TRENDS

The objective of Task 3 was to develop and validate an improved method to distinguish between random variability in observed attenuation rates and true spatial differences in remedy performance. This method uses information regarding short-term monitoring variability and the long-term contaminant attenuation rate to answer these questions:

Question 1: When will this site meet the groundwater clean-up goal (i.e., What is the long-term attenuation rate for the key contaminant at my site)?

Question 2: Do any individual wells appear to be attenuating more slowly than the source as a whole?

This project developed tools that can be used by site managers to answer these questions. In particular, the specific project objectives were to:

1) *Develop* a method to distinguish between random variations in attenuation rates and true spatial differences in remedy performance; and
2) *Create* a simple spreadsheet tool that will help site managers implement this remedy performance evaluation method and incorporate the method into comprehensive Long-Term Monitoring Optimization (LTMO) packages at DoD sites around the country.

The monitoring data evaluation method has been implemented in Excel spreadsheet form. This new evaluation method can be used to remedy effectiveness as follows:

1) Select the primary goal of long-term monitoring. This evaluation method is appropriate when the long-term monitoring data will be used to either:
   i) demonstrate that constituent concentrations are decreasing: the method will determine whether contaminant concentrations are decreasing across the plume as a whole; OR
   ii) determine how fast concentrations are decreasing or when concentrations will decrease to a clean-up goal: the method will determine the overall attenuation rate for the plume that can be used to estimate when concentrations will decrease to a clean-up goal.

2) Evaluate whether individual monitoring wells exhibit long-term trends that are truly different from the overall plume trend (as opposed to random differences between wells that reflect the effect of short-term variability).

3) If true differences in individual wells are identified, evaluate whether these differences will adversely affect attainment of the site remediation goal.

In order to evaluate typical results, the evaluation method has been applied to twenty contaminated groundwater sites: nine benzene sites, eight PCE/TCE sites, and three arsenic sites. For each site, we answered Questions 1 and 2 from above.

Question 1: When will this site meet the groundwater clean-up goal (i.e., What is the long-term attenuation rate for the key contaminant at my site)?

The remediation timeframe is estimated using the long-term attenuation rate and user-specified values for current source area concentration and remediation goal. In order to capture some of the uncertainty associated with estimating remediation timeframes, the tool uses the 25th percentile and 75th percentile attenuation rates from individual monitoring wells to calculate a time range. For the benzene and TCE/PCE sites, we used the recent concentration in the most contaminated monitoring well as the current source area concentration and 5 μg/L as the remediation goal. We did not evaluate remediation timeframes at the three arsenic sites because arsenic concentrations appeared to be increasing at two of these three sites. For the nine benzene sites, the 25th percentile remediation time ranged from 2 to 22 years, with a median of 14 years; the 75th percentile remediation time ranged from 3.3 to >1000 years, with a median of 27 years. For the eight TCE/PCE sites, the 25th percentile remediation time ranged from 3 to 76 years, with a median of 24 years; the 75th percentile remediation time ranged from 20 to >1000 years, with a median of 288 years.

Question 2: Do any individual wells appear to be attenuating more slowly than the source as a whole?

The 20 test sites included a total of 254 individual monitoring wells. Of those wells, 158 (62%) had long-term attenuation rates that were within the expected range based on the overall source attenuation rate and the expected effect of short-term variability. 50 monitoring wells showed faster than expected attenuation rates and 46 wells showed slower than expected attenuation rates. Of the 20 test sites, all of the sites had at least one monitoring well with an attenuation rate that was either faster or slower than expected. This suggests at most sites, the variation in attenuation sites between monitoring wells is only partly explained by the effects of short-term variability on observed attenuation rates. Other effects such as matrix diffusion, multiple source areas, and/or true spatial variations in attenuation processes likely contribute to observed variations in attenuation rates across individual sites.

Although all of the sites had at least one monitoring well with an attenuation rate outside of the expected range, only 10 of the 20 sites had a "slower well" in the source area such that the "slower well" might control the overall site remediation timeframe. At the other 10 sites, the slower attenuation rate wells were monitoring wells with lower contaminant concentrations and would not be expected to affect the overall time required to attain the groundwater clean-up goals. At the 10 sites where slower attenuation rates could affect the overall remediation timeframe, the user of the Monitoring Optimization and Trend Analysis Toolkit would i) evaluate whether the remediation timeframe for the slower attenuation rate wells is consistent with the remediation objectives for the site and ii) if not, target the area of the slower wells for additional remedial actions.

The full discussion of this data evaluation method is covered in a separate report (McHugh et al., 2015a):

> A New Method to Optimize Monitoring Frequency and Evaluate Long Term Concentration Trends

This report and the Monitoring Optimization and Trend Analysis Toolkit Excel-based tool and User's Guide can be found on the ESTCP web site under ER-201209.

1.0 INTRODUCTION

The purpose of this project was to i) validate sample collection methods and procedures that minimize variability in groundwater monitoring results and ii) validate improved methods to optimize monitoring frequency and assess long-term concentration trends that better account for short-term variability in groundwater monitoring results. The specific goals of the project are as follows:

1. Task 1: Validate the use of alternative field sampling procedures for the collection of groundwater samples in order to minimize variability in groundwater monitoring results.
2. Task 2: Develop and validate an improved method to optimize monitoring frequency based on a site-specific evaluation of the short-term variability and long-term attenuation rate.
3. Task 3: Develop and validate an improved method to identify long-term concentration trends that better account for the potentially confounding effects of short-term variability.

The project addresses groundwater monitoring variability in two ways: i) field methods to reduce monitoring variability and ii) improved data analysis methods that account for short-term variability.

This report focuses on the field demonstration of alternative field sampling procedures (Task 1) while McHugh et al., 2015a is a separate report that documents the development and demonstration of the improved data analysis methods (Tasks 2 and 3).

1.1 BACKGROUND

Because there is no comprehensive, national database of groundwater monitoring results, it is difficult to estimate the total number of monitoring wells at contaminated sites. However, different organizations maintain large databases that can be used to estimate the overall level of effort expended in groundwater monitoring. The California GeoTracker database, for instance, includes monitoring results for contaminated groundwater clean-up sites in California. Both the Air Force (ERPIMS) and Navy (NIRIS) have databases that include groundwater monitoring results for most of the groundwater clean-up sites being managed by these service branches. Table 1.1 summarizes the number of monitoring wells currently being sampled that are included in these databases.

Table 1.1 Number of Monitoring Wells and Monitoring Frequency in Large Monitoring Databases

Database (Year Evaluated)	Number of Monitoring Wells	Monitoring Frequency (Percentage of Wells)		
		Quarterly	Semi-Annually	Annually
California GeoTracker Database (2012)	56,000	25%	45%	30%
Air Force ERPIMS Database (2013)	11,800	4%	15%	81%
Navy NIRIS Database (2013)	9,200	Not Available	Not Available	Not Available
Army (estimate based on NRC Report)	20,000	Not Available	Not Available	Not Available

Although we were not able to obtain information on the number of monitoring wells sampled by the Army, the Army is responsible for approximately 50% of the contaminated sites being managed by the DoD (NRC, 2013). If these sites have, on average, the same number of monitoring wells as Navy and Air Force sites, then the available data suggest that the DoD is currently sampling over 40,000 monitoring wells per year. At $1,000 per sample per well (including labor cost for sample collection and data management), this would represent a cost of $40,000,000 to $120,000,000 per year depending on monitoring frequency. This estimated monitoring cost is similar to a recent estimate by the National Research Council of "over $100,000,000" annual monitoring costs at DoD facilities (NRC, 2013). If we assume that the number of monitoring wells in each state is proportional to the population, then the 56,000 monitoring wells in California represent 12% (U.S. Census Bureau, 2014) of the monitoring wells in the United States. This suggests that there are over 460,000 monitoring wells currently being sampled at least annually in the United States.

Given the number of monitoring wells at DoD sites and in the United States as a whole, it is important to quantify this variability, evaluate it in terms of overall monitoring objectives, and use it to develop cost effective and efficient monitoring programs.

Long-term monitoring (LTM) programs need to generate high-quality data by selecting monitoring points in appropriate locations and a sampling frequency that is adequate to monitor and evaluate trends at the site (USEPA, 2004; AFCEE, 2006). To ensure data quality, limits on analytical variability measured using laboratory duplicate samples (e.g., a relative percent difference, RPD, of 20%) and limits on sampling variability using field duplicates (e.g., an RPD of 30%) are established. If these data quality objectives are met, then the remaining variability in monitoring results is generally accepted as inherent to the nature of any monitoring system. However, for many monitoring programs this remaining variability is much higher than the objectives for sampling and analytical variability, and this high variability makes it more difficult to evaluate protection of receptors and remediation progress. Often, the only recommended

course of action is to conduct more intensive monitoring, because larger amounts of data are necessary to compensate for the high variability, and to identify true spatial and temporal trends in the groundwater plume.

For the purpose of this report, we are defining "short-term variability" as increases and decreases in contaminant concentrations in groundwater unrelated to the long-term reduction in source strength related to the effects of natural contaminant attenuation or active site remediation. Strategic Environmental Research and Development Program (SERDP) projects ER-1704 and ER-1705 have greatly improved our understanding of short-term variability. The short-term variability typically has a time scale of less than three months and accounts for 60 to 70% of the total variability in groundwater monitoring results with the long-term reduction in source strength accounting for the remaining 30 to 40% of total variability (McHugh et al., 2011). The project findings point to many sources of short-term variability due to well dynamics and methods of sampling. This short-term variability significantly limits our ability to understand the plume response to active remediation, source treatment, or natural attenuation.

Short-term variability distorts the long-term attenuation rate estimated from the monitoring data and the true long-term source attenuation rate. Inaccuracy in long-term monitoring trends may delay proper data interpretation and decision-making. At a minimum, variability increases monitoring costs by increasing the number of wells, sampling frequency, and data evaluation time needed to understand plume behavior. However, in many cases, variability unrelated to the true long-term concentration trend results in incorrect conclusions regarding plume stability or remedy effectiveness. In these cases, project costs can be dramatically increased by decisions to implement more aggressive remedies or to maintain frequent sampling schedules. Monitoring variability also greatly complicates the development and introduction of innovative groundwater monitoring technologies such as field-based sensors or new sampling techniques. This variability limits the ability to evaluate the accuracy, precision, and comparability of the new monitoring methods relative to the existing methods. This project utilizes the improved understanding from SERDP projects ER-1704 and ER-1705 to validate a suite of tools to minimize and manage groundwater monitoring variability.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this field demonstration is to validate the use of alternative groundwater sampling procedures to minimize short-term variability in groundwater monitoring records. For this purpose, the demonstration will compare monitoring results obtained using standard current low-flow sampling procedures to the results obtained using alternative low-flow sampling procedures and improved procedures using two no-purge sampling technologies that are increasing in popularity.

1.3 REGULATORY DRIVERS

As part of the regulatory clean-up process, monitoring of site contaminants in groundwater is typically required from the time that monitoring wells are initially installed during site assessment until regulatory closure is attained. The goals of LTM programs include: i) guarding against the migration of chemicals away from the defined areas of impact (i.e., to protect

receptors), and ii) monitoring the progress of groundwater remediation programs. Most commonly, the relevant regulatory requirements for site monitoring programs are qualitative rather than quantitative, leaving the regulatory project manager significant discretion with respect to the required number of monitoring wells and monitoring frequency. In other words, the regulations typically contain a general requirement to collect "sufficient" data to meet the program goal, leaving the responsible party to negotiate the number of wells and monitoring frequency with the regulator.

Short-term variability in groundwater monitoring results creates a significant barrier to the design and implementation of efficient LTM programs. Short-term variability increases both the amount of time and the amount of data needed to accurately characterize the long-term trend. When long-term trends are characterized without properly accounting for the potential confounding effects of short-term variability, then the analysis may result in incorrect conclusions regarding plume stability or remediation progress. The development of alternative sampling procedures to reduce short-term variability and improved data analysis methods that better account for short-term variability will improve the efficiency and utility of LTM programs.

2.0 TECHNOLOGY

The purpose of this project was to demonstrate alternative groundwater sampling procedures that reduce short-term variability in groundwater monitoring results and improved data analysis methods that better account for the confounding effects of short-term variability on the long-term concentration trend. The following sections describe Task 1, the field demonstration program.

2.1 TECHNOLOGY DESCRIPTION

A low-flow purge sampling method based on field parameter stability is currently the most common method used to collect groundwater samples from monitoring wells for laboratory analysis. This procedure entails a low rate pumping where certain field "parameters" such as pH, electrical conductivity, temperature, and dissolved oxygen concentration are measured until they are considered "stable" during the course of purging. A variety of no-purge methods (e.g., SNAP Samplers, HydraSleeve, and passive diffusion devices) are increasing in popularity. All of these sampling technologies have been validated primarily by comparing the monitoring results obtained using the technology to monitoring results obtained using a reference technology (e.g., high volume purge for validation of low-flow sampling) and demonstrating an absence of significant bias between the two methods during a single sample event. Little or no effort has been made to evaluate the relative effect of either the older or the newer technologies on variability between sampling events. In addition, there has been relatively little attention given to how the specific sampling procedures used to implement the sampling technologies affects variability between sampling events.

For many of these sampling methods, simple modifications to the current sample collection procedures can serve to reduce monitoring variability. The simple modifications may reduce variability by directly addressing some sources of variability such as in-well stratification of contaminant concentrations and by mitigating the impact of other sources of variability by minimizing differences in sample collection procedures between sampling events. For example, when using low-flow sampling, purging a pre-defined constant volume for each sample event rather than purging to parameter stability simplifies the implementation of the method and can reduce variability between sampling events. For low-flow or no-purge sampling methods, variability can be reduced by collecting the samples from exactly the same depth within the well (high precision sampler placement). For sampling methods that require transfer of the sample from the collection device to the sample container, specific "bottom fill" transfer procedures will reduce variability associated with volatile loss (Parker and Britt, 2012). This technology demonstration used multiple rounds of sampling conducted over a relatively short period of time to evaluate differences in short-term monitoring variability for sets of samples collected using different sampling methods: i) low-flow purge, ii) passive no-purge SNAP Sampler, and iii) active no-purge HydraSleeve. In addition, the demonstration program will evaluate the ability of alternative sampling procedures to reduce short-term monitoring variability. The results from the field demonstration were used to i) provide recommendations on selection of sampling methods to minimize variability in monitoring results between sampling events and ii) provide specific sampling procedures that reduce the variability associated with each specific procedure.

A detailed description of the sampling methods and procedures to be used for the demonstration is provided in Section 5.

2.2 TECHNOLOGY DEVELOPMENT

This project did not include novel technology development conducted specifically for this demonstration project. However, as discussed in Section 5.4.2 of this report, the demonstration was built upon previous studies suggesting that alternative sample procedures could reduce sample collection variability.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

This demonstration project i) compared monitoring variability associated with different low-flow and no-purge groundwater sampling methods and ii) validated the use of alternative sampling procedures with these methods in order to minimize this variability. The alternative sampling procedures were compared against standard low-flow sampling procedures.

2.3.1 Advantages of the Technology

Short-term variability in groundwater monitoring results complicates the attainment of LTM objectives by i) increasing the amount of data needed to accurately characterize the long-term concentration trend and ii) increasing the likelihood of incorrect conclusions regarding the long-term trend (e.g., concluding that the concentration is increasing when the true long-term trend is decreasing).

The use of low variability sampling methods and sampling procedures that minimize the variability associated with the selected method will improve the quantitative and qualitative evaluation of long-term monitoring results. For quantitative evaluations, a reduction in short-term variability will reduce the number of measurements and the evaluation time period required to identify a statistically significant long-term concentration trend. For qualitative evaluations, a reduction in short-term variability will reduce the occurrence of anomalous apparent concentration trends and will make it easier to accurately determine the long-term trend through visual inspection of the monitoring results. The attainment of more visually obvious concentration trends will make it easier for stakeholders to agree on remedy effectiveness and plume stability conditions.

2.3.2 Limitations of the Technology

The technologies used for validation were not expected to eliminate all sources of contaminant data variability in groundwater monitoring results. The intent was to reduce variability, not eliminate it. This is the primary limitation of the technology. SERDP Project ER-1705 identified four general categories of variability in groundwater monitoring results:

- ***Variability Source 1: Signal Variability.*** Changes in constituent concentration within the bulk groundwater in the vicinity of the monitoring well. These changes may be due to source remediation or may reflect variations in groundwater flow direction, water table

fluctuation, or other short-term changes in the fate and transport of VOCs from the source to the monitoring point that are not directly related to the long-term trend.

- ***Variability Source 2: Aquifer and Well Dynamics.*** When constituent concentrations are stratified within the aquifer, then flow dynamics within the monitoring well and the impact of the sampling method on those flow dynamics can impact the monitoring results.
- ***Variability Source 3: Sample Collection and Handling.*** VOCs, by their nature, move readily from water to air. As a result, VOC loss during sample collection and handling can contribute to variability between samples and loss of accuracy in monitoring. In conventional groundwater sampling for VOCs, the water sample is poured into a sampling vial and shipped to an off-site lab in an ice chest. Other constituents may also be affected by sample collection and handing procedures. For example, metals results can be affected by the amount of sediment in the sample.
- ***Variability Source 4: Sample Analysis.*** Monitoring accuracy depends on the accuracy, precision, and reproducibility of the laboratory analysis. However, prior studies have found that analytical variability is a small component of overall monitoring variability.

The sample collection methods and procedures served to reduce Variability Sources 2 (aquifer and well dynamics) and 3 (sample collection and handling). If these two sources of variability are not the main sources of short-term monitoring variability, then the improved methods and procedures will have a limited effect on the overall variability in the monitoring results. The magnitude of short-term monitoring variability varies between monitoring wells (McHugh et al., 2011), therefore, the effectiveness of the alternative methods for reducing variability is also expected to vary. However, we expect that the alternative sampling methods and procedures can be implemented without increasing monitoring costs and in many cases may actually reduce costs. As a result, any reduction in monitoring variability will provide benefit without cost.

3.0 PERFORMANCE OBJECTIVES

The overall objective of the demonstration was to validate sample collection procedures that minimize variability in groundwater monitoring results. In addition, the demonstration will provide a direct comparison of the short-term variability associated with three commonly used sampling methods: i) low-flow purge, ii) SNAP Sampler (Passive No Purge), and iii) HydraSleeve (Active No Purge). The objective of the field demonstration was met by:

1) Appling three sampling methods with alternative procedures to eight monitoring wells at each of two demonstration sites,
2) Appling low-flow purge to parameter stability using standard procedures as the reference sampling method for each monitoring well,
3) Conducting six rounds of sampling using each sampling method, and
4) Comparing the short-term variability associated with each sampling method.

Specific performance objectives included i) collection of groundwater samples in accordance with the specified procedures for each method, ii) attainment of accurate laboratory analytical results for each sample, and iii) appropriate comparison of the short-term variability associated with each of the sampling methods. Specific performance objectives are summarized in Table 3.1.

Table 3.1. Performance Objectives

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
Attainment of analytical results representative of constituent concentrations in the collected groundwater samples.	Results from laboratory analysis of groundwater samples. Associated QA results (e.g., laboratory QA results, duplicate analyses) to demonstrate acceptable laboratory performance.	For >90% of analyses: • Precision: RPD < 30% for field duplicate samples; RPD <20 for laboratory duplicate results • Accuracy: standard laboratory accuracy (see Appendix B) • Sensitivity: < 1 µg/L for all VOCs. See Appendix B.2 for additional details on data quality objectives.
Attainment of a complete dataset that supports multi-variate statistical analyses.	A balanced dataset based on analytical results for each planned primary sample: 480 total samples Two demonstration sites, five sampling method/procedure combinations, eight monitoring wells per site, six sampling events per method.	Analytical results for >95% of planned primary samples (i.e., analytical results for >456 samples).
Demonstration of reduced short-term variability for one or more of the sampling methods with alternative procedures compared to the reference method.	A statistically-significant difference in short-term variability between sampling methods with lower variability in the datasets obtained using the alternative methods.	A statistically-significant difference ($p<0.05$) in variability between all datasets using Levene's test, analysis of variance (or a non-parametric equivalent) and a statistically-significant difference ($p<0.05$) in variability for a pair-wise comparison of individual alternative method dataset vs. the reference method dataset using a t-test (or a non-parametric equivalent). See Section 6.0 for details on the statistical data analysis methods.
Qualitative Performance Objectives		
Collection of representative groundwater samples.	Implementation of each sampling method using the appropriate reference sampling procedures or alternative sampling procedures in accordance with the sample method SOP (see Appendix B.1).	Documentation of appropriate implementation of each sample method in accordance with the SOP.
Ease of implementation of the alternative sampling procedures.	Field experience implementing the groundwater sampling procedures.	Validated SOPs for the alternative sampling procedures that can be implemented by field sampling personnel with a typical level of qualifications and experience.

3.1 PERFORMANCE OBJECTIVE: ATTAINMENT OF REPRESENTATIVE ANALYTICAL RESULTS

Analytical results representative of constituent concentrations in the collected groundwater samples were obtained by utilizing a NELAC certified analytical laboratory capable of achieving the project-specific data quality objectives (see Appendix B.2). Quality assurance/quality control (QA/QC) samples were collected to allow for the evaluation of data precision, accuracy, completeness, representativeness, and comparability.

3.1.1 Data Requirements

QA/QC samples were collected to ensure that the dataset was representative of actual site conditions. As detailed in the QAPP (see Appendix B.2), the QA/QC samples included field duplicates and standard laboratory QA/QC samples.

3.1.2 Success Criteria

QA/QC samples were evaluated to determine the data precision, accuracy, completeness, representativeness, and comparability. Success criteria vary by sample type and are specified in the QAPP (see Appendix B.2).

3.2 PERFORMANCE OBJECTIVE: ATTAINMENT OF A COMPLETE DATASET

A complete dataset that supports multivariate statistical analysis was obtained by ensuring (to the degree feasible) that all planned groundwater samples were collected and analyzed. As discussed in the Demonstration Plan, the field program included contingency plans for replacement of samples that cannot be collected during the scheduled sampling event.

3.2.1 Data Requirements

A balanced dataset of analytical results from 480 groundwater samples based on analytical results for each planned primary sample: two demonstration sites, five sampling methods (including two variations of the alternative low-flow sampling methods), eight monitoring wells per site, six sampling events per method.

3.2.2 Success Criteria

Analytical results for >95% of planned primary samples (i.e., analytical results for >456 samples).

3.3 PERFORMANCE OBJECTIVE: DEMONSTRATION OF REDUCED VARIABILITY

The goal of the field demonstration was to validate alternative sampling procedures that yield reduced short-term variability for one or more of the sampling methods with alternative procedures compared to the reference method with standard procedures.

3.3.1 Data Requirements

The attainment of a complete dataset (see Section 6.1) supported a statistical comparison of short-term variability associated with the three demonstration sampling methods and the reference method.

3.3.2 Success Criteria

The test sample methods will be validated if we observe a statistically-significant difference ($p<0.05$) in variability between all datasets using Levene's test, analysis of variance (or a non-parametric equivalent) and a statistically-significant difference ($p<0.05$) in variability for a pair-wise comparison of individual improved method datasets vs. the reference method dataset using a t-test (or a non-parametric equivalent).

See Section 6.3 for details on the statistical data analysis methods.

3.4 PERFORMANCE OBJECTIVE: COLLECTION OF REPRESENTATIVE GROUNDWATER SAMPLES

In order to ensure that the results obtained using the test sampling methods and procedures were representative of the results that are likely to be obtained when the methods are implemented by typical field sampling crews, the sampling methods were implemented in accordance with written SOPs for each method. These written SOPs included the improved sampling procedures to be used with each sampling method (Appendix B.1).

3.4.1 Data Requirements

The proper implementation of each sampling method in accordance with the SOP was documented using field sampling forms (Appendix B.1).

3.4.2 Success Criteria

The objective was considered to be met if the >95% of samples are documented to have been collected in accordance with the SOP.

3.5 PERFORMANCE OBJECTIVE: EASE OF IMPLEMENTATION OF THE ALTERNATIVE SAMPLING PROCEDURES

In order to ensure that an observed reduction in short-term variability is attainable by other parties, the improved sampling procedures were implemented by environmental professionals with a typical level of training and experience in groundwater sampling. The improved sampling procedures should also be cost effective compared to current procedures.

3.5.1 Data Requirements

Field experience obtained during the demonstration program was evaluated. Qualitative success criteria included simplicity or complexity of the sampling procedure implementation relative to the reference procedure, and any other logistical issues and costs associated with implementation.

3.5.2 Success Criteria

The objective will be considered to be met if the SOPs for the test sampling methods were determined to be implementable and cost effective.

4.0 SITE DESCRIPTION

The improved sample collection methods were demonstrated at two field demonstration sites, at eight monitoring wells each. One field demonstration site was in the Houston, TX area. The second field demonstration site was in Los Angeles, CA.

The goal of the site selection process was to identify monitoring wells representative of those typically using for long-term monitoring of contaminant plumes. The following selection criteria were used to identify the selected sites:

Primary Selection Criteria (required characteristics):

i) Access to site for duration of demonstration;
ii) Historical monitoring data;
iii) One or more contaminants detected during >80% of historical monitoring events;
iv) Well diameter between 1 inch and 4 inches; and
v) Well screen length between 5 feet and 20 feet.

Secondary Selection Criteria (preferred characteristics):

i) Site located close to PI or Co-PI to minimize mobilization costs.

4.1 DEMONSTRATION SITE #1: HOUSTON, TEXAS

4.1.1 Site Location and History

The selected demonstration site #1 was in northwest Houston, and is the location of a former manufacturing plant, though the site is not currently active. Affected groundwater was detected in 1992, and a groundwater recovery and treatment system has been operating since May 1997.

4.1.2 Site Geology/Hydrogeology

Layers of silt, sandy clay, and clay are present from approximately 0 to 14 ft bgs, after which a layer of fine silty sand extends to 52 ft bgs, and is an unconfined aquifer. The water table in the aquifer is at approximately 29 ft bgs. Two more layers of sand (150 – 170 ft bgs) and a deeper aquifer (220 – 600 ft bgs) exist, and are separated by layers of clay.

4.1.3 Contaminant Distribution and Selected Wells

The affected groundwater plume extends approximately 950 ft in length across the property, with the following constituents: PCE, TCE, cis-1,2-DCE, VC, and 1,1-DCE.

The following table highlights the key construction information for the eight wells selected for the field demonstration, as well as the historical contaminant range at each well.

Table 4.1. Key Information on Selected Wells at Demonstration Site #1

Well ID	Well Diameter (in.)	Screen Length (ft)	Screen Depth Interval (ft bgs)	Key Contaminants	Historical Contaminant Range (mg/L)
MW-02A	2	10	30 - 40	PCE TCE cis-1,2-DCE 1,1-DCE	0.002 – 0.11
MW-06	2	10	25 - 35		0.002 – 0.5
MW-13	2	10	27 - 37		0.02 – 0.15
MW-15	2	10	25 - 35		0.002 – 0.01
MW-23A	2	10	28 - 38		0.006 – 0.02
MW-25A	2	10	28 - 38		0.001 – 0.003
MW-26	2	10	27.5 – 37.5		<0.00014 – 0.02
TW-01	2	10	27 - 37		0.005 – 0.03

Notes: PCE = tetrachloroethene; TCE = trichloroethene; cis-1,2-DCE = cis-1,2-dichloroethene; 1,1-DCE = 1,1-dichloroethene.

4.2 DEMONSTRATION SITE #2: LOS ANGELES, CALIFORNIA

4.2.1 Site Location and History

Demonstration site #2 is located in Santa Fe Springs, California near Los Angeles, and is the location of a former chemical repackaging facility. The site is currently an auto repair and staging lot. Affected groundwater was detected in the late 1980's, and soil vapor recovery and treatment system is the only on-site treatment currently operating.

4.2.2 Site Geology/Hydrogeology

The site is located in the flood plain of the San Gabriel River system south and east of Los Angeles. From approximately 0 to 40 ft bgs (below ground surface) interbedded sands, silts and gravels are present. Consistently distributed tight clay exists from about 40 to 45 ft, isolating the shallow water table from the deeper aquifer. Below 45 ft, a fairly consistent medium sand is present to approximately 80 ft. Saturation and water level in the deeper zone fluctuates, but during initial site characterization, water levels were about 55 ft deep.

4.2.3 Contaminant Distribution and Selected Wells

The affected groundwater plume extends throughout the property from both on-site and off-site sources, with the following primary constituents: PCE, TCE, cis-1,2-DCE, 1,1-DCA, 1,1-DCE, 1,4-dioxane. EDC, Chloroform, trans-1,2-DCE, and Freon-113. The following table highlights the key construction information for the eight wells selected for the field demonstration, as well as the historical contaminant range at each well.

Table 4.2. Key Information on Selected Wells at Demonstration Site #2

Well ID	Well Diameter (in.)	Screen Length (ft)	Screen Depth Interval (ft bgs)	Key Contaminants	Historical Contaminant Range (mg/L)
MW-13	2	10	52 - 62	PCE TCE cis-1,2-DCE 1,1-DCA 1,1-DCE 1,4-Dioxane EDC Chloroform trans-1,2-DCE Freon-113	0.002 – 0.45
MW-14	2	10	55 - 65		0.002 – 0.7
MW-15	2	10	54 - 64		0.002 – 0.9
MW-17	2	10	56 - 66		0.002 – 0.08
MW-20	2	10	57 - 67		0.002 – 0.11
MW-21	2	10	53 - 63		0.002 – 2.3
MW-23	4	10	71 – 81		0.002 – 0.14
MW-24	4	10	67 - 77		0.002 – 0.21

Notes: PCE = tetrachloroethene; TCE = trichloroethene; cis-1,2-DCE = cis-1,2-dichloroethene; 1,1-DCA = 1,1-dichloroethane; 1,1-DCE = 1,1-dichloroethene; EDC = 1,2-Dichloroethane; trans-1,2-DCE = trans-1,2-dichloroethene; Freon-113 = Trichlorotrifluoroethane.

5.0 TEST DESIGN

The overall objective of the demonstration was to validate sample collection procedures that minimize variability in groundwater monitoring results. In addition, the demonstration provided a direct comparison of the short-term variability associated with three commonly used sampling methods: i) low-flow purge, ii) SNAP Sampler (Passive No Purge), and iii) HydraSleeve (Active No Purge). The sample collection methods with improved sampling procedures were demonstrated in eight monitoring wells at each of two field demonstration sites (16 wells total).

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The sampling program consisted of three main types of sampling methods: i) low-flow purge, ii) Passive No Purge (SNAP Sampler) and iii) Active No Purge (HydraSleeve).

5.1.1 Sample Method/Procedure Combinations

The low-flow purge sampling method was implemented conventionally as the reference method with two variations of the method to include improved sampling procedures (fixed small volume purge and fixed large volume purge). The two no-purge sampling methods were implemented using those devices' standard sampling procedures modified to include the improved procedures that are relevant to each specific method. The sampling methods/procedures are summarized in Table 5.1 and Figure 5.1 below.

Table 5.1. Summary of Sampling Methods/Procedures

Sampling Method	Sampling Procedures	Sampling Method/Procedure Combination Used
Low-flow Purge	Reference Method (Standard)	1) Low Flow Standard
	Fixed Small Volume Purge (Alternative)	2a) Low Flow Alternative, Small Volume
	Fixed Large Volume Purge (Alternative)	2b) Low-Flow Alternative, Large-Volume
Passive No-Purge	SNAP Sampler	3) Passive No-Purge (SNAP Sampler)
Active No-Purge	HydraSleeve	4) Active No-Purge (HydraSleeve)

Although we used specific sample methods to represent general categories of sample collection methods, we would expect the project results to be applicable to other methods within the category. For example, we would expect the project findings obtained using the SNAP sampler to be applicable other Passive No Purge methods such as a Passive Diffusion Bag sampler.

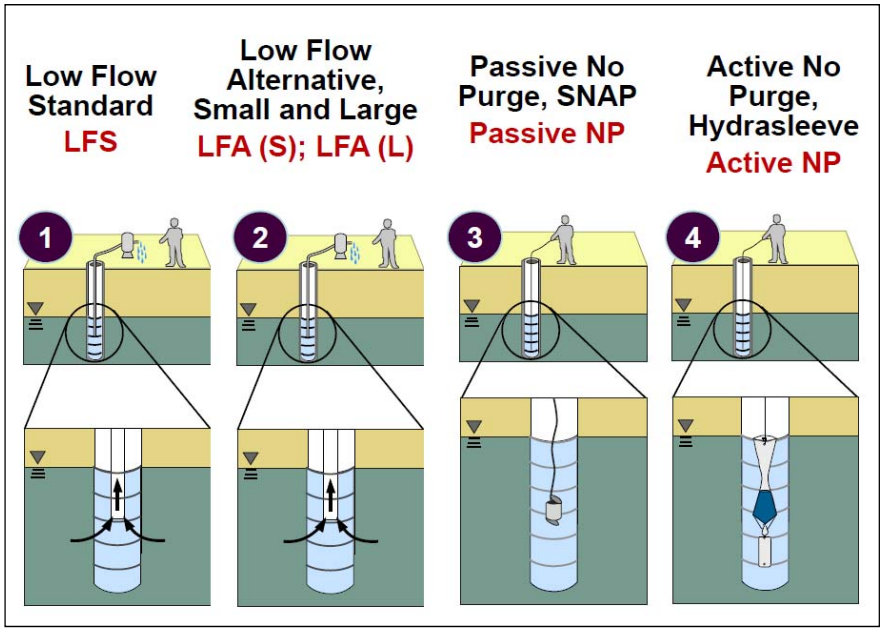


Figure 5.1. Summary of Sampling Methods Used in Demonstration Program

5.1.2 Demonstration Sites, Monitoring Wells, and Rounds of Sampling

The field program was conducted at two demonstration sites. At each site, each sample method/procedure combination was used to collect a groundwater sample from each of eight monitoring wells. Except for Low-Flow Alternative (Small Volume) and Low-Flow Alternative (Large Volume), each sampling method was implemented during separate sampling events, with 10 to 20 days between each sample event. Low-Flow Alternative (Small Volume) and Low-Flow Alternative (Large Volume) were implemented sequentially during a single sample event.

Each round of sampling consisted of four events in which all method/procedure combinations were implemented, and a total of six rounds of sample collection was conducted. Each round of sampling was completed over a period of approximately 60 days (i.e., four sampling events with 10 to 20 days between each event), resulting in a total of approximately one year to complete the six rounds of sampling. The sampling program yielded a dataset of 480 groundwater samples (i.e., five sample method/procedure combinations, eight wells, and six rounds of sampling at each of two demonstration sites).

5.2 BASELINE CHARACTERIZATION

As discussed in Section 4, the selection of demonstration sites and specific monitoring wells within each site was based on the identification of several factors. As such, no additional baseline characterization was conducted prior to executing the demonstration.

5.3 TREATABILITY OR LABORATORY STUDY RESULTS

No treatability or laboratory studies were conducted as part of this field demonstration.

5.4 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The purpose of this technology demonstration was to compare the short-term variability associated with three common groundwater sampling methods and to evaluate if implementing methods using alternative sampling procedures will reduce short-term variability.

As a result, the technology for the demonstration consisted of five sampling methods as follows:

1) Low Flow Standard
2a) Low Flow Alternative (Small Volume)
2b) Low Flow Alternative (Large Volume)
3) Passive No-Purge (SNAP Samplers)
4) Active No-Purge (HydraSleeve)

5.4.1 General Sampling Method Types Overview

The general sampling method types can be categorized as:

i) low-flow sampling,
ii) passive no-purge, and
iii) active no-purge.

The two no-purge methods avoid purging entirely, and may also equal or exceed variability reduction goals. The no-purge approaches avoid the potential artifacts introduced by purging the well by relying on native aquifer flow to deliver water to the screen interval to be sampled. Sampling these wells in their "natural" state without perturbing the ambient condition is expected to add consistency. The two no-purge methods are different in practical function. The SNAP Sampler collects a sample instantaneously at a fixed position in the well, while the HydraSleeve "cores" a sample through the water column as the device is pulled up quickly. As such, the two no-purge methods sample the well somewhat differently—passively and actively.

Low-Flow Sampling

Low-flow sampling involves use of a pump (either an above-ground peristaltic pump or a down-hole electric pump) to remove water from the monitoring well at a low flow rate (<1 L/min) to minimize drawdown and disturbance of the well. As most commonly implemented today, water is purged from the monitoring well until field parameters (e.g., temperature, pH, specific conductance, and either dissolved oxygen or oxidation-reduction potential) stabilize and then the groundwater sample is collected.

Passive No-Purge (SNAP Sampler)

Passive no-purge sampling involves placement of a sampling device (either a diffusion bag, ITRC 2004; or a SNAP Sampler, ITRC 2007) into the monitoring well approximately two weeks prior to the sampling event and allowing the sampler to equilibrate with the water in the monitoring well (Figure 5.2). After the equilibration period, the sampling device is closed (if needed) and the sample is removed from the well. The resulting sample is representative of water in the well under ambient flow conditions.

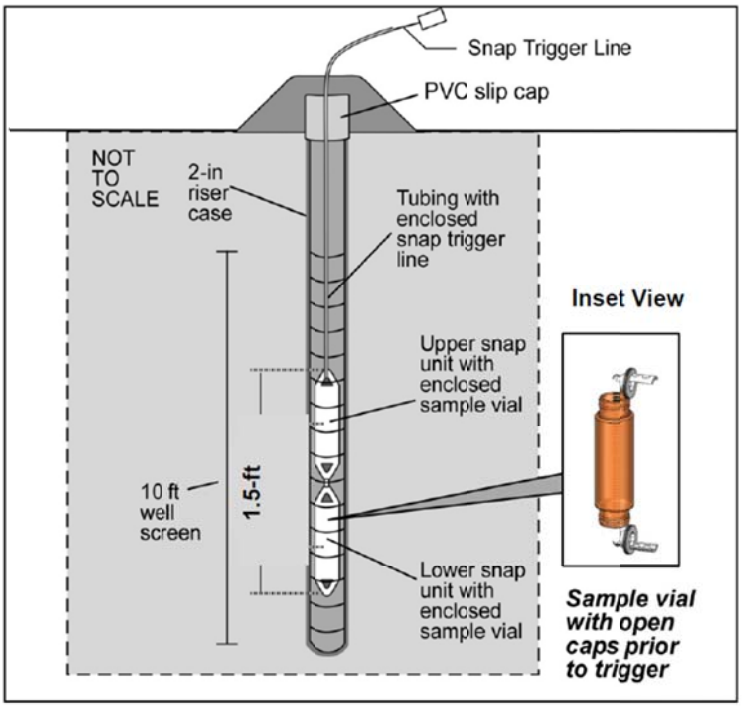


Figure 5.2. Use of SNAP Sampler to Collect Groundwater Samples

Active No-Purge (HydraSleeve)

Active no-purge sampling involves active sample collection from an unpurged monitoring well. The HydraSleeve is an active groundwater sampling device that is filled by pulling the sampler upwards through the screened interval of the monitoring well (Figure 5.3). The HydraSleeve sampler is installed in the monitoring well approximately two weeks prior to sample collection to allow the sampler to equilibrate with the groundwater and to avoid the mixing that would occur if the sampler were installed immediately prior to sample collection.

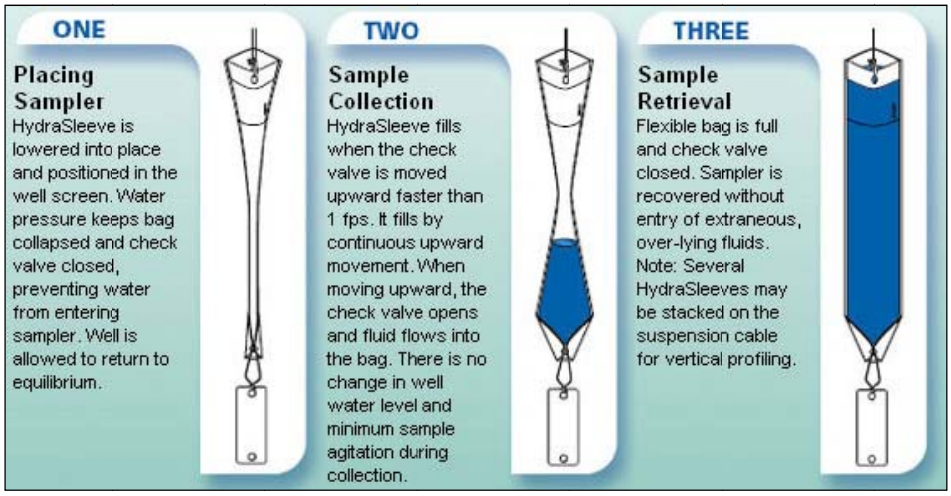


Figure 5.3. HydraSleeve Sampling System (Source: http://www.HydraSleeve.com)

5.4.2 Standard and Alternative Sampling Procedures

The specific procedures utilized during sample collection can vary somewhat between sampling teams, but are based on the procedures recommended in applicable guidance documents. These guidance documents often do not reflect the most recent innovations and improvements in sampling procedures, and implementation in this study is designed to incorporate some variations inherent to the procedures themselves. This field demonstration will demonstrate the ability of alternate sampling procedures to reduce short-term variability in groundwater monitoring results. Standard and improved sampling procedures are summarized in Table 5.2. Although some of these improved procedures are already utilized by some field sampling teams, it is uncommon for all of the improved procedures to be used together.

Table 5.2. Summary of Standard and Alternative Sampling Procedures

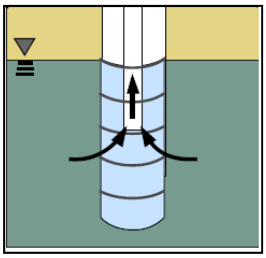
Procedure Element	Standard Procedure	Alternative Procedure
Equipment installation	Install low-flow sampling equipment immediately prior to sample collection.	Install sampling equipment at least two weeks before sample collection.
Sample collection elevation	Collect sample from approximately the same elevation within the well screen during each sample event.	Mark sampling equipment to ensure that sample is collected from the same elevation (+/- 1 inch) during each sample event.
Purge volume	Purge volume based on field parameter stability. Purge volume varies between sample events.	Constant purge volume for each sample event (3L for smaller volume purge, 18L for larger volume purge)
Pumping rate	If purge rate is >250 mL/min, then pumping rate lowered to 250 mL/min for sample collection.	Constant pumping rate used for purging and sample collection, up to 1000 mL/min.
Vial filling method and rate	Allow water to flow down the inside wall of the VOA vial.	Insert tube into vial and fill vial from bottom. Pull tube up as vial fills, keeping tube below water level in vial.
Removal of bubbles from vials	Check for bubbles in filled vials. Reopen and top-off vial to remove any bubbles larger than 1 mm in diameter.	Accept any vial at least 95% full (i.e., < 2 mL headspace). If vial contains > 2mL headspace, discard and fill new vial.

Each element of the standard and alternative procedure is discussed below. For each sampling method, these procedures have been incorporated into the sampling SOPs (Appendix B.1).

Equipment Installation: Although dedicated equipment is recommended, the ASTM Standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Groundwater Quality Investigations (ASTM, 2002) allows the use of either dedicated sampling equipment that is left in place within the monitoring well between sampling events or portable equipment that is installed immediately before the sample event. In current practice, a mix of dedicated equipment and portable equipment is used. For this demonstration, portable equipment (i.e., installed immediately prior to sample collection) will be used for the standard procedure and dedicated equipment (installed at least two weeks before sample collection) will be used for the improved

procedure. For the two no-purge methods, equipment will be installed approximately 2 weeks prior to sampling.

Sample Collection Elevation: Current sampling protocols recommend that the sampling equipment (e.g., the pump intake for low-flow sampling) should be placed at or near the middle of the well-screened interval, or slightly above the middle (Puls, 1995; ASTM, 2002). Although the sample is typically collected from approximately the same elevation for each sample event, neither the ASTM standard or USEPA guidance describe any practice to ensure that variation in sample collection depth is minimized (ASTM, 2002; USEPA, 2010).



For this demonstration, the standard procedure targeted the middle of the screened interval but did not include any specific measures to ensure a constant sample elevation. For the improved procedures, the sampling equipment was marked and the procedures ensured that the sample collection elevation was constant between sample events. For the SNAP Sampler, a fixed trigger line length assured a consistent sampler deployment position. The top vial will be identified as the primary sample and will be the only vial analyzed by the laboratory unless the secondary vial is needed due to a problem with the primary vial. For the HydraSleeve, the tether line was a fixed length.

Purge Volume: For low-flow sampling, current sampling protocols recommend purging water from the well prior to sample collection until field parameters stabilize (ASTM, 2002; USEPA, 2010). In concept, the observation of stable field parameters indicates that the recovered water is representative of water from the aquifer. However, in practice, the use of field parameter stabilization to guide sample collection results in a variation in well purge volume between each sample event and may not necessarily ensure that *only* formation water is sampled. For low purge volumes a combination of formation water and screen-zone water may be sampled (Martin-Hayden et al., 2014).

Pumping of water from a monitoring well at flow rates low enough to maintain laminar flow conditions in the monitoring well results in a predictable sampling process (in contrast to purging with a bailer, or purging with a pump, then sampling with a bailer). However, previous SERDP work has indicated that even a consistent low-flow sampling approach does not necessarily yield constant discharge concentrations (Britt, et al 2011). Initially, the recovered water consists entirely of water that was already in the well prior to initiation of pumping. As pumping continues, the proportion of fresh formation water increases in a predicable fashion. After purging three screen interval volumes (18L for a 2 inch well with a 10 ft screen), the recovered water is >90% fresh formation water (Martin-Hayden et al., 2014). As a result, purging of a large fixed volume of water prior to sample collection theoretically serves to increase consistency between sample events. Purging of a fixed volume also simplifies the sampling procedure by eliminating the equipment and labor needed to monitor field parameters.

For this demonstration, the standard sampling procedure used purge to parameter stability. For low-flow sampling, the improved procedure will use a fixed purge volume. Two purge volumes will be evaluated: small volume of 3L (0.5 screen interval volumes) and large volume of 18L (3

screen interval volumes). The 0.5 well volume comparator was selected because SERDP Project ER-1704 found that this volume is most likely to diverge from a flow weighted average concentration in the pump discharge (Martin-Hayden et al., 2014). This may seem counter-intuitive to select the position in the purge "curve" most likely to diverge, but it may also be a point of consistency when factors such as purge rate and pump position are strictly controlled. However, a comparison between the theoretical divergent fixed volume (3L) to the "recommended" fixed three well-screen volume (18L) provides the best evaluation of the impact of fixed purge volume on sample results. A large difference in quality of the results (i.e., variability or statistical bias) between the two purge volumes would suggest that the fixed purge volume is important. No clear difference in the quality of the results between the two purge volumes would suggest that purge volume is relatively unimportant.

Pumping Rate: For low-flow sampling, current sampling protocols recommend collecting samples for VOC analysis at a flow rate lower than that used for purging. For example, ASTM, 2002 recommends a maximum flow rate of 250 mL/min during collection of samples for VOC analysis. In addition, the field staff commonly turns the pump off between purging and sample collection (e.g., to remove the flow-through cell, prepare sample vials, etc.). However, Britt and others (2015) have found that changing the pumping rate and/or turning the pump off and on can change or disrupt the flow pattern within the well screened interval resulting in a change in contaminant concentration in the discharge stream.

For this demonstration, the standard sampling procedure will specify a maximum flow rate of 250 mL/min during collection of samples for VOC analysis and will allow the pump to be turned off, if needed, to prepare for sample collection. For low-flow sampling, the improved procedure will specify a constant pumping rate for purging and sample collection and will specify continuous pumping throughout the sampling event.

For the standard low-flow procedure, a slow purge rate of approximately 50 to 200 mL/min will be used to limit turbidity and accommodate the yield of the individual well. Drawdown will be minimized as much as practicable, aiming for less than 0.5 ft in total drawdown during the course of the parameter stabilization procedure. Flow rate will be determined by the sampling team during the course of purging. Adjustments to flow rate will be allowed during the first purge event. From there forward, the selected flow rate at the individual well will be used during subsequent events unless water level changes or other factors prevent the use of the predetermined flow rate.

In contrast, the fixed volume (alternative) low-flow purge sampling will utilize the *highest* flow rate practical for the individual well (up to 1 L/min), without introducing excessive drawdown (>1 ft). In some cases the standard and improved methods may utilize a similar flow rate due to poor yield, while in other cases the improved method will take advantage of better yield to achieve the fixed volume target sooner. Ultimately, this is the purpose of this aspect of the test—to demonstrate that fixed volume purging is just as effective, or more so, than the standard parameter stability approach.

Vial Filling Procedure: For low-flow sampling and active no-purge sampling, the sample must be transferred in the field from the sampling device to a sample container (e.g., a 40 mL VOA vial for volatile analyses). Sampling guidance typically recommends use of the side pour method, where the VOA vial is tilted and water is poured slowly so that it flows down in the inside wall of the vial (USEPA, 2010). In addition, the pumping rate during vial filling is recommended to be low (e.g., <250 mL/min, ASTM 2002). However, a careful study comparing vial filling procedures has found that time of water exposure and surface area exposed tends to drive VOC losses during sample vial filling (Parker and Britt, 2012).

Therefore, a bottom fill method (i.e., placing the sample tube at the bottom of the VOA vial, keeping it below the liquid level, and raising it as the vial is filled) and a higher fill rate (up to 1L/min) was employed to minimize loss of volatiles during sample transfer. For this demonstration, the standard sampling procedure will use the side fill method and a flow rate of 100-250 mL/min, appropriate to the production rates of the individual wells selected for the study. The improved procedure will use the bottom fill method also with the same flow rate as during pumping (<1000 mL/min), and as appropriate to the production rates of the individual wells.

Bubble Removal: Bubbles in VOA vials have been considered to be problematic based on the potential for volatiles to partition from the water into the bubble, reducing the VOC concentration in the water sample. To prevent this loss, many sampling protocols recommend checking for bubbles following vial filling and topping off vials (i.e., reopening vials and adding additional sample water) which are found to have bubbles of any size (e.g., USEPA, 2011; Woodard & Curran, 2002).

However, the effort to remove air bubbles may result in a loss of volatiles from the sample while the container is reopened and additional sample water is added. A study of the effect of bubbles in VOA vials found that even large bubbles (i.e., 2 mL volume in a 40 mL VOA vial) have little or no measureable effect on the concentration of volatiles in the water sample (Nadim et al., 2001). Experimental results indicated that in a 40 mL sampling vial, an air bubble/headspace volume of 2 mL showed lower recovery rates only for the most volatile compound tested (dichlorodifluoromethane; Nadim et al., 2001). For all compounds, the loss was less than predicted by equilibrium partitioning models. For the standard sampling procedure, bubbles greater than 1 mm will be removed from the sample vial. For the improved procedure, the vial will be filled as much as possible during the primary fill event. After filling, vials with a headspace of less than 5% (2 mL) will be accepted. Note, however, 5% is the maximum acceptable headspace; we expect the majority of vials to be filled >99%. Vials with a greater than 5% headspace will be discarded and replaced.

5.4.3 Five Sampling Methods and Procedures

The general sampling method types, as well as standard and improved procedures were combined to create five sampling method/procedure combinations that were used throughout the

field program demonstration. The five methods and their respective sampling procedures are summarized in Table 5.3 below.

Table 5.3. Summary of Sampling Methods and Procedures Implemented in Field Program

	1) Low-Flow Standard	2a) and 2b) Low-Flow Alternative, Small- and Large Volume	3) Passive No-Purge (SNAP Samplers)	4) Active No-Purge (HydraSleeve)
Equipment	Install day of sampling	Install dedicated equipment	Install dedicated equipment	Install dedicated equipment
Intake Depth	Approximately constant	Precise, constant sample depth	Precise, constant sample depth (sample top vial only)	Water column of 1.0 to 1.5 times length of sampler (2.5 ft) (GeoInsight, 2010)
Well Purge	Purge to parameter stability	Fixed Volume: Small (3L) and Large (18L)	None	None
Flow Rate	Varies between purge and sample, <250 mL/min	Constant during purge and sample, <1000 mL/min	None	None
Vial Fill	Side pour method	Bottom fill method	None	Bottom fill method
Vial Bubbles	Remove >1mm bubbles	>2 mL headspace, replace vial	>2 mL headspace, replace vial	>2 mL headspace, replace vial

5.5 FIELD TESTING

At each of the two demonstration sites, the field program was implemented through 24 field sampling events (i.e., six rounds of sampling with four sampling events for each round; see Table 5.4).

5.5.1 Field Program Schedule

Each sample method/procedure combination was used to collect a groundwater sample from each of eight monitoring wells. Except for the Low-Flow alternative (fixed small volume purge and fixed large volume purge), each sampling method was implemented during separate sampling events, with 10 to 20 days between each sample event. The procedures to be used during collection of groundwater samples using all five sampling method/procedure combinations are provided in Appendix B.1 (Standard Operating Procedures).

Table 5.4. Events and Method/Procedure Combinations per Round of Sampling

Sampling Event	Method	Procedure
1	Low-flow Standard	Install non-dedicated pump; conduct reference method (Low Flow Standard); install/leave dedicated pump for Event #2
2	Low-flow Alternative	Conduct fixed volume purge with small and large volumes; remove pump; install SNAP Samplers for Event #3
3	Passive No-Purge	Collect Passive No-Purge (SNAP Samplers); install HydraSleeve for Event #4
4	Active No-Purge	Collect Active No-Purge (HydraSleeve) samples; leave well with no equipment installed

Note: Each round of sampling consisted of three sampling methods and five sampling procedures, and covered approximately 60 days. See Appendix B.1 for detailed sampling procedures.

The time period between events was designed to allow the well and surrounding aquifer to restabilize to a natural/ambient state, so that each sampling method was not impacted by activities of the previous events. For the fixed volume (Low Flow Alternative) events, the first sample collection early in the purge will not affect the sample collected later in the same purge, so those will be collected during the same purge event.

Tables 5.5 and 5.6 summarize the number of sample rounds, and the general schedule of sampling events per sampling round. The methods were applied sequentially, with approximately 10-20 days waiting period between each sampling event.

Table 5.5. Field Testing Schedule

Sampling Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Program Week	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
Sample Method/Procedure																								
1) Low-Flow Standard	X				X				X				X				X				X			
2a) and 2b) Low-Flow Alternative Procedure (Small and Large Volumes)		X				X				X				X				X				X		
3) Passive No-purge (SNAP)			X				X				X				X				X				X	
4) Active No-purge (HydraSleeve)				X				X				X				X				X				X

Table 5.6. Summary of Task 1 Field Demonstration Program

No. of Demon-stration Sites	Number of Wells per Site	Sample Method/Procedure	Sample Rounds	Total Samples
2	8	Reference Method: Low-flow, Standard procedure	6	96
		Low-flow, Alternative procedure (small volume purge)	6	96
		Low-flow, Alternative procedure (large volume purge)	6	96
		Passive No-purge (SNAP Sampler)	6	96
		Active No-purge (HydraSleeve)	6	96
Total Number of Samples Collected for Primary Data Set				480

Note: Sample count does not include field and lab duplicates or other QA/QC samples.

5.5.2 Quality Assurance Procedures

The integrity of the data generated by this demonstration was maintained in adherence to the QAPP (Appendix B.2). The QAPP identifies requirements for QA/QC sampling, detection limits, methods, and field and laboratory performance. In addition, the following procedures will be followed:

- *Decontamination Procedures.* All sampling equipment used during each sampling event was either flushed before sample collection, or was of disposable material.
- *Sample Documentation.* Field documentation consisted of pre-printed tables, labels, and log forms to allow for precise notation of data collection during sampling events. Additionally, all samples submitted for laboratory analysis were submitted under chain-of-custody control. Finally, photographs were taken for visual documentation of project activities.

5.5.3 Sample Analysis

All groundwater samples were analyzed for VOCs by USEPA Method 8260B, as stated in the QAPP (Appendix B.2).

6.0 PERFORMANCE ASSESSMENT

6.1 ATTAINMENT OF A COMPLETE DATASET

6.1.1 Dataset

The field program consisted of six sample events for each of five sample methods implemented at eight monitoring wells at each of two demonstration sites (Texas and California). The complete sampling program was expected to yield 480 groundwater samples (not including field duplicates). For the Texas site, no sample was recovered using the HydraSleeve in MW-15 for Sampling Event 2 and MW-13 for Sampling Event 6, and logistical constraints prevented collection of replacement samples. As a result, the dataset consisted of analytical results from 478 samples (99.6% completeness).

In order to evaluate the effect of sample method on monitoring variability, for each monitoring well we identified the constituents detected in 90% of the demonstration samples. For the California site, ten constituents met the detection frequency (DF) threshold in all eight monitoring wells (1,1-DCA, 1,1-DCE, EDC, Chloroform, cis-1,2-DCE, PCE, trans-1,2-DCE, TCE, Trichloro-fluoromethane, Freon-113). For the Texas site, four constituents (PCE, TCE, cis-1,2-DCE, 1,1,-DCE) met the detection frequency threshold in all eight monitoring wells with the following exceptions: TCE in Well MW-25A (DF=3%), cis-1,2-DCE in Well MW-25A (DF=0%), 1,1-DCE in Well MW-25A (DF=0%). Therefore, the total dataset consisted of 3262 concentration measurements that were retained for further processing and statistical analyses.

The complete dataset consists of chemical concentration results from two sites, summarized as follows:

Table 6.1. Summary of Complete Dataset from Two Demonstration Sites

Site	Number of Wells	Sample Methods Tested[1]	Number of Sample Events per Method	Number of Samples Collected	Number of Chemicals Detected[2]	Total Concentration Measurements
Texas	8	5	6	238*	4	862*
California	8	5	6	240	10	2400
Total						**3262**

Notes:

(*) Missing data from the Texas site includes: i) TCE in Well MW-25A (DF=3%), cis-1,2-DCE in Well MW-25A (DF=0%), 1,1-DCE in Well MW-25A (DF=0%) and ii) no sample was recovered from recovered using the HydraSleeve in MW-15 for Sampling Event 2 and MW-13 for Sampling Event 6.

1. The sample methods tested include: low-flow standard, low-flow alternative (3L), low-flow alternative (18L), passive no-purge (SNAP), and active no-purge (HydraSleeve).
2. These chemicals were detected in >90% of the events/methods for at least one well at the site.

6.1.2 Data Clean-Up

Of the 3262 concentration measurements that were retained for further processing and statistical analyses, 37 were non-detect results. For these 37 data points, the detection limit was substituted for the non-detect result.

6.1.3 Data Processing: Short-Term Variability Component for Individual Measurements

The hypothesis for Task 1 was that alternative sample methods would reduce the short-term variability in groundwater monitoring results. In order to test this hypothesis, we needed to quantify the short-term variability associated with each concentration measurement. *For each concentration measurement, the short-term variability was defined as the difference between the measured concentration and the long-term concentration.* For this purpose, each monitoring well record was evaluated separately. An individual monitoring record was all of the concentration measurements for a single chemical in a single monitoring well (e.g., TCE in MW-02A). Each monitoring record consisted of 30 concentration measurements (i.e., five sampling methods each applied during six sampling events). If a monitoring record shows no consistent temporal trend, then the best estimate of the long-term concentration is the average concentration for all 30 concentration measurements. If a monitoring record does show a consistent temporal trend, then the best estimate of the long-term concentration is the concentration predicted by the best-fit trend line determined using linear regression. As discussed in the demonstration plan, we planned to use regression analysis to identify the long-term concentration for all monitoring records if more than 20% of the monitoring records showed a statistically significant temporal trend over the course of the demonstration program.

Using linear regression, 39% (44 out of 112) of monitoring records showed a statistically significant linear temporal trend. For these 44 records, the temporal trend accounted for an average of 30% of the variability in the record (i.e., the average R^2 was 0.3). Although we used a linear trend to account for temporal trends during the demonstration program, similar results were similar using an exponential trend. In other words, an exponential trend yielded a similar number of significant trends and a similar average R^2 value for the significant trends. Because more than 20% of the monitoring records showed a significant trend, we used linear regression to estimate the long-term concentration for all of the monitoring records. For each concentration measurement, the magnitude of short-term variability was calculated as shown in Figure 6.1 and summarized below:

1) Controlling for temporal trend

In order to identify the short-term variability (i.e., not associated with a linear temporal trend), we used least-squares regression to determine the best fit linear trend for each monitoring record. We used this trend to determine the residuals (i.e., the measured concentration minus the model predicted concentration). The residual represents the variability not explained by the temporal trend (i.e., the short-term variability).

2) Normalization

In order to control for differences in concentration between chemicals and between monitoring wells, we normalized each residual by dividing the residual by the model-predicted

concentration. As a result, each residual was expressed as a fraction (or percentage) of the model predicted concentration. In other words, the magnitude of short-term variability was expressed as a percentage of the long-term concentration. This data processing yielded a dataset of 3262 normalized residuals (i.e., short-term variability values). As discussed in Section 2.3.2, this short-term variability is a function of aquifer and well dynamics, sample collection factors, and analytical variability.

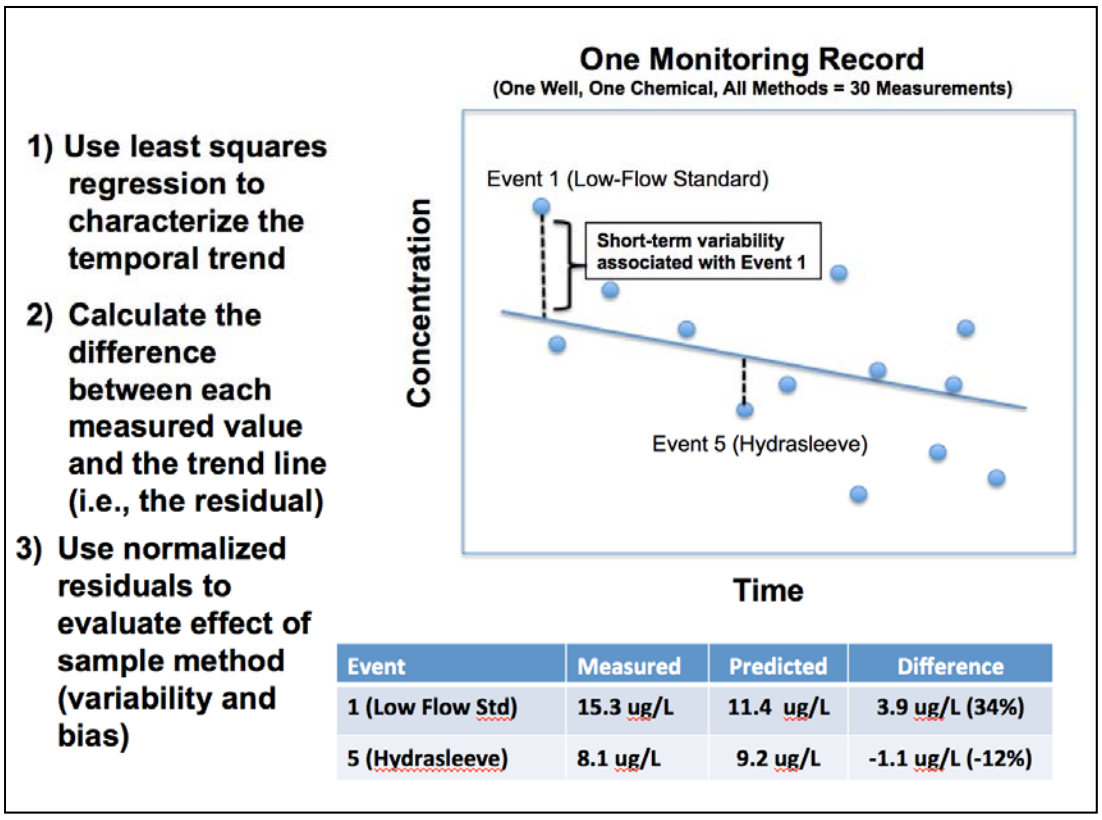


Figure 6.1. Method to Quantify the Short-Term Variability Component for Each Concentration Measurement

6.1.4 Data Processing: Paired Measurements

The short-term variability has also been evaluated by analyzing the change in concentration between paired measurements. For paired measurements, the change in concentration between the sample pair was calculated as:

> Concentration Change = (Higher Concentration – Lower Concentration) / Lower Concentration x 100%

Using this calculation method, the change in concentration is always expressed as a positive value. This calculation is similar to relative percent difference (RPD) except that the maximum possible value for RPD is 200% while there is no upper bound value for concentration change.

6.2 ATTAINMENT OF ANALYTICAL RESULTS REPRESENTATIVE OF CONSTITUENT CONCENTRATIONS IN THE COLLECTED GROUNDWATER SAMPLES

6.2.1 Sampling Procedures

Groundwater samples submitted for laboratory analysis were collected in accordance with Standard Operating Procedures (SOPs) routinely utilized by GSI, or sample collection methods validated during previous field programs, and as detailed in the Quality Assurance Project Plan (QAPP) (Appendix B.2). During the field programs covered by this report, the following deviations from planned procedures occurred:

- SNAP Sampling

  California Site, Round 1: During the first SNAP sampling event, in addition to only the upper samples being analyzed, as specified by the sampling procedures, the lower SNAP sample vials at select wells were analyzed by the laboratory. These lower SNAP sample results in select wells were included in the statistical analysis of results. The data package found in Appendix D includes all details of the laboratory results.

- HydraSleeve

  Texas Site, Round 2 and Round 6: In both cases, insufficient water was retrieved from the HydraSleeve bag to be analyzed, so no resulting concentration data could be reported for MW-15 during Round 2, and for MW-13 during Round 6.

  California Site, Round 5: During sampling on 12/31/2013 for Round 5, MW-13 was inaccessible, so the HydraSleeve was retrieved and sample submitted for analysis one week later, on 1/7/2013. No resulting laboratory issue was noted.

The two HydraSleeve samples from the Texas site were the only samples that could not be replaced during the field program. As a result, the dataset consisted of analytical results from 478 samples out of a planned 480 sample (99.6% completeness). This exceeded our completeness goal of 95%.

6.2.2 Custody Procedures, Holding Time, Arrival Temperatures

All samples submitted for analysis were received within the required holding times and within the limits specified for temperature for groundwater samples (i.e., $\leq 4°$ C). All samples were submitted under chain-of-custody control with no indication of any losses of custody. Chain of custody documentation was provided by the final recipient of the samples to document the complete series of custody transactions.

Groundwater samples from the Texas Site were analyzed by ALS Environmental in Houston, Texas. Groundwater samples from the California Site were analyzed by American Environmental Testing Laboratory Inc. (AETL), in Burbank, California. All samples were analyzed in accordance with applicable SOPs, laboratory guidelines, and the chain-of-custody.

6.2.3 Precision Assessment: Duplicate Samples, Matrix Spike (MS), Matrix Spike Duplicates (MSD), Laboratory Control Sample (LCS), and Laboratory Control Sample Duplicate (LCSD)

The precision assessment evaluates the agreement in analytical results between duplicate samples (field duplicates and laboratory duplicates). Precision was evaluated in accordance with the QAPP by calculating the relative percent difference (RPD) between duplicate samples.

Field Precision: A total of 13 and 9 field groundwater duplicate samples were collected from the Texas Site and California Site wells, respectively, and considered in the relative percent difference analysis. The precision objective for the field samples is an RPD $\leq$ 30%.

- For the Texas Site, relative percent difference values for duplicate samples were calculated for the four routinely detected compounds: i) 1,1 dichloroethene, ii) cis-1,2-dicholoroethene, iii) tetrachloroethene, and iv) trichloroethene. Three pairs of sample and duplicate results were reported as non-detect for 1,1-Dichloroethene, cis-1,2-dichloroethene, and trichloroethene. Therefore, the three pairs were not included in the RPD analysis. This yielded a dataset of 49 paired concentration measurements.

- For the California Site, relative percent difference values for duplicate samples were calculated for the ten routinely detected compounds: i) 1,1 dichloroethane, ii) 1,1 dichloroethene, iii) 1,2-dichloroethane, iv) chloroform, v) cis-1,2-dicholoroethene, vi) tetrachloroethene, vii) trans-1,2-dichloroethene, viii) trichloroethene, ix) trichlorofluoromethane, and x) trichloro-trifluoroethane. Two (2) pairs of sample and duplicate results were reported as non-detect for trichlorofluoromethane and trans-1,2-dichloroethene. These two pairs were not included in the RPD analysis. This yielded a dataset of 88 paired concentration measurements.

Note that in two instances at the California site, Rounds 2 and 4, duplicates were taken during the Snap Sampler events, but not included in overall RPD statistics. The purpose of this study's field duplicate collection was to investigate the effects on precision from field sampling and laboratory analysis of groundwater from the same source. However, Snap Sampler vials are collected from somewhat different vertical depths within the monitoring well (see Figure 5.2). As a result, the RPD results from calculations comparing upper and lower vials may be affected by stratification in VOC concentrations within the well. Therefore the Snap Sampler duplicates were not included in this precision analysis. The median RPD for the Snap Sampler duplicates was 17% compared to 5% for the other field duplicates.

Results of the field duplicate analysis at both sites are presented in Appendix C.4 and D.4, and are summarized below in Table 6.2

Table 6.2 Summary of Field Duplicate Precision

Site	Total Duplicate Analyses	Relative Percent Difference (RPD)				% Meeting RPD Standard
		> 30%	15-30%	5-15%	≤ 5%	
Texas	49	2	6	18	23	96%
California	88	12	5	28	43	86%
Combined	**137**	**14**	**11**	**46**	**66**	**90%**

At the Texas Site, 96% of RPD values were above the RPD criteria of 30%, while at the California Site, 86% of RPD values were above the RPD criteria, with therefore 90% of RPD values for the combined dataset above the RPD criteria.

Field duplicates met Data Quality Objectives for frequency of analysis (1 per 20 samples) at the Texas site, with 1 duplicate taken per 18 samples. However, because of the SNAP Sampler duplicates that were later qualified, the Data Quality Objectives for frequency of duplicate analysis was not met at the California site, with 1 duplicate taken per 27 samples.

Laboratory Precision: Laboratory precision of groundwater samples is demonstrated by RPD values calculated for matrix spike and matrix spike duplicate (MS/MSD) samples. Quality control analysis of the sample results used in this study from both the Texas and California sites resulted in all RPD values meeting the criteria of RPD ≤ 20%. It should be noted that both laboratories met the 1 in 20 samples requirement defined in the QAPP Table A.1 for MS/MSD frequency (Appendix B.2); however, some of the required MS/MSD samples were not associated with the project groundwater samples.

6.2.4 Accuracy Assessment

The objectives for field accuracy and laboratory accuracy were defined in the QAPP (Appendix B.2). The results of the data evaluation based on these objectives are provided below.

Field Accuracy: The evaluation of field accuracy was based on the analytical results obtained for groundwater trip blank samples. As defined in the QAPP, field accuracy will be met if the concentrations of the constituents in the trip blank are below project quantitation limits. All eighteen (18) trip blanks at the Texas Site successfully met the accuracy criteria. All sixteen (16) trip blanks at the California Site successfully met the accuracy criteria. In other words, no analytes were detected in the trip blanks at either site. It should be noted that this also satisfies the Data Quality Objective for minimum frequency of trip blank collection (1 per 3 days of sampling). No equipment rinsate blanks were needed as all equipment was dedicated to each well.

Laboratory Accuracy: Laboratory accuracy was assessed based on percent recoveries from MS/MSD, LCS, and surrogate samples. Exceptions for samples and analytes considered in this study were noted for 6 samples. These exceptions are shown below in Table 6.3. The laboratory issues associated with exceptions did not necessitate the removal of any extra samples from the overall analysis.

Table 6.3. Laboratory QA Result Exceptions

Site	Sample ID	Date	Reason for Exception	Comments
Texas	MW-23A-LFS-3	8/13/13	MS/MSD recoveries were below the control limits for tetrachloroethene due to matrix interference.	Result consistent with other events. Sample included in statistics.
California	MW-13-SSL-1	5/8/13	Analyzed past hold times.	Samples included in statistics.
	MW-14-SSL-1	5/8/13	Analyzed past hold times.	
	MW-17-SSL-1	5/8/13	Analyzed past hold times.	
	MW-23-SSL-1	5/8/13	Analyzed past hold times.	
	MW-24-SSL-1	5/8/13	Analyzed past hold times.	

6.2.4 Completeness Assessment

With the exceptions noted in Section 6.2.1, all necessary samples were collected and analyzed. The data quality exceptions noted in the data quality review are typical of environmental field programs and none of these exceptions limit the usability of the results obtained. The results of the data quality review are summarized below in Table 6.4.

Table 6.4 Summary of Data Evaluation Results

Data Quality Objective	Results of Data Quality Evaluation
Sampling Procedures	Acceptable*
Custody Procedures	Acceptable
Holding Time	Acceptable*
Temperature on Arrival	Acceptable
Field Duplicate Samples	Acceptable*
MS/MSD Samples	Acceptable*
LCS/LCSD Samples	Acceptable
Blank Analysis	Acceptable
Completeness Assessment	Acceptable
Overall Data Usability	**Acceptable**

Notes:

1. Acceptable = This DQO was evaluated and found to have met the requirements outlined in the QAPP.
2. Acceptable* = This DQO was evaluated and found to have deficiencies or exceptions as discussed in the text, however, the data was determined to be usable.

6.3 EFFECT OF SAMPLE METHOD ON SHORT-TERM VARIABILITY IN CONSTITUENT CONCENTRATIONS

The hypothesis for the field program was that alternative sampling methods would reduce the short-term variability in measured constituent concentrations compared to the reference method, Low Flow Standard.

6.3.1 Evaluation of Sample Methods Based on the Short-Term Variability Factor for Individual Measurements

The normalized residual (i.e., the short-term variability factor for each individual concentration measurement calculated as show in Section 6.1.3 and Figure 6.2) can be used to evaluate both bias between sample methods and differences in variability between sample methods. For example, if all of the concentration measurements for a specific sample method fall a similar distance above the long-term trend line, then the sample method has low variability but a consistent high bias (see Figure 6.2, Example 1). Alternatively, if the individual concentration measurements for a specific sample method vary widely both above and below the trend line, then the sample method has high short-term variability but little or no bias (see Figure 6.2, Example 2). In other words, the variance of the normalized residuals for a specific sample method provides a measure of the short-term variability associated with that individual measurement method.

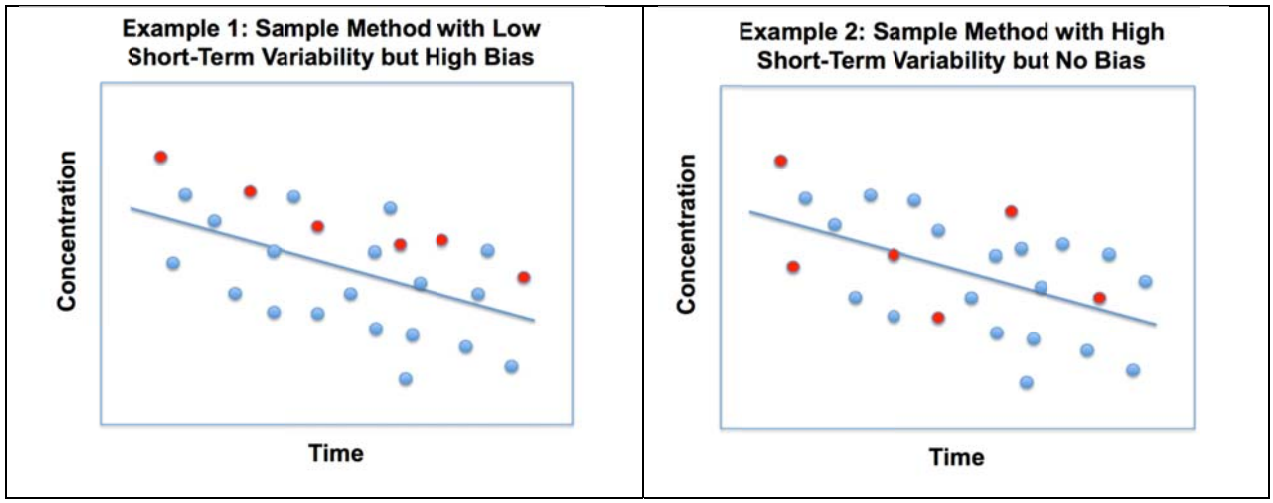


Figure 6.2. Evaluation of Short-Term Variability and Bias Associated With Specific Sample Methods (In the two examples, the red dots illustrate all of the samples collected with the specific sample method of interest and the blue dots represent samples collected with other sample methods).

Statistical Test Results: We used Levene's test to evaluate whether there were statistically significant differences in short-term variability in concentration between sample methods. In other words, Levene's test was used to test whether the variances were different for the sets of normalized residuals (short-term variability factors) associated with each sample method. Results of Levene's test using the entire dataset (i.e., data from both sites) shows a statistically significant difference in the variances for the sets of normalized residuals for the different sample methods ($p<0.001$). Levene's test also showed a statistically significant difference between methods for the two sites evaluated separately.

Low-Flow Standard and Low-Flow Alternative (Small Volume) are the least variable methods, while Low-Flow Alternative (Large Volume), Passive No Purge (SNAP) and Active No Purge (HydraSleeve) are somewhat more variable methods. This difference in variability is consistent across the two demonstration sites (except for Active No Purge, Figure 6.3) and for individual

constituents (Figure 6.4). This consistency between sites and constituents provides increased confidence that the results are likely to be applicable to other sites and chemicals.

Additionally, analysis of total purge volume from the Low Flow Standard method indicated that the median purge volumes for all wells and sampling events are similar to those of the Low Flow Alternative (Small Volume), or 3L. At the Texas site, the median value was 3.6L, while at the California Site, the median value was 7L.

A pair-wise comparison of each alternative sample method to Low-Flow Standard indicated that Low-Flow Alternative (Large Volume) and Active No Purge (HydraSleeve) were significantly more variable than Low-Flow Standard at the California site ($p<0.05$) and Low-Flow Alternative (Large Volume) and Passive No Purge (SNAP) were significantly more variable than Low-Flow Standard at the Texas site. Although the differences in variability were statistically significant, further analysis indicates that only the variability in the Active No Purge (HydraSleeve) method is likely to increase the amount of monitoring data needed to characterize the long-term change in concentration (see Section 6.3.4).

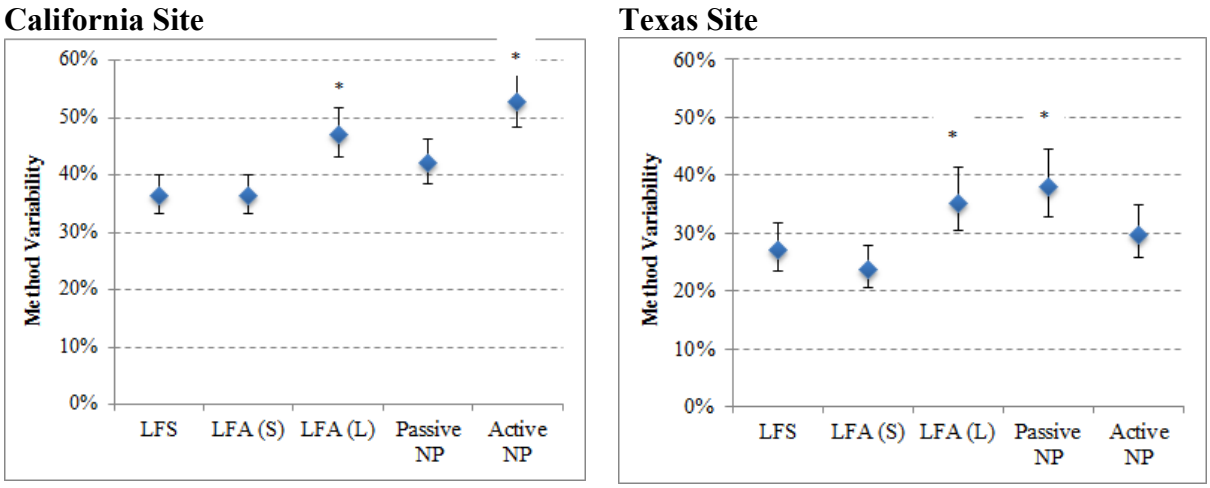


Figure 6.3. Short-Term Variability by Sample Method: Results for Individual Sites. The graphs show the standard deviation of the normalized residuals (short-term variability factors) for each sample method. The error bars show the 95% confidence interval for the standard deviation. * = method variability is significantly higher than Low Flow Standard ($p<0.05$). LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

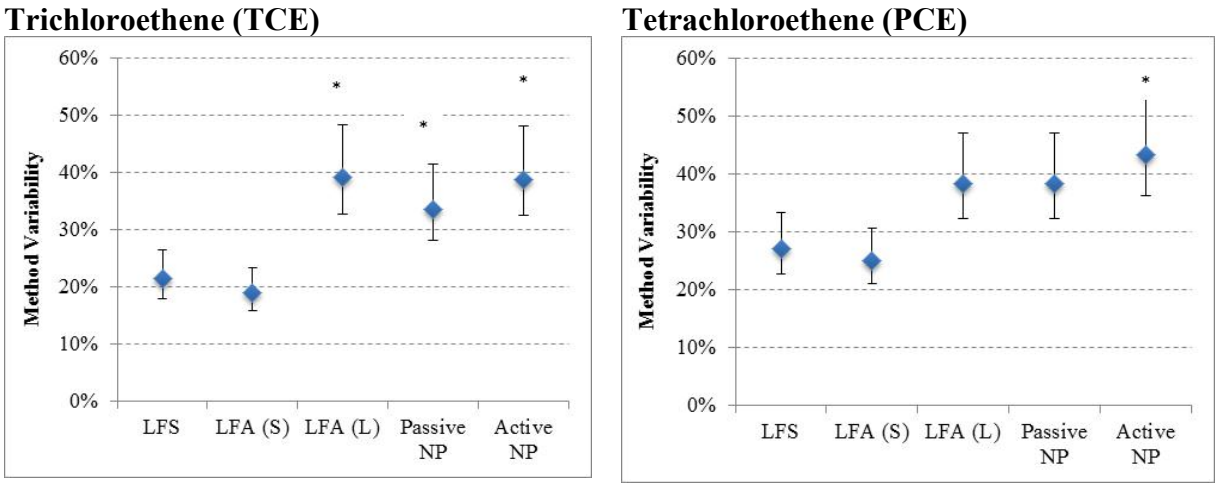


Figure 6.4. Short-Term Variability by Sample Method: Results for Individual Chemicals. The graphs show the standard deviation of the normalized residuals (short-term variability factors) for each sample method. The error bars show the 95% confidence interval for the standard deviation. * = method variability is significantly higher than Low Flow Standard ($p<0.05$). LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

6.3.2 Evaluation of Sample Methods Based on the Variability between Paired Measurements

The evaluation of variability between paired samples provides a second method to evaluate the effect of sample method on short-term variability and also of other factors contributing to the overall short-term variability. The effect of sample method on short-term variability was assessed by evaluating the difference in concentration between a sample from a well and the next sample collected from the same well using the same method using overlapping pairs. For example, the concentration measured by Low Flow Standard Sample Event 1 was compared to the concentration measured by Low Flow Standard Sample Event 2 and the concentration measured by Low Flow Standard Sample Event 2 was compared to the concentration measured by Low Flow Standard Sample Event 3. For each paired sample, the difference was calculated as the higher concentration minus the lower concentration divided by the lower concentration (see Section 6.1.4). If a sample method contributes to lower short-term variability, then the change in concentration from one sample event to the next will be lower than that for a sample method that has higher variability.

For comparison, we also looked at the difference in concentration between field duplicate samples and between Low Flow Alternative (Small Volume) samples and Low Flow Alternative (Large Volume) samples collected on the same day. As shown in Figure 6.5, the difference in concentration between sample events was similar for all sample methods except Active No Purge (HydraSleeve). For Low Flow Standard, Low Flow Alternative (Small Volume), Low Flow Alternative (Large Volume), and Passive No Purge (SNAP), the median concentration change for paired samples ranged from 20% to 24% and the 90th percentile concentration ratio ranged from 90% to 130%. However for Active No Purge (HydraSleeve), the median concentration ratio was 43% and the 90th percentile was 500%. This higher variability for Active No Purge

(HydraSleeve) was observed at the California site but not the Texas Site. The SERDP study ER-1705 also found that the Active No Purge (HydraSleeve) method yielded results that were more variable than those obtained using the Low Flow Standard method when used at the Hill AFB site. This prior finding suggests that the higher variability associated with the Active No Purge method is not unique to the California site (McHugh et al., 2015b).

The difference in concentration between sample events was similar to the difference in concentration between Low Flow Alternative (Small Volume) and Low Flow Alternative (Large Volume) samples collected on the same day (median concentration difference was 11% and 90th percentile was 100%) but was much larger than the difference in concentration between field duplicates (median difference was 6% and 90th percentile was 30%).

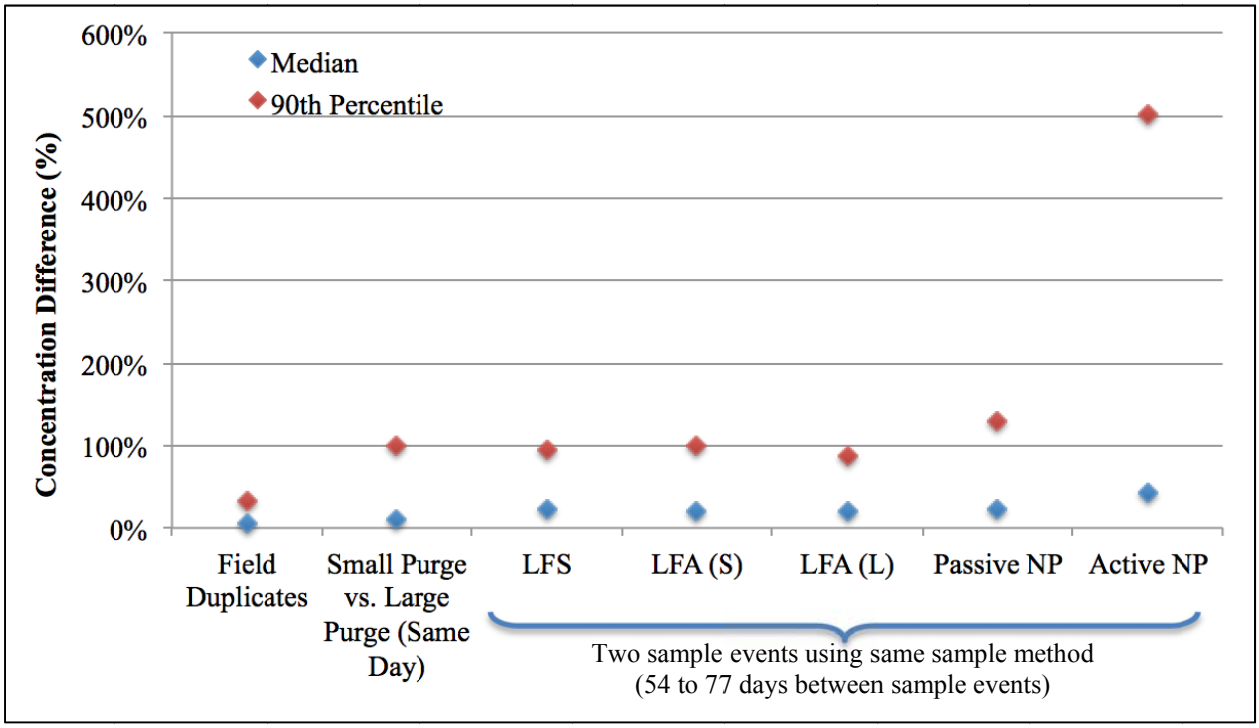


Figure 6.5. Effect of Sample Method on Variability between Paired Concentration Measurements. LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

6.3.3 Comparison to Historical Monitoring Variability

In order to further evaluate the effect of sample method on monitoring variability, we compared the variability observed during the field demonstration to variability observed in historical monitoring results from the same monitoring wells. Because the standard long-term monitoring program at the Texas site monitored for a limited set of analytes, we focused our analysis of historical variability on PCE and TCE. The historical datasets evaluated are summarized in Table 6.5.

Table 6.5. Monitoring Dataset for Evaluation of Historical Monitoring Variability.

Site	Sampling Method(s)	Monitoring Wells	Constituents	Sample Events	Total Measure-ments
Texas (Set 1)	3 Casing Volume Purge, Bailer Sampling	MW-02A, MW-06, MW-13, MW-15, MW-23A, MW-25A, MW-26, TW-01	PCE, TCE	6 (May 2005 to Aug 2009)	96
Texas (Set 2)	Low Flow Standard	MW-02A, MW-06, MW-13, MW-15, MW-23A, MW-25A, MW-26, TW-01	PCE, TCE	6 (Feb 2010 to Nov 2012)	84
California (Set 1a)	3 Casing Volume Purge, Bailer Sampling	MW-13, MW-14, MW-15, MW-17, MW-20	PCE, TCE	9 (Dec 2004 to Dec 2006)	90
California (Set 1b)	Passive No Purge (Diffusion)	MW-23, MW-24, MW-25	PCE, TCE	9 (Dec 2004 to Dec 2006)	54
California (Set 2)	Passive No Purge (SNAP)	MW-13, MW-14, MW-15, MW-17, MW-20, MW-23, MW-24, MW-25	PCE, TCE	10 (Dec 2010 to Mar 2013)	160

Note: For Texas (Set 2), only four sample events available for MW-23A and MW-25A and only five sample events available for MW-02A, and MW-06. For California (Set 1b), only eight sample events available for MW-25.

Method variability for the historical data sets was evaluated using the same approach as for the current data sets (see Section 6.1.3). The variability in the historical datasets was generally within the range of that observed in the current dataset (see Figure 6.6). For the California site, the variability for the Passive No Purge (SNAP) method was almost identical in the historical and current datasets while the historical bailer sampling was more variable than any of the current sampling methods. For the Texas site, the method variability for Low Flow Standard was higher for the historical data set than for the current data set. However, there is no way to determine whether these difference are due to differences in the way the sampling was conducted

during the two time periods, differences in other sources of variability (e.g., aquifer and well dynamics) between the two time periods, or the longer time periods covered by the historical datasets. The overall similarity in method variability between the current and historical data sets provides additional evidence that the sample method has only a small effect on the overall level of short-term monitoring variability.

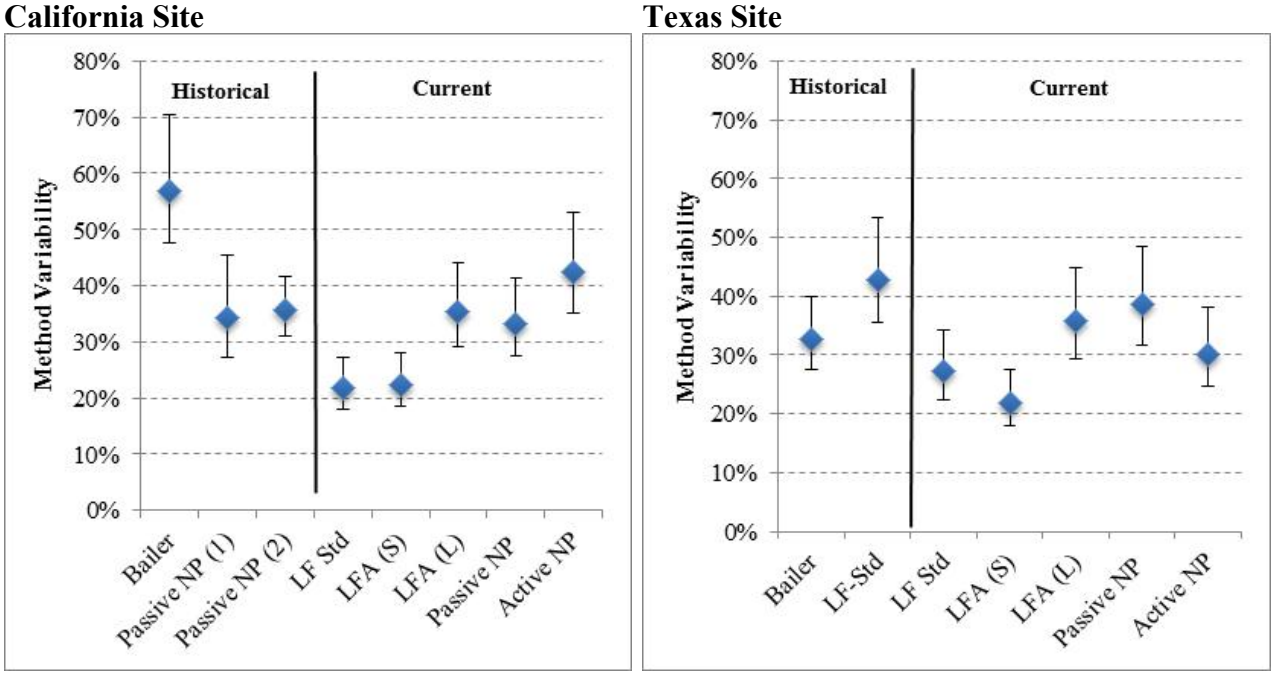


Figure 6.6. Short-Term Variability by Sample Method: Historical and Current Data Sets. The graphs show the standard deviation of the normalized residuals (short-term variability factors) for each sample method. Both the historical and current data sets include analytical results only for PCE and TCE. The error bars show the 95% confidence interval for the standard deviation.

6.3.4 Impact of Sample Method Variability on Evaluation of Long-Term Concentration Trends

The primary benefit of reducing short-term variability in groundwater monitoring results is to decrease the amount of monitoring required to characterize the true long-term trend in contaminant concentrations. Task 2 of this project has involved the development of a new groundwater monitoring optimization method based on the amount of monitoring required characterize the long-term concentration trend with a defined level of accuracy or confidence (McHugh et al., 2015a). The optimization tool developed under Task 2 can be used to quantify the effect of short-term variability on the amount of monitoring data required to characterize the long-term trend. We have utilized this tool to evaluate how the observed differences in short-term variability between sample methods affect the ability to characterize the long-term concentration trend.

For each of the five sampling methods, the Task 1 demonstration program yielded a dataset of six sampling events from a total of 16 monitoring wells with four to ten contaminants detected in each monitoring well. These five datasets were used to evaluate how the differences in short-

term variability between the sample collection methods would affect the ability to characterize the long-term monitoring trend (Table 6.7).

Table 6.7. Effect of Sample Method on Amount of Monitoring Required to Characterize the Long-Term Concentration Trend.

Sampling Method	Short-Term Variability (log scale)[1]	Quarterly Monitoring Events[2]	Increase Relative to Low Flow Std.[3]
Low Flow Std.	0.45	28	N/A
Low Flow Alternative Small Vol.	0.47	28	0%
Low Flow Alternative Large Vol.	0.50	30	7%
Passive No Purge	0.52	30	7%
Active No Purge	0.81	39	39%

Notes:

1) Short-term variability factor for Tier 2 Optimization tool; calculated as the standard deviation of the natural log of the residuals for each monitoring record.
2) Number of quarterly monitoring events required to characterize a long-term concentration trend with medium accuracy for a monitoring well with a true attenuation rate of 0.14 yr^{-1} (half-life of five years) and a short-term variability factor equal to that measured for the specific sampling method.
3) Percent increase in monitoring (relative to Low Flow Std.) required to characterize the long-term concentration trend with the same level of accuracy.

The results of this analysis indicate that the small differences in variability between Low Flow Standard, Low Flow Alternative (Small Volume), Low Flow Alternative (Large Volume), and Passive No Purge (SNAP) have little effect on the amount of data needed to characterize the long-term monitoring trend. However, the variability associated with Active No Purge (HydraSleeve) results in a 39% increase in the amount of data needed to characterize the long-term trend. As shown in Figure 6.5, the Active No Purge method resulted in some individual measurements that were very different from the average concentration. These large errors have a correspondingly large effect on the ability to accurately characterize the long-term trend. As a result, the variability associated with the Active No Purge method had a larger effect on the amount of data needed to characterize the long-term trend than the variability associated with the other sampling methods.

6.4 EVALUTION OF CONCENTRATION DIFFERENCE BETWEEN SAMPLE METHODS

The primary goal of this field demonstration was to evaluate the effect of sample method on short-term variability in monitoring results. However, the study design also allows for an evaluation of statistical bias between sample methods (i.e., the difference in concentrations).

6.4.1 Overall Statistical Bias between Methods

As illustrated in Figure 6.2, if a same method consistently yields concentration results above the trend line for the full data set, then that method is showing high statistical bias relative to the full

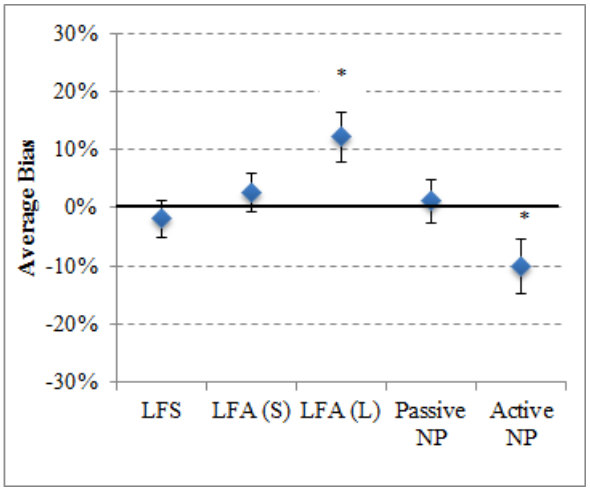
data set. In other words, that method (on average) yields a higher measured contaminant concentration compared to the other sample methods evaluated in the demonstration program.

We evaluated statistical bias between sample methods using the set of normalized residuals also used to evaluate differences in variability between methods (see Section 6.3.1). For each individual normalized residual, the sign of the residual (i.e., negative or positive) indicates whether the underlying concentration measurements were biased low (negative sign) or biased high (positive sign) relative to the full dataset. The value of the residual indicates the magnitude of the high or low statistical bias. For example, a normalized residual with a value of 0.11 indicated that the underlying concentration measurement was 11% higher than the average concentration measurement for the dataset. Therefore, average statistical bias for a single sampling method (relative to the full dataset) is equal to the average normalized residual error for the sample method.

Statistical Test Results: We used a t-test to evaluate whether individual sample methods were biased low or high relative to the full dataset. A method was determined to be biased high (or low) if the average statistical bias was different from zero at the 95% confidence level.

Overall, the biases between methods were low. The average statistical bias typically ranged from +20% to -15% (see Figure 6.7 and Figure 6.8). The most pronounced differences between methods were observed at the Texas site where the two no purge methods showed a statistical bias about +20% and the three purge methods showed a statistical bias of about -12%. However, this result was driven largely by three monitoring wells where the no purge concentrations were consistently higher than the purge concentration (see Section 6.4.2). This well-specific difference between the sample methods appeared to be more important than any well independent differences in statistical bias between the methods.

California Site



Texas Site

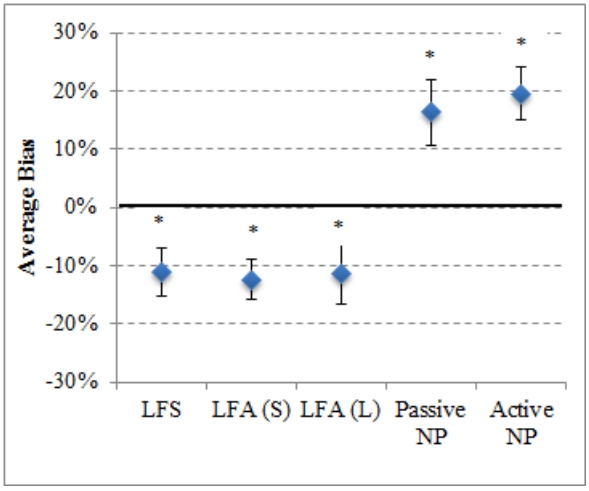


Figure 6.7. Difference in Contaminant Concentration by Sample Method: Results for Individual Sites. The graphs show the average of the normalized residuals (i.e., average statistical bias) for each sample method. The error bars show the 95% confidence interval for normalized residual. * = method bias is significantly different from zero ($p<0.05$). LFS = Low Flow Standard, LFA (L) = Low Flow

Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

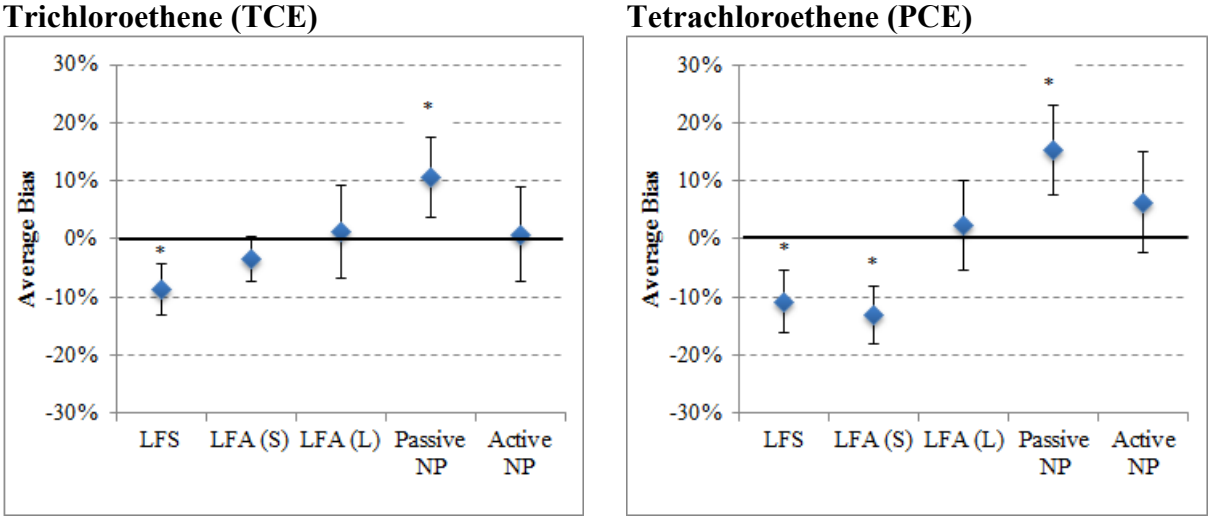


Figure 6.8. Difference in Contaminant Concentration by Sample Method: Results for Individual Chemicals. The graphs show the average of the normalized residuals (i.e., average statistical bias) for each sample method. The error bars show the 95% confidence interval for normalized residual. * = method bias is significantly different from zero ($p<0.05$). LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

6.4.2 Well-Specific Differences between Methods

Although the full dataset showed only small statistical bias with the five sample methods, larger effects were apparent in some individual monitoring wells: i) at the Texas site, both no-purge sample methods resulted in higher concentrations in three monitoring wells, ii) at the Texas site, the Passive No-Purge (SNAP) method yielded detections of vinyl chloride in some wells where the other methods yielded non-detect results, iii) at the California site, the Active No-Purge (HydraSleeve) method resulted in low biased concentrations in some monitoring wells during some monitoring events.

No Purge Methods at the Texas Site: At the Texas site, both no-purge sample methods yielded consistently higher contaminant concentrations than the three purge sample methods in three of the eight monitoring wells included in the study (MW-02A, MW-13, and MW-23A). For two of these monitoring wells (MW-02A and MW23A), the contaminant concentrations were 3x to 5x higher using the no-purge sample methods. For the third monitoring well, the contaminant concentrations were about 1.5x higher using the no-purge methods. For one well, contaminant concentrations were consistently about 1.5x higher with the Low Flow Alternative (Large Volume) method compared to the other methods. In the remaining four monitoring wells, there was no obvious difference between sample methods. There were no clear differences in screen depth or other construction characteristics between the three wells that showed the difference and the five wells that did not show the difference. Figure 6.9 shows an example of one monitoring well with this effect and one without.

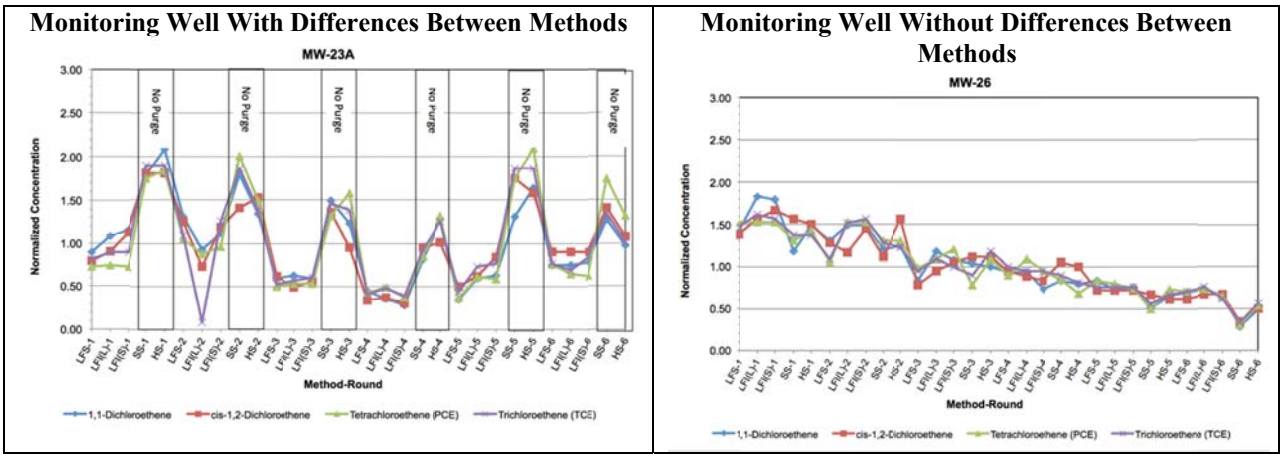


Figure 6.9. Examples of Monitoring Wells from Texas Site With and Without Bias Between No-Purge and Purge Sample Methods. LFS = Low Flow Standard, LFA (L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, Passive NP = Passive No Purge (SNAP Sampler), Active NP = Active No Purge (HydraSleeve).

Detections of Vinyl Chloride Using Passive No Purge: At the Texas site, the concentration of vinyl chloride was primarily non-detect in six of the eight monitoring wells. For these six wells, vinyl chloride was detected in only 26 of 180 samples (i.e., six wells, five sample methods, six rounds of sampling). Twenty of these 26 detections were obtained using the passive no purge samplers (Table 6.8). These results suggest that Passive No Purge (SNAP) may be more sensitive for detection of low concentrations of some volatile contaminants.

Table 6.8. Detections of Vinyl Chloride in Six Monitoring Wells with Mostly Non-Detect Results

Sample Method	Vinyl Chloride Analyses	Vinyl Chloride Detections
Low Flow Standard	30	1
Low Flow Alternative, Small Volume	30	1
Low Flow Alternative, Large Volume	30	4
Passive No Purge	30	20
Active No Purge	30	0

Active No Purge at the California Site: At the California site, the contaminant concentrations showed a distinct low statistical bias for 9 of the 36 samples (25%) collected using the active no purge method. For these samples, contaminant concentrations were 50% to 90% lower than contaminant concentrations measured during both the preceding sample events (i.e., using Passive No Purge) and the subsequent sampling event (i.e., using Low Flow Standard). Low biased sample events were observed in four different monitoring wells; however, for each of these wells there were also Active No Purge sample events that did not show this low statistical bias. These 9 low biased sample events appear to account for much or all of the increased variability in monitoring results observed in the Active No Purge dataset compared to the other sample methods. Figure 6.10 shows an example of one monitoring well with this effect and one without.

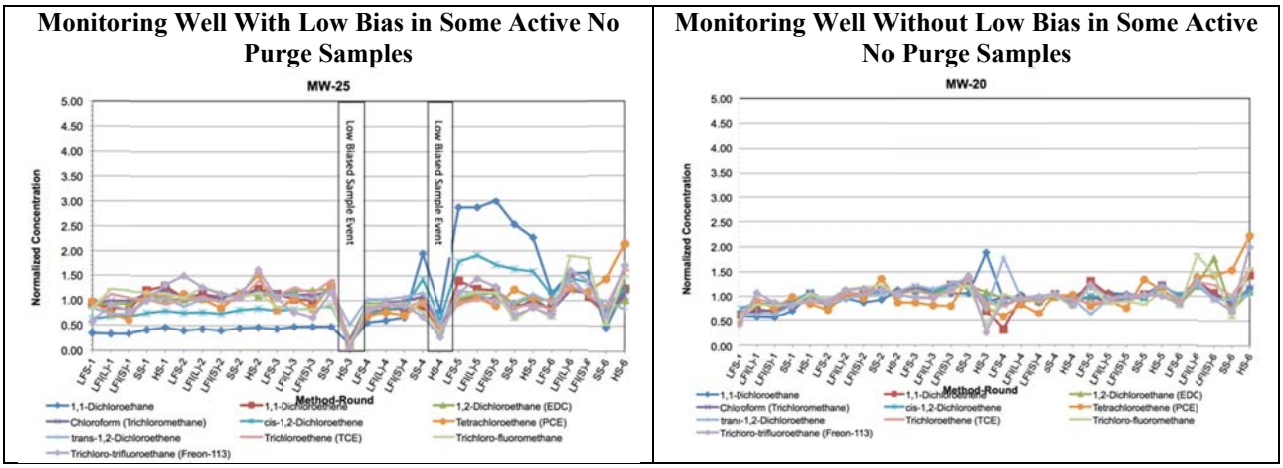


Figure 6.10. Examples of Monitoring Wells from California Site With and Without Low Bias in Some Active No Purge Samples. LFS = Low Flow Standard, LFA(L) = Low Flow Alternative, Large Volume Purge, LFA(S) = Low Flow Alternative, Small Volume Purge, SS = Passive No Purge (SNAP Sampler), HS = Active No Purge (HydraSleeve).

6.4.3 Other Studies of Statistical Bias between Sampling Methods

A number of other studies have evaluated the statistical bias between different purge and no purge groundwater sampling methods:

Britt et al., 2010: This study compares Passive No Purge (SNAP) results to Low Flow Standard results from six sites (a total of 42 monitoring wells). The median difference in concentration between the two sample methods ranged from 1% to 22% across the sites evaluated with the Passive No Purge method generally yielding the higher concentration result.

MWH, 2010. This study compared Active No Purge (HydraSleeve) to the standard 3 casing volume purge method in a 60 well comparative study. The authors found that the Active No Purge samples had statistically-significant lower TCE concentrations than standard purge methods and that than the mean difference was 40%. An additional analysis of data from Hill AFB conducted for SERDP project ER-1705 comparing TCE concentrations measured using HydraSleeve to concentrations measured using purge methods indicated that TCE concentration were, on average, 37% lower when measured using HydraSleeve.

Parker and Mulherin, 2007: This study compared Passive No Purge (SNAP) to Low Flow Standard at two sites. The authors found no significant different in VOC concentrations in samples collected using the two sampling methods.

Parker and Clark, 2004: This study compares five no purge methods to the Low Flow Standard method. The authors found only small differences (typically less than 5%) in VOC concentration between samples collected using the different methods.

Zumbro, 2014: This study compared both Active No Purge (HydraSleeve) and Passive No Purge (SNAP) to Low Flow Standard. Approximately 200 samples were compared. The authors found a statistically significant low bias in the Active No Purge sample results, but no reported

statistical difference between the Passive No Purge results and the Low Flow Standard results. Difference for the Active No Purge method indicated a median 60% low bias compared to the Low Flow Standard method for TCE.

Taken as a whole, these studies indicate little difference in concentration between sample collected using purge methods and Passive No Purge (SNAP Sampler) method. However, three studies show large (40% to 60%) and statistically-significant low bias in results obtained using Active No Purge (HydraSleeve) compared to purge methods.

6.5 CONCEPTUAL MODEL FOR SHORT-TERM VARIABILITY IN GROUNDWATER MONITORING RESULTS

The results from this demonstration combined with the results from SERDP projects ER-1704 and ER-1705 support a conceptual model that short-term variability in groundwater monitoring results is mostly attributable to small-scale spatial variability in contaminant concentrations within an aquifer (see Figure 6.11) and varying degrees of ambient mixing with the well screen between sampling events. This conceptual model is supported by the following findings:

- Field Duplicate Variability is Not Significant: The results from both ER-1705 and this project showed little variation in field duplicate concentrations (i.e., typically less than 10%). This indicates that laboratory analytical variability is small relative to other sources of variability in monitoring results.

- Few Important Differences Between Sample Methods: The results from this field demonstration show that no-purge and low flow purge sample methods yield monitoring results of similar quality when evaluated in terms of short-term variability and statistical bias (with the exception of Active No Purge at some sites). For most methods, variability associated with sample collection procedures is small relative to other sources of short-term variability.

- Concentrations Vary with Purge Volume: The results from ER-1704, ER-1705 and this project show that contaminant concentrations can vary with purge volume, however, the magnitude and pattern of change varies from well to well. The change in concentration with purge volume exceeds 2-fold in approximately 10% of wells and the direction of change appears to be random. Contaminant concentration may either increase or decrease with purge volume and in some wells may increase and then decrease (or decrease then increase). Contaminant concentrations may not stabilize when purge parameters stabilize.

- Concentrations Vary over Short Time Periods: The results from both ER-1705 and this project show that contaminant concentrations can vary over short time periods (i.e., days to weeks). The concentration change on a time scale of days to weeks is much higher than the field duplicate variability and somewhat higher than the purge variability. The variation in concentration over short time periods is mostly time independent (i.e., the magnitude of change is largely independent of the time between sampling events).

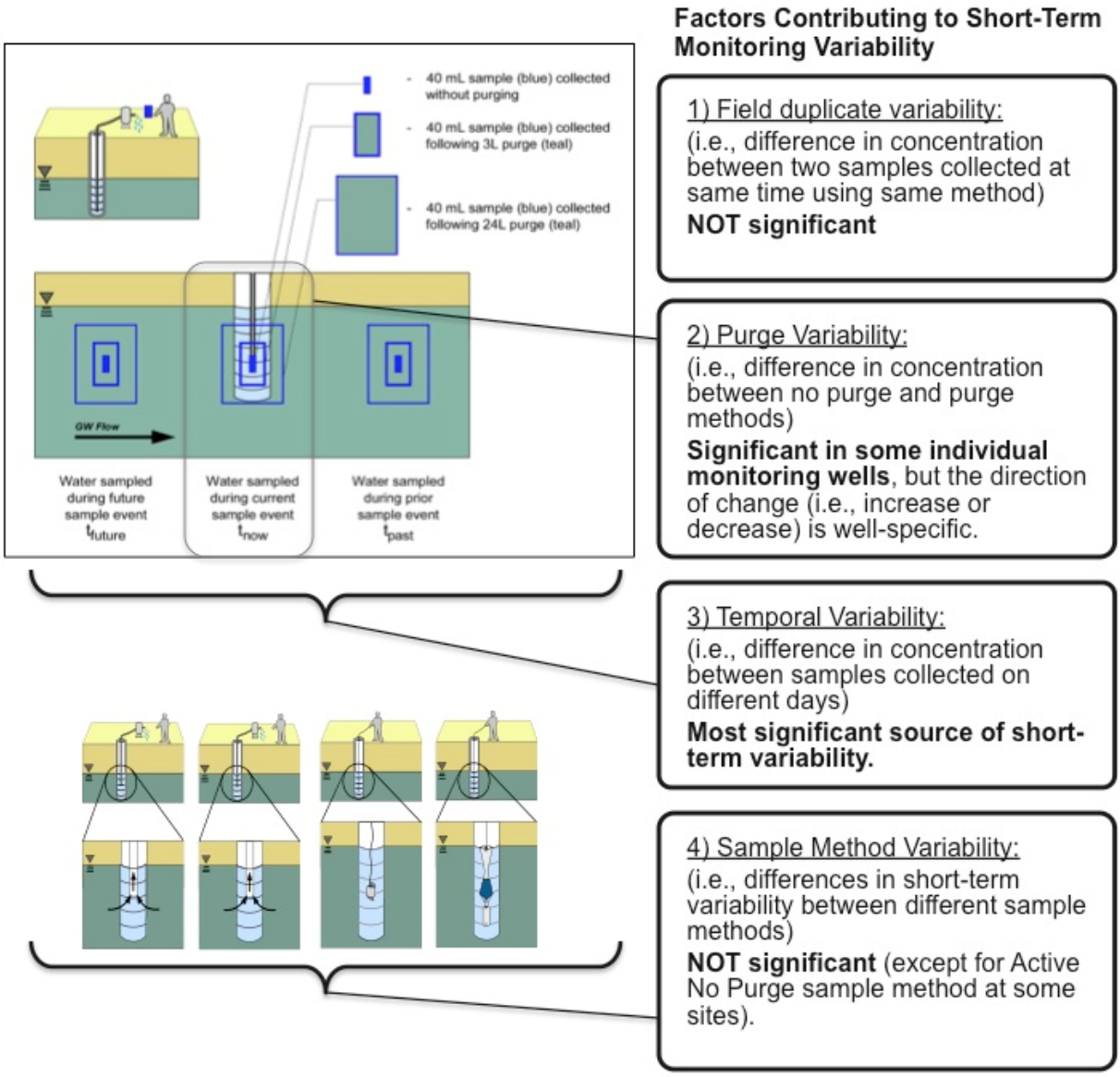


Figure 6.11. Conceptual Model for Short-Term Variability in Groundwater Monitoring Results

7.0 COST ASSESSMENT

Costs incurred during the field program demonstration for each of the four groundwater sampling methods were tracked and analyzed: Low Flow Standard, Low Flow Alternative, Passive No Purge (SNAP), and Active No Purge (HydraSleeve). Incurred costs for the field program demonstration were then extrapolated in order to estimate costs for implementing each technology at a standard site.

7.1 COST MODEL

The field demonstration included five different sampling methods, each implemented at two sites. Key cost elements that were tracked included: i) project planning and preparation, ii) field implementation, and iii) data evaluation and reporting (Table 7.1).

Table 7.1. Cost Model for Field Demonstration Program

Cost Element	Data Tracked	Examples
1. Project planning and preparation	Labor hours	Senior Project Scientist/Engineer, Project Scientist / Engineer
	Supplies	SNAP Samplers, HydraSleeve, Submersible pumps
2. Field program	Labor hours	Senior Project Scientist/Engineer, Project Scientist / Engineer
	Equipment Rental, Supplies, Shipping	Standard sampling equipment rental, operating costs, consumables
	Sample Analysis	Off-site laboratory analysis
3. Data evaluation and reporting	Labor hours	Senior Project Scientist/Engineer, Project Scientist / Engineer

7.1.1 Cost Element: Project Planning and Preparation

Project planning for the field demonstration included site selection, review of existing site data, attainment of site access, and detailed work plans for all sampling events. Additionally, supplies such as submersible pumps, SNAP Samplers and HydraSleeve samplers were purchased prior to field mobilization.

7.1.2 Cost Element: Field Program

Costs for the field program include labor hours sample collection during sampling events. Additionally, equipment rental, purchase of replacement parts as well as sample analysis was tracked.

7.1.3 Cost Element: Data Evaluation and Reporting

Following completion of the demonstration, the results and data were reviewed, analyzed, and recorded into a report to document the findings.

7.2 COST DRIVERS

Cost drivers for the specific sampling methods are presented below.

Low Flow Standard
Cost drivers for implementation of low-flow standard include: i) labor hours, ii) equipment purchase for deeper wells, iii) waste handling and disposal, and iv) equipment rental. A significant cost driver for Low Flow Standard was labor hours, which included taking measurements of water parameters, and waiting for parameter stabilization which can vary per well and event. Other cost drivers for Low Flow Standard relate to equipment needs for deeper wells. The capital cost is higher for the purchase of submersible pumps in deeper wells, whereas a peristaltic pump may be rented for shallow wells. Regardless of the pump selected, other equipment, including a water quality meter and turbidity meter, will need to be rented for each event.

Low Flow Alternative (Large Volume Purge)
Cost drivers for implementation of Low Flow Alternative (Large Volume) are the same as those for Low Flow Standard. However, the length of time associated with sampling each well for Low Flow Alternative (Large Volume) is more predictable than Low Flow Standard, since the purge volume is fixed. Additionally, Low Flow Alternative methods had higher purging rates than Low Flow Standard (i.e., average of 600 mL/min for Low Flow Alternative at the Texas site vs. less than 250 mL/min for Low Flow Standard). Additionally, no rental equipment for measuring water quality parameters was required.

Low Flow Alternative (Small Volume Purge)
Cost drivers for implementation of Low Flow Alternative (Small Volume) are the same as those for Low Flow Alternative (Large Volume). However, fewer labor hours are required because less time is needed to pump 3L rather than 18L.

Passive No Purge (SNAP)
Cost drivers associated with implementation of SNAP samplers include: i) initial equipment purchase, and ii) replacement SNAP Sampler vials per sampling event. This method requires that each well is outfitted with equipment, including: SNAP Sampler (s), trigger line, well dock, and SNAP Sampler vials. In addition, replacement vials must be purchased for each sampling event.

Active No Purge (HydraSleeve)
Cost drivers associated with implementation of HydraSleeve at the site include: i) initial equipment purchase and ii) replacement HydraSleeve purchase per sampling event. This method requires the initial purchase of bottom weights, clips and installation string/rope for each well. In addition, replacement HydraSleeves must be purchased for each sampling event.

7.3 COST ANALYSIS

The following sections describe the implementation costs at a standard site using cost data acquired during the field demonstration. In particular, these standard implementation costs are based on specific assumptions and are presented for both shallow and deep wells.

7.3.1 Cost Analysis Assumptions

The following assumptions were made for the cost analysis:

General Assumptions

- A typical site of 15 monitoring wells to be sampled during each groundwater monitoring event.
- Field mobilization indicates number of trips required to complete sampling event. Mobilization includes travel time to site for field personnel, and is assumed to be one hour round-trip.
- Labor hours include typical time spent on site based on field program experience by GSI personnel (e.g., driving time between wells at small site, ~1-hour lunch break, etc.).
- Costs that are specific to the sampling method (labor hours, capital costs) are reflected. Other costs (sample analysis, and field preparation time) are not included, as they will be the same across methods. As such, the analysis below represents the cost differential between sampling method implementation.
- Costs are separated into *first* and *subsequent* sampling event costs. First sampling event costs include capital costs that are likely a one-time expenditure. Subsequent costs include predominantly labor and minor costs associated with replacement of equipment parts as applicable to the sampling method.
- Equipment rental costs are assumed to be: Water quality meter ($75/day), turbidity meter ($23/day), peristaltic pump ($35/day), water level meter ($20/day), pump controller ($10/day), truck ($100/day).

Shallow vs. Deep Wells

- Shallow wells are defined as:
  - Low Flow Purging Methods:
    - Wells that with sampling depth less than 25 ft bgs such that a peristaltic pump can function and its use is allowed by regulatory agency. Rental of peristaltic pumps is assumed.
  - Passive No Purge (SNAP):
    - Wells with the sampling depth of <50 ft in which the use of manual trigger lines are applicable.
  - Active No Purge (HydraSleeve):
    - No equipment differences are assumed between shallow and deep wells.

- Deep wells are defined as:
  - Low Flow Purging Methods:
    - Wells that with sampling depth greater than 25 and less than 70 ft bgs which require the use of submersible pumps (e.g., 12V Proactive Monsoon Pump), or

wells at which the use of peristaltic pumps are not allowed by a regulatory agency. Purchase of dedicated submersible pumps is assumed.

- Passive No Purge (SNAP):
  - Wells with the sampling depth of >50 ft in which a pneumatic trigger and pneumatic actuator are required.
- Active No Purge (HydraSleeve):
  - No equipment differences are assumed between shallow and deep wells.

Assumptions per Sampling Method

- Low Flow Standard
  - Peristaltic pump rental assumed for shallow wells. Purchase of dedicated plastic submersible pumps (e.g., 12V Proactive Monsoon Pump) is assumed for deep wells.
  - Water quality meters are rented daily during each sampling event for parameter measurements.
  - Waste disposal of purge water included on a per drum basis, including partially filled drums. Waste disposal frequency assumed to be after every sampling event due to typical site restrictions on storing purge water on site.
  - Long term monitoring program costs include replacement of tubing and dedicated pumps every 3 years.

- Low Flow Alternative (Small and Large Volumes)
  - Flow rate assumed to be average of GSI field program at 600 mL/min and set purge volumes of 3L and 18L.
  - Peristaltic pump rental assumed for shallow wells. Purchase of dedicated electric submersible pumps is assumed for deep wells.
  - Waste disposal of purge water included on a per drum basis, including partially filled drums. Waste disposal frequency assumed to be after every sampling event due to typical site restrictions on storing purge water on site.
  - Long term monitoring program costs include replacement of tubing and dedicated pumps every 3 years.

- Passive No Purge (SNAP)
  - Dedicated SNAP Samplers are purchased for each well. SNAP Samplers are reinstalled after each sampling event.
  - Recurring costs for replacement sample vials included for subsequent sampling events.
  - No waste disposal of purge water required.

- Active No Purge (HydraSleeve)
  - After sampling a well, a new HydraSleeve is installed in the well for the next sampling event.
  - Dedicated HydraSleeve installation equipment to be purchased initially (i.e., bottom weights, clips, etc.).
  - Waste disposal costs are assumed to be negligible to due low volumes.
  - Long term monitoring program costs include replacement of installation tether every 5 years.

Long Term Monitoring Program

- Long term monitoring program costs represent the total cost of sampling 15 wells per sampling event, with 2 sampling events per year for 10 years.

7.3.2 Estimated Costs of Sampling Method Implementation

Estimated field implementation costs for the different sampling methods as well as shallow and deep wells are provided below in Tables 7.2 through 7.6. The costs provided below are not meant to reflect the total cost of field program implementation, but rather show the cost differentials between the different groundwater sampling methods.

Table 7.2. Field Implementation Costs for Shallow and Deep Wells: Low Flow Standard

Cost Category	Description	Units	Unit Cost	Subtotal
Low-Flow Standard				
Shallow Well				
Capital Cost	Tubing	1	$80	$80
Labor Hours	2 field personnel on site	14	$170/hr	$2,378
Equipment Rental	Water quality meter, turbidity meter, peristaltic pump, water level meter, truck	2	$253/day	$506
Consumables	--	--	--	--
Waste Disposal	Disposal of purge water	1	$304	$304
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	2	$170/mob	$340
			Unit Cost per Well (First / Subsequent Events)	$241 / $235
			Total Cost per Sampling Event (First / Subsequent Events)	$3,608 / $3,528
			Total 10-year Monitoring Program (2 events/yr)	$71.0 K
Deep Well				
Capital Cost	Submersible pump, tubing, 12V battery	15	$460	$6,898
Labor Hours	2 field personnel on site	15	$170/hr	$2,505
Equipment Rental	Water quality meter, turbidity meter, water level meter, pump controller, truck	2	$228/day	$456
Consumables	--	--	--	--
Waste Disposal	Disposal of purge water	1	$304	$304
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	2	$170/mob	$340
			Unit Cost per Well (First / Subsequent Events)	$700 / $240
			Total Cost per Sampling Event (First / Subsequent Events)	$10,503 / $3,605
			Total 10-year Monitoring Program (2 events/yr)	$99.7 K

Table 7.3. Field Implementation Costs for Shallow and Deep Wells: Low Flow Alternative (Large Volume)

Cost Category	Description	Units	Unit Cost	Subtotal
Low-Flow Alternative (Large Volume Purge)				
Shallow Well				
Capital Cost	Tubing	1	$80	$80
Labor Hours	2 field personnel on site	12	$170	$2,098
Equipment Rental	Peristaltic pump, water level meter, truck	2	$155	$310
Consumables	--	--	--	--
Waste Disposal	Disposal of purge water (2 drums)	1	$400	$400
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	2	$170/mob	$340
Unit Cost per Well (First / Subsequent Events)				$215 / $210
Total Cost per Sampling Event (First / Subsequent Events)				$3,228 / $3,148
Total 10-year Monitoring Program (2 events/yr)				$63.4 K
Deep Well				
Capital Cost	Submersible pump, tubing, 12V battery	15	$460	$6,898
Labor Hours	2 field personnel on site	13	$170/hr	$2,226
Equipment Rental	Water quality meter, turbidity meter, water level meter, pump controller, truck	2	$130/day	$260
Consumables	--	--	--	--
Waste Disposal	Disposal of purge water (2 drums)	1	$400	$400
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	2	$170/mob	$340
Unit Cost per Well (First / Subsequent Events)				$675 / $215
Total Cost per Sampling Event (First / Subsequent Events)				$10,123/ $3,225
Total 10-year Monitoring Program (2 events/yr)				$92.1 K

Table 7.4. Field Implementation Costs for Shallow and Deep Wells: Low Flow Alternative (Small Volume)

Cost Category	Description	Units	Unit Cost	Subtotal
Low Flow Alternative (Small Volume Purge)				
Shallow Well				
Capital Cost	Tubing	1	$80	$80
Labor Hours	2 field personnel on site	6	$170	$1,035
Equipment Rental	Peristaltic pump, water level meter, truck	1	$155	$155
Consumables	--	--	--	--
Waste Disposal	Disposal of purge water	1	$304	$304
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	1	$170/mob	$170
Unit Cost per Well (First / Subsequent Events)				$116 / $111
Total Cost per Sampling Event (First / Subsequent Events)				$1,744 / $1,664
Total 10-year Monitoring Program (2 events/yr)				$33.8 K
Deep Well				
Capital Cost	Submersible pump, tubing, 12V battery	15	$460	$6,898
Labor Hours	2 field personnel on site	7	$170/hr	$1,163
Equipment Rental	Water quality meter, turbidity meter, water level meter, pump controller, truck	1	$130/day	$130
Consumables	--	--	--	--
Waste Disposal	Disposal of purge water	1	$304	$304
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	1	$170/mob	$170
Unit Cost per Well (First / Subsequent Events)				$578 / $118
Total Cost per Sampling Event (First / Subsequent Events)				$8,665 / $1,777
Total 10-year Monitoring Program (2 events/yr)				$62.9 K

Table 7.5. Field Implementation Costs for Shallow and Deep Wells: Passive No Purge (SNAP)

Cost Category	Description	Units	Unit Cost	Subtotal
Passive No Purge (SNAP)				
Shallow Well				
Capital Cost	SNAP Samplers and related parts	15	$450	$6,755
Labor Hours	2 field personnel on site	6	$170/hr	$990
Equipment Rental	Truck	1	$120/day	$120
Consumables	Sample vials (2)	15	$32	$480
Waste Disposal	--	--	--	--
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	1	$170/mob	$170
Unit Cost per Well (First / Subsequent Events)				$568 / $117
Total Cost per Sampling Event (First / Subsequent Events)				$8,515 / $1,760
Total 10-year Monitoring Program (2 events/yr)				$42.0 K
Deep Well				
Capital Cost	SNAP Samplers and related parts	15	$630	$9,435
Labor Hours	2 field personnel on site	7	$170/hr	$1,117
Equipment Rental	Truck and water level meter	1	$120/day	$120
Consumables	Sample vials (2)	15	$32	$480
Waste Disposal	none	--	--	--
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	1	$170/mob	$170
Unit Cost per Well (First / Subsequent Events)				$755 / $126
Total Cost per Sampling Event (First / Subsequent Events)				$11,322 / $1,887
Total 10-year Monitoring Program (2 events/yr)				$47.2 K

Table 7.6. Field Implementation Costs for Shallow and Deep Wells: Active No Purge (HydraSleeve)

Cost Category	Description	Units	Unit Cost	Subtotal
Active No Purge (HydraSleeve)				
Shallow Well				
Capital Cost	String, weight, clips	15	$25	$381
Labor Hours	2 field personnel on site	6	$170/hr	$958
Equipment Rental	Truck	1	$120/day	$120
Consumables	2" HydraSleeve	15	$24	$356
Waste Disposal	--	--	--	--
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	1	$170/mob	$170
Unit Cost per Well (First / Subsequent Events)				$153/ $127
Total Cost per Sampling Event (First / Subsequent Events)				$2,290 / $1,909
Total 10-year Monitoring Program (2 events/yr)				$38.9 K
Deep Well				
Capital Cost	String, weight, clips	15	$27	$410
Labor Hours	2 field personnel on site	6	$170/hr	$1,085
Equipment Rental	Truck and water level meter	1	$120/day	$120
Consumables	2" HydraSleeve	15	$24	$356
Waste Disposal	--	--	--	--
Field Mobilizations	Number of mobilizations to site. Assume travel time of 1 hour/mob.	1	$170/mob	$170
Unit Cost per Well (First / Subsequent Events)				$163/ $136
Total Cost per Sampling Event (First / Subsequent Events)				$2,442 / $2,036
Total 10-year Monitoring Program (2 events/yr)				$41.5 K

7.3.3 Cost Comparisons between Sampling Method Implementation

As can be seen in Figures 7.1 and 7.2 below, Low Flow Standard is the most expensive groundwater monitoring technology that was analyzed. In assessing the long-term total monitoring cost at a site (10 years, 2 events/yr), the following represents the total cost from least to most expensive for shallow wells: Low Flow Alternative (Small Volume), Active No Purge (HydraSleeve), Passive No Purge (SNAP), Low Flow Alternative (Large Volume) and Low-Flow Standard.

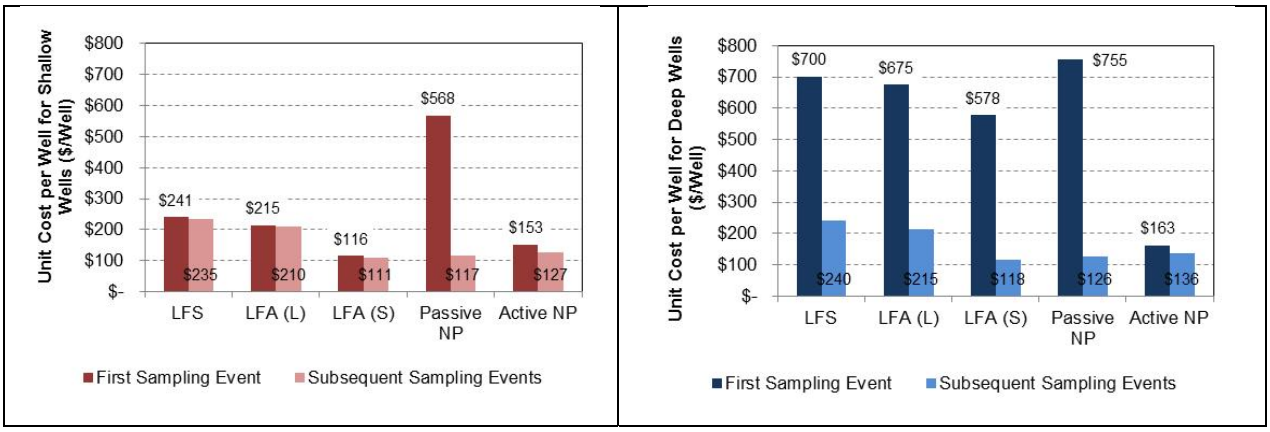


Figure 7.1. Unit Cost per Well in Shallow (left panel) and Deep (right panel) Wells. Costs for the first event (darker shade) and subsequent events (lighter shade) are also presented. LFS = Low Flow Standard, LFA (L) = Low Flow Alternative Large Volume Purge, LFA (S)= Low Flow Alternative Small Volume Purge, Passive No Purge = SNAP Samplers, Active No Purge = HydraSleeve.

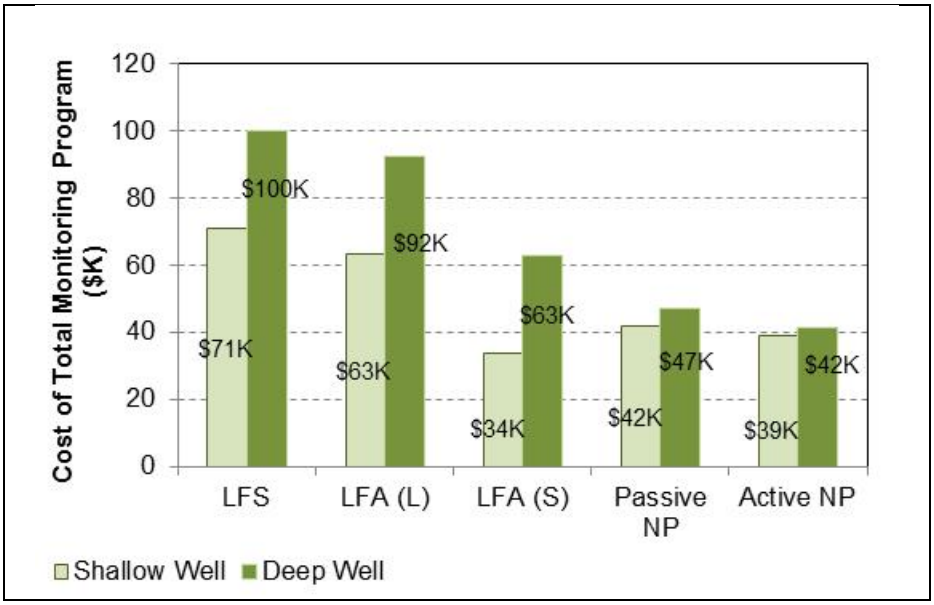


Figure 7.2. Cost of Total Monitoring Program (10 years, semi-annual sampling, 15wells, in $K) for Shallow (lighter shade) and Deep (darker shade) Wells. LFS = Low Flow Standard, LFA (L) = Low Flow Alternative Large Volume Purge, LFA (S)= Low Flow Alternative Small Volume Purge, Passive No Purge = SNAP Samplers, Active No Purge = HydraSleeve.

Additionally, the labor hours required for sampling per well at the field site varied significantly across the sampling methods. Assuming an 8-hour field day, this translated to a varying number of wells that can be sampled in one mobilization, as well as total labor cost per well per mobilization.

As seen in Table 7.7 below, the labor cost per well in one mobilization associated with applying sampling methods are as follows in increasing order: Low-Flow Alternative, Small Volume ($90/well) / HydraSleeve ($90/well), SNAP Samplers ($90/well), Low-Flow Alternative, Large Volume ($180/well) and Low Flow Standard ($220/well). Note that these are higher-end

estimates of number of wells that can be sampled in one day as they do not include time to travel between sampling wells at large sites, and minimal downtime during the 8-hour day (i.e., 1 hour break).

Table 7.7. Summary of Sampling Time in the Field and Subsequent Labor Costs

Sampling Method	Approximate Time per Well (hrs)	Estimated Number of Wells Sampled in One Field Day	Labor Cost per Well per Mobilization	Labor Cost per Well Ratio Compared to Low Flow Standard
Low Flow Standard	0.9	8	$220	1.0
Low Flow Alternative (Small Volume)	0.4	20	$90	0.4
Low Flow Alternative (Large Volume)	0.8	10	$180	0.8
SNAP Samplers (Passive No Purge)	0.4	20	$90	0.4
HydraSleeve (Active No Purge)	0.4	20	$90	0.4

Notes:
1. Assumes one field mobilization is an 8 hour day, not including travel time to site or travel between sampling wells at site.
2. Labor cost for two field personnel, approx. $170/hr rate total
3. Approximate time per well based on GSI field program experience and includes time for installation of each sampling method equipment.

8.0 IMPLEMENTATION ISSUES

8.1 TECHNOLOGY TRANSFER AND REGULATORY ACCEPTANCE: SAMPLING METHOD

This study looked at two types of active sampling and two types of passive sampling methods. All sampling methods are mature technologies, with extensive peer-reviewed literature, ESTCP studies, ASTM Standards, and regulatory acceptance for all methods at a variety of sites in recent years. Specifically, guidance includes:

- Groundwater sampling protocols are covered in ASTM D4448-01
- Guidelines for active sampling, both for the constant volume purge and purge to parameter stability, can be found in documents such as EPA Standard Operating Procedures. The ASTM Standard that applies to purge sampling is ASTM D6452-99.
- Guidelines for active and passive no-purge sampling, both for the HydraSleeve and SNAP Samplers can be found in documents such as the ITRC's 2007 report.
- The ASTM Standard that applies to passive no-purge sampling is D7929-14.

Thus, all four methods have few end-user concerns, are straightforward to master, and can be easily applied without substantial implementation issues at most sites. Both the no purge sample methods and the alternative (i.e., fixed volume) low flow purge methods were found to be more cost effective than the standard method of low flow purge to parameter stability. The no purge methods result in little to no generation of purge waste and, therefore, may be more strongly favored at sites where management of purge waste is a logistical challenge or is expensive. Sample volume constraints for the no purge methods are the principal implementation concern where certain analyte suites require large water volumes. For those sites, the low flow alternative methods may be more applicable.

Based on the results of our field program, regulatory acceptance of a novel "improved" sampling method will likely not be an issue. However, our project findings do indicate that low flow sampling with a fixed purge volume is less expensive than monitoring purge parameter stability and yield monitoring results of equal quality. There would likely be some regulatory barriers for sites that wanted to switch from purge to parameter stability to fixed volume purge. In addition, although no purge sampling methods have been fairly widely accepted, there are still some regulatory barriers for these methods.

Our plan for regulatory acceptance of sampling alternatives to low flow sampling with purge parameter stability are:

1) Publication of a journal article presenting our project results.
2) Presentation of our project results at technical conferences
3) A comprehensive ½ day workshop on groundwater sampling variability

The ½-day workshop will include a module on groundwater sampling methods. In addition to presenting the results from our field program, this module will also present results from SERDP Projects ER-1704 and ER-1705 and other lines of evidence demonstrating that monitoring of

purge parameters during low flow sampling does not improve the accuracy or stability of the concentration results. In addition to using this module in the workshop, it may be possible to present it as a webinar to regulatory stakeholders such as the EPA Groundwater Forum.

8.2 TECHNOLOGY TRANSFER AND REGULATORY ACCEPTANCE: MONITORING OPTIMIZATION AND TREND ANALYSIS TOOLKIT

Our plans for regulatory acceptance of the monitoring optimization tool are similar:

1) Publication of a journal article presenting our project results
2) Presentation of our project results at technical conferences
3) A comprehensive ½ day workshop on groundwater sampling variability

The ½-day workshop will include a module on the optimization tool that covers the technical basis for the tool and application of the tool to individual sites. Again, it may be possible to present this module as a webinar to regulatory stakeholders.

An additional option to promote the regulatory acceptance of the optimization tool would be through the application of the tool at a DoD facility with a specific need to optimize monitoring frequency (e.g., as part of a five-year review). We could work with such a facility to apply the tool to their historical monitoring dataset and to present the results the overseeing regulatory agency.

9.0 REFERENCES

AFCEE. 2006. Long-Term Monitoring Optimization Guide. Air Force Center for Environmental Excellence, Environmental Restoration Division. November 2006. http://www.afcee.brooks.af.mil/products/rpo/docs/LTM06Guidance1212.pdf

ASTM, 2002. Standard Practice for Low –Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations. Designation D 6771-02.
ASTM Standard D4448-01: Standard Guide for Sampling Ground-Water Monitoring Wells

ASTM Standard D7929-14: Standard Guide for Selection of Passive Techniques for Sampling Groundwater Monitoring Wells.

ASTM Standard D6452-99: Standard Guide for Purging Methods for Wells Used for Groundwater Quality Investigations Region 4 US EPA Science and Ecosystem Support Division (SESD) Operating Procedure Groundwater Sampling -- March 6, 2013: http://www.epa.gov/region4/sesd/fbqstp/Groundwater-Sampling.pdf

Britt, S. L., Parker, B.L., Cherry, J.A., 2010. A downhole passive sampling system to avoid bias and error from groundwater sample handling. Environ. Sci. Technol. 44 (13), pp 4917–4923.

Britt, Sanford, James Martin-Hayden, Mitchell Plummer, 2015, Final Report for SERDP Project ER-1704, An Assessment of the Aquifer/Well Flow Dynamics: Identification of Parameters Key to Passive Sampling and Application of Downhole Sensor Technologies, in press.

DNREC,. Standard Operating Procedure Duplicate Samples Sampling. Department of Natural Resources and Environmental Control, Site Investigation & Restoration Branch.

GeoInsight, 2010. Procedures for Sampling with HydraSleeve. http://www.blm.gov/pgdata/etc/medialib/blm/wy/field-offices/pinedale/papadocs/sampleplan.Par.29949.File.dat/appc.pdf (Accessed January 26, 2015).

ITRC, 2004. Technical and Regulatory Guidance for Using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater. Avaliable from http://www.itrcweb.org/Guidance/ListDocuments?TopicID=17&SubTopicID=27 (Accessed December 20, 2012)

ITRC, 2007. Protocol for Use of Five Passive Samplers to Sample for a Variety of Contaminants in Groundwater. Avaliable from http://www.itrcweb.org/Guidance/ListDocuments?TopicID=17&SubTopicID=27 (Accessed December 20, 2012

Kiff, . How to Fill a VOA Vial. Kiff Analytical LLC.

Martin-Hayden, James, Mitchell Plummer, Sanford Britt, *2014*, Controls of Wellbore Flow Regimes on Pump Effluent Composition, Groundwater v52, p. 96-104.

McHugh, T.E., Kulkarni, P.R., Beckley, L.M., Newell, C.J., Strasters, B., 2015a. A New Method to Optimize Monitoring Frequency and Evaluate Long-Term Concentration Trends, Task 2 & 3 Report, Methods for Minimization and Management of Variability in Long-Term Groundwater Monitoring Results, ESTCP Project ER-201209.

McHugh, T.E., Kulkarni, P.R., Beckley, L.M., Newell, C.J., Zumbro, M., 2015b. Low Bias in VOC Concentrations Using the Hydrasleeve in Monitoring Wells at Three Sites. Groundwater Monitoring & Remediation. Published online 21 December 2015. doi: 10.1111/gwmr.12141

McHugh, T.E., Kulkarni, P.R., Newell, C.J., 2015c. Time vs. Money: A Quantitative Evaluation of Monitoring Frequency versus Monitoring Duration. Accepted in Groundwater. December 2015.

McHugh T.E., Newell, C., Landazuri, R., Molofsky, L., Adamson, D. 2012. The Influence of Seasonal Vertical Temperature Gradients on No-purge Sampling of Wells, *Remediation Journal*, Vol. 22, No. 4: 21-36.

McHugh, T.E., Beckley, L.M., Liu, C.Y., Newell, C.J. 2011. Factors Influencing Variability in Groundwater Monitoring Data Sets, *Groundwater Monitoring and Remediation,* Vol. 31, No. 2.: 92-101. Spring 2011.

MWH, 2010. Comparing a Passive Sampling Method to Conventional Sampling Method for Long-term Monitoring at Hill AFB, Utah. May 2010.

Nadim, F., Liu, S., Hoag, G.E., 2001. The Effect of Air Bubbles and Headspace on the Aqueous Concentrations of Volatile Organic Compounds in Sampling Vials. Ground Water Monitoring & Remediation. Winter 2001.

Parker, L., Clark, C. 2004. Study of Five Discrete-Interval-Type Ground Water Sampling Devices. Groundwater Monitoring & Remediation, 24 (3) pages 111–123, August 2004

Parker, L., Britt, S., 2012. The Effect of Bottle Fill Rate and Pour Technique on the Recovery of Volatile Organics. Ground Water Monitoring & Remediation, 32, no. 4, pp 78-86.

Parker, L., Mulherin, N., Evaluation of the SNAP Sampler for Sampling Ground Water Monitoring Wells for VOCs and Explosives, Cold Regions Research and Engineering Laboratory, U.S. Army Engineer Research and Development Center, ERDC/CRREL TR-07-14, August 2007

Puls, R.W., Barcelona, M. J., 1995. Low-flow (Minimal Drawdown) Ground-water Sampling Procedures. US EPA Office of Research and Development. EPA Ground Water Issue. EPA/540/S-95/504, December 1995.

U.S. EPA, 2004. Guidance for Monitoring at Hazardous Waste Sites – Framework for Monitoring Plan Development and Implementation. U.S. EPA Office of Solid Waste and Emergency Response. OSWER Directive No. 9355.4-28. January 2004.

USEPA, 2010. Low Stress (Low-flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells. US EPA Region 1. January 19, 2010.

USEPA, 2011. Operating Procedure, Groundwater Sampling. Number: SESDPROC-301-R2. Region 4 U.S. EPA Science and Ecosystem Support Division, Athens Georgia. October 27, 2011.

Vrobleski, 2001. User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells Part 1: Deployment, Recovery, Data Interpretation, and Quality Control and Assurance, U.S. Geological Survey, Water-Resources Investigations Report 01–4060

Woodard & Curran, 2002. Standard Operating Procedure for Groundwater Sampling at the West Kingston Town Dump/URI Disposal Area Site, SOP S-4. August 2002

Zumbro, 2014. Performance Comparison of No-Purge Samplers for Long-Term Monitoring of a Chlorinated Solvent Plume, Abstract E-062, Remediation of Chlorinated and Recalcitrant Compounds-2014. Ninth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2014). Battelle Memorial Institute, Columbus, OH, www.battelle.org/chlorcon.

FINAL REPORT

Methods for Minimization and Management of Variability in Long-Term Groundwater Monitoring Results

ESTCP Project ER-201209

APPENDICES

Appendix A: Points of Contact
Appendix B: Field Program Procedures
Appendix C: Field Program Results: Demonstration Site #1
Appendix D: Field Program Results: Demonstration Site #2

APPENDICES

Appendix A: Points of Contact

Point of Contact	Organization	Phone/Fax/email	Role in Project
Thomas E. McHugh	GSI Environmental, Inc. 2211 Norfolk, Suite 1000, Houston, TX 77098-4054	Phone : 713-522-6300 Fax : 713-522-8010 Email : temchugh@gsi-net.com	PI
Poonam R. Kulkarni	GSI Environmental, Inc. 2211 Norfolk, Suite 1000, Houston, TX 77098-4054	Phone : 713-522-6300 Fax : 713-522-8010 Email : prk@gsi-net.com	Co-PI
Charles J. Newell	GSI Environmental, Inc. 2211 Norfolk, Suite 1000, Houston, TX 77098-4054	Phone : 713-522-6300 Fax : 713-522-8010 Email : cjnewell@gsi-net.com	Co-PI
Sanford L. Britt	ProHydro, Inc. 1011 Fairport Road Fairport, NY 14450	Phone : 585-385-0023 Email : Sandy.Britt@ProHydroInc.com	Co-PI

APPENDICES

Appendix B: Field Program Procedures

Contents:

APPENDICES

Appendix B.1: Standard Operating Procedures for Sampling Methods

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Standard Sampling Procedure

GENERAL

All field personnel are responsible for the safe operation of sampling activities in the field. Use the buddy system while working. Bring all personal issued PPE, and any necessary site-access requirements (i.e. TWIC card).

The Site Safety Coordinator will conduct a review of the Health and Safety Plan (HASP) for this field project. The HASP was written to address safety and hazardous waste issues associated the field program.

PRE-MOBILIZATION

The team will ensure that all necessary sampling equipment are working, and additional PPE supplies (i.e., latex gloves) are on-hand prior to arrival at site.

Equipment

- Electronic water-level indicator
- Peristaltic pump or bladder pump as appropriate for the individual well
- Air and discharge tubing
- Multi-parameter meter and flow-through-cell
- Calibration fluids
- Field Turbidity Meter
- Potable water, non-phosphate detergent, and distilled water for decontamination
- Sample bottles, sample labels, and chain of custody forms
- Field notebook, sample logs, datasheets, calculator
- Buckets/drum to contain purged water

Personal Protective Equipment (PPE)

Personal Protective Equipment is required per the site-specific HASP.

PRE-SAMPLING PROCEDURES

Equipment and Trip Blanks

Collect equipment (if applicable) and trip blanks per the requirements stated in the Demonstration Plan. Sample name: Equipment Blank: Round X.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Standard Sampling Procedure

Procedures

1. Check the condition of the monitoring well for damage and record any observations in field notes.

2. Unlock well head, and remove inner casing cap.

3. Measure the depth to water with an electronic water level indicator, and record on sampling log (to nearest 0.01 ft).

PURGING AND SAMPLING PROCEDURES

Purging

1. Position a new set of tubing until the location of the pump intake is approximately at the mid-point of the monitoring well screened interval.

2. Connect the discharge line from the pump to a flow-through cell, and position the discharge line from the flow-through cell to be above a container/bucket to contain purge water during the purging and sampling for the well.

3. Start pumping the well at a flow rate of < 0.1 to 0.5 L/min. Check water level. Maintain a steady flow rate and maintain a drawdown of less than 1 ft. If drawdown is greater than 1 ft, decrease the flow rate. Maintain flow rate throughout the purging, though certain site-specific geologic heterogeneities may require reductions in flow rate.

4. Measure the discharge rate of the pump with a stop watch and graduated cylinder, and record on the sampling log.

5. Monitor and record the following water quality indicator field parameters via the flow-through cell every three to five minutes: pH, dissolved oxygen, temperature, oxidation-reduction potential and specific conductance. Take subsequent turbidity readings using a stand-alone turbidity meter.

6. Stabilization of groundwater conditions will be achieved when three (3) sets of consecutive readings have been obtained for pH (+/- 0.2 S.U.), temperature (+/- 10%), dissolved oxygen (+/- 0.2 mg/L) and specific conductance (+/- 3%). Once these criteria have been met, a sample can be taken at the monitoring well.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Standard Sampling Procedure

Sampling

1. If pumping rate is >250 mL/min, then decrease the pumping rate to approximately 250 mL/min. Disconnect the pump's tubing from the flow-through cell; samples must be collected directly from the pump's discharge tubing.

2. When sampling, use the side fill method, where the VOA vial is tilted and water is poured slowly so that it flows down in the inside wall of the vial. Additionally, eliminate the formation of air bubbles or head space by topping off vials before capping. Fill three VOA vials using these procedures.

3. Tubing removal:

   Round #1: With tubing in the same position, make a permanent mark on the tubing with a marker or tape at the point where the tubing exits the top of the monitoring well. Leave tubing in-place for next sampling event (e.g., low-flow sampling with improved procedures).

   Round #2-6: Remove and discard existing tubing. From storage, use tubing that was marked and used from Round #1 (and labeled according to well name). Place marked tubing from Round #1 in well and leave in-place for next sampling event (e.g., low-flow sampling with improved procedures).

4. Proceed to next monitoring well, as shown in the sampling order below.

Duplicates

Duplicates shall be taken as stated in the Demonstration Plan.

Sample Naming

All samples will be labeled as the following:

MW-X-LFS-Y

Where: X - Sample location ID
LFS – Low-Flow Standard
Y - Round number (i.e. 1-6)

All duplicates will be labeled as the following:

DUP-LFS-Y

Where: DUP – Duplicate (no Sample location ID)

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Standard Sampling Procedure

LFS – Low-Flow Standard
Y - Round number (i.e. 1-6)

DECONTAMINATION

1. The electronic water-level indicator should be washed with detergent and a scrubber, and rinsed with distilled water.

2. The flow-through cell and turbidity meter should be rinsed with distilled water.

RECORD KEEPING

Complete an activity sheet, equipment use form and site safety record each day. Record any duplicates and samples times on the daily activity sheet.

Each team leader will ensure that all low-flow groundwater sampling records are completed prior to departing from each sampled well location. The purpose of these forms is to document the achievement of low-flow sampling stabilized groundwater conditions prior to the acquisition of analytical samples from each well.

SAMPLE PICKUP

Samples should be kept on ice after collection. Coolers should be dropped at the laboratory after sampling or at the office to be picked up the following morning by the laboratory.

SAMPLE WATER DISPOSAL

No water will be stored overnight in the storage tank or buckets. Water will be emptied each day before leaving the site into drums on-site.

SAMPLING ORDER

Sampling locations must be at the monitoring well with the least contamination, and the sampling order should proceed to the monitoring wells with the most contaminated ground water. The following sampling order applies:

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Standard Sampling Procedure

Location ID	Notes

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

GENERAL

All field personnel are responsible for the safe operation of sampling activities in the field. Use the buddy system while working. Bring all personal issued PPE, and any necessary site-access requirements (i.e. TWIC card).

The Site Safety Coordinator will conduct a review of the Health and Safety Plan (HASP) for this field project. The HASP was written to address safety and hazardous waste issues associated the field program.

PRE-MOBILIZATION

The team will ensure that all necessary sampling equipment are working, and additional PPE supplies (i.e., latex gloves) are on-hand prior to arrival at site.

Equipment

- SNAP Samplers for all wells (to be installed after low-flow sampling)
- SNAP Sampler trigger lines (to be installed after low-flow sampling)
- Electronic water-level indicator
- pH meter
- Turbidity meter
- Peristaltic pump
- Graduated cylinder (1 L)
- Tubing
- Large Zip-Lock Bags
- Distilled water for decontamination
- Sample bottles, sample labels, and chain of custody forms
- Field notebook, sample logs, datasheets, calculator
- Buckets/drum to contain purged water

Personal Protective Equipment (PPE)

Personal Protective Equipment is required per the site-specific HASP.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

PRE-SAMPLING PROCEDURES

Equipment and Trip Blanks

Collect equipment (if applicable) and trip blanks per the requirements stated in the Demonstration Plan. Sample name: Equipment Blank: Round X.

Procedures

1. Check the condition of the monitoring well for damage and record any observations in field notes.

2. Unlock well head, and remove inner casing cap.

3. Measure the depth to water with an electronic water level indicator, and record on sampling log (to nearest 0.01 ft).

PURGING AND SAMPLING PROCEDURES

Purging

1. Tubing equipment will have been left in the monitoring well after the prior round of sampling (low-flow standard procedure). Line up the marking on the sample tubing with the top of the monitoring well to ensure that the tube inlet is at the proper depth. All samples will be collected from the same elevation (+/- 1 inch).

2. Position the discharge line from the pump to be above a container/bucket to contain purge water during the purging and sampling for the well.

3. Round #1: Start pumping the well at a flow rate of < 0.1 to 1 L/min. Measure the flow rate using graduated cylinder and record on sampling sheet. All subsequent sampling events will be conducted using this flow rate.

   Round #2-6: Pump the well at the same flow rate determined in Round #1.

4. Measure and record time, temperature, specific conductivity and turbidity on sampling form at initial purge water (i.e. volume = 0). Monitor the total volume purged using a graduated cylinder or bucket.

   Check water level. Maintain a steady flow rate and maintain a drawdown of less than 1 ft. If drawdown is greater than 1 ft, decrease the flow rate. Maintain flow rate throughout the purging, though certain site-specific geologic heterogeneities may require reductions in flow rate.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

5. Take a set of samples after purging 3 L (i.e. small volume purge). See Sampling below for instructions on sample collection. Do not turn the pump off. A continuous and constant pumping rate should be maintained during purging and sample collection. Measure and record field parameters on sampling form AFTER collection of the sample.

6. If pumping rate is less than 200 mL/min, increase pumping rate to 200 mL/min. Purge an additional 15 L for a total of 18 L. If total drawdown reaches 5 ft prior to purging a total of 18L, then collect the second sample when total drawdown reaches 5 ft.

7. Take a set of samples after purging 18 L (i.e. large volume purge). See Sampling below for instructions on sample collection. Do not turn the pump off. A continuous and constant pumping rate should be maintained during purging and sample collection. Measure and record field parameters on sampling form AFTER collection of the sample.

Sampling

1. Maintain the pumping rate used for purging. Do not turn off the pump while preparing to collect the samples. Samples must be collected directly from the pump's discharge tubing.

2. When sampling, use the bottom-fill method, where the tubing is placed at the bottom of the VOA vial, and the vial is filled from the bottom to top. Pull tube up as vial fills, keeping tube below water level in vial. Fill vial to the extent practical without causing significant overflow. The goal is to achieve a meniscus above the top of the vial resulting in no headspace after the vial is capped. However, any vial that is at least 95% full (i.e., < 2 mL headspace) is acceptable (i.e. don't eliminate all bubbles by over-filling). If vial contains > 2mL headspace, discard sample and fill new vial. The goal is to fill the vial as quickly as possible while minimizing headspace rather than eliminating all bubbles at the cost of extending the sample collection time. Fill three VOA vials using these procedures.

3. After collecting the second (i.e., the large purge volume) sample, disconnect the pump and tubing, remove from well, and place in large Zip-Lock bag. Label the bag with the associated well name, and store for use during the next sampling round.

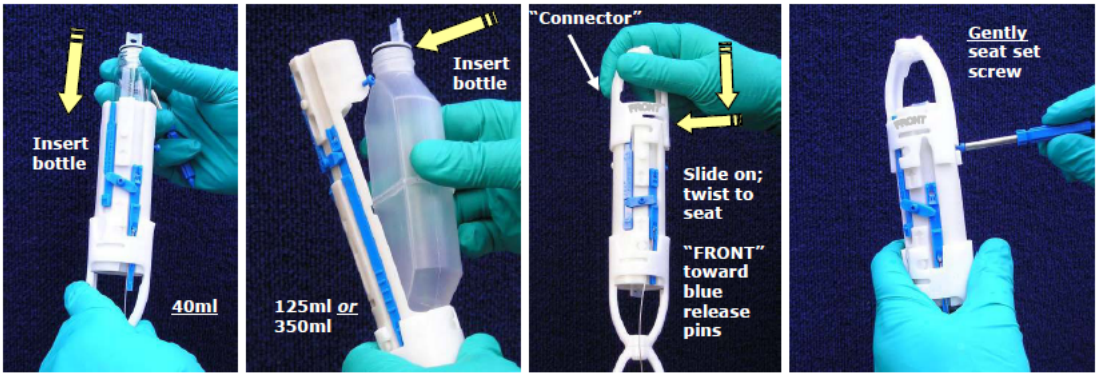
4. Prepare the well for Passive No Purge sampling during next event by installing SNAPL samplers. Installation procedures are as follows (ProHydro, 2011):

    4.1 Turn the translucent (PFA) vial cap on each end slightly to release the o-ring on the SNAP Sampler (figures below).

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

4.2 Insert the bottle into the upper end of the sampler as shown in figure below (figures below).

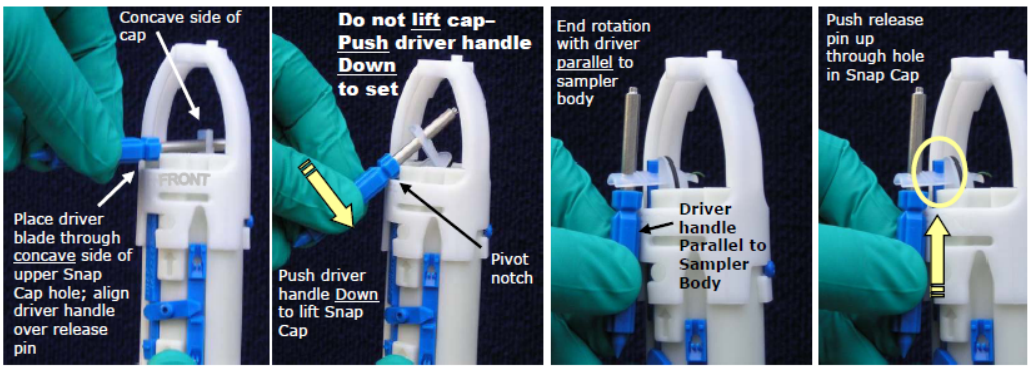
4.3 Place the sampler connector onto each end of the sampler; turn clockwise to align the set pins/screw; then gently tighten the set screw with the Snap Driver Tool (figures below).



4.4 Insert Snap Driver blade into the upper hole of the concave side of snap Cap; align driver over the release pin that you will set the Snap Cap (figures below).

4.5 Push down on Snap driver handle to lift Snap Cap; grasp driver or use thumb to push driver down; keep fingers clear of the under-side of the driver tool (figures below).

4.6 Pivot on the notch in the driver handle until driver handle is flush/parallel with sampler body and Snap Cap is in its seat. Push release pin up through lower hole in the Snap Cap (figures below).

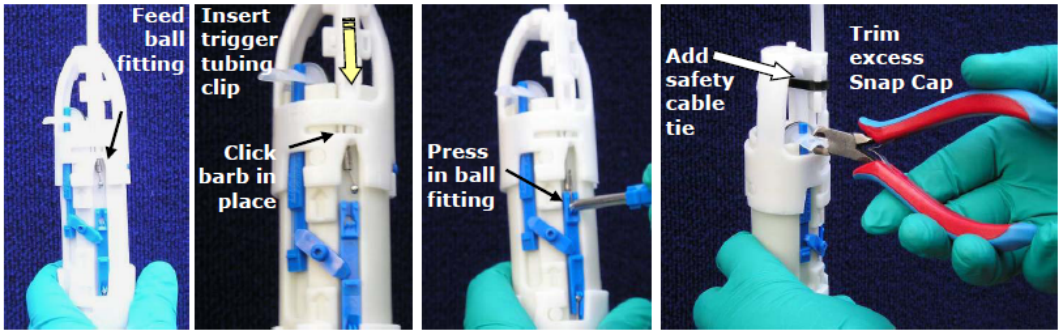


APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

4.7 Repeat above procedures for all snap Caps. If an O-ring should dislodge from its seat during setting, remove the sample bottle and carefully replace it in the o-ring grove.

4.8 For the manual trigger, feed ball-fitting end of trigger cable through lower release pin groove; click tube fitting into connector (figures below).

4.9 Press in the ball fitting to attach to lower release pin (figures below).



4.10 Deploy to selected depth with trigger cable/tubing and attach to well head docking station.

4.11 Deploy an additional SNAP Sampler in series with a single trigger. Hang trigger, close cap and secure.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

5. Proceed to next monitoring well, as shown in the sampling order below.

Duplicates

Duplicates shall be taken as stated in the Demonstration Plan.

Sample Naming

All samples will be labeled as the following:

MW-X-LFI-S-Y

Where: X - Sample location ID
LFI - S – Low-Flow Improved, Small volume purge
LFI – L – Low-Flow Improved, Larger volume purge
Y - Round number (i.e. 1-6)
All duplicates will be labeled as the following:

DUP-LFI-Y

Where: DUP – Duplicate (no Sample location ID)
LFI – Low-Flow Improved
Y - Round number (i.e. 1-6)

DECONTAMINATION

1. The electronic water-level indicator should be washed with detergent and a scrubber, and rinsed with distilled water.

2. The flow-through cell and turbidity meter should be rinsed with distilled water.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Low-Flow Alternative Sampling Procedure

RECORD KEEPING

Complete an activity sheet, equipment use form and site safety record each day. Record any duplicates and samples times on the daily activity sheet.

Each team leader will ensure that all low-flow groundwater sampling records are completed prior to departing from each sampled well location.

SAMPLE PICKUP

Samples should be kept on ice after collection. Coolers should be dropped at the laboratory after sampling or at the office to be picked up the following morning by the laboratory.

SAMPLE WATER DISPOSAL

No water will be stored overnight in the storage tank or buckets. Water will be emptied each day before leaving the site into drums on-site.

SAMPLING ORDER

Sampling locations must be at the monitoring well with the least contamination, and the sampling order should proceed to the monitoring wells with the most contaminated ground water. The following sampling order applies:

Location ID	Notes

REFERENCES

ProHydro, 2011. Standard Operating Procedure for the Snap Sampler Passive Groundwater Sampling Method. March 2011.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Passive No Purge (SNAP Samplers) Sampling Procedure

GENERAL

All field personnel are responsible for the safe operation of sampling activities in the field. Use the buddy system while working. Bring all personal issued PPE, and any necessary site-access requirements (i.e. TWIC card).

The Site Safety Coordinator will conduct a review of the Health and Safety Plan (HASP) for this field project. The HASP was written to address safety and hazardous waste issues associated the field program.

PRE-MOBILIZATION

The team will ensure that all necessary sampling equipment are working, and additional PPE supplies (i.e., latex gloves) are on-hand prior to arrival at site.

Equipment

- HydraSleeve Samplers (to be installed after sample collection)
- Suspension cables for all HydraSleeve Samplers (to be installed after sample collection)
- Small weights to hang HydraSleeve Samplers (to be installed after sample collection)
- Electronic water-level indicator
- Large Zip-Lock Bags
- Sample bottles, sample labels, and chain of custody forms
- Field notebook, sample logs, datasheets, calculator
- Bucket/drum to contain excess water

Personal Protective Equipment (PPE)

Personal Protective Equipment is required per the site-specific HASP.

PRE-SAMPLING PROCEDURES

Equipment and Trip Blanks

Collect equipment (if applicable) and trip blanks per the requirements stated in the Demonstration Plan. Sample name: Equipment Blank: Round X.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Passive No Purge (SNAP Samplers) Sampling Procedure

Procedures

1. Check the condition of the monitoring well for damage and record any observations in field notes.

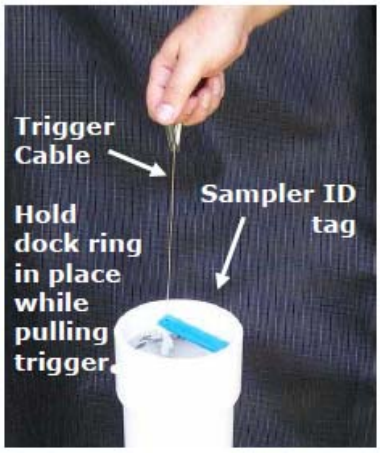
2. Unlock well head, and remove inner casing cap.

3. Measure the depth to water with an electronic water level indicator, and record on sampling log (to nearest 0.01 ft).

SAMPLING PROCEDURES

Sample Collection (ProHydro, 2011)

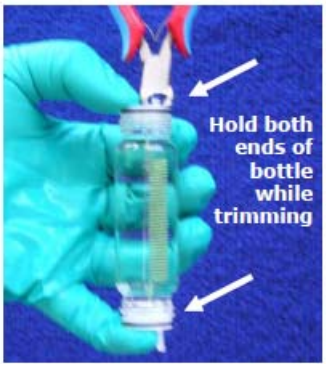
1. Hold dock ring in place, and pull up trigger cable.



2. Remove Snap Sampler VOA from Snap Sampler (see figures below).

3. Carefully trip Snap Caps as flush as possible. To trip first Snap Cap, hold ends with finger and thumb; clip carefully – making sure not to dislodge seal. Carefully screw on first septa cap. Trim second Snap Cap; slip carefully – making sure not to dislodge seal; screw on second septa cap, then re-tighten both septa caps to secure (see figures below).

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Passive No Purge (SNAP Samplers) Sampling Procedure



4. After securing the first end of the Snap Cap, trim the second Snap Cap; add 2-3 drops of preservative to the cavity in the Snap Cap. Pierce the Snap Cap membrane with the pointed end of the Driver Tool to allow preservative to mix with the sample; add preservative to form a meniscus, then secure the second septa cap (see figures below).

5. Place trigger/suspension line, and any associated SNAP equipment in a zip-lock bag and label the bag with well name. Suspension lines will be reused during each sampling round to ensure that sample is collected from the same elevation (+/- 1 inch) during each sample event.

6. Make sure to label the upper and lower SNAP Sampler units individually. See Sample Naming below. List both samples on the laboratory chain-of-custody, but only mark the "Upper" sample for analysis; mark the "Lower" sample as "Hold". Remove all other SNAP equipment, and store in a large Zip-Lock Bag or similar, and label bag with well name.

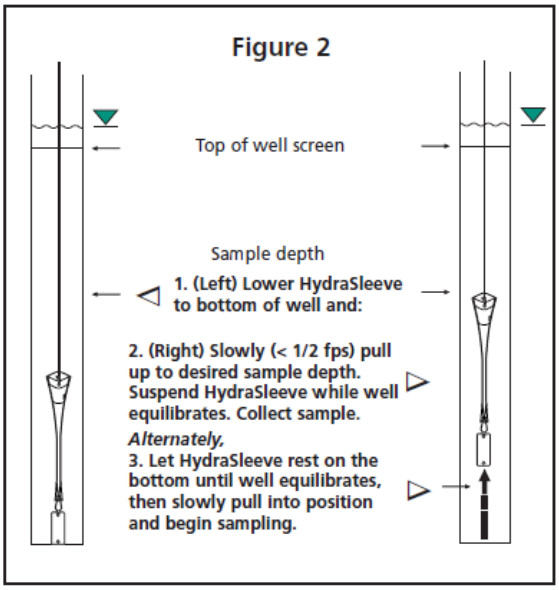
7. Install HydraSleeve samplers in preparation for next sampling event. Installation procedures are as follows (GeoInsight, 2006).

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Passive No Purge (SNAP Samplers) Sampling Procedure

7.1 Attach HydraSleeve to suspension line and attach weight to bottom of HydraSleeve.

7.2 Lower the weighted HydraSleeve and let it touch the bottom (see figure below). Let HydraSleeve rest on the bottom until sample collection.

7.3 Tie suspension line securely at the surface in order to be able to access it during sampling event.



8. Proceed to next monitoring well, as shown in the sampling order below.

Duplicates

Duplicates shall be taken as stated in the Demonstration Plan.

Sample Naming

All samples will be labeled as the following:

MW-X-SSU-Y

Where: X - Sample location ID
SSU – SNAP Sampler, Upper Unit
SSL – SNAP Sampler, Lower Unit
Y - Round number (i.e. 1-6)

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Passive No Purge (SNAP Samplers) Sampling Procedure

All duplicates will be labeled as the following:

DUP-SSU-Y

Where: DUP – Duplicate (no Sample location ID)
SSS – SNAP Sampler, Upper Unit
Y - Round number (i.e. 1-6)

DECONTAMINATION

1. The electronic water-level indicator should be washed with detergent and a scrubber, and rinsed with distilled water.

RECORD KEEPING

Complete an activity sheet, equipment use form and site safety record each day. Record any duplicates and samples times on the daily activity sheet.

Each team leader will ensure that all groundwater sampling records are completed prior to departing from each sampled well location.

SAMPLE PICKUP

Samples should be kept on ice after collection. Coolers should be dropped at the laboratory after sampling or at the office to be picked up the following morning by the laboratory.

SAMPLE WATER DISPOSAL

No water will be stored overnight in the storage tank or buckets. Water will be emptied each day before leaving the site into drums on-site.

SAMPLING ORDER

Sampling locations must be at the monitoring well with the least contamination, and the sampling order should proceed to the monitoring wells with the most contaminated ground water. The following sampling order applies:

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Passive No Purge (SNAP Samplers) Sampling Procedure

Location ID	Notes

REFERENCES

GeoInsight, 2006. HydraSleeve Field Manual. http://www.hydrasleeve.com/technical-help

ProHydro, 2011. Standard Operating Procedure for the Snap Sampler Passive Groundwater Sampling Method. March 2011.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Active No Purge (HydraSleeve) Sampling Procedure

GENERAL

All field personnel are responsible for the safe operation of sampling activities in the field. Use the buddy system while working. Bring all personal issued PPE, and any necessary site-access requirements (i.e. TWIC card).

The Site Safety Coordinator will conduct a review of the Health and Safety Plan (HASP) for this field project. The HASP was written to address safety and hazardous waste issues associated the field program.

PRE-MOBILIZATION

The team will ensure that all necessary sampling equipment are working, and additional PPE supplies (i.e., latex gloves) are on-hand prior to arrival at site.

Equipment

- Electronic water-level indicator
- Large Zip-Lock Bags
- Sample bottles, sample labels, and chain of custody forms
- Field notebook, sample logs, datasheets, calculator
- Bucket/drum to contain excess water

Personal Protective Equipment (PPE)

Personal Protective Equipment is required per the site-specific HASP.

PRE-SAMPLING PROCEDURES

Equipment and Trip Blanks

Collect equipment (if applicable) and trip blanks per the requirements stated in the Demonstration Plan. Sample name: Equipment Blank: Round X.

Procedures

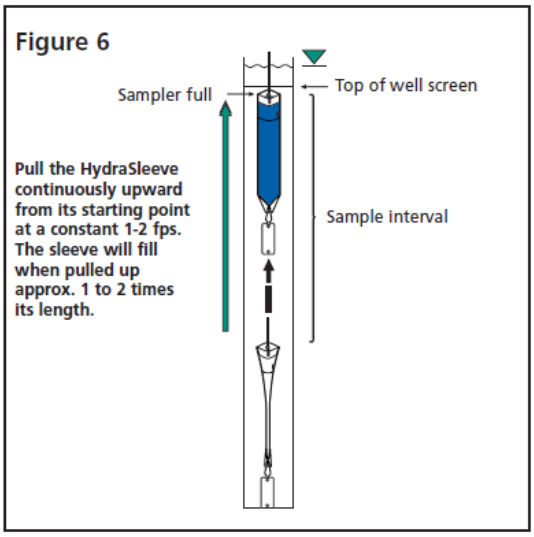
1. Check the condition of the monitoring well for damage and record any observations in field notes.
2. Unlock well head, and remove inner casing cap.
3. Measure the depth to water with an electronic water level indicator, and record on sampling log (to nearest 0.01 ft).

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Active No Purge (HydraSleeve) Sampling Procedure

SAMPLING PROCEDURES

Sample Collection (GeoInsight, 2006)

1. Pull the HydraSleeve upward at a continuous 1 to 2 ft per sec. until full of water.



2. Once above ground, squeeze the full sampler just below the top to expel water resting above the flexible check valve.

3. Push the pointed discharge tube through the outer polyethylene sleeve about 3-4 inches below the white reinforcing strip.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Active No Purge (HydraSleeve) Sampling Procedure

4. Discharge the sample into the VOA vials using the bottom-fill method, where the tube is placed at the bottom of the vial, and the vial is allowed to fill from the bottom to top. Pull the tube up as the vial fills, keeping tube below water level in vial. If you have not filled vials using this method, you should practice on a spare vial and then fill the sample vials after you are comfortable with the technique.

   Raising and lowering the bottom of the sampler or pinching the sample sleeve just below the discharge tube will control the flow of the sample. The sample sleeve can also be squeezed, forcing fluid up through the discharge tube, similar to squeezing a tube of toothpaste.

5. Fill vial to the extent practical without causing significant overflow. The goal is to achieve a meniscus above the top of the vial resulting in no headspace after the vial is capped. However, any vial that is at least 95% full (i.e., < 2 mL headspace) is acceptable (i.e. don't eliminate all bubbles by over-filling). If vial contains > 2mL headspace, discard sample and fill new vial. The goal is to fill the vial as quickly as possible while minimizing headspace rather than eliminating all bubbles at the cost of extending the sample collection time. Fill three VOA vials using these procedures.

6. Purge excess water from Hydrasleeve in bucket, and discard Hydrasleeve sampler.

7. Place suspension line in a zip-lock bag and label the bag with well name. Suspension lines will be reused during each sampling round.

8. Proceed to next monitoring well, as shown in the sampling order below.

Duplicates

Duplicates shall be taken as stated in the Demonstration Plan.

Sample Naming

All samples will be labeled as the following:

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Active No Purge (HydraSleeve) Sampling Procedure

MW-X-HS-Y

Where: X - Sample location ID
HS – HydraSleeve Sampler
Y - Round number (i.e. 1-6)

All duplicates will be labeled as the following:

DUP-HS-Y

Where: DUP – Duplicate (no Sample location ID)
HS – HydraSleeve Sampler
Y - Round number (i.e. 1-6)

DECONTAMINATION

1. The electronic water-level indicator should be washed with detergent and a scrubber, and rinsed with distilled water.

RECORD KEEPING

Complete an activity sheet, equipment use form and site safety record each day. Record any duplicates and samples times on the daily activity sheet.

Each team leader will ensure that all groundwater sampling records are completed prior to departing from each sampled well location.

SAMPLE PICKUP

Samples should be kept on ice after collection. Coolers should be dropped at the laboratory after sampling or at the office to be picked up the following morning by the laboratory.

SAMPLE WATER DISPOSAL

No water will be stored overnight in the storage tank or buckets. Water will be emptied each day before leaving the site into drums on-site.

APPENDIX B.1
STANDARD OPERATING PROCEDURE
Active No Purge (HydraSleeve) Sampling Procedure

SAMPLING ORDER

Sampling locations must be at the monitoring well with the least contamination, and the sampling order should proceed to the monitoring wells with the most contaminated ground water. The following sampling order applies:

Location ID	Notes

REFERENCES

GeoInsight, 2006. HydraSleeve Field Manual. http://www.hydrasleeve.com/technical-help

APPENDICES

Appendix B.2: Quality Assurance Project Plan (QAPP)

GSI ENVIRONMENTAL

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

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APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

TABLES

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

LIST OF ACRONYMNS

ASTM	American Society of Testing Materials
DQO	Data Quality Objective
ft	Feet, foot
GC/MS	Gas Chromatograph/Mass Spectrometer
HASP	Health and Safety Plan
IDL	Instrument Detection Limit
LCS	Laboratory Control Sample
LIMS	Laboratory Information Management System
LTO	Laboratory Task Order
mg	Milligram
MDL	Method Detection Limit
mL	Milliliter
MS	Matrix Spike
MSD	Matrix Spike Duplicate
MQL	Method Quantitation Limit
ng	Nanogram
NELAP	National Environmental Laboratory Accreditation Program
NIST	National Institute of Standards and Testing
OVA	Organic Vapor Analyzer
PE	Performance Evaluation
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RF	Response Factor
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
SOP	Standard Operating Procedure
TCL	Target Compound List
µg	Microgram
µL	Microliter
USEPA	United States Environmental Protection Agency
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

1.0 PROJECT DESCRIPTION

1.1 Project Overview

This Quality Assurance Project Plan (QAPP) has been prepared for ESTCP Project ER-201219 (Methods for Minimization and Management of Variability in Long-Term Groundwater Monitoring Results), to be conducted by GSI Environmental Inc. (GSI). The Demonstration Plan that accompanies this QAPP describes the project background and investigation objectives, including the site description and history, the project objectives, the sampling rationale, and the project schedule. The specific scope of this QAPP includes:

- Collection of groundwater samples using four technologies / procedures:
    1) Low Flow sampling: standard procedure
    2) Low Flow sampling: improved procedure
    3) Passive No Purge (e.g. SNAP Sampler)
    4) Active No Purge (e.g. Hydrasleve)

- Analysis of groundwater samples for VOCs by USEPA Method 8260B

This QAPP describes data quality objectives (DQOs) as well as the field and laboratory procedures to be implemented in order to fulfill the project objectives. This QAPP was prepared in general accordance with applicable U.S. Environmental Protection Agency (USEPA) guidance.

1.2 Objective of the QAPP

The general objective of quality assurance (QA) is to collect defensible environmental data of known quality that is adequate for the intended use of the data. To accomplish this objective, Data Quality Objectives (DQOs) have been developed for this study. DQOs are qualitative and quantitative statements which clarify the study objectives, define the most appropriate types of data to collect, determine the most appropriate conditions from which to collect data, and specify acceptable decisions regarding the data's usage (USEPA 1994a). The DQO planning process is a tool to determine which type, quality, and quantity of data will be sufficient to support the overall project objectives.

2.0 PROJECT ORGANIZATION AND RESPONSIBILITY

2.1 Project Organizational

GSI Environmental and ProHydro have overall responsibility for implementation of the Demonstration Plan. The groundwater samples will be analyzed by a commercial laboratory with NELAP (or equivalent) certification for USEPA Method 8260B. Responsibilities for project management, quality assurance, laboratory, and field personnel are defined below.

GSI ENVIRONMENTAL

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

2.2 Management Responsibilities

GSI Principal Investigator: The GSI Principal Investigator (PI, Thomas McHugh) will be responsible for implementing the project. The primary function of the PI will be to ensure that technical, financial, and scheduling objectives are achieved. The PI, supported by the GSI Project Manager and other GSI personnel will:

- Define project objectives and develop a detailed demonstration plan schedule;
- Establish project policy and procedures to address the specific needs of the project;
- Acquire and apply resources as needed to ensure performance within budget and schedule constraints;
- Orient field personnel and support staff to the project's special considerations;
- Review the work performed on each task to ensure quality, responsiveness, and timeliness;
- Review and analyze work performed relative to planned requirements and authorizations;
- Approve reports and deliverables before submittal to ESTCP;
- Retain ultimate responsibility for preparation and quality of interim and final reports; and
- Represent the project team at meetings.

ProHydro Co-Principal Investigator: The ProHydro Co-Principal Investigator (Co-PI, Sandy Britt) will be input on overall project implementation and will implement the field program at Field Demonstration Site #2:

- Provide input on project objectives and detailed demonstration plan schedule;
- Oversee implementation of the field program at Field Demonstration Site #2;
- Oversee health and safety practices associated with implementation of the field program at Field Demonstration Site #2;
- Oversee QA practices associated with implementation of the field program at Field Demonstration Site #2;
- Provide input on data analysis and interpretation;

GSI Project Manager: The GSI Project Manager will implement the field program at Field Demonstration Site #1:

- Oversee implementation of the field program at Field Demonstration Site #1;
- Provide input on data analysis and interpretation;

GSI Health and Safety Officer: The GSI Health and Safety Officer will be responsible for overall health and safety practices associated with the field work. Specific functions and duties will include the following tasks:

- Establish the requirements of the project Health and Safety Plan (HASP);
- Arrange or conduct audits of field activities to ensure that proper health and safety procedures are being used; and
- Communicate with the PI, Co-PI, GSI Technical Staff, and GSI Field Technical Staff concerning project issues related to health and safety.

Note that the Co-PI will oversee health and safety practices associated with implementation of the field program at Field Demonstration Site #2.

GSI QA Manager: The GSI QA Manager will report directly to the PI and will be responsible for reviewing QA documentation to evaluate compliance with sampling and analytical procedures.

GSI Technical Staff: The GSI Technical Staff will assist the PI in field activities such as performing field analyses, recording field measurements, and performing office activities such as data review and report development. GSI Technical Staff will be familiar with relevant project reports and plans including the Demonstration Plan, the QAPP, and the Health and Safety Plan.

Laboratory Project Manager: The Laboratory Project Manager will report to the PI. The Laboratory Project Manager will be responsible for ensuring laboratory resources are available as needed for the project and will provide oversight of final laboratory reports.

Laboratory QA Manager: The Laboratory QA Manager will have overall responsibility for data generated in the laboratory. The Laboratory QA Manager will be independent of the laboratory production responsibilities, but will communicate data issues through the Laboratory Project Manager. In addition, the Laboratory QA Manager will:

- Monitor the day-to-day quality of the laboratory data;
- Maintain and review all quality control data;
- Conduct internal performance and system audits to ensure compliance with laboratory protocols;
- Review and maintain updated Standard Operating Procedures (SOPs); and
- Prepare Performance Evaluation reports and corrective action reports.

Laboratory Technical Staff: The Laboratory Technical Staff will be responsible for sample analysis and identification of necessary corrective actions. Staff members will report directly to the Laboratory Project Manager.

3.0 QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT DATA

For the analysis of VOC concentrations by USEPA Method 8260B, quantifiable DQOs have been developed for accuracy, precision, and completeness. Acceptable levels of non-quantifiable data quality parameters (i.e., representativeness and completeness) will be assured through the proper implementation of field and laboratory SOPs.

Definitions, development, and interpretation of DQO parameters and detection limits are presented below.

3.1 Precision

3.1.1 Definition

Precision is a measure of the degree to which two or more measurements are in agreement as a result of repeated application of a process under specific conditions. The overall precision and reproducibility of a measurement system is affected by variations introduced by sampling and analysis.

3.1.2 Field Precision Objectives

Field precision will be assessed by collecting and analyzing field duplicates at a minimum rate of 1 duplicate per 20 analytical samples. The field precision objective for laboratory analysis is ±30% relative percent difference (RPD) between field duplicates (See Table 1). No other analyses will have field precision objectives.

3.1.3 Laboratory Precision Objectives

Laboratory analytical methods for this project and corresponding precision objectives for laboratory QC samples are listed on Table 1. In accordance with method requirements, laboratory precision will be assessed by analysis of various duplicates sets (e.g., laboratory duplicates, matrix spike duplicates).

3.2 Accuracy

3.2.1 Definition

Accuracy is the degree of agreement between an observed value (or an average of several values) and an accepted reference value. Deviations from standard values result from cumulative inconsistencies in the measurement system. Potential sources of variance include (but are not limited to) sample collection, preservation, and handling procedures; matrix effects, and analytical procedures.

3.2.2 Field Accuracy Objectives

Accuracy in the field will be assessed through the adherence to all sample handling, preservation (if applicable), and holding times.

3.2.3 Laboratory Accuracy Objectives

In accordance with method requirements, laboratory accuracy will be assessed by the analysis of various spike samples (e.g., spikes, matrix spikes, control standards, interference check samples, standard reference samples, and surrogates). Where required by the method, an LCS will consist of a standard purchased from a source other than that for the calibration standards. The use of an LCS will be based on the availability of a USEPA, National Institute of Standards and Testing (NIST), or commercially certified LCS.

3.3 Completeness

3.3.1 Definition

Completeness is expressed as the percentage of valid data points obtained from a measurement system or method.

3.3.2 Field Completeness Objectives

Field completeness will be assessed for target parameters by comparing the number of valid field samples to the total number of field samples collected. The validity of field samples will be assessed by comparison of documented field practices to requirements of this QAPP and the accompanying Demonstration Plan. The completeness objective for field samples will be at least 90%.

3.3.3 Laboratory Completeness Objectives

The results of a laboratory analysis will be considered valid if predetermined data quality objective standards are met or exceeded for precision and accuracy. Completeness requirements for other analytical parameters will be based on available QC data provided in accordance with applicable API and ASTM methods. Laboratory completeness will be assessed for VOCs by comparing the number of valid measurements to the total number of measurements. Completeness for laboratory samples will be at least 95%.

3.4 Representativeness

3.4.1 Definition

Representativeness is a qualitative parameter that expresses the degree to which data accurately and precisely represents a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. As such, representativeness describes whether samples collected, or the aliquots selected by the laboratory for analysis, are sufficient in number, type, location, frequency, and size to be characteristic of the substance analyzed.

3.4.2 Measures to Ensure Representativeness of Field Data

Field representativeness will be satisfied by following the sample collection procedures specified in the QAPP. In addition, collection of duplicate samples will provide a measure of the variability of analyte present in a particular sample volume.

3.4.3 Measures to Ensure Representativeness of Laboratory Data

Representativeness in the laboratory will be ensured by using the proper analytical procedures, meeting sample holding times, and analyzing and assessing field duplicates.

3.5 Comparability

3.5.1 Definition

Comparability is an expression of the confidence with which one data set can be compared with another.

3.5.2 Measures to Ensure Comparability of Field Data

Comparability of field data will be assured by adhering to standard sampling procedures described in the QAPP, using traceable calibration standards; using standard measurement and reporting units; and using the pre-determined acceptance criteria for precision and accuracy presented in this QAPP.

3.5.3 Measures to Ensure Comparability of Laboratory Data

Comparability of laboratory data will be assured by adhering to standard analytical procedures described in this QAPP, using traceable calibration standards; using standard measurement and reporting units; and using pre-determined acceptance criteria for precision and accuracy.

3.6 Level of Quality Control Effort

3.6.1 Level of Field Quality Control Effort

Requirements for collection of field quality control samples are provided on Table 1. Field precision will be assessed by collecting and analyzing field duplicate samples.

3.6.2 Level of Laboratory Quality Control Effort

Requirements for laboratory QC samples and acceptance criteria are provided on Table 1. Results from method blank samples for all constituents analyzed will be reviewed to assess potential sources of contamination associated with laboratory procedures.

Results for sample (e.g., MS/MSD) pairs will be reviewed to evaluate the effect of the sample matrix on the sample preparation and measurement methodology. Accuracy for the analysis of volatile organic compounds will be assessed by evaluating the recoveries of surrogate compounds spiked into all samples.

4.0 SAMPLING PROCEDURES

Field sampling procedures employed during this study will be consistent throughout the project, thus providing data representative of site conditions, comparability with analytical considerations, practicality, and simplicity. Consistent implementation of the sampling procedures will be ensured through the use of Standard Operating Procedures (SOPs) specific to each sampling method (see Appendix D).

Method specified sample containers, preservatives, and holding times are summarized on Table 2.

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

4.1 Groundwater Sampling Procedures

Groundwater Sample Collection

Groundwater wells will be sampled using various low flow and passive sample collection methods described in the main text. SOPs for each of the four groundwater sampling methods are provided in Appendix D.

Sampling Equipment

Groundwater monitoring wells will be sampled, to the extent practicable, using dedicated equipment. The use of dedicated equipment for groundwater collection will minimize the need for decontamination of sampling equipment between sampling episodes and the potential for cross-contamination. In the event that non-dedicated equipment is used (e.g. submersible pumps in wells with a depth to groundwater of >25 ft), that equipment will be cleaned as described above prior to use in each well. Passive samplers will be used for a single sampling event and not reused.

Groundwater Sample Handling

Groundwater samples will be collected and handled to minimized the potential for cross-contamination, loss of volatile constituents, or other interferences. Sampling personnel will wear clean latex, nitrile, or other chemical resistant, non-reactive gloves when handling sampling equipment and containers, and will minimize contact with the sampled groundwater. Care will be taken to prevent contact of down-hole equipment with the ground or other potential sources of sample contamination. Gloves will be changed between sampling locations.

When pumps are used to collect samples, the sample will be collected at low flow rates, as described in text above. As specified by USEPA SW-846, collected samples will be retained in wet ice coolers pending transport to the laboratory with adequate ice to maintain samples at a temperature of approximately 4ºC.

5.0 CUSTODY PROCEDURES

In order to generate defensible analytical data, sample custody procedures will be implemented for handling environmental samples and associated records during sample collection, shipment, transfer, and storage. These procedures will support the authenticity of sampling data by tracing samples from the time of collection, through analysis, data generation, and report preparation.

A sample is considered to be within custody if the item is i) in one's physical possession; ii) in one's view after being in one's physical possession; iii) in a locked receptacle after being in one's physical possession; or iv) in a designated secure area. Procedures described below address custody during field sample collection, laboratory analysis, and file storage.

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

When completing written records to document sample custody, errors will be corrected by drawing a single line through the error, re-entering the correct information, and initialing and dating the correction.

5.1 Field Custody Procedures

Sample containers provided by the laboratory for this project will be shipped by common carrier or other suitable method to a location designated by the PI. The laboratory will include a shipping form/laboratory chain-of-custody listing containers shipped and the purpose of each container. Containers will be considered in the custody of the laboratory until received by GSI or a designated representative. Upon receipt, the shipment will be checked to verify that all containers are intact. The containers will be maintained in the custody of the receiver in a clean, secure area until used for sample collection.

Procedures described below address custody during field sample collection, laboratory analysis, and file storage for the data collected in study.

- Field sampling personnel will be personally responsible for the care and custody of the samples until transferred or properly dispatched;
- Sample bottles and vessels will be labeled with sample numbers and locations at the time of sample collection; and
- Sample labels will be completed with permanent ink.

After collection, field sampling personnel will maintain sample custody in accordance with the following procedure:

- The sample label affixed to the container will be inspected to confirm that all of the required information has been provided;
- If appropriate (e.g., for water samples), the sample container will be sealed in a zip-lock plastic bag, wrapped in bubble pack, and packed in a wet-ice or dry-ice cooler in a manner to minimize shifting or movement;
- For each set of samples sent to the laboratory, a triplicate chain-of-custody form will be completed. Information on the chain-of-custody form and the sample container labels will be checked against the field logbook entries and the samples will be recounted. The information contained on the chain-of-custody form will include the following:
  - Site name and address or location;
  - Project number;
  - Date of sample collection;
  - Name of sampler responsible for sample submittal;
  - Identification of samples that accompany the form including:
    - Field ID number,
    - Number of samples,
    - Date/time collected,
    - Sample container type, volume, preservative,
    - Parameters/methods of interest,
    - Data level requirement (e.g., Level III),

- Comments about sample conditions,
- Signature of person relinquishing custody and signature of person accepting custody, plus date and time; and
- Identification of common carrier.

- If a commercial courier service (e.g., Federal Express) transports the samples to the laboratory, the chain-of-custody form will be signed by a member of the field team, and a copy retained by the field team. The remaining two copies of the form will be included in the package sent to the laboratory. If appropriate (e.g., for water samples), the remaining two copies of the form will be sealed in a zip-type plastic bag and placed in the cooler with the samples. The package/cooler will be sealed with packaging. Package routing documentation maintained by the courier service will serve as chain-of-custody documentation during shipment, because commercial couriers do not sign chain-of-custody forms.
- If samples are picked up by a laboratory representative, a member of the field team will sign the chain-of-custody record indicating that the samples have been transferred to the lab courier. The lab courier will also sign the form, indicating that the samples have been transferred to his or her custody. One copy of the chain-of-custody form will be retained by the field team and the remaining two copies will be sealed in the package with the samples as described above.

5.2 Laboratory Custody Procedures

For this study, normal laboratory custody procedures will be implemented. Samples received and logged into the laboratory will remain in the custody of the laboratory personnel at the laboratory until disposal.

5.2.1 Sample Receipt and Inspection

Upon arrival at the laboratory, samples will immediately be taken to the sample receiving area and logged into the laboratory sample registry in which the date and time of sample receipt will be recorded. The shipping container will be opened immediately and the temperature of the shipping container measured and documented on the appropriate laboratory form, if required by the sample media or analytical method.

Shipping containers having custody seals will be inspected for integrity upon arrival at the laboratory. The appropriate space on the chain-of-custody (i.e., "custody intact") will be checked "Y" for yes or "N" for no. If tampering of the custody seal is apparent, the sample custodian will immediately contact the Laboratory Project Manager who will be responsible to notify the GSI Project Manager.

Information on the chain-of-custody form will be checked against the sample labels and then signed by the sample custodian. The sample custodian will also inspect sample containers for leakage. A multi-phase sample which has leaked will not be acceptable for analysis, because the sample integrity has been altered. Samples in plastic containers appearing to bulge or evolve gas will be treated with caution, because toxic fumes or material of an explosive nature may be present. Discrepancies between information on sample labels and information provided on the chain-of-custody form or broken/altered samples will be resolved with the Laboratory Project Manager before the sample is assigned for analysis.

If a custody problem occurs, the sample custodian will immediately notify the Laboratory Project Manager. The Laboratory Project Manager will resolve the custody problem as soon as practical and notify the GSI Project Manager, if necessary. After notification, an initialed note will be made on the custody form which states who was notified, reason for notification, and resolution, if applicable.

5.2.2 Internal Tracking and Numbering

The sample custodian or designee will have responsibility for maintaining sample receipt logbooks, assigning a project log number to the samples, signing the chain-of-custody form, reporting inconsistencies to the Laboratory Project Manager, and distributing samples to the laboratory sections in accordance with applicable analytical procedures. The laboratory section sample custodian is responsible for ensuring that samples are placed in storage, for monitoring conditions in sample storage areas, and maintaining records for chain-of-custody within the laboratory. The Project Manager or designee is responsible for initiating paperwork for report files and analytical worksheets and logging samples into the Laboratory Information Management System (LIMS), if applicable.

Each sample will be assigned a unique laboratory sample number at the time of log-in to facilitate tracking of samples, extracts, and digests, as applicable, during analysis. The laboratory sample number will be recorded on the chain-of-custody form and Sample Registry, and logged into the computerized LIMS, if applicable. Any accompanying paper work will be placed in a project file until the order is completed. The laboratory project identification number will be recorded on all containers submitted in the project shipment.

After initiating a new log-in number, the Project Manager or designee will enter electronically or otherwise record relevant sample information, as follows:

- Laboratory sample number;
- Client project identification;
- Date received/date due;
- Matrix/sample identification;
- Date and time of sample collection;
- Storage location/container size/container type/preservative;
- Analyses required; and
- Problems/special instructions.

After assignment of the project identification number, samples will be labeled to identify the project number and sample designation. The samples will then be dispersed to the appropriate sample storage area. As required, sample storage temperature logs will be maintained for storage refrigerators or freezers to assure maintenance of proper sample temperature throughout the analyses, as applicable.

5.2.3 Internal Laboratory Custody Transfers

An internal laboratory chain-of-custody record is not required when samples are transferred to different areas of the laboratory.

5.2.4 Laboratory Storage Areas

As required, samples and extracts will be stored in uniquely identified refrigerated storage units located in secure areas of the laboratory. Samples are logged into the various department storage areas prior to preparation, analysis, or disposal. Samples to be analyzed for volatile organic compounds (VOCs) will be segregated from other samples. Samples will be stored separately from standards.

5.2.5 Requirements for Sample Disposal

Unless requested otherwise, samples, digests, and extracts, as applicable, will be disposed of as soon as holding times have expired or 30 days after results are reported to GSI.

5.2.6 Inter-Laboratory Custody Transfers

Under normal circumstances, samples will be analyzed by Columbia Analytical Services, Simi Valley, California, or the University of Southern California Earth Sciences service laboratory. In the event of a natural disaster (e.g., earthquake), samples to be analyzed by one laboratory may be sent to another in-network laboratory for analyses. When samples are transferred to another laboratory in the network, a chain-of-custody form will be initiated at shipping time by the sample custodian. A completed and signed fax of the Interdivisional Shipping Log will be sent to the receiving division custody department. This inter-laboratory chain-of-custody form will be sent with the samples and upon arrival at the division laboratory, laboratory custody procedures described above will be followed.

5.2.7 Data Archiving, Storage and Final Evidence File

Laboratory records will be maintained in a secure area with other associated project records. Hard copies of final reports, chain-of-custody forms, and any ancillary documentation pertinent to the project will be stored in a secured storage area. Analytical data stored in a LIMS will be maintained under a high level of data security by the use of passwords and file access/lock codes. At the end of a project, all custody forms will be returned to the laboratory project manager. Copies of custody information will be retained in the reporting laboratories' client files. Hard copies of reports, chain-of-custody forms and sample registries will be kept by the laboratory for a period of three years. Raw data and bench data files will be kept by the laboratory for a period of three years.

5.3 Final Evidence Files

A project file will be developed for the study data including the following items: reports, field notes, laboratory reports, signed chain-of-custody forms, sampling procedures, and any other pertinent documents, including, but not limited to the following items:

- Standard operating procedures;
- Field notes and field logbooks;

- Laboratory reports and data deliverables;
- Signed chain-of-custody documentation (tags, air bills, signed forms); and
- Photographs.

Hard copy items will be stored in a cabinet at the GSI office and access limited to concerned project personnel. The project file will be maintained at this location until the conclusion of the project. Electronic file copies will also be maintained on the GSI main project server. The GSI Project Manager will serve as the file custodian for the Vapor Intrusion Study.

6.0 LABORATORY CALIBRATION PROCEDURES AND FREQUENCY

This section describes the calibration procedures and the frequency at which these procedures will be performed for laboratory instruments.

The laboratory will employ specific procedures for the operation and calibration of analytical instruments in order to facilitate optimum instrument performance, thereby generating data of acceptable accuracy and precision. Prior to initiating sample analysis, laboratory instruments will demonstrate acceptable performance with respect to applicable standards from the manufacturer or selected reference methods (i.e., USEPA, API, or ASTM).

6.1 Storage of Standards

As soon as practical after receipt, standards will be transferred to a designated storage area in the laboratory. Volatile standards will be stored in a freezer; semi-volatile standards at room temperature; and other commercially purchased stock standards at 4°C, in a freezer, or at room temperature, as appropriate. Organic standards will be stored separately from samples. Certification sheets will be kept on file within each lab division and stored for future reference.

6.2 Traceability of Standards

Standards used for calibration of instrumentation used in analyzing samples for this study will be NIST traceable, USEPA A2LA certified, or obtained from another appropriate source. Records will be maintained to verify the traceability of all standards used and will include pertinent information such as the date, analyst, compound, purity, dilution volume, etc., as appropriate.

6.3 Instrument Calibration

Instrument calibration protocols will meet or exceed the requirements specified in the USEPA, API, or ASTM reference method employed for sample analysis. Initial instrument calibration curves will be generated, verified, and routinely monitored during instrumental analyses, as required by specific SOPs. Records of calibration, repairs, or replacement will be maintained by the designated laboratory personnel performing quality control activities and filed at the location where the work is performed.

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

7.0 ANALYTICAL PROCEDURES

This section describes the procedures for analyzing the samples collected as described in Section 5.

7.1 Laboratory Analytical and Measurement Procedures

7.1.1 List of Project Target Compounds and Laboratory Detection Limits

The selected laboratory will analyze water samples obtained during this study in accordance with USEPA SW-846 Method 8260B. Analytical procedures and project-specific laboratory reporting limits for organic compounds in water, as analyzed by USEPA SW-846 methods, are provided on Table 3. Laboratory reporting limits for SW-846 methods have been experimentally determined in accordance with Federal Register, vol. 49, no. 209, page 198-199.

Detection limits for this study will be laboratory Reporting Limits (RLs) corresponding to three to five times the method detection limit (MDL). The laboratory will report COC concentrations at the RLs described in this QAPP, unless the specified detection limits are not obtainable by the laboratory due to high parameter concentrations requiring sample dilution or matrix interferences. If requested, the laboratory will report COC concentrations less than the RL but greater than the MDL as estimated and will flag such results as estimated values in accordance with the laboratory data reduction procedures specified in Section 9 of this QAPP.

The laboratory has previously conducted a baseline detection limit study for all methods per USEPA CLP guidelines, and records of the study are maintained at the laboratory. Results of the study are periodically updated and/or revised when changes in instrumentation or methods occur within the laboratory. This study is intended to establish, in accordance with accepted regulatory procedures, the baseline (lowest possible) method detection limits (MDLs) and instrument detection limits (IDLs) obtainable by the laboratory. The laboratory maintains on file the results of the most recent detection limit study for project specific COCs.

Samples to be analyzed for volatile organics will be screened in the laboratory to determine what level they should be analyzed at. Samples will be analyzed either as low or medium level concentration samples or as a series of dilutions in order to span the expected concentration range of the site-specific compounds of interest.

7.1.2 List of Associated QC Samples

Each laboratory SOP includes a QC section addressing minimum QC requirements for the analysis of specific analyte groups.

8.0 INTERNAL QUALITY CONTROL CHECKS

8.1 Field QC Checks

Field QC samples will be collected and analyzed in order to i) evaluate field precision and accuracy, and ii) facilitate validation of sample results. Field sampling precision and accuracy will be assessed through the collection and laboratory analysis of field replicates and field blanks. Samples will be collected per applicable procedures provided in the Demonstration Plan or this QAPP.

Data from field QC samples will be examined to determine if any problems are evident for specific media or with laboratory procedures. The Contractor QA Manager will advise the Contractor Project Manager of the problems encountered so that the appropriate corrective action can be taken. Procedures for communicating corrective actions are described in Section 13 of this QAPP.

8.1.1 Blank Samples

8.1.1.1 Equipment Rinsate Blanks

For wells sampled using a portable submersible pump, the pump will be decontaminated between wells in accordance with standard field decontamination procedures. Following decontamination, an equipment rinsate blank will be collected to evaluate the effectiveness of the decontamination procedures. As an additional measure, wells sampled using a submersible pump will be sampled sequentially from least contaminated to most contaminated based on recent historic monitoring results.

8.1.1.2 Trip Blanks

If groundwater samples are collected, the effectiveness of sample handling techniques will be evaluated by submitting preserved trip blank samples for laboratory analysis. Trip blanks will consist of a pair of 40-mL VOA vials with Teflon™ lined septa, filled in the laboratory (or organization providing the sample containers) with laboratory-grade (organic-free/de-ionized or distilled) water. The unopened trip blanks will accompany the VOC sample bottles to the sampling site and back to the laboratory in the same shipping cooler. Proper labeling and documentation will be completed for trip blanks. Trip blanks will be prepared and analyzed with other samples being analyzed for VOCs at a minimum frequency of one per cooler when water samples are transmitted to the laboratory.

8.1.2 QC Check Samples

The precision of field sample collection techniques will be evaluated by collecting and analyzing field duplicates. Duplicate samples will be defined as those samples collected simultaneously from the same source under identical conditions into separate but identical containers, and preserved, stored, transported and analyzed in the same manner. Thus, to prepare a duplicate, an aliquot will be collected from a sample source and divided equally into two separate but identical sample containers, or will be co-located (i.e., in the case of indoor or ambient air samples). Each duplicate will be identically preserved, stored, transported and analyzed. Field duplicates will be given a different identification number to disguise the source of the sample from the laboratory. Field replicates will be analyzed by the same laboratory analyzing investigative samples.

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During the course of this study, duplicates will be collected at a minimum frequency of one duplicate for every 20 samples for each matrix. At a minimum, field duplicates will be analyzed for VOCs.

8.2 Laboratory QC Checks

8.2.1 Analysis of Water for COCs

The laboratory will implement a QA/QC program to ensure the reliability and validity of analyses performed in the laboratory. Analytical procedures will be documented in writing as SOPs, each including a section addressing minimum QC requirements for the procedure. Internal quality control checks differ slightly for individual procedures, but in general QC requirements will include the following:

- Method blanks;
- Instrument blanks;
- Matrix spikes/matrix spike duplicates;
- Surrogate spikes;
- Laboratory duplicates;
- Laboratory control standards;
- Surrogate spikes;
- Internal standard spikes; and
- Mass spectral tuning.

QC sample results will be properly recorded and included in the analytical data package. The data package will contain sufficient QC information to allow reconstruction and evaluation of the laboratory QC process by an independent data reviewer.

Data generated in the laboratory will be properly recorded and compiled into a deliverable package containing sufficient QC information for comparison to relevant criteria. Samples analyzed in non-conformance with the QC criteria will be re-analyzed by the laboratory if sufficient volume is available. The sample volumes listed on Table 2 generally provide sufficient volumes and/or weights of sample for re-analysis, if required.

Laboratory Internal Quality Control Program: Data quality objectives for internal laboratory control checks will be consistent with USEPA precision and accuracy criteria specified for selected analytical methods. The laboratory will continue to demonstrate an ability to produce acceptable results using the methods selected through the generation of acceptable QC data. Analytical data will be evaluated by the laboratory prior to submittal based on internal reviews of the QC data. Analytical quality control checks will be performed in the laboratory. These procedures will be based upon USEPA reference methods and generally accepted standards of good laboratory practice. Key components of the laboratory Analytical Quality Control Program include the following quality control practices and considerations:

- Designation of a Laboratory QA Manager to implement the laboratory QA/QC program;
- Adherence to specified laboratory sample acceptance procedures to maintain proper handling, processing, and storage of submitted samples;

- Use of the computerized laboratory data management system to record, document, and assimilate pertinent technical and administrative data;
- Use of USEPA reference methods and recommended instrumentation;
- Adherence to mandatory procedures for operation, calibration, and maintenance of laboratory and field instrumentation;
- Use of proper laboratory measuring equipment, glassware, water, chemical reagents, industrial gases;
- Constant surveillance and documentation of acceptable analytical method accuracy and precision through initial analytical method performance evaluations;
- Use of continuous surrogate spike recovery evaluations, where appropriate, to maintain acceptable method performance;
- Use of systematic method blank evaluations to identify analytical system interferences and background contamination levels;
- Adherence to proper laboratory documentation measures to maintain the complete integrity and legal validity of all laboratory analyses;
- Use of voluntary intra-laboratory performance evaluations to internally assess and evaluate analytical performance; and
- Participation in laboratory certifications, audits, and approval programs.

Analytical Data Quality: The principle criteria for validating data quality will be the continuous monitoring of acceptable analytical accuracy, precision, and overall method performance, through systematic analyses of quality control samples. The laboratory will conduct both initial and continuous analytical method performance evaluations to ensure that all generated analytical data meet applicable QC and method performance criteria. Each analytical method commonly used in the laboratory will utilize specific quality control procedures to continually monitor acceptable analytical method accuracy and precision. These specific quality control procedures are detailed in the analytical methods SOPs based upon USEPA reference methods.

9.0 DATA REDUCTION, VALIDATION, AND REPORTING

Data generated during field and laboratory analyses will be reduced and validated prior to reporting. No data shall be disseminated by the field crew or the laboratories until subjected to the reduction and validation procedures described below. For both field and laboratory data recording and reduction, errors will be corrected by drawing a single line through the error, re-entering the correct information, and initialing and dating the correction.

9.1 Laboratory Data Reduction

In order to convert raw data from instrument reading to reportable results, raw data will be reduced to reportable values by instrument hardware and software or by other manual procedures suggested in the applicable reference method. Reduction of laboratory measurements and laboratory reporting of analytical parameters will be conducted in accordance with the procedures specified for each USEPA, API, or ASTM analytical method. Data reduction and recordkeeping activities of the primary analyst will be as follows:

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- ***General Data Reduction:*** All methods employed for analysis of samples collected during this study will involve certain data reduction procedures following established laboratory QA/QC protocol. The analyst will record and maintain accurate laboratory records and computer files to include sample identification, weights or volumes, dilution factors, analysis date and method, and analyst initials. Proper instrument and method calibrations will be performed and verified. The analyst will confirm results of the analytical sequence or batch, including QA/QC verification. After converting raw data to final form by following proper procedures for calculations, rounding, and significant figures, sample results will be manually transcribed or automatically transferred from the instrument report to the results data sheet. Internal chain-of-custody records will be maintained as described in Section 5 of this QAPP. The laboratory will flag analytical results in order to note the conditions listed below:
  - U = Analyte was analyzed for but not detected.
  - J = Results are estimated owing to mass spectral data indicating the presence of a compound meeting applicable identification criteria, but quantitated at less than the MQL and greater than the MDL.
  - B = Analyte detected in corresponding method or laboratory blank.
  - X = Results are flagged for a reason other than specified above as noted by the laboratory.

- ***Sample Preparation:*** Preparation analysts will record accurate data used in final calculations. Such data will be maintained in extraction and digest logbooks, bench sheets, and chemist's notebooks containing sample weights or volume, final extract volumes, surrogate and spike amounts, and standard reference numbers.
- ***Instrument Analyses:*** Instrument analysts will verify calculations, analyte identifications, related QA/QC calculations, and sample results. Calculations will include surrogate spike recoveries, laboratory control sample (LCS) recoveries results of sample duplicates and matrix spikes, and results for method and matrix-specific blanks. Lab results will be recorded by the analyst on a data sheet and the associated QA/QC data sheet. Computer or integrator reduction will be employed for the analysis of volatile and semi-volatile organics by GS/MS. Instrumentation will generate a quantitation report and sample results will be calculated by computer integration, spreadsheet, or manual calculation. Positive sample results will be transcribed by the analyst to the sample results sheet and QC data entered into a QA/QC summary spreadsheet.
- ***Record Keeping:*** Bench sheets for sample extraction, digestion, and soil properties will be maintained in bound notebooks. Chromatographic documentation and data records will include sample preparation logs, extraction logs, bench sheets, instrument logs, instrument tune reports, quantitation reports, and instrument printouts. Run logs will be maintained for instrument analyses to document injection of each standard, quality control sample, and client sample. Equipment maintenance logs will be employed to document maintenance activities as discussed in Section 11 of this QAPP. Completion of chain-of-custody forms is discussed in Section 5 of this QAPP. Unused areas of the daily bench sheets and instrument logs will be crossed out, initialed and dated by the corresponding analyst or technician.

9.2 Data Validation

Data validation procedures will be performed for both field and laboratory operations as described below.

9.2.1 Procedures Used to Validate Field Data

The field data package, including field records and measurements acquired by the sampling team personnel, will be reviewed by the GSI QA Manager, as follows:

- Sampling records and chain-of-custody forms will be reviewed to verify that samples, field duplicates, and trip blanks were collected at the frequency specified in the QAPP and were properly prepared, preserved, and submitted to the laboratory; and
- Chain-of-custody forms will be reviewed for proper completion, signatures of field personnel and the laboratory sample custodian, and dates.

9.2.2 Procedures Used to Validate Laboratory Data

Data production will begin with the generation of data results by the analyst and continue through a multi-level review and validation process. Each step in the review process will be performed to assure the integrity and validity of the data generated by the laboratories. Data will be sequentially passed on to the peer review analyst of the staff chemist, the department supervisor, and finally the data entry personnel. The laboratory report will be reviewed by the Laboratory QA Manager assigned to the project and then will be certified by the laboratory manager or designee. Each step in the review process will be performed to assure the integrity and validity of the date generated by the laboratories, as follows:

Quality control data (e.g., laboratory duplicates, surrogates, matrix spikes, and matrix spike duplicates) will be compared to method acceptance criteria. Data considered to be acceptable will be entered into the laboratory computer system. Data summaries will be sent to the Laboratory QA Manager for review. If approved, data will be logged into the project database. Unacceptable data will be appropriately qualified in the project report. Case narratives will be prepared to include information concerning data falling outside acceptance limits, and any other anomalous conditions encountered during sample analysis. Data will be issued after approval by the Laboratory QA Manager.

9.3 Data Reporting

9.3.1 Field Data Reporting

Field data reporting comprises a tabulation of the results of measurements made, samples collected, methods used, or deviations from planned procedures in the field by direct recording into field notes.

9.3.2 Laboratory Data Reporting

9.3.2.1 Laboratory Analytical Services

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A LIMS will be utilized for generation of laboratory data reports. After data have been entered and verified as described in Section 9.2 above, a draft report will be generated for review by the Laboratory QA Manager. Laboratory data reports will consist of sample results plus the QA/QC data specified below. The following are general requirements for each sample analyzed by the laboratory:

- The results of each analysis;
- The list of the COCs;
- The method of analysis and the detection limit for each analyte;
- Dates of sample collection, receipt, preparation, and analysis;
- Copy of the chain-of-custody forms signed by the sample custodian;
- A narrative summarizing any QA/QC non-conformances and the corrective action taken; and
- A list relating laboratory ID to sample ID.

The list below describes the information to be provided for analysis of VOCs by GC/MS, as applicable:

- Evaluation of holding time, sample preservation, and percent solids;
- Dilutions;
- Results of bromofluorobenzene or decafluorotriphenylphosphine GC/MS tuning;
- Results of initial and continuing calibration;
- Results of blank analyses;
- Results of surrogates spikes, the expected value, control limits, and percent recovery;
- Results of matrix spike/matrix spike duplicate, control limits, expected value, RPD, and percent recovery;
- Results for laboratory control samples, expected value, control limits, and percent recovery;
- Results of internal standards;
- Compound identification, quantification, and detection limits; and
- Results of laboratory duplicates.

The laboratory will keep on file, for a period of three years, the following information:

- Sequential measurements readout records;
- Digestion logs;
- Percent solids raw data;
- Raw data calculation worksheets;
- GC/MS tuning and mass calculations sheets;
- Sample chromatograms;
- Mass spectra data for each sample; and
- Any other data that is associated with the samples analyzed.

After the Laboratory QA Manager has determined that the report summaries and case narratives meet project requirements, data will be compiled into a report for submittal to the GSI project manager.

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9.4 Third-Party Data Validation

Analytical data will be validated internally by GSI and will not be submitted to a third party for independent validation. Minimum requirements will be as follows:

- Chain-of-custody documentation associated with samples;
- A cover sheet listing samples included in the sample data group and a cross-reference between field and laboratory sample numbers;
- A case narrative describing any analytical problems encountered during analysis of the sample data group;
- Tables summarizing analytical results with reporting limits, identification, and quantification of each parameter; and
- Analytical results of quality control samples (i.e., field and laboratory blanks, initial and continuing calibration verifications, spikes, duplicates, surrogates, laboratory control samples, ICP interference check samples, chromatograms, and mass spectral data).

10.0 PERFORMANCE AND SYSTEM AUDITS

Performance and system audits will be conducted to verify that sampling and analysis are performed in accordance with applicable SOPs specified for field and laboratory activities. The audits of field and laboratory activities include two independent components: internal and external audits.

10.1 Field Performance and System Audits

10.1.1 Internal Field Audits

10.1.1.1 Internal Field Audit Responsibilities

Internal audits of field activities, including sampling and field measurements, will be conducted by the GSI Project Manager or a designated alternate. Additional team members may also be present during various phases of the audits. These audits will be conducted to evaluate performance, verify that procedures are followed, and correct deficiencies in the execution of field procedures.

10.1.1.2 Internal Field Audit Frequency

An internal field audit will be conducted at least once at the beginning of the site sample collection activities to verify that established procedures are being followed.

10.1.1.3 Internal Field Audit Procedures

To verify compliance with established procedures and implementation of appropriate QA procedures, internal audits will involve the review and examination of the following: i) field measurement and sampling records, ii) instrument operation and calibration records, iii) sample collection documentation, iv) sample handling and packaging procedures, and v) chain-of-custody procedures. Results of field performance audits will be documented on a field audit checklist. If the first audit reveals significant deficiencies,

one or more follow-up audits will be conducted to verify that QA procedures are maintained throughout the study.

10.1.2 External Field Audits

External field audits will not be conducted during this study.

10.2 Laboratory Performance and System Audits

10.2.1 Internal Laboratory Audits

10.2.1.1 Internal Laboratory Audit Responsibilities

Internal system and performance audits at Columbia Analytical Services and the University of Southern California Earth Sciences service laboratory will be the responsibility of the respective Laboratory QA Managers.

10.2.1.2 Internal Laboratory Audit Frequency

The frequency of the internal laboratory system audit will be the responsibility of the respective Laboratory QA Managers.

10.2.1.3 Internal Laboratory Audit Procedures

Performance and systems audits for sampling and analysis operations will include on-site review of laboratory quality assurance systems and on-site review of equipment for calibration and measurement techniques.

10.2.2 External Laboratory Audits

External laboratory audits will not be conducted as part of this study.

11.0 LABORATORY EQUIPMENT PREVENTATIVE MAINTENANCE

11.1 Laboratory Instrument Routine Maintenance Activities

As part of the laboratory QA/QC program, a routine preventive maintenance program will be conducted by the laboratories to minimize the occurrence of instrument failure or other system malfunction. The laboratory workload will be scheduled to accommodate planned downtime required to complete routine maintenance procedures. Trained operators will complete routine maintenance procedures (e.g., changing oven fans, replacing electronic control boards, changing vacuum pump oil, cleaning, etc.) for GC/MS instruments. An inventory of spare parts will be maintained to facilitate timely repair of instruments and minimize downtime.

When routine maintenance procedures do not correct a problem with instrumentation, outside repair services will be available on a next day basis. The laboratory will not maintain test equipment to be used in the maintenance of instrumentation; rather, service representatives will bring the necessary test equipment for the service call.

Records of preventive maintenance activities for each piece of equipment will be maintained in Calibration and Maintenance log books assigned to that instrument. Preventive maintenance performed during the project will be noted in the field logbook and the instrument Calibration and Maintenance log book.

11.2 Inspection/Acceptance Requirements for Supplies and Consumables

Supplies and spare parts will be maintained for both field and laboratory instruments to assure timely completion of sample screening and analysis. For field work, critical spare parts such as batteries will be kept on-site to reduce downtime. Backup instruments and equipment will be available on-site or within 1 day shipment to avoid delays in the field schedule. An inventory of spare parts will also be kept on hand in order to complete the routine maintenance tasks described in Section 11.1.

12.0 PROCEDURES TO ASSESS DATA QUALITY OBJECTIVES

12.1 Accuracy Assessment

In order to evaluate the accuracy of laboratory results, LCSs and MS/MSDs will be prepared at the frequency shown on Table 1 by spiking with VOCs prior to analysis. For the LCS, the ratio between the measured concentration and the known concentration in the spiked sample converted to a percentage is equal to the percent recovery. For MS/MSDs, the difference between the measured concentration in the spike and the concentration in the native sample is divided by the known spike concentration to obtain the percent recovery, as follows:

$$\%R = \frac{\text{Measured Concentration in Spike Sample} - \text{Concentration in Native Sample}}{\textit{Known Spike Concentration}} \times 100$$

Daily tabulations for each commonly analyzed organic compound will be maintained on instrument-specific, matrix-specific, and analyte-specific bases. Control charts of results obtained from LCS will be maintained for selected organic analytes to track the accuracy of laboratory data.

12.2 Precision Assessment

Spiked samples will be prepared by selecting a sample at random from each sample shipment received at the laboratory, dividing the sample into equal aliquots, and then spiking each of the aliquots with a known amount of analyte. The duplicate samples will then be included in the analytical sample set. The splitting of the sample allows the analyst to determine the precision of the preparation and analytical techniques associated with the duplicate sample. The RPD between the spike and duplicate spike (or between MS and MSD) will be calculated as follows:

$$RPD = \frac{\textit{Concentration in Spike}\,1 - \textit{Concentration in Spike}\,2}{0.5(\textit{Concentration in Spike}\,1 + \textit{Concentration in Spike}\,2)} \times 100$$

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12.3 Completeness Assessment

Completeness is the ratio of the number of valid sample results to the total number of samples analyzed with a specific matrix and/or analysis. After analytical testing, the percent completeness will be calculated as follows

$$Completeness = \frac{(number\ of\ valid\ measurements)}{(number\ of\ measurements\ planned)} \times 100$$

13.0 CORRECTIVE ACTION

Corrective action will be taken to identify, recommend, approve, and implement measures to remedy unacceptable procedures or out-of-control performances potentially affecting data quality. Corrective actions may be required for i) non-conformance with procedures specified by the QAPP, ii) malfunction of sampling or analytical equipment, or iii) changes in sampling network or frequency. Non-conformances include those instances of conducting activities outside the requirements of the QAPP (i.e., missing holding times or detecting blank contamination). Analytical and equipment problems may occur during sampling, sample handling, sample preparation, or laboratory analysis. Modifications in the sampling network may result from inaccessible locations or from inadvertent omissions in sample collection.

Any non-conformance to quality control procedures specified in the QAPP will be identified, reported, and corrected. If the non-conformance is identified during sample collection or analysis, corrective action will be implemented immediately by the field technician or laboratory analyst. If the non-conformance is identified during an internal/external audit or third-party data validation, corrective action will be implemented after notification of the GSI Project Manager, and/or the Laboratory Project Manager. Any corrective actions taken during the course of this study will be documented in the final project report described in Section 14 of this QAPP.

13.1 Field Corrective Action

13.1.1 Corrective Action for Procedural Non-Conformances

The GSI Field Technical Staff will be responsible for reporting suspected technical or QA non-conformances or deficiencies to the GSI Project Manager. The GSI Project Manager will be responsible for ensuring that any necessary corrective actions are implemented. If appropriate, the GSI Project Manager will suspend additional work depending on the nature of the non-conforming activity until the corrective action is completed. The GSI Project Manager will ensure that corrective action for the non-conformance is completed by evaluating and controlling additional work on non-conforming items, determining appropriate action, and communicating with concerned persons via telephone, e-mail, or other medium.

13.1.2 Corrective Action for Changes in Sampling Program

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The GSI Project Manager and Field Technical Staff will work to ensure that all planned groundwater samplers are collected in accordance with the Demonstration Plan. If any samples are not collected or are lost due to technical issues, the GSI Project Manager will develop a plan to replace the missing samples, if feasible. The GSI Project Manager will work to ensure that the modification does not compromise project quality assurance objectives. GSI Field Technical Staff will not initiate work program modifications without prior communication with the GSI Project Manager.

Significant plan modifications will be implemented only after obtaining the approval of the GSI Project Manager. Program changes will be documented and copies of the affected document will be distributed to recipients via e-mail or other medium. The GSI Project Manager will be responsible for the controlling, tracking, and implementation of the identified changes. A discussion of field program modifications will be included in the final project report.

If the proposed modification has the potential to adversely impact attainment of project QA objectives, the GSI Project Manager will be notified while the sampling crew is still in the field. Such a situation would result if i) a sampling location were to be eliminated; ii) a sampling location were to be moved a significant distance from its designated location owing to access limitations or obstructions; or iii) sampling frequency were to be decreased. Possible corrective actions could include i) re-mobilization to collect additional samples, or ii) evaluation to determine if data already collected were sufficient to satisfy QA objectives.

If the GSI Project Manager determines that the modification will not adversely impact the achievement of project QA objectives, no further action will be taken and a summary of the findings will be included in the final project report. If the modification has the potential to adversely impact the achievement of project QA objectives, additional locations will be sampled or additional samples will be collected and the findings documented in the final project report.

13.1.3 Field Corrective Action Reports

In cases in which corrective actions of field procedures are required, a description of the nature of the problem, an evaluation of the cause, if known, and the action taken will be prepared by the GSI Project Manager or QA Manager for inclusion in the final project report. Deficiencies identified during the data validation and assessment process will also be included in the final project report.

13.2 Laboratory Corrective Action

Data packages prepared by the laboratory will include a discussion of the QC problems encountered and corrective actions taken. If an out-of-control event or potential out-of-control event is noted in the laboratory, an investigation and corrective action will be taken appropriate to the analysis and the event. Laboratory corrective action may be required if any of the following occur:

- QC data are outside the warning or acceptable windows for precision and accuracy;
- Blanks contain target analytes above acceptable levels;

- Undesirable trends are detected in spike recoveries or RPDs between duplicates;
- Unusual changes in detection limits are noted;
- Deficiencies are detected by the QA Department during internal or external audits or from the results of performance evaluation samples; or
- Inquiries concerning data quality are received.

The Laboratory QA Manager will be responsible for implementing laboratory corrective action. Individual analysts will be responsible for assessing the results from sample analysis. Results not meeting applicable criteria will be reported to a supervisor who will recommend a corrective action to be implemented by the section manager, the QC chemist and the QA/QC Supervisor. The Laboratory QA Manager will be responsible for ensuring that corrective actions are taken, as appropriate, in the following situations:

- ***Out-of-Control Criteria:*** An out-of-control situation will exist when a blank, calibration standard, laboratory control sample, sample replicate, or spike recovery analysis fails to meet applicable quality control criteria. Corrective action procedures are often handled at the bench level by the analyst who reviews the preparation for possible errors, checks the instrument calibration, spike and calibration mixes, and instrument sensitivity. If the out-of-control situation cannot be remedied by the analyst, an investigation to determine the cause of the problem will be undertaken by the analyst and department supervisor, and a Quality Assurance Action Report will be initiated. Analyses completed during the out-of-control situation will be repeated after the out-of-control situation has been corrected. If the problem persists or cannot be identified, the matter will be referred to the laboratory supervisor, manager and/or QA Department for further investigation. After resolution, the corrective action procedure will be documented and filed with the QA Department.
- ***Warning Criteria:*** Corrective measures will be implemented when one of the following two conditions occurs: i) quality assurance data for blanks, laboratory control samples, sample replicates, or matrix spikes exceed two standard deviations of applicable limits or ii) a trend or shift is observed for the reference standard. Provided other criteria are within applicable limits, samples need not be re-analyzed. A Quality Assurance Corrective Action Report will be initiated by the analyst and the Laboratory Supervisor, and corrective action will be implemented prior to analyzing additional samples. If the situation occurs with the next sample batch, an out-of-control situation exists, and steps outlined above are taken. If matrix interference is indicated by out-of-control replicate analyses or matrix spike recovery data, re-analysis of a sample batch is necessary only when other QC data do not meet applicable specifications.
- ***Performance Audit:*** If the laboratory fails to meet applicable requirements reviewed during a performance of systems audit, corrective action will be taken. The QA/QC coordinator will notify the Laboratory Project Manager and the USEPA QA Manager in the event of a corrective action taken in response to an audit. Applicable federal and state guidelines and requirements regarding response to audit findings are observed by laboratory.

13.3 Corrective Action during Data Validation and Data Assessment

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The GSI QA Manager will review analytical reports generated by the analytical laboratory prior to data use and filing. Upon receiving data validation or data assessment results, the GSI QA Manager will identify the need for corrective action and notify concerned persons by an appropriate medium. Specified corrective action will be developed to assure meeting required QA objectives. The GSI Project Manager and the Laboratory Project Managers will be responsible for implementing corrective actions in the field and laboratory, respectively. Corrective action required may include re-sampling, collecting additional samples, or re-measurement of field parameters. The laboratory may be required to repair or re-calibrate instrumentation, re-inject or re-analyze samples, or provide additional raw data. Proposed and implemented corrective actions will be documented in the final project.

14.0 QUALITY ASSURANCE REPORTS TO MANAGEMENT

The final report for this study will be the responsibility of the GSI Project Manager. The final report will contain a section identified as the Project QA Report or similar that addresses data quality, including the accuracy, precision, and completeness of the data, results of any performance or system audits, and any corrective action needed or taken during the project.

14.1 Contents of Project QA Report

The QA report will contain i) results of field and laboratory audits conducted during the time period covered by the report, ii) an assessment of QA results with respect to data quality objectives, iii) a summary of corrective actions that may have been implemented, and iv) results of any corrective action activities. If applicable, references to QAPP modifications will be highlighted.

14.2 Frequency of QA Reports

The Project QA Report will be prepared on a one-time basis and submitted in conjunction with the final report for this study.

15.0 REFERENCES

USEPA, 1994a. *Guidance for the Data Quality Objectives Process*, U. S. Environmental Protection Agency.

USEPA, 1994b. *National Functional Guidelines for Organic Data Review*, U.S. Environmental Protection Agency, December 1994.

USEPA, 1998. *Region 5 RCRA QAPP Instructions,* U. S. Environmental Protection Agency. Revision: April1998.

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TABLES

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TABLE 1

SAMPLING REQUIREMENTS FOR LABORATORY AND FIELD QUALITY ASSURANCE SAMPLES

QA Sample Type	*Frequency*	*Data Quality Objective*
Field Duplicate	1 per 20 samples	RPD +/- 30%
Matrix Spike and Duplicates	1 per 20 samples	Per EPA Method 8260B
Trip Blanks	1 per 3 days of sampling	Concentrations < RL
Equipment Rinsate Blank	1 per 3 decontamination events	Concentrations < RL
Method Blanks	1 per 12 hours of analysis	Concentrations < RL

Notes:

1. RPD = Relative percent difference; RL = Reporting Limit.

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TABLE 2
SAMPLE CONTAINER, PRESERVATION, AND HOLDING TIME REQUIREMENTS

Parameter Group	Reference Method	Sample Container and Preservative	Sample Storage	Maximum Holding Time
Volatile Organics Water	EPA 8260B	3-40 mL glass vials, HCl to pH<2	Cooler (~4 ºC)	14 days

Notes:

1. Laboratory procedures will be conducted in accordance with the reference methods specified above.
2. NA = Not applicable to this analysis or matrix.

GSI ENVIRONMENTAL

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TABLE 3

USEPA METHOD 8260B ANALYTICAL PARAMETERS AND DATA QUALITY OBJECTIVES

Analyte	CAS Number	MDL mg/L	MQL mg/L	Investigation DQO mg/L
Volatile Organics				
1,1,1-Trichloroethane	71-55-6	0.0001	0.001	1.00E-03
1,1,2,2-Tetrachloroethane	79-34-5	0.00005	0.001	1.00E-03
1,1,2-Trichloroethane	79-00-5	0.00019	0.001	1.00E-03
1,1-Dichloroethane	75-34-3	0.00012	0.001	1.00E-03
1,1-Dichloroethene	75-35-4	0.00012	0.001	1.00E-03
1,2-Dichloroethane	107-06-2	0.0002	0.001	1.00E-03
1,2-Dichloroethene (total)	540-59-0	0.00015	0.002	2.00E-03
1,2-Dichloropropane	78-87-5	0.00012	0.001	1.00E-03
2-Hexanone	591-78-6	0.00036	0.001	1.00E-03
4-Methyl-2-pentanone (MIBK)	108-10-1	0.00024	0.001	1.00E-03
Acetone	67-64-1	0.00052	0.001	1.00E-03
Benzene	71-43-2	0.00018	0.001	1.00E-03
Bromodichloromethane	75-27-4	0.00024	0.001	1.00E-03
Bromoform	75-25-2	0.00031	0.001	1.00E-03
Bromomethane	74-83-9	0.00031	0.001	1.00E-03
Carbon Disulfide	75-15-0	0.00011	0.001	1.00E-03
Carbon Tetrachloride	56-23-5	0.00018	0.001	1.00E-03
Chlorobenzene	108-90-7	0.00011	0.001	1.00E-03
Chloroethane	75-00-3	0.0003	0.001	1.00E-03
Chloroform	67-66-3	0.00026	0.001	1.00E-03
Chloromethane	74-87-3	0.00006	0.001	1.00E-03
cis-1,2-Dichloroethene	156-59-2	0.00015	0.001	1.00E-03
cis-1,3-Dichloropropene	10061-01-5	0.00013	0.001	1.00E-03
Dibromochloromethane	124-48-1	0.00018	0.001	1.00E-03
Ethylbenzene	100-41-4	0.00014	0.001	1.00E-03
Methyl Ethyl Ketone (2-Butanone)	78-93-3	0.00046	0.001	1.00E-03
Methylene Chloride	75-09-2	0.00019	0.001	1.00E-03
Styrene	100-42-5	0.0001	0.001	1.00E-03
Tetrachloroethene	127-18-4	0.00018	0.001	1.00E-03
Toluene	108-88-3	0.00012	0.001	1.00E-03
trans-1,2-Dichloroethene	156-60-5	0.00012	0.001	1.00E-03
trans-1,3-Dichloropropene	10061-02-6	0.00021	0.001	1.00E-03
Trichloroethene	79-01-6	0.00014	0.001	1.00E-03
Vinyl Chloride	75-01-4	0.00014	0.001	1.00E-03
Xylenes (total)	1330-20-7	0.00026	0.003	3.00E-03

Notes:
1. Investigation DQOs correspond to the reporting limit (RL) for each analyte.
2. Method detection limits (MDLs) and reporting limits (RLs) shown are based on data provided by TestAmerica, Houston.

APPENDIX B.2: QUALITY ASSURANCE PROJECT PLAN

Analytical methods are referenced from "Test Methods for Evaluating Solid Wastes, SW-846, Update III, 3rd edition," December 1996.

3. Applicable results will be reported as estimated value between method detection limit (MDL) and the method quantitation limit (MQL).
4. Laboratory MDLs are continuously being evaluated and may differ slightly from these values.
5. Prep. = Digestion or extraction method.
   Det. = Determinative method for quantitation.

APPENDICES

Appendix C: Field Program Results: Demonstration Site #1

Contents:

APPENDICES

Appendix C.1: Groundwater Sampling Results – Site #1

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Appendix C.1
Groundwater Sampling Results - Site #1

	Round	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3
	Sample Date	4/4/2013	4/16/2013	4/16/2013	4/16/2013	5/1/2013	5/21/2013	6/11/2013	6/11/2013	6/25/2013	6/25/2013	7/17/2013	8/2/2013	8/2/2013	8/13/2013	8/27/2013	8/27/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L) Dup	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Standard Dup	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)
Parameter	Well ID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethene	MW-02A	1.5	1	-	1.8	3.1	3.1	1.5	-	1.1	2.1	3.6	2.9	-	1.2	0.95 J	2
	MW-06	2.3	1.3	-	1.8	1.6	3.7	3.1	-	2.4	2.4	3.5	2.6	-	1.5	1.6	1.2
	MW-13	15	19	-	20	19	27	21	-	18	20	21	25	-	17	18	23
	MW-15	0.98 J	1.4	-	1.6	1.2	1.3	1.1	-	1.2	1.2	1.1	-	-	0.81 J	1.1	1.1
	MW-23A	2.4	2.9	3.1	3.1	4.8	5.6	3.5	-	2.5	3	4.8	3.6	-	1.6	1.7	1.6
	MW-25A	<0.5	<0.5	-	<0.5	<0.5	<0.5	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
	MW-26	4.1	5.3	-	5.2	3.4	4.3	3.8	4	4.3	4.3	3.5	3.6	-	2.4	3.4	3.1
	TW-01	9.4	12	-	7.5	6.5	8	9.4	-	11	<0.2	8.2	7.3	6.4	8	14	8.3
	Trip Blank	<0.5	-	-	-	<0.5	<0.5	<0.2	-	-	-	<0.2	<0.2	-	<0.2	-	-
cis-1,2-Dichloroethene	MW-02A	35	18	-	36	52	61	31	-	17	39	65	60	-	25	16	40
	MW-06	60	32	-	49	23	98	75	-	51	61	20	57	-	36	38	30
	MW-13	61	65	-	80	75	94	74	-	62	71	84	94	-	60	64	81
	MW-15	5.4	7.5	-	7.3	6.4	6.7	6.1	-	5.6	5.8	5.8	-	-	4.3	5.8	6.4
	MW-23A	1.4	1.6	1.8	2	3.2	3.2	2.2	-	1.3	2.1	2.5	2.7	-	1.1	0.87 J	0.99 J
	MW-25A	<0.4	<0.4	-	<0.4	<0.4	<0.4	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
	MW-26	2.5	2.8	-	3	2.8	2.7	2.3	2.4	2.1	2.6	2	2.8	-	1.4	1.7	1.9
	TW-01	29	39	-	24	22	25	30	-	34	<0.2	27	27	24	25	41	29
	Trip Blank	<0.4	-	-	-	<0.4	<0.4	<0.2	-	-	-	<0.2	<0.2	-	<0.2	-	-
Tetrachloroethene (PCE)	MW-02A	2.5	1.2	-	1.9	4.3	5	2.2	-	1.6	2.9	6.8	5.4	-	2.5	1.4	2.9
	MW-06	9.6	5.1	-	5.4	4.4	9.5	11	-	10	8.1	6.4	8.2	-	6.2	6.1	2.8
	MW-13	40	38	-	43	55	69	44	-	52	53	57	76	-	47	48	53
	MW-15	1.7	2.1	-	2.1	2.2	2.5	1.8	-	2.3	2.2	2.5	-	-	1.8	2	1.9
	MW-23A	8.3	8.5	8.5	8.3	20	21	12	-	10	11	23	17	-	5.7	6.1	6.1
	MW-25A	1.3	1.2	-	1.2	1.2	1.3	0.88 J	-	0.99 J	0.95 J	1.3	1.3	-	0.96 J	1.4	1.3
	MW-26	14	14	-	14	12	13	9.6	11	14	14	12	12	-	9	10	11
	TW-01	40	43	-	20	30	35	35	-	45	28	42	38	39	36	48	28
	Trip Blank	<0.4	-	-	-	<0.4	<0.4	<0.3	-	-	-	<0.3	<0.3	-	<0.3	-	-
Trichloroethene (TCE)	MW-02A	2.4	1.1	-	2.2	4.2	4.1	2	-	<0.2	3.2	5.2	4.2	-	1.9	1.3	2.7
	MW-06	4.1	2.3	-	3.5	4.7	9.2	5.3	-	4.5	4.8	6	5.9	-	4.1	3.5	2.9
	MW-13	22	22	-	27	31	38	26	-	30	32	34	40	-	24	27	32
	MW-15	2.7	3.1	-	3.1	3.1	3.4	2.8	-	3.5	3.1	3.3	-	-	2.3	3	3
	MW-23A	2	2.2	2.3	2.2	4.7	4.7	2.7	-	<0.2	3.1	4.6	3.4	-	1.3	1.4	1.5
	MW-25A	<0.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
	MW-26	3.1	3.4	-	3.3	2.9	2.9	2.3	2.4	3.2	3.3	2.7	2.6	-	2	2.3	2.1
	TW-01	14	15	-	11	12	13	13	-	<0.2	16	15	13	14	13	17	13
	Trip Blank	<0.2	-	-	-	<0.2	<0.2	<0.2	-	-	-	<0.2	<0.2	-	<0.2	-	-
Vinyl Chloride	MW-02A	2.4	2.4	-	4.1	3.6	3.5	1.2	-	1.8	3.9	6.3	6.2	-	2.2	2	4.5
	MW-06	3.7	2.7	-	2.7	2.9	3.8	4.3	-	3.9	<0.2	8.1	3.5	-	2.2	3.2	2.5
	MW-13	<0.4	<0.4	-	<0.4	3.1	<0.4	<0.2	-	<0.2	0.38 J	1.1	<0.2	-	<0.2	<0.2	<0.2
	MW-15	<0.4	<0.4	-	<0.4	<0.4	<0.4	<0.2	-	<0.2	<0.2	<0.2	-	-	<0.2	<0.2	<0.2
	MW-23A	<0.4	<0.4	<0.4	<0.4	2.3	<0.4	<0.2	-	<0.2	<0.2	2.1	<0.2	-	<0.2	<0.2	<0.2
	MW-25A	<0.4	<0.4	-	<0.4	0.44 J	<0.4	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2
	MW-26	<0.4	<0.4	-	<0.4	3	<0.4	<0.2	<0.2	<0.2	<0.2	1.3	<0.2	-	<0.2	<0.2	<0.2
	TW-01	<0.4	0.76 J	-	<0.4	<0.4	<0.4	<0.2	-	0.58 J	<0.2	<0.2	<0.2	<0.2	<0.2	0.77 J	<0.2
	Trip Blank	<0.4	-	-	-	<0.4	<0.4	<0.2	-	-	-	<0.2	<0.2	-	<0.2	-	-

Notes
1. "-" = Not sampled.

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Appendix C.1
Groundwater Sampling Results - Site # 1

	Round	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5
	Sample Date	9/9/2013	9/30/2013	9/30/2013	10/17/2013	10/17/2013	10/29/2013	10/29/2013	10/29/2013	11/15/2013	11/27/2013	12/12/2013	12/12/2013	12/26/2013	12/26/2013	12/26/2013	1/8/2014
	Sample Collection Method	SNAP Samplers	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Standard Dup	Low-Flow Alternative (L)	Low-Flow Alternative (L) Dup	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Standard Dup	Low-Flow Alternative (L)	Low-Flow Alternative (L) Dup	Low-Flow Alternative (S)	SNAP Samplers
Parameter	Well ID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethene	MW-02A	3.6	2.2	-	1.1	-	0.84 J	-	1.7	3.8	2	0.92 J	-	0.76 J	-	2	2.6
	MW-06	3.8	1.5	-	1.6	-	0.86 J	-	<0.2	0.97 J	1.5	1.4	-	0.91 J	-	1.1	1.6
	MW-13	25	24	-	22	21	18	20	21	29	29	17	-	25	18	19	27
	MW-15	1.7	1.1	1.1	1.2	-	1.2	-	1.1	1.2	1.2	0.98 J	-	1.2	-	1.1	1.2
	MW-23A	4	3.3	-	1.2	-	0.96 J	-	0.76 J	2.2	3.4	0.93 J	-	1.6	-	1.7	3.5
	MW-25A	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2
	MW-26	3	2.9	-	2.7	-	2.7	-	2.1	2.4	2.3	2.4	2.5	2.1	-	2.2	1.5
	TW-01	9.2	10	-	12	-	16	-	7.7	8.9	9.8	10	-	14	-	7.1	8.1
	Trip Blank	<0.2	<0.2	-	<0.2	-	<0.2	-	-	<0.2	<0.2	<0.2	-	-	-	-	<0.2
cis-1,2-Dichloroethene	MW-02A	68	45	-	22	-	15	-	37	78	39	18	-	13	-	40	57
	MW-06	38	31	-	37	-	19	-	8.1	6.9	38	34	-	19	-	23	29
	MW-13	97	86	-	74	71	64	65	73	100	100	62	-	82	61	64	94
	MW-15	6.6	6.5	6.7	6.4	-	6.5	-	6.2	6.3	7	5.7	-	6.3	-	6.4	7.2
	MW-23A	2.4	1.7	-	0.61 J	-	0.67 J	-	0.54 J	1.7	1.8	0.89 J	-	1.1	-	1.5	3.1
	MW-25A	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2
	MW-26	2	2	-	1.7	-	1.6	-	1.5	1.9	1.8	1.3	1.4	1.3	-	1.3	1.2
	TW-01	29	32	-	39	-	51	-	28	29	33	36	-	44	-	26	27
	Trip Blank	<0.2	<0.2	-	<0.2	-	<0.2	-	-	<0.2	<0.2	<0.2	-	-	-	-	<0.2
Tetrachloroethene (PCE)	MW-02A	6.2	4.4	-	2	-	1.3	-	2.5	7.9	4.2	2.1	-	1.3	-	2.7	5.6
	MW-06	4.4	5.2	-	5.3	-	3.8	-	2.4	1.8	5.6	5.9	-	3.1	-	3.7	4.5
	MW-13	70	75	-	55	52	47	49	49	78	74	44	-	52	43	46	70
	MW-15	2.1	2.3	2.3	2	-	2.1	-	2.2	2.4	2.1	2	-	2	-	2	2.4
	MW-23A	15	18	-	5	-	5.6	-	4.3	9.7	15	4.2	-	7	-	6.7	20
	MW-25A	1.5	2.4	-	1.9	-	2.2	-	1.7	2.2	1.3	<0.3	-	0.48 J	-	0.43 J	0.77 J
	MW-26	7.2	10	-	8.2	-	10	-	8.7	7.8	6.2	7.6	7.2	7.3	-	6.8	4.6
	TW-01	37	51	-	50	-	62	-	27	41	40	41	-	51	-	24	35
	Trip Blank	<0.3	<0.3	-	<0.3	-	<0.3	-	-	<0.3	<0.3	<0.3	-	-	-	-	<0.3
Trichloroethene (TCE)	MW-02A	5.4	3.5	-	1.6	-	1.1	-	2.4	5.8	3	1.4	-	1	-	2.6	4.6
	MW-06	4.8	5	-	3.8	-	2.3	-	2.3	2.2	3.2	3.5	-	2	-	2.3	2.7
	MW-13	39	39	-	31	30	25	26	28	42	40	25	-	31	26	27	42
	MW-15	3.3	3.8	3.5	3	-	3	-	2.8	3	3	2.5	-	2.8	-	2.8	3.2
	MW-23A	3.6	3.4	-	1	-	1.2	-	0.97 J	2.3	3.1	1.1	-	1.8	-	1.9	4.6
	MW-25A	<0.2	0.36 J	-	0.31 J	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2
	MW-26	1.9	2.5	-	2.1	-	2	-	2	1.9	1.7	1.6	1.6	1.6	-	1.6	1.2
	TW-01	15	18	-	18	-	20	-	13	15	16	16	-	17	-	11	14
	Trip Blank	<0.2	<0.2	-	<0.2	-	<0.2	-	-	<0.2	<0.2	<0.2	-	-	-	-	<0.2
Vinyl Chloride	MW-02A	7.8	4.8	-	2.1	-	1.5	-	3.6	10	4.3	1.7	-	1.3	-	3.7	6.6
	MW-06	14	1.3	-	2.5	-	1	-	<0.2	2.7	2	2.1	-	1	-	1.3	2.5
	MW-13	2.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	0.91 J	<0.2	<0.2	-	<0.2	<0.2	<0.2	1.3
	MW-15	0.57 J	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2
	MW-23A	12	<0.2	-	<0.2	-	<0.2	-	<0.2	12	<0.2	<0.2	-	<0.2	-	<0.2	0.51 J
	MW-25A	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2
	MW-26	4.8	<0.2	-	<0.2	-	<0.2	-	<0.2	0.92 J	<0.2	<0.2	<0.2	<0.2	-	<0.2	2.1
	TW-01	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	0.46 J	-	0.72 J	-	<0.2	<0.2
	Trip Blank	<0.2	<0.2	-	<0.2	-	<0.2	-	-	<0.2	<0.2	<0.2	-	-	-	-	<0.2

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix C.1
Groundwater Sampling Results - Site # 1

	Round	5	5	6	6	6	6	6	6	6	6	6
	Sample Date	1/23/2014	1/23/2014	2/6/2014	2/6/2014	2/17/2014	2/17/2014	2/17/2014	2/17/2014	3/5/2014	3/20/2014	3/20/2014
	Sample Collection Method	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Standard Dup	Low-Flow Alternative (L)	Low-Flow Alternative (L) Dup	Low-Flow Alternative (S)	Low-Flow Alternative (S) Dup	SNAP Samplers	Hydrasleeve	Hydrasleeve Dup
Parameter	Well ID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethene	MW-02A	3.2	2.5	0.89 J	-	0.68 J	-	1.7	-	2.6	2.4	-
	MW-06	0.62 J	-	1.7	-	1.5	-	1	-	0.71 J	0.76 J	-
	MW-13	27	-	20	-	23	-	20	-	28	-	-
	MW-15	1.2	-	1.2	-	1.4	-	1.2	-	1.6	2	-
	MW-23A	4.4	-	2	-	2	-	2.1	-	3.4	2.6	-
	MW-25A	<0.2	-	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2
	MW-26	1.9	-	2	2	2.1	1.9	1.9	1.7	0.83 J	1.4	-
	TW-01	8.2	-	9.4	-	12	-	7.2	-	8.1	6	-
	Trip Blank	<0.2	-	-	-	-	-	-	-	<0.2	<0.2	-
cis-1,2-Dichloroethene	MW-02A	57	54	21	-	14	-	36	-	51	49	-
	MW-06	12	-	42	-	33	-	26	-	12	22	-
	MW-13	92	-	74	-	89	-	76	-	96	-	-
	MW-15	7	-	7.3	-	8.3	-	9.2	-	9.8	12	-
	MW-23A	2.8	-	1.6	-	1.6	-	1.6	-	2.5	1.9	-
	MW-25A	<0.2	-	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2
	MW-26	1.1	-	1.1	1.5	1.2	1.2	1.2	1.1	0.62 J	0.9 J	-
	TW-01	25	-	33	-	41	-	26	-	26	20	-
	Trip Blank	<0.2	-	-	-	-	-	-	-	<0.2	<0.2	-
Tetrachloroethene (PCE)	MW-02A	6.8	6	1.9	-	1.3	-	2.4	-	6.5	5.5	-
	MW-06	2.6	-	6.4	-	5.2	-	3.5	-	3.3	3.6	-
	MW-13	90	-	50	-	53	-	49	-	90	-	-
	MW-15	2.7	-	2.1	-	2.1	-	2.4	-	3.2	3.4	-
	MW-23A	24	-	8.7	-	7.4	-	7.1	-	20	15	-
	MW-25A	0.52 J	-	<0.3	-	<0.3	-	<0.3	-	0.63 J	0.54 J	0.53 J
	MW-26	6.7	-	6.5	8.5	6.7	6.5	5.9	5.4	2.8	4.9	-
	TW-01	42	-	37	-	39	-	20	-	42	31	-
	Trip Blank	<0.3	-	-	-	-	-	-	-	<0.3	<0.3	-
Trichloroethene (TCE)	MW-02A	5	4.9	1.5	-	1	-	2.2	-	4.4	4	-
	MW-06	2.7	-	3.7	-	2.9	-	2.5	-	2	2.8	-
	MW-13	46	-	28	-	33	-	30	-	45	-	-
	MW-15	3.4	-	2.7	-	3	-	3.4	-	4.2	5	-
	MW-23A	4.6	-	1.9	-	1.7	-	2.1	-	3.3	2.5	-
	MW-25A	<0.2	-	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2
	MW-26	1.4	-	1.5	1.9	1.6	1.6	1.3	1.3	0.69 J	1.2	-
	TW-01	14	-	13	-	15	-	10	-	14	11	-
	Trip Blank	<0.2	-	-	-	-	-	-	-	<0.2	<0.2	-
Vinyl Chloride	MW-02A	8.7	5.7	1.6	-	1.3	-	3.2	-	6.8	4.1	-
	MW-06	0.63 J	-	2.3	-	1.8	-	1.4	-	1.6	<0.2	-
	MW-13	<0.2	-	<0.2	-	<0.2	-	<0.2	-	1.2	-	-
	MW-15	<0.2	-	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	-
	MW-23A	<0.2	-	<0.2	-	<0.2	-	<0.2	-	2.3	<0.2	-
	MW-25A	<0.2	-	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2
	MW-26	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.91 J	<0.2	-
	TW-01	<0.2	-	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	-
	Trip Blank	<0.2	-	-	-	-	-	-	-	<0.2	<0.2	-

Notes
1. "-" = Not sampled.

APPENDICES

Appendix C.2: Normalized Concentration Results – Site #1

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Appendix C.2
Normalized Concentration Results - Site #1

	Round	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
	Sample Date	4/4/2013	4/16/2013	4/16/2013	5/1/2013	5/21/2013	6/11/2013	6/25/2013	6/25/2013	7/17/2013	8/2/2013	8/13/2013	8/27/2013	8/27/2013	9/9/2013	9/30/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
	X-Axis	LFS-1	LFA(L)-1	LFA(S)-1	SS-1	HS-1	LFS-2	LFA(L)-2	LFA(S)-2	SS-2	HS-2	LFS-3	LFA(L)-3	LFA(S)-3	SS-3	HS-3
Parameter	Well ID															
1,1-Dichloroethene	MW-02A	0.76	0.51	0.92	1.58	1.58	0.76	0.56	1.07	1.84	1.48	0.61	0.48	1.02	1.84	1.12
	MW-06	1.36	0.77	1.06	0.95	2.19	1.83	1.42	1.42	2.07	1.54	0.89	0.95	0.71	2.25	0.89
	MW-13	0.68	0.86	0.91	0.86	1.23	0.96	0.82	0.91	0.96	1.14	0.77	0.82	1.05	1.14	1.09
	MW-15	0.79	1.13	1.29	0.97	1.05	0.89	0.97	0.97	0.89	--	0.65	0.89	0.89	1.37	0.89
	MW-23A	0.89	1.07	1.15	1.77	2.07	1.29	0.92	1.11	1.77	1.33	0.59	0.63	0.59	1.48	1.22
	MW-25A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MW-26	1.41	1.82	1.79	1.17	1.48	1.31	1.48	1.48	1.21	1.24	0.83	1.17	1.07	1.03	1.00
	TW-01	1.03	1.32	0.82	0.71	0.88	1.03	1.21	0.02	0.90	0.80	0.88	1.54	0.91	1.01	1.10
cis-1,2-Dichloroethene	MW-02A	0.91	0.47	0.94	1.35	1.58	0.81	0.44	1.01	1.69	1.56	0.65	0.42	1.04	1.77	1.17
	MW-06	1.70	0.91	1.39	0.65	2.77	2.12	1.44	1.73	0.57	1.61	1.02	1.08	0.85	1.08	0.88
	MW-13	0.77	0.82	1.01	0.95	1.19	0.94	0.79	0.90	1.06	1.19	0.76	0.81	1.03	1.23	1.09
	MW-15	0.79	1.10	1.07	0.94	0.98	0.89	0.82	0.85	0.85	--	0.63	0.85	0.94	0.97	0.95
	MW-23A	0.79	0.90	1.13	1.81	1.81	1.24	0.73	1.18	1.41	1.52	0.62	0.49	0.56	1.35	0.96
	MW-25A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MW-26	1.38	1.55	1.66	1.55	1.49	1.27	1.16	1.44	1.10	1.55	0.77	0.94	1.05	1.10	1.10
	TW-01	0.97	1.30	0.80	0.74	0.84	1.00	1.14	0.01	0.90	0.90	0.84	1.37	0.97	0.97	1.07
Tetrachloroethene (PCE)	MW-02A	0.71	0.34	0.54	1.23	1.43	0.63	0.46	0.83	1.94	1.54	0.71	0.40	0.83	1.77	1.25
	MW-06	1.77	0.94	0.99	0.81	1.75	2.02	1.84	1.49	1.18	1.51	1.14	1.12	0.52	0.81	0.96
	MW-13	0.70	0.66	0.75	0.96	1.20	0.77	0.90	0.92	0.99	1.32	0.82	0.84	0.92	1.22	1.30
	MW-15	0.76	0.94	0.94	0.99	1.12	0.81	1.03	0.99	1.12	--	0.81	0.90	0.85	0.94	1.03
	MW-23A	0.71	0.73	0.71	1.72	1.80	1.03	0.86	0.94	1.97	1.46	0.49	0.52	0.52	1.29	1.54
	MW-25A	1.18	1.09	1.09	1.09	1.18	0.80	0.90	0.86	1.18	1.18	0.87	1.27	1.18	1.36	2.18
	MW-26	1.52	1.52	1.52	1.30	1.41	1.04	1.52	1.52	1.30	1.30	0.98	1.08	1.19	0.78	1.08
	TW-01	1.05	1.13	0.53	0.79	0.92	0.92	1.19	0.74	1.11	1.00	0.95	1.27	0.74	0.98	1.34
Trichloroethene (TCE)	MW-02A	0.85	0.39	0.77	1.48	1.44	0.70	0.07	1.13	1.83	1.48	0.67	0.46	0.95	1.90	1.23
	MW-06	1.10	0.62	0.94	1.26	2.48	1.43	1.21	1.29	1.61	1.59	1.10	0.94	0.78	1.29	1.35
	MW-13	0.68	0.68	0.84	0.96	1.18	0.81	0.93	0.99	1.05	1.24	0.74	0.84	0.99	1.21	1.21
	MW-15	0.86	0.98	0.98	0.98	1.08	0.89	1.11	0.98	1.05	--	0.73	0.95	0.95	1.05	1.21
	MW-23A	0.80	0.88	0.88	1.88	1.88	1.08	0.08	1.24	1.84	1.36	0.52	0.56	0.60	1.44	1.36
	MW-25A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MW-26	1.46	1.60	1.55	1.36	1.36	1.08	1.50	1.55	1.27	1.22	0.94	1.08	0.99	0.89	1.17
	TW-01	1.01	1.08	0.79	0.87	0.94	0.94	0.01	1.16	1.08	0.94	0.94	1.23	0.94	1.08	1.30

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Appendix C.2
Normalized Concentration Results - Site #1

4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
10/17/2013	10/29/2013	10/29/2013	11/15/2013	11/27/2013	12/12/2013	12/26/2013	12/26/2013	1/8/2014	1/23/2014	2/6/2014	2/17/2014	2/17/2014	3/5/2014	3/20/2014
Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
LFS-4	LFA(L)-4	LFA(S)-4	SS-4	HS-4	LFS-5	LFA(L)-5	LFA(S)-5	SS-5	HS-5	LFS-6	LFA(L)-6	LFA(S)-6	SS-6	HS-6
0.56	0.43	0.87	1.94	1.02	0.47	0.39	1.02	1.33	1.63	0.45	0.35	0.87	1.33	1.22
0.95	0.51	0.12	0.57	0.89	0.83	0.54	0.65	0.95	0.37	1.01	0.89	0.59	0.42	0.45
1.00	0.82	0.96	1.32	1.32	0.77	1.14	0.86	1.23	1.23	0.91	1.05	0.91	1.27	--
0.97	0.97	0.89	0.97	0.97	0.79	0.97	0.89	0.97	0.97	0.97	1.13	0.97	1.29	1.62
0.44	0.35	0.28	0.81	1.26	0.34	0.59	0.63	1.29	1.63	0.74	0.74	0.78	1.26	0.96
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0.93	0.93	0.72	0.83	0.79	0.83	0.72	0.76	0.52	0.65	0.69	0.72	0.65	0.29	0.48
1.32	1.76	0.84	0.98	1.07	1.10	1.54	0.78	0.89	0.90	1.03	1.32	0.79	0.89	0.66
0.57	0.39	0.96	2.03	1.01	0.47	0.34	1.04	1.48	1.48	0.55	0.36	0.94	1.32	1.27
1.05	0.54	0.23	0.20	1.08	0.96	0.54	0.65	0.82	0.34	1.19	0.93	0.74	0.34	0.62
0.94	0.81	0.93	1.27	1.27	0.79	1.04	0.81	1.19	1.17	0.94	1.13	0.96	1.22	--
0.94	0.95	0.91	0.92	1.03	0.84	0.92	0.94	1.06	1.03	1.07	1.22	1.35	1.44	1.76
0.34	0.38	0.30	0.96	1.02	0.50	0.62	0.85	1.75	1.58	0.90	0.90	0.90	1.41	1.07
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0.94	0.88	0.83	1.05	0.99	0.72	0.72	0.72	0.66	0.61	0.61	0.66	0.66	0.34	0.50
1.30	1.71	0.94	0.97	1.10	1.20	1.47	0.87	0.90	0.84	1.10	1.37	0.87	0.87	0.67
0.57	0.37	0.71	2.25	1.20	0.60	0.37	0.77	1.60	1.94	0.54	0.37	0.68	1.85	1.57
0.97	0.70	0.44	0.33	1.03	1.09	0.57	0.68	0.83	0.48	1.18	0.96	0.64	0.61	0.66
0.96	0.82	0.85	1.36	1.29	0.77	0.90	0.80	1.22	1.57	0.87	0.92	0.85	1.57	--
0.90	0.94	0.99	1.08	0.94	0.90	0.90	0.90	1.08	1.21	0.94	0.94	1.08	1.44	1.53
0.43	0.48	0.37	0.83	1.29	0.36	0.60	0.57	1.72	2.06	0.75	0.63	0.61	1.72	1.29
1.72	2.00	1.54	2.00	1.18	0.27	0.44	0.39	0.70	0.47	0.27	0.27	0.27	0.57	0.49
0.89	1.08	0.94	0.85	0.67	0.82	0.79	0.74	0.50	0.73	0.71	0.73	0.64	0.30	0.53
1.32	1.63	0.71	1.08	1.05	1.08	1.34	0.63	0.92	1.11	0.98	1.03	0.53	1.11	0.82
0.56	0.39	0.85	2.04	1.06	0.49	0.35	0.92	1.62	1.76	0.53	0.35	0.77	1.55	1.41
1.02	0.62	0.62	0.59	0.86	0.94	0.54	0.62	0.73	0.73	1.00	0.78	0.67	0.54	0.75
0.96	0.77	0.87	1.30	1.24	0.77	0.96	0.84	1.30	1.43	0.87	1.02	0.93	1.39	--
0.95	0.95	0.89	0.95	0.95	0.79	0.89	0.89	1.02	1.08	0.86	0.95	1.08	1.33	1.59
0.40	0.48	0.39	0.92	1.24	0.44	0.72	0.76	1.84	1.84	0.76	0.68	0.84	1.32	1.00
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0.99	0.94	0.94	0.89	0.80	0.75	0.75	0.75	0.56	0.66	0.70	0.75	0.61	0.32	0.56
1.30	1.45	0.94	1.08	1.16	1.16	1.23	0.79	1.01	1.01	0.94	1.08	0.72	1.01	0.79

APPENDICES

Appendix C.3: Graphs by Well and Chemical

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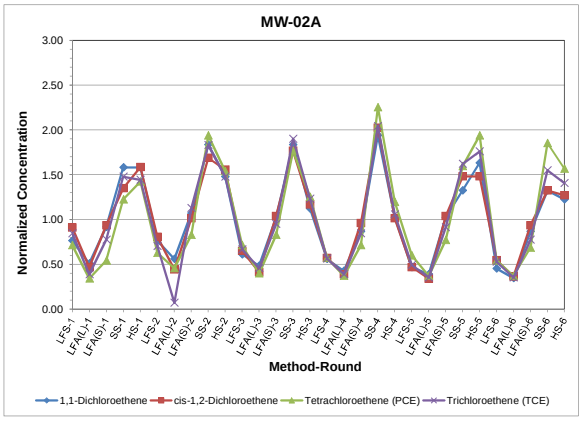
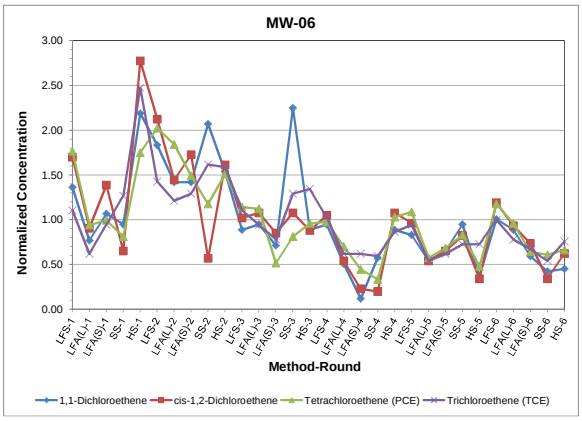
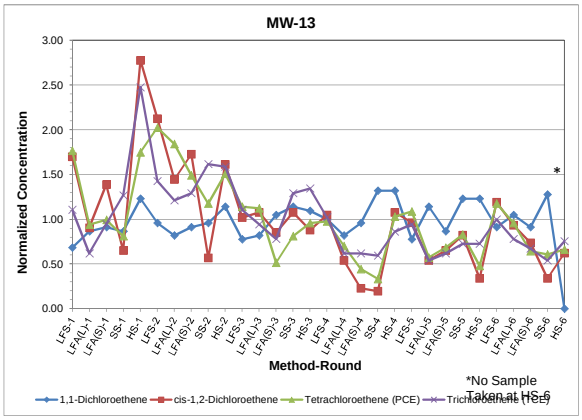
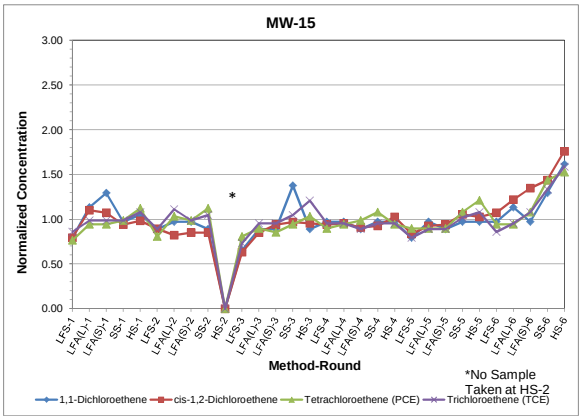
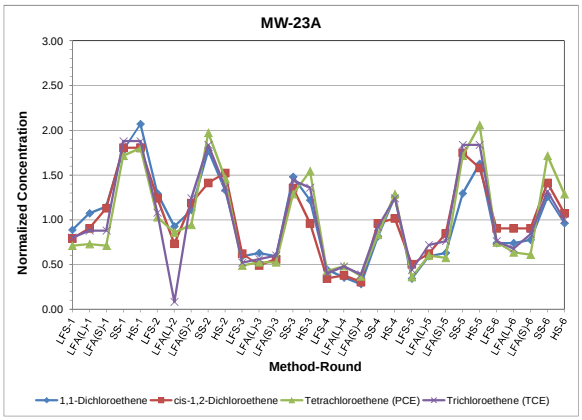
Appendix C.3
Graphs by Well and Chemical

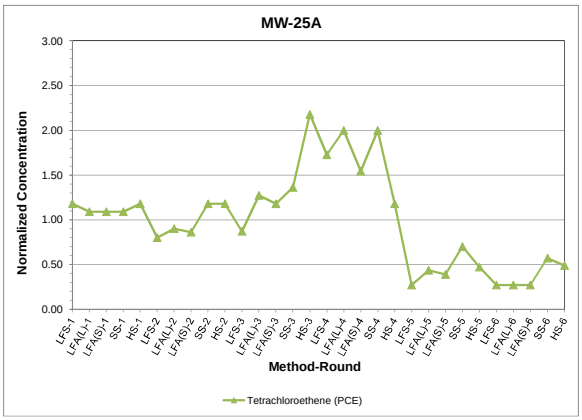


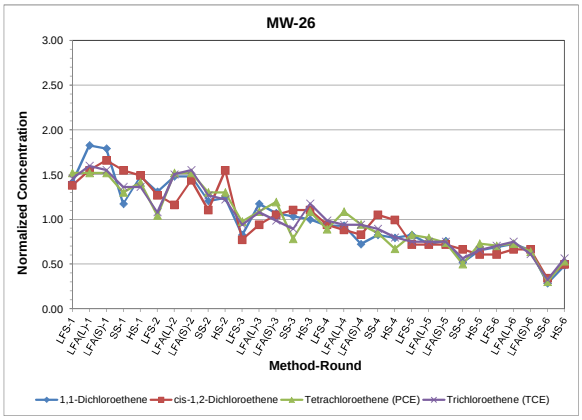


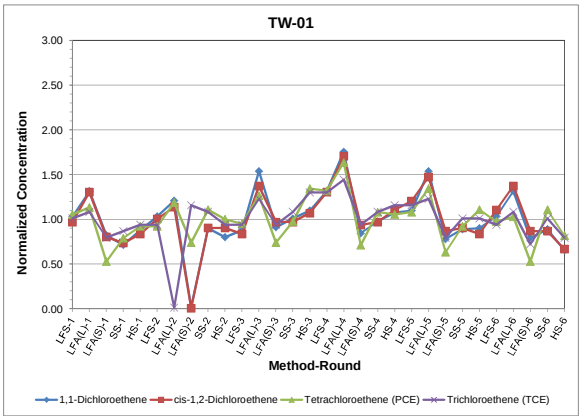












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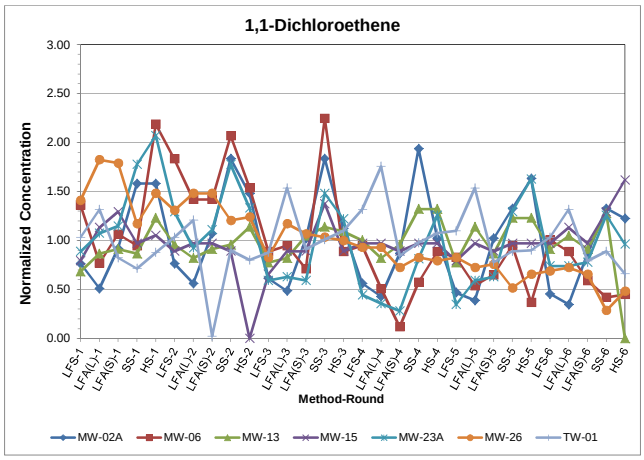
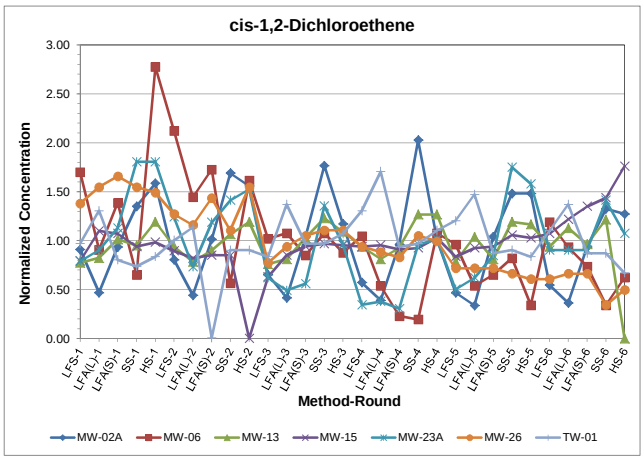
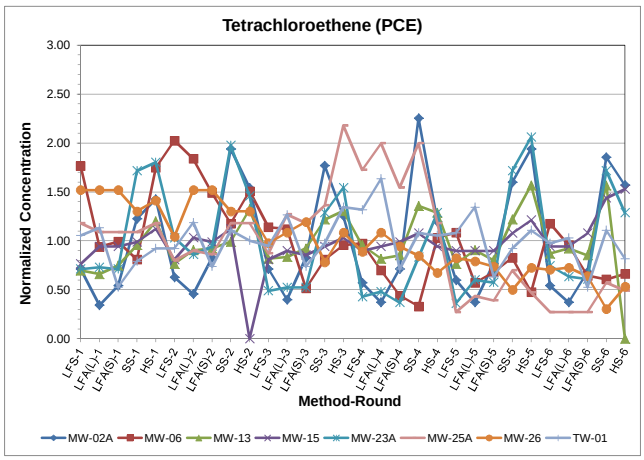
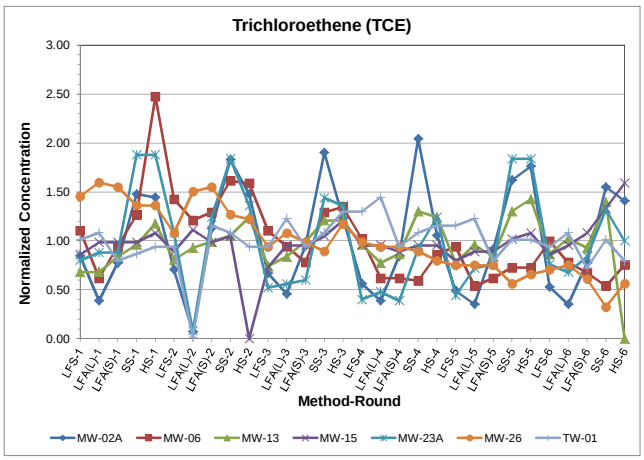
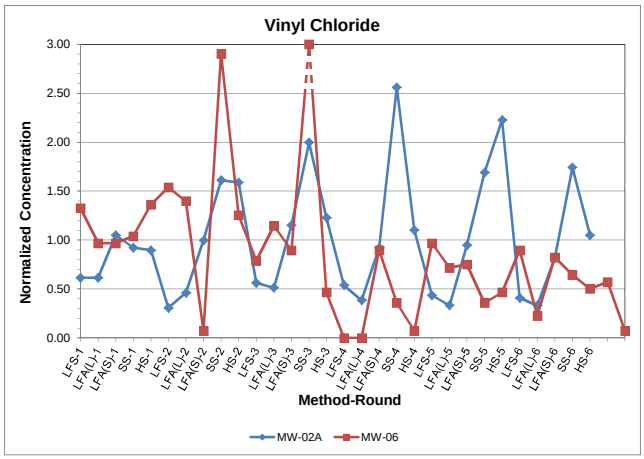
Appendix C.3
Graphs by Well and Chemical











Notes:
No samples taken at MW-15 during HS-2, and MW-13 during HS-6

APPENDICES

Appendix C.4: Relative Percent Differences (RPDs) in Constituent Concentrations between Samples and Field Duplicates

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Appendix C.4
Relative Percent Differences (RPDs) in Constituent Concentrations between Samples and Field Duplicates

Well ID	Round	Sample date	Sample collection method	1,1-Dichloroethene	RPD	cis-1,2-Dichloroethene	RPD	Tetrachloroethene (PCE)	RPD	Trichloroethene (TCE)	RPD	Average RPD for Event
MW-23A	1	4/6/2013	Low-Flow Alternative (L)	2.9 3.1	6.67%	1.6 1.8	11.76%	8.5 8.5	0.00%	2.2 2.3	4.44%	5.72%
MW-26	2	6/11/2013	Low-Flow Standard	3.8 4	5.13%	2.3 2.4	4.26%	9.6 11	13.59%	2.3 2.4	4.26%	6.81%
TW-01	2	8/2/2013	Hydrasleeve	7.3 6.4	13.14%	27 24	11.76%	38 39	2.60%	13 14	7.41%	8.73%
MW-15	3	9/30/2013	Hydrasleeve	1.1 1.1	0.00%	6.5 6.7	3.03%	2.3 2.3	0.00%	3.8 3.5	8.22%	2.81%
MW-13	4	10/17/2013	Low-Flow Standard	22 21	4.65%	74 71	4.14%	55 52	5.61%	31 30	3.28%	4.42%
MW-13	4	10/29/2013	Low-Flow Alternative (L)	18 20	10.53%	64 65	1.55%	47 49	4.17%	25 26	3.92%	5.04%
MW-26	5	12/12/2013	Low-Flow Standard	2.4 2.5	4.08%	1.3 1.4	7.41%	7.6 7.2	5.41%	1.6 1.6	0.00%	4.22%
MW-13	5	12/26/2013	Low-Flow Alternative (L)	25 18	32.56%	82 61	29.37%	52 43	18.95%	31 26	17.54%	24.60%
MW-02A	5	1/23/2014	Hydrasleeve	3.2 2.5	24.56%	57 54	5.41%	6.8 6	12.50%	5 4.9	2.02%	11.12%
MW-26	6	2/6/2014	Low-Flow Standard	2 2	0.00%	1.1 1.5	30.77%	6.5 8.5	26.67%	1.5 1.9	23.53%	20.24%
MW-26	6	2/17/2014	Low-Flow Alternative (L)	2.1 1.9	10.00%	1.2 1.2	0.00%	6.7 6.5	3.03%	1.6 1.6	0.00%	3.26%
MW-26	6	2/17/2014	Low-Flow Alternative (S)	1.9 1.7	11.11%	1.2 1.1	8.70%	5.9 5.4	8.85%	1.3 1.3	0.00%	7.16%
MW-25A	6	3/20/2014	Hydrasleeve	<0.2 <0.2	NA	<0.2 <0.2	NA	0.54 0.53	1.87%	<0.2 <0.2	NA	1.87%

Notes:

1. Non-detect values not factored in to RPD calculations when both duplicate and sample were non-detect.

APPENDICES

Appendix D: Field Program Results: Demonstration Site #2

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APPENDICES

Appendix D.1: Groundwater Sampling Results – Site #2

GSI ENVIRONMENTAL

Appendix D.1
Groundwater Sampling Results - Site #2

	Round	1	1	1	1	1	1.1	1	1	2	2	2
	Sample Date	4/9/2013	4/24/2013	4/24/2013	4/24/2013	5/8/2013	5/8/2013	5/22/2013	5/22/2013	6/5/2013	6/18/2013	6/18/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	Low-Flow Alternative (S)	SNAP Samplers (upper)	SNAP Samplers (lower)	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L)
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethane	MW-13	2.41	2.84	2.01	-	<0.5	2.19	6.86	-	3.2	2.1	-
	MW-14	81	41.4	104	-	480	352	700	-	55.4	45.1	-
	MW-15	116	26.2	99.4	-	106	-	145	-	70.9	104	-
	MW-17	1	0.9 J	1.07	-	0.62 J	<0.5	1.66	3.13	1.28	1.45	-
	MW-20	0.71 J	0.69 J	0.68 J	0.68 J	0.86 J	-	1.26	-	0.95 J	1.16	1.15
	MW-23	1.55	1.34	1.53	-	1.23	2.41	1.86	-	1.54	1.67	-
	MW-24	2.65	4.88	2.35	-	2.22	2.81	8.36	-	3.76	3.54	-
	MW-25	1.36	1.29	1.31	-	1.62	-	1.75	-	1.55	1.65	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
1,1-Dichloroethene	MW-13	177	208	162	-	39.2	273	297	-	226	210	-
	MW-14	232	398	385	-	84.8	405	428	-	294	297	-
	MW-15	62	143	54.4	-	39.4	-	47.7	-	78.3	35	-
	MW-17	110	113	116	-	43.5	39.9	183	174	186	255	-
	MW-20	81	93.5	90.4	91.6	107	-	135	-	115	140	120
	MW-23	374	242	266	-	168	401	370	-	282	310	-
	MW-24	255	345	398	-	87.4	349	189	-	278	285	-
	MW-25	241	223	212	-	314	-	338	-	275	296	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
1,2-Dichloroethane (EDC)	MW-13	4.82	5.22	4.56	-	0.95 J	6.26	6.64	-	5.58	4.92	-
	MW-14	6.29	6.28	6.59	-	6.36	8.89	9.96	-	6.21	6.75	-
	MW-15	4.67	4.16	4.6	-	4.33	-	5.33	-	3.74	3.17	-
	MW-17	4.37	4.6	4.78	-	3.72	1.24	5.98	5.64	5.16	5.87	-
	MW-20	3	3.1	3.25	3.05	3.92	-	4.56	-	3.92	4.66	4.61
	MW-23	6.1	6.05	6.52	-	5.56	7.41	6.94	-	5.96	6.58	-
	MW-24	5.87	5.66	6.55	-	4.51	7.15	4.37	-	5.63	5.96	-
	MW-25	5.23	5.24	5.27	-	6.34	-	5.86	-	5.83	5.93	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
Chloroform (Trichloromethane)	MW-13	47.2	50.3	42.7	-	9.93	65	73.8	-	56.6	49.9	-
	MW-14	59.9	61.5	60	-	25.4	66.4	57.5	-	64.6	65.2	-
	MW-15	13.4	32.9	9.17	-	6.66	-	8.46	-	17.7	25.7	-
	MW-17	33	32.6	34.6	-	21.2	10.7	51.3	50.1	48.1	57.6	-
	MW-20	23.7	24.7	25.3	24.3	29.4	-	38.3	-	31.6	37.1	35.8
	MW-23	63.8	56.3	66.1	-	51.4	81.5	73.9	-	64.7	67.9	-
	MW-24	61.5	56.6	66	-	36.8	76.5	44.9	-	60.8	62.6	-
	MW-25	55.5	56.4	56.7	-	65.7	-	69.5	-	63.2	63.5	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
cis-1,2-Dichloroethene	MW-13	11	12.5	11.2	-	2.01	12.4	20.5	-	13.4	10.9	-
	MW-14	28.2	20.8	37.8	-	51.1	80.7	209	-	23	20.2	-
	MW-15	20.2	22	23.2	-	21.8	-	23.7	-	23.3	45.3	-
	MW-17	8.59	9.43	9.61	-	4.97	2.69	11.8	11.6	9.23	9.96	-
	MW-20	7.43	8.54	8.44	8.48	8.82	-	10.8	-	9.01	10.3	9.93
	MW-23	9.83	10.6	10.3	-	7.49	12.2	13.1	-	10.1	11.6	-
	MW-24	11.8	16	13	-	7.96	13.6	18.1	-	13.5	13.8	-
	MW-25	8.85	9.62	9.65	-	10.6	-	11.2	-	10.6	10.9	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-

Notes
1. "-" = Not sampled.

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Appendix D.1
Groundwater Sampling Results - Site #2

	Round	1	1	1	1	1	1.1	1	1	2	2	2
	Sample Date	4/9/2013	4/24/2013	4/24/2013	4/24/2013	5/8/2013	5/8/2013	5/22/2013	5/22/2013	6/5/2013	6/18/2013	6/18/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	Low-Flow Alternative (S)	SNAP Samplers (upper)	SNAP Samplers (lower)	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L)
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Tetrachloroethene (PCE)	MW-13	221	384	293	-	54.1	350	409	-	286	314	-
	MW-14	218	440	348	-	107	388	301	-	339	412	-
	MW-15	78.4	270	82.8	-	71.1	-	86.7	-	109	176	-
	MW-17	245	375	337	-	103	71.8	325	342	308	404	-
	MW-20	141	277	233	210	304	-	260	-	218	320	362
	MW-23	441	323	299	-	470	503	539	-	374	479	-
	MW-24	398	405	441	-	112	441	234	-	381	336	-
	MW-25	378	286	234	-	448	-	419	-	446	404	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
trans-1,2-Dichloroethene	MW-13	0.73 J	0.62 J	0.57 J	-	<0.5	1.09	1.28	-	0.91 J	0.83 J	-
	MW-14	0.99 J	1	0.96 J	-	<0.5	1.76	2.21	-	1.02	1.17	-
	MW-15	2.97	0.87 J	2.74	-	2.38	-	3.41	-	1.57	0.93 J	-
	MW-17	0.76 J	0.65 J	0.72 J	-	<0.5	<0.5	1.15	1.11	0.9 J	0.86 J	-
	MW-20	0.51 J	<0.5	<0.5	<0.5	0.64 J	-	0.85 J	-	0.67 J	0.75 J	0.76 J
	MW-23	0.95 J	0.9 J	0.86 J	-	0.7 J	1.2	1.08	-	0.91 J	1.16	-
	MW-24	0.9 J	0.74 J	0.89 J	-	<0.5	1.18	0.81 J	-	0.93 J	0.96 J	-
	MW-25	0.83 J	0.7 J	0.7 J	-	0.98 J	-	1.03	-	0.86 J	1	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
Trichloroethene (TCE)	MW-13	151	245	175	-	33.5	209	235	-	196	198	-
	MW-14	159	277	220	-	48	192	154	-	192	219	-
	MW-15	48.5	147	51.9	-	37.1	-	45.3	-	71.8	57	-
	MW-17	104	133	130	-	37.3	30.7	142	135	156	197	-
	MW-20	77.6	121	112	121	106	-	113	-	106	136	129
	MW-23	183	227	230	-	132	235	199	-	203	226	-
	MW-24	198	284	277	-	65.8	242	136	-	221	219	-
	MW-25	178	234	221	-	217	-	196	-	218	227	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
Trichloro-fluoromethane	MW-13	51.7	81.4	58	-	13.6	91.8	88.6	-	80.7	79.5	-
	MW-14	92.6	124	113	-	18.9	131	86.1	-	107	123	-
	MW-15	12	50.9	6.21	-	3.1	-	4.92	-	17.5	28	-
	MW-17	31.8	39.8	40.8	-	12.9	13.4	63	58.8	71.8	103	-
	MW-20	23.8	37	35.8	35.7	37	-	46.1	-	41	50.3	35.3
	MW-23	93.6	113	132	-	50.5	162	114	-	107	131	-
	MW-24	78.8	101	119	-	23.3	131	59.5	-	99.3	106	-
	MW-25	81.9	120	116	-	114	-	112	-	104	124	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-
Trichloro-trifluoroethane (Freon-113)	MW-13	68	248	119	-	24.9	163	160	-	180	192	-
	MW-14	174	278	345	-	57.8	293	220	-	266	309	-
	MW-15	32	152	36.7	-	25.7	-	31.8	-	47.4	23.2	-
	MW-17	50.2	70.4	75.2	-	38.9	21.5	125	111	174	266	-
	MW-20	38.3	101	81.5	93.5	76.1	-	86.7	-	85.1	106	63.5
	MW-23	186	228	270	-	160	379	364	-	274	330	-
	MW-24	127	246	278	-	66.5	269	120	-	251	241	-
	MW-25	143	225	191	-	249	-	326	-	370	313	-
	TB	<0.5	-	-	-	-	-	<0.5	-	<0.5	-	-

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix D. 1
Groundwater Sampling Results - Site #2

	Round	2	2	2	2	2	3	3	3	3	3	3
	Sample Date	6/18/2013	7/3/2013	7/3/2013	7/17/2013	7/17/2013	7/31/2013	8/14/2013	8/14/2013	8/28/2013	9/11/2013	9/11/2013
	Sample Collection Method	Low-Flow Alternative (S)	SNAP Samplers	SNAP Samplers Dup	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Hydrasleeve Dup
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethane	MW-13	4.71	1.38	-	2.29	-	2.58	3.91	3.43	4.99	2.99	-
	MW-14	87.9	451	-	420	-	39.1	26.7	29.6	3.1	620	-
	MW-15	167	218	-	232	-	132	57.9	167	255	220	217
	MW-17	1.55	1.75	-	1.89	-	1.88	1.73	1.84	1.81	1.9	-
	MW-20	1.06	1.13	-	1.38	-	1.32	1.36	1.28	1.28	2.3	-
	MW-23	1.7	2.02	1.64	1.38	0.88 J	1.73	1.63	1.86	1.76	<0.5	-
	MW-24	3.07	5.4	-	8.87	-	2.92	4.04	2.61	10.9	7.76	-
	MW-25	1.56	1.72	-	1.76	-	1.69	1.81	1.82	1.85	<0.5	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
1,1-Dichloroethene	MW-13	222	213	-	61.9	-	140	157	116	77.5	103	-
	MW-14	326	390	-	324	-	309	265	246	317	233	-
	MW-15	38.4	32.8	-	33.7	-	90.6	144	60.2	60	21.6	22.6
	MW-17	267	338	-	235	-	214	154	70.9	417	196	-
	MW-20	135	149	-	139	-	150	140	159	171	89.6	-
	MW-23	331	396	305	184	115	362	239	285	456	13.1	-
	MW-24	308	309	-	188	-	317	296	315	190	74	-
	MW-25	279	289	-	322	-	294	267	259	331	30.9	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
1,2-Dichloroethane (EDC)	MW-13	5.31	5.26	-	2.28	-	4.05	4.04	3.31	2.41	4.14	-
	MW-14	7.15	8.67	-	8.55	-	6.76	6.27	6.34	5.94	9.14	-
	MW-15	4.16	4.03	-	3.82	-	3.71	3.09	3.65	3.53	3.4	3.5
	MW-17	6.02	6.84	-	6.46	-	6.8	6.53	6.73	6.72	6.88	-
	MW-20	4.8	5.17	-	4.66	-	5.2	4.71	5.22	5.44	4.9	-
	MW-23	6.58	7.12	6.47	5.68	3.36	6.51	6.32	6.84	6.74	0.53 J	-
	MW-24	6.16	6.08	-	4.34	-	7.12	6.43	6.76	4.48	2.95	-
	MW-25	5.91	6.55	-	6.29	-	6.39	6.75	6.86	7.05	1.19	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
Chloroform (Trichloromethane)	MW-13	54.3	53.8	-	20.9	-	40.4	40.8	31.2	21.6	33.7	-
	MW-14	68.1	59	-	51.9	-	72.8	63.1	62.2	62.9	26.9	-
	MW-15	26.2	5.1	-	3.9	-	17.4	22.3	8.94	2.67	1.28	1.19
	MW-17	61.8	71.8	-	68.5	-	75	70.8	72.7	75.1	59.4	-
	MW-20	37.6	40.9	-	39.3	-	43.5	40.5	45.3	47.2	32.7	-
	MW-23	70.2	81.3	68.3	52.1	30.6	71.1	66.1	79	77.8	3.96	-
	MW-24	68.6	67.2	-	45.2	-	75.6	66	71.3	43.7	23.1	-
	MW-25	61.4	67.9	-	67.8	-	66.6	64.7	64.4	68.1	10.3	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
cis-1,2-Dichloroethene	MW-13	16.4	10.5	-	10.6	-	11.9	13.9	13.2	16.1	12.7	-
	MW-14	30.4	107	-	135	-	18.7	17	18.3	12.1	201	-
	MW-15	25.2	33.1	-	29.2	-	41	79.2	35.1	44	29.5	29
	MW-17	9.92	11.4	-	11	-	11.3	11.4	10.8	12.5	10.1	-
	MW-20	10.1	10.8	-	10.7	-	11	11	12	12.1	9.64	-
	MW-23	10.4	12.3	10.2	11.2	6.79	11.2	12.1	12.3	12.4	1.12	-
	MW-24	13.7	16.8	-	20.1	-	14	15.6	13.7	30.9	20.6	-
	MW-25	10.4	11.4	-	11.9	-	11.3	11.7	11.9	12.8	1.83	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix D. 1
Groundwater Sampling Results - Site #2

	Round	2	2	2	2	2	3	3	3	3	3	3
	Sample Date	6/18/2013	7/3/2013	7/3/2013	7/17/2013	7/17/2013	7/31/2013	8/14/2013	8/14/2013	8/28/2013	9/11/2013	9/11/2013
	Sample Collection Method	Low-Flow Alternative (S)	SNAP Samplers	SNAP Samplers Dup	Hydrasleeve	Hydrasleeve Dup	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Hydrasleeve Dup
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Tetrachloroethene (PCE)	MW-13	277	359	-	131	-	160	208	147	157	250	-
	MW-14	355	419	-	293	-	292	367	273	474	172	-
	MW-15	153	63.7	-	56.8	-	95	144	66.4	59.6	42.9	42.2
	MW-17	350	579	-	499	-	324	399	373	580	419	-
	MW-20	294	415	-	268	-	267	249	246	421	236	-
	MW-23	382	599	509	410	340	393	340	300	603	12	-
	MW-24	427	491	-	379	-	352	339	328	261	102	-
	MW-25	336	436	-	602	-	319	411	326	520	25.6	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
trans-1,2-Dichloroethene	MW-13	0.92 J	0.89 J	-	0.53 J	-	0.65 J	0.68 J	0.59 J	0.56 J	0.53 J	-
	MW-14	1.21	1.73	-	1.83	-	1.31	1.17	1.22	1.11	1.63	-
	MW-15	2.52	2.47	-	3.06	-	1.78	0.83 J	1.93	2.1	1.74	1.46
	MW-17	0.97 J	1.15	-	1.28	-	1.26	1.86	2.1	1.27	0.76 J	-
	MW-20	0.81 J	0.83 J	-	0.87 J	-	0.97 J	0.9 J	1.01	1.07	0.58 J	-
	MW-23	0.94 J	1.32	1.05	1.21	0.71 J	1.12	1.18	1.22	1.31	<0.5	-
	MW-24	1.04	1.05	-	0.89 J	-	1.09	1.02	1.09	0.85 J	<0.5	-
	MW-25	0.96 J	1.02	-	1.15	-	1.08	1.09	1.01	1.18	<0.5	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
Trichloroethene (TCE)	MW-13	199	211	-	113	-	162	177	146	146	168	-
	MW-14	208	191	-	171	-	219	222	195	255	101	-
	MW-15	40	36.5	-	40.1	-	79.5	108	56.3	43.9	30.2	29.4
	MW-17	192	245	-	259	-	219	243	242	305	226	-
	MW-20	133	148	-	134	-	143	131	137	171	112	-
	MW-23	219	248	219	182	110	261	202	213	335	11.2	-
	MW-24	247	240	-	169	-	261	245	250	178	83.3	-
	MW-25	204	213	-	295	-	229	267	240	298	26.4	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
Trichloro-fluoromethane	MW-13	81.8	78.3	-	19.8	-	36.2	40	27.9	16.8	18.2	-
	MW-14	122	106	-	77.3	-	100	81.2	76	91.9	15.5	-
	MW-15	23.7	1.45	-	2.14	-	12.6	16.8	5.41	1.76	<0.5	<0.5
	MW-17	111	141	-	115	-	92	107	112	115	47.1	-
	MW-20	52.2	54.1	-	44.8	-	44.1	41.5	50.5	53.5	17.2	-
	MW-23	134	153	117	72.1	42.9	103	96	116	107	2.38	-
	MW-24	118	113	-	49.5	-	82.3	65.9	80.3	44	8.89	-
	MW-25	113	103	-	112	-	86.1	80.5	79.7	90.2	6.83	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-
Trichloro-trifluoroethane (Freon-113)	MW-13	181	177	-	51.3	-	61.3	73.8	51.2	43.3	24.5	-
	MW-14	307	269	-	216	-	264	195	169	278	25	-
	MW-15	21.8	11.6	-	14.1	-	26.9	32.7	13.4	13.6	2.05	2.43
	MW-17	277	367	-	335	-	126	336	360	403	92.1	-
	MW-20	108	106	-	96.9	-	90.5	90	109	134	24.8	-
	MW-23	341	228	274	196	113	350	216	243	467	2.11	-
	MW-24	263	257	-	105	-	156	120	152	113	11.2	-
	MW-25	280	264	-	401	-	259	188	164	293	7.39	-
	TB	-	<0.5	-	<0.5	-	<0.5	-	-	<0.5	<0.5	-

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix D.1
Groundwater Sampling Results - Site #2

	Round	4	4	4	4	4	4	4	5	5	5	5
	Sample Date	9/25/2013	10/9/2013	10/9/2013	10/9/2013	10/24/2013	10/24/2013	11/6/2013	11/20/2013	11/20/2013	12/4/2013	12/4/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	SNAP Samplers Dup	Hydrasleeve	Low-Flow Standard	Low-Flow Standard Dup	Low-Flow Alternative (L)	Low-Flow Alternative (L)
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethane	MW-13	5.19	7.44	-	6.87	1.42	-	1.42	3.75	3.76	4.09	4.23
	MW-14	14.5	6.19	-	3.51	8.86	-	34.9	4.51	-	4.63	-
	MW-15	197	50.6	-	146	133	-	236	208	-	186	-
	MW-17	1.53	1.43	-	1.58	1.63	-	2.28	1.66	-	1.42	-
	MW-20	1.14	1.25	-	1.06	1.25	-	1.19	1.47	-	1.31	-
	MW-23	1.46	1.16	1.26	1.49	1.61	-	0.82 J	1.82	-	1.36	-
	MW-24	5.89	3.95	-	3.09	3.68	-	3.5	5.26	-	2.86	-
	MW-25	2.21	2.38	-	2.59	7.63	8.66	3.14	11.3	-	11.3	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
1,1-Dichloroethene	MW-13	106	112	-	103	101	-	62.7	179	207	198	204
	MW-14	<0.5	109	-	28.8	150	-	149	236	-	307	-
	MW-15	44.8	177	-	79.3	103	-	78.6	88.1	-	387	-
	MW-17	165	237	-	209	258	-	239	338	-	336	-
	MW-20	41.3	125	-	117	135	-	109	170	-	132	-
	MW-23	302	185	209	232	253	-	117	375	-	256	-
	MW-24	209	209	-	180	197	-	83.1	337	-	226	-
	MW-25	199	215	-	217	231	223	105	366	-	323	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
1,2-Dichloroethane (EDC)	MW-13	2.72	3.25	-	2.99	3.28	-	2.06	3.48	3.58	4.49	4.52
	MW-14	3.65	2.73	-	3.12	3.63	-	4.17	4.89	-	5.49	-
	MW-15	2.88	3.81	-	3.05	3.87	-	3.66	4.04	-	4.23	-
	MW-17	5.43	5.5	-	5.34	6.18	-	5.35	6.39	-	5.72	-
	MW-20	4.31	4.07	-	4.14	4.43	-	4.05	4.43	-	4.26	-
	MW-23	5.28	4.9	4.97	5.46	6.25	-	3.25	6.27	-	5.46	-
	MW-24	4.53	5.45	-	5.41	5.01	-	2.44	4.92	-	5.08	-
	MW-25	5.36	5.4	-	5.64	6.23	6.32	2.85	6.02	-	6.35	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
Chloroform (Trichloromethane)	MW-13	26.8	31.6	-	29.6	31.6	-	19.2	36.5	36.6	44.3	44.9
	MW-14	30.8	24.9	-	26.5	35.1	-	36.3	45.2	-	53	-
	MW-15	4.83	34.7	-	13	15.6	-	5.4	6.75	-	26.5	-
	MW-17	58.1	58.9	-	60.2	65.1	-	55.1	61.5	-	54	-
	MW-20	35.1	34.8	-	35.2	38.4	-	33	35.7	-	32.3	-
	MW-23	56.7	45.8	51.4	60.4	66.8	-	30.4	64.7	-	51.7	-
	MW-24	47.3	58.5	-	59.9	55.4	-	23.7	54.6	-	54.2	-
	MW-25	51.4	54.6	-	57.9	61.7	60.8	28.2	57.8	-	62.2	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
cis-1,2-Dichloroethene	MW-13	12.1	13.6	-	13.7	8.69	-	7.65	10.9	10.5	11.9	12.1
	MW-14	10.5	15.5	-	11.1	20.8	-	19.7	11.7	-	13	-
	MW-15	29.3	41	-	33	45.4	-	234	100	-	189	-
	MW-17	9.08	9.69	-	9.94	11.2	-	9.64	10.8	-	10.2	-
	MW-20	8.36	9.42	-	9.44	10.3	-	8.86	10.1	-	9.55	-
	MW-23	9.57	8.1	9.32	9.56	10.8	-	6.02	11	-	9.98	-
	MW-24	19.6	16.2	-	14.1	15.7	-	9.23	20.2	-	14.2	-
	MW-25	10.4	11.7	-	12.4	20.4	22	8.56	25.3	-	27.2	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix D.1
Groundwater Sampling Results - Site #2

	Round	4	4	4	4	4	4	4	5	5	5	5
	Sample Date	9/25/2013	10/9/2013	10/9/2013	10/9/2013	10/24/2013	10/24/2013	11/6/2013	11/20/2013	11/20/2013	12/4/2013	12/4/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	SNAP Samplers Dup	Hydrasleeve	Low-Flow Standard	Low-Flow Standard Dup	Low-Flow Alternative (L)	Low-Flow Alternative (L)
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Tetrachloroethene (PCE)	MW-13	119	162	-	140	186	-	135	196	198	297	263
	MW-14	166	181	-	162	245	-	308	268	-	387	-
	MW-15	44.9	177	-	73.5	113	-	67.5	44.1	-	172	-
	MW-17	257	329	-	312	409	-	413	380	-	330	-
	MW-20	181	256	-	198	312	-	314	247	-	274	-
	MW-23	316	281	299	291	428	-	299	381	-	390	-
	MW-24	236	254	-	230	284	-	129	383	-	327	-
	MW-25	273	300	-	274	374	484	169	379	-	418	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
trans-1,2-Dichloroethene	MW-13	0.56 J	0.67 J	-	0.65 J	0.62 J	-	<0.5	0.61 J	<0.5	0.8 J	0.8 J
	MW-14	1.87	0.56 J	-	1.37	0.69 J	-	0.72 J	0.92 J	-	0.88 J	-
	MW-15	2.28	0.92 J	-	1.32	1.56	-	2.45	1.71	-	1.68	-
	MW-17	1.16	1.01	-	1.06	1.1	-	0.95 J	1.09	-	0.96 J	-
	MW-20	1.41	0.77 J	-	0.8 J	0.8 J	-	0.75 J	<0.5	-	0.75 J	-
	MW-23	0.83 J	0.8 J	0.87 J	1.05	1.13	-	0.54 J	0.93 J	-	0.91 J	-
	MW-24	0.89 J	0.91 J	-	1.03	0.93 J	-	<0.5	0.91 J	-	0.98 J	-
	MW-25	1	1	-	1.04	1.14	1.13	0.51 J	1.16	-	1.14	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
Trichloroethene (TCE)	MW-13	117	137	-	129	125	-	85.7	130	132	158	162
	MW-14	93.9	90.7	-	89.1	117	-	125	143	-	192	-
	MW-15	35.2	127	-	55.3	72.9	-	45.7	35.5	-	109	-
	MW-17	166	194	-	188	203	-	177	193	-	186	-
	MW-20	102	120	-	115	133	-	116	112	-	115	-
	MW-23	170	155	171	188	213	-	109	197	-	181	-
	MW-24	156	192	-	200	190	-	81.1	184	-	196	-
	MW-25	164	191	-	184	204	252	92.8	197	-	212	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
Trichloro-fluoromethane	MW-13	36.4	38.5	-	36.1	34.4	-	21.7	61.6	57.9	66.2	68.4
	MW-14	39.7	30.7	-	30.6	43.1	-	48.7	79.4	-	97.5	-
	MW-15	4.9	49.3	-	13.8	15.8	-	3.82	9.24	-	33.8	-
	MW-17	109	103	-	107	104	-	80.2	135	-	94.9	-
	MW-20	46.1	41.9	-	43.4	45.1	-	34.9	53	-	37.6	-
	MW-23	100	73.9	82	110	89.5	-	40.6	127	-	87.5	-
	MW-24	72.4	85.8	-	90.6	55.5	-	21	101	-	86.7	-
	MW-25	88.3	90.1	-	94	76	78.6	32.8	107	-	115	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-
Trichloro-trifluoroethane (Freon-113)	MW-13	70.8	83.8	-	74.7	73.1	-	52.2	145	139	168	176
	MW-14	73.6	55.5	-	55.2	86.7	-	113	197	-	314	-
	MW-15	15.2	113	-	35.1	48.4	-	14.6	27.7	-	109	-
	MW-17	224	255	-	260	271	-	200	373	-	342	-
	MW-20	87.4	89.3	-	92.1	99.7	-	77	117	-	91.4	-
	MW-23	265	188	206	241	283	-	99.1	384	-	280	-
	MW-24	147	185	-	204	97	-	35.8	346	-	202	-
	MW-25	203	233	-	227	166	261	65.7	288	-	356	-
	TB	<0.5	<0.5	-	-	<0.5	-	<0.5	<0.5	-	-	-

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix D.1
Groundwater Sampling Results - Site #2

	Round	5	5	5	5	6	6	6	6	6	6
	Sample Date	12/4/2013	12/18/2013	12/31/2013	1/7/2014	1/15/2014	1/29/2014	1/29/2014	1/29/2014	2/12/2014	2/28/2014
	Sample Collection Method	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,1-Dichloroethane	MW-13	3.73	1.55	-	10.2	4.1	4.81	-	2.3	80.1	16.6
	MW-14	4.11	9.99	650	-	4.03	4.32	-	7.3	2.32	17.8
	MW-15	248	297	182	-	377	631	-	605	362	805
	MW-17	1.44	1.33	2.37	-	1.43	1.37	-	5	1.23	17.3
	MW-20	1.27	1.26	1.51	-	1.18	1.63	-	1.26	1.01	1.43
	MW-23	1.48	1.35	0.67 J	-	1.39	1.82	-	1.64	1.14	<0.5
	MW-24	2.82	1.89	2.64	-	2.06	2.12	1.96	1.63	3.02	3.5
	MW-25	11.8	9.98	8.88	-	4.53	6.15	-	6.1	1.82	4.83
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
1,1-Dichloroethene	MW-13	179	207	-	132	155	162	-	160	66.4	106
	MW-14	180	167	22.5	-	174	252	-	221	46.6	179
	MW-15	149	148	30.7	-	392	425	-	358	175	133
	MW-17	257	258	278	-	252	146	-	122	197	303
	MW-20	128	134	156	-	129	171	-	138	115	185
	MW-23	298	293	70.8	-	225	317	-	300	191	9.9
	MW-24	287	188	248	-	284	248	244	281	252	264
	MW-25	315	241	235	-	226	379	-	285	191	326
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
1,2-Dichloroethane (EDC)	MW-13	4.18	5.42	-	3.76	3.78	3.55	-	3.54	1.46	2.45
	MW-14	4.12	4.21	3.46	-	3.87	5.42	-	5.01	0.830J	3.08
	MW-15	4.08	3.21	1.94	-	<0.5	3.75	-	3.28	2.12	<0.5
	MW-17	5.7	5.64	5.94	-	4.6	4.14	-	3.04	3.93	4.83
	MW-20	4.28	4.46	4.96	-	3.81	5.47	-	7.96	3.2	4.95
	MW-23	5.82	5.75	2.08	-	4.68	6.5	-	7.15	4.07	<0.5
	MW-24	5.35	4.44	4.76	-	5.31	4.44	4.37	4.54	3.65	4.95
	MW-25	6.58	5.32	6.07	-	4.49	7.34	-	6.51	4.14	5.87
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
Chloroform (Trichloromethane)	MW-13	41.7	50.1	-	39.5	40.4	39.1	-	39.6	12.6	20.4
	MW-14	38.3	36.2	2.84	-	39.7	54.7	-	50.4	9.34	27.5
	MW-15	11.9	5.71	1.54	-	17	21.8	-	18.1	7.89	4.88
	MW-17	55.1	54.2	64.8	-	50.4	44.4	-	30	44.1	38.9
	MW-20	33.8	36.2	45	-	34.7	47.8	-	36.9	31.2	42.2
	MW-23	56.1	54.6	19.7	-	50.8	73.4	-	62.8	43.2	1.99
	MW-24	57.6	44.3	55	-	62.7	55.2	53.8	56.7	46.8	53
	MW-25	60.4	48.3	58.4	-	46.9	69.4	-	66.6	43.8	63.4
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
cis-1,2-Dichloroethene	MW-13	11.5	10.1	-	13.7	11	11.8	-	10.2	54.2	20.4
	MW-14	12.9	16.8	72.2	-	15.6	17.6	-	21.5	7.66	29
	MW-15	109	116	58.4	-	309	350	-	338	185	112
	MW-17	10.5	10.4	12.8	-	10.8	9.87	-	8.09	11	17.7
	MW-20	9.76	9.58	12	-	10.3	12.5	-	9.48	9.33	11.2
	MW-23	10.4	10.3	5.04	-	11.4	14.9	-	12.9	11.1	<0.5
	MW-24	14.3	11	13.8	-	14.2	13.8	13.1	12.3	17.2	16.6
	MW-25	24.6	23.3	22.7	-	16	20.8	-	19.4	12.2	17.7
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-

Notes
1. "-" = Not sampled.

GSI ENVIRONMENTAL

Appendix D.1
Groundwater Sampling Results - Site #2

	Round	5	5	5	5	6	6	6	6	6	6
	Sample Date	12/4/2013	12/18/2013	12/31/2013	1/7/2014	1/15/2014	1/29/2014	1/29/2014	1/29/2014	2/12/2014	2/28/2014
	Sample Collection Method	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
Parameter	LocationID	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Tetrachloroethene (PCE)	MW-13	196	395	-	311	257	386	-	299	81.5	249
	MW-14	208	329	10.8	-	285	391	-	298	97.9	486
	MW-15	89.6	93.9	21.3	-	141	152	-	113	94.3	84.1
	MW-17	324	489	466	-	446	451	-	157	540	638
	MW-20	231	410	344	-	275	429	-	438	468	682
	MW-23	378	532	146	-	404	435	-	493	480	71.1
	MW-24	346	411	398	-	408	393	410	424	486	539
	MW-25	353	481	417	-	395	490	-	465	566	840
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
trans-1,2-Dichloroethene	MW-13	0.77 J	0.93 J	-	0.76 J	0.63 J	0.8 J	-	0.79 J	0.540J	<0.5
	MW-14	0.74 J	0.7 J	0.89 J	-	0.87 J	0.91 J	-	<0.5	<0.5	<0.5
	MW-15	1.69	1.26	<0.5	-	1.57	4.38	-	2.45	1.28	1.01
	MW-17	1.05	0.99 J	1.47	-	1.02	1.11	-	0.67 J	1	0.79 J
	MW-20	0.78 J	0.77 J	0.98 J	-	0.75 J	0.99 J	-	0.76 J	0.730J	0.81 J
	MW-23	1	1.01	<0.5	-	1.06	1.42	-	1.21	1.01	<0.5
	MW-24	1.03	0.73 J	0.86 J	-	1.04	1.04	0.98 J	1.02	0.900J	0.83 J
	MW-25	0.93 J	0.95 J	1.11	-	0.93 J	1.41	-	1.08	0.970J	0.82 J
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
Trichloroethene (TCE)	MW-13	141	194	-	142	138	161	-	156	59.8	114
	MW-14	126	136	5.57	-	141	200	-	152	41.5	146
	MW-15	60.9	48.9	13.6	-	84.3	104	-	74.7	49.9	47.7
	MW-17	170	200	192	-	170	172	-	96.6	183	175
	MW-20	113	131	135	-	119	166	-	157	129	196
	MW-23	172	231	63.2	-	183	247	-	244	187	13.9
	MW-24	194	174	185	-	226	215	220	236	227	268
	MW-25	218	180	199	-	173	275	-	235	188	342
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
Trichloro-fluoromethane	MW-13	60.7	66.3	-	44.4	47.4	46.4	-	45.6	5.27	27.3
	MW-14	58.6	46	<0.5	-	51.3	140	-	100	7.82	45
	MW-15	13.9	5.36	1.02	-	18.2	38.1	-	31.4	6.63	9.01
	MW-17	92.2	84.5	98.2	-	71.4	60.2	-	35.9	53.8	70.8
	MW-20	40	36.9	48.1	-	35	82	-	64.6	24.4	69.3
	MW-23	90.9	78.2	23.7	-	71.9	203	-	154	48	5.25
	MW-24	91	54.7	72.3	-	84.1	72.5	69.8	73.7	51.9	104
	MW-25	114	60.1	85.7	-	63.6	185	-	182	51.6	146
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-
Trichloro-trifluoroethane (Freon-113)	MW-13	143	177	-	125	122	134	-	128	11	84.2
	MW-14	146	125	0.82 J	-	133	263	-	163	22.3	107
	MW-15	56.2	28.5	3.73	-	42.7	59.9	-	43.8	18.8	29.7
	MW-17	249	283	283	-	260	184	-	97.4	177	360
	MW-20	95.3	97.4	93.8	-	79.2	126	-	88.5	65.1	188
	MW-23	302	330	58.6	-	210	343	-	343	152	30.1
	MW-24	264	150	167	-	226	199	190	199	139	291
	MW-25	318	174	212	-	178	397	-	346	175	421
	TB	-	<0.5	<0.5	-	<0.5	-	-	-	-	-

Notes
1. "-" = Not sampled.

APPENDICES

Appendix D.2: Normalized Concentration Results – Site #2

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Appendix D.2
Normalized Concentration Results - Site #2

	Round	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
	Sample Date	4/9/2013	4/24/2013	4/24/2013	5/8/2013	5/22/2013	6/5/2013	6/18/2013	6/18/2013	7/3/2013	7/17/2013	7/31/2013	8/14/2013	8/14/2013	8/28/2013	9/11/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
	X-Axis	LFS-1	LFA(L)-1	LFA(S)-1	SS-1	HS-1	LFS-2	LFA(L)-2	LFA(S)-2	SS-2	HS-2	LFS-3	LFA(L)-3	LFA(S)-3	SS-3	HS-3
Parameter	Well ID															
1,1-Dichloroethane	MW-13	0.36	0.42	0.30	0.33	1.02	0.48	0.31	0.70	0.21	0.34	0.38	0.58	0.51	0.74	0.45
	MW-14	0.63	0.32	0.81	2.75	5.48	0.43	0.35	0.69	3.53	3.29	0.31	0.21	0.23	0.02	4.85
	MW-15	0.51	0.12	0.44	0.47	0.64	0.31	0.46	0.74	0.96	1.03	0.58	0.26	0.74	1.13	0.97
	MW-17	0.46	0.41	0.49	0.23	0.76	0.59	0.67	0.71	0.81	0.87	0.86	0.80	0.85	0.83	0.87
	MW-20	0.58	0.56	0.56	0.70	1.03	0.78	0.95	0.87	0.93	1.13	1.08	1.11	1.05	1.05	1.88
	MW-23	1.05	0.91	1.04	1.64	1.26	1.05	1.13	1.15	1.37	0.94	1.17	1.11	1.26	1.19	0.34
	MW-24	0.65	1.20	0.58	0.69	2.06	0.93	0.87	0.76	1.33	2.18	0.72	0.99	0.64	2.68	1.91
	MW-25	0.35	0.33	0.33	0.41	0.45	0.39	0.42	0.40	0.44	0.45	0.43	0.46	0.46	0.47	0.13
1,1-Dichloroethene	MW-13	1.14	1.34	1.04	1.75	1.91	1.45	1.35	1.43	1.37	0.40	0.90	1.01	0.74	0.50	0.66
	MW-14	0.98	1.69	1.63	1.72	1.82	1.25	1.26	1.38	1.65	1.37	1.31	1.12	1.04	1.34	0.99
	MW-15	0.50	1.16	0.44	0.32	0.39	0.63	0.28	0.31	0.27	0.27	0.73	1.16	0.49	0.49	0.17
	MW-17	0.51	0.52	0.54	0.18	0.85	0.86	1.18	1.23	1.56	1.09	0.99	0.71	0.33	1.93	0.91
	MW-20	0.63	0.72	0.70	0.83	1.04	0.89	1.08	1.04	1.15	1.07	1.16	1.08	1.23	1.32	0.69
	MW-23	1.41	0.91	1.01	1.52	1.40	1.07	1.17	1.25	1.50	0.70	1.37	0.90	1.08	1.72	0.05
	MW-24	1.01	1.36	1.57	1.38	0.75	1.10	1.13	1.22	1.22	0.74	1.25	1.17	1.25	0.75	0.29
	MW-25	0.92	0.85	0.81	1.20	1.30	1.05	1.13	1.07	1.11	1.23	1.13	1.02	0.99	1.27	0.12
1,2-Dichloroethane (EDC)	MW-13	1.21	1.31	1.15	1.58	1.67	1.40	1.24	1.34	1.32	0.57	1.02	1.02	0.83	0.61	1.04
	MW-14	1.13	1.12	1.18	1.59	1.78	1.11	1.21	1.28	1.55	1.53	1.21	1.12	1.14	1.06	1.64
	MW-15	1.34	1.20	1.32	1.25	1.53	1.08	0.91	1.20	1.16	1.10	1.07	0.89	1.05	1.02	0.98
	MW-17	0.81	0.85	0.88	0.23	1.10	0.95	1.08	1.11	1.26	1.19	1.25	1.20	1.24	1.24	1.27
	MW-20	0.67	0.69	0.72	0.87	1.01	0.87	1.03	1.06	1.15	1.03	1.15	1.04	1.16	1.21	1.09
	MW-23	1.11	1.10	1.18	1.34	1.26	1.08	1.19	1.19	1.29	1.03	1.18	1.15	1.24	1.22	0.10
	MW-24	1.13	1.09	1.26	1.38	0.84	1.08	1.15	1.19	1.17	0.84	1.37	1.24	1.30	0.86	0.57
	MW-25	0.92	0.92	0.93	1.11	1.03	1.02	1.04	1.04	1.15	1.10	1.12	1.19	1.20	1.24	0.21
Chloroform (Trichloromethane)	MW-13	1.19	1.27	1.08	1.65	1.87	1.43	1.26	1.37	1.36	0.53	1.02	1.03	0.79	0.55	0.85
	MW-14	1.27	1.31	1.27	1.41	1.22	1.37	1.38	1.45	1.25	1.10	1.55	1.34	1.32	1.34	0.57
	MW-15	1.01	2.48	0.69	0.50	0.64	1.34	1.94	1.98	0.39	0.29	1.31	1.68	0.67	0.20	0.10
	MW-17	0.61	0.60	0.64	0.20	0.95	0.89	1.07	1.15	1.33	1.27	1.39	1.31	1.35	1.39	1.10
	MW-20	0.65	0.68	0.70	0.81	1.05	0.87	1.02	1.04	1.13	1.08	1.20	1.12	1.25	1.30	0.90
	MW-23	1.12	0.98	1.16	1.43	1.29	1.13	1.19	1.23	1.42	0.91	1.24	1.16	1.38	1.36	0.07
	MW-24	1.10	1.01	1.18	1.37	0.80	1.09	1.12	1.23	1.20	0.81	1.35	1.18	1.28	0.78	0.41
	MW-25	0.96	0.98	0.98	1.14	1.20	1.09	1.10	1.06	1.18	1.17	1.15	1.12	1.12	1.18	0.18
cis-1,2-Dichloroethene	MW-13	0.79	0.90	0.80	0.89	1.47	0.96	0.78	1.18	0.75	0.76	0.85	1.00	0.95	1.15	0.91
	MW-14	0.67	0.50	0.90	1.93	5.00	0.55	0.48	0.73	2.56	3.23	0.45	0.41	0.44	0.29	4.81
	MW-15	0.22	0.24	0.25	0.24	0.26	0.25	0.50	0.28	0.36	0.32	0.45	0.87	0.38	0.48	0.32
	MW-17	0.83	0.91	0.93	0.26	1.14	0.89	0.96	0.96	1.10	1.06	1.09	1.10	1.04	1.20	0.97
	MW-20	0.74	0.85	0.84	0.88	1.08	0.90	1.03	1.01	1.08	1.07	1.10	1.10	1.20	1.21	0.96
	MW-23	0.98	1.05	1.02	1.21	1.30	1.00	1.15	1.03	1.22	1.11	1.11	1.20	1.22	1.23	0.11
	MW-24	0.76	1.03	0.83	0.87	1.16	0.87	0.89	0.88	1.08	1.29	0.90	1.00	0.88	1.98	1.32
	MW-25	0.62	0.68	0.68	0.74	0.79	0.74	0.77	0.73	0.80	0.84	0.79	0.82	0.84	0.90	0.13

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Appendix D.2
Normalized Concentration Results - Site #2

	Round	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
	Sample Date	4/9/2013	4/24/2013	4/24/2013	5/8/2013	5/22/2013	6/5/2013	6/18/2013	6/18/2013	7/3/2013	7/17/2013	7/31/2013	8/14/2013	8/14/2013	8/28/2013	9/11/2013
	Sample Collection Method	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
	X-Axis	LFS-1	LFA(L)-1	LFA(S)-1	SS-1	HS-1	LFS-2	LFA(L)-2	LFA(S)-2	SS-2	HS-2	LFS-3	LFA(L)-3	LFA(S)-3	SS-3	HS-3
Parameter	Well ID															
Tetrachloroethene (PCE)	MW-13	0.90	1.57	1.20	1.43	1.67	1.17	1.28	1.13	1.46	0.53	0.65	0.85	0.60	0.64	1.02
	MW-14	0.73	1.48	1.17	1.31	1.01	1.14	1.39	1.19	1.41	0.99	0.98	1.24	0.92	1.60	0.58
	MW-15	0.77	2.67	0.82	0.70	0.86	1.08	1.74	1.51	0.63	0.56	0.94	1.42	0.66	0.59	0.42
	MW-17	0.64	0.98	0.88	0.19	0.85	0.80	1.05	0.91	1.51	1.30	0.84	1.04	0.97	1.51	1.09
	MW-20	0.46	0.90	0.76	0.99	0.85	0.71	1.04	0.96	1.35	0.87	0.87	0.81	0.80	1.37	0.77
	MW-23	1.17	0.86	0.79	1.25	1.43	0.99	1.27	1.02	1.59	1.09	1.04	0.90	0.80	1.60	0.03
	MW-24	1.13	1.15	1.25	1.25	0.66	1.08	0.95	1.21	1.39	1.08	1.00	0.96	0.93	0.74	0.29
	MW-25	0.96	0.73	0.60	1.14	1.07	1.14	1.03	0.86	1.11	1.53	0.81	1.05	0.83	1.32	0.07
trans-1,2-Dichloroethene	MW-13	1.02	0.86	0.79	1.52	1.79	1.27	1.16	1.28	1.24	0.74	0.91	0.95	0.82	0.78	0.74
	MW-14	0.90	0.91	0.87	1.60	2.01	0.93	1.07	1.10	1.58	1.67	1.19	1.07	1.11	1.01	1.48
	MW-15	1.55	0.46	1.43	1.24	1.78	0.82	0.49	1.32	1.29	1.60	0.93	0.43	1.01	1.10	0.91
	MW-17	0.72	0.62	0.68	0.47	1.09	0.85	0.82	0.92	1.09	1.21	1.20	1.76	1.99	1.20	0.72
	MW-20	0.64	0.63	0.63	0.81	1.07	0.84	0.94	1.02	1.05	1.10	1.22	1.13	1.27	1.35	0.73
	MW-23	0.96	0.91	0.87	1.21	1.09	0.92	1.17	0.95	1.33	1.22	1.13	1.19	1.23	1.32	0.50
	MW-24	0.98	0.81	0.97	1.29	0.88	1.01	1.05	1.13	1.14	0.97	1.19	1.11	1.19	0.93	0.54
	MW-25	0.85	0.72	0.72	1.00	1.06	0.88	1.02	0.98	1.05	1.18	1.11	1.12	1.03	1.21	0.51
Trichloroethene (TCE)	MW-13	0.96	1.56	1.11	1.33	1.49	1.25	1.26	1.27	1.34	0.72	1.03	1.13	0.93	0.93	1.07
	MW-14	1.00	1.74	1.38	1.21	0.97	1.21	1.38	1.31	1.20	1.07	1.38	1.40	1.23	1.60	0.63
	MW-15	0.78	2.37	0.84	0.60	0.73	1.16	0.92	0.65	0.59	0.65	1.28	1.74	0.91	0.71	0.49
	MW-17	0.57	0.73	0.71	0.17	0.78	0.85	1.08	1.05	1.34	1.42	1.20	1.33	1.32	1.67	1.24
	MW-20	0.61	0.95	0.88	0.83	0.88	0.83	1.06	1.04	1.16	1.05	1.12	1.02	1.07	1.34	0.88
	MW-23	0.96	1.19	1.20	1.23	1.04	1.06	1.18	1.15	1.30	0.95	1.37	1.06	1.12	1.75	0.06
	MW-24	0.96	1.38	1.35	1.18	0.66	1.07	1.06	1.20	1.17	0.82	1.27	1.19	1.21	0.86	0.40
	MW-25	0.85	1.11	1.05	1.03	0.93	1.04	1.08	0.97	1.01	1.40	1.09	1.27	1.14	1.41	0.13
Trichloro-fluoromethane	MW-13	1.04	1.64	1.17	1.85	1.79	1.63	1.60	1.65	1.58	0.40	0.73	0.81	0.56	0.34	0.37
	MW-14	1.23	1.64	1.50	1.73	1.14	1.42	1.63	1.62	1.40	1.02	1.32	1.08	1.01	1.22	0.21
	MW-15	0.82	3.46	0.42	0.21	0.33	1.19	1.90	1.61	0.10	0.15	0.86	1.14	0.37	0.12	0.03
	MW-17	0.38	0.48	0.49	0.16	0.75	0.86	1.23	1.33	1.69	1.38	1.10	1.28	1.34	1.38	0.56
	MW-20	0.54	0.83	0.81	0.83	1.04	0.92	1.13	1.18	1.22	1.01	0.99	0.94	1.14	1.21	0.39
	MW-23	0.96	1.15	1.35	1.65	1.16	1.09	1.34	1.37	1.56	0.74	1.05	0.98	1.18	1.09	0.02
	MW-24	1.00	1.28	1.50	1.66	0.75	1.26	1.34	1.49	1.43	0.63	1.04	0.83	1.01	0.56	0.11
	MW-25	0.84	1.23	1.19	1.17	1.15	1.06	1.27	1.16	1.05	1.15	0.88	0.82	0.81	0.92	0.07
Trichloro-trifluoroethane (Freon-113)	MW-13	0.60	2.20	1.05	1.44	1.42	1.60	1.70	1.60	1.57	0.45	0.54	0.65	0.45	0.38	0.22
	MW-14	0.96	1.53	1.89	1.61	1.21	1.46	1.70	1.69	1.48	1.19	1.45	1.07	0.93	1.53	0.14
	MW-15	0.85	4.03	0.97	0.68	0.84	1.26	0.62	0.58	0.31	0.37	0.71	0.87	0.36	0.36	0.05
	MW-17	0.22	0.31	0.33	0.09	0.54	0.76	1.16	1.20	1.60	1.46	0.55	1.46	1.57	1.75	0.40
	MW-20	0.41	1.07	0.87	0.81	0.92	0.90	1.13	1.15	1.13	1.03	0.96	0.96	1.16	1.42	0.26
	MW-23	0.74	0.90	1.07	1.50	1.44	1.08	1.31	1.35	0.90	0.78	1.38	0.85	0.96	1.85	0.01
	MW-24	0.69	1.33	1.50	1.45	0.65	1.35	1.30	1.42	1.39	0.57	0.84	0.65	0.82	0.61	0.06
	MW-25	0.58	0.91	0.77	1.00	1.32	1.49	1.26	1.13	1.07	1.62	1.05	0.76	0.66	1.18	0.03

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Appendix D.2
Normalized Concentration Results - Site #2

4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
9/25/2013	10/9/2013	10/9/2013	10/24/2013	11/6/2013	11/20/2013	12/4/2013	12/4/2013	12/18/2013	12/31/2013	1/15/2014	1/29/2014	1/29/2014	2/12/2014	2/28/2014
Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
LFS-4	LFA(L)-4	LFA(S)-4	SS-4	HS-4	LFS-5	LFA(L)-5	LFA(S)-5	SS-5	HS-5	LFS-6	LFA(L)-6	LFA(S)-6	SS-6	HS-6
0.77	1.11	1.02	0.21	0.21	0.56	0.61	0.56	0.23	1.52	0.61	0.72	0.34	11.93	2.47
0.11	0.05	0.03	0.07	0.27	0.04	0.04	0.03	0.08	5.09	0.03	0.03	0.06	0.02	0.14
0.87	0.22	0.65	0.59	1.04	0.92	0.82	1.10	1.31	0.81	1.67	2.79	2.68	1.60	3.56
0.70	0.66	0.73	0.75	1.05	0.76	0.65	0.66	0.61	1.09	0.66	0.63	2.30	0.57	7.96
0.93	1.02	0.87	1.02	0.97	1.20	1.07	1.04	1.03	1.24	0.97	1.33	1.03	0.83	1.17
0.99	0.79	1.01	1.09	0.56	1.24	0.92	1.00	0.92	0.45	0.94	1.24	1.11	0.77	0.34
1.45	0.97	0.76	0.91	0.86	1.30	0.70	0.69	0.47	0.65	0.51	0.52	0.40	0.74	0.86
0.56	0.61	0.66	1.94	0.80	2.88	2.88	3.00	2.54	2.26	1.15	1.57	1.55	0.46	1.23
0.68	0.72	0.66	0.65	0.40	1.15	1.27	1.15	1.33	0.85	1.00	1.04	1.03	0.43	0.68
0.00	0.46	0.12	0.64	0.63	1.00	1.30	0.76	0.71	0.10	0.74	1.07	0.94	0.20	0.76
0.36	1.43	0.64	0.83	0.64	0.71	3.13	1.20	1.20	0.25	3.17	3.44	2.90	1.42	1.08
0.76	1.10	0.97	1.19	1.10	1.56	1.55	1.19	1.19	1.29	1.16	0.67	0.56	0.91	1.40
0.32	0.97	0.90	1.04	0.84	1.31	1.02	0.99	1.04	1.21	1.00	1.32	1.07	0.89	1.43
1.14	0.70	0.88	0.96	0.44	1.42	0.97	1.13	1.11	0.27	0.85	1.20	1.13	0.72	0.04
0.83	0.83	0.71	0.78	0.33	1.33	0.89	1.13	0.74	0.98	1.12	0.98	1.11	1.00	1.04
0.76	0.82	0.83	0.89	0.40	1.40	1.24	1.21	0.92	0.90	0.87	1.45	1.09	0.73	1.25
0.68	0.82	0.75	0.83	0.52	0.88	1.13	1.05	1.36	0.95	0.95	0.89	0.89	0.37	0.62
0.65	0.49	0.56	0.65	0.75	0.88	0.98	0.74	0.75	0.62	0.69	0.97	0.90	0.15	0.55
0.83	1.10	0.88	1.11	1.05	1.16	1.22	1.17	0.92	0.56	0.14	1.08	0.94	0.61	0.14
1.00	1.01	0.98	1.14	0.99	1.18	1.05	1.05	1.04	1.10	0.85	0.76	0.56	0.72	0.89
0.96	0.90	0.92	0.98	0.90	0.98	0.94	0.95	0.99	1.10	0.84	1.21	1.77	0.71	1.10
0.96	0.89	0.99	1.13	0.59	1.14	0.99	1.06	1.04	0.38	0.85	1.18	1.30	0.74	0.09
0.87	1.05	1.04	0.96	0.47	0.95	0.98	1.03	0.85	0.92	1.02	0.85	0.87	0.70	0.95
0.94	0.95	0.99	1.09	0.50	1.06	1.11	1.16	0.93	1.07	0.79	1.29	1.14	0.73	1.03
0.68	0.80	0.75	0.80	0.49	0.92	1.12	1.06	1.27	1.00	1.02	0.99	1.00	0.32	0.52
0.65	0.53	0.56	0.75	0.77	0.96	1.13	0.81	0.77	0.06	0.84	1.16	1.07	0.20	0.58
0.36	2.62	0.98	1.18	0.41	0.51	2.00	0.90	0.43	0.12	1.28	1.65	1.37	0.60	0.37
1.08	1.09	1.12	1.21	1.02	1.14	1.00	1.02	1.01	1.20	0.93	0.82	0.56	0.82	0.72
0.97	0.96	0.97	1.06	0.91	0.98	0.89	0.93	1.00	1.24	0.96	1.32	1.02	0.86	1.16
0.99	0.80	1.06	1.17	0.53	1.13	0.90	0.98	0.96	0.34	0.89	1.28	1.10	0.76	0.03
0.85	1.05	1.07	0.99	0.42	0.98	0.97	1.03	0.79	0.99	1.12	0.99	1.02	0.84	0.95
0.89	0.95	1.00	1.07	0.49	1.00	1.08	1.05	0.84	1.01	0.81	1.20	1.15	0.76	1.10
0.87	0.97	0.98	0.62	0.55	0.78	0.85	0.82	0.72	0.98	0.79	0.85	0.73	3.88	1.46
0.25	0.37	0.27	0.50	0.47	0.28	0.31	0.31	0.40	1.73	0.37	0.42	0.51	0.18	0.69
0.32	0.45	0.36	0.50	2.56	1.09	2.07	1.19	1.27	0.64	3.38	3.83	3.69	2.02	1.22
0.87	0.93	0.96	1.08	0.93	1.04	0.98	1.01	1.00	1.23	1.04	0.95	0.78	1.06	1.70
0.83	0.94	0.94	1.03	0.88	1.01	0.95	0.97	0.96	1.20	1.03	1.25	0.95	0.93	1.12
0.95	0.80	0.95	1.07	0.60	1.09	0.99	1.03	1.02	0.50	1.13	1.48	1.28	1.10	0.05
1.26	1.04	0.90	1.01	0.59	1.30	0.91	0.92	0.71	0.89	0.91	0.89	0.79	1.10	1.06
0.73	0.82	0.87	1.43	0.60	1.78	1.91	1.73	1.64	1.59	1.12	1.46	1.36	0.86	1.24

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Appendix D.2
Normalized Concentration Results - Site #2

4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
9/25/2013	10/9/2013	10/9/2013	10/24/2013	11/6/2013	11/20/2013	12/4/2013	12/4/2013	12/18/2013	12/31/2013	1/15/2014	1/29/2014	1/29/2014	2/12/2014	2/28/2014
Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve	Low-Flow Standard	Low-Flow Alternative (L)	Low-Flow Alternative (S)	SNAP Samplers	Hydrasleeve
LFS-4	LFA(L)-4	LFA(S)-4	SS-4	HS-4	LFS-5	LFA(L)-5	LFA(S)-5	SS-5	HS-5	LFS-6	LFA(L)-6	LFA(S)-6	SS-6	HS-6
0.49	0.66	0.57	0.76	0.55	0.80	1.21	0.80	1.61	1.27	1.05	1.57	1.22	0.33	1.02
0.56	0.61	0.55	0.82	1.04	0.90	1.30	0.70	1.11	0.04	0.96	1.32	1.00	0.33	1.64
0.44	1.75	0.73	1.12	0.67	0.44	1.70	0.89	0.93	0.21	1.39	1.50	1.12	0.93	0.83
0.67	0.86	0.81	1.06	1.07	0.99	0.86	0.84	1.27	1.21	1.16	1.17	0.41	1.41	1.66
0.59	0.83	0.65	1.02	1.02	0.80	0.89	0.75	1.34	1.12	0.90	1.40	1.43	1.52	2.22
0.84	0.75	0.77	1.14	0.79	1.01	1.04	1.00	1.41	0.39	1.07	1.16	1.31	1.28	0.19
0.67	0.72	0.65	0.81	0.37	1.09	0.93	0.98	1.17	1.13	1.16	1.12	1.20	1.38	1.53
0.69	0.76	0.70	0.95	0.43	0.96	1.06	0.90	1.22	1.06	1.01	1.25	1.18	1.44	2.14
0.78	0.93	0.91	0.86	0.70	0.85	1.12	1.07	1.30	1.06	0.88	1.12	1.10	0.75	0.70
1.70	0.51	1.25	0.63	0.66	0.84	0.80	0.67	0.64	0.81	0.79	0.83	0.46	0.46	0.46
1.19	0.48	0.69	0.82	1.28	0.89	0.88	0.88	0.66	0.26	0.82	2.29	1.28	0.67	0.53
1.10	0.96	1.01	1.04	0.90	1.03	0.91	1.00	0.94	1.39	0.97	1.05	0.64	0.95	0.75
1.78	0.97	1.01	1.01	0.94	0.63	0.94	0.98	0.97	1.23	0.94	1.25	0.96	0.92	1.02
0.84	0.81	1.06	1.14	0.54	0.94	0.92	1.01	1.02	0.50	1.07	1.43	1.22	1.02	0.50
0.97	0.99	1.12	1.01	0.54	0.99	1.07	1.12	0.80	0.94	1.13	1.13	1.11	0.98	0.90
1.02	1.02	1.07	1.17	0.52	1.19	1.17	0.95	0.97	1.14	0.95	1.44	1.11	0.99	0.84
0.74	0.87	0.82	0.79	0.54	0.83	1.00	0.90	1.23	0.90	0.88	1.02	0.99	0.38	0.72
0.59	0.57	0.56	0.74	0.79	0.90	1.21	0.79	0.85	0.04	0.89	1.26	0.96	0.26	0.92
0.57	2.05	0.89	1.18	0.74	0.57	1.76	0.98	0.79	0.22	1.36	1.68	1.21	0.81	0.77
0.91	1.06	1.03	1.11	0.97	1.05	1.02	0.93	1.09	1.05	0.93	0.94	0.53	1.00	0.96
0.80	0.94	0.90	1.04	0.91	0.88	0.90	0.88	1.02	1.05	0.93	1.30	1.23	1.01	1.53
0.89	0.81	0.98	1.12	0.57	1.03	0.95	0.90	1.21	0.33	0.96	1.29	1.28	0.98	0.07
0.76	0.93	0.97	0.92	0.39	0.89	0.95	0.94	0.85	0.90	1.10	1.04	1.15	1.10	1.30
0.78	0.91	0.87	0.97	0.44	0.94	1.01	1.04	0.85	0.94	0.82	1.31	1.12	0.89	1.62
0.73	0.78	0.73	0.69	0.44	1.24	1.33	1.22	1.34	0.89	0.96	0.93	0.92	0.11	0.55
0.53	0.41	0.41	0.57	0.64	1.05	1.29	0.78	0.61	0.01	0.68	1.85	1.32	0.10	0.60
0.33	3.35	0.94	1.07	0.26	0.63	2.30	0.94	0.36	0.07	1.24	2.59	2.13	0.45	0.61
1.31	1.23	1.28	1.25	0.96	1.62	1.14	1.10	1.01	1.18	0.86	0.72	0.43	0.64	0.85
1.04	0.94	0.98	1.02	0.79	1.19	0.85	0.90	0.83	1.08	0.79	1.85	1.46	0.55	1.56
1.02	0.75	1.12	0.91	0.41	1.30	0.89	0.93	0.80	0.24	0.73	2.07	1.57	0.49	0.05
0.92	1.08	1.15	0.70	0.27	1.28	1.10	1.15	0.69	0.91	1.06	0.92	0.93	0.66	1.31
0.90	0.92	0.96	0.78	0.34	1.09	1.18	1.17	0.61	0.88	0.65	1.89	1.86	0.53	1.49
0.63	0.74	0.66	0.65	0.46	1.29	1.49	1.27	1.57	1.11	1.08	1.19	1.13	0.10	0.75
0.40	0.30	0.30	0.48	0.62	1.08	1.72	0.80	0.69	0.00	0.73	1.44	0.90	0.12	0.59
0.40	3.00	0.93	1.28	0.39	0.73	2.89	1.49	0.76	0.10	1.13	1.59	1.16	0.50	0.79
0.97	1.11	1.13	1.18	0.87	1.62	1.49	1.08	1.23	1.23	1.13	0.80	0.42	0.77	1.57
0.93	0.95	0.98	1.06	0.82	1.24	0.97	1.01	1.04	1.00	0.84	1.34	0.94	0.69	2.00
1.05	0.74	0.95	1.12	0.39	1.52	1.11	1.19	1.31	0.23	0.83	1.36	1.36	0.60	0.12
0.79	1.00	1.10	0.52	0.19	1.87	1.09	1.42	0.81	0.90	1.22	1.07	1.07	0.75	1.57
0.82	0.94	0.92	0.67	0.27	1.16	1.44	1.28	0.70	0.86	0.72	1.60	1.40	0.71	1.70

APPENDICES

Appendix D.3: Graphs by Well and Chemical

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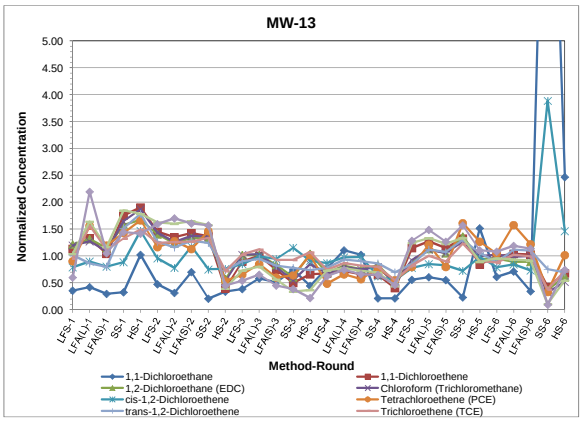
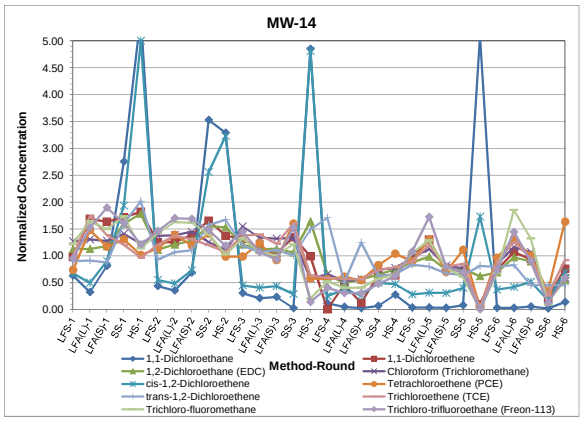
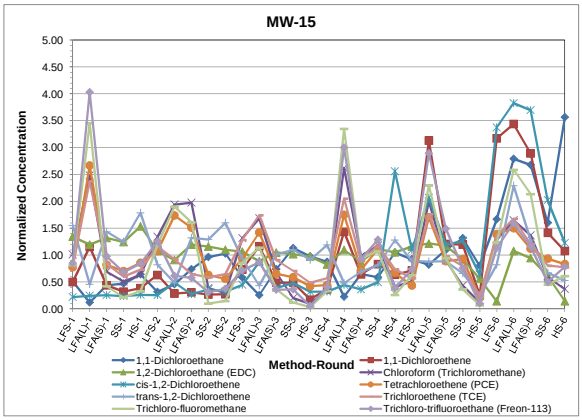
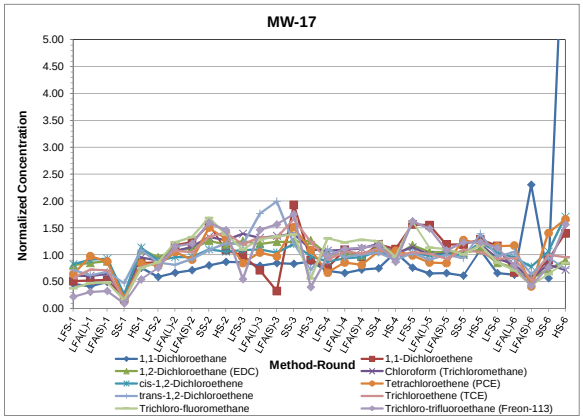
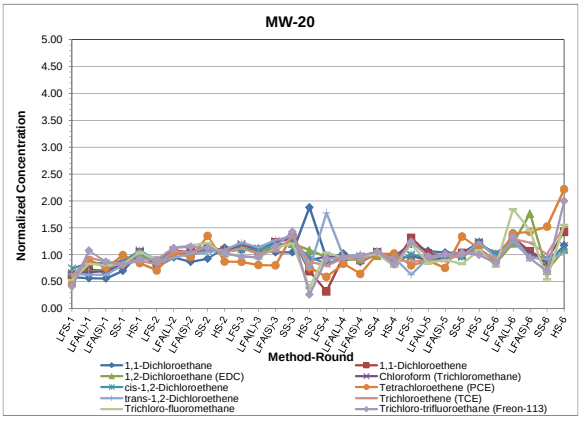
Appendix D.3
Graphs by Well and Chemical

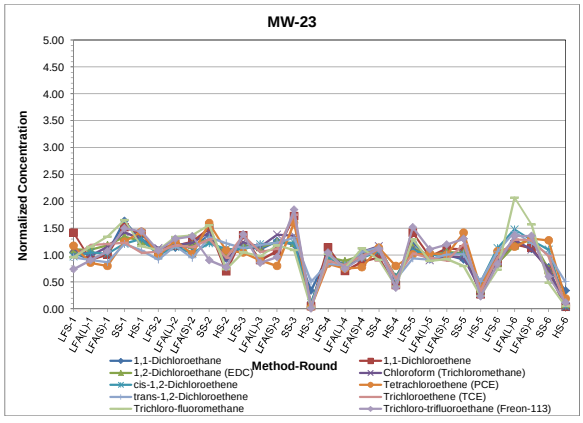


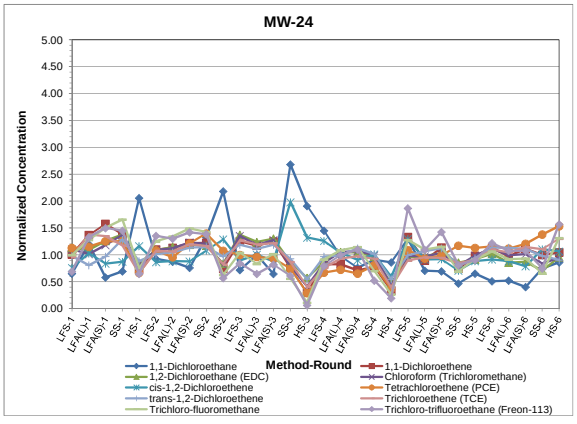


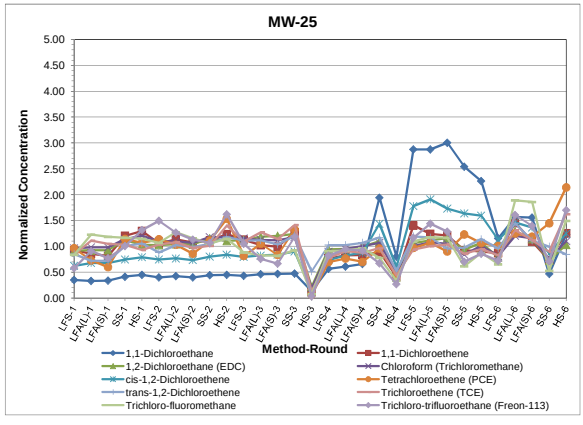












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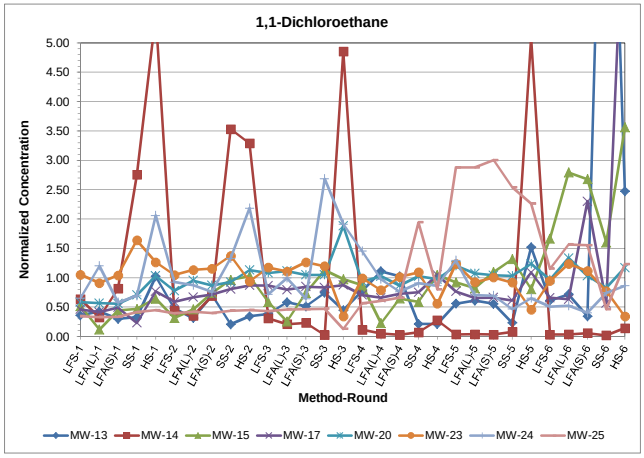
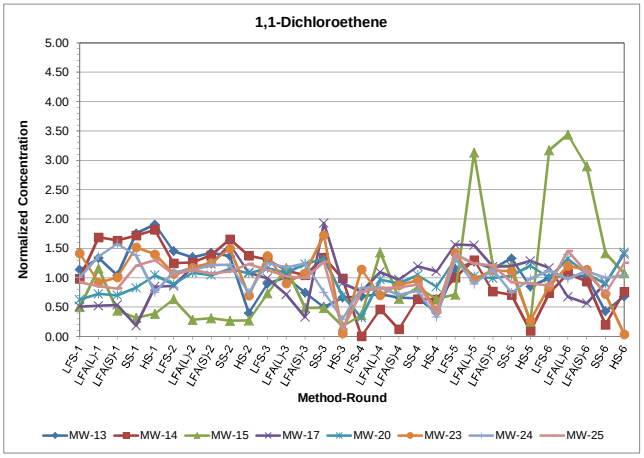
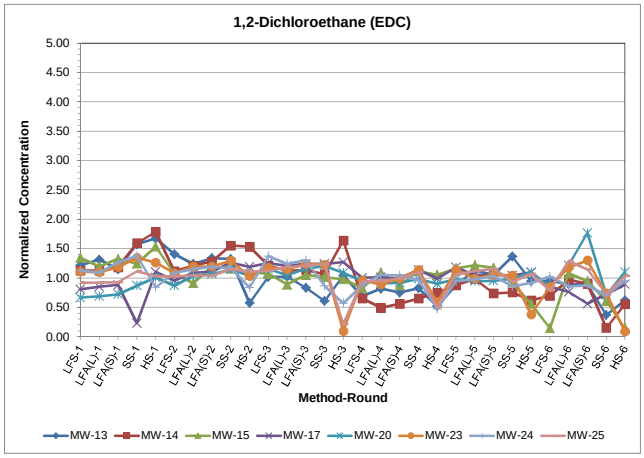
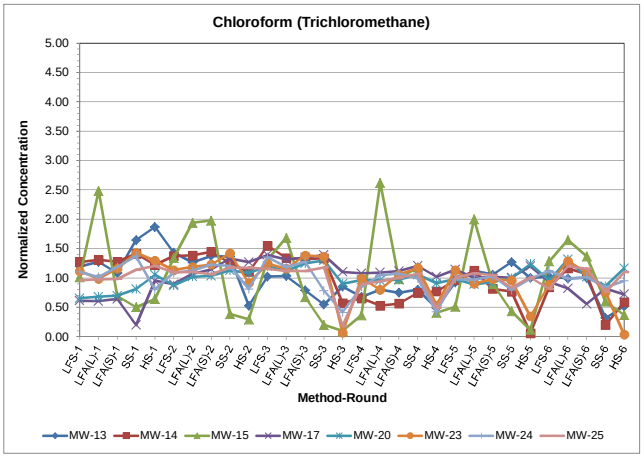
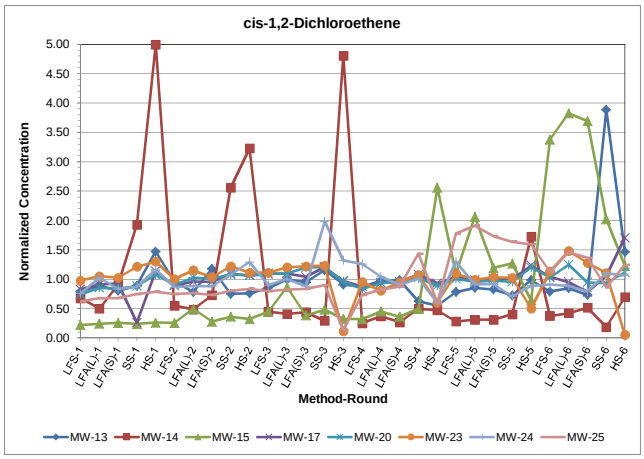
Appendix D.3
Graphs by Well and Chemical

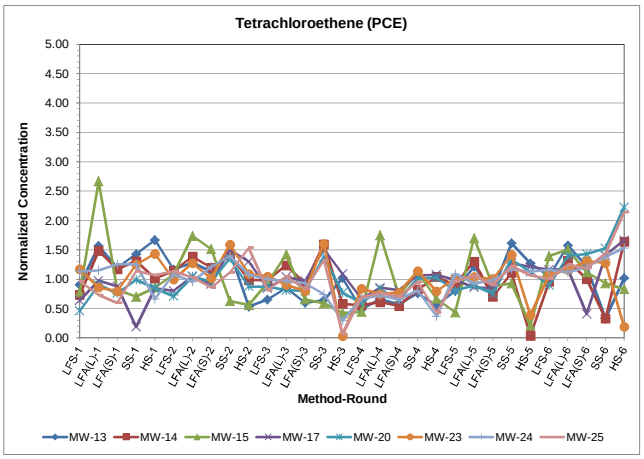












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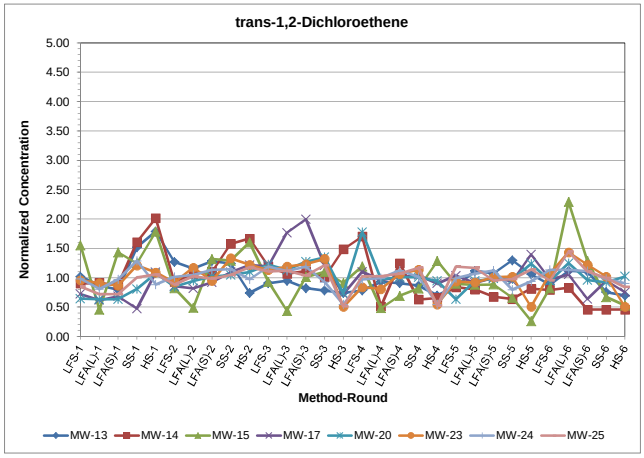
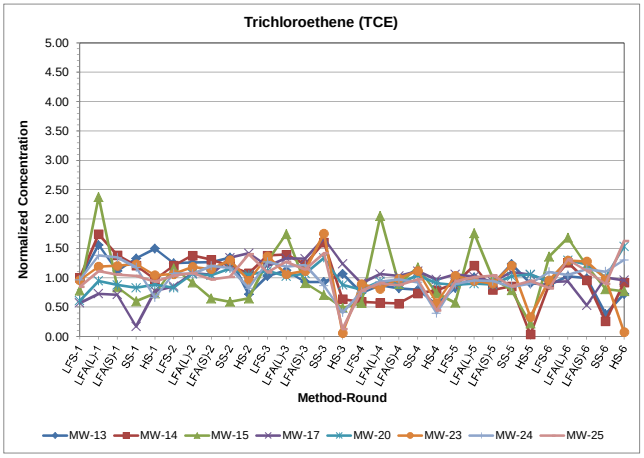
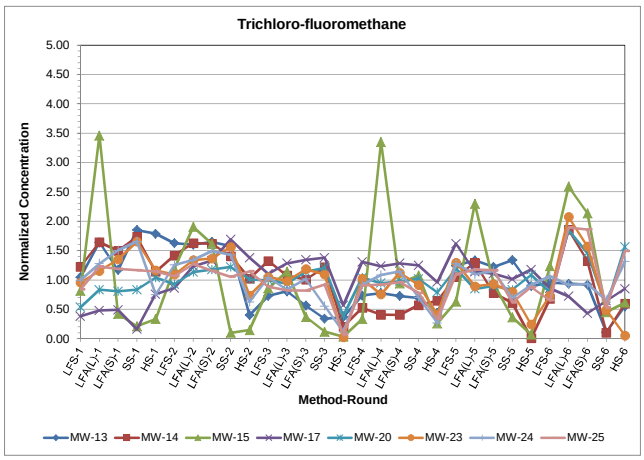
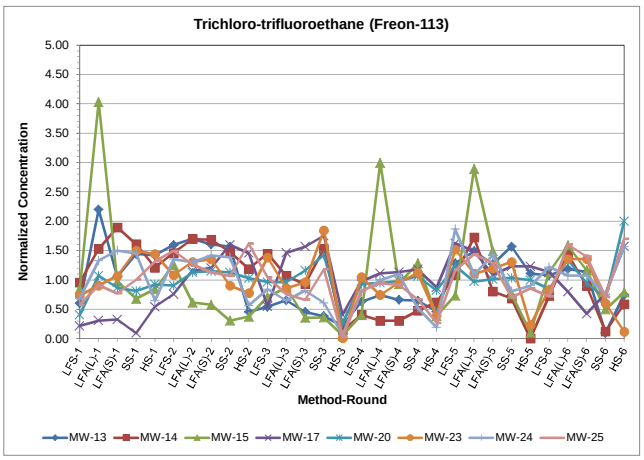
Appendix D.3
Graphs by Well and Chemical









APPENDICES

Appendix D.4: Relative Percent Differences (RPDs) in Constituent Concentrations between Samples and Field Duplicates

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Appendix D.4
Relative Percent Differences (RPDs) in Constituent Concentrations between Samples and Field Duplicates

Well ID	Round	Sample date	Sample collection method	1,1-Dichloroethane	RPD	1,1-Dichloroethene	RPD	1,2-Dichloroethane (EDC)	RPD	Chloroform (Trichloromethane)	RPD	cis-1,2-Dichloroethene	RPD	Tetrachloroethene (PCE)	RPD
MW-20	1	4/23/2013	Low-Flow	0.68 J	0.0%	90.4	1.3%	3.25	6.3%	25.3	4.0%	8.44	0.5%	233	10.4%
			Alternative	0.68 J		91.6		3.05		24.3		8.48		210	
MW-17	1	5/22/2013	Hydrasleeve	1.66	61.4%	183	5.0%	5.98	5.9%	51.3	2.4%	11.8	1.7%	325	5.1%
				3.13		174		5.64		50.1		11.6		342	
MW-20	2	6/18/2013	Low-Flow	1.16	0.9%	140	15.4%	4.66	1.1%	37.1	3.6%	10.3	3.7%	320	12.3%
			Alternative	1.15		120		4.61		35.8		9.93		362	
MW-23	2	7/17/2013	Hydrasleeve	1.38	44.2%	184	46.2%	5.68	51.3%	52.1	52.0%	11.2	49.0%	410	18.7%
				0.88 J		115		3.36		30.6		6.79		340	
MW-15	3	9/11/2013	Hydrasleeve	220	1.4%	21.6	4.5%	3.4	2.9%	1.28	7.3%	29.5	1.7%	42.9	1.6%
				217		22.6		3.5		1.19		29		42.2	
MW-23	4	10/9/2013	Low-Flow	1.16	8.3%	185	12.2%	4.9	1.4%	45.8	11.5%	8.1	14.0%	281	6.2%
			Alternative	1.26		209		4.97		51.4		9.32		299	
MW-13	5	11/20/2013	Low-Flow	3.75	0.3%	179	14.5%	3.48	2.8%	36.5	0.3%	10.9	3.7%	196	1.0%
			Standard	3.76		207		3.58		36.6		10.5		198	
MW-13	5	12/4/2013	Low-Flow	4.09	3.4%	198	3.0%	4.49	0.7%	44.3	1.3%	11.9	1.7%	297	12.1%
			Alternative	4.23		204		4.52		44.9		12.1		263	
MW-24	6	1/29/2014	Low-Flow	2.12	7.8%	248	1.6%	4.44	1.6%	55.2	2.6%	13.8	5.2%	393	4.2%
			Alternative	1.96		244		4.37		53.8		13.1		410	

Notes:

1. Non-detect values not factored in to RPD calculations when both duplicate and sample were non-detect.
2. SNAP Samplers not included in duplicate calculations (see Section 6.0 in text).
3. RPD calculations when only one result is non-detect assume the non-detect value is the sample detection limit.

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Appendix D.4
Relative Percent Differences (RPDs) in Constituent Concentrations between Samples and Field Duplicates

Well ID	Round	Sample date	Sample collection method	trans-1,2-Dichloroethene	RPD	Trichloroethene (TCE)	RPD	Trichloro-fluoromethane	RPD	Trichloro-trifluoroethane (Freon-113)	RPD	Average RPD for Event
MW-20	1	4/23/2013	Low-Flow	<0.5	NA	112	7.7%	35.8	0.3%	81.5	13.7%	4.92%
			Alternative	<0.5		121		35.7		93.5		
MW-17	1	5/22/2013	Hydrasleeve	1.15	3.5%	142	5.1%	63	6.9%	125	11.9%	10.88%
				1.11		135		58.8		111		
MW-20	2	6/18/2013	Low-Flow	0.75 J	1.3%	136	5.3%	50.3	35.0%	106	50.1%	12.87%
			Alternative	0.76 J		129		35.3		63.5		
MW-23	2	7/17/2013	Hydrasleeve	1.21	52.1%	182	49.3%	72.1	50.8%	196	53.7%	46.73%
				0.71 J		110		42.9		113		
MW-15	3	9/11/2013	Hydrasleeve	1.74	17.5%	30.2	2.7%	<0.5	NA	2.05	17.0%	6.29%
				1.46		29.4		<0.5		2.43		
MW-23	4	10/9/2013	Low-Flow	0.8 J	8.4%	155	9.8%	73.9	10.4%	188	9.1%	9.13%
			Alternative	0.87 J		171		82		206		
MW-13	5	11/20/2013	Low-Flow	0.61 J	19.8%	130	1.5%	61.6	6.2%	145	4.2%	3.84%
			Standard	<0.5		132		57.9		139		
MW-13	5	12/4/2013	Low-Flow	0.8 J	0.0%	158	2.5%	66.2	3.3%	168	4.7%	3.26%
			Alternative	0.8 J		162		68.4		176		
MW-24	6	1/29/2014	Low-Flow	1.04	5.9%	215	2.3%	72.5	3.8%	199	4.6%	3.97%
			Alternative	0.98 J		220		69.8		190		

Notes:

1. Non-detect values not factored in to RPD calculations when both duplicate and sample were non-detect.
2. SNAP Samplers not included in duplicate calculations (see Section 6.0 in text).
3. RPD calculations when only one result is non-detect assume the non-detect value is the sample detection limit.