Final Report

Water Quality Literature Review and Field Monitoring of Active Shale Gas Wells

Phase I

For

"Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations"

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List of Abbreviations

Ag	Silver
Alk	Alkalinity
Al	Aluminum
AMD	Acid mine drainage
As	Arsenic
ASTM	American Society for Testing and Materials
Ba	Barium
BOD	Biochemical oxygen demand
Br	Bromide
BTEX	Benzene, toluene, ethylbenzene and xylene
Btu	British thermal unit
Ca	Calcium
CFR	Code of Federal Regulations
Cl	Chloride
CO_3^{2-}	Carbonate
COC	Chain of custody
COD	Chemical oxygen demand
Cr	Chromium
CSR	Code of State Rules
CWA	Clean Water Act
CWT	Centralized waste treatment facility
DO	Dissolved oxygen
DRO	Diesel range organics
E&P	Exploration and production

EC	Electro-conductivity
EIA	Department of Energy's Energy Information Administration
EPA	United States Environmental Protection Agency
FB	Flowback
Fe	Iron
FR	Flame resistant
ft	Feet
gpm	Gallons per minute
GPS	Global Positioning System
GW	Groundwater
HCO_3	Bicarbonate
HF	Hydraulic fracturing, fracking or frac
HFF	Hydraulic fracturing fluids
Hg	Mercury
I	Inorganic (parameters)
K	Potassium
LPG	Liquefied petroleum gas
MBAS	Methylene blue active substances (surfactants)
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
Mg	Magnesium
mg/L	Milligrams per liter
Mn	Manganese
mrem/hr	Millirems per hour (rem = roentgen equivalent man)
MU	Makeup

Na	Sodium
ND	Not determined
Ni	Nickel
NO_2	Nitrite
NO_3	Nitrate
NORM	Naturally occurring radioactive materials
NPDES	National Pollutant Discharge Elimination System
OSHA	Occupational Safety and Health Administration
Pb	Lead
pCi/g	Picocuries per gram
pCi/L	Picocuries per liter, United States unit for volumetric concentration
PID	Photo-ionization detector
PO_4	Phosphate
POTW	Publicly owned treatment works
ppb	Parts per billion
PPE	Personal protective equipment
ppm	Parts per million
ppt	Parts per trillion
QA/QC	Quality Assurance/Quality Control
R	Radioactive (parameters)
RCRA	Resource Conservation and Recovery Act
RO	Reverse osmosis
S	Sulfide
SDWA	Safe Drinking Water Act
Se	Selenium

SO_4	Sulfate
SOPs	Standard Operating Procedures
Sr	Strontium
SVOC	Semi-volatile organic compounds
TDS	Total dissolved solids
TENORM	Technically enhanced naturally occurring radioactive material
THM	Trihalomethane
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
TSS	Total suspended solids
µg/L	Micrograms per liter
µmhos/cm	Micromhos per centimeter (1 µmhos/cm = 1 µS/cm)
µS/cm	MicroSiemens per centimeter (1 µS/cm = 1 µmhos/cm)
USGS	United States Geological Survey
VOC	Volatile organic compound
WVDEP	West Virginia Department of Environmental Protection
WVU	West Virginia University
WVWRI	West Virginia Water Research Institute
Zn	Zinc

Executive Summary

This report summarizes the results of the phase I study "Water Quality Literature Review and Field Monitoring of Active Shale Gas Wells." In addition to the literature review, the phase I report consists of solid and liquid waste stream characterization and recommendations to reduce environmental exposure. It also contains initial results of groundwater monitoring at three centralized waste water impoundments. These impoundments were constructed with double polymer liners. Monitoring wells were installed at a second impoundment site in mid February 2013. The phase II report will include results of extended monitoring at the centralized and single impoundment sites.

Legislative Direction

Although hydraulic fracturing 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. On December 14, 2011, the West Virginia Legislature (Code of State Regulations §22-6A) enacted the Natural Gas Horizontal Well Control Act. The act directs the West Virginia Department of Environmental Protection (WVDEP) to conduct several studies in order to collect information and report back its findings and recommendations. In summary the act requires a report that addresses the 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 horizontal gas well development activity impacts on air and water quality, generated light and noise, and 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 focuses on the activities undertaken to conduct the water and solid waste stream study.** Findings from the air emissions, light and noise study and the pits and impoundments safety study are contained in separate reports.

In 1988, the United States Environmental Protection Agency (EPA) issued a regulatory determination stating that control of exploration and production (E&P) wastes under the Resource Conservation and Recovery Act (RCRA) Subtitle C regulations is not warranted. Hence, E&P wastes have remained exempt from Subtitle C regulations. The RCRA Subtitle C exemption, however, did not preclude these wastes from control under state regulations, under the less stringent RCRA Subtitle D solid waste regulations, or under other federal regulations. In addition, although they are relieved from regulation as hazardous wastes, the exemption does not mean these wastes could not present a hazard to human health and the environment if improperly managed. For the purposes of this report, waste streams will be indicated as "solid or liquid wastes" as defined by RCRA Subtitle D.

Hydraulic fracturing

Hydraulic fracturing (injection of a water-based fluid and sand mixture) technology, coupled with horizontal drilling, has facilitated exploitation of huge natural gas reserves in the Devonian-age Marcellus Shale Formation of the Appalachian Basin. The most widely used technique for stimulating Marcellus gas production involves hydraulic fracturing along a horizontal wellbore to create a series of thin (generally less than 1 millimeter thick) fractures in the shale. The fractures are filled with a proppant such as sand to keep them open and conduct gas to the wellbore where it is conveyed to pipelines for transport and distribution.

The hydraulic fracturing process usually involves surface water withdrawal and disposal of waste fluids. When the injection phase is over, 10% to 40% of the injected fluid returns to the surface through the well casing. These fluids are captured for later reuse or disposal and are referred to as flowback. Flowback typically lasts for 4 to 6 weeks during which the water discharge rate decreases from about 150 gallons per minute (gpm) to about 1 gpm. Flowback water is highly saline with varying amounts of organic contamination. It can be disposed of, either by injection into an approved underground injection well, or treated to remove contaminants so that the water meets the requirements for either surface release, or for use as makeup water for subsequent hydraulic fracturing operations.

The 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 hydraulic fracturing fluids. Specific areas of review included: potential issues related to public health and the environment, and safety aspects of hydraulic fracturing development; surface and groundwater contamination; and well development practices to protect surface and groundwater sources during the well development. The literature review was used in developing an on-site water and waste stream monitoring plan by defining sample parameters and procedures. The water and waste stream monitoring plan was updated as active horizontal well sites were monitored and study design and sampling methods were adjusted to field conditions.

The focus of the study was on sampling and chemical analysis of drilling fluids, muds and cuttings along with hydraulic fracturing fluids and flowback waters of working hydraulic fracturing sites in the Marcellus Formation in West Virginia. The list of analytical parameters used in this study was developed through literature review and finalized in conjunction with the staff of WVDEP. The list includes both primary and secondary drinking water contaminants. Contaminants were evaluated based on exceedance of maximum contaminant levels as identified under the Safe Drinking Water Act (SDWA).

Permitting the construction of centralized pits for the storage of flowback water has recently begun in West Virginia. Groundwater monitoring is required for centralized pits in West Virginia and thus groundwater monitoring wells were installed by the permit holder and samples collected prior to the use of the pits to store flowback water. As of the date of this study, only one permit had been issued for a cluster of three centralized pits. This site was selected for groundwater monitoring as well as waste storage monitoring. During well development and hydraulic fracturing, these pits contained water for use in hydraulic fracturing fluid makeup. After hydraulic fracturing, the impoundments were converted to flowback storage. Water in the impoundments was analyzed before and after conversion to flowback storage. Monitoring wells were sampled to identify any groundwater contaminants before and after placement of flowback in the impoundments.

<u>Site Sampling</u>

In order to meet the timeline specified by WVDEP, sampling reported in this part of the study took place between June and December 2012. Multiple wells sites were sampled during that period in order to collect data from multiple sites during the various well development and completion stages. Active horizontally drilled and hydraulically fractured wells in northern West Virginia were sampled to determine contaminant concentrations in:

- Hydraulic fracturing fluids

- Flowback
- Drilling muds and cuttings
- Groundwater monitoring wells

WVDEP contacted natural gas developers and established access to Marcellus gas well sites for WVU researchers to collect water and waste stream samples. Liquid and solid samples were collected and analyzed for a wide range of inorganic, organic and radioactive constituents to ascertain and document the characteristics of the water and waste streams associated with the various stages of horizontal gas well development. While in the field, WVU researchers 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 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, salinity and temperature of samples were measured in the field using a multi-parameter YSI56 unit. For each stage of horizontal gas well development, at least one site was identified for sampling.

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 checklist includes information relevant to the site location, stage of well development, samples collected and field observations. Samples were sent to certified laboratories. Samples were sent to REI Consultants for organic and inorganic compound determinations and to Pace Analytical for radioactivity analysis. It is important to note that 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: vegetable oil and guar gum. The latter is a common additive in hydraulic fracturing fluids. Our analyses also included the organic compounds benzene, toluene, ethyl benzene and xylene. These, particularly benzene, are superior indicators of toxicity.

The nomenclature for hydraulic fracturing wastewaters is not standardized across the industry. For the purposes of this study *hydraulic fracturing fluids* refer to the fluids injected with proppant in order to generate sufficient pressure to create fractures within the targeted formation. The term *flowback* refers to all fluids that return to the wellhead after hydraulic fracturing and prior to gas production. This includes hydraulic fracturing fluids, gases, gas liquids and water. *Produced water* consists of fluids that return to the wellhead subsequent to gas production. In addition, reference to *brines* within this report refers to flowback waters with TDS values greater than 35,000 milligrams per liter (mg/L). As the well is drilled, *muds* are used to cool the drill bit, control well pressures and lift rock *cuttings* to the surface. *Cuttings* and *muds* are separated at the surface where *muds* are typically recycled. Spent drilling *muds* and *cuttings* are removed for disposal.

Findings

Study objectives include: 1) Characterize drilling muds and cuttings and identify pollutants, 2) compare hydraulic fracturing fluids with flowback and identify hazardous pollutants, and 3) identify if groundwater monitoring wells indicated impoundment leakage.

1. *Characterize drilling muds and cuttings and identify pollutants.* Drilling muds were analyzed as liquids while drill cuttings were analyzed as solids. With the exception of arsenic, mercury, nitrate and selenium, the average concentrations of the primary and

secondary drinking water parameters in drilling mud were in excess of all of the inorganic drinking water standards. They also exceeded the drinking water standards for benzene and surfactants (MBAS) and contained high concentrations of sodium, potassium and chloride. TPH (diesel range) was present in all drilling muds with concentrations ranging from 23 mg/L to 315 mg/L. Background levels of radiation ranged from 0.005 millirems per hour (mrem/hr) to 0.013 mrem/hr. Sample levels of radiation ranged from 0.009 mrem/hr to 0.016 mrem/hr. The standard for contamination is typically twice background. A review of the individual background levels of radiation indicated that this criterion was not exceeded.

2. *Compare hydraulic fracturing fluids with flowback and identify pollutants.* Two hydraulic fracturing fluids and thirteen flowback samples were analyzed. One hydraulic fracturing fluid sample contained benzene in measurable quantities while ten of the thirteen flowback samples contained benzene in concentrations in excess of the primary drinking water standard of 5 µg/L. Both hydraulic fracturing fluids and all of the drilling mud and flowback samples contained total petroleum hydrocarbons (TPH) in the diesel range. It is important to note this determination, also known as diesel range organics (DRO), does not indicate that diesel is present. Rather, it indicates that hydrocarbons in the range of C11 to C28 are present. This could include diesel or common hydraulic fracturing fluid additives such as guar gum, an extract of the guar bean used to increase the viscosity of the hydraulic fracturing fluid to efficiently deliver the proppant into the formation. There was no correlation between concentrations of benzene and TPH (diesel range). All flowback samples contained high concentrations of inorganic ions including sodium, chloride, bromide and barium.

3. *Impoundment leakage.* There was no evidence of significant leakage of flowback from the impoundments. Nitrate and lead were detected in monitoring wells in excess of primary drinking water standards. The concentration of nitrite exceeded the maximum contaminant level (MCL) of 1 mg/L in three of five shallow monitoring wells by a maximum of 0.47 mg/L. However, while nitrate exceeded the primary MCL in samples taken after conversion of the impoundments to accept flowback, the single lead exceedance occurred prior to conversion. As is common in West Virginia wells, iron, aluminum and manganese exceeded the secondary drinking water standard in both shallow and deep wells both before and after conversion of the impoundments from holding freshwater to flowback. The impoundment wells did not, however, indicate elevated chloride, bromide or barium concentrations as would be expected if flowback leakage occurred in significant quantities. In addition, while flowback contains measurable benzene and diesel range organics, neither was detected in the monitoring wells. While the monitoring wells detected no contaminants it is not clear that the monitoring interval of 146 days was sufficient to capture any leakage from the impoundments. A longer sampling is suggested with, perhaps, aquifer permeability testing.

Background and Objectives of Water and Waste Stream Study

In West Virginia, around 3,000 wells have been identified as targeting the Marcellus or Utica Shale Formations. These wells are reported to have the potential to recover more than 100 trillion cubic feet of natural gas (1). With current United States annual consumption rates, this quantity of natural gas could meet the energy needs of the United States for several decades.

As pressure for fossil fuel production grows, the proximity of communities to exploration and extraction operations increases along with the potential for human exposure to potential hazards and pollution. With recent increased activity tapping the gas reserves of the Devonian Shale, public concern over the potential impacts of horizontal drilling and hydraulic fracturing has also increased. Although hydraulic fracturing is not a new technique, the rate of which it has been used recently in the Marcellus Shale Formation has greatly escalated bringing with it elevated concerns of environmental impacts. Few studies have been published on the health effects of oil and gas exploration and extraction activities on nearby communities.

The Natural Gas Horizontal Well Control Act enacted by the West Virginia Legislature at CSR §22-6A on December 14, 2011, directs the West Virginia Department of Environmental Protection (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 West Virginia University (WVU), led by the West Virginia Water Research Institute (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 well development. To fulfill the obligations of the water and waste stream portion of the study titled, *"Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations,"* the objectives include:

1. Conduct a review of relevant literature on the use of hydraulic fracturing fluids and the water and waste streams created during the various stages of horizontal gas well development.
2. Based on the literature review, identify concerns with potential surface and groundwater contamination that may be caused by horizontal well development and identify protective measures for surface and groundwater during the well drilling process.
3. Develop and implement an on-site monitoring plan of the various water and waste streams associated with horizontal gas well development to identify potential health concerns or associated environmental risks.
4. Analyze the data collected during the monitoring portion of the study and compare results to primary and secondary drinking water quality standards.
5. Note any potential public health concerns or risks to the environment and include in the final report to the West Virginia Department of Environmental Protection (WVDEP).

Literature Review

Introduction

Fossil fuels – coal, oil and natural gas – supply more than 85% of the nation's energy. Natural gas has a high British thermal unit (Btu) content, is an efficient and reliable energy source and is the cleanest burning of the fossil fuels (2). Reliance on natural gas as an energy source will not diminish in the foreseeable future. With recent increasing demands on energy, easily accessible oil and gas reservoirs decreasing, and success tapping unconventional natural gas resources in the United States, natural gas from unconventional resources is anticipated to become an ever-increasing portion of the country's natural gas reserves. Natural gas from unconventional resources currently accounts for nearly half of the country's total production (3). Development of the extensive natural gas reserves contained in the Marcellus Shale deposits promises to be an important opportunity for the United States because of its proximity to major markets in the northeastern United States (4 and 5).

Shale gas is a natural gas from shale formations and consists of a combination of hydrocarbon gases but is largely made up of methane. Shale gas is found in rock formations beneath the surface of the earth and at times is present with oil deposits. Shale is a sedimentary rock made up mainly of clay-sized particles that tend to lay flat as sediments accumulate and become compacted with additional sediment deposits over time. Organic matter is trapped along with these sediments. The sheet-like clay mineral grains and layers of sediment result in a rock with limited horizontal permeability and extremely limited vertical permeability. These low permeable and often rich-organic units are thought to be the source for much of the hydrocarbon gases produced in the basins (6). In other words, shale gas is created and stored within the shale bed. Low permeability means the gas trapped in the shale cannot move easily within the rock and must be stimulated to release the gas and allow it to flow up through the wellbore hole.

Extraction of gas from the Marcellus is considered to be unconventional by the Department of Energy's Energy Information Administration (EIA) because the gas is found within a shale formation rather than sandstone or limestone (7). Major shale deposits under development in the United States all have the common characteristics of low porosity and permeability. Extraction from shale gas reservoirs like the Marcellus requires either vertical or horizontal drilling coupled with hydraulic fracturing to access and release the gas. Also required are strategies for sourcing makeup water and handling wastewater.

The Marcellus Shale Formation is thought to be among the largest natural gas reserves in the world. It covers an area of approximately 95,000 square miles overlaying much of the Appalachian Basin stretching from West Virginia in the south through New York in the north. The Marcellus Shale is a Middle Devonian-age shale, a member of the Hamilton Group; found more than a mile (5,000 to 9,000 feet) underground and ranging in thickness from 50 to 200 feet surrounded with limestone below and an additional shale layer above (5). It is an organic rich rock, the remnants of an ancient river delta, laced with trapped gas, mostly methane. Driven by application of existing technology to tap this natural gas reserve thousands of feet below the earth's surface, development of the Marcellus reservoir has transformed the energy industry sending United States natural gas prices to all-time lows and the possibility of the country becoming energy-independent within the foreseeable future to an all-time high.

Advances in refining cost-effective horizontal drilling and hydraulic fracturing practices have changed the ability to tap unconventional shale reservoirs and produce a sustainable product. However, rapid application of these technological advancements has increased concern about environmental impacts mainly because of the uncertainty that surrounds the techniques involved. It is important to understand the technologies and practices in use and what is needed to prevent or minimize potential effects of shale gas development on water resources.

Shale gas development has consisted of drilling and completing vertical and horizontal wells. Regardless of the type of well, casing and cement are installed to protect fresh and treatable water aquifers. The combination of horizontal drilling and hydraulic fracturing technologies provide several environmental and economic advantages over conventionally drilled vertical wells. Technological advances allow natural gas companies to use less surface area, drill fewer wells to access the same reserves, and generate less wastes (8). Therefore, to optimize recovery of shale gas in the most economical way, operators are using more horizontal wells. Horizontal drilling exposes more of the formation creating a huge advantage over the use of vertical wells. Multiple horizontal wells can be launched from one well pad targeting different zones. Six to eight horizontal wells drilled from only one well pad can access the same reservoir volume as sixteen vertical wells and the use of these multi-well pads reduces the overall environmental impact (3). Reducing the size of the shale operations' footprint is at the top of the list for companies seeking to become more environmentally friendly. Industry is designing their well pads to better meet their needs and reduce the impact on the surrounding environment. The use of multiple wells with multiple stages of fractures on a single pad is one way. Some companies are also moving away from freshwater for hydraulic fracturing of wells and using liquid petroleum gases or gels.

Hydraulic fracturing, pumping of a mixture of water, sand and additives under high pressure into a shale formation allowing the natural gas to flow out of the shale, is the other component that makes recovery of shale gas viable. The casing and cement that is installed during the drilling process provides protection for groundwater sources during the hydraulic fracturing process. Plus, several hundred to several thousand feet separate the top of the fracture zone of the Marcellus and the bottom of the deepest freshwater aquifer layer making it improbable for hydraulic fracturing fluids to reach groundwater used as a source of drinking water.

Sustainable development of shale gas in the Marcellus requires the management of large volumes of water necessary for the drilling and hydraulic fracturing process to unleash the gas from the formation. Challenges associated with the development of shale gas involve the management of water – transportation, storage and disposal of the water and waste streams created during all stages of well development - in a manner that does not present a threat to human health and the surrounding environment.

Water Sources for Horizontal Shale Gas Well Development in the Marcellus

Exploration of the Marcellus Shale may pose water resource and water supply challenges to the gas industry operating in the Appalachian Basin (4). Water used for drilling and hydraulic fracturing normally comes from surface waters, groundwater, municipal potable water supplies, or reuse of flowback waters, or from some other water source.

Surface Water

Currently, the preferred source of hydraulic fracturing water is surface water which may be transported to the site by pipeline or truck (9). On average, for each horizontal well drilled in the Marcellus, three to five million gallons of water are needed to drill and hydraulically fracture the well. Only about 10% to 40% of this water is recovered and it typically contains high concentrations of total dissolved solids (TDS). The remaining water stays in the formation. Due to the amount of water loss, large amounts of new makeup water are required to develop each new gas well. Depending on the number of horizontal wells that may be drilled and hydraulically fractured in any given basin, water demand may become a critical issue particularly during the latter half of the year when stream levels are lowest. The Ohio River Basin is located within southwestern New York, western Pennsylvania, and much of West Virginia. It comprises all the major rivers and streams that make up the Ohio River. The Marcellus Shale region underlies approximately 10% of the Ohio River Basin (10). The Ohio River Basin and its major tributaries – the Monongahela and Allegheny Rivers, may be seen as less challenged from a water resource perspective when compared to the other river basins within the Marcellus Shale area. However, recent evaluations conducted by the West Virginia Water Use Survey and Pennsylvania State Water Plan highlight the Ohio River watershed may face some significant water resource challenges (4). With many streams and aquifers affected by acid mine drainage, supplies of potable water are often limited (4). When comparing shale gas development water use with other activities and practices such as agriculture, power generation, recreation and municipal consumption, shale gas water use accounts for a very small portion of overall general basin use, usually less than 1% (3).

Besides quantity issues, concerns about the ecological impacts to aquatic resources from water withdrawals have been raised throughout the Marcellus Shale region (11).

Groundwater

Groundwater in West Virginia is generally of good quality with 42% of the state's population relying on groundwater as the source of their domestic water supply; but, a recent comprehensive study by the United States Geological Survey (USGS) raises concerns based on iron, manganese and radon levels found in water samples taken from 300 wells around the state. Developing a groundwater well near an active Marcellus Shale development area would have to be able to provide sufficient yield and not have any impact on nearby drinking water supply wells or surface waters (9). To ensure this does not happen, a hydrological study of the area would need to be conducted prior to drilling the groundwater well.

Potable Water Supplies

Municipal water suppliers are another option to provide a source for freshwater to drilling and hydraulic fracturing operations. To the extent that capacity exists to provide water for rate-paying customers as well as shale gas operators, the municipality may agree to provide water for hydraulic fracturing.

Flowback Water Reuse

Recycling of flowback and produced water reduces the demand on freshwater supplies and the volume of water that requires treatment or disposal. It is unknown if reusing untreated flowback waters for hydraulically fracturing new wells would impede gas production. Therefore, most shale gas operators treat flowback waters to some degree. Many technical solutions exist to treat flowback waters. These technologies are discussed under the Best Available Practices section of this report.

Other Sources

Another option may be to use treated acid mine drainage (AMD). AMD is water that has been contaminated by contact with pyrite in strip-mine operations, refuse piles or abandoned deep mines that results in the formation of sulfuric acid and iron (9). Treatment typically involves neutralization and removal of metals such as iron. Common in many areas underlain by the Marcellus Shale, treated AMD may be a plausible substitution for surface water. Scaling by divalent and trivalent ions is an issue when considering the use of AMD. Some suggest treatment to reduce total hardness to 2,500 mg/L (12). A study in 2009 conducted by ProChem Tech International, Inc. found that treated AMD was a suitable substitute for freshwater for the hydraulic fracturing process of a shale gas well. It required a simpler treatment process compared to treatment of return flowback water and allowed an alternative use for AMD other than treatment and surface discharge. Using their unique chemical process with no addition of calcium hydroxide and inclined plate clarifiers to remove iron below 20 mg/L and keep calcium well below 350 mg/L, treated AMD was used in a successful operation in Pennsylvania (12). The use of AMD water in Marcellus Shale development may provide a win-win solution for coal and natural gas industries along with the regulatory agencies that are tasked to oversee activities of both industries by providing a use for the AMD instead of treatment and monitoring required for discharge.

Water and Waste Streams Associated with Horizontal Gas Well Development

Several members of the Marcellus shale industry volunteered to participate in a study to develop an information base on the nature and composition of influent water and flowback waters associated with completions of Marcellus shale gas wells (13). Nineteen well sites were identified throughout Pennsylvania and West Virginia where hydraulic fracturing would take place. Samples were taken of the: supply water prior to blending of additives, influent water following blending with additives but before the addition of sand, flowback samples at varying time lapses after hydraulic fracturing, and water from each producing well 90 days after completion.

Results show influent water usually contains moderate to low concentrations of salts. Refer to **Table 1** (13). The concentration of TDS in flowback increased with time while the flow rate decreased with time. Samples showing moderate TDS values in the influent water indicate implementation of water reuse practices meaning those companies use flowback water in part to make up hydraulic fracturing fluid for subsequent fracturing. Oil and grease, and total organic carbon (TOC) concentrations in these samples indicate blending of flowback water with freshwater. General characteristics of the flowback and produced water are consistent with literature values. Typically the dissolved solids in flowback and produced waters from Marcellus wells consist of sodium, chloride, calcium and to a lesser extent, strontium, barium and bromide. Heavy metals of toxicological concern that are often associated with urban industrial activity were at very low levels compared to what is typically reported in sludge from municipal wastewater facilities. Among the volatile organic constituents tested, nearly 96% were found at non-detectable levels and 0.5% was above 1 mg/L. Constituents in produced waters that exceeded 100 parts per billion (ppb) included components commonly present in produced waters from natural gas operations: benzene, toluene, ethylbenzene and xylene (BTEX); naphthalene; several methylated benzene compounds and an alkylated toluene; however, few determinations of these compounds exceeded 2 parts per million (ppm; 13). Nearly all halogenated organic compounds were at non-detect levels strongly suggesting additives blended with makeup waters do not contain concentrations of organic chemicals of concern. The results of this shale gas water characterization effort indicate that PCBs, pesticides, and a large fraction of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) should be considered unnecessary for the sampling and analysis of flowback waters in the future (13).

Table 1: Chemical Characteristics of Influent and Flowback Waters

Parameter	Units	Influent Water Before Additives	Influent Water After Additives	Flowback Water 5 Days Out	Flowback Water 14 Days Out
pH	No units	6.7 – 7.4	5.2 – 8.9	5.8 – 7.2	4.9 – 6.8
Acidity	mg/L	<5 – 5.5	<5 – 1,230	<5 – 447	<5 – 473
Total Alkalinity	mg/L	6.2 – 88.8	5 – 308	48.8 – 327	26.1 – 121
Hardness as CaCO3	mg/L	18 – 1,080	26 – 9,500	5,100 – 55,000	630 – 95,000
TSS	mg/L	<2 – 24	4 – 5,290	10.8 – 3,220	17 – 1,150
Turbidity	NTU	1.3 – 33.7	2.7 – 715	2.3 – 1,540	10.5 – 1,090
Chloride	mg/L	4.1 – 3,000	18 – 10,700	26,400 – 148,000	1,670 – 181,000
Total Dissolved Solids	mg/L	35 – 5,510	221 – 27,800	38,500 – 238,000	3,010 – 261,000
Specific Conductance	µmhos/cm	55 – 10,100	177 – 34,600	79,500 – 470,000	6,800 – 710,000
Total Kjeldahl Nitrogen	mg/L	<3 – 56.4	2.3 – 400	38 – 204	5.6 – 261
Ammonia Nitrogen	mg/L	0.017 – 20.8	0.28 – 441	29.4 – 199	3.7 – 359
Nitrate-Nitrite	mg/L	<0.1 – 3.0	0.1 – 3.1	<0.1 – 1.2	<0.1 – 0.92
Nitrite as N	mg/L	<0.05 – 4.9	<0.05 – 5	1.2 – 29.3	<2.5 – 77.4
Biochemical Oxygen Demand	mg/L	<2.0 – 110	<2.0 – 2,220*	37.1 – 1,950	2.8 – 2,070
Chemical Oxygen Demand	mg/L	<10 – 924	35.3 – 47,400	195 – 17,700	228 – 21,900
Total Organic Carbon	mg/L	1.8 – 202	5.6 – 1,260	3.7 – 388	1.2 – 509
Dissolved Organic Carbon	mg/L	1.4 – 222	5 – 1,270	30.7 – 501	5 – 695
Oil and Grease	mg/L	Not detected	4.6 – 255	4.6 – 655	<4.6 – 103
Cyanide, Total	µg/L	<10 – 625	3.5 – 954	<10 – 72.1	<10
Amenable Cyanide	mg/L	<0.01 – 0.27	<0.01 – 0.87	<0.01 – 0.032	<0.01
Bromide	mg/L	<0.2 – 31.9	<0.2 – 107	185 – 1,190	15.8 – 1,600
Fluoride	mg/L	<0.05 – 1.2	<0.05 – 58.3	<0.05 – 17.3	<0.05 - <50
Total Sulfide	mg/L	1.6 – 5.6	<3 – 8.8	<3 – 5.6	<3.0 – 3.2
Sulfate	mg/L	3.8 – 139	2.9 – 2,920	2.4 – 106	<10 – 89.3
Total Phosphorus	mg/L	<0.1 – 0.14	<0.1 – 16	<0.01 – 2.5	<0.1 – 2.2
Total Recoverable Phenolics	mg/L	0.01 – 0.031	<0.01 – 0.77	<0.01 – 0.31	<0.01 – 0.31
Sulfite	mg/L	6 – 21.6	<5 – 61.6	2.5 – 38	7.2 – 73.6
Methylene Blue Active Substances (MBAS)	mg/L	<0.05 – 0.962	<0.03 – 0.506	<0.012 – 1.52	<0.05 – 4.6

*BOD readings were reported as g/L not mg/L.

Drilling Wastes – Liquid and Solid Waste Streams

Drilling a horizontal gas well begins the same way as other types of wells. A vertical well is drilled to a pre-determined depth, followed by the horizontal or lateral drilling into the targeted shale formation. The drilling process itself generates cuttings and muds that must be managed when removed from the bore hole. Cuttings are made up of rock fragments. Drilling muds are made up of a base fluid such as water, mineral oil, or a synthetic oil-based compound; weighting agent; clay; and a stabilizing organic material such as lignite (15). Drilling muds can also pick up characteristics of the various formations as drilling proceeds.

Cuttings are often transported from the well to the surface by the base fluid that serves to cool and lubricate the drill bit. This fluid, which is used only during the drilling phase of well development, is commonly referred to as “drilling muds” or “muds.” Barite is sometimes added to the fluid for weight (14). In the Marcellus, pressurized air is commonly used as the drilling “fluid” during the vertical drilling stage and a liquid waste or slurry for the horizontal drilling stage. Drilling muds and cuttings are brought to the surface where the liquids and solids are separated via shale shaker tables that consist of large sieves (15). Liquid wastes pass through the screen and are collected in an underlying basin. The solid drill cuttings are retained on the top of the screen. Shaker tables can recover up to 70% to 80% of the liquid for reuse. Disposal options for cuttings include dewatering and haulage to a licensed waste disposal site or burial on-site with the permission of the landowner and approval from the governing regulatory body. Until recently, cuttings disposal pits were generally not lined. Muds are typically reused and sent back down the well. Once drilling is completed, muds can be reused to drill another well or be properly disposed of in a landfill.

Commonly Used Hydraulic Fracturing Fluids

After a well is drilled and casing has been placed, the completion stage, or hydraulic fracturing, begins (16). Hydraulic fracturing was first developed in the 1940s to stimulate production from oil reservoirs with declining productivity (3). In the production zone of the well, a perforation gun shoots holes through the casing and cement at pre-determined locations (11). Hydraulic fracturing takes place in stages where hydraulic fracturing fluids are pumped through the perforations, and plugs are set. The process is repeated until the length of the production zone has been fractured. Hydraulic fracturing takes place under high pressure (around 10,000 psi) to create microfractures in the rock formation to allow the gas to be extracted. The sand or other proppant holds the new fractures open allowing the gas to flow freely out of the formation and into a production well for compression, transmission, and sale.

Mixed with the water and sand is a chemical cocktail of other ingredients that include friction reducers (slickwater), corrosion inhibitors, oxygen scavengers, scale inhibitors and biocides (disinfectants; 17). The resulting mixture is referred to as hydraulic fracturing fluid and is typically created on-site. The water and sand typically make up 98% to 99% of the hydraulic fracturing fluid with the rest consisting of the various chemical additives used to improve the effectiveness of the fracture and subsequent release of natural gas. Nearly all fluids currently used in Marcellus Shale hydraulic fracturing operations are water based or mixed slickwater fracturing fluids (5).

Some of the additives used in hydraulic fracturing fluids are used in many common household products and foods (8). However, hydraulic fracturing fluids have been found to contain hydrochloric or muriatic acid, petroleum distillate, ammonium bisulfate, fluorocarbons, naphthalene, butanol, and formaldehyde (18). Many of these chemicals are either carcinogenic or can cause a wide range of health problems affecting eyes, skin, lungs and the nervous system.

In 2010, the United States House of Representatives Committee on Energy and Commerce conducted an investigation into the practice of hydraulic fracturing in the United States (19). Fourteen leading oil and gas companies were asked to provide information on the types and volumes of hydraulic fracturing products used in their fluids between 2005 and 2009. The investigation yielded a total of 750 different chemicals and other components used by these companies to create their hydraulic fracturing fluids. Components were found to range from harmless (table salt and citric acid), to unexpected (instant coffee and walnut hulls), to extremely toxic (benzene and lead; 19). Methanol was found to be the most widely used chemical by the companies surveyed. Methanol is considered a hazardous air pollutant and is on the candidate list for potential regulation under the SDWA (19). Other commonly used chemicals included isopropyl alcohol (surfactant), 2-butoxyethanol (foaming agent or surfactant) and ethylene glycol (scale inhibitor) along with the silicon dioxide (sand proppant). The Committee's investigation also found that the fourteen oil and gas companies surveyed used hydraulic fracturing products containing twenty-nine chemicals that are known as or may be possible human carcinogens regulated under the SDWA due to risks to human health, or listed as hazardous air pollutants under the Clean Air Act.

Each company has their own hydraulic fracturing fluid recipes and has typically kept them secret siting proprietary information (20). The resistance of energy companies to publicly disclose the chemicals used to make up their hydraulic fracturing fluids has heightened the concern that these substances can harm the surrounding environment and negatively impact human health. This is especially true if there is a way the hydraulic fracturing fluids and thus chemicals can mix with nearby groundwater resources. Some companies post information about their fracturing fluids on their websites or general websites. An example is www.fracfocus.org which provides a general idea as to what additives are used for hydraulic fracturing in the Marcellus Shale. Adapted from the West Virginia Oil and Natural Gas Association, Energy in Depth, Geology.com, and the Society of Petroleum Engineers, common ingredients found in hydraulic fracturing fluids used in the Marcellus Shale region and the purpose each serves is summarized in **Table 2** (21, 22, 23 and 24).

Table 2: Hydraulic Fracturing Additives

Category	Main Ingredient	Purpose	Other Uses
Water	Water	Expand fracture, deliver sand	Landscaping, manufacturing
Proppant	Silica, Quartz Sand	Hold fracture open	Drinking water filtration, play sand, concrete
Gel	Guar Gum or Hydroxyethyl Cellulose	Thickens water and suspends sand	Cosmetics, baked goods, ice cream, toothpaste
Friction Reducer	1) Petroleum distillate 2) Polyacrylamide 3) Mineral oil	1) Slick water to minimize friction 2) Minimizes friction between pipe and fluids	1) Hair, makeup, skin products 2) Soil conditioner, water treatment 3) Makeup remover, laxatives
Acid	Hydrochloric or Muriatic Acid	Dissolves minerals and initiates cracks in rock	Swimming pool cleaner
Anti-Bacterial Agent	Glutaraldehyde	Eliminates bacteria in the water	Disinfectant, medical equipment sterilizer
Scale Inhibitor	Ethylene Glycol	Prevents scale deposits	Household cleansers, paints, caulk
Breaker	1) Ammonium Persulfate 2) Sodium Chloride	Allows delayed breakdown of gel	1) Hair coloring, disinfectant, manufacturing of plastics 2) Table salt
Corrosion Inhibitor (Oxygen Scavenger)	1) n,n-dimethyl formamide 2) Ammonium Bisulfite	Prevents pipe corrosion	1) Pharmaceuticals, plastics 2) Cosmetics, food and beverages
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, cosmetics
Iron Control	Citric acid	Prevents metal oxides precipitation	Food additive, beverages
Clay Stabilizer	Potassium Chloride	Creates brine carrier fluid	Table salt substitute, IV fluids
pH Adjustment Agent	Sodium or Potassium Carbonate	Maintains effectiveness of other products	Laundry detergents, soaps, water softeners
Surfactant	Isopropanol	Reduces surface tension and increases viscosity of fracturing fluids	Glass cleaner, deodorant, antiperspirant

Characteristics of Flowback Waters

Once the hydraulic fracturing process is completed and the wellbore pressure released, a portion of the fracturing fluids and water flows back up the wellbore to the well head. Referred to as flowback, this water returns over the life of the well and is collected in tanks or lined pits. The Marcellus is considered a desiccated formation. It contains little if any water in most locations. Flowback and produced water consist of organic, inorganic and radioactive compounds from the originally injected water along with constituents acquired during contact with the formation. These may include the additives that were introduced during the hydraulic fracture job as well as characteristics of the formation such as salts, oils and greases, metals and organic compounds, and may include naturally occurring radioactive materials (NORM). The primary radionuclides of concern are isotopes of radium that originate from the decay of uranium and thorium naturally present in the subsurface.

Organic compounds are either separable with de-oiling technologies (such as oils and greases) or they are soluble (such as phenol, mono-carboxylic acids glycols), requiring a more complicated removal process (9).

Radioactivity

All environmental media contain some level of radioactivity or naturally occurring radioactive materials (NORM). There are three main groups of radioactive elements that exist in all soil and rock on earth: uranium-238/radium-226 radionuclide series, the thorium-232 radionuclide series, and potassium-40 (25). Typical, natural background concentrations of uranium, radium, and thorium present in soil and rock in the eastern United States range from 0.5 to 1 pCi/g each and 10 to 30 pCi/L for potassium-40 (25). Certain commercial minerals, such as gypsum, zirconium and titanium used in paint and zircon sand and carborundum used in sandblasting and ceramics have radioactivity levels ranging from 5 to 50 pCi/L (26).

Certain materials used or generated in certain industry sectors have higher than background levels of NORM or technologically enhanced naturally occurring radioactive materials (TENORM; 27). Exposure to naturally occurring radiation makes up the majority of an average person's yearly radiation dose and is generally not considered of significance to health and safety (49). Certain industries handle significant quantities of NORM, which can mainly be found in their waste streams. As potential hazards are identified, monitoring and regulation of such materials and activities have increased. Industries known to have NORM issues include: coal, oil and gas, metal mining and smelting, phosphate fertilizer industry, building and recycling (49).

In shale gas development, NORM can be found in drill cuttings, flowback waters and natural gas (28). NORM are more noticeable in areas where sediments or precipitates tend to accumulate such as equipment, pipes and storage tanks, and as a result, exposure may occur when repair work is performed (29). Dense steel used in natural gas production blocks alpha and beta radiation and greatly reduces transmission of gamma radiation. Since distance reduces exposure, risks to the general public are possible when contaminated materials and components such as pipe and tankage are mishandled (29). According to the World Nuclear Association, NORM in the oil and gas industry poses a problem to workers particularly during maintenance, waste transport and processing, and decommissioning (49). In particular, Lead-210 deposits and films are only a concern when pipe internals become exposed (49). External exposure due to NORM in the oil and gas industry is generally low enough not to require protective measures to ensure that workers stay beneath their annual dose limits and internal exposures can be minimized through hygiene practices (49).

Radioactivity in the Marcellus Shale varies across the formation. Over time, the radioactive isotopes decay with half-lives from a few days to several hundred years. Levels of NORM in

Marcellus Shale flowback tend to be relatively low with higher concentrations in the later flowback waters and produced water. Alpha particles and Radium-226 in some produced waters in New York have been found at concentrations exceeding drinking water maximum contaminant levels of 15 pCi/L and 5 pCi/L, respectively (26).

Exposure to radionuclides, even at low levels can raise serious health concerns. Radon gas, known to exist within the Marcellus has been shown to be a primary cause of lung cancer. The EPA has established drinking water guidelines for certain radionuclides: 5 pCi/L for radium, 30 pCi/L for uranium and 15 pCi/L for total alpha emitters. EPA has also set radium-226 levels in wastewater discharges at 60 pCi/L, discharges to land surface at 5 pCi/g and 15 pCi/g to subsurface soils.

The New York Department of Health analyzed three samples of flowback waters from Marcellus wells and found elevated levels of gross alpha, gross beta, and radium-226, which is characteristic of Devonian-age shales (11). The presence of high levels of radium-226 raised several issues: monitoring of NORM need to be evaluated for Marcellus gas wells; levels of NORM in flowback waters need to be assessed to determine if additional treatment of the flowback waters are needed prior to disposal; and caution should be exercised when considering spreading brine waters on roads to keep dust down or for deicing purposes (26). Based on these findings, the New York Department of Health recommends continued sampling of flowback waters and drilling muds and cuttings. They feel analysis of gross alpha activity, gross beta activity and some gamma spectroscopy analysis to be sufficient to assess if further characterization of radioactive material is warranted. Although total gross alpha counting efficiency is uncertain in samples with high dissolved solids, it is an inexpensive screening tool, and if counts exceed 15 pCi/L, additional analysis is warranted (26). The WVDEP may want to consider following the lead of the New York Department of Health for monitoring radioactivity of water and waste streams returning up-hole. If general analysis of total gross alpha and beta counting present concern by yielding sample readings well above twice background radioactivity readings, further analysis should be conducted to characterize radiation levels measured and determine if additional protective measures need to be implemented for workers and/or nearby populations.

Environmental and Public Health Concerns Associated with Water and Waste Streams from the Development of Horizontal Shale Gas Wells

Public concerns about water quality from horizontal gas well development include: aquifer and drinking water well contamination; waste storage pit leakage; spills of hydraulic fracturing fluids; handling of flowback streams; water use and supply; drilling waste disposal; stormwater runoff; and blowouts (31). These concerns stem from two related activities: 1) well development and completion, and 2) management of water and waste streams (handling, storage and disposal). Casing and cement failure to properly bond the well annulus can result in upward migration of gas and fluids into shallow drinking water aquifers.

Identifying the cause of contamination of a nearby drinking water well can be difficult. Characterization of flowback and produced water chemistry and isotopic composition has been employed to identify migration of hydraulic fracturing wastes into drinking water supplies. A study conducted by researchers from Duke University found methane gas in drinking water wells located within one kilometer of active drilling sites (32). However, there was no baseline data available to determine if methane was present in the drinking water wells prior to nearby drilling activities commencing. And, methane was detected in nearly all of the drinking water wells tested regardless of the proximity to drilling activities. The Duke study did highlight a known concern that faulty or leaky well casings at the top of a drilling site may allow methane to migrate to nearby water supplies. In Pennsylvania, where this study took place, regulations do not exist requiring private drinking water wells to be properly drilled and cased, increasing the potential of contamination from any nearby activity. A lack of baseline testing of water wells prior to well development and completion renders interpretation of the results problematic.

Published studies and agency investigations indicate no direct connection between hydraulic fracturing of shale formations and groundwater contamination (33). A 2011 study by the Center for Rural Pennsylvania analyzed water samples from private wells within 2,500 feet of a Marcellus Shale gas well (34). Pre-drill and post-drill samples were taken to identify any changes in water quality. Samples were analyzed for TDS, chloride, sodium, sulfate, barium, strontium and methane. Results indicated there were no statistically significant increases in pollutants prominent in drilling waste fluids and the conclusion was drawn that gas well drilling had not had a significant effect on water quality of nearby drinking water wells. Nonetheless, contamination incidents attributed to poor gas well construction, as was the case of the Duke University study of nearby drinking water wells in Pennsylvania, have raised concerns regarding the adequacy and/or enforcement of state well construction regulations for both gas production and drinking water supply.

Many who express concern about potential water problems do not differentiate between the actual fracturing process and associated stages of horizontal shale gas well development and production (35). State regulators and industry representatives define hydraulic fracturing as the specific well stimulation operation. However, the general public and media outlets often use the term “hydraulic fracturing” or “fracking” to broadly refer to a range of activities associated with unconventional gas development. Few published, peer-reviewed scientific reports exist documenting potential environmental impacts from hydraulic fracturing. Studies that do exist show that the risks depend more on the quality and integrity of the borehole casing and cement job rather than the hydraulic fracturing process (36). There is little agreement regarding the risks that hydraulic fracturing operations pose to underground sources of drinking water and, as a result, Congress has directed the EPA to study the matter further (33).

Management of Water and Waste Streams

Surface activities pose an additional concern for potential groundwater contamination. Leaking pits, accidental spills or careless disposal practices of drilling fluids at the production site will increase the risk of contaminating nearby water supply wells. Storage, treatment and disposal of flowback waters also create additional water quality issues. Leaks from flowback water and waste storage pits and surface spills from transporting flowback water or fracking fluids can cause contamination of nearby surface and groundwater. Many believe that above-ground activity is a greater risk to drinking water resources than below-ground activity and may have contributed to the contamination of water supplies in Pavillion, Wyoming (37).

Lined pits that are used to store the flowback water may pose a threat to groundwater and surface water resources if these structures are not designed and constructed properly to retain the liquids until they are drained and the site closed and reclaimed. Common problems with these structures include tears in liners that allow fluids to escape and enter nearby surface waters or seep into nearby groundwater.

Surface water contamination from the hydraulic fracturing process may occur if hydraulic fracture fluid spills at the wellhead site or if the trucks carrying this fluid leak as they travel to and from the wellhead. These spills may be from unused hydraulic fracturing fluid or return hydraulic fracturing fluid that comes back up the well during the flowback process. Spill prevention measures are necessary because surface spills may pose a greater risk to groundwater than the hydraulic fracturing process. Although operators try to ensure spills do not occur, it occasionally happens and must be reported to the proper regulatory agencies. Spills are not a common occurrence because fluids lost to a spill must be replaced and remediation of contaminated soils increases operational costs (5).

One of the biggest issues with surface water contamination found during the literature review is from the treatment of the flowback water at municipal wastewater plants. Flowback water is very high in chlorides, sodium and calcium. These chemicals create high TDS levels. Other contaminants of concern found in flowback waters include bromide, barium, and traces of radiation. Typical wastewater treatment plants are not equipped to remove enough of these contaminants to allow release or final disposal into receiving surface waters. The high contaminant levels found in flowback water require specialized treatment in order to protect surface waters receiving the treated wastewater. High bromide levels have been found to exist in surface waters where publicly owned treatment works (POTW) and centralized waste treatment (CWT) facilities receiving wastewaters from oil and gas development discharge their effluent. These are the same surface waters that downstream drinking water systems pull from to supply their customers with drinking water. Most POTWs and CWTs are not equipped to treat bromide and thus it passes through their system. Bromides are not necessarily dangerous by themselves; it is only when they mix with chlorine used by drinking water systems that they become a threat to public health.

A typical Marcellus well pad site is around 3 to 5 acres in size. The area allows for the wellheads and a combination of pits, impoundments and tanks to hold drill cuttings, used drilling and hydraulic fracturing fluids, freshwater and flowback waters. Access to the well pad adds to the overall amount of disturbed land. Appropriate practices need to be in place to control stormwater runoff at the well pad as well as around the roads providing access to the site.

Blowouts are rare occurrences that happen when the fluid injected into the wellhead does not fracture the rock around the bottom of the well and the elevated pressure drives the fluid into other open and permeable pathways (36). Pathways can include the borehole, other oil and gas wells, artesian wells or abandoned wells in the vicinity that cannot handle high pressures. Old abandoned wells can also provide a potential pathway for contaminants to enter groundwater systems. States estimate that there are over 150,000 abandoned oil and gas wells in the United States (35). Blowout prevention equipment installed at the surface prevents pressurized fluids encountered during drilling from moving up the well through the space between the drill pipe and surface casing (38). A blowout in West Virginia occurred because the drillers reportedly encountered an unexpected pocket of methane in an abandoned coal mine below the surface and a blowout preventer had not yet been installed (38). Fluids spilled onto the surface from blowouts can leach into surrounding soils and groundwater and need to be cleaned up and the area remediated. These types of incidents support the need to gather accurate and complete information about the subsurface and surrounding area prior to gas well development.

Summary of Best Available Practices and Technologies for Water and Waste Streams

Water management (storage, treatment and disposal) technologies available in the Marcellus Shale region cover treatment, recycle/reuse and disposal by Class II injection wells of flowback and produced waters. Industry is looking for alternative ways to manage these wastewaters that minimize costs and impacts to the environment. Treatment is the most complex option available to manage water and wastes from the development of horizontal shale gas wells. Treatment can occur on-site or off-site and in conjunction with reuse options. All treatment methods produce some form of residual waste, liquid or sludge, and must be managed to avoid environmental harm. Depending upon the end use of the wastewater, various treatment options are available and discussed below in respective sections.

Storage Options and Practices

Large quantities of water in a short amount of time are required for hydraulic fracturing operations. Water restrictions commonly exist limiting the amount of water that can be withdrawn and transported to well sites necessitating the need for some form of water storage. The two methods often used to store water on-site or near active hydraulic fracturing operations are containment units, typically referred to as tanks, and impoundments.

Tanks are available from many vendors. Rectangular tanks, with a V-bottom or cylindrical bottom, with a 21,000 gallon capacity transported by a semi-truck, are most commonly used. Because these tanks hold a small volume of water compared to the amount needed for the average hydraulic fracturing job, hoses are used to connect several tanks together. To provide a 1,000,000 gallon storage capacity, 48 tanks are needed, requiring a considerable amount of space and an extensive hosing network. Secondary containment constructed around these units serves to provide additional environmental protection from accidental leaks and spills. Secondary containment units look similar to a tray-like structure with raised sides to prevent fluids from leaching into soil or washing into nearby surface waters.

Impoundments can be used in coordination with tanks or alone as a means to provide water storage on-site. Impoundments differ from pits in that they hold only freshwater. Pits are used to hold flowback waters and other residual water and waste streams from horizontal gas well development.

Reuse or Recycle Options and Practices

A combination of water use restrictions and increased unconventional natural gas development will likely increase the demand for non-freshwater supplies for future development operations. Care must be exercised when reusing fluids and flowback waters with little or no treatment. Flowback waters with high levels of salts, barium and calcium, may cause scaling issues over time. Besides salts, flowback waters contain heavy metals and various organic and radioactive compounds that may limit reuse options without prior advanced treatment. Major treatment processes such as reverse osmosis and distillation are very costly but have been proven to reduce constituents present in flowback waters that can cause scaling, compatibility issues with hydraulic fracturing fluid additives and increase friction on subsequent hydraulic fracturing jobs. In Pennsylvania, industrial treatment followed by reuse is a common method for managing wastewaters from the development of Marcellus gas wells (15).

Because traditional off-site disposal options are not often available in the Marcellus region, reuse options are being employed (39). Recycle or reuse of flowback waters reduces the amount of wastewater generated and the amount of freshwater needed for hydraulic fracturing operations; but, this practice can create concentrated residual by-products that will need to be dealt with. Pennsylvania allows the use of Marcellus brines to roadways as long as the brines can meet certain water quality requirements (39). Brines are a product of flowback waters that have been treated at a CWT designed specifically to handle these wastes. Although this has been a common practice in the Marcellus region, environmental concerns have recently increased resulting in a closer look at contaminant concentrations of the brines and risks of these pollutants washing into nearby waterways (39).

Land application of hydraulic fracturing fluids is considered an acceptable form of disposal in some states where hydraulic fracturing activities are ongoing; however, little information exists on impacts these fluids have on vegetation. In 2008, hydraulic fracturing fluids from a gas well were applied to a small section of a hardwood forest in West Virginia. During application, severe damage and mortality to the ground vegetation was observed (40). Two years after application, nearly half of the trees were dead. Soil samples were taken prior to application and throughout the two year study period of the application area and adjacent area to evaluate the effects of hydraulic fracturing fluids on soil chemistry. Sodium and chloride concentrations in the soil were found to be increased 50-fold after application of the hydraulic fracturing fluids (40). These concentrations did decline over time, likely due to leaching. Researchers recommend additional studies into the application rates of hydraulic fracturing fluids and effects on vegetation and land resources.

Chemical composition of hydraulic fracturing fluids is designed to optimize performance of the fracturing job (17). When reusing flowback waters for additional hydraulic fracturing, it is imperative TDS concentrations are kept in check to not negatively affect the ability of the new hydraulic fracturing fluids. Many operators will blend the flowback waters, treated or untreated, with freshwater to achieve the right consistency, keeping TDS values minimal. If the flowback waters are untreated, blending will require more freshwater to dilute TDS values. Therefore, it is beneficial to treat the flowback waters if freshwater sources are scarce.

Treatment of water and waste streams from horizontal gas well development can occur on or off site. Several companies have developed a wide variety of technologies to treat flowback waters for reuse from gas wells at the site (on-site). Some form of physical (filtration) or chemical (coagulations and flocculation) separation is needed to remove oil and grease and suspended matter. Bag or cartridge filtration systems are commonly used to remove suspended solids from flowback waters. They offer a compact footprint with a simple design but can be labor intensive. The next step for treatment concentrates on reducing levels of hydrocarbons, organics and metals. This treatment can be accomplished using a form of membrane system like reverse osmosis (RO), ion exchange, or electrodialysis. These membrane systems cannot be used as a stand-alone treatment system for Marcellus flowback waters. They require some level of pretreatment. Often, some form of disinfection is introduced into the treatment schematic as well. Disinfection is often required in unconventional shale plays like the Marcellus prior to hydraulic fracturing and especially if recycled flowback waters make up part of the hydraulic fracturing fluids (41). Ozone and ultraviolet light are two common forms of disinfection used to oxidize biological films and bacteria that may exist in flowback waters. Similar to the membrane systems, disinfection systems cannot be used as stand-alone treatment systems and also require pretreatment to be effective.

The issue of reducing TDS values has not been addressed by the treatment technologies mentioned thus far. Since TDS values are extremely high in flowback waters of the Marcellus, any of these treatment options may have difficulty processing flowback waters with TDS values over 40,000 mg/L. Thermal distillation and evaporation may be the only option to treat flowback waters with TDS values greater than 40,000 mg/L on a regular basis. As of 2010, a handful of thermal distillation facilities were operating in the Marcellus region, highlighting the need to develop and implement additional treatment processes.

Wastewater treatment processes achieve a high water recovery rate by concentrating the solids and sludges. However, no practical and cost-effective method exists to remove all NORM. Chemical precipitation, ion exchange or activated carbon can remove metals and radium. The

EPA recommends reverse osmosis treatment of water to remove most forms of radioactive particles when treating for drinking water consumption (42). This may be practical as an end of treatment process if NORM are still an issue in the discharge waters.

Energy requirements, need for pretreatment, and the system size needed for these technologies to process flowback waters must be considered when evaluating these technologies for on-site application. Treatment and reuse of flowback waters will reduce the demand on freshwater sources and potentially decrease disposal costs by reducing the amount of wastewater that must be hauled away. The disadvantages of treating flowback waters on-site still to be addressed include the fluctuations in quantity and quality of flowback waters. The treatment selection for one site may not be the best for the next given the variations from well to well and formation to formation making it difficult for a one-size-fits-all treatment solution.

Disposal Options and Practices

With the exception of underground injection via a Class II well, most wastewater management strategies for handling water and waste streams from horizontal gas well development require some level of treatment. During the treatment of these water and waste streams, residual wastes are created that will have high concentrations of heavy metals, salts and other constituents limiting disposal options. Often these residual wastes are either sent to an acceptable landfill or sent for underground injection. Current practice in the Marcellus Shale region is to transport wastewaters to treatment facilities (POTWs or CWTs) or dispose through Class II injection wells.

Direct discharge of wastewater from shale gas wells to surface waters is prohibited by federal law. POTW can accept wastewaters from shale gas extraction activities as long as the treatment facility maintains compliance with all federal, state, and local requirements governing the introduction of such wastewaters into the POTW. In other words, POTW need to maintain compliance with their national pollutant discharge elimination system (NPDES) permit. When considering accepting wastewater from shale gas development, or any other industrial activity, the POTW operator needs to know the water quality and quantity characteristics of the wastewater to determine if the POTW can process it without upsetting the treatment system or allowing pollutants to pass through and be discharged to the receiving water. Wastewater treatment facilities, POTWs, may be unable to adequately treat the levels of TDS, metals and radioactivity that is sometimes present in flowback water and waste streams.

TDS concentrations in Marcellus shale waste streams have been found to range from 300 milligrams per liter (mg/L) to well over 300,000 mg/L with chlorides typically constituting about 50% of the total makeup of TDS (7 and 13). TDS is not significantly reduced or removed by most treatment processes utilized at POTWs and therefore pretreatment of the wastewater would be required. High concentrations of TDS require advanced wastewater treatment, such as distillation, and may cause scaling which requires frequent cleaning of equipment (9). The literature reveals some of the common constituents of TDS, at concentrations much less than what is typically found in shale waste streams (including the Marcellus), and may result in inhibition of activated sludge, nitrification, and anaerobic digestion processes commonly utilized at POTWs (7).

High concentrations of chlorides have also been found to disrupt biological treatment processes and metals have also been found to precipitate out during treatment creating issues with disposal options for biosolids. Bromide, which can be present in shale gas extraction wastewater streams, has the potential to pass through the POTW and be present in the final discharge stream as a disinfection byproduct that could lead to increased effluent toxicity (43). Because of high levels of bromides and TDS found in many of the rivers and streams in Pennsylvania to which POTWs and CWTs discharge, State regulators recently asked Marcellus Shale Formation operators to voluntarily stop disposing of the drilling wastes and flowback waters to these facilities (44).

Radionuclides, referred to as NORM, have been found to exist at fairly high concentrations in waste streams from the Marcellus Shale Formation (7). Flowback water has not been extensively monitored and studied for NORM. Few studies are available to help understand the issue of NORM in POTW and CWT effluent. Because there is a possibility wastewater from shale gas extraction activities may pass through a POTW, cause the POTW to violate its permit, cause interference with the POTW's operation, or contaminate biosolids, acceptance of the waste is not advisable unless its effects on the treatment system are well understood and the wastewater is reasonably expected not to cause pass through or interference (7).

The same pollutants may be of concern to CWTs. CWTs typically use the same treatment processes found at POTW but may also include additional coagulation and precipitation techniques to help with TDS removal. Yet, many CWTs may not effectively treat shale gas extraction wastewaters and, therefore, appropriate limits and pretreatment requirements will need to be developed by the permitting and pretreatment control authorities. Additional limits may be required to address pollutants present in shale gas extraction wastewaters that were not considered in developing the original CWT effluent guideline. These limits will need to be incorporated into the CWT's NPDES permit. For such pollutants, permit writers will have to include technology-based limits developed on a case-by-case, "best professional judgment" basis (7). Very few CWTs exist within the Marcellus region, most of which exist in Pennsylvania.

Chemicals used during drilling, as part of the hydraulic fracturing fluids, or other production-related activities need to be disclosed to the POTW or CWT as well. The facility in turn must notify and receive approval from the appropriate State agency and the EPA prior to accepting any waste streams from shale gas extraction operations.

In 2011, a stream study was conducted in western Pennsylvania on the effects of discharges from POTWs and CWTs that accept wastewaters from Marcellus Shale gas sites (45). Salinity stress to freshwater systems was found to be the most significant threat to the ecological welfare of the streams. Accumulation of radioactivity in the stream sediment represented a long-term legacy of NORM in the environment. Based on these findings, researchers determined that gas-produced NORM have yet to be quantified in freshwater sediments and suggested further studies to measure NORM levels in stream sediment.

Where injection wells are available, they are used as an option for disposal of flowback waters and may provide one of the safer means for final disposal. Underground injection requires less treatment than other disposal methods, and when done with appropriate safeguards, creates the least risk of contaminant release to the environment (39). In the Marcellus region, there are a limited number of Class II injection wells scattered throughout Ohio, Pennsylvania and West Virginia. These injection wells can be near the well pad and operated by the producer, or off-site and operated by a third-party (17). Injection wells access deep formations that have sufficient porosity and ability to accept the water. These formations lay far below any groundwater aquifers.

In summary, Marcellus Shale gas operators employ all of the above mentioned options for storage, treatment, reuse and disposal of their flowback waters. If waters are not being reused, they are taken to a POTW or CWT that will accept the wastewater or dispose of it via a private or commercial injection well.

Protection of Ground and Surface Waters during Horizontal Shale Gas Well Development Stages

In addition to treatment, there are various options available to shale gas developers in the Marcellus that can be utilized to protect water resources. These options range from the type of additives used to make up the hydraulic fracturing fluids, to how fluids are handled during the various stages of well development.

Horizontal shale gas wells are typically encased in alternating layers of concrete and steel down through aquifers. For wells to produce gas, it is vital there are no leaks of either gas or hydraulic fracturing fluids into aquifers or other strata. There are rare occasions that a well may fail during drilling or does not produce enough gas to be economical and may have to be abandoned. In this case, proper procedures must be followed to abandon the well.

Many shale gas development operators have abandoned the use of diesel in favor of more environmentally friendly fluids such as high paraffinic fluids, mineral oil and plant-based oils that possess less toxicity and are reasonably biodegradable (11). There is also the option to use waterless fracturing agents such as liquefied petroleum gas (LPG), GasFrac™, or liquid carbon dioxide DryFrac™. According to GasFrac™, their system is a closed-loop system that primarily uses propane since it is a naturally-occurring hydrocarbon and does not damage the shale formations (46).

If the topography is conducive and the distance not great, natural gas developers can also use conveyance pipes to carry the various water and fluids to well pads. Depending upon the location in the Marcellus, this may be an option to help reduce spill potential and truck traffic.

Baseline monitoring studies of groundwater are needed before any drilling activity begins. Cementing of wellbore casings need to be carried out to the surface. Down-hole pressure testing and measurements and casing integrity tests are needed to ensure protection of shallow groundwater resources.

One of the best ways a community's water system source water can be protected is to have total ownership of the land, minerals, and gas and oil rights in the watershed area, or strict land-use ordinances or regulations (47). Since this kind of control is usually not possible, there are other measures nearby communities and drinking water system operators can make to protect their source waters. Source water and wellhead protection plans can be updated to reflect past and present gas well development. Transportation routes to and from well pads should be mapped and plans developed to handle potential spills that may occur along the way.

Lab test results from routine drinking water and wastewater system analyses normally obtained to meet SDWA and NPDES requirements, respectively, will help establish a baseline for any future anomalies and will be important to show changes in water quality if changes occur (47). Drinking water system operators need to keep an eye on their raw water and wastewater system operators need to watch their influent waste streams for any significant changes. Changes in TDS, TSS, conductivity, pH, bromide, chloride, or methane levels may signify that external factors may be influencing their system. Monitoring source water for drinking water systems and influent for wastewater systems should include VOCs, TDS, conductivity, total suspended solids (TSS), chloride, bromide, dissolved methane, pH and radon. Systems on a limited budget should concentrate on chloride, bromide, conductivity, TDS and pH (47).

With the boom in developing unconventional gas reservoirs through means of horizontal drilling and hydraulic fracturing operations, health and safety concerns from the public and private sectors have increased. A new American Society for Testing and Materials (ASTM) committee was recently formed to develop standards that will promote best practices for field operations and protect downstream air, land and water resources. Although in its initial stage of creation, the committee plans to look at all stages of gas well development – from initial site planning and investigation through well abandonment activities (48).

Lastly, critical evaluations of horizontal gas well development and their potential impacts on the environment must be based on peer-reviewed, scientific analyses of the data. Transparency will encourage acceptance of horizontal drilling and hydraulic fracturing activities. Open communication between industry, regulatory agencies and the general public is a must for successful development of natural gas resources that protects public health and the environment.

Water and Waste Stream Monitoring Plan

Background

The intent of the Water and Waste Stream Monitoring Plan is to characterize and document potential surface and groundwater contamination that may be caused by any of the various stages of horizontal gas well development.

Roles and Responsibilities

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

Study Design

The intent of the field sampling described in this monitoring plan is to characterize and document water and waste streams associated with the development of a horizontal gas well in the Marcellus play and to determine potential impacts from pits and impoundments on nearby groundwater resources. Marcellus gas wells at various stages of development have been selected for this project. WVWRI researchers worked with state agencies and industry representatives to identify the gas well sites and obtain access to the drilling fluids, muds and cuttings, and the hydraulic fracturing and flowback waters. WVWRI personnel also obtained information on the source water(s) that make up the hydraulic fracturing water, as well as copies of the hydraulic fracturing fluid composition breakdown. GPS coordinates were obtained and verified upon initial site visits for all gas well locations, sampling points, water withdrawals, permissible discharges, and pits and impoundments.

Water samples were collected and analyzed from all applicable impoundments and pits at each site studied. In addition, three centralized waste pits in Marshall County were monitored per requirements of §22-6A-9 (mandated for study by §22-6A-23). Background samples were collected from each monitoring well prior to pit use and post-pit acceptance of waste streams. The leak detection systems were monitored for the presence of leaked fluid. One monitoring well was placed up-gradient of the pit and two were placed down-gradient of the pit at each study location. Additional monitoring wells were installed down-gradient of two of the study pits in a deeper aquifer to provide further characterization. Part of this study focuses on sampling and analyzing the chemical makeup of drilling fluids, muds and cuttings along with hydraulic fracturing and flowback waters of Marcellus gas wells, paying specific attention to organic compounds, and determining which of these compounds are of concern for potential groundwater contamination. Water samples and samples of solids (cuttings, muds, etc.) from the drilling process were also analyzed for radioactivity.

An overview of the various stages of gas well development that were monitored, how often samples were collected during each stage, the type of sample - liquid or solid, and the sampling date is provided in **Table 3**. A listing of parameters analyzed for each sample by a commercial laboratory facility is provided in **Table 4**. Method detection limits (MDLs) and EPA method numbers for each parameter are also provided in **Table 4**. Total count and exposure radiation were monitored for all liquids and solids from impoundments and pits, as well as all groundwater samples. Sampling results were compared to primary and secondary federal drinking water standards. Daily maximum values, values that exceed maximum contaminant levels, and average results for all parameters for each well development stage were determined from sampling results.

Duplicate samples were randomly collected for approximately 10% of all samples taken. Field parameters such as pH, specific conductivity (µS/cm), total dissolved solids (mg/L), and temperature (ºC) were measured in the field using a multi-parameter YSI 556 unit. Duplicate samples were obtained prior to sample collection in the field. WVWRI researchers also noted visual observations of the surrounding environment and obtained photographs during sampling visits.

On any field investigation, a minimum of two WVWRI staff were present. Each staff member was required to carry personal protective equipment (PPE) and flame-resistant (FR) clothing necessary for access to a well development or well development activity-related site. Minimum PPE requirements included: hardhat, safety glasses, metatarsal boots, metacarpal gloves and FR clothing. In addition, WVWRI personnel were required to have on hand: full-face respirators with combination P100 and organic vapor filters, first aid kits, a flotation device, a handheld radiation alert detector displaying current radiation levels in millirems per hour (mrem/hr) and a 6-gas photo ionizer detector (PID). The radiation alert detector and PID were used to scan the working environment prior to any sampling or monitoring activity on-site.

Table 3: Water and Waste Stream Sampling Plan

	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	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) TBD (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) TBD (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) TBD (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	6	(1) 6/4, 6/7 and 6/19 - initial; 10/31 - 11/1 - final (2) TBD	(1) N/A (2) N/A	(1) Consol/Noble - three centralized pits (2) EQT Smithburg 28, Dodderidge Co

Table 4: 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

	Parameter	Preservative	MDL (mg/L)	Method	EPA MCL (mg/L unless noted)	Lab
	Phosphate	H_2SO_4	0.02	EPA SM4500-P BE	NA	REIC
	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	NA	REIC
Radio-activity	Gross Alpha	(pH<2) HNO_3	NA	EPA 900.0m	15 pCi/L	Pace
	Gross Beta	(pH<2) HNO_3	NA	EPA 900.0m	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

Sampling Sites

Marcellus gas wells at the various stages of development were selected for this project. WVWRI researchers worked with state agencies and industry representatives to identify the gas well sites and obtain access to the drilling fluids, muds and cuttings, and the hydraulic fracturing and flowback waters. Eight different well sites were monitored as part of this study. Refer to **Table 5** for site location information. A combination of the eight sites was used to capture all phases of drilling activity. More information on each site is given in **Appendix B**.

Table 5: Sampling Site Locations

Site	Sampling Date	Sample County	Sample Location	Well Development Stage
Impoundments (prior to conversion to pit)				
SHL - 1 IMP	6/7/12	Marshall	Impoundment edge	Freshwater
SHL – 2 IMP	6/7/12	Marshall	Impoundment edge	Freshwater
SHL – 3 IMP	6/7/12	Marshall	Impoundment edge	Freshwater
MW – 3 IMP	8/28/12	Wetzel	Impoundment edge	Freshwater
Groundwater Monitoring				
SHL – 2, MW - 1	Dry	Marshall	Monitoring well	Freshwater
	11/1/12	Marshall	Monitoring well	After pit conversion
SHL – 2, MW - 2	6/4/12	Marshall	Monitoring well	Freshwater
	10/31/12	Marshall	Monitoring well	After pit conversion
SHL – 2 MW - 3	6/4/12	Marshall	Monitoring well	Freshwater
	10/31/12	Marshall	Monitoring well	After pit conversion
SHL – 2 MW - 4	6/19/12	Marshall	Monitoring well	Freshwater
	11/1/12	Marshall	Monitoring well	After pit conversion
SHL – 4 MW – 1	6/4/12	Marshall	Monitoring well	Freshwater
	10/31/12	Marshall	Monitoring well	After pit conversion
SHL – 4 MW – 2	6/4/12	Marshall	Monitoring well	Freshwater
	10/31/12	Marshall	Monitoring well	After pit conversion
SHL – 4 MW - 3	6/4/12	Marshall	Monitoring well	Freshwater
	10/31/12	Marshall	Monitoring well	After pit conversion
SHL – 3 MW - 4	6/19/12	Marshall	Monitoring well	Freshwater
	11/1/12	Marshall	Monitoring well	After pit conversion
Hydraulic Fracturing (HF)				
HF Water (Waco Donna pad)	7/25/12	Marion	Impoundment edge	Make-up water
Comb HF (Waco Donna pad)	7/25/12	Marion	Blender sample port	Combination make-up water and fracturing

Site	Sampling Date	Sample County	Sample Location	Well Development Stage
				chemicals
HF Water (Maury pad)	9/11/12	Wetzel	Holding tank	Make-up water
Comb. HF (Maury pad)	9/11/12	Wetzel	After blender	Combination make-up water and fracturing chemicals
Vertical Drilling				
ST 1-1 liquid (Lemons pad)	8/8/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-1 solid (Lemons pad)	8/8/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-2 liquid (Lemons pad)	8/15/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-2 solid (Lemons pad)	8/15/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-3 (Lemons pad)	8/15/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-3 solid (Lemons pad)	8/15/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-4 (Lemons pad)	10/2/12	Wetzel	Shaker Table	Vertical Drilling
ST 1-4 solid (Lemons pad)	10/2/12	Wetzel	Shaker Table	Vertical Drilling
ST 2 liquids (Mills Wetzel 2 pad)	8/8/12	Wetzel	Shaker Table	Vertical Drilling
ST 2 solids (Mills Wetzel 2 pad)	8/8/12	Wetzel	Shaker Table	Vertical Drilling
DNR ST 3-1-L	10/25/12	Brooke	Shaker Table	Vertical Drilling
DNR ST 3-1-S	10/25/12	Brooke	Shaker Table	Vertical Drilling
Waste Storage/Flowback Stream				
FS – 1 (Waco Donna pad)	7/27/12	Marion	Condensate Tank	Flowback
FS –2 (Waco Donna pad)	8/2/12	Marion	Condensate Tank	Flowback
FS – 3 (Waco Donna pad)	8/9/12	Marion	Condensate Tank	Flowback
FS – Final (Waco Donna pad)	8/30/12	Marion	Condensate Tank	Flowback
Donna Pit C (Waco Donna pad)	8/30/12	Marion	Condensate Tank	Waste Storage
FS – 1 – SHL - 3	8/13/12	Brooke	Impoundment Edge	Waste Storage
FS – 2 – SHL - 3	8/20/12	Brooke	Impoundment Edge	Waste Storage
FS – 3 – SHL - 3	8/28/12	Brooke	Impoundment Edge	Waste Storage
FS – Final – SHL - 3	9/17/12	Brooke	Impoundment Edge	Waste Storage
SHL – 4 – Comp	9/17/12	Brooke	Impoundment Edge	Waste Storage
Weekley – FS – 1	8/15/12	Wetzel	Separator before disposal tank	Flowback
Weekley – FS – 2	8/20/12	Wetzel	Separator before disposal tank	Flowback
Maury – FS – 1	10/2/12	Wetzel	Separator before disposal tank	Flowback

Sampling occurred for each stage of drilling activity at the following sites:

Water Storage (Impoundment)

1. Consol/Noble Centralized Impoundments, Impoundments SHL-3 and SHL-2 *(sampled 6/7/2012)*
2. Mills Wetzel Pad #3 - Stone Energy *(sampled 8/28/2012)*

Figure 1 is a map of the three Consol/Noble centralized impoundments-to-pits with incorporated coordinates. **Figures 2 and 3** illustrate initial sampling activities of the impoundments.

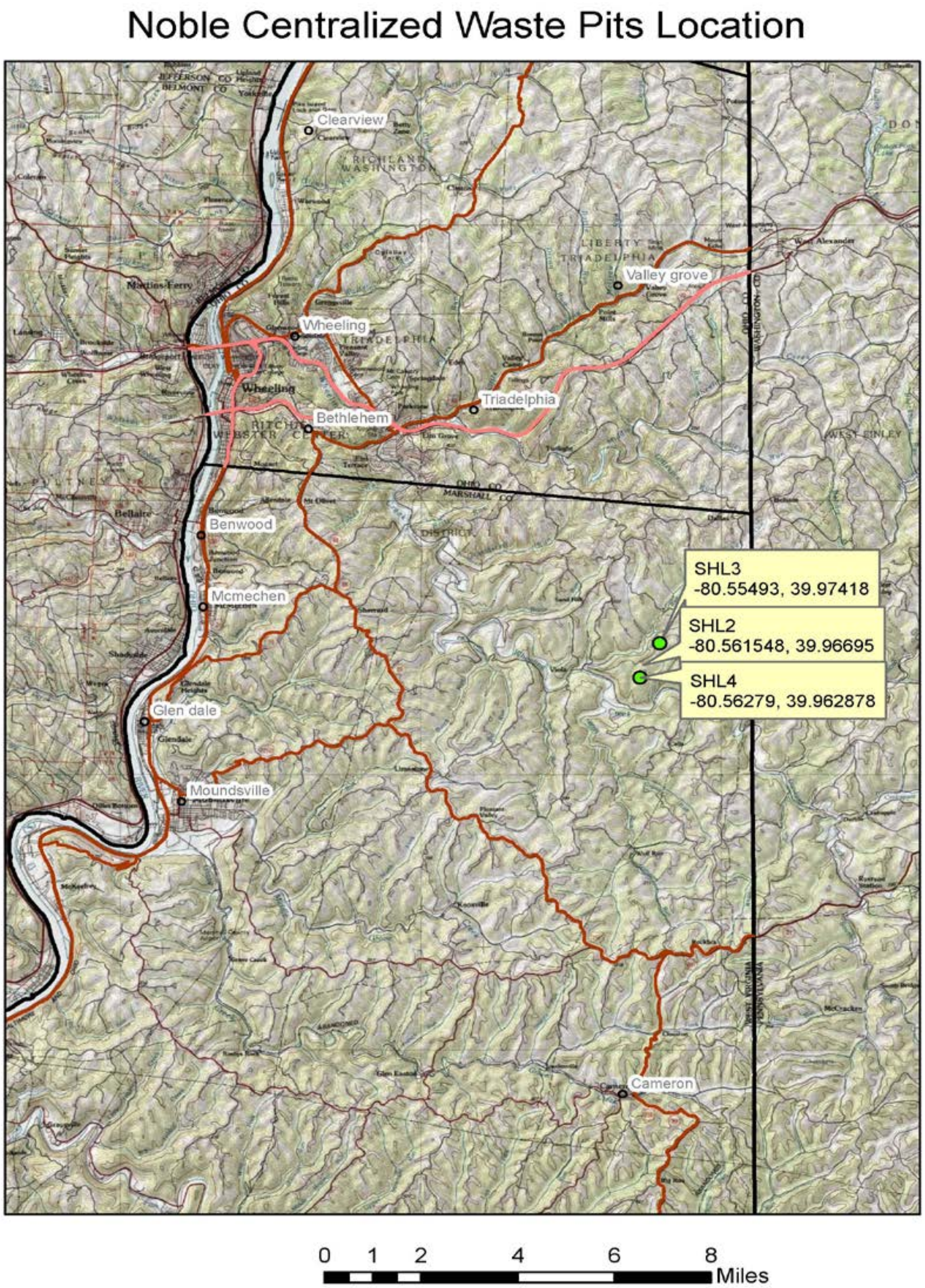

Figure 1: Centralized Pits Locations

Figure 2: SHL-1 Impoundment Sampling

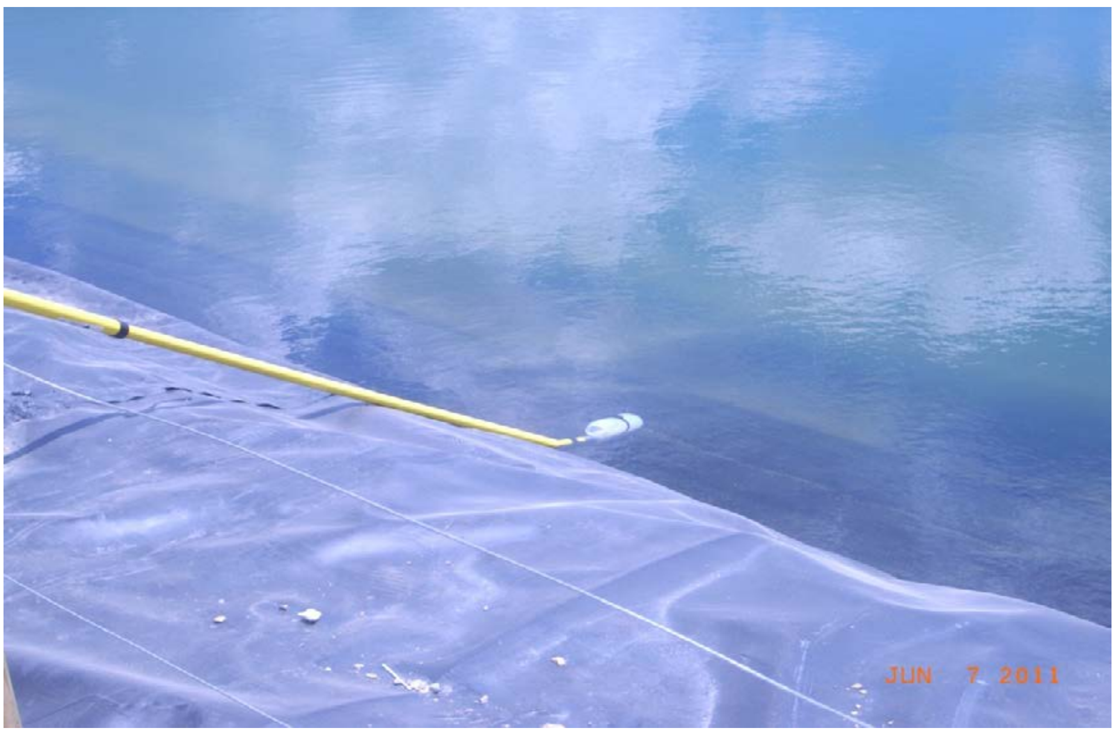

Figure 3: SHL-1 Impoundment Sampling

Drilling wastes (vertical section)

1. Lemons Pad – Stone Energy (*Sampled 8/8/2012, 8/15/2012, 8/22/2012, and 10/2/12)*
2. WVDNR A Pad – Chesapeake Energy *(Sampled 10/25/12)*

Four samples of liquids and solids (muds and cuttings) generated during the vertical drilling phase of a horizontal well were collected from the Lemons Pad – Stone Energy site. The last of these samples was taken while air monitoring equipment was in use on the site. The point of collection for both the liquid and solid samples at the Lemons Pad is illustrated in **Figures 4 and 5** and **Figure 6** shows a sample of the drilling fluids. For the WVDNR A site, one sample of the produced drilling solids and liquids was collected. Sample collection at both sites was coordinated with the air monitoring team.

Figure 4: Lemons Pad – Shaker Table Liquids

Figure 5: Lemons Pad – Shaker Table Solids

Figure 6: Lemons Pad – Vertical Drilling Fluids

Drilling wastes (horizontal section)

1. Mills Wetzel Pad #2 – Stone Energy *(sampled 8/8/2012, sampling attempted 8/20/2012, 8/22/2012 and 8/24/2012)*

2. WVDNR A Pad – Chesapeake Energy *(Sampling not completed due to weather and operator finishing drilling early)*

One sample of the produced drilling liquids and solids was collected from the Mills Wetzel Pad #2 site. However, this sample was not a "true" horizontal drilling sample as the operator was still drilling the curve in the borehole and was not yet in the Marcellus shale strata. Information on this sample can be found in the vertical drilling section of this study. Several attempts were made to obtain additional samples from the Mills Wetzel Pad #2 site. However, due to drilling malfunctions and scheduling issues, WVDEP and the WVU project team decided to forgo sampling at this site in order to sample water and air at additional sites during various well development stages. The shaker table where liquid and solids samples were collected is shown in **Figure 7.**

Sample collection was planned for the WVDNR A Pad site during the vertical drilling phase. However, due to a combination of the operator completing drilling more quickly than anticipated and poor weather conditions, no sample was obtained.

Figure 7: Mills Wetzel Pad #2 Shaker Table (where samples were pulled)

Hydraulic Fracturing Fluids

1. Donna Pad - Waco/ECA *(sampled on 7/25/2012)*
2. Maury Pad – Stone Energy *(sampled on 9/11/2012)*

Samples of the water used to mix with the hydraulic fracturing fluids (makeup water) were taken from the Donna Pad storage pit by using a swing sampler as shown in **Figure 8**. Samples of the hydraulic fracturing fluids and water mixture were taken from the blender prior to entering the Donna Pad well. Hydraulic fracturing sampling activities of well pad staff and the location of the sampling point are illustrated in **Figures 9 and 10**. Sample collection was coordinated with the air monitoring team at each of the sites. Hydraulic fracturing samples were taken on 9/11/12 at the Maury Pad. The makeup water sample was retrieved from an on-site holding tank and the hydraulic fracturing fluid sample was taken after the blender, prior to entering the Maury Pad well. Sampling at the Maury pad was coordinated with the air monitoring team.

Figure 8: Donna Pad Pit Sampling of Hydraulic Fracturing (Makeup) Water

Figure 9: Sampling Hydraulic Fracturing Fluids and Water Mixture before Entering Well

Figure 10: Sampling Location of Hydraulic Fracturing Fluids

Flowback

1. Donna Pad - WACO/ECA *(sampled 7/27/2012, 8/2/2012, 8/9/2012 and 8/30/2012)*
2. Weekley Site #1 - Stone Energy *(sampled 8/15/2012 and 8/20/2012)*
3. Consol/Noble Centralized Pits (SHL-3 and SHL-4) *(sampled 8/13/2012, 8/20/2012, 8/28/2012 and 9/17/2012)*
4. EQT Smithburg 28 *(will be sampled after monitoring well completion)*
5. Maury Site – Stone Energy *(sampled 10/2/12)*

For each site, a water sample of the fluid stream coming back up-hole was collected at the onset of well flowback. Depending upon the site operations, up to three additional water samples of the fluid stream from the well were taken during flowback and produced water phases. The point of collection depended upon the site and operating procedures in place. These samples were collected prior to entering storage facilities or after being contained in storage facilities. A composite sample was taken near the end of the flowback stage from the storage facility on-site (i.e., pit, container) at the same time the last flowback water sample was taken.

Flowback samples were collected at a condensate tank on the Donna Pad – WACO/ECA as shown in **Figure 11**. **Figure 12** shows the point-of-collection for the composite liquid and solids sample of flowback/produced water on the Donna Pad. This type of pit structure is typical among the sites visited. **Figure 13** is the sample area at the Weekley pad. The sample was taken from a separator. **Figure 14** is the Sand Hill #3 and #4 pits. A composite sample was taken from six different points (each corner and the middle of the long sides) in the pit from the Sand Hill #4 Pit (SHL-4). The six samples were combined into a composite sample, which was used to fill all sampling bottleware.

Figure 11: Flowback Sampling Point at Condensate Tanks, Donna Pad

Figure 12: Composite Flowback Stream Sample at Donna Pad Single-Lined Pit

Figure 13: Weekley Pad Sample Area – Sample taken from the nozzle (see arrow)

Figure 14: Sample area at the Sand Hill # 3 and #4 (at lower right) Pits

<u>Groundwater Monitoring</u>

1. Consol/Noble Centralized Pits – Sand Hill Location Pits SHL2, SHL3 and SHL4 *(sampled 6/4/2012, 6/7/2012, 6/19/2012 (initial sampling) and 10/31/12 and 11/112 (final))*
2. EQT Smithburg 28 *(Monitoring wells were not drilled and completed in time for inclusion in this report. The results of these wells will be included in the Water and Waste Report, Phase II.*

Please refer to **Table 6** and **Figures 15, 16 and 17** for additional information concerning the groundwater monitoring wells relative to their depths and proximity to the storage pits.

Table 6: Groundwater Monitoring Wells at Consol/Noble Centralized Pits

Site Name	Sample Date	Location Relative to Pit	Total Well Depth (ft)	Depth to Water (ft)
SHL-2, MW-1, Noble Pits	6/4/2012	up-gradient	77.02	DRY
SHL-2, MW-2, Noble Pits	6/4/2012	down-gradient	47.61	28.38
SHL-2, MW-3, Noble Pits	6/4/2012	down-gradient	56.98	44.77
SHL-2, MW-4, Noble Pits (deep)	6/19/2012	down-gradient	43.7	26.1
SHL-3, MW-1, Noble Pits	6/4/2012	up-gradient	63.70	DRY
SHL-3, MW-2, Noble Pits	6/4/2012	down-gradient	60.59	DRY
SHL-3, MW-3, Noble Pits	6/4/2012	down-gradient	61.83	DRY
SHL-3, MW-4, Noble Pits (deep)	6/19/2012	down-gradient	45.65	40.65
SHL-4, MW-1, Noble Pits	6/4/2012	up-gradient	51.4	38.7
SHL-4, MW-2, Noble Pits	6/4/2012	down-gradient	56.92	40.11
SHL-4, MW-3, Noble Pits	6/4/2012	down-gradient	46.82	39.98
SHL-2, MW-1 Noble Pits	11/1/2012	up-gradient	77.02	49.36
SHL-2, MW-2, Noble Pits	10/31/2012	down-gradient	47.61	22.07
SHL-2, MW-3, Noble Pits	10/31/2012	down-gradient	56.98	44.51
SHL-2, MW-4, Noble Pits (deep)	11/1/2012	down-gradient	43.7	29.97
SHL-3, MW-1, Noble Pits	11/1/2012	up-gradient	63.70	DRY
SHL-3, MW-2, Noble Pits	11/1/2012	down-gradient	60.59	DRY
SHL-3, MW-3, Noble Pits	11/1/2012	down-gradient	61.83	DRY
SHL-3, MW-4, Noble Pits (deep)	11/1/2012	down-gradient	45.65	39.46
SHL-4, MW-1, Noble Pits	10/31/2012	up-gradient	51.4	22.22
SHL-4, MW-2, Noble Pits	10/31/2012	down-gradient	56.92	39.24
SHL-4, MW-3, Noble Pits	10/31/2012	down-gradient	46.82	28.19

Deep wells were installed a further distance downslope of the pits and are in a different aquifer.
The location of SHL-3, MW-4 (a deep well) is down-gradient from the SHL-3 pit as well.

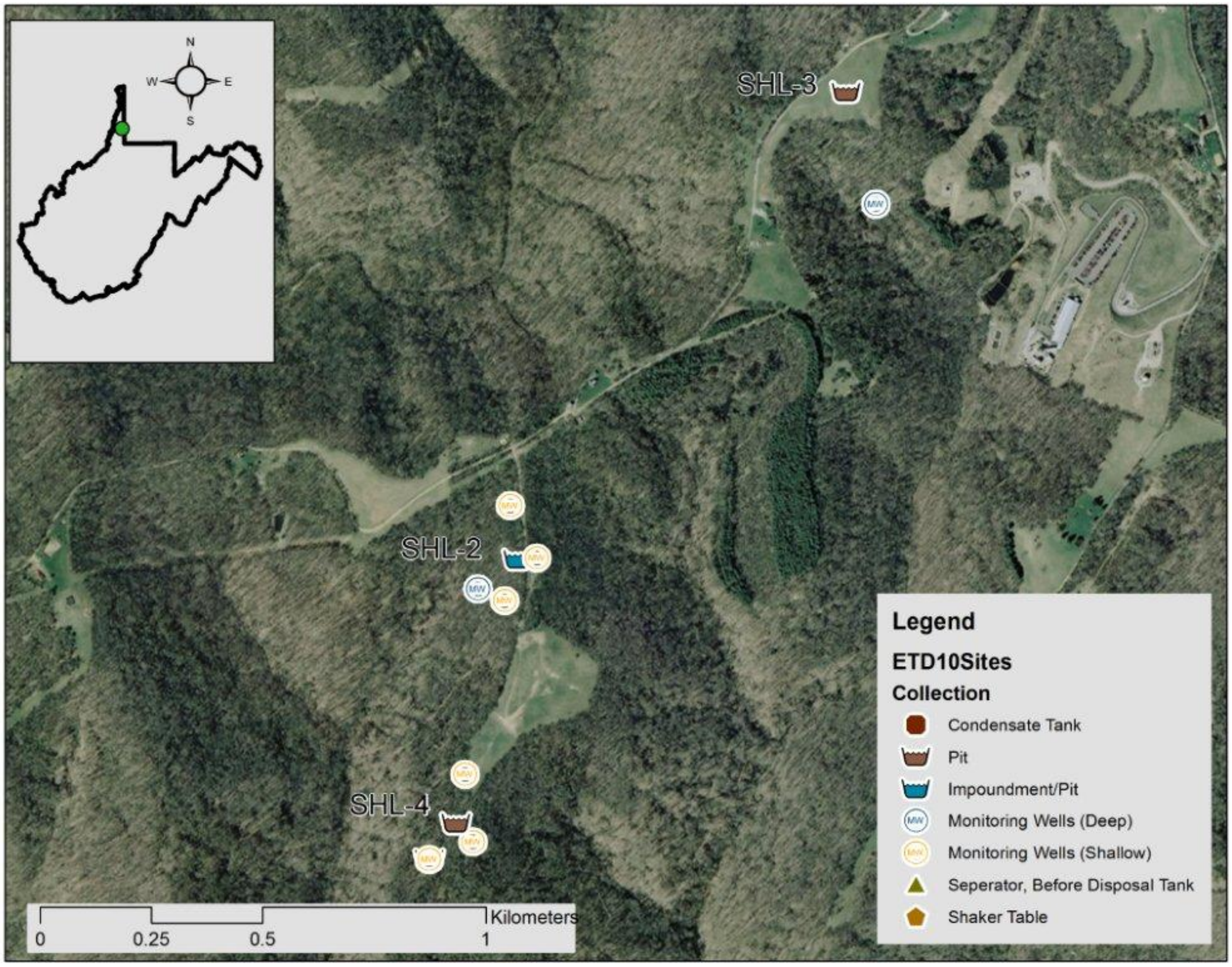

Figure 15: Location of Consol/Noble Centralized Pits

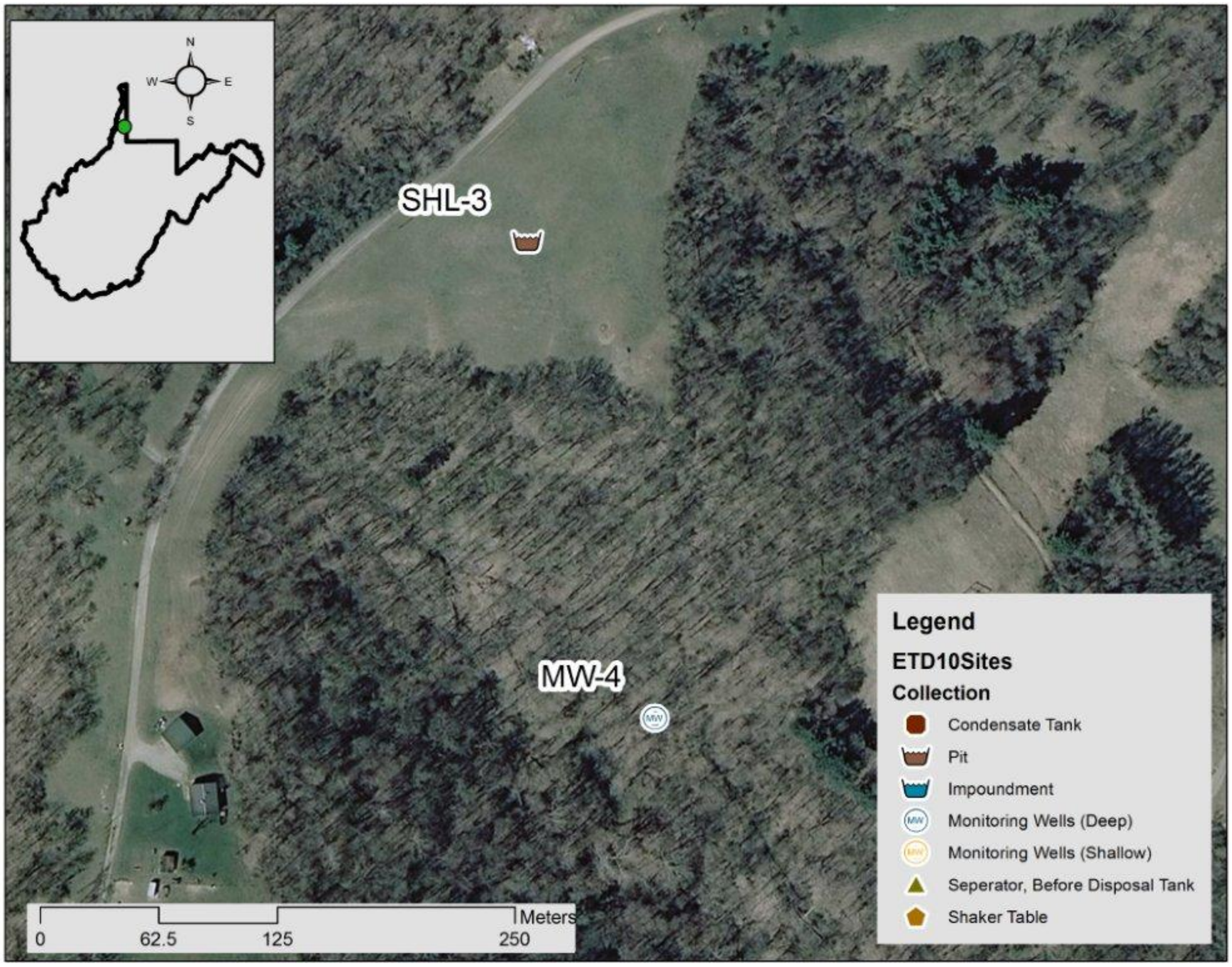

Figure 16: Consol/Noble Centralized Pit SHL3

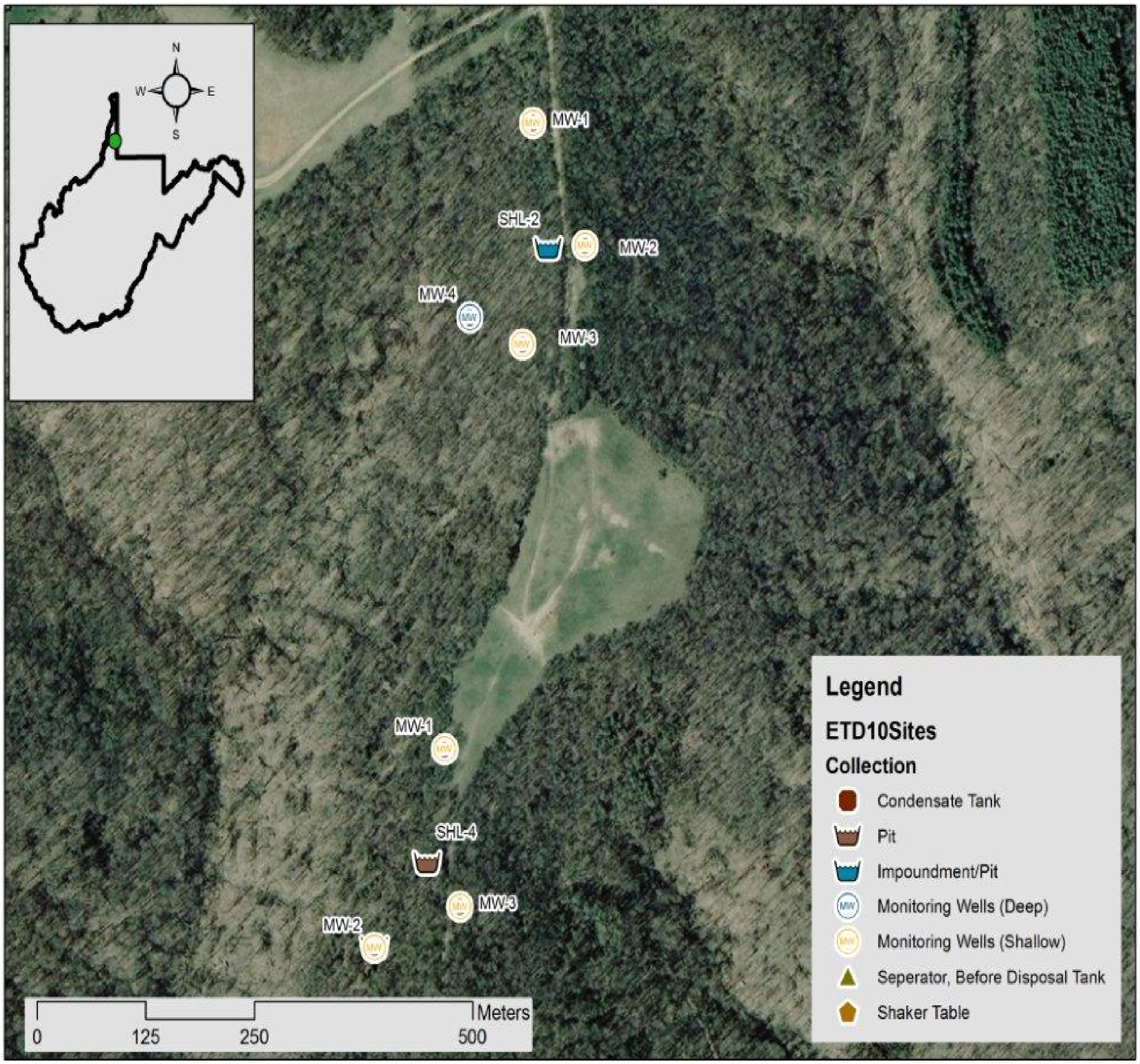

Figure 17: Consol/Noble Centralized Pits SHL2 and SHL4

Sampling at the EQT Smithburg 28 pad is planned pending the completion of monitoring wells. Due to landowner issues, progress was delayed and EQT is in the process of obtaining approvals and permits to drill the groundwater monitoring wells.

Various sampling bottles needed for groundwater sampling collection are shown in **Figure 18**. Sample collection is illustrated in **Figure 19**. Groundwater monitoring well equipment used for the low-flow sampling method (51) is shown in **Figure 20.**

Figure 18: Bottles for Typical Groundwater Sample

Figure 19: Collection of Groundwater Sample from Consol/Noble Centralized Pit SHL2

Figure 20: Low Flow Sampling at SHL3 Groundwater Monitoring Well

Field Sampling Methods

Refer to **Table 3** for corresponding information for the sub-sections below. Sample bottles were prepared by the commercial laboratory, REI Consultants (REIC), and provided to WVWRI researchers for use. An example of the REIC chain-of-custody form is attached as **Appendix C**. The Pace Analytical chain-of-custody is attached as **Appendix D**. Samples were stored according to the various EPA analytical methods and pick-ups were arranged with REIC and Pace Analytical to ensure analysis of samples within specified holding times.

<u>General Equipment List</u>

1. Decontamination materials
2. All sample containers
3. Cooler with ice

4. Photo-Ionization Detector (PID)
5. GPS unit
6. Handheld radiation alert detector (Radiation Alert Inspector EXP)
7. Field notebook, calculator and field data sheets
8. Multi-parameter water-quality meter with accompanying flow-through cell (YSI-556)
9. Calibration fluids
10. Health and safety plan and all personal protective equipment
11. Five-gallon buckets
12. Nitrile gloves
13. Tools and batteries for all equipment

Groundwater Monitoring

Specified Equipment List for Groundwater Sampling

1. Electronic interface probe for determination of liquid products present and depth-to-water
2. Adjustable rate peristaltic pump and/or standard performance PVC pump with controller
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)

Sampling Procedures for Groundwater Sampling Events

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. Equipment that was not dedicated to a specific well was decontaminated using a mild detergent free of interfering residues between sampled wells. This approaches follows EPA procedures for "Field Equipment Cleaning and Decontamination" that can be found at http://www.epa.gov/epawaste/hazard/testmethods/faq/faqs_sampl.htm.

Water was tested for radioactivity using a radiation alert detector at both the onset of purging activities and post-sampling activities. Duplicate samples were obtained for 10% of collected samples. Equipment blanks and/or field blanks were also used to ensure sample quality control. Sampling procedures were as follows:

1. The lock and cap were removed from the well casing and the headspace of the well was monitored for volatile organic compounds (VOCs) with a PID. PID data was recorded in a field book.
2. 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.
3. 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 a field book.
4. (For wells with depth-to-water 27 feet or less from the top of casing). Teflon® tubing was lowered to approximately the middle of the pre-determined screened interval. Teflon® tubing was connected to the peristaltic pump using silicon tubing and the flow-through cell with multi-meter was connected to the opposite side of the peristaltic pump.

Teflon® tubing was attached to the exit point of the flow-through cell and routed into a 5 gallon bucket to collect purge water. The pump was connected to a power source.

5. (For wells with depth-to-water greater than 27 feet from the top of casing). 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 (EC), temperature (in degrees Celsius), total dissolved solids (TDS), oxidation Salinity (Sal), and dissolved oxygen (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 5 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 3 to 5 minutes, depending 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 chain-of-custody was completed and all samples were shipped or delivered to the laboratory within specified holding times.
10. All appropriate equipment was decontaminated using a mild soap/water solution and all purge water was properly disposed of following proper EPA procedures for "Field Equipment Cleaning and Decontamination" that can be found at: http://www.epa.gov/epawaste/hazard/testmethods/faq/faqs_sampl.htm.

Water Storage for Well Development

Specified Equipment List for Sampling Freshwater Impoundments

1. Swing samplers (dippers)
2. Disposable bottles for use with swing samplers
3. Five-gallon buckets

Sampling Procedures for Freshwater Impoundments

The sample locations selected were dependent on the availability of access to the impoundment as well as the safety and well-being of the sampler. If possible, samples were taken from the inlet pipes. If the inlet pipes were not discharging water, samples were taken from the edge of the impoundment near the inflow point. Grab samples were the method employed for the impoundments. Swing samplers and/or direct method sampling via five-gallon buckets were used to obtain the sample. The following procedures were used during sample collection:

1. Sample locations were recorded using a GPS. A PID was used to check for background off-gassing of VOCs. The coordinates and PID data were recorded in a field book. A handheld radiation alert detector was also used to check for background radiation levels, and this data was also recorded in a field book.

2. A multi-parameter water-quality meter was used to determine water quality readings of pH, EC, temperature, TDS, salinity, and DO. One water quality reading was recorded during each sampling date due to limited impoundment access.
3. Samples were retrieved via the direct sampling method by using a swing sampler with a disposable bottle or a five-gallon bucket. Handheld radiation alert detector, PID, and water quality readings were determined and recorded.
4. If additional water was needed to fill all sample containers, a second sample was obtained using step 3.
5. Sample bottles were filled in the order of volatile organic compound bottles first, followed by semi-volatile organic compounds, inorganics, and other unfiltered samples.
6. Samples were immediately cooled and prevented from exposure to sunlight by placing them on ice in a dedicated sample cooler. A chain of custody was completed and all samples were shipped or delivered to the laboratory within specified holding times.
7. All appropriate equipment was decontaminated after each use.

Moving Waste Stream

Specified Equipment List for Sampling Vertical Drilling Operations

1. Sediment samplers (sludge judge)
2. Five-gallon bucket

Sampling Procedures for Vertical Drilling Operations

Drilling produced muds and cuttings were collected once per week for three weeks from a shaker table and a final sample was taken six weeks after the third sample. Both liquid and solid phase wastes were sampled. The WVDNR A site was only sampled once due to late inclusion into the study.

Shaker Table Samples

1. Sample locations were recorded using a GPS. A PID was used to check for background off-gassing of VOC's. The coordinates and PID data were recorded in a field book. A handheld radiation alert detector was also used to check for background radiation levels, and this data was also recorded in a field book.
2. A liquid grab sample was obtained using a swing sampler or five-gallon bucket. Water quality, PID and radiation alert detector readings were taken and recorded.
3. Liquid samples were filled in the order of volatile organic compound bottles first, followed by semi-volatile organic compounds, inorganics, and other unfiltered samples.
4. Solid samples were obtained using the grab sample method and placed in laboratory approved sample bottles. PID and radiation alert detector head space readings were taken and recorded.
5. Samples were immediately cooled and prevented from exposure to sunlight by placing them on ice in a dedicated sample cooler. A chain-of-custody was completed and all samples were shipped or delivered to the laboratory within specified holding times.
6. All appropriate equipment was decontaminated after each use.

Pit Samples

The pit samples were grab samples. Swing samplers and/or direct method sampling via five-gallon buckets were used. Sample locations were dependent on the accessibility of the pits and the safety and well-being of the sample handler.

1. Sample locations were recorded using a GPS. A PID was used to check for background off-gassing of VOC's. The coordinates and PID data were recorded in a field book. A handheld radiation alert detector was also used to check for background radiation levels, and this data was also recorded in a field book.

2. Due to site access issues, swing samplers and/or a five-gallon bucket were used to obtain the sample from the edge of the pit. Radiation alert detector, water quality, and PID readings were taken and recorded.
3. Step 2 was repeated (if needed) to obtain another sample and fill all sample bottles. All remaining water was properly disposed of.
4. Liquid samples were filled in the order of VOC bottles first, followed by semi-volatile organic compounds, inorganics, and other unfiltered samples.
5. Using a sludge judge sediment sampler, a solid sample was collected from the bottom of a pit at the same location as the liquid sample and placed in laboratory-approved sample bottles. The solid sample was collected from one point; however, this sample approximated a composite sample, as all of the wells flowed into the pit. PID and radiation alert detector head space readings were also recorded from the sludge sample.
6. Sample bottles were filled in the order of VOC bottles first, followed by semi-volatile organic compounds and inorganics.
7. Samples were immediately cooled and prevented from exposure to sunlight by placing them on ice in a dedicated sample cooler. A chain-of-custody was completed and all samples were shipped or delivered to the laboratory within established holding times.
8. All appropriate equipment was decontaminated after each use.

Sampling Procedures for Horizontal Drilling Operations

The sampling procedures for horizontal drilling operations followed the same direct methods as the vertical drilling operations.

Sampling Procedures for Hydraulic Fracturing

Hydraulic fracturing fluid (chemical mixture only) was not sampled because a sample could not be obtained immediately after the individual chemicals were mixed together. The chemicals were mixed with water before a sample could be obtained. Hydraulic fracturing water (makeup water) was sampled once from a pit (Donna site) and once from a tank (Maury site). Methods from the "sampling procedures for freshwater impoundments" listed above were followed for the pit sample. The tank sample was obtained using a five-gallon bucket. Water quality, radioactivity, and VOC readings were monitored and recorded in a field book at each site.

The combined hydraulic fracturing fluid and freshwater mixture was sampled once. The sample was obtained in a five-gallon bucket from a sampling port on the blender truck. Water quality, radioactivity, and VOC readings were monitored and recorded in a field book. All methods for sampling during hydraulic fracturing operations (such as filling bottle ware, sample handling, and decontamination) followed proper methods and protocols as aforementioned in this document.

Waste Storage

Flowback Stream

The flowback stream was sampled at various locations during the well production and development process. Sample location was dependent upon site accessibility. Methods ranged from obtaining grab samples at a pit to sampling ports on separators and condensate tanks. All methods for sampling the waste storage (such as filling bottle ware, sample handling, and decontamination) followed proper methods and protocols as aforementioned in this document.

Analytical Methods

Standard operating procedures are designed to optimize the accuracy and representativeness of water chemistry data. WVWRI technicians 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 chain-of-custody requirements were adhered to.

Organics and Inorganics

Samples were stored as required by the various EPA analytical methods and pick-ups arranged with the certified laboratory, REIC Consultants, within specified holding times. An example of the chain-of-custody form used by REI Consultants is attached as **Appendix C**. All sample analyses and laboratory activities were performed based on REI Consultants standard operating procedures and EPA sampling and analyses protocols. **Table 7** provides an overview of REI Consultants quality assurance and quality control (QA/QC) procedures. This information is excerpted from the REI Consultants Quality Manual (52). 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. REI Consultants were 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 by the various EPA analytical methods and pick-ups arranged with the certified laboratory, Pace Analytical, within specified holding times. An example of the chain-of-custody form used by Pace Analytical is attached as **Appendix D**. All sample analyses and laboratory activities were performed based on Pace Analytical SOPs and EPA sampling and analyses protocols. **Table 8** provides an overview of Pace Analytical quality assurance and quality control (QA/QC) procedures. This information is excerpted from the Pace Analytical Quality Manual (53). QC 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 7: 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 8: 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 written in field record books and transferred to an electronic data file located on the WVWRI shared server once field technicians returned to the office. Times, dates and personnel involved in data collection were also recorded in field record books and transferred to the electronic data file. Copies of chain-of-custody forms for each set of samples sent to REI Consultants 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 well development was recorded in field record books. As needed, the data transferred to the electronic data file was reviewed and reported to the WVDEP as part of the monthly progress updates. Photographs were used to assist with documenting field activities and conditions. Data collected in the field and analytical results obtained from REI Consultants 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 include unexplained spikes in data or unexplained zero/negative readings.

Reference of field and analytical laboratory results to other commercial and industrial activities were made as a basis for comparison and understanding of horizontal gas well development impacts on the surrounding environment. Based on the data analysis, potential health concerns or risks associated with the well development occurring at that site were noted and are included as part of the Results section of this report. Long-term monitoring recommendations are included as part of the final report to WVDEP as well.

Data Analysis, Results and Comparison with Water Quality Standards

The study sought to:

1. Characterize drilling muds and cuttings and identify pollutants.
2. Compare hydraulic fracturing fluids with flowback and identify pollutants.
3. Identify whether the groundwater monitoring wells indicate contamination of surrounding groundwater as a result of impoundment leakage.

In the following analysis all determinations below the detection limit were assigned a value of zero.

Drilling Muds and Cuttings Characterization and Pollutant Identification

Drilling muds were analyzed as liquids while drill cuttings were analyzed as solids. With the exception of arsenic, mercury, nitrate and selenium, the average concentrations of the primary and secondary drinking water parameters in drilling mud were in excess of all of the inorganic drinking water standards as shown in **Table 9**. They also exceeded the drinking water standard for benzene and surfactant (MBAS) as illustrated in **Table 10**. Drilling muds contained very high concentrations of sodium, potassium and chloride. TPH (diesel range) was present in all drilling muds. Concentrations ranged from 23 to 315 mg/L.

Air monitoring requirements, with respect to the Occupational Safety and Health Administration (OSHA), vary depending according to materials and exposures. Monitoring was based on the requirements of Hazardous Waste Operations and Emergency Response Regulations (29 CFR 1910.120(h)) and the United States Environmental Protection Agency Standard Operating Safety Guide (Publication 9285.1-03). Nearly all drilling mud and drill cutting samples were higher than background with regard to radioactivity. The relation between these field readings and regulatory standards is not evident as shown in **Table 11**. Radiation monitoring was conducted utilizing an Inspector EXP Geiger Mueller with an external pancake probe. The Inspector EXP is capable of detecting alpha, beta and gamma radiation as required by the previously referenced regulations. The meter determined background levels of radiation in milliroentgens per hour (mrem/hr). Further, samples were screened for potential radioactivity for possible worker exposure and compared to background levels. Alpha, beta and gamma radiation were included in background determinations since readings were taken in the open air. However, readings from the samples in containers would most likely only represent gamma radiation since alpha and beta typically cannot escape the sample container.

Radioactivity readings were obtained for 46 of the 51 samples obtained. Background levels of radiation ranged from 0.005 mrem/hr to 0.022 mrem/hr. Sample levels of radiation ranged from 0.007 mrem/hr to 0.018 mrem/hr. The standard for contamination is typically twice background. A review of the individual background levels of radiation indicated that criterion was not exceeded in any sample. One sample was exactly twice the background level of radiation for that site but less than some of the other background levels from previous readings. The acceptable annual dose of radiation for individuals working with radioactive materials is 5,000 mrem. Based on the readings obtained from the field instrumentation, appropriate sampling techniques and Personal Protective Equipment (PPE) would minimize exposure of sampling staff to radioactivity.

Table 12 includes radioactivity results received to date for drilling mud samples and one flowback solids sample. In the absences of standards for semi-solid to solid materials, the drinking water standards for the radioactive parameters were used. Only the standard for gross alpha radiation was exceeded. According to EPA (http://www.epa.gov/radiation/understand/alpha.html):

The health effects of alpha particles depend heavily upon how exposure takes place. External exposure (external to the body) is of far less concern than internal exposure because alpha particles lack the energy to penetrate the outer dead layer of skin. However, if alpha emitters have been inhaled, ingested (swallowed), or absorbed into the blood stream, sensitive living tissue can be exposed to alpha radiation. The resulting biological damage increases the risk of cancer; in particular, alpha radiation is known to cause lung cancer in humans when alpha emitters are inhaled. The greatest exposure to alpha radiation for average citizens comes from the inhalation of radon and its decay products, several of which also emit potent alpha radiation.

Hydraulic Fracturing Fluids and Flowback Comparison and Pollutant Identification

Three types of liquids used in the horizontal drilling and hydraulic fracturing processes were evaluated to determine if drinking water standards were exceeded: *Makeup (MU) water* consists of varying proportions of fresh water and recycled flowback water that is mixed with chemicals to make *hydraulic fracturing fluids (HFF)* which are injected into the formation along with a proppant, and *flowback (FB)* is the fluid which returns via the wellhead to the surface after hydraulic fracturing is complete.

Table 13 compares these fluids with regard to their drinking water exceedances. All flowback samples exceeded drinking water standards for barium, chloride, iron, manganese, total dissolved solids and radium 226. Eighty-percent of flowback samples exceeded drinking water standards for gross alpha, beta and radium 228. The organic parameters benzene, toluene, MBAS and styrene exceeded drinking water standards at rates of 77, 23, 15 and 8%, respectively. Selenium exceeded the drinking water standard in 23% of flowback samples while chromium and lead exceeded their drinking water standards in 8% of the flowback samples. Overall, drinking water standards were exceeded for eighteen parameters in the flowback samples.

Six parameters in the hydraulic fracturing fluids exceeded drinking water standards. The hydraulic fracturing fluids in this case consisted of diluted flowback which may explain the presence of contaminants such as barium, chloride, iron, manganese and benzene albeit in lower concentrations than found in flowback. The results suggest that many of the exceedances are the result of contaminants acquired while the fluids are in contact with the Marcellus Formation.

Four freshwater (makeup water) samples, two hydraulic fracturing fluids and thirteen flowback samples were analyzed. Water quality of water and waste streams deteriorated as gas well development stages progressed. The hydraulic fracturing fluid samples included two of makeup water only and two of the fully formulated hydraulic fracturing water for injection. One hydraulic fracturing fluid sample contained benzene in measurable quantities while ten of thirteen flowback samples contained benzene in concentrations in excess of the primary drinking water standard of 5 µg/L.

Both hydraulic fracturing fluids, all of the drilling muds and flowback samples contained detectable TPH (diesel range); but, there is no drinking water standard for TPH (diesel range). It is important to note, this determination, also known as diesel range organics (DRO) does not indicate that diesel is present. Rather, it indicates that hydrocarbons in the range of C11 to C28 are present. This could include diesel or common hydraulic fracturing fluid additives such as guar gum, an extract of the guar bean used to increase the viscosity of the hydraulic fracturing fluid to efficiently deliver the proppant into the formation.

Figure 21 indicates that there is no correlation between benzene and TPH (diesel range). It also indicates that for most of the flowback samples, benzene exceeded the primary drinking water standard. Only one drilling mud sample and one hydraulic fracturing fluid sample contained detectable benzene while all but one hydraulic fracturing fluid/drilling muds sample contained detectable TPH (diesel range). This suggests that the source of benzene is likely in the formation, rather than the hydraulic fracturing fluid. All flowback samples contained high ionic concentrations including sodium, chloride, bromide and barium. **Table 9** summarizes the average values of the inorganic constituents and **Table 10** summarizes the average organic concentrations.

Flowback was tested for radioactivity. The SDWA lists four radioactivity parameters under its primary drinking water standards. Our results were compared with the applicable SDWA standards. **Table 14** indicates that flowback water exceeded the SDWA standard with respect to alpha radiation and radium (226 and 228).

Impoundment Integrity

The impoundments initially contained freshwater which was a mixture of Ohio River water and treated mine drainage. Water quality of the freshwater impoundment is indicated in **Table 9** under the column labeled "FW impound." It contained no constituents in excess of SDWA limits. There was no evidence of significant leakage of flowback from the impoundments. Nitrate and lead were detected in monitoring wells in excess of primary drinking water standards. The concentration of nitrite exceeded the MCL (1 mg/L) in three of five shallow monitoring wells by a maximum of 0.47 mg/L. However, while nitrate exceeded the primary MCL in samples taken after conversion of the impoundments to accept flowback, the single lead exceedance occurred prior to conversion as shown in **Table 9**. As is common in West Virginia wells, iron, aluminum and manganese exceed the secondary drinking water standards in both shallow and deep wells before and after conversion of the impoundments from holding fresh water to flowback (54). After conversion to storage of flowback water, the groundwater monitoring wells around the 'impoundments' did not, however, indicate elevated chloride, bromide or barium concentrations as would be expected if flowback leakage occurred in significant quantities. In addition, while flowback contains measurable benzene and TPH (diesel), neither was detected in the monitoring wells. See Table 10. One of the deep monitoring wells exceeded the primary drinking water level for gross alpha radiation. However, this occurred while the impoundment was holding freshwater. See **Table 15**.

Figure 22 illustrates the relationship between chloride and bromide appears to be a good indicator of flowback. All of the flowback samples were aligned along the high end of the trendline while hydraulic fracturing fluids (and their makeup water) were aligned along the lower end of the same curve indicating lower concentrations of both chloride and bromide. This is a log-log graph and zero values cannot be plotted so coordinates with non-detect levels of bromide or chloride do not appear. While the chloride and bromide concentrations were high in drilling mud, its trendline deviated from the flowback and hydraulic fracturing fluid trendlines mainly due to the higher chloride content of drilling mud relative to bromide. This may be due to the common use of sodium chloride in drilling mud. In contrast, the water from the freshwater impoundments and their groundwater monitoring wells contained almost no bromide and little chloride. Refer to the lower left hand corner of **Figure 22**. Samples of Monongahela River water from another study are included for comparison. They also appear in the lower left hand corner and the trendline is essentially horizontal. These results suggest that the high bromide concentrations in flowback water are acquired by salt dissolution within the Marcellus formation. The alignment of both hydraulic fracturing fluid and makeup water along the Bromide/Chloride (Br/Cl) trendline suggests that the makeup water includes some amount of recycled flowback.

Three centralized impoundments were sampled before and after they were converted from freshwater storage to flowback storage. In addition, their respective monitoring wells were sampled before and after the conversion. The barium/chloride (Ba/Cl) ratios were plotted for impoundment water and the monitoring wells. Barium was used in this case because it is, like bromide, a good marker for flowback water. The Ba/Cl-relationship clearly discriminated between flowback and freshwater. **Figure 23** shows the clustering of groundwater samples at the lower left corner of the figure along with the freshwater impoundment samples (the three samples overlay each other). Flowback, on the other hand trends far to the upper right with much higher concentrations of both barium and chloride. Note that the highest monitoring well values of both barium and chloride occurred when the impoundments were used for freshwater storage. Only one of fourteen monitoring well samples exceeded a drinking water standard. That sample was for a deep monitoring well during the period when the impoundment was used for freshwater storage. The chloride concentration was 348 mg/L while bromide was below detect and barium was 0.28 mg/L. The monitoring wells thus showed no evidence of receiving leakage from the impoundments. Most significantly, no evidence of flowback leakage was detected in the impoundment monitoring. While the monitoring wells detected no contaminants it is not clear that the monitoring interval of 146 days was sufficient to capture any leakage from the impoundments. A longer sampling is suggested with, perhaps, aquifer permeability testing.

Table 9: Average Concentrations of Inorganic Parameters

	MDL	units	DW std	MCL	FW impound	MWS FW	MWS FB	MWD FW	MWD FB	Drilling mud (vert sec)	HF fluid	FB
As	0.007	mg/L	a	0.01	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00
Ba	0.002	mg/L	a	2	0.05	0.08	0.08	0.58	0.26	12.81	5.70	514.68
Cr	0.001	mg/L	a	0.1	0.00	0.00	0.00	0.04	0.00	2.60	0.00	0.03
Hg	0.0001	mg/L	a	0.002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	0.02	mg/L	a	10	0.03	0.37	1.07	0.07	0.13	3.18	0.00	0.02
Nitrite	0.05	mg/L	a	1	0.15	0.09	1.10	0.04	0.00	4.90	0.00	0.06
Pb	0.003	mg/L	a	0.015	0.00	0.00	0.00	0.02	0.00	1.15	0.00	0.01
Se	0.008	mg/L	a	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Ag	0.001	mg/L	b	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al	0.04	mg/L	b	0.05	0.0	0.8	2.7	15.0	9.8	1208.0	0.1	1.4
Cl	0.1	mg/L	b	250	22.8	2.8	5.9	181.7	5.7	14640.0	4712.3	42683.1
Fe	0.01	mg/L	b	0.3	0.0	2.0	3.2	24.8	14.1	2192.0	9.1	67.1
Mn	0.001	mg/L	b	0.05	0.0	0.2	0.1	2.2	1.5	22.3	0.6	5.5
pH		mg/L	b	6.5	7.01	6.66	6.47	6.83	7.20	9.24	7.17	6.61
SO4	1	mg/L	b	250	62.2	28.2	28.8	41.6	33.6	1567.7	65.7	38.7
TDS	5	mg/L	b	500	241.0	233.6	175.2	408.0	259.0	34550.0	9369.5	74710.8
Zn	0.003	mg/L	b	5	0.0	0.0	0.0	0.1	0.1	5.9	0.5	0.1
Br	0.05	mg/L			0.06	0.00	0.00	0.05	0.00	22.50	54.60	465.96
Ca	0.05	mg/L			36.78	59.24	51.82	86.80	101.00	1842.50	528.75	7269.23
K	0.03	mg/L			2.54	1.69	2.25	6.12	6.10	8791.50	29.66	260.06
Mg	0.05	mg/L			6.96	12.68	9.16	18.40	25.80	394.71	68.69	835.00
Na	0.3	mg/L			20.47	4.68	7.08	13.00	10.01	2858.50	2202.50	26202.31
Ni	0.002	mg/L			0.00	0.00	0.00	0.03	0.03	2.19	0.00	0.00
S	0.05	mg/L			23.10	12.91	10.84	14.75	14.55	992.50	19.74	36.16
Sr	0.001	mg/L			0.20	0.23	0.17	0.42	0.44	40.15	62.63	1365.38
alk CO3	1	mg/L			109.78	203.20	103.88	199.00	210.50	1705.00	111.95	187.23
alk HCO3	1	mg/L			0.00	0.00	0.00	0.00	0.00	379.33	0.00	0.00
alk tot	1	mg/L			109.78	203.20	103.88	199.00	210.50	3127.50	111.95	187.23
EC	NA	µS/cm			428.75	382.60	302.00	762.00	470.00	59550.00	15680.00	107861.54
Hardness	1	mg/L			120.35	200.20	478.00	332.00	358.50	4973.33	1600.00	19588.15
PO4	0.02	mg/L			0.01	0.10	0.00	0.46	0.00	15.53	2.94	8.03
TSS	5	mg/L			2.00	170.20	110.17	2720.00	284.00	47300.00	118.25	211.85

- Average concentrations of inorganic parameters tested in Summer and Fall of 2012
- Shaded cells indicate drinking water standard exceeded.
- MDL=minimum detection limit
- DW=SDWA drinking water standard: a=primary b=secondary FW=freshwater
- MW=impoundment monitoring well: S=shallow, D=deep, FB=flowback, HF=hydraulic fracturing

Table 10: Average Concentrations of Organic Parameters

	MDL	units	DW std	MCL	FW impound	MWS FW	MWS FB	MWD FW	MWD FB	Drilling mud (vert sec)	HF fluid	FB
Benzene	0.42	µg/L	a	5	0.00	0.00	0.00	0.00	0.00	40.25	7.35	149.59
Ethylbenze	0.43	µg/L	a	700	0.00	0.00	0.00	0.00	0.00	9.55	2.18	52.52
Styrene	0.38	µg/L	a	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.85
Toluene	0.42	µg/L	a	1000	0.00	0.00	0.77	0.30	0.00	80.43	22.08	621.71
Xylene (m,p)	0.9	µg/L	a	10000	0.00	0.00	0.00	0.00	0.00	87.50	41.00	698.71
Xylene (o)	0.41	µg/L	a	10000	0.00	0.00	0.00	0.00	0.00	22.20	8.75	142.27
MBAS	0.1	mg/L	b	0.5	0.08	0.00	0.00	0.00	0.00	67.68	0.00	0.19
COD	4	mg/L			14.25	0.00	0.00	0.00	7.00	5875.00	539.50	1420.08
Ethane	NA	µl/L			0.00	0.00	0.00	0.00	0.00		0.00	571.19
Methane	NA	µl/L			0.00	0.00	0.00	0.00	0.00		88.50	3420.48
O&G	2	mg/L			0.00	0.46	1.18	3.80	2.40	53.30	5.95	63.52
propane	NA	µg/L			0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.92
Tetrachloroethene	0.49	µg/L			0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00
TOC	0.2	mg/L			2.51	0.58	1.70	0.34	1.22	2362.50	105.36	176.35
TPH (Diesel)	0.067	mg/L			0.00	0.00	0.00	0.00	0.00	130.23	38.71	60.56
TPH (Gas)	0.25	mg/L			0.00	0.00	0.00	0.00	0.00	3.85	1.58	25.75
TPH (Oil)	0.053	mg/L			0.08	0.00	0.00	0.00	0.00	98.45	3.27	10.23

- Average concentrations of organic parameters testing in Summer and Fall of 2012
- Shaded cells indicate drinking water standard exceeded.
- MDL=minimum detection limit
- DW=SDWA drinking water standard: a=primary b=secondary FW=freshwater
- MW=impoundment monitoring well: S=shallow, D=deep, FB=flowback, HF=hydraulic fracturing

Table 11: Field Radiation Readings for Drill Cuttings and Drilling Muds

Drill cuttings (solids) Drilling Mud (liquid) Mixture (slurry)	Radioactivity (mrem/hr) Background	Radioactivity (mrem/hr) Sample
ST2 at 13:00 (solids)	0.008	0.009
ST1-1 at 11:00 (solids)	0.013	0.013
ST1-2 at 10:30 (solids)	0.011	0.016
ST1-3 at 11:00 (solid)	0.005	0.009
ST1-4 at 1:30 (solids)	0.008	0.015
ST1-1 at 11:00 (liquid)	0.013	0.013
ST1-2 at 10:30 (liquid)	0.011	0.016
ST1-3 at 11:00 (liquid)	0.005	0.009
ST1-4 at 1:30 (liquid)	0.008	0.009
ST2 a6t 13:00 (slurry)	0.008	0.009

The Inspector EXP displays current radiation levels in millirem per hour (mrem/hr), where rem = roentgen equivalent man (55).

- Radiation readings taken with handheld field alert detector.
- Shaded cells indicate that the samples exceeded background levels.

Table 12: Radioactivity Results of Drilling Muds and Flowback Solids Samples

Solids	units	Drilling mud ST 1-1 8/8/2012	ST 1-2 8/15/2012	ST 1-3 8/22/2012	ST 1-4 10/2/2012	DNR-ST-3-1 (Solids) 10/25/2012	average	Flowback solids Donna Pit-C (Solids) 8/30/2012
Gross Alpha	pCi/g	16.5	8.93	9.23	28.3	23.8	17.35	65.1
Gross Beta	pCi/g	30.1	27.9	26.1	17.3	24.7	25.22	28.8
Potassium-40	pCi/g	30.388	29.745	31.758	11.471	19.202	24.51	19.691
Radium-226	pCi/g	0.95	1.284	1.192	1.346	1.308	1.22	26.953
Radium-228	pCi/g	1.208	1.929	1.737	0.715	1.08	1.33	5.123
Thorium-228	pCi/g	1.25	1.91	1.63	0.694	0.647	1.23	2.33
Thorium-230	pCi/g	0.727	1.06	1.32	0.55	1.38	1.01	1.1
Thorium-232	pCi/g	0.66	0.99	1.61	0.55	0.68	0.90	1.11
Uranium-234	pCi/g	0.75	1.08	0.996	0.548	1.16	0.91	1.08
Uranium-235	pCi/g	0.036	0.036	0.047	0.036	0.014	0.03	0.074
Uranium-238	pCi/g	0.714	0.988	1.08	0.436	1.05	0.85	0.694

- Shaded cells indicate SDWA MCL was exceeded.

Table 13: Exceedances of Drinking Water Standards

Horizontal Drilling and Hydraulic Fracturing Fluids

- makeup water (MU)
- hydraulic fracturing fluid (HFF)
- flowback (FB)

Water Quality Parameters

- Inorganic (I)
- Organic (O)
- Radioactive (R)

The latter determinations were only available for five flowback samples.

type		drinking water std.*	% exceedances of drinking water standard		
			MU, n=4	HFF, n=2	FB, n=**
I	Ba	a	0%	100%	100%
I	Cl	b	0%	100%	100%
I	Fe	b	0%	100%	100%
I	Mn	b	0%	100%	100%
I	TDS	b	0%	100%	100%
R	Radium-226	a			100%
R	Gross Alpha	a			80%
R	Gross Beta	a			80%
R	Radium-228	a			80%
O	Benzene	a	0%	50%	77%
I	pH	b	50%	0%	38%
I	Al	b	0%	0%	31%
I	Se	a	0%	0%	23%
O	Toluene	a	0%	0%	23%
O	MBAS	b	0%	0%	15%
I	Cr	a	0%	0%	8%
I	Pb	a	0%	0%	8%
O	Styrene	a	0%	0%	8%
I	As	a	0%	0%	0%
I	Hg	a	0%	0%	0%
I	Nitrate	a	0%	0%	0%
I	Nitrite	a	0%	0%	0%
I	Ag	b	0%	0%	0%
I	SO4	b	0%	0%	0%
I	Zn	b	0%	0%	0%
O	Ethylbenze	a	0%	0%	0%
O	Xylene (m,p)	a	0%	0%	0%
O	Xylene (o)	a	0%	0%	0%
R	Uranium-238	a			0%
R	Uranium-238	a			0%

* =primary drinking water standard

* =secondary drinking water standard

** n=5, Radioactive parameters

** n=13, organic and inorganic parameters

Table 14: Summary of Radioactive Determinations from Flowback Liquids Samples

parameter	reported units	MCL	MCL units	FB,FS-1 (SHL-3) 8/13/2012	FB,FS 2 (SHL-3) 8/20/2012	FB,FS-3 (SHL-3) 8/28/2012	FB,FS Final (SHL-3) 9/17/2012	FB,Comp. (SHL-4) 9/17/2012
Gross Alpha	pCi/L	15	pCi/L	8.69	527	372	965	184
Gross Beta	pCi/L	4	mr/yr	34	317	138	226	67.8
Lead-210	pCi/L			-62.3	NR	NR	-46.4	-258
Radium-226	pCi/L	5	pCi/L	29.6	1,194	15.4	397	154
Radium-228	pCi/L	5	pCi/L	4.99	216	53.5	132	66.5
Thorium-228	pCi/L			2.35	0.3	0.595	2.24	0.952
Thorium-230	pCi/L			0.411	9.37	0.846	0	0.032
Thorium-232	pCi/L			0.375	-0.008	0	-0.009	0.006
Uranium-238	pCi/L	30	µg/L	1.22	-0.022	0.356	0.097	0.042
Potassium-40	pCi/L			52.8	221	-11.596	6.82	43.2

- Shaded cells indicate SDWA MCL was exceeded.

Table 15: Summary of Radioactive Determinations from Groundwater Monitoring Wells

Liquids	units	SDWA MCL	MCL units	MW (shallow) SHL-2, MW-2, 6/4/2012	SHL-2, MW-3, 6/4/2012	SHL-4, MW-1, 6/4/2012	SHL-4, MW-2, 6/4/2012	SHL-4, MW-3, 6/4/2012	average
Gross Alpha	pCi/L	15	pCi/L	1.14	-0.253	3.17	0.214	1.08	1.07
Gross Beta	pCi/L	50	pCi/L	1.8	0.715	3.32	0.649	1.82	1.66
Lead-210	pCi/L			216	-54.4	334	512	746	351
Radium-226	pCi/L	5	pCi/L	0.646	0.0553	0.229	0.167	0.411	0.30
Radium-228	pCi/L	5	pCi/L	0.637	0.407	0.835	0.283	0.748	0.58
Thorium-228	pCi/L			0.142	0.008	0.538	0.223	-0.023	0.18
Thorium-230	pCi/L			-0.029	-0.003	0.29	0.01	0.008	0.06
Thorium-232	pCi/L			0.17	0.006	0.506	0.069	-0.01	0.15
Uranium-238	pCi/L	30	µg/L	0.456	0.19	0.53	0.441	0.531	0.43
Uranium-238	µg/L	30	µg/L	0.68	0.28	0.79	0.66	0.79	0.64
Potassium-40	pCi/L			-1.36	-6.23	-32.5	-25.2	-30.8	-19.22

Liquids	units	SDWA MCL	MCL units	MW (deep) SHL-2-MW-4, 6/19/2012	SHL-3-MW-4, 6/19/2012	average
Gross Alpha	pCi/L	15	pCi/L	37.8	11.6	24.7
Gross Beta	pCi/L	50	pCi/L	18.6	6.73	12.665
Lead-210	pCi/L			-1,170	-1,050	-1,110
Radium-226	pCi/L	5	pCi/L	2.82	4.74	3.78
Radium-228	pCi/L	5	pCi/L	0.466	0.679	0.5725
Thorium-228	pCi/L			0.485	1.02	0.7525
Thorium-230	pCi/L			0.029	0.133	0.081
Thorium-232	pCi/L			0.226	0.521	0.3735
Uranium-238	pCi/L	30	µg/L	0.197	0.659	0.428
Uranium-238	µg/L	30	µg/L	0.29	0.98	0.64
Potassium-40	pCi/L			13.2	105	59.1

Liquids	units	SDWA MCL	MCL units	flowback FS 2, Noble Pits (SHL-3) 8/20/2012	FS-3, Noble Pits (SHL-3) 8/28/2012	FS Final, Noble Pits (SHL-3) 9/17/2012	SHL-4 Composite, Noble Pits (SHL-9/17/2012	FS-1, Weekly Pad 8/15/2012	average
Gross Alpha	pCi/L	15	pCi/L	8.69	527	372	965	184	411.338
Gross Beta	pCi/L	50	pCi/L	34	317	138	226	67.8	156.56
Lead-210	pCi/L			-62.3	NR	NR	-46.4	-258	-122.233333
Radium-226	pCi/L	5	pCi/L	29.6	1,194	15.4	397	154	358
Radium-228	pCi/L	5	pCi/L	4.99	216	53.5	132	66.5	94.598
Thorium-228	pCi/L			2.35	0.3	0.595	2.24	0.952	1.2874
Thorium-230	pCi/L			0.411	9.37	0.846	0	0.032	2.1318
Thorium-232	pCi/L			0.375	-0.008	0	-0.009	0.006	0.0728
Uranium-238	pCi/L	30	µg/L	1.22	-0.022	0.356	0.097	0.042	0.3386
Uranium-238	µg/L	30	µg/L	1.82	-0.03	0.53	0.14	0.06	0.51
Potassium-40	pCi/L			52.8	221	-11.596	6.82	43.2	62.4448

- Shaded cells indicate SDWA MCL was exceeded.
- Radioactive results from flowback samples are included for comparison purposes.

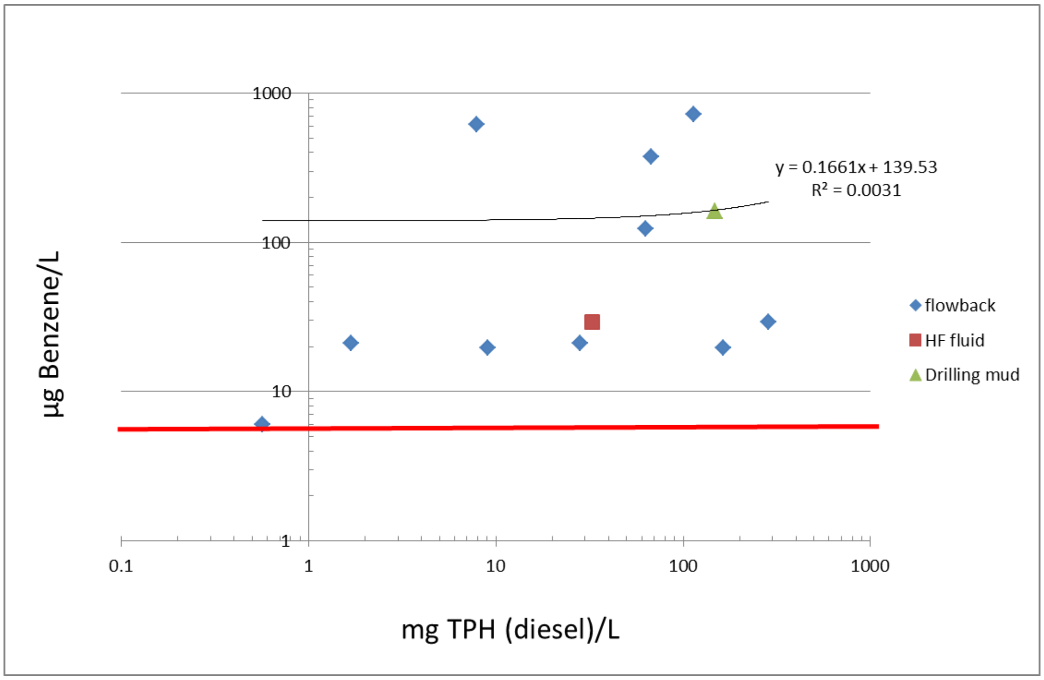

Figure 21: Relationship between TPH and Benzene

- The relationship between TPH (diesel range) and benzene is plotted for all samples.
- Note this is a log-log plot and zero (non-detect) values are not plotted.
- The red, horizontal line is the primary drinking water limit for benzene.

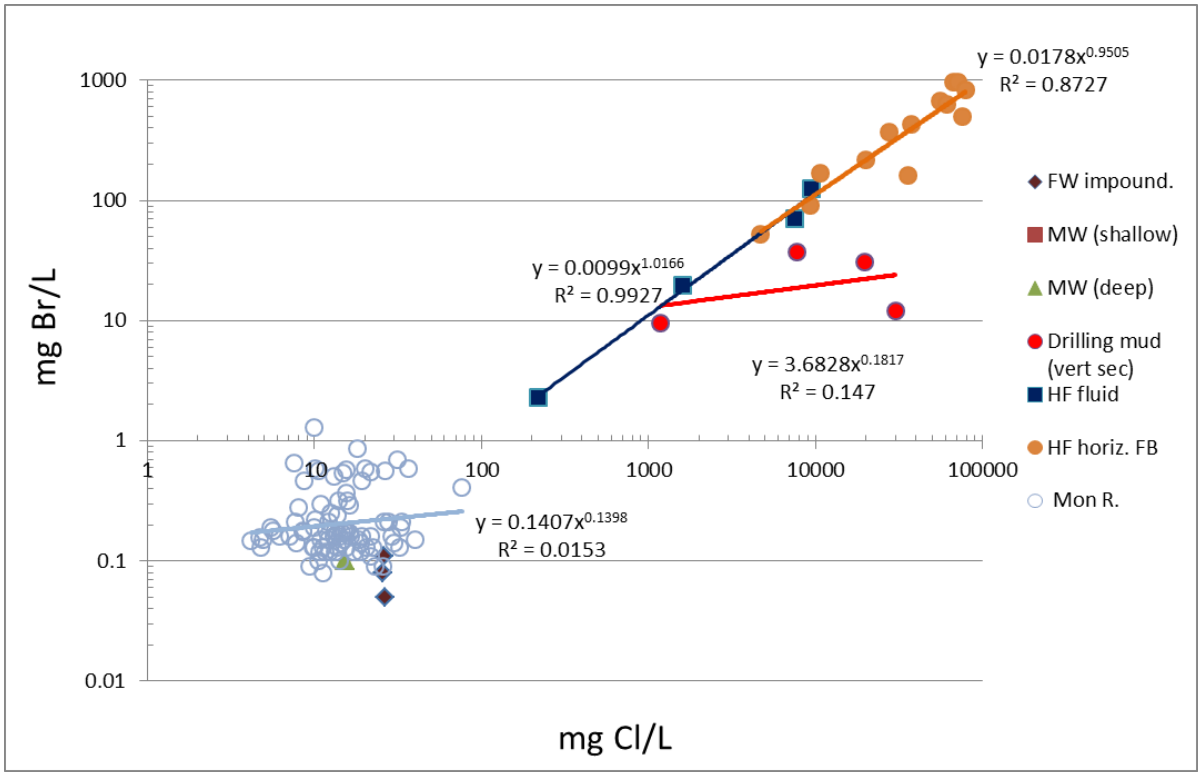

Figure 22: Relationship of Chloride and Bromide in Source Waters

- All samples were plotted on chloride/bromide axes to determine the orientation of the various source waters.
- Note this is a log-log plot and zero (non-detect) values are not plotted.
- Trendlines are included along with their models and correlation coefficients.

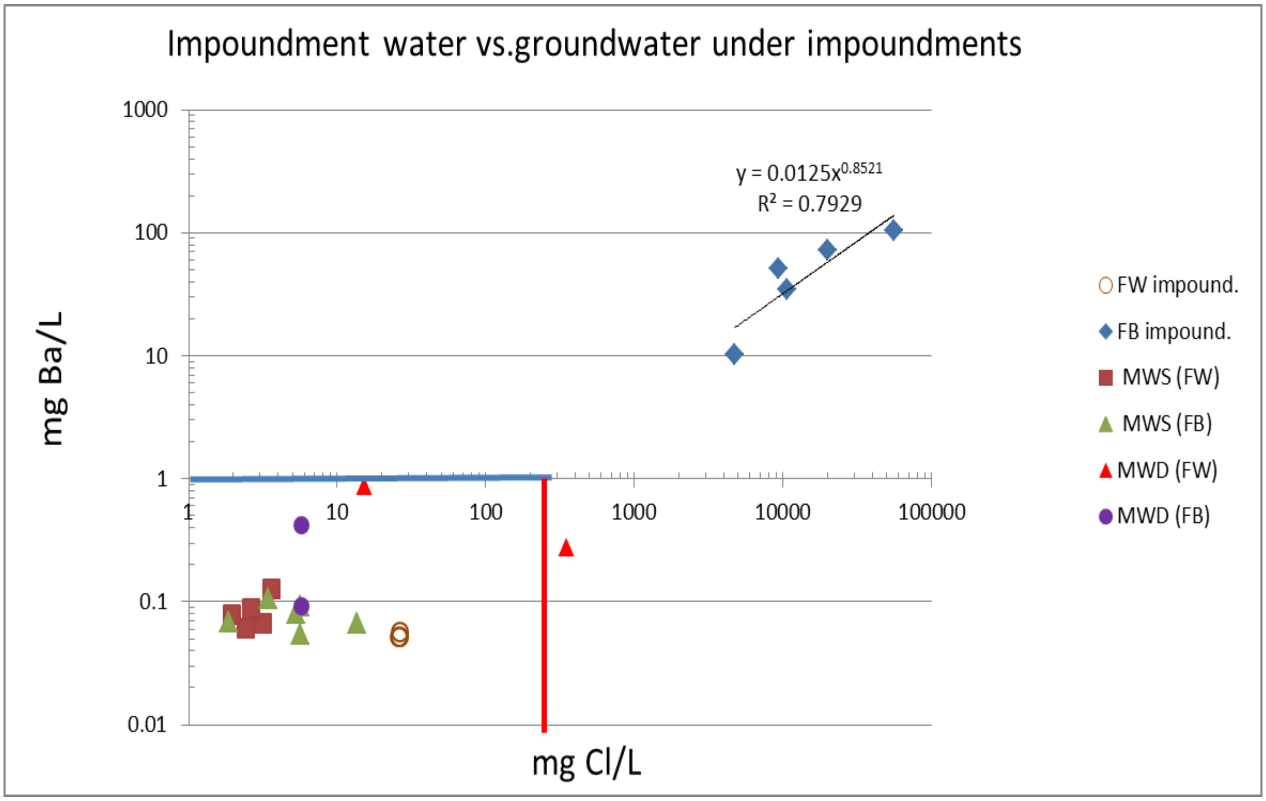

Figure 23: Barium/Chloride (Ba/Cl) Relationship in Impoundment Water and Groundwater

- Groundwater was monitored at three centralized impoundments at the Noble Site. All were converted from freshwater (FW) to flowback (FB) storage during the study.
- The figure shows the Ba/Cl ratios of the impoundment waters, the monitoring well shallow (MWS) and monitoring well deep (MWD) monitoring wells before and after the conversion.
- The blue, horizontal line is the primary drinking water limit for barium and the red, vertical line is the secondary drinking water limit for chloride.

Identification of Potential Health Concerns and Recommendations

Three types of water and one solid waste were studied:

- Flowback water
- Drilling muds
- Hydraulic fracturing fluids
- Drill cuttings

Flowback, drilling muds and hydraulic fracturing fluids all exceeded SDWA limits to varying degrees. The extent to which they are properly and safely handled will determine the degree of human exposure via drinking water. An attempt to prioritize the potential for human exposure via groundwater contamination is reflected in **Table 16**. Transported volume and liquid/solid rankings are binomial. It is assumed that exposure increases with volume, particularly to the extent that the material is transported off-site. Liquid contaminants are simply more mobile than any of the solid materials in this study and therefore pose a greater exposure risk.

Table 16: Groundwater Exposure to Shale Gas Waste Streams

		transported	liquid=2	SDWA exceedences		
Material type	n	volume	solid=1	primary	secondary	radioactivity
flowback	13	2	2	18%	47%	85%
hydrofractring fluid	2	1	2	11%	40%	ND
drilling mud(vertical section)	4	1	2	30%	68%	ND
drilling mud (horizontal section)	0	1	2	ND	ND	ND
drill cuttings (vertical section)	10	1	1	NA	NA	NA
drill cuttings (horizontal section)	0	1	1	NA	NA	NA

ND=not determined
NA=not applicable

Some materials could not be sampled and are marked ND for not determined. **Table 16** is not complete as not all of the materials could be sampled within the timeframe of project. With that qualification, flowback yields the highest exposure since: it is a liquid; it is transported off site; it has multiple toxicities and it is produced in high volume. Hydraulic fracturing fluid is not as toxic as flowback and it is usually prepared on-site, minimizing transportation risk. It may be spilled on the drill pad through accident or during a blowout. Proper lining and containment on-site, however, would minimize exposure to groundwater. Both flowback and hydraulic fracturing fluid may escape the wellbore if it is not installed and cemented. The risk of migration of these fluids from the target formation to drinking water, considering the distance is remote but not absent. Care must be taken to avoid faults and old gas wells that may conduct these fluids to potable aquifers.

Drilling mud exceeded the primary and secondary SDWA standards more than the previous two materials but its volume is much lower than flowback or hydraulic fracturing fluid. While drill cuttings will contain contaminants, the volume is generally such that they are easily isolated on-site and taken to landfills for disposal. Therefore, their exposure risk is low if properly handled. For example, storage of flowback in large impoundments resulted in no evidence of leakage. This is of particular interest since the impoundment geotechnical study which is part of this effort identified several design and construction flaws in impoundment construction. That no flowback leakage was detected suggests that the designs are robust.

This project has significantly improved knowledge of the human health risks associated with shale gas development. As a result, diagnostic tools such as the Br/Cl and Ba/Cl ratios for identifying flowback contamination have been developed. Flowback was identified as the primary waste stream of concern. Practices that prevent environmental and human health exposures are critical. The following are recommended:

- Ensure the integrity of the handling chain for each of the waste streams, identify the weak points and focus the inspectors' attention to those areas.
- Ensure the integrity of wellbores and cement.

Future research should focus on filling out the remainder of **Table 16**. In addition, while the scope of this project is limited to the well development and completion stages of shale gas extraction, future work regarding chemical exposures at the producing well sites is needed to supplement this work.

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Appendix A: WVWRI Project Staff

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Appendix B: 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

SAMPLE LOG & ANALYSIS REQUEST

TURNAROUND TIME	RUSH TURNAROUND
(●) NORMAL	( ) 5 DAY ( ) 3 DAY ( ) 2 DAY ( ) 1 DAY

*Rush work needs prior laboratory approval and will incur additional charges

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

ANALYSIS & METHOD REQUESTED

SAMPLE ID	No. & Type of Containers	Sampling Date/ Time	Matrix	Sample Comp/Grab	Se (total)	Se (dissolved)							
					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 C: Pace Analytical Chain of Custody Form

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

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED: COMPOSITE START DATE	COMPOSITE START TIME	COMPOSITE END/GRAB DATE	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	Analysis Test / Y/N	Requested Analysis Filtered (Y/N)	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		Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
PRINT Name of SAMPLER:					
SIGNATURE of SAMPLER:	DATE Signed (MM/DD/YY):				

Appendix D: Individual Site Checklists

Site Checklist – Chesapeake DNR A Pad

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Chesapeake DNR Pad (A)
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Chesapeake
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted from Chesapeake for sampling **muds and cuttings** from the shaker table during the vertical portion of the drilling process
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	Vertical Drilling – 10/25/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site (if relevant)	Not Applicable
Hydraulic Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing fluids (if relevant)	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	40° 19' 16.1"N 80° 32' 12.2"W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	• pH = 9.38 • EC = 4 µS/cm • Temperature = 33.06° • TDS = 2 mg/L, oil-like substance causing interference with reading • DO = 9.39 mg/L • Salinity = 0.0 ppt Refer to *Appendix E* also
Duplicate Samples	Identify duplicate sampling events	Full Duplicate on 10/25/2012
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	No Photos Taken (Operator Preference)
Permitting	Provide copies of permit for each site to WRI	Not Available

Description	**Task**	**Completed/Notes**
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Received November 2012
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	Received November 2012
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	Received November 2012
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings to be noted	• 11:00 am, 10/25/2012, JF/BM • Samples taken from shaker table • Drilling depth approximately 5,300 feet • 73°F, sunny with some cloud cover • For PID and RAD readings, refer to *Appendix E*
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Lemons Pad

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Lemons Pad
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Stone Energy
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted from Stone Energy for sampling **muds and cuttings** from the shaker table during the vertical portion of the drilling process
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	Vertical drilling – 8/8, 8/15, 8/22, and 10/2/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Not Applicable
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing 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	39°39'03.3''N 80°47'39.6''W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	Refer to *Appendix E* for all field measurements during each individual sampling event at this site
Duplicate Samples	Identify duplicate sampling events	Collected one complete duplicate set of both solids and liquids on 10/2/2012
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report
Permitting and Drilling	Provide copies of permit and drilling logs for each site to WRI	Partial data received November 2012

Description	Task	Completed/Notes
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	No
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	Partial data received November 2012
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	Refer to *Appendix E* for all sampling specifics during each individual sampling event at this site
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Maury Pad

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Maury Pad
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Stone Energy
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted from Stone Energy for sampling **makeup water and hydraulic fracturing fluid** during the hydraulic fracturing process, as well as **flowback water** during the flowback stage
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	Hydraulic Fracturing – 9/11/2012 Flowback – 10/2/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Mixture of recycled water and freshwater from local source (11%:89%)
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing fluids	Received February 2013
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	39°36’58.6’’N 80°47’00.7’’W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	Refer to *Appendix E* for all field measurements during each individual sampling event at this site
Duplicate Samples	Identify duplicate sampling events	None
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report
Permitting	Provide copies of permit for each site to WRI	No
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Not Applicable

Description	Task	Completed/Notes
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	No
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	No
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	Refer to *Appendix E* for all sampling specifics during each individual sampling event at this site
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Mills Wetzel Pad #2

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Mills Wetzel Pad #2
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Stone Energy
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted from Stone Energy for sampling **muds and cuttings** from the shaker table during the vertical portion of the drilling process
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	Vertical Drilling – 8/8/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Not Applicable
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing 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	39°"N 80°"W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	• pH = 9.06 • EC = 173,962 µS/cm • Temperature = 34.22 °C • TDS = 96,160 mg/L • DO = 0.17 mg/L • Salinity = 117.14 ppt Refer to *Appendix E* also
Duplicate Samples	Identify duplicate sampling events	None
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report

Description	Task	Completed/Notes
Permitting	Provide copies of permit for each site to WRI	No
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Yes, partial information received on-site
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	No
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	No
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	• 1:00 pm, 8/8/2012, JF/BM • Samples taken from shaker table • Drilling depth approximately 5,226 feet, not yet horizontal • 92 °F, sunny with few clouds • For PID and RAD readings, refer to *Appendix E*
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Mills Wetzel Pad #3

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Mills Wetzel Pad #3 Single-Lined Impoundment
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Stone Energy
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted for sampling the **impoundment** near the Mills Wetzel #3 Pad
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	Impoundment – 8/28/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Not Applicable
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing 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	39°31'57.69"N 80°40'21.88"W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	• pH = 8.09 • EC = 231 μS/cm • Temperature = 30.46 °C • TDS = 150 mg/L • DO = 7.68 mg/L • Salinity = 0.11 ppt Refer to *Appendix E* also
Duplicate Samples	Identify duplicate sampling events	None
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report
Permitting	Provide copies of permit for each site to WRI	No

Description	Task	Completed/Notes
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Not Applicable
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	No
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	No
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	• 4:30 pm, 8/28/2012, JF/BM • Samples taken from MW3 impoundment • 84 °F, mostly sunny • For PID and RAD readings, refer to *Appendix E*
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Sand Hill Location

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-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluid • Hydraulic fracturing 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**-6/7/2012 **Groundwater** – (6/4, 6/7 and 6/19/2012 – Initial), (10/31 and 11/1/2012 – Final) **Flowback**-8/13, 8/20, 8/28 and 9/17/2012 **Pits**-9/17/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Ohio River, Wheeling Creek, and return water from previous operations
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing 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 (EC) • Temperature, °C • TDS • DO • Salinity	Refer to *Appendix E* for all field measurements during each individual sampling event at this site
Duplicate Samples	Identify duplicate sampling events	SHL-4-MW-3, Collected a complete set of duplicates during groundwater sampling on 10/31/12

Description	Task	Completed/Notes
Site Observations	Document visual observations of site	Refer to *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report
Permitting	Provide copies of permit for each site to WRI	Yes, Received from Consol and WVU CEE
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Not Applicable
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	Yes, Received from Consol
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	Yes, Received from Consol
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	Refer to *Appendix E* for all sampling specifics during each individual sampling event at this site
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Weekley Pad

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Weekley Pad
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Stone Energy
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted from Stone Energy for sampling **flowback water** during the flowback stage
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	Flowback – 8/15/12 and 8/20/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Unknown
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing fluids	Yes, Received February 2013
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	39°36’58.6’’N 80°47’00.7’’W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	Refer to *Appendix E* for all field measurements during each individual sampling event at this site
Duplicate Samples	Identify duplicate sampling events	None
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report
Permitting	Provide copies of permit for each site to WRI	No

Description	Task	Completed/Notes
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Not Applicable
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	No
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location	No
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	Refer to *Appendix E* for all sampling specifics during each individual sampling event at this site
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Site Checklist – Waco/Donna Pad

Description	Task	Completed/Notes
Site Identification	Identify site for ETD-10 study	Waco Donna Pad
Industry Contact	Initial contact w/ companies to establish site access	Main contact-Waco Oil and Gas
Access to Site	Confirm access to water & waste streams based on well stage development: • Impoundment-freshwater • Groundwater • Drilling fluids • Muds & cuttings • Hydraulic fracturing fluids • Hydraulic fracturing water • Flowback/Produced water • Pits-flowback storage	Access granted for sampling **flowback water storage** from the single-lined pit, **hydraulic fracturing fluids**, and **flowback water** from the flowback stage
Contact and Scheduling	Contact companies/site supervisor establish sampling date(s) and meeting locations	**Pit**-7/25/12 and 8/30/2012 (Pit was makeup water for hydraulic fracturing process) **Flowback-**7/27, 8/2, 8/9 and 8/30/2012 **Hydraulic Fracturing-** 7/25/2012
Source Water	Identify and obtain information on source water for hydraulic fracturing operations for each site	Nearby pond (surface water source)
Hydro Fracturing Fluids	Obtain list/breakdown of hydraulic fracturing fluids	Yes, Received November 2012
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	**Pit-** 39° 34’ 29.30’’ N 80° 17’ 31.40 W **Pad-** 39° 34’ 27.19’’ N 80° 17’ 39.89’’ W
Field Measurements	Measurement of field parameters: • pH • Electric conductivity (EC) • Temperature, °C • TDS • DO • Salinity	Refer to *Appendix E* for all field measurements during each individual sampling event at this site
Duplicate Samples	Identify duplicate sampling events	None
Site Observations	Document visual observations of site	Refer to the *Water and Waste Stream Monitoring Plan* section of the report

Description	Task	Completed/Notes
Photographic Documentation	Obtain permission prior to and take photos of site, sample collection, and catalog and document photos	Completed, included as part of the *Water and Waste Stream Monitoring Plan* section of the report
Permitting	Provide copies of permit for each site to WRI	Yes, Received November 2012
Drilling Logs	Obtain and provide copies of drilling logs to WRI	Yes, Received November 2012
Health and Safety/Emergency Response	Obtain copies of company specific Environmental Health & Safety Plans and Emergency Response Plans for recordkeeping purposes only	No
Site Mapping	Obtain and provide copies of maps/diagrams of pad layout & location to WRI	Yes, Received November 2012
Sampling Specifics	Describe pad activities at time of sampling Collect samples, noting: • Time, date, sampler(s) • Sampling point • PID measurements • RAD sweep readings • Weather conditions • Other field/environmental surroundings needing to be noted	Refer to *Appendix E* for all sampling specifics during each individual sampling event at this site
Preparation of Samples	Sample preparation: • Equipment • Labeling • Storage • Transport • COC forms • Sample pick-up/delivery to certified lab	Refer to the *Water and Waste Stream Monitoring Plan* section of the report
Sample Verification	• Receive results verifying all parameters analyzed	Yes
Data Entry	Enter data into master spreadsheets	Entered, MO/JF
Results	Note daily maximum values, average results, values exceeding MCLs if applicable	Refer to the *Data Analysis* section of the report

Appendix E: Field Spreadsheets

			Field Readings/Observations						
			units	°C	µS/cm	(mg/L)	pH	(mg/L)	ppt
Stage	Target	Sample Identification and Location	Date	Temp.	EC	TDS	pH	DO	Salinity
Fresh Water Impoundment	Fresh Water	SHL-3-IMP, Noble Pits	6/7/2012	20.72	364	258	8.75	7.51	NS
		SHL-2-IMP, Noble Pits	6/7/2012	NS	NS	NS	NS	NS	NS
		SHL-1-IMP, Noble Pits	6/7/2012	22.76	387	263	8.61	9.28	NS
		Mills Wetzel #3 IMP	8/28/2012	30.46	231	150	8.09	7.68	0.11
Pits: Centralized	Monitoring Wells (Shallow)	SHL-2, MW-2, Noble Pits	6/4/2012	12.48	286	244	7.08	3.24	NS
		SHL-2, MW-3, Noble Pits	6/4/2012	13.53	274	228	7.27	5.63	NS
		SHL-4, MW-1, Noble Pits	6/4/2012	13.51	297	248	7.3	6.84	NS
		SHL-4, MW-2, Noble Pits	6/4/2012	12.28	281	241	7.73	8.74	NS
		SHL-4, MW-3, Noble Pits	6/4/2012	12.28	277	238	7.52	4.61	NS
		SHL-2 MW-1, Noble Pits	11/1/2012	11.84	909	590	7.75	4.89	0.45
		SHL-2, MW-2, Noble Pits	10/31/2012	11	175	113	6.42	13.12	0.08
		SHL-2, MW-3, Noble Pits	10/31/2012	11.05	386	251	7.44	7.35	0.19
		SHL-4, MW-1, Noble Pits	10/31/2012	12.2	308	200	6.75	4.35	0.15
		SHL-4, MW-2, Noble Pits	10/31/2012	10.64	467	304	7.05	8.73	0.23
		SHL-4, MW-3, Noble Pits	10/31/2012	12.31	184	119	6.32	11.89	0.09
Pits: centralized	Monitoring Wells (Deep)	SHL-2 MW-4, Noble Pits	6/19/2012	14.82	338	273	7.29	6.36	NS
		SHL-3 MW-4, Noble Pits	6/19/2012	21.48	492	342	7.51	6.31	NS
		SHL-2 MW-4, Noble Pits	11/1/2012	11.28	427	277	7.3	7.39	0.21
		SHL-3 MW-4, Noble Pits	11/1/2012	11.25	470	306	7.32	6.19	0.23
Hydraulic Fracturing	HF Water	HF Water, Donna Pad	7/25/2012	26.14	7242	4611	7.96	5.88	NS
	Frac Fluid	Comb. HF, Donna Pad	7/25/2012	28.99	24192	14602	7.02	7.49	NS
	HF Water	HF Water, Maury Pad	9/11/2012	13.26	965	627	6.78	4.85	0.48
	Frac Fluid	Comb. HF, Maury Pad	9/11/2012	23.29	20,597	13,390	6.63	5.78	12.32
Vertical Drilling	Drilling - produced waste	ST 2 at 13:00 (slurry) Mills Wetzel #2	8/8/2012	34.22	173962	96160	9.06	0.17	117.14
		ST 2 at 13:00 (solids) Mills Wetzel #2	8/8/2012						
		ST 1-1 at 11:00 (liquid) Lemons Pad	8/8/2012	29.06	110145	66420	10.01	4.11	74.48
		ST 1-1 at 11:00 (solids) Lemons Pad	8/8/2012						
		ST 1-2 at 10:30 (liquid) Lemons Pad	8/15/2012	29.61	42203	27450	7.35	4.63	27.02
		ST 1-2 at 10:30 (solids) Lemons Pad	8/15/2012						
		ST 1-3 at 11:00 (liquid) Lemons Pad	8/22/2012	29.77	14963	9731	8.82	4.19	8.66
		ST 1-3 at 11:00 (solid) Lemons Pad	8/22/2012						
		ST 1-4 at 1:30 (liquid) Lemons Pad	10/2/2012	24.66	10457	6799	12.71	7.31	5.91
		ST 1-4 at 1:30 (solid) Lemons Pad	10/2/2012						
		DNR ST 3-1-L (sludge) DNRA Pad	10/25/2012	33.06	4	2	9.38	9.39	0
		DNR ST 3-1-L (sludge) DUP DNRA Pad	10/25/2012	33.06	4	2	9.38	9.39	0
		DNR ST 3-1-S (solid) DNRA Pad	10/25/2012						
		DNR ST 3-1-S (solid) DUP DNRA Pad	10/25/2012						
Flowback	Site Pit	FS -1, Donna Pad	7/27/2012	40.35	94345	47450	6.92	1.47	49.57
		FS-2, Donna Pad	8/2/2012	25.86	160501	102700	6.49	0.74	NS
		FS-3, Donna Pad	8/9/2012	17.47	133036	101000	7.07	1.28	124.67
		FS -Final, Donna Pad	8/30/2012	20.87	170,822	111,000	6.61	1.46	141.44
	Centralized Pits	FS-1, Noble Pits (SHL-3)	8/13/2012	28.51	16,283	10,590	6.99	1.55	9.5
		FS 2, Noble Pits (SHL-3)	8/20/2012	24.8	125901	81830	6.9	2.69	96.01
		FS-3, Noble Pits (SHL-3)	8/28/2012	28.39	26426	17180	6.16	0.57	16.1
		FS Final, Noble Pits (SHL-3)	9/17/2012	33.04	54461	35400	6.22	1.29	36.08
		SHL-4 Composite, Noble Pits (SHL-4)	9/17/2012	27.2	40499	2632	7.07	2.57	25.83
	Site Pit	FS-1, Weekly Pad	8/15/2012	27.79	119,710	77,800	6.81	1.24	90.16
		FS-2, Weekly Pad	8/20/2012	25.83	132,680	86,230	6.75	0.9	102.48
		FS-1, Maury Pad	10/2/2012	28.61	112879	73330	6.86	1.08	83.81
		Donna Pit-C (liquid) Donna Pad	8/30/2012	28.23	84044	54630	7.82	9.53	59.11
		Donna Pit-C (solid) Donna Pad	8/30/2012						

			Field Readings/Observations					
			units		mr/hr	mr/hr	parameter dependent	parameter dependent
Stage	Target	Sample Identification and Location	Date	Weather Conditions	Radioactivity (Background)	Radioactivity (Sample)	6-Gas (Background)	6-Gas (Sample)
Fresh Water Impoundment	Fresh Water	SHL-3-IMP, Noble Pits	6/7/2012	83° F, Sunny w/some cloud cover	0.011	0.011	Non Detect	1% LEL
		SHL-2-IMP, Noble Pits	6/7/2012	83° F, Sunny w/some cloud cover	0.008	0.016	Non Detect	Non Detect
		SHL-1-IMP, Noble Pits	6/7/2012	83° F, Sunny w/some cloud cover	0.008	0.011	Non Detect	Non Detect
		Mills Wetzel #3 IMP	8/28/2012	84° F, Mostly Sunny	0.009	0.014	7% LEL	7% LEL
Pits: Centralized	Monitoring Wells (Shallow)	SHL-2, MW-2, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	NS	NS	Non Detect	Non Detect
		SHL-2, MW-3, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	NS	NS	Non Detect	Non Detect
		SHL-4, MW-1, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	NS	NS	Non Detect	Non Detect
		SHL-4, MW-2, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	NS	NS	Non Detect	Non Detect
		SHL-4, MW-3, Noble Pits	6/4/2012	86° F, Sunny w/little cloud cover	NS	NS	Non Detect	Non Detect
		SHL-2 MW-1, Noble Pits	11/1/2012	38° F, Overcast, Rain	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	0.016	0.013	21.5% O2	Non Detect
		SHL-2, MW-3, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	0.013	0.013	21.3% O2	Non Detect
		SHL-4, MW-1, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	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	0.012	0.016	EL, 21.1% O2, 2ppm IBL	21.3% O2, 2ppm IBL
		SHL-4, MW-3, Noble Pits	10/31/2012	40° F, Overcast, Drizzle	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	0.009	0.015	Non Detect	Non Detect
		SHL-3 MW-4, Noble Pits	6/19/2012	92° F, Sunny, clear	0.011	0.013	Non Detect	Non Detect
		SHL-2 MW-4, Noble Pits	11/1/2012	38° F, Overcast, Rain	0.022	0.09	21.8% O2	21.6% O2
		SHL-3 MW-4, Noble Pits	11/1/2012	38° F, Overcast, Rain	0.015	0.013	1% LEL, 21.5% O2	1% LEL, 21.6% O2, 1ppm IBL
Hydraulic Fracturing	HF Water	HF Water, Donna Pad	7/25/2012	89° F, Sunny w/few clouds	0.015	0.018	Non Detect	Non Detect
	Frac Fluid	Comb. HF, Donna Pad	7/25/2012	89° F, Sunny w/few clouds	0.01	0.012	7.8% LEL	Non Detect
	HF Water	HF Water, Maury Pad	9/11/2012	70°, Sunny, clear	0.016	0.014	87% LEL, 21.9 O2	44% LEL, 21.9 O2
	Frac Fluid	Comb. HF, Maury Pad	9/11/2012	70°, Sunny, clear	0.011	0.01	1% LEL	2% LEL
Vertical Drilling	Drilling - produced waste	ST 2 at 13:00 (slurry) Mills Wetzel #2	8/8/2012	92° F, Sunny w/few clouds	0.008	0.009	4% LEL	5%LEL
		ST 2 at 13:00 (solids) Mills Wetzel #2	8/8/2012	92° F, Sunny w/few clouds	0.008	0.009	4% LEL	5%LEL
		ST 1-1 at 11:00 (liquid) Lemons Pad	8/8/2012	89° F, Sunny w/few clouds	0.013	0.013	Non Detect	Non Detect
		ST 1-1 at 11:00 (solids) Lemons Pad	8/8/2012	89° F, Sunny w/few clouds	0.013	0.013	Non Detect	Non Detect
		ST 1-2 at 10:30 (liquid) Lemons Pad	8/15/2012	90° F, Sunny	0.011	0.016	Non Detect	2% LEL
		ST 1-2 at 10:30 (solids) Lemons Pad	8/15/2012	90° F, Sunny	0.011	0.016	Non Detect	2%LEL
		ST 1-3 at 11:00 (liquid) Lemons Pad	8/22/2012	84° F, Partly Sunny	0.005	0.009	2% LEL	1%LEL
		ST 1-3 at 11:00 (solid) Lemons Pad	8/22/2012	84° F, Partly Sunny	0.005	0.009	2% LEL	1%LEL
		ST 1-4 at 1:30 (liquid) Lemons Pad	10/2/2012	66° F, Overcast, Drizzle	0.008	0.009	20% LEL	20% LEL
		ST 1-4 at 1:30 (solid) Lemons Pad	10/2/2012	66° F, Overcast, Drizzle	0.008	0.015	20% LEL	20% LEL
		DNR ST 3-1-L (sludge) DNRA Pad	10/25/2012	73° F, Sunny w/little cloud cover	0.008	0.01	Non Detect	403 IBL, 100% LEL, 77.6 ppm VOC's
		DNR ST 3-1-L (sludge) DUP DNRA Pad	10/25/2012	73° F, Sunny w/little cloud cover	0.008	0.01	Non Detect	403 IBL, 100% LEL, 77.6 ppm VOC's
		DNR ST 3-1-S (solid) DNRA Pad	10/25/2012	73° F, Sunny w/little cloud cover	0.007	0.008	1% LEL	30% LEL, 43.2 ppm VOC's
		DNR ST 3-1-S (solid) DUP DNRA Pad	10/25/2012	73° F, Sunny w/little cloud cover	0.007	0.008	1% LEL	30% LEL, 43.2 ppm VOC's
Flowback	Site Pit	FS -1, Donna Pad	7/27/2012	83° F, Sunny w/some cloud cover	0.019	0.017	3% LEL	Non Detect
		FS-2, Donna Pad	8/2/2012	80° F, Sunny w/some cloud cover	0.011	0.013	Non Detect	2% LEL
		FS-3, Donna Pad	8/9/2012	79° F, Sunny w/some cloud cover	0.009	0.013	91% LEL	91% LEL
		FS -Final, Donna Pad	8/30/2012	80° F, Sunny, clear	0.011	0.01	1% LEL, 21.2% O2	1% LEL, 21.2% O2
	Centralized Pits	FS-1, Noble Pits (SHL-3)	8/13/2012	77° F, Sunny w/some cloud cover	0.014	0.008	Non Detect	6% LEL
		FS 2, Noble Pits (SHL-3)	8/20/2012	89° F, Sunny w/some cloud cover	0.014	0.01	5% LEL	5% LEL
		FS-3, Noble Pits (SHL-3)	8/28/2012	84° F, Mostly Sunny	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	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	0.09	0.009	6% LEL	6% LEL, 2ppm IBL
	Site Pit	FS-1, Weekly Pad	8/15/2012	90° F, Sunny	0.01	0.007	2% LEL	2% LEL
		FS-2, Weekly Pad	8/20/2012	88° F, Sunny	0.008	0.009	3% LEL, 21.2% O2	21% O2
		FS-1, Maury Pad	10/2/2012	68° F, Rain, Cloudy	0.011	0.013	26% LEL, >100ppm H2S	38.8% LEL, >2000ppm IBL
		Donna Pit-C (liquid) Donna Pad	8/30/2012	80° F, Sunny, clear	0.014	0.007	4% LEL	3% LEL
		Donna Pit-C (solid) Donna Pad	8/30/2012	80° F, Sunny, clear	0.014	0.007	4% LEL	3% LEL