Oil & Natural Gas Technology

DOE Award No.: DE-FE0024297

Quarterly Research Performance

Progress Report (Period Ending 12/30/2020)

Marcellus Shale Energy and Environment Laboratory (MSEEL)

Project Period (October 1, 2014 – September 30, 2021)

Submitted by:
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Signature

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Executive Summary
Quarterly Progress Report

October 1 – December 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 have started to diminish, as laboratories reopened in many cases. Still impacted is the work of Dr. Sharma (Task 3 in this report), which has lab chemical safety requirements for multiple persons in the lab when testing is underway. This is reflected in updated dates for milestones/deliverables. Other work has progressed relatively on-schedule, and analysis from the samples and data collected from the Boggess Pad has continued as planned. However, our Schlumberger PETREL license required renewal and update for our computer system. We were unable to access the software which is used for both 3D visualization and reservoir simulation. This has been rectified in early January.

This quarter's work focused on monitoring initial production from the MSEEL Phase 3 wells at the Boggess Pad. As of this report total production ranges from 2.2 to 3.0 Bcf. Two wells were geometrically completed, a private consultant engineered two wells, and two wells were engineered using software developed by the MSEEL team (1H and 3H). While it is still early, it appears based on rate transit analysis (RTA), the fracture analysis (Fracpro) and production that the wells engineered using software developed by the MSEEL team may be some of the better wells on the pad. The paper presented at the SPE ACTE (Li, L. et al. 2020) ranked as one of the top downloaded papers from onepetro.org. In addition, we presented our research in the online SMART Annual Review Meeting November 2-3, 2020.

Research on machine learning for improved production efficiency with 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 are integrating the core data received from the Schlumberger/Terra Tek lab and using that data to revise the production analysis and to prepare for flow simulation.

We continue to sample and monitor produced fluids, and monitor air quality and performance at both MSEEL sites (MIP and Boggess).

We continue to develop software to process the 108 terabytes of DAS and completion data from the Boggess pad and are working to develop an improved workflow for delivering the data to the public.

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 4th quarter of FY2020 (July 1 through September 30, 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.

A summary of major lessons learned to this point of the project are provided as bullet points and will be added to as research progresses. New lessons listed below are:

- The engineered wells at the Boggess Pad (1H and 3H) show the importance of designed stages and cluster placement to improved well performance.

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 0.1). 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 have data from the upper stages through the heel and continue to download the data. 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.

Based on production, rate transient analysis (RTA), and fracture analysis (FRACPRO) the new methodology appears to improve completion efficiency. As the wells have come on production, the 1H and 3H wells still have a higher gross 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 design provided which only used the geomechanical logs and ignored the imaged fractures (5H and 13H) (Figure 0.2). On a net 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 are gaining on their counterparts (Figure 0.3).

We have finally received the core analysis, and initiated a 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 will permit 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 continue to gather 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.

We are working on a new workflow for simplified access to MSEEL data especially the large multi-terabyte data from the Boggess pad.

We have worked with NETL, LANL, and other labs on various projects of the Marcellus at the MIP and Boggess site.

Figure 0.1: Boggess Pad with new generation permanent fiber in the central well (Boggess 5H, red star)) and deployable fiber in adjoining wells skipping one (orange stars). We were able to monitor in near-real time fracture stimulation in the central 3 wells (3H, 5H and 9H). A vertical pilot was drilled, cored and logged. We continue to collect DTS data from the 5H.

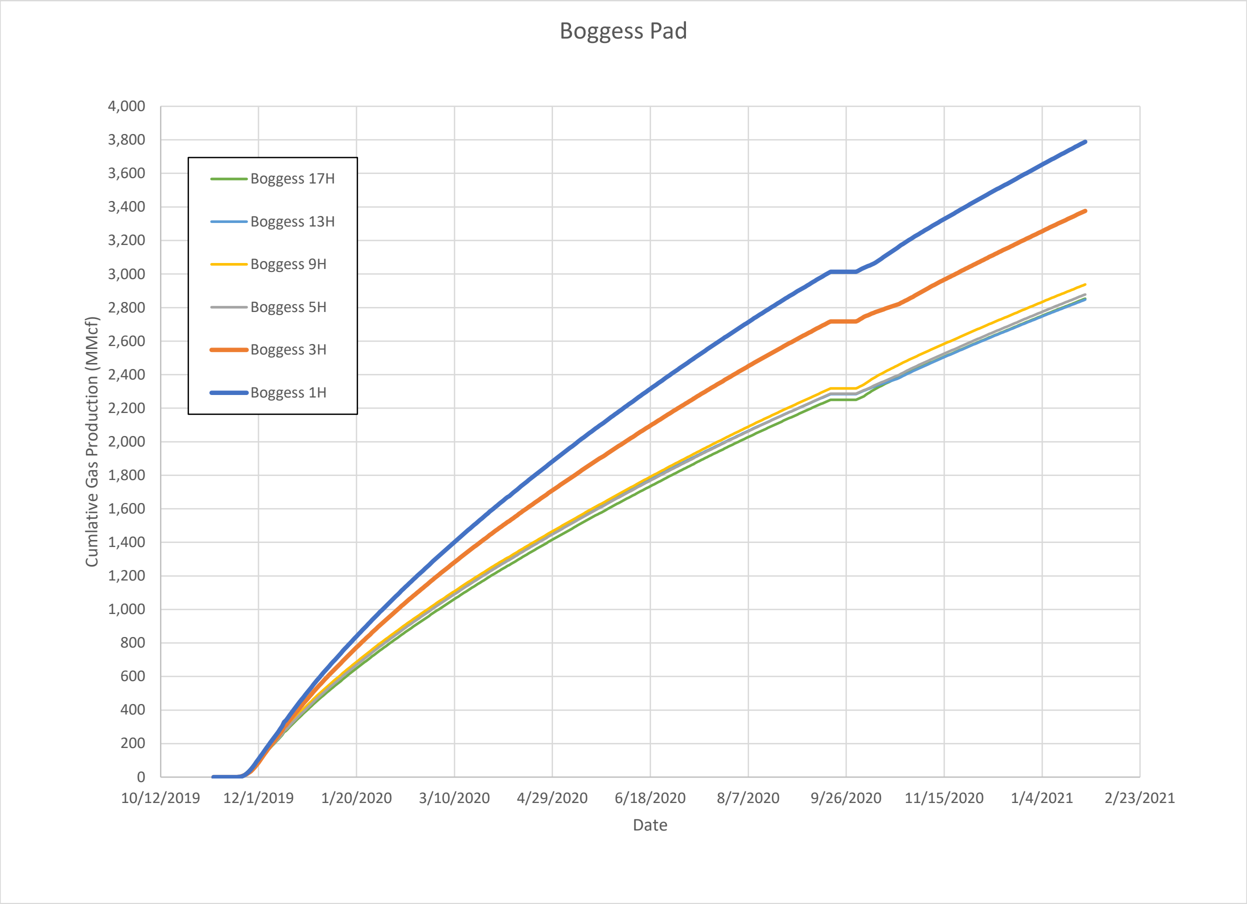


Figure 0.2: Initial daily gross production from the Boggess Pad. The wells engineered using the MSEEL software are highlighted with thicker lines (1H and 3H). Wells have different lateral lengths that need to be evaluated to derive a better evaluation of production efficiency. Also outside wells typically perform better than interior wells due to reduced competition. The production is very early and the picture could very easily change. The wells were shut-in for a period because of low gas prices.

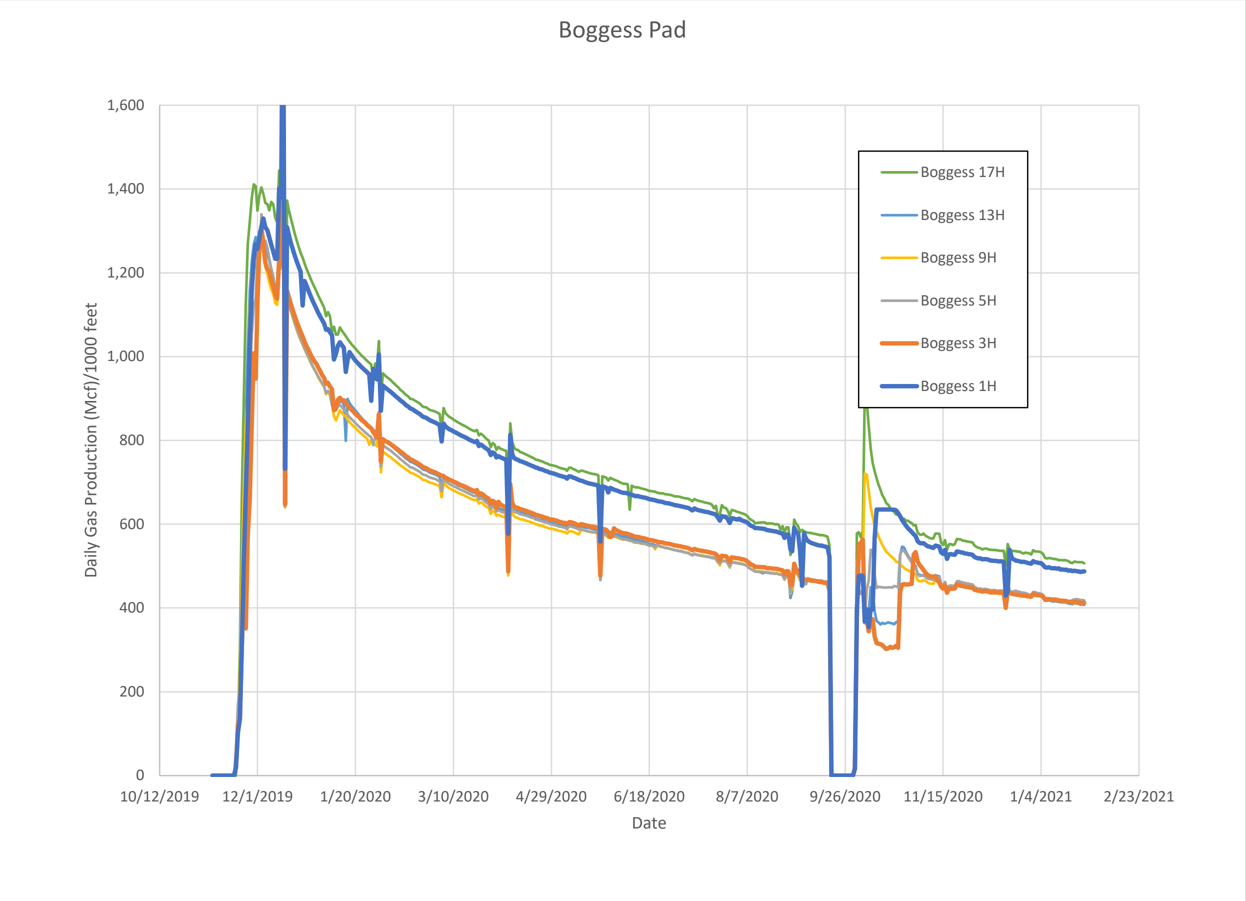


Figure 0.3: Initial daily net production from the Boggess Pad adjusted for Mcf per 1000' of completed lateral. The wells engineered using the MSEEL software are highlighted with thicker lines (1H and 3H). As you can see outside wells (1H and 17H) perform better than interior wells due to reduced competition. 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, it is producing more than any other interior well. In the case of the 17H more sand was used per stage and we need to adjust for sand per foot. The production is early and is in transient flow. The picture could easily change. The wells were shut-in for a period because of low gas prices.

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	Delayed due to lab closures from COVID-19. Expect results by March 2021.	21-Mar
4.	3.1.2	Isotopic characterization of produced water and gases - comparison between MIP and Boggess wells and other wells in Marcellus and interpretation.	Complete.	20-Jun
5.	3.1.2	High-pressure and temperature fracture fluid/shale interaction experiments complete.	Delayed due to lab closures from COVID-19. Expect results by March 2021.	21-March
6.	3.1.4	Complete final reservoir characterization using Boggess 17H pilot well. Compare 17H to MIP 3H	Delayed due to lab closures from COVID-19. Expect results by March 2021.	21-March
7.	3.2.1	Methane Audit 14 Completed	Complete	20-Jun

8.	3.4.2	Synthetic data developed for model use	Delayed due to lab closures from COVID-19. Expect results by March 2021.	21-March
9.	3.2.1	Energy Audit Model Completed	Initial data analysis completed, model development continues.	20-Sep
10.	3.1.4	Extend reservoir characterization using logs, completion data and production data to identify good producing stages in Boggess wells.	Delayed due to impacts from COVID-19, including delays in PETREL license renewals. Expect results by June 2021.	21-June

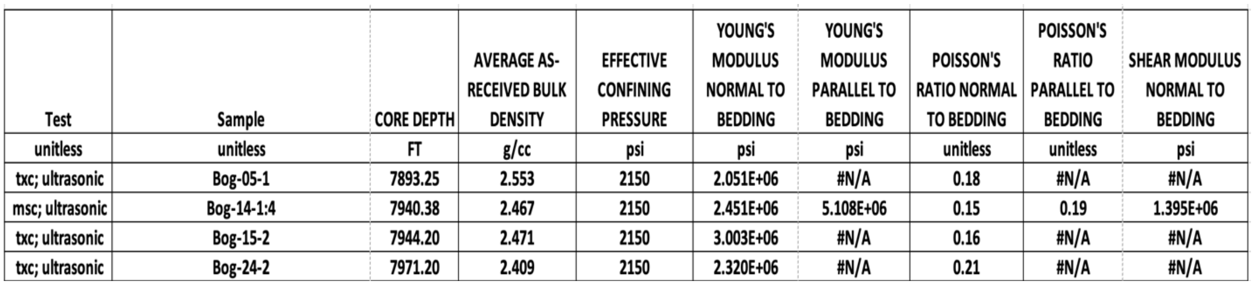
Topic 1 – Geologic Engineering

Approach

Well performance analysis of Boggess wells Results and Discussion

The objective of this task is to obtain the hydraulic fracture geometries (i.e., fracture half length, fracture height and fracture width) and proppant placements at different stages of the 6 wells drilled and completed in Boggess pad using Fracpro hydraulic fracturing commercial software. The outcome of this task then will be used in CMG reservoir simulation to obtain the probabilistic production forecasting models.

In this task the treatment schedule of all the stages for 6 wells in Boggess pad are imported to Fracpro and hydraulic fracture simulations are performed including the fracture interference effect. For this purpose, the 3D Shear-decoupled fracture model is used with Lumped-Parameter leak off model and proppant settling included to have better understanding of the fracture propped length. According to the treatment reports provided, the acid used was 7.5% HCl while the slurry contains slick water with 100 and 40/70 mesh sand. The actual pumping schedule of each stage, ranging from the pumping of acid, pad water, slurry, and the flush water is imported for every stage. For each process, the flow rate, proppant concentration, and the clean volume were calculated and imported to the software. The fracture growth after shut-in is allowed and the wellbore configuration including information on perforation intervals, casing and directional survey is imported to Fracpro for each well. The reservoir parameters of the target zone are obtained from well logs and core samples. The geomechanical properties of the reservoir, which include the stress gradient, Young's Modulus, and Poisson's ratio were determined from the core samples obtained from well 17H are imported in Fracpro for fracture modeling (Table 1.1).

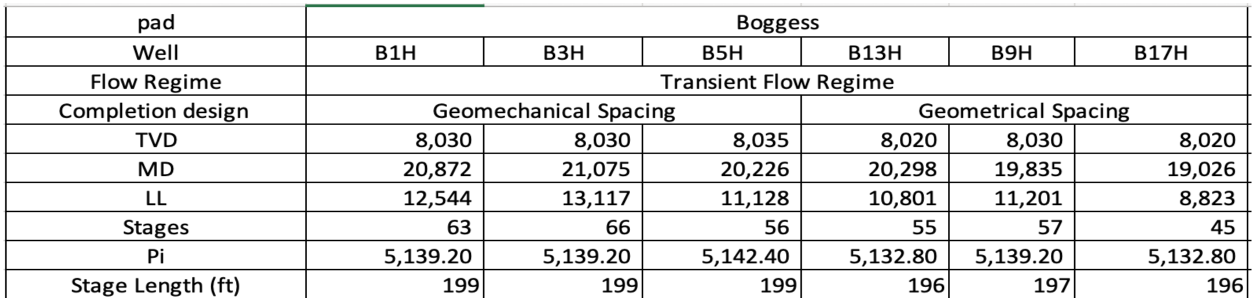


Test	Sample	CORE DEPTH	AVERAGE AS-RECEIVED BULK DENSITY	EFFECTIVE CONFINING PRESSURE	YOUNG'S MODULUS NORMAL TO BEDDING	YOUNG'S MODULUS PARALLEL TO BEDDING	POISSON'S RATIO NORMAL TO BEDDING	POISSON'S RATIO PARALLEL TO BEDDING	SHEAR MODULUS NORMAL TO BEDDING
unitless	unitless	FT	g/cc	psi	psi	psi	unitless	unitless	psi
txc; ultrasonic	Bog-05-1	7893.25	2.553	2150	2.051E+06	#N/A	0.18	#N/A	#N/A
msc; ultrasonic	Bog-14-1:4	7940.38	2.467	2150	2.451E+06	5.108E+06	0.15	0.19	1.395E+06
txc; ultrasonic	Bog-15-2	7944.20	2.471	2150	3.003E+06	#N/A	0.16	#N/A	#N/A
txc; ultrasonic	Bog-24-2	7971.20	2.409	2150	2.320E+06	#N/A	0.21	#N/A	#N/A

Table 1.1. Summary of Geomechanical Properties Obtained for 6 samples generated by Schlumberger Reservoir Laboratory 9/2/2020.

Results & Discussion

Table 2 shows the Boggess wells summary of TVD, MD, lateral length (LL), number of stages, initial pressure and stage length as well as completion design and flow regimes. Figure 1 shows the effective fracture half-length and fracture propped height obtained stage by stage for the Boggess wells 1H, 3H, 5H, 9H and 17H using Fracpro commercial.



pad	Boggess					
Well	B1H	B3H	B5H	B13H	B9H	B17H
Flow Regime	Transient Flow Regime					
Completion design	Geomechanical Spacing			Geometrical Spacing		
TVD	8,030	8,030	8,035	8,020	8,030	8,020
MD	20,872	21,075	20,226	20,298	19,835	19,026
LL	12,544	13,117	11,128	10,801	11,201	8,823
Stages	63	66	56	55	57	45
Pi	5,139.20	5,139.20	5,142.40	5,132.80	5,139.20	5,132.80
Stage Length (ft)	199	199	199	196	197	196

Table 1.2. Boggess wells analysis summary

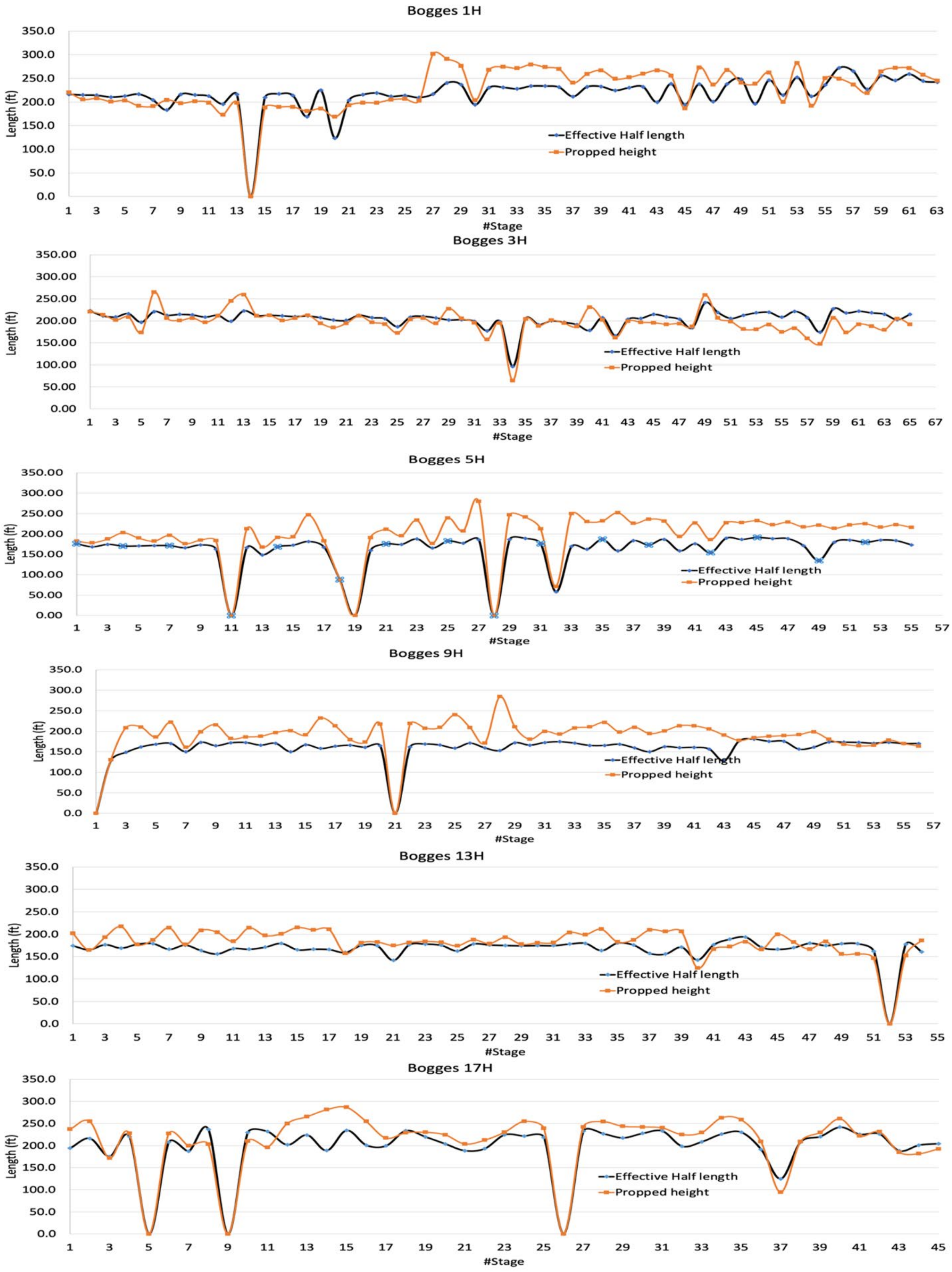


Figure 1.1. Effective fracture half-length and propped fracture height of Boggess wells

Figure 1.2 and Table 1.3 show the comparison between average of effective fracture half-length and average fracture propped height of Boggess wells. Well 1H and 3H show the highest effective fracture half-length in comparison to other wells completed in this pad. This observation is in line with our previous observations using advanced RTA where the 1H showed the highest flow capacity. Also this confirms the modified completion of the 1H and 3H based on the WVU procedures to avoid differences in geomechanical properties and mapped fractures. Figure 1.3 shows the comparison study between our previous rate transient analysis and Fracpro simulations on hydraulic fracture half-length. Reasonably good correlation with R^2= 0.86 has been achieved between these two separate studies.

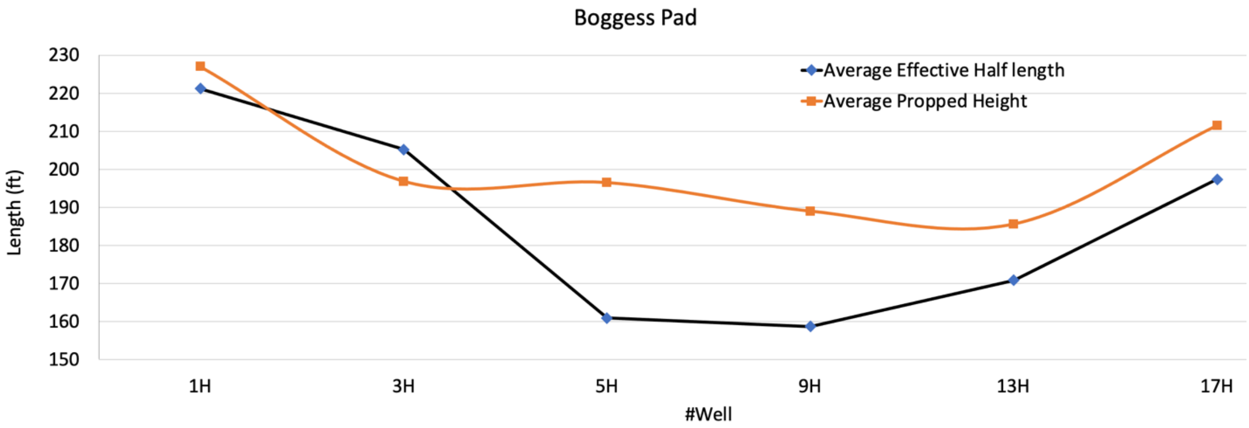


Figure 1.2. Average effective half-length and propped height for all the wells in Boggess

Average For All Stages (With Fracture Interference)

Well	Average Propped Width (in)	Average Prop Height (ft)	Average Effective Propped Length (ft)
1H	0.0539	227	221
3H	0.0322	197	205
5H	0.0354	197	161
9H	0.041	189	159
13H	0.04	186	171
17H	0.0583	212	197

Table 1.3. Average of Hydraulic fracture geometries for all the wells in Boggess Pad

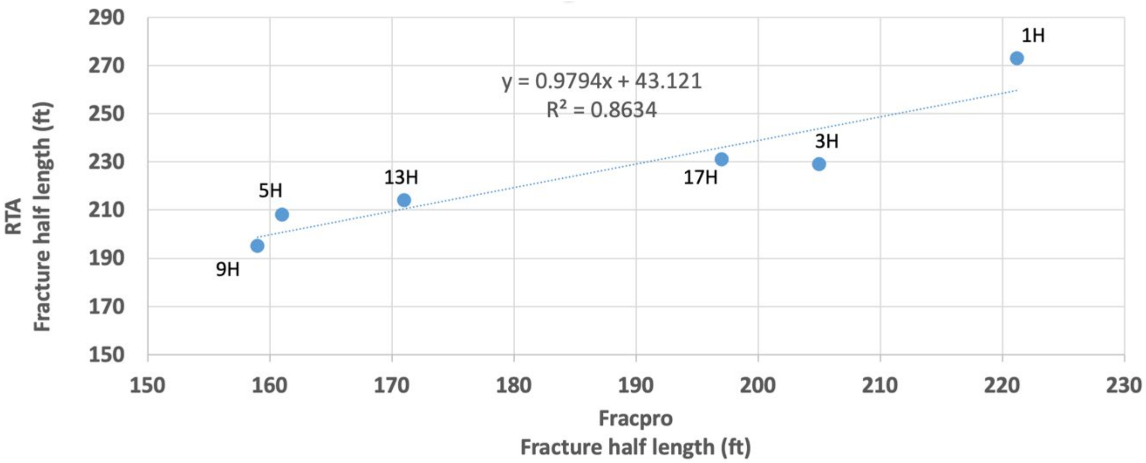


Figure 1.3. Hydraulic fracture half-length comparison between RTA and Fracpro analysis

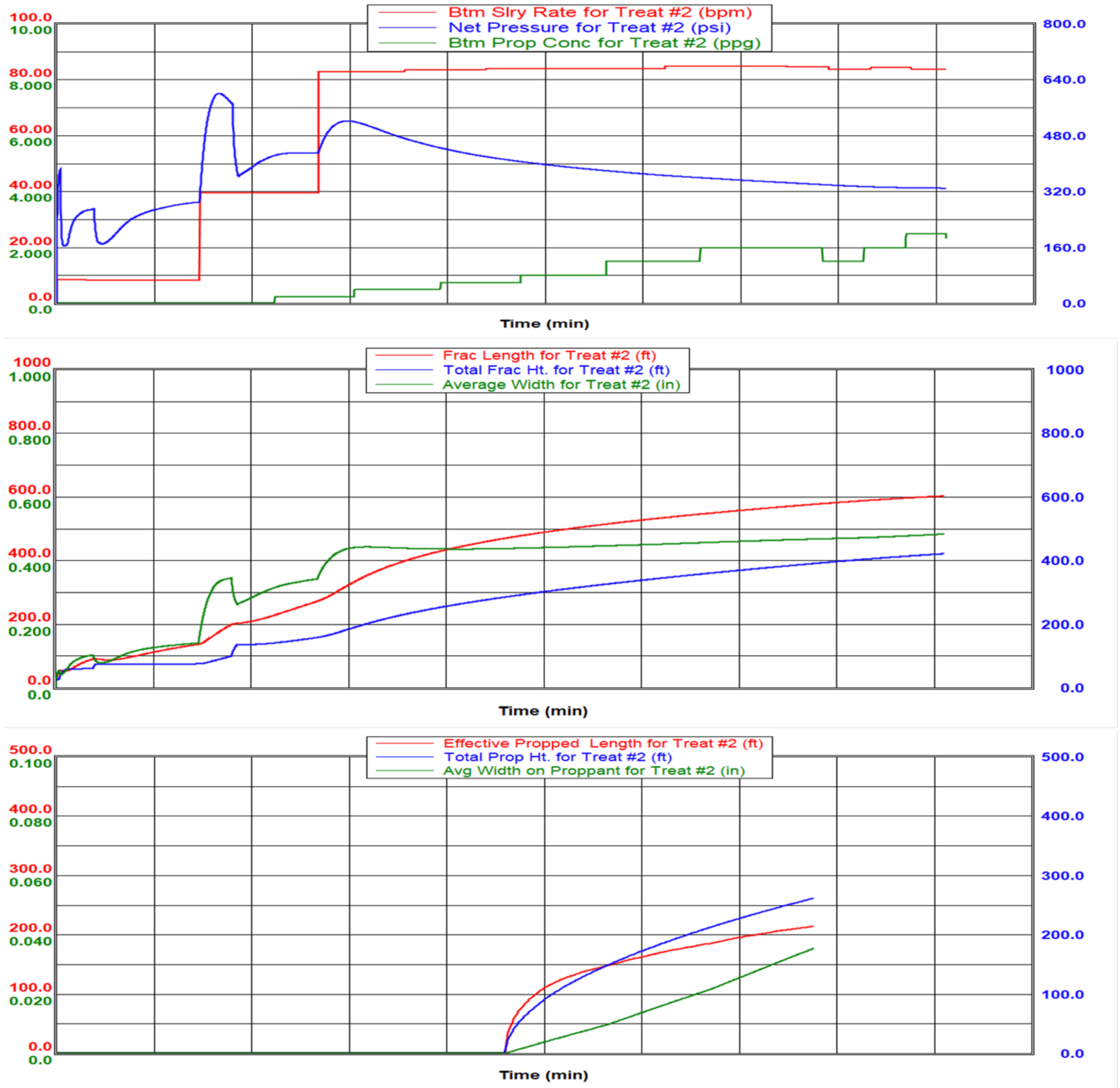


Figure 1.2. Boggess 1H stage 2 Fracpro summary

Products

For Boggess completion operation data, hundreds of csv files were used to record the field completion and stored on the ftp site. To improve the workflow with these large datasets in completion operations, a Python script to visualize the information, conduct quality evaluation, annotation and automation was developed.

Automation can avoid manually combing through large datasets. The computational workflow was implemented in order to increase the data quality (Figure 1.5).

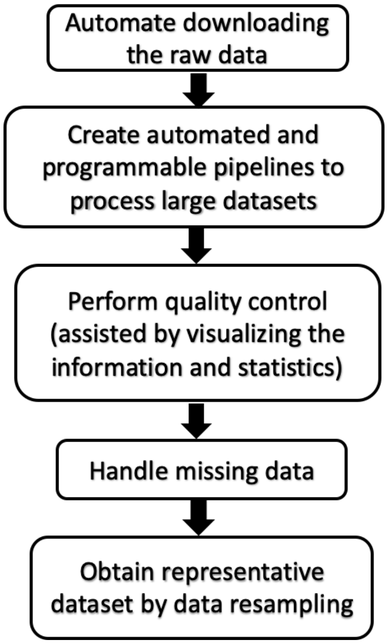


Figure 1.5. Data pipeline for completion data quality improvement.

The example result for pumping schedule is shown (Figure 1.6). This computational workflow will be helpful in the detailed fracture analysis and can also be applied on the DAS data to reduce the storage required without losing important data features.

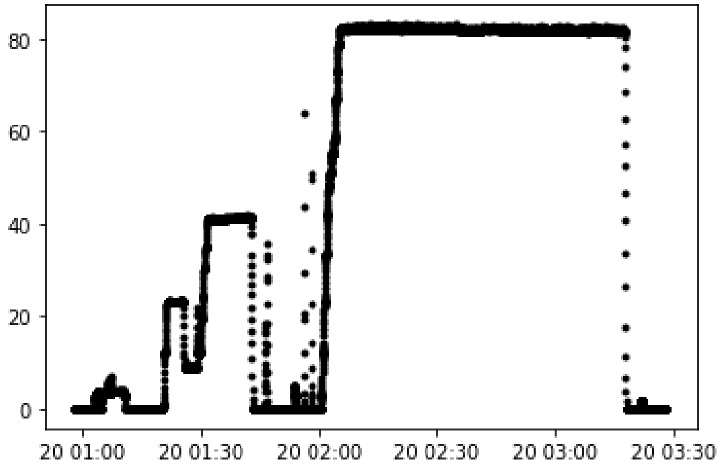


Figure 1.6. Resampled (per 10 minutes) pumping schedule data.

The deep learning ATCE paper[1] using Boggess data ranked as one of the top downloaded paper from onepetro.org. In addition, we presented our research at the online SMART Annual Review Meeting November 2-3, 2020.

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[1] Liwei Li, N.M. Nasrabadi and T.R. Carr, Completion design improvement using a deep convolutional network, SPE ATCE, Houston, Texas, October 27-29, 2020.

Plan for Next Quarter

1- Hydraulic fracture dimensions will be used in history matched CMG and PETREL models to generate probabilistic production forecasting models.
2- Since all the Boggess wells are still in transient flow regime this analysis provides only the minimum of OGIP and EUR. More monitoring and analysis of Boggess wells are required to come up with more robust and accurate estimation.
3- Compositional reservoir simulation model will be built for Boggess pad and production and pressure of the wells will be history matched using commercial software CMG-GEM.
4- Develop improved tools to directly access the large data sets stored on the MSEEL FTP site and use these in further analysis and online displays.

Topic 2 – Geophysical & Geomechanical

Approach

We received a detailed geomechanical model prepared by Premier Oil field Group and this will be integrated into a 3D visualization of Boggess and eventually the MIP sites.

Results & Discussion

Work using the newly acquired core analyses was completed on calibrating Young's Modulus, Poisson's Ratio and SH_{min} derived from Fracture-ID logs that were run in the vertical Boggess pilot well and extend the analysis to the laterals.

This portion of the project was largely on hold until PETREL licenses were renewed, which will occur in January.

Products

None to report.

Plan for Next Quarter

Available data will be used to compare the geo-mechanical properties to lithological properties derived from XRD and XRF analyses. The testing was completed in Schlumberger's lab in Houston and the core has been shipped back to the NETL lab in Morgantown and West Virginia University. We will develop a 3D visualization of lithologic and geomechanical properties along the path of the horizontal wells at the Boggess and MIP pads.

Topic 3 – Deep Subsurface Rock, Fluids, & Gas

Sharma Group MSEEL Report

1. **Characterization of organic matter - kerogen extraction and characterization.** Kerogen extraction of the core sample from the producing zone of Boggess 17H is completed. Kerogen sample is sent for the ^{13}C solid state analysis to determine its structural parameters. The NMR analysis of the samples are delayed due to COVID-19 but they are planned to be completed by March 2021.

   Deliverables: 1) Complete NMR analysis and kerogen unit structural model building by March 2021 2) Present key findings in a conference in Summer-Fall 2021.

2. **High-pressure and temperature fracture fluid/shale interaction experiments.** Shale-hydraulic fracturing fluid experiments (HFF) were conducted using core shale sample from the producing zone of Boggess 17H well. Experiments were conducted to determine the impact of a new oxidative breaker sodium bromate on produced fluid chemistry and contaminant release. The experiment has been completed. The reacted fluids were analyzed on GC-MS analysis to determine the concentration of organic compounds (VOCs and PAHs) (Table. 1 and Table. 2). Additionally, DIC and DOC analyses were performed to understand the impact of oxidative breaker on OM degradation (Table. 1 and Table. 2). The organic analysis detected several toxic and probable carcinogenic VOCs such as Acetone, Bromoform, Carbon disulfide, Chlorodibromomethane, and Chloroform in high concentrations. GC-MS analysis also indicated the release of PAH 2-Methylnaphthalene from these reactions. We plan to perform IC and ICP-MS analysis to get a whole suite of major, minor, and trace elements released by shale-HFF reactions.

Table 3.1. Volatile Organic Compounds detected by GC-MS analysis of reacted fluid collected from a batch reactor in which Boggess shale sample was reacted with HFF containing sodium bromate for 14 days.

Compound	**Detection Limit**	**Units**	**Conc. Detected**
Acetone	282 ug/l	ug/l	1280
Bromobenzene	2.95 ug/l	ug/l	5.86
Bromoform	3.22 ug/l	ug/l	1880
Carbon disulfide	2.41 ug/l	ug/l	185
Chlorodibromomethane	3.5 ug/l	ug/l	281
Chloroform	2.78 ug/l	ug/l	289
Dibromomethane	3.05 ug/l	ug/l	98.3
1,2 Dichloroethane	2.05 ug/l	ug/l	3.75

Table 3.2: PAH compound detected by GC-MS analysis of reacted fluid collected from a batch reactor in which Boggess shale sample was reacted with HFF containing sodium bromate for 14 days.

Compound	Detection Limit	Unit	Conc. Detected
2-Methylnaphthalene	0.0280 ug/l	ug/l	0.0593

Table 3.3: Concentration of inorganic and organic carbon species detected reacted fluid collected from a batch reactor in which Boggess shale sample was reacted with HFF containing sodium bromate for 14 days.

Inorganic Carbon	92.05 mg/l
Non-purgeable organic carbon	286.61 mg/l

Deliverables: 1) Finish IC and ICP-MS analysis, compile and analyze the results to understand and model the underlying reaction mechanisms by the end of Spring. 2) Present critical findings at a conference in Summer-Fall 2021.

Ohio State Input: MSEEL Fiscal Year 2021

Quarter 1 input (Oct-Dec 2020)

Mouser Group:

Collected samples at MSEEL II in December 2020. The fluids are being used in enrichment bioreactor studies in my lab.

Two AGU presentations:

*Colosimo F, Purvine SO, Kyle JE, Olson HM, Wong AR, Eder EK, Hoyt DW, Callister SJ, Chu RK, and Mouser PJ. (Poster, 2020). 'Omics analyses of the hydraulically fractured shale isolate Halanaerobium highlights membrane modifications that underpin adaptation under deep subsurface biogeochemical drivers. AGU20 Fall Meeting, San Francisco, CA, December 7-11, 2020.

*Adhikari J, Colosimo F, Aghababaei M and Mouser PJ. (Poster, 2020). Microbial Adaptations to High Salinity in Hydraulically Fractured Shale Enabled through Integrated ‘Omics’ Analysis. AGU20 Fall Meeting, San Francisco, CA, December 7-11, 2020.

Cole Group:

Two publications, one published and one just submitted:

Comparative geochemistry of flowback chemistry from the Utica/Point Pleasant and Marcellus formations

Susan A. Welch, Julia M. Sheets, Rebecca A. Daly, Andrea Hanson, Shikha Sharma, Thomas Darrah, John Olesik, Anthony Lutton, Paula J. Mouser, Kelly C. Wrighton, Michael J. Wilkins, Tim Carr, David R. Cole

Chemical Geology
doi.org/10.1016/j.chemgeo.2020.120041

A mineralogy, microfabric and pore assessment of core from the Utica/Point Pleasant sub-basin of Ohio, West Virginia, and Pennsylvania

Julia M. Sheets, Susan A. Welch, Tingting Liu, Edwin R. Buchwalter, Alexander M. Swift, Steve Chipera, Lawrence M. Anovitz, and David R. Cole

Submitted to *International Journal of Coal Geology*

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 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 4.2. 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							
Day/Month	24-Jan	5-Mar	6-May	13-Jun	18-Sep	21-Oct	21-Nov	30-Dec
3H	X	X	X	X	X	X	X	X
4H	X	X					X	X
5H	X	X	X	X	X	X	X	X
6H		X					X	X

Year	2020									
Day/Month	30-Jan	27-Feb	25-Mar	28-Apr	27-May	30-Jul	5-Oct	26-Oct	24-Nov	16-Dec
3H	X	X	X	X	X	X	X	X	X	X
4H	X	X	X	X	X				X	X
5H		X	X	X	X	X	X	X	X	X
6H	X	X	X	X						X

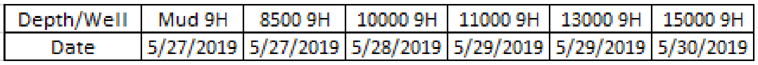
Boggess Site

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

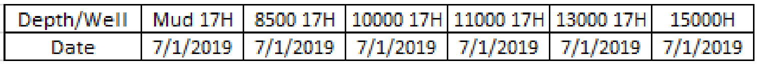
Tophole was completed in Feb 2019 for 9H and Jan 2019 for 17H. Samples of vertical drilling were not obtained due to completion prior to the start of the Boggess project.

Horizontals were initiated on 19 June 2019 for 17H and 20 May 2019 for 9H (Table 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 4.3. 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 4.4. Solids analysis list.

Analysis	Method	Units	Parameter
Diesel Range Organics by GC-FID	SW8015M	mg/kg-dry	DRO (C10-C28)
			ORO (C28-C40)
		% Rec	Surr: 4-terphenyl-d14
Gasoline Range Organics by GC-FID	SW8015D	ug/Kg	GRO C6-C10)
		% Rec	Surr: Toluene-d8
Volatile Organic Compounds	SW8260B	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	pCi/g	Potassium-40
			Radium-226
			Radium-228
	9310		Gross Alpha
			Gross Beta
Inorganics	SW9056A	mg/kg-dry	Br
			Cl
			SO4
	SW9034		sulfide
	E353.2		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		Ag
			Al
			As
			Ba
			Ca
			Cr
			Fe
			K
			Li
			Mg
			Mn
			Na
			Ni
			Pb
			Se
			Sr
			Zn
Moisture	E160.3M	%	Moisture
Chemical Oxygen Demand	E4104 R2.0	mg/kg-dry	COD
Organic Carbon - Walkley-Black	TITRAMETRIC	% by wt-dry	OC-WB
Oil & Grease	SW9071B - OG	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). Monthly sampling began following the initial weekly sampling effort. Samples were not collected in June and August.

Table 4.5. Boggess sampling events are indicated with an "X".

Year	2019			
Day/Month	18-Nov	25-Nov	2-Dec	10-Dec
9H	X	X	X	X
17H	X	X	X	X

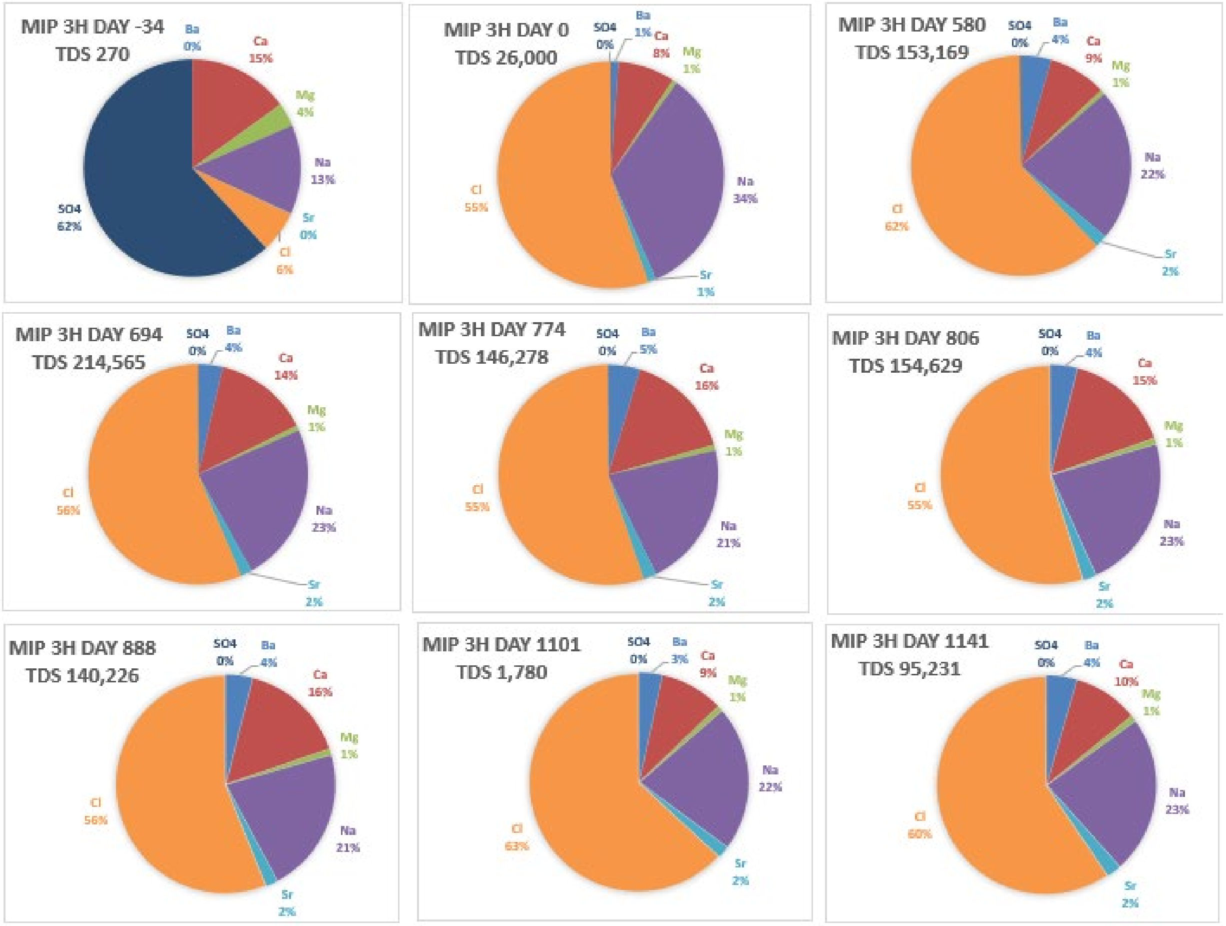
Year	2020									
Day/Month	30-Jan	27-Feb	25-Mar	28-Apr	27-May	30-Jul	5-Oct	26-Oct	24-Nov	16-Dec
9H	X	X	X	X	X	X	X	X	X	X
17H	X	X	X	X	X	X	X	X	X	X

Results & Discussion

MIP Site

<u>Major ions – trends in produced water chemistry</u>

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**).



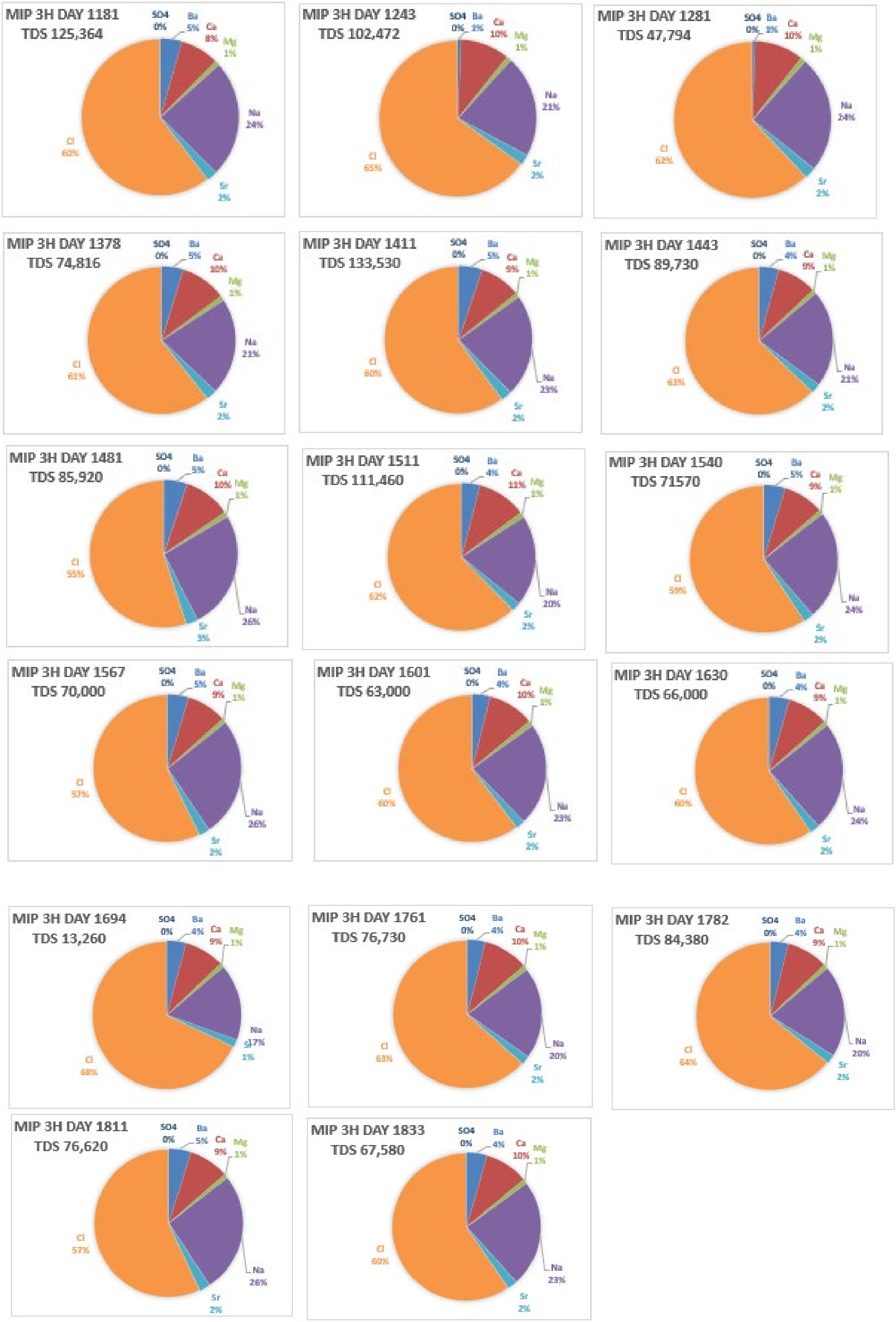


Figure 4.3. Changes in major ion concentrations in produced water from well MIP 3H. Top left Day -34 represents makeup water from the Monongahela River, top center is produced water on the first day (Day 0) and the remainder of pie charts show flowback and produced water on sampling dates through the 1833rd 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) and 1761 (e.g. October 2020), TDS declined in both wells. It's uncertain if the wells were shut down between sampling events, which might explain the decrease in TDS.

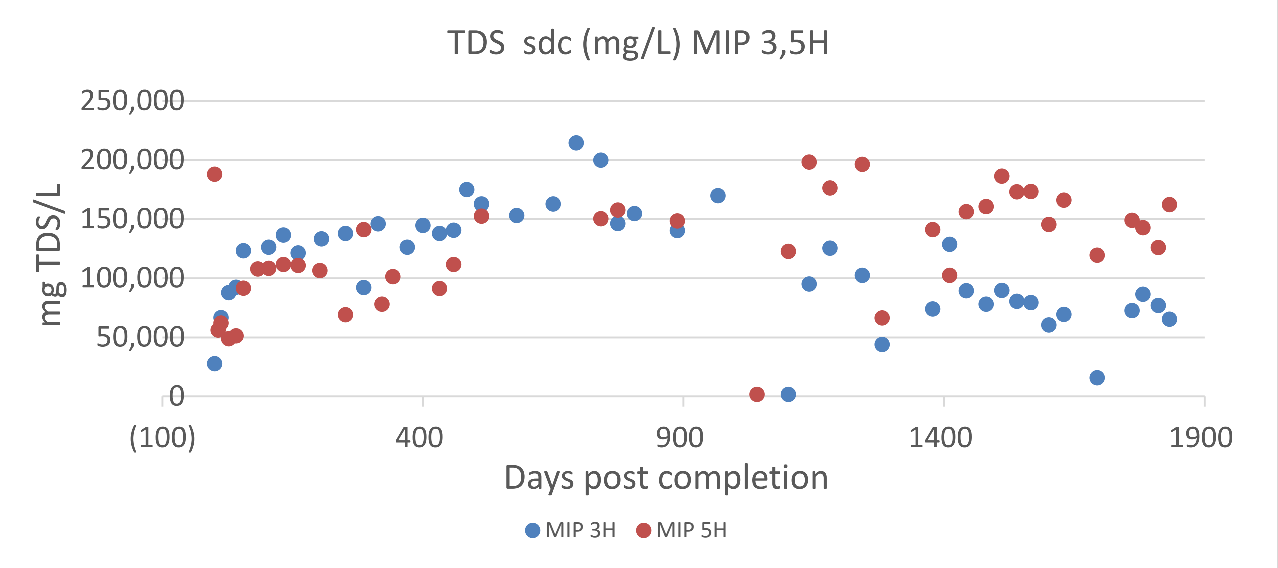


Figure 4.4. Changes in produced water TDS sdc (sum of dissolved constituents) through the first 1833 days post completion (3,5H).

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, again after March 2019 through November 2019, and again after April 2020 through December 2020. 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. 6H noted an increase from 21,708 to 91,211 mg/L TDS between day 3018 and 3052, then dropped back down to 33,390 mg/L TDS when it came back online in December 2020. (Figure 3).

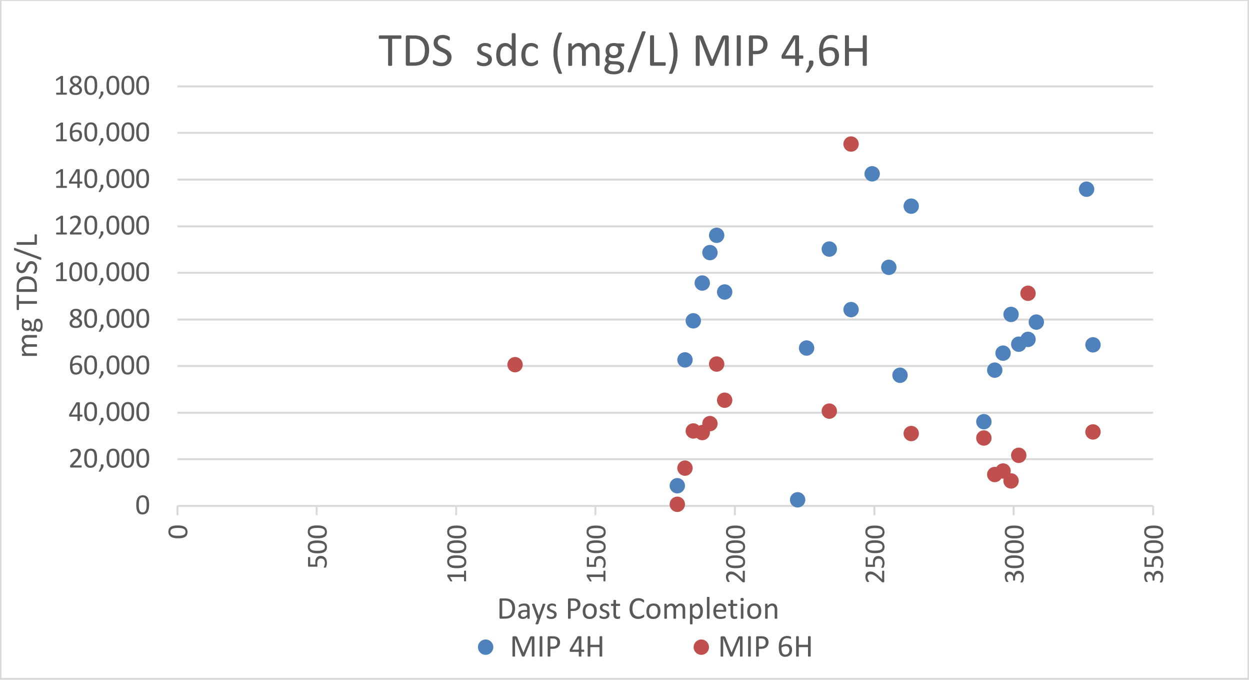


Figure 4.5. Changes in produced water TDS sdc (sum of dissolved constituents) through the first 1793 through 3284 days post completion (4,6H).

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 314 and 694, benzene has remained below 30 µg/L (Figure 4.4). 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.

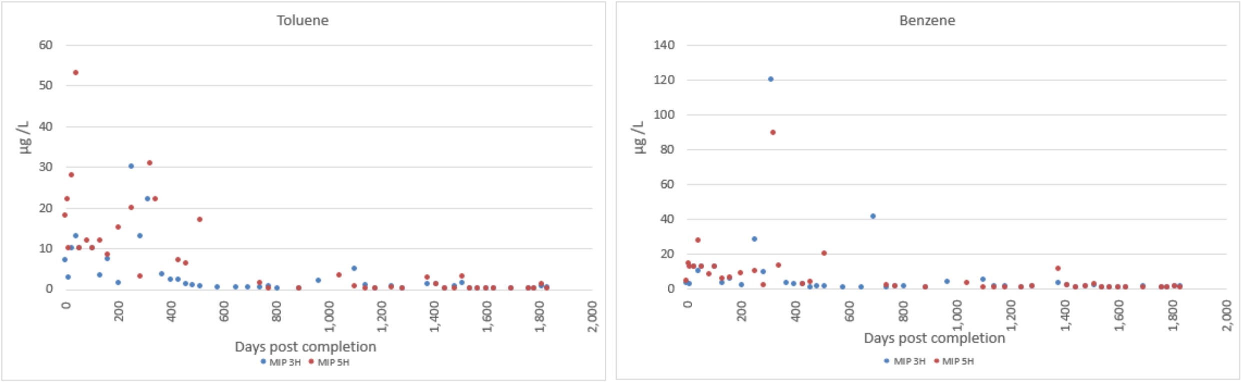


Figure 4.6. Changes in benzene and toluene concentrations. The figure shows data from well both 3H and 5H through day 1833.

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 1833 (Figure 4.5).

Radioactivity in produced water

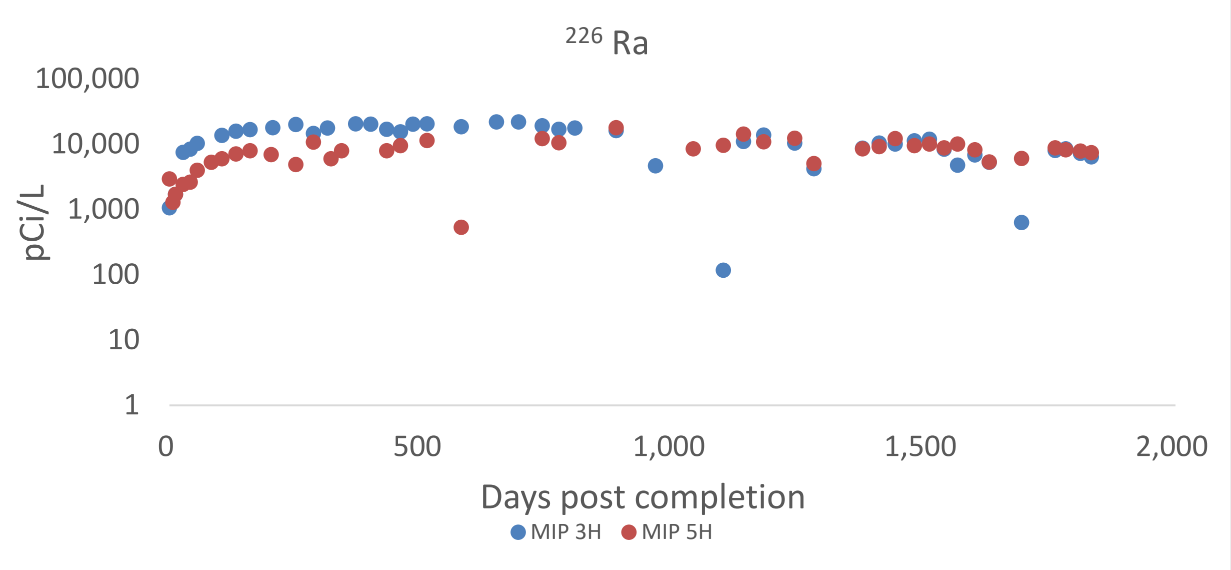


Figure 4.7. The radium isotopes are plotted against days post well completion through day 1833.

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 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 are frequently shut down during summer months which makes it difficult to determine overall trends.

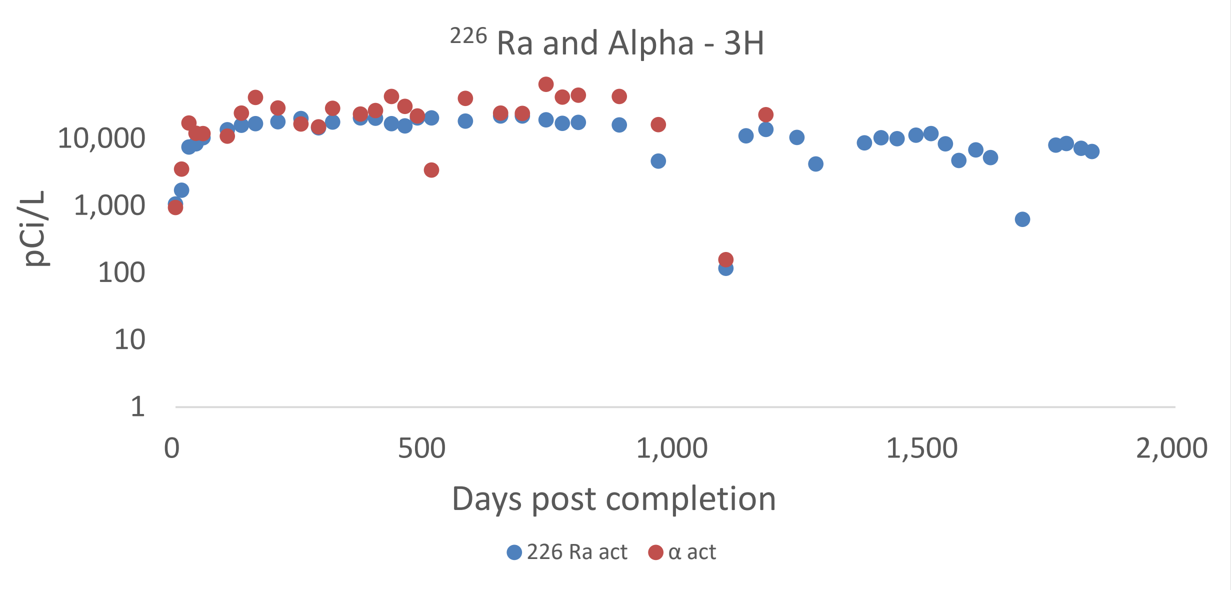


Figure 4.8. The radium isotopes are plotted against days post well completion through day 3284.

Figure 4.7 and Figure 8 show the relationship between gross alpha and ^{226}Ra at 3H and 5H through day 1833. Analysis for alpha was not conducted after day 1181.

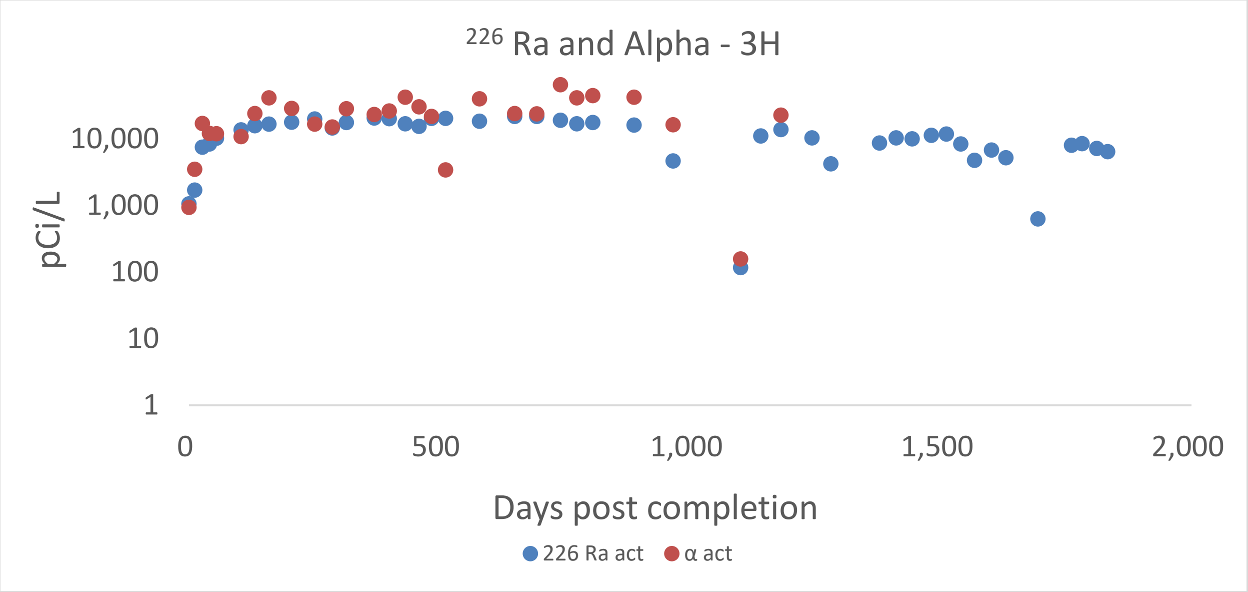


Figure 4.9. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 3H. Note: analysis for alpha was not conducted after day 1181.

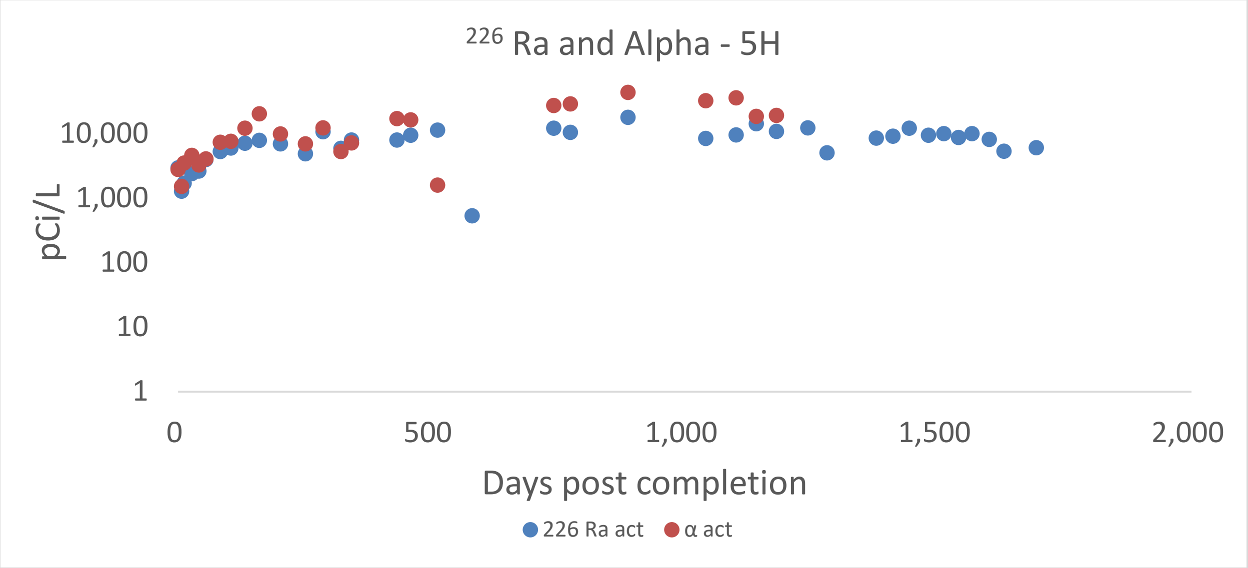


Figure 4.10. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 5H. Note: analysis for alpha was not conducted after day 1181.

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. Alpha was not determined after day 2632. Sample volume was not sufficient to perform analysis for radiologicals at 6H on day 3284.

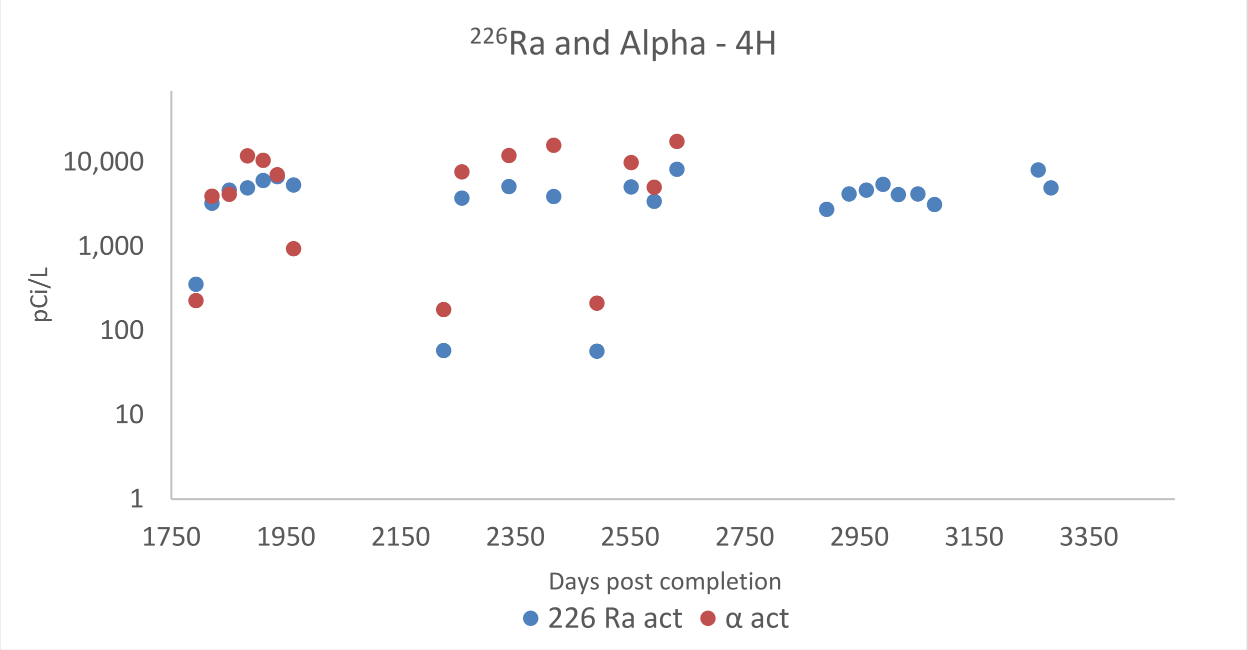


Figure 4.11. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 4H. Note: analysis for alpha was not conducted after day 2632.

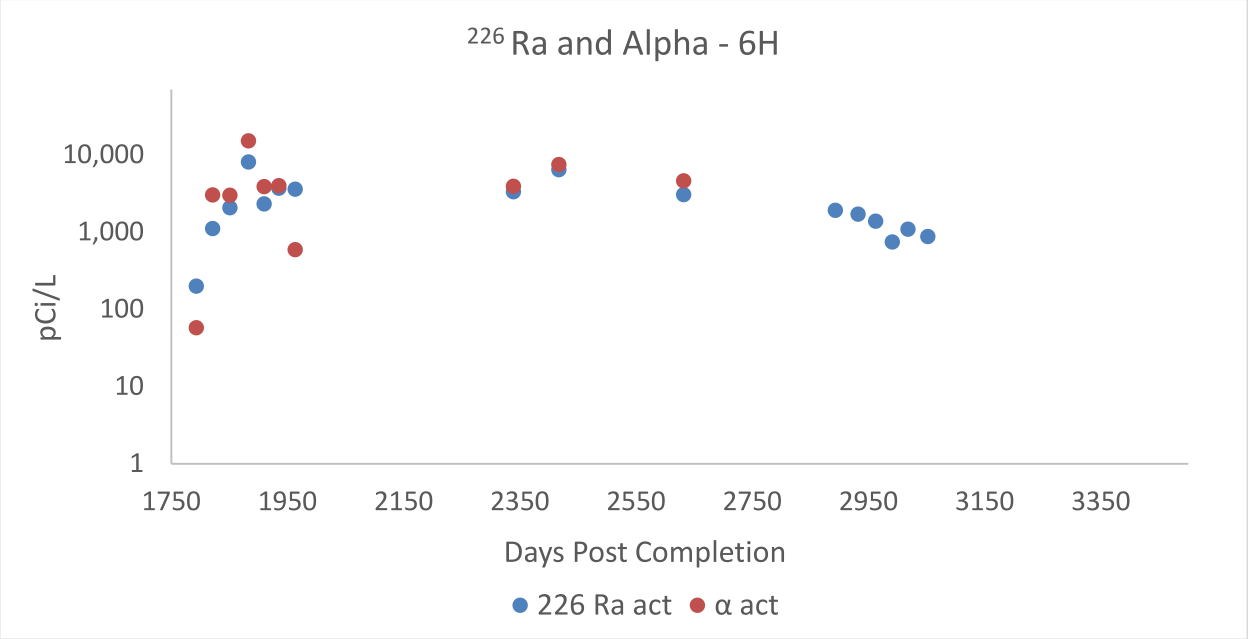


Figure 4.12. The relationship between gross alpha and ^{226}Ra as a function of time post completion at 6H. Note: analysis for alpha was not conducted after day 2632.

Boggess Well

The drilling mud and drill cutting samples were prepared using USEPA method SW3050. The resulting extracts were then analyzed using ICPMS. Method SW3050B uses both hydrochloric acid, nitric acid and hydrogen peroxide. It is used to identify components of the solid matrix that are or may become mobile. It does not normally break down a rock's alumino-silicate structure. The acids would dissolve any carbonates and the peroxide would oxidize pyrites which are abundant in the Marcellus formation. This accounts for the high concentrations of Ca, Mg and Fe. Presumably most sulfates generated during pyrite oxidation would precipitate as gypsum, barite and strontianite given the abundance of Ca, Ba and Sr in Marcellus formation fluids.

Solids

Drilling muds and cuttings were collected from 9H at depth intervals of 8,500ft; 10,000ft; 11,000ft; 13,000ft; and 15,000ft. Parameters (e.g. alk, Al, Ba, Ca, Cl, Fe, K, Mg, Mn, Na, and Sr) are shown in Figure 11. Drill cuttings from 9H are predominately calcium (Ca) and iron (Fe). The full list of solids parameters and methods are shown in Figure 3.

Figure 4.13. Anions/cations of drilling mud and cutting solids from 9H.

Figure 4.12 depicts parameters for drilling mud and cuttings from 17H. Shallower depths showed more variability in chemical composition in 17H in comparison to 9H. Deeper depths were predominately iron and calcium.

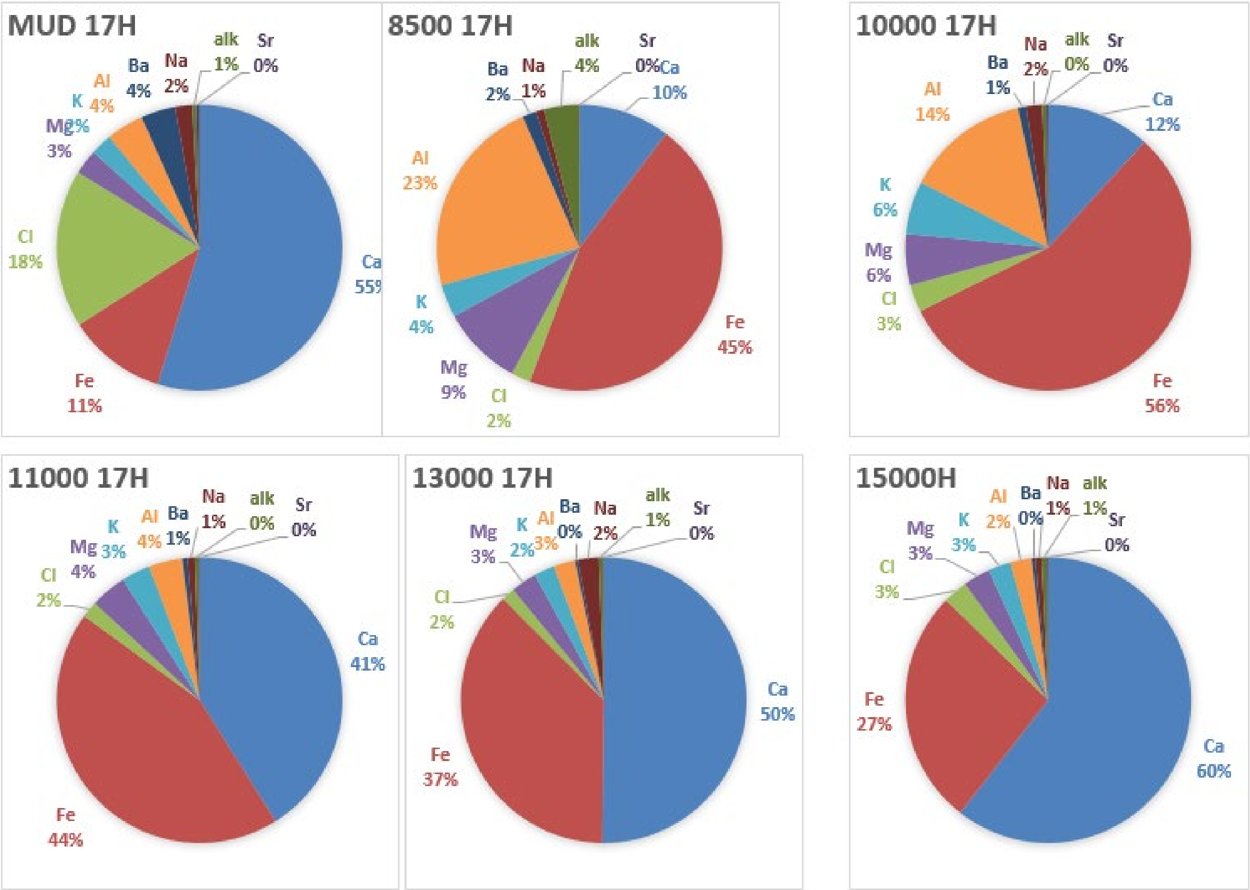


Figure 4.14. Anions/cations of drilling mud and cuttings solids from 17H.

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

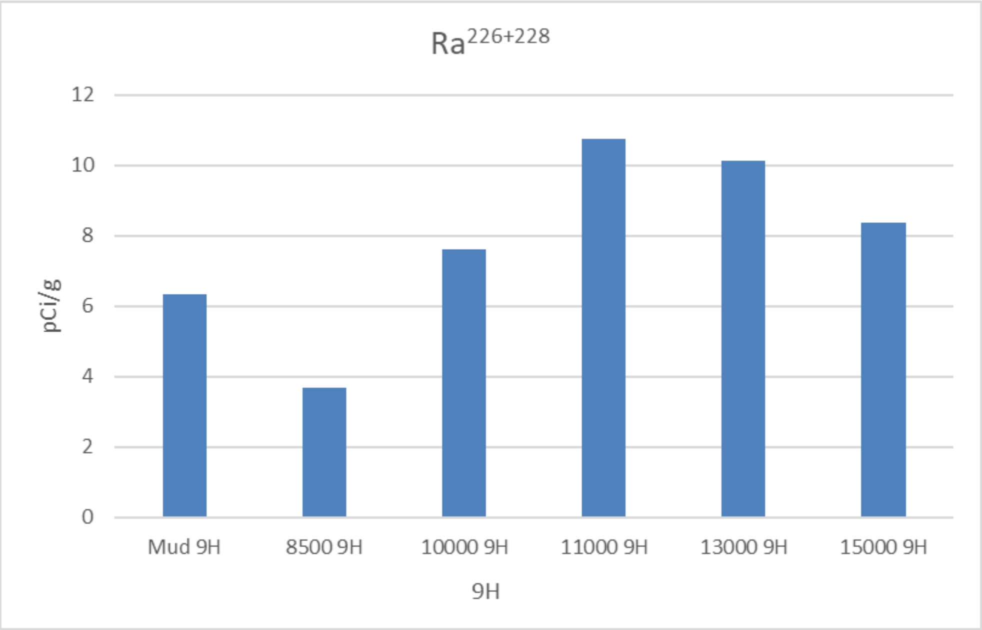


Figure 4.15. 9H Combined radium 226 and 228 for drilling mud and cuttings solids.

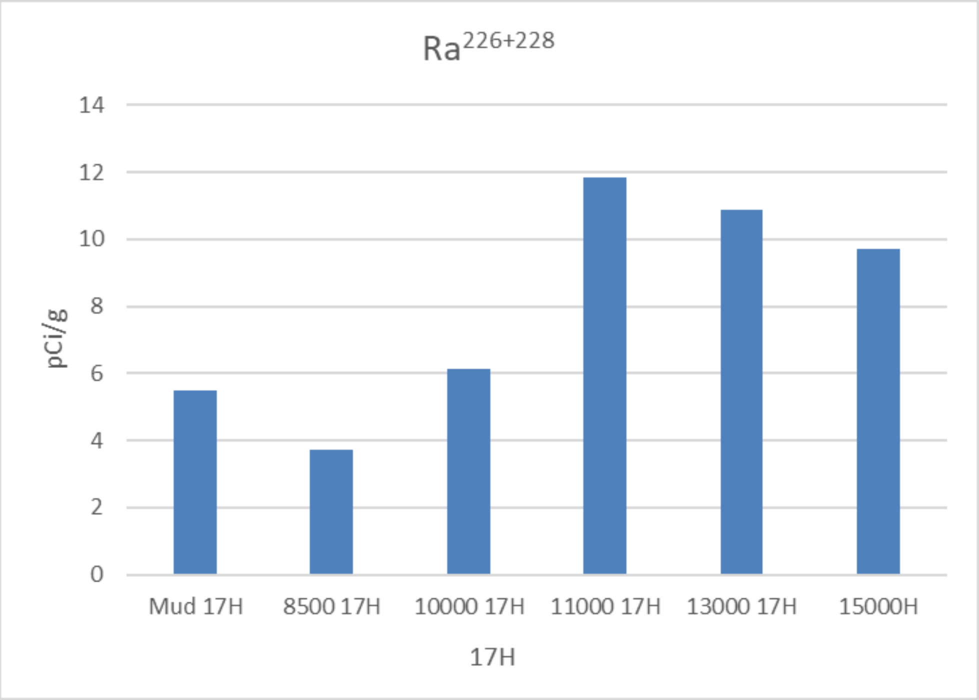


Figure 4.16. 17H Combined radium 226 and 228 for drilling mud and cuttings solids.

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.

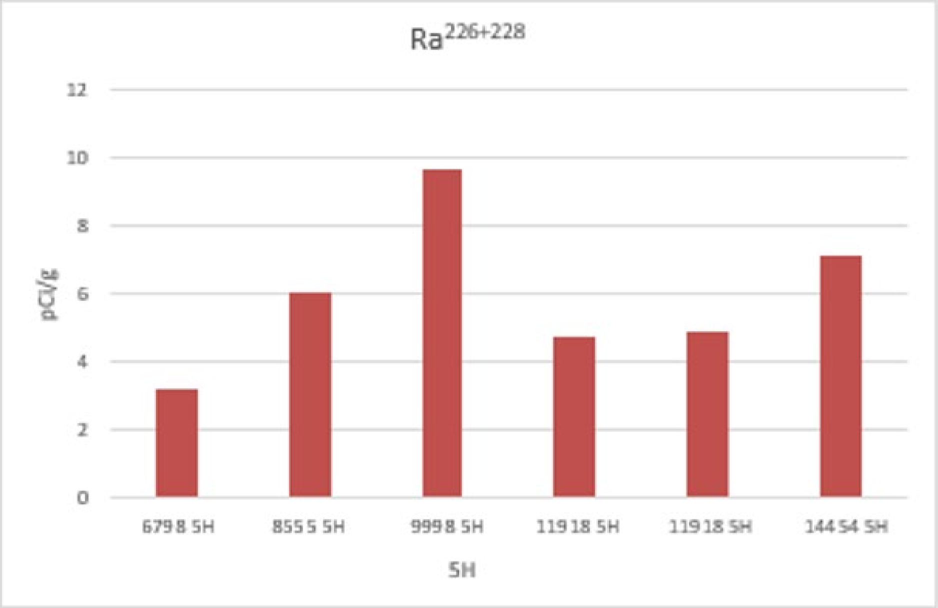


Figure 4.17. Combined Ra 226 + 228 for 5H MIP sites.

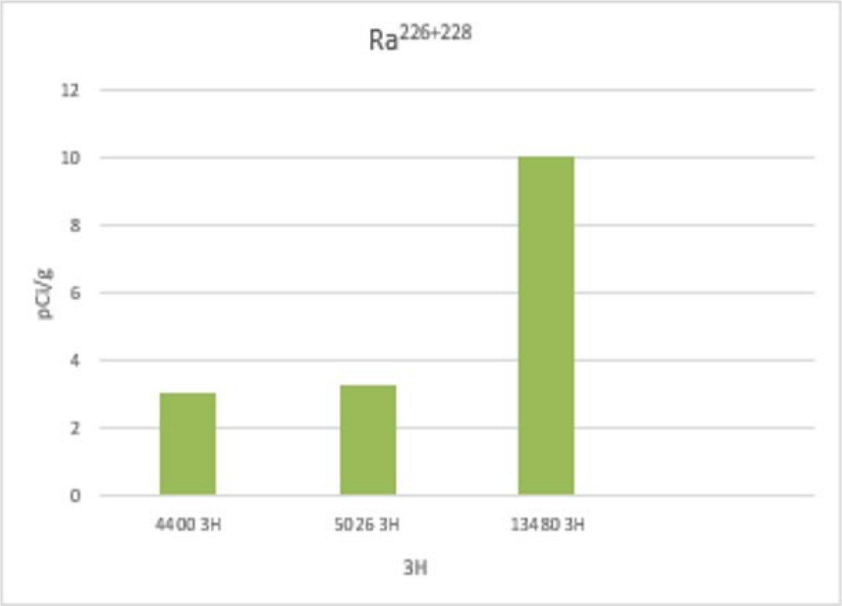
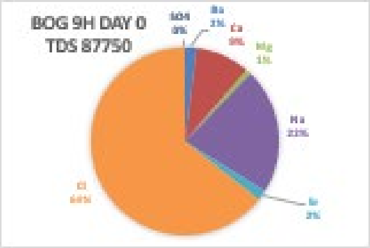
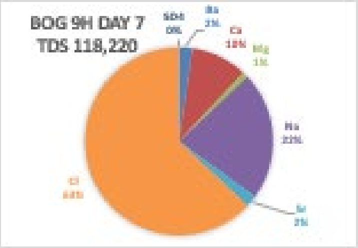


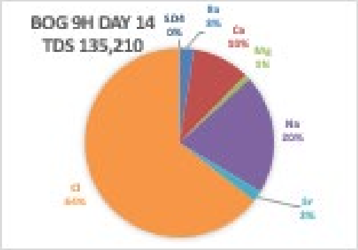
Figure 4.18. Combined Ra 226 + 228 for 3H MIP sites.

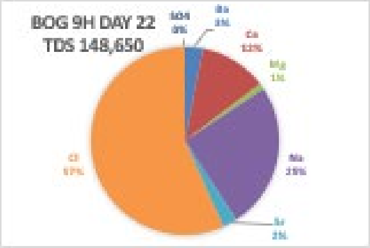
Major ions – trends in produced water chemistry

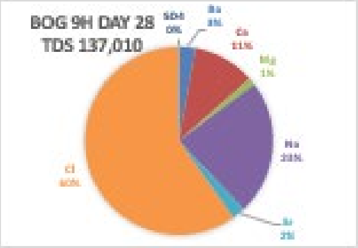
While makeup water was characterized by low TDS and a dominance of calcium and sulfate ions, produced water from initial flowback is essentially a sodium/calcium chloride water as noted in the earlier discussion regarding results from MIP. Preliminary results from days 0-394 at Boggess 9H and 17H are consistent with earlier results from MIP (Figure 4.17).

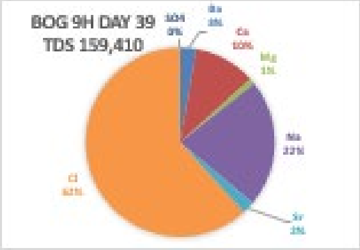

BOG 9H DAY 0
TDS 87750
SO4 0%
Ba 2%
Ca 9%
Mg 1%
Na 22%
Sr 2%
Cl 64%

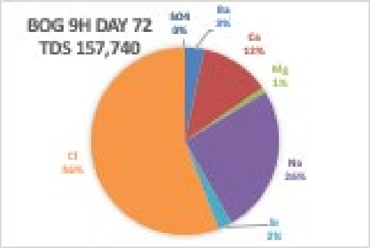

BOG 9H DAY 7
TDS 118,220
SO4 0%
Ba 2%
Ca 10%
Mg 1%
Na 22%
Sr 2%
Cl 63%

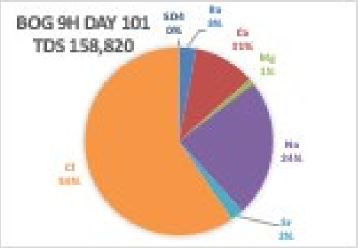

BOG 9H DAY 14
TDS 135,210
SO4 0%
Ba 3%
Ca 10%
Mg 1%
Na 20%
Sr 2%
Cl 64%


BOG 9H DAY 22
TDS 148,650
SO4 0%
Ba 3%
Ca 12%
Mg 1%
Na 25%
Sr 2%
Cl 57%


BOG 9H DAY 28
TDS 137,010
SO4 0%
Ba 3%
Ca 11%
Mg 1%
Na 23%
Sr 2%
Cl 60%


BOG 9H DAY 39
TDS 159,410
SO4 0%
Ba 3%
Ca 10%
Mg 1%
Na 22%
Sr 2%
Cl 62%


BOG 9H DAY 72
TDS 157,740
SO4 0%
Ba 3%
Ca 12%
Mg 1%
Na 26%
Sr 2%
Cl 56%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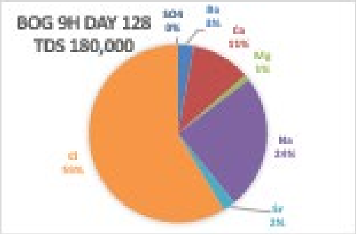
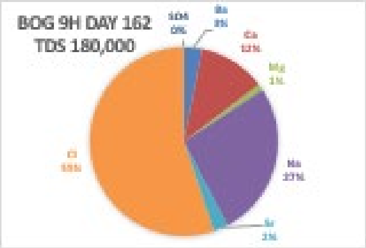
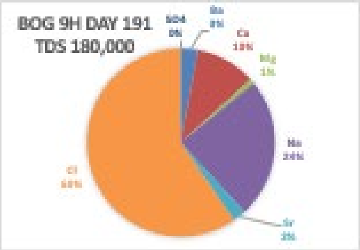
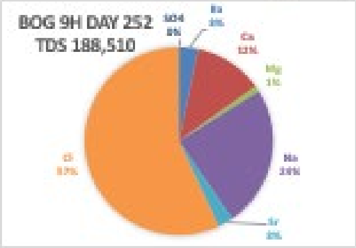
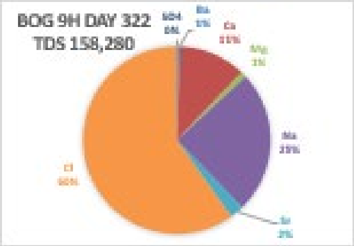
TDS 158,820
SO4 0%
Ba 3%
Ca 11%
Mg 1%
Na 24%
Sr 2%
Cl 59%

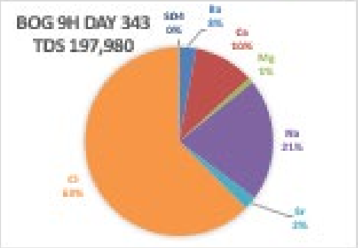

BOG 9H DAY 128
TDS 180,000
SO4 0%
Ba 3%
Ca 11%
Mg 1%
Na 24%
Sr 2%
Cl 59%

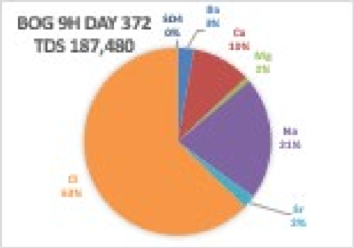

BOG 9H DAY 162
TDS 180,000
SO4 0%
Ba 3%
Ca 12%
Mg 1%
Na 27%
Sr 2%
Cl 55%

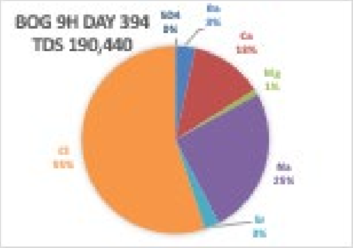

BOG 9H DAY 191
TDS 180,000
SO4 0%
Ba 3%
Ca 10%
Mg 1%
Na 24%
Sr 2%
Cl 60%


BOG 9H DAY 252
TDS 188,510
SO4 0%
Ba 3%
Ca 12%
Mg 1%
Na 25%
Sr 2%
Cl 57%


BOG 9H DAY 322
TDS 158,280
SO4 0%
Ba 1%
Ca 11%
Mg 1%
Na 25%
Sr 2%
Cl 60%


BOG 9H DAY 343
TDS 197,980
SO4 0%
Ba 3%
Ca 10%
Mg 1%
Na 21%
Sr 2%
Cl 63%


BOG 9H DAY 372
TDS 187,480
SO4 0%
Ba 3%
Ca 10%
Mg 1%
Na 21%
Sr 2%
Cl 63%


BOG 9H DAY 394
TDS 190,440
SO4 0%
Ba 3%
Ca 13%
Mg 1%
Na 25%
Sr 2%
Cl 55%

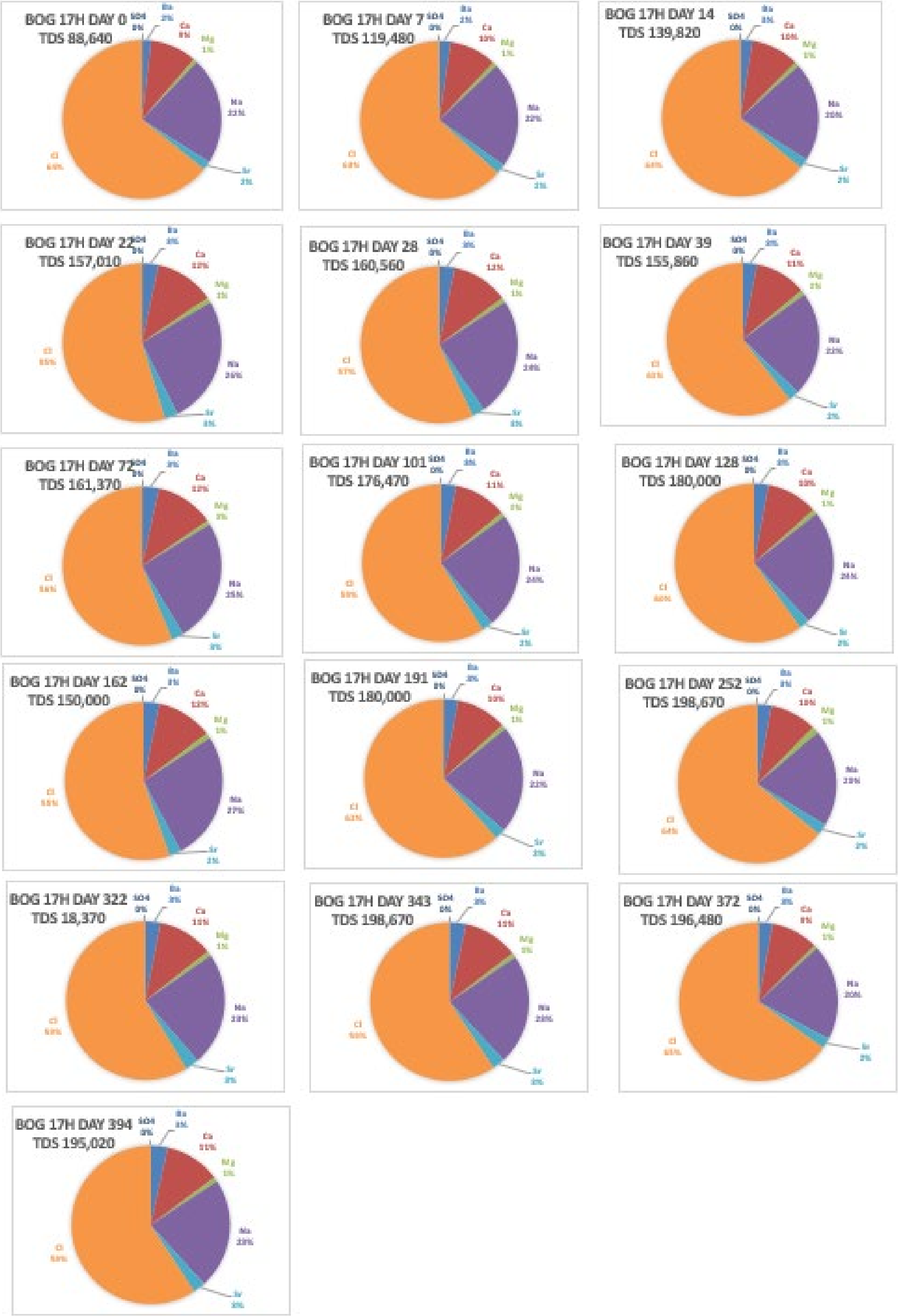


Figure 4.19. Major ion concentrations in produced water from wells BOGGESS 9H and 17H.

Preliminary TDS (sdc) at Boggess 9H and 17H show a slight upward trend between days 0 and 394 with an exception of day 322 (Figure 18 and 19). Benzene was 19 µg/L (Figure 20) and

Toluene was 23 µg/L (Figure 21) on day 322 at 17H which could indicate well stimulation occurred prior to sample collection, resulting in low TDS.

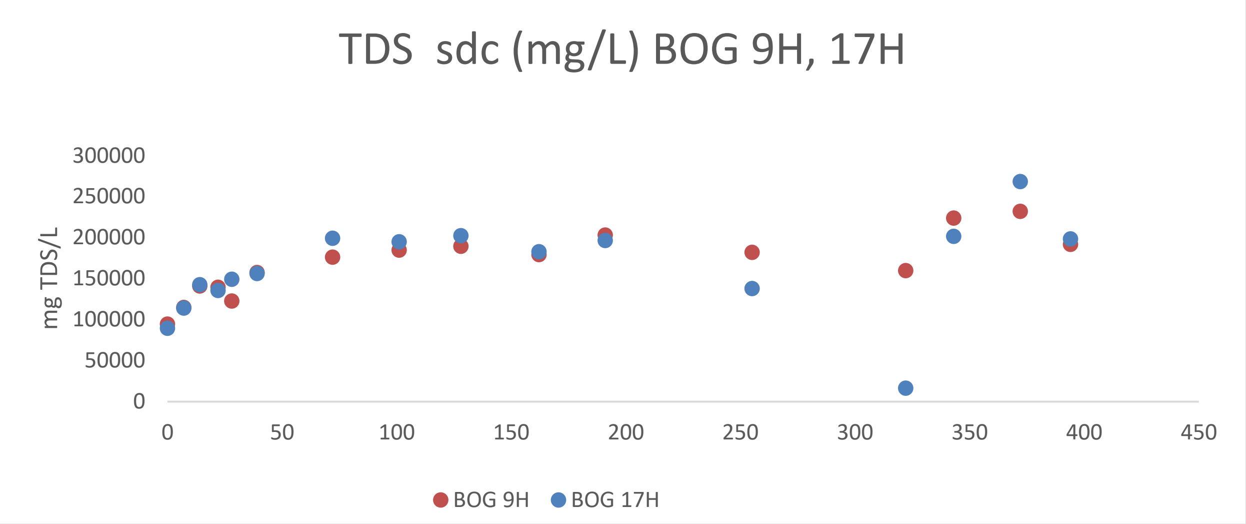


Figure 4.20. TDS (sdc) at Boggess 9H and 17H; days 0-394

Radium concentrations were below 15,000 pCi/L at both 9H and 17H at 394 days post completion (Figure 4.19).

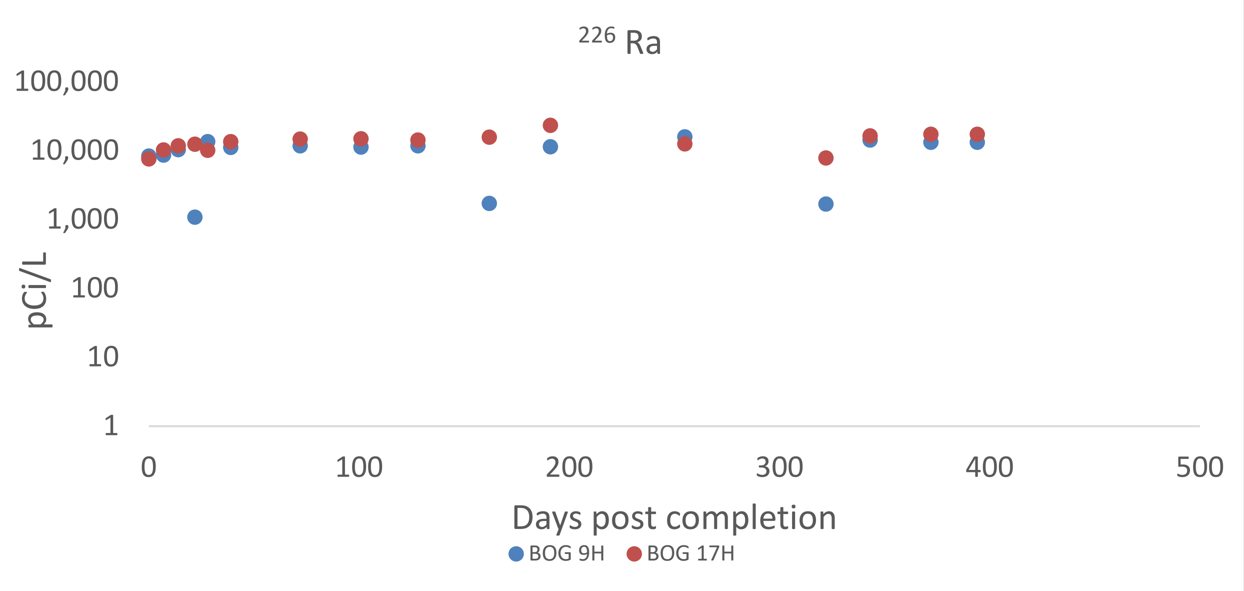


Figure 4.21. The radium isotopes are plotted against days post well completion at Boggess 9H and 17H; days 0-394.

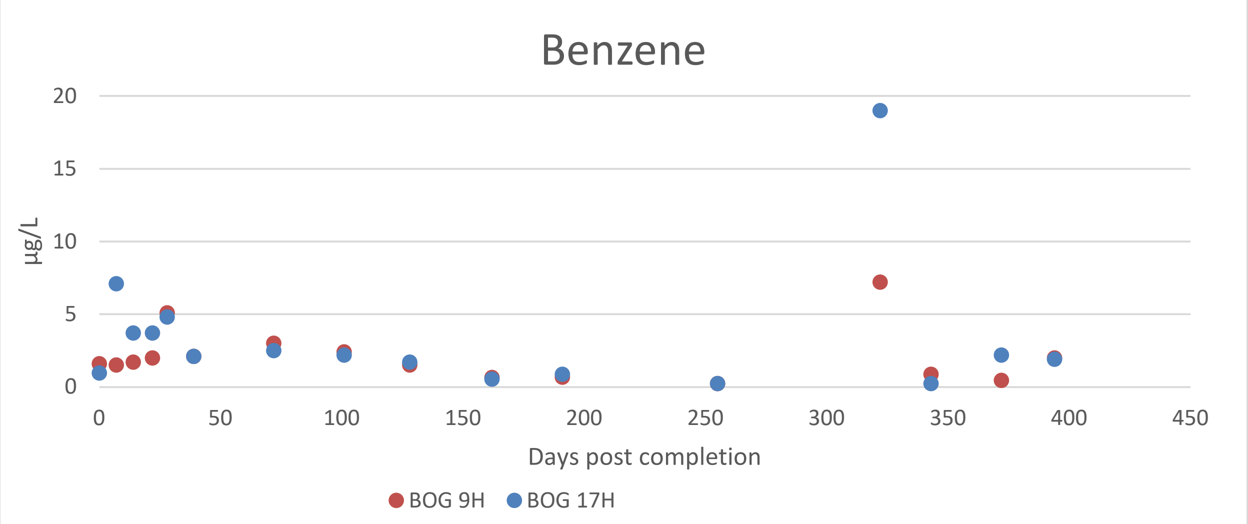


Figure 4.22. Benzene (µg/L) at BOG 9H and 17H through day 394.

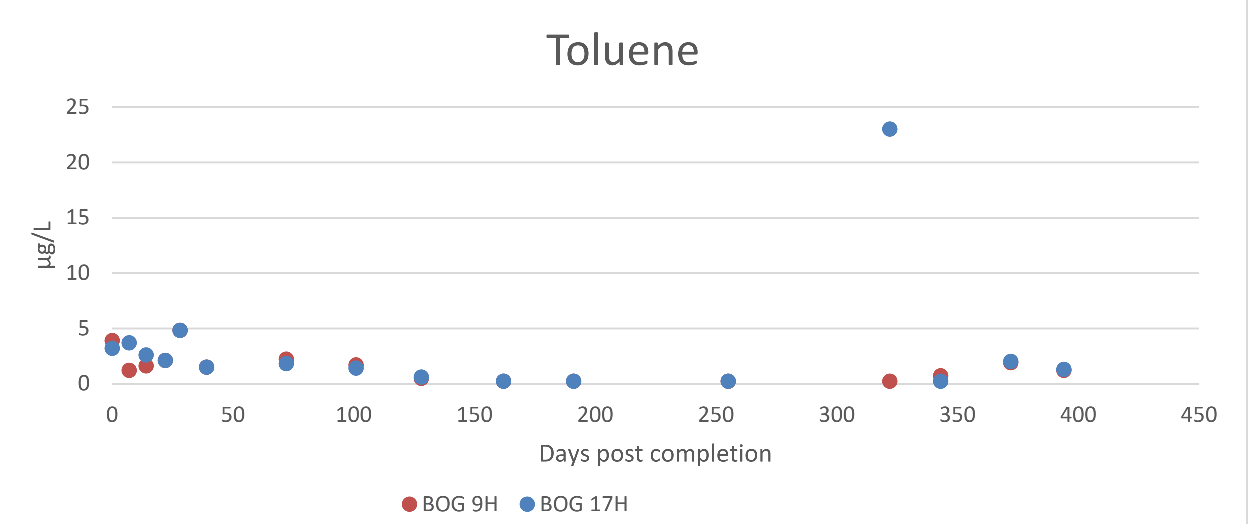


Figure 4.23. Toluene (µg/L) at BOG 9H and 17H through day 394.

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 produced water at Boggess Pad control wells 9H and 17H on a monthly basis. 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

The Environmental Monitoring Team was only scheduled to complete 16 audits under the MSEEL 1.0 project. However, during the last quarter and due to availability of resources we conducted an additional 17th audit. This ensured that we completed 5 direct quantification audits that occurred in and around when the NSF methane monitoring system was in place. Since the tower collected a year of data, it is in the decommissioning and removal phase. Research continues on expanding typical eddy covariance and OTM 33A methods using the tower data. We are currently examining the use of artificial neural networks and random forest regression, as led by Mr. Robert Heltzel. The goal will be to combine multiple data sets to reduce uncertainty of the indirect measurement results by training methods to meet the known emissions values of the five direct audits. Dr. Johnson is currently analyzing the complete data set of direct emissions and comparing with natural gas and produced water throughput rates to examine any trends. Dr. Johnson and Mr. Heltzel are also working to complete a Monte Carlo analysis to account for what appears to be heavily stochastic results to determine a throughout normalized loss value for MSEEL. Regarding, our energy audit work, Mr. Diego Dranuta continues to examine combined heat and power (CHP) as a method to reduce energy consumption during winter months. We previously reported on the use of CHEM-CAD as tool to model/size heat exchangers focused recapturing exhaust heat. We have also collaborated with CAIN Industries to obtain costs and design characteristics of similar exhaust recovery systems. In addition to the exhaust heat recovery, Mr. Dranuta has also worked to incorporate engine coolant heat that is typically rejected to ambient air. A summary of key findings is presented below.

Results and Discussion

Methane Emissions

Figure 5.1 shows the final results of the 17 direct quantification audits. The final mean emissions were just over 4.2 kg/hr, however as we noted before, the results were not normally distributed. The geometric mean was only about 800 g/hr. In reviewing the literature, we have seen that most measurements across the natural gas supply chain are not normally distributed. Literature has identified that data are not even log normally distributed and often skewed by fat-tailed super emitters. Some have used 26 kg/hr as the threshold for super-emitter classification. Audit 7 results were around 43 kg/hr and so this condition was likely a super-emitting event. Our analysis is ongoing, but Figure 5.2 shows the distribution of measurement results by major category and all combined. We see that even the measurements of categories by themselves are highly skewed.

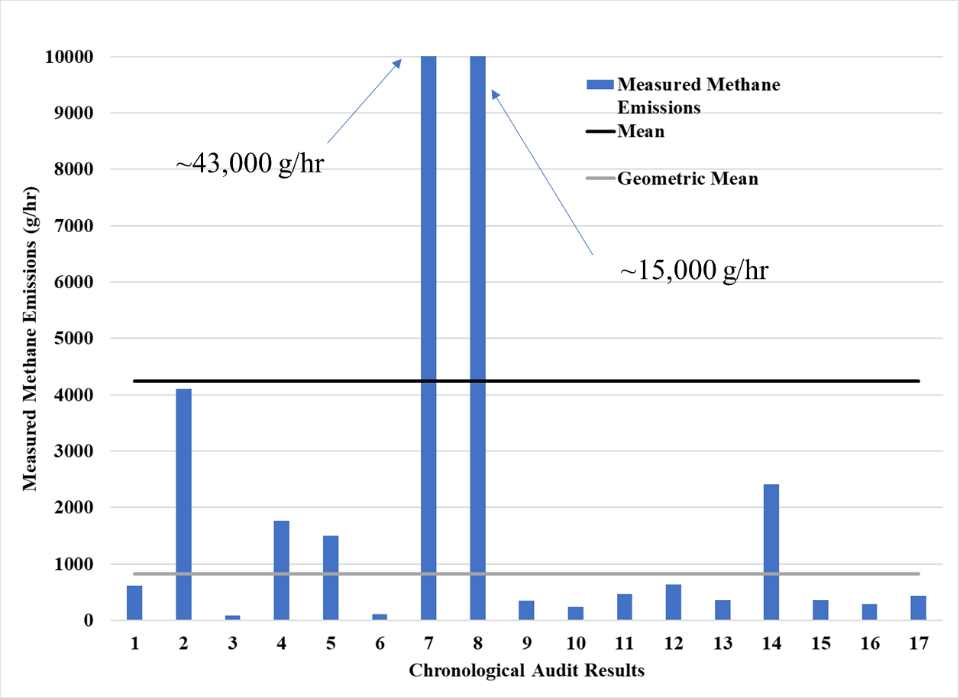


Figure 5.1: Results of all MSEEL direct quantification audits over four years.

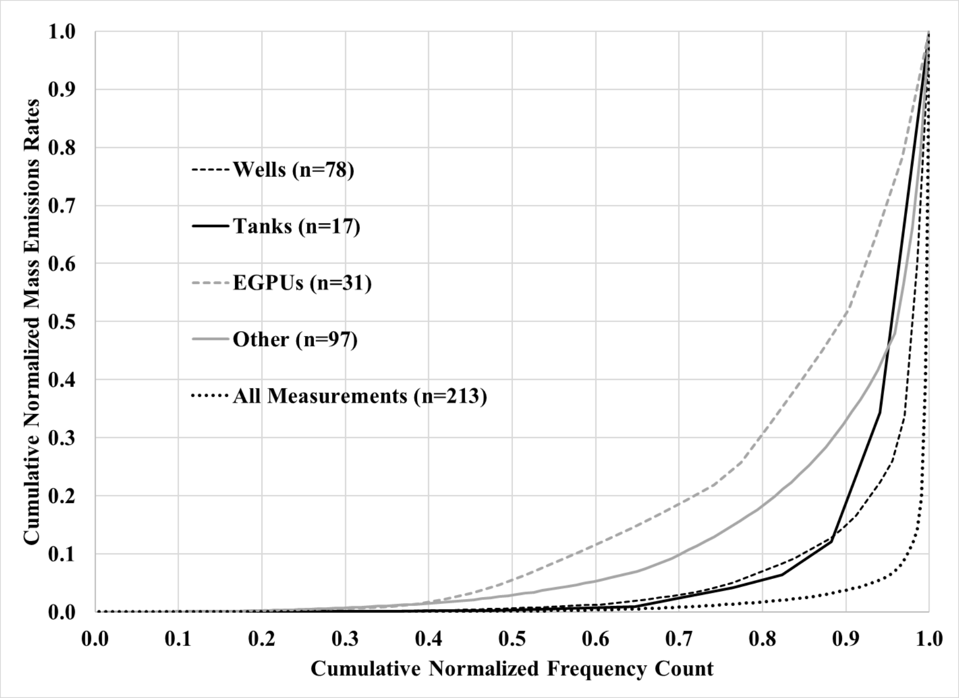


Figure 5.2: Distribution of mass measurements by category and total as a function of normalized frequency count.

Table 5.1 presents the summary of methane losses as a percentage of total gas throughout. We continue to analyze final natural gas and produced water throughput to determine if any relationships exist or if the results are purely stochastic. Since it appears that no strong correlations exist, we are moving forward with an analysis using probably distribution functions from each category along with a Monte Carlo analysis to create a population 10^4 methane emissions rates that will be randomly assigned to daily production rates over the four year period to determine a representative loss rate over the period of analysis (November 2016 – November 2020). We see that due to the skewed natural of the methane mass emissions, the throughput normalized emissions (TNE) are also variable. Methane losses were as low was 0.002% and as high as 2.361%. The average TNE was 0.169% while the geometric mean was only 0.017%

Table 5.1: Throughput normalized emissions (TNE) as a percentage of gas produced.

Audit Date	Audit Number	Methane Emissions	Daily Whole Gas Production	Daily Whole Gas Mass	TNE
		g/hr	mcf/day	g/day	%
11/22/2016	**1**	605	7,202	6,065,760	0.010
4/10/2017	**2**	4,102	5,831	4,910,943	0.084
7/19/2017	**3**	78	3,154	2,656,283	0.003
11/20/2017	**4**	1,768	9,791	8,246,401	0.021
5/23/2018	**5**	1,496	2,978	2,508,635	0.060
8/7/2018	**6**	106	5,660	4,766,832	0.002
10/12/2018	**7**	43,438	2,185	1,840,165	2.361
12/13/2018	**8**	15,020	7,800	6,570,005	0.229
2/8/2019	**9**	346	7,548	6,357,140	0.005
4/17/2019	**10**	242	4,651	3,917,604	0.006
6/14/2019	**11**	469	4,420	3,722,671	0.013
11/14/2019	**12**	633	8,998	7,578,934	0.008
1/13/2020	**13**	361	8,822	7,430,274	0.005
3/18/2020	**14**	2,408	7,361	6,199,654	0.039
6/25/2020	**15**	363	2,996	2,523,156	0.014
9/23/2020	**16**	291	6,327	5,329,151	0.005
11/5/2020	**17**	432	5,984	5,039,946	0.009

Energy Audits

We previously presented basic analysis based on designing an acceptable heat exchanger using the CHEMCAD tool. While this tool utilizes complex relationships to better represent realistic heat exchange effectiveness less than 100%, it does not account for some basic construction issues. In order to compare the CHEMCAD designed exhaust heat exchanger, a commercial exhaust heat exchanger was also analyzed and compared. CAIN industries is an exhaust heat recovery and steam generator system manufacturer with a vast experience and many units installed worldwide for different purposes. They usually work with large gensets; therefore, their largest heat exchanger was analyzed to compare to the simulated heat exchanger. Table 5.2 shows the heat recovered by the CHEMCAD design and the real CAIN heat exchanger for four representative activity cases. The highlighted cells show the cases where all boiler heat demand could be replaced be recovery of exhaust heat. Only by using the CHEMCAD modeled exhaust heat exchanger the amount of heat demanded vs recovered for each cycle is: 115.6, 123.2, 88.1, and 47.9% respectively. By using the commercial CAIN Industries exhaust heat exchangers these percentages are 90.2, 116.1, 93.1, and 77.4% respectively.

Table 5.2: Heat Demanded by the boiler compared to Modeled and Real heat exchangers (HEX).

Cycle	Heat Demanded by Boiler	Heat Recovered by CHEMCAD HEX	Heat Recovered by CAIN HEX
Name	kJ	kJ	kJ
2 Engines 1 Hour	2.79E+06	3.23E+06	2.52E+06
3 Engines 1 Hour	2.49E+06	3.07E+06	2.89E+06
24 Hours	6.48E+07	5.71E+07	6.03E+07
TP 1 Hour	2.55E+06	1.22E+06	1.97E+06

Most building, industrial, or at home combined heat power (CHP) systems also recover jacket water heat from any engines used for electricity generation. The same could be applied during well development by replacing the jacket-water radiators with jacket-water heat exchanges. To assess the inclusion of this available heat, we used collected field data with engine specifications and engineering assumptions. Data were collected for four general modes of operation based on engine load. CAT recommends use of thermostats that open at 99 °C. We used the ECU coolant temperatures to determine a temperature difference across standard air radiators. Table 5.3 shows the heat rejected ratings and temperature from specification sheets and data collected in the field.

Table 5.3: Known heat rejected, and field data collected for a jacket-water (engine coolant) HEX.

Percent Load	Q	JW out	JW in	ΔT	m Calculated	m Calculated
%	kW	°C	°C	°C	kg/s	kg/hr
50	263	99	78.7	20.3	3.07	11065
75	340	99	82.5	16.5	4.89	17606
100	412	99	86.3	12.7	7.70	27735

To examine the coolant and heated recover water, these points were used with thermodynamic models to create a respective heat rejection map across engine loads from 0-100%. The modeled error at the above known points were within 5%. While we did not have access to acceptable pump pressure drops for the diesel engines used in the field, we did have similar pump capacities for similar CAT G3512 engines. With these assumed values a second HEX of the liquid-liquid type was modeled with CHEMCAD. The model again focused on creating steam to completely replace the boiler in so water was fixed at 110 PSIG with a maximum pressure drop across the HEX of 30 PSIG which is the upper limit of similar water pumps. Table 5.4 shows the heat demand for the four cases analyzed along with heat recovered by the new jacket water recovery system and the combination of a full CHP system. We see that even though the rejected jacket water heat is at a lower quality compared to the exhaust heat, the combination of a liquid-liquid HEX as a pre-heater to the exhaust heat recover system could completely offset the boiler demand for all cases examined. In addition, we show that the heat exchanger effectiveness required for the additional liquid-liquid HEX would only need to be 67% to offset all boiler demand.

Table 5.5: Heat demand and heat recovery.

Cycle	Heat Demand by Boiler	Heat Recov by JW HEX	Heat Recov HEX+JW	HEX+JW vs Demand	Heat Recov CAIN+JW	CAIN+JW vs Demand	JW HEX eff needed + CAIN	JW HEX eff needed + CHEMCAD HEX
Name	**kJ**	**kJ**	**kJ**	**%**	**kJ**	**%**	**%**	**%**
2 Engines 1 Hour	2.79E+06	2.27E+06	5.49E+06	196	4.79E+06	171	12	0.00
3 Engines 1 Hour	2.49E+06	2.52E+06	5.59E+06	224	5.41E+06	217	0.00	0.00
24 Hours	6.48E+07	4.99E+07	1.07E+08	165	1.10E+08	170	9	13
TP 1 Hour	2.55E+06	1.39E+06	2.61E+06	102	3.36E+06	132	41	67

Products

Nothing to report at this time.

Plan for Next Quarter

- Finalize mobile tower removal from MSEEL 1.0.
- Complete and submit a journal publication on the long term temporal variations in methane emissions from MSEEL.
- Complete a draft publication for the energy audit and CHP studies.
- A specific exhaust heat exchanger for Waukesha L7044GSI natural gas gensets will be asked to be quoted to CAIN industries
- CAIN heat exchanger natural gas engine performance will be modeled and loaded into the Simulink model for comparison.
- CO_2 emissions reduction due to the use of the heat exchangers will be calculated in the model

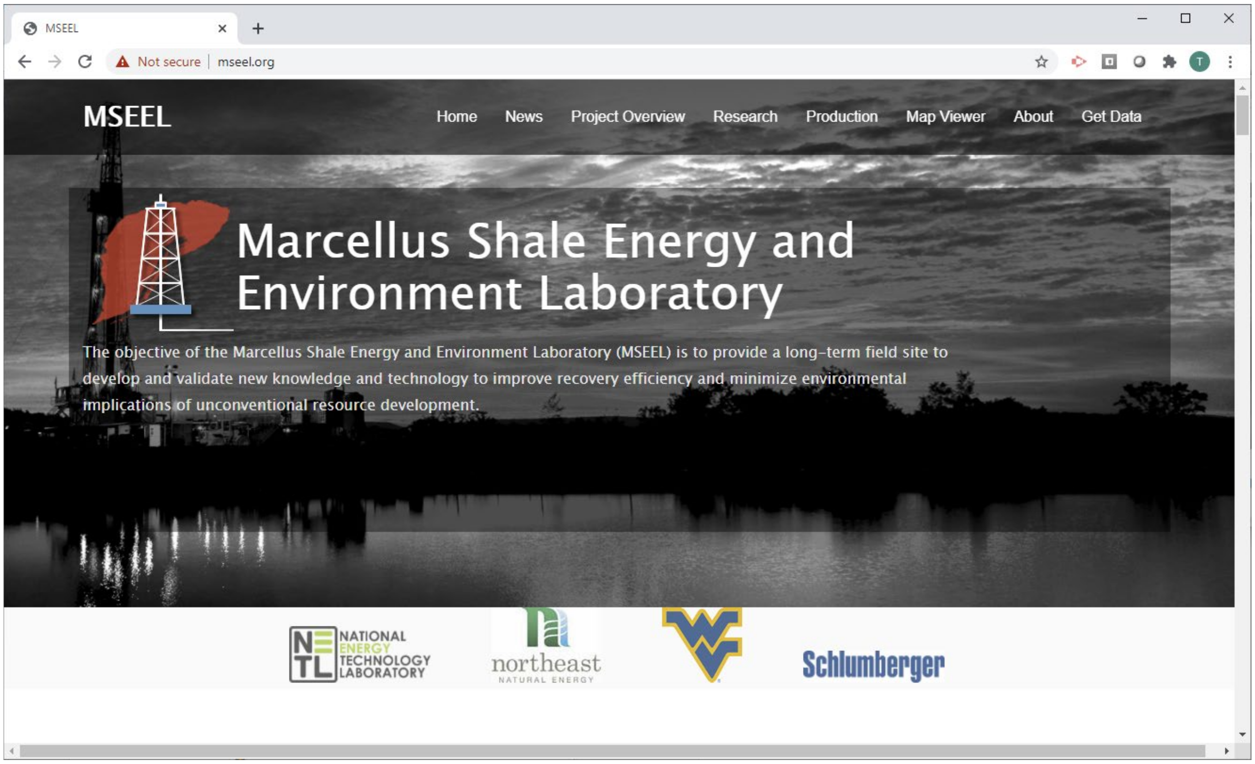
Topic 6 – Water Treatment

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

Topic 7 – Database Development

Approach

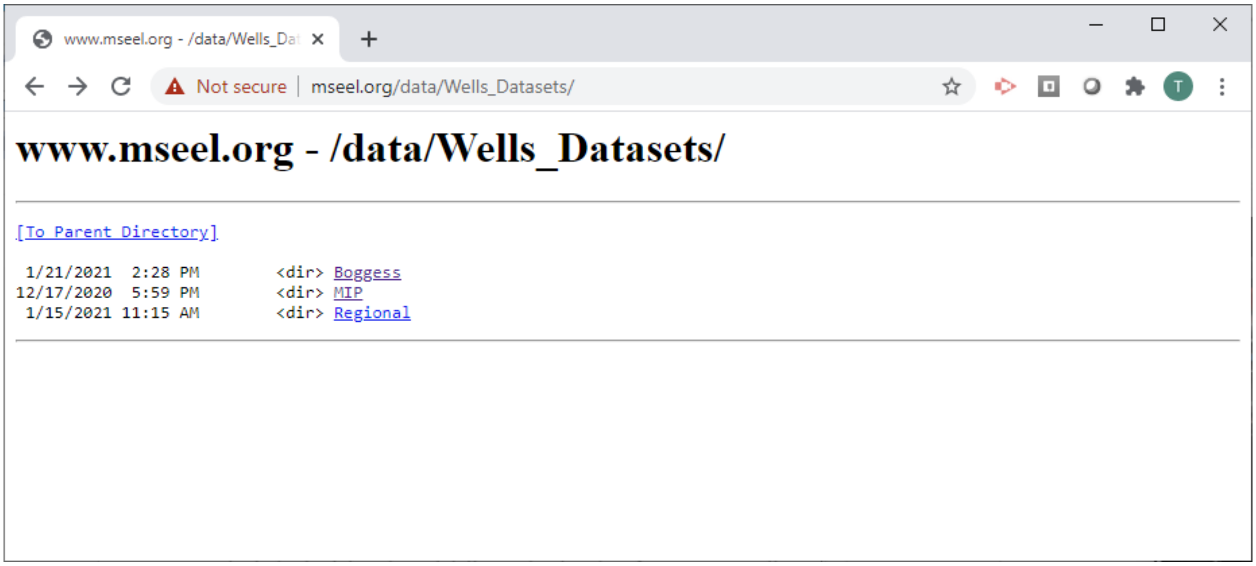
In December, we met the self-imposed deadline of adding the Boggess data to the web site one year after initial product. All MSEEL data from the MIP and Boggess pads are now online and available to researchers via the ***Get Data*** link (FTP) (Figures 7.1, 7.2 and 7.3). We will work to improve the navigation for obtaining the data. The website has been updated to include new navigation and adding the latest production for both the MIP and Boggess pads (Figure 7.4).



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/.

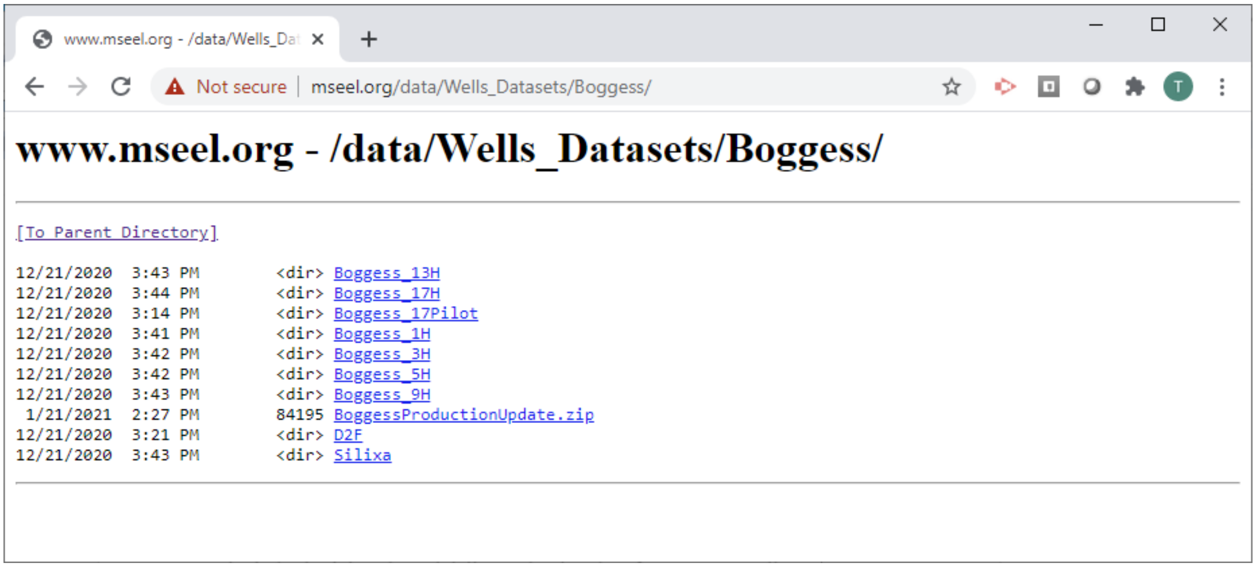


www.mseel.org - /data/Wells_Datasets/

```
[To Parent Directory]

 1/21/2021  2:28 PM        <dir> Boggess
12/17/2020  5:59 PM        <dir> MIP
 1/15/2021 11:15 AM        <dir> Regional
```

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

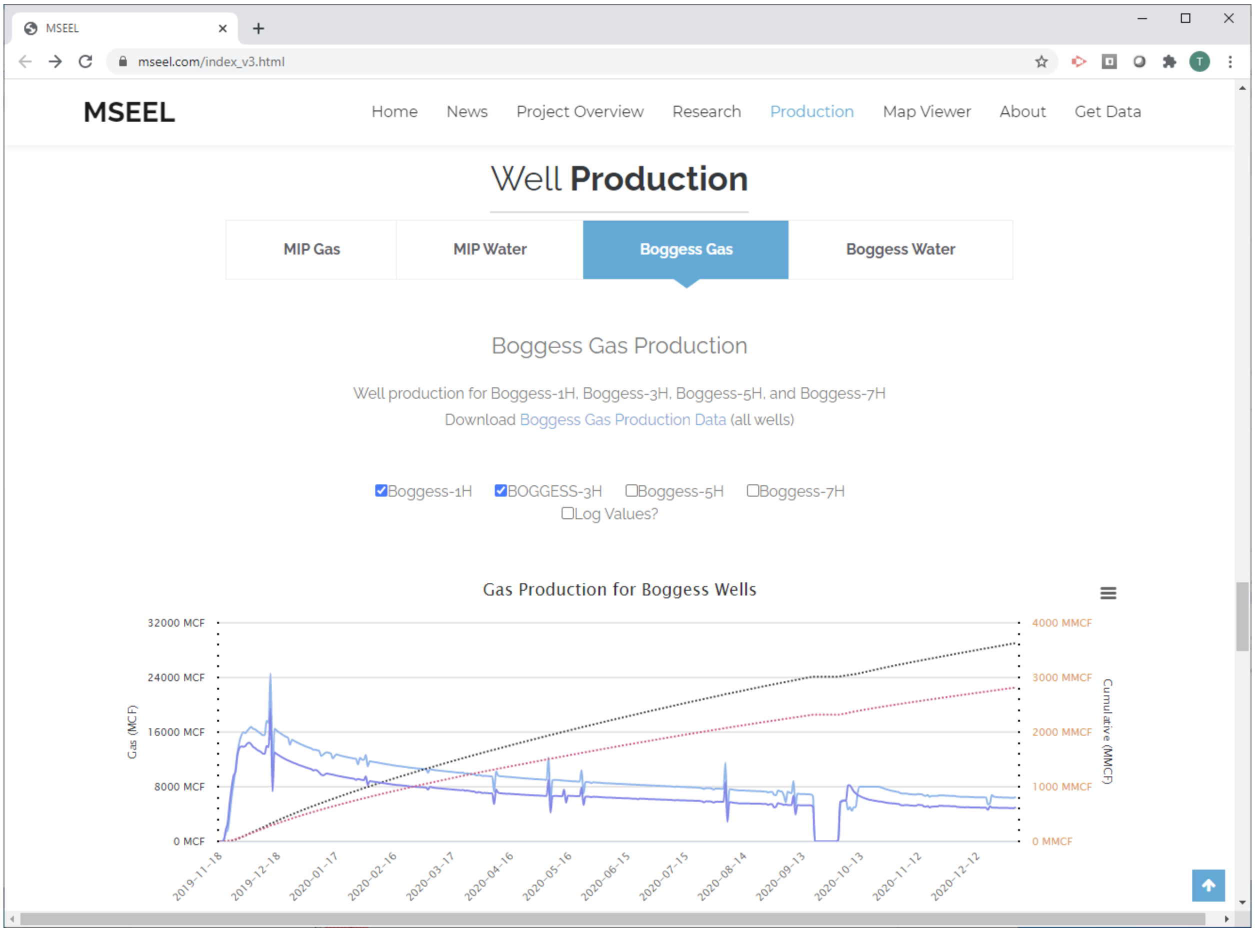


www.mseel.org - /data/Wells_Datasets/Boggess/

[To Parent Directory]

```
12/21/2020  3:43 PM        <dir> Boggess_13H
12/21/2020  3:44 PM        <dir> Boggess_17H
12/21/2020  3:14 PM        <dir> Boggess_17Pilot
12/21/2020  3:41 PM        <dir> Boggess_1H
12/21/2020  3:42 PM        <dir> Boggess_3H
12/21/2020  3:42 PM        <dir> Boggess_5H
12/21/2020  3:43 PM        <dir> Boggess_9H
 1/21/2021  2:27 PM        84195 BoggessProductionUpdate.zip
12/21/2020  3:21 PM        <dir> D2F
12/21/2020  3:43 PM        <dir> Silixa
```

Figure 7.3: Example of data files from the Boggess Pad now available for download at http://mseel.org/.



Well **Production**

Boggess Gas Production

Well production for Boggess-1H, Boggess-3H, Boggess-5H, and Boggess-7H
Download Boggess Gas Production Data (all wells)

☑Boggess-1H ☑BOGGESS-3H ☐Boggess-5H ☐Boggess-7H
☐Log Values?

Figure 7.4: Production plots with new navigation to show gas and water production from both the MIP Pad and the Boggess Pad. Gas and water production have been updated through the end of the quarter are available at http://mseel.org/. Addition detailed production data (e.g., pressure etc.) are also available as spreadsheets (such as BoggessProductionUpdate.zip from the Get Data section, Figure 7.3)

Results & Discussion

SCADA production data is often messy and we investigated detailed reports from the SCADA at both hourly and daily scale for Boggess wells. In order to confirm the data quality, the hourly time series data was summed for each day to compare with daily production data files. A code was written to perform automatic anomaly detection and checked for missing values in production from SCADA website. Anomalous data can be further investigated. Anomalies were detected at the MIP site and working with NNE corrected. The QC of the production data for Boggess 1H as an example is shown in Figure 7.5. We confirmed that the production data in September 2020 is accurate caused by shut in due to gas prices (Figure 7.4).

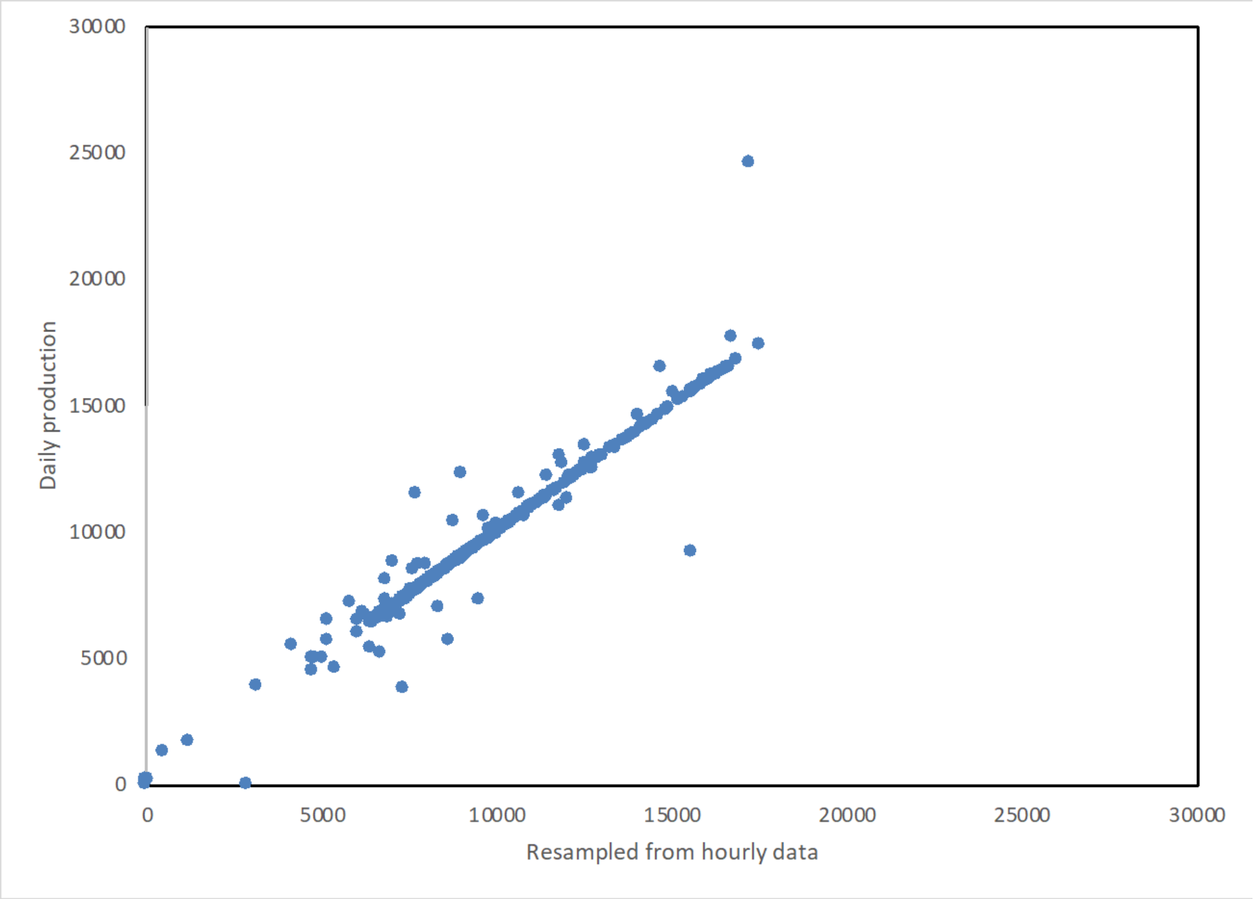


Figure 7.5: Example from the Boggess 1H of resampled hourly time series data compared to daily production data files. A code was written to perform automatic anomaly detection and to check for missing values in production from SCADA website. Anomalous data can be further investigated.

Quality controlled production data are now available at http://mseel.org/.

Products

Web site enhanced and updated.

Plan for Next Quarter

Working to improve web site navigation and increase access to data.

Topic 8 – Economic and Societal

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

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)
<u>Baseline Cost Plan</u>	(From 424A, Sec. D)			
<u>(from SF-424A)</u>				
Federal Share				$9,128,731
Non-Federal Share				$4,520,922
Total Planned (Federal and Non-Federal)				$13,649,653
Cumulative Baseline Costs				
<u>Actual Incurred Costs</u>				
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
<u>Uncosted</u>				
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)
Baseline Cost Plan	(From 424A, Sec. D)			
(from SF-424A)				
Federal Share				$11,794,054
Non-Federal Share				$5,222,242
Total Planned (Federal and Non-Federal)				$17,016,296.00
Cumulative Baseline Costs				
Actual Incurred Costs				
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
Uncosted				
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	$159,437.40	$276,916.50
Non-Federal Share	$3,163,776.74	$750,301.90	$0.00	$163,643.13
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$6,262,114.18	$1,485,659.98	$159,437.40	$440,559.63
Cumulative Incurred Costs	$26,480,972.96	$27,966,632.94	$28,126,070.34	$28,566,629.97
Uncosted				
Federal Share	$1,629,041.48	$893,683.40	$734,246.00	$1,079,195.50
Non-Federal Share	-$2,942,573.44	-$3,692,875.34	-$3,692,875.34	-$3,856,518.47
Total Uncosted - Quarterly (Federal and Non-Federal)	-$1,313,531.96	-$2,799,191.94	-$2,958,629.34	-$2,777,322.97

Start: 10/01/2014

End: 09/30/2021

Baseline Reporting Quarter

	Q25 (12/31/20)	Q26 (3/31/21)	Q27 (6/30/21)	Q28 (9/30/21)
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	$191,315.03			
Non-Federal Share	$90,883.68			
Total Incurred Costs - Quarterly (Federal and Non-Federal)	$282,198.71			
Cumulative Incurred Costs	$28,848,828.68			
Uncosted				
Federal Share	$887,880.47			
Non-Federal Share	-$3,947,402.15			
Total Uncosted - Quarterly (Federal and Non-Federal)	-$3,059,521.68			

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.
Daly RA, Borton MA, Wilson T, Welch S., Cole D. R., Sharma S., et. al., 2016. Microbes in the Marcellus Shale: Distinguishing Between Injected and Indigenous Microorganisms, Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
Evert M, Panescu J, Daly R, Welch S, Hespen J, Sharma S, Cole D, Darrah TH, Wilkins M, Wrighton K, Mouser PJ 2016. Temporal Changes in Fluid Biogeochemistry and Microbial Cell Abundance after Hydraulic Fracturing in Marcellus Shale. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016

Hanson AJ, Trexler RV, Mouser PJ (2016). Analysis of Microbial Lipid Biomarkers as Evidence of Deep Shale Microbial Life. Eastern Section American Association of Petroleum Geology (AAPG), Lexington, KY, Sept 25-27, 2016.
Lopano, C.L., Stuckman, M.Y., and J.A. Hakala (2016) Geochemical characteristics of drill cuttings from Marcellus Shale energy development. Annual Geological Society of America Meeting, Denver, CO, September 2016.
Pansecu J, Evert M, Hespen J, Daly RA, Wrighton KC, Mouser PJ (2016). Arcobacter isolated from the produced fluids of a Marcellus shale well may play a currently unappreciated role in sulfur cycling. Eastern Section American Association of Petroleum Geology (AAPG), Lexington, KY, Sept 25-27, 2016.
Sharma S, Carr T, Vagnetti R, Carney BJ, Hewitt J. 2016. Role of Marcellus Shale Energy and Environment Laboratory in Environmentally Prudent Development of Shale Gas. Annual Geological Society of America Meeting, Denver, CO, September 2016.
Sharma S, Agrawal V, Akondi R, and Warrier A. 2016. Understanding biogeochemical controls on spatiotemporal variations in total organic carbon in cores from Marcellus Shale Energy and Environment Laboratory. Eastern Section American Association of Petroleum Geologists' Meeting, Lexington, Kentucky, September 2016
Trexler RV, Akondi R, Pfiffner S, Daly RA, Wilkins MJ, Sharma S, Wrighton KC, and Mouser, PJ (2016). Phospholipid Fatty Acid Evidence of Recent Microbial Life in Pristine Marcellus Shale Cores. Eastern Section American Association of Petroleum Geology (AAPG), Lexington, KY, Sept 25-27, 2016.
Wilson T and Sharma S 2016. Assessing biogeochemical interactions in the reservoir at Marcellus Shale Energy and Environment Laboratory Annual Geological Society of America Meeting, Denver, CO, September 2016.
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
MSEEL Water and Waste Findings - Eastern Sec. AAPG annual meeting
Sharma S., 2016. Unconventional Energy Resources: A view from the Appalachian Basin. US Embassy Berlin, Germany 25 May 2016.
Sharma S., 2016. Biogeochemistry of Marcellus Shale. German National Research Centre for Earth Sciences GFZ, Postdam, Germany. May 22, 2016
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Sharma S. 2016. Marcellus Shale Energy and Environment Laboratory (MSEEL), West Virginia University Extension Conference, Clarksburg, WV. May 18, 2016.
Sharma S. 2016. Role of Geochemistry in Unconventional Resources Development. Appalachain Geological Society Meeting, Morgantown, April 5, 2016.
Sharma S. 2016. Marcellus Shale Energy and Environment Laboratory (MSEEL), Exxon WVU visit, Morgantown, June 23, 2016.
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
Sharma S. 2016, Role of Geochemistry in Unconventional Resource Development. Invited talk at Appalachian Geological Society Meeting, Morgantown, April 5 2016. Hakala, J.A., Stuckman, M., Gardiner, J.G., Phan, T.T., Kutchko, B., Lopano, C. 2016
Application of voltammetric techniques towards iron and sulfur redox speciation in geologic fluids from coal and shale formations, American Chemical Society Fall Meeting 2016 Philadelphia, PA.
Phan, T.T., Hakala, J.A. 2016. Contribution of colloids to major and trace element contents and isotopic compositions (Li and Sr) of water co-produced with natural gas from Marcellus Shale. American Chemical Society Fall Meeting 2016 Philadelphia, PA.
Environmentally Friendly Drilling Conference on 11/15/2015 by Sunil Moon and Michael McCawley, Diesel Traffic Volume Correlates with Ultrafine Particle Concentrations but not PM2.5.
Agrawal V, Sharma S , Chen R, Warrier A, Soeder D, Akondi R. 2015. Use of biomarker and pyrolysis proxies to assess organic matter sources, thermal maturity, and paleoredox conditions during deposition of Marcellus Shale. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.
Akondi R, Sharma S, Pfiffner SM, Mouser PJ, Trexler R, Warrier A. 2015. Comparison of phospholipid and diglyceride fatty acid biomarker profiles in Marcellus Shale cores of different maturities. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.

Mouser, PJ, Daly, RA, Wolfe, R. and Wrighton, KC (2015). Microbes living in unconventional shale during energy extraction have diverse hydrocarbon degradation pathways. Oral presentation presented at 2015 Geological Society of America Annual Conf. Baltimore, MD, Nov 1-4.
Sharma S and Wilson T. 2015. Isotopic evidence of microbe-water-rock interaction in Shale gas produced waters. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.
Sharma S, Chen R, Agrawal V. 2015 Biogeochemical evidences of oscillating redox conditions during deposition of organic-rich intervals in the middle Devonian Marcellus Shale. Annual Geological Society of America Meeting, Baltimore, MD, November 1-4.
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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