Oil & Natural Gas Technology

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Quarterly Research Performance

Progress Report (Period Ending 03/31/2020)

Marcellus Shale Energy and Environment Laboratory (MSEEL)

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

Submitted by:
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Office of Fossil Energy

Executive Summary
Quarterly Progress Report

January 1 – March 31, 2020

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.

Impacts from COVID-19 were significant in the late portions of this reporting quarter, with travel and on-campus work fully curtailed by the end of March 2020. Principally impacted in this were the geochemical work of Dr. Sharma (Task 3 in this report), and water sampling and analysis work of Dr. Ziemkiewicz (Task 5 in this report). Other work has progressed relatively on-schedule, as work transitioned to home offices. Analysis from the samples and data collected from the Boggess Pad has continued as planned.

This quarter's work focused on continued monitoring of initial production from the MSEEL Phase 3 wells at the Boggess Pad. As of this report total production since mid-November 2019, ranges from 1.39 to 1.85 billion cubic feet (Bcf). Two wells were geometrically completed (9H and 17H), two wells were engineered by a private consultant (5H and 13H and two wells were engineered using software developed by the MSEEL team (1H and 3H). While it is early in the production record, it appears that the wells engineered using software developed by the MSEEL team are some of the better wells on the pad. A paper on the MSEEL completion approach is being prepared for AAPG (June), URTeC (July) and SPE (October). In April, we will present a paper to the online series sponsored by America Rock Mechanics Association (ARMA). A listing of numerous papers and publications are listed in Appendices A-C.

Research on machine learning for improved production efficiency with Los Alamos National Laboratory (LANL) continues and we have provided data and consultation and have contributed to a paper on use of artificial intelligence for a better understanding of reservoir properties.

We continue to process the 108 terabytes of data from the downhole microseismic sensors and the fiber-optic data to better understand geomechanical properties and slow slip events during hydraulic fracture stimulation. Several manuscripts and technical published over the project are listed in this report.

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 FY2020 (January 1 through March 31, 2020).

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.

Numerous publications and presentations are planned for various professional conferences. A listing of past papers and publications are listed in Appendices A-C

Phase 3 Plans

Phase 3 of MSEEL has completed the stimulation and started production from the Boggess Pad in this reporting quarter. Six 10,000+ foot horizontal Marcellus Shale wells off a single pad (Boggess) are near the initial MIP pad (Figure 1.1). The pad has one permanent fiber optic (FO) cable installed in the Boggess 5H lateral provided digital acoustic sensing (DAS) during stimulation and was monitored during initial production. Distributed temperature sensing (DTS) was monitored during stimulation and continues during initial and long-term production. We acquired DAS data for the entire 5H well, but the FO failed around stage 30 and we do not have long-term DTS data below that stage to the toe. We do have data from the upper stages through stage 30 and continue to acquire DTS data from the 5H during production. Deployable FO systems were proposed (Boggess 1H and 17H), but due to the fiber failure in the 5H the fiber was not placed in the 17H. However, we acquired significant DAS and DTS and microseismic data from the 5H and 1H that provided insight of stimulation effectiveness in near real-time and the 100's of terabytes of data to evaluate and model the reservoir across each individual stage, and at individual clusters within stages for the 5H, which will be used for all Boggess wells. We are talking to various parties interested in processing using advanced algorithms the DAS and DTS.

We have developed technique to use the permanent DAS and DTS monitoring in the 5H along with the logging while drilling (LWD) image and geomechanical logs to design an improved methodology to complete wells. This methodology uses computed Shmin from the downhole drilling and logging while drilling data and avoidance of fracture locations to complete the 1H and 3H wells. The new methodology appears to improve completion efficiency. As the wells have come on production, the 1H and 3H wells continue to have a higher production efficiency that either the geometrically completed wells (9H and 17H with identical 200 feet stages with identical number of clusters in each stage) or the commercial fracture stimulation design provided, which only used the geomechanical logs and largely ignored the imaged fractures (5H and 13H) (Figure 1.2). On a daily production efficiency controlling for variable lateral length (Mcf/1000') outside wells (1H and 17H) are better than interior wells, but engineered wells had a slower ramp-up but continue to gain- on their counterparts (Figure 1.3). We also need to control for the amount of sand per stage since the shorter 17H received significantly more sand per stage. We monitored the 5H DAS for several days during initial flow-back and continue to monitor the DTS during production. The production is early, and the picture could very easily change.

We are undertaking detailed analysis of the cored and logged vertical pilot well to develop a high-resolution geomechanical model (stratigraphy) to type each 6 inches of the Marcellus. Logging while drilling (LWD) logs in each of the six laterals provided similar geomechanical logs and image logs to geomechanically type each foot of the laterals as the horizontal laterals move stratigraphically up and down through the Marcellus. This approach permitted direct coupling and evaluation of cost-effective LWD technologies to the relatively high-cost permanent FO data and the basis for engineering stages in all wells. It was applied to two of the Boggess wells.

We used the LWD and permanent FO in the one well (extremely large big data) and the LWD and microseismic only (relatively "thin" data) in two other wells to engineer stage and cluster spacing. Coupled with production data from all the wells including the control wells, this will provide the basis to evaluate the reservoir through modeling and direct monitoring to develop a first ever, publicly available, multi-well unconventional fractured reservoir simulation.

We are gathering fiber optic and production data from the Boggess wells to compare across each of the six wells, and with the two wells at the MIP pad (MSEEL 1) and use these data to form the basis for robust big data modeling. One aspect will be to compare zipper fracturing to sequential fracture treatment and the use of recycled water in the Boggess wells to the 100% fresh water in the MIP wells. The MIP wells generated almost 10 terabytes of data and created approaches and capabilities to handle and process big data sets (i.e., volume, variety, velocity and veracity) from a single well to address the spacing between laterals and stage length, the importance of modeling at multiple scales from nanopores in kerogen to healed fractures spaced along the lateral, and the approaches to engineering stage and cluster design and stimulation processes. The multiple wells at Boggess Pad using the new generation high resolution fiber and LWD tools provided 108 terabytes of data in a series of similar wells under controlled conditions to test and enhance the understanding of shale reservoirs. We moved the data from Houston to the servers at West Virginia University (15 December 2019). MSEEL will test new technologies and approaches to provide robust models that can be modified in near real-time using "thick" relatively high-cost data sets limited to science wells, or when calibrated more cost-effective "thin" data sets that could be used in broader field development and basin evaluation.

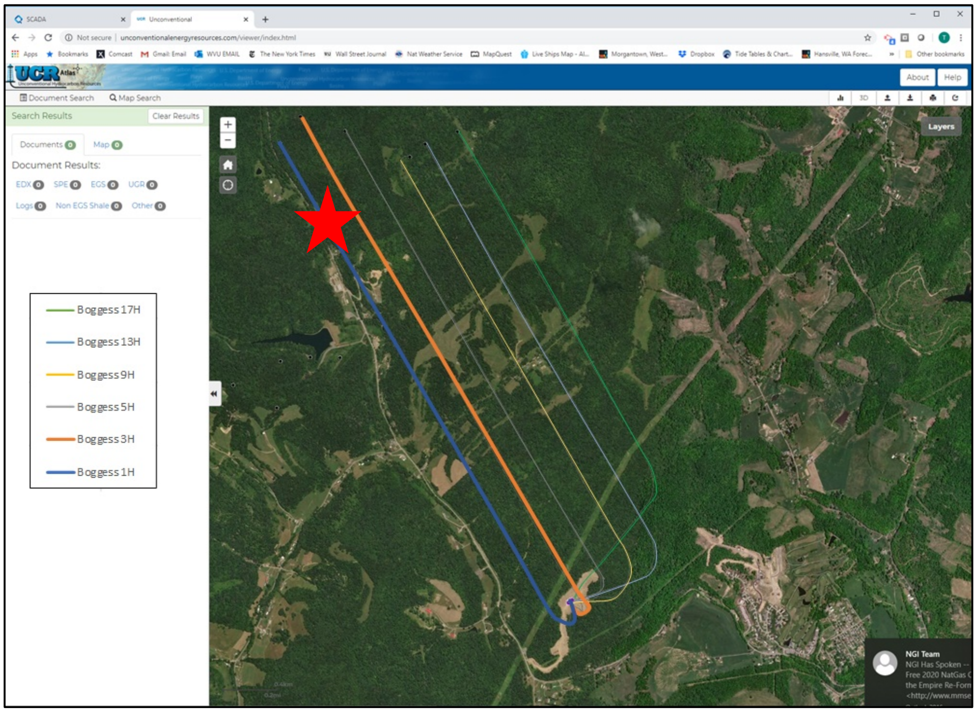


Figure 1.1: Boggess Pad as shown in the new MSEEL map viewer (http://mseel.org/viewer/) with the wells highlighted with colors used in subsequent production plots. The wells using the WVU completion design are the 1H and 3H with the bolder lines. The new generation permanent fiber is located in the central well (Boggess 5H, red star). A vertical pilot well (17H) was drilled, cored and logged prior to drilling the lateral.

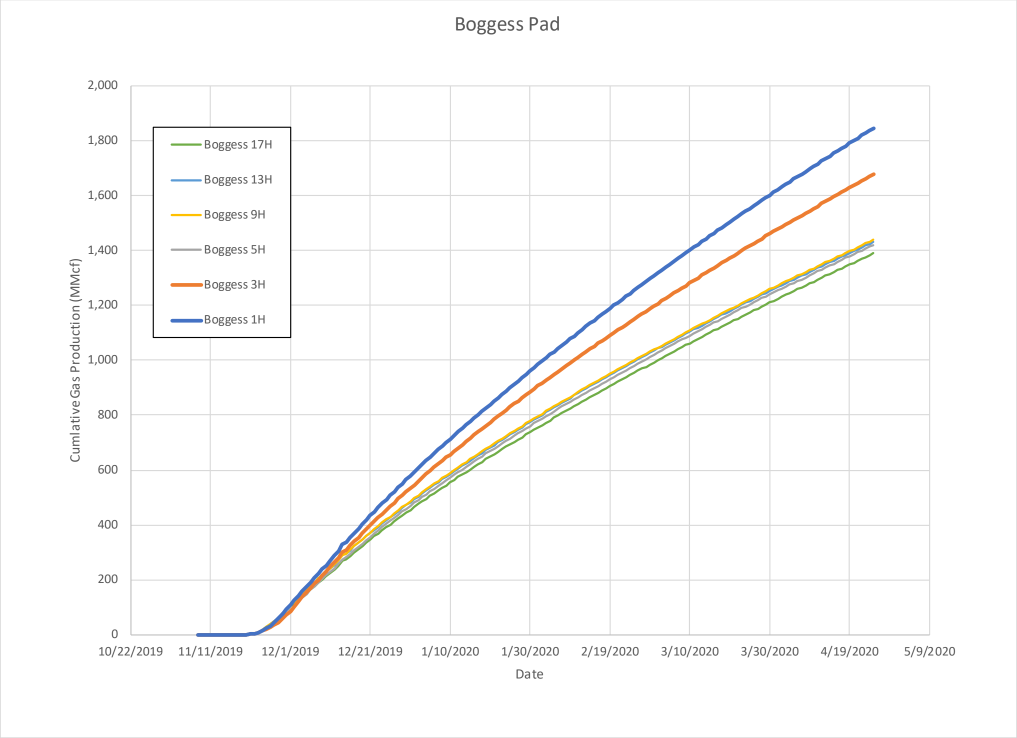


Figure 1.2: Cumulative production from the Boggess Pad. The wells engineered using the MSEEL software are highlighted with thicker lines (1H and 3H). Wells have different lateral lengths require normalization to derive a better evaluation of production efficiency. Also, outside wells typically perform better than interior wells due to reduced competition. The production remains at an early stage, and the picture could very easily change.

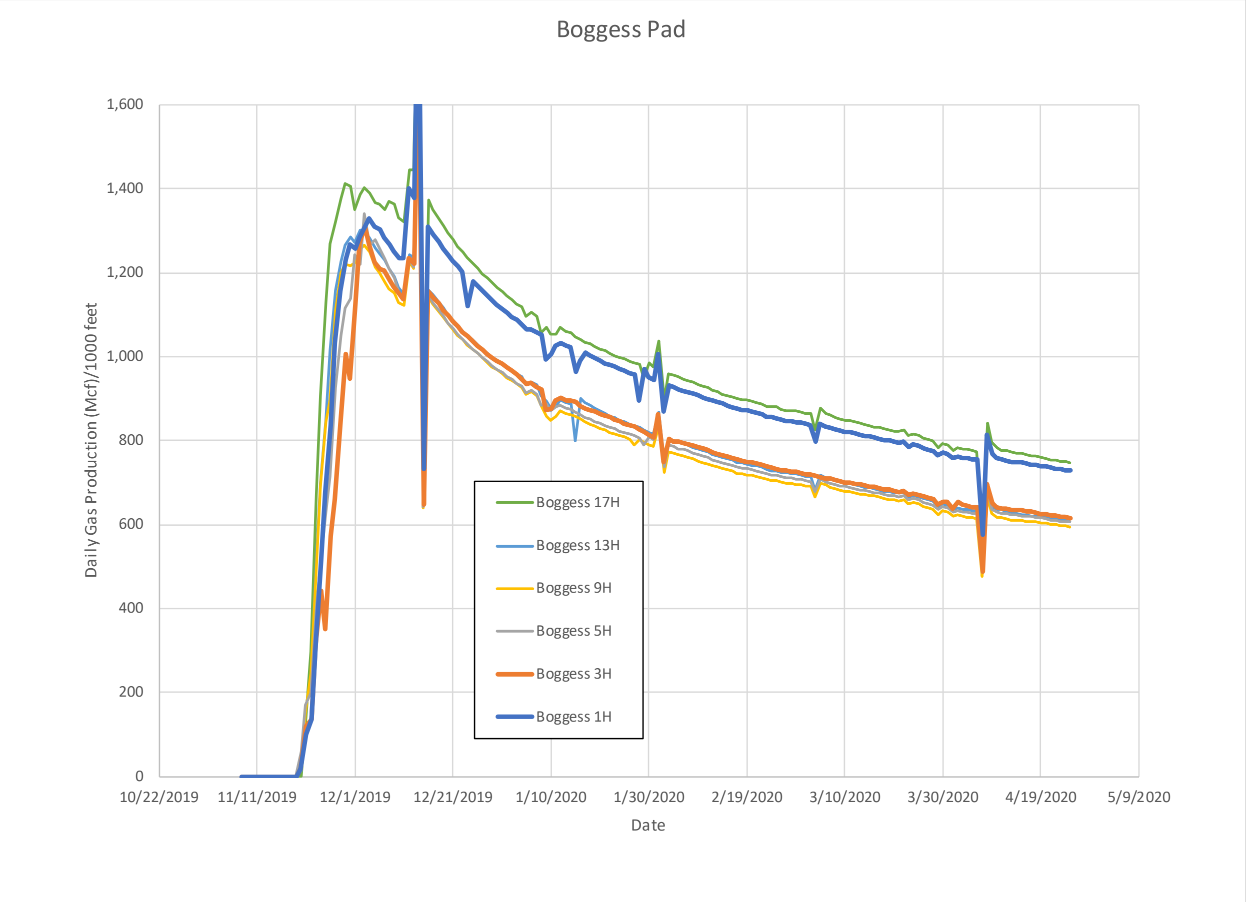


Figure 1.3: Initial daily production from the Boggess Pad normalized for Mcf per 1000' of completed lateral. The wells engineered using the MSEEL software are highlighted with thicker lines (1H and 3H). As you can see outside wells (1H and 17H) perform better than interior wells due to reduced competition. Also wells engineered using the MSEEL approach got off to a slower start but have narrowed the gap in daily production and in the case of the 3H are producing more than any other interior well. In the case of the 1H compared to 17H the gap is narrowing. In the 17H, more sand was used per stage and we need to adjust for sand per foot. The production is early, and the picture could very easily change.

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 ten (10) milestones in this budget period.

	Task	Milestone	Status	Due Date
1.	3.2.1	Sample collection and analysis of flowback/produced water; data analysis	Complete	20-Mar
2.	3.2.1	Comparison of OTM33A vs. Methane Audits vs. Eddy Covariance System Measurements Complete	This task is ongoing, with initial results expected next quarter (June 2020). There was a short delay in tower deployment at MSEEL 1.0. During this delay, the team focused on the baseline analysis of controlled data from the NSF project. This will lead to two collaborative publications to highlight refinement of approach prior to application to MSEEL data. Early analysis of MSEEL 1.0 have been completed to detect periods for further analysis.	20-Mar
3.	3.1.2	Characterization of organic matter - kerogen extraction and characterization complete		20-Jun
4.	3.1.2	Isotopic characterization of produced water and gases - comparison between MIP and Boggess wells and other wells in Marcellus and interpretation.		20-Jun
5.	3.1.2	High-pressure and temperature fracture fluid/shale interaction experiments complete.		20-Jun
6.	3.1.4	Complete final reservoir characterization		20-Jun

		using Boggess 17H pilot well. Compare 17H to MIP 3H		
7.	3.2.1	Methane Audit 14 Completed		20-Jun
8.	3.4.2	Synthetic data developed for model use		20-Jun
9.	3.2.1	Energy Audit Model Completed		20-Sep
10.	3.1.4	Extend reservoir characterization using logs, completion data and production data to identify good producing stages in Boggess wells.		20-Dec

Topic 1 – Geologic Engineering

Approach

In addition to advances in improving our understanding of chemical evolution of produced water, methane emissions, microbiology and rock-fluid geochemistry, we worked to better understand the geologic controls on completion efficiency. Based on the results in the Boggess 5H showing the prevalence pre-existing cemented fractures imaged by logging while drilling (LWD) image logs and their control on hydraulic fracture stimulation as indicated on the DAS data shown in the previous quarterly report, we undertook engineered completion for Boggess 1H and 3H a consistent perforation optimization methodology was developed based on drilling data, geomechanical properties and most importantly LWD fracture imaging. The well paths of the six wells at the Boggess site (1H, 3H, 5H, 9H, 13H and 17H) are shown with the two WVU engineered wells highlighted (Figure 1.1).

Results and Discussion

Our analysis relies on an integration of signals obtained during measurement while drilling (MWD) and logging while drilling (LWD) (Table 1.1). Natural fracture intensities and azimuths were interpreted based on borehole amplitudes images for 1H and 3H. In addition, for Boggess 3H, geomechanical data was derived from accelerations measured at the drilling bit. The acceleration data and derived geomechanical properties were not available in the 1H due to tool failure and changes in mechanic specific energy (MSE) was used

To develop a completion strategy, unlabeled depth intervals are grouped based on rock physics into clusters and assigned scores. As an example, for Stage 36 in Boggess 3H (Figure 1.4). The

Sh_{min} values are upscaled per 5 ft and the intervals are grouped. Grading is based on the minimum horizontal stress (Sh_{min}) patterns with concentration in the most abundant Sh_{min} class (according to histogram). The MWD data including gamma ray and drilling parameters are screened for quality control.

	Data Acquisition
Drilling Mechanics	Gamma ray Rotary per minute Weight on bit Rate of penetration Mechanical specific energy
Fracture Interpretations	Acoustic amplitudes
Geomechanical Properties	Triaxial Accelerations*

Table 1.1: Summary of types of data typically collected during MWD and LWD for Boggess wells. For well 1H, the measurement not being conducted is indicated with an asterisk (*).

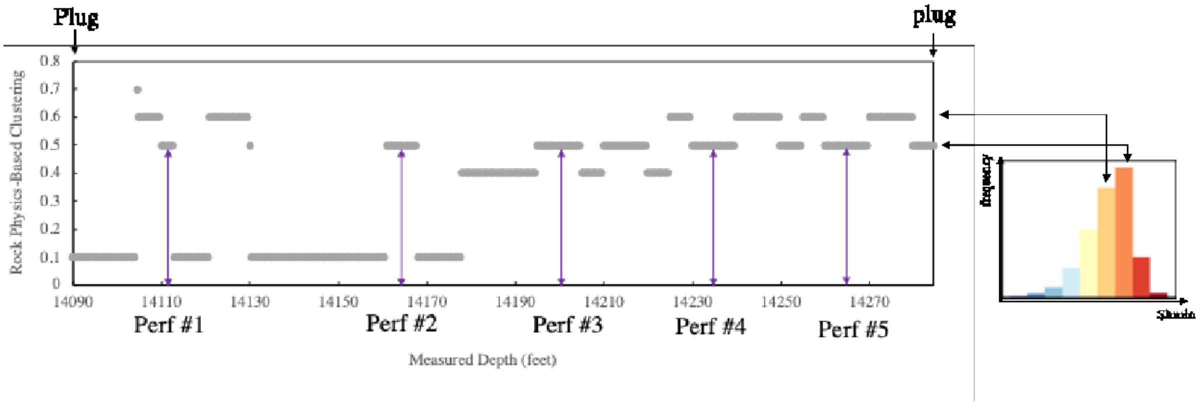


Figure 1.4: Clustering analysis based on rock physics parameters (Shmin) for the initial step in optimizing design of perforation locations. Stage 36 in Boggess 3H is shown.

Products

Interpreted borehole fracture intensities and Sh_{min} values were integrated with a data management Python platform for both programmable plots and grading clusters. Areas of consistent Sh_{min} and low fracture intensity are rated to be the optimal geomechanical candidates for cluster locations (green color Figure 1.5). Finally, an attempt is made by adjusting stage length to distribute the cluster intervals as evenly as possible across the stage. A total of 64 stages are analyzed for 3H, while 63 stages are analyzed for 1H. The stage length varies between 170 to 230 ft. Figure 1.5 illustrates the obtained combo logs and optimized cluster perforations for Stage 36 in Boggess 3H.

The results of this approach are reflected in the increased production in the Boggess 3H normalized to 1000-foot intervals compared to the other interior wells (Figure 1.3). Normalized daily production is 10 – 20 Mcf/1,000 greater than the Boggess 5H, 9H or 13H wells.

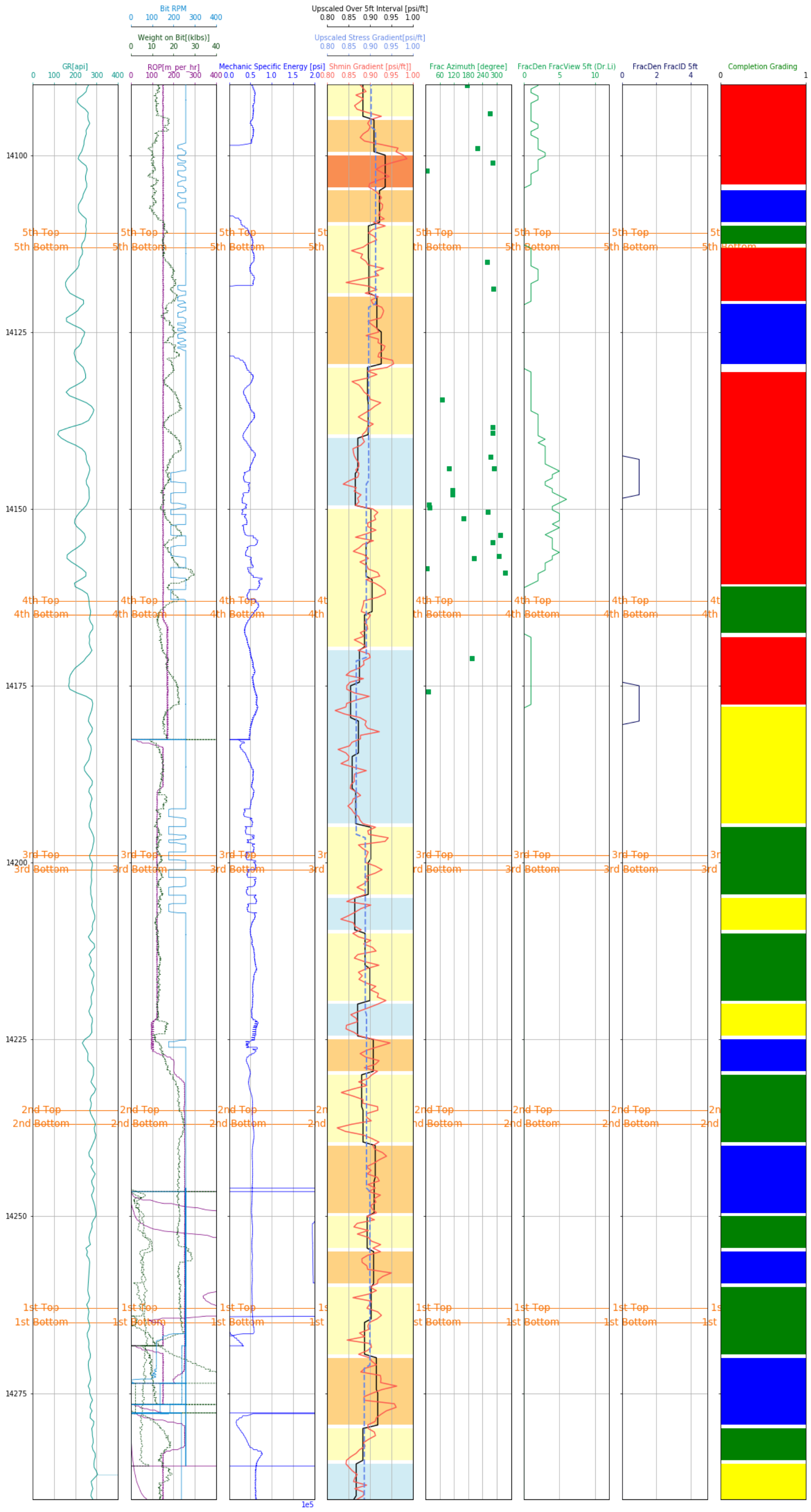


Figure 1.5: Combo well logs and grading results developed using Python for Stage 36 in the Boggess 3H. In the completion grading column, the intervals with fractures are colored as red. Then the intervals that have similar values of Shmin and occurred most frequent are colored as green. Second most frequent Shmin intervals are colored as blue. Third most frequent Shmin intervals are colored as yellow.

Plan for Next Quarter

Project team is working to develop codes using the vibrational data in the acoustic LWD logging tool to better understand geomechanical properties and the relation to imaged fractures. A paper is being prepared for the SPE ATC conference in early October.

Topic 2 – Geophysical & Geomechanical

Approach

Geophysical and Geomechanical

We continue working with Los Alamos National Lab (LANL) to understand the influence of a discrete fracture network on the growth of hydraulic fractures was investigated using numerical modeling. The numerical model updated in a previous quarter was used to compute hydraulic fracture dimensions for stage 26 through stage 30 of well MIP-5H.

Results & Discussion

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. All numerical modeling results were synthesized along with microseismic data results.

The match between numerical model calculated fracture heights and lengths and microseismic estimated height and length data is not currently considered to be excellent. The current modeling study will be continued to evaluate the influence of geomechanical properties on fracture geometries in comparison to microseismic estimates.

Products

A statistical methodology is being explored to better reconcile numerical model calculated fracture heights and lengths, and microseismic height and length estimates.

Plan for Next Quarter

Continue work and biweekly meetings with LANL

Topic 3 – Deep Subsurface Rock, Fluids, & Gas

Sharma Group MSEEL Report

1. Characterization of organic matter - Characterization of organic matter - kerogen extraction and characterization. Core samples from Boggess 17 H were collected, crushed to 200 mesh size, and kerogen was isolated using chemical and physical separation techniques. A modified kerogen isolation method was used to preserve the structure and morphology of pores present in kerogen. In this method, soluble organic matter was removed using a dichloromethane and MeOH–acetone–CHCl3(15:15:70 v/v) mixture. Carbonates mineral were dissolved by adding 6 N HCl and silicate minerals using 50% HF. Heavy minerals such as pyrite were removed by separating the denser phase by using 2.2 gm/cc zinc bromide. To avoid generation of any artifacts in kerogen pore structure by oven drying, the residue (isolated kerogen) was dried using a critical point dryer (CPD). The isolated kerogen will be analyzed using a ^{13}C solid-state NMR to determine its chemical composition and to build its molecular structure. It will also be analyzed to characterize its pore structure and pore size distribution using N_2 adsorption isotherm. Since the labs are shut down due to COVID-19, the analysis of kerogen has been delayed.

Deliverables: 1) Present key findings in a conference in fall-early spring 2020.

2. High-pressure and temperature fracture fluid/shale interaction experiments. The chemical additives and the other supplies for conducting the high P-T shale- hydraulic fracturing fluids (HFF) experiments have been acquired. The fracturing fluids to be used in these reactions have also been prepared. One batch of shale-HFF experiments with a sample (sample LM-1) from dry gas window is complete. The results from these experiments will be compared with shale-HFF experiments performed using Boggess shale cores. The experiments on Boggess cores were planned for early summer 2020; however, due to lab shutdown, the experiments are delayed.

Deliverable: 1) Conduct shale-HFF interaction experiments on Boggess core sample by late summer-fall 2020. 2) Present key findings in a conference in Spring 2021.

3. Isotopic characterization of produced water and gases - sampling and analysis. Isotopic measurements of produced water and gases from Boggess wells are complete. The interpretation of the data is underway.

Deliverable: 1) Present key findings in a conference in fall-Spring

Cole Lab MSEEL Report

Project Title	Milestone Name	Milestone Description	Estimated Completion Date
Marcellus Shale Energy and Environment Laboratory (MSEEL)	Investigate sulfidogenic microbial behavior in shales flowback fluids. (Wrighton/Wilkins team)	L. Cliffe, S. Nixon, R.A. Daly, B. Eden, K.G. Taylor, C. Boothman, M.J. Wilkins, K.C. Wrighton, J.R. Lloyd. Identification of persistent sulfidogenic bacteria in shale gas produced waters. *Frontiers in Microbiology*. 2020. doi: 10.3389/fmicb.2020.00286	Completed
Marcellus Shale Energy and Environment Laboratory (MSEEL)	Characterization of intact polar lipids in MSEEL core and fluid samples. (Mouser team)	Extensive revisions and editing are on-going. We now expect to submit this paper for review next quarter.	05/30/2020
Marcellus Shale Energy and Environment Laboratory (MSEEL)	Completed modeling of Marcellus and Utica flowback fluids (Cole team)	A manuscript draft completed on a comparison of geochemistry of flowback fluids between Utica and Marcellus undergoes final editing prior to submission. Flowback fluid signals from the Appalachian Basin: Focus on the Marcellus and Utica-Point Pleasant. Susan A. Welch, Julia M. Sheets, Rebecca A. Daly, Andrea J. Hanson, Anthony Lutton, John Olesik, Shikha Sharma, Tim Carr and David R. Cole (for *Applied Geochemistry*)	05/30/2020
Marcellus Shale Energy and Environment Laboratory	Completed assessment of MSEEL rock core (Cole team)	A manuscript draft near completion on the mineralogy and its relationship to pore features in MSEEL core.	05/30/2020

(MSEEL)		Mineralogical, geochemical and petrophysical observations of core from the MSEEL: observations of lower Marcellus hydraulic fracturing target and associated formations. Authors: Julia M. Sheets, Susan A. Welch, Alexander M. Swift, Tingting Liu, Rebecca A. Daly, Andrea J. Hanson, Tim Kneafsey, Stefano Cabrini, Paula Mouser, Shikha Sharma, Tim Carr and David R. Cole (for *AAPG Bulletin*)	
Marcellus Shale Energy and Environment Laboratory (MSEEL)	Characterization of water and gas samples for noble gas completed (Darrah team)	Two papers are nearing completion: The changing composition of hydrocarbon and noble gases during the early production of a Marcellus Shale Gas Well; Authors: T. Darrah, C.J. Whyte, D. Cole, S. Sharma, and T. Carr; (Planned submission to *Geochimica et Cosmochimica Acta*) Determining the residence time of natural gas produced from the Marcellus Shale using radiogenic noble gas isotopes. Authors: T. Darrah, C.J. Whyte, B. Lary, D. Cole, S. Sharma, and T. Carr; Planned submission to (*Geochimica et Cosmochimica Acta*)	05/30/2020

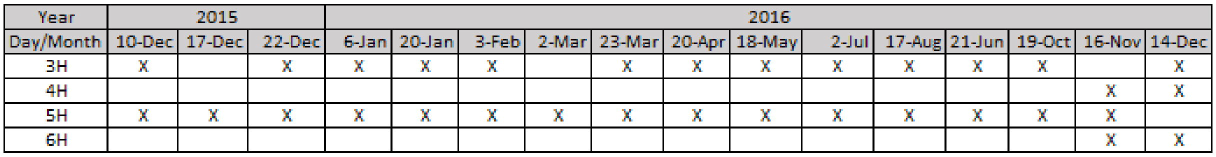
Topic 4 – Produced Water and Solid Waste Monitoring

Approach

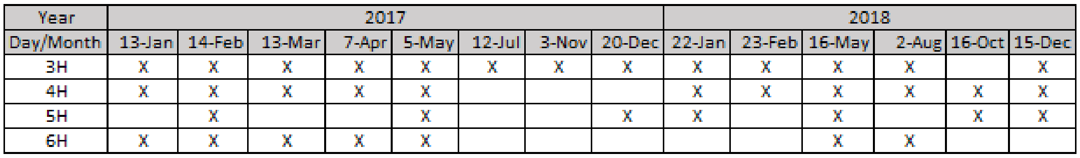
MIP Site

Over three years into the post completion part of the program, the produced water and solid waste component of MSEEL has continued to systematically monitor changes in produced water quality and quantity. During year one of the study, hydraulic fracturing fluid, flowback, produced water, drilling muds and drill cuttings were characterized according to their inorganic, organic and radiochemistries. 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 1 indicate that samples were not collected, due to lack of availability of produced water from the well(s).

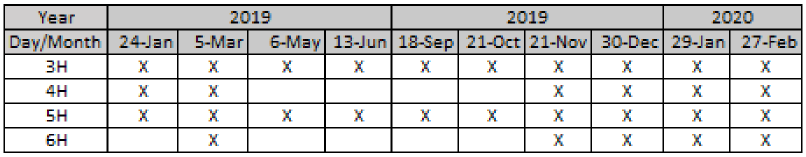
Table 4.1. MIP sampling events are indicated with an "X".



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	3-Nov	20-Dec	22-Jan	23-Feb	16-May	2-Aug	16-Oct	15-Dec
3H	X	X	X	X	X	X	X	X	X	X	X	X		X
4H	X	X	X	X	X				X	X	X	X	X	X
5H		X			X			X	X		X		X	X
6H	X	X	X	X	X						X	X		



Year	2019				2019				2020	
Day/Month	24-Jan	5-Mar	6-May	13-Jun	18-Sep	21-Oct	21-Nov	30-Dec	29-Jan	27-Feb
3H	X	X	X	X	X	X	X	X	X	X
4H	X	X					X	X	X	X
5H	X	X	X	X	X	X	X	X	X	X
6H		X					X	X	X	X

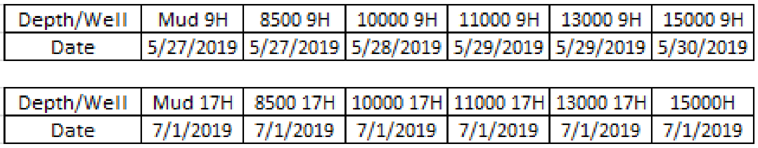
Boggess Site

Two control wells; 9H and 17H were selected for solids and aqueous studies at the newly developed Boggess well site.

Tophole was completed in Feb 2019 for 9H and Jan 2019 for 17H. Samples of vertical drilling were not obtained due to completion prior to the start of the Boggess project.

Horizontals were initiated on 19 June 2019 for 17H and 20 May 2019 for 9H (Table 4.2). A drilling mud sample along with depth samples at 8,500ft; 10,000ft; 11,000ft; 13,000ft; and 15,000ft were collected and analyzed for parameters shown in Table 4.3.

Table 4.2. Sample depth and dates for collection of horizontal drilling mud and cutting samples.



Depth/Well	Mud 9H	8500 9H	10000 9H	11000 9H	13000 9H	15000 9H
Date	5/27/2019	5/27/2019	5/28/2019	5/29/2019	5/29/2019	5/30/2019

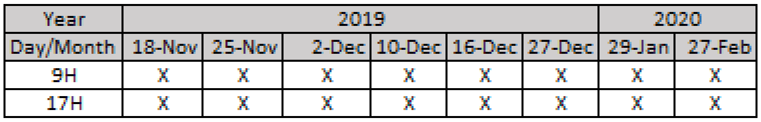
Depth/Well	Mud 17H	8500 17H	10000 17H	11000 17H	13000 17H	15000H
Date	7/1/2019	7/1/2019	7/1/2019	7/1/2019	7/1/2019	7/1/2019

Table 4.3. Solids analysis list.

Analysis	Analysis Method	Prep Method	Units	Parameter
Gasoline Range Organics by GC-FID	SW8015D	SW5035	ug/Kg	GRO C6-C10)
			% Rec	Surr: Toluene-d8
Volatile Organic Compounds	SW8260B	SW5035	ug/Kg-dry	Ethylbenzene
				m,p- Xylene
				o- Xylene
				Styrene
				Toluene
				Xylenes total
			% Rec	Surr: 1,2- Dichloroethane-d4
				Surr: 4-Bromofluorobenzene
				Surr: Dibromofluoromethane
				Surr: Tolouene-d8
Radionuclides	EPA 901.1	N/A	pCi/g	Potassium-40
				Radium-226
				Radium-228
	9310			Gross Alpha
				Gross Beta
Inorganics (note: metals analyzed as total metals)	SW9056A	Extract	mg/Kg-dry	Br
				Cl
				SO4
	SW9034	SW9030B		sulfide
	E353.2	Extract		nitrate
	E354.1			nitrite
	A2510M		µS/cm	EC
	SW9045D		units	pH
	A4500-CO2 D		mg/Kg-dry	alk bicarb
				alk carb
				alk t
	E365.1 R2.0			TP
	SW6020A	SW3050B		Ag
				Al
				As
				Ba
				Ca
				Cr
				Fe
				K
				Li
				Mg
				Mn
				Na
				Ni
				Pb
				Se
				Sr
				Zn
Moisture	E160.3M	N/A	%	Moisture
Chemical Oxygen Demand	E4104 R2.0	Extract	mg/Kg-dry	COD
Organic Carbon - Walkley-Black	TITRAMETRIC	N/A	% by wt-dry	OC-WB
Oil & Grease	SW9071B - OG	N/A	mg/Kg-dry	O&G

Flowback sampling was initiated on 18 Nov 2019 with weekly collection at 9H and 17H for the first four weeks (Table 4.4). Monthly sampling began following the initial weekly sampling effort.

Table 4.4. Boggess sampling events are indicated with an "X".



Year	2019						2020	
Day/Month	18-Nov	25-Nov	2-Dec	10-Dec	16-Dec	27-Dec	29-Jan	27-Feb
9H	X	X	X	X	X	X	X	X
17H	X	X	X	X	X	X	X	X

Results & Discussion

MIP Site

Major ions – trends in produced water chemistry

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**).

Figure 4.1. Changes in major ion concentrations in produced water from well MIP 3H. Top left Day -34 represents makeup water from the Monongahela River, top center is produced water on the first day (Day 0) and the remainder of pie charts show flowback and produced water on sampling dates through the 1540th day post completion.

In wells 3H and 5H, TDS increased rapidly over the initial 90 days post completion while TDS stabilized between 100,000 and 200,000 mg/L through day 1181(3H) (Figure 2). Note that 3H and 5H were both shut-in near day 966 and brought back online prior to sampling on day 1101. 3H and 5H are showing an upward trend following day through day 1243 (e.g. May 2019). Results from day 1281 (e.g. June 2019), TDS declined in both wells. It's uncertain if the wells were shut down between day 1243 and day 1281, which might explain the decrease in TDS.

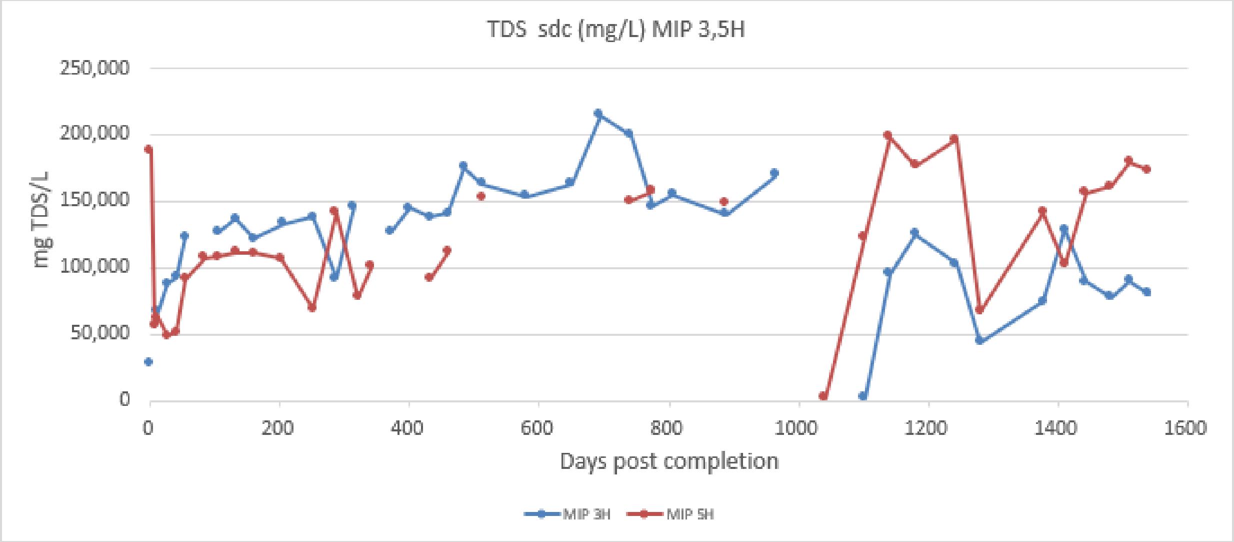


Figure 4.2. Changes in produced water TDS sdc (sum of dissolved constituents) through the first 1540 days post completion (3,5H).

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 similarly low TDS trend was noted when well 4H went back online around 1793 days post-completion (after being shut-in for 315 days) and again when 6H went online around day 2339, a rise in TDS subsequently follows the initial return to online status with TDS on an upward trend, reaching 160,000 mg/L for 6H. MIP 6H was shut down between August 2018 and March 2019 and again after March 2019 through November 2019. TDS was 30,970 mg/L on day 2632 (March 2019) and is downward trending following day 2893 (November 2019) through day 2991 at 10,683 mg/L at day 2991 (Figure 4.3).

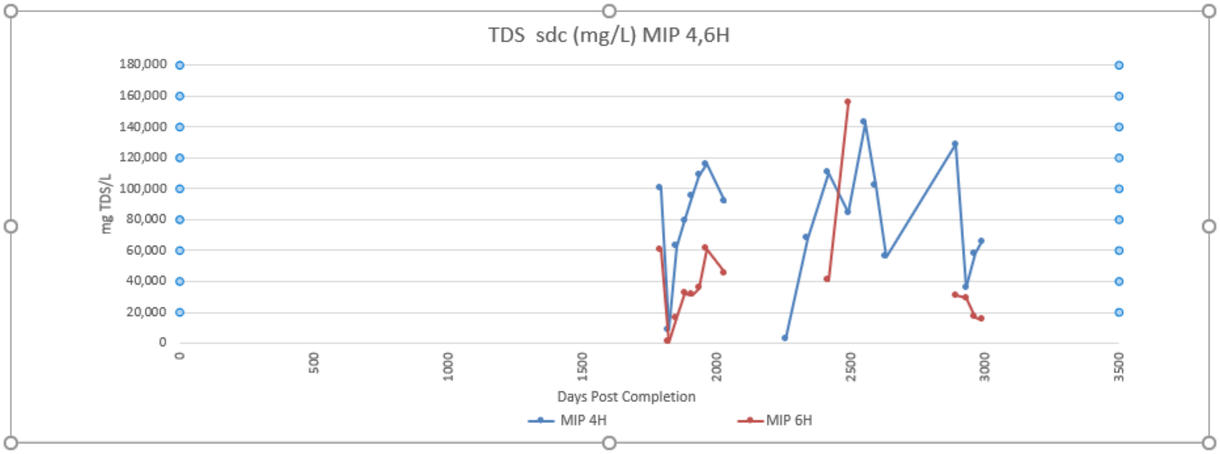


Figure 4.3. Changes in produced water TDS sdc (sum of dissolved constituents) through the first 1793 through 2991 days post completion (4,6H).

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). This seems to be a characteristic of dry gas geologic units. After five years, benzene has mostly declined below the drinking water standard of 5 µg/L. An exception to this was a measurement of 41 µg/L at 3H on day 694 and 11 µg/L noted on day 1378 at 5H.

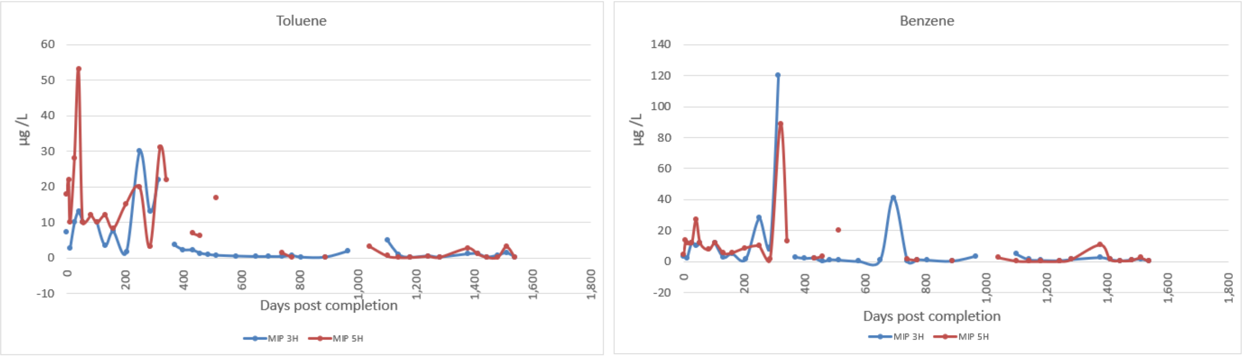


Figure 4.4. Changes in benzene and toluene concentrations. The figure shows data from well both 3H and 5H.

Radium isotopes

The radiochemical concentrations were determined by Pace Analytical in Greensburg PA, a state certified analytical lab. Radium concentrations generally increased through 800 days post completion at wells MIP 3H and 5H. Maximum levels of the radium isotopes reached about 21,800 pCi/L at the unchoked 3H well and around 17,800 pCi/L 5H. After returning online prior to day 966, both wells have remained below 15,000 pCi/L through day 1540 (Figure 4.5).

Radioactivity in produced water

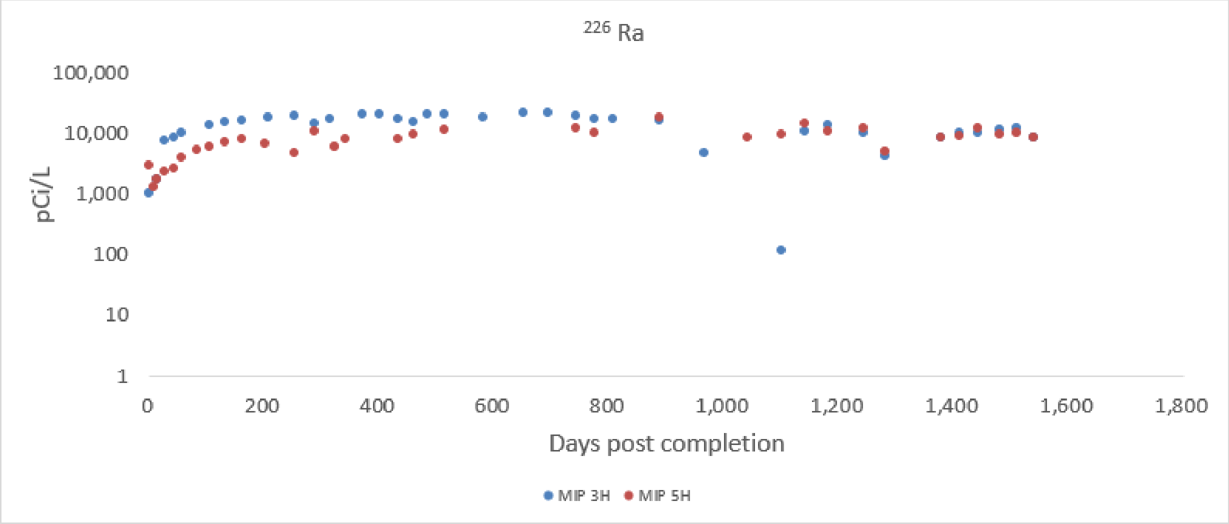


Figure 4.5. The radium isotopes are plotted against days post well completion. Well 5H was choked more periodically the 5H. 3H produced less water and lower concentrations of radium.

Radium concentrations at wells 4H and 6H were below 9,000 pCi/L during all sampling periods. Both wells were choked after 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) peaked at 5,127 pCi/L then returned to 3,892 pCi/L. The same trend is noted at day 2339 when 4H returned online with 57 pCi/L then peaked at day 2632 with 8,197 pCi/L. Both wells were shut down during summer months, between days 2632 and 2893. 6H is on a downward trend from 1901 pCi/L to 739 pCi/L from day 2893 through the most recent collection on day 2991. Additional data is needed to capture long-term trends.

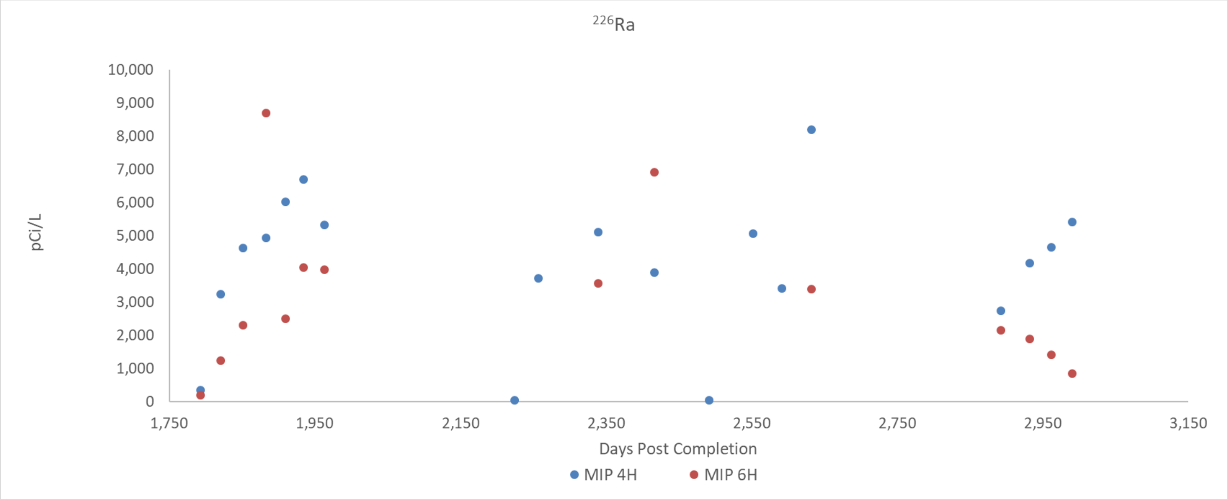


Figure 4.6. The radium isotopes are plotted against days post well completion. Well 4H and 6H were choked at day 1963 and again at day 2632. At day 2225, 4H was reopened showing a value of 58 pCi/L and reopened again at day 2192 showing a value of 57 pCi/L.

Figure 4.7 show the relationship between gross alpha and ^{226}Ra at 3H and 5H. Analysis for alpha was not conducted after day 1181.

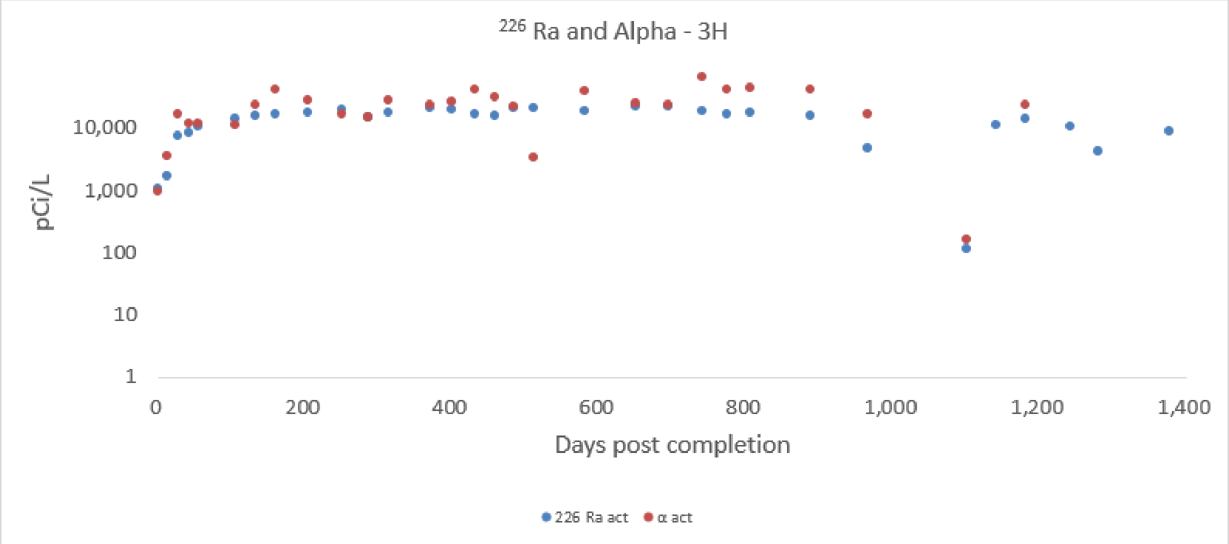


Figure 4.7. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 3H. Note: analysis for alpha was not conducted after day 1181.

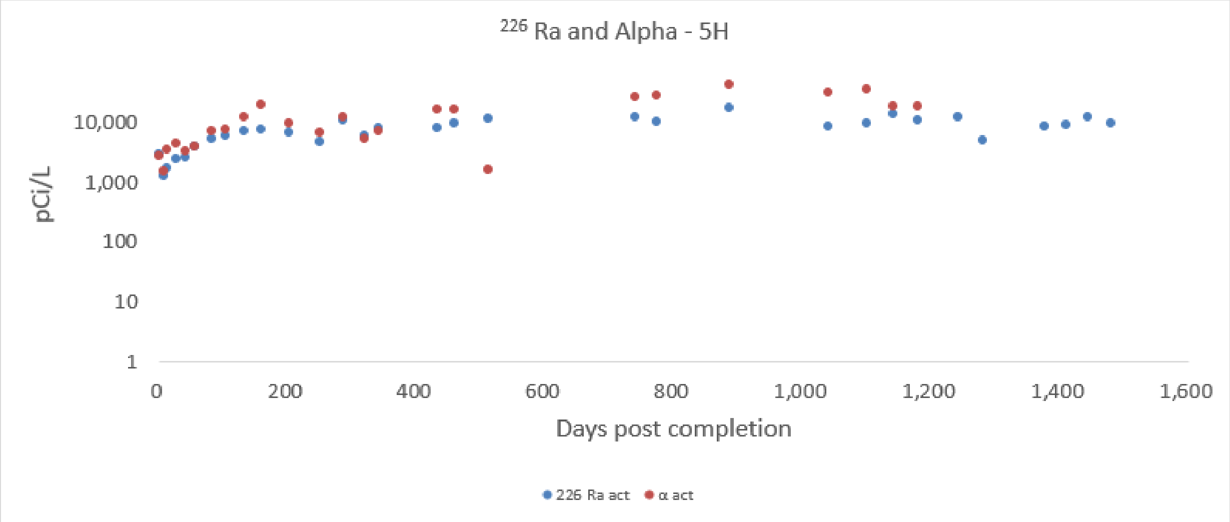


Figure 4.8. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 5H.

The highest values reported in the older wells at 4H and 6H were 17,550 pCi/L gross alpha and 8,197 pCi/L ^{226}Ra. The relationship between gross alpha and ^{226}Ra for wells 4H and 6H are shown in figures 4.9 and 4.10.

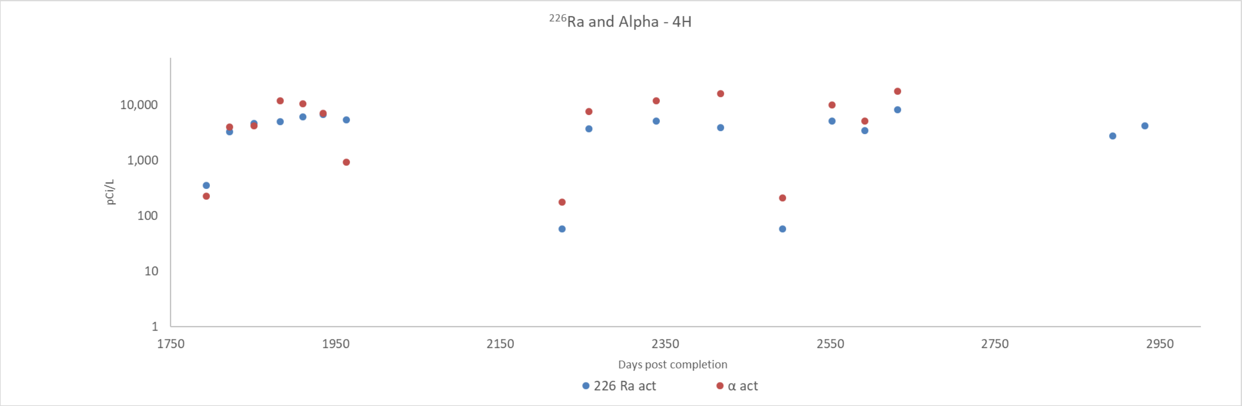


Figure 4.9. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 4H.

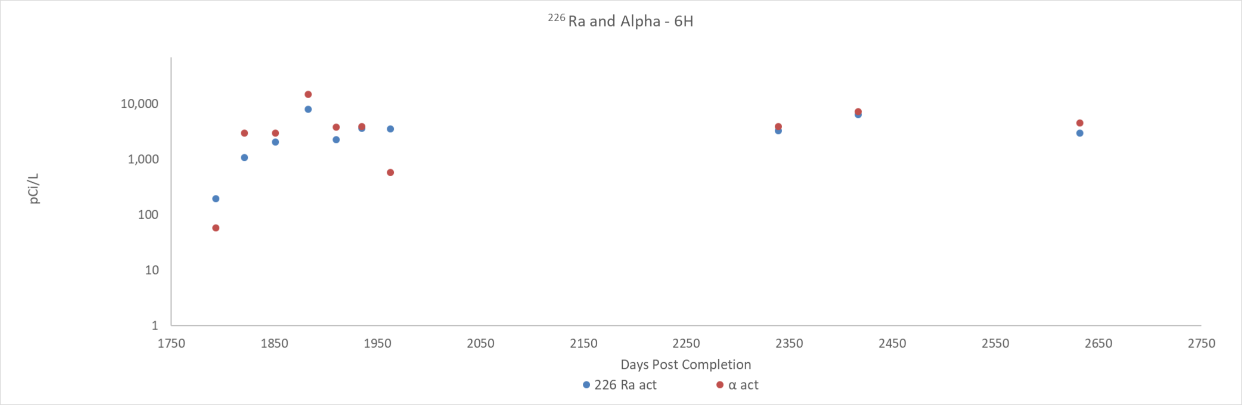


Figure 4.10. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 6H.

Boggess Well

Solids

Analytical results have been received for drilling muds and cuttings collected at 9H at depth intervals of 8,500ft; 10,000ft; 11,000ft; 13,000ft; and 15,000ft. Anions (e.g. Br, Cl, and SO4) and Cations (e.g. Ba, Ca, Mg, Mn, Na, and Sr) are shown in Figure 4.11. Drill cuttings from 9H are predominately Calcium. The full list of solids parameters and methods are shown in Table 4.3.

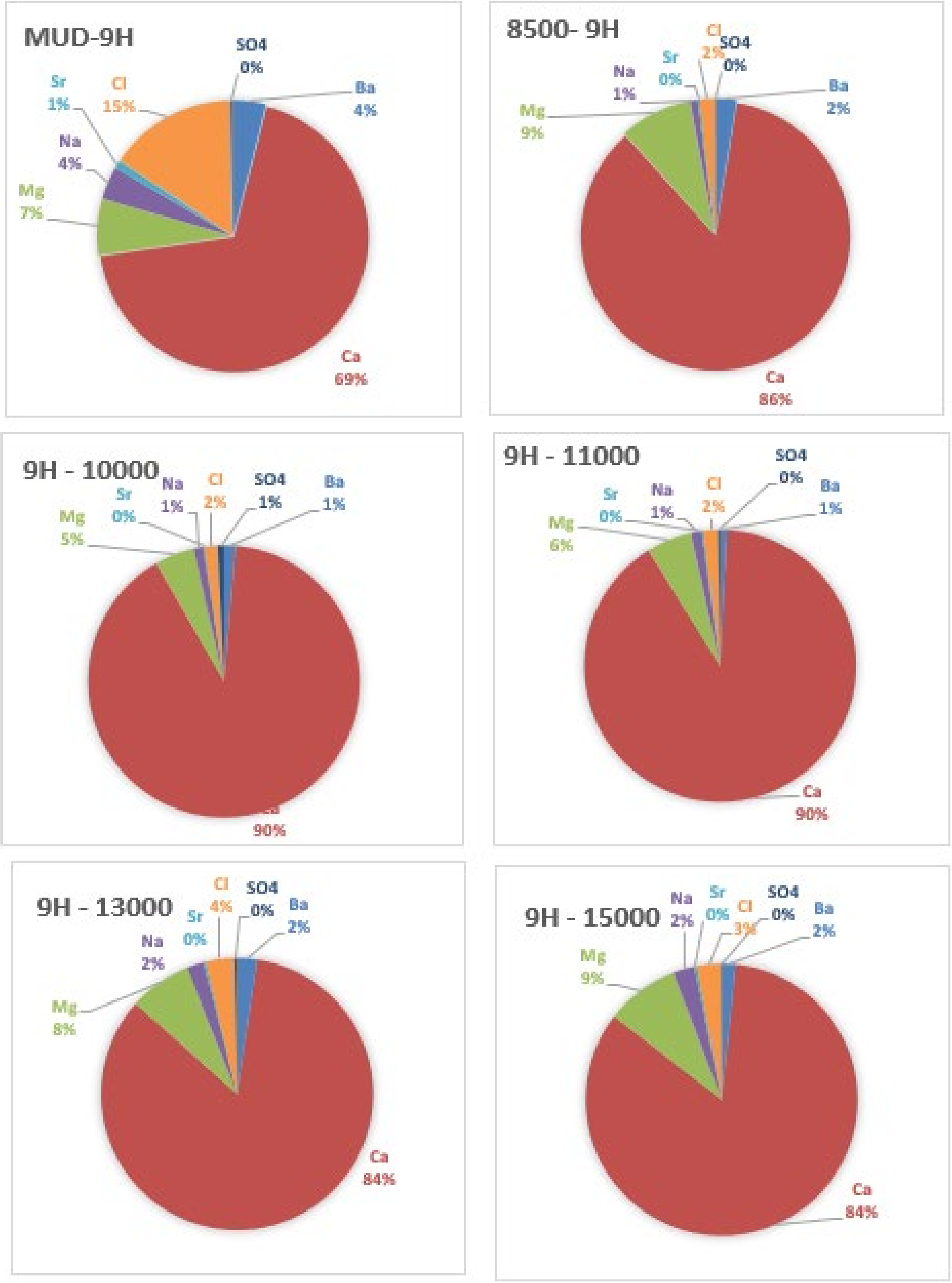


Figure 4.11. Anions/cations of drilling mud and cutting from 9H.

Figure 4.12 depicts anions/cations of drilling mud and cuttings from 17H. Magnesium was more prevalent in the 8,500ft and 10,000ft depths for 17H in comparison to the same depths for 9H.

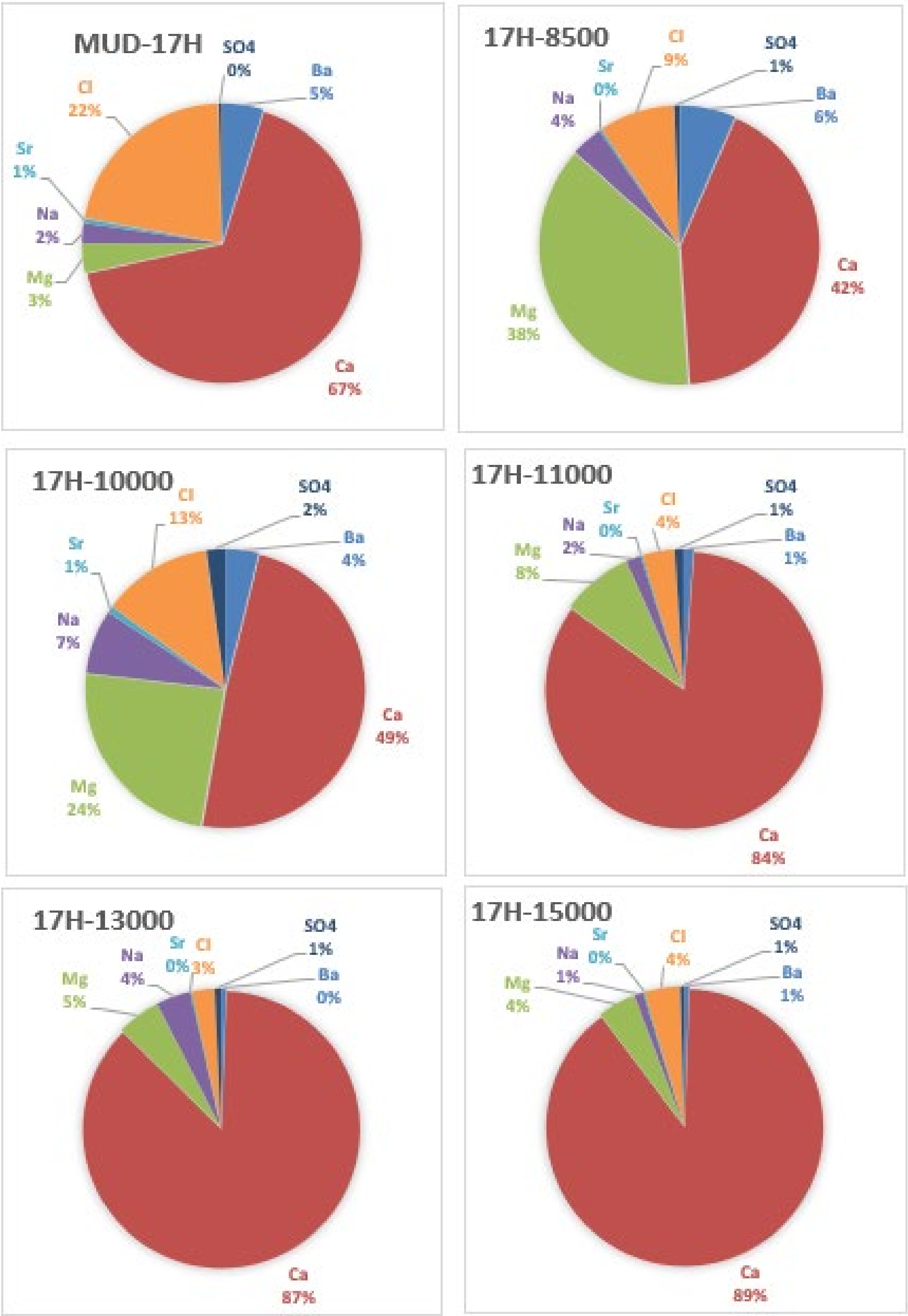


Figure 4.12. Anions/cations of drilling mud and cuttings from 17H.

Figure 4.13 and 4.14 depict combined radium 226 and 228 of solids in drilling mud and cuttings from 9H and 17H.

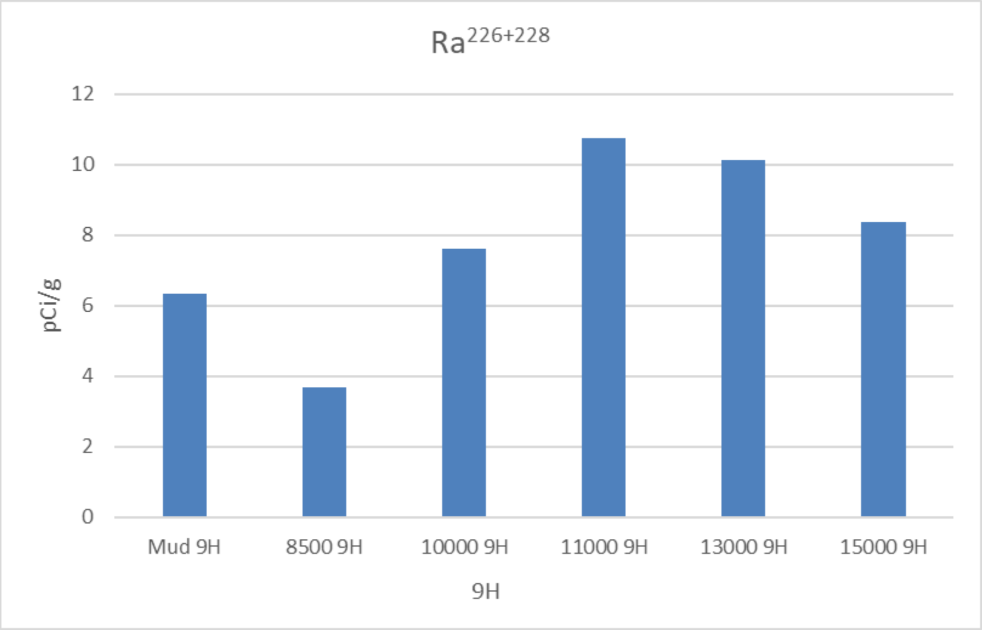


Figure 4.13. 9H Combined radium 226 and 228 for drilling mud and cuttings.

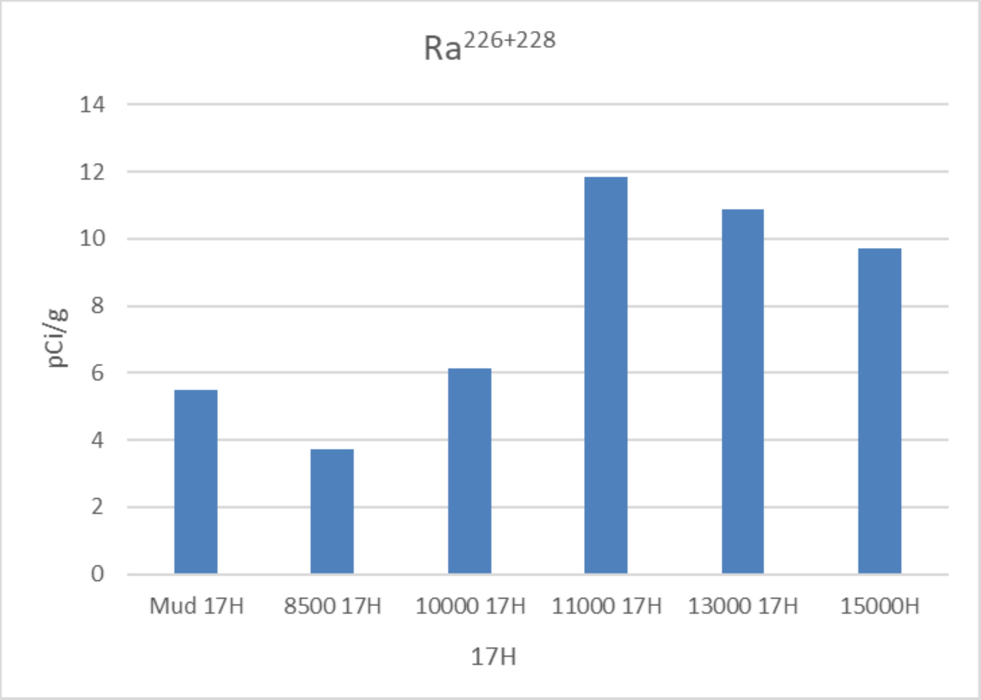


Figure 4.14. 17H Combined radium 226 and 228 for drilling mud and cuttings.

For comparison purposes, solids radium analysis from MIP 5H and 3H are shown in Figure 4.15 and Figure 4.16. In all wells analyzed, 3H and 5H from MIP along with 9H and 17H at Boggess, combined radium 226 and 228 remained below 12 pCi/g.

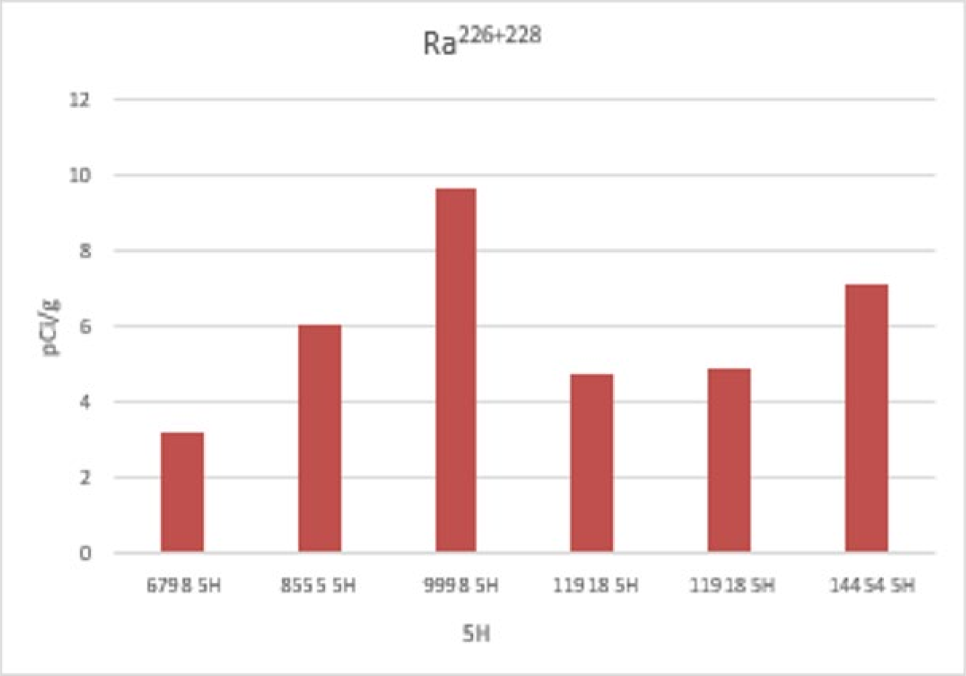


Figure 4.15. Combined Ra 226 + 228 for 5H MIP sites.

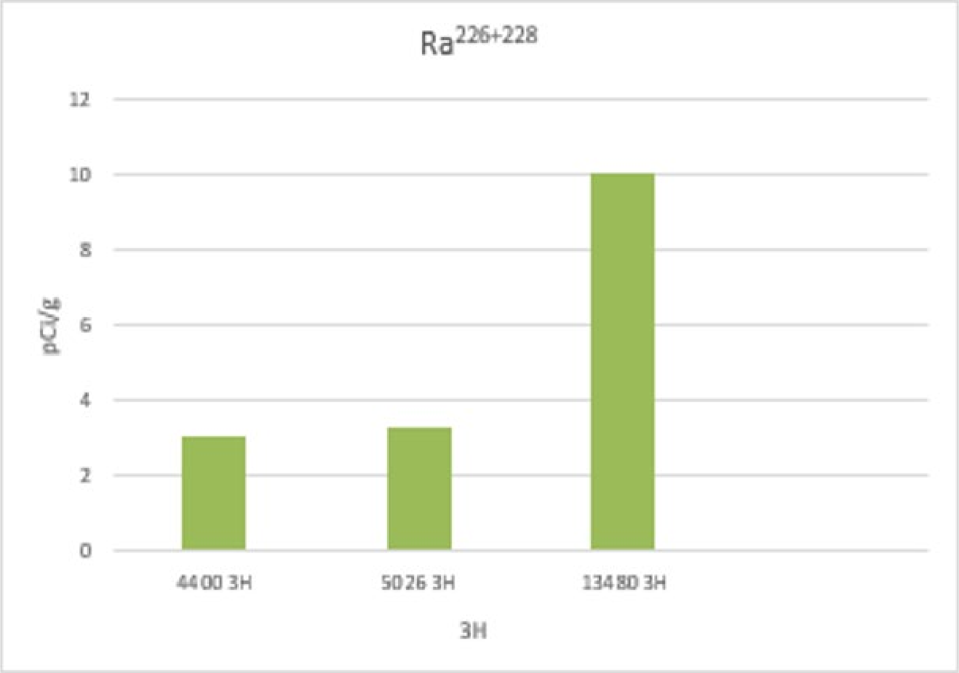


Figure 4.16. Combined Ra 226 + 228 for 3H MIP sites.

Major ions – trends in produced water chemistry

While makeup water was characterized by low TDS and a dominance of calcium and sulfate ions, produced water from initial flowback is essentially a sodium/calcium chloride water as noted in the earlier discussion regarding results from MIP. Preliminary results from days 0-101 at Boggess 9H and 17H are consistent with earlier results from MIP (Figure 4.17).

Figure 4.17. Major ion concentrations in produced water from wells BOGGESS 9H and 17H.

Preliminary TDS (sdc) at Boggess 9H and 17H show a slight upward trend between days 0 and 101 (Figure 4.18).

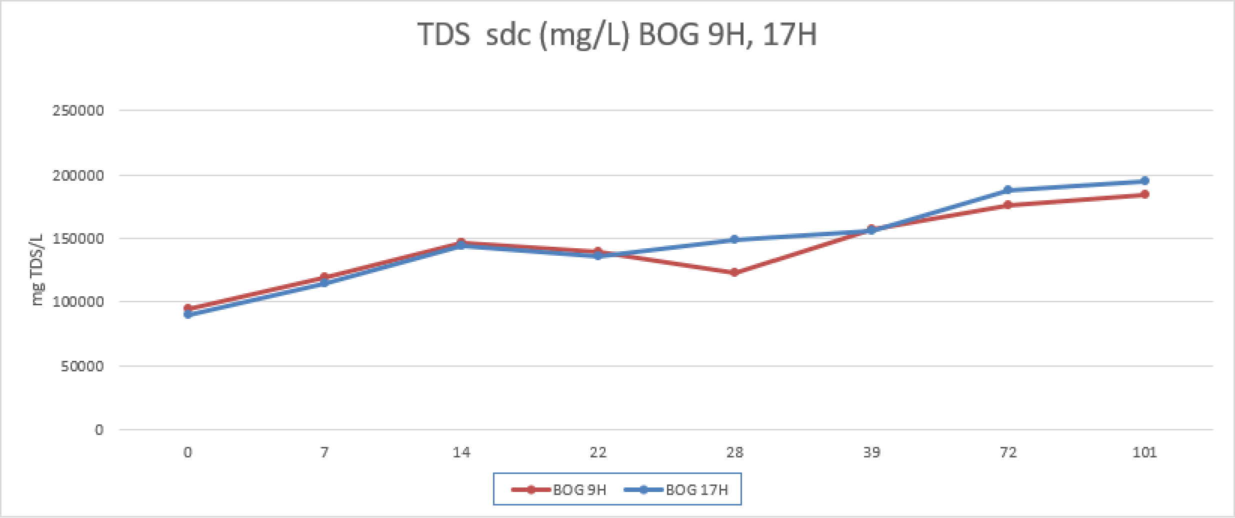


Figure 4.18. TDS (sdc) at Boggess 9H and 17H; days 0-14.

Radium concentrations were below 15,000 pCi/L at both 9H and 17H at 101 days post completion (Figure 4.19).

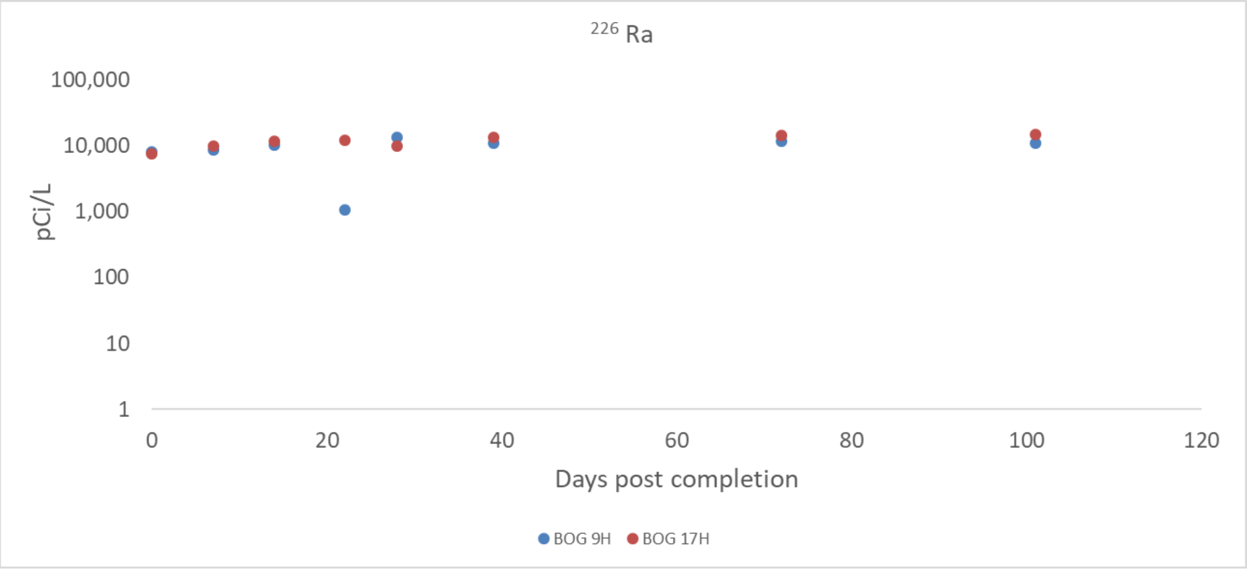


Figure 4.19. The radium isotopes are plotted against days post well completion.

Products

None for this quarter.

Plan for Next Quarter

We will continue monthly sampling at MIP and analyze flowback/produced water (FPW) from MIP 3H, 4H, 5H and 6H if they are online.

We will continue sampling at Boggess Pad control wells 9H and 17H. Plans include collection of flowback/produced water. Following the same protocols used at MIP wells, we will continue to characterize their inorganic, organic and radio chemistries.

Topic 5 – Environmental Monitoring: Air & Vehicular

Approach

We have made considerable progress to make up for previous setbacks. We completed the 13th and 14th audits in January and March of 2020. The OTM/Eddy Covariance Trailer Tower has been continuously collecting data at the MIP site throughout Q1. The 13th and 14th audits included ethane results that were previously excluded due to uncertainty with analyzer. The confidence of the analyzer was improved with an external calibration. Figure 5.1 presents the calibration curve of the MEA.

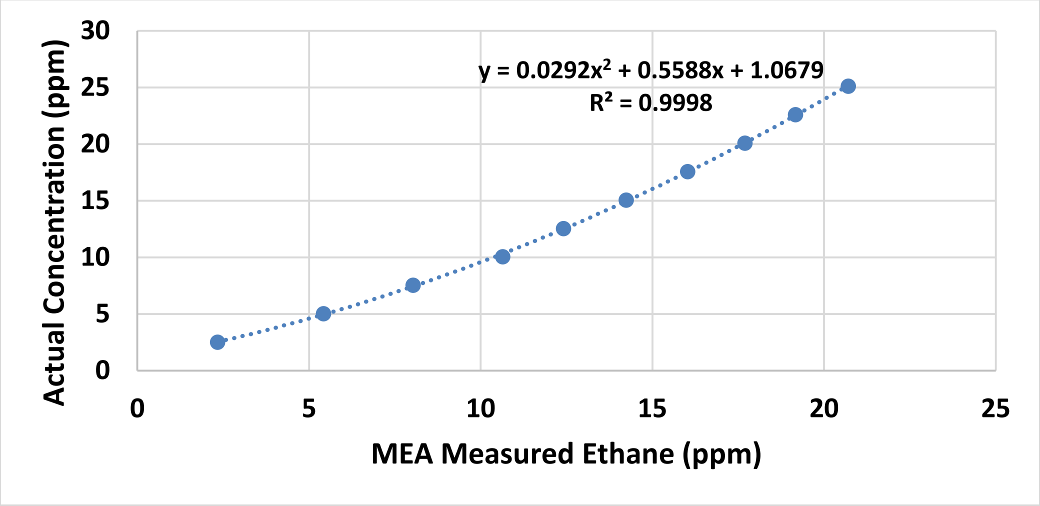


Figure 5.1: MEA ethane calibration curve.

On February 17th, 2020 the boiler and gensets were instrumented on the McClellan pad on Fairview, WV area. Two flowmeters equipped with temperature sensors were installed on the boiler along with thermocouples on its exhaust and water day tank. Additionally, the DAQ box was installed on the gensets along with multiple thermocouples recording temperatures at the engine exhausts, before and after the radiator, inside the DAQ box, and ambient. The DAQ box also communicated through Deutsch 9 connectors to each of the engines. ECU data were recorded through a PCAN to USB connector directly on the solid-state computers by the CAFEE-developed software Scimitar. Due to delay in instrumentation, a model is still under development. We note that with the project extension and our successful data collection effort during late winter weather, we could collect additional data for validation prior to the end of the project.

Results & Discussion

As presented, the 13th and 14th audits were completed. The total average methane emissions from those audits were 0.36 and 2.41 kg/hr, respectively. Figure 5.2 presents an updated graphic of all audits to date. The mean and geometric mean methane leak rates are now 5.08 and 0.98 kg/hr, respectively. The ethane rates from the two audits performed were 13 and 1.2 g/hr, respectively. These rates were significantly lower than methane as the composition previously indicated that the gas composition from these wells was over 95% methane.

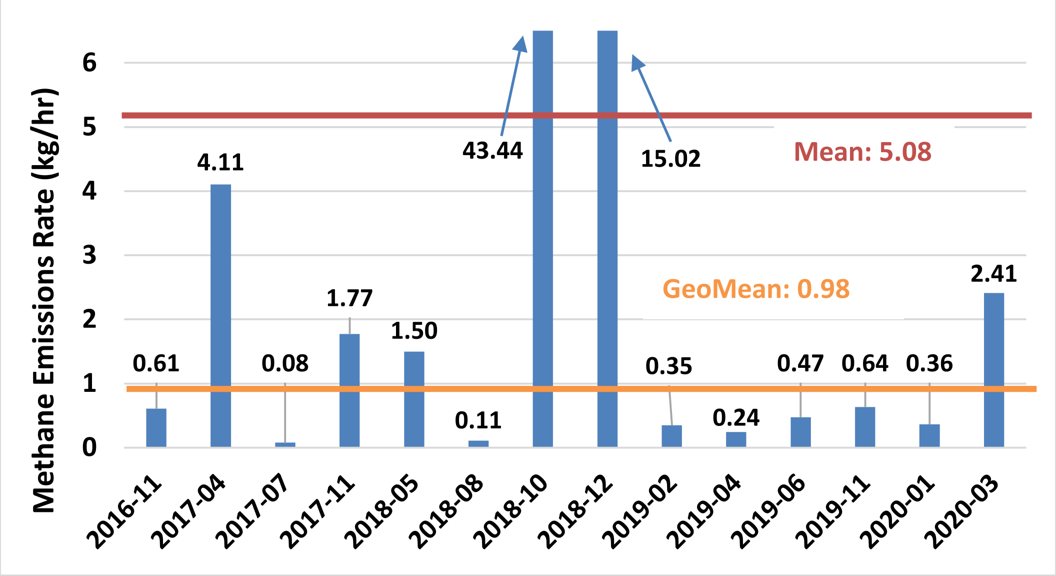


Figure 5.2: Results of Audits 1-14 at MIP (MSEEL 1.0).

Data from the monitoring tower have been analyzed from an OTM 33A and Eddy Covariance perspective. The OTM 33A analysis used the average distance to potential sources from the tower location. The Eddy Covariance calculations were performed with EddyPro® Express Mode. Figure 5.3 presents the results of these analyses along with the dates when audits were performed (shown in orange). The periods of interest due to expected high leak rates were identified for further analysis and are circled.

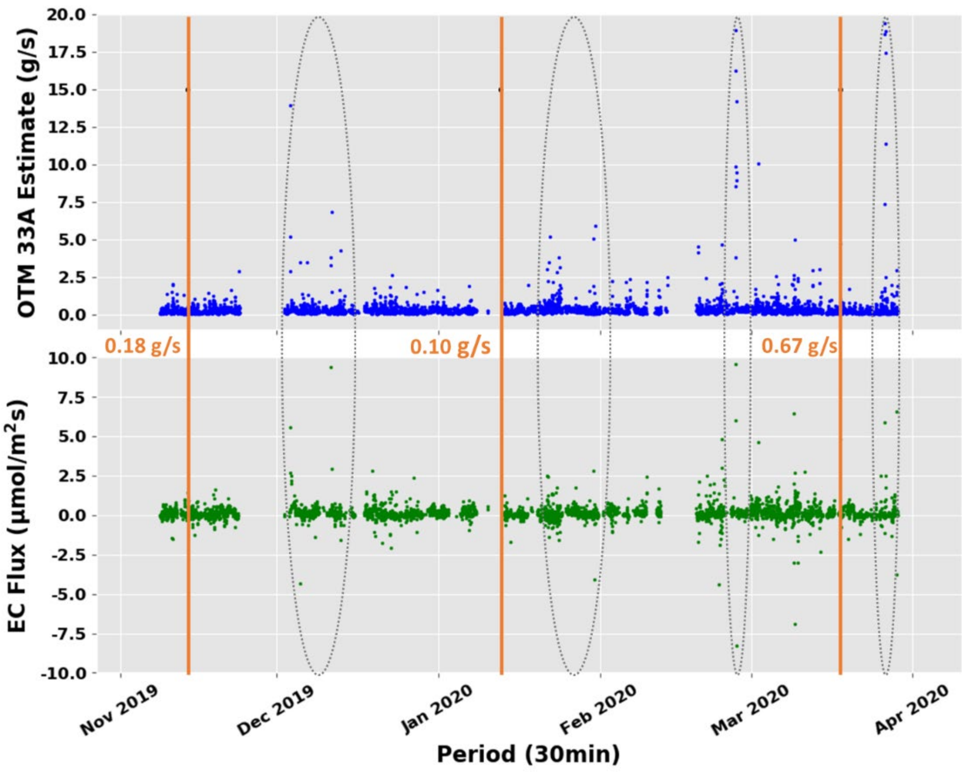


Figure 5.3: Results of initial indirect ambient methane monitoring at MIP (MSEEL 1.0).

Recorded ECU data from the energy audit at the McClellan pad included absolute time, percent load, fuel consumption, engine speed, power, coolant temperatures, air intake pressures, intake manifold pressures, and turbo pressures and temperatures. These data were collected continuously from February 21st until March 20th when the rig was moved to the next well location. Total well energy demand will be estimated from installation until completion. The boiler was active for fourteen days, six of which required continuous operation. On March 6th the boiler was permanently deactivated.

Products

Nothing to report.

Plan for Next Quarter

- Conduct Audit 15 at MIP (MSEEL 1.0)
- Further investigate OTM 33A and Eddy Covariance results from targeted periods
- Investigate leak estimation accuracy by verifying with audit data.
- Develop a MATLAB®-SIMULINK-Excel integrated model using the 20 Gb of collected energy data
- Estimate potential of waste heat recovery using developed model

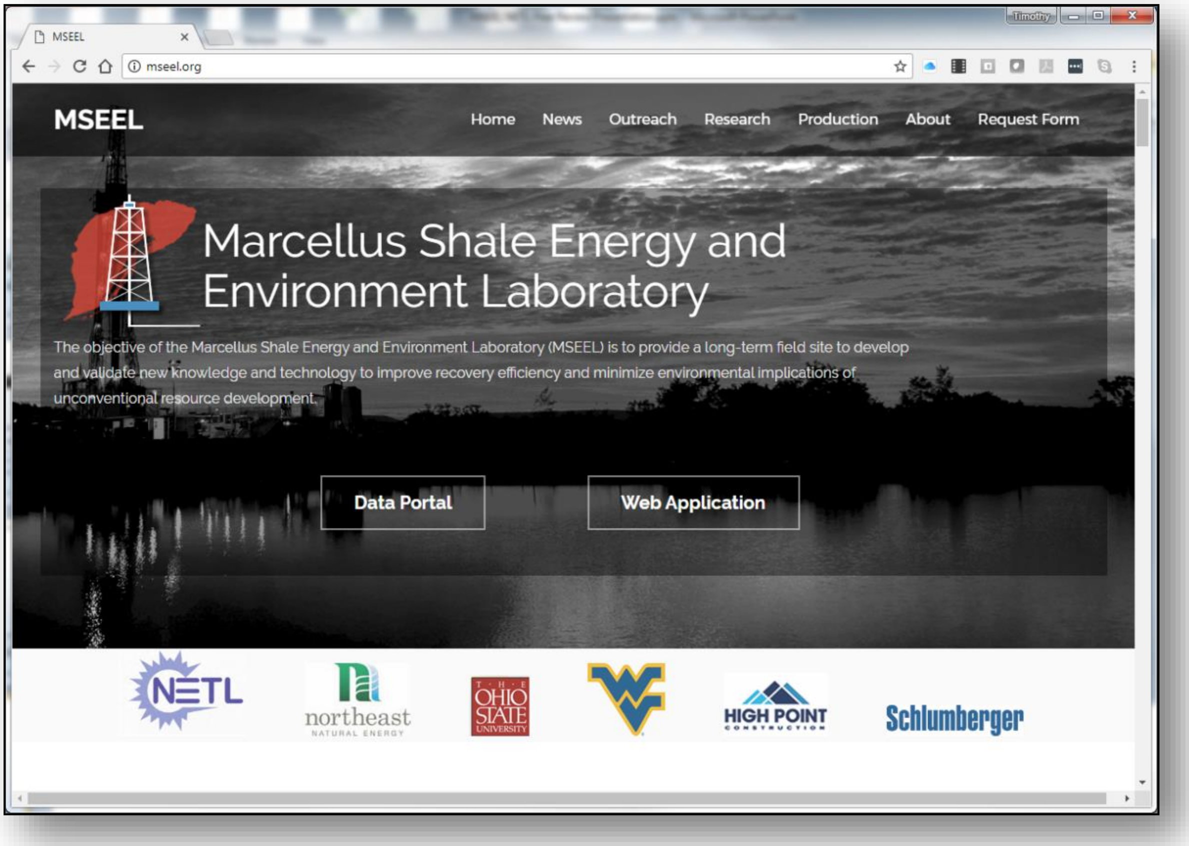
Topic 6 – Water Treatment

This task is complete and will not be updated in future reports.

Topic 7 – Database Development

Approach

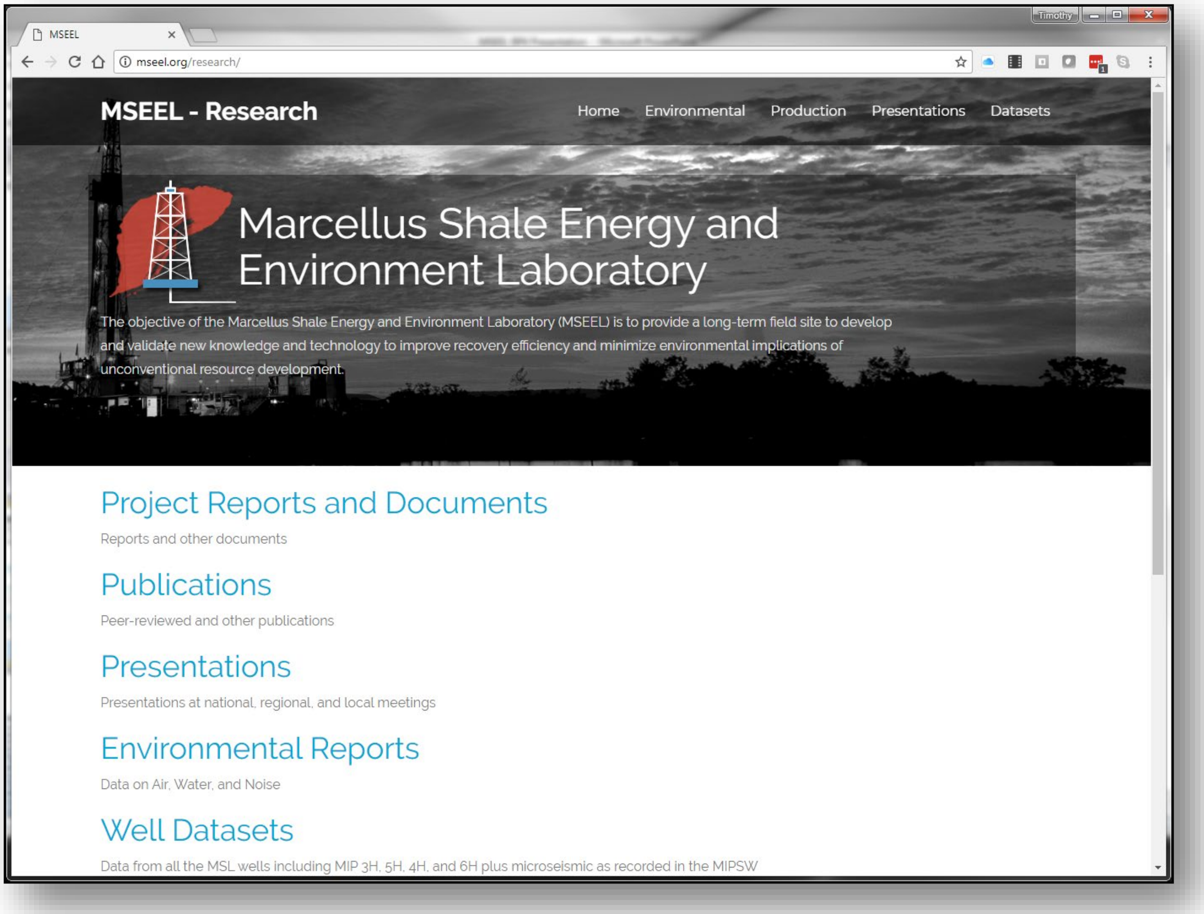
All MSEEL data is online and available to researchers (Figure 7.1 and 7.2). The website has been updated with the latest production beyond the end of the quarter (Figure 7.3). Also, a map viewer for regional perspective (Figure 7.4). Work continues and we are adding data from MSEEL 3 Boggess Pad.



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

Home Environmental Production Presentations Datasets

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

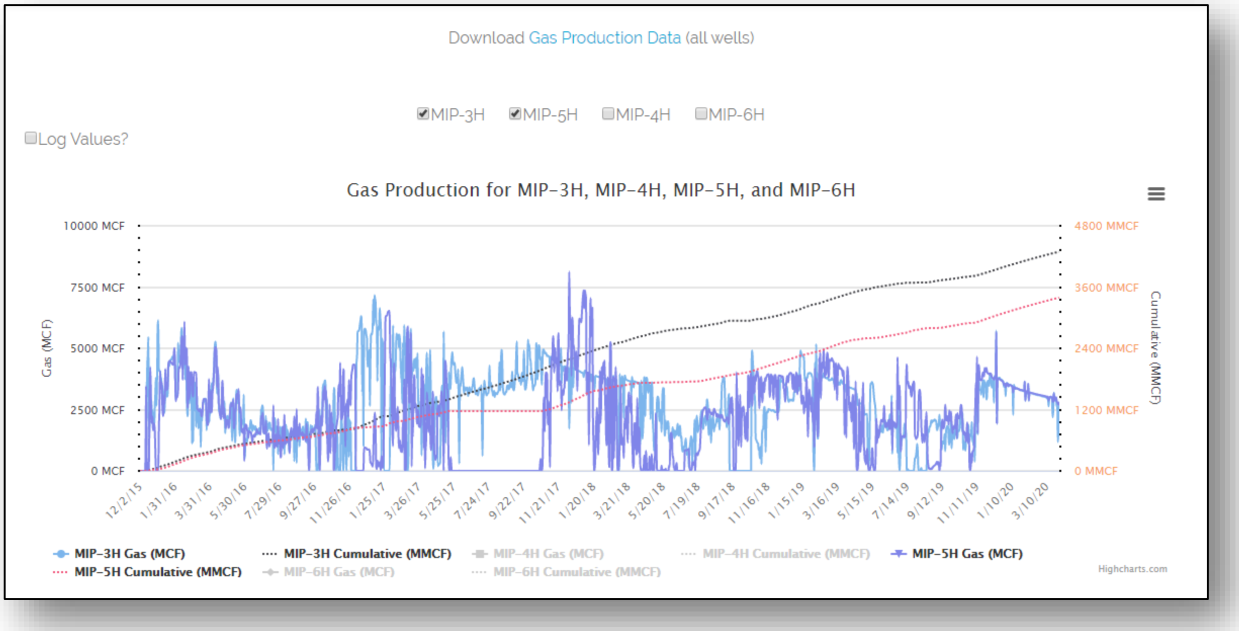
Environmental Reports

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/.



Download Gas Production Data (all wells)

☑MIP-3H ☑MIP-5H ☐MIP-4H ☐MIP-6H

☐Log Values?

Gas Production for MIP-3H, MIP-4H, MIP-5H, and MIP-6H

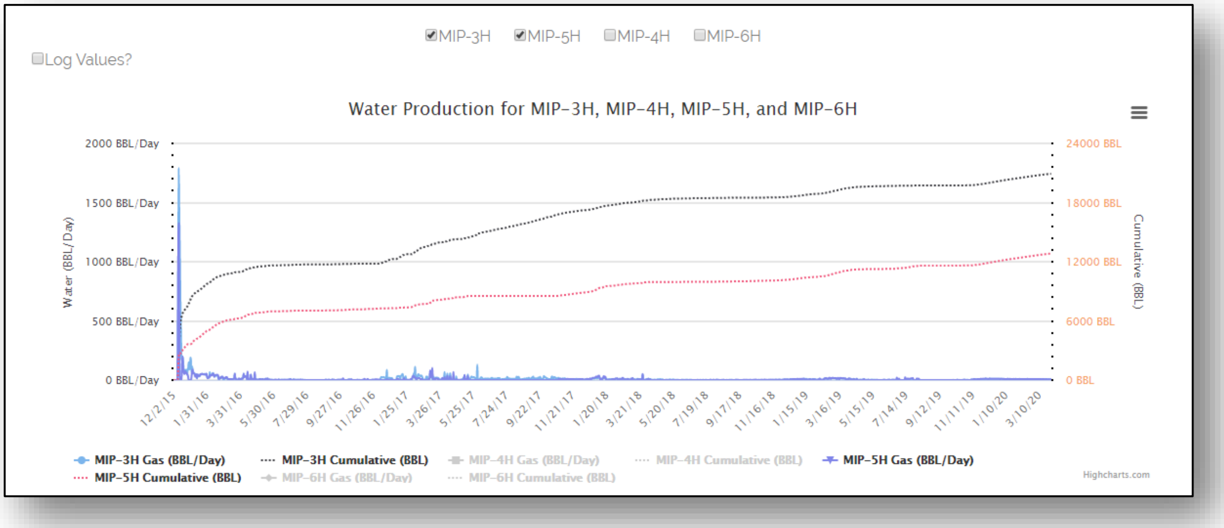


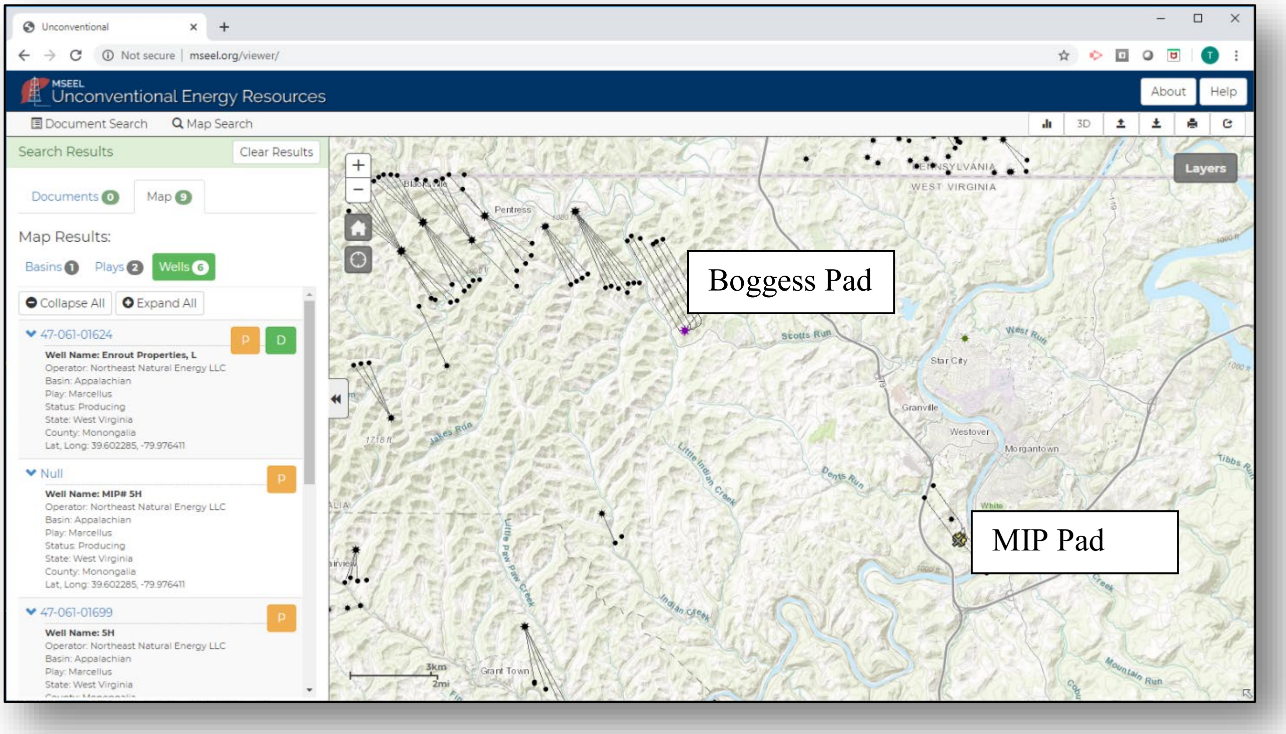
Figure 7.3: Gas and water production have been updated through the end of the quarter and are available at http://mseel.org/.

Results & Discussion

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

Products

Web site enhanced and updated to include a map viewer (figures 7.4 and 1.1)



47-061-01624 P D

Well Name: Enrout Properties, L
Operator: Northeast Natural Energy LLC
Basin: Appalachian
Play: Marcellus
Status: Producing
State: West Virginia
County: Monongalia
Lat, Long: 39.602285, -79.976411

Null P

Well Name: MIP# 5H
Operator: Northeast Natural Energy LLC
Basin: Appalachian
Play: Marcellus
Status: Producing
State: West Virginia
County: Monongalia
Lat, Long: 39.602285, -79.976411

47-061-01699 P

Well Name: 5H
Operator: Northeast Natural Energy LLC
Basin: Appalachian
Play: Marcellus
State: West Virginia

Figure 7.4: Map viewer showing MSEEL wells and other Marcellus wells across the Appalachian basin. The MIP and Boggess pads are labeled and data from the MIP wells is shown. The MSEEL map viewer is available at http://mseel.org/.

Plan for Next Quarter

Working to add data from the new Boggess Pad

Topic 8 – Economic and Societal

<u>This task is complete and will not be updated in future reports.</u>

Cost Status

Year 1

Start: 10/01/2014 End: 09/30/2019

Baseline Reporting Quarter

	Q1 (12/31/14)	Q2 (3/31/15)	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:
09/30/2019

Baseline Reporting Quarter

	Q5 (12/31/15)	Q6 (3/31/16)	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: 09/30/2019

Baseline Reporting Quarter	Q9 (12/31/16)	Q10 (3/31/17)	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	$11,624,535.17	$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: 09/30/2019

Baseline Reporting Quarter	Q13 (12/31/17)	Q14 (3/31/18)	Q15 (6/30/18)	Q16 (9/30/18)
<u>Baseline Cost Plan</u>	(From 424A, Sec. D)			
<u>(from SF-424A)</u>				
Federal Share				$11,794,054
Non-Federal Share				$5,222,242
Total Planned (Federal and Non-Federal)				$17,016,296.00
Cumulative Baseline Costs				
<u>Actual Incurred Costs</u>				
Federal Share	$112,075.89	$349,908.08	$182,207.84	$120,550.20
Non-Federal Share	$0.00	$31,500.23	$10,262.40	$4,338.00
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$112,075.89	$381,408.31	$192,470.24	$124,888.20
Cumulative Incurred Costs	$12,884,599.79	$13,266008.10	$13,458,478.34	$13,583,366.54
<u>Uncosted</u>				
Federal Share	$588,114.74	$238,206.66	$55,998.82	$2,600,771.62
Non-Federal Share	$176,938.47	$145,438.24	$135,175.84	$832,157.84
Total Uncosted - Quarterly (Federal and Non-Federal)	$765,053.21	$383,644.90	$191,174.66	$3,432,929.46

Start: 10/01/2014 End: 09/30/2019

Baseline Reporting Quarter	Q17 (12/31/18)	Q18 (3/31/19)	Q19 (6/30/19)	Q20 (9/30/19)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share			$15,686,642.00	
Non-Federal Share			$9,180,952.00	
Total Planned (Federal and Non-Federal)			$24,867594.00	
Cumulative Baseline Costs				
Actual Incurred Costs				
Federal Share	$80,800.03	$133,776.98	$714,427.48	$1,136,823.21
Non-Federal Share	$4,805.05	$130,449.21	$4,099,491.20	$334,919.08
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$85,605.08	$264,226.19	$4,813,918.68	$1,471,742.29
Cumulative Incurred Costs	$13,668,971.62	$13,933,197.81	$18,747,116.49	$20,218,858.78
Uncosted				
Federal Share	$2,519,971.59	$2,386,194.61	$5,564,355.13	$4,427,531.92
Non-Federal Share	$827,352.79	$696,903.58	$412,612.38	$221,203.30
Total Uncosted - Quarterly (Federal and Non-Federal)	$3,347,324.38	$3,083,098.19	$5,976,967.51	$4,948,735.22

Start: 10/01/2014

End: 09/30/2020

Baseline Reporting Quarter	Q21 (12/31/19)	Q22 (3/31/20)	Q23 (6/30/20)	Q24 (9/30/20)
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	$3,098,337.44	$735,358.08		
Non-Federal Share	$3,163,776.74	$750,301.90		
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$6,262,114.18	$1,485,659.98		
Cumulative Incurred Costs	$26,480,972.96	$27,966,632.94		
Uncosted				
Federal Share	$1,629,041.48	$893,683.40		
Non-Federal Share	-$2,942,573.44	-$3,692,875.34		
Total Uncosted - Quarterly (Federal and Non-Federal)	-$1,313,531.96	-$2,799,191.94		

APPENDIX A – Scientific Journal Submissions Supported By MSEEL

Scientific Journals and Associated Media
Evans MV, Sumner A, Daly RA, *Luek JL, Plata D, Wrighton KC, Mouser PJ. Hydraulically fractured natural-gas well microbial communities contain genomic (de)halogenation potential. (2019). *Environmental Science & Technology* Letters, 6, (10), 585-591.
The manuscript from Nixon et al. was published in mSphere. S.L. Nixon, R.A. Daly, M.A. Borton, L.M. Solden, S.A. Welch, D.R. Cole, P.J. Mouser, M.J. Wilkins, K.C. Wrighton. Genome-resolved metagenomics extends the environmental distribution of the Verrucomicrobia phylum to the deep terrestrial subsurface. mSphere. DOI: 10.1128/mSphere.00613-19
Sharma, S., Agrawal, V., & Akondi, R. N. 2020. Role of biogeochemistry in efficient shale oil and gas production. *Fuel,* 259, 116207.
We have worked with LANL to generate a conference paper for the spring meeting of the Association for the Advancement of Artificial Intelligence (March 23-25) at Stanford University. The paper is entitled Physics-informed Machine Learning for Real-time Unconventional Reservoir Management
Sharma, S. Agrawal, V., Akondi R. 2019. Role of Biogeochemistry in efficient shale oil and gas production. Fuel. https://doi.org/10.1016/j.fuel.2019.116207
Phan T., Hakala A., Sharma S. 2019. Application of geochemical signals in unconventional oil and gas reservoir produced waters towards characterizing in situ geochemical fluid-shale reactions. International Journal of Coal Geology (in review)
Akondi, R., Sharma S., Texler, R., Pfifnner S. (2019). Effects of Sampling and Long-Term Storage on Microbial Lipid Biomarker Distribution in Deep Subsurface Marcellus Shale Cores. Geomicrobiology (in review)
Agrawal, V. and Sharma, S. 2019. Are we modelling properties of unconventional shales correctly? Fuel (in review)
Evans, Morgan, Andrew J. Sumner, Rebecca A. Daly, Jenna L. Luek, Desiree L. Plata, Kelly C. Wrighton, and Paula J. Mouser, 2019, Hydraulically Fractured Natural-Gas Well Microbial Communities Contain Genomic Halogenation and Dehalogenation Potential, Environmental Science and Technology Letters, online preprint, 7p., DOI: 10.1021/acs.estlett.9b00473.
Song, Liaosha, Keithan Martin, Timothy R. Carr, Payam Kavousi Ghahfarokhi, 2019, Porosity and storage capacity of Middle Devonian shale: A function of thermal maturity, total organic carbon, and clay content, Fuel 241, p. 1036-1044, https://doi.org/10.1016/j.fuel.2018.12.106 .
Akondi, R., Sharma S., Texler, R., Pfifnner S. (2019). Effects of Sampling and Long Term Storage on Microbial Lipid Biomarker Distribution in Deep Subsurface Marcellus Shale Cores. Frontiers in Microbiology *(in review)*.
Johnson, D., Heltzel, R., and Oliver, D., “Temporal Variations in Methane Emissions from an Unconventional Well Site,” *ACS Omega*, 2019. DOI: 10.1021/acsomega.8b03246.
Evans MV, Daly RA, *Luek JL, Wrighton KC, Mouser PJ. (Accepted with revisions). Hydraulically fractured natural-gas well microbial communities contain genomic (de)halogenation potential. *Environmental Science & Technology Letters*.
Plata DL, Jackson RB, Vengosh A, Mouser PJ. (2019). More than a decade of hydraulic fracturing and horizontal drilling research. *Environmental Sciences: Processes & Impacts* 21 (2), 193-194.

Pilewski, J., S. Sharma, V. Agrawal, J. A. Hakala, and M. Y. Stuckman, 2019, Effect of maturity and mineralogy on fluid-rock reactions in the Marcellus Shale: Environmental Science: Processes & Impacts, doi:10.1039/C8EM00452H.

Phan, T. T., J. A. Hakala, C. L. Lopano, and S. Sharma, 2019, Rare earth elements and radiogenic strontium isotopes in carbonate minerals reveal diagenetic influence in shales and limestones in the Appalachian Basin: Chemical Geology, v. 509, p. 194–212, doi: 10.1016/j.chemgeo.2019.01.018.

Booker AE, Hoyt DW, Meulia T, Eder E, Nicora CD, Purvine SO, Daly RA, Moore JD, Wunch K, Pfiffner SM, Lipton MS, Mouser PJ, Wrighton KC, and Wilkins MJ (2019) Deep Subsurface Pressure Stimulates Metabolic Plasticity in Shale-Colonizing *Halanaerobium*. *Applied and Environmental Microbiology*. doi:10.1128/AEM.00018-19

Kavousi Ghahfarokhi, P., Wilson, T.H., Carr, T.R., Kumar, A., Hammack, R. and Di, H., 2019. Integrating distributed acoustic sensing, borehole 3C geophone array, and surface seismic array data to identify long-period long-duration seismic events during stimulation of a Marcellus Shale gas reservoir. Interpretation, *7*(1), pp. SA1-SA10. https://doi.org/10.1190/INT-2018-0078.1.

Borton MA, Daly RA, O'Banion B, Hoyt DW, Marcus DN, Welch S, Hastings SS, Meulia T, Wolfe RA, Booker AE, Sharma S, Cole DR, Wunch K, Moore JD, Darrah TH, Wilkins MJ, and Wrighton KC (2018) Comparative genomics and physiology of the genus Methanohalophilus, a prevalent methanogen in hydraulically fractured shale. *Environmental Microbiology*. doi: 10.1111/1462-2920.14467

Booker AE, Hoyt DW, Meulia T, Eder E, Nicora CD, Purvine SO, Daly RA, Moore JD, Wunch K, Pfiffner S, Lipton MS, Mouser PJ, Wrighton KC, and Wilkins MJ. Deep subsurface pressure stimulates metabolic flexibility in shale-colonizing *Halanaerobium*. Submitted to *Applied and Environmental Microbiology*. In review.

Additionally since the last report, the team's shale virus paper has been published in *Nature Microbiology*. Citation provided below:

Daly RA, Roux S, Borton MA, Morgan DM, Johnston MD, Booker AE, Hoyt DW, Meulia T, Wolfe RA, Hanson AJ, Mouser PJ, Sullivan MB, Wrighton KC, and Wilkins MJ (2018) Viruses control dominant bacteria colonizing the terrestrial deep biosphere after hydraulic fracturing. *Nature Microbiology*. doi: 10.1038/s41564-018-0312-6

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.

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.

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.

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.

Luek JL, Hari M, Schmitt-Kopplin P, Mouser PJ, Gonsior M. (2018). Organic sulfur fingerprint indicates continued injection fluid signature 10 months after hydraulic fracturing. *Environmental Science: Processes & Impacts*. Available in advance at doi: 10.1039/C8EM00331A.
Evans MV, Panescu J, Hanson AJ, Sheets J, Welch SA, Nastasi N, Daly RA, Cole DR, Darrah TH Wilkins MJ, Wrighton KC, Mouser PJ. (*in press*, 2018), Influence of *Marinobacter* and *Arcobacter* taxa on system biogeochemistry during early production of hydraulically fractured shale gas wells in the Appalachian Basin. *Frontiers of Microbiology*.
“Economic Impacts of the Marcellus Shale Energy and Environment Laboratory” has been released by the WVU Regional Research Institute,
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.
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.
*“*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.
“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.
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.
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.
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)
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)
*“*In vitro *interactions scaled to* in situ *conditions: microorganisms predict field scale biogeochemistry in hydraulically fractured shale.”* Review comments have been

“Comparison of Methanohalophilus *strains reveals adaptations to distinct environments.”* Invited to submit to Frontiers in Microbiology special topic edition Geobiology in the Terrestrial Subsurface, to be submitted June 2018. An undergraduate researcher, Bridget O’Banion in the Wrighton lab, led this research.
Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN. Interpretation. 50p. published December 4, 2017, Interpretation, Society Exploration Geophysicists https://doi.org/10.1190/int-2016-0199.1 Thomas H. Wilson , Tim Carr , B. J. Carney , Malcolm Yates , Keith MacPhail , Adrian Morales , Ian Costello , Jay Hewitt , Emily Jordon , Natalie Uschner , Miranda Thomas , Si Akin , Oluwaseun Magbagbeola , Asbjoern Johansen , Leah Hogarth , Olatunbosun Anifowoshe , and Kashif Naseem,
Akondi R, Trexler R, Pfiffner SM, Mouser PJ, Sharma S 2017. Modified Lipid Extraction Method for Deep Subsurface Shale. Frontiers in Microbiology https://doi.org/10.3389/fmicb.2017.01408
the paper was submitted to the Journal Interpretation. The journal submission is titled Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN
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
Preston County Journal: http://www.theet.com/news/local/wvu-project-setting-the-standard-for-researching-oil-and-gas/article_25e0c7d0-279d-59c1-9f13-4cbe055a1415.html
The statesman: http://www.thestatesman.com/news/science/fracking-messiah-or-menace/81925.html
Nova Next article: http://www.pbs.org/wgbh/nova/next/earth/deep-life/
NPR interview: http://www.wksu.org/news/story/43880
Midwest Energy News : http://midwestenergynews.com/2015/11/17/researchers-study-microbes-living-in-shale-and-how-they-can-impact-drilling/
McClatchyDC News: “Could deep earth microbes help us frack for oil?”S. Cockerham http://www.mcclatchydc.com/news/nation-world/national/article29115688.html

APPENDIX B – Conference Papers/Presentations MSEEL

Conference Paper/Presentation
Agrawal, V., S. Sharma, N. Mahlstedt 2019, Determining the type, amount and kinetics of hydrocarbons generated in a Marcellus shale maturity series. Eastern Section AAPG 48th Annual Meeting in Columbus, OH.
Carney BJ, Carr TR, Hewitt J, Vagnetti R, Sharma S, Hakala A. 2019. Progress and Findings from “MSEEL 1” and the Transition to “MSEEL 2”: Creating Value from a Cooperative Project. Annual Eastern Section AAPG Meeting, Columbus, Ohio.
Phan TT, Hakala JA, Lopano C L, & Sharma S. 2019. Rare earth elements and radiogenic strontium isotopes in carbonate minerals reveal diagenetic influence in shales and limestones in the Appalachian Basin. GAC-MAC-IAH conference, Quebec City, Quebec, Canada.
Ferguson, B., Sharma, S., Agrawal, V., Hakala, A., 2019. Investigating controls on mineral precipitation in hydraulically fractured wells. Geological Society of America Annual Meeting, Phoenix, (GSA), Annual meeting, Phoenix, Arizona.
Akondi R, Sharma S. 2019. Microbial Signatures of Deep Subsurface Shale Biosphere. Geological Society of America (GSA), Annual meeting, Phoenix, Arizona.
Carr, Timothy R. MSEEL Seismic Attribute Application of Distributed Acoustic Sensing Data, presentation at 53rd US Rock Mechanics / Geomechanics Symposium, 2019 American Rock Mechanics Association (ARMA) Annual Meeting, New York City, NY.
Agrawal, V., S. Sharma, N. Mahlstedt 2019, Determining the type, amount and kinetics of hydrocarbons generated in a Marcellus shale maturity series. Eastern Section AAPG 48th Annual Meeting in Columbus, OH
Evans M, Luek J, Daly R, Wrighton KC, Mouser PJ. (2019). Microbial (de)halogenation in hydraulically fractured natural-gas wells in the Appalachian Basin. ACS annual conference, Orlando, FL, Mar 31-Apr 4, 2019.
Luek J, Murphy C, Wrighton KC, Mouser PJ. (2019). Detection of antibiotic and metal resistance genes in deep shale microbial community members. ACS annual conference, Orlando, FL, Mar 31-Apr 4, 2019.
Kumar, A., E. V. Zorn, R. Hammack, and W. Harbert, 2017a, Seismic monitoring of hydraulic fracturing activity at the Marcellus shale energy and environment laboratory (MSEEL) Site, West Virginia: Presented at the Unconventional Resources Technology Conference, Paper 2670481.
Tufts University, Dept. of Civil and Environmental Engineering. Microbial Survival and Sustenance in Fractured Shale 10/2018.
University of New Hampshire, Dept. of Earth Science. Microbial Survival and Sustenance in Fractured Shale 09/2018.
GSA conference in Indianapolis, Indiana. 2019
AAPG 2019, San Antonio, Texas.
Agrawal, V., Sharma, S., 2018. New models for determining thermal maturity and hydrocarbon potential in Marcellus Shale. Eastern Section AAPG 47th Annual Meeting in Pittsburgh, WV
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)

Kelly Wrighton -19th Annual Microbiology Student Symposium, University of California Berkeley, April 28, 2018
Kelly Wrighton - ASM Microbe, Atlanta, Georgia, June 9, 2018
Mouser PJ, Heyob KM, Blotevogel J, Lenhart JJ, Borch T (2018). Pathways and Mechanisms for Natural Attenuation of Nonionic Surfactants in Hydraulic Fracturing Fluids if Released to Agricultural Soil and Groundwater. ACS annual conference, New Orleans, LA, Mar 19-22, 2018.
Hanson AJ, Lipp JS, Hinrich K-U, Mouser PJ (2018). Microbial lipid biomarkers in a Marcellus Shale natural gas well: From remnant molecules to adapted communities. ACS annual conference, New Orleans, LA, Mar 19-22, 2018
University of Maine, Department of Biology and Ecology. Biodegradation of Organic Compounds in the Hydraulically Fractured Shale Ecosystem, 2/2018.
“*Top-down and bottom-up controls on* Halanaerobium *populations in the deep biosphere*.” Poster presentation at the Department of Energy’s Joint Genome Institute ‘Genomics of Energy and Environment Meeting’, San Francisco, CA, March 2018. A researcher, Rebecca Daly, in the Wrighton lab, led this work.
Sharma S, Wilson T, Wrighton, K, Borton M & O’Banion. 2017 Can introduction of hydraulic fracturing fluids induce biogenic methanogenesis in the shale reservoirs? Annual American Geophysical Union Conference, Dec 11-15, New Orleans, LA.
Booker AE, Borton MA, Daly R, C. Nicora, Welch S, Dusane D, Johnston M, Sharma S et. al., 2017. Potential Repercussions Associated with Halanaerobium Colonization of Hydraulically Fractured Shales. Annual American Geophysical Union Conference, Dec 11-15, New Orleans, LA.
Mouser P. *Colorado State University, Civil and Environmental Engineering* and *CSU Water Center*, From the Land Down Under: Microbial Community Dynamics and Metabolic processes influencing organic additives in black shales, 11/2017.
Presentation at ISES (International Society for Exposure Science), Raleigh, NC Oct. 16th, 2017 on “Techniques for Estimating Community Exposure from Hydraulic Fracturing Operations
Kavousi, Payam, Timothy R. Carr, Robert J Mellors, Improved interpretation of Distributed Acoustic Sensing (DAS) fiber optic data in stimulated wells using seismic attributes, [S33B-0865] presented at December 2017 Fall Meeting, AGU, New Orleans, LA, 11-15,https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/282093
Mellors Robert J, Christopher Scott Sherman, Frederick J Ryerson, Joseph Morris, Graham S Allen, Michael J Messerly, Timothy Carr, Payam Kavousi, Modeling borehole microseismic and strain signals measured by a distributed fiber optic sensor, [S33B-0869] presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15, https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/264800
Song, Liaosha and Timothy R. Carr, Microstructural Evolution of Organic Matter Pores in Middle Devonian Black Shale from West Virginia and Pennsylvania, USA, SEPM – AAPG Hedberg Research Conference, Mudstone Diagenesis, Santa Fe, New Mexico, October 16-19. http://www.searchanddiscovery.com/pdfz/abstracts/pdf/2017/90283hedberg/abstracts/ndx_song.pdf.html

Carr, Timothy R., The Importance of Field Demonstration Sites: The View from the Unconventional Resource Region of the Appalachian Basin (Invited), [H21K-06] presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/242523
Ghahfarokhi, P. K., Carr, T., Song, L., Shukla, P., & Pankaj, P. (2018, January 23). Seismic Attributes Application for the Distributed Acoustic Sensing Data for the Marcellus Shale: New Insights to Cross-Stage Flow Communication. Society of Petroleum Engineers, doi:10.2118/189888-MS.
Presentation of paper at 2017 Annual International SEG meeting: The paper *titled "Relationships of brittleness index, Young's modulus, Poisson's ratio and high TOC for the Marcellus Shale, Morgantown, West Virginia"* by Thomas H. Wilson*, Payam Kavousi, Tim Carr, West Virginia University; B. J. Carney, Northeast Natural Energy LLC; Natalie Uschner, Oluwaseun Magbagbeola and Lili Xu, Schlumberger, was presented at the annual SEG meeting, this past September in Houston, TX.
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, 2016, Microseismic and model stimulation of natural fracture networks in the Marcellus Shale, West Virginia: SEG International Exposition and 86th Annual Meeting, 3088-3092, https://doi.org/10.1190/segam2016-13866107.1.
Sharma S 2017. Shale Research at Marcellus Shale Energy and Environment laboratory. 23rd Annual CNSF Exhibition, May 16, Rayburn House, Washington DC.
Elsaig, M., Black, S., Aminian, K., and S. Ameri, S.: "Measurement of Marcellus Shale Properties," SPE-87523, SPE Eastern Regional Conf., Lexington, KY, October 2017.
El Sgher, M., Aminian, K., and S. Ameri: "The Impact of Stress on Propped Fracture Conductivity and Gas Recovery in Marcellus Shale," SPE-189899, SPE Hydraulic Fracturing Technology Conf., Woodlands, TX, January 2018.
Ebusurra, M.: "Using Artificial Neural Networks to Predict Formation Stresses for Marcellus Shale with Data from Drilling Operations." MS Thesis, Petroleum & Natural Gas Engineering, West Virginia University, August 2017.
M. El Sgher, K. Aminian, S. Ameri: "The impact of the hydraulic fracture properties on gas recovery from Marcellus Shale," SPE 185628, SPE Western Regional Conf., Bakersfield, California, April 2017.
Elsaig, M., Aminian, K., Ameri, S. and M. Zamirian: "Accurate Evaluation of Marcellus Shale Petrophysical Properties," SPE-Error! Reference source not found.84042, SPE Eastern Regional Conf., Canton, OH, September 2016.
Filchock, J.J., Aminian, K. and S. Ameri: "Impact of Completion Parameters on Marcellus Shale Production," SPE-184073, SPE Eastern Regional Conf., Canton, OH, September 2016.
Tawfik Elshehabi and H. Ilkin Bilgesu: "Well Integrity and Pressure Control in Unconventional Reservoirs: A Comparative Study of Marcellus and Utica Shales," SPE 184056, SPE Eastern Regional Conf., Canton, OH, September 2016

Meso- and Macro-Scale Facies and Chemostratigraphic Analysis of Middle Devonian Marcellus Shale in Northern West Virginia, USA for Eastern Section American Association of Petroleum Geologists Annual Meeting September 26-27. Authors: Thomas Paronish, Timothy Carr, West Virginia University; Dustin Crandall and Jonathan Moore, National Energy Technology Laboratory, U.S. Department of Energy
The presentation was made at the annual SEG convention in Dallas (see http://library.seg.org/doi/pdf/10.1190/segam2016-13866107.1) and the paper was submitted to the Journal Interpretation. The journal submission is titled Marcellus Shale model stimulation tests and microseismic response yield insights into mechanical properties and the reservoir DFN
McCawley M, Dzomba A, Knuckles T, and Nye M. 2017. Use of trace elements for estimating community exposure to Marcellus shale development operations. Poster presented at: Van Liere Poster Competition. WVU Health Sciences Center; 2017; Morgantown, WV
Khajouei Golnoosh, Hoil Park, Jenna Henry, Harry Finklea, Lian-Shin Lin. *Produced water treatment using electrochemical softening system*. Institute of Water Security and Science (IWSS) symposium, February 28, Morgantown, West Virginia.
Wilson T, and Sharma S. 2017. Inferring biogeochemical interactions in deep shale reservoirs at the Marcellus Shale Energy and Environment Laboratory (MSEEL). Joint 52nd northeastern annual section/ 51st north-central annual section meeting March 19-21, Pittsburgh, PA.
Agrawal V, Sharma S, and Warrier A. 2016. Understanding kerogen composition and structure in pristine shale cores collected from Marcellus Shale Energy and Environment Laboratory. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
Akondi R, Trexler RV, Pfiffner SM, Mouser PJ, Sharma S. 2016. Comparing Different Extraction Methods for Analyses of Ester-linked Diglyceride Fatty Acids in Marcellus Shale. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
Booker AE, Borton MA, Daly R, Welch S, Nicora CD, Sharma S, et. al., 2016. Sulfide Generation by Dominant Colonizing Halanaerobium Microorganisms in Hydraulically Fractured Shales. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
Crandall D, Moore J, Paronish T, Hakala A, Sharma S, and Lopano C 2016. Preliminary analyses of core from the Marcellus Shale Energy and Environment Laboratory. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016.
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Marcellus Shale Energy and Environment Laboratory (MSEEL): Subsurface Reservoir Characterization and Engineered Completion; Presenter: Tim Carr; West Virginia University (2670437)
Depositional environment and impact on pore structure and gas storage potential of middle Devonian organic rich shale, Northeastern West Virginia, Appalachian Basin; Presenter: Liaosha Song, Department of Geology and Geography, West Virginia University, Morgantown, WV, (2667397)
Seismic monitoring of hydraulic fracturing activity at the Marcellus Shale Energy and Environment Laboratory (MSEEL) site, West Virginia; Presenter: Abhash Kumar, DOE, National Energy Technology Laboratory (2670481)
Geomechanics of the microseismic response in Devonian organic shales at the Marcellus Shale Energy and Environment Laboratory (MSEEL) site, West Virginia; Presenter: Erich Zorn, DOE, National Energy Technology Laboratory (2669946)
Application of Fiber-optic Temperature Data Analysis in Hydraulic Fracturing Evaluation- a Case Study in the Marcellus Shale; Presenter: Shohreh Amini, West Virginia University (2686732)
The Marcellus Shale Energy and Environmental Laboratory (MSEEL): water and solid waste findings-year one; Presenter: Paul Ziemkiewicz WRI, West Virginia University (2669914)
Role of organic acids in controlling mineral scale formation during hydraulic fracturing at the Marcellus Shale Energy and Environmental Laboratory (MSEEL) site; Presenter: Alexandra Hakala, National Energy Technology Laboratory, DOE (2670833)

MSEEL Water and Waste Findings - RPSEA Onshore Workshop
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Sharma S., 2016. Unconventional Energy Resources: A view from the Appalachian Basin. US Embassy Berlin, Germany 25 May 2016.
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On July 20, 2016, Paul Ziemkiewicz, Task 5a lead investigator gave a presentation titled: WVU – Northeast Natural Energy Marcellus Hydraulic Fracture Field Laboratory Environmental Research Update at the WVU/PTTC/NETL/RPSEA Onshore Technology WorkshopAppalachian Basin Technology in Canonsburg, PA.
Abstract entitled “Addressing Health Issues Associated with Air Emissions around UNGD Sites” by Michael McCawley, Travis Knuckles, Maya Nye and Alexandria Dzomba accepted for the 2016 Eastern Section – American Association of Petroleum Geologists’ meeting in Lexington, Kentucky on September 27, 2016.
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
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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.
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Trexler RV, Pfiffner SM, Akondi R, Sharma S, Mouser PJ.(2015) Optimizing Methods for Extracting Lipids from Organic-Rich Subsurface Shale to Estimate Microbial Biomass and Diversity. Poster session presented at: 2015 Geological Society of America Annual Meeting. 2015 Nov 1-4; Baltimore, MD.
Wrighton, KC; Daly, R; Hoyt, D; Trexler, R; MacRae, J; Wilkins, M; Mouser, PJ (2015), Oral presentation at the American Geophysical Union Annual Meeting. Something new from something old? Fracking stimulated microbial processes. Presentation# B13K-08. San Francisco, CA, Dec 14-18, 2015.
Mouser, P, The Impact of Fracking on the Microbiology of Deep Hydrocarbon Shale, American Society for Microbiology (ASM) Annual Conference, New Orleans, LA, May 30-June 2, 2015.
Wrighton et al, Drivers of microbial methanogenesis in deep shales after hydraulic fracturing. American Society of Microbiology. New Orleans, LA. May 30-June 2, 2015.
Daly et al, Viral Predation and Host Immunity Structure Microbial Communities in a Terrestrial Deep Subsurface, Hydraulically Fractured Shale System. American Society of Microbiology. New Orleans, LA.

APPENDIX C – Special MSEEL Sessions

Paper prepared for presentation at the Unconventional Resources Technology Conference (URTeC) held in Denver, Colorado, USA, 22-24 July 2019, 10 pages, DOI 10.15530/urtec-2019- 415.
Odegaarden, Natalie and Timothy Carr, Vein Evolution due to Thermal Maturation of Kerogen in the Marcellus Shale, Appalachian Basin, Paper presented at the Annual Meeting of the Geological Society of America 22-25 September 2019 Phoenix, AZ.
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. 2019
8/15/2017 - Coordinate and hold MSEEL session at URTEC 2017 (Scheduled 8/30/2017; Completed 8/30/2017)
4/30/2017 - Conduct preliminary analysis of production log data and present to DOE. (Completed and being worked into a new reservoir simulation – Review meeting held at WVU
26 Jul 2017: URTeC, Austin, TX, Manuscript attached
27 Sep 2017: Marcellus Shale Coalition, Shale Insight,
SPE-184073, SPE Eastern Regional Conf., Canton, OH, September 2016.
2016 SEG meeting in Dallas
2014 American Geophysical Union (AGU) Fall Meeting in December 2014 to discuss next steps in the project. At AGU, we hosted a special session on Biogeochemistry of Deep Shale,

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