Water Quality Literature Review and Field Monitoring of

Active Shale Gas Wells

Phase II

For

"Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations"

Prepared for:
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List of Abbreviations

ANA	Analysis not available
Ba	Barium
Br	Bromide
°C	Celsius (degree Celsius)
Ca	Calcium
Cl	Chloride
CO_3	Carbonate
DM	Drilling mud
DO	Dissolved oxygen
°F	Fahrenheit (degree Fahrenheit)
FB	Flowback
Fe	Iron
FR	Flame resistant
FS	Flowstream
FW	Freshwater
HAZWOPER	Hazardous Waste Operations and Emergency Response
HCO_3	Bicarbonate
HF	Hydraulic fracturing
IMP	Impoundment (freshwater)
K	Potassium
LEL	Lower Explosive Limit
Mg	Magnesium
MDL	Method Detection Limit

mg/L	milligrams per liter
MP	Measuring Point
mrem/hr	millirem per hour (rem = roentgen equivalent man)
m/s	meter(s) per second
MSDS	Material Safety Data Sheet
MW	Monitoring well
MWD	Monitoring well - deep
MWS	Monitoring well - shallow
Na	Sodium
ND	Non detect
NS	Not sampled
pCi/g	picocuries per gram
pCi/L	picocuries per liter, United States unit for volumetric concentration
PID	Photo-ionization detector
PPE	Personal protection equipment
ppm	Parts per million
QA/QC	Quality Assurance/Quality Control
REIC	REI Consultants
Sal	Salinity
SO_4	Sulfate
SOP	Standard Operating Procedure
Sr	Strontium
TDS	Total dissolved solids
TPH	Total petroleum hydrocarbons

µS/cm	MicroSiemens per centimeter (1 µS/cm = 1 µmhos/cm)
USEPA	U. S. Environmental Protection Agency
VOC	Volatile organic compound
WVDEP	West Virginia Department of Environmental Protection
WVU	West Virginia University
WVWRI	West Virginia Water Research Institute

Executive Summary

Phase II of the project contract with the West Virginia Department of Environmental Protection (WVDEP) required the West Virginia Water Research Institute (WVWRI) to monitor groundwater wells at the centralized pits site monitored during phase I and at a single-lined pit site. The respective energy companies developed the groundwater monitoring wells. For the centralized pits site in Marshall County, Consol/Noble Energy installed shallow groundwater monitoring wells the week of May 14, 2012, and deep groundwater monitoring wells the week of June 11, 2012. For the single-lined pit site in Doddridge County, EQT installed groundwater monitoring wells the week of February 4, 2013. To allow for groundwater monitoring at both sites and submission of the phase II final report, the project was extended from the original project end date of December 31, 2012, to October 15, 2013.

This report summarizes the results of the phase II portion of the study, *Water Quality Literature Review and Field Monitoring of Active Shale Gas Wells*. Phase II consisted of: 1) hydrogeological testing and monitoring of the perimeter groundwater monitoring wells surrounding the three centralized pits in Marshall County and 2) monitoring of perimeter groundwater wells and nearby first order streams at the single-lined pit site in Doddridge County.

<u>Legislative Direction</u>

Although hydraulic fracturing (HF) is not a new technique, its rapid development in the Marcellus Shale Formation has caused concern regarding the potential risks to human health and the environment (1). On December 14, 2011, the West Virginia Legislature (§22-6A) enacted the *Natural Gas Horizontal Well Control Act*. The *Act* directed the West Virginia Department of Environmental Protection (WVDEP) to conduct several studies in order to collect information and report back its findings and recommendations addressing potential human health issues related to:

- Light and noise
- Air emissions
- Impoundment safety
- Water and waste streams

The scope of the study begins with initial well development and ends with the initiation of gas production. In support of these legislative mandates, the WVDEP solicited a team of researchers from West Virginia University (WVU) to conduct these studies. Led by the West Virginia Water Research Institute (WVWRI), the WVU researchers studied effects on air and water quality, generated light and noise, and the structural integrity and safety of the pits and impoundments retaining fluids from well development. The studies included literature reviews followed by direct field monitoring. **This report details the activities undertaken during phase II of the water study focusing on groundwater monitoring around a single-lined pit and the three centralized pits in operation in the state at the initiation of the study.** The literature review was completed during phase I and is part of the phase I final report, *Final Report Water Quality Literature Review and Field Monitoring of Active Shale Gas Wells Phase I*, dated February 15, 2013 (1). Findings from the air emissions, light and noise study, and the pits and impoundments safety study are contained in separate reports: *Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations*, dated May 3, 2013, and *Pits and Impoundments Final Report*, dated December 17, 2012 (2 and 3).

The Study

During phase I of the water study, an extensive literature review was conducted to characterize the water and waste streams associated with the development of horizontal shale gas wells including commonly used HF fluids. Specific areas of review included: 1) public health and the environment, 2) surface and groundwater contamination, and 3) well development practices to protect surface and groundwater during well development. The literature review was used to develop an on-site water and waste stream monitoring plan by defining sample parameters and sampling procedures. The monitoring plan was continuously updated throughout the study period to reflect actual field conditions and included details of each study site. Phase I of the water study focused on sampling and chemical analysis of drilling fluids, muds and cuttings, along with HF fluids and flowback waters of active horizontal gas well sites in the Marcellus Formation in West Virginia.

Consistent with the phase I water study and following the phase I monitoring plan, a phase II monitoring plan was developed to meet the phase II study objectives. The *Phase II Monitoring Plan* was also continuously updated throughout the study period to reflect actual field conditions and included details of the phase II study sites. Phase II activities included sampling and analysis of groundwater and determining the hydrogeological properties of the centralized pits site and a single-lined pits site. Focus of the Phase II water study was to determine if the pits leaked and if the groundwater monitoring system in place would detect any pit leakage.

Site Sampling

Hydrogeological tests and water sampling during phase II took place between February and May 2013. At the single-lined pit (EQT SMI-28) site, pump tests were conducted within two weeks of the installation of perimeter groundwater monitoring wells. Groundwater samples, first order stream samples, and samples of pit content were taken throughout phase II at the single-lined pit site. At the site of the centralized pits (Consol/Noble Energy SHL), final groundwater samples were taken from each of the nine perimeter groundwater wells that produced water. No additional samples of pit content were taken at the centralized pits during the phase II sampling period. Pump tests were conducted on the same day groundwater samples were collected at the centralized pits site.

Samples were collected and analyzed for the same suite of inorganic, organic, and radioactive constituents determined with WVDEP input for phase I sampling. While in the field, WVU researchers noted current weather and site conditions during sampling events. They conducted a general radiation sweep of the sampling site with a handheld radiation alert detector and scanned for off-gases of volatile organic compounds (VOCs) with a photo-ionization detector (PID) as part of personal safety procedures. Parameters such as pH, specific conductivity, total dissolved solids (TDS), dissolved oxygen (DO), salinity, and temperature of samples were measured in the field using a multi-parameter YSI-556 unit. **Appendices A and B** provides a summary of the field data collected during each sampling event at the single-lined pit and the centralized pits sites, respectively. Water monitoring and sampling procedures stayed consistent throughout both phases of the water study.

Water samples were sent to state-certified laboratories for chemical analysis. Samples were sent to REI Consultants (REIC) for organic and inorganic parameter determinations and to Pace Analytical for radioactivity analysis. Consistent with phase I of the water study, all chemical determinations are for total as opposed to dissolved concentrations. It is also important to note that one of the organic parameters, TPH (diesel range), is a measure of all hydrocarbons in the range of C11 to C28. This range includes not only diesel fuel but the plant products: 1) vegetable oil and 2) guar gum. The latter is a common additive in HF fluids. Our analyses also included the organic compounds benzene, toluene, ethyl benzene, and xylene.

As noted in phase I of the study, the nomenclature for HF wastewaters is not standardized across the industry. For the purpose of phase II of the water study, *hydraulic fracturing (HF) fluids* refer to the fluids injected with proppant in order to generate sufficient pressure to create fractures within the target formation. The term *flowback* refers to all fluids that return to the wellhead after HF and prior to gas production. This includes HF fluids, gases, gas liquids, and water. *Produced water* consists of fluids that return to the wellhead subsequent to gas production.

<u>Findings</u>

The use of the term "elevated" in this report refers to results above the initial (background) levels of measured water quality parameters (contaminants) and not necessarily to the level of exceeding primary or secondary drinking water standards. A result of measured parameters that exceeds primary or secondary drinking water standards is specifically noted as an "exceedance" in the report.

Phase II water study objectives included: 1) determination of the hydrogeological properties of the two natural gas well development sites and 2) determination of whether or not the groundwater monitoring wells indicated pit leakage.

1. Determination of the hydrogeological properties of the two natural gas well development sites.

Groundwater monitoring wells peripheral to each pit were installed and developed by the respective energy companies. With the exception of the two deep wells at the centralized pits site, monitoring wells were perforated in the upper 5-25 feet of the water table. Most wells were in the range of 15 to 150 feet distance from the berm of the respective pits.
Pump tests were conducted by pumping at a constant discharge using low-flow (0.23-3.0 gallons/minute) pumps and monitoring the drawdown response of each well using Onset 10-m range sealed pressure transducers with barometric correction. Transmissivity, average hydraulic conductivity, and other hydrogeological parameters from the pumping test data for each monitoring well were interpreted for each aquifer test. Test results were applied to estimate approximate groundwater velocities and subsurface groundwater horizontal travel times to nearby surface drainage from beneath the pits. These times were extremely short at the single-lined pit (EQT SMI-28) site (25 to 40 days) and extremely long at the centralized pits (SHL) site (700 to 700,000 days). The differences are attributed to differences in subsurface geology between the two locations.

Results indicate the groundwater flow rates and aquifer parameters varied dramatically between the two sites due to naturally-occurring differences in local hydrogeology. At the EQT SMI-28 single-lined pit site, transport of contaminants to points of discharge might be expected to occur within a few weeks. At the Consol/Noble SHL centralized pits site, flow velocities are so slow that transport to discharge might take multiple years.

2. Determination of whether or not the groundwater monitoring wells indicated pit leakage.

The quality of flowback water stored in the pits differed between the two sites. Flowback at the SHL centralized pits site was highly saline. At the SMI-28 single-lined pit site, flowback salinity was much lower. The groundwater monitoring results indicated no <u>significant</u> contamination of either shallow groundwater or surface water in the vicinity of the groundwater wells around the pits.

This study focused on the risk to human health as a result of shale gas development. With respect to water, the risk pathway was assumed to be contamination of shallow aquifers and domestic drinking water wells. Therefore, the U. S. Environmental Protection Agency (USEPA) primary and secondary drinking water standards were used to evaluate the potential for risks to human health. With one exception, all groundwater monitoring well sampling results were below the primary and secondary drinking water limits (See **Table 2** for a list of the parameters analyzed.) for the respective contaminants. The exception was the initial sample for the deep monitoring well (MW4) at the SHL-3 centralized pit site. The sample was taken on June 19, 2012, less than two weeks after the pit/impoundment began receiving fresh water, and yielded a Chloride (Cl) level in excess of the secondary drinking water standard (348 mg/L compared to the standard of 250 mg/L). WVWRI researchers confirmed with site personnel the water received was a combination of water from the Ohio River, Wheeling Creek, and return water from previous operations, the latter being a likely source of any elevated chloride readings. However, subsequent samples of this groundwater monitoring well yielded Cl readings of 4.2

and 5.7 mg/L. Analysis of the baseline sample results indicated a poor charge balance of the initial groundwater monitoring well sample. The anion/cation ratio was 2.1 indicating an overestimation of the dominant anion, Cl. Failure to replicate the high Cl readings in subsequent sampling suggests the initial Cl result may have been a faulty determination at the analytical lab.

Groundwater monitoring well results must be viewed in the context of poorly defined groundwater flow paths which are influenced by heterogeneous zones of rock porosity in both the vertical and horizontal axes. The groundwater monitoring wells were installed by the respective energy companies and for the centralized pits, the State of West Virginia's *Design and Construction Standards for Centralized Pits* were to be followed. Given the small number of groundwater monitoring wells and the hydrogeological conditions of each site, it cannot be determined if the groundwater monitoring wells would have intercepted a critical groundwater flow path.

Background and Objectives of Water Study

The Natural Gas Horizontal Well Control Act enacted by the West Virginia Legislature, Code §22-6A on December 14, 2011, directs the WVDEP to conduct several studies in order to collect information and report back its findings and recommendations. In particular, the following studies were directed by the new legislation:

§22-6A-12 (e) Well location restrictions.

The secretary shall, by December 31, 2012, report to the Legislature on the noise, light, dust and volatile organic compounds generated by the drilling of horizontal wells as they relate to the *well location restrictions regarding occupied dwelling structures pursuant to this section. Upon finding, if any, by the secretary that the well location restrictions regarding occupied dwelling structures are inadequate or otherwise require alteration to address the items examined in the study required by this subsection, the secretary shall have the authority to propose for promulgation legislative rules establishing guidelines and procedures regarding reasonable levels of noise, light, dust and volatile organic compounds relating to drilling horizontal wells, including reasonable means of mitigating such factors, if necessary.*

§22-6A-22 Air quality study and rulemaking.

The secretary shall, by July 1, 2013, report to the Legislature on the need, if any, for further regulation of air pollution occurring from well sites, including the possible health impacts, the need for air quality inspections during drilling, the need for inspections of compressors, pits and impoundments, and any other potential air quality impacts that could be generated from this type of drilling activity that could harm human health or the environment. If he or she finds that specialized permit conditions are necessary, the secretary shall promulgate legislative rules establishing these new requirements.

§22-6A-23 Impoundment and pit safety study; rulemaking.

The secretary shall, by January 1, 2013, report to the Legislature on the safety of pits and impoundments utilized pursuant to section nine of this article including an evaluation of whether testing and special regulatory provision is needed for radioactivity or other toxins held in the pits and impoundments. Upon a finding that greater monitoring, safety and design *requirements or other specialized permit conditions are necessary, the secretary shall propose for promulgation legislative rules establishing these new requirements.*

In support of these legislative mandates and at the request of WVDEP, a team of researchers from WVU, led by the WVWRI, examined the effects of gas drilling on surrounding air and groundwater and identified potential environmental health and safety impacts of the large pits and impoundments used to retain liquids and solids associated with the development of shale gas wells. Research teams conducted literature reviews and developed and implemented environmental monitoring studies to identify the effects of horizontal gas well development on air and water quality, generated light and noise, and structural integrity and safety of the pits and impoundments retaining fluids from natural gas well development.

To fulfill the final obligations of the water and waste stream portion of the study titled, *Assessing Environmental Impacts of Horizontal Gas Well Drilling Operation*, the objectives of phase II included:

1. Determine hydrogeological properties of the single-lined pit site and the centralized pits site using the perimeter groundwater monitoring wells to assist with determining aquifer recharge rates.
2. Determine whether or not the groundwater monitoring wells indicated pit leakage.

Phase II Monitoring Plan

The *Phase II Monitoring Plan* served to guide the activities involved with the characterization and documentation of potential surface water and groundwater contamination that may have originated from pit leakage. Standard Operating Procedures (SOPs) followed for field sampling methods were also included as part of the *Phase II Monitoring Plan*. These SOPs were modeled after WVDEP's *Quality Assurance/Quality Control Plan & Standard Operating Procedures for Groundwater Sampling*, *WVDEP-DWWM-PP-GW*-001, and EPA guidance documents: 1) *RCRA Groundwater Monitoring: Draft Technical Guidance, EPA/530/R-93/001*; 2) *Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures, EPA/540/S-95/504*; and 3) *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, EPA SW-846*.

Roles and Responsibilities

A list of WVWRI team members directly involved in this study is included in **Appendix C** along with their contact information.

Study Design

The intent of the field sampling described in the *Phase II Monitoring Plan* was to characterize and document the potential for groundwater contamination from pit leakage and the approximate scale of time it would take for a pit leak to travel into surface drainage via the water table. WVWRI researchers worked with the WVDEP and industry representatives to gain access to the sites. Information on the source water(s) stored in each of the pits was provided to the researchers by the respective energy companies. GPS coordinates were obtained and verified upon initial site visits.

An overview of gas well development stages monitored during phase I and phase II of the water study, sample collection points, sampling frequency, and sampling dates is provided in **Table 1**. Refer to the Waste Storage and Groundwater Monitoring stages of gas well development in **Table 1** for information specific to phase II activities. A list of parameters analyzed by commercial laboratory is provided in **Table 2** for both phase I and phase II. Method detection limits (MDLs) and EPA method numbers for each parameter are also provided in **Table 2**. Duplicate samples were randomly collected for approximately 10% of all samples taken. Water samples were sent to state-certified laboratories for chemical analysis. Samples were sent to REI Consultants for organic and inorganic parameter determinations and to Pace Analytical for radioactivity analysis.

While in the field, WVWRI team members noted current weather conditions and sampling time. They conducted a general radiation sweep of the site and of the collected samples with a handheld radiation alert detector that displayed current radiation levels in millirems per hour (mrem/hr). They also scanned for off-gases of VOCs with a PID as part of personal safety procedures. Parameters such as pH, specific conductivity (µS/cm), TDS, DO, salinity and temperature (°C) of samples were measured in the field using a multi-parameter YSI-556 unit. WVWRI researchers also noted visual observations of the surrounding environment and obtained photographs during sampling visits. To ensure complete site information was obtained and field monitoring and sampling activities remained consistent from site to site, a site checklist was developed. The checklists included information relevant to the site location, stage of well development, samples collected, and field observations and are provided in **Appendix D**.

Monitoring and analysis of field parameters for groundwater monitoring wells and first order streams were conducted on a weekly basis at the single-lined pit site once the pit began receiving water and are summarized in **Appendix A**. The initial (baseline) sample was collected on the same day pump tests were conducted on the groundwater monitoring wells. The baseline and final samples were analyzed for the full suite of parameters listed in **Table 2**. For the weekly sampling events, if any sample was found with a field reading for specific conductance >20% of the baseline value, samples were collected for analysis of inorganic parameters (see **Table 2**) from that point forward.

For the centralized pits, phase II consisted of the final groundwater samples being collected from each of the monitoring wells producing water. Each sample was analyzed for the full suite of parameters listed in **Table 2**. Pump tests were also performed on each groundwater monitoring well producing water the same day the final groundwater sample was collected. A summary of the field parameters and notes taken during each sampling event at the centralized pits site is provided in **Appendix B**.

Table 1: Sampling Plan by Stage of Gas Well Development

	Stage	Target	Water/Waste Stream Sample Frequency	Water/ Waste Stream Sample Phase	Water/Waste Stream Point of Collection	# Water / Waste Samples per Site	Water and Waste Stream Sampling Dates, 2012 unless noted	Air Monitoring Dates, 2012	Pad Site for Water/Waste Stream Monitoring
Water Storage for Well Development	Fresh Water Impoundment	Fresh water	Site specific (# of samples pulled determined by size of impoundment)	Liquid	Various locations	dependent upon impoundment size, up to 8	(1) 6/7 (2) 8/28	(1) N/A (2) WAMS only: moved on 8/25 staying 6 days	(1) Consol/Noble Centralized Impoundment (2) Mills Wetzel Pad #3
Well Drilling and Hydraulic Fracturing	Vertical Drilling	Drilling - produced waste	Once/week and composite	Liquid	Liquid from shaker table, Composite (pit)	3	(1) 8/8, 8/15, 8/22, 10/2 (2) 10/25	(1) Trailer 9/26 - 10/16: WAMS 9/27 - 10/2 (2) WAMS 10/19 - 10/25: Trailer on 10/17, collected 10/19 on	(1) Lemons Pad (+25 days from 9/6) (2) WVDNR A Pad - Chesapeake
				Solid	Muds from shaker table, Composite (pit)	3	(1) 8/8, 8/15, 8/22, 10/2 (2) 10/25		
	Horizontal Drilling	Drilling fluid	Once	Liquid	Determined by site operator	1	(1) 8/8, attempted on 8/20, 8/22, 8/24 (2) Storm - completed drilling before samples could be collected	(1) WAMS collected 8/18 - 8/25: Trailer on 8/16, collected 8/17 - 8/24, off 8/24 (2) Equipment previously on site during vertical, Trailer continuously monitoring since 10/19; drilling occurred 10/25-10/31 but generator unplugged by Chesapeake no data collected: WAMS 10/26 - 10/29	(1) Mills Wetzel Pad #2 (2) WVDNR A Pad - Chesapeake
		Drilling - produced waste	Once/week and composite	Liquid	Liquid from shaker table, Composite (pit)	3	(1) 8/8, attempted on 8/20, 8/22, 8/24 (2)Storm - completed drilling before samples could be collected		
				Solid	Muds from shaker table, Composite (pit)	3	(1) 8/8, attempted on 8/20, 8/22, 8/24 (2) Storm - completed drilling before samples could be collected		
	Hydraulic Fracturing	Hydraulic Fracturing Water	Once/week (recording stage of frac)	Liquid	Tankers/Impoundments /Containers	2	(1) 7/25 only 1 sample (2) 9/11 only 1 sample	(1) WAMS on 7/20, sampled 7/23 - 7/28: Trailer on 7/19, collected 7/20 - 8/2, off 8/2 (2) WAMS on 8/25, sampling 9/7 - 9/13: Trailer on 8/24, some instruments collecting 8/24 , remaining collecting 8/29, both til 9/14	(1) Waco - ECA Donna Pad (2) Maury Site
		Combined Hydraulic Fracturing Fluid & Freshwater			Stream of fluid going down hole	2	(1) 7/25 only 1 sample (2) 9/11 only 1 sample		
Waste Storage	Pits: 1 single-lined pit, 3 centralized pits	Flowback stream	Initial	Liquid	Stream of fluid coming up	1	(1) 7/27, 8/2, 8/9 and 8/30 (2) 8/15 and 8/20 (3) 8/13, 8/20, 8/28 and 9/17 (4) 4/25/13, 5/1/13, 5/8/13, and 5/15/13 (5) 10/2 - one sample only short flowback stage	(1) WAMS on 7/20, sampled 7/23 - 7/28: Trailer on 7/19, collected 7/20 - 8/2, off 8/2 (2) WAMS sampled 8/7 - 8/13, one WAM til 8/18: Trailer on 8/2, collected 8/3 - 8/16, off 8/16 (3) N/A (4) N/A (5) Equipment previously on-site during fracking, ALL Trailer equipment monitoring continuously 8/29 - 9/26: WAMS	(1) Waco ECA Donna Pad (2) Weekley Site #1 (3) Consol/Noble Centralized Pits (4) EQT Smithburg 28, Dodderidge Co (5) Maury Site HF done 9/14, Flowback did not start until 10/1, scheduled through 10/6
			1/week for first 3 weeks, during week 6			4			
		Composite samples	Composite	Solid	Storage of flowback	1	(1) 8/30/12 (2) 8/15 and 8/20 (3) 9/17 for SHL 3 & 4 only (4) 4/25/13, 5/1/13, 5/8/13, and 5/15/13 (5) 10/2 - one sample only		
				Liquid		1	(1) 8/30 (2) 8/15 and 8/20 (3) 9/17 for SHL 3 & 4 only (4) 4/25/13, 5/1/13, 5/8/13, and 5/15/13 (5) 10/2 - one sample only		
Groundwater Monitoring	Pits: 1 single-lined pit, 3 centralized pits	Each pit's monitoring wells	Prior to any waste entering pit, one following completion of waste entering the pit	Liquid	Monitoring wells	site dependent	(1) 6/4, 6/7, 6/19, 10/31 - 11/1, and 5/9/13 (2) 2/19/13, 4/25/13, 5/1/13, 5/8/13, and 5/15/13	(1) N/A (2) N/A	(1) Consol/Noble - three centralized pits (9 GW wells) (2) EQT Smithburg 28, Dodderidge Co (3 GW wells)

Table 2: Water and Waste Stream Parameters

	Parameter	Preservative	MDL (mg/L)	Method	EPA MCL (mg/L unless noted)	Lab
Inorganics	Silver	HNO_3	0.001	EPA E200.7	0.1 mg/L, 2º	REIC
	Alk, Total	None	1	EPA SM2320 B	NA	REIC
	Aluminum	HNO_3	0.04	EPA E200.7	0.05-0.2, 2º	REIC
	Arsenic	HNO_3	0.007	EPA E200.7	0.01	REIC
	Barium	HNO_3	0.002	EPA E200.7	2	REIC
	Bromide	None	0.05	EPA E300.0	NA	REIC
	Calcium	HNO_3	0.05	EPA E200.7	NA	REIC
	Chloride	None	0.1	EPA E300.0	250, 2º	REIC
	Conductivity	None	NA	EPA SM 2510 B	NA	REIC & Field
	Chromium	HNO_3	0.001	EPA E200.7	0.1	REIC
	Iron	HNO_3	0.01	EPA E200.7	0.3, 2º	REIC
	Mercury	HNO_3	0.0001	EPA E245.1	0.002	REIC
	Magnesium	HNO_3	0.05	EPA E200.7	NA	REIC
	Manganese	HNO_3	0.001	EPA E200.7	0.05, 2º	REIC
	Sodium	HNO_3	0.03	EPA E200.7	NA	REIC
	Nickel	HNO_3	0.002	EPA E200.7	NA	REIC
	pH	None	NA	EPA SM4500-H +-B	6.5-8.5	REIC & Field
	Lead	HNO_3	0.003	EPA E200.7	0.015 action level	REIC
	Potassium	HNO_3	0.03	EPA E200.7	NA	REIC
	Nitrite	H_2SO_4	0.05	EPA 300.0	1	REIC
	Nitrate	H_2SO_4	0.2	EPA 300.0	10	REIC
	Sulfur	HNO_3	0.05	EPA E200.7	NA	REIC
	Selenium	HNO_3	0.008	EPA E200.7	0.05	REIC
	Sulfate	None	1	EPA E300.0	250, 2º	REIC
	Strontium	HNO_3	0.001	EPA E200.7	NA	REIC
	Zinc	HNO_3	0.003	EPA E200.7	5, 2º	REIC
	Hardness	None	1	EPA SM2340 B	NA	REIC
	Carbonate	None	1	EPA SM2320 B	NA	REIC
	Bicarbonate	None	1	EPA SM2320 B	NA	REIC
	Phosphate	H_2SO_4	0.02	EPA SM4500-P BE	NA	REIC

	Parameter	Preservative	MDL (mg/L)	Method	EPA MCL (mg/L unless noted)	Lab
	Total Dissolved Solids	None	5	EPA SM 2540 C	500, 2º	REIC
	Total Suspended Solids	None	5	EPA SM 2540 D	NA	REIC
Organics	Methane	None	NA	EPA OSW3810 M	NA	REIC
	Ethane	None	NA	EPA OSW3810 M	NA	REIC
	Propane	None	NA	EPA SW8260 B	NA	REIC
	Total Organic Carbon	H_2SO_4	0.2	EPA SM 5310 C	Treatment technique	REIC
	Chemical Oxygen Demand	H_2SO_4	4	EPA E410.4	NA	REIC
	Oil & Grease	HCl	2	EPA E1664 A	NA	REIC
	BTEX	HCl		EPA SW8260 B	B-0.005, T-1, E-0.7, X-10	REIC
	Styrene	HCl	0.38	EPA SW8260 B	0.1	REIC
	Tetrachloro-ethylene	HCl	0.49	EPA SW8260 B	0.005	REIC
	Surfactants (MBAS)	None	0.1	EPA SM5540 C	0.05, 2º	REIC
	Petroleum Hydrocarbons	None	0.25	EPA SW8015 C	NA	REIC
Radioactivity	Gross Alpha	(pH<2) HNO_3	NA	EPA 900.0m or SM 7110C	15 pCi/L	Pace
	Gross Beta	(pH<2) HNO_3	NA	EPA 900.0m or SM 7110C	4 mR/yr	Pace
	Lead-210	(pH<2) HNO_3	NA	EPA 901.1m	NA	Pace
	Radium-226	(pH<2) HNO_3	NA	EPA 901.1m *	5 pCi/L combined 226/228	Pace
	Radium-228	(pH<2) HNO_3	NA	EPA 901.1m *	5 pCi/L Combined 226/228	Pace
	Thorium-230, -228, -232	(pH<2) HNO_3	NA	HASL 300m	NA	Pace
	Uranium-238,	(pH<2) HNO_3	NA	HASL 300m	30 µg/L (238)	Pace
	Potassium-40	(pH<2) HNO_3	NA	EPA 901.1m	NA	Pace

*For liquid samples, Radium-226 is EPA 903.1 and Radium-228 is EPA 904.0.
2° = secondary standards

On any field investigation, a minimum of two WVWRI team members were present. Each team member was provided proper personal protective equipment (PPE) and flame-resistant (FR) clothing necessary for access to a well or well development activity-related site. Minimum PPE requirements included: 1) hardhat, 2) safety glasses, 3) metatarsal boots, 4) gloves, and 5) FR clothing. In addition, WVWRI personnel were required to have on hand: 1) full-face respirators with combination P100 and organic vapor filters, 2) a first aid kit, 3) a flotation device, 4) a handheld radiation alert detector, and 5) a 6-gas PID that measured methane, oxygen, hydrogen sulfide, carbon monoxide, carbon dioxide, and isobutylene. The radiation alert detector and PID were used to scan the working environment prior to any sampling or monitoring activity on site.

Sites

Two sites, the Consol/Noble Energy SHL centralized pits and the EQT SMI-28 single-lined pit sites, were studied during phase II. WVWRI team members worked with WVDEP and industry representatives to obtain site access and schedule monitoring activities. GPS coordinates were obtained and verified upon initial site visits of the well development site, groundwater monitoring wells, sampling points, and pits. **Table 3** provides details on the well development site, sample locations, and dates for phase II sampling activities.

Table 3: Sampling Site Locations

Site	Pit Type	Phase II Sampling Date	West Virginia County	Sample Location	Well Development Stage
Groundwater Monitoring					
SHL2, MW1	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL2, MW2	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL2, MW3	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL2, MW4	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL3, MW4	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL4, MW1	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL4, MW2	Central	5/9/13	Marshall	Monitoring well	After pit conversion
SHL4, MW3	Central	5/9/13	Marshall	Monitoring well	After pit conversion
EQT – MW1	Single	2/19/13	Doddridge	Monitoring well	Freshwater
EQT – MW2	Single	2/19/13	Doddridge	Monitoring well	Freshwater
EQT – MW3	Single	2/19/13	Doddridge	Monitoring well	Freshwater
EQT – MW1	Single	5/1/13	Doddridge	Monitoring well	After pit conversion
EQT – MW1	Single	5/8/13	Doddridge	Monitoring well	After pit conversion
EQT – MW1	Single	5/15/13	Doddridge	Monitoring well	After pit conversion
EQT – MW2	Single	5/15/13	Doddridge	Monitoring well	After pit conversion
EQT – MW3	Single	5/15/13	Doddridge	Monitoring well	After pit conversion
Waste Storage/Flowback Stream					
FS – 1 (EQT)	Single	4/25/13	Doddridge	Pit Edge	Mixed Water
FS –2 (EQT)	Single	5/1/13	Doddridge	Pit Edge	Mixed Water
FS – 3 (EQT)	Single	5/8/13	Doddridge	Pit Edge	Mixed Water
FS – Final (EQT)	Single	5/15/13	Doddridge	Pit Edge	Mixed Water
First order Stream					
Tributary A (EQT)	Single	4/25/13	Doddridge	Directly from Stream	After pit conversion
Tributary A (EQT)	Single	5/1/13	Doddridge	Directly from Stream	After pit conversion
Tributary A (EQT)	Single	5/8/13	Doddridge	Directly from Stream	After pit conversion
Tributary A (EQT)	Single	5/15/13	Doddridge	Directly from Stream	After pit conversion

Centralized Pits Site

The Consol/Noble Energy SHL site located in Marshall County consisted of three active centralized pits, SHL2, SHL3, and SHL4. This site was monitored per requirements of §22-6A-9 (mandated for study by §22-6A-23) during phase I and phase II of the project. During phase I, groundwater samples were collected from each monitoring well prior to pit use (baseline sample) and post-pit acceptance (active samples) of waste streams. The leak detection systems were monitored for the presence of leaked fluid. One monitoring well was placed up-gradient of each pit and two were placed down-gradient of each pit at the site. Additional monitoring wells were installed in a deeper aquifer down-gradient of the SHL2 and SHL3 centralized pits to provide further groundwater characterization, illustrated in blue, **Figure 1**.

Phase II included obtaining a final round of samples from these monitoring wells, performing pump tests at the site, and doing a hydrogeological assessment of the site. **Figure 1** shows the location of the centralized pits and the groundwater monitoring wells.

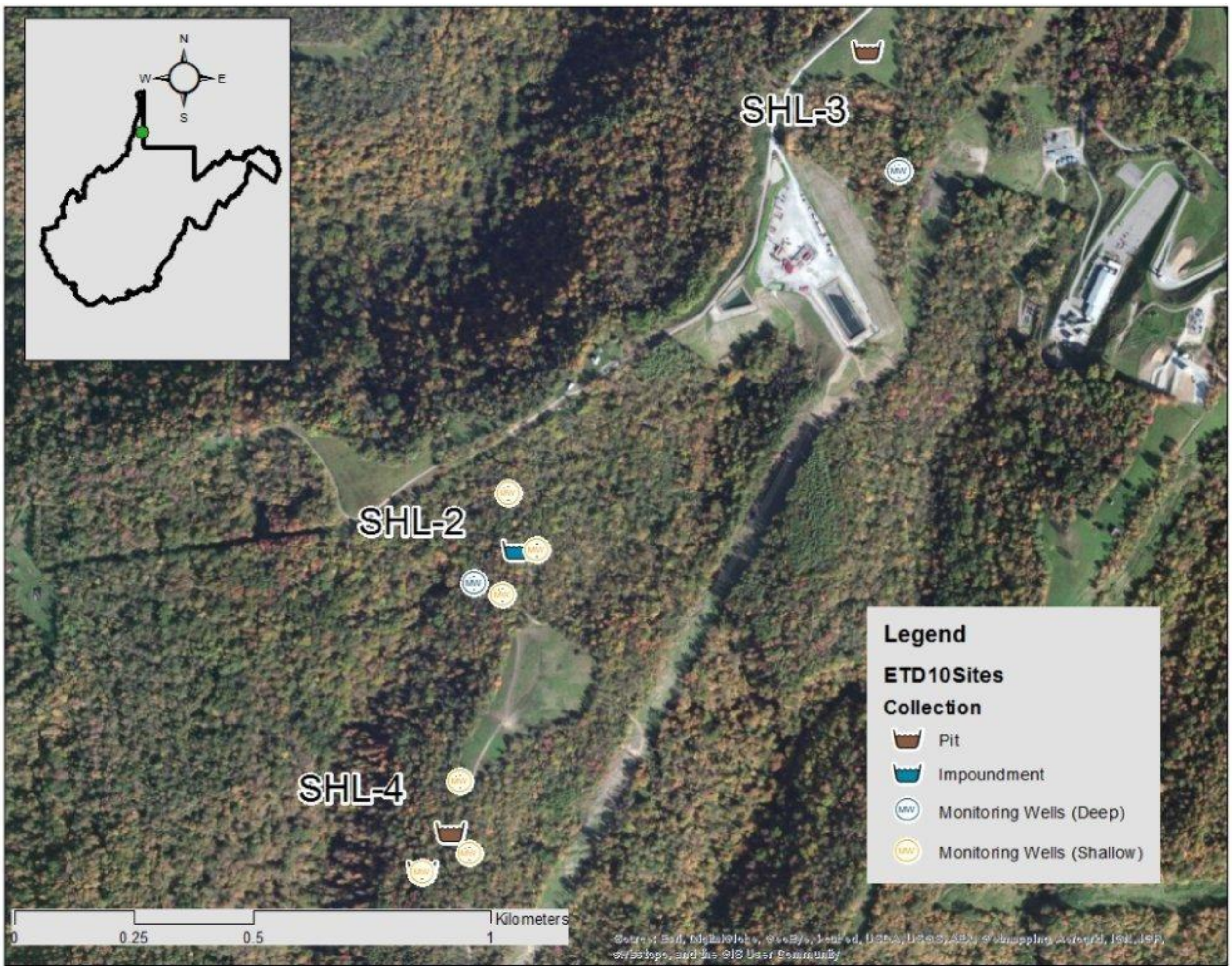

Figure 1: Consol/Noble Energy SHL centralized pits sampling points.

Single-lined Pit Site

The EQT SMI-28 site located in Doddridge County was selected as the single-lined pit site for groundwater and nearby surface water (streams) monitoring. In addition to sampling the groundwater monitoring wells, a nearby first order stream (fresh water tributary), and contents of the single-lined pit were sampled. Sampling points shown in **Figure 2** included: 1) perimeter groundwater monitoring wells (MW1 up-gradient, and MW2 and MW3 down-gradient of the pit); 2) the mouth of a nearby first order stream (marked SW); and 3) the single-lined storage pit outlined in black.

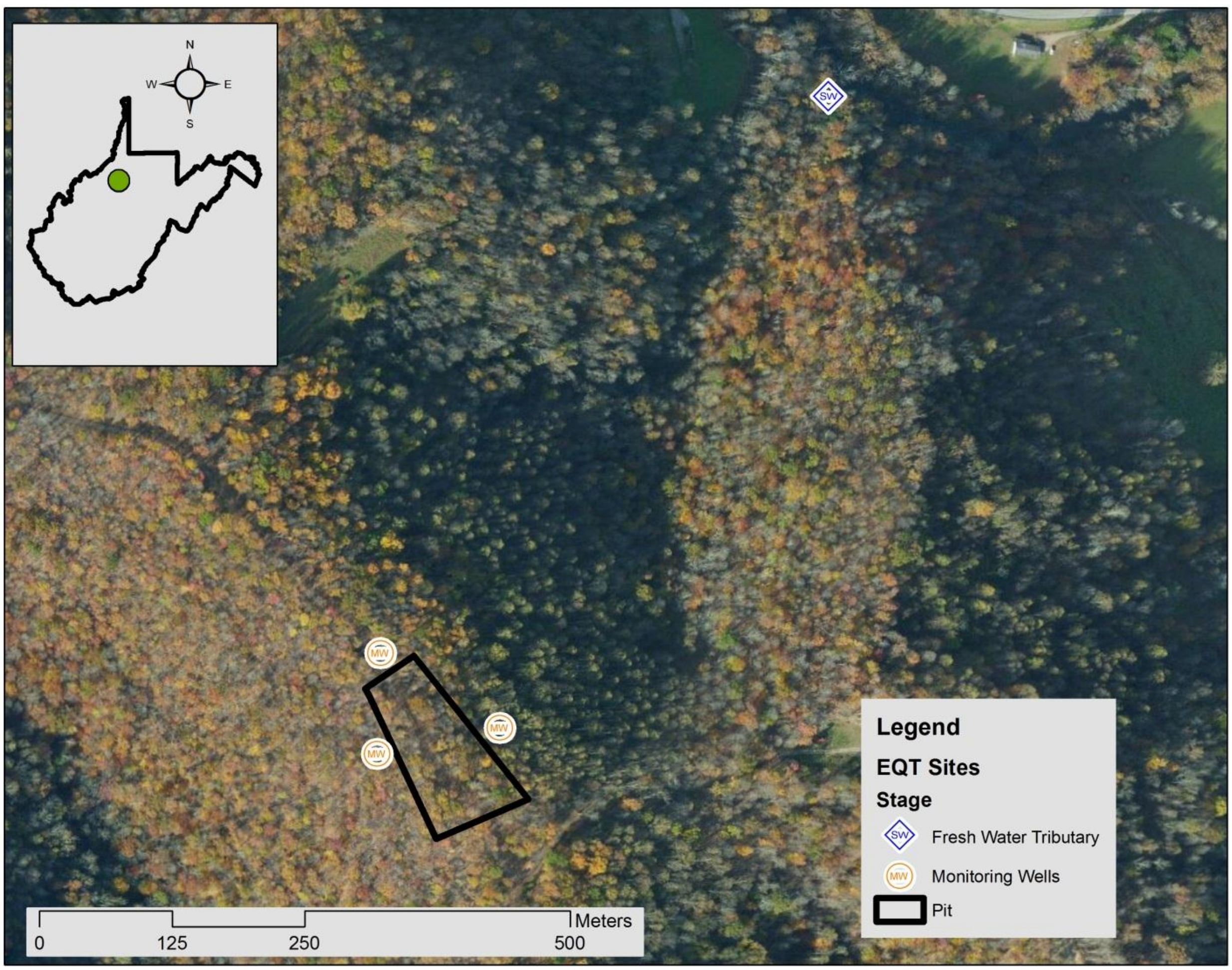

Figure 2: EQT SMI-28 single-lined pit sampling points.

Pump tests were performed on each of the groundwater monitoring wells and a hydrogeological assessment was conducted of the site.

Sampling Strategy

The monitoring locations for surface and ground water were: 1) perimeter monitoring wells at the edge of the pit berms and 2) receiving streams and/or springs in hollows adjacent to the pit and immediately downslope. There was no evidence of springs; therefore, first order streams were identified on each side of the topographic ridge divide and samples were taken at its confluence with the main downstream watercourse. However, one of the first order streams was located on private property and attempts to locate the owner for access were unsuccessful. The WVWRI expectation was to locate surface water sampling sites within 2,000 feet of the pit.

<u>Groundwater Monitoring</u>

1. **Consol/Noble Energy SHL centralized pits – Sand Hill Location pits: SHL2, SHL3 and SHL4:**

   [All wells sampled 6/4/2012, 6/7/2012, 6/19/2012, and 10/31/12 - 11/1/12 (phase I sampling), and 5/9/13 (phase II sampling), for full analytical list].

A map of the three Consol/Noble Energy SHL centralized impoundments-to-pits with incorporated GPS coordinates is provided in **Figure 3**. (Refer back to **Figure 1** for the location of the groundwater monitoring wells around the three SHL centralized pits.) One monitoring well was placed up-gradient of each pit and two were placed down-gradient of each pit at the site. Two additional monitoring wells were installed in a deeper aquifer down-gradient of the SHL2 and SHL3 centralized pits to provide further groundwater characterization. **Figures 4 and 5** illustrate sampling activities related to the groundwater monitoring wells at the centralized pits site. Pump tests were conducted on each of the groundwater monitoring wells producing water. Field parameters were measured for each sample and final samples from each of the nine perimeter groundwater monitoring wells were collected and analyzed for the full suite of parameters (inorganic, organic, and radioactive) listed in **Table 2**.

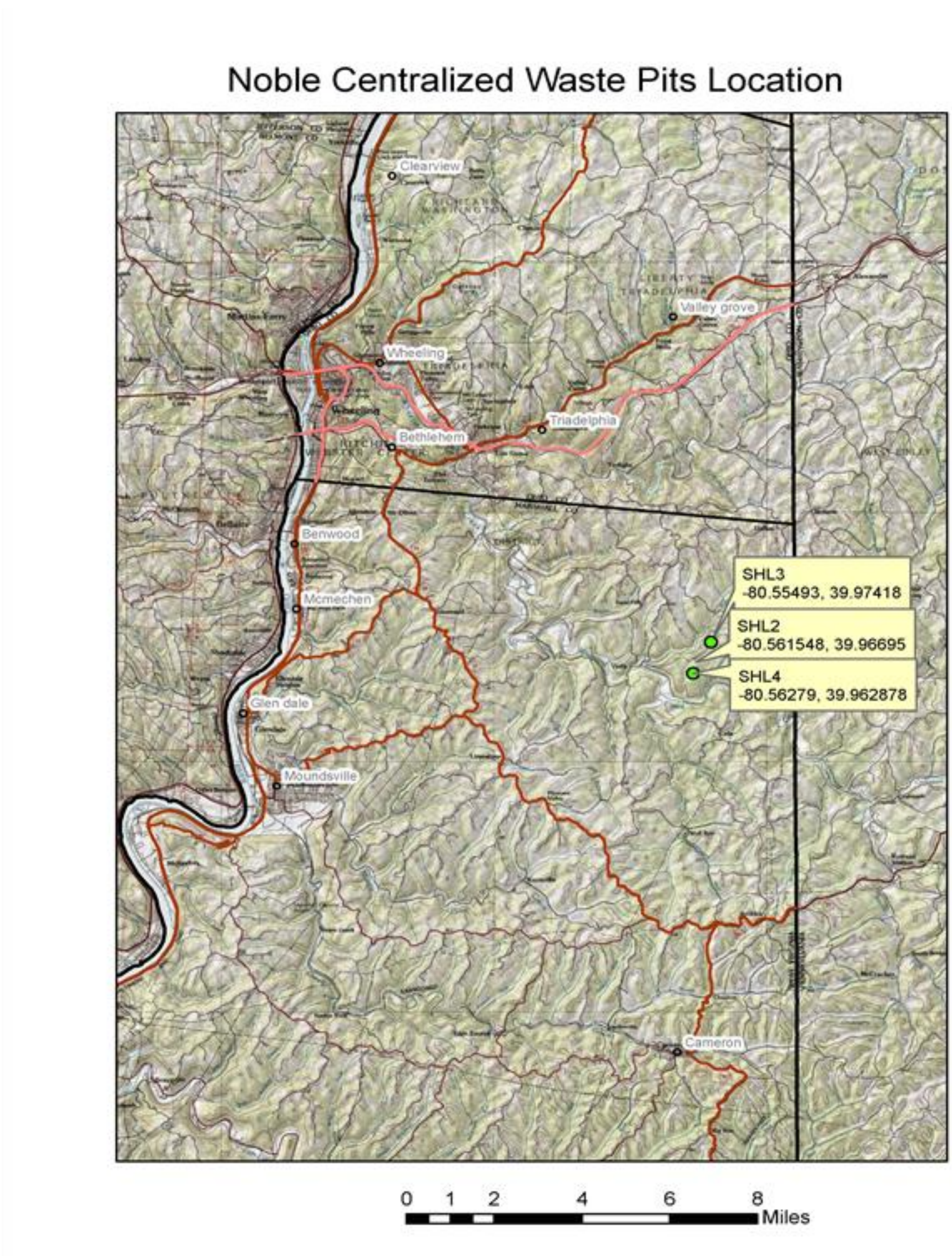

Figure 3: Map showing location of Consol/Noble Energy SHL centralized pits.

Figure 4: Measuring depth-to-bottom and depth-to-water at the SHL centralized pits site.

Figure 5: Groundwater sampling activities post purging of a well at the SHL centralized pits site (split sampling with Moody & Associates).

2. **EQT SMI-28 single-lined pit:**
   [All wells were sampled 2/19/2013, 4/25/2013, 5/1/2013, 5/8/2013, and 5/15/2013 for the full analytical list].

Three groundwater monitoring wells, one up-gradient and two down-gradient, were installed peripherally to the single-lined pit (EQT SMI-28) site in Doddridge County on February 12, 2013. Pump tests were conducted of the groundwater monitoring wells and the initial (baseline) groundwater samples collected on February 19, 2013. Flowback water, a combination of water from various nearby pads, was first stored in the EQT SMI-28 pit the week of April 15, 2013, with weekly monitoring of the groundwater wells beginning the following week. (Refer back to **Figure 2** for the location of the groundwater monitoring wells around the perimeter of the single-lined pit.)

Prior to any water samples collected for laboratory analysis, field parameters [total dissolved solids (TDS), dissolved oxygen (DO), pH, temperature, specific conductance, and salinity] were measured. The baseline and final water samples for each of the groundwater monitoring wells were analyzed for the full suite of parameters listed in **Table 2**. For the weekly sampling events, if the field reading for specific conductance was >20% of the baseline sample value, water samples were collected for analysis of inorganic parameters (See **Table 2**.) from that point forward. **Table 4** summarizes the parameters analyzed for each groundwater monitoring well sampling event.

Table 4: Single-lined Pit Groundwater Samples

	2/19/13 Baseline	4/25/13	5/1/13	5/8/13	5/15/13 Final
MW1 (up-gradient)	Full Suite & Field	Field	Field & Inorganics	Field & Inorganics	Full Suite & Field
MW2 (down-gradient)	Full Suite & Field	Field	Field	Field	Full Suite & Field
MW3 (down-gradient)	Full Suite & Field	Field	Field	Field	Full Suite & Field

During the February 19, 2013, sampling event, the day started off with weather conditions around 38°F (Fahrenheit) with heavy rain. Initially, the pump and flow through cell was used to reliably sample the MW1 groundwater monitoring well and take field readings for the MW3 groundwater monitoring well. Just after taking the field readings at MW3, the pump and flow through cell quit working. A second pump and battery set-up was tried but also failed to work. WVWRI team members and the EQT's environmental consultants present for split sampling determined the temperature was below freezing (26°F) and the rain had changed to a sleet-snow mix. The deteriorating weather conditions may have been the cause of the equipment failure and the decision was made by both parties to hand bail water for the sample. MW3 had a very fast recharge rate and team members were confident upon completion of well purging, a water sample of formation water was obtained. At the MW2 groundwater monitoring well, WVWRI team members again tried to use the pumps to sample the well; however, the pumps were still not functioning. The temperature continued to drop and the sleet-snow mix had turned to all snow. WVWRI team members and EQT's environmental consultants again decided to hand bail one well volume for well purging and then begin to collect the water sample. MW2 also had a very high recharge rate and team members were confident a formation water sample was obtained.

Figures 6 and 7 illustrate sampling activities related to the groundwater monitoring wells at the single-lined pit site.

Figure 6: Post groundwater sampling activities at the single-lined pit site.

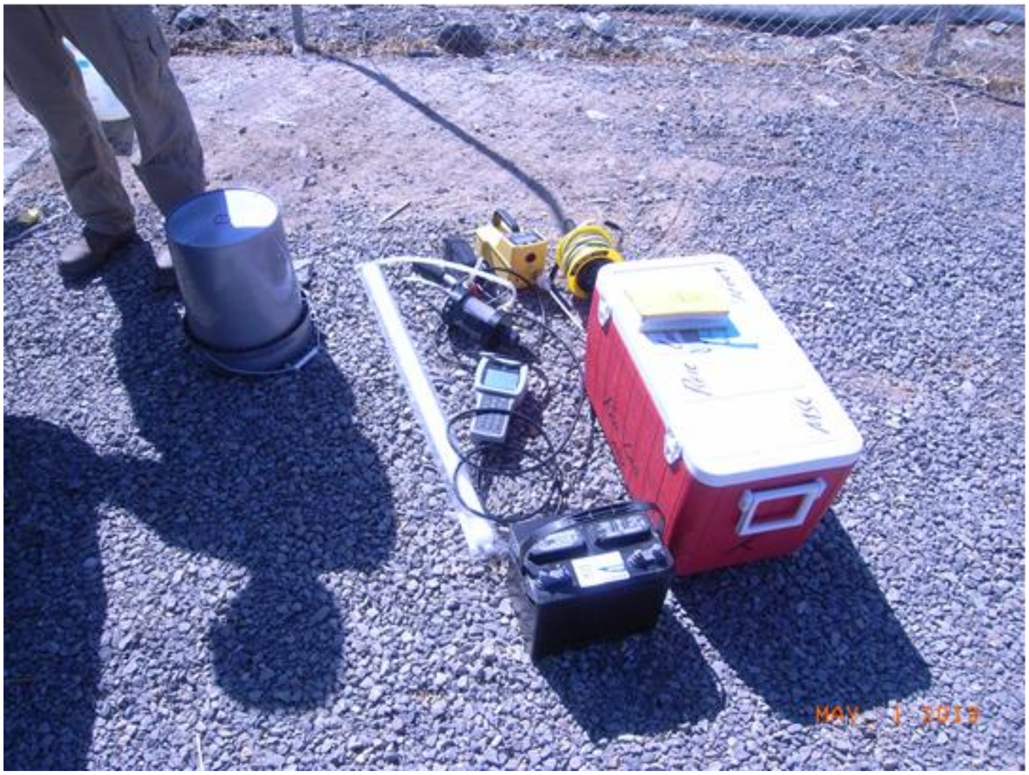

Figure 7: Equipment check prior to monitoring and sampling activities.

Water Storage (Single-Lined Pit)

1. **EQT SMI-28:**

   [Pit content was sampled 4/25/13, 5/1/13, 5/8/13, and 5/15/13 for full analytical list].

Figures 8 and 9 illustrate water storage sampling activities at the single-lined pit site. A single natural gas well development phase could not be attributed to these samples; the pit water contained freshwater, flowback water, and recycled water from various nearby EQT horizontal gas well pad locations. The pit began receiving water the week of April 15, 2013, with the first sample collected within two weeks and sampling continuing weekly for the duration of the monitoring period. Due to safety considerations and permissible EQT procedures, pit samples consisted of a single grab sample from the edge of the pit. An EQT consultant retrieved the sample during each sampling event in view of WVWRI team members. Monitoring activities consisted of measuring field parameters (TDS, DO, pH, temperature, specific conductance, and salinity) and collecting samples of the pit water. All water samples were analyzed for the full suite of parameters listed in **Table 2**.

Figure 8: Water sample collection at the EQT single-lined pit site.

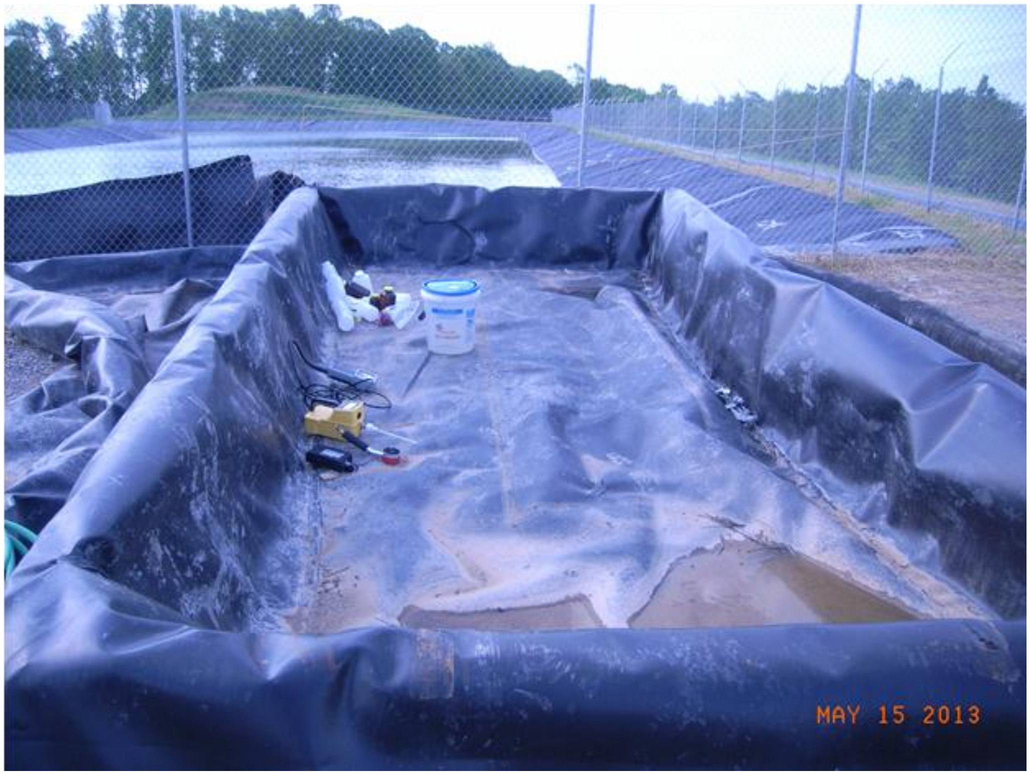

Figure 9: Pit sampling equipment for the EQT single-lined pit site.

First Order Stream

1. **EQT SMI-28 "Tributary A":**

   [Water sampled on 4/4/13 and 5/15/13 for full analytical list, and sampled 4/25/13, 5/1/13 and 5/8/13 for inorganics only].

Figures 10 and 11 illustrate sampling activities that took place at the first order stream labeled as "*Tributary A*" or "*Trib A*." In the phase II plan, samples were to be taken from two tributaries (first order streams) on either side of topographic ridge divide. However, access could only be obtained for one location. Samples were taken from the mouth of this un-named tributary before it entered the *Meathouse Fork* stream.

The initial, or baseline, sample from the first order stream was taken on April 4, 2013, approximately two weeks prior to the pit receiving flowback water. The pit began receiving water the week of April 15, 2013, with weekly monitoring of the first order stream beginning the following week. (Refer back to **Figure 2** for the location for the first order stream sampling point.) Once the baseline sample was collected, monitoring of field parameters was conducted on a weekly basis. Baseline (April 4, 2013) and final (May 15, 2013) samples were analyzed for the full suite of parameters listed in **Table 2**. For the weekly sampling events, samples were found with a field reading for specific conductance >20% of the baseline value; therefore, water samples were collected for analysis of inorganic parameters (See **Table 2**.) on April 25, 2013, May 1, 2013, and May 8, 2013. **Table 4** summarizes the parameters analyzed first order stream sampling event.

Figure 10: First order stream sampling at the EQT single-lined pit site.

Figure 11: First order stream sampling station at the EQT single-lined pit site.

Table 5: Tributary Samples at Single-lined Pit Site

	4/4/2013 Baseline	4/25/2013	5/1/2013	5/8/2013	5/15/2013 Final
Tributary A	Full Suite & Field	Field & Inorganics	Field & Inorganics	Field & Inorganics	Full Suite & Field

<u>Hydrogeological Tests</u>

1. **Consol/Noble Energy SHL centralized pits**
2. **EQT SMI-28 single-lined pit**

Groundwater monitoring wells peripheral to each pit were installed and developed by the respective energy companies. With the exception of the two deep wells at the centralized pits site, monitoring wells were perforated in the upper 5-25 feet of the water table. Most wells were in the range of 15 to 150 feet distant from the berm of the respective pits.

Pump tests were conducted by pumping at a constant discharge using low-flow (0.23-3.0 gallons/minute) pumps and monitoring the drawdown response of each well using Onset 10-m range sealed pressure transducers with barometric correction. Transmissivity, average hydraulic conductivity, and other hydrogeological parameters from the pumping test data for each monitoring well were interpreted for each aquifer test. Test results were applied to estimate approximate groundwater velocities and subsurface groundwater horizontal travel times to nearby surface drainage from beneath the pits. These times were extremely short at the single-lined pit (EQT SMI-28) site (25 to 40 days) and extremely long at the centralized pits (Consol/Noble Energy SHL) site (700 to 700,000 days). The differences were attributed to the differences in subsurface geology between the two locations.

Field Sampling Methods (Standard Operating Procedures)

This section describes activities related to and procedures followed for the collection of field samples in support of the ETD-10, *Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations* project. These standard operating procedures (SOPs) are applicable for the collection of groundwater samples, representative surface water samples ranging from first order tributaries to streams and rivers, and water impoundment samples. These are standard (i.e., typically applicable) operating procedures which may be varied or changed dependent upon site conditions, equipment limitations, or limitations imposed by the procedure. In all instances, the procedures employed have been documented and were modeled after WVDEP's *Quality Assurance/Quality Control Plan & Standard Operating Procedures for Groundwater*

Sampling, *WVDEP-DWWM-PP-GW*-001, and EPA guidance documents: 1) *RCRA Groundwater Monitoring: Draft Technical Guidance, EPA/530/R-93/001*; 2) *Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures, EPA/540/S-95/504*; and 3) *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, EPA SW-846*.

Personal Protection

Each team member was provided proper PPE necessary for access to a natural gas well or natural gas well development activity-related site. Minimum PPE requirements included: 1) hardhat, 2) safety glasses, 3) metatarsal boots, 4) gloves, and 5) FR clothing. In addition, WVWRI personnel were required to have on hand: 1) full-face respirators with combination P100 and organic vapor filters, 2) a first aid kit, 3) a flotation device, 4) a handheld radiation alert detector, and 5) a 6-gas PID. Because collecting samples in cold weather, especially around cold water bodies, carries the risk of hypothermia and collecting samples in extremely hot and humid weather carries the risk of dehydration and heat stroke, sampling team members were also equipped with adequate clothing necessary for protection in cold weather and carried an adequate supply of water for protection against dehydration in hot weather. Appropriate footwear for stream wading consisted of hip waders with non-slip soles and were worn during surface water sampling events. Cellular telephones were carried by team members and site health and safety plans were requested for review upon initial arrival at each site.

Team members received Hazardous Waste Operations and Emergency Response (HAZWOPER) training prior to the initiation of phase I and completed a HAZWOPER refresher course prior to the initiation of phase II. WVU also required team members to obtain additional safety and health training and participate in the WVU Employee Medical Surveillance Program. Team members conducting any field sampling activities were trained in proper EPA sampling techniques.

Chemicals

The toxicity or carcinogenicity of the chemicals used for calibrating sampling equipment has not been precisely determined; therefore, these chemicals were treated as a potential health hazard. Exposure was reduced to the lowest possible level. Reference files with the Material Data Safety Sheets (MSDSs) were made available to the sampling team members.

The standard solution for calibrating conductivity contained potassium chloride. Sampling team members avoided inhalation, skin contact, eye contact, and ingestion when using the solution by following the manufacturer's recommended calibration procedures which included proper chemical handling procedures.

Standard solutions for pH calibration contained the following compounds:

- *pH 4 Solutions:* potassium hydrogen phthalate, red food coloring, water.
- *pH 7 Solutions:* potassium phosphate monobasic, sodium hydroxide, yellow food coloring, and water.
- *pH 10 Solutions:* potassium hydroxide, disodium EDTA dehydrate, potassium carbonate, potassium borate, bromophenol blue, sodium salt, bromocresol green, sodium salt, and water.

Sampling team members avoided inhalation, skin contact, eye contact, and ingestion when using any of the pH solutions by following the manufacturer's recommended calibration procedures which included proper chemical handling procedures.

General Equipment List

1. Decontamination materials
2. Sample containers supplied by certified analytical laboratories (REIC and Pace Analytical for this study)
3. Cooler with ice
4. Deionized water
5. 6-Gas Meter (Photo-Ionization Detector/PID)
6. GPS unit
7. Handheld radiation alert detector (Radiation Alert Inspector EXP)
8. Field notebook, pen, calculator, and field data sheets
9. YSI-556 (for field measurements) with temperature, pH, and conductivity probes
10. Conductivity standard
11. pH standards
12. Calibration fluids and cups
13. Health and safety plan and PPE
14. Chain-of-custody forms
15. Five-gallon buckets
16. Nitrile gloves, dry cloth or paper towels
17. Tools and batteries for all equipment

Calibration

All instrument probes were calibrated before measuring environmental samples. The YSI-556 sensors, except temperature, required periodic calibration to assure high performance. The YSI-556 multi-parameter water quality document, *User Manual*: *YSI Calibration, Maintenance & Troubleshooting Tips for YSI-556 & Sensors Summary of Methods*, was followed to ensure proper calibration for each sensor prior to sampling events. During the warm-up period, the display was checked to determine the unit's battery level and if battery replacement was necessary.

The PID and radiation alert detector did not require calibration prior to each sampling event. Calibration for the PID and radiation alert detector occurred on a regular basis following the user's manual by WVWRI team members and periodically by WVU Environmental Health & Safety Officials.

Sample Preservation, Containers, Handling, and Storage

Refer back to **Table 1** for corresponding information to the sampling sub-sections below.

Sample bottles for inorganic and organic parameters were prepared by REIC and provided to WVWRI team members. An example of the REIC chain-of-custody (COC) form is attached as **Appendix E**. Sample bottles for the radioactive parameters were prepared by Pace Analytical and provided to WVWRI team members. An example of the Pace Analytical COC is attached as **Appendix F**. REIC and Pace Analytical COC forms also included *Request for Sample Analysis* information that may sometimes exist as a separate form. All sample bottles were examined by WVWRI team members in the WVWRI laboratory and prior to use in the field to ensure proper sample preservation fixatives were present. Labeling of samples included a sample identifier, collector's initials, and time and place of sample collection. Samples were immediately stored in designated coolers with ice. Sample pick-ups were arranged with REIC and Pace Analytical to ensure analyses of samples within specified holding times.

The following general procedures were performed during all sampling events:

1. Sample(s) were collected in suitable containers specific for the chemical analyses to be performed. Samples were collected in the order of organic (volatile then semi-volatile), inorganic, and radioactive parameters. Caution was exercised to protect the sampling equipment from coming into contact with a contaminated surface prior to insertion into a groundwater monitoring well or collection of a sample.

2. Sample containers were labeled with a sample name, time, and place and each container was initialed by the collector.
3. The sample containers were capped and immediately placed in a cooler with ice.
4. Pertinent data was recorded in the site field notebook and/or on field data sheets not already detailed in the *Phase II Monitoring Plan*.
5. COC forms were completed.
6. Samples were submitted to the certified laboratories (REI Consultants and Pace Analytical) via respective courier service. Courier service was arranged in advance of each sampling event. The laboratories received and processed the samples within 24 hours of sample collection.
7. All non-dedicated sampling equipment was decontaminated prior to the collection of additional samples. Decontamination water was properly disposed according to the site operator's standard procedures.

<u>Decontamination</u>

Because decontamination procedures are time consuming, WVWRI often utilized multiple sampling tools (e.g., pumps, tubing, buckets) during sampling events to reduce the number of times decontamination procedures were performed in the field. Surface water samples were collected using the direct method; therefore, extensive decontamination was not warranted since most equipment did not come into contact with the water sample and new sampling containers were used at each sampling location. Equipment decontamination consisted of the following materials:

1. Detergent wash (Liquinox®)
2. Distilled water
3. Deionized water rinse
4. Five-gallon buckets

Following the manufacturer's instructions, the Liquinox® solution was pre-mixed in the WVWRI laboratory prior to field sampling activities. Decontamination consisted of placing the pump in a five-gallon bucket of the Liquinox® solution and running the pump for one to two minutes to allow the solution to pass through the pump and associated tubing. The pump was then placed into another five-gallon bucket with distilled water and run for another one to two minutes to rinse out the solution. The tubing was then disconnected and any remaining water from the pump and tubing was drained off prior to repeated use. Periodically, WVWRI team members would replace the tubing between sampling to further reduce the risk of contamination. All field materials were decontaminated after each sampling event. Decontaminated equipment was allowed to dry thoroughly and stored in a dirt- and dust-free environment. All decontamination water was disposed of either in the site pit or in drums provided by the energy company's environmental firm present for split sampling.

The Liquinox® solution was also used to decontaminate the YSI-556 flow-through cell and interface meter between sampling events. The same steps outlined above were followed to decontaminate the YSI-556 with the exception that the decontamination procedure took place in the WVWRI laboratory.

First Order Stream Sampling

First order stream sampling procedures are detailed below and are a compilation of the EPA guidance documents: 1) *Standard Operating Procedures: Surface Water Sampling, (SOP#2013)*; and 2) *EPA Method 1669: Sampling Ambient Water for Determination of Metals at EPA Water Quality Criteria Levels*. The YSI-556 multi-parameter water quality document, *User Manual*: *YSI*

Calibration, Maintenance & Troubleshooting Tips for YSI-556 & Sensors Summary of Methods, was also followed and relevant information used in the sampling procedures below.

Direct Method Sampling

Sampling frequency for the first order stream was determined prior to the initiation of phase II sampling activities and is detailed in the *Sampling Strategy* section of this report. This section is referenced from the EPA, *Standard Operating Procedures: Surface Water Sampling, (SOP#2013)*. Additional steps were also added due to the extensive nature of the sampling requirements.

1. For streams, rivers and other surface waters, the direct sampling method was followed to collect water samples directly into the sample container(s).
2. Health and safety considerations were addressed by following standard WVWRI health and safety procedures during sampling activities where specific field conditions existed (e.g., stream crossings, adverse weather conditions) that warrant the use of additional safety equipment.
3. Equipped with adequate protective clothing and gear, WVWRI team members accessed the first order stream, *Tributary A*, sampling station. For sampling of *Tributary A*, dependent upon the water level of *Meathouse Fork*, different crossing routes were taken for phase II sampling events.
4. The sampling station on *Tributary A* was considered a shallow stream station; thus, the sample was collected under the water surface while pointing the sample container upstream. Collectors were cautious to ensure the sample container was upstream and samples were taken in a downstream to upstream direction. This process protected against disturbing the substrate.
5. An additional sample was collected in a non-preserved bottle and screened with the PID meter and handheld radiation detector.

6. The YSI-556 probe was placed directly into the moving surface water. Readings were allowed to stabilize and the field parameters (temperature, specific conductance, TDS, pH, DO, and salinity) were recorded.
7. As necessary, samples were collected in a non-preserved laboratory-approved container and transferred to proper sample bottles provided by the laboratories conducting the chemical analyses. This collection alternative minimized the potential for loss of chemical preservative from the sample bottles.

Groundwater Monitoring

Equipment List

1. Electronic interface probe for determination of liquid products present and depth-to-water
2. Low-flow pump [WVWRI used proactive low flow with power booster I controller and LCD (SS Mega-typhoon)]
3. Teflon® and silicon tubing
4. Power source
5. Graduated cylinder (flow measuring device)
6. Five-gallon bucket
7. Fifty-five gallon drum for purge water
8. Activated carbon unit (purge water filtration device, if needed)

Sampling Procedures

Sampling frequency for each site was determined prior to the initiation of phase II sampling activities and is detailed in the *Sampling Strategy* section of this report. Depth-to-bottom and depth-to-water for each groundwater monitoring well was measured prior to each sampling event. Water levels were measured with a precision of ±0.01 feet using a flat tap water level meter with interface probe. Water level measuring equipment was decontaminated prior to use at each groundwater monitoring well and equipment was periodically inspected for wear-related issues. Each groundwater monitoring well was purged prior to sampling. Groundwater monitoring wells were purged at rates below 0.5 liters per minute until the field parameters (temperature, specific conductance, TDS, DO, pH, and salinity) stabilized. Purging equipment not dedicated to a specific groundwater monitoring well was decontaminated using the Liquinox® solution and followed the decontamination procedures outlined above between sampling groundwater monitoring wells. Purged water was either disposed into the site pit or the fifty-five gallon drum provided by the energy company's environmental firm present for split sampling.

Water was tested for radioactivity using a radiation alert detector at both the onset of purging activities and post-sampling activities. Initial groundwater samples were taken from each groundwater monitoring well at the centralized pits site and the single-lined pit site at least one week after wells were constructed. Duplicate samples were obtained for 10% of collected samples.

Groundwater sampling proceeded from up-gradient of the pit/impoundment to down-gradient. Nitrile gloves were used during all sampling procedures and were changed between well locations to prevent sample contamination. Sampling procedures included:

1. GPS coordinates for each groundwater monitoring well were verified at each site prior to initial (baseline) sampling.
2. The lock and cap were removed from the well casing and the headspace of the well was monitored for VOCs with a PID. PID data was recorded in the field notebook.
3. The depth-to-water was measured from a marked reference point on the casing to the nearest 0.01 feet using the interface probe. The initial reading was confirmed by a second measurement.

4. The total volume of water in the well casing was determined and recorded, along with all other appropriate data, including GPS location, date, time, and screened interval in the field notebook.
5. (For wells with depth-to-water greater than 27 feet from the top of casing - All wells in Phase II). Teflon® tubing was connected to the standard performance PVC pump and slowly lowered to approximately the middle of the pre-determined screened interval. The flow-through cell with multi-meter was connected to the pump. Teflon® tubing was attached to the exit point of the flow-through cell and routed into a five-gallon bucket to collect purge water. The pump was connected to a power source.
6. Groundwater was pumped at a rate no greater than 0.5 liters per minute. Water-quality readings of pH, electrical conductance, temperature, TDS, oxidation salinity, and DO were recorded from the multi-parameter meter after the flow-through cell had been purged and after a minimum of one tubing volume. Water-level measurements were taken every 30 seconds to five minutes, which allowed the sampler to control the pumping rate. Water drawdown did not exceed 0.33 feet.
7. Water quality data was recorded every three to five minutes, dependent on pumping rate and water drawdown. Grab sampling commenced after stabilization of water quality parameters (three consecutive readings of all parameters within 10% of the previous reading).
8. Sample bottles were filled in the order of volatile organic compound bottles first followed by semi-volatile organic compounds, inorganics, and other unfiltered samples.
9. Samples were immediately cooled and prevented from exposure to sunlight by placing them on ice in a dedicated sample cooler. A COC was completed and all samples were collected and transported to the respective laboratories by their courier service and within specified holding times.
10. All appropriate equipment was decontaminated using the Liquinox® solution and all purge water was properly disposed of following the site operator's standard procedures (e.g., pit or drum).

Pit Samples

The pit samples were grab samples taken from the edge of the pit. Direct method sampling via five-gallon buckets was used. Sample locations were dependent on the accessibility of the pit and the safety and well-being of the sample collector. The following procedures were used during sample collection:

1. Sample locations were recorded using a GPS.
2. A PID was used to check for background off-gassing of VOCs. The coordinates and PID data were recorded in the field notebook. A handheld radiation alert detector was also used to check for background radiation levels and this data was also recorded in the field notebook.
3. Due to site access issues, a five-gallon bucket was used to obtain the sample from the edge of the pit. Radiation alert detector, water quality, and PID readings were taken and recorded.
4. Step three was repeated, if needed, to obtain additional sample volume to fill all sample bottles. All remaining water was properly disposed of following the site operator's standard procedures.
5. Liquid samples were filled in the order of VOC bottles first, followed by semi-volatile organic compounds, inorganics, and other unfiltered samples.
6. Sample bottles were filled in the order of VOC bottles first, followed by semi-volatile organic compounds and inorganics for sludge (solids) samples.
7. Samples were immediately cooled and prevented from exposure to sunlight by placing them on ice in a dedicated sample cooler. A COC was completed and all samples were collected and transported to the respective laboratories by their courier service and within specified holding times.
8. All appropriate equipment was decontaminated using the Liquinox® solution after each use and the decontamination water was properly disposed of following the site operator's standard procedures (e.g., pit or drum).

Analytical Methods

Standard operating procedures are designed to optimize the accuracy and representativeness of water chemistry data. WVWRI team members have been certified for sample collection following EPA standard methods and procedures. Guidelines were followed for sample preparation, collection, packaging and transport to maintain the integrity of the samples. Proper COC requirements were followed.

Organics and Inorganics

Samples were stored as required using the various EPA analytical methods and pick-ups arranged with the certified laboratory, REIC, within specified holding times. An example of the COC form used by REIC is attached as **Appendix E**. All sample analyses and laboratory activities were performed based on REIC standard operating procedures and EPA sampling and analyses protocols. **Table 4** provides an overview of REIC quality assurance and quality control (QA/QC) procedures. This information is excerpted from the *REIC Quality Manual*. QC is specifically spelled out in the individual standard operating procedures (SOPs) for each analytical test. This table is an overview of QC samples that were included and/or required for the various analytical tests.

Each REIC analytical report detailed laboratory SOPs that incorporated appropriate quality control procedures as described in the applicable methods. Results of equipment and field blanks were also contained in these reports. REIC was responsible for the regular instrumentation maintenance and quality checks required of a certified laboratory. WVWRI was responsible for the regular maintenance, quality checks and calibrations of field sampling and monitoring equipment.

Radioactivity

Samples were stored as required using the various EPA analytical methods and pick-ups were arranged with the certified laboratory, Pace Analytical, within specified holding times. An example of the COC form used by Pace Analytical is attached as **Appendix F**. All sample analyses and laboratory activities were performed based on Pace Analytical SOPs and EPA sampling and analyses protocols. **Table 5** provides an overview of Pace Analytical QA/QC procedures. This information is excerpted from the *Pace Analytical Quality Manual*. QC data is specifically spelled out in the individual SOPs for each analytical test. This table is an overview of QC samples that were included and/or required for the various analytical tests. Pace Analytical was responsible for the regular instrumentation maintenance and quality checks required of a certified laboratory. WVWRI was responsible for the regular maintenance, quality checks and calibrations of field sampling and monitoring equipment.

Table 6: REI Consultants – Inorganic and Organic Data Check

Inorganic Data Checks	Organics Data Check
Sample Chain of Custody (COC)	Sample Chain of Custody (COC)
Extraction & Analysis sample holding times	Extraction & Analysis sample holding times
Calibration:	Initial Calibration
• Initial Calibration Verification (ICV)	Continuing Calibration Verification (CCV)
• Initial Calibration Verification	Blanks
• Continuing Calibration Verification (CCV)	Surrogate Recoveries
Blanks	Duplicate Samples
Laboratory Control Spike (LCS)	Matrix Spike (MS)/Matrix Spike Duplicate (MSD)
Quality Control Spike (QCS) Sample	Internal Standard Performance
Duplicate (DUP) Sample	Compound Identification
Matrix Spike (MS) Sample	Compound Quantitation and Reporting Limits
Field Duplicates	System Performance
Method Specific QC	Field Duplicates
Overall Assessment	Equipment Blanks
	Chromatogram Retention Times
	Mass Spectrometer Tuning Criteria Compliance
	Method Specific QC
	Overall Assessment

Table 7: Pace Analytical – Radioactivity data Check

Radioactivity Data Checks
Blanks
Method Blank
Laboratory Control Sample (LCS)
Matrix Spike/Matrix Spike Duplicate (MS/MSD)
Sample Duplicates
Surrogates
Internal Standards
Field Blanks
Trip Blanks

Data Management

Routine data related to the collection of samples was recorded during each site visit. Data was recorded in field notebooks and transferred to an electronic data file located on the WVWRI shared server once team members returned to the office. Times, dates, and personnel involved in data collection were also recorded in field notebooks and transferred to the electronic data file. Copies of COC forms for each set of samples sent to REIC and Pace Analytical were scanned and included as part of the electronic data file. Other data regarding sampling methods or other pertinent information regarding visits and natural gas well development was recorded in field notebooks. As needed, the data transferred to the electronic data file was reviewed and reported to the WVDEP as part of progress updates. Photographs were used to assist with documenting field activities and conditions. Data collected in the field and analytical results obtained from REIC and Pace Analytical were reviewed after each site visit and upon receipt from the respective laboratories. Any measurements (parameter, concentration) above environmental water quality standards were noted and potential causes were investigated. Potential outliers of data were reviewed as well. Outliers included unexplained spikes in data or unexplained zero/negative readings.

Results and Discussion

The use of the term "elevated" in this report refers to results above the initial (background) levels of measured water quality parameters (contaminants) and not necessarily to the level of exceeding primary or secondary drinking water standards. A result of measured parameters that exceeds primary or secondary drinking water standards is specifically noted as an "exceedance" in the report.

Water Quality

The concentration of select parameters was compared to sequential groundwater monitoring well samples to indicate if the parameters increased during the monitoring period. In **Figures**

12 and 13, each site's respective groundwater monitoring wells are represented by connected blue diamonds and the first point in each series represents background concentrations. Background concentrations were determined by taking groundwater samples for chemical analyses prior to the pits receiving water. **Figure 12** graphically displays results from the Consol/Noble SHL (SHL) centralized pits site and **Figure 13** shows results from the EQT SMI-28 (EQT) single-lined pit site. The red triangles indicate the average flowback concentration of the given parameter while the blue diamonds indicate temporal trends in the groundwater monitoring wells at the respective pit site. Neither site shows strong trends during the monitoring period indicating no contamination from the pits.

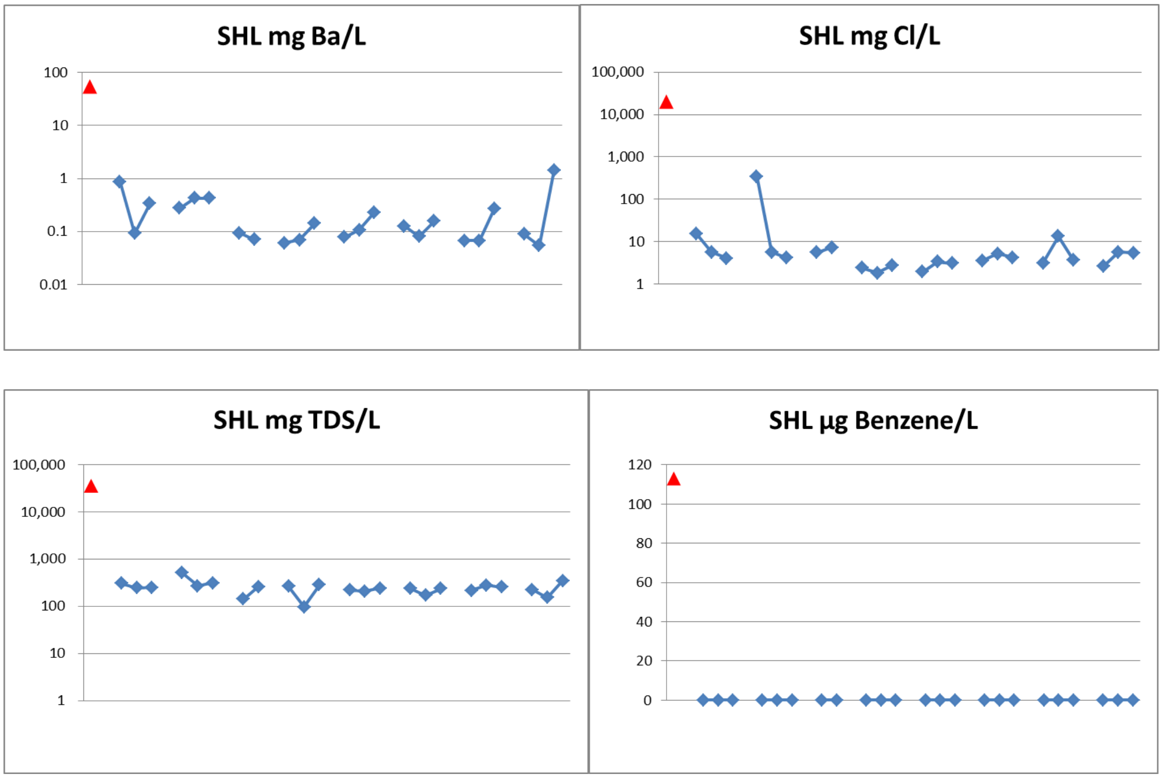

Figure 12: Water quality results from SHL centralized pits site.

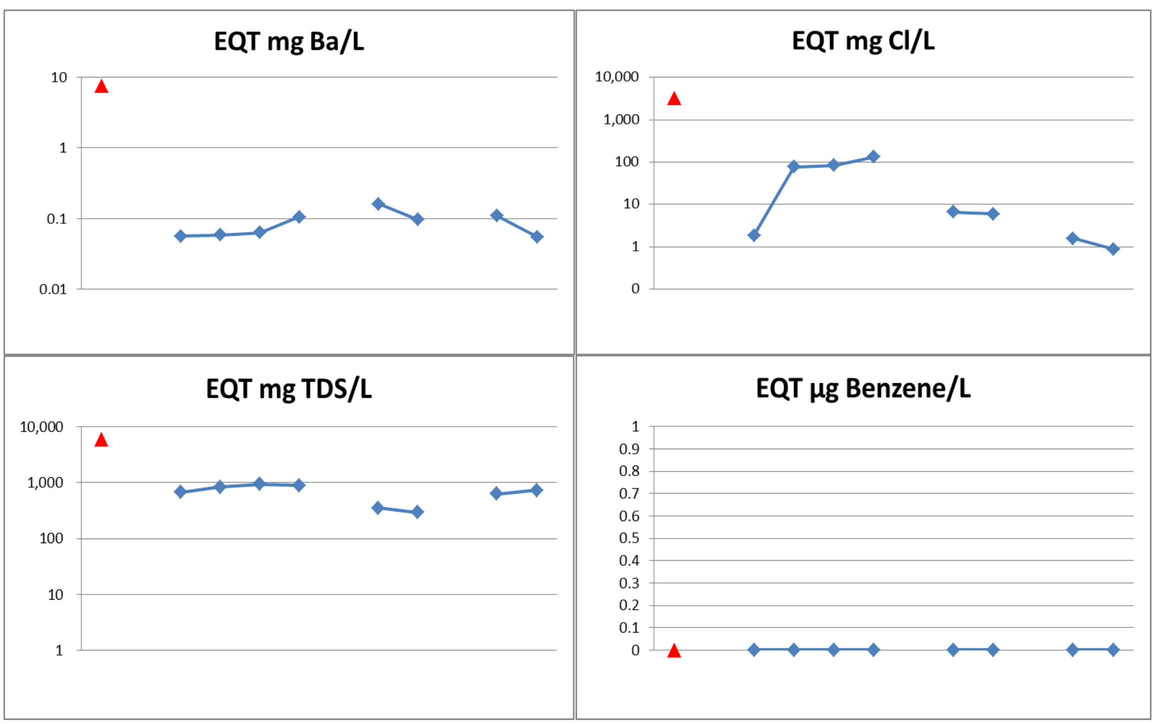

Figure 13: Water quality results from the EQT single-lined pits site.

The nearest stream proximal to the EQT site was also monitored prior to and after the pit was filled with flowback water. **Figure 14** indicates a modestly increasing trend in barium (Ba); however, levels are well below the primary drinking water standard (0.154 mg/L compared to the standard of 2 mg/L) and, in general, there was no indication of significant leakage.

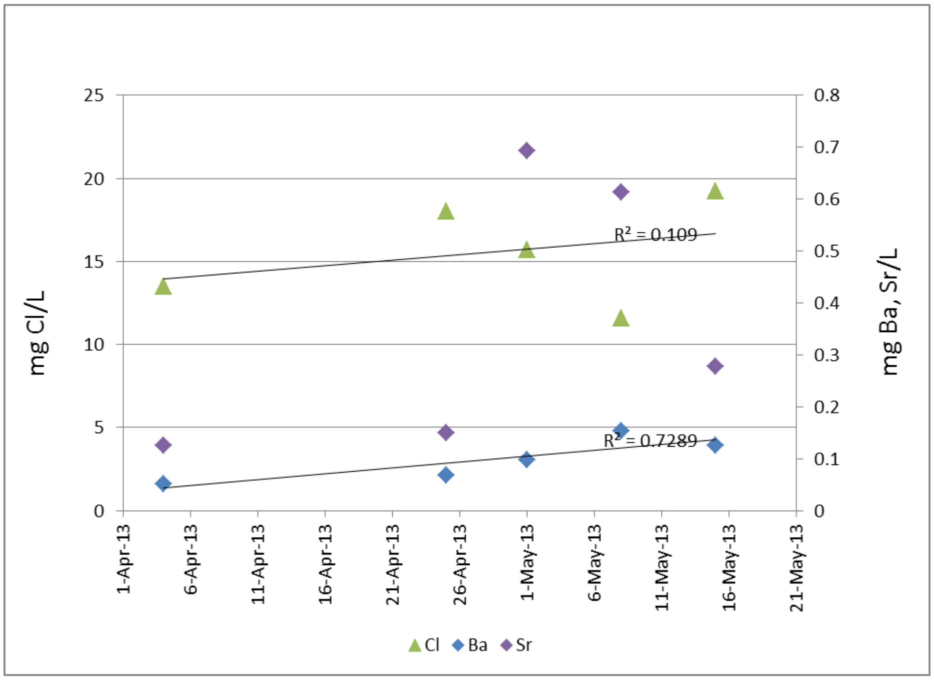

Figure 14: Trends in concentrations of Cl, Ba, and Br in stream near the EQT single-lined pit site.

Table 8 shows a comparison of water chemical statistics, in mg/L, for groundwater monitoring well water, separated into the EQT and SHL sites, and for flowback (FB) water from both sites. **Figure 15** shows a *Piper* trilinear diagram showing dominant geochemical trends in major ion chemistry for calcium, magnesium, sodium + potassium, chloride, sulfate, and bicarbonate (Ca, Mg, Na+K, Cl, SO_4, and HCO_3), plotted on an equivalent concentration basis. The FB waters in **Figure 15** are shown as red circles, the EQT groundwater monitoring wells as blue triangles, and the SHL groundwater monitoring wells as orange squares. The points of both triangles represent 100% of an equivalent chemical basis of that cation or anion with respect to the sum of all cations or anions.

Table 8: Summary Statistics for Chemistry of all Flowback Water and Groundwater Monitoring Wells at the EQT and SHL Sites

		Ca	Mg	Na	K	HCO3	SO4	Cl	TDS	pH	Fe	Br
all Flowback	mean	2428	266	5646	141	140	30.7	12618	22684	6.9	21.8	147
	minimum	503	60	1240	44	66	ND	2610	5510	5.8	0.8	ND
	maximum	8670	944	20800	315	285	79.0	56000	93700	7.9	57.0	675
EQT wells	mean	215	56.4	14.5	3.8	400	187.0	39	668		6.6	ND
	minimum	86	18.0	3.9	2.4	226	84.8	1	294		1.0	ND
	maximum	383	124.0	33.9	5.5	521	274.0	131	941		20.8	ND
SHL wells	mean	77	17.9	6.4	5.1	206	30.9	20	250	6.7	18.5	ND
	minimum	35	4.9	0.0	1.3	72	12.8	2	98	5.9	0.3	ND
	maximum	152	51.5	19.3	26.6	303	67.6	348	510	7.4	186.0	ND

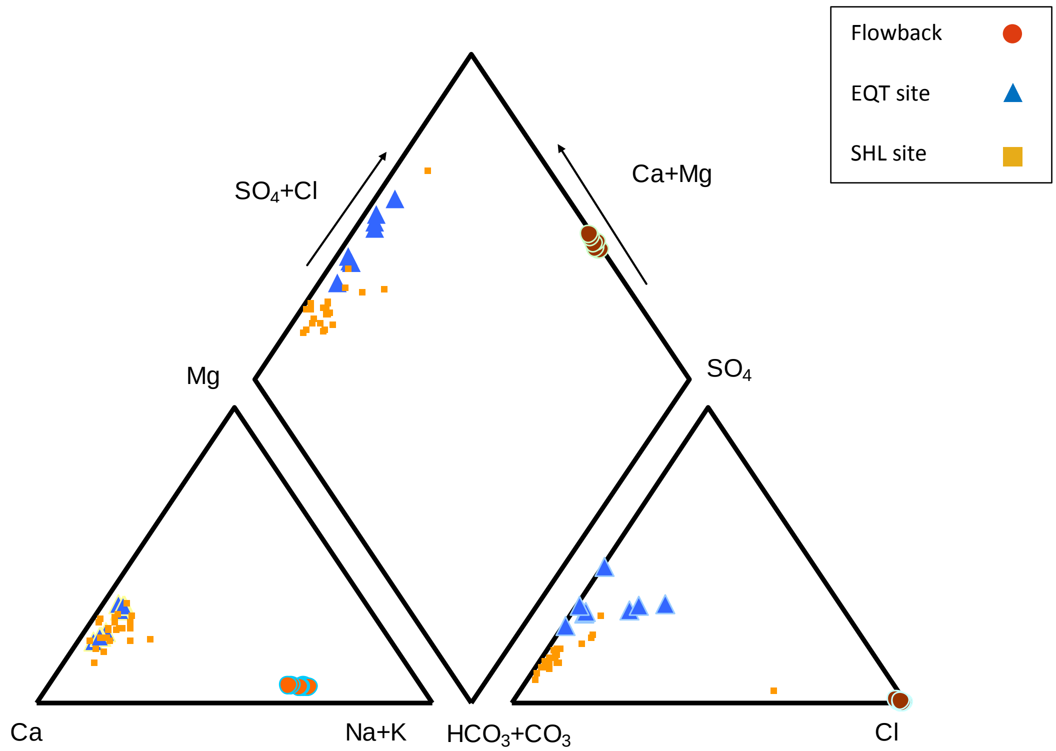

Figure 15: Piper trilinear diagram of major ion chemistry for flowback waters, groundwater monitoring wells at EQT site and groundwater monitoring wells at SHL site.

There is a distinct difference in the major-ion chemistry of both **Table 8** and **Figure 15**. The FB waters were saline brines of Cl-Na with minor Ca dominance. The shallow groundwater sample results showed Ca-Mg and HCO_3-SO_4 dominance, with the EQT groundwater samples being slightly more SO_4-rich than the SHL groundwater samples. The average TDS of the FB waters (22,684 mg/L) was approximately two-orders of magnitude higher than the groundwater well means at the EQT and SHL sites (668 and 250 mg/L, respectively).

A similar difference existed for mean Cl (12,618 mg/L versus 39 and 20 mg/L, respectively), mean Na (5646 mg/L versus 14 and 6 mg/L, respectively), and mean K concentrations (131 mg/L versus 3.8 and 5.1 mg/L, respectively). Bromide (Br) was present at elevated levels in all but one FB samples and observed in very minor levels in only one sample, each, at the EQT and SHL groundwater monitoring wells. Other parameters (pH, iron, Mg, HCO_3, and SO_4) were more similar between FB and well waters, and in fact SO_4 was higher in the EQT wells than the FB waters.

There was some evidence for possible contamination observed in groundwater. MW1, the up-gradient well located between the drilling pad and the pit (see **Figure 2**), at the EQT site had three samples which showed Cl values from 77 to 131 mg/L in May 2013 after the pit was in use. These concentrations are not a toxicity threat; however, they are well above the baseline levels and were observed in consecutive sample dates. Well SHL3-MW4 (deep well) at the SHL site showed 348 mg/L Cl in June 2012. Otherwise, there was no indication of contamination. While the source of the elevated Cl levels at the EQT well (MW1) were not known, this well is located within approximately 50 feet of the pipe connection for trucks emptying into the pit, and one plausible explanation is potential surface spillage from trucks delivering FB water at this location.

Groundwater monitoring well results must be viewed in the context of poorly defined groundwater flow paths which are influenced by heterogeneous zones of rock porosity in both the vertical and horizontal axes. The groundwater monitoring wells were installed by the respective energy company under the guidance of WVDEP. For the centralized pits, the State of West Virginia's *Design and Construction Standards for Centralized Pits* were to be followed. Given the small number of groundwater monitoring wells and the hydrogeological conditions of each site, it cannot be determined if the groundwater monitoring wells would have intercepted a critical groundwater flow path.

Hydrogeological Properties

Both of the sites, (SHL) centralized and (EQT SMI-28) single-lined, contained pits in a similar topographic configuration, perched on top of relatively level ridges that are from 300-400 feet vertically above nearby surface water bodies or springs within 1,000 lateral feet. Due to topographic position, the pits are likely to be directly overlying, or very close to groundwater divides, separating flow systems moving into different shallow groundwater flow systems. Nearby streams and springs are the likely candidates to receive groundwater discharge from these flow systems. While it is impossible to map these divides with available data or to predict where exactly groundwater or baseflow discharge will occur, it is not difficult to estimate generally where this may happen. For the single-lined pit, the potential discharges are either into *Meathouse Fork* (northeastward flow) or into its tributary drainages south and westward. For the centralized pits, the two potential discharges are into *Turkey Run* (northward flow, possible from SHL2 and SHL3) or into *Middle Wheeling Creek* (southward flow, possible from SHL2, SHL3, and SHL4). Discharge may occur directly into the creek; but, it is just as likely to take place into first order or second order tributary streams, either as baseflow or as head-of-hollow springs.

Using the identified "presumed discharge locations" for each well site, hydraulic head differences and lateral flow distances from each well to its closest discharge area were estimated. Head differences were on the order of 300-400 feet and lateral flow distances on the order of 1,000-2,400 feet. Using these, an approximate hydraulic gradient was estimated.

With this gradient, the calculated *K* values from the aquifer tests, and an estimate of effective porosity of 0.05, groundwater velocities and travel times from the pit groundwater well sites to the potential discharge area were estimated. These are first-cut estimates done using many simplified assumptions and are only an indication of the approximate scale of time it would take for a pit leak or spill to travel into surface drainage via the water table.

EQT SMI-28 Single-lined Pit Site

Figure 16 shows the log time-log drawdown plots for the short pumping tests of the three groundwater monitoring wells at the EQT site. The test for MW1 (up-gradient well) was a step-drawdown test and for MW2 and MW3 (down-gradient wells), single-step constant-discharge tests. The pumping rates were relatively small **(Table 7)** and thus the region of drawdown around each well was limited in size. These results may be considered very localized measures of transmissivity in the upper 10-20 feet of the unconfined water-table aquifer. The measuring point (MP) engineering-GPS survey data and drillhole logs were provided by Groundwater Resources LLC, the EQT environmental contractor. The saturated thicknesses were calculated from static water levels on February 12, 2013, and measured total depths from the drillhole logs.

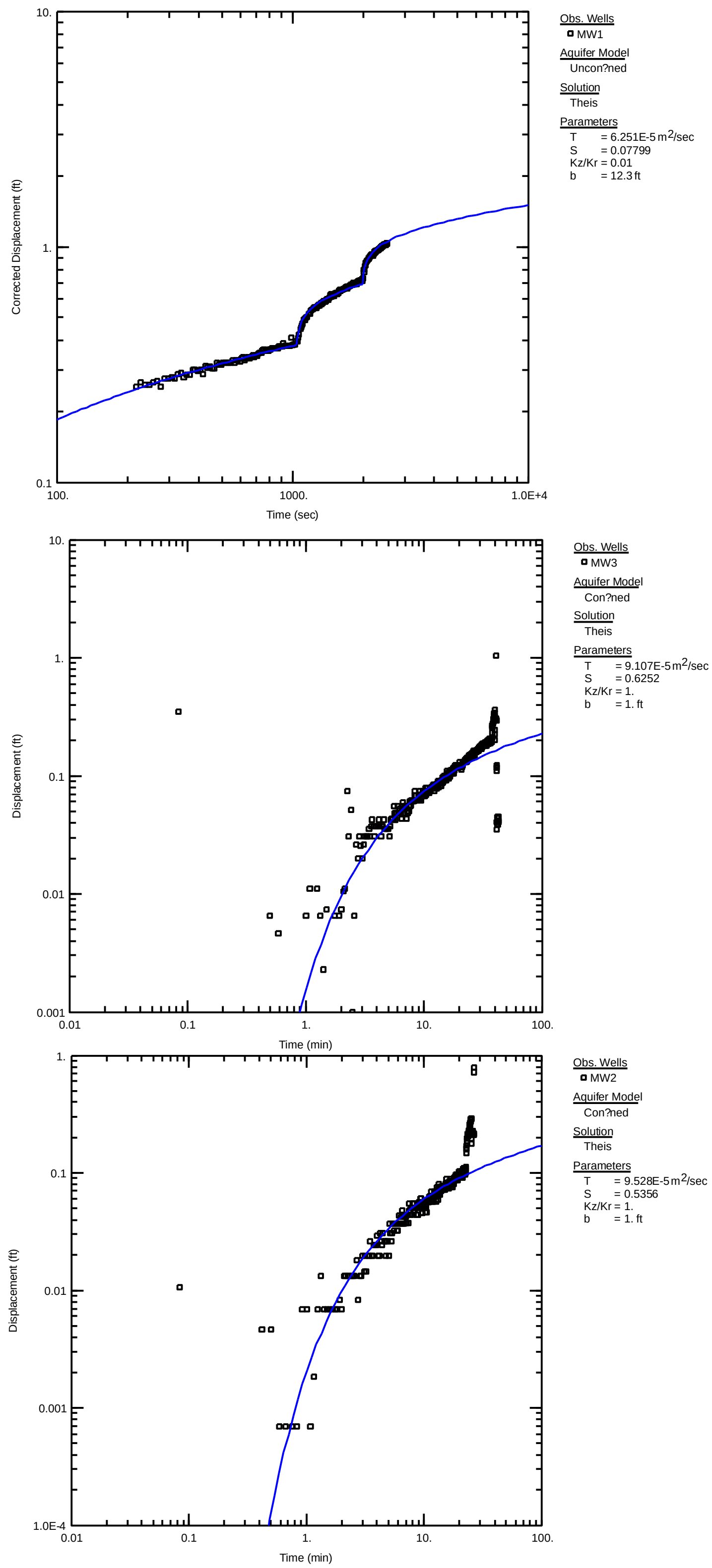

Figure 16: Aquifer test plots for the EQT single-lined pit monitoring wells.

Table 9: Summary of Well, Aquifer, and Groundwater Velocity Calculations

Operator	well	pit	test date	test duration minutes	pumping rate gpm	saturated thickness feet	elevation feet	static water depth feet	hydraulic head feet	transmissivity m2/s	K m/s	S	Sy	hydraulic gradient	velocity m/s	distance ft	Dt days
EQT	**MW1**		2/19/13	42.1	1.25, 2.1, 3.3 *	12.3	1262.80	36.46	1226.34	6.25E-05	1.67E-05	--	--	0.280283333	9.35E-05	1200	45.3
EQT	**MW2**		5/15/13	26.7	0.33	13.3	1225.42	42.18	1183.24	9.53E-05	2.35E-05	--	--	0.280283333	1.32E-04	1200	32.1
EQT	**MW3**		5/15/13	33	0.22	10.4	1228.24	42.12	1186.12	9.11E-05	2.87E-05	--	--	0.280283333	1.61E-04	1200	26.3
Noble	**MW1**	**SHL-2**	5/9/13	12	1.2	25	1315	41.85	1273.15	1.36E-06	1.78E-07	0.003	0.026	0.191075	6.82E-07	2000	10344.6
Noble	**MW2**	**SHL-2**	5/9/13	15.5	1.31	17.9	1316	29.06	1286.94	7.79E-07	1.43E-07	0.007	0.128	0.197970	5.65E-07	2000	12480.5
Noble	**MW3**	**SHL-2**	5/9/13	12.5	1.37	13.6	1324	46.75	1277.25	2.01E-06	4.85E-07	0.002	0.083	0.193125	1.87E-06	2000	3767.2
Noble	**MW4**	**SHL-2**	5/9/13	11	2.01	12.4	1309	30.71	1278.29	9.72E-08	2.57E-08	0.0003	0.046	0.193645	9.96E-08	2000	70837.8
Noble	**MW4**	**SHL-3**	5/9/13	8	0.55	5.1	1235	40.03	1194.97	3.27E-06	2.10E-06	0.045	0.0043	0.168872	7.10E-06	1800	893.8
Noble	**MW1**	**SHL-4**	5/9/13	3.9	0.86	5.4	1298	40.07	1257.93	4.83E-06	2.93E-06	0.007	0.086	0.197361	1.16E-05	2300	700.5
Noble	**MW2**	**SHL-4**	5/9/13	12.6	1.08	17.4	1290	45.60	1244.40	1.79E-06	3.38E-07	0.007	0.113	0.191478	1.29E-06	2300	6277.6
Noble	**MW3**	**SHL-4**	5/9/13	3.9	1.09	6.6	1278	38.88	1239.12	3.87E-06	1.92E-06	0.007	0.081	0.189183	7.28E-06	2300	1114.7

* indicates step drawdown test

Pumping test results were analyzed successfully using the *Theis* solution, as relatively little drawdown was induced and the saturated thickness was not greatly changed during the test. The noisy appearance of the datasets for MW2 and MW3 are due to the low drawdown induced. Results fit the *Theis* solution adequately at drawdowns greater than about 0.03 feet, the approximate noise level in the pressure transducers. Hydraulic conductivities for this interval were over a fairly narrow range from 1.6 to 2.9 x 10^{-5} meters/second (m/s).

Results **(Table 7)** include transmissivity for the aquifer zone penetrated by each groundwater monitoring well and hydraulic conductivity (*K*) based on the thickness of each zone. The resulting hydraulic conductivity ranged from 1.6 to 2.8 x 10^{-5} m/s for the three wells. The results were thus consistent over a very narrow range and suggest that the hydraulic conductivity conditions are relatively homogeneous at this site. The drillhole lithologic logs suggest that much of the groundwater is coming from an approximate five feet thick limestone bed within a shaly sequence of the basal Dunkard Group, the underlying bedrock unit along the ridgetops at this site. Limestone beds in the Dunkard Group are normally thin, marly freshwater lake deposits of local extent, in contrast to marine limestone units.

The groundwater flow scenario was based on northeast flow into the headwaters of the unnamed tributary leading to *Meathouse Fork*. This is the same tributary discharge that was sampled and designated *Tributary A*. Calculated travel velocities based on these *K* values and estimated hydraulic gradients and distances to surface discharge were on the order of 23-45 days, at a rapid velocity of 0.9-1.8 m/s **(Table 7)**.

Consol/Noble Centralized Pits Site

Figure 17 shows the log time-log drawdown plots for the SHL2 pit wells and **Figure 18** for the SHL3 and SHL4 wells. All are single-step constant-discharge tests. The response observed at these wells was quite different than for the single-lined pit (EQT) site. The groundwater monitoring well water levels drew down quickly and a number went dry in less than ten minutes. This normally suggests low horizontal hydraulic conductivity and a localized steep cone of depression with much local vertical drainage.

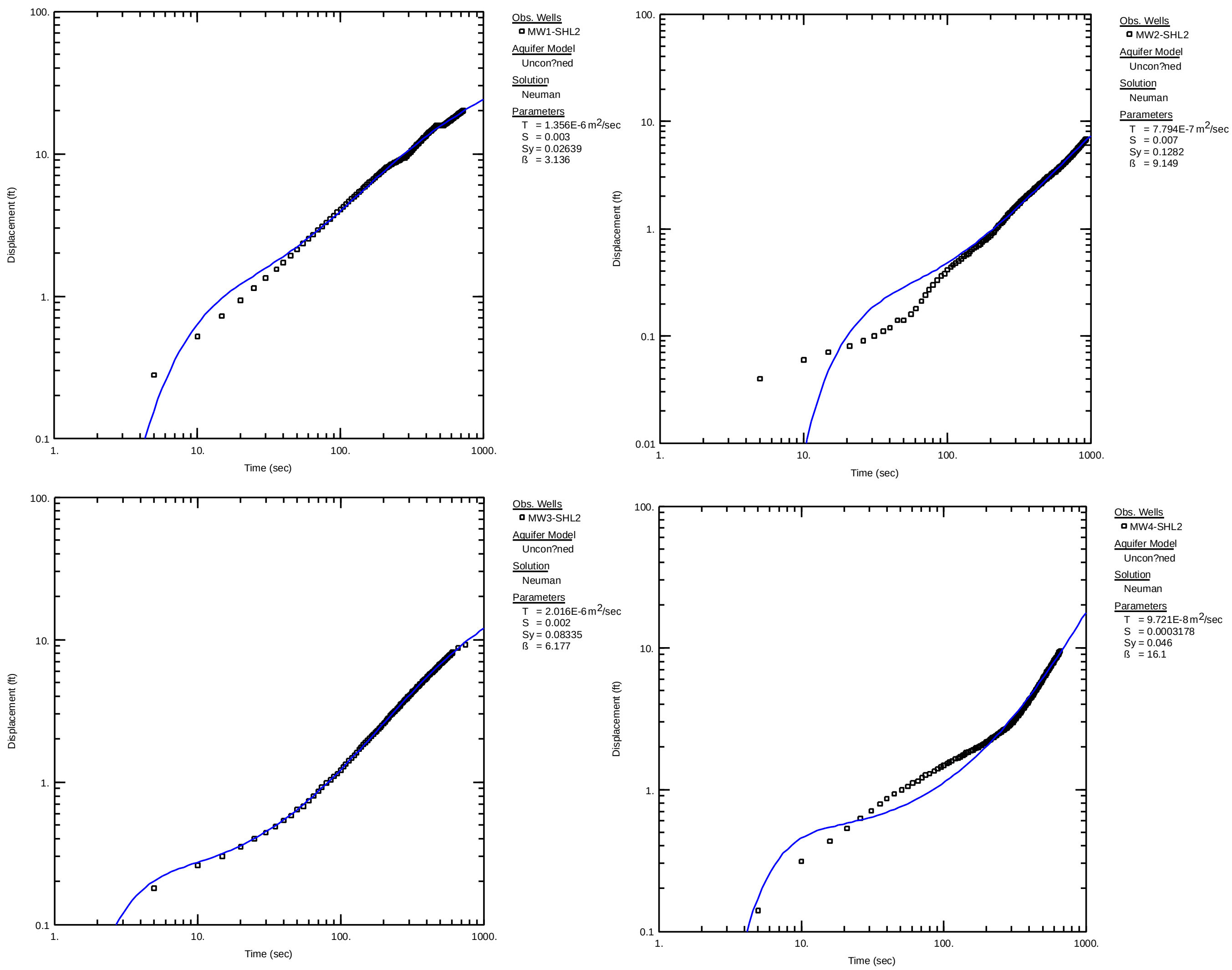

Figure 17: Aquifer test plots for the SHL centralized pits monitoring wells SHL2 (MW1, MW2, MW3, and MW4).

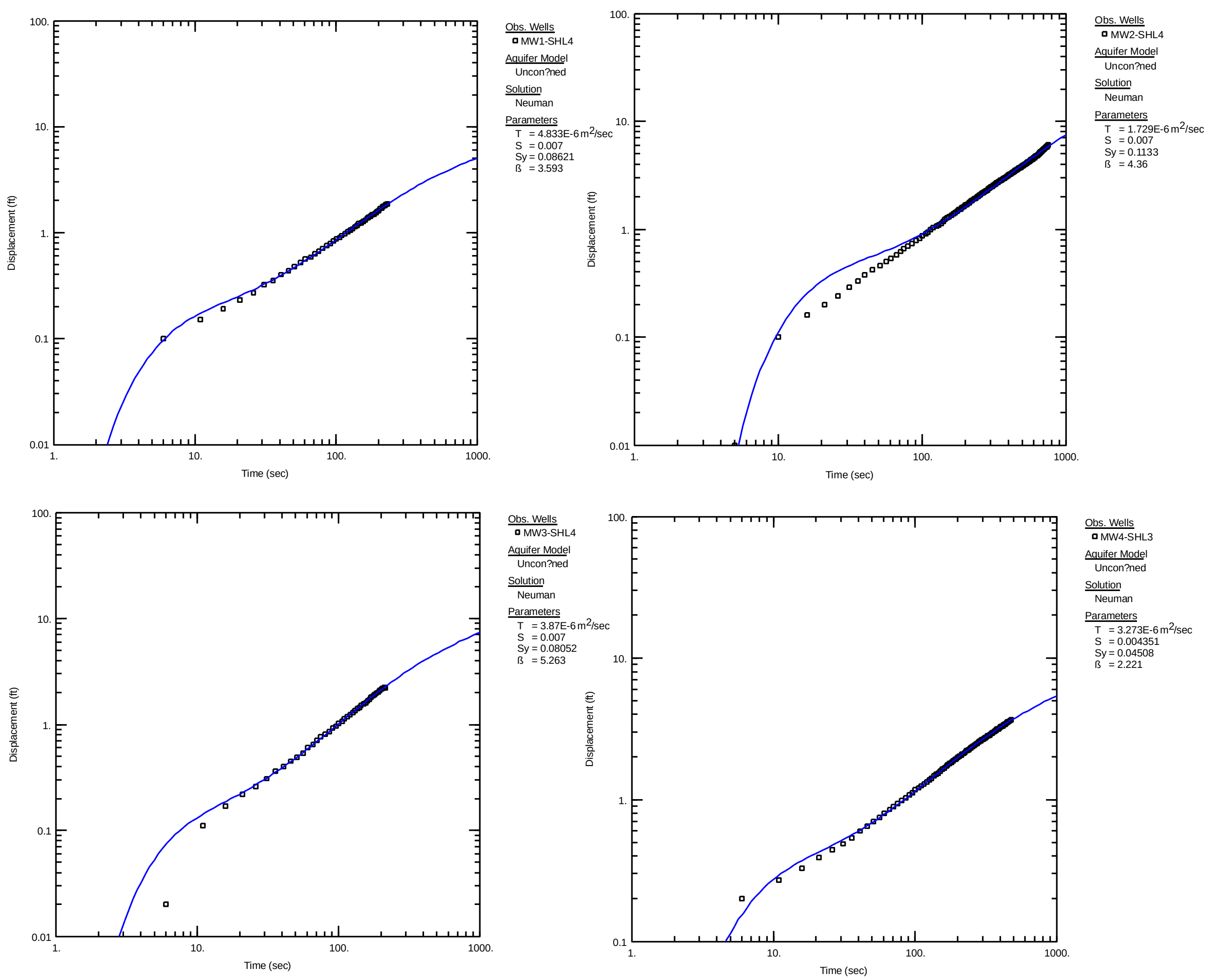

Figure 18: Aquifer test plots for the SHL centralized pits monitoring wells SHL3 (MW4) and SHL4 (MW1, MW2, and MW3).

The resulting drawdown curves **(Figures 17 and 18)** were close to linear (excepting an early non-linear segment) on the log-log scale, unlike the classic arcing curve of the *Theis* solution (**Figure 16**). The analytical model which best fit the pumping data was that of *Neumann* (1974) for unconfined aquifers with a “delayed yield” response caused by anisotropy in *K* in the vertical and horizontal directions. The value of the parameter β in these data fits is much larger than typical (ranging from 2 to 16), indicating that vertical *K* greatly exceeds the horizontal. Results are interpreted to indicate that this aquifer is “tight” in the horizontal direction but undergoes rapid vertical drainage, likely through fractures that commonly result in well dewatering.

Results **(Table 7)** included transmissivity for only the upper aquifer zone and hydraulic conductivity based on saturated thickness of the zone penetrated by each groundwater monitoring well. The resulting K ranged considerably from 2.5×10^{-8} to 2.9×10^{-6} m/s; all of these values were a factor of 10 or more lower than for the single-lined pit (EQT) site. The geology of the site is also Dunkard Group, although lithologic logs were not available. The groundwater flow scenario was based on either northward flow into *Turkey Run* or southward to *Middle Fork Wheeling Creek*. Travel times were on the order of 700-70,000 days, indicating the velocities here are extremely slow in comparison to the single-lined pits site results **(Table 7)**.

These results indicate that groundwater flow rates and aquifer parameters vary dramatically between the two sites due to naturally-occurring differences in local hydrogeology. At the EQT single-lined pit site, transport of contaminants to points of discharge might be expected to occur within a few weeks. At the SHL centralized pits site, flow velocities are so slow that transport to discharge might take multiple years.

Recommendations and Conclusions

This study focused on the risk to human health as a result of shale gas development. With respect to water, the risk pathway was assumed to be contamination of shallow aquifers and domestic drinking water wells. Therefore, the USEPA primary and secondary drinking water standards were used to evaluate the potential for risks to human health. With one exception, all groundwater monitoring well sampling results were below the primary and secondary drinking water limits (See **Table 2** for a list of the parameters analyzed.) for the respective contaminants. The exception was the initial sample for the deep monitoring well (MW4) at the SHL-3 centralized pit site. The sample was taken on June 19, 2012, less than two weeks after the pit/impoundment began receiving fresh water, and yielded a Chloride (Cl) level in excess of the secondary drinking water standard (348 mg/L compared to the standard of 250 mg/L). WVWRI researchers confirmed with site personnel the water received was a combination of water from the Ohio River, Wheeling Creek, and return water from previous operations, the latter being a likely source of any elevated Cl readings. However, subsequent samples of this groundwater monitoring well yielded Cl readings of 4.2 and 5.7 mg/L. Analysis of the data indicated a poor charge balance of the initial groundwater monitoring well sample. The anion/cation ratio was 2.1 indicating an overestimation of the dominant anion, Cl. Failure to replicate the high Cl readings in subsequent sampling suggests the initial Cl result may have been a faulty determination at the analytical lab.

No evidence was found of significant groundwater contamination from monitoring the perimeter groundwater wells at either site and no significant surface water contamination was found from monitoring activities of the nearby first order stream at the single-lined pit site. The quality of flowback water stored in the pits differed between the two sites. Flowback at the SHL centralized (double-lined) pits site was highly saline. At the SMI-28 single-lined pit site, flowback salinity was much lower. The flowback itself is severely contaminated and must be isolated from the environment. Therefore, the recommendations from the *Phase I Overview*

Report are considered best practices to develop shale gas while protecting surface and groundwater supplies.

References

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2. Pits and Impoundments Final Report; J. Quarranta, R. Wise, and A. Darnell; West Virginia University, Department of Civil and Environmental Engineering; December 2012.
3. Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations; M. McCawley; West Virginia University, School of Public Health; May 2013.

Appendix A: EQT SMI-28 Single-Lined Pit Field Data Spreadsheet

					Field Readings/Observations									
		units			°C	µS/cm	(mg/L)	pH	(mg/L)	ppt	mrem/hr	mrem/hr	parameter dependent	parameter dependent
Stage	Target	Sample Indentification and Location	Date	Weather	Temp.	EC	TDS	pH	DO	Salinity	Radioactivity (Background)	Radioactivity (Sample)	6-Gas (Background)	6-Gas (Sample)
Pit: Single-lined	First Order Stream	Tributary A, EQT Smithburg	4/4/2013	50° F, Partly Cloudy	4.12	120	131	5.95	16.46	0.1	0.01	0.01	Non Detect	Non Detect
			4/25/2013	60° F, Partly Cloudy	9.82	168	154	7.21	12.49	0.11	0.013	0.014	Non Detect	Non Detect
			5/1/2013	65° F, Sunny	10.68	188	168	7.56	19.07	0.12	0.01	0.013	0.1% CO2	0.1% CO2
			5/8/2013	60° F, Overcast	11.42	179	157	7.31	20.55	0.12	0.012	0.015	Non Detect	Non Detect
			5/15/2013	68° F, Partly Cloudy	10.92	170	150	7.12	12.43	0.11	0.011	0.017	Non Detect	Non Detect
	Monitoring Wells (Shallow)	MW-1, EQT Smithburg	2/19/2013	38° F, Rain and Sleet	12.26	863	740	6.6	0.35	0.57	0.008	0.016	4% LEL	2%LEL
			4/25/2013	60° F, Partly Cloudy	13.48	1032	868	6.54	5.07	0.67	0.011	0.013	Non Detect	Non Detect
			5/1/2013	65° F, Sunny	14.59	1093	886	6.62	4.43	0.69	0.01	0.016	1% LEL, 20.7% O2	1% LEL, 20.7% O2
			5/8/2013	60° F, Overcast	13.01	1100	922	6.54	4.67	0.72	0.011	0.011	Non Detect	Non Detect
			5/15/2013	68° F, Partly Cloudy	13.79	1163	962	6.49	4.5	0.75	0.018	0.011	Non Detect	Non Detect
		MW-2, EQT Smithburg	2/19/2013	38° F, Rain and Sleet	9.05	437	409	6.94	6.83	0.31	0.009	0.009	Non Detect	Non Detect
			4/25/2013	60° F, Partly Cloudy	12.54	412	352	6.63	5.85	0.26	0.009	0.01	Non Detect	Non Detect
			5/1/2013	65° F, Sunny	12.04	418	361	6.42	6.83	0.27	0.02	0.016	1% LEL, 0.2% CO2	1% LEL, 0.2% CO2
			5/8/2013	60° F, Overcast	12.48	422	361	6.5	5.8	0.27	0.019	0.013	Non Detect	Non Detect
			5/15/2013	68° F, Partly Cloudy	12.78	415	352	6.41	5.82	0.26	0.016	0.017	Non Detect	Non Detect
		MW-3, EQT Smithburg	2/19/2013	38° F, Rain and Sleet	12.28	845	7.26	6.9	4.58	0.56	0.009	0.008	Non Detect	1% LEL
			4/25/2013	60° F, Partly Cloudy	13.47	844	703	6.76	5.9	0.54	0.01	0.011	Non Detect	Non Detect
			5/1/2013	65° F, Sunny	12.81	835	707	6.58	5.87	0.54	0.02	0.021	2% LEL, 0.2% CO2	2% LEL, 0.2% CO2
			5/8/2013	60° F, Overcast	13.27	841	704	6.65	6.1	0.54	0.011	0.012	Non Detect	Non Detect
			5/15/2013	68° F, Partly Cloudy	13.3	848	710	6.35	4.4	0.55	0.02	0.013	Non Detect	Non Detect
	Site Pit	Flowback (FS-1), EQT Smithburg	4/25/2013	60° F, Partly Cloudy	14.73	7912	6398	7.01	5.91	5.57	0.011	0.007	2% LEL	2% LEL
		Flowback (FS-2), EQT Smithburg	5/1/2013	65° F, Sunny	23.11	9702	6546	7.71	10.38	5.68	0.013	0.011	0.15% CO2	0.2% CO2
		Flowback (FS-3), EQT Smithburg	5/8/2013	60° F, Overcast	18.96	8665	6307	7.8	11.44	5.54	0.012	0.009	Non Detect	2%LEL
		Flowback (FS-Final), EQT Smithburg	5/15/2013	68° F, Partly Cloudy	17.47	8429	6397	7.19	9.94	5.57	0.012	0.007	1% LEL	1% LEL

MW = Monitoring Well
FS = Flow Stream
LEL = Lower Explosive Limit
NS = Not Sampled
ND = Non Detect

Values recorded as "Non Detect" (ND) in the field notes are represented by the following concentrations/values:

Methane:	0% LEL
Oxygen (O2):	20.90%
Hydrogen Sulfide (H2S):	0 ppm
Carbon Monoxide (CO):	0 ppm
Carbon Dioxide (CO2):	0%
Isobutylene:	0 ppm

Appendix B: SHL Centralized Pits Field Data Spreadsheet

			Field Readings/Observations											
			units		°C	µS/cm	(mg/L)	pH	(mg/L)	ppt	mrem/hr	mrem/hr	parameter dependent	parameter dependent
Stage	**Target**	**Sample Identification and Location**	**Date**	**Weather Conditions**	**Temp.**	**EC**	**TDS**	**pH**	**DO**	**Salinity**	**Radioactivity (Background)**	**Radioactivity (Sample)**	**6-Gas (Background)**	**6-Gas (Sample)**
Phase II														
Fresh Water Impoundment	Fresh Water	SHL-3-IMP, Noble Pits	6/7/2012	83° F, Sunny w/some cloud cover	20.72	364	258	8.75	7.51	NS	0.011	0.011	Non Detect	1% LEL
		SHL-2-IMP, Noble Pits	6/7/2012	83° F, Sunny w/some cloud cover	NS	NS	NS	NS	NS	NS	0.008	0.016	Non Detect	Non Detect
		SHL-1-IMP, Noble Pits	6/7/2012	83° F, Sunny w/some cloud cover	22.76	387	263	8.61	9.28	NS	0.008	0.011	Non Detect	Non Detect
Pits: Centralized	Monitoring Wells (Shallow)	SHL-2, MW-2, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	12.48	286	244	7.08	3.24	NS	NS	NS	Non Detect	Non Detect
		SHL-2, MW-3, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	13.53	274	228	7.27	5.63	NS	NS	NS	Non Detect	Non Detect
		SHL-4, MW-1, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	13.51	297	248	7.3	6.84	NS	NS	NS	Non Detect	Non Detect
		SHL-4, MW-2, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	12.28	281	241	7.73	8.74	NS	NS	NS	Non Detect	Non Detect
		SHL-4, MW-3, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	12.28	277	238	7.52	4.61	NS	NS	NS	Non Detect	Non Detect
		SHL-2 MW-1, Noble Pits	11/1/2012	38° F, Overcast, Rain	11.84	909	590	7.75	4.89	0.45	0.012	0.01	1% LEL, 21.5% O2	1% LEL, 21.5% O2
		SHL-2, MW-2, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	11	175	113	6.42	13.12	0.08	0.016	0.013	21.5% O2	Non Detect
		SHL-2, MW-3, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	11.05	386	251	7.44	7.35	0.19	0.013	0.013	21.3% O2	Non Detect
		SHL-4, MW-1, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	12.2	308	200	6.75	4.35	0.15	0.017	0.013	2% LEL, 21.5% O2	1% LEL, 21.3% O2
		SHL-4, MW-2, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	10.64	467	304	7.05	8.73	0.23	0.012	0.016	1% LEL, 21.1% O2, 2ppm IBL	21.3% O2, 2ppm IBL
		SHL-4, MW-3, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	12.31	184	119	6.32	11.89	0.09	0.016	0.011	1% LEL, 21.1% O2	1% LEL, 21.1% O2
Pits: Centralized	Monitoring Wells (Deep)	SHL-2 MW-4, Noble Pits	6/19/2012	92° F, Sunny, clear	14.82	338	273	7.29	6.36	NS	0.009	0.015	Non Detect	Non Detect
		SHL-3 MW-4, Noble Pits	6/19/2012	92° F, Sunny, clear	21.48	492	342	7.51	6.31	NS	0.011	0.013	Non Detect	Non Detect
		SHL-2 MW-4, Noble Pits	11/1/2012	38° F, Overcast, Rain	11.28	427	277	7.3	7.39	0.21	0.022	0.09	21.8% O2	21.6% O2
		SHL-3 MW-4, Noble Pits	11/1/2012	38° F, Overcast, Rain	11.25	470	306	7.32	6.19	0.23	0.015	0.013	1% LEL, 21.5% O2	1% LEL, 21.6% O2, 1ppm IBL
Flowback	Centralized Pits	FS-1, Noble Pits (SHL-3)	8/13/2012	77° F, Sunny w/some cloud cover	28.51	16283	10590	6.99	1.55	9.5	0.014	0.008	Non Detect	6% LEL
		FS 2, Noble Pits (SHL-3)	8/20/2012	89° F, Sunny w/some cloud cover	24.8	125901	81830	6.9	2.69	96.01	0.014	0.01	5% LEL	5% LEL
		FS-3, Noble Pits (SHL-3)	8/28/2012	84° F, Mostly Sunny	28.39	26426	17180	6.16	0.57	16.1	0.008	0.013	3% LEL	5%LEL, 43ppm-H2S
		FS Final, Noble Pits (SHL-3)	9/17/2012	75° F, Sunny w/some cloud cover	33.04	54461	35400	6.22	1.29	36.08	0.011	0.008	5% LEL	2% LEL, >100ppm H2S
		SHL-4 Composite, Noble Pits (SHL-4)	9/17/2012	75° F, Sunny w/some cloud cover	27.2	40499	2632	7.07	2.57	25.83	0.09	0.009	6% LEL	6% LEL, 2ppm IBL
Phase II														
Pits: Centralized	Monitoring Wells (Shallow)	SHL-2, MW-1, Noble Pits	5/9/2013	60° F, Overcast	12.99	371	313	6.83	5.21	0.23	0.017	0.014	Non Detect	Non Detect
		SHL-2, MW-2, Noble Pits	5/9/2013	60° F, Overcast	12.92	338	286	6.49	2.77	0.21	0.019	0.013	Non Detect	Non Detect
		SHL-2, MW-3, Noble Pits	5/9/2013	60° F, Overcast	13.83	331	273	7.07	7.89	0.2	0.02	0.013	Non Detect	Non Detect
		SHL-4, MW-1, Noble Pits	5/9/2013	60° F, Overcast	13.97	296	244	6.77	4.99	0.18	0.011	0.013	Non Detect	Non Detect
		SHL-4, MW-2, Noble Pits	5/9/2013	60° F, Overcast	20.16	418	300	7.11	7.45	0.22	0.02	0.012	Non Detect	Non Detect
		SHL-4, MW-3, Noble Pits	5/9/2013	60° F, Overcast	14.54	402	327	6.93	3.64	0.24	0.019	0.013	Non Detect	Non Detect
Pits: centralized	Monitoring Wells (Deep)	SHL-2 MW-4, Noble Pits	5/9/2013	60° F, Overcast	12.5	379	324	6.96	5.16	0.24	0.017	0.009	Non Detect	Non Detect
		SHL-3 MW-4, Noble Pits	5/9/2013	60° F, Overcast	13.11	412	347	6.84	5.24	0.26	0.017	0.013	Non Detect	Non Detect

MW = Monitoring Well
FS = Flow Stream
LEL = Lower Explosive Limit
NS = Not Sampled
ND = Non Detect

Values recorded as "Non Detect" (ND) in the field notes are represented by the following concentrations/values:

Methane:	0% LEL	Carbon Dioxide (CO_2):	0%
Oxygen (O_2):	20.90%	Isobutylene (IBL):	0 ppm
Hydrogen Sulfide (H_2S):	0 ppm		
Carbon Monoxide (CO):	0 ppm		

Appendix C: WVWRI Project Staff

Name	Role	Email	Office Telephone	Address
Paul Ziemkiewicz, PhD	Principal Investigator	paul.ziemkiewicz@mail.wvu.edu	304-293-6958	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
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Jennifer Hause	Project Manager	jhause@wvu.edu	304-293-7003	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Brady Gutta	Program Coordinator/Geologist	brady.gutta@mail.wvu.edu	304-293-7002	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
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Jason Fillhart	Environmental Scientist	jefillhart@mail.wvu.edu	304-293-7074	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Melissa O'Neal	Environmental Technician/Laboratory Manager	melissa.o'neal@mail.wvu.edu	304-293-7006	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Doug Patchen, PG	Geologist	doug.patchen@mail.wvu.edu	304-293-6216	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064

Appendix D: Phase II Site Checklists

EQT SMI-28 Site Checklist

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	EQT – Smithburg Location
Industry Contact	Initial contact w/ companies to establish site access	Main contact-EQT Subcontractor-Groundwater Resources
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-fresh water • Groundwater • Drilling fluids • Muds & cuttings • HF fluids • HF water • Flowback/Produced Water • Pits-flowback storage	Access granted for sampling the site pit (flowback, freshwater, recycled water), groundwater (via groundwater monitor wells), and a first order tributary
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	**Pit** - 4/25/13, 5/1/13, 5/8/13, 5/15/13 **Groundwater** - 2/19/13, 4/25/13, 5/1/13, 5/8/13, 5/15/13 **Tributary A** - 4/4/13, 4/25/13, 5/1/13, 5/8/13, 5/15/13
Source Water	Identify and obtain information on source water for hydro fracturing operations for each site	Various return water from previous and other ongoing operations
Hydro Fracturing Fluids	Obtain list/breakdown of HF fluids	Not Applicable
Locations	Obtain & confirm GPS coordinates for: • Well pad location • Sampling points (if off pad) • Water withdrawals (if relevant) • Permitted discharges (if relevant) • Pits • Impoundments • GW monitoring wells	-MW-1 39° 15' 44.5314" 80° 44' 12.624" -MW-2 39° 15' 42.408" 80° 44' 10.068" -MW-3 39° 15' 41.7954" 80° 44' 13.812" -Pit Center 39° 15' 41.9544" 80° 44' 11.6484" -Tributary A 39° 15' 57.312" 80° 44' 0.06"
Field Measurements	Measurement of field parameters: • pH • Electric conductivity • Temperature • TDS • DO • Salinity	Refer to Appendix A

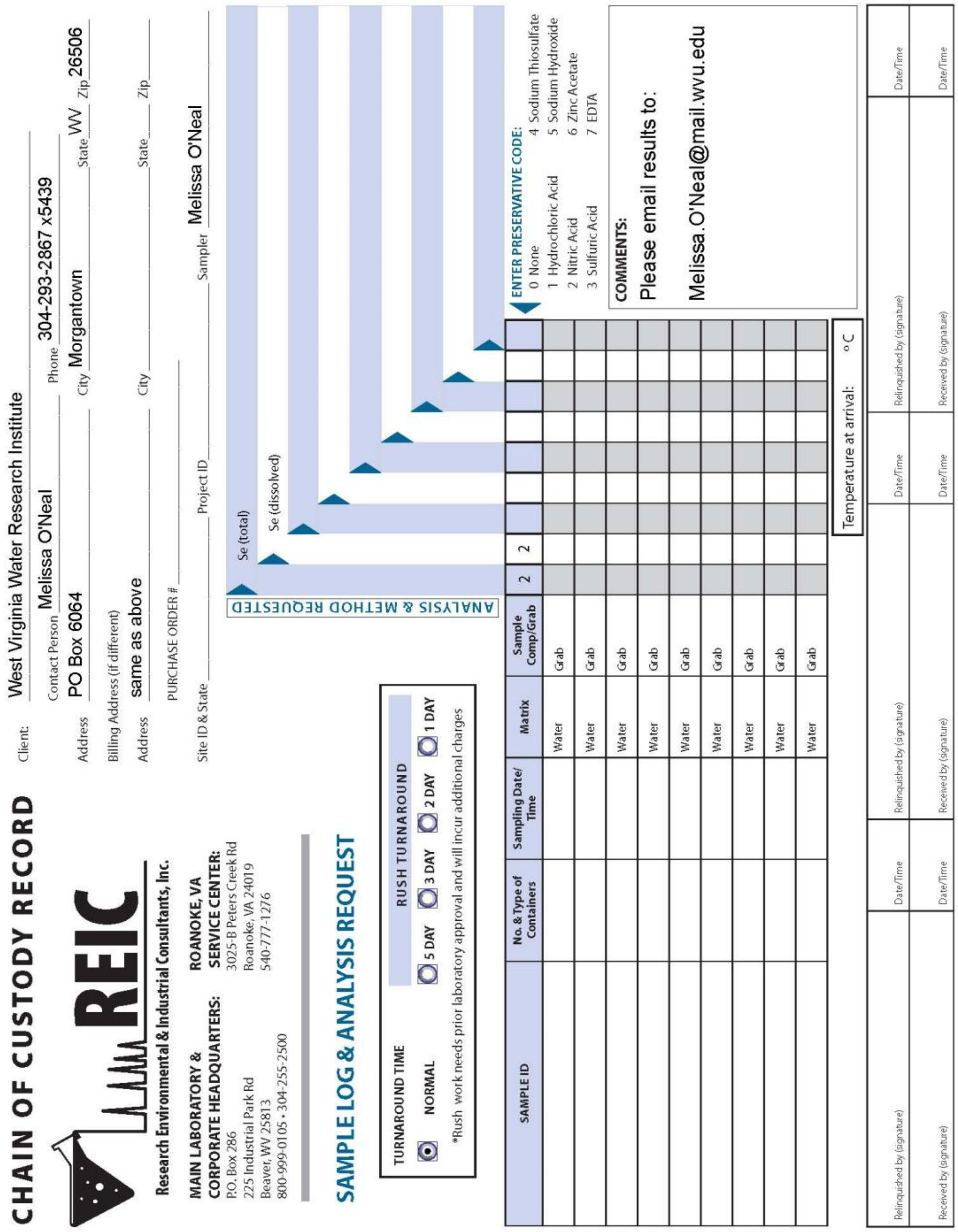
Description	Task	Completed/Notes
Duplicate Samples	Identify duplicate sampling events	MW-1, Collected a complete set of duplicates during groundwater sampling on 2/19/13
Site Observations	Document visual observations of site	Refer to the *Phase II Monitoring Plan* section of the phase II final report.
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Refer to the *Phase II Monitoring Plan* section of the phase II final report.
Permitting	Provide copies of permit for each site to WVWRI	Pending Receipt from WVDEP
Drilling Logs	Obtain and provide copies of drilling logs to WVWRI	Not Applicable
Health and Safety/Emergency Response	Obtain copies of company specific environmental health & safety plans and Emergency Response Plans for recordkeeping purposes only	Plans are kept at office on site and can be reviewed upon request. Copies were requested but not received.
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location to WVWRI	Maps were provided by EQT
Sampling Specifics	Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/envtl surroundings needing to be noted Pad activities	Refer to Appendix A
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Phase II Monitoring Plan* section of the phase II final report.
Sample Verification	• Receive results verifying all parameters analyzed	REI Consultants and Pace Analytical provided reports for all samples received.
Data Entry	Enter data into master spreadsheets	Data entered and verified by JF.
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Results and Discussion* section of the phase II final report.

Consol/Noble SHL Site Checklist

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	SHL-1, 2, 3, and 4, Consol/Noble Sand Hill location
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Noble Energy and Subcontractor-Moody & Associates
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-fresh water • Groundwater • Drilling fluids • Muds & cuttings • HF fluids • HF water • Flowback/Produced Water • Pits-flowback storage	Access granted for sampling centralized impoundments/pits, flowback, and groundwater (via groundwater monitor wells).
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	**Impoundments**-6/7/12 **Groundwater** – (6/4, 6/7, 6/19/12 – Initial), (10/31, 11/1/12), (5/9/13 – Final) **Flowback**-8/13, 8/20, 8/28, 9/17/12 **Pits**-9/17/12
Source Water	Identify and obtain information on source water for hydro fracturing operations for each site	Ohio River, Wheeling Creek, and return water from previous operations
Hydro Fracturing Fluids	Obtain list/breakdown of HF fluids	Not Applicable
Locations	Obtain & confirm GPS coordinates for: • Well pad location • Sampling points (if off pad) • Water withdrawals (if relevant) • Permitted discharges (if relevant) • Pits • Impoundments • GW monitoring wells	**SHL2** -MW-1 39°58'03.79" 80°33'42.87" -MW-2 39°58'00.85" 80 33'40.94" -MW-3 39°57'58.49" 80 33'43.26" -MW-4 39°57'59.14" 80°33'45.22" -Pit Center 39°58'00.78" 80 33'42.31" **SHL3** -MW-4 39°58'20.57" 80°33'16.32" -Pit Center 39°58'26.80" 80°33'18.49" **SHL4** -MW-1 39°57'48.81" 80°33'46.15" -MW-2 39°57'44.06" 80°33'48.76" -MW-3 39°57'45.05" 80°33'45.58" -Pit Center 39°57'46.09" 80°33'46.80"
Field Measurements	Measurement of field parameters: • pH • Electric conductivity • Temperature • TDS • DO • Salinity	Refer to Appendix B
Duplicate Samples	Identify duplicate sampling events	SHL-4-MW-3, Collected a complete set

Description	Task	Completed/Notes
		of duplicates during groundwater sampling on 10/31/12
Site Observations	Document visual observations of site	Refer to *Phase II Monitoring Plan* section of the phase II final report.
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Refer to *Phase II Monitoring Plan* section of the phase II final report.
Permitting	Provide copies of permit for each site to WVWRI	Pending Receipt from WVDEP
Drilling Logs	Obtain and provide copies of drilling logs to WVWRI	Not Applicable
Health and Safety/Emergency Response	Obtain copies of company specific environmental health & safety plans and Emergency Response Plans for recordkeeping purposes only	Copies of plans were provided by Noble Energy.
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location to WVWRI	Maps were provided by Noble Energy.
Sampling Specifics	Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/envtl surroundings needing to be noted Pad activities	Refer to Appendix B
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to *Phase II Monitoring Plan* section of the phase II final report.
Sample Verification	• Receive results verifying all parameters analyzed	REI Consultants and Pace Analytical provided reports for all samples received.
Data Entry	Enter data into master spreadsheets	Data entered and verified by JF.
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Results and Discussion* section of the phase II final report.

Appendix E: REI Consultants Chain-of-Custody Form



CHAIN OF CUSTODY RECORD

REIC

Research Environmental & Industrial Consultants, Inc.

MAIN LABORATORY & CORPORATE HEADQUARTERS:
P.O. Box 286
225 Industrial Park Rd
Beaver, WV 25813
800-999-0105 • 304-255-2500

ROANOKE, VA SERVICE CENTER:
3025-B Peters Creek Rd
Roanoke, VA 24019
540-777-1276

Client: West Virginia Water Research Institute
Contact Person Melissa O'Neal Phone 304-293-2867 x5439
Address PO Box 6064 City Morgantown State WV Zip 26506
Billing Address (if different)
Address same as above City ____ State ____ Zip ____
PURCHASE ORDER # ____
Site ID & State ____ Project ID ____ Sampler Melissa O'Neal

SAMPLE LOG & ANALYSIS REQUEST

TURNAROUND TIME: (•) NORMAL
RUSH TURNAROUND: ( ) 5 DAY ( ) 3 DAY ( ) 2 DAY ( ) 1 DAY
*Rush work needs prior laboratory approval and will incur additional charges

ANALYSIS & METHOD REQUESTED: Se (total); Se (dissolved)

SAMPLE ID	No. & Type of Containers	Sampling Date/ Time	Matrix	Sample Comp/Grab	2	2							
			Water	Grab									
			Water	Grab									
			Water	Grab									
			Water	Grab									
			Water	Grab									
			Water	Grab									
			Water	Grab									
			Water	Grab									
			Water	Grab									

ENTER PRESERVATIVE CODE:
0 None
1 Hydrochloric Acid
2 Nitric Acid
3 Sulfuric Acid
4 Sodium Thiosulfate
5 Sodium Hydroxide
6 Zinc Acetate
7 EDTA

COMMENTS:
Please email results to:
Melissa.O'Neal@mail.wvu.edu

Temperature at arrival: °C

Relinquished by (signature)	Date/Time	Relinquished by (signature)	Date/Time	Relinquished by (signature)	Date/Time
Received by (signature)	Date/Time	Received by (signature)	Date/Time	Received by (signature)	Date/Time

Appendix F: Pace Analytical Chain-of-Custody

Pace Analytical™
www.pacelabs.com

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Page: of

Section A Required Client Information:		Section B Required Project Information:	Section C Invoice Information:
Company:		Report To:	Attention:
Address:		Copy To:	Company Name:
			Address:
Email To:		Purchase Order No.:	Pace Quote Reference:
Phone:	Fax:	Project Name:	Pace Project Manager:
Requested Due Date/TAT:		Project Number:	Pace Profile #:

REGULATORY AGENCY

- ☐ NPDES ☐ GROUND WATER ☐ DRINKING WATER
- ☐ UST ☐ RCRA ☐ OTHER

Site Location

STATE:

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Y/N ↓ Analysis Test ↓												Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1																															
2																															
3																															
4																															
5																															
6																															
7																															
8																															
9																															
10																															
11																															
12																															

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER:

SIGNATURE of SAMPLER: DATE Signed (MM/DD/YY):

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)