REDUCING THE ENVIRONMENTAL IMPACT OF SHALE GAS DEVELOPMENT

ADVANCED ANALYTICAL METHODS FOR AIR AND STRAY GAS EMISSIONS AND PRODUCED BRINE CHARACTERIZATION

FINAL TECHNICAL REPORT

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REDUCING THE ENVIRONMENTAL IMPACT OF SHALE GAS DEVELOPMENT

ADVANCED ANALYTICAL METHODS FOR AIR AND STRAY GAS EMISSIONS AND PRODUCED BRINE CHARACTERIZATION

Baseline Sampling for Dissolved Methane
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ABSTRACT

Consistent, scientifically-based protocols are needed to accurately characterize i) water quality in residential water wells surrounding active shale oil and gas operations; ii) air emissions from flowback storage ponds and other impoundments; and iii) the chemical composition of flowback/produced water for potential reuse and/or disposal. Under RPSEA Project 11122-45, GSI Environmental Inc. and its teaming partners at Texas A&M University assembled a multi-disciplinary team of scientists, researchers, industry, government, and regulatory representatives to evaluate current sampling methodologies and analytical technologies, conduct field trials in a multiple shale plays, and develop recommended practices for:

Baseline Sampling for Dissolved Methane: Development of recommendations for improved sample collection methods and data interpretation for pre-drill and post-drill sampling programs, based on an improved understanding of the variability associated with sampling methodology and temporal factors.

Advanced Analytical Air Monitoring: Development of a protocol for measurement of air emissions from production facilities and open impoundments using a monostatic Open Path Fourier Transform Infrared (OP-FTIR) spectrometer, integrated meteorological sensors and an optical imaging camera.

Flowback/Produced Water Characterization: Evaluation of analytical technologies for on-site analysis of key chemical and microbial constituents in produced water to facilitate cost-effective reuse, treatment, and/or disposal of flowback/produced water.

Key findings and recommendations from the study include:

- Sampling methodology plays an important role in the variability of methane concentrations at residential water wells, where a closed-system sampling method yields the most accurate methane concentrations under effervescing conditions. Natural variability of methane concentrations was found to correlate closely with changes in salinity indicators, suggesting well mixing dynamics is an important factor contributing to the observed variability of dissolved methane.
- The OP-FTIR, optical imaging camera and integrated meteorological sensors successfully delineated sources of constituents of concern (methane, ethane and carbon monoxide) emissions during preliminary trials, pilot and field tests. Use of the three instruments together provides a robust and defensible dataset for determination of ambient downwind concentrations and development of emission rate / dispersion modeling at production facilities and disposal ponds.
- Real-time measurements of organic components, dissolved ions, and microbial activity in produced waters were attained using a portable GC/MS, water quality field screening kits, and various fluorescence-based bacterial monitoring technologies.

The high level of interest and participation on this project from industry and regulatory stakeholders concerned with environmental impacts associated with shale oil and gas development vastly increased its value to GSI, DOE NETL and RPSEA. The recommended practices, protocols, and technology assessments developed from this project support stakeholder decision-making with respect to pre-drill and post-drill sampling of water wells, air emissions monitoring of oil and gas operations, and management of flowback/produced waters.

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ACRONYMS AND ABBREVIATIONS

3σ	Three Standard Deviations
AACG	Alamo Area Council of Governments
API	American Petroleum Institute
APB	Acid Producing Bacteria
APS	Adenosine-5'-Phosphosulfonate
ATP	Adenosine Triphosphate
b/d	barrels/day
BART	Biological Activity Reaction Test
BDL	Below Detection Limits
BLM	Bureau of Land Management
BOL	Bureau of Laboratories
BP	British Petroleum
BTEX	Benzene, toluene, ethylbenzene and xylene
BTOC	Below top of casing
CAPP	Canadian Association of Petroleum Producers
CFU/mL	Colony-forming unit per milliliter
CH_4	Methane
COGCC	Colorado Oil and Gas Conservation Commission
CO	Carbon monoxide
CV	Coefficient of Variation
CLS	Classical Least Squares
DO	Dissolved Oxygen
DIC	Dissolved Inorganic Carbon
DOC	Demonstration of Capability
DOE	Department of Energy
EC	Electrical Conductivity
EDF	Environmental Defense Fund
EDA	Exploratory data analysis
EFD	Environmentally Friendly Drilling
EFD-TIP	Environmentally Friendly Drilling Systems-Technology Integration Program
FOG	Free oil and grease
FT-MIR	Fourier Transform Mid-Infrared
USEPA	Environmental Protection Agency
Gal	Gallons
GC/MS	Gas chromatograph/mass spectrometer
GPRI	Global Petroleum Research Institute
Gpm	gallons per minute
GSI	GSI Environmental Inc.
GWPC	Groundwater Protection Council
HARC	Houston Advanced Research Center
HAB	Heterotrophic Aerobic Bacteria
IOGCC	Interstate Oil and Gas Compact Commission
IRB	Iron-Reducing Bacteria
IRNR	Institute of Renewable Natural Resources
ISE	Ion-Selective Electrode
KGS	Kentucky Geological Survey
lpm	liters per minute
mS/cm	Millisiemens per centimeter

MDL	Method detection limit
µg/L	Micrograms per liter
METS	Meteorological Station
MSC	Marcellus Shale Coalition
ND DMR	North Dakota Department of Mineral Resources
NELAC	National Environmental Laboratory Accreditation
NETL	National Energy Technology Laboratory
NEA	Method Noise Equivalency Assurance
NGO	Non-Governmental Organization
NRMRL	National Risk Management Research Laboratory
NYSDEC	New York State Department of Environmental Conservation
OCC	Oklahoma Corporation Commission
ODNR	Ohio Department of Natural Resources
OP-FTIR	Open Path Fourier Transform Infrared
ORD	Office of Research and Development
ORP	Oxidation Reduction Potential
OSU	Ohio State University
PADEP	Pennsylvania Department of Environmental Protection
PDB	Pee Dee Belemnite
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per trillion
PTAC	Petroleum Technology Alliance Canada
RAM 2000	Remote Air Monitor-2000
RPSEA	Research Partnership to Secure Energy for America
r_s	Spearman's rho
SCWO	Supercritical water oxidation
SLYM	Slime-Forming Bacteria
SRB	Sulfate Reducing Bacteria
TASC	Technical Advisory Steering Committees
TAMU	Texas A&M University
TAMU-SA	Texas A&M University San Antonio
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TEES	Texas A&M Engineering Experiment Station
TIC	Total inorganic carbon
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
TRRC	Railroad Commission of Texas
TSS	Total suspended solids
UK/KGS	University or Kentucky and Kentucky Geological Survey
USGS	United States Geological Survey
VOA	Volatile organic analysis
VOC	Volatile organic compound
VSMOW	Vienna Standard Mean Ocean Water

EXECUTIVE SUMMARY

Evaluation of the environmental risks of shale oil and gas development can be complicated by the lack of accurate and consistent procedures and practices for characterizing potential impacts and/or waste streams associated with shale oil and gas development. Inconsistencies in characterization efforts include monitoring time frames, constituents of concern, analytical tools and methods, sample collection methods, and reporting. Consistent, scientifically-based procedures are needed to accurately characterize i) water quality in residential water wells surrounding active shale oil and gas development; ii) air emissions from oil and gas infrastructure; and iii) the chemical composition of flowback/produced water for potential reuse and/or disposal.

GSI Environmental Inc. (GSI) and its teaming partners at Texas A&M's Global Petroleum Research Institute (GPRI) and Institute of Renewable Natural Resources (IRNR), and the Houston Advanced Research Center (HARC) were awarded a three-year research project from the Research Partnership to Secure Energy for America (RPSEA) program to evaluate current sampling methodologies and analytical technologies, conduct field trials in multiple shale plays, and develop recommended practices for baseline sampling of dissolved methane at residential water wells, real-time monitoring of air emissions from production facilities and open impoundments, and on-site characterization of flowback/ produced water. This report summarizes the approach and key results from each of the three principal research components of the project.

Baseline Sampling for Dissolved Methane

The overall goal of this research study is to form a better understanding of the inherent variability in pre-drill and post-drill analytical results and develop recommended practices for improved sample collection methods, sample analysis, and data interpretation for pre-drill and post-drill sampling programs in areas of active shale oil and gas development. Field studies were completed in Northeastern Pennsylvania in the Marcellus shale play to quantify the variability of sampling methodologies (purge volumes, sampling containers, fill methods, sample location) and temporal changes (seasonal factors) in dissolved gas concentrations, isotopic composition of methane, and other general water quality parameters in groundwater.

Our findings suggest that sampling methodology can play an important role in the variability of methane concentrations, where a closed-system sampling method yields the most accurate methane concentrations in effervescing conditions. Regardless of the volume of water purged prior to sampling or the timing of sampling events, changes in methane concentration greater than two-fold were rarely observed. At a subset of wells, the natural variability of methane concentrations during purging or over time was found to correlate closely with changes in sodium and specific conductance of the water. This suggests that mixing dynamics within wells can be an important factor contributing to the natural variability of dissolved methane concentration.

Findings from this study contribute to the design and implementation of pre-drill and post-drill groundwater monitoring programs and subsequent data interpretation by i) providing practical recommendations for sampling of dissolved methane in residential water wells and ii) highlighting simple relationships for improved data interpretation. These recommended procedures for sampling of residential water wells were tested by the Kentucky Geological Survey in Eastern Kentucky, as part of the baseline sampling effort in the emerging Rogersville shale.

Advanced Analytical Air Monitoring

The overall objective of the Advanced Analytical Air Monitoring project is to develop a technical protocol for the measurement of oil and gas ambient emissions using a monostatic Open Path Fourier Transform Infrared (OP-FTIR) spectrometer with integrated meteorological sensors and an optical imaging camera. The project involved four major components i) quality assurance

testing via controlled methane releases at Texas A&M San Antonio (TAMU-SA), ii) pilot testing of beam configurations and integrated systems at Clover Lawn Park, iii) field trials at SHAPE Ranch located in South Texas Eagle Ford Shale Play, and iv) development of an air measurement protocol for the OP-FTIR that was used during a joint-industry project to measure air emissions from produced water ponds in Wyoming.

The OP-FTIR and integrated meteorological sensors successfully delineated and differentiated emissions from the controlled methane release at TAMU-SA outdoor lab, as well as nearby background emissions from construction activity at Clover Lawn Park. Quality assurance techniques included method noise equivalency, accuracy, precision, return beam intensity, stray light, resolution, non-linear instrument response and determination of water vapor.

The South Texas field trials validated technical procedures within the protocol, which was then used to guide air emissions monitoring from multiple produced water ponds in the Upper Green River Basin in Wyoming, part of a joint-industry project being performed by the Advanced Analytics team. Data and results from field efforts have culminated in a final technical protocol.

Flowback/Produced Water Characterization

The overall goal of the Flowback/Produced Water Characterization component of the project was to test and evaluate on-site analytical technologies to characterize flowback and produced water from unconventional oil and gas operations and support cost-effective reuse, treatment, or disposal of produced waters. A three-year program of pilot plant and field trials was conducted by GPRI to identify effective on-site analytical technologies for rapid quantification of key parameters such as biological activity, organics and oils, cations and anions, and dissolved and suspended solids in flowback and produced water. Based on the results of field trials, technology summaries (or “fact sheets”) were developed to support the testing and deployment of new “field ready” products facilitating rapid produced water characterization.

Produced and flowback water samples from numerous field trials in several shale plays were collected to evaluate the field readiness of analytical technologies. Field trials enabled the GPRI team to i) characterize the complex variety of organics and oils, dissolved ions, and microbial contents of produced waters, and ii) use the real-time results to optimize the treatment process train, such that contaminants in produced water can be removed in a cost-effective and timely manner. The GPRI team successfully attained real-time measurements of organic components, dissolved ions, and microbial activity in produced waters using a portable GC/MS, water quality field screening kits, and various fluorescence-based bacterial monitoring technologies.

Technology Transfer

A critical component of this project has been the high level of participation and interest from industry stakeholders concerned with environmental impacts associated with shale oil and gas development. Technical Advisory Steering Committees (TASCs) consisting of >100 participants from industry, government, regulatory agencies, non-governmental organizations, academia, and consulting were assembled to provide recommendations and feedback on project activities over the three-year program. GSI and its teaming partners hosted fifteen conference calls and conducted multiple one-on-one meetings with TASC members. In addition, project update memos were issued semi-annually to keep TASC members informed of upcoming field programs, preliminary findings, and data analysis. Knowledge gained from this program was disseminated though technical presentations at conferences and workshops, publication of technical papers, and public education programs (e.g., webinars). The high level of participation on this project from industry and regulatory stakeholders concerned with environmental impacts associated with shale oil and gas development vastly increased its value to GSI, DOE NETL and RPSEA.

1.0 INTRODUCTION

Evaluation of the environmental risks of shale oil and gas development can be complicated by the lack of accurate and consistent procedures and practices for characterizing potential impacts and/or waste streams associated with shale oil and gas development. Consistent, scientifically-based procedures are needed to accurately characterize i) water quality in residential water wells surrounding active shale oil and gas development; ii) air emissions from production facilities and storage impoundments; and iii) the chemical composition of flowback/produced water for potential reuse and/or disposal.

GSI Environmental Inc. (GSI) and its teaming partners at Texas A&M's Global Petroleum Research Institute (GPRI) and Institute of Renewable Natural Resources (IRNR), and the Houston Advanced Research Center (HARC) were awarded a three-year research project from the Research Partnership to Secure Energy for America (RPSEA) program to evaluate current sampling and testing technologies and develop recommended practices for baseline sampling of dissolved methane at residential water wells, real-time monitoring of air emissions, and on-site characterization of flowback/ produced water. This report summarizes the technical approach and key results from each of the three principal research components of the project.

1.1 Baseline Sampling for Dissolved Methane

The media and general public have expressed significant concerns regarding the potential impact of shale oil and gas development on surrounding drinking water resources. Determining whether changes in groundwater chemistry (methane, salts, etc.) are natural in origin or caused by drilling operations can be difficult, particularly when inconsistent sampling and analytical methodologies are employed, and water quality can vary naturally over time due to various factors (e.g., intensity of residential water use, well construction, aquifer geochemistry, precipitation events, temperature, weather patterns, and road salting). Greater understanding of the effect of sample methodologies and temporal variability on dissolved gas concentrations, isotopic signature, and other water quality parameters in residential water wells can facilitate design of pre-drill and post-drill sampling programs to better differentiate natural changes in water quality from anthropogenic impacts (e.g., stray gas events).

The overall goal of the Baseline Sampling component of the project is to characterize the inherent variability in pre-drill and post-drill analytical results and develop recommendations for improved sample collection methods and data interpretation for pre-drill and post-drill sampling programs.

1.2 Advanced Analytical Air Monitoring

The *President's 2014 Climate Action Plan, Strategy to Reduce Methane Emissions* called for "better data collection and measurement" to improve understanding of methane and other greenhouse gas (GHG) sources and trends, and enable more effective management of opportunities to reduce emissions. It advocates for the use of new measurement technologies to reduce the uncertainty associated with GHG emissions inventories.

The overall goal of the Advanced Analytical Air Monitoring component of the project is to develop a protocol that supports real-time, accurate quantification of emissions concentrations from oil and gas operations using OP-FTIR instrumentation, integrated meteorological sensors and optical imaging cameras. Data acquired during this project will increase the understanding of emission characterization and provide practical scientific guidelines for consistent and defensible measurement of air emissions.

1.3 Flowback/Produced Water Characterization

Hydraulic fracturing requires significant quantities of injected water to stimulate gas production. Injection water returning to the surface after subsurface fracturing, known as "flowback," and water produced from the formation itself (i.e., "produced water") contain inorganic and organic constituents that complicate treatment, recycle and disposal activities. Therefore, rapid field evaluation of the chemical characteristics of wastewater associated with hydraulic fracturing is critical to developing effective treatment and cost-effective disposal options. Accurate and timely analysis of field fluids at any point in the treatment train is a necessary step if oil and gas operators are to meet new environmental reporting requirements for fracturing fluids and effectively manage and treat flowback and produced water.

The overall goal of the Flowback/Produced Water Characterization component of the project was to test and evaluate on-site analytical technologies to characterize flowback and produced water from oil and gas operations and support cost-effective reuse, treatment, or disposal of produced waters. Based on the results of field trials, technology summaries (or "fact sheets") were developed to support the testing and deployment of new "field ready" products facilitating rapid produced water characterization.

1.4 Report Organization

This report consists of six sections as described below.

Sections 2.0, 3.0, and 4.0 summarize the technical approach and key results for the Baseline Sampling, Air Emissions, and Flowback/ Produced Water Characterization components of the project, respectively. One-page project summaries precede each section to provide a brief "snapshot" of objectives, technical approach, results, recommendations and implications of the research.

Section 5.0 outlines technology transfer activities that were completed during the project.

Section 6.0 summarizes major conclusions and recommendations from the three components of the project.

BASELINE SAMPLING FOR DISSOLVED METHANE IN AREAS OF SHALE OIL AND GAS DEVELOPMENT

Wellhead water level and headspace measurements

Objectives: This study developed practical recommendations for the collection and interpretation of pre-drill and post-drill dissolved methane data used to screen residential water wells for stray gas impacts. Specifically, this study sought to characterize two key sources of variability of naturally occurring dissolved methane concentrations at 11 residential water wells in northeastern Pennsylvania: i) sampling methodology, including sample collection method, sampling point, and purge volumes; and ii) temporal changes in concentration over multiple sampling events.

Technical Approach: To evaluate the effect of sample collection methods on dissolved methane concentrations, samples were collected: 1) using three common sampling methods [i.e., the Direct-fill method (open system), the Inverted bottle method (semi-closed system), and the IsoFlask™ (closed system)]; 2) from two different sampling points located before and after the pressure tank; and 3) after the removal of 4 different purge volumes ranging from one-half gallon to 3-casing volumes at each residential water well. In addition, to evaluate temporal variability of dissolved methane concentrations, stable isotopic composition of dissolved methane, and water quality in the study area, samples were collected over a two-year timeframe.

Results: Our findings suggest that sampling methodology can play an important role in the variability of methane concentrations, where a closed-system sampling method yields the most accurate methane concentrations in effervescing conditions. Regardless of the volume of water purged prior to sampling or the timing of sampling events, changes in methane concentration greater than two-fold were rarely observed. Nevertheless, at a subset of wells, the natural variability of methane concentrations during purging or over time was found to correlate closely with changes in sodium and specific conductance of the water. This suggests that mixing dynamics within these wells (i.e., varying mixtures of relatively saline vs. fresh water sourced from different fractures or layers intersected by the well) are an important factor contributing to the natural variability of dissolved methane concentration during multiple sampling events.

Recommendations: Findings from this study contribute to the design and implementation of pre-drill and post-drill groundwater monitoring programs and subsequent data interpretation by i) providing practical recommendations for sampling of dissolved methane in residential water wells and ii) highlighting simple relationships for improved data interpretation.

- *Sampling Method:* For effervescing samples, a closed-system method performs best. For non-effervescing conditions, all three methods were found to produce similar results. The Inverted Bottle method provided no advantage over the Direct-Fill method.
- *Purge Volume:* Purging the volume of water sufficient to remove standing water from pressure tank and lines is beneficial, but there appears to be no benefit to purging larger volumes of water. Rather, consistent purging procedures should be followed from one event to the next.
- *Temporal Variability:* For wells with dissolved methane concentrations greater than 1 mg/L in the study area, changes in concentration greater than two-fold were not commonly observed.
- *Evaluating Change in Concentration:* At a subset of wells, changes in methane concentrations closely tracked with changes in sodium and other salinity indicators, reflecting the dynamic mixing of fresh and saline water sources in the wells. Significant changes in methane (i.e., 2x) accompanied by significant changes in sodium can be strong evidence for natural variation.

2.0 BASELINE SAMPLING FOR DISSOLVED METHANE IN AREAS OF SHALE OIL AND GAS DEVELOPMENT

2.1 Problem Statement & Objectives

Significant concerns have been expressed regarding the potential impact of shale oil and gas development on surrounding drinking water resources. In particular, the migration of methane from shale gas operations into residential water wells has garnered widespread attention from the media and public. Methane occurs naturally in elevated concentrations in several parts of the country (e.g., Breen et al., 2007, Kresse et al., 2012; Sloto, 2013, Senior, 2014; Nicot et al., 2015; Siegel et al., 2015b, 2016). In these areas, determining whether a change in dissolved methane concentration in groundwater is natural in origin or caused by nearby drilling and extraction operations can be difficult since natural methane concentrations can vary due to multiple factors (e.g., volume of water purged prior to sample collection, natural temporal variability, use of different sampling methodologies). While stable isotopic analysis of methane can help discriminate sources of methane in the shallow subsurface (e.g., Fuex, 1977; Schoell, 1990; Baldassare and Laughrey, 1997; Coleman, 1994; and Clayton, 1991), it may not always clearly differentiate between naturally-occurring methane and stray gas. For example, methane from gas-charged units that are either intersected or targeted for production by shale gas wells can naturally migrate into shallow groundwater through existing fault and fracture networks in some areas (e.g., Baldassare et al., 2014). As a further complication, recommended practices for pre-drill and post-drill sampling of residential water wells vary considerably between states and organizations, imparting additional potential variability on dissolved methane and water quality analytical results. An improved understanding of the effect of sample methodologies and temporal variability on dissolved methane concentrations, the stable isotopic composition of methane, and other water quality parameters in residential water wells is needed to design pre-drill and post-drill sampling programs to better differentiate sources of natural variability in residential water wells from induced variations (e.g., stray gas events).

The overall goal of this study is to form a better understanding of the inherent variability in baseline dissolved methane analytical results and develop recommended practices for improved sample collection methods and data interpretation for pre-drill and post-drill sampling programs used to screen residential water wells for stray gas impacts. Two sources of variability related to dissolved methane in groundwater were investigated in the study – sampling variability and temporal variability – to address the following key questions associated with pre-drill and post-drill sampling at residential water wells:

1. **Sampling Methodology:** How should a residential water well be sampled to obtain accurate and representative dissolved methane concentrations?
    a) What sampling method for dissolved methane provides the most accurate results?
    b) Does water lose dissolved methane as it moves through the pressure tank?
    c) How much water should be purged from the well prior to sample collection?
2. **Temporal Variability:** What magnitude of variability in dissolved methane concentrations can be expected over time at residential water wells due to natural effects?
3. **Key Relationships with Methane:** What water quality parameters are important for understanding the occurrence of natural methane and distinguishing natural variability from anthropogenic changes?

2.2 Current Regulations

Currently, thirteen state agencies in the U.S. have final regulations for baseline sampling of local water sources in areas of shale oil and gas development (AK, CA, CO, ID, IL, MI, NV, NC, OH, PA, TN, WV, and WY). Existing baseline sampling regulations and guidance share common elements (listed below); however, within each element, specific requirements can vary considerably among state agencies. A complete list of state regulations and guidance and their specific requirements is available in **Appendix A (Tables A1-A3)**.

- **Sample Location:** Most pre-drill sampling guidelines specify a radial distance within which sampling of various water sources is mandated or recommended; however, this distance varies considerably from 1,320 ft [IL, MI] to 5,280 ft [NV] away from active and proposed shale gas operations (see **Appendix A; Table A2**).
- **Sampling Timeframe and Frequency:** The time frame for pre-drill sampling ranges from 7 days [MI] to up to 1 year [CO, NV, WY] prior to shale gas activities; post-drill sampling recommendations range from 60 days [CA] to 72 months [CO, NV] after well development (see **Appendix A; Table A2**).
- **Sampling Methodology:** Five state agencies (CO, MI, OH, PA and WY) offer guidance, including best management practices, sampling and analysis procedures, and water well sampling fact sheets to support their pre-drill and post-drill sampling regulations. Other state agencies (CA, NC, and TN) reference existing federal and state agency guidance documents for sampling of groundwater and surface water sources (see **Appendix A; Table A2**).
- **Analytical Suite:** The number of field-measured parameters and analytes required for pre-drill and post-drill sampling programs ranges from 4 [MI] to 46 [AK]. Constituents most frequently required for analysis are total dissolved solids (TDS) (12 states); pH and chloride (11 states); and dissolved methane, barium, iron, sulfate, and benzene, toluene, ethylbenzene, and xylenes (BTEX) (10 states) (see **Appendix A, Table A3**).
- **Action Levels:** Eight state agencies (AK, CO, IL, MI, NV, NC, PA, and WY) have action levels (i.e., threshold concentrations, change in concentrations relative to pre-drill conditions) for specific analytes that trigger additional sampling, analysis, and/or state agency notification. For example, gas compositional analysis and stable isotope analysis of methane (^{12}C, ^{13}C, ^{1}H, ^{2}H) are required if dissolved methane concentrations exceed the following limits: 1 mg/L (AK, CO, MI, and NC), 5 mg/L (WY) or 10 mg/L (NV).
- **Reporting:** For most states, the operator provides copies of the final laboratory analytical results to the respective state agency and water source owner (or landowner) within a specified timeframe after sampling or upon receipt of the analytical results. Some state regulations allow for disclosure of analytical results to the public either by i) posting results and/or locations to a state agency website (e.g., CO, WY) or ii) upon request by a member of the public (e.g., AK, NV, MI, and WV).

In Pennsylvania and other states (e.g., IL, NC, and WV), pre-drill sampling is not required *per se*; however, the burden of proof remains with the operator should cases of alleged groundwater impacts be brought forward by surrounding well owners (see **Appendix A, Table A1**). **Table 2-1** provides a summary of the sampling requirements established by the Pennsylvania Department of Environmental Protection (PADEP).

Table 2-1. *Baseline Sampling Regulations in Pennsylvania*

Criterion	Pennsylvania Regulations
Pre-drill Sampling	Not required, but if drinking water becomes contaminated, operator must follow gas migration response rules. If no baseline sampling data exists to prove operator did not contaminate the well, then operator is responsible for providing temporary water supply and investigating the incident.
Sample Location	All water sources within 2,500 ft of proposed shale gas well pad
Post-drill Sampling	Post-drill sampling is conducted if a formal complaint is filed by a landowner within 12 months following completion of the shale gas well.
Analytical Suite	Alkalinity, hardness, pH, Specific Conductivity, TDS, TSS, Turbidity, Total petroleum hydrocarbons, Calcium, Iron, Magnesium, Manganese, Potassium, Sodium, Bromide, Chloride, Sulfate, Aluminum, Arsenic, Barium, Lithium, Strontium, Selenium, Zinc, Methane, Ethane, Propane, Total Coliform If dissolved methane concentrations are greater than 7 mg/L, stable carbon and hydrogen isotope analysis is performed.
Analytical Methods	Samples must be collected by third party professionals and analyzed by independent certified laboratories
Data Reporting	An operator must report all sampling results to PADEP and the landowner within 10 business days.

In addition, numerous oil and gas and environmental stakeholder organizations have developed, or referenced, guidance for conducting baseline sampling of water sources in areas of shale oil and gas development. These include international and national organizations (e.g., American Petroleum Institute, Canadian Association of Petroleum Producers, Interstate Oil and Gas Conservation Commission, Groundwater Protection Council, National Groundwater Association) and regional organizations (e.g., Center for Sustainable Shale Development, Marcellus Shale Coalition). Several countries where shale oil and gas development is currently underway or being considered (e.g., Canada, Columbia, Mexico, and New Zealand) have also issued oil and gas regulations that specify pre-drill sampling requirements or guidance. A list of organizations and international agencies with pre-drill sampling requirements is available in **Appendix A (Table A4)**.

2.3 Technical Approach

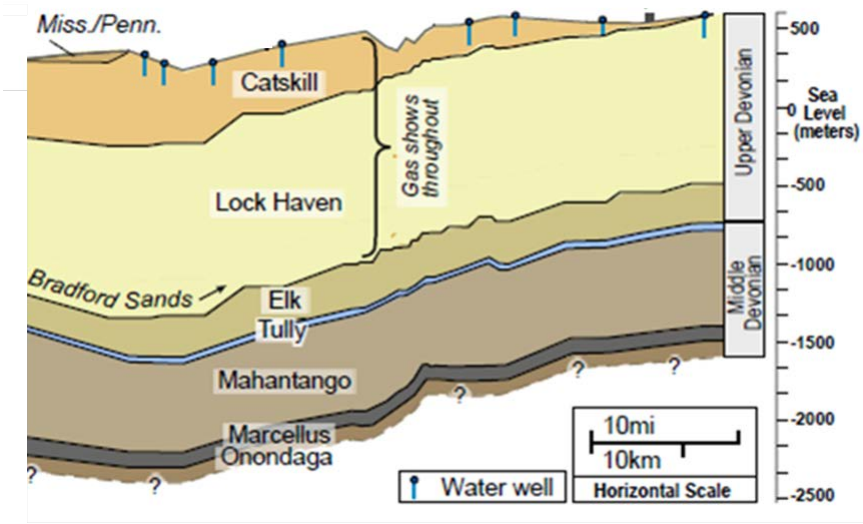
2.3.1 *Site Background*

Figure 2-1. *Project Location Map*

Field studies were conducted at a series of residential water wells located in Susquehanna and Bradford counties, Pennsylvania (**see Figure 2-1**). This region has been the subject of focused research on the potential impacts of shale gas operations on drinking water resources (Osborn et al., 2011; Molofsky et al., 2011, 2013, 2016a; Jackson et al., 2013; Warner et al., 2012, 2014, Siegel et al., 2015a) and offers a unique opportunity to improve our understanding of the variability of naturally occurring dissolved methane concentrations and associated water quality and isotopic parameters in the region.

The great majority of residential water wells in this area penetrate the fractured Catskill and Lock Haven formations, a series of interbedded sandstone, siltstone and shale deposits formed during the Upper Devonian period (359 to 385 million years ago) (Lohman, 1937, 1939; Taylor, 1984) (see **Figure 2-2**). The movement of groundwater in these formations is dominated by fracture flow

through vertical north-south oriented fractures, and to a lesser extent, subvertical east-west oriented joints and subhorizontal joints (Hollowell and Koester, 1975; Geyer and Wilhusen, 1982; Geiser and Engelder, 1983; Taylor, 1984). Most of the bedrock water wells are unsealed open-hole completions, with casing terminating in the shallow bedrock to draw water from multiple horizons at typical depths of 100 to 500 feet below ground surface (Taylor, 1984; PGWIS, 2014) **Figure 2-3** depicts the standard construction of a residential water well in Pennsylvania, along with typical components (e.g., pressure tank and wellhead) of the well system.



Adapted from Molofsky et al. (2013)

Figure 2-2. *Generalized cross section of Upper and Middle Devonian formations in Susquehanna County*

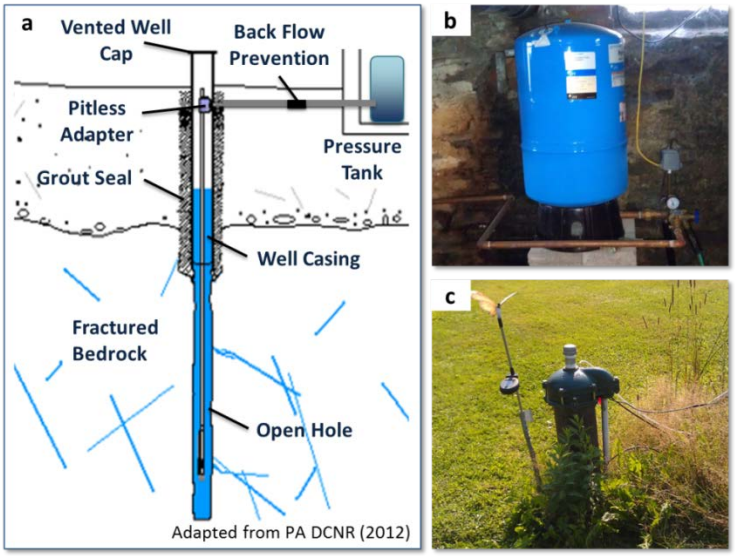


Figure 2-3. *Residential Water Well Construction (a), with site photos a typical pressure tank (b) and well head (c).*

The Catskill and Lock Haven Formations have historically been explored locally for reservoirs of early thermogenic natural gas. The Bradford Sands, a series of thick sandstone deposits, form

the base of the Lock Haven Formation, and are underlain by the Brallier Formation (locally known as the Elk Formation) and the Trimmers Rock Formation, which are comprised of interbedded sandstone, siltstone, and shale stratum of Upper Devonian age. The Tully limestone is the youngest unit of the Middle Devonian age strata, which include the Mahantango Formation, consisting of laminated siltstone, sandstone and shales, and the organic-rich Marcellus shale, estimated to contain as much as 127 trillion cubic feet of thermogenic gas (Engelder 2009; EIA 2012).

2.3.2 *Residential Water Wells*

A total of 11 residential water wells were sampled in the sampling and temporal variability components of this study. In addition, a 12th well was sampled by one of our teaming partners, Cabot Oil and Gas Corporation, as part of a contributing study on temporal variability of naturally occurring methane at residential wells in Susquehanna County (see **Section 2.3.7**). Select photos of the study wells and field program activities are provided in **Appendix B**.

Wells were selected based on well construction and aquifer characteristics (e.g., well depth, well yield, pump rate, pressure tank volume), historical dissolved gas concentrations, and site accessibility. All but one of the wells were located in Susquehanna county, with one well located in Bradford county. Each were greater than 2,500 ft from the nearest existing or proposed gas well location (the current pre-drill sampling radius as defined by PADEP [see **Table 2-1**]). Nine of the wells were included in the sampling variability study and 11 wells were included in the temporal variability study. Well depths ranged from 61 to 438 ft below top of casing (BTOC) and well casing volumes ranged from 75 to 1,879 gallons. Characteristics of the residential water wells sampled in this study (e.g., well construction, historical dissolved methane concentrations, location of monitoring and weather station equipment) are provided in **Table 2-2**.

Table 2-2. *Residential Water Well Characteristics*

Well ID	County	Study	Historical Methane Conc. (Direct-Fill VOA) (mg/L) [1]	Well Depth Well Depth (ft BTOC)	Pressure Tank Volume (gal)	Casing Volume Casing Volume (gal)	Monitoring Equipment	
							F	T
Cas	Susquehanna	Cabot Study	4.3-19	197	N/A	255	No	Yes
Iri	Susquehanna	Temporal Variability	<0.005-0.6	25	N/T	1,879	No	Yes
Jon	Susquehanna	Both	18-29	61	20	75	Yes	Yes
Loc	Susquehanna	Both	6.6-13	438	32	506	Yes	Yes
Marc	Susquehanna	Both	5.3	159	N/A	209	Yes	Yes
Rath	Bradford	Both	28.6-35.9	197	20	254	Yes	Yes
Sbar	Susquehanna	Both	9	195	42	212	Yes	Yes
Sdel	Susquehanna	Both	12	150	19	195	Yes	Yes
Sieb	Susquehanna	Both	45	227	20	295	Yes	Yes
Sim	Susquehanna	Both	3.4	117	20	136	Yes	Yes
Wal	Susquehanna	Both	1.2-2	300	N/A	388	No	No
Web	Susquehanna	Both	8.4-13	122	85	172	Yes	Yes

F = Flowmeter; T = Water Level Transducer; N/A = Information not available; N/T = No tank.

[1] Historic dissolved methane concentrations (based on analysis of 40 ml VOA vials filled via the direct fill method) may underestimate the range of dissolved methane concentrations observed in these wells using IsoFlask™ sample containers (see **Section 2.4.1**).

Well owner interviews were conducted prior to sample collection to gain information about water usage, current and historical water quality, and maintenance activities, along with on-site inspections to note well system configurations and system components. Well owner interview and site inspection forms are provided in **Appendix C**. Where permission was granted, the following monitoring equipment was installed at the residential water wells to continuously measure water level and cumulative water usage:

- **In-Situ Troll 700:** continuously measures water level within the well.
- **Great Plains Industries TM100-N-P 1" water meter:** continuously measures flow rate and cumulative volume of water purged from the well.
- **Campbell Scientific CR 200 and CR1000 Dataloggers:** records and stores data.

2.3.3 *Sampling Variability Study*

The objective of the sampling variability study was to evaluate the effect of current sampling procedures and collection methods on the variability of dissolved methane concentrations and associated water quality and isotopic parameters from nine residential water wells in Susquehanna and Bradford Counties, Pennsylvania (see **Table 2-2**). This program consisted of three sampling events conducted at 9 wells over a two week period (February – March, 2014), and four sampling events conducted at 8 wells over a 7 month period (April - December, 2015) (note: one well owner declined to participate in the last four sampling events). Key variables addressed in this study included sample collection methodology and container type, sample location before versus after the pressure tank, and the volume of water purged prior to sampling, as described below.

Effect of Sampling Collection Method on Dissolved Methane Concentration

The objective of this component of the study was to i) assess whether a particular sample container/collection method yields more accurate dissolved methane concentrations than other methods commonly utilized, and ii) evaluate the reproducibility of dissolved methane concentrations reported for samples collected using different sample containers/collection methods. Samples were collected during four sampling events in February 2014 and September/October 2015. All samples were collected from a faucet at the base of a pressure tank prior to any water treatment devices (e.g., filters and water softeners). This is consistent with the access point most commonly sampled for baseline sampling programs in the Appalachian Basin and other basins across the U.S.

Prior to sample collection, the flowrate was reduced from 3 gallons per minute (gpm) to approximately 0.5 gpm to minimize turbulent flow. At a minimum, the samples were collected after initial stabilization of field parameters (i.e., specific conductivity, pH, temperature). However, in some cases additional purging was conducted prior to sample collection as part of a larger and more comprehensive study on short-term variability. During all sampling events, matched water samples were collected using the Direct-Fill VOA and IsoFlask™ collection methods. This resulted in 70 pairs of matched samples collected using both sampling methods. In addition, for 43 of the 70 pairs, an additional sample was collected using the Inverted VOA method. Two variations of the Inverted VOA method were used: i) low-flush Inverted VOA (16 samples), and ii) high-flush Inverted VOA (27 samples). Matched samples were collected consecutively immediately after one another. Brief descriptions of the sampling methods are provided below, and the sampling methods are illustrated in **Figure 2-4.**

a) **Direct-fill Method (Open System Method):** two upright 40 ml VOA vials with Teflon lined silicone septum were filled directly from the faucet (or via ¼" tubing connected to the faucet)

after the pressure tank. Fifty-four of the samples were preserved using hydrochloric acid, and 16 samples were unpreserved. The use of preservative had no measurable effect on methane concentration (Molofsky et al., 2016b).

b) **Inverted Bottle Method (Semi-Closed System Method):** two 40 ml VOA vials were inverted and submerged in a 5 gallon bucket filled with well water, and subsequently filled through ¼" tubing attached to the faucet. The Inverted VOA method can be considered a semi-closed system because, although the sample is not directly exposed to the atmosphere, the liquid in the bucket is still in contact with the atmosphere during sample collection. Two variants of the Inverted VOA method were tested in this study: low-flush and high-flush, as described below.

- **Low-flush:** Water was flushed through the inverted VOA vial at a rate of 0.5 liters per minute (lpm) for 10 seconds (equal to approximately 2 VOA vial volumes) prior to capping the submerged vial near the base of the filled bucket. The Marcellus Shale Coalition has recommended this low-flush approach to minimize entrapment of bubbles within the VOA vial (MSC, 2012).
- **High-flush:** Water was flushed through the inverted VOA vial at a rate of 0.5 gpm for 1 minute (equal to approximately 40 VOA volumes) prior to capping the submerged vial near the base of the filled bucket. The high-flush variation was included to evaluate the effect of flush volume on results.

c) **IsoFlask™ (Closed System):** For each sample, a single 750 ml IsoFlask™ container was filled directly through a sampling line connected to the pressure tank faucet. The IsoFlask™ is a flexible, evacuated plastic container pre-loaded with a benzalkonium chloride bactericide capsule and constructed with a Luer® valve that enables direct connection to a sampling manifold or sample location. In combination, the IsoFlask™ and sampling line serve as a closed system, designed to collect bulk samples of water and any exsolving gases (Isotech 2014).

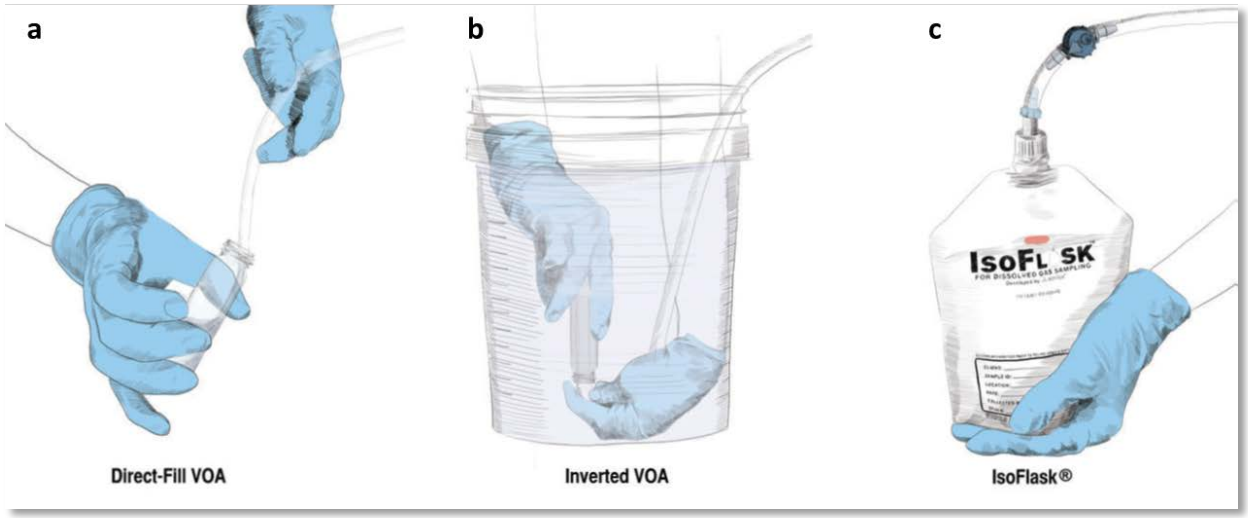


Figure 2-4. *Sample collection using a) the Direct-Fill Method, b) the Inverted Bottle Method, and c) the IsoFlask™ (Molofsky et al., 2016b)*

In addition to the collection of matched samples using different sample collection methods, the field sampling program included the collection of 27 field duplicates for each sample collection method. Field duplicate samples were collected consecutively immediately after one another.

Effect of Sample Location on Dissolved Methane Concentration

The objective of this component of the study was to evaluate the variability of dissolved gas concentrations in samples collected prior to the pressure tank versus after the pressure tank. The faucet at the outlet of the pressure tank is the most common location for sample collection since it is generally the closest sampling point to the well head. For this component of the study, access points were installed before the pressure tank at 7 wells; an eighth well had an access point located prior to the pressure tank before the study commenced. Pre- and post-pressure tank samples were collected from these wells during 4 sampling events (April – December 2015) in IsoFlask™ containers after purging 3-casing volumes (i.e., while the pump was actively pumping water). This amounted to 32 paired pre- and post-pressure tank samples. During each event, the post-pressure tank sample was collected immediately before the pre-pressure tank sample.

Effect of Purge Volume on Measured Methane Concentration

Purging a designated volume of water from a monitoring well to sample the influx of "fresh" groundwater has been the conventional sampling method since the late 1970's; however, baseline groundwater sampling for oil and gas operations is typically conducted at residential water wells as they represent potential receptors. Unlike monitoring wells, residential water wells i) commonly have long screened intervals or open bore-holes designed to maximize the capture of water from one or more aquifers and increase in-well storage capacity; ii) are regularly utilized for water supply (and therefore, groundwater influx occurs on a regular basis), and iii) are equipped with a constant high-rate water well pump (rather than an adjustable rate temporary pump). Consequently, different purge strategies may be more appropriate at residential water wells than those utilized for sampling monitoring wells.

The recommended volume of water to be purged from a monitoring well prior to sampling has been a topic of much debate (e.g., Barcelona et al., 2005). For volatile organic compounds (VOCs) in particular, purging "stagnant" water from a well was thought to prevent the collection of samples that had lost a portion of the contaminant to volatilization, resulting in low-biased concentrations (Powell and Puls 1993; Adamson et al., 2012). Barcelona et al. (1985) proposed that purging one or more well volumes removes "stagnant" water from the monitoring well, producing a flow weighted average sample, and thus providing the most representative sample of groundwater feeding the well. However, purging multiple well volumes of water can be time-consuming and produces a large volume of water requiring disposal or treatment. As an alternative, purging at a low flow rate (i.e., ≤0.5 gpm) until field parameter "stabilization" was proposed (Puls and Powell, 1992; Puls and Barcelona, 1996). In this technique, monitoring wells are purged at a low flow rate to minimize disturbance of the overlying "static" water column until three successive stable readings of field parameters (e.g., stable readings of pH, temperature, and specific. conductivity) are recorded, where this initial stabilization of field parameters is thought by many to indicate the attainment representative and stable aquifer conditions thereafter (and therefore, stable concentrations of parameters of interest). Although purging to initial parameter stabilization was proposed for monitoring wells, it has also been widely used to sample residential water wells during pre-drill and post-drill sampling in the Appalachian Basin (e.g., MSC, 2012) and other basins across the U.S.. At residential water wells, purging is rarely conducted at a low flow rate of ≤0.5 gpm, as most of these wells are equipped with a constant high-rate water pump.

The objective of this component of the study was to i) evaluate the effect of purge volume on dissolved methane concentration and associated isotopic and water quality parameters; and ii) identify which purge volume(s) (if any) minimize variability between sampling results collected over multiple sampling events. This study consisted of three purge events conducted at 9 wells over a two-week period (February – March, 2014), and four purge events conducted at 8 wells

over a 7-month period (April - December, 2015) (note: one well owner declined to participate in the last four events).

During the first three purge events, IsoFlask™ samples were collected from a faucet at the base of the residential pressure tank after two successive purge volumes were removed:

- Purge to initial parameter stability (i.e., three successive readings of pH: ± 0.2; Temperature: ± 0.2°C; Conductivity: ±5%) *(Low-volume purge)*
- 3 casing volumes *(High-volume purge)*

During the last four purge events, IsoFlask™ samples were collected from the same location after four successive purge volumes were removed:

- One-half gallon purge *(Minimal purge)*
- 2 pressure tank volumes *(Low-volume purge)*
- 1 casing volume *(Medium-volume purge)*
- 3 casing volumes *(High-volume purge)*

During the vast majority of sampling events, initial field parameter stabilization was achieved after purging between within 1 – 3 pressure tank volumes (i.e., <100 gallons). As a result, samples collected after purging to initial field parameter stabilization (during the first three purge events) and purging 2 pressure tank volumes (during the last four purge events) are collectively referred to as “low-volume” purge samples. The purge steps spanned the range of purge volumes recommended by current pre-drill sampling guidelines.

All samples collected after successive purge volumes were analyzed for dissolved methane concentrations (using IsoFlask™ containers). Samples were also collected after the low-volume purge and high-volume purge for stable carbon and hydrogen isotopic analysis of methane, stable isotopic analysis of dissolved inorganic carbon and water, and a suite of general water quality analytes (e.g., dissolved and total metals, alkalinity, total dissolved solids). A complete list of the analytical suite is provided in **Appendix D**.

Throughout the entire purging process, field parameters (i.e., temperature, pH, and specific conductivity) were monitored in the purge water and recorded electronically using a flow-through multiparameter meter (e.g., YSI flow-through cell). In addition, the water level and quantity of water used during and between successive purge events was monitored.

2.3.4 *Temporal Variability Study*

The objective of the temporal variability study was to assess variability in dissolved methane concentration and associated isotopic and water quality parameters over short (i.e., days to weeks) and long (i.e., up to two years) time periods at eleven residential water wells (see **Table 2-2**). As noted previously, pre-drill and post-drill samples in the Appalachian Basin are typically collected at the base of the pressure tank after purging to initial field parameter stabilization, which was regularly attained between 1 and 3 pressure tank volumes in this study (i.e., a low-volume purge). Consequently, to provide the most useful information for practitioners on the temporal variability of naturally occurring dissolved methane concentrations in the study area, only samples collected after a low-volume purge (as opposed to a high-volume purge) were evaluated for this study component. All samples were collected using an IsoFlask™ container at a location post-pressure tank and before any water treatment. One well, the Iri well (the only shallow hand-dug well in the study), exhibited concentrations that were typically less than 5 ppb. Although this well showed higher variability (i.e., a 4.5-fold change in methane concentration over time), it was not

included in the quantitative analysis of temporal variability because the magnitude of concentration change was not of concern in this low concentration range, nor necessarily representative of the range typically seen at wells with higher methane concentrations or more common construction. The resulting dataset was comprised of 80 sampling events at 10 residential water wells that all exhibited methane concentrations greater than 1 mg/L. Sampling events were conducted from December 2013 to December 2015, although not all wells were sampled consistently or the same number of times during this period. Spacing between sampling events at each well ranged from 2 days to 440 days.

2.3.5 *Laboratory Analyses & Quality Assurance*

Analysis of dissolved methane and ethane concentrations in IsoFlask™ containers, as well as stable isotopic analysis of methane, ethane (if detected), dissolved inorganic carbon (DIC) and water was completed at Isotech Laboratories (Isotech). Analysis of dissolved methane and ethane in Direct-Fill VOA and Inverted VOA samples, as well as all water quality analysis, was conducted at Eurofins Lancaster Laboratories, Inc. (Lancaster). A detailed discussion of the analytical techniques used for dissolved methane and ethane analysis at each laboratory is provided in Molofsky et al. (2016b).

Field duplicate samples were collected at a frequency of at least 1 every 10 samples, though more frequent duplicate samples were collected to address specific research questions in parts of the study. Calibration of all field meters and analytical equipment was performed at the beginning of each work day and immediately following any significant change in conditions that could impact instrument response.

2.3.6 *Data Analysis/Statistical Approach*

The data collected in the sampling and temporal variability studies were stored in a relational database that included details of sample location, analytical results, analytical methods and associated metadata sufficient to statistically evaluate the data. Exploratory data analysis (EDA) was applied to all datasets to provide insight into the fundamental data structures (e.g., detection frequency, data normality, presence of outliers) and inform choice of appropriate data models. For samples for which the lab reported no detectable concentrations, one-half the detection limit was utilized for purpose of the statistical calculations. Based on the results of the EDA, the following statistical analyses were used to evaluate results from the temporal and sampling variability studies:

Percent Variability

The variability between paired samples was compared through the analysis of the percent variability, where:

$$Percent\ Variability = \frac{(Max - Min)}{Min} * 100\%$$

Where appropriate, a *directional* percent variability was calculated to indicate the direction of concentration change from one sample to another, where the sign of the percent variability (positive or negative) signified an increase or decrease in concentration from a reference sample.

Coefficient of Variation

The variability in the value of a particular parameter between samples, or wells, was commonly characterized using the coefficient of variation (CV):

$$CV = \frac{Std.Deviation}{Mean}$$

where:

Std. Deviation = the standard deviation for analytical results from a single well

Mean = the arithmetic mean for analytical results from a single well

Tests for Significant Differences

- **Central Tendencies:** Median values were used to represent central tendencies of datasets because medians are less sensitive to outliers than means.
- **F-test of Overall Significance:** The F-Test of Overall Significance was used to determine whether the slope of a line (i.e., relationship between two parameters) calculated using a linear regression was different than zero.
- **Comparison of Two Sample Sets:** The statistical significance of differences between two datasets was evaluated either using the Wilcoxon-Mann-Whitney test, (i.e., the non-parametric equivalent of the independent samples t-test), or the Wilcoxon signed rank sum test (i.e., the non-parametric version of a paired samples t-test).

2.3.7 *Supplemental Studies*

Several supplemental studies were conducted to support the field program in northeastern Pennsylvania, as described below.

Supplemental Temporal Variability (conducted by Cabot Oil & Gas Corp.): For the 11 wells in this study, additional sampling events were conducted over a two-year period by our teaming industry partner, Cabot Oil and Gas Corporation, prior to the start of the RPSEA study. These samples were collected to evaluate natural temporal variability of dissolved methane concentrations and other water quality parameters after purging to initial parameter stability over a short-term and long-term timeframe, amounting to 6 to 28 sampling events at each well (181 total sampling events). During these events, dissolved gas samples were exclusively collected in 40 ml VOA vials using the Direct-Fill method, rather than in IsoFlask™ containers, and samples were collected for isotopic analysis (in 1L bottles), and general water quality analysis. In addition, at five of the wells, real-time measurements of parameters including, but not limited to water temperature, pH, specific conductivity, oxidation reduction potential (ORP), and barometric pressure, were recorded for an extended period of time from a weather station and down-hole sensors. These data are discussed in detail in **Appendix E**.

Laboratory Methods: During the sampling variability component of the study, duplicate samples were collected for dissolved methane analysis by the Pennsylvania Department of Environmental Protection (PADEP) Bureau of Laboratories (BOL) and the Ohio Department of Natural Resources (ODNR) Laboratory. The collection of these samples was intended to improve understanding of the effect of different sample collection method and analytical procedures on dissolved methane concentrations reported by these laboratories. Full results and discussion of these analyses are provided in **Appendix F**.

Noble Gas Sampling: Samples were collected from six residential water wells in this study for analysis of noble gases and dissolved methane and fixed gas concentrations by Dr. Tom Darrah at Ohio State University (OSU). Full results and discussion of these analyses are provided in **Appendix G**.

Baseline Sampling in the Berea and Rogersville Shale Plays: The University of Kentucky/ Kentucky Geological Survey (UK/KGS), in partnership with GSI, conducted a baseline sampling program at 51 residential water wells in six counties in Eastern Kentucky to i) establish spatial variability of dissolved gases and water quality, ii) confirm key relationships indicative of natural

methane occurrence (e.g., water type); and iii) evaluate the origin of methane (e.g., microbial vs. thermogenic). Further, the field program tested the recommended sampling practices developed by GSI to sample residential water wells in northeastern Pennsylvania. Findings from the UK/KGS baseline sampling program are presented in a separate report.

2.4 Results and Discussion

Findings from the sampling and temporal variability studies are summarized in the sections below. Research questions, relevant findings, and potential implications for the findings are highlighted in blue boxes, followed by a detailed summary of key results and recommendations. Complete analytical results and supporting data analyses for the sampling and temporal variability studies are provided in **Appendix H and I**, respectively.

2.4.1 *Effect of Sample Collection Method on Dissolved Methane Concentration*

Research Question 1

Of the three common sampling collection methods used for dissolved methane, which produces the most reliable results?

Key Findings

1. In the absence of effervescence, the difference in the dissolved methane concentrations measured by the Direct-Fill VOA (open system), Inverted VOA (semi-closed system), and IsoFlask™ (closed system) sampling methods was relatively small.
2. When methane concentrations equaled or exceeded the approximate concentration at which effervescence occurs in the study area (i.e., 20 mg/L), IsoFlask™ samples yielded significantly higher methane concentrations than Direct-Fill VOA samples, and Inverted VOA samples yielded lower concentrations than Direct-Fill VOA samples.
3. For all three methods, the duplicate variability was relatively small (i.e., typically less than 15%) (see **Appendix I**).

Recommendations

For effervescing conditions, the IsoFlask™ (closed-system) provides the most accurate means for measurement of dissolved methane in groundwater. For non-effervescing conditions, all three sampling methods produce similar results. Use of the Inverted VOA method (semi-closed system) provides no advantage over the Direct-Fill VOA method (open-system).

For methane concentrations below 20 mg/L (the approximate concentration at which effervescence occurred in the study area), the difference between matched samples from all three sampling methods was relatively small. Specifically, for samples with a Direct-Fill VOA methane concentration less than 20 mg/L, 78% (38/49) of the matched IsoFlask™ samples and 93% (28/30) of the matched Inverted VOA samples (high-flush and low-flush combined) yielded concentrations within 30% of the Direct-Fill VOA samples (see **Figure 2-5**). Although overall differences in measured concentrations between methods were small, IsoFlask™ results were consistently higher than either Direct-Fill VOA or Inverted VOA results (i.e., median concentration difference of +16%).

For samples with Direct-Fill VOA methane concentrations at or above 20 mg/L, there were significantly larger differences in methane concentrations between the three sampling methods. For these samples, 52% (11/21) of matched IsoFlask™ samples yielded a methane concentration more than 30% higher than the Direct-Fill VOA result, while none of the IsoFlask™ samples yielded a methane concentration lower than the Direct-Fill VOA result (see **Figure 2-5a**).

Conversely, the Inverted VOA method reported lower methane concentrations than the Direct-Fill VOA method when methane concentrations were at or above 20 mg/L. For the 13 matched Direct-Fill VOA and Inverted VOA samples, 92% (12/13) of the Inverted VOA samples (high-flush and low-flush combined) yielded a lower methane concentration than the Direct-Fill VOA result, with 38% (5/13) of the Inverted VOA samples yielding a methane concentration more than 30% lower than the Direct-Fill VOA result (see **Figure 2-5b**).

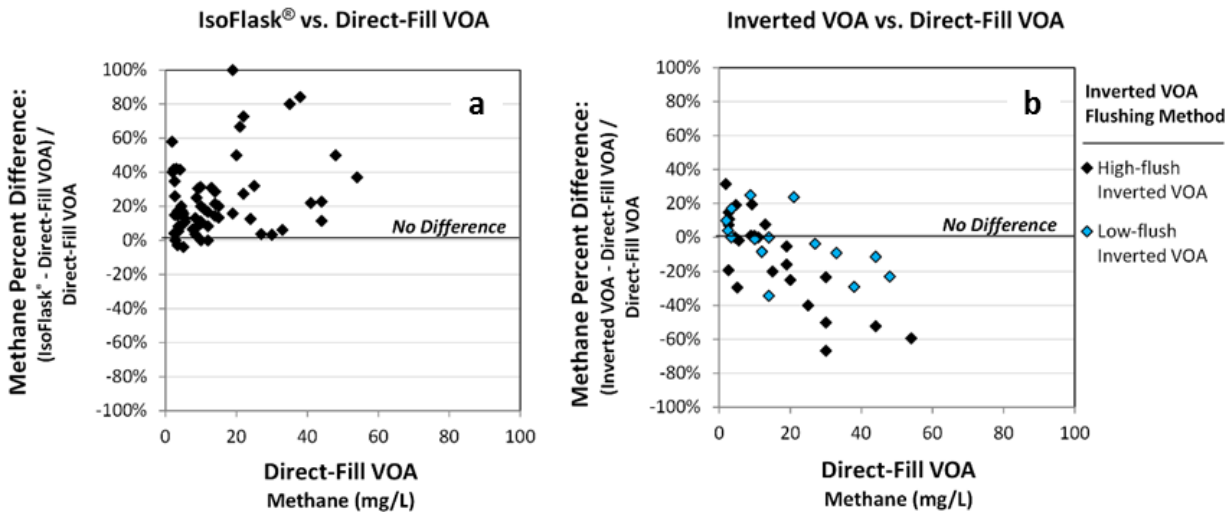


Figure 2-5. *Percent difference between methane concentrations reported for a) IsoFlask™ and matched Direct-Fill VOA samples, and b) Inverted VOA and matched Direct-Fill VOA samples*

2.4.2 *Effect of Sampling Location on Dissolved Methane Concentration*

Research Question 2

Does water lose dissolved methane as it moves through the pressure tank, resulting in a lower concentration?

Key Findings

For the population of study wells, no significant difference ($p > 0.05$) was observed between samples collected before and after the pressure tank.

Recommendations

When possible, sampling prior to the pressure tank is recommended because there may be pressure tank configurations that do result in a significant methane loss (e.g., air-over water pressure tank). However, there is no meaningful pattern in this dataset to suggest that sampling post-pressure tank results in a significant change in methane concentration. Sampling at a consistent location will minimize any potential variability among sampling events.

Of the 8 wells sampled, 7 were equipped with a bladder or diaphragm pressure tank, while 1 well (the Sbar well) was equipped with an air-over-water pressure tank. The difference in dissolved methane concentrations between IsoFlask™ samples collected pre- and post-pressure tank at these wells was evaluated by calculating the percent variability between pre- and post-pressure tank measurements after 3-casing volumes had been purged (i.e., at a time when water was actively flowing through the pressure tank). For this analysis, the *directional* percent variability was considered positive if the methane concentration increased from pre- to post-pressure tank

samples, and negative if it decreased. Of the 31 paired samples (from all 8 wells), 7 pairs (23%) exhibited a higher post-pressure tank than pre-pressure tank concentration, 8 pairs (26%) exhibited no difference, and 16 pairs (52%) exhibited a lower post-pressure tank than pre-pressure tank concentration (see **Figure 2-6**). Of note, the Sbar well (equipped with an air over water pressure tank) exhibited a lower post-pressure tank than pre-pressure tank concentration during all 4 sampling events (ranging from -13% to -44%). Among the population of wells as a whole, the difference between pre- and post-pressure tank methane concentrations was not found to be statistically significant (p=0.998, one-sided Wilcoxon signed rank sum test). In addition, for all 31 pairs, the median directional percent variability between pre- and post-pressure tank samples was relatively small (i.e., -3%, where post-pressure tank samples exhibited methane concentrations that were 3% lower than pre-pressure tank samples).

Combined, there is no meaningful pattern in this dataset to suggest that sampling at one location (i.e., pre- versus post-pressure tank) is necessarily more accurate than the other. However, the wells sampled in this study were predominantly equipped with bladder and diaphragm pressure tanks. We recommend sampling pre-pressure tank when possible because there may be less common pressure tank configurations that do result in a significant methane loss.

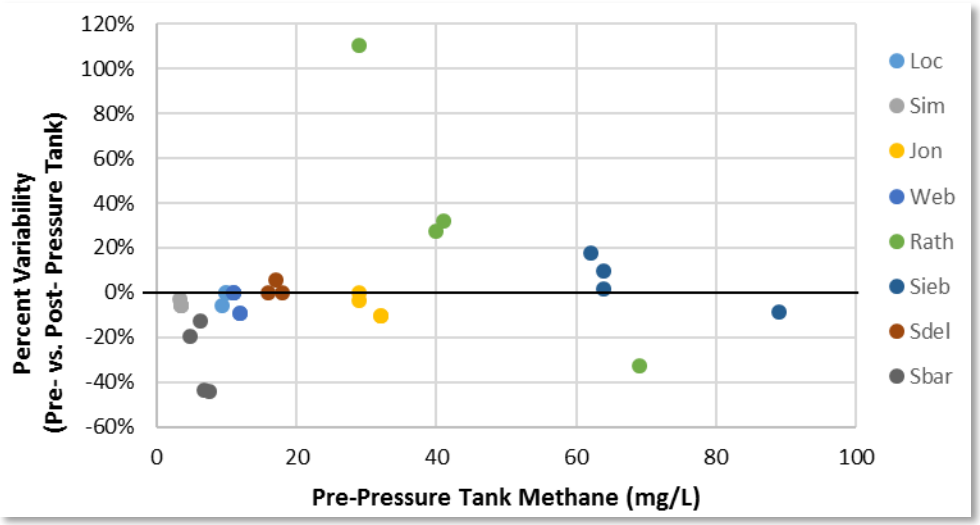


Figure 2-6. *Directional percent variability in methane concentration between samples collected before and after the pressure tank at 8 wells*

2.4.3 *Effect of Purge Volume on Dissolved Methane Concentration*

Research Question 3

How much water should be purged before collecting a sample for analysis of dissolved methane concentration?

Key Findings

1. Purging to initial parameter stabilization typically removed the volume of water in the lines and pressure tank, thus enabling the sampling of "fresh" well water representative of conditions at the pump inlet of a well. However, initial parameter stabilization does not necessarily represent the attainment of stable water quality conditions within the well thereafter. Rather, dynamic mixing of fluids throughout the purging process as one or more casing volumes are removed results in changes to the water composition, including dissolved methane concentration, within the well.
2. The population of wells did not display a consistent increase or decrease in methane concentration with increasing purge volume (i.e., from a low-volume purge to a high-volume purge). However, individual wells typically displayed consistency in both the magnitude and direction of concentration change with increasing purge volume (e.g., an increase of 25% versus a decrease of 25%).
3. Regardless of the trend in methane concentration observed at individual wells, the typical change in methane concentration with purge volume was relatively small. Specifically, for the 59 purge events (7 events at 8 wells and 3 events at 1 well), the median percent variability of methane from a low-volume purge to high-volume purge was 18%. Only 3 out of 59 purge events (5% of purge events) displayed a percent variability in methane concentration from a low-volume purge to high-volume purge larger than 100%.
4. No one purge volume was found to produce significantly more consistent methane concentrations throughout multiple sampling events over time. The variability of dissolved methane concentrations among samples collected after purging one or more casing volumes is not significantly different than the variability measured among samples collected after only purging low water volumes (see **Appendix I**).

Recommendations

Purging the volume of water sufficient to remove standing water from pressure tank and lines is recommended. However, there appears to be no necessary advantage to purging larger volumes of water from the well prior to collecting pre-drill and post-drill samples used to screen wells for potential impacts from oil and gas operations. Rather, it appears that at many wells, samples collected after a low-volume purge (i.e., with limited water level drawdown) are more representative of water quality experienced by the resident on a regular basis than samples collected after a high-volume purge (potentially resulting in larger water level drawdown and a change in water composition that is not sustained during regular use). To achieve relatively consistent results, we recommend that consistent purging procedures be followed from one sampling event to the next. If the pressure tank volume is known, purging of 2 pressure tank volumes is generally sufficient to flush the tank and tubing above the pump inlet before sampling; otherwise, purging of approximately 100 gallons before sampling should be adequate.

To evaluate the variability of dissolved methane concentration with purge volume, data were assessed from IsoFlask™ samples during 27 purge events post-pressure tank after purging i) minimal volume (~0.5 gallons), ii) low-volume (initial field parameter stabilization or 2 pressure

tank volumes), iii) medium-volume (1 casing volume), and iv) large volume (3 casing volumes). During the vast majority of sampling events, initial field parameter stabilization was achieved between 1 – 3 pressure tank volumes (i.e., less than 100 gallons).

Relationship Between Initial Parameter Stabilization and Dissolved Methane

To assess whether purging to initial field parameter stabilization offered an advantage over other purge volumes at residential water wells in this study, we evaluated whether: i) dissolved methane concentrations are low-biased in samples collected before initial parameter stabilization is achieved, and ii) whether methane concentrations stabilize after field parameter stabilization.

To determine whether samples collected before initial parameter stabilization exhibited lower dissolved methane concentrations, we compared the concentration difference in sample pairs collected after a minimal purge versus samples collected after the initial stabilization of field parameters. There were 22 sampling events with samples collected after both a minimal purge and initial parameter stabilization. For these 22 events, we calculated the percent variability for samples collected after a minimal purge versus initial parameter stabilization. For this analysis, the *directional* percent variability was considered positive if the methane concentration increased from a minimal purge to initial parameter stabilization, and negative if it decreased.

Of the 22 purge events, a little over half the events (13 events) showed an increase in methane concentrations from minimal purge to initial parameter stabilization, 6 events showed no change, and only 3 events showed a decrease (see **Figure 2-7**). Of note, of the 13 events where methane concentration increased from a minimal purge to initial parameter stabilization, the change in concentration was typically relatively small (i.e., <10% change). Nevertheless, at least one well consistently exhibited a change in concentration >25%, suggesting that the water present in the lines or pressure tank at the time of sampling may have lost a portion of dissolved methane to volatilization.

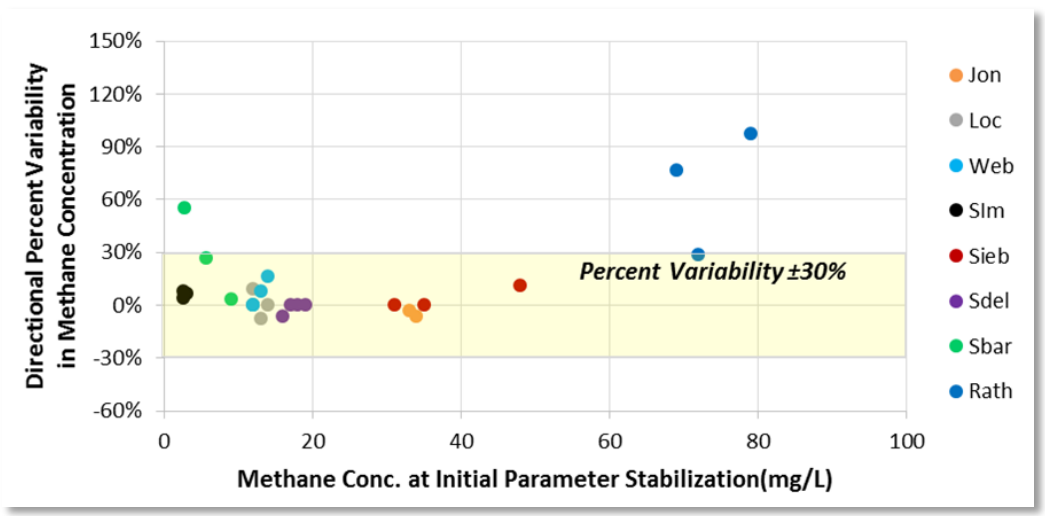


Figure 2-7. *Directional percent variability in methane concentration from a minimal purge to initial parameter stabilization*

To evaluate whether the dissolved methane concentration remained constant among samples collected after field parameters initially stabilized, we assessed the percent variability in dissolved methane concentration from parameter stabilization to a high-volume purge for these same 22 purge events. If purging to parameter stability was correlated with a stabilization of methane

concentration, the percent variability in methane concentration from parameter stabilization to a high-volume purge should theoretically be smaller than the variability in methane concentration before parameter stabilization was achieved.

However, the opposite trend was observed among the population of wells in this study. Specifically, the percent variability in methane concentration from parameter stabilization to a high-volume purge was, on the whole, larger than that from a minimal purge to parameter stabilization (p= 0.0047, one-sided Wilcoxon Signed Rank test) (see **Figure 2-8),** indicating that methane concentrations continued to change throughout the purging process during many purging events.

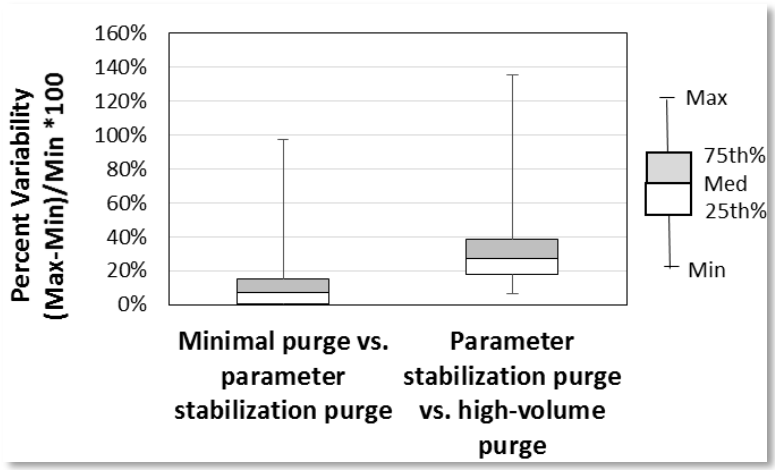


Figure 2-8. *Comparison of percent variability in dissolved methane concentration from a) minimal purge to parameter stabilization vs. b) parameter stabilization to high-volume purge*

At many of the wells tested, field parameters also continued to change after initial parameter stabilization (i.e., evolved out of the "range of stability"). In particular, changes in specific conductivity after initial parameter stabilization were found to be correlated with changes in methane concentration and water chemistry (as detailed in the discussion of Research Question 5, **Section 2.4.5**). An example of a purge event at the Sieb well where specific conductivity evolved out of the range of initial parameter stabilization during continuous purging is shown on **Figure 2-9a**. This suggests that mixing dynamics of fluids from different fractures feeding the well can continue to change throughout the purging process (as described by Holmes, 2001, who suggested that variable parameter readings in monitoring wells throughout the purging process were associated with variable mixing of fluids). In sum, these data suggest that the attainment of initial parameter stabilization does not necessarily indicate that a stable and well-mixed source of water can be sampled thereafter, but rather that the standing fluid within the pressure tank and lines has been flushed.

While all three field parameters (i.e., specific conductivity, pH, and temperature) are commonly used to determine initial parameter stabilization, the best indicator of the removal of standing water in the pressure tank and lines appears to be temperature. Specifically, water that has sat in the pressure tank or lines may be warmer or cooler relative to water within the well, depending on the relative difference in air temperature vs. the temperature of water within the aquifer at any given time of year. This temperature difference can serve as a signal of the transition between "standing water" in the pressure tank and lines to "fresh" well water during purging. In contrast,

there is no clear or consistent mechanism that would change the specific conductivity or pH in the pressure tank and lines from that in the aquifer itself.

In addition, temperature was rarely observed to change significantly after initial parameter stabilization, as compared to notable changes in specific conductivity (e.g., see stable temperature reading at the Sieb well throughout the purging process while specific conductivity values changed significantly, **Figure 2-9b**). The relative stability of temperature measurements throughout the purging process can be explained by the observation that groundwater temperature does not change significantly below 10 meters (33 feet) or more below surface (McHugh et al., 2011). Because the static water level at most residential water wells is 30 feet or more below ground surface, it follows that regardless of the evolving mixture of fluids from different fractures feeding the well, the temperature would not change significantly.

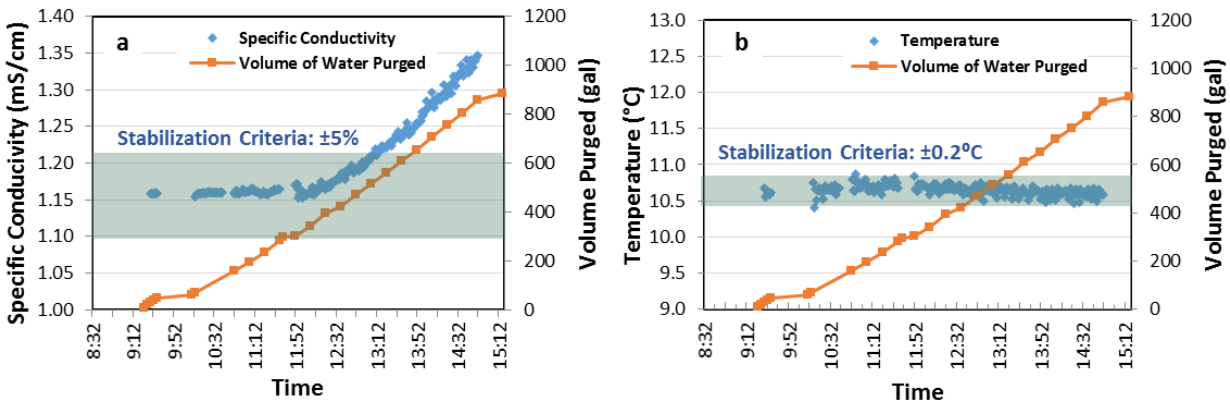


Figure 2-9. *a) Specific conductivity measurements (blue diamonds) and b) temperature measurements (blue diamonds) vs. total purge volume (red squares) at the Sieb well during a purging event up to 3-casing volumes (high-volume purge)*

Trend in Dissolved Methane Concentration with Purge Volume at Individual Wells

After the removal of standing water in the lines and pressure tank (i.e., the purging of 1 – 3 pressure tank volumes, referred to as a "low-volume" purge hereafter), some wells displayed increasing trends in methane concentration with purge volume, while other wells displayed decreasing trends. Specifically, of the 59 purge events with data for both low-volume purge and high-volume purge samples, 34 events (57%) showed a decrease in methane concentration from samples collected after a low-volume purged compared to samples collected after a high-volume purge. Twenty events (34%) showed an increase in methane concentration, and 5 purge events (8%) showed no change in methane concentration. The lack of a consistent increase or decrease in methane concentration with the removal of a large purge volume demonstrates that the relationship between purge volume and dissolved methane concentrations is largely specific to individual water wells.

On an individual basis, however, many of the residential water wells exhibited a consistent trend in both the magnitude and direction of change in methane concentration (i.e., increasing or decreasing) with increasing purge volume. To illustrate this, **Figure 2-10** shows the directional percent variability in methane concentration from a low-volume purge to high-volume purge for the purge events at each well. As described previously, the directional percent variability was considered positive if the methane concentration increased with increasing purge volume, and negative if it decreased. Purge events were conducted during a 2-week timeframe from February

- March 2013, and a 7-month timeframe from April – December 2015 (amounting to 7 purge events total over a 3-year timeframe).

For example, for the purge events at the Rath well, methane concentration consistently decreased with increasing purge volume, changing by -30% to -75% from a low-volume to high- volume purge (see **Figure 2-10**). Conversely, at the Sieb well, methane concentrations consistently increased with increasing purge volume by +70% to +135% from a low-volume purge to high-volume purge (see **Figure 2-10**). Of note, the change in methane concentration from a medium-volume to high-volume purge was relatively small to non-existent at some wells, suggesting that relatively stable water quality conditions had been obtained within the well by 1-casing volume (i.e., medium-volume purge) at these wells. In general, the change in methane concentration with increasing purge volume was correlated with the change in specific conductivity, sodium, chloride, total dissolved solids (TDS), and bromide concentrations (detailed in the discussion of Research Question 5, **Section 2.4.5**) suggesting that evolving mixing dynamics within the well during purging can explain the trends observed in methane concentration and water quality observed at individual wells.

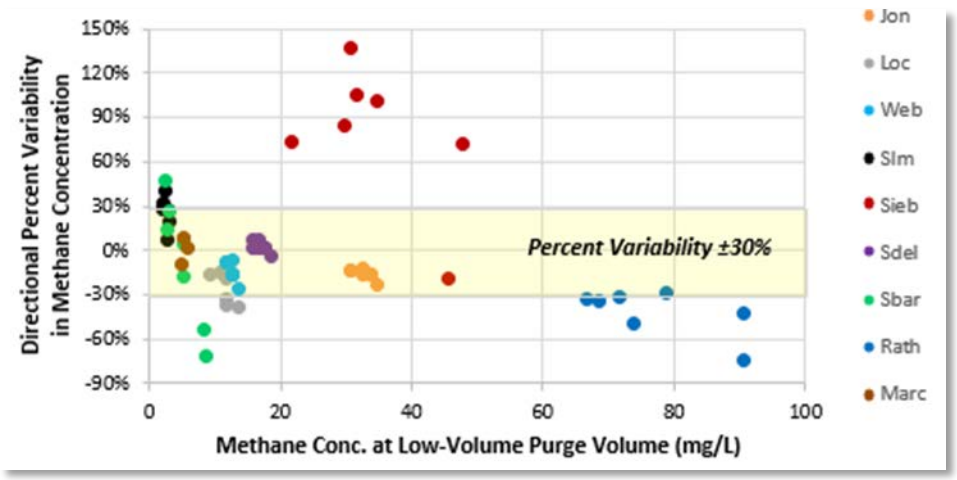


Figure 2-10. *Directional percent variability in methane concentration from a low-volume purge to high-volume purge*

Typical Magnitude of Change in Dissolved Methane Concentration with Purge Volume

For the population of wells in this study, we evaluated the typical magnitude of change in methane concentration associated with purging more or less water from a well prior to sampling by calculating the percent variability between methane concentrations reported after a low-volume purge versus a high-volume purge. For the 59 purge events (7 events at 8 wells and 3 events at 1 well), the median percent variability from a low-volume purge to high-volume purge was 18%. Only 3 out of 49 purge events (5% of purge events, all from the Sbar well) displayed a percent variability in methane concentration from a low-volume purge to high-volume purge larger than 100% (i.e., a 2-fold change). The minimum, median, and maximum percent variabilities of methane concentrations from a low-volume purge to high-volume purge for the purge events at each well are shown in **Table 2-3**. In this dataset, there was no clear relationship between the percent variability of methane concentration with purge volume and the average methane concentration (i.e., of the four wells with a median methane percent variability >25%, two exhibited methane concentration well above 20 mg/L, and two exhibited methane concentrations well below 20 mg/L).

Table 2-3. *Minimum, median, and maximum percent variabilities of methane concentrations from a low-volume purge to high-volume purge for the purge events at each wel*

Well	Number of purge events	Average Methane Conc. (µg/L)	Percent Variability of Methane Concentration from a Low-Volume Purge to 3-Casing Volume Purge	
			Range (%)	Median (%)
Jon	7	30,500	12 – 20	15
Loc	7	10,700	14 – 29	17
Marc	3	6,400	0 – 15	7
Rath	7	66,000	23 – 43	26
Sbar	7	5,100	4 – 46	26
Sdel	7	17,400	0 – 6	0
Sieb	7	47,500	17 – 136	83
Sim	7	3,200	7 – 39	27
Web	7	11,800	8 – 15	8
All Wells	**59**		**0 – 136**	**18**

2.4.4 *Temporal Variability of Dissolved Methane Concentration*

Research Question 4

How much do dissolved methane concentrations change over time (i.e., days to years)?

Key Findings

1. For the 10 wells evaluated with dissolved methane concentrations >1 mg/L, the median event-to-event variability for samples collected in IsoFlask™ containers was 8%. Only 5% of event pairs exhibited an event-to-event variability greater than 100% (i.e., a 2-fold change).
2. The typical event-to-event variability in methane concentrations for samples collected using the Direct-Fill VOA method was slightly larger than that exhibited by the IsoFlask™ samples, but still relatively low (i.e., median methane event-to-event variability of 20%; 7% of samples exhibiting an event-to-event variability greater than 100%, where variability of Direct-Fill VOA samples was only evaluated for wells that were not effervescing).
3. The maximum change in methane concentration over time was 3-fold or less for 9 out of 10 wells, with a maximum change of 3.7-fold reported at any given well (based on both IsoFlask™ and Direct-Fill VOA datasets).
4. A longer time interval between sampling events does not result in greater variability of dissolved methane concentration than a shorter time interval between events (see **Appendix I**).

Recommendations

For wells with naturally occurring methane concentrations greater than 1 mg/L in the study area, it is unlikely that a change in methane concentrations greater than 2-fold would be observed between any two sampling events at a well (assuming samples were collected using a consistent purge volume and sampling method during both events).

As noted previously, pre-drill and post-drill samples in the Appalachian Basin are almost universally collected after purging to initial field parameter stabilization, which was typically attained between 1 and 3 pressure tank volumes in this study (i.e., a low-volume purge). Consequently, to provide the most useful information for practitioners on temporal variability of naturally occurring dissolved methane concentrations in the study area, only samples collected after a low-volume purge (as opposed to a high-volume purge) were utilized to evaluate temporal variability of dissolved methane concentrations over time. Samples collected using an IsoFlask™ container as part of this study, and samples collected using the Direct-Fill VOA Method as part of a supplemental Cabot Oil and Gas Corp. study (see **Appendix E**), were evaluated separately.

Temporal Variability of Dissolved Methane Concentrations (IsoFlask™)

As a first step to evaluating temporal variability of dissolved methane among the population of wells, we determined whether any wells exhibited trends over time in methane concentration (i.e., increasing or decreasing). Two wells were found to exhibit a statistically significant trend that was confirmed visually in plots of concentration versus time (**Appendix I**). However, at both wells, the magnitude of change in methane concentration over time (i.e., the percent variability) was ≤17%, and the stable carbon isotopic composition of methane remained relatively unchanging over the 2-year timeframe, suggesting that these trends are related to natural phenomena. Secondly, we evaluated whether long-term temporal variability (i.e., spacing of a week or more between sampling events) was greater than short-term variability (i.e., spacing of days between sampling events) for samples collected after a low-volume purge. As discussed in **Appendix I**, among the population of wells, a longer spacing between sampling events (i.e., weeks or months) does not appear to be associated with greater variability in dissolved methane concentrations. Consequently, all sampling events (regardless of their spacing) were included in the evaluation of temporal variability of methane concentration over time.

The range of methane concentrations exhibited by each of the 10 wells over time is shown in **Figure 2-11**. For the population of eight wells that exhibited no trend in methane concentration over time, the median event-to-event variability was 14% (see **Table 2-4**). Only 18 of 220 event pairs (i.e., 8% of event pairs) exhibited an event-to-event variability greater than 100%. If we expand this dataset to include the two wells (Jon and Wal) that exhibited a trend in methane concentration over time (discussed in **Appendix I**), the median event-to-event variability was 8% (see **Table 2-4**), and 18 of 352 event pairs (i.e., 5% of event pairs) exhibited an event-to-event variability greater than 100%. Based on this analysis, the inclusion of the two wells that exhibit trends in methane concentration over time actually results in a slight lowering of the event-to-event variability calculated for the population of wells.

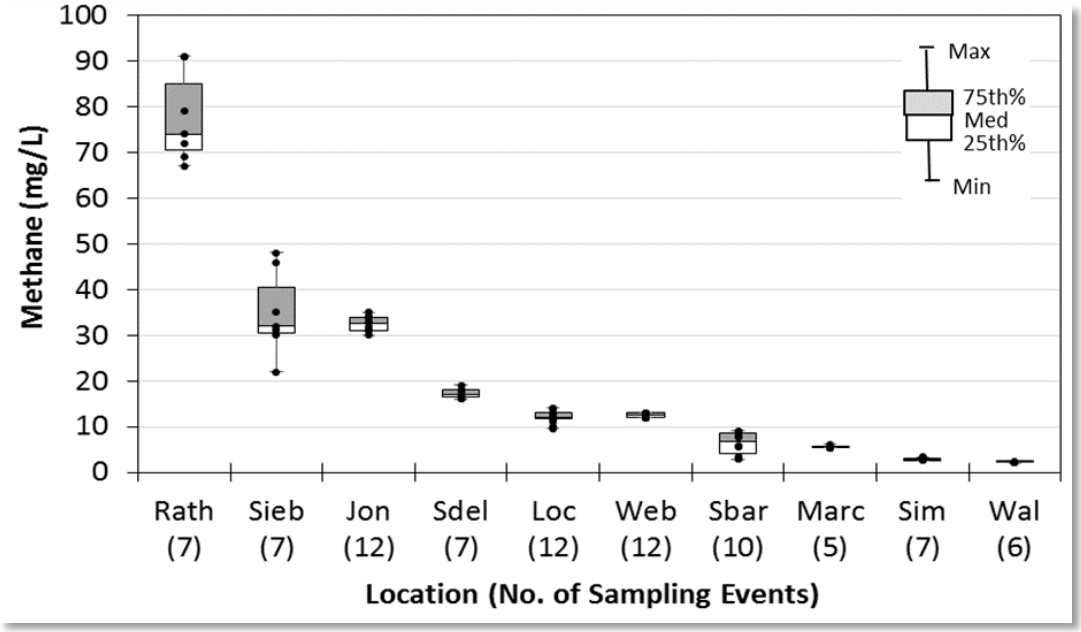


Figure 2-11. *Range of methane concentrations in IsoFlask™ samples collected after a low-volume purge at each of the 10 wells over time*

Table 2-4. *Event-to-event variability of IsoFlask™ samples collected after a low-volume purge for population of 8 wells that exhibit no trend in methane concentration over time, and the population of all 10 wells with methane >1 mg/L in study*

Well Population	Number of Sampling Events	Number of Event Pairs	Event-to-Event Percent Variability				
			Min	Med	75th%	90th %	Max
8 wells	67	220	0%	14%	31%	63%	221%
10 wells	85	352	0%	8%	18%	48%	221%

For the population of all 10 wells, the maximum change in methane concentration at any one well over time was typically less than a factor of 3 (see **Table 2-5**). Specifically, 8 of 10 wells exhibited a ratio of maximum to minimum concentrations less than 2, with two wells (Sieb and Sbar) exhibiting maximum/minimum concentration ratios of 2.2 and 3.2. Of note, these wells also exhibited the greatest variability in methane concentration associated with purge volume (i.e., some of the greatest percent changes in methane concentration during the purging process, as well as some of the most unpredictable (see **Figure 2-11**). This suggests that greater temporal variability may be associated with more significant and complicated changes in mixing dynamics within the well during water purging and over time, as detailed in the discussion of Research Question 5 (**Section 2.4.5**). For the population of 10 wells in this analysis (all with methane concentrations > 1 mg/L), the variability of methane over time was not found to be strongly associated with lower or higher methane concentrations.

Table 2-5. *Event-to-event variability and maximum changes in methane concentration for IsoFlask™ samples collected after a low-volume purge at each well*

					Event-to-Event Variability					
Well	**Time Period of Sampling**	**No. of Events**	**No. of Event Pairs**	**Average Methane (µg/L)**	**Min**	**Med**	**75th%**	**90th%**	**Max**	**Ratio of Max/Min Methane Conc. of all Sampling Events**
Sbar	658	10	45	6,344	1%	59%	154%	198%	221%	3.2
Sieb	651	7	21	33,000	3%	41%	54%	99%	118%	2.2
Loc	712	12	66	12,055	0%	12%	20%	32%	46%	1.5
Rath	93	7	21	75,333	0%	15%	26%	35%	36%	1.4
Sim	657	7	21	2,800	0%	11%	19%	31%	31%	1.3
Sdel	662	7	21	17,333	0%	6%	13%	18%	19%	1.2
Jon	718	12	66	32,636	0%	6%	10%	13%	17%	1.2
Marc	93	5	10	5,400	0%	3%	13%	15%	15%	1.2
Wal	141	6	15	2,140	0%	5%	10%	12%	15%	1.2
Web	721	12	66	12,545	0%	8%	8%	8%	8%	1.1

For the population of 11 wells in this study, additional sampling events were conducted over a two-year period by our teaming partner, Cabot Oil and Gas Corporation, prior to the start of the RPSEA study. These samples were collected to evaluate natural temporal variability of dissolved methane concentrations and other water quality parameters after purging to initial parameter stability over a short- and long-term timeframe, amounting to 6 to 28 sampling events at each well (181 total sampling events). During these events, dissolved gas samples were collected in 40 ml VOA vials using the Direct-Fill method, rather than in IsoFlask™ containers. As addressed in the discussion of Research Question 1 (**Section 2.4.1**) in this report, the use of the Direct-Fill method to collect 40 ml VOA vial samples for analysis can result in a low-biased methane concentration in the presence of effervescence (i.e., at methane concentrations ≥20 mg/L in the study area). In addition, at dissolved methane concentrations below 20 mg/L, 40 ml VOA vial samples analyzed at Lancaster Laboratories reported a median methane concentration that was 16% lower concentration than paired IsoFlask™ samples collected, a difference that may be attributable to a difference in sample preparation or calibration at the two laboratories. As a result of the differences observed between methane concentrations reported for the two sample collection methods, we determined it was inappropriate to combine 40 ml VOA vial and IsoFlask™ datasets in the evaluation of temporal variability of dissolved methane among the population of wells.

However, for wells with methane concentrations less than 20 mg/L (i.e., 9 wells), a separate evaluation of the temporal variability of 40 ml VOA vial methane concentrations for samples collected after a low-volume purge was conducted using the additional dataset. One well, the Iri well (the only shallow hand-dug well in the study), exhibited concentrations that were consistently less than 1 mg/L, and thus was not included in the quantitative analysis of temporal variability because the magnitude of change was not of concern in this low concentration range, nor necessarily representative of that which may be typically seen at wells with higher methane concentrations or more common construction. The remaining dataset was comprised of 99 samples from 8 wells, all with methane concentrations > 1 mg/L.

For the population of 8 wells, the median event-to-event variability (i.e., percent variability of methane concentrations between any 2 sampling events at the same well) was 20% (see **Table 2-6**). Only 56 of 855 event pairs (i.e., 7% of event pairs) exhibited an event-to-event variability greater than 100%. Among the 8 wells, the maximum change in methane concentration at any one well was typically less than a factor of 3 (see **Table 2-6**). Specifically, 7 of the 8 wells exhibited a ratio of maximum to minimum concentrations less than 3, with one wells (Sbar) exhibiting a maximum/minimum concentration ratio of 3.7.

In total, the variability exhibited by the 40 ml VOA vial samples over time from these 8 wells was slightly larger than that exhibited by the IsoFlask™ samples (as presented in **Table 2-5**), but still relatively low (i.e., median methane event-to-event variability of 8% for IsoFlask™ sample vs. 20% for 40 ml VOA samples; 5% of IsoFlask™ sampling events exhibiting an event-to-event variability greater than 100% vs. 7% for 40 ml VOA samples).

Table 2-6. *Event-to-event variability and maximum changes in methane concentration for 40 ml VOA vial samples collected after a low-volume purge using the Direct-Fill method at each well*

					Event-to-Event Variability					
Well	**Time Period Of Sampling**	**No. of Events**	**No. of Event Pairs**	**Average Methane (µg/L)**	**Min**	**Med**	**75th%**	**90th %**	**Max**	**Ratio of Max/Min Methane Conc. of all Sampling Events**
Cas	433	15	105	13,813	0%	42%	92%	121%	153%	2.5
Loc	743	24	276	10,233	0%	25%	45%	74%	169%	2.7
Marc	93	5	10	5,060	0%	11%	17%	22%	22%	1.2
Sbar	93	6	15	4,817	0%	96%	171%	221%	274%	3.7
Sdel	6	3	3	14,000	7%	8%	12%	14%	15%	1.2
Sim	6	3	3	2,733	0%	4%	4%	4%	4%	1.0
Wal	572	20	190	1,595	0%	25%	45%	75%	190%	2.9
Web	764	23	253	10,896	0%	10%	20%	35%	76%	1.8
All Wells	**764**	**99**	**855**	**--**	**0%**	**20%**	**42%**	**74%**	**274%**	**--**

2.4.5 *Key Relationships with Dissolved Methane Concentration*

Research Question 5

What factors help explain variations in dissolved methane concentration between sampling events?

Key Findings

1. At a subset of wells in this study, changes in dissolved methane concentration strongly correlated with changes in several salinity indicator parameters (i.e., sodium, chloride, specific conductivity, TDS, and bromide). These parameters are associated with sodium-bicarbonate or sodium-chloride water types, where both water types have been shown to contain elevated concentrations of naturally occurring methane in the Appalachian Basin.
2. Changes in the $\delta^{13}C$ value of dissolved inorganic carbon (DIC) were found to be significantly correlated with changes in dissolved methane and sodium concentration at a subset of wells. These data suggest that, at the study wells, $\delta^{13}C$-DIC primarily reflects the different sources of alkalinity associated with various fluids mixing within the wellbore environment or being captured by the well.
3. At a subset of wells, change in methane concentration displayed a correlation with water level, suggesting that a change in the hydraulic head may be responsible for the changing mixing dynamics within the well.
4. No significant relationship was observed between dissolved methane concentration and residential water usage prior to sampling (see **Appendix I**).

Recommendations

Measurements of sodium and other parameters associated with sodium-bicarbonate or sodium-chloride water types provide an important tool for evaluating the cause of significant methane variation (i.e., a 2-fold change) in a well over time. Specifically, if an increase in methane is associated with a significant increase in sodium, the change in methane is likely a function of an increased contribution from sodium-rich fluids mixing within the wellbore environment or being captured by the well. To best recognize whether a change in methane concentration is associated with a change in the relative proportions of different fluids naturally entering a well, we recommend analysis of major cations and anions with dissolved methane concentration during pre-drill and post-drill sampling. For a detailed understanding of well dynamics, analysis of bromide (used to determine a Cl/Br ratio) and $\delta^{13}C$-DIC can also be valuable indicators of the mixing of different fluid sources.

To evaluate the relationship between methane and other water quality parameters, isotopic values, and well characteristics (e.g., water level, residential water use), data were evaluated from IsoFlask™ and water quality samples collected post-pressure tank after low-volume and high-volume purges at residential water wells sampled in both the purging and temporal variability parts of the study. In addition, water level measurements within the well and residential water use data for the 72 hours prior to each sampling event were evaluated, where available.

In the Appalachian Basin, naturally elevated concentrations of methane in residential wells have been found to be associated with elevated salinity and reducing conditions, where methane occurs more frequently in sodium-bicarbonate and sodium-chloride rich waters (McPhillips et al., 2014; Molofsky et al., 2016a; Siegel et al., 2015b, 2016; Heisig and Scott, 2013), and in waters with low nitrate and low sulfate concentrations (Van Stempvoort et al., 2005; Molofsky et al., 2016a, Siegel et al., 2015b, 2016). The wells in this study were primarily selected because they

exhibited detectable, and often elevated, concentrations of dissolved methane. It is therefore anticipated that these wells may also exhibit elevated concentrations of sodium, chloride, and other parameters associated with sodium-rich water types (e.g., specific conductivity, bromide, TDS). As shown in **Appendix I**, methane was found to correlate strongly with parameters associated with a sodium-rich water source (i.e., TDS, specific conductivity, sodium, chloride, and bromide) and reducing conditions (i.e., sulfate) among the population of wells in this study. A more detailed discussion of how methane and these parameters co-vary during purging of a well and over time is provided below.

Relationship between Changes in Dissolved Methane and Salinity Indicator Parameters with Purge Volume

To evaluate whether changes in methane concentration with purge volume are associated with changes in salinity and redox indicator parameters, we compared the directional percent variability of methane from a low-volume purge to high-volume purge to the directional percent variability of other parameters for the same samples. For this evaluation, the directional percent variability was considered positive when methane concentrations increased from a low-volume purge to high-volume purge, and negative when methane concentrations decreased from a low-volume purge to high-volume purge. This evaluation utilized IsoFlask™ and water quality data from all 59 purge events (i.e., 7 purge events from 8 wells, and 3 purge events from 1 well).

Based on this evaluation, changes in concentrations of salinity indicator parameters were found to predict between 40 and 70% of the changes in dissolved methane concentration with increasing purge volume among the population of wells (see **Table 2-7**). For example, as shown on **Figure 2-12** an increase in methane concentration with purge volume is significantly correlated with an increase in sodium and vice-versa (R^2 = 0.63, $p<0.001$, F-test of Overall Significance). Conversely, an increase in methane concentration with purge volume is significantly associated with a decrease in sulfate concentration (R^2 = 0.19), although the relationship is less strong than that with salinity indicator parameters. Of note, in previous studies, sodium-rich water in the Appalachian basin was found to exhibit slightly elevated pH, and lower ORP and DO than calcium-rich water (e.g., Molofsky et al., 2016a, McPhillips et al., 2014, Heisig and Scott, 2013, Siegel et al., 2015b). Although these relationships may be present on a broad scale, changes in pH, ORP, and DO were not significantly correlated with changes in methane concentration in this study.

Table 2-7. *Slope, R^2 value, p-value, and statistical significance of best fit line through directional percent variability of methane with purge volume versus directional percent variability of salinity indicators and field parameters with purge volume*

Well	Slope	R^2 Value	P-value	Statistically Significant?
Sodium	0.87	0.63	4.83 E-14	**Yes (95% Conf.)**
TDS	0.99	0.65	1.6 E-14	**Yes (95% Conf.)**
Specific Conductivity	1.01	0.67	1.73 E-15	**Yes (95% Conf.)**
Chloride	0.62	0.58	2.55 E-12	**Yes (95% Conf.)**
Bromide	0.42	0.43	1.64 E-8	**Yes (95% Conf.)**
Sulfate	-0.04	0.19	4.94E-4	**Yes (95% Conf.)**
Temperature	-2.47	0.04	0.11	No
pH	1.04	0.01	0.37	No
ORP	0.15	0.05	0.08	No
DO	0.01	0.01	0.43	No

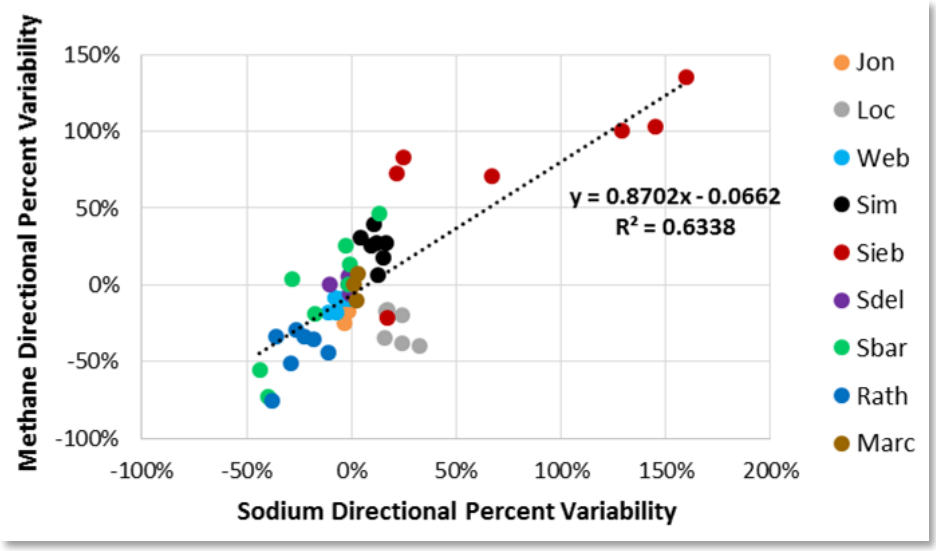


Figure 2-12. *Relationship between directional percent variability of methane with purge volume and directional percent variability of sodium from a low-volume purge to high- volume purge among the 59 purge events at the population of 9 wells sampled*

One well (the Loc well) exhibited an inverse relationship between methane and salinity indicator parameters with purge volume (e.g., when methane increases, sodium decreases, and vice versa). This well also exhibits the only stable isotopic composition of methane consistent with microbial origin (formed via CO_2 reduction) of the 9 wells evaluated in the purge study. Although microbial methane has commonly been observed to occur in sodium-rich flowpaths with more reducing conditions (e.g., Kresse et al., 2012), there are reasons that an inverse relationship may exist between sodium and methane in some wells. For example, in certain settings, both microbial and thermogenic methane could be present in calcium-dominated fluids that exhibit highly reducing conditions. The inverse relationship between methane and sodium may also be explained by dilution with sodium-sulfate fluid (where sodium-sulfate fluids are relatively rare and would not be expected to contain elevated naturally occurring methane concentrations).

These findings suggest that, among the population of wells, changes in methane concentration with purge volume are commonly associated with changes in the origin or relative proportions of water feeding the well from different flowpaths, where an increase in the volume of sodium-rich water (which is more likely to naturally contain elevated methane concentrations) results in an increase in the dissolved methane concentration, and vice-versa (i.e., dilution by calcium-rich water results in a decrease in dissolved methane concentration). Of note, in any given residential water well, there could be multiple sources of sodium-bicarbonate or sodium-chloride fluids feeding the wellbore or capture zone. When evaluating pre-drill and post-drill data from water wells of concern, an assessment of the Cl/Br mass ratio and δ13C-DIC value (which can help identify different sources of alkalinity, as discussed below) can be valuable for further understanding how natural changes in the various proportions of fluids within the wellbore affect dissolved methane concentration.

Relationship between Changes in Dissolved Methane and Salinity Indicator Parameters Over Time

To evaluate whether changes in methane concentration over time are associated with changes in salinity and redox indicator parameters, we compared the directional percent variability of

methane between any two sampling events at the same well to the directional percent variability of other parameters for the same samples. The directional percent variability was considered positive when methane concentrations increased over time, and negative when methane concentrations decreased over time. In total, this amounted to 352 event pairs from 10 wells (all with methane concentrations greater than 1 mg/L).

As shown on **Figure 2-13**, relative changes in concentrations of sodium were found to predict about 60 to 70% of the relative changes in dissolved methane concentration over time (R^2 = 0.67, slope = 2.02, p<0.001, F-test of Overall Significance). Similarly, relative change in chloride was found to predict between 60 to 70% of the relative change in dissolved methane over time, although relative changes in TDS and specific conductivity were less predictive (see **Table 2-8**). Of note, the strength of these relationships are predominantly driven by the Sbar and Sieb wells, which exhibit both larger relative changes in methane and larger relative changes in salinity indicator parameter concentrations over time (see **Figure 2-13**).

Table 2-8. *Slope, R^2 value, p-value, and statistical significance of best fit line through directional percent variability of methane between any two paired sampling events over time versus the directional percent variability of salinity indicators between the same sampling events*

Well	Slope	R^2 Value	P-value	Statistically Significant?
Sodium	2.02	0.67	9.0E-87	**Yes (95% Conf.)**
TDS	1.74	0.15	3.2E-14	**Yes (95% Conf.)**
Specific Conductivity	1.36	0.17	5.2E-16	**Yes (95% Conf.)**
Chloride	0.51	0.63	1.6E-77	**Yes (95% Conf.)**
Bromide	0.002	0.01	1.5E-01	No
Sulfate	-0.03	0.45	8.6E-47	**Yes (95% Conf.)**

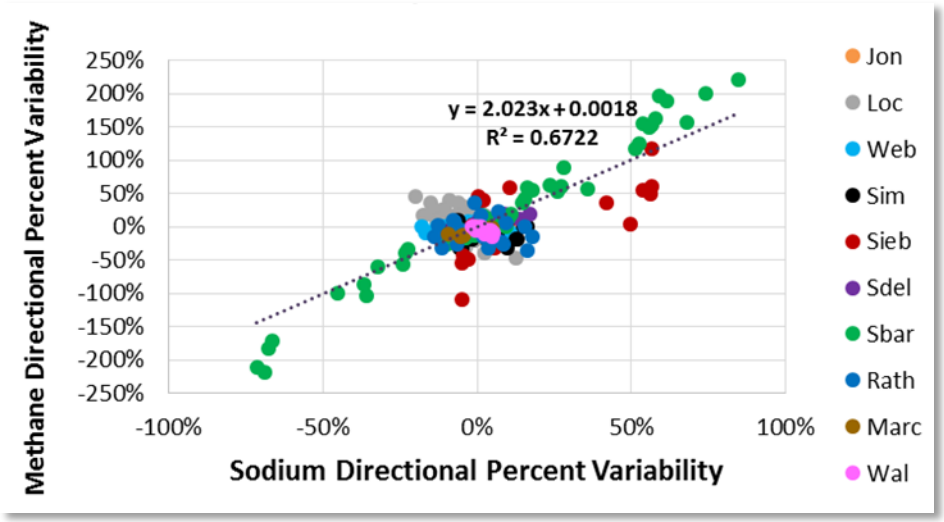


Figure 2-13. *Relationship between methane percent variation (IsoFlask™ samples) and sodium percent variation between any two paired sampling events over time*

To evaluate whether this relationship was also seen in 40 ml VOA vial samples collected via the Direct-Fill method over time, we evaluated the relationship between the directional percent variability of methane versus sodium in the dataset of Direct-Fill VOA samples collected by our

teaming industry partner, Cabot Oil and Gas Corporation, at a subset of wells over time (see **Figure 2-14**). For this evaluation, wells with methane concentrations greater than 1 mg/L and less than 20 mg/L, the approximate concentration at which effervescence occurs in the study area, were utilized. As shown in **Figure 2-14**, two wells (the Cas and Sbar wells) display a strong relationship between larger changes in methane concentration and larger changes in sodium concentration over time. However, two other wells that display larger changes in methane concentration over time (the Wal and Loc) wells, do not exhibit similarly significant changes in sodium concentration. Of note, the relationship between methane and sodium concentration is still statistically significant at these two wells, although the sodium concentration changes by a much smaller percentage than the methane concentration.

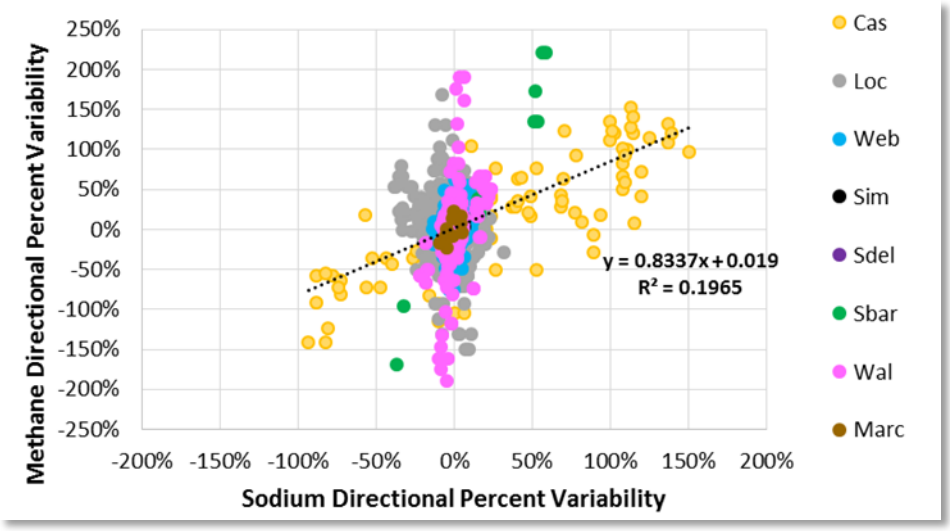


Figure 2-14. *Relationship between methane percent variation (Direct-Fill VOA samples) and sodium percent variation between any two paired sampling events over time*

Combined, these two datasets suggest that, while changes in methane concentration are commonly accompanied by changes in sodium concentration, the relationship between the relative percent changes of the two parameters is unique to individual wells and their mixing dynamics. Significant percent changes in methane concentration (i.e., ±100%) that are accompanied by significant percent changes in sodium concentration are evidence for natural variability driven by changes in mixing dynamics; however, significant percent changes in methane concentration that are not accompanied by similar percent changes in sodium concentration do not necessarily suggest an impact.

Relationship between Dissolved Methane and Water Level

The relationship between methane and water level was apparent at a small subset of wells (where all methane concentrations were reported for IsoFlask™ samples). Specifically, there was a statistically significant correlation between methane concentration and water level at 3 of the 10 wells evaluated: Loc, Web, and Sim (see **Table 2-9**). In addition, two other wells (Rath and Sieb) appear to show a loose correlation between methane and water level that may be confounded by one or two outliers (see **Table 2-9**). Overall, this suggests that changes in water level at these wells may play a role in changes in controlling mixing dynamics within the well. Specifically, a change in water level could affect the volume of water flowing in and out of fractures with different pressures relative to another, leading to larger or smaller volumetric percentages of sodium-rich

water within the well (depending on the unique dynamics of each well and the fractures feeding it). Changes in the composition of water within a well could also feasibly be affected by the capture radius of the well during pumping, which can increase without a drop in water level.

Of note, many of the wells exhibited a relatively rapid recovery of water level when the flow-rate was decreased (i.e., during the collection of samples) or after the cessation of pumping. Combined with the on-off cycling of the pump during regular water usage, this suggests that the water level at many wells may rebound too quickly to maintain a water composition representative of high-volume (i.e., 3-casing volume) purge for an extended period of time. From a practical perspective, this implies that the sample collected after a low-volume purge (i.e., with limited water level drawdown) is more representative of water quality experienced by the resident on a regular basis than samples collected after a high-volume purge (potentially resulting in larger water level drawdown and a change in water composition that is not sustained during regular use).

Table 2-9. *R^2 value and statistical significance of best-fit line through methane concentration versus water level for all samples collected at each well after low-volume and high-volume purges*

Well	Number of Samples	R^2 value of best-fit line through methane vs. water level	P-value	Statistically Significant?
Jon	19	0.00	0.95	No
Loc	19	0.44	0.0037	**Yes (95% Conf.)**
Marc	8	0.01	0.84	No
Rath	14	0.25	0.07	No
Sbar	17	0.08	0.27	No
Sdel	14	0.04	0.47	No
Sieb	14	0.21	0.103	No
Sim	14	0.29	0.046	**Yes (95% Conf.)**
Wal	6	0.08	0.59	No
Web	19	0.40	0.0039	**Yes (95% Conf.)**

Relationship between Dissolved Methane and Stable Isotopic Composition of Dissolved Inorganic Carbon

Of the 10 wells evaluated, 9 wells exhibited an isotopic signature of methane consistent with early thermogenic gas (Baldassare et al., 2014). One well (Loc well) exhibited an isotopic composition consistent with microbial gas formed from CO_2 reduction (see **Figure 2-15**). Among all IsoFlask™ samples collected from each well in the purge study and over time (i.e., low-volume purge and high-volume purge samples), the change in the stable carbon isotopic composition of methane at these wells was relatively small (i.e., maximum $\delta^{13}C$-CH_4 change at any one well of ±2.62‰), with the stable hydrogen isotopic composition exhibiting a maximum δD-CH_4 change at any one well of ±13.1‰ (see **Figure 2-15**).

The stable oxygen and hydrogen isotopic values of water from study wells were consistent with local meteoric water sources (see **Figure 2-16**). Similar to the stable isotopic composition of methane, the isotopic composition of water changed relatively little at each well, with minor variations (i.e., maximum $\delta^{18}O$-H_2O and δD-H_2O change among samples at any one well of ±0.42‰ and ±4.1‰, respectively). Among the population of samples from each well, there was

no clear relationship between the stable isotopic composition of water and the methane concentration.

The stable isotopic composition of dissolved inorganic carbon (δ^{13}C-DIC, where inorganic carbon includes carbon dioxide, carbonic acid, bicarbonate, and carbonate) exhibited a maximum change at any one well of ±6.2‰. At 7 of the wells (Jon, Loc, Sbar, Rath, Sieb, Sim, and Web), the stable isotopic composition of DIC was found to be significantly correlated ($p<0.05$, F-test of Overall Significance) with methane concentration (as reported in IsoFlask™ samples) (see **Figure 2-17**). In addition, at several wells, (Loc, Sbar, Rath, Sieb, and Web), δ^{13}C-DIC was also significantly correlated with sodium. Combined, these data suggest that variation in δ^{13}C-DIC at the study wells primarily reflects the different sources of alkalinity associated with fluids mixing within the wellbore environment or capture radius of the well.

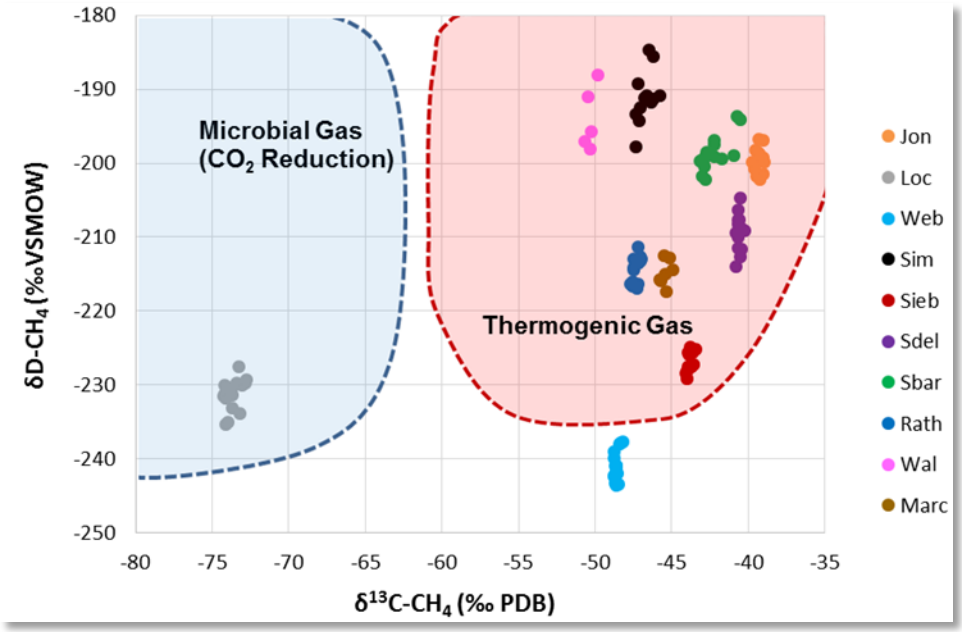


Figure 2-15. *Stable isotopic composition of methane at study wells*

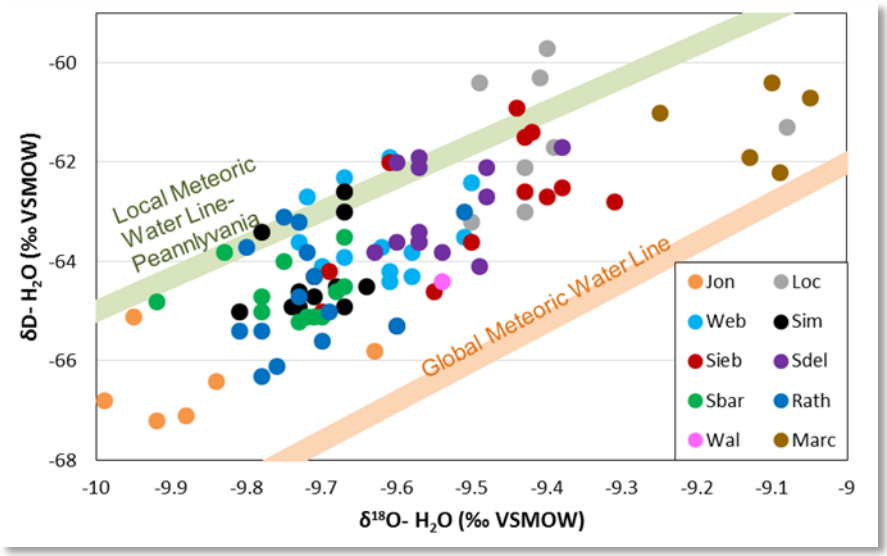


Figure 2-16. *Stable isotopic composition of water at study wells*

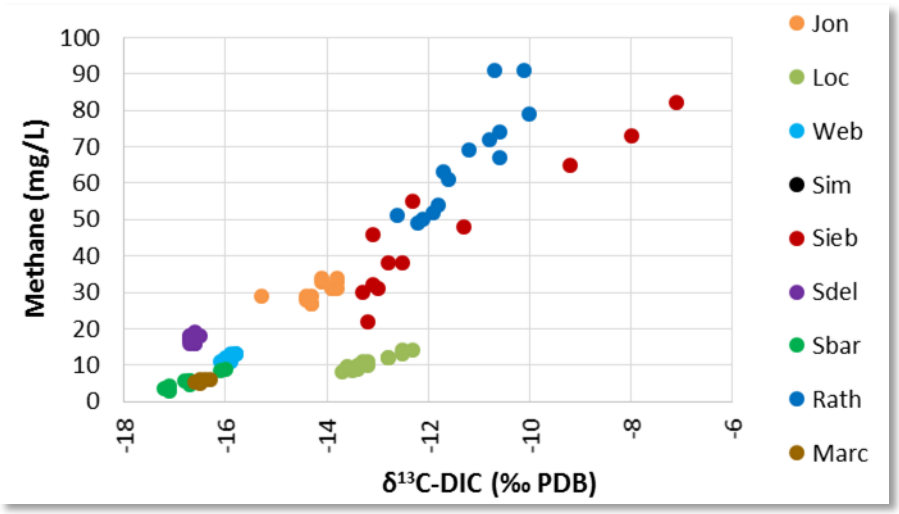


Figure 2-17. *Methane concentration versus δ^{13}C-DIC composition at study wells*

2.5 Recommendations for Baseline Sampling

Based on the results of this study, key recommendations for the sampling and interpretation of pre-drill and post-drill dissolved methane data used to screen residential water wells for stray gas impacts were developed to address the following questions:

1. **Sampling Methodology:** How should a residential water well be sampled to obtain accurate and representative dissolved methane concentrations?
   a) What sampling method for dissolved methane provides the most accurate results?
   b) Does water lose dissolved methane as it moves through the pressure tank?
   c) How much water should be purged from the well prior to sample collection?

2. **Temporal Variability:** What magnitude of variability in dissolved methane concentrations can be expected over time at residential water wells due to natural effects?
3. **Key Relationships with Methane:** What water quality parameters are important for understanding the occurrence of natural methane and distinguishing natural variability from anthropogenic changes?

Tables 2-10a-e lists recommendations for sampling methodology, purging practices, and interpretation of temporal variability for baseline sampling programs at residential water wells. The applicability of each recommendation and any important considerations (e.g., cost, sample location) are listed alongside the recommendation.

Some of these recommendations are broadly applicable in any setting, while others are specific to the study area (e.g., residential water wells in the Northeastern Appalachian Basin fed predominantly by fracture-flow). These recommendations are designed to maximize accuracy and minimize variability of reported dissolved methane concentrations and enhance the accurate interpretation of that data. If a factor evaluated in this study (e.g., sampling location before or after the pressure tank) had no practical effect on accuracy or variability of dissolved methane concentration from one event to another, recommendations were based on other considerations including ease of accessibility and cost.

Table 2-10. *Recommendations for Baseline Sampling of Dissolved Methane at Residential Water Wells*

a) Sample Collection Method **What sampling method for dissolved methane provides the most accurate results?**	
Study Findings	▪ **For non-effervescing samples, all three sampling methods performed similarly.** ▪ **For effervescing samples, a closed-system method performs best.** For effervescing samples, the IsoFlask™ (closed-system) captures gases that might otherwise be lost to the atmosphere or unaccounted for during analysis of Direct-Fill VOA and Inverted VOA samples. Closed-system sampling provides the most accurate measurements of elevated dissolved gas concentrations.
Considerations	▪ **Analytical cost.** Analysis of IsoFlasks™ is currently only offered at Isotech Laboratories. Cost of IsoFlask™ analysis for dissolved light hydrocarbon gases and fixed gases is typically 3 to 4 times more than the cost for analysis of dissolved methane, ethane, and propane in 40 ml VOA vials. However, laboratory cost is usually a small component of the total cost for a field sampling program which also includes labor for sample collection, data analysis, and reporting. ▪ **Effervescence can occur at different methane concentrations.** Effervescence is driven by the combined partial pressures of gases dissolved in groundwater. Due to the presence of dissolved gases other than methane in groundwater (e.g., CO_2, N_2), effervescence may occur at a concentration well below the solubility of methane in certain settings. As a conservative approach, samplers may choose to use a closed-system sampling method when methane concentrations exceed 1 mg/L (a common concentration at which stable isotopic analysis of methane is performed).
Recommendations	▪ **If elevated methane concentrations are suspected/known or effervescence is observed,** collect samples using a closed-system method (e.g., IsoFlask™) to avoid exsolution of gases. ▪ **If methane concentration is unknown, three options are:** o **Option A**: Sample using Direct-Fill VOA method. Collect IsoFlask™ duplicates and hold for analysis if VOA vial concentrations are elevated (e.g., methane >1 mg/L). Automatically analyze IsoFlask™ if effervescence is suspected or observed. (Note: IsoFlasks™ can be held for several months prior to analysis). o **Option B:** Sample using Direct-Fill VOA method. Return to water well to collect IsoFlask™ sample if VOA vial concentrations are elevated (e.g., methane> 1 mg/L). o **Option C**: Sampling exclusively using IsoFlask™ if more accurate concentrations are needed.
Applicability	▪ **Universal** (i.e., not specific to any area or type of water well).

b) Sampling Location
Does water lose dissolved methane as it moves through the pressure tank?

Study Findings	▪ **Presence of pressure tank did not affect dissolved methane concentration.** In this study, there was no statistically significant difference in dissolved methane concentrations of samples collected from pre- versus post-pressure tank sample locations while water was actively flowing through the pressure tank (i.e., after a purge of 3-casing volumes).
Considerations	▪ **Limited availability of access before pressure tank:** Access points prior to the pressure tank are typically not available at residential water wells. In most cases, the closest sample point to the wellhead is the tap at the base of the pressure tank. ▪ **Water treatment devices (e.g., water softeners, filters) are common components of a residential water system.** Treatment devices are typically located after the pressure tank. Water treatment devices change the chemistry of the water.
Recommendations	▪ **Sampling at a consistent location is recommended, preferably as close to the wellhead as possible:** Although this study did not find a significant difference in pre- versus post-pressure tank samples for the population of wells, we recommend sampling pre-pressure tank when possible because there may be less common pressure tank configurations that do result in a significant methane loss. Regardless, sampling at a consistent location will minimize any potential variability between sampling events. ▪ **Sampling before water treatment devices is advised:** Samples collected after treatment devices are not representative of water quality in the well. ▪ **Record location of sample point:** Field notes should always include the location of the sample point relative to pressure tanks, cisterns, water treatment, etc.
Applicability	▪ **Universal** (i.e., not specific to any area or type of water well).

c) Volume of Water Purged Prior to Sampling
How much water should be purged from the well prior to sample collection?

Study Findings	▪ **Regardless of purge volume, dissolved methane concentration typically did not change significantly.** Changes in methane concentration from a low-volume purge to high-volume purge were generally less than 2-fold. ▪ **Purging to initial parameter stabilization removes water in pressure tank and lines, but does not achieve stable water quality conditions.** At residential water wells, purging to initial parameter stabilization (particularly temperature) commonly serves to remove any water present in the lines or pressure tank that may have lost methane, thus enabling the sampling of water representative of conditions at the pump inlet of the well. However, it does not necessarily represent the attainment of stable water quality conditions within the well thereafter. Rather, additional purging of up to one or more casing volumes can cause dynamic mixing of multiple fluid sources within the wellbore or capture radius of the well, resulting in changes to the water composition within the well. ▪ **There appears to be no benefit to purging larger volumes of water.** At many wells, samples collected after a low-volume purge (i.e., with limited water level drawdown) are more representative of water quality experienced by the resident on a regular basis than samples collected after a high-volume purge (potentially resulting in larger water level drawdown and a change in water composition that is not observed during regular use).
Considerations	▪ **Water wells in fracture-flow systems vs. unconsolidated aquifers.** In water wells fed by fracture flow systems, water quality may continue to evolve during purging due to changes in the volumetric proportions of different water sources feeding the well or mixing within the wellbore. In water wells fed by unconsolidated aquifers, mixing dynamics within the wellbore and throughout the purging process may not be as pronounced. ▪ **Volume of water in the well system.** If the water well is unusually deep, or the first access point for sampling is some distance from the pressure tank, it may be valuable to also purge the volume of water in the tubing above the pump intake and lines to the pressure tank.
Recommendations	▪ **Purge water in the pressure tank and lines.** If the pressure tank volume is known, purging of 2 pressure tank volumes should be adequate to remove standing water from the tank and lines. Alternatively, purging ~100 gallons will likely achieve the same result. There is no need to purge several casing volumes to achieve “representative” results. ▪ **For wells without permanent pump or pressure tank.** A sampling pump can be lowered to bottom third of screen or open borehole and used to purge ~100 gallons. ▪ **Understand and record residential water use prior to sampling.** Record the typical water usage prior to the sampling event. Water wells primarily used for irrigation or livestock draw significantly more water on a regular basis than residential wells. Sampling at any well should be targeted for a time that is representative of typical usage. ▪ **Consistent purge volume prior to sampling.** Use of a consistent purge volume prior to sample collection during each sampling event is recommended. Use of significantly different purge volumes from event to event could artificially increase methane variability.
Applicability	▪ **Universal** (i.e., not specific to any area or type of water well).

d) Temporal Variability of Dissolved Methane

What magnitude of variability in dissolved methane concentrations can be expected over time at residential water wells due to natural effects?

Study Findings	▪ **Larger than 2-fold change in concentration in study area not common.** For wells with naturally occurring methane concentrations greater than 1 mg/L in the study area, it is unlikely (though not impossible) that a change in methane concentrations greater than 2-fold would be observed between any two sampling events at a well (assuming samples were collected using a consistent purge volume and sampling method during both events)
Considerations	▪ **Magnitude of methane concentration.** Based on this study and that published by Smith et al. (2016), water wells with methane concentrations <1 mg/L in northeastern Pennsylvania can show larger relative variability of methane concentrations over time (e.g.,10X) than that observed in this study. This is likely related to the fact that small differences in methane concentration at these wells can constitute a large *percentage* change in concentration. The findings of this study specifically apply to water wells with methane > 1 mg/L, where changes in methane concentration are of greatest concern.
Recommendations	▪ **For wells with naturally occurring methane >1 mg/L, a methane concentration change of up to 2X is expected.** Changes in dissolved methane concentration of 2X or less are representative of natural variability.
Applicability	▪ **Applicable to water wells fed by fracture flow in the Appalachian Basin** where methane has been observed to occur in sodium-rich water. May be applicable in other basins that exhibit similar relationship between methane and water type.

e) Factors Correlated with Natural Methane Occurrence and Variability:
What water quality parameters are important for understanding the occurrence of natural methane?

Study Findings	▪ **Naturally occurring methane concentrations are positively correlated with sodium** and other parameters associated with sodium-bicarbonate and sodium-chloride type fluids. Conversely, dissolved methane concentrations are negatively correlated with calcium-dominated fluids. The covariance between dissolved methane and sodium-rich water suggests that changes in dissolved methane concentration commonly occur when the volumetric ratio of different aquifer fluids mixing within and near the wellbore environment changes.
Considerations	▪ **Association between methane and sodium-rich water types.** Both sodium-bicarbonate and sodium-chloride water types have been shown to contain elevated concentrations of naturally occurring methane in the Appalachian Basin, and other parts of the country. However, in any given area of interest, evaluation of existing baseline datasets is important to determine if, and the degree to which, the association exists.
Recommendations	▪ **Evaluating changes in methane concentration.** Significant changes in methane concentration (i.e., 2x) accompanied by significant changes in sodium can be strong evidence for natural variation. However, the inverse (i.e., a change in dissolved methane concentration that is not accompanied by a change in sodium concentration) could be associated with either natural variation or anthropogenic impacts (stray gas). To best recognize whether a change in methane concentration is associated with a change in the relative proportions of different fluids naturally entering a well, we recommend analysis of major cations and anions with dissolved methane concentration during pre-drill and post-drill sampling. For a detailed understanding of well dynamics, analysis of bromide (used to determine a Cl/Br ratio) and δ^{13}C-DIC can also be valuable indicators of the mixing of different fluids sources. ▪ **Comparison to background statistics.** Where possible, use existing baseline water quality data to determine if associations exist between naturally occurring methane and salinity indicator parameters. If natural relationships exist, develop summary statistics (e.g., Upper Prediction Limit) to show likelihood of natural occurrence of elevated methane concentration in a particular setting (e.g., sodium-dominated vs. calcium-dominated water types, where the latter commonly lacks naturally occurring methane).
Applicability	▪ **Generally applicable to water wells fed by vertically connected fracture flow** or stacked aquifers in the Appalachian Basin (e.g., Hallowell and Koester 1975; Geyer and Wilhusen 1982; Geiser and Engelder 1983; Taylor 1984). May be applicable to other basins as well (area-specific evaluation of baseline data is recommended).

ADVANCED ANALYTICAL AIR MONITORING

Objectives: The overall objective of the project is to develop a technical protocol for the measurement of oil and gas ambient emissions using a monostatic Open Path Fourier Transform Infrared (OP-FTIR) spectrometer with integrated meteorological sensors and an optical imaging camera.

Technical Approach: The Advanced Analytical Air Monitoring project involved four major components i) quality assurance testing via controlled methane releases at Texas A&M San Antonio, ii) Pilot testing of beam configurations and integrated systems at Clover Lawn Park, iii) Field trials at SHAPE Ranch located in South Texas Eagle Ford Shale Play, and iv) development of the air measurement protocol for the OP-FTIR. The equipment chosen for this study included a Kassay RAM2000 G2 OP-FTIR monostatic spectrometer with an integrated Climatronix F460 meteorological sensor, and an EyeCGas optical gas imaging camera rated as intrinsically safe to operate in explosive environments.

OP-FTIR spectrometer and weather station

Results: The OP-FTIR and integrated meteorological sensors successfully delineated the source during preliminary trials and pilot tests. Methane was detected most often and had the highest concentrations (averaging 2,184 parts per billion) throughout the monitoring period at SHAPE Ranch. Methane/ethane/carbon monoxide ratios were representative of energy production rather than agricultural sources. Concentration roses were used to pinpoint sources for each compound using the average concentration as a function of wind direction over time. The results demonstrated a high likelihood that methane was primarily coming from tanks and compressors located north and east of the weather station, respectively. Xylene was emitted from the lone tank (storage for condensate, a known emitter for xylene) located east/southeast of the weather station. The only carbon monoxide source was the compressor which possessed a combustion engine.

Conclusions/Recommendations: Field procedures for sampling at remote sites should include careful planning for safety, power needs and site access. Following a repeatable procedure for data collection and analysis will ensure that results are defensible.

When sampling at facilities with complex hydrocarbon plumes, caution should be taken to account for multiple compounds potentially absorbing within the same infrared regions. There are currently no commercially available instruments capable of addressing such spectral overlap in real-time. However, experimental methods that summarize total hydrocarbons over the averaged infrared path length proved successful for the purposes of this study. Further laboratory grade experiments are recommended to verify accuracy with this method. There is also value in the creation of a compound list that alerts researchers to compounds with high likelihood of absorbance in the same spectral regions. Running a sample with these compounds together should be avoided and instead, the use of a surrogate compound could be used (e.g., a compound likely to co-occur with the other compound). However, which compounds would serve best as surrogates for others is not well studied.

Benefits: Producers will benefit from real-time data collection, improved delineation of potential air emissions, and more accurate quantification of concentrations from oil and gas operations.

3.0 ADVANCED ANALYTICAL AIR MONITORING

3.1 Problem Statement & Objectives

Measurement data of ambient air emissions from unconventional oil and gas operations are either scarce or specific to industrial processes in a particular facility. Further, current models being used to estimate these emissions have a heavy reliance on numerous default factors for chemical constants/coefficients and values that are not site-specific, thus creating a significant variance in the models and leading to errors in estimation of emissions.

Innovative technologies and methods are needed to support *real-time data collection*, *quantify actual emission concentrations*, and *improve delineation of air emissions* from oil and gas operations. The use of OP-FTIR spectroscopy in combination with concurrent site-specific thermal imaging and meteorological measurements largely answers these needs. However, specific procedures are needed to address equipment standards, instrumentation configurations and data analysis procedures.

The overall goal of the Advanced Analytical Air Monitoring component of the project is to develop a protocol that supports real-time, accurate quantification of emissions concentrations from oil and gas operations using OP-FTIR instrumentation, integrated meteorological sensors and optical imaging cameras. Multiple field trials were performed to develop comprehensive ambient emissions data from production facilities and storage impoundments to validate the protocol.

3.2 Current Literature & Regulations

A review of applicable literature and regulations was conducted to summarize and link together current and publically available information regarding the use of monostatic OP-FTIRs. Available information is described below.

Open Path Literature: The closest related standard for emission measurement utilizing OP-FTIR is the *Standard Guide for Open-Path Fourier Transform Infrared (OP-FTIR) Monitoring of Gases and Vapors in Air* (ASTM, 2013). This standard guide is focused solely on industrial facilities, hazardous waste sites and landfills and does not address oil and gas operations. Additionally, this standard does not purport to address all of the safety concerns associated with its use. Other ASTM standards related to open path beam technologies include *Terminology Relating to Molecular Spectroscopy* (ASTM, 2015a), *Practices for General Techniques of Infrared Quantitative Analysis*, which was withdrawn in 2015 (ASTM, 2015a), *Practice for Describing and Measuring Performance of Fourier Transform Mid-Infrared (FT-MIR) Spectrometers: Level Zero and Level One Tests* (ASTM, 2015b), *Practices for Infrared Multivariate Quantitative Analysis* (ASTM, 2012).

Other Test Methods by USEPA: The USEPA OTM10 was written in 2006 and focuses on methodologies for characterizing gaseous emissions from non-point pollutant sources. These methodologies use an Open-Path, Path-Integrated Optical Remote Sensing system in multiple beam configurations to directly identify “hot spots” and measure emission fluxes (USEPA, 2006). Emission measurement instrumentation has seen significant advancement since 2006 making this OTM outdated. Furthermore, the emission flux measurement methodology described in OTM10 is cost-prohibitive and difficult to execute due to the necessity of multiple OP-FTIR instruments, beam configurations and nonintegrated data logging software.

Compendium Methods by USEPA: USEPA method TO16 was written in 1999 and was prepared for publication in the *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air* (USEPA, 1999). This is a generalized method that discusses data acquisition procedures for 1999-model instruments as well as the processing of spectra so that

gas concentrations may be obtained. At the time of this method publication, OP-FTIR technology was incapable of performing real-time data analysis. In 2010, OP-FTIR technology began to include integrated software capable of reading the spectra and yielding concentrations with a high degree of accuracy. Spectral data could also be stored for quality assurance purposes and further analysis of interfering atmospheric gases such as water vapor. Weather servers from interconnected meteorological sensors could also be integrated with OP-FTIR instrumentation to minimize post-processing time. Currently, no published compendium methods or other technical methods have been developed for newer integrated systems.

Regulatory Drivers: New Source Performance Standards are pollution control requirements that were established under Section 111 of the Clean Air Act (40 CFR Part 60). These standards are mandated nationally to regulate industrial activities relating to the emission of greenhouse gases, particulate matter and volatile organic compounds (VOCs). More recently, the *President's Climate Action Plan, Strategy to Reduce Methane Emissions* (CAP, 2014) called for "better data collection and measurement" to improve understanding of methane and other GHG sources and trends, and enable more effective management of opportunities to reduce emissions. It advocates the use of new measurement technologies to reduce the uncertainty associated with GHG emissions inventories.

3.3 Technical Approach

3.3.1 *Instrumentation*

The Advanced Analytics project included use of the following technologies: i) OP-FTIR, ii) meteorological sensors, and iii) optical gas imaging camera, employed in parallel and series, as appropriate. The Remote Air Monitor-2000 (RAM 2000) G2 system sold by Kassay Field Services is a complete OP-FTIR spectroscopy system that is accredited by the National Environmental Laboratory Accreditation Council (NELAC) and has passed the USEPA Environmental Technology Verification Program. It consists of an OP-FTIR spectrometer, a retroreflector, a computer system, the RMMSoft analysis software, spectral reference libraries and a chemical database (see **Figure 3-1**). The system was upgraded to include a 37 cubed retroreflector. The larger corner cubed surface allowed for longer infrared beam path lengths when sampling at larger facilities. The system was also upgraded with a cryocooler to avoid the logistical challenges and safety hazards of liquid nitrogen transportation, storage and handling at remote sites.

Figure 3-1. *RAM 2000 G2 OP-FTIR Spectrometer*

The integrated Climatronics F460 meteorological sensor (see **Figure 3-2a**) included its own weather server software and was designed to align with concentration measurements. The meteorological sensor is equipped with a wind speed sensor (cups), a wind direction sensor (vane), barometer, temperature sensor and a relative humidity sensor. The data logger is protected within an environmental enclosure box. A tripod, extender pole, and cross arm were employed to enable turn-key set up of the meteorological sensor.

An EyeCGas Optical Gas Imaging Camera sold by Heath Consultants (see **Figure 3-2b**) was used to detect and visualize leaks from sources. This camera is rated as intrinsically-safe to operate in explosive environments, is lightweight, rugged and sealed for industrial use. The camera has video/audio recording capability and is sensitive enough to detect light hydrocarbon gases such as methane.

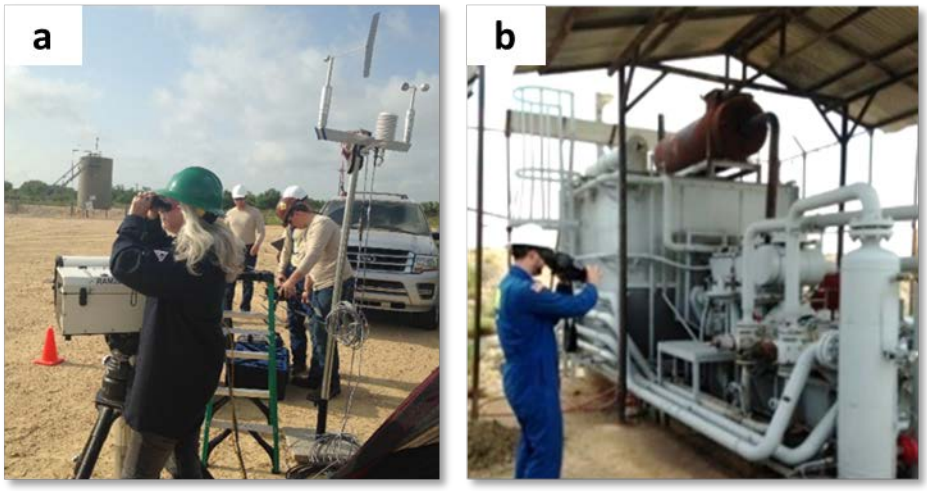


Figure 3-2. *a) Integrated Climatronics F460 meteorological sensor; b) EyeCGas Optical Gas Imaging Camera*

3.3.2 *Field Trials*

The Advanced Analytical Air Monitoring project involved four major field components: i) quality assurance testing and controlled methane release trials at TAMU-SA, ii) a pilot test at a construction site (i.e., Clover Lawn Park, San Antonio) to validate integrated meteorological sensors, iii) a field trial in South Texas (i.e., SHAPE Ranch, Dimmit County) to monitor emissions from various components of an oil and gas production facility, and iv) a joint-industry project in Wyoming to apply the air emissions protocol to produced water ponds. The field components of the study are described in **Table 3-1** and discussed in the sections below. A map of the field trial locations and select photos of the OP-FTIR instrumentation and field trials are provided in **Appendix K**.

Table 3-1. *Description of Field Trials*

Field Trial	Description
Quality Assurance Testing and Controlled Methane Release	Validate instrumentation accuracy and test various infrared beam configurations.
Pilot Test Study Site – Clover Lawn Park and Surrounding Construction	Perform downwind measurement of a construction site to further validate desired beam configurations (observed at the TAMU-SA preliminary trials), refine quality assurance techniques and validate the technology integration of meteorological sensors within a complex ambient air setting.
Field Trial – SHAPE Ranch	Collect and analyze spectral data from a production facility in the Eagle Ford Shale Play that would serve as the foundation of the protocol.
Application of Protocol – Wyoming field Trial	Measure air emissions from oilfield waste disposal ponds in the Upper Green River Basin, Wyoming using the OP-FTIR and other air emission measurement technologies. Use Air Emissions Protocol to guide OP-FTIR and meteorological station testing methodologies.

3.4 Results and Discussion

3.4.1 *Quality Assurance Testing and Methane Release*

This section describes quality assurance testing that was performed prior to field trial implementation and a methane test release to confirm all systems were communicating and

collecting data. A schematic of the OP-FTIR set-up process for the controlled methane release studies is provided in **Figure 3-3**. Quality control procedures are discussed below.

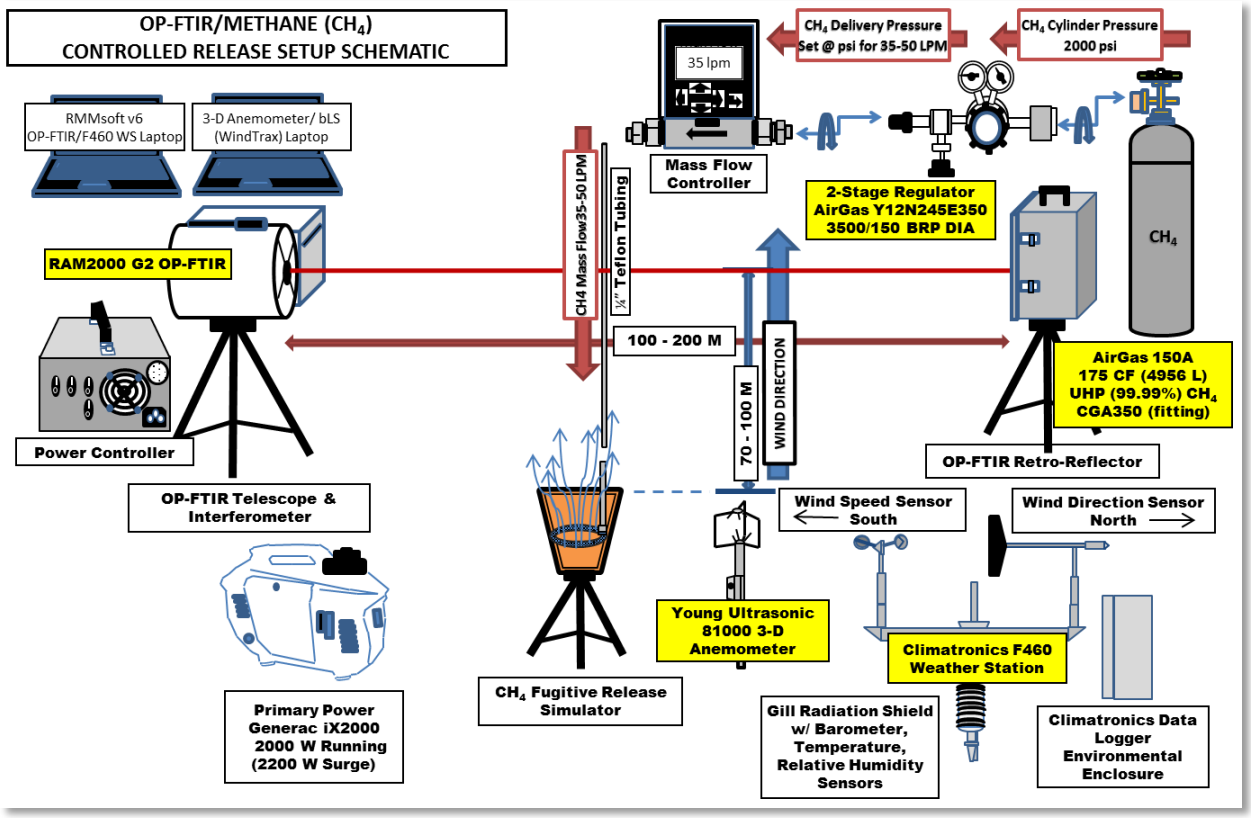


Figure 3-3. *Process Schematic for the Controlled Methane Release*

Quality Assurance. Before the instrumentation was used, it was verified that the OP-FTIR, meteorological sensor and optical imaging camera met functional and performance specifications outlined in their respective user manuals. During operation, each instrument was periodically inspected, verified and calibrated. Instruments were labeled with the calibration status, indicating the dates of the last successful calibration and the next scheduled performance verification and calibration. Recommended quality assurance procedures for the OP-FTIR are detailed in the protocol and include the following:

- Method Noise Equivalency Assurance (NEA)
- Gas Calibration to Measure Accuracy and Precision
- Return Beam Intensity
- Stray Light
- Resolution
- Non-Linear Instrument Response
- Determination of Water Vapor
- Demonstration of Capability (DOC)

Setting up the Chemical Inventory. The OP-FTIR includes a complete list of compounds in the RMMSoft chemical database. All available compounds were measured by the OP-FTIR for the preliminary trials, pilot tests and field trials (**Appendix J**). However, since there were hundreds of compounds, a subset of 16 relevant compounds were selected for the initial analysis (**Table 3-2**).

Table 3-2. *Selected compounds chosen for real-time analysis*

Selected Compounds	
Benzene	Propane
Toluene	Ammonia
Ethylbenzene	Carbon Monoxide
o-xylene	Ethane
m-xylene	Methane
p-xylene	Carbon Dioxide
Formaldehyde	Nitric Oxide
Nitrogen Dioxide	Water (added as an interferent)

The spectrometer used in this study possesses software that automatically adjusts for water vapor present in both background data and downwind data runs for all sample spectra. As an interferent for each compound, water was also calculated algorithmically for each sample frame. It is important to ensure water vapor is identified as an interferent within OP-FTIR software settings since water vapor produces an overlap between the broad infrared absorbance of water and other gaseous compounds identified by the spectrometer.

Alignment of the OP-FTIR. The OP-FTIR spectrometer was aligned to the retroreflector in order to maximize the signal return. A maximized signal return translates to increased system sensitivity and increased path length performance. Optimal voltage was determined to be between 10 to 15 volts. If the voltage was too low, data accuracy was considered compromised. If the voltage is too high (18V or above), the signal was considered to be saturated. Beam configurations and alignment procedures were refined until the desired voltage was achieved.

Collecting Background Spectra. Background spectra were measured to identify potential upwind emitting sources contributing to emissions at the study sites. Background spectra consisted of a single interferogram that was used as a reference spectrum for Classical Least Squares (CLS) processing. A new background spectrum was collected prior to each sampling event at each site. **Figure 3-4** provides an example of the background signal output from the OP-FTIR software.

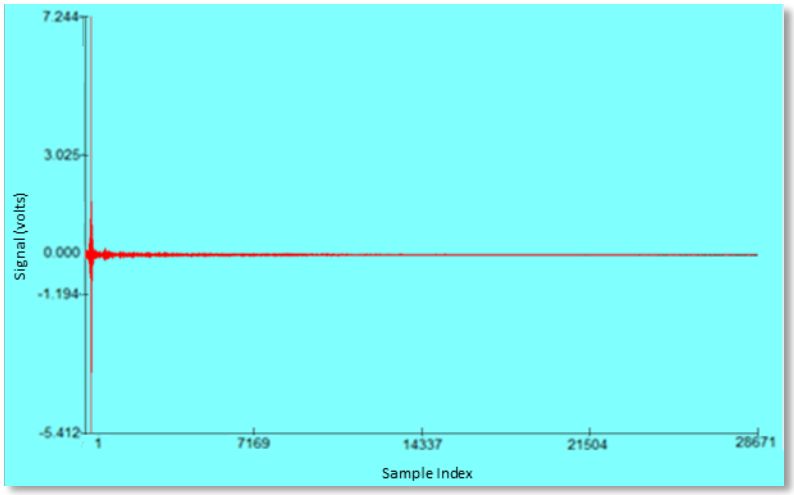


Figure 3-4. *Background Signal Output from the OP-FTIR*

Collecting Signal Data. Concentrations were monitored on a frame by frame basis during the field trials. Data were collected in 2.5 minute intervals for approximately 4 hours at each site. Real-time analysis was selected for each of the 16 compounds (see **Table 3-2**) as well as selected weather data (i.e., temperature, barometric pressure, wind direction, relative humidity, wind speed, and wind tilt).

Post Processing and Modeling. A concentration rose was developed (see **Figure 3-5**) that demonstrated the methane average concentration and average MDL values as a function of wind direction over time. This was particularly useful when determining the source of emissions released in a given area. There are four rings on the plot. Each ring represents a different average value, as delineated in the text box to the left of the plot. The directions indicate the direction from which the wind is blowing (standard meteorological definition), not to which direction the chemical is blowing.

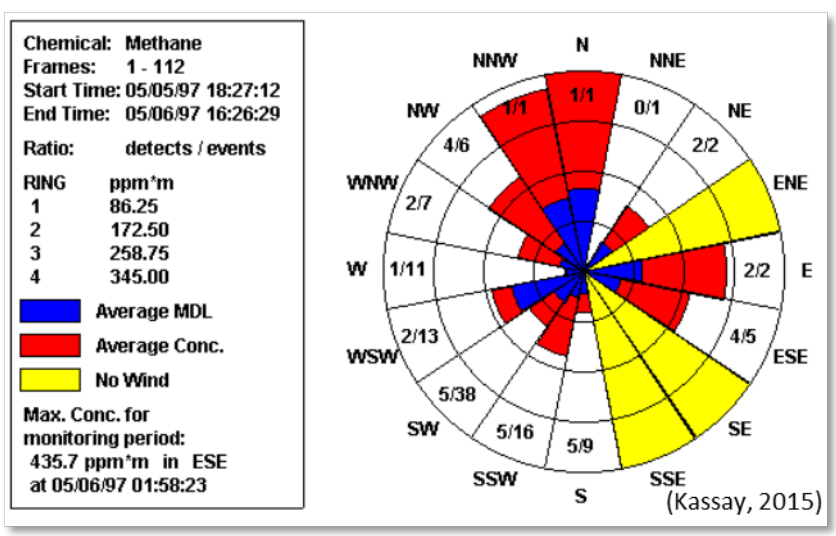


Figure 3-5. *Concentration Rose Output from the OP-FTIR*

Weather data can be presented in either English or Metric units, and include the following:

- Temperature in Fahrenheit, Celsius or Kelvin
- Wind Speed in either miles per hour or meters per second
- Relative humidity (as a percent of full saturation)
- Barometric pressure
- Wind velocity
- Wind Direction

An analysis summary report was developed for all signal-processing algorithms performed for all relevant compounds. For each compound, the concentration, the standard deviation and a detailed analysis report was developed that contained chemical processing results for each region for which it was analyzed to include the start frequency (wavenumbers), stop frequency, concentration, and 3σ values.

3.4.2 *Methane Release Test – TAMU-SA*

Two controlled methane release tests were conducted at TAMU-SA on April 10, 2014 and May 1, 2014 to validate instrumentation accuracy and test various infrared beam configurations. Setup of the OP-FTIR spectrometer, weather station, retroreflector, and methane release system for the April test is illustrated in **Figure 3-6**.

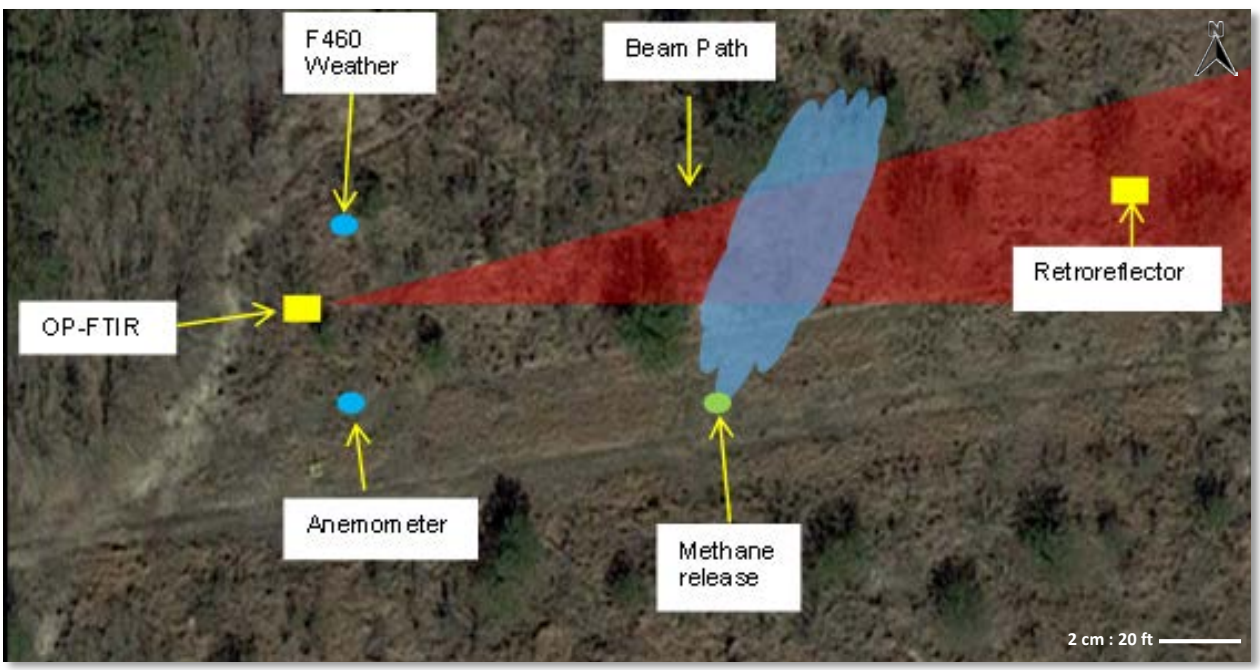


Figure 3-6. *Preliminary Trial Study Site, TAMU-SA, Texas – April 10, 2014*

Figure 3-7 displays methane concentrations exceeding the default warning value indicators (i.e., the Warning and Trigger levels). Note the correlation to the spectral graph just below the columns. The small peak at the bottom is a small amount of o-xylene. To test the OP-FTIR's ability to detect an increase in methane, the cylinder release rate was increased from 41 liters per minute (lpm) to over 60 lpm. The release spikes are shown in **Figure 3-8**.

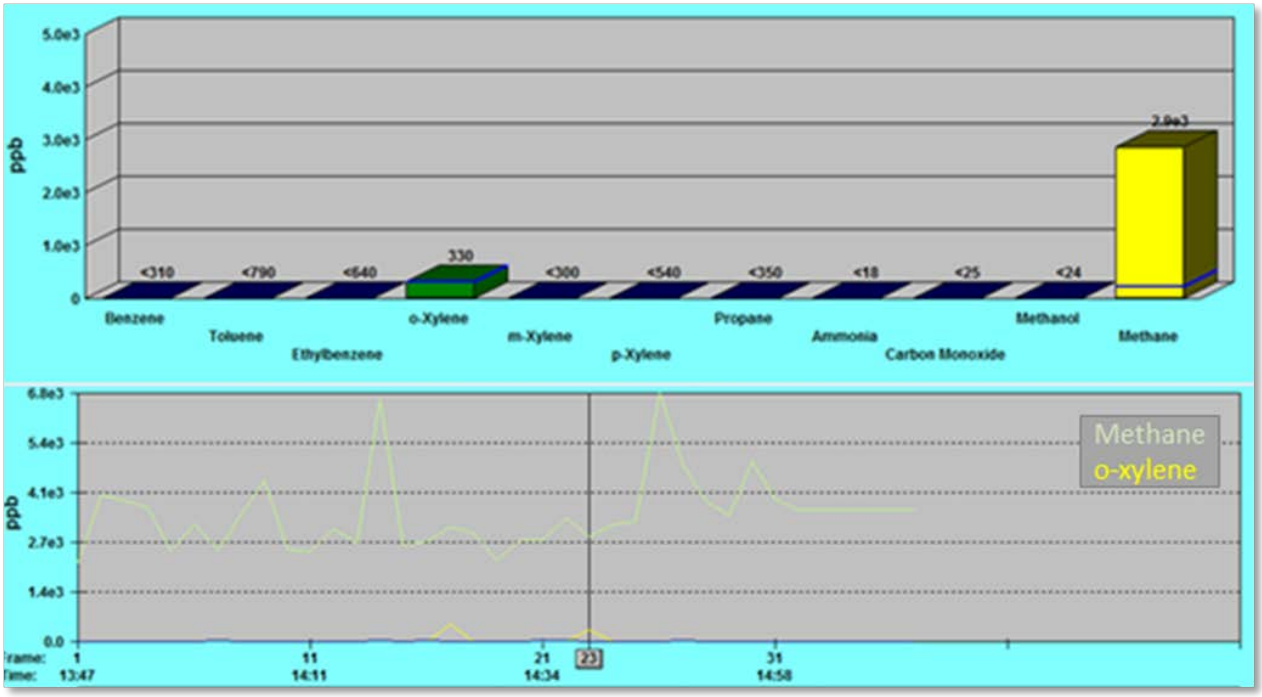


Figure 3-7. *Preliminary Trial - Concentration Graph for Methane Release Rate of 41 lpm*

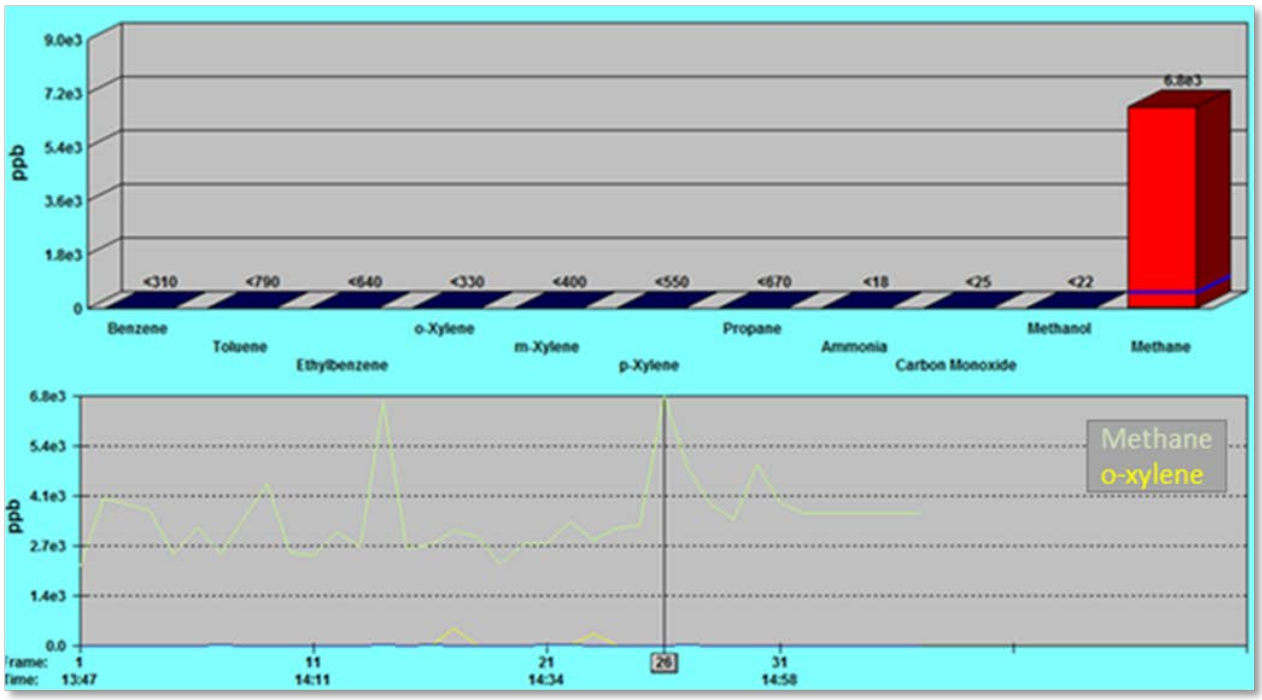
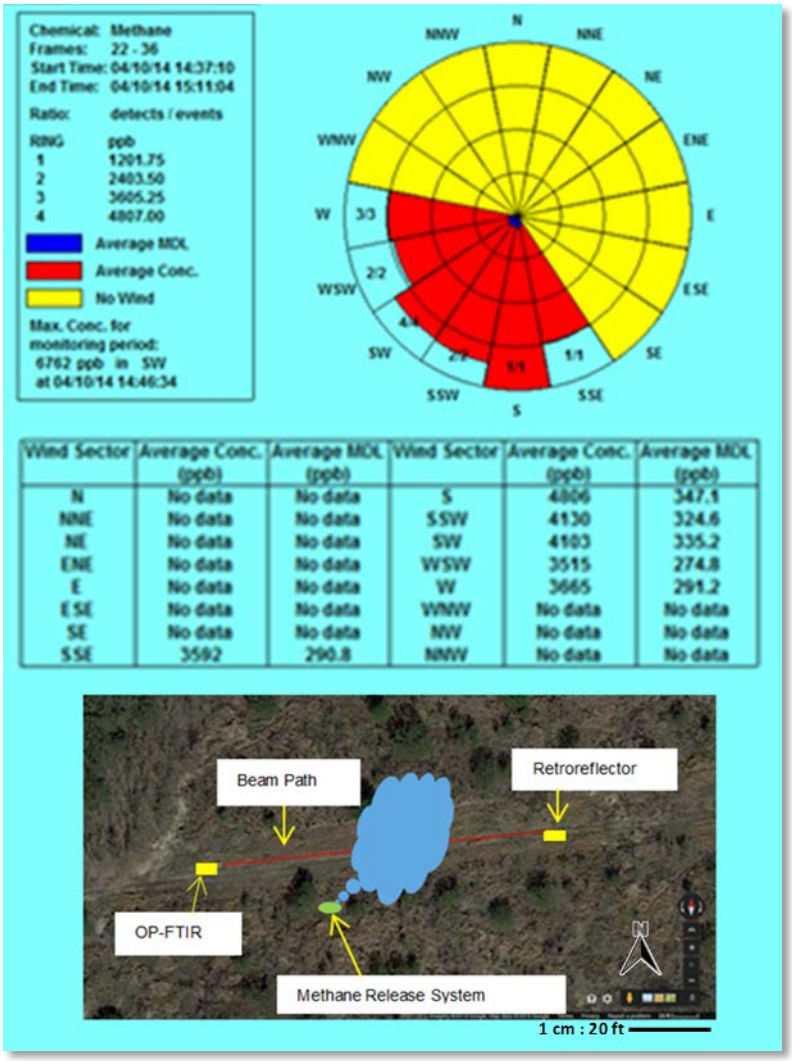


Figure 3-8. *Preliminary Trial - Concentration Graph for Methane Release Rate of 60 lpm*

The integrated meteorological sensor indicated that the source of the methane originated from the southwest, which was the precise location of the methane release system (see **Figure 3-9**).



Wind Sector	Average Conc. (ppb)	Average MDL (ppb)	Wind Sector	Average Conc. (ppb)	Average MDL (ppb)
N	No data	No data	S	4806	347.1
NNE	No data	No data	SSW	4130	324.6
NE	No data	No data	SW	4103	335.2
ENE	No data	No data	WSW	3515	274.8
E	No data	No data	W	3665	291.2
ESE	No data	No data	WNW	No data	No data
SE	No data	No data	NW	No data	No data
SSE	3592	290.8	NNW	No data	No data

Figure 3-9. *Preliminary Trial - Concentration Rose and a Top View of the Study Site*

3.4.3 *Pilot Test - Clover Lawn Park*

The primary objective of the Clover Lawn pilot tests was to further validate desired beam configurations (observed at the TAMU-SA preliminary trials), refine quality assurance techniques and validate the technology integration of meteorological sensors within a complex ambient air setting. Pilot tests were conducted on April 17, 2014 and April 25, 2014, to test emissions in the air that may be occurring from nearby construction. Setup of the OP-FTIR spectrometer and associated equipment is illustrated in **Figure 3-10**.

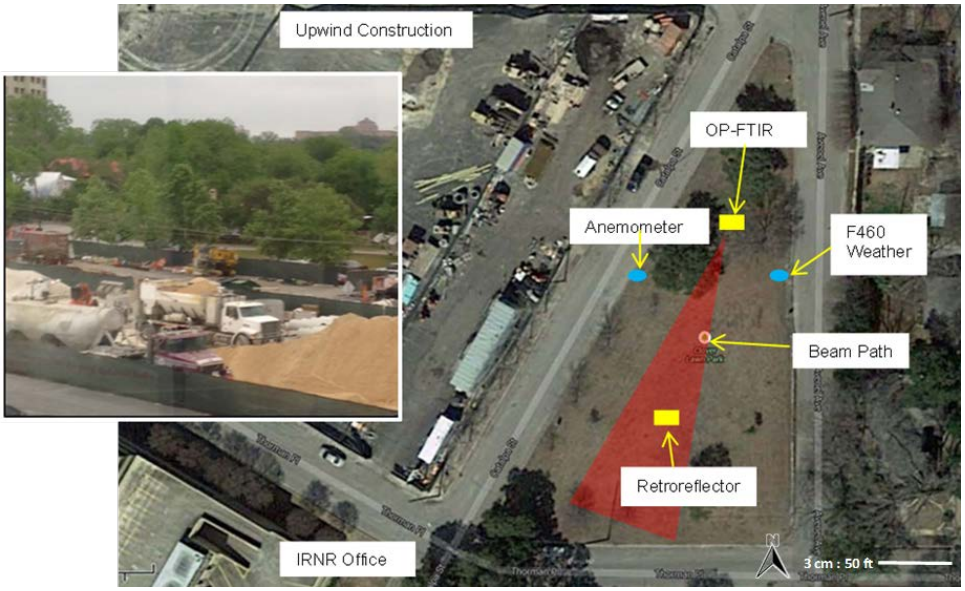


Figure 3-10. *Pilot Test Site, Clover Lawn Park, San Antonio, TX; Inset: Photo of Construction Adjacent to the Pilot Test Site*

Results from the April 17 test yielded detection of multiple emissions including toluene, o-xylene, m-xylene, and carbon monoxide - all below their respective warning and trigger levels (see **Figure 3-11**).

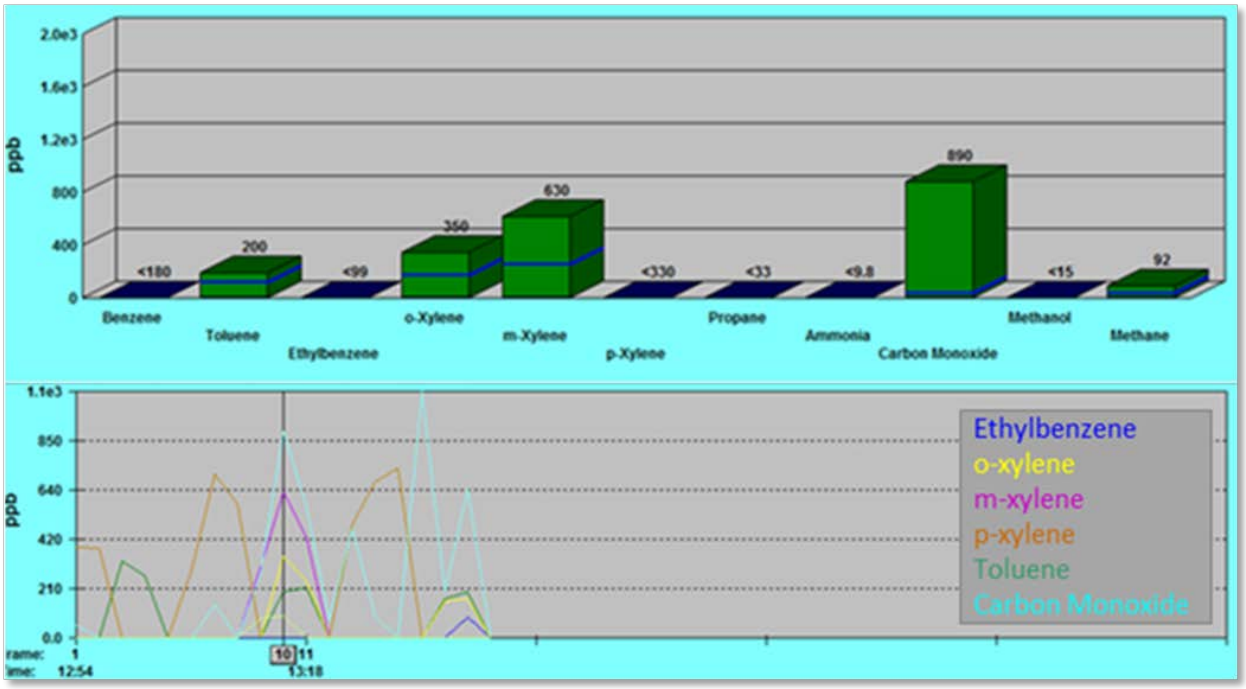
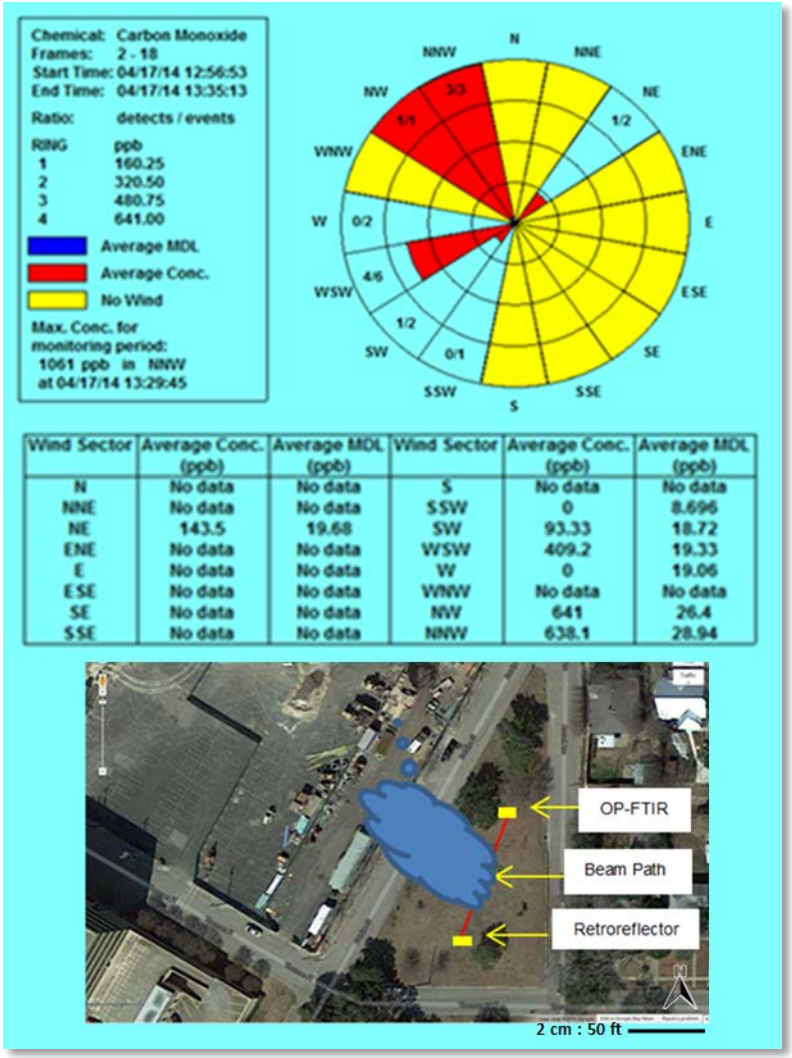


Figure 3-11. *Clover Lawn Pilot Test - Concentration Graph*

To detect the source of carbon monoxide, a concentration rose was developed and demonstrated that carbon monoxide was flowing from the northwest, the same direction as the construction activities (see **Figure 3-12**).



Wind Sector	Average Conc. (ppb)	Average MDL (ppb)	Wind Sector	Average Conc. (ppb)	Average MDL (ppb)
N	No data	No data	S	No data	No data
NNE	No data	No data	SSW	0	8.696
NE	143.5	19.68	SW	93.33	18.72
ENE	No data	No data	WSW	409.2	19.33
E	No data	No data	W	0	19.06
ESE	No data	No data	WNW	No data	No data
SE	No data	No data	NW	641	26.4
SSE	No data	No data	NNW	638.1	28.94

Figure 3-12. *Pilot Test - Concentration Rose Showing Direction of Carbon Monoxide Source*

For the April 25th pilot test, emissions detected included toluene, ethylbenzene, m-xylene, p-xylene, and methane. As was the case with the April 17th test, all concentrations were below their respective warning and trigger levels. However, on the 25th, construction activity was relatively low compared to idling vehicles on the surrounding roads due to traffic congestion in the area. An example is ethylbenzene, a common VOC resulting from vehicles. A spike of ethylbenzene, along with lower levels of methane, can be seen in **Figure 3-13**.

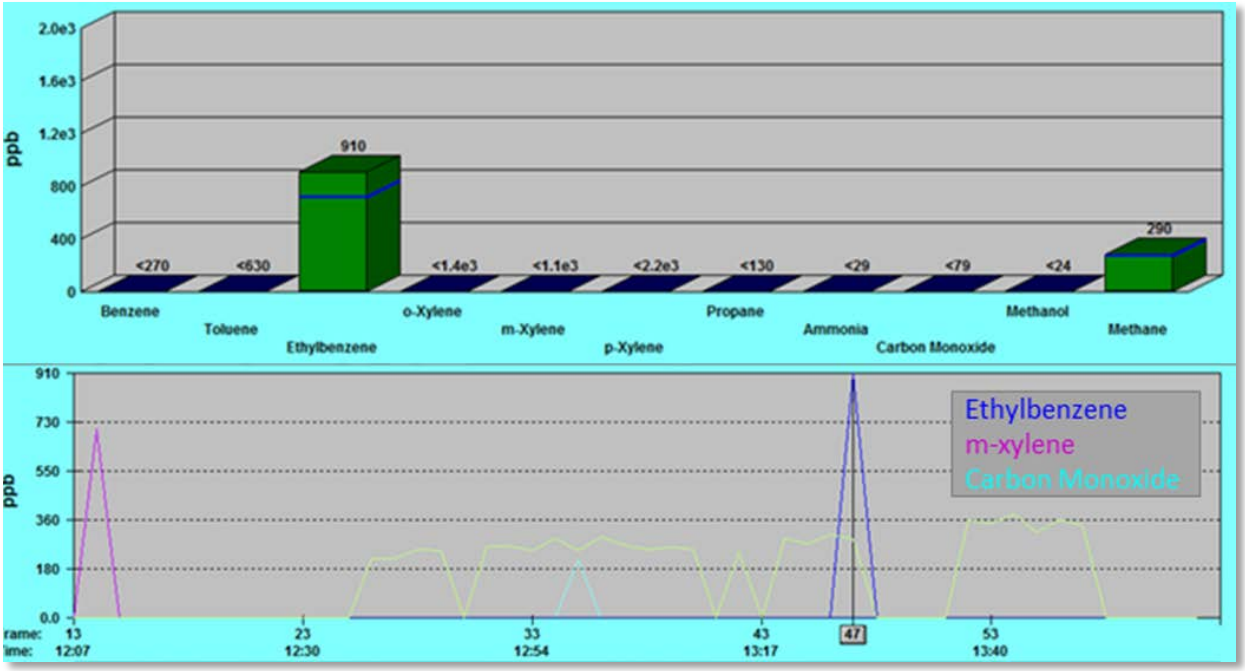
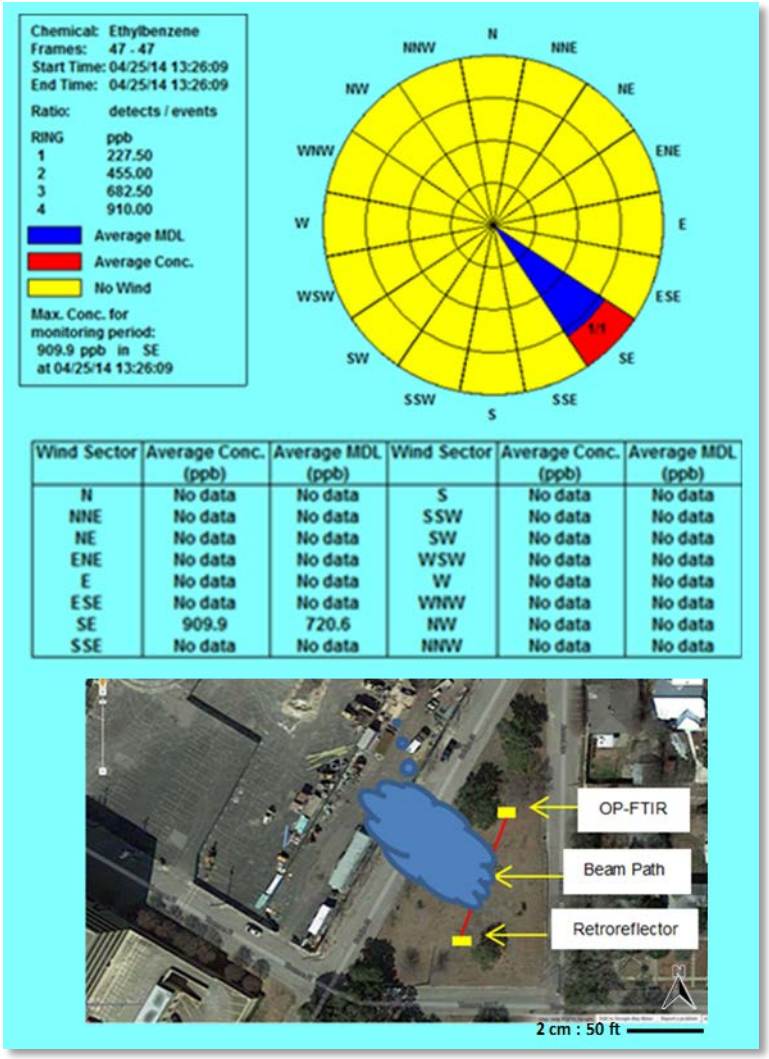


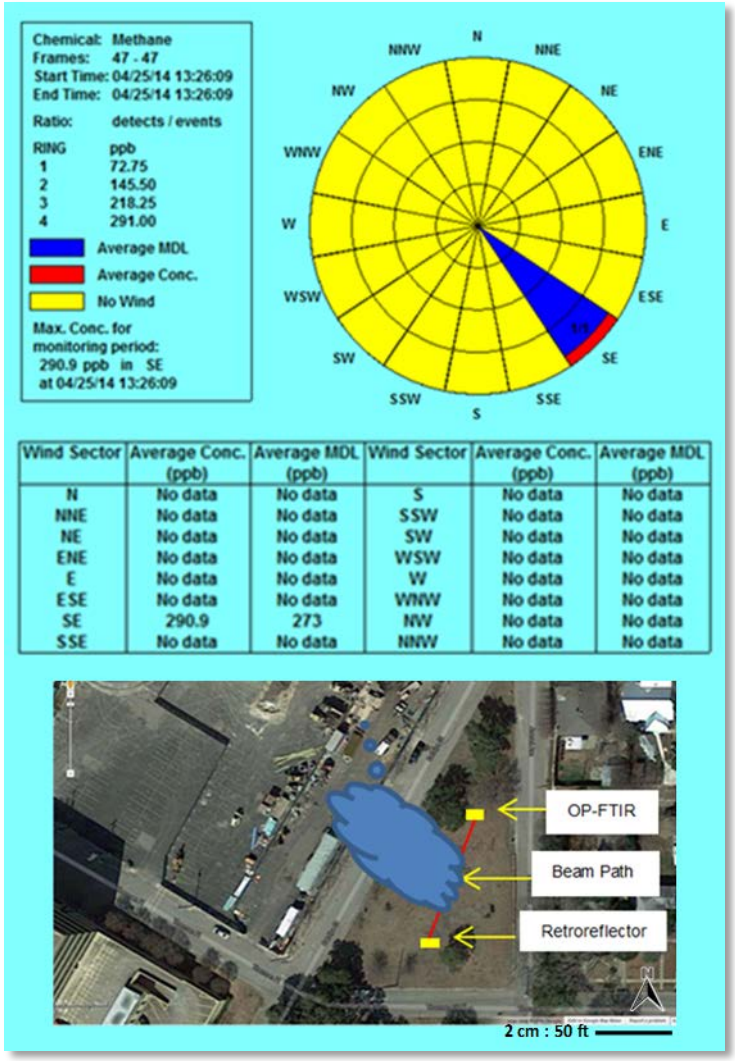
Figure 3-13. *Pilot Test 2 - Concentration Graph showing Ethylbenzene and Methane*

The concentration roses for ethylbenzene and methane show that both concentrations were coming from the southeast which would most likely be from idling and/or operating vehicles on the roadway (see **Figures 3-14** and **3-15**). Therefore, if the construction site were of interest in this study, we would, in theory, determine that the ethylbenzene and methane emissions did not result from the construction activity.



Wind Sector	Average Conc. (ppb)	Average MDL (ppb)	Wind Sector	Average Conc. (ppb)	Average MDL (ppb)
N	No data	No data	S	No data	No data
NNE	No data	No data	SSW	No data	No data
NE	No data	No data	SW	No data	No data
ENE	No data	No data	WSW	No data	No data
E	No data	No data	W	No data	No data
ESE	No data	No data	WNW	No data	No data
SE	909.9	720.6	NW	No data	No data
SSE	No data	No data	NNW	No data	No data

Figure 3-14. *Pilot Test 2 - Concentration Rose for Ethylbenzene*



Wind Sector	Average Conc. (ppb)	Average MDL (ppb)	Wind Sector	Average Conc. (ppb)	Average MDL (ppb)
N	No data	No data	S	No data	No data
NNE	No data	No data	SSW	No data	No data
NE	No data	No data	SW	No data	No data
ENE	No data	No data	WSW	No data	No data
E	No data	No data	W	No data	No data
ESE	No data	No data	WNW	No data	No data
SE	290.9	273	NW	No data	No data
SSE	No data	No data	NNW	No data	No data

Figure 3-15. *Pilot Test 2 - Concentration Rose for Methane*

3.4.4 *Field Trial – SHAPE Ranch*

The primary objective for the SHAPE ranch field trial was to collect and analyze spectral data from a production facility in the Eagle Ford Shale Play that would serve as the foundation of the protocol. SHAPE Ranch is located in the southwestern portion of Dimmit County, Texas – a 53,000-acre series of parcels that includes bison farming, honey bee farming and energy development. The site location (see **Figure 3-16**) is an oil and gas gathering and distribution point that includes oil tanks, water tanks, compressors, transfer points, separators, heater treaters, pipelines, and flares. The site was constructed in 1978 and has the potential to be a high emitter due to the aging technology and industrial processes performed at the site.

Figure 3-16. *Field Trial Sampling Site, SHAPE Ranch - May 27, 2015*

Of the 16 compounds measured, 5 were observed above background levels: methane, ethane, carbon monoxide, o-xylene and propane. Compounds were identified and quantified via a computer-based spectral search involving sequential, compound-specific analyses and comparison to the system's internal reference spectra library. Methane was detected most frequently and had the highest concentrations averaging 2,184.80 ppb throughout the monitoring period. Methane concentrations rose to 3,581.80 ppb at 1:46pm. Ethane followed a similar pattern as methane but at a lower average of 783.73 ppb. Carbon monoxide also followed a similar pattern to methane and had a high rate of detection with average concentrations of 887.99 ppb and a spike in concentration at 1:43pm that reached 2,508.00 ppb. O-Xylene was detected at an average of 1,726.60 ppb; increasing in concentration later in the afternoon. O-xylene had a high concentration of 2,669.10 ppb at 2:02pm. Propane was detected throughout the sampling period at very low concentrations (460.37 ppb at 13:29 and 197.46 ppb at 14:11). Similarly, benzene, toluene, and ethylbenzene were detected sporadically throughout the sampling period at very low concentrations (< 200 ppb) (see **Table 3-4** and **Figure 3-17**).

Table 3-3*. Concentration Summary Report (ppb) - May 27, 2016 Sampling Event*

Time	Methane	Ethane	Carbon Monoxide	o-Xylene	Propane
13:22:32	3,188.80	1,020.60	2,125.10	0.00	0.00
13:24:53	2,800.70	1,125.60	554.12	0.00	0.00
13:27:14	767.96	0.00	446.55	1,035.40	0.00
13:29:34	3,499.90	1,338.10	2,023.60	0.00	460.37
13:31:55	3,152.60	1,102.50	2,004.80	0.00	0.00
13:34:19	1,904.80	580.65	217.85	1,596.00	0.00
13:36:39	0.00	0.00	67.19	0.00	0.00
13:39:05	2,961.10	1,106.00	1,212.50	0.00	0.00

Time	Methane	Ethane	Carbon Monoxide	o-Xylene	Propane
13:41:26	3,138.00	1,213.70	1,925.00	0.00	0.00
13:43:46	2,960.10	935.68	2,508.50	0.00	0.00
13:46:07	3,581.80	1,330.40	2,370.20	0.00	0.00
13:48:28	1,607.40	468.27	974.58	1,272.70	0.00
13:50:49	1,259.20	374.27	69.32	1,184.10	0.00
13:53:10	2,375.10	622.28	1,089.40	0.00	0.00
13:55:31	2,188.20	658.26	1,109.90	1,909.30	0.00
13:57:51	1,971.40	659.07	655.68	1,957.00	0.00
14:00:12	3,514.30	1,162.90	1,921.40	0.00	0.00
14:02:33	3,426.60	1,152.80	2,025.10	2,669.10	0.00
14:04:54	2,216.20	657.83	670.49	1,654.40	0.00
14:07:15	2,132.50	711.79	369.15	2,104.50	0.00
14:09:36	1,779.70	469.48	658.40	1,508.40	0.00
14:11:57	1,511.90	403.12	233.41	1,542.50	197.46
14:16:11	2,128.20	573.59	1,041.50	0.00	0.00
14:18:46	2,128.20	573.59	1,041.50	0.00	0.00
14:23:09	1,320.70	451.49	291.73	1,098.00	0.00
14:25:37	1,320.70	451.49	291.73	1,098.00	0.00

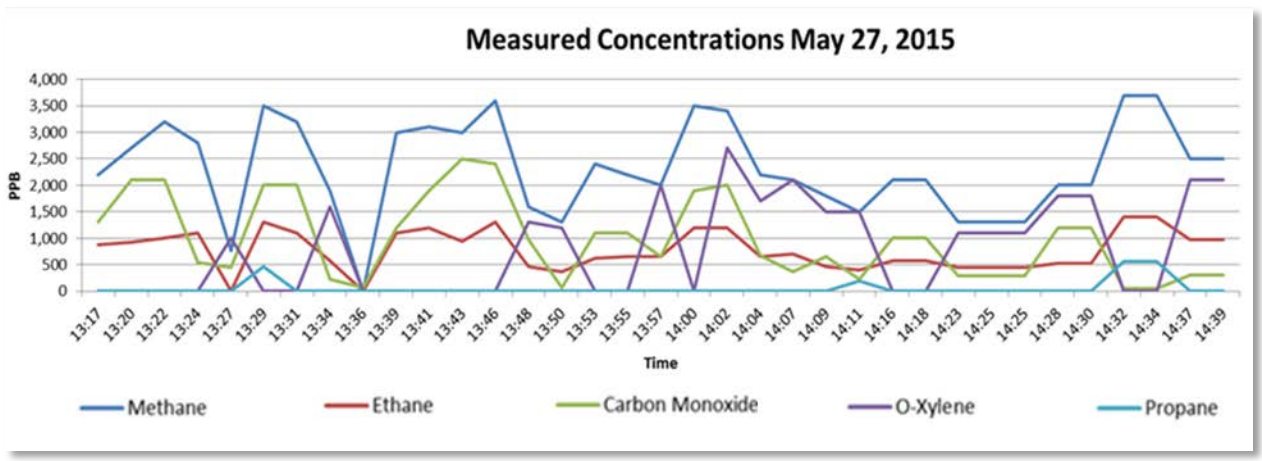


Figure 3-17. *Concentrations Measured Over Time*

The similar ratios of methane and ethane demonstrated in **Figure 3-17** implies that the sources of methane are primarily thermogenic rather than biogenic because natural gas formed by thermogenic processes (such as the formation of shale gas) will also contain ethane. However, when bacteria generate "microbial" gas (such as enteric fermentation), they create mainly methane. The similar ratio of carbon monoxide to both methane and ethane more specifically implies that this particular source of methane originated from a combustion engine. This makes sense because a compressor was observed operating directly upwind of the sample site.

A concentration rose analysis was performed using average compound concentrations as a function of the wind direction over time. This analysis was particularly useful for determining the

direction of the sources. **Figures 3-18a** and **b** graphically demonstrate a high likelihood that concentrations of methane were primarily coming from tanks (Source 2) and compressors (Source 1) located just north and east of the meteorological sensor and that xylene was emitted more from the lone tank (Source 3) located east/southeast of the meteorological sensor. This makes sense since the lone tank is storage for condensate which is a known emitter of xylene. **Figure 3-18c** demonstrates that carbon monoxide was emitting solely from the compressors. This makes sense since the compressors are the only sources at the site that possess a combustion engine.

To further pinpoint the exact locations of leaks from the sources identified with the OP-FTIR, a thermal gas imaging camera was employed. Thermal images of the suspected sources confirmed leaks from tanks at the thief hatches (Red Circle - **Figure 3-19a**) and leaks from the compressors at the unloading bolts (see **Figure 3-19b**). The chimneys at the top of tanks (green circle) were allowed to vent under permit. However, after viewing the footage, the operator agreed to explore various flaring technology that pipes the currently vented gas to a flare.

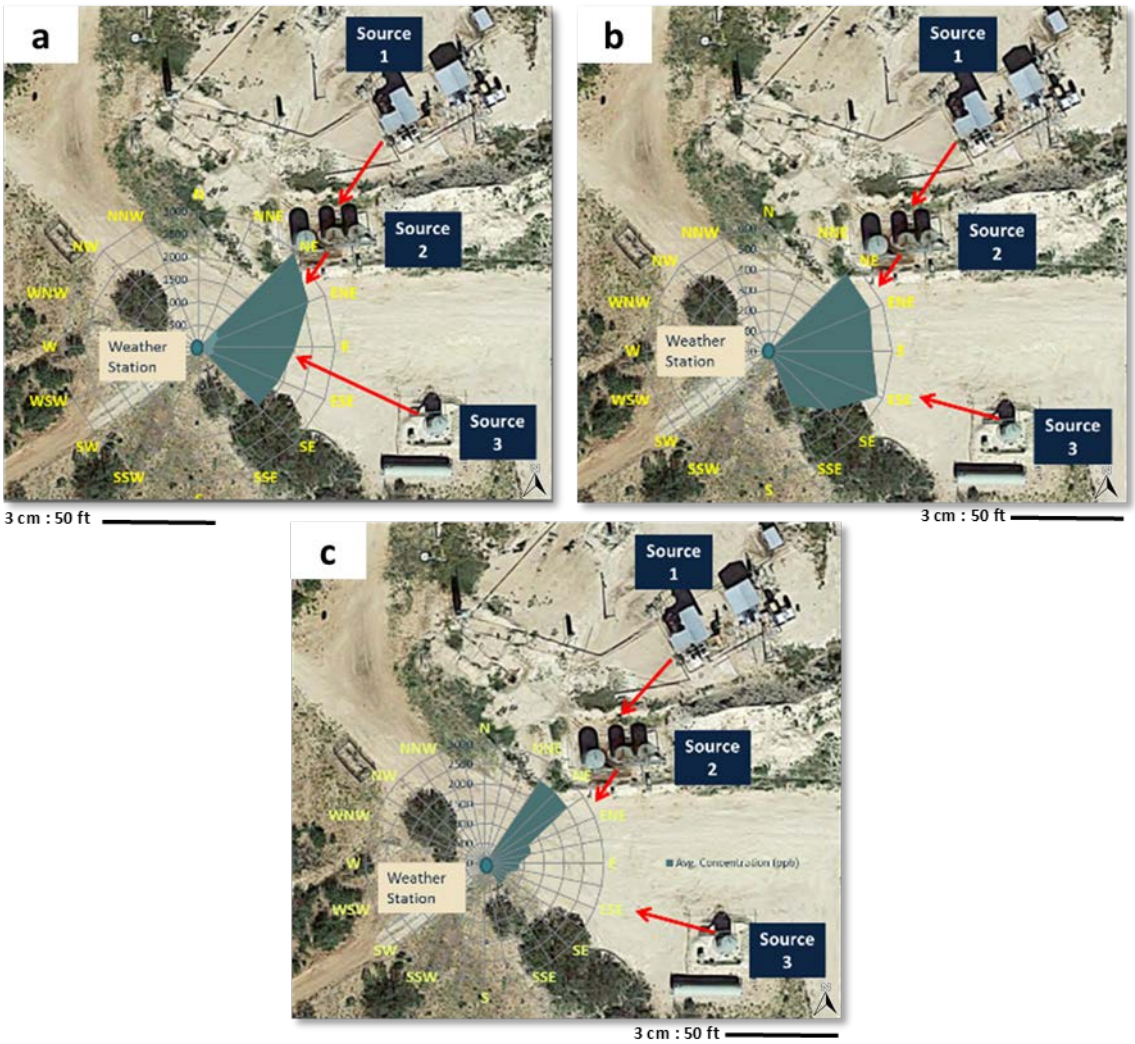


Figure 3-18. *Concentration Roses for a) Methane, b) Xylene, and c) Carbon Monoxide*

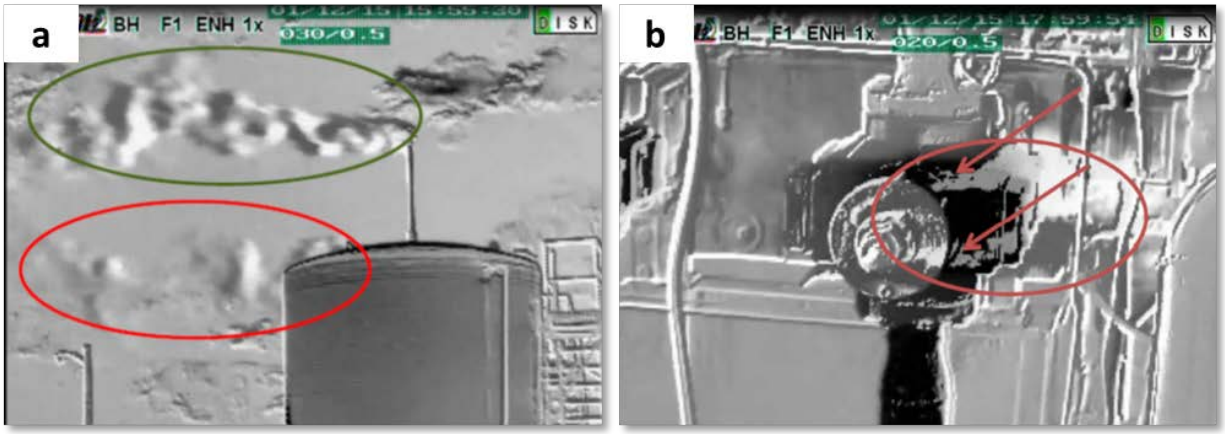


Figure 3-19. *a) Leak Detected from Tank Thief Hatch. Chimney Vent Permitted; b) Leak Detected at the Compressor*

At SHAPE Ranch, standard deviations of compound concentrations were monitored to determine times when data quality improved and when it deteriorated. For data with higher standard deviation, concentrations were compared with wind direction, wind speed and humidity to assess relationships. Deviations from analytical curve linearity in absorption spectra were avoided by applying curve fitting and Fourier convolution to the transmission spectra. Standard deviation (3σ) was compared against humidity and wind speed. **Figures 3-20** and **3-21** demonstrate a correlation between spectral interference and weather conditions. Note that as humidity decreases, the spectral interference and therefore the standard deviation also decrease. This makes sense because water vapor interferes with infrared absorbance. Similarly, spectral interference was well correlated with wind speed. As wind speed varies, standard deviation for methane exhibits similar variation.

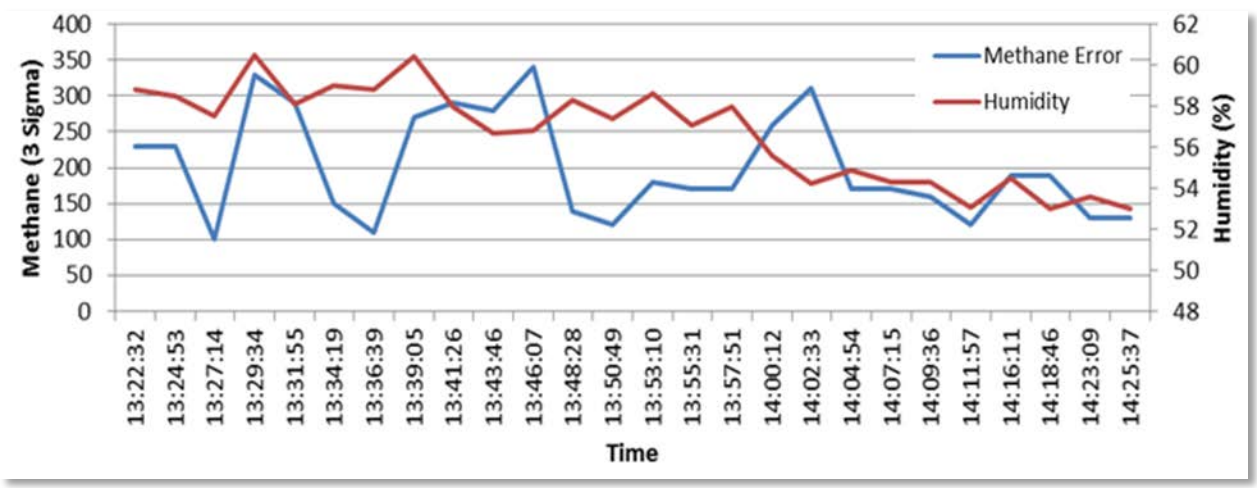


Figure 3-20. *Standard Deviation of Methane Measurements vs. Humidity*

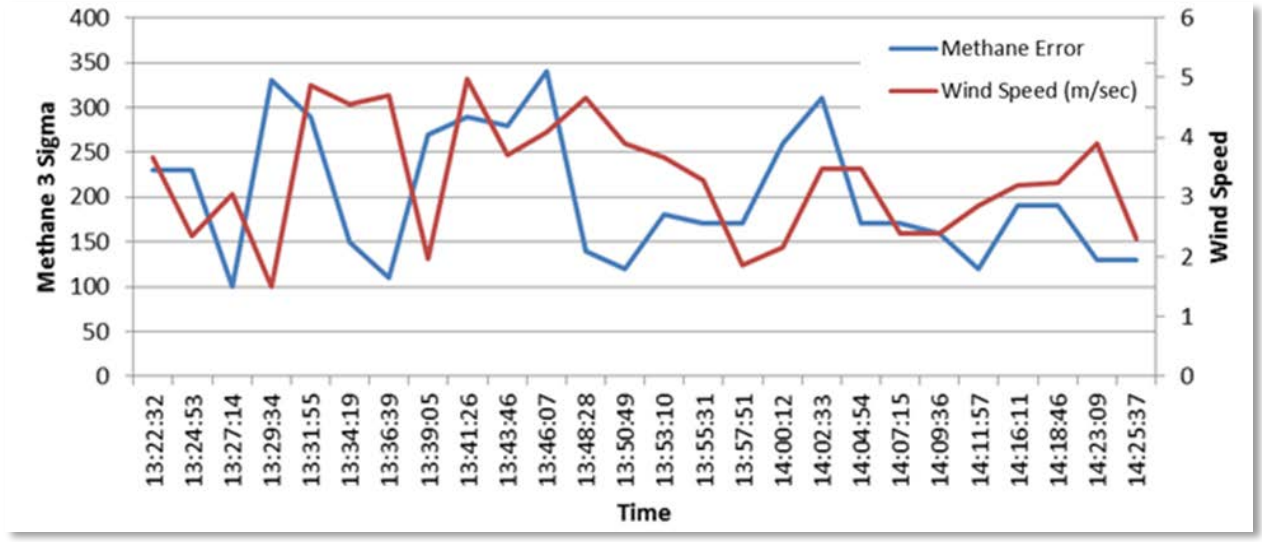


Figure 3-21. *Standard Deviation of Methane Measurements vs. Wind Speed*

3.5 Application of Protocol – Wyoming Field Trial

The protocol was used to guide air emissions monitoring from multiple produced water ponds in the Upper Green River Basin in Wyoming, part of a joint-industry project being performed by the Advanced Analytics lead, GSI. The project involved measurement of emissions using OP-FTIR, flux chamber (Utah State), meteorological sensors and summa canisters along with water sampling to develop a tool to predict air emissions using dissolved concentrations of compounds and weather conditions.

The OP-FTIR measured total absorbance of infrared energy by compounds present along the OP-FTIR beam. Synchronous meteorological data, including wind speed, wind direction, standard deviation of wind direction ("sigma theta"), and ambient temperature were collected at 5-minute intervals during OP-FTIR sampling at all transect locations. These data were collected using a portable, tower-mounted meteorological sensors positioned adjacent to the OP-FTIR instrument and a fixed on-site meteorological sensor adjacent to the pond being monitored. "Walking" air samples were collected in Summa canisters with 15-minute flow controllers and analyzed for C_2-C_{10} non-methane hydrocarbons, methanol, ethanol, and isopropanol. A model was used to predict a unit mass of VOC emissions from the pond surface and then scale the emission rate to match observed path-integrated concentrations.

The ability to disaggregate individual hydrocarbon species in a high concentration mixture of many compounds was the key challenge for analyzing OP-FTIR data. Detection limits for most compounds were increased due to interferences among the infrared absorbance peaks, causing non-detect results for many compounds that were detected by other methods. This challenge was largely overcome by the development reference spectra for lumped hydrocarbons in the C_2-C_8 and C_9-C_{12} ranges. The Wyoming project is ongoing. Preliminary results are included as an addendum to the final protocol.

3.6 Conclusions & Recommendations

The OP-FTIR was successful at speciating multiple compounds simultaneously downwind of point sources such as tanks, compressors and well heads, and its ability to collect and store concentration data on all 262 spectral compounds was useful for re-running datasets based on

new suspected compounds discovered at the sample sites. Complex plumes typically observed at ponds required the addition of summa canister sampling to help identify and speciate compounds with similar infrared absorbance. Furthermore, supplementing air sampling with water sampling aided the research team in identifying compounds likely to be present in air samples at disposal ponds where water chemistry is in constant flux.

At the SHAPE Ranch production facility, the incorporation of meteorological sensors was successful in determining the direction of the sources. The development of concentration roses clearly pointed to known emitters in both the field trials and quality assurance tests. The optical imaging camera allowed the research team to not only determine the location of the source, but also pinpoint the leak(s) at each source. This additional imaging technology proved useful to the operators of the SHAPE Ranch production facility who were interested in mitigation and repair of leaking equipment.

At the Wyoming Disposal Ponds, the OP-FTIR data was supplemented with meteorological data collected both at the pond surface and 6 feet above the berm. This proved useful for modeling dispersion occurring at the pond surface, up and over the berm. The optical imaging camera was used to scan adjacent storage tanks to establish the background profile.

Overall, the use of these three instruments together provided a robust and defensible dataset for determination of ambient downwind concentrations, as well as a defensible foundation for the development of emission rate / dispersion modeling at both production facilities and disposal ponds. Based on field trial results, a protocol was developed that provides general procedures and best practices for obtaining ambient air analysis results using an OP-FTIR with an integrated meteorological sensor and an optical imaging camera.

3.6.1 *Lessons Learned*

The ability to disaggregate individual hydrocarbon species in a high concentration mixture of many compounds was the key challenge for analyzing OP-FTIR data at disposal ponds with complex plumes and low concentrations. Detection limits for most compounds were increased due to overlap among the infrared absorbance peaks, increasing the method detection limit (MDL) and causing non-detect results for many compounds that were detected by other methods. This challenge was largely overcome by the development of reference spectra for lumped hydrocarbons in the C_2-C_8 and C_9-C_{12} ranges.

There are currently no commercially available instruments or labs capable of addressing such spectral overlap. However, there are experimental methods to calculate a total hydrocarbon reading over the averaged infrared path length with the OP-FTIR. Further laboratory grade experiments are needed to verify accuracy with this method. There is also value in the creation of a compound list that alerts researchers to compounds with high likelihood of absorbance in the same spectral region. Running a sample with these compounds together should be avoided and instead, the use of a surrogate compound could be suggested (ex. a compound likely to present in the presence of the other compound).

3.6.2 *Next Steps*

Next steps for research related to measurement of air emissions from oil and gas operations using the OP-FTIR, optimal imaging camera and meteorological sensors include:

- **Disaggregating leak rate and frequency:** Leak rates and leak frequency from oil and gas operations such as production and storage facilities are not well understood. With a repeatable and defensible methodology in place, leak rate and frequency can be measured with enough statistical confidence to develop emission factors.

- **Addressing spectral overlap with an OP-FTIR total hydrocarbon method or surrogate compounds:** A list of compounds that absorb in the same spectral region, (i.e., causing increases in error) should be created and tested to reduce uncertainty due to multiple (sometimes hundreds) of compounds absorbing within the same infrared regions.
- **Miniaturizing and mobilizing the OP-FTIR:** Although highly accurate, the OP-FTIR is heavy and cumbersome to set up and tear down. Mobilizing the OP-FTIR via trailer mounting or even miniaturizing the technology will make field measurements more efficient.
- **Understanding the plume in its entirety:** The OP-FTIR is a ground-based instrument and therefore misses the upper boundaries of large plumes. It also misses heated plumes from flares. Recommended future research should include deploying elevated sensors to capture more of the plume at higher elevations and compare to ground-based measurements.
- **Use of tracer gases at production facilities:** Use tracer gas to produce defensible area source emission rates for production facility equipment. Tracers require placement of instrumentation at least 500 feet downwind of the source to allow for appropriate mixing of tracer and plume. Therefore, tracer gases, tracer ratio methods and modeling software require additional validation and field testing to produce defensible area source emission rates.

FLOWBACK/PRODUCED WATER CHARACTERIZATION

Objectives: The objective of the project was to test and evaluate on-site analytical technologies to characterize flowback and produced water from unconventional oil and gas operations and support cost-effective reuse, treatment, or disposal of produced waters. Real-time measurement of key water quality parameters, paired with microbial monitoring, provides an effective system for guiding produced water management decisions with respect to well production optimization, selection of effective treatment techniques, and evaluation of produced water end uses.

GPRI Mobile Laboratory

Technical Approach: Multiple field trials were conducted to evaluate new analytical technologies for rapid quantification of dissolved ions, organics and oils, suspended solids, and bacteria in flowback and produced water. Trials were performed at the Texas A&M Riverside Pilot Plant and using the GPRI mobile laboratory in different shale plays (e.g., Permian Basin, Eagle Ford Shale in Texas, and the Woodford Shale in Oklahoma). The mobile laboratory facilitates testing of analytical instrumentation and treatment technologies under actual field conditions, which ultimately benefits oil and gas operators in determining effective treatment options to achieve water quality that will allow for recycling of produced waters or brine disposal.

Results: Produced and flowback water samples from numerous field trials were collected to evaluate the field readiness of analytical technologies. Field trials enabled the GPRI team to i) characterize the complex variety of organics and oils, dissolved ions, and microbial contents of produced waters, and ii) use the real-time results to optimize the treatment process train, such that contaminants in produced water can be removed in a cost-effective and timely manner. The GPRI team successfully attained real-time measurements of organic components, dissolved ions, and microbial activity in produced waters using a portable GC/MS, water quality field screening kits, and various fluorescence-based bacterial monitoring technologies.

Conclusions/Recommendations: Field-based technologies offer rapid qualitative (and semi-quantitative) measurement of organics and oils, water quality, and microbial activity; however, for accurate measurement of individual constituents or bacterial species, the use of a certified laboratory is recommended. Further testing needs to be conducted to achieve laboratory-quality analysis in field-ready technologies that will efficiently and accurately analyze flowback and produced waters for oil concentrations, microbial activity (affecting the production life of a new well), and dissolved ions.

Benefits to Producers: Hydraulic fracturing costs can be significantly reduced if produced brines or brackish water are reused for completions operations. Numerous studies have shown that such waters must be pre-treated before mixing with fracturing fluid chemicals. Rapid field evaluation of the chemical characteristics of wastewater associated with hydraulic fracturing is critical to developing effective treatment and cost-effective disposal options. Accurate and timely analysis of field fluids at any point in the treatment train is a necessary step if oil and gas operators are to meet new environmental reporting requirements for fracturing fluids and effectively manage and treat flowback and produced water.

4.0 FLOWBACK/PRODUCED WATER CHARACTERIZATION

4.1 Problem Statement & Objectives

Production engineers who are responsible for unconventional operations have discovered that water management is a critical, and potentially expensive, component of oil and gas development (Bailey et al., 2000). With hydraulic fracturing operations requiring millions of gallons of water per well, the acquisition, transportation, storage, treatment and disposal of water can represent a significant percentage of total project cost. Fortunately, industry is reaching a consensus that fresh water is not always necessary for hydraulic fracturing operations and produced water can be reused if proper analysis, and subsequently treatment, is performed.

The use of recycled water for hydraulic fracturing operations is becoming more common as tougher government regulations on water come into place and as production wells are drilled in areas prone to drought. However, high salinity brines can be problematic for reuse. Produced water generally contains high concentrations of dissolved ions, which can serve as electron acceptors and donors for bacterial growth reactions in both aerobic and anaerobic waters. In addition, water hardness (calcium and magnesium content) can cause issues with water transport, use, and storage through precipitation of dissolved minerals (or scaling). Removal of scaling ions and assessing the compatibility of makeup waters with “frac chemical packages” are important considerations for oil and gas professionals. Real-time measurement of key water quality parameters, paired with microbial monitoring, provides an effective system for guiding produced water management decisions with respect to well production optimization, selection of effective treatment techniques, and evaluation of produced water end uses.

The overall goal of the Flowback/Produced Water Characterization component of the project was to test and evaluate on-site analytical technologies to characterize flowback and produced water from unconventional oil and gas operations and support cost-effective reuse, treatment, or disposal of produced waters. A three-year program of pilot plant and field trials was conducted by GPRI to identify effective on-site analytical technologies for rapid quantification of key parameters such as biological activity, organics and oils, cations and anions, and dissolved and suspended solids in flowback and produced water. Based on the results of field trials, technology summaries (or “fact sheets”) were developed to support the testing and deployment of new “field ready” products facilitating rapid produced water characterization.

4.2 Current Analytical Technologies

Analytical techniques presently used to analyze flowback water and produced brines often fail to sufficiently characterize chemical compositions in a timely manner. This is due to the highly ionic, multi-phase, and time-variable composition of fluids generated during hydraulic fracturing. Flowback and produced water presents specific chemical and bacteriological characteristics that differ from all other natural, surface water or groundwater sources or industrial wastewater sources, limiting the applicability of traditional water quality testing methods. As a result, poor documentation, inappropriate treatment and improper disposal threaten the efficiency of hydraulic fracturing operations.

Advanced on-site brine analysis methods were first used by GPRI in their mobile laboratory in a technology field trial for produced water treatment for beneficial reuse in upstate New York in 2011 (Burnett et al., 2012; 2015). Efforts there, and additional work in the Marcellus Shale (Burnett et al. 2012), showed the need for higher level analytical monitoring of processing techniques to analyze and treat brines. As gas shale development has grown, the need for a more focused approach on monitoring and analytics has become apparent.

A variety of analytical technologies are available to oil and gas professionals that have been adapted from drinking water and wastewater applications for quantification of bacteria, organics and oils, and water quality parameters (e.g., cations and anions, dissolved and suspended solids).

Bacteria: Standard plate count methods for quantifying bacteria in water samples are time-consuming, potentially underestimate bacteria populations, and often do not provide information on specific bacteria type. Newer fluorescence-based technologies can be used on a variety of water matrices, but some can be prone to false negative and false positive results when employed for use on produced waters, due to high salinity and matrix interferences.

Organics and Oils: Typically, analytical methods such as USEPA 1664A employ hydrophobic solvents to extract organics from the sample, followed by quantification using a variety of methods: infrared absorption, gravimetric-based method, or gas chromatography and flame ionization (Yang, 2011). Although these standard methods are well-established, they are time-consuming and do not support real-time, on-site decision-making for produced water management.

Water Quality: Water quality field kits and other measurement technologies are currently available to oil and gas professionals for rapid testing of various parameters in produced water. Key dissolved constituents and field indicator parameters include ammonia, nitrate, chloride, boron, total dissolved solids (TDS), turbidity, electrical conductivity (EC), pH, and others. Field-ready kits that use colorimetric and ion-selective electrode analyses offer an advantage over standard laboratory analytical methods that are often expensive and have long turnaround times. However, the kits are not intended to provide full quantitative analysis, but rather serve as a screening tool for further water characterization, where necessary.

4.3 Technical Approach

Multiple field trials were conducted to evaluate new analytical technologies for produced water characterization under actual field conditions. Trials were performed at the Texas A&M Riverside Pilot Plant (receiving produced waters from the Austin Chalk, Buda and Eaglebine formations), and in the GPRI Mobile Laboratory in different shale plays, including the Permian Basin, Eagle Ford Shale in Texas, and the Woodford Shale in Oklahoma. All new technologies assessed under this project were initially tested in GPRI's pilot plant prior to inclusion in GPRI Mobile Laboratory field tests. At each location, the team performed on-site and real-time measurement of produced water constituents including bacteria, dissolved and suspended solids, cations and anions, organics and oils, and assessment of overall process train performance.

4.3.1 *GPRI Mobile Laboratory*

The GPRI team constructed a field mobile laboratory, capable of testing flowback and produced water real-time using advanced analytical technologies to monitor water quality during each step of the treatment process (see **Figure 4-1**). The mobile laboratory facilitates testing of analytical instrumentation and treatment technologies under actual field conditions, which ultimately benefits oil and gas operators in determining effective treatment options to achieve water quality that will allow for recycling of produced waters or brine disposal. Recently, the mobile laboratory was upgraded to increase processing from 20 barrels/day (b/d) to 200 b/d and was instrumented to allow for 24-hour unattended filtration testing with remote monitoring. A schematic of the treatment process train is depicted in **Figure 4-2** including pre-treatment units (i.e., screen, coalescer), micro- and nano-filtration columns, and sampling locations (6) for feed and permeate waters throughout the water treatment process.

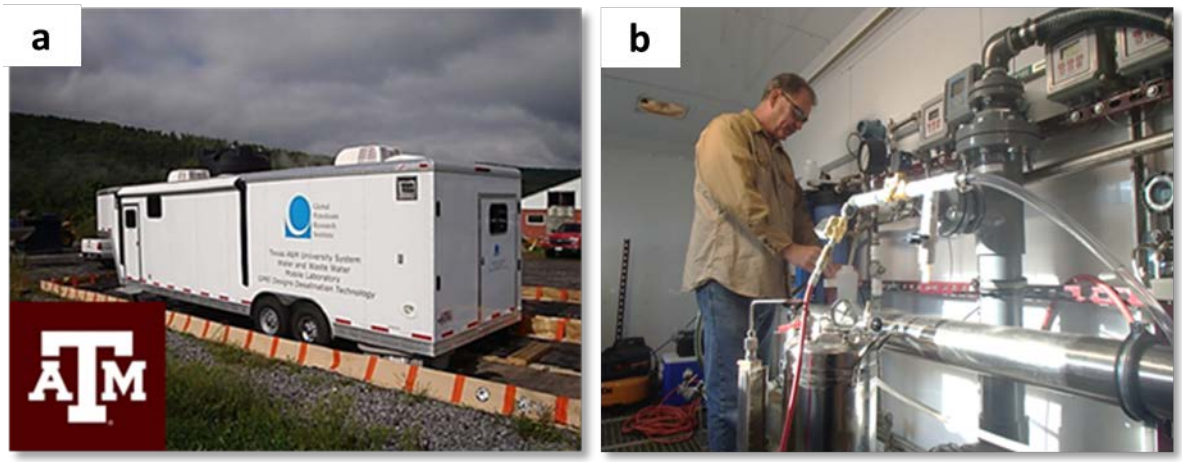


Figure 4-1. *a) Exterior and b) interior view of the GPRI mobile laboratory*

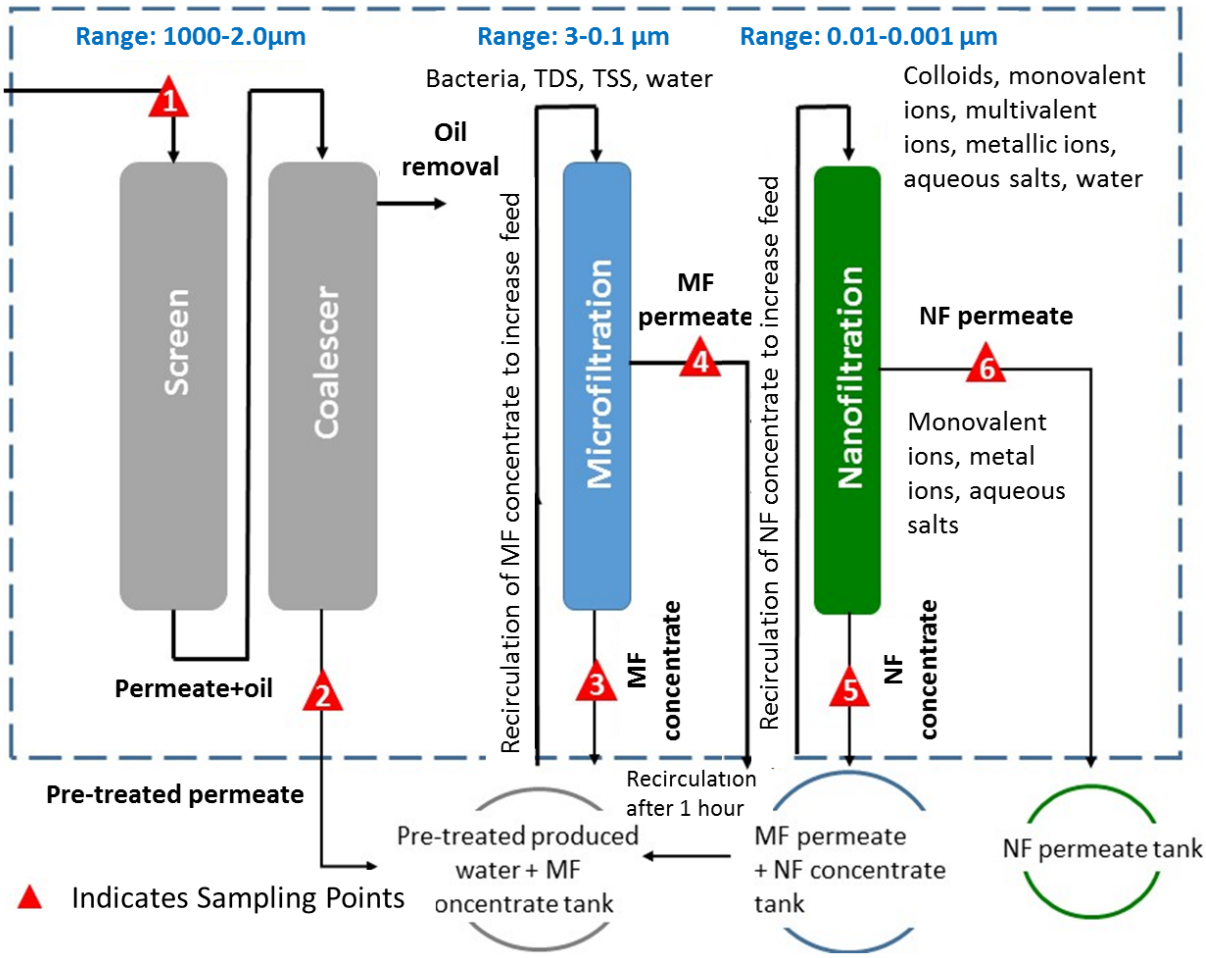


Figure 4-2. *Schematic of GPRI mobile laboratory treatment train*

For many field trials, feed and permeate samples collected from various stages of the treatment process were used for two purposes: i) to perform side-by-side comparisons of on-site analytical

instrumentation for real-time quantification of various produced water constituents (e.g., bacteria, organics and oils, TSS, and water quality parameters) and ii) to evaluate the efficacy of various filtration technologies as part of the Environmentally Friendly Drilling Systems (EFD) Technology Integration Program (TIP) (RPSEA 10122-06, 2016).

4.3.2 *Field Trial Locations*

Field trials were conducted in the Woodford Shale, Permian Basin, and Eagleford Shale, in addition to the Texas A&M Riverside Pilot Plant where produced waters of varying composition were received from a nearby disposal facility for testing. Additional field trials were conducted by the GPRI team to investigate water quality concerns from homeowners located in close proximity to oil and gas production facilities. GPRI field trials are listed in **Table 4-1** and described in detail in the sections below. Select photos of the GPRI mobile laboratory, Texas A&M Riverside Pilot Plant, and field trials are provided in **Appendix L**.

Table 4-1. *Field Trial Locations*

Field Site	Date	Description
Texas A&M Riverside Pilot Plant	Spring 2014 Spring 2015 Summer 2015	Testing and equipment calibrations performed in A&M GPRI lab and surrounding oil and gas production operations allowed researchers to choose analytical technologies that best suited the scope of the study
Woodford Shale, Tishomingo, OK	Fall 2013	Preliminary field trial to test analytical technologies and treatment process train and to train student technicians
Permian Basin, Midland, TX	Fall 2014	Mobile laboratory set up at a salt water disposal (SWD) facility, which received brines from three different pads and multiple wells. The purpose was to test analytical technologies for evaluating modified ceramic microfiltration treatment efficacy
Eagle Ford Shale, Lee, Dimmit, and DeWitt Counties, TX	Spring 2015	Texas A&M technicians provided assistance to Texas Agri-Life County Extension agents' work with landowners in the Eagle Ford Shale, answering their questions about water quality in residential wells and ponds

Texas A&M Riverside Pilot Plant, Brazos County, TX. Texas A&M's Riverside campus lies adjacent to a number of oil and gas operating leases with production from the Buda, the Austin Chalk, and the Eaglebine Formations. The Eaglebine is the northern most extension of the Eagle Ford formation and has been actively developed in the past 5 years. Surrounding the Eagle Ford Shale, the Austin Chalk (directly overlying) and Buda Limestone (one layer below) are commercial oil reservoirs located along a 250-mile trend through South Texas. In Spring 2014, the GPRI team took advantage of the proximity of leases and numerous salt water disposal wells in the area to create a large-scale pilot plant, facilitating testing of new on-line analytical sensors under field conditions using local produced water. The pilot plant provided a side-by-side comparison of analytical technologies appropriate for field operations in concert with the treatment technologies evaluated as part of the EFD-TIP program (RPSEA 10122-06, 2016).

Woodford Shale, Johnston County, OK. The GPRI team moved the mobile laboratory to the Tishomingo, Oklahoma field site in November 2013 and set up for operation at the main yard of Nitro Lift Technologies. This location is set up with newly lined tanks to hold produced water that is trucked in from nearby production wells in the Woodford Shale. The team tested the GE *InnovOx*, HAPSITE GC/MS, and HACH ultra high salinity analytics during this field trial. Favorable results from this early field work and technology evaluation (details in **Section 4.4.2**) allowed for alterations to procedures and technologies used in the later field trials.

Permian Basin, Ector County, TX. Trials were performed during the fall of 2014, to determine which analytical technologies to confirm treatment of produced water from Permian wells using a modified process train which included ceramic microfiltration. The trial was set up at a salt water disposal facility which received brines from three different well pads and a number of individual wells. Analytical technologies for measurement of total organic carbon (TOC), total suspended solids (TSS), and TDS were evaluated along with microbial activity monitoring in both untreated and treated brines.

One of the major trials performed at this site was to test microbial activity in the "communal" source waters of field operations—water that multiple operators use for completions activities. At the time of the trials, the most common field technique was to use HACH Biological Activity Reaction Test (BART) vials to perform semi-quantitative analysis of microbial activity. Testing required incubation of field samples for at least five days to determine possible presence of offending biological activity. For microbial monitoring, the HACH BART vials were used alongside a new analytical procedure for quantifying microbial activity, called the Modern Water QuickChek™ Sulfate Reducing Bacteria (SRB), as well as the Mycometer Bactiquant®. Results are discussed in **Section 4.4.1**.

Eagle Ford Shale Field Trials. GPRI technicians worked with Texas A&M Agri-Life Extension agents to assist landowners in the Eagle Ford Shale with questions about water quality of residential wells and ponds. Water samples were collected and analyzed using HACH BART bottles and the Rancher's Water Quality Field Sample Kit (Rancher's Water Kit; see **Section 4.4.3**) from landowners in Lee, Dimmit, and DeWitt Counties in Texas, as described below.

- ***Lee County, TX.*** In Lincoln, Texas, about 45 miles east of Austin, the GPRI team responded to a landowner's complaint about the quality of water from a residential well that had been problem-free for years. Because of the analysis of the HACH BART bottles, the landowner was able identify and quantify bacterial populations and alter the use of the water well based on GPRI technicians' suggestions.
- ***Dimmit County, TX.*** A South Texas ranch owner requested GPRI establish a monitoring program to assess the possible effects of petroleum-related activities near his ranch property. SHAPE Ranch is a 53,000 acre series of parcels that include bison farming, honey bee farming, and energy development. The GPRI team collected six samples from various water sources on the ranch (ponds, residential water well, house faucet). Analysis using the HACH BART bottles was performed immediately after sampling to determine possible microbiological activity. Having a reliable and rapid analytical technique for monitoring bacteria activity allowed the field team to notify the ranch owner that certain ranch water sources were "off limits" for potable use. Since two sites (well and house) were sampled from a fresh water aquifer uncontaminated by bacteria, the landowner was able to continue to use his well water for personal use.
- ***DeWitt County, TX.*** The Chalk Hill Ranch site near Cheapside, Texas is surrounded by leased ranch land and oil and gas production facilities, currently operated by BHP Petroleum. At the owner's request, the GPRI team established a monitoring program to measure the possible effects of petroleum-related activities adjacent to ranch property. In 2013 and 2014, the GPRI team collected samples on a quarterly basis from a water well and a stock pond for water quality analysis using the Rancher's Water Kit.

Field trial results for the HACH BART and Rancher's Water Kit are presented in **Section 4.4.1** and **Section 4.4.3**, respectively.

4.3.3 *Analytical Technologies Evaluated*

The team tested multiple analytical technologies for measurement of bacteria (e.g., total and active bacteria, various types of bacteria), organics and oils (e.g., BTEX and other VOCs, TOC), and water quality parameters (e.g., cations, anions, metals, alkalinity) as shown in **Table 4-2**. Ease of use, portability, sampling requirements, sample preparation, repeatability, cost per analysis, and testing time were considered during various field trials in the shale plays discussed above to evaluate efficacy of the analytical technologies.

Table 4-2. *Analytical Technologies Evaluated*

Bacteria	Organics & Oils	Water Quality
• Modern Water QuickChek™ SRB Assay • Modern Water DeltaTox II Luminometer • Vivione Biosciences Rapid-B Flow Cytometer • Mycometer Bactiquant® • HACH Biological Activity Reaction Test (BART)	• InnovOx Analyzer • Inficon HAPSITE • Horiba Aqualog Brine Analyzer • Fluid Imaging FlowCAM	• HACH CEL Water Analysis Kit • La Motte HydraFrac Water Screening Kit • Titralyte Water Lens™ • LaMotte TDS Tester Probe • Ranchers Water Quality Field Sample Kit

4.4 Results & Discussion

The following sections describe the analytical technologies for bacteria, organics and oils, and water quality parameters that were evaluated by the GPRI team, and the respective field trial results.

4.4.1 *Bacteria*

Bacteria are a critical concern for the treatment and reuse of produced waters from oil and gas operations. Bacterial growth can cause a wide range of problems for operations, including microbial induced corrosion, well souring from hydrogen sulfide production, formation of biofilms in product pipelines, and reduced downhole formation production. High nutrient levels and anaerobic conditions common in produced water are ideal environments for increased bacteria growth. Further, pumping and aerating produced water can lead to rapid growth of various types of bacteria which can lead to pitting corrosion of pipelines and surface production equipment such as pump-jack rods, oil/water separators, and gas dehydrators (Tischler et al, 2009; Burnett et al., 2015).

Many hydraulic fracturing and drilling operations utilize biocides to manage bacterial growth, which can be costly depending on the volume of produced water to be treated (PSAC, 2015). It is also difficult to estimate the effective dosage necessary to reduce bacteria to acceptable levels (Robertson et al., 2016). Understanding the benefits and limitations of current analytical technologies and improving bacteria analysis are critical steps in addressing microbial issues in the field.

The GPRI Team evaluated five commercially-available analytical technologies to i) confirm the presence or absence of various types of bacteria and ii) quantify active and/or total bacteria concentrations in oil and gas flowback and produced waters:

- Modern Water QuickChek™ SRB Assay
- Vivione Biosciences Rapid-B Cytometer
- Mycometer Bactiquant®

- HACH BART
- LuminUltra™ Adenosine Triphosphate (ATP) Assay

In addition, a sample of raw produced water was submitted to a commercial laboratory for metagenomics analyses to identify dominant microbial species in the water. Metagenomics results are presented in **Appendix M**.

Modern Water QuickChek™ SRB Assay

The QuickChek™ SRB Assay (Modern Water; see **Figure 4-3**) is a rapid enzyme-linked immunosorbent assay that uses antibodies to detect the adenosine-5'-phosphosul-fonate (APS) reductase, an enzyme that is common in all strains of SRB. Following a series of filtration steps, APS reductase enzymes are released from lysed SRB cells and reacted with lyophilised antibodies and chromogens to generate a color. The color intensity is directly proportional to the SRB concentration in the sample (Modern Water, 2016). In the October 2014 Permian Basin field trial near Midland, TX, raw feed produced water samples were compared to filter treated permeate using the QuickChek™ SRB Assay. Results showed reduction of SRB from 10^4 - 10^5 cells/mL in raw feed samples to below detection limits (BDL) in all treated samples with temperatures ranging from 21 to 35 ^oC (see **Table 4-3**).

Figure 4-3. *Modern Water QuickChek™*

Table 4-3. *Permian Basin Field Trial - SRB results using the QuickChek™ SRB Assay*

Sample	Temp. (^oC)	Concentration (cells/ml)
Raw Feed (10/6/14 9:20)	21.0	10^5
Raw Feed (10/6/14 9:20)	22.6	10^4
Nanofiltration Permeate (10/7/14 10:05)	24.5	BDL
Nanofiltration Permeate (10/7/14 10:05)	25.4	BDL

Vivione Biosciences Rapid-B Flow Cytometer

The Rapid-B Flow Cytometer (Vivione Biosciences) uses immuno-based reagents containing an excitable fluorophore to target specific bacteria of interest within a water sample. Live viable cells are detected by fluorescent dye. This complex benchtop unit can analyze a wide range of bacteria and particles within complicated matrices and provides results within 3-15 minutes (Buzatu et al., 2014). After testing in multiple field trials, the Rapid-B Flow Cytometer proved to be overly complex and required a high amount of sample preparation and lab skills to obtain results. Additionally, this technology was fairly expensive on a per sample basis, costing $20 per test. Rapid-B results, as compared to other analytical technologies, are shown in **Table 4-8** at the end of this section.

Mycometer Bactiquant® Water Test

The Bactiquant® Water Test (Mycometer Instruments) is a rapid method for quantification of total bacteria in water and other fluids. It uses an enzyme-targeted analysis and fluorescence technology to quantify active bacteria in water samples. Bacteria are collected on a membrane

and saturated with an enzyme substrate which reacts to generate fluorophores. The fluorescence signal, measured by a field fluorometer, is directly proportional to the amount of active bacteria in the sample. The advantage of this method is that it fluoresces only in living bacteria that metabolize the enzyme, eliminating false positives (Mycometer, 2015).

The instrument enabled real-time measurement of bacteria in produced water during continuous treatment (micro- and nano-filtration) at trials conducted at the Texas A&M Riverside pilot plant. The graph below (see **Figure 4-4a**) shows total bacteria levels decreasing from raw feed to the final filtration step. These monitoring results can provide useful information for operators experiencing microbial issues and can aid in selecting the appropriate treatment to reduce bacteria concentrations to a specific level. One significant disadvantage of the method is that the units (i.e., Bactiquant Value) are not directly comparable to units of other common bacteria tests, which are usually colony-forming unit per milliliter (CFU/ml). The manufacturer is currently working on this conversion.

A follow-up study was conducted using the Bactiquant® test to evaluate microbial growth under two storage conditions: open air and sealed tank. Exposure of the produced water sample to air for a short period of time (4 days) resulted in an order of magnitude increase in bacterial counts compared to the initial feed water. **Figure 4-4b** illustrates a four-fold increase in the amount of active bacteria in an open air environment as opposed to the sealed tank. While these results are useful, the inability to convert the Bactiquant® value units to other standards (i.e. CFU/ml) for comparison to other technologies remains a limiting factor for this technology.

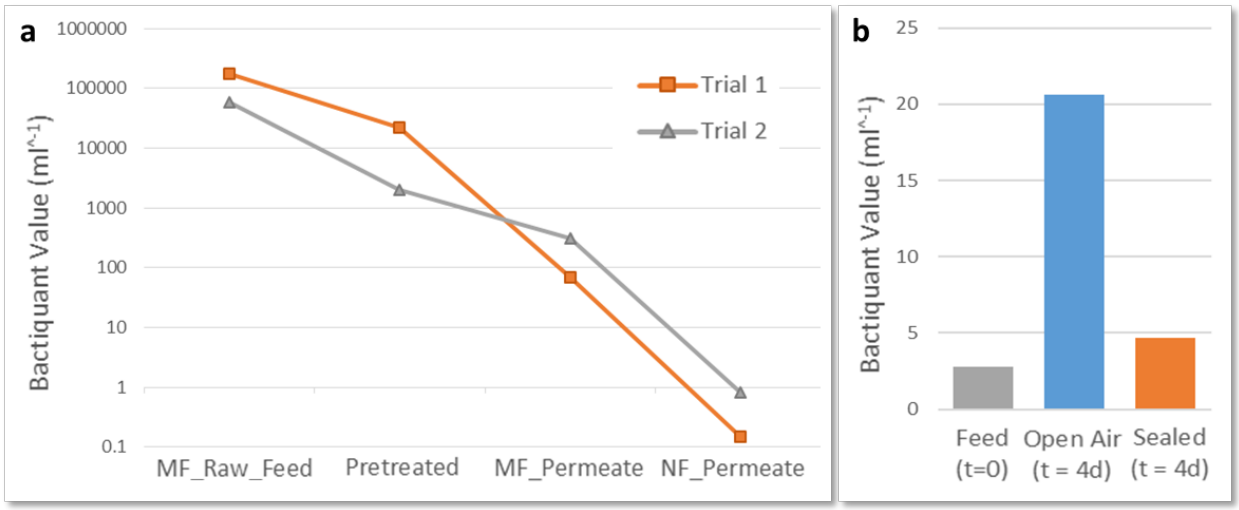


Figure 4-4. *Texas A&M Riverside Pilot Plant Trial – a) Bactiquant® results before and after micro-filtration (MF) and nano-filtration (NF) of produced water; b) Open air and sealed tank sample storage comparison using Bactiquant® Water Test*

HACH Biological Activity Reaction Test (BART)

The HACH BART bottles are colorimetric tests to determine the presence or absence of various groups of bacteria, including acid producing bacteria (APB), heterotrophic aerobic bacteria (HAB), iron-reducing bacteria (IRB), slime-forming bacteria (SLYM), and sulfate-reducing bacteria (SRB). Sample aliquots are added to BART vials containing culture-specific nutrients which encourage microbial growth under aerobic and anaerobic conditions. The rate of growth, which is demonstrated by a color change, foam production, precipitation, or cloudiness, is observed over 6-10 days and used to estimate the concentration of bacteria in CFU/ml (HACH, 2014).

Concentrations of bacterial populations are estimated using manufacturer-developed tables, summarized in **Table 4-4.** The HACH BART bottles are offered as part of the HACH Hydraulic Fracturing Water Analysis Kit (discussed further in **Section 4.4.3**).

Table 4-4. *Estimated Concentrations for Bacterial Populations using the HACH BART Bottles*

Type of Bacteria	No. of Days to Reaction – Approximate Population (CFU/ml)		
	Aggressive Population	Moderate Population	Not Aggressive Population
Sulfate Reducing (SRB)	1 – 2,200,000 2 – 500,000 3 – 115,000 4 – 27,000 5 – 6,000	6 – 1,400 7 – 325 8 – 75	9 – 20 10 – 5 11 – <1
Slime Forming (SLYM)	1 – 1,750,000 2 – 440,000 3 – 67,000	4 – 13,000 5 – 2,500 6 – 500	7 – 100 8 – <20
Heterotrophic Aerobic (HAB)	1 – 5,400,000 2 – 575,000	3 – 61,000 4 – 6,500	5 – 700 6 – <75
Acid Producing (APB)	1 –475,000 2 – 82,000 3 – 14,000	4 – 4,500 5 – 450 6 – 75	7 – 10 8 – <2
Iron Reducing (IRB)	1 – 570,000 2 – 140,000 3 – 35,000 4 – 9,000	5 – 2,200 6 – 500 7 – 150 8 – 25	9 – 8 10 – <1

For the Permian Basin field trials (Fall 2014), HACH BART results identified "aggressive" populations of APB, SLYM, HAB, IRB, and SRB in untreated (feed) produced waters. As shown in **Table 4-5**, visual confirmation of bacterial growth was observed after 1 day for the SLYM, HAB, and URB, 2 days for APB, and 3 days for SRB.

Table 4-5. *Permian Basin Field Trial – Bacteria results using the HACH BART bottles*

Type of Bacteria	Incubation Time (d)				Approx. Concentration (CFU/ml)
	1	2	3	6	
Sulfate Reducing (SRB)	✗	✗	✓	✓	115,000
Slime Forming (SLYM)	✓	✓	✓	✓	1,750,000
Heterotrophic Aerobic (HAB)	✓	✓	✓	✓	5,400,000
Acid Producing (APB)	✗	✓	✓	✓	82,000
Iron Reducing (IRB)	✓	✓	✓	✓	570,000

For the Dimmit County field trial, the GPRI team collected six samples from various water sources on the ranch: four samples from livestock ponds, one sample from the residential water well, and one sample from the house faucet. After 8 days of incubation, HACH BART results identified high concentrations of bacteria in the livestock ponds, while samples from the water well and main house faucet (sourced from the Carizzo Springs fresh water aquifer) were not contaminated with bacteria. As shown in **Table 4-6**, samples from the ponds yielded bacterial growth by the third or

fourth day of incubation, translating to moderate to aggressive (4,500 – 14,000 CFU/mL) growth of APB populations. Similar results were observed for other types of bacteria tested in the ponds.

Table 4-6. *Dimmit County Field Trial – Acid-Producing Bacteria (APB) Results Using HACH BART*

Sample Location	Incubation Time (d)								Approx. Conc. (CFU/ml)	Description
	1	2	3	4	5	6	7	8		
Pond – Location 1	✗	✗	✓	✓	✓	✓	✓	✓	14,000	Aggressive
Pond – Location 2	✗	✗	✗	✓	✓	✓	✓	✓	4,500	Moderate
Pond – Location 3	✗	✗	✓	✓	✓	✓	✓	✓	14,000	Aggressive
Pond – Location 4	✗	✗	✓	✓	✓	✓	✓	✓	14,000	Aggressive
Water Well	✗	✗	✗	✗	✗	✗	✗	✗	0	None
Main House Faucet	✗	✗	✗	✗	✗	✗	✗	✗	0	None

For the Lee County field trial, HACH BART bottles successfully screened samples from the residential well and found evidence of "aggressive" populations of HAB, SLYM, and IRB which affected the taste and odor of the well water. Further, the Rancher's Water Kit (see **Section 4.4.3**) found that the water had minimal turbidity (2.2. NTU) and near neutral pH (6.8).

Table 4-7*. Lee County Field Trial – Field Results*

Analyte	Result
Turbidity	2.2 NTU
pH	6.8
Slime Forming (SLYM)	440,000 CFU/ml
Heterotrophic Aerobic (HAB)	575,000 CFU/ml
Iron Reducing (IRB)	140,000 CFU/ml

LuminUltra™ ATP Assay

This instrument uses Adenosine Triphosphate (ATP) concentration as a direct measurement of active or total bacteria abundance in a sample. To quantify active bacteria concentrations, cells are lysed to free ATP which is reacted with the luciferase enzyme to generate light. The intensity of light is measured using a photometer, which is directly proportional to the amount of ATP or active bacteria present in the sample (ATP LuminUltra, 2016). The LuminUltra was very easy to use, conveniently portable, and cost only $7 per test (see **Table 4-8**). The instrument, shown in **Figure 4-5**, was efficient in identifying microbial activity in field trials, however, a small lag in ATP degradation and fluorescence was observed during biocide application (Robertson, 2016).

Figure 4-5. *LuminUltra ATP Assay*

Summary of Findings

General findings for the bacteria measurement technologies, with respect to ease of use, testing time, cost, and other practical considerations are summarized below and in **Table 4-8**.

- LuminUltra™ ATP Assay was efficient in identifying microbial activity in field trials, however, a small lag in ATP degradation and fluorescence was observed during biocide application (Robertson, 2016).
- The Vivione Biosciences Rapid-B Flow Cytometer was very complex and required a high amount of sample preparation and lab skills to obtain results.
- Mycometer Bactiquant® was used in many field trials due to its real-time analysis, reproducible and repeatable results (relative standard deviation < 7%), and the technology is USEPA verified (Mycometer, 2016). One significant disadvantage is that units (i.e., Bactiquant Value) are not comparable to units of other common bacteria tests, typically CFU/mL.
- Modern Water QuickChek™ is a rapid, portable, semi-quantitative test used to observe the presence of SRB in high salinity samples. However, the detection limit is relatively high (1,000 CFU/mL), and the test is specific to only SRB (Modern Water, 2016).
- The HACH BART bottles were the least expensive and required no extensive setup or sample preparation, but results are qualitative and the long incubation time does not allow for real-time evaluation of produced water.

Table 4-8. *Characteristics of Bacterial Analytical Technologies*

Analytical Technology	Ease of Use	Testing Time	Portability	Type of Bacteria	Cost per Test
LuminUltra™ ATP Assay	Easy	5 min	Very Good	Viable and total bacteria	$7
Mycometer Bactiquant®	Moderate	11 min	Very Good	Viable and total bacteria	$20
Modern Water QuickChek™	Moderate	10 min	Very Good	SRB only	$14
Vivione Biosciences Rapid-B Flow Cytometer	Complex	3-15 min	Benchtop Based	Various bacteria types	$20
HACH BART Bottles	Easy	8 days	Benchtop Based	Various bacteria types	$0.60

4.4.2 *Organics and Oils*

Organics and oils in produced water are key issues for oil and gas operations with respect to process optimization, treatment strategy selection, and regulatory compliance. Accumulation of organics and oils in process infrastructure can cause fouling of equipment and costly system shutdowns. In addition, organics serve as a food source for various types of bacteria, which can lead to other operational challenges: formation of biofilms (biofouling), microbial induced corrosion, and well souring (hydrogen sulfide production). Organics and oils found in produced water are generally characterized as VOCs, free oil and grease (FOG), and soluble organics. VOCs are lower molecular weight compounds (e.g., BTEX); FOGs (also called dispersed oil) represent insoluble compounds (e.g., crude oil) present as small, discrete droplets suspended in the water; and soluble organics (also called dissolved oil) are miscible in water (e.g., organic acids) (Guerra, 2011; Yang, 2011).

Produced water can contain hundreds of individual organic compounds, making it difficult to accurately characterize a sample. Broader metrics such as total petroleum hydrocarbons (TPH) or TOC are frequently used to gain insight on the general organic composition of produced water. Rapid, on-site measurement of bulk metrics for organics and oils is important for guiding produced water management decisions for well production optimization and selection of effective treatment techniques.

The GPRI team evaluated four commercially-available analytical technologies used to characterize several types of organics and oils in various sources of produced water:

- GE InnovOx TOC Analyzer
- Inficon HAPSITE GC/MS
- Horiba Aqualog Oil Content Analyzer
- Fluid Imaging FlowCAM

InnovOx TOC Analyzer

The *InnovOx* TOC Analyzer (GE Analytical Services) measures TOC, total inorganic carbon (TIC), and non-purgeable organic carbon in real-time (see **Figure 4-6**). This instrument can analyze complex samples such as brine and high particulates similar to produced waters. TOC is measured using a supercritical water oxidation (SCWO) technique to oxidize organic carbon into carbon dioxide, which is quantified via a non-dispersive infrared detector (GE, 2015). Using SCWO and a non-dispersive infrared detector, the device allows for the direct measurement of organic material in ultra-high saline waters without requiring any preparation or dilution prior to analysis. Ultra-high salinity brines do not interfere with or degrade results from the instrument.

***Figure 4-6**. GE InnovOx TOC Analyzer*

The *InnovOx* TOC Analyzer was used to analyze TOC and non-purgeable organic carbon of the produced water from the Woodford Shale in Oklahoma and evaluate the performance of microfiltration units for the removal of organics from produced water. In addition, the TOC analyzer was upgraded to allow more accurate readings of organic content in brine samples. As shown in **Figure 4-7**, TOC was reduced by approximately 25% via micro-filtration. This technology provides a general evaluation of filtration effectiveness for removing oil and grease particles, but if further chemical-specific treatment is needed, other instruments can be used in conjunction with the GE *InnovOx*.

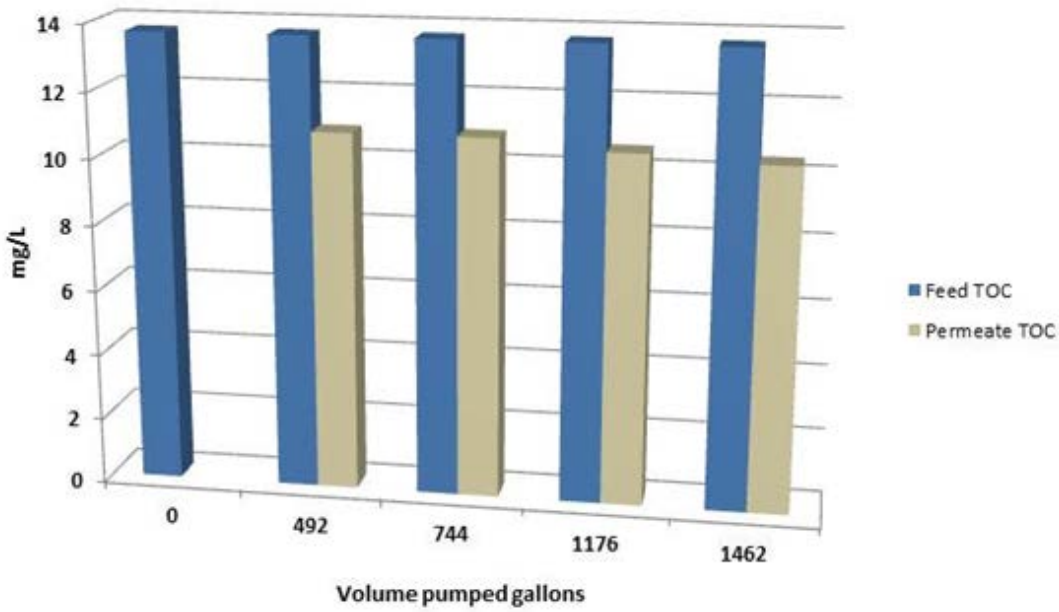


Figure 4-7. *Woodford Shale Field Trial – TOC results in the feed and permeate of microfiltration units*

Inficon HAPSITE Portable GC/MS

Figure 4-8*. HAPSITE Portable GC/MS*

The Inficon HAPSITE is a field-portable gas chromatograph/ mass spectrometer (GC/MS) capable of identifying and quantifying hundreds of VOCs and semi-VOCs real-time (within minutes) (see **Figure 4-8**). The HAPSITE utilizes a capillary column, which separates molecules in a water mixture based on their affinity to the column. Molecules eluted from the column are ionized and detected by the MS, providing specific information on individual VOCs (including BTEX) present in a sample. Detection limits are in the parts per million to parts per trillion (ppm - ppt) range for most analytes (Inficon, 2008). The HAPSITE is designed to be used by personnel without extensive training in analytical chemistry; however, some additional training may be needed for complex produced water applications.

Results from the Woodford Shale field trial illustrate the HAPSITE's ability to identify numerous VOCs in produced water with high resolution (subset of analytes shown in **Figure 4-9**). The field trial tested the efficiency of two types of filters (a fouling resistant polymer-coated filter and an uncoated filter) relative to the raw feed. Although VOC concentrations in the permeate of both filters decreased relative to the raw feed, for most VOCs, the coated filter did not offer improved VOC removal relative to the uncoated filter. While micro-filtration did not significantly alter brine content, any subsequent membrane treatment (nano-filtration or reverse osmosis) could clearly be evaluated using the HAPSITE. Despite the HAPSITE's rapid assessment capabilities, GPRI noted that these instruments required a high level of user proficiency to operate accurately in the field.

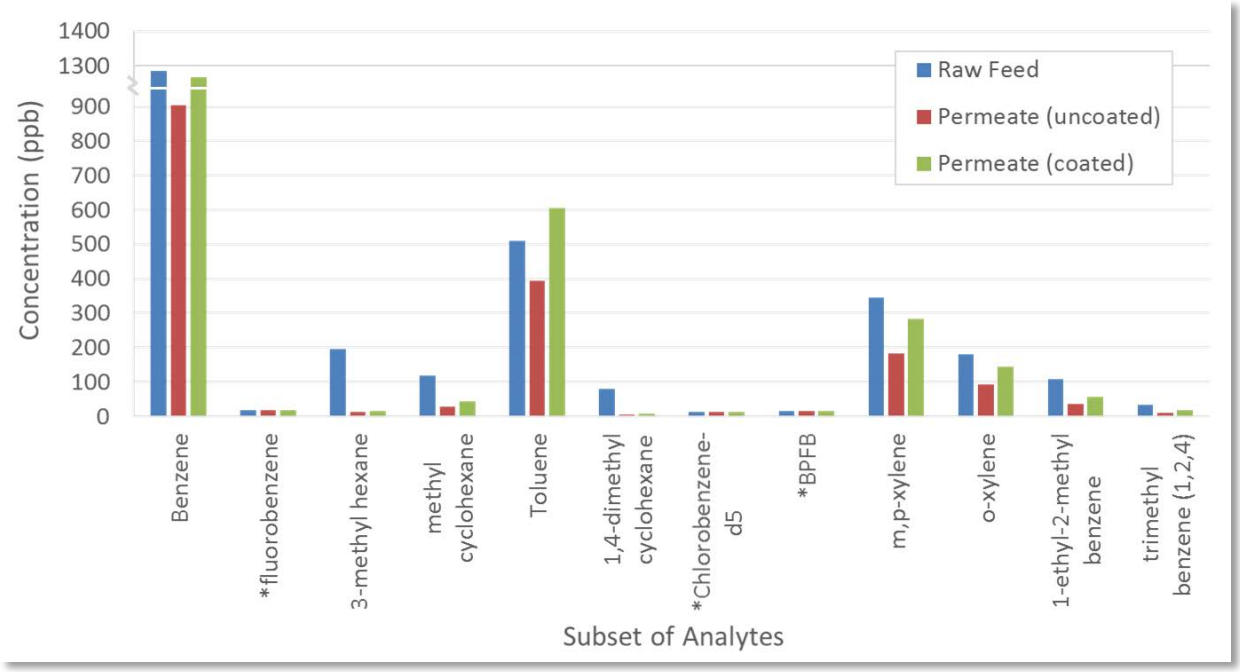


Figure 4-9. *Woodford Shale Field Trial – HAPSITE results for a subset of analytes before and after microfiltration of produced water*

Horiba Aqualog Oil Content Analyzer

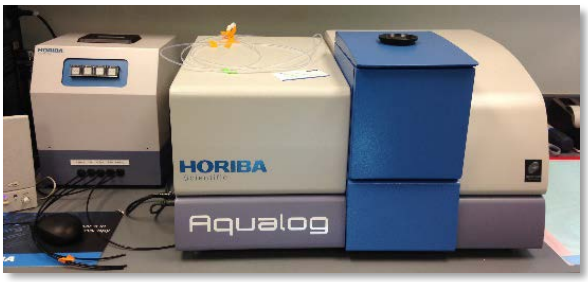


Figure 4-10. *Horiba Aqualog*

The Horiba Aqualog measures absorbance spectra and fluorescence spectra simultaneously to detect a wide range of organics in water, soil, or any industrial surface for environmental applications (see **Figure 4-10**). Using an absorbance scanning range of 200-800 nm and fluorescence excitation wavelength starting at 230 nm, this instrument is capable of capturing organic compounds that may be difficult to detect on other analytical instruments. The instrument is recommended for monitoring wastewater influent and effluent, checking bilge and ballast discharge, and monitoring the efficiency of oil/water separation processes (Horiba, 2013).

Placed on loan to GPRI, the modified Horiba Aqualog brine analyzer was used to measure concentrations of organics and oils from produced water sites, to evaluate the effectiveness of GPRI's membrane separation process, and to address specific compounds of concern in regards to treatment modification. **Figure 4-11** shows a subset of data collected from a field trial, showing relative concentrations of proteins, oil, humic and fulvic acid in water samples. The relatively high level of oil in Sample 1 may be treated using pre-treatment methods. The high level of proteins in Sample 3, however, may require specialized treatment to reduce the total amount of organic material for disposal or reuse purposes.

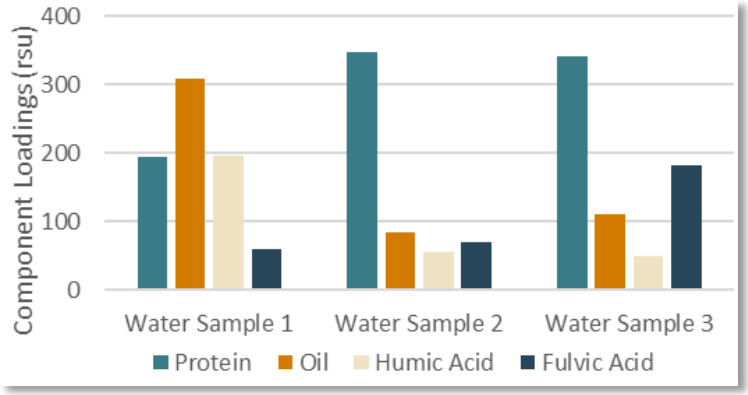


Figure 4-11. *Horiba Aqualog results for a produced water sample*

Fluid Imaging FlowCAM

Figure 4-12. *Fluid Imaging FlowCAM*

The Fluid Imaging FlowCAM is a dynamic imaging particle analysis system that offers image-quality and automated statistical pattern recognition software for all particles between 2 µm and 2 mm in diameter. The system differentiates particles by determining over 30 different quantities per particle, including basic shape, morphology, and color. The system detects oils, agglomerates, and solids in produced water in real-time, based on image attributes. Tens of thousands of images per minute are measured with FlowCAM, and the software enables filtering and sorting based on any of the 30 parameters measured, such that oil droplets can be distinguished from particulates. This allows for more effective treatment to be applied to site-specific produced water (Fluid Imaging, 2015).

Produced water samples were analyzed using the FlowCAM at the Texas A&M Riverside Pilot Plant in 2015. **Figure 4-13** shows results of the FlowCAM dynamic imaging of produced brine prior to treatment where the software has extracted information for each individual particle. The software allows the user to select certain particle images and then filter the rest of the images based on automatically determined similarities to those selected.

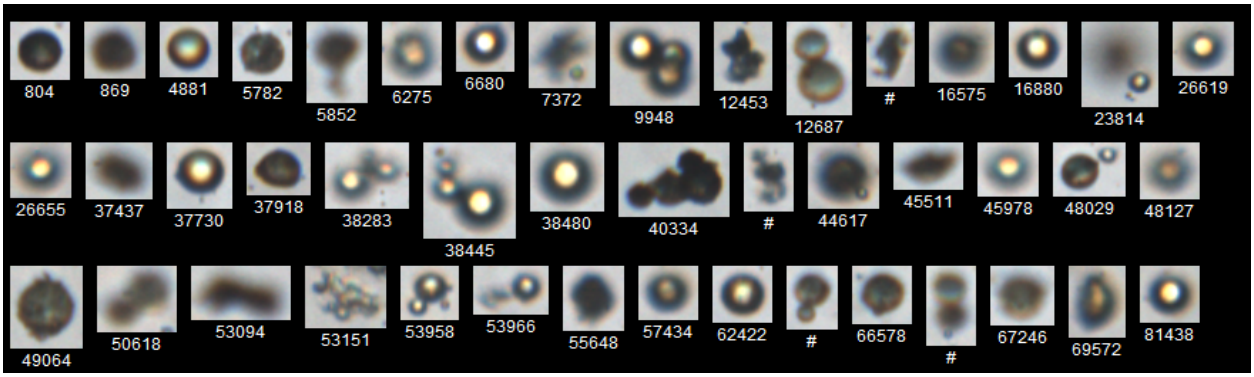


Figure 4-13*. Dynamic imaging of suspended solids and oil droplets in produced brine*

Figure 4-14 shows the pattern recognition software user interface displaying quantities of oil droplets and solids. The data has been filtered to show only the summary statistics of oil droplets and suspended solids captured from the sample. The percent volume and frequency versus diameter plots indicate that while 71% of the particles captured were identified as solids, those solids account for only 51.6% of the sample volume. The aspect ratio scattergram (width / length) assists in filtering particles by their shape characteristics, and the light intensity scattergram quantifies color spectrum measurements. Such information helps to optimize the efficiency of treatment and pre-treatment options. For example, pre-treatment options, like coagulant and micro-filtration steps, can be used for produced water containing many large particulates and oils to prevent clogging of treatment equipment in the process train. Applications in hydraulic fracturing proppant also lend significant benefits, as the size and shape of proppant particles has a direct effect on the production performance of a well due to its effect on conductivity (Fluid Imaging, 2015).

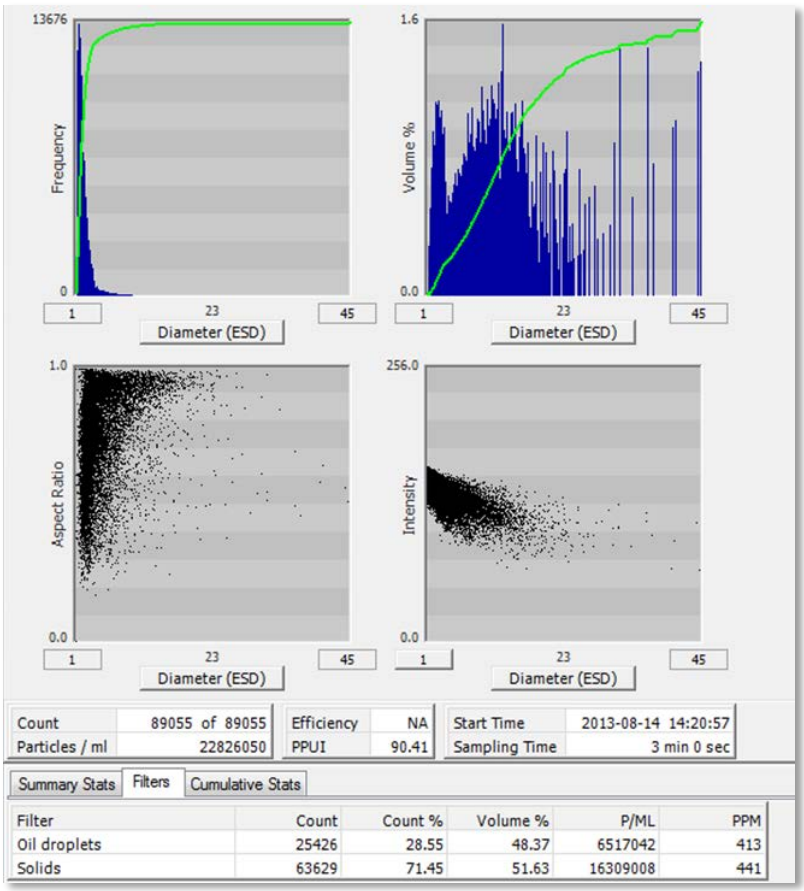


Figure 4-14. *FlowCAM pattern recognition software*

Summary of Findings

General findings for measurement of organics and oils are summarized below.

- Instrumentation setup and calibrations for the technologies tested were often challenging and required additional training.

- Although TOC can be accurately and reproducibly analyzed in the field using the GE InnovOx, the instrument does require a higher capital investment and extensive setup, so the cost-benefit should be considered.
- Field-based technologies offer rapid qualitative (and semi-quantitative) measurement of organics and oils; however, for accurate measurement of individual organic constituents, the use of certified laboratories is recommended.
- Advanced planning is recommended for organics and oil analysis of flowback and produced water, including consideration of how and where to analyze samples, since these parameters are critical constituents for water reuse applications.

4.4.3 *Water Quality Parameters*

Analysis of water quality parameters is a critical component of produced water management because: i) dissolved and suspended constituents serve as nutrients for bacteria, which can lead to corrosion and biofouling of oil and gas operations equipment, ii) cost-effective optimization of treatment techniques is based on site-specific water characteristics, and iii) beneficial use specifications and discharge limits need to be achieved. Produced water generally contains high concentrations of dissolved ions, which can serve as electron acceptors and donors for bacterial growth reactions in both aerobic and anaerobic waters. In addition, water hardness (calcium and magnesium content) can cause issues with water transport, use, and storage through precipitation of dissolved minerals (known as scaling). Since high salinity brines can be problematic for reuse, removal of scaling ions and assessing the compatibility of makeup waters are important considerations for oil and gas professionals. Real-time measurement of key water quality parameters, paired with microbial monitoring, provides an effective system for guiding produced water management decisions with respect to well production optimization, selection of effective treatment techniques, and evaluation of produced water end uses.

Water quality field kits and other measurement technologies are currently available to oil and gas professionals for rapid testing of various parameters in produced water. Key dissolved constituents and field indicator parameters include ammonia, nitrate, chloride, boron, total TDS, turbidity, electrical conductivity (EC), pH, and others. The technologies of these kits are based on extensive work in fresh water environmental monitoring but have been modified to handle the measurement of the contents of high ionic strength solutions in brines.

Field-ready kits that use colorimetric and ion-selective electrode (ISE) analyses offer an advantage over standard laboratory analytical methods that are often expensive and have long turnaround times. However, the kits are not intended to provide full quantitative analysis, but rather serve as a screening tool for further water characterization, where necessary.

The GPRI Team evaluated three commercially-available analytical technologies used to provide rapid characterization of various sources of flowback and produced waters:

- Titralyte Water Lens
- HACH CEL Hydraulic Fracturing Water Analysis Kit
- La Motte HydraFrac Water Screening Kit

Titralyte Water Lens™

Titralyte Water Lens™ is a “lab on a chip” technology designed to offer fast quantitative analysis of flowback and produced water using a compact, portable reader (see **Figure 4-15**). A 96-vial tray of sample cells is preloaded with chemical-specific reactants which develop characteristic

colors when in contact with complex waters. Utilizing patent-pending technology from the biotechnology industry, the Water Lens™ offers fast and inexpensive quantitative analysis of complex produced water compositions. It is currently capable of measuring alkalinity, barium, bicarbonate/carbonate, boron, calcium, chlorides, iron, magnesium, pH, sodium, sulfate, TDS, and turbidity (Water Lens, 2013). The manufacturer is currently working to incorporate additional parameters to the analytical suite.

Figure 4-15. *Titralyte Water Lens™*

The Titralyte Water Lens™ is in its early stages, but with the assistance of the Advanced Analytics program, it was able to get field experience to exhibit its usefulness with minimal cost. In the Permian Basin field trial, the Water Lens™ kit was compared with results from a commercial laboratory. **Table 4-9** summarizes a subset of the dissolved ions in raw feed samples from the field trials. The Water Lens™ compared relatively well for some parameters; however some inconsistencies were observed (e.g. iron). While the analytical technology may yield accurate results in some cases, a more extensive sampling campaign and additional data are required to conclusively evaluate its utility for produced waters.

Table 4-9. *Permian Field Trial – Titralyte Water Lens dissolved ion results for feed water*

Analyte	Sample	Water Lens	Commercial Lab
Turbidity (NTU)	Feed 10/07/14	819	532
Calcium (mg/L)	Feed 10/07/14	1,920	2,040
Iron (mg/L)	Feed 10/07/14	1.4	49.6
Iron (mg/L)	Feed 9/30/14	32	30.1

HACH Hydraulic Fracturing Water Analysis Kit

The HACH CEL Hydraulic Fracturing Water Analysis Kit includes reagents and instruments necessary to measure 11 critical oil and gas parameters: alkalinity, bacteria, barium, boron, chloride, conductivity, hardness, iron, pH, sulfate, and sulfide. The HQ40d Dual Input Multi-parameter Digital Meter supports a number of ISE measurement kits including ammonia, chloride and nitrate. The DR 900 Colorimeter uses a silicon photodiode detector with a spectral response from 420-610 nm to test up to 90 water test methods, lending flexibility to the array of parameters tested by the kit. Operating in either transmittance (%), absorbance, or concentration, the colorimeter works by shining an LED source lamp into the sample cell and measuring the reflected

absorbance spectrum by converting light to current (HACH, 2011). The kit also includes HACH BART for analysis of key bacterial groups, discussed in **Section 4.4.1.**

Figure 4-16. *HACH CEL Hydraulic Fracturing Water Analysis Kit*

Results from the HACH water kit compared well with commercial lab results for a number of water quality parameters including chloride and iron, as shown in **Figure 4-17**. Alkalinity and calcium concentrations were overestimated using the HACH kit. These data indicate that HACH colorimetry methods were generally reliable in their performance compared to USEPA-approved analytical techniques over a wide-range of complex water matrices, although some variations were observed.

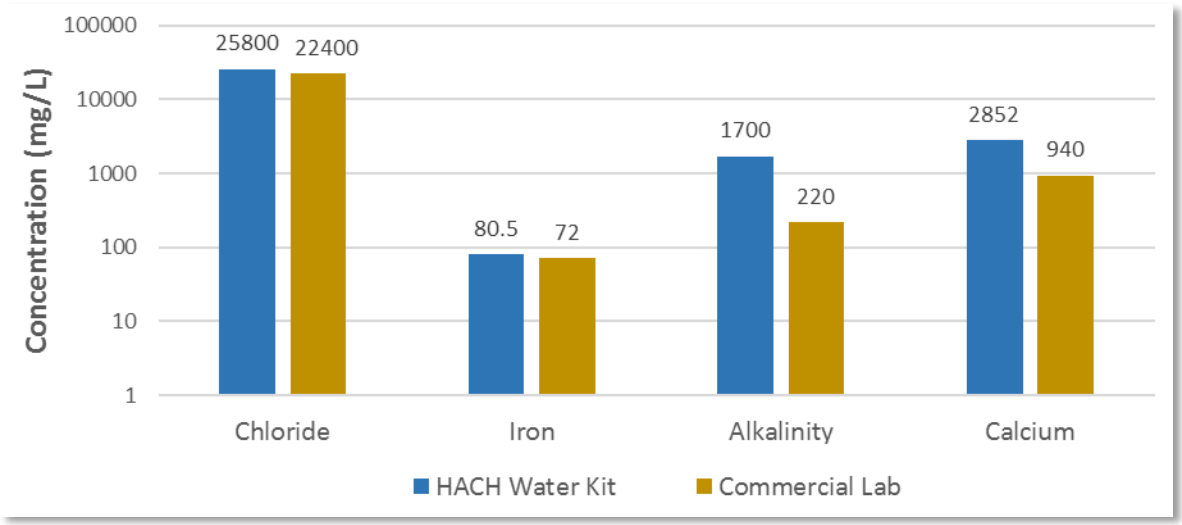


Figure 4-17. *Comparison of Commercial Lab Results and HACH Water Kit Results*

La Motte HydraFrac Water Screening Kit

The La Motte HydraFrac Water Screening Kit measures pH, electrical conductivity, TDS, and dissolved oxygen and includes various test strips to obtain real-time qualitative data for 15 parameters in the field, with the option to expand the analyte suite using the SMART3 Colorimeter. The optional SMART3 Colorimeter, outfitted with an LED source lamp and silicon photodiode,

incorporates all wavelength filters (428, 525, 568, and 635 nm) for an expandable parameter range of over 80 tests (La Motte, 2016).

With the analytical experience of the GPRI team, the La Motte TDS Tester Probe was chosen as a reliable instrument and was used in many field trials. **Figure 4-18** provides results from an Eaglebine Shale field trial where the HACH Water Analysis Kit and the La Motte TDS probe were used to monitor dissolved ion concentrations of feed and permeate samples. In this case, results indicate that efforts to remove key dissolved ions with nano-filtration were largely unsuccessful. Reverse osmosis is likely to be more effective (Burnett et al, 2015).

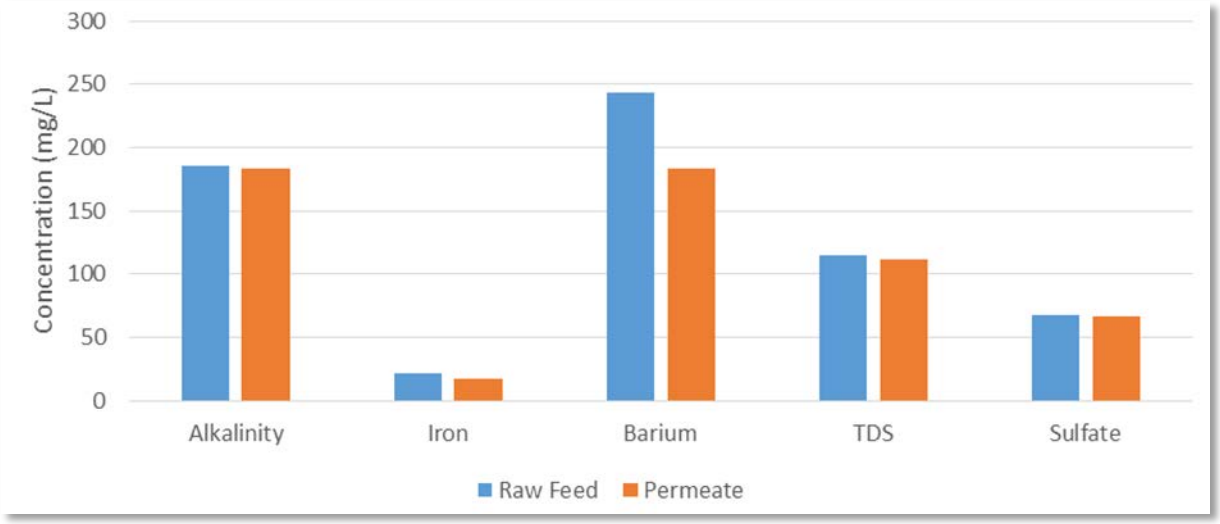


Figure 4-18. *HACH and La Motte results from raw feed and permeate water samples*

Ranchers Water Quality Field Sample Kit

Based on their experience monitoring constituents in produced water, the GPRI team developed a field-ready water test kit, called the Rancher's Water Quality Field Sample Kit, for screening water quality in a variety of water sources (e.g., residential water wells and surface waters; see **Figure 4-19**). The kit is designed to help landowners monitor the water quality of water sources proximate to oil and gas operations. Elements from the HACH and LaMotte Water Kits were selected for inclusion in the Rancher's Water Kit based on their ease of use, portability, and sampling requirements. Integrating the *HACH DR 900 Colorimeter, HQ40d Dual Input Multi-parameter Digital Meter, Digital Titrator, La Motte TDS Tester Probe,* as well as various biological monitors, the Rancher's Water Kit provides reliable qualitative characterization of water sources real-time.

Figure 4-19. *Rancher's Water Quality Field Sample Kit*

For the Dewitt County field trial, samples were collected from a water well and stock pond on a quarterly basis for about two years. Nine parameters were monitored using the Rancher's Water Kit: chloride, nitrate, phosphorus, specific conductivity, sulfate, TDS, TSS, and turbidity. Quarterly TDS results from the water well and stock pond are shown in **Figure 4-20**.

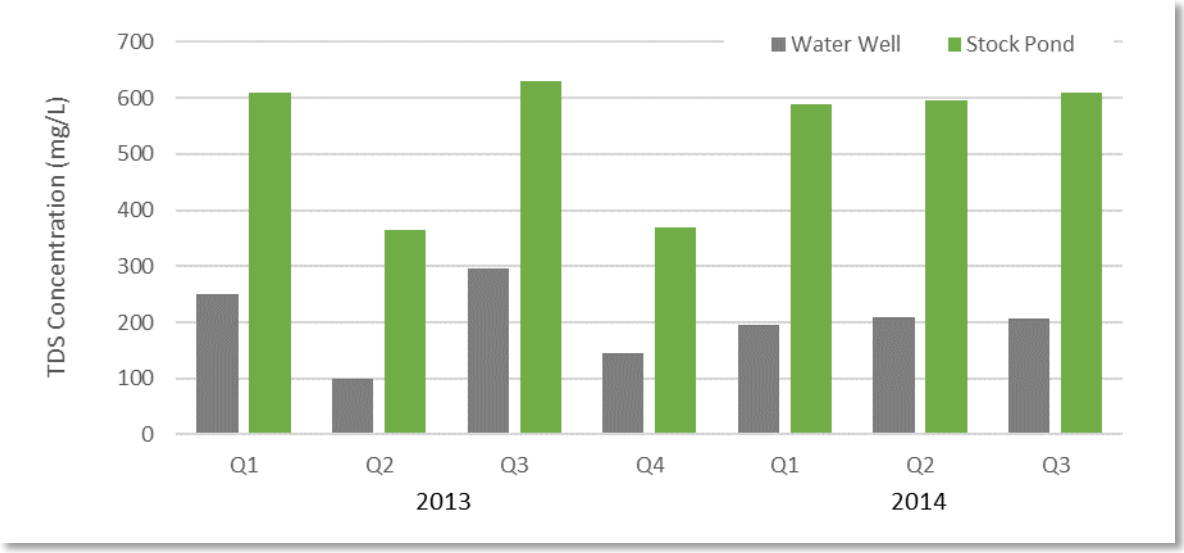


Figure 4-20. *Dewitt County Field Trial – Quarterly Sampling Results at the Water Well & Stock Pond*

Summary of Findings

The feasibility of produced water reuse in oil and gas operations hinges on the unstable chemical makeup of the water and pre-treatment procedures, well justifying the use of these mostly qualitative field analysis kits. While lab analysis may still be required in cases where precise quantification of certain ions is needed, these field-ready water quality technologies allow rapid on-site characterization of produced water parameters, allowing operators to choose the appropriate pre-treatment methods and make water management decisions. General findings and specifications for the water quality measurement technologies are summarized below and in **Table 4-10**.

- The Titralyte Water Lens™, still in the early stages of design, has not been widely field tested. Manufacturers are currently working on improvements for a cohesive, simple to use and inexpensive system that will work well in the field.
- The HACH CEL Hydraulic Fracturing Water Analysis Kit successfully detected dissolved constituents in a wide-range of complex produced water matrices, enabling quick pre-treatment decisions to be made. The HACH kit reliably screened water quality parameters in many field trials, but in cases where more precise quantification of certain dissolved ions is needed, lab analysis may be required.
- The La Motte HydraFrac Water Screening Kit performed similarly to the HACH kit; however, it should be noted that the standard HydraFrac Water Screening Kit contains qualitative test strips, and the SMART3 Colorimeter is available as a worthwhile upgrade.

Table 4-10. *Summary of Water Quality Screening Technologies*

Technology	TDS	Dissolved Oxygen	Turbidity	Alkalinity	Conductivity	pH	Acidity	Hardness, Total	Hardness, as $CaCO_3$	Ammonia	Barium	Bicarbonate	Boron	Calcium	Chloride as Cl^-	Chromium	Iron	Fluoride	Magnesium	Nitrate/Nitrite	Sodium	Sulfate	Sulfide
Titralyte	●		●	●		●		●			●	●	●	●	●		●		●		●	●	●
HACH		●		●	●	●		●	●	●	●		●		●		●	●				●	●
La Motte	●	●		●		●	●			●	●				●	●	●			●		●	

4.5 Conclusions & Recommendations

The technologies tested as a part of this study yielded promising analytical and operational results. Further testing needs to be conducted to identify technologies that will efficiently and accurately analyze flowback and produced waters for oil concentrations, microbial activity (affecting the production life of a new well), and dissolved ions. Key findings and recommendations include:

- By understanding the biological composition of produced water, industry can make better decisions on the use of biocides in hydraulic fracturing fluids and produced waters.
- Advanced technologies identified in this project are adaptable to other areas where the quality of water resources is critical. Municipal, as well as industrial, operations can benefit from the use of many of these portable analytical technologies.
- Field-based technologies offer rapid qualitative (and semi-quantitative) measurement of organics and oils, water quality, and microbial activity; however, for accurate measurement of individual constituents or bacterial species, the use of a certified laboratory is recommended.

5.0 TECHNOLOGY TRANSFER

The high level of interest and participation on this project from industry and regulatory stakeholders concerned with environmental impacts associated with shale oil and gas development vastly increased its value to GSI, DOE NETL and RPSEA. Technical Advisory Steering Committees (TASCs) consisting of participants from industry, regulatory agencies, non-governmental organizations, academia, and consulting were assembled to provide recommendations and feedback on project activities over the three-year program. A list of TASC participants is provided in the **Table 5-1**. When the proposal was submitted for this project in 2013, approximately 10 letters of commitment from interested parties were included with the proposal. Within the first year, the number of interested parties increased to ~50, with the total currently hovering around 100+ from >50 organizations.

Table 5-1. *List of TASC Participants*

Industry			
Accutest	Chevron	ExxonMobile	Pioneer
Anadarko	Chief Oil & Gas	Exxon XTO	Range Resources
Apache Corporation	ConocoPhillips	Halliburton	Schlumberger
Aramco	Devon	Hess Corporation	Shell
Baker Hughes	Drazan Energy	Isotech Laboratories	Statoil
BG Group	Encana	Marathon	Southwestern
BP	ENI Petroleum	MI-SWACO	Talisman
Cabot Oil & Gas	EQT	National Oilwell Varco	
Chesapeake	ESSO	Noble Energy	
Regulatory Agencies			
Alberta Energy Reg	NYSDEC	PADEP	USEPA
BLM	ND DMR	TCEQ	USEPA ORD/NRMRL
COGCC	ODNR	TRRC	USEPA Region 6
KGS	OCC	US DOE NETL	USGS
Non-Governmental Organizations			
AACG	CAPP	HARC	PTAC
API	GWPC	IOGCC	EDF
Academia & Consulting			
Echelon	TAMU EES	UGC, Inc.	West Virginia University
Mississippi State University	TAMU GPRI	University of Kentucky	
Ohio State University	TAMU IRNR	University of Oklahoma	

TASCs formed for this project represented two-way exchanges of information. GSI and our teaming partners hosted fifteen conference calls and conducted multiple one-on-one meetings with TASC members. In addition, project update memos were issued semi-annually to keep TASC members informed of upcoming field programs, preliminary findings, and data analysis. Specific feedback from participants was compiled and considered as next steps were planned and implemented. For example, during one of the baseline sampling conference calls, an Industry representative asked **"**How does the parameter stability manifest itself and is it necessary?" leading the project to evaluate the applicability of field parameter stability (pH, temperature, specific conductivity) as a metric for the timing of sample collection at wells (see **Section 2.4.3**).

The knowledge gained from this program was also disseminated though technical presentations at conferences and workshops, publication of technical papers, and public education programs. A complete list of technology transfer activities is presented in **Appendix N**. This project provided key stakeholders with recommended practices and technology summaries for making informed decisions regarding the characterization of air emissions, groundwater quality, and flowback/produced water characteristics.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Key findings and recommendations for the three principal research components of the project are summarized below.

Baseline Sampling for Dissolved Methane

The greatest challenge in responding to reports of changes in water quality at residential wells is the determination of whether increases in methane concentrations are natural or induced. Project findings have contributed to the design and implementation of pre-drill and post-drill groundwater monitoring programs and subsequent determinations by i) providing recommended practices for sampling methodologies and ii) highlighting simple and meaningful relationships for improved data interpretation. In addition, better understanding of current baseline sampling regulations has raised industry awareness of the need for consistent and scientifically-based regulations and guidelines. Key findings and recommendations include:

- **Sampling Method:** For effervescing samples, a closed-system method performs best. For non-effervescing conditions, all three methods were found to be acceptable (Direct-fill method, the Inverted bottle method, and the closed system). The inverted bottle method provided no advantage over the direct fill method.
- **Purge Volume:** Purging the volume of water sufficient to remove standing water from pressure tank and lines is beneficial, but there appears to be no necessary benefit to purging larger volumes of water (and in fact, samples collected after a high-volume purge may not be representative of the water quality typically experienced by the resident). Rather, to achieve relatively consistent results, it is recommended that consistent purging procedures be followed from one sampling event to the next.
- **Temporal Variability:** For wells with methane concentrations greater than 1 mg/L in the study area, measured concentrations of methane in a well can vary up to 2-fold over time due natural conditions and sampling variability alone. Changes greater than 2-fold were not commonly observed.
- **Evaluating Change in Concentration:** At a subset of water wells, changes in methane concentrations closely track changes in sodium and other salinity indicators, where both are reflective of the dynamic mixing of fresh and saline water sources in the well. Therefore, significant changes in methane concentration (i.e., 2x) accompanied by significant changes in sodium can be strong evidence for natural variation. However, the inverse (i.e., a change in dissolved methane concentration that is not accompanied by a change in sodium concentration) could be associated with either natural variation or stray gas. To best recognize whether a change in methane concentration is associated with a change in the relative proportions of different fluids naturally entering a well, we recommend analysis of major cations and anions with dissolved methane concentration during pre-drill and post-drill sampling. Analysis of bromide (used to determine a Cl/Br ratio) and δ^{13}C-DIC can also be valuable indicators of the mixing of different fluids sources.

Advanced Analytical Air Monitoring

The *President's Climate Action Plan, Strategy to Reduce Methane Emissions* (CAP, 2014) called for "better data collection and measurement" to improve understanding of methane and other GHG sources and trends, and enable more effective management of opportunities to reduce emissions. The Plan advocates the use of new measurement technologies to reduce uncertainty associated with GHG emissions inventories. Until recently, accurate and repeatable measurements of air emissions from unconventional oil and gas operations have been difficult to

achieve. Further, current models being used to estimate emissions have a heavy reliance on default factors for chemical constants/coefficients. These factors are not site-specific, thus creating a significant variance in the models and leading to errors in emissions estimations.

Innovative technologies and methods are needed to support *real-time data collection*, *quantify actual emission concentrations*, and *improve delineation of air emissions* from oil and gas operations. The use of OP-FTIR spectroscopy in combination with concurrent site-specific thermal imaging and meteorological measurements largely answers these needs. The Advanced Analytical Air Monitoring Protocol, which instructs real-time, accurate quantification of emissions concentrations from oil and gas operations using these technologies, was developed under this project and applied during field operations at oil and gas sites with a wide range of equipment and operations (e.g., compressors, tanks, ponds). Specific findings and recommendations include:

- The OP-FTIR was successful at speciating multiple compounds simultaneously downwind of point sources such as tanks, compressors and well heads, and its ability to collect and store concentration data on all 262 spectral compounds was useful for re-running data sets based on new suspected compounds discovered at the sample sites.
- At the SHAPE Ranch production facility, the incorporation of meteorological sensors was successful in determining the direction of the sources. The development of concentration roses clearly pointed to known emitters in both the field trials and quality assurance tests. The optical imaging camera allowed the research team to not only determine the location of the source, but also pinpoint the leak(s) at each source. This additional imaging technology proved useful to the operators of the SHAPE Ranch production facility who were interested in mitigation and repair of leaking equipment.
- At the Wyoming Disposal Ponds, the OP-FTIR data was supplemented with meteorological data collected both at the pond surface and 6 feet above the berm. This proved useful for modeling dispersion occurring at the pond surface, up and over the berm. The optical imaging camera was used to scan adjacent storage tanks to establish the background profile. Overall, the use of these three instruments together provided a robust and defensible data set for determination of ambient downwind concentrations, as well as a defensible foundation for the development of emission rate/dispersion modeling at both production facilities and disposal ponds.

Flowback/Produced Water Characterization

The use of recycled water for hydraulic fracturing operations is becoming more common as tougher government regulations on water come into place and as production wells are drilled in areas prone to drought. However, produced waters can be problematic for reuse due to high concentrations of dissolved ions and the potential for bacterial growth. Real-time measurement of key water quality parameters, paired with microbial monitoring, provides an effective system for guiding produced water management decisions with respect to well production optimization, selection of effective treatment techniques, and evaluation of produced water end uses. Based on results from field trials in various shale plays, technology summaries (or “fact sheets”) were developed to support the testing and deployment of new “field ready” products facilitating rapid produced water characterization. Key findings and recommendations include:

- By understanding the biological composition of produced water, industry can make better decisions on the use of biocides in hydraulic fracturing fluids and produced waters.

- Advanced technology identified in this project are adaptable to other areas where the quality of water resources is critical. Municipal as well as industrial operations can benefit from the use of many of these portable analytical technologies.
- Field-based technologies offer rapid qualitative (and semi-quantitative) measurement of organics and oils, water quality, and microbial activity; however, for accurate measurement of individual constituents or bacterial species, the use of a certified laboratory is recommended.

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APPENDIX A

BASELINE SAMPLING FOR DISSOLVED METHANE

REGULATIONS AND GUIDANCE FOR BASELINE SAMPLING OF WATER SOURCES IN AREAS OF SHALE OIL & GAS DEVELOPMENT

Table A-1. *State Agency Regulations and Guidance for Pre-drill and Post-drill Sampling of Water Sources*

State	Status of Regulation	Agency	Regulation and Guidance Sources
Alaska (AK)	Final; adopted in 2015	AK Oil and Gas Conservation Commission (AOGCC)	Alaska Administrative Code, April 2015, Title 20, Chapter 25, Section 283 (20 AAC 25.283): "Hydraulic Fracturing" http://doa.alaska.gov/ogc/Regulations/20AAC25-005c13.pdf
California (CA)	Final 2015; adopted in 2013	CA Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR); State Water Resources Control Board (SWRCB)	California Water Boards, July 7, 2015, "Model Criteria for Groundwater Monitoring in Areas of Oil and Gas Well Stimulation". http://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/docs/model_criteria_final_070715.pdf Senate Bill No. 4 (SB 4), September 20, 2013, Chapter 313: "Interim Well Stimulation Treatment Regulations: Final Text of Readopted Emergency Regulations". http://www.conservation.ca.gov/index/Documents/FInal%20Text%20of%20Readopted%20SB%204%20Interim%20WST%20Regulations%20with%20Revised%20IWSTN%20Form.pdf
Colorado (CO)	Final; adopted in 2013	CO Oil and Gas Conservation Commission (COGCC)	Rule 609, 2013, "Statewide Groundwater Baseline Sampling and Monitoring" http://cogcc.state.co.us/documents/reg/Rules/LATEST/600Series.pdf Rule 318A.e(4), May 1, 2013, "Groundwater Baseline Sampling and Monitoring" (Greater Wattenberg Area). http://cogcc.state.co.us/documents/reg/Rules/LATEST/300Series.pdf Model Sampling and Analysis Plan, May 1, 2013, Rules 609 and 318.e(4), Version 1. https://cogcc.state.co.us/COGIS_Help/COGCC_Model_SAP_05012013.pdf
Idaho (ID)	Final; adopted in 2012	ID Department of Lands, Oil and Gas Conservation Commission (ID OGCC)	Idaho Administrative Procedure, 2012, Act 20, Title 07, Chapter 02 (IDAPA 20.07.02): "Conservation of Crude Oil and Natural Gas in the State of Idaho-Section 210. Well Treatments- Fresh Water Protections for Well Treatments". http://adminrules.idaho.gov/rules/current/20/0702.pdf
Illinois † (IL)	Final; adopted in 2014	IL Department of Natural Resources (IDNR), Office of Oil & Gas Resource Management	Illinois Administrative Code, November 14, 2014, Title 62: "Mining", Chapter I: "Department of Natural Resources", Part 245: "Hydraulic Fracturing Regulatory Act". http://www.dnr.illinois.gov/adrules/documents/62-245.pdf
Michigan (MI)	Final; adopted in 2015	MI Department of Environmental Quality (MDEQ), Office of Oil, Gas, and Minerals	Michigan Administrative Code, March 11, 2015, Rule 324.1404: "Ground water baseline sampling for high volume hydraulic fracturing". http://w3.lara.state.mi.us/orr/Files/AdminCode/1298_2013-101EQ_AdminCode.pdf Oil & Gas Pre-Drill Water Well Testing, September 2012, EQP 6553. http://www.michigan.gov/documents/deq/EQP_6553_Homeowner_Water_Sampling_Information_399756_7.pdf
Nevada (NV)	Final; adopted in 2014	NV Commission on Mineral Resources (NVCMR), Division of Minerals	Legislative Counsel Bureau (LCB), October 24, 2014, File No. R011-14, Section 9. http://minerals.nv.gov/uploadedFiles/mineralsnvgov/content/Programs/Oil_and_Gas/R011-14A_Final_Approved_By_Legislative_Commission.pdf
North Carolina † * (NC)	Final; adopted in 2015	NC Department of Environmental and Natural Resources (NCDENR), Division of Energy, Mineral, and Land Resources	NC General Statutes, 2013, Chapter 113, Subchapter V, Article 27, Section 113-421 "(a) Presumptive Liability for Water Contamination" and Section 113-423 "(f) Pre-Drilling Testing of Water Supplies". http://www.ncleg.net/EnactedLegislation/Statutes/HTML/ByArticle/Chapter_113/Article_27.html North Carolina Administrative Code, March 2015, Title 15A, Subchapter 5H,"15A NCAC 05H.1803 Water Supply Testing Procedures". http://ncrules.state.nc.us/ncac/title%2015a%20-%20environment%20and%20natural%20resources/chapter%2005%20-%20mining%20-%20mineral%20resources/subchapter%20h/15a%20ncac%2005h%20.1803.pdf
Ohio (OH)	Final; adopted in 2014	OH Department of Natural Resources (ODNR), Division of Oil and Gas Resources Management	Amended Substitute Senate Bill Number 315, September 20, 2012, Title 15, Section 1509.06 (A). http://archives.legislature.state.oh.us/bills.cfm?ID=129_SB_315 Best Management Practices for Pre-Drilling Water Sampling, September 20, 2012. http://oilandgas.ohiodnr.gov/Portals/oilgas/pdf/BMP_PRE_DRILLING_WATER_SAMPLING.pdf
Pennsylvania † (PA)	Final; adopted in 2016	PA Department of Environmental Protection-Office of Oil and Gas Management (PADEP)	House Bill 1950, 2012, Act 13 Title 58: "Oil and Gas", Section 3218. "Protection of water supplies". http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/2012/act13.pdf 25 PA Code, 2015, Chapter 78 Subchapter C, Section 78.52,"Predrilling or prealteration survey" and Subchapter D, Section 78.89 "Gas migration response". http://www.pacode.com/secure/data/025/chapter78/chap78toc.html PADEP, April 2014, Recommended Basic Oil and Gas Pre-Drill Parameters, 8000-FS-DEP4300. http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-100259/8000-FS-DEP4300.pdf
Tennessee (TN)	Final; adopted 2013	TN Department of Environment and Conservation (TDEC)	Rules of the Oil and Gas Program, June 2013, Division of Water Resources, Chapter 0400-52-02 "Permits". http://share.tn.gov/sos/rules/0400/0400-52/0400-52-02.20130618.pdf

State	Status of Regulation	Agency	Regulation and Guidance Sources
West Virginia † (WV)	Final; adopted in 2011 and 2013	WV Department of Environmental Protection (WVDEP), Office of Oil and Gas	West Virginia Code, 2011, Chapter 22 Article 6A: "Natural Gas Horizontal Well Control Act". http://www.legis.state.wv.us/WVcode/Code.cfm?chap=22&art=6A#06A Legislative Rule, 2013, Title 35, Series 8: "Rules Governing Horizontal Well Development". http://apps.sos.wv.gov/adlaw/csr/readfile.aspx?DocId=25702&Format=PDF
Wyoming (WY)	Final; adopted in 2014	WY Oil and Gas Conservation Commission (WOGCC)	Chapter 3, March 1, 2014, Section 46: "Groundwater Baseline Sampling, Analysis, and Monitoring". http://soswy.state.wy.us/Rules/RULES/9584.pdf Appendix K, 2014, Sampling and Analysis Procedures for the Wyoming Oil and Gas Conservation Commission Groundwater Baseline Sampling, Analysis, and Monitoring Program. http://wogcc.state.wy.us/downloads/5072014_K_Sampling_and_Analysis_Procedures.pdf

Notes:

† = Regulation includes a rebuttable presumption or presumption of liability. *= Current injunction on hydraulic fracturing activities pending court ruling.

Table A-2. *Key Elements of State Agency Regulations for Pre-drill and Post-drill Sampling of Water Sources*

State	Water Source	Sampling Radius	No. of Sampling Locations	Pre-Drill		Post-Drill		Sampling Methodology
				No. of Events	Timeframe	No. of Events	Timeframe	
AK	water wells	within 1/2 mile (2,640 ft) of wellbore trajectory	ns	1	ns	ns	ns	ns
CA [a]	water wells, surface water	within a 1,500 ft of production well *or* 500 ft. from horizontal projection of all subsurface portions of the well	OR	1	ns	1	60 days after completion of well stimulation	In accordance with "U.S. EPA Groundwater Sampling Guidelines for Superfund and RCRA Project Managers" (May 2002) http://www2.epa.gov/quality/ground-water-sampling-guidelines-superfund-and-rcra-project-managers "U.S. EPA Science and Ecosystem Support Division Operating Procedure for Groundwater Sampling" (March 2013) http://www2.epa.gov/sites/production/files/2015-06/documents/Groundwater-Sampling.pdf
CO	water wells, springs	within 1/2 mile (2,640 ft) radius of production well within the quarter section of the well; if no water source identified, search is expanded to any unsampled quarter section that intersects a 1/2 mile radius of well [b]	≤4 [c] 1 [b]	1	within 12 months prior to setting conductor pipe	2+ 1 [b]	6-12 and 60-72 months after completion of well [c] 6-12 months after completion of well [b]	in accordance with "State of Colorado Oil & Gas Conservation Commission Model Sampling and Analysis Plan" (May 2013) https://cogcc.state.co.us/COGIS_Help/COGCC_Model_SAP_05012013.pdf
ID	water wells, surface water	within 1/4 mile (1,320 ft) of treated well; radius may be enlarged if no water sources identified within 1/4 mile	ns	1	ns	1	ns	ns
IL	water wells, springs, surface water	within 1,500 ft of the well site	all	3+	ns	3	6, 18, and 30 months after fracturing operations completed	ns
MI	water wells	within 1/4 mile (1,320 ft) of well location	≤10 [c]	1	between 7 days and 6 months prior to initiation of drilling operations	ns	ns	ns
NV	water wells, springs	within 1 mile (5,280 ft) radius of well *and* any surface projection of any lateral component of wellbore	≤4 [c]	1	within 12 months prior to commencement of hydraulic fracturing	2	6-12 and 60-72 months after hydraulic fracturing	ns

State	Water Source	Sampling Radius	No. of Sampling Locations	Pre-Drill		Post-Drill		Sampling Methodology
				No. of Events	Timeframe	No. of Events	Timeframe	
NC	water wells, springs, surface water	within 1/2 mile (2,640 ft) of wellhead	all [d] (OR)	1	30 days to 12 months prior to drilling	5+	6,12, 18, 24 months after production has commenced; 30 days after completion of production activities	in accordance with "U.S. EPA Science and Ecosystem Support Division Operating Procedure for Groundwater Sampling" (Mar 2013); Surface Water Sampling (Feb 2013) http://www2.epa.gov/sites/production/files/201403/documents/appendix_l_groundwater_sampling.pd http://www2.epa.gov/sites/production/files/2015-06/documents/Surfacewater-Sampling.pdfUSGS "National Field Manual for Collection of Water Quality Data" Book 9, Handbooks for Water-Resources Investigations http://water.usgs.gov/owq/FieldManual/
OH	water wells	within 1,500 ft of horizontal wellhead	all	1	ns	ns	ns	in accordance with "Ohio Department of Natural Resources Best Management Practices For Pre-drilling Water Sampling" (September 2012) http://oilandgas.ohiodnr.gov/Portals/oilgas/pdf/BMP_PREDRILLING_WATER_SAMPLING.pdf
PA	water wells, springs, surface water	within 2,500 ft of vertical wellbore	all [d]	1	ns	ns	ns	ns
TN	water wells	within 1/2 mile (2,640 ft) radius measured from terminus of horizontal wellbore	OR	1	ns	ns	ns	comparable to "State of TN Dept of Env. & Cons. Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water" (August 2011) http://www.tn.gov/assets/entities/environment/attachments/ChemSOP03QUAP.pdf
WV	water wells, springs	within 1,500 ft from center of well pad *and* 2,000 ft if no water sources identified within 1,500 ft radius	OR, 1 [e]	1	ns	ns	ns	ns
WY	water wells, springs	within 1/2 mile (2,640 ft) of well location	≤4 [c]	1	within 12 months prior to spudding the well	2+	12-24 and 36-48 months after setting the production casing [f]	in accordance with "Appendix K: Sampling and Analysis Procedures for the WY O&G Cons. Commission Groundwater Baseline Sampling, Analysis, and Monitoring Program http://wogcc.state.wy.us/downloads/5072014_K_Sampling_and_Analysis_Procedures.pdf

Notes:

ns = not specified in available regulations and guidance
OR = sampling must be requested by land or water source owner
all = all water sources within the specified radial distance
a = designated contractor sampling and testing requirements (SWRCB 2015)
b = applies only to wells in the Greater Wattenberg Area (Rule 318Ae)
c = selection criteria established if more water sources identified
d = not specified but implied under the rebuttable presumption
e = if no request, operator required to sample one water source within radius
f = sampling events must be ≥24 months apart

Table A-3. *State Agency Required Analytical Suite for Pre-drill Sampling of Water Sources*

State	Water Quality & Field Observations	Organics	Major Cations	Major Anions	Minor & Trace Elements	Dissolved Gases	Radionuclides	Bacteria
AK	alk, pH, SC, TDS, bubbles, color, efferv, odor, sediment	BTEX, TPH, GRO, DRO, PAH	Ca, Fe, Mg, Mn, K, Na	HCO_3, Br, Cl, F, OH, I, NO_3+NO_2, P, SO_4	As, Ba, B, Cd, Cr, Li, Se, Si, Sr	CH_4, C_2H_6, C_3H_8	^{226}Ra+^{228}Ra	IRB, SFB, SRB
CA[a]	pH, SC, temp, DO, ORP, TDS	BTEX, TPH, PAH, GRO, DRO, Trimethylbenzene, acetone, methylene chloride, TOC, DOC	Major & minor cations (incl. Ca, Fe, Mg, Mn, K, Na, NH_4)	Major & minor anions (incl. NO_3, NO_2, Cl, F, SO_4, Br, I)	As, B ,Ba, Cd, Cr, Pb, Hg, Li, Se, Sr	C_2H_6, CH_4, C_3H_8, H_2S	^{226}Ra+^{228}Ra, U	-
CO*	alk, pH, SC, TDS, bubbles, color, efferv, odor, sediment	BTEX, TPH	Ca, Fe, Mg, Mn, K, Na	Br, Cl, F, NO_3+NO_2, P, SO_4	Ba, B, Se, Sr	CH_4, C_2H_6, C_3H_8	-	IRB, SFB, SRB
ID[b]	-	-	-	-	-	-	-	-
IL	alk, pH, SC, TDS	BTEX	Ca, Fe, Mg, Mn	Cl, SO_4	As, Ba, Cd, Cr, Pb, Hg, Se, Ag	CH_4, C_2H_6, C_3H_8	Gross α, Gross β	-
MI	TDS	BTEX	-	Cl	-	CH_4	-	-
NV	alk, hardness, SC, pH, color, TDS, turbidity	BTEX	Ca, Fe, Mg, Mn, K, Na	F, NO_3+NO_2, SO_4	As, Ba, B, Co, Cu, Si, Zn	CH_4, C_2H_6, C_3H_8, H_2S	-	TC, E.Coli
NC*	alk, pH, SC, TDS, turbidity	BTEX, TPH, DRO, GRO, PAH, THM	Ca, Fe, Mg, Mn, K, Na	Br, Cl, F, SO_4	As, Ba, B, Cr, Pb, Li, Se, Sr, Zn	CH_4, C_2H_6, C_3H_8	^{226}Ra+^{228}Ra, ^{87}Sr+^{86}Sr, U	-
OH	alk, pH, SC, TDS	-	Ca, Fe, Mg, K, Na	Cl, SO_4	Ba	-	-	-
PA	alk, hardness, pH, SC, TDS, TSS, turbidity	TPH	Ca, Fe, Mg, Mn, K, Na	Br, Cl, SO_4	Al, As, Ba, Li, Sr, Se, Zn	CH_4, C_2H_6, C_3H_8	-	TC
TN	pH, TDS	BTEX, TOC, TPH	-	Cl	-	-	-	-
WV	pH, TDS	BTEX, TPH (GRO, DRO, ORO), detergents	Ca, Fe, Mn, Na	Cl, SO_4	Al, As, Ba	CH_4, C_2H_6, C_3H_8, C_4H_{10}	-	TC
WY	alk, DO, pH, ORP, SC, temp, TDS, turbidity, bubbles, color, efferv, odor, sediment	BTEX, TPH, naphthalene	Ca, Fe, Mg, Mn, K, Na	Br, Cl, F, NO_3+NO_2, P, SO_4	Ba, B, Se, Sr	CH_4, C_2H_6, C_3H_8	-	IRB, SFB, SRB

LEGEND

Water Quality & Field Observations
Alkalinity (HCO_3 + CO_3 as $CaCO_3$) ..... alk
Dissolved Oxygen ..... DO
Effervescence ..... efferv
Hydrogen Sulfide…… ..... HS
Oxidation-Reduction Potential ..... ORP
pH ..... pH
Specific Conductance ..... SC
Temperature ..... temp
Total Dissolved Solids ..... TDS
Total Suspended Solids ..... TSS
Water Color ..... color

Organics
Benzene, Toluene, Ethylbenzene, Xylene .. BTEX
Diesel Range Organics ..... DRO
Dissolved Organic Carbon ..... DOC
Gasoline Range Organics ..... GRO
Oil Range Organics ..... ORO

Organics (cont)
Polycyclic Aromatic Hydrocarbons ... PAH
Total Organic Carbon ..... TOC
Total Petroleum Hydrocarbons ..... TPH
Trihalomethanes ..... THM
Volatile Organic Compounds ..... VOC

Major Cations
Ammonium ..... NH_4
Calcium ..... Ca
Iron ..... Fe
Magnesium ..... Mg
Manganese ..... Mn
Potassium ..... K
Sodium ..... Na

Major Anions
Bicarbonate ..... HCO_3
Bromide ..... Br
Chloride Cl

Major Anions (cont)
Fluoride ..... F
Hydroxide ..... OH
Iodide I
Nitrate ..... NO_3
Nitrate + Nitrite ..... NO_3+NO_2
Phosphorus ..... P
Sulfate SO_4

Minor & Trace Elements
Aluminum ..... Al
Antimony ..... Sb
Arsenic ..... As
Barium ..... Ba
Beryllium ..... Be
Boron ..... B
Cadmium ..... Cd
Chromium ..... Cr
Cobalt ..... Co

Minor & Trace Elements (cont)
Copper ..... Cu
Lead ..... Pb
Lithium Li
Mercury ..... Hg
Molybdenum ..... Mo
Nickel ..... Ni
Selenium ..... Se
Silicon ..... Si
Silver ..... Ag
Strontium ..... Sr
Thallium ..... Tl
Vanadium V
Zinc ..... Zn

Dissolved Gases
Dissolved Butane ..... C_4H_{10}
Dissolved Ethane ..... C_2H_6
Dissolved Methane ..... CH_4

Dissolved Gases (cont)
Dissolved Propane ..... C_3H_8
Hydrogen Sulfide ..... H_2S

Radionuclides
Gross alpha ..... Gross α
Gross beta ..... Gross β
Radium-226 ..... ^{226}Ra
Radium-228 ..... ^{228}Ra
Strontium-86 ..... ^{86}Sr
Strontium-87 ..... ^{87}Sr
Uranium ..... U

Bacteria
Escherichia coli ..... E. coli
Iron-related bacteria ..... IRB
Slime-forming bacteria ..... SFB
Sulfate-reducing bacteria ..... SRB
Total Coliform TC

Note: * Post-drill analytical suite may be different from the pre-drill analytical suite specified.
a = Designated contractor sampling and testing requirements (SWRCB 2015)
b=No analyte list, the operator must propose a list of analytes for agency approval in their water quality monitoring plan (ID 2014)

Table A-4. *Organizations and International Agencies with Guidance for Pre-drill and Post-drill Sampling of Water Sources*

Organization	Guidance Title	Water Source	Pre-Drill	Post-Drill	COCs	Location	Timeframe	Link
International & National Organizations								
American Petroleum Institute (API)	Hydraulic Fracturing Operations - Well Construction and Integrity Guidelines. API Guidance Document HF1, 1st Edition (2009); Water Management Associated with Hydraulic Fracturing. API Guidance Document HF2. 1st Edition (2010)	Rivers, creeks, lakes, ponds, water wells	✓	×	✓	✓	×	http://www.api.org/~/media/files/policy/exploration/api_hf1.pdf http://www.api.org/~/media/files/policy/exploration/hf2_e1.pdf
American Water Works Association (AWWA)	Water and Hydraulic Fracturing (2013)	Surface water, groundwater	✓	✓	✓	×	×	http://www.awwa.org/Portals/0/files/legreg/documents/AWWAFrackingReport.pdf
Canadian Association of Petroleum Producers (CAPP)	CAPP Hydraulic Fracturing Operating Practice: Baseline Groundwater Testing (2012)	Domestic water wells	✓	×	✓	✓	×	http://www.capp.ca/publications-and-statistics/publications/218135
Groundwater Protection Council (GWPC) & the Interstate Oil & Gas Conservation Commission (IOGCC)	FracFocus Chemical Disclosure Registry "Groundwater Quality and Testing" (website accessed 2015)	Groundwater, Water wells	✓	✓	✓	×	×	https://fracfocus.org/groundwater-protection/groundwater-quality-testing
International Association of Oil & Gas Producers (OGP) and International Petroleum Industry Environmental Conservation Association (IPIECA)	Good Practice Guidelines for the Development of Shale Oil and Gas (2013)	Groundwater, surface water	✓	✓	×	×	×	http://www.ipieca.org/publication/ogp-ipieca-good-practice-guidelines-development-shale-oil-and-gas
National Groundwater Association (NGWA)	Water Wells in Proximity to Natural Gas or Oil Development: What You Need to Know (2012)	Groundwater, Water wells	✓	✓	✓	×	✓	http://www.ngwa.org/Documents/ClipCopy/Hydraulic_Fracturing_Info_Sheet.pdf
State Review of Oil & Natural Gas Environmental Regulations, Inc. (STRONGER)	2015 STRONGER Guidelines (2015)	Groundwater	✓	×	×	×	×	http://www.strongerinc.org/wp-content/uploads/2015/08/2015-STRONGER-Guidelines.pdf
Regional Organizations								
Appalachian Shale Recommended Practices Group (ASRPG)	Recommended Standards and Practices (2012)	Surface water, private & public wells	✓	×	×	✓	×	http://asrpg.org/pdf/ASRPG_standards_and_practices-April2012.pdf

Organization	Guidance Title	Water Source	Pre-Drill	Post-Drill	COCs	Location	Timeframe	Link
Center for Sustainable Shale Development (CSSD)	Performance Standards (2013)	Surface water, groundwater	✓	✓	×	✓	✓	https://www.sustainableshale.org/wp-content/uploads/2014/01/Performance-Standards-v.-1.1.pdf
Marcellus Shale Coalition (MSC)	Recommended Practices: Pre-Drill Water Supply Surveys (2013)	Water wells, springs, ponds	✓	×	✓	×	×	http://marcelluscoalition.org/wp-content/uploads/2013/03/RP_Pre_Drill_Water.pdf
International Regulatory Agencies								
New Brunswick, Canada *Province of New Brunswick, Department of Energy and Mines*	Responsible Environmental Management of Oil and Natural Gas Activities in New Brunswick- Rules for Industry (2013)	Surface water, groundwater	✓	✓	✓	✓	✓	http://www2.gnb.ca/content/dam/gnb/Corporate/pdf/ShaleGas/en/RulesforIndustry.pdf
Columbia *Ministry of Environment and Sustainable Development, National Environmental Licensing Authority*	Terms of Reference for Environmental Impact Study Development, Exploratory Oil Drilling Projects (2014)	Aquifers for consumption/ agriculture, surface water	✓	×	✓	×	×	http://www.anla.gov.co/documentos/normativa/TdR%20exploracion%20HC%20VF%20Para%20adopci%C3%B3n%20sin%20CC.pdf
European Union (EU) *European Commission*	Commission recommendation on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing (2014)	Surface water, groundwater, drinking water	✓	✓	✓	×	×	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014H0070&from=EN
Mexico *Secretary of Environment and Natural Resources (SEMARNAT)*	Environmental Criteria Guide for Exploration and Extraction of Shale Hydrocarbons (2015)	Aquifers, surface water bodies	✓	✓	✓	✓	✓	http://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/Libros2011/CD001945.pdf
New Zealand *Ministry for the Environment*	Managing Environmental Effects of Onshore Petroleum Development Activities (Including Hydraulic Fracturing): Guidelines for Local Government (2014)	Groundwater and surface water	✓	✓	✓	✓	✓	http://www.mfe.govt.nz/sites/default/files/managing-environmental-effects-of-onshore-petroleum-development-activities-pdf.pdf

Notes:

Pre-drill = pre-drill sampling required or recommended.

Post-drill = post-drill sampling required or recommended.

COCs = specifies constituents to be analyzed and typically reported.

Location = specifies sample distance or radius from well site or other location.

Timeline = specifies timeline for pre-drill or post-drill sampling.

APPENDIX B

BASELINE SAMPLING FOR DISSOLVED METHANE

PHOTO LOG

Monitoring equipment (including meteorological station) at wellhead

Water Well System Components: *Wellhead and field equipment*

Water Well System Components: *Water treatment system*

Water Well System Components: *Pressure Tank*

Field Equipment: *YSI multiparameter meter*

Field Equipment: *YSI flow-through cell*

Field Equipment: *HACH Turbidimeter*

Field Equipment: *Flowmeter assembly*

Sample Collection: *Sample location (outlet of the pressure tank)*

Sample Collection: *Dissolved gases using the Direct-Fill Method*

Sample Collection: *Dissolved gases using the Inverted Bottle Method*

Sample Collection: *Dissolved gases using IsoFlask™*

***Sample Collection**: 40 ml VOA vials*

***Sample Collection:** IsoFlask™*

Sample Collection: Purge water

Sample Collection: Effervescing well water

APPENDIX C

BASELINE SAMPLING FOR DISSOLVED METHANE

WELL OWNER INTERVIEW AND SITE INSPECTION FORMS

GSI ENVIRONMENTAL

WELL OWNER INTERVIEW FORM

Well: _____
Date: _____
Page: _____of_____

GENERAL INFORMATION	
Water Well Name/ID:	**Date:**
Latitude:	**Time of Arrival:**
Longitude:	**Time of Departure:**
Client:	**Personnel:**
Project:	**Interview: ☐ Phone ☐ In Person**
RESIDENT INFORMATION	
Person Interviewed:	**☐ Property Owner ☐ Resident ☐ Other:**
Address:	
Cell phone no.:	**Home/Business phone no.:**
Email Address:	
Additional Information:	
INTERVIEW QUESTIONS	
History of the Well	
How long has the resident lived at the location?	
Have water samples been previously collected from the well? ☐ Yes ☐ No	
If yes, when were the samples collected? ***(request copy of analytical results)***	
Is the owner aware of any nearby oil and gas operations, strip mining, or other industrial activity? ☐ Yes ☐ No	
If so, approximately how close is the property to the reported industrial activity?	
Are the roads salted in the winter? ☐ Yes ☐ No	
Maintenance	
What type of maintenance has been conducted on the well (e.g., shock treatment)?	
How often is maintenance of the well conducted? When was the last maintenance?	
Water Usage	
What is the estimated volume of water used on a daily basis?	
Can the resident describe water usage in the days prior to this sampling event?	
Are there any seasons or days where water use may differ?	
Does the well ever pump off or run dry (i.e., start pulling in air)?	
Water Quality Information	
What is the resident's description of odor, appearance, and taste of the water?	

GSI ENVIRONMENTAL

WELL OWNER INTERVIEW FORM

Well: _____
Date: _____
Page: _____of_____

INTERVIEW QUESTIONS	
Water Quality Information Continued	
Has the resident observed any changes in water quality during the past month? Or any time in the past?	
What is the owner's description of treatment system and reason for treatment (if present)?	
Is the resident aware of any bubbling or previously elevated gas concentrations in their well?	
Are there any other problems reported by the resident?	
If yes, when did the resident first become aware of the problem(s)?	
Can the resident relate the onset of the observed problem(s) to any oil and gas or industrial activities in the area?	
Additional Information:	
DESCRIPTION OF WATER WELL AND SYSTEM	
How many water wells are on the property?	
If available, list all water well ID(s) (*state or other*):	
Does the resident have any information about well construction?	
Date Installed:	**Total Depth:**
Casing Information:	**Pump Depth:**
Well Diameter:	**Pump Type:**
Driller:	**Drilling Record: ☐ Yes ☐ No *(if yes, request copy of record)***
What is the primary use of water well (domestic, agricultural, irrigation)?	
Does the water well supply other properties?	
Presence and appearance of well cap (i.e., can headspace gas concentrations be measured?):	
Access to water well wellbore (e.g., Is the drop-pipe blocking access to water column? Is the well cap unable to be removed?):	
Presence and appearance of drop pipe:	
Presence and location of any discharge pipes or water faucets where sampling may be conducted:	
Type of pump and set pump rate (if known). Can the purge rate be altered?	
Type of pressure tank and pressure tank volume, if present:	
Location and type of water treatment devices (e.g., filtration, water softeners), if present:	
Additional Information:	

GSI ENVIRONMENTAL

BASELINE SAMPLING FIELD FORM

Well: _____
Date: _____
Page: _____of_____

SAMPLING INFORMATION		
Sampling Location		
Describe sampling location (e.g., wellhead, outside faucet, before/after pressure tank, inside faucet):		
Describe method of sample collection (e.g., existing well pump, sampling pump, bailer, low flow):		
Other observations/notes:		
Field Meters		
Meter Type:	**Serial Number:**	**Calibrated:** ☐ **Yes** ☐ **No**
Meter Type:	**Serial Number:**	**Calibrated:** ☐ **Yes** ☐ **No**
Meter Type:	**Serial Number:**	**Calibrated:** ☐ **Yes** ☐ **No**
Meter Type:	**Serial Number:**	**Calibrated:** ☐ **Yes** ☐ **No**
Laboratory Information		
Chain of custody attached? ☐ **Yes** ☐ **No**	**Name of Certified Laboratory:**	
Sketch of water system components and location where sample was collected:		

PHOTOGRAPHIC DOCUMENTATION		
Photographer:		
Photo Number	**Time**	**Description of Photo**
		Close-up of residential water well
		Wide angle of the well
		Landscape view of the well and residential location
		Close up of the pressure tank
		View of initial purge water
		View of final purge water
		View of sampling location
		Picture of well owner (if they agree)

APPENDIX D

BASELINE SAMPLING FOR DISSOLVED METHANE

ANALYTICAL SUITE FOR SAMPLING AND TEMPORAL VARIABILITY STUDIES

Table D-1. *Sampling Variability Study Analytical Suite – Eurofins Lancaster Laboratories*

Analytical Test	Method	Hold Time	Parameter(s)	Requested Detection Limits – Year 2 of Study
Dissolved Gas Concentrations	RSKSOP-175 modified	14 days	Methane, Ethane, Propane, Isobutane, n-butane	
15 Metals (Total)	EPA 200.7 rev 4.4 and EPA 200.8 rev 5.4	6 months	Aluminum, Arsenic, Barium, Cadmium, Calcium, Chromium, Iron, Lead, Magnesium, Manganese, Potassium, Selenium, Silver, Sodium, Strontium	Manganese – 0.05 mg/L Iron – 0.1 mg/L
15 Metals (Dissolved - field filtered) If Turbidity >10 NTU	EPA 200.7 rev 4.4 and EPA 200.8 rev 5.4	6 months	Aluminum, Arsenic, Barium, Cadmium, Calcium, Chromium, Iron, Lead, Magnesium, Manganese, Potassium, Selenium, Silver, Sodium, Strontium	Manganese – 0.05 mg/L Iron – 0.1 mg/L
Total Dissolved Solids	SM 2540 C-1997	7 days	Total Dissolved Solids	
Total Suspended Solids	SM 2540 D-1997	7 days	Total Suspended Solids	
Chloride	EPA 300.0	28 days	Chloride	
Sulfate	EPA 300.0	28 days	Sulfate	Sulfate - 0.5 mg/L
Sulfide	EPA 376.2	7 days	Sulfide	Sulfide - 0.5 mg/L
Nitrate	EPA 353.2 OR EPA 300.0	48 hours	Nitrate	Nitrate - 0.5 mg/L
Nitrite	EPA 353.2 OR EPA 300.0	28 days OR 48 hours	Nitrite	Nitrite - 0.5 mg/L
Total Alkalinity (as CaCO3)	SM 2320 B-1997	14 days	Total Alkalinity (as CaCO3)	
Bicarbonate Alkalinity	SM20 2320 B	14 days	Bicarbonate Alkalinity	
Bromide (Low Level)	EPA 300.0	28 days	Bromide	Bromide - 0.1 mg/L
Lab pH		15 minutes	pH	

Table D-2. *Sampling Variability Study Analytical Suite – Isotech Laboratories*

Analytical Test	Method	Hold Time	Parameter(s)	Minimum Concentrations / Volume Required	Detection Limits
Full compositional analysis of gas samples (including fixed gases and hydrocarbon gases) with dissolved methane, ethane, and propane calculation	Helium headspace equilibration/ GC analysis	90 days	Methane (ppm), Ethane (ppm)	NA – headspace will be created with helium	Methane- 2 ppm in gas phase Ethane- 1 ppm in gas phase
Carbon and hydrogen isotope analysis of methane	IRMS or CRDS Laser	30-90+ days	$\delta^{13}C$ – Methane, $\delta^{2}H$ – Methane	Methane – ~1% in gas phase	
Carbon isotope analysis of ethane, if detected	IRMS	30-90+ days	$\delta^{13}C$ – Ethane	Ethane and Propane– 10 ppm in gas phase	
Hydrogen and oxygen Isotope analysis of Water	CRDS laser	1 year	$\delta^{2}H$ – Water, $\delta^{18}O$ – Water	Volume – 2 ml	
Carbon isotope analysis of dissolved inorganic carbon	IRMS	1 week	$\delta^{13}C$ – DIC	Volume – 20 ml	

Table D-3. *Temporal Variability Study Analytical Suite – Eurofins Lancaster Laboratories*

Analytical Test	Method	Hold Time	Parameter(s)	Requested Detection Limits – Year 2 of Study
Dissolved Gas Concentrations	RSKSOP-175 modified	14 days	Methane, Ethane, Propane, Isobutane, n-butane	
15 Metals (Total)	EPA 200.7 rev 4.4 and EPA 200.8 rev 5.4	6 months	Aluminum, Arsenic, Barium, Cadmium, Calcium, Chromium, Iron, Lead, Magnesium, Manganese, Potassium, Selenium, Silver, Sodium, Strontium	Manganese – 0.05 mg/L Iron – 0.1 mg/L
15 Metals (Dissolved - field filtered) If Turbidity >10 NTU	EPA 200.7 rev 4.4 and EPA 200.8 rev 5.4	6 months	Aluminum, Arsenic, Barium, Cadmium, Calcium, Chromium, Iron, Lead, Magnesium, Manganese, Potassium, Selenium, Silver, Sodium, Strontium	Manganese – 0.05 mg/L Iron – 0.1 mg/L
Total Dissolved Solids	SM 2540 C-1997	7 days	Total Dissolved Solids	
Total Suspended Solids	SM 2540 D-1997	7 days	Total Suspended Solids	
Chloride	EPA 300.0	28 days	Chloride	

Table D-3. *Temporal Variability Study Analytical Suite – Eurofins Lancaster Laboratories (cont)*

Analytical Test	Method	Hold Time	Parameter(s)	Requested Detection Limits – Year 2 of Study
Sulfate	EPA 300.0	28 days	Sulfate	Sulfate - 0.5 mg/L
Sulfide	EPA 376.2	7 days	Sulfide	Sulfide - 0.5 mg/L
Nitrate	EPA 353.2 OR EPA 300.0	48 hours	Nitrate	Nitrate - 0.5 mg/L
Nitrite	EPA 353.2 OR EPA 300.0	28 days OR 48 hours	Nitrite	Nitrite - 0.5 mg/L
Total Alkalinity (as CaCO3)	SM 2320 B-1997	14 days	Total Alkalinity (as $CaCO_3$)	
Bicarbonate Alkalinity	SM20 2320 B	14 days	Bicarbonate Alkalinity	
Bromide (Low Level)	EPA 300.0	28 days	Bromide	Bromide - 0.1 mg/L
Lab pH		15 minutes	pH	

Table D-4. *Temporal Variability Study Analytical Suite – Benchmark Analytics*

Analytical Test	Method	Hold Time	Parameter(s)	Specific Notes
Total Coliform/E. Coli	SM20 9223 B	30 hours	Total Coliform/ E. Coli	

Table D-5. *Temporal Variability Study Analytical Suite – Isotech Laboratories*

Analytical Test	Method	Hold Time	Parameter(s)	Minimum Concentrations/ Volume Required	Detection Limits
Full compositional analysis of gas samples (including fixed gases and hydrocarbon gases) with dissolved methane, ethane, and propane calculation	Helium headspace equilibration/ GC analysis	90 days	Methane (ppm), Ethane (ppm)	NA – headspace will be created with helium	Methane- 2 ppm in gas phase Ethane- 1 ppm in gas phase
Carbon and hydrogen isotope analysis of methane	IRMS or CRDS Laser	30-90+ days	$\delta^{13}C$ – Methane, $\delta^{2}H$ – Methane	Methane – ~1% in gas phase	
Carbon isotope analysis of ethane and propane	IRMS	30-90+ days	$\delta^{13}C$ – Ethane, $\delta^{13}C$ – Propane	Ethane and Propane– 10 ppm in gas phase	
Hydrogen and oxygen Isotope analysis of Water	CRDS laser	1 year	$\delta^{2}H$ – Water, $\delta^{18}O$ – Water	Volume – 2 ml	
Carbon isotope analysis of dissolved inorganic carbon	IRMS	1 week	$\delta^{13}C$ – DIC	Volume – 20 ml	

APPENDIX E

BASELINE SAMPLING FOR DISSOLVED METHANE

CABOT OIL & GAS TEMPORAL VARIABILITY STUDY

APPENDIX E

BASELINE SAMPLING FOR DISSOLVED METHANE IN AREAS OF SHALE OIL AND GAS DEVELOPMENT

Temporal Variability Study Conducted by Cabot Oil & Gas Corporation

For the 11 wells in this study, additional sampling events were conducted over a two-year period by our teaming industry partner, Cabot Oil and Gas Corporation, prior to the start of the RPSEA study. These samples were collected to evaluate natural temporal variability of dissolved methane concentrations and other water quality parameters after purging to initial parameter stability over a short- and long-term timeframe, amounting to 6 to 28 sampling events at each well (181 total sampling events). During these events, dissolved gas samples were collected in 40 ml VOA vials using the Direct-Fill method, rather than in IsoFlask™ containers, and samples for isotopic analysis and general water quality analysis were collected. In addition, at five of the wells, real-time measurements of parameters including, but not limited to water temperature, pH, specific conductivity, oxidation reduction potential (ORP), and barometric pressure, were recorded for an extended period of time from a weather station and down-hole sensors.

The magnitude of variability in methane concentrations for samples collected over time as a part of this study is discussed in full in the technical report. In addition, the technical report includes a detailed discussion of the relationship between dissolved methane concentration and sodium concentration over time for this dataset. The full dataset is provided in **Table E-1**.

This appendix discusses the relationship between dissolved methane concentration and real-time measurements of parameters including, but not limited to water temperature, pH, specific conductivity, oxidation reduction potential (ORP), and barometric pressure. These field and meteorological parameters were measured continuously at five wells in the study (i.e., the Cas, Iri, Jon, Web, and Sbar wells) using the following equipment:

- ***In situ* Troll 9500 with optional RDO Sensor**: continuously measures conductivity, dissolved oxygen, pH, and ORP in groundwater.
- **Davis Instruments Vantage Pro II weather station**: measures precipitation, ambient temperature, relative humidity, barometric pressure, and wind velocity at the field site.
- **Campbell Scientific CR 200 and CR1000 Dataloggers**: records and stores real-time information from the downhole sensors, water meter, and weather station.

The objective of this component of the study was to determine whether these parameters exhibited any correlation with dissolved methane concentration (as measured using 40 ml VOA vials filled via the Direct-Fill method). Of note, one well (the Jon well), reported methane concentrations above 20 mg/L for 40 ml VOA vial samples. In this range of concentration, we anticipate that the reported methane concentrations are in fact low-biased, limiting the interpretation of the data at that well. The remaining four wells reported methane concentrations less than 20 mg/L, with the Iri well reporting methane concentrations in the very low µg/L range. To evaluate the relationship between dissolved methane concentration and the parameters recorded by the down-hole sensors and weather station, we evaluated whether any parameter exhibited a statistically significant relationship with the dissolved methane concentration over time. Specifically, we determined whether the slope of the line through dissolved methane vs. the parameter value at the time of sample collection was significantly different from zero.

As shown in **Table E-2,** no single parameter exhibited a consistently significant relationship with dissolved methane concentration among the population of wells. However, certain parameters were found to be statistically associated with dissolved methane concentration over time at a subset of wells. For example, dissolved methane concentration exhibited a statistically significant relationship with specific conductivity at two wells (Cas and Iri), where specific conductivity was found to predict roughly 40 – 50% of dissolved methane variability. As discussed in the technical report, this relationship is mirrored by the strong statistical association between dissolved methane and sodium concentration at a subset of wells, where the correlation between methane and salinity indicator parameters over time appears to be related to changes in the volumetric mixing ratios of different aquifer fluids mixing within the wellbore environment or being captured by the well.

Of the remaining parameters, ORP was found to predict approximately 30 - 60% of dissolved methane variability at the Web and Sbar wells, temperature predicted ~50% of the variability at the Iri well, and barometric pressure was found to predict between 20 and 30% of the variability observed at the Iri and Jon wells. Because these parameters correlated with dissolved methane concentration in only a few wells, and there was no strong relationship between these field parameters and IsoFlask™ dissolved methane concentration (as reported in the main body of the technical report), it appears unlikely that the real-time measurement of these parameters down-hole (within the well) or using a meteorological station would predict trends in methane variability across a larger population of wells.

Table E-2. *Slope, R^2 value, and statistical significance of best fit line through methane concentrations versus field parameter values over time at each well.*

	Temperature					pH				
Well	n	Timeframe (days)	P-value	R^2	Slope	n	Timeframe (days)	P-value	R^2	Slope
Cas	15	400	0.36	0.06	48707	12	369	0.75	0.01	398
Iri	15	481	0.005	0.47	34.4	15	481	0.438	0.06	-8.6
Jon	22	489	0.94	2.88E-04	-275	22	397	0.62	0.02	-202
Web	20	495	0.97	9.12E-05	-254	20	337	0.87	0.002	45
Sbar	8	63	0.59	0.05	-41667	8	63	0.13	0.34	2581

	ORP					Specific Conductivity				
Well	n	Timeframe (days)	P-value	R^2	Slope	n	Timeframe (days)	P-value	R^2	Slope
Cas	15	400	0.23	0.11	-7.67	12	400	0.02	0.43	4.12
Iri	15	481	0.875	0.002	-0.01	15	481	0.002	0.54	0.95
Jon	22	489	0.41	0.03	-3.71	22	489	0.48	0.02	12.0
Web	20	365	0.03	0.29	8.89	20	365	0.69	0.01	-11.8
Sbar	8	63	0.02	0.62	-14.9	8	63	0.12	0.36	39.0

	Barometric Pressure				
Well	n	Timeframe (days)	P-value	R^2	Slope
Cas	16	433	0.06	0.23	4832
Iri	15	538	0.029	0.24	-313
Jon	22	766	0.003	0.30	6426
Web	20	764	0.48	0.02	-432
Sbar	8	93	0.58	0.05	-1763

Note: statistically significant p-value <0.05 and associated R^2 value highlighted in yellow

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

								Analyte Group:	Dissolved Light Hydrocarbon Gases (Direct-Fill VOA)					Dissolved Light Hydrocarbon Gases & Isotopes (IsoFlask)				
									Gas	Gas	Gas	Gas	Gas	Gas	Gas	Isotope	Isotope	Isotope
								Analyte:	Methane	Ethane	Propane	Isobutane	n-Butane	Methane	Ethane	$\delta^{13}C\ CH_4$	$\delta^{13}C\ C_2H_6$	$\delta D\ CH_4$
								Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Isotech	Isotech	Isotech	Isotech	Isotech
Well #	**Location ID**	**Purge Abbreviation**	**Purge Volume**	**Pre / Post Pressure Tank**	**Sample Date**	**Sample Time**	**Sample Type**	**Sample ID**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**‰**	**‰**	**‰**
W12	Cas	P2	Purge to parameter stability	Post	10/13/2012	8:16:00 AM	N	Cas_1_E0_P2_TV_Post_N_10/13/2012_8:16:00 AM	8600	0.5	0.5	0.5	0.5					
W12	Cas	P2	Purge to parameter stability	Post	11/15/2012	6:40:00 PM	N	Cas_1_E0_P2_TV_Post_N_11/15/2012_6:40:00 PM	19000	0.5	0.5	0.5	0.5					
W12	Cas	P2	Purge to parameter stability	Post	12/14/2012	4:50:00 PM	N	Cas_1_E0_P2_TV_Post_N_12/14/2012_4:50:00 PM	8500	0.5	0.5	0.5	0.5					
W12	Cas	P2	Purge to parameter stability	Post	1/26/2013	9:25:00 AM	N	Cas_1_E0_P2_TV_Post_N_1/26/2013_9:25:00 AM	9900	0.5	0.5	0.5	0.5			-40.74		-216.5
W12	Cas	P2	Purge to parameter stability	Post	2/22/2013	4:35:00 PM	N	Cas_1_E0_P2_TV_Post_N_2/22/2013_4:35:00 PM	19000	5.3	0.5	0.5	0.5			-41.11		-217.3
W12	Cas	P2	Purge to parameter stability	Post	3/22/2013	3:10:00 PM	N	Cas_1_E0_P2_TV_Post_N_3/22/2013_3:10:00 PM	7900	0.5	0.5	0.5	0.5			-41.12		-216.3
W12	Cas	P2	Purge to parameter stability	Post	4/23/2013	7:10:00 PM	N	Cas_1_E0_P2_TV_Post_N_4/23/2013_7:10:00 PM	12000	0.5	0.5	0.5	0.5			-40.68		-216.9
W12	Cas	P2	Purge to parameter stability	Post	5/21/2013	7:10:00 PM	N	Cas_1_E0_P2_TV_Post_N_5/21/2013_7:10:00 PM	14000	0.5	0.5	0.5	0.5			-40.78		-214.7
W12	Cas	P2	Purge to parameter stability	Post	6/20/2013	6:50:00 PM	N	Cas_1_E0_P2_TV_Post_N_6/20/2013_6:50:00 PM	20000	6.2	0.5	0.5	0.5			-41.28		-218.1
W12	Cas	P2	Purge to parameter stability	Post	7/25/2013	7:00:00 PM	N	Cas_1_E0_P2_TV_Post_N_7/25/2013_7:00:00 PM	14000	0.5	0.5	0.5	0.5			-40.8		-212.5
W12	Cas	P2	Purge to parameter stability	Post	8/20/2013	7:17:00 PM	N	Cas_1_E0_P2_TV_Post_N_8/20/2013_7:17:00 PM	18000	5.2	0.5	0.5	0.5			-40.7		-217.6
W12	Cas	P2	Purge to parameter stability	Post	9/24/2013	7:15:00 PM	N	Cas_1_E0_P2_TV_Post_N_9/24/2013_7:15:00 PM	17000	5.2	0.5	0.5	0.5			-40.67		-218.5
W12	Cas	P2	Purge to parameter stability	Post	10/22/2013	6:45:00 PM	N	Cas_1_E0_P2_TV_Post_N_10/22/2013_6:45:00 PM	9300	0.5	0.5	0.5	0.5			-40.01		-216.6
W12	Cas	P2	Purge to parameter stability	Post	11/19/2013	6:32:00 PM	N	Cas_1_E0_P2_TV_Post_N_11/19/2013_6:32:00 PM	19000	0.5	0.5	0.5	0.5			-40.27		-218.4
W12	Cas	P2	Purge to parameter stability	Post	12/20/2013	1:10:00 PM	N-Dup	Cas_1_E01_P2_TV_Post_N-Dup_12/20/2013_1:10:00 PM	11000	0.5	0.5	0.5	0.5	10000	2.7	-40.01		-216
W12	Cas	P2	Purge to parameter stability	Post	12/20/2013	1:10:00 PM	Dup	Cas_1_E01_P2_TV_Post_Dup_12/20/2013_1:10:00 PM	12000	0.5	0.5	0.5	0.5	11000	2.6	-39.86		-216.5
W11	Iri	P2	Purge to parameter stability	Post	11/29/2012	10:20:00 AM	N	Iri_1_E0_P2_TV_Post_N_11/29/2012_10:20:00 AM	580	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	12/28/2012	11:10:00 AM	N	Iri_1_E0_P2_TV_Post_N_12/28/2012_11:10:00 AM	65	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	1/22/2013	9:15:00 AM	N	Iri_1_E0_P2_TV_Post_N_1/22/2013_9:15:00 AM	1.5	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	2/21/2013	8:51:00 AM	N	Iri_1_E0_P2_TV_Post_N_2/21/2013_8:51:00 AM	18	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	3/21/2013	9:23:00 AM	N	Iri_1_E0_P2_TV_Post_N_3/21/2013_9:23:00 AM	1.5	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	4/23/2013	8:25:00 AM	N	Iri_1_E0_P2_TV_Post_N_4/23/2013_8:25:00 AM	1.5	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	5/21/2013	8:35:00 AM	N	Iri_1_E0_P2_TV_Post_N_5/21/2013_8:35:00 AM	13	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	6/20/2013	4:20:00 PM	N	Iri_1_E0_P2_TV_Post_N_6/20/2013_4:20:00 PM	29	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	7/23/2013	8:14:00 AM	N	Iri_1_E0_P2_TV_Post_N_7/23/2013_8:14:00 AM	33	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	8/20/2013	5:47:00 PM	N	Iri_1_E0_P2_TV_Post_N_8/20/2013_5:47:00 PM	150	0.5	0.5	0.5	0.5			-65.8		-306
W11	Iri	P2	Purge to parameter stability	Post	9/24/2013	1:40:00 PM	N	Iri_1_E0_P2_TV_Post_N_9/24/2013_1:40:00 PM	81	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	10/22/2013	11:15:00 AM	N	Iri_1_E0_P2_TV_Post_N_10/22/2013_11:15:00 AM	110	0.5	0.5	0.5	0.5			-64.7		-296
W11	Iri	P2	Purge to parameter stability	Post	11/19/2013	2:13:00 PM	N	Iri_1_E0_P2_TV_Post_N_11/19/2013_2:13:00 PM	230	0.5	0.5	0.5	0.5			-63.1		-290
W11	Iri	P2	Purge to parameter stability	Post	12/19/2013	5:45:00 PM	N	Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM	1.5	0.5	0.5	0.5	0.5	1.7	0.1			
W11	Iri	P2	Purge to parameter stability	Post	1/21/2014	5:30:00 PM	N	Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM	1.5	0.5	0.5	0.5	0.5	1.1	0.1			
W11	Iri	P2	Purge to parameter stability	Post	2/18/2014	10:45:00 AM	N	Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM	1.5	0.5	0.5	0.5	0.5	1.3	0.15			
W11	Iri	P2	Purge to parameter stability	Post	3/25/2014	10:43:00 AM	N	Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM	1.5	0.5	0.5	0.5	0.5	1.2	0.1			
W11	Iri	P2	Purge to parameter stability	Post	4/23/2014	5:05:00 PM	N-Dup	Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM	1.5	0.5	0.5	0.5	0.5	0.82	0.1			
W11	Iri	P2	Purge to parameter stability	Post	4/23/2014	5:05:00 PM	Dup	Iri_1_E05_P2_TV_Post_Dup_4/23/2014_5:05:00 PM	1.5	0.5	0.5	0.5	0.5					
W11	Iri	P2	Purge to parameter stability	Post	5/21/2014	7:37:00 AM	N	Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM	1.5	0.5	0.5	0.5	0.5	3.7	0.1			
W3	Jon	P2	Purge to parameter stability	Post	4/16/2012	12:50:00 PM	N	Jon_1_E0_P2_TV_Post_N_4/16/2012_12:50:00 PM	18000	18	0.5	0.5	0.5					
W3	Jon	P2	Purge to parameter stability	Post	9/21/2012	12:05:00 PM	N	Jon_1_E0_P2_TV_Post_N_9/21/2012_12:05:00 PM	23000	18	0.5	0.5	0.5					
W3	Jon	P2	Purge to parameter stability	Post	10/25/2012	3:15:00 PM	N	Jon_1_E0_P2_TV_Post_N_10/25/2012_3:15:00 PM	22000	6.6	0.5	0.5	0.5					
W3	Jon	P2	Purge to parameter stability	Post	11/26/2012	1:05:00 PM	N	Jon_1_E0_P2_TV_Post_N_11/26/2012_1:05:00 PM	20000	7.6	0.5	0.5	0.5					
W3	Jon	P2	Purge to parameter stability	Post	12/20/2012	12:40:00 PM	N	Jon_1_E0_P2_TV_Post_N_12/20/2012_12:40:00 PM	24000	6.7	0.5	0.5	0.5					
W3	Jon	P2	Purge to parameter stability	Post	1/22/2013	3:10:00 PM	N	Jon_1_E0_P2_TV_Post_N_1/22/2013_3:10:00 PM	29000	7.8	0.5	0.5	0.5			-39.48		-197.9
W3	Jon	P2	Purge to parameter stability	Post	2/21/2013	2:15:00 PM	N	Jon_1_E0_P2_TV_Post_N_2/21/2013_2:15:00 PM	25000	7.6	0.5	0.5	0.5			-39.47		-203.3
W3	Jon	P2	Purge to parameter stability	Post	3/21/2013	1:27:00 PM	N	Jon_1_E0_P2_TV_Post_N_3/21/2013_1:27:00 PM	28000	8.9	0.5	0.5	0.5			-39.54		-192.7
W3	Jon	P2	Purge to parameter stability	Post	4/23/2013	2:30:00 PM	N	Jon_1_E0_P2_TV_Post_N_4/23/2013_2:30:00 PM	26000	9.3	0.5	0.5	0.5			-39.55		-203.4
W3	Jon	P2	Purge to parameter stability	Post	5/21/2013	12:30:00 PM	N	Jon_1_E0_P2_TV_Post_N_5/21/2013_12:30:00 PM	27000	9.1	0.5	0.5	0.5			-39.56		-203.2
W3	Jon	P2	Purge to parameter stability	Post	6/20/2013	10:50:00 AM	N	Jon_1_E0_P2_TV_Post_N_6/20/2013_10:50:00 AM	24000	9.9	0.5	0.5	0.5			-39.66		-199.9
W3	Jon	P2	Purge to parameter stability	Post	7/23/2013	2:45:00 PM	N	Jon_1_E0_P2_TV_Post_N_7/23/2013_2:45:00 PM	24000	8.1	0.5	0.5	0.5			-39.41		-204.2
W3	Jon	P2	Purge to parameter stability	Post	8/20/2013	9:15:00 AM	N	Jon_1_E0_P2_TV_Post_N_8/20/2013_9:15:00 AM	31000	8.8	0.5	0.5	0.5			-39.25		-200.3
W3	Jon	P2	Purge to parameter stability	Post	9/24/2013	9:50:00 AM	N	Jon_1_E0_P2_TV_Post_N_9/24/2013_9:50:00 AM	23000	8.4	0.5	0.5	0.5			-39.47		-202.3
W3	Jon	P2	Purge to parameter stability	Post	10/22/2013	9:20:00 AM	N	Jon_1_E0_P2_TV_Post_N_10/22/2013_9:20:00 AM	24000	6.5	0.5	0.5	0.5			-39.81		-197.7
W3	Jon	P2	Purge to parameter stability	Post	11/19/2013	9:20:00 AM	N	Jon_1_E0_P2_TV_Post_N_11/19/2013_9:20:00 AM	28000	9	0.5	0.5	0.5			-39.47		-202.5
W3	Jon	P2	Purge to parameter stability	Post	12/19/2013	9:20:00 AM	N	Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM	31000	15	0.5	0.5	0.5	30000	11	-39.06		-201.5
W3	Jon	P2	Purge to parameter stability	Post	1/21/2014	9:15:00 AM	N-Dup	Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM	26000	11	0.5	0.5	0.5	31000	11	-39.49		-201.7
W3	Jon	P2	Purge to parameter stability	Post	1/21/2014	9:15:00 AM	Dup	Jon_1_E02_P2_TV_Post_Dup_1/21/2014_9:15:00 AM	26000	9.9	0.5	0.5	0.5					
W3	Jon	P2	Purge to parameter stability	Post	2/17/2014	3:51:00 PM	N-Dup	Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM	30000	14	0.5	0.5	0.5	31000	11	-39.25		-199.2
W3	Jon	P2	Purge to parameter stability	Post	2/17/2014	3:51:00 PM	Dup	Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM	29000	13	0.5	0.5	0.5	31000	11	-39.27		-201.8
W3	Jon	P2	Purge to parameter stability	Post	2/21/2014	8:54:00 AM	N-Dup	Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM	30000	7	0.5	0.5	0.5	31000	11	-39.22		-202.2
W3	Jon	P2	Purge to parameter stability	Post	2/21/2014	8:54:00 AM	Dup	Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM	30000	7.7	0.5	0.5	0.5	31000	11			
W3	Jon	P2	Purge to parameter stability	Post	2/24/2014	9:08:00 AM	N-Dup	Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM	25000	12	0.5	0.5	0.5	33000	12	-39.27		-199.4
W3	Jon	P2	Purge to parameter stability	Post	2/24/2014	9:08:00 AM	Dup	Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM	28000	8.6	0.5	0.5	0.5	32000	12			
W3	Jon	P2	Purge to parameter stability	Post	3/26/2014	9:37:00 AM	N	Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM	30000	16	0.5	0.5	0.5	32000	12	-39.31		-198.6
W3	Jon	P2	Purge to parameter stability	Post	4/23/2014	12:00:00 PM	N	Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM	28000	8.4	0.5	0.5	0.5	34000	12	-39.31		-199.3
W3	Jon	P2	Purge to parameter stability	Post	5/22/2014	9:40:00 AM	N	Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM	26000	12	0.5	0.5	0.5	31000	11			

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

								Analyte Group:	**Dissolved Light Hydrocarbon Gases (Direct-Fill VOA)**					**Dissolved Light Hydrocarbon Gases & Isotopes (IsoFlask)**				
									Gas	**Gas**	**Gas**	**Gas**	**Gas**	**Gas**	**Gas**	**Isotope**	**Isotope**	**Isotope**
								Analyte:	**Methane**	**Ethane**	**Propane**	**Isobutane**	**n-Butane**	**Methane**	**Ethane**	**$\delta^{13}C$ CH_4**	**$\delta^{13}C$ C_2H_6**	**δD CH_4**
								Laboratory:	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Isotech**	**Isotech**	**Isotech**	**Isotech**	**Isotech**
Well #	**Location ID**	**Purge Abbreviation**	**Purge Volume**	**Pre / Post Pressure Tank**	**Sample Date**	**Sample Time**	**Sample Type**	**Sample ID**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**‰**	**‰**	**‰**
W1	Loc	P2	Purge to parameter stability	Post	5/8/2012	12:00:00 PM	N	Loc_1_E0_P2_TV_Post_N_5/8/2012_12:00:00 PM	10000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	9/21/2012	9:15:00 AM	N	Loc_1_E0_P2_TV_Post_N_9/21/2012_9:15:00 AM	6900	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	10/25/2012	10:20:00 AM	N	Loc_1_E0_P2_TV_Post_N_10/25/2012_10:20:00 AM	10000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	11/26/2012	11:05:00 AM	N	Loc_1_E0_P2_TV_Post_N_11/26/2012_11:05:00 AM	7800	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	12/20/2012	10:30:00 AM	N	Loc_1_E0_P2_TV_Post_N_12/20/2012_10:30:00 AM	8800	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	1/22/2013	11:20:00 AM	N	Loc_1_E0_P2_TV_Post_N_1/22/2013_11:20:00 AM	12000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	2/21/2013	11:00:00 AM	N	Loc_1_E0_P2_TV_Post_N_2/21/2013_11:00:00 AM	10000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	3/21/2013	11:00:00 AM	N	Loc_1_E0_P2_TV_Post_N_3/21/2013_11:00:00 AM	13000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	4/23/2013	10:55:00 AM	N	Loc_1_E0_P2_TV_Post_N_4/23/2013_10:55:00 AM	12000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	5/21/2013	10:20:00 AM	N	Loc_1_E0_P2_TV_Post_N_5/21/2013_10:20:00 AM	13000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	6/20/2013	1:00:00 PM	N	Loc_1_E0_P2_TV_Post_N_6/20/2013_1:00:00 PM	11000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	7/23/2013	10:58:00 AM	N	Loc_1_E0_P2_TV_Post_N_7/23/2013_10:58:00 AM	7700	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	8/20/2013	10:55:00 AM	N	Loc_1_E0_P2_TV_Post_N_8/20/2013_10:55:00 AM	12000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	9/24/2013	11:15:00 AM	N	Loc_1_E0_P2_TV_Post_N_9/24/2013_11:15:00 AM	12000	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	10/22/2013	2:30:00 PM	N	Loc_1_E0_P2_TV_Post_N_10/22/2013_2:30:00 PM	5200	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	11/19/2013	10:40:00 AM	N	Loc_1_E0_P2_TV_Post_N_11/19/2013_10:40:00 AM	7600	0.5	0.5	0.5	0.5					
W1	Loc	P2	Purge to parameter stability	Post	12/19/2013	12:56:00 PM	N	Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM	14000	1.5	0.5	0.5	0.5	12000	0.62	-73.69		-233.2
W1	Loc	P2	Purge to parameter stability	Post	1/21/2014	12:06:00 PM	N	Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM	12000	1.5	0.5	0.5	0.5	14000	0.47	-74.12		-231.8
W1	Loc	P2	Purge to parameter stability	Post	2/19/2014	11:24:00 AM	N-Dup	Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM	9200	0.5	0.5	0.5	0.5	12000	0.59	-73.19		-233.9
W1	Loc	P2	Purge to parameter stability	Post	2/19/2014	11:24:00 AM	Dup	Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM	12000	0.5	0.5	0.5	0.5	11000	0.45	-73.65		-232.3
W1	Loc	P2	Purge to parameter stability	Post	2/22/2014	9:35:00 AM	N-Dup	Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM	8900	0.5	0.5	0.5	0.5	9600	0.48	-73.39		-229.7
W1	Loc	P2	Purge to parameter stability	Post	2/22/2014	9:35:00 AM	Dup	Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM	9000	0.5	0.5	0.5	0.5	9400	0.61			
W1	Loc	P2	Purge to parameter stability	Post	2/26/2014	9:30:00 AM	N-Dup	Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM	9900	0.5	0.5	0.5	0.5	11000	0.64	-73.82		-231.1
W1	Loc	P2	Purge to parameter stability	Post	2/26/2014	9:30:00 AM	Dup	Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM	9800	0.5	0.5	0.5	0.5	11000	0.57			
W1	Loc	P2	Purge to parameter stability	Post	3/26/2014	6:10:00 PM	N	Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM	12000	0.5	0.5	0.5	0.5	13000		-73.94		-235
W1	Loc	P2	Purge to parameter stability	Post	4/23/2014	10:25:00 AM	N	Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM	11000	0.5	0.5	0.5	0.5	12000	0.5	-74.14		-235.3
W1	Loc	P2	Purge to parameter stability	Post	5/21/2014	9:08:00 AM	N-Dup	Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM	9600	1.25	0.5	0.5	0.5	10000	0.52			
W1	Loc	P2	Purge to parameter stability	Post	5/21/2014	9:08:00 AM	Dup	Loc_1_E06_P2_TV_Post_Dup_5/21/2014_9:08:00 AM	8800	1.15	0.5	0.5	0.5					
W6	Marc	P2	Purge to parameter stability	Post	2/18/2014	5:27:00 PM	N-Dup	Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM	5500	0.5	0.5	0.5	0.5	6100	1.7	-45.71		-215.9
W6	Marc	P2	Purge to parameter stability	Post	2/18/2014	5:27:00 PM	Dup	Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM	5400	0.5	0.5	0.5	0.5	6100	1.6			
W6	Marc	P2	Purge to parameter stability	Post	2/21/2014	1:00:00 PM	N-Dup	Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM	4700	0.5	0.5	0.5	0.5	5500	1.6	-45.49		-212.5
W6	Marc	P2	Purge to parameter stability	Post	2/21/2014	1:00:00 PM	Dup	Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM	5000	0.5	0.5	0.5	0.5	5300	1.5	-45.49		-212.7
W6	Marc	P2	Purge to parameter stability	Post	2/24/2014	12:35:00 PM	N-Dup	Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM	4500	0.5	0.5	0.5	0.5	5400	1.6	-45.17		-212.8
W6	Marc	P2	Purge to parameter stability	Post	2/24/2014	12:35:00 PM	Dup	Marc_1_E3_P2_SV_Post_Dup_2/24/2014_12:35:00 PM	4900	0.5	0.5	0.5	0.5					
W6	Marc	P2	Purge to parameter stability	Post	4/22/2014	9:55:00 AM	N	Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM	5500	0.5	0.5	0.5	0.5	5400	1.7	-45.44		-215
W6	Marc	P2	Purge to parameter stability	Post	5/22/2014	2:08:00 PM	N	Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM	5100	0.5	0.5	0.5	0.5	5300	1.5			
W5	Rath	P2	Purge to parameter stability	Post	2/20/2014	11:03:00 AM	N-Dup	Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM	44000	17	0.5	0.5	0.5	91000	52	-47.68		-216.4
W5	Rath	P2	Purge to parameter stability	Post	2/20/2014	11:03:00 AM	Dup	Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM	33000	17	0.5	0.5	0.5	69000	43			
W5	Rath	P2	Purge to parameter stability	Post	2/23/2014	9:10:00 AM	N-Dup	Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM	30000	27	0.5	0.5	0.5	67000	42	-47.27		-216.9
W5	Rath	P2	Purge to parameter stability	Post	2/23/2014	9:10:00 AM	Dup	Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM	35000	26	0.5	0.5	0.5	68000	44	-47.41		-212.9
W5	Rath	P2	Purge to parameter stability	Post	2/25/2014	9:45:00 AM	N-Dup	Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM	54000	36	0.5	0.5	0.5	74000	46	-47.37	-35.7	-216.6
W5	Rath	P2	Purge to parameter stability	Post	2/25/2014	9:45:00 AM	Dup	Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM	50000	29	0.5	0.5	0.5	71000	44			
W9	Sbar	P2	Purge to parameter stability	Post	2/18/2014	10:58:00 AM	N-Dup	Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM	5100	0.5	0.5	0.5	0.5	5600	2.1	-41.72		-199.4
W9	Sbar	P2	Purge to parameter stability	Post	2/18/2014	10:58:00 AM	Dup	Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM	4600	0.5	0.5	0.5	0.5	6000	2.1			
W9	Sbar	P2	Purge to parameter stability	Post	2/23/2014	2:24:00 PM	N-Dup	Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM	2600	0.5	0.5	0.5	0.5	3500	1.4	-40.76		-193.7
W9	Sbar	P2	Purge to parameter stability	Post	2/23/2014	2:24:00 PM	Dup	Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM	2700	0.5	0.5	0.5	0.5	3700	1.5			
W9	Sbar	P2	Purge to parameter stability	Post	2/26/2014	2:30:00 PM	N-Dup	Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM	1900	0.5	0.5	0.5	0.5	3000	1.2	-40.5		-194.1
W9	Sbar	P2	Purge to parameter stability	Post	2/26/2014	2:30:00 PM	Dup	Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM	2800	0.5	0.5	0.5	0.5	3700	1.5	-40.79		-190.9
W9	Sbar	P2	Purge to parameter stability	Post	3/25/2014	3:15:00 PM	N	Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM	6100	0.5	0.5	0.5	0.5	7600	2.7	-40.98		-198.9
W9	Sbar	P2	Purge to parameter stability	Post	4/22/2014	4:30:00 PM	N	Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM	6100	0.5	0.5	0.5	0.5	8900	2.7	-43.12		-199.7
W9	Sbar	P2	Purge to parameter stability	Post	5/22/2014	12:52:00 PM	N	Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM	7100	0.5	0.5	0.5	0.5	7900	2.4			
W8	Sdel	P2	Purge to parameter stability	Post	2/20/2014	10:32:00 AM	N-Dup	Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM	13000	0.5	0.5	0.5	0.5	17000	5.1	-40.82		-214
W8	Sdel	P2	Purge to parameter stability	Post	2/20/2014	10:32:00 AM	Dup	Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM	14000	0.5	0.5	0.5	0.5	17000	5.2			
W8	Sdel	P2	Purge to parameter stability	Post	2/23/2014	9:28:00 AM	N-Dup	Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM	15000	5.2	0.5	0.5	0.5	18000	5.2	-40.64		-206.4
W8	Sdel	P2	Purge to parameter stability	Post	2/23/2014	9:28:00 AM	Dup	Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM	15000	0.5	0.5	0.5	0.5	17000	5.3			
W8	Sdel	P2	Purge to parameter stability	Post	2/26/2014	9:35:00 AM	N-Dup	Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM	14000	6.8	0.5	0.5	0.5	16000	5.1	-40.55		-212.6
W8	Sdel	P2	Purge to parameter stability	Post	2/26/2014	9:35:00 AM	Dup	Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM	14000	6.4	0.5	0.5	0.5	17000	5	-40.63		-212.4
W7	Sieb	P2	Purge to parameter stability	Post	2/19/2014	11:50:00 AM	N-Dup	Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM	19000	10	0.5	0.5	0.5	46000	15	-43.94		-225.7
W7	Sieb	P2	Purge to parameter stability	Post	2/19/2014	11:50:00 AM	Dup	Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM	18000	10	0.5	0.5	0.5	49000	15			
W7	Sieb	P2	Purge to parameter stability	Post	2/22/2014	9:48:00 AM	N-Dup	Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM	19000	6.5	0.5	0.5	0.5	22000	8.4	-43.44		-225.2
W7	Sieb	P2	Purge to parameter stability	Post	2/22/2014	9:48:00 AM	Dup	Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM	20000	8.4	0.5	0.5	0.5	30000	11	-43.55		-227.5
W7	Sieb	P2	Purge to parameter stability	Post	2/25/2014	9:31:00 AM	N-Dup	Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM	20000	10	0.5	0.5	0.5	30000	10	-43.8		-227.4
W7	Sieb	P2	Purge to parameter stability	Post	2/25/2014	9:31:00 AM	Dup	Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM	21000	11	0.5	0.5	0.5	36000	12			
W2	Sim	P2	Purge to parameter stability	Post	2/18/2014	2:00:00 PM	N-Dup	Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM	2700	0.5	0.5	0.5	0.5	3400	0.63	-46.62		-190.9

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

								Analyte Group:	**Dissolved Light Hydrocarbon Gases (Direct-Fill VOA)**					**Dissolved Light Hydrocarbon Gases & Isotopes (IsoFlask)**				
									Gas	**Gas**	**Gas**	**Gas**	**Gas**	**Gas**	**Gas**	**Isotope**	**Isotope**	**Isotope**
								Analyte:	**Methane**	**Ethane**	**Propane**	**Isobutane**	**n-Butane**	**Methane**	**Ethane**	**$\delta^{13}C$ CH_4**	**$\delta^{13}C$ C_2H_6**	**δD CH_4**
								Laboratory:	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Isotech**	**Isotech**	**Isotech**	**Isotech**	**Isotech**
Well #	**Location ID**	**Purge Abbreviation**	**Purge Volume**	**Pre / Post Pressure Tank**	**Sample Date**	**Sample Time**	**Sample Type**	**Sample ID**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**ug/L**	**‰**	**‰**	**‰**
W2	Sim	P2	Purge to parameter stability	Post	2/18/2014	2:00:00 PM	Dup	Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM	2500	0.5	0.5	0.5	0.5	3200	0.75			
W2	Sim	P2	Purge to parameter stability	Post	2/21/2014	2:58:00 PM	N-Dup	Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM	2700	0.5	0.5	0.5	0.5	3100	0.76	-46.37		-191.7
W2	Sim	P2	Purge to parameter stability	Post	2/21/2014	2:58:00 PM	Dup	Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM	3000	0.5	0.5	0.5	0.5	3200	0.78			
W2	Sim	P2	Purge to parameter stability	Post	2/24/2014	2:45:00 PM	N-Dup	Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM	2800	0.5	0.5	0.5	0.5	2800	0.71	-46.2		-191.3
W2	Sim	P2	Purge to parameter stability	Post	2/24/2014	2:45:00 PM	Dup	Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM	3000	0.5	0.5	0.5	0.5	3200	0.71	-46.6		-192.7
W10	Wal	P2	Purge to parameter stability	Post	10/25/2012	12:40:00 PM	N	Wal_1_E0_P2_TV_Post_N_10/25/2012_12:40:00 PM	1900	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	11/29/2012	1:30:00 PM	N	Wal_1_E0_P2_TV_Post_N_11/29/2012_1:30:00 PM	1800	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	12/28/2012	12:45:00 PM	N	Wal_1_E0_P2_TV_Post_N_12/28/2012_12:45:00 PM	1400	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	1/22/2013	1:27:00 PM	N	Wal_1_E0_P2_TV_Post_N_1/22/2013_1:27:00 PM	2000	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	2/21/2013	1:40:00 PM	N	Wal_1_E0_P2_TV_Post_N_2/21/2013_1:40:00 PM	1200	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	3/20/2013	1:45:00 PM	N	Wal_1_E0_P2_TV_Post_N_3/20/2013_1:45:00 PM	1200	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	4/25/2013	1:30:00 PM	N	Wal_1_E0_P2_TV_Post_N_4/25/2013_1:30:00 PM	1800	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	5/21/2013	1:10:00 PM	N	Wal_1_E0_P2_TV_Post_N_5/21/2013_1:10:00 PM	1800	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	6/25/2013	12:15:00 PM	N	Wal_1_E0_P2_TV_Post_N_6/25/2013_12:15:00 PM	1500	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	7/23/2013	1:15:00 PM	N	Wal_1_E0_P2_TV_Post_N_7/23/2013_1:15:00 PM	1700	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	8/20/2013	1:15:00 PM	N	Wal_1_E0_P2_TV_Post_N_8/20/2013_1:15:00 PM	1500	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	9/23/2013	12:12:00 PM	N	Wal_1_E0_P2_TV_Post_N_9/23/2013_12:12:00 PM	1600	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	10/24/2013	12:15:00 PM	N	Wal_1_E0_P2_TV_Post_N_10/24/2013_12:15:00 PM	690	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	11/22/2013	12:40:00 PM	N	Wal_1_E0_P2_TV_Post_N_11/22/2013_12:40:00 PM	1100	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	12/30/2013	1:05:00 PM	N	Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM	1900	0.5	0.5	0.5	0.5	2300	1.1	-49.8		-188
W10	Wal	P2	Purge to parameter stability	Post	1/21/2014	2:50:00 PM	N	Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM	1400	0.5	0.5	0.5	0.5	2200	0.4	-50.67		-197.1
W10	Wal	P2	Purge to parameter stability	Post	2/26/2014	1:20:00 PM	N-Dup	Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM	2000	0.5	0.5	0.5	0.5	2200	0.41	-50.45		-191
W10	Wal	P2	Purge to parameter stability	Post	2/26/2014	1:20:00 PM	Dup	Wal_1_E03_P2_TV_Post_Dup_2/26/2014_1:20:00 PM	1700	0.5	0.5	0.5	0.5					
W10	Wal	P2	Purge to parameter stability	Post	3/26/2014	1:13:00 PM	N	Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM	1600	0.5	0.5	0.5	0.5	2200	0.47	-50.32		-198.1
W10	Wal	P2	Purge to parameter stability	Post	4/30/2014	1:10:00 PM	N	Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM	2000	0.5	0.5	0.5	0.5	2100	0.41	-50.26		-195.7
W10	Wal	P2	Purge to parameter stability	Post	5/20/2014	1:00:00 PM	N	Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM	1800	0.5	0.5	0.5	0.5	2000	0.42			
W4	Web	P2	Purge to parameter stability	Post	4/17/2012	11:55:00 AM	N	Web_1_E0_P2_TV_Post_N_4/17/2012_11:55:00 AM	10000	0.5	0.5	0.5	0.5					
W4	Web	P2	Purge to parameter stability	Post	10/8/2012	3:30:00 PM	N	Web_1_E0_P2_TV_Post_N_10/8/2012_3:30:00 PM	11000	0.5	0.5	0.5	0.5					
W4	Web	P2	Purge to parameter stability	Post	11/15/2012	3:20:00 PM	N	Web_1_E0_P2_TV_Post_N_11/15/2012_3:20:00 PM	8400	0.5	0.5	0.5	0.5					
W4	Web	P2	Purge to parameter stability	Post	12/14/2012	3:10:00 PM	N	Web_1_E0_P2_TV_Post_N_12/14/2012_3:10:00 PM	10000	0.5	0.5	0.5	0.5					
W4	Web	P2	Purge to parameter stability	Post	1/22/2013	9:50:00 AM	N	Web_1_E0_P2_TV_Post_N_1/22/2013_9:50:00 AM	12000	0.5	0.5	0.5	0.5			-48.79		-240.5
W4	Web	P2	Purge to parameter stability	Post	2/21/2013	10:53:00 AM	N	Web_1_E0_P2_TV_Post_N_2/21/2013_10:53:00 AM	12000	0.5	0.5	0.5	0.5			-48.74		-242.7
W4	Web	P2	Purge to parameter stability	Post	3/21/2013	10:47:00 AM	N	Web_1_E0_P2_TV_Post_N_3/21/2013_10:47:00 AM	13000	0.5	0.5	0.5	0.5			-48.79		-241.4
W4	Web	P2	Purge to parameter stability	Post	4/23/2013	12:00:00 PM	N	Web_1_E0_P2_TV_Post_N_4/23/2013_12:00:00 PM	12000	0.5	0.5	0.5	0.5			-48.82		-242.7
W4	Web	P2	Purge to parameter stability	Post	5/21/2013	10:40:00 AM	N	Web_1_E0_P2_TV_Post_N_5/21/2013_10:40:00 AM	10000	0.5	0.5	0.5	0.5			-48.71		-239
W4	Web	P2	Purge to parameter stability	Post	6/20/2013	2:25:00 PM	N	Web_1_E0_P2_TV_Post_N_6/20/2013_2:25:00 PM	11000	0.5	0.5	0.5	0.5			-48.78		-239.1
W4	Web	P2	Purge to parameter stability	Post	7/23/2013	9:32:00 AM	N	Web_1_E0_P2_TV_Post_N_7/23/2013_9:32:00 AM	11000	0.5	0.5	0.5	0.5			-48.77		-242.1
W4	Web	P2	Purge to parameter stability	Post	8/20/2013	4:25:00 PM	N	Web_1_E0_P2_TV_Post_N_8/20/2013_4:25:00 PM	13000	0.5	0.5	0.5	0.5			-48.78		-238.8
W4	Web	P2	Purge to parameter stability	Post	9/24/2013	12:35:00 PM	N	Web_1_E0_P2_TV_Post_N_9/24/2013_12:35:00 PM	11000	0.5	0.5	0.5	0.5			-48.68		-243.4
W4	Web	P2	Purge to parameter stability	Post	10/22/2013	3:50:00 PM	N	Web_1_E0_P2_TV_Post_N_10/22/2013_3:50:00 PM	7400	0.5	0.5	0.5	0.5			-48.86		-239.6
W4	Web	P2	Purge to parameter stability	Post	11/19/2013	12:28:00 PM	N	Web_1_E0_P2_TV_Post_N_11/19/2013_12:28:00 PM	9900	0.5	0.5	0.5	0.5			-48.82		-242.6
W4	Web	P2	Purge to parameter stability	Post	12/19/2013	2:45:00 PM	N	Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM	12000	0.5	0.5	0.5	0.5	12000	2.7	-48.5		-243.4
W4	Web	P2	Purge to parameter stability	Post	1/21/2014	8:05:00 PM	N	Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM	11000	0.5	0.5	0.5	0.5	13000	2.8	-48.75		-239.9
W4	Web	P2	Purge to parameter stability	Post	2/17/2014	10:30:00 AM	N-Dup	Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM	9900	0.5	0.5	0.5	0.5	13000	2.9	-48.65		-243.6
W4	Web	P2	Purge to parameter stability	Post	2/17/2014	10:30:00 AM	Dup	Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM	11000	0.5	0.5	0.5	0.5	13000	2.8	-48.61		-241.5
W4	Web	P2	Purge to parameter stability	Post	2/21/2014	9:33:00 AM	N-Dup	Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM	11000	0.5	0.5	0.5	0.5	13000	2.7	-48.52		-242
W4	Web	P2	Purge to parameter stability	Post	2/21/2014	9:33:00 AM	Dup	Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM	11000	0.5	0.5	0.5	0.5	12000	2.7			
W4	Web	P2	Purge to parameter stability	Post	2/24/2014	9:45:00 AM	N-Dup	Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM	12000	0.5	0.5	0.5	0.5	13000	2.8	-48.62		-241
W4	Web	P2	Purge to parameter stability	Post	2/24/2014	9:45:00 AM	Dup	Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM	12000	0.5	0.5	0.5	0.5	13000	2.8			
W4	Web	P2	Purge to parameter stability	Post	3/26/2014	3:57:00 PM	N-Dup	Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM	11000	0.5	0.5	0.5	0.5	12000	2.7	-48.75		-239
W4	Web	P2	Purge to parameter stability	Post	3/26/2014	3:57:00 PM	Dup	Web_1_E04_P2_TV_Post_Dup_3/26/2014_3:57:00 PM	11000	0.5	0.5	0.5	0.5					
W4	Web	P2	Purge to parameter stability	Post	4/23/2014	2:45:00 PM	N	Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM	11000	0.5	0.5	0.5	0.5	13000	2.9	-48.73		-242.3
W4	Web	P2	Purge to parameter stability	Post	5/21/2014	12:56:00 PM	N	Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM	11000	0.5	0.5	0.5	0.5	13000	3.1			

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality																			
	Bacteria	Bacteria	HC	Inorganic	Inorganic	Inorganic	Inorganic	Inorganic	WQP	Inorganic	Inorganic	Inorganic	Inorganic	Inorganic	Metals	Metals	Metals	Metals	Metals	Metals
Analyte:	E. Coli	Total Coliforms	HEM (oil & grease)	Bromide	Chloride	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as $CaCO_3$	Phenolphthalein Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Sulfate	Sulfide	Total Nitrite/Nitrate Nitrogen	Nitrate Nitrogen	Nitrite Nitrogen	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Cas_1_E0_P2_TV_Post_N_10/13/2012_8:16:00 AM	0.5	0.5	0.7	1.6	175		97.5	0.35	102	8.5	0.027	0.38			0.00325		0.0002	2.27		
Cas_1_E0_P2_TV_Post_N_11/15/2012_6:40:00 PM	0.5	1	0.7	3.3	403		114	0.35	117	2.1	0.027	0.11			0.00445		0.0002	4.98		
Cas_1_E0_P2_TV_Post_N_12/14/2012_4:50:00 PM	0.5	0.5	0.7	1.6	190		98.9	0.35	106	7.3	0.027	0.53			0.00445		0.0002	3.02		
Cas_1_E0_P2_TV_Post_N_1/26/2013_9:25:00 AM	0.5	0.5	0.7	1.5	210		101	0.35	104	7.4	0.027	0.63			0.00445		0.0002	2.81		
Cas_1_E0_P2_TV_Post_N_2/22/2013_4:35:00 PM	0.5	0.5	7.2	3.4	398		114	0.35	116	2.3	0.027	0.15			0.00445		0.0002	4.56		
Cas_1_E0_P2_TV_Post_N_3/22/2013_3:10:00 PM	0.5	1	0.7	1.5	185		100	0.35	101	8.3	0.027	0.61			0.00445		0.0002	2.53		
Cas_1_E0_P2_TV_Post_N_4/23/2013_7:10:00 PM	0.5	0.5	0.7	1.6	196		96	0.35	106	7.9	0.027	0.6			0.00445		0.00021	2.61		
Cas_1_E0_P2_TV_Post_N_5/21/2013_7:10:00 PM	0.5	0.5	0.7	2.4	302		104	0.35	102	4.9	0.027	0.34			0.00445		0.00021	3.61		
Cas_1_E0_P2_TV_Post_N_6/20/2013_6:50:00 PM	0.5	0.5	0.7	4	443		114	0.35	116	0.15	0.027	0.02			0.00715		0.00021	5.28		
Cas_1_E0_P2_TV_Post_N_7/25/2013_7:00:00 PM	0.5	0.5	0.7	2.2	308		107	0.35	105	3.7	0.027	0.13			0.00715		0.00021	4.1		
Cas_1_E0_P2_TV_Post_N_8/20/2013_7:17:00 PM	0.5	0.5	0.7	3.3	437		113	0.35	115	1.5	0.027	0.02			0.00715		0.00021	5.21		
Cas_1_E0_P2_TV_Post_N_9/24/2013_7:15:00 PM	0.5	0.5	0.7	3.4	442		115	0.35	117	0.15	0.027	0.02			0.00715		0.00021	5.75		
Cas_1_E0_P2_TV_Post_N_10/22/2013_6:45:00 PM	0.5	0.5	0.7	2.7	369		113	0.35	116	2.3	0.027	0.02			0.00715		0.00039	5.38		
Cas_1_E0_P2_TV_Post_N_11/19/2013_6:32:00 PM	0.5	0.5	0.7	3	442		118	0.35	112	0.15	0.027	0.02			0.00715		0.00021	5.4		
Cas_1_E01_P2_TV_Post_N-Dup_12/20/2013_1:10:00 PM	0.5	0.5		1.4	189	102	102			6.8	0.027		0.75	0.0075	0.00715		0.00021	3.1		
Cas_1_E01_P2_TV_Post_Dup_12/20/2013_1:10:00 PM				1.4	205	102	102			6.8	0.027		0.73	0.0075	0.00715		0.00021	2.98		
Iri_1_E0_P2_TV_Post_N_11/29/2012_10:20:00 AM	0.5	0.5	0.7	0.0075	2.7		65.9	0.35	79.7	22.6	0.027	0.02			0.00445		0.0104	0.0455		
Iri_1_E0_P2_TV_Post_N_12/28/2012_11:10:00 AM	1	1	0.7	0.0075	2.3		37.8	0.35	62.2	24.9	0.027	0.7			0.00445		0.0002	0.0373		
Iri_1_E0_P2_TV_Post_N_1/22/2013_9:15:00 AM	0.5	1	0.7	0.0075	2.2		32.3	0.35	58.4	25.4	0.027	0.49			0.00445		0.0002	0.0327		
Iri_1_E0_P2_TV_Post_N_2/21/2013_8:51:00 AM	0.5	1	0.7	0.0075	2.4		25	0.35	53.2	27.4	0.027	0.62			0.00445		0.0002	0.0315		
Iri_1_E0_P2_TV_Post_N_3/21/2013_9:23:00 AM	0.5	1	0.7	0.0075	2.1		22.5	0.35	49.5	27	0.027	0.75			0.00445		0.0002	0.0286		
Iri_1_E0_P2_TV_Post_N_4/23/2013_8:25:00 AM	0.5	1	0.7	0.0075	2.1		24.1	0.35	50.9	25.6	0.027	0.36			0.00445		0.00021	0.029		
Iri_1_E0_P2_TV_Post_N_5/21/2013_8:35:00 AM	1	1	0.7	0.0075	2		26.9	0.35	51.4	26.8	0.027	0.02			0.00445		0.00021	0.0304		
Iri_1_E0_P2_TV_Post_N_6/20/2013_4:20:00 PM	1	1	0.7	0.0075	1.9		30.6	0.35	55	26.6	0.027	0.02			0.00715		0.00021	0.0294		
Iri_1_E0_P2_TV_Post_N_7/23/2013_8:14:00 AM	1	1	0.7	0.0075	1.8		34.9	0.35	59.8	26.3	0.027	0.02			0.00715		0.00021	0.0314		
Iri_1_E0_P2_TV_Post_N_8/20/2013_5:47:00 PM	1	1	0.7	0.0075	1.9		36.7	0.35	60.3	25.8	0.027	0.02			0.00715		0.00021	0.0333		
Iri_1_E0_P2_TV_Post_N_9/24/2013_1:40:00 PM	1	1	0.7	0.0075	2		39.9	0.35	65.3	25.2	0.027	0.02			0.00715		0.00021	0.0334		
Iri_1_E0_P2_TV_Post_N_10/22/2013_11:15:00 AM	0.5	1	0.7	0.0075	3.9		40.8	0.35	65.1	26.7	0.027	0.02			0.00715		0.00039	0.0341		
Iri_1_E0_P2_TV_Post_N_11/19/2013_2:13:00 PM	0.5	1	0.7	0.0075	2.1		41.3	0.35	63.9	25.7	0.027	0.02			0.00715		0.00021	0.0503		
Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM	0.5	1		0.0075	2	25.5	25.5			27.8	0.027		0.16	0.0075	0.00715		0.00021	0.0283		
Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM	0.5	1		0.015	2	17.4	17.4			27.5	0.027		0.76	0.0075	0.00715		0.00021	0.0291		
Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM	0.5	0.5		0.0075	2.2	16.6	16.6			27.5	0.027		0.52	0.0075	0.00715		0.00021	0.0285		
Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM	0.5	1		0.016	1.9	14.4	14.4			28.9	0.027		1.1	0.0075	0.00715		0.00039	0.0298		
Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM				0.0075	1.8	12.5	12.5			21.1	0.027		2	0.0075	0.00715		0.00039	0.0285		
Iri_1_E05_P2_TV_Post_Dup_4/23/2014_5:05:00 PM				0.0075	1.8	12.1	12.1			23.3	0.027		2	0.0075	0.00715		0.00039	0.0277		
Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM				0.0075	1.8	16.5	16.5			22.2	0.027		1.3	0.0075	0.00715		0.00039	0.0313		
Jon_1_E0_P2_TV_Post_N_4/16/2012_12:50:00 PM			0.7	0.2	37.3					0.15		0.02			0.00515	0.00021	0.0192	1.57	0.000065	0.119
Jon_1_E0_P2_TV_Post_N_9/21/2012_12:05:00 PM	0.5	1	0.7	0.42	47.5		142	0.35	78.2	0.15	0.027	0.02			0.00325		0.0002	1.8		
Jon_1_E0_P2_TV_Post_N_10/25/2012_3:15:00 PM	0.5	1	0.7	0.46	46.7		147	0.35	77.4	0.15	0.027	0.02			0.00325		0.0002	1.83		
Jon_1_E0_P2_TV_Post_N_11/26/2012_1:05:00 PM	0.5	1	0.7	0.43	47.3		148	0.35	80	0.15	0.027	0.02			0.00445		0.0002	1.88		
Jon_1_E0_P2_TV_Post_N_12/20/2012_12:40:00 PM	0.5	1	0.7	0.45	49.2		149	0.35	82.2	0.15	0.027	0.02			0.00445		0.0002	1.83		
Jon_1_E0_P2_TV_Post_N_1/22/2013_3:10:00 PM	0.5	1	0.7	0.4	53.7		145	0.35	82.9	0.15	0.027	0.02			0.00445		0.0002	1.8		
Jon_1_E0_P2_TV_Post_N_2/21/2013_2:15:00 PM	0.5	1	0.7	0.5	51.9		149	0.35	84.3	0.15	0.027	0.02			0.00445		0.0002	1.81		
Jon_1_E0_P2_TV_Post_N_3/21/2013_1:27:00 PM	0.5	0.5	0.7	0.46	51.1		143	3.7	83.7	0.15	0.027	0.02			0.00445		0.0002	1.88		
Jon_1_E0_P2_TV_Post_N_4/23/2013_2:30:00 PM	0.5	1	0.7	0.45	53		142	0.35	86.7	0.15	0.027	0.02			0.00445		0.00021	1.79		
Jon_1_E0_P2_TV_Post_N_5/21/2013_12:30:00 PM	0.5	1	0.7	0.52	57		143	0.35	84.2	0.15	0.027	0.02			0.00445		0.00021	2.06		
Jon_1_E0_P2_TV_Post_N_6/20/2013_10:50:00 AM	0.5	1	0.7	0.51	59.5		144	0.35	87.8	0.15	0.027	0.02			0.00715		0.00021	1.99		
Jon_1_E0_P2_TV_Post_N_7/23/2013_2:45:00 PM	0.5	1	0.7	0.45	59		144	0.35	86.6	0.15	0.027	0.02			0.00715		0.00021	2.05		
Jon_1_E0_P2_TV_Post_N_8/20/2013_9:15:00 AM	0.5	1	0.7	0.41	68.3		145	0.35	87.5	0.15	0.027	0.02			0.00715		0.00021	2.07		
Jon_1_E0_P2_TV_Post_N_9/24/2013_9:50:00 AM	0.5	1	0.7	0.42	59.7		147	0.35	91.3	0.15	0.027	0.02			0.103		0.00021	2.02		
Jon_1_E0_P2_TV_Post_N_10/22/2013_9:20:00 AM	0.5	1	0.7	0.45	60.2		145	0.35	90.3	0.15	0.027	0.02			0.00715		0.00039	2.1		
Jon_1_E0_P2_TV_Post_N_11/19/2013_9:20:00 AM	0.5	1	0.7	0.41	57.1		142	0.35	89.2	0.15	0.027	0.02			0.00715		0.00021	1.91		
Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM	0.5	1		0.37	58	143	143			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.92		
Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM	0.5	0.5		0.4	56.6	141	141			0.15	0.027		0.02	0.0075	0.109		0.00021	2.06		
Jon_1_E02_P2_TV_Post_Dup_1/21/2014_9:15:00 AM				0.41	56.5	144	144			0.15	0.027		0.02	0.0075	0.107		0.00021	2.08		
Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM	0.5	0.5		0.3	62.4	143	143			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.71		
Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM				0.36	60.3	142	142			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.79		
Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM				0.33	59.7	143	143			0.15	0.027		0.02	0.0075	0.00715		0.00021	2.01		
Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM																				
Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM				0.34	39	135	135			0.15	0.027		0.02	0.0075	0.00715		0.00039	2.14		
Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM																				
Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM	0.5	0.5		0.52	59.2	142	142			0.15	0.027		0.02	0.0075	0.00715		0.00039	2.11		
Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM				0.45	58.2	143	143			0.15	0.027		0.02	0.0075	0.00715		0.00039	1.97		
Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM				0.5	59.1	140	140			0.15	0.027		0.02	0.0075	0.00715		0.00039	1.91		

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality																			
	Bacteria	Bacteria	HC	Inorganic	Inorganic	Inorganic	Inorganic	Inorganic	WQP	Inorganic	Inorganic	Inorganic	Inorganic	Inorganic	Metals	Metals	Metals	Metals	Metals	Metals
Analyte:	E. Coli	Total Coliforms	HEM (oil & grease)	Bromide	Chloride	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as $CaCO_3$	Phenolphthalein Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Sulfate	Sulfide	Total Nitrite/Nitrate Nitrogen	Nitrate Nitrogen	Nitrite Nitrogen	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Loc_1_E0_P2_TV_Post_N_5/8/2012_12:00:00 PM			0.7	0.2	1.5		0.35		94.3	0.15	0.027	0.02			0.00515		0.107	0.651		
Loc_1_E0_P2_TV_Post_N_9/21/2012_9:15:00 AM	0.5	1	0.7	0.0075	2		184	0.35	76.2	2.3	0.18	0.02			0.00325		0.0824	0.517		
Loc_1_E0_P2_TV_Post_N_10/25/2012_10:20:00 AM	0.5	0.5	0.7	0.0075	2		200	0.35	77.8	1.6	0.027	0.02			0.00325		0.0898	0.522		
Loc_1_E0_P2_TV_Post_N_11/26/2012_11:05:00 AM	0.5	0.5	0.7	0.0075	2.7		197	0.35	63.9	3.2	0.027	0.02			0.00445		0.0747	0.42		
Loc_1_E0_P2_TV_Post_N_12/20/2012_10:30:00 AM	0.5	0.5	0.7	0.0075	1.6		196	0.35	94.6	1.5	0.027	0.02			0.00445		0.0968	0.62		
Loc_1_E0_P2_TV_Post_N_1/22/2013_11:20:00 AM	0.5	0.5	0.7	0.0075	1.5		190	0.35	87.3	1.3	0.027	0.02			0.00445		0.0943	0.49		
Loc_1_E0_P2_TV_Post_N_2/21/2013_11:00:00 AM	0.5	0.5	0.7	0.0075	2.1		196	0.35	86.6	1.4	0.19	0.02			0.00445		0.0953	0.491		
Loc_1_E0_P2_TV_Post_N_3/21/2013_11:00:00 AM	0.5	0.5	0.7	0.0075	1.6		191	0.35	94.6	0.15	0.027	0.02			0.00445		0.104	0.573		
Loc_1_E0_P2_TV_Post_N_4/23/2013_10:55:00 AM	0.5	0.5	0.7	0.0075	1.6		193	0.35	95.7	0.15	0.027	0.02			0.00445		0.104	0.535		
Loc_1_E0_P2_TV_Post_N_5/21/2013_10:20:00 AM	0.5	0.5	0.7	0.0075	1.6		193	0.35	93.3	0.15	0.027	0.02			0.00445		0.092	0.602		
Loc_1_E0_P2_TV_Post_N_6/20/2013_1:00:00 PM	0.5	0.5	0.7	0.0075	1.9		200	0.35	87.9	1.2	0.027	0.02			0.00715		0.0904	0.544		
Loc_1_E0_P2_TV_Post_N_7/23/2013_10:58:00 AM	0.5	0.5	0.7	0.0075	1.6		178	0.35	81.6	1.2	0.027	0.02			0.00715		0.0822	0.489		
Loc_1_E0_P2_TV_Post_N_8/20/2013_10:55:00 AM	0.5	0.5	0.7	0.0075	2.1		203	0.35	93.4	1.3	0.027	0.02			0.00715		0.0862	0.653		
Loc_1_E0_P2_TV_Post_N_9/24/2013_11:15:00 AM	0.5	0.5	0.7	0.0075	1.6		197	0.35	96.4	0.15	0.027	0.02			0.00715		0.102	0.607		
Loc_1_E0_P2_TV_Post_N_10/22/2013_2:30:00 PM	0.5	0.5	0.7	0.0075	4.3		196	0.35	85.1	0.15	0.027	0.02			0.00715		0.0946	0.517		
Loc_1_E0_P2_TV_Post_N_11/19/2013_10:40:00 AM	0.5	0.5	0.7	0.0075	1.7		191	0.35	99.6	0.15	0.027	0.02			0.00715		0.102	0.56		
Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM	0.5	0.5		0.0075	1.7	190	190			1.2	0.027		0.02	0.0075	0.00715		0.101	0.624		
Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM	0.5	0.5		0.028	1.8	192	192			0.82	0.027		0.02	0.0075	0.00715		0.102	0.585		
Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM	0.5	0.5		0.0075	1.8	188	188			2.2	0.19		0.02	0.0075	0.00715		0.0945	0.645		
Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM				0.0075	1.7	190	190			2.2	0.21		0.02	0.0075	0.00715		0.0936	0.627		
Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM				0.0075	1.9	185	185			2.5	0.2		0.02	0.0075	0.00715		0.086	0.599		
Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM																				
Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM				0.0075	1.8	181	181			1.7	0.17		0.02	0.0075	0.00715		0.0869	0.634		
Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM																				
Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM	0.5	0.5		0.0075	1.1	182	182			3.7	0.027		0.02	0.0075	0.00715		0.105	0.597		
Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM				0.0075	1.8	191	191			1.4	0.027		0.02	0.0075	0.00715		0.0909	0.558		
Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM				0.0075	1.8	185	185			1.6	0.027		0.02	0.0075	0.00715		0.0905	0.597		
Loc_1_E06_P2_TV_Post_Dup_5/21/2014_9:08:00 AM				0.0075	1.8	187	187			1.6	0.027		0.02	0.0075	0.00715		0.0917	0.608		
Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM				0.54	106	100	100			2.6	0.53		0.02	0.0075	0.00715		0.00039	2.88		
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																				
Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM				0.49	102	100	100			3	0.55		0.02	0.0075	0.00715		0.00021	2.73		
Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM				0.5	103	102	102			3.2	0.55		0.02	0.0075	0.00715		0.00021	2.76		
Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM				0.45	95.4	97.2	97.2			2.7	0.55		0.02	0.0075	0.00715		0.00039	2.88		
Marc_1_E3_P2_SV_Post_Dup_2/24/2014_12:35:00 PM																				
Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM				0.64	101	100	100			2.6	0.58		0.02	0.0075	0.00715		0.00039	2.76		
Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM				0.72	103	101	101			3.2	0.55		0.02	0.0075	0.00715		0.00039	2.85		
Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM				0.7	137	250	273			0.46	0.027		0.02	0.0075	1.23		0.00021	0.126		
Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM																				
Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM				0.72	157	234	280			0.39	0.17		0.02	0.0075	0.29		0.00039	0.122		
Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM				0.71	159	234	280			0.41	0.027		0.02	0.0075	0.153		0.00039	0.111		
Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM				0.68	141	235	267			0.42	0.027		0.02	0.0075	0.28		0.00039	0.118		
Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM																				
Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM	0.5	0.5		0.07	18.2	114	126			3.3	0.027		0.02	0.0075	0.00715		0.00021	0.536		
Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM																				
Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM				0.016	9.4	119	123			8.2	0.027		0.02	0.0075	0.00715		0.00039	0.657		
Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM																				
Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM				0.02	10.3	121	121			7.6	0.027		0.02	0.0075	0.00715		0.00039	0.685		
Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM				0.018	8.2	119	119			7.6	0.027		0.02	0.0075	0.00715		0.00039	0.703		
Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM	0.5	0.5		0.15	17.1	120	130			3.8	0.027		0.02	0.0075	0.00715		0.00039	0.438		
Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM				0.24	35.4	121	121			0.15	0.027		0.02	0.0075	0.00715		0.00039	0.536		
Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM				0.28	34.9	121	121			1.2	0.027		0.02	0.0075	0.00715		0.00039	0.548		
Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM				0.82	141	133	133			1	0.34		0.02	0.0075	0.00715		0.00021	2.46		
Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM																				
Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM				0.8	139	133	133			1	0.35		0.02	0.0075	0.00715		0.00039	2.44		
Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM																				
Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM				0.75	120	127	127			1	0.37		0.02	0.0075	0.00715		0.00039	2.53		
Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM				0.76	132	130	130			1	0.38		0.02	0.0075	0.00715		0.00039	2.57		
Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM				1.6	315	117	118			0.99	0.027		0.02	0.0075	0.00715		0.00039	3.21		
Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM																				
Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM				1.5	288	116	117			0.89	0.027		0.02	0.0075	0.00715		0.00021	3.19		
Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM				1.5	275	116	119			0.89	0.027		0.02	0.0075	0.00715		0.00021	3		
Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM				1.4	283	112	112			0.88	0.027		0.02	0.0075	0.00715		0.00039	3.19		
Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM																				
Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM				0.1	25.7	122	122			4.1	0.7		0.02	0.0075	0.00715		0.00039	0.569		

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality																			
	Bacteria	Bacteria	HC	Inorganic	Inorganic	Inorganic	Inorganic	Inorganic	WQP	Inorganic	Inorganic	Inorganic	Inorganic	Inorganic	Metals	Metals	Metals	Metals	Metals	Metals
Analyte:	E. Coli	Total Coliforms	HEM (oil & grease)	Bromide	Chloride	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as $CaCO_3$	Phenolphthalein Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Sulfate	Sulfide	Total Nitrite/Nitrate Nitrogen	Nitrate Nitrogen	Nitrite Nitrogen	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM																				
Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM				0.11	27.6	123	123			4.4	0.78		0.02	0.0075	0.00715		0.00021	0.584		
Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM																				
Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM				0.11	27.8	116	116			3.5	0.68		0.02	0.0075	0.00715		0.00039	0.559		
Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM				0.11	25.6	119	119			3.3	0.66		0.02	0.0075	0.00715		0.00039	0.579		
Wal_1_E0_P2_TV_Post_N_10/25/2012_12:40:00 PM	0.5	0.5	0.7	0.24	27.8		117	0.35	53.4	2.7	0.26	0.02			0.00325		0.0002	1.14		
Wal_1_E0_P2_TV_Post_N_11/29/2012_1:30:00 PM	0.5	0.5	0.7	0.21	24.5		116	0.35	55.7	3.3	0.26	0.02			0.00445		0.0002	1.14		
Wal_1_E0_P2_TV_Post_N_12/28/2012_12:45:00 PM	0.5	0.5	0.7	0.22	24.3		115	0.35	55.8	3.2	0.23	0.02			0.00445		0.0002	1.05		
Wal_1_E0_P2_TV_Post_N_1/22/2013_1:27:00 PM	0.5	0.5	0.7	0.2	25.1		113	0.35	56.3	2.8	0.25	0.02			0.00445		0.0002	1.06		
Wal_1_E0_P2_TV_Post_N_2/21/2013_1:40:00 PM	0.5	0.5	0.7	0.15	15.2		111	0.35	63	5.5	0.2	0.02			0.00445		0.0002	1.06		
Wal_1_E0_P2_TV_Post_N_3/20/2013_1:45:00 PM	0.5	0.5	0.7	0.14	17.7		114	0.35	59.6	4.4	0.21	0.02			0.00445		0.0002	1.1		
Wal_1_E0_P2_TV_Post_N_4/25/2013_1:30:00 PM	0.5	0.5	0.7	0.2	23.5		117	0.35	56.7	2.6	0.28	0.02			0.00445		0.0002	1.13		
Wal_1_E0_P2_TV_Post_N_5/21/2013_1:10:00 PM	0.5	1	0.7	0.21	24.8		113	0.35	54.3	2.6	0.34	0.02			0.00445		0.0002	1.1		
Wal_1_E0_P2_TV_Post_N_6/25/2013_12:15:00 PM	1	1	0.7	0.19	23.1		111	0.35	56.5	3.5	0.21	0.02			0.00715		0.00021	1.15		
Wal_1_E0_P2_TV_Post_N_7/23/2013_1:15:00 PM	0.5	0.5	0.7	0.17	23.4		111	0.35	56	3.1	0.25	0.02			0.00715		0.00021	1.1		
Wal_1_E0_P2_TV_Post_N_8/20/2013_1:15:00 PM	0.5	0.5	0.7	0.13	20.5		111	0.35	57.1	3.6	0.027	0.02			0.00715		0.00021	1.1		
Wal_1_E0_P2_TV_Post_N_9/23/2013_12:12:00 PM	0.5	0.5	0.7	0.17	23.2		110	0.35	56.7	2.9	0.24	0.02			0.00715		0.00021	0.973		
Wal_1_E0_P2_TV_Post_N_10/24/2013_12:15:00 PM	0.5	0.5	0.7	0.14	22		112	0.35	55.9	3.2	0.29	0.02			0.00715		0.00039	1.13		
Wal_1_E0_P2_TV_Post_N_11/22/2013_12:40:00 PM	0.5	1	0.7	0.12	24.9		113	0.35	56.1	3.5	0.33	0.02			0.00715		0.00039	1.17		
Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM	0.5	0.5		0.13	23.8	113	113			2.9	0.31		0.02	0.0075	0.00715		0.00021	1.13		
Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM	0.5	0.5		0.13	18.9	113	113			3.2	0.26		0.02	0.0075	0.00715		0.00021	1.1		
Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM	0.5	0.5		0.087	10.6	110	110			3.1	0.26		0.02	0.0075	0.00715		0.00039	1.13		
Wal_1_E03_P2_TV_Post_Dup_2/26/2014_1:20:00 PM				0.093	18.5	110	110			3	0.27		0.02	0.0075	0.00715		0.00039	1.09		
Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM	0.5	0.5		0.16	19.8	111	111			0.15	0.25		0.02	0.0075	0.00715		0.00039	1.13		
Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM				0.14	23	110	110			4.1	0.29		0.02	0.0075	0.00715		0.00039	1.14		
Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM				0.17	21.1	111	111			3	0.28		0.02	0.0075	0.00715		0.00039	1.09		
Web_1_E0_P2_TV_Post_N_4/17/2012_11:55:00 AM			0.7	0.53	48.1					0.15		0.02			0.00515	0.00021	0.000475	1.94	0.000065	0.113
Web_1_E0_P2_TV_Post_N_10/8/2012_3:30:00 PM	0.5	0.5	0.7	0.27	44.1		118	0.35	75	0.15	0.027	0.02			0.00325		0.0002	1.75		
Web_1_E0_P2_TV_Post_N_11/15/2012_3:20:00 PM	0.5	0.5	0.7	0.34	39.8		126	0.35	76	0.15	0.027	0.02			0.00445		0.0002	1.71		
Web_1_E0_P2_TV_Post_N_12/14/2012_3:10:00 PM	0.5	0.5	0.7	0.36	47.4		126	0.35	75.3	0.15	0.027	0.02			0.00445		0.0002	1.74		
Web_1_E0_P2_TV_Post_N_1/22/2013_9:50:00 AM	0.5	0.5	0.7	0.33	45.8		123	0.35	74.8	0.15	0.027	0.02			0.00445		0.0002	1.66		
Web_1_E0_P2_TV_Post_N_2/21/2013_10:53:00 AM	0.5	0.5	0.7	0.42	48.3		128	0.35	76.8	0.15	0.027	0.02			0.00445		0.0002	1.73		
Web_1_E0_P2_TV_Post_N_3/21/2013_10:47:00 AM	0.5	0.5	0.7	0.37	46.9		122	3.4	75	0.15	0.027	0.02			0.00445		0.0002	1.74		
Web_1_E0_P2_TV_Post_N_4/23/2013_12:00:00 PM	0.5	0.5	0.7	0.35	41.3		124	0.35	77.9	0.15	0.027	0.02			0.00445		0.00021	1.69		
Web_1_E0_P2_TV_Post_N_5/21/2013_10:40:00 AM	0.5	1	0.7	0.37	45.8		122	0.35	77.1	0.15	0.027	0.02			0.00445		0.00021	1.76		
Web_1_E0_P2_TV_Post_N_6/20/2013_2:25:00 PM	0.5	0.5	0.7	0.38	45.4		124	0.35	76.2	0.15	0.027	0.02			0.00715		0.00021	1.81		
Web_1_E0_P2_TV_Post_N_7/23/2013_9:32:00 AM	0.5	0.5	0.7	0.32	44.6		123	0.35	75.1	0.15	0.027	0.02			0.00715		0.00021	1.77		
Web_1_E0_P2_TV_Post_N_8/20/2013_4:25:00 PM	0.5	0.5	0.7	0.27	44.5		123	0.35	74.3	0.15	0.027	0.02			0.00715		0.00021	1.72		
Web_1_E0_P2_TV_Post_N_9/24/2013_12:35:00 PM	0.5	0.5	0.7	0.34	45.1		125	0.35	77.6	0.15	0.027	0.02			0.00715		0.00021	1.79		
Web_1_E0_P2_TV_Post_N_10/22/2013_3:50:00 PM	0.5	0.5	0.7	0.3	40.6		124	0.35	80.9	0.15	0.027	0.02			0.00715		0.00039	1.78		
Web_1_E0_P2_TV_Post_N_11/19/2013_12:28:00 PM	0.5	1	0.7	0.27	38.3		123	0.35	73.5	0.15	0.027	0.02			0.00715		0.00021	1.7		
Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM	0.5	0.5		0.23	38.2	123	123			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.64		
Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM	0.5	0.5		0.25	35.8	122	124			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.75		
Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM	0.5	0.5		0.22	40.5	122	122			0.41	0.027		0.02	0.0075	0.00715		0.00021	1.44		
Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM				0.22	40.3	122	122			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.67		
Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM				0.2	39.7	122	123			0.15	0.027		0.02	0.0075	0.00715		0.00021	1.7		
Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM																				
Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM				0.21	38.4	117	117			0.15	0.027		0.02	0.0075	0.00715		0.00039	1.71		
Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM																				
Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM	0.5	0.5		0.33	38.4	121	121			1.8	0.027		0.02	0.0075	0.00715		0.00039	1.71		
Web_1_E04_P2_TV_Post_Dup_3/26/2014_3:57:00 PM				0.33	39.8	120	120			6.6	0.027		0.02	0.0075	0.00715		0.00039	1.73		
Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM				0.3	40.5	122	122			0.15	0.027		0.02	0.0075	0.00715		0.00039	1.65		
Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM				0.34	42.4	124	124			0.15	0.027		0.02	0.0075	0.00715		0.00039	1.73		

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

GSI ENVIRONMENTAL

Water Quality

Analyte Group:	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals
Analyte:	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Lithium	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Thallium	Tin	Titanium
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Cas_1_E0_P2_TV_Post_N_10/13/2012_8:16:00 AM	0.000041	31.7	0.00025			0.01665	0.000017		3.86	0.0679	0.000035		2.76	0.00025	0.00005	107	2.02			
Cas_1_E0_P2_TV_Post_N_11/15/2012_6:40:00 PM	0.000041	31.8	0.00025			0.01665	0.0000235		4.97	0.0795	0.000035		4.97	0.00025	0.00005	230	4.41			
Cas_1_E0_P2_TV_Post_N_12/14/2012_4:50:00 PM	0.000041	32.3	0.00025			0.01665	0.0014		4.16	0.0718	0.000035		3.4	0.00025	0.00005	127	2.67			
Cas_1_E0_P2_TV_Post_N_1/26/2013_9:25:00 AM	0.00006	33.4	0.00025			0.01665	0.0000235		4.17	0.0401	0.000035		3.38	0.00025	0.00005	122	2.54			
Cas_1_E0_P2_TV_Post_N_2/22/2013_4:35:00 PM	0.00006	34.3	0.00025			0.01665	0.0000365		5.23	0.068	0.000035		4.89	0.00025	0.00005	217	4.1			
Cas_1_E0_P2_TV_Post_N_3/22/2013_3:10:00 PM	0.00006	32.2	0.00025			0.01665	0.0000365		3.95	0.0459	0.000035		3.15	0.00025	0.00005	119	2.29			
Cas_1_E0_P2_TV_Post_N_4/23/2013_7:10:00 PM	0.000115	31.8	0.00025			0.01665	0.0000365		3.93	0.041	0.000035		3.03	0.00025	0.00005	122	2.29			
Cas_1_E0_P2_TV_Post_N_5/21/2013_7:10:00 PM	0.000115	29.9	0.00025			0.01665	0.0000365		4.26	0.0508	0.000035		3.59	0.00025	0.00005	151	3.16			
Cas_1_E0_P2_TV_Post_N_6/20/2013_6:50:00 PM	0.000115	32.1	0.00025			0.0215	0.0000425		5.34	0.0648	0.00003		5.35	0.00025	0.000055	254	4.69			
Cas_1_E0_P2_TV_Post_N_7/25/2013_7:00:00 PM	0.000115	31.6	0.00025			0.0215	0.0000425		4.7	0.0723	0.00003		4.43	0.00025	0.000055	182	3.6			
Cas_1_E0_P2_TV_Post_N_8/20/2013_7:17:00 PM	0.000115	32.7	0.00025			0.0215	0.0000425		5.39	0.0721	0.00003		5.03	0.00025	0.000055	254	4.56			
Cas_1_E0_P2_TV_Post_N_9/24/2013_7:15:00 PM	0.000115	32.9	0.00025			0.0215	0.0000425		5.67	0.0904	0.00003		5.62	0.00025	0.000055	268	4.97			
Cas_1_E0_P2_TV_Post_N_10/22/2013_6:45:00 PM	0.000115	33.1	0.00025			0.0215	0.0000425		5.38	0.0744	0.00003		5.14	0.00025	0.000055	231	4.93			
Cas_1_E0_P2_TV_Post_N_11/19/2013_6:32:00 PM	0.000115	34.5	0.00025			0.0215	0.0000425		6.03	0.0698	0.00003		6.15	0.00025	0.000055	256	4.75			
Cas_1_E01_P2_TV_Post_N-Dup_12/20/2013_1:10:00 PM	0.000115	33.5	0.00025			0.00815	0.0000425		4.28	0.0449			3.47	0.00025	0.000055	147	2.67			
Cas_1_E01_P2_TV_Post_Dup_12/20/2013_1:10:00 PM	0.000115	33.1	0.00025			0.00815	0.0000425		4.13	0.0463			3.33	0.00025	0.000055	137	2.53			
Iri_1_E0_P2_TV_Post_N_11/29/2012_10:20:00 AM	0.000041	29	0.00025			1.23	0.0000235		1.58	2.17	0.000035		1.91	0.00025	0.00005	2.53	0.121			
Iri_1_E0_P2_TV_Post_N_12/28/2012_11:10:00 AM	0.000041	22.1	0.00025			0.01665	0.0000235		1.23	0.303	0.000035		1.6	0.00025	0.00005	2.15	0.0892			
Iri_1_E0_P2_TV_Post_N_1/22/2013_9:15:00 AM	0.00006	21.1	0.00025			0.01665	0.0000235		1.19	0.293	0.000035		1.46	0.00025	0.00005	2.27	0.0836			
Iri_1_E0_P2_TV_Post_N_2/21/2013_8:51:00 AM	0.00006	20.7	0.00025			0.01665	0.0000365		1.08	0.129	0.000035		1.4	0.00025	0.00005	2.26	0.0752			
Iri_1_E0_P2_TV_Post_N_3/21/2013_9:23:00 AM	0.00006	17.6	0.00025			0.01665	0.0000365		1	0.0546	0.000035		1.21	0.00025	0.00005	1.92	0.0742			
Iri_1_E0_P2_TV_Post_N_4/23/2013_8:25:00 AM	0.000115	17.5	0.00025			0.01665	0.0000365		0.966	0.236	0.000035		1.15	0.00025	0.00005	1.88	0.0697			
Iri_1_E0_P2_TV_Post_N_5/21/2013_8:35:00 AM	0.000115	17.8	0.00025			0.01665	0.0000365		1.01	0.605	0.000035		1.24	0.00025	0.00005	1.87	0.0725			
Iri_1_E0_P2_TV_Post_N_6/20/2013_4:20:00 PM	0.000115	19.3	0.00025			0.0215	0.0000425		1.07	0.885	0.00003		1.36	0.00025	0.000055	1.96	0.0755			
Iri_1_E0_P2_TV_Post_N_7/23/2013_8:14:00 AM	0.000115	19.9	0.00025			0.0215	0.0000425		1.11	1.36	0.00003		1.52	0.00025	0.000055	1.94	0.0827			
Iri_1_E0_P2_TV_Post_N_8/20/2013_5:47:00 PM	0.000115	20.9	0.00025			0.0215	0.0000425		1.18	1.5	0.00003		1.56	0.00025	0.000055	2	0.0828			
Iri_1_E0_P2_TV_Post_N_9/24/2013_1:40:00 PM	0.000115	22.2	0.013			0.0215	0.0000425		1.22	1.91	0.00003		1.61	0.00025	0.000055	2.12	0.0896			
Iri_1_E0_P2_TV_Post_N_10/22/2013_11:15:00 AM	0.000115	22.4	0.007			0.0215	0.0000425		1.23	1.91	0.00003		1.62	0.00025	0.000055	2.05	0.0868			
Iri_1_E0_P2_TV_Post_N_11/19/2013_2:13:00 PM	0.000115	23.2	0.0758			0.0215	0.0000425		1.29	1.67	0.00003		1.6	0.00025	0.000055	2.25	0.102			
Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM	0.000115	18.9	0.00025			0.00815	0.0000425		1.04	0.0638			1.32	0.00025	0.000055	2.1	0.0731			
Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM	0.000115	17	0.0099			0.00815	0.0000425		0.952	0.0098			1.36	0.00025	0.000055	1.84	0.0664			
Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM	0.000115	16.4	0.0146			0.00815	0.0000425		0.894	0.0117			1.22	0.00025	0.000055	1.77	0.0658			
Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM	0.000115	17.4	0.00025			0.00815	0.0000425		0.983	0.0064			1.54	0.00025	0.000055	1.97	0.0692			
Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM	0.000115	16	0.00025			0.00815	0.0000425		0.903	0.0049			1.18	0.00025	0.000055	1.6	0.0612			
Iri_1_E05_P2_TV_Post_Dup_4/23/2014_5:05:00 PM	0.000115	15.4	0.00025			0.00815	0.0000425		0.835	0.005			1.16	0.00025	0.000055	1.54	0.0641			
Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM	0.000115	15.6	0.00025			0.00815	0.0000425		0.857	0.072			1.11	0.00025	0.000055	1.47	0.0645			
Jon_1_E0_P2_TV_Post_N_4/16/2012_12:50:00 PM	0.0001	20.1	0.0003	0.00005	0.00019	0.188	0.00004	0.0861	6.3	0.185	0.000013	0.00025	1.3	0.000135	0.000455	54.7	0.61	0.000075	0.00215	0.00023
Jon_1_E0_P2_TV_Post_N_9/21/2012_12:05:00 PM	0.000041	19.1	0.00025			0.01665	0.000017		6.34	0.0769	0.000035		1.35	0.00025	0.00005	55.3	0.662			
Jon_1_E0_P2_TV_Post_N_10/25/2012_3:15:00 PM	0.000041	19.5	0.00025			0.268	0.0012		6.52	0.0784	0.000035		1.42	0.00025	0.00005	57.8	0.67			
Jon_1_E0_P2_TV_Post_N_11/26/2012_1:05:00 PM	0.000041	20	0.00025			0.01665	0.0000235		7	0.0784	0.000035		1.6	0.00025	0.00005	59.4	0.69			
Jon_1_E0_P2_TV_Post_N_12/20/2012_12:40:00 PM	0.000041	20.1	0.00025			0.208	0.0000235		6.7	0.0746	0.000035		1.52	0.00025	0.00005	59	0.695			
Jon_1_E0_P2_TV_Post_N_1/22/2013_3:10:00 PM	0.00006	20.2	0.00025			0.244	0.0000235		6.78	0.0813	0.000035		1.49	0.00025	0.00005	59.5	0.671			
Jon_1_E0_P2_TV_Post_N_2/21/2013_2:15:00 PM	0.00006	22.7	0.00025			0.01665	0.0015		6.87	0.0752	0.000035		1.69	0.00025	0.00005	67.4	0.666			
Jon_1_E0_P2_TV_Post_N_3/21/2013_1:27:00 PM	0.00006	20.2	0.00025			0.01665	0.0000365		6.76	0.077	0.000035		1.53	0.00025	0.00005	58.6	0.748			
Jon_1_E0_P2_TV_Post_N_4/23/2013_2:30:00 PM	0.000115	20.7	0.00025			0.01665	0.0015		6.88	0.0779	0.000035		1.47	0.00025	0.00005	60.9	0.653			
Jon_1_E0_P2_TV_Post_N_5/21/2013_12:30:00 PM	0.000115	21.7	0.00025			0.233	0.0026		7.29	0.0873	0.000035		1.58	0.00025	0.00005	62.7	0.729			
Jon_1_E0_P2_TV_Post_N_6/20/2013_10:50:00 AM	0.000115	21.3	0.00025			0.268	0.0027		7.1	0.0864	0.00003		1.52	0.00025	0.000055	61.2	0.751			
Jon_1_E0_P2_TV_Post_N_7/23/2013_2:45:00 PM	0.000115	22.3	0.00025			0.27	0.0000425		7.45	0.081	0.00003		1.55	0.00025	0.000055	63.5	0.752			
Jon_1_E0_P2_TV_Post_N_8/20/2013_9:15:00 AM	0.000115	22	0.00025			0.354	0.0000425		7.33	0.085	0.00003		1.58	0.00025	0.000055	62.8	0.728			
Jon_1_E0_P2_TV_Post_N_9/24/2013_9:50:00 AM	0.000115	22.5	0.00025			0.494	0.0000425		7.52	0.0973	0.00003		1.6	0.00025	0.000055	63.9	0.739			
Jon_1_E0_P2_TV_Post_N_10/22/2013_9:20:00 AM	0.000115	22.3	0.00025			0.302	0.0000425		7.39	0.0828	0.00003		1.66	0.00025	0.000055	62.7	0.766			
Jon_1_E0_P2_TV_Post_N_11/19/2013_9:20:00 AM	0.000115	22.3	0.00025			0.34	0.0000425		7.55	0.0863	0.00003		1.54	0.00025	0.000055	63.6	0.707			
Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM	0.000115	22.6	0.00025			0.425	0.0000425		7.42	0.076			1.57	0.00025	0.000055	64.2	0.688			
Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM	0.000115	21.5	0.00025			0.396	0.0000425		7.1	0.0966			1.5	0.00025	0.000055	60.8	0.757			
Jon_1_E02_P2_TV_Post_Dup_1/21/2014_9:15:00 AM	0.000115	22.3	0.00025			0.41	0.0000425		7.48	0.099			1.63	0.00025	0.000055	63	0.745			
Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM	0.000115	21.9	0.00025			0.468	0.0000425		7.34	0.0787			1.59	0.00025	0.000055	63.6	0.645			
Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM	0.000115	22.5	0.00025			0.415	0.0000425		7.49	0.0792			1.7	0.00025	0.000055	64	0.656			
Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM	0.000115	20.9	0.00025			0.359	0.0000425		6.92	0.0845			1.38	0.00025	0.000055	59.5	0.739			
Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM																				
Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM	0.000115	22.7	0.00025			0.372	0.0000425		7.47	0.0845			1.65	0.00025	0.000055	65.1	0.784			
Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM																				
Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM	0.000115	23.6	0.00025			0.384	0.0000425		7.77	0.0788			1.74	0.00025	0.000055	67.7	0.777			
Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM	0.000115	22.3	0.00025			0.256	0.0000425		7.46	0.0815			1.55	0.00025	0.000055	63.3	0.737			
Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM	0.000115	22.4	0.00025			0.346	0.0000425		7.33	0.0824			1.53	0.00025	0.000055	63.4	0.71			

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

										Water Quality										
Analyte Group:	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**	**Metals**
Analyte:	**Cadmium**	**Calcium**	**Chromium**	**Cobalt**	**Copper**	**Iron**	**Lead**	**Lithium**	**Magnesium**	**Manganese**	**Mercury**	**Nickel**	**Potassium**	**Selenium**	**Silver**	**Sodium**	**Strontium**	**Thallium**	**Tin**	**Titanium**
Laboratory:	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**	**Lancaster**
Sample ID	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Loc_1_E0_P2_TV_Post_N_5/8/2012_12:00:00 PM	0.0001	28.7	0.0003			5.22	0.00004		4.97	1.28	0.000013		1.92	0.000135	0.000049	44.5	0.961			
Loc_1_E0_P2_TV_Post_N_9/21/2012_9:15:00 AM	0.000041	22.3	0.00025			3.84	0.000017		3.75	0.964	0.000035		1.8	0.00025	0.00005	47.8	0.798			
Loc_1_E0_P2_TV_Post_N_10/25/2012_10:20:00 AM	0.000041	22.9	0.00025			4.05	0.000017		3.82	0.964	0.000035		1.78	0.00025	0.00005	50.6	0.807			
Loc_1_E0_P2_TV_Post_N_11/26/2012_11:05:00 AM	0.000041	19	0.00025			3.55	0.0000235		3.35	0.782	0.000035		1.77	0.00025	0.00005	58.6	0.681			
Loc_1_E0_P2_TV_Post_N_12/20/2012_10:30:00 AM	0.000041	28	0.00025			4.78	0.0000235		4.72	1.08	0.000035		2.07	0.00025	0.00005	43.7	0.947			
Loc_1_E0_P2_TV_Post_N_1/22/2013_11:20:00 AM	0.00006	26.5	0.00025			5.26	0.0000235		4.47	1.12	0.000035		1.98	0.00025	0.00005	45.7	0.797			
Loc_1_E0_P2_TV_Post_N_2/21/2013_11:00:00 AM	0.00006	29.3	0.00025			5.72	0.0000365		4.32	1.08	0.000035		2.2	0.00025	0.00005	53	0.78			
Loc_1_E0_P2_TV_Post_N_3/21/2013_11:00:00 AM	0.00006	27.1	0.00025			5.36	0.0000235		4.56	1.26	0.000035		2.02	0.00025	0.00005	43.3	0.86			
Loc_1_E0_P2_TV_Post_N_4/23/2013_10:55:00 AM	0.000115	28.2	0.00025			5.57	0.0000365		4.7	1.21	0.000035		1.95	0.00025	0.00005	42.5	0.864			
Loc_1_E0_P2_TV_Post_N_5/21/2013_10:20:00 AM	0.000115	27.5	0.00025			4.99	0.0000365		4.65	1.14	0.000035		1.99	0.00025	0.00005	44.1	0.902			
Loc_1_E0_P2_TV_Post_N_6/20/2013_1:00:00 PM	0.000115	25.4	0.00025			6.02	0.01		4.28	1.12	0.00003		1.9	0.00025	0.000055	52	0.791			
Loc_1_E0_P2_TV_Post_N_7/23/2013_10:58:00 AM	0.000115	23.9	0.00025			4.24	0.0000425		4.01	0.952	0.00003		2	0.00025	0.000055	44.1	0.821			
Loc_1_E0_P2_TV_Post_N_8/20/2013_10:55:00 AM	0.000115	27.9	0.00025			4.26	0.0000425		4.77	0.978	0.00003		2.1	0.00025	0.000055	50.8	0.895			
Loc_1_E0_P2_TV_Post_N_9/24/2013_11:15:00 AM	0.000115	29	0.00025			5.35	0.0000425		4.89	1.14	0.00003		2.09	0.00025	0.000055	46	0.859			
Loc_1_E0_P2_TV_Post_N_10/22/2013_2:30:00 PM	0.000115	25.2	0.00025			4.63	0.0000425		4.2	1.09	0.00003		2.39	0.00025	0.000055	47.3	0.813			
Loc_1_E0_P2_TV_Post_N_11/19/2013_10:40:00 AM	0.000115	28	0.00025			5.25	0.0000425		4.76	1.22	0.00003		2.02	0.00025	0.000055	46.2	0.867			
Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM	0.000115	28.8	0.00025			5.06	0.0000425		4.86	1.03			2.09	0.00025	0.000055	43.8	0.878			
Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM	0.000115	28.1	0.00025			5.36	0.0000425		4.8	1.15			2.01	0.00025	0.000055	42.3	0.907			
Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM	0.000115	27.8	0.00025			5.69	0.0000425		4.68	1.08			2.01	0.00025	0.000055	45.3	0.913			
Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM	0.000115	28.3	0.00025			5.47	0.0000425		4.77	1.13			2.08	0.00025	0.000055	46.3	0.947			
Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM	0.000115	26.1	0.00025			4.68	0.0000425		4.39	0.952			2.05	0.00025	0.000055	47.7	0.934			
Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM																				
Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM	0.000115	26.3	0.00025			4.67	0.0000425		4.43	0.843			1.86	0.00025	0.000055	44	0.835			
Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM																				
Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM	0.000115	30	0.00025			5.75	0.0000425		4.93	0.984			2.18	0.00025	0.000055	45	0.834			
Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM	0.000115	27.2	0.00025			4.68	0.0000425		4.59	1.04			1.95	0.00025	0.000055	46.7	0.843			
Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM	0.000115	27.4	0.00025			4.63	0.0000425		4.54	1.05			1.94	0.00025	0.000055	43.4	0.863			
Loc_1_E06_P2_TV_Post_Dup_5/21/2014_9:08:00 AM	0.000115	28.1	0.00025			4.53	0.0000425		4.64	1.06			1.94	0.00025	0.000055	44.5	0.881			
Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM	0.000115	25.8	0.00025			0.00815	0.0000425		3.12	0.0323			3.44	0.00025	0.000055	76.2	2.78			
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																				
Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM	0.000115	24	0.00025			0.00815	0.0000425		2.9	0.0278			2.99	0.00025	0.000055	69.6	2.69			
Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM	0.000115	25.6	0.00025			0.00815	0.0000425		3.1	0.0282			3.33	0.00025	0.000055	73.9	2.65			
Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM	0.000115	25.9	0.00025			0.00815	0.0000425		3.08	0.0338			3.29	0.00025	0.000055	73	2.76			
Marc_1_E3_P2_SV_Post_Dup_2/24/2014_12:35:00 PM																				
Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM	0.000115	25.9	0.00025			0.00815	0.0000425		3.15	0.0305			3.32	0.00025	0.000055	72.8	2.73			
Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM	0.000115	25.2	0.00025			0.00815	0.0000425		3.01	0.03			3.12	0.00025	0.000055	72.3	2.66			
Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM	0.000115	2.77	0.005			2.02	0.0019		0.706	0.0202			1.86	0.00025	0.000055	202	0.233			
Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM																				
Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM	0.000115	2.69	0.0037			0.466	0.0000425		0.484	0.007			1.77	0.00025	0.000055	235	0.253			
Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM	0.000115	2.75	0.0035			0.303	0.0000425		0.479	0.0057			1.84	0.00025	0.000055	238	0.238			
Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM	0.000115	2.54	0.0037			0.473	0.0000425		0.419	0.007			1.9	0.00025	0.000055	218	0.226			
Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM																				
Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM	0.000115	8.66	0.00025			0.418	0.0026		1.23	0.101			2.06	0.00025	0.000055	54	0.574			
Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM																				
Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM	0.000115	18.7	0.00025			0.00815	0.0011		2.54	0.0676			2.34	0.00025	0.000055	40.9	0.945			
Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM																				
Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM	0.000115	17.8	0.00025			0.00815	0.0000425		2.4	0.0517			2.22	0.00025	0.000055	39.5	0.859			
Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM	0.000115	17.7	0.00025			0.00815	0.0000425		2.38	0.0524			2.14	0.00025	0.000055	39	0.963			
Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM	0.000115	7.37	0.00025			0.00815	0.0000425		1.03	0.017			2.2	0.00025	0.000055	61.9	0.484			
Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM	0.000115	9.94	0.00025			0.00815	0.0000425		1.43	0.0341			2.3	0.00025	0.000055	62.8	0.655			
Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM	0.000115	9.62	0.00025			0.102	0.0000425		1.39	0.0379			2.22	0.00025	0.000055	62.3	0.662			
Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM	0.000115	29.5	0.00025			0.882	0.0000425		5.32	0.0367			3.16	0.00025	0.000055	96.6	2.54			
Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM																				
Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM	0.000115	32.6	0.00025			0.146	0.0000425		5.86	0.0375			3.49	0.00025	0.000055	103	2.6			
Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM																				
Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM	0.000115	31.7	0.00025			0.443	0.0000425		5.73	0.0336			3.38	0.00025	0.000055	101	2.63			
Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM	0.000115	31	0.00025			0.349	0.0000425		5.62	0.0326			3.27	0.00025	0.000055	99.8	2.65			
Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM	0.000115	15.9	0.00025			0.126	0.0000425		2.75	0.0388			4.59	0.00025	0.000055	218	2.89			
Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM																				
Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM	0.000115	15.3	0.00025			0.00815	0.0000425		2.64	0.0349			4.43	0.00025	0.000055	208	2.83			
Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM	0.000115	15.2	0.00025			0.00815	0.0000425		2.61	0.0335			4.44	0.00025	0.000055	210	2.84			
Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM	0.000115	15.1	0.00025			0.00815	0.0000425		2.55	0.0336			4.5	0.00025	0.000055	208	2.8			
Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM																				
Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM	0.000115	25.2	0.00025			0.23	0.0000425		5.7	0.0535			1.88	0.00025	0.000055	34.7	0.727			

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Water Quality

Analyte Group:	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals	Metals
Analyte:	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Lithium	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Thallium	Tin	Titanium
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM																				
Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM	0.000115	22.8	0.00025			0.184	0.0000425		5.16	0.0425			1.33	0.00025	0.000055	33.7	0.73			
Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM																				
Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM	0.000115	25.6	0.00025			0.213	0.0000425		5.71	0.0482			1.54	0.00025	0.000055	35.9	0.735			
Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM	0.000115	25.1	0.00025			0.174	0.0000425		5.62	0.0526			1.34	0.00025	0.000055	34.1	0.699			
Wal_1_E0_P2_TV_Post_N_10/25/2012_12:40:00 PM	0.000041	14.1	0.00025			0.01665	0.000017		4.04	0.0291	0.000035		1.57	0.00025	0.00005	42.9	0.679			
Wal_1_E0_P2_TV_Post_N_11/29/2012_1:30:00 PM	0.000041	14.3	0.00025			0.01665	0.0000235		4	0.0283	0.000035		1.64	0.00025	0.00005	41.3	0.696			
Wal_1_E0_P2_TV_Post_N_12/28/2012_12:45:00 PM	0.000041	14.4	0.00025			0.01665	0.0012		4.1	0.029	0.000035		1.63	0.00025	0.00005	41.7	0.612			
Wal_1_E0_P2_TV_Post_N_1/22/2013_1:27:00 PM	0.00006	14.6	0.00025			0.01665	0.0000235		4.14	0.0278	0.000035		1.63	0.00025	0.00005	41.6	0.636			
Wal_1_E0_P2_TV_Post_N_2/21/2013_1:40:00 PM	0.00006	17.8	0.00025			0.01665	0.0000365		4.39	0.0359	0.000035		1.69	0.00025	0.00005	35.2	0.675			
Wal_1_E0_P2_TV_Post_N_3/20/2013_1:45:00 PM	0.00006	16.2	0.00025			0.01665	0.0000235		4.41	0.0375	0.000035		1.6	0.00025	0.00005	35.3	0.671			
Wal_1_E0_P2_TV_Post_N_4/25/2013_1:30:00 PM	0.00006	14.5	0.00025			0.01665	0.001		4.16	0.0279	0.000035		1.62	0.00025	0.00005	43.6	0.701			
Wal_1_E0_P2_TV_Post_N_5/21/2013_1:10:00 PM	0.00006	14.2	0.00025			1.38	0.0000235		4.08	0.0443	0.000035		1.56	0.00025	0.00005	43.1	0.64			
Wal_1_E0_P2_TV_Post_N_6/25/2013_12:15:00 PM	0.000115	14.3	0.00025			0.0215	0.0000425		4.08	0.0296	0.00003		1.58	0.00025	0.000055	40.4	0.678			
Wal_1_E0_P2_TV_Post_N_7/23/2013_1:15:00 PM	0.000115	15.3	0.00025			0.0215	0.0000425		4.4	0.0295	0.00003		1.68	0.00025	0.000055	43	0.634			
Wal_1_E0_P2_TV_Post_N_8/20/2013_1:15:00 PM	0.000115	15.2	0.00025			0.0215	0.0000425		4.27	0.0326	0.00003		1.66	0.00025	0.000055	40.2	0.642			
Wal_1_E0_P2_TV_Post_N_9/23/2013_12:12:00 PM	0.000115	14.3	0.00025			0.0215	0.0000425		4.09	0.0278	0.00003		1.68	0.00025	0.000055	42.6	0.577			
Wal_1_E0_P2_TV_Post_N_10/24/2013_12:15:00 PM	0.000115	14.5	0.00025			0.0215	0.0000425		4.11	0.029	0.00003		1.54	0.00025	0.000055	39.6	0.66			
Wal_1_E0_P2_TV_Post_N_11/22/2013_12:40:00 PM	0.000115	14.7	0.00025			3.83	0.0000425		4.2	0.0608	0.00003		1.66	0.00025	0.000055	41.1	0.7			
Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM	0.000115	14.7	0.00025			0.00815	0.0000425		4.16	0.0305			1.73	0.00025	0.000055	40.2	0.677			
Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM	0.000115	14.8	0.00025			0.00815	0.0000425		4.2	0.0303			1.63	0.00025	0.000055	40.6	0.695			
Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM	0.000115	14.9	0.00025			0.00815	0.0000425		4.21	0.0273			1.59	0.00025	0.000055	41.1	0.668			
Wal_1_E03_P2_TV_Post_Dup_2/26/2014_1:20:00 PM	0.000115	14.8	0.00025			0.00815	0.0000425		4.21	0.0268			1.67	0.00025	0.000055	41.2	0.659			
Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM	0.000115	16.2	0.00025			0.00815	0.0000425		4.42	0.029			1.7	0.00025	0.000055	40.5	0.688			
Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM	0.000115	14.3	0.00025			0.00815	0.0000425		4.04	0.0304			1.67	0.00025	0.000055	42.3	0.668			
Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM	0.000115	15.2	0.00025			0.00815	0.0000425		4.23	0.029			1.67	0.00025	0.000055	42.1	0.654			
Web_1_E0_P2_TV_Post_N_4/17/2012_11:55:00 AM	0.0001	22.5	0.0003	0.00005	0.00019	0.0057	0.00004	0.139	5.2	0.0268	0.000013	0.00025	1.91	0.000135	0.000455	51.3	1.16	0.000075	0.00215	0.00023
Web_1_E0_P2_TV_Post_N_10/8/2012_3:30:00 PM	0.000041	20.2	0.00025			0.01665	0.000017		4.5	0.0251	0.000035		1.77	0.00025	0.00005	45.6	1.06			
Web_1_E0_P2_TV_Post_N_11/15/2012_3:20:00 PM	0.000041	21.5	0.00025			0.01665	0.0000235		4.69	0.026	0.000035		1.86	0.00025	0.00005	45.4	1.05			
Web_1_E0_P2_TV_Post_N_12/14/2012_3:10:00 PM	0.000041	20.5	0.00025			0.01665	0.0000235		4.52	0.0254	0.000035		1.83	0.00025	0.00005	45.2	1.03			
Web_1_E0_P2_TV_Post_N_1/22/2013_9:50:00 AM	0.00006	21.1	0.00025			0.01665	0.0000235		4.73	0.0264	0.000035		1.93	0.00025	0.00005	49.7	1.02			
Web_1_E0_P2_TV_Post_N_2/21/2013_10:53:00 AM	0.00006	20.7	0.00025			0.01665	0.0000365		4.67	0.0273	0.000035		1.9	0.00025	0.00005	50.4	1.02			
Web_1_E0_P2_TV_Post_N_3/21/2013_10:47:00 AM	0.00006	20.9	0.00025			0.01665	0.0000365		4.72	0.0272	0.000035		1.94	0.00025	0.00005	49.4	1.08			
Web_1_E0_P2_TV_Post_N_4/23/2013_12:00:00 PM	0.000115	20.7	0.00025			0.01665	0.0000365		4.62	0.0247	0.000035		1.88	0.00025	0.00005	49.5	0.994			
Web_1_E0_P2_TV_Post_N_5/21/2013_10:40:00 AM	0.000115	21.4	0.00025			0.01665	0.0000365		4.8	0.0266	0.000035		1.84	0.00025	0.00005	48.6	1.04			
Web_1_E0_P2_TV_Post_N_6/20/2013_2:25:00 PM	0.000115	21.8	0.00025			0.0215	0.0000425		4.89	0.0259	0.00003		1.96	0.00025	0.000055	50.6	1.08			
Web_1_E0_P2_TV_Post_N_7/23/2013_9:32:00 AM	0.000115	21.4	0.00025			0.0215	0.0000425		4.84	0.0248	0.00003		1.86	0.00025	0.000055	48.8	1.05			
Web_1_E0_P2_TV_Post_N_8/20/2013_4:25:00 PM	0.000115	21.2	0.00025			0.274	0.0000425		4.76	0.0254	0.00003		1.89	0.00025	0.000055	48.2	0.978			
Web_1_E0_P2_TV_Post_N_9/24/2013_12:35:00 PM	0.000115	21.1	0.00025			0.0215	0.0000425		4.7	0.0267	0.00003		1.86	0.00025	0.000055	48.6	1.04			
Web_1_E0_P2_TV_Post_N_10/22/2013_3:50:00 PM	0.000115	20.8	0.00025			0.0215	0.0000425		4.59	0.0236	0.00003		1.97	0.00025	0.000055	48	1.06			
Web_1_E0_P2_TV_Post_N_11/19/2013_12:28:00 PM	0.000115	20.8	0.00025			0.0215	0.0000425		4.69	0.0252	0.00003		1.86	0.00025	0.000055	47.8	1			
Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM	0.000115	20.5	0.00025			0.00815	0.0000425		4.54	0.0225			1.84	0.00025	0.000055	48.1	0.953			
Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM	0.000115	20.5	0.00025			0.00815	0.0000425		4.67	0.0253			1.94	0.00025	0.000055	48.1	1.07			
Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM	0.000115	21	0.00025			0.00815	0.0000425		4.7	0.0229			1.98	0.00025	0.000055	49.1	0.885			
Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM	0.000115	20.8	0.00025			0.00815	0.0000425		4.64	0.0233			1.91	0.00025	0.000055	48.8	0.998			
Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM	0.000115	19.7	0.00025			0.00815	0.0000425		4.38	0.0232			1.69	0.00025	0.000055	45.3	1.03			
Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM																				
Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM	0.000115	21.7	0.00025			0.00815	0.0000425		4.75	0.024			1.95	0.00025	0.000055	49.4	1.02			
Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM																				
Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM	0.000115	22.1	0.00025			0.00815	0.0000425		4.82	0.0221			2.06	0.00025	0.000055	50.2	1			
Web_1_E04_P2_TV_Post_Dup_3/26/2014_3:57:00 PM	0.000115	21.7	0.00025			0.00815	0.0000425		4.74	0.0226			2.01	0.00025	0.000055	49.6	1.03			
Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM	0.000115	20.5	0.00025			0.00815	0.0000425		4.58	0.0248			1.85	0.00025	0.000055	48.8	0.994			
Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM	0.000115	20.6	0.00025			0.101	0.0047		4.53	0.0253			1.86	0.00025	0.000055	49.7	1.01			

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality																			
	Metals	Metals	Metals	Metals	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved
Analyte:	Uranium	Uranium	Vanadium	Zinc	Aluminum, dissolved	Antimony, dissolved	Arsenic, dissolved	Barium, dissolved	Beryllium, dissolved	Boron, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Cobalt, dissolved	Copper, dissolved	Iron, dissolved	Lead, dissolved	Lithium, dissolved	Magnesium, dissolved	Manganese, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	pCi/L	ug/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Cas_1_E0_P2_TV_Post_N_10/13/2012_8:16:00 AM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_11/15/2012_6:40:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_12/14/2012_4:50:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_1/26/2013_9:25:00 AM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_2/22/2013_4:35:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_3/22/2013_3:10:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_4/23/2013_7:10:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_5/21/2013_7:10:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_6/20/2013_6:50:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_7/25/2013_7:00:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_8/20/2013_7:17:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_9/24/2013_7:15:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_10/22/2013_6:45:00 PM	0.17	0.25																		
Cas_1_E0_P2_TV_Post_N_11/19/2013_6:32:00 PM	0.17	0.25																		
Cas_1_E01_P2_TV_Post_N-Dup_12/20/2013_1:10:00 PM					0.00715		0.00021	2.85			0.000115	34.2	0.00025			0.00815	0.0000425		4.26	0.0413
Cas_1_E01_P2_TV_Post_Dup_12/20/2013_1:10:00 PM					0.00715		0.00021	2.97			0.000115	34.2	0.00025			0.00815	0.0000425		4.26	0.0412
Iri_1_E0_P2_TV_Post_N_11/29/2012_10:20:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_12/28/2012_11:10:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_1/22/2013_9:15:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_2/21/2013_8:51:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_3/21/2013_9:23:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_4/23/2013_8:25:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_5/21/2013_8:35:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_6/20/2013_4:20:00 PM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_7/23/2013_8:14:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_8/20/2013_5:47:00 PM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_9/24/2013_1:40:00 PM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_10/22/2013_11:15:00 AM	0.17	0.25																		
Iri_1_E0_P2_TV_Post_N_11/19/2013_2:13:00 PM	0.17	0.25																		
Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM					0.00715		0.00021	0.028			0.000115	18.9	0.00025			0.00815	0.0000425		1.04	0.0647
Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM																				
Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM																				
Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM																				
Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM																				
Iri_1_E05_P2_TV_Post_Dup_4/23/2014_5:05:00 PM																				
Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM																				
Jon_1_E0_P2_TV_Post_N_4/16/2012_12:50:00 PM			0.00009	0.002	0.00515	0.00021	0.0198	1.48	0.000065	0.12	0.0001	20.5	0.0003	0.00005	0.00019	0.106	0.00004	0.0892	6.48	0.185
Jon_1_E0_P2_TV_Post_N_9/21/2012_12:05:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_10/25/2012_3:15:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_11/26/2012_1:05:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_12/20/2012_12:40:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_1/22/2013_3:10:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_2/21/2013_2:15:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_3/21/2013_1:27:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_4/23/2013_2:30:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_5/21/2013_12:30:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_6/20/2013_10:50:00 AM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_7/23/2013_2:45:00 PM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_8/20/2013_9:15:00 AM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_9/24/2013_9:50:00 AM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_10/22/2013_9:20:00 AM	0.17	0.25																		
Jon_1_E0_P2_TV_Post_N_11/19/2013_9:20:00 AM	0.17	0.25																		
Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM					0.00715		0.00021	1.95			0.000115	22.1	0.00025			0.00815	0.0000425		7.28	0.077
Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM					0.00715		0.00021	2.07			0.000115	21.3	0.00025			0.00815	0.0000425		7.07	0.0963
Jon_1_E02_P2_TV_Post_Dup_1/21/2014_9:15:00 AM																				
Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM																				
Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM																				
Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM																				
Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM																				
Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM																				
Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM																				
Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM					0.00715		0.00039	2			0.000115	23.7	0.00025			0.105	0.0000425		7.8	0.0786
Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM																				
Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM																				

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality																			
	Metals	Metals	Metals	Metals	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved
Analyte:	Uranium	Uranium	Vanadium	Zinc	Aluminum, dissolved	Antimony, dissolved	Arsenic, dissolved	Barium, dissolved	Beryllium, dissolved	Boron, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Cobalt, dissolved	Copper, dissolved	Iron, dissolved	Lead, dissolved	Lithium, dissolved	Magnesium, dissolved	Manganese, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	pCi/L	ug/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Loc_1_E0_P2_TV_Post_N_5/8/2012_12:00:00 PM					0.00515		0.0978	0.534			0.0001	27.9	0.0003			3.62	0.00004		4.82	1.25
Loc_1_E0_P2_TV_Post_N_9/21/2012_9:15:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_10/25/2012_10:20:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_11/26/2012_11:05:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_12/20/2012_10:30:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_1/22/2013_11:20:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_2/21/2013_11:00:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_3/21/2013_11:00:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_4/23/2013_10:55:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_5/21/2013_10:20:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_6/20/2013_1:00:00 PM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_7/23/2013_10:58:00 AM	0.85	1.25																		
Loc_1_E0_P2_TV_Post_N_8/20/2013_10:55:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_9/24/2013_11:15:00 AM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_10/22/2013_2:30:00 PM	0.17	0.25																		
Loc_1_E0_P2_TV_Post_N_11/19/2013_10:40:00 AM	0.17	0.25																		
Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM					0.00715		0.0999	0.611			0.000115	28.8	0.00025			4.82	0.0000425		4.88	1.02
Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM																				
Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM																				
Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM																				
Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM																				
Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM																				
Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM																				
Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM																				
Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM																				
Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM																				
Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM																				
Loc_1_E06_P2_TV_Post_Dup_5/21/2014_9:08:00 AM																				
Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM																				
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																				
Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM																				
Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM																				
Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM																				
Marc_1_E3_P2_SV_Post_Dup_2/24/2014_12:35:00 PM																				
Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM																				
Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM																				
Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM					0.00715		0.00021	0.11			0.000115	2.42	0.00025			0.00815	0.0000425		0.365	0.0033
Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM																				
Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM					0.00715		0.00039	0.109			0.000115	2.32	0.00025			0.00815	0.0000425		0.343	0.0024
Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM					0.00715		0.00039	0.107			0.000115	2.21	0.00025			0.00815	0.0000425		0.318	0.0022
Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM					0.00715		0.00039	0.118			0.000115	2.4	0.00025			0.00815	0.0000425		0.352	0.0034
Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM																				
Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM																				
Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM																				
Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM																				
Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM																				
Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM																				
Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM																				
Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM																				
Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM																				
Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM																				
Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM																				
Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM																				
Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM																				
Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM																				
Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM																				
Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM																				
Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM																				
Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM																				
Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM																				
Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM																				
Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM																				
Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM																				
Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM																				

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality																			
	Metals	Metals	Metals	Metals	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved
Analyte:	Uranium	Uranium	Vanadium	Zinc	Aluminum, dissolved	Antimony, dissolved	Arsenic, dissolved	Barium, dissolved	Beryllium, dissolved	Boron, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Cobalt, dissolved	Copper, dissolved	Iron, dissolved	Lead, dissolved	Lithium, dissolved	Magnesium, dissolved	Manganese, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	pCi/L	ug/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM																				
Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM																				
Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM																				
Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM																				
Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM																				
Wal_1_E0_P2_TV_Post_N_10/25/2012_12:40:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_11/29/2012_1:30:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_12/28/2012_12:45:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_1/22/2013_1:27:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_2/21/2013_1:40:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_3/20/2013_1:45:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_4/25/2013_1:30:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_5/21/2013_1:10:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_6/25/2013_12:15:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_7/23/2013_1:15:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_8/20/2013_1:15:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_9/23/2013_12:12:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_10/24/2013_12:15:00 PM	0.17	0.25																		
Wal_1_E0_P2_TV_Post_N_11/22/2013_12:40:00 PM	0.2125	0.3125																		
Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM					0.00715		0.00021	1.13			0.000115	14.4	0.00025			0.00815	0.0000425		4.09	0.0298
Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM																				
Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM																				
Wal_1_E03_P2_TV_Post_Dup_2/26/2014_1:20:00 PM																				
Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM																				
Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM																				
Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM																				
Web_1_E0_P2_TV_Post_N_4/17/2012_11:55:00 AM			0.00009	0.002	0.00515	0.00021	0.000475	1.88	0.000065	0.112	0.0001	22.3	0.0003	0.00005	0.00019	0.0057	0.00004	0.138	5.13	0.0267
Web_1_E0_P2_TV_Post_N_10/8/2012_3:30:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_11/15/2012_3:20:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_12/14/2012_3:10:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_1/22/2013_9:50:00 AM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_2/21/2013_10:53:00 AM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_3/21/2013_10:47:00 AM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_4/23/2013_12:00:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_5/21/2013_10:40:00 AM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_6/20/2013_2:25:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_7/23/2013_9:32:00 AM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_8/20/2013_4:25:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_9/24/2013_12:35:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_10/22/2013_3:50:00 PM	0.17	0.25																		
Web_1_E0_P2_TV_Post_N_11/19/2013_12:28:00 PM	0.17	0.25																		
Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM					0.00715		0.00021	1.72			0.000115	20.8	0.00025			0.00815	0.0000425		4.59	0.0222
Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM																				
Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM																				
Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM																				
Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM																				
Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM																				
Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM																				
Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM																				
Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM																				
Web_1_E04_P2_TV_Post_Dup_3/26/2014_3:57:00 PM																				
Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM																				
Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM																				

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality															
	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	WQP	WQP	WQP	WQP
Analyte:	Mercury, dissolved	Nickel, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	Thallium, dissolved	Tin, dissolved	Titanium, dissolved	Vanadium, dissolved	Zinc, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Turbidity
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	NTU
Cas_1_E0_P2_TV_Post_N_10/13/2012_8:16:00 AM														383	0.5	1.6
Cas_1_E0_P2_TV_Post_N_11/15/2012_6:40:00 PM														744	0.5	0.07
Cas_1_E0_P2_TV_Post_N_12/14/2012_4:50:00 PM														443	0.5	0.07
Cas_1_E0_P2_TV_Post_N_1/26/2013_9:25:00 AM														459	0.5	1.3
Cas_1_E0_P2_TV_Post_N_2/22/2013_4:35:00 PM														792	0.5	1.9
Cas_1_E0_P2_TV_Post_N_3/22/2013_3:10:00 PM														415	0.5	1.5
Cas_1_E0_P2_TV_Post_N_4/23/2013_7:10:00 PM														827	0.5	0.07
Cas_1_E0_P2_TV_Post_N_5/21/2013_7:10:00 PM														544	0.5	1.3
Cas_1_E0_P2_TV_Post_N_6/20/2013_6:50:00 PM														842	0.5	0.07
Cas_1_E0_P2_TV_Post_N_7/25/2013_7:00:00 PM														662	0.5	1.2
Cas_1_E0_P2_TV_Post_N_8/20/2013_7:17:00 PM														786	0.5	1.8
Cas_1_E0_P2_TV_Post_N_9/24/2013_7:15:00 PM														784	0.5	0.07
Cas_1_E0_P2_TV_Post_N_10/22/2013_6:45:00 PM														740	0.5	0.07
Cas_1_E0_P2_TV_Post_N_11/19/2013_6:32:00 PM														827	0.5	0.07
Cas_1_E01_P2_TV_Post_N-Dup_12/20/2013_1:10:00 PM			3.44	0.00025	0.000055	141	2.45						7.4	338	0.5	
Cas_1_E01_P2_TV_Post_Dup_12/20/2013_1:10:00 PM			3.4	0.00025	0.000055	138	2.55						7.2	454	0.5	
Iri_1_E0_P2_TV_Post_N_11/29/2012_10:20:00 AM														131	0.5	2.6
Iri_1_E0_P2_TV_Post_N_12/28/2012_11:10:00 AM														98.5	0.5	2.1
Iri_1_E0_P2_TV_Post_N_1/22/2013_9:15:00 AM														99.5	0.5	0.07
Iri_1_E0_P2_TV_Post_N_2/21/2013_8:51:00 AM														88.5	0.5	1.4
Iri_1_E0_P2_TV_Post_N_3/21/2013_9:23:00 AM														101	0.5	1.8
Iri_1_E0_P2_TV_Post_N_4/23/2013_8:25:00 AM														74.5	0.5	0.07
Iri_1_E0_P2_TV_Post_N_5/21/2013_8:35:00 AM														77	0.5	1.1
Iri_1_E0_P2_TV_Post_N_6/20/2013_4:20:00 PM														84	0.5	0.07
Iri_1_E0_P2_TV_Post_N_7/23/2013_8:14:00 AM														89	0.5	0.07
Iri_1_E0_P2_TV_Post_N_8/20/2013_5:47:00 PM														83	0.5	0.07
Iri_1_E0_P2_TV_Post_N_9/24/2013_1:40:00 PM														96.5	0.5	0.07
Iri_1_E0_P2_TV_Post_N_10/22/2013_11:15:00 AM														97	0.5	0.07
Iri_1_E0_P2_TV_Post_N_11/19/2013_2:13:00 PM														97.5	0.5	0.07
Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM			1.39	0.00025	0.000055	2.07	0.0713						6.7	4.85	0.5	
Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM													6.8	77	0.5	
Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM													6.7	80.5	0.5	
Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM													6.9	75	0.5	
Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM													6.9	69	0.5	
Iri_1_E05_P2_TV_Post_Dup_4/23/2014_5:05:00 PM													6.9	78	0.5	
Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM													6.7	77.5	0.5	
Jon_1_E0_P2_TV_Post_N_4/16/2012_12:50:00 PM	0.000013	0.00025	1.3	0.000135	0.000455	55.9	0.574	0.000075	0.00215	0.00023	0.00009	0.002		224	0.5	
Jon_1_E0_P2_TV_Post_N_9/21/2012_12:05:00 PM														229	0.5	0.045
Jon_1_E0_P2_TV_Post_N_10/25/2012_3:15:00 PM														213	0.5	0.07
Jon_1_E0_P2_TV_Post_N_11/26/2012_1:05:00 PM														234	0.5	0.07
Jon_1_E0_P2_TV_Post_N_12/20/2012_12:40:00 PM														229	0.5	0.07
Jon_1_E0_P2_TV_Post_N_1/22/2013_3:10:00 PM														236	0.5	1.1
Jon_1_E0_P2_TV_Post_N_2/21/2013_2:15:00 PM														242	0.5	1.1
Jon_1_E0_P2_TV_Post_N_3/21/2013_1:27:00 PM														257	0.5	3.8
Jon_1_E0_P2_TV_Post_N_4/23/2013_2:30:00 PM														236	0.5	1.4
Jon_1_E0_P2_TV_Post_N_5/21/2013_12:30:00 PM														242	0.5	1.8
Jon_1_E0_P2_TV_Post_N_6/20/2013_10:50:00 AM														253	0.5	1.3
Jon_1_E0_P2_TV_Post_N_7/23/2013_2:45:00 PM														237	0.5	1.6
Jon_1_E0_P2_TV_Post_N_8/20/2013_9:15:00 AM														245	0.5	1.5
Jon_1_E0_P2_TV_Post_N_9/24/2013_9:50:00 AM														251	0.5	1.7
Jon_1_E0_P2_TV_Post_N_10/22/2013_9:20:00 AM														243	0.5	0.07
Jon_1_E0_P2_TV_Post_N_11/19/2013_9:20:00 AM														244	0.5	1.1
Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM			1.56	0.00025	0.000055	62.5	0.72						8	236	0.5	
Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM			1.46	0.00025	0.000055	59.9	0.776						8.1	238	0.5	
Jon_1_E02_P2_TV_Post_Dup_1/21/2014_9:15:00 AM													8.2	236	0.5	
Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM													8.2	246	0.5	
Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM													8.2	247	0.5	
Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM													8.3	234	0.5	
Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM																
Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM													8.2	250	0.5	
Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM																
Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM			1.74	0.00025	0.000055	68.1	0.731						8.3	248	0.5	
Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM													8.2	242	0.5	
Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM													8.1	237	0.5	

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality															
	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	WQP	WQP	WQP	WQP
Analyte:	Mercury, dissolved	Nickel, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	Thallium, dissolved	Tin, dissolved	Titanium, dissolved	Vanadium, dissolved	Zinc, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Turbidity
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	NTU
Loc_1_E0_P2_TV_Post_N_5/8/2012_12:00:00 PM	0.000013		1.89	0.000135	0.000049	43.1	0.929							210	9.4	30.9
Loc_1_E0_P2_TV_Post_N_9/21/2012_9:15:00 AM														219	5	39.5
Loc_1_E0_P2_TV_Post_N_10/25/2012_10:20:00 AM														193	5.8	31.7
Loc_1_E0_P2_TV_Post_N_11/26/2012_11:05:00 AM														213	0.5	33.6
Loc_1_E0_P2_TV_Post_N_12/20/2012_10:30:00 AM														209	3.6	21
Loc_1_E0_P2_TV_Post_N_1/22/2013_11:20:00 AM														202	3.3	21.5
Loc_1_E0_P2_TV_Post_N_2/21/2013_11:00:00 AM														203	4.8	38.6
Loc_1_E0_P2_TV_Post_N_3/21/2013_11:00:00 AM														238	3.2	50.8
Loc_1_E0_P2_TV_Post_N_4/23/2013_10:55:00 AM														199	9.5	35.1
Loc_1_E0_P2_TV_Post_N_5/21/2013_10:20:00 AM														208	4.2	41
Loc_1_E0_P2_TV_Post_N_6/20/2013_1:00:00 PM														227	0.5	50.8
Loc_1_E0_P2_TV_Post_N_7/23/2013_10:58:00 AM														192	0.5	32.3
Loc_1_E0_P2_TV_Post_N_8/20/2013_10:55:00 AM														223	0.5	35.6
Loc_1_E0_P2_TV_Post_N_9/24/2013_11:15:00 AM														206	5.9	38.9
Loc_1_E0_P2_TV_Post_N_10/22/2013_2:30:00 PM														205	8.7	36.3
Loc_1_E0_P2_TV_Post_N_11/19/2013_10:40:00 AM														197	6.8	38.8
Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM			2.1	0.00025	0.000055	43.7	0.884						7.4	187	0.5	
Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM													7.6	199	10.4	
Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM													7.7	205	6.4	
Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM													7.6	202	9.1	
Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM													7.8	209	3.6	
Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM																
Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM													7.3	203	3.8	
Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM																
Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM													7.7	201	6.2	
Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM													7.6	204	8.2	
Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM													7.6	201	8.5	
Loc_1_E06_P2_TV_Post_Dup_5/21/2014_9:08:00 AM													7.6	202	8.3	
Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM													8.1	281	0.5	
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																
Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM													8.2	269	0.5	
Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM													8.2	271	0.5	
Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM													8.1	280	0.5	
Marc_1_E3_P2_SV_Post_Dup_2/24/2014_12:35:00 PM																
Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM													7.9	275	0.5	
Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM													8	271	0.5	
Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM			1.65	0.00025	0.000055	215	0.216						8.7	547	37.5	
Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM																
Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM			1.64	0.00025	0.000055	223	0.221						8.9	581	9.1	
Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM			1.55	0.00025	0.000055	218	0.221						8.9	580	8.3	
Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM			1.77	0.00025	0.000055	219	0.231						8.8	571	7.1	
Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM																
Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM													8.6	177	0.5	
Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM																
Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM													8.4	165	0.5	
Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM																
Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM													8.2	164	0.5	
Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM													8.2	163	0.5	
Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM													8.6	175	0.5	
Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM													8.1	182	0.5	
Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM													8.2	183	0.5	
Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM													8.1	365	0.5	
Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM																
Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM													8.2	353	0.5	
Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM																
Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM													8	365	0.5	
Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM													8	366	0.5	
Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM													8.3	614	0.5	
Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM																
Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM													8.3	616	0.5	
Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM													8.3	620	0.5	
Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM													8.2	598	0.5	
Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM																
Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM													8.1	177	0.5	

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

TABLE E-1
ANALYTICAL RESULTS:
CABOT OIL AND GAS CORPORATION TEMPORAL VARIABILITY STUDY

Analyte Group:	Water Quality															
	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	Metals - Dissolved	WQP	WQP	WQP	WQP
Analyte:	Mercury, dissolved	Nickel, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	Thallium, dissolved	Tin, dissolved	Titanium, dissolved	Vanadium, dissolved	Zinc, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Turbidity
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	NTU
Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM																
Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM													8.3	166	0.5	
Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM																
Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM													8.2	178	0.5	
Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM													8.1	179	0.5	
Wal_1_E0_P2_TV_Post_N_10/25/2012_12:40:00 PM														152	0.5	0.07
Wal_1_E0_P2_TV_Post_N_11/29/2012_1:30:00 PM														174	0.5	0.07
Wal_1_E0_P2_TV_Post_N_12/28/2012_12:45:00 PM														164	0.5	0.07
Wal_1_E0_P2_TV_Post_N_1/22/2013_1:27:00 PM														174	0.5	0.07
Wal_1_E0_P2_TV_Post_N_2/21/2013_1:40:00 PM														147	0.5	0.07
Wal_1_E0_P2_TV_Post_N_3/20/2013_1:45:00 PM														148	0.5	0.07
Wal_1_E0_P2_TV_Post_N_4/25/2013_1:30:00 PM														178	0.5	0.07
Wal_1_E0_P2_TV_Post_N_5/21/2013_1:10:00 PM														160	0.5	10.8
Wal_1_E0_P2_TV_Post_N_6/25/2013_12:15:00 PM														149	0.5	1.2
Wal_1_E0_P2_TV_Post_N_7/23/2013_1:15:00 PM														155	0.5	0.07
Wal_1_E0_P2_TV_Post_N_8/20/2013_1:15:00 PM														159	0.5	0.07
Wal_1_E0_P2_TV_Post_N_9/23/2013_12:12:00 PM														163	0.5	0.07
Wal_1_E0_P2_TV_Post_N_10/24/2013_12:15:00 PM														167	0.5	0.07
Wal_1_E0_P2_TV_Post_N_11/22/2013_12:40:00 PM														141	4.5	9.6
Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM			1.67	0.00025	0.000055	39.7	0.683						7.9	150	0.5	
Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM													8.2	156	0.5	
Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM													8.1	162	0.5	
Wal_1_E03_P2_TV_Post_Dup_2/26/2014_1:20:00 PM													8.2	165	0.5	
Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM													8.3	161	0.5	
Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM													7.9	175	0.5	
Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM													8.1	167	0.5	
Web_1_E0_P2_TV_Post_N_4/17/2012_11:55:00 AM	0.000013	0.00025	1.93	0.000135	0.000455	50.5	1.09	0.000075	0.00215	0.00023	0.00009	0.002		226	0.5	
Web_1_E0_P2_TV_Post_N_10/8/2012_3:30:00 PM														202	0.5	1.9
Web_1_E0_P2_TV_Post_N_11/15/2012_3:20:00 PM														196	0.5	0.07
Web_1_E0_P2_TV_Post_N_12/14/2012_3:10:00 PM														195	0.5	0.07
Web_1_E0_P2_TV_Post_N_1/22/2013_9:50:00 AM														206	0.5	0.07
Web_1_E0_P2_TV_Post_N_2/21/2013_10:53:00 AM														203	0.5	2
Web_1_E0_P2_TV_Post_N_3/21/2013_10:47:00 AM														203	0.5	1.3
Web_1_E0_P2_TV_Post_N_4/23/2013_12:00:00 PM														196	0.5	0.07
Web_1_E0_P2_TV_Post_N_5/21/2013_10:40:00 AM														213	0.5	0.07
Web_1_E0_P2_TV_Post_N_6/20/2013_2:25:00 PM														213	0.5	1.6
Web_1_E0_P2_TV_Post_N_7/23/2013_9:32:00 AM														187	0.5	1.1
Web_1_E0_P2_TV_Post_N_8/20/2013_4:25:00 PM														196	0.5	1.2
Web_1_E0_P2_TV_Post_N_9/24/2013_12:35:00 PM														196	0.5	0.07
Web_1_E0_P2_TV_Post_N_10/22/2013_3:50:00 PM														199	0.5	0.07
Web_1_E0_P2_TV_Post_N_11/19/2013_12:28:00 PM														188	0.5	0.07
Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM			1.91	0.00025	0.000055	48.4	1.02						8	174	0.5	
Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM													8.3	193	0.5	
Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM													8.2	186	0.5	
Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM													8.2	194	0.5	
Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM													8.3	187	0.5	
Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM																
Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM													8.3	196	0.5	
Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM																
Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM													8.3	192	0.5	
Web_1_E04_P2_TV_Post_Dup_3/26/2014_3:57:00 PM													8.3	200	0.5	
Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM													7.9	196	0.5	
Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM													8.1	204	0.5	

Notes:
1) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample.

APPENDIX F

BASELINE SAMPLING FOR DISSOLVED METHANE

PADEP AND ODNR LABORATORY METHOD COMPARISON

APPENDIX F

BASELINE SAMPLING FOR DISSOLVED METHANE IN AREAS OF SHALE OIL AND GAS DEVELOPMENT

Laboratory Methods: Comparison of Dissolved Methane Concentrations Reported by Isotech, PADEP BOL, and ODNR Laboratories

During the sampling variability study, paired samples were collected for dissolved methane analysis by Isotech Laboratories (Isotech), the Pennsylvania Department of Environmental Protection (PaDEP) Bureau of Laboratories (BOL) and the Ohio Department of Natural Resources (ODNR) Laboratory. These samples were collected to further evaluate differences between dissolved methane concentration results reported by different laboratories (some of which require different sample containers/ collection methods, and utilize different analytical procedures).

Samples collected for analysis at the three laboratories included:

- IsoFlask™ samples for analysis at Isotech Laboratories: 16 samples.
- IsoFlask™ samples for analysis at the PaDEP BOL (where both methane in the water and headspace phases of the IsoFlask™ were accounted for): 16 primary and 8 duplicate samples.
- 22 ml crimp cap vials collected via the Inverted Bottle method for analysis at the ODNR Laboratory (where this sample container and collection method are utilized by the ODNR): 16 primary and 8 duplicate samples.

All paired and duplicate samples were collected consecutively immediately after one another. Dissolved methane concentrations for respective samples analyzed by each laboratory are shown in **Table F-1**.

Comparison of Isotech and PaDEP BOL IsoFlask™ Results

IsoFlask™ samples were analyzed by both Isotech Laboratories and the PaDEP BOL. As shown on **Figure F-1a,** the PaDEP BOL typically reported dissolved methane concentrations that are lower than, but still commonly within 15% of those reported by Isotech Laboratories. This relatively minor concentration difference could be associated with small differences in analytical procedures (e.g., calibration) between the laboratories.

Comparison of Isotech IsoFlask™ Results to ODNR 22 ml Crimp Cap Vial Results

Samples analyzed for dissolved methane concentration at the ODNR were collected using a 22 ml crimp cap vial filled via the Inverted Bottle method (as described in Molofsky et al., 2016). The results of these sample analyses were compared to the concentrations reported for paired IsoFlask™ samples analyzed at Isotech Laboratories. As shown on **Figure F-1b**, ODNR samples exhibited notably lower dissolved methane concentrations in the range of 10–35 mg/L, and scattered methane concentrations (i.e., some higher, some lower than paired IsoFlask™ samples) when methane concentrations exceeded 50 mg/L.

This pattern may be attributable to part of the analytical procedure utilized by the ODNR during sample analysis that is complicated by the presence of pre-existing bubbles of exsolved gas. Specifically, to create a headspace in the 22 ml crimp cap vials, the ODNR injects a set volume of helium (i.e., 10 – 12 ml) into the container, simultaneously displacing the same volume of water. However, several of the 22 ml crimp cap vials collected in this study already contained headspace comprised of exsolved gases (i.e., methane and CO_2) that were captured by the Inverted bottle

method during sample collection. In these samples, a significant mass of methane in the sample is contained in a pre-existing bubble in the vial (where that mass is comprised of effervescing methane captured at the time of sample collection and methane that partitioned into the headspace after sample collection but before analysis).

For these samples, the injection of 10-12 ml of helium and simultaneous displacement of 10-12 ml of water does not necessarily result in the removal of half the methane mass contained in the vial. This can result in unpredictable analytical results, as the assumptions on which the procedure is based (i.e., that the vial does not contain a headspace comprised predominantly of methane) no longer hold true.

Table F-1. *Dissolved methane concentrations for paired samples analyzed at Isotech Laboratories, the PaDEP BOL, and the ODNR Laboratory.*

Well Number	Location ID	Sample Date	Purge Volume	Sample Type	Methane (µg/L)				
					Isotech IsoFlask™	PaDEP BOL IsoFlask™		ODNR Inverted Bottle (22 ml crimp cap vial)	
					Primary	Primary	Duplicate	Primary	Duplicate
W1	Loc	12/1/2015	P2	N	13000	13807		5310	
W1	Loc	12/1/2015	P5	N	11000	10610	10936	6590	6650
W2	Sim	12/7/2015	P2	N	2600	2590		1450	
W2	Sim	12/7/2015	P5	N	3400	3276	4310	2050	1510
W3	Jon	12/7/2015	P2	N	34000	26541		20100	
W3	Jon	12/7/2015	P5	N	29000	21830	22913	16700	17200
W4	Web	12/10/2015	P2	N	12000	11195		7350	
W4	Web	12/10/2015	P5	N	11000	9866	10283	4750	7560
W5	Rath	12/3/2015	P2	N	69000	59195		77900	
W5	Rath	12/3/2015	P5	N	51000	45452	49610	49600	39300
W7	Sieb	12/2/2015	P2	N	48000	42920		82800	
W7	Sieb	12/2/2015	P5	N	82000	73657	70249	63100	97700
W8	Sdel	12/14/2015	P2	N	19000	15010		7990	
W8	Sdel	12/14/2015	P5	N	18000	15266	17151	8760	9300
W9	Sbar	12/8/2015	P2	N	9000	8893		5590	
W9	Sbar	12/8/2015	P5	N	5200	5724	5954	3450	3410

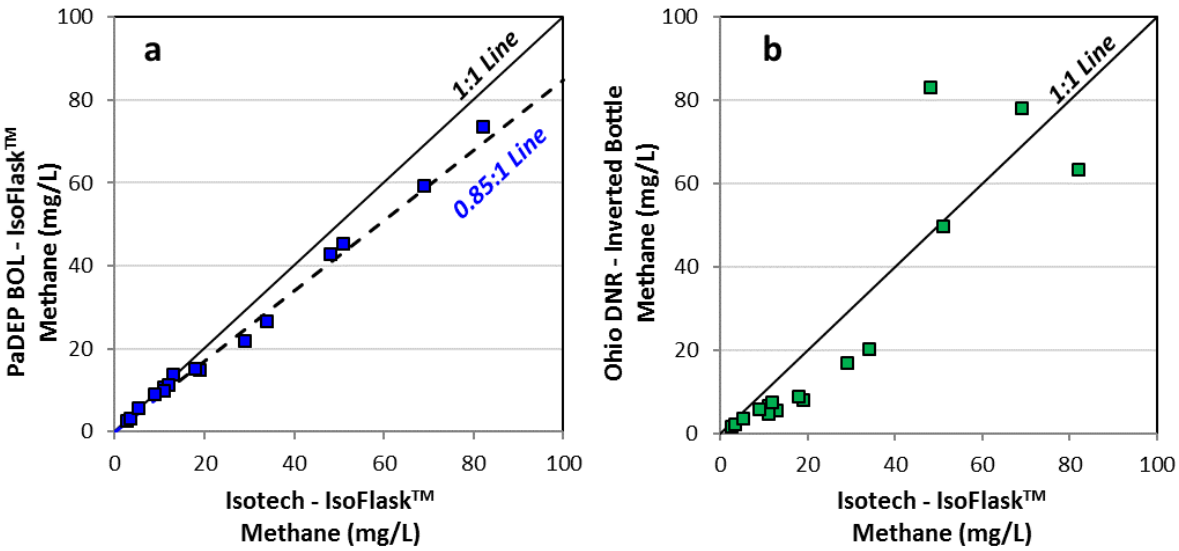

Figure F-1. *Methane concentrations reported for* ***a)*** *IsoFlask™ samples analyzed by PaDEP BOL vs. Isotech;* ***b)*** *22 ml crimp cap vial samples (filled via the Inverted Bottle method) analyzed by the ODNR vs. IsoFlask™ samples analyzed by Isotech.*

APPENDIX G

BASELINE SAMPLING FOR DISSOLVED METHANE

NOBLE GAS ANALYSIS (OHIO STATE UNIVERSITY)

APPENDIX G

BASELINE SAMPLING FOR DISSOLVED METHANE IN AREAS OF SHALE OIL AND GAS DEVELOPMENT

Noble Gas Analysis with Ohio State University

In April and May of 2015, samples were collected for analysis of noble gases and concentrations of methane and fixed gases from six water supply wells sampled in Susquehanna and Bradford County as part of the "Baseline Sampling for Dissolved Methane in Areas of Shale Gas and Oil Development" study. Samples were collected at a sampling location prior to the pressure tank after 3 casing volumes of water had been purged from each well in accordance with the methods presented in Darrah et al. (2014). Samples were analyzed by Dr. Thomas Darrah at Ohio State University as described in Darrah et al. (2014). Results of those analyses are shown in **Table G-1** below.

Four of the six wells sampled exhibited a noble gas composition that appear consistent with what has previously been identified as naturally occurring methane in Northeastern Pennsylvania (i.e., Darrah et al., 2014). One well, the "Rath" well, fell slightly outside the range previously defined as naturally occurring in Darrah et al. (2014), but still displayed a noble gas composition much closer to that of naturally occurring early thermogenic gases than that identified as being potentially related to stray gas migration.

References

Darrah, T., Vengosh, A., Jackson, R.B., Warner, N.R., and R. J. Poreda. 2014. Noble gases identify the mechanisms of fugitive gas contamination in drinking water wells overlying the Marcellus and Barnett Shales. Proceedings of the National Academy of Sciences, vol. 111, no. 39, 14076-14081.

Table G-1. *Results of Noble Gas Analysis at 6 Water Supply Wells (Ohio State University)*

Well	Sample Date	Sample Mass (g)	Total cc's of gas/L	H_2 cc/L	CH_4 cc/L	N_2 cc/L	O_2 cc/L	^{3}He pcc/L	^{4}He µcc/L	^{20}Ne µcc/L	^{21}Ne µcc/L
Rath	5/1/2015	14.80	46.13	<0.02	33.3	10.1	bdl	1434.1	44664.3	857.3	2.5
Sieb	5/11/2015	14.70	53.18	<0.02	39.7	11.3	0.0	693.6	28336.7	608.2	1.8
Loc	5/4/2015	13.90	41.10	<0.02	11.1	16.5	0.0	105.6	593.8	149.1	0.4
Sim	4/30/2015	14.50	30.64	<0.02	4.4	15.4	0.0	154.5	4318.0	359.2	1.1
Web	5/12/2015	14.60	26.98	<0.02	9.6	14.2	0.0	680.7	25171.5	428.5	1.3
Sbar	5/9/2015	15.80	32.74	<0.02	7.1	13.2	0.0	119.5	5737.4	260.5	0.8

Well	Sample Date	^{22}Ne µcc/L	Ne µcc/L	^{36}Ar µcc/L	^{38}Ar µcc/L	^{40}Ar cc/L	Ar cc/L	R/R_A	$^{20}Ne/^{22}Ne$	$^{21}Ne/^{22}Ne$
Rath	5/1/2015	87.6	947.5	843.4	160.0	0.251	0.252	0.023	9.782	0.029
Sieb	5/11/2015	62.1	672.1	987.6	185.2	0.292	0.294	0.018	9.791	0.029
Loc	5/4/2015	15.2	164.8	1185.1	223.7	0.355	0.356	0.128	9.782	0.029
Sim	4/30/2015	36.7	397.0	1152.5	216.7	0.342	0.344	0.026	9.784	0.029
Web	5/12/2015	43.8	473.5	1051.1	200.1	0.312	0.314	0.019	9.791	0.029
Sbar	5/9/2015	26.5	287.9	1119.7	209.1	0.332	0.333	0.015	9.814	0.029

Well	Sample Date	$^{38}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$	$^{4}He/^{20}Ne$	$^{20}Ne/^{36}Ar$	$^{4}He/^{36}Ar$	N_2/Ar	$^{4}He/CH_4$ x10^{6}	$CH_4/^{36}Ar$
Rath	5/1/2015	0.190	298.1	52.1	1.016	53.0	40.0	1340.1	39516.3
Sieb	5/11/2015	0.188	296.1	46.6	0.616	28.7	38.5	713.3	40221.9
Loc	5/4/2015	0.189	299.2	4.0	0.126	0.5	46.5	53.7	9330.5
Sim	4/30/2015	0.188	297.1	12.0	0.312	3.7	45.0	988.3	3790.9
Web	5/12/2015	0.190	297.1	58.7	0.408	23.9	45.3	2619.0	9144.1
Sbar	5/9/2015	0.187	296.2	22.0	0.233	5.1	39.9	803.6	6376.4

APPENDIX H

BASELINE SAMPLING FOR DISSOLVED METHANE

ANALYTICAL DATA TABLES

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

													Analyte Group:	Dissolved Light Hydrocarbon Gases (IsoFlask)			Isotopes					
													Analyte:	Methane	Ethane	Propane	$\delta^{13}C$ DIC	$\delta^{18}O$ H_2O	δD H_2O	$\delta^{13}C$ CH_4	$\delta^{13}C$ C_2H_6	δD CH_4
													Laboratory:	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech
Well #	Location ID	Phase	Year Month	Purge Volume Abbreviation	Purge Volume	Pre / Post Pressure Tank	Study	Sample Date	Sample Time	Field Parameter Time	Sample Type	Sample ID		ug/L	ug/L	ug/L	‰ VPDB	‰ VSMOW	‰ VSMOW	‰ VPDB	‰ VPDB	‰ VSMOW
W11	Iri	1	2013-12	P2	Purge to parameter stability	Post	Temp	12/19/2013	5:45:00 PM	5:38:00 PM	N	Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM		1.7	<0.2							
W11	Iri	1	2014-01	P2	Purge to parameter stability	Post	Temp	1/21/2014	5:30:00 PM	5:24:00 PM	N	Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM		1.1	<0.2		-17.4	-8.52	-55.7			
W11	Iri	1	2014-02	P2	Purge to parameter stability	Post	Temp	2/18/2014	10:45:00 AM	10:44:00 AM	N	Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM		1.3	<0.3							
W11	Iri	1	2014-03	P2	Purge to parameter stability	Post	Temp	3/25/2014	10:43:00 AM	10:40:00 AM	N	Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM		1.2	<0.2	<0.3						
W11	Iri	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/23/2014	5:05:00 PM	5:02:00 PM	N-Dup	Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM		0.82	<0.2	<0.3						
W11	Iri	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/21/2014	7:37:00 AM	7:37:00 AM	N	Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM		3.7	<0.2	<0.3						
W3	Jon	1	2013-12	P2	Purge to parameter stability	Post	Temp	12/19/2013	9:20:00 AM	9:15:18 AM	N	Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM		30000	11					-39.06		-201.5
W3	Jon	1	2014-01	P2	Purge to parameter stability	Post	Temp	1/21/2014	9:15:00 AM	9:09:30 AM	N-Dup	Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM		31000	11		-13.9	-9.63	-65.8	-39.49		-201.7
W3	Jon	1	2014-02	P2	Purge to parameter stability	Post	Both	2/17/2014	3:51:00 PM	3:47:05 PM	N-Dup	Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM		31000	11		-13.8	-9.88	-67.1	-39.25		-199.2
W3	Jon	1	2014-02	P2	Purge to parameter stability	Post	Both	2/17/2014	3:51:00 PM	3:47:05 PM	Dup	Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM		31000	11		-13.9	-9.91	-66.3	-39.27		-201.8
W3	Jon	1	2014-02	P5	3 casing volumes	Post	Purge	2/17/2014	5:33:00 PM	5:28:05 PM	N	Jon_1_E1_P5_SV_Post_N_2/17/2014_5:33:00 PM		27000	9.7		-14.3	-9.98	-66.4	-39.71		-199.9
W3	Jon	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	8:54:00 AM	8:53:19 AM	N-Dup	Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM		31000	11		-13.9	-9.84	-66.4	-39.22		-202.2
W3	Jon	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	8:54:00 AM	8:53:19 AM	Dup	Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM		31000	11							
W3	Jon	1	2014-02	P5	3 casing volumes	Post	Purge	2/21/2014	10:24:00 AM	10:19:19 AM	N	Jon_1_E2_P5_SV_Post_N_2/21/2014_10:24:00 AM		27000	10		-14.3	-9.94	-66.1	-39.6		-200.8
W3	Jon	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	9:08:00 AM	9:04:15 AM	N-Dup	Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM		33000	12		-14.1	-9.92	-67.2	-39.27		-199.4
W3	Jon	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	9:08:00 AM	9:04:15 AM	Dup	Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM		32000	12							
W3	Jon	1	2014-02	P5	3 casing volumes	Post	Purge	2/24/2014	10:34:00 AM	10:30:15 AM	N	Jon_1_E3_P5_SV_Post_N_2/24/2014_10:34:00 AM		28000	10		-14.4	-9.91	-65.9	-39.61		-200.1
W3	Jon	1	2014-03	P2	Purge to parameter stability	Post	Temp	3/26/2014	9:37:00 AM	9:37:54 AM	N	Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM		32000	12	<0.3				-39.31		-198.6
W3	Jon	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/23/2014	12:00:00 PM	11:58:04 AM	N	Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM		34000	12	<0.4				-39.31		-199.3
W3	Jon	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/22/2014	9:40:00 AM	9:40:00 AM	N	Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM		31000	11	<0.4						
W3	Jon	2	2015-04	P1	One-half gallon	Post	Purge	4/28/2015	10:14:00 AM	10:38:28 AM	N	Jon_2_E1_P1_Both_Post_N_4/28/2015_10:14:00 AM		34000	11	<0.3						
W3	Jon	2	2015-04	P2	2 pressure tank volumes	Post	Both	4/28/2015	10:49:00 AM	10:47:28 AM	N	Jon_2_E1_P2_Both_Post_N_4/28/2015_10:49:00 AM		34000	11	<0.3	-13.8	-9.99	-66.8	-39.04		-196.9
W3	Jon	2	2015-04	P4	1 casing volume	Post	Both	4/28/2015	11:22:00 AM	11:14:28 AM	N	Jon_2_E1_P4_Both_Post_N_4/28/2015_11:22:00 AM		34000	11	<0.3						
W3	Jon	2	2015-04	P5	3 casing volumes	Post	Purge	4/28/2015	1:05:00 PM	12:22:28 PM	N	Jon_2_E1_P5_Both_Post_N_4/28/2015_1:05:00 PM		29000	9.4	<0.3	-15.3	-9.85	-66.1	-39.5		-198.2
W3	Jon	2	2015-07	P1	One-half gallon	Post	Purge	7/16/2015	9:21:00 AM	9:32:46 AM	N	Jon_2_E2_P1_Both_Post_N_7/16/2015_9:21:00 AM		34000	10	<0.3						
W3	Jon	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/16/2015	9:45:00 AM	9:42:46 AM	N	Jon_2_E2_P2_Both_Post_N_7/16/2015_9:45:00 AM		33000	11	<0.3	-13.8	-9.95	-65.1	-38.94		-199.9
W3	Jon	2	2015-07	P4	1 casing volume	Post	Both	7/16/2015	10:14:00 AM	10:11:46 AM	N	Jon_2_E2_P4_Both_Post_N_7/16/2015_10:14:00 AM		33000	11	<0.3						
W3	Jon	2	2015-07	P5	3 casing volumes	Post	Purge	7/16/2015	11:12:00 AM	11:07:46 AM	N	Jon_2_E2_P5_Both_Post_N_7/16/2015_11:12:00 AM		29000	9.8	<0.3	-14.3	-9.87	-64.4	-39.34		-196.8
W3	Jon	2	2015-09	P1	One-half gallon	Post	Purge	9/28/2015	2:49:00 PM	2:53:25 PM	N	Jon_2_E3_P1_Both_Post_N_9/28/2015_2:49:00 PM		35000	11	<0.3						
W3	Jon	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/28/2015	3:15:00 PM	3:04:25 PM	N	Jon_2_E3_P2_Both_Post_N_9/28/2015_3:15:00 PM		35000	11	<0.3	-14.1	-9.98	-65.1	-38.53		-199.1
W3	Jon	2	2015-09	P4	1 casing volume	Post	Both	9/28/2015	3:45:00 PM	3:41:25 PM	N	Jon_2_E3_P4_Both_Post_N_9/28/2015_3:45:00 PM		30000	9.6	<0.3						
W3	Jon	2	2015-09	P5	3 casing volumes	Post	Purge	9/28/2015	4:49:00 PM	4:38:25 PM	N	Jon_2_E3_P5_Both_Post_N_9/28/2015_4:49:00 PM		28000	9.1	<0.3	-14.6	-9.92	-65.7	-39.37		-197.8
W3	Jon	2	2015-12	P1	One-half gallon	Post	Purge	12/7/2015	9:39:00 AM	9:46:37 AM	N	Jon_2_E4_P1_Both_Post_N_12/7/2015_9:39:00 AM		36000	11	<0.3						
W3	Jon	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/7/2015	10:05:00 AM	9:57:37 AM	N-Dup	Jon_2_E4_P2_Both_Post_N-Dup_12/7/2015_10:05:00 AM		34000	11	<0.3	-14.1	-9.81	-65	-39.01		-199.2
W3	Jon	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/7/2015	10:05:00 AM	9:57:37 AM	Dup	Jon_2_E4_P2_Both_Post_Dup_12/7/2015_10:05:00 AM		34000	11	<0.3	-14.1	-9.84	-65.1	-39.3		-198.8
W3	Jon	2	2015-12	P4	1 casing volume	Post	Purge	12/7/2015	10:54:00 AM	9:57:37 AM	N	Jon_2_E4_P4_Both_Post_N_12/7/2015_10:54:00 AM		31000	10	<0.3						
W3	Jon	2	2015-12	P5	3 casing volumes	Post	Purge	12/7/2015	11:57:00 AM	11:51:37 AM	N	Jon_2_E4_P5_Both_Post_N_12/7/2015_11:57:00 AM		29000	9.4	<0.3	-14.4	-9.97	-65.1	-39.31		-198.6
W1	Loc	1	2013-12	P2	Purge to parameter stability	Post	Temp	12/19/2013	12:56:00 PM	12:51:21 PM	N	Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM		12000	0.62					-73.69		-233.2
W1	Loc	1	2014-01	P2	Purge to parameter stability	Post	Temp	1/21/2014	12:06:00 PM	12:05:28 PM	N	Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM		14000	0.47		-12.5	-9.5	-63.2	-74.12		-231.8
W1	Loc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/19/2014	11:24:00 AM	11:24:04 AM	N-Dup	Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM		12000	0.59		-12.8	-9.39	-61.7	-73.19		-233.9
W1	Loc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/19/2014	11:24:00 AM	11:24:04 AM	Dup	Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM		11000	0.45		-12.8	-9.23	-61.3	-73.65		-232.3
W1	Loc	1	2014-02	P5	3 casing volumes	Post	Purge	2/19/2014	8:42:00 PM	8:39:04 PM	N	Loc_1_E1_P5_SV_Post_N_2/19/2014_8:42:00 PM		8700	0.93		-13.5	-9.3	-62	-73.7		-231.4
W1	Loc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/22/2014	9:35:00 AM	9:35:08 AM	N-Dup	Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM		9600	0.48		-13.6	-9.43	-62.1	-73.39		-229.7
W1	Loc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/22/2014	9:35:00 AM	9:35:08 AM	Dup	Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM		9400	0.61							
W1	Loc	1	2014-02	P5	3 casing volumes	Post	Purge	2/22/2014	6:40:00 PM	6:34:08 PM	N	Loc_1_E2_P5_SV_Post_N_2/22/2014_6:40:00 PM		8200	0.81		-13.7	-9.44	-62.9	-73.71		-230.3
W1	Loc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/26/2014	9:30:00 AM	9:29:01 AM	N-Dup	Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM		11000	0.64		-13.2	-9.43	-63	-73.82		-231.1
W1	Loc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/26/2014	9:30:00 AM	9:29:01 AM	Dup	Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM		11000	0.57							
W1	Loc	1	2014-02	P5	3 casing volumes	Post	Purge	2/26/2014	6:30:00 PM	6:24:01 PM	N	Loc_1_E3_P5_SV_Post_N_2/26/2014_6:30:00 PM		9500	0.96		-13.6	-9.43	-62.4	-74.17		-230
W1	Loc	1	2014-03	P2	Purge to parameter stability	Post	Temp	3/26/2014	6:10:00 PM	6:10:51 PM	N	Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM		13000		<0.3				-73.94		-235
W1	Loc	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/23/2014	10:25:00 AM	10:23:20 AM	N	Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM		12000	0.5	<0.3				-74.14		-235.3
W1	Loc	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/21/2014	9:08:00 AM	9:08:05 AM	N-Dup	Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM		10000	0.52	<0.4						
W1	Loc	2	2015-05	P1	One-half gallon	Post	Purge	5/4/2015	9:55:00 AM	9:59:27 AM	N	Loc_2_E1_P1_Both_Post_N_5/4/2015_9:55:00 AM		12000	0.43	<0.3						
W1	Loc	2	2015-05	P2	2 pressure tank volumes	Post	Both	5/4/2015	10:15:00 AM	10:12:27 AM	N	Loc_2_E1_P2_Both_Post_N_5/4/2015_10:15:00 AM		12000	0.45	<0.3	-12.8	-9.08	-61.3	-74.17		-231.2
W1	Loc	2	2015-05	P4	1 casing volume	Post	Both	5/4/2015	12:58:00 PM	12:56:28 PM	N	Loc_2_E1_P4_Both_Post_N_5/4/2015_12:58:00 PM		10000	0.8	<0.3						
W1	Loc	2	2015-05	P5	3 casing volumes	Post	Purge	5/4/2015	6:40:00 PM	6:31:28 PM	N	Loc_2_E1_P5_Both_Post_N_5/4/2015_6:40:00 PM		10000	0.85	<0.3	-13.4	-9.33	-61.4	-74.27		-231.6
W1	Loc	2	2015-07	P1	One-half gallon	Post	Purge	7/14/2015	9:29:00 AM	9:45:51 AM	N	Loc_2_E2_P1_Both_Post_N_7/14/2015_9:29:00 AM		11000	0.64	<0.3						
W1	Loc	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/14/2015	10:06:00 AM	10:03:51 AM	N	Loc_2_E2_P2_Both_Post_N_7/14/2015_10:06:00 AM		12000	0.43	<0.3	-12.8	-9.41	-60.3	-73.93		-230.5
W1	Loc	2	2015-07	P4	1 casing volume	Post	Both	7/14/2015	12:51:00 PM	12:49:51 PM	N	Loc_2_E2_P4_Both_Post_N_7/14/2015_12:51:00 PM		10000	0.99	<0.3						
W1	Loc	2	2015-07	P5	3 casing volumes	Post	Purge	7/14/2015	6:30:00 PM	6:27:51 PM	N	Loc_2_E2_P5_Both_Post_N_7/14/2015_6:30:00 PM		8900	0.88	<0.3	-13.4	-9.47	-60.3	-73.9		-231.1
W1	Loc	2	2015-09	P1	One-half gallon	Post	Purge	9/23/2015	10:18:00 AM	10:23:00 AM	N	Loc_2_E3_P1_Both_Post_N_9/23/2015_10:18:00 AM		14000	0.95	<0.3						
W1	Loc	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/23/2015	10:55:00 AM	10:42:00 AM	N-Dup	Loc_2_E3_P2_Both_Post_N-Dup_9/23/2015_10:55:00 AM		14000	0.91	<0.3	-12.3	-9.4	-59.7	-73.08		-230
W1	Loc	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/23/2015	10:55:00 AM	10:42:00 AM	Dup	Loc_2_E3_P2_Both_Post_Dup_9/23/2015_10:55:00 AM		14000	0.99	<0.3	-12.4	-9.38	-61.1	-72.76		-228.9
W1	Loc	2	2015-09	P4	1 casing volume	Post	Purge	9/23/2015	1:47:00 PM	1:42:00 PM	N	Loc_2_E3_P4_Both_Post_N_9/23/2015_1:47:00 PM		11000	1.5	<0.3						
W1	Loc	2	2015-09	P5	3 casing volumes	Post	Purge	9/23/2015	7:36:00 PM	7:21:00 PM	N	Loc_2_E3_P5_Both_Post_N_9/23/2015_7:36:00 PM		10000	1.4	<0.2	-13.2	-9.34	-59.8	-72.82		-229.8
W1	Loc	2	2015-12	P1	One-half gallon	Post	Purge	12/1/2015	10:55:00 AM	11:08:23 AM	N	Loc_2_E4_P1_Both_Post_N_12/1/2015_10:55:00 AM		14000	0.88	<0.3						
W1	Loc	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/1/2015	11:30:00 AM	11:17:23 AM	N	Loc_2_E4_P2_Both_Post_N_12/1/2015_11:30:00 AM		13000	0.76	<0.3	-12.5	-9.49	-60.4	-72.78		-229.3
W1	Loc	2	2015-12	P4	1 casing volume	Post	Both	12/1/2015	2:13:00 PM	2:05:23 PM	N	Loc_2_E4_P4_Both_Post_N_12/1/2015_2:13:00 PM		12000	1.5	<0.3						
W1	Loc	2	2015-12	P5	3 casing volumes	Post	Purge	12/1/2015	7:40:00 PM	7:29:23 PM	N	Loc_2_E4_P5_Both_Post_N_12/1/2015_7:40:00 PM		11000	1.3	<0.3	-13.3	-9.45	-60.8	-73.25		-227.5
W6	Marc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	5:27:00 PM	5:23:00 PM	N-Dup	Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM		6100	1.7		-16.4	-9.09	-62.2	-45.71		-215.9

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

													Analyte Group:	Dissolved Light Hydrocarbon Gases (IsoFlask)			Isotopes					
													Analyte:	Methane	Ethane	Propane	$\delta^{13}C$ DIC	$\delta^{18}O$ H_2O	δD H_2O	$\delta^{13}C$ CH_4	$\delta^{13}C$ C_2H_6	δD CH_4
													Laboratory:	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech
Well #	Location ID	Phase	Year Month	Purge Volume Abbreviation	Purge Volume	Pre / Post Pressure Tank	Study	Sample Date	Sample Time	Field Parameter Time	Sample Type	Sample ID		ug/L	ug/L	ug/L	‰ VPDB	‰ VSMOW	‰ VSMOW	‰ VPDB	‰ VPDB	‰ VSMOW
W6	Marc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	5:27:00 PM	5:23:00 PM	Dup	Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM		6100	1.6							
W6	Marc	1	2014-02	P5	3 casing volumes	Post	Purge	2/18/2014	9:15:00 PM	9:11:00 PM	N	Marc_1_E1_P5_SV_Post_N_2/18/2014_9:15:00 PM		6100	1.7		-16.3	-8.96	-61.4	-45.76		-215.8
W6	Marc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	5:27:00 PM	5:23:00 PM	Dup	Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM		6100	1.6							
W6	Marc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	1:00:00 PM	12:56:07 PM	N-Dup	Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM		5500	1.6		-16.5	-9.13	-61.9	-45.49		-212.5
W6	Marc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	1:00:00 PM	12:56:07 PM	Dup	Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM		5300	1.5		-16.6	-9.07	-60.5	-45.49		-212.7
W6	Marc	1	2014-02	P5	3 casing volumes	Post	Purge	2/21/2014	4:54:00 PM	4:41:07 PM	N	Marc_1_E2_P5_SV_Post_N_2/21/2014_4:54:00 PM		5900	1.5		-16.5	-9.25	-61	-45.38		-217.4
W6	Marc	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	12:35:00 PM	12:31:41 PM	N-Dup	Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM		5400	1.6		-16.6	-9.1	-60.4	-45.17		-212.8
W6	Marc	1	2014-02	P5	3 casing volumes	Post	Purge	2/24/2014	4:12:00 PM	4:01:41 PM	N	Marc_1_E3_P5_SV_Post_N_2/24/2014_4:12:00 PM		4900	1.5		-16.5	-9.05	-60.7	-44.94		-214.4
W6	Marc	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/22/2014	9:55:00 AM	9:55:00 AM	N	Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM		5400	1.7	<0.3				-45.44		-215
W6	Marc	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/22/2014	2:08:00 PM	2:08:01 PM	N	Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM		5300	1.5	<0.3						
W5	Rath	1	2014-02	P2	Purge to parameter stability	Post	Both	2/20/2014	11:03:00 AM	10:57:51 AM	N-Dup	Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM		91000	52		-10.7	-9.81	-65.4	-47.68		-216.4
W5	Rath	1	2014-02	P2	Purge to parameter stability	Post	Both	2/20/2014	11:03:00 AM	10:57:51 AM	Dup	Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM		69000	43							
W5	Rath	1	2014-02	P5	3 casing volumes	Post	Purge	2/20/2014	3:18:00 PM	3:17:51 PM	N	Rath_1_E1_P5_SV_Post_N_2/20/2014_3:18:00 PM		63000	39		-11.7	-9.7	-65.6	-47.47		-214.1
W5	Rath	1	2014-02	P2	Purge to parameter stability	Post	Both	2/23/2014	9:10:00 AM	8:59:13 AM	N-Dup	Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM		67000	42		-10.6	-9.78	-65.4	-47.27		-216.9
W5	Rath	1	2014-02	P2	Purge to parameter stability	Post	Both	2/23/2014	9:10:00 AM	8:59:13 AM	Dup	Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM		68000	44		-10.6	-9.88	-64.7	-47.41		-212.9
W5	Rath	1	2014-02	P5	3 casing volumes	Post	Purge	2/23/2014	2:00:00 PM	1:50:13 PM	N	Rath_1_E2_P5_SV_Post_N_2/23/2014_2:00:00 PM		50000	33		-12.1	-9.73	-64.7	-47.22		-211.4
W5	Rath	1	2014-02	P2	Purge to parameter stability	Post	Both	2/25/2014	9:45:00 AM	9:35:36 AM	N-Dup	Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM		74000	46		-10.6	-9.76	-66.1	-47.37	-35.7	-216.6
W5	Rath	1	2014-02	P2	Purge to parameter stability	Post	Both	2/25/2014	9:45:00 AM	9:35:36 AM	Dup	Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM		71000	44							
W5	Rath	1	2014-02	P5	3 casing volumes	Post	Purge	2/25/2014	2:35:00 PM	2:28:36 PM	N	Rath_1_E3_P5_SV_Post_N_2/25/2014_2:35:00 PM		49000	33		-12.2	-9.78	-66.3	-47.45		-212.9
W5	Rath	2	2015-05	P1	One-half gallon	Post	Purge	5/1/2015	9:37:00 AM	9:46:56 AM	N	Rath_2_E1_P1_Both_Post_N_5/1/2015_9:37:00 AM		43000	25	<0.3						
W5	Rath	2	2015-05	P2	2 pressure tank volumes	Post	Both	5/1/2015	10:05:00 AM	10:00:56 AM	N	Rath_2_E1_P2_Both_Post_N_5/1/2015_10:05:00 AM		91000	53	<0.3	-10.1	-9.69	-65	-47.56	-35.7	-216.7
W5	Rath	2	2015-05	P4	1 casing volume	Post	Purge	5/1/2015	11:26:00 AM	11:24:56 AM	N	Rath_2_E1_P4_Both_Post_N_5/1/2015_11:26:00 AM		57000	34	<0.2						
W5	Rath	2	2015-05	P5	3 casing volumes	Post	Purge	5/1/2015	2:25:00 PM	2:14:56 PM	N	Rath_2_E1_P5_Both_Post_N_5/1/2015_2:25:00 PM		52000	31	<0.2	-11.9	-9.6	-65.3	-47.45	-35.7	-214.4
W5	Rath	2	2015-07	P1	One-half gallon	Post	Purge	7/16/2015	2:55:00 PM	3:21:26 PM	N	Rath_2_E2_P1_Both_Post_N_7/16/2015_2:55:00 PM		40000	23	<0.3						
W5	Rath	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/16/2015	3:35:00 PM	3:32:26 PM	N-Dup	Rath_2_E2_P2_Both_Post_N-Dup_7/16/2015_3:35:00 PM		79000	47	<0.3	-10	-9.73	-63.2	-47.55	-35.9	-216
W5	Rath	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/16/2015	3:35:00 PM	3:32:26 PM	Dup	Rath_2_E2_P2_Both_Post_Dup_7/16/2015_3:35:00 PM		73000	44	<0.3	-9.9	-9.92	-63.8	-47.51	-35.8	-214.3
W5	Rath	2	2015-07	P4	1 casing volume	Post	Purge	7/16/2015	5:08:00 PM	5:04:26 PM	N	Rath_2_E2_P4_Both_Post_N_7/16/2015_5:08:00 PM		55000	33	<0.3						
W5	Rath	2	2015-07	P5	3 casing volumes	Post	Purge	7/16/2015	8:05:00 PM	8:01:26 PM	N	Rath_2_E2_P5_Both_Post_N_7/16/2015_8:05:00 PM		61000	39	<0.2	-11.6	-9.8	-63.7	-47.2	-35.8	-216.4
W5	Rath	2	2015-09	P1	One-half gallon	Post	Purge	9/24/2015	10:03:00 AM	10:07:52 AM	N	Rath_2_E3_P1_Both_Post_N_9/24/2015_10:03:00 AM		56000	33	<0.2						
W5	Rath	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/24/2015	10:30:00 AM	10:18:52 AM	N	Rath_2_E3_P2_Both_Post_N_9/24/2015_10:30:00 AM		72000	44	<0.3	-10.8	-9.51	-63	-47.06	-36.1	-213.3
W5	Rath	2	2015-09	P4	1 casing volume	Post	Purge	9/24/2015	11:54:00 AM	11:51:52 AM	N	Rath_2_E3_P4_Both_Post_N_9/24/2015_11:54:00 AM		57000	35	<0.2						
W5	Rath	2	2015-09	P5	3 casing volumes	Post	Purge	9/24/2015	2:50:00 PM	2:35:52 PM	N	Rath_2_E3_P5_Both_Post_N_9/24/2015_2:50:00 PM		54000	31	<0.3	-11.8	-9.75	-63.1	-47		-213
W5	Rath	2	2015-12	P1	One-half gallon	Post	Purge	12/3/2015	9:45:00 AM	9:55:26 AM	N	Rath_2_E4_P1_Both_Post_N_12/3/2015_9:45:00 AM		39000	22	<0.3						
W5	Rath	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/3/2015	10:10:00 AM	10:03:26 AM	N	Rath_2_E4_P2_Both_Post_N_12/3/2015_10:10:00 AM		69000	43	<0.2	-11.2	-9.71	-64.3	-47.23	-35.2	-213.5
W5	Rath	2	2015-12	P4	1 casing volume	Post	Purge	12/3/2015	11:42:00 AM	11:39:26 AM	N	Rath_2_E4_P4_Both_Post_N_12/3/2015_11:42:00 AM		57000	35	<0.2						
W5	Rath	2	2015-12	P5	3 casing volumes	Post	Purge	12/3/2015	2:43:00 PM	2:35:26 PM	N	Rath_2_E4_P5_Both_Post_N_12/3/2015_2:43:00 PM		51000	31	<0.2	-12.6	-9.72	-63.8	-47.07	-35.3	-212.7
W9	Sbar	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	10:58:00 AM	11:00:00 AM	N-Dup	Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM		5600	2.1		-16.7	-9.72	-65.1	-41.72		-199.4
W9	Sbar	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	10:58:00 AM	11:00:00 AM	Dup	Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM		6000	2.1							
W9	Sbar	1	2014-02	P5	3 casing volumes	Post	Purge	2/18/2014	2:52:00 PM	2:49:00 PM	N	Sbar_1_E1_P5_SV_Post_N_2/18/2014_2:52:00 PM		5800	1.7		-16.8	-9.71	-65.1	-42.92		-199.6
W9	Sbar	1	2014-02	P2	Purge to parameter stability	Post	Both	2/23/2014	2:24:00 PM	2:20:05 PM	N-Dup	Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM		3500	1.4		-17.2	-9.67	-64.5	-40.76		-193.7
W9	Sbar	1	2014-02	P2	Purge to parameter stability	Post	Both	2/23/2014	2:24:00 PM	2:20:05 PM	Dup	Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM		3700	1.5							
W9	Sbar	1	2014-02	P5	3 casing volumes	Post	Purge	2/23/2014	6:03:00 PM	5:48:05 PM	N	Sbar_1_E2_P5_SV_Post_N_2/23/2014_6:03:00 PM		4400	1.5		-17.1	-9.78	-64.7	-42.22		-196.9
W9	Sbar	1	2014-02	P2	Purge to parameter stability	Post	Both	2/26/2014	2:30:00 PM	2:27:09 PM	N-Dup	Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM		3000	1.2		-17.1	-9.68	-64.6	-40.5		-194.1
W9	Sbar	1	2014-02	P2	Purge to parameter stability	Post	Both	2/26/2014	2:30:00 PM	2:27:09 PM	Dup	Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM		3700	1.5		-17.1	-9.63	-64.9	-40.79		-190.9
W9	Sbar	1	2014-02	P5	3 casing volumes	Post	Purge	2/26/2014	5:55:00 PM	5:51:09 PM	N	Sbar_1_E3_P5_SV_Post_N_2/26/2014_5:55:00 PM		3400	1.1		-17.1	-9.78	-65	-42.26		-197.5
W9	Sbar	1	2014-03	P2	Purge to parameter stability	Post	Temp	3/25/2014	3:15:00 PM	3:15:05 PM	N	Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM		7600	2.7	<0.4				-40.98		-198.9
W9	Sbar	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/22/2014	4:30:00 PM	4:29:03 PM	N	Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM		8900	2.7	<0.3				-43.12		-199.7
W9	Sbar	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/22/2014	12:52:00 PM	12:52:00 PM	N	Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM		7900	2.4	<0.3						
W9	Sbar	2	2015-05	P1	One-half gallon	Post	Purge	5/19/2015	9:40:00 AM	9:54:27 AM	N	Sbar_2_E1_P1_Both_Post_N_5/19/2015_9:40:00 AM		4500	1.1	<0.3						
W9	Sbar	2	2015-05	P2	2 pressure tank volumes	Post	Both	5/19/2015	10:22:00 AM	10:19:27 AM	N	Sbar_2_E1_P2_Both_Post_N_5/19/2015_10:22:00 AM		5700	1.8	<0.3	-16.7	-9.7	-65.1	-42.24		-199.1
W9	Sbar	2	2015-05	P4	1 casing volume	Post	Purge	5/19/2015	11:18:00 AM	11:12:27 AM	N	Sbar_2_E1_P4_Both_Post_N_5/19/2015_11:18:00 AM		5300	1.5	<0.3						
W9	Sbar	2	2015-05	P5	3 casing volumes	Post	Purge	5/19/2015	1:43:00 PM	1:33:27 PM	N	Sbar_2_E1_P5_Both_Post_N_5/19/2015_1:43:00 PM		4800	1.4	<0.3	-16.7	-9.73	-65.2	-42.97		-199.4
W9	Sbar	2	2015-07	P1	One-half gallon	Post	Purge	7/23/2015	2:25:00 PM	2:34:12 PM	N	Sbar_2_E2_P1_Both_Post_N_7/23/2015_2:25:00 PM		5200	<0.2	<0.2						
W9	Sbar	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/23/2015	3:06:00 PM	3:03:12 PM	N	Sbar_2_E2_P2_Both_Post_N_7/23/2015_3:06:00 PM		8700	2.5	<0.2	-16.1	-9.92	-64.8	-42.72		-198.5
W9	Sbar	2	2015-07	P4	1 casing volume	Post	Purge	7/23/2015	4:02:00 PM	3:59:12 PM	N	Sbar_2_E2_P4_Both_Post_N_7/23/2015_4:02:00 PM		5900	1.7	<0.3						
W9	Sbar	2	2015-07	P5	3 casing volumes	Post	Purge	7/23/2015	6:25:00 PM	6:18:12 PM	N	Sbar_2_E2_P5_Both_Post_N_7/23/2015_6:25:00 PM		5600	1.7	<0.3	-16.7	-9.75	-64	-42.98		-201.7
W9	Sbar	2	2015-10	P1	One-half gallon	Post	Purge	10/5/2015	9:59:00 AM	10:06:22 AM	N	Sbar_2_E3_P1_Both_Post_N_10/5/2015_9:59:00 AM		1800	0.37	<0.3						
W9	Sbar	2	2015-10	P2	2 pressure tank volumes	Post	Both	10/5/2015	10:43:00 AM	10:30:22 AM	N	Sbar_2_E3_P2_Both_Post_N_10/5/2015_10:43:00 AM		2800	1.2	<0.2	-17.2	-9.55	-63.4	-40.45		-190.4
W9	Sbar	2	2015-10	P4	1 casing volume	Post	Purge	10/5/2015	11:38:00 AM	11:35:22 AM	N	Sbar_2_E3_P4_Both_Post_N_10/5/2015_11:38:00 AM		3000	1.1	<0.3						
W9	Sbar	2	2015-10	P5	3 casing volumes	Post	Purge	10/5/2015	2:26:00 PM	2:03:22 PM	N	Sbar_2_E3_P5_Both_Post_N_10/5/2015_2:26:00 PM		4100	1.5	<0.3	-16.9	-9.67	-64.3	-42.36		-199.6
W9	Sbar	2	2015-12	P1	One-half gallon	Post	Purge	12/8/2015	10:38:00 AM	10:45:14 AM	N	Sbar_2_E4_P1_Both_Post_N_12/8/2015_10:38:00 AM		8700	2.6	<0.3						
W9	Sbar	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/8/2015	11:18:00 AM	11:10:14 AM	N	Sbar_2_E4_P2_Both_Post_N_12/8/2015_11:18:00 AM		9000	2.7	<0.3	-16	-9.83	-63.8	-42.77		-202.2
W9	Sbar	2	2015-12	P4	1 casing volume	Post	Purge	12/8/2015	12:25:00 PM	12:21:14 PM	N	Sbar_2_E4_P4_Both_Post_N_12/8/2015_12:25:00 PM		6600	2	<0.3						
W9	Sbar	2	2015-12	P5	3 casing volumes	Post	Purge	12/8/2015	2:57:00 PM	2:47:14 PM	N	Sbar_2_E4_P5_Both_Post_N_12/8/2015_2:57:00 PM		5200	1.7	<0.3	-16.7	-9.67	-63.5	-42.87		-200.5
W8	Sdel	1	2014-02	P2	Purge to parameter stability	Post	Both	2/20/2014	10:32:00 AM	10:31:23 AM	N-Dup	Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM		17000	5.1		-16.7	-9.6	-65.3	-40.82		-214
W8	Sdel	1	2014-02	P2	Purge to parameter stability	Post	Both	2/20/2014	10:32:00 AM	10:31:23 AM	Dup	Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM		17000	5.2							
W8	Sdel	1	2014-02	P5	3 casing volumes	Post	Purge	2/20/2014	2:24:00 PM	2:10:23 PM	N	Sdel_1_E1_P5_SV_Post_N_2/20/2014_2:24:00 PM		17000	5.2		-16.7	-9.63	-63.8	-40.69		-211.5
W8	Sdel	1	2014-02	P2	Purge to parameter stability	Post	Both	2/23/2014	9:28:00 AM	9:24:53 AM	N-Dup	Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM		18000	5.2		-16.7	-9.57	-63.4	-40.64		-206.4
W8	Sdel	1	2014-02	P2	Purge to parameter stability	Post	Both	2/23/2014	9:28:00 AM	9:24:53 AM	Dup	Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM		17000	5.3							

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

													Analyte Group:	Dissolved Light Hydrocarbon Gases (IsoFlask)			Isotopes					
													Analyte:	Methane	Ethane	Propane	$\delta^{13}C$ DIC	$\delta^{18}O$ H_2O	δD H_2O	$\delta^{13}C$ CH_4	$\delta^{13}C$ C_2H_6	δD CH_4
													Laboratory:	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech
Well #	Location ID	Phase	Year Month	Purge Volume Abbreviation	Purge Volume	Pre / Post Pressure Tank	Study	Sample Date	Sample Time	Field Parameter Time	Sample Type	Sample ID		ug/L	ug/L	ug/L	‰ VPDB	‰ VSMOW	‰ VSMOW	‰ VPDB	‰ VPDB	‰ VSMOW
W8	Sdel	1	2014-02	P5	3 casing volumes	Post	Purge	2/23/2014	1:12:00 PM	1:07:53 PM	N	Sdel_1_E2_P5_SV_Post_N_2/23/2014_1:12:00 PM		18000	5.6		-16.7	-9.57	-63.6	-40.68		-208.3
W8	Sdel	1	2014-02	P2	Purge to parameter stability	Post	Both	2/26/2014	9:35:00 AM	9:31:18 AM	N-Dup	Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM		16000	5.1		-16.6	-9.49	-64.1	-40.55		-212.6
W8	Sdel	1	2014-02	P2	Purge to parameter stability	Post	Both	2/26/2014	9:35:00 AM	9:31:18 AM	Dup	Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM		17000	5		-16.6	-9.61	-63.8	-40.63		-212.4
W8	Sdel	1	2014-02	P5	3 casing volumes	Post	Purge	2/26/2014	1:12:00 PM	1:07:18 PM	N	Sdel_1_E3_P5_SV_Post_N_2/26/2014_1:12:00 PM		17000	5.2		-16.6	-9.57	-63.6	-40.55		-209.1
W8	Sdel	2	2015-04	P1	One-half gallon	Post	Purge	4/29/2015	9:55:00 AM	10:06:04 AM	N	Sdel_2_E1_P1_Both_Post_N_4/29/2015_9:55:00 AM		17000	4.8	<0.2						
W8	Sdel	2	2015-04	P2	2 pressure tank volumes	Post	Both	4/29/2015	10:25:00 AM	10:21:04 AM	N	Sdel_2_E1_P2_Both_Post_N_4/29/2015_10:25:00 AM		17000	4.5	<0.3	-16.6	-9.6	-63.6	-40.6		-207.7
W8	Sdel	2	2015-04	P4	1 casing volume	Post	Purge	4/29/2015	11:46:00 AM	11:39:04 AM	N	Sdel_2_E1_P4_Both_Post_N_4/29/2015_11:46:00 AM		17000	4.7	<0.3						
W8	Sdel	2	2015-04	P5	3 casing volumes	Post	Purge	4/29/2015	2:25:00 PM	2:19:04 PM	N	Sdel_2_E1_P5_Both_Post_N_4/29/2015_2:25:00 PM		18000	5	<0.3	-16.6	-9.54	-63.8	-40.67		-207.7
W8	Sdel	2	2015-07	P1	One-half gallon	Post	Purge	7/20/2015	12:02:00 PM	12:19:05 PM	N	Sdel_2_E2_P1_Both_Post_N_7/20/2015_12:02:00 PM		17000	4.6	<0.3						
W8	Sdel	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/20/2015	12:35:00 PM	12:33:05 PM	N	Sdel_2_E2_P2_Both_Post_N_7/20/2015_12:35:00 PM		16000	4.6	<0.3	-16.7	-9.57	-62.1	-40.56		-204.7
W8	Sdel	2	2015-07	P4	1 casing volume	Post	Purge	7/20/2015	1:52:00 PM	1:48:05 PM	N	Sdel_2_E2_P4_Both_Post_N_7/20/2015_1:52:00 PM		17000	4.5	<0.2						
W8	Sdel	2	2015-07	P5	3 casing volumes	Post	Purge	7/20/2015	4:35:00 PM	4:29:05 PM	N	Sdel_2_E2_P5_Both_Post_N_7/20/2015_4:35:00 PM		16000	4.5	<0.3	-16.6	-9.6	-62	-40.48		-211.6
W8	Sdel	2	2015-09	P1	One-half gallon	Post	Purge	9/22/2015	11:43:00 AM	11:52:12 AM	N	Sdel_2_E3_P1_Both_Post_N_9/22/2015_11:43:00 AM		18000	5	<0.3						
W8	Sdel	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/22/2015	12:19:00 PM	12:04:12 PM	N	Sdel_2_E3_P2_Both_Post_N_9/22/2015_12:19:00 PM		18000	5.1	<0.3	-16.6	-9.57	-61.9	-40.47		-208.9
W8	Sdel	2	2015-09	P4	1 casing volume	Post	Purge	9/22/2015	1:35:00 PM	1:30:12 PM	N	Sdel_2_E3_P4_Both_Post_N_9/22/2015_1:35:00 PM		18000	5.1	<0.3						
W8	Sdel	2	2015-09	P5	3 casing volumes	Post	Purge	9/22/2015	4:15:00 PM	4:01:12 PM	N	Sdel_2_E3_P5_Both_Post_N_9/22/2015_4:15:00 PM		18000	5.1	<0.3	-16.6	-9.38	-61.7	-40.26		-209.2
W8	Sdel	2	2015-12	P1	One-half gallon	Post	Purge	12/14/2015	9:53:00 AM	9:58:42 AM	N	Sdel_2_E4_P1_Both_Post_N_12/14/2015_9:53:00 AM		19000	5.2	<0.3						
W8	Sdel	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/14/2015	10:17:00 AM	10:09:42 AM	N	Sdel_2_E4_P2_Both_Post_N_12/14/2015_10:17:00 AM		19000	5.2	<0.3	-16.6	-9.48	-62.1	-40.64		-210
W8	Sdel	2	2015-12	P4	1 casing volume	Post	Purge	12/14/2015	11:37:00 AM	11:33:42 AM	N	Sdel_2_E4_P4_Both_Post_N_12/14/2015_11:37:00 AM		18000	5.1	<0.3						
W8	Sdel	2	2015-12	P5	3 casing volumes	Post	Purge	12/14/2015	2:03:00 PM	1:58:42 PM	N	Sdel_2_E4_P5_Both_Post_N_12/14/2015_2:03:00 PM		18000	5.1	<0.3	-16.5	-9.48	-62.7	-40.78		-209.5
W7	Sieb	1	2014-02	P2	Purge to parameter stability	Post	Both	2/19/2014	11:50:00 AM	11:49:58 AM	N-Dup	Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM		46000	15		-13.1	-9.38	-62.5	-43.94		-225.7
W7	Sieb	1	2014-02	P2	Purge to parameter stability	Post	Both	2/19/2014	11:50:00 AM	11:49:58 AM	Dup	Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM		49000	15							
W7	Sieb	1	2014-02	P5	3 casing volumes	Post	Purge	2/19/2014	5:32:00 PM	5:30:58 PM	N	Sieb_1_E1_P5_SV_Post_N_2/19/2014_5:32:00 PM		38000	14		-12.5	-9.31	-62.8	-43.95		-227.5
W7	Sieb	1	2014-02	P2	Purge to parameter stability	Post	Both	2/22/2014	9:48:00 AM	9:34:05 AM	N-Dup	Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM		22000	8.4		-13.2	-9.4	-62.7	-43.44		-225.2
W7	Sieb	1	2014-02	P2	Purge to parameter stability	Post	Both	2/22/2014	9:48:00 AM	9:34:05 AM	Dup	Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM		30000	11		-13.2	-9.53	-62.6	-43.55		-227.5
W7	Sieb	1	2014-02	P5	3 casing volumes	Post	Purge	2/22/2014	3:04:00 PM	2:50:05 PM	N	Sieb_1_E2_P5_SV_Post_N_2/22/2014_3:04:00 PM		38000	14		-12.8	-9.43	-62.6	-43.58		-227.3
W7	Sieb	1	2014-02	P2	Purge to parameter stability	Post	Both	2/25/2014	9:31:00 AM	9:27:10 AM	N-Dup	Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM		30000	10		-13.3	-9.7	-65	-43.8		-227.4
W7	Sieb	1	2014-02	P2	Purge to parameter stability	Post	Both	2/25/2014	9:31:00 AM	9:27:10 AM	Dup	Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM		36000	12							
W7	Sieb	1	2014-02	P5	3 casing volumes	Post	Purge	2/25/2014	2:23:00 PM	2:17:10 PM	N	Sieb_1_E3_P5_SV_Post_N_2/25/2014_2:23:00 PM		55000	18		-12.3	-9.69	-64.2	-44.08		-228.5
W7	Sieb	2	2015-05	P1	One-half gallon	Post	Purge	5/11/2015	1:45:00 PM	1:57:00 PM	N	Sieb_2_E1_P1_Both_Post_N_5/11/2015_1:45:00 PM		31000	9.9	<0.3						
W7	Sieb	2	2015-05	P2	2 pressure tank volumes	Post	Both	5/11/2015	2:09:00 PM	2:09:00 PM	N	Sieb_2_E1_P2_Both_Post_N_5/11/2015_2:09:00 PM		31000	10	<0.2	-13	-9.5	-63.6	-43.82		-224.9
W7	Sieb	2	2015-05	P4	1 casing volume	Post	Purge	5/11/2015	3:46:00 PM	3:46:00 PM	N	Sieb_2_E1_P4_Both_Post_N_5/11/2015_3:46:00 PM		43000	14	<0.3						
W7	Sieb	2	2015-05	P5	3 casing volumes	Post	Purge	5/11/2015	7:00:00 PM	7:00:00 PM	N	Sieb_2_E1_P5_Both_Post_N_5/11/2015_7:00:00 PM		73000	25	<0.3	-8	-9.55	-64.6	-44		-229.2
W7	Sieb	2	2015-07	P1	One-half gallon	Post	Purge	7/22/2015	10:29:00 AM	10:34:43 AM	N	Sieb_2_E2_P1_Both_Post_N_7/22/2015_10:29:00 AM		32000	9.9	<0.3						
W7	Sieb	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/22/2015	10:48:00 AM	10:45:43 AM	N	Sieb_2_E2_P2_Both_Post_N_7/22/2015_10:48:00 AM		32000	9.8	<0.3	-13.1	-9.42	-61.4	-43.89		-226
W7	Sieb	2	2015-07	P4	1 casing volume	Post	Purge	7/22/2015	12:30:00 PM	12:24:43 PM	N	Sieb_2_E2_P4_Both_Post_N_7/22/2015_12:30:00 PM		40000	12	<0.2						
W7	Sieb	2	2015-07	P5	3 casing volumes	Post	Purge	7/22/2015	3:45:00 PM	3:40:43 PM	N	Sieb_2_E2_P5_Both_Post_N_7/22/2015_3:45:00 PM		65000	21	<0.2	-9.2	-9.43	-61.5	-43.98		-228.2
W7	Sieb	2	2015-09	P1	One-half gallon	Post	Purge	9/29/2015	10:38:00 AM	10:48:13 AM	N	Sieb_2_E3_P1_Both_Post_N_9/29/2015_10:38:00 AM		35000	10	<0.3						
W7	Sieb	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/29/2015	11:12:00 AM	10:58:13 AM	N	Sieb_2_E3_P2_Both_Post_N_9/29/2015_11:12:00 AM		35000	11	<0.3	-12.7	-9.45	-62	-43.49		-224.3
W7	Sieb	2	2015-09	P4	1 casing volume	Post	Purge	9/29/2015	12:46:00 PM	12:42:13 PM	N	Sieb_2_E3_P4_Both_Post_N_9/29/2015_12:46:00 PM		51000	16	<0.2						
W7	Sieb	2	2015-09	P5	3 casing volumes	Post	Purge	9/29/2015	4:20:00 PM	4:04:13 PM	N	Sieb_2_E3_P5_Both_Post_N_9/29/2015_4:20:00 PM		70000	22	<0.3	-8.5	-9.52	-61.9	-43.47		-227.4
W7	Sieb	2	2015-12	P1	One-half gallon	Post	Purge	12/2/2015	10:35:00 AM	10:40:02 AM	N	Sieb_2_E4_P1_Both_Post_N_12/2/2015_10:35:00 AM		43000	13	<0.2						
W7	Sieb	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/2/2015	11:00:00 AM	10:51:02 AM	N	Sieb_2_E4_P2_Both_Post_N_12/2/2015_11:00:00 AM		48000	14	<0.2	-11.3	-9.44	-60.9	-43.63		-225.6
W7	Sieb	2	2015-12	P4	1 casing volume	Post	Purge	12/2/2015	12:54:00 PM	12:49:02 PM	N	Sieb_2_E4_P4_Both_Post_N_12/2/2015_12:54:00 PM		61000	19	<0.2						
W7	Sieb	2	2015-12	P5	3 casing volumes	Post	Purge	12/2/2015	4:15:00 PM	4:02:02 PM	N	Sieb_2_E4_P5_Both_Post_N_12/2/2015_4:15:00 PM		82000	27	<0.3	-7.1	-9.61	-62	-43.71		-227.6
W2	Sim	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	2:00:00 PM	1:59:11 PM	N-Dup	Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM		3400	0.63		-17.2	-9.67	-64.9	-46.62		-190.9
W2	Sim	1	2014-02	P2	Purge to parameter stability	Post	Both	2/18/2014	2:00:00 PM	1:59:11 PM	Dup	Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM		3200	0.75							
W2	Sim	1	2014-02	P5	3 casing volumes	Post	Purge	2/18/2014	5:05:00 PM	5:02:11 PM	N	Sim_1_E1_P5_SV_Post_N_2/18/2014_5:05:00 PM		4000	0.67		-17.2	-9.64	-64.5	-47.37		-197.8
W2	Sim	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	2:58:00 PM	2:56:14 PM	N-Dup	Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM		3100	0.76		-17.3	-9.81	-65	-46.37		-191.7
W2	Sim	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	2:58:00 PM	2:56:14 PM	Dup	Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM		3200	0.78							
W2	Sim	1	2014-02	P5	3 casing volumes	Post	Purge	2/21/2014	5:45:00 PM	5:38:14 PM	N	Sim_1_E2_P5_SV_Post_N_2/21/2014_5:45:00 PM		3900	0.75		-17.2	-9.73	-64.9	-47.16		-194.2
W2	Sim	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	2:45:00 PM	2:37:30 PM	N-Dup	Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM		2800	0.71		-17.2	-9.74	-64.9	-46.2		-191.3
W2	Sim	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	2:45:00 PM	2:37:30 PM	Dup	Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM		3200	0.71		-17.2	-9.8	-65.2	-46.6		-192.7
W2	Sim	1	2014-02	P5	3 casing volumes	Post	Purge	2/24/2014	5:30:00 PM	5:22:30 PM	N	Sim_1_E3_P5_SV_Post_N_2/24/2014_5:30:00 PM		3900	0.78		-17.2	-9.68	-64.5	-47.32		-193.3
W2	Sim	2	2015-04	P1	One-half gallon	Post	Purge	4/30/2015	3:40:00 PM	3:45:18 PM	N	Sim_2_E1_P1_Both_Post_N_4/30/2015_3:40:00 PM		2900	0.55	<0.3						
W2	Sim	2	2015-04	P2	2 pressure tank volumes	Post	Both	4/30/2015	4:00:00 PM	3:56:18 PM	N	Sim_2_E1_P2_Both_Post_N_4/30/2015_4:00:00 PM		3100	0.59	<0.3	-17.2	-9.73	-64.6	-46.5		-184.7
W2	Sim	2	2015-04	P4	1 casing volume	Post	Purge	4/30/2015	4:45:00 PM	4:42:18 PM	N	Sim_2_E1_P4_Both_Post_N_4/30/2015_4:45:00 PM		3300	0.51	<0.2						
W2	Sim	2	2015-04	P5	3 casing volumes	Post	Purge	4/30/2015	6:25:00 PM	6:18:18 PM	N	Sim_2_E1_P5_Both_Post_N_4/30/2015_6:25:00 PM		3300	0.56	<0.3	-17.2	-9.71	-64.7	-47.2		-189.3
W2	Sim	2	2015-07	P1	One-half gallon	Post	Purge	7/15/2015	10:46:00 AM	10:54:40 AM	N	Sim_2_E2_P1_Both_Post_N_7/15/2015_10:46:00 AM		2500	0.6	<0.3						
W2	Sim	2	2015-07	P2	2 pressure tank volumes	Post	Both	7/15/2015	11:08:00 AM	11:05:40 AM	N	Sim_2_E2_P2_Both_Post_N_7/15/2015_11:08:00 AM		2600	0.62	<0.3	-17.4	-9.67	-63	-46.24		-185.5
W2	Sim	2	2015-07	P4	1 casing volume	Post	Purge	7/15/2015	11:59:00 AM	11:55:40 AM	N	Sim_2_E2_P4_Both_Post_N_7/15/2015_11:59:00 AM		3100	0.58	<0.3						
W2	Sim	2	2015-07	P5	3 casing volumes	Post	Purge	7/15/2015	1:40:00 PM	1:35:40 PM	N	Sim_2_E2_P5_Both_Post_N_7/15/2015_1:40:00 PM		3300	0.6	<0.3	-17.3	-9.71	-64.3	-47.05		-192.5
W2	Sim	2	2015-09	P1	One-half gallon	Post	Purge	9/28/2015	10:05:00 AM	10:11:40 AM	N	Sim_2_E3_P1_Both_Post_N_9/28/2015_10:05:00 AM		2400	0.59	<0.3						
W2	Sim	2	2015-09	P2	2 pressure tank volumes	Post	Both	9/28/2015	10:33:00 AM	10:21:40 AM	N	Sim_2_E3_P2_Both_Post_N_9/28/2015_10:33:00 AM		2600	0.78	<0.3	-17.3	-9.81	-63.7	-45.82		-185.2
W2	Sim	2	2015-09	P4	1 casing volume	Post	Purge	9/28/2015	11:22:00 AM	11:16:40 AM	N	Sim_2_E3_P4_Both_Post_N_9/28/2015_11:22:00 AM		2800	0.62	<0.3						
W2	Sim	2	2015-09	P5	3 casing volumes	Post	Purge	9/28/2015	1:12:00 PM	12:48:40 PM	N	Sim_2_E3_P5_Both_Post_N_9/28/2015_1:12:00 PM		3300	0.79	<0.3	-17.2	-9.81	-63.6	-46.66		-191.4
W2	Sim	2	2015-12	P1	One-half gallon	Post	Purge	12/7/2015	1:48:00 PM	1:55:28 PM	N	Sim_2_E4_P1_Both_Post_N_12/7/2015_1:48:00 PM		2800	0.72	<0.2						
W2	Sim	2	2015-12	P2	2 pressure tank volumes	Post	Both	12/7/2015	2:13:00 PM	2:05:28 PM	N	Sim_2_E4_P2_Both_Post_N_12/7/2015_2:13:00 PM		2600	0.71	<0.2	-17.3	-9.78	-63.4	-45.8		-190.8
W2	Sim	2	2015-12	P4	1 casing volume	Post	Purge	12/7/2015	3:13:00 PM	3:04:28 PM	N	Sim_2_E4_P4_Both_Post_N_12/7/2015_3:13:00 PM		3000	0.61	<0.3						

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

													Analyte Group:	Dissolved Light Hydrocarbon Gases (IsoFlask)			Isotopes					
													Analyte:	Methane	Ethane	Propane	$\delta^{13}C$ DIC	$\delta^{18}O$ H_2O	δD H_2O	$\delta^{13}C$ CH_4	$\delta^{13}C$ C_2H_6	δD CH_4
													Laboratory:	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech	Isotech
Well #	**Location ID**	**Phase**	**Year Month**	**Purge Volume Abbreviation**	**Purge Volume**	**Pre / Post Pressure Tank**	**Study**	**Sample Date**	**Sample Time**	**Field Parameter Time**	**Sample Type**	**Sample ID**		**ug/L**	**ug/L**	**ug/L**	**‰ VPDB**	**‰ VSMOW**	**‰ VSMOW**	**‰ VPDB**	**‰ VPDB**	**‰ VSMOW**
W2	Sim	2	2015-12	P5	3 casing volumes	Post	Purge	12/7/2015	4:46:00 PM	4:40:28 PM	N	Sim_2_E4_P5_Both_Post_N_12/7/2015_4:46:00 PM		3400	0.73	<0.2	-17.2	-9.67	-62.6	-46.79		-191.2
W10	Wal	1	2013-12	P2	Purge to parameter stability	Post	Temp	12/30/2013	1:05:00 PM	1:00:00 PM	N	Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM		2300	1.1					-49.8		-188
W10	Wal	1	2014-01	P2	Purge to parameter stability	Post	Temp	1/21/2014	2:50:00 PM	2:44:00 PM	N	Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM		2200	0.4		-17.2	-9.54	-64.4	-50.67		-197.1
W10	Wal	1	2014-02	P2	Purge to parameter stability	Post	Temp	2/26/2014	1:20:00 PM	12:56:00 PM	N-Dup	Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM		2200	0.41					-50.45		-191
W10	Wal	1	2014-03	P2	Purge to parameter stability	Post	Temp	3/26/2014	1:13:00 PM	1:29:00 PM	N	Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM		2200	0.47	<0.3				-50.32		-198.1
W10	Wal	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/30/2014	1:10:00 PM	1:10:00 PM	N	Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM		2100	0.41	<0.3				-50.26		-195.7
W10	Wal	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/20/2014	1:00:00 PM	1:00:00 PM	N	Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM		2000	0.42	<0.3						
W4	Web	1	2013-12	P2	Purge to parameter stability	Post	Temp	12/19/2013	2:45:00 PM	2:39:01 PM	N	Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM		12000	2.7					-48.5		-243.4
W4	Web	1	2014-01	P2	Purge to parameter stability	Post	Temp	1/21/2014	8:05:00 PM	8:00:54 PM	N	Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM		13000	2.8		-15.8	-9.58	-64.3	-48.75		-239.9
W4	Web	1	2014-02	P2	Purge to parameter stability	Post	Both	2/17/2014	10:30:00 AM	10:27:01 AM	N-Dup	Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM		13000	2.9		-15.8	-9.58	-63.8	-48.65		-243.6
W4	Web	1	2014-02	P2	Purge to parameter stability	Post	Both	2/17/2014	10:30:00 AM	10:27:01 AM	Dup	Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM		13000	2.8		-15.8	-9.56	-63.9	-48.61		-241.5
W4	Web	1	2014-02	P5	3 casing volumes	Post	Purge	2/17/2014	1:45:00 PM	1:41:01 PM	N	Web_1_E1_P5_SV_Post_N_2/17/2014_1:45:00 PM		12000	2.4		-16	-9.51	-63.5	-48.67		-242.2
W4	Web	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	9:33:00 AM	9:30:53 AM	N-Dup	Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM		13000	2.7		-15.9	-9.61	-64.4	-48.52		-242
W4	Web	1	2014-02	P2	Purge to parameter stability	Post	Both	2/21/2014	9:33:00 AM	9:30:53 AM	Dup	Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM		12000	2.7							
W4	Web	1	2014-02	P5	3 casing volumes	Post	Purge	2/21/2014	12:50:00 PM	12:39:53 PM	N	Web_1_E2_P5_SV_Post_N_2/21/2014_12:50:00 PM		11000	2.4		-16	-9.7	-64.1	-48.66		-243.3
W4	Web	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	9:45:00 AM	9:38:39 AM	N-Dup	Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM		13000	2.8		-15.8	-9.61	-64.2	-48.62		-241
W4	Web	1	2014-02	P2	Purge to parameter stability	Post	Both	2/24/2014	9:45:00 AM	9:38:39 AM	Dup	Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM		13000	2.8							
W4	Web	1	2014-02	P5	3 casing volumes	Post	Purge	2/24/2014	1:00:00 PM	12:48:39 PM	N	Web_1_E3_P5_SV_Post_N_2/24/2014_1:00:00 PM		11000	2.4		-16	-9.67	-63.9	-48.4		-238
W4	Web	1	2014-03	P2	Purge to parameter stability	Post	Temp	3/26/2014	3:57:00 PM	3:57:23 PM	N-Dup	Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM		12000	2.7	<0.3				-48.75		-239
W4	Web	1	2014-04	P2	Purge to parameter stability	Post	Temp	4/23/2014	2:45:00 PM	2:44:00 PM	N	Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM		13000	2.9	<0.3				-48.73		-242.3
W4	Web	1	2014-05	P2	Purge to parameter stability	Post	Temp	5/21/2014	12:56:00 PM	12:56:01 PM	N	Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM		13000	3.1	<0.3						
W4	Web	2	2015-05	P1	One-half gallon	Post	Purge	5/12/2015	1:40:00 PM	1:40:30 PM	N	Web_2_E1_P1_Both_Post_N_5/12/2015_1:40:00 PM		12000	2.3	<0.3						
W4	Web	2	2015-05	P1.5	1 pressure tank volume	Post	Purge	5/12/2015	2:10:00 PM	2:08:30 PM	N	Web_2_E1_P1.5_Both_Post_N_5/12/2015_2:10:00 PM		13000	2.4	<0.3						
W4	Web	2	2015-05	P2/P4	2 pressure tank volumes/ 1 casing volume	Post	Both	5/12/2015	2:40:00 PM	2:39:30 PM	N-Dup	Web_2_E1_P2_Both_Post_N-Dup_5/12/2015_2:40:00 PM		12000	2.2	<0.3	-15.9	-9.62	-63.7	-48.63		-241.5
W4	Web	2	2015-05	P2	2 pressure tank volumes	Post	Both	5/12/2015	2:40:00 PM	2:39:30 PM	Dup	Web_2_E1_P2_Both_Post_Dup_5/12/2015_2:40:00 PM		11000	2.4	<0.2	-15.9	-9.59	-63.8	-48.62		-241.4
W4	Web	2	2015-05	P5	3 casing volumes	Post	Purge	5/12/2015	4:45:00 PM	4:41:30 PM	N	Web_2_E1_P5_Both_Post_N_5/12/2015_4:45:00 PM		11000	2.2	<0.3	-15.9	-9.73	-63.6	-48.66		-240.9
W4	Web	2	2015-07	P1	One-half gallon	Post	Purge	7/23/2015	9:35:00 AM	9:42:15 AM	N	Web_2_E2_P1_Both_Post_N_7/23/2015_9:35:00 AM		12000	2.2	<0.3						
W4	Web	2	2015-07	P1.5	1 pressure tank volume	Post	Purge	7/23/2015	10:08:00 AM	9:42:15 AM	N	Web_2_E2_P1.5_Both_Post_N_7/23/2015_10:08:00 AM		14000	2.6	<0.3						
W4	Web	2	2015-07	P2/P4	2 pressure tank volumes/ 1 casing volume	Post	Both	7/23/2015	10:43:00 AM	10:05:15 AM	N	Web_2_E2_P2_Both_Post_N_7/23/2015_10:43:00 AM		12000	2.2	<0.3	-15.9	-9.72	-62.7	-48.76		-242.5
W4	Web	2	2015-07	P5	3 casing volumes	Post	Purge	7/23/2015	12:48:00 PM	12:43:15 PM	N	Web_2_E2_P5_Both_Post_N_7/23/2015_12:48:00 PM		11000	2.2	<0.3	-16.1	-9.67	-62.3	-48.62		-241
W4	Web	2	2015-09	P1	One-half gallon	Post	Purge	9/30/2015	10:35:00 AM	10:39:17 AM	N	Web_2_E3_P1_Both_Post_N_9/30/2015_10:35:00 AM		12000	2.6	<0.2						
W4	Web	2	2015-09	P1.5	1 pressure tank volume	Post	Purge	9/30/2015	11:08:00 AM	11:03:17 AM	N	Web_2_E3_P1.5_Both_Post_N_9/30/2015_11:08:00 AM		12000	2.7	<0.2						
W4	Web	2	2015-09	P2/P4	2 pressure tank volumes/ 1 casing volume	Post	Both	9/30/2015	11:51:00 AM	11:36:17 AM	N	Web_2_E3_P2_Both_Post_N_9/30/2015_11:51:00 AM		12000	2.7	<0.2	-15.9	-9.59	-62.8	-47.67		-238.3
W4	Web	2	2015-09	P5	3 casing volumes	Post	Purge	9/30/2015	2:15:00 PM	1:56:17 PM	N	Web_2_E3_P5_Both_Post_N_9/30/2015_2:15:00 PM		11000	2.4	<0.2	-16	-9.64	-62.6	-48.22		-237.7
W4	Web	2	2015-12	P1	One-half gallon	Post	Purge	12/10/2015	9:58:00 AM	10:05:00 AM	N	Web_2_E4_P1_Both_Post_N_12/10/2015_9:58:00 AM		12000	2.8	<0.3						
W4	Web	2	2015-12	P1.5	1 pressure tank volume	Post	Purge	12/10/2015	10:31:00 AM	10:27:00 AM	N	Web_2_E4_P1.5_Both_Post_N_12/10/2015_10:31:00 AM		12000	2.7	<0.3						
W4	Web	2	2015-12	P2/P4	2 pressure tank volumes/ 1 casing volume	Post	Both	12/10/2015	11:11:00 AM	11:01:00 AM	N	Web_2_E4_P2_Both_Post_N_12/10/2015_11:11:00 AM		12000	2.6	<0.3	-15.9	-9.61	-61.9	-48.19		-237.7
W4	Web	2	2015-12	P5	3 casing volumes	Post	Purge	12/10/2015	1:33:00 PM	1:23:00 PM	N	Web_2_E4_P5_Both_Post_N_12/10/2015_1:33:00 PM		11000	2.6	<0.3	-16	-9.5	-62.4	-48.37		-237.8

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

Analyte Group:	Water Quality																										
Analyte:	E. Coli	Total Coliforms	Bicarbonate Alkalinity as $CaCO_3$	Total Alkalinity as $CaCO_3$	Bromide	Chloride	Nitrate Nitrogen	Nitrite Nitrogen	Sulfate	Sulfide	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Iron	Lead	Magnesium	Manganese	Potassium	Selenium	Silver	Sodium	Strontium	Aluminum, dissolved	Arsenic, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM	Absence	Presence	25.5	25.5	<0.015	2	0.16	<0.015	27.8	<0.054	<0.0143	<0.00042	0.0283	<0.00023	18.9	<0.0005	<0.0163	<0.000085	1.04	0.0638	1.32	<0.0005	<0.00011	2.1	0.0731	<0.0143	<0.00042
Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM	Absence	Presence	17.4	17.4	0.015	2	0.76	<0.015	27.5	<0.054	<0.0143	<0.00042	0.0291	<0.00023	17	0.0099	<0.0163	<0.000085	0.952	0.0098	1.36	<0.00050	<0.00011	1.84	0.0664		
Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM	Absence	Absence	16.6	16.6	<0.015	2.2	0.52	<0.015	27.5	<0.054	<0.0143	<0.00042	0.0285	<0.00023	16.4	0.0146	<0.0163	<0.000085	0.894	0.0117	1.22	<0.00050	<0.00011	1.77	0.0658		
Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM	Absence	Presence	14.4	14.4	0.016	1.9	1.1	<0.015	28.9	<0.054	<0.0143	<0.00078	0.0298	<0.00023	17.4	<0.00050	<0.0163	<0.000085	0.983	0.0064	1.54	<0.00050	<0.00011	1.97	0.0692		
Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM			12.5	12.5	<0.015	1.8	2	<0.015	21.1	<0.054	<0.0143	<0.00078	0.0285	<0.00023	16	<0.00050	<0.0163	<0.000085	0.903	0.0049	1.18	<0.00050	<0.00011	1.6	0.0612		
Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM			16.5	16.5	<0.015	1.8	1.3	<0.015	22.2	<0.054	<0.0143	<0.00078	0.0313	<0.00023	15.6	<0.00050	<0.0163	<0.000085	0.857	0.072	1.11	<0.00050	<0.00011	1.47	0.0645		
Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM	Absence	Presence	143	143	0.37	58	<0.04	<0.015	<0.3	<0.054	<0.0143	<0.00042	1.92	<0.00023	22.6	<0.0005	0.425	<0.000085	7.42	0.076	1.57	<0.0005	<0.00011	64.2	0.688	<0.0143	<0.00042
Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM	Absence	Absence	141	141	0.4	56.6	<0.040	<0.015	<0.30	<0.054	0.109	<0.00042	2.06	<0.00023	21.5	<0.00050	0.396	<0.000085	7.1	0.0966	1.5	<0.00050	<0.00011	60.8	0.757	<0.0143	<0.00042
Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM	Absence	Absence	143	143	0.3	62.4	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.71	<0.00023	21.9	<0.00050	0.468	<0.000085	7.34	0.0787	1.59	<0.00050	<0.00011	63.6	0.645		
Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM			142	142	0.36	60.3	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.79	<0.00023	22.5	<0.00050	0.415	<0.000085	7.49	0.0792	1.7	<0.00050	<0.00011	64	0.656		
Jon_1_E1_P5_SV_Post_N_2/17/2014_5:33:00 PM			141	141	0.29	57.6	<0.040	<0.015	0.39	<0.054	<0.0143	0.0092	1.82	<0.00023	22.4	<0.00050	0.303	<0.000085	7.33	0.13	1.57	<0.00050	<0.00011	62.1	0.696		
Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM			143	143	0.33	59.7	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	2.01	<0.00023	20.9	<0.00050	0.359	<0.000085	6.92	0.0845	1.38	<0.00050	<0.00011	59.5	0.739		
Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM																											
Jon_1_E2_P5_SV_Post_N_2/21/2014_10:24:00 AM			145	145	0.29	55.8	<0.040	<0.015	0.42	<0.054	0.123	0.0095	1.88	<0.00023	21.1	<0.00050	0.429	<0.000085	6.81	0.136	1.32	<0.00050	<0.00011	56.8	0.717		
Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM			135	135	0.34	39	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	2.14	<0.00023	22.7	<0.00050	0.372	<0.000085	7.47	0.0845	1.65	<0.00050	<0.00011	65.1	0.784		
Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM																											
Jon_1_E3_P5_SV_Post_N_2/24/2014_10:34:00 AM			135	135	0.3	51.9	<0.040	<0.015	0.48	<0.054	<0.0143	0.0078	2.1	<0.00023	22.9	<0.00050	0.213	<0.000085	7.38	0.134	1.58	<0.00050	<0.00011	61.9	0.788		
Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM	Absence	Absence	142	142	0.52	59.2	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	2.11	<0.00023	23.6	<0.00050	0.384	<0.000085	7.77	0.0788	1.74	<0.00050	<0.00011	67.7	0.777	<0.0143	<0.00078
Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM			143	143	0.45	58.2	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	1.97	<0.00023	22.3	<0.00050	0.256	<0.000085	7.46	0.0815	1.55	<0.00050	<0.00011	63.3	0.737		
Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM			140	140	0.5	59.1	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	1.91	<0.00023	22.4	<0.00050	0.346	<0.000085	7.33	0.0824	1.53	<0.00050	<0.00011	63.4	0.71		
Jon_2_E1_P1_Both_Post_N_4/28/2015_10:14:00 AM																											
Jon_2_E1_P2_Both_Post_N_4/28/2015_10:49:00 AM			145	145	0.49	63.7	<0.040	<0.015	0.3	<0.054	<0.0082	<0.00082	2.06	<0.00017	21.8	<0.00050	0.223	<0.000082	7.37	0.0823	1.5	<0.00050	<0.00013	63.7	0.783		
Jon_2_E1_P4_Both_Post_N_4/28/2015_11:22:00 AM																											
Jon_2_E1_P5_Both_Post_N_4/28/2015_1:05:00 PM			139	139	0.39	71	0.68	<0.015	1.4	<0.054	<0.0082	0.0141	2.2	<0.00017	24.3	<0.00050	0.418	<0.000082	7.78	0.395	1.67	<0.00050	<0.00013	61.4	0.771		
Jon_2_E2_P1_Both_Post_N_7/16/2015_9:21:00 AM																											
Jon_2_E2_P2_Both_Post_N_7/16/2015_9:45:00 AM			139	139	0.44	67.7	<0.04	0.054	0.31	<0.054	<0.026	<0.0004	2.03	<0.00023	22.6	<0.0007	0.146	<0.00013	7.6	0.0817	1.58	<0.0005	<0.00011	64.9	0.727		
Jon_2_E2_P4_Both_Post_N_7/16/2015_10:14:00 AM																											
Jon_2_E2_P5_Both_Post_N_7/16/2015_11:12:00 AM			145	145	0.4	64	<0.04	<0.015	0.37	<0.054	<0.026	0.0093	1.85	<0.00023	22.7	<0.0007	0.21	<0.00013	7.4	0.153	1.47	<0.0005	<0.00011	61.6	0.708		
Jon_2_E3_P1_Both_Post_N_9/28/2015_2:49:00 PM																											
Jon_2_E3_P2_Both_Post_N_9/28/2015_3:15:00 PM			137	137	0.51	55.2	<0.04	<0.015	<0.3	<0.054	<0.026	0.001 J	1.95	<0.00023	21.1	<0.0007	0.158	0.00072 J	7.17	0.0899	1.48	<0.0005	<0.00011	60.8	0.721		
Jon_2_E3_P4_Both_Post_N_9/28/2015_3:45:00 PM																											
Jon_2_E3_P5_Both_Post_N_9/28/2015_4:49:00 PM			137	137	0.47	51.6	<0.04	<0.015	0.37	<0.054	0.0901 J	0.0123	1.85	<0.00023	22	<0.0007	0.333	0.00071 J	7.15	0.171	1.38	<0.0005	<0.00011	58.7	0.702		
Jon_2_E4_P1_Both_Post_N_12/7/2015_9:39:00 AM																											
Jon_2_E4_P2_Both_Post_N-Dup_12/7/2015_10:05:00 AM			146	146	0.5	55.4	<0.04	<0.015	<0.3	<0.054	<0.026	0.003	2.03	<0.00023	23.4	<0.0007	0.118	0.00019 J	7.81	0.0912	1.61	<0.0005	<0.00011	66.3	0.763		
Jon_2_E4_P2_Both_Post_Dup_12/7/2015_10:05:00 AM			146	146	0.49	57.3	<0.04	<0.015	<0.3	<0.054	<0.026	0.0031	2.05	<0.00023	23.2	<0.0007	0.134	0.00015 J	7.84	0.0948	1.61	<0.0005	<0.00011	66.2	0.792		
Jon_2_E4_P4_Both_Post_N_12/7/2015_10:54:00 AM																											
Jon_2_E4_P5_Both_Post_N_12/7/2015_11:57:00 AM			148	148	0.47	54.8	<0.04	<0.015	0.33	<0.054	<0.026	0.0103	1.95	<0.00023	24	<0.0007	0.272	0.00041 J	7.9	0.153	1.6	<0.0005	<0.00011	65.2	0.746		
Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM	Absence	Absence	190	190	<0.015	1.7	<0.04	<0.015	1.2	<0.054	<0.0143	0.101	0.624	<0.00023	28.8	<0.0005	5.06	<0.000085	4.86	1.03	2.09	<0.0005	<0.00011	43.8	0.878	<0.0143	0.0999
Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM	Absence	Absence	192	192	0.028	1.8	<0.040	<0.015	0.82	<0.054	<0.0143	0.102	0.585	<0.00023	28.1	<0.00050	5.36	<0.000085	4.8	1.15	2.01	<0.00050	<0.00011	42.3	0.907		
Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM	Absence	Absence	188	188	<0.015	1.8	<0.040	<0.015	2.2	0.19	<0.0143	0.0945	0.645	<0.00023	27.8	<0.00050	5.69	<0.000085	4.68	1.08	2.01	<0.00050	<0.00011	45.3	0.913		
Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM			190	190	<0.015	1.7	<0.040	<0.015	2.2	0.21	<0.0143	0.0936	0.627	<0.00023	28.3	<0.00050	5.47	<0.000085	4.77	1.13	2.08	<0.00050	<0.00011	46.3	0.947		
Loc_1_E1_P5_SV_Post_N_2/19/2014_8:42:00 PM			187	187	<0.015	2.5	<0.040	<0.015	3.8	<0.054	<0.0143	0.0761	0.555	<0.00023	22.9	<0.00050	4.13	<0.000085	3.84	0.829	1.85	<0.00050	<0.00011	56.3	0.75		
Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM			185	185	<0.015	1.9	<0.040	<0.015	2.5	0.2	<0.0143	0.086	0.599	<0.00023	26.1	<0.00050	4.68	<0.000085	4.39	0.952	2.05	<0.00050	<0.00011	47.7	0.934		
Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM																											
Loc_1_E2_P5_SV_Post_N_2/22/2014_6:40:00 PM			182	182	<0.015	2.6	<0.040	<0.015	3.9	0.16	<0.0143	0.0751	0.5	<0.00023	22.2	<0.00050	3.84	<0.000085	3.72	0.745	1.91	<0.00050	<0.00011	55.7	0.7		
Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM			181	181	<0.015	1.8	<0.040	<0.015	1.7	0.17	<0.0143	0.0869	0.634	<0.00023	26.3	<0.00050	4.67	<0.000085	4.43	0.843	1.86	<0.00050	<0.00011	44	0.835		
Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM																											
Loc_1_E3_P5_SV_Post_N_2/26/2014_6:30:00 PM			181	181	<0.015	2.5	<0.040	<0.015	3	<0.054	<0.0143	0.0784	0.598	<0.00023	22.7	<0.00050	3.95	<0.000085	3.82	0.858	1.87	<0.00050	<0.00011	51.5	0.756		
Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM	Absence	Absence	182	182	<0.015	1.1	<0.040	<0.015	3.7	<0.054	<0.0143	0.105	0.597	<0.00023	30	<0.00050	5.75	<0.000085	4.93	0.984	2.18	<0.00050	<0.00011	45	0.834		
Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM			191	191	<0.015	1.8	<0.040	<0.015	1.4	<0.054	<0.0143	0.0909	0.558	<0.00023	27.2	<0.00050	4.68	<0.000085	4.59	1.04	1.95	<0.00050	<0.00011	46.7	0.843		
Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM			185	185	<0.015	1.8	<0.040	<0.015	1.6	<0.054	<0.0143	0.0905	0.597	<0.00023	27.4	<0.00050	4.63	<0.000085	4.54	1.05	1.94	<0.00050	<0.00011	43.4	0.863		
Loc_2_E1_P1_Both_Post_N_5/4/2015_9:55:00 AM																											
Loc_2_E1_P2_Both_Post_N_5/4/2015_10:15:00 AM			189	189	<0.015	2	<0.040	<0.015	1.2	<0.054	<0.0082	0.0946	0.582	<0.00017	27.5	<0.00050	4.94	<0.000082	4.78	1.11	1.85	<0.00050	<0.00013	42.6	0.892		
Loc_2_E1_P4_Both_Post_N_5/4/2015_12:58:00 PM																											
Loc_2_E1_P5_Both_Post_N_5/4/2015_6:40:00 PM			192	192	0.023	2.6	<0.040	<0.015	2.6	<0.054	<0.0082	0.0763	0.572	<0.00017	22.8	<0.00050	3.65	<0.000082	3.98	0.834	1.79	<0.00050	<0.00013	52.9	0.775		
Loc_2_E2_P1_Both_Post_N_7/14/2015_9:29:00 AM																											
Loc_2_E2_P2_Both_Post_N_7/14/2015_10:06:00 AM			185	185	0.043	1.5	<0.04	<0.015	1	<0.054	<0.026	0.0976	0.642	<0.00023	29.7	<0.0007	5.14	<0.00013	5.02	1.12	2.12	<0.0005	<0.00011	46.6	0.936		
Loc_2_E2_P4_Both_Post_N_7/14/2015_12:51:00 PM																											
Loc_2_E2_P5_Both_Post_N_7/14/2015_6:30:00 PM			182	182	0.045	2.1	<0.04	<0.015	2.6	<0.054	<0.026	0.0758	0.63	<0.00023	24.6	<0.0007	3.81	<0.00013	4.2	0.864	1.97	<0.0005	<0.00011	54	0.842		
Loc_2_E3_P1_Both_Post_N_9/23/2015_10:18:00 AM																											
Loc_2_E3_P2_Both_Post_N-Dup_9/23/2015_10:55:00 AM			187	187	0.06	1.1	<0.04	<0.015	0.52	<0.054	<0.026	0.104	0.708	<0.00023	31.2	<0.0007	5.83	0.00023 J	5.33	1.28	2.11	<0.0005	<0.00011	39.8	1.04		
Loc_2_E3_P2_Both_Post_Dup_9/23/2015_10:55:00 AM			193	193	0.062	1.1	<0.04	<0.015	0.51	0.081 J	<0.026	0.102	0.68	<0.00023	30.3	<0.0007	5.68	0.00025 J	5.17	1.25	2.06	<0.0005	<0.00011	38.2	0.99		
Loc_2_E3_P4_Both_Post_N_9/23/2015_1:47:00 PM																											
Loc_2_E3_P5_Both_Post_N_9/23/2015_7:36:00 PM			191	191	0.06	2.1	<0.04	<0.015	2.4	0.11 J	0.0446 J	0.0803	0.599	<0.00023	23.3	<0.0007	3.94	<0.00013	4.06	0.912	1.79	<0.0005	<0.00011	52.6	0.81		
Loc_2_E4_P1_Both_Post_N_12/1/2015_10:55:00 AM																											
Loc_2_E4_P2_Both_Post_N_12/1/2015_11:30:00 AM			197	197	0.044	1.1	<0.04	<0.015	0.52	0.11 J	<0.026	0.103	0.677	<0.00023	31	<0.0007	4.99	0.00016 J	5.32	1.12	2.14	<0.0005	<0.00011	41.5	0.965		
Loc_2_E4_P4_Both_Post_N_12/1/2015_2:13:00 PM																											
Loc_2_E4_P5_Both_Post_N_12/1/2015_7:40:00 PM			195	195	0.048	2	<0.04	<0.015	2.3	0.13 J	<0.026	0.0737	0.589	<0.00023	22.4	<0.0007	3.47	0.00033 J	3.81	0.8	1.86	<0.0005	<0.00011	51	0.763		
Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM			100	100	0.54	106	<0.040	<0.015	2.6	0.53	<0.0143	<0.00078	2.88	<0.00023	25.8	<0.00050	<0.0163	<0.000085	3.12	0.0323	3.44	<0.00050	<0.00011	76.2	2.78		

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

Analyte Group:	Water Quality																										
Analyte:	E. Coli	Total Coliforms	Bicarbonate Alkalinity as $CaCO_3$	Total Alkalinity as $CaCO_3$	Bromide	Chloride	Nitrate Nitrogen	Nitrite Nitrogen	Sulfate	Sulfide	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Iron	Lead	Magnesium	Manganese	Potassium	Selenium	Silver	Sodium	Strontium	Aluminum, dissolved	Arsenic, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																											
Marc_1_E1_P5_SV_Post_N_2/18/2014_9:15:00 PM			100	100	0.55	109	<0.040	<0.015	2.7	0.49	<0.0143	<0.00078	2.86	<0.00023	26.2	<0.00050	<0.0163	<0.000085	3.16	0.0322	3.44	<0.00050	<0.00011	77.2	2.95		
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																											
Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM			100	100	0.49	102	<0.040	<0.015	3	0.55	<0.0143	<0.00042	2.73	<0.00023	24	<0.00050	<0.0163	<0.000085	2.9	0.0278	2.99	<0.00050	<0.00011	69.6	2.69		
Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM			102	102	0.5	103	<0.040	<0.015	3.2	0.55	<0.0143	<0.00042	2.76	<0.00023	25.6	<0.00050	<0.0163	<0.000085	3.1	0.0282	3.33	<0.00050	<0.00011	73.9	2.65		
Marc_1_E2_P5_SV_Post_N_2/21/2014_4:54:00 PM			101	101	0.54	110	<0.040	<0.015	2.7	0.58	<0.0143	<0.00042	2.88	<0.00023	23.6	<0.00050	<0.0163	<0.000085	2.87	0.0298	3.01	<0.00050	<0.00011	71.6	2.78		
Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM			97.2	97.2	0.45	95.4	<0.040	<0.015	2.7	0.55	<0.0143	<0.00078	2.88	<0.00023	25.9	<0.00050	<0.0163	<0.000085	3.08	0.0338	3.29	<0.00050	<0.00011	73	2.76		
Marc_1_E3_P5_SV_Post_N_2/24/2014_4:12:00 PM			97.2	97.2	0.47	96.9	<0.040	<0.015	2.7	0.55	<0.0143	<0.00078	2.92	<0.00023	25.6	<0.00050	<0.0163	<0.000085	3.06	0.0416	3.35	<0.00050	<0.00011	74.6	2.79		
Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM			100	100	0.64	101	<0.040	<0.015	2.6	0.58	<0.0143	<0.00078	2.76	<0.00023	25.9	<0.00050	<0.0163	<0.000085	3.15	0.0305	3.32	<0.00050	<0.00011	72.8	2.73		
Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM			101	101	0.72	103	<0.040	<0.015	3.2	0.55	<0.0143	<0.00078	2.85	<0.00023	25.2	<0.00050	<0.0163	<0.000085	3.01	0.03	3.12	<0.00050	<0.00011	72.3	2.66		
Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM			250	273	0.7	137	<0.040	<0.015	0.46	<0.054	1.23	<0.00042	0.126	<0.00023	2.77	0.005	2.02	0.0019	0.706	0.0202	1.86	<0.00050	<0.00011	202	0.233	<0.0143	<0.00042
Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM																											
Rath_1_E1_P5_SV_Post_N_2/20/2014_3:18:00 PM			215	254	0.4	109	<0.040	<0.015	1.9	0.19	0.221	<0.00042	0.163	<0.00023	6.84	0.0029	0.444	<0.000085	1.2	0.0137	1.65	<0.00050	<0.00011	182	0.318	<0.0143	<0.00042
Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM			234	280	0.72	157	<0.040	<0.015	0.39	0.17	0.29	<0.00078	0.122	<0.00023	2.69	0.0037	0.466	<0.000085	0.484	0.007	1.77	<0.00050	<0.00011	235	0.253	<0.0143	<0.00078
Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM			234	280	0.71	159	<0.040	<0.015	0.41	<0.054	0.153	<0.00078	0.111	<0.00023	2.75	0.0035	0.303	<0.000085	0.479	0.0057	1.84	<0.00050	<0.00011	238	0.238	<0.0143	<0.00078
Rath_1_E2_P5_SV_Post_N_2/23/2014_2:00:00 PM			215	253	0.39	106	<0.040	<0.015	1.8	0.19	0.358	<0.00078	0.167	<0.00023	7.07	0.0031	0.415	0.0013	1.31	0.0149	1.66	<0.00050	<0.00011	173	0.317	<0.0143	<0.00078
Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM			235	267	0.68	141	<0.040	<0.015	0.42	<0.054	0.28	<0.00078	0.118	<0.00023	2.54	0.0037	0.473	<0.000085	0.419	0.007	1.9	<0.00050	<0.00011	218	0.226	<0.0143	<0.00078
Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM																											
Rath_1_E3_P5_SV_Post_N_2/25/2014_2:35:00 PM			222	243	0.4	99.1	<0.040	<0.015	1.5	0.2	0.42	<0.00078	0.174	<0.00023	7.41	0.0031	0.521	<0.000085	1.37	0.0171	1.96	<0.00050	<0.00011	169	0.337	0.111	<0.00078
Rath_2_E1_P1_Both_Post_N_5/1/2015_9:37:00 AM																											
Rath_2_E1_P2_Both_Post_N_5/1/2015_10:05:00 AM			250	279	1.2	189	<0.040	<0.015	0.41	<0.054	1.31	<0.00082	0.134	<0.00017	3.27	0.0069	2.16	0.0029	0.929	0.023	2.26	<0.00050	<0.00013	233	0.269	0.41	<0.00082
Rath_2_E1_P4_Both_Post_N_5/1/2015_11:26:00 AM																											
Rath_2_E1_P5_Both_Post_N_5/1/2015_2:25:00 PM			232	253	0.75	125	<0.040	<0.015	1.6	0.16	0.513	<0.00082	0.176	<0.00017	7.44	0.0039	0.5	<0.000082	1.37	0.0123	1.83	<0.00050	<0.00013	169	0.351	<0.0082	<0.00082
Rath_2_E2_P1_Both_Post_N_7/16/2015_2:55:00 PM																											
Rath_2_E2_P2_Both_Post_N-Dup_7/16/2015_3:35:00 PM			245	264	0.94	167	<0.04	<0.015	0.42	0.17	0.788	<0.0004	0.133	<0.00023	3.76	0.0047	1.72	0.0018	0.886	0.0198	2.06	<0.0005	<0.00011	238	0.27	<0.026	<0.0004
Rath_2_E2_P2_Both_Post_Dup_7/16/2015_3:35:00 PM			248	265	0.95	166	<0.04	<0.015	0.42	0.16	0.827	<0.0004	0.136	<0.00023	3.68	0.0051	1.68	0.0013	0.859	0.0201	2.07	<0.0005	<0.00011	240	0.271	0.124	<0.0004
Rath_2_E2_P4_Both_Post_N_7/16/2015_5:08:00 PM																											
Rath_2_E2_P5_Both_Post_N_7/16/2015_8:05:00 PM			229	238	0.55	120	<0.04	<0.015	1.5	<0.054	0.337	<0.0004	0.2	<0.00023	10.5	0.0033	0.658	<0.00013	1.99	0.0184	1.96	<0.0005	<0.00011	188	0.418	<0.026	<0.0004
Rath_2_E3_P1_Both_Post_N_9/24/2015_10:03:00 AM																											
Rath_2_E3_P2_Both_Post_N_9/24/2015_10:30:00 AM			239	258	0.95	145	<0.04	<0.015	0.47	0.14 J	1.48	0.00093 J	0.135	<0.00023	3.04	0.0043	2.17	0.0014	0.833	0.0234	2.18	<0.0005	<0.00011	219	0.231	0.702	0.0007 J
Rath_2_E3_P4_Both_Post_N_9/24/2015_11:54:00 AM																											
Rath_2_E3_P5_Both_Post_N_9/24/2015_2:50:00 PM			245	251	0.7	117	<0.04	<0.015	1.5		0.685	0.00061 J	0.178	<0.00023	7.32	0.0038	0.592	0.00054 J	1.44	0.0147	1.74	<0.0005	<0.00011	179	0.342	<0.026	0.00056 J
Rath_2_E4_P1_Both_Post_N_12/3/2015_9:45:00 AM																											
Rath_2_E4_P2_Both_Post_N_12/3/2015_10:10:00 AM			264	279	0.79	125	<0.04	<0.015	0.35	0.14 J	0.265	<0.0004	0.125	<0.00023	3.05	0.0024	0.726	0.0011	0.757	0.0116	1.78	<0.0005	<0.00011	209	0.225	<0.026	<0.0004
Rath_2_E4_P4_Both_Post_N_12/3/2015_11:42:00 AM																											
Rath_2_E4_P5_Both_Post_N_12/3/2015_2:43:00 PM			226	246	0.57	102	<0.04	<0.015	1.7	0.22	0.122	0.00059 J	0.196	<0.00023	8.16	0.002 J	0.266	0.00026 J	1.5	0.0139	1.61	<0.0005	<0.00011	177	0.384	<0.026	0.0007 J
Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM	Absence	Absence	114	126	0.07	18.2	<0.040	<0.015	3.3	<0.054	<0.0143	<0.00042	0.536	<0.00023	8.66	<0.00050	0.418	0.0026	1.23	0.101	2.06	<0.00050	<0.00011	54	0.574		
Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM																											
Sbar_1_E1_P5_SV_Post_N_2/18/2014_2:52:00 PM			119	119	0.072	20.4	<0.040	<0.015	5.7	<0.054	<0.0143	<0.00042	0.651	<0.00023	16.4	<0.00050	<0.0163	<0.000085	2.22	0.0571	2.25	<0.00050	<0.00011	42.2	0.905		
Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM			119	123	0.016	9.4	<0.040	<0.015	8.2	<0.054	<0.0143	<0.00078	0.657	<0.00023	18.7	<0.00050	<0.0163	0.0011	2.54	0.0676	2.34	<0.00050	<0.00011	40.9	0.945		
Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM																											
Sbar_1_E2_P5_SV_Post_N_2/23/2014_6:03:00 PM			121	121	0.038	14	<0.040	<0.015	7.6	<0.054	<0.0143	<0.00078	0.668	<0.00023	19.9	<0.00050	<0.0163	<0.000085	2.69	0.0782	2.39	<0.00050	<0.00011	39.9	0.937		
Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM			121	121	0.02	10.3	<0.040	<0.015	7.6	<0.054	<0.0143	<0.00078	0.685	<0.00023	17.8	<0.00050	<0.0163	<0.000085	2.4	0.0517	2.22	<0.00050	<0.00011	39.5	0.859		
Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM			119	119	0.018	8.2	<0.040	<0.015	7.6	<0.054	<0.0143	<0.00078	0.703	<0.00023	17.7	<0.00050	<0.0163	<0.000085	2.38	0.0524	2.14	<0.00050	<0.00011	39	0.963		
Sbar_1_E3_P5_SV_Post_N_2/26/2014_5:55:00 PM			117	117	0.03	14.7	<0.040	<0.015	7.2	<0.054	<0.0143	<0.00078	0.69	<0.00023	20	<0.00050	<0.0163	<0.000085	2.72	0.0574	2.34	<0.00050	<0.00011	39.1	1.1		
Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM	Absence	Absence	120	130	0.15	17.1	<0.040	<0.015	3.8	<0.054	<0.0143	<0.00078	0.438	<0.00023	7.37	<0.00050	<0.0163	<0.000085	1.03	0.017	2.2	<0.00050	<0.00011	61.9	0.484		
Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM			121	121	0.24	35.4	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	0.536	<0.00023	9.94	<0.00050	<0.0163	<0.000085	1.43	0.0341	2.3	<0.00050	<0.00011	62.8	0.655		
Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM			121	121	0.28	34.9	<0.040	<0.015	1.2	<0.054	<0.0143	<0.00078	0.548	<0.00023	9.62	<0.00050	0.102	<0.000085	1.39	0.0379	2.22	<0.00050	<0.00011	62.3	0.662		
Sbar_2_E1_P1_Both_Post_N_5/19/2015_9:40:00 AM																											
Sbar_2_E1_P2_Both_Post_N_5/19/2015_10:22:00 AM			119	123	0.14	21	<0.040	<0.015	3.4	<0.054	<0.0082	<0.00040	0.586	<0.00017	12.6	<0.00050	<0.0131	<0.000082	1.74	0.0291	2.18	<0.00050	<0.00013	50.6	0.784		
Sbar_2_E1_P4_Both_Post_N_5/19/2015_11:18:00 AM																											
Sbar_2_E1_P5_Both_Post_N_5/19/2015_1:43:00 PM			120	120	0.15	20.7	<0.040	<0.015	4.9	<0.054	<0.0082	<0.00040	0.634	<0.00017	17.7	<0.00050	<0.0131	<0.000082	2.41	0.045	2.33	<0.00050	<0.00013	43.2	0.974		
Sbar_2_E2_P1_Both_Post_N_7/23/2015_2:25:00 PM																											
Sbar_2_E2_P2_Both_Post_N_7/23/2015_3:06:00 PM			121	125	0.2	30.9	<0.04	<0.015	<0.3	0.098 J	<0.026	<0.0004	0.486	<0.00023	6.09	<0.0007	<0.023	0.00021 J	0.949	0.0116	2.18	<0.0005	<0.00011	63.7	0.531		
Sbar_2_E2_P4_Both_Post_N_7/23/2015_4:02:00 PM																											
Sbar_2_E2_P5_Both_Post_N_7/23/2015_6:25:00 PM			108	128	0.15	21.8	<0.04	<0.015	5	0.076 J	<0.026	<0.0004	0.594	<0.00023	16.1	<0.0007	0.0287 J	0.0002 J	2.23	0.0386	2.27	<0.0005	<0.00011	44.3	0.905		
Sbar_2_E3_P1_Both_Post_N_10/5/2015_9:59:00 AM																											
Sbar_2_E3_P2_Both_Post_N_10/5/2015_10:43:00 AM			122	122	0.086	6.9	<0.04	<0.015	9	0.13 J	<0.026	<0.0004	0.66	<0.00023	20.7	<0.0007	0.0294 J	0.00021 J	2.78	0.0455	2.32	<0.0005	<0.00011	37.2	1.03		
Sbar_2_E3_P4_Both_Post_N_10/5/2015_11:38:00 AM																											
Sbar_2_E3_P5_Both_Post_N_10/5/2015_2:26:00 PM			118	118	0.15	15.7	<0.04	<0.015	6.6	0.12 J	<0.026	<0.0004	0.68	<0.00023	20.1	<0.0007	0.04 J	0.00017 J	2.75	0.0502	2.48	<0.0005	<0.00011	42.1	1.08		
Sbar_2_E4_P1_Both_Post_N_12/8/2015_10:38:00 AM																											
Sbar_2_E4_P2_Both_Post_N_12/8/2015_11:18:00 AM			129	129	0.27	32	<0.04	<0.015	0.38	0.15 J	<0.026	<0.0004	0.511	<0.00023	8.29	<0.0007	0.0232 J	0.00078 J	1.21	0.0165	2.27	<0.0005	<0.00011	68.7	0.604		
Sbar_2_E4_P4_Both_Post_N_12/8/2015_12:25:00 PM																											
Sbar_2_E4_P5_Both_Post_N_12/8/2015_2:57:00 PM			123	123	0.19	21.4	<0.04	<0.015	4.8	0.13 J	<0.026	<0.0004	0.658	<0.00023	17.5	<0.0007	0.0239 J	0.00021 J	2.46	0.0402	2.39	<0.0005	<0.00011	49.2	0.968		
Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM			133	133	0.82	141	<0.040	<0.015	1	0.34	<0.0143	<0.00042	2.46	<0.00023	29.5	<0.00050	0.882	<0.000085	5.32	0.0367	3.16	<0.00050	<0.00011	96.6	2.54		
Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM																											
Sdel_1_E1_P5_SV_Post_N_2/20/2014_2:24:00 PM			135	135	0.81	134	<0.040	<0.015	1.2	0.34	<0.0143	<0.00042	2.54	<0.00023	28.8	<0.00050	0.272	<0.000085	5.18	0.0354	3.02	<0.00050	<0.00011	95	2.61		
Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM			133	133	0.8	139	<0.040	<0.015	1	0.35	<0.0143	<0.00078	2.44	<0.00023	32.6	<0.00050	0.146	<0.000085	5.86	0.0375	3.49	<0.00050	<0.00011	103	2.6		
Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM																											

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

Analyte Group:	Water Quality																											
Analyte:	E. Coli	Total Coliforms	Bicarbonate Alkalinity as $CaCO_3$	Total Alkalinity as $CaCO_3$	Bromide	Chloride	Nitrate Nitrogen	Nitrite Nitrogen	Sulfate	Sulfide	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Iron	Lead	Magnesium	Manganese	Potassium	Selenium	Silver	Sodium	Strontium	Aluminum, dissolved	Arsenic, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sdel_1_E2_P5_SV_Post_N_2/23/2014_1:12:00 PM			133	133	0.81	143	<0.040	<0.015	1.2	0.32	<0.0143	<0.00078	2.37	<0.00023	31.4	<0.00050	0.197	<0.000085	5.66	0.0354	3.4	<0.00050	<0.00011	93.1	2.5		
Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM			127	127	0.75	120	<0.040	<0.015	1	0.37	<0.0143	<0.00078	2.53	<0.00023	31.7	<0.00050	0.443	<0.000085	5.73	0.0336	3.38	<0.00050	<0.00011	101	2.63		
Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM			130	130	0.76	132	<0.040	<0.015	1	0.38	<0.0143	<0.00078	2.57	<0.00023	31	<0.00050	0.349	<0.000085	5.62	0.0326	3.27	<0.00050	<0.00011	99.8	2.65		
Sdel_1_E3_P5_SV_Post_N_2/26/2014_1:12:00 PM			129	129	0.77	125	<0.040	<0.015	1.2	0.33	<0.0143	<0.00078	2.08	<0.00023	30.9	<0.00050	<0.0163	<0.000085	5.63	0.0339	3.28	<0.00050	<0.00011	100	2.17		
Sdel_2_E1_P1_Both_Post_N_4/29/2015_9:55:00 AM																											
Sdel_2_E1_P2_Both_Post_N_4/29/2015_10:25:00 AM			134	134	1.1	154	<0.040	<0.015	1.3	0.34	<0.0082	<0.00082	2.47	<0.00017	31.5	<0.00050	<0.0131	<0.000082	5.78	0.0332	3.55	<0.00050	<0.00013	101	2.6		
Sdel_2_E1_P4_Both_Post_N_4/29/2015_11:46:00 AM																											
Sdel_2_E1_P5_Both_Post_N_4/29/2015_2:25:00 PM			134	134	1.1	153	<0.040	<0.015	1.4	0.27	<0.0082	<0.00082	2.45	<0.00017	31.4	<0.00050	<0.0131	<0.000082	5.78	0.034	3.49	<0.00050	<0.00013	99.8	2.63		
Sdel_2_E2_P1_Both_Post_N_7/20/2015_12:02:00 PM																											
Sdel_2_E2_P2_Both_Post_N_7/20/2015_12:35:00 PM			128	128	0.88	145	<0.04	<0.015	1.1	0.34	<0.026	<0.0004	2.59	<0.00023	32.2	<0.0007	0.0239 J	<0.00013	5.81	0.0343	3.42	<0.0005	<0.00011	93.8	2.68		
Sdel_2_E2_P4_Both_Post_N_7/20/2015_1:52:00 PM																											
Sdel_2_E2_P5_Both_Post_N_7/20/2015_4:35:00 PM			131	131	0.88	144	<0.04	<0.015	1.2	0.28	<0.026	<0.0004	2.69	<0.00023	32.3	<0.0007	<0.023	0.00021 J	5.79	0.0354	3.45	<0.0005	<0.00011	93.3	2.76		
Sdel_2_E3_P1_Both_Post_N_9/22/2015_11:43:00 AM																											
Sdel_2_E3_P2_Both_Post_N_9/22/2015_12:19:00 PM			128	128	1.1	144	<0.04	<0.015	1.1	0.28	<0.026	<0.0004	2.51	<0.00023	32.8	<0.0007	0.0328 J	<0.00013	6.02	0.0361	3.52	<0.0005	<0.00011	102	2.71		
Sdel_2_E3_P4_Both_Post_N_9/22/2015_1:35:00 PM																											
Sdel_2_E3_P5_Both_Post_N_9/22/2015_4:15:00 PM			136	136	1.1	143	<0.04	<0.015	1.1	0.26	<0.026	<0.0004	2.62	<0.00023	33.3	<0.0007	0.0398 J	<0.00013	6.05	0.0387	3.51	<0.0005	<0.00011	102	2.84		
Sdel_2_E4_P1_Both_Post_N_12/14/2015_9:53:00 AM																											
Sdel_2_E4_P2_Both_Post_N_12/14/2015_10:17:00 AM			149	149	<0.015	155	<0.04	<0.015	1.2	0.31	<0.026	<0.0004	2.8	<0.00023	33.9	<0.0007	0.0264 J	<0.00013	6.24	0.0393	3.68	<0.0005	<0.00011	110	2.92		
Sdel_2_E4_P4_Both_Post_N_12/14/2015_11:37:00 AM																											
Sdel_2_E4_P5_Both_Post_N_12/14/2015_2:03:00 PM			147	147	<0.015	160	<0.04	<0.015	1.2	0.28	<0.026	<0.0004	2.74	<0.00023	34.3	<0.0007	<0.023	<0.00013	6.32	0.038	3.65	<0.0005	<0.00011	109	2.84		
Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM			117	118	1.6	315	<0.040	<0.015	0.99	<0.054	<0.0143	<0.00078	3.21	<0.00023	15.9	<0.00050	0.126	<0.000085	2.75	0.0388	4.59	<0.00050	<0.00011	218	2.89		
Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM																											
Sieb_1_E1_P5_SV_Post_N_2/19/2014_5:32:00 PM			120	124	1.6	356	<0.040	<0.015	0.81	<0.054	<0.0143	<0.00078	3.06	<0.00023	13.9	<0.00050	<0.0163	<0.000085	2.39	0.0327	5.11	<0.00050	<0.00011	255	2.81		
Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM			116	117	1.5	288	<0.040	<0.015	0.89	<0.054	<0.0143	<0.00042	3.19	<0.00023	15.3	<0.00050	<0.0163	<0.000085	2.64	0.0349	4.43	<0.00050	<0.00011	208	2.83		
Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM			116	119	1.5	275	<0.040	<0.015	0.89	<0.054	<0.0143	<0.00042	3	<0.00023	15.2	<0.00050	<0.0163	<0.000085	2.61	0.0335	4.44	<0.00050	<0.00011	210	2.84		
Sieb_1_E2_P5_SV_Post_N_2/22/2014_3:04:00 PM			116	119	1.9	348	<0.040	<0.015	0.88	<0.054	<0.0143	<0.00042	3.09	<0.00023	13.6	<0.00050	0.104	<0.000085	2.33	0.031	4.97	<0.00050	<0.00011	253	2.82		
Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM			112	112	1.4	283	<0.040	<0.015	0.88	<0.054	<0.0143	<0.00078	3.19	<0.00023	15.1	<0.00050	<0.0163	<0.000085	2.55	0.0336	4.5	<0.00050	<0.00011	208	2.8		
Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM																											
Sieb_1_E3_P5_SV_Post_N_2/25/2014_2:23:00 PM			114	114	1.9	383	<0.040	<0.015	0.82	<0.054	<0.0143	<0.00078	3.53	<0.00023	14.7	<0.00050	<0.0163	<0.000085	2.45	0.0312	5.36	<0.00050	<0.00011	259	3.25		
Sieb_2_E1_P1_Both_Post_N_5/11/2015_1:45:00 PM																											
Sieb_2_E1_P2_Both_Post_N_5/11/2015_2:09:00 PM			118	118	2.4	294	<0.040	<0.015	0.56	<0.054	<0.0082	<0.00082	3.26	<0.00017	14.6	<0.00050	<0.0131	<0.000082	2.52	0.0335	4.43	<0.00050	<0.00013	212	2.91		
Sieb_2_E1_P4_Both_Post_N_5/11/2015_3:46:00 PM																											
Sieb_2_E1_P5_Both_Post_N_5/11/2015_7:00:00 PM			116	116	7.4	849	<0.040	<0.015	0.34	<0.054	<0.0082	<0.00082	8.7	<0.00017	31.9	<0.00050	<0.0131	<0.000082	5.19	0.0619	9.89	<0.00050	<0.00013	551	8.16		
Sieb_2_E2_P1_Both_Post_N_7/22/2015_10:29:00 AM																											
Sieb_2_E2_P2_Both_Post_N_7/22/2015_10:48:00 AM			114	114	1.9	288	<0.04	<0.015	0.77	<0.054	<0.026	<0.0004	3.3	<0.00023	16.4	<0.0007	0.0555 J	<0.00013	2.81	0.0361	4.85	<0.0005	<0.00011	209	2.82		
Sieb_2_E2_P4_Both_Post_N_7/22/2015_12:30:00 PM																											
Sieb_2_E2_P5_Both_Post_N_7/22/2015_3:45:00 PM			113	113	5.1	813	<0.04	<0.015	<0.3	0.082 J	<0.026	<0.0004	7.12	<0.00023	27.5	<0.0007	0.0715 J	<0.00013	4.55	0.0551	9.09	<0.0005	<0.00011	512	6.47		
Sieb_2_E3_P1_Both_Post_N_9/29/2015_10:38:00 AM																											
Sieb_2_E3_P2_Both_Post_N_9/29/2015_11:12:00 AM			114	114	2.5	309	<0.04	<0.015	0.34	<0.054	<0.026	<0.0004	3.53	<0.00023	17.1	<0.0007	0.101	0.00014 J	2.96	0.045	4.7	<0.0005	<0.00011	230	3.1		
Sieb_2_E3_P4_Both_Post_N_9/29/2015_12:46:00 PM																											
Sieb_2_E3_P5_Both_Post_N_9/29/2015_4:20:00 PM			110	110	6.5	803	<0.04	<0.015	<0.3	<0.054	<0.13	<0.0004	8.42	<0.00023	32.1	<0.0035	<0.115	<0.00013	5.29	0.0711	8.91	<0.0005	<0.00011	527	7.75		
Sieb_2_E4_P1_Both_Post_N_12/2/2015_10:35:00 AM																											
Sieb_2_E4_P2_Both_Post_N_12/2/2015_11:00:00 AM			120	120	3.7	494	<0.04	<0.015	<0.3	0.081 J	<0.026	<0.0004	4.84	<0.00023	20.7	<0.0007	0.0822 J	0.00025 J	3.51	0.0476	6.32	<0.0005	<0.00011	326	4.5		
Sieb_2_E4_P4_Both_Post_N_12/2/2015_12:54:00 PM																											
Sieb_2_E4_P5_Both_Post_N_12/2/2015_4:15:00 PM			118	118	7.2	916	<0.04	<0.015	<0.3	<0.054	<0.026	<0.0004	9.38	<0.00023	33.9	<0.0007	0.0968 J	<0.00013	5.54	0.0721	9.89	<0.0005	<0.00011	544	8.82		
Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM			122	122	0.1	25.7	<0.040	<0.015	4.1	0.7	<0.0143	<0.00078	0.569	<0.00023	25.2	<0.00050	0.23	<0.000085	5.7	0.0535	1.88	<0.00050	<0.00011	34.7	0.727		
Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM																											
Sim_1_E1_P5_SV_Post_N_2/18/2014_5:05:00 PM			123	123	0.16	32.3	<0.040	<0.015	2.5	0.65	<0.0143	<0.00078	0.645	<0.00023	25.1	<0.00050	<0.0163	<0.000085	5.67	0.0429	1.66	<0.00050	<0.00011	39.9	0.761		
Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM			123	123	0.11	27.6	<0.040	<0.015	4.4	0.78	<0.0143	<0.00042	0.584	<0.00023	22.8	<0.00050	0.184	<0.000085	5.16	0.0425	1.33	<0.00050	<0.00011	33.7	0.73		
Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM																											
Sim_1_E2_P5_SV_Post_N_2/21/2014_5:45:00 PM			125	125	0.15	32.7	<0.040	<0.015	2.8	0.74	<0.0143	<0.00042	0.638	<0.00023	22.5	<0.00050	<0.0163	<0.000085	5.07	0.037	1.34	<0.00050	<0.00011	36.9	0.751		
Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM			116	116	0.11	27.8	<0.040	<0.015	3.5	0.68	<0.0143	<0.00078	0.559	<0.00023	25.6	<0.00050	0.213	<0.000085	5.71	0.0482	1.54	<0.00050	<0.00011	35.9	0.735		
Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM			119	119	0.11	25.6	<0.040	<0.015	3.3	0.66	<0.0143	<0.00078	0.579	<0.00023	25.1	<0.00050	0.174	<0.000085	5.62	0.0526	1.34	<0.00050	<0.00011	34.1	0.699		
Sim_1_E3_P5_SV_Post_N_2/24/2014_5:30:00 PM			120	120	0.15	34.9	<0.040	<0.015	2.2	0.66	<0.0143	<0.00078	0.692	<0.00023	26.4	<0.00050	<0.0163	<0.000085	5.87	0.0443	1.6	<0.00050	<0.00011	39.8	0.789		
Sim_2_E1_P1_Both_Post_N_4/30/2015_3:40:00 PM																											
Sim_2_E1_P2_Both_Post_N_4/30/2015_4:00:00 PM			124	124	0.18	23.3	<0.040	<0.015	3.3	0.71	<0.0082	<0.00082	0.556	<0.00017	24.3	<0.00050	<0.0131	<0.000082	5.57	0.0444	1.54	<0.00050	<0.00013	33.8	0.746		
Sim_2_E1_P4_Both_Post_N_4/30/2015_4:45:00 PM																											
Sim_2_E1_P5_Both_Post_N_4/30/2015_6:25:00 PM			127	127	0.21	39.3	<0.040	<0.015	3.1	0.69	<0.0082	<0.00082	0.622	<0.00017	24	<0.00050	<0.0131	<0.000082	5.45	0.0372	1.55	<0.00050	<0.00013	38.1	0.778		
Sim_2_E2_P1_Both_Post_N_7/15/2015_10:46:00 AM																											
Sim_2_E2_P2_Both_Post_N_7/15/2015_11:08:00 AM			120	120	0.17	21.5	<0.04	<0.015	3.2	0.74	<0.026	<0.0004	0.551	<0.00023	24.2	<0.0007	<0.023	<0.00013	5.55	0.0439	1.46	<0.0005	<0.00011	33.1	0.72		
Sim_2_E2_P4_Both_Post_N_7/15/2015_11:59:00 AM																											
Sim_2_E2_P5_Both_Post_N_7/15/2015_1:40:00 PM			119	119	0.18	26.4	<0.04	<0.015	2.4	0.7	<0.026	<0.0004	0.617	<0.00023	24.5	<0.0007	<0.023	0.0016	5.58	0.0402	1.54	<0.0005	<0.00011	38.5	0.762		
Sim_2_E3_P1_Both_Post_N_9/28/2015_10:05:00 AM																											
Sim_2_E3_P2_Both_Post_N_9/28/2015_10:33:00 AM			117	117	0.23	19	<0.04	<0.015	3.1	0.79	<0.026	<0.0004	0.534	<0.00023	23.5	<0.0007	0.0789 J	<0.00013	5.46	0.0441	1.47	<0.0005	<0.00011	32.8	0.691		
Sim_2_E3_P4_Both_Post_N_9/28/2015_11:22:00 AM																											
Sim_2_E3_P5_Both_Post_N_9/28/2015_1:12:00 PM			121	121	0.23	25.1	<0.04	<0.015	2.3	0.7	<0.026	<0.0004	0.56	<0.00023	23.3	<0.0007	0.0268 J	<0.00013	5.39	0.0382	1.47	<0.0005	<0.00011	36.7	0.668		
Sim_2_E4_P1_Both_Post_N_12/7/2015_1:48:00 PM																											
Sim_2_E4_P2_Both_Post_N_12/7/2015_2:13:00 PM			127	127	0.65	19.7	<0.04	<0.015	3.5	0.37	<0.026	<0.0004	0.545	<0.00023	25.7	<0.0007	0.0644 J	<0.00013	5.96	0.0478	1.57	<0.0005	<0.00011	38.1	0.704		
Sim_2_E4_P4_Both_Post_N_12/7/2015_3:13:00 PM																											

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

Analyte Group:	Water Quality																										
Analyte:	E. Coli	Total Coliforms	Bicarbonate Alkalinity as $CaCO_3$	Total Alkalinity as $CaCO_3$	Bromide	Chloride	Nitrate Nitrogen	Nitrite Nitrogen	Sulfate	Sulfide	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Iron	Lead	Magnesium	Manganese	Potassium	Selenium	Silver	Sodium	Strontium	Aluminum, dissolved	Arsenic, dissolved
Laboratory:	Benchmark	Benchmark	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster
Sample ID	NR	NR	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sim_2_E4_P5_Both_Post_N_12/7/2015_4:46:00 PM			128	128	0.24	25.2	<0.04	<0.015	2.4	0.69	<0.026	<0.0004	0.594	<0.00023	26.1	<0.0007	0.0455 J	<0.00013	5.99	0.0431	1.64	<0.0005	<0.00011	39.8	0.737		
Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM	Absence	Absence	113	113	0.13	23.8	<0.04	<0.015	2.9	0.31	<0.0143	<0.00042	1.13	<0.00023	14.7	<0.0005	<0.0163	<0.000085	4.16	0.0305	1.73	<0.0005	<0.00011	40.2	0.677	<0.0143	<0.00042
Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM	Absence	Absence	113	113	0.13	18.9	<0.040	<0.015	3.2	0.26	<0.0143	<0.00042	1.1	<0.00023	14.8	<0.00050	<0.0163	<0.000085	4.2	0.0303	1.63	<0.00050	<0.00011	40.6	0.695		
Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM	Absence	Absence	110	110	0.087	10.6	<0.040	<0.015	3.1	0.26	<0.0143	<0.00078	1.13	<0.00023	14.9	<0.00050	<0.0163	<0.000085	4.21	0.0273	1.59	<0.00050	<0.00011	41.1	0.668		
Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM	Absence	Absence	111	111	0.16	19.8	<0.040	<0.015	<0.30	0.25	<0.0143	<0.00078	1.13	<0.00023	16.2	<0.00050	<0.0163	<0.000085	4.42	0.029	1.7	<0.00050	<0.00011	40.5	0.688		
Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM			110	110	0.14	23	<0.040	<0.015	4.1	0.29	<0.0143	<0.00078	1.14	<0.00023	14.3	<0.00050	<0.0163	<0.000085	4.04	0.0304	1.67	<0.00050	<0.00011	42.3	0.668		
Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM			111	111	0.17	21.1	<0.040	<0.015	3	0.28	<0.0143	<0.00078	1.09	<0.00023	15.2	<0.00050	<0.0163	<0.000085	4.23	0.029	1.67	<0.00050	<0.00011	42.1	0.654		
Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM	Absence	Absence	123	123	0.23	38.2	<0.04	<0.015	<0.3	<0.054	<0.0143	<0.00042	1.64	<0.00023	20.5	<0.0005	<0.0163	<0.000085	4.54	0.0225	1.84	<0.0005	<0.00011	48.1	0.953	<0.0143	<0.00042
Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM	Absence	Absence	122	124	0.25	35.8	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.75	<0.00023	20.5	<0.00050	<0.0163	<0.000085	4.67	0.0253	1.94	<0.00050	<0.00011	48.1	1.07		
Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM	Absence	Absence	122	122	0.22	40.5	<0.040	<0.015	0.41	<0.054	<0.0143	<0.00042	1.44	<0.00023	21	<0.00050	<0.0163	<0.000085	4.7	0.0229	1.98	<0.00050	<0.00011	49.1	0.885		
Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM			122	122	0.22	40.3	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.67	<0.00023	20.8	<0.00050	<0.0163	<0.000085	4.64	0.0233	1.91	<0.00050	<0.00011	48.8	0.998		
Web_1_E1_P5_SV_Post_N_2/17/2014_1:45:00 PM			120	120	0.22	39.7	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.56	<0.00023	21.5	<0.00050	<0.0163	<0.000085	4.74	0.023	1.93	<0.00050	<0.00011	45.5	0.944		
Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM			122	123	0.2	39.7	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.7	<0.00023	19.7	<0.00050	<0.0163	<0.000085	4.38	0.0232	1.69	<0.00050	<0.00011	45.3	1.03		
Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM																											
Web_1_E2_P5_SV_Post_N_2/21/2014_12:50:00 PM			121	121	0.19	37.9	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00042	1.69	<0.00023	19.6	<0.00050	<0.0163	<0.000085	4.36	0.0241	1.65	<0.00050	<0.00011	40.9	1		
Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM			117	117	0.21	38.4	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	1.71	<0.00023	21.7	<0.00050	<0.0163	<0.000085	4.75	0.024	1.95	<0.00050	<0.00011	49.4	1.02		
Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM																											
Web_1_E3_P5_SV_Post_N_2/24/2014_1:00:00 PM			115	115	0.2	42.6	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	1.85	<0.00023	22.7	<0.00050	<0.0163	<0.000085	4.93	0.0258	1.95	<0.00050	<0.00011	46.2	1.09		
Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM	Absence	Absence	121	121	0.33	38.4	<0.040	<0.015	1.8	<0.054	<0.0143	<0.00078	1.71	<0.00023	22.1	<0.00050	<0.0163	<0.000085	4.82	0.0221	2.06	<0.00050	<0.00011	50.2	1		
Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM			122	122	0.3	40.5	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	1.65	<0.00023	20.5	<0.00050	<0.0163	<0.000085	4.58	0.0248	1.85	<0.00050	<0.00011	48.8	0.994		
Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM			124	124	0.34	42.4	<0.040	<0.015	<0.30	<0.054	<0.0143	<0.00078	1.73	<0.00023	20.6	<0.00050	0.101	0.0047	4.53	0.0253	1.86	<0.00050	<0.00011	49.7	1.01		
Web_2_E1_P1_Both_Post_N_5/12/2015_1:40:00 PM																											
Web_2_E1_P1.5_Both_Post_N_5/12/2015_2:10:00 PM																											
Web_2_E1_P2_Both_Post_N-Dup_5/12/2015_2:40:00 PM			121	121	0.32	39.2	<0.040	<0.015	0.31	<0.054	<0.0082	<0.00040	1.71	<0.00017	20.7	<0.00050	<0.0131	<0.000082	4.7	0.0236	1.89	<0.00050	<0.00013	47.2	1.04		
Web_2_E1_P2_Both_Post_Dup_5/12/2015_2:40:00 PM			125	125	0.31	39.2	<0.040	<0.015	<0.30	<0.054	<0.0082	<0.00040	1.73	<0.00017	20.4	<0.00050	<0.0131	<0.000082	4.64	0.0242	1.78	<0.00050	<0.00013	46.4	1.06		
Web_2_E1_P5_Both_Post_N_5/12/2015_4:45:00 PM			119	119	0.31	38.1	<0.040	<0.015	0.3	<0.054	<0.0082	<0.00040	1.76	<0.00017	20.9	<0.00050	<0.0131	<0.000082	4.72	0.0372	1.83	<0.00050	<0.00013	45.4	1.06		
Web_2_E2_P1_Both_Post_N_7/23/2015_9:35:00 AM																											
Web_2_E2_P1.5_Both_Post_N_7/23/2015_10:08:00 AM																											
Web_2_E2_P2_Both_Post_N_7/23/2015_10:43:00 AM			117	117	0.26	38.9	<0.04	<0.015	<0.3	<0.054	<0.026	<0.0004	1.64	<0.00023	20.1	<0.0007	0.0279 J	<0.00013	4.55	0.0237	1.8	<0.0005	<0.00011	45.8	0.97		
Web_2_E2_P5_Both_Post_N_7/23/2015_12:48:00 PM			115	115	0.25	38.1	<0.04	<0.015	<0.3	<0.054	<0.026	<0.0004	1.7	<0.00023	20.4	<0.0007	0.0282 J	<0.00013	4.6	0.0234	1.8	<0.0005	<0.00011	43.3	1.01		
Web_2_E3_P1_Both_Post_N_9/30/2015_10:35:00 AM																											
Web_2_E3_P1.5_Both_Post_N_9/30/2015_11:08:00 AM																											
Web_2_E3_P2_Both_Post_N_9/30/2015_11:51:00 AM			116	116	0.32	36.5	<0.04	<0.015	<0.3	<0.054	<0.13	<0.0004	1.64	<0.00023	20.7	<0.0035	<0.115	<0.00013	4.62	0.0247	1.83	<0.0005	<0.00011	46.2	0.985		
Web_2_E3_P5_Both_Post_N_9/30/2015_2:15:00 PM			116	116	0.31	35.6	<0.04	<0.015	<0.3	<0.054	<0.026	<0.0004	1.74	<0.00023	20.9	<0.0007	0.0288 J	<0.00013	4.65	0.0241	1.86	<0.0005	<0.00011	43.9	1.04		
Web_2_E4_P1_Both_Post_N_12/10/2015_9:58:00 AM																											
Web_2_E4_P1.5_Both_Post_N_12/10/2015_10:31:00 AM																											
Web_2_E4_P2_Both_Post_N_12/10/2015_11:11:00 AM			121	121	0.32	36.4	<0.04	<0.015	<0.3	<0.054	<0.026	<0.0004	1.6	<0.00023	20	<0.0007	0.0385 J	<0.00013	4.42	0.0225	1.74	<0.0005	<0.00011	42.6	0.944		
Web_2_E4_P5_Both_Post_N_12/10/2015_1:33:00 PM			122	122	0.33	37.1	<0.04	<0.015	<0.3	<0.054	<0.026	<0.0004	1.63	<0.00023	20	<0.0007	0.0458 J	0.00016 J	4.38	0.024	1.73	<0.0005	<0.00011	42.4	0.971		

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

Analyte Group:	Water Quality																Field Parameters / Water Level							
Analyte:	Barium, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Iron, dissolved	Lead, dissolved	Magnesium, dissolved	Manganese, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Conductivity	Dissolved Oxygen	ORP	pH	Specific Conductivity	Temperature	Turbidity	Water Level
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Field	Field	Field	Field	Field	Field	Field	Field
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	mS/cm	mg/L	mV	s.u.	mS/cm	°C	NTU	ft BTOC
Iri_1_E01_P2_TV_Post_N_12/19/2013_5:45:00 PM	0.028	<0.00023	18.9	<0.0005	<0.0163	<0.000085	1.04	0.0647	1.39	<0.0005	<0.00011	2.07	0.0713	6.7	<9.7	<1	0.084	0.34	114.2	6.73	0.123	8.77	0.97	11.96
Iri_1_E02_P2_TV_Post_N_1/21/2014_5:30:00 PM														6.8	77	<1.00	0.08	0.47	132.2	6.32	0.119	8.26	1.68	9.51
Iri_1_E03_P2_TV_Post_N_2/18/2014_10:45:00 AM														6.7	80.5	<1.00	0.076	0.53	120.8	6.12	0.116	6.11	0.64	10.96
Iri_1_E04_P2_TV_Post_N_3/25/2014_10:43:00 AM														6.9	75	<1.00	0.073	0.8	130.3	5.99	0.116	5.91	1.11	9.33
Iri_1_E05_P2_TV_Post_N-Dup_4/23/2014_5:05:00 PM														6.9	69	<1.00	0.066	0.27	175.6	6.24	0.102	6.37	2.1	3.95
Iri_1_E06_P2_TV_Post_N_5/21/2014_7:37:00 AM														6.7	77.5	<1.00	0.076	0.67	156.5	6.54	0.117	6.95	1.2	4.4
Jon_1_E01_P2_TV_Post_N_12/19/2013_9:20:00 AM	1.95	<0.00023	22.1	<0.0005	<0.0163	<0.000085	7.28	0.077	1.56	<0.0005	<0.00011	62.5	0.72	8	236	<1	0.321	0.26	-201	8.03	0.46	9.18	3.38	10.09
Jon_1_E02_P2_TV_Post_N-Dup_1/21/2014_9:15:00 AM	2.07	<0.00023	21.3	<0.00050	<0.0163	<0.000085	7.07	0.0963	1.46	<0.00050	<0.00011	59.9	0.776	8.1	238	<1.00	0.331	0.17	-201	8.32	0.479	8.75	3.86	8.7
Jon_1_E1_P2_Both_Post_N-Dup_2/17/2014_3:51:00 PM														8.2	246	<1.00	0.325	0.23	-152	8.05	0.465	9.16	2.6	8.91
Jon_1_E1_P2_Both_Post_Dup_2/17/2014_3:51:00 PM														8.2	247	<1.00	0.325	0.23	-152	8.05	0.465	9.16	2.6	8.91
Jon_1_E1_P5_SV_Post_N_2/17/2014_5:33:00 PM														8.2	237	<1.00	0.32	0.08	-198	8.13	0.455	9.45	2.75	10.35
Jon_1_E2_P2_SV_Post_N-Dup_2/21/2014_8:54:00 AM														8.3	234	<1.00	0.329	0.13	-127	8.09	0.471	9.26	3.05	8.54
Jon_1_E2_P2_SV_Post_Dup_2/21/2014_8:54:00 AM																	0.329	0.13	-127	8.09	0.471	9.26	3.05	8.54
Jon_1_E2_P5_SV_Post_N_2/21/2014_10:24:00 AM														8.1	238	<1.00	0.325	0.05	-176	8.1	0.461	9.58	4.15	9.57
Jon_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:08:00 AM														8.2	250	<1.00	0.324	0.12	-157	8.09	0.465	9.06	1.87	7.38
Jon_1_E3_P2_SV_Post_Dup_2/24/2014_9:08:00 AM																	0.324	0.12	-157	8.09	0.465	9.06	1.87	7.38
Jon_1_E3_P5_SV_Post_N_2/24/2014_10:34:00 AM														8.2	241	<1.00	0.321	0.05	-190	8.08	0.457	9.35	2.74	7.53
Jon_1_E04_P2_TV_Post_N_3/26/2014_9:37:00 AM	2	<0.00023	23.7	<0.00050	0.105	<0.000085	7.8	0.0786	1.74	<0.00050	<0.00011	68.1	0.731	8.3	248	<1.00	0.3	0.42	-187	8.16	0.44	8.36	14.6	9.1
Jon_1_E05_P2_TV_Post_N_4/23/2014_12:00:00 PM														8.2	242	<1.00	0.317	0.1	-157	8.19	0.445	10	1.88	8.14
Jon_1_E06_P2_TV_Post_N_5/22/2014_9:40:00 AM														8.1	237	<1.00		0.28	-195.2	8.2	0.463	10.81	4.52	9.11
Jon_2_E1_P1_Both_Post_N_4/28/2015_10:14:00 AM																	0.32	0.56	-110	7.56	0.462	8.93	1.3	8.44
Jon_2_E1_P2_Both_Post_N_4/28/2015_10:49:00 AM														8.1	252	<1.00	0.33	0.24	-51	7.89	0.462	10.06	2.33	9.33
Jon_2_E1_P4_Both_Post_N_4/28/2015_11:22:00 AM																	0.331	0.15	-83	7.91	0.461	10.21	2.04	8.56
Jon_2_E1_P5_Both_Post_N_4/28/2015_1:05:00 PM														7.9	254	<1.00	0.342	0.1	-67	7.58	0.476	10.3	3.2	8.61
Jon_2_E2_P1_Both_Post_N_7/16/2015_9:21:00 AM																	0.389	3.87	-185.8	7.31	0.484	14.7	1.07	8.73
Jon_2_E2_P2_Both_Post_N_7/16/2015_9:45:00 AM														8.1	249	<1	0.345	2.78	-245.4	7.98	0.485	9.86	1.71	11.41
Jon_2_E2_P4_Both_Post_N_7/16/2015_10:14:00 AM																	0.343	0.46	-248.7	8.1	0.483	9.8	1.8	9.47
Jon_2_E2_P5_Both_Post_N_7/16/2015_11:12:00 AM														8.1	248	<2	0.334	3.32	-252	8.1	0.472	9.66	3.13	10.74
Jon_2_E3_P1_Both_Post_N_9/28/2015_2:49:00 PM																	0.393	2.82	-139.2	7.97	0.497	13.99	2.11	11.36
Jon_2_E3_P2_Both_Post_N_9/28/2015_3:15:00 PM														8.2	269	7.5	0.35	0.41	-230.3	8.17	0.497	9.45	1.02	11.13
Jon_2_E3_P4_Both_Post_N_9/28/2015_3:45:00 PM																	0.338	0.24	-230.4	8.12	0.483	9.31	1.14	11.21
Jon_2_E3_P5_Both_Post_N_9/28/2015_4:49:00 PM														8.2	260	2.1 J	0.334	0.24	-240.5	8.1	0.48	9	2.92	11.23
Jon_2_E4_P1_Both_Post_N_12/7/2015_9:39:00 AM																	0.326	5.41	-44.1	7.65	0.461	9.66	1.17	11.11
Jon_2_E4_P2_Both_Post_N-Dup_12/7/2015_10:05:00 AM														7.8	262	2.8 J	0.329	4.88	-127.8	8.3	0.458	10.23	1.97	10.69
Jon_2_E4_P2_Both_Post_Dup_12/7/2015_10:05:00 AM														7.8	251	2.1 J	0.329	4.88	-127.8	8.3	0.458	10.23	1.97	10.69
Jon_2_E4_P4_Both_Post_N_12/7/2015_10:54:00 AM																	0.329	4.88	-127.8	8.3	0.458	10.23	2.29	10.69
Jon_2_E4_P5_Both_Post_N_12/7/2015_11:57:00 AM														7.9	243	1.4 J	0.321	0.17	-150.4	8.33	0.445	10.41	3.54	10.24
Loc_1_E01_P2_TV_Post_N_12/19/2013_12:56:00 PM	0.611	<0.00023	28.8	<0.0005	4.82	<0.000085	4.88	1.02	2.1	<0.0005	<0.00011	43.7	0.884	7.4	187	<1	0.262	0.37	-167	7.14	0.372	9.55	0.64	
Loc_1_E02_P2_TV_Post_N_1/21/2014_12:06:00 PM														7.6	199	10.4	0.264	0.16	-103	6.99	0.383	8.74	2.62	
Loc_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:24:00 AM														7.7	205	6.4	0.378	0.18	-191	7.05	0.261	8.76	3.42	110.39
Loc_1_E1_P2_Both_Post_Dup_2/19/2014_11:24:00 AM														7.6	202	9.1	0.378	0.18	-191	7.05	0.261	8.76	3.24	110.39
Loc_1_E1_P5_SV_Post_N_2/19/2014_8:42:00 PM														7.9	201	8.2	0.367	0.03	-267	7.4	0.257	9.28	2.53	145.48
Loc_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:35:00 AM														7.8	209	3.6	0.266	2.33	-237	7.9	0.388	8.54	2.41	111.43
Loc_1_E2_P2_SV_Post_Dup_2/22/2014_9:35:00 AM																	0.266	2.33	-237	7.9	0.388	8.54	2.41	111.43
Loc_1_E2_P5_SV_Post_N_2/22/2014_6:40:00 PM														7.9	213	<1.00	0.263	0.44	-277	7.95	0.376	9.28	2.05	143
Loc_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:30:00 AM														7.3	203	3.8	0.25	0.14	-223	7.02	0.364	8.58	2.31	109.71
Loc_1_E3_P2_SV_Post_Dup_2/26/2014_9:30:00 AM																	0.25	0.14	-223	7.02	0.364	8.58	2.31	109.71
Loc_1_E3_P5_SV_Post_N_2/26/2014_6:30:00 PM														7.6	211	3.4	0.254	0.01	-280	7.34	0.366	9.05	2.17	142.83
Loc_1_E04_P2_TV_Post_N_3/26/2014_6:10:00 PM														7.7	201	6.2	0.238	0.38	-156	6.97	0.349	8.31	7.24	100.7
Loc_1_E05_P2_TV_Post_N_4/23/2014_10:25:00 AM														7.6	204	8.2	0.256	0.13	-141	6.98	0.359	9.95	0.82	100.63
Loc_1_E06_P2_TV_Post_N-Dup_5/21/2014_9:08:00 AM														7.6	201	8.5	0.277	0.59	-174	7.38	0.385	10.36	0.3	100.74
Loc_2_E1_P1_Both_Post_N_5/4/2015_9:55:00 AM																	0.248	6.71	-102	6.06	0.357	8.98	1.45	99.6
Loc_2_E1_P2_Both_Post_N_5/4/2015_10:15:00 AM														7.7	190	<2.00	0.258	0.27	-219	6.61	0.366	9.63	1.02	107.09
Loc_2_E1_P4_Both_Post_N_5/4/2015_12:58:00 PM																	0.274	0.08	-323	7.2	0.383	10.14	0.87	131.37
Loc_2_E1_P5_Both_Post_N_5/4/2015_6:40:00 PM														7.8	195	4.67	0.266	0.03	-329	7.27	0.373	10.01	1.03	144.92
Loc_2_E2_P1_Both_Post_N_7/14/2015_9:29:00 AM																	0.283	0.28	-168.3	7.43	0.38	11.64	1.67	105.19
Loc_2_E2_P2_Both_Post_N_7/14/2015_10:06:00 AM														7.8	208	3.3	0.273	0.13	-206.4	7.68	0.392	9.05	2.01	109.24
Loc_2_E2_P4_Both_Post_N_7/14/2015_12:51:00 PM																	0.276	0.13	-257	7.74	0.397	9.03	1.26	129.69
Loc_2_E2_P5_Both_Post_N_7/14/2015_6:30:00 PM														7.8	220	<1	0.273	0.1	-281.6	7.62	0.389	9.4	1.05	141.74
Loc_2_E3_P1_Both_Post_N_9/23/2015_10:18:00 AM																	0.306	7.72	-80.1	6.59	0.4	12.73	1.86	100.76
Loc_2_E3_P2_Both_Post_N-Dup_9/23/2015_10:55:00 AM														7.7	221	4.18 J	0.283	0.96	-188.2	6.96	0.408	8.95	2.07	111.25
Loc_2_E3_P2_Both_Post_Dup_9/23/2015_10:55:00 AM														7.8	221	15.1	0.283	0.96	-188.2	6.96	0.408	8.95	2.07	111.25
Loc_2_E3_P4_Both_Post_N_9/23/2015_1:47:00 PM																	0.29	0.8	-214.2	7.27	0.419	8.83	1.39	132.62
Loc_2_E3_P5_Both_Post_N_9/23/2015_7:36:00 PM														7.7	266	1.2 J	0.282	2.07	-249.6	7.33	0.408	8.74	1.98	142.19
Loc_2_E4_P1_Both_Post_N_12/1/2015_10:55:00 AM																	0.265	0.56	-158.5	7.76	0.369	10.23	0.24	107.41
Loc_2_E4_P2_Both_Post_N_12/1/2015_11:30:00 AM														7.6	201	8	0.272	0.34	-164.1	7.68	0.378	10.24	0.91	116.18
Loc_2_E4_P4_Both_Post_N_12/1/2015_2:13:00 PM																	0.279	0.09	-174.1	7.83	0.387	10.44	0.73	143.67
Loc_2_E4_P5_Both_Post_N_12/1/2015_7:40:00 PM														7.8	223	5.75	0.275	0.04	-190	8.01	0.38	10.44	0.87	148.49
Marc_1_E1_P2_Both_Post_N-Dup_2/18/2014_5:27:00 PM														8.1	281	<1.00	0.396	0.13	-146	8.25	0.552	10.15	0.92	14.89

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

Analyte Group:	Water Quality																Field Parameters / Water Level							
Analyte:	Barium, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Iron, dissolved	Lead, dissolved	Magnesium, dissolved	Manganese, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Conductivity	Dissolved Oxygen	ORP	pH	Specific Conductivity	Temperature	Turbidity	Water Level
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Field	Field	Field	Field	Field	Field	Field	Field
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	mS/cm	mg/L	mV	s.u.	mS/cm	°C	NTU	ft BTOC
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																	0.396	0.13	-146	8.25	0.552	10.15	0.92	14.89
Marc_1_E1_P5_SV_Post_N_2/18/2014_9:15:00 PM														8.1	287	<1.00	0.401	0.06	-201	8.23	0.559	10.22	0.49	15.11
Marc_1_E1_P2_Both_Post_Dup_2/18/2014_5:27:00 PM																	0.396	0.13	-146	8.25	0.552	10.15	0.92	14.89
Marc_1_E2_P2_SV_Post_N-Dup_2/21/2014_1:00:00 PM														8.2	269	<1.00	0.385	0.19	72	8.07	0.544	9.69	0.52	13.83
Marc_1_E2_P2_SV_Post_Dup_2/21/2014_1:00:00 PM														8.2	271	<1.00	0.385	0.19	72	8.07	0.544	9.69	0.52	13.83
Marc_1_E2_P5_SV_Post_N_2/21/2014_4:54:00 PM														8.2	276	<1.00	0.4	0.02	-176	8.11	0.563	9.87	0.51	14.87
Marc_1_E3_P2_SV_Post_N-Dup_2/24/2014_12:35:00 PM														8.1	280	<1.00	0.377	0.11	-125	8.08	0.533	9.7	0.78	13.26
Marc_1_E3_P5_SV_Post_N_2/24/2014_4:12:00 PM														8.1	278	<1.00	0.382	0.01	-195	8.06	0.539	9.75	0.51	13.45
Marc_1_E05_P2_TV_Post_N_4/22/2014_9:55:00 AM														7.9	275	<1.00	0.391	0.13	-131	8.1	0.532	11.16	0.4	17.25
Marc_1_E06_P2_TV_Post_N_5/22/2014_2:08:00 PM														8	271	<1.00	0.412	0.22	-190	8.21	0.547	12.04	0.37	17.23
Rath_1_E1_P2_Both_Post_N-Dup_2/20/2014_11:03:00 AM	0.11	<0.00023	2.42	<0.00050	<0.0163	<0.000085	0.365	0.0033	1.65	<0.00050	<0.00011	215	0.216	8.7	547	37.5	0.74	0.46	-238	8.94	1.04	9.9	52.4	41.02
Rath_1_E1_P2_Both_Post_Dup_2/20/2014_11:03:00 AM																	0.74	0.46	-238	8.94	1.04	9.9	52.4	41.02
Rath_1_E1_P5_SV_Post_N_2/20/2014_3:18:00 PM	0.15	<0.00023	6.64	<0.00050	<0.0163	<0.000085	1.14	0.0093	1.62	<0.00050	<0.00011	186	0.298	8.8	461	5	0.602	0.04	-270	8.92	0.852	9.63	15.1	55.17
Rath_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:10:00 AM	0.109	<0.00023	2.32	<0.00050	<0.0163	<0.000085	0.343	0.0024	1.64	<0.00050	<0.00011	223	0.221	8.9	581	9.1	0.742	0.27	-235	8.89	1.047	9.74	11.2	38
Rath_1_E2_P2_SV_Post_Dup_2/23/2014_9:10:00 AM	0.107	<0.00023	2.21	<0.00050	<0.0163	<0.000085	0.318	0.0022	1.55	<0.00050	<0.00011	218	0.221	8.9	580	8.3	0.742	0.27	-235	8.89	1.047	9.74	11.2	38
Rath_1_E2_P5_SV_Post_N_2/23/2014_2:00:00 PM	0.157	<0.00023	7.06	<0.00050	<0.0163	<0.000085	1.23	0.0108	1.59	<0.00050	<0.00011	180	0.308	8.8	455	4.8	0.555	0.01	-276	8.9	0.782	9.81	19	56.49
Rath_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:45:00 AM	0.118	<0.00023	2.4	<0.00050	<0.0163	<0.000085	0.352	0.0034	1.77	<0.00050	<0.00011	219	0.231	8.8	571	7.1	0.693	0.19	-220	8.99	0.981	9.66	14.9	42.286
Rath_1_E3_P2_SV_Post_Dup_2/25/2014_9:45:00 AM																	0.693	0.19	-220	8.99	0.981	9.66	14.9	42.286
Rath_1_E3_P5_SV_Post_N_2/25/2014_2:35:00 PM	0.181	<0.00023	8.48	<0.00050	0.103	<0.000085	1.51	0.0135	1.8	<0.00050	<0.00011	173	0.364	8.7	497	4.6	0.566	0.02	-277	8.94	0.801	9.68	20.3	35.42
Rath_2_E1_P1_Both_Post_N_5/1/2015_9:37:00 AM																	0.531	12.69	54	5.72	0.679	13.57	17	28.11
Rath_2_E1_P2_Both_Post_N_5/1/2015_10:05:00 AM	0.124	<0.00017	3.05	<0.00050	0.638	<0.000082	0.581	0.0086	1.91	<0.00050	<0.00013	224	0.262	8.7	591	37.3	0.736	0.28	-202	8.73	1.001	11.15	51.4	42.81
Rath_2_E1_P4_Both_Post_N_5/1/2015_11:26:00 AM																	0.62	0.07	-106	8.74	0.846	10.99	43.9	55.44
Rath_2_E1_P5_Both_Post_N_5/1/2015_2:25:00 PM	0.19	<0.00017	8.86	<0.00050	<0.0131	<0.000082	1.57	0.0107	1.54	<0.00050	<0.00013	166	0.391	8.6	472	4.4	0.6	0.04	-96	8.82	0.823	10.82	13.6	59.04
Rath_2_E2_P1_Both_Post_N_7/16/2015_2:55:00 PM																	0.567	0.72	-256.4	7.77	0.805	9.51	31.4	31.19
Rath_2_E2_P2_Both_Post_N-Dup_7/16/2015_3:35:00 PM	0.121	<0.00023	3.24	<0.0007	0.152	<0.00013	0.515	0.0055	1.77	<0.0005	<0.00011	239	0.264	8.7	574	39.7	0.799	2.81	-268.7	8.66	1.137	9.45	50	43.44
Rath_2_E2_P2_Both_Post_Dup_7/16/2015_3:35:00 PM	0.126	<0.00023	3.24	<0.0007	0.21	<0.00013	0.528	0.0062	1.74	<0.0005	<0.00011	239	0.264	8.6	614	37.6	0.799	2.81	-268.7	8.66	1.137	9.45	50	43.44
Rath_2_E2_P4_Both_Post_N_7/16/2015_5:08:00 PM																	0.629	0.42	-309	8.79	0.901	9.19	40.2	55.49
Rath_2_E2_P5_Both_Post_N_7/16/2015_8:05:00 PM	0.198	<0.00023	9.89	<0.0007	<0.023	<0.00013	1.76	0.0133	1.58	<0.0005	<0.00011	181	0.418	8.5	459	11.8	0.638	0.81	-306.2	8.82	0.922	8.91	33.6	63.42
Rath_2_E3_P1_Both_Post_N_9/24/2015_10:03:00 AM																	0.655	2.46	-162.5	8.53	0.955	8.54	41.6	57.24
Rath_2_E3_P2_Both_Post_N_9/24/2015_10:30:00 AM	0.127	<0.00023	3.05	0.0022	1.01	0.00061 J	0.645	0.0129	1.79	<0.0005	<0.00011	219	0.229	8.6	584	44.5	0.703	1.05	-223.6	8.85	1.019	8.73	51.6	57.24
Rath_2_E3_P4_Both_Post_N_9/24/2015_11:54:00 AM																	0.516	1.62	-282	8.9	0.75	8.66	63.2	57.24
Rath_2_E3_P5_Both_Post_N_9/24/2015_2:50:00 PM	0.172	<0.00023	7.35	<0.0007	0.0462 J	<0.00013	1.33	0.0108	1.49	<0.0005	<0.00011	173	0.355	8.4	519	3.5	0.589	1.34	-293.7	8.78	0.844	9.16	20.7	61.7
Rath_2_E4_P1_Both_Post_N_12/3/2015_9:45:00 AM																	0.655	2.05	-161.9	9.72	0.906	10.47	26.8	37.41
Rath_2_E4_P2_Both_Post_N_12/3/2015_10:10:00 AM	0.119	<0.00023	2.63	<0.0007	<0.023	<0.00013	0.397	0.0033	1.54	<0.0005	<0.00011	206	0.234	8.5	520	28.4	0.648	0.93	-180.9	9.73	0.89	10.79	41.8	44.74
Rath_2_E4_P4_Both_Post_N_12/3/2015_11:42:00 AM																	0.603	0.35	-209.5	9.75	0.829	10.7	46.5	55.9
Rath_2_E4_P5_Both_Post_N_12/3/2015_2:43:00 PM	0.227	<0.00023	9.85	<0.0007	0.0321 J	<0.00013	1.76	0.0135	1.55	<0.0005	<0.00011	159	0.446	8.7	430	5	0.588	0.25	-212.5	9.8	0.81	10.62	14.3	62.89
Sbar_1_E1_P2_Both_Post_N-Dup_2/18/2014_10:58:00 AM														8.6	177	<1.00	0.214	1.59	5	8.63	0.309	8.9	3.84	51.17
Sbar_1_E1_P2_Both_Post_Dup_2/18/2014_10:58:00 AM																	0.214	1.59	5	8.63	0.309	8.9	3.84	51.17
Sbar_1_E1_P5_SV_Post_N_2/18/2014_2:52:00 PM														8.3	180	<1.00	0.214	0.24	-164	8.31	0.305	9.44	1.23	55.62
Sbar_1_E2_P2_SV_Post_N-Dup_2/23/2014_2:24:00 PM														8.4	165	<1.00	0.194	2.54	50	8.28	0.275	9.45	0.83	50.91
Sbar_1_E2_P2_SV_Post_Dup_2/23/2014_2:24:00 PM																	0.194	2.54	50	8.28	0.275	9.45	0.83	52.24
Sbar_1_E2_P5_SV_Post_N_2/23/2014_6:03:00 PM														8.3	155	<1.00	0.197	0.35	-142	8.13	0.279	9.63	0.85	55.03
Sbar_1_E3_P2_SV_Post_N-Dup_2/26/2014_2:30:00 PM														8.2	164	<1.00	0.192	2	13	8.27	0.274	9.45	1.35	51.15
Sbar_1_E3_P2_SV_Post_Dup_2/26/2014_2:30:00 PM														8.2	163	<1.00	0.192	2	13	8.27	0.274	9.45	1.35	53.38
Sbar_1_E3_P5_SV_Post_N_2/26/2014_5:55:00 PM														8.1	165	<1.00	0.195	0.55	-118	8.01	0.277	9.53	1.65	56.17
Sbar_1_E04_P2_TV_Post_N_3/25/2014_3:15:00 PM														8.6	175	<1.00	0.204	1.78	-160	8.72	0.302	8	0.47	52.41
Sbar_1_E05_P2_TV_Post_N_4/22/2014_4:30:00 PM														8.1	182	<1.00	0.244	1.9	-54	8.5	0.345	9.68	0.84	54.44
Sbar_1_E06_P2_TV_Post_N_5/22/2014_12:52:00 PM														8.2	183	<1.00	0.256	2.1	-144	8.47	0.35	11	1.98	12.77
Sbar_2_E1_P1_Both_Post_N_5/19/2015_9:40:00 AM																	0.25	2.83	289	7.43	0.305	15.43	0.27	55.13
Sbar_2_E1_P2_Both_Post_N_5/19/2015_10:22:00 AM														8.4	175	<1.00	0.225	0.63	74	8.4	0.308	10.87	0.37	56.08
Sbar_2_E1_P4_Both_Post_N_5/19/2015_11:18:00 AM																	0.221	0.4	-35	8.29	0.307	10.33	0.22	56.38
Sbar_2_E1_P5_Both_Post_N_5/19/2015_1:43:00 PM														8.1	175	<1.00	0.22	1.95	-151	8.29	0.305	10.36	0.17	57.03
Sbar_2_E2_P1_Both_Post_N_7/23/2015_2:25:00 PM																	0.311	1.96	-75	7.57	0.375	16.03	4.74	54.44
Sbar_2_E2_P2_Both_Post_N_7/23/2015_3:06:00 PM														8.4	204	<1	0.242	0.37	-228	8.66	0.356	8.32	0.92	58.95
Sbar_2_E2_P4_Both_Post_N_7/23/2015_4:02:00 PM																	0.221	0.29	-223	8.4	0.323	8.36	0.84	60.28
Sbar_2_E2_P5_Both_Post_N_7/23/2015_6:25:00 PM														8.7	181	<1	0.218	0.32	-225	8.35	0.321	8.3	0.57	55.85
Sbar_2_E3_P1_Both_Post_N_10/5/2015_9:59:00 AM																	0.188	2.53	-40.9	7.49	0.262	10.2	2.52	56.08
Sbar_2_E3_P2_Both_Post_N_10/5/2015_10:43:00 AM														8.2	167	<1	0.202	1.21	-186.8	7.96	0.3	7.84	0.22	58.28
Sbar_2_E3_P4_Both_Post_N_10/5/2015_11:38:00 AM																	0.203	2.86	-185.3	7.92	0.303	7.76	0.25	56.3
Sbar_2_E3_P5_Both_Post_N_10/5/2015_2:26:00 PM														8.1	207	<1	0.213	2.64	-209.2	7.84	0.317	7.78	0.11	58.32
Sbar_2_E4_P1_Both_Post_N_12/8/2015_10:38:00 AM																	0.247	3.97	-56.8	8.25	0.353	9.34	2.02	53.99
Sbar_2_E4_P2_Both_Post_N_12/8/2015_11:18:00 AM														8.3	187	<1	0.243	0.76	-149.9	9.1	0.345	9.63	0.39	54.84
Sbar_2_E4_P4_Both_Post_N_12/8/2015_12:25:00 PM																	0.225	0.35	-161.3	8.97	0.318	9.68	0.15	55.48
Sbar_2_E4_P5_Both_Post_N_12/8/2015_2:57:00 PM														7.7	182	<1	0.218	0.23	-165.2	8.88	0.307	9.72	0.33	56.55
Sdel_1_E1_P2_Both_Post_N-Dup_2/20/2014_10:32:00 AM														8.1	365	<1.00	0.51	0.08	-54	7.81	0.701	10.73	2.79	7.5
Sdel_1_E1_P2_Both_Post_Dup_2/20/2014_10:32:00 AM																	0.51	0.08	-54	7.81	0.701	10.73	2.79	7.5
Sdel_1_E1_P5_SV_Post_N_2/20/2014_2:24:00 PM														8.1	359	<1.00	0.51	0.02	-157	7.84	0.699	10.84	2.5	8.01
Sdel_1_E2_P2_SV_Post_N-Dup_2/23/2014_9:28:00 AM														8.2	353	<1.00	0.497	0.1	-112	7.83	0.69	10.32	1.42	4.65
Sdel_1_E2_P2_SV_Post_Dup_2/23/2014_9:28:00 AM																	0.497	0.1	-112	7.83	0.69	10.32	1.42	4.65

Notes:

1) **Study**: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) **Sample Type:** N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) **Purge Abbreviation:** P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

GSI ENVIRONMENTAL

Analyte Group:	Water Quality																Field Parameters / Water Level							
Analyte:	Barium, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Iron, dissolved	Lead, dissolved	Magnesium, dissolved	Manganese, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Conductivity	Dissolved Oxygen	ORP	pH	Specific Conductivity	Temperature	Turbidity	Water Level
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Field	Field	Field	Field	Field	Field	Field	Field
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	mS/cm	mg/L	mV	s.u.	mS/cm	°C	NTU	ft BTOC
Sdel_1_E2_P5_SV_Post_N_2/23/2014_1:12:00 PM														8.2	353	<1.00	0.498	0.02	-167	7.88	0.686	10.63	0.94	5.71
Sdel_1_E3_P2_SV_Post_N-Dup_2/26/2014_9:35:00 AM														8	365	<1.00	0.505	0.12	-91	7.81	0.699	10.43	0.64	6.19
Sdel_1_E3_P2_SV_Post_Dup_2/26/2014_9:35:00 AM														8	366	<1.00	0.505	0.12	-91	7.81	0.699	10.43	0.64	6.19
Sdel_1_E3_P5_SV_Post_N_2/26/2014_1:12:00 PM														8	383	<1.00	0.506	0.02	-185	7.86	0.698	10.6	0.96	6.74
Sdel_2_E1_P1_Both_Post_N_4/29/2015_9:55:00 AM																	0.564	0.59	-129	6.98	0.726	13.31	0.18	4.23
Sdel_2_E1_P2_Both_Post_N_4/29/2015_10:25:00 AM														8	387	<1.00	0.522	0.21	-73	7.62	0.714	10.97	0.67	5.97
Sdel_2_E1_P4_Both_Post_N_4/29/2015_11:46:00 AM																	0.539	0.08	-80	7.82	0.724	11.63	0.19	5.98
Sdel_2_E1_P5_Both_Post_N_4/29/2015_2:25:00 PM														8	398	<1.00	0.542	0.04	-82	7.89	0.73	11.51	0.41	7.88
Sdel_2_E2_P1_Both_Post_N_7/20/2015_12:02:00 PM																	0.638	1.53	-188	6.95	0.783	15.31	7.3	5.51
Sdel_2_E2_P2_Both_Post_N_7/20/2015_12:35:00 PM														7.9	380	<1	0.567	0.4	-202	7.91	0.781	10.69	2.06	5.76
Sdel_2_E2_P4_Both_Post_N_7/20/2015_1:52:00 PM																	0.56	2.03	-224	8.04	0.778	10.31	0.65	8.17
Sdel_2_E2_P5_Both_Post_N_7/20/2015_4:35:00 PM														8	380	<1	0.564	1.19	-232	7.94	0.786	10.24	0.52	6.64
Sdel_2_E3_P1_Both_Post_N_9/22/2015_11:43:00 AM																	0.634	3.75	-142.4	6.43	0.799	14.24	0.73	7.52
Sdel_2_E3_P2_Both_Post_N_9/22/2015_12:19:00 PM														8	385	<1	0.572	0.69	-165	7.79	0.806	9.84	3.61	8.94
Sdel_2_E3_P4_Both_Post_N_9/22/2015_1:35:00 PM																	0.569	0.57	-176.7	7.93	0.804	9.67	0.99	10.23
Sdel_2_E3_P5_Both_Post_N_9/22/2015_4:15:00 PM														8	385	<1	0.559	0.58	-190.5	8.01	0.8	9.21	1.06	9.77
Sdel_2_E4_P1_Both_Post_N_12/14/2015_9:53:00 AM																	0.575	2.46	-100.6	7.58	0.763	12.1	0.26	5.88
Sdel_2_E4_P2_Both_Post_N_12/14/2015_10:17:00 AM														7.6	385	<1	0.564	0.84	-120.6	8.31	0.765	11.25	0.26	5.77
Sdel_2_E4_P4_Both_Post_N_12/14/2015_11:37:00 AM																	0.557	0.17	-138.4	8.42	0.758	11.13	0.19	7.34
Sdel_2_E4_P5_Both_Post_N_12/14/2015_2:03:00 PM														7.7	389	<1	0.564	0.1	-144.3	7.94	0.763	11.35	0.22	9.36
Sieb_1_E1_P2_Both_Post_N-Dup_2/19/2014_11:50:00 AM														8.3	614	<1.00	0.847	26.12	-36	8.44	1.176	10.37	3.17	30.35
Sieb_1_E1_P2_Both_Post_Dup_2/19/2014_11:50:00 AM																	0.847	26.12	-36	8.44	1.176	10.37	3.17	30.35
Sieb_1_E1_P5_SV_Post_N_2/19/2014_5:32:00 PM														8.4	708	<1.00	0.996	2.15	1	6.95	1.386	10.26	2.33	30.77
Sieb_1_E2_P2_SV_Post_N-Dup_2/22/2014_9:48:00 AM														8.3	616	<1.00	0.841	0.15	7	8.29	1.16	10.58	1.63	29.46
Sieb_1_E2_P2_SV_Post_Dup_2/22/2014_9:48:00 AM														8.3	620	<1.00	0.841	0.15	7	8.29	1.16	10.58	1.63	29.46
Sieb_1_E2_P5_SV_Post_N_2/22/2014_3:04:00 PM														8.4	718	<1.00	0.974	0.03	-201	8.36	1.344	10.59	1.09	30.48
Sieb_1_E3_P2_SV_Post_N-Dup_2/25/2014_9:31:00 AM														8.2	598	<1.00	0.798	0.17	3	8.31	1.107	10.4	1.44	29.58
Sieb_1_E3_P2_SV_Post_Dup_2/25/2014_9:31:00 AM																	0.798	0.17	3	8.31	1.107	10.4	1.44	29.58
Sieb_1_E3_P5_SV_Post_N_2/25/2014_2:23:00 PM														8.2	792	<1.00	1.046	0.01	-211	8.38	1.447	10.51	0.62	30.29
Sieb_2_E1_P1_Both_Post_N_5/11/2015_1:45:00 PM																	0.889	1.15	-125	7.39	1.196	11.54	1.18	28.55
Sieb_2_E1_P2_Both_Post_N_5/11/2015_2:09:00 PM														8.2	578	<1.00	0.863	0.3	-188	8.24	1.171	11.22	0.67	30.05
Sieb_2_E1_P4_Both_Post_N_5/11/2015_3:46:00 PM																	1.231	0.11	-224	8.55	1.673	11.15	0.3	29.65
Sieb_2_E1_P5_Both_Post_N_5/11/2015_7:00:00 PM														8.1	1490	<1.00	2.069	0.11	-235	8.53	2.831	10.89	0.18	30.19
Sieb_2_E2_P1_Both_Post_N_7/22/2015_10:29:00 AM																	0.949	2.25	-141	6.85	1.279	11.5	7.8	29.72
Sieb_2_E2_P2_Both_Post_N_7/22/2015_10:48:00 AM														8	625	<1	0.907	0.48	-225	8.46	1.273	9.95	0.98	29.08
Sieb_2_E2_P4_Both_Post_N_7/22/2015_12:30:00 PM																	1.201	0.19	-268	8.49	1.697	9.68	1.02	29.77
Sieb_2_E2_P5_Both_Post_N_7/22/2015_3:45:00 PM														8	1300	<1	1.912	0.2	-272	8.48	2.726	9.36	0.58	30.31
Sieb_2_E3_P1_Both_Post_N_9/29/2015_10:38:00 AM																	0.986	16.25	-93.7	7.7	1.396	9.64	0.61	30.09
Sieb_2_E3_P2_Both_Post_N_9/29/2015_11:12:00 AM														8.2	655	<1	0.967	1.11	-234.8	7.81	1.4	8.82	0.76	29.91
Sieb_2_E3_P4_Both_Post_N_9/29/2015_12:46:00 PM																	1.467	2.74	-249.1	7.5	2.133	8.65	0.75	30.49
Sieb_2_E3_P5_Both_Post_N_9/29/2015_4:20:00 PM														8.1	1540	<1	2.267	2.92	-256.3	8.44	3.285	8.77	0.38	31.05
Sieb_2_E4_P1_Both_Post_N_12/2/2015_10:35:00 AM																	1.11	1.53	-118.5	7.86	1.508	11.18	0.61	28.97
Sieb_2_E4_P2_Both_Post_N_12/2/2015_11:00:00 AM														8.3	940	<1	1.328	0.33	-172.1	9.05	1.826	10.73	0.81	29.07
Sieb_2_E4_P4_Both_Post_N_12/2/2015_12:54:00 PM																	1.776	0.09	-168.9	8.56	2.443	10.7	0.25	29.51
Sieb_2_E4_P5_Both_Post_N_12/2/2015_4:15:00 PM														8.3	1670	<1	2.66	0.05	-167.3	8.23	3.666	10.64	0.19	30.15
Sim_1_E1_P2_Both_Post_N-Dup_2/18/2014_2:00:00 PM														8.1	177	<1.00	0.22	0.21	-213	8.09	0.324	8.16	2.61	28.47
Sim_1_E1_P2_Both_Post_Dup_2/18/2014_2:00:00 PM																	0.22	0.21	-213	8.09	0.324	8.16	2.61	28.47
Sim_1_E1_P5_SV_Post_N_2/18/2014_5:05:00 PM														8.1	193	<1.00	0.237	0.05	-343	8.18	0.351	8.01	0.86	31.14
Sim_1_E2_P2_SV_Post_N-Dup_2/21/2014_2:58:00 PM														8.3	166	<1.00	0.232	0.24	-200	8.23	0.343	7.95	2.92	29.79
Sim_1_E2_P2_SV_Post_Dup_2/21/2014_2:58:00 PM																	0.232	0.24	-200	8.23	0.343	7.95	2.92	29.79
Sim_1_E2_P5_SV_Post_N_2/21/2014_5:45:00 PM														8.2	181	<1.00	0.248	0.04	-205	8.23	0.367	8	1.61	31.32
Sim_1_E3_P2_SV_Post_N-Dup_2/24/2014_2:45:00 PM														8.2	178	<1.00	0.22	0.36	-202	8.01	0.327	7.91	2.72	29.27
Sim_1_E3_P2_SV_Post_Dup_2/24/2014_2:45:00 PM														8.1	179	<1.00	0.22	0.36	-202	8.01	0.327	7.91	2.72	29.27
Sim_1_E3_P5_SV_Post_N_2/24/2014_5:30:00 PM														8.2	179	<1.00	0.239	0.05	-222	8.2	0.355	7.87	1.67	31.57
Sim_2_E1_P1_Both_Post_N_4/30/2015_3:40:00 PM																	0.213	7.44	-114	7.97	0.312	8.38	1.8	27.25
Sim_2_E1_P2_Both_Post_N_4/30/2015_4:00:00 PM														7.9	174	<1.00	0.214	0.26	-174	7.73	0.307	9.09	1.16	27.77
Sim_2_E1_P4_Both_Post_N_4/30/2015_4:45:00 PM																	0.227	0.08	-73	7.96	0.325	9.25	0.91	28.8
Sim_2_E1_P5_Both_Post_N_4/30/2015_6:25:00 PM														8.1	185	<1.00	0.232	0.05	-89	8.03	0.332	9.33	0.66	30.3
Sim_2_E2_P1_Both_Post_N_7/15/2015_10:46:00 AM																	0.227	2.09	-202.4	7.33	0.323	9.38	2.07	27.21
Sim_2_E2_P2_Both_Post_N_7/15/2015_11:08:00 AM														8.1	174	<1	0.226	0.73	-250.6	7.88	0.326	8.96	1.44	29.62
Sim_2_E2_P4_Both_Post_N_7/15/2015_11:59:00 AM																	0.232	0.78	-266.6	8.06	0.339	8.57	1.49	28.46
Sim_2_E2_P5_Both_Post_N_7/15/2015_1:40:00 PM														8	179	<1	0.239	1.64	-280.3	8.05	0.347	8.71	1.92	29.51
Sim_2_E3_P1_Both_Post_N_9/28/2015_10:05:00 AM																	0.233	1.56	-172.4	7.74	0.324	10.3	0.55	29.32
Sim_2_E3_P2_Both_Post_N_9/28/2015_10:33:00 AM														8.1	179	<1	0.221	5.82	-243.6	7.7	0.322	8.53	0.51	29.82
Sim_2_E3_P4_Both_Post_N_9/28/2015_11:22:00 AM																	0.232	0.59	-258.2	7.73	0.342	8.21	0.73	31.98
Sim_2_E3_P5_Both_Post_N_9/28/2015_1:12:00 PM														8.2	186	<1	0.238	2.66	-265.7	7.56	0.351	8.13	0.64	31.48
Sim_2_E4_P1_Both_Post_N_12/7/2015_1:48:00 PM																	0.233	2.11	441.9	7.07	0.334	9.17	0.8	25.94
Sim_2_E4_P2_Both_Post_N_12/7/2015_2:13:00 PM														7.8	171	<1	0.241	0.54	514.6	7.51	0.343	9.45	0.96	29.56
Sim_2_E4_P4_Both_Post_N_12/7/2015_3:13:00 PM																	0.223	0.38	-177.3	8.94	0.317	9.53	0.82	29.76

Notes:

1) **Study**: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) **Sample Type:** N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) **Purge Abbreviation:** P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-1
ANALYTICAL RESULTS:
PURGE AND TEMPORAL VARIABILITY STUDIES

Analyte Group:	Water Quality																Field Parameters / Water Level							
Analyte:	Barium, dissolved	Cadmium, dissolved	Calcium, dissolved	Chromium, dissolved	Iron, dissolved	Lead, dissolved	Magnesium, dissolved	Manganese, dissolved	Potassium, dissolved	Selenium, dissolved	Silver, dissolved	Sodium, dissolved	Strontium, dissolved	pH	Total Dissolved Solids	Total Suspended Solids	Conductivity	Dissolved Oxygen	ORP	pH	Specific Conductivity	Temperature	Turbidity	Water Level
Laboratory:	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Lancaster	Field	Field	Field	Field	Field	Field	Field	Field
Sample ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	s.u.	mg/L	mg/L	mS/cm	mg/L	mV	s.u.	mS/cm	°C	NTU	ft BTOC
Sim_2_E4_P5_Both_Post_N_12/7/2015_4:46:00 PM														7.8	173	1 J	0.228	0.13	-189.6	8.69	0.325	9.29	0.52	29.33
Wal_1_E01_P2_TV_Post_N_12/30/2013_1:05:00 PM	1.13	<0.00023	14.4	<0.0005	<0.0163	<0.000085	4.09	0.0298	1.67	<0.0005	<0.00011	39.7	0.683	7.9	150	<1	0.205	0.26	31.6	8.22	0.291	9.48	1.2	36.15
Wal_1_E02_P2_TV_Post_N_1/21/2014_2:50:00 PM														8.2	156	<1.00	0.19	0.09	-130.1	8.27	0.288	9.47	0.81	36.69
Wal_1_E03_P2_TV_Post_N-Dup_2/26/2014_1:20:00 PM														8.1	162	<1.00	0.2	0.23	-188.8	8.36	0.285	9.08	0.4	35.52
Wal_1_E04_P2_TV_Post_N_3/26/2014_1:13:00 PM														8.3	161	<1.00	0.178	0.38	-186.8	8.22	0.271	8.22	0.72	35.63
Wal_1_E05_P2_TV_Post_N_4/30/2014_1:10:00 PM														7.9	175	<1.00	0.207	0.24	-147.2	8.07	0.291	9.73	0.56	36.51
Wal_1_E06_P2_TV_Post_N_5/20/2014_1:00:00 PM														8.1	167	<1.00	0.209	0.25	-233.8	8.26	0.289	10.42	0.61	36.29
Web_1_E01_P2_TV_Post_N_12/19/2013_2:45:00 PM	1.72	<0.00023	20.8	<0.0005	<0.0163	<0.000085	4.59	0.0222	1.91	<0.0005	<0.00011	48.4	1.02	8	174	<1	0.252	1.6	-184	8.17	0.36	9.28	0.8	6.71
Web_1_E02_P2_TV_Post_N_1/21/2014_8:05:00 PM														8.3	193	<1.00	0.263	0.13	-111	8.23	0.372	9.67	1.67	4.59
Web_1_E1_P2_Both_Post_N-Dup_2/17/2014_10:30:00 AM														8.2	186	<1.00	0.255	0.16	-175	8.2	0.368	8.91	0.72	10.39
Web_1_E1_P2_Both_Post_Dup_2/17/2014_10:30:00 AM														8.2	194	<1.00	0.255	0.16	-175	8.2	0.368	8.91	0.72	10.39
Web_1_E1_P5_SV_Post_N_2/17/2014_1:45:00 PM														8.2	185	<1.00	0.252	0	-200	8.18	0.358	9.49	0.82	13.63
Web_1_E2_P2_SV_Post_N-Dup_2/21/2014_9:33:00 AM														8.3	187	<1.00	0.263	0.41	-169	8.22	0.38	8.89	2.11	7.97
Web_1_E2_P2_SV_Post_Dup_2/21/2014_9:33:00 AM																	0.263	0.41	-169	8.22	0.38	8.89	2.11	7.97
Web_1_E2_P5_SV_Post_N_2/21/2014_12:50:00 PM														8.2	184	<1.00	0.26	0.03	-189	8.31	0.372	9.25	1.37	11.17
Web_1_E3_P2_SV_Post_N-Dup_2/24/2014_9:45:00 AM														8.3	196	<1.00	0.254	0.26	-188	8.36	0.369	8.67	3.21	7.94
Web_1_E3_P2_SV_Post_Dup_2/24/2014_9:45:00 AM																	0.254	0.26	-188	8.36	0.369	8.67	3.21	7.94
Web_1_E3_P5_SV_Post_N_2/24/2014_1:00:00 PM														8.2	186	<1.00	0.251	0.03	-198	8.33	0.359	9.35	1.49	10.27
Web_1_E04_P2_TV_Post_N-Dup_3/26/2014_3:57:00 PM														8.3	192	<1.00	0.236	0.37	-150	8.23	0.34	8.98	2.69	5.85
Web_1_E05_P2_TV_Post_N_4/23/2014_2:45:00 PM														7.9	196	<1.00	0.25	0.09	-125	8.25	0.347	10.35	0.65	4.4
Web_1_E06_P2_TV_Post_N_5/21/2014_12:56:00 PM														8.1	204	<1.00	0.295	0.58	-185	8.35	0.405	10.73	0.72	5.52
Web_2_E1_P1_Both_Post_N_5/12/2015_1:40:00 PM																	0.005	5.43	134	6.18	0.004	31.74	2.69	10.16
Web_2_E1_P1.5_Both_Post_N_5/12/2015_2:10:00 PM																	0.271	0.21	-179	8.08	0.367	11.37	0.45	7.11
Web_2_E1_P2_Both_Post_N-Dup_5/12/2015_2:40:00 PM														8	190	<1.00	0.265	0.15	-177	8.28	0.363	10.89	1.15	8.85
Web_2_E1_P2_Both_Post_Dup_5/12/2015_2:40:00 PM														8	196	<1.00	0.265	0.15	-177	8.28	0.363	10.89	1.15	8.85
Web_2_E1_P5_Both_Post_N_5/12/2015_4:45:00 PM														8.1	194	<1.00	0.26	0.09	-181	8.25	0.357	10.77	0.71	12.35
Web_2_E2_P1_Both_Post_N_7/23/2015_9:35:00 AM																	0.271	1.02	-225	7.44	0.369	11.1	3.83	9.54
Web_2_E2_P1.5_Both_Post_N_7/23/2015_10:08:00 AM																	0.271	1.02	-225	7.44	0.369	11.1	1.01	9.54
Web_2_E2_P2_Both_Post_N_7/23/2015_10:43:00 AM														8	195	<1	0.265	0.3	-247	8.22	0.375	9.62	0.43	8.08
Web_2_E2_P5_Both_Post_N_7/23/2015_12:48:00 PM														7.9	184	<1	0.261	0.16	-236	8.25	0.367	9.92	0.61	8.57
Web_2_E3_P1_Both_Post_N_9/30/2015_10:35:00 AM																	0.269	4.8	-34.6	6.84	0.382	9.53	0.16	6.41
Web_2_E3_P1.5_Both_Post_N_9/30/2015_11:08:00 AM																	0.263	1.03	-195.8	6.8	0.382	8.69	0.09	9.3
Web_2_E3_P2_Both_Post_N_9/30/2015_11:51:00 AM														8.2	234	<1	0.26	3.66	-188.9	6.75	0.378	8.64	0.52	8.9
Web_2_E3_P5_Both_Post_N_9/30/2015_2:15:00 PM														8.1	206	<1	0.256	3.1	-192.3	7.04	0.373	8.51	0.18	10.92
Web_2_E4_P1_Both_Post_N_12/10/2015_9:58:00 AM																	0.257	1.89	-175.6	8.16	0.357	10.34	0.95	9.76
Web_2_E4_P1.5_Both_Post_N_12/10/2015_10:31:00 AM																	0.258	0.4	-170.6	8.76	0.358	10.37	0.47	7.21
Web_2_E4_P2_Both_Post_N_12/10/2015_11:11:00 AM														8	200	4.2	0.254	0.29	-149.6	8.59	0.353	10.38	0.36	9.92
Web_2_E4_P5_Both_Post_N_12/10/2015_1:33:00 PM														8	185	<1	0.251	0.12	-159.2	8.49	0.347	10.47	0.46	11.83

Notes:

1) Study: Temp = Temporal variability evaluation; Purge = purging variability evaluation; Both = samples utilized in both evaluations

2) Sample Type: N = Primary sample; N-dup = primary sample with a paried duplicate; Dup = duplicate sample (Note: some duplicate samples were just collected for water quality analysis.)

3) Purge Abbreviation: P1 = one-half gallon, P1.5 = 1 pressure tank volume; P2 = parameter stabilization or 2 pressure tank volumes; P4 = 1 casing volume; P5 = 3 casing volumes

(Note: At the Web well, 2 pressure tank volumes and 1 casing volume were approximately equal.)

TABLE H-2
ANALYTICAL RESULTS:
SAMPLES COLLECTED FROM LOCATIONS PRE- VERSUS POST-PRESSURE TANK

								Analyte Group:	**Dissolved Light Hydrocarbon Gases (IsoFlask)**		
								Analyte:	**Methane**	**Ethane**	**Propane**
								Laboratory:	**Isotech**	**Isotech**	**Isotech**
Well #	**Location ID**	**Purge Abbreviation**	**Purge Volume**	**Pre / Post Pressure Tank**	**Sample Date**	**Sample Time**	**Sample Type**	**Sample ID**	**ug/L**	**ug/L**	**ug/L**
W1	Loc	P5	3 casing volumes	Pre	5/4/2015	6:40:00 PM	N	Loc_2_E1_P5_Both_Pre_N_5/4/2015_6:40:00 PM	10000	0.9	<0.3
W1	Loc	P5	3 casing volumes	Post	5/4/2015	6:40:00 PM	N	Loc_2_E1_P5_Both_Post_N_5/4/2015_6:40:00 PM	10000	0.85	<0.3
W1	Loc	P5	3 casing volumes	Pre	7/14/2015	6:30:00 PM	N	Loc_2_E2_P5_Both_Pre_N_7/14/2015_6:30:00 PM	9400	0.85	<0.3
W1	Loc	P5	3 casing volumes	Post	7/14/2015	6:30:00 PM	N	Loc_2_E2_P5_Both_Post_N_7/14/2015_6:30:00 PM	8900	0.88	<0.3
W1	Loc	P5	3 casing volumes	Pre	9/23/2015	7:34:00 PM	N	Loc_2_E3_P5_Both_Pre_N_9/23/2015_7:34:00 PM	10000	1.3	<0.3
W1	Loc	P5	3 casing volumes	Post	9/23/2015	7:36:00 PM	N	Loc_2_E3_P5_Both_Post_N_9/23/2015_7:36:00 PM	10000	1.4	<0.2
W1	Loc	P5	3 casing volumes	Pre	12/1/2015	7:40:00 PM	N	Loc_2_E4_P5_Both_Pre_N_12/1/2015_7:40:00 PM	11000	1.4	<0.3
W1	Loc	P5	3 casing volumes	Post	12/1/2015	7:40:00 PM	N	Loc_2_E4_P5_Both_Post_N_12/1/2015_7:40:00 PM	11000	1.3	<0.3
W2	Sim	P5	3 casing volumes	Pre	4/30/2015	6:25:00 PM	N	Sim_2_E1_P5_Both_Pre_N_4/30/2015_6:25:00 PM	3500	0.56	<0.3
W2	Sim	P5	3 casing volumes	Post	4/30/2015	6:25:00 PM	N	Sim_2_E1_P5_Both_Post_N_4/30/2015_6:25:00 PM	3300	0.56	<0.3
W2	Sim	P5	3 casing volumes	Pre	7/15/2015	1:40:00 PM	N	Sim_2_E2_P5_Both_Pre_N_7/15/2015_1:40:00 PM	3400	0.58	<0.3
W2	Sim	P5	3 casing volumes	Post	7/15/2015	1:40:00 PM	N	Sim_2_E2_P5_Both_Post_N_7/15/2015_1:40:00 PM	3300	0.6	<0.3
W2	Sim	P5	3 casing volumes	Pre	9/28/2015	1:09:00 PM	N	Sim_2_E3_P5_Both_Pre_N_9/28/2015_1:09:00 PM	3500	0.87	<0.3
W2	Sim	P5	3 casing volumes	Post	9/28/2015	1:12:00 PM	N	Sim_2_E3_P5_Both_Post_N_9/28/2015_1:12:00 PM	3300	0.79	<0.3
W2	Sim	P5	3 casing volumes	Pre	12/7/2015	4:46:00 PM	N	Sim_2_E4_P5_Both_Pre_N_12/7/2015_4:46:00 PM	3600	0.78	<0.3
W2	Sim	P5	3 casing volumes	Post	12/7/2015	4:46:00 PM	N	Sim_2_E4_P5_Both_Post_N_12/7/2015_4:46:00 PM	3400	0.73	<0.2
W3	Jon	P5	3 casing volumes	Pre	4/28/2015	1:05:00 PM	N	Jon_2_E1_P5_Both_Pre_N_4/28/2015_1:05:00 PM	32000	10	<0.3
W3	Jon	P5	3 casing volumes	Post	4/28/2015	1:05:00 PM	N	Jon_2_E1_P5_Both_Post_N_4/28/2015_1:05:00 PM	29000	9.4	<0.3
W3	Jon	P5	3 casing volumes	Pre	7/16/2015	11:12:00 AM	N	Jon_2_E2_P5_Both_Pre_N_7/16/2015_11:12:00 AM	29000	9.8	<0.3
W3	Jon	P5	3 casing volumes	Post	7/16/2015	11:12:00 AM	N	Jon_2_E2_P5_Both_Post_N_7/16/2015_11:12:00 AM	29000	9.8	<0.3
W3	Jon	P5	3 casing volumes	Pre	9/28/2015	4:47:00 PM	N	Jon_2_E3_P5_Both_Pre_N_9/28/2015_4:47:00 PM	29000	9.4	<0.3
W3	Jon	P5	3 casing volumes	Post	9/28/2015	4:49:00 PM	N	Jon_2_E3_P5_Both_Post_N_9/28/2015_4:49:00 PM	28000	9.1	<0.3
W3	Jon	P5	3 casing volumes	Pre	12/7/2015	11:57:00 AM	N	Jon_2_E4_P5_Both_Pre_N_12/7/2015_11:57:00 AM	32000	10	<0.3
W3	Jon	P5	3 casing volumes	Post	12/7/2015	11:57:00 AM	N	Jon_2_E4_P5_Both_Post_N_12/7/2015_11:57:00 AM	29000	9.4	<0.3
W4	Web	P5	3 casing volumes	Pre	5/12/2015	4:45:00 PM	N	Web_2_E1_P5_Both_Pre_N_5/12/2015_4:45:00 PM	12000	2	<0.3
W4	Web	P5	3 casing volumes	Post	5/12/2015	4:45:00 PM	N	Web_2_E1_P5_Both_Post_N_5/12/2015_4:45:00 PM	11000	2.2	<0.3
W4	Web	P5	3 casing volumes	Pre	7/23/2015	12:48:00 PM	N	Web_2_E2_P5_Both_Pre_N_7/23/2015_12:48:00 PM	11000	2	<0.2
W4	Web	P5	3 casing volumes	Post	7/23/2015	12:48:00 PM	N	Web_2_E2_P5_Both_Post_N_7/23/2015_12:48:00 PM	11000	2.2	<0.3
W4	Web	P5	3 casing volumes	Pre	9/30/2015	2:18:00 PM	N	Web_2_E3_P5_Both_Pre_N_9/30/2015_2:18:00 PM	11000	2.5	<0.3
W4	Web	P5	3 casing volumes	Post	9/30/2015	2:15:00 PM	N	Web_2_E3_P5_Both_Post_N_9/30/2015_2:15:00 PM	11000	2.4	<0.2
W4	Web	P5	3 casing volumes	Pre	12/10/2015	1:33:00 PM	N	Web_2_E4_P5_Both_Pre_N_12/10/2015_1:33:00 PM	12000	2.6	<0.3
W4	Web	P5	3 casing volumes	Post	12/10/2015	1:33:00 PM	N	Web_2_E4_P5_Both_Post_N_12/10/2015_1:33:00 PM	11000	2.6	<0.3
W5	Rath	P5	3 casing volumes	Pre	5/1/2015	2:25:00 PM	N	Rath_2_E1_P5_Both_Pre_N_5/1/2015_2:25:00 PM	69000	42	<0.2
W5	Rath	P5	3 casing volumes	Post	5/1/2015	2:25:00 PM	N	Rath_2_E1_P5_Both_Post_N_5/1/2015_2:25:00 PM	52000	31	<0.2
W5	Rath	P5	3 casing volumes	Pre	7/16/2015	8:05:00 PM	N	Rath_2_E2_P5_Both_Pre_N_7/16/2015_8:05:00 PM	29000	8.1	<0.3
W5	Rath	P5	3 casing volumes	Post	7/16/2015	8:05:00 PM	N	Rath_2_E2_P5_Both_Post_N_7/16/2015_8:05:00 PM	61000	39	<0.2
W5	Rath	P5	3 casing volumes	Pre	9/24/2015	2:52:00 PM	N	Rath_2_E3_P5_Both_Pre_N_9/24/2015_2:52:00 PM	41000	17	<0.2
W5	Rath	P5	3 casing volumes	Post	9/24/2015	2:50:00 PM	N	Rath_2_E3_P5_Both_Post_N_9/24/2015_2:50:00 PM	54000	31	<0.3
W5	Rath	P5	3 casing volumes	Pre	12/3/2015	2:43:00 PM	N	Rath_2_E4_P5_Both_Pre_N_12/3/2015_2:43:00 PM	40000	12	<0.3
W5	Rath	P5	3 casing volumes	Post	12/3/2015	2:43:00 PM	N	Rath_2_E4_P5_Both_Post_N_12/3/2015_2:43:00 PM	51000	31	<0.2
W7	Sieb	P5	3 casing volumes	Pre	5/11/2015	7:00:00 PM	N	Sieb_2_E1_P5_Both_Pre_N_5/11/2015_7:00:00 PM	62000	20	<0.3
W7	Sieb	P5	3 casing volumes	Post	5/11/2015	7:00:00 PM	N	Sieb_2_E1_P5_Both_Post_N_5/11/2015_7:00:00 PM	73000	25	<0.3
W7	Sieb	P5	3 casing volumes	Pre	7/22/2015	3:45:00 PM	N	Sieb_2_E2_P5_Both_Pre_N_7/22/2015_3:45:00 PM	64000	20	<0.2
W7	Sieb	P5	3 casing volumes	Post	7/22/2015	3:45:00 PM	N	Sieb_2_E2_P5_Both_Post_N_7/22/2015_3:45:00 PM	65000	21	<0.2
W7	Sieb	P5	3 casing volumes	Pre	9/29/2015	4:23:00 PM	N	Sieb_2_E3_P5_Both_Pre_N_9/29/2015_4:23:00 PM	64000	20	<0.2
W7	Sieb	P5	3 casing volumes	Post	9/29/2015	4:20:00 PM	N	Sieb_2_E3_P5_Both_Post_N_9/29/2015_4:20:00 PM	70000	22	<0.3
W7	Sieb	P5	3 casing volumes	Pre	12/2/2015	4:15:00 PM	N	Sieb_2_E4_P5_Both_Pre_N_12/2/2015_4:15:00 PM	89000	30	<0.3
W7	Sieb	P5	3 casing volumes	Post	12/2/2015	4:15:00 PM	N	Sieb_2_E4_P5_Both_Post_N_12/2/2015_4:15:00 PM	82000	27	<0.3
W8	Sdel	P5	3 casing volumes	Pre	4/29/2015	2:25:00 PM	N	Sdel_2_E1_P5_Both_Pre_N_4/29/2015_2:25:00 PM	17000	4.6	<0.3
W8	Sdel	P5	3 casing volumes	Post	4/29/2015	2:25:00 PM	N	Sdel_2_E1_P5_Both_Post_N_4/29/2015_2:25:00 PM	18000	5	<0.3
W8	Sdel	P5	3 casing volumes	Pre	7/20/2015	4:35:00 PM	N	Sdel_2_E2_P5_Both_Pre_N_7/20/2015_4:35:00 PM	16000	4.4	<0.3
W8	Sdel	P5	3 casing volumes	Post	7/20/2015	4:35:00 PM	N	Sdel_2_E2_P5_Both_Post_N_7/20/2015_4:35:00 PM	16000	4.5	<0.3

Notes:
1) Sample Type: N = Primary sample

TABLE H-2
ANALYTICAL RESULTS:
SAMPLES COLLECTED FROM LOCATIONS PRE- VERSUS POST-PRESSURE TANK

								Analyte Group:	**Dissolved Light Hydrocarbon Gases (IsoFlask)**		
								Analyte:	**Methane**	**Ethane**	**Propane**
								Laboratory:	**Isotech**	**Isotech**	**Isotech**
Well #	**Location ID**	**Purge Abbreviation**	**Purge Volume**	**Pre / Post Pressure Tank**	**Sample Date**	**Sample Time**	**Sample Type**	**Sample ID**	**ug/L**	**ug/L**	**ug/L**
W8	Sdel	P5	3 casing volumes	Pre	9/22/2015	4:20:00 PM	N	Sdel_2_E3_P5_Both_Pre_N_9/22/2015_4:20:00 PM	18000	5.2	<0.3
W8	Sdel	P5	3 casing volumes	Post	9/22/2015	4:15:00 PM	N	Sdel_2_E3_P5_Both_Post_N_9/22/2015_4:15:00 PM	18000	5.1	<0.3
W9	Sbar	P5	3 casing volumes	Pre	5/19/2015	1:43:00 PM	N	Sbar_2_E1_P5_Both_Pre_N_5/19/2015_1:43:00 PM	6900	1.8	<0.3
W9	Sbar	P5	3 casing volumes	Post	5/19/2015	1:43:00 PM	N	Sbar_2_E1_P5_Both_Post_N_5/19/2015_1:43:00 PM	4800	1.4	<0.3
W9	Sbar	P5	3 casing volumes	Pre	7/23/2015	6:25:00 PM	N	Sbar_2_E2_P5_Both_Pre_N_7/23/2015_6:25:00 PM	6300	1.8	<0.2
W9	Sbar	P5	3 casing volumes	Post	7/23/2015	6:25:00 PM	N	Sbar_2_E2_P5_Both_Post_N_7/23/2015_6:25:00 PM	5600	1.7	<0.3
W9	Sbar	P5	3 casing volumes	Pre	10/5/2015	2:19:00 PM	N	Sbar_2_E3_P5_Both_Pre_N_10/5/2015_2:19:00 PM	4900	1.9	<0.3
W9	Sbar	P5	3 casing volumes	Post	10/5/2015	2:26:00 PM	N	Sbar_2_E3_P5_Both_Post_N_10/5/2015_2:26:00 PM	4100	1.5	<0.3
W9	Sbar	P5	3 casing volumes	Pre	12/8/2015	2:57:00 PM	N	Sbar_2_E4_P5_Both_Pre_N_12/8/2015_2:57:00 PM	7500	2.4	<0.3
W9	Sbar	P5	3 casing volumes	Post	12/8/2015	2:57:00 PM	N	Sbar_2_E4_P5_Both_Post_N_12/8/2015_2:57:00 PM	5200	1.7	<0.3

Notes:
1) Sample Type: N = Primary sample

APPENDIX I

BASELINE SAMPLING FOR DISSOLVED METHANE

SUPPORTING DATA ANALYSES

APPENDIX I

BASELINE SAMPLING FOR DISSOLVED METHANE IN AREAS OF SHALE OIL AND GAS DEVELOPMENT

Supporting Data Analyses

I1. Effect of Sample Collection Method on Measured Methane Concentrations

<u>Key Finding:</u> For all three methods, the variability associated with field duplicate samples was small (typically less than 15%).

To evaluate the variability of dissolved methane concentrations for duplicate samples collected for each of the three methods, we calculated the percent variability between each pair of duplicate samples. For all three methods, the variability associated with field duplicate samples was small. Specifically, 85% (23/27) of Direct-Fill VOA field duplicate pairs, 74% (20/27) of Inverted VOA field duplicate pairs (all collected using the high-flush variant), and 85% (22/26) of IsoFlask™ field duplicate pairs had a percent variability less than 15% (see **Figure I-1**). Of the three methods, the high-flush Inverted VOA method exhibited the highest duplicate variabilities of the three sample collection methods (median percent variability = 9.1%). This was significantly higher than the duplicate variabilities for samples collected using the IsoFlask™ method (median percent variability =5.0%, p=0.016, one-sided Wilcoxon-Mann-Whitney test). Conversely, the Direct-Fill VOA and IsoFlask™ methods exhibited similar duplicate variabilities (i.e., median percent variability of 6.4% versus 5%, respectively, p=0.219, one-sided Wilcoxon-Mann-Whitney test). For all sampling methods, there was no clear relationship between percent variability and methane concentrations (i.e., higher duplicate variability did not necessarily occur in association with higher methane concentrations) (see **Figure H-1**).

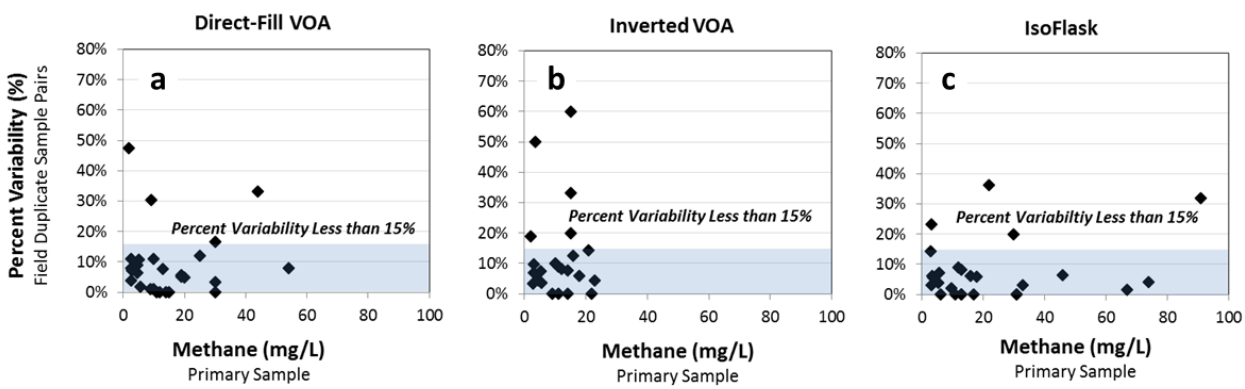

Figure I-1. *Percent variability of methane concentrations for field duplicate samples collected using a) Direct-Fill VOA method, b) Inverted VOA Method, and c) IsoFlask™ method.*

I2. Effect of Purge Volume on Measured Methane Concentrations

<u>Key Finding:</u> The variability of dissolved methane concentrations among samples collected after purging one or more casing volumes is not significantly different the variability measured among samples collected after only purging low water volumes.

Lastly, to assess whether purging 1- to 3-casing volumes produced more consistent methane concentrations across multiple sampling events over time than a low-volume purge, the variability of methane concentrations reported for the three purge volumes at a given well was evaluated by

calculating the coefficient of variation (CV) of reported methane concentrations for each purge volume at each well. Results are summarized in **Table I-1.** The similar median CVs calculated for a low-volume purge, medium-volume purge, and a high-volume purge (i.e., 0.11, 0.07, and 0.10, respectively) suggest that purging larger volumes of water (e.g., 1- to 3-casing volumes) does not produce more consistent dissolved methane concentrations over time than a low-volume purge (i.e., a purge volume between 1 and 3 pressure tank volumes).

Table I-1. *Range and median CV for the samples collected during multiple purge events over time after a) a low-volume purge, b) medium-volume purge, and c) a high-volume purge.*

Purge Step	Number of Purge Events	Range of CVs Calculated for Wells	Median CV Reported for Wells
Low-Volume Purge	59 (9 wells)	0.04 – 0.47	0.11
Medium-Volume Purge	32 (8 wells)	0.02 – 0.30	0.07
High-Volume Purge	59 (9 wells)	0.03 – 0.53	0.10

I3. Temporal Variability of Measured Methane Concentrations

<u>Supporting Finding:</u> Two wells exhibit a statistically significant trend in naturally occurring methane concentration over time.

As a first step to evaluating temporal variability of dissolved methane among the population of wells, we determined whether any wells exhibited trends over time in methane concentration (i.e., increasing or decreasing). Specifically, we evaluated plots of concentration versus time and determined whether the slope of the best-fit line for methane concentration versus time at each well displayed a statistically significant difference from a zero slope (see **Table I-2**). Based on this analysis, 8 out of 10 wells did not exhibit any trend in methane concentration over time (where one well, the Web well, exhibited a statistically significant trend that was found to be an artifact of random variability (see **Figure I-2a**). Two wells were found to exhibit a statistically significant trend (i.e., Jon, p=0.004, Wal, p=0.01, F-test of Overall Significance) that was visually confirmed in plots of concentration versus time (see **Figures I-2b,c**). For these wells, we evaluated the magnitude of change over time in a) methane concentration and b) isotopic composition of methane to confirm that the apparent trends are related to natural phenomena. At both wells, the magnitude of change in methane concentration over time (i.e., the percent variability) was ≤17%, and the stable carbon isotopic composition of methane remained relatively unchanging over the 2-year timeframe at (i.e., $\delta^{13}C \pm 1‰$ compared to maximum laboratory variability of ±0.4‰). The fact that both wells appear to have a relatively constant source of methane, in combination with the small relative variability in methane concentration (i.e., 15 – 17%), suggests that these trends are related to natural phenomena.

Table I-2. *Slope, R^2 value, and statistical significance of best fit line through methane concentrations over time at each well.*

Well	Slope	R^2 Value	P-value	Statistically Significant?
Jon	4.58	0.58	0.004	**Yes (95% Conf.)**
Loc	1.86	0.13	0.24	No
Marc	-4.45	0.35	0.30	No
Rath	-4.34	0.02	0.78	No
Sbar	1.55	0.03	0.64	No
Sdel	1.41	0.14	0.40	No
Sieb	10.00	0.11	0.48	No
Sim	-0.76	0.51	0.07	No
Wal	-1.71	0.83	0.01	**Yes (95% Conf.)**
Web	-1.25	0.43	0.02	**Yes (95% Conf.)**

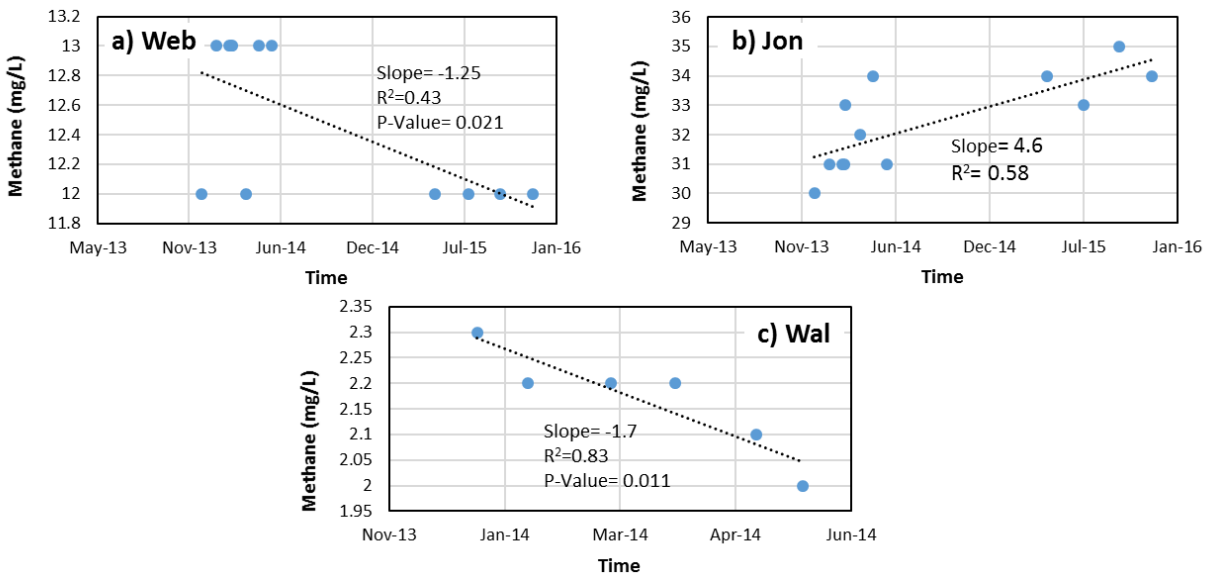

Figure I-2. *Dissolved methane concentrations for low-volume purge samples over time and best-fit lines at a) Web well, b) Jon well, and c) the Wal well.*

<u>Key Finding:</u> A longer time interval between sampling events does not result in greater variability of dissolved methane concentration than a shorter time interval between events.

For the 8 wells that did not exhibit any trend in methane concentration over time, the first step in evaluating temporal variability of dissolved methane was to determine whether long-term temporal variability (i.e., spacing of a week or more between sampling events) was greater than short-term variability (i.e., spacing of days between sampling events) for samples collected after a low-volume purge. To evaluate whether events spaced further apart showed more variability in dissolved methane concentration than those spaced closer together, the percent variability in methane concentrations reported after a low-volume purge for any combination of two sampling events at the same well (i.e., Event 1 vs. Event 2, Event 2 vs. Event 3, Event 1 vs. Event 3, and so-forth) was compared to the number of days between sampling events (see **Figure I-3**). Event pairs were divided into four groups: a) sampling events separated by 7 days or less (20 event

pairs), b) sampling events separated by >7 to 50 days (21 event pairs), c) sampling events separated by >50 to 365 days (77 event pairs), and d) sampling events separated by 365 days or more (102 event pairs). As shown in **Table I-3**, all four groups exhibited median percent variabilities between 12% and 17%. In addition, there was no statistically significant difference between the three groups of event pairs using a two-sided Wilcoxon-Mann-Whitney test ($p > 0.05$ for all pair-wise comparisons), indicating that a longer spacing between sampling events (i.e., weeks or months) does not appear to be associated with greater variability in dissolved methane concentrations. Consequently, all sampling events from these 8 wells were included in the evaluation of temporal variability of methane concentration over time.

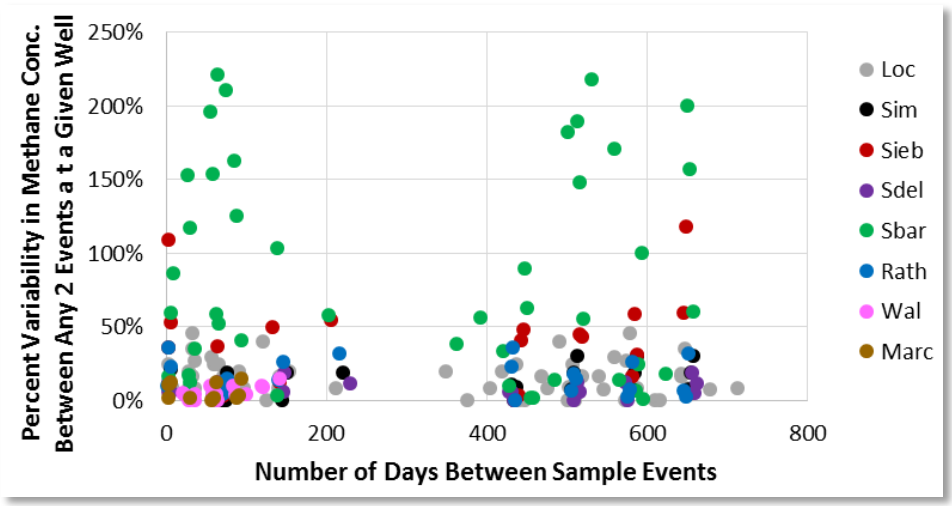

Figure I-3. *Percent variability of methane concentration between any two sampling events at a given water well (where every sample was collected in an IsoFlask™ after a low-volume purge) versus the number of days between sampling events.*

Table I-3. *Percent variability in methane concentration for event pairs where events were spaced a) ≤ 7 days, b) >7 to ≤ 30 days, c) >30 to 365 days, and d) >365 days.*

Spacing Between Sampling Events	Number of Event Pairs	Range of Percent Variability Reported for Event Pairs	Median Percent Variability
≤ 7 days	20	0 to 109%	14%
>7 to ≤ 50 days	21	0 to 153%	17%
>50 to ≤ 365 days	77	0 to 221%	12%
>365 days	102	0 to 218%	16%

I4. Relationship between Dissolved Methane and Salinity Indicator Parameters

<u>Key Finding:</u> Among the population of wells, dissolved methane concentration is positively correlated with parameters associated with increasing volumetric contributions of sodium-chloride and sodium-bicarbonate water types (i.e., sodium, chloride, specific conductivity, TDS, bromide).

To assess the relationship between dissolved methane concentration and concentrations of other parameters at the study wells, methane concentrations reported for all 150 IsoFlask™ samples collected after a low-volume purge and high-volume purge in the study were evaluated for

statistical associations with the full suite of water quality and field parameters for which data were available (i.e., 24 water quality parameters and 5 field parameters, as listed below **Table I-4**).

Specifically, the strength of the relationship between dissolved methane concentration and water quality parameters was evaluated using the Spearman's rank correlation coefficient for non-parametric data (where the distribution of dissolved methane concentrations in the 150 samples evaluated did not display a normal bell-shaped pattern). For the Spearman's rank correlation coefficient, the correlation (or dependence) between two variables is assigned a value between -1 and +1, where -1 is a perfect negative correlation, 0 is no correlation, and +1 is a perfect positive correlation. The Spearman's rho (r_s) value is classified according to the strength of the relationship as shown below.

Spearman's rho (r_s)	Strength of Relationship
.00 - .19	Very Weak
.20 - .39	Weak
.40 - .59	Moderate
.60 - .79	Strong
.80 – 1.0	Very Strong

The statistical confidence in the relationship described by the correlation coefficient is expressed through a p-value, where a p-value less than 0.5 suggests a 95% probability that the relationship is real, and a p-value less than 0.1 suggests a 99% probability that the relationship is real.

As shown on **Table I-4** below, based on a Spearman's correlation test, detected concentrations of dissolved methane in the dataset of 150 samples from 10 residential water wells (91 samples collected after stability low-volume purge and 59 samples collected after a high-volume purge) exhibited a very strong or strong correlation with the following 6 parameters: total dissolved solids (TDS), specific conductivity, sodium, chloride, bromide, and sulfate. These findings suggest that methane correlates strongly with parameters associated with a sodium-rich water source and reducing conditions in this dataset, as seen in prior studies (e.g., McPhillips et al., 2014; Molofsky et al., 2013, 2016a; Perry et al., 2012; Siegel et al., 2015b, 2016).

Table I-4. *Statistically Significant Relationships (p<0.01) between Methane and other Parameters, as Described by Spearman's r_s Statistic.*

Parameter	Spearman's r Statistic (r_s)	p-value	Strength of Relationship with Methane
Total Dissolved Solids	0.85012	4.61E-43	Very strong
Specific Conductivity	0.84951	6.08E-43	Very strong
Sodium	0.82413	2.30E-38	Very strong
Chloride	0.71977	3.14E-25	Strong
Bromide	0.67644	2.11E-21	Strong
Sulfate	-0.66893	8.35E-21	Strong
Bicarbonate Alkalinity as $CaCO_3$	0.52702	4.27E-12	Moderate
Iron	0.42953	4.14E-08	Moderate
Temperature (°C)	0.40719	2.33E-07	Moderate

*Based on statistical evaluation of relationship between methane and following parameters:

- **Water quality analytes:** aluminum, arsenic, barium, bicarbonate alkalinity, bromide, cadmium, calcium, chloride, chromium, iron, lead, magnesium, manganese, nitrate, nitrite, potassium, selenium, sodium, strontium, sulfate, sulfide, total alkalinity, total dissolved solids (TDS), total suspended solids (TSS)

- **Field parameters:** specific conductivity, temperature, pH, oxidation reduction potential (ORP), dissolved oxygen (DO)

I5. Relationship between Residential Water Use and Dissolved Methane

***Key Finding:* No significant relationship was present between dissolved methane concentration and residential water usage prior to sampling.**

To evaluate whether there was an association between water usage prior the sampling event and the reported methane concentration for the IsoFlask^{TM} low-volume purge sample throughout multiple sampling events, water usage was compiled for the 72, 48, 24, 12, 6, 2, and 1 hours prior to each purging event at the 8 residential water wells where water usage information was available. Generally, water usage did not show a strong relationship with methane concentration. For example, within the 12-hour timeframe prior to sampling, only one of well exhibited a statistically significant relationship (Jon well, p=0.04, F-test of Overall Significance). Of note, residential water usage prior to sampling may not have a strong effect on methane concentration at the population of wells in the study because water usage was rarely more than 1-casing volume during the 24 hour period prior to sampling. In addition, as discussed previously, many wells show relatively rapid rebound of water level after cessation of pumping. In other words, the regular usage of these water supply wells was generally not sufficient to maintain a water composition associated with larger water level drawdown during a high-volume purge (which would typically be conducted over a time period of a few hours, as opposed to a day or more).

References

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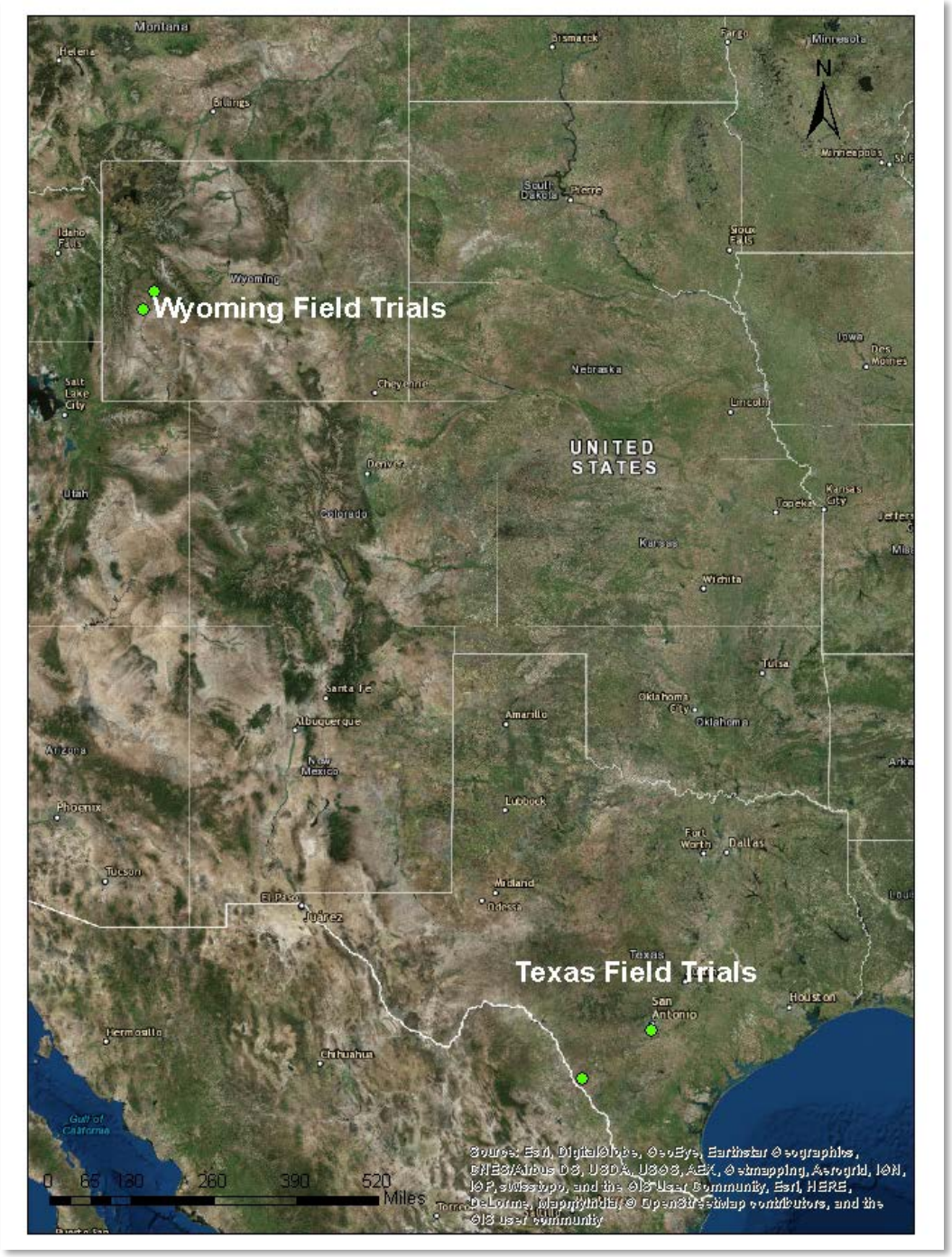
Siegel, D., B. J. Smith, E. A. Perry, R. L. Bothun, and M. Hollingsworth. 2015b. Pre-drilling water-quality data of groundwater prior to shale gas drilling in the Appalachian Basin: Analysis of the Chesapeake Energy Corporation dataset. Applied Geochemistry, 63: 37-57.

Siegel, D., B. Smith, E. Perry, R. Bothun, M. Hollingsworth. 2016. Dissolved methane in shallow groundwater of the Appalachian Basin: results from the Chesapeake Energy predrilling geochemical database. Environmental Geoscientists 23(1): 1-47.

APPENDIX J

ADVANCED ANALYTICAL AIR EMISSIONS

PHOTO LOG

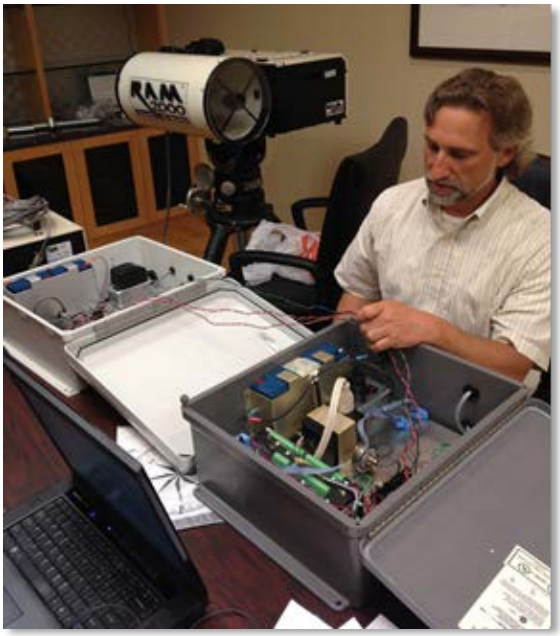


Field Site Locations in Texas and Wyoming

Instrumentation: *RAM2000 FTIR Spectrometer*

Instrumentation: *RAM2000 Retroreflector*

Instrumentation: *Weather station set up with 3-D ultrasonic anemometer and F460 Climatronics Meterological sensors (left) and meteorological translator schematic (right)*



Instrumentation: *Integrating the F460 and 3-D anemometer weather stations*

Instrumentation: *Filling the RAM2000 liquid nitrogen dewar*

Controlled Methane Release Trials: *Methane release apparatus*

Controlled Methane Release Trials: *OP-FTIR spectrometer setup; Research Triangle Park in collaboration with EPA*

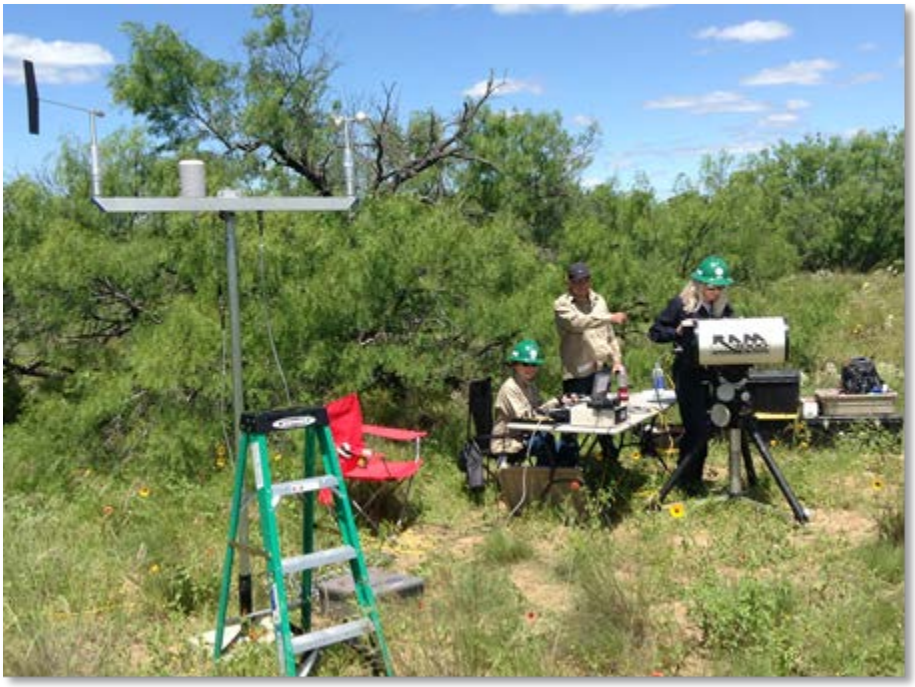
Controlled Methane Release Trials: *Meteorological station setup; Research Triangle Park in collaboration with EPA*

Pilot Test (Clover Lawn Park): *Integrated meteorological meter testing*

SHAPE Ranch: *Aerial satellite image of central facility*

SHAPE Ranch: *Compressor station*

SHAPE Ranch: *Gas Flare*



SHAPE Ranch: *Meteorological station and FTIR setup*

APPENDIX K

ADVANCED ANALYTICAL AIR EMISSIONS

OP-FTIR DETECTABLE CHEMICAL SPECIES

Table K-1. *List of RAM2000™ Detectable Chemical Species*

COMPOUNDS DETECTED AND MEASURED BY RAM 2000™

Acetaldehyde	Carbon monoxide	Dichlorodifluoromethane
Acetic acid	Carbon tetrachloride	1,1 Dichloroethane
Acetone	Carbonyl fluoride	1,2 Dichloroethane
Acetonitrile	Carbonyl sulfide	cis-1,2 Dichloroethene
Acetophenone	Chloroacetic acid	Dichloro-1-fluoroethane
Acetyl Chloride	Chloroacetophenone	Dichloromethane
Acetylene	Chlorobenzene	1,2 Dichloropropane
Acrolein	2-Chloro-1,3-butadiene	1,3 Dichloropropane
Acrylic acid	1-Chloro-1,1-difluoroethane	1,3 Dichloropropene
Acrylonitrile	Chlorodifluoromethane	1,2-Dichlorotetrafluoroethane
Allyl alcohol	Chloroethane	Dichlorotrifluoroethane
Allyl chloride	Chloroform	Diethyl amine
Ammonia	Chloromethane	Diethyl ether
Arsine	bis-Chloromethyl ether	Diethyl ketone
Benzaldehyde	Chloromethyl methyl ether	Diethyl sulfate
Benzene	Chloropentafluoroethane	Difluoroethane
Benzotrichloride	Chlorotetrafluoroethane	Di-isopropyl ether
Benzyl alcohol	2-Chlorotoluene	Dimethyl ether
Benzyl chloride	4-Chlorotoluene	N,N-Dimethyl formamide
Boron trichloride	Chlorotrifluoroethylene	1,1 Dimethyl hydrazine
Bromobenzene	Chlorotrifluoromethane	Dimethyl sulfate
Bromochloromethane	m-Cresol	Dimethyl sulfide
Bromoform	o-Cresol	Dinitrogen pentoxide
Bromomethane	p-Cresol	Dinitrogen tetroxide
Bromotrifluoromethane	Crotonaldehyde	Ethane
1,3 Butadiene	Cyclohexane	Ethanol
Butane	Cyclohexene	Ethyl acetate
2-Butanone	Cyclopentene	Ethyl acrylate
1-Butene	Cyclopropane	Ethyl benzene
cis-2-Butene	1,2-Dibromo-3-chloropropane	Ethyl butyrate
trans-2-Butene	1,2 Dibromoethane	Ethyl formate
n-Butyl acetate	Dibromomethane	Ethylene
n-Butyl alcohol	Dibutyl,monobutyl phosphate	Ethylene oxide
n-Butyraldehyde	m-Dichlorobenzene	Ethyl vinyl ether
Carbon dioxide	o-Dichlorobenzene	Fluorobenzene
Carbon disulfide	p-Dichlorobenzene	Formaldehyde

Table K-1. *List of RAM2000™ Detectable Chemical Species (cont.)*

Formic acid	3-Methyl pentane	Quinoline
Furan	2-Methyl-1 pentene	Silane
Glyceryl trinitrate	2-Methyl-2-pentene	Silicon tetrafluoride
n-Heptane	4-Methyl-2-pentene	Styrene
Hexachloro-1,3-butadiene	Methyl tert-butyl ether	Styrene oxide
Hexachlorocyclobutadiene	Methyl vinyl ether	Sulfur dioxide
Hexachloroethane	Methyl vinyl ketone	Sulfur hexafluoride
Hexamethyl phosphoramide	Naphthalene	Sulfur monochloride
n-Hexane	Nitric acid	Tertiary-butyl benzene
2-Hexanone	Nitric oxide	1,1,1,2 Tetrachloroethane
Hydrazine	Nitro benzene	1,1,2,2-Tetrachloroethane
Hydrogen bromide	Nitro ethane	Tetrachloroethylene
Hydrogen chloride	Nitrogen dioxide	1,1,1,2 Tetrafluoroethane
Hydrogen cyanide	Nitroso benzene	Tetrafluoromethane
Hydrogen fluoride	Nitro methane	Tetrahydrofuran
Hydrogen iodide	Nitrous acid	Tetrahydrothiophene
Hydrogen peroxide	Nitrous oxide	Thionyl chloride
Hydrogen sulfide	n-Octane	Thiophene
Iodomethane	Ozone	Toluene
Iso-butane	n-Pentane	2,4-Toluene diisocyanate
Iso-butanol	1-Pentene	o-Toluidene
Iso-butylene	2-Pentene	Tributyl phosphate
Iso-cyanic acid	Pentafluoroethane	1,2,4-Trichlorobenzene
Iso-phorone	Perfluorobutane	1,1,1 Trichloroethane
Iso-prene	Peroxy acetyl nitrate	1,1,2 Trichloroethane
Iso-propanol	α-Pinene	Trichloroethylene
Iso-propylbenzene	β-Pinene	Trichlorofluoromethane
Mesitylene	Phenol	2,4,5-Trichlorophenol
Methane	Phosgene	2,4,6-Trichlorophenol
Methanol	Phosphine	1,2,3-Trichloropropane
Methyl acetate	Phosphorus trichloride	Trichlorotrifluoroethane
Methyl acrylate	Propane	Triethylamine
Methyl amine	n-Propanol	Trifluoroethane
2-Methyl butane	b-Propriolactone	1,2,4-Trimethyl benzene
2-Methyl-2-butene	Propionaldehyde	2,2,4-Trimethylpentane
3-Methyl-1-butene	Propionic acid	Vinyl acetate
Methyl formate	n-propyl acetate	Vinyl bromide
Methyl hydrazine	n-propyl benzene	Vinyl chloride
Methyl isobutyl ketone	Propylene	Vinylidene chloride
Methyl mercaptan	Propylene glycol methyl ether acetate	Water
Methyl methacrylate	Propylene imine	m-Xylene
Methyl nitrite	Proplylene oxide	o-Xylene
2-Methyl pentane	n-Propyl nitrate	p-Xylene

APPENDIX L

FLOWBACK/PRODUCED WATER CHARACTERIZATION

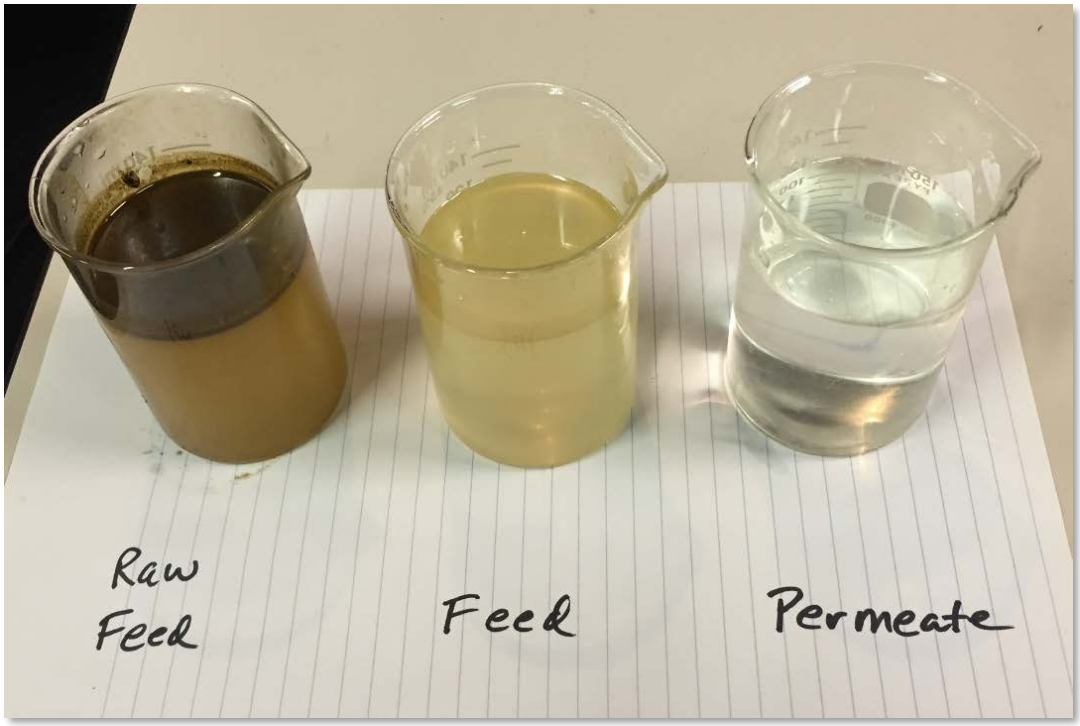
PHOTO LOG

GPRI mobile laboratory

Interior of GPRI mobile laboratory

Texas A&M Riverside Pilot Plant

Storage of raw feed water for the Texas A&M Pilot Plant



Example of raw produced water (raw feed), treated water after oil removal (feed), and treated water after microfiltration (permeate)

APPENDIX M

FLOWBACK/PRODUCED WATER CHARACTERIZATION

LABORATORY METAGENOMIC ANALYSIS OF PRODUCED WATER

APPENDIX M

FLOWBACK/PRODUCED WATER CHARACTERIZATION

Laboratory Metagenomic Analysis of Produced Water

In a Midland, TX field study, over 130 samples were collected to evaluate field-ready analytical tools and perform a comprehensive microbial survey, including samples from formation core material, drilling muds, fracturing fluid source waters, production wells, failed pipe surfaces, and salt water disposal facilities (Robertson, 2016). A sample from the raw feed water destined for salt water disposal (SWD) was sent to a commercial laboratory for metagenomic analysis to identify and quantify specific bacterial classes and species present in the sample. Metagenomic analysis involves the use of advanced DNA sequencing technologies to determine the exact order of nucleotides in a DNA molecule, each representative of dominant bacterial classes and specific genus within the microbial community. Oil and gas professionals can use these results to tailor site specific treatment strategies and biocide applications according to the microbial populations present, resulting in more efficient, effective, and safe handling of produced waters towards a variety of end uses/reuses.

Dominant bacterial classes and species identified by metagenomics in the raw produced water are presented in **Figure M-1** and **Table M-1**, respectively.

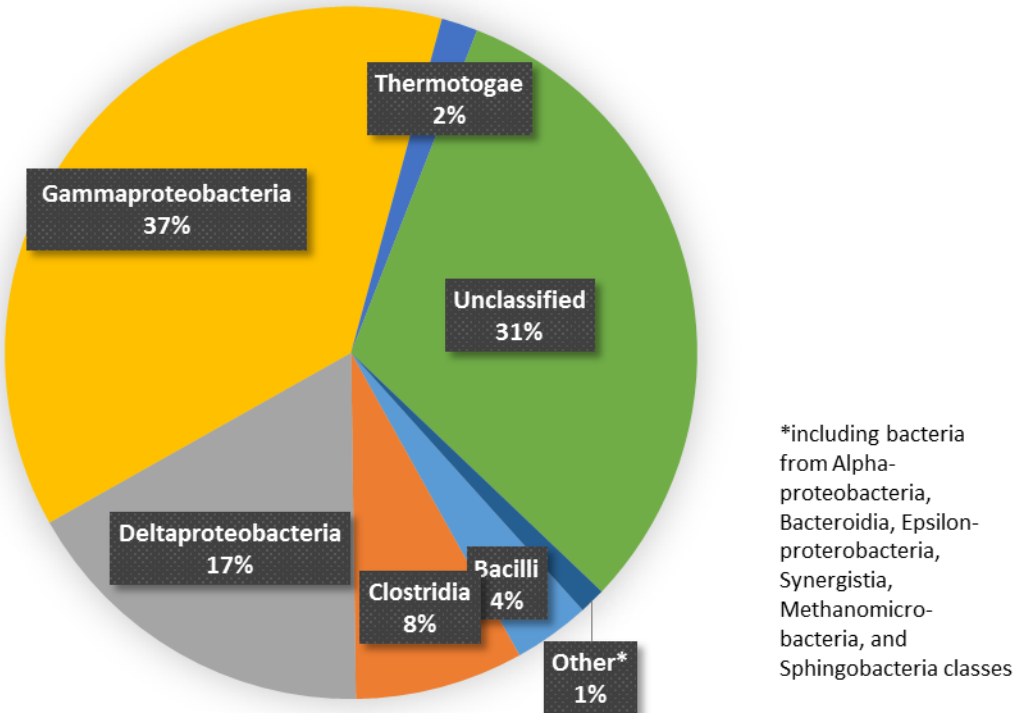


Figure M-1. *Dominant bacterial classes present in a raw produced water sample from a Midland, TX field trial (adapted from Robertson, 2016)*

Table M-1. *Dominant microbial genus in the raw produced water from Midland, TX field trial*

Bacterial Class	Genus	% of Class	% of total
Gammaproteobacteria	Salinivibrio sp	99%	37%
	Acinetobacter sp	<1%	11.5%
Deltaproteobacteria	Desulfovibrio alaskensis	85%	14.5%
	Desulfovibrio sp	10%	1.7%
Clostridia	Clostridium sp	53%	4%
	Geosporobacler sp	18%	1.4%
	Clostridiisalibacter paucivorans	16%	1.3%
Bacilli	Bacillus weihenstephanensis	76%	2.7%
	Enterrococcus sp	20%	<1%
Thermotogae	Oceanotoga sp	86%	1.5%
	Petrotoga mexicana	11%	<1%

As shown in **Figure M-1**, Gammaproteobacteria made up the majority of the microbial community found in the sample, with one species, *Salinivibrio sp*, responsible for 99% of the Gammaproteobacteria detected (**Table M-1**). A prolific SRB and sulfidogen often implicated with corrosion of copper tubing and other oilfield equipment, *Desulfovibrio alaskensis*, accounts for 85% of the Deltaproteobacteria detected (14.5% of total). Species included in the Clostridia class (*Clostridium sp, Clostridiisalibacter paucivorans*, among others) take on a variety of traits, including IRB and homoacetogens. *Bacillus weihenstephanensis* represents 76% of the Bacilli class shown in the chart. Another SRB and sulfidogen, *Oceanotoga sp*, is responsible for 86% of Thermotogae class bacteria detected in the sample. The “Other” slice of the pie chart includes bacteria from the Alphaproteobacteria, Bacteroidia, Epsilonproterobacteria, Synergistia, Methanomicrobacteria, and Sphingobacteria classes.

References

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APPENDIX N

TECHNOLOGY TRANSFER

Table N-1. *Technology Transfer Events*

Event Title	Date	Organization	Description
National Environmental Monitoring, Orange County, CA	Aug-2016	National Environmental Monitoring Conference	Presented by PADEP on the Effect of Sample Collection Technique on the Concentration of Methane in Water
WVU/PTTC/NETL/RPSEA Onshore Technology Workshop, Pittsburgh, PA	Jul-2016	WVU/PTTC/NETL/RPSEA	Susan Stuver and Jenna Kromann presented on final RPSEA projects
Achieving Water Quality Required, Unconventional Resource Technical Conference	Jul-2016	Society of Petroleum Engineers	Rapid Economic Microbial Monitoring Methodologies for Determining Treated Water Stability, Paper and presentation
Groundwater-Quality Sampling in the Berea Sandstone and Rogersville Oil and Gas Plays	Jun-2016	University of Kentucky News	Article published on Kentucky study.
AAPG 2016 Annual Convention and Exhibition Calgary, Canada	Jun-2016	American Association of Petroleum Geologists	Stephen Richardson presented on Sources of Variability in Dissolved Methane Concentrations at Residential Water Wells and protocols to test wells.
GWPC Annual UIC Conference, Denver, CO	Feb-2016	Groundwater Protection Council	Stephen Richardson presented on Sources of Variability in Dissolved Methane Concentrations at Residential Water Wells.
Community Perceptions of Geothermal Energy	Nov-2015	Texas Renewable Energy Industry Association	Presentation
Use of Miniature Detection Technologies for Produced Water Analytics	Nov-2015	Industrial Water	Presentation
SPE Environmental Stewardship, Galveston, TX	Oct-2015	Society of Petroleum Engineers	Stephen Richardson presented a review of state and international agency regulations for baseline sampling of water sources
Developing Protocols and Tools for Testing and Analyzing Produced and Flowback Water for Treatment and Reuse	Oct-2015	Shale Water Expo 2015	Presentation
Shale Insight 2015 A Marcellus Shale Coalition Conference, Philadelphia, PA	Sep-2015	Marcellus Shale Coalition	GSI will attend the conference to meet with regulators and industry partners to discuss current issues with baseline sampling and stray gas incident response
SPE Annual Technical Conference and Exhibition (ATCE), Houston, TX	Sep-2015	Society of Petroleum Engineers	GSI will attend the conference to meet with regulators and industry partners to discuss current issues with baseline sampling and stray gas incident response
GWPC Annual Forum, Oklahoma City, OK	Sep-2015	Groundwater Protection Council	Members from the team attended the conference.
Overview of Advanced Analytics Program and Application to Poland's Gas Shale Sector	Sep-2015	Gdansk University of Technology	Presentation

Event Title	Date	Organization	Description
RPSEA Workshop and Field Trip, Denver, CO	Aug-2015	RPSEA	Stephen Richardson will present an overview of the project and summarize findings from the Phase I and II programs
Onshore Technology Workshop and Field Trip, Denver, Colorado	Aug-2015	RPSEA	Stuver Presentation: Novel Methods for Measurement of Volatile Organic Compounds at Oil and Gas Production Facilities
Simple Chemistry for Simple Answers	Aug-2015	A&M Water Treatment Workshop	Presentation
Unconventional Resources Technology Conference, San Antonio, Texas	Jul-2015	URTEC	Stuver Presentation: Advanced Methods for Open Path FTIR Technology – Research Update
Collaborative Research Planning Workshop and Tour, San Antonio, Texas	Jul-2015	South West Research Institute	Stuver Presentation: Developing an Environmentally Friendly Workforce
Anadarko and Landowner Environmental Planning Charrette, Houston, Texas	Jun-2015	Anadarko	Stuver Presentation: Environmental Studies at SHAPE Ranch, Dimmit County Texas
American Association of Petroleum Geologists (AAPG) 2015 Annual Conference and Convention, Denver, CO	Jun-2015	American Association of Petroleum Geologists	Platform presentation by Lisa Molofsky on the Phase I sampling variability results
Low Temperature Geothermal Waste Heat to Power	May-2015	Dallas Geological Society	Presentation to local geophysicists organization
Advanced Produced Water Treatment Research	May-2015	Texas A&M Energy Engineering	Webinar to Association
Texas Energy Innovation Challenge: Water Quality Requirements for Fracturing Fluids--Analytic Testing Technology	May-2015	Power across Texas Energy Innovation Challenge	Presentation
AWMA Symposium, San Antonio Texas	Apr-2015	AWMA	Stuver Presentation: Challenges with Air Quality Measurements
Update on Advanced Analytical Services for Field Operations	Apr-2015	A&M Water Treatment Workshop	Presentation
Association for Environmental Health and Sciences Foundation (AEHS) 26th Annual International Conference on Soil, Water, Energy, and Air, San Diego, CA	Mar-2015	Association for Environmental Health and Sciences Foundation	Platform presentation by Stephen Richardson on Phase I sampling variability results and baseline sampling regulations
RemTEC Summit, Westminster, CO	Mar-2015	RemTEC	Poster presentation by David Adamson on the Baseline Sampling and Stray Gas Investigation component of the RPSEA project
Environmental Impacts of Unconventional Gas Development	Mar-2015	U. of Michigan Fracturing Committee Briefing	Presentation
Groundwater Protection Council (GWPC) UIC Annual Conference, Austin, TX	Feb-2015	Groundwater Protection Council	Platform presentation by Stephen Richardson on Phase I sampling variability results and baseline sampling regulations

Event Title	Date	Organization	Description
Advanced Analytical Technology for REE Isolation and Recovery	Feb-2015	Texas A&M Kingsville	Presentation on Produced Water Technologies
Advanced Analytical Technology for REE Isolation and Recovery	Feb-2015	SMU Geothermal Lab	Presentation on Produced Water Technologies
Department of Energy Air Emission Project Meeting, Pennsylvania	Jan-2015	National Energy Technology Laboratory	Stuver Webinar Presentation: Advanced Analytical Protocol for Measurement of Emissions with Open Path Fourier Transform Infrared and Integrated Weather Sensors- research update
Advanced Technology for Desalination of Brackish Ground Water for Municipal Use, McAllen, TX	Jan-2015	Public Utilities Board	Presentation
Water Resources: Training Center for Advanced Analytical Technology	Jan-2015	Port of San Antonio, TX	Presentation and training
American Geophysical Union (AGU) Fall Meeting, San Francisco, CA	Dec-2014	American Geophysical Union	Platform presentations by Stephen Richardson and Jenna Kromann on indicators of natural methane occurrence and baseline sampling regulations
Water Resource Management in the Oil Field	Dec-2014	Judges & Commissioners Conference, TX	Presentation on Produced Water Innovations in Treatment
NGWA Workshop- Groundwater Quality and Unconventional Gas Development: Is There a Connection?	Nov-2014	National Groundwater Association	Platform presentations by Stephen Richardson and Lisa Molofsky on the sampling and temporal variability results from Phase I.
Environmentally Friendly Drilling (EFD) Sponsors Meeting, Woodlands, TX	Nov-2014	Houston Advanced Research Center (HARC)	Platform presentation by Ann Smith on the components of the RPSEA project.
Pioneer Industry Partners Meeting, Laredo, Texas	Nov-2014	Pioneer Natural Resources	Stuver Presentation: Methods for Measurement with Open Path Technology
Career Day, San Antonio, Texas	Nov-2014	Judson Independent School District	Stuver Hands on Presentation: What Makes Science Fun?
Drilling in Environmentally Sensitive Ecosystems	Nov-2014	German-American Trade Mission, Consulate	Presentation on Produced Water Innovations in Treatment
SPE Annual Technical Conference and Exhibition (ATCE), Amsterdam, Netherlands	Oct-2014	Society of Petroleum Engineers	Project team members presented and hosted a technical panel for the Environmental Impact session
Shale Insight 2014 A Marcellus Shale Coalition Conference, Pittsburgh, PA	Sep-2014	Marcellus Shale Coalition	Stephen Richardson attended the conference and participated in a training course on baseline sampling and stray gas incident response
Environmental Conference, Society of Petroleum Engineers, Austin, Texas	Sep-2014	Society of Petroleum Engineers	Stuver Presentation: Bad Science leads to Bad Media leads to Bad Policy
Reducing the Impact of Gas Shale Development	Sep-2014	RPSEA Project Review	Presentation and update
26th Annual Texas Environmental Super Conference, Austin, TX	Aug-2014	Texas State Bar Association	Platform presentation by Lisa Molofsky in the Oil & Gas Environmental Issues session

Event Title	Date	Organization	Description
Research Planning Charrette, Houston Advanced Research Center	Jun-2014	Pioneer Natural Resources	Stuver Presentation: Advanced Analytical Protocol for Measurement of Emissions with Open Path Fourier Transform Infrared and Integrated Weather Sensors
Battelle Monterey International Conference	May-2014	Battelle	Stephen Richardson presented one platform presentation and two posters related to the project
Work Shop, Hydraulic Fracturing, an Environmental Perspective, Calgary Canada	May-2014	Petroleum Technology Alliance of Canada	Stuver Presentation: Advanced Analytical Protocol for Measurement of Emissions with Open Path Fourier Transform Infrared and Integrated Weather Sensors
Petroleum Technology Alliance of Canada Work Shop, Hydraulic Fracturing, an Environmental Perspective, Calgary Canada	May-2014	Petroleum Technology Alliance of Canada	Stuver Panel Presentation: Green House Gas – the Big Picture in the United States
Marcellus Shale Coalition's Monthly Meeting	Apr-14	Marcellus Shale Coalition	GSI gave a presentation to the Pre-Drill Sampling Group within the Marcellus Shale Coalition to discuss the project, protocol development, and assessment of methane impacts.
Hands-on Demo to TAMU-SA Ecology Students, San Antonio Texas	Apr-2014	TAMU-SA	Stuver Hands on Demonstration: Importance of Protocol for Emission Measurement
Water Use in the Eagle Ford Shale, College Station, TX	Apr-2014	Texas A&M Bush School of Business	Team Briefing/Presentations
SAME TEXOMA and Missouri River Joint Engineer Training Symposium	Mar-2014	Society of American Military Engineers	Ann Smith presented Environmental Issues Related to Shale Gas Production and Hydraulic Fracturing
USEPA planning charrette Research Triangle Park, North Carolina	Mar-2014	USEPA Working Group	Stuver Presentation: Development of Advanced Analytical Protocol for use of Open Path Infrared Technologies
Advanced Produced Water Treatment Research	Mar-2014	Doosan Industrial Div. (Water Treatment)	Presentation on Produced Water Innovations in Treatment
Clean Frac'ing Conference, in Houston, TX	Feb-2014	Petroleum Connection	Susan Stuver was a Moderator: Air Innovation Panel Discussion, Ann Smith was a Moderator for Clean Water Innovations
Life Long Learning Institute Symposium, Houston Texas	Feb-2014	Life Long Learning Institute	Stuver Presentation Oil and Gas Hype and Health Hazards
Statoil Industry Partner Meeting, Houston Texas	Feb-2014	Statoil	Stuver New Methods for Air Emission Measurement using Open Path Beam Technologies
Clean Frac'ing Conference, Houston Texas	Feb-2014	Clean Fracking Coalition	Stuver Moderator: Air Innovation Panel Discussion, Advanced Air Emission Inventories for Drilling and Completions
IPEC Conference, San Antonio, Texas	Nov-2013	International Petroleum Environmental Association	Stuver Presentation: Developing Advanced Analytical Sampling Protocol for Produced Water, Stray Methane Gas and Fugitive Emissions

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Waste Water Short Course, , College Station, TX	Aug-2013	Texas A&M Petroleum Engineering	Balancing Water Supply and Demand for Industrial Use: Challenges with Perception at the Local Level
Oil Water and Gas Planning Seminar, Austin County, Texas	Jul-2013	Agrilife Extension	Presentation: Hydraulic Fracturing Hype or Health Hazard
GWPC Symposium, Grapevine Texas	Jul-2013	Groundwater Research and Education Foundation	Stuver Presentation: Advanced Analytics for Stray Methane Gas, Produced Water Sampling and Fugitive Emission Measurement