


MARCELLUS SHALE ENERGY AND ENVIRONMENTAL LABORATORY UPDATE: WATER AND WASTE

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RPSEA Onshore Workshop
Appalachian Basin Technology
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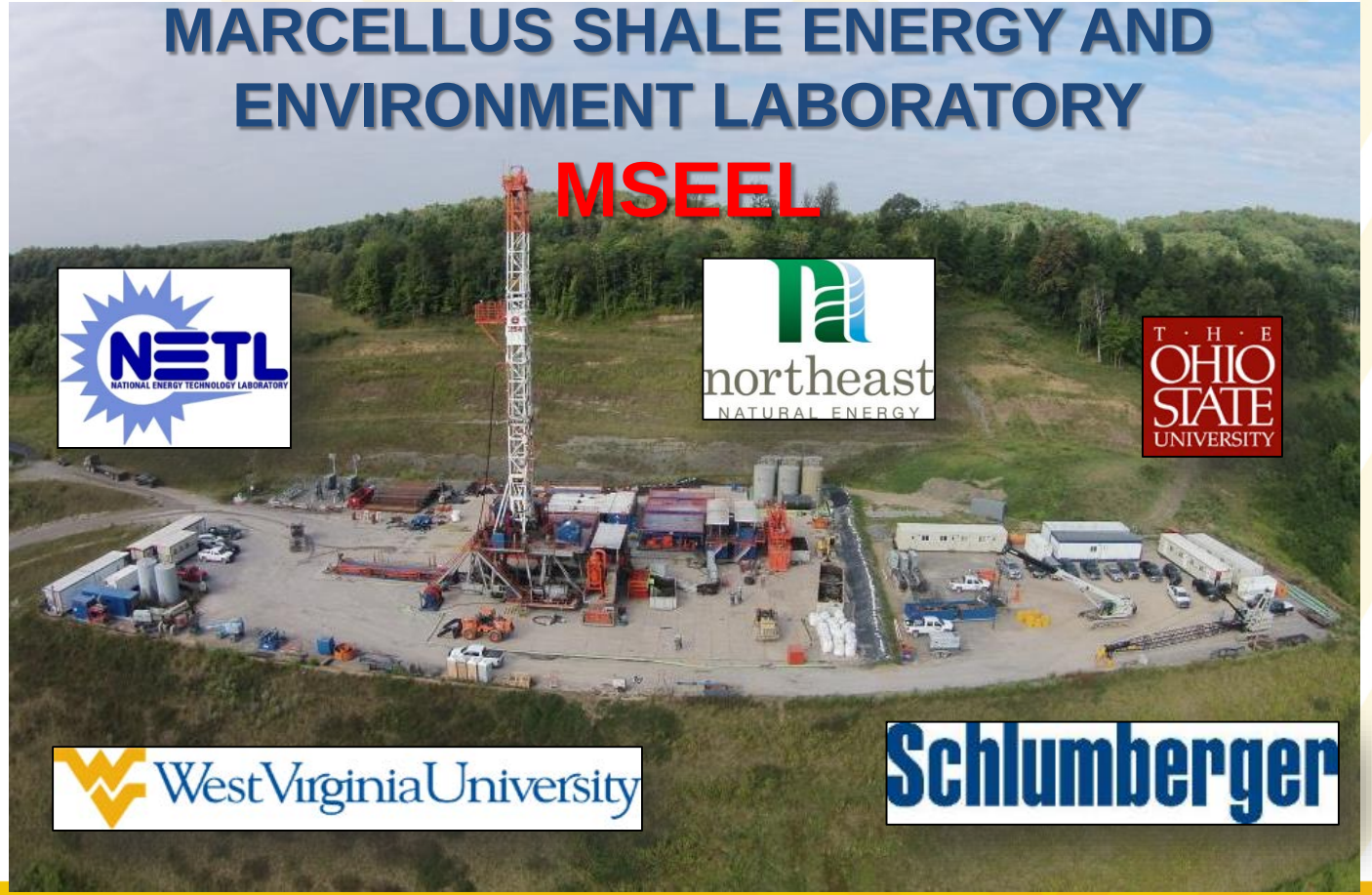
MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY

MSEEL



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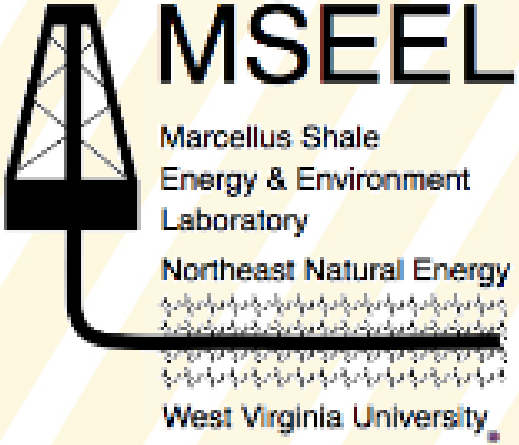
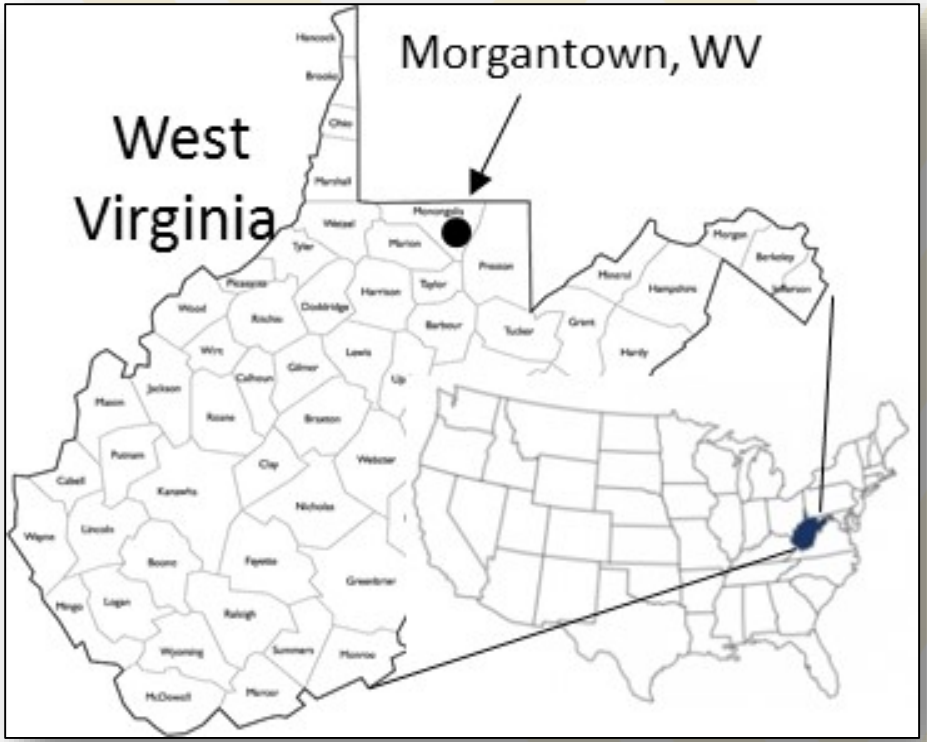


The objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to provide a long-term collaborative field site to develop and validate new knowledge and technology to improve recovery efficiency and minimize environmental implications of unconventional resource development

MSEEL VISION

- Demonstrate the Best Practices to Drill, Complete and Produce a New Horizontal Well That Minimizes Any Environmental/Societal Costs While Maximizing Economic Productivity
- Monitor and Document Impacts in a Controlled Environment
  - Greenhouse Gas Emissions
  - Local Air Pollution
  - Water Supply and Quality
  - Noise and Activity
  - Societal Impacts
- Develop New Technologies to Maximize Production
  - Microseismic Monitoring
  - Production Monitoring
  - Advanced Logging
  - Simulation
- Develop New Scientific and Engineering Approaches to Apply to Multi-disciplinary and Multi-institutional Natural Resource Studies

MSEEL Site



MSEEL
Drilling MIP 3H and 5H

MSEEL
Completion MIP 3H and 5H

PROJECT TEAM

Program Management

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WATER AND SOLID WASTE STUDIES: CHARACTERIZATION AND MANAGEMENT

Water

- Hydrofrac fluids
- Makeup water
- Flowback
- Produced water

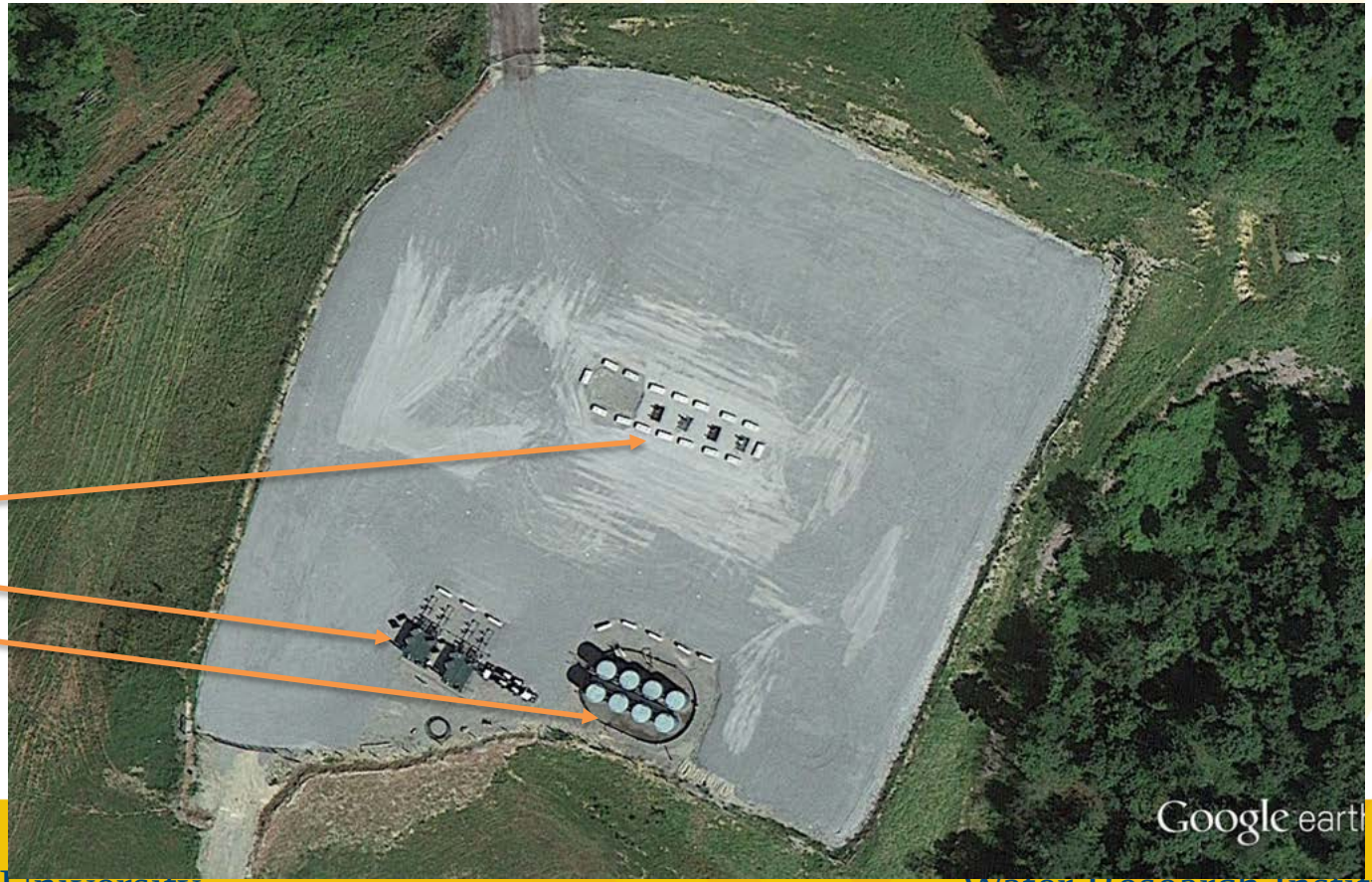
Solid wastes

- Drill cuttings
- Mud

PRODUCING MARCELLUS WELL PAD: 4 WELLS

2 hectares total
- access/service road
- out slopes

1.2 hectares pad
- well heads
- separators
- condensate tanks

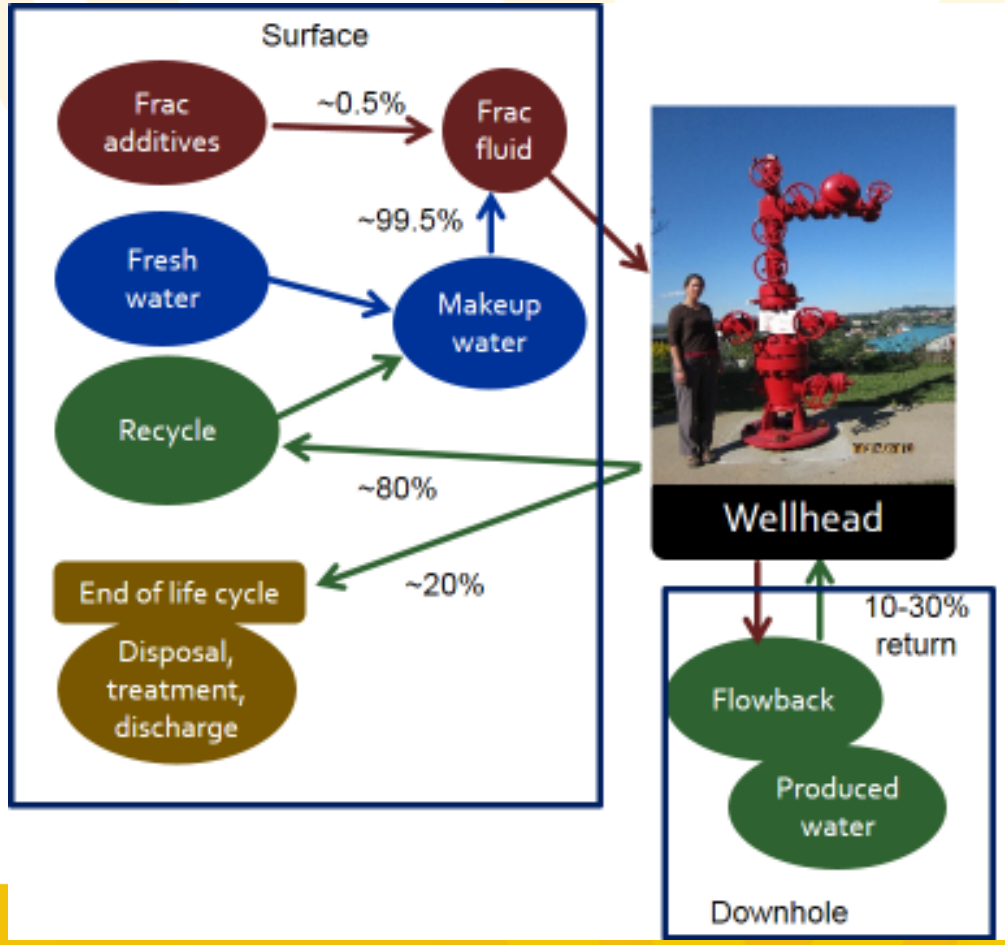


PRODUCING WELL SITE WITH IMPOUNDMENT

6 hectares:

- access/service road
- well heads
- separators
- condensate tanks

FLUIDS AT THE WELL SITE

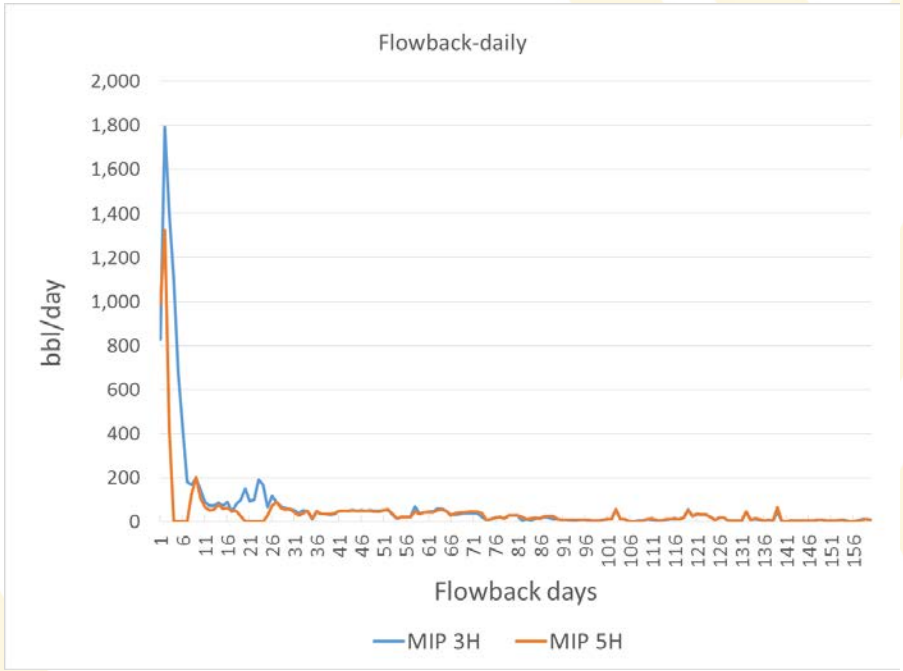


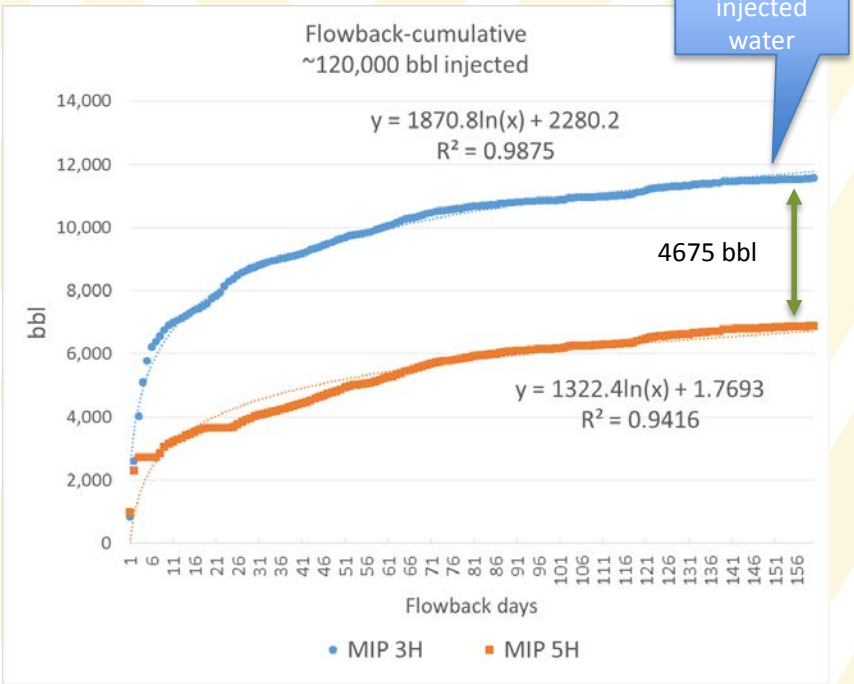
PRODUCED WATER VOLUMES: MIP 3,5H AFTER160 DAYS

3H PRODUCED 92% MORE WATER, 30% MORE GAS

1 BBL=0.16 M^3

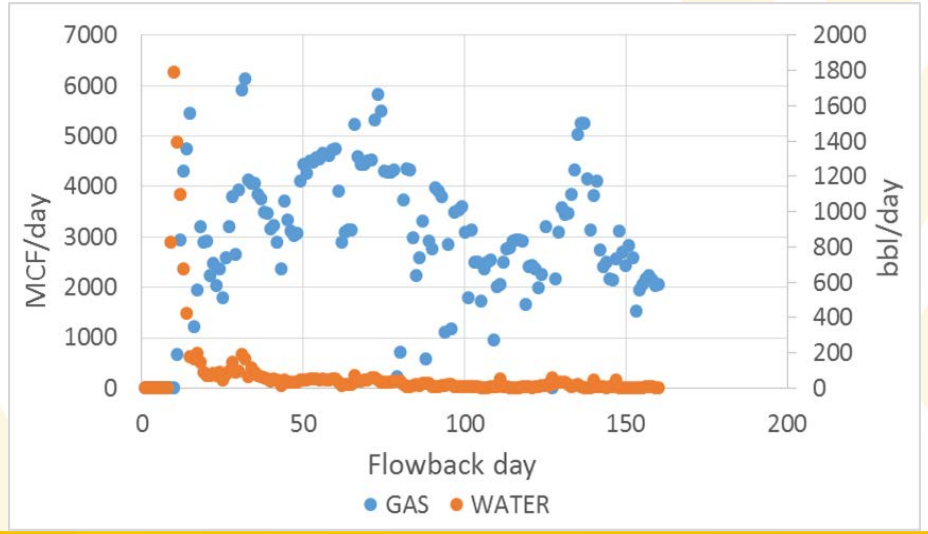
6.25 BBL/M^3





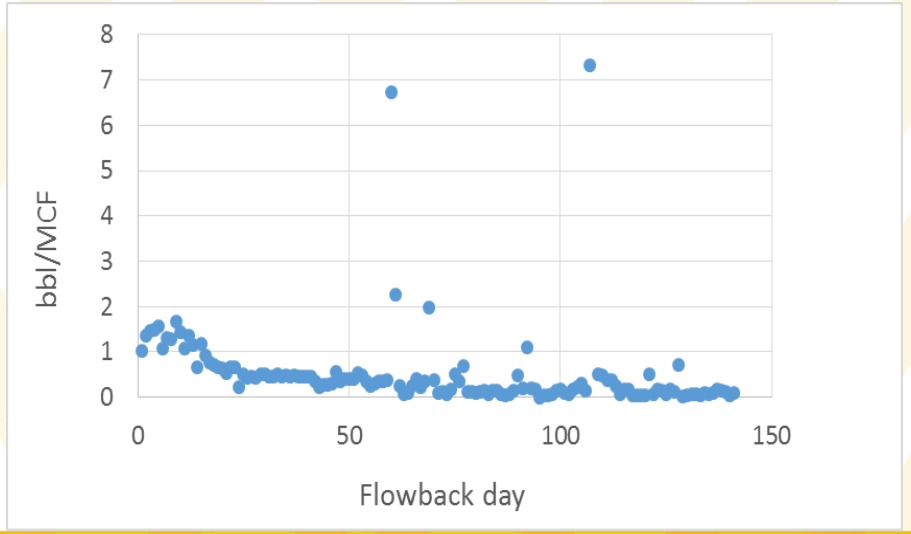
Gas/water trends

Gas vs. water production



Water/gas ratio

average ~ 0.5 bbl/MCF



Chemical Characterization

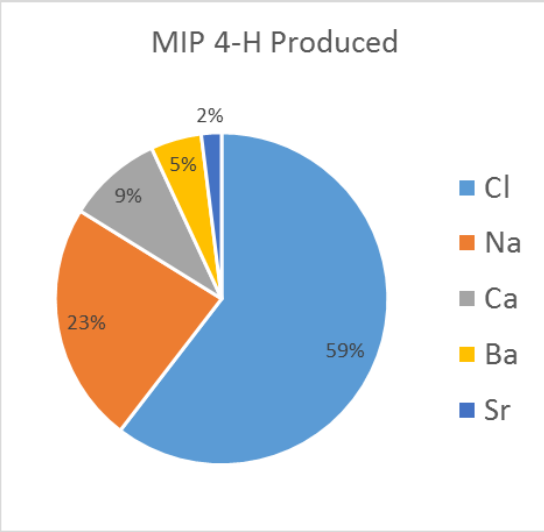
- Flowback/produced water
  - Sampled at upstream end of separators
- Hydraulic fracturing fluid
- Drilling mud

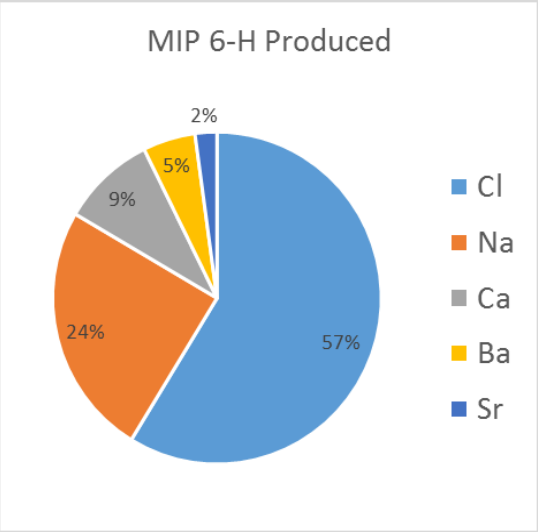
Flowback day 863 (% TDS)

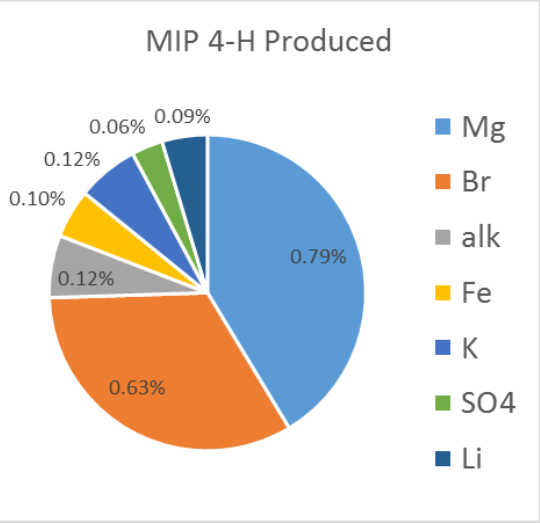
Major (98%)

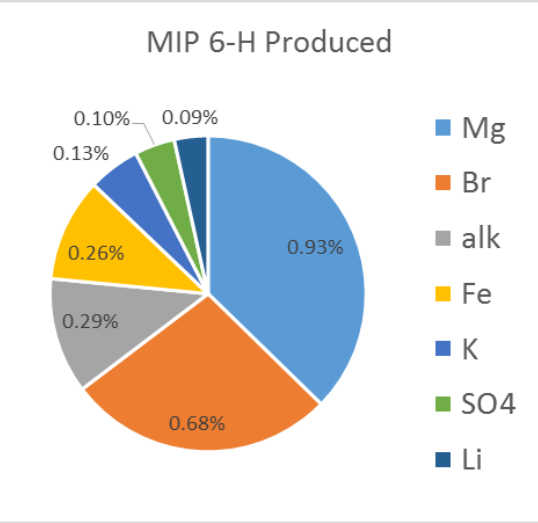
and

Minor ions







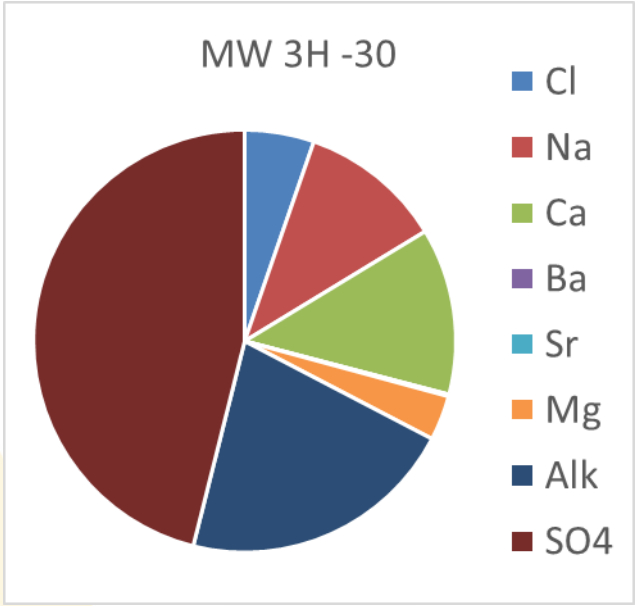


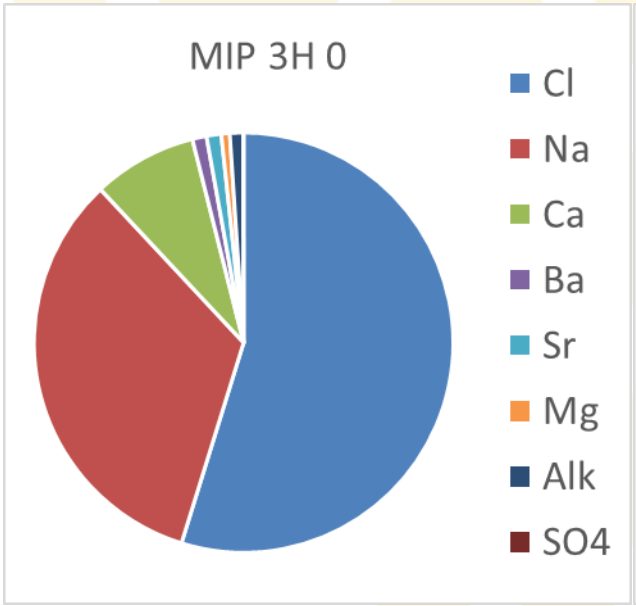
Produced water evolution: MIP 3H

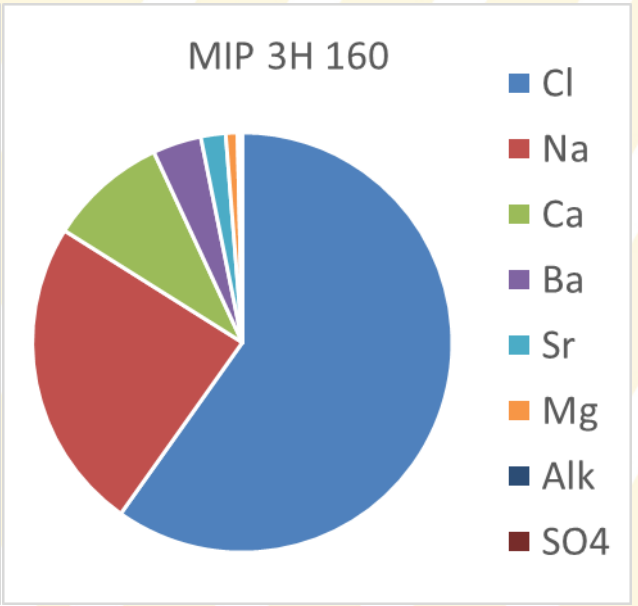
Makeup-Mon River
TDS: 285 mg/L

Flowback day 0
TDS: 27,812 mg/L

Flowback day 160
TDS: 121,536 mg/L







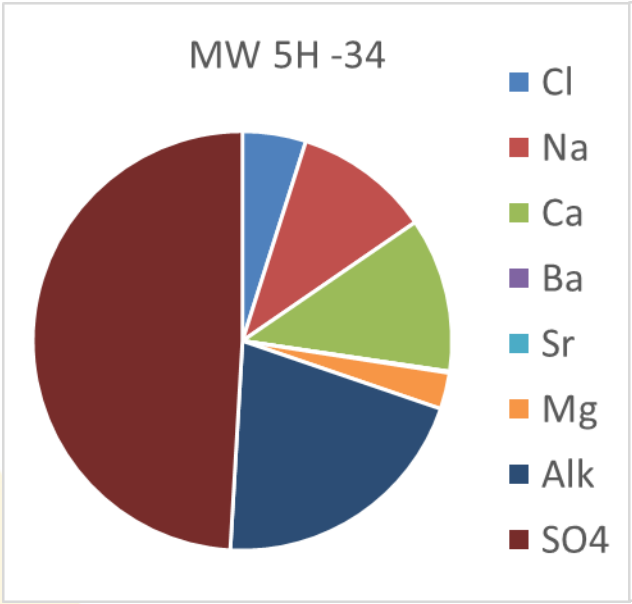
30 days post completion

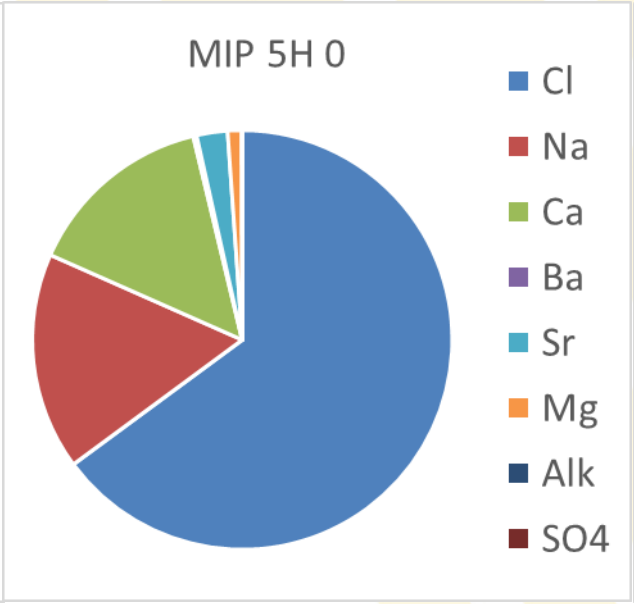
Produced water evolution: MIP 5H

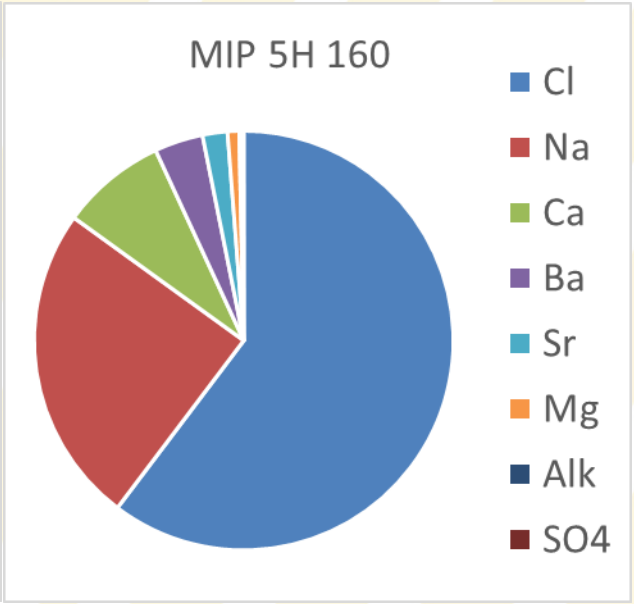
Makeup-Mon River
TDS: 289 mg/L

Flowback day 0
TDS: 188,113 mg/L

Flowback day 160
TDS: 110,620 mg/L







34 days post completion

NEARLY ALL PARAMETERS WERE HIGHER IN FLOWBACK THAN FRAC FLUID

PINK: EXCEEDS DRINKING WATER MCL

	Date	10-Nov-15	10-Nov-15	18-May-16
	well	MW 3H	HF 3H	MIP 3H
analyte	FB days	-30	-30	160
Na	mg/L	31.0	62.0	29,000
Ca	mg/L	36.0	35.0	11,000
Ba	mg/L	0.1	0.0	4,500
Sr	mg/L	0.4	0.3	2,300
Mg	mg/L	9.7	9.7	1,100
Fe	mg/L	0.1	3.9	320
K	mg/L	2.5	4.3	180
Mn	mg/L	0.0	0.2	13.0
Zn	mg/L	0.0	0.1	0.6
Ni	mg/L	0.0	0.0	0.2
As	mg/L	0.0	0.0	0.1
Cr	mg/L	0.0	0.0	0.1
Pb	mg/L	0.0	0.0	0.0
Al	mg/L	0.0	0.8	BDL
Se	mg/L	0.0	0.0	BDL
Ag	mg/L	0.0	0.0	BDL
Cl	mg/L	15	48	72,000
Br	mg/L	0	BDL	693
Alk	mg/L	60	80	330
SO4	mg/L	130	120	BDL
TDS	mg/L	260	420	120,000

IN PRODUCED WATER CHLORIDE IS THE DOMINANT ANION:
SOLUBILITY VS. SULFATE AND CARBONATE MINERALS

chlorides		sulfates		carbonates	
mineral	solubility (mg/L)	mineral	solubility (mg/L)	mineral	solubility (mg/L)
a) NaCl	360,000	a) Na_2SO_4	281,000	a) Na_2CO_3	307,000
a) $MgCl_2$	560,000	a) $MgSO_4$	357,000	a) $MgCO_3$	390
a) $CaCl_2$	813,000	a) $CaSO_4$	2,505	b) $CaCO_3$	5.8
a) $SrCl_2$	547,000	b) $SrSO_4$	108	b) $SrCO_3$	3.5
a) $BaCl_2$	370,000	b) $BaSO_4$	2.4	b) $BaCO_3$	10
a) $RaCl_2$	245,000	b) $RaSO_4$	2.1	c) $RaCO_3$	insoluble

a) from solubility table

b) derived from K_{sp}

c) reported insoluble, no K_{sp} available

MW: Makeup water, HF: Hydraulic fracturing fluid, MIP: produced water

	Date	10-Nov-15	10-Nov-15	18-May-16
	well	MW 3H	HF 3H	MIP 3H
analyte	FB days	-30	-30	160
pH		6.8	6.7	6.2
Benzene	µg/L	0.1	0.1	5.1
Ethylbenze	µg/L	0.1	0.1	0.3
m,p-Xylene	µg/L	0.2	0.2	1.0
o-Xylene	µg/L	0.1	0.1	0.7
Toluene	µg/L	0.0	0.8	7.4
Xylene t	µg/L	0.3	0.3	1.7
α act	pCi/L	2	3	41,290
β act	pCi/L	2	5	11,170
$^{226+228}$Ra act	pCi/L	1	3	17,521

TERMINOLOGY: SOLID WASTES

- **Drilling mud**
  - Returns to the surface with cuttings during drilling
  - Recycled after cuttings removed
  - To disposal after well completed
- **Drill cuttings**
  - Rock fragments-clay to fine gravel
  - ~500-800 tons/well or 25 to 50 truckloads
  - To disposal after separation from drilling mud
- **Flowback Solids**-filter cake, precipitates, suspended solids

DRILLING WASTES

Mud

Cuttings

SOLIDS SEPARATION

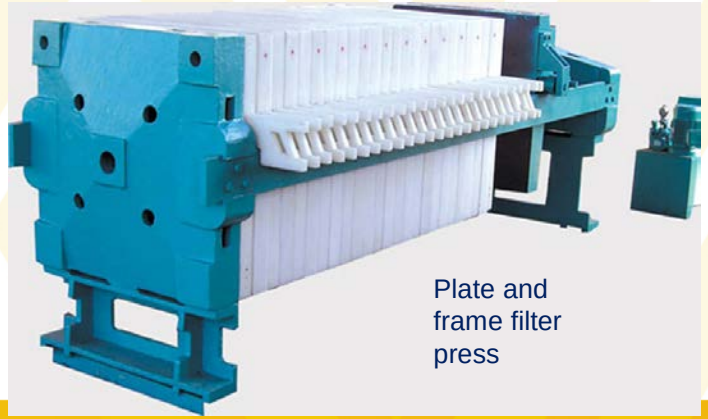


Plate and frame filter press

CONVENTIONAL DRILLING MUD

DRILL CUTTINGS % SAMPLES (LIQUID FRACTION) > TCLP LIMIT

Drill Cuttings: Vertical Section				
Drill Cuttings	%> TCLP	min	max	
Cr	100%	6.7	32.8	mg/L
As	90%	2.4	30.6	mg/L
Pb	80%	3.5	84.9	mg/L
Ba	70%	23.9	7,870.0	mg/L
Benzene	70%	0.0	300.0	µg/L
Se	40%	0.0	3.3	mg/L
Hg	10%	0.0	0.3	mg/L

Using ‘Green’ Drilling Mud no parameters exceeded TCLP

- In the Vertical and Horizontal (Marcellus) sections:
  - TCLP organics-no exceedances
  - TCLP inorganics-no exceedances

Drilling mud: Bio-Base^{tm} 365

Property	Unit	Value	Test Method
Physical state		Liquid	Visual
Biodegradation, 28 days		%m 55-60	OECD 301
Potential carcinogenic label		- No	-
BTEX**	mg/kg	< 1 *	ASTM 5790 mod.
PAH	mg/kg	< 0.1 *	EPA 8100

**Below the detection level of the method.*
***BTEX (Benzene, Ethylbenzene, Toluene, Xylene).*

Radiochemistry: drill cuttings

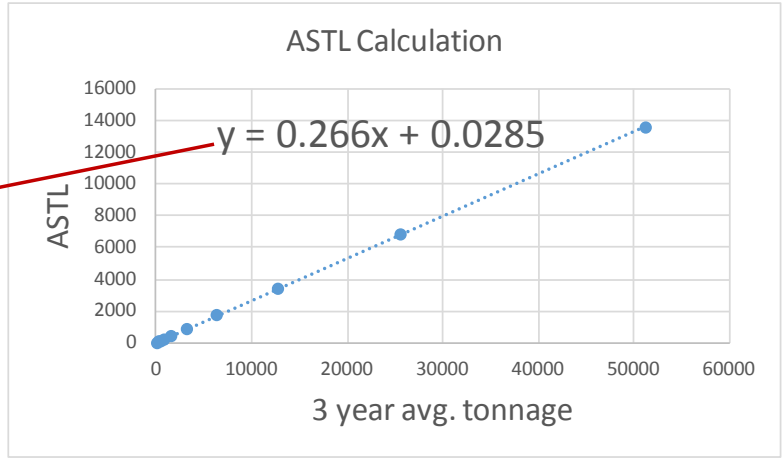
USDOT low level radioactive waste: 2,000 pCi/g

EPA 901.1	α pCi/g	β pCi/g	$^{226+228}$Ra pCi/g	^{40}K pCi/g
MIP 4400	28.32	1.22	16.82	24.50
MIP 5026	24.28	1.35	12.40	19.40
MIP 6798 5H	27.36	1.76	18.54	27.80
MIP 8555 5H	25.90	4.71	28.34	36.90
MIP 8555 5H DUP	24.63	4.56	39.22	29.80
MIP 9998 5H	16.70	9.15	47.28	42.90
MIP 11918 5H	21.80	4.01	25.12	23.00
MIP 11918 5H	19.69	4.17	24.56	28.70
MIP 13480 3H	17.66	9.22	56.51	35.40
MIP 13480 3H DUP	18.49	9.72	60.33	35.00
MIP 13480 3H Mud	12.89	5.56	60.49	42.50
MIP 14454 5H	20.07	5.77	30.13	37.50

PADEP LANDFILL GUIDANCE FOR TENORM OIL AND GAS = RWC 804

Acceptance Criteria

2013 collected tonnage	5000
2014 collected tonnage	6000
2015 collected tonnage	1500
3 yr collected tons avg.	4167
allowed source term loading (ASTL)	1108
monthly source term allocation (MSTA)	92



waste origin if transported directly to a landfill from an oil or gas well site			actual reading from handheld device							
well name	municipality	county	right side centerline mid point dose rate (µR/hr)	left side centerline mid point dose rate (µR/hr)	isotope	TENORM tons	multiplier	load source term (µR/hr)*tons)	MSTA remaining (µR/hr)*tons)	additional comments
									92	
Bobo 1	Harborview	Greene	2	2		15	1.5	45	47	
Bobo 1	Harborview	Greene	25	15		1	1.5	30	17	
Bobo 1	Harborview	Greene	3	3		15	1.5	68	-50	REJECT

West Virginia's Solid Waste Management Rule: Drill cuttings and associated drilling wastes

- Prior to permitting:
  - Composite vertical and horizontal samples
  - Testing: TCLP-metals, VOC, SVOC, TPH
- Disposal in lined cells
- Leachate collection/testing

West Virginia's Solid Waste Management Rule: Drill cuttings and associated drilling wastes At the landfill

- If incoming load exceeds 10 µR/hr above local background (~24+10=37 µR/hr)
- R=Roentgen= γ, x radiation only
- Determine $^{226+228}Ra$
- ^{226}Ra by USEPA method 903 takes 28 days
- Must be less than 5 pCi/g above local background
- If greater, reject load

CONCLUSIONS

- Produced water is highly contaminated
  - Saline
  - Organics (much less in dry gas wells)
  - Radiochemicals
  - All increase through production cycle
  - Managed through recycle as makeup water
- Drill cuttings toxicity controlled by drilling fluids
- Drill cuttings radioactivity is low

FOR MORE INFORMATION PLEASE CONTACT:

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