Oil & Natural Gas Technology

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Quarterly Research Performance

Progress Report (Period Ending 06/30/2018)

Marcellus Shale Energy and Environment Laboratory (MSEEL)

Project Period (October 1, 2014 – September 30, 2019)

Submitted by:
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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

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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 work focused on integrating results and moving these results to publications and to high-profile presentations. A software system FIBPRO has been developed to analysis fiber-optic distributed acoustic sensing (DAS) and distributed temperature sensing (DTS) data and has been used to analysis the MSEEL data. Machine learning has been incorporated to better understand production as related to fiber-optic data. The microseismic data observed well above the Marcellus Shale can be understood as the extension of pre-existing fractures and geomechanical properties in the Marcellus and overlying Mahantango Formation and may not represent effective hydraulic fractures. Long-period long-duration (LPLD) slow slip events that may represent effective stimulation may have been overlooked in microseismic and can be crudely recognized on our older generation fiber-optic DAS data.

Kerogen extracted from the lower and upper Marcellus Shale samples were characterized using 13C solid-state NMR. The structural parameters of kerogen determined from 13C NMR were used to develop new regression models to accurately determine thermal maturity and hydrocarbon potential of shale. Significant papers are being assembled covering the biologic activity in the MSEEL wells in relation to biofilm formation and various new microbial communities.

Water production continues to be monitored and other than slight increases in the proportion of barium and strontium, the ionic composition of produced water changed very little through 888 days post completion. Organic compounds were never very high. After five years, benzene has declined below the drinking water standard of 5 µg/L.

In addition to updating production data and revision of logos, new log viewer has been prototyped to provide online generation of plots of MSEEL data. Prototype viewer is available at: http://157.182.4.178/wvulogviewer/log.html.

A report titled "Economic Impacts of the Marcellus Shale Energy and Environment Laboratory" has been released by the WVU Regional Research Institute, which cover the MSEEL site and documents the labor impact of the MSEEL (MIP3H and MIP5H) activities at 99 to 121 FTE's. The report can be found at http://rri.wvu.edu/wp-content/uploads/2018/06/MSEEL-Impacts.pdf, and is included as an appendix to this report.

Quarterly Progress Report

April 1 – June 30, 2018

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 FY2018 (April 1 through June 30, 2018).

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.

A summary of major lessons learned to this point of the project are provided as bullet points and will be added to as research is completed. New lessons are highlighted.

1) Synthetic based drilling mud is ecofriendly as well as helps with friction which resulted in faster drilling and reduced costs while leading to drilling waste from both the vertical and horizontal portions of the wells that passed all toxicity standards.
2) Microseismic monitoring does not completely define propped fractures and the extent of stimulated reservoir volume from hydraulic fracture stimulation. Requires integration of data from core, logs and slow slip seismic monitoring.
3) Production logging documents significant variations in production between completion types, stages and even clusters. Variations in production provide the necessary data for robust reservoir simulation.
4) Complex geology in laterals can lead to intercommunication between stages and reduced fracture stimulation efficiency. This can be mitigated with limited entry (engineered completions) that significantly improves fracture stimulation efficiency. NNE has continued the practice in subsequent wells. Planned production logging will help to define production efficiency.
5) The significant part of air emissions are in truck traffic, not in drilling and fracture operations on the pad. Emissions from both the pad and trucking can be reduced with operational modifications such as reducing dust and truck traffic during fracture stimulation (e.g., Sandbox) from bifuel (natural gas-diesel) engine operations.
6) Dual fuel engines demonstrated lower carbon monoxide (CO) emissions than diesel only operation. Dual fuel operations could reduce onsite diesel fuel consumption by 19 to 63% for drilling and 52% for hydraulic stimulation.
7) Biologic activity cannot be eliminated with biocides, only delayed. The biologic activity results in a unique biota that may affect operations. There may be other methods to control/influence biologic activity.
8) Water production changes rapidly after fracture stimulation in terms of volume (500 bbl/day to less than 1 bbl/day) and total dissolved solids (TDS from freshwater, 100 to 150g/L). Radioactivity is associated with produced water, not drill cuttings.
9) Drill cutting radioactivity levels were within West Virginia DEP standards of 5 pCi/g above background. This was true of both vertical and horizontal (Marcellus) sections.
10) Using the green drilling fluid Bio-Base 365, all drill cutting samples, vertical and horizontal, passed the USEPA's method 1311 (Toxicity Characteristics Leaching Procedure or TCLP) for inorganic and organic contaminants. This indicates that under Federal and West Virginia solid waste rules, these solid wastes would not be considered hazardous.

11) The absence of hazardous TCLP findings suggest that drilling fluids, not the inherent properties of the Marcellus formation, play the dominant role in determining drill cutting toxicity.
12) Concerning produced water quality, hydraulic fracturing fluid was nearly identical to makeup (Monongahela River) water. Initial produced water underwent a radical change in ionic composition and a two order of magnitude increase in total dissolved solids (TDS).
13) Produced water is highly saline and total dissolved solids (TDS) rapidly increased to a maximum between 100 and 150 g/L. There was negligible change in ionic composition between the initially produced water and that sampled five years post completion.
14) Concentrations of both 226 Ra and 228 Ra increased rapidly through the produced water cycle to combined maximum concentrations of 20,000 pCi/L in the first year post completion. These radium isotopes are critical regulatory determinants.
15) The volume of produced water decreased rapidly from nearly 500 bbl/day to less than 1 bbl/day after one year. Over this cycle produced water averaged about 6 bbl/day.
16) Developed a new frequency attribute calculated from the DAS data that reveals cross-stage fluid communication during hydraulic fracturing.
17) New microorganisms have been recognized in the deep biosphere represented by the Marcellus Shale. Understanding these organisms could reduce downhole well damage and precipitation of Ra in surface facilities.
18) Developed two different neural-network and support vector regression models to identify key parameters predicting potential screen out events and ultimate well performance.
19) Developed a new process to better analysis long-term fiber-optic DTS data to better understand differences in production efficiency and relation to completion efficiency as displayed by microseismic and DAS data.
20) Marcellus fractures result in cross-flow between stages and reduced completion efficiency that appears to affect production efficiency.
21) Improved understanding on the propagation of microseismic indications of fracturing upward into the overlying Mahantango Formation.
22) Machine learning can be used to better predict production based on fiber-optic data and identify individual stages that contribute significant production.
23) The cross-flow can be detected using advanced seismic attributes applied to fiber-optic DAS data. This is the first instance of using this approach with DAS data and has resulted in the development of software and a patent discovery.
24) Geochemical data is providing insight into the structure and chemistry of kerogen in the Marcellus and its interaction with completion fluids.

Project Management Update

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

The project team is tracking nine (9) milestones in this budget period.

	Task	Milestone	Status	Due Date
1.	2.1.2	Develop kerogen models of shale from different zones of MSEEL well and compare them to shales from wells in other parts of the basin	On Track Kerogen samples extracted from sidewall cores covering the whole Marcellus formation (ranging from Marcellus Top to Marcellus-Onondaga transition) have been analyzed using 13C NMR. New schematic kerogen models are being developed using lattice parameters and being compared to models of kerogen derived from wells in less mature part of the basin. Plan to synthesize results and submit publications in Fall 2018.	9/30/2018
2.	2.1.8	Geostatistical Well Analysis	On Track A paper will be presented at URTeC (July) on a predictive data-driven machine learning model to understand the MSEEL well's performance and forecast the gas production using DTS data and daily flowing time as dynamic inputs. Papers using image analysis and nitrogen adsorption to quantify nano-pores in the Marcellus have been submitted.	9/30/2018
3.	2.1.7	Improved Reservoir Simulation for field implementation	On Track An improved history match that incorporates the unconventional fracture model and how to use this knowledge to increase production, efficiently space laterals and reduce cost. A manuscript has been accepted for presentation to the Society of Petroleum Engineers Annual Meeting.	10/31/2018
4.	2.1.5	Create a Comprehensive Fracture Model	On Track A provisional patent application for analysis of fiber-optic data is moving forward. Papers are accepted for fall meetings of SPE (Eastern Regional and National) and AAPG.	11/30/2018

5.	2.2.1	Completion of four additional methane audits to further assess temporal variability in methane emissions	On Track Four previous audits have shown significant temporal variability. Four or more (up to 8 more over 2 years) audits well help us understand (by increasing sample size) if variability correlates with temporal production, cumulative production, age, water production, or seasonal variability. Results will be presented in reporting, publications are possible.	12/31/2018
6.	2.1.2	Understanding the type, amount and origin of natural gas	On Track Data analysis and interpretations of pyrolysis data are currently underway. We expect to generate some preliminary data and make some conference presentations in Fall 2018 and submit publications by Spring 2019	3/30/2019
7.	2.2.1	Successful deployment of an open path methane monitoring system during site audits	On Track Industry seeks to reduce costs of audits and streamline greenhouse gas reporting programs. This will teach us if near-field, indirect quantification or detection methods are applicable to the Appalachia region, versus the well-established research in relatively flat and calm Barnett and Fayetteville plays.	3/30/2019
8.	2.2.1	Characterize chemical transformations during produced water storage from well 3H	On Track Will complete characterization of changes in produced water chemistry (specifically Fe, Sr, Ba, Ra 226, Ra 228) and biological activity (CO2 and CH4 production) that occur during short term storage (20 days). Measures of Ra activity (Ra 226 and Ra 228) of the solid precipitate formed during short term storage of produced water will also be completed.	3/30/2019
9.	N/A	Decision on Phase 3 Wells		12/31/2018

Topic 1 – Geologic Engineering

Approach

We submitted several additional papers using MSEEL results to show the importance of multidisciplinary and multi-institutional approaches to integrate geoscience, engineering and environmental studies to develop new knowledge of subsurface geology and engineering and to identify best practices that can optimize hydraulic fracture stimulation to increase flow rates, estimated ultimate recovery in order to reduce the number of wells and environmental impact.

Results and Discussion

A final paper was submitted to URTeC (URTeC: 2902641) for presentation in Houston (July) by Payam Kavousi Ghahfarokhi, Timothy Carr, Shuvajit Bhattacharya, Justin Elliott, Alireza Shahkarami and Keithan Martin entitled A Fiber-optic Assisted Multilayer Perceptron Reservoir Production Modeling: A Machine Learning Approach in Prediction of Gas Production from the Marcellus Shale. The study utilized the recorded data of a distributed temperature sensing (DTS) and distributed acoustic sensing (DAS) fiber-optic system from the MIP3H. A predictive data-driven model was developed to understand the well's performance and forecast the gas production using DTS data and daily flowing time as dynamic inputs, from May 2016 to May 2018. We used 1320 DTS measurements along the lateral of the well MIP-3H for each day and upscaled to a stage scale by an averaging method. A multi-layer perceptron neural network (MLPNN) was trained with stage-based daily DTS data, and daily flowing time to predict gas production for the next day. We carried out a sensitivity analysis by removing each stage DTS attribute from the input dataset to identify the most influential stages in predicting gas production. The sensitivity analysis (SA) shows that several stages carry higher weights in predicting gas production, while several stages have less impact on prediction accuracy. In contrast to DTS, DAS data was only recorded during hydraulic fracturing of the well. DAS energy variance attribute, which could be inversely related to stage stimulation efficiency, was computed for each stage and compared with the results of the neural network SA. Stages with higher variance in DAS energy (less efficient stimulation) have less effect on neural network accuracy. This relationship is more significant for stages that are completed with limited entry approach in zones with similar minimum horizontal stress. The results of the sensitivity analysis was also compared with flow scanner production logging data. Results suggests that DAS data is more correlated with sensitivity analysis results than production logging data.

Plan for Next Quarter

We will work to integrate the machine learning module into the FIBPRO software system.

Topic 2 – Geophysical & Geomechanical

Approach

Geophysical

Working to integrate all the microseismic and fiber-optic data to improve the resolution of both techniques. The fiber-optic data along with examination of the microseismic at very low has high potential to recognize long-period long-duration (LPLD) seismic events that are generally overlooked but could be the major result of fracture stimulation. A manuscript has been submitted to the Journal Interpretation. The abstract is provided under the Geophysical section.

Geomechanical

During this quarterly period, the influence of a discrete fracture network on the growth of hydraulic fractures was investigated through the use of numerical modeling. The numerical model updated in a previous quarter was used to compute hydraulic fracture dimensions for stage 11 through stage 20 of well MIP-5H.

Results & Discussion

Geophysical

Microseismic monitoring, fiber-optic distributed acoustic sensing (DAS), and distributed temperature sensing (DTS) observations were made during the hydraulic fracture stimulation of the MIP-3H well in the Marcellus Shale in northern West Virginia. DAS and DTS data measure strain and temperature, respectively, along a fiber optic cable located behind the casing of the well. The presence of long-period long-duration (LPLD) events, similar in appearance to tectonic tremors, is documented in the microseismic events generated during stimulation of the MIP-3H. LPLD events are generally overlooked, but reveal the presence of significant deformation produced during hydraulic fracture stimulation. The image logs, well logs and drilling reports reveal numerous pre-existing natural fractures or faults with unfavorable orientations in the ambient stress field for tensile failures. Comparison of microseismic and DAS amplitude spectra reveal the presence of local low frequency energy events with duration of several hundred seconds (Figure 2.1). These low frequency events are interpreted as LPLD events. The spatial and temporal similarities of these events indicate that DAS data could be used to identify LPLD events during hydraulic fracture stimulation.

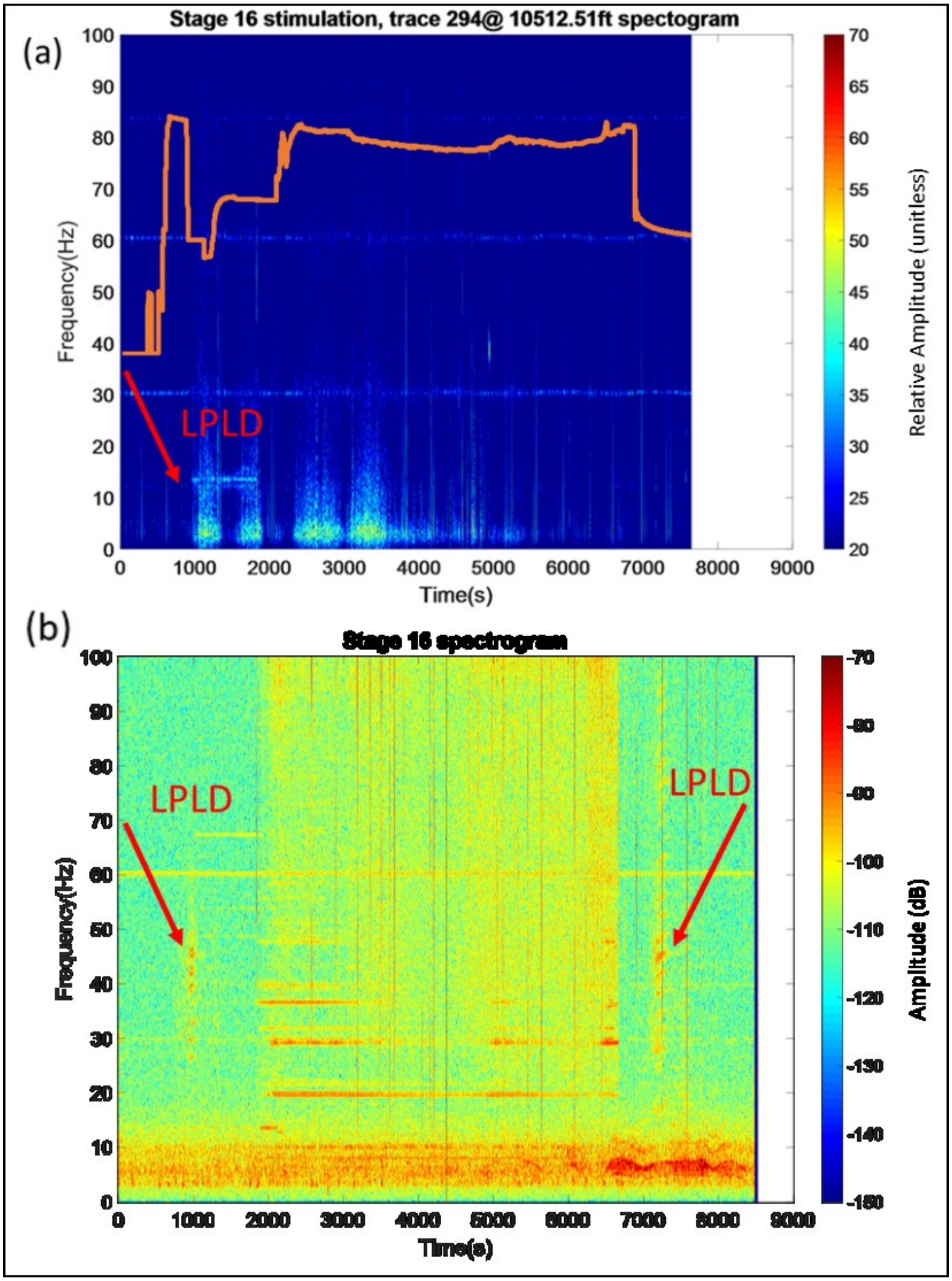


Figure 2.1. Stage 16 stimulation cause low frequency zones in DAS trace#294, which is in Stage 15. b) Spectrogram of sum of the z-components of Stage 16 microseismic. Note the common pumping noise at 30 and 60Hz.

Geomechanical

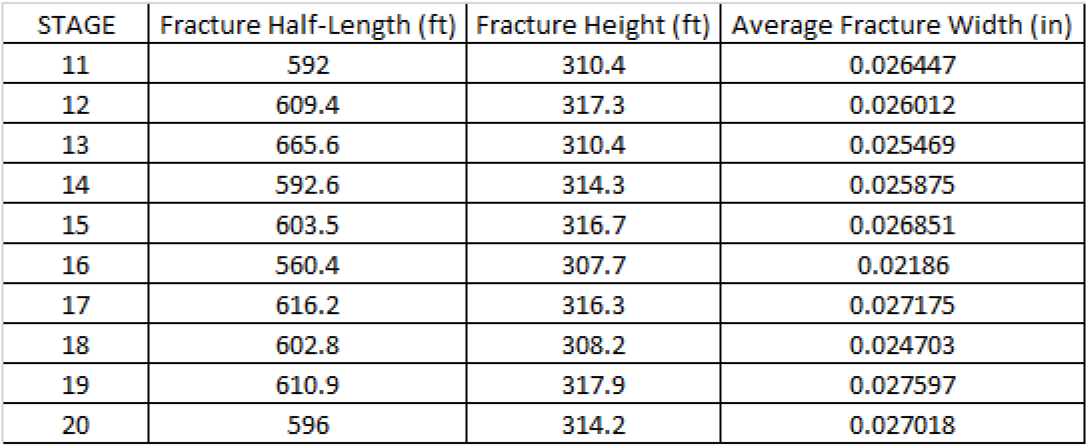
A paper was submitted to the proceedings of the Eastern Section SPE and AAPG by Yixuan Zhu and T. R, Carr entitled *Estimation of "Fracability" of Marcellus Shale: A Case Study from the MIP3H in Monongalia County, WV, USA*. The paper will be presented in Pittsburgh, PA during the meeting (October 9-11)

The paper discusses that the traditional brittleness index may not be unique and explicit index of fracability. There is a discrepancy between the brittleness index calculated from mineralogy and elastic moduli. Compared with microseismic data, brittleness index does not provide an explanation for distribution of microseismic events. At the MSEEL site conditions are favorable for fracture growth vertically upwards and pre-existing fractures may easily connect with each other. A study on stress state using Mohr's circle, indicates that overpressure observed in Marcellus Shale at the MSEEL site may maintain fractures at certain dip angle open, although most of them are in non-active state. In addition, fractures in an overpressure formation may be easily activated as pore pressure is increased by hydraulic fracturing. Unconfined compressive strength (UCS) is used to estimate rock strength in overpressure strata. The result calculated from empirical equation indicates that Marcellus Shale has significantly lower rock strength than the underlying Onondaga Limestone. Rock strength of Mahantango is higher than Marcellus and increases upwards, but the difference is not great, which may permit hydraulic fractures to propagate upwards.

Work continues on a stage by stage analysis of fracture stimulation. Table 2.1 shows the computed hydraulic fracture geometries for the modeled MIP-5H stage 11 through stage 20. As an example, Figure 2.2 shows the hydraulic fracture geometry for one of the primary induced hydraulic fractures in stage 20 of well MIP-5H. Figure 2.3 shows the cumulative proppant mass versus time (calculated and measured), Figure 2.4 shows the slurry volume injected versus time (calculated and measured), and Figure 2.5 shows the surface pressure versus time (calculated and measured) for stage 20 of well MIP-5H.

Microseismic data was available for all stages modeled during this quarterly period for well MIP-5H. Microseismic, well, and hydraulic fracture geometry data are presented in a three-dimensional space, as shown below. Figures 2.6 through 2.15 show side views of modeled hydraulic fracture geometries and available measured microseismic events and magnitudes for stage 11 through stage 20, respectively, for well MIP-5H. Figure 2.16 shows an overview of all newly modeled hydraulic fracture geometries, available microseismic event data, and the entire MIP-5H wellbore. Figure 2.17 shows a top view of all newly modeled hydraulic fracture geometries, available microseismic event data, and the nearby section of the MIP-5H wellbore. Figure 2.18 shows an orthogonal projection of all newly modeled hydraulic fracture geometries, available microseismic event data, and the nearby section of the MIP-5H wellbore.

Table 2.1. Computed Hydraulic Fracture Geometries – Stage 11 through Stage 20 – MIP-5H



STAGE	Fracture Half-Length (ft)	Fracture Height (ft)	Average Fracture Width (in)
11	592	310.4	0.026447
12	609.4	317.3	0.026012
13	665.6	310.4	0.025469
14	592.6	314.3	0.025875
15	603.5	316.7	0.026851
16	560.4	307.7	0.02186
17	616.2	316.3	0.027175
18	602.8	308.2	0.024703
19	610.9	317.9	0.027597
20	596	314.2	0.027018

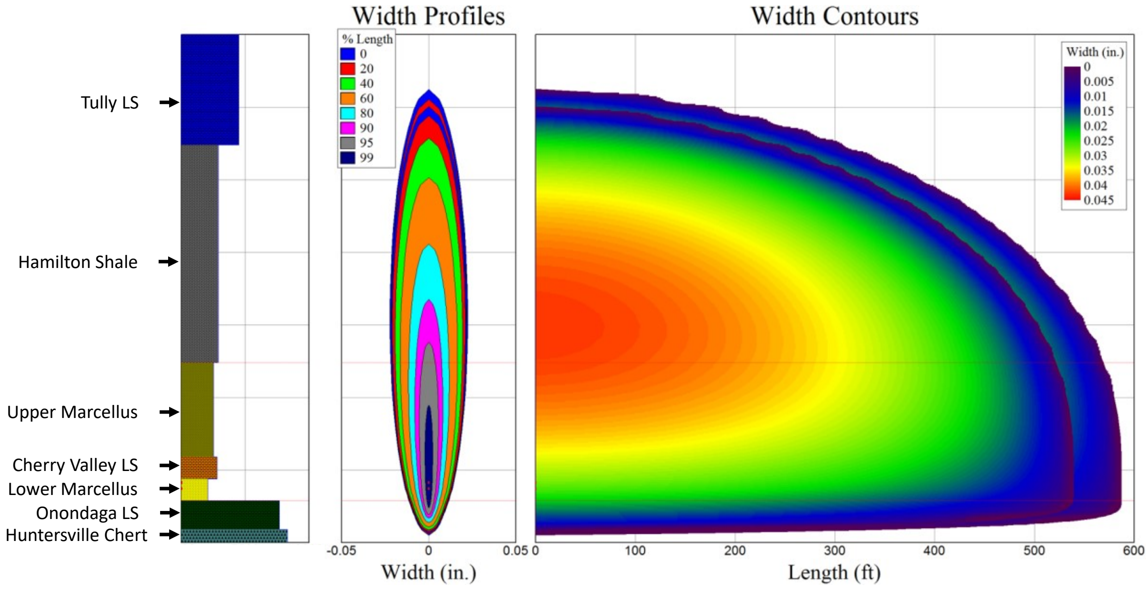


Figure 2.2. Primary Hydraulic Fracture Geometry for Stage 20 – MIP-5H

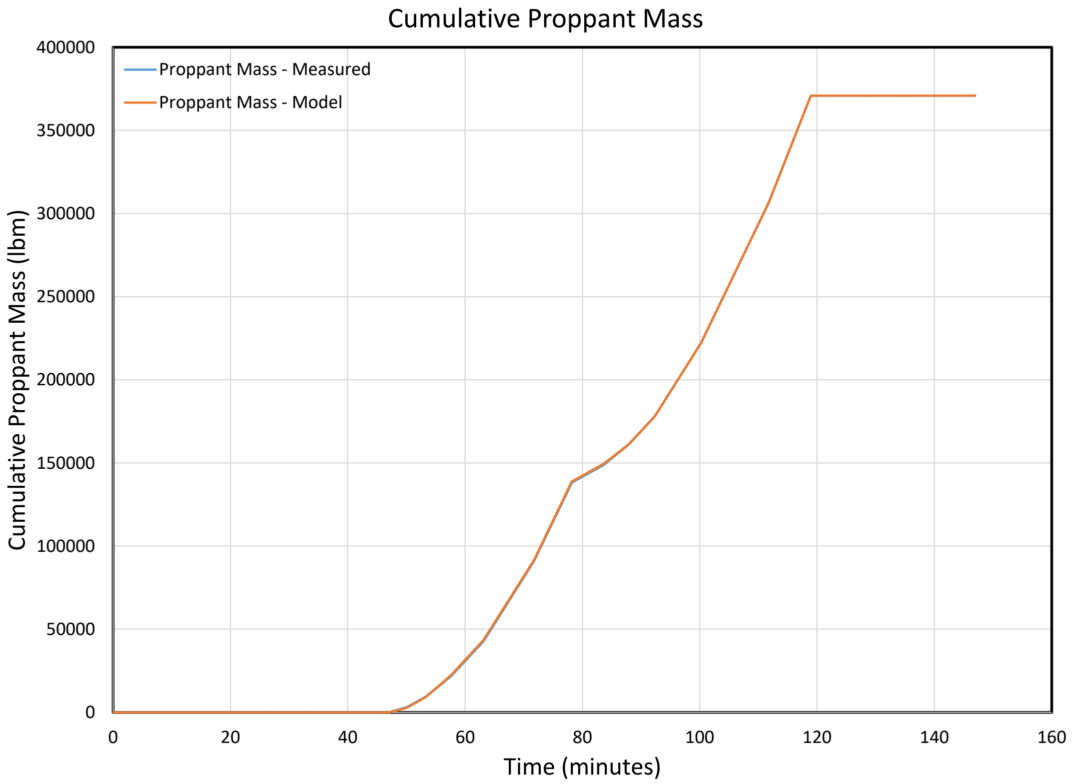


Figure 2.3. Cumulative Proppant Mass Injected for Stage 20 – MIP-5H

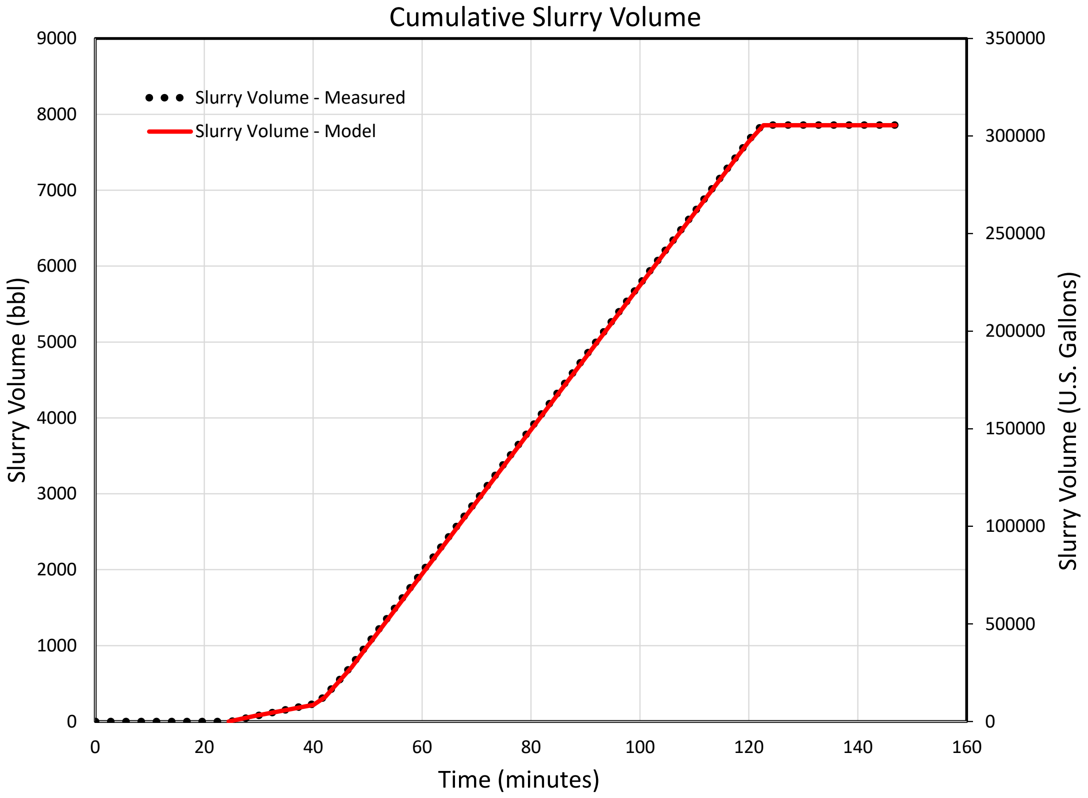


Figure 2.4. Cumulative Slurry Volume Injected for Stage 20 – MIP-5H

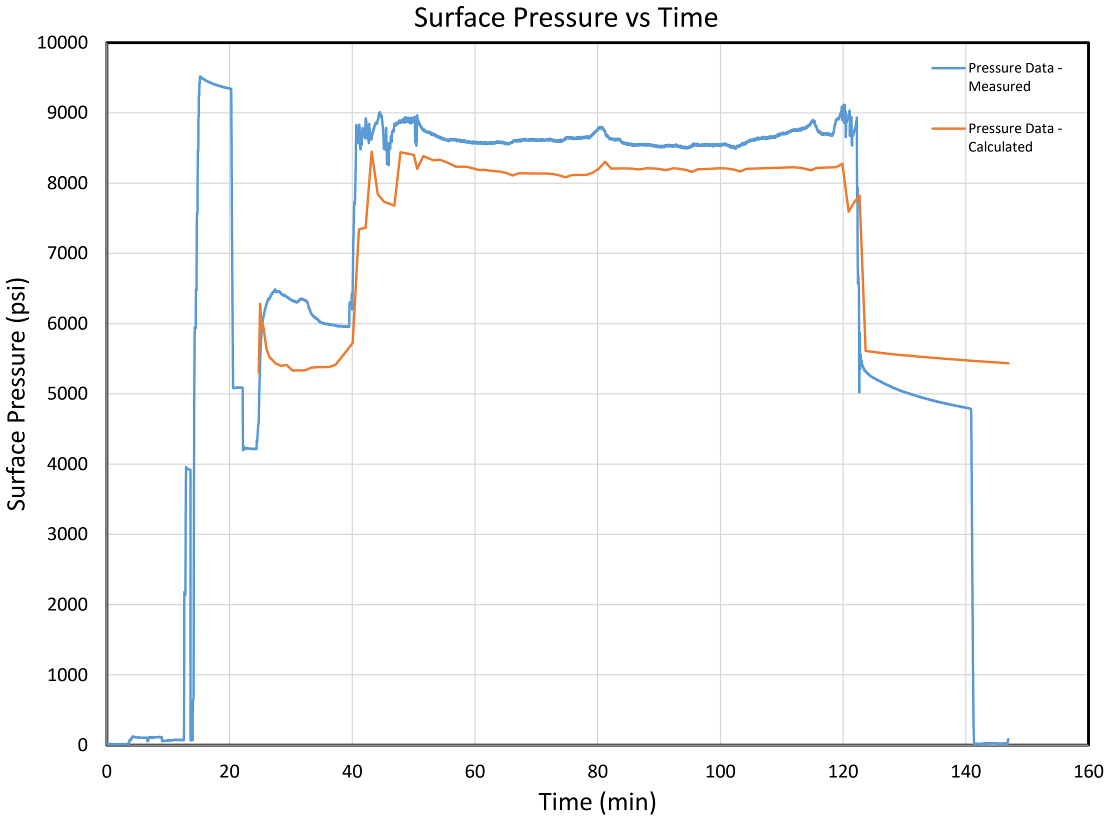


Figure 2.5. Surface Pressure versus Time for Stage 20 – MIP-5H

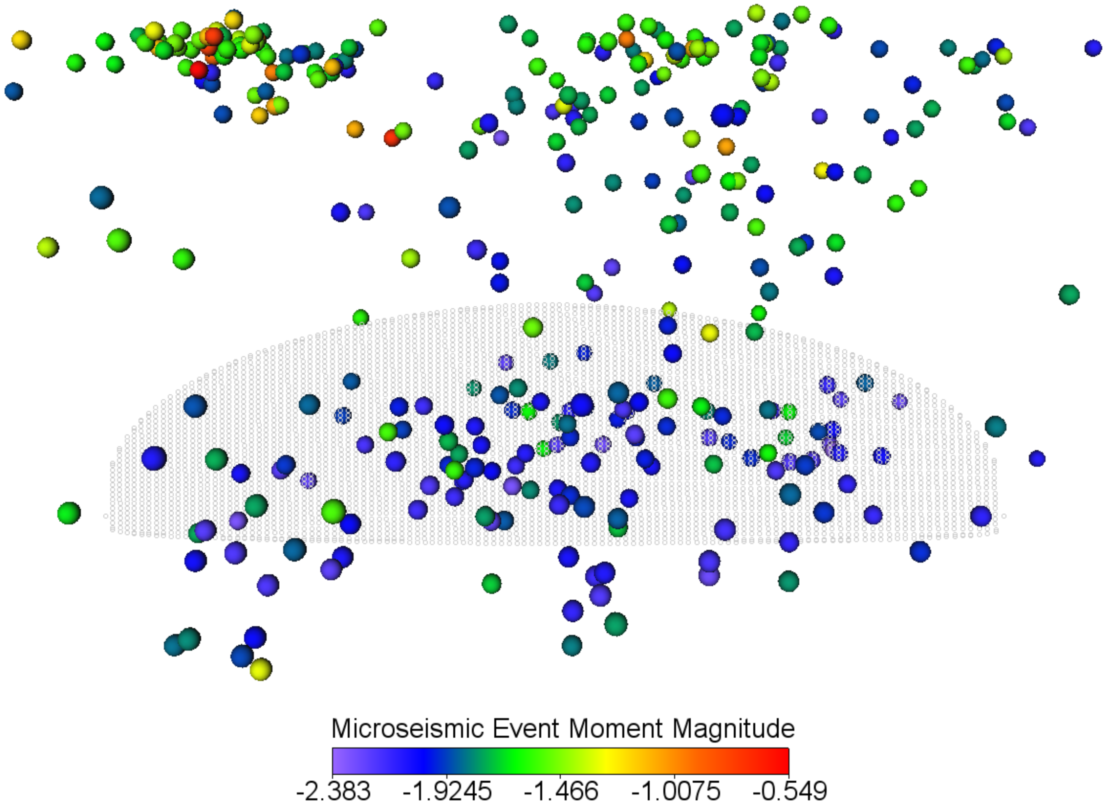


Figure 2.6: Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 11 – MIP-5H

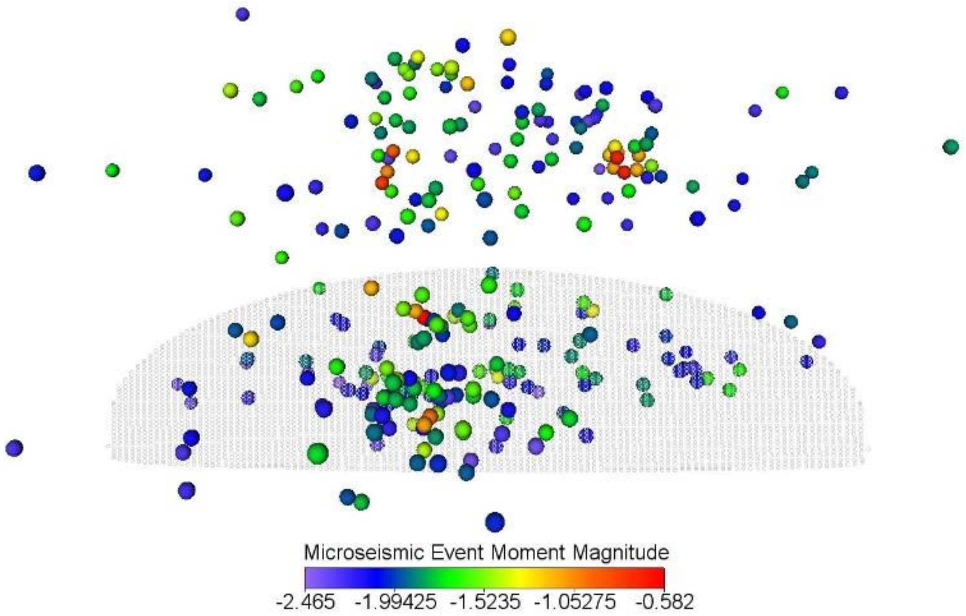


Figure 2.7. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 12 – MIP-5H

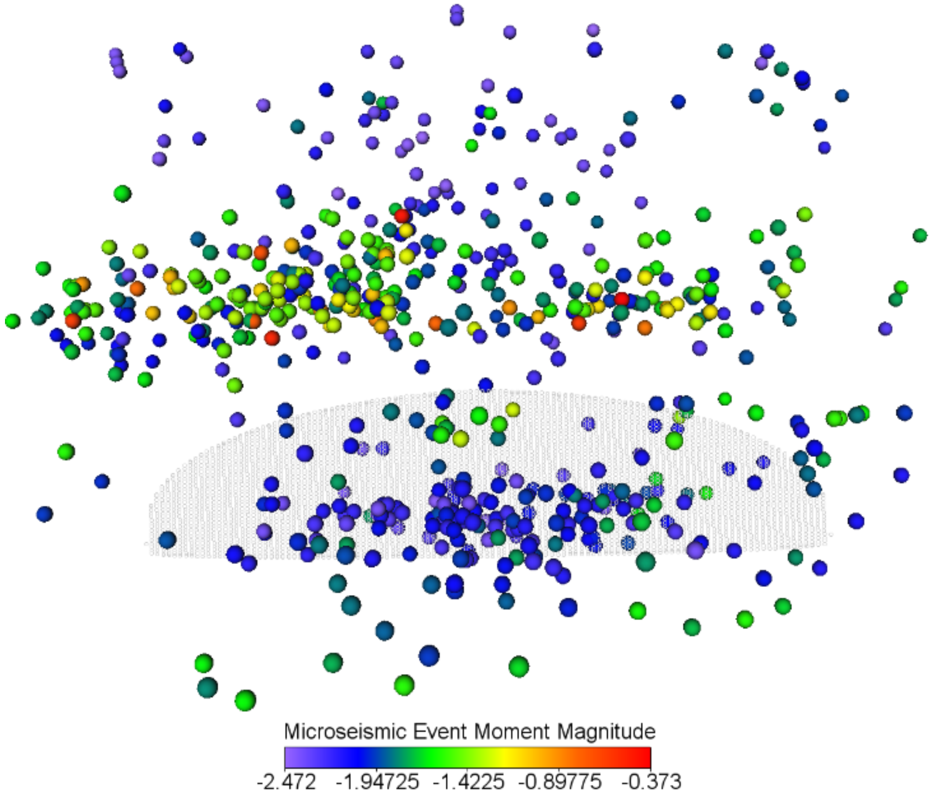


Figure 2.8. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 13 – MIP-5H

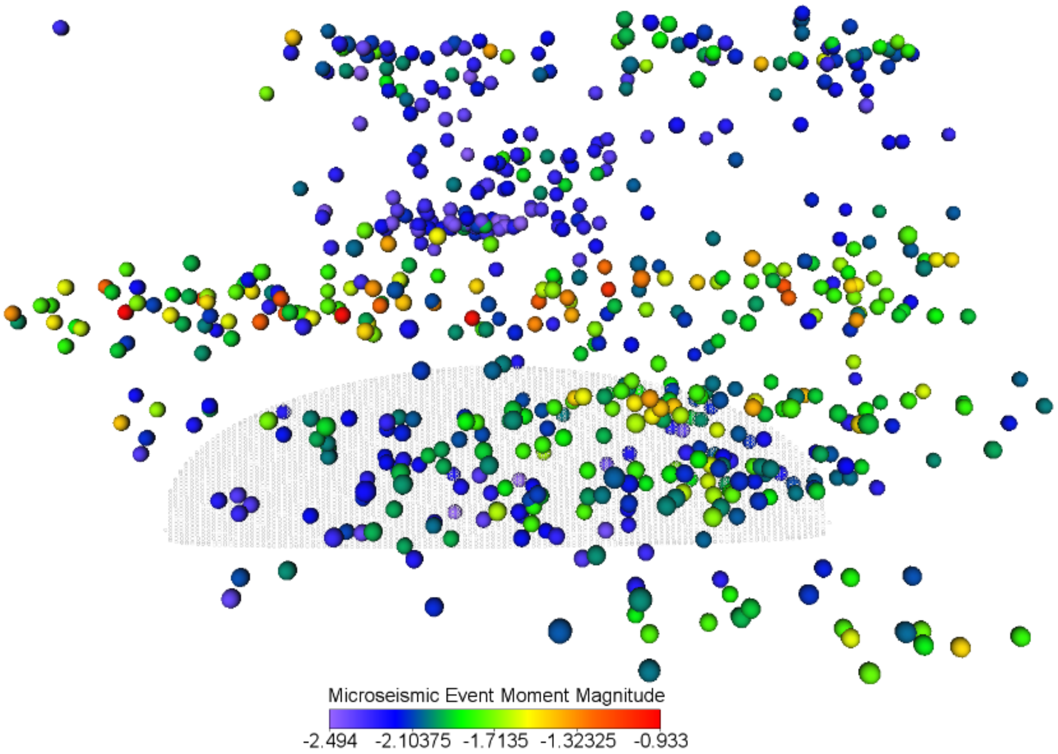


Figure 2.9. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 14 – MIP-5H

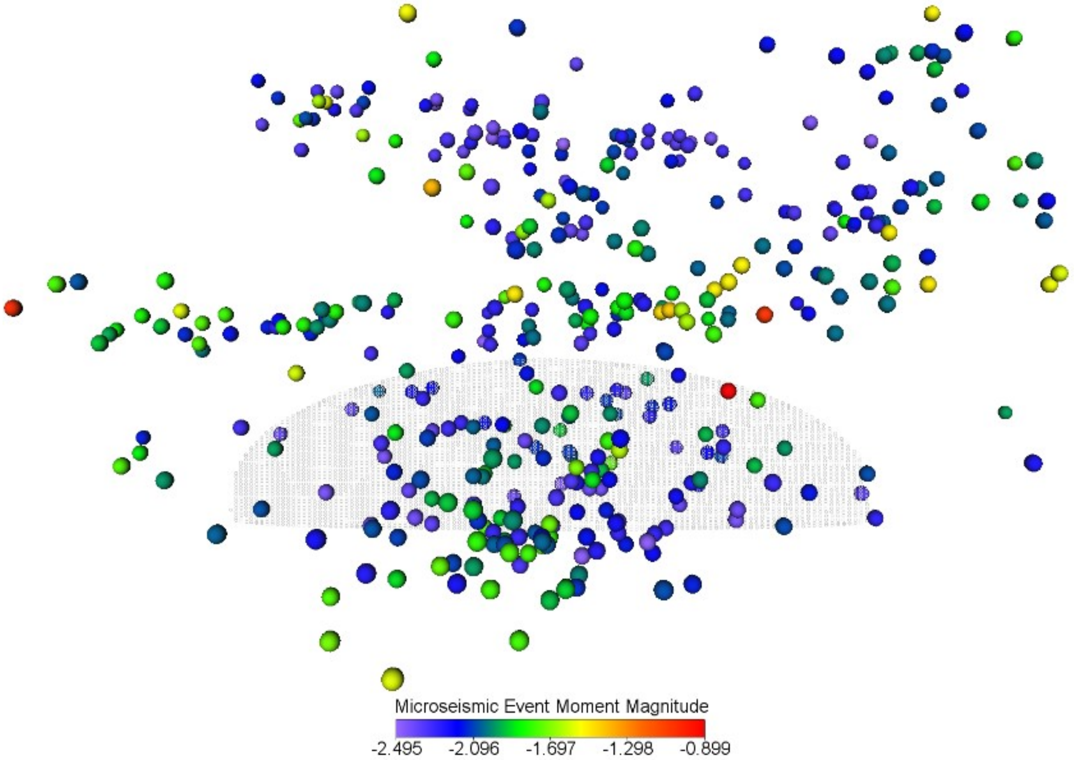


Figure 2.10. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 15 – MIP-5H

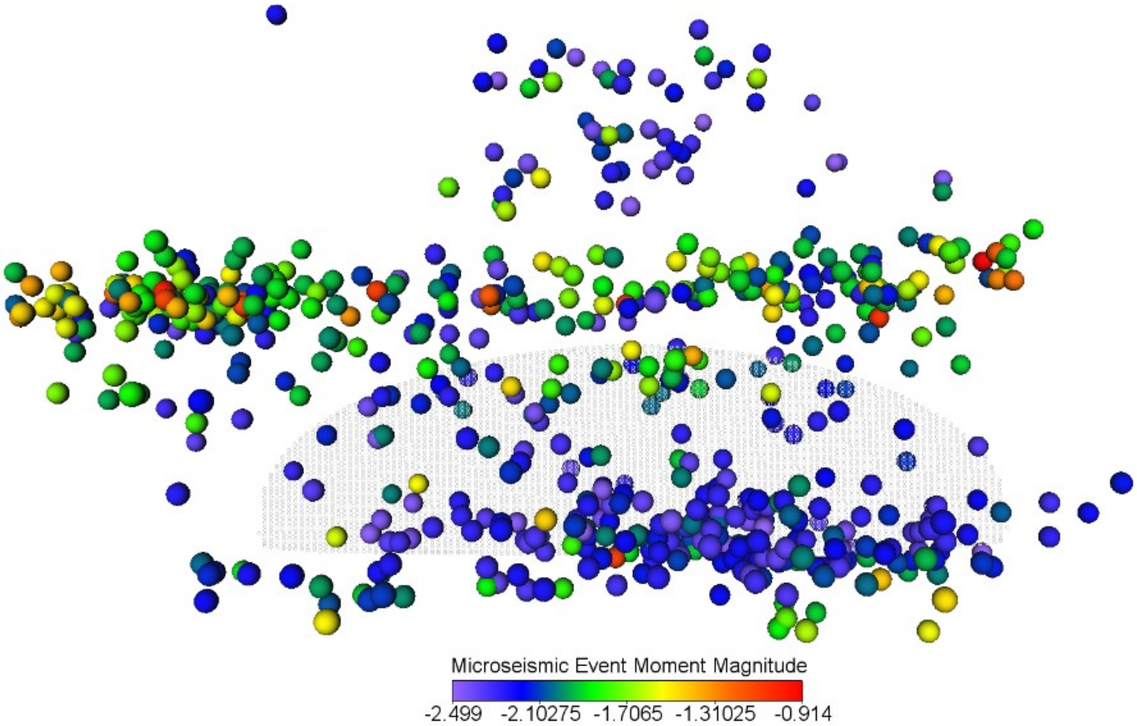


Figure 2.11. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 16 – MIP-5H

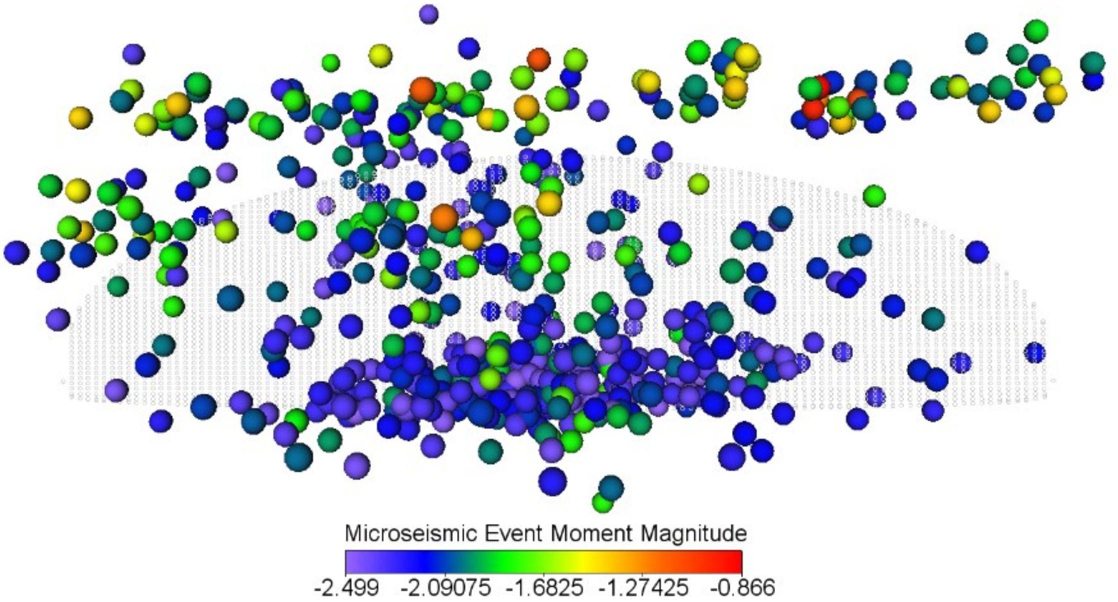


Figure 2.12. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 17 – MIP-5H

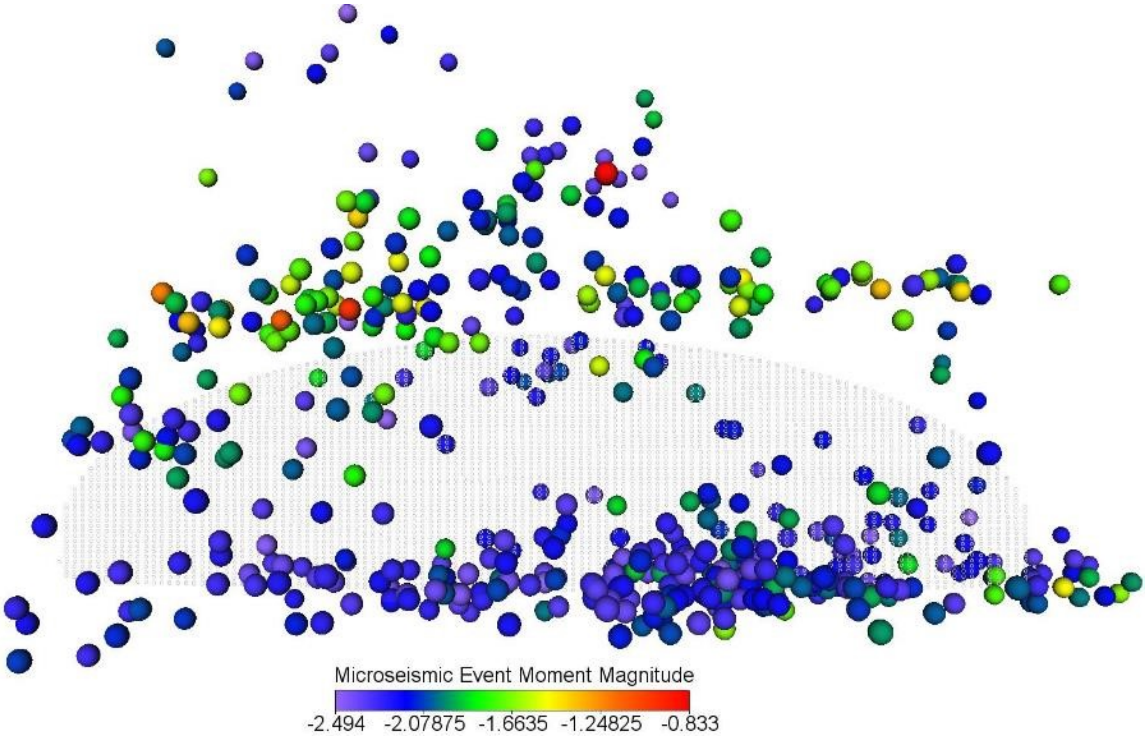


Figure 2.13. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 18 – MIP-5H

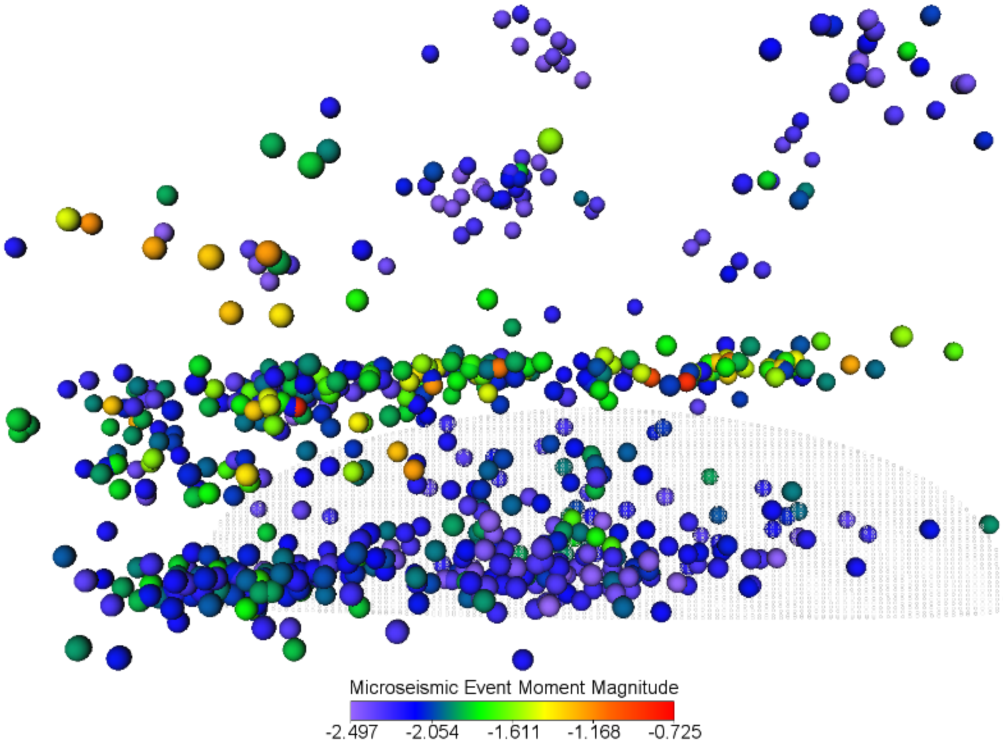


Figure 2.14. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 19 – MIP-5H

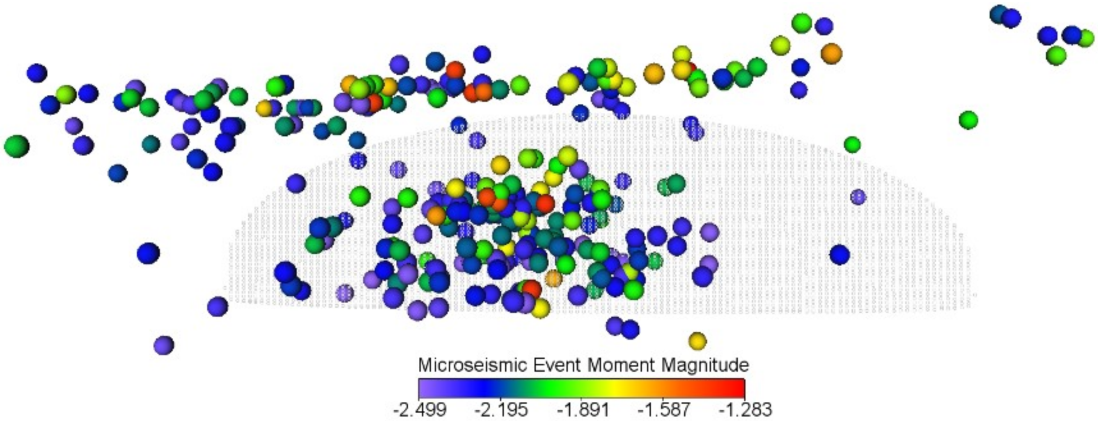


Figure 2.15. Side View of Calculated Primary Hydraulic Fracture and Measured Microseismic Events and Magnitudes for Stage 20 – MIP-5H

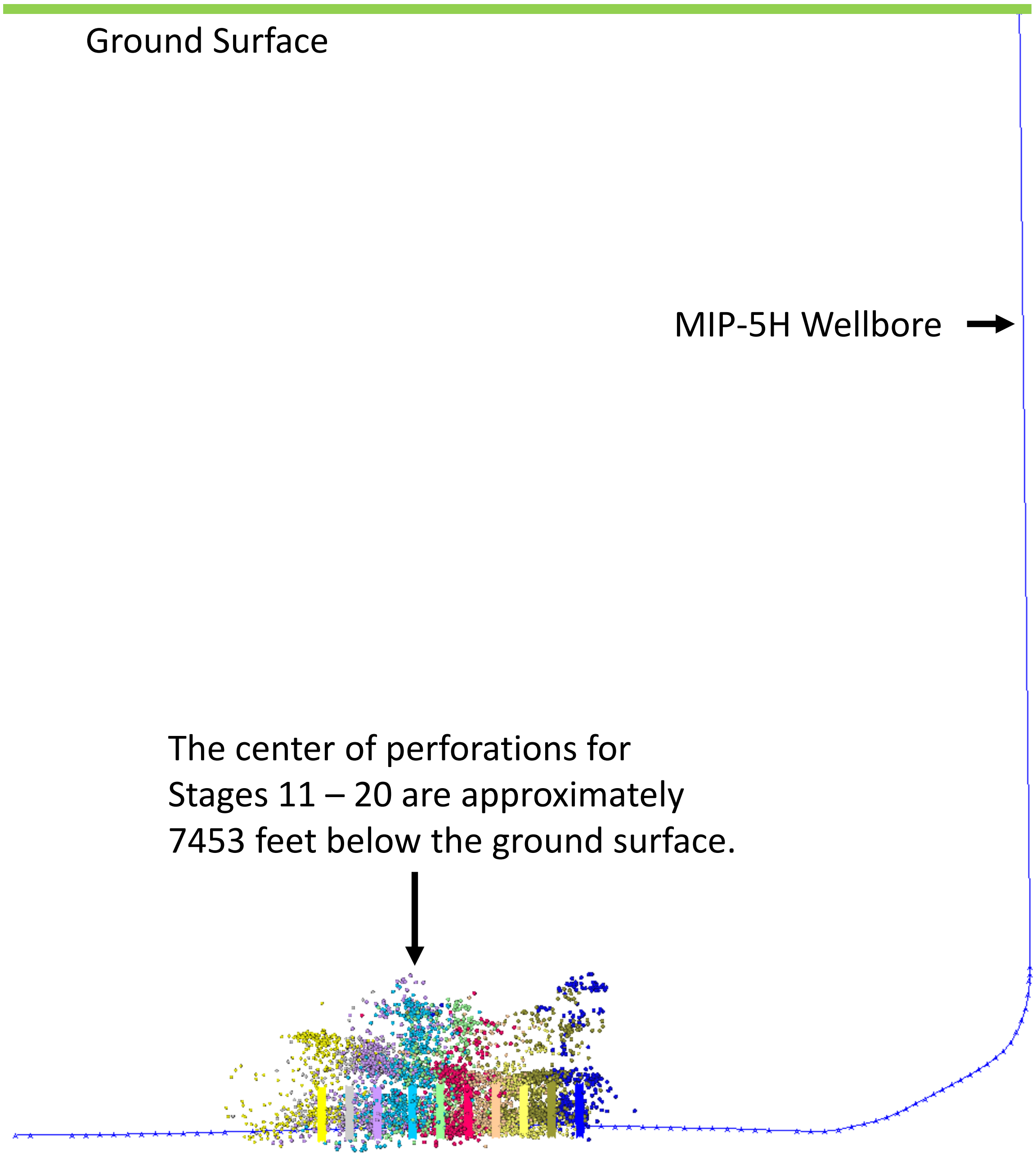


Figure 2.16. Overview of Calculated Primary Hydraulic Fracture Geometries, Available Measured Microseismic Events, and Entire Wellbore for Stage 11 through Stage 20 – MIP-5H

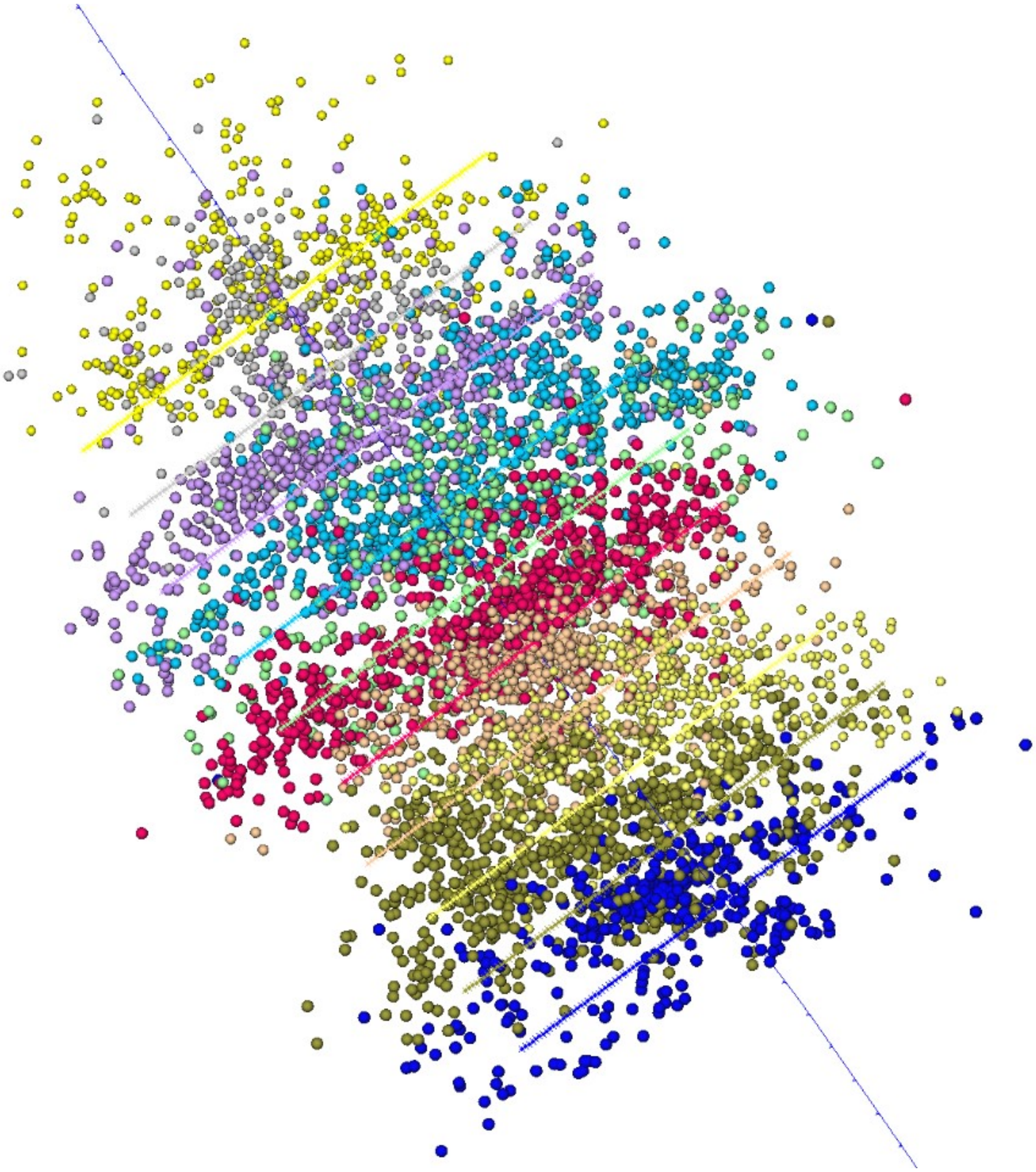


Figure 2.17. Top View of Calculated Primary Hydraulic Fracture Geometries, Available Measured Microseismic Events, and Nearby Wellbore for Stage 11 through Stage 20 – MIP-5H

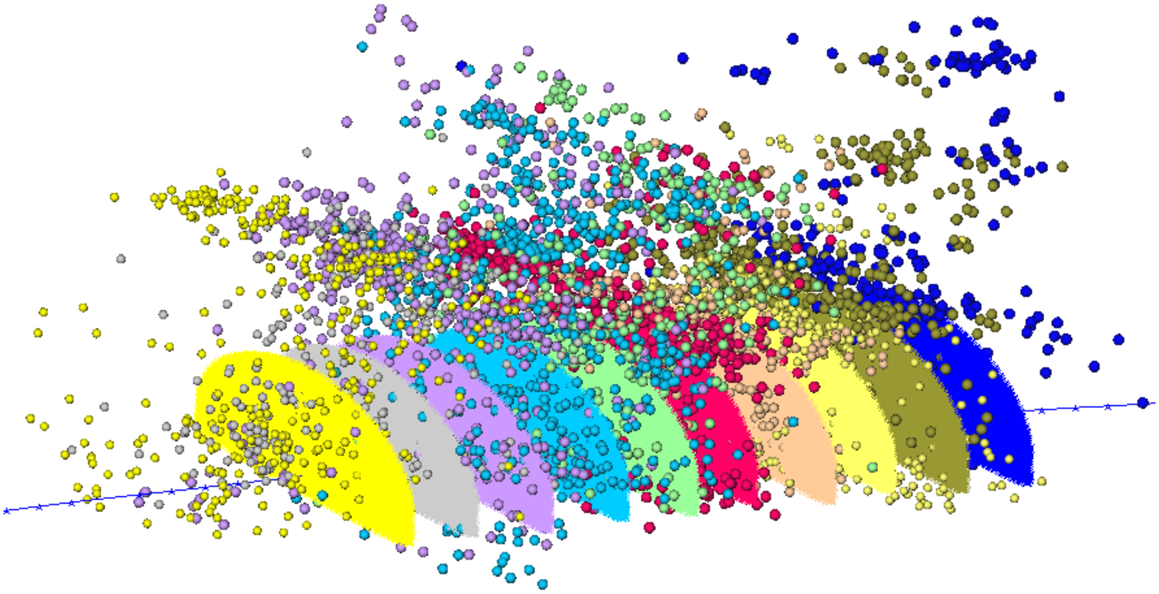


Figure 2.18. Orthogonal View of Calculated Primary Hydraulic Fracture Geometries, Available Measured Microseismic Events, and Nearby Wellbore for Stage 11 through Stage 20 – MIP-5H

Plan for Next Quarter

Geophysical

Continue work to revise LPLD paper submitted to the Journal Interpretation and to integrate the microseismic analysis into the FIBPRO software.

Geomechanical

The modeling study will be continued to investigate additional stimulation stages at well MIP-5H through the use of available information on the hydraulic fracturing field parameters (fluid volumes, pumping rate, proppant schedule, and geophysical data). The analysis of microseismic data will be continued and a comparison of hydraulic fracture geometries will be made with available microseismic data

Topic 3 – Deep Subsurface Rock, Fluids, & Gas

Approach

The main focus of the subsurface team led by Sharma this quarter was to analyze core, fluid and gas samples collected from the MSEEL site. Members of Sharma's lab group (Dr. Warrier and Mr. Wilson) and Dr. Hanson from Mouser's lab group continue to coordinate and supervise all sample collections. Samples were also distributed to the research team at OSU and NETL for analysis under different sub-tasks. Several talks and presentations were given at local and regional conferences /universities.

Results & Discussion

Sharma’s Lab

Understanding spatial heterogeneity of kerogen across the entire Marcellus basin

Kerogen was extracted from the lower and upper Marcellus Shale samples from MSEEL and other parts of the basin (to cover a maturity ranging of 0.8 VRo to 3 VRo). All samples were characterized using 13C solid-state NMR. The structural parameters of kerogen determined from 13C NMR were used to develop new regression models to accurately determine thermal maturity and hydrocarbon potential of shales. A Manuscript currently under review in the journal Scientific Reports. Results will be presented at the upcoming Eastern Section AAPG conference in Pittsburgh.

Developing new structural models for kerogen extracted from MSEEL well

Schematic models have been developed for kerogen extracted from sidewall cores from an entire depth ranging from Marcellus Top to Marcellus Onondaga transition. For example, the kerogen structure for Marcellus Top is shown in Figure 3.1.

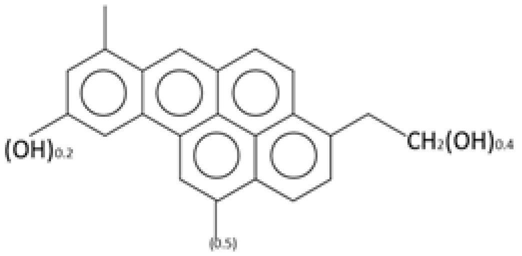


Figure. 1 Unit kerogen structure of kerogen extracted Marcellus Top from MSEEL well.

The molecular structures of MSEEL kerogen samples were then compared with the previously published kerogen structural models of similar kerogen ‘type’ and maturity. The comparison highlighted the limitation of using a general kerogen “type” for developing molecular models and determining physicochemical properties of kerogen. A manuscript summarizing key findings is currently under review in the journal *Scientific Reports*. Results will be presented at conferences in spring 2019.

Experiments to understand kerogen-frac fluid and interaction

The high P-T shale- fracturing fluid interaction experiments were conducted by students J. Pilweski and Vikas Agarwal in Sharma’s lab. The samples include a shale sample from the producing zone in MSEEL well and two other shale samples from other parts of the basin to cover a maturity range from 0.8 VRo to 3 VRo. The inorganic and organic analysis of the samples has been completed and reported in John Pilweski’s MS thesis. Currently, the team is working on the process of extracting kerogen from all the shale samples used in these high P-T experiments. Pilweski has completed his MS thesis and manuscript summarizing his results is currently under preparation for journal Environmental Science and Technology.

Understanding the type, amount and origin of gas.

Results from the open and closed pyrolysis experiments are currently being analyzed by Ph.D. student V. Agrawal. The samples used in these studies include samples from MSEEL as well as from other parts of the basin covering the entire maturity range from 0.8 VRo to 3 VRo. Researchers will submit a manuscript to the journal AAPG bulletin by Spring- Summer 2019.

Microbial lipid analysis of sidewall cores from MSEEL

Ph.D. student Rawlings Akondi finished all analysis and is currently finalizing the interpretations of the lipid biomarker distribution and variety in samples obtained from the Marcellus Shale and Mahantango Formations. A manuscript summarizing the results is currently under review in journal Geomicrobiology.

Analyzing the effect of storage on microbial community structure in subsurface cores.

Differences in yield and variety of microbial lipid biomarkers will be examined between fresh sidewall cores collected from the MSEEL and an old Marcellus core stored in Geological Survey for a very long time. The team will compare the lipids to understand the effect of storage on the distribution of the signature lipid biomarkers. A manuscript summarizing results will be submitted to the Frontiers in Microbiology in Spring-Summer 2019.

Wilkins Lab:

The team worked extensively with confocal laser-scanning microscopy to image biomass and associated ‘extracellular polymeric substances; EPS’ under both atmospheric and high-pressure conditions. Using probes that bind specifically to DNA and sugars in EPS to image these constituents, the preliminary data indicate that *Halanaerobium* generates more EPS under high-pressure conditions (a finding supported by complementary proteomics datasets), driving ‘clumping’ behavior of the biomass.

Figure 3.2. Clumping biomass within high-pressure incubation vials that have been incubated at 5000 psi at 40 °C. The ‘wispy’ filaments visible within the tubes are mixtures of biomass and EPS material.

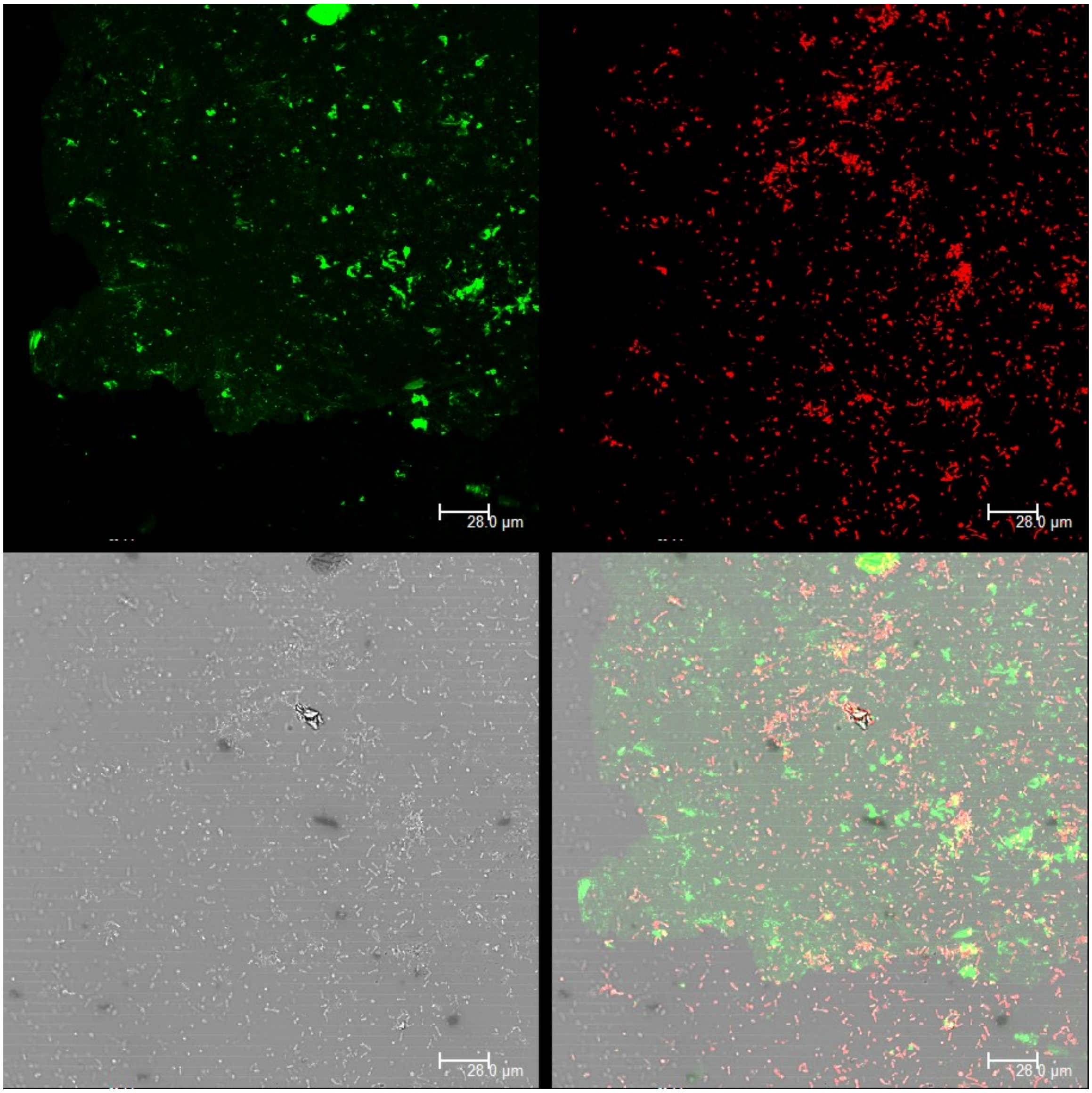


Figure 3.3. Confocal Laser Scanning Microscopy image of *Halanaerobium* biomass incubated under 5000 psi conditions. Top-left: A sugar-binding probe that indicates the distribution of EPS material within the field of view. Top-right: DNA stain for *Halanaerobium*. The composite image (bottom-right) shows the association of biomass with EPS material. Our group is currently working on statistical analyses between images generated under high- and atmospheric-pressure conditions.

Cole Lab

Fluid Analysis

This quarter, Cole Lab worked on interpreting data from the fluid analysis from both MSEEL wells (MIP 3H and MIP 5H), and comparing the geochemical evolution of brines from this location to other hydraulic fracturing sites. Precipitates from several of the fluid samples were analyzed by SEM. The mineralogy of secondary mineral phases was dominated by akaganeite. In addition, $BaCl_2$ was identified in the solid phase, suggesting that solubility of this phase may be limiting Ba in these fluids (Figure 3.4). This may have implications for geochemistry of other elements such as Ra.

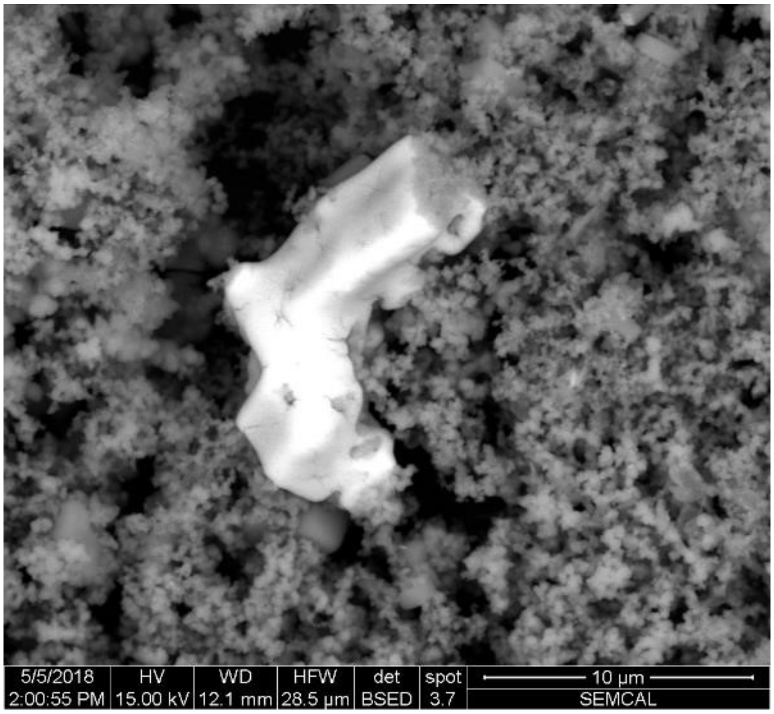


Figure 3.4. Barium chloride (bright center) surrounded by fine grained akaganeite from MIP3H fluids.

Additionally, the team are contributing authors for the paper led by Morgan V. Evans (Mouser Lab) on microbes in hydraulic fracturing fluids, including review of supporting fluid chemistry data that we have. This involved inspection of the raw data output to try to determine if any of the trace species were detectable in from the analysis of our fluid samples.

Products

Sharma's Lab

Agrawal V and Sharma S, 2018. Molecular characterization of kerogen and its implications for determining hydrocarbon potential, organic matter sources and thermal maturity in Marcellus Shale. Fuel 228: 429–437.

Agrawal V and Sharma S, 2018. Testing utility of organogeochemical proxies to assess sources of organic matter, paleoredox conditions and thermal maturity in mature Marcellus Shale. Frontiers in Energy Research 6:42.

Agrawal, V. & Sharma, S. 2018. Improved Kerogen models for determining hydrocarbon potential and thermal maturity of shales. Scientific Reports (in review)

Agrawal, V. & Sharma, S. 2018. Pitfalls in modeling physicochemical properties of Shale using kerogen type. Scientific Reports (in review)

Akondi R, Sharma S, Trexler R, Mouser PJ, Pfiffner SM, 2018. Microbial Lipid Biomarkers Detected in Deep Subsurface Black Shales Geomicrobiology (in review)

Akondi R, Sharma S, Trexler R, Mouser PJ, Pfiffner SM, 2018. Stable Carbon Isotope Ratios of Lipid Biomarkers in Deep Subsurface Formations of the Marcellus Shale. Biogeosciences (in preparation)

Wrighton's Lab

A manuscript incorporating data from MSEEL has been published, led by Mikayla Borton, a graduate student in the Wrighton laboratory:

> M.A. Borton, D.W. Hoyt, S. Roux, R.A. Daly, S.A. Welch, C.D. Nicora, S. Purvine, E.K. Eder, A.J. Hanson, J.M. Sheets, D.M. Morgan, S. Sharma, T.R. Carr, D.R. Cole, P.J. Mouser, M.S. Lipton, M.J. Wilkins, K.C. Wrighton. Coupled laboratory and field investigations resolve microbial interactions that underpin persistence in hydraulically fractured shales. *Proceedings of the National Academy of Sciences*. June 2018, 201800155; DOI: 10.1073/pnas.1800155115.

A manuscript incorporating data from MSEEL is in revision. Review comments were received from Nature Microbiology and we have been encouraged to submit a revised manuscript. This work was led by Rebecca Daly, a researcher in the Wrighton laboratory.

> R.A. Daly, S. Roux, M.A. Borton, D.M. Morgan, M.D. Johnston, A.E. Booker, D.W. Hoyt, T. Meulia, R.A. Wolfe, A.J. Hanson, P.J. Mouser, M.B. Sullivan, K.C. Wrighton, M.J. Wilkins. Viruses control dominant bacteria colonizing the terrestrial deep biosphere after hydraulic fracturing. *Nature Microbiology.* (in revision)

An invited book chapter in the Springer Protocols series in is press. This book chapter details best practices in contamination control, handling core material, and extraction of nucleic acids from shale cores, based on protocols developed for MSEEL cores. This work was led by Rebecca Daly, a researcher in the Wrighton laboratory.

> R.A. Daly, K.C. Wrighton, M.J. Wilkins. Characterizing the deep terrestrial subsurface microbiome. In R. Beiko, W. Hsiao, J. Parkinson (Eds.), *Microbiome analysis: methods and protocols,* Methods in Molecular Biology. Clifton, NJ: Springer Protocols. (in press)

Two manuscripts are in preparation/review from the Wrighton laboratory which incorporate MSEEL microbial data:

- *"Genomic Comparisons of* Methanohalophilus *and* Halanaerobium *strains reveals adaptations to distinct environments."* This work is led by two graduate students: Mikayla Borton in the Wrighton lab and Anne Booker in the Wilkins lab.
- *"*Candidatus *Marcellius: a novel genus of Verrucomicrobia discovered in a fractured shale ecosystem."* To be submitted to Microbiome journal. This research is led by a visiting post-doc, Sophie Nixon, in the Wrighton laboratory.

Kelly Wrighton gave two invited talks presenting MSEEL data:

- 19th Annual Microbiology Student Symposium, University of California Berkeley, April 28, 2018
- ASM Microbe, Atlanta, Georgia, June 9, 2018

Wilkins Lab

Revisions have been performed for a manuscript submission to Nature Microbiology (Daly et al.)

A manuscript (Booker et al.) is currently being drafted that focuses on biofilm formation by a dominant shale-dwelling microorganism (*Halanaerobium*) under high-pressure conditions that are representative of the deep subsurface.

Mouser's Lab

Panescu J, Daly R, Wrighton K, Mouser, PJ. (2018). Draft Genome Sequences of Two Chemosynthetic Arcobacter Strains Isolated from Hydraulically Fractured Wells in Marcellus and Utica Shales. Genome Announcements, 6 (20), e00159-18. doi:10.1128/genomeA.00159-18.

University of Vermont seminar, Department of Civil and Environmental Engineering. The Role of Microbial Communities in Hydraulically Fractured Shale Wells and Produced Wastewater, 4/2018.

Gordon Research Conference, Environmental Sciences: Water. The Outsiders: Microbial Survival and Sustenance in Fractured Shale, 6/2018.

Plan for Next Quarter

Sharma's Lab

Finish analysis of all kerogen samples using 13C solid state NMR by the end of Fall 2018, 3) Develop schematic kerogen models to understand any change on interaction with fracturing fluids.

Mouser's Lab

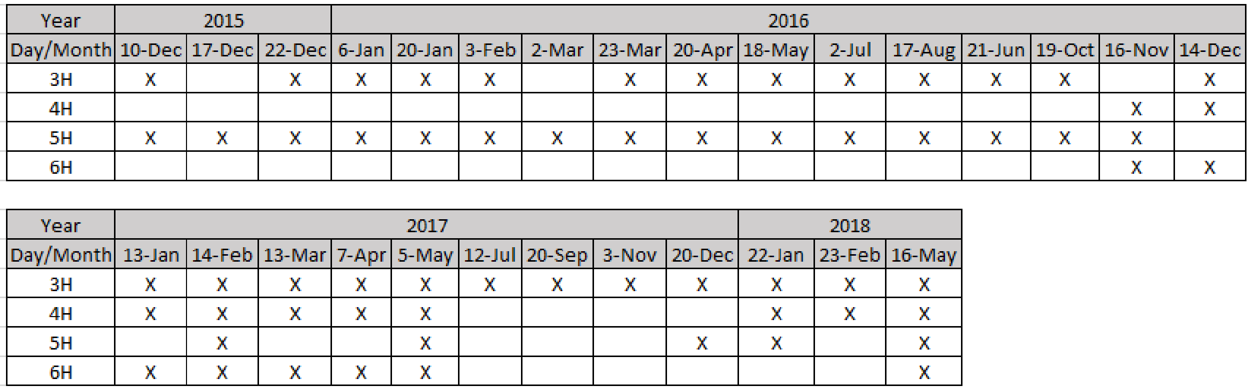
Morgan Volker has a paper in review by co-authors and a second paper in preparation related to MSEEL; these manuscripts will be submitted for peer review in the next quarter.

Topic 4 – Environmental Monitoring – Surface Water & Sludge

Approach

Almost two and a half years into the post completion part of the program, the water and solid waste component of MSEEL has continued to systematically sample flowback and produced water volumes. During year one of the study, hydraulic fracturing fluid, flowback, produced water, drilling muds and drill cuttings were characterized by their inorganic, organic and radio chemistries. In addition, surface water in the nearby Monongahela River was monitored upstream and downstream of the MSEEL drill pad. Toxicity testing per EPA method 1311 (TCLP) was conducted on drill cuttings in both the vertical and horizontal (Marcellus) sections to evaluate their toxicity potential. Sampling frequency has been slowly scaled back following well development. **Table 4.1** shows an "X" for sample collection dates. Wells 4H and 6H were brought back online in late 2016. Other blank sample dates in **Table 4.1** indicate that samples were not collected, due to lack of availability of produced water from the well(s).

Table 4.1. MIP sampling events are indicated with an "X".



Year	2015			2016												
Day/Month	10-Dec	17-Dec	22-Dec	6-Jan	20-Jan	3-Feb	2-Mar	23-Mar	20-Apr	18-May	2-Jul	17-Aug	21-Jun	19-Oct	16-Nov	14-Dec
3H	X		X	X	X	X		X	X	X	X	X	X	X		X
4H															X	X
5H	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
6H															X	X

Year	2017									2018		
Day/Month	13-Jan	14-Feb	13-Mar	7-Apr	5-May	12-Jul	20-Sep	3-Nov	20-Dec	22-Jan	23-Feb	16-May
3H	X	X	X	X	X	X	X	X	X	X	X	X
4H	X	X	X	X	X					X	X	X
5H		X			X				X	X		X
6H	X	X	X	X	X							X

Results & Discussion

Trends in produced water chemistry

Major ions

While makeup water was characterized by low TDS (total dissolved solids) and a dominance of calcium and sulfate ions, produced water from initial flowback is essentially a sodium/calcium chloride water (Figure 4.1). Other than slight increases in the proportion of barium and strontium, the ionic composition of produced changed very little through 888 days post completion.

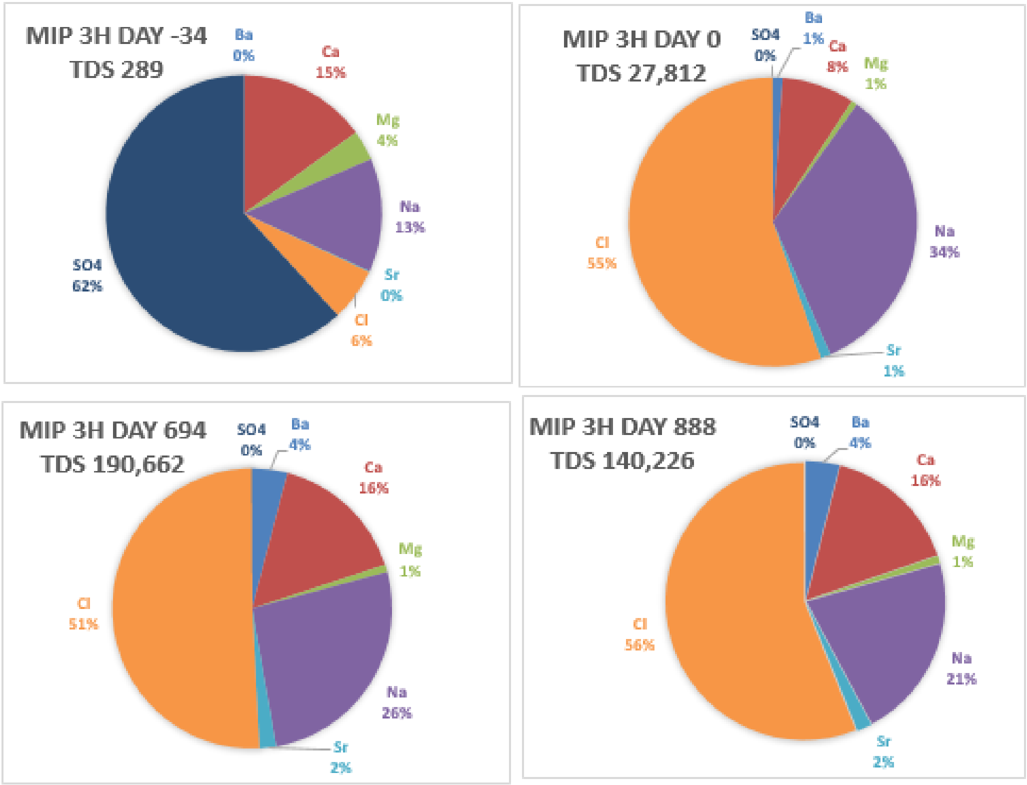


Figure 4.1. Changes in major ion concentrations in produced water from well MIP 3H. From left to right the charts represent makeup water from the Monongahela River, produced water on the first day of flowback and produced water on the 888th day post completion.

While TDS increased rapidly over the initial 90 days post completion values had been consistently between 100,000 and 150,000 mg/L through day 888 and have since continued an upward trend, increasing to around 225,000 mg/L for 3H (Figure 4.2).

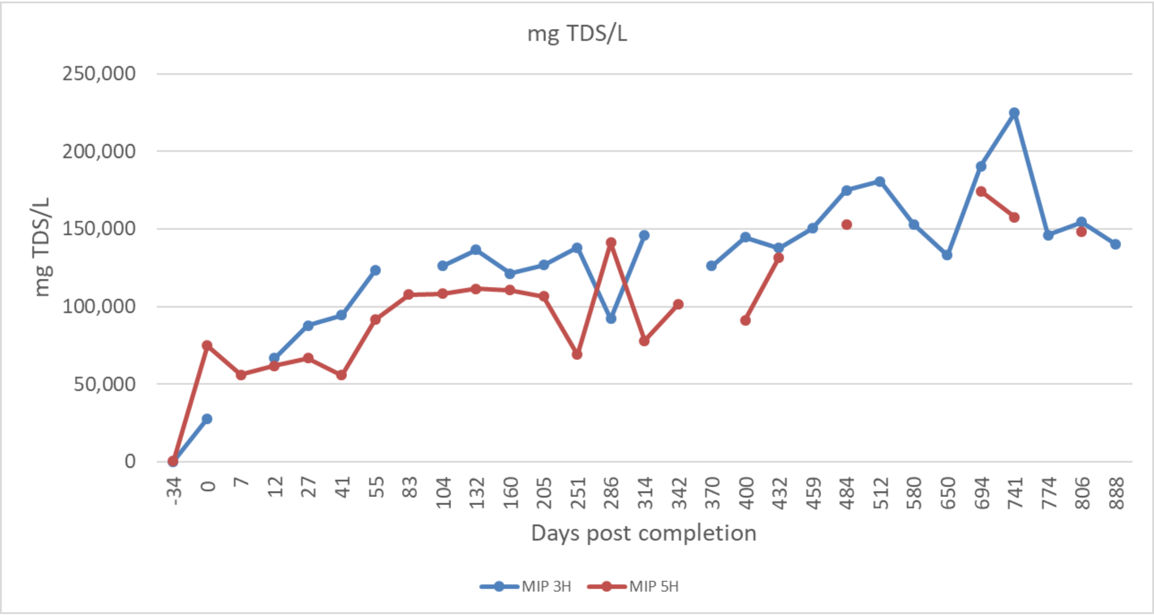


Figure 4.2. Changes in produced water TDS sdc (sum of dissolved constituents) through the first 806 days post completion (3,5H).

The older 4H and 6H wells offer insight into the longer-term TDS trend. Those wells only came back on line during this quarter after a shut-in period of 315 days and those results vary but they are much lower than the current values for wells MIP 3H and 5H. Both 4H and 6H were shut down during late 2017. TDS was very low at MIP 4H during the first sampling event of early 2018. Calculated TDS was 2,455 mg/L and lab reported TDS was 2,300 mg/L. A similar low TDS trend was noted when wells went back online around 1,793 days post-completion (after being shut-in for 315 days). A rise in TDS subsequently follows the initial return to online status with TDS maxing out around 120,000 for MIP 4H and 60,000 for 6H.

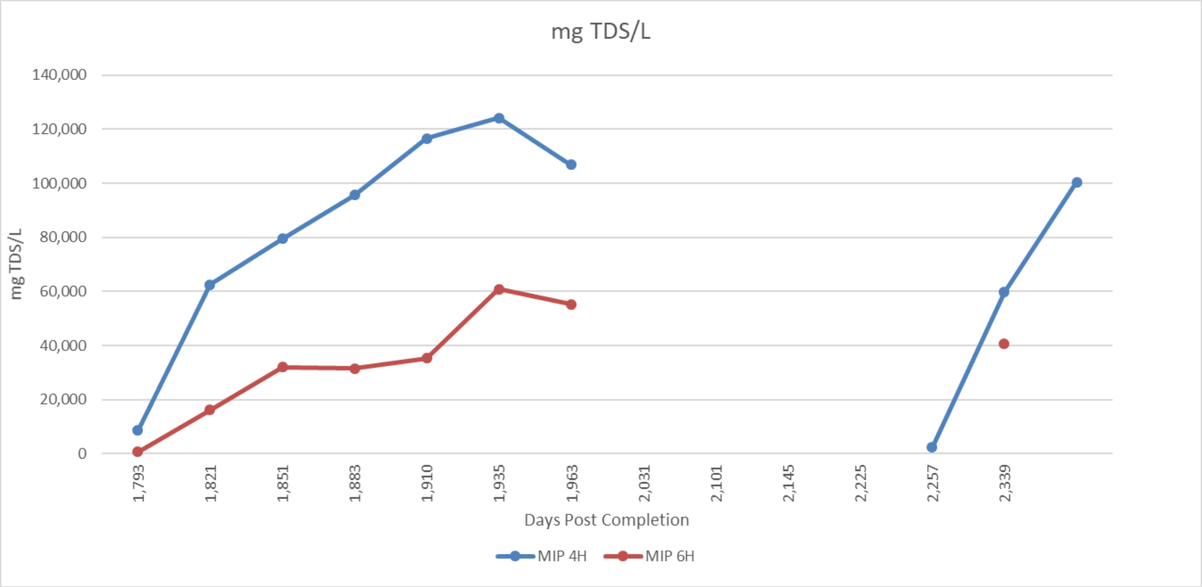


Figure 4.3. Changes in produced water TDS sdc (sum of dissolved constituents) through the days 1793 to 2339 post completion (4,6H).

Water soluble organics

The water soluble aromatic compounds in produced water: benzene, toluene, ethylbenzene and xylene were never high. With two exceptions at post completion day 321 and 694, benzene has remained below 30 µg/L (Figure 4.4) Researchers are awaiting confirmation from the analytical lab for this reported value of 41 µg/L for day 694. Apart from the spikes, this seems to be a characteristic of dry gas geologic units. After five years, benzene has declined below the drinking water standard of 5 µg/L.

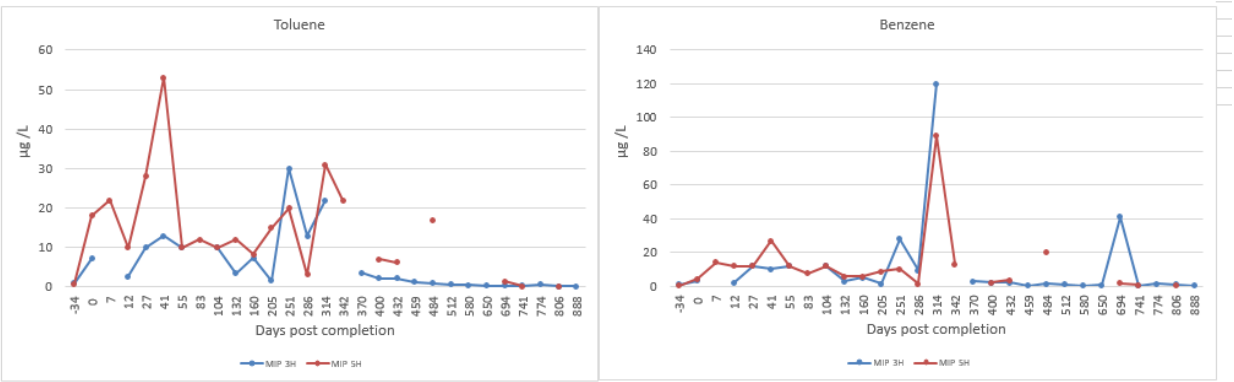


Figure 4.4. Changes in benzene and toluene concentrations. The figure shows data from well both 3H and 5H.

Radium isotopes

<u>Radioactivity in produced water</u>

Radium concentrations generally increased through 700 days post completion at wells MIP 3H and 5H. Maximum levels of the radium isotopes reached about 20,000 pCi/L at the unchoked 3H well and about half that amount at 5H (Figure 4.5.5). Both wells appear to be on a downward trend post 700 days.

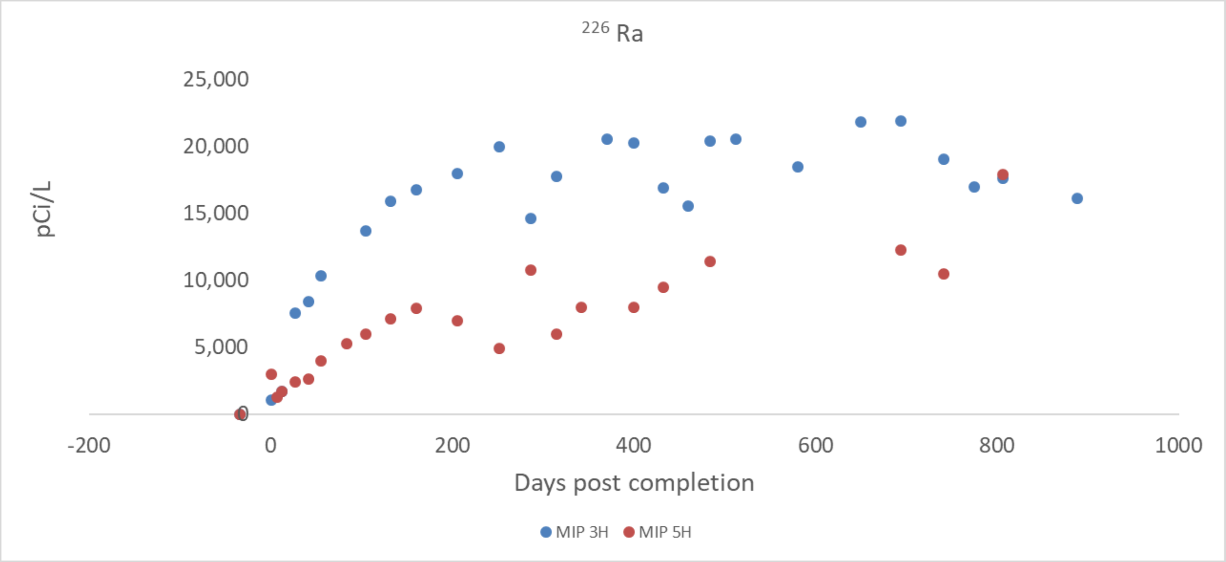


Figure 4.5. The radium isotopes are plotted against days post well completion. Well 5H was choked periodically. It produced less water and lower concentrations of radium.

Radium concentrations at wells 4H and 6H were below 9,000 pCi/L during all sampling periods. Both wells were choked at day 1963. Well 4H was reopened at day 2225, radium was 58 pCi/L on the first sampling after the reopening and 3719 pCi/L at day 2257, a month later (Figure 4.6) and continues on an upward trend at day 2339.

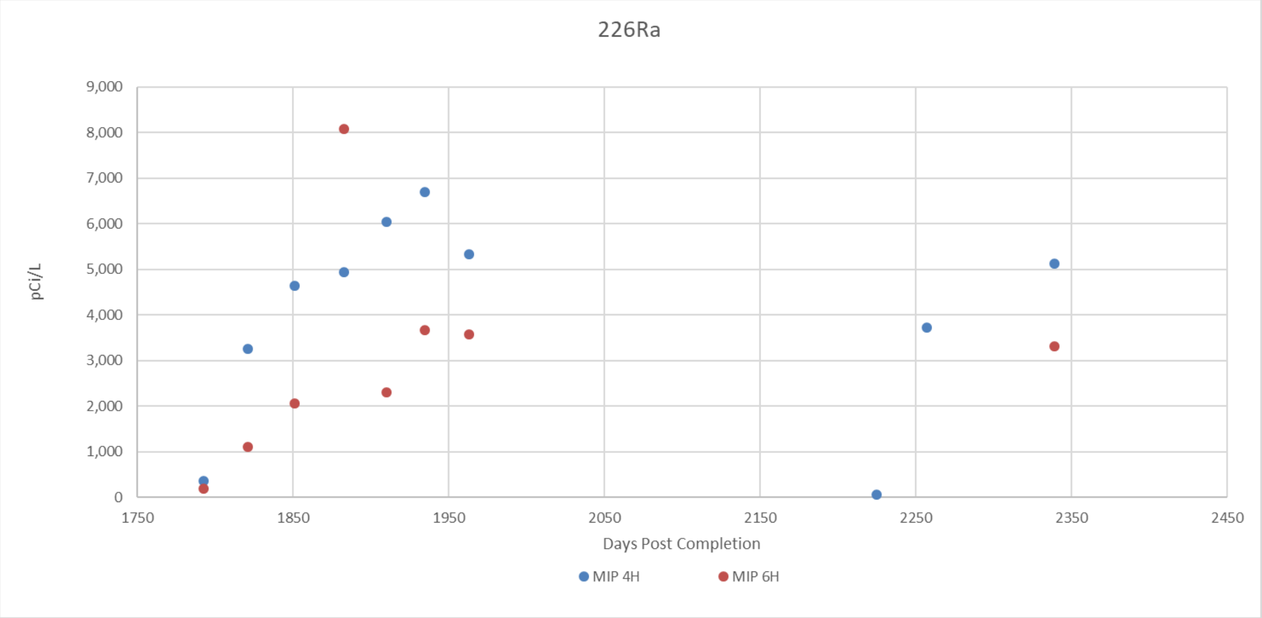


Figure 4.6. The radium isotopes are plotted against days post well completion. Well 4H and 6H were choked at day 1963. At day 2225, 4H was reopened showing a value of 58 pCi/L.

The radiochemical concentrations were determined by Pace Analytical in Greensburg PA, a state certified analytical lab. Figure 4.7 shows the relationship between gross alpha and ^{226}Ra. The relationship between alpha and ^{226}Ra is clear but the correlation coefficients show much more variance in the alpha readings. So, individual values can diverge to a far greater extent than the modelled values. Earlier studies (e.g. Ziemkiewicz and He, 2015) often relied on samples taken from several wells over short time spans so the apparent differences between alpha and, individual isotope concentrations may well be analytical artifact. The MDCs and uncertainty levels reported by the lab indicated that both the alpha and radium levels were within ranges that would be considered reliable. This may illustrate the limitations of survey level parameters such as gross alpha.

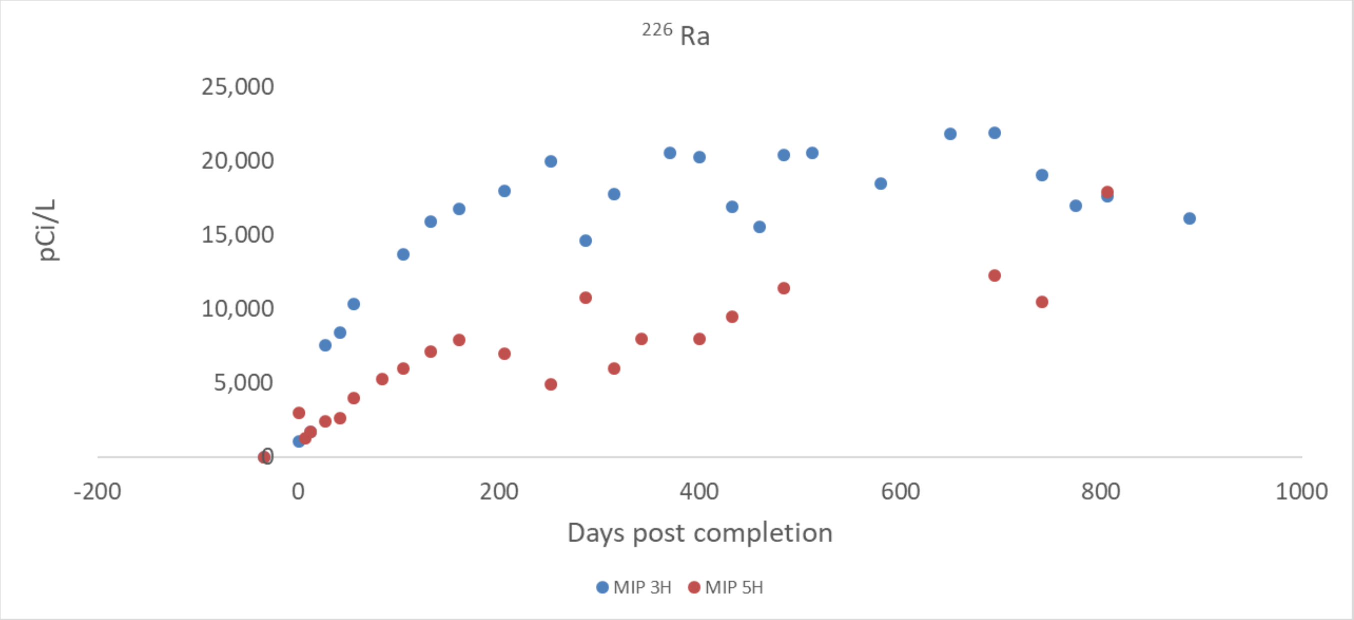


Figure 4.7. The relationship between gross alpha and 226Ra as a function of time post completion.

Plan for Next Quarter

The team will continue to sample and analyze flowback/produced water (FPW) from MIP 3H, 4H, 5H and 6H if they are online.

References

Ziemkiewicz, P.F. and He, Y.T. 2015. Evolution of water chemistry during Marcellus shale gas development: A case study in West Virginia. Chemosphere 134:224-231.

Topic 5 – Environmental Monitoring: Air & Vehicular

Approach

We previously noted that due to analyzer calibrations and their deployment in the field that a quarterly audit was not performed during the previous quarter. However, an audit was completed in this quarter (May) and we will complete the remaining Year 4 methane audits in late July/early August, late September/ early October, and December. During the last report we mentioned that the high-speed open-path analyzer and high-speed anemometer were acquired an integrated into the data acquisition system. They were deployed in the last audit to assess the data collection capabilities. Figure 5.1 shows the system mounted on a vehicle that was parked at the upwind edge of the well pad and downwind near the water retainment pond. Brief results are presented in the following section.

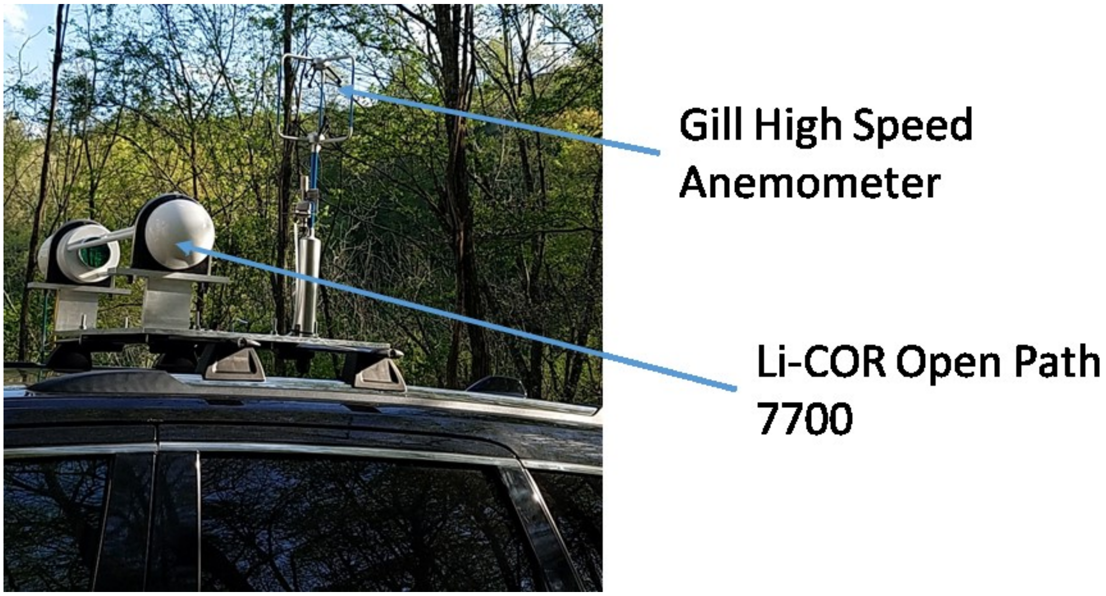


Figure 5.1: New mobile monitoring system integrated within vehicle for indirect methane monitoring.

Results & Discussion

Direct Quantification

The fifth site audit was completed in May 2018. Each of the wellheads was measured for methane flux in addition to 8 leak/losses, the water tank, and the EGPUs. No stack emissions were collected since neither of the EPGU burners was active. As was seen in the previous audit, the water tank was the dominant source of methane emissions (72%). The total site emissions for this audit were 1496 grams per hour (g/hr). Table 5.1 presents the new results as compared with the previous Year

3 audits. Figure 5.2 also presents a column chart with these data as compared to the current MSEEL average and the average of well sites presented in Rella et al.

Table 5.1 Year 3 and New Year 4 Audits Results.

Component	CH$_4$ Loss Rate (g/hr)				
	Nov-16	Apr-17	Jul-17	Nov-17	May-18
Wellheads	0.85	139.43	1.65	1.68	5.82
EGPU Housing	356.50	69.89	8.43	188.20	200.38
Water Tank	83.98	3731.40	17.25	1032.31	1074.27
Leaks	227.40	163.10	8.45	546.00	215.45
NG Burner	0.82	N/A	N/A	N/A	N/A
Total	669.55	4103.81	35.77	1768.19	1495.91

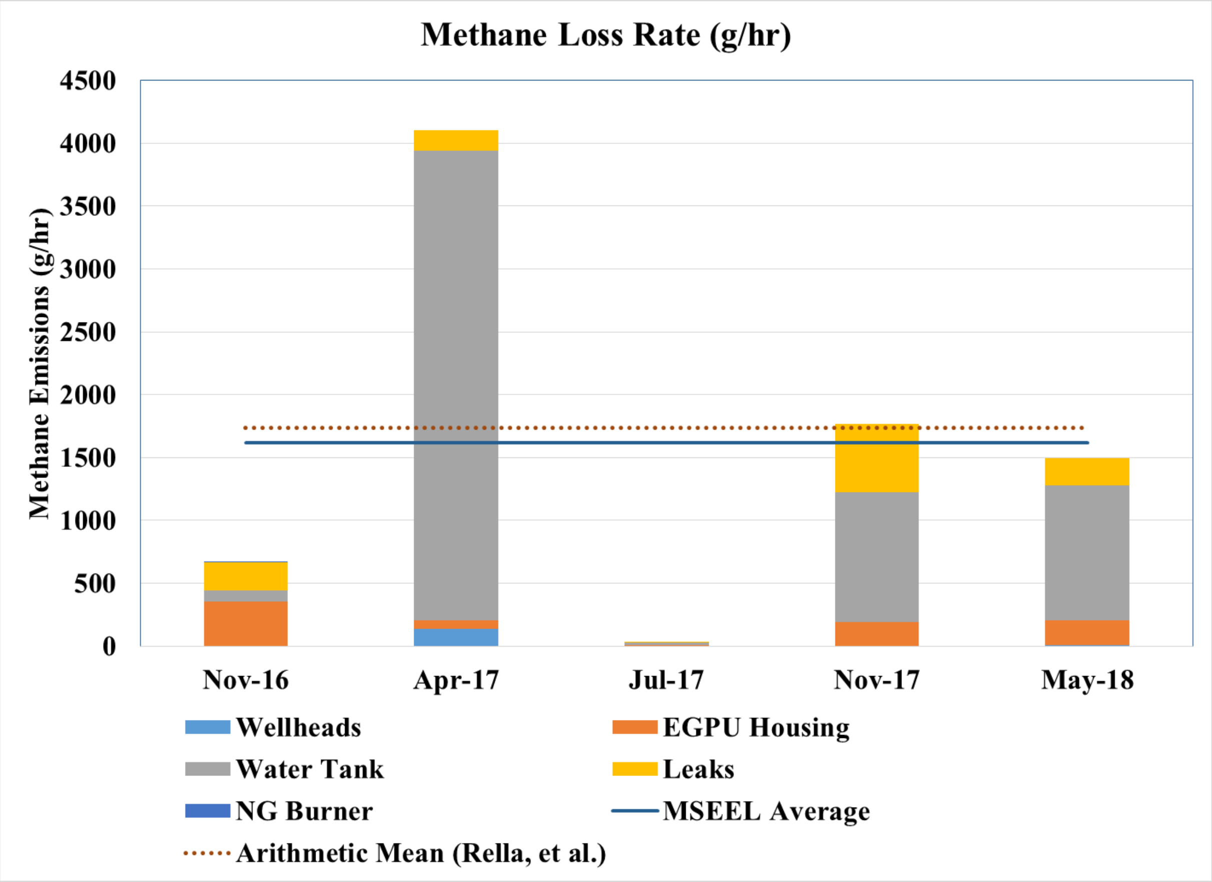


Figure 5.2 Updated Methane Loss Rate Including this Quarter's Audit as Compared to Rella et al. and the MSEEL average.

Indirect System

Figure 5.3 shows the locations of the upwind (A) and downwind (B) sampling locations during the initial deployment of the fast response mobile monitoring system. The general wind direction was from left to right. The north direction "N" faced into the wind. Note that alignments and wind directions have not been refined.

Figure 5.3 General layout during initial deployment of the fast response mobile monitoring system.

Based on Figure 5.3 we see that A is the upwind and B is the downwind direction. As such, we would expect that the downwind methane concentrations would be higher due to dispersion. Figure 5.4 shows the initial results for wind direction and methane concentration enhancements from the upwind location. An average background measurement was used to estimate enhancements. The figure shows that most upwind enhancements were from 70 to 90 ppb. Figure 5.5 shows the downwind enhancements. Downwind enhancements ranged from above 200 ppb to just above 600 ppb.

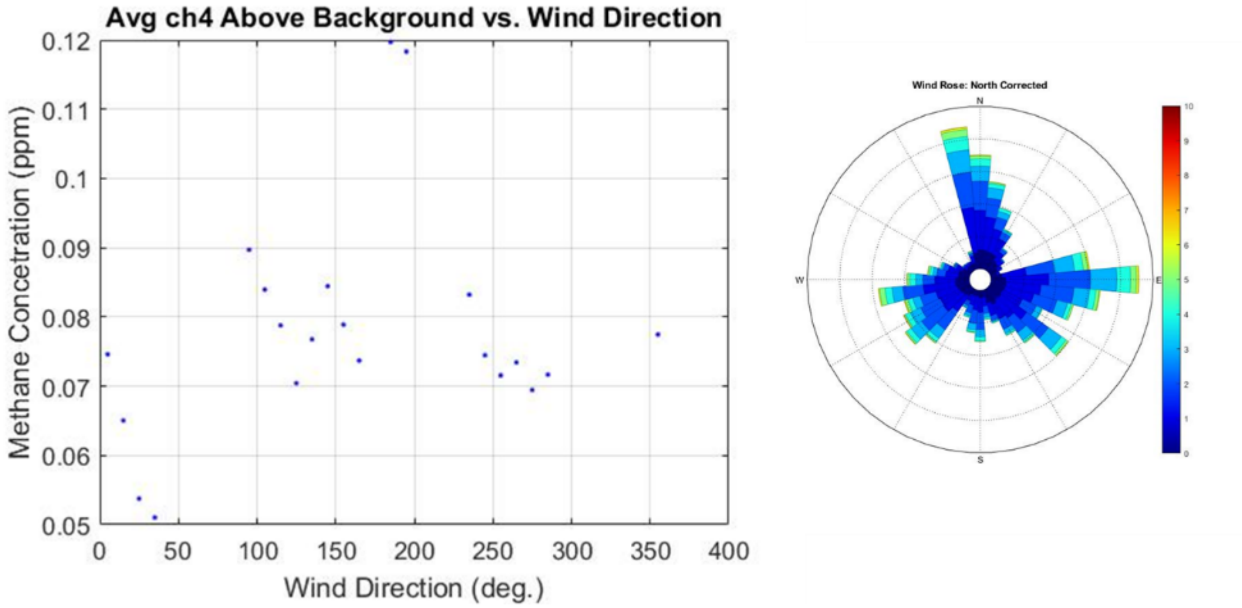


Figure 5.4 Data collected at location A - upwind.

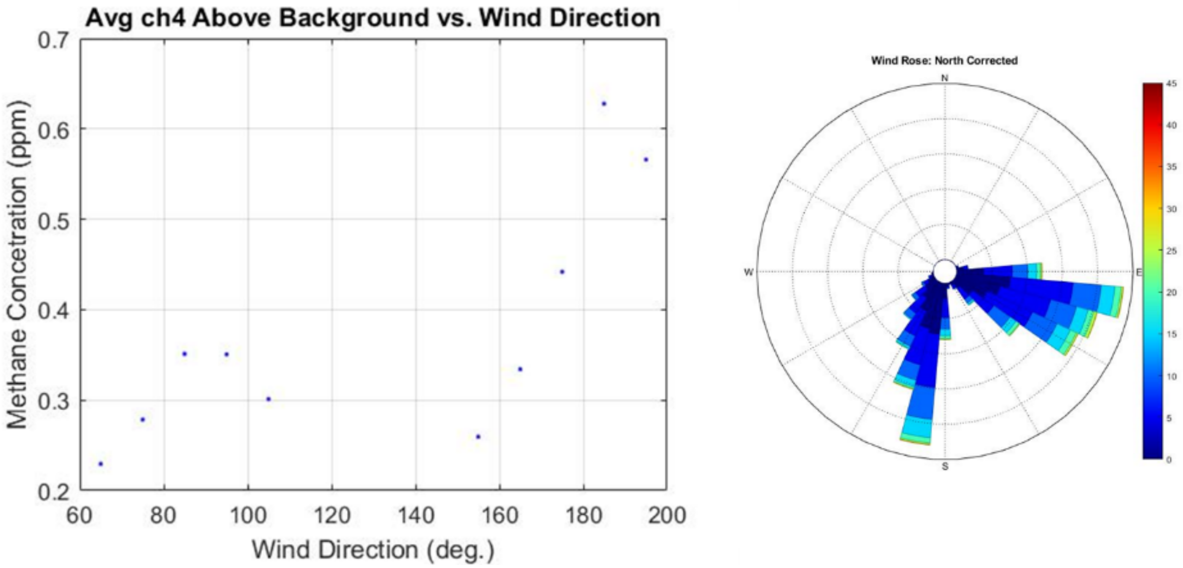


Figure 5.5 Data collected at location B – downwind.

These data represent an initial data collection effort to ensure the monitoring system was functional. Future work will focus on extensive data collection efforts necessary to assess if near field application of OTM 33A could be used to predict site-wide emissions. As mentioned in prior reports, we have developed and submitted an NSF to further extend this research to examine both OTM 33A and eddy-covariance methods as a means to better quantify methane with indirect methods. The proposal was reviewed favorably and recommended for funding by the program manager and direct. Pending agreement finalizations, this additional funding may be available to begin work in the next quarter.

Products

We had previously discussed an audit publication; this publication is still under review with the ACS journal OMEGA. We present the following summarized list of all publications that have referenced data collected at MSEEL under our additional project. The project close out was presented at NETL in early July.

Papers Referencing both DE-FE0013689 (CAFEE Methane) and DE-FE0024297 (MSEEL)

1.) **Johnson, D.**, Heltzel, R.*, Nix, A., and Barrow, R.*, “Development of Engine Activity Cycles for the Prime Movers of Unconventional, Natural Gas Well Development,” *Journal of the Air and Waste Management Association*, 2016. DOI: 10.1080/10962247.2016.1245220.

2.) **Johnson, D.**, Heltzel, R.*, Nix, A., Clark, N., and Darzi, M.*, “Greenhouse Gas Emissions and Fuel Efficiency of In-Use High Horsepower Diesel, Dual Fuel, and Natural Gas Engines for Unconventional Well Development,” *Applied Energy*, 2017. DOI: 10.1016/j.apenergy.2017.08.234.

3.) **Johnson, D.**, Heltzel, R.*, Nix, A., Clark, N., and Darzi, M.*, “Regulated Gaseous Emissions from In-Use High Horsepower Drilling and Hydraulic Fracturing Engines,” *Journal of Pollution Effects and Control*, 2017. DOI: 10.4176/2375-4397.1000187.

4.) **Johnson, D.,** Heltzel, R.*, Nix, A., Darzi, M.*, and Oliver, D.*, “Estimated Emissions from the Prime-Movers of Unconventional Natural Gas Well Development Using Recently Collected In-Use Data in the United States,” *Environmental Science and Technology*, 2018.

DOI: 10.1021/acs.est.7b06694.

5.) **Johnson, D.**, Heltzel, R.*, Nix, A., Clark, N., and Darzi, M.*, “In-Use Efficiency of Oxidation and Threeway Catalysts Used In High-Horsepower Dual Fuel and Dedicated Natural Gas Engines,” *SAE International Journal of Engines*, 2018. DOI: 10.4271/03-11-03-0026.

* Denotes students

Plan for Next Quarter

- Complete a second and possible third site audit.
- Deploy the mobile system for extended periods during the audit.
- Refine the mobile system data collection and analysis system.
- Publication of the OMEGA article.

Topic 6 – Water Treatment

Approach

As part of this subtask, Dr. Morrissey is characterizing the chemical and biological factors that influence radium accumulation in sludge from produced water. This research could lead to the development of low cost treatments for produced water that prevent the accumulation or radioactive sludge. This work is in service of Milestone 33: *Results of techniques for low cost treatment of flowback waters*. The team is performing a series of laboratory microcosm experiments. Produced water is incubated for 21 days in the laboratory with or without additions of sulfate (200 or 2000mg/L) and nutrients (carbon, nitrogen and phosphorus). The addition of nutrients is intended to stimulate the activity of microorganisms to immobilize sulfate and prevent it from precipitating with radium. Tests thus far have utilized produced water from the 3H.

Results & Discussion

This quarter, Morrissey's completed one laboratory microcosm experiment and completed water chemistry analysis from previous incubations. Preliminary results suggest that sulfate is below detection in the produced water from well 3H. In the absence of added sulfate, dissolved concentrations of Sr, Ba, Ra 226 and Ra 228 did not change over the incubation period (Figure 6.1) suggesting that these materials will not precipitate into solids during the holding of produced waters with chemistry similar to 3H. When high concentrations of sulfate were added (2000 mg/L) concentrations of Ba concentrations immediately dropped ~50% (Fig 1A) and concentrations of Ra 226 & Ra 228 declined after over time (Figures 1 C & D). Concentrations of Sr were slightly reduced by sulfate addition (Figure 1B). As suggested by the decrease in dissolved concentrations, high sulfate addition caused an accumulation of Ra 226 in the precipitated solids. These results suggest that produced water with substantial sulfate and Ra concentrations could result in the rapid accumulation of Ra in to produced solids.

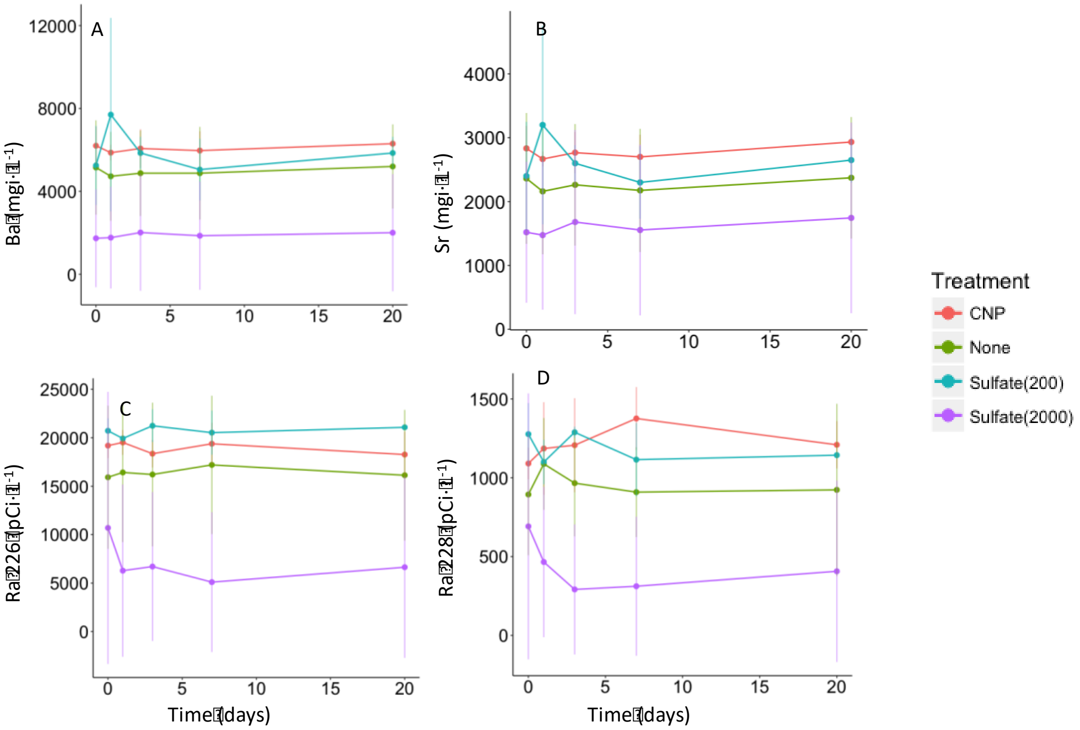


Figure 6.1. Concentrations of dissolved Ba (A), Sr (B), Ra 226 (C), and Ra 228 (D) in laboratory microcosms of produced water incubated with no additions (None), with added sulfate (at 200 or 2000mg/L), and with added nutrients (CNP, carbon, nitrogen and phosphorus).

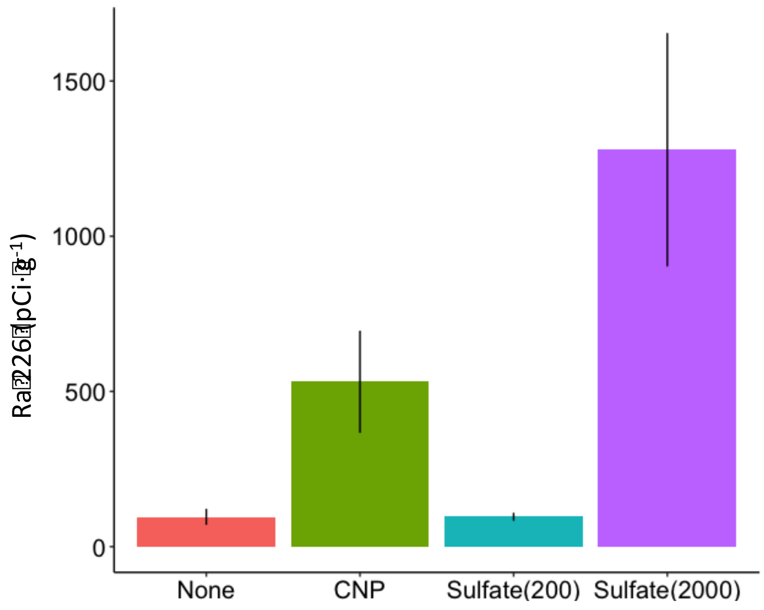


Figure 6.2 Concentrations Ra 226 (mean and s.d.) in precipitated solids from laboratory microcosms of produced water incubated with no additions (None), with added sulfate (at 200 or 2000mg/L), and with added nutrients (CNP, carbon, nitrogen and phosphorus).

During the last month we have also had and undergraduate student extracting DNA from the precipitated solids associated with the laboratory microcosm incubations. The student has successfully extracted and amplified DNA from the solid material.

Products

Preliminary results from this work were be presented to researchers at Kansas University who are also studying produced water.

As sample analyses are still underway we have yet to submit this work for publication.

Plan for Next Quarter

In the next quarter Dr. Morrissey will continue laboratory microcosm experiments to determine if the preliminary results reported above can be replicated and are statistically significant. As sulfate concentrations from well 3H are low, Dr. Morrissey and her team will determine if microorganisms can reduce or delay the precipitation of Ra in high sulfate produced waters by performing a microcosm study where nutrients (C,N, and P) are added in combination with sulfate. The team also plans to send DNA samples to an analytical facility for sequencing to characterize the microbial communities in the produced water samples and solids.

Topic 7 – Database Development

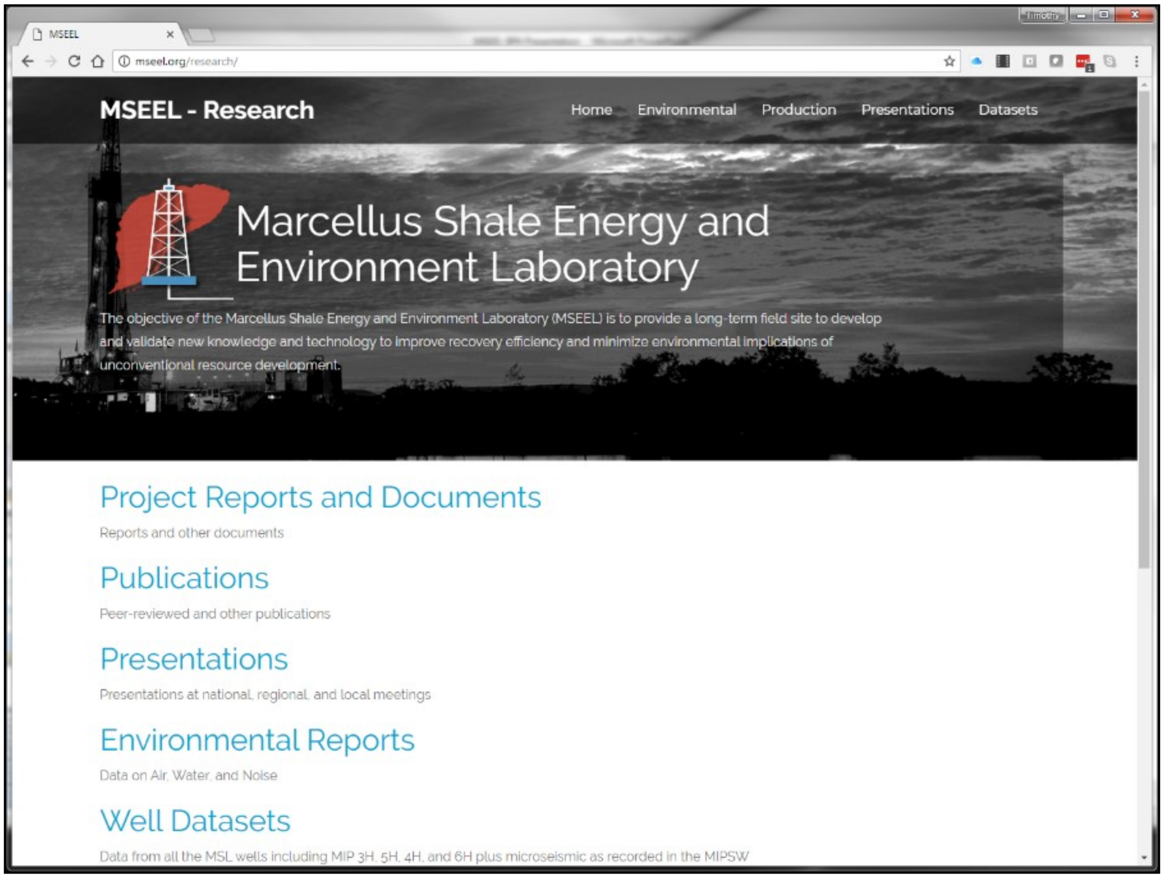
Approach

All MSEEL data is now online and available to researchers (Figure 7.1 and 7.2). The website has been updated with the latest production beyond the end of the quarter (Figure 7.3). Work continues and we have uploaded the logos, publications and production data.

Marcellus Shale Energy and Environment Laboratory

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.

Figure 7.1: MSEEL website at http://mseel.org/.



MSEEL - Research

Marcellus Shale Energy and Environment Laboratory

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.

Project Reports and Documents

Reports and other documents

Publications

Peer-reviewed and other publications

Presentations

Presentations at national, regional, and local meetings

Environmental Reports

Data on Air, Water, and Noise

Well Datasets

Data from all the MSL wells including MIP 3H, 5H, 4H, and 6H plus microseismic as recorded in the MIPSW

Figure 7.2: All data generated by the MSEEL project is available for download at http://mseel.org/.

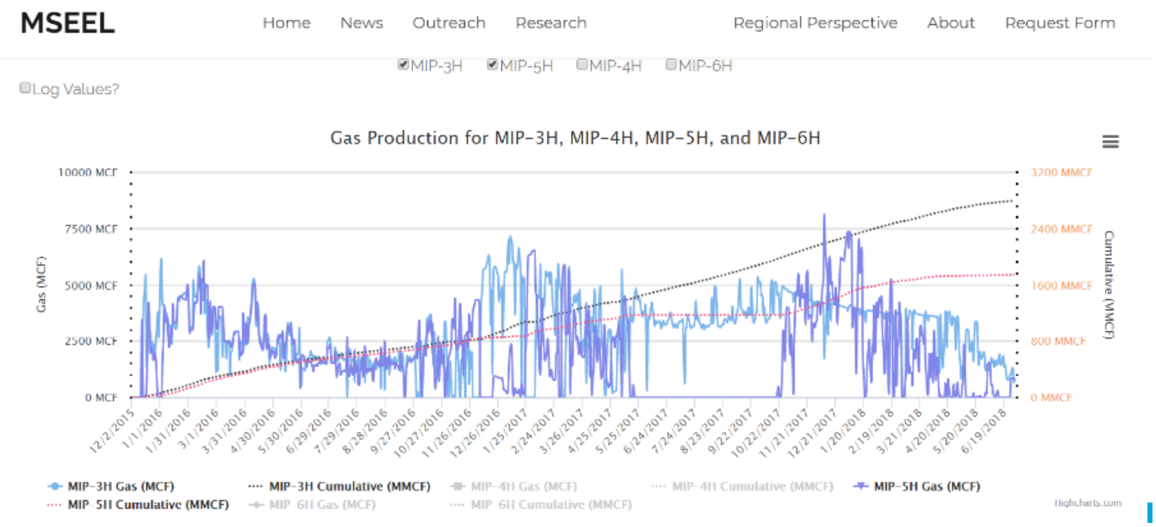


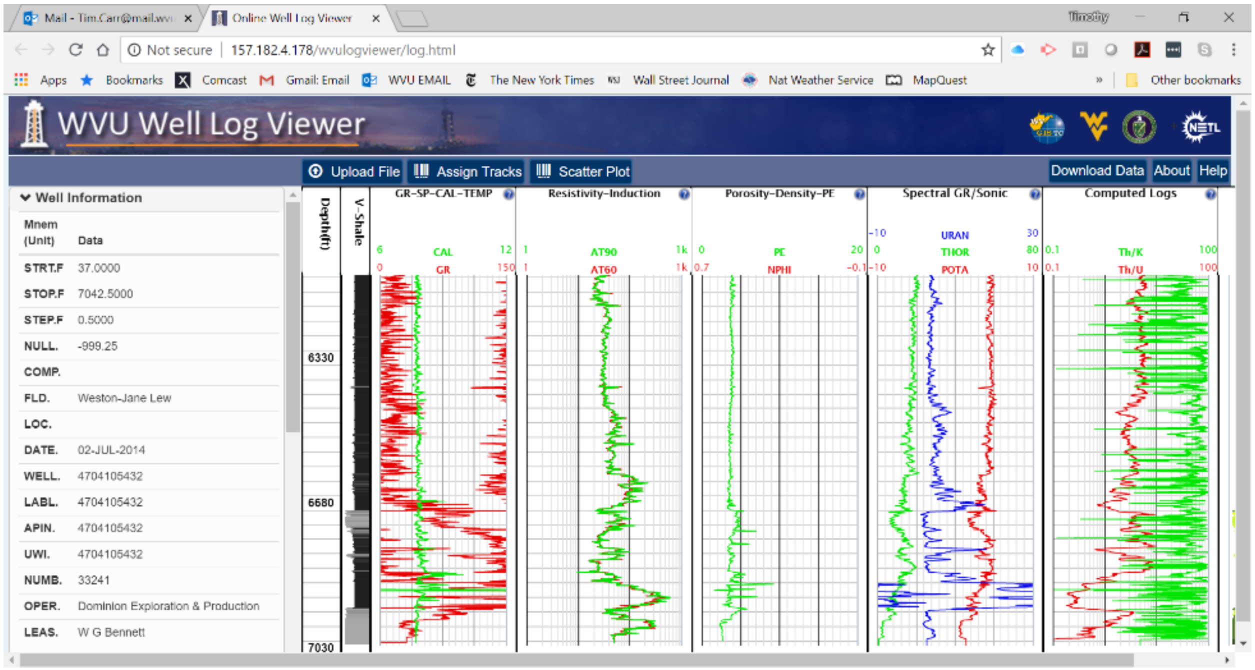
Figure 7.3: Gas and water production have been updated through the end of the quarter and are available at http://mseel.org/.

Results & Discussion

Data and publications are now available at http://mseel.org/.

Products

Web site enhanced and updated. A prototype log viewer, which will be integrated into the MSEEL site is now functioning at: http://157.182.4.178/wvulogviewer/log.html (Figure 7.4).



Mnem (Unit)	Data
STRT.F	37.0000
STOP.F	7042.5000
STEP.F	0.5000
NULL.	-999.25
COMP.	
FLD.	Weston-Jane Lew
LOC.	
DATE.	02-JUL-2014
WELL.	4704105432
LABL.	4704105432
APIN.	4704105432
UWI.	4704105432
NUMB.	33241
OPER.	Dominion Exploration & Production
LEAS.	W G Bennett

Plan for Next Quarter

Work remains to develop the interactive programs to display user selected welllogs and geochemical data for the MSEEL wells. The scale of the plots is a challenge. A mock-up of the type of display is shown in Figure 7.5.

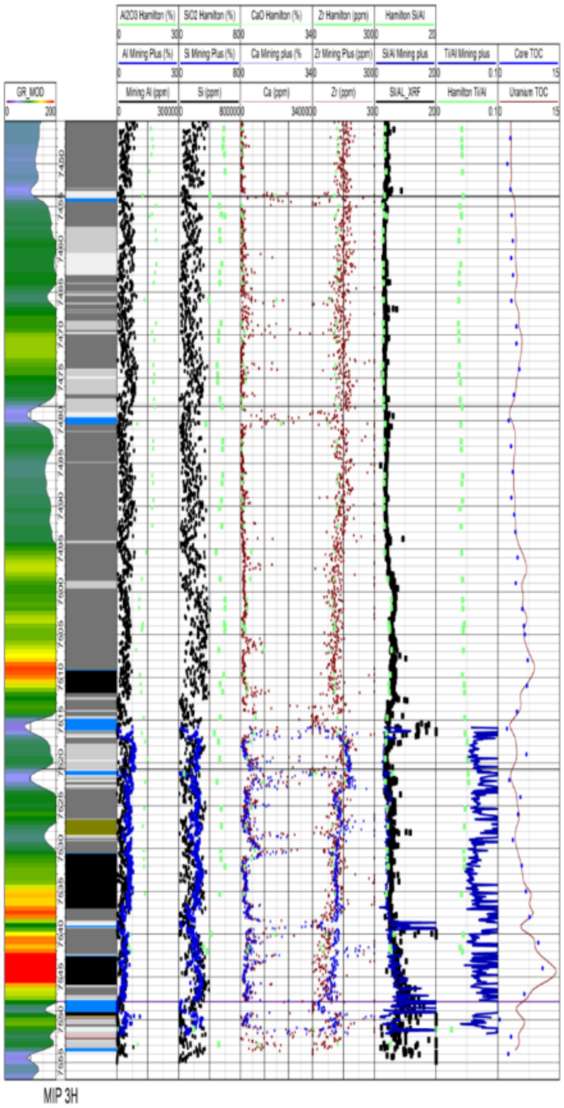


Figure 7.5: Mock up showing log and geochemical data for the MIP 3H pilot hole. The user will be able to select the type of data and scale of displays.

Topic 8 – Economic and Societal

A paper was published by Caleb Stair and Randal Jackson entitled *Economic Impacts of the Marcellus Shale Energy and Environment Laboratory (MSEEL)* and is included below.

Appendix 1

Regional Research Institute
West Virginia University

Resource Document Series

Economic Impacts of the Marcellus Shale Energy and Environment Laboratory (MSEEL)

Caleb Stair, Graduate Research Assistant, Regional Research Institute, WVU

Randall Jackson, Department of Geology and Geography, Director, Regional Research Institute, WVU

RRI Resource Doc 2018-02

Date submitted: 6/6/2018

Key words: Shale Gas, Economic Development, Environmental Economics

JEL codes: Q33 Q38 Q40 Q53 R10

Introduction

The Marcellus Shale Energy and Environmental Laboratory (MSEEL) project in Morgantown, WV has provided 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. The project also gives researchers access to a dedicated science well for subsurface geophysical observation while Northeast Natural Energy (NNE) deploys a range of next-generation well-completion technologies designed to increase operational efficiency and reduce environmental impact. MSEEL also has provided a venue for training and educating next-generation scientists and engineers.

This report summarizes the economic impacts of the MSEEL project for both the state of West Virginia and the Morgantown metropolitan area. It uses two types of data; the first is project data provided by NNE and processed using a Cost Estimation Tool developed by the authors, and second is worker survey data collected during the drilling phase.

Data

This report uses NNE data that were processed using the Cost Estimation Tool developed at the Regional Research Institute as a part of this project. The tool summarizes and transforms the MSEEL shale gas well expenditures data provided by NNE management into a data base that can be used to estimate a generalized production function that subsequently can be embedded within economic systems models. The Cost Estimation Tool results are based in purchaser prices, which include wholesale and retail trade margins and transport cost margins.

Because available input-output models for the study regions are denominated in producer costs, purchaser costs were converted to producer prices. Producer prices are prices paid to producers, which exclude trade and transport margins and other taxes or fees paid by the purchaser[1]. The U.S. Bureau of Economic Analysis provides transportation, wholesale, and retail margins data in their "Margins after Redefinitions" table.[2] To convert purchaser prices to producer prices

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[1] The Bureau of Economic Analysis provides a term glossary that can be consulted for definitions of many conventional terms used throughout this report. The glossary can be accessed at https://www.bea.gov/glossary/glossary_a.htm

[2] The relevant tables can be found on the BEA website at https://www.bea.gov/industry/more.htm.

requires the calculation of the percentages of purchaser prices that are allocated to producer prices, transportation margins, wholesale margins, and retail trade margins.

Percentages for the four subcategories are then used to decompose the purchaser prices. The margins, extracted from all paid purchasers' prices, are summed over all goods and services purchased and are then assigned to the corresponding margins by sectors (Transportation, Wholesale Trade, and Retail Trade).[3]

The converted data were then used as drivers for the input-output analysis, which results in an impact assessment for the 69 industry categories listed in Table 1 that represent the entire regional economy.[4] The results reported include direct impacts, employment and employee compensation impacts, tax impacts, gross operating surplus impacts, and total value-added impacts[5]. The analysis was run twice, once for the state of West Virginia and once for the Morgantown Metropolitan Statistical Area (MSA), which includes Monongalia and Preston counties and is anchored by the city of Morgantown. The state of West Virginia data are included by default in the software used, which also supports the creation of user-defined regions. We used BEA data to create the impacts model for the Morgantown MSA region. The two regional models used the processed data to drive the impacts assessments analysis. However, because smaller regions import goods from the rest of the economy, the direct impacts are adjusted by industry-specific regional supply percentages and reflect each region's estimated ability to satisfy demand placed on its own industries.

The MSEEL science well allows the MSEEL research team to gather continually geological, environmental, and other data. This meant there were additional expenditures associated with scientific instrumentation, and that their installation and monitoring are not typical for production wells. For this reason, we conducted the impacts assessments with and without the additional science well expenditures to provide more generalizable impacts assessments. Figure 1 below shows the distribution of the compiled direct impacts for the state of West Virginia and

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[3] This means that if there were 10 affected industries, there would be 10 Wholesale Trade values, 10 Retail trade values, and 10 Transportation values. The sums of these values for the three margins sectors would become the direct impact values for those three sectors.

[4] The input-output software used is called IO-Snap (Input-Output – State and national analysis program). Details can be found at www.IO-Snap.com.

[5] According to the BEA website, the taxes referenced here consist of Federal excise taxes and customs duties, state and local sales taxes, property taxes (including residential real estate taxes), motor vehicle licenses, severance taxes, and special assessments. These are taxes that are borne by the producing industries and are estimated as proportions to industry output impacts. See the BEA glossary of terms and definitions for more information.

Morgantown with the science well expenditures included and excluded.[6] The two largest direct impacts are on the *Support Activities for Mining* industry sector (52% and 60%) and the *Oil and Gas Extraction* (19%) sector. *Truck Transportation*, *Primary Metals*, and *Legal Services* sectors accounted for most of the remaining changes for both the state and the MSA.

Table 1: Input-output Model Industries

Farms
Forestry, fishing, and related activities
Oil and gas extraction
Mining, except oil and gas
Support activities for mining
Utilities
Construction
Wood products
Nonmetallic mineral products
Primary metals
Fabricated metal products
Machinery
Computer and electronic products
Electrical equipment, appliances, and components
Motor vehicles, bodies and trailers, and parts
Other transportation equipment
Furniture and related products
Miscellaneous manufacturing
Food and beverage and tobacco products
Textile mills and textile product mills
Apparel and leather and allied products
Paper products
Printing and related support activities
Petroleum and coal products
Chemical products
Plastics and rubber products
Wholesale trade
Motor vehicle and parts dealers
Food and beverage stores
General merchandise stores
Other retail
Air transportation
Rail transportation
Water transportation
Truck transportation
Transit and ground passenger transportation
Pipeline transportation
Other transportation and support activities
Warehousing and storage
Publishing industries, except internet (includes softw
Motion picture and sound recording industries
Broadcasting and telecommunications
Data processing, internet publishing, and other infor
Federal Reserve banks, credit intermediation, and re
Securities, commodity contracts, and investments
Insurance carriers and related activities
Funds, trusts, and other financial vehicles
Real estate
Rental and leasing services and lessors of intangible
Legal services
Computer systems design and related services
Miscellaneous professional, scientific, and technical
Management of companies and enterprises
Administrative and support services
Waste management and remediation services
Educational services
Ambulatory health care services
Hospitals
Nursing and residential care facilities
Social assistance
Performing arts, spectator sports, museums, and rel
Amusements, gambling, and recreation industries
Accommodation
Food services and drinking places
Other services, except government
Federal government enterprises
Federal general government
State and local government enterprises
State and local general government

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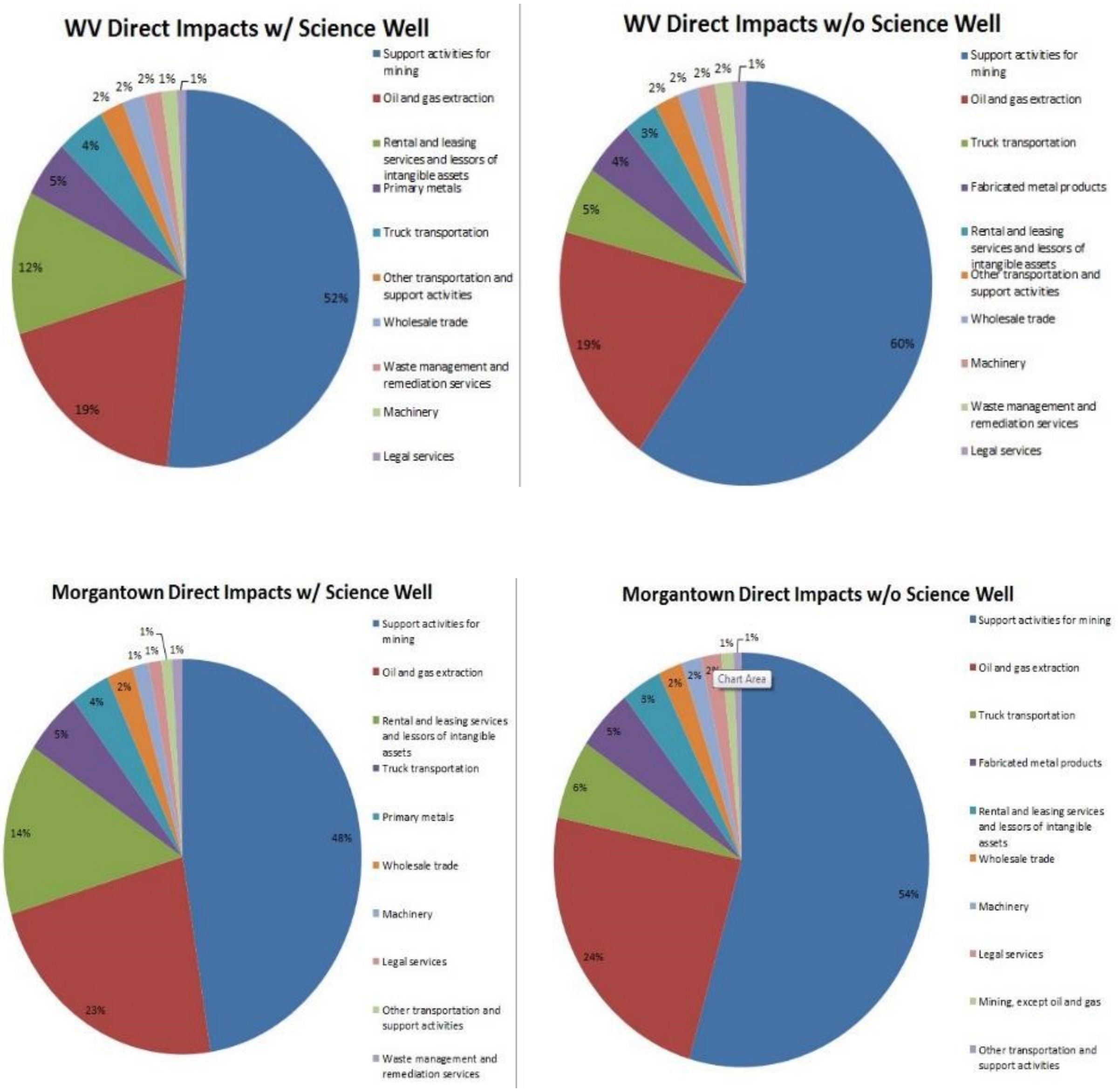
[6] The same graph for the Morgantown MSA is in the Appendix.

Figure 1: Direct Impacts



These direct changes can then be used in the model to drive the impact analyses.[7] Even though every industry does not have a corresponding direct change, all industries can be affected directly and indirectly through interindustry linkages.

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[7] For the sake of confidentiality, precise direct impacts values for each individual sector are not shown.

Results

This section highlights the results of the impact analysis of MSEEL drilling operations in both the state and in Morgantown. Table 2 below shows the combined direct, indirect, and income-induced impacts of MSEEL drilling operations on the state of West Virginia and in Morgantown.[8] MSEEL drilling operations (with the science well related expenditures included) supported 121 full-time equivalent employees (FTEs) in the state and 110 FTEs in the Morgantown metropolitan area.[9] There was a $6.12M and $5.45M employment compensation impact in the state and in Morgantown MSA respectively.[10] The parallel analysis that excludes the science well reduced the number of FTEs by roughly 15 and 11 for the state and MSA analyses, and compensation impacts for West Virginia and Morgantown were reduced accordingly to $5.44M and $4.94M respectively.

An FTE represents the equivalent of a full-time job; this can correspond to three workers working four months each, six workers working two months each, etc., so these estimates should not be confused with numbers of workers. Further, because many of the materials used at the well site are acquired through vendor workers, there are on-site labor costs embedded in the materials costs. Consequently, the number of employees (FTEs) who participated directly in on- site activities cannot be precisely estimated with the available data; this also makes it difficult to estimate direct compensation impacts. Nevertheless, the total FTEs represent best estimates of employment and compensation impacts derived from published data on FTEs and compensation per industry dollar output.

Total Value-Added as reported in Table 2 is the sum of Employment Compensation, Tax, and Gross Operating Surplus.[11] With the science well included, the total valued-added is $8.65M for West Virginia and $7.49M for the Morgantown MSA. If the science well is excluded, total value-added falls to $7.14M and $6.31M for the state and the MSA respectively.

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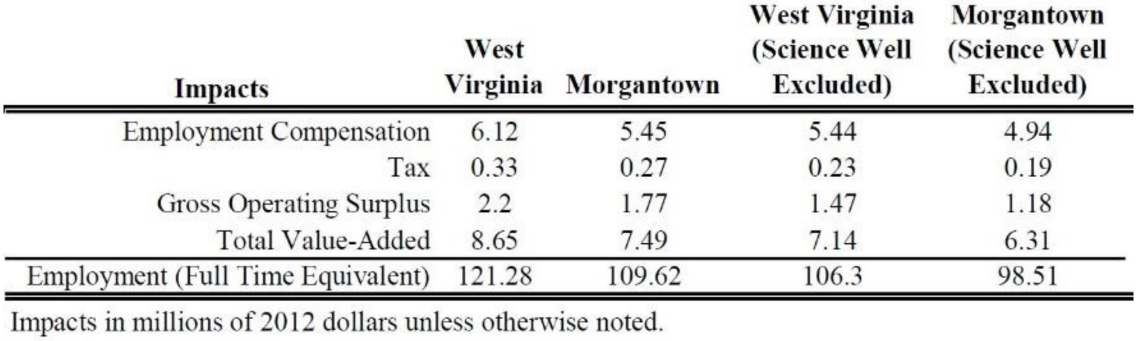
[8] Impacts were generated using 2012 IO-Snap data, which is the data year that most closely corresponds with the timing of the expenditures. This means that the respective model structures are based on the 2012 structures of the two regional economies

[9] Impacts are Type-2 Commodity Driven, which include direct, indirect, and income-induced impacts.

[10] Due to the way in which some materials are delivered, there are some on-site labor costs embedded in the materials. This results in some unavoidable but unmeasurable inaccuracies, likely underestimating actual labor and compensation impacts. As such, the impacts reported here are likely to be conservative estimates.

[11] Value-added is alternatively defined as the difference between gross output and intermediate inputs and includes the value of labor and capital used in producing gross output, and indirect taxes and fees.

Table 2: Overall Impacts of MSEEL drilling in West Virginia and Morgantown



Impacts	West Virginia	Morgantown	West Virginia (Science Well Excluded)	Morgantown (Science Well Excluded)
Employment Compensation	6.12	5.45	5.44	4.94
Tax	0.33	0.27	0.23	0.19
Gross Operating Surplus	2.2	1.77	1.47	1.18
Total Value-Added	8.65	7.49	7.14	6.31
Employment (Full Time Equivalent)	121.28	109.62	106.3	98.51

Impacts in millions of 2012 dollars unless otherwise noted.

Figure 2 (below) highlights the top eight sectors by employment impacts for the state of West Virginia. The majority of employment impacts (approximately 16) were in the *Support Activities for Mining* sector, irrespective of whether the science well expenditures were included. *Oil and Natural Gas Extraction*, *Wholesale Trade*, and *Miscellaneous Professional, Scientific, and Technical Services* were also in the top eight sectors. Figure 3 (below) highlights the top eight sectors by employment impact for the Morgantown MSA. The *Support Activities for Mining* sector again had the majority of employment impacts. The *Ambulatory Health Care Services* sector replaces the *Administrative and Support Services* sector in the top eight sectors for Morgantown.

Figure 2: Top 8 Sectors by Employment Impacts in West Virginia (Science Well Include v. Science Well Excluded)

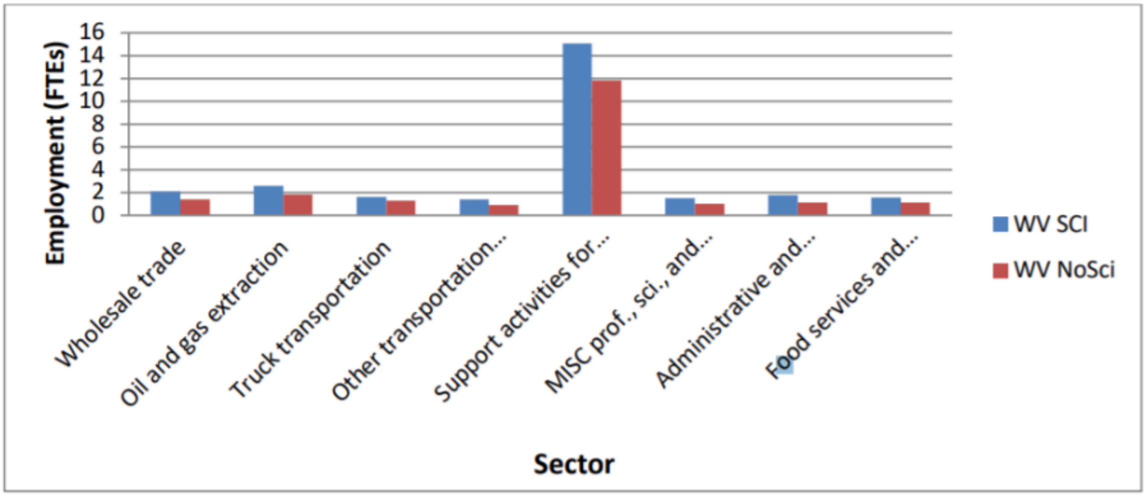
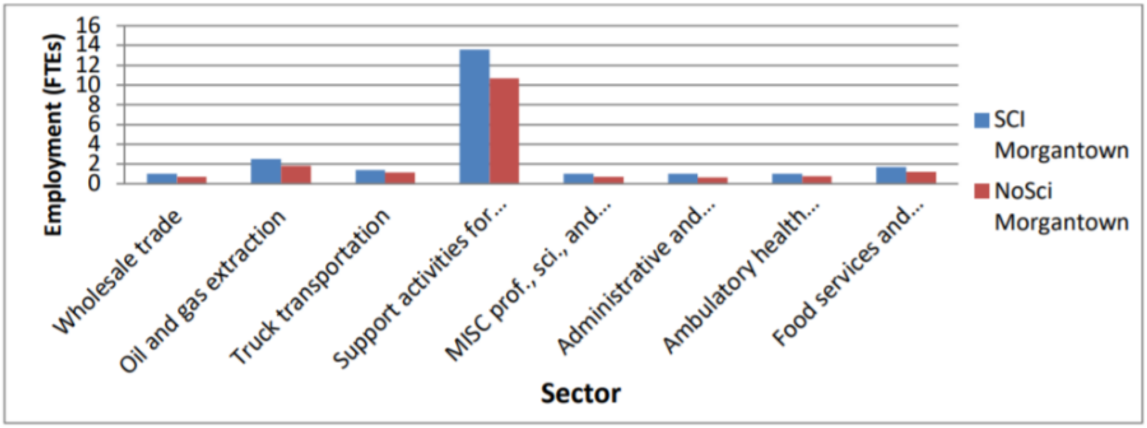


Figure 3: Top 8 Sectors by Employment Impacts in Morgantown (Science Well Included v. Science Well Excluded)



Worker Expenditure Results

Many contractors reside outside of the study regions. These workers will impact the local economy primarily through their needs for accommodations, food and beverage providers, and local retail. Almost 70 workers were surveyed, although not all of the survey questionnaires were completed. Questions on the survey included workers backgrounds and experiences, local interactions, personal information, and economic information. Best efforts were used to glean useful information from the survey. Missing or omitted data for some returned questionnaires were imputed using averages for reported data from similar respondents. The economic information from the survey of the workers was used to generate the results regarding lodging, transportation, and food. The total addition to final demand from workers' expenditures was approximately $80K. This change would have been sufficient to support two FTEs, adding and an additional $90k to total value-added. In practice, employment impacts this limited in proportion to the host economy can often be absorbed by existing workers. Many of the jobs that were supported by the drilling activity were filled by non-residents. Of those who responded to a question on typical hotel expenditures, roughly three out of four reported using a hotel for one or more nights. As expected, the top industries in employment impacts were *Accommodation* and *Food Services and Drinking Places*.

Summary & Discussion

This document reports the results of impact analyses based on the Marcellus Shale Energy and Environmental Laboratory (MSEEL) and using models that correspond to two different study regions: the state (West Virginia) and the Morgantown MSA. The estimates indicate that the MSEEL project supported between 99 and 121 FTEs directly and indirectly. The impacts are presented in FTE, and because the majority of labor required is known to have been on-site for periods of less than one year, the actual number of individual workers involved will have been greater than the numbers of FTEs. The majority of the direct impacts occurred in the *Support Activities for Mining* sector. Other sectors like *Truck Transportation*, *Oil and Gas Extraction*, and *Rental and Leasing Services and Lessors of Intangible Assets* were also positively affected.

It is customary in impacts assessments like these to report multiplier values calculated as ratios of total impacts to direct impacts. For purposes of future generalization, the output multiplier values for the MSA and WV were 1.57 and 1.75.

Cost Status

Year 1

Start: 10/01/2014 End:
09/30/2017

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

Start: 10/01/2014 End:
09/30/2017

Baseline Reporting Quarter

	Q5 (12/31/15)	Q6 (3/30/16)	Q7 (6/30/16)	Q8 (9/30/16)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share	$6,247,367		$7,297,926	
Non-Federal Share	2,814,930		$4,342,480	
Total Planned (Federal and Non-Federal)	$9,062,297	$9,062,297.00	$11,640,406	
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$577,065.91	$4,480,939.42	$845,967.23	$556,511.68
Non-Federal Share	$0.00	$2,189,863.30	$2,154,120.23	$0.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$577,065.91	$6,670,802.72	$3,000,087.46	$556,551.68
Cumulative Incurred Costs	$1,130,203.32	$7,801,006.04	$10,637,732.23	$11,194,243.91
Uncosted				
Federal Share	$5,117,163.68	$636,224.26	$1,004,177.30	$447,665.62
Non-Federal Share	$2,814,930.00	$625,066.70	($1,503.53)	($1,503.53)
Total Uncosted - Quarterly (Federal and Non-Federal)	$2,418,796.68	$1,261,290.96	$1,002,673.77	$446,162.09

Start: 10/01/2014 End: 09/30/2017

Baseline Reporting Quarter	Q9 (12/31/16)	Q10 (3/30/17)	Q11 (6/30/17)	Q12 (9/30/17)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				$9,128,731
Non-Federal Share				$4,520,922
Total Planned (Federal and Non-Federal)				$13,649,653
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$113,223.71	$196,266.36	$120,801.19	$1,147,988.73
Non-Federal Share	$0.00	$0.00	$0.00	$0.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$113,223.71	$196,266.36	$120,801.19	$1,147,988.73
Cumulative Incurred Costs	$11,307,467.62	$11,503,733.98	$11,624535.17	$12,772,523.90
Uncosted				
Federal Share	$334,441.91	$138,175.55	$17,374.36	$700,190.63
Non-Federal Share	($1,503.53)	($1,503.53)	($1,503.53)	$176,938.47
Total Uncosted - Quarterly (Federal and Non-Federal)	$332,938.38	$136,672.02	$15,870.83	$877,129.10

Start: 10/01/2014 End: 09/30/2017

Baseline Reporting Quarter	Q13 (12/31/17)	Q14 (3/30/18)	Q15 (6/30/18)	Q15 (9/30/18)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				
Non-Federal Share				
Total Planned (Federal and Non-Federal)				
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$112,075.89	$349,908.08	$182,207.84	
Non-Federal Share	$0.00	$31,500.23	$10,262.40	
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$112,075.89	$381,408.31	$192,470.24	
Cumulative Incurred Costs	$12,884,599.79	$13,266,008.10	$13,458,478.34	
Uncosted				
Federal Share	$588,114.74	$238,206.66	$55,998.82	
Non-Federal Share	$176,938.47	$145,438.24	$135,175.84	
Total Uncosted - Quarterly (Federal and Non-Federal)	$765,053.21	$383,644.90	$191,174.66	

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