Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report

(Period ending: 3/31/2016)

Marcellus Shale Energy and Environment Laboratory (MSEEL)

Project Period: October 1, 2014 – September 30, 2019

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Quarterly Progress Report

January 1 – March 31, 2016

Executive Summary

The objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to provide a long-term field site to develop and validate new knowledge and technology to improve recovery efficiency and minimize environmental implications of unconventional resource development.

This quarter continued to be very active, as the team has started in-depth analysis of the almost four terabytes of data collected during well development. The team held several meetings, including a large team meeting on February 12, 2016 to discuss project progress, and for team breakout sessions to discuss technical work plans and sample (rock, water, etc) workflows to ensure that all project partners had access to needed materials. Monitoring of the wells continued through this quarter during the initial production phase. The team also has worked to update the Project Management Plan to capture the plans developed at the team meeting on 2/12.

Quarterly Progress Report

January 1 – March 31, 2016

Project Performance

This report summarizes the activities of Cooperative Agreement DE-FE0024297 (Marcellus Shale Energy and Environment Laboratory – MSEEL) with the West Virginia University Research Corporation (WVURC) during the second quarter of the FY2016 (January 1 through March 31, 2016).

This report outlines the approach taken, including specific actions by subtopic. If there was no identified activity during the reporting period, the appropriate section is included but without additional information.

Topic 1 – Project Management and Planning

Subtopic 1.1. – Project Management

Approach

The project management team will work to generate timely and accurate reporting, and to maintain project operations, including contracting, reporting, meeting organization, and general oversight.

Results and Discussion

This quarter has continued to be very active, as the team has started in-depth analysis of the data collected during well development. The team held several meetings, including a large team meeting on February 12, 2016 to discuss project progress, and four team breakout sessions to discuss technical work plans and sample (rock, water, etc) workflows to ensure that all project partners had access to needed materials. A total of 80 people participated in the meeting. Monitoring of the wells continued through this quarter during the initial production phase. The team also has worked to update the Project Management Plan to capture the plans developed at the team meeting on 2/12.

The project team is tracking four milestones in this budget period.

1. Complete/Stimulate Production Wells (NNE 3H, 5H) – 12/31/2015 (Complete)
    a. Completed with successful gathering of subsurface data from the fiber-optic cable and from advanced logging.

2. Complete Preliminary Analysis of Surface and Subsurface Data – 3/31/2016
    a. Core was received, CT scanned and visually logged, an initial round of samples have been distributed to investigators. Preliminary examination from geomechanical logging and fracture analysis have been completed, but results have raised numerous questions that need to be addressed, including the effectiveness and the direction of fracture stimulation. Analysis of cuttings, produced water and air have been completed and are ongoing during production phase.

3. Complete SEM, XRD and PPAL imaging and Core Analysis – 9/30/2016 (was 12/31/2016)
    a. Initial results are coming in and will be available this summer. We have taken a very careful approach to calibrate results among labs, including WVU, OSU, NETL and Schlumberger. This has taken longer than expected, but should be completed well before 9/30/16

4. 3D Fracture Modeling Complete – 12/31/2016. (was 6/30/2016)
    a. This is advancing very quickly with the integration of microseismic and fracture logs (see write up for this quarter). Still need to integrate the sonic and temperature data from the fiber-optics. This should be well along by the end of summer.

Subtopic 1.2. – Database Development

Approach

We have used CKAN, open source data portal software (www.ckan.org). This platform is used by NETL-EDX and Data.gov among other organizations and agencies. We will use this platform to store, manage, publish and find datasets.

Results and Discussion

CKAN is up and running and is used to share data among numerous researchers from the existing wells and presentations among research personnel (Task 1.2). There is now a very large amount of data on the MSEEL portal that includes 76 data entries and measuring almost 4 terabytes in compressed form. Data covers all aspects of drilling and completion of the wells. Additional data is being generated by various laboratory analyses. The MSEEL web site has been enhanced with MSEEL News articles, a time line and with images. We have generated static and dynamic 3D images of the surface and subsurface at the MSEEL site (Figure 1.1)

A comprehensive list of data available in the MSEEL database is provided in Appendix 1.

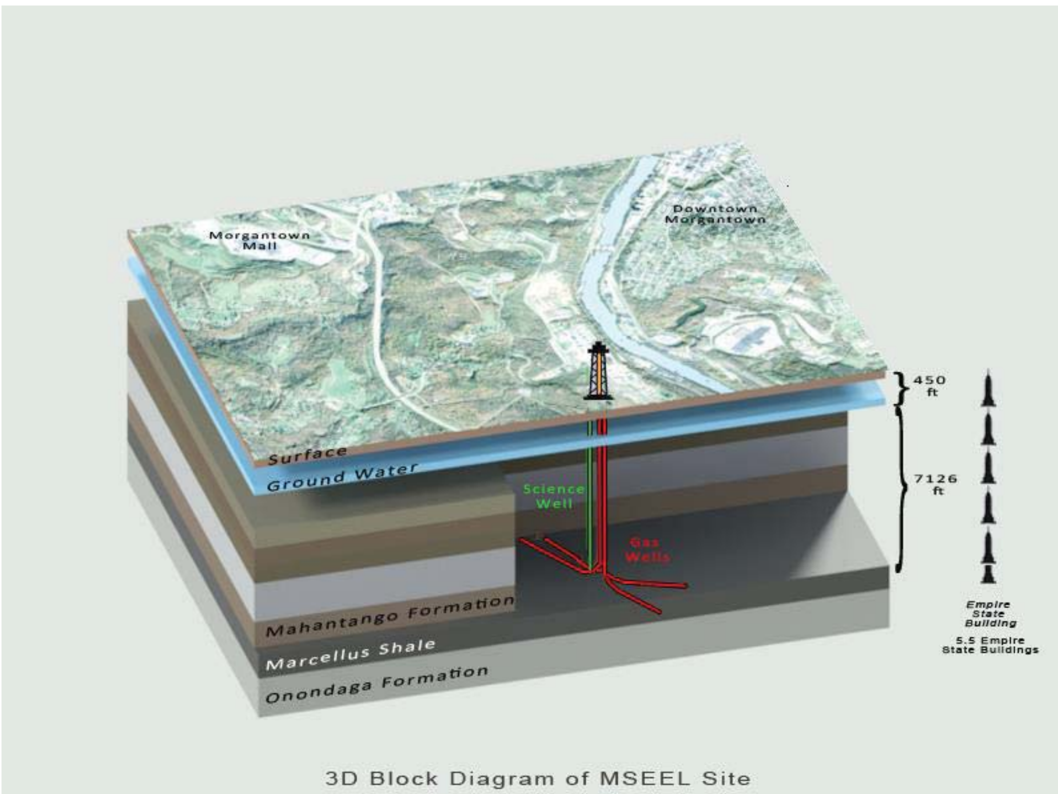


Figure 1.1. Static 3D image of the MSEEL sit showing the existing production wells and the two new production wells along with the science/observation well.

Plan for Next Quarter

Upload additional datasets and 3D static and dynamic images to online site and federate MSEEL portal with EDX. These are being submitted at an increasing rate. We have hired a post-doc for the summer to organize and further curate the data.

Topic 2 – Geologic Engineering

Approach

The geologic engineering team will work to generate to improve the effectiveness of fracture stage design. Evaluating innovative stage spacing and cluster density practices to optimize recovery efficiency. The team will use a data driven approach to integrate geophysical, fluid flow and mechanical properties logs, microseismic and core data to better to characterize subsurface rock properties, faults and fracture systems to model and identify the best practices for field implementation, and assess potential methods that could enhance shale gas recovery through experimental and numerical studies integrated with the results of the production wells at the MSEEL site.

Task 2a – Rock Analysis

Core plug samples from the science well have been obtained. The established protocols for sample analysis have been implemented to characterize the core plugs. The base set of experiments using Helium for measurement of porosity, permeability, and compressibility are under way.

The analysis of the production and stimulation data from the existing horizontal wells at the MIP site as well as other horizontal Marcellus shale wells in the region is nearly complete.

In addition, the analysis of the data generated during drilling wells MIP-3H and MIP-5H at NNE site is in progress. The determining formation characteristics from wireline and thermal logs is also in progress.

Task 2b – Water Treatment

Our first research activity of produced water treatment focuses on developing an (bio)electrochemical method to remove scale-forming cations as a pre-treatment system for produced water treatment. A two-chamber bioelectrochemical system used in this study contained an anode and cathode chambers separated by a cation exchange membrane. Each chamber contained graphite woven felt electrodes. An electric current was used to create a pH unbalance between the anode and cathode. The high-pH cathlyte was then used to treat raw produced water to remove multi-valent cations as a softening process. Produced water sample was collected at the MSEEL site and used in the study. The treatment method was shown to be effective in removing scale-forming cations.

Results and Discussion

1. Produced water chemical characterization (Table 1)

Table 2.b.1. Chemical characterization of the raw produced water collected from the MSEEL site.

Parameter	Unit	Concentration	Parameter	Unit	Concentration
pH		4.55	Aluminum (Al)	mg/L	0.29
TSS	g/L	0.21	Magnesium (Mg)	g/L	2.30
COD	mg/L	958	Strontium (Sr)	g/L	3.85
Alkalinity	mg $CaCO_3$/L	107.84	Calcium (Ca)	g/L	38.64
Acidity	mg $CaCO_3$/L	280.87	Sodium (Na)	g/L	27.00
Conductivity	mS/cm	109.70	Iron (Fe)	mg/L	156.00
Sulfate (SO_4^{2-})	mg/L	5.00	Manganese (Mn)	mg/L	3.56
Chloride (Cl)	g/L	68.20	Barium (Ba)	g/L	11.01

2. Bioelectrochemical treatment for produced water softening
   Catholye pH reached as high as 11.5 depending on the current intensity applied. Mixing the catholyte with the raw produced water at different ratios resulted in excellent removal of scale-forming cations. Figure 1 shows removal calcium and magnesium for different volumetric mixing ratios (raw produced water:catholyte). Other results of the study include those from miscroscopic and chemical analyses of the precipitated materials and chemical composition evolution in the anode and cathode chambers.

Products

Plan for Next Quarter

The measurement on the core plug samples will continue to obtain a complete set of characteristics. In addition, experiments with Carbon Dioxide or Methane will be initiated to evaluate the adsorption characteristic of the core plugs.

Topic 3 – Deep Subsurface Rock, Fluids, and Gas

Approach

The “Deep Subsurface Rock, Fluids & Gas” team will be responsible for high resolution temporal and/or spatial characterization of the core, produced fluids, and produced gases. The team will use whole and sidewall core and geophysical logs from the science well to conduct various petrophysical analyses to analyze physical rock properties. Data generated by all team members will be integrated to answer following key research questions: 1) geological controls on microbial distribution, diversity and function and how it can effect gas productivity, potential for fracture and pore clogging, well infrastructure and souring 2) major controls on distribution/source/type of organic matter that has implications for oil vs gas production, frackability, restimulation and porosity/permeability effects 3) what are spatiotemporal variations in elemental, isotopic, mineralogical and petrological properties that control presence, geological migration, and modern flow of fluids, water, gases and microorganisms and also effect long-term production behavior of reservoir 4) what are possible water-rock-microbial interactions as a result of injection of fracturing fluids, and 5) does hydraulic fracturing create new pathways for fluid/gas migration

Plan is to develop specific methodology for testing during the next quarter, so that all scientific objectives can be achieved.

Results and Discussion

Accomplishments:

The main focus of this quarter was to start analyzing core, fluid and gas samples collected from the MSEEL site. Members of Sharma's lab group (Dr. Warrier and Mr. Wilson) and Daly from Wirghton's lab group coordinated and supervised all sample collection. Samples were also distributed to research team at OSU and NETL for analysis under different sub-tasks. Several talks and presentations were given at local and regional conferences /universities. Sharma submitted a proposal to Environmental Molecular Sciences Laboratory at Pacific Northwest National Laboratory to conduct kerogen studies

1. <u>Major goals – progress towards</u>

Goal 1: Sample collection and Analysis

Sidewall and Vertical Core

The side wall cores are curated at OSU and WVU. Based on the geophysical logs eight samples were selected from different lithologies i.e. zones where we expect to see maximum biogeochemical variations. Samples were homogenized and distributed among different PI's are currently being processed for biomarker, isotope analysis, elemental analysis, porosity/pore structure, and noble gas analysis and expected to complete by end of summer 2016. The remaining intact and cleaned sidewall cores are archived in Sharma's Lab at WVU and Mouser lab at OSU for future analysis. Cole lab used a zeiss crossbeam 1540 focused ion beam (FIB)/scanning electron microscope (SEM) was used to interrogate a MSEEL sidewall core sample from Marcellus Top (depth 7451.5 feet). These mages reveal differences among organic matter (OM) regions, with regard to pores and mineral associations, including large regions devoid of pores (tens of micrometers, near top of image), and small-scale porous OM intimately associated with pyrite and within packets of phyllosilicates. In addition, they analyzed chips of several of the sidewall cores with the FEI Quanta FEG SEM at SEMCAL, obtaining backscattered electron (BSE) images and EDXS microanalyses. Analyses at SEMCAL of Marcellus Top show the large OM (nonporous) regions are strongly associated with dendritic chlorite, euhedral quartz, and calcite.

For whole core analysis a meeting was held at NETL's Morgantown office and everyone was briefed on how the cores taken from 1 foot interval through the 111 feet of whole were distributed among different research groups. And plan was to start developing method for grinding and processing of these samples to be developed by WVU research group. Drill cuttings have been digested by Hakala's group at NETL and analyzed for major cations to evaluate geochemical trends across the horizontal, and will undergo sequential extraction leaching tests to evaluate their potential for leaching trace metals during different drill cuttings disposal scenarios.

Produced Fluid and Gas

Produced water samples were collected in 5 gallon carboys just after the seperartor every 6 hours first few days of flowback, slowly spacing out daily to weekly/biweekly and currently we are on monthly sampling. The samples were the tranported, filtered and processed in Sharma Laboratory at WVU. All water samples were collected in different containers using different methods/ preservatives etc. specified for different kinds of analysis. All PI's at OSU and NETL and provided their detailed sampling instructions. Dr. Warrier, Wilson from WVU and Daly from OSU were primarirly incharge of sample collection and distribution among different PI's at WVU, OSU and NETL. The collected fluids are curretly being processsed for biomass, reactive chemistry, organic acids, and noble gas and stable isotope analysis at different institutes.

A set of samples is being analyzed by Hakala's group at NETL for major cations, trace metals, and anions, by standard analytical chemistry techniques (ICP-MS, ICP-OES, IC) and results are undergoing analysis. Aliquots of these samples also were tested for the presence of reduced iron and samples are being prepared for Sr and Li isotope analysis. Another set of geochemical analysis was carried out at OSU within 48 hours of sample collection. Reactive geochemistry species, including sulfide, ferrous iron, total dissolved iron, nitrate, nitrite, phosphate and ammonium have been analyzed in the Mouser and Cole lab. OSU group analyzed all of the fluid samples on the ion chromatograph for anions and some organic acids Mouser is curating a master database of geochemistry data, which will be posted to MSEEL by June 2016. Flowback waters are dominated by Cl^-, with Cl^- concentrations ranging from ~ 20,000 to 55,000 ppm Cl. SO_4^{2-} is near detection (~ 1 ppm) in all but the first samples. PO_4^{3-} and NH_3 have been analyzed using the Skalar nutrient analyzer. Phosphate concentrations determined by IC and the Skalar are comparable, ~ 1 to 2 ppm P. Several of the filters from the flow back fluids have been analyzed using the SEM (Figure 1). Results of these show that microbial cells are present, though not as abundant as what was observed in the production wells. In addition SEM studies identified iron-oxyhydroxide precipitates, lithic fragments (mostly quartz, some clay and precipitate from carbonates), barite and barium chloride.

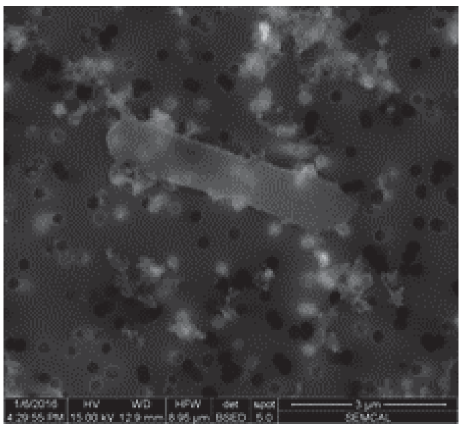


Figure 3.1 Microbial cell and FeOOH precipitate from MIP3H.

The produced gas samples were collected from well heads of the two production wells and transported to Sharma Lab at WVU and analyzed for molecular composition and C/H isotope composition of methane, ethane and CO_2 . Preliminary results of isotope analysis at Sharma lab are listed in Table 1. A duplicate set of gas samples were then sent to Darrah's lab at OSU for

Table 3.1: Carbon isotope and molecular composition of natural gas samples collected from wells 5H and 3H

Well	Sampling date	δ^{13}C Methane (‰ vs PDB)	δ^{13}C Ethane (‰ vs PDB)	Methane (mole %)	Ethane (mole %)	Propane (mole %)
5H	12/10/2015	-36.5	-39.3	96.80	2.45	0.14
	12/12/2015	-36.6	-39.1	97.10	2.50	0.15
	2/3/2016	-36.4	-39.4	97.60	2.40	0.15
3H	12/11/2015	-36.5	-39.1	97.02	2.50	0.15
	12/12/2015	-36.4	In process	97.21	2.46	0.14
	12/13/2015	-36.6	In process	97.09	2.46	0.16

He, Ne, Ar, Kr, and Xe concentration analysis by quadruple mass spectrometry; and helium, neon, and isotopes by noble gas mass spectrometry. Both flow back fluids and produced gas samples have shown low levels atmospheric gases, indicating the acquisition of high quality samples (a known challenge in sampling for noble gases). The samples reflect dominantly crustal composition. Noble gas concentrations range from [^{4}He]= 161-196 μcc/cc); [^{20}Ne]= 0.042-0.078 μcc/cc; [^{36}Ar= μcc/cc]; and the isotopic values range from ^{3}He/^{4}He= 0.016 to 0.024Ra; ^{20}Ne/^{22}Ne=9.467 to 9.681 and ^{21}Ne/^{22}Ne= 0.02893 to .03124; ^{38}Ar/^{36}Ar=0.1875 to 0.1896 and ^{40}Ar/^{36}Ar=296.1 to 462.3).

Goal 2: Test methods biomarker extraction, identification and quantification

Out of the 44 sidewall cores collected from the well 3H 8 cores were selected for analysis. Biomarkers were extracted in Dr. Sharma's lab at WVU. Biomarker identification and quantification is complete. Using an extraction method that was optimized for lipids within the shale matrix, the Mouser and Sharma labs have extracted the phospholipid fatty acids (PLFA's) and diglyceride fatty acids (DGFA's) from 3 different shale cores, including the Mahantango, Marcellus top, and Upper Marcellus. The Mouser lab also extracted lipids from contamination controls to compare with pristine samples, including drilling muds and washes. Data reduction for these 3 cores is currently underway. We expect to present this data at an upcoming conference (e.g. ACS, AGU) and submit two peer-authored manuscripts during 2016-2017 in conjunction on methods development and pristine core analysis.

Goal 3: Microbial DNA analysis and microbial cultivation

The Wrighton lab has extracted microbial DNA from 8 side wall cores and sent all wash samples (375 total samples) to DOE's Joint Genome Institute (JGI) for 16S rRNA gene sequence analysis. Data from this sequencing effort will be curated and available for use by June 2016. Data from contamination control samples will be included in the phospholipid fatty acid presentation and manuscript. Using pristine cleaned core materials the Wilkins lab has set up enrichments in 8 different media types for native microbial communities. Enrichments include carbohydrate fermenters, iron reducing bacteria, sulfate reducing bacteria, acetoclastic methanogens, hydrogenotrophic methanogens, hydrocarbon fermenters, and both aerobic and anaerobic hydrocarbon oxidizers. In addition, three sets of enrichments were performed at both atmospheric pressure and under 8,000 psi using Wilkin's high-pressure culturing equipment. The Mouser/Wrighton/Wilkins labs are triaging enrichments to isolate key bacteria and archaea from flowback fluids. At current, we have several enrichments underway and expect to sequence the genomes of isolates cultured from these fluids. Genome data will enable comparisons with metagenomics data, while the availability of relevant isolates will allow more detailed laboratory physiology studies to understand how such species persist in deep shales.

2. Training/Professional Development?

- PhD. student. V. Agarwal in Sharma lab trained in extraction and XPS/ FTIR analysis of kerogen extracted from the side wall cores
- PhD. Student R. Akondi trained in extraction and analysis of PLFA and DGFA samples extracted from sidewall cores and in using different statistical approaches to represent biomarker diversity

- Ms. Student T. Wilson trained in sample collection for wide range of geochemical and dissolved gas and microbial analysis.
- Agarwal, Wilson, Akondi and gave presentations on their MSEEL work progress

3. Data Dissemination

- Sharma S. 2016, Environmentally Prudent Development of Unconventional Shale Gas: Role of Integrated Field Laboratories. Invited talk at International Shale Gas and Oil Workshop , India, 28-29 January, 2016
- Sharma S. 2016, Role of Geochemistry in Unconventional Resource Development. Invited talk at Appalachian Geological Society Meeting, Morgantown, April 5 2016.
- Hakala, J.A., Stuckman, M., Gardiner, J.G., Phan, T.T., Kutchko, B., Lopano, C. 2016 Application of voltammetric techniques towards iron and sulfur redox speciation in geologic fluids from coal and shale formations, American Chemical Society Fall Meeting 2016 Philadelphia, PA.
- Phan, T.T., Hakala, J.A. 2016. Contribution of colloids to major and trace element contents and isotopic compositions (Li and Sr) of water co-produced with natural gas from Marcellus Shale. American Chemical Society Fall Meeting 2016 Philadelphia, PA.

Plan for Next Quarter

- Sharma lab will be working on preparing and analyzing samples for C/N/S isotopes
- Sharma lab will work on extraction and analysis of biomarkers from selected sidewall and plugs from vertical core
- Sharma lab will work on refining the kerogen extraction method for higher recovery and get trained in new techniques like XPS and FTIR
- Mouser group will continue processing fluid samples from MSEEL wells. Circulate preliminary chemistry data to identify samples for future metagenomics/lipid analysis.
- Students from Mouser and Sharma labs travelled UTK for lipid extraction of sidewall cores.
- Mouser/Wrighton/Wilkins labs are triaging enrichments to isolate key bacteria and archaea from flowback fluids.
- Cole lab will continue FIB/SEM analysis to provide 3-D rendering of the material to assess the distribution of minerals, organic matter, and pores. The SEMCAL SEM work will further inform this by adding mineral microanalysis (high resolution BSE, EDXS) to distinguish minerals and their associations with OM and pores.
- Darrah lab will work on analysis of argon, krypton, and xenon isotopes by high resolution, high precision noble gas mass spectrometry in the near future.

Topic 4 – Geophysical and Geomechanical

Approach

Team will conduct microseismic analyses during the frac jobs of the production wells and tie that data back to the geophysical logs obtained from the science well, providing a clearer picture of proppant placement through the establishment of a detailed rock velocity model. Some inferences toward fracture quantity and patterns will also be vetted.

Plan is to identify specific methodology to obtain the data that will provide most understanding of subsurface rock model

Results and Discussion

Task 4a - Geophysics:

The effort this past quarter involved: 1) The structural model of the area was refined using data provided by NNE; 2) Several additional simulation tests were conducted; 3) this included testing of several discrete fracture models; 4) indications of stress shadowing effects based on ISIPs were evaluated; 5) a stress gradient was introduced in the model to produce asymmetry in the stimulation; 6) paper was prepared for the 2016 Dallas SEG meeting.

FY16 effort to date: 1.3 FTE months.

Summary

This past quarter (see also Wilson et al., in prep.), we took a preliminary look at microseismic data collected along the length of two Marcellus shale horizontal wells (the 3H and 5H) drilled by Northeast Natural Energy LLC (NNE) in Morgantown, West Virginia. We incorporated detailed log data along the length of the 3H that provided a wealth of information concerning geomechanical properties, fracture trends and fracture intensity variations. Preliminary interpretation of the microseismic cluster trends revealed orientations on average of about N59°E. Image logs in the vertical pilot well reveal similar average open fracture trend of ~N58°E along with an average healed fracture trend of ~N88°E. The orientation of S_{Hmax} estimated from induced fractures observed in the vertical pilot well is ~N57°E, while that from breakouts is about N64°E. The majority of the induced fractures are observed in the Marcellus, while the breakouts are largely observed about 2000 feet above the Marcellus. Image logs collected along approximately 7400' of lateral provided additional insights into the fracture network within the Marcellus target zone. Over 1600 fractures were interpreted by the Schlumberger analyst. The distribution was unimodal with average fracture trend of N78°E. Along the length of the lateral, average trends of fracture clusters varied from about N64°E to N110°E.

S_{hmin} in the area is approximately 6500 psi with horizontal stress anisotropy of between 100 to 400psi in agreement with the acoustic scanning platform data. The vertical stress (S_v) is approximately 8800psi. Asymmetry in the microseismicity associated with the well is interpreted to be associated with a drop in S_{hmin} toward the 5H well located northeast. Hydraulic fracture stimulation of the local fracture network along the 3H well required introduction of a negative horizontal stress gradient in S_{hmin} northeast towards the 5H well that was treated a few days earlier to produce observed asymmetry in the microseismic distribution. Variation in stage-to-stage shut-in pressures did not suggest significant stress shadowing or increase in S_{hmin} stage-to-stage (see Nagel et al., 2013a and b) toward the heel or between wells.

In this initial look at the microseismic data, model fracture stimulation patterns are compared to microseismicity from a single stage along the 3H lateral. Initial uncalibrated MEM and stochastic based DFN models suggest that the observed microseismic event trends require interaction of the local N83°E fracture set observed in the image log along the horizontal wellbore in this area with a more regional, ~N59°E, fracture set. Although the inferred N59°E set is not prominent in the image log interpretations in the target landing zone, it is a prominent open fracture set in the vertical pilot well and its presence appears to control microseismic event trends and natural fracture stimulation at the site. This set appears to provide tensile conduits that channel fluids into and facilitate microseismically audible rupture of east-northeast fractures that are observed in the vicinity of the stage and that fail through shear.

Introduction

The study area is located in the central Appalachian foreland near Morgantown, WV (Figure 1). The focus of the study is on two horizontal wells drilled about 7000 feet through an organic rich zone near the base of the Marcellus shale along an approximate N36^{o}W heading (Figure 2). Breakouts and induced fracture trends measured in an image log from the vertical pilot well provide information on the orientation of S_{Hmax}. The induced fracture trends are consistent with an approximate S_{Hmax} trend of N57^{o}E. The 3H lateral (Figure 2) also had image logs run along its entire length. The histogram of natural fracture trends intersected along the length of the lateral has a mean orientation of about N78^{o}E±18^{o}. Fracture trends are generally concentrated between N40^{o}E and N130^{o}E.

Figure 4.a.1: Location of the study area, Morgantown, West Virginia.

Interpretation of the image log from the vertical pilot well revealed the presence of both open and healed natural fractures. The open fractures have average N58^{o}E trend, while the healed fractures have average N88^{o}E trend (Figure 3).

Interpretation of microseismic cluster trends, cluster-by-cluster, for several stages (e.g. Figure 4) suggested an average cluster trend of about N59ºE. This trend nearly coincides with the average open fracture trend observed in image logs from the vertical pilot well.

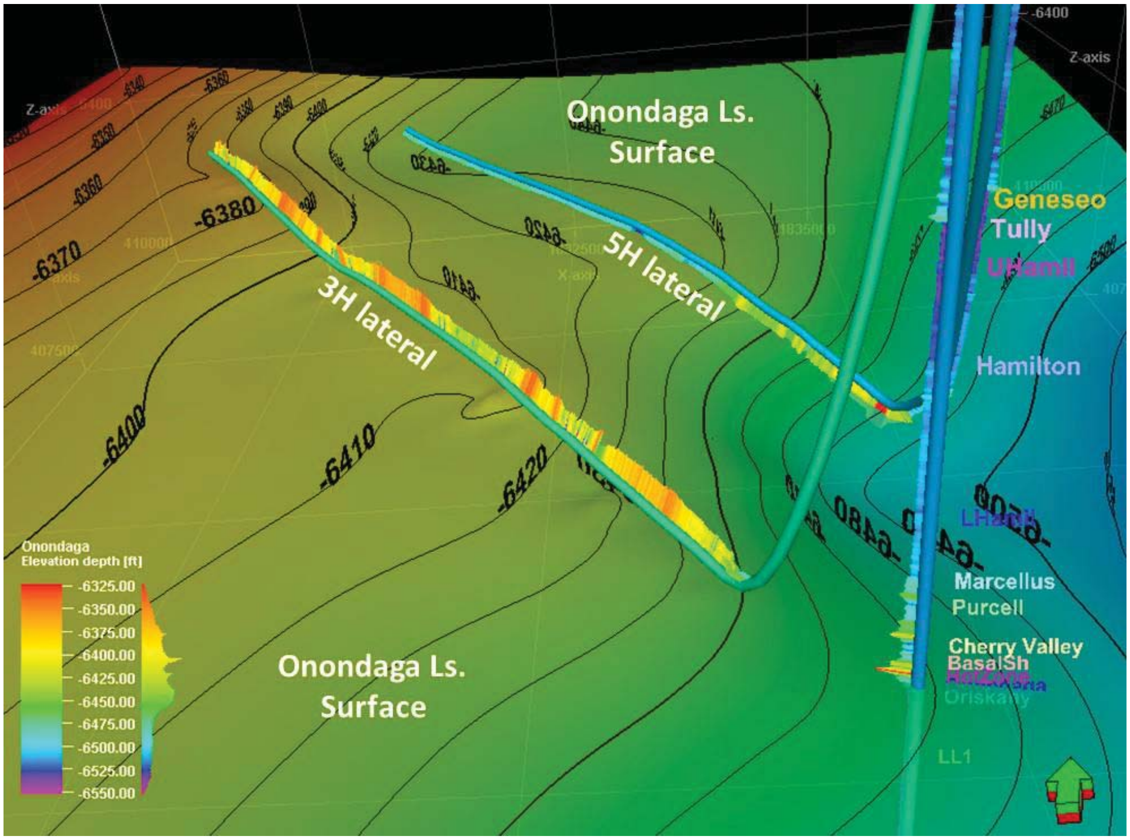


Figure 4.a.2: The Marcellus shale wells (3H and 5H) located on the Morgantown NNE LLC site. Structure on the Onondaga Ls. surface is shown and coincides with structure on the base of the Marcellus.

Reservoir Fracture network and initial stimulation

Completion design, treatment fluids, proppant and pump schedules were provided by NNE and used to constrain the model stimulations. Model discrete fracture networks (DFNs) were designed for individual stages at certain distances along the length of the lateral. The initial DFN incorporated a single fracture set with mean trend of N83ºE inferred from image log observations in the vicinity of this stage (Figure 3A).

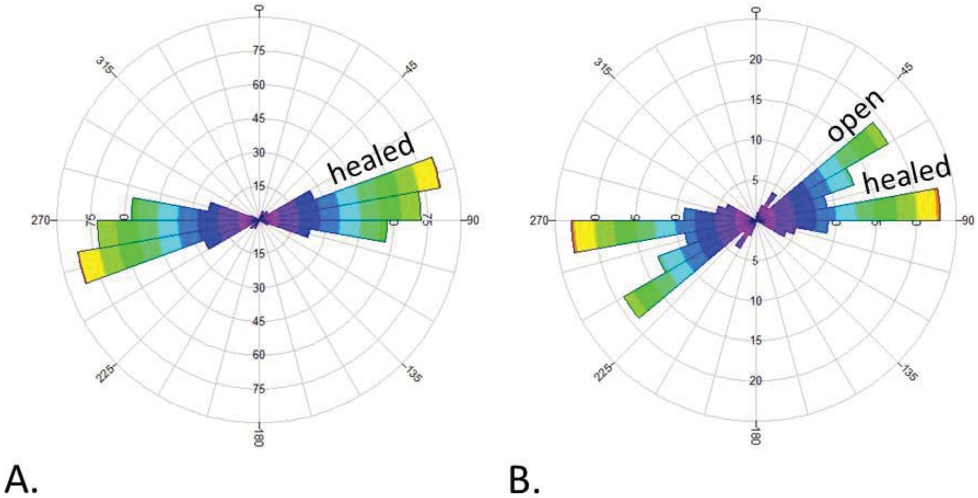


Figure 4.a.3: Fracture trends observed along the lateral and vertical pilot wells. A) Healed fractures observed along the 3H lateral in the vicinity of the stage modeled in this study. B) Orientations of open and healed fractures observed in the vertical pilot well.

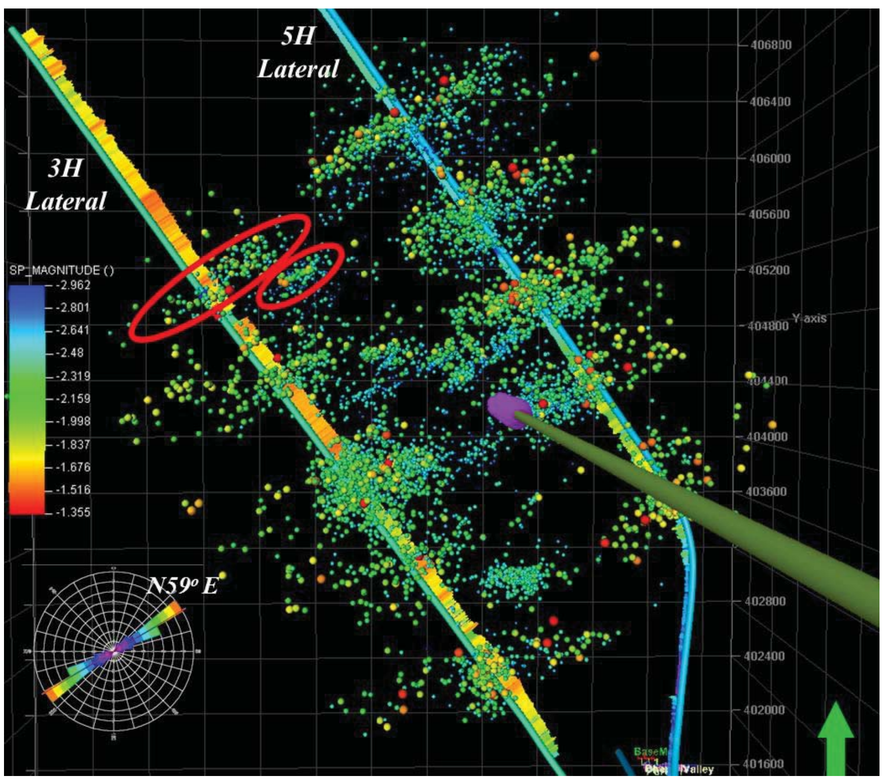


Figure 4.a.4: Microseismic events from select stages along the length of the NNE 3H and 5H laterals. Events are colored by magnitude. Rose diagram of microseismic event trends shown lower left.

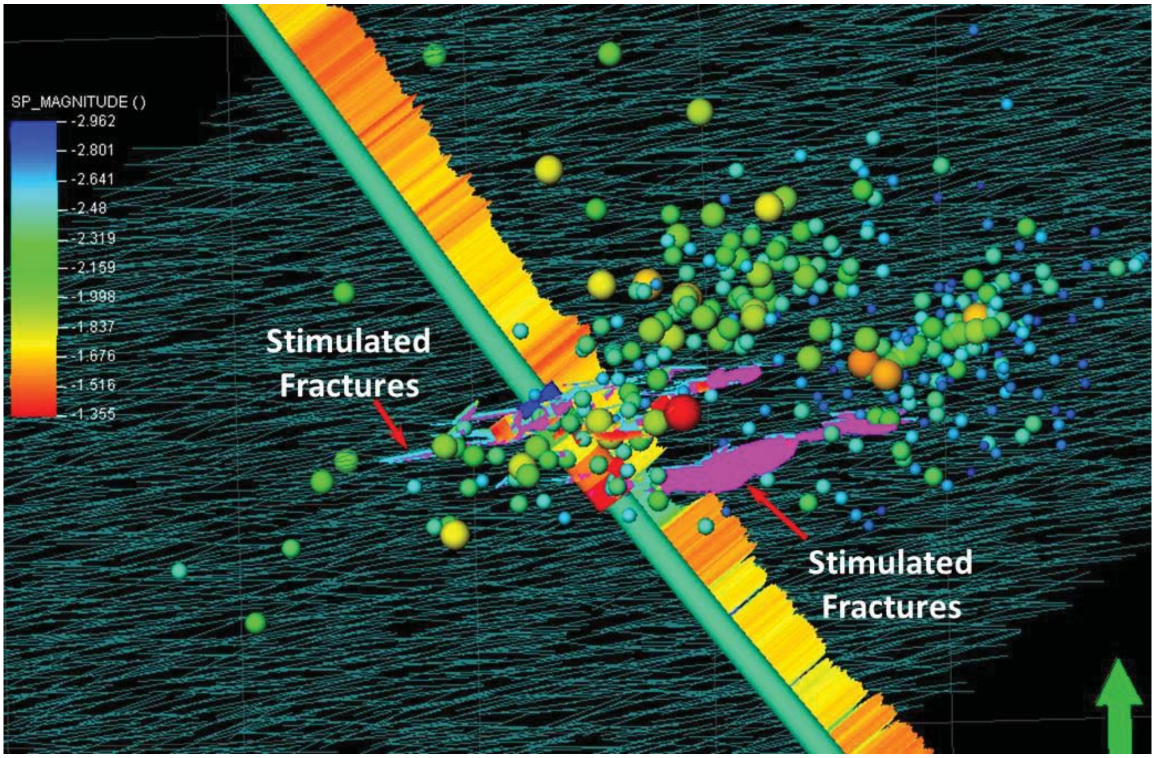


Figure 4.a.5: Fracture stimulation conducted for a DFN consisting of the single N83ºE set inferred from image logs through the reservoir in the vicinity of this stage. The microseismic events shown here are circled in Figure 4. They are colored and sized by magnitude.

An initial model stimulation test (Figure 5) incorporated a DFN based on the single N83ºE fracture set observed in this area along the lateral. The model stimulation revealed little correlation between the distribution of microseismic and stimulated fracture distribution (Figure 5). Stimulated fractures varied from symmetric, relative to the perforation clusters, to asymmetric to the east. The extent of stimulation into the surrounding reservoir was limited to about 500 feet, whereas microseismicity extended out more than 1000 feet from the perforation cluster.

The generation of microseismic events along the N59ºE trend (the approximate orientation of S_{Hmax}) requires the presence of a fracture set in the reservoir that facilitates interconnection to fractures that undergo shear failure and produce audible microseismic events. Incorporation of this trend is supported by observations in the vertical well that reveal presence of an open fracture set with ~N58ºE trend (Figure 3).

Hydraulic fracture stimulation tests

Fracture stimulation tests were simulated for a variety of cases using a two-set DFN which consisted of N50ºE to N59ºE sets and the N83ºE set (e.g. Figure 6) but in all cases the stimulation failed to produce fracture rupture in the vicinity of the offset cluster located to the east of the main cluster (Figure 4). This was also the case when the 2D fracture grid used in the simulation was extracted from a 3D fracture network that was designed using microseismic event density recorded during treatment (Figure 6B & C).

The vertical pressure at reservoir depths (S_v) is about 8800 psi. The average injection pressure for the stage investigated in this study was approximately 8250psi. The minimum horizontal stress along the lateral is about 6500psi. The stress anisotropy (S_{Hmax}-S_{hmin}) ranged between 100 to 400 psi and the orientation of S_{Hmax} was varied from N55ºE to N65ºE. While fracture rupture in some models was diverted to the east toward the second cluster (e.g. Figure 6A), extension into the detached cluster of microseismicity was not achieved. However, within the main cluster, we do see shear failure along the distributed fracture network with some branching to the east. Failure was modeled using a coefficient of friction (μ) along pre-existing fractures of 0.6 and that are assumed to be critically stressed with cohesion (S_o) of 0 (e.g. Zoback, 2007).

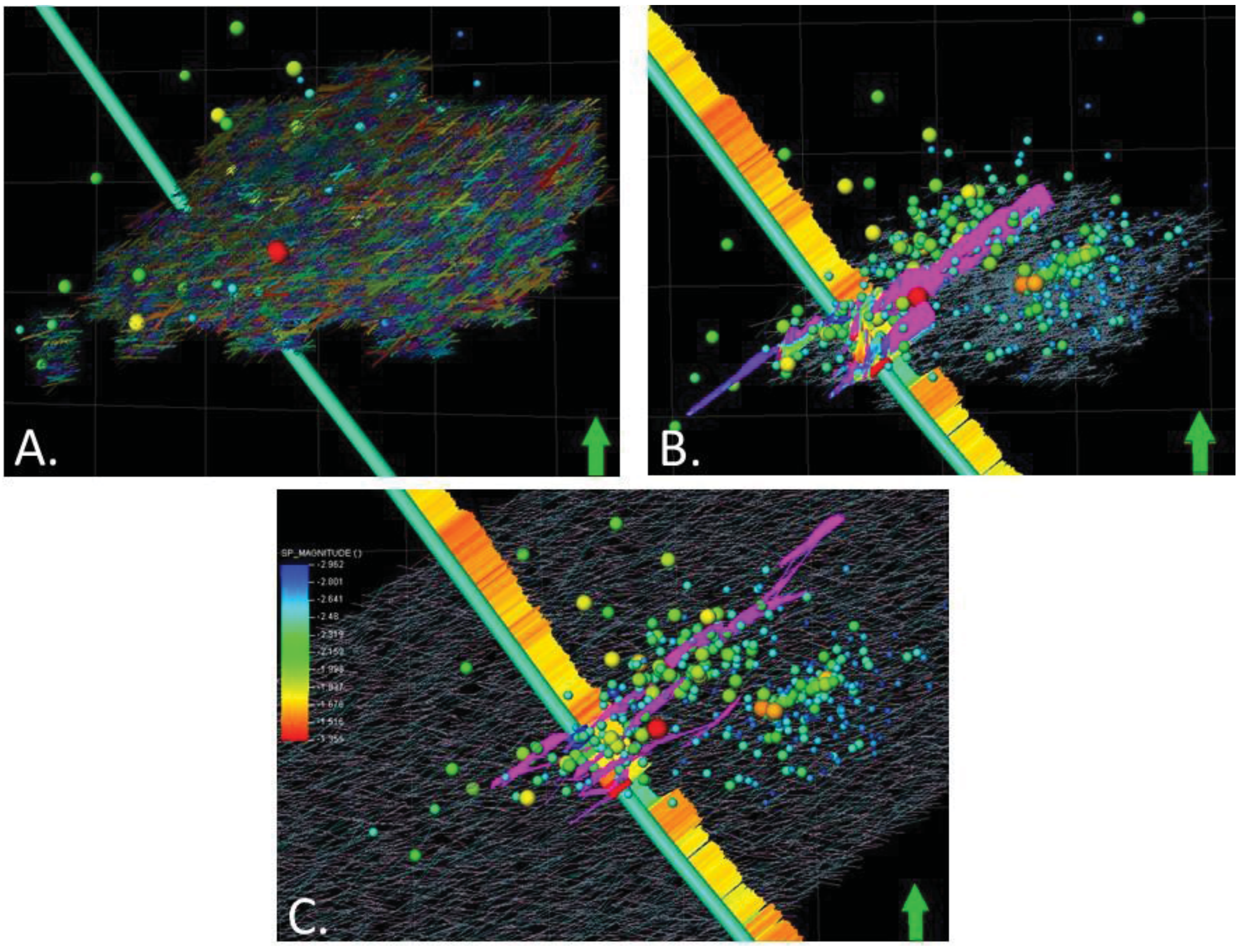


Figure 4.a.6: Stimulation test runs: A) model 3D DFN derived from microseismic event density; B) stimulation of 3D network viewed at the level of the perforations C) S_{Hmax} orientation of N55ºE is close to that of the induced fracture orientations in this more regional DFN.

Discussion

The hydraulic fracture is generally considered to be microseismically quiet (Maxwell, 2011; Lee et al., 2014). The formation of the hydraulic fracture is a low frequency process where the power related to fluid injection is dominated by spectral periods of approximately an hour duration that are not audible at the much higher seismic monitoring frequencies of the sensors used to record microseismic events (Maxwell, 2011).

In this study, S_{Hmax} is oriented very close to the open fractures observed in the vertical pilot well, while the healed fractures are oriented on average at about 18^{o} to 28^{o} east of S_{Hmax}. Maxwell (2011) proposed two speculative models to explain possible interactions of the hydraulic fracture 1) with subparallel natural fractures and 2) with nearly orthogonal natural fractures. In the present case, the natural fractures include a set generally subparallel to the anticipated orientation of the hydraulic fracture. Those most likely to fail in the vicinity of the stimulation test were estimated using the Coulomb failure criterion to have an average orientation of about N82^{o}E. A similar average of N85^{o}E was found for the healed natural fractures most likely to fail that were observed in the vertical pilot well.

The interpreted average microseismic cluster trend of ~N59^{o}E may develop easily out along the open natural fractures observed in the pilot well. The N59^{o}E fractures likely undergo tensile failure, while the sub-parallel healed fractures will likely rupture in response to shear. This network of intersecting open and healed natural fractures may facilitate and help extend stimulation of the reservoir away from the main hydraulic fracture.

Rutledge et al. (2004) also observed microseismic events produced by rupture of natural fractures subparallel to S_{Hmax} in the Carthage Cotton Valley Gas Field, Texas. Analysis of Cotton Valley events produced during treatment presented by Fisher and Guest (2011) revealed the presence of tensile failure along natural fractures oriented at less than 10o with S_{Hmax} and shear failure on natural fractures oriented at about 30^{o} to S_{Hmax}.

In addition to the trend of microseismic clusters in the area, the asymmetry of the clusters in the stage investigated in this study is pronounced (figures 4, 5 and 6). The sub-cluster is also offset and displaced entirely east-northeast of the lateral. While the main cluster extends a short distance southwest of the lateral it is largely distributed in the region to the northeast (e.g. Figure 6A). Producing asymmetry in the stimulated natural fracture network shown in preliminary models required introduction of a drop of S_{hmi}n in the N60^{o}E direction. We speculate that the pressure disturbance associated with earlier treatment of the 5H lateral may have brought critically stressed fractures closer to failure making them easier to rupture. We also note that the local structure (Figure 2) deviates from the regional structural trend in the area of approximately N30oE into a northwesterly, nearly cross-strike trend. The local structure between the two laterals takes a bend toward the north and northwest and drops down to the east from the 3H to 5H laterals. The perturbation in local structure suggests that a local tear fault may cut through the area and weaken the strata and local fracture network across it. This asymmetry is more common toward the toe of the laterals.

Conclusions

In this study we model stimulation of the local natural fracture network for a single stage along a Marcellus gas horizontal production well in the central Appalachian foreland of West Virginia. Models are developed to replicate features resulting from stimulation of this stage. Overall, microseismicity observed during stimulation of the two parallel laterals in this study has similar cluster trends with ~N59^{o}E average trend.

Detailed interpretation of the image log run along the 3H lateral reveals natural fractures with average trend of N78^{o}E. Within the vicinity of the stage modeled in this study, fractures observed in the image log have average trend of about N83^{o}E. Model stimulation of a discrete fracture network consisting of this single set produces stimulation symmetrically distributed across the lateral with ~N83^{o}E trend. The initial model does not replicate the ~N59^{o}E microseismic cluster trend or northeast cluster asymmetry about the lateral.

Although much more limited in numbers, natural fractures observed in the vertical pilot well consisted of two sets. The majority of open fractures observed in the vertical well have average trend of ~N58^{o}E with the majority of healed fractures oriented ~N88^{o}E. Preliminary model simulations incorporating the N58^{o}E set along with the N83^{o}E set observed along the lateral yielded model stimulation of the DFN with the NE microseismic trend. Northeast cluster asymmetry suggests the presence of a gradient in Shmin that drops northeast toward an adjacent well that and may be tectonic in origin.

We conclude that although the ~N59^{o}E set of fractures has limited expression along the length of the lateral through the target zone, its presence in significant numbers is required to produce the ~N59oE microseismic cluster trends and to facilitate significant branching through shear into intersecting healed fractures with the more easterly trend. This network of intersecting fractures facilitates reservoir stimulation away from the main hydraulic fracture.

Task 4b - Geomechanical:

During this quarterly period, numerical modeling simulations were conducted to investigate the influence of fluid injection rate, fluid injection volume, and proppant mass on hydraulic fracture geometry. The mesh size of the proppant used was 40/70. Slickwater fluid was used for all injection scenarios. The depth of the Marcellus shale was assumed to be 8,200 feet below the ground surface, and the Marcellus shale thickness was assumed to be 100 feet thick in all injection scenarios. Four simultaneously propagating hydraulic fractures were assumed for each simulated stage. Table 1 shows the numerical modeling simulations performed.

Table 4.b.1: Numerical Modeling Simulations Performed

Fluid Injection Rate (BPM)	Fluid Injection Volume (U.S. Gallons)	Proppant Mass Injected (lbm)
70	400,000	500,000
80	400,000	500,000
90	300,000	400,000
90	400,000	500,000
90	500,000	600,000
100	400,000	500,000
110	400,000	500,000
120	400,000	500,000

These 9 simulation scenarios were developed and carried out using numerical modeling software. Figure 1 shows the influence of the fluid injection rate on the hydraulic fracture lengths for the scenarios using 400,000 U.S. Gallons of fluid and 500,000 lbm of proppant. As the fluid injection rate increases, the hydraulic fracture length generally increases. Figure 2 shows the influence of fluid injection rate on hydraulic fracture height for the scenarios using 400,000 U.S. Gallons of fluid and 500,000 lbm of proppant. As the fluid injection rate increases, the hydraulic fracture height generally increases. Figure 3 shows the influence of the fluid injection rate on the average hydraulic fracture width for scenarios using 400,000 U.S. Gallons of fluid and 500,000 lbm of proppant. As the fluid injection rate increases, the average hydraulic fracture width generally decreases. Figure 4 shows the influence of fluid injection volume on hydraulic fracture length. For the fluid injection volumes of 300,000, 400,000, and 500,000 U.S. Gallons, proppants masses of 400,000, 500,000, and 600,000 lbm were used, respectively. As the fluid injection volume increases, the hydraulic fracture length increases. Figure 5 shows the influence of fluid injection volume on hydraulic fracture height. As the fluid injection volume increases, the hydraulic fracture height increases. Figure 6 shows the influence of fluid injection volume on average hydraulic fracture width. As the fluid injection volume increases, the average hydraulic fracture width increases. Hydraulic fracture width contours and profiles are shown in Figure 7 through Figure 14 for the injection scenarios presented in Table 1.

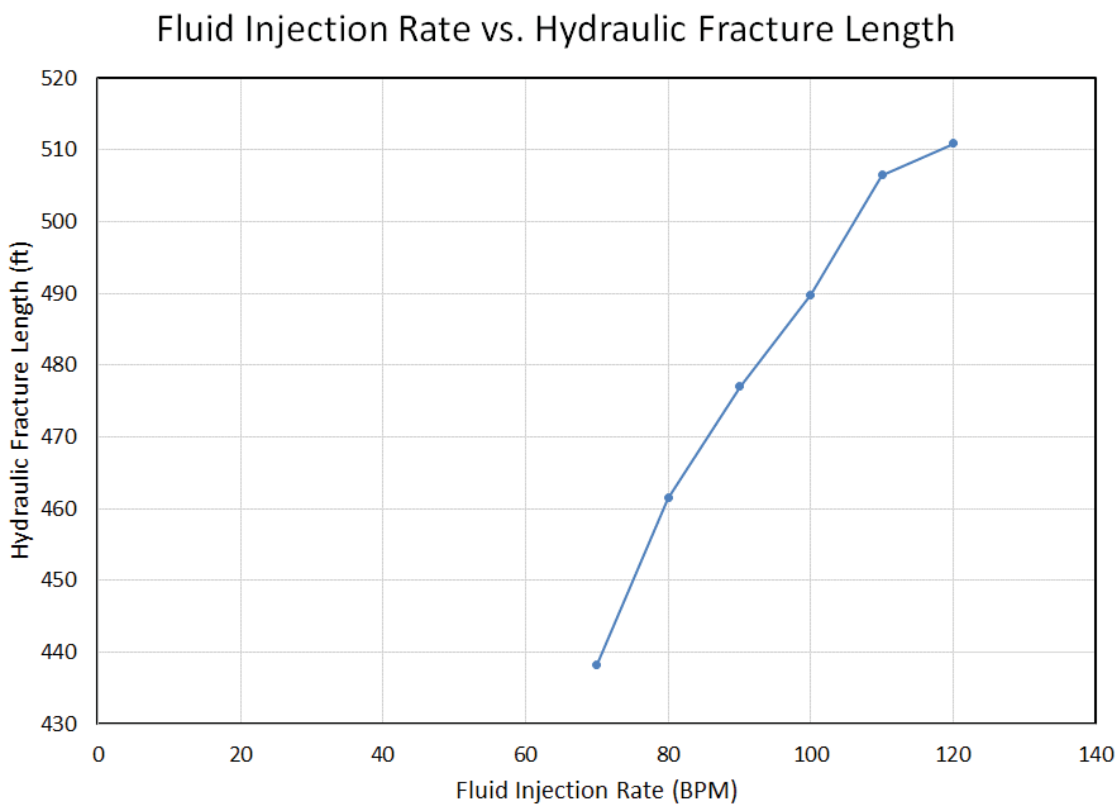


Figure 4.b.1: Influence of Fluid Injection Rate on Hydraulic Fracture Length

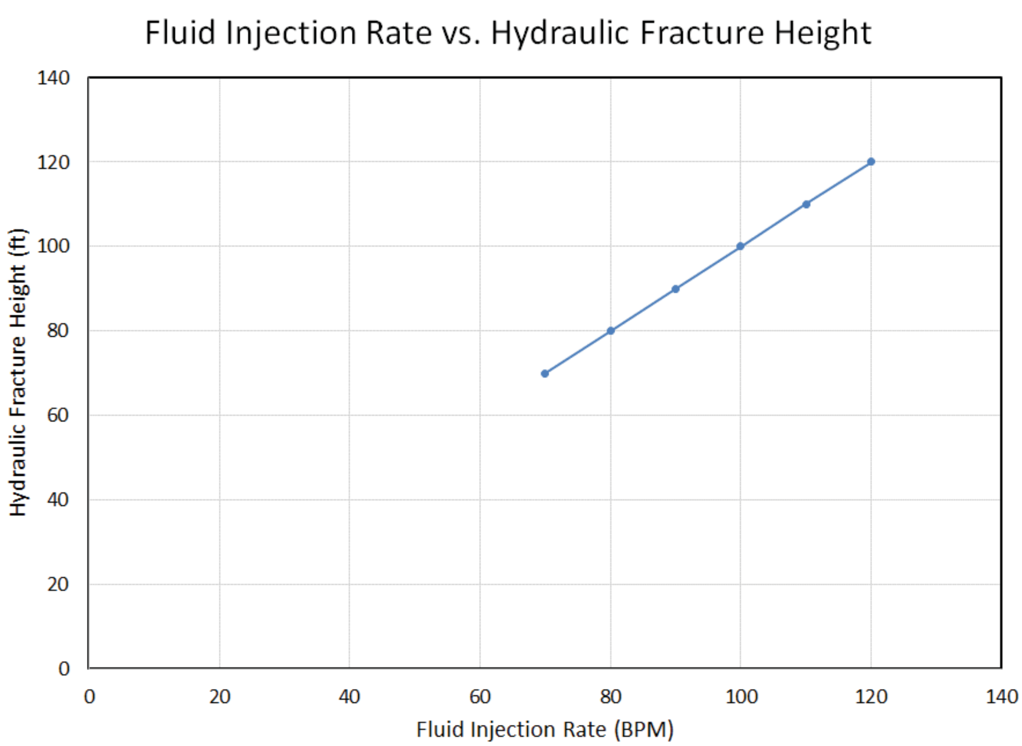


Figure 4.b.2: Influence of Fluid Injection Rate on Hydraulic Fracture Height

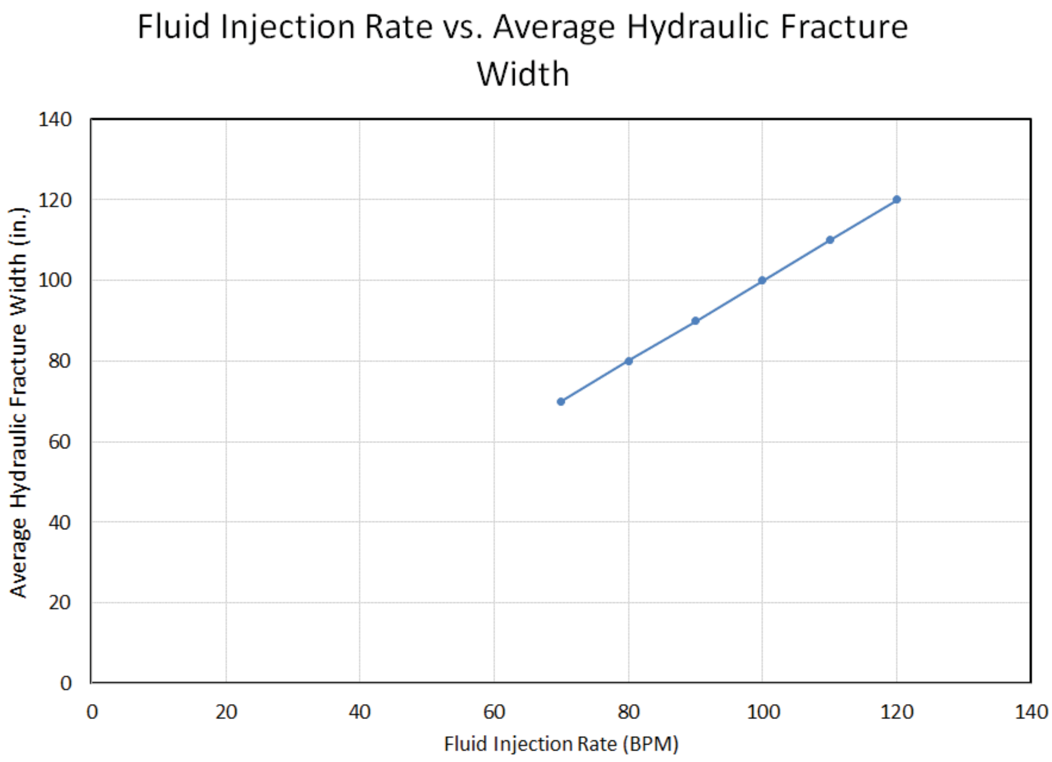


Figure 4.b.3: Influence of Fluid Injection Rate on Average Hydraulic Fracture Width

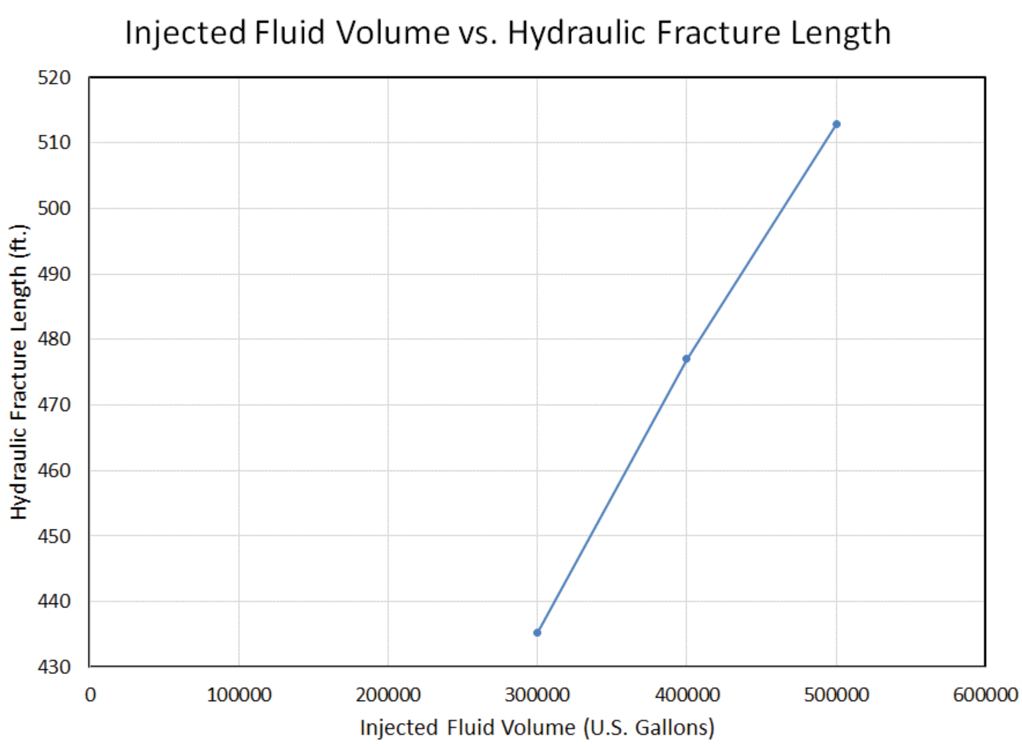


Figure 4.b.4: Influence of Fluid Injection Volume on Hydraulic Fracture Length

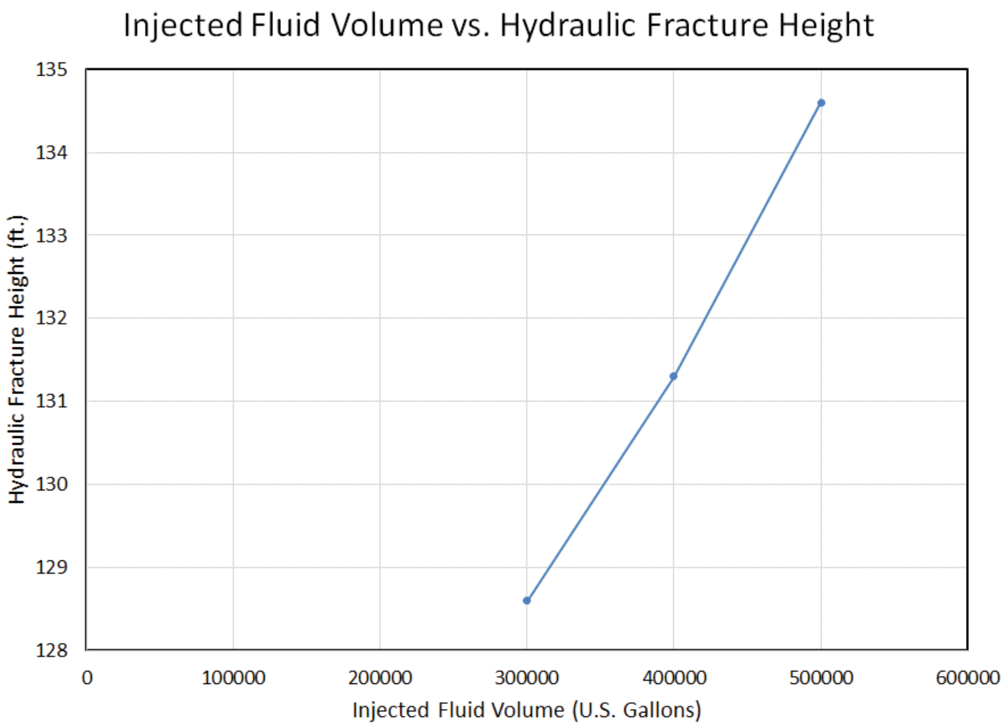


Figure 4.b.5: Influence of Fluid Injection Volume on Hydraulic Fracture Height

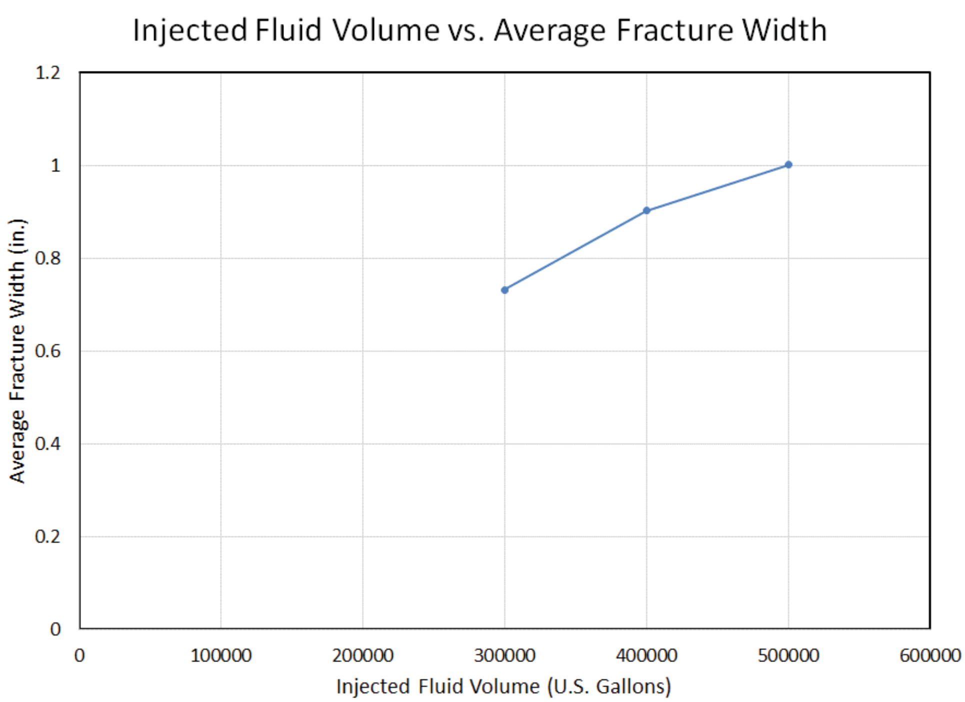


Figure 4.b.6: Influence of Fluid Injection Volume on Average Hydraulic Fracture Width

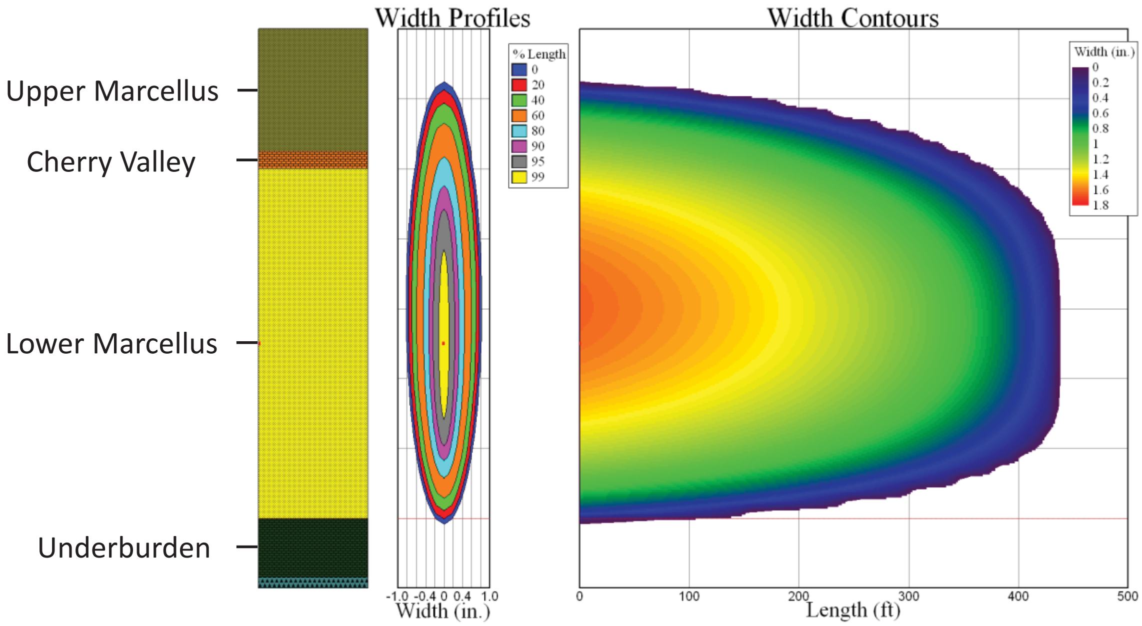


Figure 4.b.7: Fracture Width Profiles and Contours for the 400,000 U.S. Gallon Fluid, 500,000 lbm Proppant, and 70 BPM Injection Rate Scenario

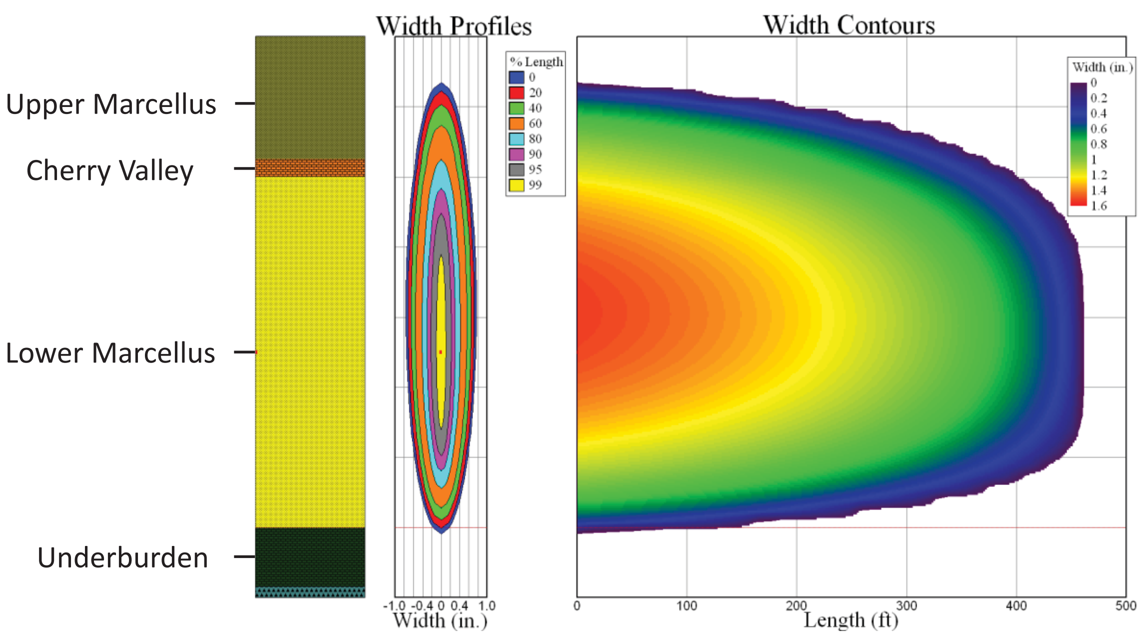


Figure 4.b.8: Fracture Width Profiles and Contours for the 400,000 U.S. Gallon Fluid, 500,000 lbm Proppant, and 80 BPM Injection Rate Scenario

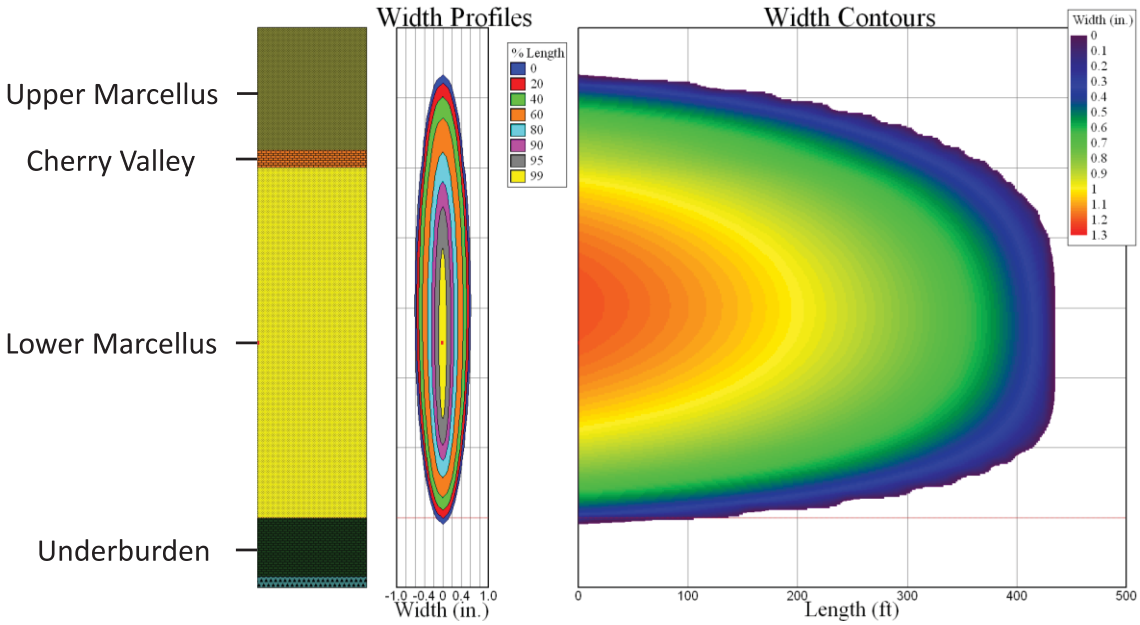


Figure 4.b.9: Fracture Width Profiles and Contours for the 300,000 U.S. Gallon Fluid, 400,000 lbm Proppant, and 90 BPM Injection Rate Scenario

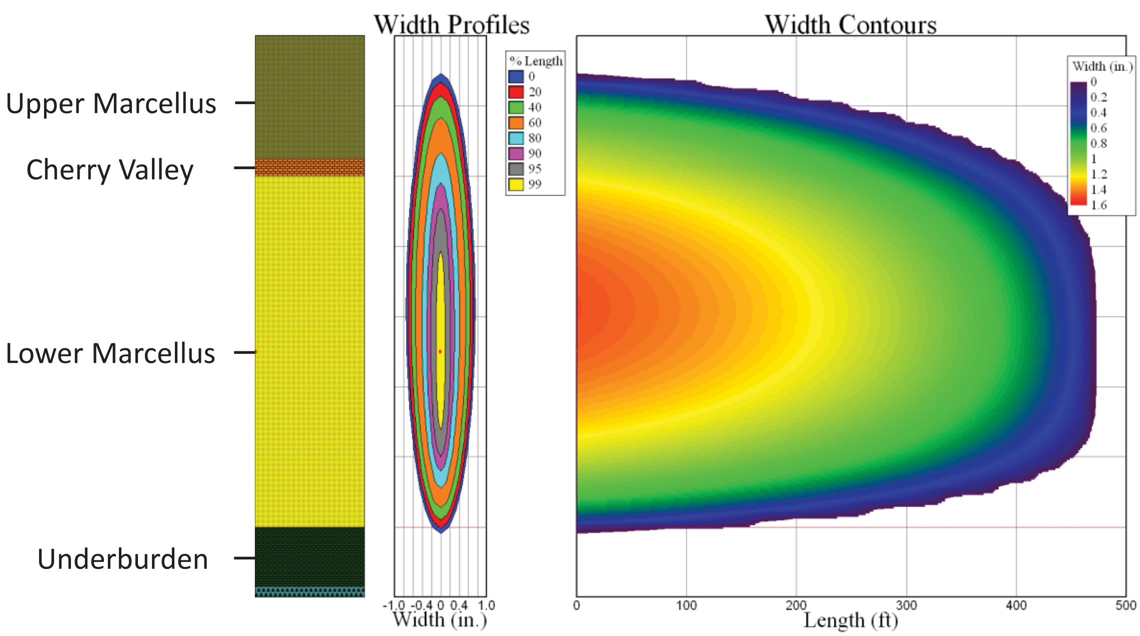


Figure 4.b.10: Fracture Width Profiles and Contours for the 400,000 U.S. Gallon Fluid, 500,000 lbm Proppant, and 90 BPM Injection Rate Scenario

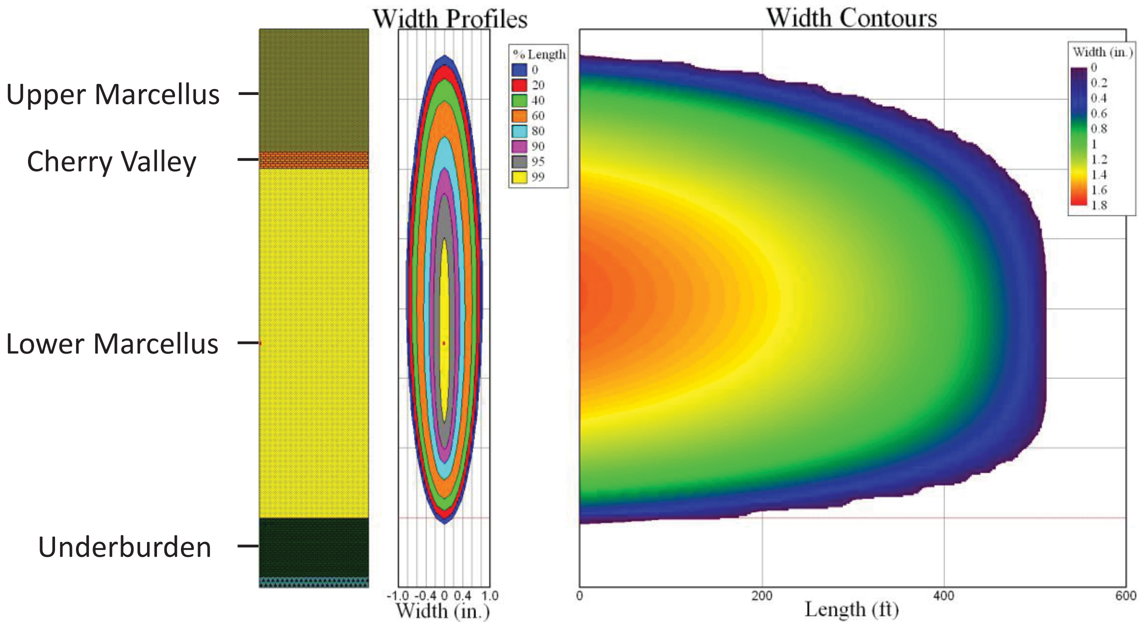


Figure 4.b.11: Fracture Width Profiles and Contours for the 500,000 U.S. Gallon Fluid, 600,000 lbm Proppant, and 90 BPM Injection Rate Scenario

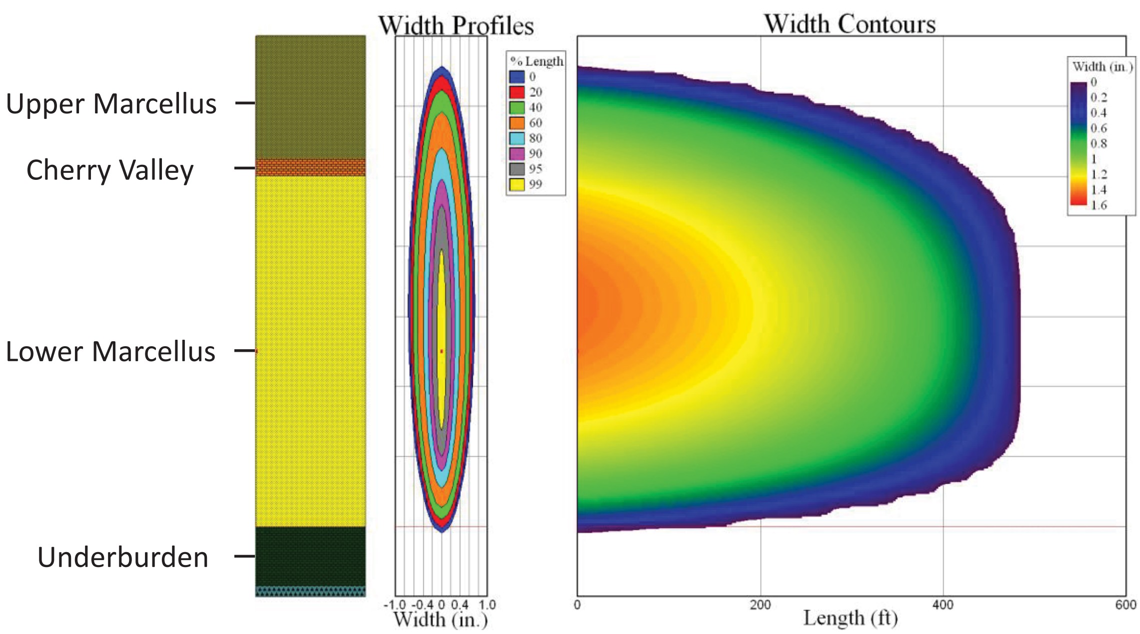


Figure 4.b.12: Fracture Width Profiles and Contours for the 400,000 U.S. Gallon Fluid, 500,000 lbm Proppant, and 100 BPM Injection Rate Scenario

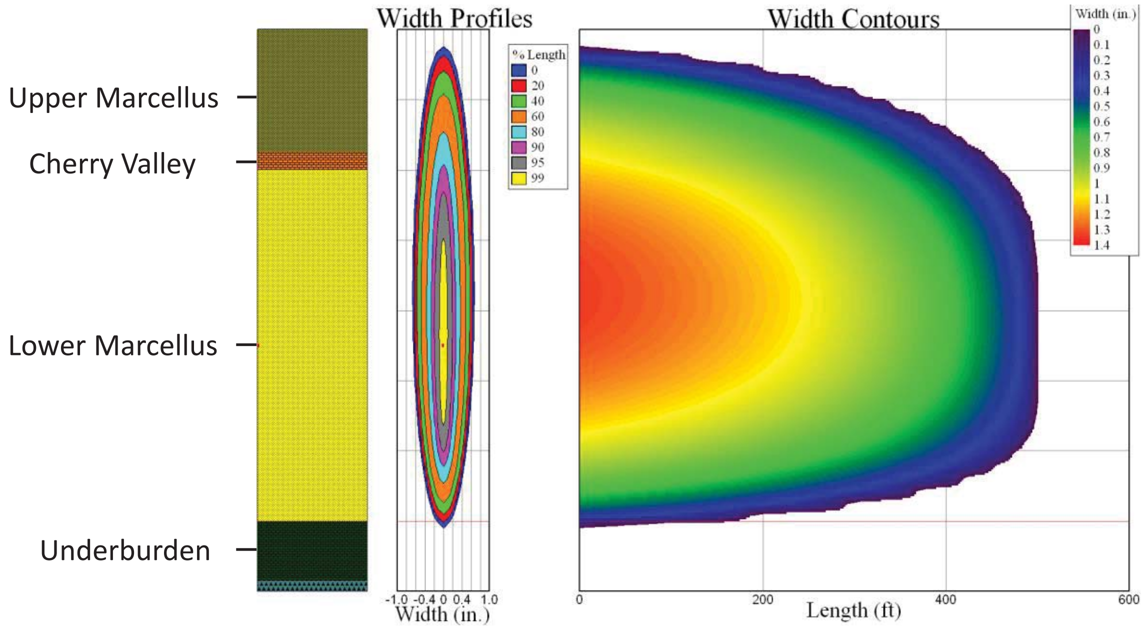


Figure 4.b.13: Fracture Width Profiles and Contours for the 400,000 U.S. Gallon Fluid, 500,000 lbm Proppant, and 110 BPM Injection Rate Scenario

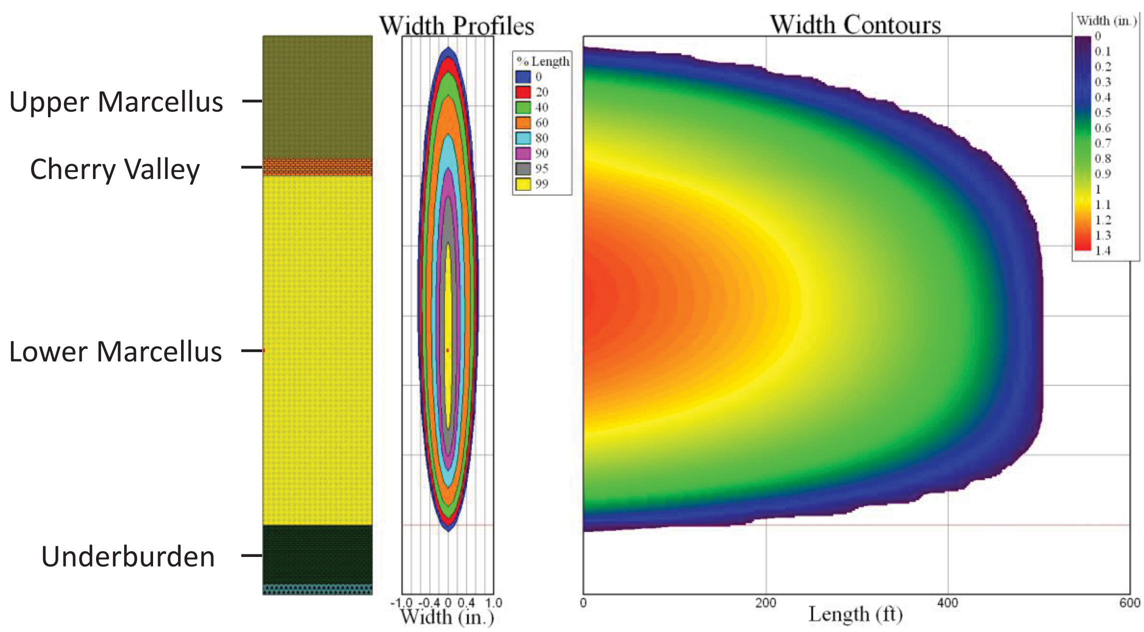


Figure 4.b.14: Fracture Width Profiles and Contours for the 400,000 U.S. Gallon Fluid, 500,000 lbm Proppant, and 120 BPM Injection Rate Scenario

Products

Plan for Next Quarter

Task 4a – Geophysical:

Much of the following depends on available funding and student assistance.

1) The following paper will be submitted for review for inclusion in in the 2016 SEG meeting volume of expanded abstracts:

Thomas H. Wilson and Tim Carr, West Virginia University; B. J. Carney, Jay Hewitt, Ian Costello, Emily Jordon, Northeast Natural Energy LLC; Keith MacPhail, Oluwaseun Magbagbeola, Adrian Morales, Asbjoern Johansen, Leah Hogarth, Olatunbosun Anifowoshe, Kashif Naseem, Natalie Uschner, Mandy Thomas, Si Akin, Schlumberger, in prep.: **Microseismic and model stimulation of natural fracture networks in the Marcellus Shale, West Virginia,** 5p.

2) Additional experiments will be designed and incorporated into the zone set property grid as part of continued efforts to model fracture stimulation of reservoir intervals and better understand microseismic activity associated with HFT.
3) Fiber optic observations will be incorporated in the model studies noted in 1 and 2 above.
4) Direct geophysics student (if student and funds available) in the analysis of b-values stage-by-stage following the format of efforts undertaken by Zhu, Y., T. Wilson, P. Sullivan, 2016 (submitted) - Variations of microseismic b-values and their relationship to 3D seismic structure in the Marcellus Shale: Southwestern Pennsylvania: submitted for presentation at the 86th Annual International Meeting, SEG in Dallas, TX., 5p.

5) Direct geophysics student (if funding and student available) to assist with additional stage-by-stage simulations.

6) Use calculated seismic moment for microseismic events observed along the 3H and 5H wells to develop stage-by-stage 3D function to distribute intensity of stimulated fractures following the efforts of Wilson and Sullivan (submitted) - Microseismic energy density and event trend constraints on model DFN development for hydraulically fractured reservoirs: Marcellus shale, southwestern Pennsylvania, U. S. A.: submitted for presentation at the 86th Annual International Meeting, SEG in Dallas, TX, 5p.

Task 4b - Geomechanical:

Information on the hydraulic fracturing field parameters (fluid volumes, pumping rate, proppant schedule, and geophysical data) from the field operations will be incorporated into the modeling study. A comparison of fracture geometries will be made with available microseismic data.

Topic 5 – Surface Environmental

Task 5a – Surface Environmental – Water

Approach

Surface water baseline sampling was conducted in June at the three points selected along the Monongahela River. Based on the timeline for gas well development being shortened and activities moved up, two separate sampling events were conducted. Figure 5.1 shows the locations of sampling points MR-1, MR-2, and MR-3 in red with the Northeast Energy site indicated in purple.

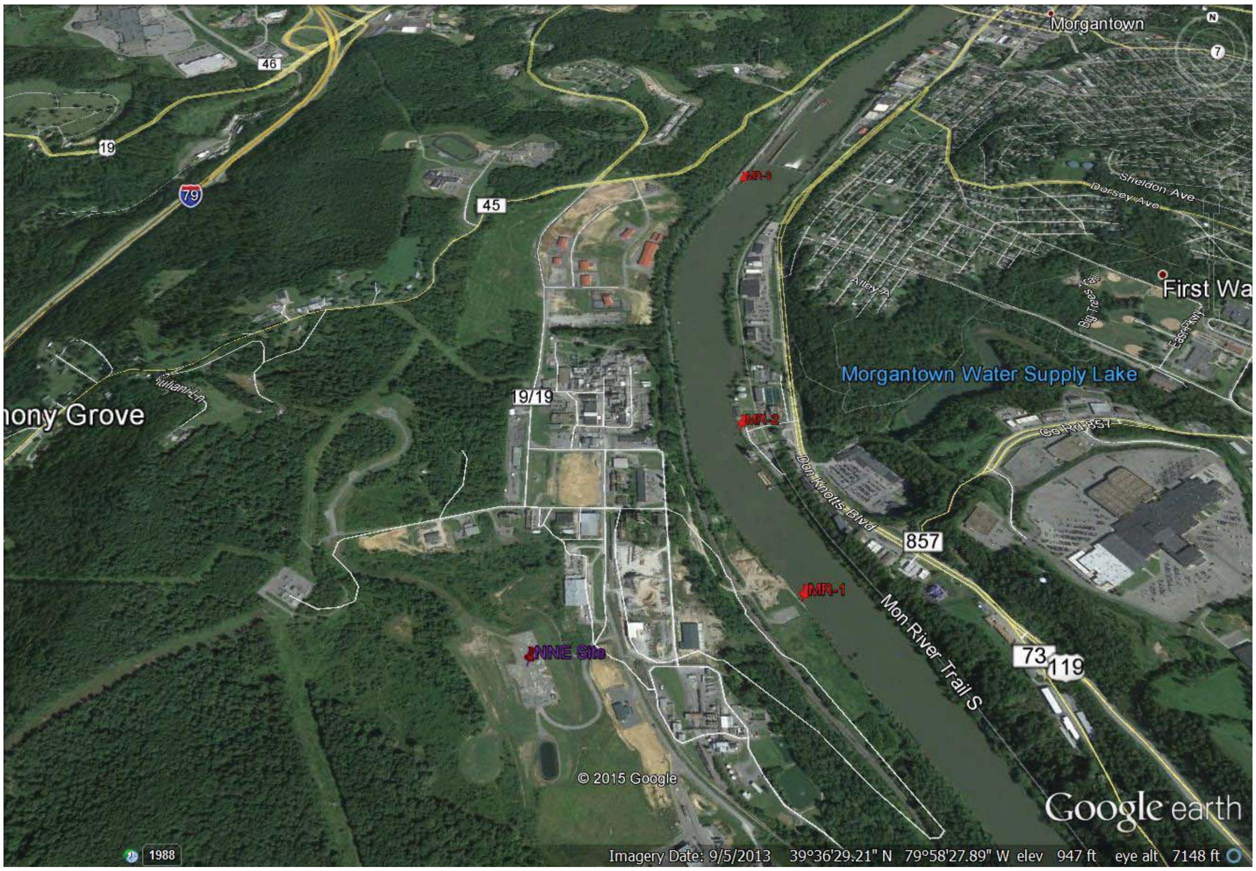


Figure 5.a.1: MSEEL surface water sampling locations

The sampling schedule for surface water and gas well development water/waste streams is detailed in Table 5.a.1.

Table 5.a.1: MSEEL sampling schedule

	Freshwater		Aqueous/Solids: drilling/completion/production									
	Mon River	ground water	HF fluid makeup	HF fluids	flowback/ produced	drilling fluids	drilling muds*	drilling cuttings	total aqueous	total solids	Sampling Dates	Notes
Sampling Stations	3	0	2	2	2	2	2	2				
Subtask 1.4.1 Test surface sampling plan												
ID and review existing GW/SW data	Completed-flow path identification, otherwise no other value											
Finalize project surface sampling plan	Completed-see below											
Subtask 1.4.3 Develop water quality baseline												
Groundwater baseline prior to drilling	Access denied-groundwater will not be sampled											
Surface water baseline prior to drilling	3								3		6/12/2015	
	4								4		6/25/2015	Field duplicate taken
Subtask 2.1.1 Environmental monitoring-Drilling												
Vertical drilling	3								3		7/8/2015	surface water only
								1		1		
								1		1		
Horizontal drilling	3					1	1	1	5	2		liquids & solids fraction of muds
						1	1	1	2	2		liquids & solids fraction of muds
Subtask 2.2.1 Environmental monitoring-Completion												
Hydraulic fracturing	3		2	2					7			
flowback Initial	3				2				5			
Flowback 1 week	3				2				5			
Flowback 2 weeks	3				2				5			
Flowback 4 weeks	3				2				5			
Flowback 8 weeks	3				2				5			
Subtask 2.3.1 Environmental monitoring-Production												
Production 3 stations x 3/yr x 4 yrs	36				24				60			

Surface water samples are being analyzed for the following parameters, see Table 5.a.2.

Table 5.a.2: Analytical parameters

Aqueous chemistry parameters					
Inorganics				Organics	Radionuclides
	Anions	Cations			
pH	Alkalinity	Ag	Mg	Benzene	α
TDS	Br	Al	Mn	Toluene	β
TSS	Cl	As	Na	Ethylbenzene	^{40}K
Conductance	SO_4	Ba	Ni	Xylene	^{226}Ra
		Ca	Pb	MBAS	^{228}Ra
		Cr	Se		
		Fe	Sr		
		K	Zn		

Results and Discussion

Parameters analyzed for each surface water sample are listed in Table 5.a.1. In addition to these parameters, field readings for temperature, electric conductivity, total dissolved solids, dissolved oxygen and pH are measured at each sampling point during each sampling event. Figures 5.a.2 and 5.a.3 graphically represent two common parameters of interest along the Monongalia River at each of the three surface water sampling points upstream and downstream of the MIP well pad site over the course of monitoring activities.

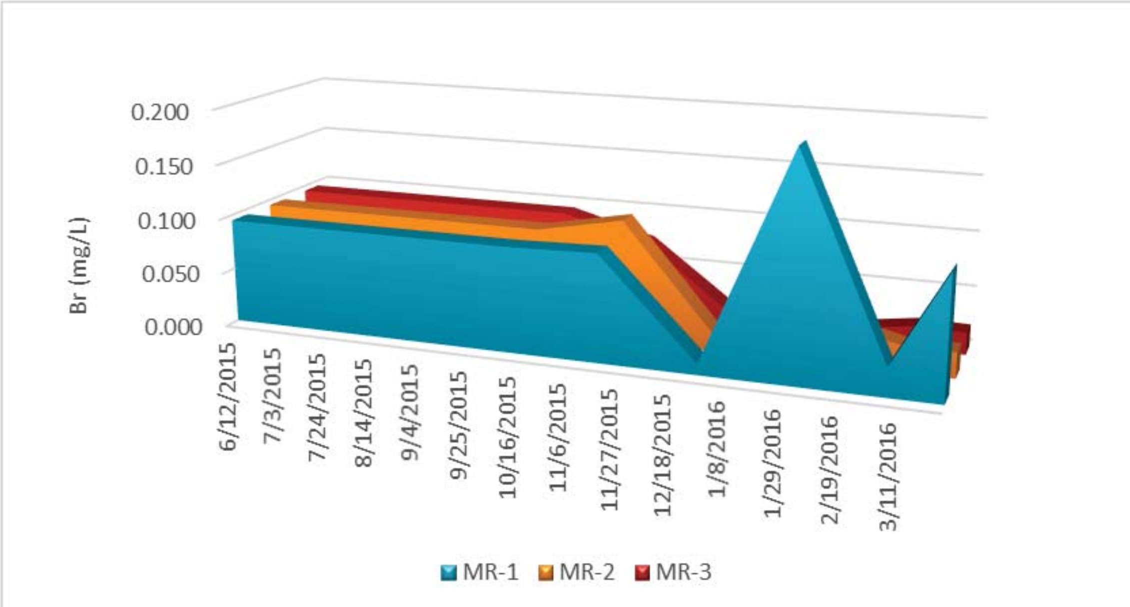


Figure 5.a.2 Bromide levels

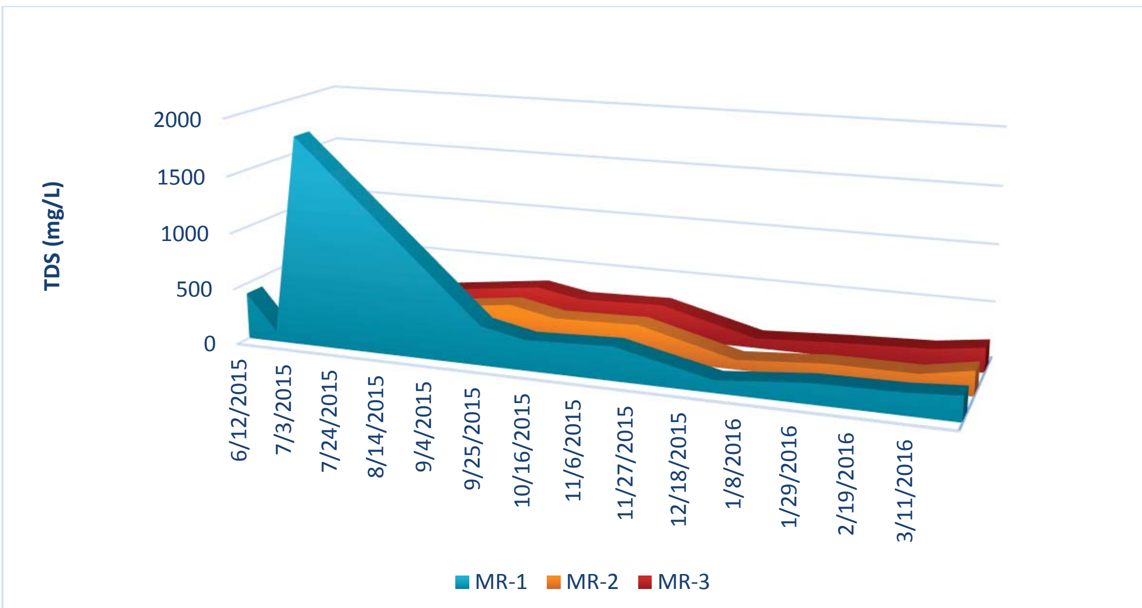


Figure 5.a.3 Total Dissolved Solids (TDS)

Samples of the cuttings and muds, hydraulic fracturing fluids and makeup water (HF), and the flowback/produced water (FPW) from each of the two wells drilled at the MSEEL site were sampled. Parameters analyzed for cuttings and muds are provided in Table 5.a.3. Samples of drill cuttings were collected from the shaker tables. Analytical results are provided in Appendix A with radionuclides and selected TCLPs shown graphically in Tables 5.a.4 through 5.a.6. Both 3H and 5H are considered green completion wells.

Table 5.a.3 Solids chemistry parameters – cuttings and muds

Solids chemistry parameters - Cuttings & Muds								
Inorganics				Organics	Radionuclides	TCLPs		
	Anions	Cations*		Propane				
alkalinity**	Br	Ag	Mg	DRO	α	Arsenic	1,4-Dichlorobenzene	Methly ethyl ketone
conductance	Cl	Al	Mn	ORO	β	Barium	1,2-Dichloroethane	Nitrobenzene
pH	SO_4	As	Na	GRO	^{40}K	Benzene	1,1-Dichloroethylene	Pentrachlorophenol
bicarbonate**	sulfide	Ba	Ni	Ethylbenzene	^{226}Ra	Cadmium	2,4-Dinitrotoluene	Pyridine
carbonate**	nitrate	Ca	Pb	m,p-xylene	^{228}Ra	Carbon tetrachloride	Endrin	Selenium
TP	nitrite	Cr	Se	o-xylene		Chlordane	Heptachlor	Silver
		Fe	Sr	Styrene		Chlorobenzene	Heptachlor epoxide	Tetrachloroethene
		K	Zn	Toluene		Chloroform	Hexachlorobenzene	Toxaphene
				Total xylenes		Chromium	Hexachlorobutadiene	Trichloroethylene
				TOC		o-Cresol	Hexachlororethane	2,4,5-Trichlorophenol
				COD		m-Cresol	Lead	2,4,6-Trichlorophenol
				O&G		p-Cresol	Lindane	2,4,5-TP (Silvex)
						Cresol	Mercury	Vinyl chloride
						2,4-D	Methoxychlor	

*total and dissolved

**performed on leachate

Table 5.a.4 Radiochemistry of drill cuttings

Radionuclides (pCi/g)

vertical	EPA 901.1									9310					
Marcellus	^{40}K			^{226}Ra			^{228}Ra			alpha			beta		
	Act	Unc	MDC	Act	Unc	MDC	Act	Unc	MDC	Act	Unc	MDC	Act	Unc	MDC
MIP 4400 3H	28	4.8	1.0	1.2	0.3	0.3	1.8	0.5	0.3	15.0	7.1	9.8	24.5	6.3	5.6
MIP 5026 3H	24	4.4	1.4	1.4	0.3	0.2	1.9	0.5	0.3	10.5	5.8	9.2	19.4	4.8	4.1
MIP 6798 5H	27	4.5	0.9	1.8	0.3	0.2	1.4	0.4	0.5	17.1	7.7	11.2	27.8	6.7	5.4
MIP 8555 5H	26	4.2	1.1	4.7	0.7	0.2	1.3	0.4	0.4	27.0	9.6	10.2	36.9	8.6	6.6
MIP 8555 5H DUP	25	4.6	1.5	4.6	0.7	0.3	1.1	0.6	0.6	38.1	11.1	9.1	29.8	6.8	4.9
MIP 9998 5H	17	4.3	2.7	9.2	1.3	0.3	0.5	0.9	0.9	46.8	11.0	4.7	42.9	9.0	5.9
MIP 11918 5H	22	3.7	1.1	4.0	0.7	0.2	0.7	0.5	0.5	24.4	9.2	10.3	23.0	6.2	6.2
MIP 11918 5H	20	3.4	1.1	4.2	0.6	0.2	0.8	0.4	0.6	23.8	6.8	5.2	28.7	6.3	5.1
MIP 13480 3H	18	3.2	1.2	9.2	1.3	0.2	0.8	0.6	0.5	55.7	14.7	11.5	35.4	8.2	5.8
MIP 13480 3H DUP	18	3.5	1.4	9.7	1.4	0.3	1.1	0.4	0.3	59.2	14.9	9.3	35.0	7.8	4.6
MIP 13480 3H Mud	13	3.0	1.1	5.6	0.9	0.2	0.5	0.3	0.8	60.0	15.9	10.5	42.5	9.6	6.1
MIP 14454 5H	20	3.8	1.1	5.8	0.9	0.2	1.3	0.5	0.6	28.8	7.9	6.5	37.5	8.0	5.4

Figure 5.a.4 Radionuclides from 5H cuttings

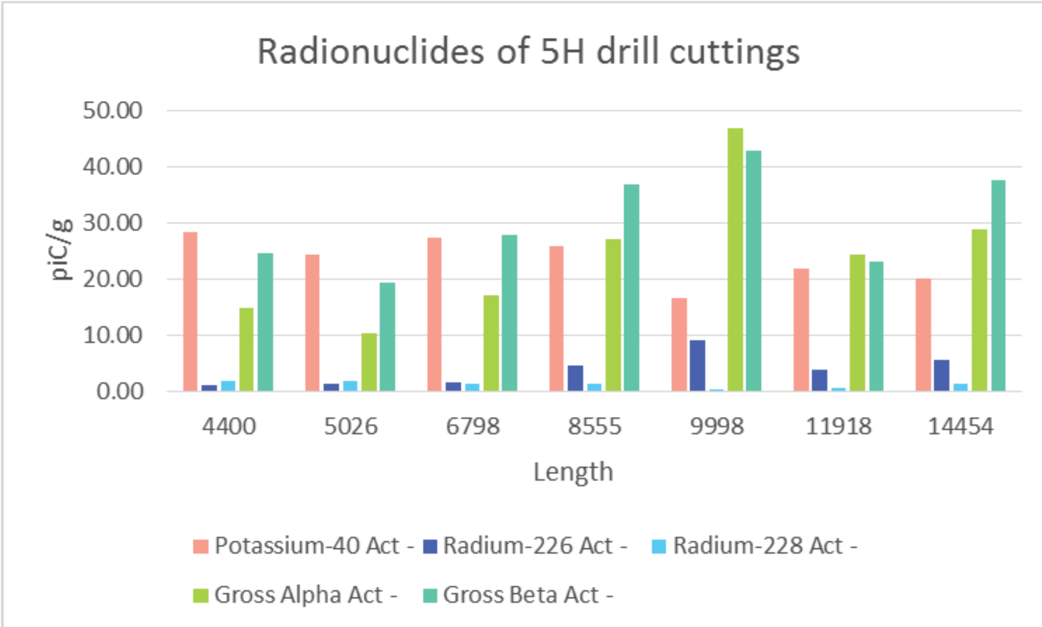
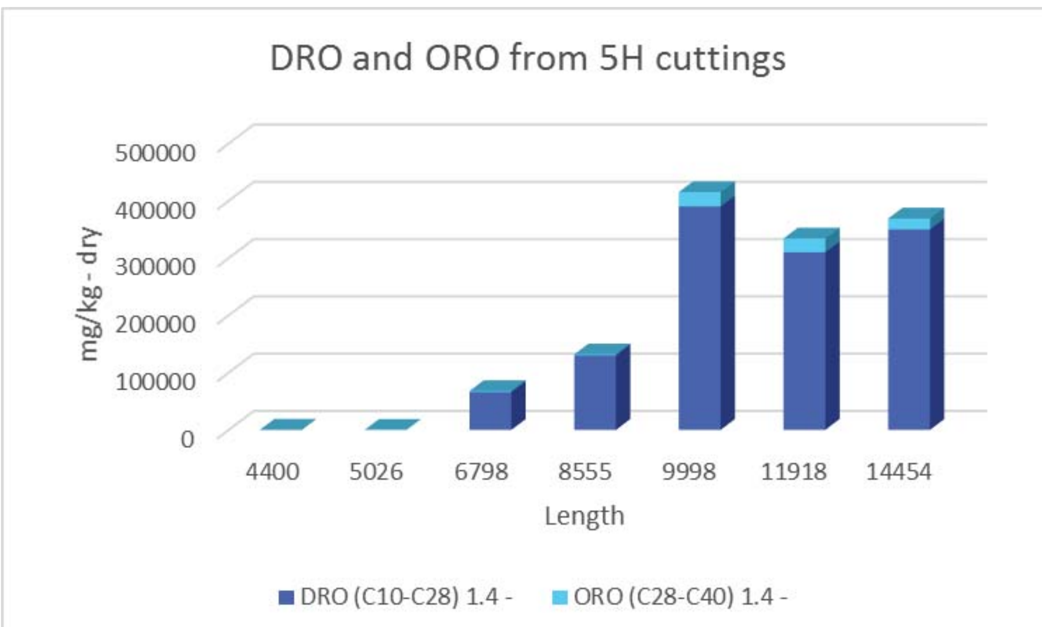


Figure 5.a.5 Hydrocarbons from 5 H cuttings



Makeup water was pumped from the Monongahela River and mixed with the hydraulic fracturing fluids. Samples of HF were collected after the mixing had occurred. FPW samples were taken at the upstream end of each well's separator.

FPW is strongly saline, typical values will run from 10,000 to 250,000 mg TDS/liter. Inorganics consist mainly of sodium, magnesium, calcium, strontium, barium, chloride, and bromide. Benzene, toluene, ethylene, and xylene (BTEX) is the organic of concern in FPW along with naturally occurring radioactive material levels for gross alpha, gross beta, and radium-228 and -228. Because the quality of the FPW samples are not typical aqueous samples, non-radiochemical parameters are subject to detection limit dilution. For this reason, we follow the USEPA standard convention of reporting below detection limits as one-half the actual detection limit. During flowback into production, FPW discharges drop off rapidly within the first few weeks with ion concentrations increase during this time. FPW volumes are shown in Tables 5.a.6 and 5.a.7, daily production and cumulative, respectively.

Figure 5.a.6 FPW daily production

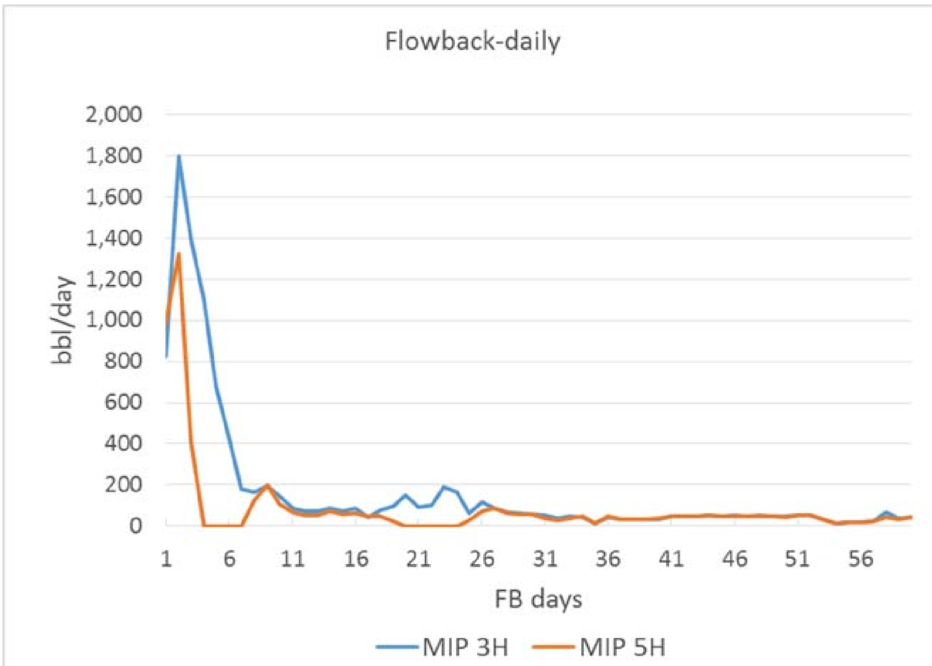
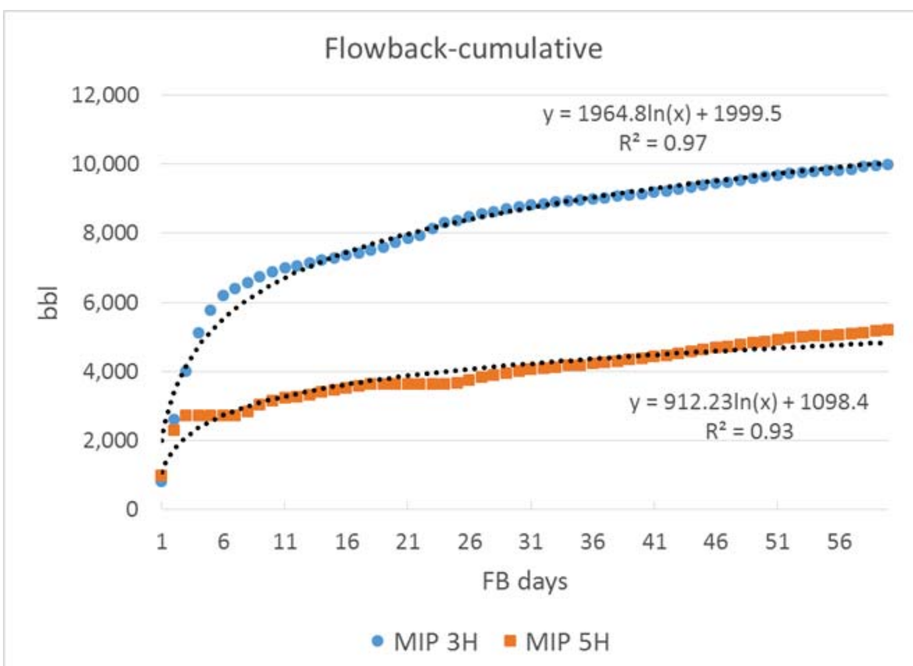


Table 5.a.7 FPW cumulative production



Cation-to-chloride ion pairs dominate in FPW. Looking at analytical results from the previous two wells drilled on the MIP pad, 4H and 6H, chloride, sodium, and calcium dominate the makeup of the FPW, nearly 4 years out in production, see Table 5.a.7. Most of the contaminants of concern come from the formation, not from the HF put downhole as shown in Table 5.a.8.

Table 5.a.7 4H and 6H FPW characterization

	Produced water (mg/L)	
	MIP 4H	MIP 6H
Parameter	14-Apr-15	14-Apr-15
Chloride	59,300	34,700
Sodium	23,700	15,000
Calcium	9,480	5,550
Barium	4,970	3,040
Strontium	1,970	1,310
Magnesium	809	571
Bromide	643	416
Potassium	146	93
Lithium	93	53
Iron	93	155
Sulfate	63	63
Manganese	3	4
Aluminum	1	0
EC *	143,000	99,300
Alkalinity	124	180
TDS	104,000	65,100
TSS	75	99

* μS/cm

Table 5.a.8 Comparison of HF and FPW

MDL		units	SDWA MCL	MIP 3H HF	MIP 3H FB day 42	MIP 5H HF	MIP 5H FB day 42
0.0011	Al	mg/L	0.05	0.42	0.00055	0.02	0.00055
0.0007	As	mg/L	0.01	0.00	0.35	0.00	0.35
0.0002	Ba	mg/L	2	0.04	2500	0.048	1100
0.4	Ca	mg/L		35.5	6800	34	2900
0.0001	Cr	mg/L	0.1	0.003305	0.05	0.00005	0.05
0.01	Fe	mg/L	0.3	1.996	140	0.005	120
0.0001	Pb	mg/L	0.015	0.00	0.005	0.00	0.005
0.019	Mg	mg/L		9.70	710	8.00	330
0.0002	Mn	mg/L	0.05	0.11	11	0.00	1.8
0.0004	Ni	mg/L		0.01	0.2	0.00	0.2
0.03	K	mg/L		3.40	130	2.50	120
0.001	Se	mg/L	0.05	0.00	0.5	0.00	0.5
0.0001	Ag	mg/L	0.1	0.00	0.05	0.00	0.05
0.1	Na	mg/L		46.50	21000	30.00	13000
0.0003	Sr	mg/L		0.34	1400	0.27	630
0.02	Zn	mg/L	5	0.07	1.2	0.04	1.2
4.3	Alk	mg/L		70.00	140	64.00	240
0.09	Br	mg/L		0.17		0.95	
0.29	Cl	mg/L	250	31.50	61000	34.50	37000
3	SO4	mg/L	250	125.00	7	140.00	7
7.6	TDS	mg/L	500	340.00	88000	565.00	55000
0.25	Benzene	µg/L	5	0.13	10	0.13	27
0.2	Toluene	µg/L	1000	0.43	13	0.01	53
0.22	Ethylbenze	µg/L	700	0.11	1.1	0.11	4
0.62	Xylene tot	µg/L	10000	0.32	3.2	0.32	23
0.005	MBAS	mg/L	0.5	0.00	0.38	0.00	0.26

Data results for benzene, total dissolved solids (TDS), and radium-226 are graphed, see figures 5.a.8 through 5.a.10.

Table 5.a.8 FPW – Benzene from 3H and 5H

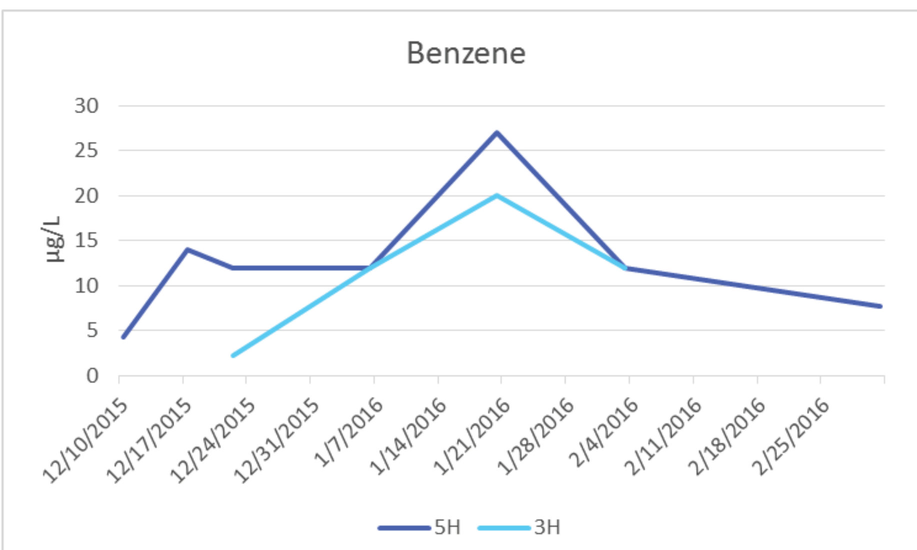


Table 5.a.9 FPW – TDS from 3H and 5H

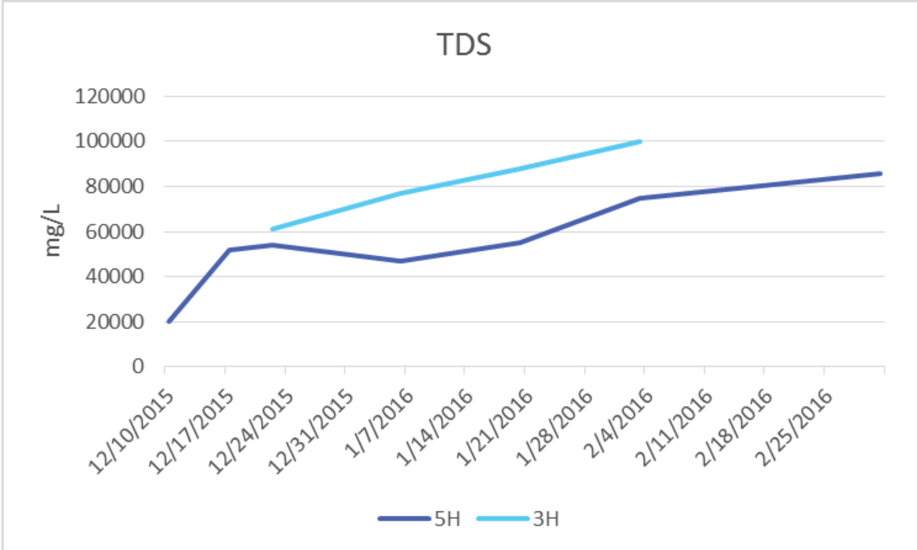
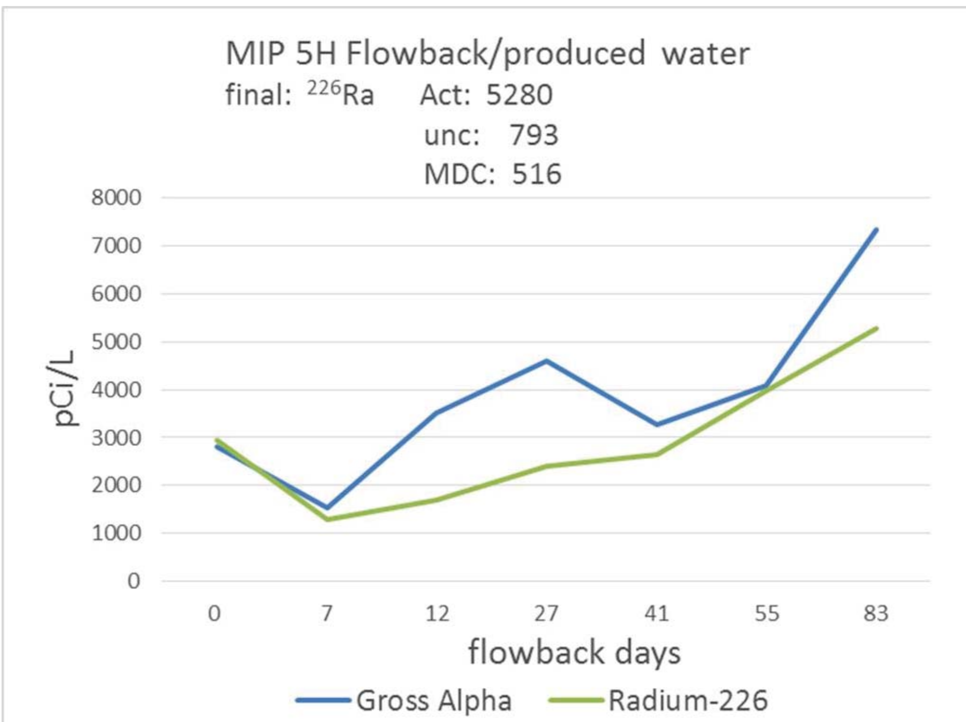


Table 5.a.10 FPW – Radionuclides from 5H



The sampling schedule for surface water and gas well development water/waste streams is detailed in Appendix B.

Products

None this quarter.

Plan for Next Quarter

Activities moving forward will follow the schedule provided in Appendix 2.

Task 5b – Surface Environmental – Air and Vehicular

The approach to the CAFEE portion of Topic 5 has been focused on methane and other emissions associated with unconventional well development. As data analyses are completed, our approach will transition to quantify methane emissions from typical site operation. These audits will be completed with the use of WVU's Full Flow Sampling System (FFS).

Results and Discussion

A summary of the fuel consumption data and gaseous emissions was provided last quarter. All site operators and contractors have reviewed these summary data. Particulate matter emissions are still under internal review for quality control and quality assurance. A summary of these data will be provided within the next two quarters.

The MSEEL results are currently being integrated with data collected under DE-FE0013689. The activity data from both drilling and hydraulic fracturing data have been included in the database of engine activity. The combined data set has been processed. A Markov Chain Monte Carlo method and genetic algorithms were employed to construct emissions test cycles that will be used in year three of DE-FE0013689. The fuel consumption and gaseous emissions data have also been integrated with the results from two additional sites under DE-FE0013689. More information is provided below in the products section.

We have also worked with Northeast Natural Energy, the National Energy Technology Laboratory, and KeyLogics, Inc. to develop and submit a full proposal to ARPA-E under DE-FOA-0001546 – MONITOR Field Test Site Program. This proposal includes possible use of the research well as a candidate test site for the evaluation of 11 different methane detection technologies developed under ARPA-E's MONITOR program. The proposal also included the development of an offsite model well pad based on the active MSEEL site and NNE's processing equipment. Successful technologies may also be demonstrated on the active MSEEL site. We are currently in discussions with the Environmental Defense Fund, LiCOR, and FLIR on possible instrumentation or use of current technologies at the MSEEL site during non-development activities (durations between well drilling and completions).

Products

The data summary that was presented last quarter has been integrated with data under DE-FE0013689. We are currently developing three publications that will be submitted to the Journal of Air and Waste Management, Environmental Science and Technology, and Proceedings of the National Academy of Sciences or others. The first publication will focus on the creation of activity cycles using MSEEL data and data collected across the US. The second publication will be an integrated case study on the effects of implementing dual fuel technologies in unconventional well development. The final publication will use data collected from both programs to estimate a national inventory of emissions associated with unconventional well development.

Plan for Next Quarter

- Continue QC/QA of PM Data
- Publish 3 papers
- Transition focus to site-wide methane audits
- Continue to highlight MSEEL with new collaborators

Topic 6 – Economic and Societal

Approach

The lead on the political and societal project will work to identify and evaluate the factors shaping the policymaking response of local political actors. Included in this assessment will be an accounting, past and present, of the actions of public and private individuals and groups acting in favor of or opposed to shale gas drilling at the MSEEL site.

First year activity includes developing, distributing, collecting and compiling the responses from a worker survey and a vendor survey. The worker survey will address job characteristics and offsite expenditures. The vendor survey will help to identify per-well cost structures.

Results and Discussion

The worker survey has come to completion, with the completion of normal operations. The project team collected a total of 70 responses. The data is being aggregated and quality controlled at this time. Additionally, data for drilling expenditures has been collected, and will be utilized to compile a production function representation for Marcellus drilling operations. Other information will be useful in providing context and confirmation for the worker survey, and for estimating total numbers of workers for purposes of estimating survey response rate.

This data source will be a primary focus for the next 1-2 quarters.

Products

Plan for Next Quarter

Cost Status

Project Title: Marcellus Shale Energy and Environment Laboratory at West Virginia University

DOE Award Number: DE-FE0024297

Year 1

Start: 10/01/2014 End: 09/30/2015

Baseline Reporting Quarter

	Q1 (12/31/14)	Q2 (3/30/15)	Q3 (6/30/15)	Q4 (9/30/15)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share	$549,000		$3,549,000	
Non-Federal Share	$0.00		$0.00	
Total Planned (Federal and Non-Federal)	$549,000		$3,549,000	
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$0.00	$14,760.39	$237,451.36	$300,925.66
Non-Federal Share	$0.00	$0.00	$0.00	$0.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$0.00	$14,760.39	$237,451.36	$300,925.66
Cumulative Incurred Costs	$0.00	$14,760.39	$252,211.75	$553,137.41
Uncosted				
Federal Share	$549,000	$534,239.61	$3,296,788.25	$2,995,862.59
Non-Federal Share	$0.00	$0.00	$2,814,930.00	$2,814,930.00
Total Uncosted - Quarterly (Federal and Non-Federal)	$549,000	$534,239.61	$6,111,718.25	$5,810,792.59

Cost Status

Project Title: Marcellus Shale Energy and Environment Laboratory at West Virginia University

DOE Award Number: DE-FE0024297

Year 1

Start: 10/01/2014 End: 09/30/2015

Baseline Reporting Quarter Q5 (12/31/15)

Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share	$6,247,367			
Non-Federal Share	2,814,930			
Total Planned (Federal and Non-Federal)	$9,062,297			
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$577,065.91			
Non-Federal Share	$0.00			
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$577,065.91			
Cumulative Incurred Costs	$1,130,203.32			
Uncosted				
Federal Share	$5,117,163.68			
Non-Federal Share	$2,814,930.00			
Total Uncosted - Quarterly (Federal and Non-Federal)	$2,418,796.68			

Appendix 1

A listing of the 76 datasets available on the MSEEL Portal. Datasets total almost 4 terabytes. Private datasets can only be viewed by participants and require a login with password.

Background – 23 Datasets

- **PRIVATE MSEEL_Final_2_12_16**
  - Powerpoints presented
  - pptx
- **PRIVATE MSEEL_Meeting_11-20_2015**
  - Advisory Committee Meeting
  - pptx
- **PRIVATE MSEEL MEETING 2_12_16**
  - Slides of short presentations
  - PDF
- **PRIVATE Old Information for Previous Wells**
- **PRIVATE MSEEL Microseismic Evaluation Schlumberger**
  - Presentation by Adrian Morales from SLB on Microseismic in the MIP wells
- **PRIVATE MSEEL Requests**
  - A zipped file of MSEEL External Requests
  - ZIP
- **PRIVATE EFD 11-15 MCCAWLEY**
  - Poster Presentation on Ait Quality
  - pptx
- **PRIVATE 3H Poster of Lateral Well Interprtation**
  - Poster from SLB showing lateral well logs
  - png
- **PRIVATE MSEEL Review Nov 2015**
  - Review to External Advisory Committee

- pptx

- **MSEEL Review Sept 2015**
  - Power Point Slides of Review to External Committee
  - pptx

- **PRIVATE Continuation Presentation 8 3 2015**
  - Presentation to NETL concerning progress in budget period 1 and plans for budget period 2. Also changes in project objectives,
  - PDF

- **PRIVATE 3D Video Tests**
  - .mp4
  - .avi
  - .swf

- **PRIVATE MSEEL Well Locations Map**
  - Surface map designating existing and proposed well locations
  - PDF

- **PRIVATE MSEEL Presentation 5_18_2015**
  - Review of MSEEL Program to Advisory Board

- **PRIVATE Aminian Precision Petrophysical Analysis**
  - Precision Core Analysis for Shale
  - PDF

- **PRIVATE MIP Coring**
  - Coring plan for Science Well
  - PDF

- **PRIVATE NETL Core Scanning**
  - CT Scanning and Other Core Analysis
  - PDF

- **PRIVATE Sidewall Coring for Isotopes and BioMarkers**

  - Sidewall Coring for Isotopes and Biomarkers
  - PDF

- **PRIVATE MSEEL Plans 5 12**
  - Presentation Slides
  - PDF

- **Surface GIS Data for Morgantown Industrial Park**
  - Road, railroad, elevation, political boundary, drainage and other GIS layer data for the MSEEL site and vicinity.
  - esri gdb
- PRIVATE MIP Air_Noise Presentations 3_25_2015
  - Presentations by NNE and WVU on Air and noise sampling
  - PDF
- PRIVATE MIP Air_Noise Monitoring
  - Presentation by NNE for Air_Noise Monitoring
  - PDF
- PRIVATE Observation Well Permit
  - The permit for the Science/Observation well 47-061-01705 is complete.
  - PDF

Deep Subsurface Geochemistry – 1 dataset

- **PRIVATE Isotope Samples of Water**
  - Isotope Samples of Flowback/Produced water
  - PDF

Geologic Engineering – 14 datasets

- PRIVATE Fiber Optics Data
  - Fiber optics Data contains all of the files from Stage 1 to 28. Each stage is in individual compressed folder. Complete dataset is about 1.2 Terabytes. Data can be downloaded...
  - sgy
- PRIVATE NNE MIP 5H Frac Stage ASCII Files
  - Frac Stages ASCII files
  - ZIP
- PRIVATE NNE MIP 3H Frac Stage ASCII Files
  - Ascii data for frac stages in MIP 3H
  - ZIP
- PRIVATE Production data
  - Production data with water and gas from the MIP 3H and 5H from initial production on 12/10/2015 through 2/7/2016

    - XLS
- PRIVATE Therma Files
    - Therma modeling and analysis software instructions and license. Requires additional software and dongle. Contact Tim Carr to check out software
    - ZIP
- PRIVATE DTS Data
    - Zip file of DTS data from MIP3H
    - ZIP
- PRIVATE Completions Data for 3H and 5H
    - ZIP
- PRIVATE MIP_SW_Drilling_Rig_Data
    - MIP_SW_Drilling_Rig_Data in time and depth in various formats
    - ZIP
- PRIVATE MIP5H_Drilling_Rig_Data
    - MIP 5H drilling data in time and depth in various formats
    - ZIP
- PRIVATE 3H Drilling Rig Data
    - Data is in Time and Depth and in various formats.
    - ZIP
- PRIVATE MIP 5H drilling
    - MIP 5H drilling
    - ZIP
- PRIVATE MIP 3H Drilling
    - MIP 3H Drilling
    - ZIP
- PRIVATE MIP SW drilling data
    - MIP SW drilling data
    - ZIP
- PRIVATE 3H Fracture Stimulation Plan
    - XLS

Geophysical – 28 datasets

- PRIVATE SLB Fiber Presentation
    - Schlumberger PowerPoint presentation on fiber-optic analysis
    - pptx
- PRIVATE Seismic Observer Notes
    - Seismic Observer notes during completion of MIP 3H and 5H
    - XLS
- PRIVATE Microseismic Report
    - Microseismic Report on events during the completion of the MIP 3H and 5H
    - PDF
- PRIVATE SLB Microseismic Presentation
    - Images of Presentation of Microseismic Presentation on MIP Wells
    - PDF

- PRIVATE Microseismic Event Files
    - Microseismic event files in CSV and RDV formats. Folder is zipped
    - ZIP
- PRIVATE Pump Data
    - Pump Data from the MIP 5H and 3H
    - ZIP
- PRIVATE Petrel File of Microseismic Events
    - Petrel File of Microseismic Events from the MIP 3H and 5H
    - ZIP
- PRIVATE Microseismic_NNE-MIP-3H-5H-Location
    - x, y, z, t, M coordinate
    - ZIP
- PRIVATE MIP 6H Survey
    - Direction Survey for MIP 6H
    - TXT
- PRIVATE MIP 6H LWD LAS
    - LWD log in LAS Format
    - las
- PRIVATE GAMMA_NNE_PATTERSON_254_MIP_5H
    - Gamma Log from the MIP 5H
- PRIVATE 3H Fracture Files LAS (Zipped)
    - ZIP
- PRIVATE 3H Pilot Core Gamma Ray png Format
- PRIVATE 3H Pilot Core Gamma Ray pdf Format
    - PDF
- PRIVATE 3H Pilot Core Gamma Ray LAS Format
    - Core Gamma Ray from the 3H Pilot Hole - LAS Data
    - las
- PRIVATE 3H Number of Fractures by Stage
    - XLS
- PRIVATE 3H Fractures_by_stage_stages15thru28
    - Rose Diagrams of Fractures by stage for stages 15 thru 28 in 3h
    - ZIP
- PRIVATE 3H Fractures_by_stage_stages1thru14
    - Fractures by stage for stages 1 thru 14 in 3H Rose Diagrams
    - ZIP
- PRIVATE Horizontal Image log (QuantaGeo)
- PRIVATE MIP 3H Lateral Sonic Scanner raster log
    - MIP 3H lateral logs in .pdf format
    - PDF
- PRIVATE MIP 3H Lateral Sonic Scanner Digital log
    - LAS file for MIP 3H lateral log
    - las
- PRIVATE MIP 3H mudlog
    - mudlog data from 3H well, both pilot and horizontal

- PRIVATE MIP 3H pilot log data
    - all log data for the MIP 3H pilot hole.
- PRIVATE MIP 3H Processed CT Data
    - Some preliminary processing of the MIP 3H Computed Tomography Data
    - pptx
    - PDF
    - docx
- PRIVATE MIP 3H CT TIF Stacks
    - Medical CT scan of MIP 3H core 4" diameter core Data is in tif stack, where each voxel has a resolution of 0.43 mm x 0.43 mm x 0.5 mm. The 0.43 mm x 0.43 mm voxel...
    - tif
- PRIVATE MIP 3H Vertical Logs LAS
    - Logs from vertical wellbore MIP3H in LAS format
    - ZIP
- PRIVATE MIP 3H Vertical Logs Pdf
    - Vertical Logs from the MIP3H Vertical wellbore in pdf images
    - ZIP
- PRIVATE Fiber optic proposal
    - Proposal from Schlumberger on fiber optics
    - PDF

Northeast Natural Energy – 10 datasets

- PRIVATE Completion
    - completion data for the MIP project
- PRIVATE MIP SW Drilling
    - MIP SW Drilling
- PRIVATE MIP 3H Drilling
    - Drilling files for MIP 3H drilling
- PRIVATE MIP 5H Drilling
    - Drilling data
- PRIVATE AFE MSEEL Wells Revised July 2015
    - AFE for MSEEL wells MIP 3H, MIP 5H and SW
    - PDF
- **Presentations**
    - Presentations
- **SDS**
    - Safety Data Sheets
- **Safety Sign In Sheets**
    - Sign in Sheet
- Safety
    - Presentation, Code of Conduct, PPE requirements and Tier explanations
- JSA
    - Job Safety Analysis

Project Management 10 datasets

- PRIVATE MSEEL Quarterly FY 2016 Q1
  - PDF
- PRIVATE MSEEL Quarterly FY 2015 Q4
  - PDF
- PRIVATE MSEEL Quarterly FY 2015 Q3
  - PDF
- PRIVATE MSEEL Project Management Plan Revised July 2015
  - Due to weather and other issues the original Project Management Plan with Statement of Project Objectives was revised
  - PDF
- PRIVATE Science Well Slump
  - Work proposed by GSI to correct major slump above the Science Well Pad.
  - PDF
- PRIVATE Project Proposal
  - Original project proposal, including narrative, budget, NEPA forms.
- PRIVATE Award Documents
  - Awards and Amendments from DOE
- PRIVATE Invoices
  - Invoices Submitted to Project
- PRIVATE Subawards
  - Subaward Documents for NNE and OSU

Surface Environmental - 5 datasets

- PRIVATE MUB Historical Surface Water Data
  - Surface Water Data Collected from the Mon River from MUB
- PRIVATE April May Air Quality Synopsis
  - Short synopsis of some particulate background data from April and May 2015 for PM2.5 and Ultrafine (PM0.1) from Mike McCawley
  - doc
- PRIVATE Background Dust Data for April & May 2015 Downtown
  - Dust Track PM2.5 and PTrack PM0.1 data taken on Beechhurst Ave., 200m north of intersection of Beechurst and University Ave with PTrack and Dust Track side by side. See June...
- PRIVATE MSEEL Surface Water Samples 1
  - Geochemical results of the initial water samples from the three MSEEL Stations
- PRIVATE MSEEL Monitoring Stations
  - Air Monitoring Stations in Morgantown
  - jpg

Appendix 2 – Water Sampling Plan and Results

	Freshwater		Aqueous/Solids:								
	Mon River	Ground water	HF fluid makeup	HF fluids	flowbac k/	drilling fluids	drilling cuttings	total aqueou	total solids	Sampling Dates	Sampling Notes
Sampling Stations	3	0	2	2	2	2	2				
Subtask 1.4.1 Test surface sampling plan											
ID and review existing GW/SW data	**Completed-flow path identification, otherwise no other value**										
Finalize project surface sampling plan	**Completed-see below**										
Subtask 1.4.3 Develop water qualiity baseline											
Groundwater baseline prior to drilling	**Access denied-groundwater will not be sampled**										
Surface water baseline prior to drilling along the Monongalia River	3							3		6/12/2015	point upstream near NEE water withdrawal, two points downstream are lock and dam and MUB property (opposite side of river)
Surface water baseline prior to drilling along the Monongalia River	4							4		6/25/2015	Surface water samples + field duplicate included
Subtask 2.1.1 Environmental monitoring-Drilling											
Vertical Drilling of MIP 3H and 5H											
Surface water sampling during vertical drilling	3							3		7/8/2015	Surface water samples only from along the Monongalia River
Cuttings sample from MIP 3H during vertical drilling							1		1	7/13/2015	MIP 3H well @ 4400'
Cuttings sample from MIP 3H during vertical drilling							1		1	7/13/2015	MIP 3H well @ 5026'
Horizontal drilling of MIP 5H											liquids & solids fraction of muds from 5H: curve + 2 horizontal
Cuttings and muds samples from MIP 5H during horizontal drilling							3		3	9/11/2015	Curve - 8555', true vertical depth - 7469', 1 - cuttings, 1 - muds, plus cuttings duplicate
Cuttings sample from MIP 5H during horizontal drilling							1		1	9/25/2015	Obtained 1 cuttings samples from Carr. Sample was collected by NEE reps on 9/13/15 at approximately 12000'
Horizontal drilling of MIP 3H											liquids & solids fraction of muds from 3H: curve + 2 horizontal
Cuttings and muds samples from MIP 3H during horizontal drilling							3		3	9/21/2015	Horizontal - 13480', 1 - cuttings, 1 - muds, plus cuttings duplicate
Surface water sampling after horizontal drilling of MIP 5H and 3H	3							3		9/25/2015	surface water only, 1st round after both production wells drilled
Surface water sampling after horizontal drilling of MIP 5H and 3H	3							3		10/14/2015	surface water only, 2nd round after both production wells drilled
Subtask 2.2.1 Environmental monitoring-Completion											
Hydraulic fracturing - 3H			1	1				2		11/10/2015	one sample of makeup water + one sample of HF mixture for 3H
Hydraulic fracturing - 5H			1	1				2		11/6/2015	one sample of makeup water + one sample of HF mixture for 5H
Surface water sampling after completions (HF) of MIP 5H and 3H	3							3		11/19/2015	surface water only once HF was completed
Flowback initial - 3H					1			1		12/10/2015	one sample from 3H, 11:00am
Flowback initial - 5H					1			1		12/10/2015	one sample from 5H, 8:00am
Flowback @ 1 week - 3H					1			1		12/17/2015	one sample from 3H, 10:00 am
Flowback @ 1 week - 5H					1			1		12/17/2015	one sample from 5H; 10:00 am
Flowback @ 2 weeks - 3H					1			1		12/22/2015	partial sample from 3H (well cutback), 9:45 am
Flowback @ 2 weeks - 5H					1			1		12/22/2015	one sample from 5H: 9:00 am
Surface water sampling	3							3		12/29/2015	surface water sampling after 2 weeks production
Flowback @ 4 weeks - 3H					1			1		1/6/2016	one sample from 3H, 10:00 am
Flowback @ 4 weeks - 5H					1			1		1/6/2016	one sample from 5H, 10:30 am
Flowback @ 6 weeks - 3H					1			1		1/20/2016	one sample 3H, collected during 10:00-11:00 am

Flowback @ 6 weeks - 5H		1	1	1/20/2016	one sample 5H, 10:00 am
Surface water sampling	3		3	2/3/2016	surface water sampling after 7 weeks production
Flowback @ 8 weeks - 3H		1	1	2/3/2016	one sample from 3H, not enough quantity for Rads analysis (apprx 2.5 gallons), 9:30 am
Flowback @ 8 weeks - 5H		1	1	2/3/2016	one sample from 5H, 9:00 am
Subtask 2.3.1 Environmental monitoring-Production					
Flowback @ 11 weeks - 3H		1	1	3/2/2016	one sample 3H not obtained, heater froze up during the night
Flowback @ 11 weeks - 5H		1	1	2/24/2016	one sample 5H collected, 9:07am
Surface water sampling	3		3	3/9/2016	surface water sampling after 11 weeks production
Flowback @ 15 weeks - 3H		1	1	3/23/2016	one sample 3H
Flowback @ 15 weeks - 5H		1	1	3/23/2016	one sample 5H
Surface water sampling	3		3	3/30/2016	surface water sampling after 15 weeks production
Flowback @ 19 weeks - 3H		1	1	scheduled for 4/20/2016	one sample 3H
Flowback @ 19 weeks - 5H		1	1	scheduled for 4/20/2016	one sample 5H
Surface water sampling	3		3	scheduled for 4/27/2016	surface water sampling after 19 weeks production
Flowback @ 23 weeks - 3H		1	1	scheduled for 5/18/2016	one sample 3H
Flowback @ 23 weeks - 5H		1	1	scheduled for 5/18/2016	one sample 5H
Surface water sampling	3		3	scheduled for 5/25/2016	surface water sampling after 23 weeks production
Flowback @ 29 weeks - 3H		1	1	scheduled for 6/29/2016	one sample 3H
Flowback @ 29 weeks - 5H		1	1	scheduled for 6/29/2016	one sample 5H
Surface water sampling	3		3	scheduled for 7/6/2016	surface water sampling after 29 weeks production
Flowback @ 35 weeks - 3H		1	1	scheduled for 8/10/2016	one sample 3H
Flowback @ 35 weeks - 5H		1	1	scheduled for 8/10/2016	one sample 5H
Surface water sampling	3		3	scheduled for 8/17/2016	surface water sampling after 35 weeks production
Flowback @ 41 weeks - 3H		1	1	scheduled for 9/21/2016	one sample 3H
Flowback @ 41 weeks - 5H		1	1	scheduled for 9/21/2016	one sample 5H
Surface water sampling	3		3	scheduled for 9/28/2016	surface water sampling after 41 weeks production
Surface water (3) and Production (2) @ 4/yr for 3 yrs	36	24	60		one sample from each - 3H and 5H, per Production sampling event; 3 surface water samples per sampling event

ND = Non Detect								4400 5H	5026 5H	6798 5H	8555 5H	8555 5H DUP	9998 5H	11918 5H	11918 5H	14454 5H	13480 3H	13480 3H DUP	13480 3H Mud
Analysis	Method	Units	Parameter	MDL	TCLP Limit	EPA drinking water MCL	Universal Trtmt Stds Sewage	7/13/2015	7/13/2015	10/6/2015	9/11/2015	9/11/2015	10/6/2015	9/25/2015	10/6/2015	10/6/2015	9/21/2015	9/21/2015	9/21/2015
TCLP Herbicides	SW8151	ug/L	2,4,5-TP (Silvex)	0.062	1			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			2,4D	0.051	10			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		% Rec	Surr: DCAA	-	-			90.20	97.40	109.00	109.00	114.00	110.00	86.60	97.60	103	86.00	94.00	95.60
TCLP Pesticides	SW8081	ug/L	Chlordane technical	0.42	0.03			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Endrin	0.009	0.02			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			gamma-BHC (Lindane)	0.0075	-			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Heptachlor	0.0085	-			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Heptachlor epoxide	0.006	0.008			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Methoxychlor	0.006	10			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Toxaphene	0.14	0.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		% Rec	Surr: Decachlorobiphenyl	-	-			90.00	91.00	71.00	98.00	98.00	78.00	85.00	78.00	60	72.00	62.00	65.00
			Surr: Tetrachloro-m-xylene	-	-			64.00	68.00	52.00	66.00	67.00	58.00	71.00	53.00	50	48.00	44.00	54.00
TCLP Mercury by CVAA	SW7470A	mg/L	Hg	0.00018	0.2	0.002	0.15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCLP Metals Analysis By ICP-MS	SW6020A	mg/L	As	0.007	5	0.01	1.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Ba	0.002	100	2	1.2	0.82	0.99	0.84	2.50	2.50	2.80	2.70	2.70	2.7	2.20	2.30	2.00
			Cd	0.001	1	0.005	0.2	ND	ND	0.00	ND	ND	0.00	ND	ND	ND	ND	ND	0.00
			Cr	0.001	5	0.1	0.37	0.00	0.00	ND	0.00	0.00	0.00	0.00	0.00	0.25	0.01	0.01	0.01
			Pb	0.001	5	0.015	0.28	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.0088	0.01	0.01	0.00
			Se	0.01	1	0.05	0.82	ND	ND	ND	ND	ND	ND	0.01	ND	ND	ND	ND	ND
			Ag	0.001	5	-	0.29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCLP Semi-Volatile Organics	SW8270	ug/L	1,4- Dichlorobenzene	8.2	7.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			2,4,5- Trichlorophenol	5.8	400			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			2,4,6- Trichlorophenol	5	2			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			2,4- Dinitrotoluene	2.8	*0.13			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Hexachloro-1,3- butadiene	7.4	0.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Hexachlorobenzene	4.6	*0.13			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Hexachloroethane	9.4	3			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			m-Cresol	4.8	200			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Nitrobenzene	4.6	2			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			o-Cresol	2.8	**200			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			p-Cresol	4.8	**200			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Pentachlorophenol	10	100			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Pyridine	61	*5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		% Rec	Surr: 2,4,6- tribromophenol	-	-			70.20	80.20	78.60	103.00	95.70	66.20	79.20	73.70	66.7	76.60	79.40	74.00
			Surr: 2- Fluorobiphenyl	-	-			57.40	52.10	58.30	75.80	74.00	59.40	65.10	56.00	86.9	68.30	70.80	66.40
			Surr: 2- Fluorophenol	-	-			40.50	38.10	43.20	52.70	46.90	37.50	42.40	42.80	39.4	44.30	47.60	39.50
			Surr: 4- Terphenyl-d14	-	-			64.70	51.50	82.70	114.00	95.40	80.30	79.90	80.30	90	83.30	86.20	85.90
			Surr: Nitrobenzene-d5	-	-			55.60	50.80	57.40	82.30	67.50	52.90	63.70	54.00	65.6	67.40	69.80	67.80
			Surr: Phenol-d6	-	-			23.60	26.00	30.20	38.80	34.50	30.20	29.40	31.50	31.7	30.70	32.90	27.60
TCLP Volatile Organics	SW8260B	ug/L	1,1- Dichloroethene	4.7	0.7			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			1,2- Dichloroethane	5.3	0.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			2- Butanone	17	-			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Benzene	5	0.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Carbon Tetrachloride	2.8	0.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Chlorobenzene	3.7	100			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Chloroform	4.9	6			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Tetrachloroethene	4.9	0.7			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Trichloroethene	6.9	0.5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Vinyl Chloride	3.8	0.2			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		% Rec	Surr: 1,2- Dichloroethane-d4	-	-			96.20	98.40	99.90	99.00	102.00	93.40	95.50	95.10	94.8	102.00	102.00	103.00
			Surr: 4-bromofluorobenzene	-	-			94.60	98.00	98.60	96.70	99.00	94.60	96.20	98.40	96.2	100.00	98.00	102.00
			Surr: Dibromofluoromethane	-	-			98.30	98.00	95.70	96.00	103.00	101.00	106.00	103.00	99.4	102.00	101.00	99.60
			Surr: Toluene-d8	-	-			96.40	97.80	98.60	98.00	99.60	95.30	96.80	102.00	98.4	98.80	99.10	99.60
Diesel Range Organics by GC-FID	SW8015M	mg/Kg-dry	DRO (C10-C28)	1.4	-			250.00	85.00	66000.00	130000.00	130000.00	390000.00	310000.00	260000.00	350000	85000.00	87000.00	230000.00
			ORO (C28-C40)	1.4	-			65.00	34.00	1800.00	1800.00	1500.00	25000.00	24000.00	20000.00	19000	1100.00	1100.00	19000.00
		% Rec	Surr: 4-terphenyl-d14	-	-			89.80	63.50	598.00	169.00	121.00	250.00	290.00	248.00	245	187.00	226.00	210.00
Gasoline Range Organics by GC-FID	SW8015D	ug/Kg	GRO C6-C10)	1200	-			60000.00	ND	43000.00	880000.00	400000.00	390000.00	470000.00	34000.00	430000	240000.00	330000	450000.00
		% Rec	Surr: Toluene-d8	-	-			96.30	95.20	102.00	105.00	104.00	103.00	102.00	104.00	101	106.00	102	103.00
Volatile Organic Compounds	SW8260B	ug/Kg-dry	Ethylbenzene	1300	-			58.00	29.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			m,p- Xylene	2700	-			430.00	240.00	8700.00	ND	ND	8800.00	ND	8000.00	8300	ND	ND	ND
			o- Xylene	1500	-			130.00	60.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Styrene	1300	-			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Toluene	1300	-			370.00	200.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Xylenes total	4200	-			560.00	300.00	8700.00	ND	ND	8800.00	ND	7900.00	8400	ND	ND	ND
		% Rec	Surr: 1,2- Dichloroethane-d4	-	-			102.00	108.00	101.00	104.00	103.00	99.20	101.00	102.00	101	102.00	101	103.00
			Surr: 4-Bromofluorobenzene	-	-			97.40	93.20	94.40	96.40	93.90	94.30	95.20	95.50	96.8	100.00	92.8	92.20
			Surr: Dibromofluoromethane	-	-			103.00	108.00	99.10	98.40	102.00	92.80	99.20	98.00	100	102.00	93.4	96.80
			Surr: Tolouene-d8	-	-			94.00	92.90	100.00	96.10	100.00	102.00	99.40	102.00	100	98.80	100	99.60
Radionuclides	EPA 901.1	pCi/g	Potassium-40		-			28.32	24.28	27.36	25.90	24.63	16.70	21.80	19.69	20.073	17.66	18.486	12.892
								4.81	4.42	4.53	4.25	4.62	4.27	3.74	3.41	3.799	3.21	3.471	2.98
								0.99	1.41	0.87	1.08	1.53	2.73	1.13	1.08	1.055	1.20	1.371	1.083
			Radium-226		-	5		1.22	1.35	1.76	4.71	4.56	9.15	4.01	4.17	5.774	9.22	9.715	5.563
								0.31	0.34	0.35	0.71	0.74	1.33	0.67	0.63	0.891	1.32	1.371	0.866
								0.28	0.18	0.20	0.22	0.27	0.29	0.25	0.25	0.249	0.24	0.335	0.153
			Radium-228		-			1.82	1.90	1.44	1.34	1.12	0.48	0.72	0.76	1.327	0.81	1.131	0.486
								0.48	0.45	0.45	0.37	0.58	0.89	0.47	0.39	0.52	0.55	0.388	0.346
								0.25	0.29	0.52	0.42	0.61	0.95	0.51	0.57	0.611	0.49	0.312	0.826
	9310		Gross Alpha		-	15		15.00	10.50	17.10	27.00	38.10	46.80	24.40	23.80	28.8	55.70	59.2	60
								7.05	5.75	7.65	9.62	11.10	11.00	9.18	6.75	7.88	14.70	14.9	15.9
								9.76	9.15	11.20	10.20	9.05	4.69	10.30	5.24	6.53	11.50	9.31	10.5
			Gross Beta		-			24.50	19.40	27.80	36.90	29.80	42.90	23.00	28.70	37.5	35.40	35	42.5
								6.26	4.79	6.65	8.56	6.84	8.98	6.21	6.34	7.95	8.21	7.75	9.6
								5.64	4.13	5.38	6.62	4.94	5.89	6.17	5.07	5.41	5.83	4.55	6.14
Inorganics	SW9056A	mg/Kg-dry	Br	0.2	-			2.80	7.30	2.70	5.20	4.60	3.90	4.80	4.30	7	4.50	1.60	11.00
			Cl	52	-			260.00	750.00	1100.00	1700.00	1700.00	1300.00	1600.00	1100.00	1800	1100.00	440.00	2800.00
			SO4	0.75	-			36.00	46.00	21.00	36.00	35.00	16.00	17.00	13.00	16	26.00	17.00	39.00
	SW9034		sulfide	74	-			ND	ND	ND	ND	ND	ND	ND	270.00	140	ND	ND	ND
	E353.2		nitrate	1	-			0.10	1.40	0.70	0.16	0.54	0.69	1.00	0.06	0.84	10.00	5.10	7.90
	E354.1		nitrite	1	-			0.04	0.01	0.03	0.03	0.03	0.04	ND	0.26	0.041	0.01	ND	0.04
	A2510M	µmhos/cm	conductance	0.56	-			1200.00	1900.00	20000.00	3900.00	6500.00	24000.00	8900.00	21000.00	21000	9800.00	9100	60000.00
	SW9045D	units	pH	0	-			8.80	9.20	9.61	10.00	10.00	10.06	11.00	9.80	9.98	9.90	9.9	9.80
	A4500-CO2 D	mg/Kg-dry	alkalinity, bicarbonate	54	-			150.00	140.00	84.00	ND	ND	200.00	ND	ND	ND	ND	ND	ND
			alkalinity, carbonate	54	-			130.00	270.00	56.00	280.00	280.00	710.00	820.00	500.00	470	440.00	300.00	600.00
			alkalinity, total	54	-			280.00	410.00	140.00	730.00	650.00	910.00	1000.00	510.00	550	1300.00	610.00	940.00
	E365.1 R2.0		TP	6.6	-			220.00	240.00	330.00	160.00	130.00	57.00	59.00	450.00	62	170.00	200	190
	SW6020A		Ag	6.5	-			0.03	0.03	ND	0.44	0.37	1.30	0.53	ND	ND	0.49	0.54	0.48
			Al	5.1	-			7500.00	11000.00	17000.00	6600.00	6600.00	3000.00	3300.00	3000.00	2900	2500.00	2700.00	3100.00
			As	0.25	-			12.00	13.00	15.00	25.00	22.00	55.00	29.00	34.00	37	32.00	35.00	20.00
			Ba	0.45	-			40.00	42.00	7600.00	1600.00	1500.00	5500.00	2600.00	4900.00	5900	590.00	540.00	2000.00
			Ca	17	-			9400.00	9700.00	19000.00	22000.00	25000.00	63000.00	58000.00	63000.00	40000	31000.00	29000.00	52000.00
			Cr	0.25	-			11.00	22.00	28.00	11.00	11.00	14.00	8.20	9.80	12	8.10	7.60	19.00
			Fe	4.8	-			23000.00	40000.00	38000.00	27000.00	25000.00	34000.00	18000.00	22000.00	27000	29000.00	30000.00	19000.00
			K	11	-			710.00	1200.00	3300.00	2600.00	2600.00	2400.00	2400.00	2500.00	2500	2600.00	2500.00	2700.00
			Mg	1.8	-			4100.00	5400.00	9300.00	2800.00	3100.00	2400.00	3300.00	3600.00	1900	2600.00	2700.00	2000.00
			Mn	0.26	-			570.00	660.00	670.00	190.00	230.00	280.00	200.00	270.00	240	200.00	210.00	420.00
			Na	6.5	-			420.00	850.00	1000.00	1100.00	1100.00	1200.00	970.00	1100.00	780	2200.00	6000.00	6000.00
			Ni	0.27	-			20.00	24.00	55.00	92.00	74.00	200.00	87.00	110.00	130	140.00	140.00	140.00
			Pb	0.038	-			11.00	7.80	13.00	25.00	25.00	38.00	20.00	24.00	29	27.00	27.00	28.00
			Se	0.25	-			0.45	0.35	ND	4.80	4.60	15.00	6.50	12.00	11	15.00	16.00	7.30
			Sr	0.051	-			13.00	24.00	610.00	460.00	580.00	1000.00	640.00	810.00	790	570.00	530.00	1600.00
			Zn	0.64	-			36.00	43.00	95.00	130.00	730.00	340.00	160.00	220.00	120	380.00	480.00	230.00
Moisture	E160.3M	%	Moisture	0.05	-			15.00	14.00	10.00	14.00	14.00	16.00	15.00	14.00	16	14.00	14.00	36.00
Chemical Oxygen Demand	E4104 R2.0	mg/Kg-dry	COD	140	-			-	-	3000.00	4000.00	4600.00	5300.00	3600.00	3800.00	3700	970.00	890.00	2600.00
)rganic Carbon - Walkley-Blac	TITRAMETRIC	% by wt-dry	OC-WB	0.011	-			ND	ND	4.00	5.60	5.80	6.50	6.50	7.70	11	10.00	1.5	2.26
Oil & Grease	SW9071B - OG	mg/Kg-dry	O&G	110	-			370.00	150.00	64000.00	59000.00	83000.00	130000.00	110000.00	110000.00	130000	20000.00	34000	130000

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