west virginia department of environmental protection

Office of Oil and Gas
601 57th Street, S.E.
Charleston, WV 25304
Phone: (304) 926-0450
Fax: (304) 926-0452

Earl Ray Tomblin, Governor
Randy C. Huffman, Cabinet Secretary
www.dep.wv.gov

March 7, 2013

The Honorable Jeffrey V. Kessler
Senate President
Building 1, Room 227-M
State Capitol Complex
Charleston, WV 25305

The Honorable Richard Thompson
Speaker of the House of Delegates
Building 1, Room 228-M
State Capitol Complex
Charleston, WV 25305

Re: W. Va. Code §22-6A-23 Impoundment and Pit Safety Study

Dear President Kessler and Speaker Thompson:

As directed by the Natural Gas Horizontal Well Control Act enacted by the West Virginia Legislature on December 14, 2011, please find enclosed the Department of Environmental Protection's (DEP) Office of Oil and Gas (OOG) report pursuant to W. Va. Code §22-6A-23 on the safety of large pits and impoundments (W. Va. Code §22-6A-9) used in the drilling of horizontal natural gas wells that are not associated with a specific well work permit. Also, please find enclosed the accompanying study reports by West Virginia University's (WVU) Water Research Institute and Department of Civil and Environmental Engineering, along with OOG's response to issues discovered during the study.

Based on the results of this study, OOG finds that no additional rules are immediately necessary for the design and construction of these large pits and impoundments. Please note that WVU provided numerous recommendations based on field sampling results and literature review. Many of the recommendations, while outside the specific scope of the legislative mandate of W. Va. Code §22-6A-23, are already addressed by the OOG's existing regulatory framework, which ensures adequate controls for these large pits and impoundments (W. Va. Code §22-6A-9).[1] The study confirmed that "future construction, if done in accordance with the WVDEP guidelines, should pose minimal risk."

[1] The Rules Governing Horizontal Well Development (35CSR8), proposed for consideration during the 2013 legislative session, contains additional language detailing requirements associated with W. Va. Code §22-6A-9 structures.

Please note the study required by W. Va. Code §22-6A-12(e) on the noise, light, dust and volatile organic compounds, generated by the drilling of horizontal natural gas wells as they relate to the well location restrictions regarding occupied dwelling structures, is still underway. The field component of this study has been completed, and WVU is currently compiling and analyzing the data.

Should you have any questions or require additional information, please do not hesitate to contact me.

Sincerely,

James A. Martin, Chief
Office of Oil & Gas

JAM/lmb

cc w/enclosures:
Joseph A. Lazell, Chief Counsel to Senate Judiciary Committee
Joseph A. Altizer, Chief Counsel to House Judiciary Committee

SAFETY OF CENTRALIZED LARGE PITS AND IMPOUNDMENTS USED IN THE DRILLING OF HORIZONTAL NATURAL GAS WELLS

By the West Virginia Department of Environmental Protection's
Office of Oil and Gas
Pursuant to W. Va. Code §22-6A-23
March 7, 2013

INTRODUCTION

As directed by the Natural Gas Horizontal Well Control Act (the Act) enacted by the West Virginia Legislature on December 14, 2011, the following is in fulfillment of the mandate pursuant to W. Va. Code §22-6A-23 that the Department of Environmental Protection's (DEP) Office of Oil and Gas (OOG) report on the safety of centralized large pits and impoundments (W. Va. Code §22-6A-9) used in the drilling of horizontal natural gas wells that are not associated with a specific well work permit. The sampling, data analysis, and literature review comprising the study supporting this report were performed by staff of the West Virginia University's (WVU) Water Research Institute and the faculty and students of the Department of Civil and Environmental Engineering.

BACKGROUND

One of the major concerns with the hydraulic fracturing process associated with horizontal drilling is that it requires large quantities of water. This water, along with any returned flowback and produced water, is then frequently stored in centralized large capacity pits and impoundments at or near the well location. To address the legislative mandate and these concerns, a study was conducted that focused on the structural integrity and safety of these large pits and impoundments. All three centralized pits constructed under the auspices of W. Va. Code §22-6A-9 during the short period of time between the passage of the Act and the deadline for the submission of study findings to the Legislature, were evaluated for safety and monitored for leakage. Groundwater monitoring wells were installed and sampled periodically around each of the three centralized pits. WVU also studied 12 large capacity pits and impoundments that existed prior to passage of the Act. [1] The OOG selected a broad spectrum of sites for the study,

[1] Late in the sampling and data collection phase of this study, another large capacity pit being newly constructed was added to the study. Groundwater monitoring well sampling around this structure is underway, and will be documented reported separately. While not a centralized pit, the evaluation and sampling at this single-lined pit will provide data on newer structures associated with well work permits.

including pits and impoundments constructed using a variety of construction techniques. WVU developed a relative scoring mechanism to rate these sites in a consistent manner, while evaluating the construction, operation and maintenance of these pits and impoundments. Therefore, this study provides insights into the safety of large capacity pits and impoundments as they were constructed both before and after passage of the Act and implementation of current policy.

In addition to the safety of the structures themselves, the Legislature directed OOG to evaluate whether testing and special regulatory provision is needed for radioactivity or toxins held in the pits and impoundments. To that end, WVU sampled and analyzed the solids and liquids held in the structures to determine if it exhibited radioactivity or contained other constituents of concern. In particular, WVU sampled the returned flowback from the Marcellus Formation and cuttings from the shallower formations drilled (i.e. only from the vertical portion of the drilling process). While WVU provided a comparison of sampling results with drinking water standards as a way to prioritize potential health impacts, it is important to note that these process streams are not allowed to be discharged into surface waters. In fact, the OOG's regulatory framework provides for practices to prevent and minimize such environmental and human health exposure.

CONCLUSIONS

Based on sample results of both the material held in the structures and the groundwater below them, the study showed that no leakage was detected from the examined structures. Further, sites designed and constructed to the current OOG standards scored higher (using WVU's relative scoring mechanism) than those built prior to the Act. Finally, the study showed that radiological exposure from material both on the well pads and at the centralized structures is within acceptable limits.[2] Thus, the structures subject to this study posed no imminent threat to public health or the environment. Therefore, OOG is able to conclude that the current regulatory framework is sufficient to properly regulate the construction, operation, and maintenance of large capacity pits and impoundments.

During the study, operators were not always complying with current rules and policies in both the construction and the operation/maintenance of the pits and impoundments. Problems included the placement of woody debris in the fill, improper compaction, surface erosion, slope movements, inadequately secured liners, bulges in liners, seepages and wet zones in embankments, small slips and cracks, standing water on berms, and debris on liners. Therefore, inspectors followed up with the subject operators to require corrective action.

Based on the study, the OOG provided additional training specific to the proper design, construction, and maintenance of large capacity pits and impoundments to agency personnel and

[2] This study did not address the health effects of continued, long-term exposure of gas field workers to the radiation associated with the development of Devonian shale gas. WVU measured most samples they collected in activity rather than exposure. Those samples that were measured for exposure showed rates that were much lower than Occupational Safety and Health Administration (OSHA) standards and therefore safer. Of the samples measured for activity, WVU reported that some exceeded drinking water standards; however, since there is no route of exposure, drinking water standards are not applicable for comparison, as those standards assume that people are directly ingesting the material.

the regulated community. Continuous improvement through training has been, and will continue to be, ongoing at numerous events in order to stay apprised of the new and constantly changing industrial activities associated with horizontal well drilling. In addition, the OOG developed a standard inspection checklist to ensure that the inspection of pits and impoundments is standardized across the Office of Oil and Gas. The OOG will continue these endeavors to make certain that all parties involved in the construction, operation, maintenance, and regulation of these structures understand and are fully able to implement best construction and maintenance practices in order to minimize potential adverse impacts that may result from noncompliance. Further, additional revenues received, because of an increase in application fees in the Act, have allowed the OOG to hire additional inspectors to help ensure that operators adhere to current rules, policies, engineering standards, and best management practices during both construction and operation/maintenance of these structures. The OOG concurs with WVU that "future construction, if done in accordance with the WVDEP guidelines, should pose minimal risk."

WVU has suggested numerous recommendations based on their field sampling results and literature review throughout the study reports. Many of the recommendations, while outside the specific scope of the legislative mandate of W. Va. Code §22-6A-23, are already addressed by the OOG's existing regulatory framework. The OOG also has specific authority to condition the issuance of certificate of approvals and individual permits. This framework ensures adequate controls are in place for these large pits and impoundments (W. Va. Code §22-6A-9), and no greater monitoring, safety or design requirements or other specialized permit conditions are necessary at this time to effectively regulate the construction, operation, and maintenance of centralized large capacity pits and impoundments.[3]

SUPPORTING INFORMATION

Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations AGM 064, Project Overview: Water and Waste Stream Study & Pits and Impoundments Study, West Virginia Water Research Institute, West Virginia University, February 15, 2013, submitted February 20, 2013. This document is an overview of the water quality, as well as pits and impoundment reports submitted to OOG to date.

Pits and Impoundments Final Report for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project), John Quaranta, Ph.D., Richard Wise, Andrew Darnell, M.S.C.E, E.I.T. Department of Civil and Environmental Engineering, West Virginia University. December 17, 2012 (second version with this date), re-submitted February 15, 2013. This document addresses the structural integrity of the pits and impoundments.

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," Paul Ziemkiewicz, Ph.D., Director, Jennifer Hause, Brady Gutta, Jason Fillhart, Ben Mack,

[3] The Rules Governing Horizontal Well Development (35CSR8), proposed for consideration during the 2013 legislative session, contains additional language detailing requirements associated with W. Va. Code §22-6A-9 structures.

Melissa O'Neal, West Virginia Water Research Institute, West Virginia University, February 15, 2013, submitted February 20, 2013. This document addresses groundwater, as well as the toxicity and radioactivity of the materials held by the pits and impoundments.

Pit and Impoundment Evaluation and Sampling Plan For Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project), John Quaranta, Richard Wise, Andrew Darnell, Michael Kulbacki, Matt Idleman, Justin Pentz, Department of Civil and Environmental Engineering, West Virginia University, December 10, 2012.

Memorandum: WVU Large Impoundment/Pit Study Recognition and Response by Office of Oil and Gas Personnel by David J. Belcher, December 3, 2012. This memorandum documents the follow-up inspections OOG performed on the studied structures after training its personnel.

Standardized impoundment and pit inspection checklist, November 8, 2012. This document ensures consistency when the structures are inspected by DEP's Office of Oil and Gas personnel.

Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations

AGM 064

Project Overview:

Water and Waste Stream Study

&

Pits and Impoundments Study

Prepared for:

West Virginia Department of Environmental Protection

Division of Air Quality

601 57th Street, SE

Charleston, WV 25304

Prepared by:

West Virginia Water Research Institute

West Virginia University

PO Box 6064

Morgantown, WV 26506-6064

Date:

February 15, 2013

Disclaimer

The contents of these reports reflect the views of the authors who are responsible for the facts and the accuracy of the data presented. The contents DO NOT necessarily reflect the official views or policies of the State. These reports do not constitute a standard, specification, or regulation. Trade or manufacturers' names which may appear herein are cited only because they are considered essential to the objectives of these reports. The State of West Virginia does not endorse products or manufacturers. These reports were prepared for the West Virginia Department of Environmental Protection.

Table of Contents

List of Tables

List of Abbreviations

ASTM	American Society for Testing and Materials
Ba	Barium
BOPs	Blowout preventers
Br	Bromide
CEE	Civil and Environmental Engineering
Cl	Chloride
DO	Dissolved oxygen
DRO	Diesel range organics
EAP	Emergency Action Plan
FB	Flowback
ft	Feet
GPS	Global Positioning System
HF	Hydraulic fracturing, fracking or frac
HFF	Hydraulic fracturing fluids
I	Inorganic (parameters)
MBAS	Methylene blue active substances (surfactants)
MCL	Maximum contaminant level
mrem/hr	Millirems per hour (rem = roentgen equivalent man)
MU	Makeup
ND	Not determined (also shown as N/A)
O	Organic (parameters)
PID	Photo-ionization detector
R	Radioactive (parameters)
SDWA	Safe Drinking Water Act

TDS	Total dissolved solids
TPH	Total petroleum hydrocarbons
VOC	Volatile organic compound
WVCSR	West Virginia Code of State Regulations
WVDEP	West Virginia Department of Environmental Protection
WVU	West Virginia University
WVWRI	West Virginia Water Research Institute

Project Overview

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 focuses on:

- Light, noise, dust and volatile organic compounds air emissions as they relate to the well location restrictions regarding occupied dwelling structures
- Impoundment and pit safety
- Possible health impacts from water, waste and air emissions related to horizontal drilling and completion activities

In support of these legislative mandates, the WVDEP solicited a team of researchers from WVU to conduct these studies. Led by the West Virginia Water Research Institute (WVWRI), the WVU researchers studied the potential for horizontal gas well development to affect air and water quality. Effects of light and noise, and the structural integrity and safety of wastewater pits and impoundments were also studied. Literature reviews were conducted and followed by direct field monitoring of air, noise and light and well development water and waste streams. This overview document focuses on the activities undertaken to characterize the process waste streams as well as the pits and impoundments safety study.

This overview deals with impoundment and pit safety, including an evaluation of process waste streams associated with horizontal well drilling. The study does not address the potential for human exposure via fluid movement from the fracturing zone upwards toward drinking water supplies. The air emissions, light and noise report will be the subject of a future submittal from WVU.

Water and Waste Stream 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: public health, environmental, and safety aspects of hydraulic fracturing development. The review also included surface and groundwater contamination and well development practices commonly used to protect surface and groundwater during 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 well sites were monitored and study design and sampling methods were adjusted to field conditions.

This field study focused 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).

West Virginia recently began permitting the construction of centralized pits for the storage of flowback water. Groundwater monitoring is required for centralized pits in West Virginia and groundwater monitoring wells are installed by the permit holder. As of the date of this report, only one permit had been issued for centralized waste storage pits. This site was selected for groundwater monitoring and was one of several sites used for flowback characterization. The centralized impoundments initially stored makeup water (a combination of Ohio River water and treated mine water). After hydraulic fracturing, the impoundments were converted to flowback water 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.

Site Sampling

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 total dissolved solids (TDS) values greater than 35,000 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.

Active hydraulic fracturing 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 solids samples were collected and analyzed for a wide range of inorganic, organic and radioactive constituents to characterize 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 sampling area and individual samples with a handheld radiation alert detector that displayed current radiation levels in millirem per hour (mrem/hr) and scanned for off-gases of volatile organic compounds (VOCs) with a photo-ionization detector (PID) as part of personal safety procedures. Parameters such as pH, specific conductivity, TDS, dissolved oxygen (DO), salinity and temperature of samples were measured in the field using a multi-parameter YSI56 unit. At least one site, for each stage of horizontal gas well development, was sampled.

To ensure completeness and consistency in sampling, a site checklist was developed. The checklist covers information relevant to the site location, stage of well development, samples collected and field observations. Samples were sent to certified laboratories, REI Consultants for organic and inorganic compound determinations and Pace Analytical for radioactivity analysis. It is important to note that all chemical determinations are for total as opposed to dissolved concentrations. It is important to note that one of the organic parameters: Total petroleum hydrocarbons (TPH) (diesel range) measure all hydrocarbons in the range of C11 to C28. That 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.

Findings

Study objectives include: 1) Characterize drilling muds and cuttings and identify pollutants, 2) compare hydraulic fracturing fluids with flowback water and identify pollutants, and 3) identify if 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 muds were in excess of all of the inorganic drinking water standards. They also exceeded the drinking water standards for benzene and surfactant (MBAS). 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.

   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.* 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. One hydraulic fracturing fluid sample exceeded the drinking water standard for 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). 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.

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 1 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.

Table 1: 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.

			% exceedances of drinking water standard		
type		drinking water std.*	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

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 fresh water 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.

Identification of Potential Health Concerns

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 2**. 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 that any of the solid materials in this study and therefore pose a greater exposure risk.

Table 2: Groundwater Exposure to Shale Gas Waste Streams

Material type	n	transported volume	liquid=2 solid=1	SDWA exceedences primary	SDWA exceedences secondary	SDWA exceedences 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 2** is not complete as not all of the materials could be sampled during Phase I of the study. 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 fluids are not as toxic as flowback and it is usually prepared on-site, minimizing transportation risk. It may be spilled on the drill pad due to an accident or during a blowout. Proper lining and containment on-site, however, would minimize exposure to groundwater. Both flowback and hydraulic fracturing fluids may escape the wellbore if it is not properly 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 muds exceeded the primary and secondary SDWA standards more than the previous two water streams; however, its volume is much lower than flowback water or hydraulic fracturing fluids. 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

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 2**. 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 would supplement this study.

Recommendations

The liquid and solid wastes generated during shale gas drilling and well completion can be contained and disposed of in a manner that protects human health and the environment. Problems occur when leakage occurs. Leakage points include:

Hydraulic fracturing fluid

- Spillage prior to injection
- Blowout during hydraulic fracturing

Flowback

- The well bore
- Blowout after hydraulic fracturing
- Impoundment failure
- Impoundment leakage
- Fluid spillage at the well site
- Improper disposal

Drilling muds and cuttings

- Storage pit leakage
- Fluid spillage at the well site
- Improper disposal

Major types of waste, cause of release and control mechanisms are summarized in **Table 3**.

Table 3: Control Options for Potential Releases

cause of release	control
HF fluid:	
Spillage prior to injection	Containment for 1 stage volume on drill pad
Blowout during fracking	Primary and backup BOPs
Flowback	
Leakage in the well bore	Hydrostatic well test prior to frac
Blowout after fracking	Primary and backup BOPs
Impundment failure	Follow WVDEP Impoundment Guidelines
Impoundment leakage	Use double polymer liner for pits and impoundments
Fluid spillage at the well site	Containment for 1 stage volume on drill pad
Improper disposal	Enforceable disposal plan
Drilling muds and cuttings	
Storage pit leakage	Use double polymer liner for pits and impoundments
fluid spillage at the well site	Containment for 1 stage volume on drill pad
Improper disposal	Enforceable disposal plan

Recommended Release Control Program

The potential for release of hazardous fluids and solids from drilling and completion operations involves a limited number of substances and release points. A five point release control program that would address the major risks that would affect drinking water is recommended. The following list of control measures should be considered for further refinement:

1. *On-site containment.* A single horizontal well is typically completed with ten hydraulic fracturing stages. A hydraulic fracturing stage includes about one tenth of the typical, total hydraulic fracturing fluid volume of 5,000,000 gallons. The hydraulic fracturing fluid intended for a stage would thus, be about 500,000 gallons. This represents the maximum amount of fluid that could be spilled on the drill pad in a single event. It would be contained within a volume of about 74,000 cubic feet with a safety factor of 1.1 or slightly greater. That would be roughly 150 ft square by 3.25 ft deep.

Flowback may escape via a blowout during a single fracturing stage or leakage during the return period. The former volume could be no greater than the injected hydraulic fracturing fluid volume. Flowback includes the total volume of fluid that flows back out of the well prior to production. Loss of hydraulic fracturing fluids in the formation are typically between 70 and 90% in the Marcellus Formation so the cumulative volume of flowback that reports to the wellhead from a five million gallon injection would be about 150,000 gallons after three weeks. Flowback generally converts to produced water after about six weeks at which time a total of about 200,000 gallons of flowback would have arrived at the surface. This volume would represent about 27,000 cubic feet. In summary, while individual well conditions would differ in degree, a containment volume of 74,000 cubic feet would contain any realistic spill on the drill pad.

2. *Blowout Preventers.* The above scenario allows for flowback to spill on the well pad for up to six weeks without exceeding the recommended containment capacity. In reality, any uncontrolled flowback would be brought under control almost immediately by installation of blowout preventers (BOPs). BOPs may be automatic, responding to drastic pressure changes, or manual. The latter can be engaged in the event the automatic BOP fails.

3. *Wellbore Integrity.* Flowback, as well as production gasses, may escape the wellbore as a result of casing failure or inadequate grouting. Pre-fracturing pressure testing of the wellbore to pressures in excess of the design strength of the wellbore will indicate if adequate wellbore integrity has been achieved. It is recommended the WVDEP select a testing protocol and engineering standard to be applied to all future horizontal hydraulic fractured wells.

4. *Impoundment Integrity.* The pits and impoundment study identified a number of construction shortcomings that would be corrected by simply following WVDEP's guidelines: *Design and Construction Standards for Centralized Pits*, developed by the Office of Oil and Gas in 2011. It is recommended these guidelines be the basis for future construction and inspection/certification.

4. Groundwater monitoring wells were installed to detect leakage from centralized pits as part of this study. The centralized pits employ double polymer liners. No leakage was detected. 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.

5. *Disposal Plans.* Plans for disposing of flowback, drilling muds and cuttings should specify the type of disposal facility, the facility's name and location and the types and volumes of material to be disposed in each. Documentation of compliance with these conditions should be required as part of the horizontal gas well's permit.

An alternative approach would involve the installation of groundwater monitoring wells around the well development site to allow for groundwater sampling prior to drilling for the establishment of background conditions. Groundwater monitoring can then be performed throughout drilling, hydraulic fracturing and flowback and production stages allowing for potential contamination issues to be more readily identified and corrected. Instituting these recommendations will significantly reduce the risk of accidental release of hazardous solid and liquid wastes associated with shale gas development.

Pits and Impoundments Study

The purpose of studying pits and impoundments was to determine the suitability of the construction and use of these structures in minimizing the potential environmental effects related to horizontal drilling. This task was performed by researchers from the West Virginia University Department of Civil and Environmental Engineering (CEE).

The broad scope of the CEE research included the following areas:

- review of field construction practices
- engineering reviews of approved permit plans for consistency with requirements
- field evaluations to assess the as-built sites with the permitted plans
- limited geotechnical soil property testing
- assessment of data findings related to construction and evaluation of mechanisms for groundwater contamination such as pumps, piping, and geomembrane liners
- preparation of a final topical report of findings

The CEE researchers coordinated with the WVDEP for the review of oil and gas permit files and the selection of candidate sites. A short-list of eighteen sites was provided for review based on a set of CEE criteria that included the age, size, use, construction material and method, and placement of the structure. Certain sites selected were known by the WVDEP to have problems. The selection incorporated sites constructed before and after the enactment of §22-6A in order to assess the implementation and effects of the new regulations on industry practices. Initially, fourteen sites were selected for evaluation, but prior to the completion of the project, one additional site was added, making fifteen total sites visited.

Site Evaluations

Field evaluations and soil property testing were used to ascertain and document the safety and structural integrity of the pits and impoundments. The field observations were performed using an evaluation form developed for the project to maintain consistent data collection across all sites. The evaluation form contained the following sections: permit information, field as-built construction and site conditions, observation checklist, and site operations and maintenance questionnaire. Using this approach, researchers made visual observations of the site and the surrounding environment, documenting items of concern with Global Positioning System (GPS) referenced pictures. Field soil samples were collected using hand shovels at various locations on each site and were subsequently tested in the WVU CEE geotechnical laboratory in accordance with the American Society for Testing and Materials (ASTM) Standards. The specific laboratory soil property tests performed were field moisture content, grain-size distribution and hydrometer analysis, Atterberg limits, specific gravity, Standard Proctor, hydraulic conductivity, and shear strength. Of the fifteen sites evaluated, six were chosen for *in situ* field compaction density and moisture content testing. The laboratory testing and the data collected in the field were compiled and served as the basis for the results of this study.

Permit Review Results

The permit reviews of the candidate sites revealed that the permit files for 10 sites constructed prior to the enactment of §22-6A lacked geotechnical investigation reports. The permits for the three sites constructed after the enactment of §22-6A contained this information. Additionally, the permit information for two sites was not provided by the WVDEP at the time of the evaluation. An analysis of the permits compared the permitted storage volumes with the storage volume requirements of dams as regulated by the WVDEP (WVCSR §22-14 & WVCSR §47-34). No sites were found to meet the requirements of a dam. However, the large quantities of water could be a potential hazard to the public and the environment if a failure were to occur because of the ridge-top location of several sites.

The permit reviews of the candidate sites revealed that the permit files for 10 sites constructed prior to the enactment of §22-6A lacked geotechnical investigation reports. The permits for the three sites constructed after the enactment of §22-6A contained this information. Additionally,

the permit information for two sites was not provided by the WVDEP at the time of the evaluation.

An analysis of the permits compared the permitted storage volumes with the storage volume requirements of dams as regulated by the WVDEP (WVCSR §22-14 & WVCSR §47-34). No sites were found to meet the requirements of a dam. However, the large quantities of water could be a potential hazard to the public and the environment if a failure were to occur because of the ridge-top location of several sites.

Laboratory Results

Results of the laboratory testing indicated that none of the post §22-6A sites had soil conforming to the soil types specified by the WVDEP Design and Construction Standards for Centralized Pits. Of the remaining twelve pre §22-6A sites, only one site met the soil standards. However, the laboratory testing indicated that the soil types present at the sites may be suitable for the construction of pits and impoundments if proper compaction is achieved.

An assessment of the soil properties in the available site geotechnical investigations revealed several discrepancies when compared with laboratory data. The soil properties contained within the permit were characteristic of the top layers of excavation, which are not necessarily representative of the soils at the bottom of the excavation. Thus, the engineering properties of the soil tested during the excavation may not be consistent with the properties of the fill material used during construction. Furthermore, the foundation and slope designs of the structure may include soil properties that are not representative of site soil, which can contribute to post-construction issues. For the six sites where *in situ* field compaction density and moisture content testing was performed, the field data was compared with laboratory Standard Proctor density data. This analysis consisted of ascertaining the distribution of field data points in relation to the optimum compaction range for each site. The following areas of concern were identified:

- Three of the six sites had field data points within the optimum compaction range. Two of the sites had 14% of data points in compliance, and the other site had 22% of data points in compliance.
- The field data from the remaining three sites had 0% compliance with the optimum compaction range.
- Based on a total of seventy samples taken across all six sites, only six data points were within the acceptable range (8.5%).
- As a result of insufficient soil compaction density, the slopes of the pits and impoundments have a higher potential of developing subsurface erosion and elevated pore water pressures leading to slope instability.

In summary, the recurring problems and deficient areas from the field evaluations included the following:

- insufficient compaction density of site soil and excessive soil lift height
- surface soil erosion
- slope movement
- buried woody debris
- seepage and wet zones
- geomembrane liner deficiencies
- unsupported pipes

Overall, these deficiencies reflect a lack of adherence to the best management practices set forth in the West Virginia Erosion and Sediment Control Field Manual, as well as poor construction knowledge. These construction practices combined with a lack of field quality control and assurance are indicators of the source and frequency of the problems observed across all evaluated sites.

Operational Review

The Site Operations and Infrastructure Evaluation consisted of a questionnaire for the WVDEP Office of Oil and Gas Inspector and on-site company representative, although the company personnel present at the time of the field visit may or may not have been the principle site inspectors. The responses obtained for each question were compiled for analysis, and trends were established across all sites. The results indicated that none of the WVDEP inspectors had any formal training related to pits and impoundments inspection. In addition, no standardized method was used by the inspectors, which resulted in the use of the state regulations as an inspection guide. Consequently, the inspectors only targeted the readily apparent problems such as slips and slides, while not recognizing, or fully understanding, the smaller problem indicators.

Another area of concern was that the responses from WVDEP inspectors and company representatives revealed that there was no set frequency for site inspections to be performed. The actual frequency of inspections, by the WVDEP or the company, varied from every three days to once every two months, and the inspection frequency by a Professional Engineer (PE) ranged from weekly to never. Infrequent inspections may allow problem areas to go unnoticed or delay corrective actions.

Emergency Action Plans (EAPs) were not required prior to the enactment of §22-6A, and the new regulations stipulate that EAPs are only required for centralized pits and impoundments. The company representative at the post §22-6A sites in this study was not aware that the sites had an EAP, had not received training, and did not know if the EAP had been evaluated for practicality in an emergency situation. Also, at the time of the field visit, the EAP was not available on-site. Therefore, the company representative on-site was unprepared to act in a timely and efficient manner if an emergency situation were to occur.

The EAPs for the post §22-6A sites did not contain any evacuation protocol, with the justification that there were no nearby structures that would be impacted by a failure. No inundation maps were provided in the EAPs to support this statement. During the field evaluations for these sites, a slope failure was found, which is illustrated and described in this report. These site conditions demonstrate the necessity of properly developed and implemented EAPs at Marcellus Shale pits and impoundments.

Recommendations

Based on the findings in the study, the following recommendations were developed:

- Improve WVDEP inspector training requirements and methods.
- Improve the field quality control and assurance for construction and inspection to ensure that the as-built dimensions do not exceed the permitted design.
- Thoroughly test the site soil to determine the geotechnical properties for all fill materials.
- Review the allowable soil type specifications so that suitable soils may be used, or remove the stipulation from the WVDEP Design and Construction Standards for Centralized Pits.
- Develop EAPs for all pits and impoundments, pre and post §22-6A, to improve the safety of these sites.
- Do not allow pre §22-6A sites to be re-permitted as centralized pits or impoundments because the designs do not incorporate §22-6A design standards.

Although there was construction deficiencies noted based on a review of the West Virginia Erosion and Sediment Control Field Manual and the WVDEP Design and Construction Standards for Centralized Pits, none of the deficiencies indicated imminent pit or impoundment failure potential at the time of the site visit. The problems identified do constitute a real hazard and present risk if allowed to progress; but, all problems observed in the field are correctable. Future construction, if done in conformance with the WVDEP guidelines should pose minimal risk.

Pits and Impoundments Final Report

For

Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project)

Prepared for:

Office of Oil and Gas
West Virginia Department of Environmental Protection
601 57th Street, SE
Charleston, WV 25304

Submitted by:

John Quaranta, Ph.D., P.E.
Richard Wise, M.S.C.E., E.I.T.
Andrew Darnell, M.S.C.E, E.I.T.

Department of Civil and Environmental Engineering
West Virginia University
PO Box 6103
Morgantown, WV 26506-6103

December 17, 2012

Table of Contents

List of Figures

List of Tables

Executive Summary

Background

On December 14, 2011, the Natural Gas Horizontal Well Control Act §22-6A was enacted by the State of West Virginia. With this Act, the West Virginia Department of Environmental Protection (WVDEP) was mandated to conduct studies regarding horizontal drilling and related potential environmental impacts in order to provide recommendations for the next legislative session.

In order to examine the potential environmental effects associated with horizontal drilling, a research project was implemented with West Virginia University and managed by the West Virginia Water Research Institute (WVWRI). The research concentrated on the potential health and safety concerns related to natural gas wells. The three key task areas of the study were i) air and water quality; ii) generated light and noise; and iii) structural integrity and safety of the flowback water pits and freshwater impoundments for the gas wells. The purpose of studying pits and impoundments to determine the suitability of the construction and use of these structures in minimizing the potential environmental effects related to horizontal drilling. This task was performed by researchers from the West Virginia University Department of Civil and Environmental Engineering (CEE).

CEE Scope of Work

The broad scope of the CEE research included the following areas:

- review of field construction practices
- engineering reviews of approved permit plans for consistency with requirements
- field evaluations to assess the as-built sites with the permitted plans
- limited geotechnical soil property testing
- assessment of data findings related to construction and evaluation of mechanisms for groundwater contamination such as pumps, piping, and geomembrane liners
- preparation of a final topical report of findings

Review of Construction Practices

The CEE researchers coordinated with the WVDEP for the review of oil and gas permit files and the selection of candidate sites. A short-list of 18 sites was provided for review based on a set of CEE criteria that included the age, size, use, construction material and method, and placement of the structure. Certain sites selected were known by the WVDEP to have problems. The selection incorporated sites constructed before and after the enactment of §22-6A in order to assess the implementation and effects of the new regulations on industry practices. Initially, 14 sites were selected for evaluation, but prior to the completion of the project, one additional site was added, making 15 total sites visited.

Field evaluations and soil property testing were used to ascertain and document the safety and structural integrity of the pits and impoundments. The field observations were performed using an evaluation form developed for the project to maintain consistent data collection across all sites. The evaluation form contained the following sections: permit information, field as-built construction and site conditions, observation checklist, and site operations and maintenance questionnaire. Using this approach, researchers made visual observations of the site and the surrounding environment, documenting items of concern with Global Positioning System (GPS) referenced pictures. Field soil samples were collected using hand shovels at various locations on each site and were subsequently tested in the WVU CEE geotechnical laboratory in accordance with the American Society for Testing and Materials (ASTM) Standards. The specific laboratory soil property tests performed were field moisture content, grain-size distribution and hydrometer analysis, Atterberg limits, specific gravity, Standard Proctor, hydraulic conductivity, and shear strength. Of the 15 sites evaluated, six were chosen for *in situ* field compaction density and moisture content testing. The laboratory testing and the data collected in the field were compiled and served as the basis for the results of this study.

Results of Permit Reviews

The permit reviews of the candidate sites revealed that the permit files for 10 sites constructed prior to the enactment of §22-6A lacked geotechnical investigation reports. The permits for the three sites constructed after the enactment of §22-6A contained this information. Additionally, the permit information for two sites was not provided by the WVDEP at the time of the evaluation.

An analysis of the permits compared the permitted storage volumes with the storage volume requirements of dams as regulated by the WVDEP (WVCSR §22-14 & WVCSR §47-34). No sites were found to meet the requirements of a dam. However, the large quantities of water could be a potential hazard to the public and the environment if a failure were to occur because of the ridge-top location of several sites.

Results of Field Evaluation

At the start of each field evaluation, measurements of the pit or impoundment as-built construction were made and compared to the permitted design. Findings identified discrepancies between the permit and as-built dimensions for eight sites. The measurement discrepancies included larger as-built volume capacities, smaller crest berm widths, and steeper upstream and downstream slopes than the permitted design specified. The significance of these deficiencies is summarized as follows:

- The as-built dimension discrepancies result in the pit or impoundment holding larger volumes of flowback water or freshwater than the permitted design.
- The differences in the crest berm width distances and the steepness of the slopes can negatively affect the safety and slope stability of the pit or impoundment.
- These deficiencies introduce uncertainty into the safety of the pit or impoundment due to unknown storage volumes and stresses on the foundation, slopes, and geomembrane liner systems.

The analysis of the field evaluations consisted of ranking the field data into a numeric scoring system. Using this method, a numerical score was obtained, and each site was ranked in terms of the field anomaly severity and frequency of occurrence. This score was based on a total of 100%, and the results ranged from a low of 59% to a high of 88%.

Results of Laboratory and Field Geotechnical Evaluation

Results of the laboratory testing indicated that none of the post §22-6A sites had soil conforming to the soil types specified by the WVDEP Design and Construction Standards for Centralized Pits. Of the remaining twelve pre §22-6A sites, only one site met the soil standards. However, the laboratory testing indicated that the soil types present at the sites may be suitable for the construction of pits and impoundments if proper compaction is achieved.

An assessment of the soil properties in the available site geotechnical investigations revealed several discrepancies when compared with laboratory data. The soil properties contained within the permit were characteristic of the top layers of excavation, which are not necessarily representative of the soils at the bottom of the excavation. Thus, the engineering properties of the soil tested during the excavation may not be consistent with the properties of the fill material used during construction. Furthermore, the foundation and slope designs of the structure may include soil properties that are not representative of site soil, which can contribute to post-construction issues. For the six sites where *in situ* field compaction density and moisture content testing was performed, the field data was compared with laboratory Standard Proctor density data. This analysis consisted of ascertaining the distribution of field data points in relation to the optimum compaction range for each site. The following areas of concern were identified:

- Three of the six sites had field data points within the optimum compaction range. Two of the sites had 14% of data points in compliance, and the other site had 22% of data points in compliance.

- The field data from the remaining three sites had 0% compliance with the optimum compaction range.
- Based on a total of 70 samples taken across all six sites, only six data points were within the acceptable range (8.5%).
- As a result of insufficient soil compaction density, the slopes of the pits and impoundments have a higher potential of developing subsurface erosion and elevated pore water pressures leading to slope instability.

In summary, the recurring problems and deficient areas from the field evaluations include the following:

- insufficient compaction density of site soil and excessive soil lift height
- surface soil erosion
- slope movement
- buried woody debris
- seepage and wet zones
- geomembrane liner deficiencies
- unsupported pipes

Overall, these deficiencies reflect a lack of adherence to the best management practices set forth in the West Virginia Erosion and Sediment Control Field Manual, as well as poor construction knowledge. These construction practices combined with a lack of field quality control and assurance are indicators of the source and frequency of the problems observed across all evaluated sites.

Site Operations and Infrastructure Evaluation

The Site Operations and Infrastructure Evaluation consisted of a questionnaire for the WVDEP Office of Oil and Gas Inspector and on-site company representative, although the company personnel present at the time of the field visit may or may not have been the principle site inspectors. The responses obtained for each question were compiled for analysis, and trends were established across all sites. The results indicate that none of the WVDEP inspectors had any formal training related to pits and impoundments inspection. In addition, no standardized method was used by the inspectors, which resulted in the use of the state regulations as an inspection guide. Consequently, the inspectors only targeted the readily-apparent problems such as slips and slides, while not recognizing, or fully understanding, the smaller problem indicators.

Another area of concern was that the responses from WVDEP inspectors and company representatives revealed that there was no set frequency for site inspections to be performed. The actual frequency of inspections, by the WVDEP or the company, varied from every three days to once every two months, and the inspection frequency by a Professional Engineer (PE) ranged from weekly to never. Infrequent inspections may allow problem areas to go unnoticed or delay corrective actions.

Emergency Action Plans (EAPs)

Emergency Action Plans (EAPs) were not required prior to the enactment of §22-6A, and the new regulations stipulate that EAPs are only required for centralized pits and impoundments. The company representative at the post §22-6A sites in this study was not aware that the sites had an EAP, had not received training, and did not know if the EAP had been evaluated for practicality in an emergency situation. Also, at the time of the field visit, the EAP was not available on-site. Therefore, the company representative on-site was unprepared to act in a timely and efficient manner if an emergency situation were to occur.

The EAPs for the post §22-6A sites did not contain any evacuation protocol, with the justification that there were no nearby structures that would be impacted by a failure. No inundation maps were provided in the EAPs to support this statement. During the field evaluations for these sites, a slope failure was found, which is illustrated and described in this report. These site conditions demonstrate the necessity of properly developed and implemented EAPs at Marcellus Shale pits and impoundments.

Recommendations

Based on the findings in the study, the following recommendations were developed:

- Improve WVDEP inspector training requirements and methods.
- Improve the field quality control and assurance for construction and inspection to ensure that the as-built dimensions do not exceed the permitted design.
- Thoroughly test the site soil to determine the geotechnical properties for all fill materials.
- Review the allowable soil type specifications so that suitable soils may be used, or remove the stipulation from the WVDEP Design and Construction Standards for Centralized Pits.
- Develop EAPs for all pits and impoundments, pre and post §22-6A, to improve the safety of these sites.
- Do not allow pre §22-6A sites to be re-permitted as centralized pits or impoundments because the designs do not incorporate §22-6A design standards.

Preparation of Final Topical Report

The preparation of this final report included two reviews performed by representatives of the WVDEP Office of Oil and Gas. The first review was performed in October 2012 and the second in early December 2012. The WVDEP prepared written comments for each report draft which were then addressed by WVU. The reviews focused on identifying terminology, permitting issues, and initial report findings for corrective action purposes. This process served to provide an internal level of quality assurance for the report development (WVU Review and Back-Check Memorandum, 2012).

An immediate benefit from this process was that the WVDEP was able to implement corrective actions that included developing and presenting an industry construction training seminar on October 24, 2012 and initiating internal WVDEP inspector training.

Concluding Remarks

There were several construction deficiencies out of compliance with the West Virginia Erosion and Sediment Control Field Manual, and the WVDEP Design and Construction Standards for Centralized Pits. However, none of the deficiencies indicated imminent pit or impoundment failure potential at the time of the site visit. The problems identified do constitute a real hazard and present risk if allowed to progress, but all problems that were observed in the field could be corrected. Future construction, if done in conformance with the WVDEP guidelines, should pose minimal risk.

1.0 Background and Objectives

Marcellus Shale is a rock formation located under regions of West Virginia, Pennsylvania, and New York. This formation contains large reserves of natural gas that are commonly being explored using recently developed horizontal drilling and hydraulic fracturing techniques. The West Virginia Legislature enacted the Natural Gas Horizontal Well Control Act §22-6A on December 14, 2011. As part of this Act, the West Virginia Department of Environmental Protection (WVDEP) is to perform studies concerning the practices involved with horizontal drilling and the associated environmental impacts, followed by a report of the findings and recommendations.

In order to examine these environmental impacts, the WVDEP contracted with the West Virginia Water Research Institute (WVWRI) who organized and directed a research study focusing on the potential health and safety concerns resulting from horizontal drilling techniques. Among the key areas of research were the surrounding air and water quality, the generated light and noise, and the structural integrity and safety of the pits and impoundments retaining fluids for the gas wells. The intent of the pits and impoundments component of this study was to ascertain and document the suitability of the construction and use of these structures in minimizing the potential environmental effects related to horizontal drilling. The pits and impoundments research was performed by the Department of Civil and Environmental Engineering (CEE) at West Virginia University (WVU). Specific objectives of this aspect of the research are listed below.

1) Conduct an engineering review of pits and impoundments to determine the current state of practice used in field construction.

2) Perform engineering reviews of submitted and approved permit plans from various energy companies operating in West Virginia.

3) Conduct site investigations of various pits and impoundments to include audits of submitted plans versus actual field practices and limited geotechnical soil property testing.

4) Assess data findings from field studies to address topics such as leak detection, methodology, and data evaluation to determine methods for locating and detecting sources of groundwater contamination, such as pumps, piping, and geomembrane liners.

5) Compile a final report of field studies of pits and impoundments including recommendations for improving industry standards and practices.

2.0 Study Design

The intent of the field evaluations and soil property testing in this study was to ascertain and document the safety and structural integrity of the pits and impoundments used to retain hydraulic fracturing and flowback fluids for Marcellus Shale horizontal gas wells. Pits are man-made excavations that contain waste fluids from the development of horizontal wells which could impact surface water or groundwater. Conversely, an impoundment is a man-made excavation that contains only freshwater. In order to examine current industry practices for the construction, operation, and maintenance of these structures, both pits and impoundments were considered for evaluation in the study. Cooperating with the WVDEP, WVU personnel received eighteen candidate permit files for pits and impoundments with varying characteristics. Based on the permit files and site availability, twelve sites were initially selected for evaluation, six of which were chosen for further in-depth soil property testing. Because of scheduling and site access availability, three additional sites were visited in this study, resulting in a total of fifteen sites.

The WVDEP established site access by contacting the natural gas developers. Researchers coordinated with the regional WVDEP Office of Oil and Gas Inspectors to schedule and conduct field evaluations and soil property testing on the sites. During the field visits, research personnel made visual observations of the surrounding environment and collected pictures to document areas of concern. Site soil was collected using shovels at various locations on each site. These locations were predetermined based on WVDEP permit reviews. The site soil was tested in accordance with American Society for Testing and Materials (ASTM) Standards at the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory. The specific soil property tests performed were field moisture content, grain-size distribution and hydrometer analysis, Atterberg limits, specific gravity, Standard Proctor, hydraulic conductivity (rigid wall), and shear strength.

3.0 Site Selection

Site selection was conducted by analyzing a set of 18 candidate permits provided by the WVDEP based on a set of criteria set forth by WVU. These criteria were used to choose sites with a variety of pit and impoundment characteristics for evaluation. The factors encompassed in the criteria include the following:

- Location within the State of West Virginia
- Company Size: small, medium, or large
- Pit Characteristics:
  - Permit Number/Site Name
  - Age
  - Size (area, depth)
  - Use (flowback water, freshwater, centralized, associated)
  - Construction Material (natural soil, HDPE lined)
  - Construction Method (incised, berm)
  - Placement (hill crest, cut into slope, valley)

Based on these criteria, twelve sites were selected for evaluation, but the determination was made to evaluate the three SHL pits individually, bringing the total number of sites to fourteen. One additional site, Shields FWI, was visited to observe current construction practices. Certain sites selected were known by the WVDEP to have problems. In Table 1, the fifteen sites are listed, along with the company, county, and whether the site was constructed before or after the enactment of new regulations stipulated by the Natural Gas Horizontal Well Control Act §22-6A. Of the fifteen sites evaluated, further in-depth soil testing was performed on six sites. These six sites had field density and moisture content tests performed by a subcontractor, Potesta and Associates, Inc. Figure 1 displays the names and locations of the sites overlain on a county map of West Virginia.

Site Name	Company	County	Pre/Post §22-6A
Donna Completion Pit	Energy Corporation of America	Marion	Pre §22-6A
Donna Completion Impoundment	Energy Corporation of America	Marion	Pre §22-6A
Pribble Freshwater Impoundment	Stone Energy Company	Wetzel	Pre §22-6A
Burch Ridge Wastewater Pit	Gastar Exploration USA, Inc.	Marshall	Pre §22-6A
MIP Freshwater Impoundment	Northeast Natural Energy	Monongalia	Pre §22-6A
Ball 1H Impoundment #2	PetroEdge Energy, LLC.	Tyler	Pre §22-6A
Mills-Wetzel Freshwater Impoundment	Stone Energy Company	Wetzel	Pre §22-6A
SHL 2 Centralized Pit	Noble Energy, Inc.	Marshall	Post §22-6A
SHL 3 Centralized Pit	Noble Energy, Inc.	Marshall	Post §22-6A
SHL 4 Centralized Pit	Noble Energy, Inc.	Marshall	Post §22-6A
Shields FWI	Gastar Exploration USA, Inc.	Marshall	Pre §22-6A
Flanigan Pit	Antero Resources Appalachian Corp.	Harrison	Pre §22-6A
Larry Pad	Antero Resources Appalachian Corp.	Harrison	Pre §22-6A
MWV Large Water Storage Pond 1	Bluescape Resources Company, LLC.	Nicholas	Pre §22-6A
Plum Creek South Fork	Bluescape Resources Company, LLC.	Greenbrier	Pre §22-6A

Table 1: Evaluation Sites

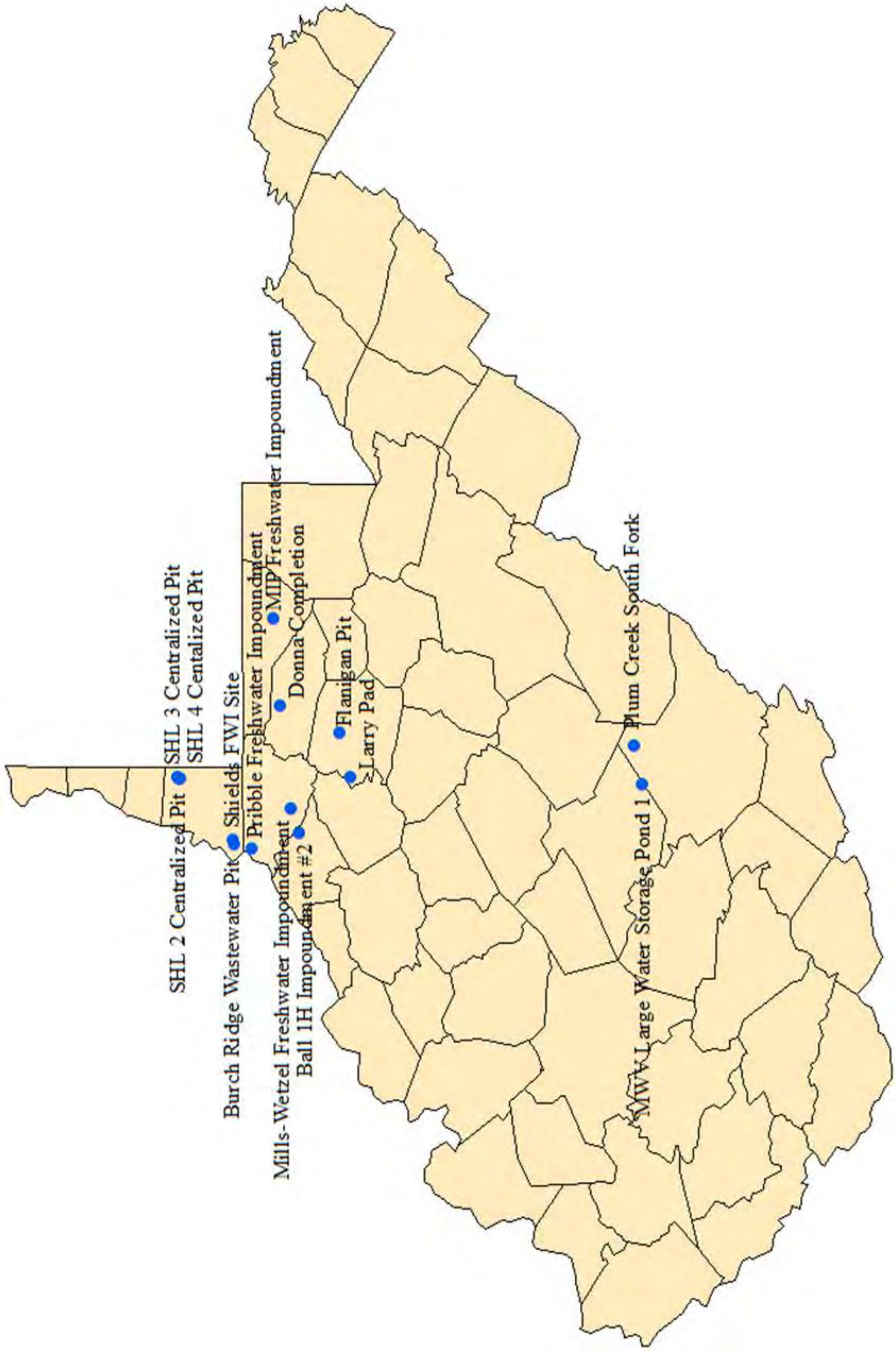


Figure 1: Site Locations

4.0 Field Evaluation Methods

Prior to conducting field evaluations, WVU researchers completed the 40-hour HAZWOPER (Hazardous Waste Operations and Emergency Response) training. On each field evaluation, at least four WVU personnel were present. Each member wore all required personal protective equipment (PPE) as specified by the company to perform field evaluations and soil collection on horizontal gas drilling sites.

In compliance with WVU Environmental Health & Safety policies and HAZWOPER training requirements, all WVU personnel underwent a medical screening to determine a medical health baseline for each member prior to any field work. Personnel will also receive medical screenings within one year of the project's completion. Further medical monitoring will be conducted if recommended by WVU's Department of Occupational Medicine.

Before each field evaluation, WVU field personnel attended site safety meetings to identify potential hazards and all procedures in place in the event an incident/accident occurred. If a hazard or danger had been found at a sampling site, the field personnel would have exited without delay, and the situation immediately reported to the WVDEP.

4.1 Site Evaluation Methods

Once the 15 sites for evaluation were selected, field visits to those sites were conducted for verification, visual evaluation, and data collection. To evaluate the pits and impoundments, a standardized checklist form was developed to ensure the field observations were recorded in a consistent method and format for comparison between sites. The evaluation form is shown in Figure 2.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME	County		Company	
WEATHER	Latitude		Pit Name	
	Longitude		API No.	

A. PERMIT INFORMATION

Pit Width (ft.)		Minimum Berm Crest Width (ft.)		Construction Type	
Pit Length (ft.)		Upstream Slope (H:V)		Liner Type	
Depth (ft.)		Downstream Slope (H:V)		Date Built	
Freeboard(ft.)				Date Reclaimed	

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)		Berm Crest Width (ft.)		Crest Height (ft.)	
Pit Length (ft.)		Upstream Slope (H:V)		Up Slope Length (ft.)	
Depth (ft.)		Downstream Slope (H:V)		Down Slope Length (ft.)	
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?		Is the pit/impoundment within 1000 feet of a public water source?	
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?		Is the pit/impoundment within 100 feet of a wetland?	

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?					
2	Are there any slope movements or animal burrows?					
3	Are there any depressions, sinkholes, or slides into the pit present?					
4	Are there any signs of mine subsidence on or adjacent to the embankment?					
5	Are there any observed trees, tall weeds, or other vegetation?					
6	Are there any seeps, wet zones, or losses of soil?					
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?					
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?					
9	Are there any areas where the liner is strained?					
10	Are there any areas where the liner has rock or debris on top of it?					
11	Is there any tear potential for the liner?					
12	Are there any deformations, cracks, or settlements around the anchor trench?					
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?					
14	Are there any areas where the pipe is not properly supported?					
15	Are there any signs of pipes having significant sagging in line?					
16	Are there any signs of obstructions (trees, garbage, etc.)?					
17	Are there any signs of water in ditch associated with pit?					
18	Are there any obstructions around the discharge outlet?					
19	Are there any signs of downstream slope movement into ditch?					

WVU (Name / Signature)	DATE
WVDEP (Name / Signature)	
Company Representative (Name / Signature)	

Figure 2: Evaluation Form

The first section of the evaluation form was used to document the weather conditions at the time of the field visit and general information regarding the site such as location, company, and site identification.

Section A was used to record key permitted characteristics of the site such as dimensions, slopes, and construction type. However, the permit information lacked geotechnical investigation reports for ten sites, and the permit information for two sites was not provided by the WVDEP at the time of the evaluation.

In Section B, the pit or impoundment characteristics were measured in the field to compare the permitted design with the as-built construction. Also, Section B outlined the WVDEP areas where construction of these structures is prohibited.

Section C is the observation checklist containing the specific areas of concern associated with the integrity of the structure. In Questions 1 through 6, the embankment slopes were evaluated to determine the severity of erosion present. In Question 1, the effects of surface water at the site which may indicate insufficient erosion control measures, soil compaction, and drainage were dealt with. Slope movements and animal burrows were evaluated in Question 2 to determine if the downstream face was stable and providing the necessary support against slope slippage and failure. In Question 3, the upstream face was assessed for any depressions, sinkholes, or slides that may compromise the containment of the pit or impoundment. Mine subsidence was an area of concern in Question 4 because any noticed subsidence around these structures would indicate the possibility of movement or unstable ground that could lead to slope deformation. Question 5 pertains to the prevalence of trees, tall weeds, and other vegetation that may inhibit the detection of critical problems during inspections. Additionally, woody debris was included in this question because the presence of woody debris in the fill material may increase the potential for surface erosion or slope movements. Seeps, wet zones, and losses of soil were covered in Question 6, as these problems are indicative of subsurface water movement that could cause slope failures.

Questions 7 through 12 focus on the containment system at the pit or impoundment and any potential for leakage. In Question 7, the presence of eddies and whirlpools was evaluated to determine if the liner system had a leak or puncture and whether the structure was losing fluid. Question 8 was used to assess liner tears, bulges, holes, wind uplift, and seam separation in order to ensure the containment system was functional and intact. Question 9 relates to strain in the liner that may result in tears or displacement of the liner. Rock and debris on the liner was covered by Question 10, as the added weight from the material may cause the anchor trench to pull out of the soil and impair the functionality of the liner. Question 11 pertains to the tear potential of the liner, including areas where the liner was stretched over rock and other debris. In Question 12, the anchor trench was examined for deformations, cracks, or settlements which may indicate improper soil compaction on the crest leading to pathways for water seepage. Furthermore, Question 12 addresses the embedment of the anchor trench to ensure that the liner was secured in place.

Another potential area of concern was the condition of the pipes at the site, which was covered in Questions 13 through 15. Any leakage or rupture of the pipes which convey water or flowback fluids would have an environmental impact to the surface water and groundwater. Pipe abnormalities were evaluated using Question 13, focusing on gouges, leaks, and cracks that may impair the pipe's ability to sustain an open cross-section and transport fluids under pressure. In Question 14, the placement of pipes at the site was dealt with because unsupported pipes present safety and health hazards due to the potential for rolling, slipping, pinching, and leaking. In Question 15, sagging in the pipe was assessed to determine the potential for flow restrictions, buckling, and leakage which may lead to environmental problems.

In Questions 16 through 19, the drainage measures at the site were evaluated to determine their functionality in removing excess surface water. Question 16 pertains to any signs of obstructions found inside the pits or impoundments such as trees or garbage that could possibly clog transfer pumps. Standing water in ditches was evaluated using Question 17 in order to ascertain the ability of the ditches to remove excess surface water from the sites. Obstructions around the discharge outlet that may interfere with the discharge of water when required was the focus of Question 18. In Question 19, slopes on the downstream face were examined to determine whether slope movements were restricting flow in the ditch, thereby impairing drainage.

Two WVU personnel discussed the ranking for each question on the evaluation form during the field assessments. Data was written in the evaluation form, and a review was conducted on-site to ensure that all items had been evaluated. Field signatures were obtained from the WVDEP and company personnel observing the evaluation.

The second part of the field visits consisted of the Site Operations and Infrastructure Evaluation, shown in Figure 3. This evaluation was a questionnaire for the WVDEP Office of Oil and Gas Inspector on site and/or the company representative, although the company personnel present during the field visit may or may not have been the party primarily responsible for the site inspections.

The questionnaire addressed inspector training and background in regards to pit and impoundment safety. Other questions pertained to the operation and maintenance procedures for the site as well as safety plans such as Emergency Action Plans (EAPs), which are required for sites permitted after the enactment of §22-6A.

Site Operations & Infrastructure Evaluation	
Date:	Pit/Impoundment Name:
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking)
2	What type of training or background does the inspector possess relative to pit/impoundment inspection?
3	How many years of training does the inspector have in evaluating pits/impoundments?
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection?
5	Who developed the form and how is the information used to evaluate pit/impoundment safety?
6	Are there safety and emergency procedures for the pit/impoundment?
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers?
8	Has the pit/impoundment inspector been trained on how to use the EAP?
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?)
10	Does the company have a policy on pit/impoundment safety?
11	How frequently does a Professional Engineer inspect the site?
12	Other comments:

Figure 3: Evaluation Questionnaire

4.2 Field Sampling Methods

The field sampling was performed by WVU researchers and consisted of digging several test holes with hand shovels at key locations across each site, such as the toe, face, and crest of the pit or impoundment slope. The test hole locations were planned prior to the site visit based on the information gathered from WVDEP permit files. One bucket of site soil was collected during each field visit in order to perform soil classification testing. On sites where *in situ* field compaction and moisture content testing was performed, two additional buckets of soil were collected to perform further in-depth engineering testing, such as compaction, permeability, and strength. Table 2 contains the date of each site visit and the type of soil testing performed for each site.

Site Name	Date of Site Visit	Type of Soil Testing
Donna Completion Pit	7/12/12	Classification
Donna Completion Impoundment	7/12/12	Classification
Pribble Freshwater Impoundment	7/16/12	Classification
Burch Ridge Wastewater Pit	7/16/12	Classification
MIP Freshwater Impoundment	7/18/12	Classification & In-Depth
Ball 1H Impoundment #2	7/24/12	Classification & In-Depth
Mills-Wetzel Freshwater Impoundment	7/24/12	Classification & In-Depth
SHL 2 Centralized Pit	7/30/12	Classification & In-Depth
SHL 3 Centralized Pit	7/30/12	Classification & In-Depth
SHL 4 Centralized Pit	7/30/12	Classification & In-Depth
Shields FWI	8/1/12	Classification
Flanigan Pit	8/2/12	Classification & In-Depth
Larry Pad	8/2/12	Classification & In-Depth
MWV Large Water Storage Pond 1	8/6/12	Classification
Plum Creek South Fork	8/6/12	Classification

Table 2: Site Visits and Soil Testing Plan

The soil gathered from the test holes was labeled with the site name, date, and location of the test hole. The sample locations were restored to the original conditions to ensure that no damage was made to the pit or impoundment. WVU personnel also made visual observations of the surrounding environment and collected geo-referenced pictures during sampling visits. After the collection of soil samples, all tools were cleaned and stored in containers to avoid cross-contamination between sites. In addition, the tools were inspected for damage after each use. All personal protective equipment (PPE) was similarly decontaminated, and all disposable materials were removed from the site in a garbage bag. Once collected, the soil was taken to the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory for soil property testing and further analysis.

In addition to the field sampling performed by the WVU researchers, *in situ* field compaction and moisture content data on the six in-depth soil testing sites was collected by Potesta and

Associates, Inc. The testing was performed at various locations on each site, including the crest, mid-slope, and toe of the downstream face. These results were incorporated into the analysis along with the laboratory soil testing performed by WVU.

4.3 Data Management

Once WVU field personnel returned to the office, the evaluation forms were transferred to project computers located in the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory. Information regarding times, dates, and personnel involved in data collection were also transferred to the electronic data file. The electronic copies were saved on an external hard-drive, and one back-up was created. As needed, once the data was transferred to the electronic data file, a review of the information was conducted and reported to the WVDEP as part of the monthly progress updates. Photographs were used to assist with documenting field activities and conditions. All hardcopy and electronic records were delivered to the WVWRI Project Manager for retention and were available to the WVDEP upon request. All raw and processed data was made available to the WVDEP as part of the monthly progress updates, and the intermittent and final reporting activities.

5.0 Laboratory Soil Testing Methods

Geotechnical soil property testing consisted of collecting soil samples for laboratory testing in order to obtain independent verification of soil properties and site conditions. This work was specific to the soils used to construct the pits and impoundments. Specific soil testing was performed at the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory and included the following: field moisture content, grain-size distribution and hydrometer, Atterberg limits, specific gravity, Standard Proctor, hydraulic conductivity (rigid wall), and shear strength. The soil property tests and associated ASTM Standards are listed in Table 3. The necessary equipment and the procedure for each of these soil property tests are detailed in Appendix P.

Soil Property Test	ASTM Standard
Field Moisture Content	D2216
Grain-Size Distribution and Hydrometer	D422
Atterberg Limits	D4318
Specific Gravity	D854
Standard Proctor	D698
Hydraulic Conductivity (Rigid Wall)	D5856
Shear Strength	D3080/D3080M

Table 3: Soil Tests and Standards

6.0 Data Reduction and Results

Following laboratory soil testing, the results were compiled into a tabular format for comparisons to permit reviews and other published site data. This analysis led to a determination of the suitability and relative importance of the findings. Graphical outputs were generated to illustrate data trends and meaningful observations. The results are organized into three sections: Field Evaluation Results, Questionnaire Responses, and Laboratory Testing Results.

6.1 Field Evaluation Results

In order to provide an understanding of how the evaluations were conducted, the field observations for the Donna Completion Impoundment are shown in Table 4. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specified that the problem was very prevalent at the site and carried a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicated that the problem was not observed at the site. By summing the rankings for each question, a total score was obtained out of 76 total points. Using this point system, a percentage was assigned, which was used as a comparison for the sites. To illustrate the conditions that were marked as Moderate or High at the Donna Completion Impoundment, pictures collected during the field visit are presented with notes describing the specific observations depicted.

Fifteen sites were evaluated in this study, each having site conditions with varying problem areas and levels of severity. The Donna site was selected for discussion because the observed deficiencies best illustrated the field evaluation methodology used throughout the study. The WVDEP indicated full awareness of the Donna site's conditions prior to and during the evaluation.

	Donna Completion Impoundment	Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	Yes			✓	1
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	No				4
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		2
9	Are there any areas where the liner is strained?	Yes			✓	1
10	Are there any areas where the liner has rock or debris on top of it?	Yes			✓	1
11	Is there any tear potential for the liner?	Yes			✓	1
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	Yes			✓	1
15	Are there any signs of pipes having significant sagging in line?	Yes		✓		2
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	No				4
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	Yes			✓	1

Total:	**45**	(Out of 76)
Percentage:	**59.2%**	

Table 4: Observation Checklist for Donna Completion Impoundment

Figure 4: Settlement Cracks in Anchor Trench

Figure 4 shows settlement cracks on the crest of the impoundment around the anchor trench. The significance of this observation is that these cracks can serve as pathways for water to infiltrate and saturate the soil. The wet soil adds weight to the top of the slopes and is a recognized mechanism for surface water infiltration leading to slope instability.

Figure 5: Bulges on Downstream Face

In Figure 5, the bulges underneath the liner indicate slope movements on the downstream face. The slope movements are evidence that the slope is no longer stable and that the ability for the structure to retain fluid has been compromised.

Figure 6: Slope Movement into Impoundment

Figure 6 depicts a slide into the impoundment. This slide is putting strain on the liner, endangering the anchor trench and increasing the tear potential for the liner. Additionally, the slide is just below the site access road and is thereby threatening the integrity of the roadway. The displacement of the liner threatens the entire containment system due to an increased potential for tears or punctures leading to impounding water loss.

Figure 7: Vegetation on Berm

The vegetation shown in Figure 7 poses a problem for inspection procedures. The excessive vegetative growth on the crest may conceal potential areas of concern. Thus, corrective actions may not be implemented at an appropriate time.

Figure 8: Rock and Debris on Liner

In Figure 8, a high amount of soil and rock is present on the liner, including a large boulder in danger of sliding into the impoundment or puncturing the liner. A possible consequence related to this problem is that the rock and debris add weight to the liner, straining the embedment of the anchor trench and posing a hazard to the containment system.

Figure 9: Anchor Trench Exposed

Figure 9 illustrates an improper anchor trench for the liner. With the liner exposed, the potential for wind uplift is greatly increased, which could lead to displacement of the liner and possible failure of the containment system.

Figure 10: Unsupported Pipe

Figure 10 shows unsupported pipes along the hillside above the access road. Due to this placement, there is a greater likelihood of damage to the pipes that may lead to leakage and uncontrolled release of liquids. Any leakage or rupture of the pipes which convey water or flowback fluids would have an environmental impact to the surface water and groundwater.

Figure 11: Downstream Slope Movement into Ditch

Figure 11 depicts a downstream slope movement, as evidenced by the bulges underneath the liner and the movement of the grade stakes. A stream is located at the top right-hand corner of the picture. Thus, the slope movement is encroaching on the stream and threatening to disrupt the natural ecosystem.

In order to determine the recurring problem areas across all sites, each question on the observational checklist was analyzed individually. First, the number of No, Low, Moderate, and High rankings was totaled for each question. Next, the total number of points for the question was computed by multiplying the number of occurrences in each category by the numerical ranking for that category, and then summing the values for all the categories. Lastly, the weighted average for the question was calculated by dividing the total number of points by the number of sites evaluated.

Table 5 contains a breakdown of each question on the observation checklist, including the number of occurrences for each category and the average ranking for each question. To further illustrate this procedure, the average ranking for Question 5 is presented. For Question 5, two sites received a No ranking (4 points), seven sites were ranked Low (3 points), three sites were ranked Moderate (2 points), and two sites were ranked High (1 point). To calculate the total points for Question 5, the number of sites is multiplied by the points for each category, and these values are summed, as shown below:

$$\text{Total number of points} = (2 \times 4) + (7 \times 3) + (3 \times 2) + (2 \times 1) = 37$$

Once the total number of points is calculated, the average ranking for the question is computed by dividing the total points by the total number of sites evaluated. Since the Shields FWI site was still under construction, no evaluation was completed for this site, resulting in a total of 14 sites. The average ranking calculation is illustrated below:

$$\text{Average ranking} = 37 \div 14 = 2.64$$

Using this procedure, the average ranking for each question was calculated. Since an average ranking of three or above corresponds to a Low Significance or No Occurrence, all rankings below three were considered recurring problem areas across all sites. These problem areas are highlighted in Table 5. As examples of the significance of these problem areas, pictures collected during the field evaluations from several sites are presented.

	Question	No (4)	Yes: Low (3)	Moderate (2)	High (1)	Average Ranking (Out of 4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	0	6	2	6	2.00
2	Are there any slope movements or animal burrows?	6	0	2	6	2.43
3	Are there any depressions, sinkholes, or slides into the pit present?	12	0	1	1	3.64
4	Are there any signs of mine subsidence on or adjacent to the embankment?	14	0	0	0	4.00
5	Are there any observed trees, tall weeds, or other vegetation?	2	7	3	2	2.64
6	Are there any seeps, wet zones, or losses of soil?	2	4	3	5	2.21
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	14	0	0	0	4.00
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	0	7	4	3	2.29
9	Are there any areas where the liner is strained?	11	1	0	2	3.50
10	Are there any areas where the liner has rock or debris on top of it?	1	11	1	1	2.86
11	Is there any tear potential for the liner?	10	2	0	2	3.43
12	Are there any deformations, cracks, or settlements around the anchor trench?	1	10	3	0	2.86
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	7	7	0	0	3.50
14	Are there any areas where the pipe is not properly supported?	6	4	1	3	2.93
15	Are there any signs of pipes having significant sagging in line?	11	0	2	1	3.50
16	Are there any signs of obstructions (trees, garbage, etc.)?	5	9	0	0	3.36
17	Are there any signs of water in ditch associated with pit?	4	8	1	1	3.07
18	Are there any obstructions around the discharge outlet?	14	0	0	0	4.00
19	Are there any signs of downstream slope movement into ditch?	12	1	0	1	3.71

Table 5: Average Ranking By Question

Figure 12: Surface Erosion at Mills-Wetzel

One problem area observed at all sites was surface erosion, found in Question 1 on the observation checklist. This problem was the most observed and, hence, received the lowest average ranking of 2.00. Figure 12 shows an example of the surface erosion present at the Mills-Wetzel Freshwater Impoundment. The gully shown formed rapidly, as evidenced by the lack of vegetation. The formation of the gully may be a result of excessive slope length or angle on the downstream face. The West Virginia Erosion and Sediment Control Field Manual states that terracing shall be constructed for each additional 50 vertical feet of slope and shall be a minimum of 10 feet wide. This best management practice was not followed on the Mills-Wetzel site.

Figure 13: Slope Movement at SHL 4

Question 2 on the checklist related to the prevalence of slope movements on the downstream face. Two sites were found to have moderate slope movements, and severe slope movements were present on six sites. Figure 13 shows a severe slope movement on the SHL 4 Centralized Pit. Above the slope movement, there was a significant amount of standing water on the crest, and signs of seepage were found in the form of wet soil inside the depleted soil zone. Slope movements are a problem because the structural integrity of the downstream face has been compromised. This slope failure is an example of a shallow face failure with characteristics including a pronounced scarp, zones of depletion and accumulation, and flanks defining the width of the failed soil, which is approximately where the WVU field personnel are located.

Figure 14: Woody Debris at SHL 2

Question 5 was used to evaluate any observed trees, tall weeds, or other vegetation, but the most prevalent concern was woody debris found in the fill of the slopes on all but two sites. Figure 14 depicts one instance of woody debris found on the SHL 2 Centralized Pit, where a log was compacted into the fill material on the downstream face of the pit. Woody debris is a problem due to the complications that may arise over time. One possible consequence is that the woody debris may form a barrier preventing the infiltration of water into the soil, causing erosion around the woody debris and on the slope directly below the debris. Another possible consequence is that the decomposition of the woody debris may result in pathways for surface water to seep into the slope, which reduces slope stability.

Figure 15: Seepage at Pribble

Seepage and wet zones (addressed in Question 6) were problem areas found at all but two sites. Figure 15 shows a seepage area on the downstream face of the Pribble Freshwater Impoundment. Due to the lack of vegetation on the slope, the area where the grass is growing depicts seepage and moving water on the slope. Thus, water is being transported through the soil, which may lead to instability in this area.

Figure 16: Liner Bulges at MWV

Another area of concern was bulges, tears, or holes in the liner, as indicated by Question 8. This problem was present at every site evaluated, with seven sites ranked as Low, four ranked as Moderate, and three ranked as High. Figure 16 depicts a liner stretched over an improperly prepared slope at the MWV Large Water Storage Pond 1. The underlying rock pressing on the liner and the strain caused by the bulges have a high likelihood to create tears or punctures in the liner and threaten the integrity of the containment system.

Figure 17: Debris on Liner at Flanigan

Question 10 involved the presence of rock or debris on top of the liner. This problem was observed at all sites except one. Figure 17 illustrates an example of a severe case of debris on the liner at the Flanigan Pit. At the Flanigan Pit as well as other sites visited, surface water was present on the berm and in the anchor trench. This practice is not in accordance with the West Virginia Erosion and Sediment Control Field Manual, which states that surface water must be diverted from the pit. The water washing the rock and debris into the pit adds weight to the containment system which can lead to strain and dislodgement of the anchor trench. Also, with the rock washing down over the liner, there is a higher potential for tears to form.

Figure 18: Improper Anchor Trench Embedment at Ball 1H

Deformations, cracks, and settlements around the anchor trench affect the integrity of the liner, and these concerns were addressed in Question 12 of the observation checklist. During field evaluations, this question was expanded to include the embedment of the anchor trench. All sites with the exception of one were found to have issues related to the anchor trench. Figure 18 illustrates improper anchor trench embedment at the Ball 1H Impoundment #2, as indicated by the liner protruding out of the ground. Improper embedment may result in an increased likelihood of the anchor trench pulling out of the soil, affecting the ability of the liner to retain fluids. Another potential issue is the possibility of wind lifting the liner and causing tears leading to a failure of the containment system.

Figure 19: Unsupported Pipe at Plum Creek

The last observed trend was unsupported pipes. Question 14 addressed this concern, and pipes were not properly supported on eight of the fourteen sites. Figure 19 depicts a severe instance at the Plum Creek South Fork Impoundment. At this site, the pipe was unsupported along the crest of the impoundment and the adjoining hillside, hanging across a depression. Associated areas of concern include the pipe having the freedom to roll or slide, the possibility of the pipe buckling or pinching and restricting flow, and the increased potential for gouges and leakage. Any leakage or rupture of the pipes which convey water or flowback fluids would have an environmental impact to the surface water and groundwater.

Table 6 shows the score for each site, ranked from lowest to highest. The Donna Completion Impoundment received the lowest score among all sites visited. Of the three sites constructed after the enactment of the Natural Gas Horizontal Well Control Act §22-6A, two sites (SHL 2 and SHL 3) were among the sites receiving the highest scores, although SHL 4 received a low score due to a slope failure on the downstream face. As a result, slope failures may be an issue for SHL 2 and SHL 3 in the future.

Site #	Site Name	Score
1	Donna Completion Impoundment	59.2%
2	Mills-Wetzel Freshwater Impoundment	68.4%
3	Pribble Freshwater Impoundment	72.4%
4	MWV Large Water Storage Pond 1	75.0%
5	SHL 4 Centralized Pit	76.3%
6	Ball 1H Impoundment #2	77.6%
7	Plum Creek South Fork	77.6%
8	MIP Freshwater Impoundment	80.3%
9	Larry Pad	82.9%
10	Donna Completion Pit	84.2%
11	Flanigan Pit	85.5%
12	Burch Ridge Wastewater Pit	88.2%
13	SHL 2 Centralized Pit	88.2%
14	SHL 3 Centralized Pit	88.2%

Table 6: Summary of Site Scores

While certain sites evaluated were known to have problems prior to the field evaluations, a visit to the Shields FWI site illustrated that current construction practices were characteristic of the problem areas observed in all the site visits. Thus, poor construction methods may be an initiator of the problems observed in the field. As an illustration of the construction practices at the Shields FWI site, pictures collected during the visit are presented.

Figure 20: Improper Compaction Practices

In Figure 20, the excavator is placing the lift of soil, and the lift is being compacted by a sheepsfoot roller, followed by a vibratory roller. According to the West Virginia Erosion and Sediment Control Field Manual, each lift shall be compacted by compaction equipment, sheepsfoot or pad roller, with compaction to visible non-movement of the embankment material. Thus, the use of both a sheepsfoot roller and a vibratory roller violates the best management practice in the manual. This construction practice is creating a shear plane on which water can move through the soil, possibly resulting in a slope failure. The sheepsfoot roller kneads the soil, interlocking the soil lifts and benefiting compaction efforts, but the vibratory roller is negating this interlocking by smoothing the soil.

Figure 21: Woody Debris in Soil Lift

Figure 21 depicts woody debris that has been compacted into the fill, which was a recurring area of concern on a majority of the sites evaluated. The West Virginia Erosion and Sediment Control Field Manual states that the fill material shall be clean mineral soil, free of roots, woody vegetation, stumps, sod, large rocks, or other objectionable material. As Figure 21 shows, this best management practice is not being followed at the Shields FWI site. Organic material compacted into the fill may create pathways for water to infiltrate the soil and cause internal erosion, which is a possible failure mode for the structure.

Figure 22: Excessive Lift Thickness

According to the West Virginia Erosion and Sediment Control Field Manual, soil lifts must be as thin as the suitable random excavated material will permit, typically from 6 to 12 inches. In Figure 22, the lift thickness is 16 inches, so this construction practice is not in accordance with the best management practice specified in the manual.

6.2 Questionnaire Responses

Once the evaluation of the site conditions was completed, the Site Operations and Infrastructure Evaluation was conducted. This evaluation consisted of questions for the WVDEP Office of Oil and Gas Inspector on site and/or the company representative. However, the company personnel present at the time of the field visit may or may not have been the principle site inspectors. The questionnaire covered the inspector training and background in regards to pit and impoundment safety, the operation and maintenance procedures for the site, and safety plans such as Emergency Action Plans (EAPs). The responses to the questionnaire are contained within the appropriate sites' Appendices. By comparing the responses across all sites, several conclusions were made about the overall inspection, operation, and maintenance of these structures.

Questions 1 and 11 concerned the type and frequency of company site inspections performed by field personnel and Professional Engineers (PEs). The responses from WVDEP inspectors and company representatives varied from every three days to once every two months. Thus, there is no set frequency for site inspections to be performed at pits and impoundments. Infrequent inspections allow for problem areas to progress and may lead to failure if the problems are not addressed in a timely manner. Another concern is the varied responses for the frequency of site inspections by a PE, which ranged from weekly to never. The PE for the site may offer additional insight into the site conditions, so irregular visits may result in problem areas going unnoticed or a delay in the implementation of corrective actions.

The background and type of training that the site inspectors possessed was the focus of Questions 2 and 3. A majority of the WVDEP inspectors had prior oil and gas industry experience, but neither the WVDEP inspectors nor the company representatives had any background in regards to the inspection of structures that impound water. Despite this lack of experience, the inspectors had not received any type of formal training. As a result, the inspectors may not fully understand how to identify problem areas that need to be addressed or the possible consequences associated with those issues. This lack of training may have significant impacts on the safety of the structure at all stages from construction through reclamation.

In addition to the lack of training for inspectors, the site inspection procedures were also found to contribute to the areas of concern observed during field evaluations. Responses to Questions 4 and 5 revealed that no standardized form existed for the WVDEP inspectors to refer to during inspections, which resulted in the inspectors using state regulations as a guide. Furthermore, the inspectors only focused on readily apparent problems such as slips and slides, while not recognizing the smaller issues such as tension cracks and slope deformation that may lead to large-scale problems.

Another important aspect of pit and impoundment safety is the development of safety and emergency plans, which was covered in Questions 6, 7, 8, 9, and 10. While the majority of sites had safety plans covering the normal daily operations, only four sites had plans in place in the event of an emergency. Emergency Action Plans (EAPs) were not required before the enactment of the Natural Gas Horizontal Well Control Act §22-6A, and under the new law, only centralized pits and impoundments are required to develop EAPs. As a result, the only sites evaluated in this study which were required to have EAPs were the SHL 2, SHL 3, and SHL 4 Centralized Pits. The company representative at the SHL sites was not aware that an EAP existed, was not trained on the EAP, and did not know whether the EAP had been evaluated for practicality in the event of an emergency. In addition, the EAP was not available on-site during the field evaluation. As a result, the company representative was unprepared to respond to an emergency, which could lead to the endangerment of lives or the destruction of property. In the EAP for the SHL sites, no evacuation protocol was provided, with the following justification:

> "*Due to the location of the pit described in this plan, no evacuation will be necessary in any case. The pit is a temporary structure that is fully incised in existing ground and that will be reclaimed once the Marcellus drilling in the surrounding region is complete. There are no nearby structures or facilities that would be affected by its breach or failure.*"

While the location of the pit may be remote, no inundation maps are provided in the EAP to support this statement. The SHL site also exhibited a slope failure as referenced in Figure 13. The incorporation of these maps would increase awareness of the full extent of the damage resulting from a failure and possibly highlight endangered areas that were not previously considered. Therefore, the addition of inundation maps to EAPs for all pits and impoundments constructed after the enactment of §22-6A would facilitate emergency planning for the structures. Additionally, the development of EAPs for all pits and impoundments, including those already constructed, would further benefit the safety of these structures and the surrounding areas.

6.3 Laboratory Testing Results

Once the laboratory testing was completed, the results from the various tests were compiled into tables and graphs in order to present the results in a convenient manner. Figure 23 illustrates the results of the Atterberg limits testing for each site. The range of moisture content values between the Plastic Limit (PL) and Liquid Limit (LL) is shown for each site, and the field moisture content is graphed as an illustration of the soil condition at the site. These values are displayed numerically in Table 7, where the results from the grain-size distribution and Atterberg limits tests for each site were used to classify the soil according to the ASTM D2487 Standard. According to the WVDEP Design and Construction Standards for Centralized Pits, the following soil classifications are acceptable for post §22-6A sites: Clayey Gravel (GC), Silty Gravel (GM), Clayey Sand (SC), Silty Sand (SM), Clay (CL), and Silt (ML). The laboratory testing results indicated that none of the post §22-6A sites met this requirement, and of the remaining 12 pre §22-6A sites, only one site met the soil standards.

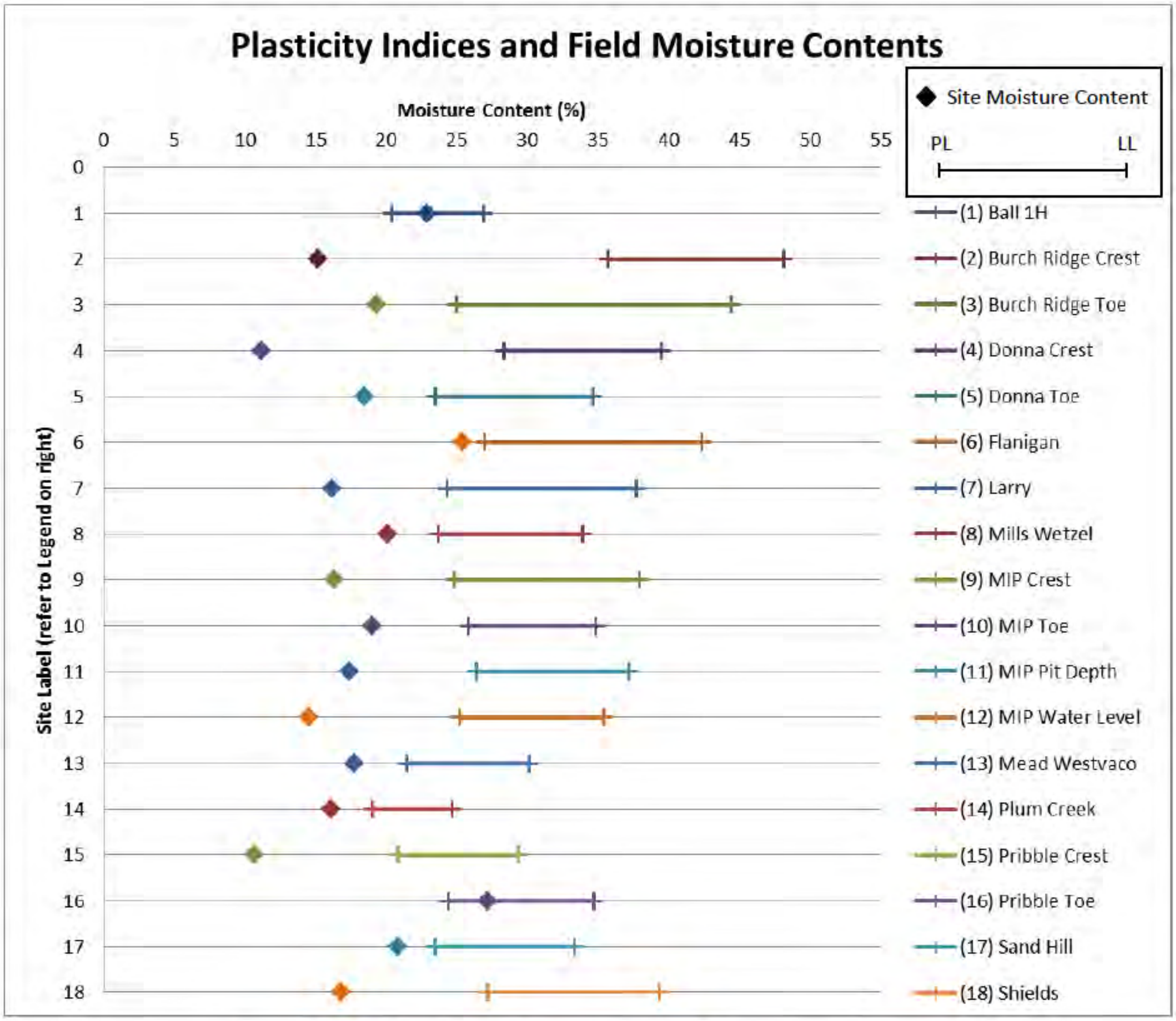


Figure 23: Atterberg Limits and Field Moisture Content

SITE SOIL CLASSIFICATION AND COMPLIANCE WITH WVDEP DESIGN AND CONSTRUCTION STANDARDS FOR CENTRALIZED PITS											
	Grain size distribution (ASTM D422)				Atterberg Limits (ASTM D4318)			Classification (ASTM D2487)		
Site Name	% Retained on #4 Sieve	% Retained on 200 Sieve	% Passing 200 Sieve	Gradation Profiles Cu &Cc	PL	LL	PI	Group Symbol	Group Name	Criterion Compliance to WVDEP Design and Construction Standards (GC,GM,SC,SM, CL, ML)
Ball 1H	11%	88%	12%	CU = 14.3 CC = 1.5	20.4	26.9	6.5	SC	Clayey Sand	YES & Not Required
Burch Ridge Crest	46.50%	98%	2%	CU = 13.7 CC = 1.5	35.7	48.1	12.4	SP	Poorly Graded Sand	NO & Not Required
Burch Ridge Toe	9.50%	90%	10%	CU = 18.8 CC = 2.3	25	44.4	19.4	SW-SC	Well Graded Sand w/ Clay	NO & Not Required
Donna Crest	25.50%	95%	5%	CU = 13.2 CC = 1.4	28.3	39.5	11.2	SW	Well Graded Sand	NO & Not Required
Donna Toe	18.50%	95.50%	4.50%	CU = 12.1 CC = 1.1	23.5	34.6	11.1	SW	Well Graded Sand	NO & Not Required
Flanigan	12%	94%	6%	CU = 11.5 CC = 1.3	27	42.3	15.3	SW-SC	Well Graded Sand w/ Clay	NO & Not Required
Larry	12.50%	96.50%	3.50%	CU = 9.0 CC = 1.1	24.3	37.7	13.4	SW	Well Graded Sand	NO & Not Required
Mills-Wetzel	12%	90.50%	9.50%	CU = 11.6 CC = 1.1	23.7	33.9	10.2	SW-SC	Well-Graded Sand w/ Clay	NO & Not Required
MIP Crest	16%	95%	5%	CU = 11.2 CC = 1.3	24.8	37.9	13.1	SW	Well-Graded Sand	NO & Not Required
MIP Toe	9%	91%	9%	CU = 15.6 CC = 1.4	25.8	34.8	9	SW-SC	Well Graded Sand w/ Clay	NO & Not Required
MIP Pit Depth	12.50%	94.50%	~5%	CU = 12.6 CC = 1.1	26.4	37.2	10.8	SW	Well Graded Sand	NO & Not Required
MIP Water Level	10%	93%	7%	CU = 13.1 CC = 1.1	25.2	35.4	10.2	SW-SC	Well Graded Sand w/ Clay	NO & Not Required
Mead Westvaco	13%	90.50%	9.50%	CU = 24.0 CC = 2.6	21.5	30.1	8.6	SW-SC	Well Graded Sand w/ Clay	NO & Not Required
Plum Creek	6%	86.50%	13.50%	CU = 12.3 CC = 0.885	19	24.7	PI = 5.7% (plots above A line)	CH	Fat Clay	NO & Not Required
Pribble Crest	41%	97%	3%	CU = 10.9 CC = 1.3	20.8	29.3	8.5	SW	Well Graded Sand	NO & Not Required
Pribble Toe	9.50%	89%	11%	CU = 31.7 CC = 3.3	24.4	34.7	10.3	SP-SC	Poorly Graded Sand w/ Clay	NO & Not Required
SHL (2, 3, 4)	46%	97%	3%	CU = 8.3 CC = 0.8	23.5	33.3	9.8	SP	Poorly Graded Sand	NO
Shields	26.50%	97.50%	2.50%	CU = 10.7 CC = 1.1	27.2	39.3	12.1	SW	Well Graded Sand	NO & Not Required

Table 7: Soil Classification

In addition to the classification testing, further soil testing was performed on six sites. During the field visits to these sites, WVU subcontractor Potesta and Associates, Inc. collected *in situ* field compaction and moisture content data using a nuclear density gauge. Readings were taken at various locations on each site, including the crest, mid-slope, and toe of the downstream face. Furthermore, WVU researchers collected two additional buckets of soil on these sites in order to perform laboratory compaction, hydraulic conductivity, and strength testing on the soil.

After performing the laboratory compaction tests for each of the six sites, a graph was generated showing the relationship between the dry density of the soil and the moisture content. Thus, the optimum dry density and moisture content for each site were determined. Saturation curves depicting the values where the soil was 100% and 90% saturated were computed using the following equation:

$$\gamma_{\mathrm{d}} = \frac{G_s \gamma_w}{1 + (\frac{\omega \mathrm{G_s}}{\mathrm{S}})}$$

In this equation, G_s is the specific gravity of the soil, as determined by the laboratory testing performed at WVU. γ_w is the unit weight of water, which is 62.4 lb/ft^3; ω is the moisture content of the soil, for which a range of values was used in accordance with the observed moisture contents at the site; and S is the degree of saturation, expressed as a decimal rather than a percentage. Entering these values into the equation yielded a range of dry densities (γ_{d}), which were plotted on the compaction graph. To better illustrate this procedure, a sample table showing the results of these calculations for the Mills-Wetzel Freshwater Impoundment is shown in Table 8.

S = 100%			
Moisture Content (%)	Specific Gravity	Water Density (lb/ft^3)	Dry Density (lb/ft^3)
6	2.78	62.4	148.67
8	2.78	62.4	141.91
10	2.78	62.4	135.74
12	2.78	62.4	130.08
14	2.78	62.4	124.87
16	2.78	62.4	120.07
18	2.78	62.4	115.62
20	2.78	62.4	111.49
22	2.78	62.4	107.64

Table 8: Saturation Calculations

The West Virginia Erosion and Sediment Control Field Manual requires that soil lifts shall be compacted to a standard Proctor density of at least 95% and that compaction effort shall not exceed optimum moisture contents. In order to compare the adherence of site construction practices to this standard, a standard Proctor density of 95% of the optimum dry density was computed for each site. To achieve proper compaction on-site, the moisture content should be on the dry side of the optimum moisture content. Therefore, the appropriate compaction density and moisture content range was plotted on the graphs, signified by red lines. Lastly, the field data obtained by the nuclear density gauge readings was organized by the location of the reading (crest, mid-slope, toe) and graphed to determine how the field compaction compared with the laboratory results. The graphs for the Mills-Wetzel Freshwater Impoundment and the Larry Pad are presented in Figures 24 and 25, respectively, while the graphs for the remaining sites are contained in the corresponding Appendices.

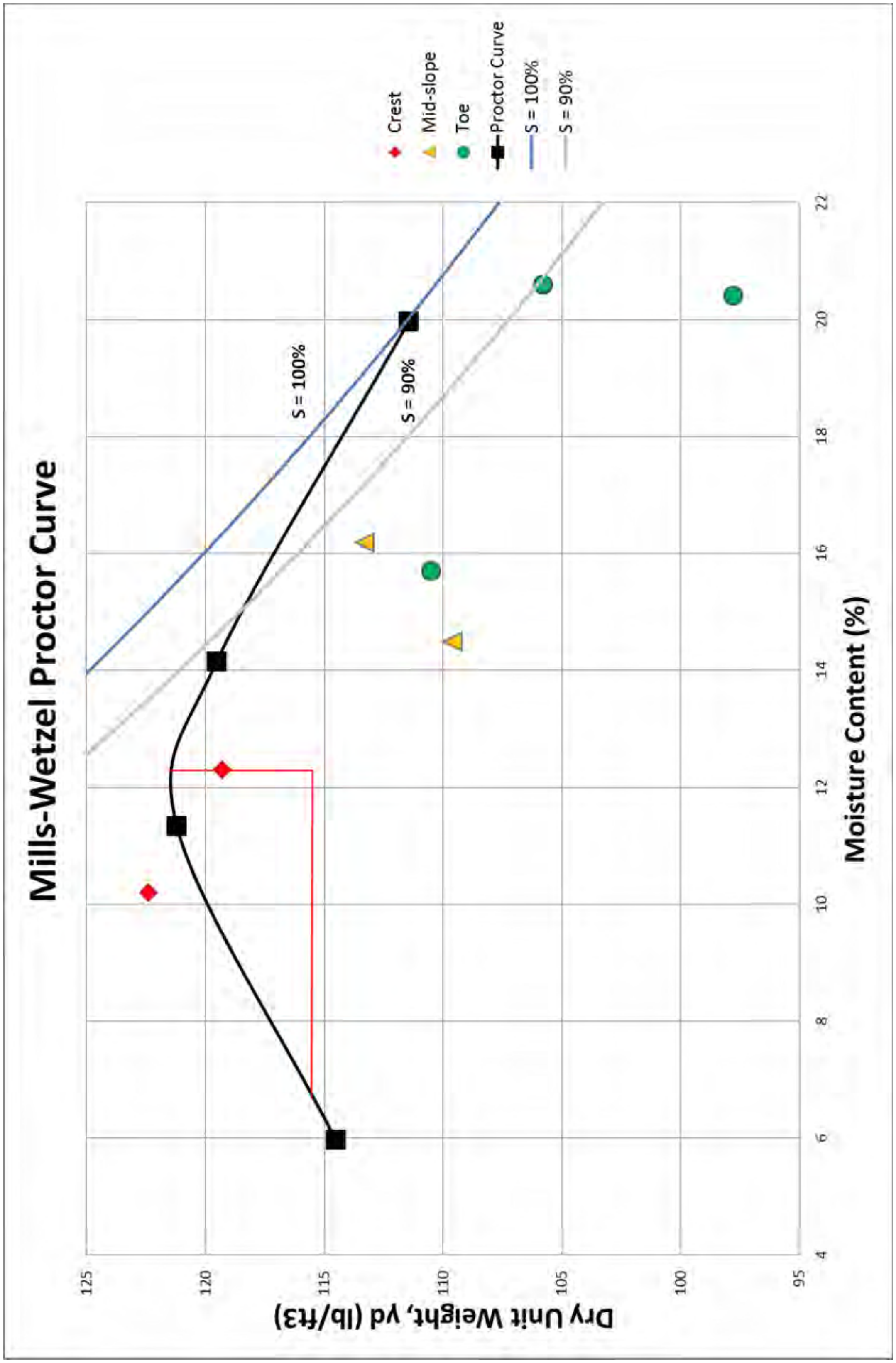


Figure 24: Mills-Wetzel Compaction

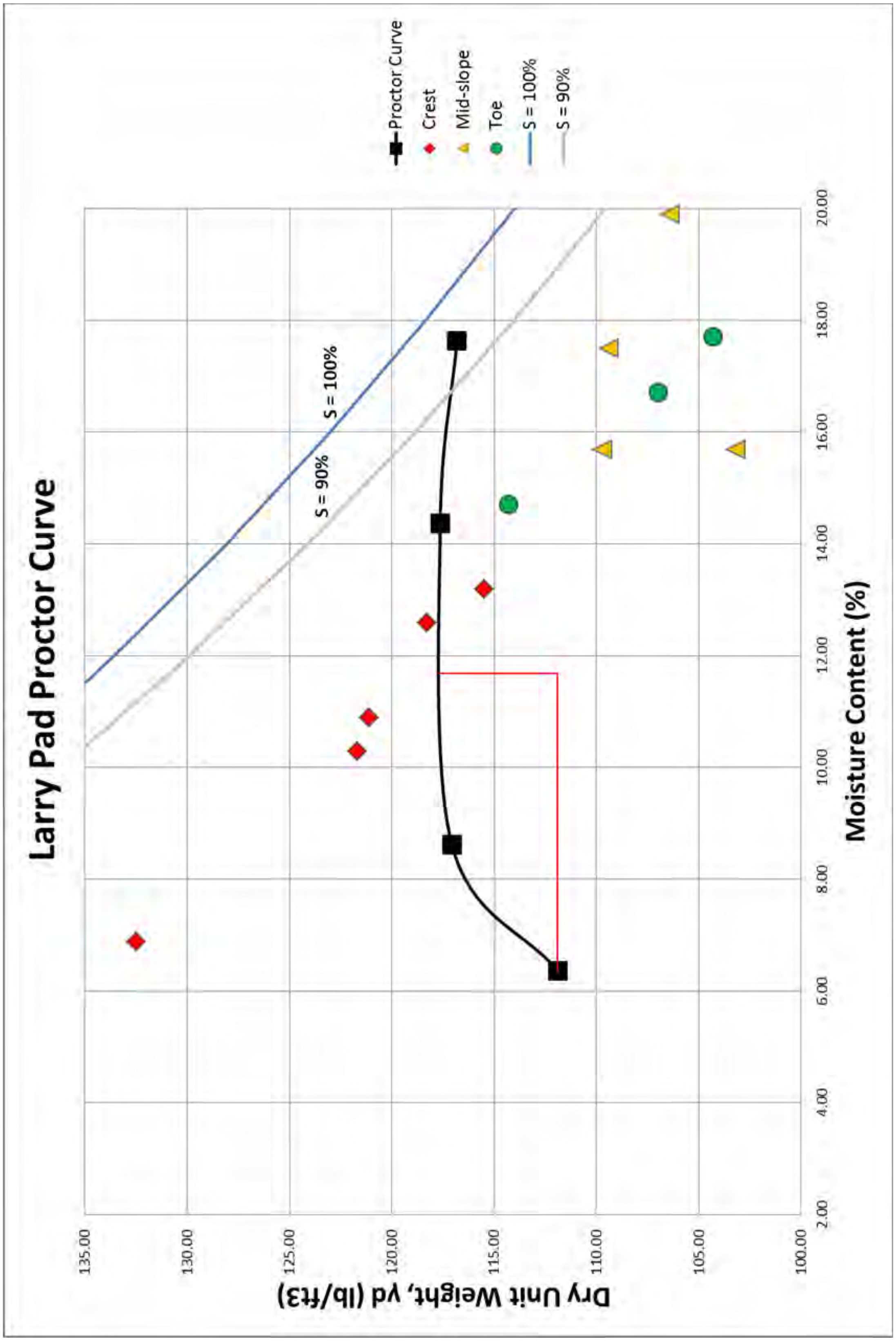


Figure 25: Larry Compaction

The compaction results show that the soils on the crests tended to be overcompacted, which would render the point on the wet side of optimum if compared with a higher compaction energy. Also, the soils at the mid-slopes and toes of the downstream faces were consistently under-compacted and contained moisture content values higher than optimum. As a result, the soils at these locations exhibited high saturation values. These conditions may result in lower unit weight and strength for the soil, leading to a higher potential for slope deformation, internal erosion, and seepage. These observations were found to be trends across all sites, as only three of the six sites contained data points within the appropriate compaction range. Only 14% of field data points were in compliance at two of the sites, and 22% were in compliance at the third site. Overall, a total of seventy data points were taken across all six sites, and only six points were within the acceptable compaction range, which corresponds to 8.5% compliance with WVDEP standards. Table 9 further illustrates these trends by comparing the optimum moisture content and density with the ranges observed in the field for each site. Based on these findings, the compaction practices at the sites evaluated do not conform to the best management practices specified in the West Virginia Erosion and Sediment Control Field Manual.

Site Name	Optimum Moisture Content	Optimum Density (lb/ft^3)	Field Moisture Content	Minimum Moisture Content	Maximum Moisture Content	Minimum Density (lb/ft^3)	Maximum Density (lb/ft^3)
MIP Freshwater Impoundment	17.2%	113.8	16.83%	11.5%	25.5%	72.0	112.6
Ball 1H Impoundment #2	15.6%	117.5	22.91%	14.8%	22.7%	95.9	113.1
Mills-Wetzel Freshwater Impoundment	12.2%	121.5	20.14%	10.2%	20.6%	97.8	122.4
SHL 2 Centralized Pit	13.7%	122.1	20.83%	7.1%	20.7%	86.3	109.5
SHL 3 Centralized Pit	13.7%	122.1	20.83%	6.5%	37.9%	88.0	115.5
SHL 4 Centralized Pit	13.7%	122.1	20.83%	11.4%	23.5%	89.1	120.4
Flanigan Pit	15.8%	114.5	25.39%	12.2%	18.5%	108.9	123.1
Larry Pad	11.7%	117.8	16.19%	6.9%	19.9%	103.2	132.5

Table 9: Laboratory and Field Moisture Content and Compaction Results

Once the Standard Proctor testing was completed, hydraulic conductivity and shear strength testing was performed. The hydraulic conductivity testing consisted of preparing two samples for each site, one compacted at the field moisture content and one compacted at the optimum moisture content determined by laboratory testing. After the hydraulic conductivity was determined, the sample compacted at the optimum moisture content was used for shear strength testing to obtain the internal angle of friction (ϕ). The results of these tests are contained in the appropriate site Appendices and are summarized in Table 10.

Site Name	ASTM Soil Classification	Hydraulic Conductivity		Angle of Friction (ϕ)
		Field (cm/s)	Lab (cm/s)	
MIP Freshwater Impoundment	SW-SC	3.0E-08	7.0E-08	40.2°
Ball 1H Impoundment #2	SC	6.4E-08	2.2E-08	43.7°
Mills-Wetzel Freshwater Impoundment	SW-SC	2.8E-08	2.0E-08	40.6°
SHL Centralized Pits	SP	1.5E-08	2.0E-08	40.2°
Flanigan Pit	SW-SC	1.2E-08	4.4E-09	42.6°
Larry Pad	SW	1.3E-08	1.8E-08	40.7°

Table 10: Hydraulic Conductivity and Friction Angle

The hydraulic conductivity values obtained were comparable between the field and laboratory conditions at each site. The differences in the values are attributed to the moisture contents under which the soils were prepared. The internal friction angles obtained indicate that the soils have high shear strength potential. Although the Ball 1H Impoundment #2 was the only site that contained soil conforming to the post §22-6A soil classification types specified by the WVDEP, these results indicate that the site soils are adequate if proper compaction is achieved. Therefore, the WVDEP should review the acceptable soil types specified in the WVDEP Design and Construction Standards for Centralized Pits.

After the completion of the laboratory testing at WVU, a comparison was made between the results obtained in the laboratory and the geotechnical investigations performed prior to the construction of the pit or impoundment. Since several permits lacked geotechnical investigation reports or were not provided at the time of the evaluation, the WVDEP permits that contained geotechnical investigations were analyzed. As an example, the review of the SHL 3 Centralized Pit is presented.

According to the SHL 3 permit, three boring holes were drilled at opposite ends and in the middle of the pit to evaluate the subsurface conditions at the site. The test borings were drilled to depths ranging from 26 feet to 42 feet, which corresponded to depths of five feet to 20 feet below the final elevation of the bottom of the pit. The results of the borings indicate that clay was found at the site to a depth of eight feet and that bedrock was found underlying the clay. Laboratory testing was performed on representative samples of the clay soil and soft bedrock, and the specific tests conducted were field moisture content, Atterberg limits, grain-size distribution, standard Proctor, and hydraulic conductivity.

The laboratory results in the permit contained values differing from those obtained through the testing performed at WVU for the SHL 3 Centralized Pit. The results from the three boring holes are compared with the results obtained by WVU in Table 11.

Property	Permit Results	WVU Results
Field Moisture Content	12.9% - 19.7%	20.83%
Plasticity Index	14 - 21	9.8
Soil Classification	Clay (CL)	Poorly Graded Sand (SP)
Optimum Density (lb/ft^3)	108.1 - 115.0	122.1
Optimum Moisture Content	14.7% - 17.6%	13.7%
Hydraulic Conductivity (cm/s)	5.8E-08	1.5E-08

Table 11: Comparison of Permit to WVU Laboratory Results for SHL 3

The reason for the discrepancies between the laboratory results may be linked to the field sampling procedures. According to the boring logs and testing results in the SHL 3 permit, the soil samples used for the engineering properties testing were taken from a depth of zero feet to five feet. The natural elevation of the site ranged from 1,308 feet to 1,325 feet, and the bottom of the pit was excavated to slope from elevation 1,298 feet to 1,294 feet. As a result, the soil from the top five feet of the excavation may not be representative of the fill material used to construct the bottom of the pit, the upstream faces, and the downstream faces. This observation may be supported by the testing performed on soil from a depth of 10 feet to 15 feet in one of the boring holes. While this soil was not classified, the optimum density was found to be 117.1 lb/ft^3, which is closer to the 122.1 lb/ft^3 determined by the testing performed by WVU personnel. Also, the optimum moisture content for this soil was 13.7%, which is in agreement with the optimum moisture content found by WVU for the site. Thus, the fill soil exhibits engineering properties that differ from those obtained by testing the top layers of the site soil prior to construction, which may be another factor contributing to the post-construction issues observed during the field evaluations. By expanding the geotechnical investigations to include the soils at pit depth, the appropriate engineering properties for the fill soil can be determined, thereby benefiting the overall stability of the pit or impoundment.

7.0 West Virginia Dam Safety

While the pits and impoundments evaluated in this study are not classified as dams, the quantities of fluids impounded by these structures are comparable to the storage volumes of dams. According to the Dam Control and Safety Act – WV Code 22-14 and the Dam Safety Rule (47CSR34), Sections 3.2 a and c denote that for incised reservoirs the volume of water retained below ground surface is not included in determining whether the pit or impoundment meets the dam criteria.

Table 12 contains the permitted storage volume for each site evaluated in the study. No site met the designation for status as a dam per the Dam Control and Safety Act.

Site Name	Permit Volume (Acre-Feet)	WV Dam Status
Donna Completion Impoundment	N/A	N/A
Mills-Wetzel Freshwater Impoundment	~20.56	No
Pribble Freshwater Impoundment	37.83	No
MWV Large Water Storage Pond 1	55.98	No
SHL 2 Centralized Pit	12.07	No
SHL 3 Centralized Pit	11.47	No
SHL 4 Centralized Pit	12.39	No
Ball 1H Impoundment #2	23.28	No
Plum Creek South Fork	45.85	No
MIP Freshwater Impoundment	7.32	No
Larry Pad	N/A	N/A
Donna Completion Pit	7.81	No
Flanigan Pit	12.41	No
Burch Ridge Wastewater Pit	11.19	No

Table 12: Comparison of Storage Volumes and Dam Requirements

The permit file for the Donna Completion Impoundment was not provided, and the permit file for the Larry Pad did not contain the storage volume; thus, no determination could be reached regarding these structures.

8.0 Conclusions and Recommendations

The goals of this study were to conduct engineering reviews of submitted and approved permit plans, construction practices, and geotechnical investigations of pits and impoundments associated with Marcellus Shale horizontal gas wells. The overall purpose was to ascertain and document the suitability of the construction and use of these structures in minimizing the potential environmental effects related to horizontal drilling.

After obtaining the permits for various pits and impoundments from the WVDEP, engineering reviews revealed areas of concern. The permit files provided to WVU researchers for 10 sites constructed prior to the enactment of the Natural Gas Horizontal Well Control Act §22-6A lacked geotechnical investigations. However, the permits for the three post §22-6A sites contained geotechnical information. Also, the WVDEP did not provide the permits for two sites at the time of the evaluation.

An analysis of the permits compared the permitted storage volumes with the storage volume requirements of dams as regulated by the WVDEP (WVCSR §22-14 & WVCSR §47-34). No sites were found to meet the requirements of a dam. However, the large quantities of water could be a potential hazard to the public and the environment if a failure were to occur because of the ridge-top location of several sites.

While issues were found in the development of the permits for the pits and impoundments, further concerns were observed during the field evaluations of the construction practices for these structures. The as-built construction dimensions were inconsistent with those found in the permit, including larger capacities, smaller berm widths, and steeper slopes than the permitted designs specified. These discrepancies create unknown stresses on the structure that may lead to instability. Additionally, quality control and assurance were found to be lacking during the construction of the structures, with no field compaction standards, improper soil types, excessive slope lengths, insufficient erosion control, and buried debris. Furthermore, the placement of pipelines and geosynthetic liners was found to be inconsistent with industry practices, posing potential safety and environmental concerns. Any leakage or rupture of the pipes or liner systems would have an adverse environmental impact to the surface water and groundwater. Therefore, the best management practices set forth by the WVDEP are not being adhered to throughout the construction process for pits and impoundments. A stricter application of WVDEP best management practices and an increased quality assurance and control process during construction and operation are recommended to significantly improve the long-term safety of these structures by mitigating possible problems.

Based on hydraulic conductivity and shear strength testing, the site soils in this study appear to be suitable even though none of the post §22-6A sites had soil conforming to the soil classifications specified by the WVDEP. Therefore, the soil classifications in the WVDEP Design and Construction Standards for Centralized Pits should be reviewed for applicability. A comparison of the field compaction data on six sites with the Standard Proctor results revealed that only 8.5% of the field data points met the optimum compaction density and moisture content range. Insufficient compaction density can result in lower shear strength potential, the development of subsurface erosion, and elevated pore water pressures in the slopes of pits and impoundments, which may contribute to slope instability.

On sites that provided geotechnical investigations, such as the SHL 3 Centralized Pit, discrepancies were found with the soil properties and classification. Properties such as field moisture content, plasticity index, optimum density, optimum moisture content, and soil classification differed from WVU laboratory testing results. These differences show that the soil reported by the company may not be representative of the fill material used to construct the structure, and may be a contributing factor to any post-construction issues. Therefore, thorough geotechnical property testing of site soil is recommended to evaluate all fill material at the pit or impoundment foundation depth rather than only the top soil layers excavated.

The operation and maintenance of the pits and impoundments contributed to the problems observed in the field. The frequency of site inspections varied across the sites, and no standardized method for performing the inspections existed. Also, the inspectors and field personnel had not received any formal training related to pit and impoundment inspection, resulting in the observed areas of concern being overlooked. Proper training for company and state inspectors is recommended so that the competency and quality of inspections can be increased and problem areas can be identified and addressed in an effective manner. Although §22-6A requires that all centralized pits and impoundments have EAPs, the EAPs must be evaluated for emergency situations, and all company personnel must be properly trained on how to use the plans. Also, the expansion of this requirement to sites constructed prior to the enactment of §22-6A is recommended to benefit the safety of these structures and the surrounding areas.

During the study, the WVDEP discussed that the MIP Freshwater Impoundment permit was to be evaluated for converting this pre §22-6A site to a centralized impoundment. This practice is not recommended for this site, or for any pre §22-6A sites, as these sites were not designed for this function and exhibited a high frequency of latent construction problems.

There were several construction deficiencies out of compliance with the West Virginia Erosion and Sediment Control Field Manual, and the WVDEP Design and Construction Standards for Centralized Pits. However, none of the deficiencies indicated imminent pit or impoundment failure potential at the time of the site visit. The problems identified do constitute a real hazard and present risk if allowed to progress, but all problems that were observed in the field could be corrected. Future construction, if done in conformance with the WVDEP guidelines, should pose minimal risk.

9.0 References

ASTM Standard D422, 2007. *Standard Method for Particle-Size Analysis of Soils.* ASTM International. West Conshohocken, PA. 2007. DOI: 10.1520/D0422-63R07. www.astm.org.

ASTM Standard D698, 2007e1. *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.* ASTM International. West Conshohocken, PA. 2007e1. DOI: 10.1520/D0698-07E01. www.astm.org.

ASTM Standard D854, 2010. *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D0854-10. www.astm.org.

ASTM Standard D2216, 2010. *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D2216-10. www.astm.org.

ASTM Standard D3080/D3080M, 2011. *Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.* ASTM International. West Conshohocken, PA. 2011. DOI: 10.1520/D3080_D3080M-11. www.astm.org.

ASTM Standard D4318, 2010. *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D4318-10. www.astm.org.

ASTM Standard D5856, 2007. *Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter*. ASTM International. West Conshohocken, PA. 2007. DOI: 10.1520/D5856-95R07. www.astm.org.

"Dam Safety Rule." WV Code §47-34. 1995.

"Dam Control and Safety Act." WV Code §22-14. 2009.

Design and Construction Standards for Centralized Pits. Office of Oil and Gas, West Virginia Department of Environmental Protection, 2011. http://www.dep.wv.gov/oil-and-gas/Documents/Centralized%20Pits--Design%20and%20Construction%20Standards.pdf.

Gabr, Mohammad A. *Laboratory Manual CE 351 Introductory Soil Mechanics*. Department of Civil and Environmental Engineering, West Virginia University, 1997.

"Natural Gas Horizontal Well Control Act." WV Code §22-6A. 2011.

West Virginia Erosion and Sediment Control Field Manual. Office of Oil and Gas, West Virginia Department of Environmental Protection, 2012. http://www.dep.wv.gov/oil-and-gas/Documents/Erosion%20Manual%2004.pdf.

WVU Review and Back-Check Memorandum, 2012. Project File contents of WVDEP review comments and resolutions.

Appendix A: WVU Project Personnel

A list of West Virginia University (WVU) personnel directly involved in this study is included below.

John Quaranta, Ph.D., P.E., Principal Investigator

- Provided oversight and direction of project
- Provided technical oversight concerning soil property testing on pits and impoundments
- Served as lead investigator for pits and impoundments
- Oversaw field sampling efforts for soil property testing

Richard Wise, MSCE, EIT, Research Engineer

- Selected, scheduled, and directed activities of the field staff to complete the planned sampling activities
- Served as primary point of contact for pits and impoundments team
- Assisted with preparation of reports and presentations to WVDEP

Andrew Darnell, MSCE, EIT, Research Engineer

- Assisted with selecting and scheduling to complete the planned sampling activities
- Oversaw and assisted with preparation of reports and presentation to WVDEP

Michael Kulbacki, BSCE, Research Associate

- Conducted field sampling activities
- Assisted with compilation and reporting of field and laboratory data and results

Matthew Idleman, BSCE, Research Associate

- Conducted field sampling activities
- Assisted with compilation and reporting of field and laboratory data and results

Justin Pentz, BSCE, Research Associate

- Assisted with compilation and reporting of field and laboratory data and results

Appendix B: Donna Completion Pit

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Donna Completion Pit
Date of Site Evaluation: 7/12/12

Permit Observations / Anomalies:

Measurements of the field as-built construction were consistent with the permitted design, except for the berm width. The berm crest width measured a minimum width of 9.83 feet, while the permitted dimension is 17 feet in width. Thus, berm width is a deficiency.

The as-built dimensions of the pit were in agreement the permitted dimensions. The permitted size is 142 feet wide by 355 feet long, and the as-built dimensions are 141 feet wide by 357 feet long.

Hydrology

Visual evaluation of the berm and downstream faces found several instances of rill and gully formation. Furthermore, rock movement was noted at the crest and on the slopes. No slope movements were observed on the downstream faces as a result of erosion control measures.

Containment

The liner for the pit is an HDPE geomembrane. Bulges in the liner were noticed at several locations, and there was a minor amount of soil and rock on the liner. The anchor trench was exposed in places due to insufficient embedment, and settlement cracks were found on the berm near the anchor trench.

Slope

Rills, gullies, and rock movement were observed in several locations on the downstream faces. Woody debris was found in the fill on the downstream slopes. Erosion control fabric was in place on the eastern downstream face.

Other Comments

There was an unsupported pipe that ran along the roadway and berm. One pipe was lying across the safety fence. A trash pile was found in a ditch below the pit. The thickness of the HDPE liner appeared to be thinner than 60 millimeters. No company representative was present for the site evaluation.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/12/12 9:00 AM	County	Marion	Company	Energy Corporation of America
WEATHER Mostly Sunny	Latitude	N 39° 34' 29.5"	Pit Name	Donna Completion Pit
	Longitude	W 80° 17' 33.1"	ID No.	

A. PERMIT INFORMATION

Pit Width (ft.)	142 ft.	Minimum Berm Crest Width (ft.)	17 ft.	Construction Type	Incised Crest
Pit Length (ft.)	355 ft.	Upstream Slope (H:V)	3:1	Liner Type	HDPE
Depth (ft.)	14.5 ft.	Downstream Slope (H:V)	2:1	Date Built	2011
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	141 ft.	Berm Crest Width (ft.)	9.83 ft.	Crest Height (ft.)	
Pit Length (ft.)	357 ft.	Upstream Slope (H:V)	3:1	Up Slope Length (ft.)	12 ft.
Depth (ft.)		Downstream Slope (H:V)		Down Slope Length (ft.)	64.5 ft.
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

	C. PIT/IMPOUNDMENT	Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			Rills, rock movement at crest and face
2	Are there any slope movements or animal burrows?	No				
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Woody debris
6	Are there any seeps, wet zones, or losses of soil?	No				
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes		✓		Soil/rock on top of liner
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes		✓		Anchor trench exposed in places, cracking
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	Yes			✓	Unsupported along road
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Bottles in pit
17	Are there any signs of water in ditch associated with pit?	No				
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

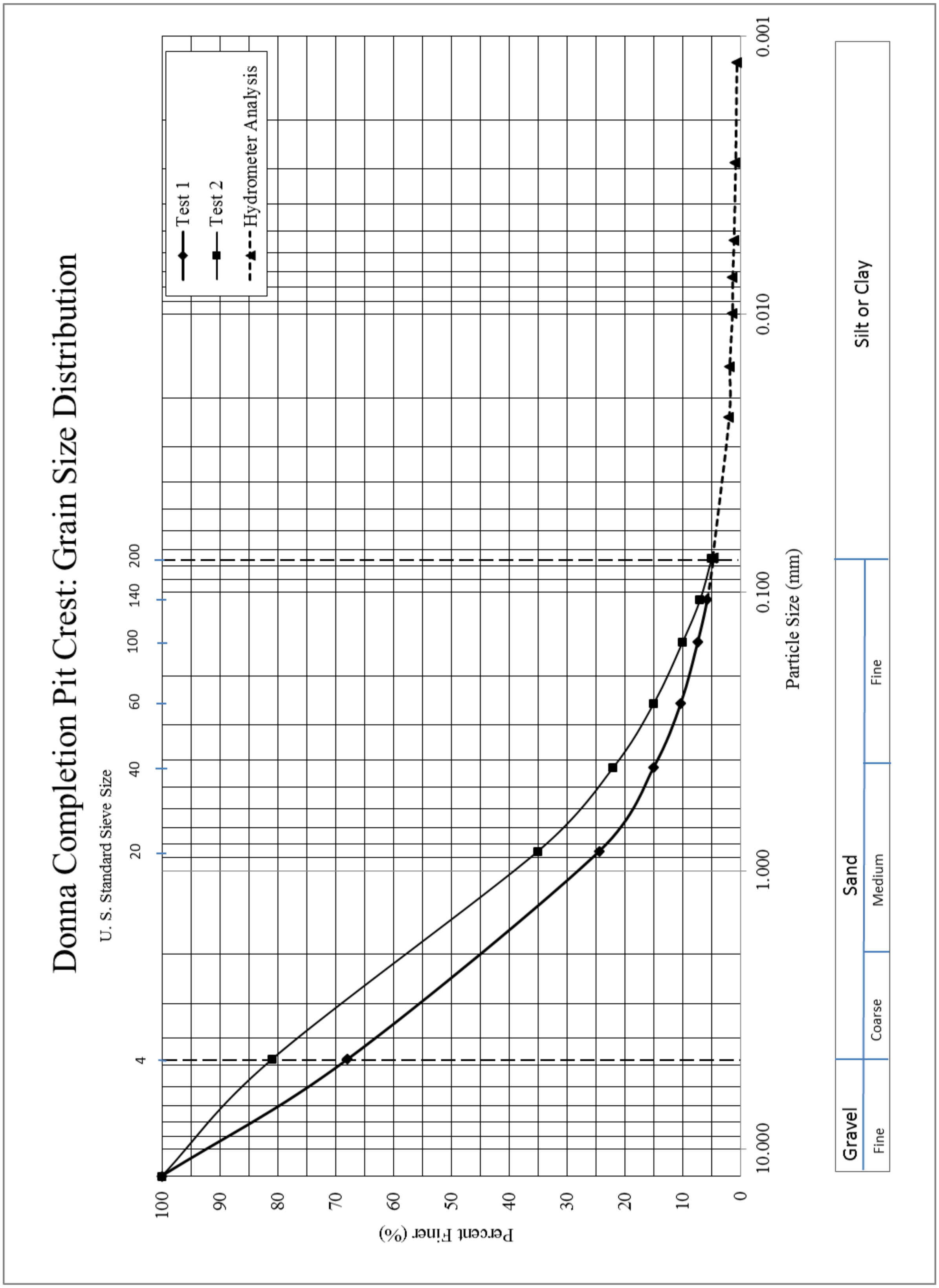
WVU (Name / Signature) Andrew Darnell	DATE 7/12/12
WVDEP (Name / Signature) William Hendershot	7/12/12
Company Representative (Name / Signature)	

Site Operations & Infrastructure Evaluation	
Date: 7/12/12	Pit/Impoundment Name: Donna Completion Pit
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Routine inspection performed once every two months
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Worked in the oil and gas industry 21 years but has no formal state training
3	How many years of training does the inspector have in evaluating pits/impoundments? 0, he has been on the job for 36 months
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No standardized form, he performs general inspections looking for slips
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? The state of West Virginia
6	Are there safety and emergency procedures for the pit/impoundment? He doesn't know of any procedures, but he reports any issues
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? He believes there is one, but he doesn't know it
8	Has the pit/impoundment inspector been trained on how to use the EAP? No
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) He doesn't know
10	Does the company have a policy on pit/impoundment safety? Would have to contact the company to find out
11	How frequently does a Professional Engineer inspect the site? Every 7 days
12	Other comments: Liner is thinner than 60 mil There are trees marked to be cut down on the eastern downstream face Woody debris is present on the berm and downstream faces There is a trash pile in a ditch below the pit

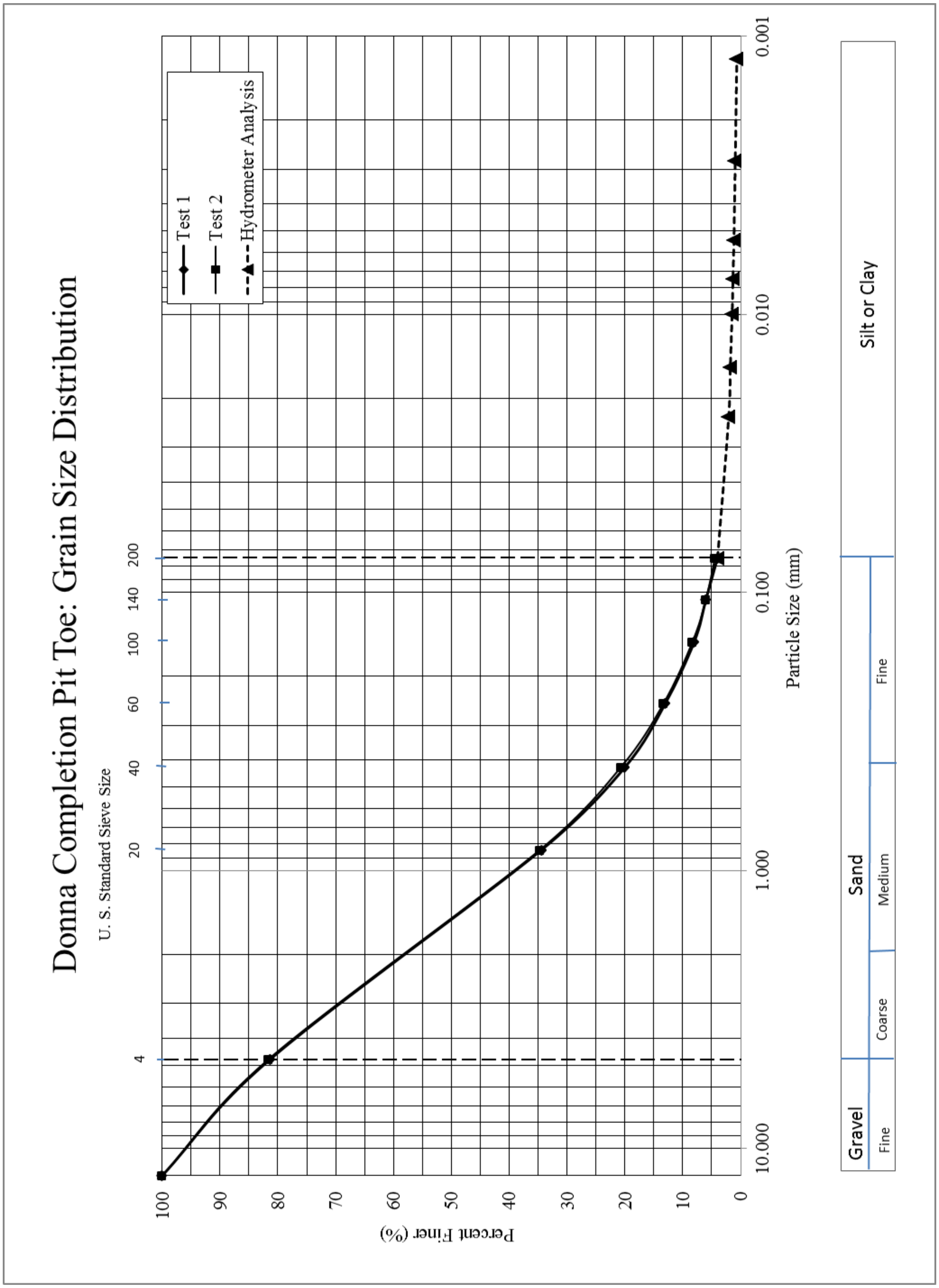
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

Donna Completion Pit		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low <33%	Moderate 33 - 66%	High >66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			3
2	Are there any slope movements or animal burrows?	No				4
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	No				4
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		2
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes		✓		2
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes		✓		2
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	Yes			✓	1
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	No				4
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

Total:	**64**	(Out of 76)
Percentage:	**84.2%**	



Donna Completion Pit Crest: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


Donna Completion Pit Toe: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

Appendix C: Donna Completion Impoundment

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Donna Completion Impoundment
Date of Site Evaluation: 7/12/12

Permit Observations / Anomalies:

The as-built dimensions of the impoundment measured 276 feet long by 129 feet wide, and the berm width was 10 feet. No permit information was provided for this impoundment.

Hydrology

Numerous slips, settlements, and slope movements were observed on the berm, upstream face, and downstream face. A large slip was found on the upstream face, where a large rock was sliding into the impoundment. Also, downstream slope movement into the ditch was noted.

Containment

The liner for the impoundment is an HDPE geomembrane. Bulges in the liner were noticed at several locations, and there were holes in the liner where posts had been removed. The liner was strained in several areas as a result of the slips and settlements, increasing tear potential. The anchor trench was exposed in places due to insufficient embedment. A high amount of rock and soil were on top of the liner, including the large rock in the slip on the upstream face.

Slope

Slips, settlements, and slope movements were observed in multiple locations on both the upstream and downstream faces. The soil on the downstream slopes appeared to be uncompacted.   Cracks were also present at the crest of the slope. The slope movements at the impoundment were significant and may lead to a failure.

Other Comments

Garbage was found in the impoundment. Vegetation was observed on the berm. Floatation devices were tied up and covered by the fencing. No company representative was present for the site evaluation.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/12/12 10:15 AM WEATHER Mostly Sunny	County	Marion	Company	Energy Corporation of America
	Latitude	N 39° 34' 29.5"	Pit Name	Donna Impoundment
	Longitude	W 80° 17' 33.1"	ID No.	

A. PERMIT INFORMATION

Pit Width (ft.)		Minimum Berm Crest Width (ft.)		Construction Type	Incised
Pit Length (ft.)		Upstream Slope (H:V)		Liner Type	HDPE
Depth (ft.)		Downstream Slope (H:V)		Date Built	
Freeboard(ft.)				Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	129 ft.	Berm Crest Width (ft.)	10 ft.	Crest Height (ft.)	
Pit Length (ft.)	276 ft.	Upstream Slope (H:V)		Up Slope Length (ft.)	13 ft.
Depth (ft.)		Downstream Slope (H:V)		Down Slope Length (ft.)	14 ft.
Freeboard (ft.)	3 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	Yes	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	Settlements on upstream face, berm
2	Are there any slope movements or animal burrows?	Yes			✓	Upstream face
3	Are there any depressions, sinkholes, or slides into the pit present?	Yes			✓	Slip on upstream face
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Grown up around fence
6	Are there any seeps, wet zones, or losses of soil?	No				
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		Bulges, holes from driven posts
9	Are there any areas where the liner is strained?	Yes			✓	Slips, settlements
10	Are there any areas where the liner has rock or debris on top of it?	Yes			✓	Large rock in slip
11	Is there any tear potential for the liner?	Yes			✓	Holes, strains
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Anchor trench exposed in places, cracking
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	Yes			✓	Unsupported
15	Are there any signs of pipes having significant sagging in line?	Yes		✓		Sagging in line
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Garbage
17	Are there any signs of water in ditch associated with pit?	No				
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	Yes			✓	Ground uncompacted

WVU (Name / Signature) Richard Wise	DATE 7/12/12
WVDEP (Name / Signature) William Hendershot	7/12/12
Company Representative (Name / Signature)	

Site Operations & Infrastructure Evaluation	
Date: 7/12/12	Pit/Impoundment Name: Donna Completion Impoundment
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Routine inspection performed once every two months
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Worked in the oil and gas industry 21 years but has no formal state training
3	How many years of training does the inspector have in evaluating pits/impoundments? 0, he has been on the job for 36 months
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No standardized form, he performs general inspections looking for slips
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? The state of West Virginia
6	Are there safety and emergency procedures for the pit/impoundment? He doesn't know of any procedures, but he reports any issues
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? He believes there is one, but he doesn't know it
8	Has the pit/impoundment inspector been trained on how to use the EAP? No
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) He doesn't know
10	Does the company have a policy on pit/impoundment safety? Would have to contact the company to find out
11	How frequently does a Professional Engineer inspect the site? Every 7 days
12	Other comments: Holes in HDPE liner where posts were driven in for the fence and removed Fence runs through center of berm Fish in impoundment

The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

Donna Completion Impoundment		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	Yes			✓	1
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	No				4
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		2
9	Are there any areas where the liner is strained?	Yes			✓	1
10	Are there any areas where the liner has rock or debris on top of it?	Yes			✓	1
11	Is there any tear potential for the liner?	Yes			✓	1
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	Yes			✓	1
15	Are there any signs of pipes having significant sagging in line?	Yes		✓		2
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	No				4
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	Yes			✓	1

Total:	**45**	(Out of 76)
Percentage:	**59.2%**	

Appendix D: Pribble Freshwater Impoundment

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Pribble Freshwater Impoundment
Date of Site Evaluation: 7/16/12

Permit Observations / Anomalies:

Measurements of the field as-built construction agreed with the minimum berm crest width; the permit specified a minimum berm width of 24 feet, and the measured berm widths were all greater than 25 feet.

The as-built dimensions of the impoundment exceeded the permitted dimensions. Therefore, the impoundment has a larger volume capacity than permitted. The permitted size is 260 feet wide by 390 feet long, while the as-built dimensions are 271.5 feet wide by 405 feet long. As a result, the as-built size and volume exceed the permit.

Hydrology

The visual evaluation of the impoundment found several areas requiring attention. Numerous rills, gullies, and slope movements were observed on the northern, western, and eastern downstream faces. Also, seepage was noted on the downstream faces, as evidenced by increased vegetation growth on the slope and discharge from the pipes on the western and eastern faces. Surface erosion was observed as a result of drainage from the pipes on the downstream faces. Additionally, there was a storage tank collecting water seeping off the eastern face, and the tank was beginning to overflow at the time of the site evaluation. Water was found in the ditch at the toe of the eastern face.

Containment

The liner for the impoundment is a 30-millimeter geomembrane. Several patches were found on the liner at the upstream face, as well as poor seals on the seams. Additionally, small tears were observed, and a minor amount of rock and soil was found on the liner, increasing the tear potential. Bulges in the liner were also noticed at a few locations. The anchor trench was exposed in places due to insufficient embedment.

Slope

Rills, gullies, and cracks were observed in multiple locations on the downstream faces. Slope movements were found below the access road on the northern face, above and below the tram road on the western face, and on the eastern face. Woody debris was prevalent on the downstream faces in the fill material as well as resting on top of the fill in several locations.

Other Comments

Trash was found in the impoundment. Gouges were observed in an unsupported pipe on the western face. There was a drainage pipe that directed water over the western face, causing gully formation.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/16/12 11:00 AM	County	Wetzel	Company	Stone Energy Company
	Latitude	N 39° 41' 9.28"	Pit Name	Pribble Freshwater Impoundment
WEATHER Mostly Sunny	Longitude	W 80° 49' 16.3"	ID No.	Permit #: WMP-00277

A. PERMIT INFORMATION

Pit Width (ft.)	260 ft.	Minimum Berm Crest Width (ft.)	24 ft.	Construction Type	Hill Crest
Pit Length (ft.)	390 ft.	Upstream Slope (H:V)	2:1	Liner Type	30 mil.
Depth (ft.)	24 ft.	Downstream Slope (H:V)	2:1	Date Built	
Freeboard(ft.)	1 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	271.5 ft.	Berm Crest Width (ft.)	>25 ft.	Crest Height (ft.)	65.6 ft.
Pit Length (ft.)	405 ft.	Upstream Slope (H:V)	2:1	Up Slope Length (ft.)	37.5 ft.
Depth (ft.)		Downstream Slope (H:V)	2.5:1	Down Slope Length (ft.)	181.5 ft., 84 ft.
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	Gullies on downstream face, erosion at pipe
2	Are there any slope movements or animal burrows?	Yes			✓	Above tram road
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes		✓		Woody debris on faces
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	Discharge from pipe
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes			✓	Many repairs, poor seams
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rocks and soil
11	Is there any tear potential for the liner?	Yes	✓			Seams, small tears
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			HDPE exposed
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Gouges in pipe on downstream face
14	Are there any areas where the pipe is not properly supported?	Yes	✓			Unsupported
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Bottles in impoundment
17	Are there any signs of water in ditch associated with pit?	Yes	✓			
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

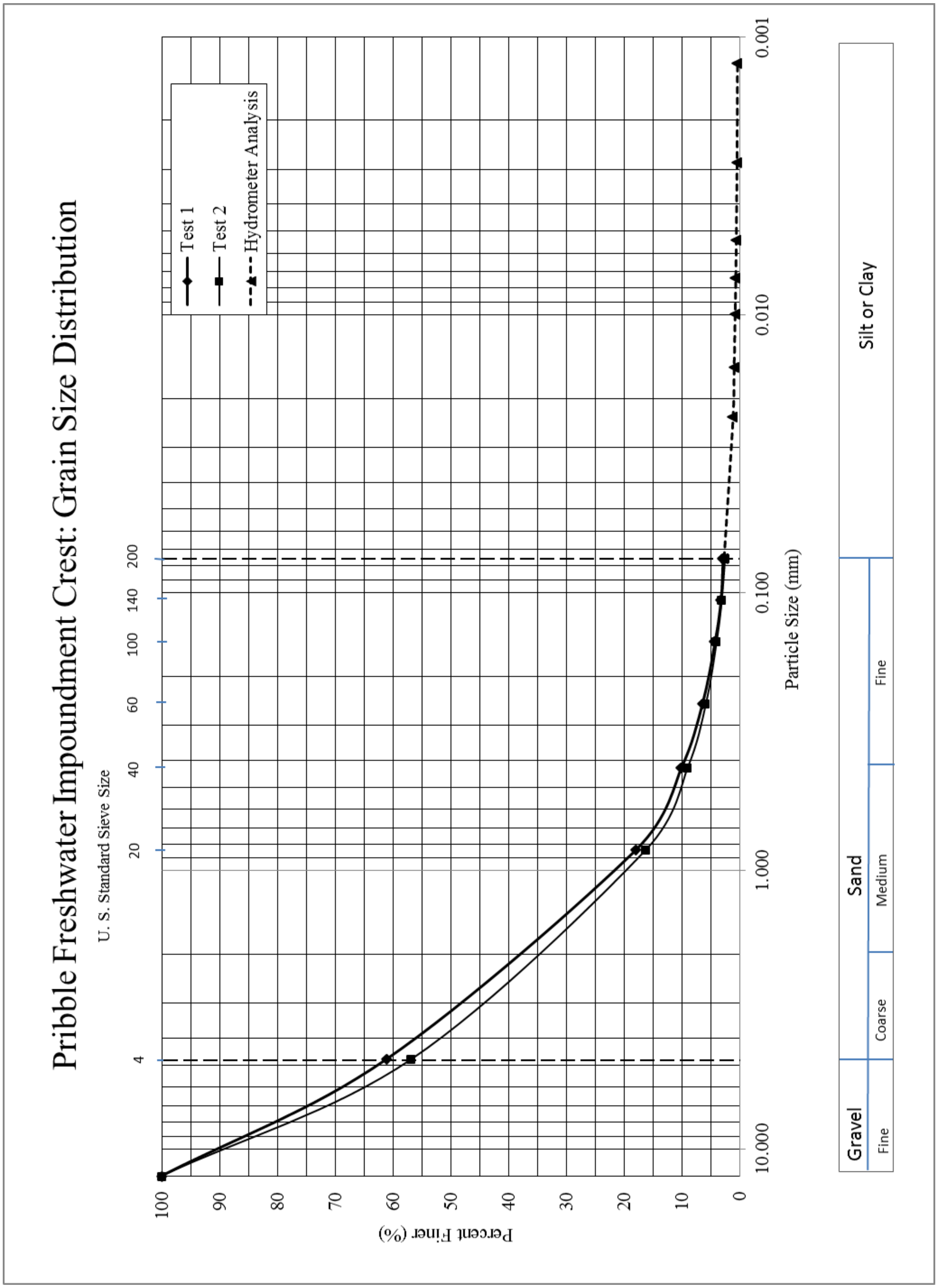
WVU (Name / Signature) Andrew Darnell	DATE 7/16/12
WVDEP (Name / Signature) Derek Haught	7/16/12
Company Representative (Name / Signature) Ron Shafer	7/16/12

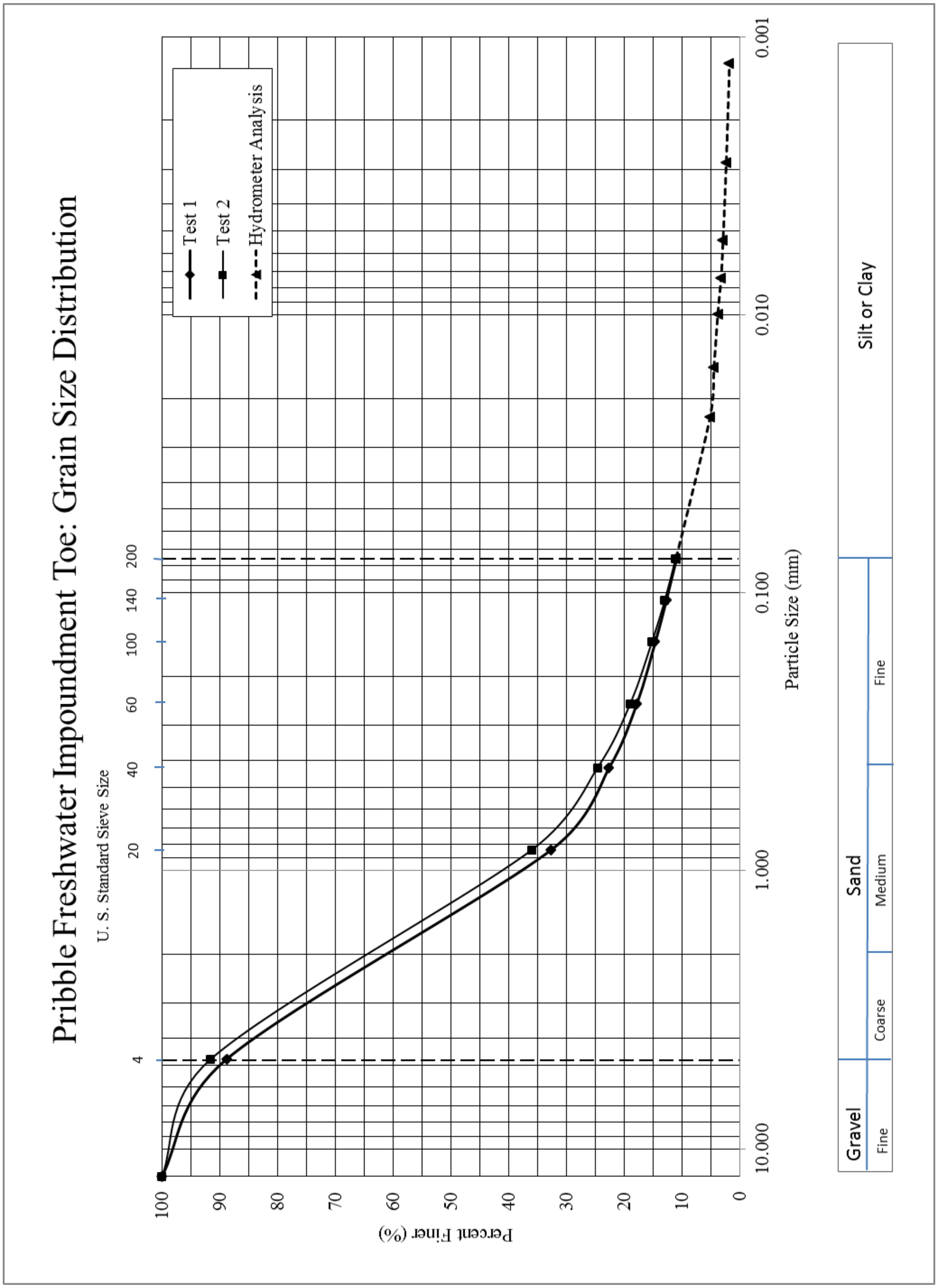
Site Operations & Infrastructure Evaluation	
Date: 7/16/12	Pit/Impoundment Name: Pribble Freshwater Impoundment
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Walking and visual inspections, no set frequency (once a month usually)
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Worked in oil and gas industry for 10 years, has no specific training
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? Uses a well report form, nothing specific to pits and impoundments
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? General form developed around 50 years ago
6	Are there safety and emergency procedures for the pit/impoundment? Life vests, fences, notifications
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? No action plan except for fixing leaks and damage control, best construction practices
8	Has the pit/impoundment inspector been trained on how to use the EAP? No
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) No
10	Does the company have a policy on pit/impoundment safety? An alarm goes off when the water level gets too high, and they pump out water
11	How frequently does a Professional Engineer inspect the site? Once a year, consultants do bi-monthly inspections
12	Other comments: Erosion problems on slope originally outside construction zone, didn't experience problems until after construction, engineering fix on erosion Previous slip on face caused by liner breaches, patched bad seams and corrected slip Company representative mentioned that there was no way to communicate downstream if there was a failure

The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

Pribble Freshwater Impoundment		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes		✓		2
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	1
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes			✓	1
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	Yes	✓			3
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	Yes	✓			3
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

Total:	**55**	(Out of 76)
Percentage:	**72.4%**	


Pribble Freshwater Impoundment Crest: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


Pribble Freshwater Impoundment Toe: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
100
90
80
70
60
50
40
30
20
10
0
Percent Finer (%)
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

Appendix E: Burch Ridge Wastewater Pit

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Burch Ridge Wastewater Pit
Date of Site Evaluation: 7/16/12

Permit Observations / Anomalies:

The field as-built construction of the pit measured consistently with the permitted design. The berm crest width measured a minimum width of 20 feet, in accordance with the permit.

The as-built dimensions of the pit were reasonably close to the permitted dimensions. The permitted size is 158.5 feet wide by 378.9 feet long, while the as-built dimensions are 165 feet wide by 375 feet long.

Hydrology

A visual evaluation of the berm found tension cracks forming along the crest and at the toe of the downstream faces. Also, rills and gullies were observed at various locations on the downstream faces due to surface erosion. While there were no observed slope movements, the lack of vegetation on the downstream faces makes those faces susceptible to additional surface erosion and possible movements. Furthermore, moist soil was found along the toe of the downstream faces.

Containment

The liner for the pit is a 60-millimeter geomembrane. Patches were found on the liner at the upstream face. Bulges in the liner were also noticed at a few locations. Settlement cracks were found around the anchor trench of the geomembrane, and the anchor trench was exposed in places.

Slope

Rills, gullies, and cracks were observed in multiple locations on the downstream faces, but no slope movements were found. Woody debris was prevalent on the downstream faces in the fill material as well as resting on top of the fill in several locations.

Other Comments

There was an unsupported pipe along the access road.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/16/12 1:00	County	Marshall	Company	Gastar Exploration USA, Inc.	
	Latitude	N 39° 45' 15.6"	Pit Name	Burch Ridge Wastewater Pit	
WEATHER Mostly Sunny	Longitude	W 80° 48' 17.4"	ID No.	051-01508	

A. PERMIT INFORMATION

Pit Width (ft.)	158.5 ft.	Minimum Berm Crest Width (ft.)	20 ft.	Construction Type	Incised
Pit Length (ft.)	378.9 ft.	Upstream Slope (H:V)	2:1	Liner Type	60 mil
Depth (ft.)	15 ft.	Downstream Slope (H:V)	2:1	Date Built	5/2012
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	165 ft.	Berm Crest Width (ft.)	20 ft.	Crest Height (ft.)	49.7 ft.
Pit Length (ft.)	375 ft.	Upstream Slope (H:V)	1.2:1	Up Slope Length (ft.)	11 ft.
Depth (ft.)		Downstream Slope (H:V)	2.1:1	Down Slope Length (ft.)	115.5 ft., 75 ft
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

	C. PIT/IMPOUNDMENT	Existence Yes/No/NA	If YES then Evaluate Significance of Problem: Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes		✓		Gullies, cracks at crest Little vegetation
2	Are there any slope movements or animal burrows?	No				
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes			✓	Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			Moist soil at toe
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	No				
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Anchor trench exposed, cracks in places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	Yes	✓			Unsupported
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	No				
17	Are there any signs of water in ditch associated with pit?	N/A				
18	Are there any obstructions around the discharge outlet?	N/A				
19	Are there any signs of downstream slope movement into ditch?	N/A				

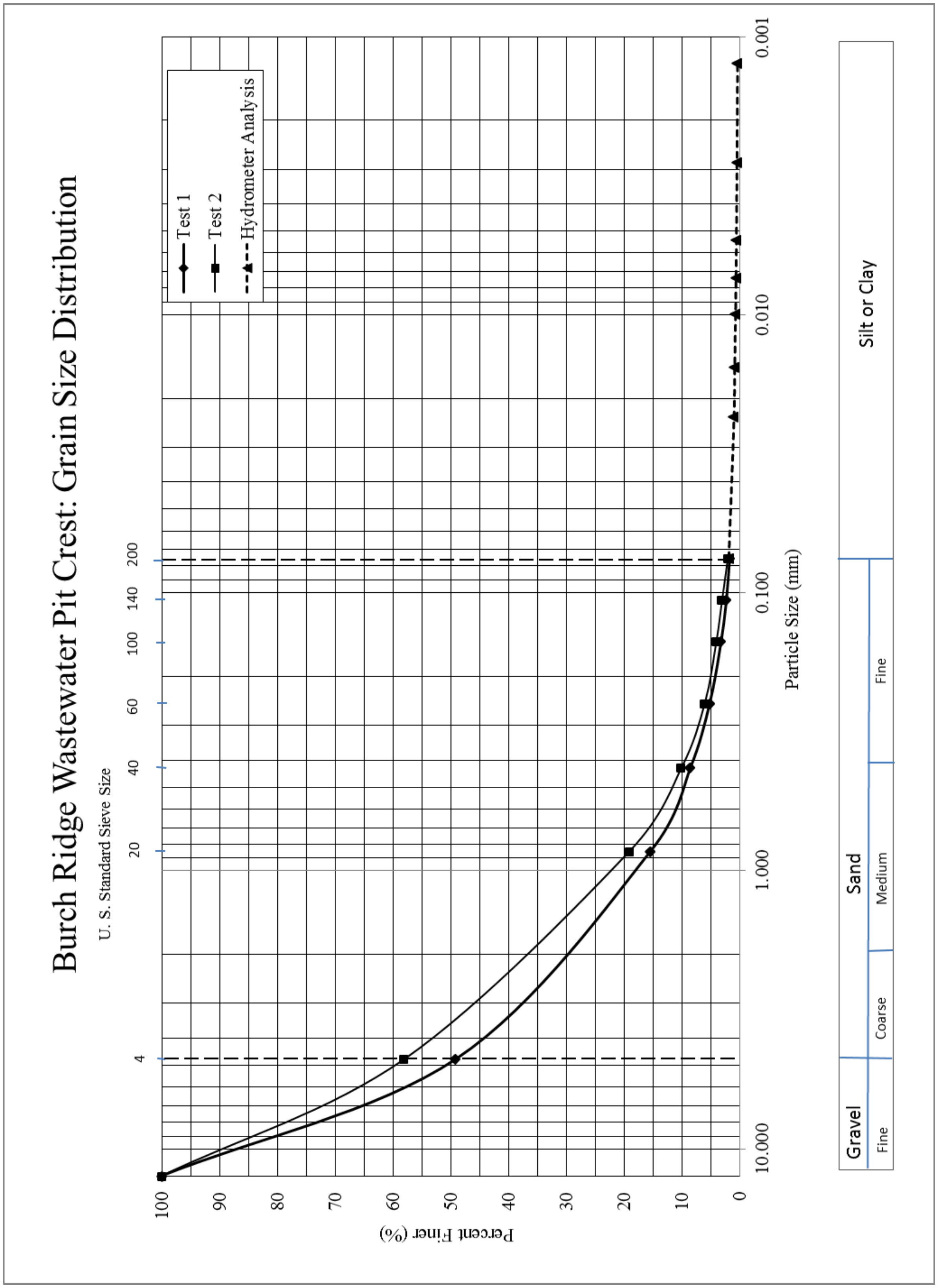
WVU (Name / Signature) Andrew Darnell	DATE 7/16/12
WVDEP (Name / Signature) Derek Haught	7/16/12
Company Representative (Name / Signature) Jerry Duelley	7/16/12

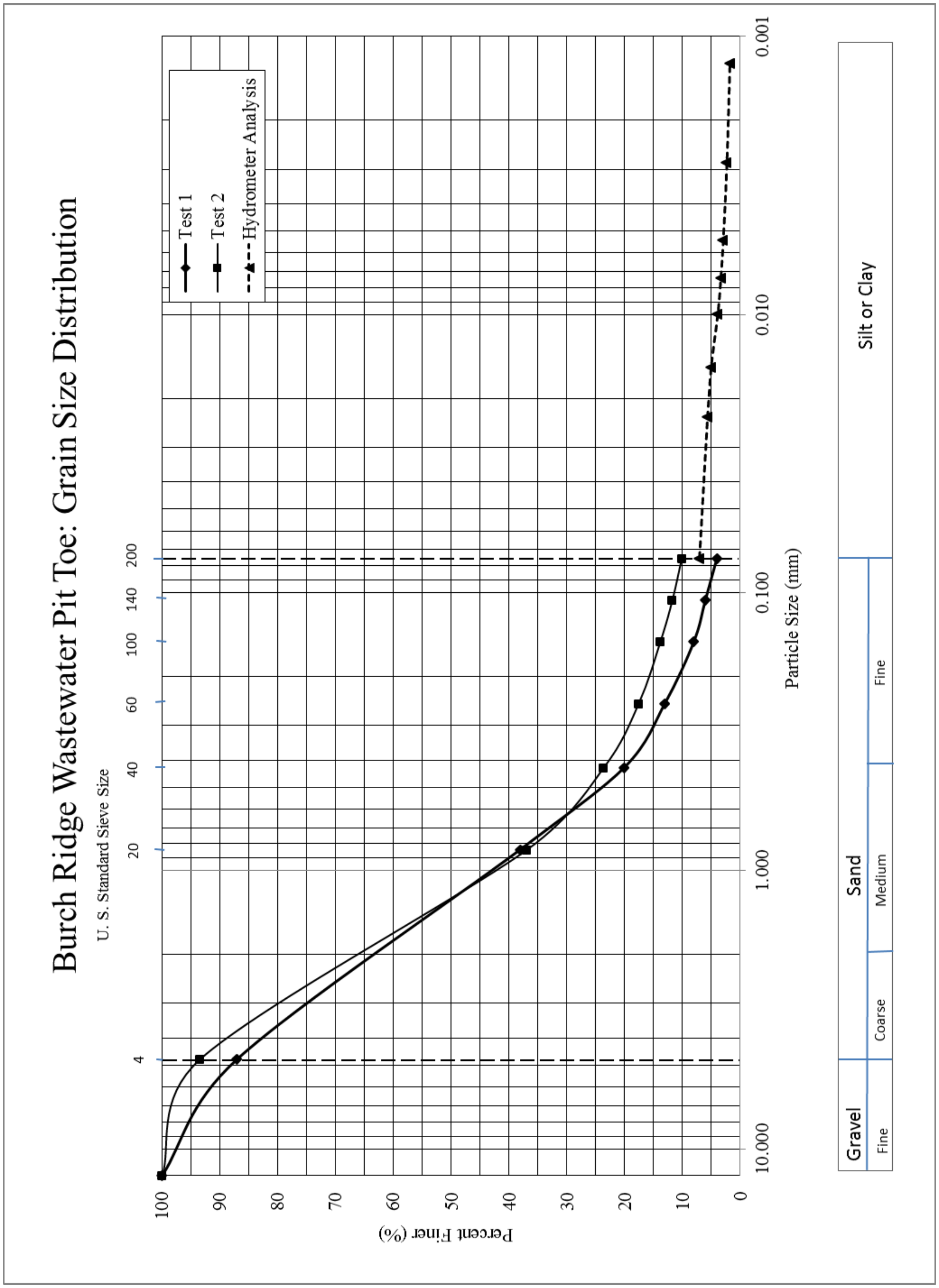
Site Operations & Infrastructure Evaluation	
Date: 7/16/12	Pit/Impoundment Name: Burch Ridge Wastewater Pit
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Visual inspection every 3 days
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Worked in oil and gas industry for 10 years, has no specific training
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? Uses a well report form, nothing specific to pits and impoundments
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? General form developed around 50 years ago
6	Are there safety and emergency procedures for the pit/impoundment? Buoys, fences
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Site safety plan posted in site trailers, call 911 (seemed to be guessing on who to contact and in what order)
8	Has the pit/impoundment inspector been trained on how to use the EAP? Inspector is the first to review the site safety plan prior to the permit
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) N/A
10	Does the company have a policy on pit/impoundment safety? Site safety plan posted in site trailers, call 911 (seemed to be guessing on who to contact and in what order)
11	How frequently does a Professional Engineer inspect the site? At construction, bi-monthly inspections certified every month
12	Other comments:

The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

Burch Ridge Wastewater Pit		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes		✓		2
2	Are there any slope movements or animal burrows?	No				4
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes			✓	1
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			3
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	No				4
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	Yes	✓			3
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	No				4
17	Are there any signs of water in ditch associated with pit?	No				4
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

Total:	**67**	(Out of 76)
Percentage:	**88.2%**	


Burch Ridge Wastewater Pit Crest: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


Burch Ridge Wastewater Pit Toe: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

Appendix F: MIP Freshwater Impoundment

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: MIP Freshwater Impoundment
Date of Site Evaluation: 7/18/12

Permit Observations / Anomalies:

Measurements of the field as-built construction differed from the permitted design. The berm crest width measured a minimum width of 7 feet, while the permitted dimension is a uniform 20 feet in width. Therefore, berm width is a deficiency.

The as-built dimensions of the impoundment exceeded the permitted dimensions. Therefore, the impoundment has a larger volume capacity than permitted. The permitted size is 121.3 feet wide by 266.5 feet long, while the as-built dimensions are 135 feet wide by 279 feet long. The as-built size and volume exceed the permit.

Hydrology

There were observed surface erosions at several locations on the site. Tension cracks were noticed at the berm and along the downstream face. Slope movements were observed on the hillside above the impoundment. Rills and gullies were also found at various locations on the downstream face due to surface erosion. There was a high degree of slope deformation observed above the impoundment. Some moist soil was found in the ditch above the impoundment.

Containment

The liner for the impoundment is a textured 30-millimeter geomembrane. Patches were found on the liner at the upstream face. Bulges in the liner were also noticed at a few locations, and there was minor rock and soil debris on the liner. Settlement cracks were found around the anchor trench of the geomembrane, and the anchor trench was exposed in places due to insufficient embedment.

Slope

Rills, gullies, and cracks were observed in multiple locations on the downstream face. Slope movements towards the impoundment were found on the up-gradient hillside. Woody debris was noticed in the fill on the downstream face. Minor slope movement into the ditch was observed around a non-functioning drainage pipe. Overall slope movement appears to have stabilized with no observed bulges at the down-gradient toe or scarps on the slope face.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the impoundment. Data was collected up-gradient, at the perimeter of the impoundment crest, and on the down-gradient slope of the impoundment.

Other Comments

There was some erosion due to a drainage pipe under the berm emptying into the ditch.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/18/12 9:45 AM	County	Monongalia	Company	Northeast Natural Energy
	Latitude	N 39° 36' 00.7"	Pit Name	MIP Freshwater Impoundment
WEATHER Mostly Cloudy	Longitude	W 79° 58' 32.8"	ID No.	47-6101622

A. PERMIT INFORMATION

Pit Width (ft.)	121.3 ft.	Minimum Berm Crest Width (ft.)	20 ft.	Construction Type	Incised
Pit Length (ft.)	266.5 ft.	Upstream Slope (H:V)	2.5:1	Liner Type	30 mil
Depth (ft.)	14.12 ft.	Downstream Slope (H:V)	2:1	Date Built	
Freeboard(ft.)				Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	135 ft.	Berm Crest Width (ft.)	7 ft.	Crest Height (ft.)	26.2 ft.
Pit Length (ft.)	279 ft.	Upstream Slope (H:V)	1.8:1	Up Slope Length (ft.)	14 ft.
Depth (ft.)	11 ft.	Downstream Slope (H:V)	1.8:1	Down Slope Length (ft.)	54 ft.
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence Yes/No/NA	If YES then Evaluate Significance of Problem: Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	
2	Are there any slope movements or animal burrows?	Yes			✓	Above impoundment
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes		✓		Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			Above impoundment
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor soil/rock
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Anchor trench exposed in places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	No				
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Bottles in impoundment
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Moist soil
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	Yes	✓			By pipe

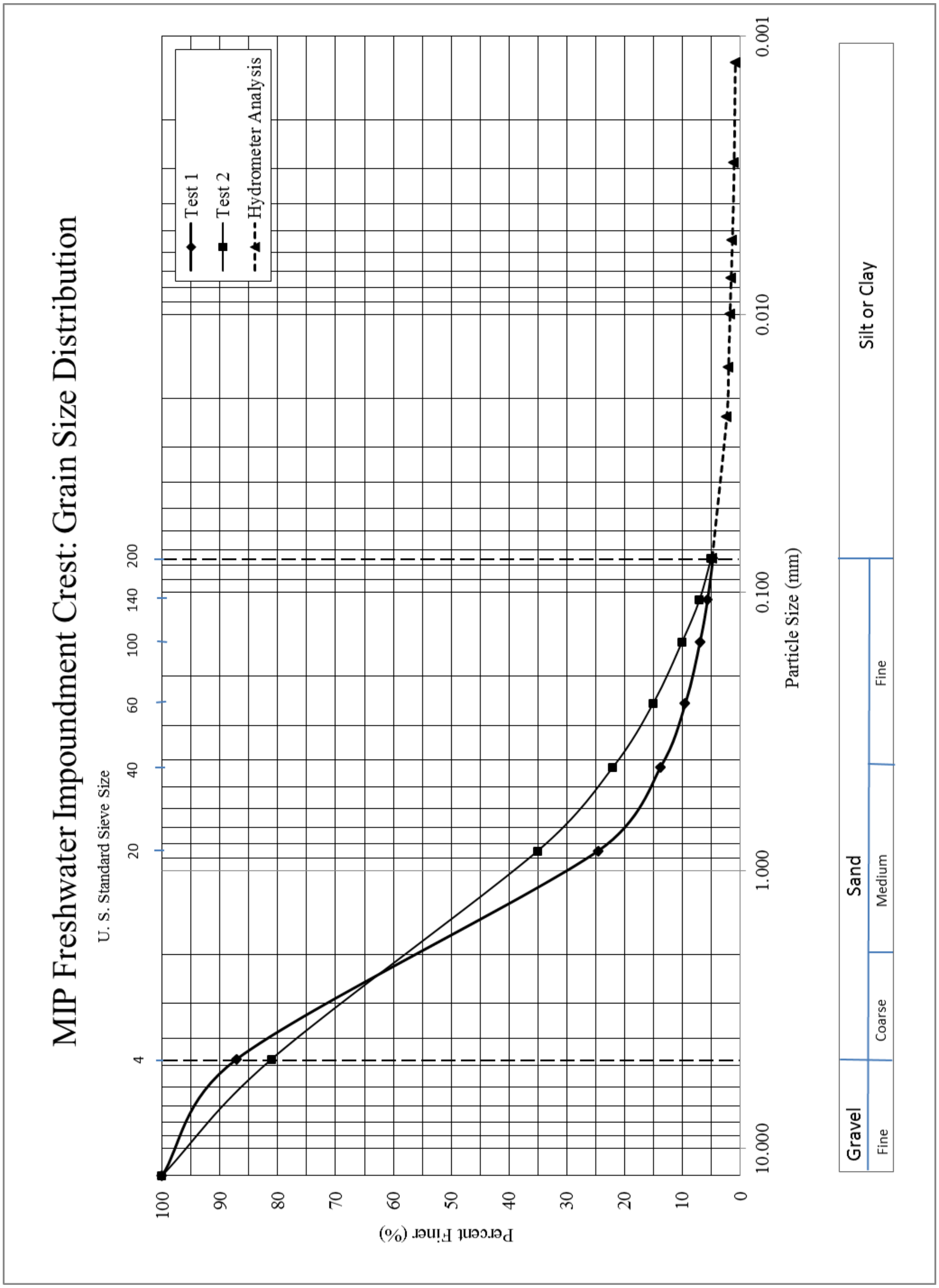
	DATE
WVU (Name / Signature) Richard Wise	7/18/12
WVDEP (Name / Signature) Samuel D. Ward II	7/18/12
Company Representative (Name / Signature) David A. McDougal	7/18/12

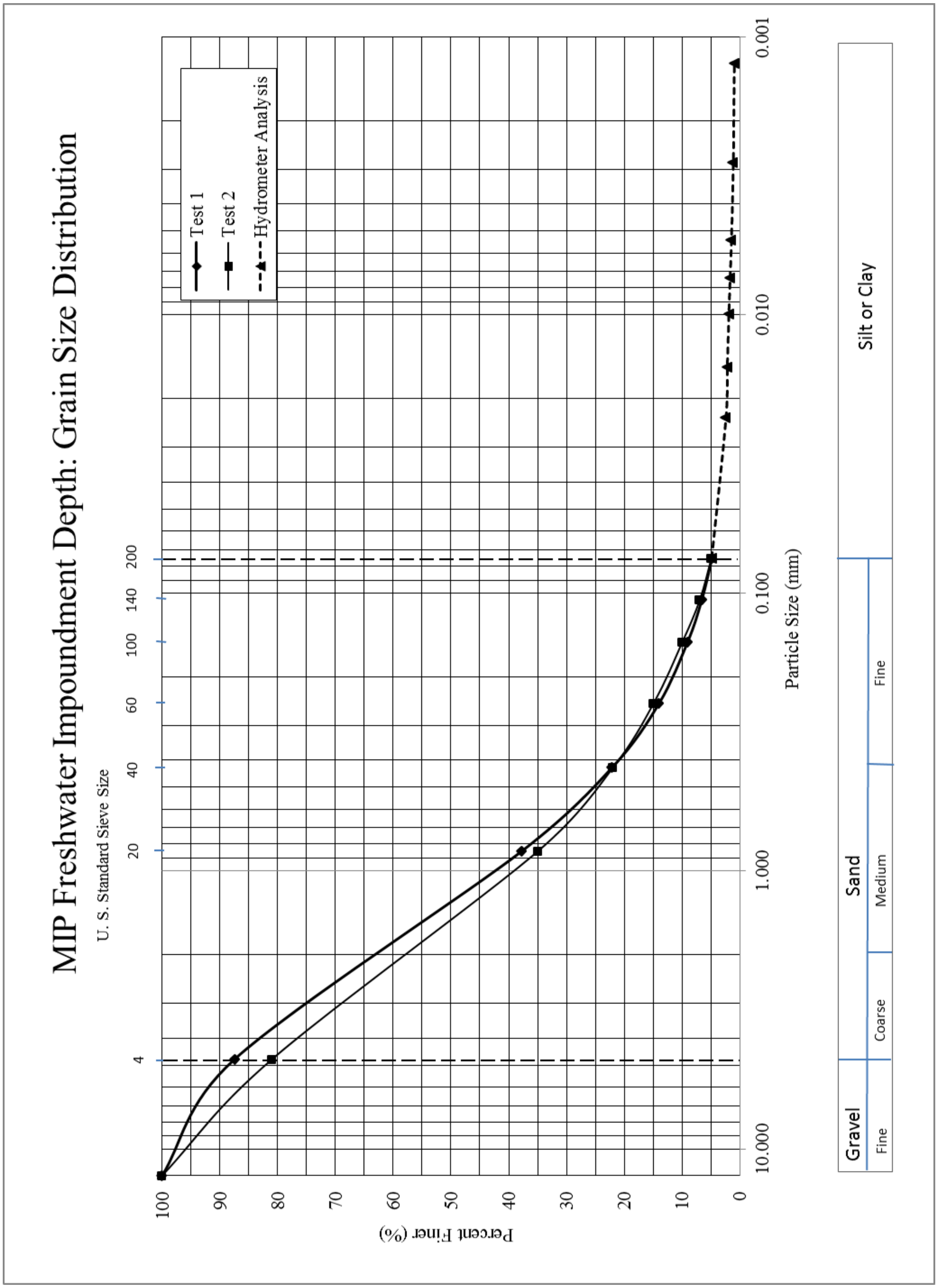
Site Operations & Infrastructure Evaluation	
Date: 7/18/12	Pit/Impoundment Name: MIP Freshwater Impoundment
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Once a week during drilling operations, once a month during post-drilling operation
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? None, follows state regulations
3	How many years of training does the inspector have in evaluating pits/impoundments? None, follows state regulations
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No, follows state regulations, looks at freeboard, slips, and movements and reports to company if any serious problems are observed
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? N/A
6	Are there safety and emergency procedures for the pit/impoundment? Northeast Natural Energy safety policy, fence, and floatation devices
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? No, not required due to volume, location, and state law
8	Has the pit/impoundment inspector been trained on how to use the EAP? N/A
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) N/A
10	Does the company have a policy on pit/impoundment safety? Yes, safety policy during drilling operations
11	How frequently does a Professional Engineer inspect the site? Once after post-construction to sign-off on as-built drawings
12	Other comments: West side of impoundment relatively flat outside of berm (slight upward slope) Cracking at anchor trench, berm, and ditch outside of safety fence Textured 30 mil geomembrane Minor bulging of liner Liner not secured on South berm

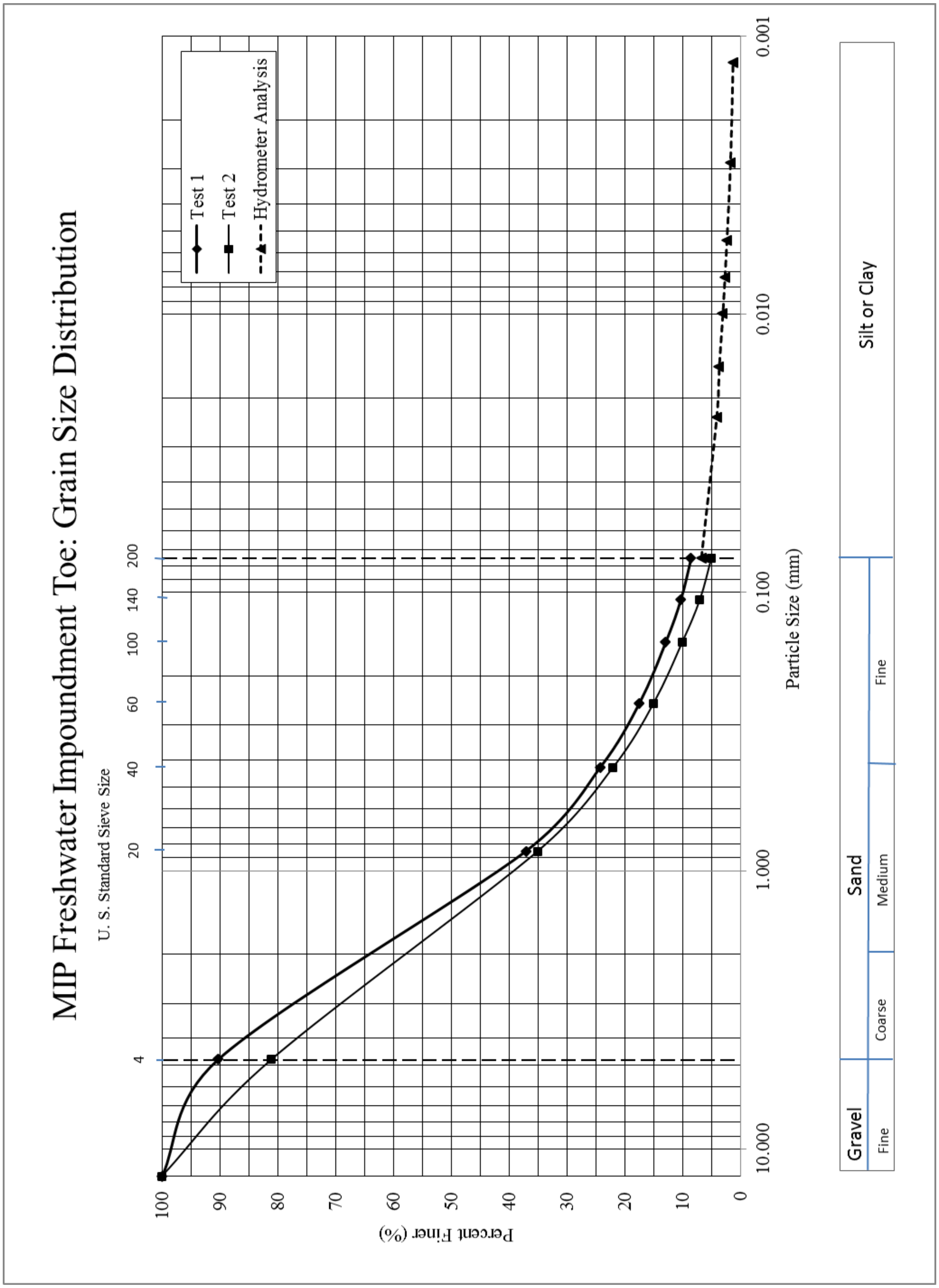
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

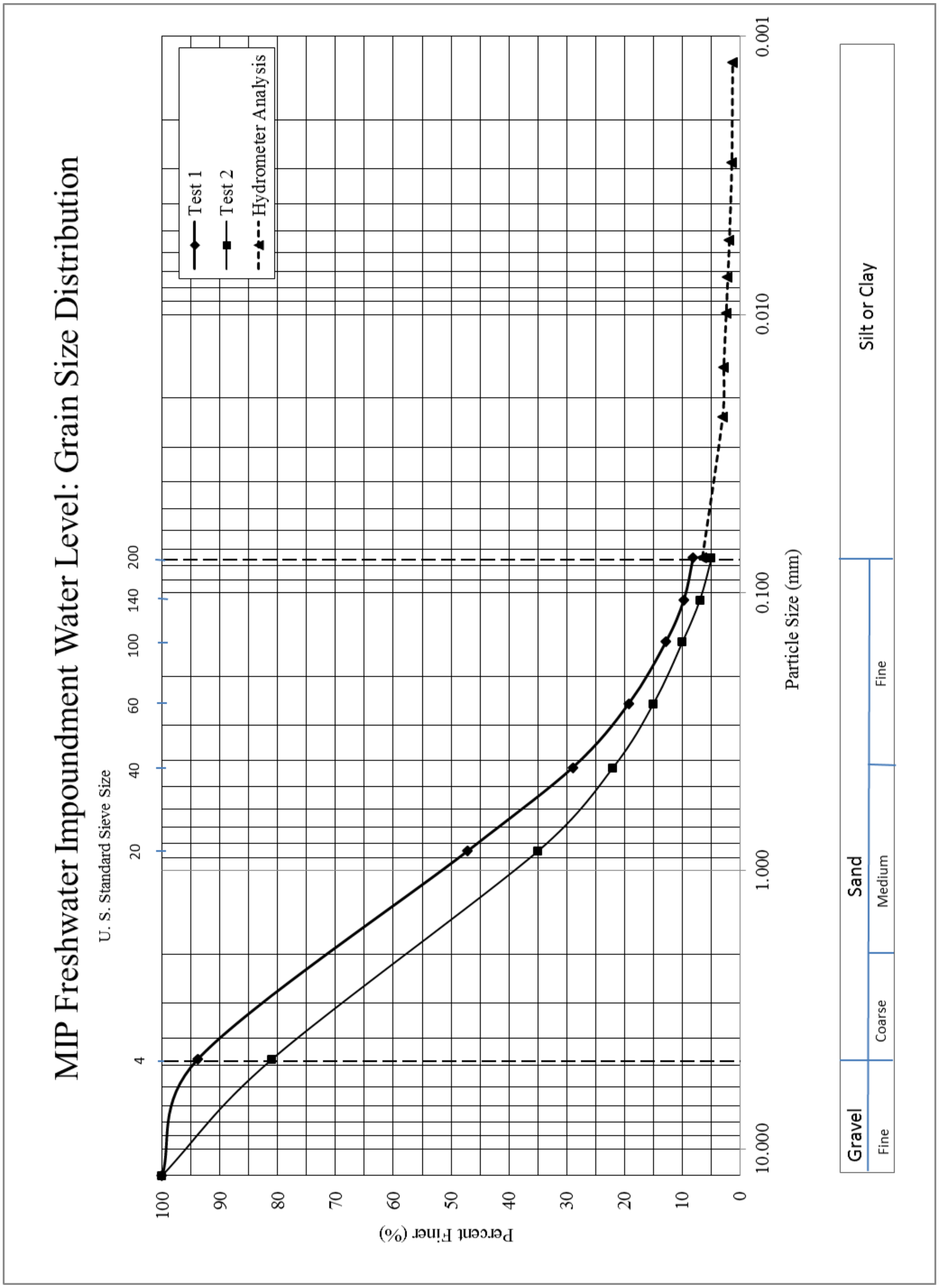
MIP Freshwater Impoundment		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes		✓		2
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			3
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	No				4
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	Yes	✓			3

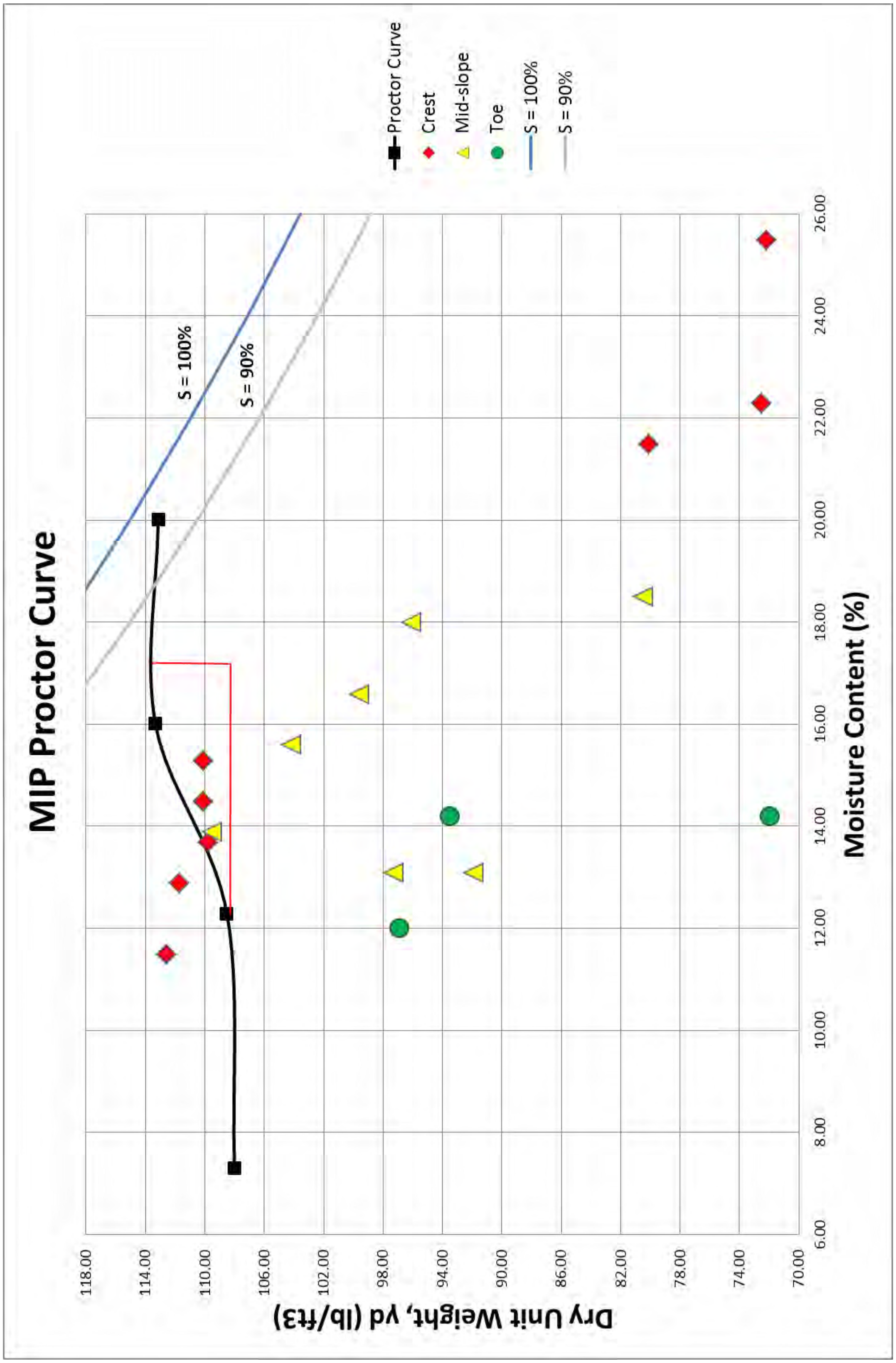
Total:	**61**	(Out of 76)
Percentage:	**80.3%**	


MIP Freshwater Impoundment Crest: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

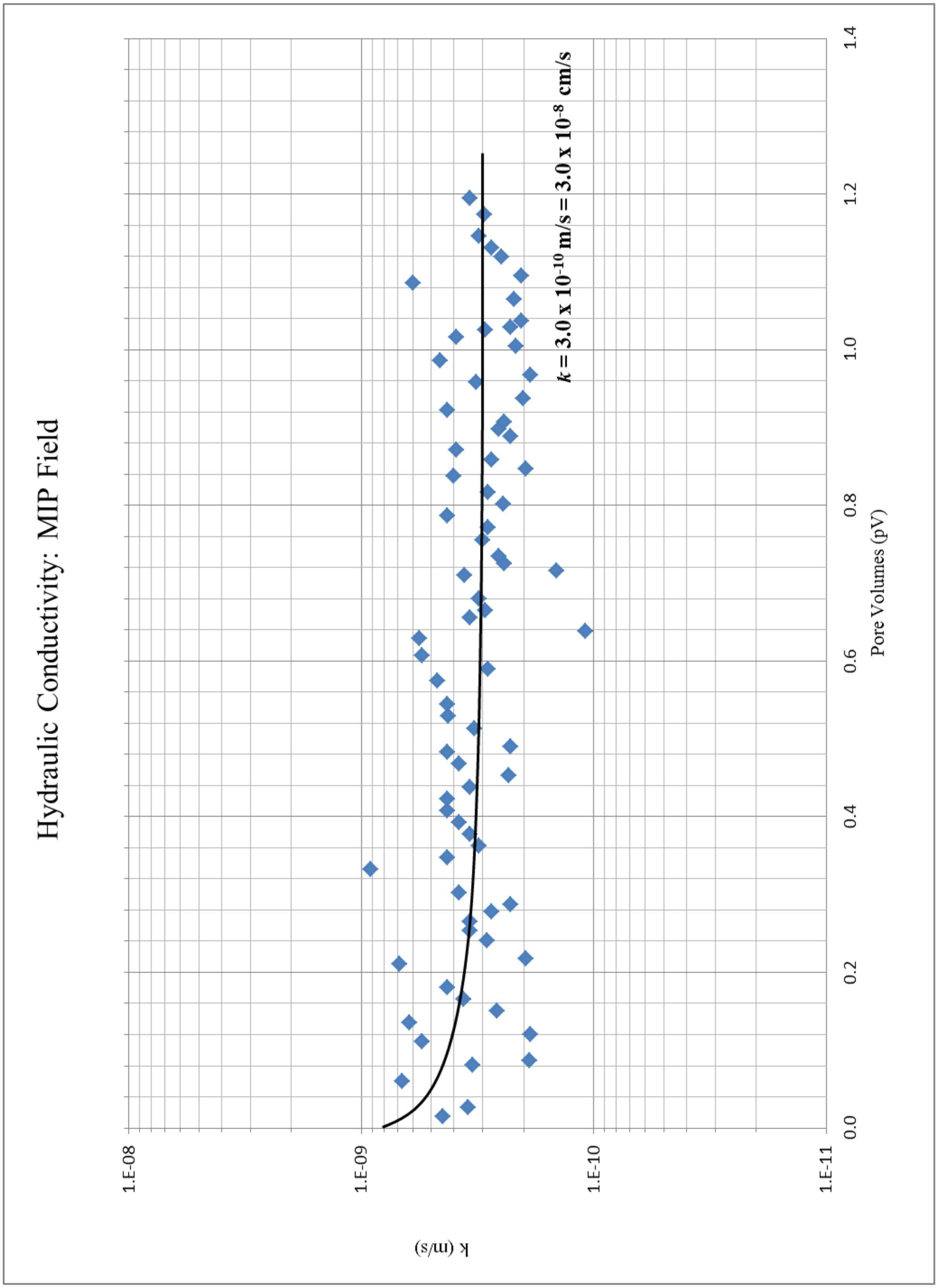

MIP Freshwater Impoundment Depth: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

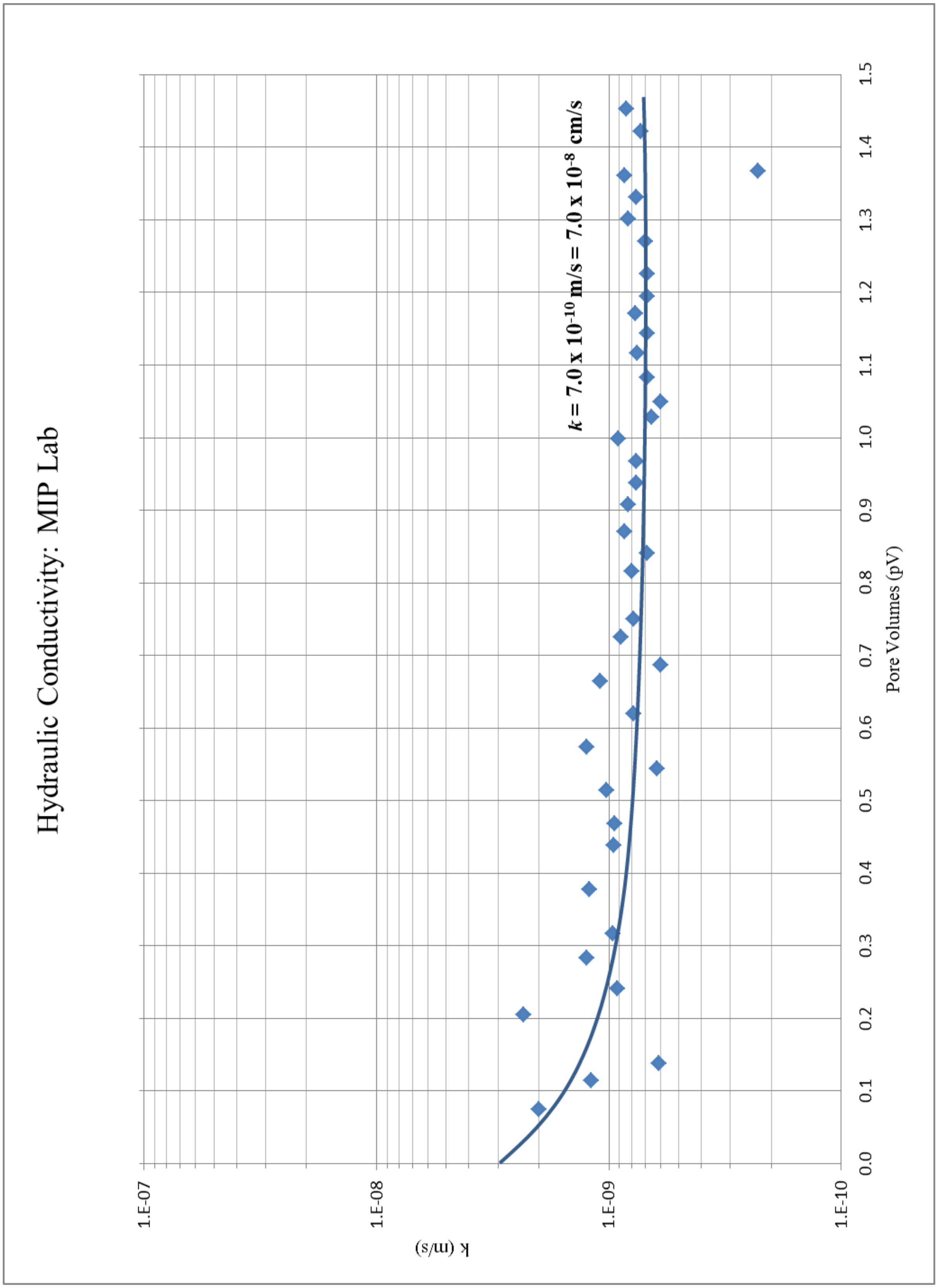

MIP Freshwater Impoundment Toe: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

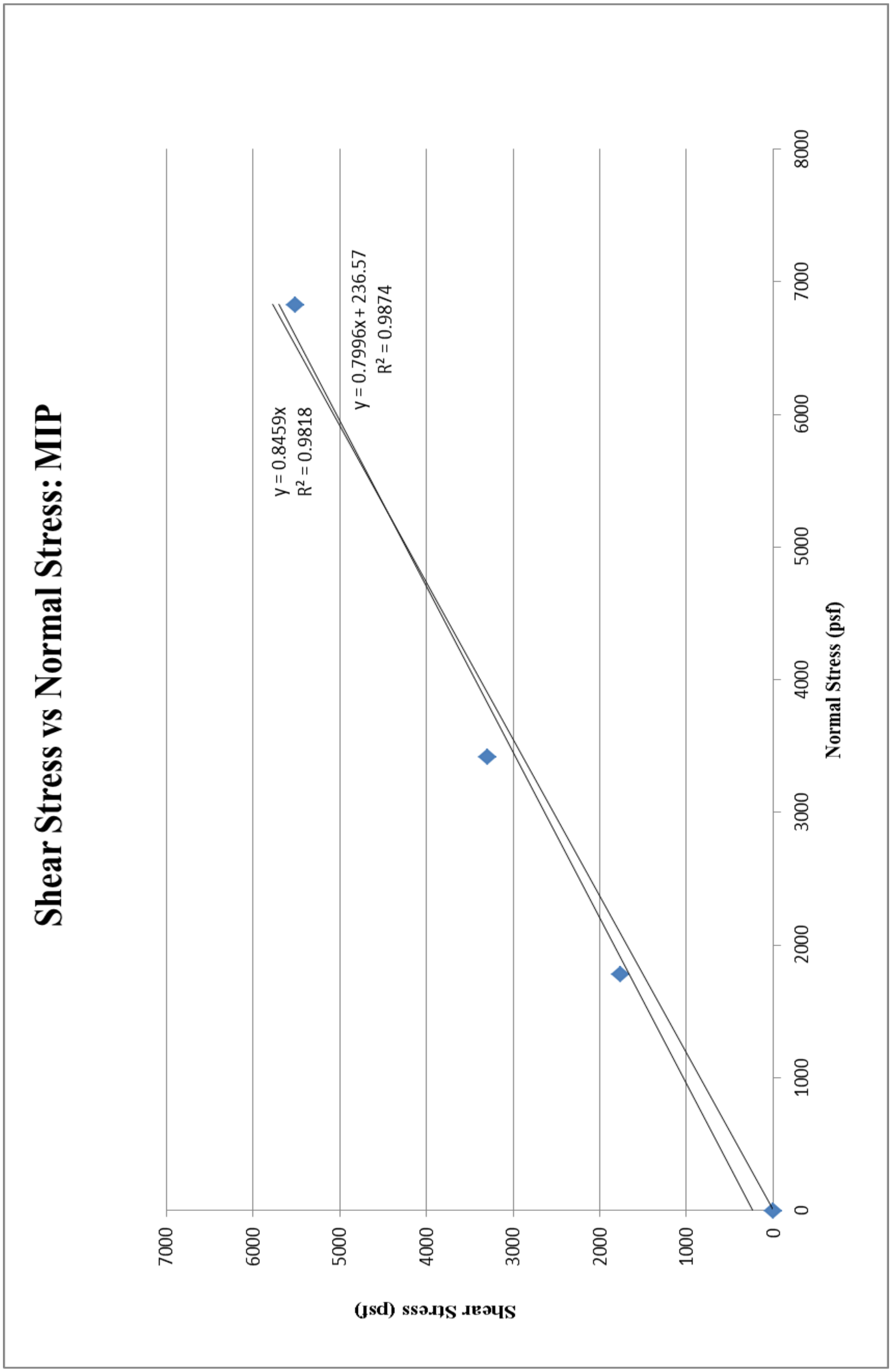

MIP Freshwater Impoundment Water Level: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay



MIP Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
118.00
114.00
110.00
106.00
102.00
98.00
94.00
90.00
86.00
82.00
78.00
74.00
70.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
24.00
26.00
S = 100%
S = 90%
Proctor Curve
Crest
Mid-slope
Toe
S = 100%
S = 90%


Hydraulic Conductivity: MIP Field
k = 3.0 x 10-10 m/s = 3.0 x 10-8 cm/s
k (m/s)
Pore Volumes (pV)
1.E-08
1.E-09
1.E-10
1.E-11
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4


Hydraulic Conductivity: MIP Lab
k = 7.0 x 10^-10 m/s = 7.0 x 10^-8 cm/s
k (m/s)
1.E-07
1.E-08
1.E-09
1.E-10
Pore Volumes (pV)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5


Shear Stress vs Normal Stress: MIP
y = 0.8459x
R² = 0.9818
y = 0.7996x + 236.57
R² = 0.9874
Shear Stress (psf)
0
1000
2000
3000
4000
5000
6000
7000
Normal Stress (psf)
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (MIP)			
Date	**Sample**	**Compaction**	**Material**
11/5/2012	MIP	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress (psf)**	**Normal Stress (psf)**
High	5.509	5509	6830
Medium	3.296	3296	3421
Low	1.766	1766	1786
4	0	0	0
m	0.7996	m	0.8459
ϕ' (degrees)	38.646	$\phi'_{c'=0}$ (degrees)	40.228
c' (psf)	236.570	c' (psf)	0.0

Appendix G: Ball 1H Impoundment #2

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Ball 1H Impoundment #2
Date of Site Evaluation: 7/24/12

Permit Observations / Anomalies:

Measurements of the field as-built construction differed from the permitted design. The berm crest width measured a minimum of 7 feet, as opposed to the 6 feet noted in the permit.

The as-built dimensions of the impoundment were smaller than the permitted dimensions. The permitted size is 176 feet wide by 1,095 feet long, while the as-built dimensions measured 154.5 feet wide by 978 feet long. Thus, the as-built capacity is smaller than the permitted design.

Hydrology

Visual evaluations of the berm and downstream faces found cracks, rills, and gullies under the erosion control fabric. Slope movements such as scarps and slides were also observed in several places on the downstream faces. Wet zones were observed on the berm as well as on the downstream toe. A sinkhole was found on the berm on the northeastern side of the impoundment.

Containment

The liner for the impoundment is a 15-millimeter geomembrane. Patches were found on the liner at the upstream face. Bulges in the liner and seam separations were also noticed at a few locations. Settlement cracks were found around the anchor trench of the geomembrane, and the anchor trench was exposed in places due to insufficient embedment. A minor amount of rock and soil were on top of the liner.

Slope

Rills, gullies, and cracks were observed in multiple locations on the downstream face, and several slope movements were found. Woody debris was noticed on the downstream faces in the fill material. Erosion control fabric was in place on the berm and downstream faces.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the impoundment. Data was collected at the perimeter of the impoundment crest and on the down-gradient slope of the impoundment.

Other Comments

The impoundment was constructed within 36 feet of a perennial stream and within 200 feet of a dwelling. Cut material was heaped into a pile near the southeastern corner of the impoundment.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/24/12 9:45am	County	Tyler	Company	PetroEdge Energy, LLC.	
	Latitude	N 39° 30' 2.12"	Pit Name	Ball 1H Impoundment #2	
WEATHER Partly Cloudy	Longitude	W 80° 45' 41.9"	API No.	095-02032	

A. PERMIT INFORMATION

Pit Width (ft.)	176 ft.	Minimum Berm Crest Width (ft.)	6 ft.	Construction Type	Incised
Pit Length (ft.)	1,095 ft.	Upstream Slope (H:V)	2:1	Liner Type	15 mil.
Depth (ft.)	10 ft.	Downstream Slope (H:V)	2:1	Date Built	
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	154.5 ft.	Berm Crest Width (ft.)	7 ft.	Crest Height (ft.)	4.7 ft.
Pit Length (ft.)	978 ft.	Upstream Slope (H:V)	1.6:1	Up Slope Length (ft.)	13 ft.
Depth (ft.)		Downstream Slope (H:V)	2:1	Down Slope Length (ft.)	49.5 ft., 13 ft.
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	Yes	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	Cracks, scarps, slides, rills, gullies
2	Are there any slope movements or animal burrows?	Yes			✓	On downstream faces
3	Are there any depressions, sinkholes, or slides into the pit present?	Yes		✓		Sinkhole on berm
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Woody debris, weeds
6	Are there any seeps, wet zones, or losses of soil?	Yes		✓		Berm, toe
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		Bulges, seam separation
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Rocks/soil on liner
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes		✓		Cracks, anchor trench exposed in places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	No				
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Fabric, woody debris
17	Are there any signs of water in ditch associated with pit?	No				
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

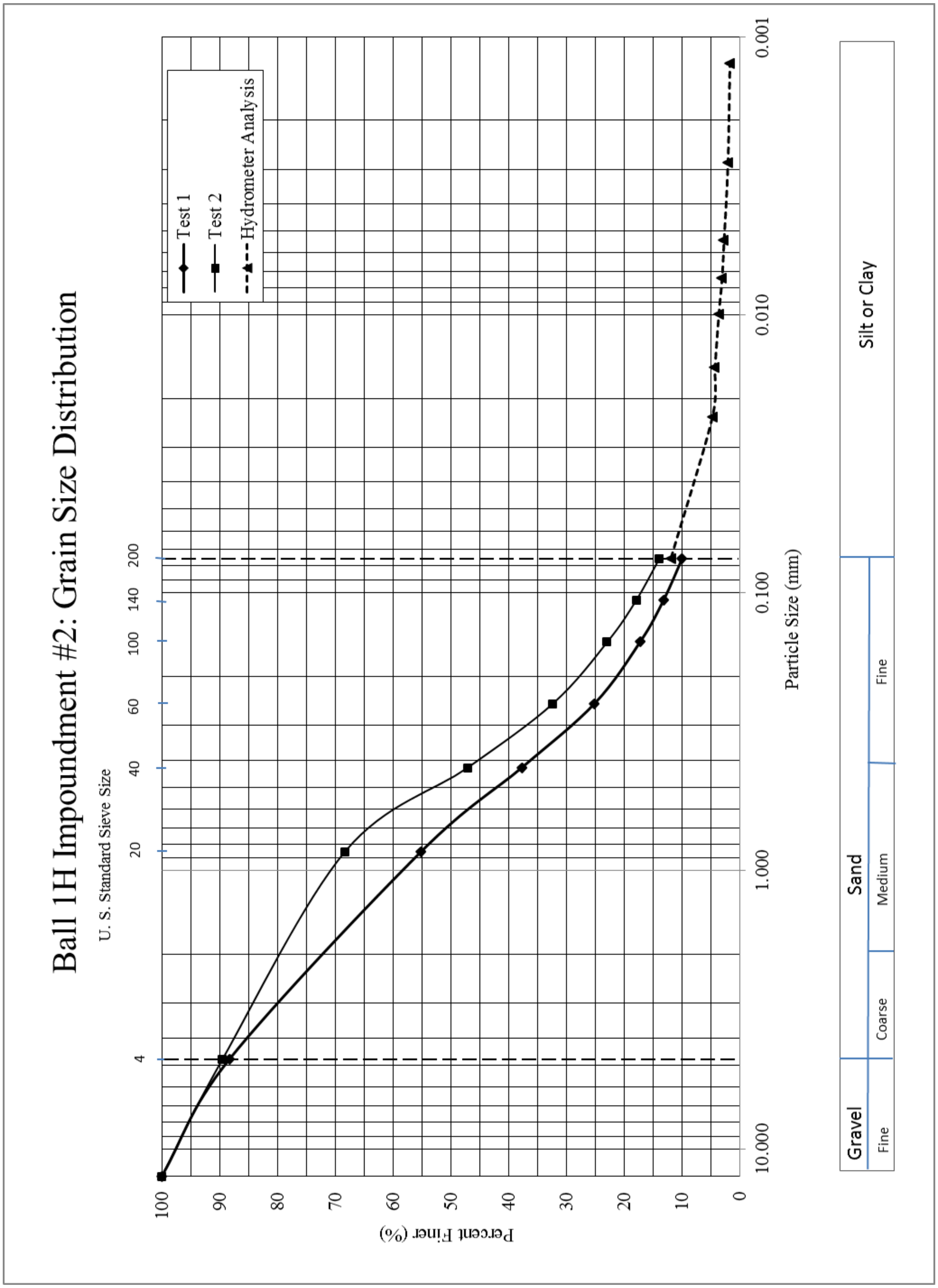
WVU (Name / Signature) Andrew Darnell	DATE 7/24/12
WVDEP (Name / Signature) Joe Taylor	7/24/12
Company Representative (Name / Signature) Dan Mullins	7/24/12

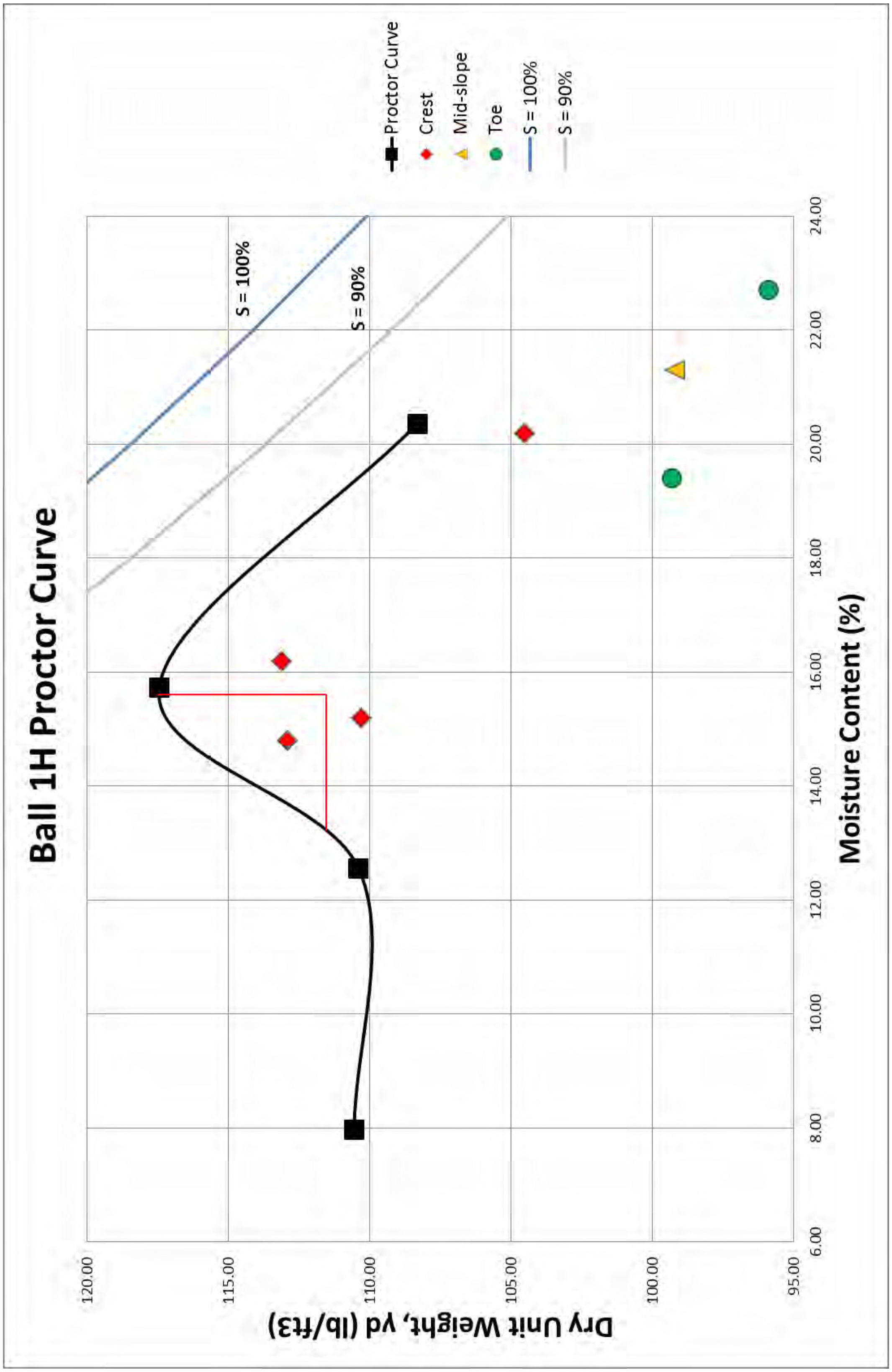
Site Operations & Infrastructure Evaluation	
Date: 7/24/12	Pit/Impoundment Name: Ball 1H Impoundment #2
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Walking and visual inspections every 2 weeks or after a heavy rain
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Dan Mullins has worked in the field for 15 years Joe Taylor has worked 10 years in the oil and gas industry, and he has been with the WVDEP for 3 years
3	How many years of training does the inspector have in evaluating pits/impoundments? No formal training
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? General state form submitted to WVDEP
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? The state of West Virginia
6	Are there safety and emergency procedures for the pit/impoundment? No formal written plans
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? No, evacuation notifications exist, residents have the company's contact information
8	Has the pit/impoundment inspector been trained on how to use the EAP? N/A
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) N/A
10	Does the company have a policy on pit/impoundment safety? Safety measures such as fences
11	How frequently does a Professional Engineer inspect the site? At least once a month
12	Other comments: Cracks and slides under erosion control mat Pieces of liner in impoundment Impoundment within 36 ft. of a perennial stream

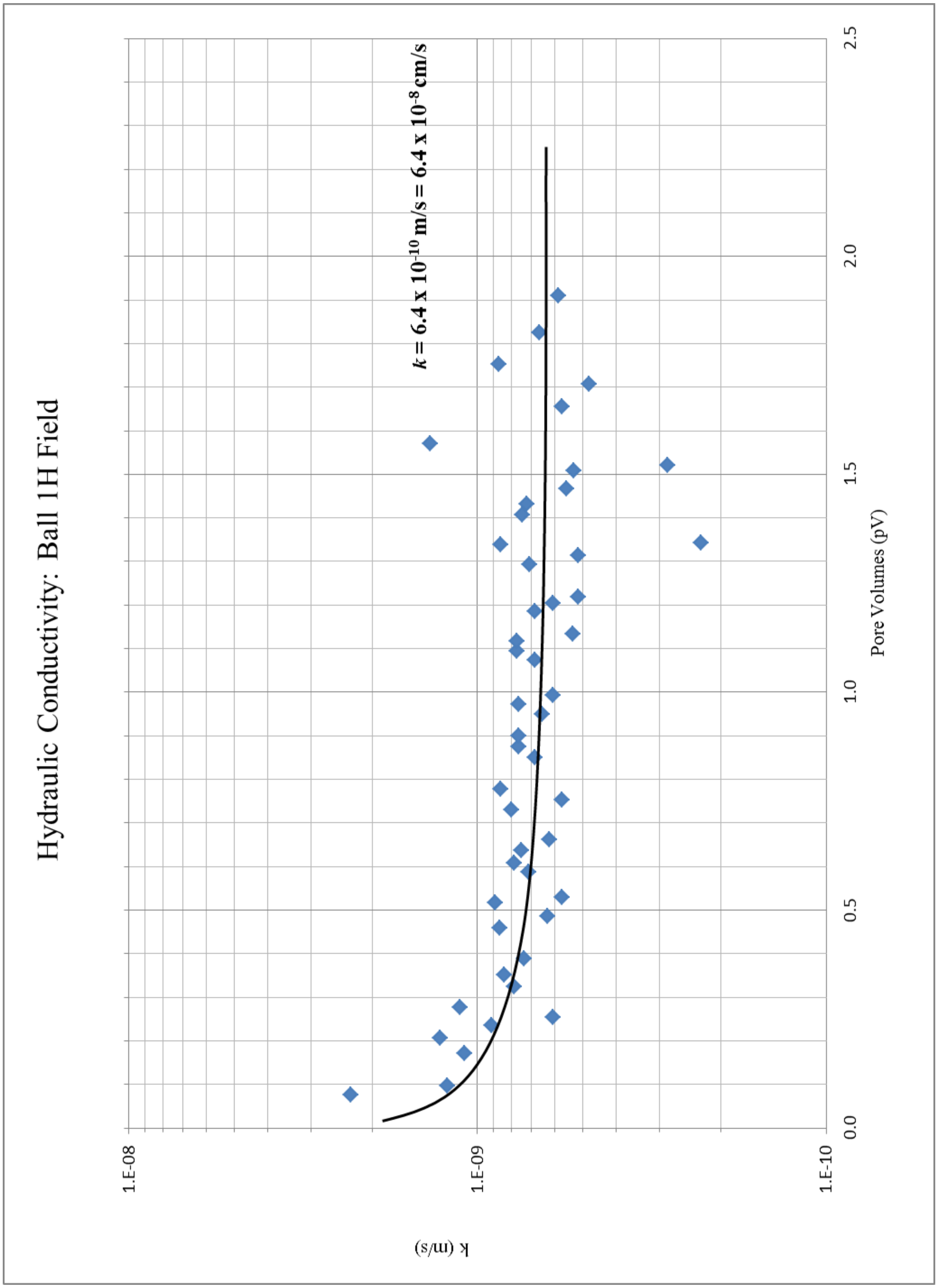
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

Ball 1H Impoundment #2		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	Yes		✓		2
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	Yes		✓		2
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		2
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes		✓		2
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	No				4
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	No				4
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

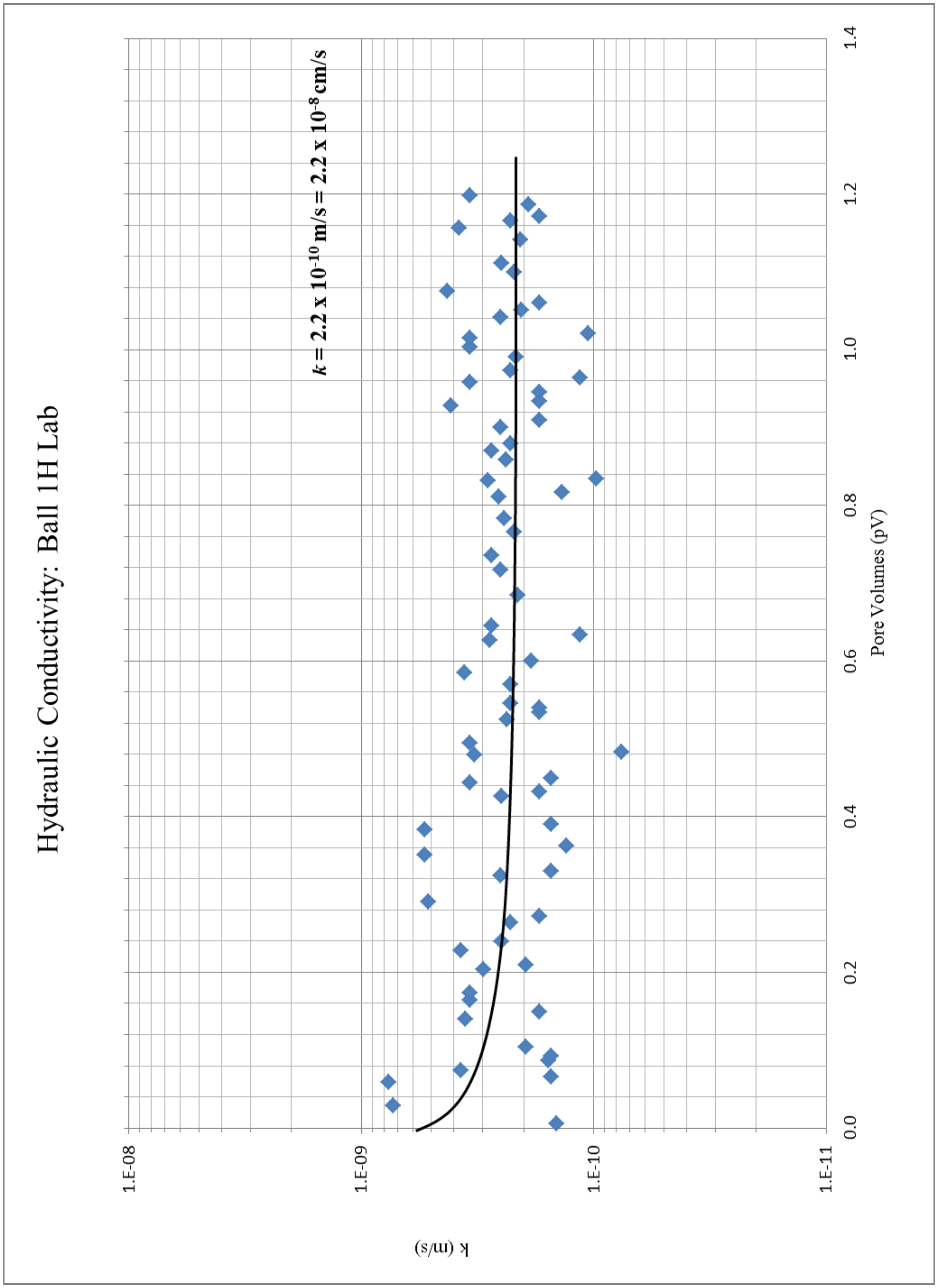
Total:	**59**	(Out of 76)
Percentage:	**77.6%**	

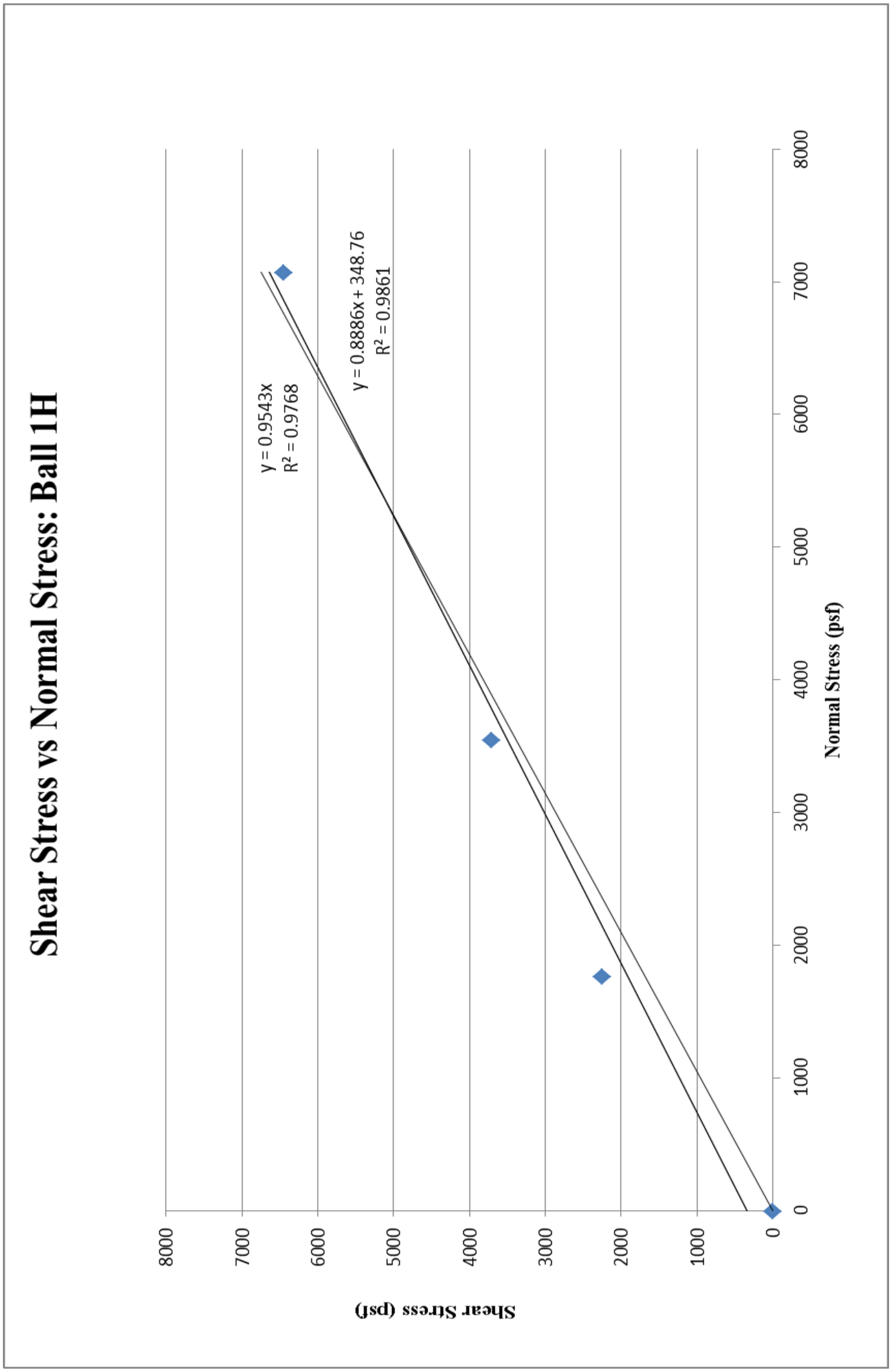

Ball 1H Impoundment #2: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


Ball 1H Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
120.00
115.00
110.00
105.00
100.00
95.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
24.00
S = 100%
S = 90%
Proctor Curve
Crest
Mid-slope
Toe
S = 100%
S = 90%



Hydraulic Conductivity: Ball 1H Field
k = 6.4 x 10-10 m/s = 6.4 x 10-8 cm/s
k (m/s)
1.E-08
1.E-09
1.E-10
Pore Volumes (pV)
0.0
0.5
1.0
1.5
2.0
2.5


Hydraulic Conductivity: Ball 1H Lab
k = 2.2 x 10-10 m/s = 2.2 x 10-8 cm/s
k (m/s)
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4


Shear Stress vs Normal Stress: Ball 1H
Shear Stress (psf)
Normal Stress (psf)
y = 0.9543x
R² = 0.9768
y = 0.8886x + 348.76
R² = 0.9861
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (Ball 1H)			
Date	**Sample**	**Compaction**	**Material**
11/5/2012	Ball 1H	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress (psf)**	**Normal Stress (psf)**
High	6.451	6451	7075
Medium	3.705	3705	3548
Low	2.249	2249	1768
4	0.00	0	0
m	0.8886	m	0.9543
ϕ' (degrees)	41.624	$\phi'_{c'=0}$ (degrees)	43.660
c' (psf)	348.760	c' (psf)	0.0

Appendix H: Mills-Wetzel Freshwater Impoundment

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Mills-Wetzel Freshwater Impoundment
Date of Site Evaluation: 7/24/12

Permit Observations / Anomalies:

Measurements of the field as-built construction were consistent with the permitted design. The berm crest width measured a minimum of 13 feet, which is in agreement with the permitted berm width of 12.5 ft.

The as-built dimensions of the impoundment were also consistent with the permitted dimensions. The permitted size is 812.5 feet long with a minimum width of 100 feet and a maximum width of 325 feet; the as-built dimensions measured 810 feet long with a minimum width of 99 feet and a maximum width of 333 feet.

Hydrology

Visual observations of the downstream faces revealed several areas of concern. The slope had little vegetation in most areas, leading to rill and gully formation on the slope as well as slips. Also, several areas of seepage were noted, as indicated by wet zones and vegetation such as the growth of cattails on the slope.

Containment

The liner for the impoundment is a 30-millimeter geomembrane. Patches were found on the liner at the upstream face. Bulges in the liner were also noticed at a few locations. The anchor trench was exposed in places due to insufficient embedment, leading to an increased susceptibility to uplift. The liner was held down by rocks in places, and a minor amount of rock and soil were on top of the liner.

Slope

Rills, gullies, and slips were observed in multiple locations on the downstream face, and several areas of seepage were found. Woody debris was noticed on the downstream faces in the fill material. Cracks and wet zones were also present at the berm and the toe of the slope.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the impoundment. Data was collected at the perimeter of the impoundment crest, at the midpoint of the downstream face, and at the toe of the downstream face.

Other Comments

Unsupported pipes were observed at the site, one along the access road and one on the eastern side of the impoundment. Gouges in the pipes were also noted.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/24/12 1:45 WEATHER Mostly Sunny	County	Wetzel	Company	Stone Energy Company
	Latitude	N 39° 31' 56.8"	Pit Name	Mills-Wetzel Freshwater Impoundment
	Longitude	W 80° 40' 19.1"	API No.	

A. PERMIT INFORMATION

Pit Width (ft.)	100 ft., 325 ft.	Minimum Berm Crest Width (ft.)	12.5 ft.	Construction Type	Hill Crest
Pit Length (ft.)	812.5 ft.	Upstream Slope (H:V)	2:1	Liner Type	30 mil.
Depth (ft.)	10 ft.	Downstream Slope (H:V)	2.5:1	Date Built	3/2010
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	99 ft., 333 ft.	Berm Crest Width (ft.)	13 ft.	Crest Height (ft.)	121.7 ft.
Pit Length (ft.)	810 ft.	Upstream Slope (H:V)	1.7:1	Up Slope Length (ft.)	24.5 ft.
Depth (ft.)		Downstream Slope (H:V)	2.1:1	Down Slope Length (ft.)	288 ft., 252 ft.
Freeboard (ft.)	6.2 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

	C. PIT/IMPOUNDMENT	Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	Cracks at toe, rills and gullies
2	Are there any slope movements or animal burrows?	Yes		✓		Some slides
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes			✓	Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	Major seepage
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes			✓	Uplift, bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor soil/rock
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes		✓		Anchor trench exposed in places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Gouges
14	Are there any areas where the pipe is not properly supported?	Yes		✓		Along roadway
15	Are there any signs of pipes having significant sagging in line?	Yes		✓		Unsupported
16	Are there any signs of obstructions (trees, garbage, etc.)?	No				
17	Are there any signs of water in ditch associated with pit?	Yes		✓		Moist soil
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

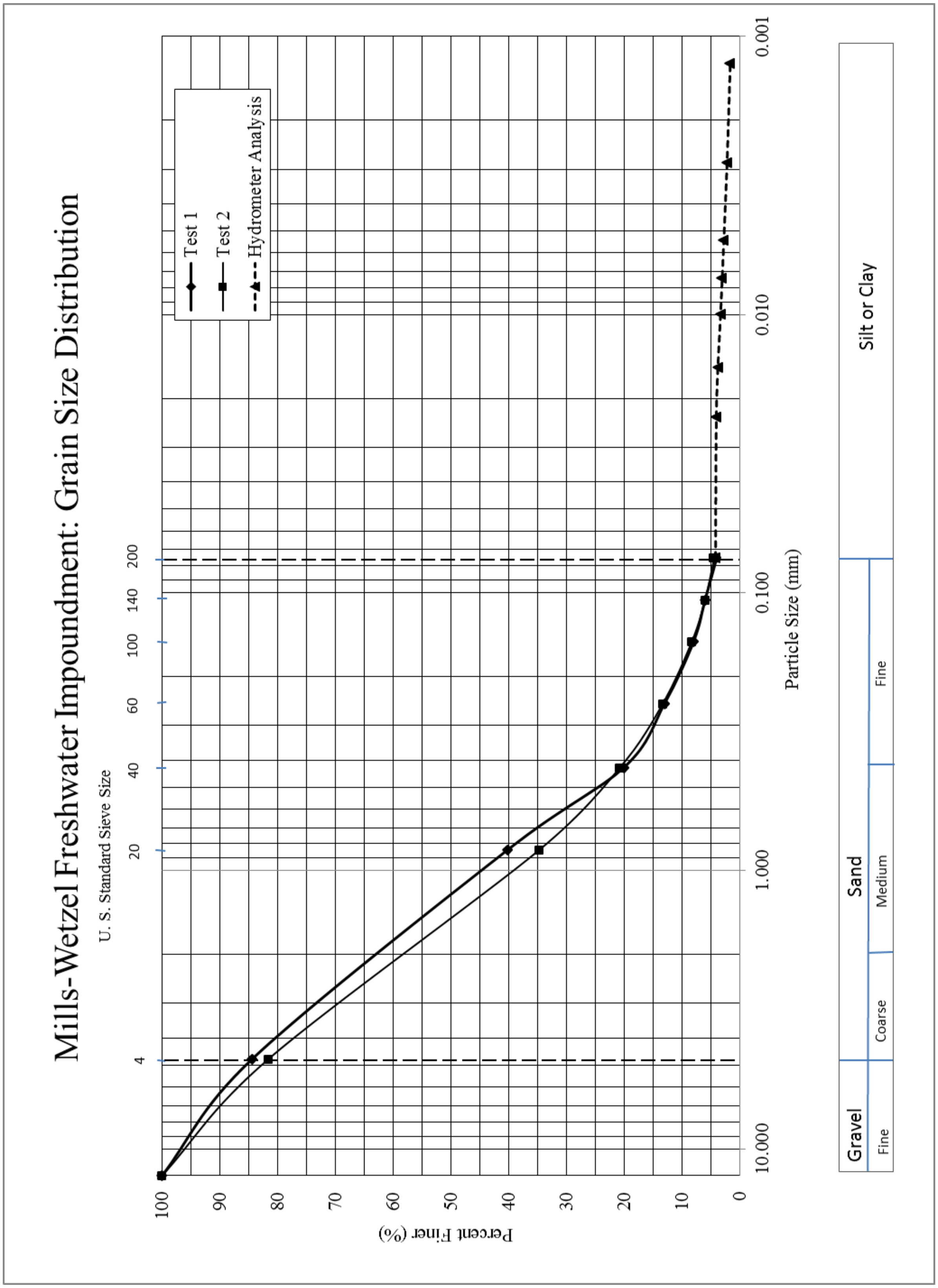
WVU (Name / Signature) Richard Wise	DATE 7/24/12
WVDEP (Name / Signature) Derek M. Haught	7/24/12
Company Representative (Name / Signature) Donald John Ellender	7/24/12

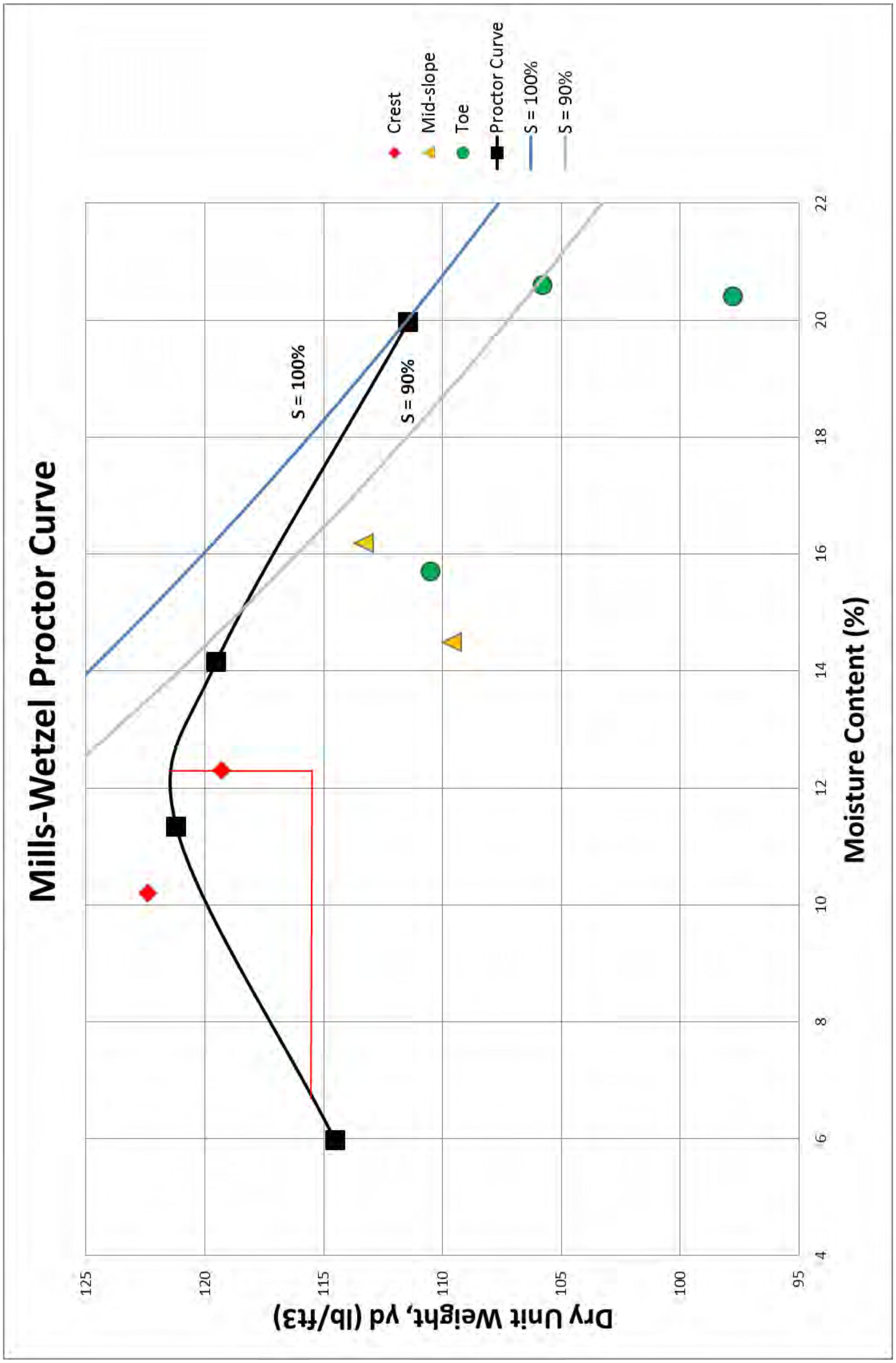
Site Operations & Infrastructure Evaluation	
Date: 7/24/12	Pit/Impoundment Name: Mills-Wetzel Freshwater Impoundment
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Weekly visual and walking inspections, separate inspectors for construction and environmental
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Environmental inspector has a Master's Degree
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? Yes
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? Stone Energy
6	Are there safety and emergency procedures for the pit/impoundment? Yes, written plan, safety measures such as fence, ropes, and buoys
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Yes, O'Brien's Response Management plans
8	Has the pit/impoundment inspector been trained on how to use the EAP? Yes, inspectors are members of the Incident Management Team
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) Yes, Table Top Reviews performed every year (next one scheduled for October)
10	Does the company have a policy on pit/impoundment safety? Yes, follow WVDEP guidelines, fencing being replaced by chain-link
11	How frequently does a Professional Engineer inspect the site? Right after construction, every year once new regulations are passed
12	Other comments: Cracks at the toe of the slope Some woody debris in the slope Rill and gully formation on the slope Downstream face has three drainage ditches, each with a check Wet zones at toe of slope Major seepage problem on downstream face, cattails growing

The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

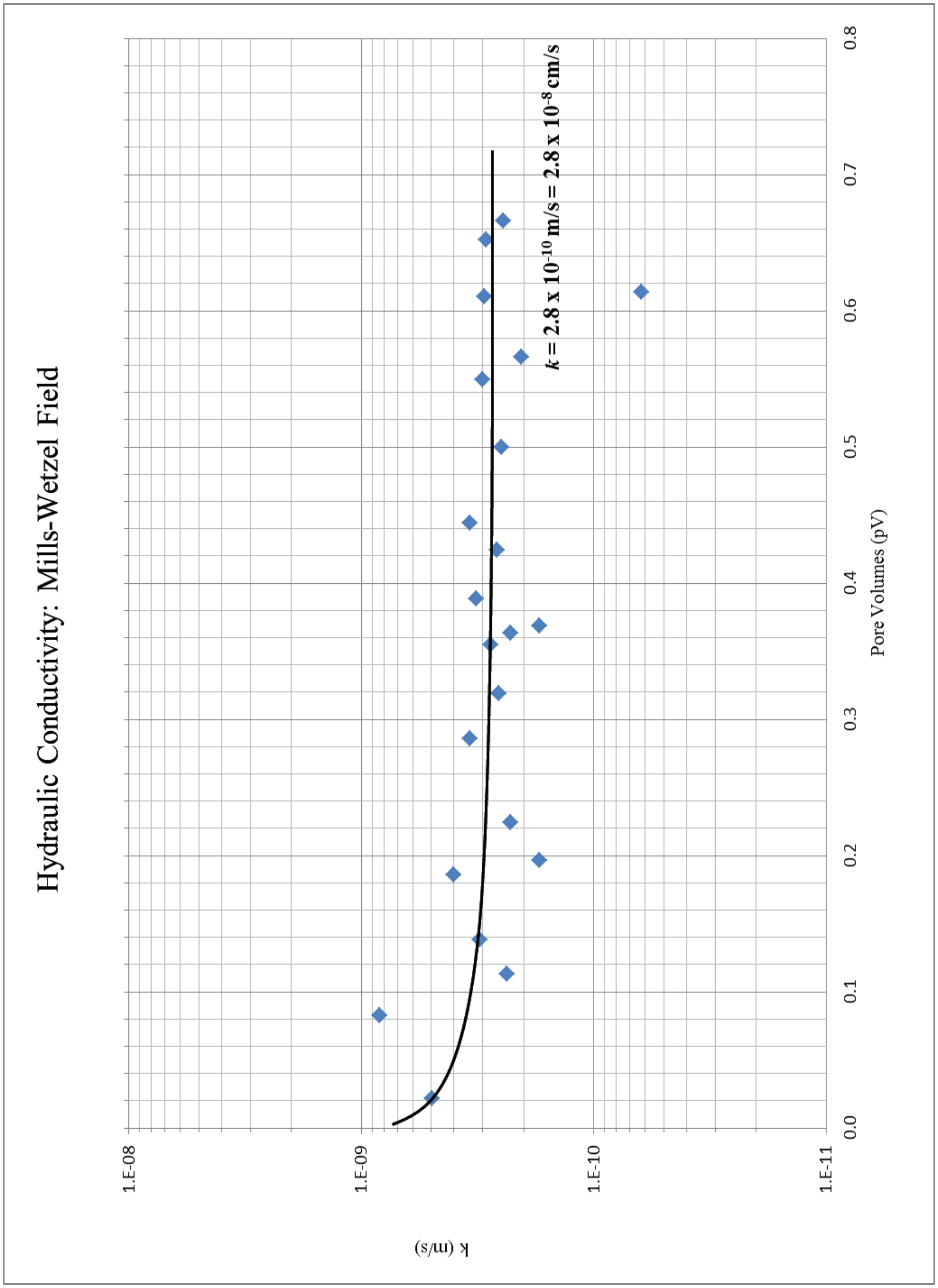
Mills-Wetzel Freshwater Impoundment		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes		✓		2
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes			✓	1
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	1
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes			✓	1
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes		✓		2
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	Yes		✓		2
15	Are there any signs of pipes having significant sagging in line?	Yes		✓		2
16	Are there any signs of obstructions (trees, garbage, etc)?	No				4
17	Are there any signs of water in ditch associated with pit?	Yes		✓		2
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

Total:	**52**	(Out of 76)
Percentage:	**68.4%**	

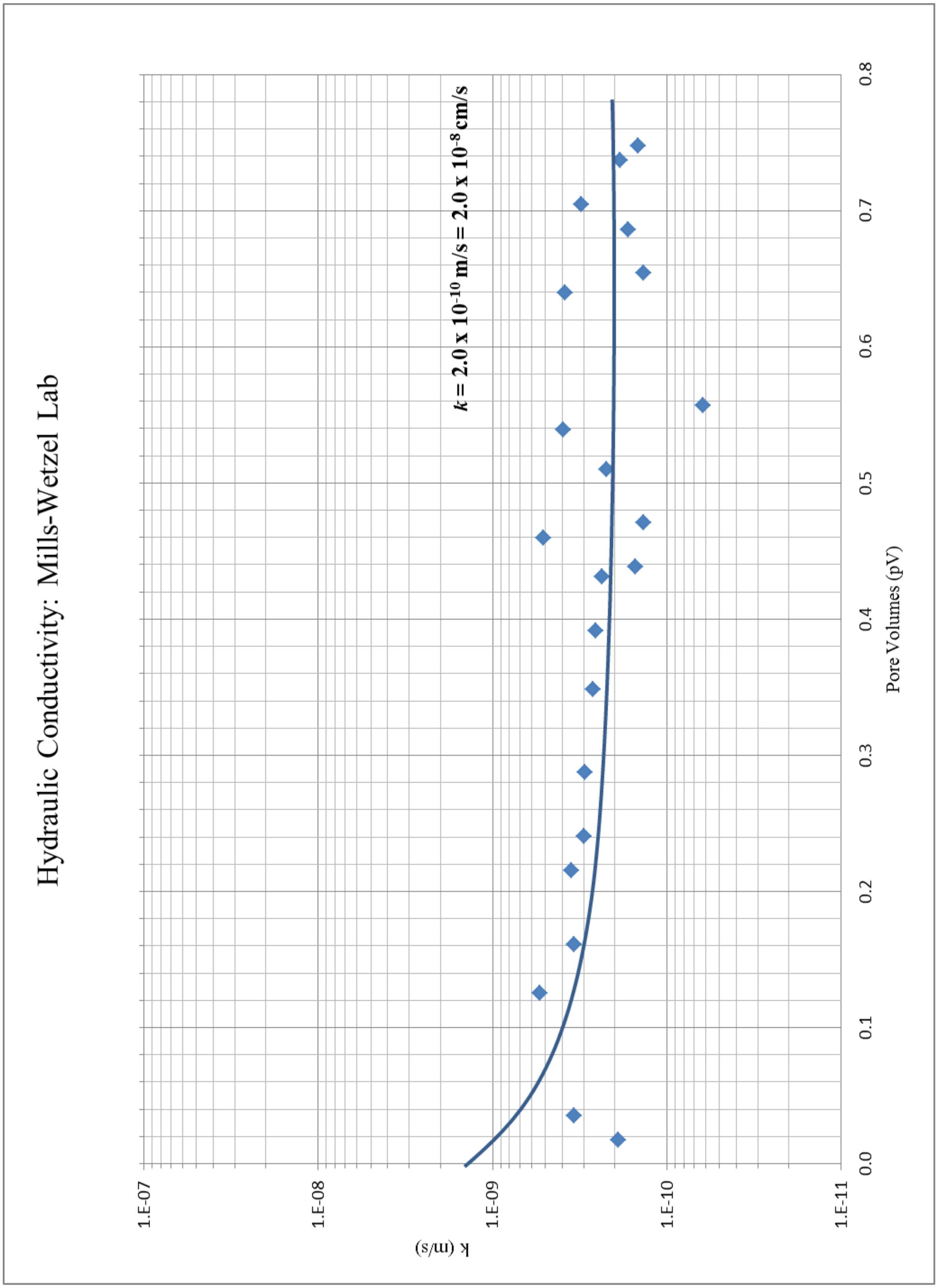

Mills-Wetzel Freshwater Impoundment: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

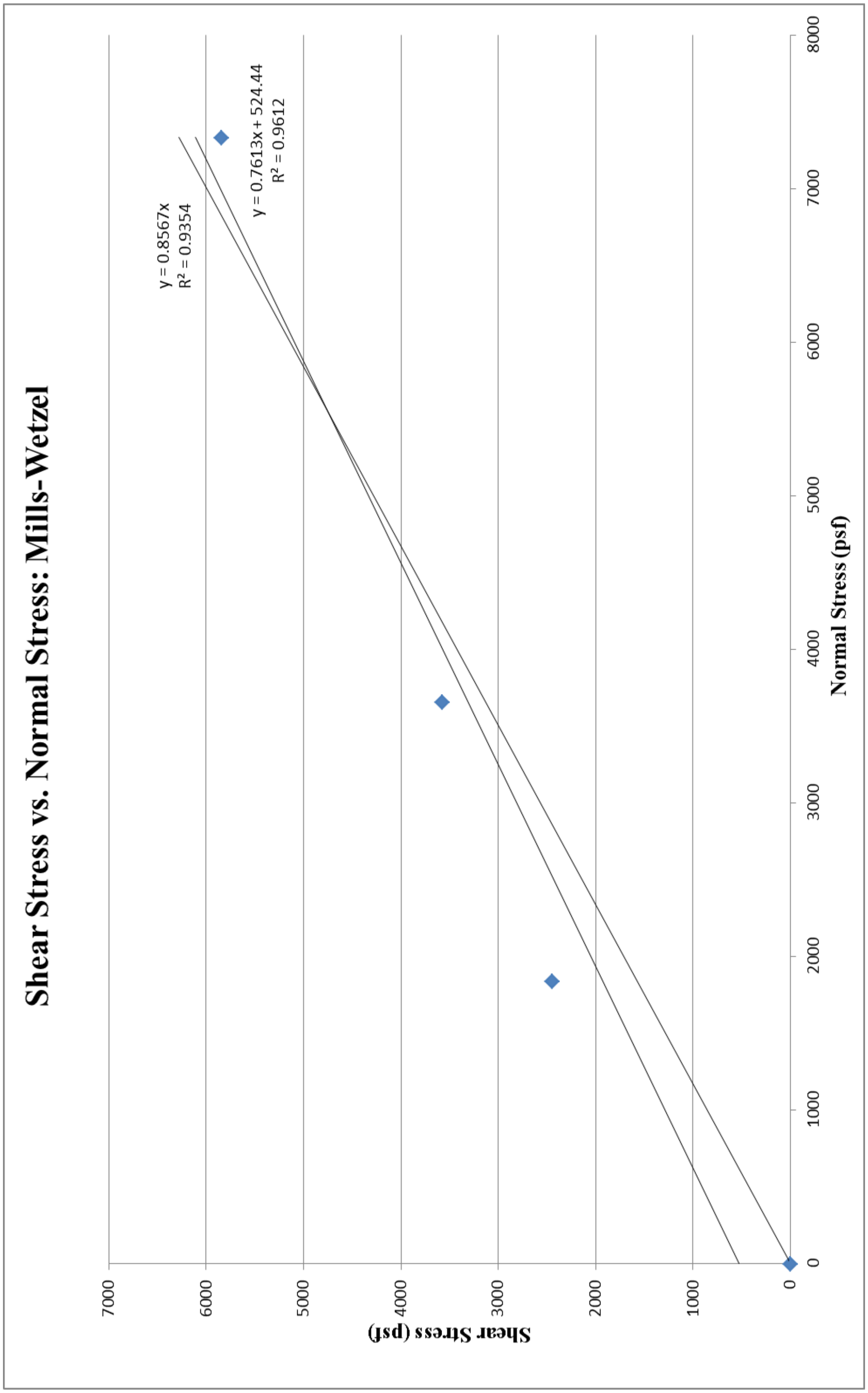


Mills-Wetzel Proctor Curve
Dry Unit Weight, γd (lb/ft3)
125
120
115
110
105
100
95
Moisture Content (%)
4
6
8
10
12
14
16
18
20
22
S = 100%
S = 90%
Crest
Mid-slope
Toe
Proctor Curve
S = 100%
S = 90%



Hydraulic Conductivity: Mills-Wetzel Field
k = 2.8 x 10-10 m/s = 2.8 x 10-8 cm/s
k (m/s)
Pore Volumes (pV)
1.E-08
1.E-09
1.E-10
1.E-11
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


Hydraulic Conductivity: Mills-Wetzel Lab
k = 2.0 x 10-10 m/s = 2.0 x 10-8 cm/s
k (m/s)
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


Shear Stress vs. Normal Stress: Mills-Wetzel
Shear Stress (psf)
Normal Stress (psf)
y = 0.8567x
R² = 0.9354
y = 0.7613x + 524.44
R² = 0.9612
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (Mills-Wetzel)			
Date	**Sample**	**Compaction**	**Material**
11/28/2012	Mills-Wetzel	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress(psf)**	**Normal Stress (psf)**
High	5.847	5847	7337
Medium	3.577	3577	3661
Low	2.447	2447	1839
4	0	0	0
m	0.7613	m	0.8567
ϕ' (degrees)	37.282	$\phi_{c'=0}'$ (degrees)	40.587
c' (psf)	524.440	c' (psf)	0.0

Appendix I: SHL 2 Centralized Pit

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: SHL 2 Centralized Pit
Date of Site Evaluation: 7/30/12

Permit Observations / Anomalies:

Field measurements of the as-built construction differed from the permitted design. The berm crest width measured a minimum of 6 feet, as opposed to the 40 feet in the permit.

The as-built dimensions of the pit were larger than the permitted dimensions. The permitted size is 135 feet wide by 450 feet long, while the as-built dimensions measured 145.5 feet wide by 474 feet long. As a result, the as-built capacity is larger than the permitted design.

Hydrology

Visual evaluations of the pit found rill and gully formation on the crest and downstream faces, but no slope movements were observed. A moderate amount of wet zones were present in the form of standing water in the ditches and on the berm, as well as seepage and wet zones on the northeast downstream face.

Containment

The liner for the pit is a 60-millimeter geomembrane. Bulges in the liner were noticed at a few locations, and a minor amount of rock and soil were on top of the liner. Furthermore, the anchor trench was exposed in places due to insufficient embedment.

Slope

Minor rills and gullies were present on the downstream faces. No slope movements were noted, but woody debris was noticed on the downstream faces in the fill material. Possible seepage was found on the downstream face, as evidenced by wet zones.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the pit. Data was collected at the pit crest and on the down-gradient slope of the pit.

Other Comments

Minor gouge marks were noticed in the pipes. Water from Wheeling Creek and mine operations on the Ohio River were being pumped into the pit.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/30/12 12:30 pm	County	Marshall	Company	Noble Energy, Inc.
	Latitude	N 39° 58' 1.05"	Pit Name	SHL 2 Centralized Pit
WEATHER Mostly Sunny	Longitude	W 80° 33' 41.6"	ID No.	051-WPC-00001

A. PERMIT INFORMATION

Pit Width (ft.)	135 ft.	Minimum Berm Crest Width (ft.)	40 ft.	Construction Type	Incised
Pit Length (ft.)	450 ft.	Upstream Slope (H:V)	3:1	Liner Type	60 mil.
Depth (ft.)	15 ft.	Downstream Slope (H:V)	2:1	Date Built	4/2012
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	145.5 ft.	Berm Crest Width (ft.)	6 ft.	Crest Height (ft.)	31.1 ft.
Pit Length (ft.)	474 ft.	Upstream Slope (H:V)	3:1	Up Slope Length (ft.)	8 ft.
Depth (ft.)		Downstream Slope (H:V)	2.2:1	Down Slope Length (ft.)	76.5 ft.
Freeboard (ft.)	2 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

	C. PIT/IMPOUNDMENT	Existence Yes/No/NA	If YES then Evaluate Significance of Problem: Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			Rills/gullies
2	Are there any slope movements or animal burrows?	No				
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes		✓		Wet zones on NE face
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock and soil
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Anchor trench exposed in places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Minor gouge marks
14	Are there any areas where the pipe is not properly supported?	No				
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	No				
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Standing water
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

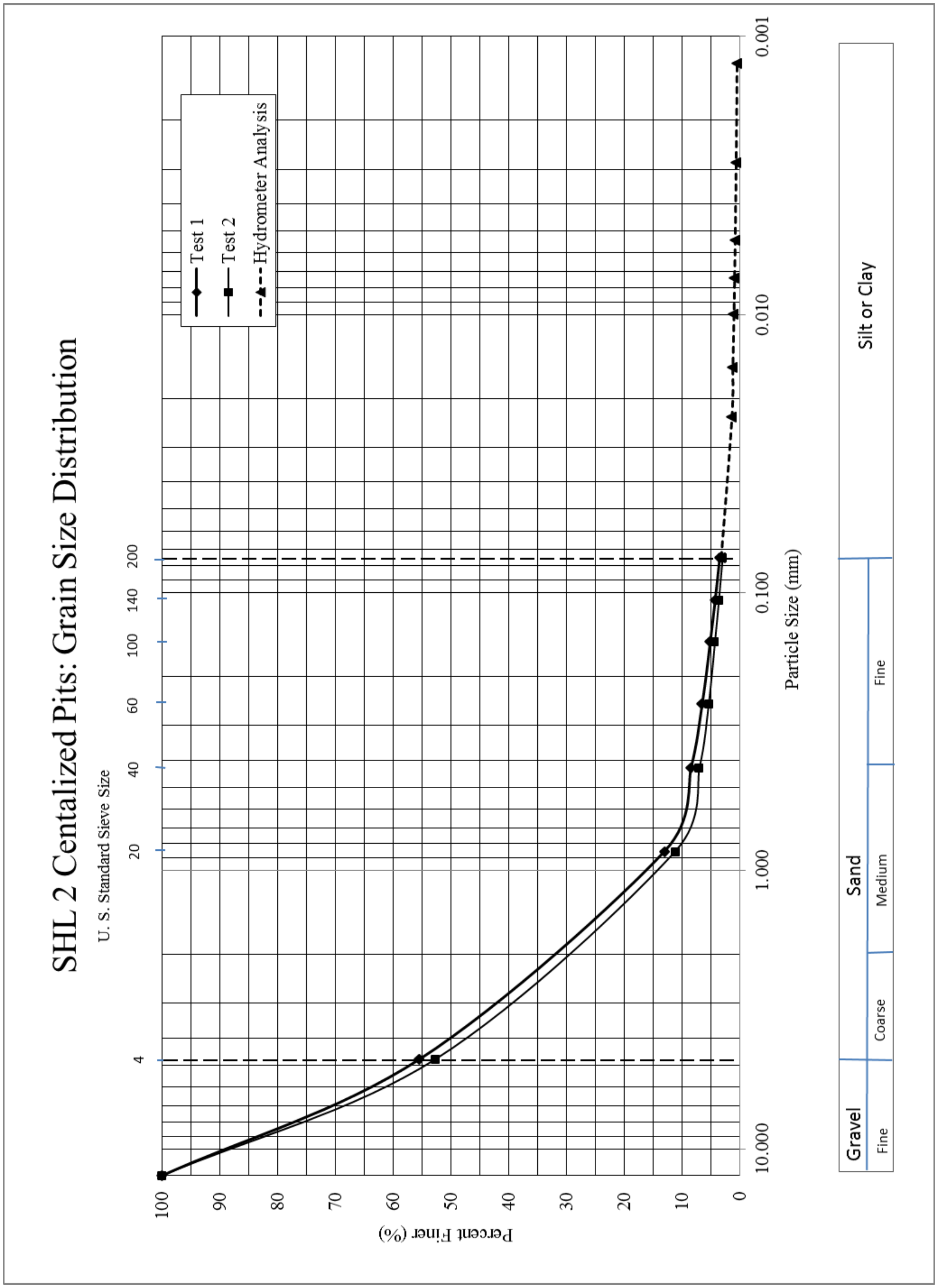
	DATE
WVU (Name / Signature) Andrew Darnell	7/30/12
WVDEP (Name / Signature) John Kearney	7/30/12
Company Representative (Name / Signature) Bob Fedinetz	7/30/12

Site Operations & Infrastructure Evaluation	
Date: 7/30/12	Pit/Impoundment Name: SHL 2 Centralized Pit
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Inspector is on site usually every day, performs walking/visual inspection weekly at minimum
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Just follows state regulations while the sites are in start-up mode, will be hiring a compliance person specializing in inspection
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No, records visual operations of cracks, seeps, etc. and reports to environmental coordinator
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? N/A
6	Are there safety and emergency procedures for the pit/impoundment? Fencing, floatation devices, signage, early leak detection system (inspected weekly), future fencing plans include complete enclosure, emergency number at the entrance to the sites
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Sites have an emergency access number for failure/warnings (if something goes wrong, someone will know what to do)
8	Has the pit/impoundment inspector been trained on how to use the EAP? No, would call back to the office if a problem occurs
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) No
10	Does the company have a policy on pit/impoundment safety? Regulatory group would know
11	How frequently does a Professional Engineer inspect the site? Regulatory group would know
12	Other comments: Water from Wheeling Creek and mine operations on the Ohio River were being pumped into the pit Signs of seepage on downstream face of pit

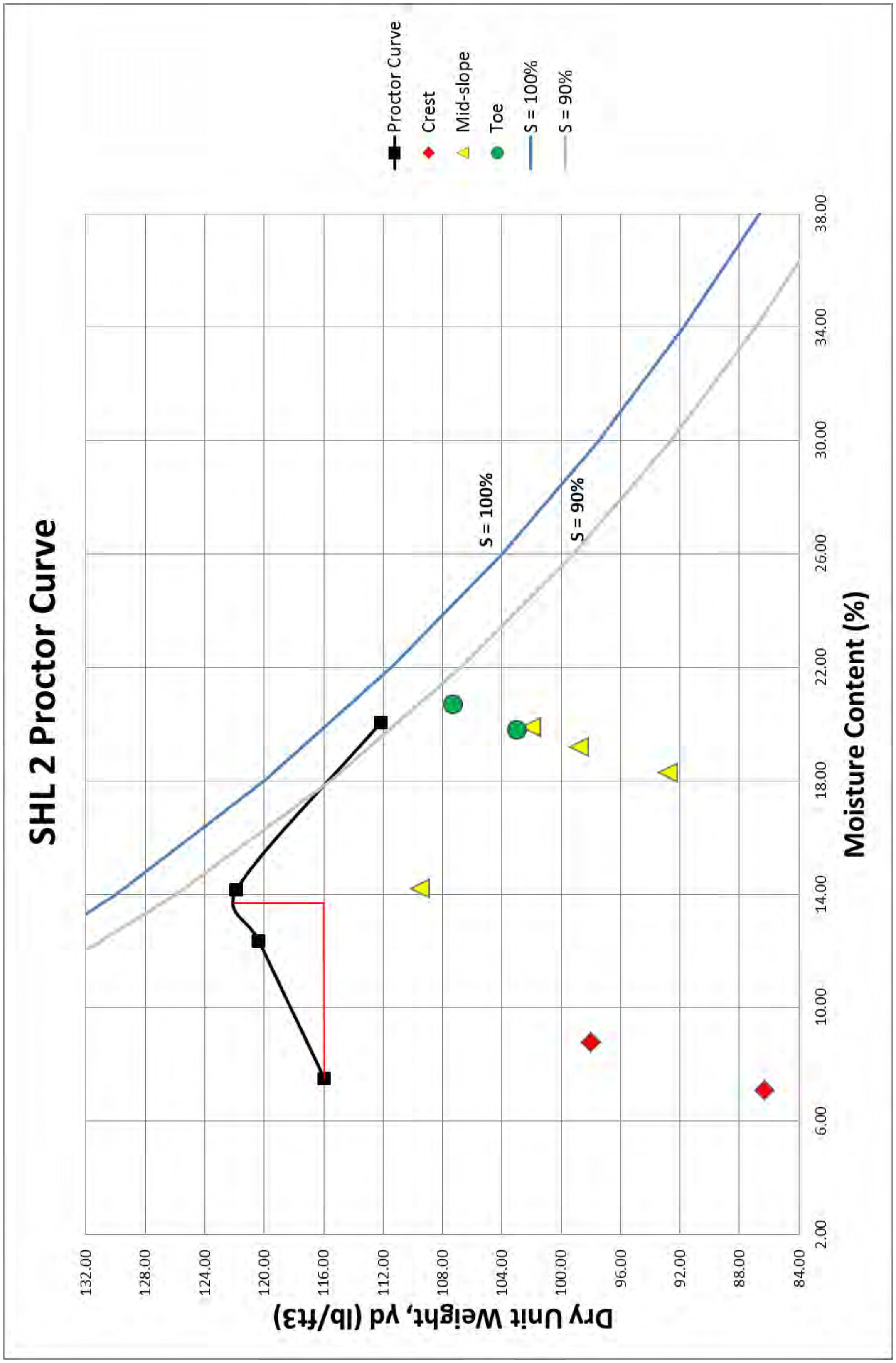
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

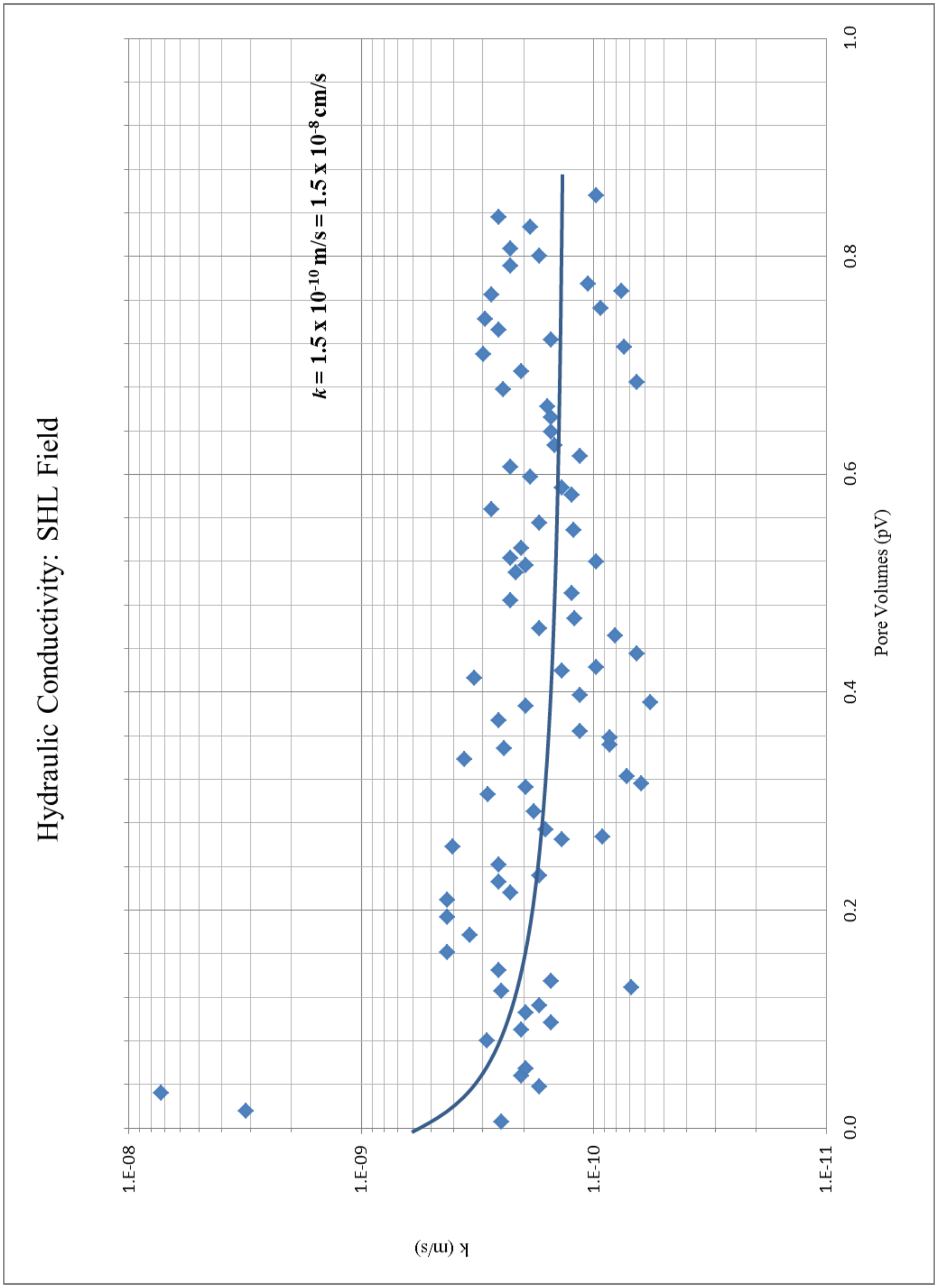
SHL 2 Centralized Pit		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			3
2	Are there any slope movements or animal burrows?	No				4
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	Yes		✓		2
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	No				4
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	No				4
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

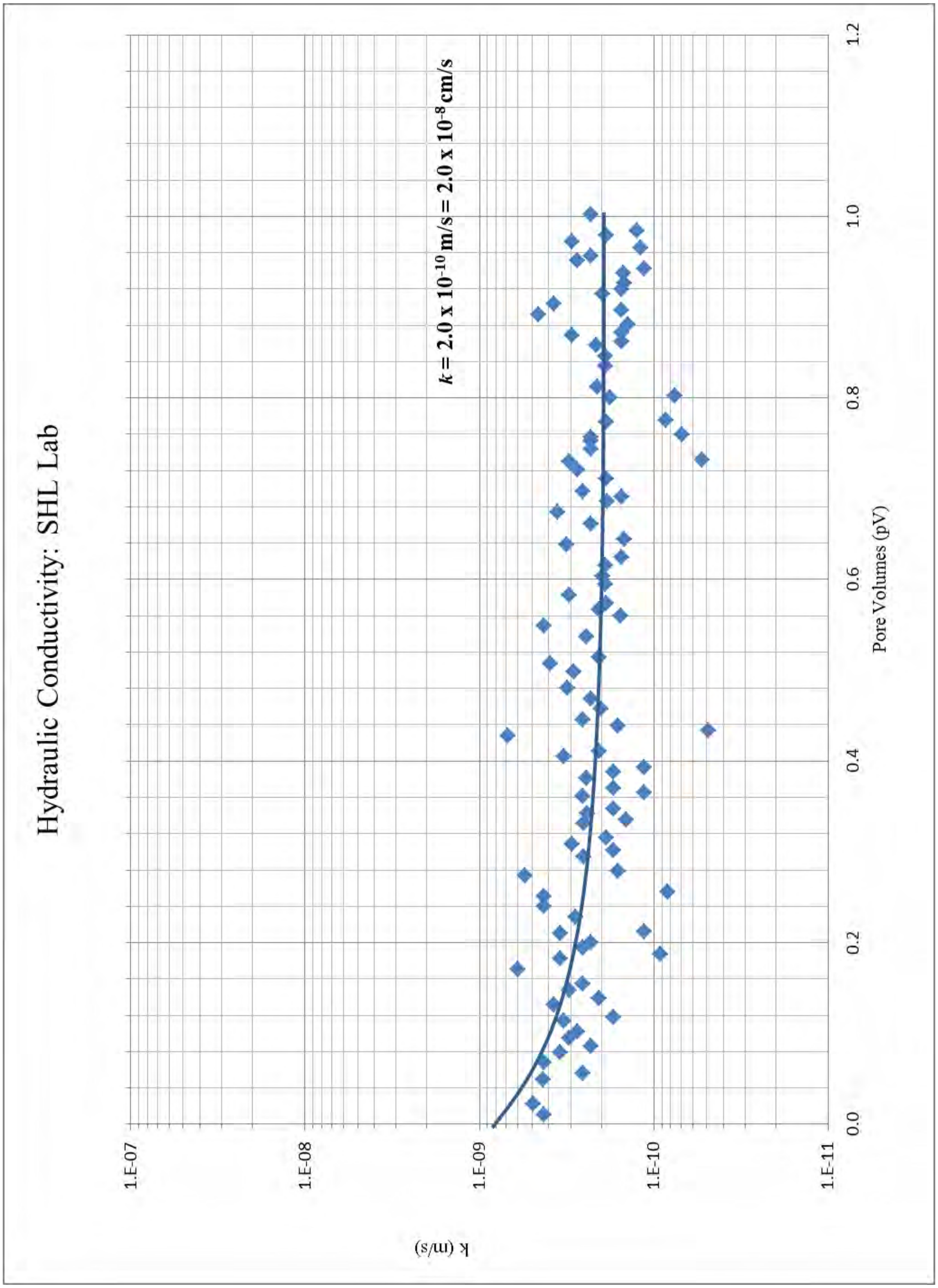
Total:	**67**	(Out of 76)
Percentage:	**88.2%**	

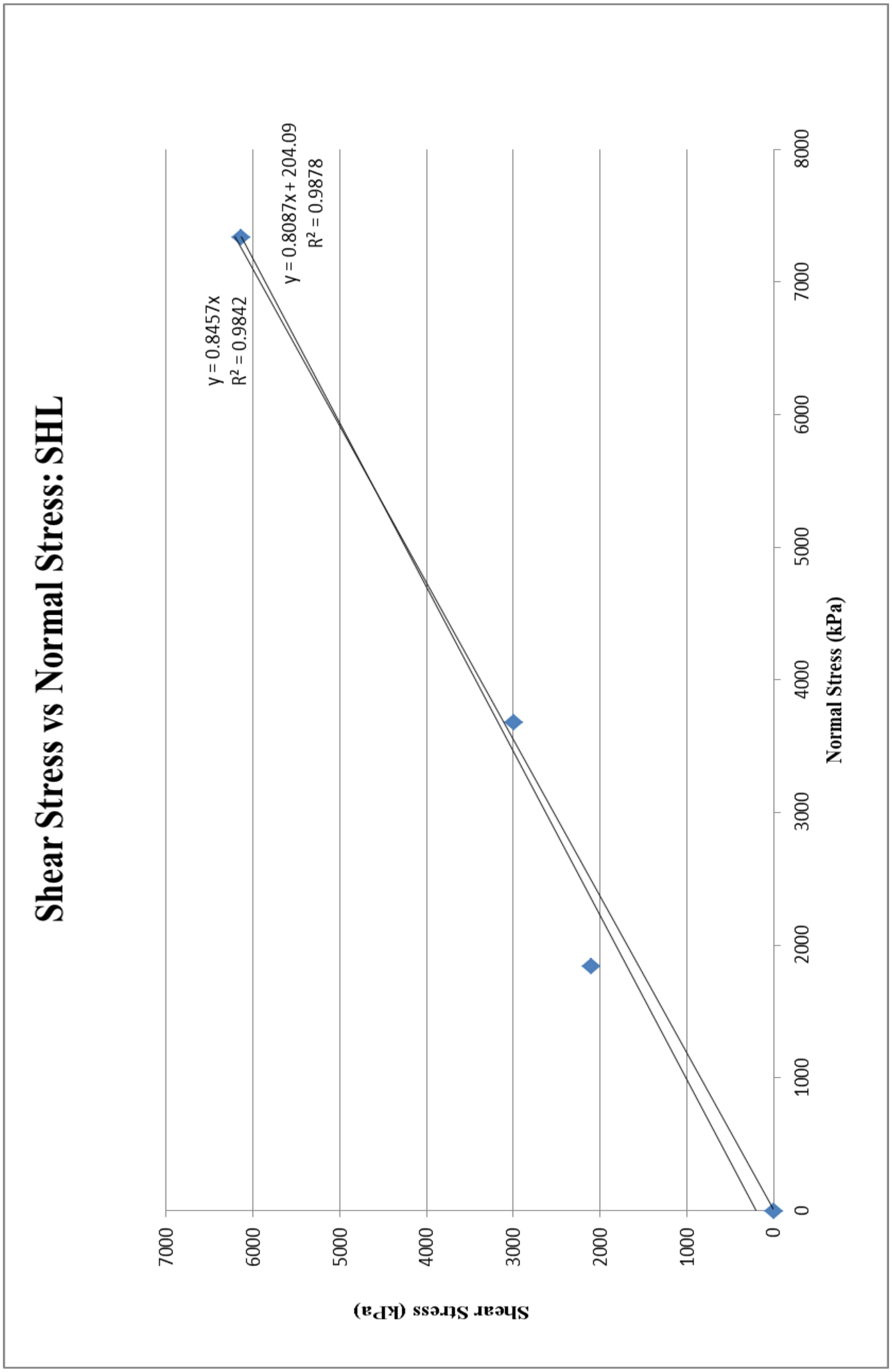


SHL 2 Centalized Pits: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


SHL 2 Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
132.00
128.00
124.00
120.00
116.00
112.00
108.00
104.00
100.00
96.00
92.00
88.00
84.00
2.00
6.00
10.00
14.00
18.00
22.00
26.00
30.00
34.00
38.00
S = 100%
S = 90%
Proctor Curve
Crest
Mid-slope
Toe
S = 100%
S = 90%


Hydraulic Conductivity: SHL Field
k = 1.5 x 10-10 m/s = 1.5 x 10-8 cm/s
k (m/s)
Pore Volumes (pV)
1.E-08
1.E-09
1.E-10
1.E-11
0.0
0.2
0.4
0.6
0.8
1.0


Hydraulic Conductivity: SHL Lab
$k = 2.0 \times 10^{-10}$ m/s = 2.0×10^{-8} cm/s
k (m/s)
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2


Shear Stress vs Normal Stress: SHL
y = 0.8457x
R² = 0.9842
y = 0.8087x + 204.09
R² = 0.9878
Shear Stress (kPa)
Normal Stress (kPa)
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (SHL)			
Date	**Sample**	**Compaction**	**Material**
11/5/2012	SHL	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress (psf)**	**Normal Stress (psf)**
High	6.137	6137	7342
Medium	2.995	2995	3688
Low	2.095	2095	1844
4	0	0	0
m	0.8087	m	0.8457
ϕ' (degrees)	38.962	$\phi'_{c'=0}$ (degrees)	40.221
c' (psf)	204.090	c' (psf)	0.0

Appendix J: SHL 3 Centralized Pit

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: SHL 3 Centralized Pit
Date of Site Evaluation: 7/30/12

Permit Observations / Anomalies:

Field measurements of the as-built construction differed from the permitted design. The berm crest width measured a minimum of 12 feet, as opposed to the 24 feet in the permit.

The as-built dimensions of the pit were larger than the permitted dimensions. The permitted size is 185 feet wide by 387 feet long, while the as-built dimensions measured 208.5 feet wide by 417 feet long. As a result, the as-built capacity is larger than the permitted design.

Hydrology

Rills and gullies were noticed on the downstream face of the pit; however, no slope movements were observed. Standing water was found in the ditch above the pit, which may indicate that the gradient of the ditch is insufficient for drainage. Moist soil was found on the northeast area of the downstream face, which may be a sign of seepage.

Containment

The liner for the pit is a 60-millimeter geomembrane. Bulges in the liner were noticed at a few locations, and a minor amount of rock and soil were on top of the liner. Furthermore, the anchor trench was exposed in two locations due to insufficient embedment.

Slope

Minor rill and gully formation was present on the downstream face. No slope movements were noted, but woody debris was noticed on the downstream face in the fill material. Possible seepage was found on the downstream face, as evidenced by a wet zone.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the pit. Data was collected at the pit crest and on the down-gradient slope of the pit.

Other Comments

Minor gouge marks were noticed in the pipes, and garbage was found in the pit. A buried telephone line is located below the drainage ditch at the toe of the downstream face.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/30/12 11:00 am	County	Marshall	Company	Noble Energy, Inc.
	Latitude	N 39° 58' 27.1"	Pit Name	SHL 3 Centralized Pit
WEATHER Mostly Sunny	Longitude	W 80° 33' 17.8"	ID No.	051-WPC-00002

A. PERMIT INFORMATION

Pit Width (ft.)	185 ft.	Minimum Berm Crest Width (ft.)	24 ft.	Construction Type	Incised
Pit Length (ft.)	387 ft.	Upstream Slope (H:V)	3:1	Liner Type	60 mil.
Depth (ft.)	15 ft.	Downstream Slope (H:V)	2:1	Date Built	4/2012
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	208.5 ft.	Berm Crest Width (ft.)	12 ft.	Crest Height (ft.)	68.6 ft.
Pit Length (ft.)	417 ft.	Upstream Slope (H:V)	2:1	Up Slope Length (ft.)	
Depth (ft.)		Downstream Slope (H:V)	2.4:1	Down Slope Length (ft.)	175.5 ft.
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	Yes	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			Rills/gullies
2	Are there any slope movements or animal burrows?	No				
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			Moist soil on face
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock and soil
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Anchor trench exposed in two places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Minor gouge marks
14	Are there any areas where the pipe is not properly supported?	No				
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Bottles/garbage
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Water in ditch above
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

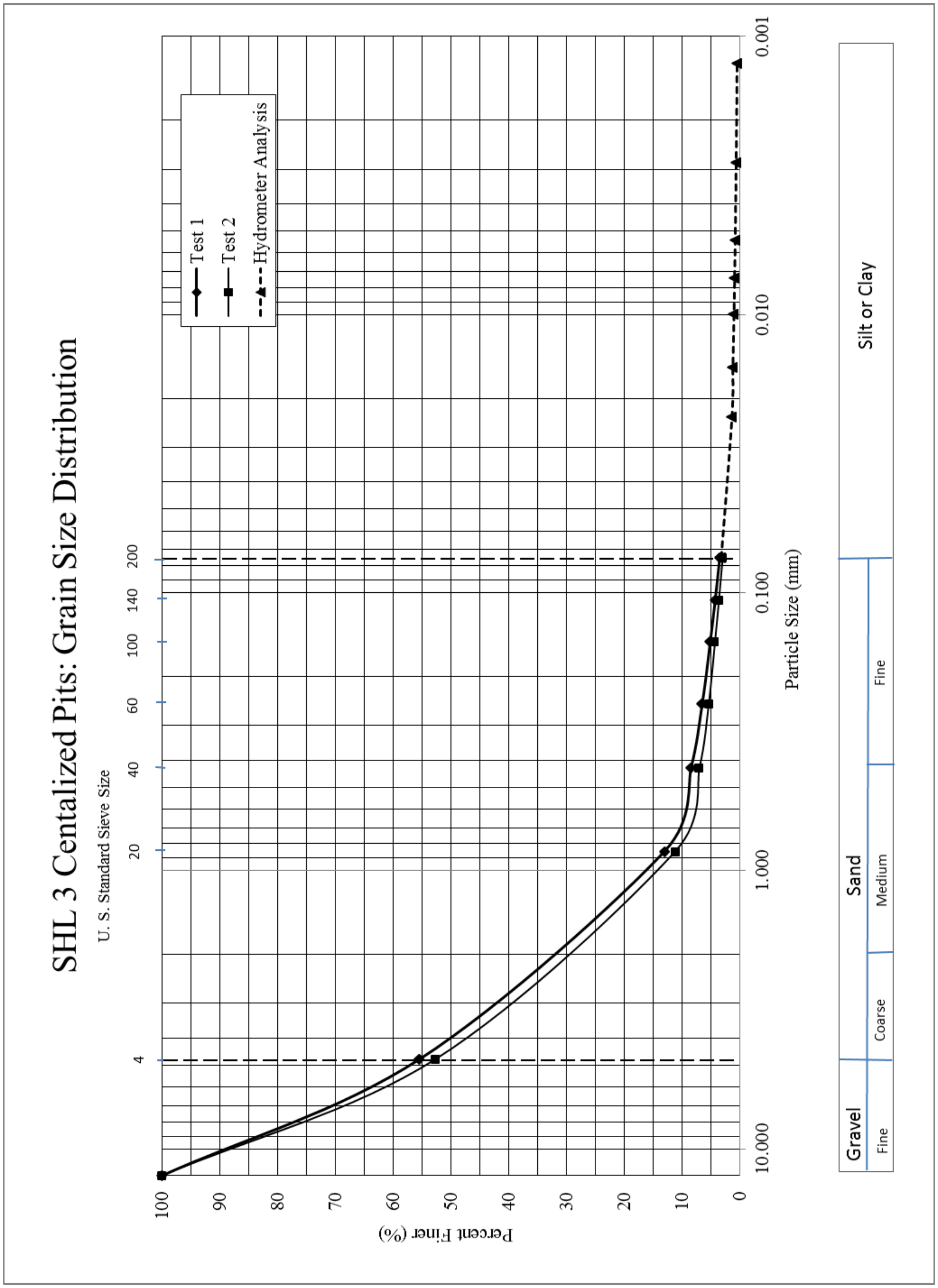
WVU (Name / Signature) Richard Wise	DATE 7/30/12
WVDEP (Name / Signature) John Kearney	7/30/12
Company Representative (Name / Signature) Bob Fedinetz	7/30/12

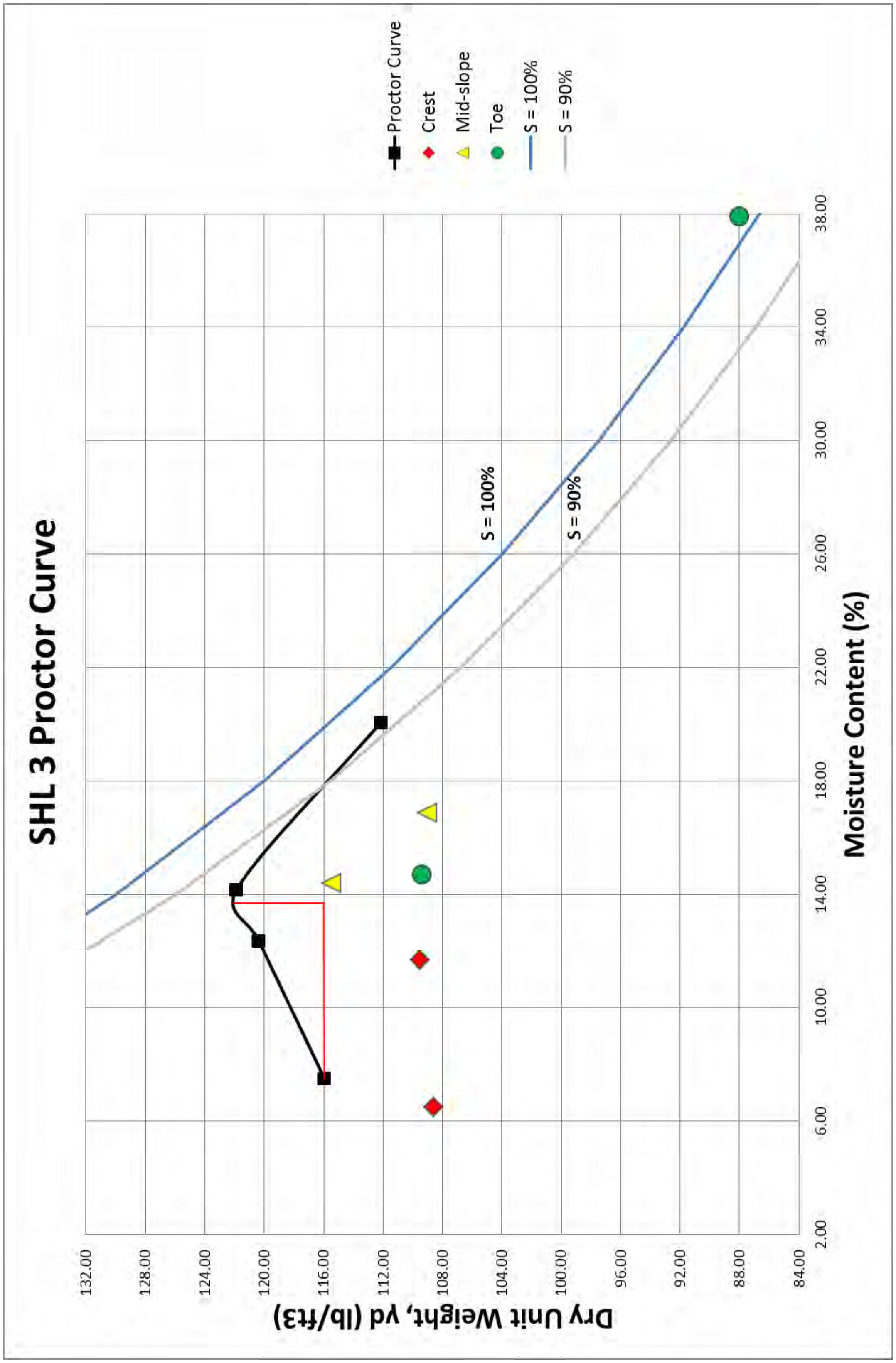
Site Operations & Infrastructure Evaluation	
Date: 7/30/12	Pit/Impoundment Name: SHL 3
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Inspector is on site usually every day, performs walking/visual inspection weekly at minimum
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Just follows state regulations while the sites are in start-up mode, will be hiring a compliance person specializing in inspection
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No, records visual operations of cracks, seeps, etc. and reports to environmental coordinator
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? N/A
6	Are there safety and emergency procedures for the pit/impoundment? Fencing, floatation devices, signage, early leak detection system (inspected weekly), future fencing plans include complete enclosure, emergency number at the entrance to the sites
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Sites have an emergency access number for failure/warnings (if something goes wrong, someone will know what to do)
8	Has the pit/impoundment inspector been trained on how to use the EAP? No, would call back to the office if a problem occurs
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) No
10	Does the company have a policy on pit/impoundment safety? Regulatory group would know
11	How frequently does a Professional Engineer inspect the site? Regulatory group would know
12	Other comments: Moist soil on the northeast downstream face Buried telephone line below drainage ditch Standing water in ditch Nearest dwelling is 414 feet away

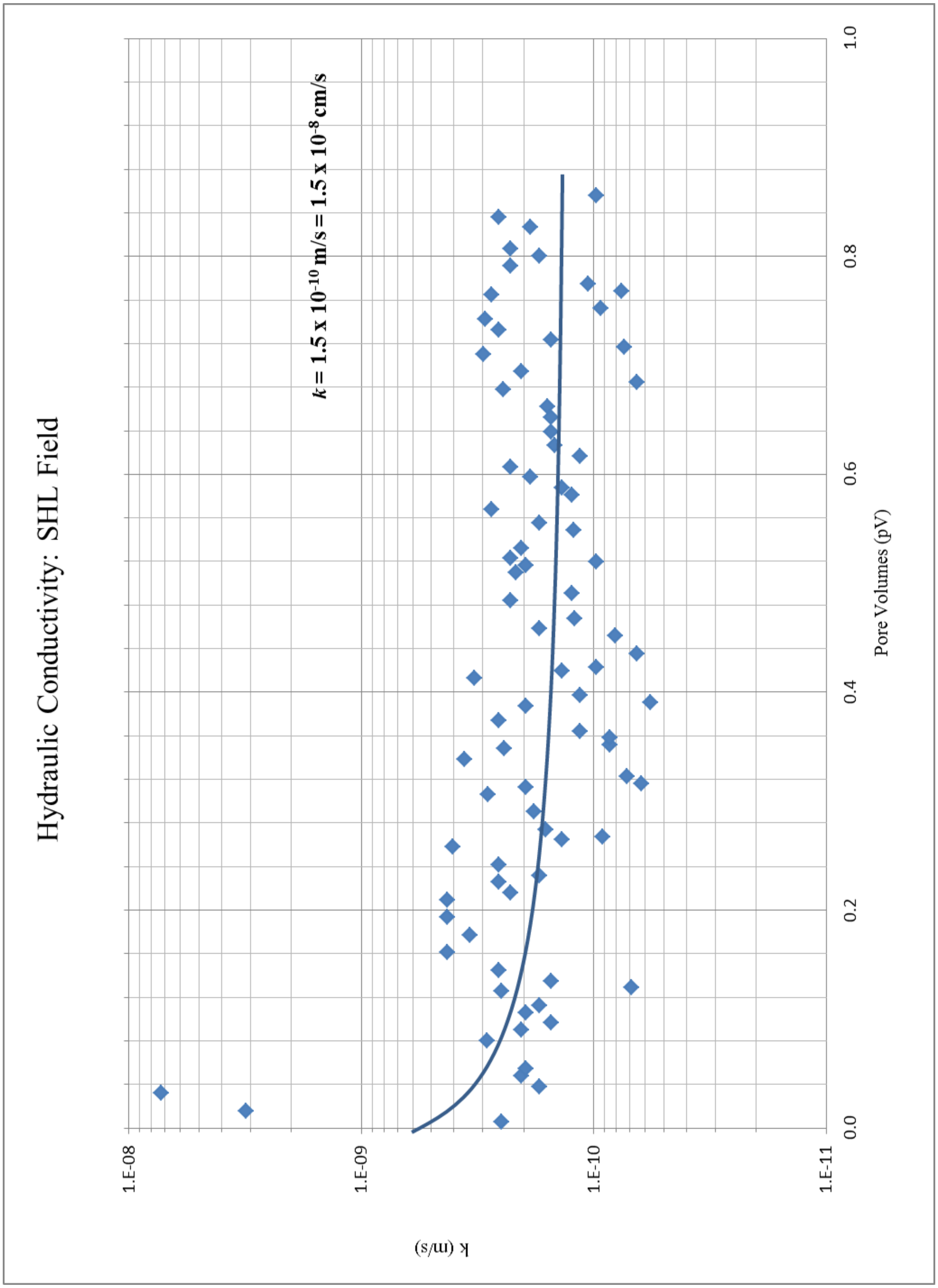
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

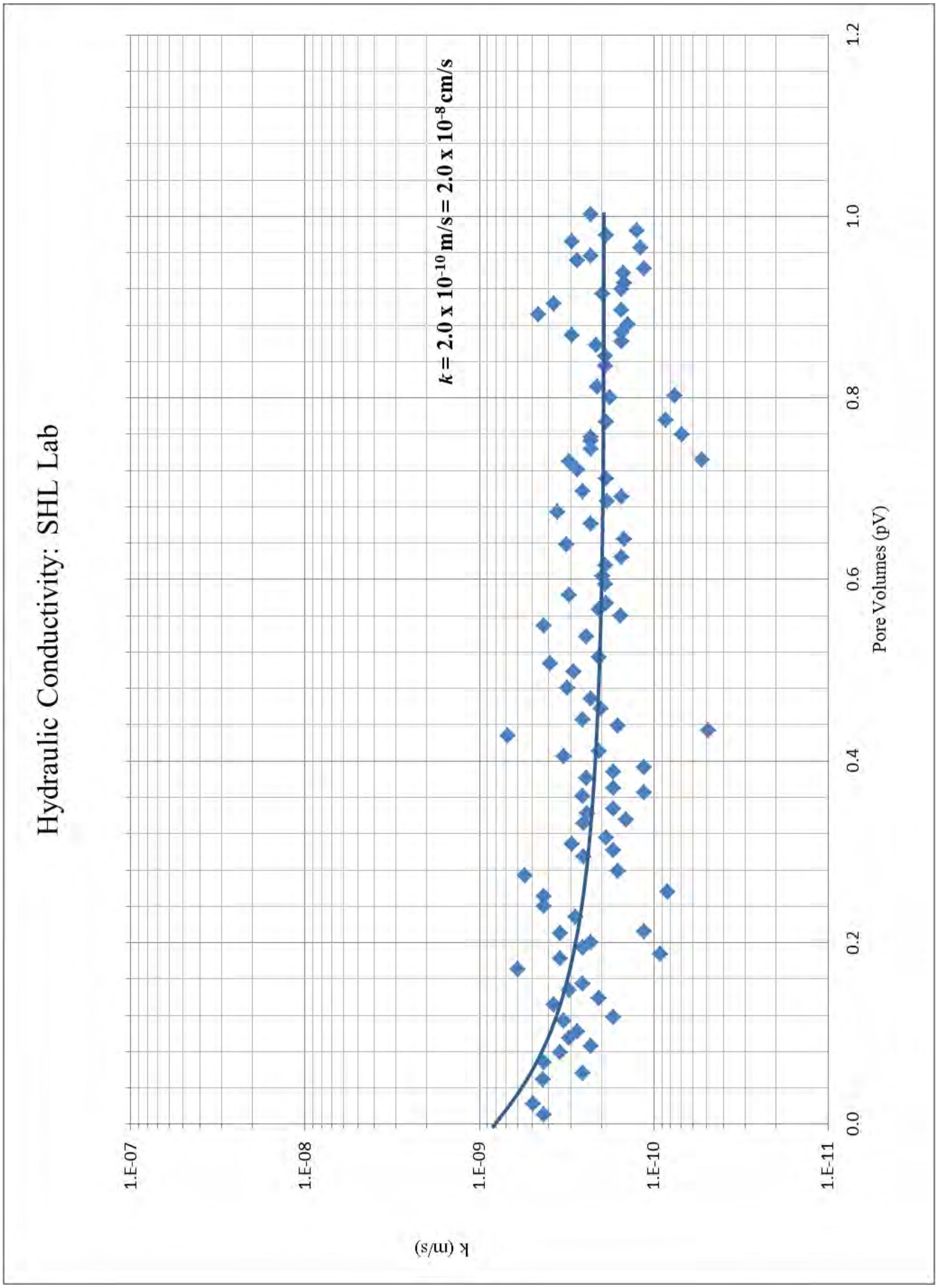
SHL 3 Centralized Pit		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			3
2	Are there any slope movements or animal burrows?	No				4
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			3
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	No				4
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

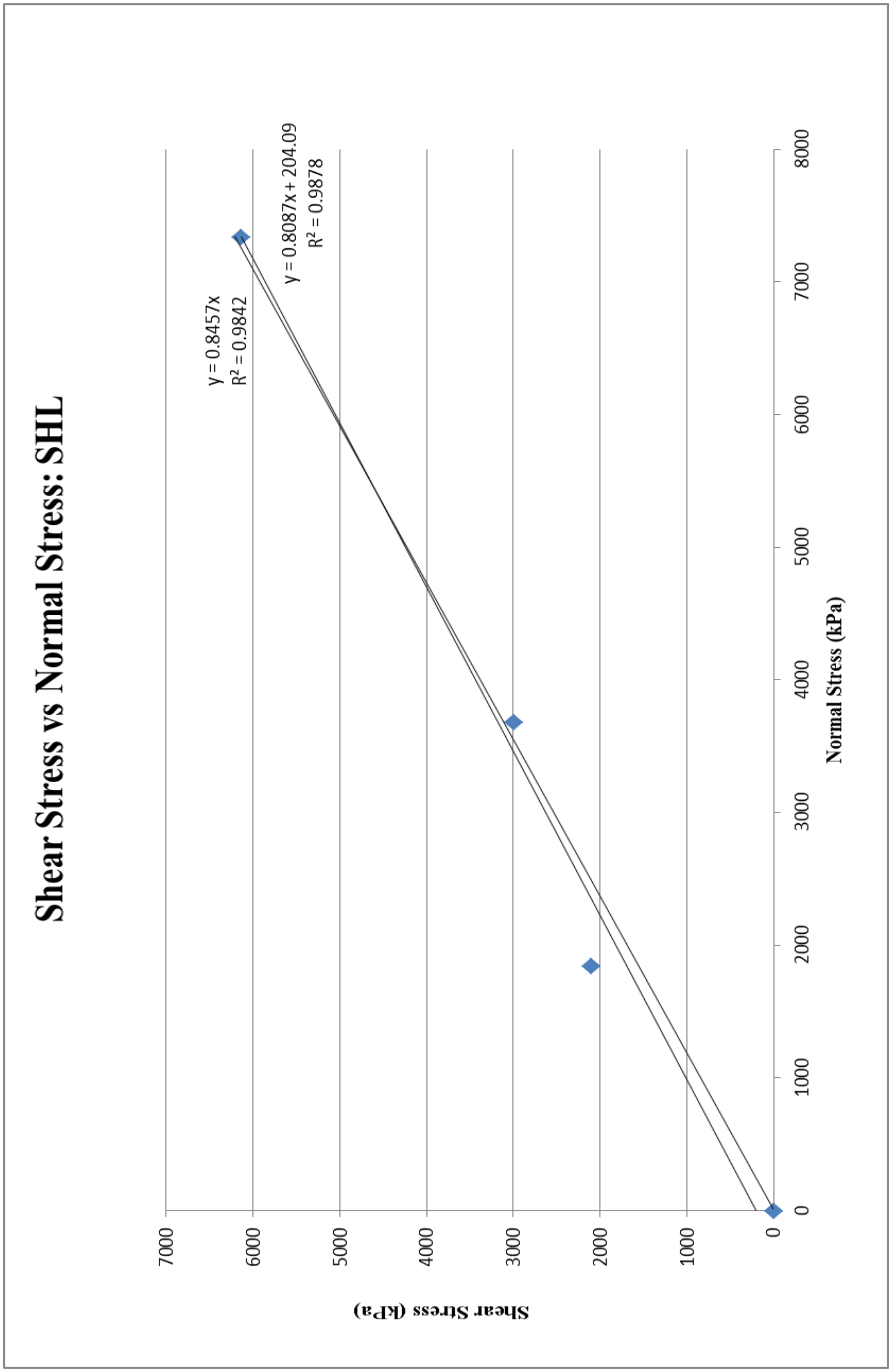
Total:	**67**	(Out of 76)
Percentage:	**88.2%**	


SHL 3 Centalized Pits: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


SHL 3 Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
132.00
128.00
124.00
120.00
116.00
112.00
108.00
104.00
100.00
96.00
92.00
88.00
84.00
2.00
6.00
10.00
14.00
18.00
22.00
26.00
30.00
34.00
38.00
S = 100%
S = 90%
Proctor Curve
Crest
Mid-slope
Toe
S = 100%
S = 90%


Hydraulic Conductivity: SHL Field
k = 1.5 x 10^-10 m/s = 1.5 x 10^-8 cm/s
k (m/s)
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.2
0.4
0.6
0.8
1.0


Hydraulic Conductivity: SHL Lab
k = 2.0 x 10^{-10} m/s = 2.0 x 10^{-8} cm/s
k (m/s)
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2


Shear Stress vs Normal Stress: SHL
Shear Stress (kPa)
Normal Stress (kPa)
0
1000
2000
3000
4000
5000
6000
7000
8000
y = 0.8457x
R² = 0.9842
y = 0.8087x + 204.09
R² = 0.9878

Max Shear Stress vs. Normal Stress (SHL)			
Date	**Sample**	**Compaction**	**Material**
11/5/2012	SHL	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress (psf)**	**Normal Stress (psf)**
High	6.137	6137	7342
Medium	2.995	2995	3688
Low	2.095	2095	1844
4	0	0	0
m	0.8087	m	0.8457
ϕ' (degrees)	38.962	$\phi'_{c'=0}$ (degrees)	40.221
c' (psf)	204.090	c' (psf)	0.0

Appendix K: SHL 4 Centralized Pit

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: SHL 4 Centralized Pit
Date of Site Evaluation: 7/30/12

Permit Observations / Anomalies:

Field measurements of the as-built construction differed from the permitted design. The berm crest width measured a minimum of 7.5 feet, as opposed to the 27 feet in the permit.

The as-built dimensions of the pit were larger than the permitted dimensions. The permitted size is 150 feet wide by 400 feet long, while the as-built dimensions measured 165 feet wide by 405 feet long. As a result, the as-built capacity is larger than the permitted design.

Hydrology

Visual evaluations of the pit found several areas of concern. The downstream faces both had minor rill and gully formation, although woody debris was prevalent on the slopes which may contribute to further erosion. Also, wet zones were present in the anchor trench and in several areas on the berm, especially on the east side of the pit. This wet zone may have contributed to a large slope movement which was found on the eastern downstream face. The soil in the slip was moist, and signs of seepage were found on the slope both above and in the slip. The collection ditch at the bottom of the western downstream face also contained water.

Containment

The liner for the pit is a 60-millimeter geomembrane. Bulges in the liner were noticed at a few locations, and a minor amount of rock and soil were on top of the liner. Furthermore, the anchor trench was exposed in places due to insufficient embedment.

Slope

Rills and gullies were observed on the downstream faces, and a large slope movement was present on the eastern downstream face. Woody debris was noticed on the downstream faces in the fill material.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the pit. Data was collected at the pit crest and on the down-gradient slope of the pit, including above and below the slip on the eastern downstream face.

Other Comments

Minor gouge marks were noticed in the pipes, and one pipe was resting on a bucket and thus was not supported properly. Additionally, garbage was found in the pit. The eastern downstream face had three drainage pipes.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 7/30/12 1:30 pm	County	Marshall	Company	Noble Energy, Inc.
	Latitude	N 39° 57' 46.1"	Pit Name	SHL 4 Centralized Pit
WEATHER Mostly Sunny	Longitude	W 80° 33' 46.8"	ID No.	051-WPC-00003

A. PERMIT INFORMATION

Pit Width (ft.)	150 ft.	Minimum Berm Crest Width (ft.)	27 ft.	Construction Type	Incised
Pit Length (ft.)	400 ft.	Upstream Slope (H:V)	3:1	Liner Type	60 mil.
Depth (ft.)	15 ft.	Downstream Slope (H:V)	2:1	Date Built	4/2012
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	165 ft.	Berm Crest Width (ft.)	7.5 ft.	Crest Height (ft.)	40.2 ft.
Pit Length (ft.)	405 ft.	Upstream Slope (H:V)	3:1	Up Slope Length (ft.)	13 ft.
Depth (ft.)		Downstream Slope (H:V)	2.4:1	Down Slope Length (ft.)	105 ft.
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			Minor rills/gullies
2	Are there any slope movements or animal burrows?	Yes			✓	Huge slope movement
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes		✓		Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	At slope movement
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock/soil
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Anchor trench exposed
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Minor gouge marks
14	Are there any areas where the pipe is not properly supported?	Yes	✓			Resting on bucket
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Garbage in pit
17	Are there any signs of water in ditch associated with pit?	Yes			✓	Water east side on berm
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

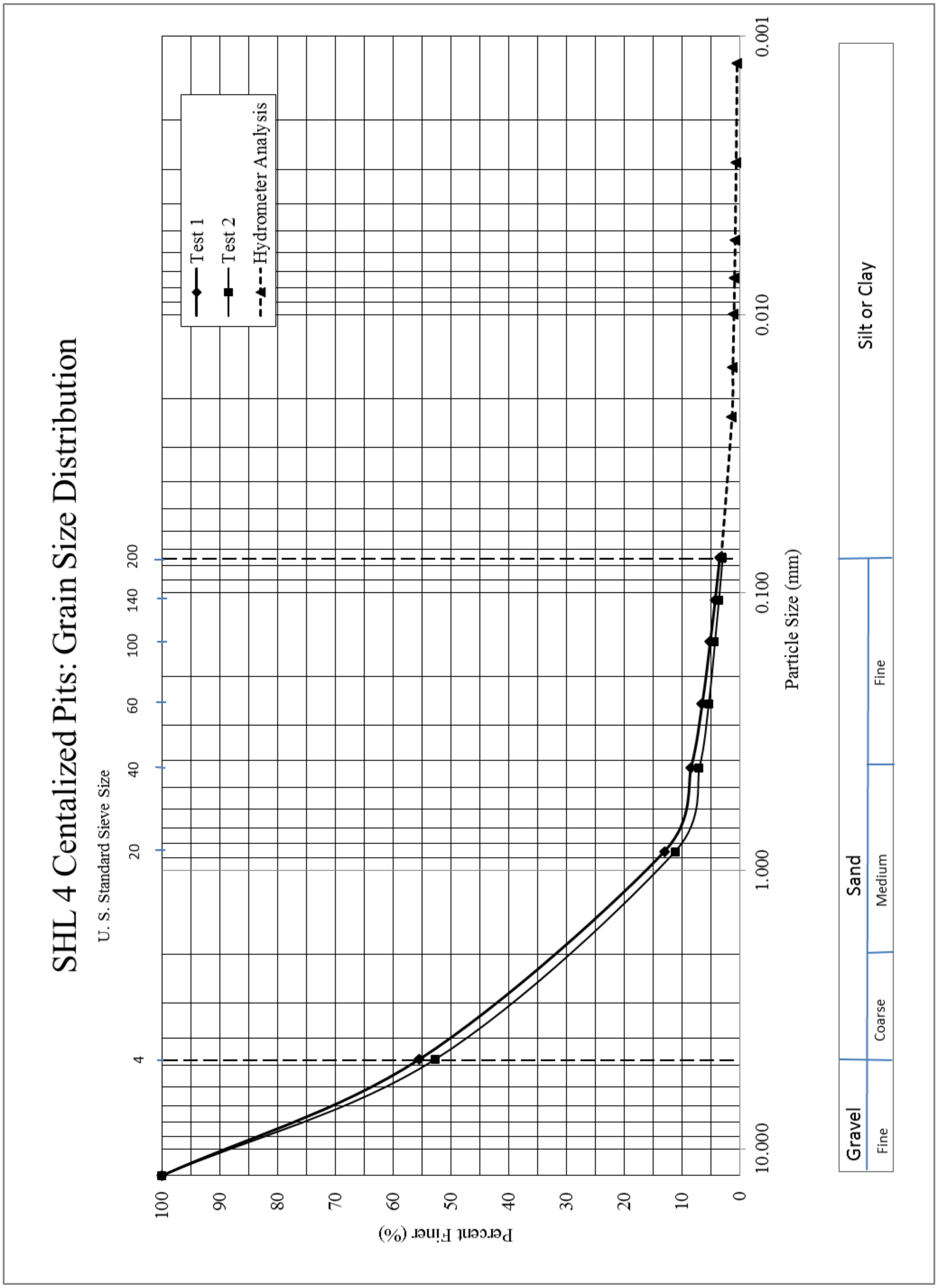
WVU (Name / Signature) Richard Wise	DATE 7/30/12
WVDEP (Name / Signature) John Kearney	7/30/12
Company Representative (Name / Signature) Bob Fedinetz	7/30/12

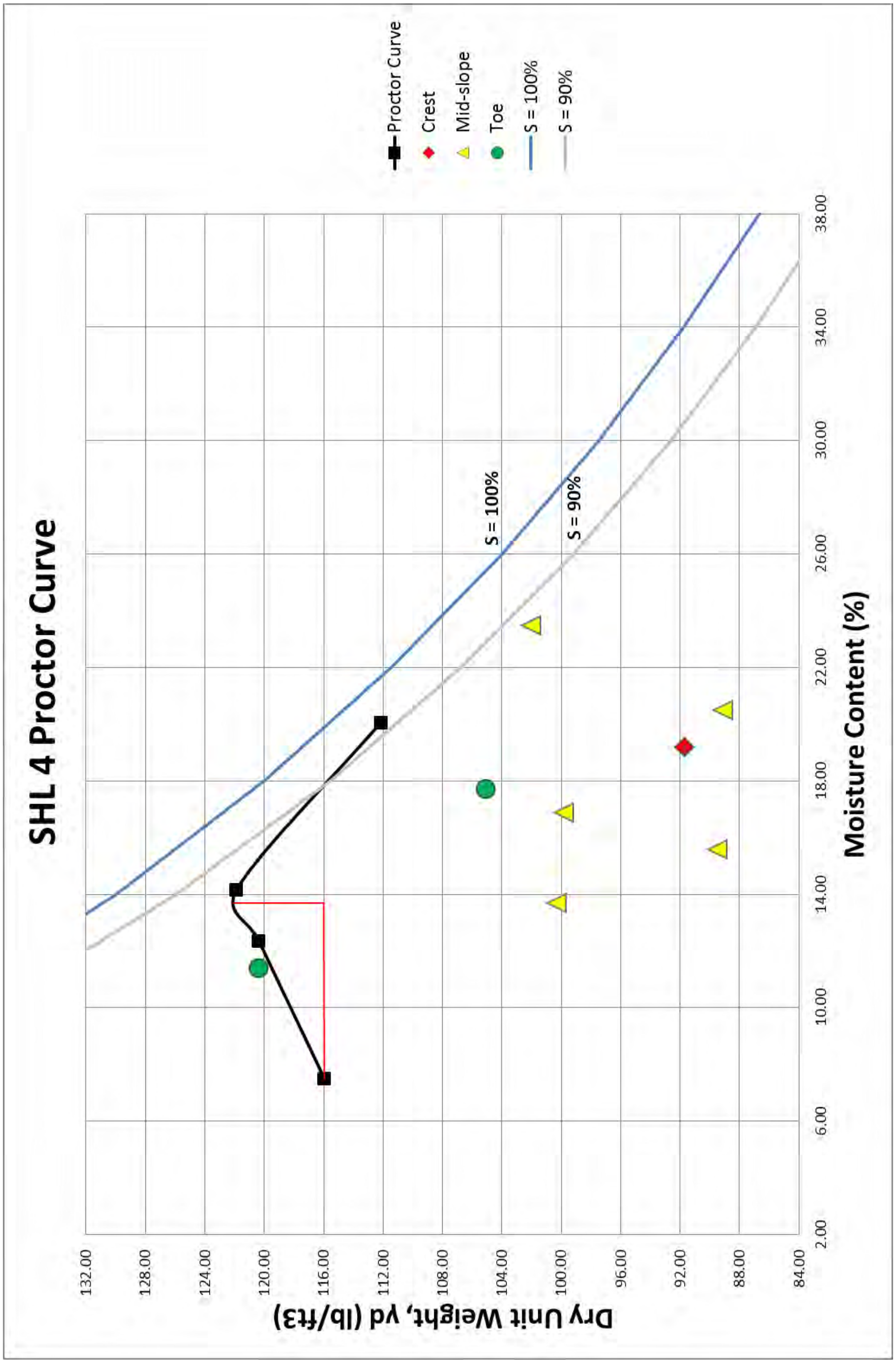
Site Operations & Infrastructure Evaluation	
Date: 7/30/12	Pit/Impoundment Name: SHL 4
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Inspector is on site usually every day, performs walking/visual inspection weekly at minimum
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Just follows state regulations while the sites are in start-up mode, will be hiring a compliance person specializing in inspection
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No, records visual operations of cracks, seeps, etc. and reports to environmental coordinator
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? N/A
6	Are there safety and emergency procedures for the pit/impoundment? Fencing, floatation devices, signage, early leak detection system (inspected weekly), future fencing plans include complete enclosure, emergency number at the entrance to the sites
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Sites have an emergency access number for failure/warnings (if something goes wrong, someone will know what to do)
8	Has the pit/impoundment inspector been trained on how to use the EAP? No, would call back to the office if a problem occurs
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) No
10	Does the company have a policy on pit/impoundment safety? Regulatory group would know
11	How frequently does a Professional Engineer inspect the site? Regulatory group would know
12	Other comments: Water in collection ditch at toe of west downstream face Large slide, three pipes on east downstream face

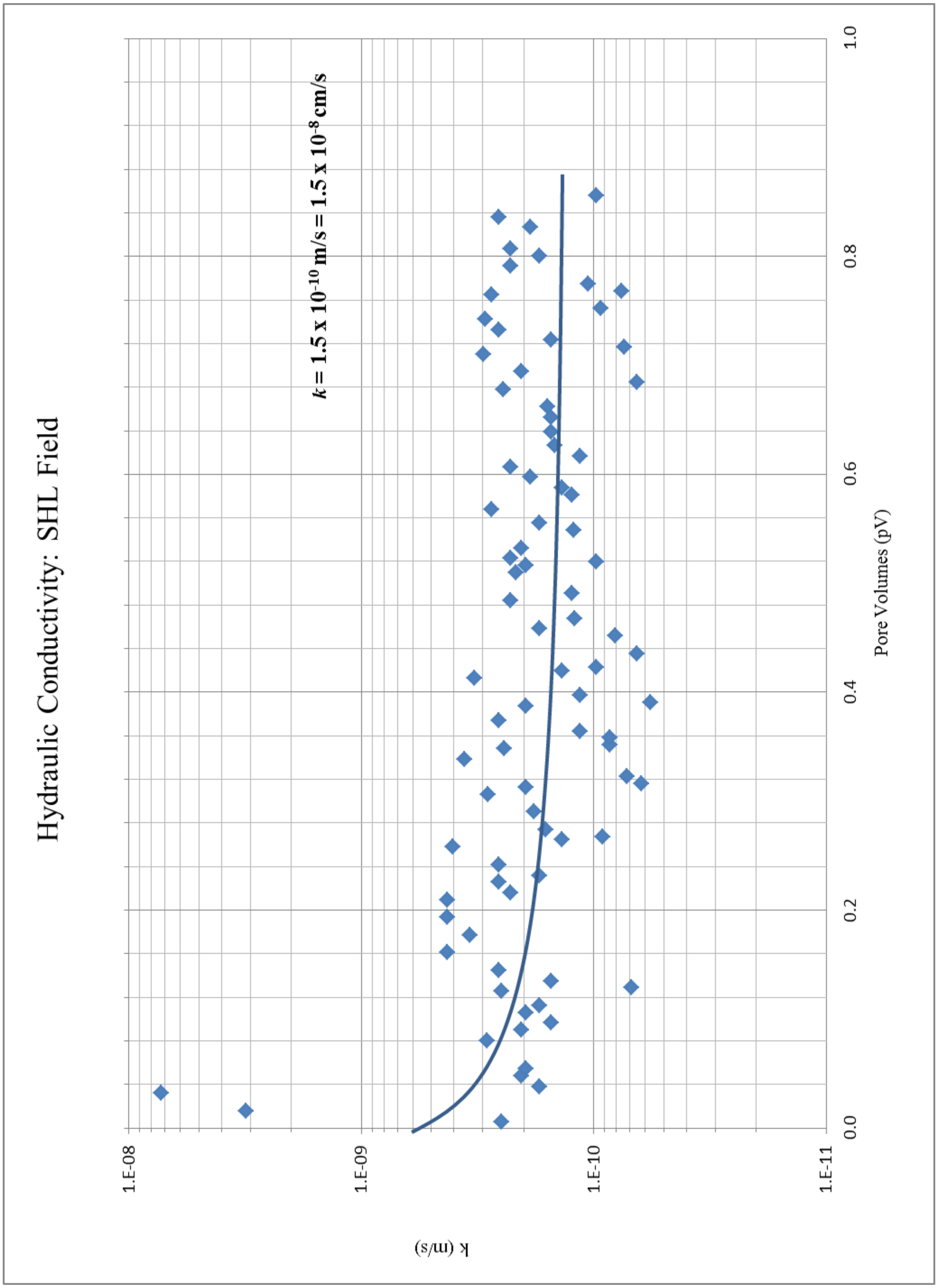
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

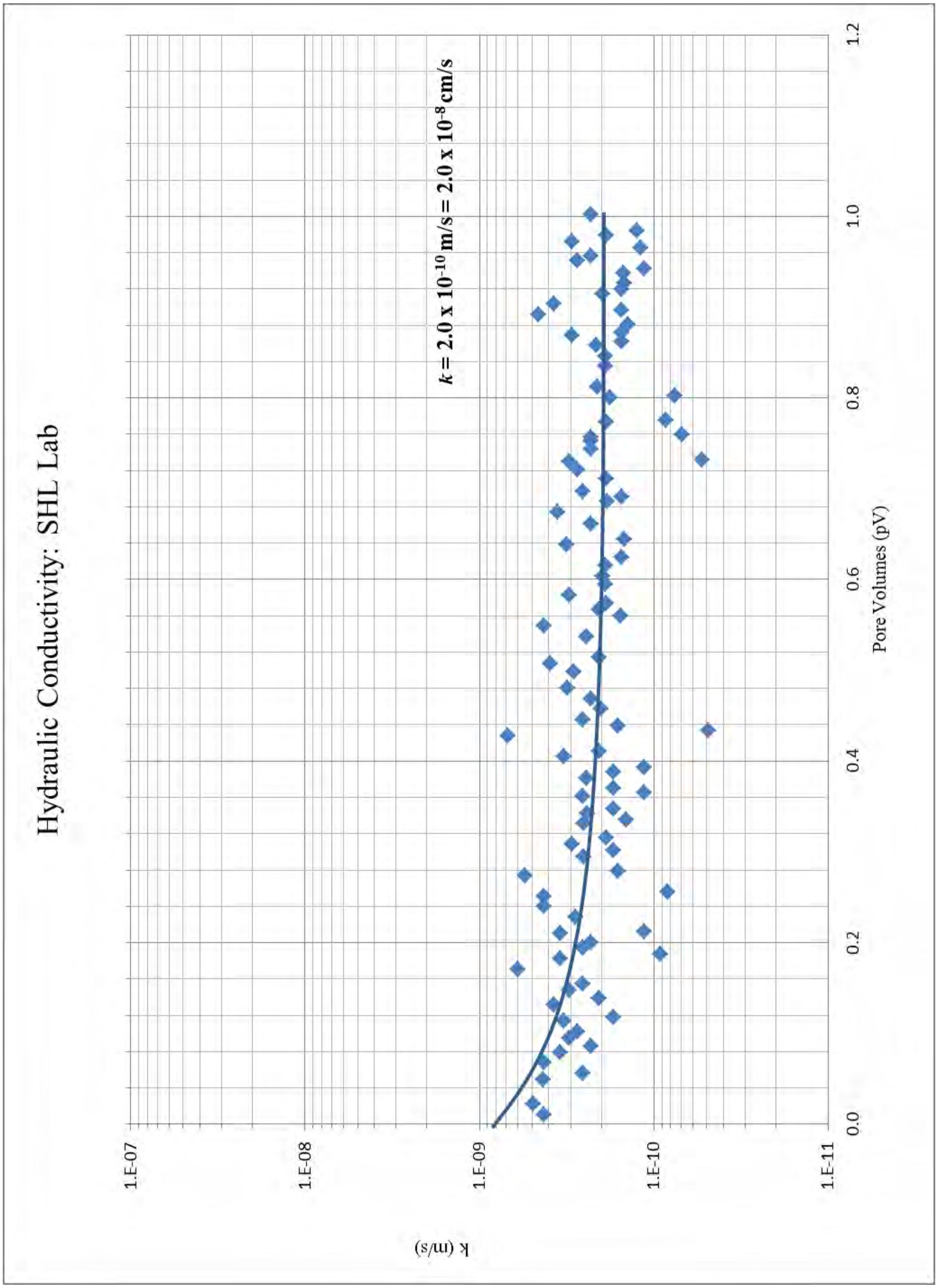
SHL 4 Centralized Pit		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			3
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes		✓		2
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	1
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	Yes	✓			3
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	Yes			✓	1
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

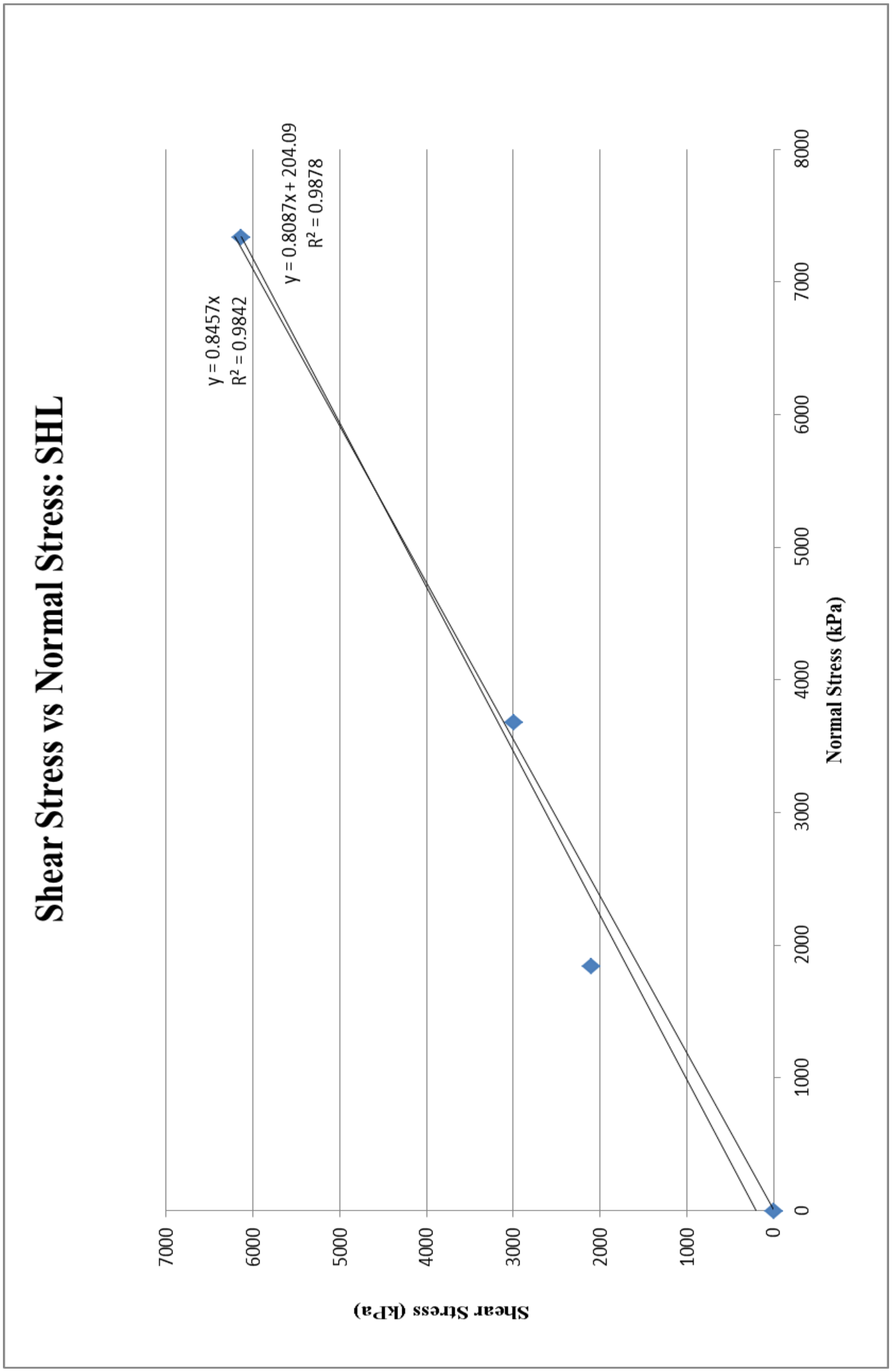
Total:	**58**	(Out of 76)
Percentage:	**76.3%**	


SHL 4 Centalized Pits: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


SHL 4 Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
132.00
128.00
124.00
120.00
116.00
112.00
108.00
104.00
100.00
96.00
92.00
88.00
84.00
2.00
6.00
10.00
14.00
18.00
22.00
26.00
30.00
34.00
38.00
S = 100%
S = 90%
Proctor Curve
Crest
Mid-slope
Toe
S = 100%
S = 90%


Hydraulic Conductivity: SHL Field
k = 1.5 x 10-10 m/s = 1.5 x 10-8 cm/s
k (m/s)
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.2
0.4
0.6
0.8
1.0


Hydraulic Conductivity: SHL Lab
$k = 2.0 \times 10^{-10}$ m/s = 2.0×10^{-8} cm/s
k (m/s)
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2


Shear Stress vs Normal Stress: SHL
y = 0.8457x
R² = 0.9842
y = 0.8087x + 204.09
R² = 0.9878
Shear Stress (kPa)
Normal Stress (kPa)
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (SHL)			
Date	**Sample**	**Compaction**	**Material**
11/5/2012	SHL	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress (psf)**	**Normal Stress (psf)**
High	6.137	6137	7342
Medium	2.995	2995	3688
Low	2.095	2095	1844
4	0	0	0
m	0.8087	m	0.8457
ϕ' (degrees)	38.962	$\phi'_{c'=0}$ (degrees)	40.221
c' (psf)	204.090	c' (psf)	0.0

Appendix L: Flanigan Pit

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Flanigan Pit
Date of Site Evaluation: 8/2/12

Permit Observations / Anomalies:

Field measurements of the as-built construction differed from the permitted design. The berm width measured a minimum of 12 feet, while the permitted berm width is 15 feet.

The as-built dimensions were larger than the permitted design. The as-built dimensions of the pit were 178.5 feet wide by 289.5 feet long, as opposed to the permitted dimensions of 152.72 feet wide by 277.81 feet. Thus, the as-built capacity is larger than the permitted design.

Hydrology

Minor rills and gullies were found at the crest of the pit and on the downstream face, and numerous wet zones were observed at the anchor trench and berm. Water was found at the toe of the downstream face, and moist soil was noticed in the ditch associated with the pit.

Containment

The liner for the pit is a 60-millimeter geomembrane. Bulges in the liner were observed on the upstream face of the pit. A minor amount of rock and soil were on top of the liner. Settlements and sinkholes were also observed at the anchor trench.

Slope

Rills and gullies were observed at the crest and on the downstream face, but no slope movements were found. Minor woody debris was present in the fill material on the berm and downstream face.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the crest of the pit and at the toe of the downstream face.

Other Comments

The fence measured 6’ 11” high, and the base of the fence was 11” off the ground. The pipe was unsupported across the well pad, and gouges were found on the pipe.

West Virginia University – Civil & Environmental Engineering ETD-10 Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form					
DATE & TIME 8/2/12 10:45 am	County	Harrison	Company	Antero Resources Appalachian Corp.	
WEATHER Sunny	Latitude	N 39° 20' 46.0"	Pit Name	Flanigan Pit	
	Longitude	W 80° 23' 44.2"	ID No.		

A. PERMIT INFORMATION

Pit Width (ft.)	152.72 ft.	Minimum Berm Crest Width (ft.)	15 ft.	Construction Type	Incised
Pit Length (ft.)	277.81 ft.	Upstream Slope (H:V)	2:1	Liner Type	60 mil.
Depth (ft.)		Downstream Slope (H:V)	2:1	Date Built	3/2012
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	178.5 ft.	Berm Crest Width (ft.)	12 ft.	Crest Height (ft.)	
Pit Length (ft.)	289.5 ft.	Upstream Slope (H:V)	1.7:1	Up Slope Length (ft.)	34.5 ft.
Depth (ft.)	22 ft.	Downstream Slope (H:V)		Down Slope Length (ft.)	26 ft.
Freeboard (ft.)	2 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			Rills/gullies
2	Are there any slope movements or animal burrows?	No				
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Minor woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	Water on anchor trench
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock/soil
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Cracks, anchor trench exposed in places
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Gouges
14	Are there any areas where the pipe is not properly supported?	Yes	✓			
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc)?	No				
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Moist soil in ditch
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

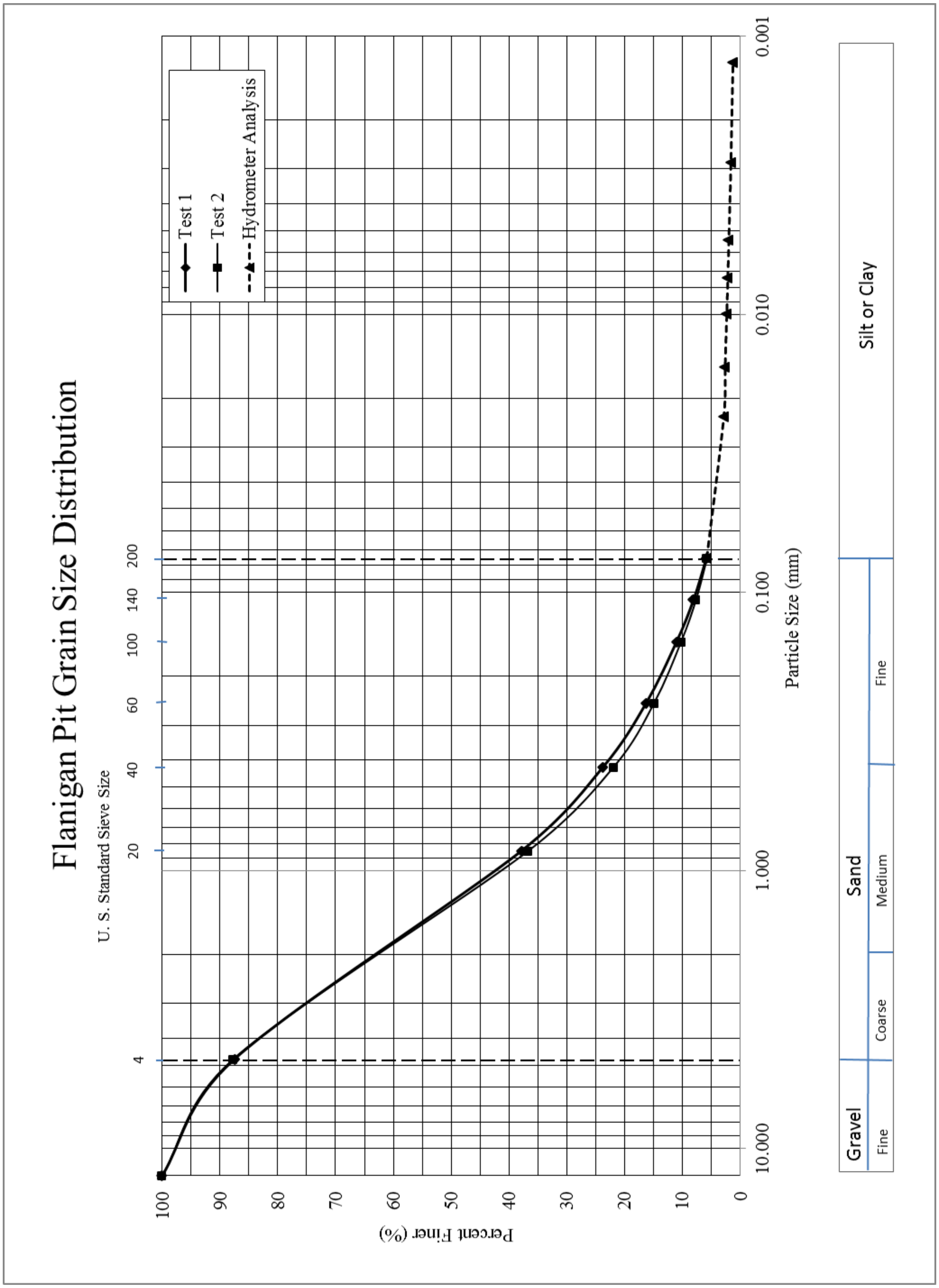
WVU (Name / Signature) Andrew Darnell	DATE 8/2/12
WVDEP (Name / Signature) John Kearney	8/2/12
Company Representative (Name / Signature) Jason Parson	8/2/12

Site Operations & Infrastructure Evaluation	
Date: 8/2/12	Pit/Impoundment Name: Flanigan Pit
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Walking inspection twice a week, checks water levels
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Not very much
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No, emails comments/readings to Denver
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? N/A
6	Are there safety and emergency procedures for the pit/impoundment? Yes, kept at the office
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Yes, CEC out of Pittsburgh develops the safety plans
8	Has the pit/impoundment inspector been trained on how to use the EAP? Yes, keeps a list of people to call
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) Doesn't know
10	Does the company have a policy on pit/impoundment safety? Yes, have to contact the safety group for the plans
11	How frequently does a Professional Engineer inspect the site? Weekly
12	Other comments: Water in anchor trench and on berm The fence is 6' 11" high and is 11" off the ground Rills at crest Minor woody debris

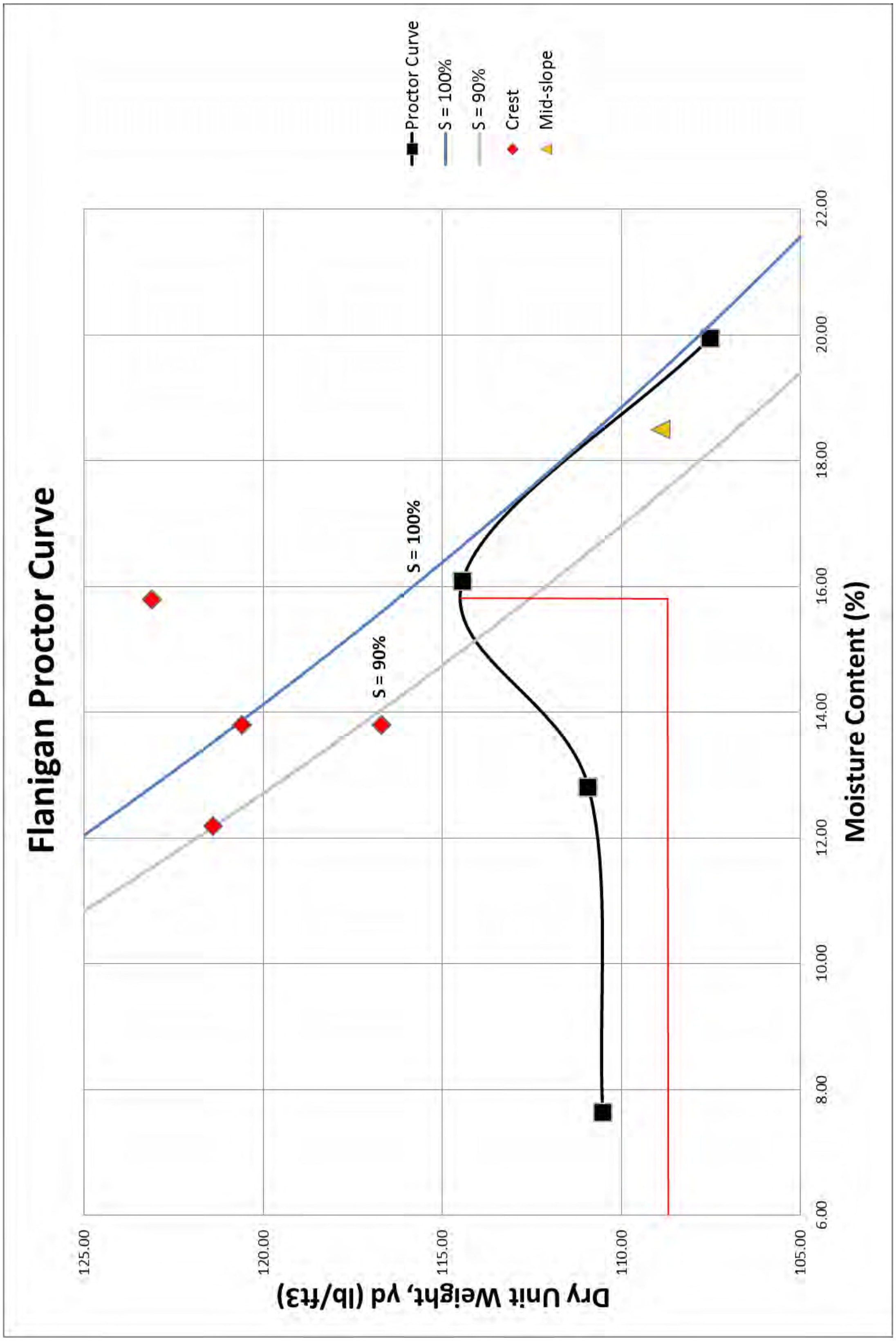
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

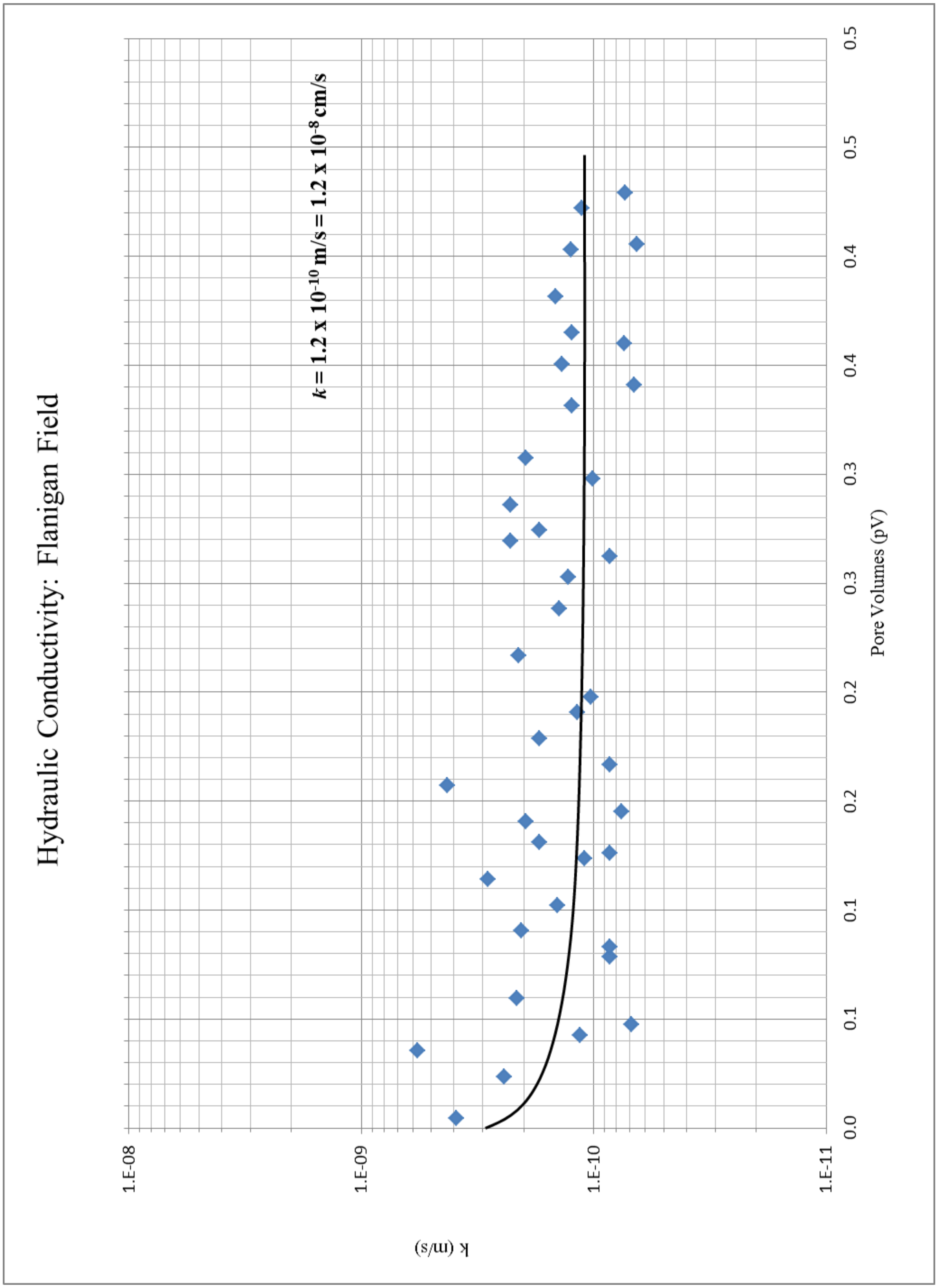
Flanigan Pit		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			3
2	Are there any slope movements or animal burrows?	No				4
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	1
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	Yes	✓			3
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	No				4
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

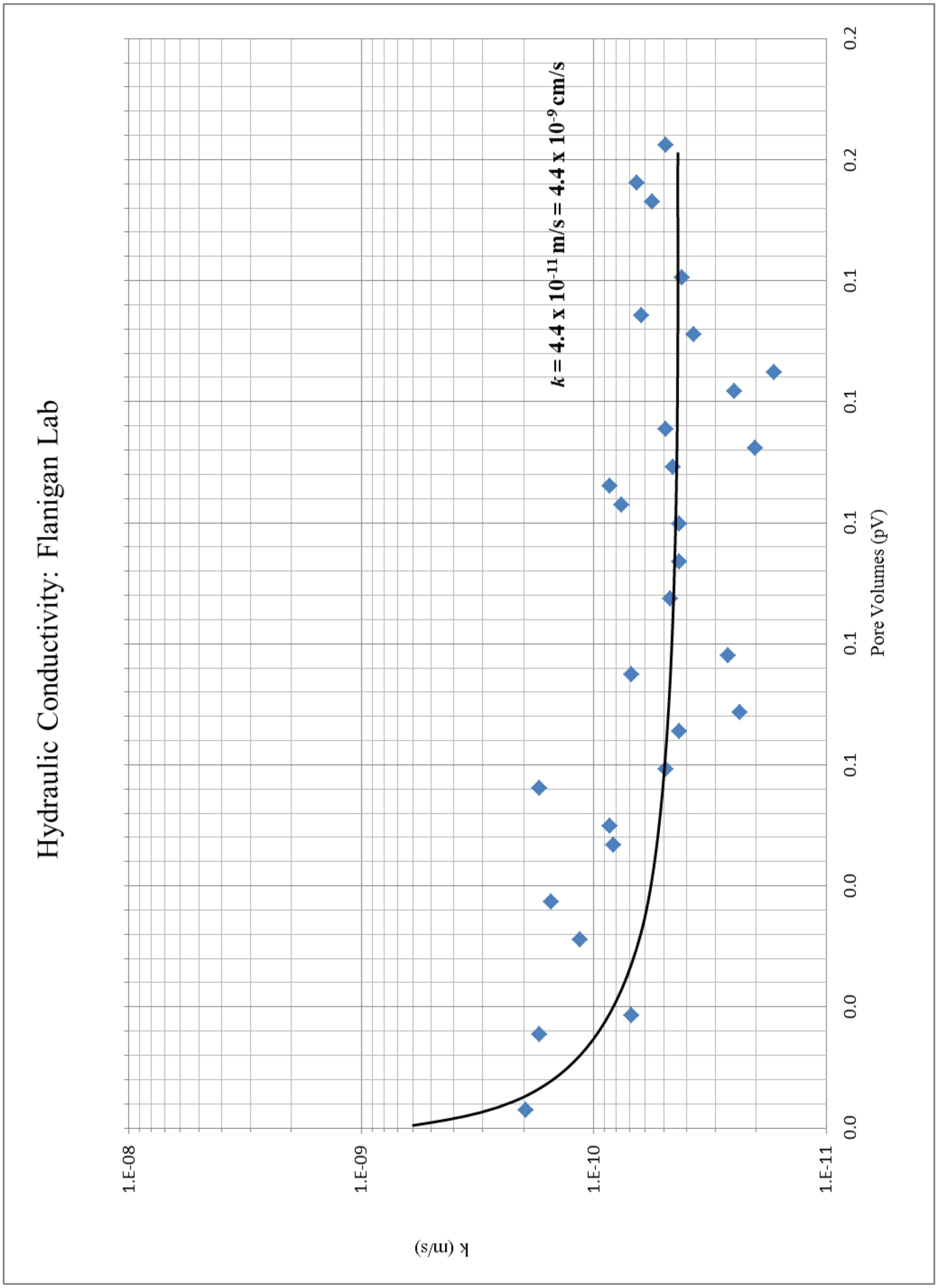
Total:	**65**	(Out of 76)
Percentage:	**85.5%**	

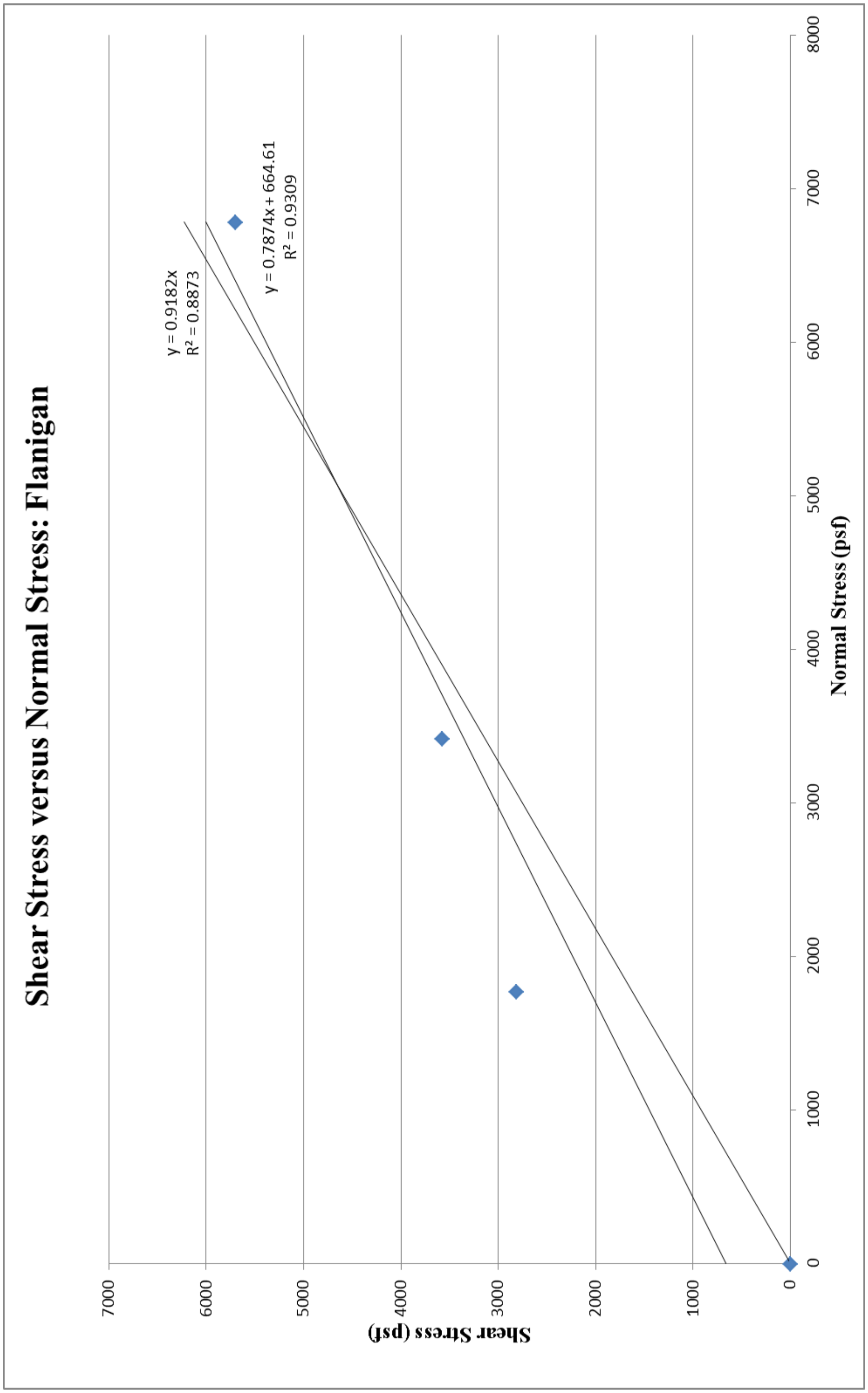


Flanigan Pit Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
Particle Size (mm)
10.000
1.000
0.100
0.010
0.001
Test 1
Test 2
Hydrometer Analysis
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


Flanigan Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
125.00
120.00
115.00
110.00
105.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
S = 100%
S = 90%
Proctor Curve
S = 100%
S = 90%
Crest
Mid-slope


Hydraulic Conductivity: Flanigan Field
$k = 1.2 \times 10^{-10}$ m/s = 1.2×10^{-8} cm/s
k (m/s)
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.1
0.1
0.2
0.2
0.3
0.3
0.4
0.4
0.5
0.5


Hydraulic Conductivity: Flanigan Lab
k = 4.4 x 10-11 m/s = 4.4 x 10-9 cm/s
k (m/s)
Pore Volumes (pV)
1.E-08
1.E-09
1.E-10
1.E-11
0.0
0.0
0.0
0.1
0.1
0.1
0.1
0.1
0.2
0.2


Shear Stress versus Normal Stress: Flanigan
y = 0.9182x
R² = 0.8873
y = 0.7874x + 664.61
R² = 0.9309
Shear Stress (psf)
Normal Stress (psf)
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (Flanigan)			
Date	**Sample**	**Compaction**	**Material**
11/30/2012	Flanigan	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress(psf)**	**Normal Stress (psf)**
High	5.703	5703	6786
Medium	3.574	3574	3423
Low	2.815	2815	1771
4	0	0	0
m	0.7874	m	0.9182
ϕ' (degrees)	38.217	$\phi_{c'=0}'$ (degrees)	42.558
c' (psf)	664.610	c' (psf)	0.0

Appendix M: Larry Pad

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Larry Pad
Date of Site Evaluation: 8/2/12

Permit Observations / Anomalies:

The berm width measured a minimum of 13 feet, and the as-built dimensions of the pit were 171 feet wide by 468 feet long. No permit information was provided for this pit.

Hydrology

A high amount of rills and gullies were found at the crest of the pit and on the downstream face, and slope movements were also observed on the downstream face. Wet zones were present on the berm and at the toe of the downstream face. Water was present in the ditch associated with the pit.

Containment

The liner for the pit is an HDPE geomembrane. Bulges in the liner were observed on the upstream face of the pit. A minor amount of rock and soil were on top of the liner. Cracks were observed in the soil on the berm and at the anchor trench.

Slope

Rills and gullies were observed at the crest of the pit and on the downstream face, and several slope movements were found. Woody debris was present in the fill material on the berm and downstream face.

Soil Density Testing

In situ soil density and moisture content testing was performed at various locations around the pit. Data was collected at the pit crest and on the down-gradient slope of the pit.

Other Comments

Sandbags were noticed in the pit on top of the liner. A slope movement was observed on the hillside above the pit.

West Virginia University – Civil & Environmental Engineering ETD-10 Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form					
DATE & TIME 8/2/12 12:00pm	County	Harrison	Company	Antero Resources Appalachian Corp.	
WEATHER Sunny	Latitude		Pit Name	Larry Pad	
	Longitude		ID No.		

A. PERMIT INFORMATION

Pit Width (ft.)		Minimum Berm Crest Width (ft.)		Construction Type	
Pit Length (ft.)		Upstream Slope (H:V)		Liner Type	
Depth (ft.)		Downstream Slope (H:V)		Date Built	
Freeboard (ft.)				Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	171 ft.	Berm Crest Width (ft.)	13 ft.	Crest Height (ft.)	9.1 ft.
Pit Length (ft.)	468 ft.	Upstream Slope (H:V)	1.5:1	Up Slope Length (ft.)	25 ft.
Depth (ft.)	14 ft.	Downstream Slope (H:V)	3.5:1	Down Slope Length (ft.)	33 ft.
Freeboard (ft.)	2 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

	C. PIT/IMPOUNDMENT	Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	Rills/gullies
2	Are there any slope movements or animal burrows?	Yes		✓		Slope movements
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			Woody debris
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	Berm, downstream face
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			Bulges
9	Are there any areas where the liner is strained?	No				
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock/soil
11	Is there any tear potential for the liner?	No				
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Cracks
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	No				
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	No				
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Standing water
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

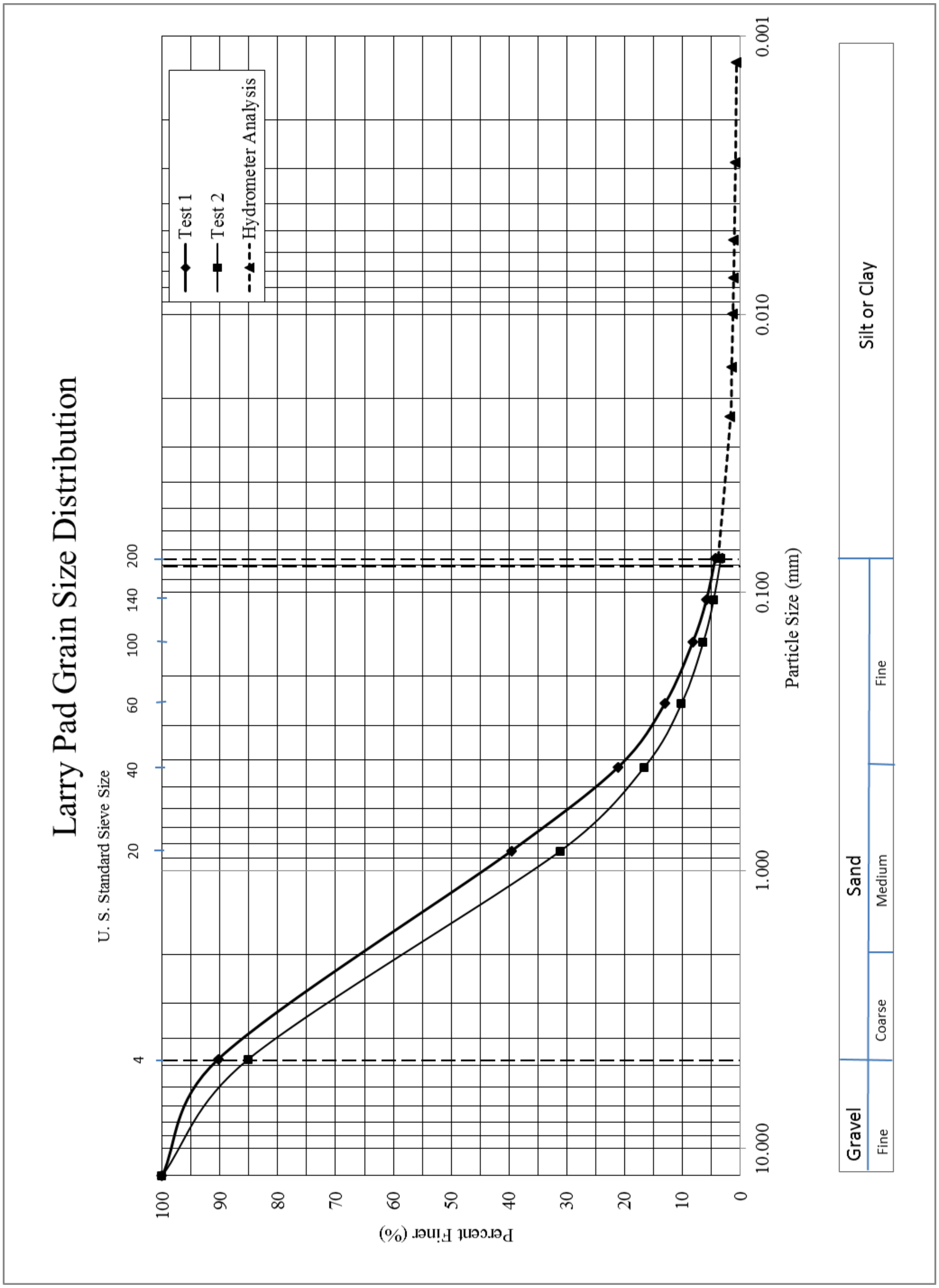
WVU (Name / Signature) Richard Wise	DATE 8/2/12
WVDEP (Name / Signature) John Kearney	8/2/12
Company Representative (Name / Signature) Jason Parson	8/2/12

Site Operations & Infrastructure Evaluation	
Date: 8/2/12	Pit/Impoundment Name: Larry Pad
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Walking inspection twice a week, checks water levels
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Not very much
3	How many years of training does the inspector have in evaluating pits/impoundments? 0
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? No, emails comments/readings to Denver
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? N/A
6	Are there safety and emergency procedures for the pit/impoundment? Yes, kept at the office
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Yes, CEC out of Pittsburgh develops the safety plans
8	Has the pit/impoundment inspector been trained on how to use the EAP? Yes, keeps a list of people to call
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) Doesn't know
10	Does the company have a policy on pit/impoundment safety? Yes, have to contact the safety group for the plans
11	How frequently does a Professional Engineer inspect the site? Weekly
12	Other comments: Woody debris dug out of slope Water in anchor trench, at the toe of the downstream face, and on the berm Wet zones are present on the downstream face Sand bags are in the pit Cattails growing in the drainage ditch Slides are present on the hillside above the pit

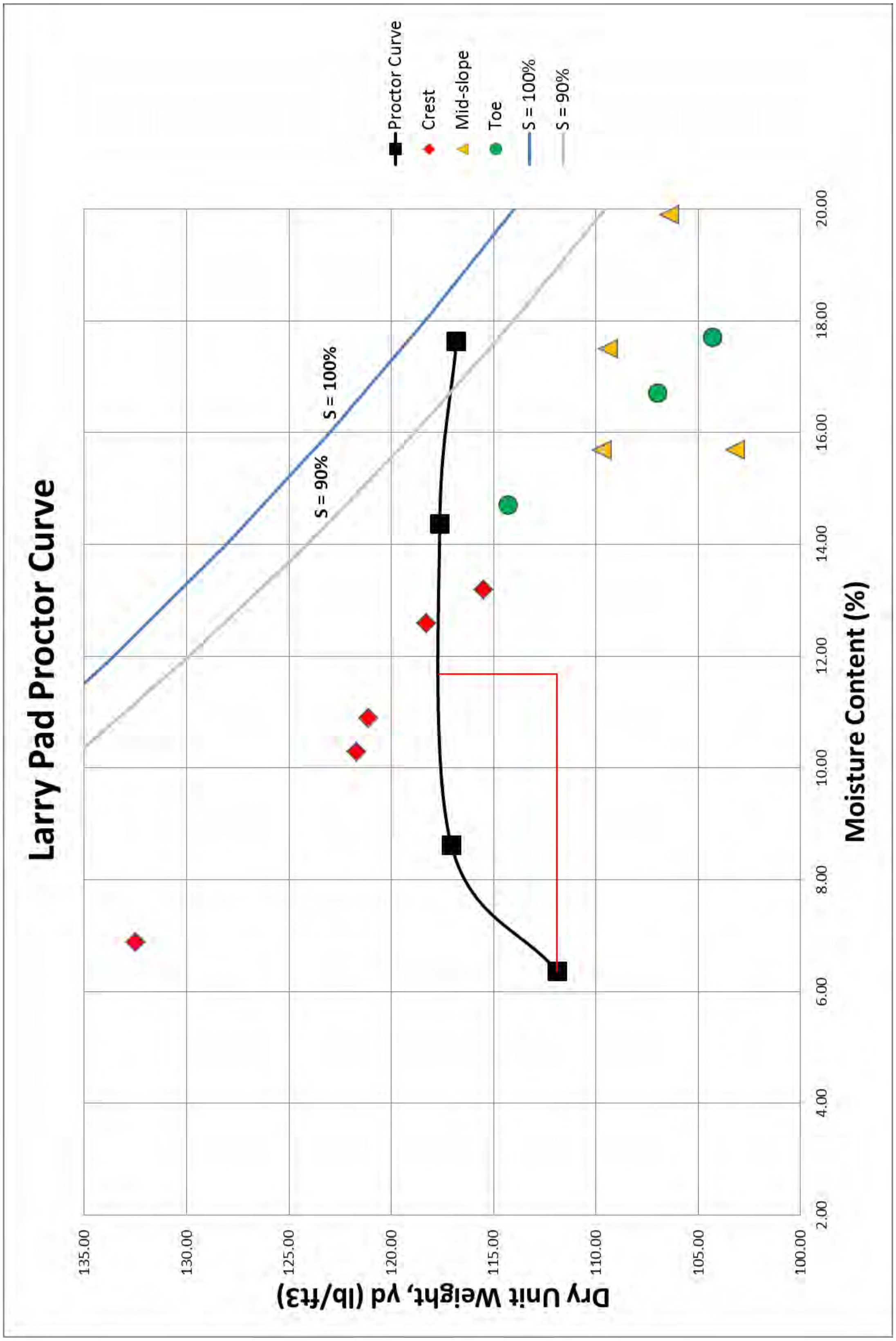
The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

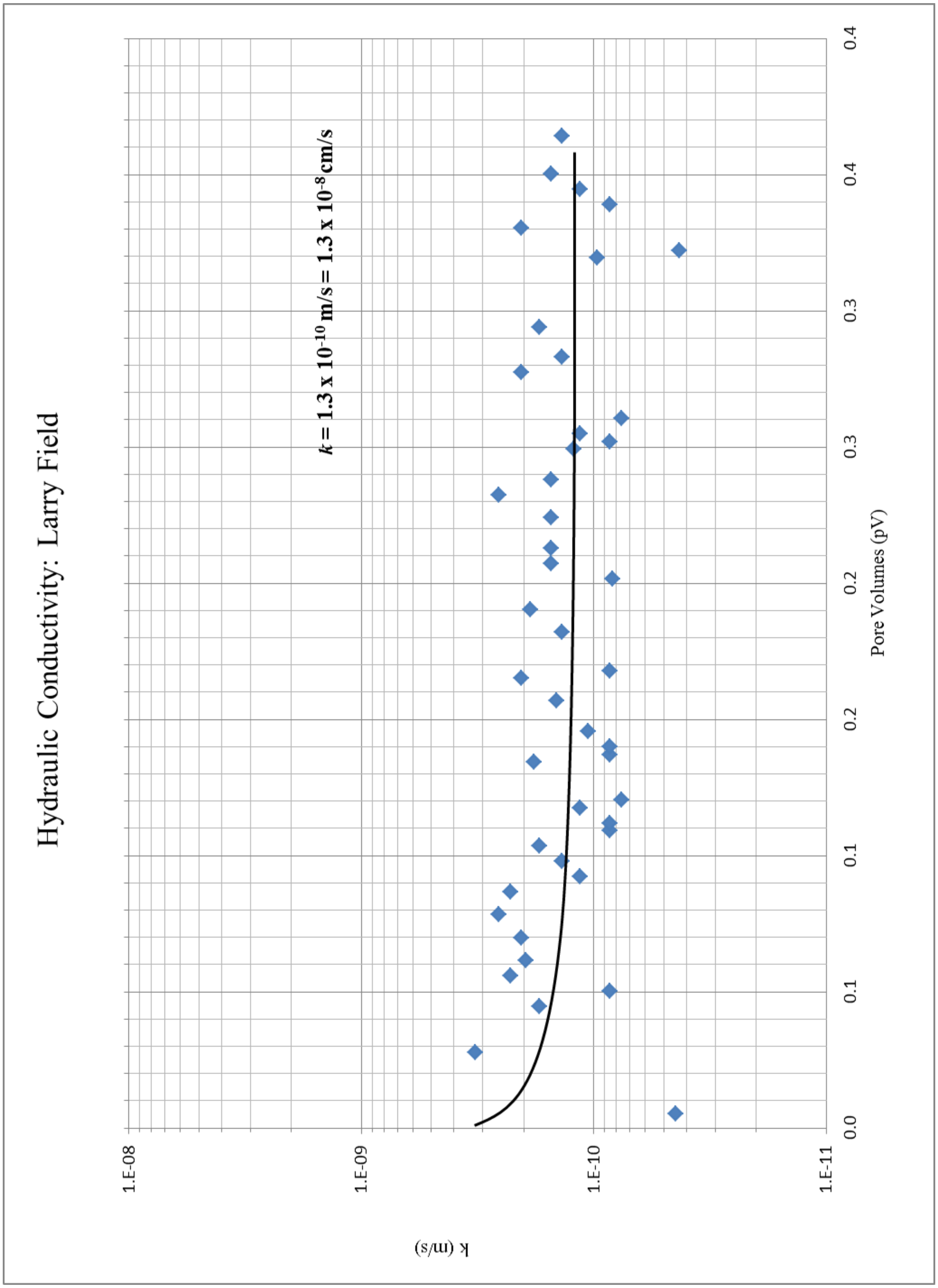
Larry Pad		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes			✓	1
2	Are there any slope movements or animal burrows?	Yes		✓		2
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	Yes	✓			3
6	Are there any seeps, wet zones, or losses of soil?	Yes			✓	1
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes	✓			3
9	Are there any areas where the liner is strained?	No				4
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	No				4
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	No				4
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	No				4
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

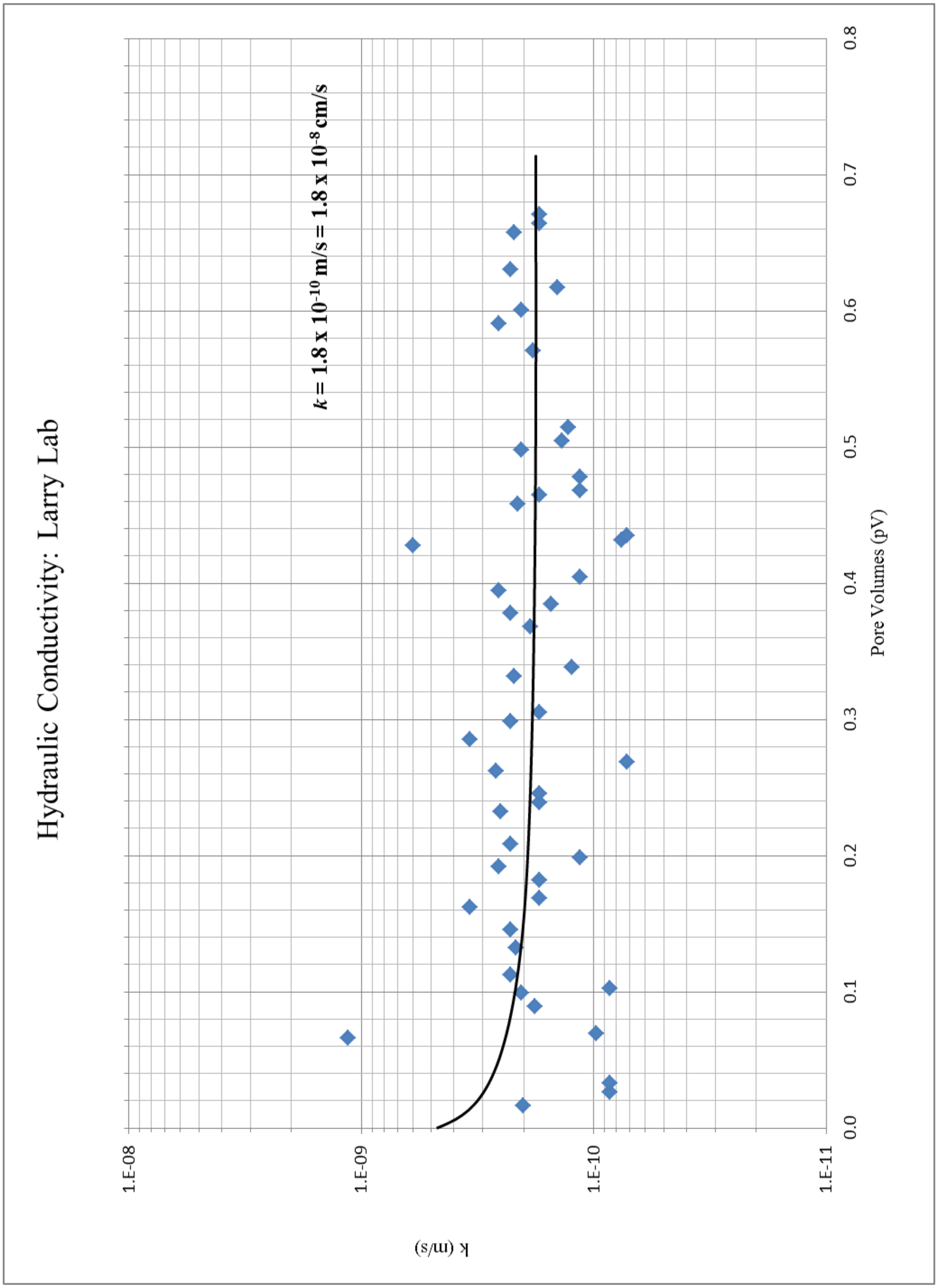
Total:	**63**	(Out of 76)
Percentage:	**82.9%**	



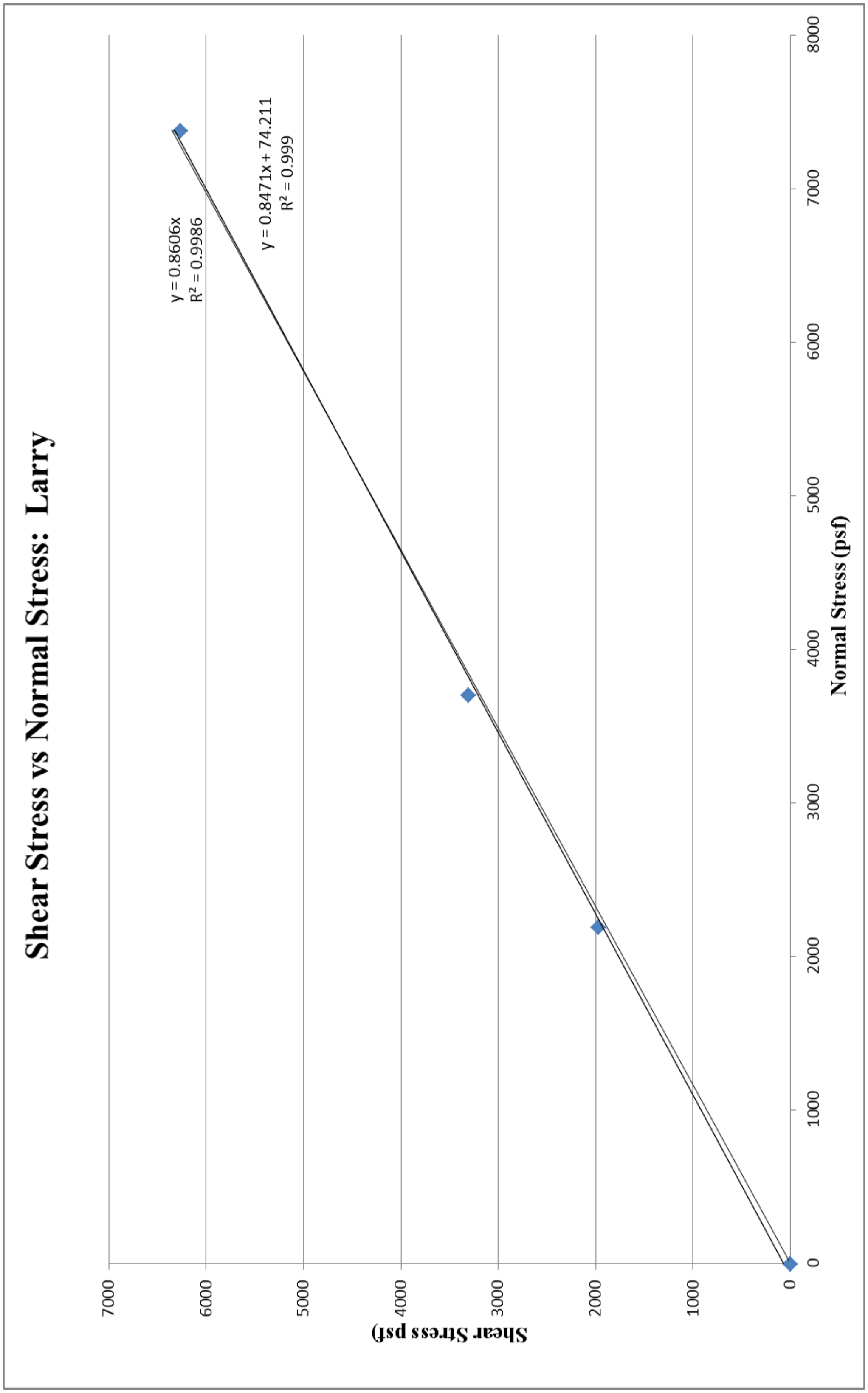
Larry Pad Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Test 1
Test 2
Hydrometer Analysis
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay


Larry Pad Proctor Curve
Dry Unit Weight, γd (lb/ft3)
Moisture Content (%)
135.00
130.00
125.00
120.00
115.00
110.00
105.00
100.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
S = 100%
S = 90%
Proctor Curve
Crest
Mid-slope
Toe
S = 100%
S = 90%


Hydraulic Conductivity: Larry Field
k = 1.3 x 10^-10 m/s = 1.3 x 10^-8 cm/s
k (m/s)
Pore Volumes (pV)
1.E-08
1.E-09
1.E-10
1.E-11
0.0
0.1
0.1
0.2
0.2
0.3
0.3
0.4
0.4



Hydraulic Conductivity: Larry Lab
k = 1.8 x 10^-10 m/s = 1.8 x 10^-8 cm/s
k (m/s)
1.E-08
1.E-09
1.E-10
1.E-11
Pore Volumes (pV)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


Shear Stress vs Normal Stress: Larry
y = 0.8606x
R² = 0.9986
y = 0.8471x + 74.211
R² = 0.999
Shear Stress psf)
Normal Stress (psf)
0
1000
2000
3000
4000
5000
6000
7000
8000

Max Shear Stress vs. Normal Stress (Larry)			
Date	**Sample**	**Compaction**	**Material**
11/28/2012	Larry	25 Blows/Layer, 5 Layers	Passing No. 4
Specimen Number	**Max Shear Stress (ksf)**	**Max Shear Stress(psf)**	**Normal Stress (psf)**
High	6.268	6268	7382
Medium	3.31	3310	3705
Low	1.97	1970	2195
4	0	0	0
m	0.8471	m	0.8606
ϕ' (degrees)	40.268	$\phi_{c'=0}'$ (degrees)	40.715
c' (psf)	74.210	c' (psf)	0.0

Appendix N: MWV Large Water Storage Pond 1

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: MWV Large Water Storage Pond 1
Date of Site Evaluation: 8/6/12

Permit Observations / Anomalies:

Measurements of the field as-built construction were consistent with the permitted design for berm crest width. The berm width measured a minimum of 15 feet, as noted in the permit.

The as-built dimensions of the impoundment were larger than the permitted dimensions. The permitted size is 265 feet wide by 760 feet long, while the as-built dimensions measured 282 feet wide by 780 feet long. Thus, the as-built capacity is larger than the permitted design.

Hydrology

A moderate amount of rills and gullies were found on the downstream faces of the impoundment. Also, a slope movement was noted on the eastern downstream face. Wet zones were present on the berm, in the anchor trench, and at the toe of the southeastern downstream face. Standing water was also observed in the ditch associated with the impoundment.

Containment

The liner for the impoundment is an HDPE geomembrane. Bulges in the liner were observed at numerous locations on the upstream face of the impoundment. These bulges seemed to be formed by stretching the liner over rock, thus straining the liner and resulting in increased tear potential for the liner. A minor amount of rock and soil was on top of the liner.

Slope

Rills and gullies were observed in multiple locations on the downstream face, and a slope movement was found. The downstream slopes appeared to be unprepared, with material pushed over the side of the impoundment and placed at the bottom of the slope. There was no silt fence at the bottom of the slopes.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 8/6/12 11:20 am	County	Nicholas	Company	Bluescape Resources Company, LLC.
	Latitude	N 38° 10' 12.17"	Pit Name	MWV Large Water Storage Pond 1
WEATHER Mostly Cloudy	Longitude	W 80° 34' 49.40"	ID No.	

A. PERMIT INFORMATION

Pit Width (ft.)	265 ft.	Minimum Berm Crest Width (ft.)	15 ft.	Construction Type	Incised
Pit Length (ft.)	760 ft.	Upstream Slope (H:V)	2:1	Liner Type	HDPE
Depth (ft.)	13.7 ft.	Downstream Slope (H:V)	2:1	Date Built	
Freeboard(ft.)	2 ft.			Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)	282 ft.	Berm Crest Width (ft.)	15 ft.	Crest Height (ft.)	17.5 ft.
Pit Length (ft.)	780 ft.	Upstream Slope (H:V)	Varies	Up Slope Length (ft.)	Varies
Depth (ft.)	21.5 ft.	Downstream Slope (H:V)	1.6:1	Down Slope Length (ft.)	33 ft.
Freeboard (ft.)	5 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes		✓		Rills/gullies
2	Are there any slope movements or animal burrows?	Yes			✓	Slope movement
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	No				
6	Are there any seeps, wet zones, or losses of soil?	Yes		✓		Water in anchor trench
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes			✓	Bulges
9	Are there any areas where the liner is strained?	Yes			✓	Strained from below
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock/soil
11	Is there any tear potential for the liner?	Yes			✓	From rock below
12	Are there any deformations, cracks, or settlements around the anchor trench?	No				
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	No				
14	Are there any areas where the pipe is not properly supported?	No				
15	Are there any signs of pipes having significant sagging in line?	No				
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Garbage
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Standing water
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

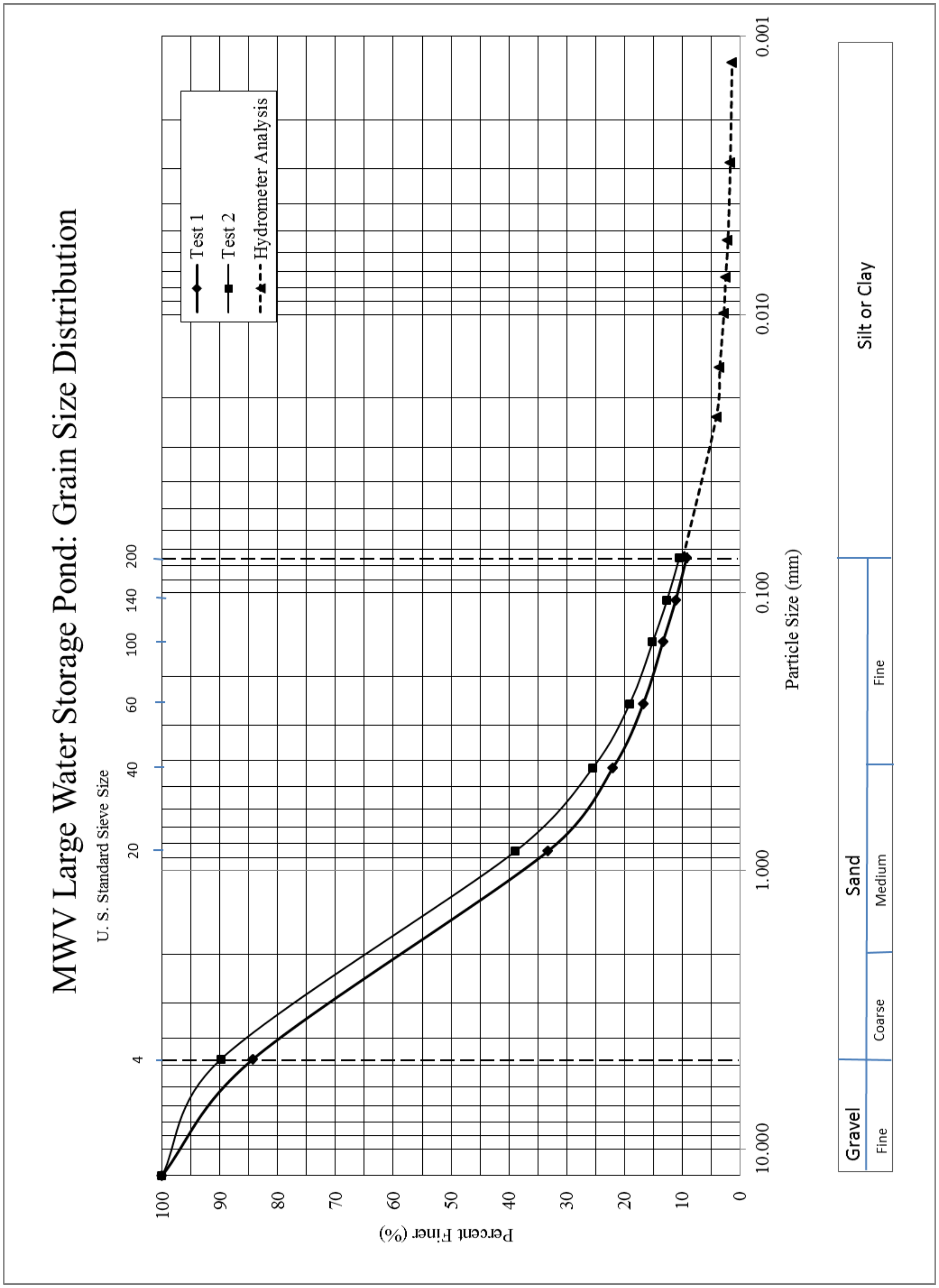
WVU (Name / Signature) Richard Wise	DATE 8/6/12
WVDEP (Name / Signature) John Kearney	8/6/12
Company Representative (Name / Signature) Walter Jenko	8/6/12

Site Operations & Infrastructure Evaluation	
Date: 8/6/12	Pit/Impoundment Name: MWV Large Water Storage Pond 1
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Weekly inspections, or after heavy rains
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Doesn't know
3	How many years of training does the inspector have in evaluating pits/impoundments? N/A
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? Yes, made the inspection form one month ago
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? Walter Jenko
6	Are there safety and emergency procedures for the pit/impoundment? Doesn't know
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Doesn't know
8	Has the pit/impoundment inspector been trained on how to use the EAP? N/A
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) N/A
10	Does the company have a policy on pit/impoundment safety? Doesn't know
11	How frequently does a Professional Engineer inspect the site? No PE inspecting the site
12	Other comments: Downstream slopes appeared to be unprepared with material just pushed over the side Standing water at toe on southeastern downstream face Slip on eastern downstream face No silt fence at the bottom of the slopes

The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

MWV Large Water Storage Pond 1		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes		✓		2
2	Are there any slope movements or animal burrows?	Yes			✓	1
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	No				4
6	Are there any seeps, wet zones, or losses of soil?	Yes		✓		2
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes			✓	1
9	Are there any areas where the liner is strained?	Yes			✓	1
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	Yes			✓	1
12	Are there any deformations, cracks, or settlements around the anchor trench?	No				4
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	No				4
14	Are there any areas where the pipe is not properly supported?	No				4
15	Are there any signs of pipes having significant sagging in line?	No				4
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

Total:	**57**	(Out of 76)
Percentage:	**75.0%**	


MWV Large Water Storage Pond: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

Appendix O: Plum Creek South Fork

ETD-10 Pits and Impoundments Evaluation Report Site Observations / Comments

Site: Plum Creek South Fork
Date of Site Evaluation: 8/6/12

Permit Observations / Anomalies:

The berm width measured a minimum of 12 feet, and the as-built dimensions of the impoundment were 369 feet wide by 420 feet long. No permit information was provided for this impoundment.

Hydrology

Minor rills were found at the crest of the impoundment, and wet zones were observed at the anchor trench and berm. Water was present in the ditch associated with the impoundment.

Containment

The liner for the impoundment is an HDPE geomembrane. Bulges in the liner were observed at several locations on the upstream face of the impoundment. These bulges seemed to be formed by stretching the liner over rock, thus straining the liner and resulting in increased tear potential for the liner. A minor amount of rock and soil was on top of the liner. Settlements were observed at the anchor trench.

Slope

Rills were observed at the crest of the downstream face, but no slope movements were found. Large rocks were present on the downstream face.

Other Comments

The pipe running along the crest of the downstream face was unsupported along its length. Also, the pipe had significant sagging where it was spanning a depression in the topography. Garbage was noticed in the impoundment, and oil was spilled on the access road to the impoundment.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME 8/6/12 1:30 pm	County	Greenbrier	Company	Bluescape Resources Company, LLC.
	Latitude	N 38° 12' 10.29"	Pit Name	Plum Creek South Fork
WEATHER Mostly Cloudy/Rainy	Longitude	W 80° 26' 28.48"	API No.	47-025-00035, 47-025-00039

A. PERMIT INFORMATION

Pit Width (ft.)		Minimum Berm Crest Width (ft.)		Construction Type	
Pit Length (ft.)		Upstream Slope (H:V)		Liner Type	
Depth (ft.)		Downstream Slope (H:V)		Date Built	
Freeboard(ft.)				Date Reclaimed	N/A

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft)	369 ft.	Berm Crest Width (ft)	12 ft.	Crest Height (ft)	14 ft.
Pit Length (ft)	420 ft.	Upstream Slope (H:V)	1.7:1	Up Slope Length (ft)	7.8 ft.
Depth (ft)	35 ft.	Downstream Slope (H:V)	2.4:1	Down Slope Length (ft)	36 ft.
Freeboard (ft)	4 ft.	Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?	No	Is the pit/impoundment within 1000 feet of a public water source?	No
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?	No	Is the pit/impoundment within 100 feet of a wetland?	No

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			At crest
2	Are there any slope movements or animal burrows?	No				
3	Are there any depressions, sinkholes, or slides into the pit present?	No				
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				
5	Are there any observed trees, tall weeds, or other vegetation?	No				
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			Anchor trench and berm
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		Bulges
9	Are there any areas where the liner is strained?	Yes	✓			Strained from below
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			Minor rock/soil
11	Is there any tear potential for the liner?	Yes	✓			Rocks underneath
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			Settlements
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?	Yes	✓			Gouges
14	Are there any areas where the pipe is not properly supported?	Yes			✓	For entire length
15	Are there any signs of pipes having significant sagging in line?	Yes			✓	On hillside
16	Are there any signs of obstructions (trees, garbage, etc.)?	Yes	✓			Garbage
17	Are there any signs of water in ditch associated with pit?	Yes	✓			Water
18	Are there any obstructions around the discharge outlet?	No				
19	Are there any signs of downstream slope movement into ditch?	No				

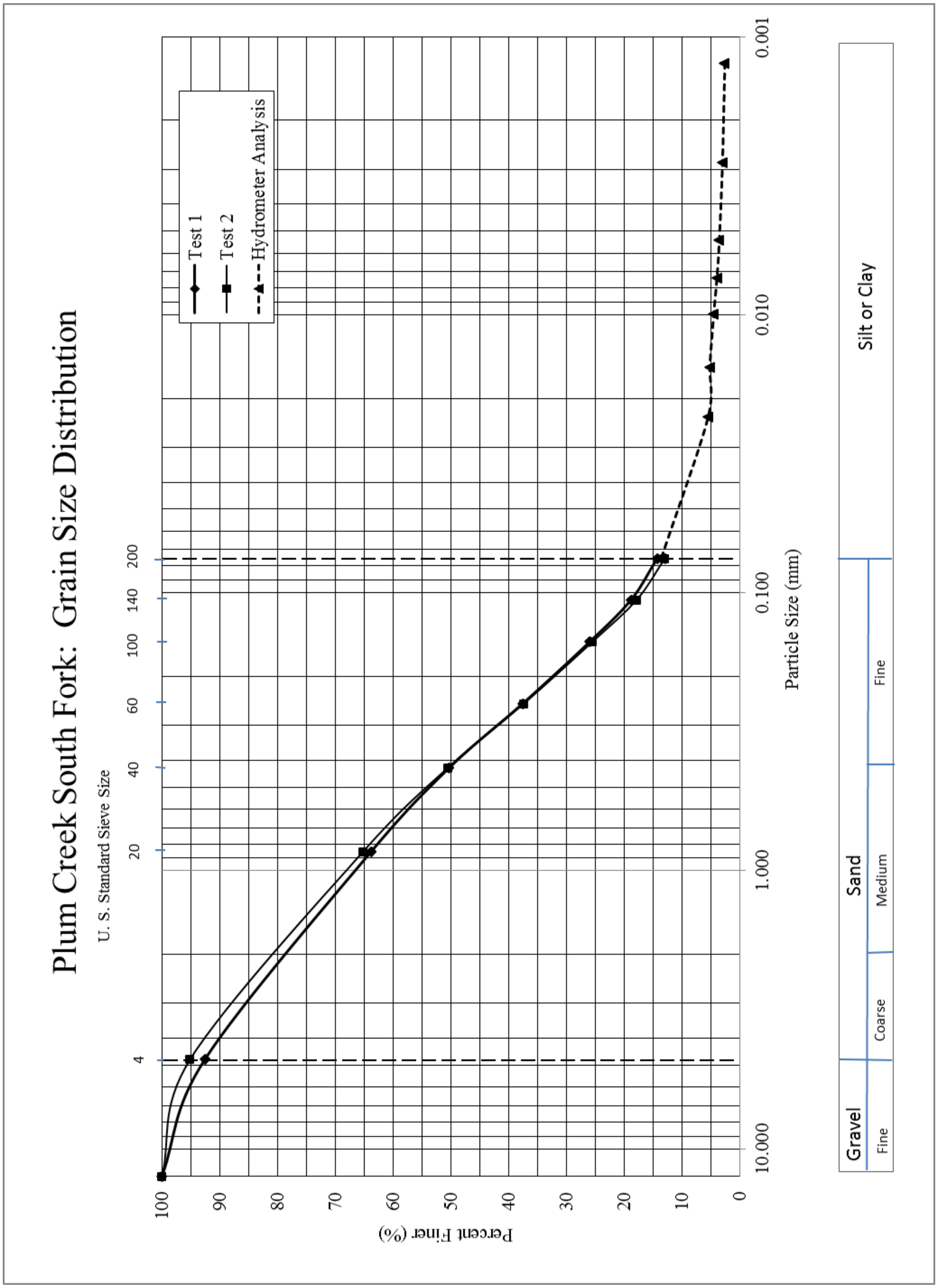
WVU (Name / Signature) Andrew Darnell	DATE 8/6/12
WVDEP (Name / Signature) John Kearney	8/6/12
Company Representative (Name / Signature) Walter Jenko	8/6/12

Site Operations & Infrastructure Evaluation	
Date: 8/6/12	Pit/Impoundment Name: Plum Creek South Fork
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking) Weekly inspections, or after heavy rains
2	What type of training or background does the inspector possess relative to pit/impoundment inspection? Doesn't know
3	How many years of training does the inspector have in evaluating pits/impoundments? N/A
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection? Yes, made the inspection form one month ago
5	Who developed the form and how is the information used to evaluate pit/impoundment safety? Walter Jenko
6	Are there safety and emergency procedures for the pit/impoundment? Doesn't know
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers? Doesn't know
8	Has the pit/impoundment inspector been trained on how to use the EAP? N/A
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?) N/A
10	Does the company have a policy on pit/impoundment safety? Doesn't know
11	How frequently does a Professional Engineer inspect the site? No PE inspecting the site
12	Other comments: Oil/Diesel leak on access road to impoundment

The following table shows the field observations from the site evaluation. The ranking column indicates the level of severity for each question, signified by a scale of one to four. A ranking of one specifies that the problem is very prevalent at the site and carries a high significance in regards to the structural integrity and safety of the pit or impoundment. A ranking of four indicates that the problem was not observed at the site. By summing the rankings for each question, a total score is obtained out of 76 total points. Using this point system, a percentage is assigned for each site, which is used as a comparison for the sites.

Plum Creek South Fork		**Existence**	**If YES then Evaluate Significance of Problem**			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Ranking (1-4)
1	Are there any observed surface erosions, cracks, settlements, or scarps?	Yes	✓			3
2	Are there any slope movements or animal burrows?	No				4
3	Are there any depressions, sinkholes, or slides into the pit present?	No				4
4	Are there any signs of mine subsidence on or adjacent to the embankment?	No				4
5	Are there any observed trees, tall weeds, or other vegetation?	No				4
6	Are there any seeps, wet zones, or losses of soil?	Yes	✓			3
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?	No				4
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?	Yes		✓		2
9	Are there any areas where the liner is strained?	Yes	✓			3
10	Are there any areas where the liner has rock or debris on top of it?	Yes	✓			3
11	Is there any tear potential for the liner?	Yes	✓			3
12	Are there any deformations, cracks, or settlements around the anchor trench?	Yes	✓			3
13	Are there any signs of pipe abnormalities (gouges marks, leaks, cracks)?	Yes	✓			3
14	Are there any areas where the pipe is not properly supported?	Yes			✓	1
15	Are there any signs of pipes having significant sagging in line?	Yes			✓	1
16	Are there any signs of obstructions (trees, garbage, etc)?	Yes	✓			3
17	Are there any signs of water in ditch associated with pit?	Yes	✓			3
18	Are there any obstructions around the discharge outlet?	No				4
19	Are there any signs of downstream slope movement into ditch?	No				4

Total:	**59**	(Out of 76)
Percentage:	**77.6%**	



Plum Creek South Fork: Grain Size Distribution
U. S. Standard Sieve Size
4
20
40
60
100
140
200
Test 1
Test 2
Hydrometer Analysis
Percent Finer (%)
100
90
80
70
60
50
40
30
20
10
0
10.000
1.000
0.100
0.010
0.001
Particle Size (mm)
Gravel
Fine
Sand
Coarse
Medium
Fine
Silt or Clay

Appendix P: Laboratory Soil Testing Procedures

Field Moisture Content (ASTM D2216)

Field moisture content is important for the analysis of the site soil conditions at the time of the evaluation, which may be useful in studying the phreatic surface. The procedure for determining the field moisture content followed ASTM D2216. Site soil samples were collected in soil jars that were sealed to ensure the moisture content remained constant until tested upon return from the field visit.

<u>Specified Equipment For This Soil Property Test:</u>

1. Drying oven
2. Balances
3. Specimen containers (with lids)
4. Heat resistant tongs

<u>Laboratory Soil Testing Procedure:</u>

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D2216 "Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass".

1. Determine the mass of a dry, clean moisture content container and record the number printed on the container and the mass of the container on a data sheet.

2. Place a representative sample of soil in the container. Weigh the container plus moist soil and record the mass on a data sheet.

3. Place the container and soil in an oven and allow the soil to dry overnight (at least 15 to 16 hours).

4. Determine the mass of the container and contents after the soil is dry, and record the mass on a data sheet.

Grain-Size Distribution and Hydrometer (ASTM D422)

Grain-size distribution is useful in estimating hydraulic conductivity and also in finding the engineering properties of soil. The ASTM method used for the grain-size distribution testing was ASTM D422. The grain-size distribution testing was performed by placing soil samples in the sieve shaker for five minutes. Table 13 gives the list of sieves used for the grain-size distribution throughout this study. The sieves were cleaned after each use. The sieve shaker used for performing the grain-size distribution testing is shown in Figure 26.

Sieve No.	Particle diameter (mm)
No. 4	4.76
No. 20	0.840
No. 40	0.425
No. 60	0.250
No. 100	0.150
No. 140	0.106
No. 200	0.075

Table 13: List of Sieves Used

Figure 26: Sieve Shaker

The uniformity of soil is defined using the uniformity coefficient (C_u) and the coefficient of curvature (C_c). C_u is defined as the ratio of D_{60} to D_{10}, where D_{60} is the particle diameter at which 60 percent of the soil weight is finer and D_{10} is the particle diameter at which 10 percent of the soil weight is finer. C_c is expressed in terms of D_{10}, D_{60} and D_{30}, where D_{30} is the particle diameter at which 30 percent of the soil weight is finer. The equations used to calculate C_u and C_c are shown below.

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_C = \frac{D_{30}^2}{(D_{10} * D_{60})}$$

The sieve analysis and particle diameters were used to classify the soil using the USCS classification methodology. Soil particles that passed the No. 200 sieve were used to perform the hydrometer testing as per the ASTM method. The hydrometer tests were conducted by making a blend of water, soil particles passing the No. 200 sieve, and the dispersing agent sodium hexametaphosphate. A calibrated hydrometer was used to measure the suspension of the soil particles in the blend at total elapsed times of 2, 5, 15, 30, 60, 250, and 1440 minutes. Two 1000 milliliter graduated cylinders were used for the test. After each reading, the hydrometer was kept in another 1000 milliliter graduated cylinder filled with water to clean the hydrometer between readings. The hydrometer testing apparatus is shown in Figure 27. Figure 28 shows hydrometer readings being careful observed and recorded.

Figure 27: Hydrometer Analysis

Figure 28: Hydrometer Readings

Specified Equipment For These Soil Property Tests:

1. Balances
2. Hard bristle brush
3. Various-sized round, stackable testing sieves (ASTM E 11 or AASHTO M 92)
4. Vibratory table
5. Two graduated cylinders (one liter)
6. Hydrometer
7. High-speed electric mixer with steel mixing cup
8. Deflocculating agent (sodium hexametaphosphate)
9. Thermometer
10. 600 mL glass beaker
11. Spatula
12. Squirt bottles
13. Distilled water supply
14. Chemical weighing spoon
15. Chemical weighing dish

Laboratory Soil Testing Procedure for Grain-Size Distribution:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D422 "Standard Method for Particle-Size Analysis of Soils".

1. Weigh out a 500 g soil sample, oven-dried according to ASTM recommendations.
2. Record the mass of each clean sieve and the pan on a data sheet.
3. Place the soil sample in the uppermost sieve and secure with a lid.
4. Put the stack of sieves in the mechanical sieve shaker and shake for 5 minutes.
5. Remove the sieves from the shaker and set aside to allow dust to settle.
6. Remove each sieve from the stack, starting at the top.
7. Shake the first sieve over a sheet of paper until no particles fall onto the paper. Empty any soil particles on the paper into the next sieve.
8. Weigh the first sieve and record the mass of the sieve and soil retained on the data sheet.
9. Repeat Steps 7 and 8 for each sieve.

Laboratory Soil Testing Procedure for Hydrometer Analysis:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D422 "Standard Method for Particle-Size Analysis of Soils".

1. Weigh out exactly 50 g of oven-dried soil in a 600 mL glass beaker.
2. Fill one 1-liter graduated cylinder with distilled water and place the hydrometer slowly inside.
3. Place the filled graduated cylinder and one empty 1-liter graduated cylinder on a stable counter in an area where the cylinders will not be shaken or moved for at least two hours.
4. Weigh out 2.5 g of sodium hexametaphosphate into a small dish.

5. Mix the soil with 250 mL of distilled water in a 500 mL glass beaker. Stir the slurry with a spatula and break the clumps of clay down into individual particles as much as possible.

6. Pour the slurry into a steel mixing cup and wash the remaining soil into the mixing cup.

7. Add the deflocculating agent (sodium hexametaphosphate).

8. Use distilled water to fill the mixing cup to two-thirds full.

9. Turn on the high-speed mixer and mix the soil slurry for one minute. Wash the suspension into the empty 1-liter graduated cylinder.

10. Add distilled water to fill the cylinder to the 1-liter mark and place a rubber stopper on the open end of the cylinder.

11. Cover the stopper with a hand and repeatedly turn the cylinder upside-down and right-side-up again until the suspension is thoroughly mixed.

12. Take hydrometer readings at total elapsed times of 2, 5, 15, 30, 60, 250, and 1440 minutes, and record the readings on a data sheet.

13. After each reading, remove the hydrometer from the cylinder and store in the graduated cylinder filled with clean water. Place a thermometer in the clean water to determine the temperature of the hydrometer.

Atterberg Limits (ASTM D4318)

Atterberg limits are the limits of water content used to define the soil behavior and classify the soil. Increasing the water content causes the soil to progress from a solid state, to a semi-solid state, to a plastic state, and finally to a liquid state. The limits that are used to define the soil behavior are the liquid limit (LL) and the plastic limit (PL). The liquid limit is defined as the water content at which the soil behaves as a liquid. The plastic limit is defined as the water content at which the soil crumbles when rolled into 1/8 inch diameter threads. The Plasticity Index (PI) is defined as the difference between the liquid limit and the plastic limit, and is useful in the classification of soil.

The ASTM D4318 method was used to determine the Atterberg Limits for this study. Specific water contents were taken to blend with the soil. The blend was placed in a liquid limit apparatus, shown in Figure 29, and a groove was made using a standard-width grooving tool. The cup was dropped until the groove closed, and the number of blows was counted. The water content at which the groove closes at 25 blows is defined as the liquid limit. The plastic limit was determined by rolling the soil into 1/8 inch diameter threads and measuring the water content at which the threads crumbled. The Plasticity Index was then calculated using the liquid limit and plastic limit values. This testing procedure is illustrated in Figure 30.

Figure 29: Liquid Limit Device (Casagrande Cup)

Figure 30: Atterberg Limits Testing

Specified Equipment For These Soil Property Tests:

1. Liquid limit device
2. Grooving tool
3. Moisture content containers
4. Glass or plastic plate
5. Soil mixing equipment (dish, spatula, and water bottle)
6. Balance

Laboratory Soil Testing Procedure for Liquid Limit:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D4318 "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils".

1. Obtain a sample of air-dry, pulverized clay weighing 100 g.

2. Measure the height of the fall for the liquid limit device.

3. Place the air-dry soil in an evaporating dish and mix with 15 to 20 mL of distilled water, or until the soil is near the liquid limit.

4. Place the soil in the liquid limit device to a maximum thickness of 1 cm and smooth with a spatula.

5. Use a grooving tool to cut a groove into the soil.

6. Lift and drop the cup by turning the crank at a rate of about two drops per second until the groove closes along a distance of one-half inch.

7. Add soil and repeat process until the number of blows for closure is the same on two consecutive tests.

8. Record the number of blows on a data sheet.

9. Remove a slice of soil from the portion of soil that closed the groove together and place in a moisture content container to determine the water content.

10. Add more water to the soil as needed in order to perform the test three times with blow counts between five and 50.

Laboratory Soil Testing Procedure for Plastic Limit:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D4318 "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils".

1. Mix 15 g of air-dry soil with water so that the soil is slightly wet of the estimated plastic limit.
2. Roll the soil into a thread with a diameter of one-eighth inch on a glass or plastic plate.
3. Break the thread into six or eight pieces.
4. Squeeze the pieces together into a uniform mass and reroll to a thread with one-eighth inch diameter.
5. Repeat Steps 2-4 until the soil can no longer be rolled into a thread.
6. Gather the portions of crumbled soil together and place in a moisture content container to determine the water content.

Specific Gravity (ASTM D854)

Specific gravity is defined as the ratio of the unit weight of a given material to the unit weight of distilled water at 4^{o}C. Specific gravity testing is performed to find the dry density, void ratio, and degree of saturation, and the results are also used in the hydrometer analysis calculations. The method used for the determination of specific gravity was ASTM D854 - Method A, in which a water pycnometer was used. The test was performed by weighing the pycnometer containing soil particles suspended in distilled water and taking the weight of equal volume of water in the same pycnometer. An air vacuum was applied for 2 hours during the test. The apparatus used for the specific gravity test is shown in Figure 31.

Figure 31: Specific Gravity

<u>Specified Equipment For This Soil Property Test:</u>

1. 250 ml volumetric flask
2. 500 ml volumetric flask
3. Thermometer
4. Balance
5. Vacuum hoses with rubber stoppers to fit on volumetric flasks
6. Small vibratory table
7. Medicine dropper

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D854 "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer".

1. Obtain 150 g of soil, 50 g of which is used to measure specific gravity while the remaining soil is used to determine water content.
2. Weigh a clean, dry volumetric flask and record on a data sheet.
3. Pour 50 g of soil into the flask.
4. Fill the flask two-thirds full with distilled water.
5. Place the vacuum hose with rubber stopper on the neck of the flask and open the valve to apply a vacuum to the soil-water mixture.
6. Fill the flask to the etch mark with distilled water, using the medicine dropper near the end.
7. Use a paper towel to dry the outside of the flask and the inside of the neck above the water level.
8. Weigh the flask plus soil and water and record the mass on a data sheet.
9. Place a thermometer inside the flask to determine the temperature of the mixture and record on a data sheet.
10. Empty the soil from the flask, and repeat Steps 6-9 using only distilled water.

Standard Proctor (ASTM D698)

In Marcellus Shale pits and impoundments, soil is compacted to a design density and used as structural fill. Due to the compaction, the flow of water (seepage) through soil reduces, and the material acquires strength which helps in the construction of the structure. During construction, compaction is performed by using rollers and dozers.

The objective of compaction testing was to determine the optimum moisture content and maximum dry density of the soil within a given compactive effort. Compaction testing was also used to determine the engineering properties of the soil such as hydraulic conductivity. Standard Proctor tests were used for the compaction testing, in accordance with Method A in ASTM D698. The equipment used for the compaction testing was a 4 inch diameter compaction mold with removable collar and base, a hammer, a mixer for blending the soil with water, and a jack to remove the compacted sample from the mold. The compaction mold and hammer are shown in Figure 32.

Figure 32: Compaction Mold and Hammer

Four samples from each site were prepared using different water contents. The soil samples were mixed with water and compacted in three layers with 25 blows per layer, in accordance with the ASTM method. After the compaction, the collar was removed, and the excess soil was trimmed to the surface of the mold. Figure 33 depicts the removal of the sample from the mold using a jack, leaving the compacted sample shown in Figure 34. After weighing each sample, discrete moisture contents were taken by cutting the sample into three equal layers and collecting a small amount of soil from the top, middle, and bottom layers. Using the results of the compaction testing, graphs of water content versus respective dry densities were developed, presenting the optimum moisture content and the maximum dry density of the sample.

Figure 33: Removal of Compacted Specimen from Mold Using Jack

Figure 34: Compacted Mold

Specified Equipment For This Soil Property Test:

1. Compaction mold
2. Compaction hammers
3. Soil mixer
4. Sharpened straight edge
5. Tools for breaking apart compacted samples (hammer, ice pick, etc.)
6. Extruder to remove samples from mold
7. Large scoop for handling soil
8. Balance
9. Oven
10. Moisture cans

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D698 "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort".

1. Weigh out 3,000 g of air-dried soil.

2. Weigh the mold (not including the weight of the collar).

3. Determine the amount of water to add to the soil sample in order to obtain a specific, or known, water content.

4. Place the soil in the mixer and slowly add water to bring the water content of the soil to the desired value.

5. Remove the soil from the mixer and compact into the mold using three equal lifts and twenty-five blows for each lift with the compaction hammer.

6. Remove the collar and trim the soil flush with the top of the mold using a sharpened straight edge.

7. Weigh the mold plus the soil and record on a data sheet.

8. Extrude the soil from the mold using the extruder.

9. Cut the sample into three equal layers and place representative portions of soil from each layer into a moisture content container to determine water content.

10. Break the sample into reasonably fine pieces and place back into the mixer, adding water to achieve the next desired compaction water content. Repeat the process as necessary.

Hydraulic Conductivity-Rigid Wall (ASTM D5856)

Hydraulic conductivity is a measure of the permeability of a soil and is useful in determining the flow of water through the soil. This soil property depends on several factors, including the grain-size distribution, void ratio, pore-size distribution, roughness of mineral particles, and degree of saturation. These factors vary between soil types, resulting in distinct hydraulic conductivity ranges for different soils.

Hydraulic conductivity testing was performed using the ASTM D5856 method. The objective of the hydraulic conductivity testing was to determine the permeability of water through a test specimen at the optimum and field moisture contents of the material at each site. Two samples were compacted to optimum and field moisture contents using the Standard Proctor procedure outlined above. Once compacted, the samples were connected to a head-water reservoir and a pressure board to push water through the samples at a hydraulic gradient of 100 pounds per square inch. Readings were taken at varying intervals depending on the sample, or until the readings stabilized. After the hydraulic conductivity readings reached equilibrium, the hydraulic conductivity was determined. Figure 35 depicts four samples undergoing hydraulic conductivity testing.

Figure 35: Hydraulic Conductivity Testing

Specified Equipment For This Soil Property Test:

1. Permeameter
2. Two porous stones
3. Two pieces of filter paper
4. Vacuum hoses
5. Membrane expander
6. O-rings
7. Compaction mold
8. Compaction hammers
9. Soil mixer
10. Sharpened straight edge
11. Tools for breaking apart compacted samples (hammer, ice pick, etc.)
12. Extruder to remove samples from mold
13. Large scoop for handling soil
14. Balance
15. Oven
16. Moisture cans

Laboratory Soil Testing Procedure:

The following section is based on ASTM standard D5856 "Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter".

1. Compact moist soil into a Standard Proctor mold following procedure outlined previously.
2. Record all physical properties of the soil sample on a data sheet.
3. Soak two porous stones and two pieces of filter paper in the permeating fluid until saturated.
4. Place one porous stone over the bottom plate of the permeameter cell and cover with filter paper.
5. Extrude the soil sample and place on top of the filter paper.
6. Place the remaining filter paper, porous stone, and top plate on top of the soil sample.
7. Place hydraulic grease around the outside of both top and bottom.
8. Place the membrane inside the membrane expander with at least two inches of excess at both ends.
9. Use a vacuum to expand the membrane.
10. Use the membrane expander to lower the membrane until the soil sample, top plate and bottom plate are encompassed.
11. Unclasp the vacuum line and allow the membrane to collapse around the sample.
12. Remove the membrane from the expander.
13. Fold the top and bottom of the membrane to remove any wrinkles.
14. Place two O-rings on one end of the membrane expander and place the membrane expander over the soil sample with the O-rings on the bottom of the expander.
15. Remove the O-rings so that the membrane is held tight against the top and bottom plates.
16. Secure the tail-water lines to the top plate.
17. Place the acrylic cover over the sample and secure with top cap.

18. Open the top valve to allow air to escape and fill the cell with water through the bottom valve.

19. Close both valves when water comes out the top.

20. Secure all lines from the pressure board to the cell.

21. Fill all three reservoirs with water, leaving at least two inches of air at the top of the reservoirs.

22. Set the cell water pressure to 10 psi, the head-water pressure to 8 psi, and the tail-water pressure to 6 psi.

23. Open the head-water valve that is connected to the head-water reservoir.

24. Open the head-water valve beside the first and allow the water to flow until all air bubbles are removed. Close both valves and repeat with the tail-water lines.

25. Open both the head-water and tail-water valves to allow the sample to saturate. Close both valves when air bubbles stop.

26. Drain the tail-water reservoir until there is only 1 cm of water.

27. Fill the head-water reservoir to 30 cm of water.

28. Measure the height of water in the head-water, tail-water, and cell-water reservoirs and record on a data sheet.

29. Set a time to start the test and turn both valves on at that time.

30. Record the height of water in the head-water, tail-water, and cell-water reservoirs as well as time of the readings and record on a data sheet.

31. Turn off both the head-water and tail-water valves when the head-water reservoir is nearly empty.

32. Take the last reading of the heights and the final time and record on a data sheet.

33. Disassemble the cell and take final moisture contents for the top, middle, and bottom layers of the sample.

Shear Strength (ASTM D3080/D3080M)

A major factor in the structural integrity of all geotechnical construction is the strength of the soil. Shear strength is a measure of the resistance of a soil to shearing stresses and is dependent upon the cohesion and internal friction between soil particles. The shear strength testing was performed on a GeoJac direct shear testing device. The testing followed the procedures outlined in ASTM D3080/D3080M. Once the hydraulic conductivity testing for a site was completed, three cylinders measuring 2.5 inches in diameter and 1 inch in height were cut from the top, middle, and bottom of each sample. Each test was performed at an optimum and field condition. The internal angle of friction (ϕ) was calculated using Mohr-Coulomb failure criterion concepts. The testing setup and equipment are shown in Figure 36.

Figure 36: Direct Shear Testing

Specified Equipment For This Soil Property Test:

1. Shear device
2. Shear box
3. Porous stones
4. Device for applying and measuring the normal force
5. Device for applying and measuring the horizontal force
6. Timer
7. Deformation devices

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D3080/D3080M "Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions".

1. Assemble the shear box in the direct shear frame, placing porous stones on top and bottom.

2. Place the loading cap.
3. Attach and adjust the vertical displacement measurement device.
4. Obtain an initial reading for the vertical displacement device and a reading for the horizontal displacement device. Record the measurements on a data sheet.
5. Consolidate the soil sample under the appropriate force.
6. Measure the vertical deformation as a function of time and plot the time-settlement curve to determine the time to 50 percent consolidation.
7. Shear the soil sample and take readings of the horizontal displacement until the shear force peaks, remains constant, or results in a deformation of 10 percent of the original diameter of the sample.

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"

Prepared for:
West Virginia Department of Environmental Protection
Division of Air Quality
601 57th Street, SE
Charleston, WV 25304

Prepared by:
Paul Ziemkiewicz, Ph.D., Director
Jennifer Hause, M.S.
Brady Gutta, B.S.
Jason Fillhart, M.S., M.Ed.
Ben Mack M.S.
Melissa O'Neal, B.S.

West Virginia Water Research Institute
West Virginia University
PO Box 6064
Morgantown, WV 26506-6064

Date:
February 15, 2013

Disclaimer

The contents of these reports reflect the views of the authors who are responsible for the facts and the accuracy of the data presented. The contents DO NOT necessarily reflect the official views or policies of the State. These reports do not constitute a standard, specification, or regulation. Trade or manufacturers' names which may appear herein are cited only because they are considered essential to the objectives of these reports. The State of West Virginia does not endorse products or manufacturers. These reports were prepared for the West Virginia Department of Environmental Protection.

Table of Contents

List of Figures

List of Tables

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.

<u>Legislative Direction</u>

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.

<u>The Study</u>

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.

Site Sampling

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.

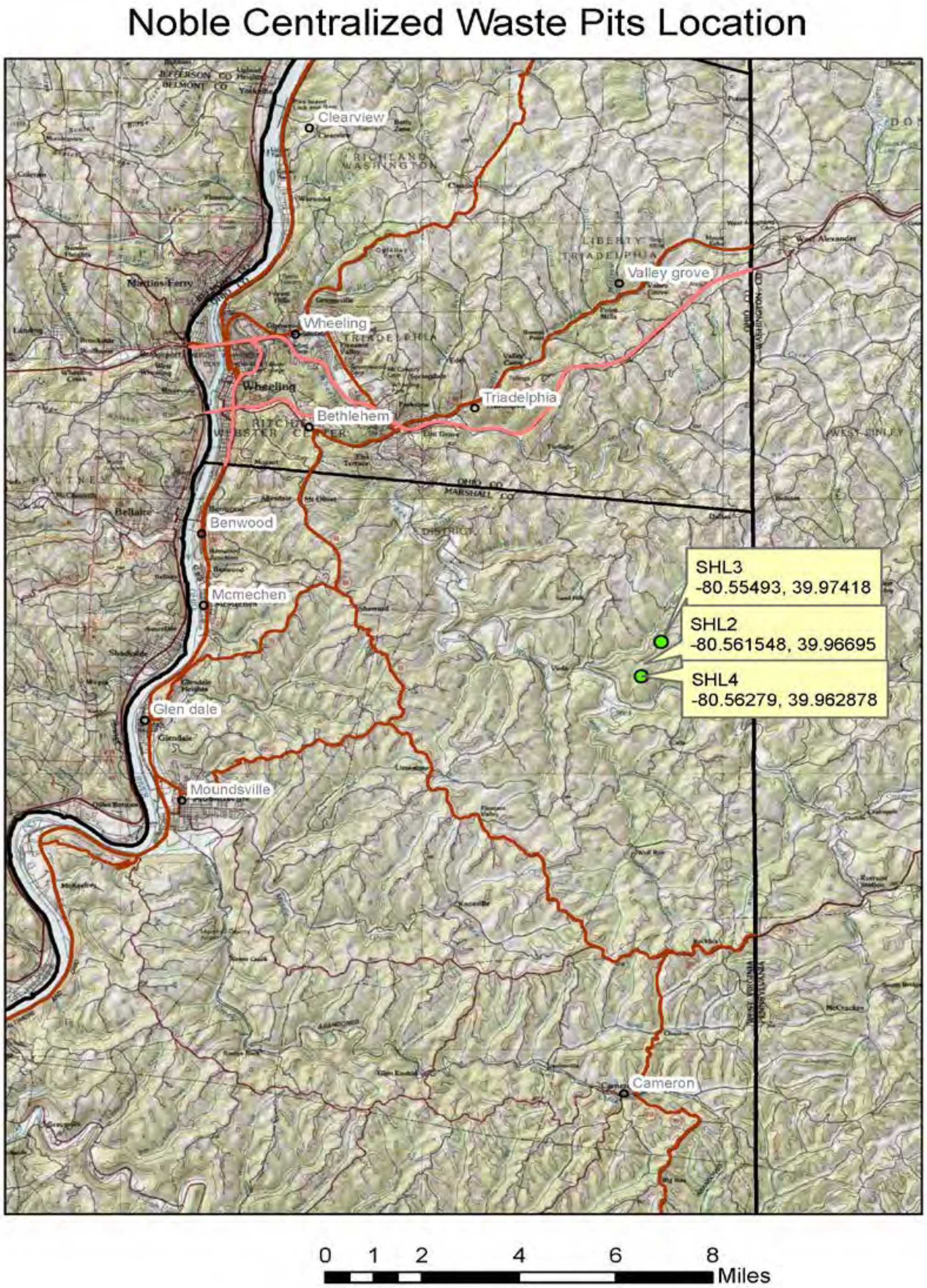


Figure 1: Centralized Pits Locations

Figure 2: SHL-1 Impoundment Sampling

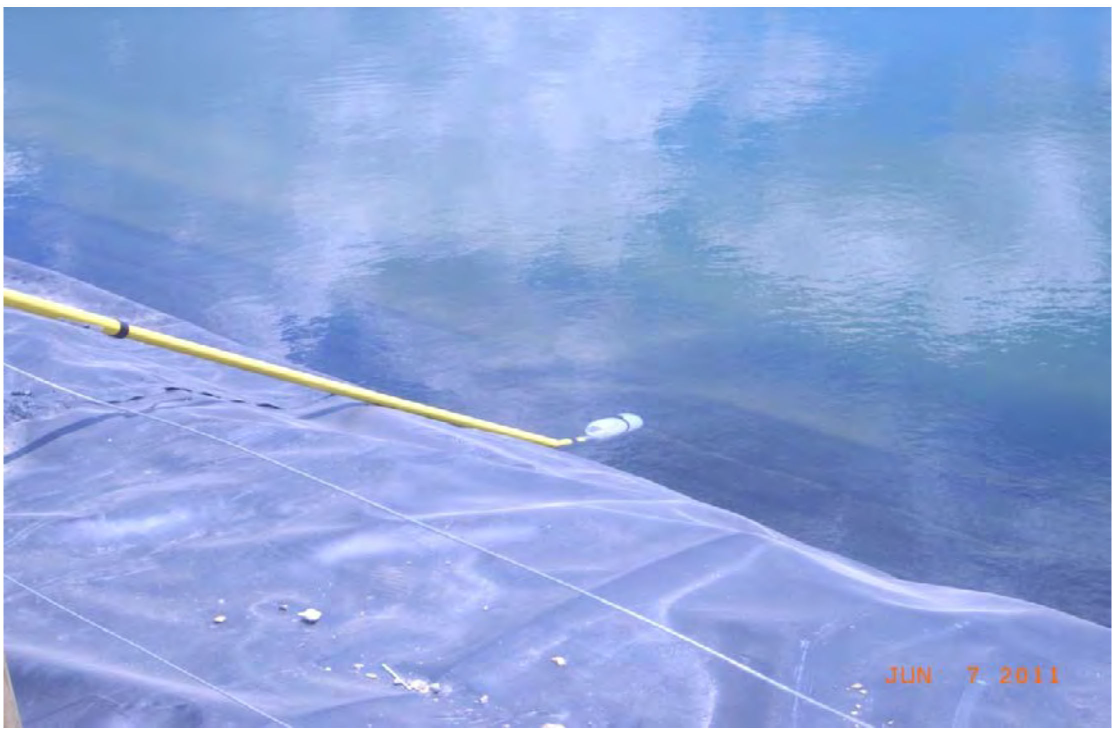


Figure 3: SHL-1 Impoundment Sampling

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)

<u>Hydraulic Fracturing Fluids</u>

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

<u>Flowback</u>

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.

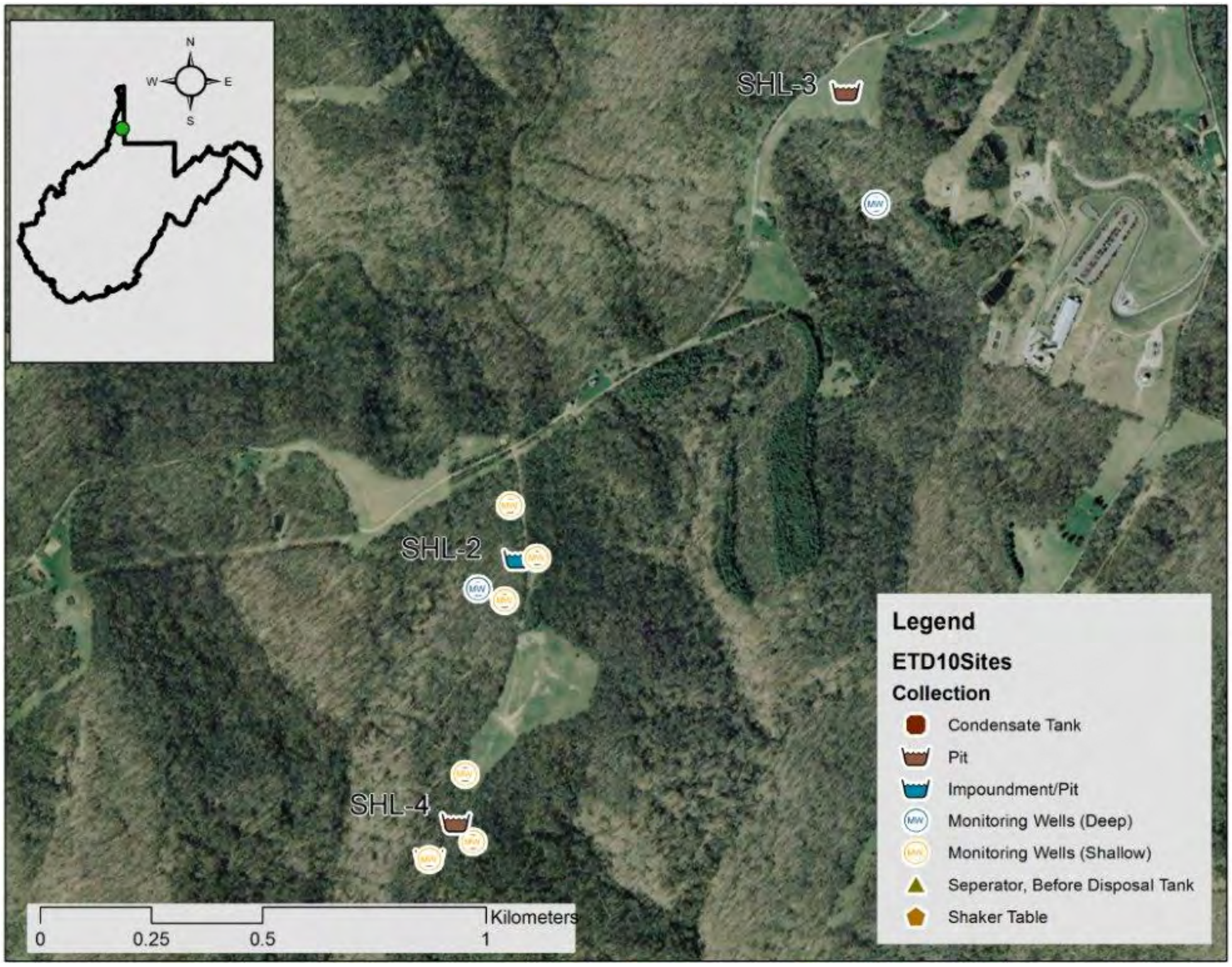


Figure 15: Location of Consol/Noble Centralized Pits

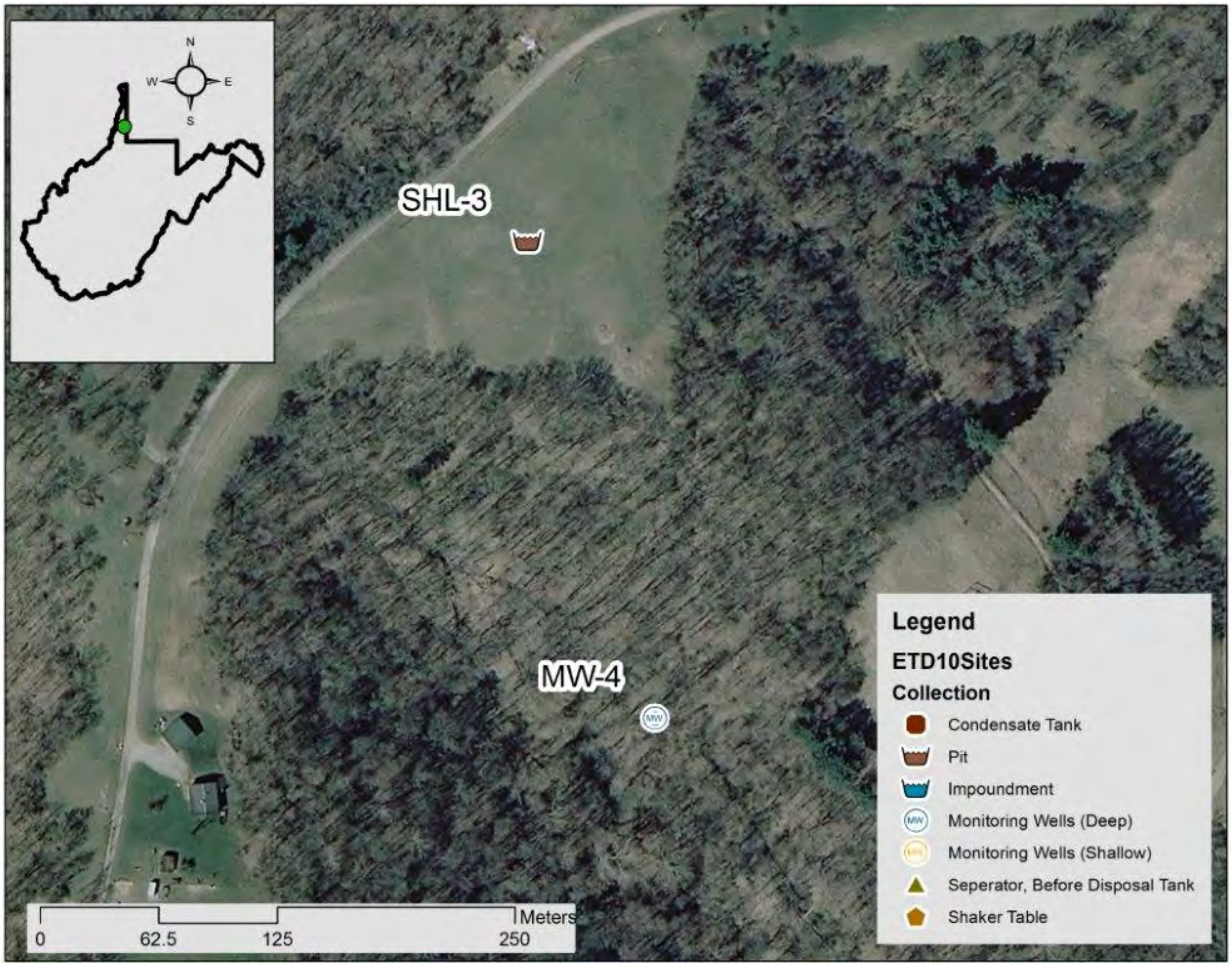


Figure 16: Consol/Noble Centralized Pit SHL3

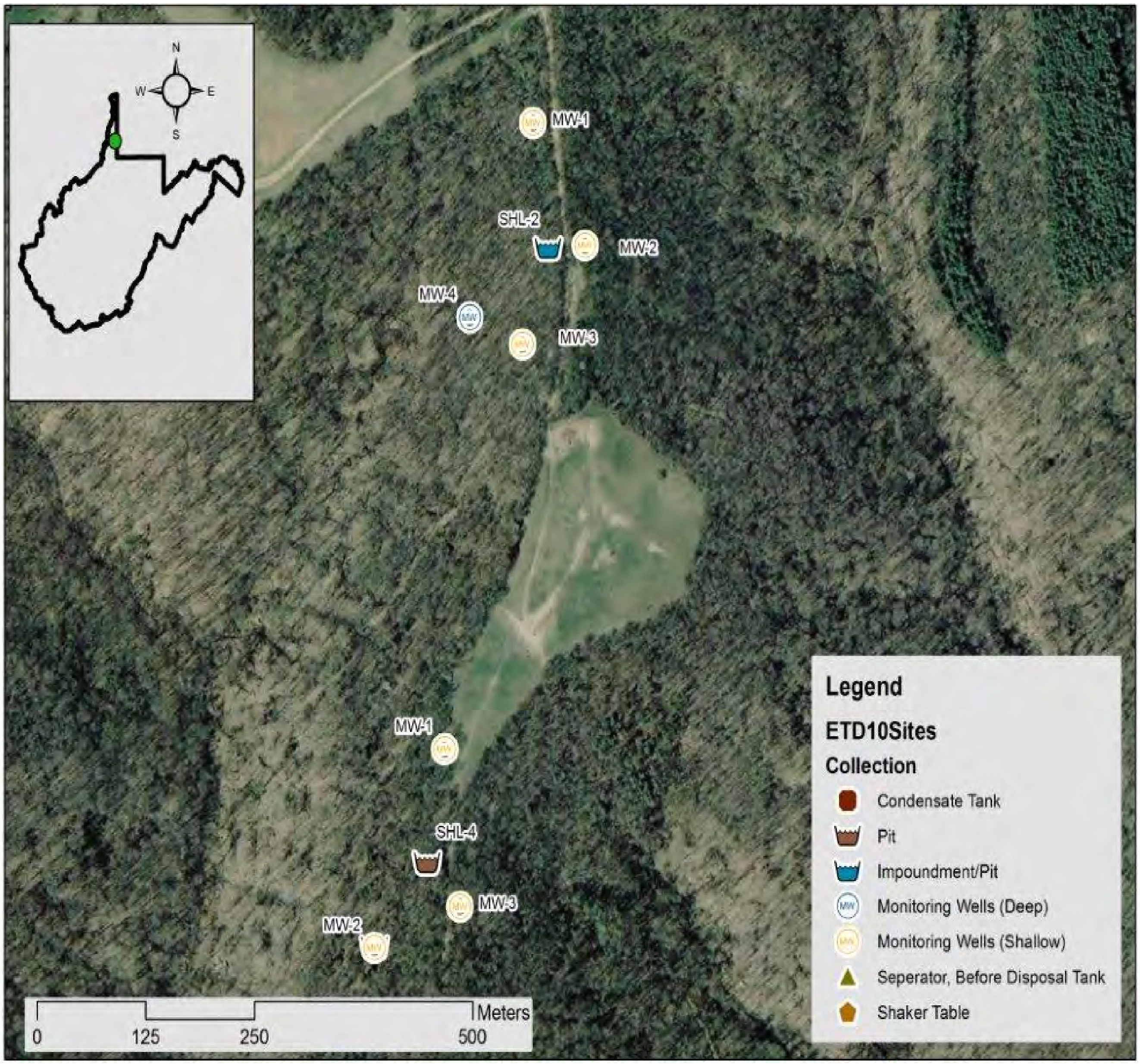


Figure 17: Consol/Noble Centralized Pits SHL2 and SHL4

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.

<u>Sampling Procedures for Horizontal Drilling Operations</u>

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

<u>Sampling Procedures for Hydraulic Fracturing</u>

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

		Drilling mud						Flowback solids
						DNR-ST-3-1		Donna Pit-C
		ST 1-1	ST 1-2	ST 1-3	ST 1-4	(Solids)		(Solids)
Solids	units	8/8/2012	8/15/2012	8/22/2012	10/2/2012	10/25/2012	average	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

				MW (shallow)					
Liquids	units	SDWA MCL	MCL units	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

				MW (deep)		
Liquids	units	SDWA MCL	MCL units	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

				flowback					
Liquids	units	SDWA MCL	MCL units	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.

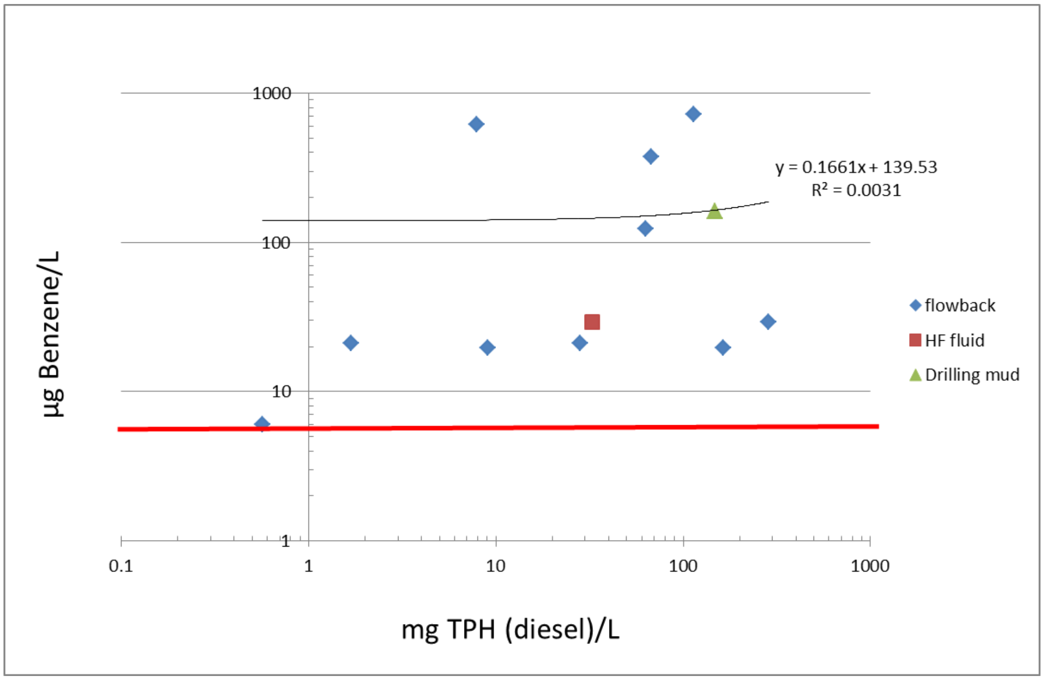


Figure 21: Relationship between TPH and Benzene

- 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.

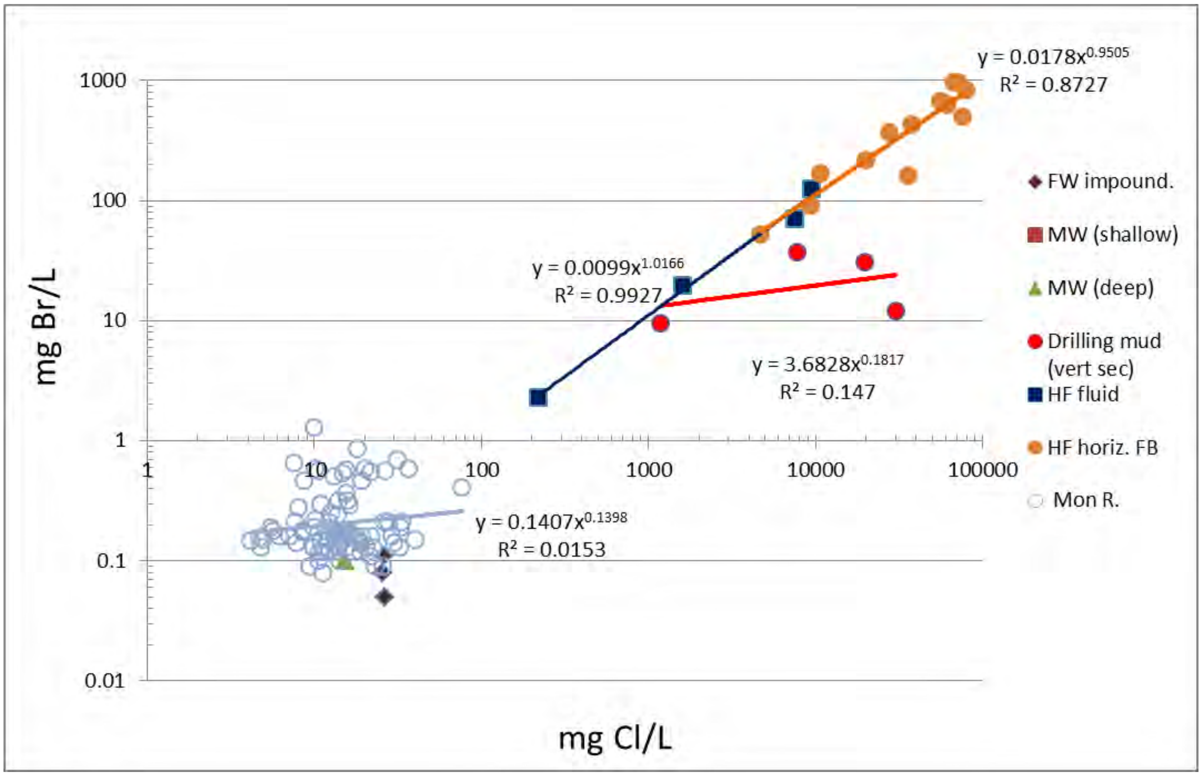


Figure 22: Relationship of Chloride and Bromide in Source Waters

- 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.

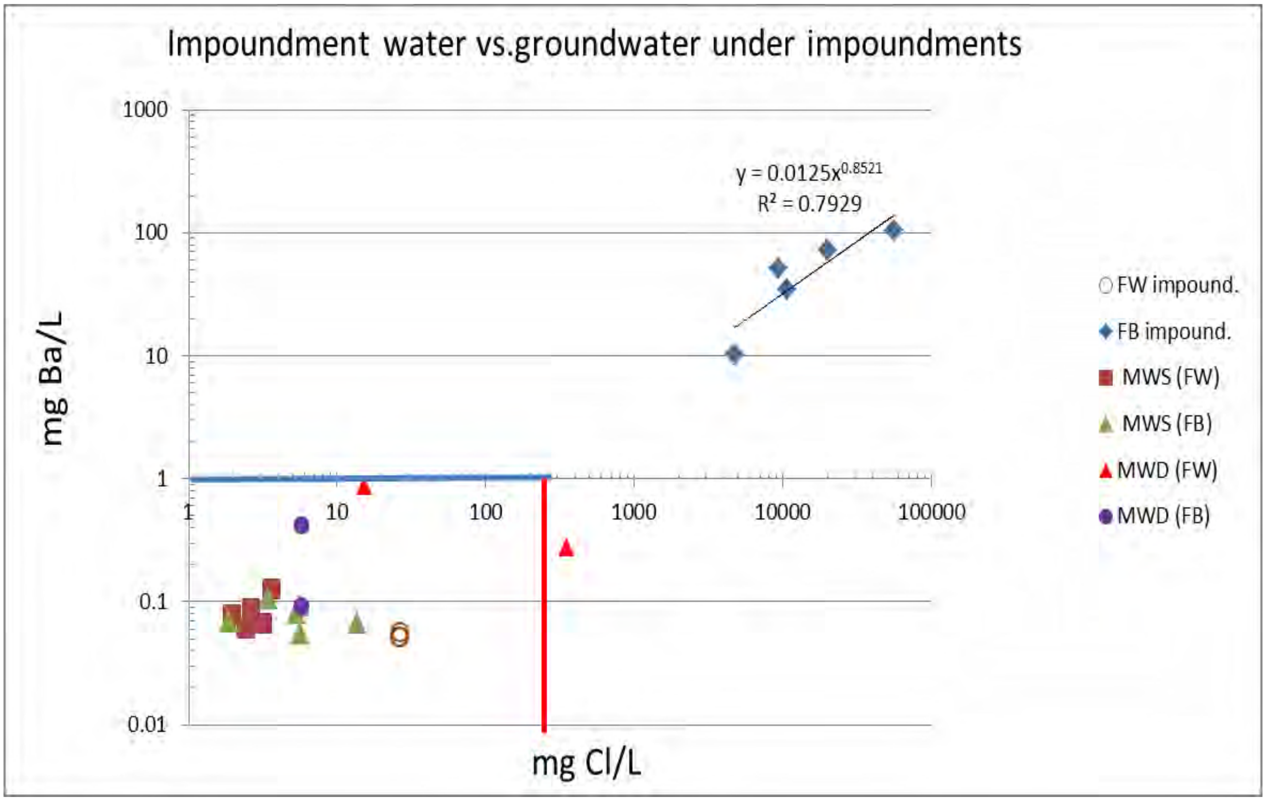


Figure 23: Barium/Chloride (Ba/Cl) Relationship in Impoundment Water and Groundwater

- 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

Material type	n	transported volume	liquid=2 solid=1	SDWA exceedences primary	SDWA exceedences secondary	SDWA exceedences 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.

References

1. Drilling for Answers: Marcellus Shale 101; West Virginia University Benjamin M. Statler College of Engineering & Mineral Resources; *Engineering West Virginia*; Volume 8 Issue 1, Spring 2012.

2. Water Resources and Natural Gas Production from the Marcellus Shale, Daniel Soeder and William Kappel; USGS Fact Sheet 2009-3032; May 2009.

3. Modern Shale Gas Development in the United States: A Primer; Ground Water Protection Council and ALL Consulting; Department of Energy Office of Fossil Energy DE-FG26-04NT15455; April 2009.

4. Development of the Marcellus Shale – Water Resource Challenges; R. Timothy Weston K&L Gates; 2008.

5. *Hydraulic Fracturing Considerations for Natural Gas Wells of the Marcellus Shale*; Daniel Arthur, Brian Bohm and Mark Layne, ALL Consulting; The Ground Water Protection Council 2008 Annual Forum; 2008.

6. Fact Sheet: What We Learned from Pennsylvania; New York State Department of Environmental Conservation; NYS DEC NEWS; http://www.dec.ny.gov/energy/75410.html.

7. Natural Gas Drilling in the Marcellus Shale NPDES Program Frequently Asked Questions, Attachment to memorandum from James Hanlon Director of EPA's Office of Wastewater Management to the EPA Regions titled *Natural Gas Drilling in the Marcellus Shale under the NPDES Program*; March 2011.

8. The Real Facts about Fracture Stimulation: The Technology Behind America's New Natural Gas Supplies; American Exploration & Production Council; January 2010.

9. Marcellus Shale Water Management Challenges in Pennsylvania; A.W. Gaudlip and L.O. Paugh, SPE, Range Resources Appalachia LLC, and T.D. Hayes, Gas Technology Institute, Society of Petroleum Engineers; SPE 119898; 2008 SPE Shale Gas Production Conference; November 2008.

10. Water Resources and Use for Hydraulic Fracturing in the Marcellus Shale Region; J. Daniel Arthur, Mike Uretsky and Preston Wilson, ALL Consulting; 2010.

11. Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities; David Kargbo, Ron Wilhelm and David Campbell; USEPA; *Environmental Science & Technology*; Volume 44; Number 2010.

12. Treatment of Abandoned Mine Drainage for Use as Marcellus Gas Well Hydrofracture Makeup Water; ProChem Tech, International, Inc.; www.prochemtech.com; 2009.

13. Sampling and Analysis of Water Streams Associated with the Development of Marcellus Shale Gas Final Report; Thomas Hayes, Gas Technology Institute; for Marcellus Shale Coalition; December 2009.

14. Radioactivity in Marcellus Shale Report prepared for Residents for the Preservation of Lowman and Chemung (RFPLC); Marvin Resnikoff, Ekaterina Alexandrova and Jackie Travers, Radioactive Waste Management Associates; May 2010.

15. Waste Management of Cuttings, Drilling Fluids, Hydrofrack Water and Produced Water; New York State Water Resources Institute; www.wri.eas.cornell.edu/gas_wells_waste.html.

16. America's New Energy Future: The Unconventional Oil and Gas Revolution and the U.S. Economy Volume 1: National Economic Contributions; An IHS Report; October 2012.

17. Water Management Technologies Used by Marcellus Shale Gas Producers Final Report; John Veil, Argonne National Laboratory; Department of Energy Office of Fossil Energy FWP-49462; July 2010.

18. Data Confirm Safety of Well Fracturing; Kevin Fisher, The American Oil & Gas Reporter, www.aogr,com; July 2010.

19. Chemicals Used in Hydraulic Fracturing; for U.S. House of Representatives Committee on Energy & Commerce Minority Staff; April 2011.

20. 'Environmentally Friendly' No Longer an Oxymoron to Oil and Gas; Tayvis Dunnahoe, *Hydraulic Fracturing*; www.EPmag.com; August 2012.

21. Marcellus Shale in West Virginia: Hydraulic Fracturing Chart; WVONGA 2012.

22. A Fluid Situation: Typical Solution Used in Hydraulic Fracturing; www.energyindepth.org.

23. Hydraulic Fracturing Fluids – Composition and Additives; www.geology.com; republished from: *Modern Shale Gas Development in the United States* by the Department of Energy; 2009.

24. Critical Evaluations of Additives Used in Shale Slickwater Fracs; P. Kaufman and G.S. Penny, CESI Chemical a Flotek Co., and J. Paktinat, Universal Well Services; Inc. SPE 119900; 2008 SPE Shale Gas Production Conference; November 2008.

25. Radiological Survey Report: Marcellus Shale Drilling Cuttings; CoPhysics Corporation; April 2010.

26. Marcellus Shale Potential Public Health Concerns Correspondence and Supplemental Reports: Supplemental Generic Environmental Impact Statement on the Oil & Gas Regulatory Program – Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs; State of New York Department of Health; July 2009.

27. Incidental TENORM: A Guidance for State Solid Waste Managers; Association of State and Territorial Solid Waste Management Officials; April 2011.

28. Radiation Sources in Natural Gas Well Activities; Gayle Nicoll, Occupational Health & Safety Online; http://ohsonline.com/articles/.

29. Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs; J. Daniel Arthur, Brian Bohm, Bobbi Jo Coughlin and Mark Layne, ALL Consulting; 2008.

30. NORM Survey Summary; IOGA News; April 1995.

31. Regulatory Issues in the US, Nancy Sauer; *Hydraulic Fracturing*; www.EPmag.com; August 2012.

32. Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing; Stephen Osborn, Avner Vengosh, Nathaniel Warner and Robert Jackson, Duke University, Durham, North Carolina; www.pnas.org/cgi/doi/10.1073/pnas.1100682108; PNAS Early Edition 2011.

33. Hydraulic Fracturing and Safe Drinking Water Act Issues; Mary Tiemann and Adam Vann, Congressional Research Service;7-5700; www.crs.gov; R41760; July 2012.

34. The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies; Elizabeth Boyer, Bryan Swistock, James Clark, Mark Madden and Dana Rizzo, Pennsylvania State University; for The Center for Rural Pennsylvania; March 2012.

35. Hydraulic Fracturing & Water Resources: Separating the Frack from the Fiction; Heather Cooley and Kristina Donnelly, Pacific Institute; June 2012.

36. Hydraulic Fracturing or 'Fracking': A Short Summary of Current Knowledge and Potential Environmental Impacts; Dave Healy, University of Aberdeen; Aberdeen, United Kingdom; May 2012.

37. OIL AND GAS: Information on Shale Resources, Development and Environmental and Public Health Risks; United States Government Accounting Office Report to Congressional Requestors; September 2012.

38. Addressing the Environmental Risks from Shale Gas Development – Briefing Paper 1; Mark Zoback, Stanford University, Saya Kitasei, WorldWatch Institute, and Brad Copithorne, Environmental Defense Fund; WorldWatch Institute Natural Gas and Sustainable Energy Institute; July 2010.

39. In Fracking's Wake: New Rules are needed to Protect Our Health and Environment from Contaminated Wastewater; Rebecca Hammer, Natural Resource Defense Council, Jeanne VanBriesen, Carnegie Mellon University and Larry Levine, Natural Resource Defense Council; NRDC Issue Brief, 1B:12-05-A, May 2012.

40. Land Application of Hydrofracturing Fluids Damages a Deciduous Forest Stand in West Virginia; Mary Beth Adams, USDA Forest Service; *Journal of Environmental Quality*, Volume 40, July/August 2011.

41. Water Management Essential in Hydraulic Fracturing; Jerry Greenberg; *Hydraulic Fracturing*, www.EPmag.com; August 2012.

42. How to Remove Radioactive Iodine-131 From Drinking Water; Jeff McMahon, Forbes; www.forbes.com; April 2011.

43. Local Limits Development Guidance Appendices; USEPA; EPA 833-R-04-002B; July 2004.

44. Pa.: Marcellus wastewater shouldn't go to treatment plants; Don Hopey and Sean Hamill, Pittsburgh Post-Gazette; http://www.post-gazette.com/sotires/local/breaking/; March 2012.

45. Disposal of Produced Water from Oil & Gas Exploration: Environmental Impacts on Waterways in Western Pennsylvania, Thesis; Cidney Christie, Nicholas School of the Environment, Duke University; Durham, North Carolina; April 2012.

46. Service Companies Ease Operator Efforts; MJ Selle; *Hydraulic Fracturing*; www.EPmag.com; August 2012.

47. Tech Brief: Oil & Gas Extraction & Source Water Protection; Zane Satterfield, National Environmental Services Center; DWFSOM154DL; Volume 11, Issue 2, Fall/Winter 2011.

48. Hydraulic Fracturing: New ASTM International Subcommittee to Develop Needed Standards; http://www.astm.org/; Standardization News, November/December 2012.

49. Naturally-Occurring Radioactive Materials (NORM); www.world-nuclear.org, August 2011.

50. Groundwater Quality in West Virginia, 1993 – 2008; Douglas Chambers, Mark Kozar, Jeremy White and Katherine Paybins, USGS West Virginia Water Science Center; Scientific Investigations Report, 2012–5186, 60p; 2012.

51. 1996 Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures; Robert W. Puls and Michael J. Barcelona; Environmental Protection Agency; April 1996.

52. Comprehensive Quality Assurance Plan: Revision 28; Effective Date: July 25, 2011; REI Consultants, Inc. 2011.

53. Quality Assurance Manual: Revision 15.1; Effective Date: May 5, 2012; Pace Analytical Services, Inc. 2012.

54. Ground-water quality in unmined areas and near reclaimed surface coal mines in the northern and central Appalachian coal regions, Pennsylvania and West Virginia; McAuley, S.D. and Kozar, M.D.; U.S. Geological Survey Scientific Investigations Report 2006-5059, 57p; 2006.

55. Radiation Alert Quality Handheld Detectors, Inspector+ and Inspector EXP+ User Manual, August 29, 2006.

Appendix A: WVWRI Project Staff

Name	Role	Email	Office Telephone	Address
Paul Ziemkiewicz, PhD	Principal Investigator	paul.ziemkiewicz@mail.wvu.edu	304-293-6958	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Jennifer Hause	Project Manager	jhause@wvu.edu	304-293-7003	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Brady Gutta	Program Coordinator/Geologist	brady.gutta@mail.wvu.edu	304-293-7002	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Benjamin Mack	Research Associate	ben.mack@mail.wvu.edu	304-293-7009	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Jason Fillhart	Environmental Scientist	jefillhart@mail.wvu.edu	304-293-7074	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Melissa O'Neal	Environmental Technician/Laboratory Manager	melissa.o'neal@mail.wvu.edu	304-293-7006	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064
Doug Patchen, PG	Geologist	doug.patchen@mail.wvu.edu	304-293-6216	WV Water Research Institute West Virginia University PO Box 6064 Morgantown, WV 26506-6064

Appendix 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

Client: West Virginia Water Research Institute

Contact Person: Melissa O'Neal   Phone: 304-293-2867 x5439

Address: PO Box 6064   City: Morgantown   State: WV   Zip: 26506

Billing Address (if different)

Address: same as above   City: ____   State: ____   Zip: ____

PURCHASE ORDER # ____

Site ID & State: ____   Project ID: ____   Sampler: Melissa O'Neal

SAMPLE LOG & ANALYSIS REQUEST

TURNAROUND TIME

(●) NORMAL

RUSH TURNAROUND

( ) 5 DAY   ( ) 3 DAY   ( ) 2 DAY   ( ) 1 DAY

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

ANALYSIS & METHOD REQUESTED

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

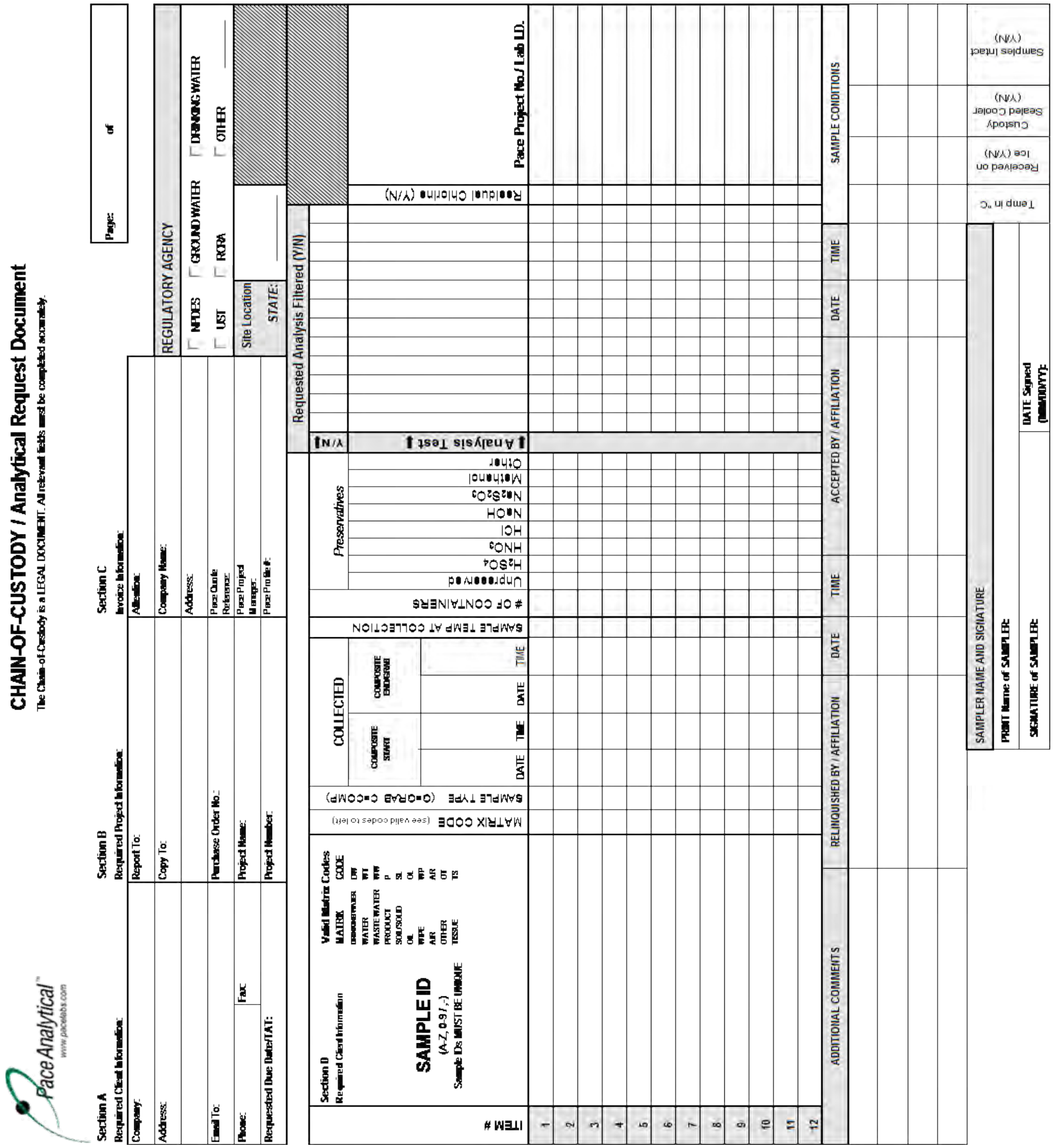
COMMENTS:
Please email results to:

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.

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 #:

Page: of

REGULATORY AGENCY

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

Site Location

STATE:

Requested Analysis Filtered (Y/N)

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	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test / 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			
							Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

SAMPLER NAME AND SIGNATURE

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

Pit and Impoundment Evaluation and Sampling Plan

For

Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project)

Prepared for:

West Virginia Department of Environmental Protection
Divisions of Air Quality
601 57th Street, SE
Charleston, WV 25304

Submitted by:

John Quaranta
Richard Wise
Andrew Darnell
Michael Kulbacki
Matt Idleman
Justin Pentz

Department of Civil and Environmental Engineering
West Virginia University
PO Box 6103
Morgantown, WV 26506-6103

Table of Contents

1.0 Background

Marcellus Shale is a rock formation located under parts of West Virginia, Pennsylvania, and New York. This rock formation contains large reserves of natural gas that are commonly being explored using recently developed horizontal drilling and hydraulic fracturing techniques. The West Virginia Legislature enacted the Natural Gas Horizontal Well Control Act §22-6A on December 14, 2011. As part of this Act, the West Virginia Department of Environmental Protection (WVDEP) is to perform studies concerning the practices involved with horizontal drilling, followed by a report of the findings and recommendations.

A research study is being performed, focusing on the potential health and safety concerns resulting from horizontal drilling techniques. Among the key areas of research are the surrounding air quality, the generated light and noise, and the structural integrity and safety of the pits and impoundments retaining fluids for the gas wells. The intent of the Pit and Impoundment Evaluation and Sampling Plan is to ascertain and document the suitability of the construction and use of these structures in minimizing the potential environmental effects related to horizontal drilling.

2.0 Roles and Responsibilities

A list of West Virginia University Department of Civil and Environmental Engineering (WVU CEE) personnel directly involved in this study is included in **Appendix A** along with contact information.

John Quaranta, Ph.D., P.E., Principal Investigator

- Provide oversight and direction of project
- Provide technical oversight concerning soil property testing on pits and impoundments
- Serve as lead investigator for pits and impoundments
- Oversee field sampling efforts for soil property testing

Richard Wise, MSCE, EIT, Research Engineer

- Select, schedule, and direct activities of field staff to complete the planned sampling activities
- Serve as primary point of contact for pits and impoundments team
- Assist with preparation of reports to WVDEP

Andrew Darnell, MSCE, EIT, Research Engineer

- Assist with selecting and scheduling to complete the planned sampling activities
- Oversee and assist with preparation of reports to WVDEP

Michael Kulbacki, BSCE, Research Associate

- Conduct field sampling activities
- Assist with compilation and reporting of field and laboratory data and results

Matt Idleman, BSCE, Research Associate

- Conduct field sampling activities
- Assist with compilation and reporting of field and laboratory data and results

Justin Pentz, BSCE, Research Associate

- Assist with compilation and reporting of field and laboratory data and results

3.0 Study Design

The intent of the field sampling and soil property testing in this plan is to ascertain and document the safety and structural integrity of the pits and impoundments used to retain fluids during the development of horizontal gas wells for Marcellus Shale. Cooperating with the WVDEP, WVU personnel will receive 18 candidate permit files for pits and impoundments with varying characteristics, from which 12 sites will be selected for field visit and evaluation, leading to a determination of six sites for in-depth soil property testing by a subcontractor.

The WVDEP will establish site access by contacting the natural gas developers. WVU will coordinate with the WVDEP to schedule and conduct soil property testing on the horizontal gas well sites. Furthermore, WVU personnel will make visual observations of the surrounding environment and take Global Positioning System (GPS) referenced pictures during sampling visits to assist with site evaluation.

Collection of site soil will be performed by WVU personnel at various locations on each site. These locations will be predetermined based on WVDEP permit reviews. The site soil will be tested in accordance with American Society for Testing and Materials (ASTM) Standards at the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory. The specific soil property tests to be performed are field moisture content, grain-size distribution and hydrometer, Atterberg Limits, Specific Gravity, Standard Proctor, hydraulic conductivity (rigid wall) and shear strength.

4.0 Sampling Sites

Site selection will be conducted by analyzing a set of 18 candidate permits provided by the WVDEP based on a set of criteria set forth by WVU. These criteria will be used to choose 12 sites with a variety of pit characteristics for evaluation. The factors encompassed in the criteria include the following:

- Location within the State of West Virginia
- Company Size: small, medium, or large
- Pit Characteristics:
  - Permit Number/Site Name
  - Age
  - Size (area, depth)
  - Use (flowback water, freshwater, centralized, associated)
  - Construction Material (natural soil, HDPE lined)
  - Construction Method (incised, berm)
  - Placement (hill crest, cut into slope, valley)

Once the 12 sites for evaluation are selected, field visits to those sites will be conducted for verification, visual observations, and checklist data collection using the evaluation form shown in Figure 1. Six sites will be selected from the candidate list of 12 sites for further in-depth soil testing. These six sites will have field soil compaction density tests performed by a WVU subcontractor, Potesta and Associates, Inc.

West Virginia University – Civil & Environmental Engineering ETD-10
Marcellus Horizontal Gas Well Flowback Water and Centralized Pits Evaluation Form

DATE & TIME	County		Company	
WEATHER	Latitude		Pit Name	
	Longitude		API No.	

A. PERMIT INFORMATION

Pit Width (ft.)		Minimum Berm Crest Width (ft.)		Construction Type	
Pit Length (ft.)		Upstream Slope (H:V)		Liner Type	
Depth (ft.)		Downstream Slope (H:V)		Date Built	
Freeboard(ft.)				Date Reclaimed	

B. FIELD AS-BUILT CONSTRUCTION AND SITE CONDITIONS

Pit Width (ft.)		Berm Crest Width (ft.)		Crest Height (ft.)	
Pit Length (ft.)		Upstream Slope (H:V)		Up Slope Length (ft.)	
Depth (ft.)		Downstream Slope (H:V)		Down Slope Length (ft.)	
Freeboard (ft.)		Water Elevation		Groundwater Elevation	

Is the pit/impoundment in the NFIP 100-yr floodplain?		Is the pit/impoundment within 1000 feet of a public water source?	
Is the pit/impoundment within 500 feet of a dwelling, perennial stream, or private water source?		Is the pit/impoundment within 100 feet of a wetland?	

C. PIT/IMPOUNDMENT		Existence	If YES then Evaluate Significance of Problem			
		Yes/No/NA	Low < 33%	Moderate 33 - 66%	High > 66%	Remarks
1	Are there any observed surface erosions, cracks, settlements, or scarps?					
2	Are there any slope movements or animal burrows?					
3	Are there any depressions, sinkholes, or slides into the pit present?					
4	Are there any signs of mine subsidence on or adjacent to the embankment?					
5	Are there any observed trees, tall weeds, or other vegetation?					
6	Are there any seeps, wet zones, or losses of soil?					
7	Are there any eddies/whirlpools or other signs of leakage or seeps present?					
8	Are there any liner tears, bulges, holes, wind uplifts, or seam separations?					
9	Are there any areas where the liner is strained?					
10	Are there any areas where the liner has rock or debris on top of it?					
11	Is there any tear potential for the liner?					
12	Are there any deformations, cracks, or settlements around the anchor trench?					
13	Are there any signs of pipe abnormalities (gouge marks, leaks, cracks)?					
14	Are there any areas where the pipe is not properly supported?					
15	Are there any signs of pipes having significant sagging in line?					
16	Are there any signs of obstructions (trees, garbage, etc.)?					
17	Are there any signs of water in ditch associated with pit?					
18	Are there any obstructions around the discharge outlet?					
19	Are there any signs of downstream slope movement into ditch?					

WVU (Name / Signature)	DATE
WVDEP (Name / Signature)	
Company Representative (Name / Signature)	

Site Operations & Infrastructure Evaluation	
Date:	Pit/Impoundment Name:
1	What is the type and frequency of company site inspections at the pit/impoundment? (routine or special inspection) (visual, walking)
2	What type of training or background does the inspector possess relative to pit/impoundment inspection?
3	How many years of training does the inspector have in evaluating pits/impoundments?
4	Is there a standardized form/procedure used to inspect and record observations of the pit/impoundment inspection?
5	Who developed the form and how is the information used to evaluate pit/impoundment safety?
6	Are there safety and emergency procedures for the pit/impoundment?
7	Is there an Emergency Action Plan (EAP) for the pit/impoundment? Is the EAP posted at the site with contact numbers?
8	Has the pit/impoundment inspector been trained on how to use the EAP?
9	Has the EAP been evaluated using a Table Top Review or other method? (If so, when?)
10	Does the company have a policy on pit/impoundment safety?
11	How frequently does a Professional Engineer inspect the site?
12	Other comments:

Figure 1: Evaluation Form

5.0 Field Sampling Methods

For the field testing, several items will be purchased. These items are organized into two categories: personal protective equipment (PPE) and field tools. The following list contains the items that will be purchased.

Personal Protective Equipment (PPE)

Hard hats
Steel-toed shoes (metatarsal)
Coveralls (flame retardant)
Leather gloves

Field Tools

Range Finder
100-foot tape
Jerricans
Soil jars
Latex gloves
Small garden hand shovels
Tape measures
Ziploc bags (quart)
Ziploc bags (gallon)
5 gallon buckets with lids
Duct Tape

During the site evaluations, WVU personnel will abide by all safety and PPE requirements mandated by the company on whose site the field sampling is being performed. The field sampling will consist of digging several test holes at key locations across each site, such as the toe, face, and crest of the pit or impoundment slope. The test hole locations will be planned prior to the site visit based on the information gathered from WVDEP permit files. The soil gathered from the test holes will be labeled with the site name, date, and location of the test hole. The sample locations will be restored to the original conditions to ensure that no damage will be done to the pit or impoundment. WVU personnel will also make visual observations of the surrounding environment and take GPS-referenced pictures during sampling visits. After the collection of soil samples, all tools will be cleaned and stored in containers to avoid cross-contamination between sites. In addition, the tools will be inspected for damage after each use. All PPE will be similarly decontaminated, and all disposable materials will be removed from the site in a garbage bag. Once collected, the soil will be taken to the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory for soil property testing.

In addition to the field sampling performed by WVU, *in situ* field compaction and moisture content data from various locations on six sites will be collected by Potesta and Associates, Inc. This field testing will involve using a nuclear surface gauge such as a Troxler 3430 model. The gauge measures approximately 30 inches long by 14 inches wide by 17 inches tall, and will be placed on a flat base prepared with a shovel. The tests will be performed in accordance with ASTM D-6938-06. The planned locations will comprise the toe, mid-slope, and crest of the downstream slope. Approximately four to twelve data points will be taken at each site. These field soil results will be incorporated into the analysis along with the laboratory soil testing performed by WVU. The importance of this data is to correlate the *in situ* soil density with the engineering plans and specifications.

6.0 Laboratory Soil Testing Methods

Geotechnical soil property testing will consist of collecting soil samples for laboratory testing in order to obtain independent verification of properties and site conditions. This work will be specific to the soils used to construct the pits and impoundments. Specific soil testing will be performed at the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory and will include the following: field moisture content, grain-size distribution and hydrometer, Atterberg Limits, Specific Gravity, Standard Proctor, hydraulic conductivity (rigid wall) and shear strength. The soil property tests and associated ASTM Standards are listed in Table 1. The necessary equipment and the procedure for each of these soil property tests are detailed in the following sections.

Soil Property Test	ASTM Standard
Field Moisture Content	D2216
Grain-Size Distribution and Hydrometer	D422
Atterberg Limits	D4318
Specific Gravity	D854
Standard Proctor	D698
Hydraulic Conductivity (Rigid)	D5856
Shear Strength	D3080/D3080M

Table 1: Soil Tests and Standards

6.1 Field Moisture Content (ASTM D2216)

Specified Equipment For This Soil Property Test:

1. Drying oven
2. Balances
3. Specimen containers (with lids)
4. Heat resistant tongs

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D2216 "Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass".

1. Determine the mass of a dry, clean moisture content container and record the number printed on the container and the mass of the container on a data sheet.

2. Place a representative sample of soil in the container. Weigh the container plus moist soil and record the mass on a data sheet.

3. Place the container and soil in an oven and allow the soil to dry overnight (at least 15 to 16 hours).

4. Determine the mass of the container and contents after the soil is dry, and record the mass on a data sheet.

6.2 Grain-Size Distribution and Hydrometer (ASTM D422)

Specified Equipment For These Soil Property Tests:

1. Balances
2. Hard bristle brush
3. Various-sized round, stackable testing sieves (ASTM E 11 or AASHTO M 92)
4. Vibratory table
5. Two graduated cylinders (one liter)
6. Hydrometer
7. High-speed electric mixer with steel mixing cup
8. Deflocculating agent (sodium hexametaphosphate)
9. Thermometer
10. 600 mL glass beaker
11. Spatula
12. Squirt bottles
13. Distilled water supply
14. Chemical weighing spoon
15. Chemical weighing dish

Laboratory Soil Testing Procedure for Grain-Size Distribution:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D422 "Standard Method for Particle-Size Analysis of Soils".

1. Weigh out a 500 g soil sample, oven-dried according to ASTM recommendations.

2. Record the mass of each clean sieve and the pan on a data sheet.

3. Place the soil sample in the uppermost sieve and secure with a lid.

4. Put the stack of sieves in the mechanical sieve shaker and shake for 5 minutes.

5. Remove the sieves from the shaker and set aside to allow dust to settle.

6. Remove each sieve from the stack, starting at the top.

7. Shake the first sieve over a sheet of paper until no particles fall onto the paper. Empty any soil particles on the paper into the next sieve.

8. Weigh the first sieve and record the mass of the sieve and soil retained on the data sheet.

9. Repeat Steps 7 and 8 for each sieve.

<u>Laboratory Soil Testing Procedure for Hydrometer Analysis:</u>

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D422 "Standard Method for Particle-Size Analysis of Soils".

1. Weigh out exactly 50 g of oven-dried soil in a 600 mL glass beaker.

2. Fill one 1-liter graduated cylinder with distilled water and place the hydrometer slowly inside.

3. Place the filled graduated cylinder and one empty 1-liter graduated cylinder on a stable counter in an area where the cylinders will not be shaken or moved for at least two hours.

4. Weigh out 2.5 g of sodium hexametaphosphate into a small dish.

5. Mix the soil with 250 mL of distilled water in a 500 mL glass beaker. Stir the slurry with a spatula and break the clumps of clay down into individual particles as much as possible.

6. Pour the slurry into a steel mixing cup and wash the remaining soil into the mixing cup.

7. Add the deflocculating agent (sodium hexametaphosphate).

8. Use distilled water to fill the mixing cup to two-thirds full.

9. Turn on the high-speed mixer and mix the soil slurry for one minute. Wash the suspension into the empty 1-liter graduated cylinder.

10. Add distilled water to fill the cylinder to the 1-liter mark and place a rubber stopper on the open end of the cylinder.

11. Cover the stopper with a hand and repeatedly turn the cylinder upside-down and right-side-up again until the suspension is thoroughly mixed.

12. Take hydrometer readings at total elapsed times of 15, 30, 60, and 120 seconds without removing the hydrometer, and record the readings on a data sheet. Remix the suspension and repeat the four readings until a consistent pair of readings is obtained.

13. Remix the suspension and restart the test, taking no readings until two minutes have passed.

14. Take hydrometer readings at total elapsed times of 2, 4, 8, 15, 30, 60, and 90 minutes, and record the readings on a data sheet.

15. After each reading, remove the hydrometer from the cylinder and store in the graduated cylinder filled with clean water. Place a thermometer in the clean water to determine the temperature of the hydrometer.

6.3 Atterberg Limits (ASTM D4318)

Specified Equipment For These Soil Property Tests:

1. Liquid limit device
2. Grooving tool
3. Moisture content containers
4. Glass or plastic plate
5. Soil mixing equipment (dish, spatula, and water bottle)
6. Balance

Laboratory Soil Testing Procedure for Liquid Limit:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D4318 "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils".

1. Obtain a sample of air-dry, pulverized clay weighing 100 g.

2. Measure the height of the fall for the liquid limit device.

3. Place the air-dry soil in an evaporating dish and mix with 15 to 20 mL of distilled water, or until the soil is near the liquid limit.

4. Place the soil in the liquid limit device to a maximum thickness of 1 cm and smooth with a spatula.

5. Use a grooving tool to cut a groove into the soil.

6. Lift and drop the cup by turning the crank at a rate of about two drops per second until the groove closes along a distance of one-half inch.

7. Add soil and repeat process until the number of blows for closure is the same on two consecutive tests.
8. Record the number of blows on a data sheet.
9. Remove a slice of soil from the portion of soil that closed the groove together and place in a moisture content container to determine the water content.
10. Add more water to the soil as needed in order to perform the test three times with blow counts between five and 50.

<u>Laboratory Soil Testing Procedure for Plastic Limit:</u>

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D4318 "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils".

1. Mix 15 g of air-dry soil with water so that the soil is slightly wet of the estimated plastic limit.
2. Roll the soil into a thread with a diameter of one-eighth inch on a glass or plastic plate.
3. Break the thread into six or eight pieces.
4. Squeeze the pieces together into a uniform mass and reroll to a thread with one-eighth inch diameter.
5. Repeat Steps 2-4 until the soil can no longer be rolled into a thread.
6. Gather the portions of crumbled soil together and place in a moisture content container to determine the water content.

6.4 Specific Gravity (ASTM D854)

<u>Specified Equipment For This Soil Property Test:</u>

1. 250 ml volumetric flask
2. 500 ml volumetric flask
3. Thermometer
4. Balance
5. Vacuum hoses with rubber stoppers to fit on volumetric flasks
6. Small vibratory table
7. Medicine dropper

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D854 "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer".

1. Obtain 150 g of soil, 50 g of which is used to measure specific gravity while the remaining soil is used to determine water content.
2. Weigh a clean, dry volumetric flask and record on a data sheet.
3. Pour 50 g of soil into the flask.
4. Fill the flask two-thirds full with distilled water.
5. Place the vacuum hose with rubber stopper on the neck of the flask and open the valve to apply a vacuum to the soil-water mixture.
6. Fill the flask to the etch mark with distilled water, using the medicine dropper near the end.
7. Use a paper towel to dry the outside of the flask and the inside of the neck above the water level.
8. Weigh the flask plus soil and water and record the mass on a data sheet.
9. Place a thermometer inside the flask to determine the temperature of the mixture and record on a data sheet.
10. Empty the soil from the flask, and repeat Steps 6-9 using only distilled water.

6.5 Standard Proctor (ASTM D698)

Specified Equipment For This Soil Property Test:

1. Compaction mold
2. Compaction hammers
3. Soil mixer
4. Sharpened straight edge
5. Tools for breaking apart compacted samples (hammer, ice pick, etc.)
6. Extruder to remove samples from mold
7. Large scoop for handling soil
8. Balance
9. Oven
10. Moisture cans

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D698 "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort".

1. Weigh out 3,000 g of air-dried soil.
2. Weigh the mold (not including the weight of the collar).
3. Determine the amount of water to add to the soil sample in order to obtain a specific, or known, water content.
4. Place the soil in the mixer and slowly add water to bring the water content of the soil to the desired value.
5. Remove the soil from the mixer and compact into the mold using three equal lifts and twenty-five blows for each lift with the compaction hammer.
6. Remove the collar and trim the soil flush with the top of the mold using a sharpened straight edge.
7. Weigh the mold plus the soil and record on a data sheet.
8. Extrude the soil from the mold using the extruder.
9. Cut the sample into three equal layers and place representative portions of soil from each layer into a moisture content container to determine water content.
10. Break the sample into reasonably fine pieces and place back into the mixer, adding water to achieve the next desired compaction water content. Repeat the process as necessary.

6.6 Hydraulic Conductivity-Rigid Wall (ASTM D5856)

Specified Equipment For This Soil Property Test:

1. Permeameter
2. Two porous stones
3. Two pieces of filter paper
4. Vacuum hoses
5. Membrane expander
6. O-rings
7. Compaction mold
8. Compaction hammers

9. Soil mixer
10. Sharpened straight edge
11. Tools for breaking apart compacted samples (hammer, ice pick, etc.)
12. Extruder to remove samples from mold
13. Large scoop for handling soil
14. Balance
15. Oven
16. Moisture cans

<u>Laboratory Soil Testing Procedure:</u>

The following section is based on ASTM standard D5856 "Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter".

1. Compact moist soil into a Standard Proctor mold following procedure outlined previously.
2. Record all physical properties of the soil sample on a data sheet.
3. Soak two porous stones and two pieces of filter paper in the permeating fluid until saturated.
4. Place one porous stone over the bottom plate of the permeameter cell and cover with filter paper.
5. Extrude the soil sample and place on top of the filter paper.
6. Place the remaining filter paper, porous stone, and top plate on top of the soil sample.
7. Place hydraulic grease around the outside of both top and bottom.
8. Place the membrane inside the membrane expander with at least two inches of excess at both ends.
9. Use a vacuum to expand the membrane.
10. Use the membrane expander to lower the membrane until the soil sample, top plate and bottom plate are encompassed.
11. Unclasp the vacuum line and allow the membrane to collapse around the sample.
12. Remove the membrane from the expander.
13. Fold the top and bottom of the membrane to remove any wrinkles.

14. Place two O-rings on one end of the membrane expander and place the membrane expander over the soil sample with the O-rings on the bottom of the expander.
15. Remove the O-rings so that the membrane is held tight against the top and bottom plates.
16. Secure the tail-water lines to the top plate.
17. Place the acrylic cover over the sample and secure with top cap.
18. Open the top valve to allow air to escape and fill the cell with water through the bottom valve.
19. Close both valves when water comes out the top.
20. Secure all lines from the pressure board to the cell.
21. Fill all three reservoirs with water, leaving at least two inches of air at the top of the reservoirs.
22. Set the cell water pressure to 10 psi, the head-water pressure to 8 psi, and the tail-water pressure to 6 psi.
23. Open the head-water valve that is connected to the head-water reservoir.
24. Open the head-water valve beside the first and allow the water to flow until all air bubbles are removed. Close both valves and repeat with the tail-water lines.
25. Open both the head-water and tail-water valves to allow the sample to saturate. Close both valves when air bubbles stop.
26. Drain the tail-water reservoir until there is only 1 cm of water.
27. Fill the head-water reservoir to 30 cm of water.
28. Measure the height of water in the head-water, tail-water, and cell-water reservoirs and record on a data sheet.
29. Set a time to start the test and turn both valves on at that time.
30. Record the height of water in the head-water, tail-water, and cell-water reservoirs as well as time of the readings and record on a data sheet.
31. Turn off both the head-water and tail-water valves when the head-water reservoir is nearly empty.
32. Take the last reading of the heights and the final time and record on a data sheet.

33. Disassemble the cell and take final moisture contents for the top, middle, and bottom layers of the sample.

6.7 Shear Strength (ASTM D3080/D3080M)

Specified Equipment For This Soil Property Test:

1. Shear device
2. Shear box
3. Porous stones
4. Device for applying and measuring the normal force
5. Device for applying and measuring the horizontal force
6. Timer
7. Deformation devices

Laboratory Soil Testing Procedure:

The following section is referenced from the CE 351 Introductory Soil Mechanics Laboratory Manual, Department of Civil and Environmental Engineering, West Virginia University. This procedure is based on ASTM standard D3080/D3080M "Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions".

1. Assemble the shear box in the direct shear frame, placing porous stones on top and bottom.

2. Place the loading cap.

3. Attach and adjust the vertical displacement measurement device.

4. Obtain an initial reading for the vertical displacement device and a reading for the horizontal displacement device. Record the measurements on a data sheet.

5. Consolidate the soil sample under the appropriate force.

6. Measure the vertical deformation as a function of time and plot the time-settlement curve to determine the time to 50 percent consolidation.

7. Shear the soil sample and take readings of the horizontal displacement until the shear force peaks, remains constant, or results in a deformation of 10 percent of the original diameter of the sample.

7.0 Data Management

Field evaluation data and observations will be recorded during each site visit. Data will be written in evaluation forms and field notebooks, and a review will be conducted on-site to ensure that all items have been evaluated. Field signatures will be obtained for all personnel involved with the evaluation. Once field personnel return to the office, the evaluation form will be transferred to project computers located in the WVU Department of Civil and Environmental Engineering Soil Mechanics Laboratory. Times, dates, and personnel involved in data collection will also be recorded in field notebooks and transferred to the electronic data file. The electronic copies will be saved on an external hard-drive, and one back-up will be created. As needed, once the data is transferred to the electronic data file, a review of the information will be conducted and reported to the WVDEP as part of the monthly progress updates. Photographs will be used to assist with documenting field activities and conditions. All hardcopy and electronic records will be delivered to the West Virginia Water Research Institute (WVWRI) Project Manager for retention and will be made available to the WVDEP upon request. All raw and processed data will be made available to the WVDEP as part of the monthly progress updates and final reporting activities.

8.0 Data Reduction

Following laboratory soil testing, the results will be compiled into a tabular format to allow for comparisons to permit reviews and other published site data. Reference of field and laboratory testing results to other engineering infrastructure activities will be made as a basis for comparison and analysis of the safety of the pits and impoundments. This analysis will lead to a determination of the suitability and relative importance of the findings. Graphical outputs will also be generated to illustrate data trends and meaningful observations.

9.0 Health and Safety

Prior to conducting field evaluations, WVU personnel will be completing the 40-hour HAZWOPER (Hazardous Waste Operations and Emergency Response) training. On each field evaluation, at least four WVU personnel will be present. WVU personnel will abide by all safety and PPE requirements mandated by the company on whose site the field evaluations and soil collection is being conducted.

In compliance with WVU Environmental Health & Safety policies and HAZWOPER training requirements, all WVU personnel will undergo a medical screening to determine a medical health baseline for each member prior to any field work. WVU personnel will also receive medical screenings within one year of the project's completion. Further medical monitoring will be conducted if recommended by WVU's Department of Occupational Medicine.

Before each field evaluation, WVU field personnel will attend site safety meetings to identify potential hazards and all procedures in place in the event an incident/accident occurs. If a hazard or danger is found at a sampling site, the field personnel will exit without delay, and the situation will be immediately reported to the WVDEP.

10.0 References

ASTM Standard D422, 2007. *Standard Method for Particle-Size Analysis of Soils.* ASTM International. West Conshohocken, PA. 2007. DOI: 10.1520/D0422-63R07. www.astm.org.

ASTM Standard D698, 2007e1. *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.* ASTM International. West Conshohocken, PA. 2007e1. DOI: 10.1520/D0698-07E01. www.astm.org.

ASTM Standard D854, 2010. *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D0854-10. www.astm.org.

ASTM Standard D2216, 2010. *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D2216-10. www.astm.org.

ASTM Standard D3080/D3080M, 2011. *Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.* ASTM International. West Conshohocken, PA. 2011. DOI: 10.1520/D3080_D3080M-11. www.astm.org.

ASTM Standard D4318, 2010. *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D4318-10. www.astm.org.

ASTM Standard D5084, 2010. *Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.* ASTM International. West Conshohocken, PA. 2010. DOI: 10.1520/D5084-10. www.astm.org.

ASTM Standard D5856, 2007. *Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter.* ASTM International. West Conshohocken, PA. 2007. DOI: 10.1520/D5856-95R07. www.astm.org.

Gabr, Mohammad A. *Laboratory Manual CE 351 Introductory Soil Mechanics*. Department of Civil and Environmental Engineering, West Virginia University, 1997.

Appendix A: WVU CEE Project Personnel

Name	Role	Email	Office Telephone	Address
John Quaranta	Principal Investigator	jdquaranta@mail.wvu.edu	(304) 293-9942	West Virginia University PO Box 6103 Morgantown, WV 26506-6103
Richard Wise	Research Engineer	richard.wise@mail.wvu.edu	(304) 293-9947	West Virginia University PO Box 6103 Morgantown, WV 26506-6103
Andrew Darnell	Research Engineer	andrew.darnell@mail.wvu.edu	(304) 293-9947	West Virginia University PO Box 6103 Morgantown, WV 26506-6103
Michael Kulbacki	Research Associate	mkulback@mix.wvu.edu	(304) 293-9947	West Virginia University PO Box 6103 Morgantown, WV 26506-6103
Matt Idleman	Research Associate	midlema1@mix.wvu.edu	(304) 293-9947	West Virginia University PO Box 6103 Morgantown, WV 26506-6103
Justin Pentz	Research Associate	jpentz1@mix.wvu.edu	(304) 293-9947	West Virginia University PO Box 6103 Morgantown, WV 26506-6103

Appendix B: WVU Personnel Biographies

John Quaranta, Principal Investigator

John D. Quaranta, Ph.D., P.E. is an Assistant Professor with the Department of Civil and Environmental Engineering at West Virginia University. He has been involved with High Hazard dam safety projects in West Virginia since 2003. His research spanning 2003 to 2009 focused on improving dam structural safety and emergency action planning. His current research involves identifying risk reduction options based on consequences of failure scenarios in down-stream communities for dams located in mountainous terrain.

Dr. Quaranta has developed and implemented dam safety training manuals and exercise programs; exercise reports on emergency action plan training; technical publications related to high hazard dam safety; and has attended or participated in dam safety workshops/seminars, all related to the steep mountainous terrain of West Virginia.

Richard Wise, Research Engineer

Richard Wise is from Morgantown, West Virginia, and graduated from West Virginia University in December with a Master's Degree in Geotechnical Engineering. While attending graduate school, he worked on a project with the United States Army Corps of Engineers where he created inundation maps and served as an evaluator for an emergency exercise. In addition to a Master's Degree, he also received a Bachelor's Degree with a minor in mathematics from West Virginia University in 2010. Throughout his undergraduate education, he was member of the engineering honor society, Tau Beta Pi, and interned with the Natural Resources Conservation Service and the West Virginia Department of Transportation.

Andrew Darnell, Research Engineer

Andrew Darnell is a West Virginia native, originally from Morgantown and currently living in Bruceton Mills. He graduated from West Virginia University with a Bachelor's Degree in Civil Engineering in 2010 and a Master's Degree in Civil Engineering in 2011. His thesis was based on a project with the United States Army Corps of Engineers, in which he created time-stepped inundation maps for a potential dam failure. Before attending graduate school, he completed two summer internships with the Pennsylvania Department of Transportation, where he served as a construction inspector and as an intern in the environmental design unit. He also interned with the Natural Resources Conservation Service, assisting with earthen dam modeling and rehabilitation studies.

Michael Kulbacki, Research Associate

Michael Kulbacki received a Bachelor of Science degree in Civil and Environmental Engineering from West Virginia University in 2012. He was a member of the West Virginia University Rifle team from 2008-2012; achievements during this duration include a National Championship (2008) and a three time All-American. Michael will attend West Virginia University's Graduate Program to seek a Master's Degree in Geotechnical Engineering.

Matt Idleman, Research Associate

Matt Idleman, from Keyser, West Virginia, received a Bachelor of Science degree in Civil and Environmental Engineering from West Virginia University in 2012. He is Treasurer of Chi Epsilon (Civil Engineering Honors Society), as well as an active member of the American Society of Civil Engineers, and a leader in the Mountaineer Maniacs organization, which is the largest student club on campus. Matt is currently planning to continue his schooling in pursuit of his Master's Degree.

Justin Pentz, Research Associate

Justin Pentz received a Bachelor of Science degree in Civil and Environmental Engineering from West Virginia University in 2012. He was a member of the West Virginia Rifle Team from 2008-2012; achievements during his duration include a Team National Championship in 2009 and a four-time individual All-American. Justin will attend West Virginia University's Graduate Program to seek a Master's Degree in Geotechnical Engineering.

west virginia department of environmental protection

Office of Oil and Gas
601 57th Street SE, Charleston, WV 25304
(304) 926-0450 office (304) 926-0452 fax

Earl Ray Tomblin, Governor
Randy C. Huffman, Cabinet Secretary
dep.wv.gov

MEMORANDUM

Re: WVU LARGE IMPOUNDMENT / PIT STUDY
[Volume capacity designs greater than 5000 barrels]

Acknowledgement: Recognition and Response by Office of Oil and Gas Personnel

Date: December 3rd, 2012

Reported by: David J. Belcher, Assistant Chief – Enforcement

Attached are inspection documents for the fifteen site candidates of large impoundments and pits presented in the WVU study. These documents are the results of follow-up reviews by the Office of Oil and Gas (OOG) field inspector staff.

This memorandum recognizes the WVU 2012 large impoundment/pit study and hereby reports the actions and measures taken by the OOG as a response. WVU presented their investigations of selected impoundments and pits during the 2012 period. This involved various county locations and seven different owner/operators (company). WVU's observations were based on as-built conditions and included a few observations of the construction phases and maintenance performances by the companies represented; also interviews with the OOG Inspectors were added. WVU's concerns address training, maintenance, and construction; concerns reported as correctable areas of need. The fifteen structures covered by the WVU team are of three categories which represent the OOG large impoundment/pit inventory; centralized waste facilities, fresh water impoundments, and well-permitted waste pits. All fifteen are under the authority and registry with the OOG.

Due to this study, the OOG implemented in-house training with all field and office staff members. OOG field staff thereafter conducted inspections of all fifteen structures. They also directed corrective actions necessary on their findings. All company representatives accompanied those efforts for each site but one. Inspectors plan follow-up inspections for the corrective actions necessary.

Findings the inspectors report are somewhat similar in respect to the WVU findings; and they found no areas of imminent danger. Inspectors attempted to locate each survey deficiency reported by the WVU team. Inspectors applied the data from the survey and also utilized an in-house inspection checklist; this checklist was designed by the OOG Professional Engineer on staff that has experience inspecting impoundment structures. They briefed those criteria with the operating representatives. Upon conclusion of their findings, parties agreed on the repair work necessary. Inspectors submitted those reports to the office which noted their findings and actions necessary for the repair work. The following briefly describes those efforts:

- Donna Completion Pit – Oil and Gas Inspector Hendershot inspected on November 16th and found the pit closed and reclaimed by the Energy Corporation of America. Vegetation is started. Pit is associated with the well permit activity API 47-049-02183.

- Donna Completion Impoundment – Oil and Gas Inspector Hendershot inspected on November 16th and found the pit closed and reclaimed by the Energy Corporation of America. Vegetation started. Pit is associated with the well permit activity API 47-049-02183.

- Pribble Freshwater Impoundment – Oil and Gas Inspector Haught inspected on November 30th in sunny conditions and found the following:
    1. Impoundment perimeter contained no safety devices – Stone Energy Company representative agreed to installation of safety equipment.
    2. Liner revealed a small tear near the anchor trench – Stone Energy Company representative agreed to patch the tear.
    3. Minor slope movement along the access road – Stone Energy Company representative agreed to make the necessary repairs to prevent further movement.
    4. Erosion on fill slope – Stone Energy Company representative agreed to dress slope and apply seed and mulch materials.
    5. Standing water on the crest – Stone Energy Company representative agreed to work crest to ensure proper drainage.

  This is a centralized fresh water impoundment registered with OOG as #WMP-00277.

- Burch Ridge Wastewater Pit – Oil and Gas Inspector Haught inspected on November 28th in sunny conditions and found the following:
    1. Signage missing – Gastar Exploration USA, Inc. representative agreed to installation of safety equipment.
    2. Cracks found on crest where standing waters were during wet periods – Gastar Exploration USA, Inc. representative agreed to dress the crest and apply seed and mulch materials.

  This is a waste pit associated with the well permit activity API 47-051-01505.

- MIP Freshwater Impoundment – Oil and Gas Inspector Ward inspected on November 27th in light snow and rain conditions and found standing waters on the crest isolated in minor areas and found some minor erosions. Corrections of the erosion areas were already being addressed by the Northeast Natural Energy. Inspector also reports the weather conditions did not hinder his inspection. Impoundment is associated with the well permit activity of API 47-061-01622 and 47-061-01624.

- Ball 1H Impoundment #2 – Oil and Gas Inspector Gainer and Supervisor Campbell inspected on November 28th in sunny conditions. Findings report only single crack on crest but minor and shallow believed a non-structural concern. Inspector and Supervisor report no corrective actions needed at this time. This is a large volume storage impoundment associated with the well permit activity API 47-095-02032.

- Mills-Wetzel Freshwater Impoundment – Oil and Gas Inspector Haught inspected on November 30th in sunny conditions and found the following:
    1. Trash observed around impoundment perimeter – Stone Energy Company representative agreed to address recovery and removal of trash.
    2. Fencing was down in areas – Stone Energy Company representative agreed to fence repairs.
    3. Standing waters on the crest – Stone Energy Company representative agreed to work crest to ensure proper drainage.

  This is a fresh water impoundment associated with the well permit activity of API 47-103-02704.

- SHL 2 Centralized Pit – Oil and Gas Inspector Haught inspected on November 29th in sunny conditions and a minor amount of trash observed around the pit. Noble Energy representative agreed to address the trash recovery and removals. Inspector also observed bird netting installed. This is a centralized waste pit registered with OOG as #051-WV-0001.

- SHL 3 Centralized Pit – Oil and Gas Inspector Haught inspected on November 29th in sunny conditions and a minor amount of trash observed around the pit. Noble Energy representative agreed to address the trash recovery and removals. Inspector also observed bird netting installed. This is a centralized waste pit registered with OOG as #051-WV-0002.

- SHL 4 Centralized Pit – Oil and Gas Inspector Haught inspected on November 29th in sunny conditions and found the following:
    1. Areas for improvements needed with vegetation – Noble Energy representative agreed to address vegetation corrections.
    2. Slips located below two sediment traps – Nobel Energy representative agreed to the repairs and plans removal of traps instead install vegetative strips as a replacement.
    3. Inspector found bird netting installed.

  This is a centralized waste pit registered with OOG as #051-WV-0003.

- Shields FW1 – Oil and Gas Inspector Haught inspected on November 28th in sunny conditions and found the following:
    1. Signage and safety equipment missing – Gastar Exploration USA, Inc. representative agreed to installation of signage and safety equipment.
    2. Minor erosion areas on fill slope – Gastar Exploration USA, Inc. representative agreed to dress areas on slope and install straw matting.

3. Standing water on the crest – Gastar Exploration USA, Inc. representative agreed to work crest to ensure proper drainage.

This is a waste pit associated with the well permit activity API 47-051-01533.

- Flanigan Pit – Oil and Gas Inspector Jenkins and Supervisor Harris inspected on November 27th in light snow and rain conditions and found small puddles rain waters on liner and ditch line. Inspector and Supervisor report no corrective actions necessary by the Antero Resources. Pit is associated with the well permit activity API 47-033-05570.

- Larry Pit – Oil and Gas Inspector Jenkins and Supervisor Harris inspected on November 27th in light snow and rain conditions and found some standing rain on the crest. Also Inspector and Supervisor found small erosion trench on fill slope; instructed company to monitor. Inspector and Supervisor report no corrective actions needed at this time; this is a temporary impoundment to be closed in a few months by the Antero Resources. Pit is associated with the well permit activity API 47-033-05538.

- MWV Large Water Storage Pond 1 – Oil and Gas Inspector Gainer and Supervisor Campbell inspected on November 27th in fog conditions and findings were positive with no issues. Inspector and Supervisor report no corrective actions needed at this time. This is a large volume storage impoundment associated with the well permit activity API 47-067-0940, API 47-067-0941, API 47-067-0942, and API 47-067-0943.

- Plum Creek South Fork – Oil and Gas Inspector Gainer and Supervisor Campbell inspected on November 27th in rain and fog conditions. Findings were positive with no issues detected. Inspector and Supervisor report no corrective actions needed at this time. This is a large volume storage impoundment associated with the well permit activity API 47-025-00035, and API 47-025-00039.

Large impoundments and pits addressed in this WVU study are recognized under the regulatory authority of the OOG. In this state such structures did not enter into activities as a common practice for completions until the year 2007. Applications began then with the Marcellus completions containing high volumes of fracturing fluids and fracturing stages; those interests by industry remain so today. Various regulatory requirements are in place for large structures; this includes necessities for engineering controls, vigilant monitoring, OOG reviews, and regulatory assurances with routine and quality inspections. Presently one hundred sixty large impoundments and pits are on file and registered; few are closed and reclaimed yet new applications are submitted routinely.

In conclusion, the OOG recognizes a continuous need for in-house training programs provided for its field staff. Workshops for industry must continue. Also recognized are the needs for routine field visits and quality reviews by the OOG; this is predicted to improve by the on-going progress in the hiring additional Inspectors and the sustained training initiatives.

Form IR-11A

State of West Virginia
Office of Oil and Gas

INSPECTORS REPORT

Operator: Wako + ECA

API Number: 4902183

Findings:

Upon Inspection of Reclaimed Freshwater impoundment + Frac Fluid pit I Found Both Have Been Reclaimed + Hav vegitation Growing on Them as of 11/16/12 Some vegitation is spoty on impoundment The vegitation on The Flow Back pit is in Good condition
pictures 1-4 impoundment 4-10-15 The Flow Back pit

[signature]

Oil & Gas Inspector

11-16-12

Date

IMPOUNDMENT/PIT INSPECTION CHECKLIST IR-11B 11/8/12

API# WMP-00277

COMPANY Stone Energy

WELL PAD

DATE 11-30-12

WEATHER CONDITIONS Sunny 53°

CURRENT FREEBOARD(FT.) 15'

INSPECTOR Derek M. Haught

IMPOUNDMENT/PIT (NAME) Pribble FWI

ASSOCIATED ______ CENTRALIZED ✓

COMPANY PERSONNEL AT SITE Scott Hutson

GATED--YES ✓ NO ______ FENCING INTACT--YES ✓ NO ______

IS VEGETATION ADEQUATE--YES ✓ NO ______

STANDING WATER ON CREST--YES ✓ NO ______

SIGNS & SAFETY--YES ______ NO ✓

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ______ NO ✓

SLOPE EROSION--YES ✓ NO ______

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ✓ NO ______

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ______ NO ✓ ; IF YES, ESTIMATE FLOW ______

DOES LINER APPEAR INTACT--YES ______ NO ✓

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

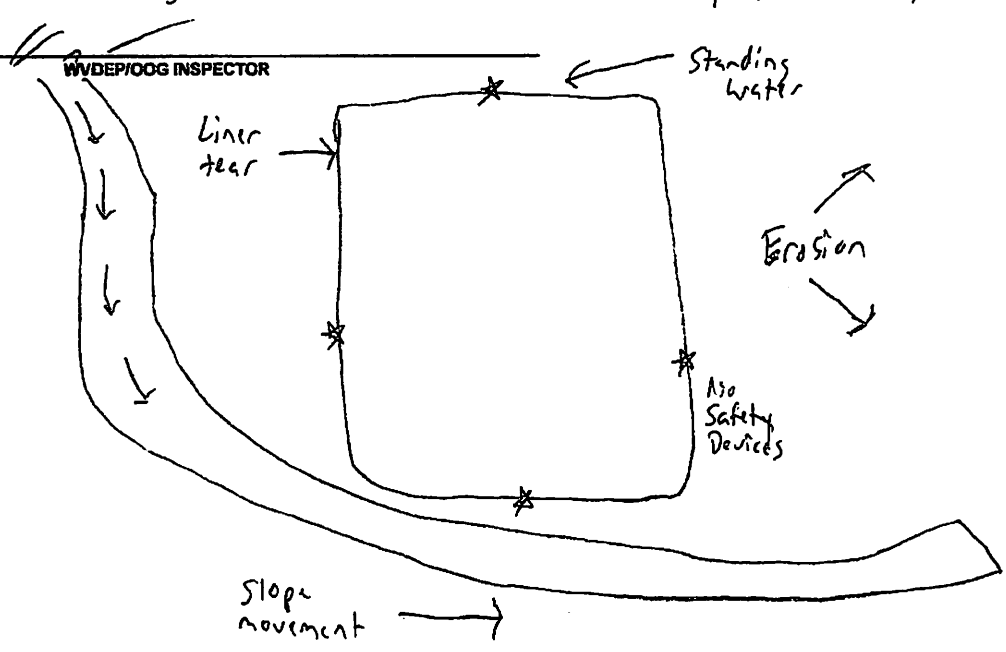
1. There are no safety devices around impoundment.
Stone has agreed to install safety equipment.

2. Liner has small tear near anchor trench.
Stone has agreed to patch.

3. Minor slope movement along access road.
Stone has agreed to make necessary repairs to prevent further movement.

4. There is erosion on fill slope.
Stone has agreed to dress slope and re-seed/mulch.
5. There is standing water on the crest.
Stone has agreed to work crest to ensure proper drainage.

[signature]
WVDEP/OOG INSPECTOR



IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 051-01505

COMPANY Gastar Exploration USA, Inc.

WELL PAD Burch Ridge

DATE 11-28-12

WEATHER CONDITIONS Sunny 39°

CURRENT FREEBOARD(FT.) 17'

INSPECTOR Derek M Haught

IMPOUNDMENT/PIT (NAME) Burch Ridge Wastewater Pit

ASSOCIATED ✓ CENTRALIZED ____

COMPANY PERSONNEL AT SITE Jerry Duelley

GATED--YES ✓ NO ____ FENCING INTACT--YES ✓ NO ____ IS VEGETATION ADEQUATE--YES ✓ NO ____

STANDING WATER ON CREST--YES ____ NO ✓ SIGNS & SAFETY--YES ____ NO ✓

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ✓ NO ____ SLOPE EROSION--YES ____ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ____ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ____ NO ✓ ; IF YES, ESTIMATE FLOW ____

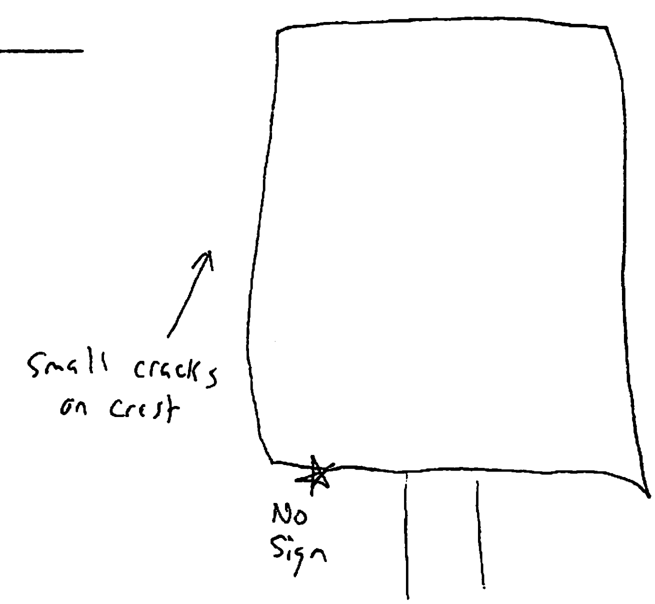
DOES LINER APPEAR INTACT--YES ✓ NO ____

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

1. There is no sign.
Gastar has agreed to have signs made and installed at all pits.

2. There are cracks on crest where water has been standing during wet periods.
Gastar has agreed to dress crest and seed/mulch.

[signature]
WVDEP/OOG INSPECTOR



IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 47-61-1622/1624

COMPANY Northeast Natural Energy

INSPECTOR Sam Ward

WELL PAD MIP

IMPOUNDMENT/PIT (NAME) MIP

DATE 11/27/12

ASSOCIATED ✓ CENTRALIZED ____

WEATHER CONDITIONS Rain/Snow

COMPANY PERSONNEL AT SITE Dave McDougal

CURRENT FREEBOARD(FT.) 13'4"

GATED–YES ✓ NO ____ FENCING INTACT–YES ✓ NO ____ IS VEGETATION ADEQUATE–YES ✓ NO ____

STANDING WATER ON CREST--YES ✓ NO ____ SIGNS & SAFETY–YES ✓ NO ____

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ____ NO ✓ SLOPE EROSION–YES ____ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ____ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ____ NO ✓ ; IF YES, ESTIMATE FLOW ____

DOES LINER APPEAR INTACT--YES ✓ NO ____

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

Standing water on the crest of the impoundment is minor areas which appear to be old tire track depressions. There are some minor erosion areas that are being addressed already. For the most part, any problems listed in the Impoundment Study are minor at best, and some I disagree with completely

Rain + Snow was not a hinderance to my inspection SDW 11/28/2012

S. D. Ward II WV DEP
WVDEP/OOG INSPECTOR

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 095-02032

COMPANY Petro Edge

INSPECTOR Ed Gainer Rick Campbell

WELL PAD

IMPOUNDMENT/PIT (NAME) Bell 1H #2

DATE 11/29/12

ASSOCIATED ✓ CENTRALIZED

WEATHER CONDITIONS Sunny 40°

COMPANY PERSONNEL AT SITE No

CURRENT FREEBOARD(FT.) 3'

GATED--YES ✓ NO

FENCING INTACT--YES NO

IS VEGETATION ADEQUATE--YES ✓ NO

STANDING WATER ON CREST--YES NO ✓

SIGNS & SAFETY--YES ✓ NO

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ✓ NO

SLOPE EROSION--YES NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES NO ✓ ; IF YES, ESTIMATE FLOW

DOES LINER APPEAR INTACT--YES NO

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

Pit liner was intact and very good condition.
Noted in report that cracks and rills were found on fill top but were above water level and not deep enough to be structural or as failure problems.

[signature]

WVDEP/OOG INSPECTOR

Rick Campbell

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 103-02704

COMPANY Stone Energy

INSPECTOR Derek A. Haught

WELL PAD

IMPOUNDMENT/PIT (NAME) Mills-Wetzel FWI

DATE 11-30-12

ASSOCIATED ______ CENTRALIZED ✓

WEATHER CONDITIONS Sunny 35°

COMPANY PERSONNEL AT SITE Scott Hutson

CURRENT FREEBOARD(FT.) 12'

GATED--YES ✓ NO ______ FENCING INTACT--YES ______ NO ✓ IS VEGETATION ADEQUATE--YES ✓ NO ______

STANDING WATER ON CREST--YES ✓ NO ______ SIGNS & SAFETY--YES ✓ NO ______

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ______ NO ✓ SLOPE EROSION--YES ______ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ______ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ______ NO ✓; IF YES, ESTIMATE FLOW ______

DOES LINER APPEAR INTACT--YES ✓ NO ______

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

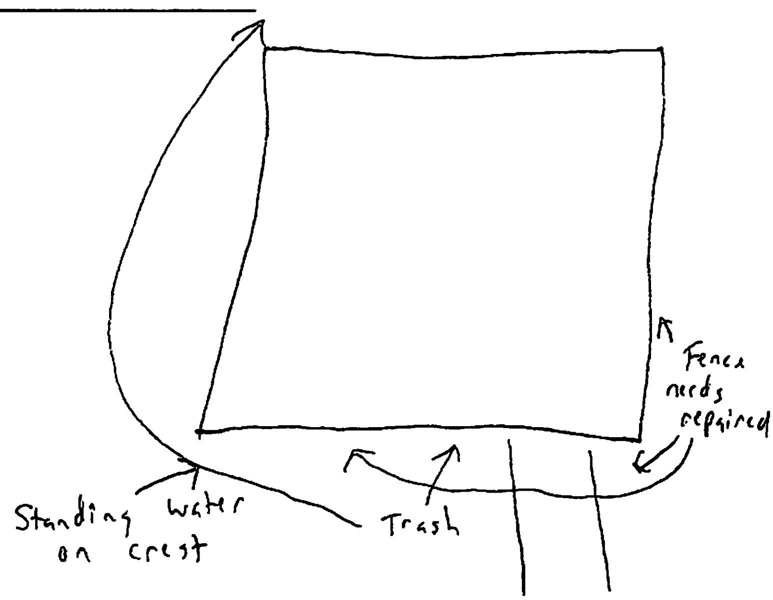
1. Trash observed around impoundment.
Stone has agreed to address.

2. Fence is down in areas.
Stone has agreed to repair.

3. There is water standing on crest during wet periods.
Stone has agreed to work crest and ensure proper drainage.

[signature]

WVDEP/OOG INSPECTOR



IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 051-WPC-00001 WV-051-0001

COMPANY Noble Energy

INSPECTOR Derek M. Haught

WELL PAD

IMPOUNDMENT/PIT (NAME) SHL 2 Centralized Pit

DATE 11-29-12

ASSOCIATED ____ CENTRALIZED ✓

WEATHER CONDITIONS Sunny 34°

COMPANY PERSONNEL AT SITE Clayton Murrell

CURRENT FREEBOARD(FT.) 4'

GATED--YES ✓ NO ____ FENCING INTACT--YES ✓ NO ____ IS VEGETATION ADEQUATE--YES ✓ NO ____

STANDING WATER ON CREST--YES ____ NO ✓ SIGNS & SAFETY--YES ✓ NO ____

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ____ NO ✓ SLOPE EROSION--YES ____ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ____ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ____ NO ✓ ; IF YES, ESTIMATE FLOW ____

DOES LINER APPEAR INTACT--YES ✓ NO ____

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

1. Minor amount of trash observed around pit. Noble has agreed to address.

Note: Bird netting has been installed.

[signature]

WVDEP/OOG INSPECTOR

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 051-WPC-00002 WV-051-0002

COMPANY Noble Energy

INSPECTOR Derek R. Haught

WELL PAD

IMPOUNDMENT/PIT (NAME) SHL 3 Centralized Pit

DATE 11-29-12

ASSOCIATED ____ CENTRALIZED ✓

WEATHER CONDITIONS Sunny 34°

COMPANY PERSONNEL AT SITE Clayton Burrell

CURRENT FREEBOARD(FT.) 3'

GATED--YES ✓ NO ____ FENCING INTACT--YES ✓ NO ____ IS VEGETATION ADEQUATE--YES ✓ NO ____

STANDING WATER ON CREST--YES ____ NO ✓ SIGNS & SAFETY--YES ✓ NO ____

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ____ NO ✓ SLOPE EROSION--YES ____ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ____ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ____ NO ✓ ; IF YES, ESTIMATE FLOW ____

DOES LINER APPEAR INTACT--YES ✓ NO ____

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

1. Minor amount of trash observed around pit. Noble has agreed to address.

Note: Bird netting has been installed.

[signature]

WVDEP/OOG INSPECTOR

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 051- WPL-00003 051-WV-0003

COMPANY Noble Energy

INSPECTOR Derek M. Haught

WELL PAD

IMPOUNDMENT/PIT (NAME) SHL 4 Centralized Pit

DATE 11-29-12

ASSOCIATED ____ CENTRALIZED ✓

WEATHER CONDITIONS Sunny 34°

COMPANY PERSONNEL AT SITE Clayton Murrel

CURRENT FREEBOARD(FT.) 3'

GATED--YES ✓ NO ____ FENCING INTACT--YES ✓ NO ____ IS VEGETATION ADEQUATE--YES ✓ NO ____

STANDING WATER ON CREST--YES ____ NO ✓ SIGNS & SAFETY--YES ✓ NO ____

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ____ NO ✓ SLOPE EROSION--YES ____ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ____ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ____ NO ✓ ; IF YES, ESTIMATE FLOW ____

DOES LINER APPEAR INTACT--YES ✓ NO ____

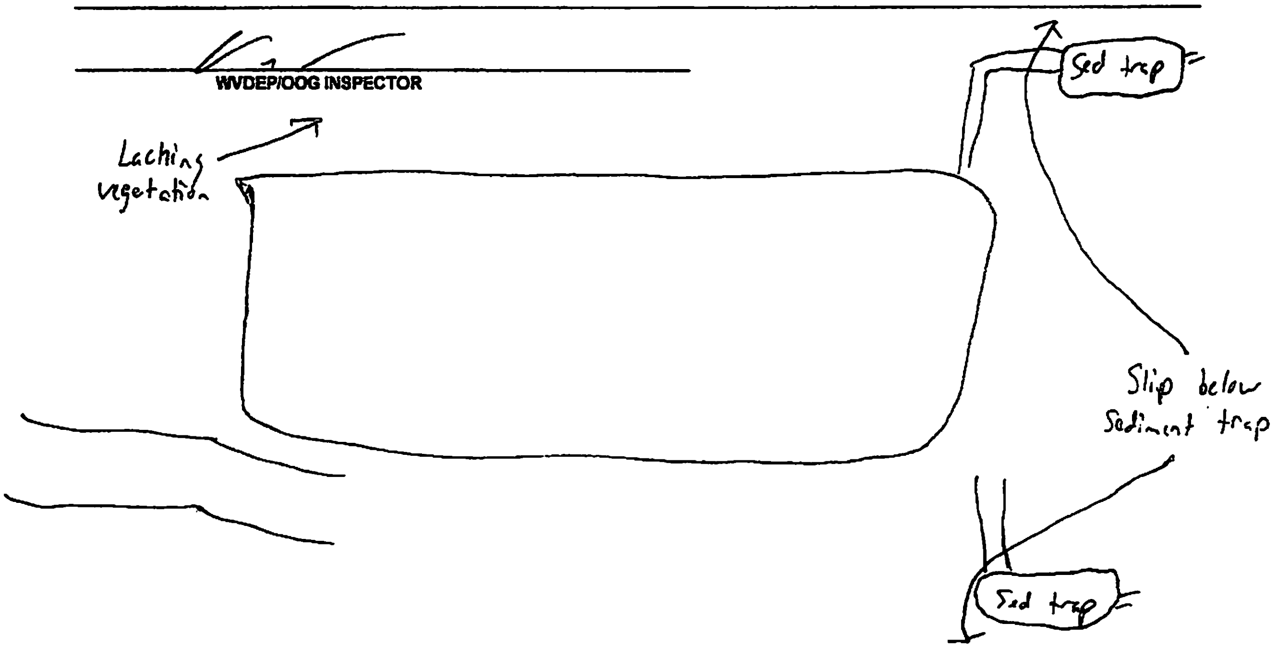
FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

1. There are areas where the vegetation could be improved.
Noble has agreed to address vegetation concerns next spring.

2. There are slips below both sediment traps.
Noble has agreed to repair slips. In order to repair, sediment traps will be removed and replaced by vegetative strips.

Note: Bird netting has been installed.

[signature]
WVDEP/OOG INSPECTOR



IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 051-01533

COMPANY Caster Exploration USA, Inc.

INSPECTOR Derek M. Haught

WELL PAD Shields

IMPOUNDMENT/PIT (NAME) Shields Wastewater Pit

DATE 11-28-12

ASSOCIATED ✓ CENTRALIZED ____

WEATHER CONDITIONS Sunny 36°

COMPANY PERSONNEL AT SITE Jerry Dudley

CURRENT FREEBOARD(FT.) 14'

GATED--YES ✓ NO ____ FENCING INTACT--YES ✓ NO ____ IS VEGETATION ADEQUATE--YES ____ NO ✓

STANDING WATER ON CREST--YES ✓ NO ____ SIGNS & SAFETY--YES ____ NO ✓

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ____ NO ✓ SLOPE EROSION--YES ✓ NO ____

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ____ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ____ NO ✓; IF YES, ESTIMATE FLOW ____

DOES LINER APPEAR INTACT--YES ✓ NO ____

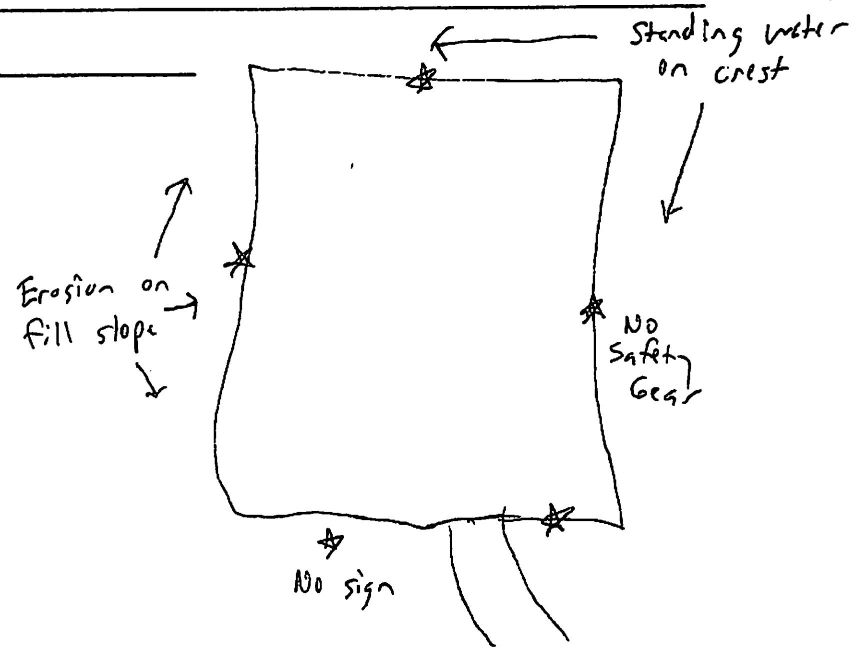
FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

1. There is no sign or safety equipment.
Caster has agreed to install sign and safety equipment.

2. There are minor erosion areas on fill slope.
Caster has agreed to dress areas and install straw matting.

3. There is standing water on crest.
Caster has agreed to work crest to ensure proper drainage.

[signature]
WVDEP/OOG INSPECTOR



IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 47-33 05570

COMPANY Antero

INSPECTOR Tristan Jenkins

WELL PAD Flannigan

IMPOUNDMENT/PIT (NAME) impoundment

DATE 27 Nov 12

ASSOCIATED ✓ CENTRALIZED ______

WEATHER CONDITIONS Light Snow/Rain

COMPANY PERSONNEL AT SITE Telly Wycoff

CURRENT FREEBOARD(FT.) 3

GATED--YES ✓ NO ______ FENCING INTACT--YES ______ NO ______

IS VEGETATION ADEQUATE--YES ✓ NO ______

STANDING WATER ON CREST--YES ✓ small puddles NO ______

SIGNS & SAFETY--YES ✓ NO ______

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES ______ NO ✓

SLOPE EROSION--YES ______ NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES ______ NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES ______ NO ✓ ; IF YES, ESTIMATE FLOW ______

DOES LINER APPEAR INTACT--YES ✓ NO ______

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

small puddles on liner and in ditch due to Rain

[signature]

WVDEP/OOG INSPECTOR

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 47-33-05538

COMPANY Antero

INSPECTOR TRistan Jenkins

WELL PAD LArry

IMPOUNDMENT/PIT (NAME) impoundment

DATE 27NOV12

ASSOCIATED ✓ CENTRALIZED

WEATHER CONDITIONS Light snow/Rain

COMPANY PERSONNEL AT SITE Terry wycoff

CURRENT FREEBOARD(FT.) 3

GATED--YES ✓ NO

FENCING INTACT--YES ✓ NO

IS VEGETATION ADEQUATE--YES ✓ NO

STANDING WATER ON CREST--YES ✓ NO

SIGNS & SAFETY--YES ✓ NO

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES NO ✓

SLOPE EROSION--YES ✓ NO

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES NO ✓; IF YES, ESTIMATE FLOW

DOES LINER APPEAR INTACT--YES ✓ NO

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

some standing water due To RAin on crest

small erosion trench on Fill slope

No corrective action needed at this time
Tempory impoundment to be closed in a few months — R.H.

[signature]

WVDEP/OOG INSPECTOR

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 47-067-0940, 0941, 0942, 0943

COMPANY BRC - Blue Scope Resources

INSPECTOR Ed Gainer

WELL PAD Rupert Pad 1 & 2

IMPOUNDMENT/PIT (NAME) MWV - Meade West Vaco

DATE 11/27/12

ASSOCIATED ✓ CENTRALIZED

WEATHER CONDITIONS Fog + cold

COMPANY PERSONNEL AT SITE Sam Sweatt

CURRENT FREEBOARD(FT.) 6 Ft +

GATED--YES ✓ NO

FENCING INTACT--YES ✓ NO

IS VEGETATION ADEQUATE--YES ✓ NO

STANDING WATER ON CREST--YES NO ✓

SIGNS & SAFETY--YES ✓ NO

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES NO ✓

SLOPE EROSION--YES NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES NO ✓; IF YES, ESTIMATE FLOW

DOES LINER APPEAR INTACT--YES ✓ NO

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

2nd inspection since WVU inspection. Unable to find associate problems. Rills listed were dozer tracking, no slope movement or slips were found, no seepage, no liner problems.

[signature]

WVDEP/OOG INSPECTOR

Richard Campbell

IMPOUNDMENT/PIT INSPECTION CHECKLIST

IR-11B 11/8/12

API# 47-025-00035 + 025-00039

COMPANY BRC - Blue Scope Resources

INSPECTOR Ed Grainer

WELL PAD PCSF Pad #2

IMPOUNDMENT/PIT (NAME) PCSF Plum Cr. South FK.

DATE 11/27/12

ASSOCIATED ✓ CENTRALIZED

WEATHER CONDITIONS Rain + Fog

COMPANY PERSONNEL AT SITE Sam Sweatt

CURRENT FREEBOARD(FT.) 20'

GATED--YES ✓ NO

FENCING INTACT--YES NO

IS VEGETATION ADEQUATE--YES ✓ NO

STANDING WATER ON CREST--YES NO ✓

SIGNS & SAFETY--YES ✓ NO

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES NO ✓

SLOPE EROSION--YES NO ✓

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES NO ✓

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES NO ✓ ; IF YES, ESTIMATE FLOW

DOES LINER APPEAR INTACT--YES ✓ NO

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

2nd inspection since WVU report. Unable to find rills, seepage, no slip bulges or slope movement apparent. Trash in impoundment was 1 pop bottle + fence post tops - wooden, not safe to retrieve. Pump and plastic piping had been removed. No problems were detected.

WVDEP/OOG INSPECTOR

Richard Campbell

IMPOUNDMENT/PIT INSPECTION CHECKLIST

API#____

COMPANY_______________________________________ INSPECTOR_________________________________

WELL PAD_______________________________________ IMPOUNDMENT/PIT____________________________
(NAME)

DATE____ ASSOCIATED__________ CENTRALIZED____________

WEATHER CONDITIONS_____________________________ COMPANY PERSONNEL AT SITE___________________

CURRENT FREEBOARD(FT.)__________________________ ____

GATED--YES________ NO__________ FENCING INTACT--YES______ NO______ IS VEGETATION ADEQUATE--YES_________ NO_________

STANDING WATER ON CREST--YES__________ NO____________ SIGNS & SAFETY--YES_________ NO__________

ANY CRACKS/SLUMPS/DEPRESSIONS ON CREST--YES__________ NO__________ SLOPE EROSION--YES__________ NO__________

ANY SLIPS, BULGES OR SLOPE MOVEMENTS ON FILL SLOPES--YES__________ NO___________

ANY SEEPAGE EVIDENT ON FILL SLOPES--YES___________ NO____________; IF YES, ESTIMATE FLOW______________________________

DOES LINER APPEAR INTACT--YES____________ NO_____________

FOR ANY ANSWERS ABOVE, PROVIDE EXPLANATION AND ATTACH SKETCH OR COPY OF STRUCTURE FROM PLANS AND SHOW APPROXIMATE LOCATION OF FEATURES INDENTIFIED ABOVE. TAKE PHOTOS OF ANY FEATURES IDENTIFIED ABOVE, AND ATTACH THEM TO THIS INSPECTION REPORT.

____
____
____
____
____
____
____
____
____
____
____
____
____
____
____
____

____
WVDEP/OOG INSPECTOR